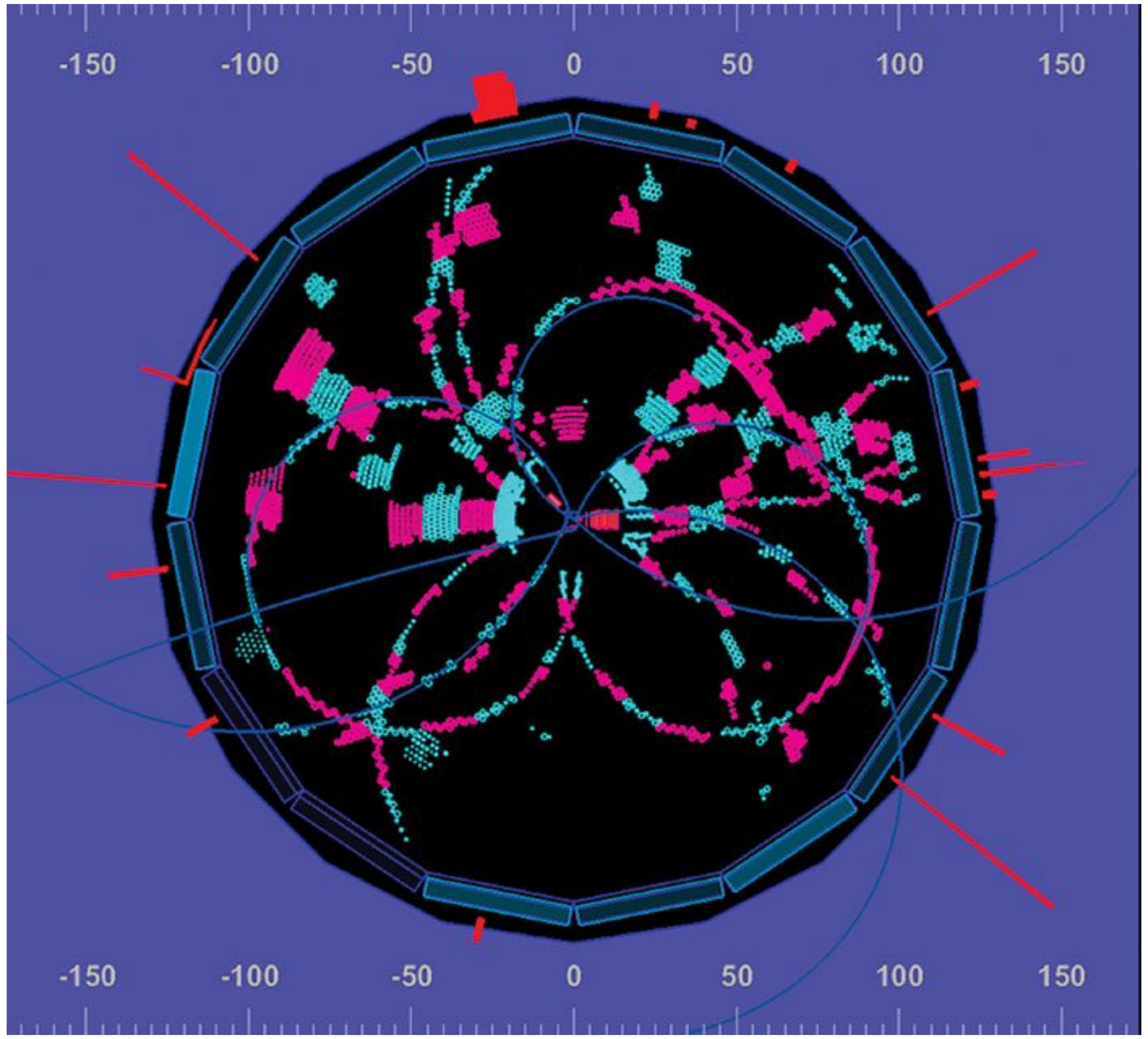
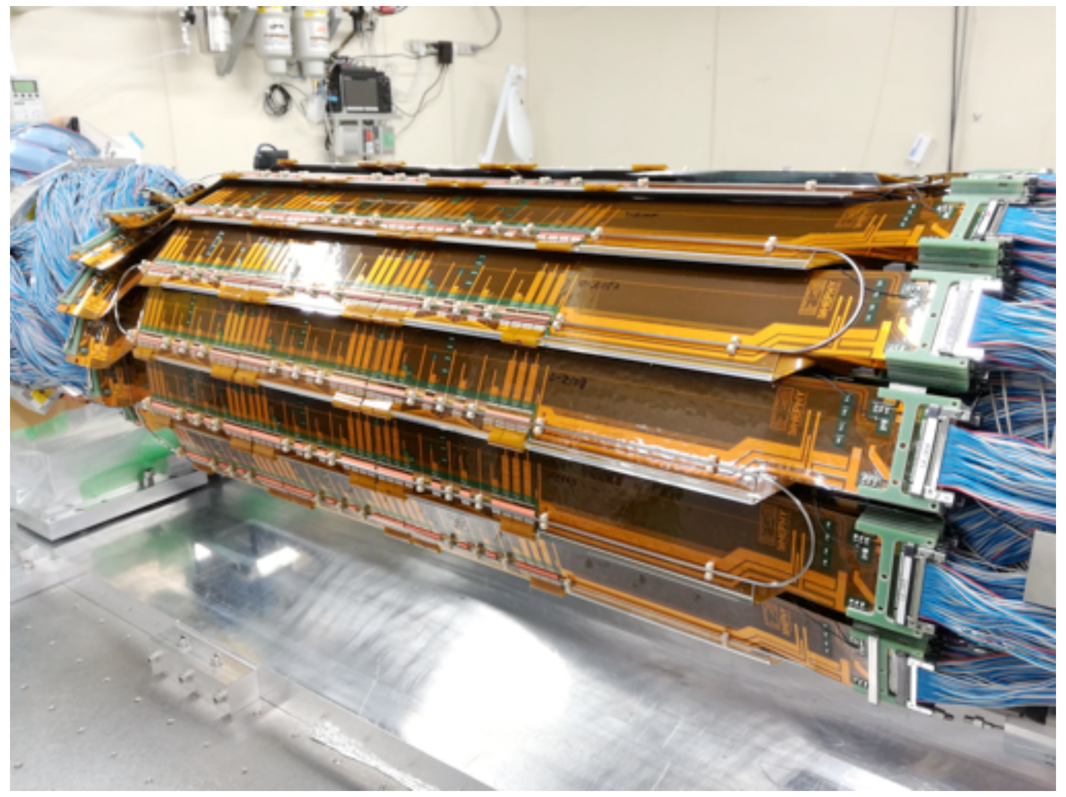
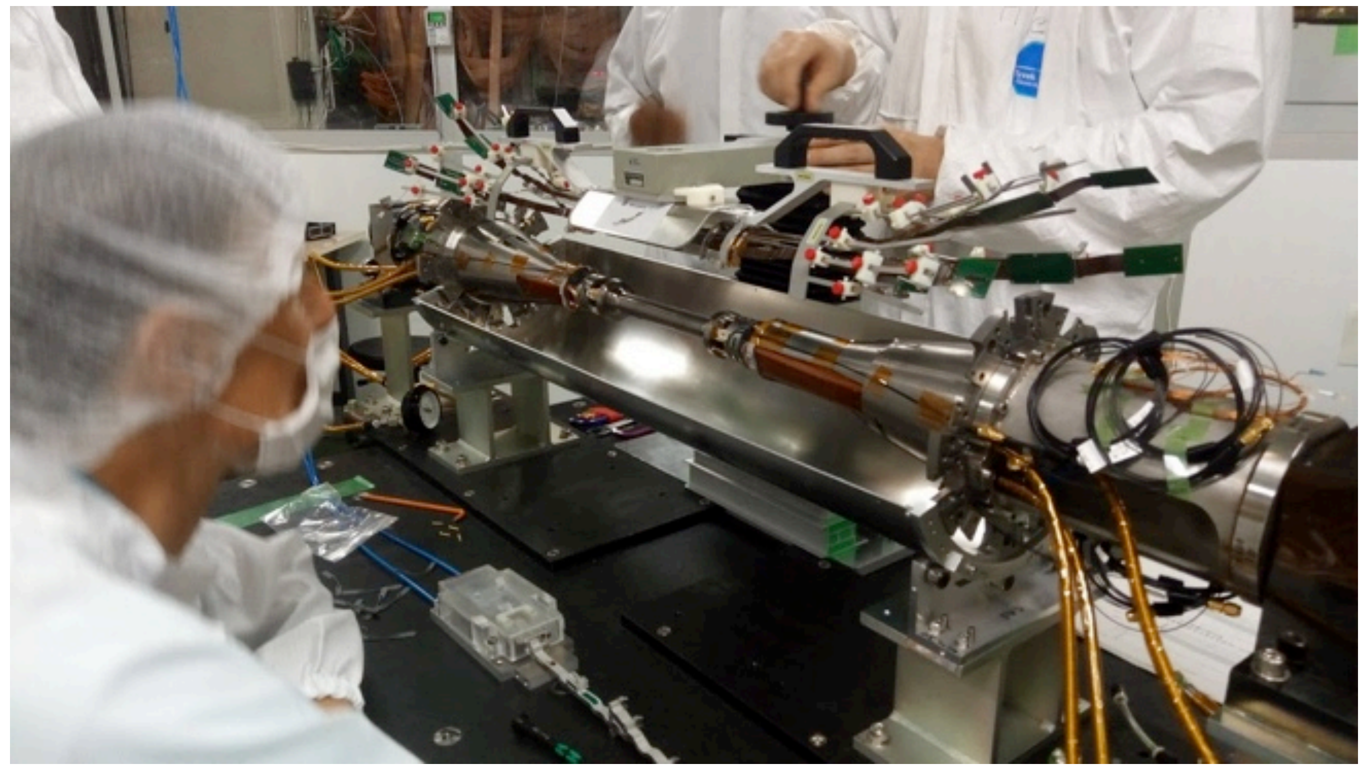
Physics Session Summary

Phillip Urquijo
The University of Melbourne



Y(4S) candidate from the 2018 Belle II / SuperKEKB commissioning run



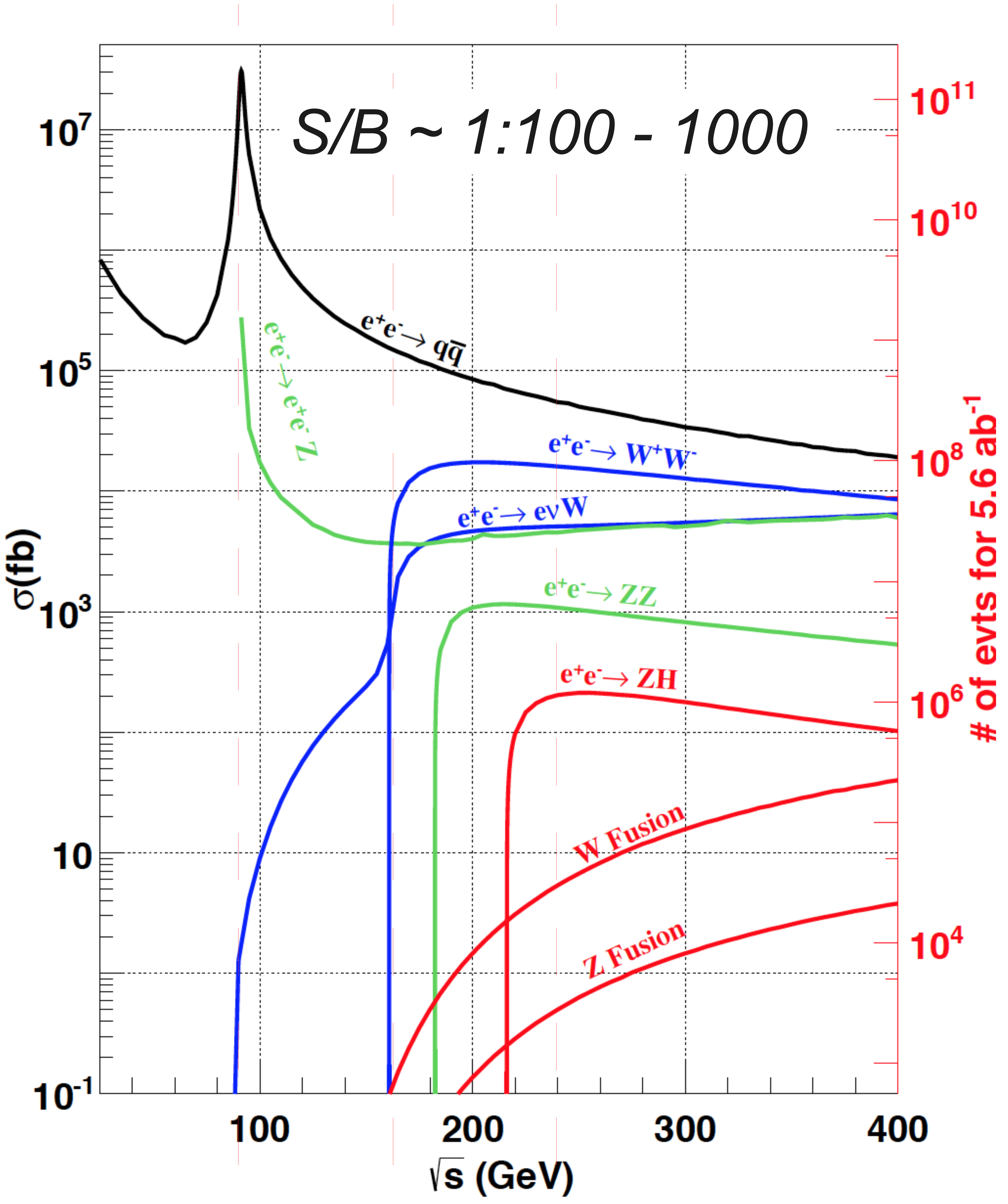


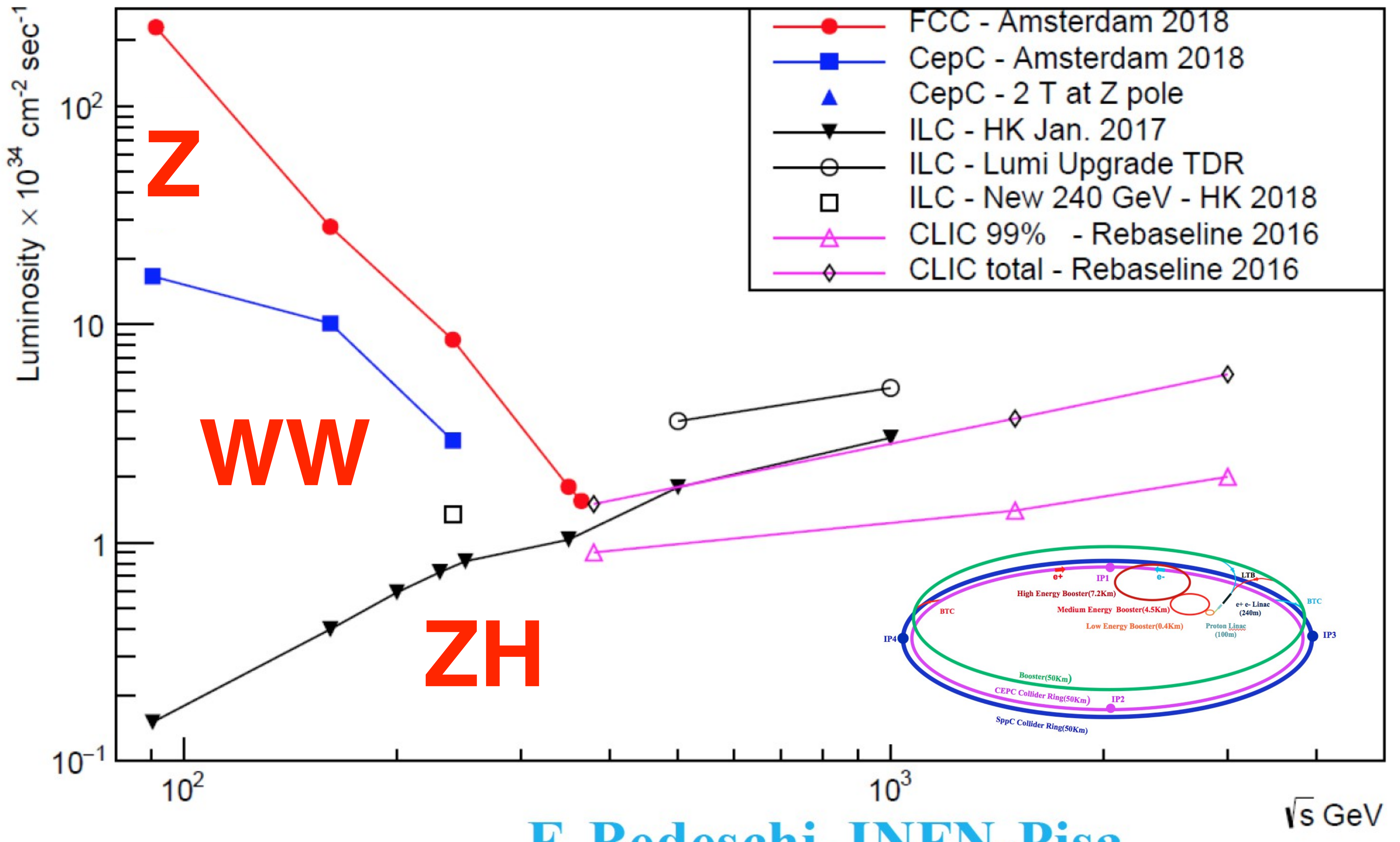
Completion of the 2nd SVD half shell; 1st PXD half-shell at KEK

Presentations in the physics session

1. **Higgs, W, Z factories**
   1. New Physics Reach with EW and Higgs Precision Measurements, M. Ruan
   2. Higgs Physics at the Higgs Factory and Complementarity with Hadron Colliders, P. Giacomelli
   3. Electroweak Physics at CEPC, Z. Liang
   4. The Ideal Detector (for a high E collider), J. G. da Costa
2. **Heavy flavour factories**
   1. Experimental Program for a Super Charm-Tau Factory, X-R. Lyu
   2. B factory flavour physics: Belle II, P. U.

High energy program overview





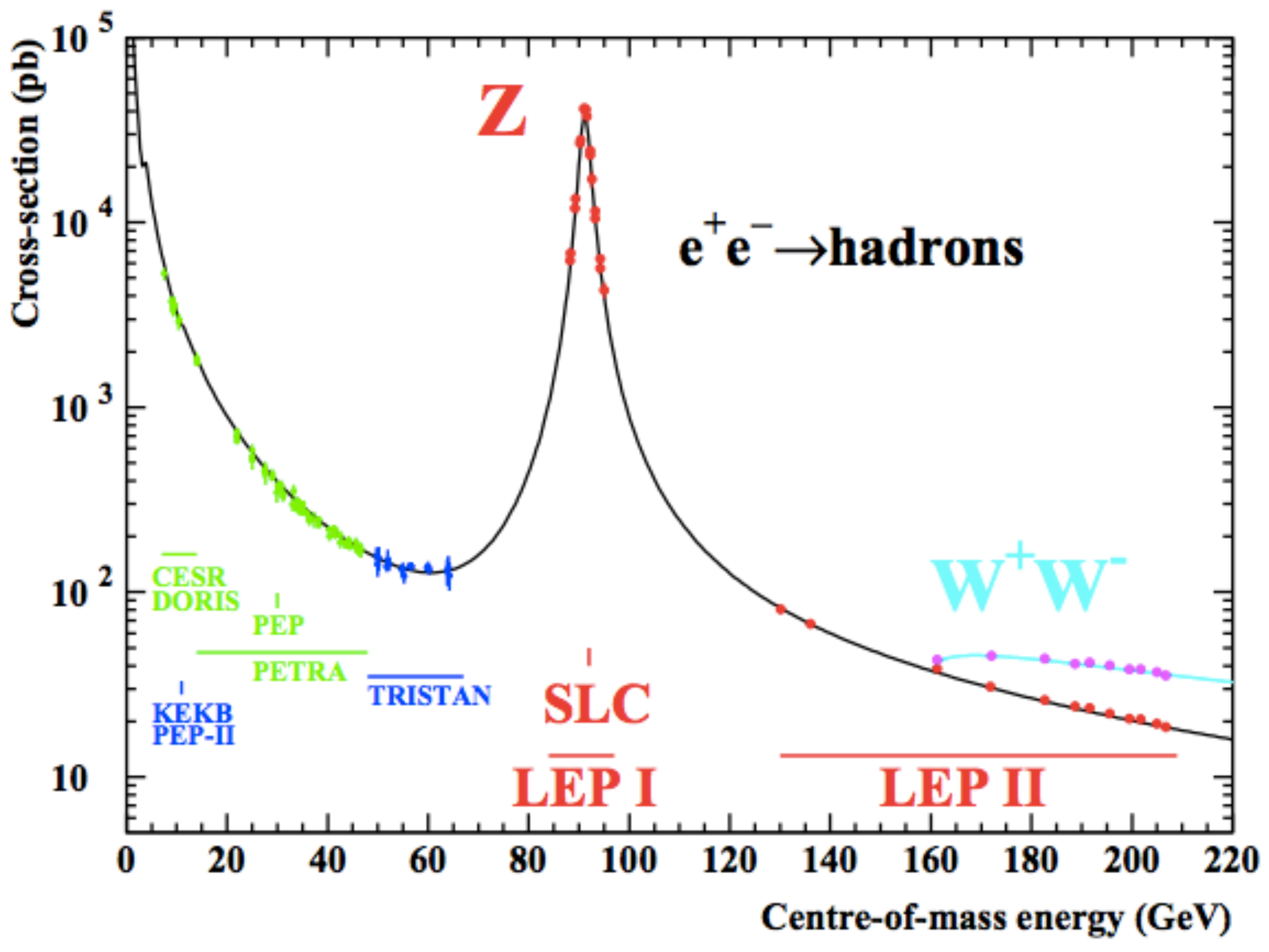
F. Bedeschi. INFN-Pisa

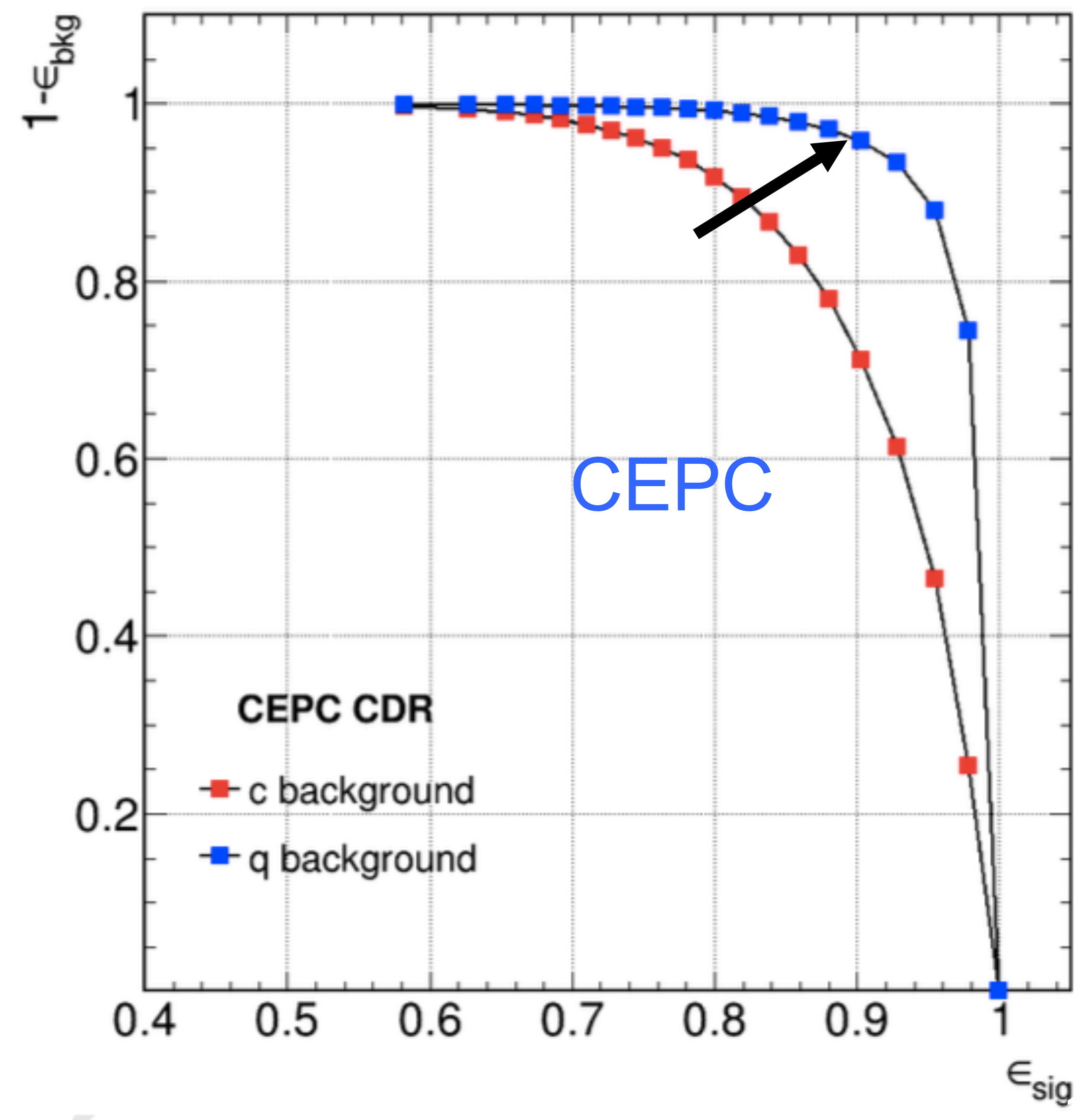
Anticipated CEPC data sets

Operation mode	Z factory	W threshold scan	Higgs factory
$\sqrt{s}$ (GeV)	91.2	158 - 172	240
L ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	16-32	10	3
Running time (years)	2	1	7
Integrated Luminosity (ab^{-1})	8 - 16	2.6	5.6
Higgs yield	-	-	10^6
W yield	-	10^7	10^8
Z yield	10^{11-12}	10^9	10^9

Z SM precision

- Measure the Z line-shape by accumulating 10^{12} Z bosons in a energy scan
- At LEP reached ~$2\cdot10^{-5}$ and gained a lot of experience on centre-of- mass energy determination with resonant depolarisation
  - Could potentially reach ~$10^{-5\text{-}6}$ (500 keV on M_Z)
  - Improves the knowledge of other observables, e.g. R_l and related $\alpha_s(M_Z)$.
- **$R_b = \Gamma(Z\to bb)/\Gamma(Z\to hadrons) = 0.21594 \pm 0.00066$ (LEP): Better b-tagging at CEPC (Si detectors)**



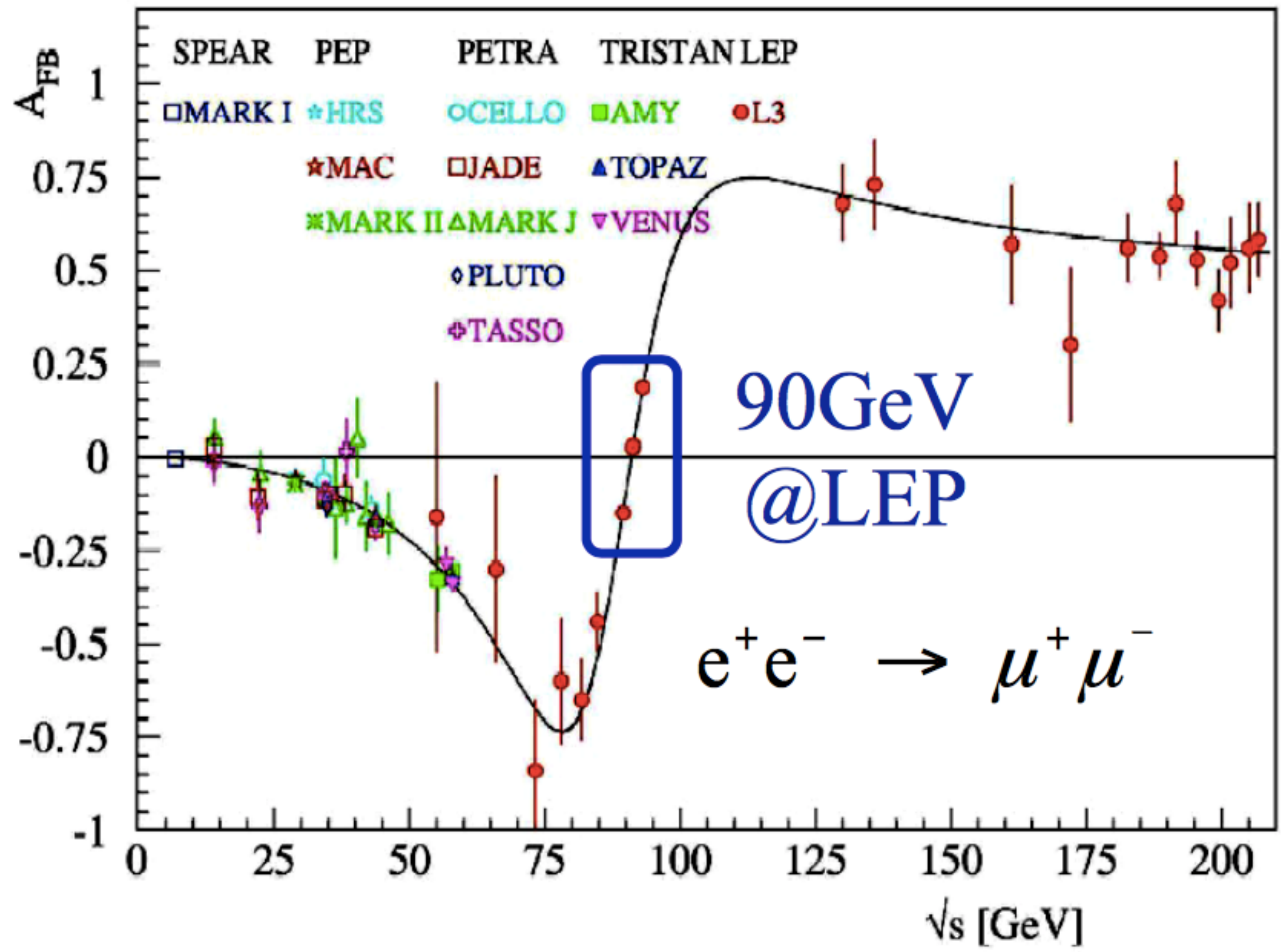


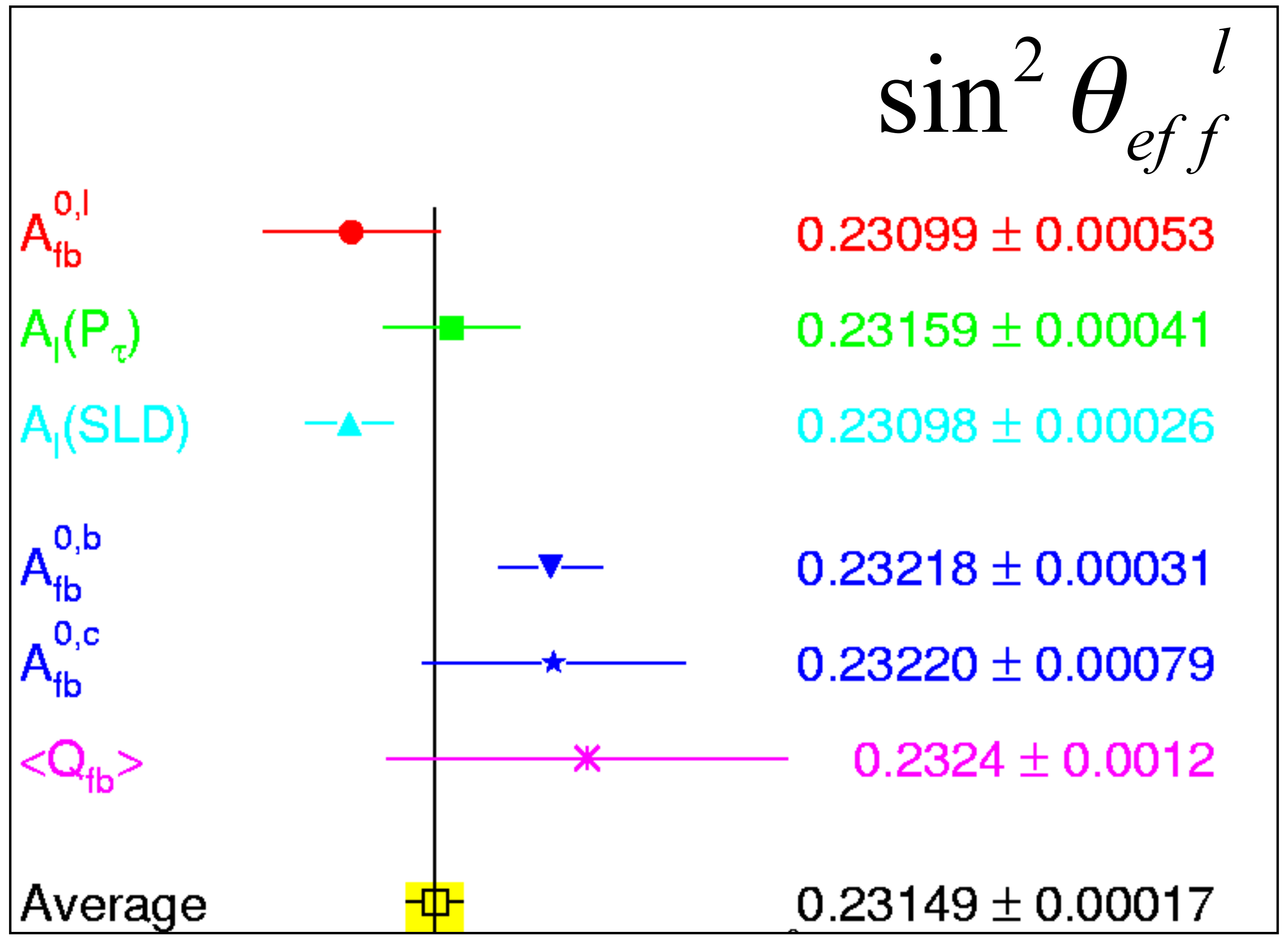
Observable	LEP precision	CEPC precision	CEPC runs	CEPC $\int \mathcal{L}dt$
m_Z	2 MeV	0.5 MeV	Z pole	8 ab^{-1}
$A_{FB}^{0,b}$	1.7%	0.1%	Z pole	8 ab^{-1}
$A_{FB}^{0,\mu}$	7.7%	0.3%	Z pole	8 ab^{-1}
$A_{FB}^{0,e}$	17%	0.5%	Z pole	8 ab^{-1}
$\sin^2\theta_W^{\text{eff}}$	0.07%	0.001%	Z pole	8 ab^{-1}
R_b	0.3%	0.02%	Z pole	8 ab^{-1}
R_μ	0.2%	0.01%	Z pole	8 ab^{-1}
N_ν	1.7%	0.05%	ZH runs	5.6 ab^{-1}
m_W	33 MeV	2–3 MeV	ZH runs	5.6 ab^{-1}
m_W	33 MeV	1 MeV	WW threshold	2.6 ab^{-1}

Z A_{FB}, $\sin^2\theta_{eff}$

- Long standing difference between A_l, A_{FB} (L) and A_{FB}(b)
- A_{FB} in μμ
  - Improved angular resolution
  - Precise beam energy measurement
- A_{FB} in bb
  - Lepton from b/c decay (B→X l ν)
  - Jet charge difference (Q_F - Q_B)

- Pixel detectors and high statistics should improve precision substantially.
- Could potentially reach ~10^{-6} on $\sin^2\theta$



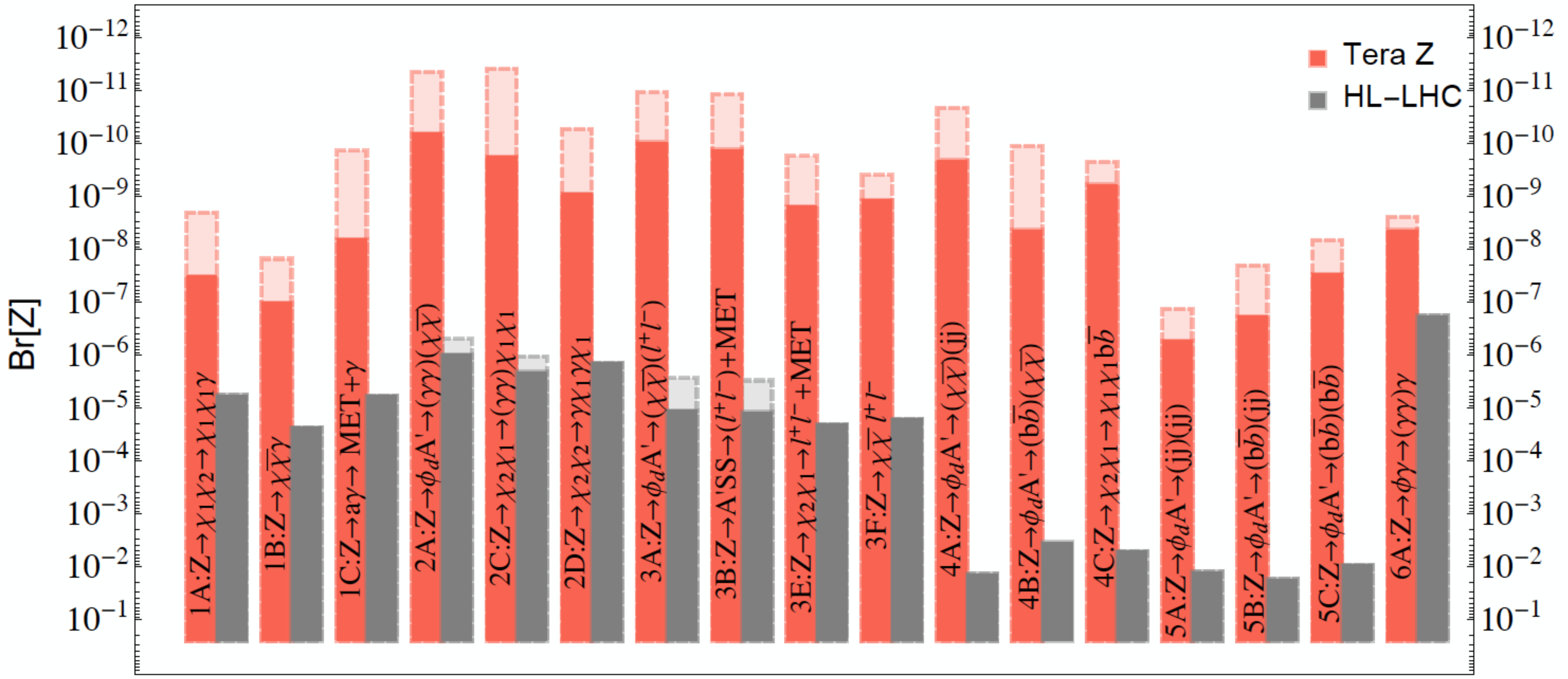


Improvement compared to LEP results	CEPC
A_{FB} (Z->ee)	~30
A_{FB} (Z->μμ)	20-30
A_{FB} (Z->ττ)	NA
A_{FB} (Z->bb)	~10
Weak mixing angle	~70

Neutrino families, Z invisible width and BSM modes

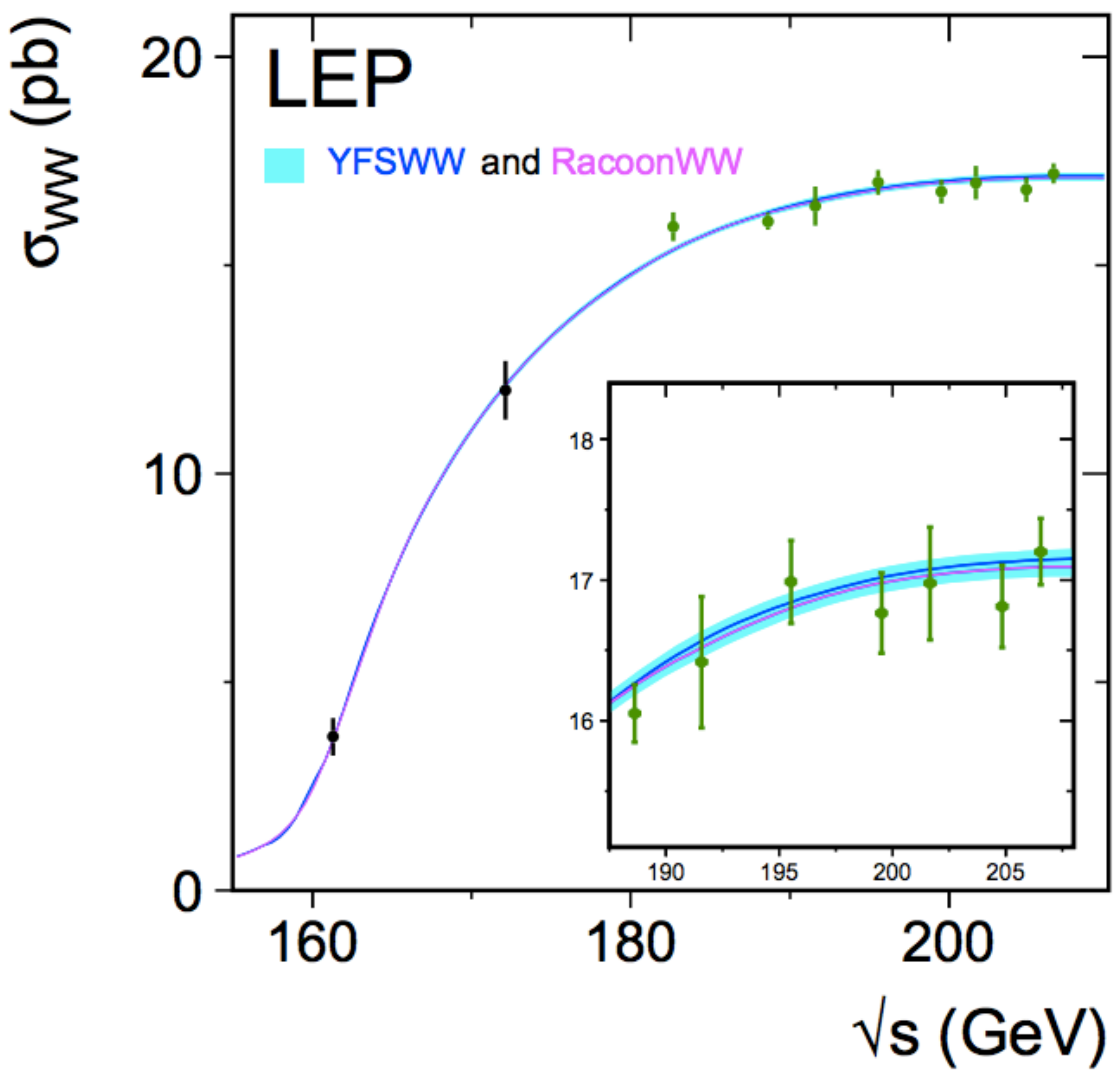
- Number of neutrino families from LEP Z line-shape (INDIRECT) **N_ν=2.984±0.008**
- Potential to improve the measurement to ±0.001 with $e^+e^- \to Z\gamma$ (DIRECT) experiment at CEPC
  - **N_ν=2.92±0.05** (1.7% stat, 1.5% sys)
  - High granularity calorimeter and fast readout improves γ identification.
- Radiative return method can be used for dark sector searches.

Systematics source	LEP	CEPC
Photon trigger and Identification efficiency	~0.5%	<0.1%
Calorimeter energy scale	0.3~0.5%	<0.2%



W mass

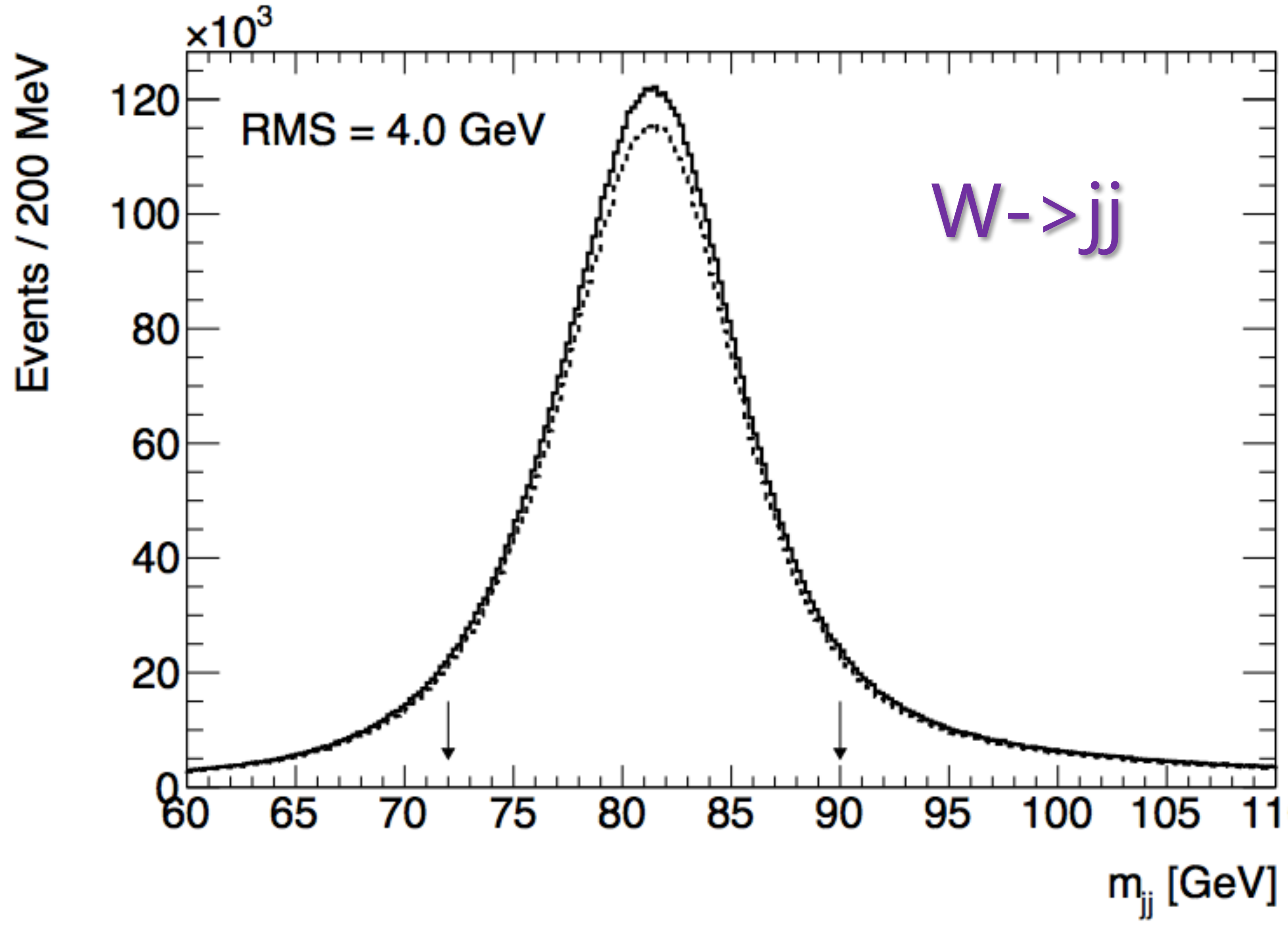
- Perform a precise measurement from the WW threshold scan. Could potentially reach ~ 0.5 MeV
- Revisit the LEP2 method of direct reconstruction in ZH 240 GeV run (there is room for improvement, *e.g.* beam energy, large statistics on semileptonic events, etc.)

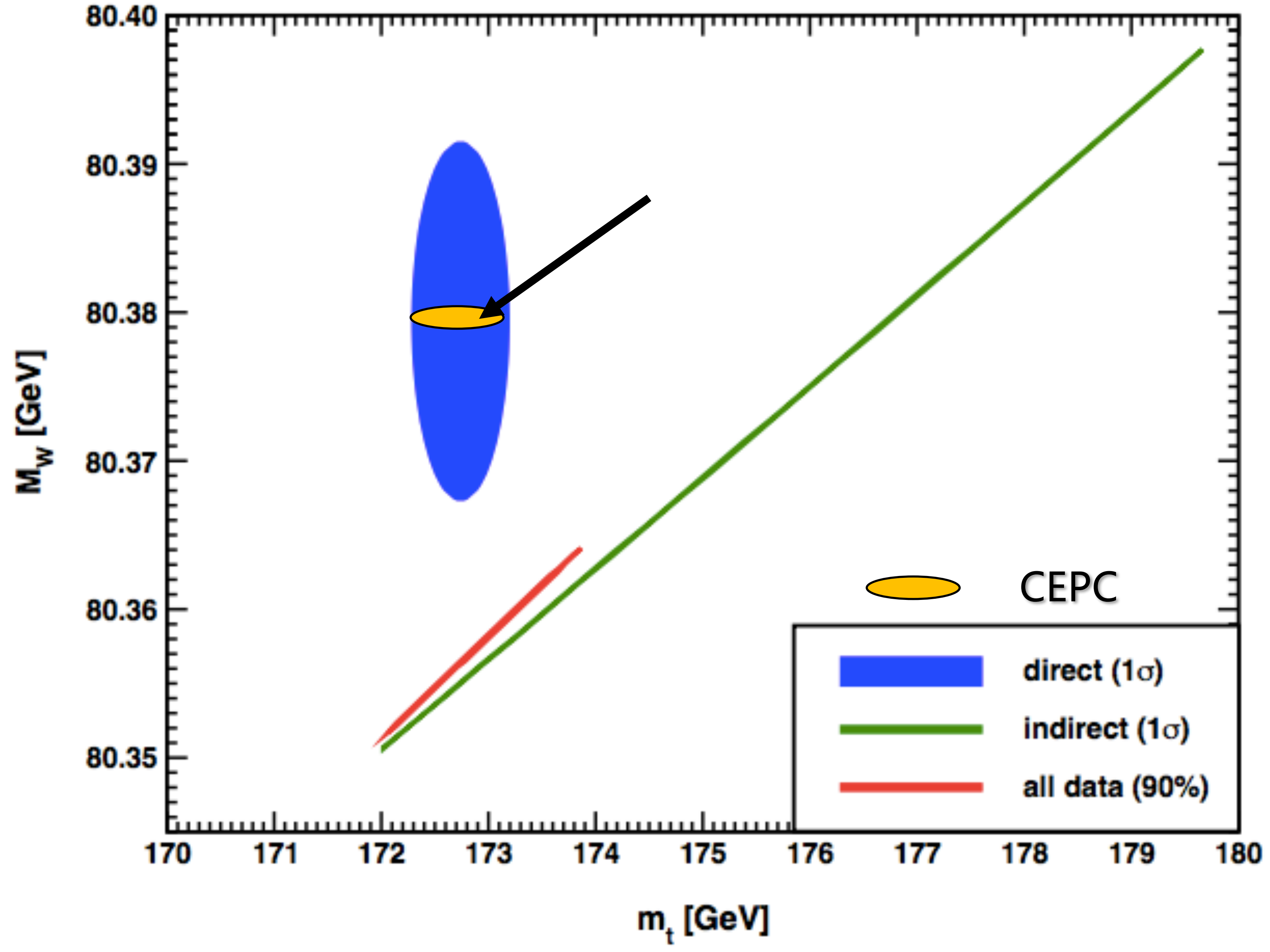


Threshold scan

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8

Direct @ CEPC

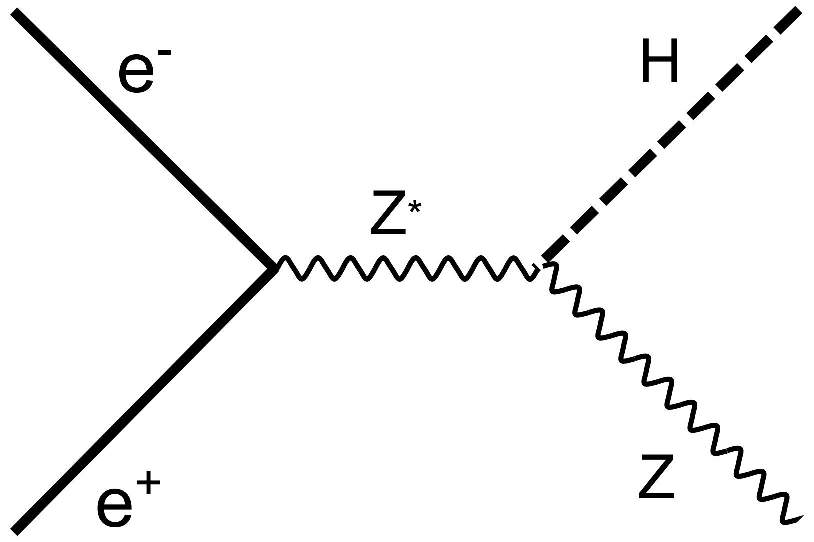


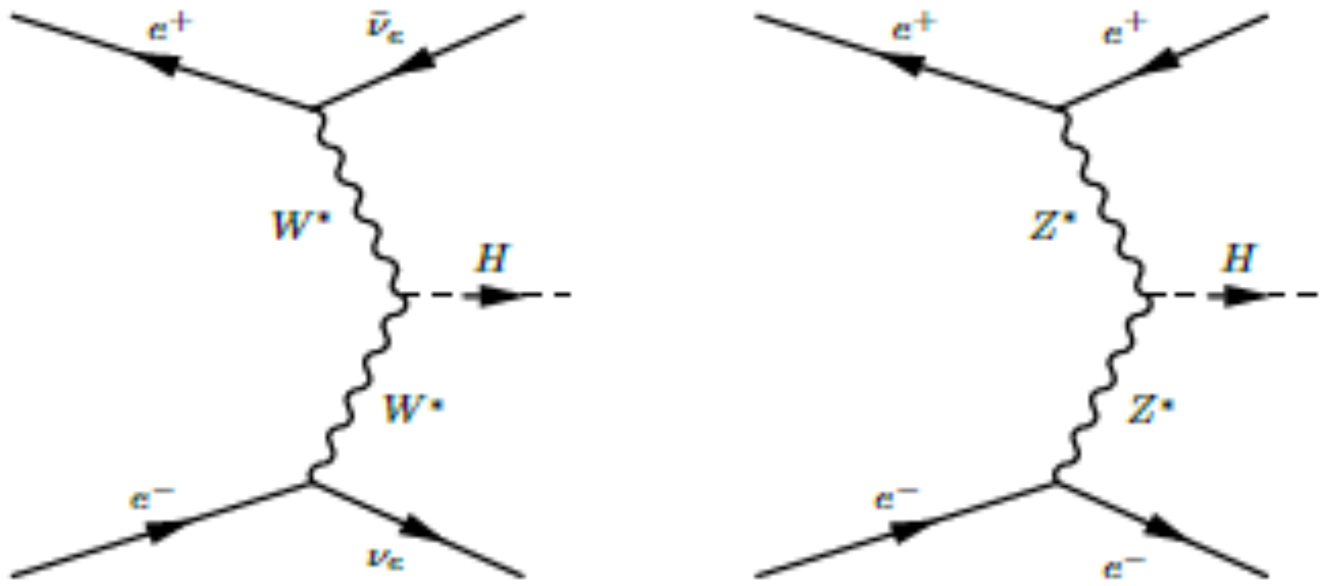


Higgs total width

- 1) Z-tagging by missing mass at 240 GeV
  $10^{34}\ cm^{-2}s^{-1} \rightarrow$ 20 000 HZ events per year

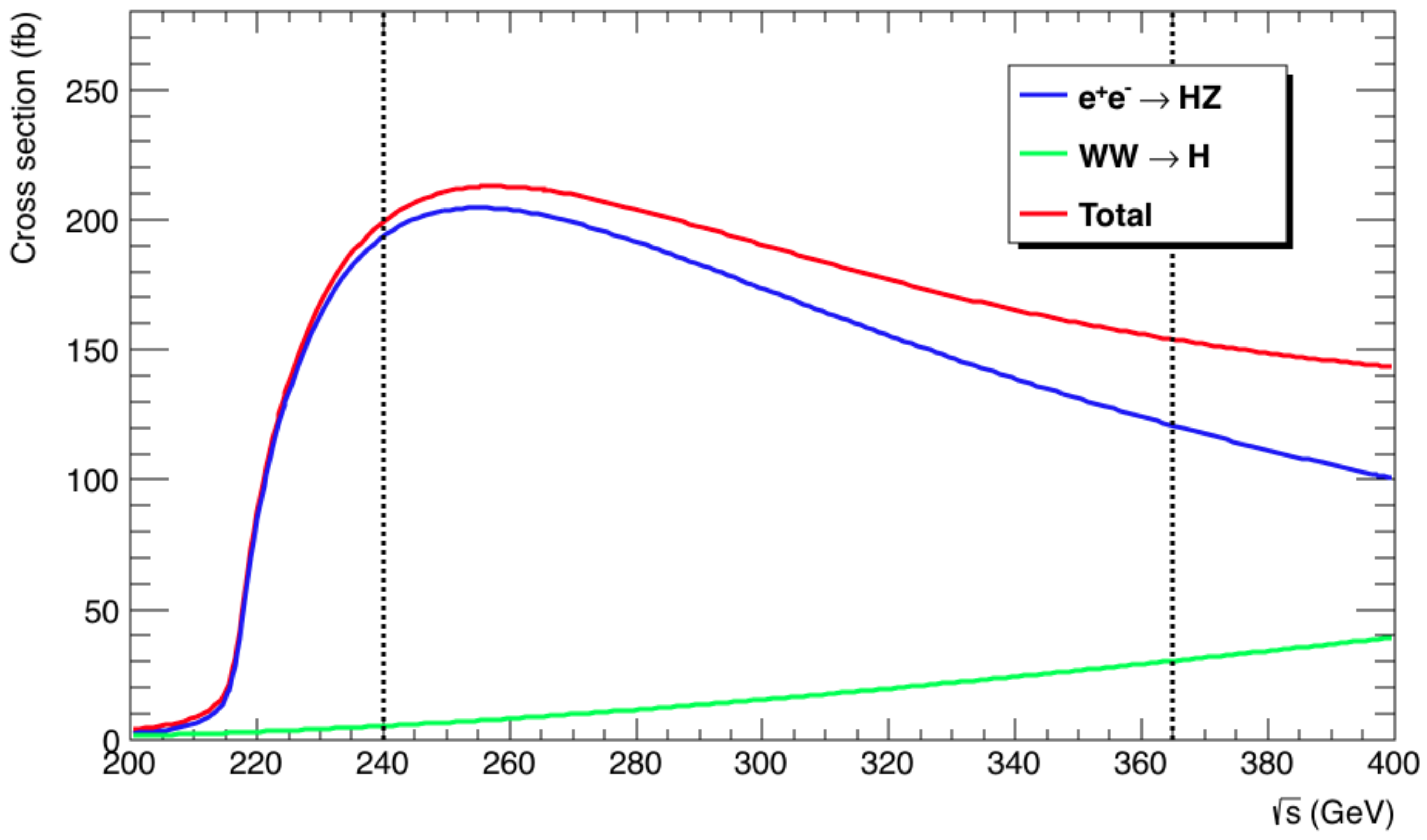
$$\sigma(\mathrm{ee} \to \mathrm{ZH}) \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{ZZ}) \propto \frac{g_{HZ}^4}{\Gamma}$$



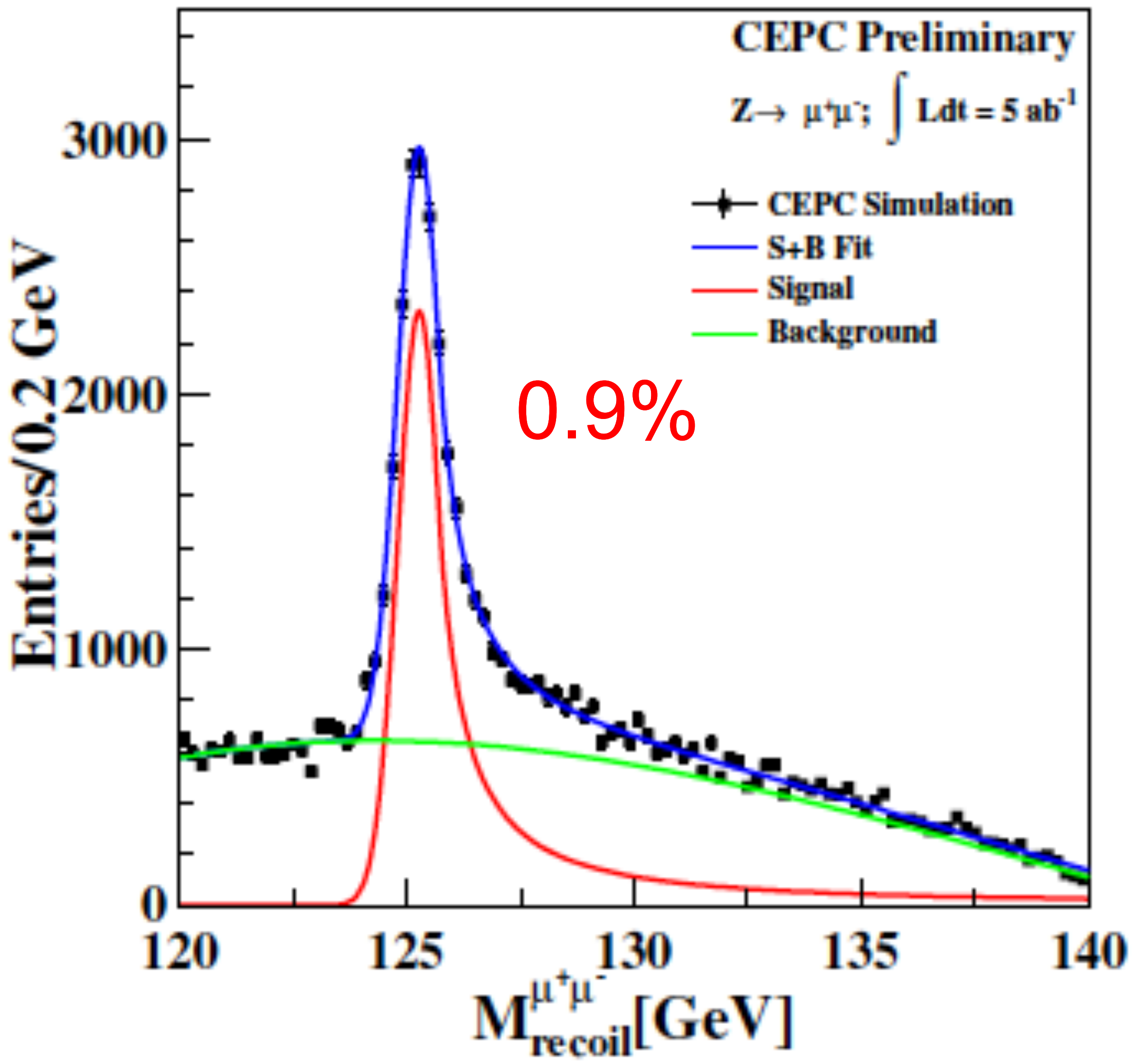


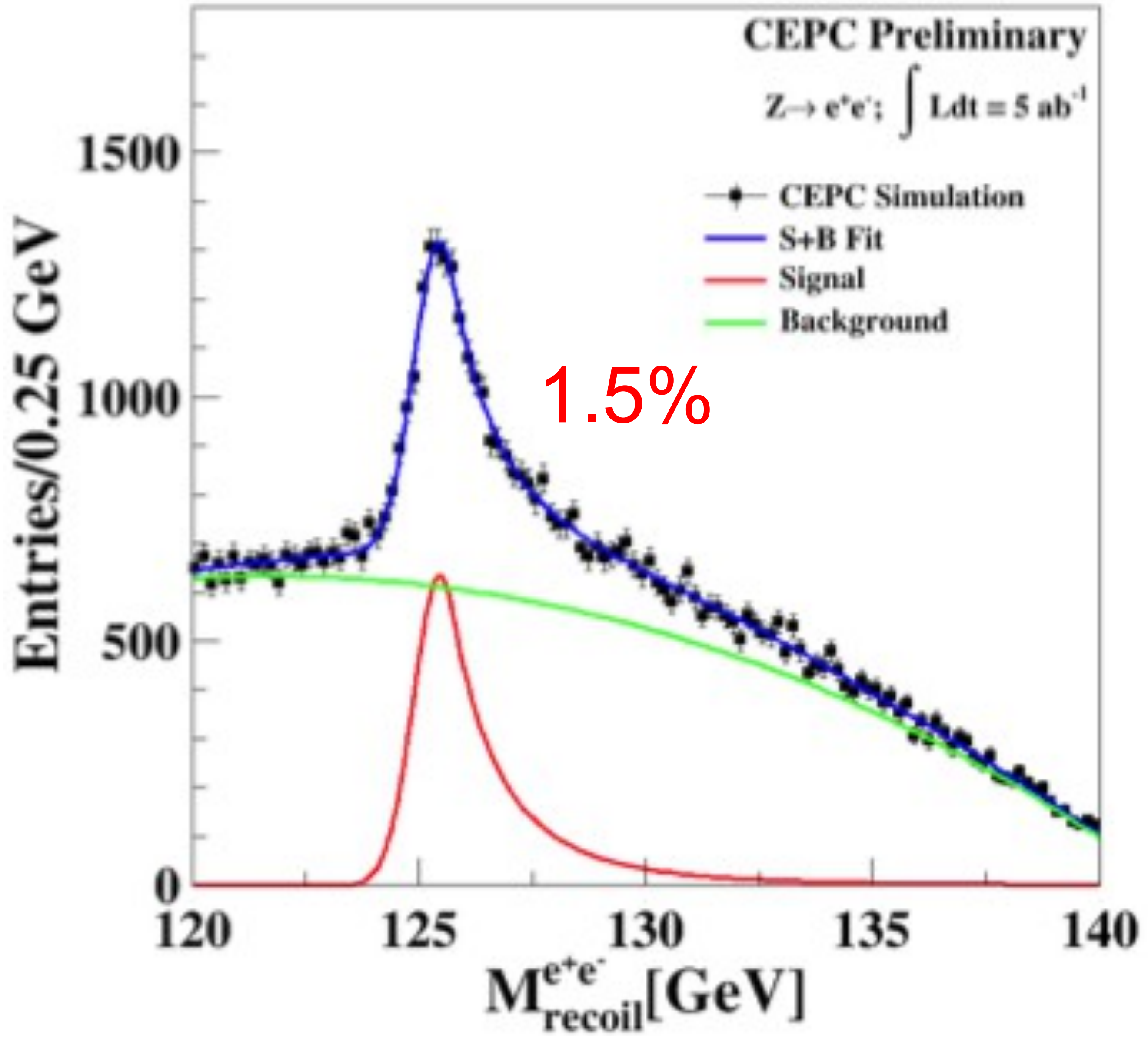
- 2) Vector boson fusion at 365 GeV

$$\frac{\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{WW})\cdot\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}{\sigma(\mathrm{ee}\to\nu\nu\mathrm{H})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})} \propto \frac{g_{HZ}^4}{\Gamma}$$



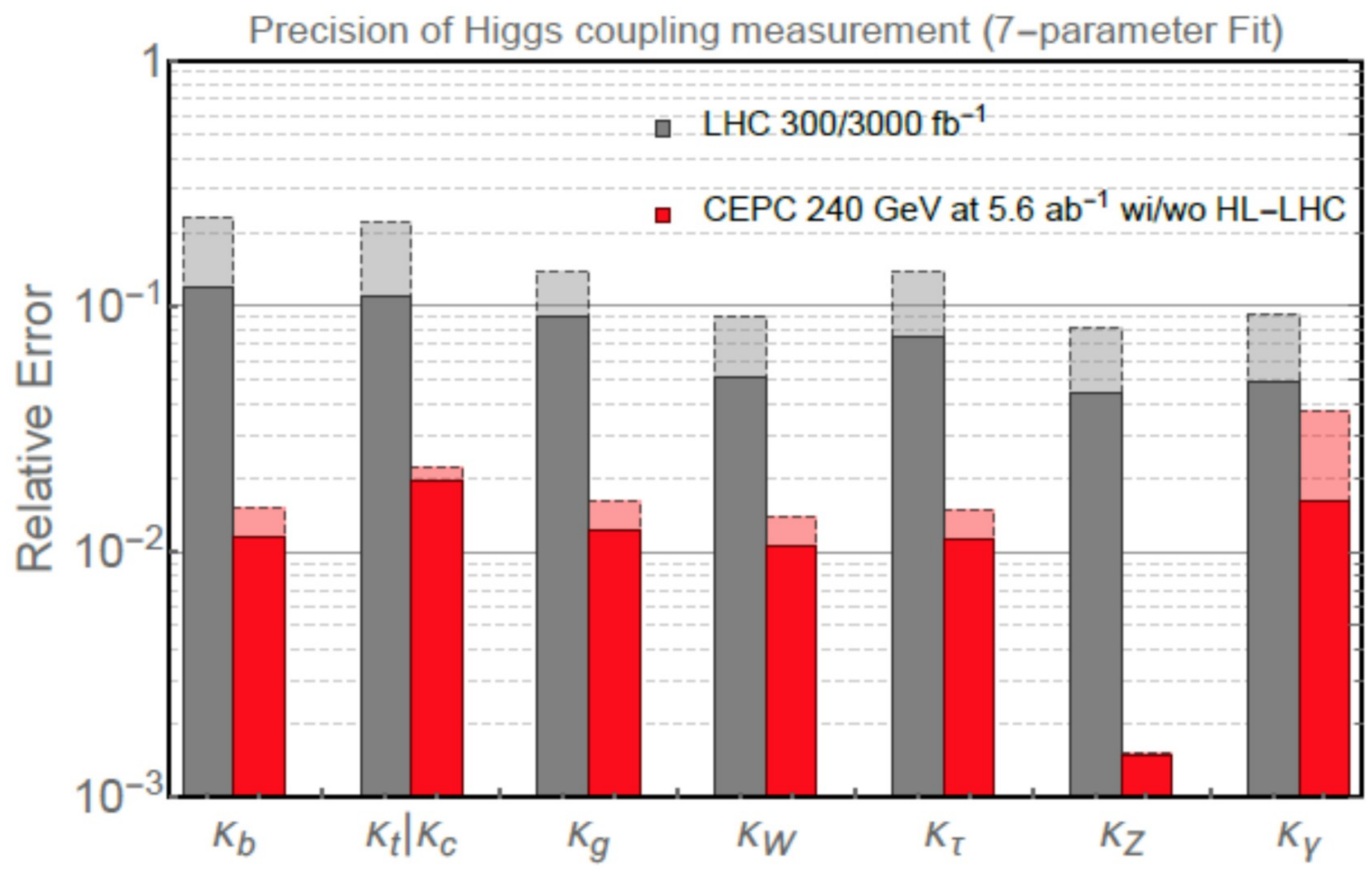
- 3) Combination of results



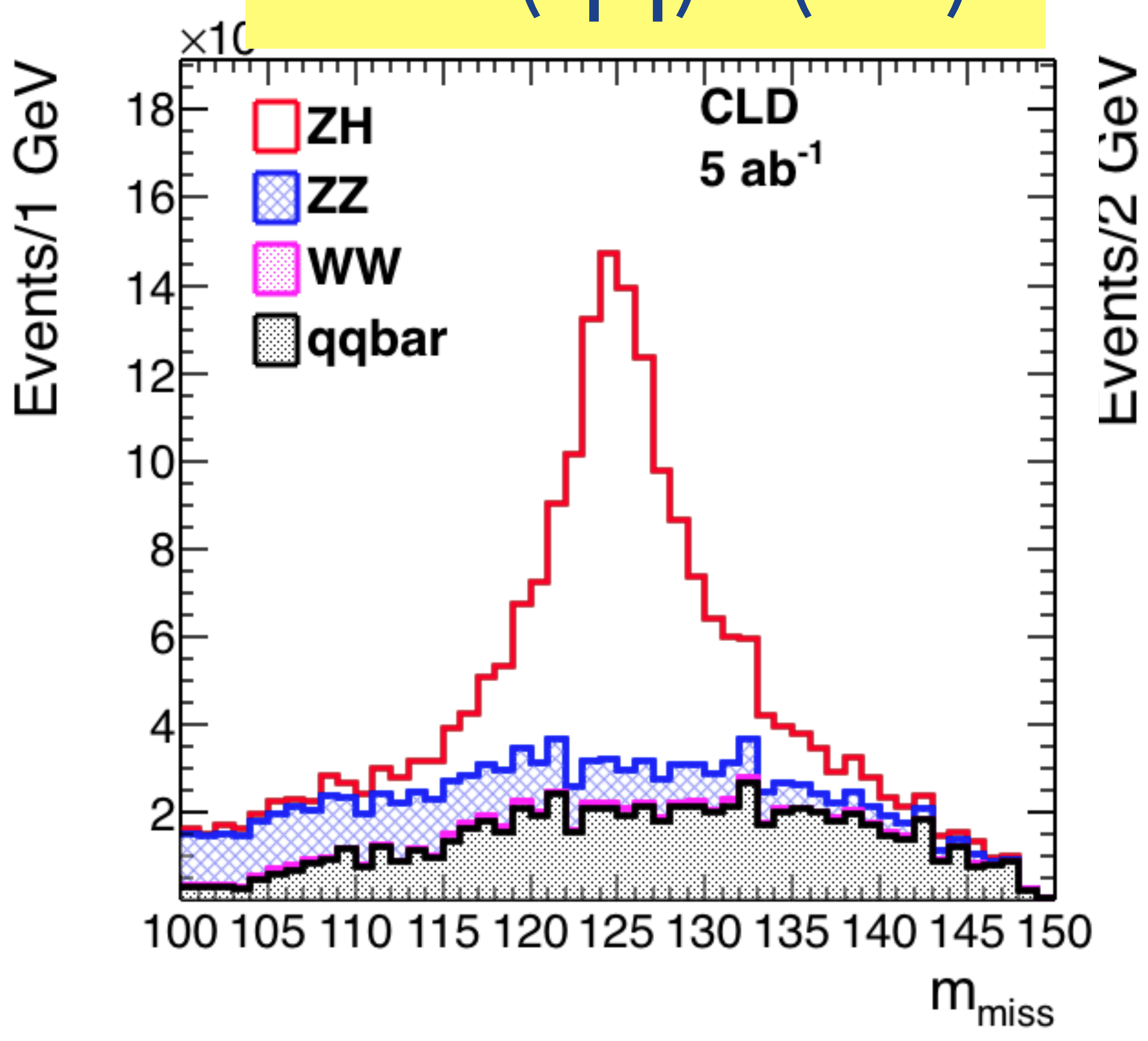


Higgs couplings

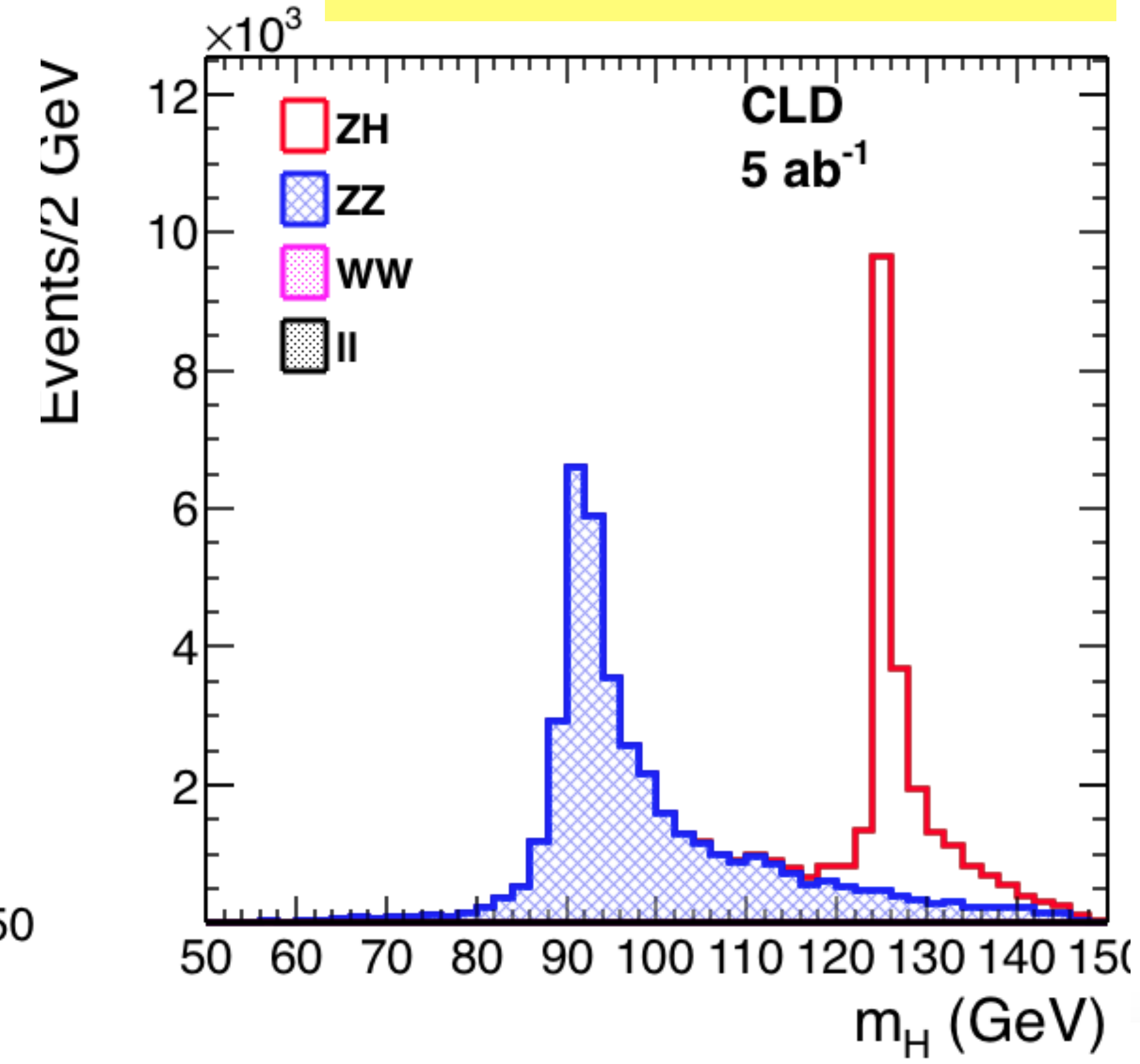
- Absolute coupling measurements enabled by HZ cross section and total width measurement
- **Data at 365 GeV constrains total width** - precision shown for global fit study
- FCC ee Statistical uncertainties are shown for **5 ab^{-1} @240 GeV** and **1.5 ab^{-1} @365 GeV**

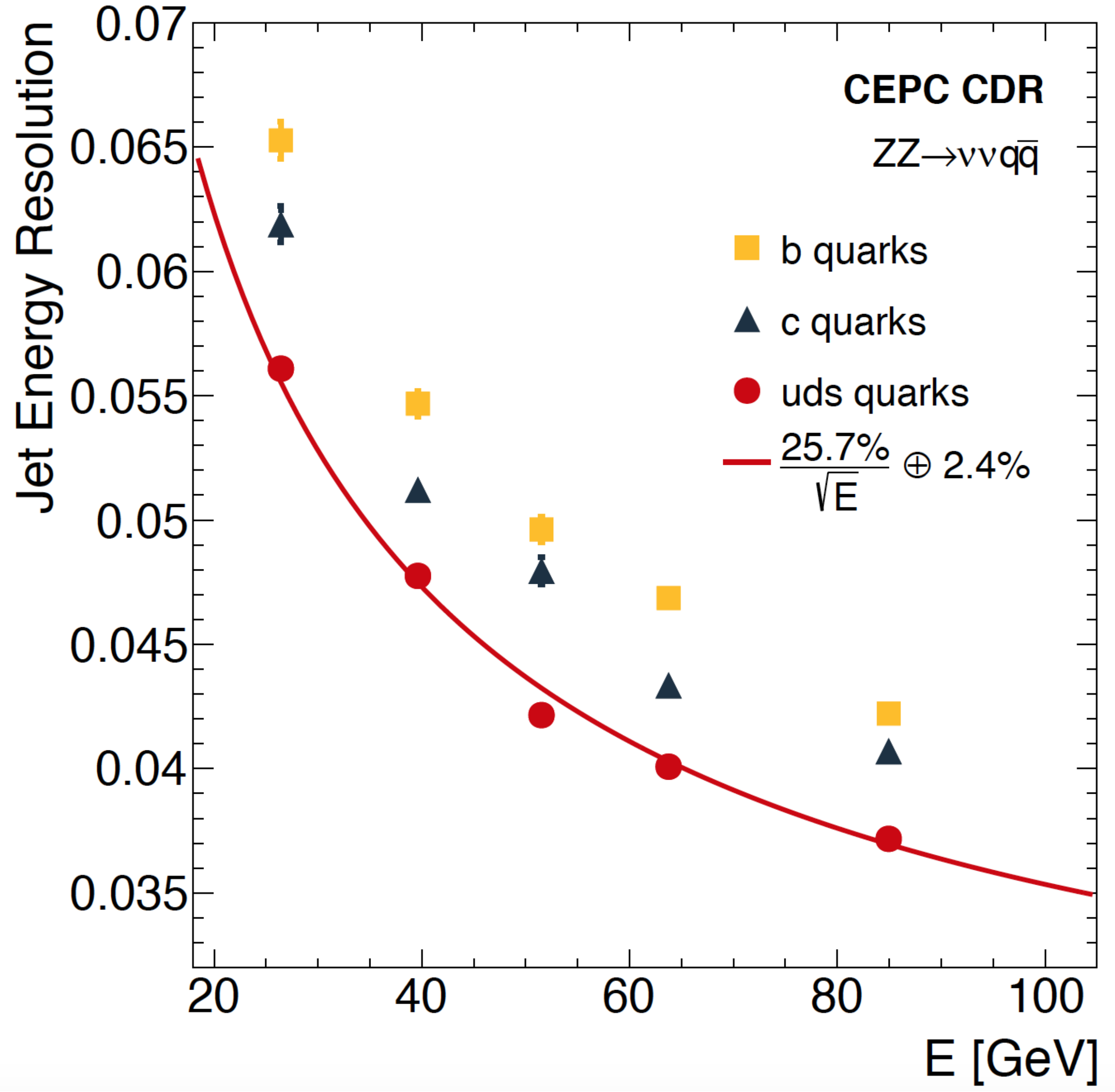


ee→Z(qq)H(bb)



ee→Z(ll)H(bb)

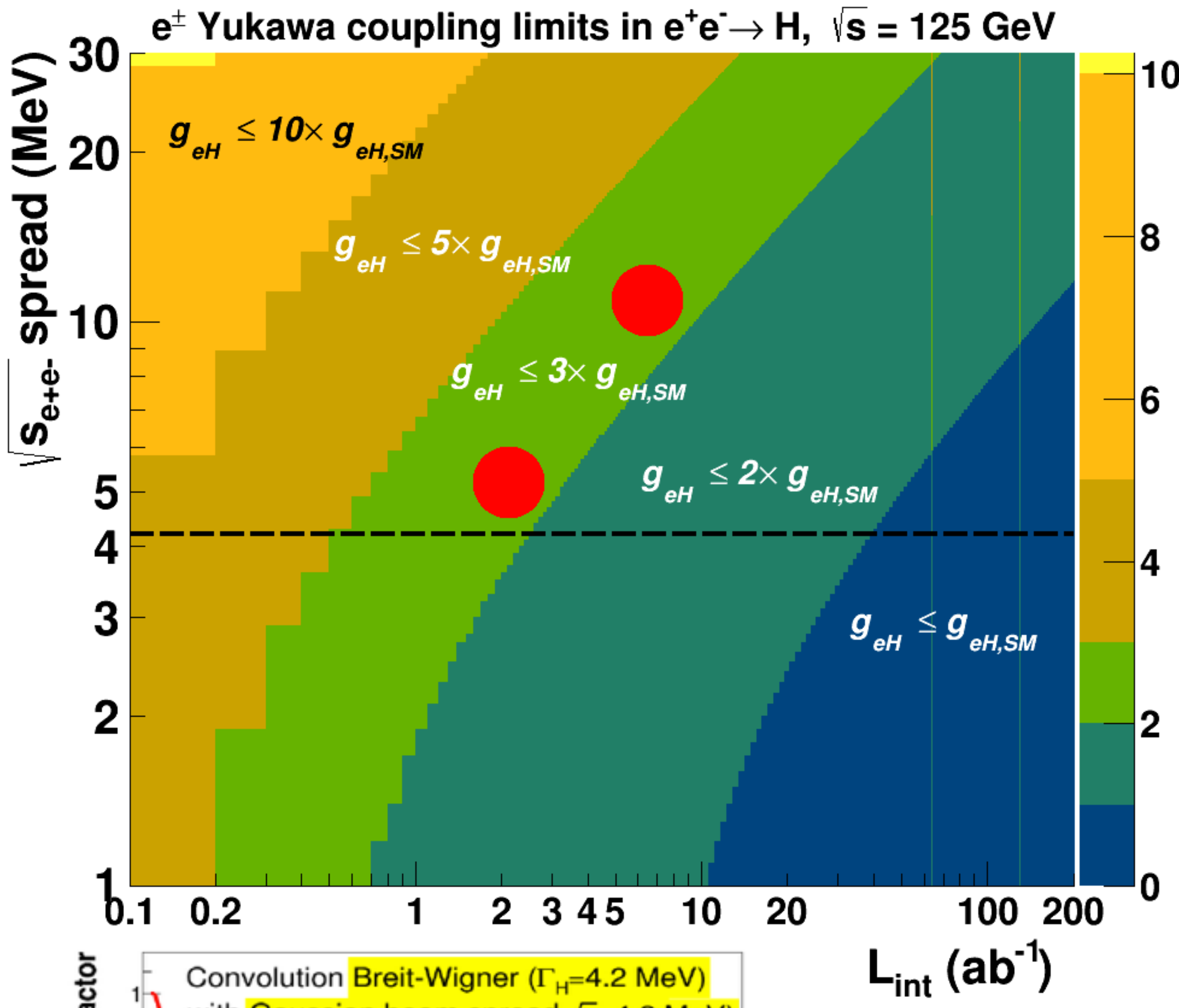


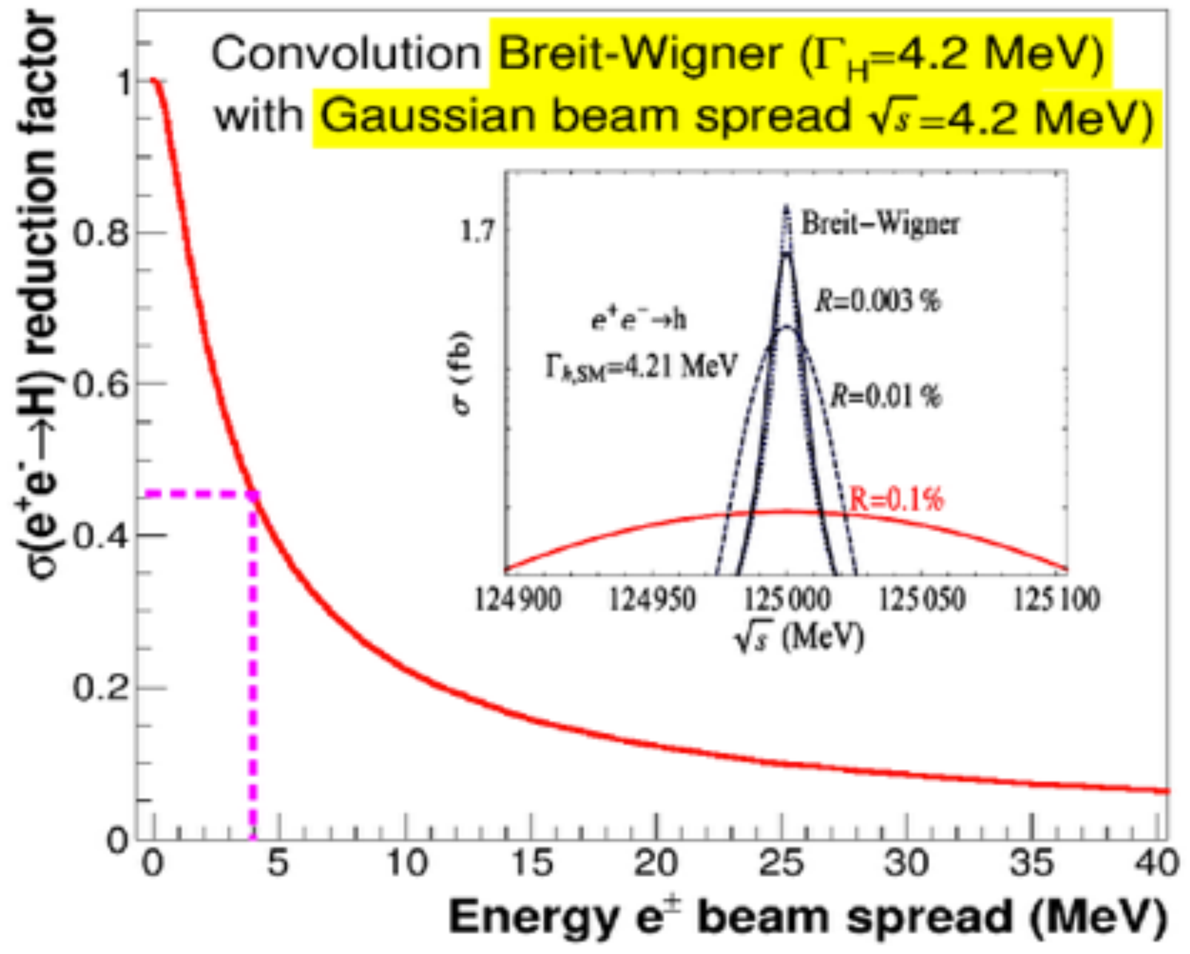


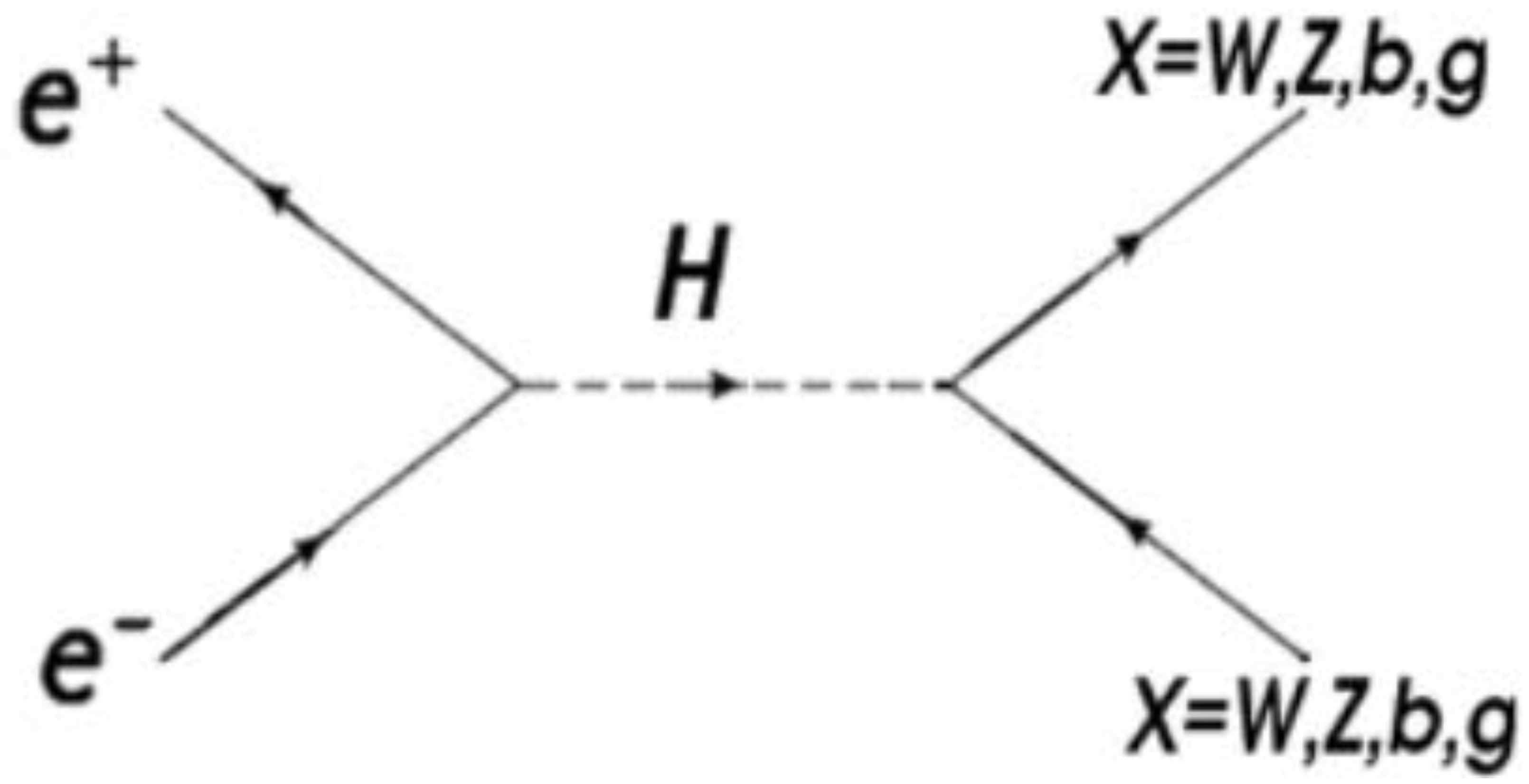
in %	FCC-ee 240 GeV	+FCC-ee 365 GeV	+HL-LHC
δg_{HZZ}	0.25	0.22	0.21
δg_{HWW}	1.3	0.47	0.44
δg_{Hbb}	1.4	0.68	0.58
δg_{Hcc}	1.8	1.23	1.20
δg_{Hgg}	1.7	1.03	0.83
$\delta g_{H\tau\tau}$	1.4	0.8	0.71
$\delta g_{H\mu\mu}$	9.6	8.6	3.4
$\delta g_{H\gamma\gamma}$	4.7	3.8	1.3
δg_{Htt}			3.3
$\delta\Gamma_H$	2.8	1.56	1.3

Higgs s-channel (e-coupling)

- Highly challenging; σ (ee→H) = 1.6 fb
- Studied monochromatisation scenarios
  - Baseline: 6 MeV spread, L = 2 ab^{-1}
  - Optimised: 10 MeV spread, L = 7 ab^{-1}
  - Limit near 3.5 x SM in both cases



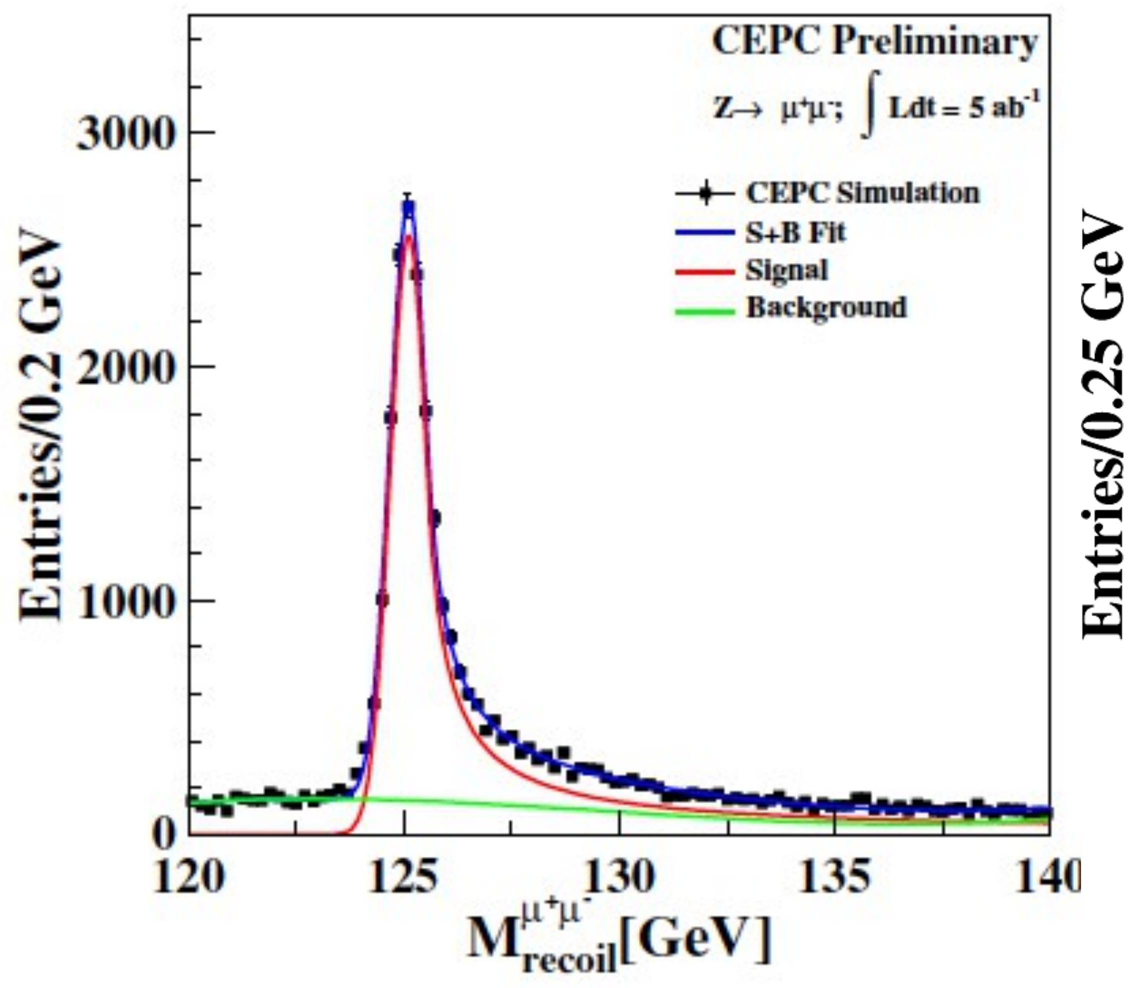


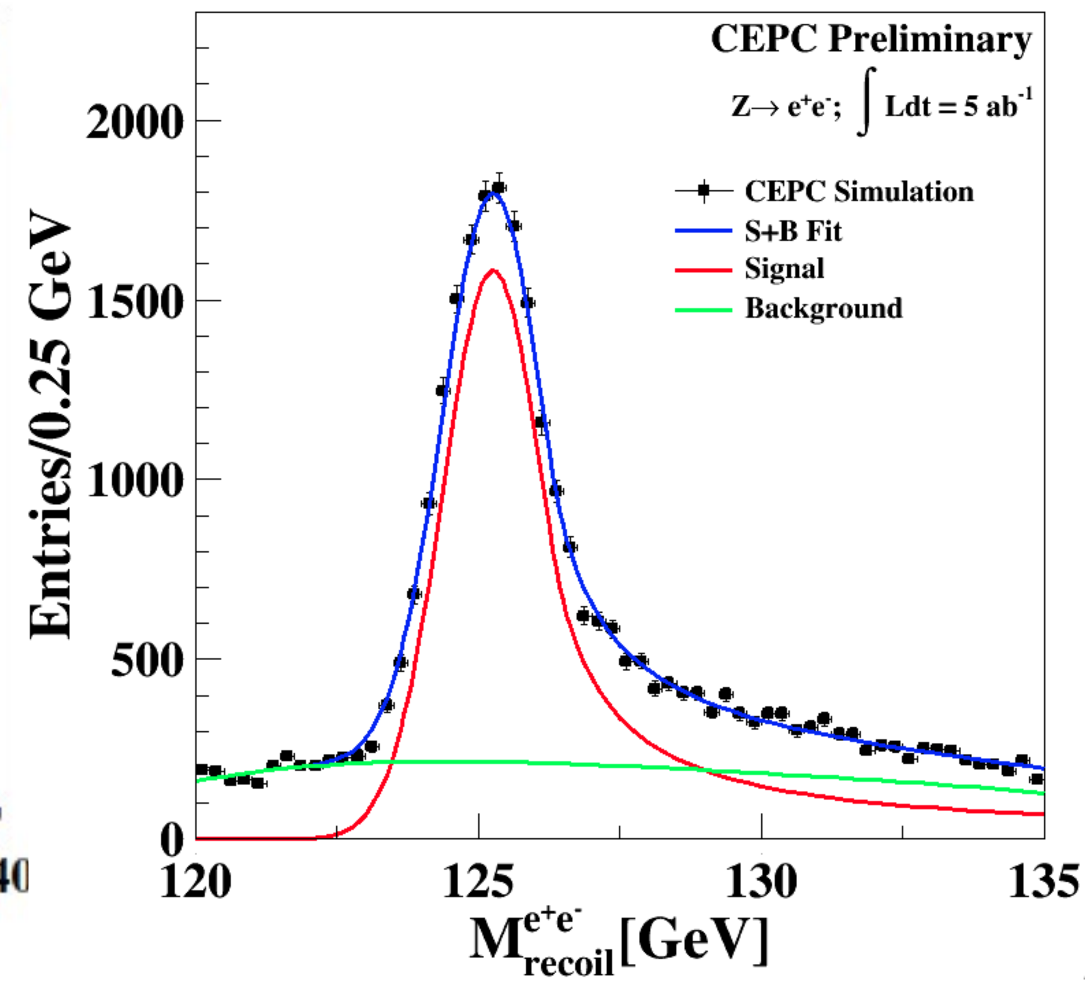


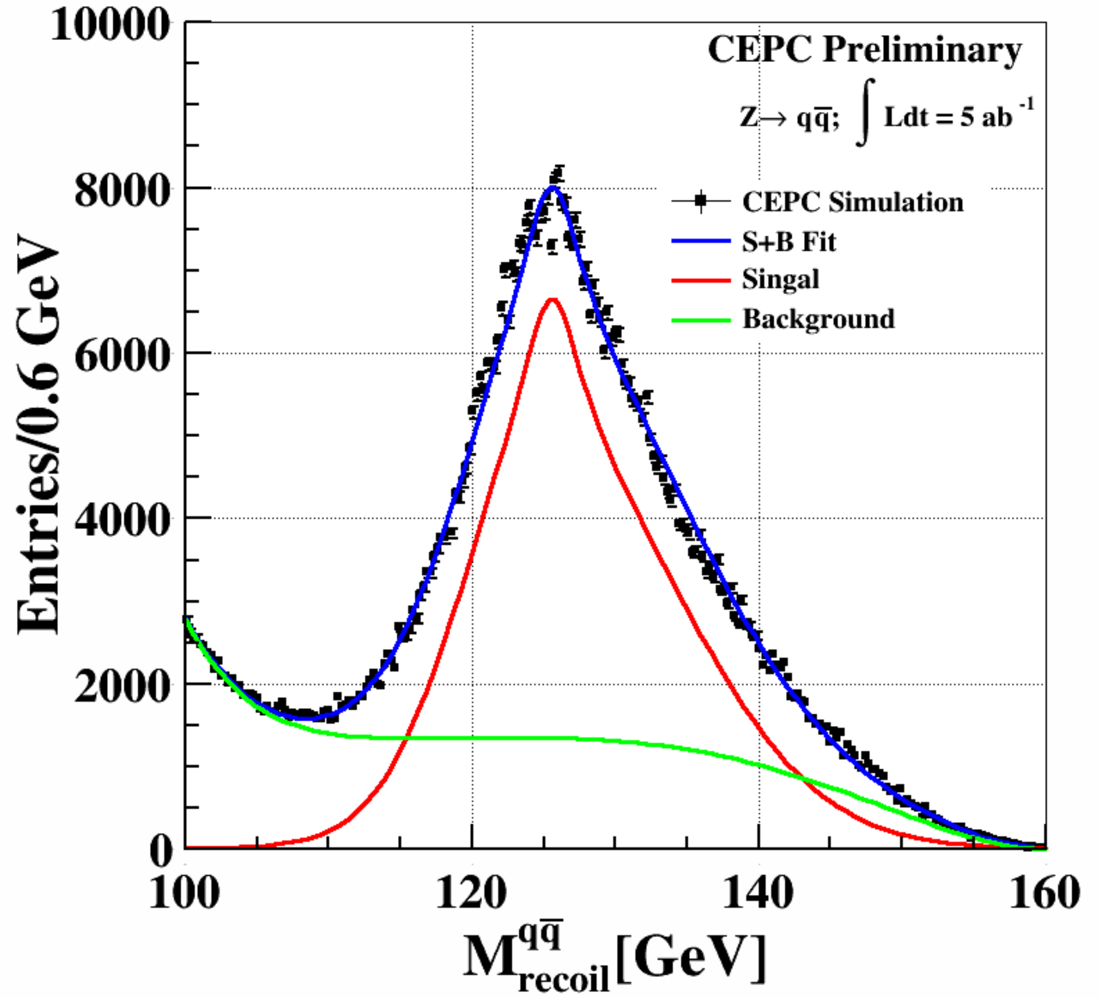
Higgs invisible and BSM

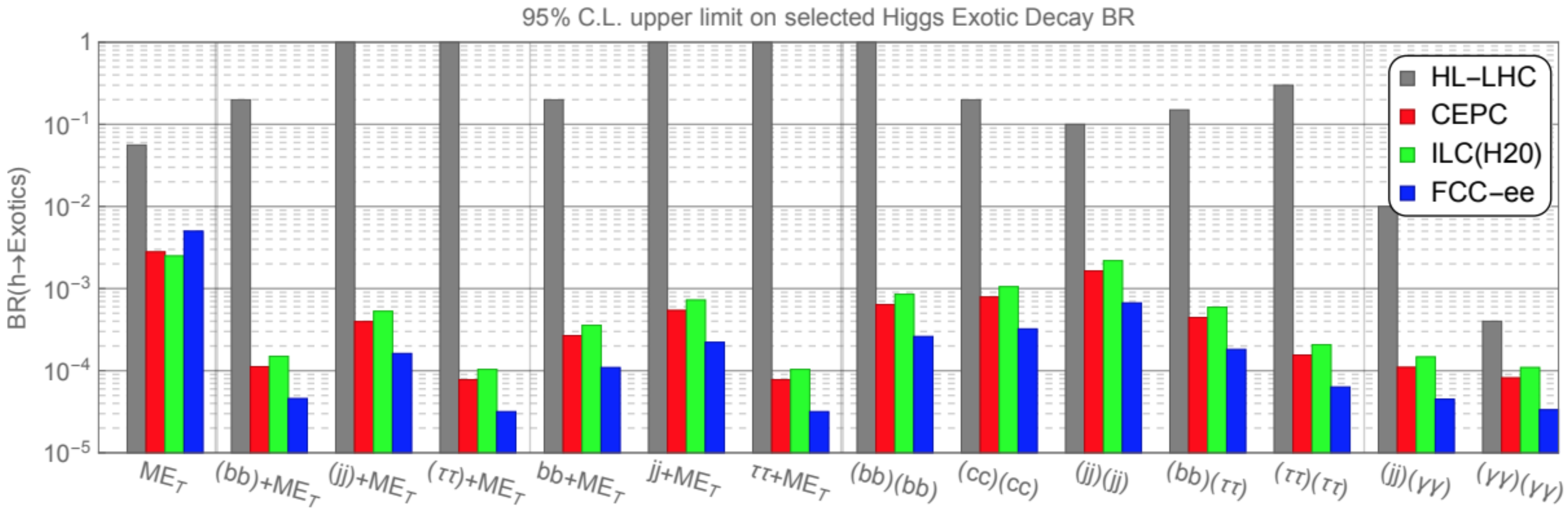
- Higgs boson to invisible decays are predicted for instance in the Higgs - portal model of Dark Matter .

Assuming σ(ZH) x Br(H→invisible)=200 fb



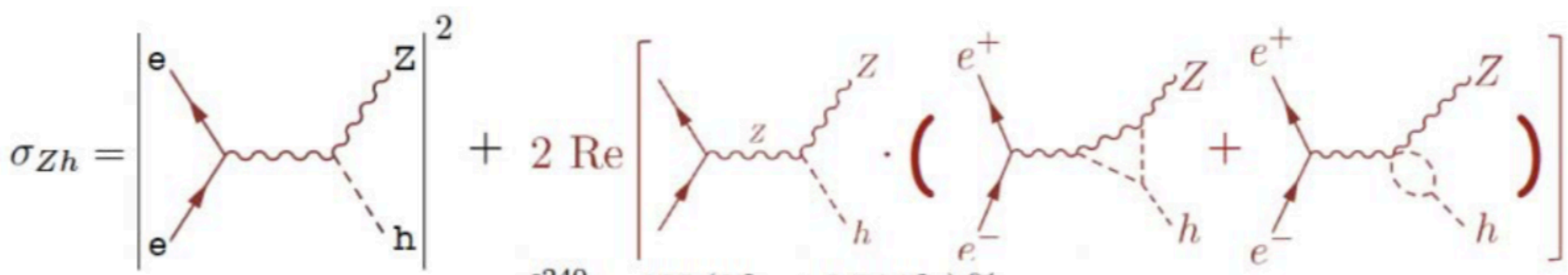




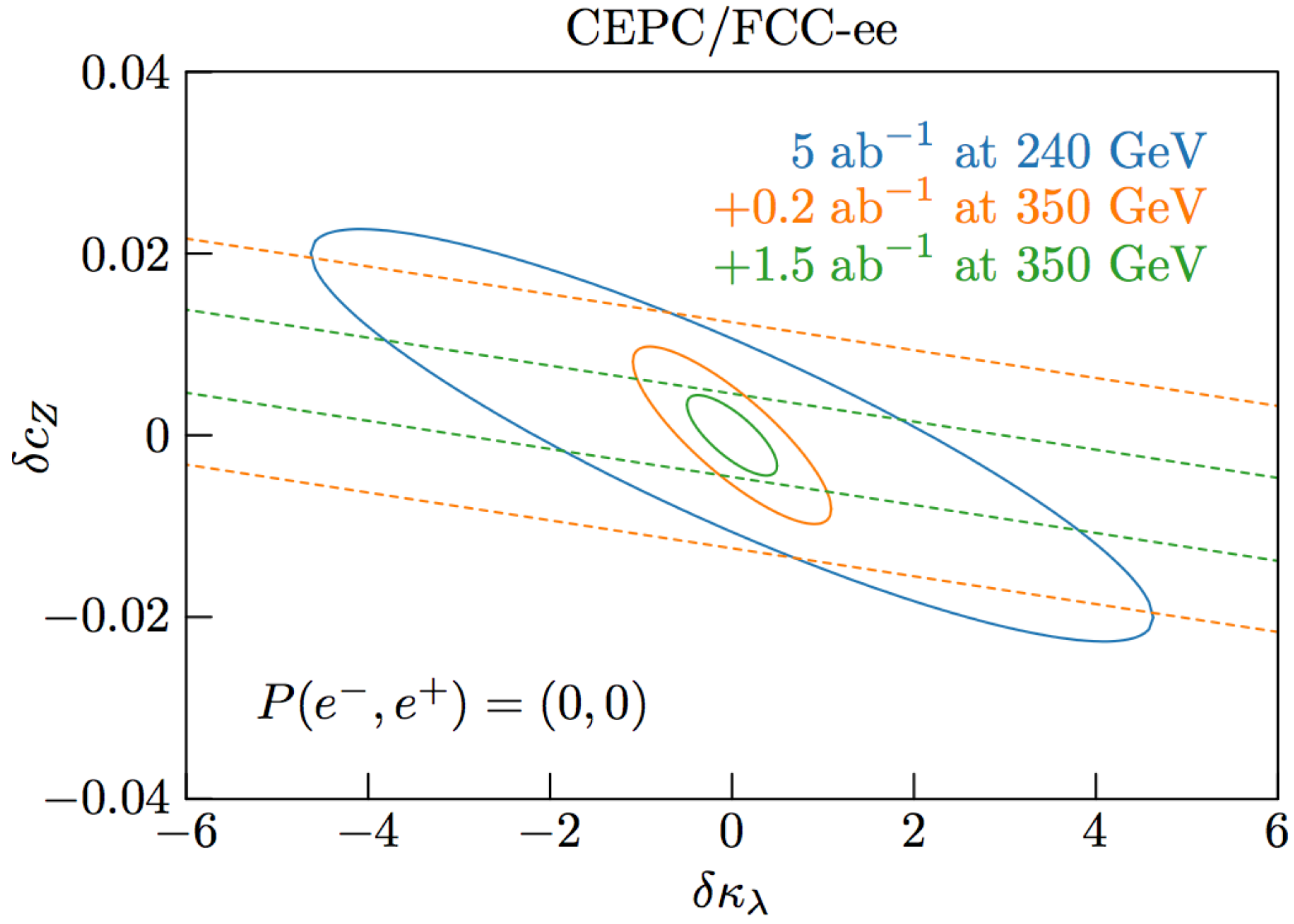


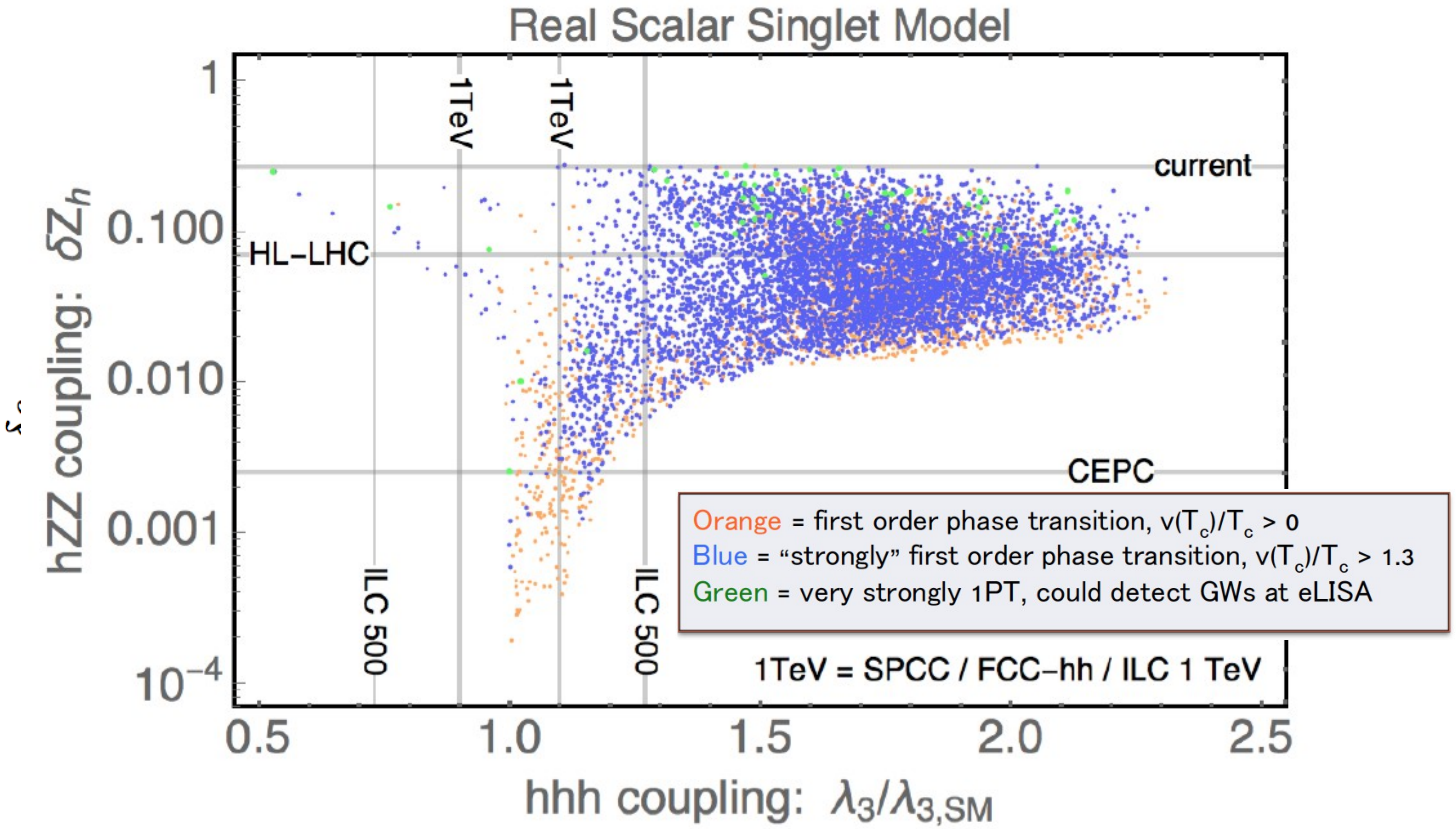
Higgs self coupling & EW phase transition

- Precision on $\delta_{\kappa\lambda}$ of ±40% can be achieved, and of ±35 % in combination with HL - LHC .
- If c_Z if fixed to its SM value, then the precision on $\delta_{\kappa\lambda}$ improves to ±20 %



$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$





Detectors (Requirements)

- 2 baseline detectors (CEPC)
  - ILD like (3 Tesla), Particle flow approach
  - Low magnetic field, calorimeter outside solenoid

Momentum resolution :

- Higgs recoil mass, Higgs coupling to muons, smuon endpoint

$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\mathrm{GeV}^{-1}$ for high-p_T

Impact parameter resolution:

- c/b-tagging, Higgs branching ratios

$\sigma_{r\phi} \sim a \oplus b/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\ \mu m$

a = 5 µm, b = 10-15 µm

Jet energy resolution:

- Separation of W/Z/H in di-jet modes

$\sigma_E/E \sim 3.5\ \%$ for jets above 50 GeV

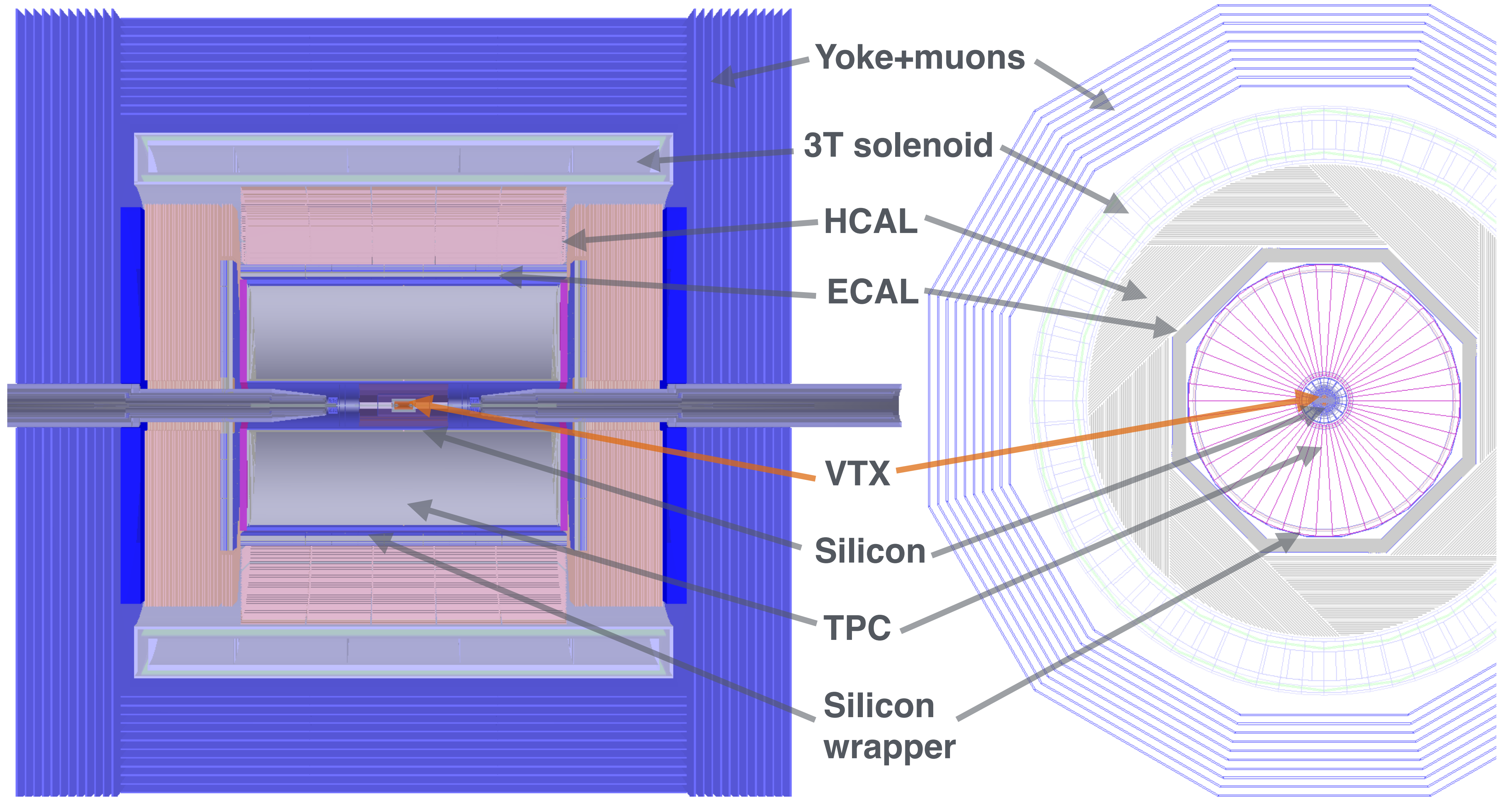
Large angular coverage

- Forward electron and photon tagging

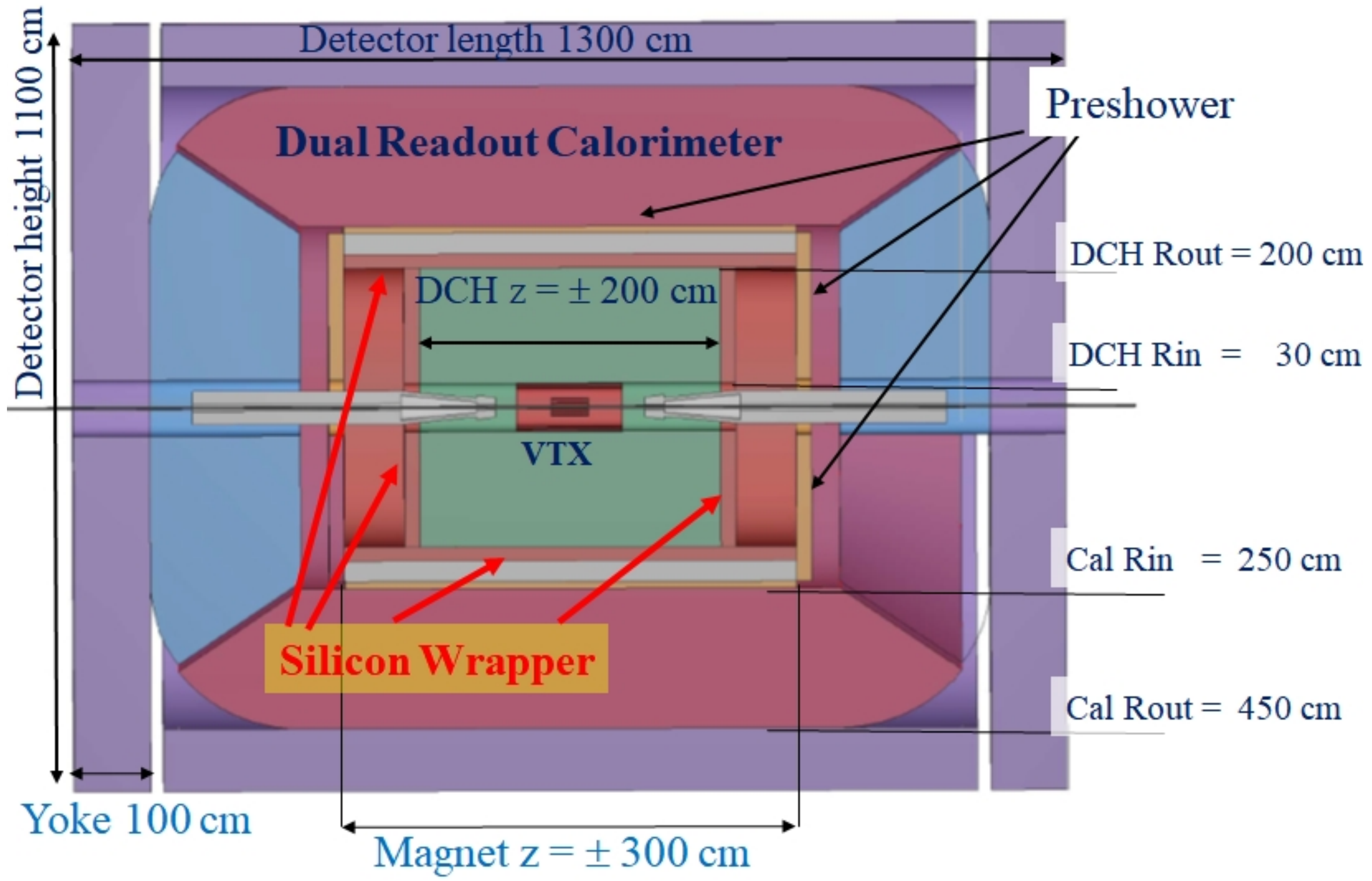
Requirements from beam environment

- Solenoid field, beam structure, beam induced backgrounds

ILD-like



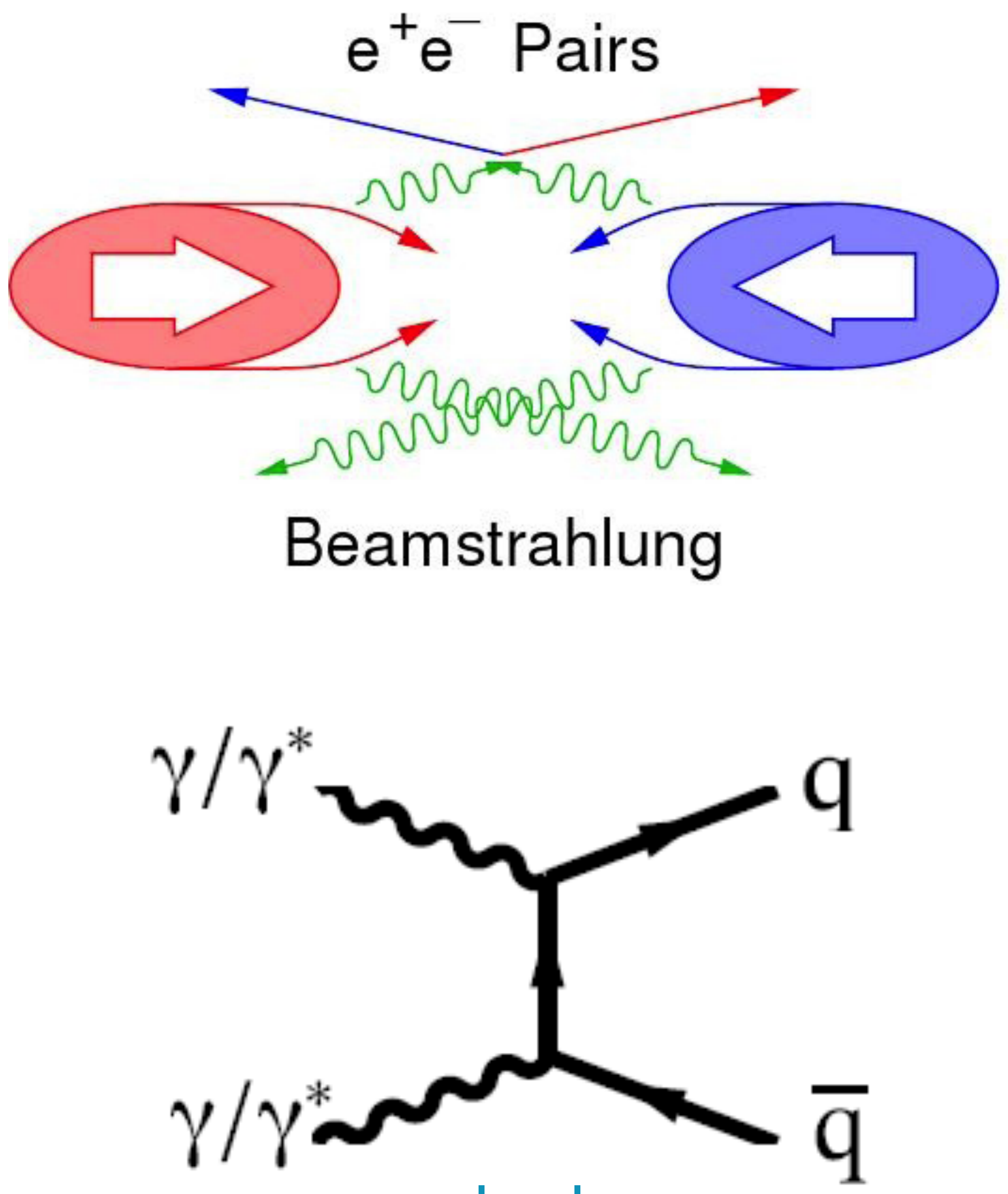
Low B - FCCee



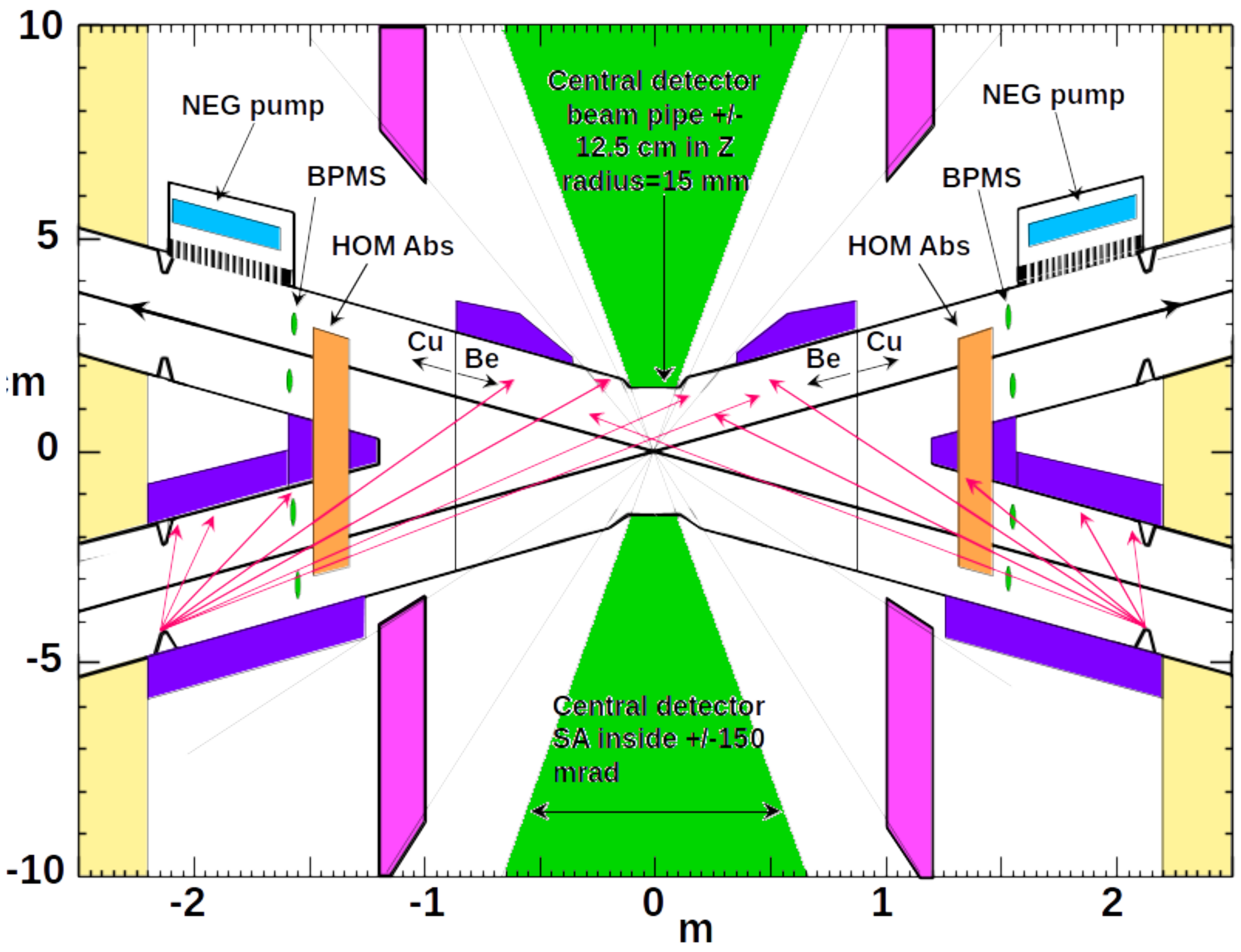
Detector background

- Beam-induced backgrounds dominating source of radiation damage
- Hadronic radiation damage only relevant in very forward detectors

- Shielding added to prevent synchrotron radiation/secondary radiation to enter the detector
- Cooling / extra material required near IP.



$\gamma\gamma \rightarrow$ hadrons



Vertex reconstruction & Silicon detectors

Large surfaces: ~ 1 m²

Single point resolution → **Pixel pitch**
σ < 3 – 5 μm → **~ 16 – 25 μm**

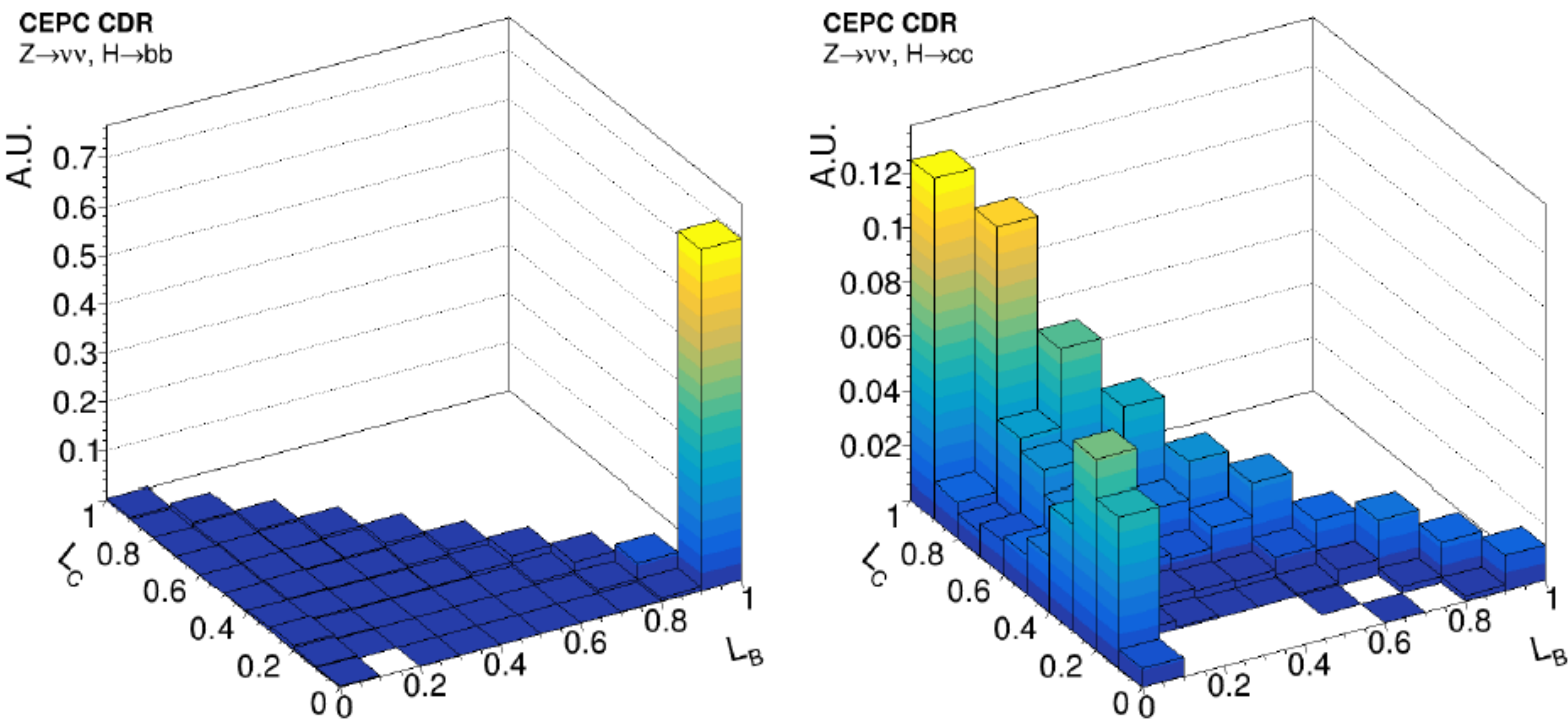
Low material budget
< 0.1 — 0.3%X_0 per layer
→ **Thin sensors and ASICs**
Light-weight support
→ **Power pulsing (LC)**
Air cooling
↓
Low power dissipation
≤ 50 mW/cm²

Time stamping
~10 ns (CLIC)
~300 ns — μs (ILC/CC)

Typical Performance at Z pole sample:

B-tagging:
eff/purity = 80%/90%

C-tagging:
eff/purity = 60%/60%



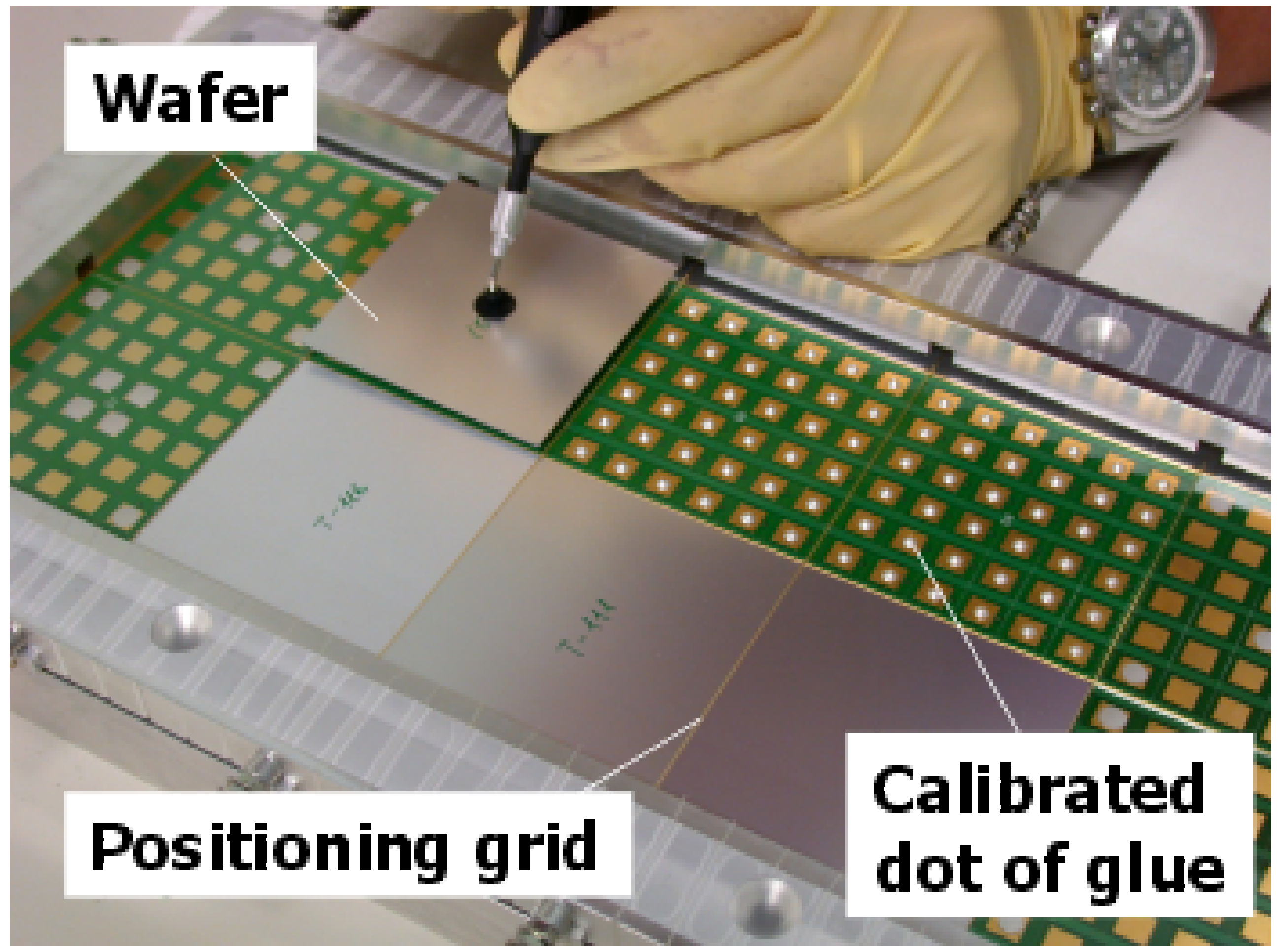
Circular colliders: continuous operation → more cooling → more material

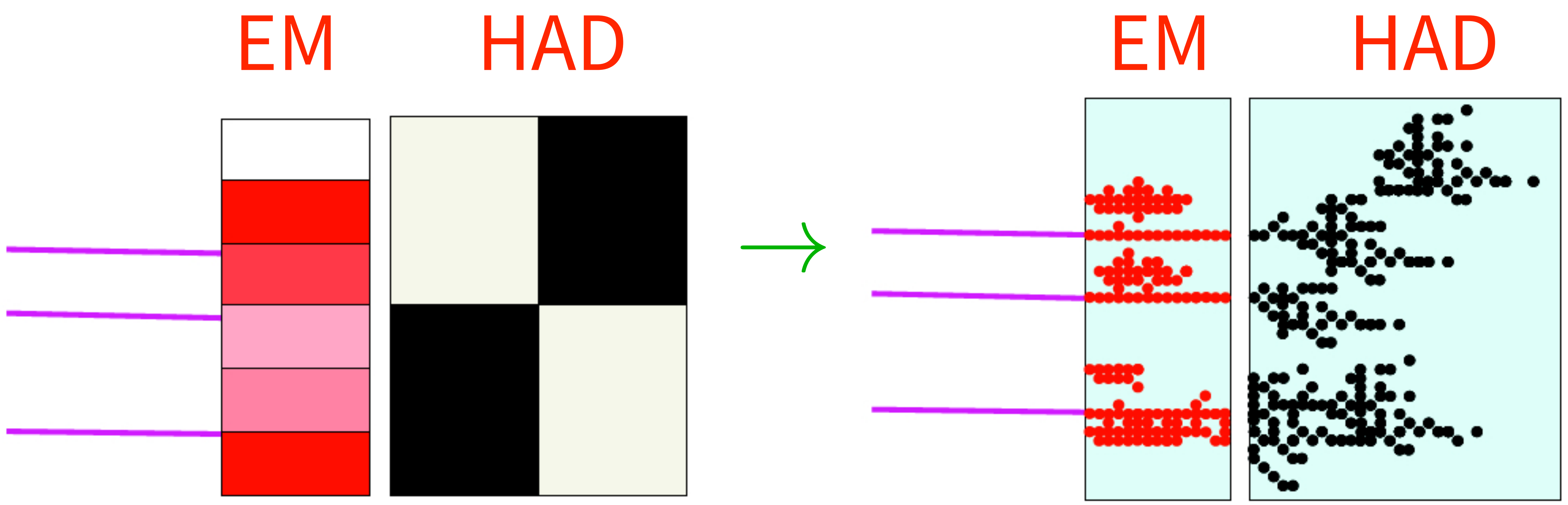
CLICPix, MAPS, ALPIDE CMOS + Carbon nanotubes, Graphene support etc.

Detector calorimetry

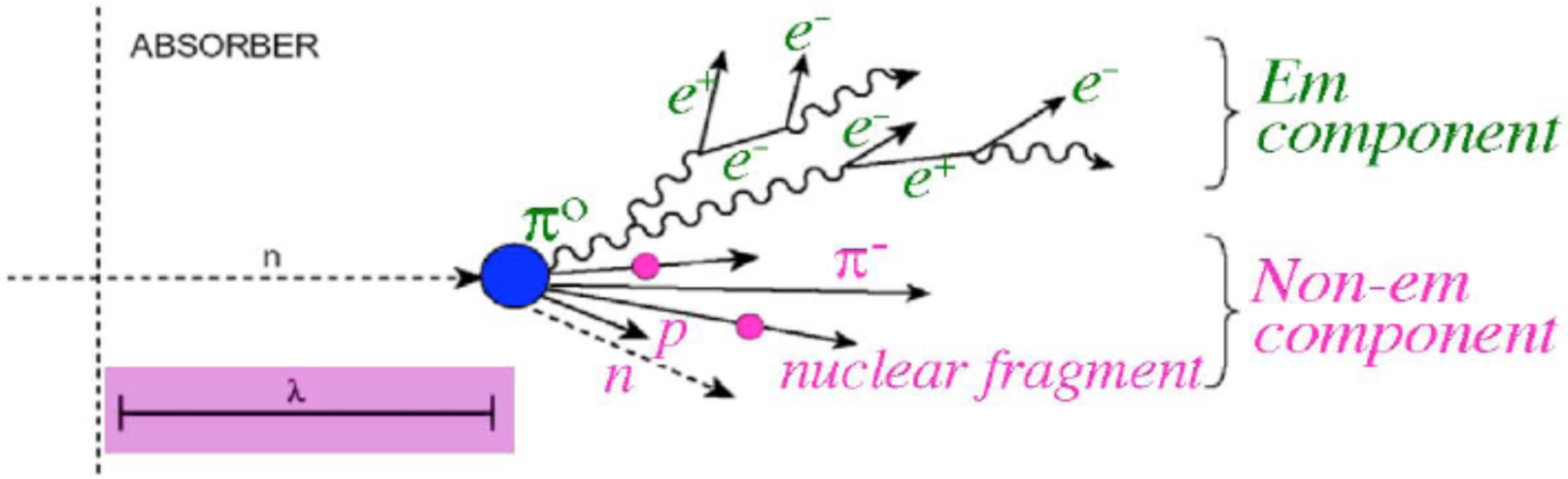
- Particle flow calorimeter - high granularity.

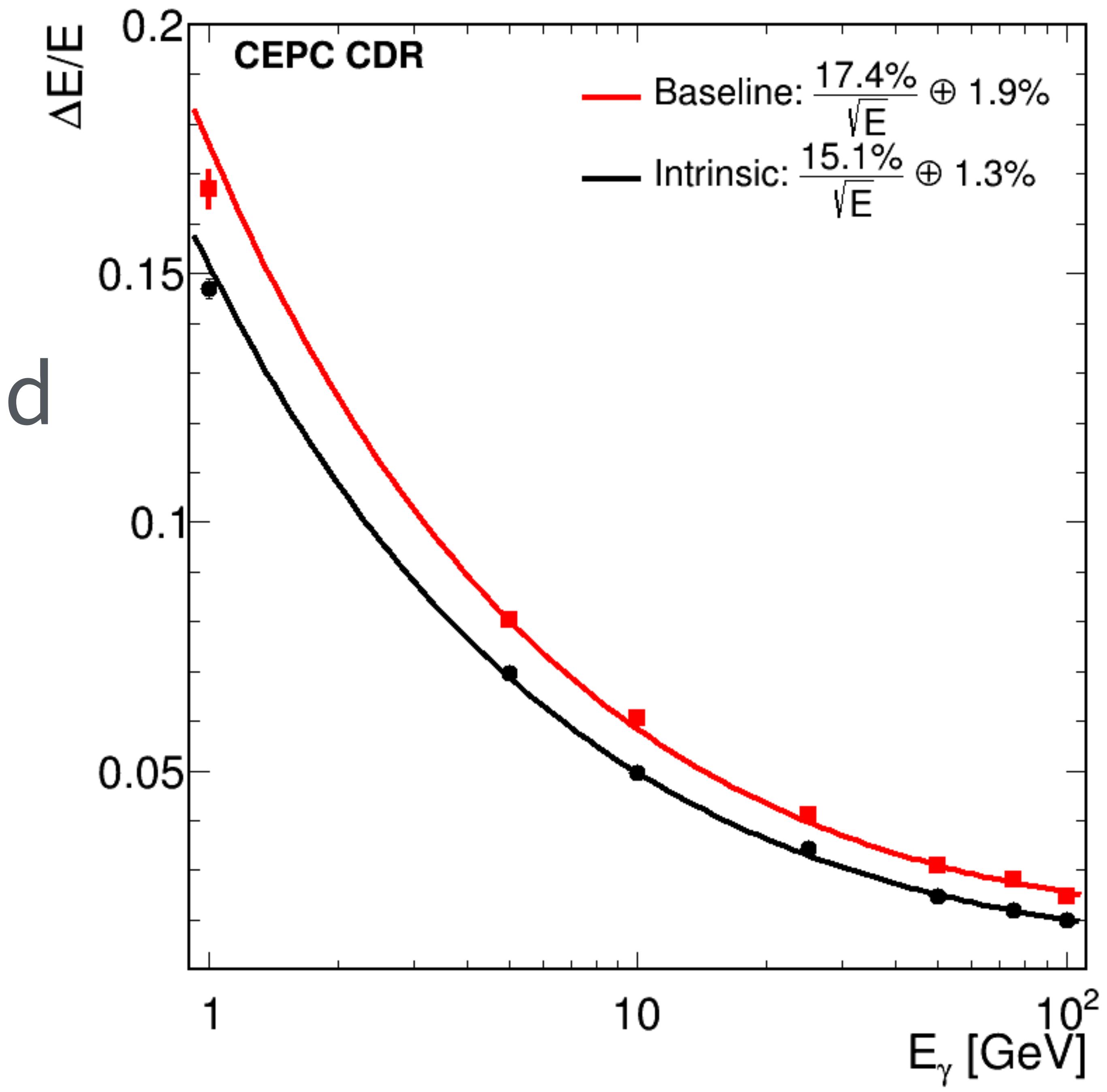
Silicon PIN diodes ($1 \times 1\,\mathrm{cm}^2$ in 6×6 matrices)

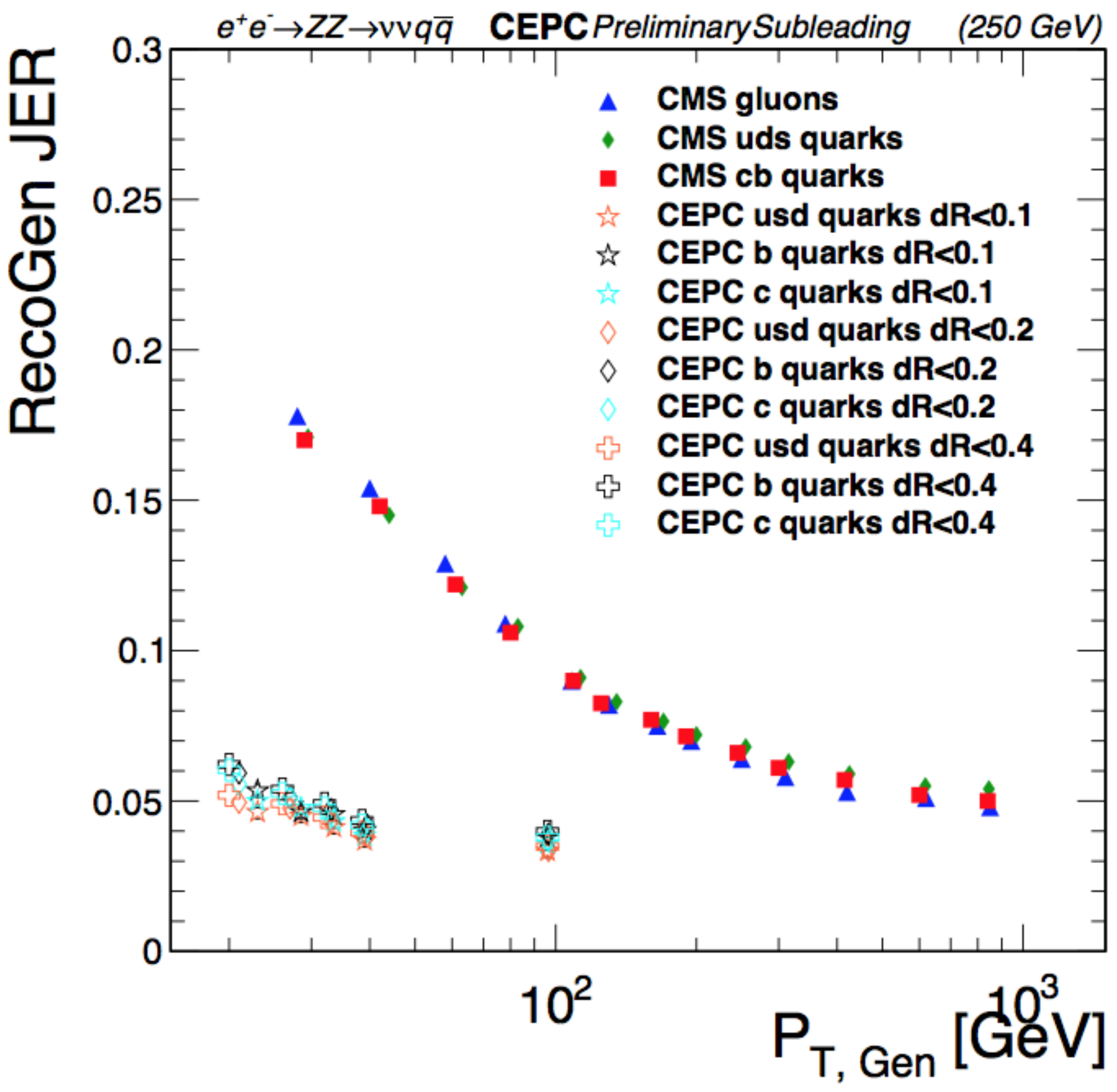




- Dual readout calorimeter measures both:
  - EM & non-EM component, Cherenkov and scintillator (DREAM / RD52)

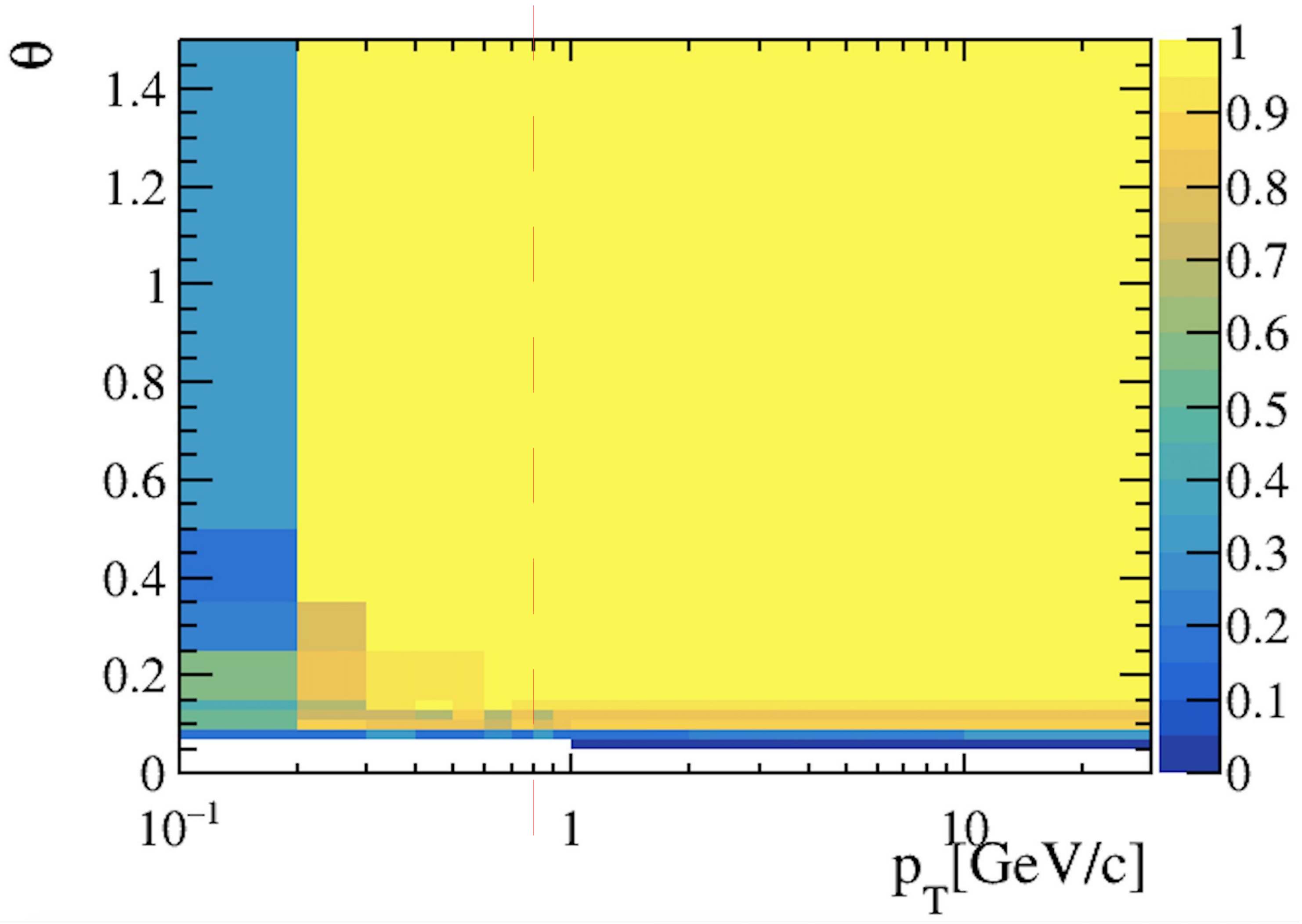


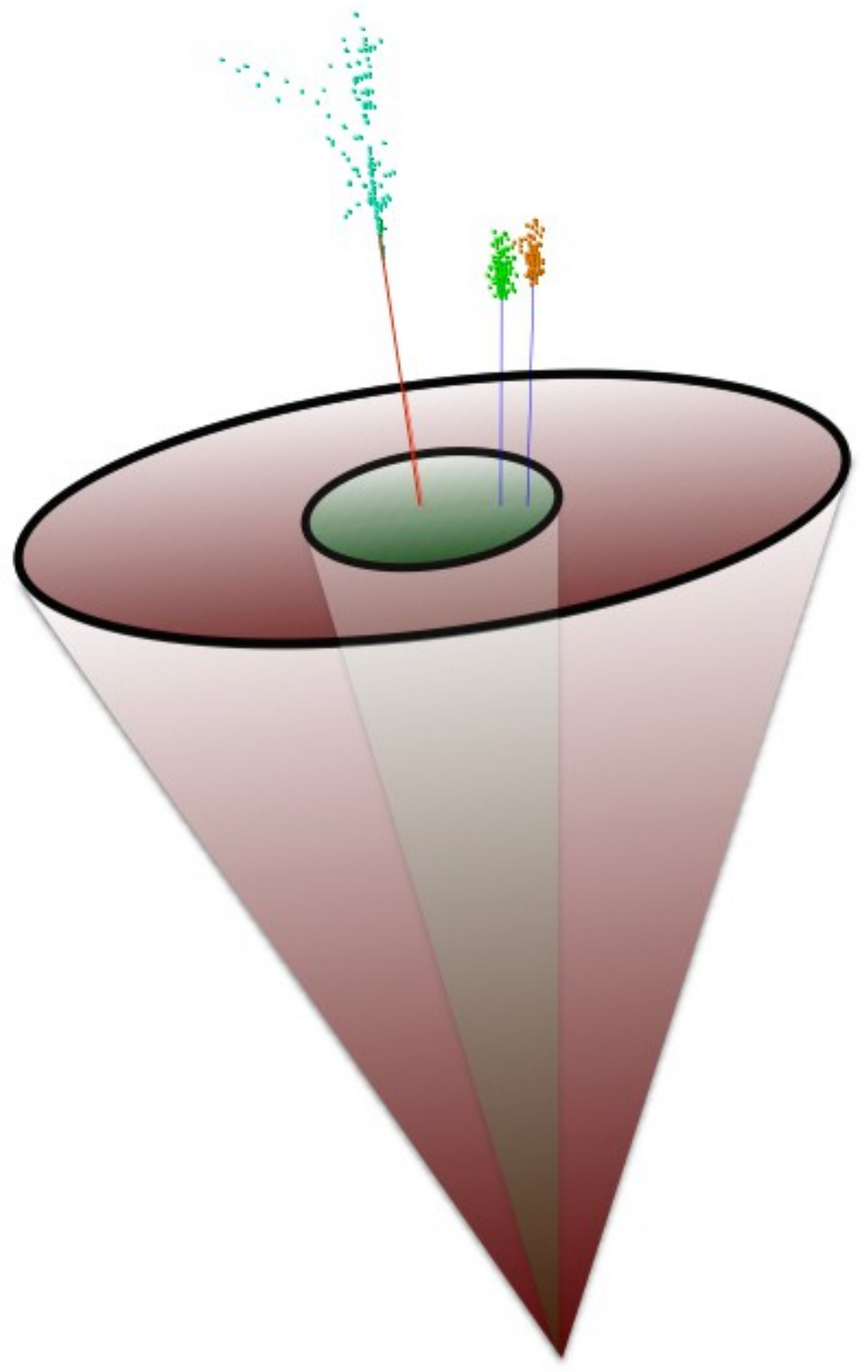


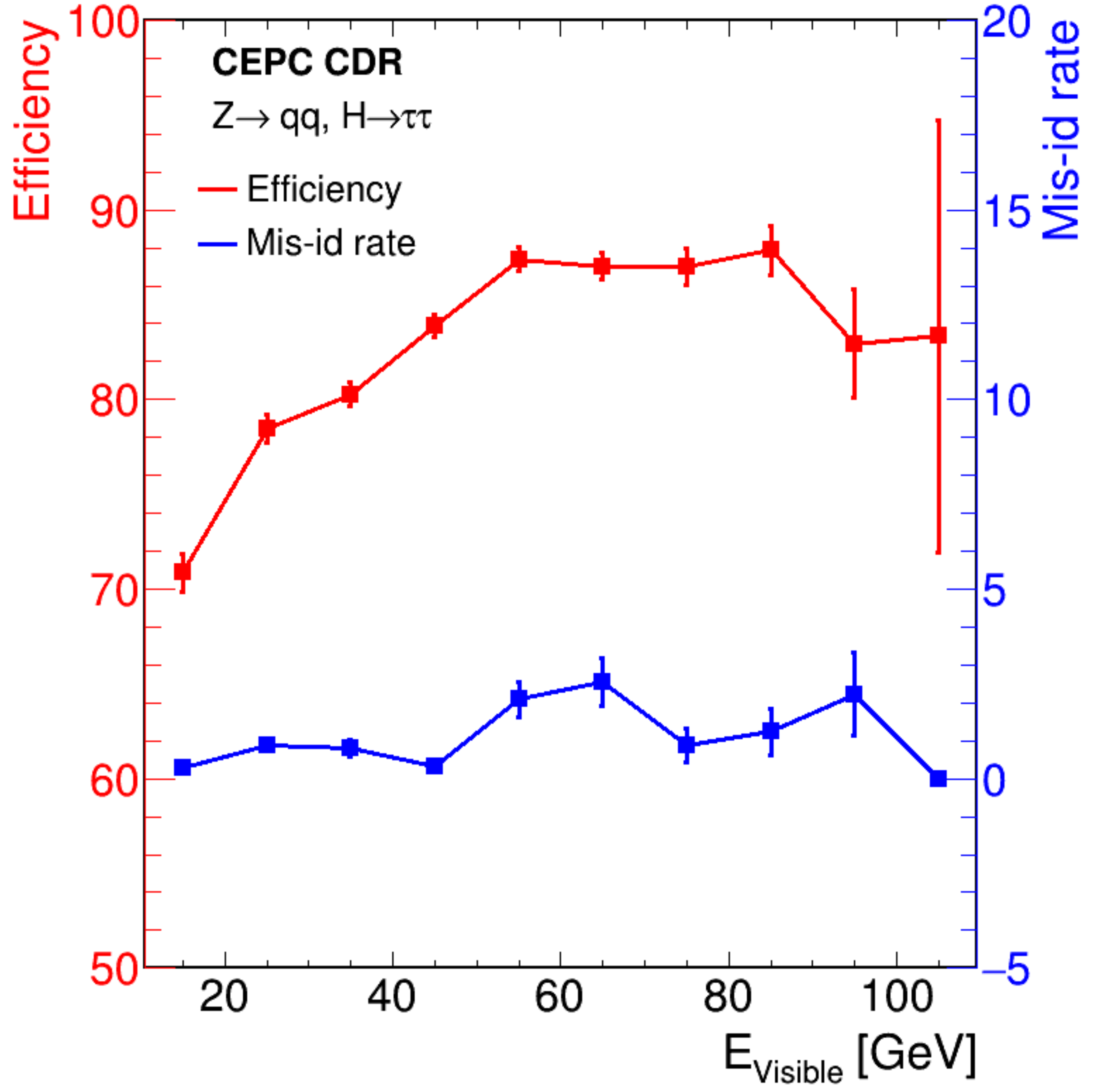


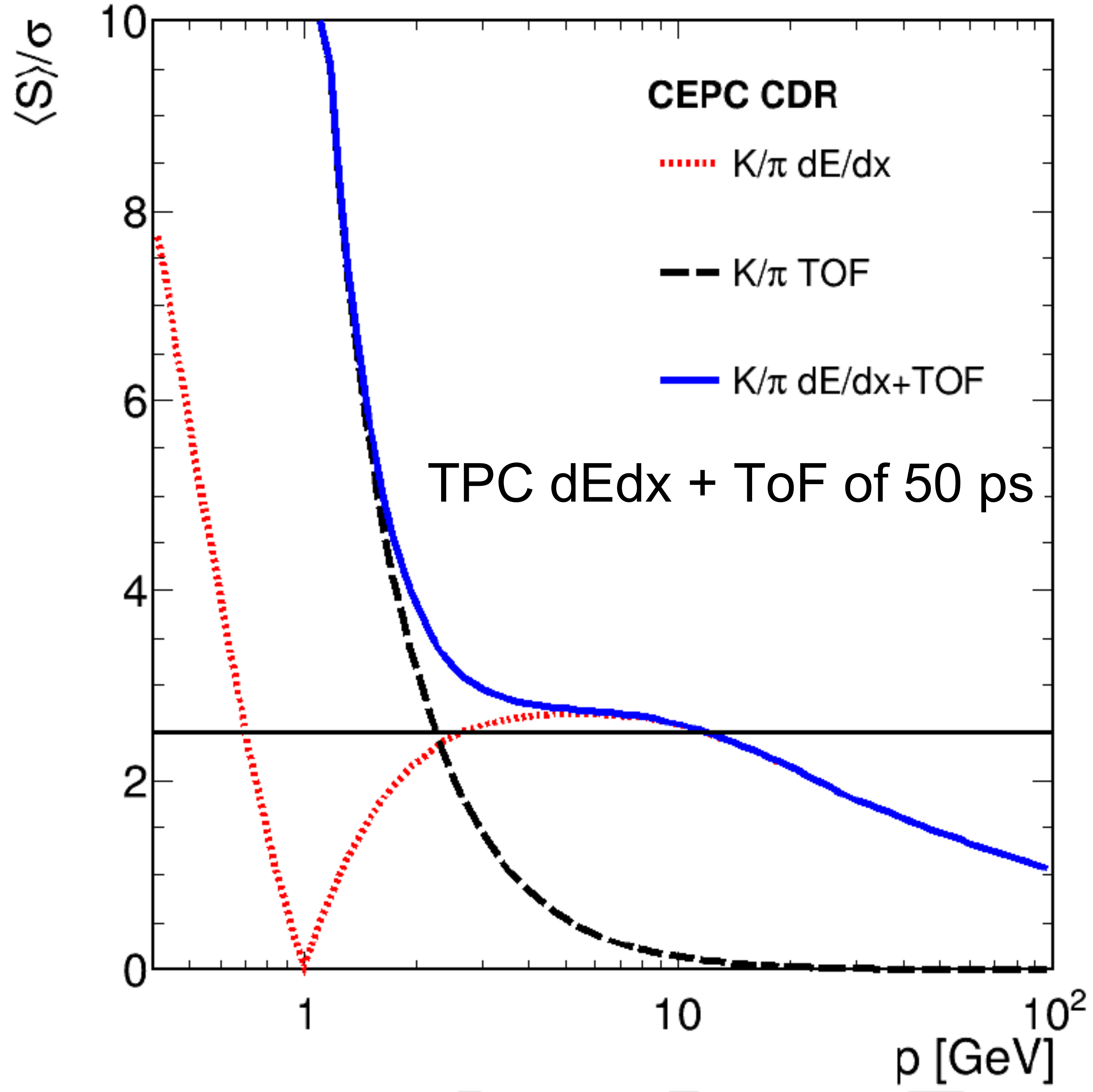
CEPC Particle reconstruction

- Good tracking efficiency down to 200 MeV
- Particle ID (K / π) separation from TPC dE/dx and ToF.
- τ-ID using τ-cone algorithm.









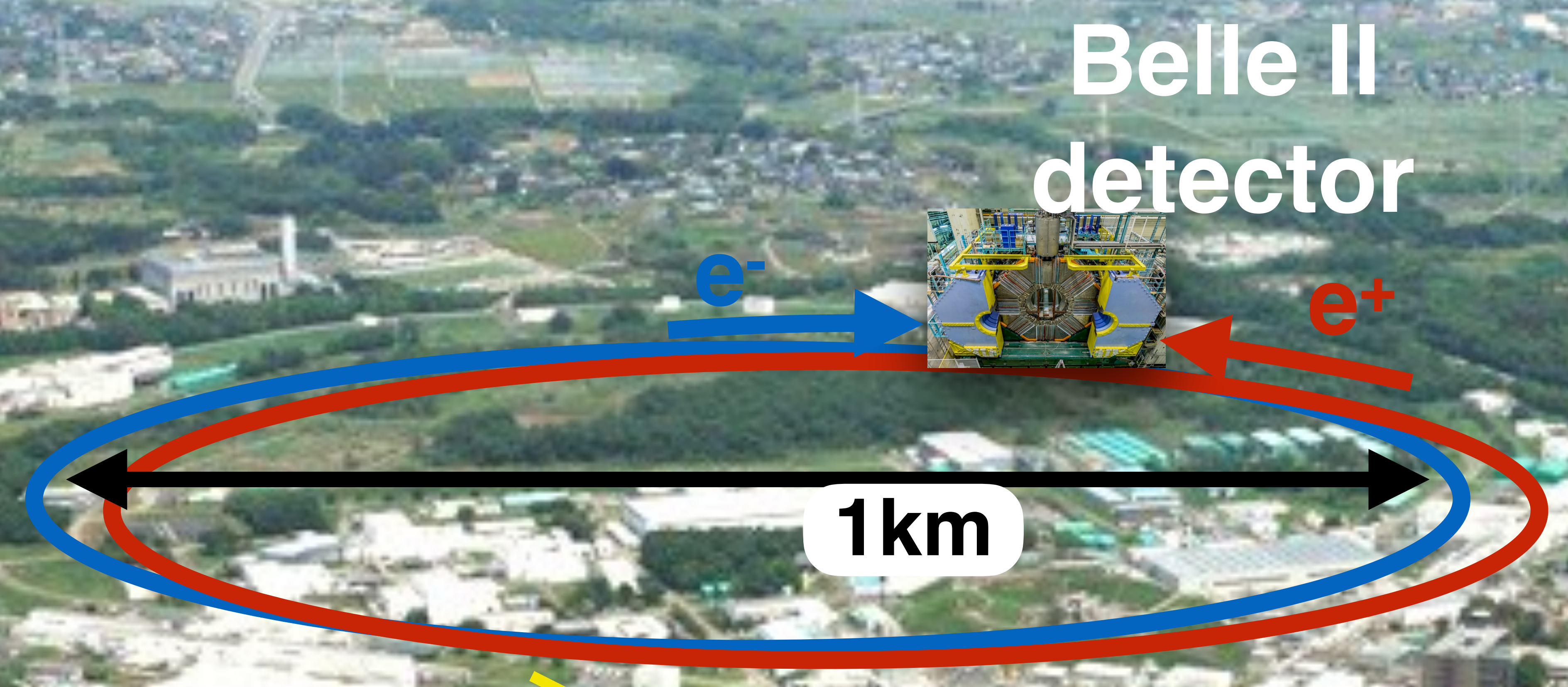
Flavour program overview

- B, D, τ: CKM metrology, rare and missing energy decays, quarkonia, dark sectors.
  - SuperKEKB is the first new major collider since the LHC.
  - Also planning for a super τ - charm factory.

Expt.	∫ *L* dt	σ(bb)	σ(cc)	σ(ττ)	Operation
Babar	530 fb^{-1}	1.1 nb	1.6 nb	0.9 nb	1999-2008
Belle	1040 fb^{-1}	1.1 nb	1.6 nb	0.9 nb	1999-2010
Belle II	**0.5 fb^{-1} (50 ab^{-1})**	**1.1 nb**	**1.6 nb**	0.9 nb	**2018-**
BESIII	~16 fb^{-1}	-	6 nb (3770 MeV)	3.6 nb (4250 MeV)	2008-
LHCb	1 + 2 + >5 fb^{-1}	250-500 μb	1200-2400 μb		2009-

Belle II @ Super-KEKB

Intensity frontier B-factory experiment, Successor to Belle @KEKB (1999-2010)

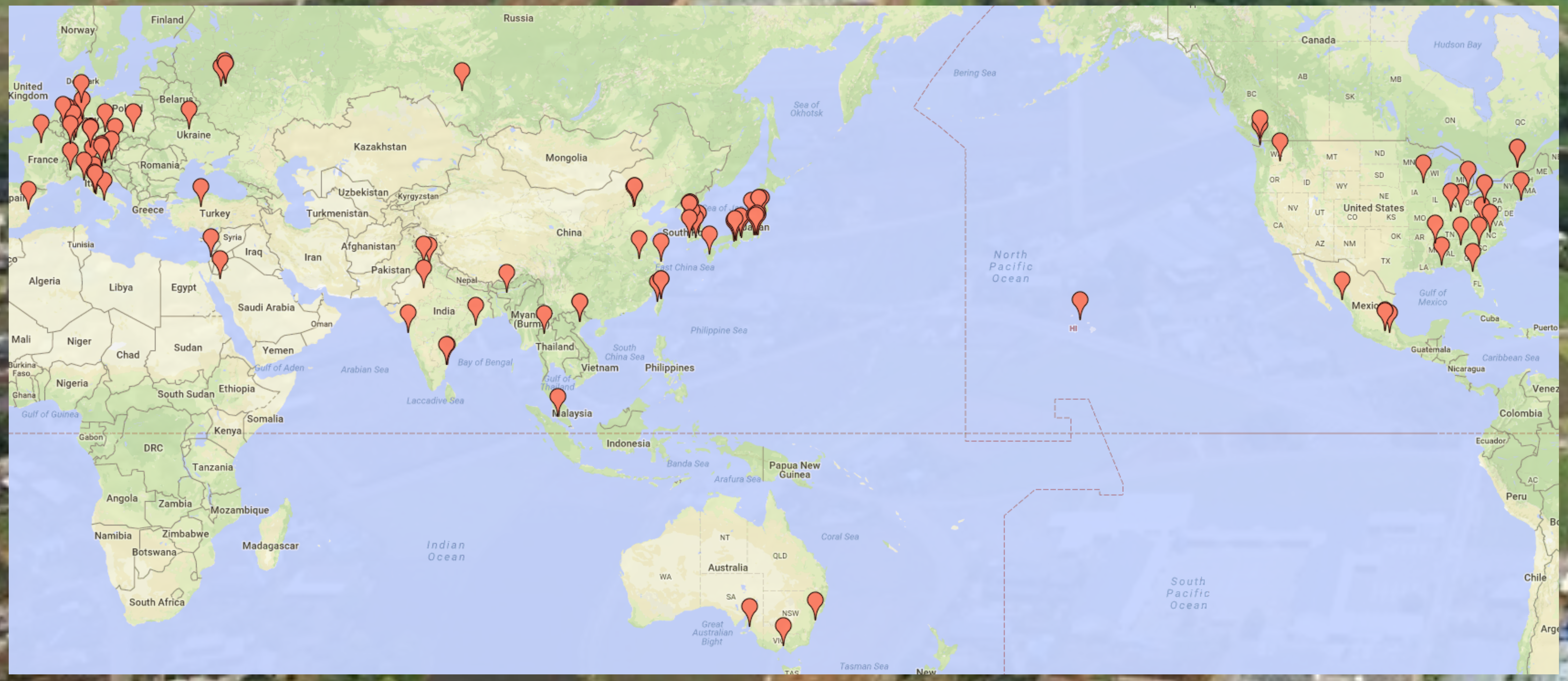


7 GeV e^-, 4 GeV e^+

E_{CM} Y(4S) = 10.58 GeV + scans

Y(4S) → B anti-B

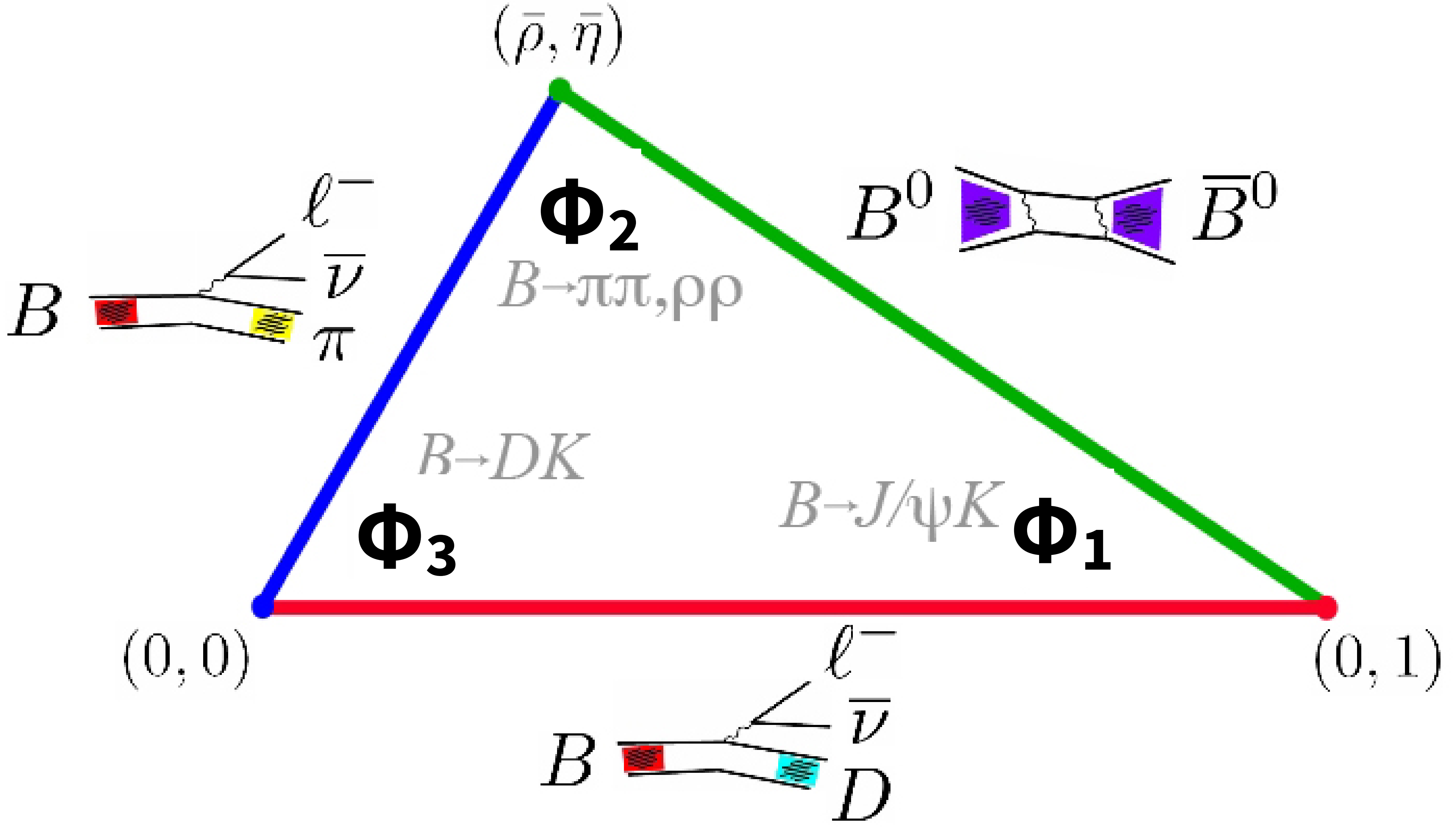
B + Charm + τ factory



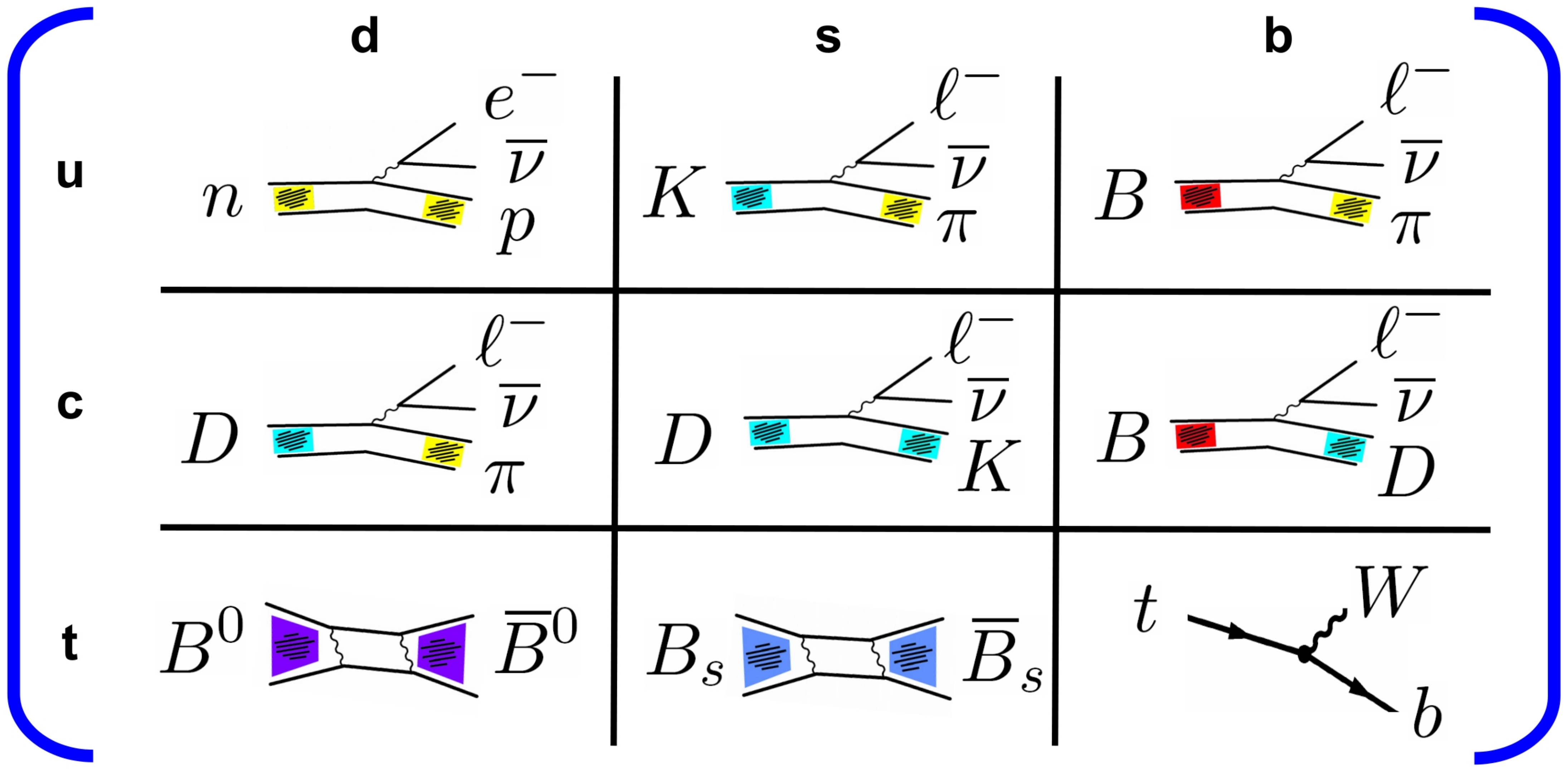
Belle II now has grown to ~800 researchers (267 grad students) from 25 countries

CKM and CPV SM Metrology: Belle II core program

- Measurement of the CKM matrix parameters.



V =



$B \to \pi\pi$, ρρ	α / Φ2	$B \to D^* l\nu$ / $b \to c\, l\nu$	$\lvert V_{cb}\rvert$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	γ / Φ3	$B \to \pi\, l\nu$ / $b \to u\, l\nu$	$\lvert V_{ub}\rvert$ via Form factor / OPE
$B \to J/\psi\, K_S$	β / Φ1	$M \to l\nu\,(\gamma)$	$\lvert V_{UD}\rvert$ via Decay constant f_M
$B_s \to J/\psi\, \Phi$	β_s	Δm_d, Δm_s	$\lvert V_{tb} V_{t\{d,s\}}\rvert$ via Bag factor B_B

WA HFLAV & CKMfitter 2018

$\sin 2\Phi_1 = 0.70 \pm 0.02$

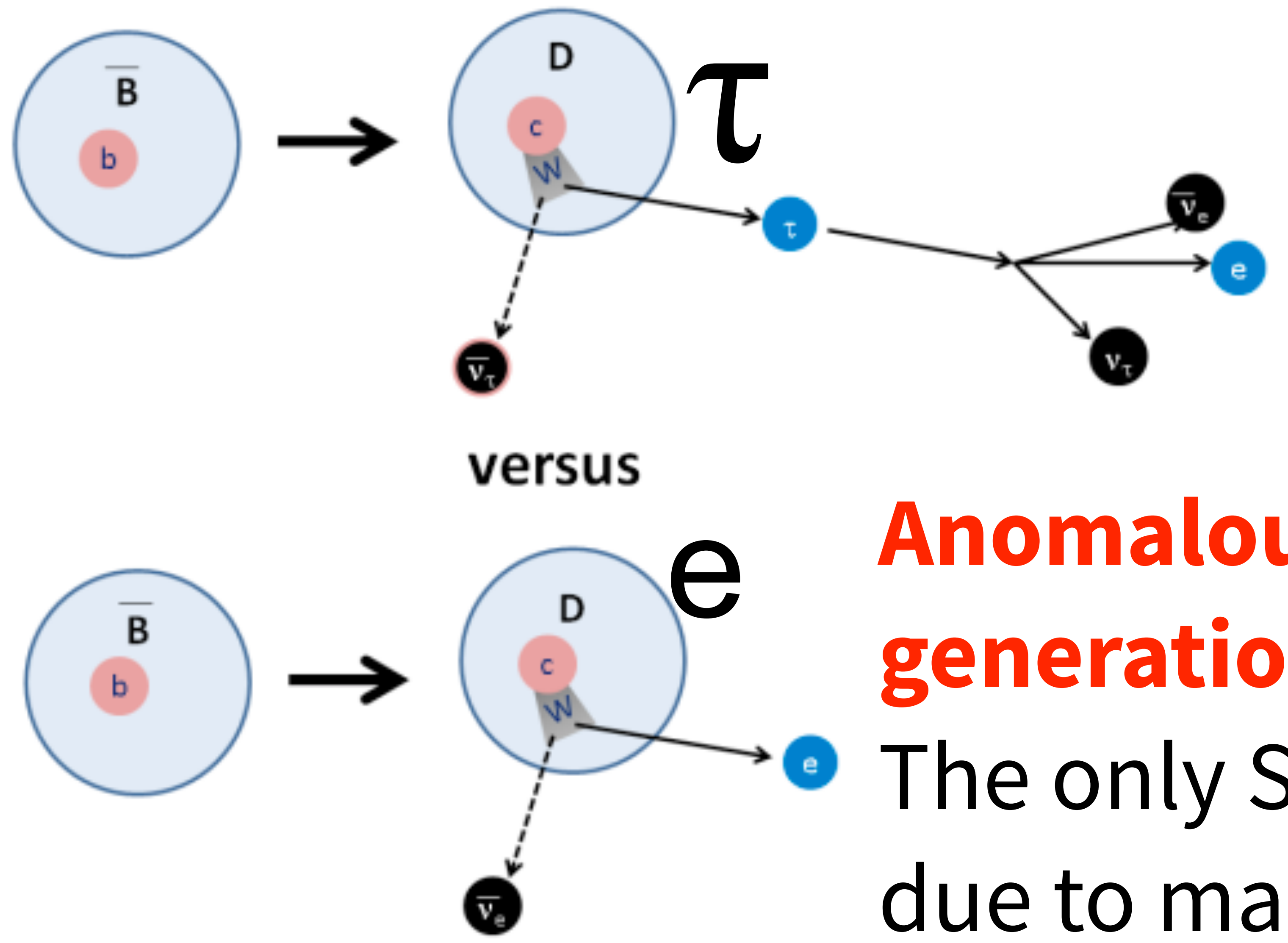
$\Phi_2 = (84.9^{+5.1}_{-4.5})°$

$\Phi_3 = (73.5^{+4.2}_{-5.1})°$

$|V_{ub}| = (3.98 \pm 0.08 \pm 0.22)\ 10^{-3}$

$|V_{cb}| = (41.8 \pm 0.4 \pm 0.6) \times 10^{-3}$

R(D) and R(D*) Tree anomalies

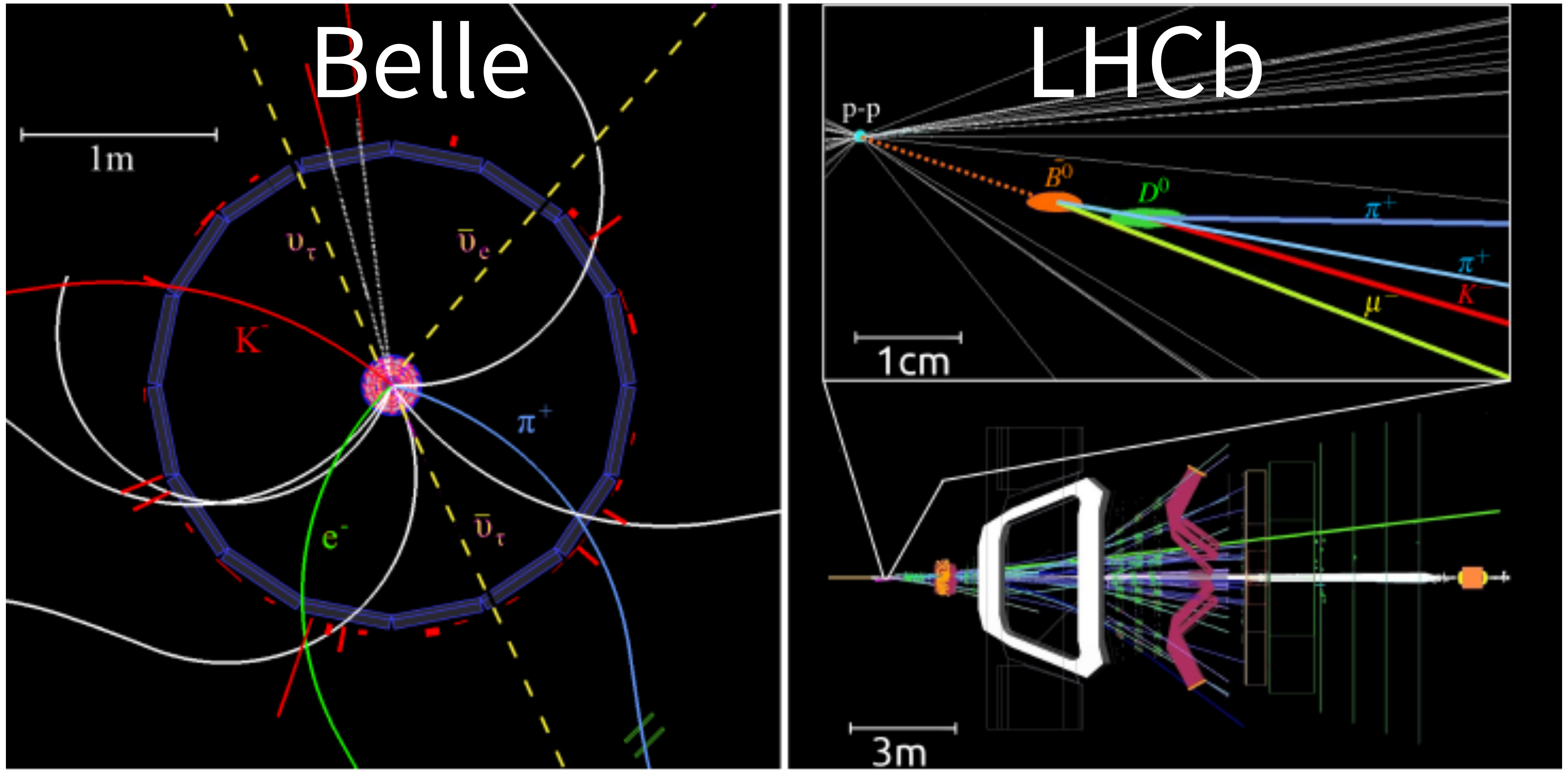


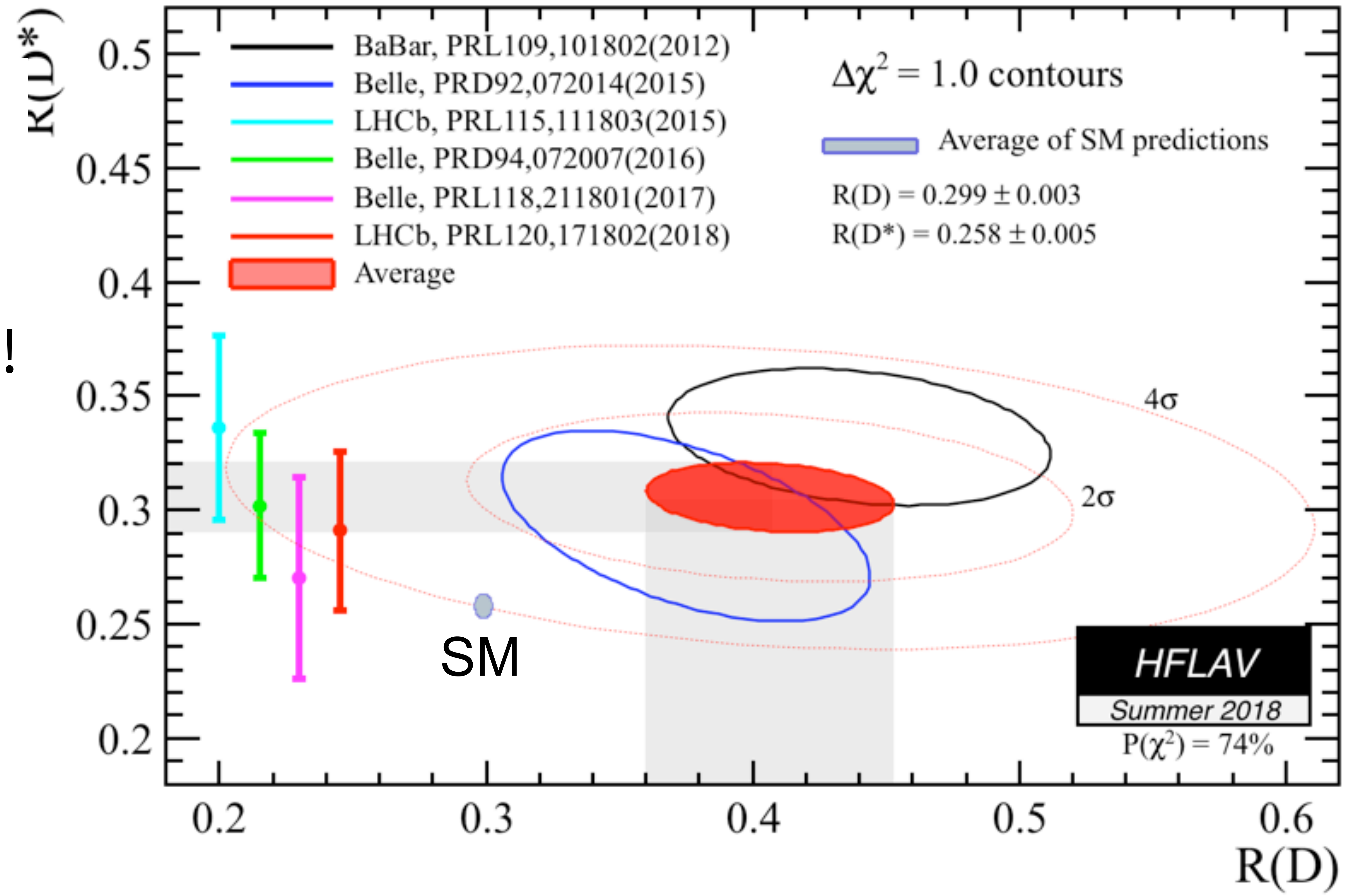
$$R = \frac{\mathcal{B}(b \to q\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(b \to q\,\ell\,\bar{\nu}_\ell)}$$

$$\ell = e, \mu$$

Anomalous couplings to 3rd generation b and τ.

The only SM differences are are due to masses - easy* to calculate!

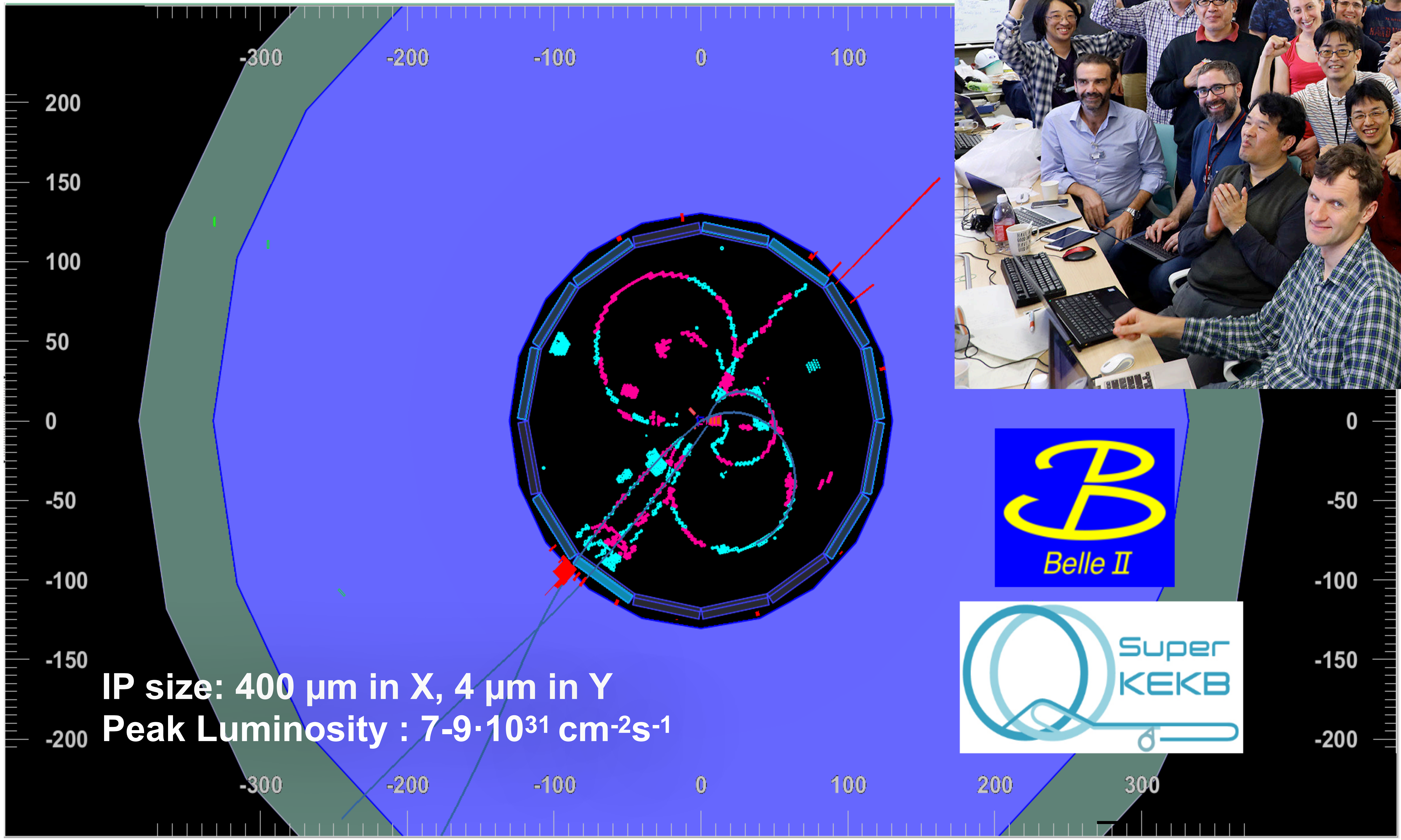




2018 summer

World Average is (still) 4σ from the SM

First collisions (April 26)



SuperKEKB/Belle II joins DORIS/ARGUS, CESR/CLEO, and PEP-II/BaBar and KEKB/Belle.

Probably $e^+e^- \to \gamma^* \to q\bar{q}$

SuperKEKB / Belle II data sets

see talk by Ohnishi

Phase 2 run, April-July 2018
Full vertex detector not installed

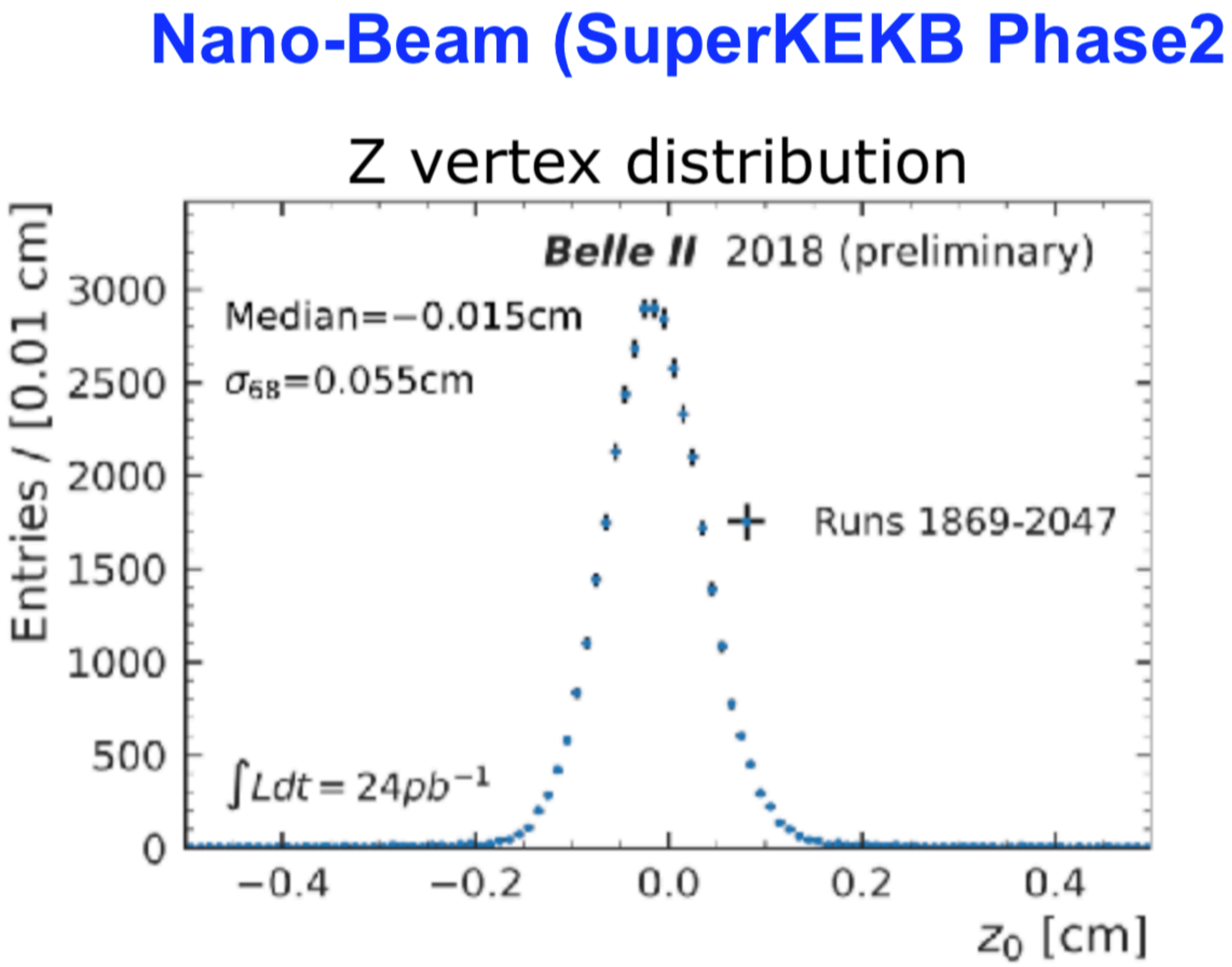
$L_{peak} = 5.5 \times 10^{33}/cm^2/s$

Integrated luminosity ~ 500/pb (parasitic to accelerator commissioning)

Measured with ee→ ee(γ), γγ, μμ(γ)

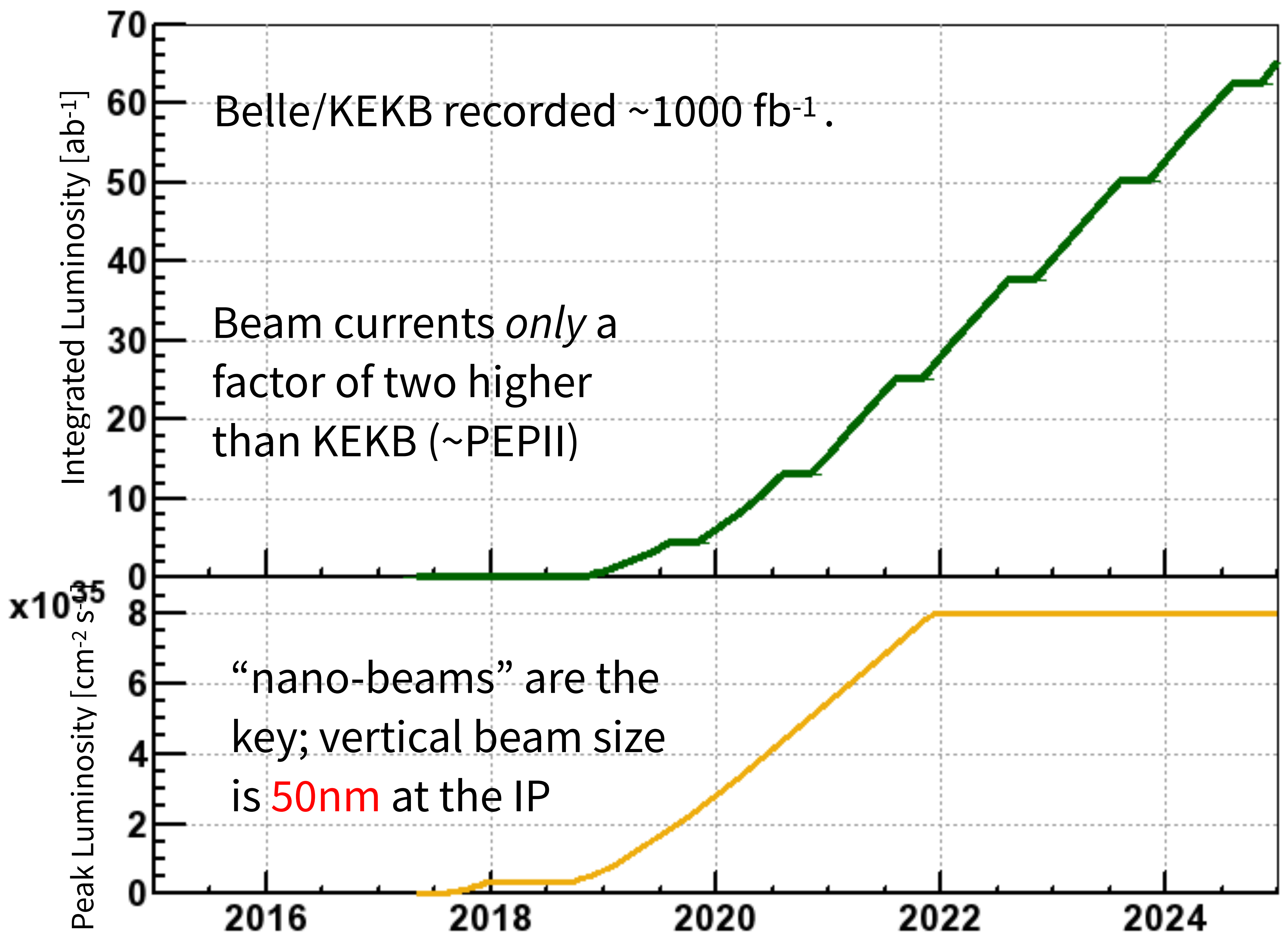
Effective bunch length *reduced* from ~5 mm (KEKB) to 0.5 mm (SuperKEKB)

Measured in 2-track events in Belle II with one wedge of the silicon detector.



Beam background appear higher than expected - under study.

50 ab^{-1} by 2025 (see talk by Ohnishi)



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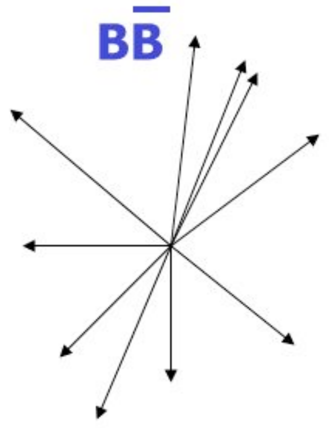
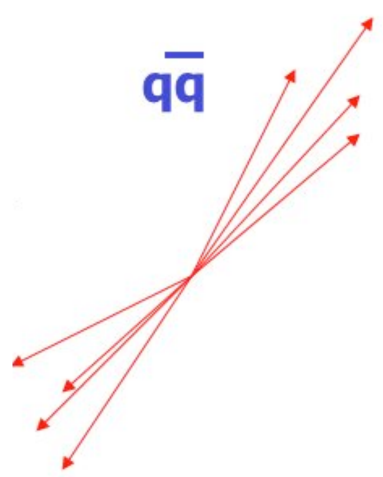
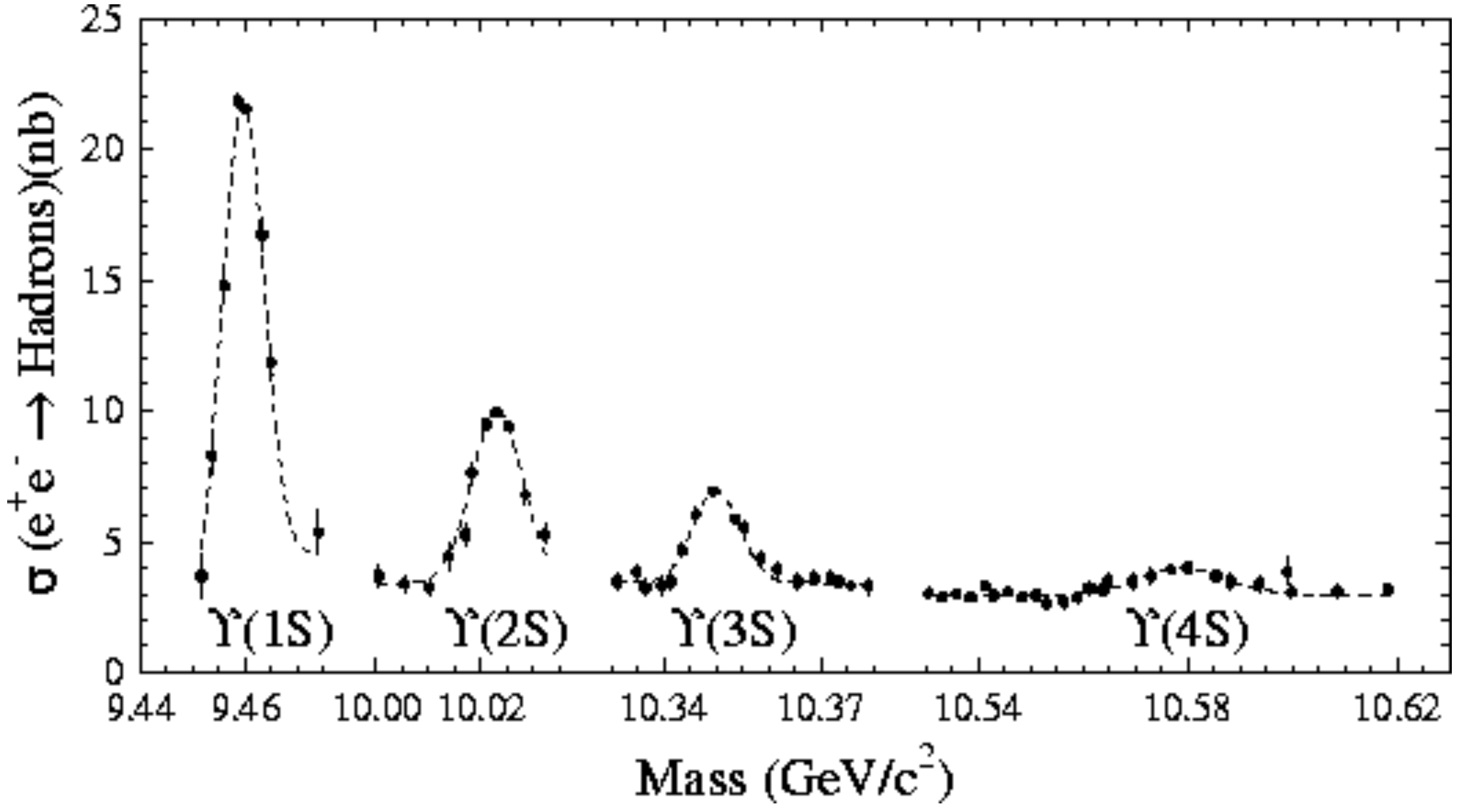
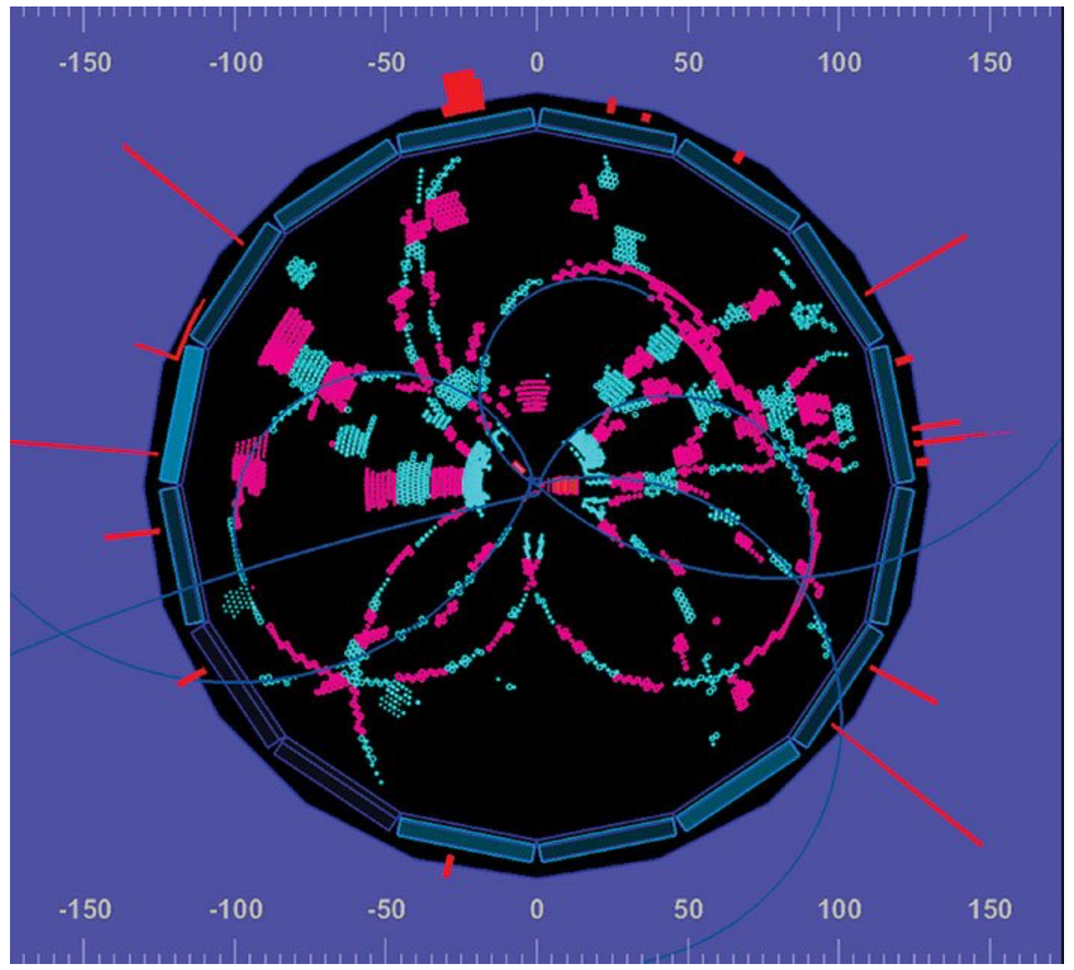
B production

B pairs produced at rest in the CM with no extra particles

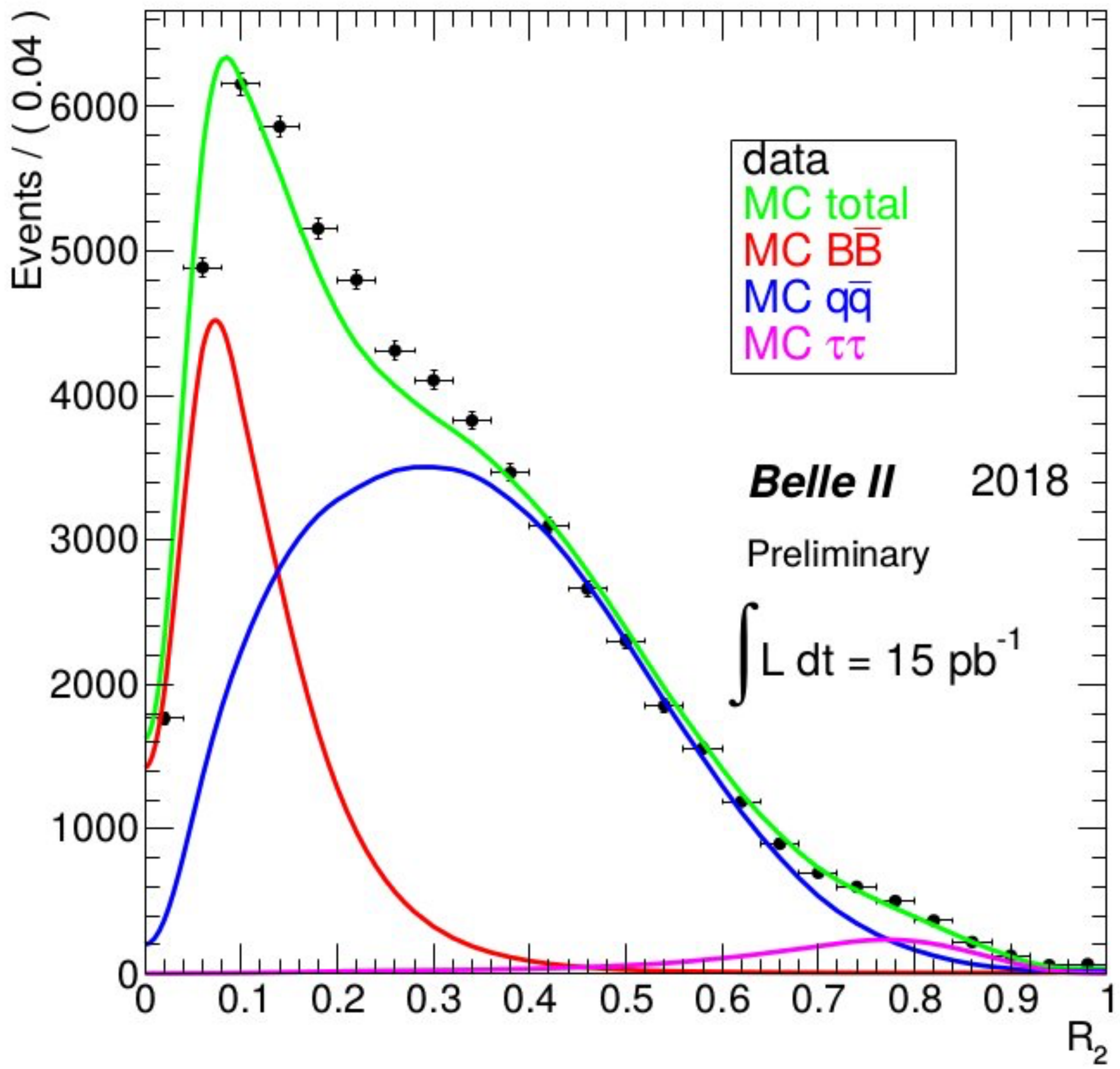








Probably a Υ(4S) event



- We are on the Υ(4S) resonance and recording B anti-B pairs with ~99% efficiency.
- *Not so obvious: When we change accelerator optics, we remain on Υ(4S).*

Event Topology (fits to R_2) tells us we are seeing B's

$$R_2 = H_2/H_0$$

$$H_l = \sum_{i,j} \frac{|\mathbf{p}_i||\mathbf{p}_j|}{E_{\mathrm{vis}}^2} P_l(\cos\theta_{ij}),$$

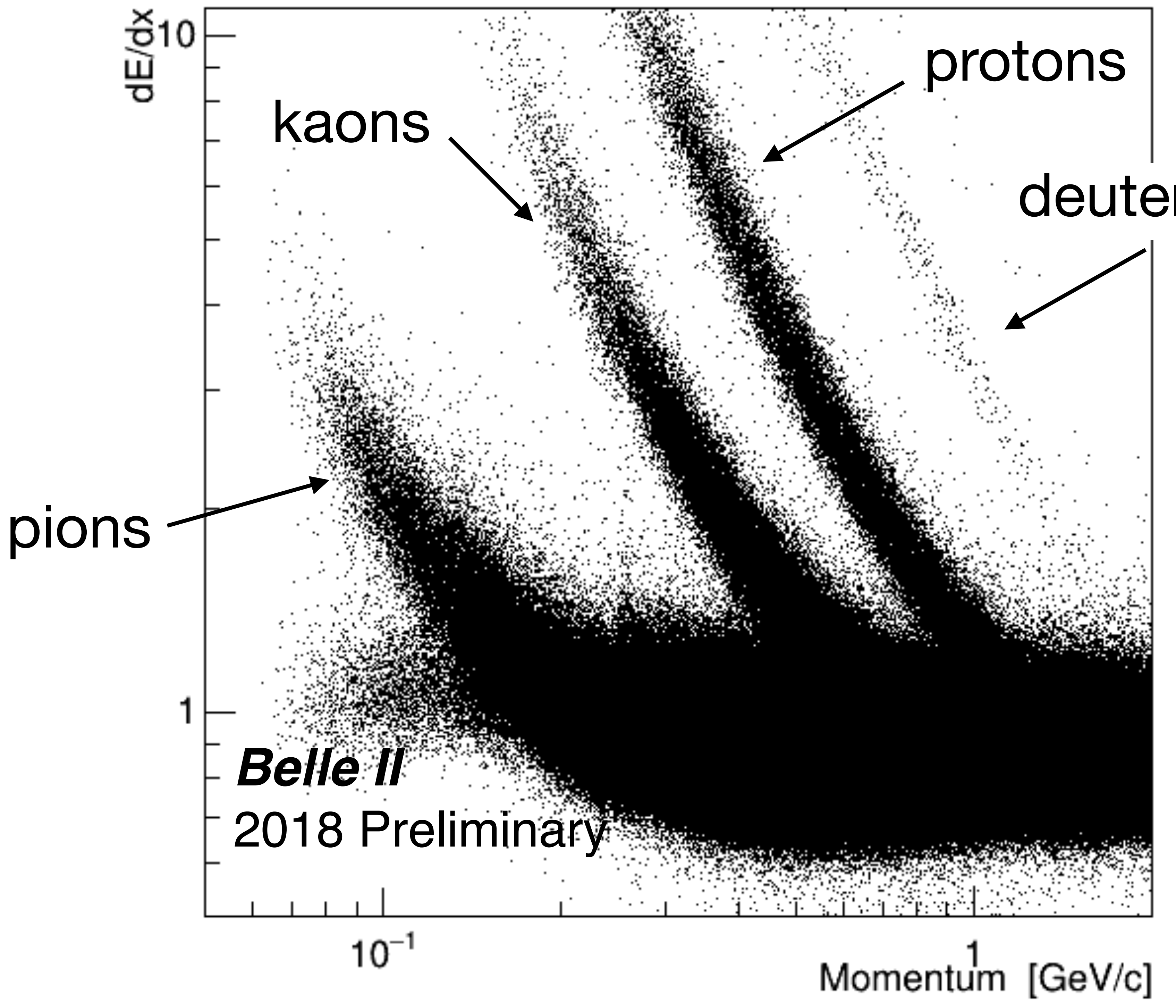
Particle identification in 2018

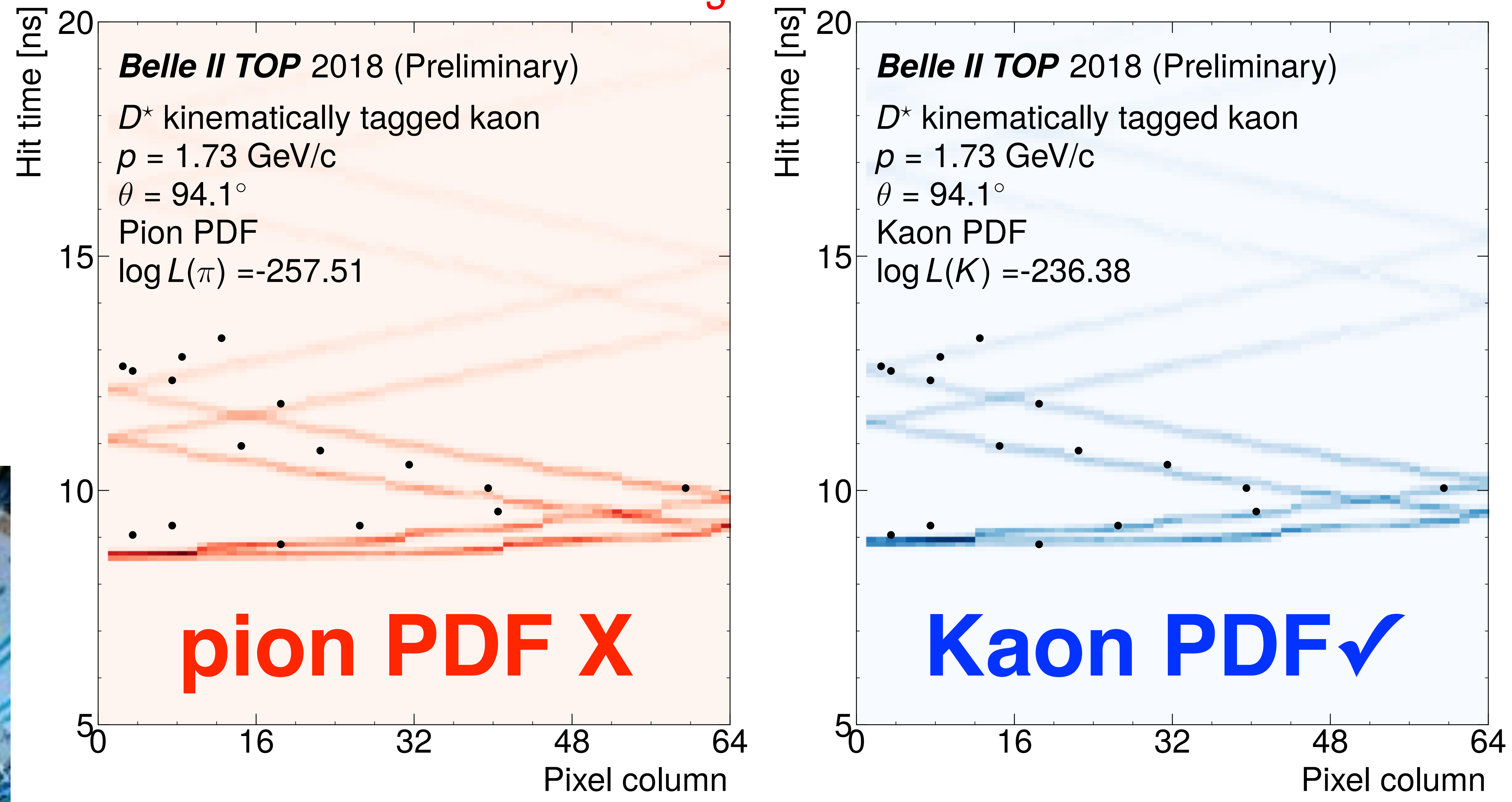
- Central Drift Chamber dE/dx & Time of propagation Cherenkov patterns - 2018 data

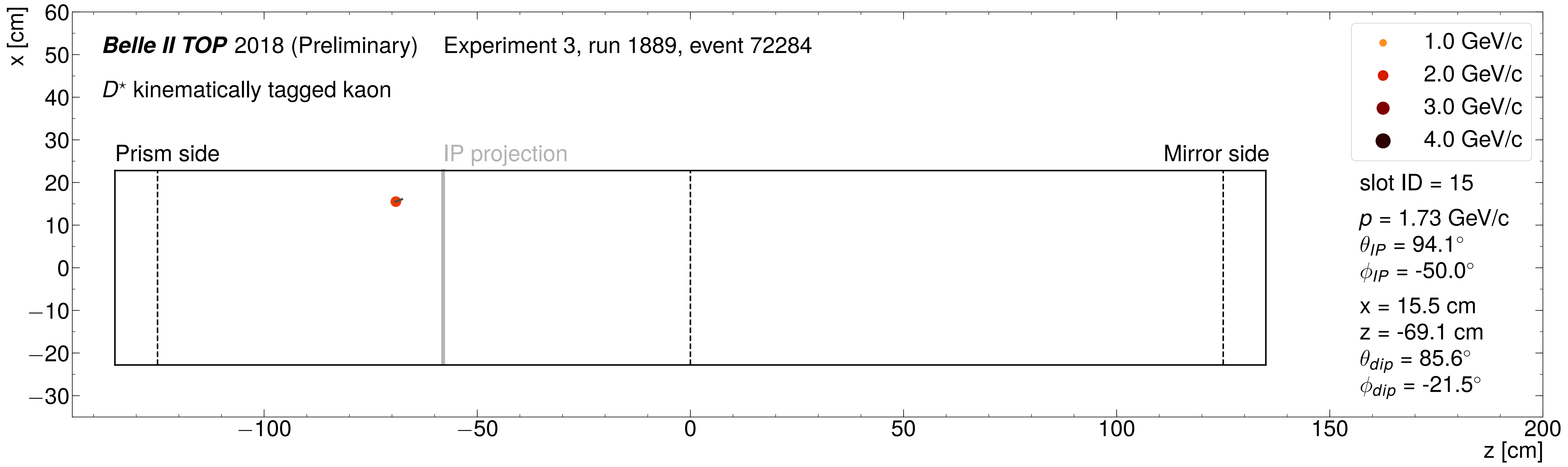
Kinematically identified kaon from D^{*+} in TOP; x vs t pattern (mapping of Cherenkov ring)

$$D^{*+} \to D^0 \pi_s^+ ; D^0 \to K^- \pi^+$$

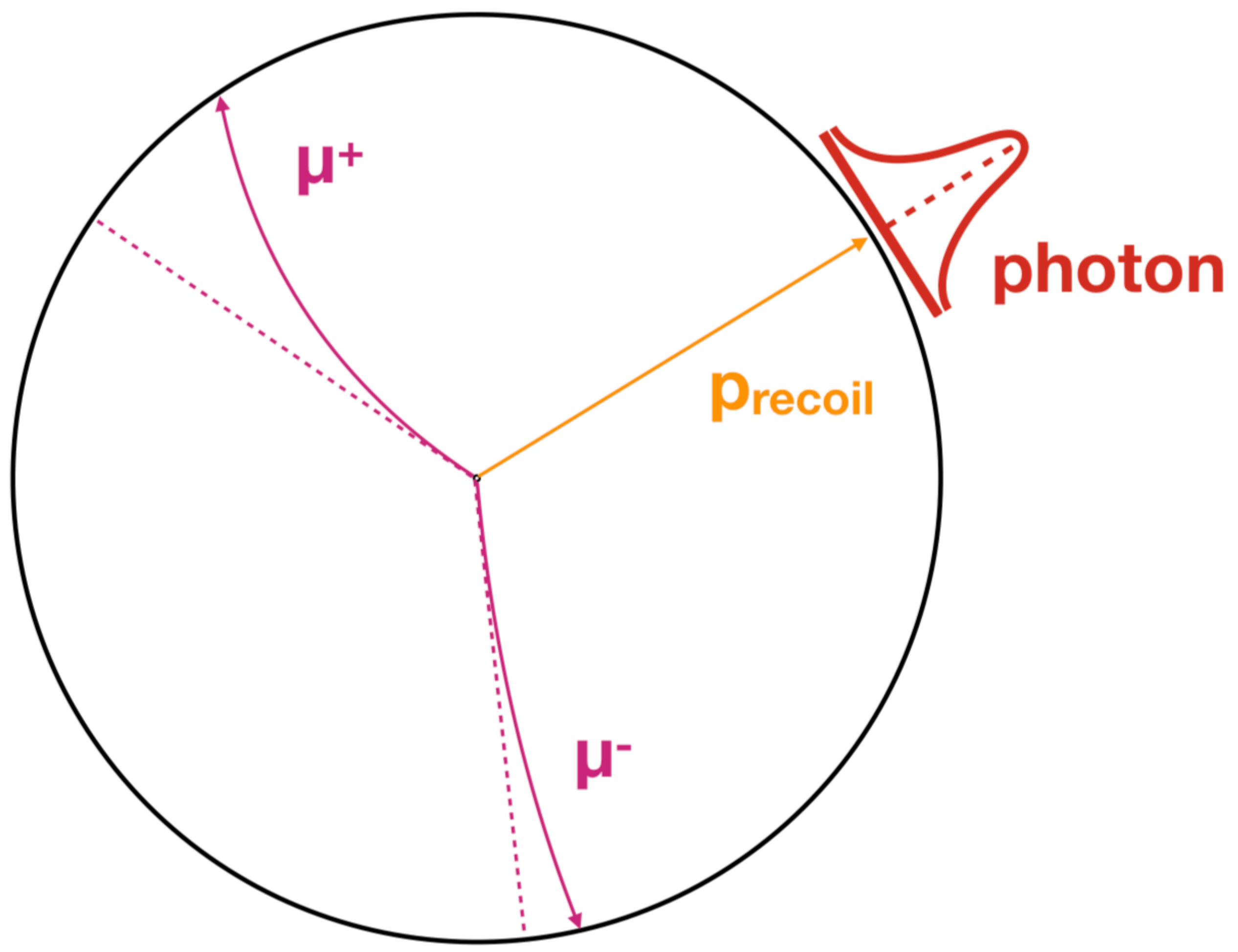
CDC dE/dx

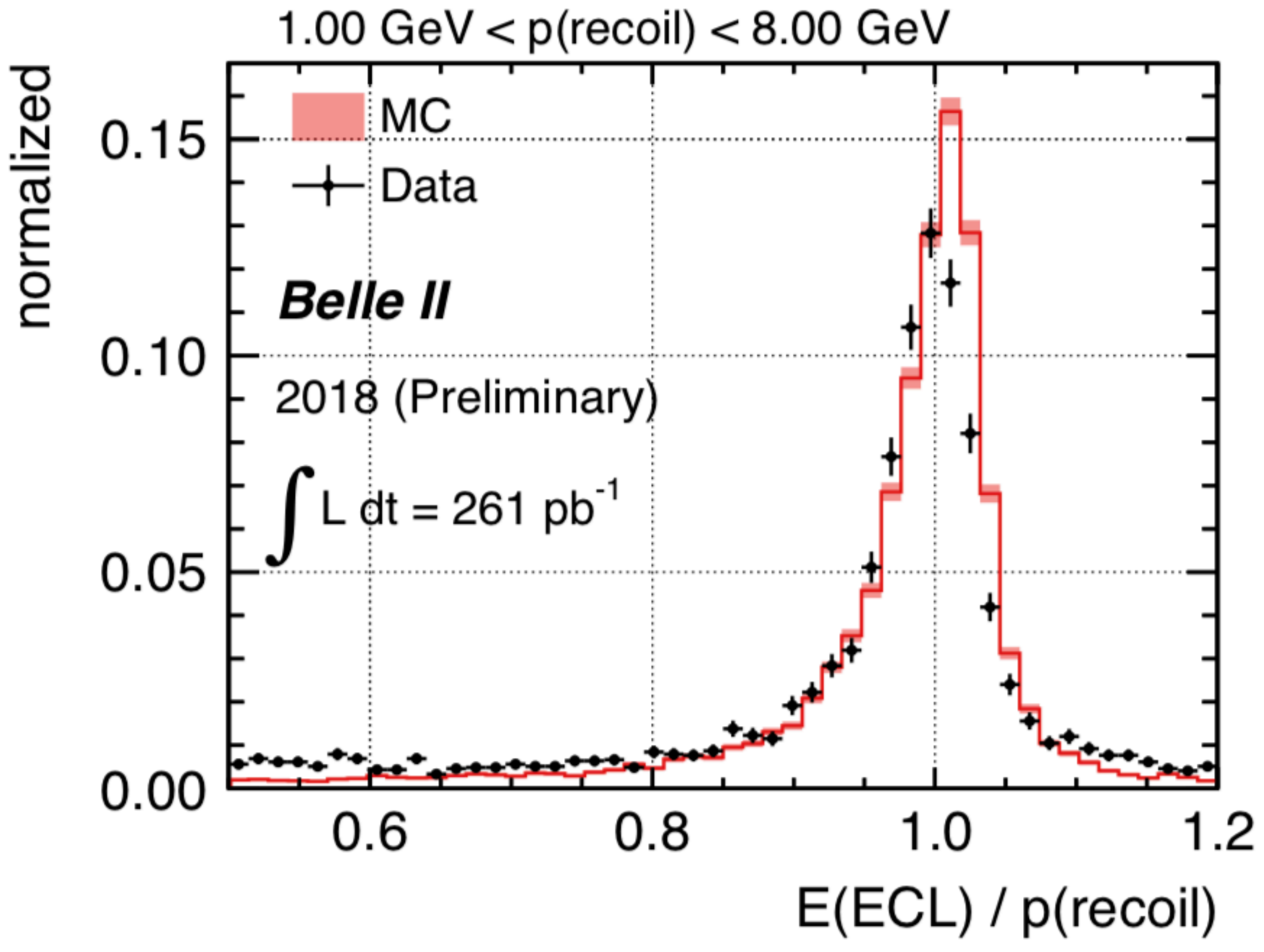


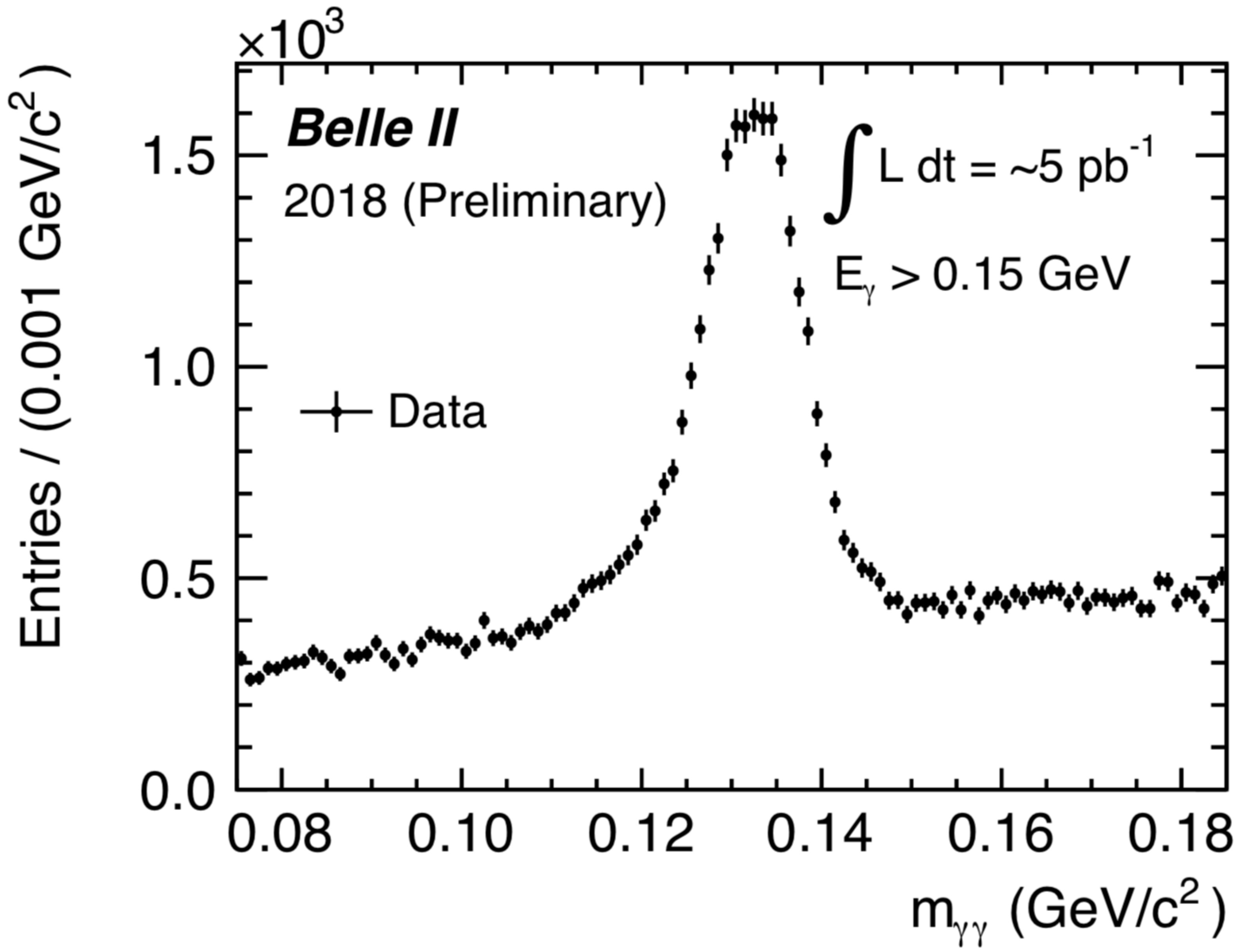




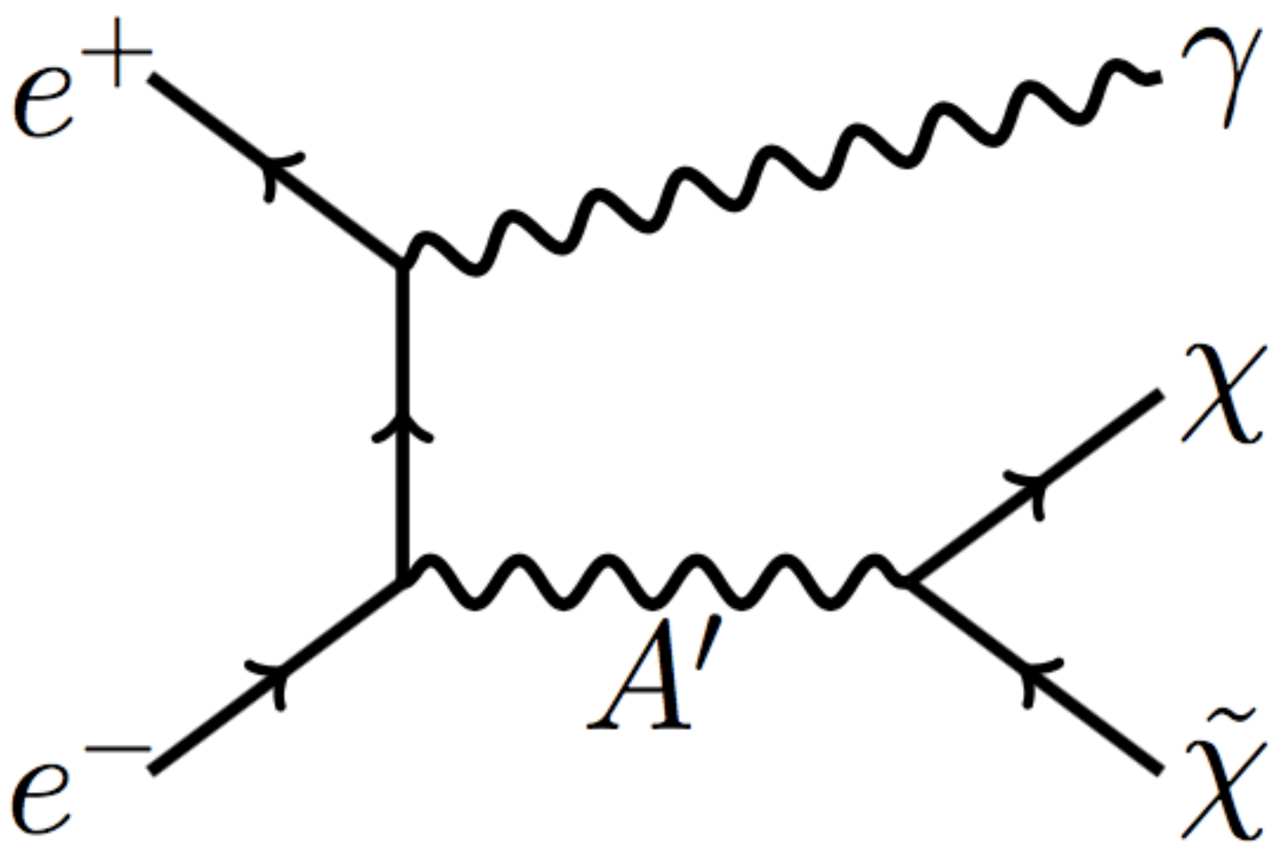
Nice examples of signal involving photons

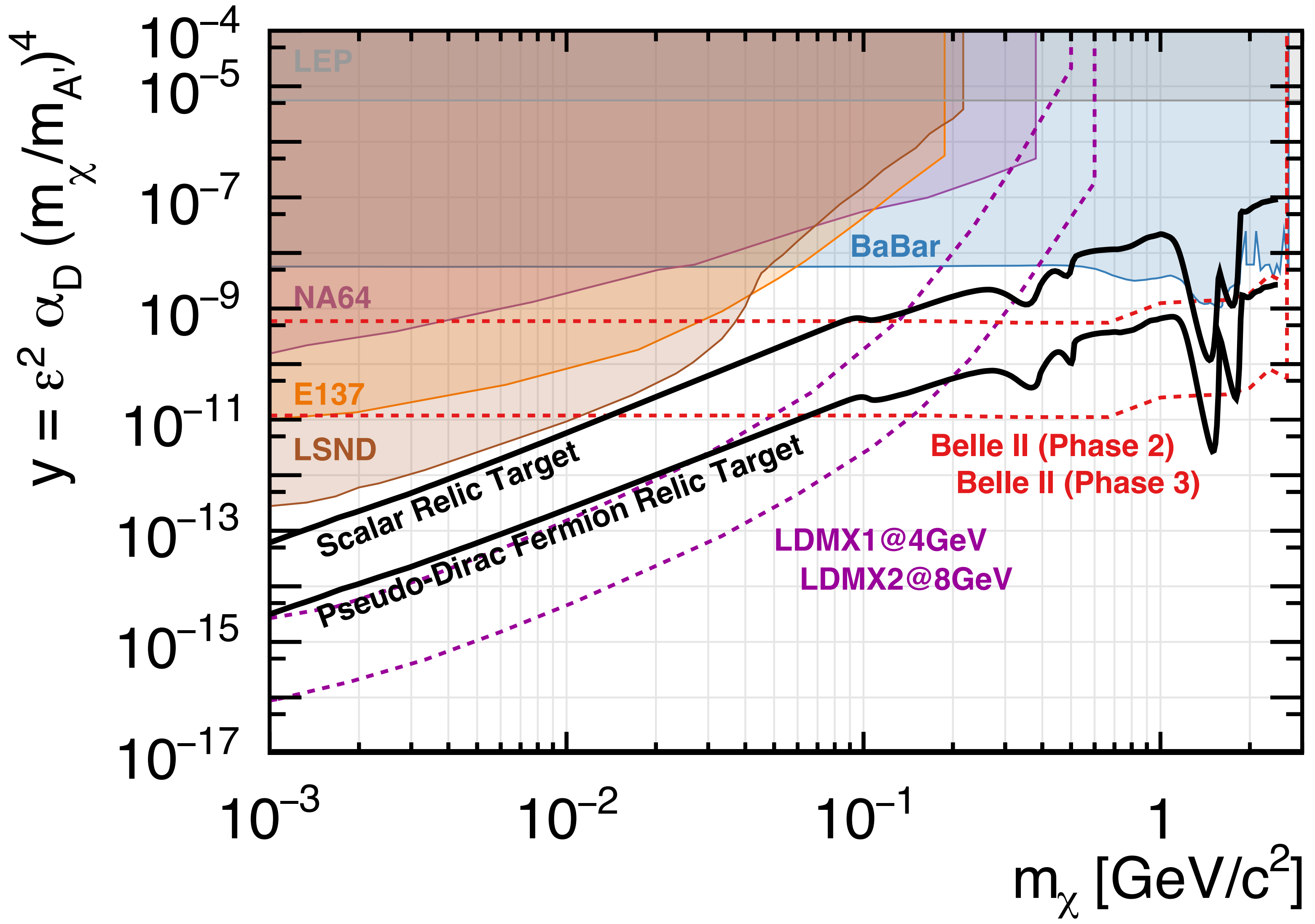






Single Photon Lines





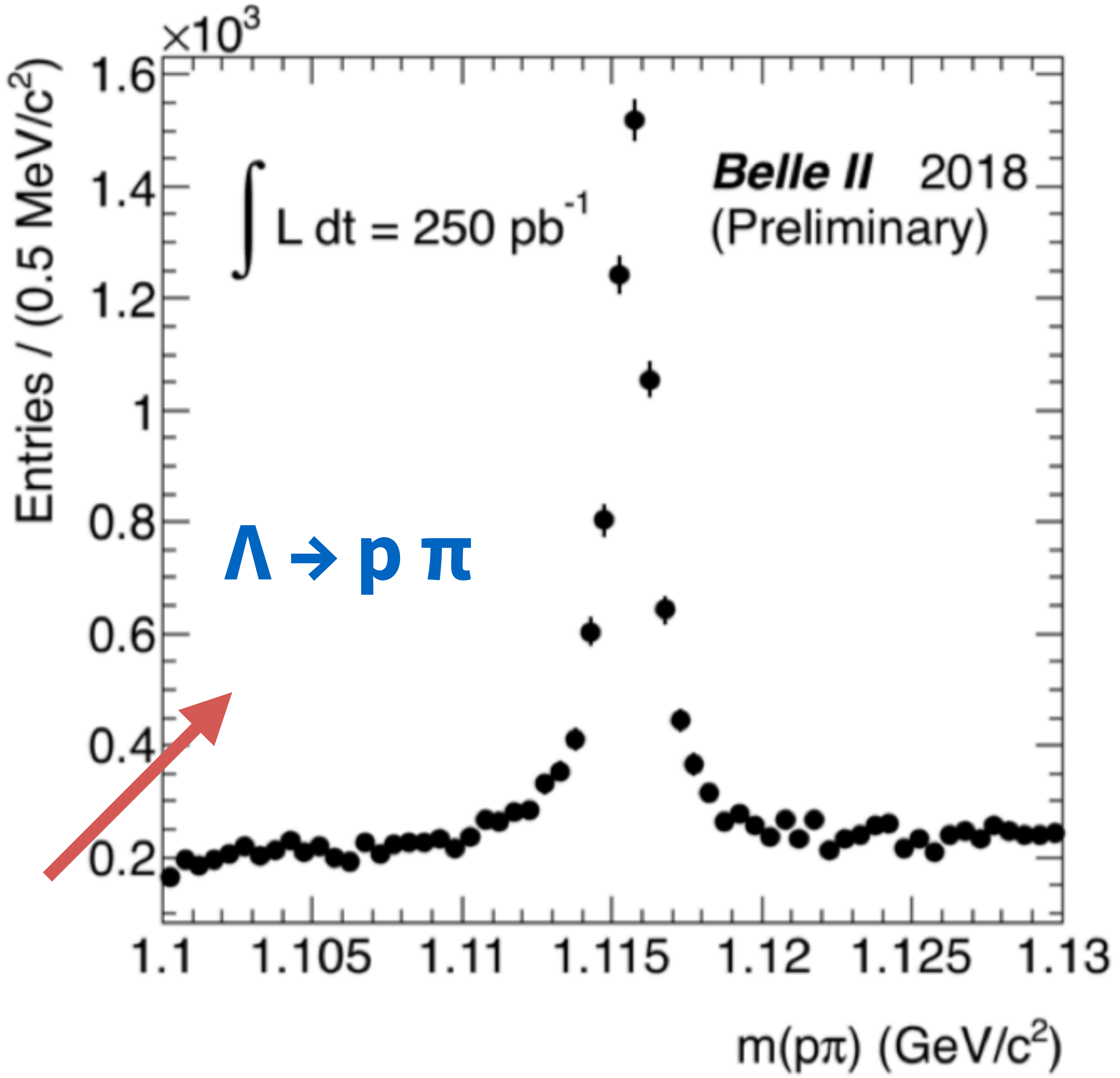
Ready for the dark sector !

$e^+e^- \to \gamma X$

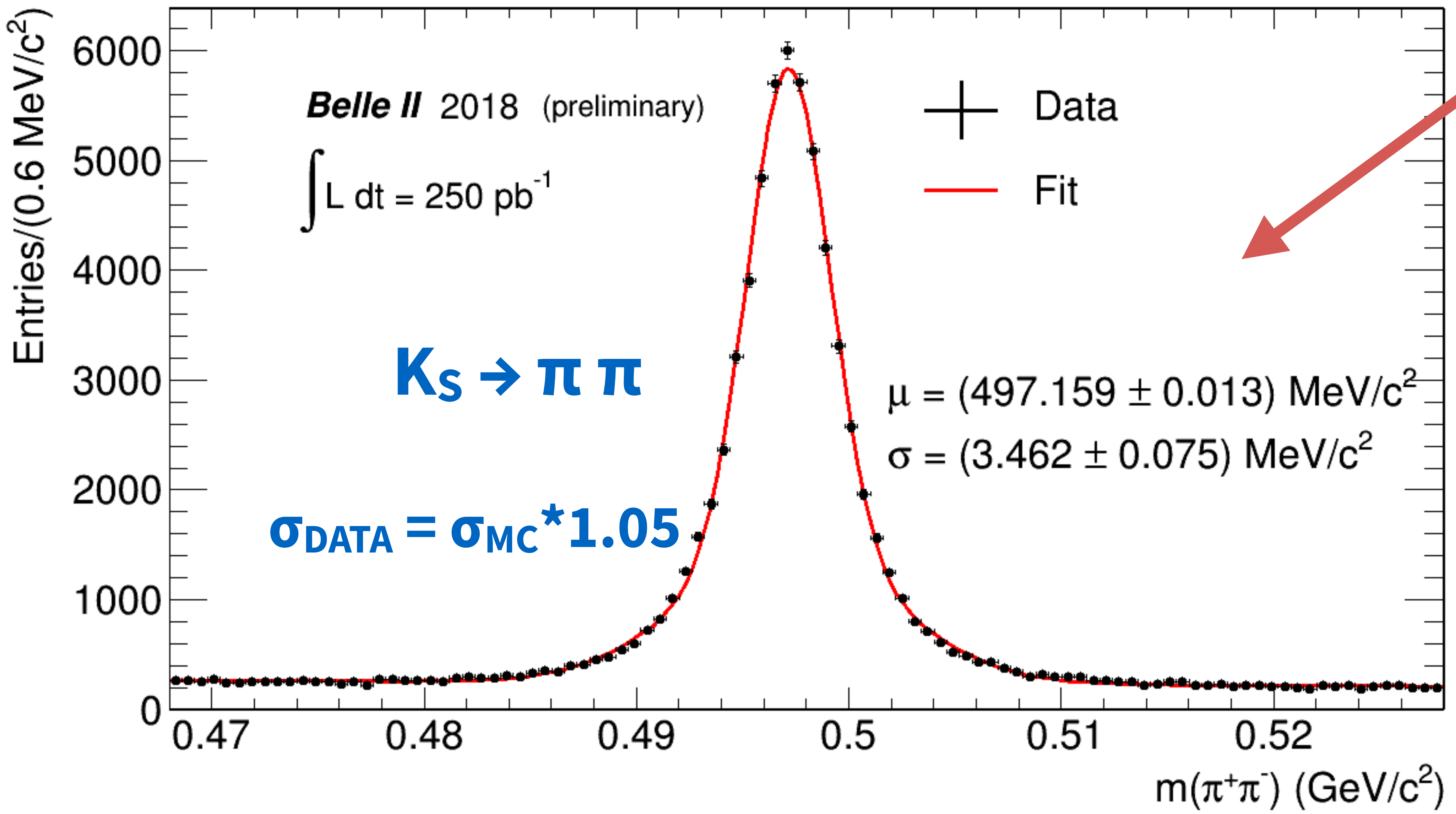
$e^+e^- \to \gamma$ ALP $(\to\gamma\gamma)$

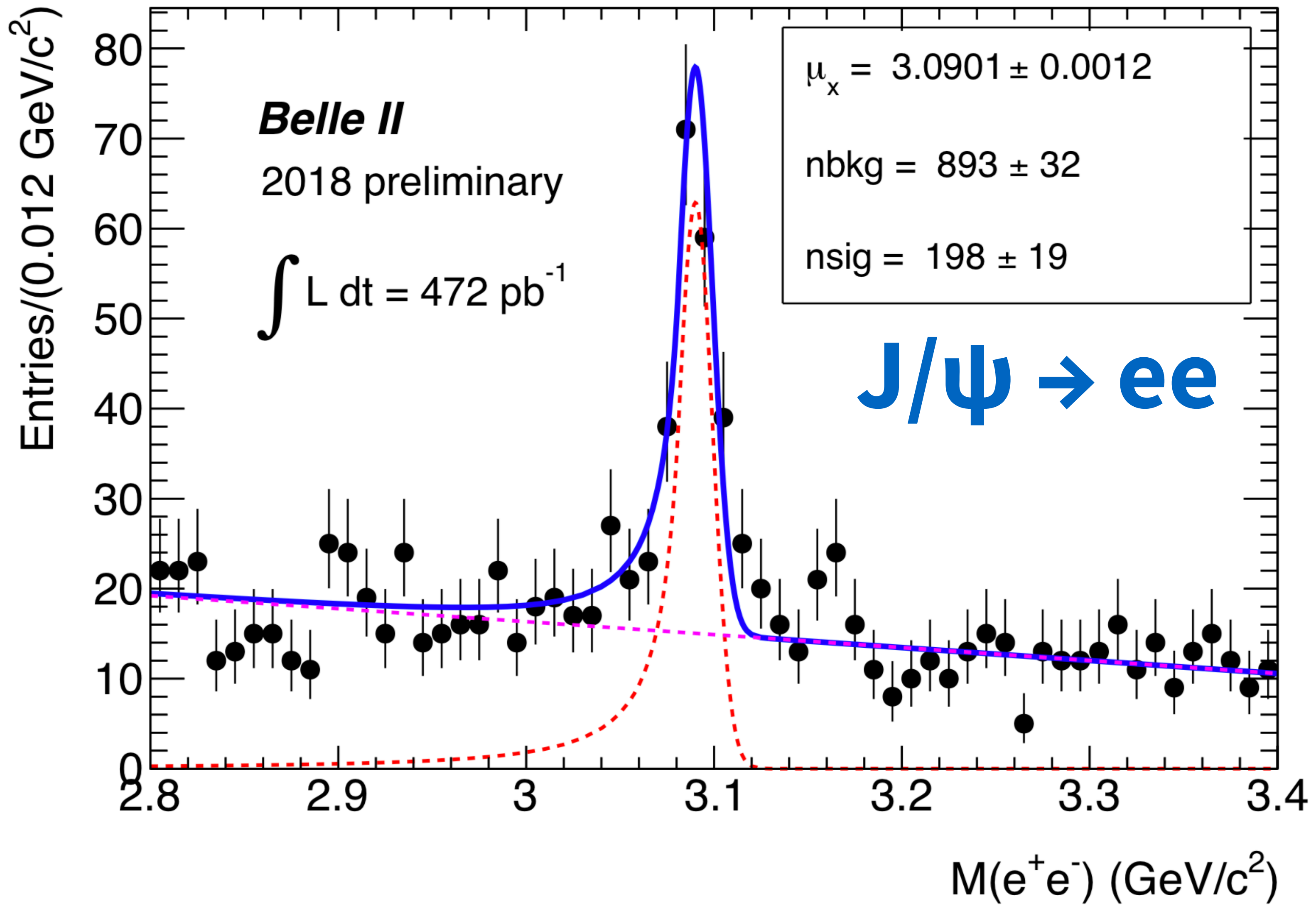
Signal involving charged tracks

- Most subsystems work well.
- Within days / first calibration, neutrals and track resolution good to better than 5%.
  - Calibrated as well as Belle already!



V⁰ particles

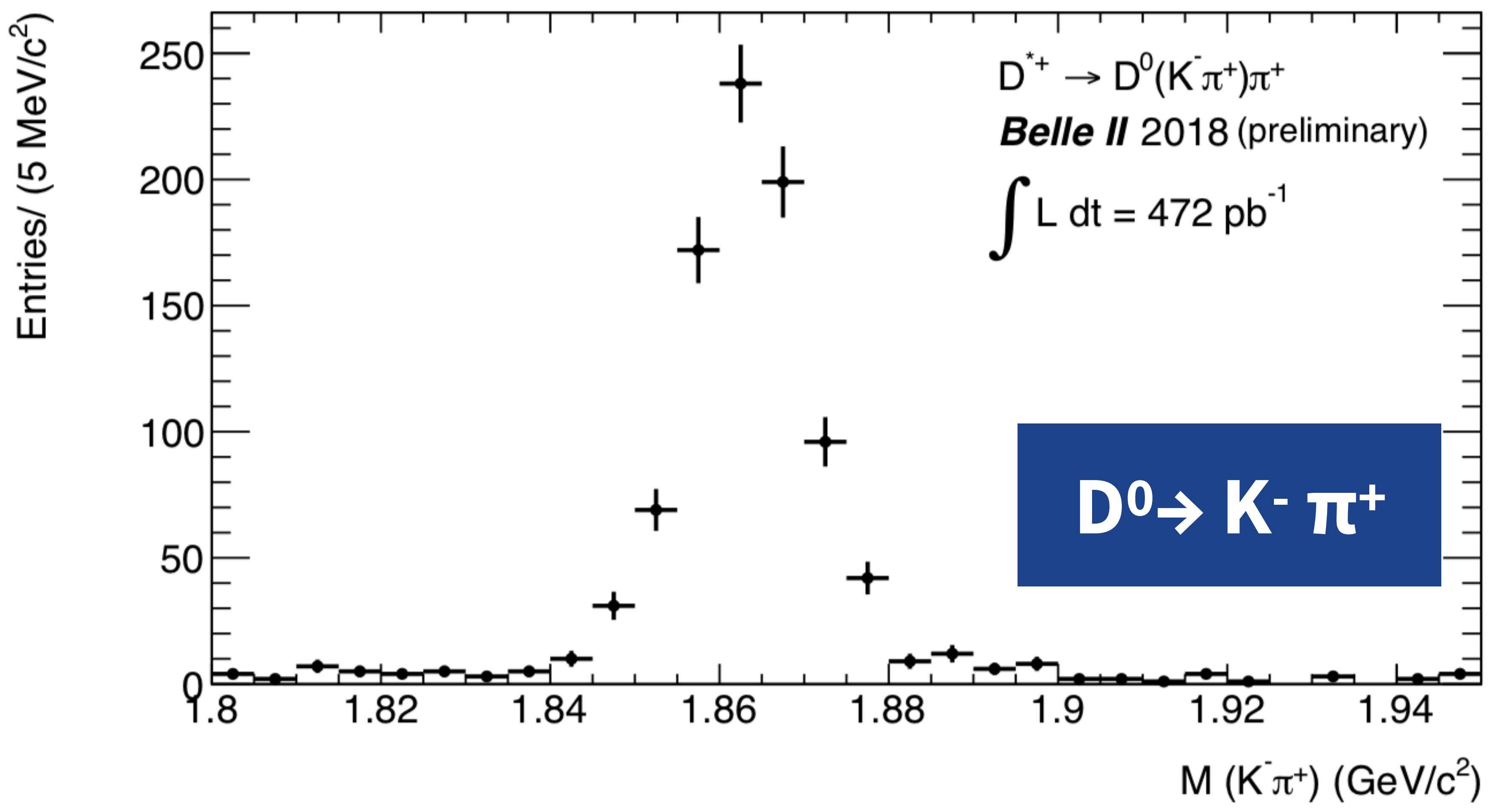


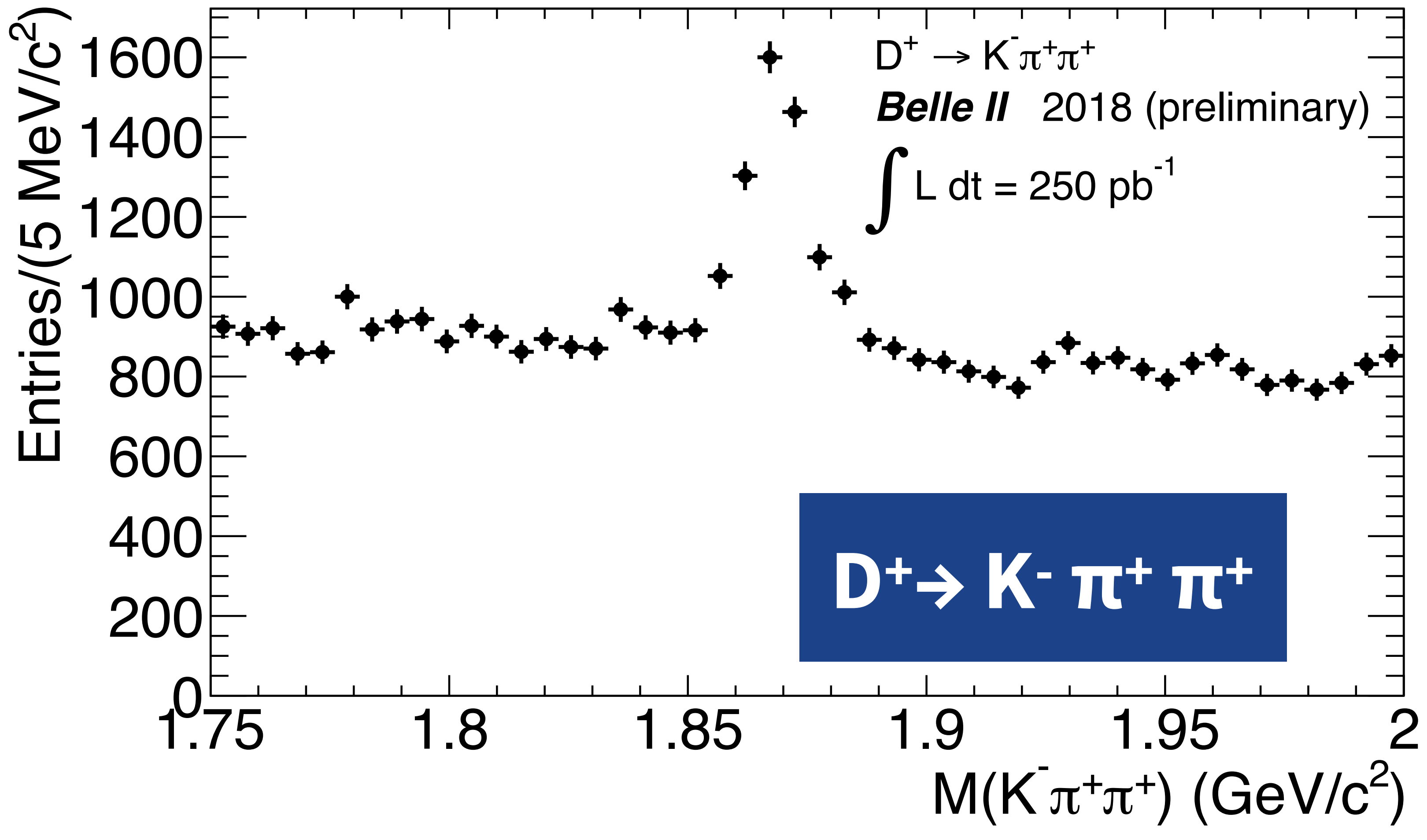


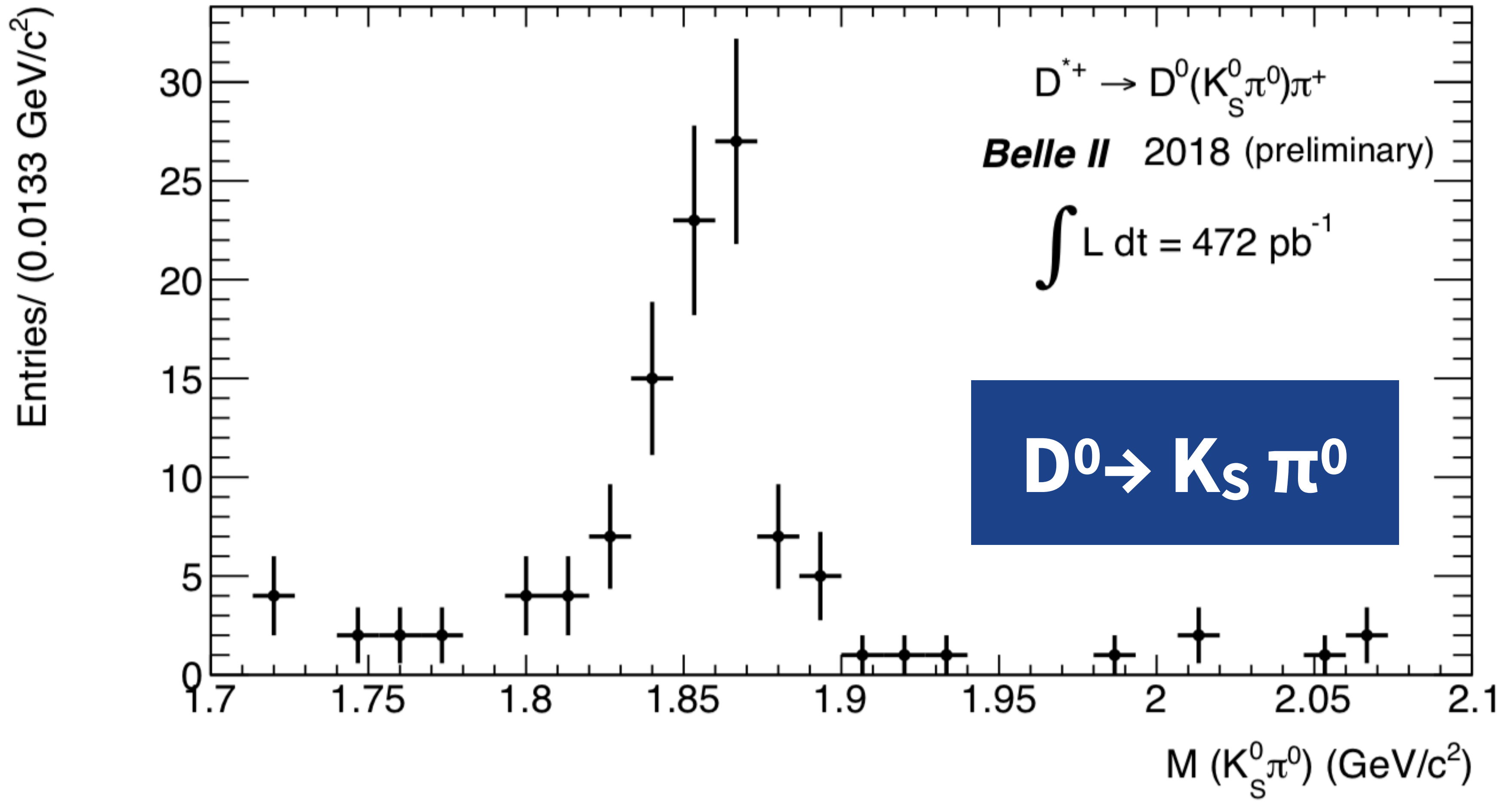
Charm "rediscovery"

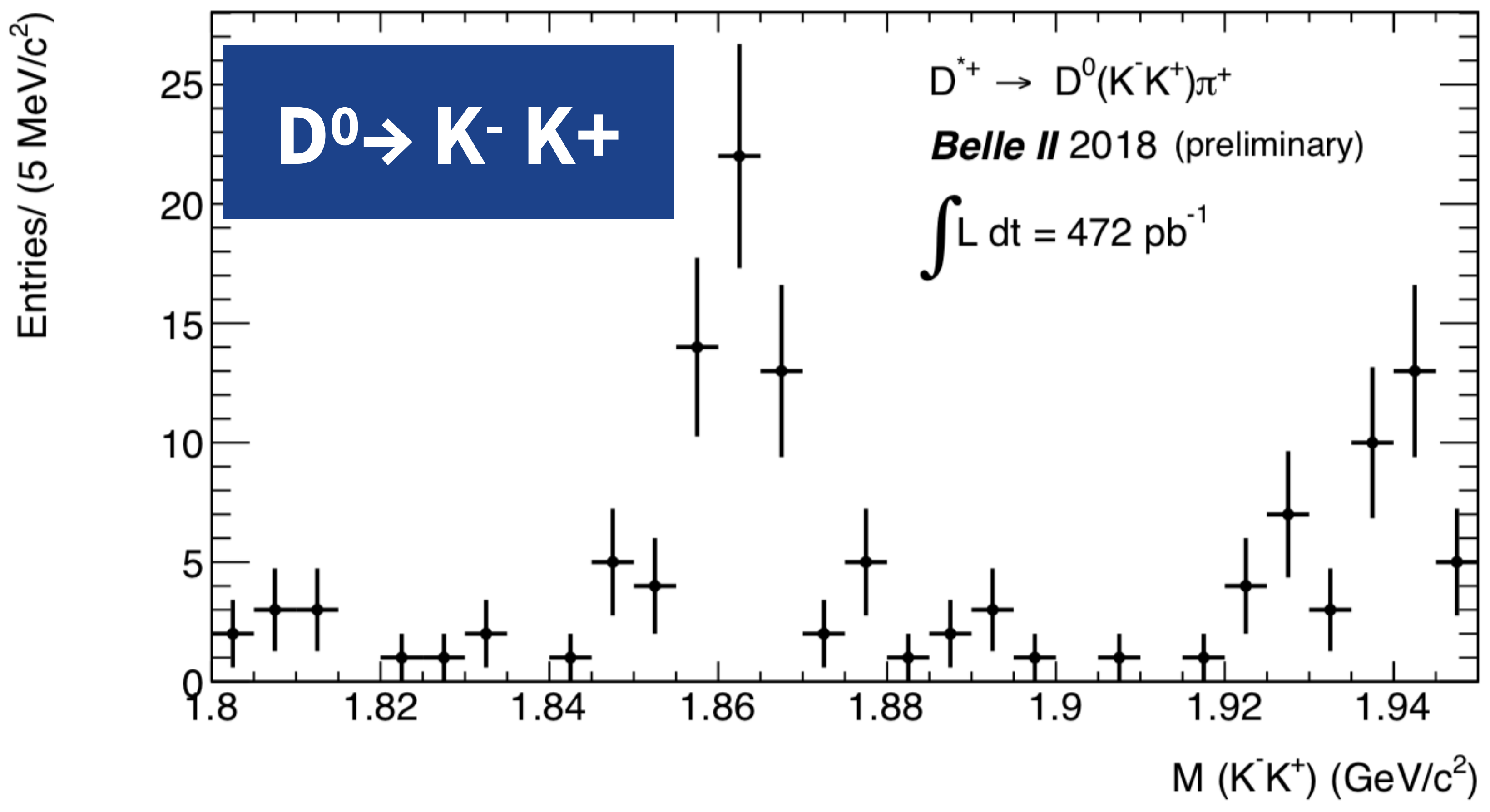
$e^+e^- \rightarrow c$ anti-c

- Open charm, D^0, D^+, D_s^+, D^{*+}, D^{*0} and Charmonium J/ψ. Found the difficult to see $D^0 \rightarrow K_S \pi^0$.









- Clearly illustrates the capabilities of Belle II and the potential for charm physics and the building blocks of B mesons.
- CP Eigenstate $D^0 \rightarrow K_S \pi^0$ impossible to see at LHCb!

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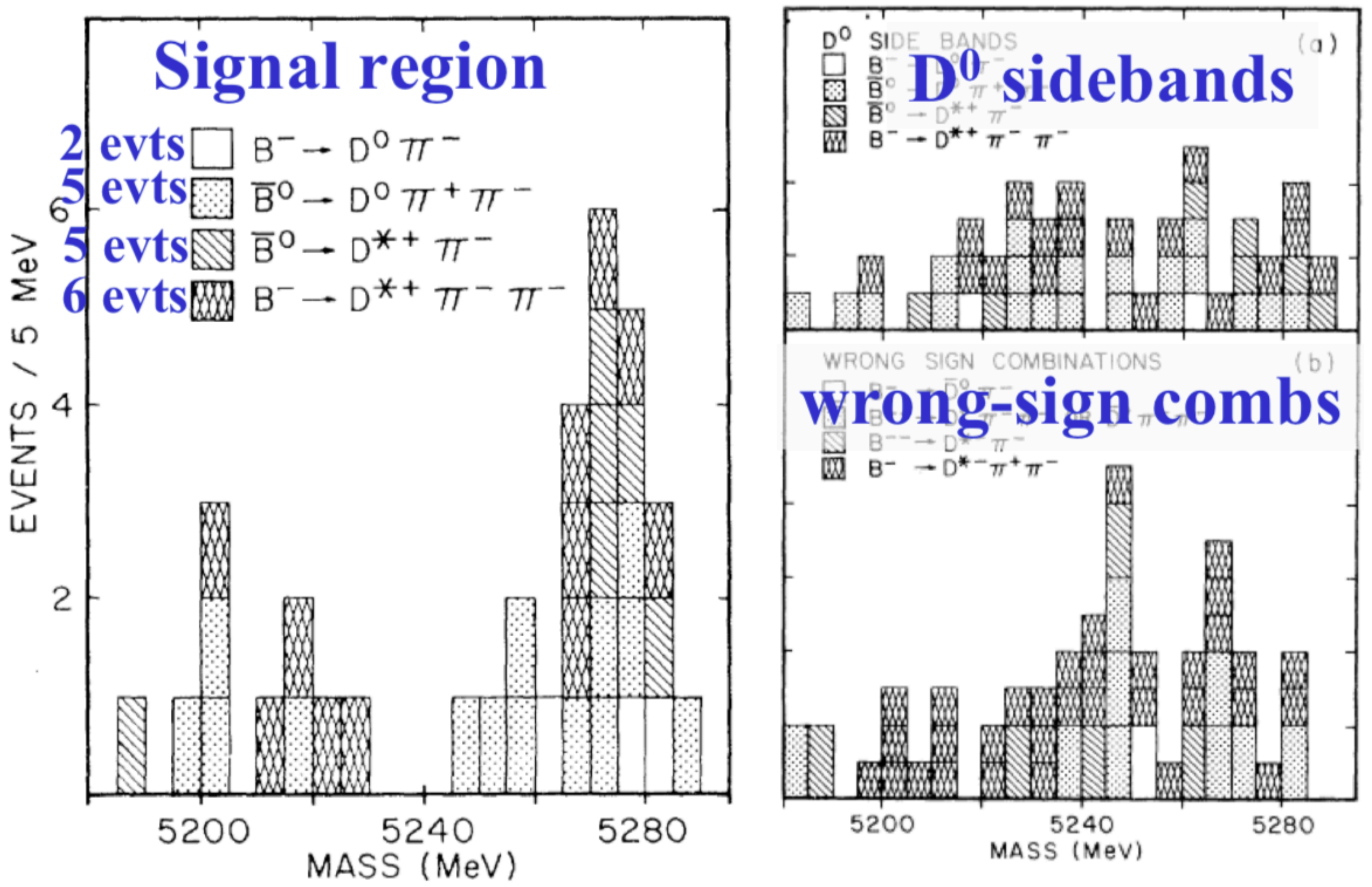
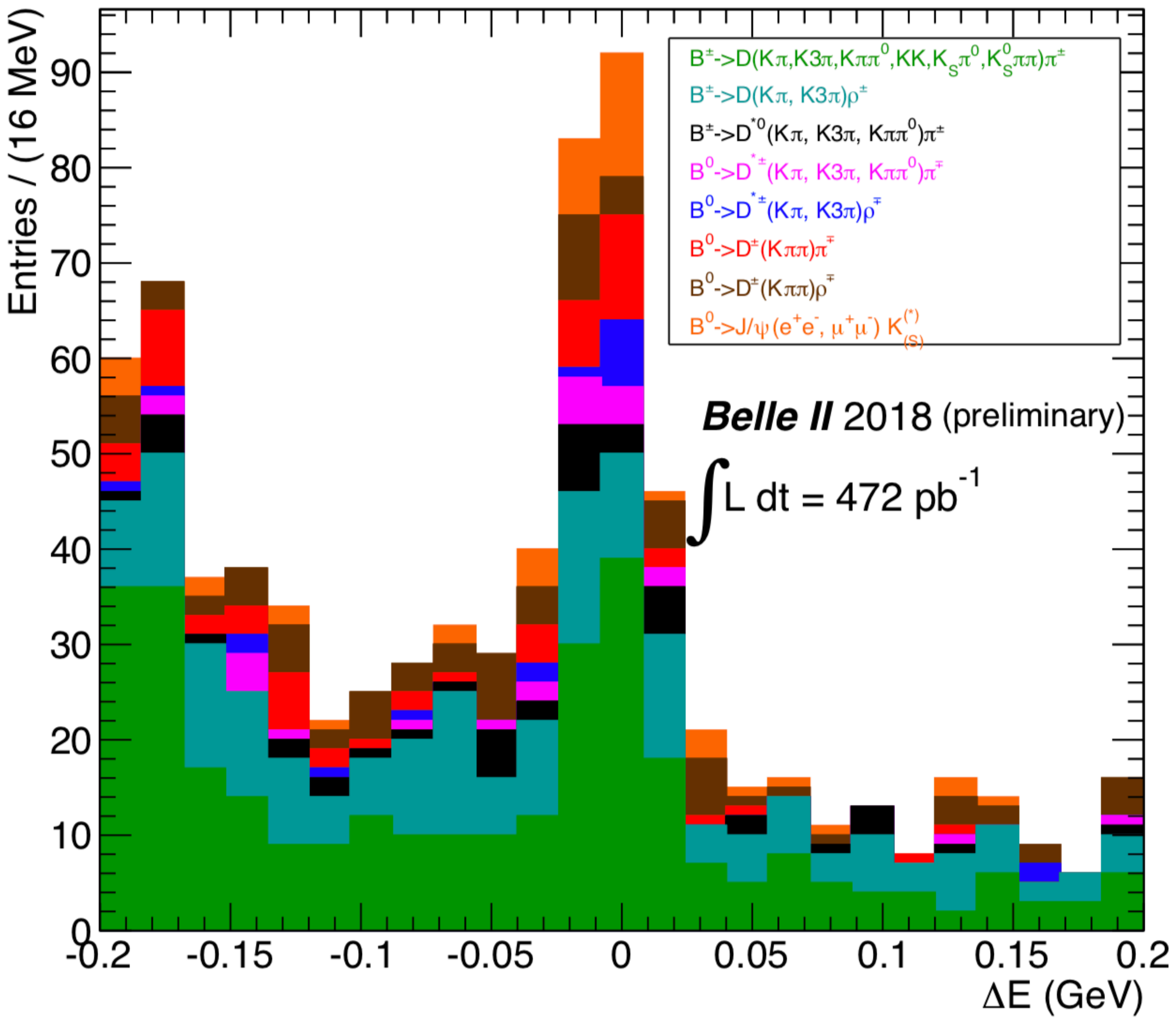
Beauty "Rediscovery" (cut-based analysis)

- Recreating CLEO & ARGUS
  - > 200 B candidates in hadronic modes (470/pb)
  - ~14 $B \to D^* e \nu$ found (250/pb)

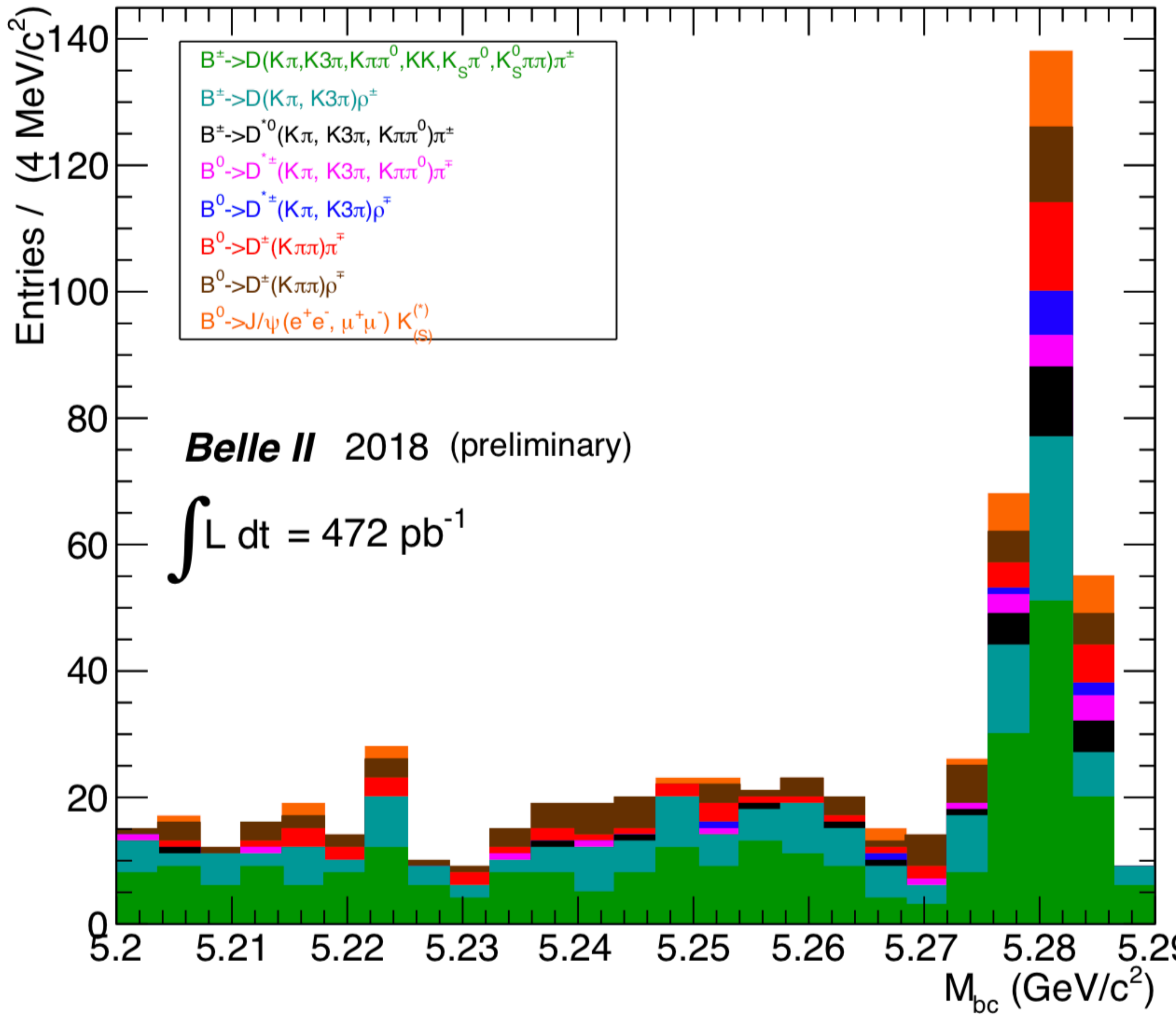
> VOLUME 50, NUMBER 12 — PHYSICAL REVIEW LETTERS — 21 MARCH 1983
>
> **Observation of Exclusive Decay Modes of b-Flavored Mesons** 40.7 pb^{-1}
>
> B-meson decays to final states consisting of a D^0 or $D^{*\pm}$ and one or two charged pions have been observed. The charged-B mass is 5270.8 ± 2.3 ± 2.0 MeV and the neutral-B mass is 5274.2 ± 1.9 ± 2.0 MeV.



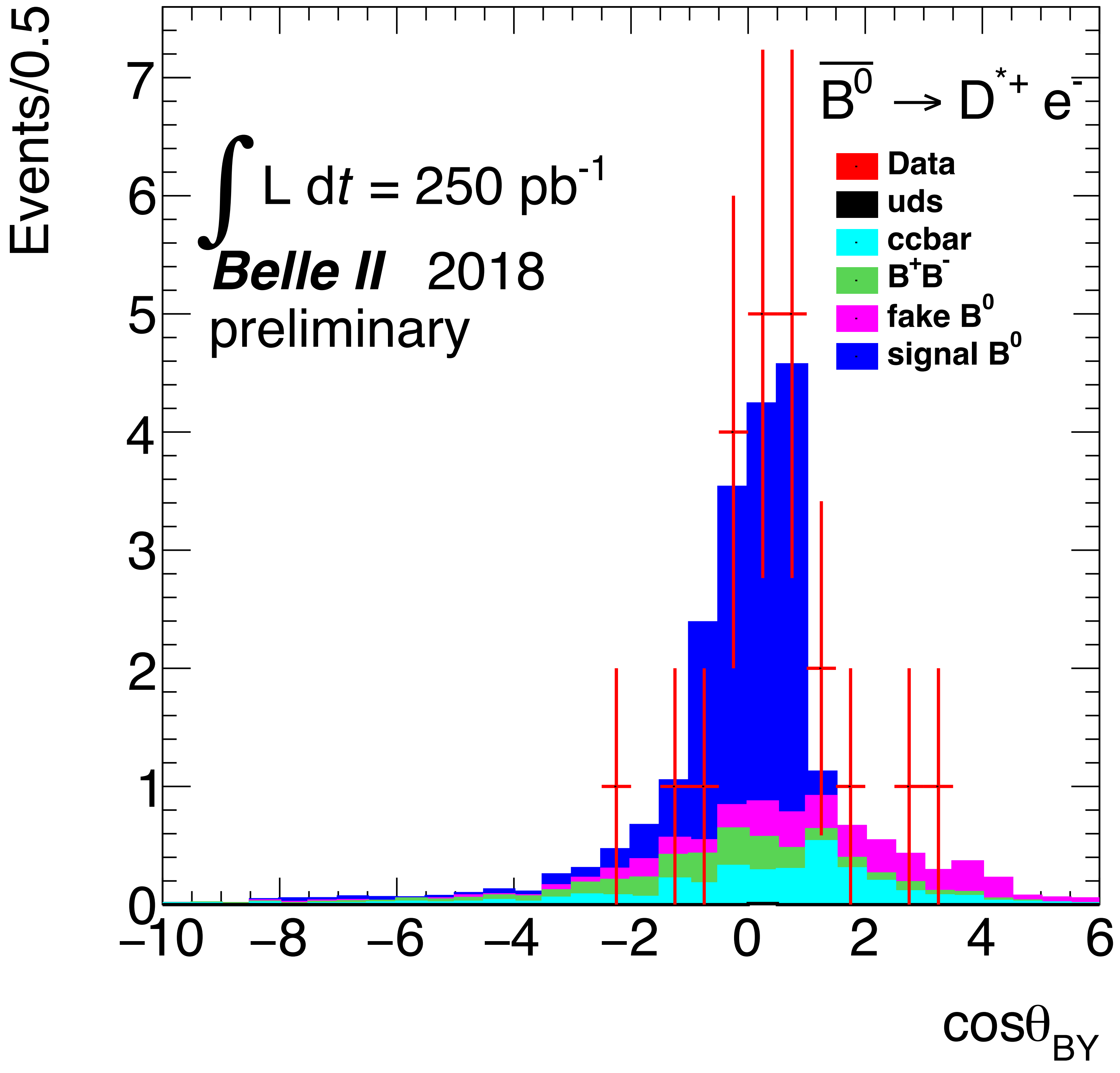
$$\Delta E = E_{cm}/2 - E_{recon}$$



$$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$$



$B \to D^* e \nu$



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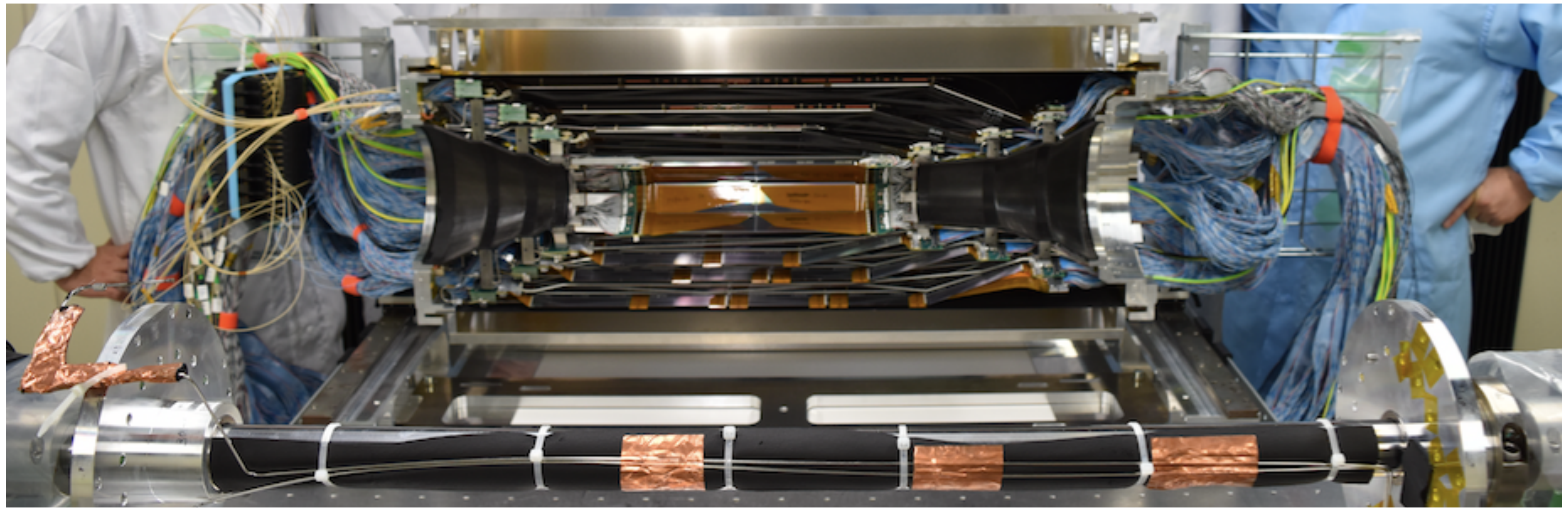
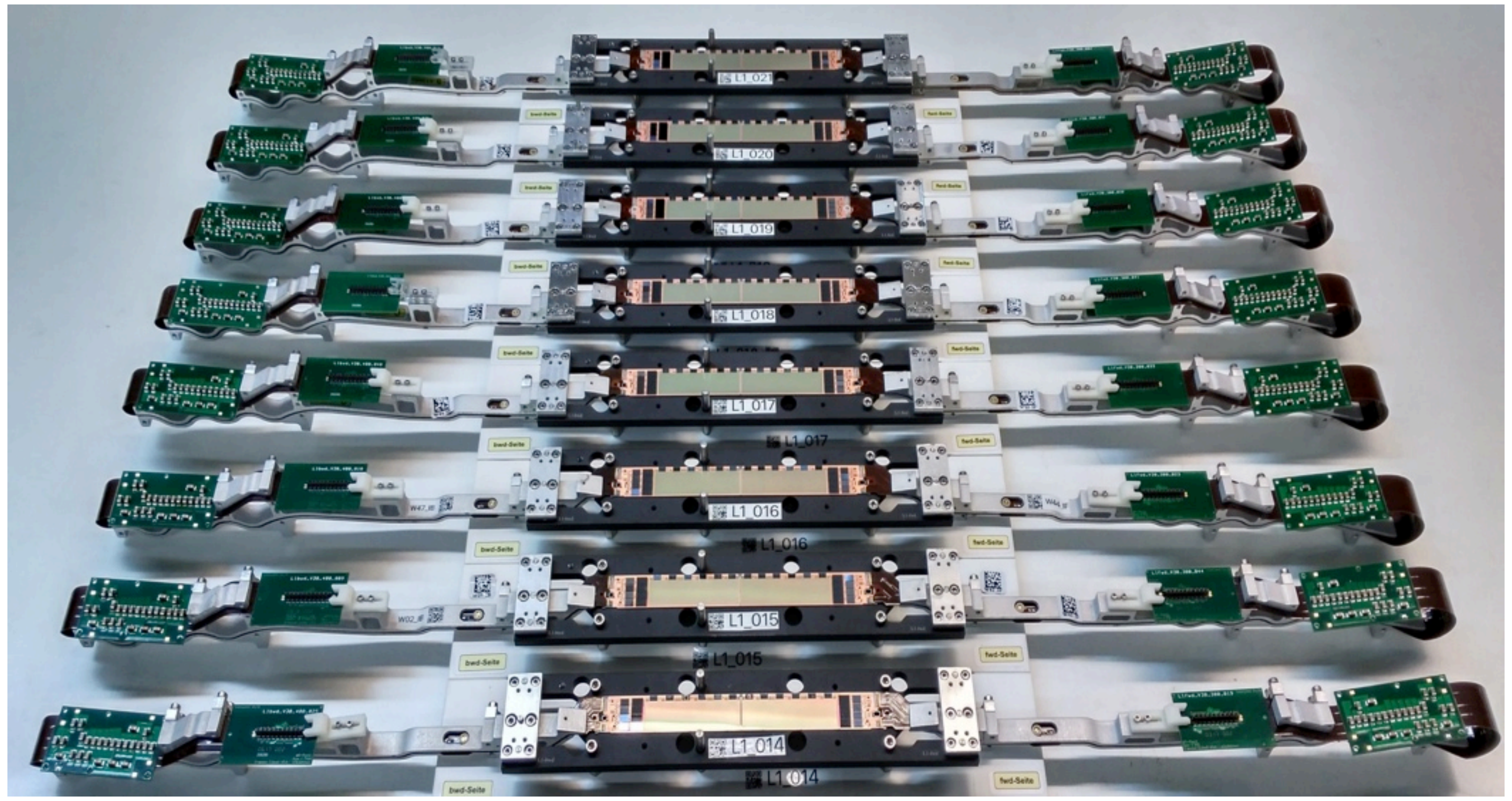
Towards Phase 3 and the Physics Run

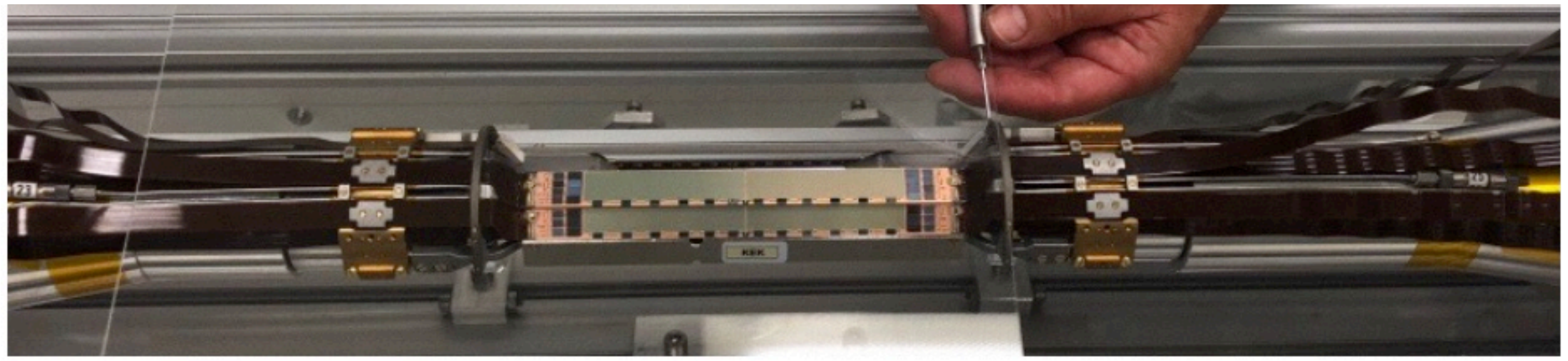
The VXD will be installed in Phase 3. Restart Belle II data taking in late February 2019.

SVD +x half-shell, Jan 2018 KEK



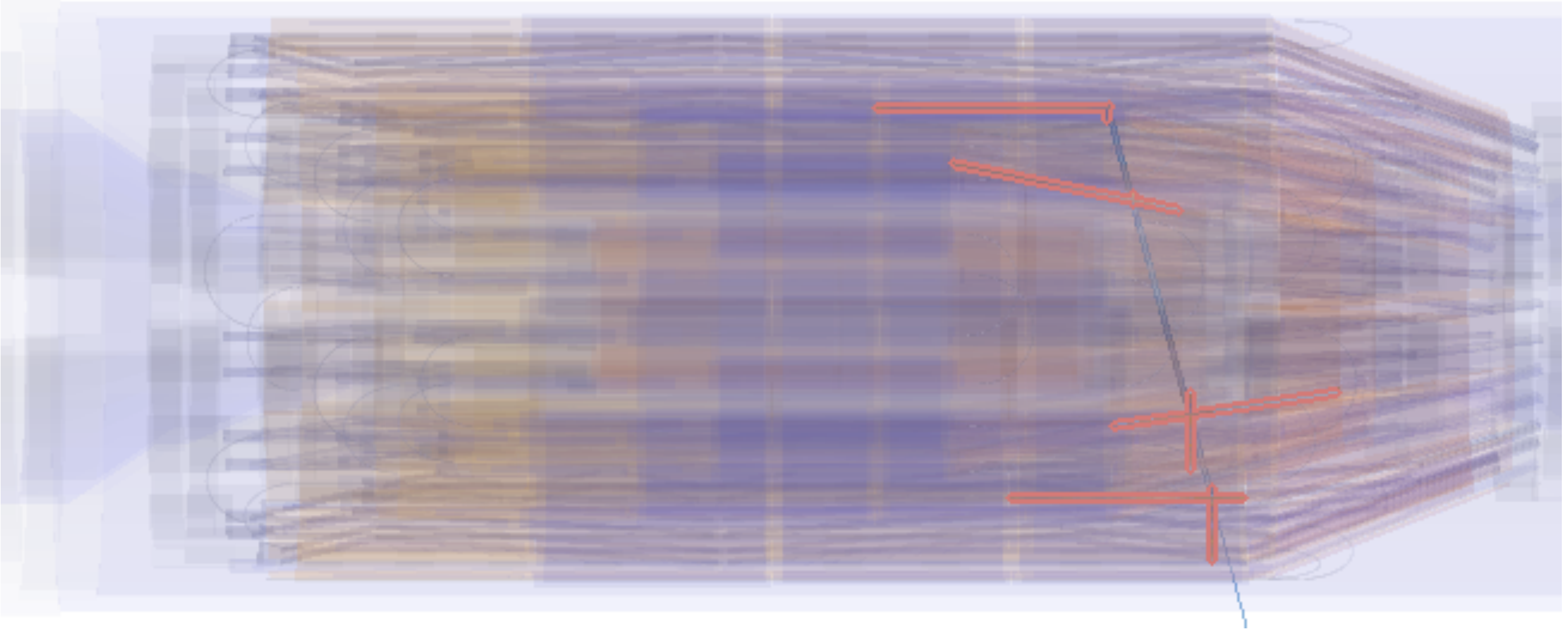


PXD layer 1 ladders, Feb 2018

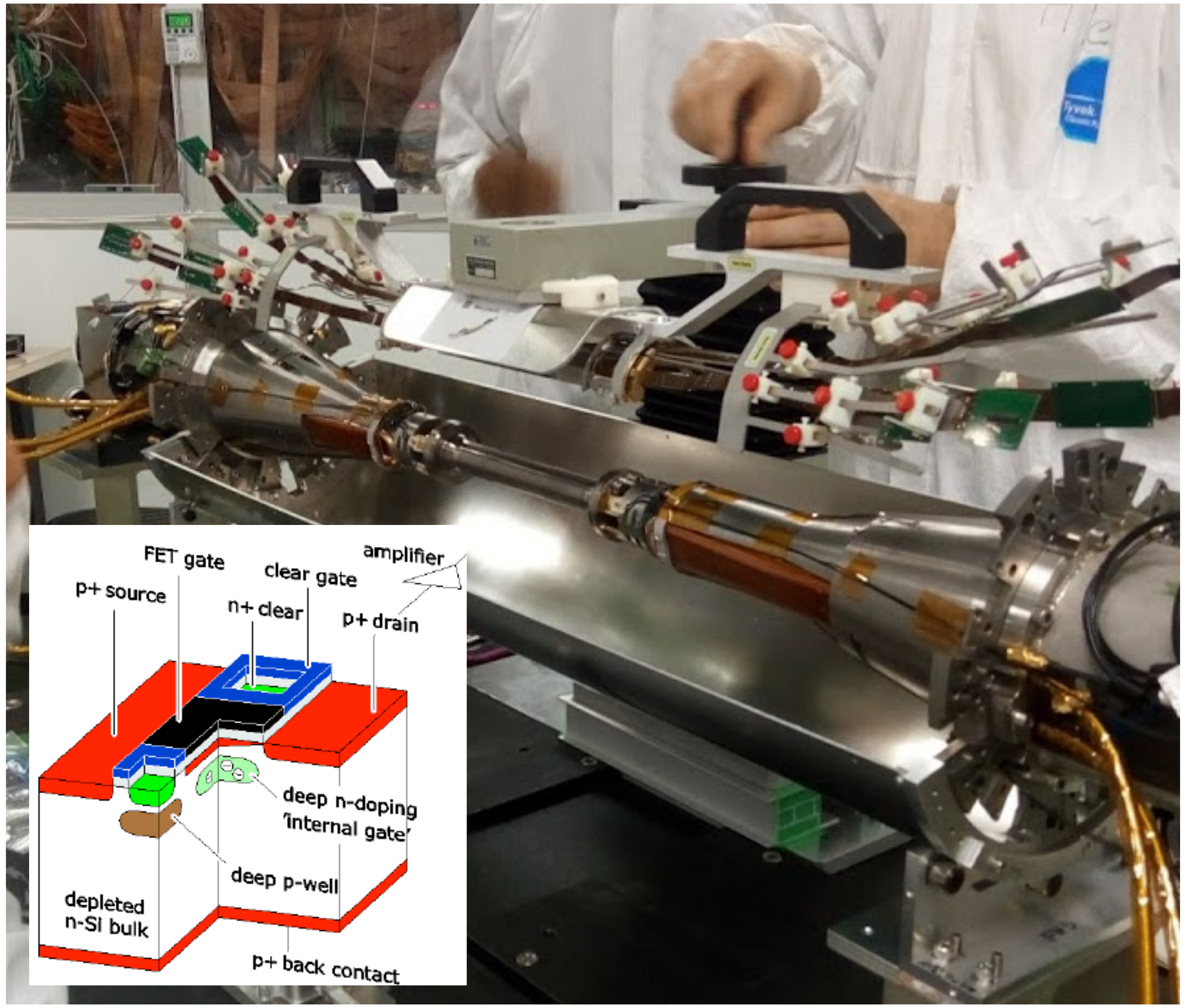


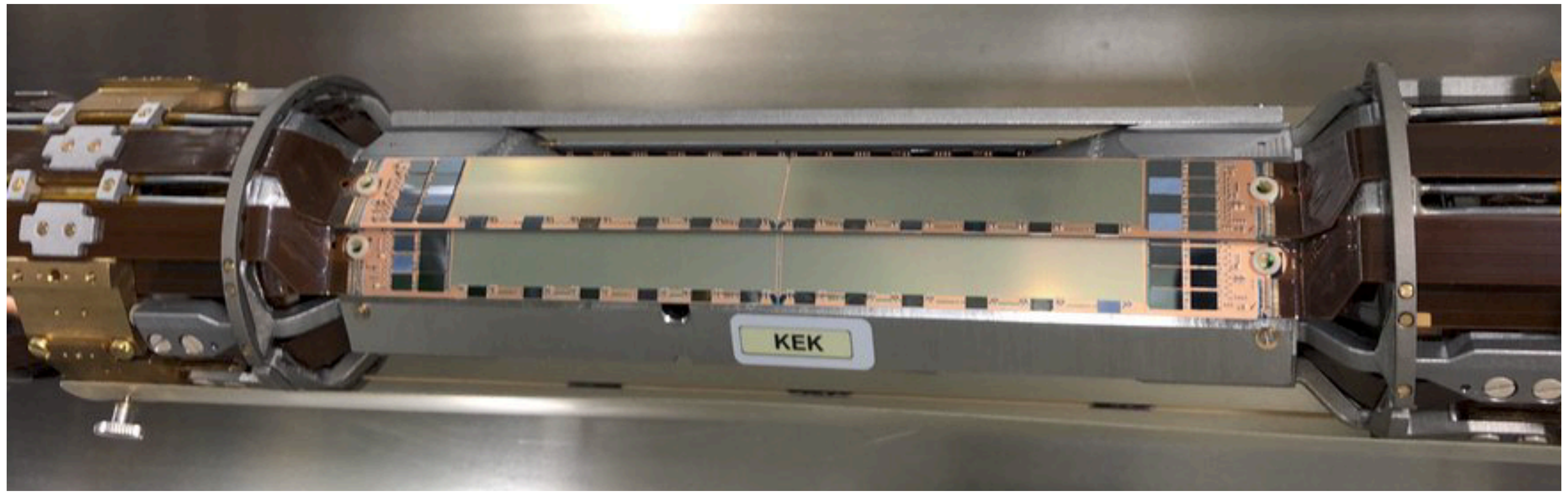
First PXD half-shell being tested at DESY, July 2018

First Cosmic Ray Muon in the full SVD at KEK, August 2018

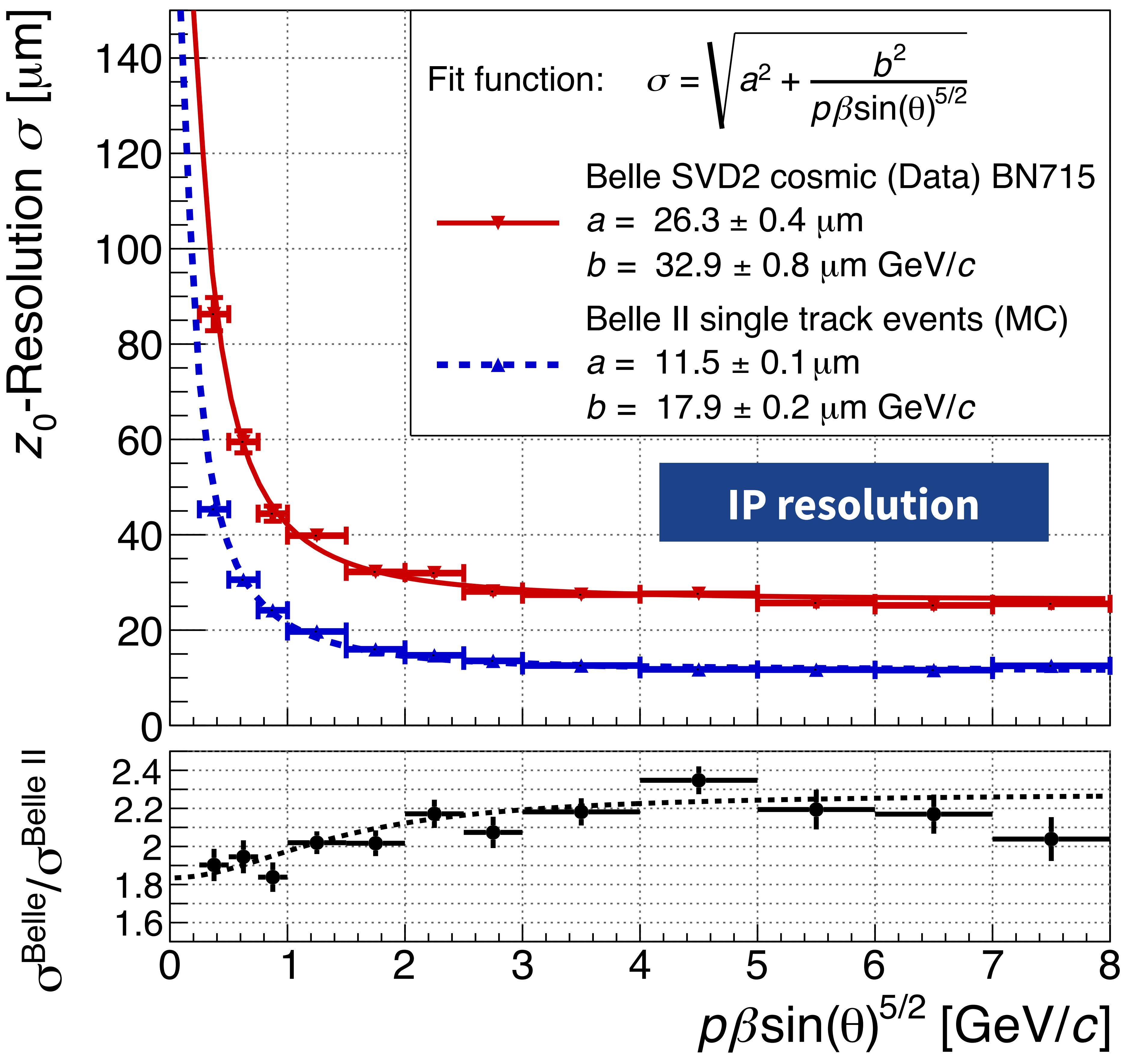


Pixel detector ready





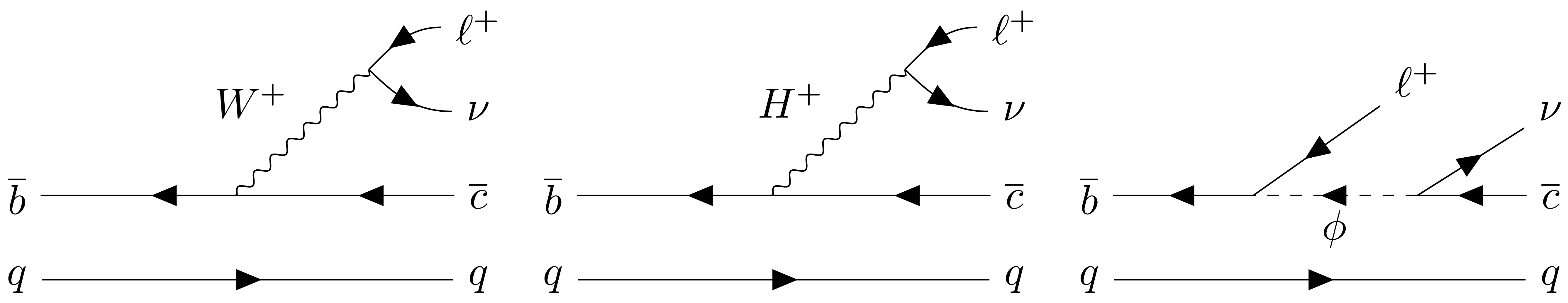
PXD mounted onto SuperKEKB beam pipe at KEK. The full VXD (PXD+SVD) should be completed within weeks.



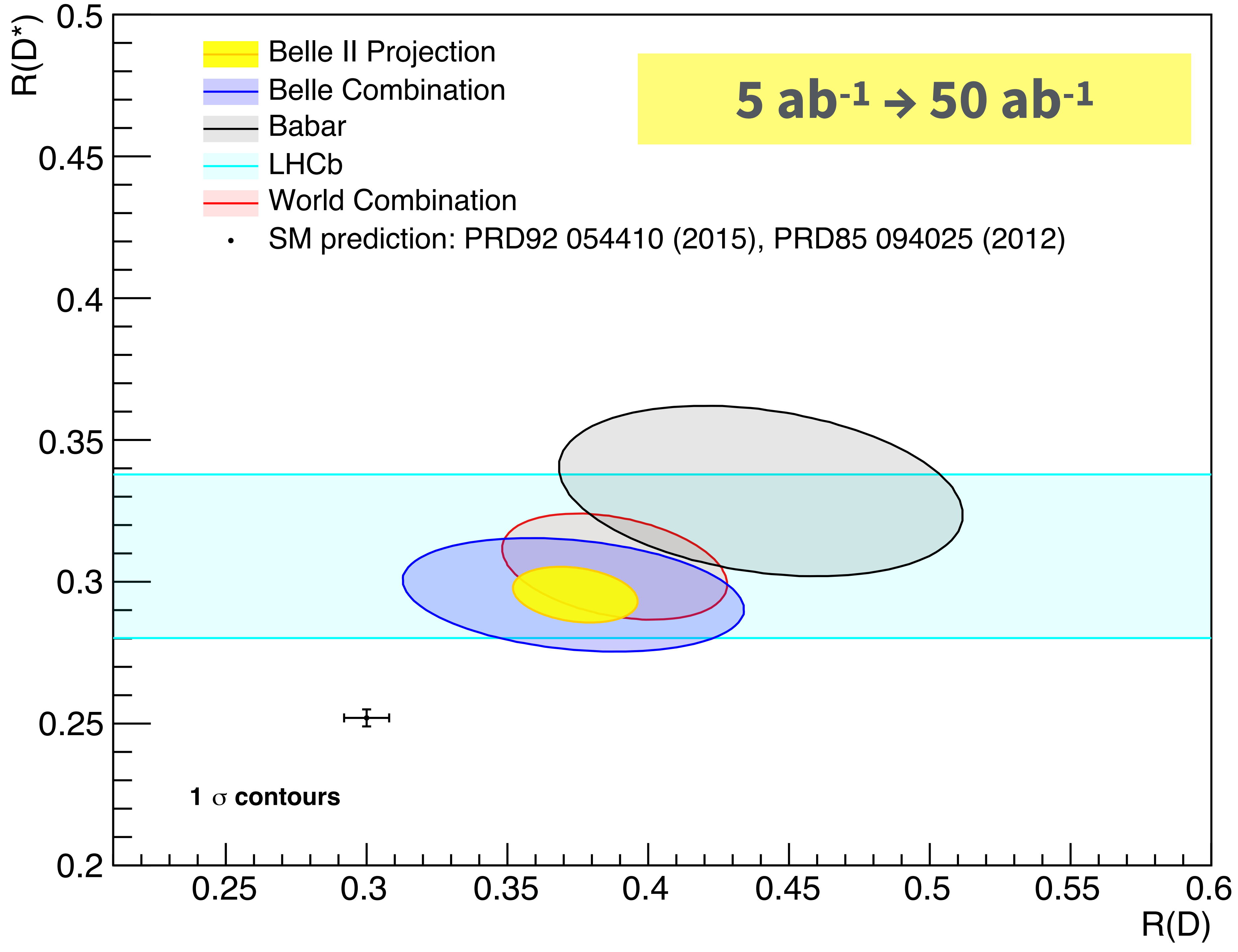
- Impact parameters: σ_{d0} Belle II < 0.5 x σ_{d0} Belle, Mass: σ_M Belle II ~ 0.7 x σ_M Belle

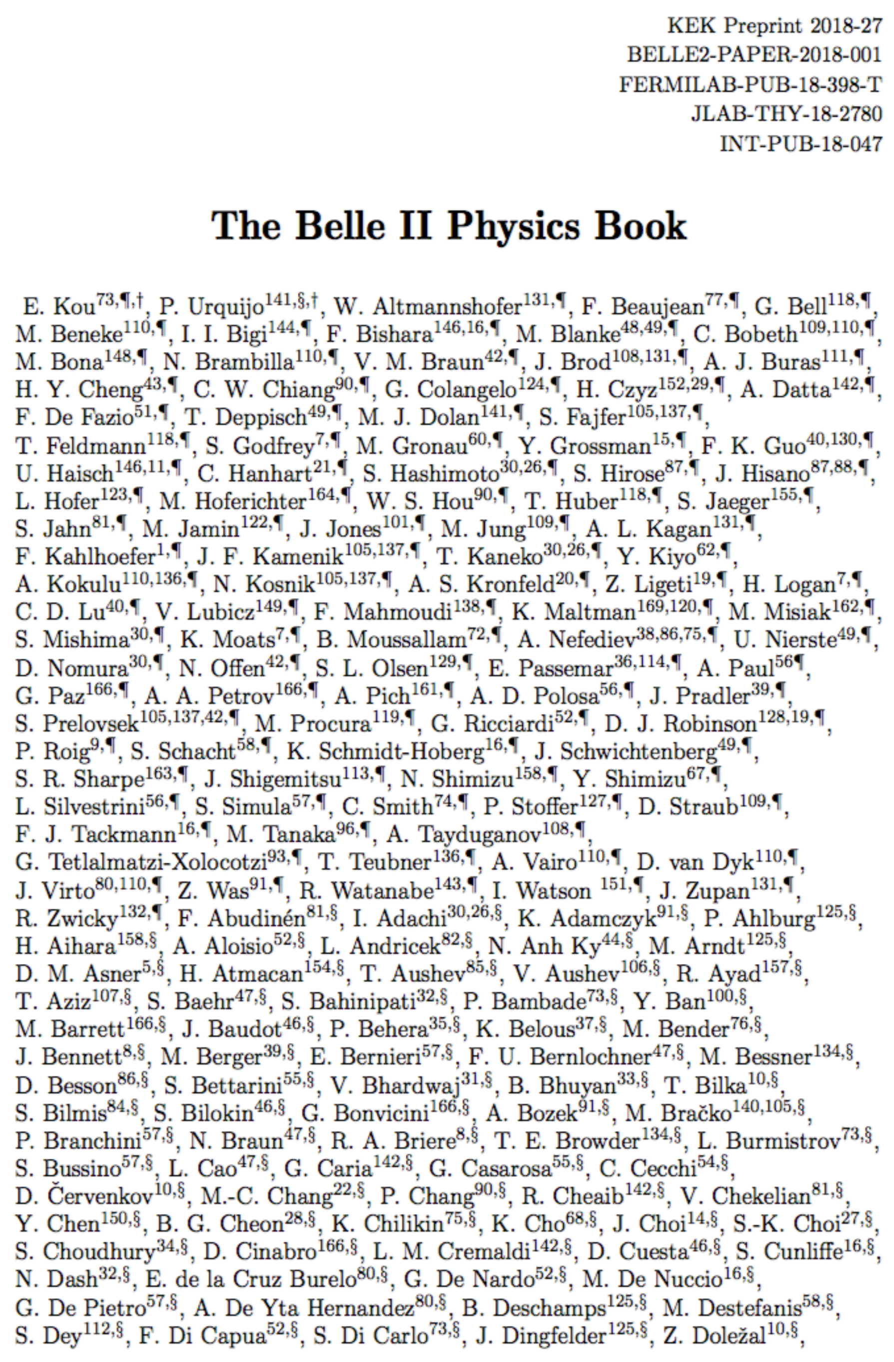
Towards phase 3: B→D$^{(*)}$ τ ν Anomaly

- Belle II should confirm/deny anomaly with 5 ab^{-1} (2 years of full operation)
- **Determine the type of mediator by analysis of kinematic spectra with 50 ab^{-1}**



E. Kou, PU (Editors) et al., arXiv: 1808.10567 (688p), Submitted to PTEP




KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047

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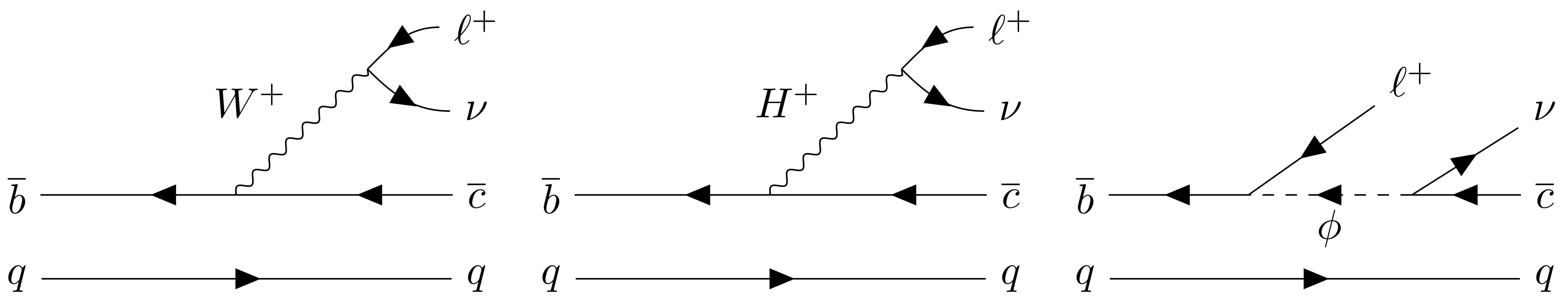

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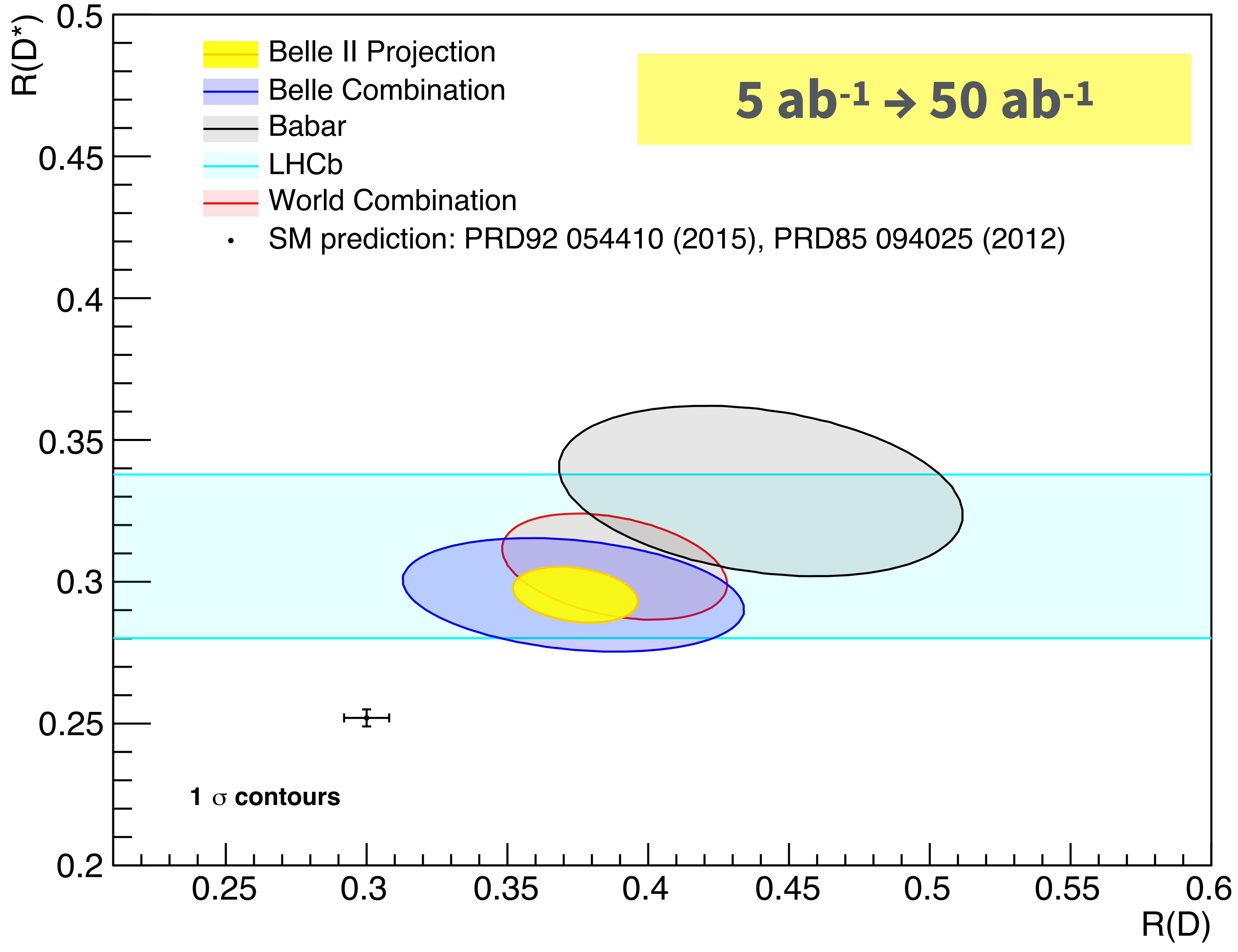

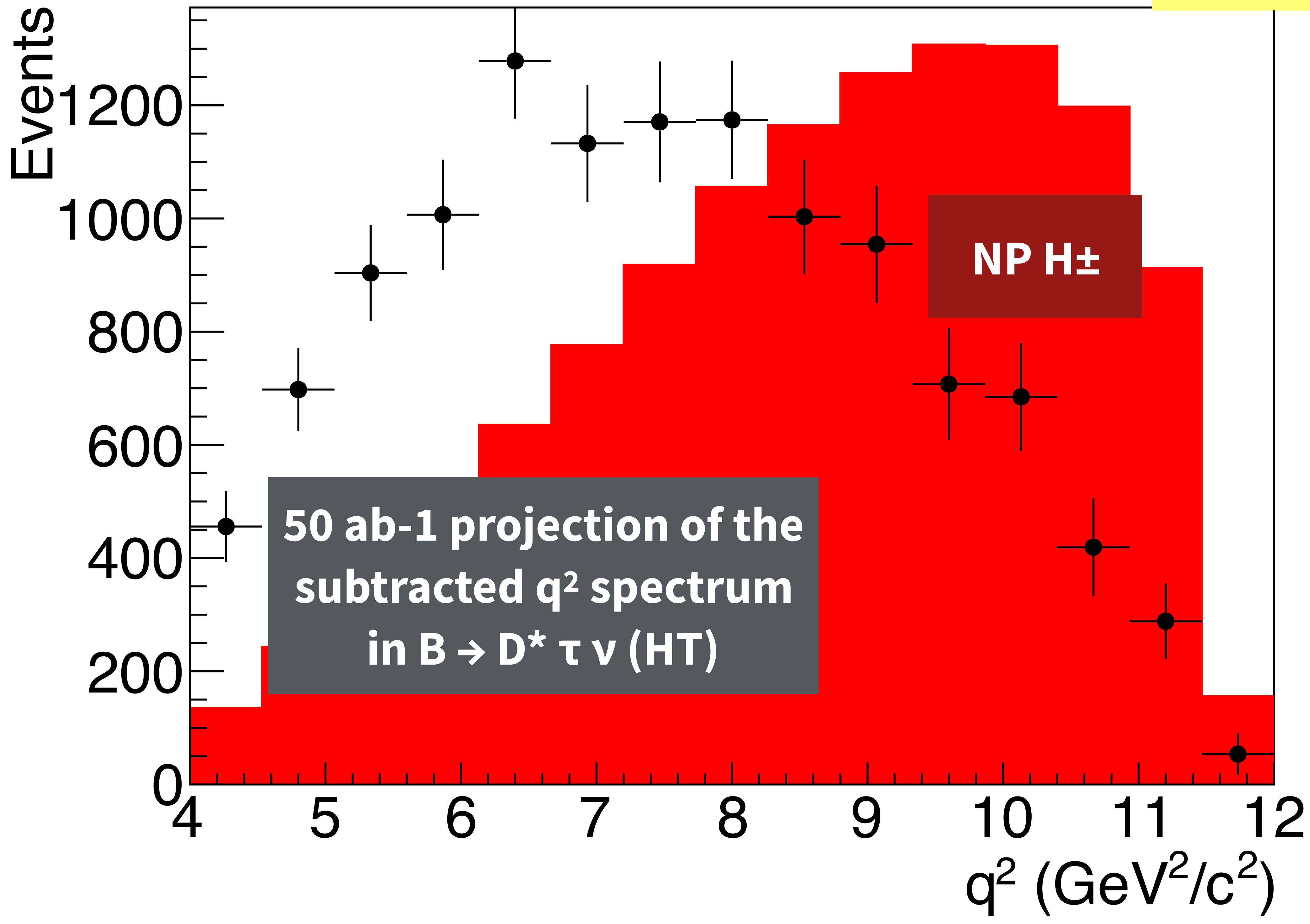

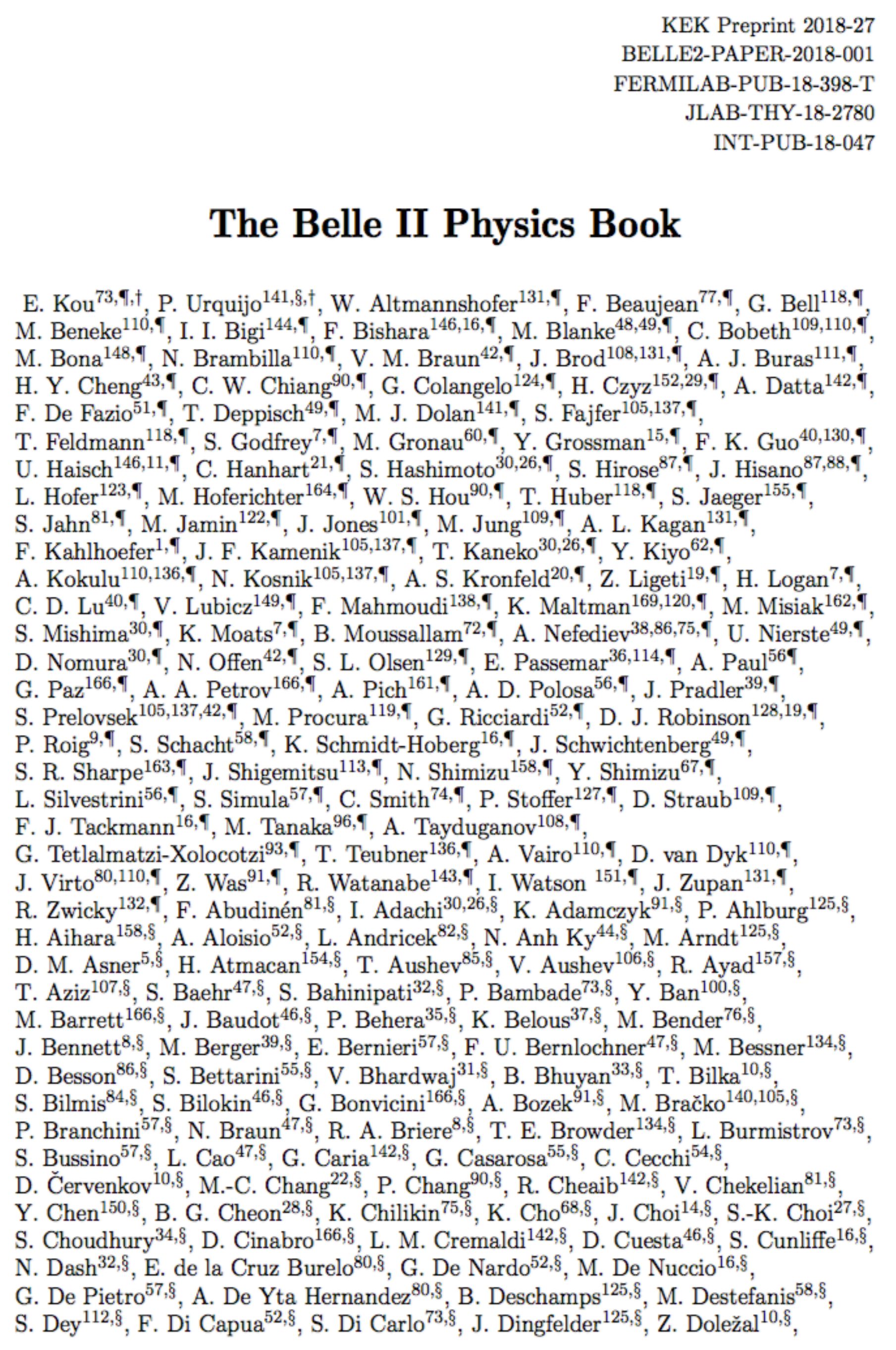

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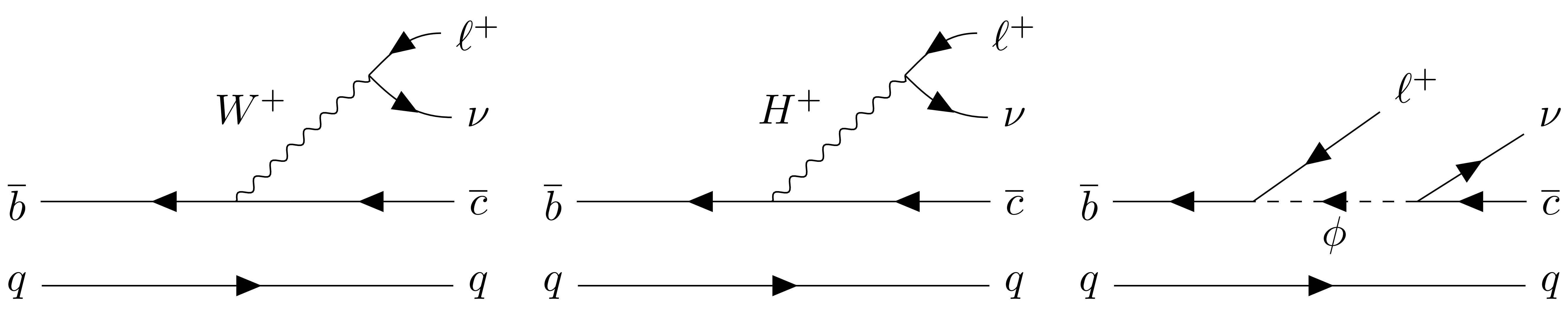

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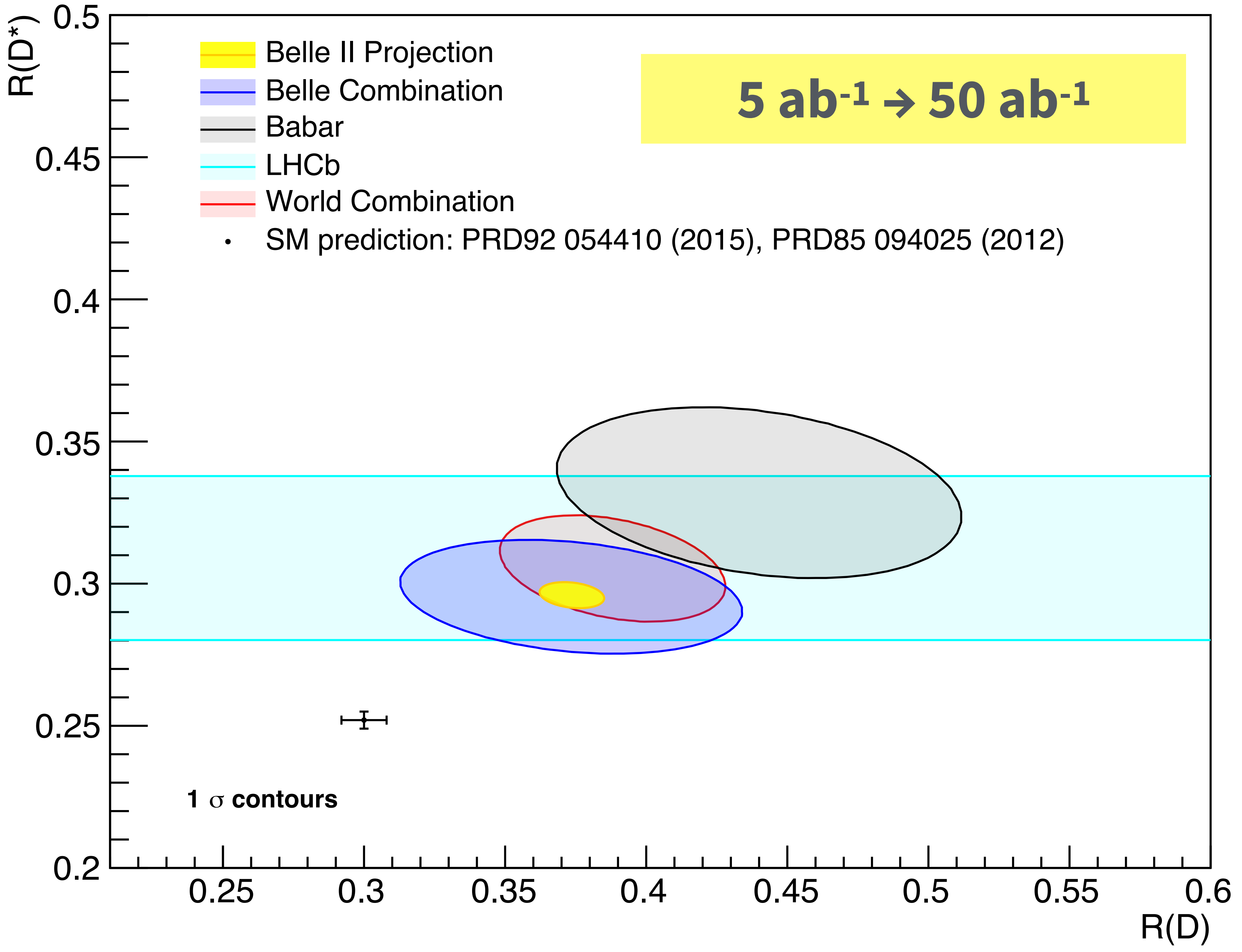

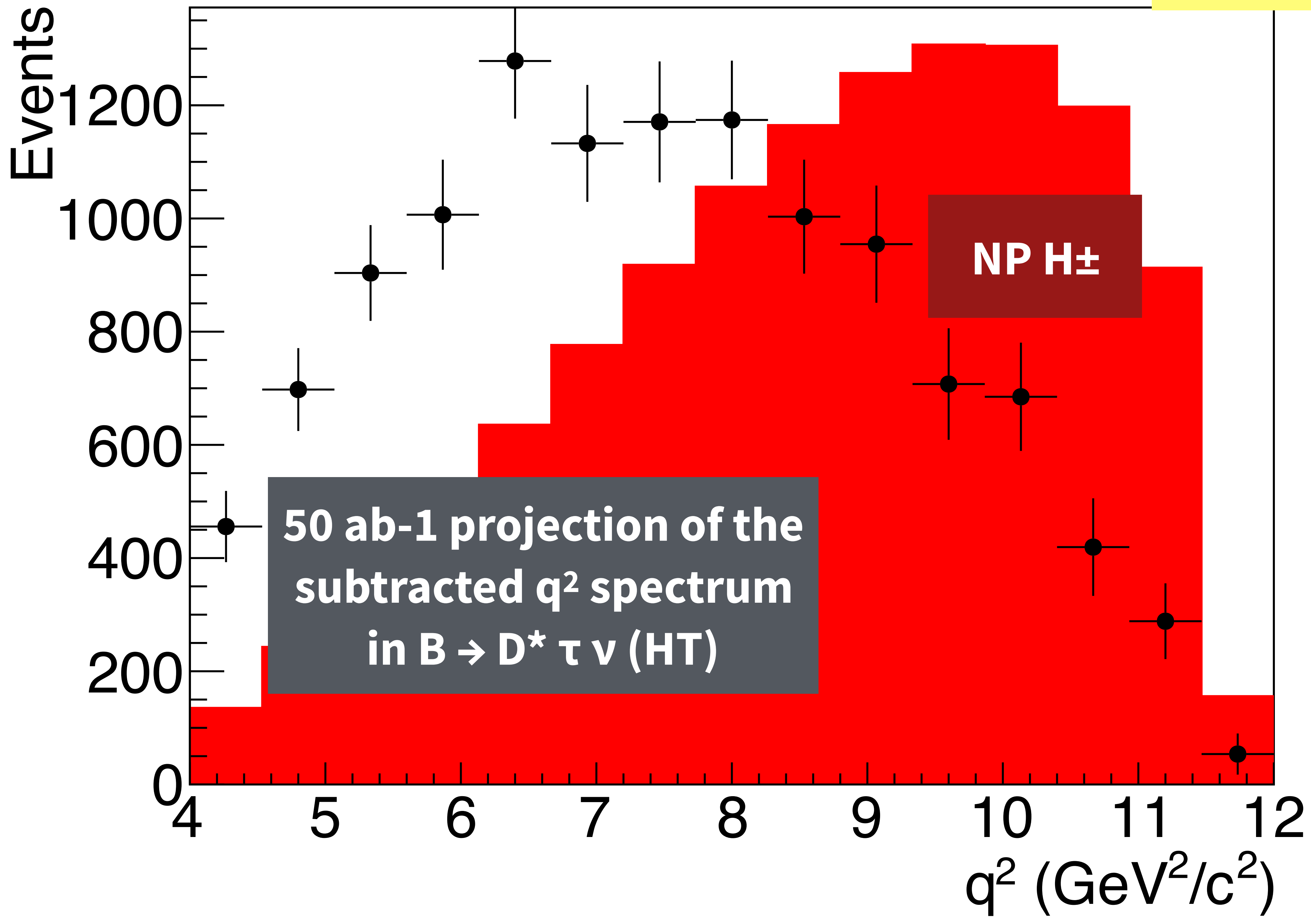

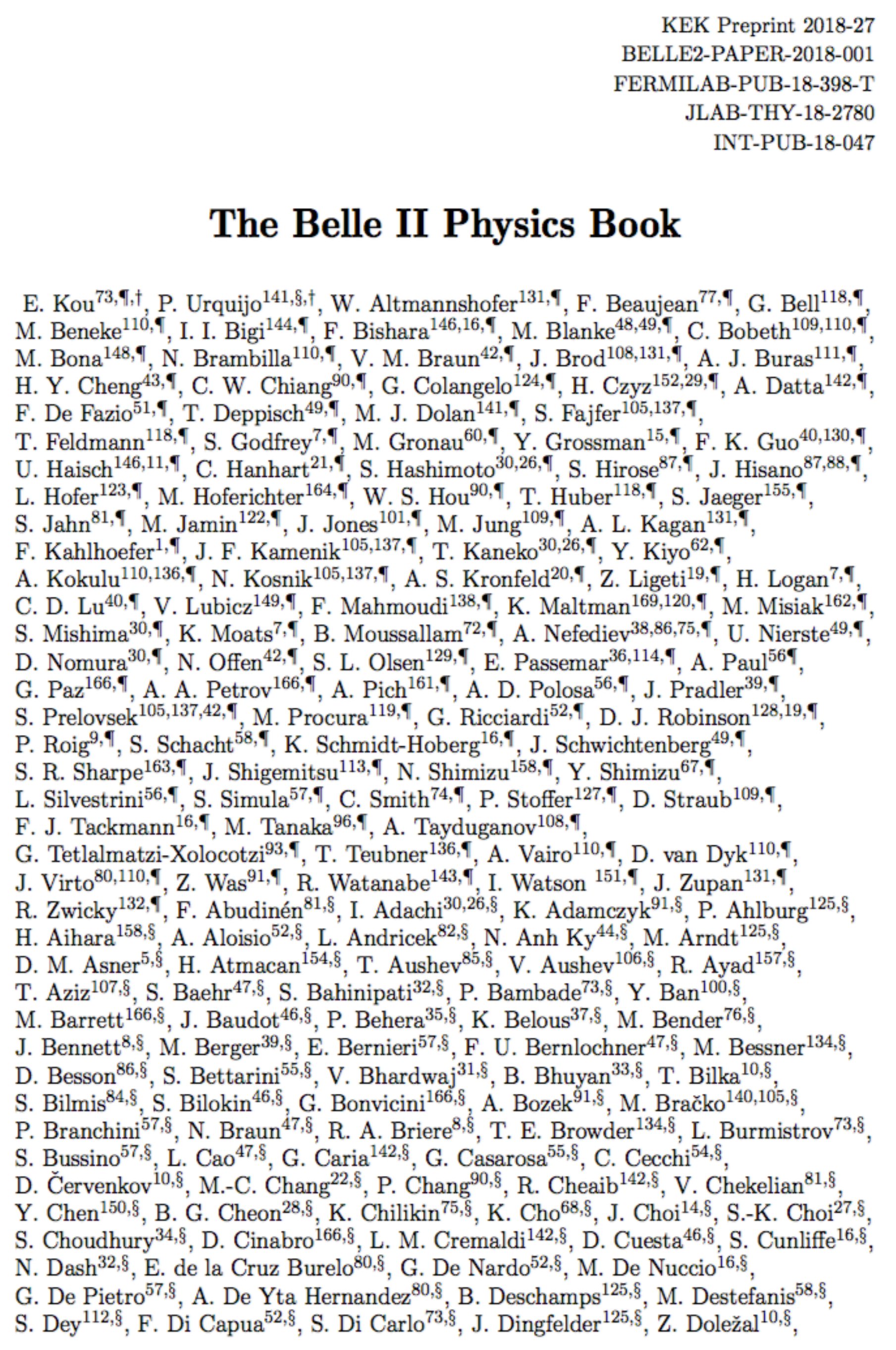
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FERMILAB-PUB-18-398-T
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INT-PUB-18-047

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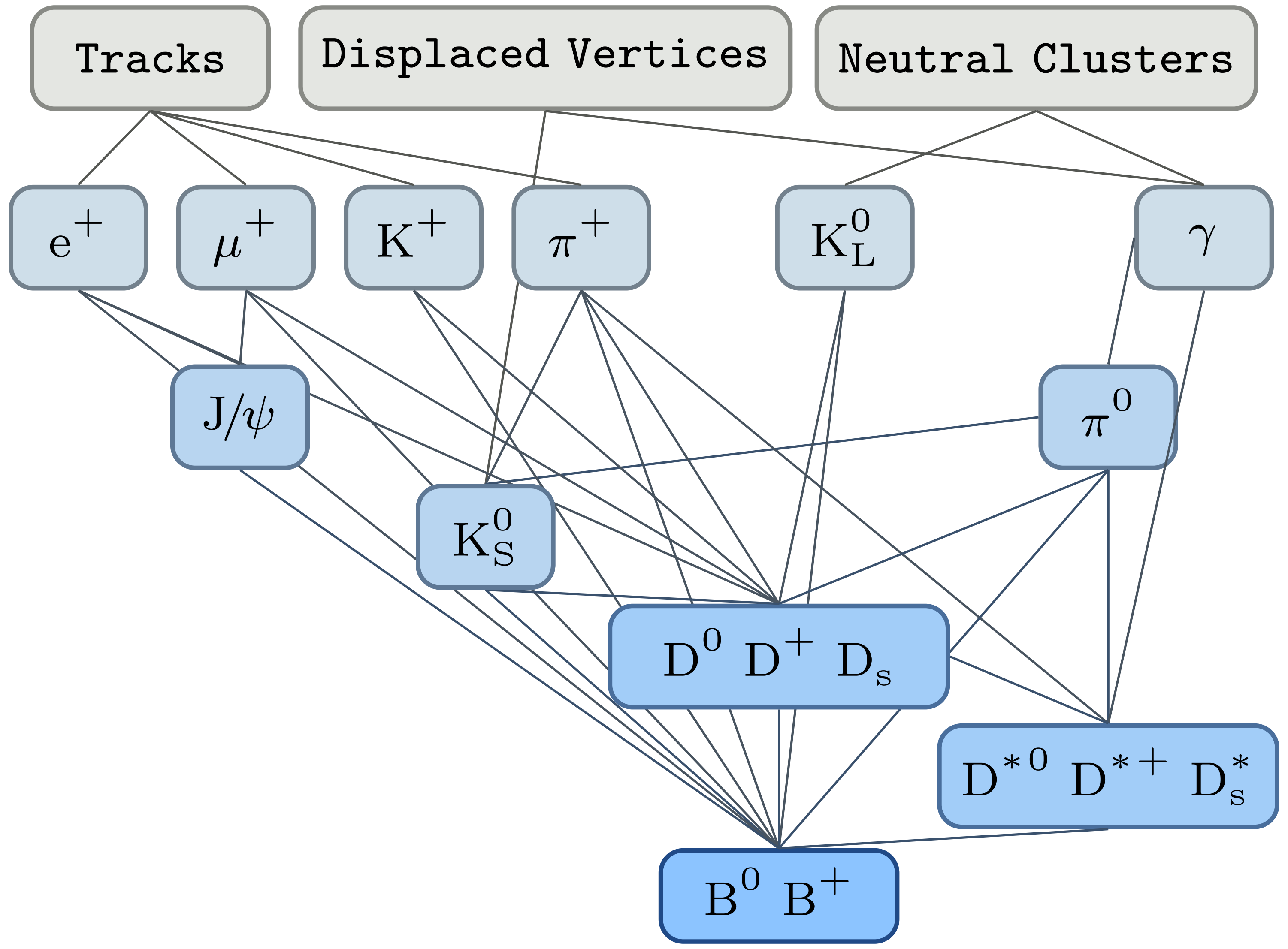
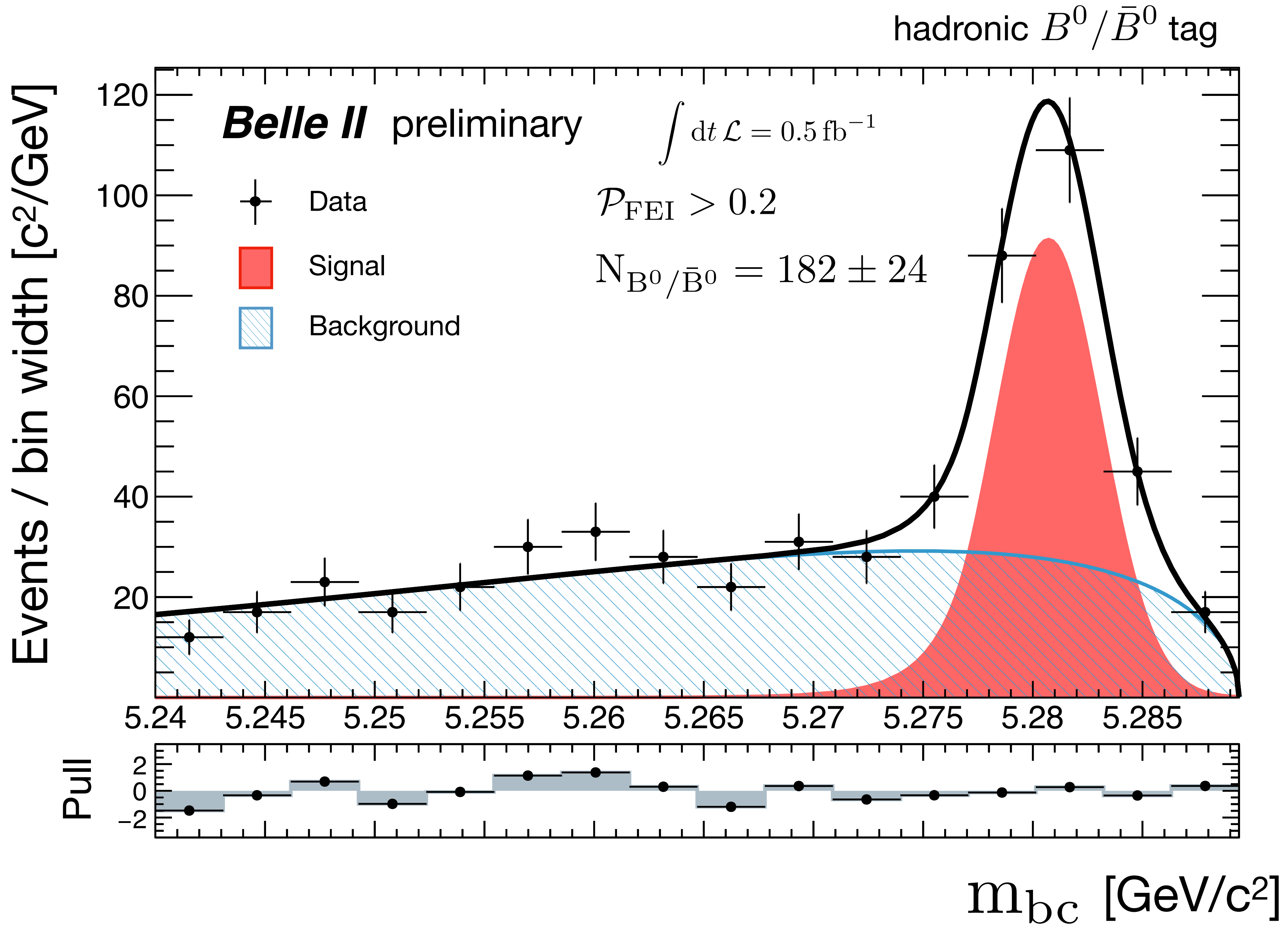
B-full reconstruction in 2018

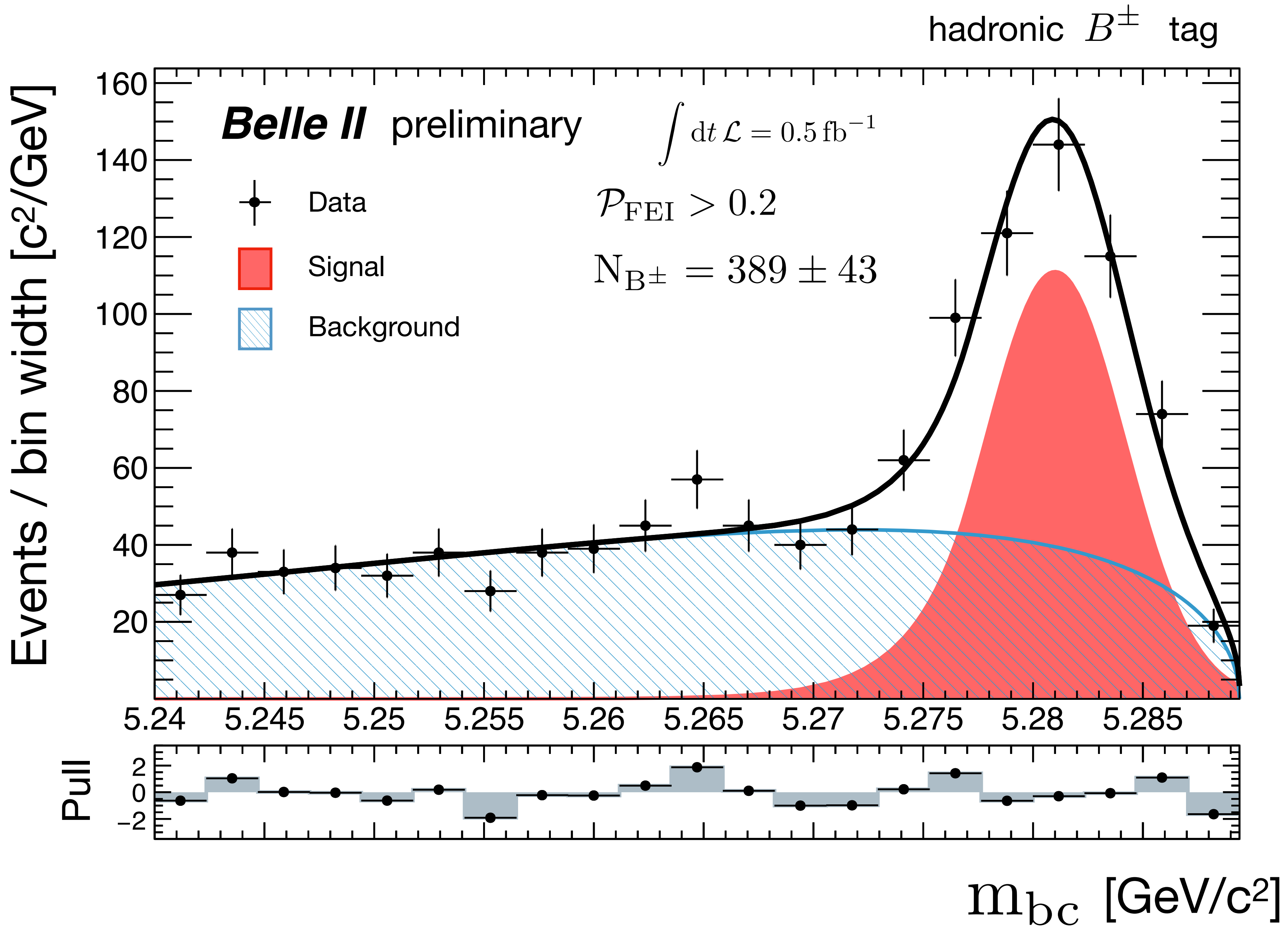
- B→D* τ ν (neutrino reco) requires high efficiency full reconstruction tag algorithms
- Recursive reconstruction algorithm (FEI): **> 5000 decay modes**!
  - the Belle II "killer app".
- Boosted decision tree classifier. Tested with 2018 data.

Missing mass

Tag reconstruction







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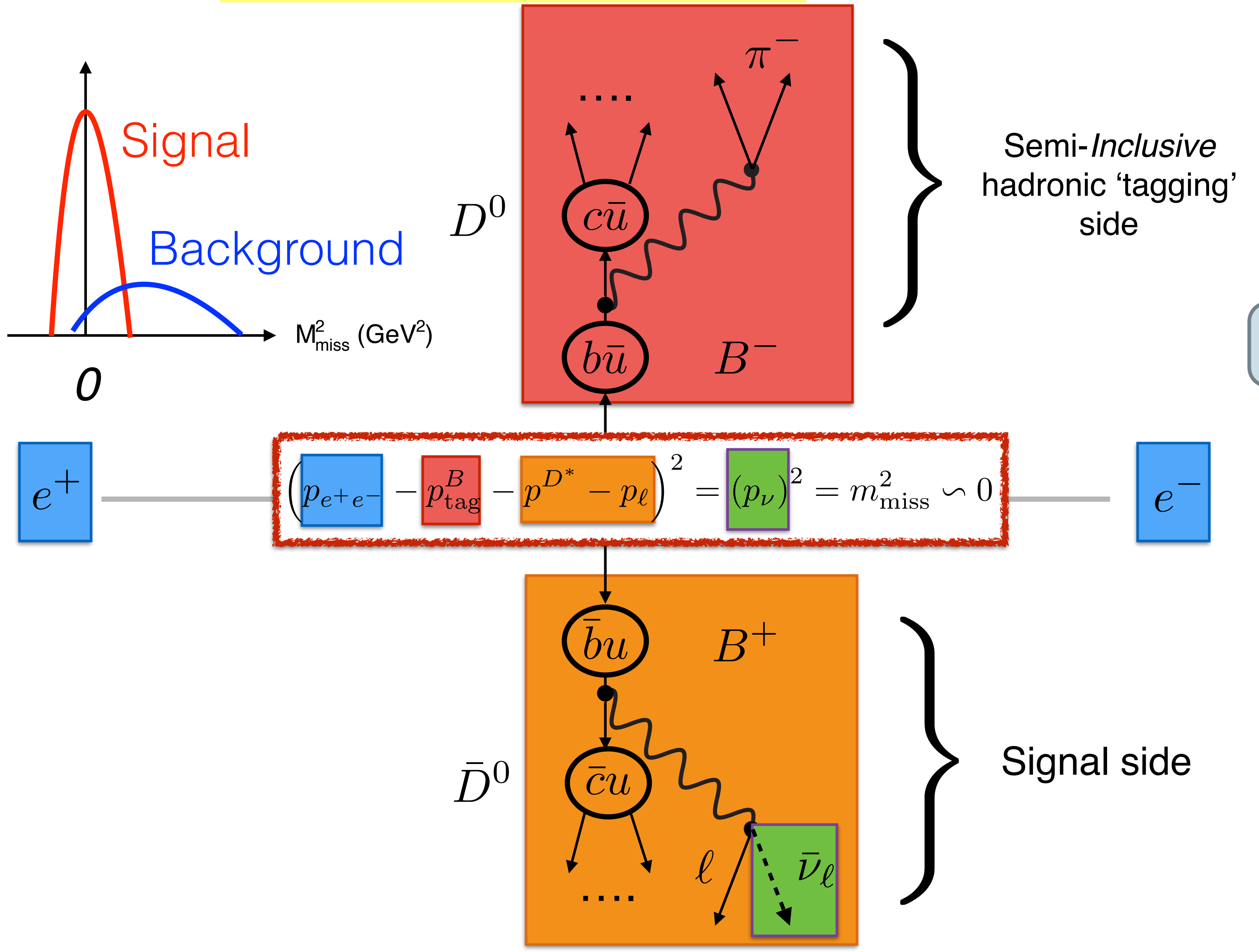
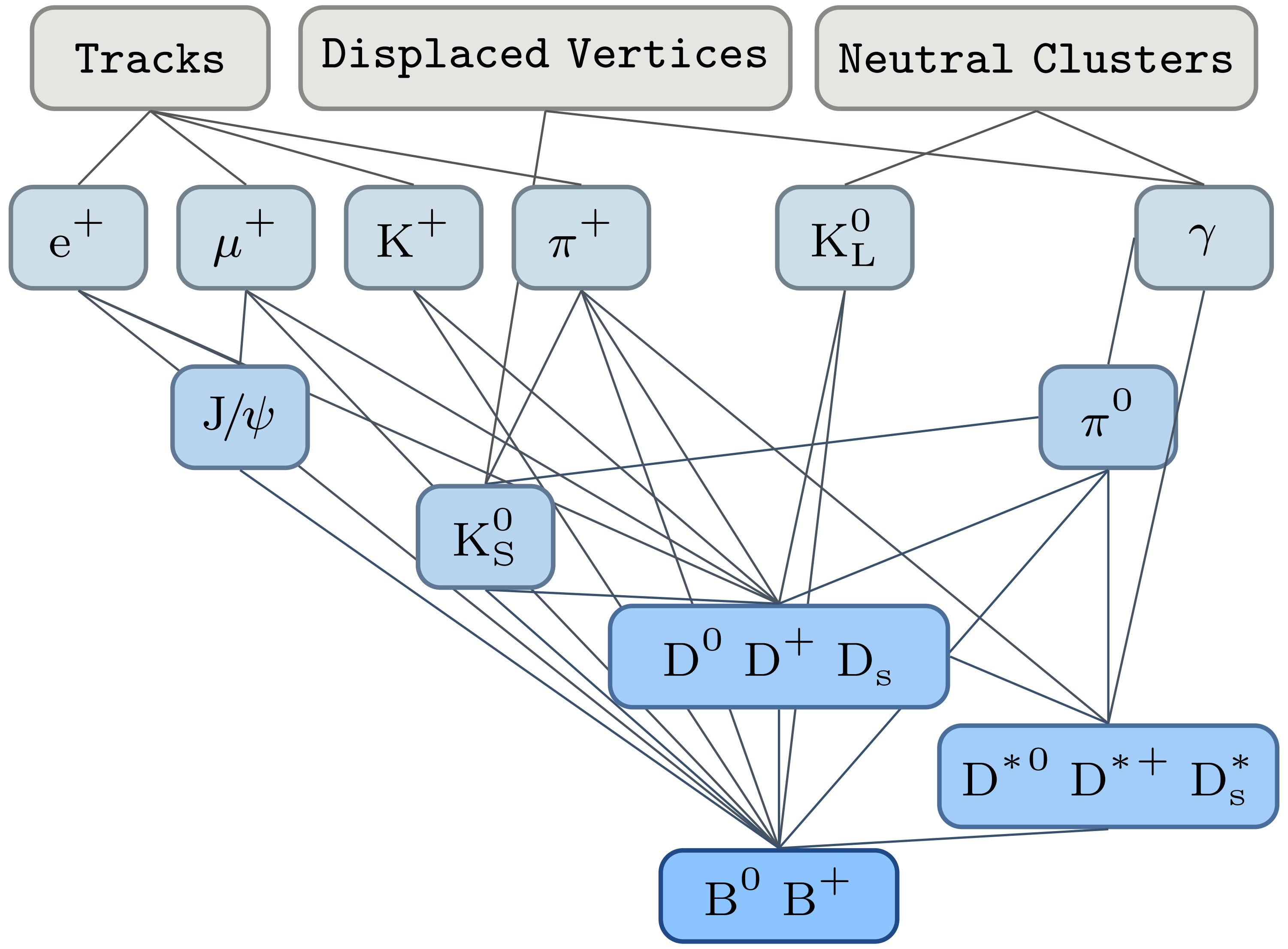
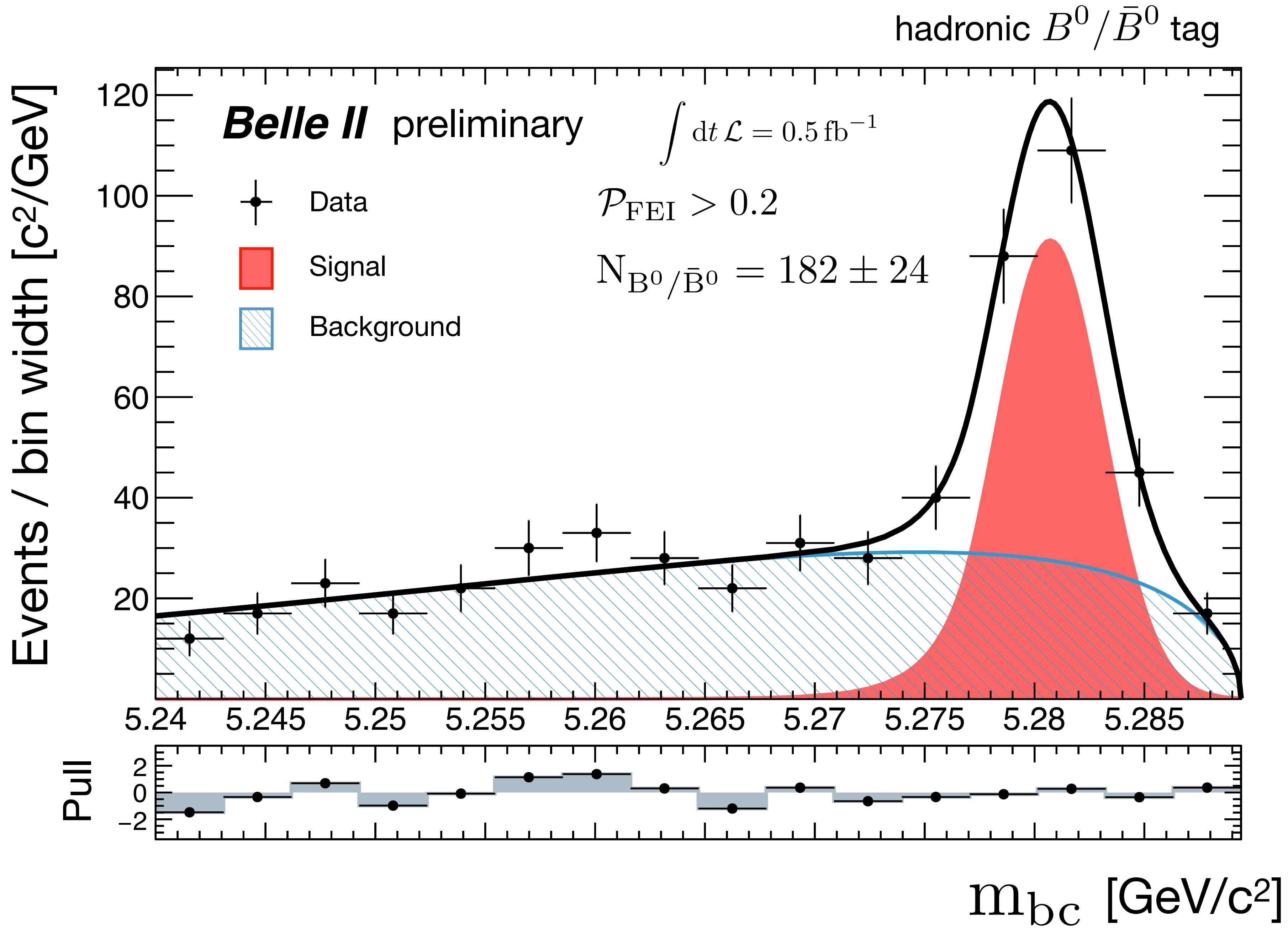
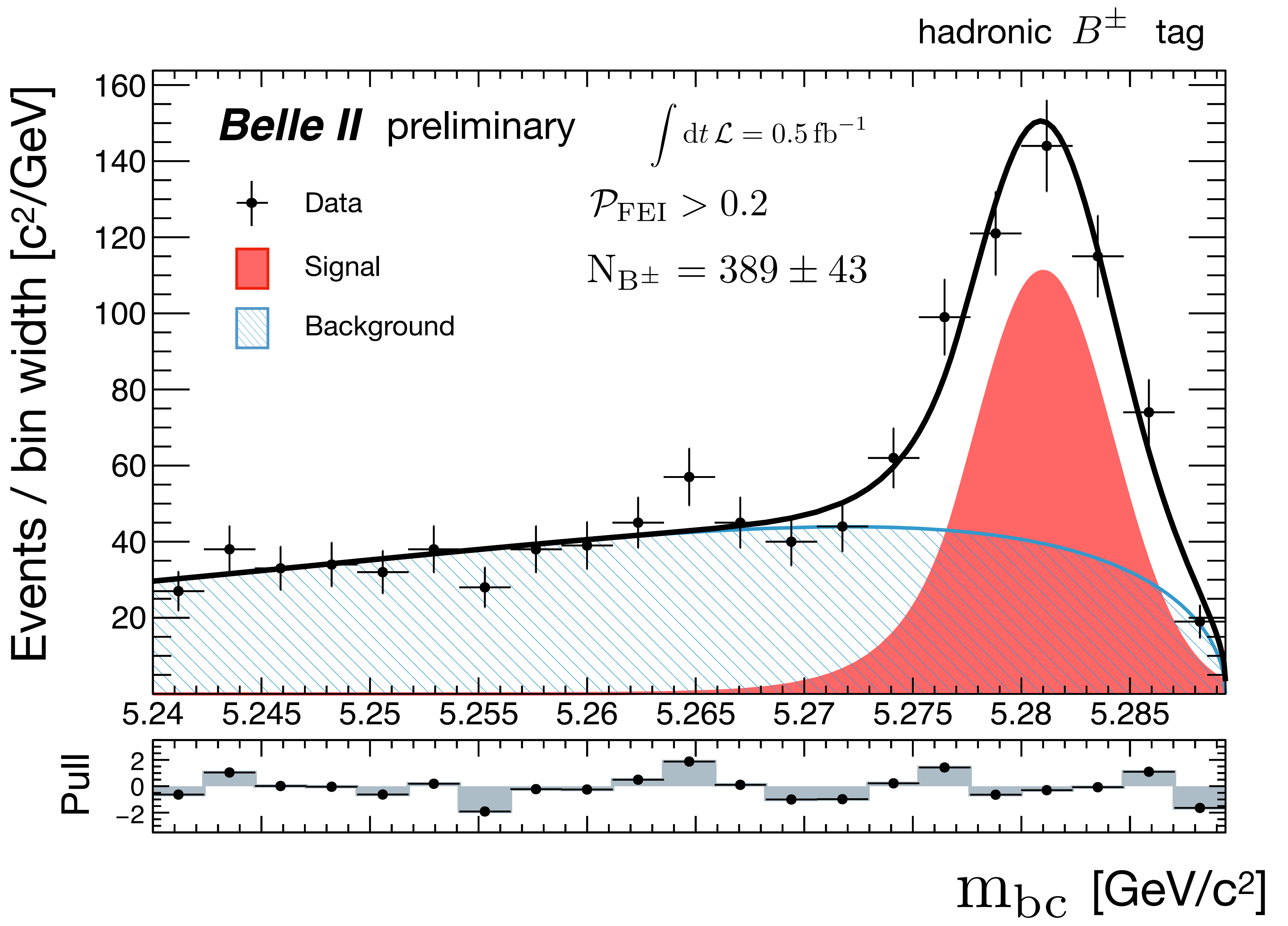


Tag reconstruction







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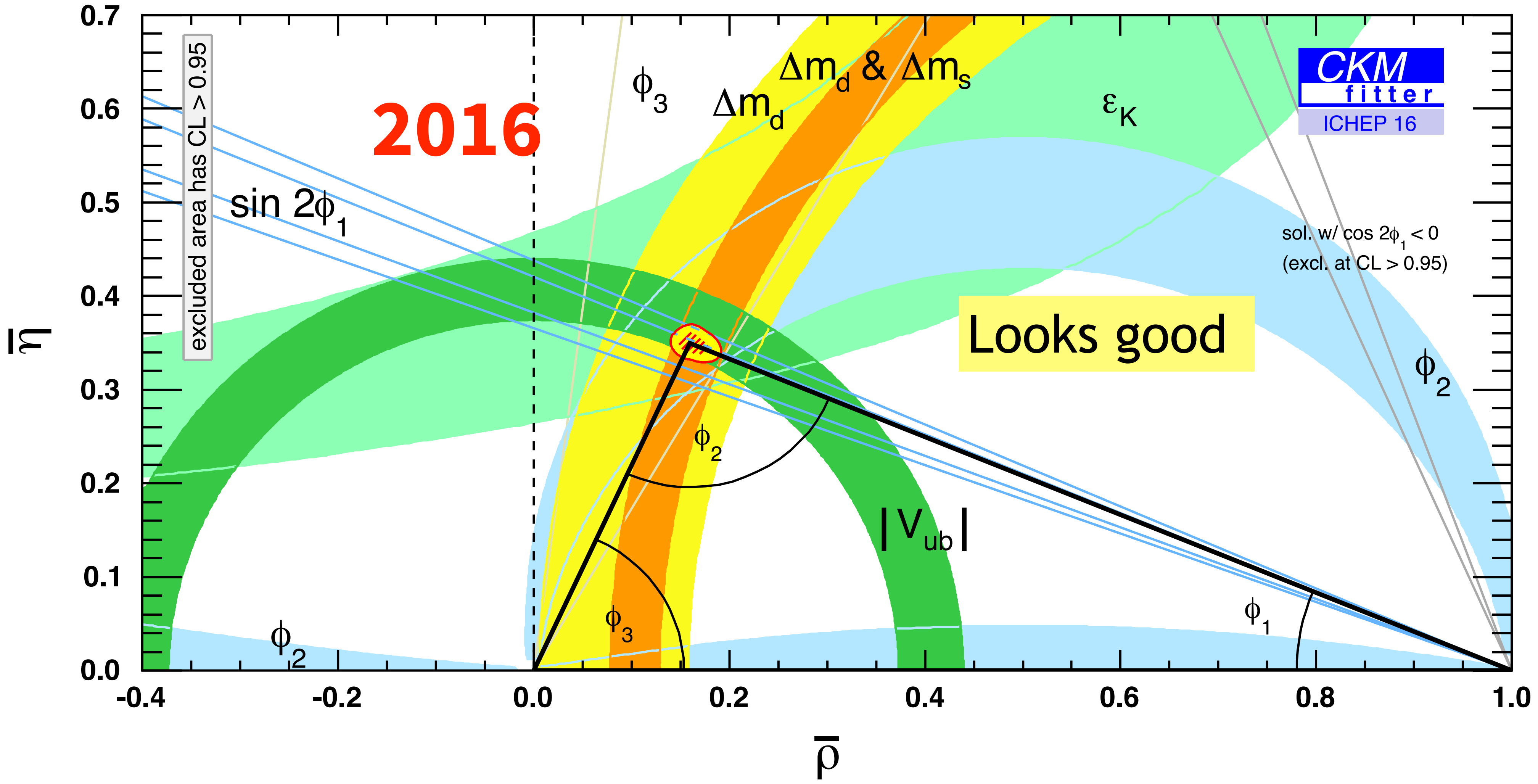
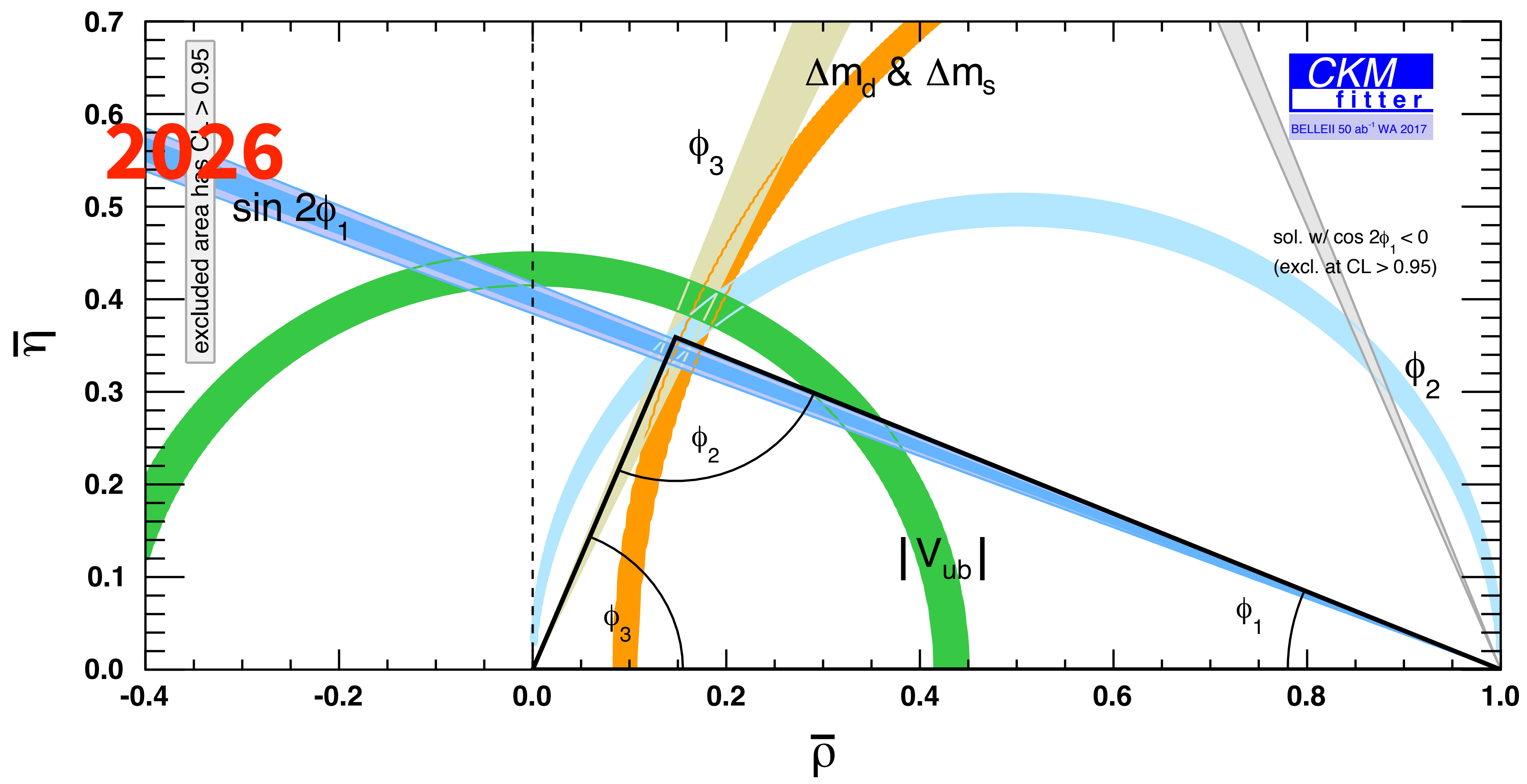
CKM Global Fit Projection: Belle II

E. Kou, PU et al. arXiv: 1808.10567





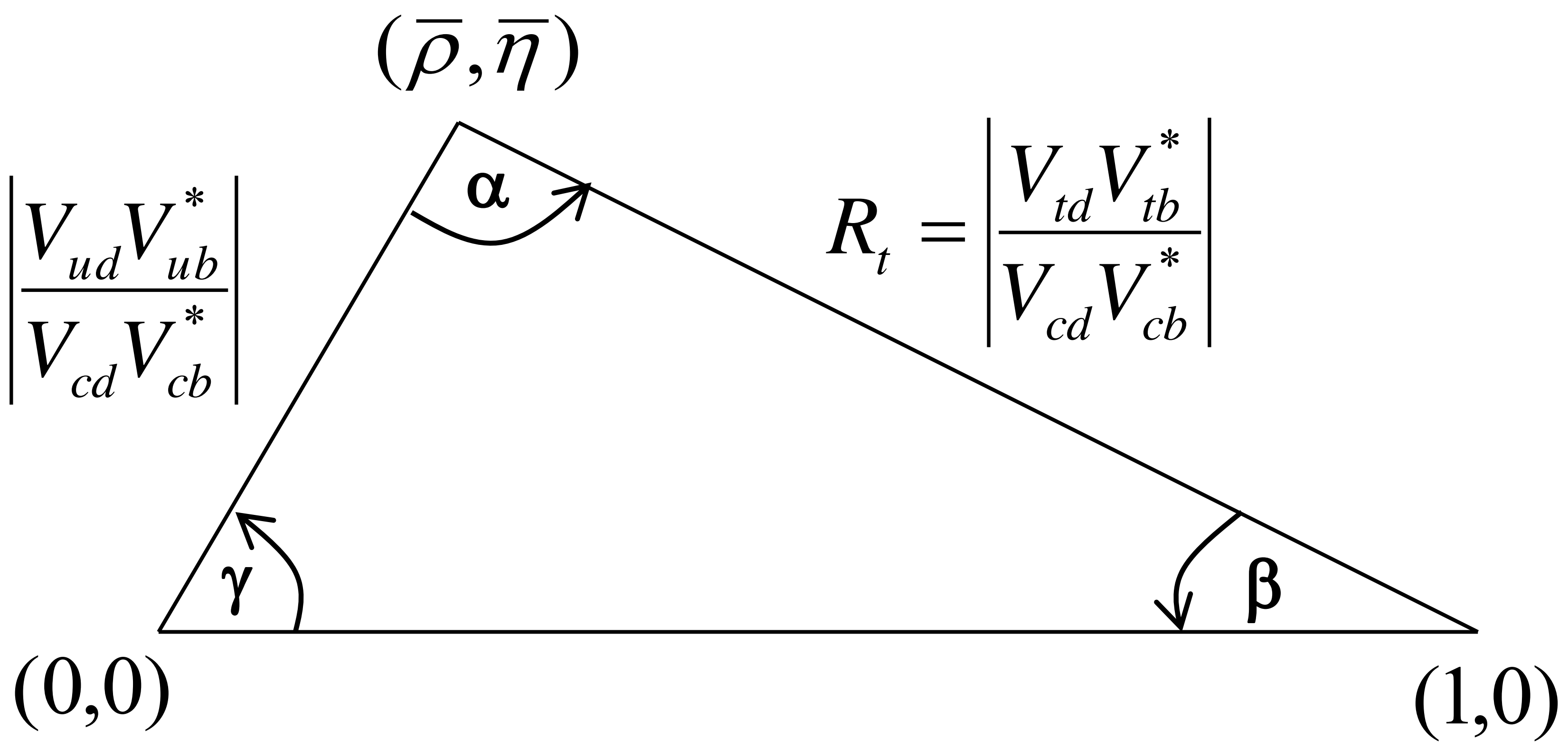
Φ_1 3% → @ 0.7%,

Φ_2 5° → <1°,

Φ_3 5° → ~1°

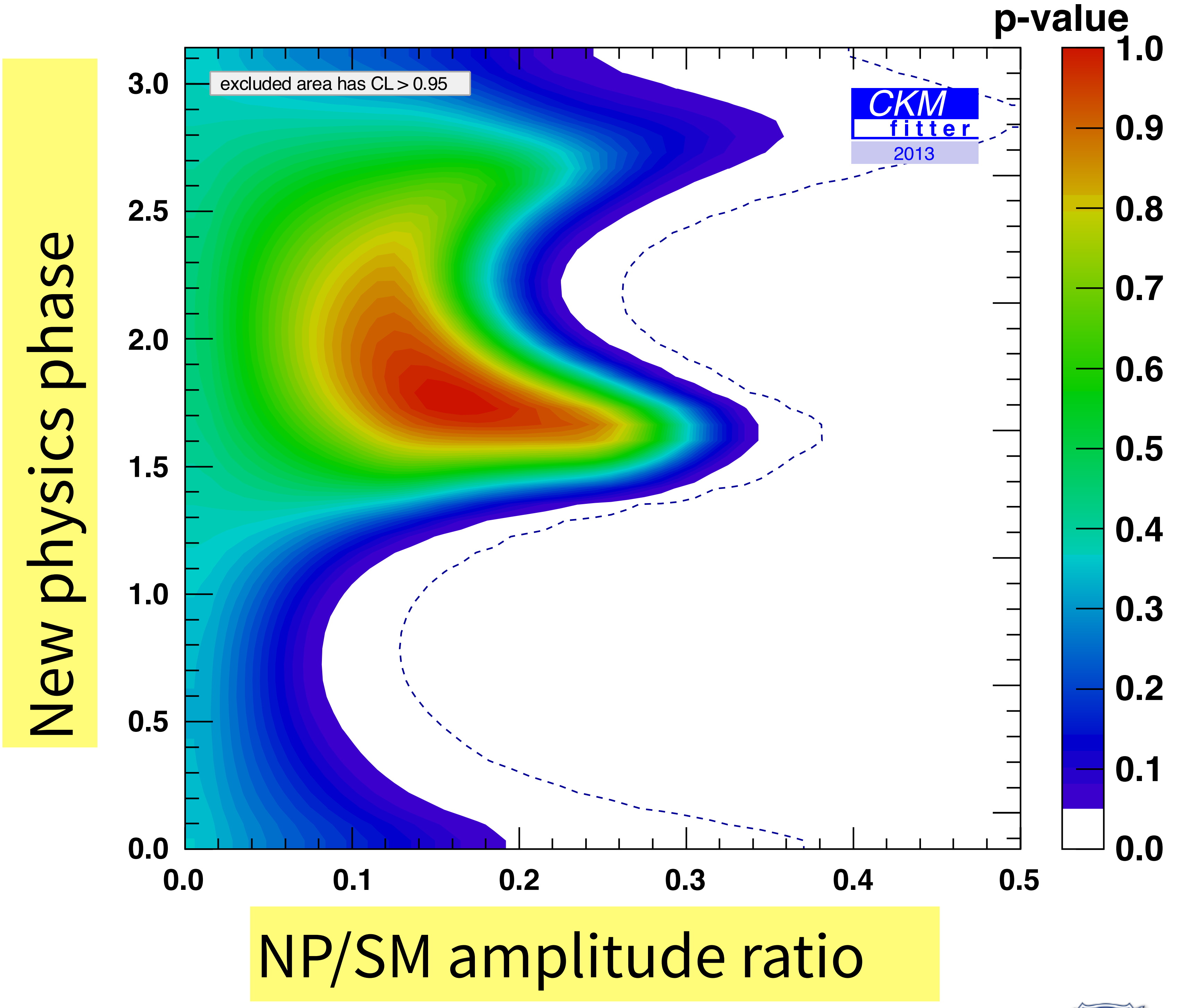
$|V_{ub}|$ ~ 10 → 1%

$$V_{\text{CKM}} \propto \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|\, e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|\, e^{-i\beta} & -|V_{ts}|\, e^{-i\beta_s} & |V_{tb}| \end{pmatrix}$$



$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| \qquad R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$$

But a 10-20% NP amplitude in B_d mixing is perfectly compatible with all current data.



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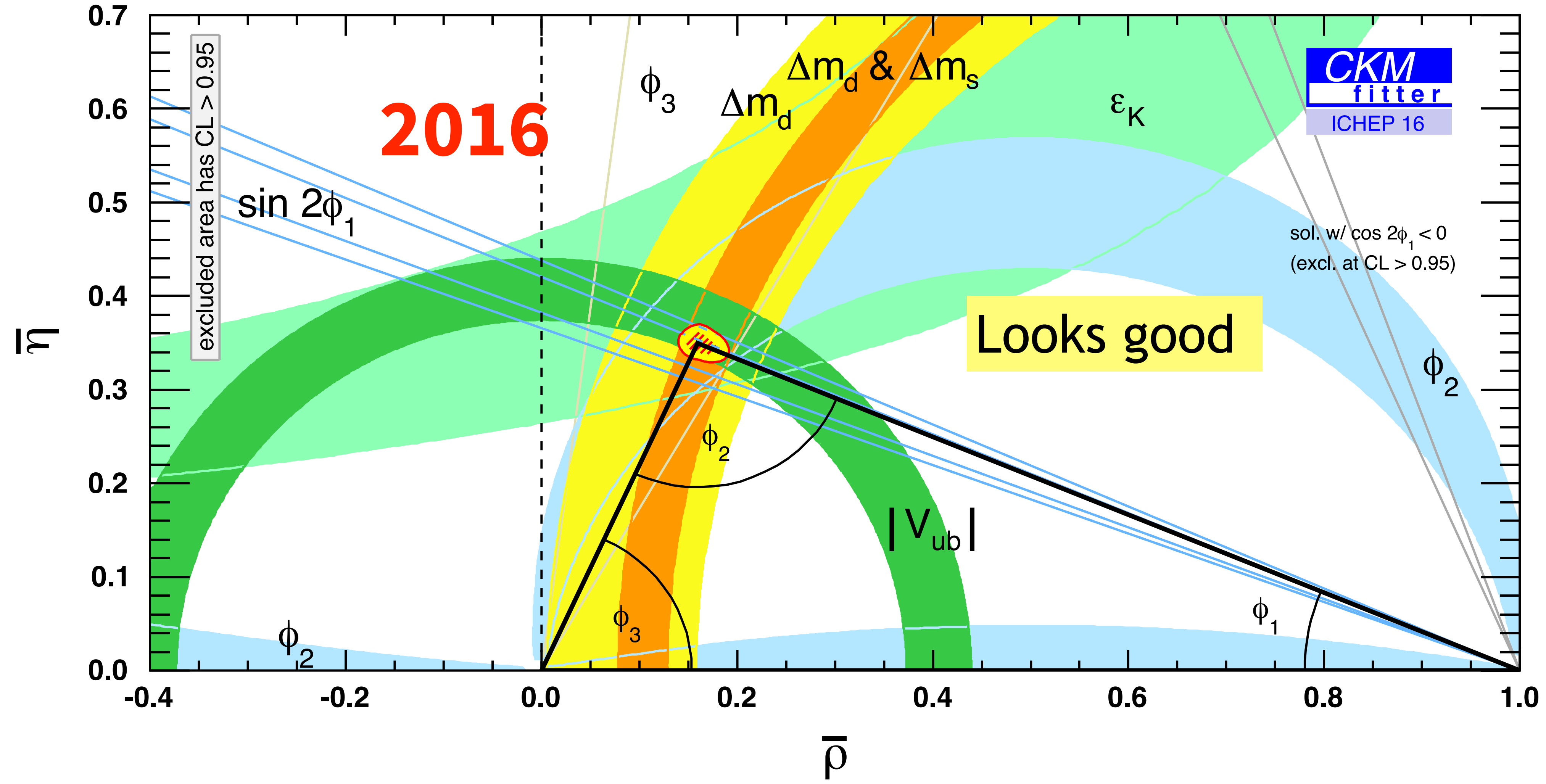

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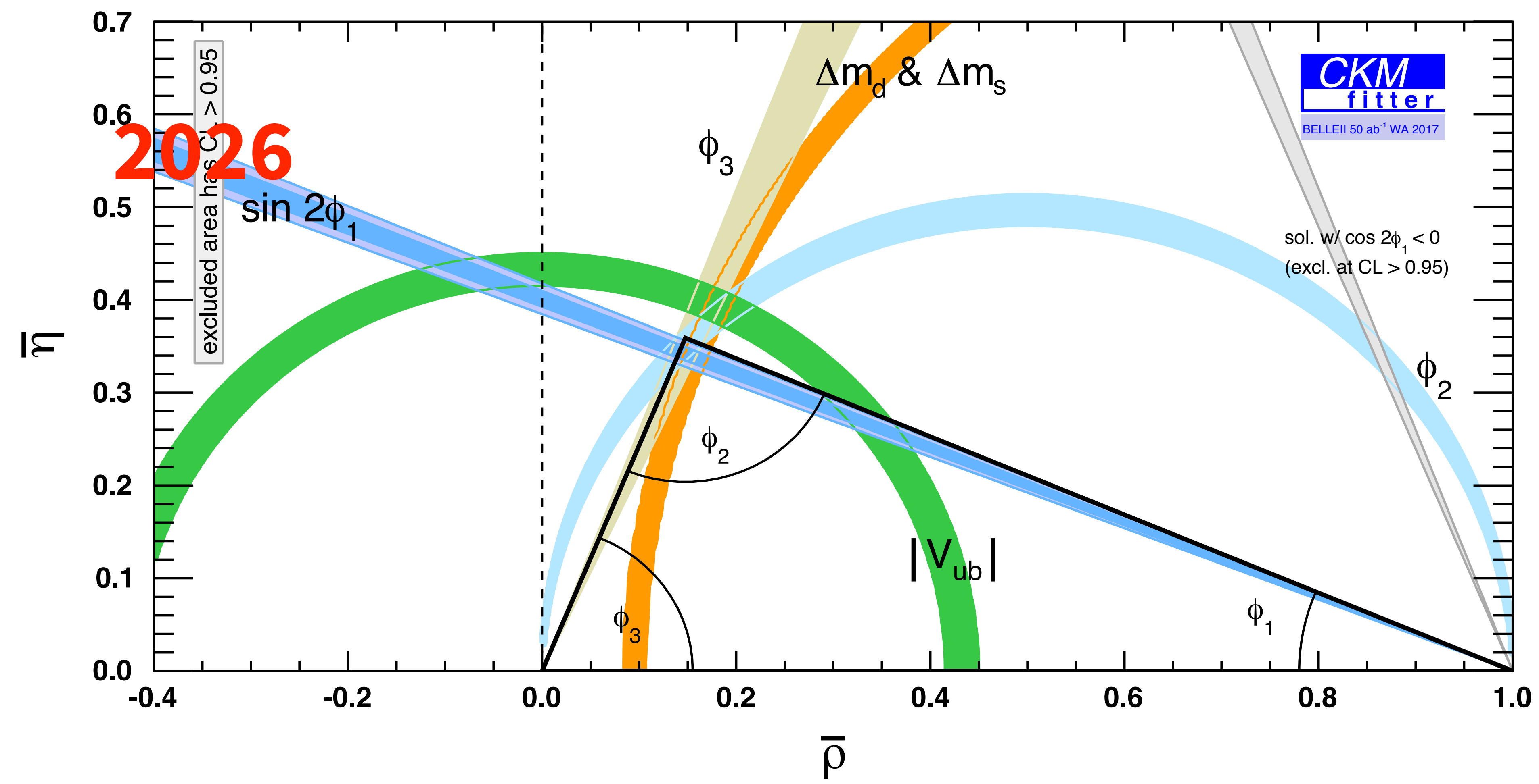

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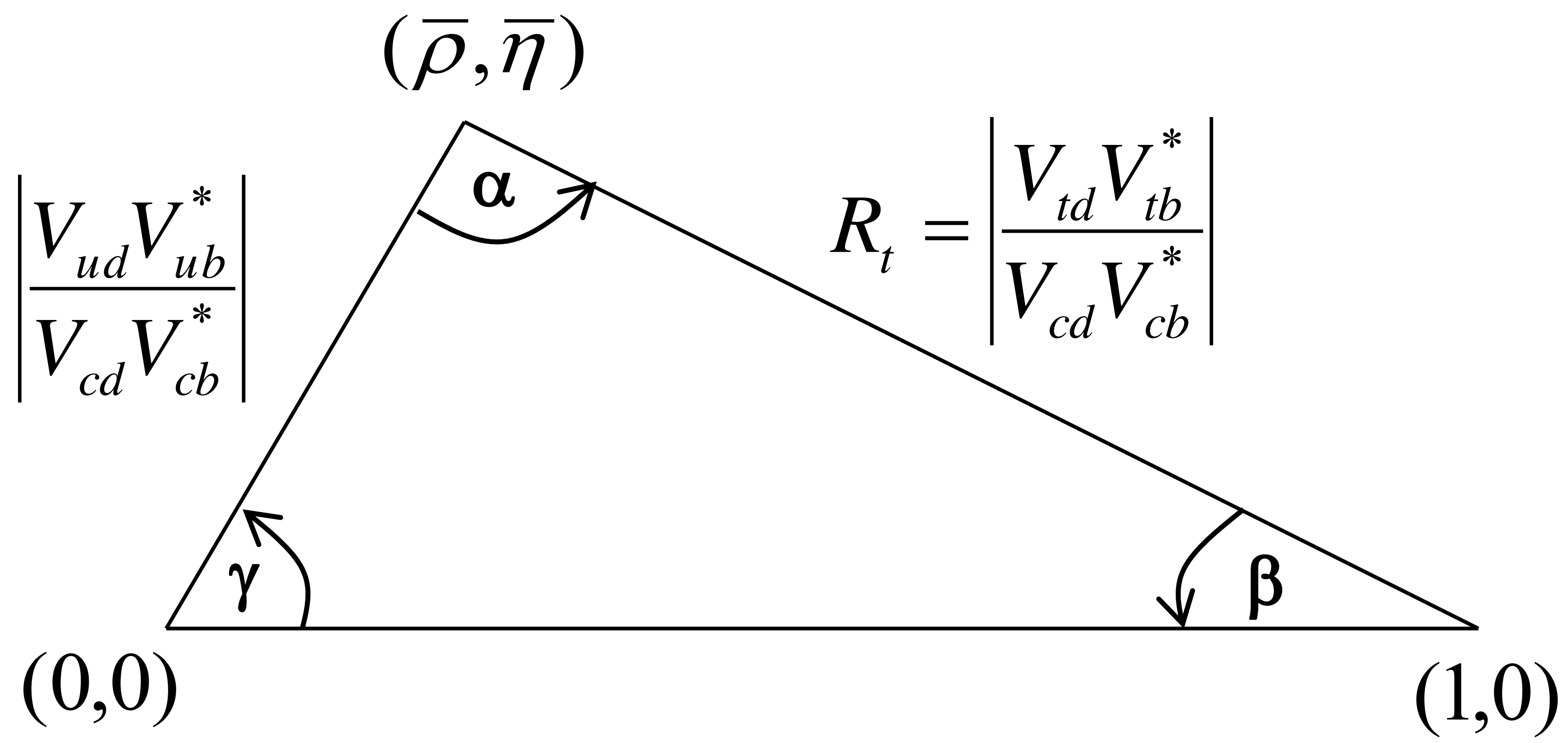

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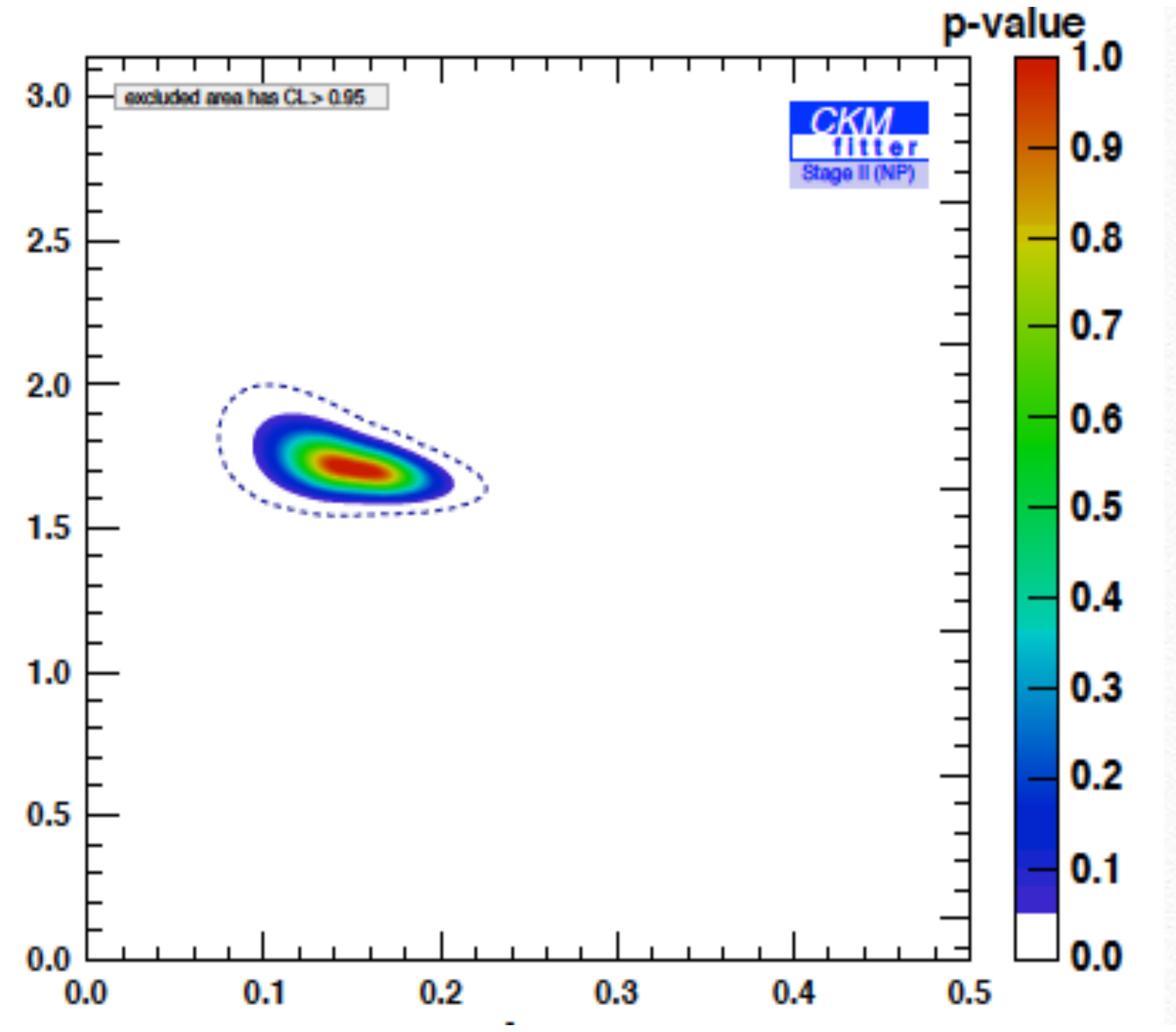
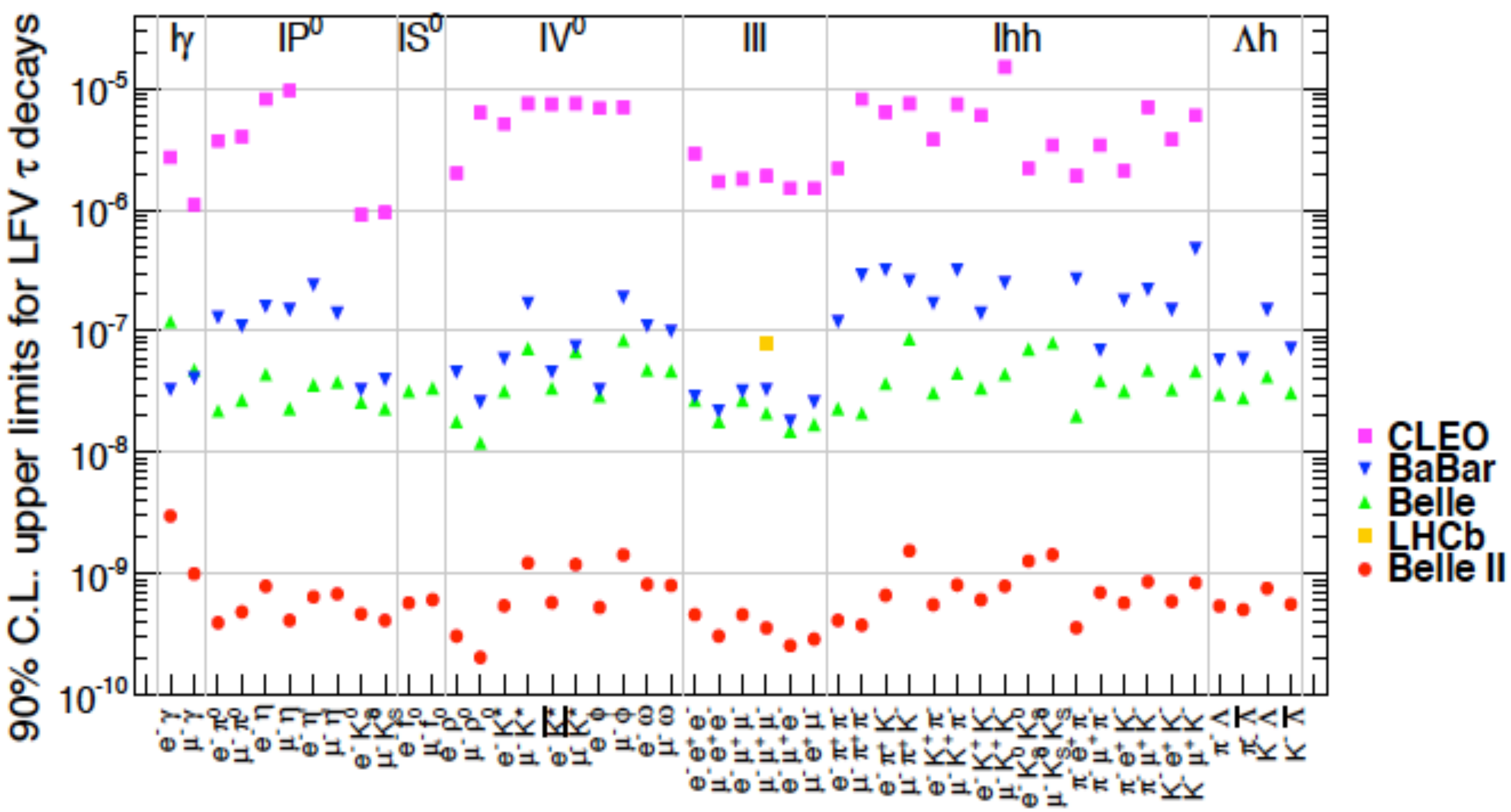
New physics phase

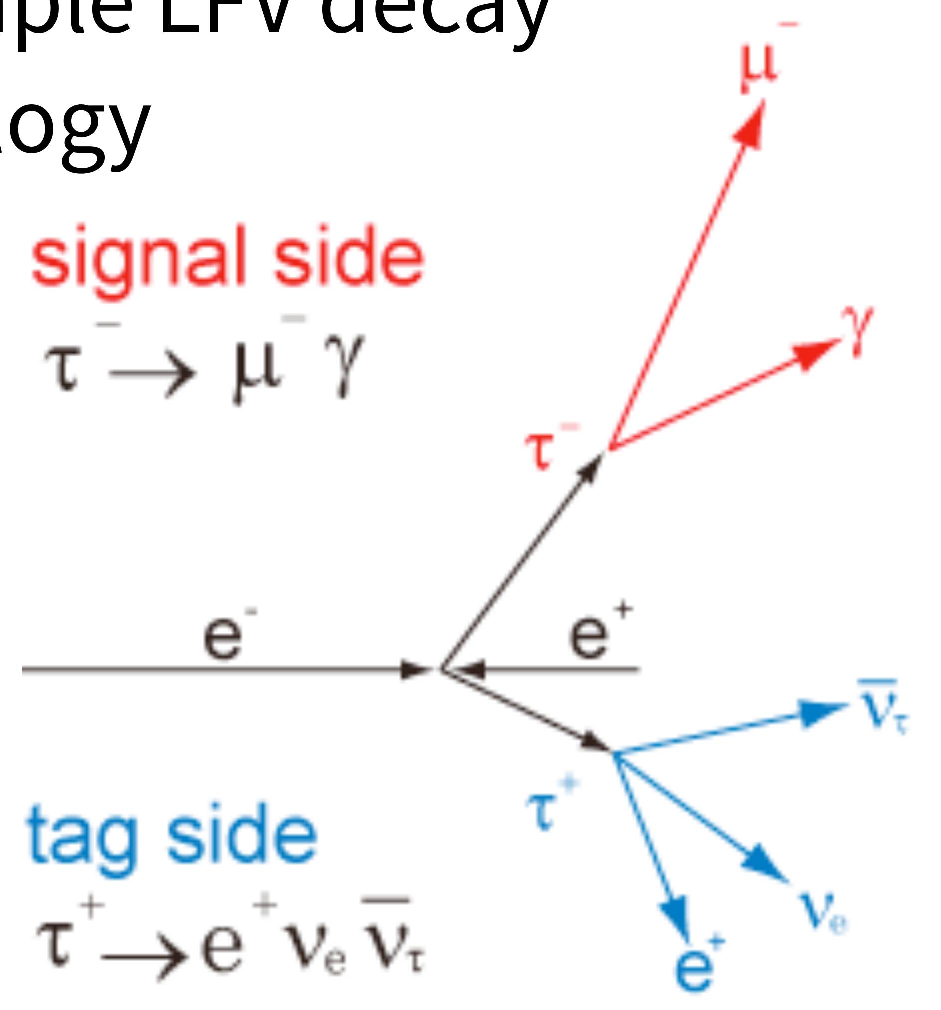


NP/SM amplitude ratio

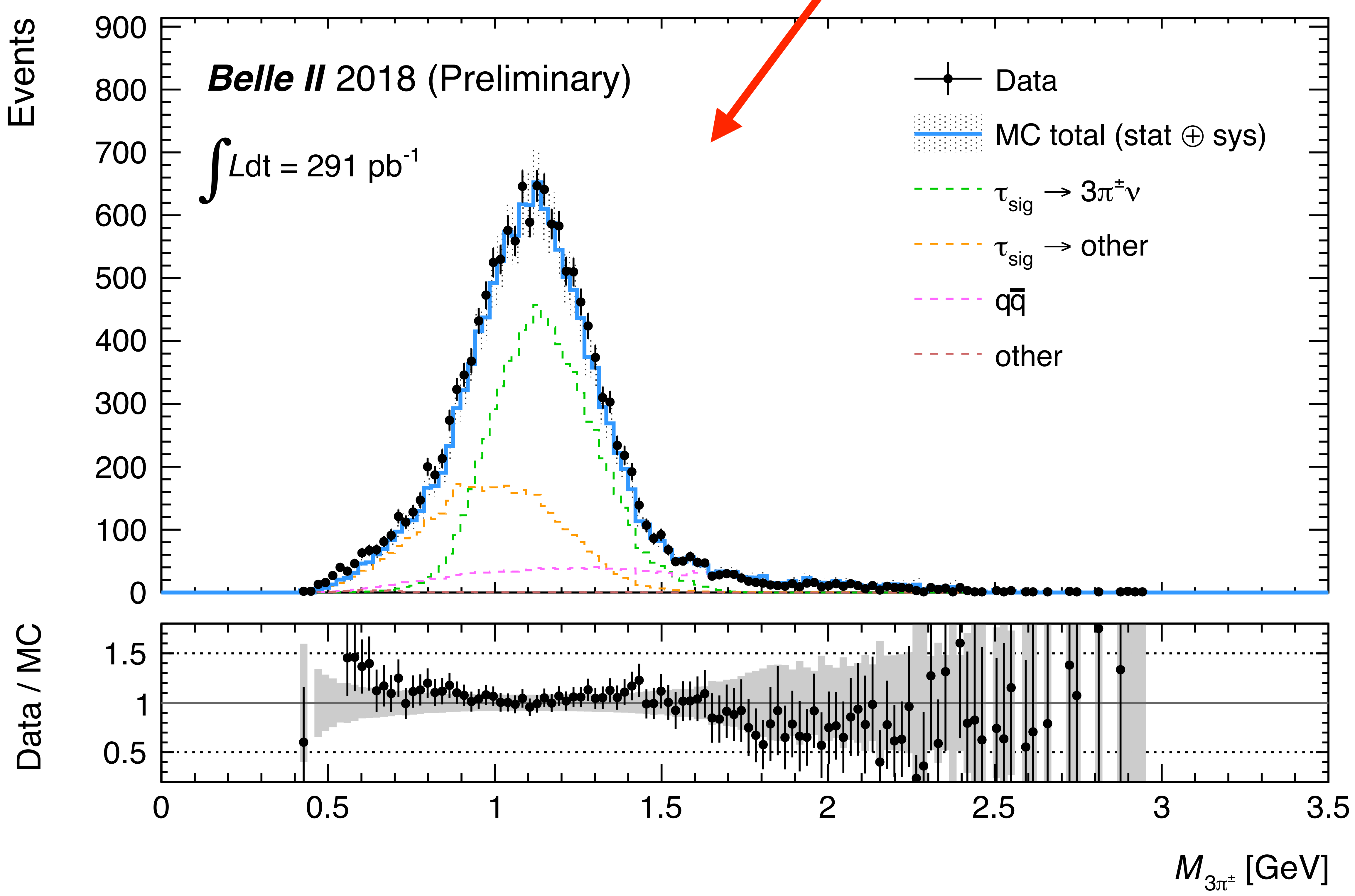
τ Lepton Flavour Violation



Example LFV decay topology

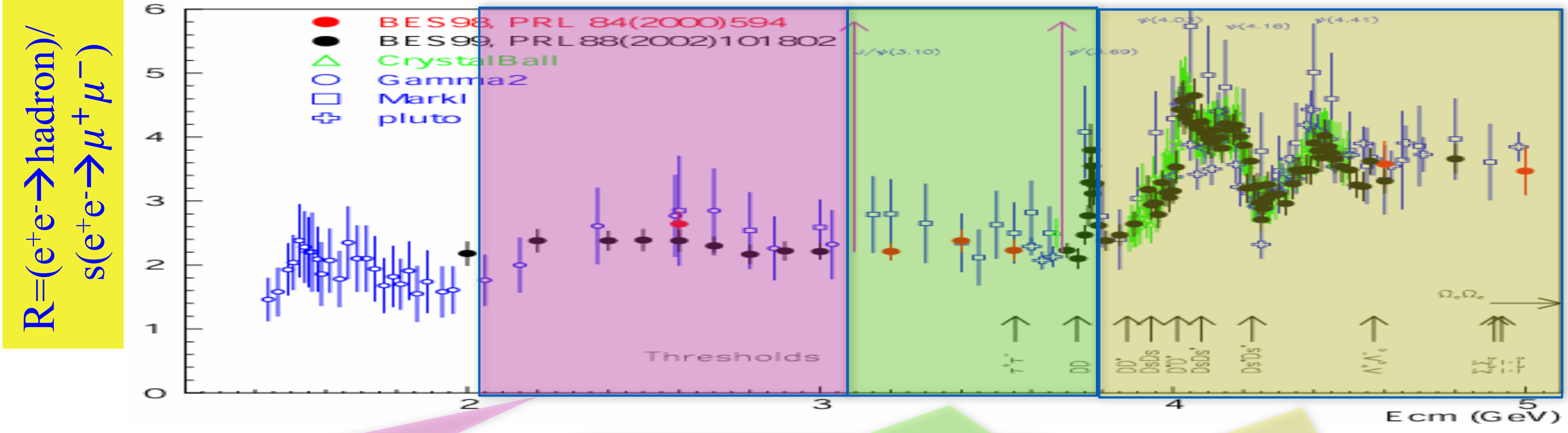


- ~7500 τ→1-Prong, vs τ→3-Prong
- CDC track triggered.
- τ-mass



<u>Belle II will push many limits below 10^{-9}</u>; LHCb, CMS and ATLAS have very *limited* capabilities.

Super τ - charm factory motivation



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- Physics with $D_{(s)}$ mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

R scan

- **Precision $\Delta\alpha_{QED}$, a_μ, charm quark mass extraction.**
- **Hadron form factor (nucleon, hyperon, *c*-ed baryon).**

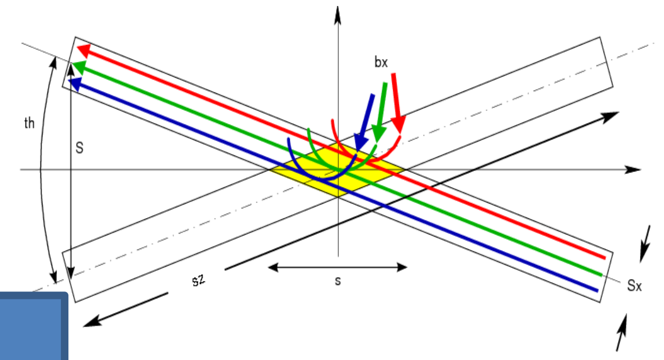
Super τ - charm factories

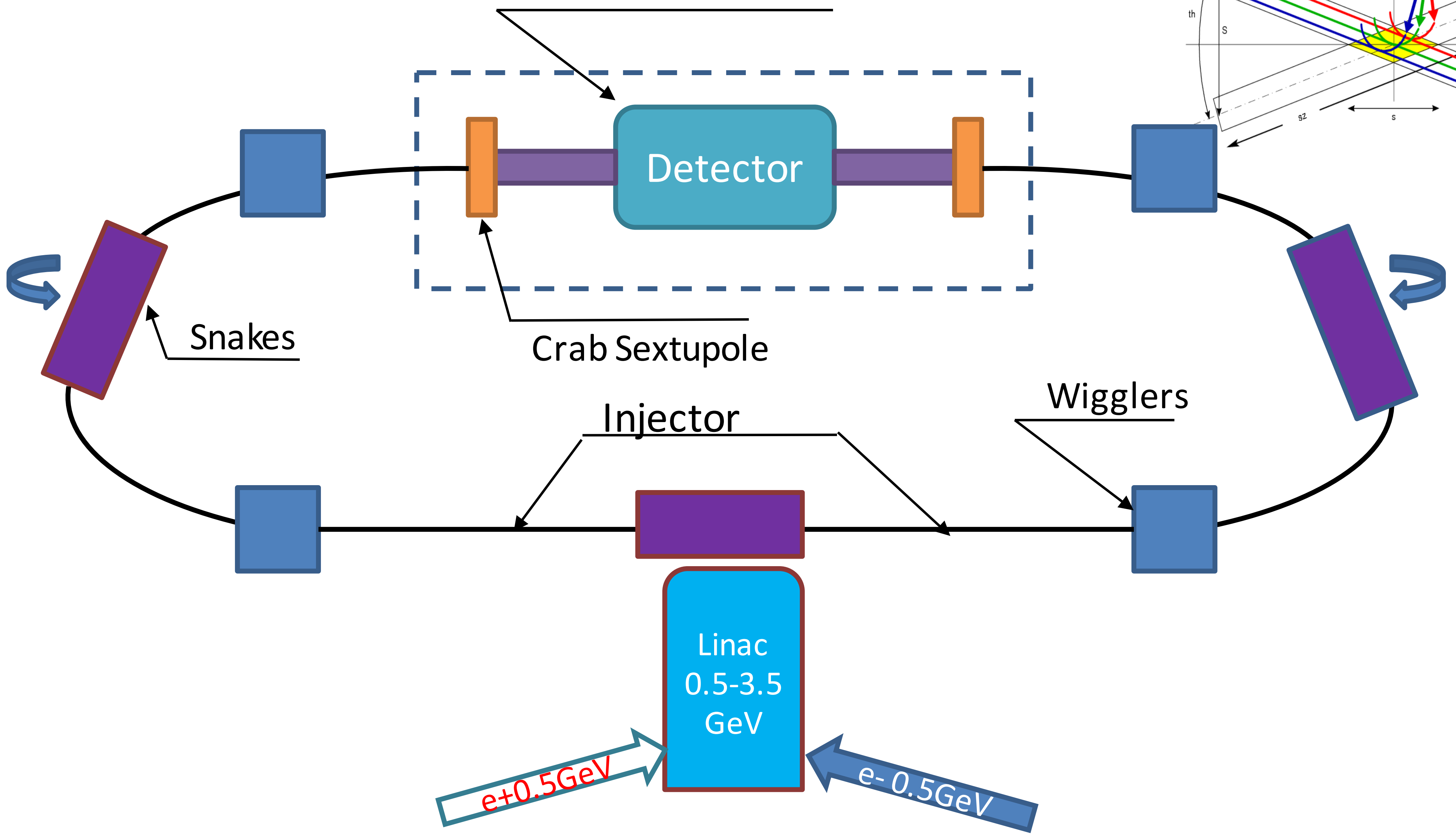
Naïve estimations @ STCF

$L_{peak} = 10^{35} cm^{-1}s^{-1}$, 1 year running = $10^6 pb^{-1}$ = $1ab^{-1}$

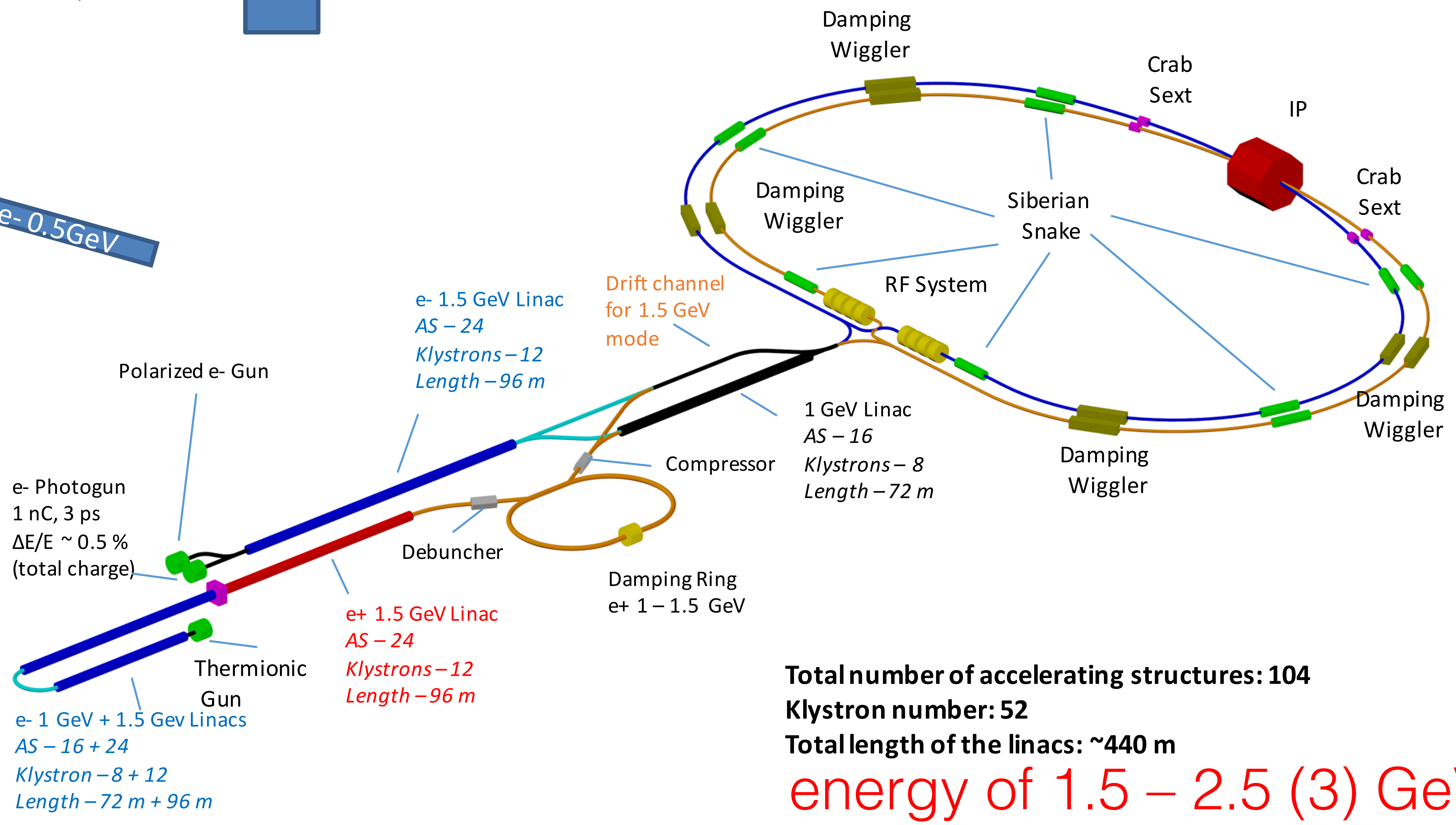
a BESIII-like detector

- Potential facilities for high luminosity τ, charm, charmonium production near threshold.





HIEPA in China



Super-CT Project in Russia

Total number of accelerating structures: 104
Klystron number: 52
Total length of the linacs: ~440 m

energy of 1.5 – 2.5 (3) GeV

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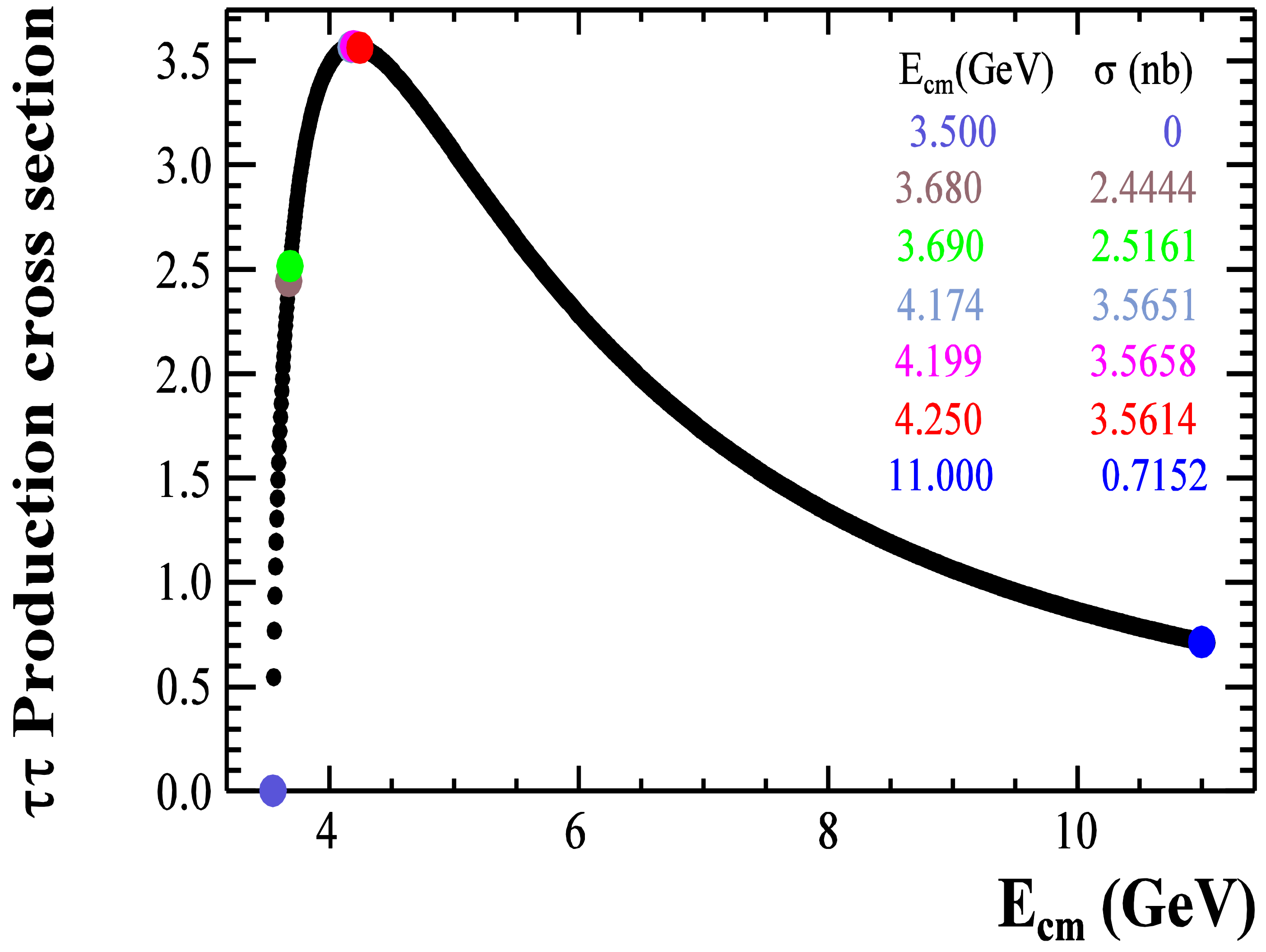
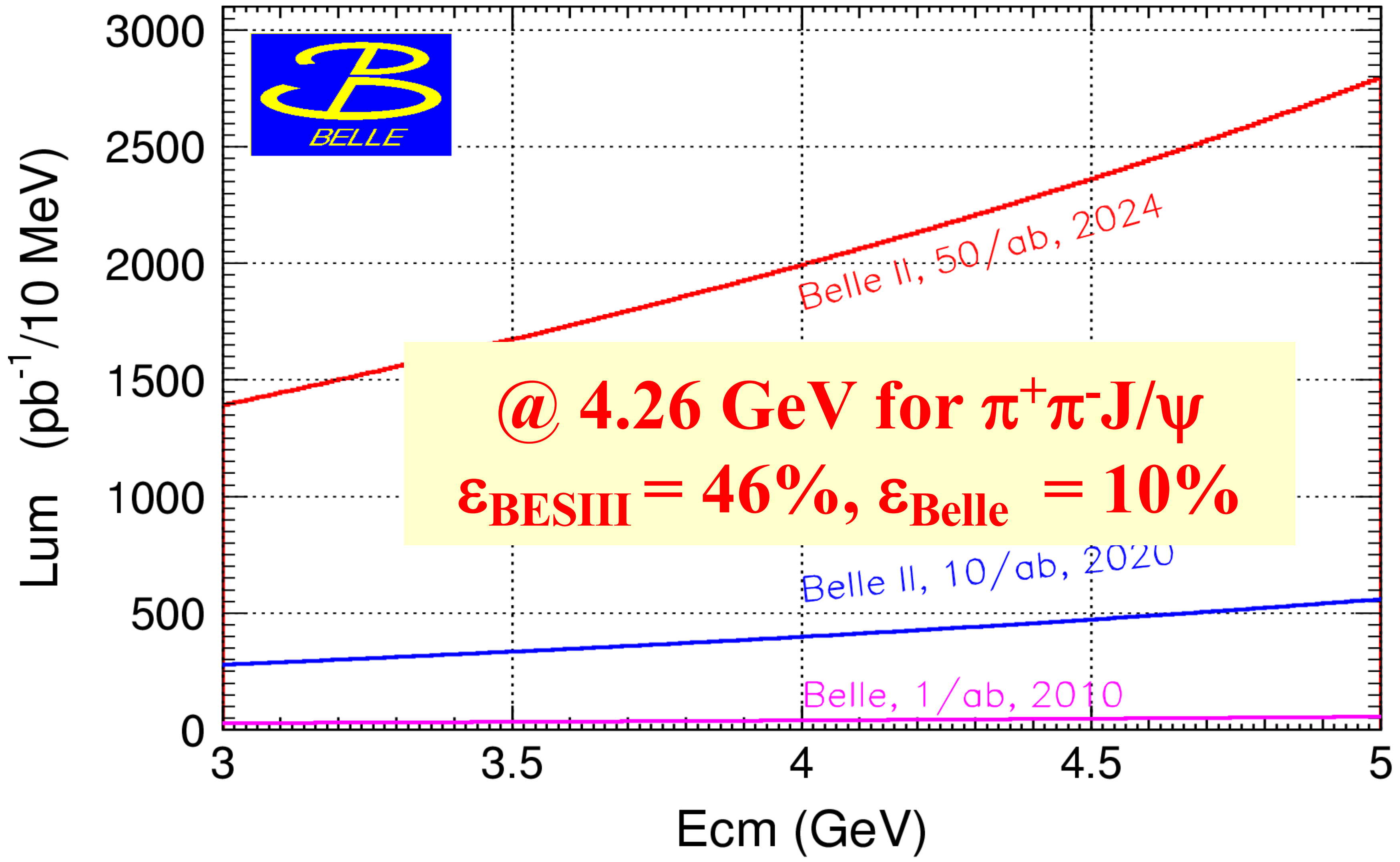
Super τ - charm Vs. Belle II

Yields / ab^{-1}

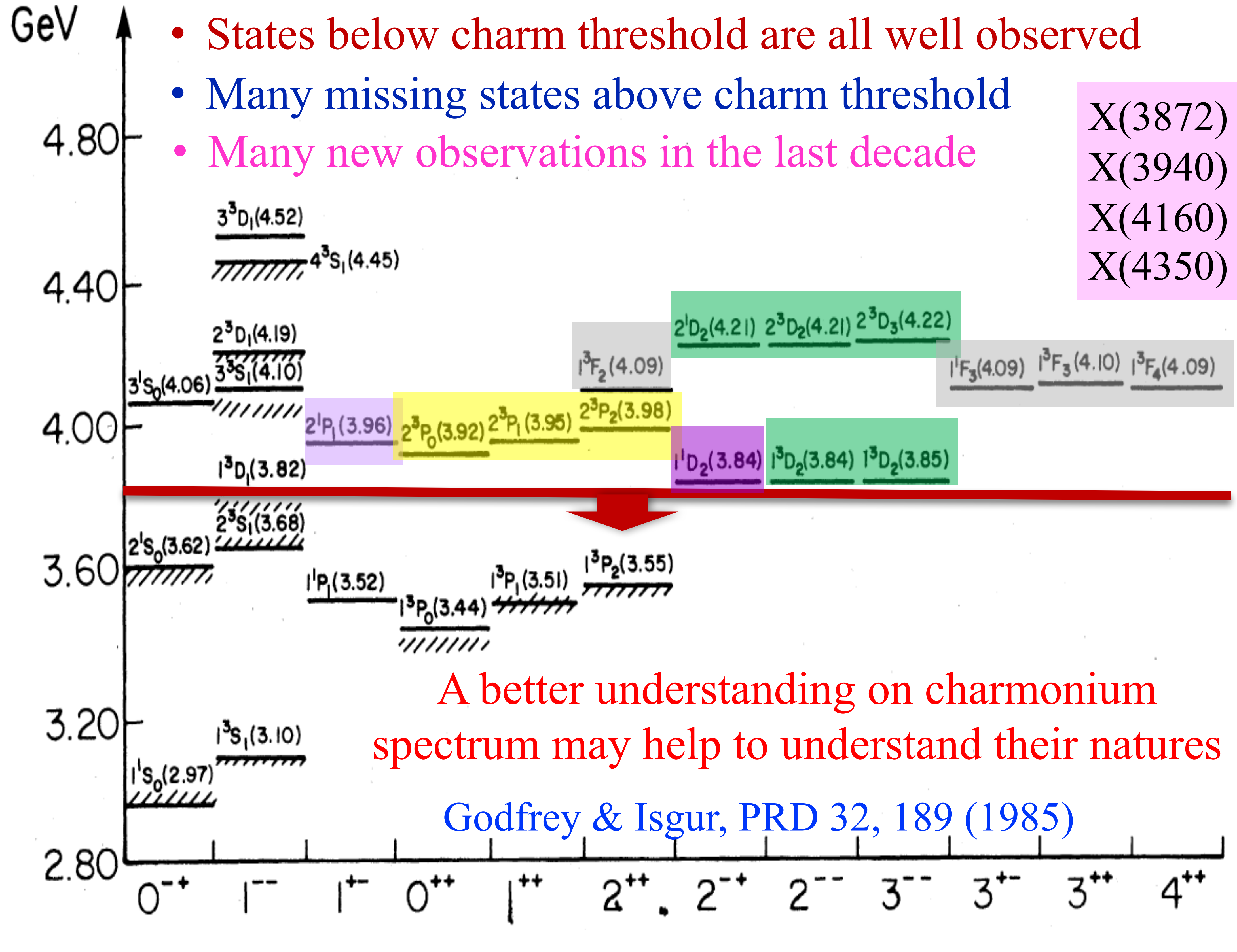
	STCF					Belle II		
Data Set	process	σ/nb	N	ST eff./%	ST N	σ/nb	N	Tag N
J/ψ	–	–	1.0×10^{12}	–	–	–	–	–
$\psi(2S)$	–	–	3.0×10^{11}	–	–	–	–	–
D^0	$D^0\bar{D}^0(3.77)$	~ 3.6	3.6×10^9	10.8	0.78×10^9	–	1.4×10^9	–
D^+	$D^+D^-(3.77)$	~ 2.8	2.8×10^9	9.4	0.53×10^9	–	7.7×10^8	–
D_s	$D_sD_s^*(4.18)$	~ 0.9	0.9×10^9	6.0	0.11×10^9	–	2.5×10^8	–
τ^+	$\tau^+\tau^-(3.68)$	~ 2.4	2.4×10^9	–	–	0.9	0.9×10^9	–
	$\tau^+\tau^-(4.25)$	~ 3.6	3.5×10^9	–	–	–	–	–
Λ_c	$\Lambda_c\Lambda_c(4.64)$	~ 0.6	5.5×10^8	5.0	0.55×10^8	–	1.6×10^8	$3.6 \times 10^{4*}$





STCF charmonium (exotic hadron searches)

- **The new particle zoo.**
- X, Y, Z exotic states
- Possible new structures - glue-balls
- *Inclusive (recoil) and radiative (E1) transitions require high stats and clean environment.*



X	Y	Z
X(3872)	Y(3940)	Z(3900)
X(3940)	Y(4008)	Z(4020)
X(4160)	Y(4260)	Z(4050)
X(4350)	Y(4360)	Z(4200)
	Y(4660)	Z(4250)
		Z(4430)

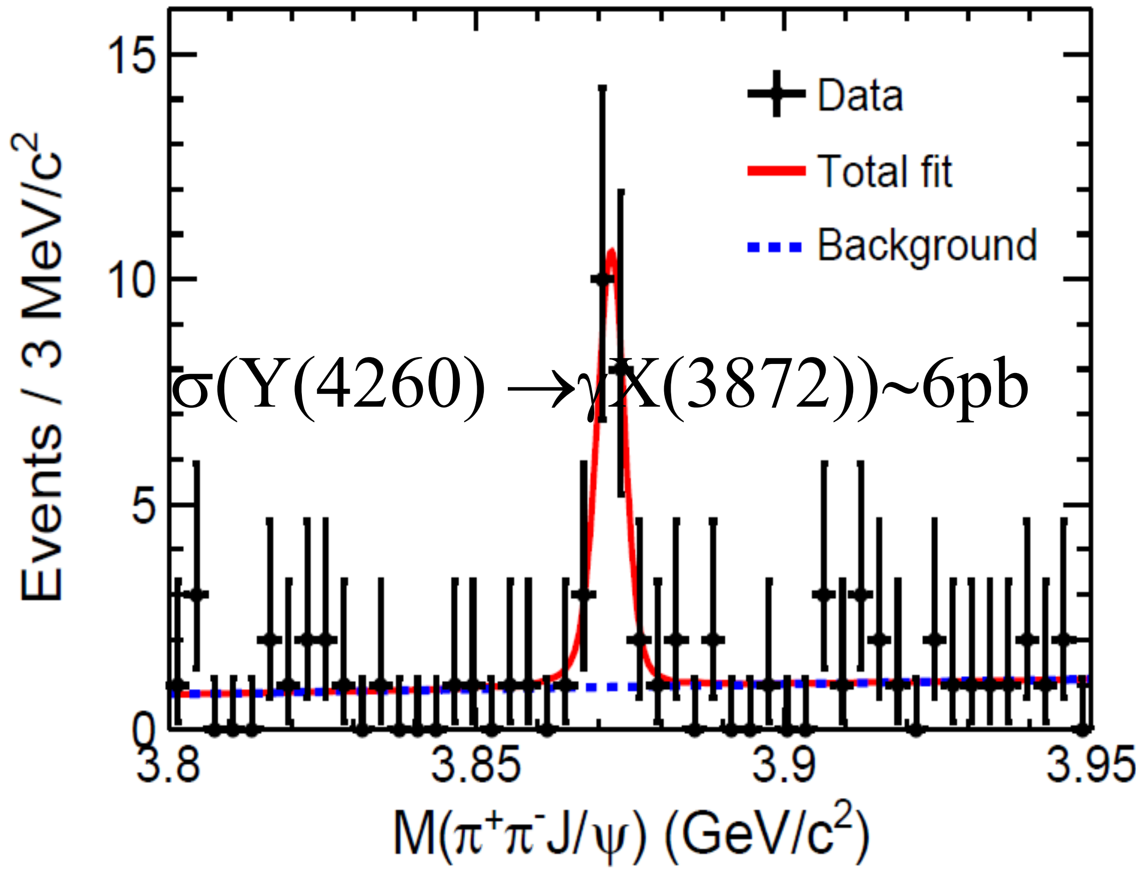
Nature unclear

- Charmonium?
- Hybrid?
- Tetraquark?
- Molecule?
- Non-resonance?

Examples

- **Ψ/Y/hybrid(ccg) (1^{--}) produced in e^+e^- collisions**
- **Charge parity c=+1 states**
  - Decay rates of ψ(nS/nD)→**γ**X(3872), **γ**X(3940)
  - Search for $\chi_{cJ}(2P)$, $\chi_{cJ}(3P)$ etc.
- **New states from hadronic transitions**
- **1^{--} Hybrids produced in e^+e^-, and γ decay.**
- **Many processes have σ ~ 10-100 pb - tens to hundreds of events per year at STCF**

BESIII Y→ γX

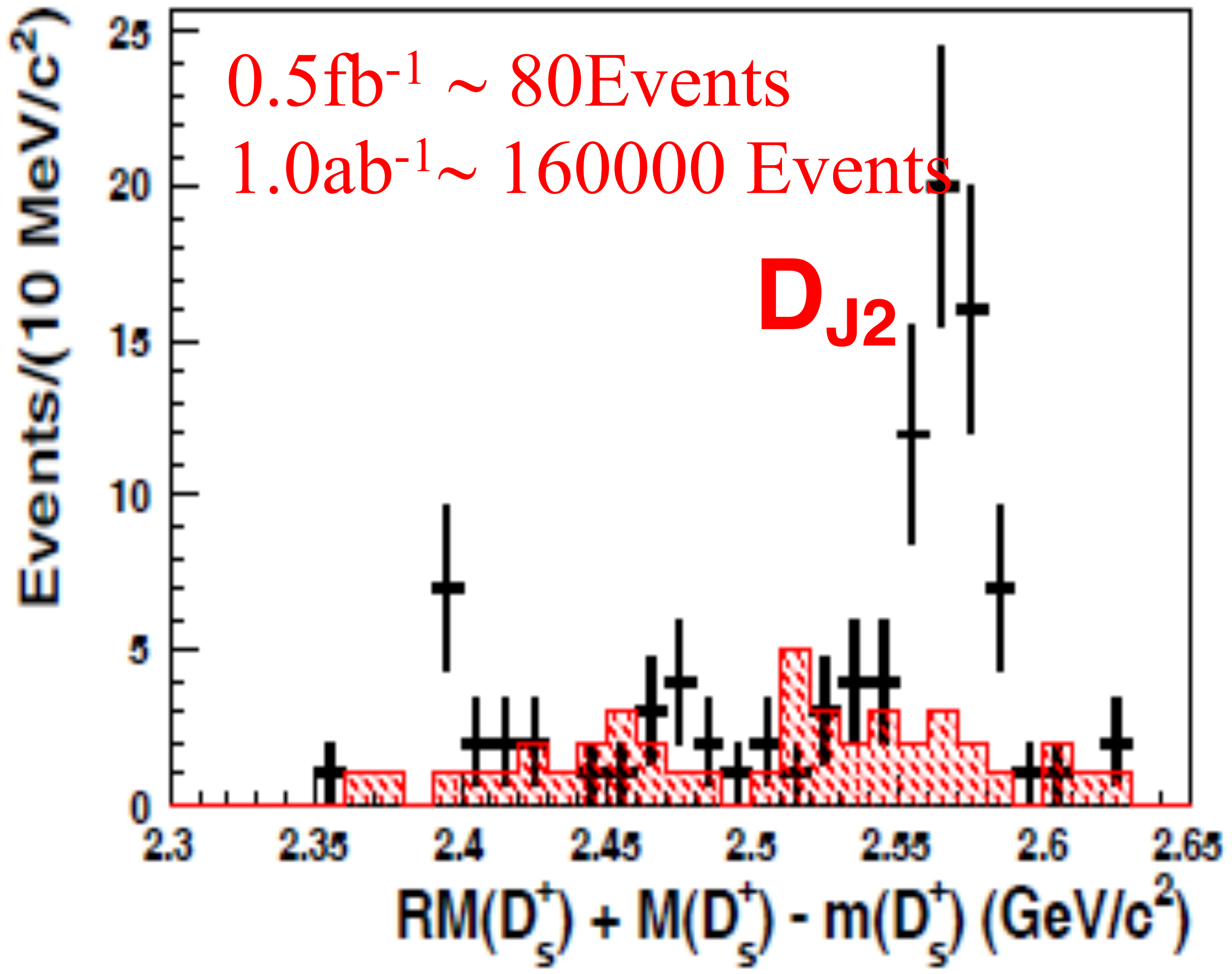


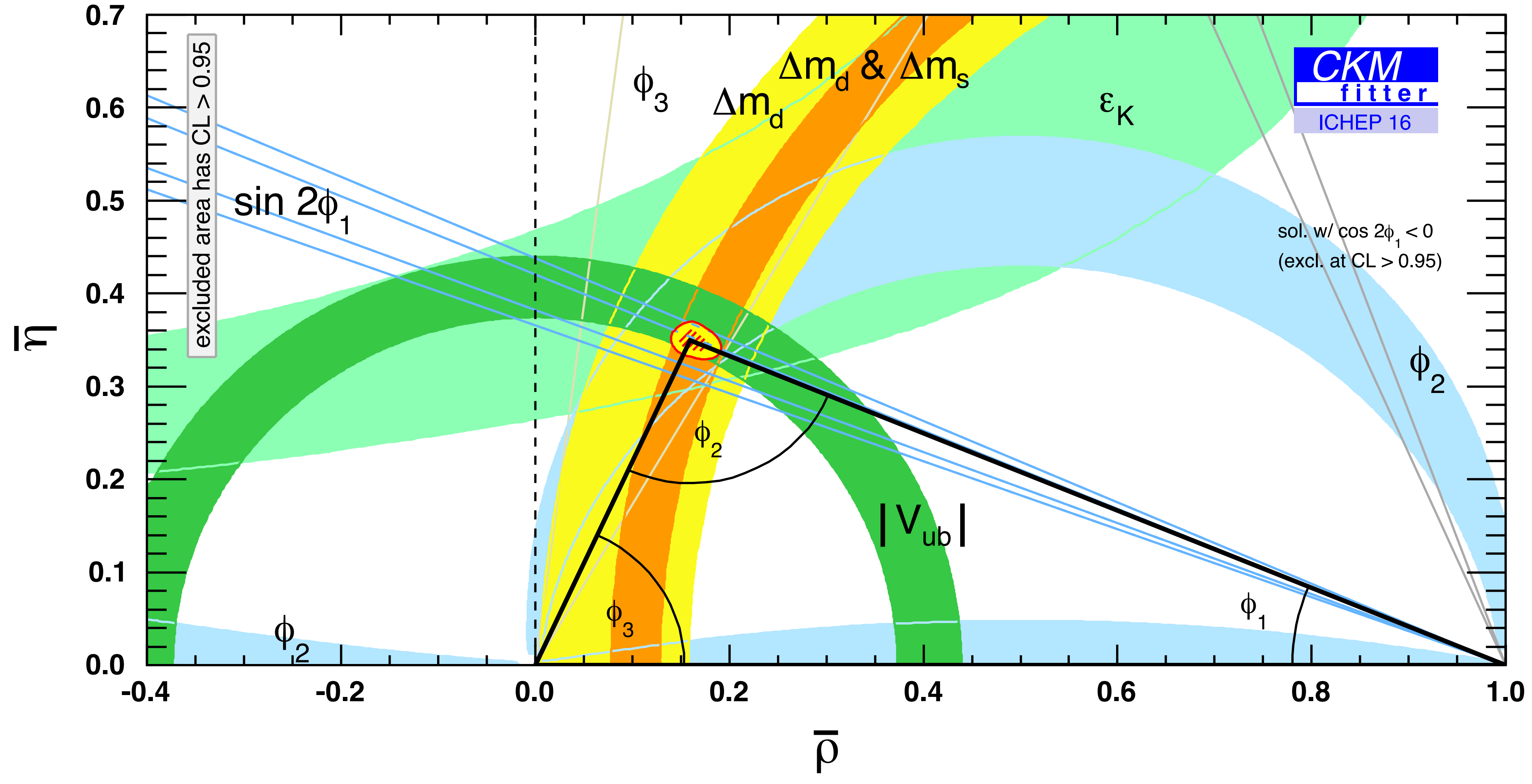
STFC $\chi_{c2}(1^1D_2)$

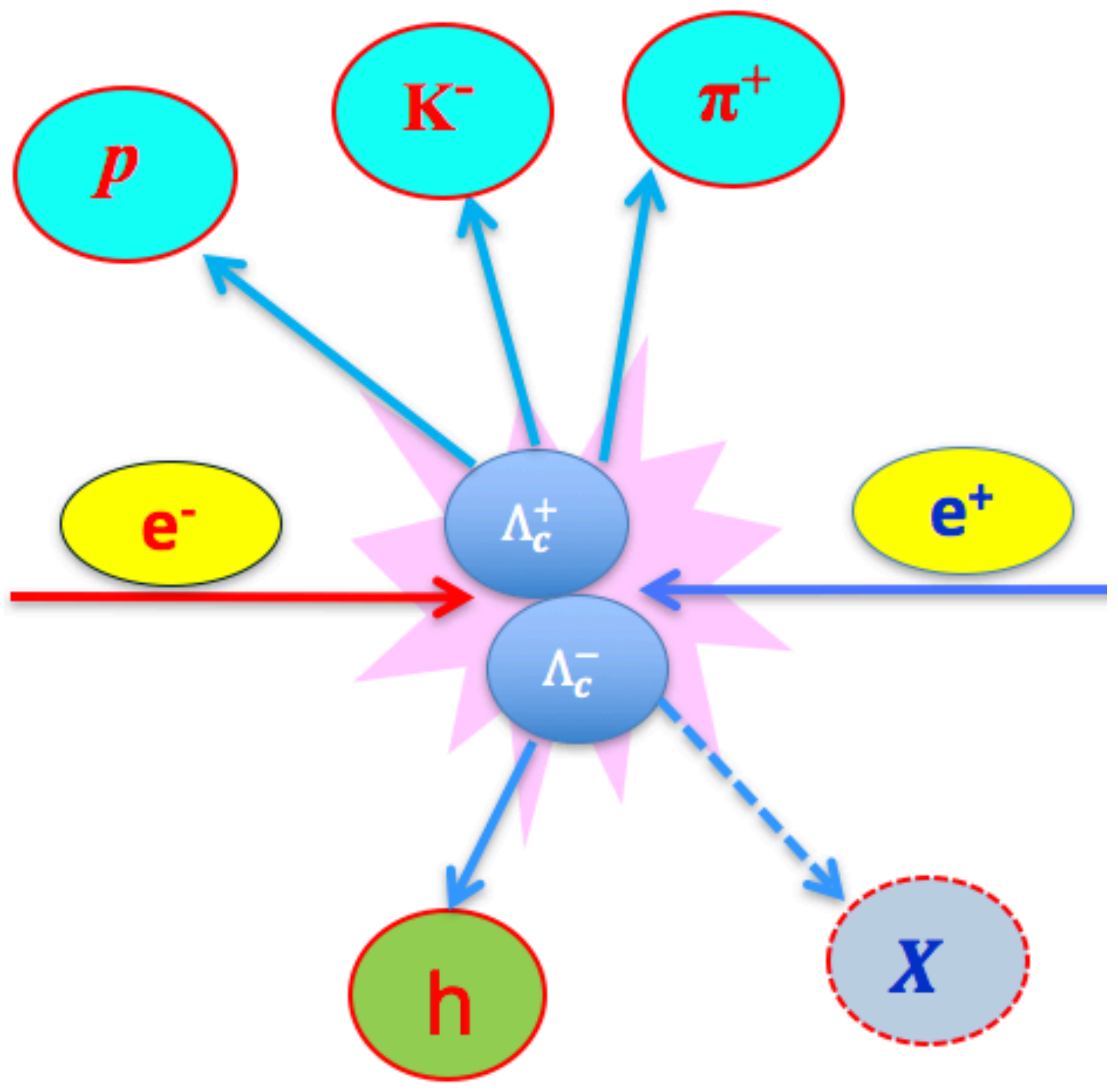
- $\sigma(e^+e^- \to \pi^+\pi^- h_c(2P))$~20pb
- Nobs=20 events / year @ STFC
- Low background

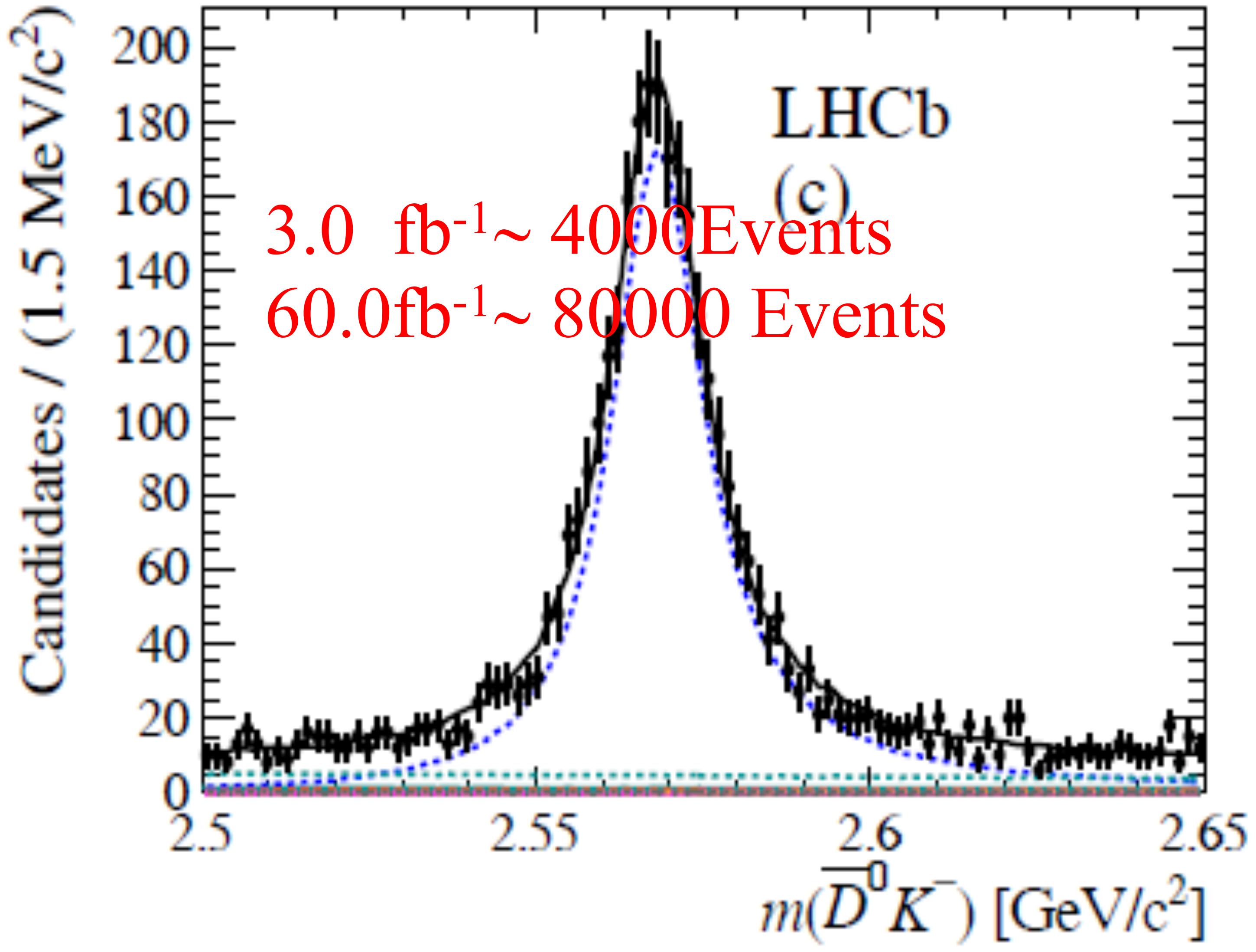
STCF charm

- **Competition to Belle II: Multiplicity is lower (on threshold), Cleaner tagging**
  - Produced in QM coherent state, $J^{PC}=1^{--}$ for DD, $J^{PC}=0^{++}$ for γDD
- **Highlighted Physics programs**
  - Leptonic, semi-leptonic decay (f_D, f_{Ds}, V_{cd}, V_{cs})
  - D^0- anti-D^0 mixing, CPV, and D strong phases for Φ3/γ
  - Rare (FCNC, LFV, LNV....)
  - Excited charm D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
  - Baryons (J^{PC}, Decay modes, absolute BF)





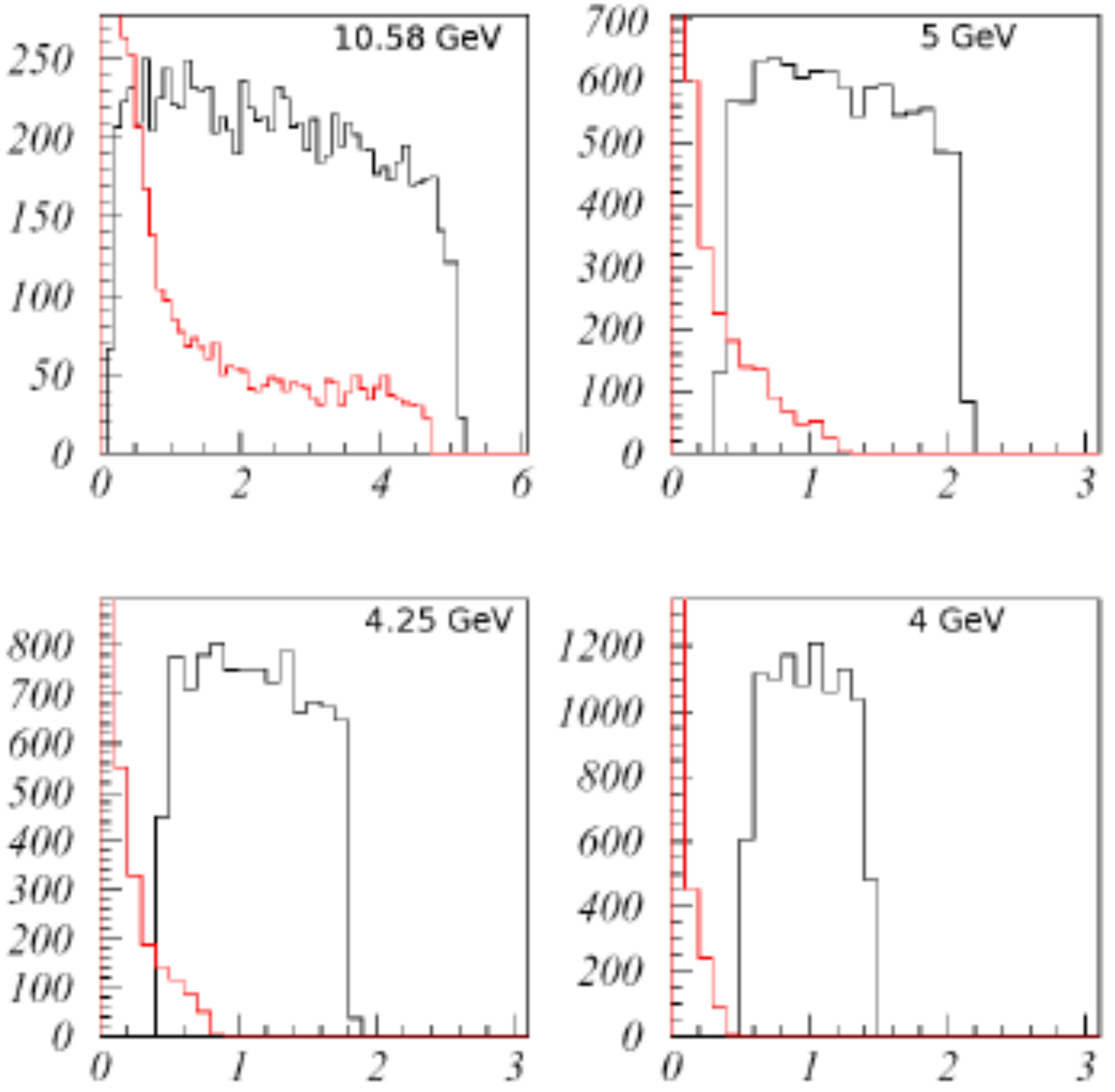




STCF τ & low-multiplicity

- τ- physics near threshold may offer lower background environment than Belle II
  - Precision measurements of α_s, m_s, V_{us}
  - Lepton Universality and lorentz structure
  - LFV and CPV
  - Rare hadronic decays
- Low-multiplicity
  - Exclusive processes, R=s($e^+e^-\to$hadrons)/ s($e^+e^-\to\mu^+\mu^-$) at low energies, Two photon Physics

Background $e^+e^-\to\tau^+\tau^-\gamma$



Photon energy [GeV] of $\tau\to\mu\gamma$

Dominant BKG @ B Factory

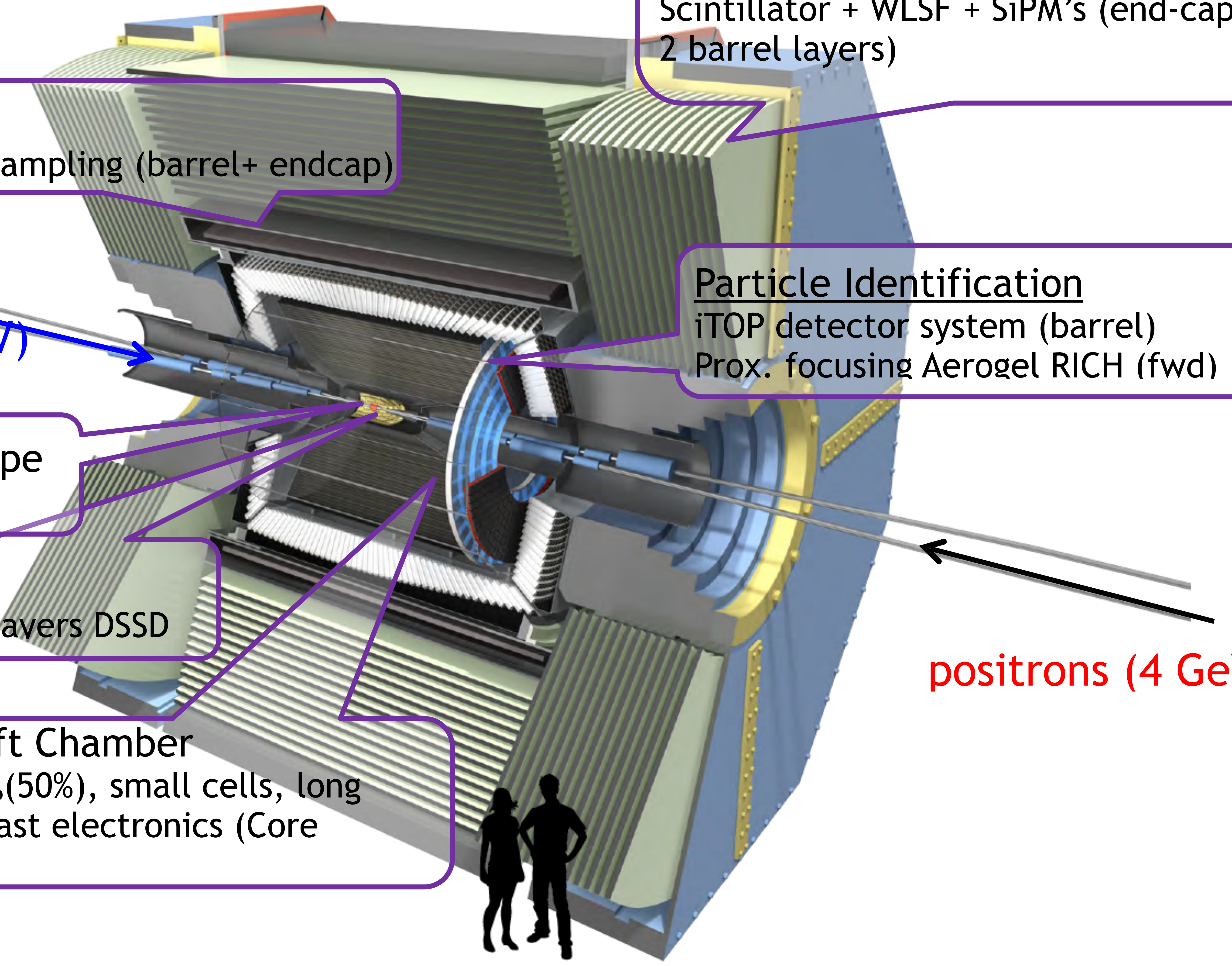
ee → τ τ γ does not contribute below 4.1 GeV

Summary

- e^+e^- machines are critical in challenging the SM at VERY high precision.
  - H, Z, W, B, D, τ
- **Energy**
  - A high energy circular collider would provide very high precision measurements of electroweak observables.
  - ZH combined with VBF will deliver detailed characterisation of the Higgs boson.
- **Flavour**
  - SuperKEKB and Belle II are online - the full vertex detector will be installed by Feb 2019. Both will be ready for full physics analysis of B, D, τ in 2019.
  - The super τ-charm (threshold) factory will provide complementary information.

Backup

Belle II Detector



K-Long and muon detector:
Resistive Plate Chambers (barrel outer layers)
Scintillator + WLSF + SiPM’s (end-caps , inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel+ endcap)

electrons (7 GeV)

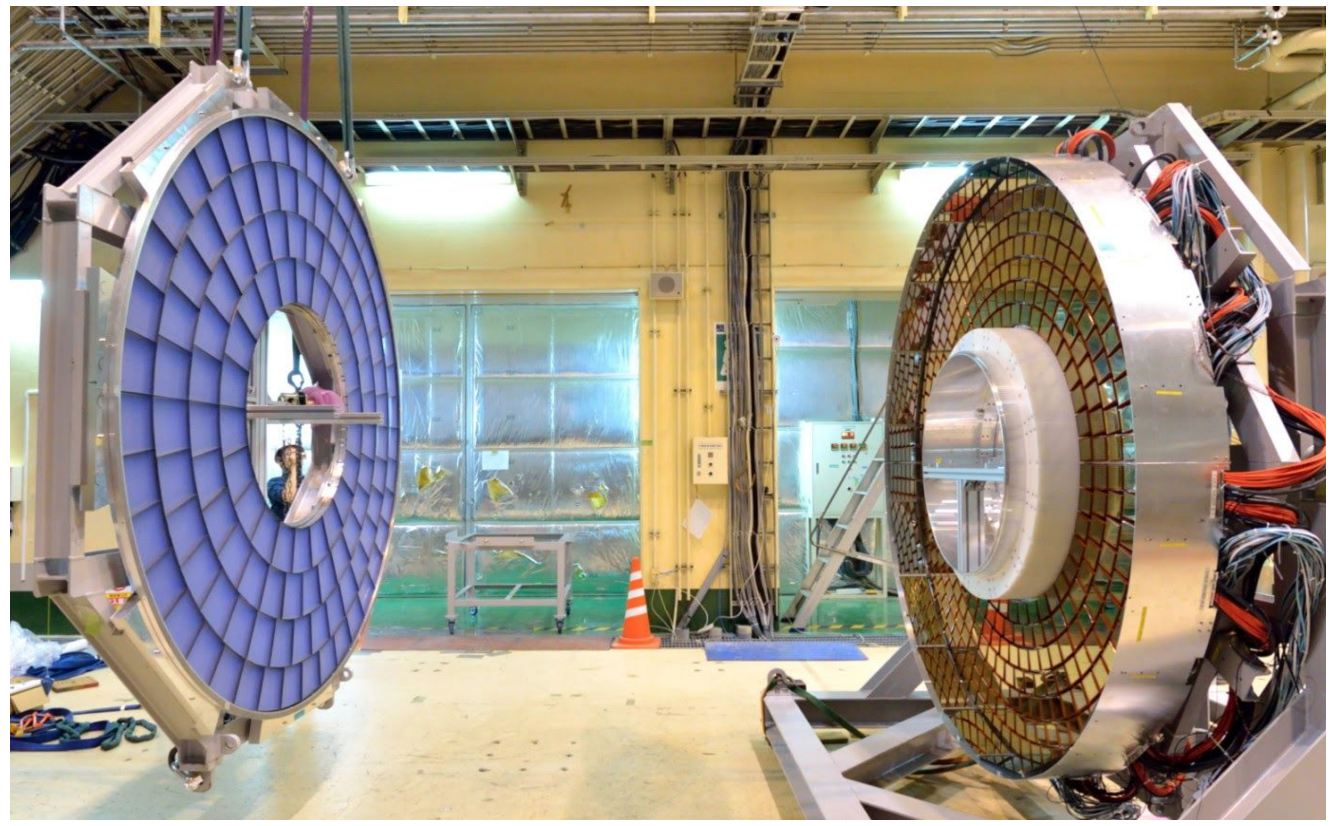
Particle Identification
iTOP detector system (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

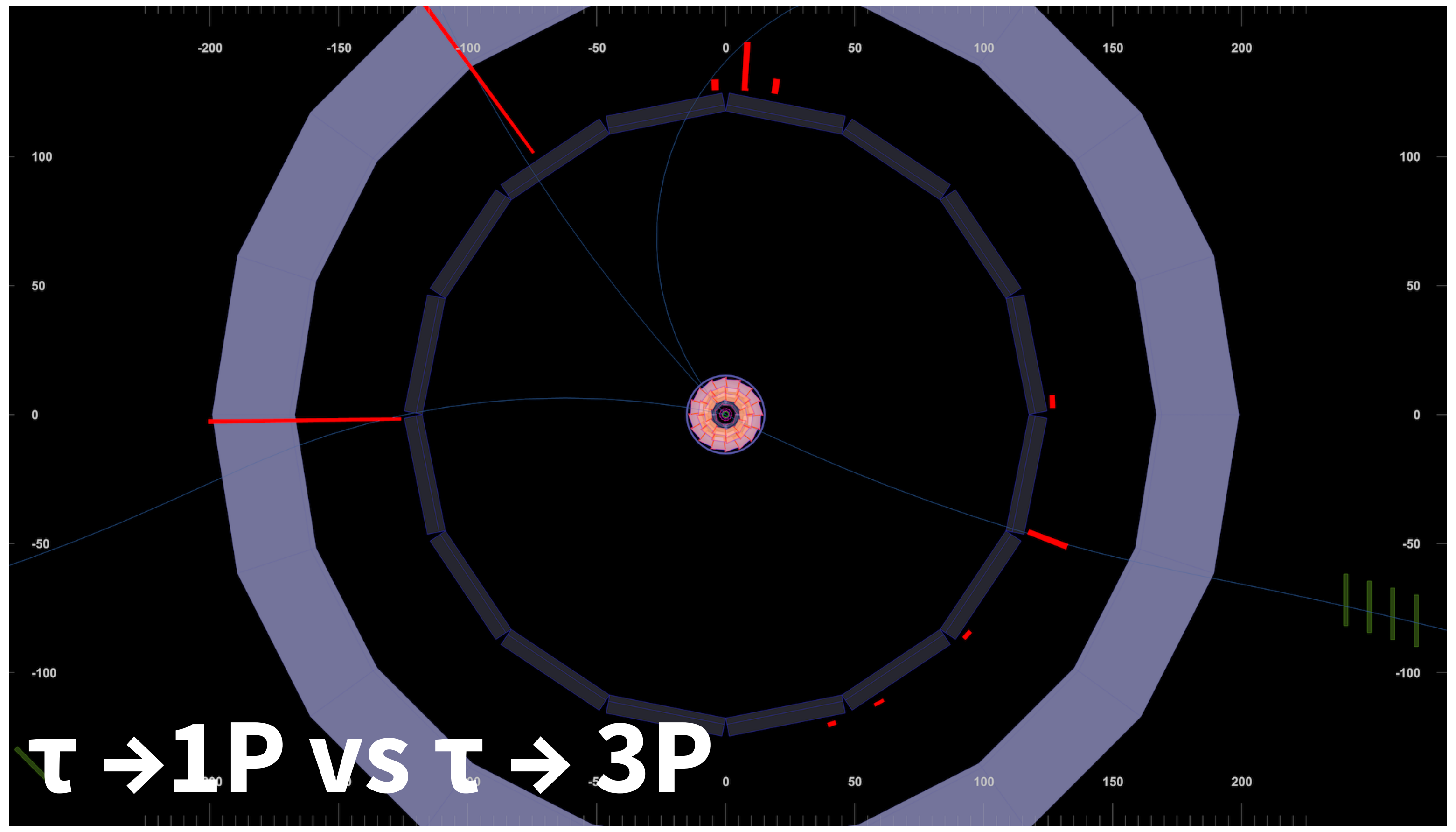
positrons (4 GeV)

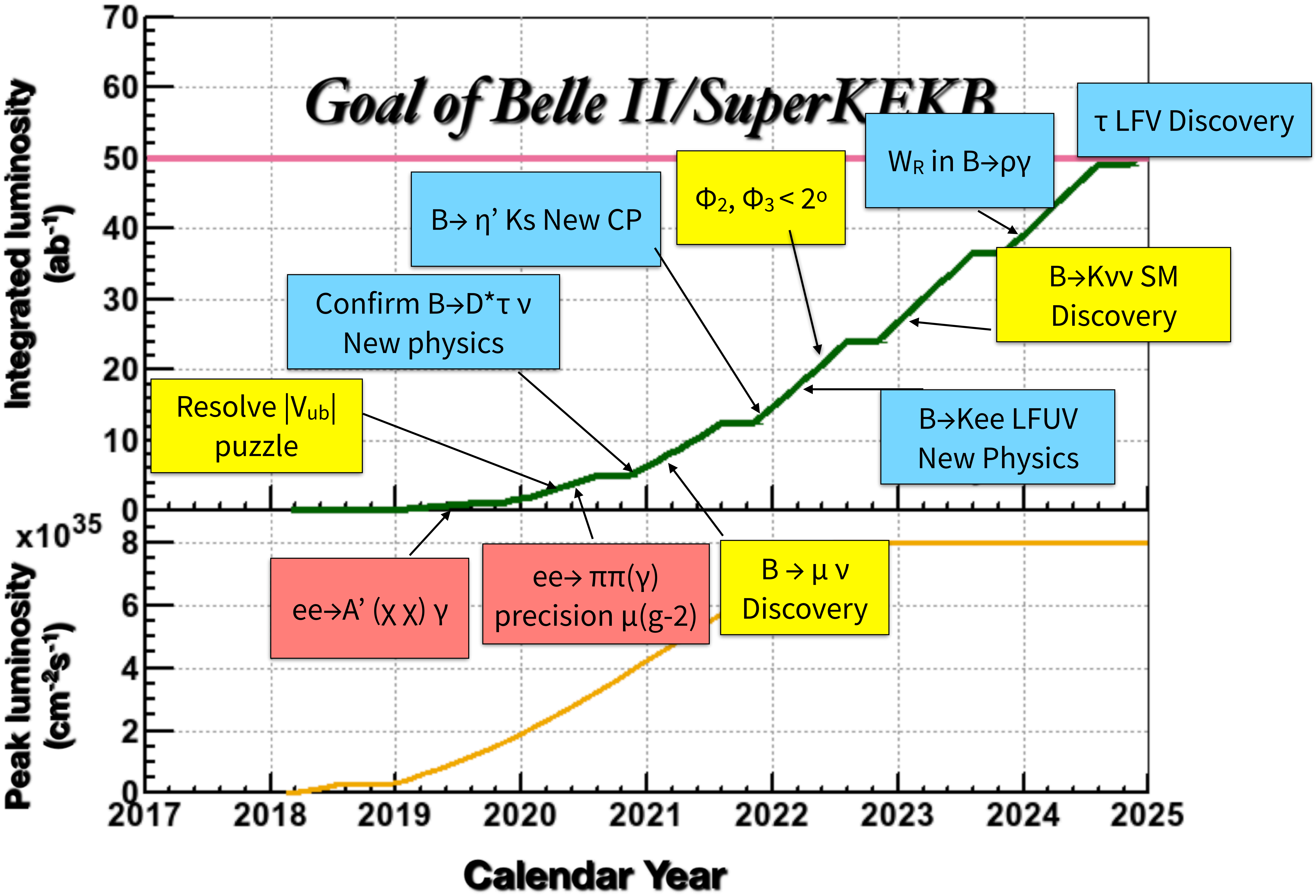
Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics (Core element)



Roadmap

- Our most powerful tests will continue to be statistics limited, clean theoretically and systematically.





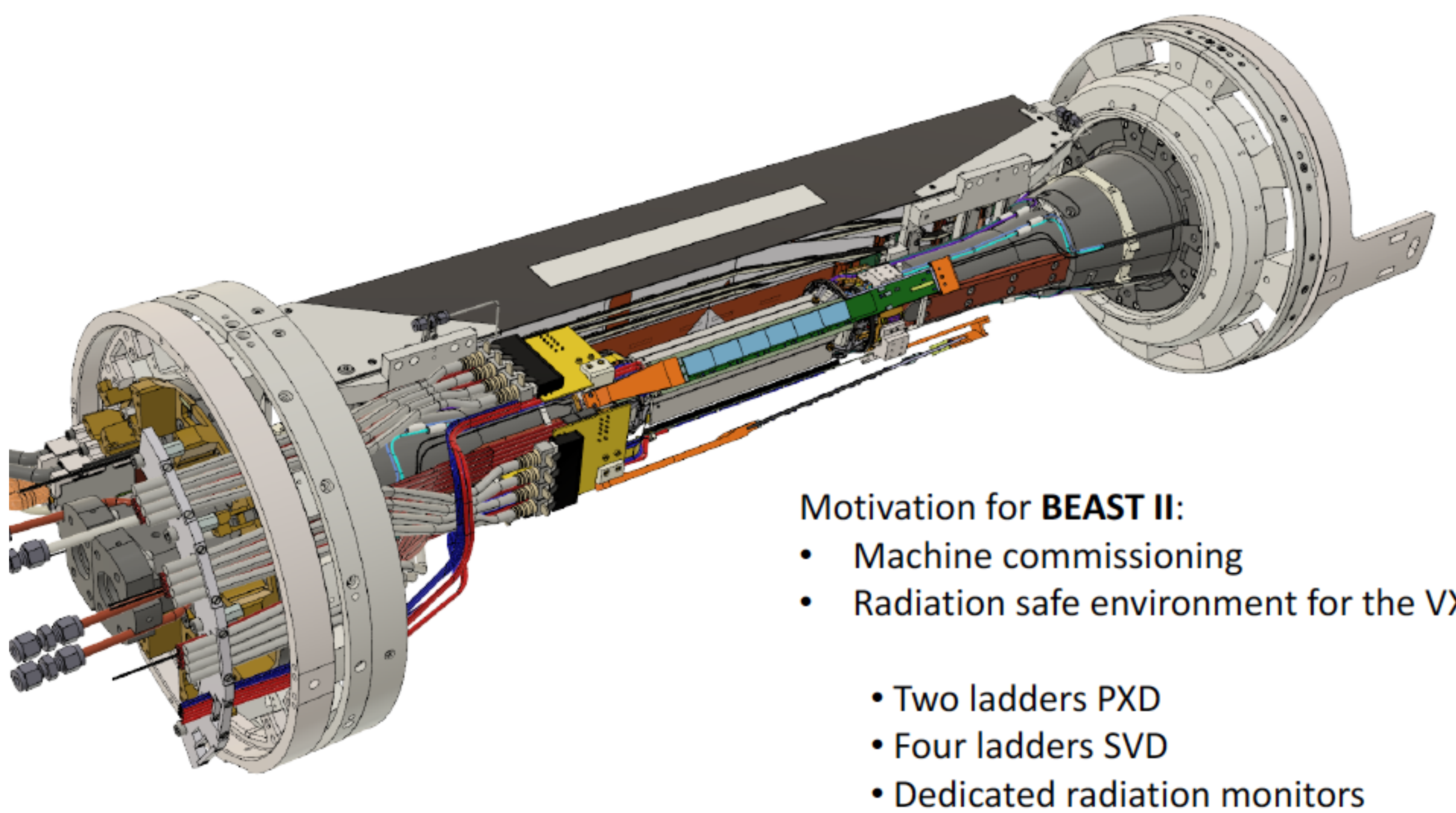
Belle II program

Observables	Expected the. accuracy		Expected exp. uncertainty	Facility (2025)
UT angles & sides				
ϕ_1 [°]	***		0.4	Belle II
ϕ_2 [°]	**		1.0	Belle II
ϕ_3 [°]	***	**CKM**	1.0	LHCb/Belle II
$\lvert V_{cb}\rvert$ incl.	***		1%	Belle II
$\lvert V_{cb}\rvert$ excl.	***		1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	**		3%	Belle II
$\lvert V_{ub}\rvert$ excl.	**		2%	Belle II/LHCb
CPV				
$S(B \to \phi K^0)$	***	**CPV**	0.02	Belle II
$S(B \to \eta' K^0)$	***		0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***		4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***		0.20	LHCb/Belle II
(Semi-)leptonic				
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**		3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	**SL**	7%	Belle II
$R(B \to D\tau\nu)$	***		3%	Belle II
$R(B \to D^*\tau\nu)$	***		2%	Belle II/LHCb
Radiative & EW Penguins				
$\mathcal{B}(B \to X_s\gamma)$	**		4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***		0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***		0.03	Belle II
$S(B \to \rho\gamma)$	**		0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	**EWP**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***		15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***		20%	Belle II
$R(B \to K^*\ell\ell)$	***		0.03	Belle II/LHCb
Charm				
$\mathcal{B}(D_s \to \mu\nu)$	***		0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	**D**	2%	Belle II
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**		0.03	Belle II
$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	***		0.03	Belle II
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***		4	Belle II
Tau				
$\tau \to \mu\gamma$ $[10^{-10}]$	***	**τ**	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***		< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***		< 3	Belle II/LHCb

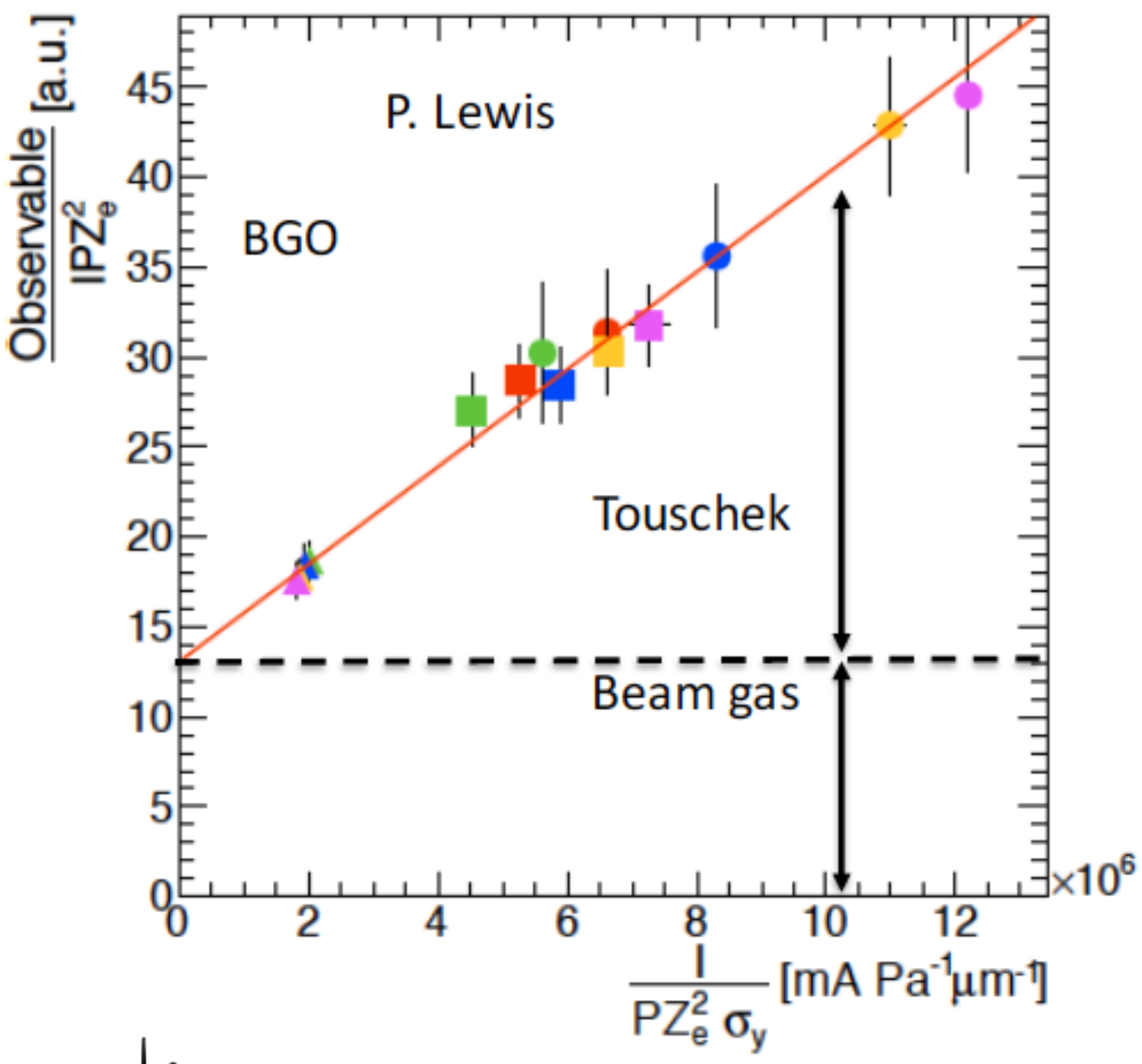
Beam background / Commissioning

Phase 1 2016 : Simple background commissioning detector (diodes, diamonds TPCs, crystals…). No final focus. Only single beam studies.

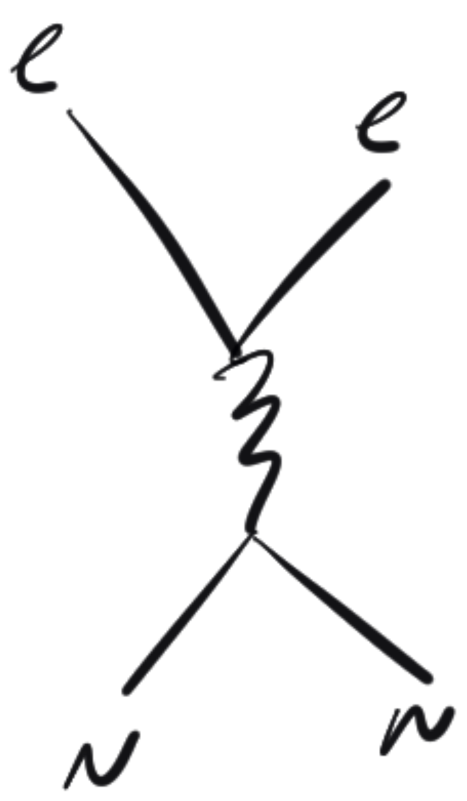
Phase 2 VXD Volume



Motivation for **BEAST II**:
- Machine commissioning
- Radiation safe environment for the VXD:
  - Two ladders PXD
  - Four ladders SVD
  - Dedicated radiation monitors FANGS, CLAWS, PLUME



Phase 2 2018: Full Belle II outer detector. Full superconducting final focus. *Collisions ! Result: Safe to install silicon detectors!*

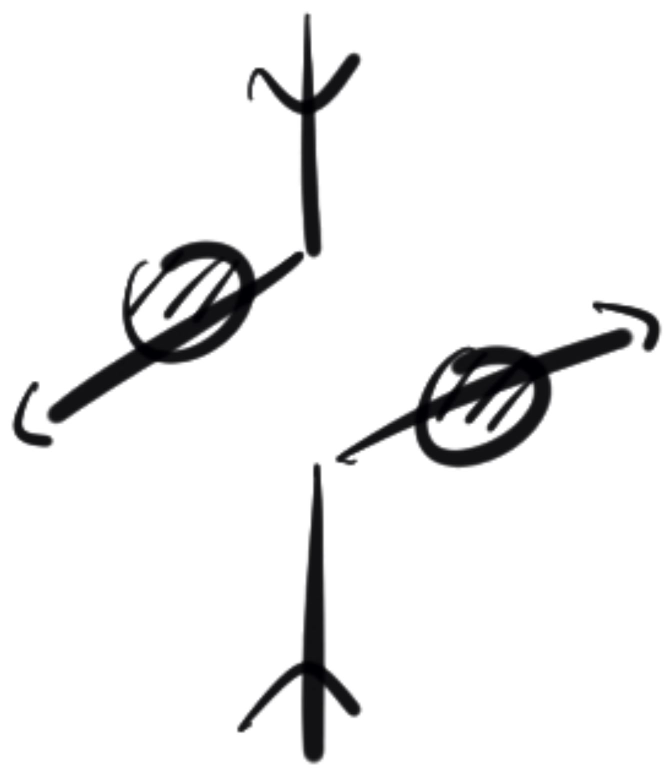


Coulomb scattering

Bremsstrahlung

Bhabha scattering σ~ 100 nb

2-photon σ~10^7 nb



Intra-bunch Coulomb scattering, “Touschek scattering”

+ Synchrotron, beam gas …

Belle II

- Belle II will explore New Physics on the Luminosity or Intensity Frontier.
- Belle II / SuperKEKB came online in 2018 - rediscovered heavy flavour : charm, beauty and τ.
- We are ready to start a long physics run in the Super Factory mode (Phase 3). This requires *high-efficiency* data-taking by Belle II and *extensive running* by Super KEK-B, soon to be the world's highest luminosity accelerator.
- There is competition and complementarity with LHCb and BES III.

E. Kou, PU (Editors) et al., arXiv: 1808.10567 (688p), Submitted to PTEP

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047

The Belle II Physics Book

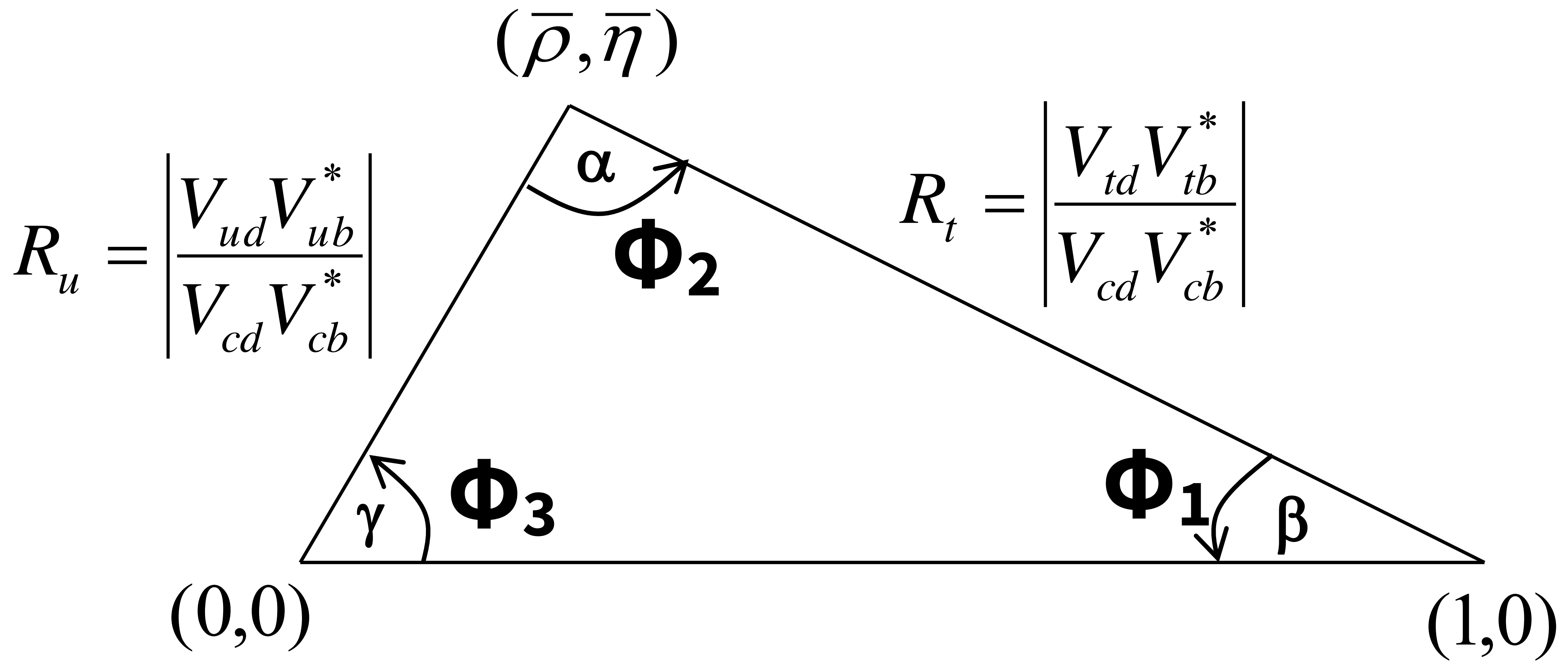
E. Kou[73,¶,†], P. Urquijo[141,§,†], W. Altmannshofer[131,¶], F. Beaujean[77,¶], G. Bell[118,¶], M. Beneke[110,¶], I. I. Bigi[144,¶], F. Bishara[146,16,¶], M. Blanke[48,49,¶], C. Bobeth[109,110,¶], M. Bona[148,¶], N. Brambilla[110,¶], V. M. Braun[42,¶], J. Brod[108,131,¶], A. J. Buras[111,¶], H. Y. Cheng[43,¶], C. W. Chiang[90,¶], G. Colangelo[124,¶], H. Czyz[152,29,¶], A. Datta[142,¶], F. De Fazio[51,¶], T. Deppisch[49,¶], M. J. Dolan[141,¶], S. Fajfer[105,137,¶], T. Feldmann[118,¶], S. Godfrey[7,¶], M. Gronau[60,¶], Y. Grossman[15,¶], F. K. Guo[40,130,¶], U. Haisch[146,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[87,¶], J. Hisano[87,88,¶], L. Hofer[123,¶], M. Hoferichter[164,¶], W. S. Hou[90,¶], T. Huber[118,¶], S. Jaeger[155,¶], S. Jahn[81,¶], M. Jamin[122,¶], J. Jones[101,¶], M. Jung[109,¶], A. L. Kagan[131,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[105,137,¶], T. Kaneko[30,26,¶], Y. Kiyo[62,¶], A. Kokulu[110,136,¶], N. Kosnik[105,137,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[40,¶], V. Lubicz[149,¶], F. Mahmoudi[138,¶], K. Maltman[169,120,¶], M. Misiak[162,¶], S. Mishima[30,¶], K. Moats[7,¶], B. Moussallam[72,¶], A. Nefediev[38,86,75,¶], U. Nierste[49,¶], D. Nomura[30,¶], N. Offen[42,¶], S. L. Olsen[129,¶], E. Passemar[36,114,¶], A. Paul[56¶], G. Paz[166,¶], A. A. Petrov[166,¶], A. Pich[161,¶], A. D. Polosa[56,¶], J. Pradler[39,¶], S. Prelovsek[105,137,42,¶], M. Procura[119,¶], G. Ricciardi[52,¶], D. J. Robinson[128,19,¶], P. Roig[9,¶], S. Schacht[58,¶], K. Schmidt-Hoberg[16,¶], J. Schwichtenberg[49,¶], S. R. Sharpe[163,¶], J. Shigemitsu[113,¶], N. Shimizu[158,¶], Y. Shimizu[67,¶], L. Silvestrini[56,¶], S. Simula[57,¶], C. Smith[74,¶], P. Stoffer[127,¶], D. Straub[109,¶], F. J. Tackmann[16,¶], M. Tanaka[96,¶], A. Tayduganov[108,¶], G. Tetlalmatzi-Xolocotzi[93,¶], T. Teubner[136,¶], A. Vairo[110,¶], D. van Dyk[110,¶], J. Virto[80,110,¶], Z. Was[91,¶], R. Watanabe[143,¶], I. Watson [151,¶], J. Zupan[131,¶], R. Zwicky[132,¶], F. Abudinén[81,§], I. Adachi[30,26,§], K. Adamczyk[91,§], P. Ahlburg[125,§], H. Aihara[158,§], A. Aloisio[52,§], L. Andricek[82,§], N. Anh Ky[44,§], M. Arndt[125,§], D. M. Asner[5,§], H. Atmacan[154,§], T. Aushev[85,§], V. Aushev[106,§], R. Ayad[157,§], T. Aziz[107,§], S. Baehr[47,§], S. Bahinipati[32,§], P. Bambade[73,§], Y. Ban[100,§], M. Barrett[166,§], J. Baudot[46,§], P. Behera[35,§], K. Belous[37,§], M. Bender[76,§], J. Bennett[8,§], M. Berger[39,§], E. Bernieri[57,§], F. U. Bernlochner[47,§], M. Bessner[134,§], D. Besson[86,§], S. Bettarini[55,§], V. Bhardwaj[31,§], B. Bhuyan[33,§], T. Bilka[10,§], S. Bilmis[84,§], S. Bilokin[46,§], G. Bonvicini[166,§], A. Bozek[91,§], M. Bračko[140,105,§], P. Branchini[57,§], N. Braun[47,§], R. A. Briere[8,§], T. E. Browder[134,§], L. Burmistrov[73,§], S. Bussino[57,§], L. Cao[47,§], G. Caria[142,§], G. Casarosa[55,§], C. Cecchi[54,§], D. Červenkov[10,§], M.-C. Chang[22,§], P. Chang[90,§], R. Cheaib[142,§], V. Chekelian[81,§], Y. Chen[150,§], B. G. Cheon[28,§], K. Chilikin[75,§], K. Cho[68,§], J. Choi[14,§], S.-K. Choi[27,§], S. Choudhury[34,§], D. Cinabro[166,§], L. M. Cremaldi[142,§], D. Cuesta[46,§], S. Cunliffe[16,§], N. Dash[32,§], E. de la Cruz Burelo[80,§], G. De Nardo[52,§], M. De Nuccio[16,§], G. De Pietro[57,§], A. De Yta Hernandez[80,§], B. Deschamps[125,§], M. Destefanis[58,§], S. Dey[112,§], F. Di Capua[52,§], S. Di Carlo[73,§], J. Dingfelder[125,§], Z. Doležal[10,§],

CKM and CPV SM Metrology: Belle II core program

- The SM describes the mixing of quarks of different generations through the weak force.

$$V_{\mathrm{CKM}} \propto \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|\, e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|\, e^{-i\beta} & -|V_{ts}|\, e^{-i\beta_s} & |V_{tb}| \end{pmatrix}$$

3 Generations, 1 Phase: single source of CPV in the SM.

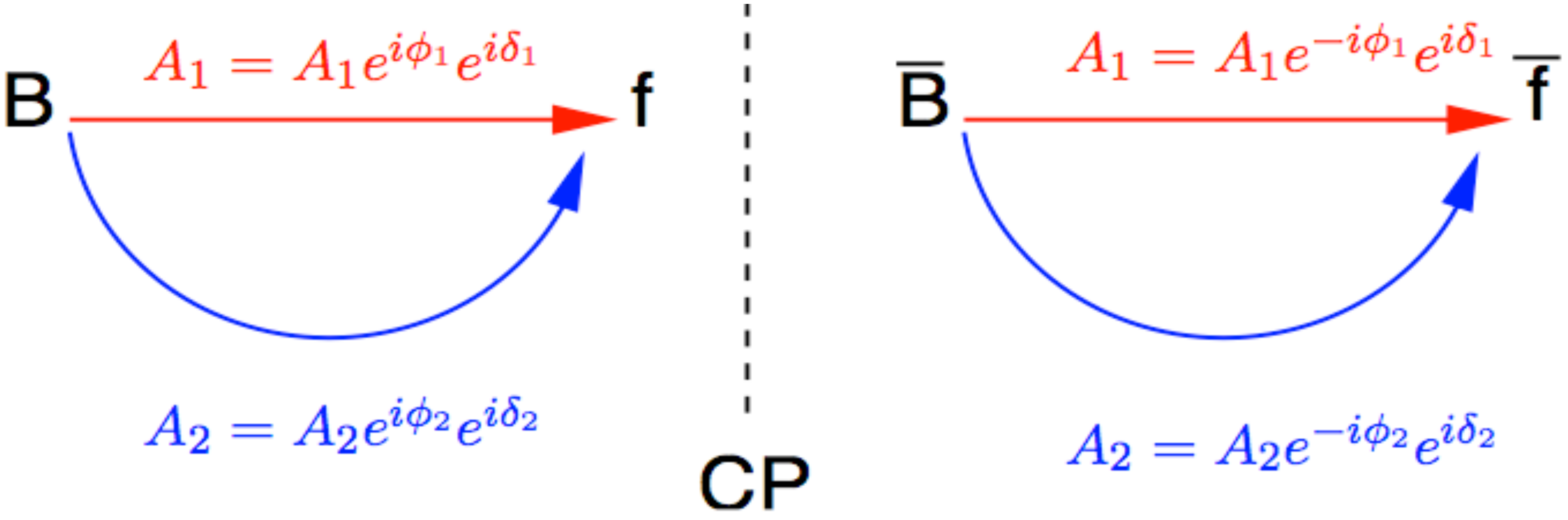


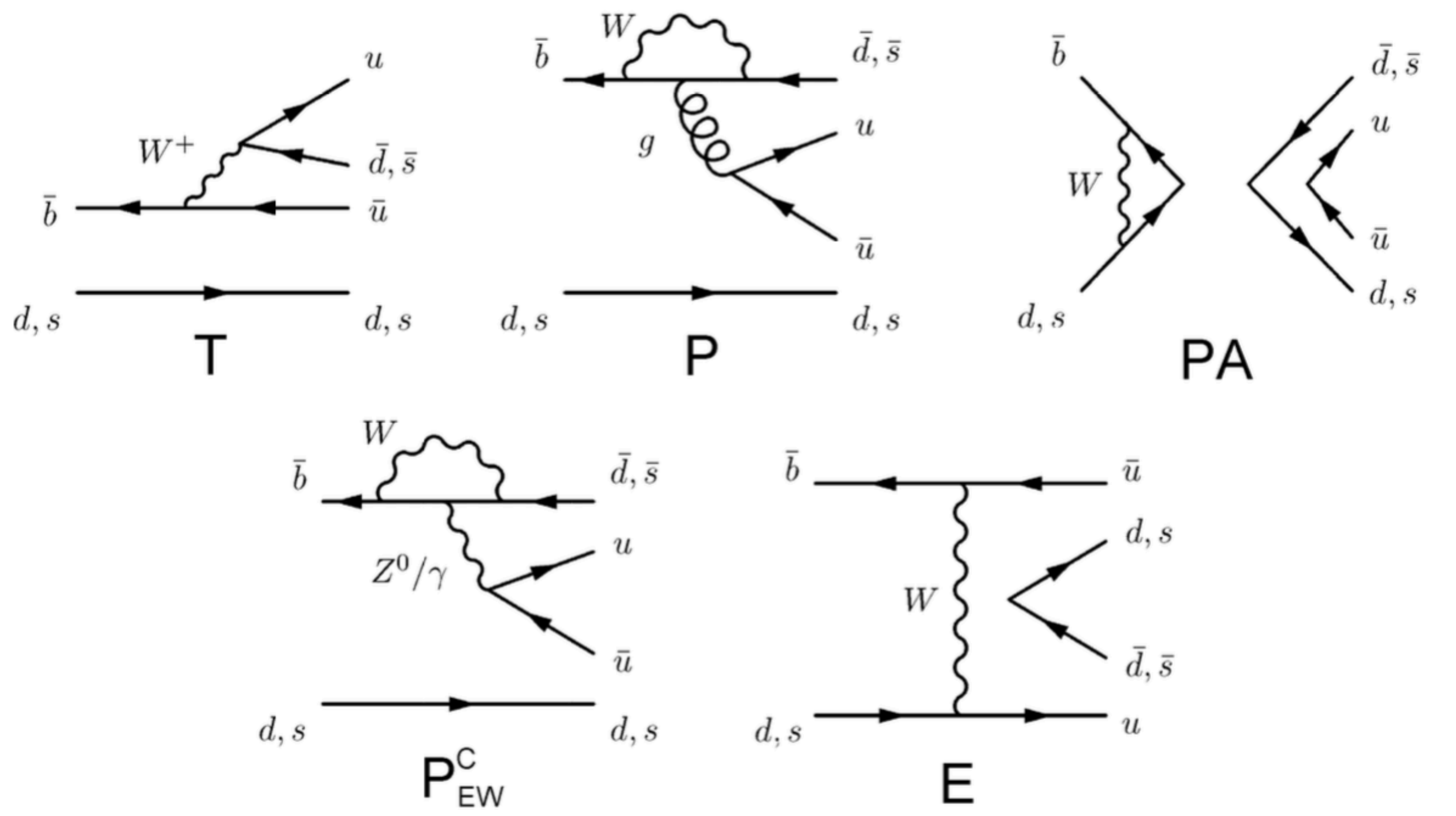
Wolfenstein parameterisation: Phase invariant, conserving CKM matrix unitarity at any order in λ.

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

Direct CP Violation

Φ_1 relies on ΔF=2 (mixing+decay), but we can also use ΔF=1 (direct) as a precise probe





$$\text{CPV: } |A_f|^2 \neq |\bar{A}_{\bar{f}}|^2 \Rightarrow \Delta\phi \text{ and } \Delta\delta \neq 0$$

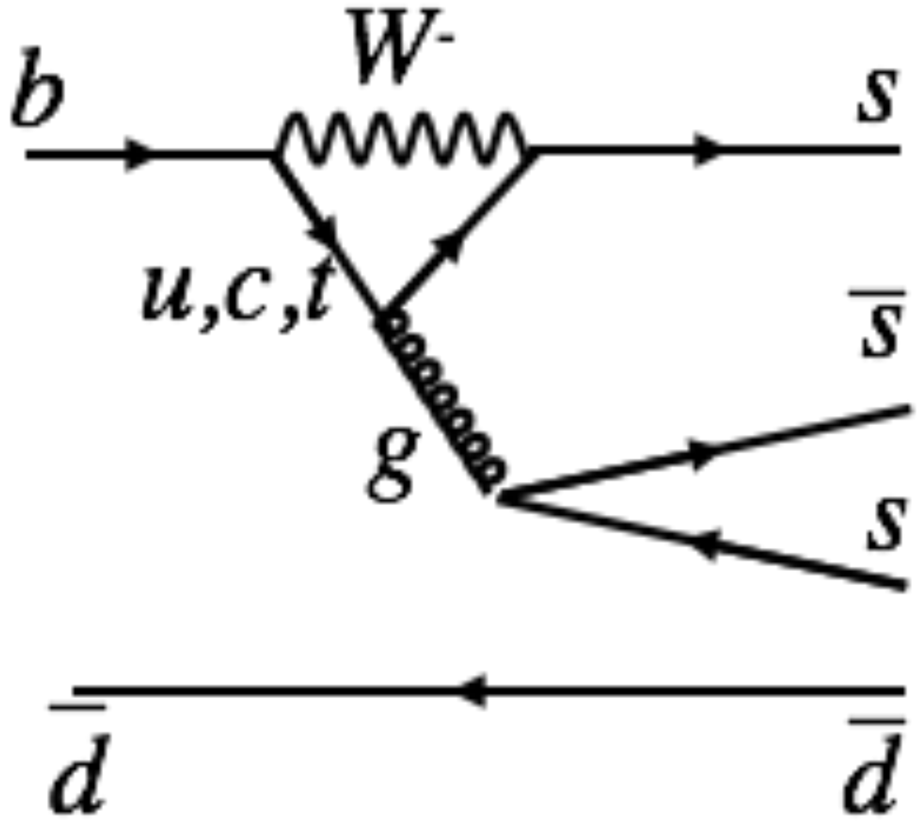
For CPV A_1 and A_2 need to have **different weak phases Φ** and different **CP invariant (e.g. strong) phases δ.**

To measure Φ you need to know δ, and ratio of amplitudes -

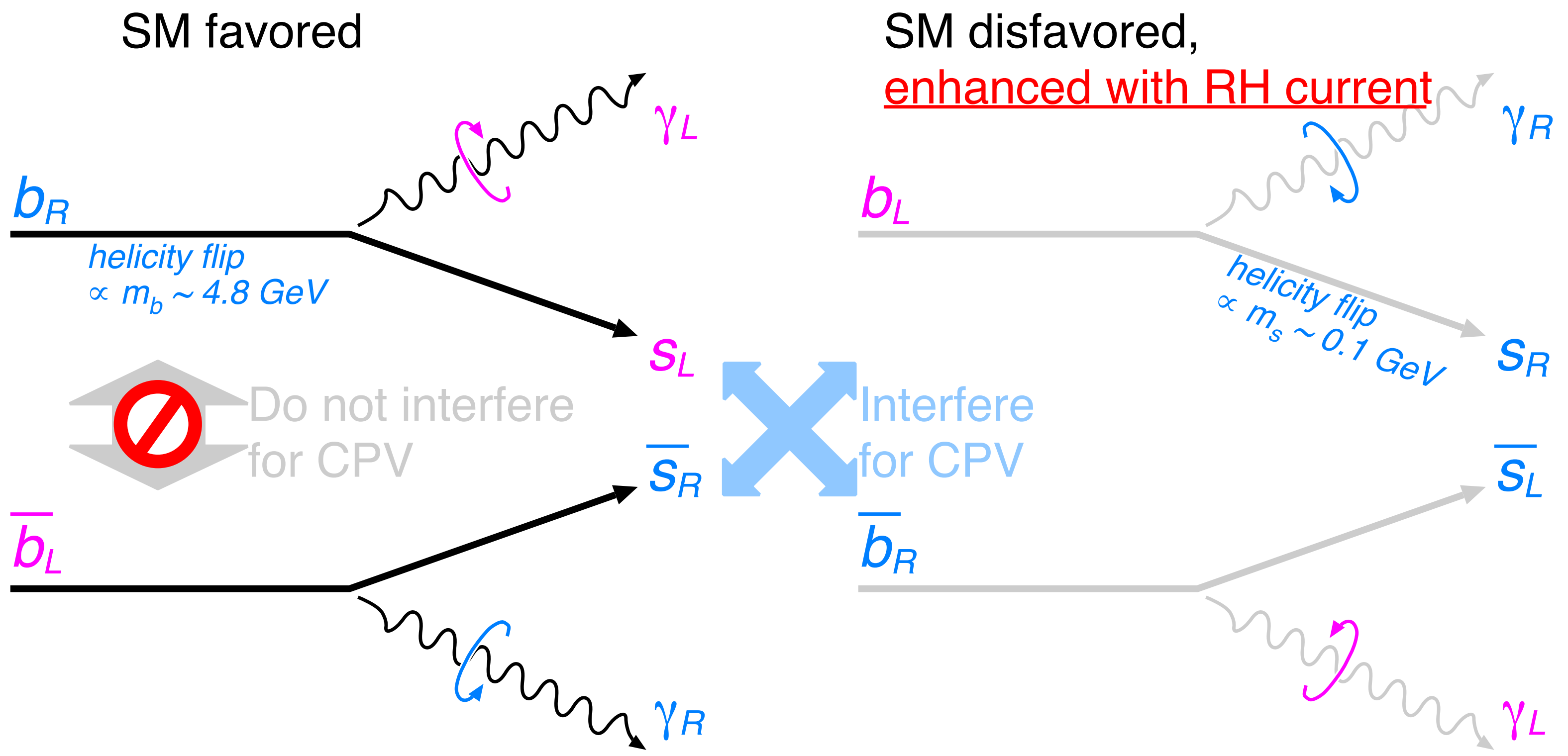
e.g. in γ/Φ_3 measurements the relative strength of V_{ub} and V_{cb} processes and colour suppression.

CP Violation

- **Φ_1 @ 0.7%, Φ_2<1°, Φ_3~1°**
- Search for new phases in b→s gluon and EW penguins
- TDCP Violation flavour tagging at Belle II ~ 35%

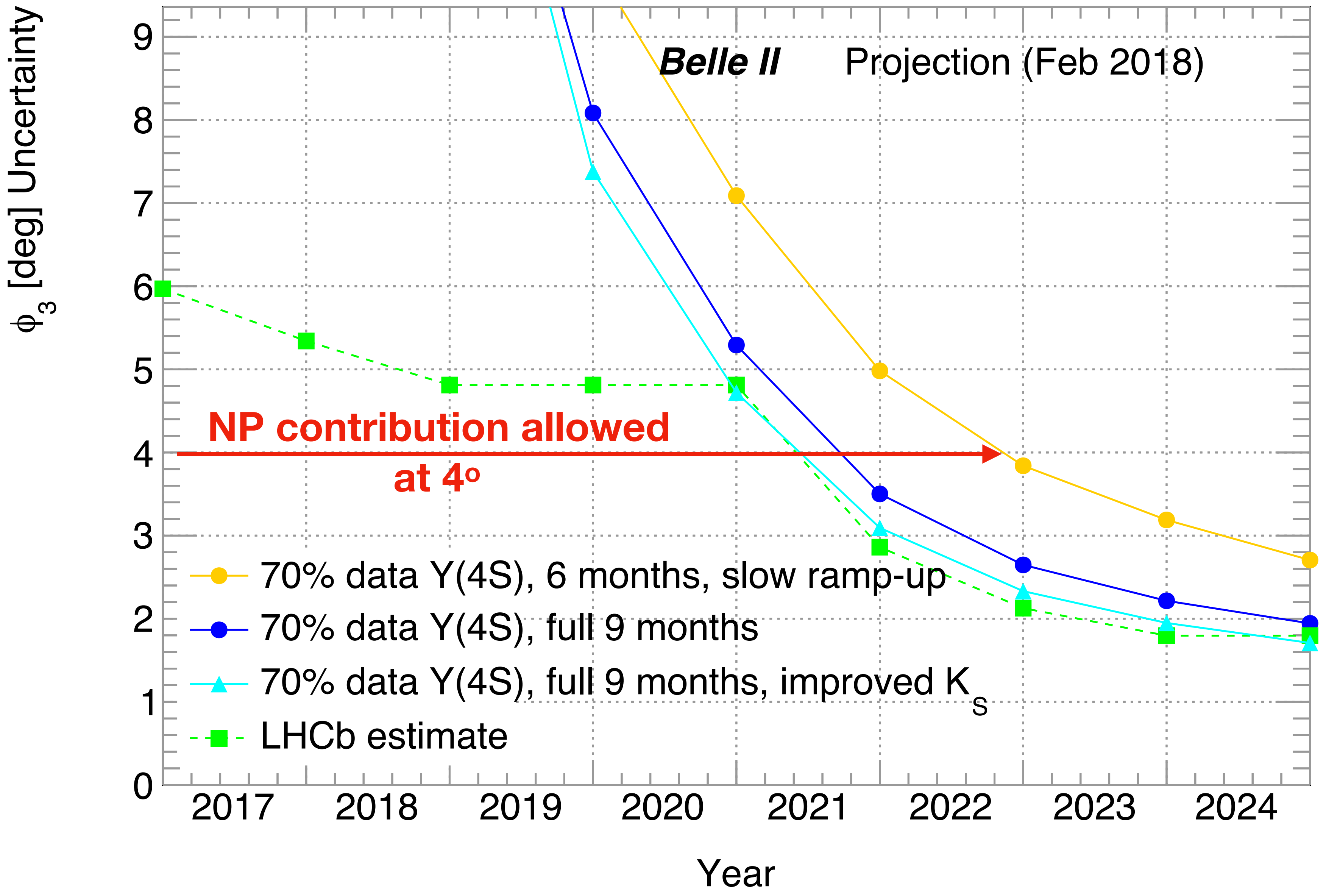


- *Gluonic Penguin (NP sensitive)*

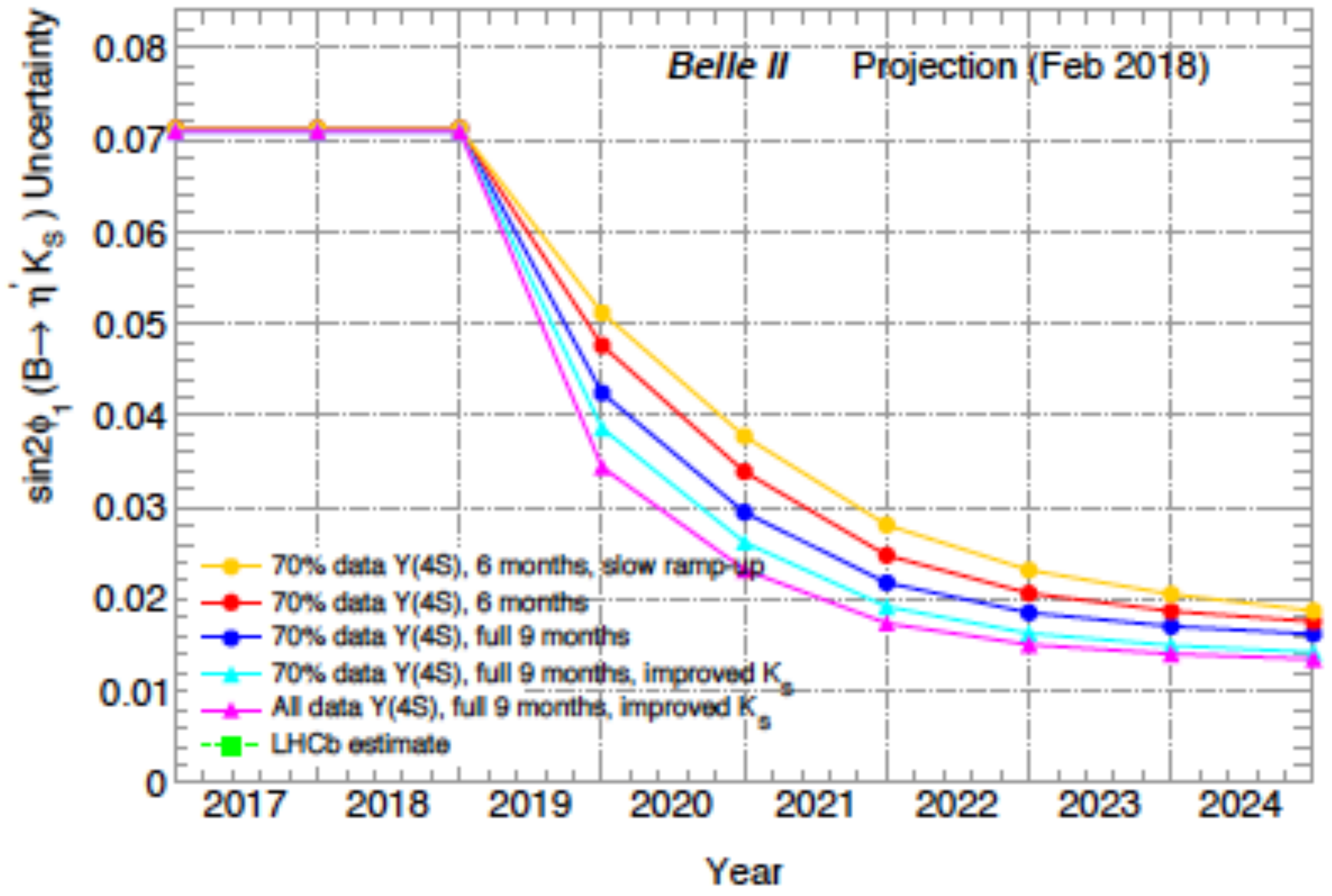


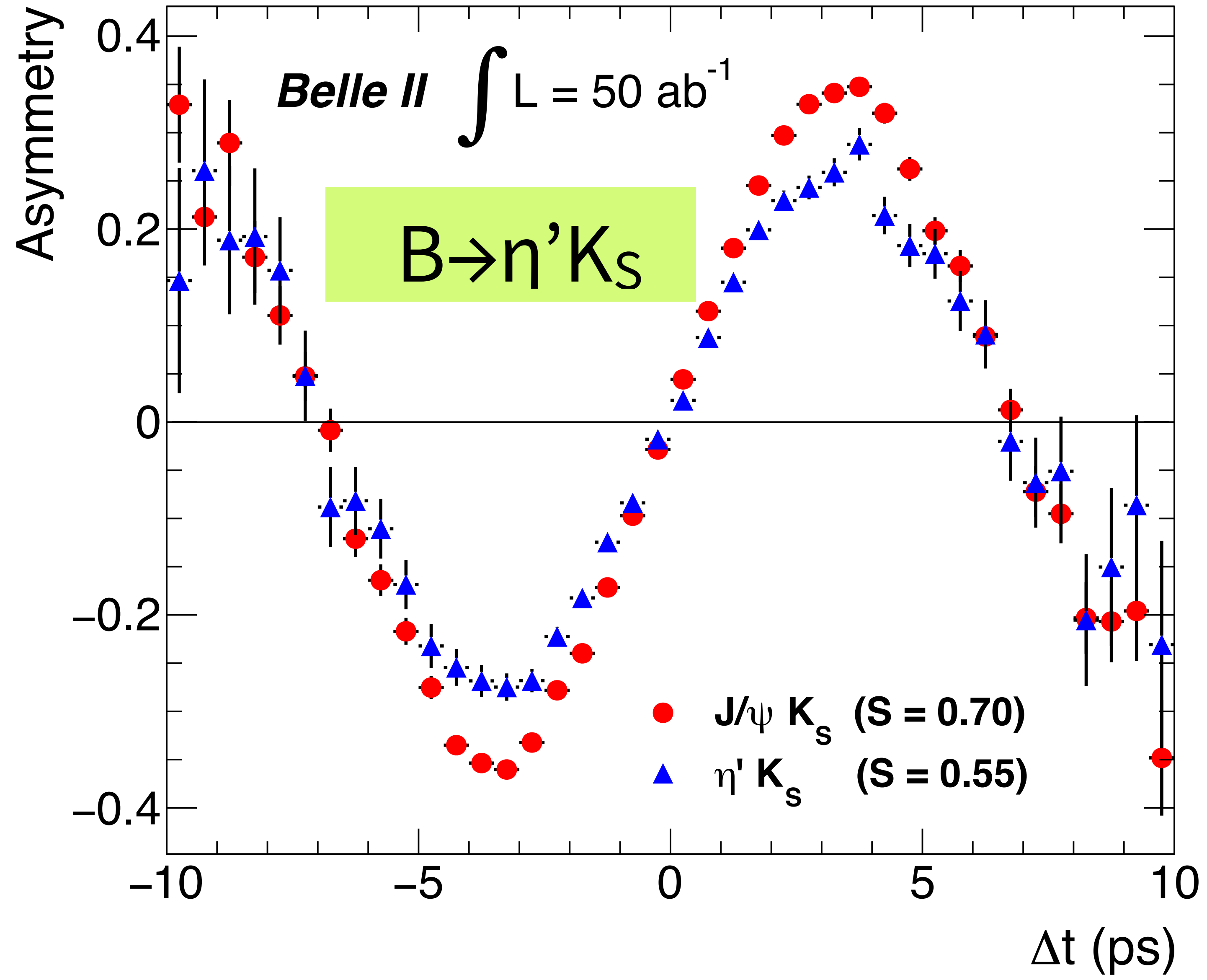
- *EW Radiative Penguin (NP sensitive)*

(phase of V_{ub}) - $B \to D^{(*)}K^{(*)}$



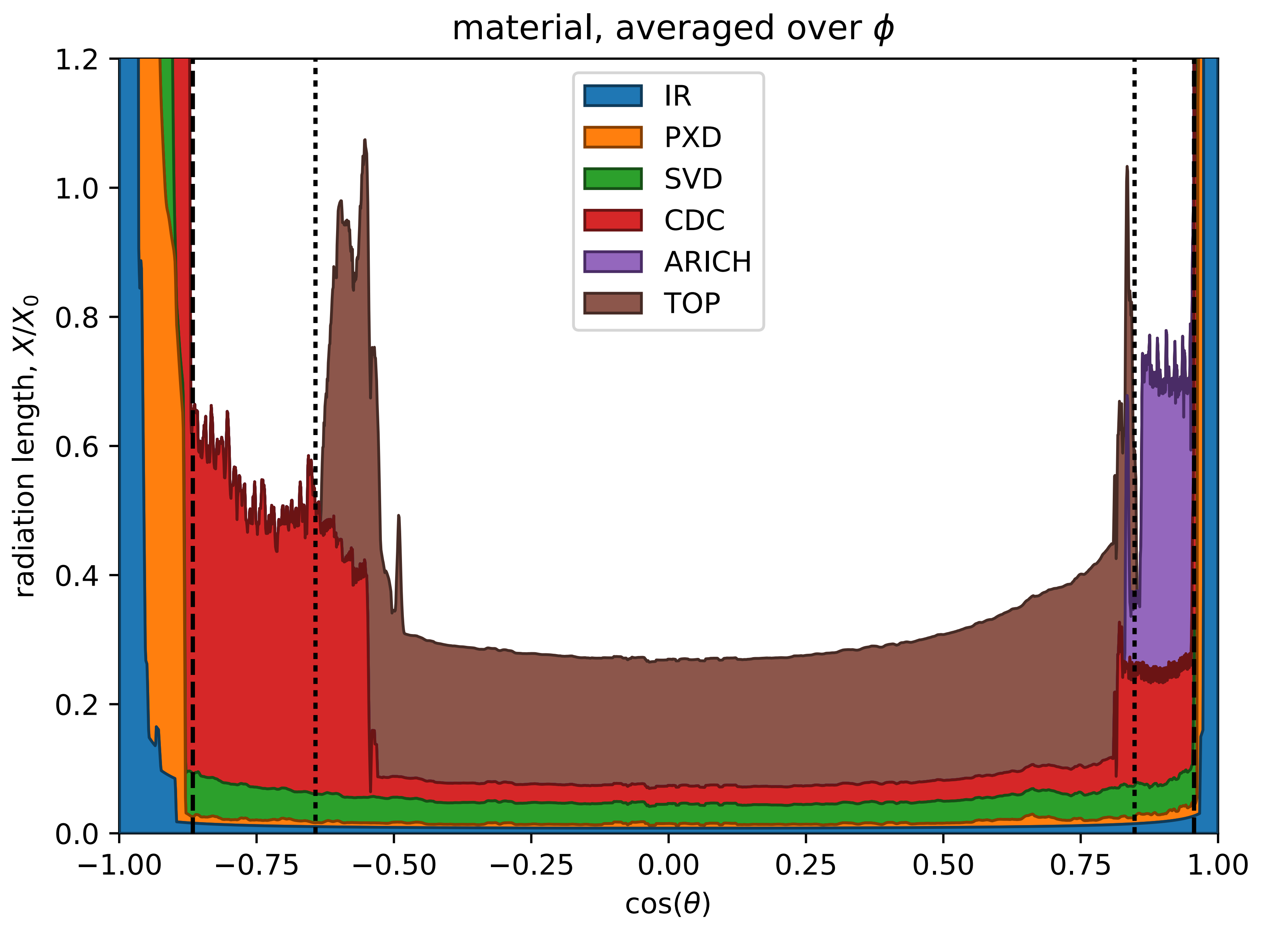
(phase of V_{ub}) - $B \to D^{(*)}K^{(*)}$

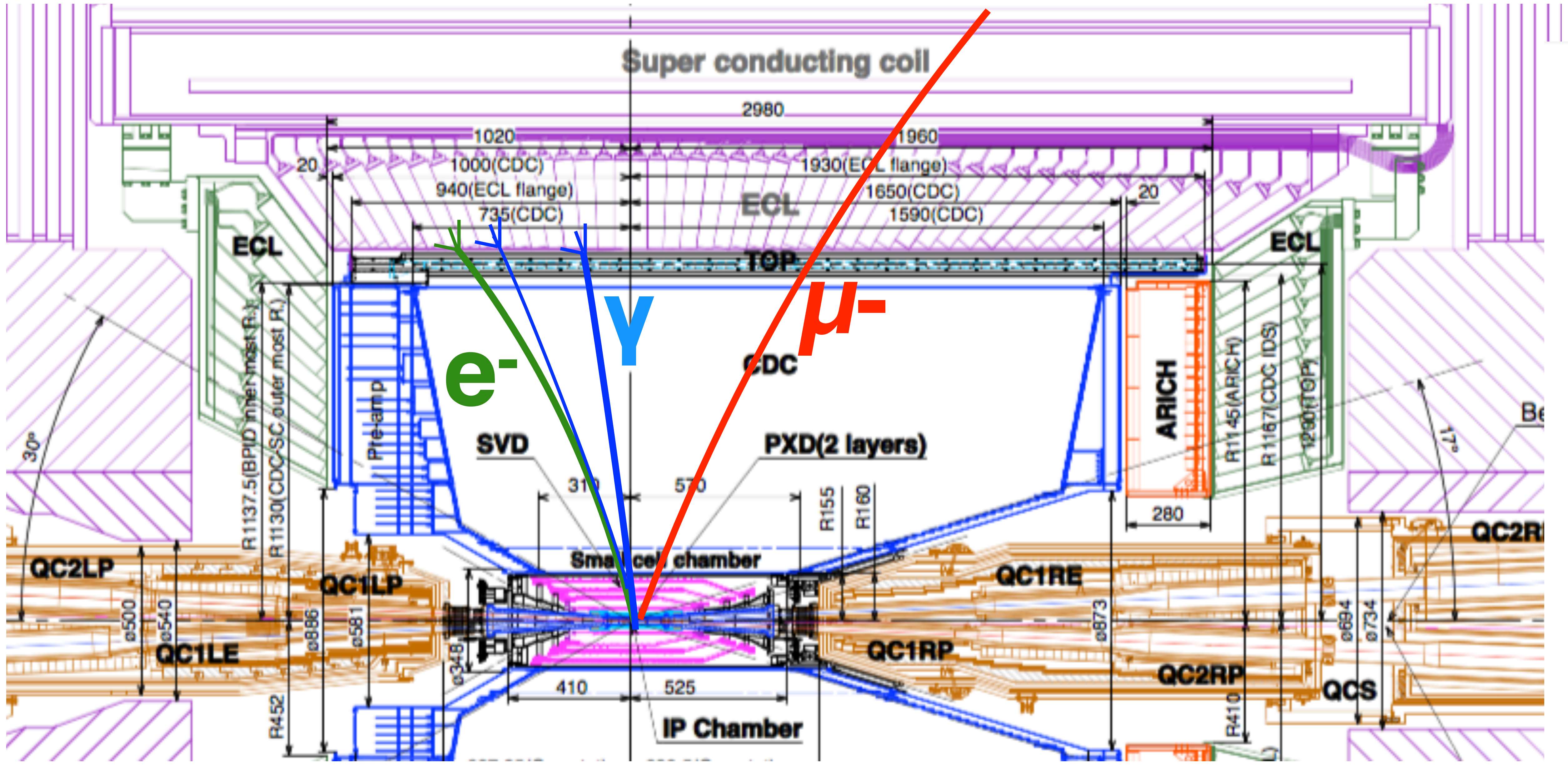


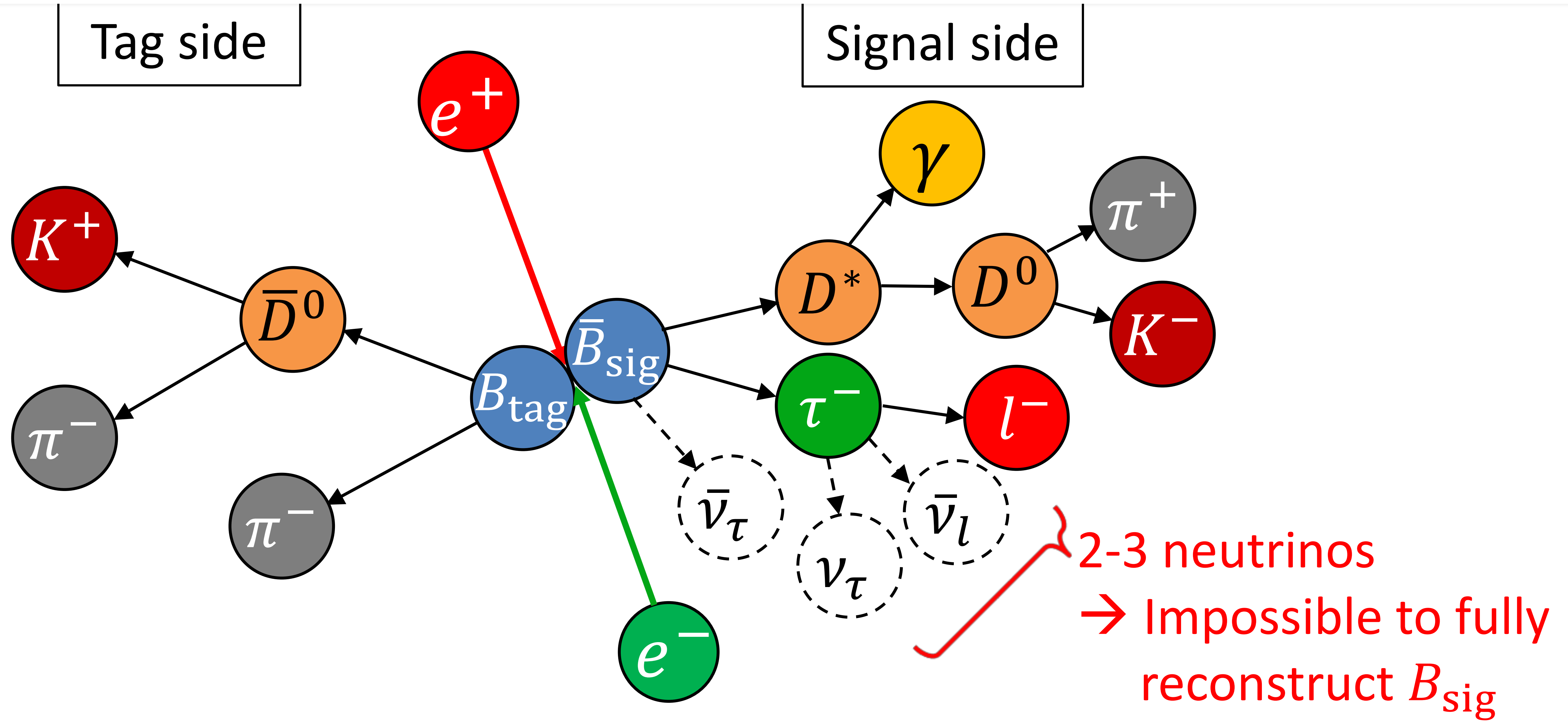


Lepton reconstruction non-universality

- **Muons**: Little to **no radiation** (heavy), **Stable** within particle detectors, no strong interactions
- **Electrons** are light: Final state radiation, Bremsstrahlung in material is likely.
- **Taus** lifetime is 10^{-12} s: background mimics signal where daughters are lost e.g. K_L, π^0.







Belle (II) Reconstruction

- Belle (II) analyses use semileptonic and hadronic “tagging”.

- Based on M_{miss}^2 and calorimeter extra energy $E_{ECL/extra}$

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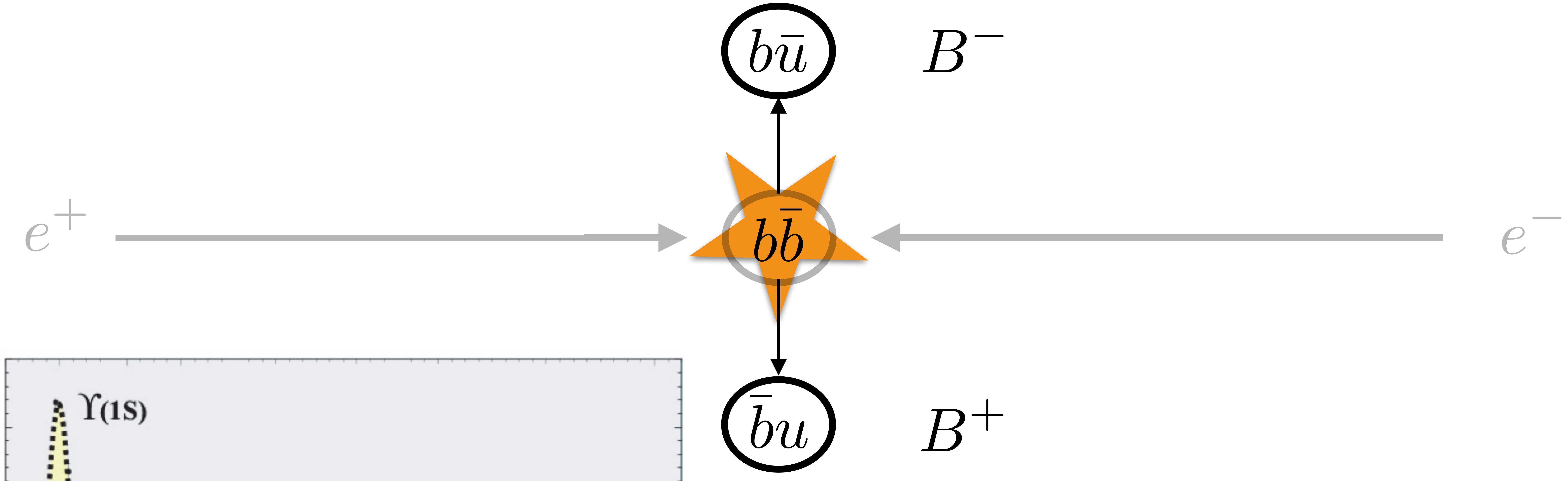

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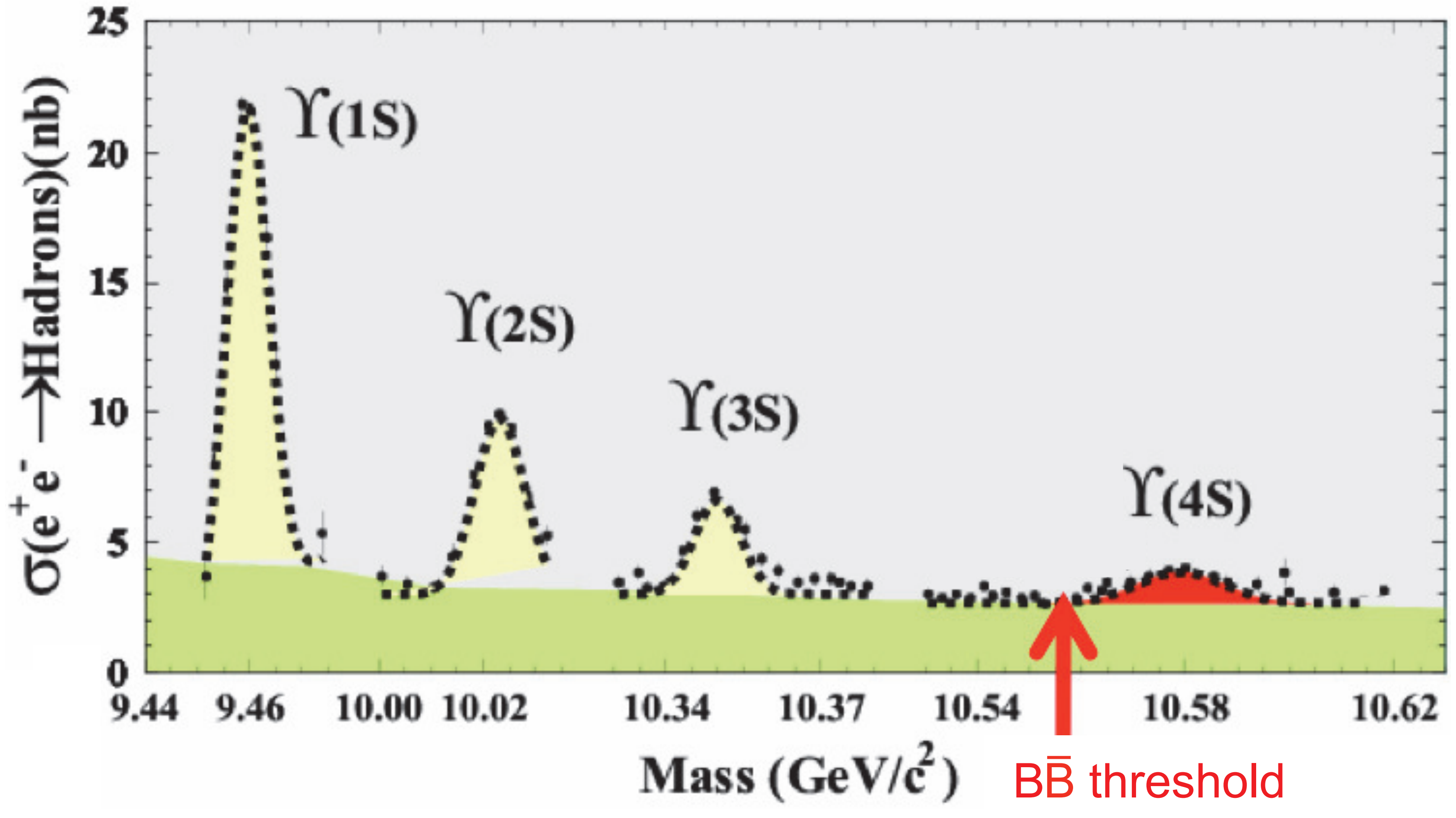

$$\Upsilon(1S) = \langle b\bar{b} \rangle$$

$$\Upsilon(4S) = \langle b\bar{b} \rangle$$

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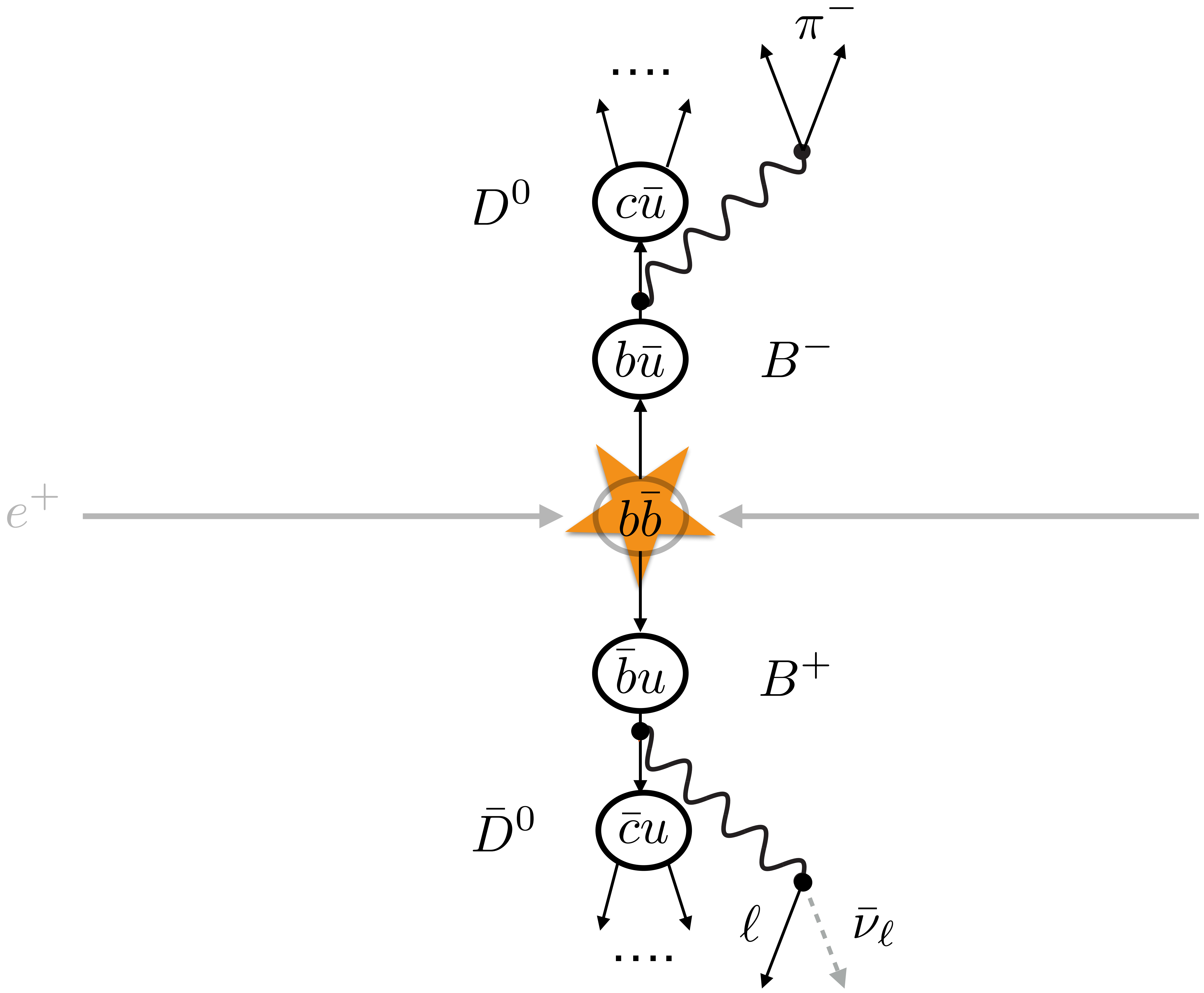

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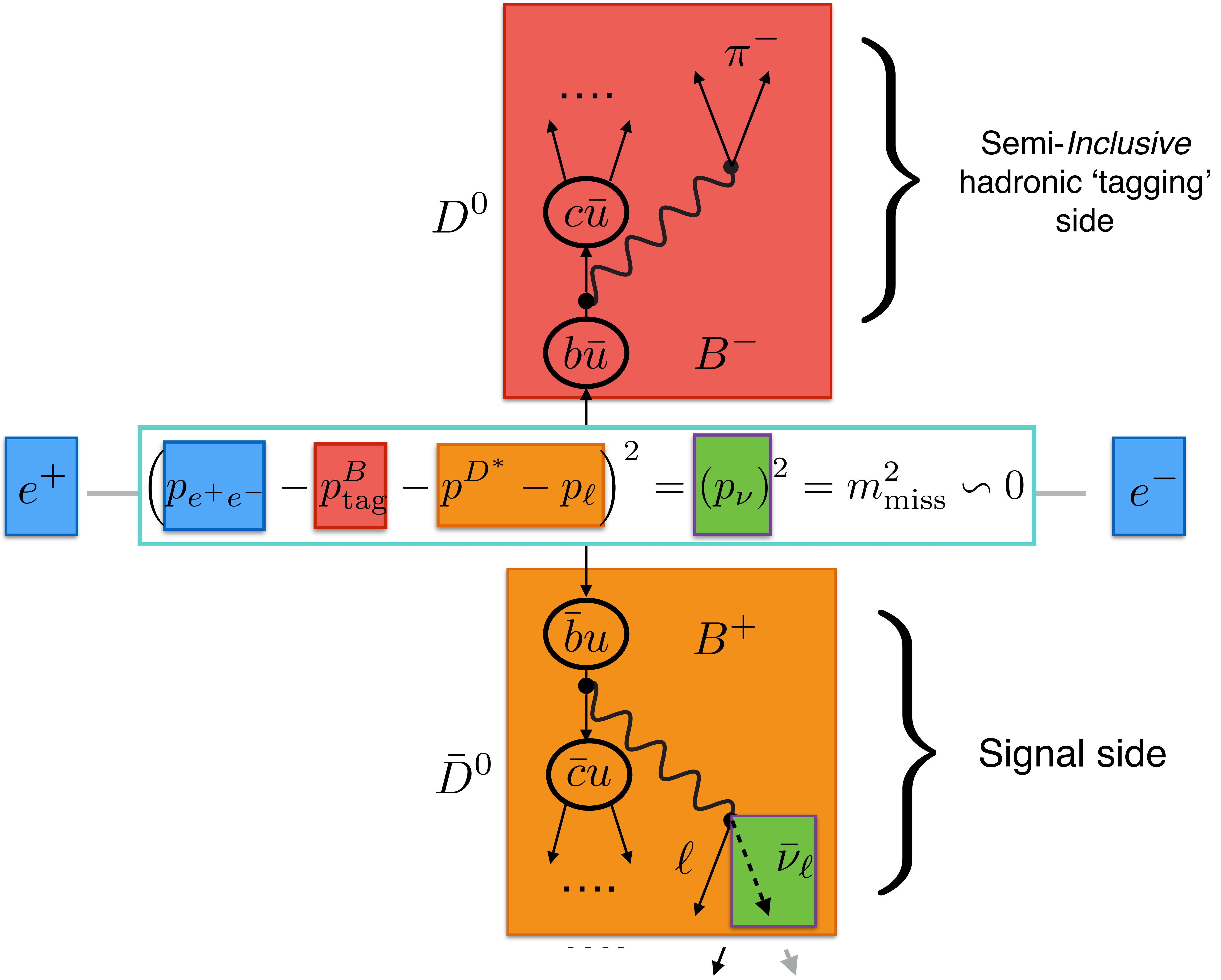
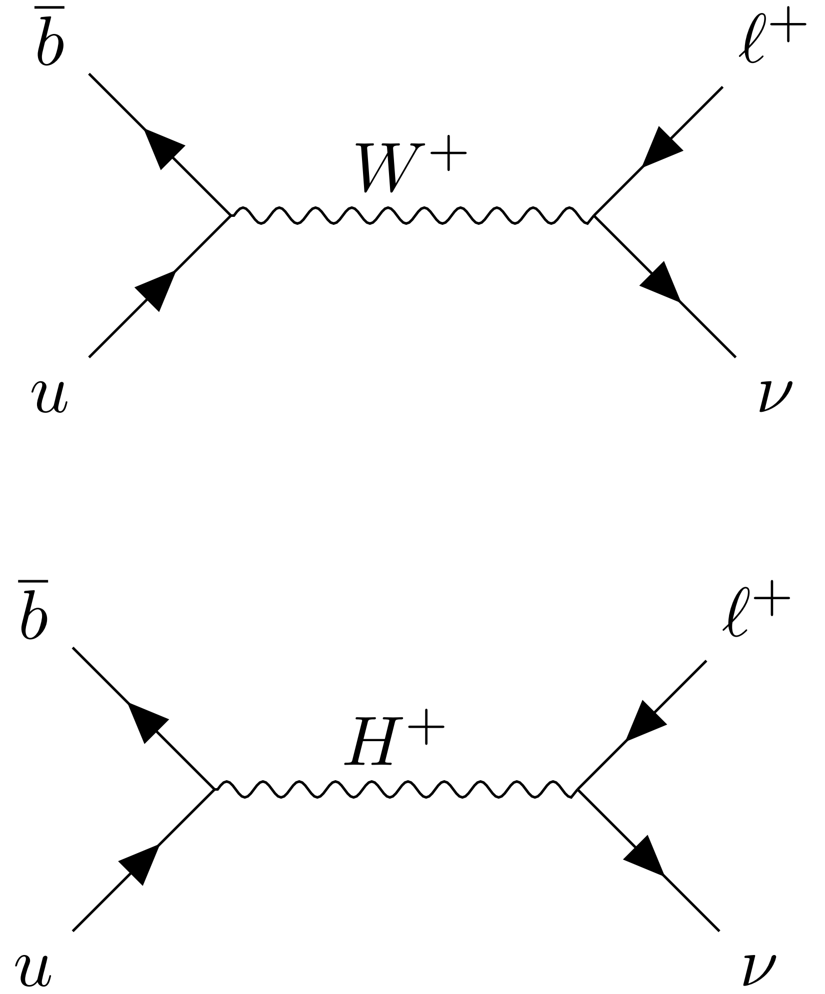


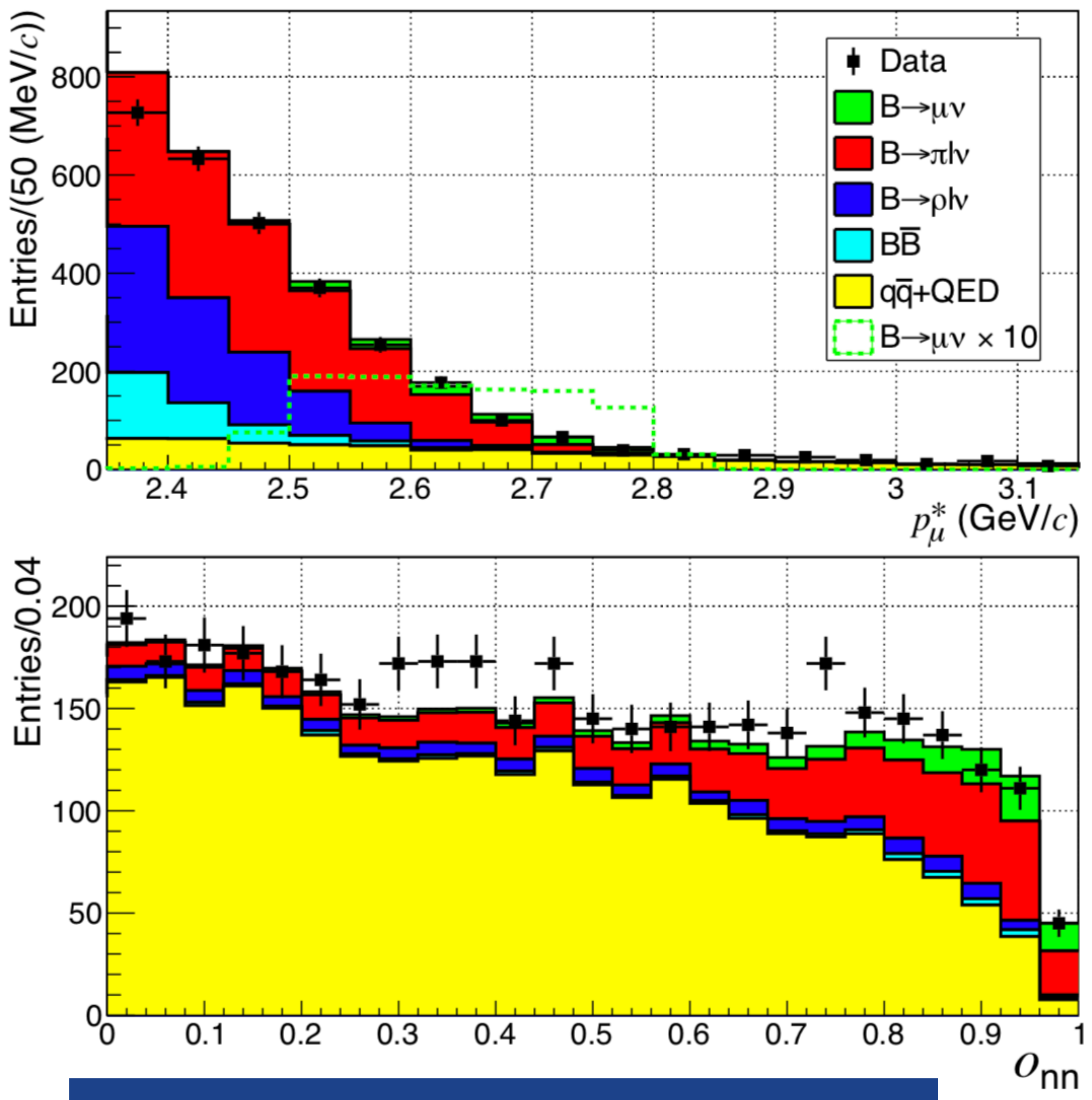
$|V_{ub}|$ and B→lν

- $|V_{ub}|$ only measured to about 10% accuracy → 1% at Belle II.
- 5 σ discoveries of B→ τ ν and B→ μ ν expected with < 5 ab^{-1}.

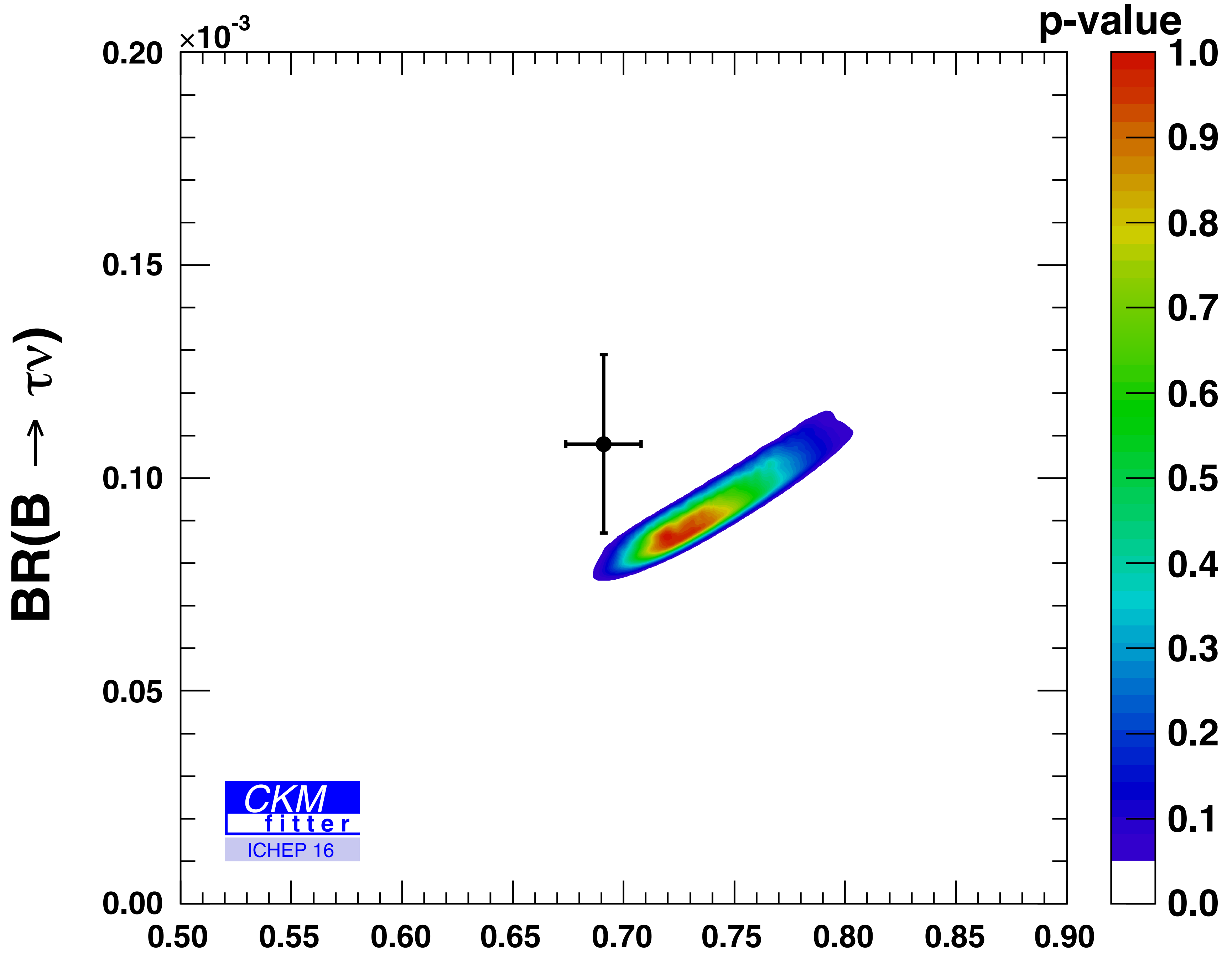


E. Kou, PU et al. arXiv: 1808.10567

L [ab^{-1}]		σ $|V_{ub}|$ [%]
50	B→ π l ν	1.2
	B→ τ ν	1.5 - 2
	B→ μ ν	5

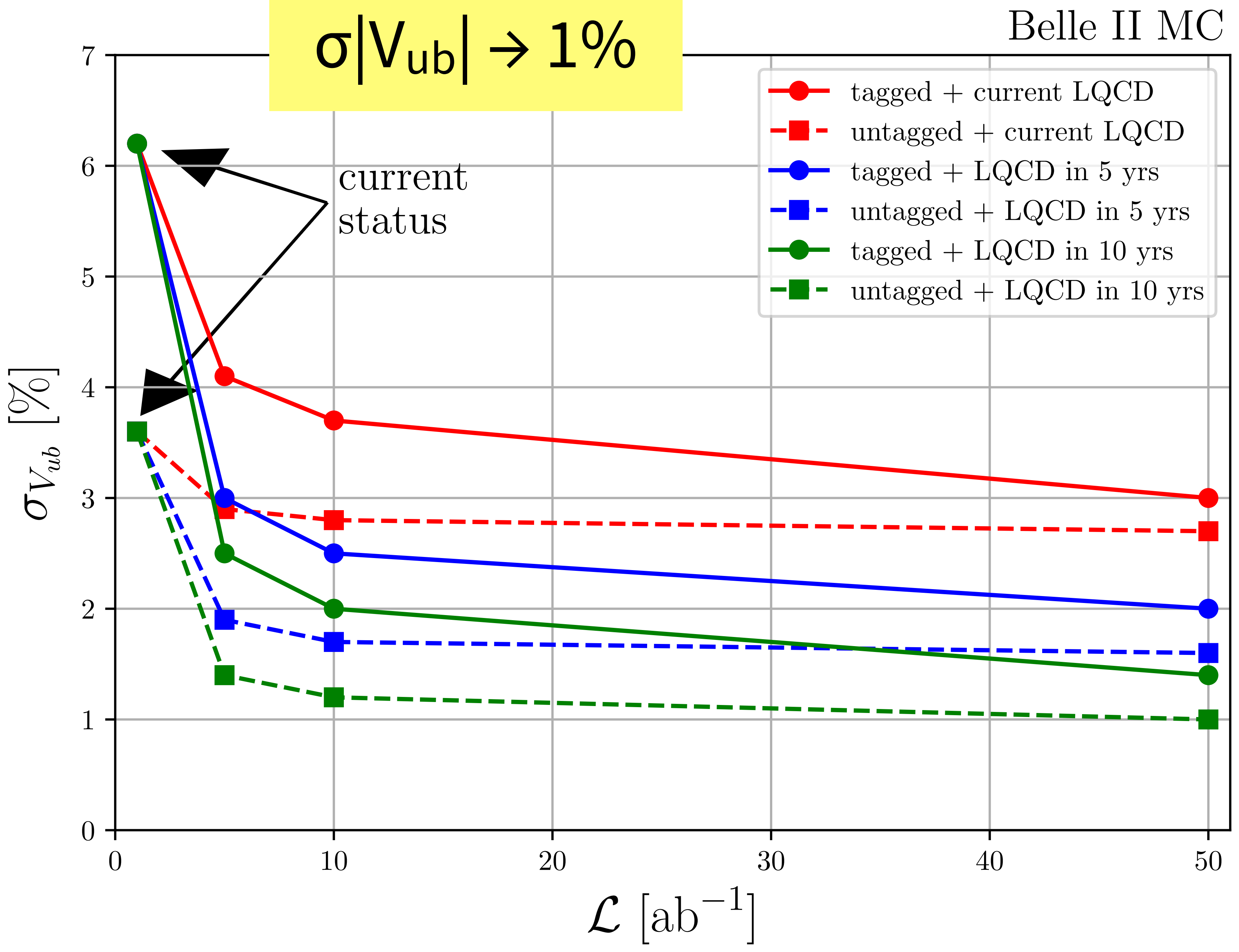


Belle arXiv: 1712.04123
B(B→ μ ν)=(6.5±2.2±1.6)10^{-7}



Phase of Vtd

σ$|V_{ub}|$ → 1%



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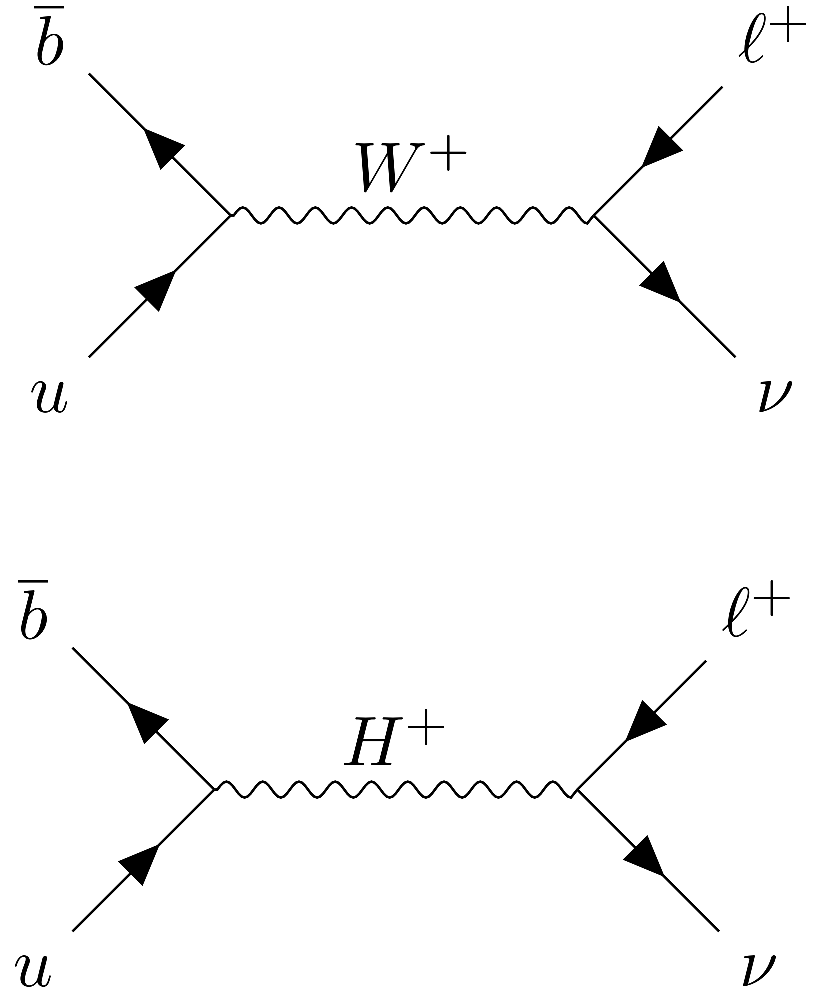
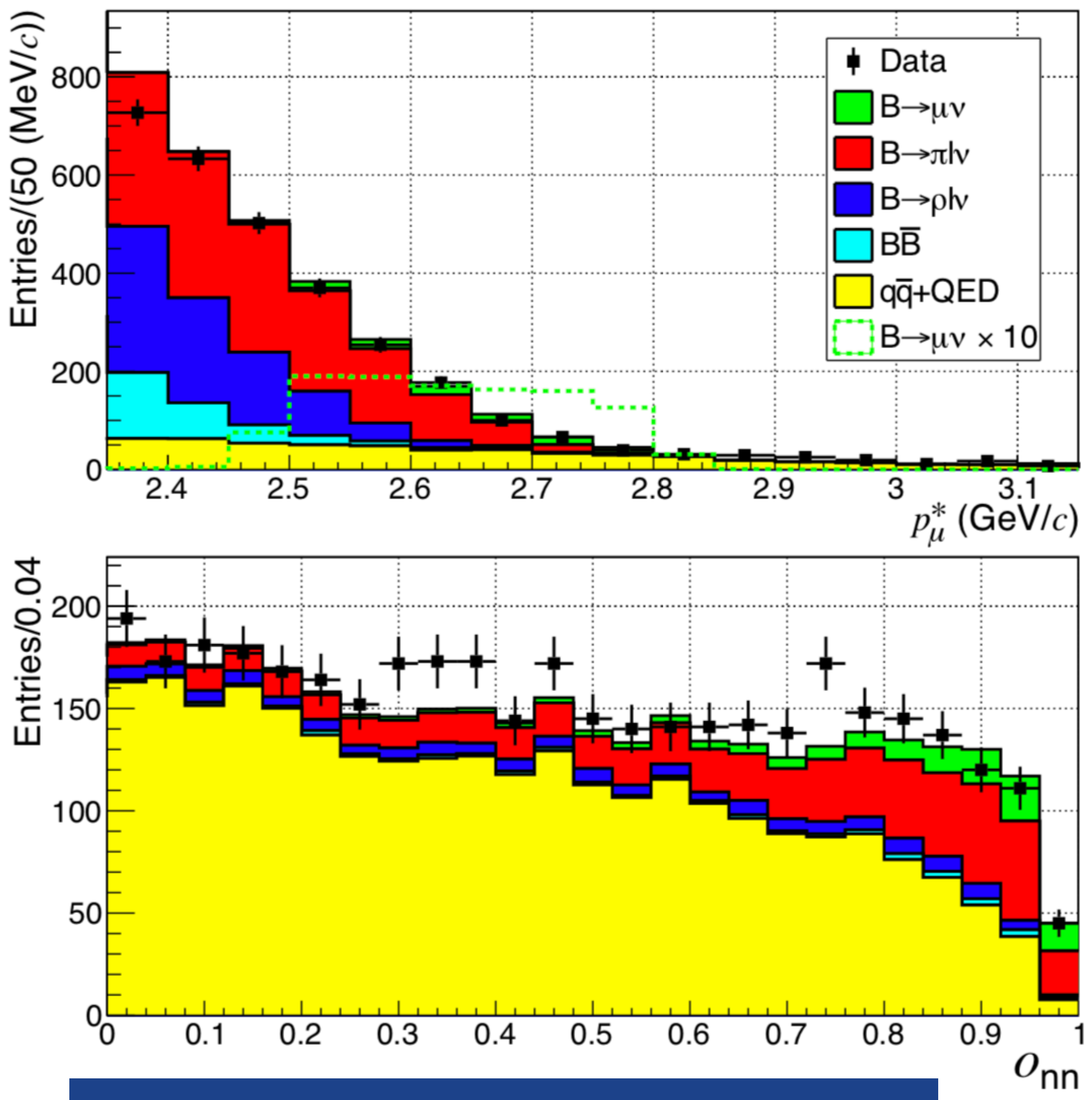
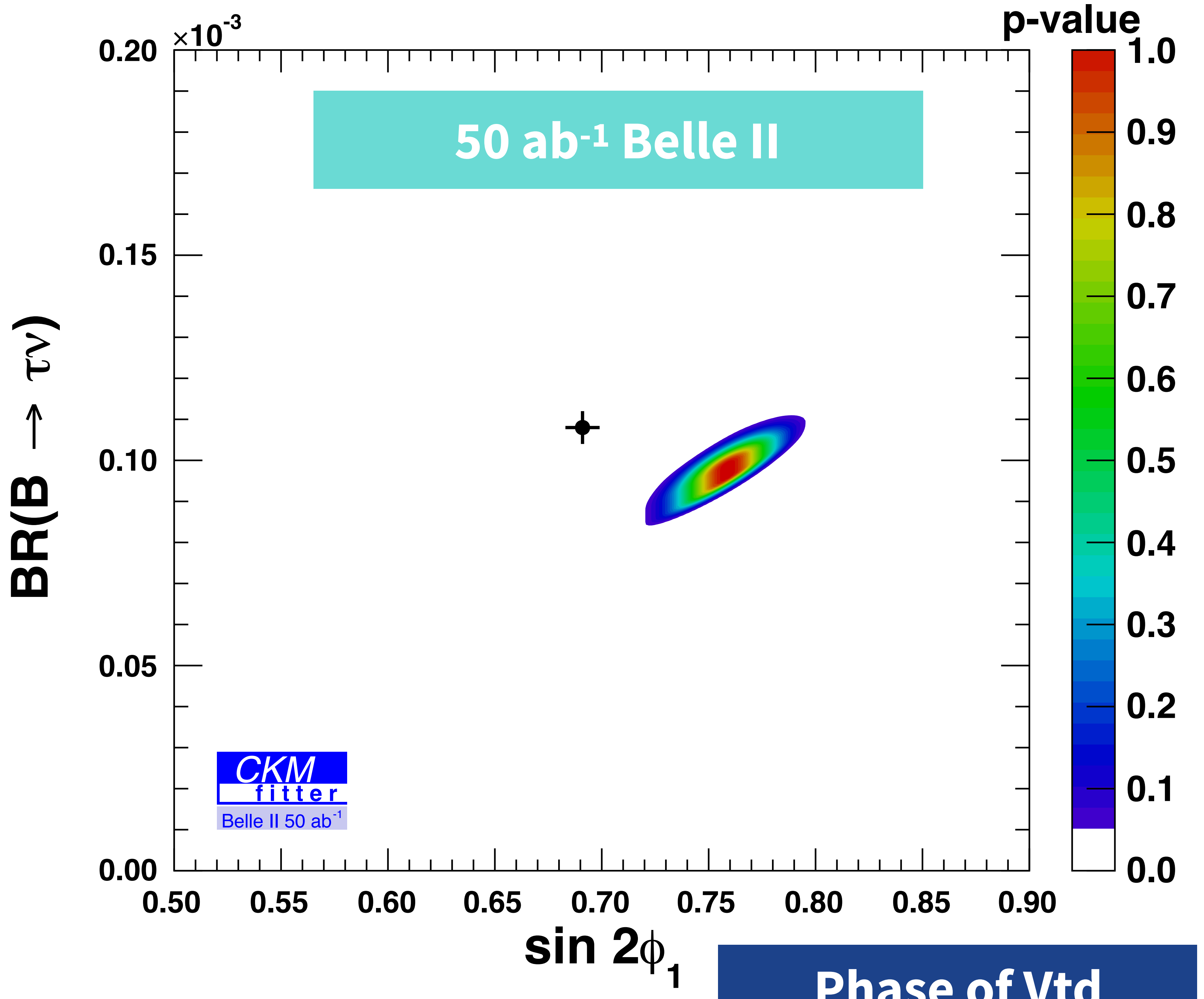


E. Kou, PU et al. arXiv: 1808.10567

L [ab^{-1}]		σ $|V_{ub}|$ [%]
50	B→ π l ν	1.2
	B→ τ ν	1.5 - 2
	B→ μ ν	5

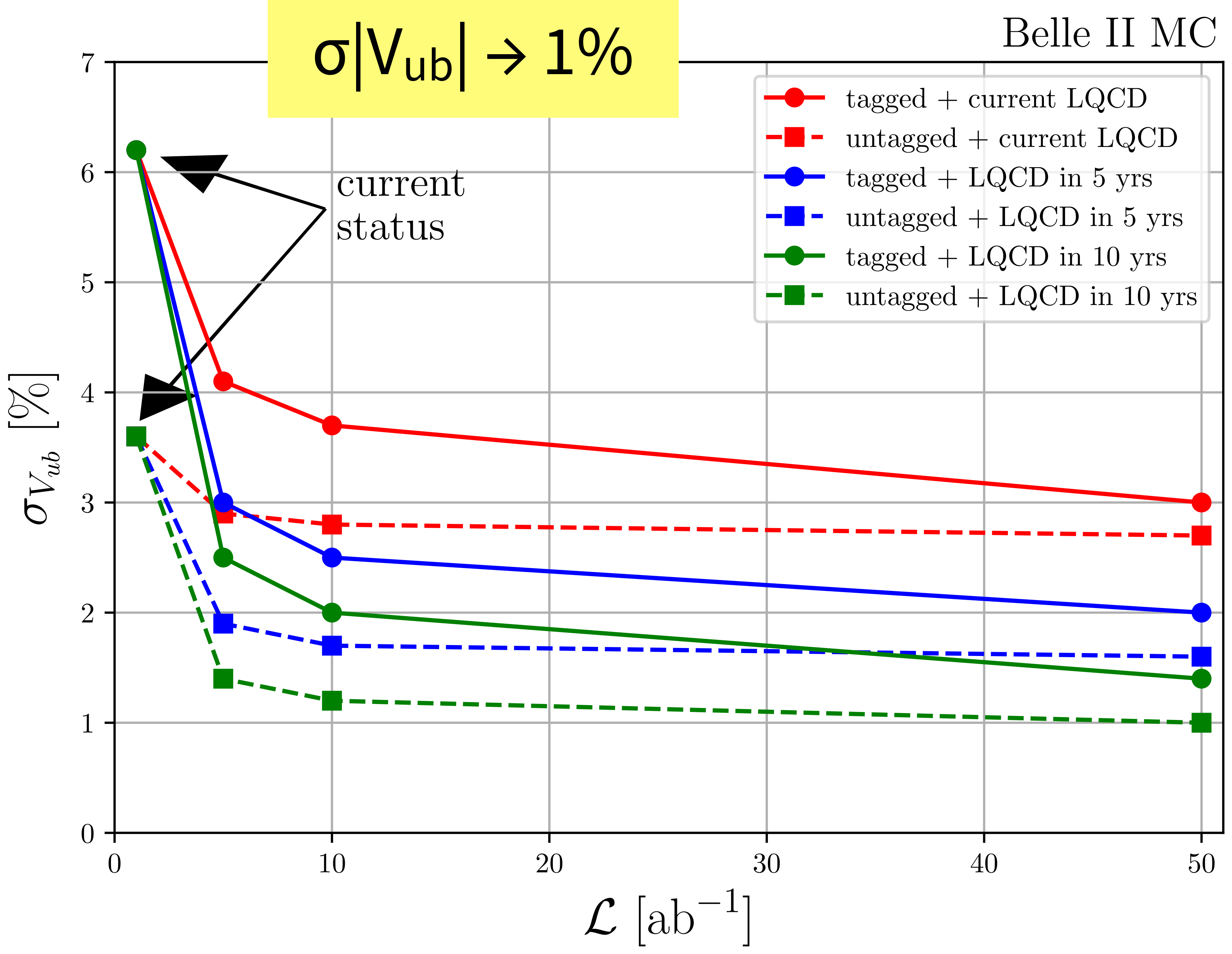


Belle arXiv: 1712.04123
B(B→ μ ν)=(6.5±2.2±1.6)10^{-7}



Phase of Vtd

σ$|V_{ub}|$ → 1%



B → D* τ⁻ ν Measurements

- Belle: Semileptonic tag, 772M B anti-B pairs
  - B0 → D*⁻ τ+ ν : 231±23(stat) events
    B0 → D*⁻ l+ ν: 2800±57(stat.) events.
- R(D*) = 0.302±0.030±0.011

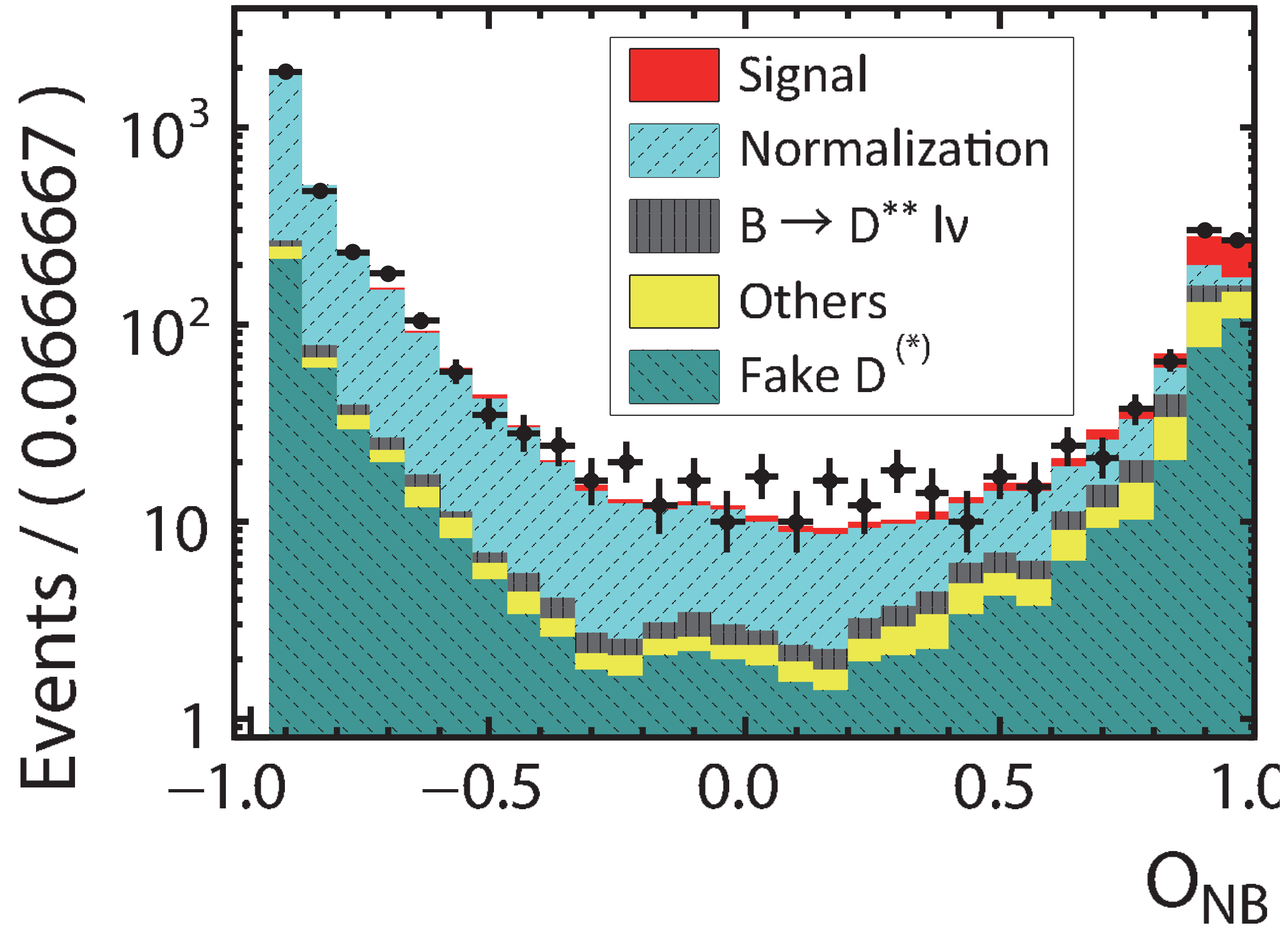
Belle PRD 94, 072007 (2016)

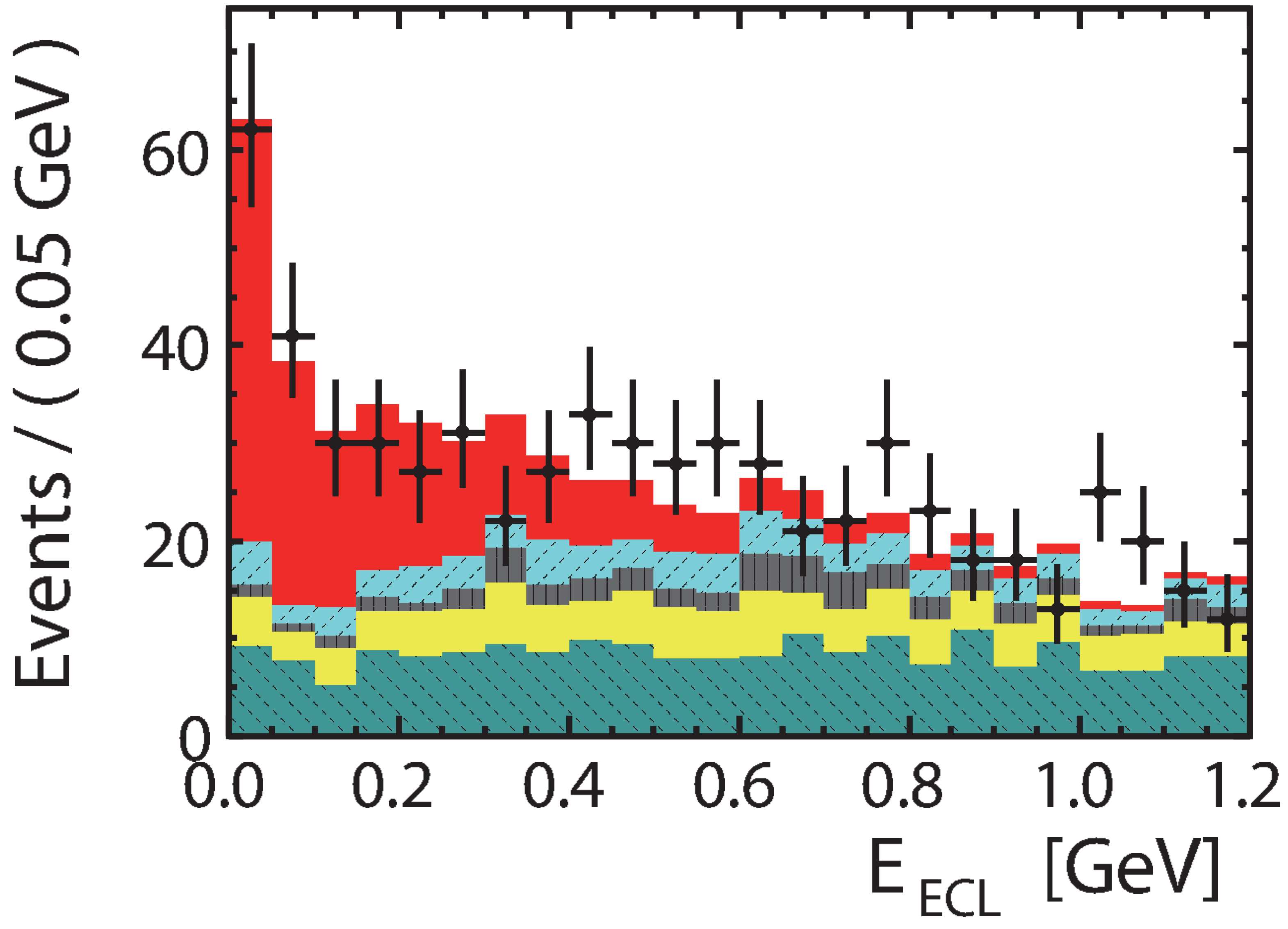
Belle PRL 118, 211801 (2017)
Belle arXiv:1709.00129

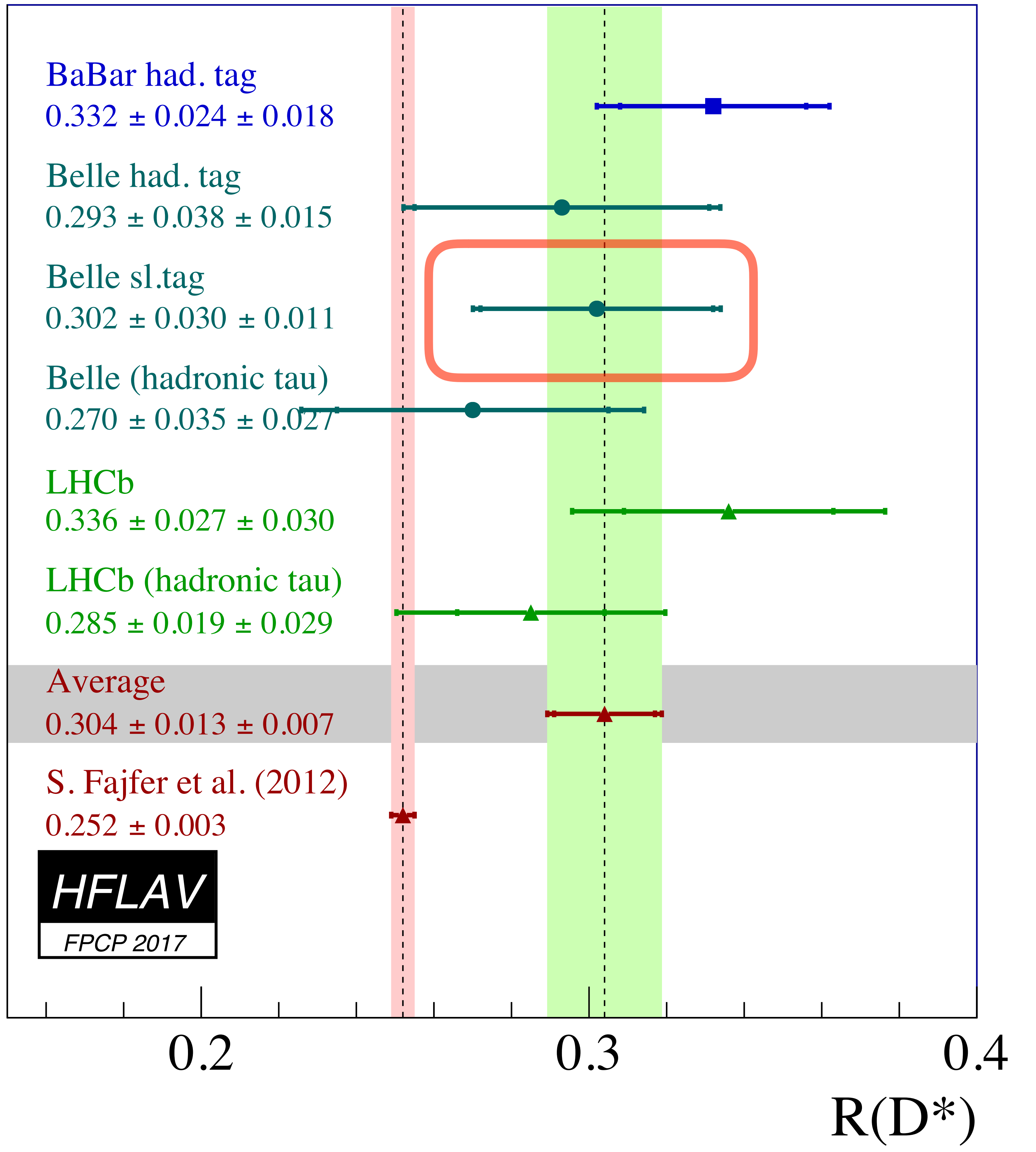
LHCb arXiv:1711.02505

LHCb arXiv:1711.05623

$\cos\theta^{sig}_{B-D^*l}$
M^2_{miss}
Total energy of $B_{tag} + B_{sig}$



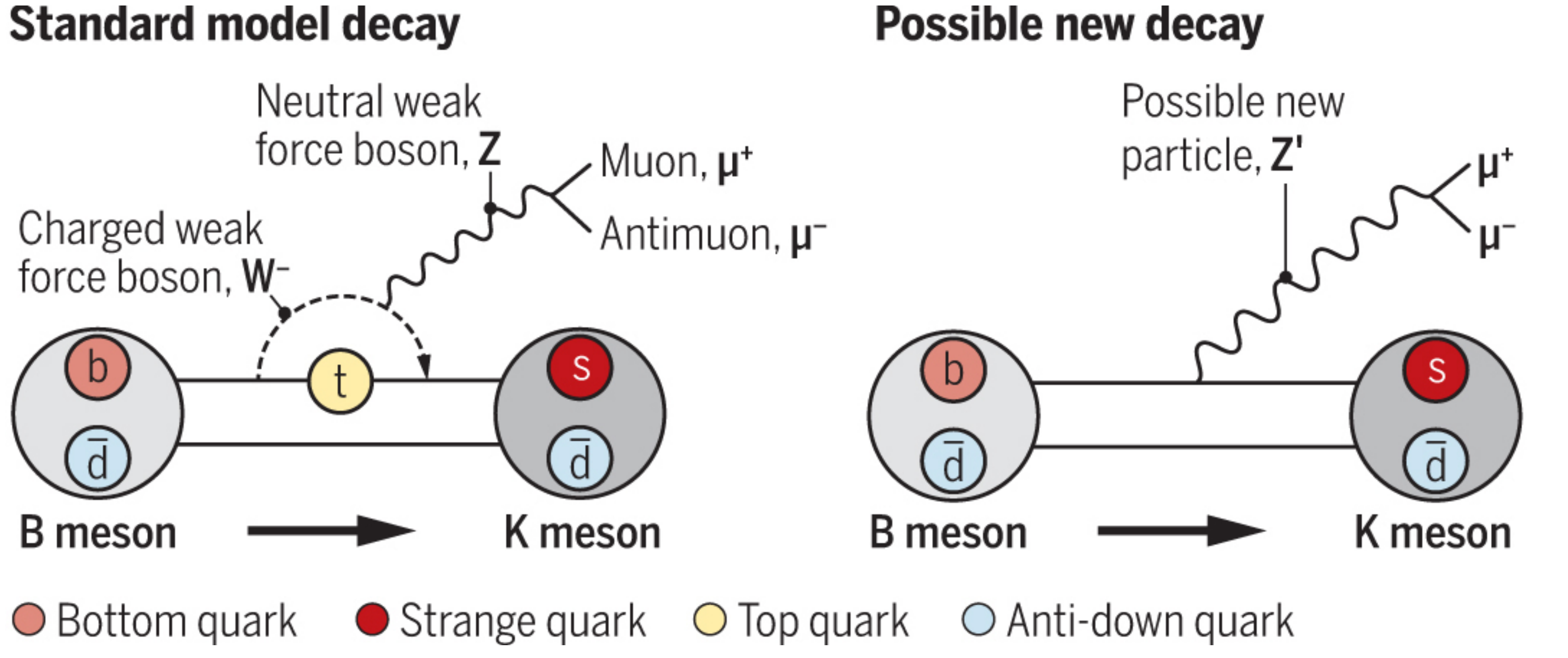


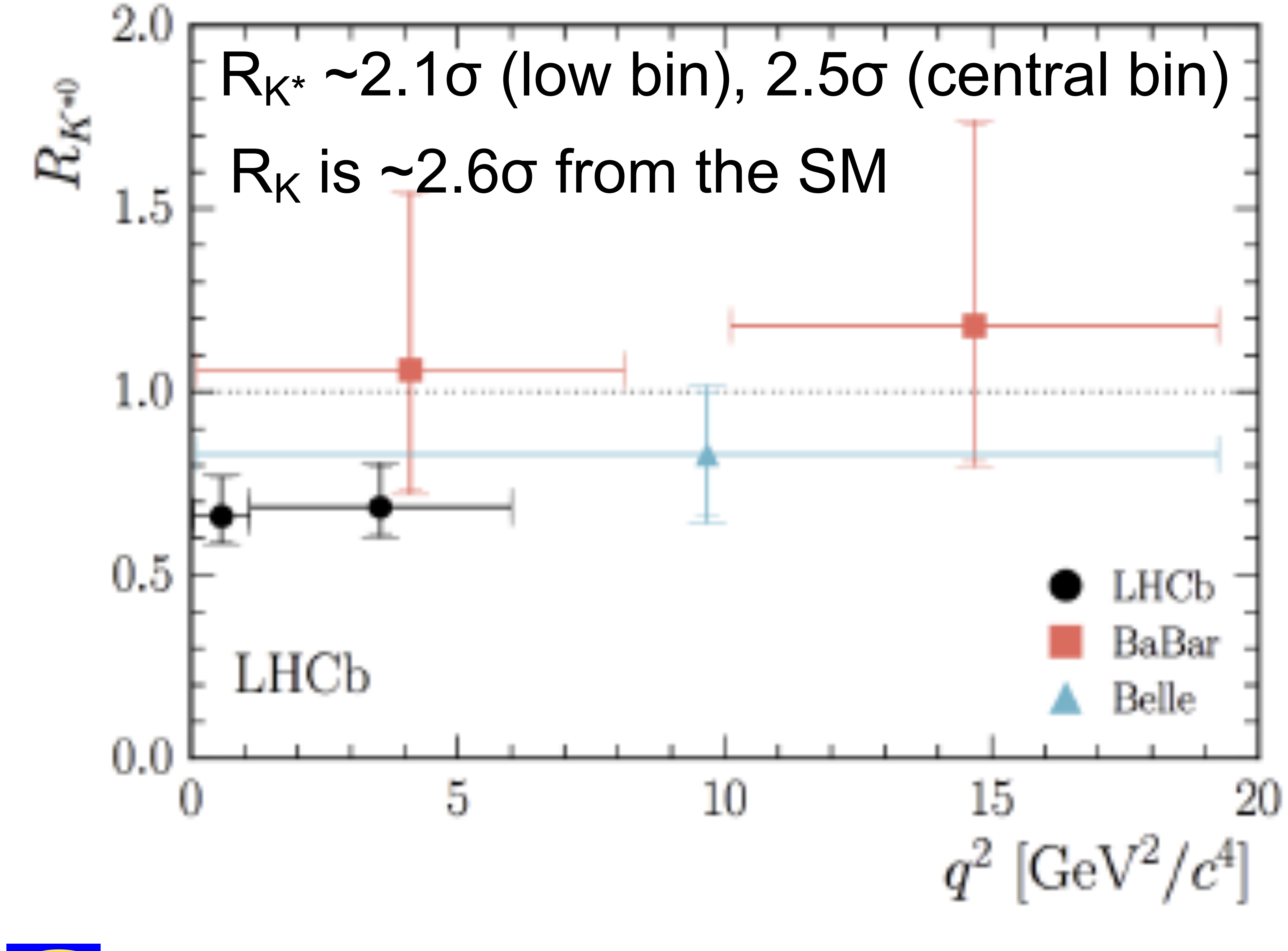


The RACE for R(K*) NP discovery

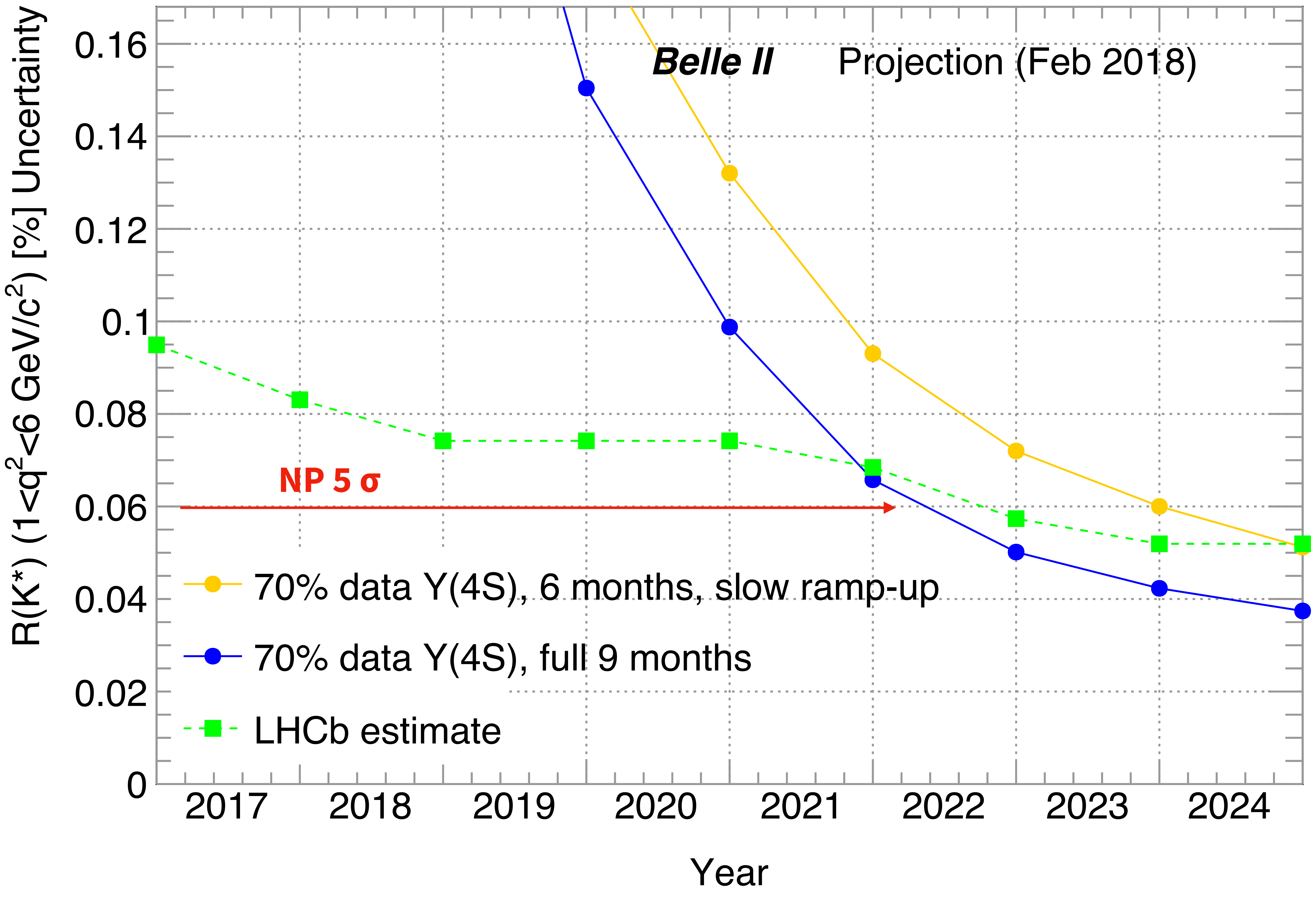
Belle PRL. 118 (2017) no.11, 111801
E. Kou, PU et al. arXiv: 1808.10567

$$R_{K^{(*)}}(q^2) = \frac{BF(B \to K^{(*)}\mu^+\mu^-)}{BF(B \to K^{(*)}e^+e^-)}$$

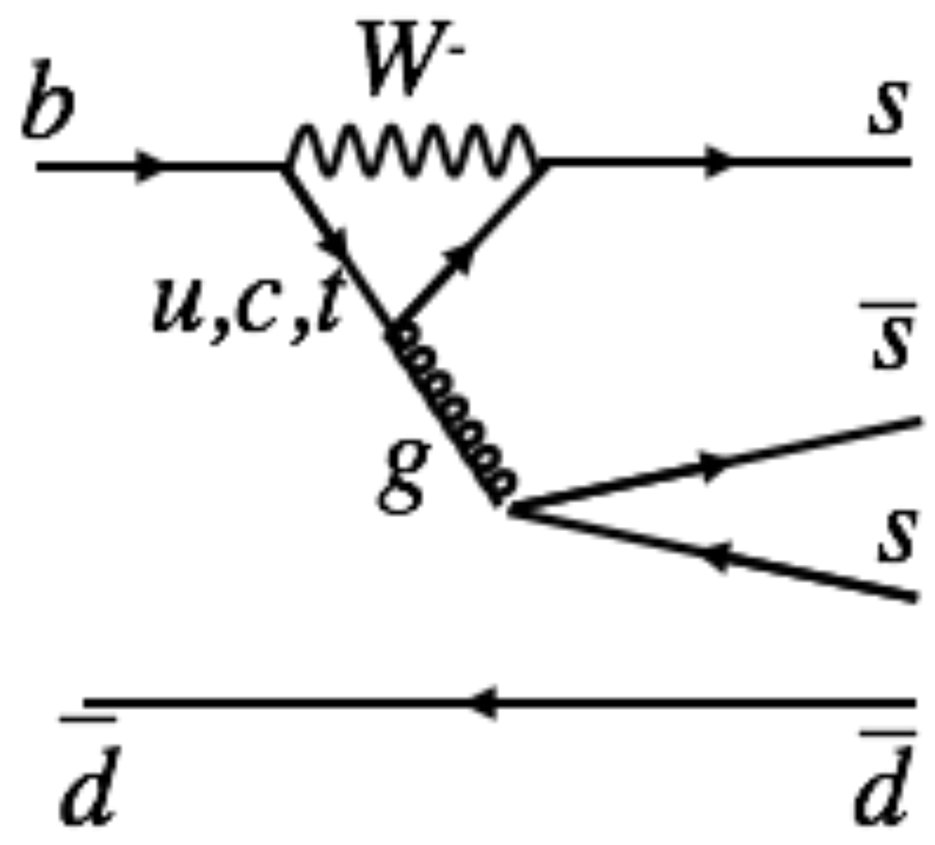




Belle II can do both inclusive and exclusive.
Equally strong capabilities for electrons and muons
(LHCb not as good for e)

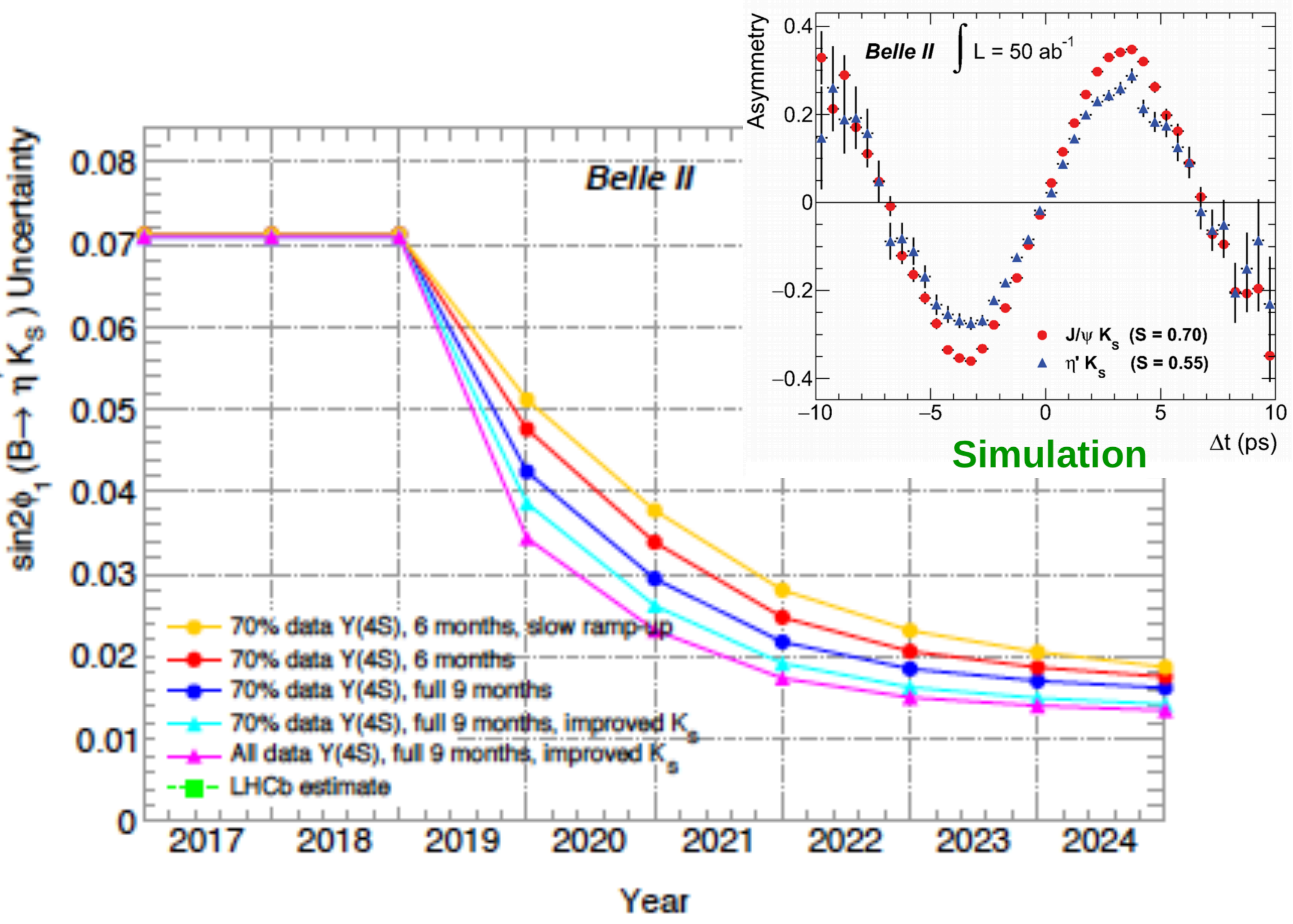


New sources of CP Violation & Rare decays

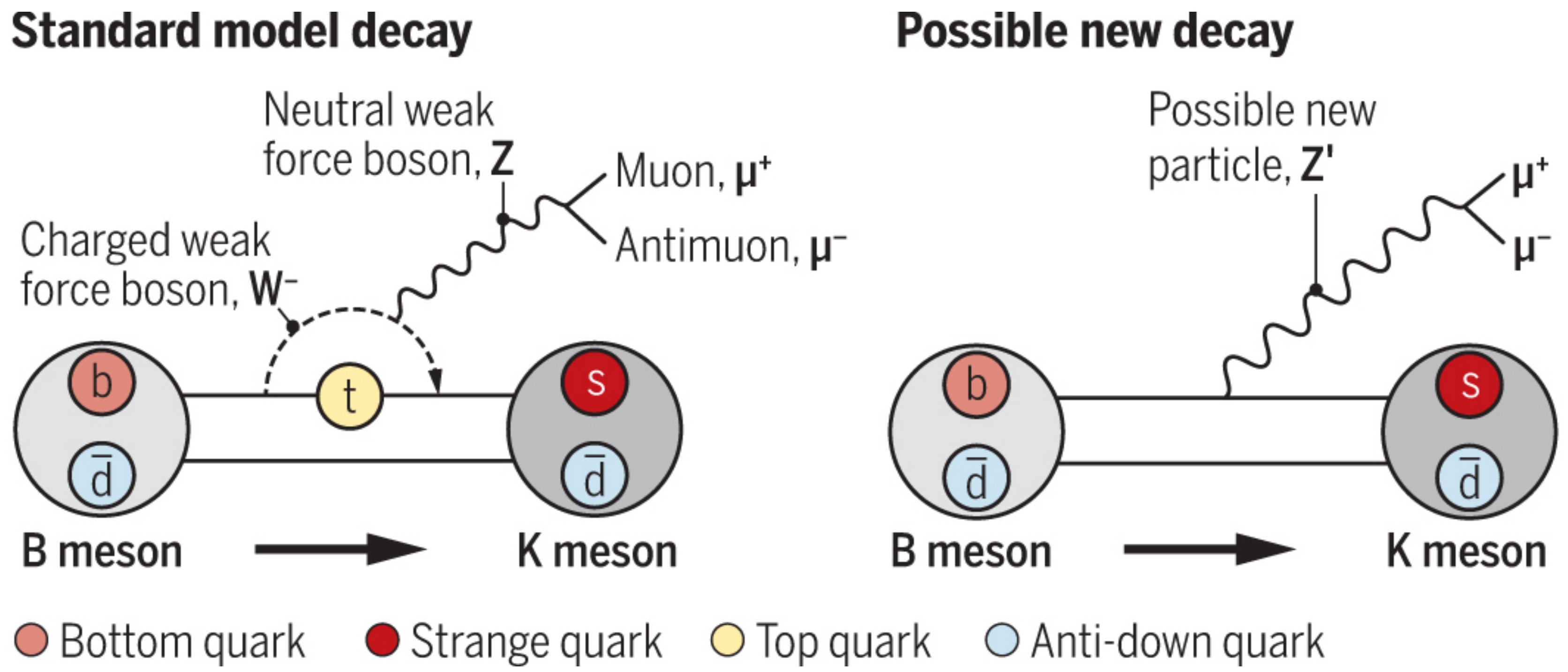


- *Gluonic Penguin (NP sensitive)*

Belle II has unique sensitivity to Time dependent CPV in B_d



$$R_{K^{(*)}}(q^2) = \frac{BF(B \to K^{(*)}\mu^+\mu^-)}{BF(B \to K^{(*)}e^+e^-)}$$



Belle II can do both inclusive and exclusive. Equally strong capabilities for electrons and muons (LHCb not as good for e)