Belle II Status and Prospects

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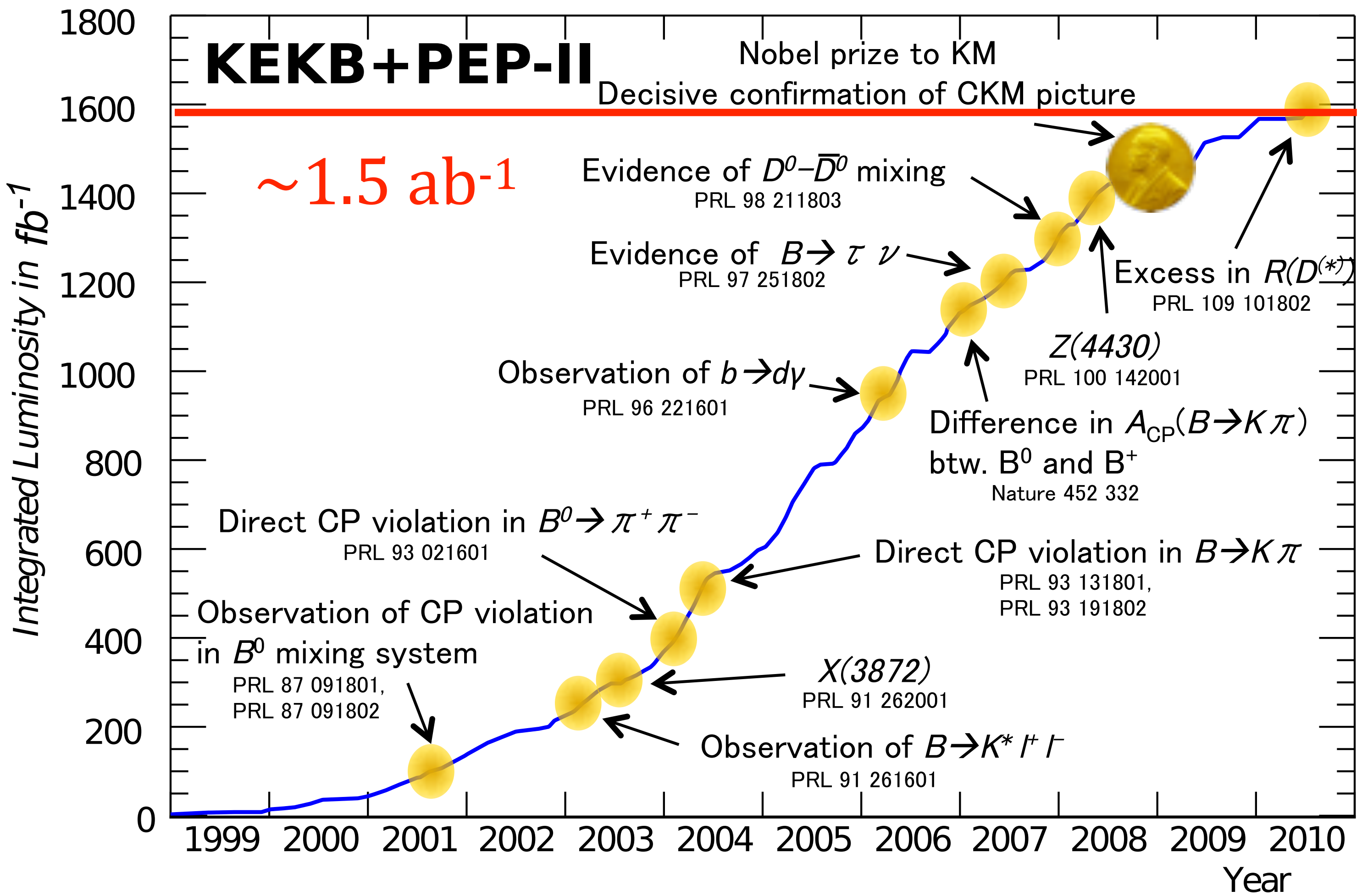
56th International Winter Meeting on Nuclear Physics
Bormio, 22-26 January 2018

Belle II

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

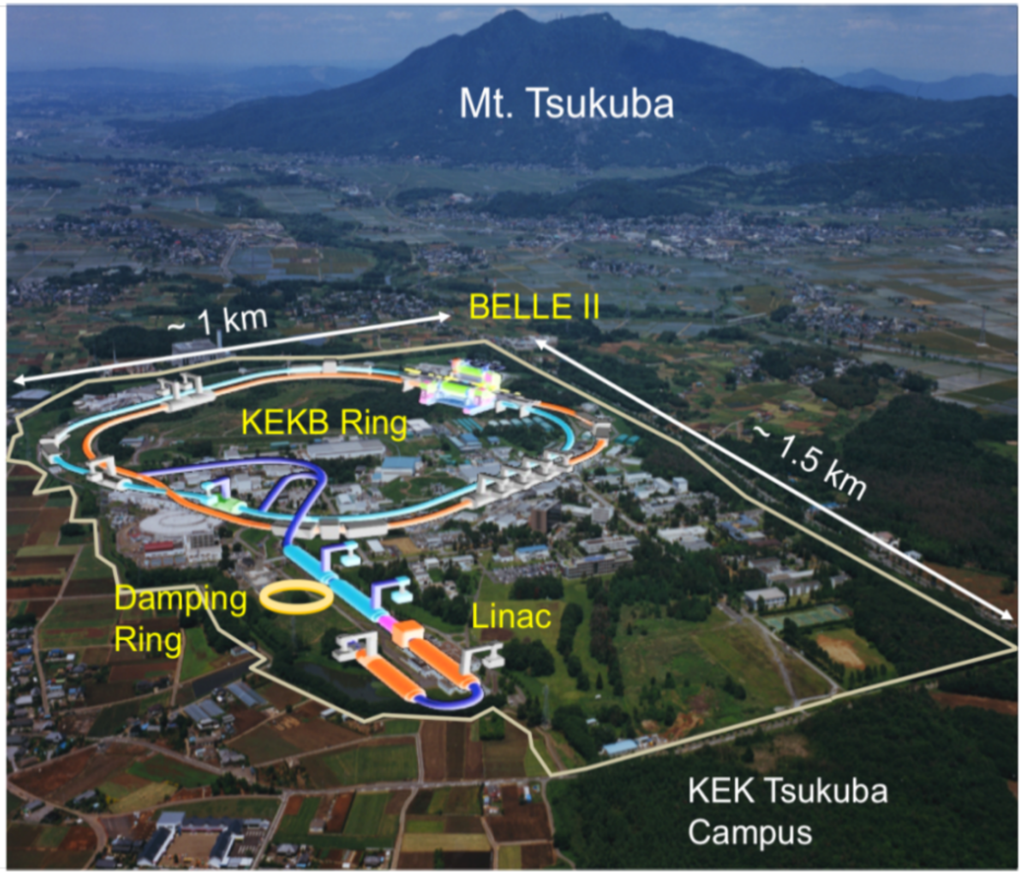
The B Factory Legacy

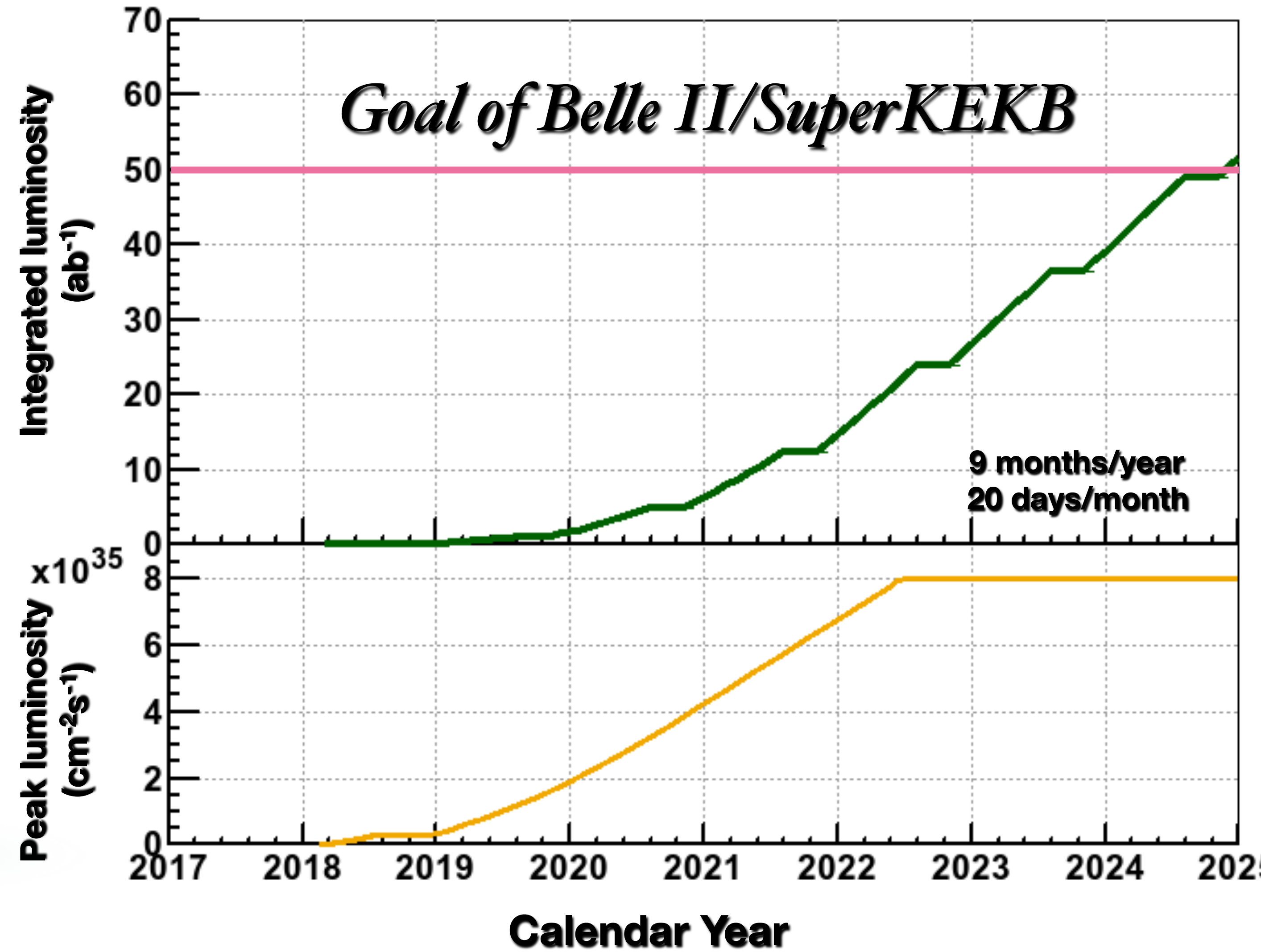
Eur. Phys. J. C (2014) 74:3026



- SM and CKM mechanism confirmed by precision measurements at B-factories
  - However, several few sigma discrepancies emerged in more than one experiment. Could these "flavour anomalies" be a manifestation of new physics?
- We know that the SM not sufficient to explain several open questions
  - universe's baryon asymmetry, fermion mass hierarchy, neutrino masses, nature of dark energy and dark matter…

Luminosity profile of the next generation B factory @ KEK

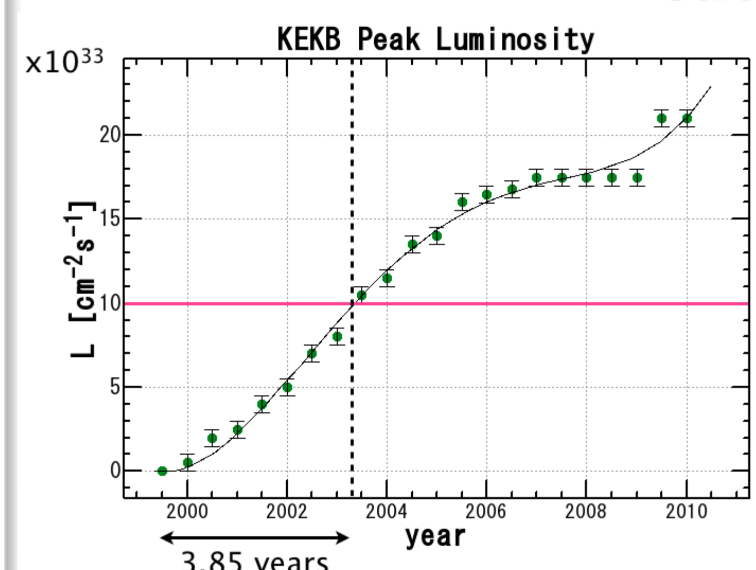




Expected data sample @ full luminosity

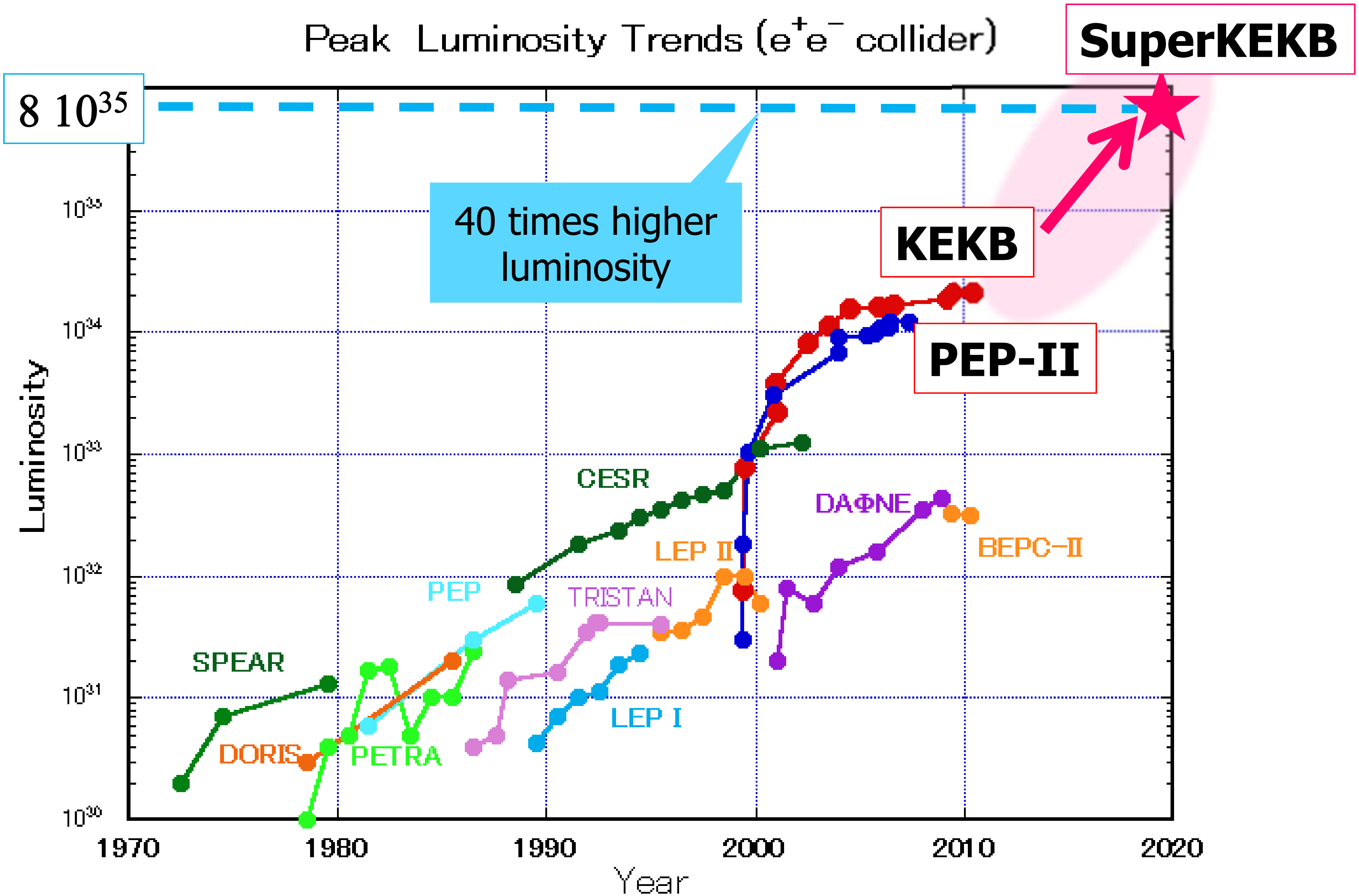
Channel	Belle	BaBar	Belle II (per year)*
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

* assuming 100% running at each energy



- Assumptions:
  - same commissioning time to reach nominal luminosity as in KEKB
  - 9 months/year running
  - 20 days/month

$2 \cdot 10^{34} \rightarrow 8 \cdot 10^{35}$



KEK & SuperKEKB parameters

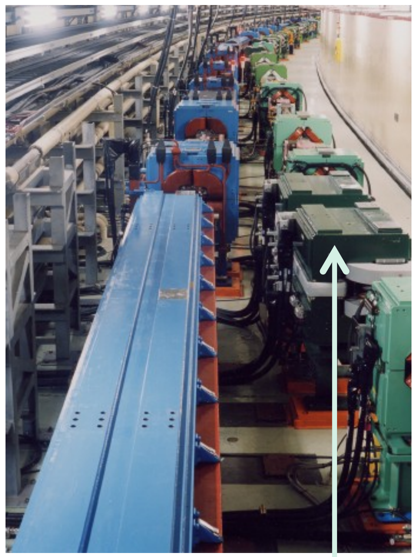
Parameter	KEKB Design	KEKB Achieved	SuperKEKB Design
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\frac{\varepsilon_y}{\varepsilon_x}$ (%)	1	0.85/0.64	0.27/0.24
σ_y (μm)	1.9	0.94 → 1/20 →	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6/7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19 → x2 →	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity ($10^{34}cm^{-2}s^{-1}$)	1.0	2.11 → x40 →	80

- Lower E_{HER} (RF power)
- Higher E_{LER} (Touschek lifetime)

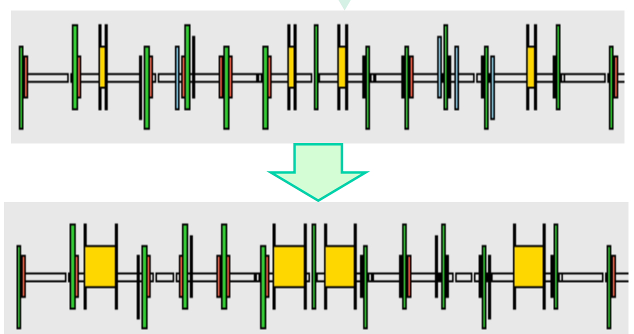
→ **Boost 0.42 → 0.28**

From KEKB to SuperKEKB

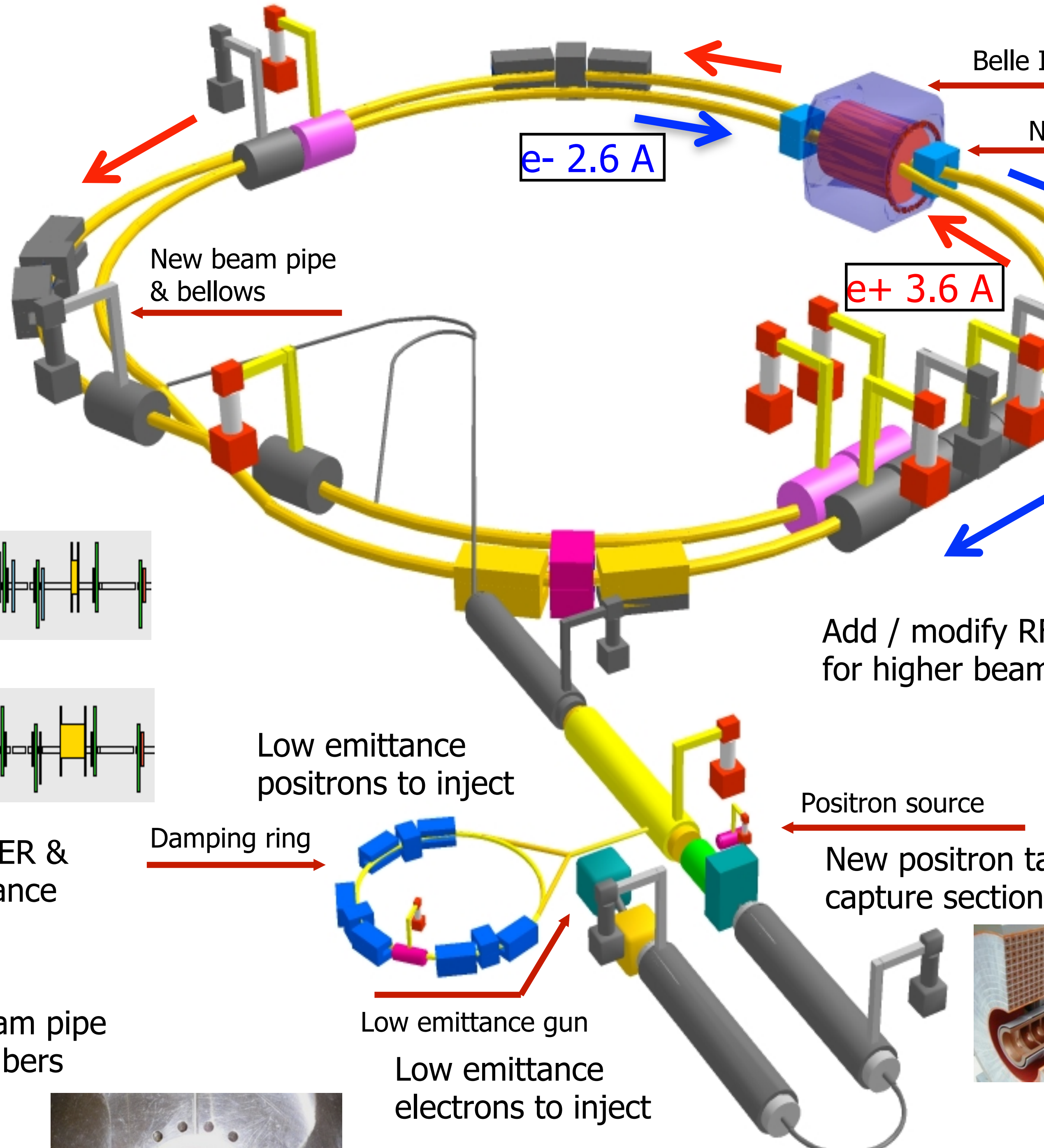
Grey is recycled, coloured is new



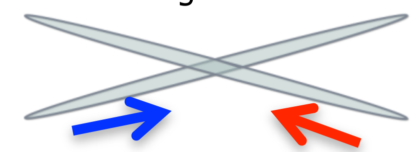
Replace short dipoles with longer ones (LER)



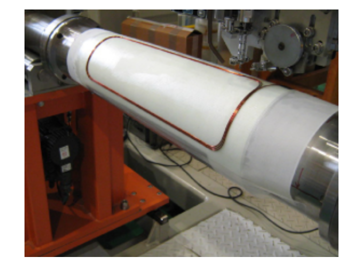
Redesign the lattices of HER & LER to squeeze the emittance



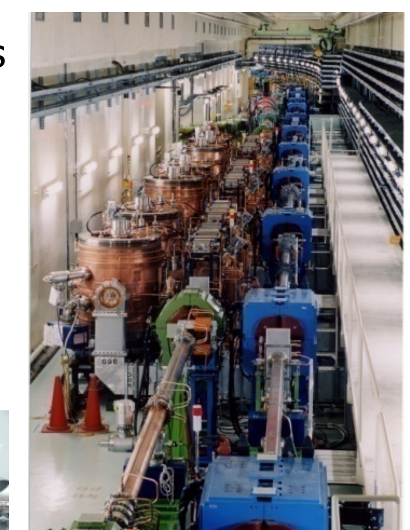
Colliding bunches



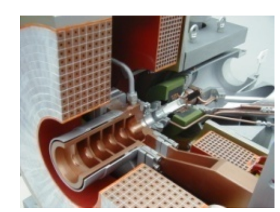
New superconducting / permanent final focusing quads near the IP



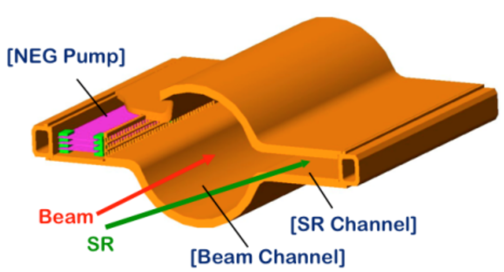
Add / modify RF systems for higher beam current

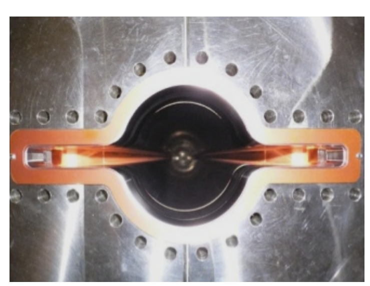


New positron target / capture section



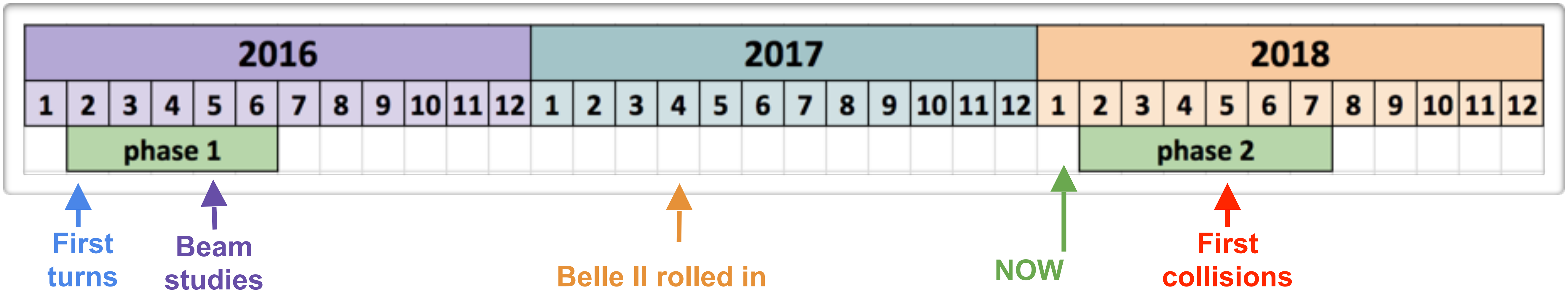
TiN-coated beam pipe with antechambers





Almost entirely new machine!

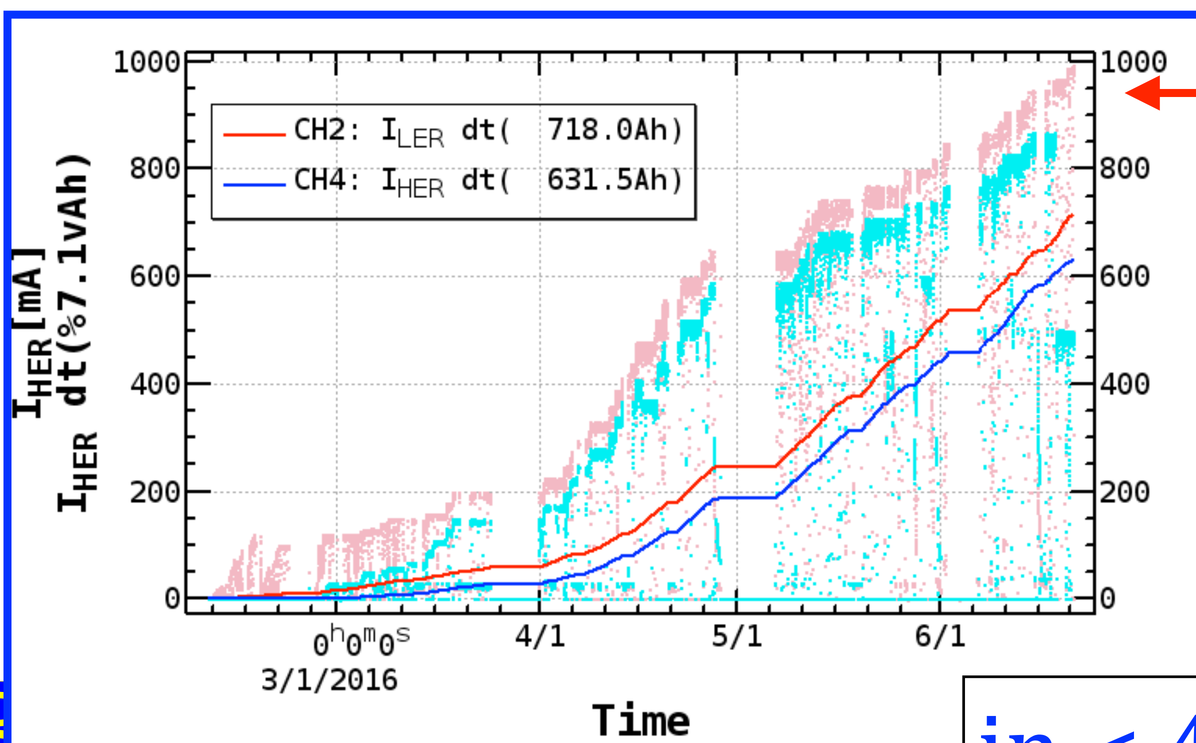
SuperKEKB Commissioning



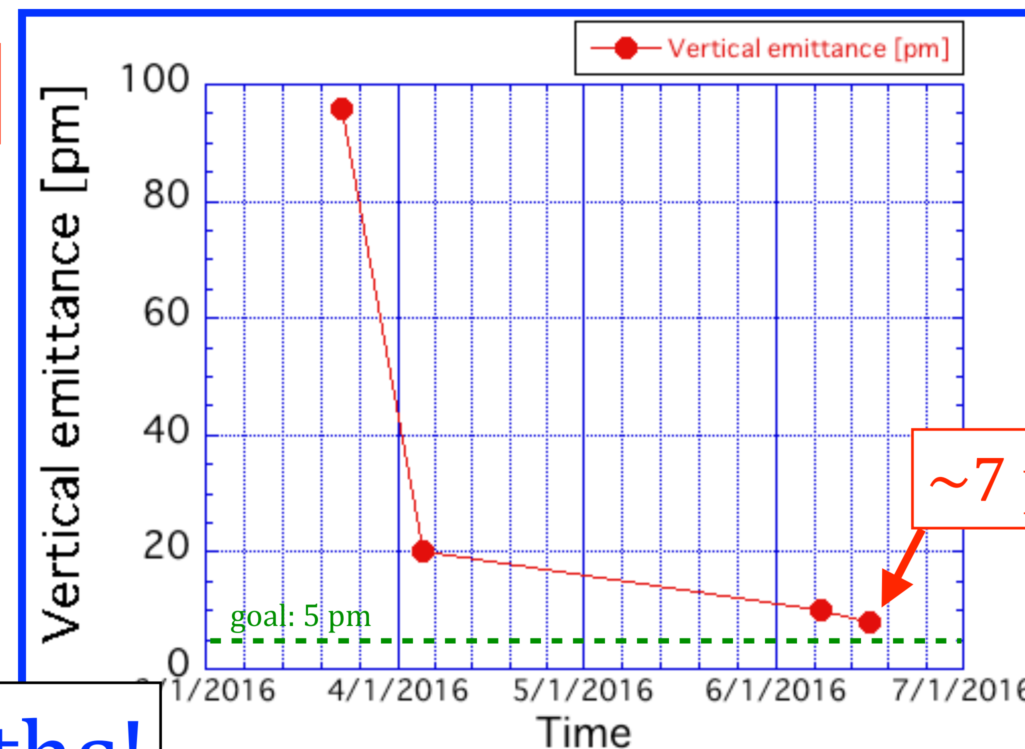
Phase I (2016): NO Belle II, circulate both beams, NO collisions

Phase II (2018): Belle II, NO vertex detector, first collisions

Very successful phase 1 run



1 Amp



~7 pm

in < 4 months!

Belle II Detector

Factor x40 luminosity also brings in:

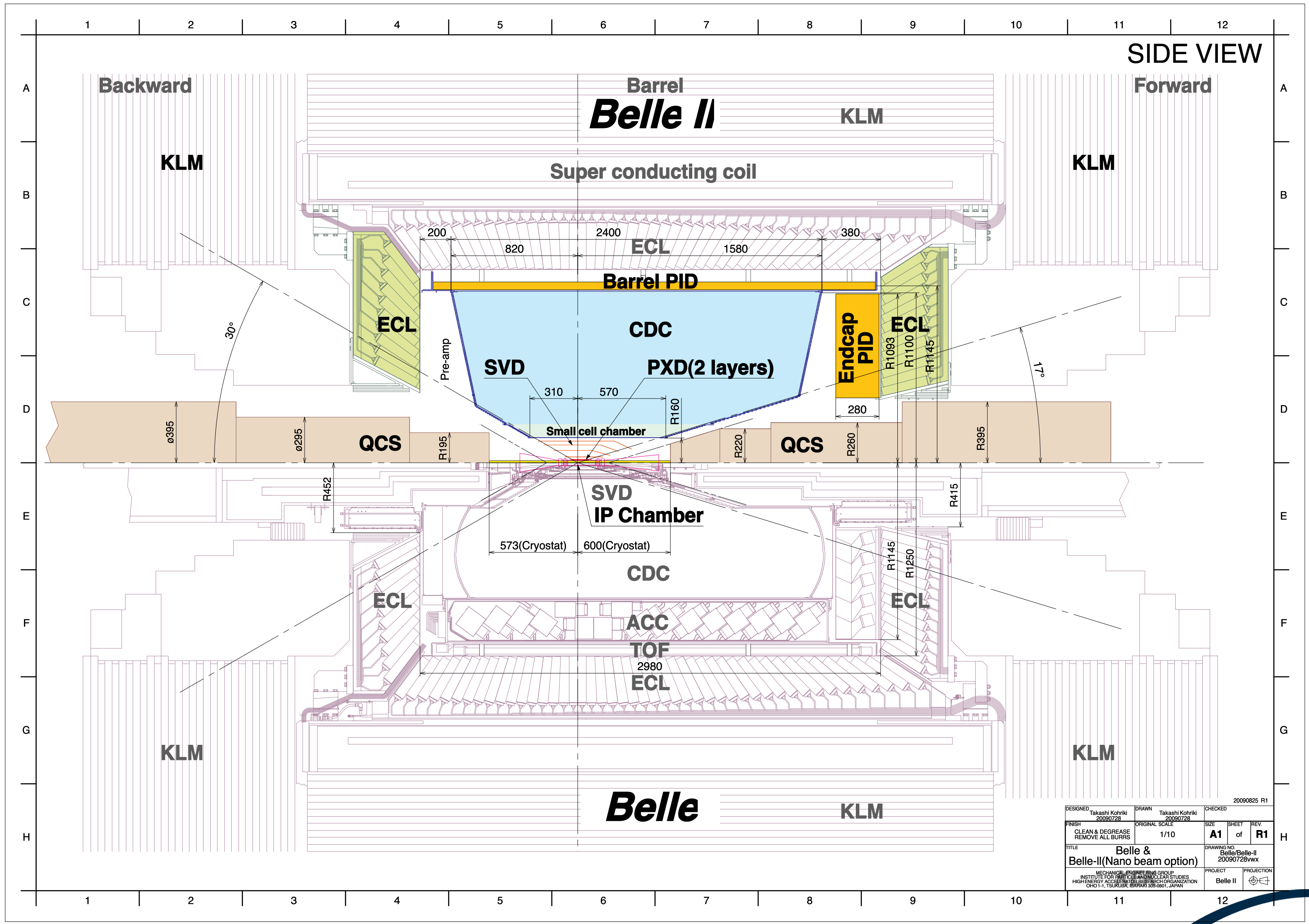
- Higher occupancy, pile-up, fake hits
- increased trigger and DAQ rates
- radiation damage

Upgrade the Belle detector

- starting point is the Belle detector
- in practice, reuse the crystal CsI(Tl) calorimeter, the solenoid, the KLM barrel detector

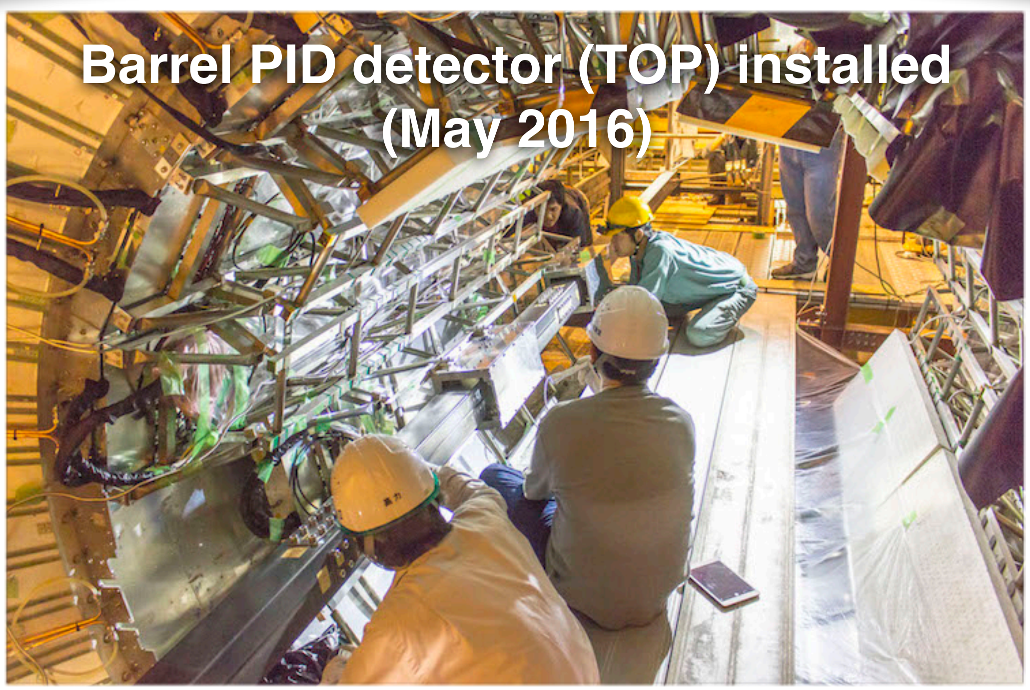
Improvements over Belle

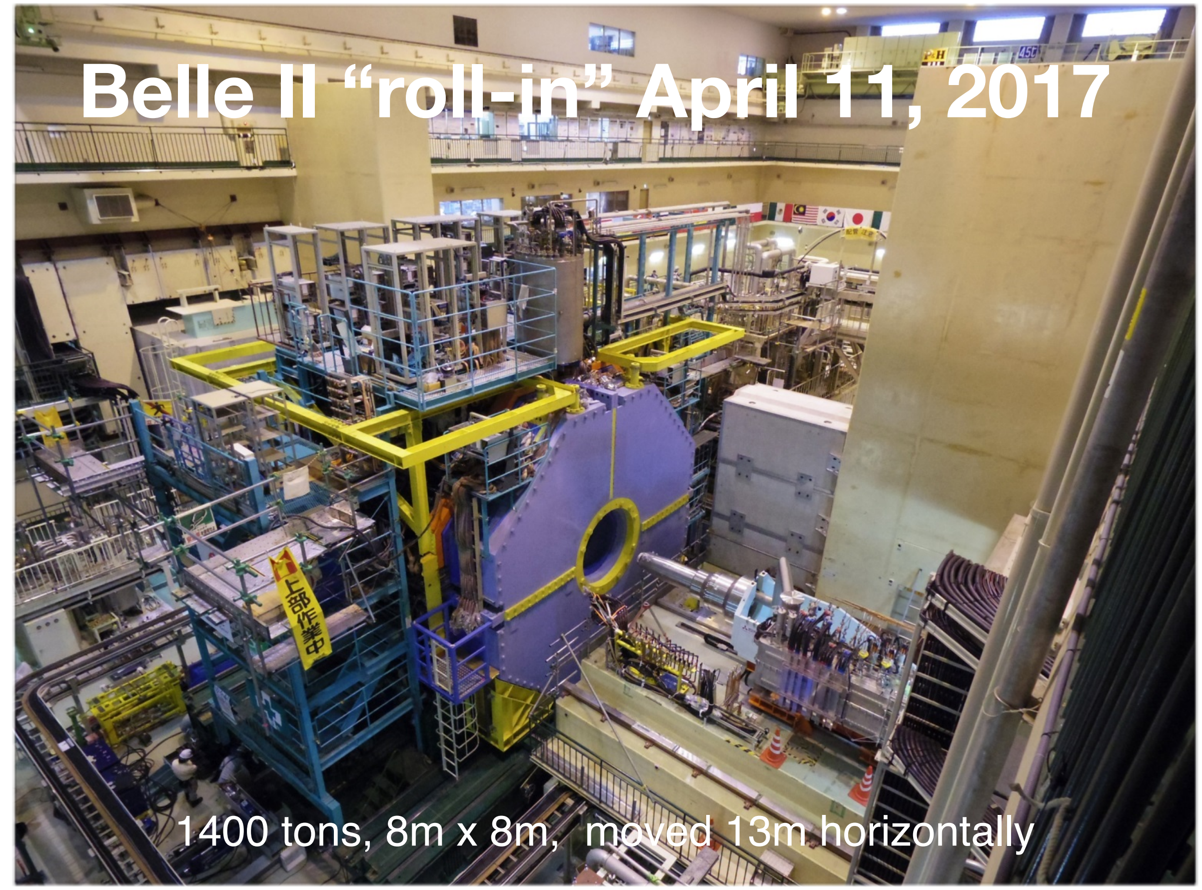
- Fast signal shaping and waveform fit of e.m. calorimeter signals to preserve excellent energy resolution in high-pileup environment
- Increase K_S efficiency (by ~30%)
- Improve IP and secondary vertex resolution (~factor 2)
- Better K/π separation (π fake rate decreases by ~2.5)
- Improve π^0 reconstruction



Belle II Detector Commissioning Progress

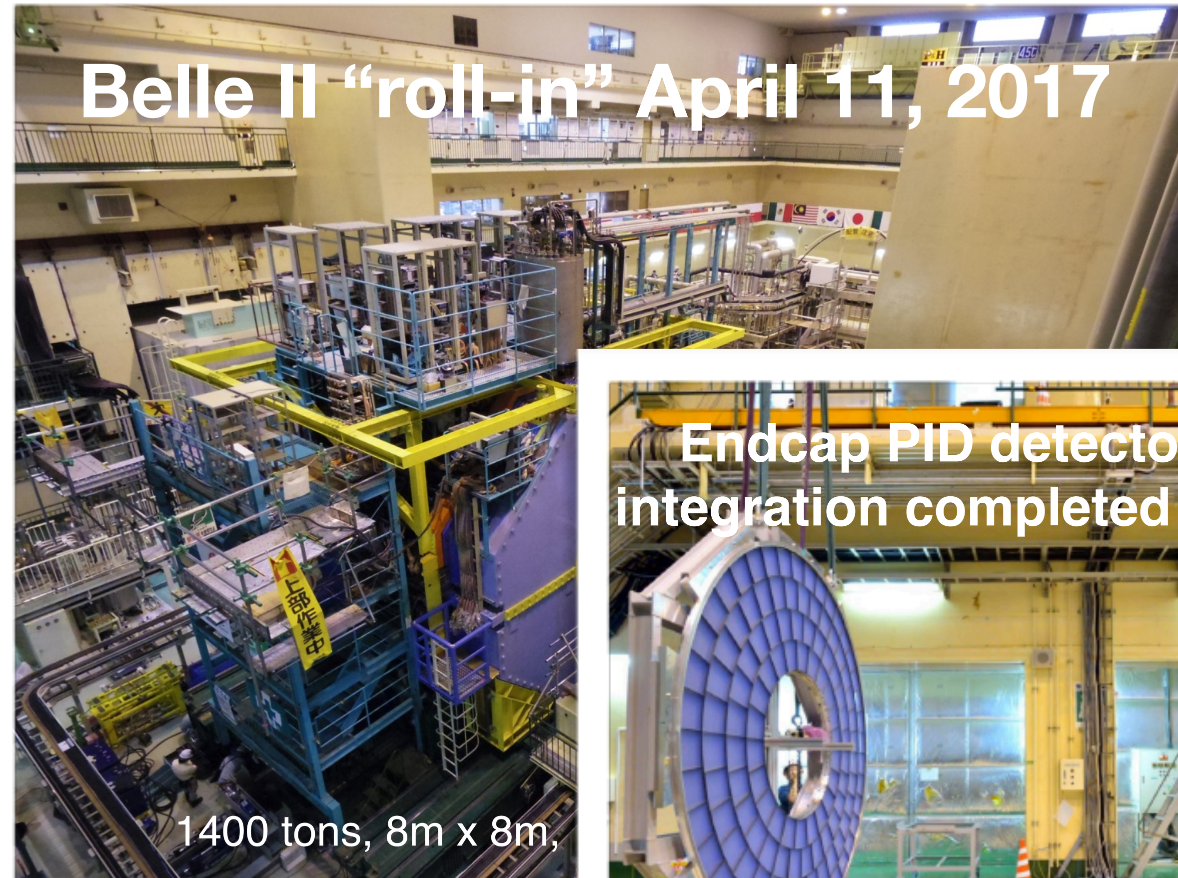

Central drift chamber (CDC) installed (October 2016)

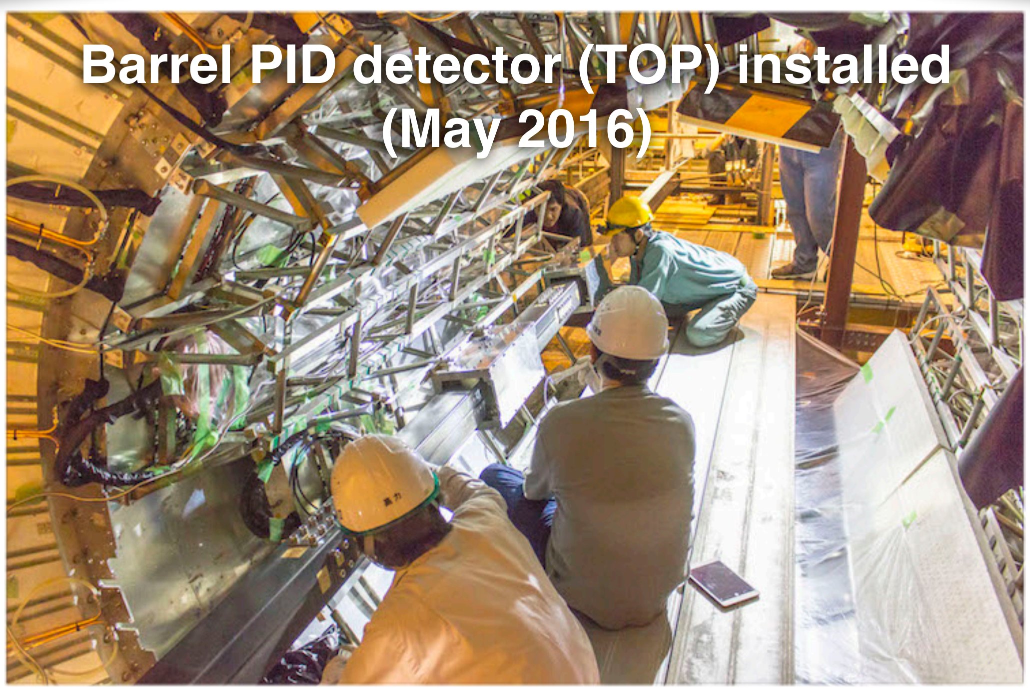

Barrel PID detector (TOP) installed (May 2016)


Belle II "roll-in" April 11, 2017

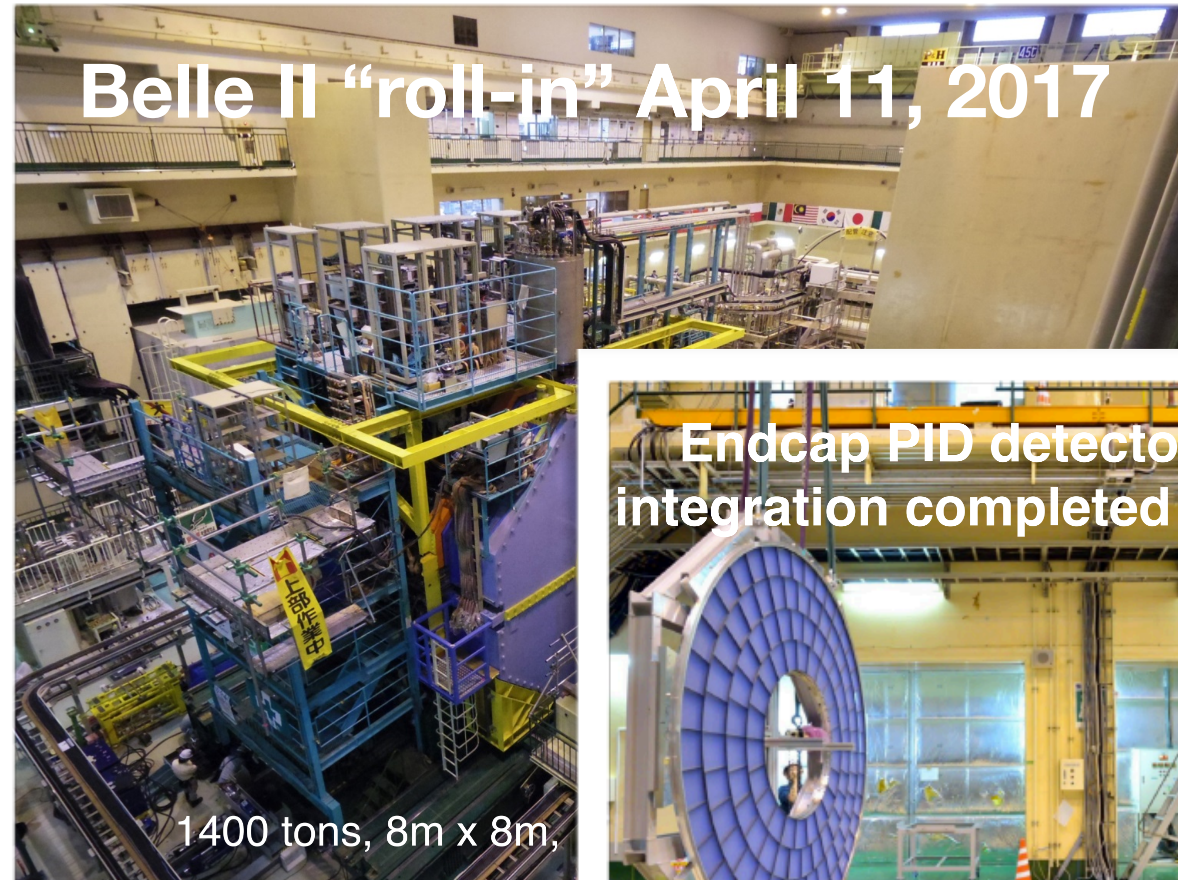
1400 tons, 8m x 8m, moved 13m horizontally

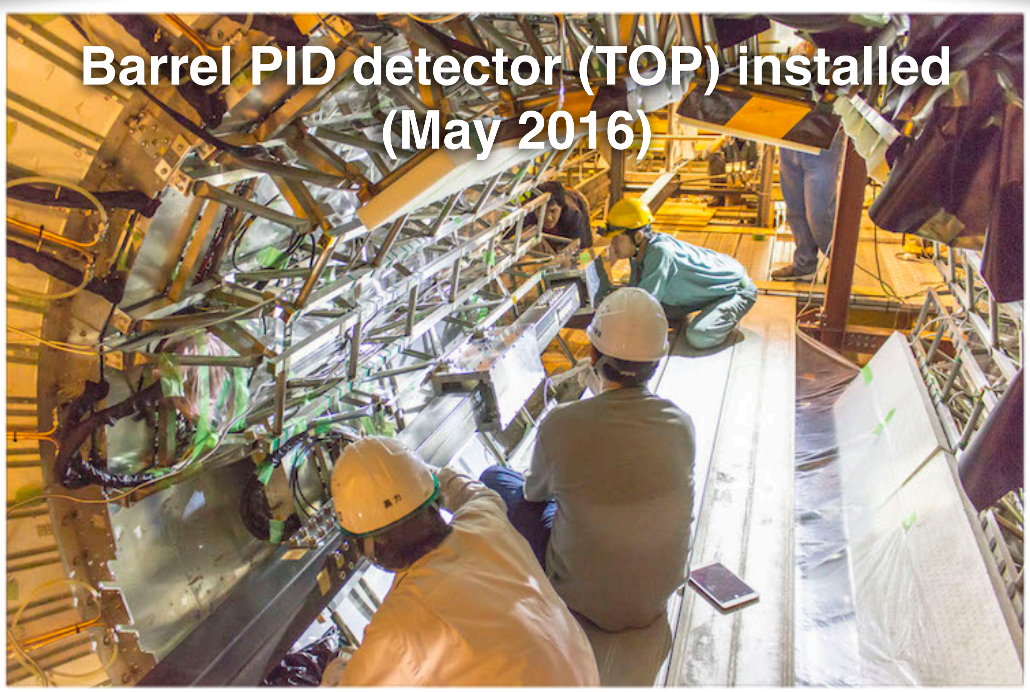
Belle II Detector Commissioning Progress

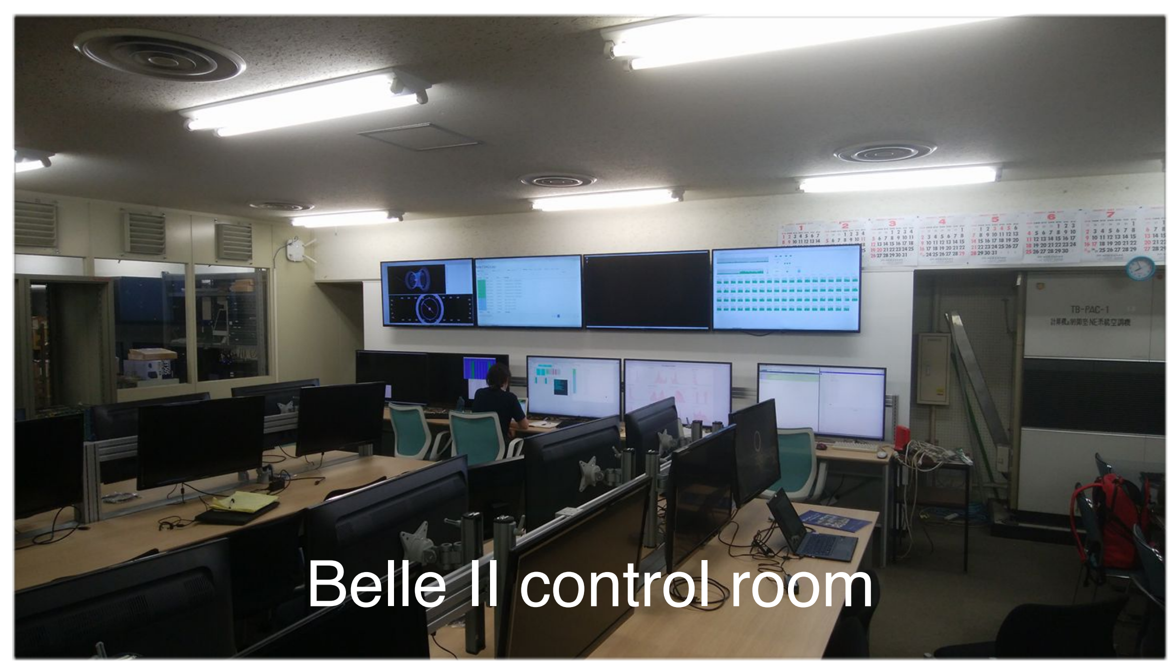




Belle II Detector Commissioning Progress







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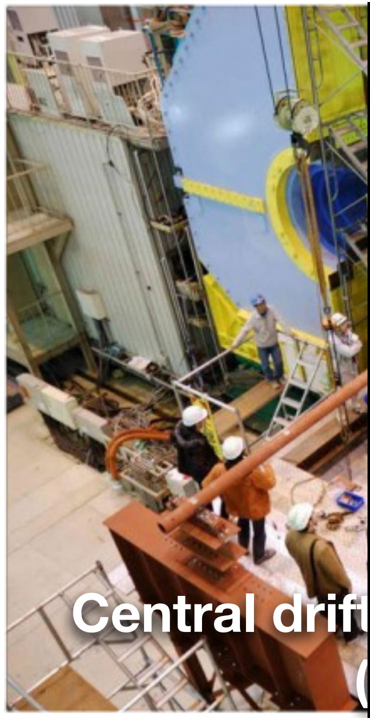
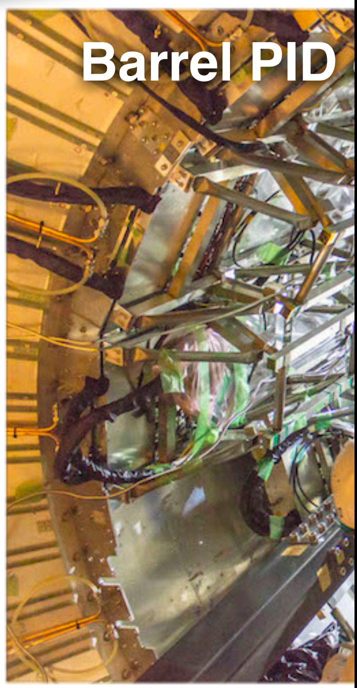
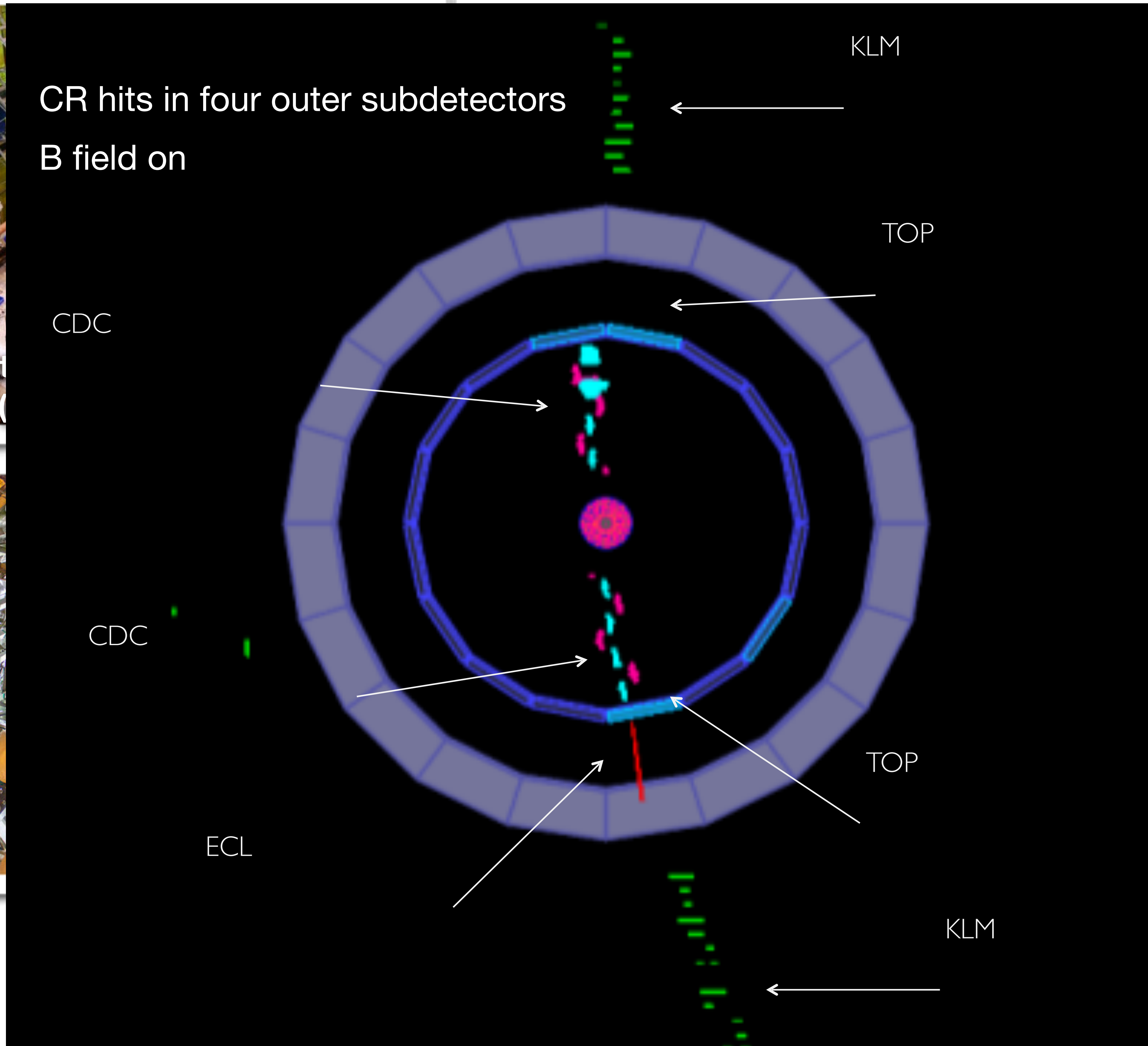
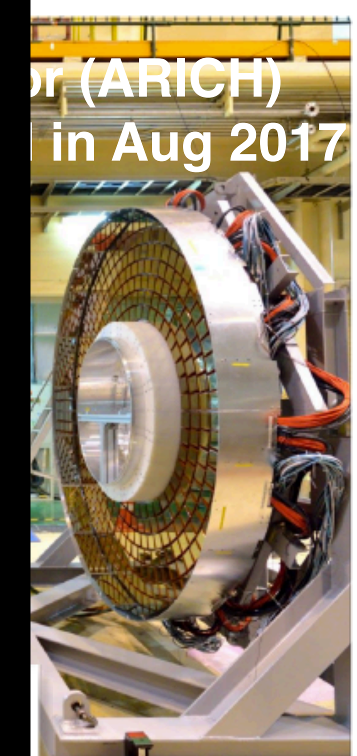








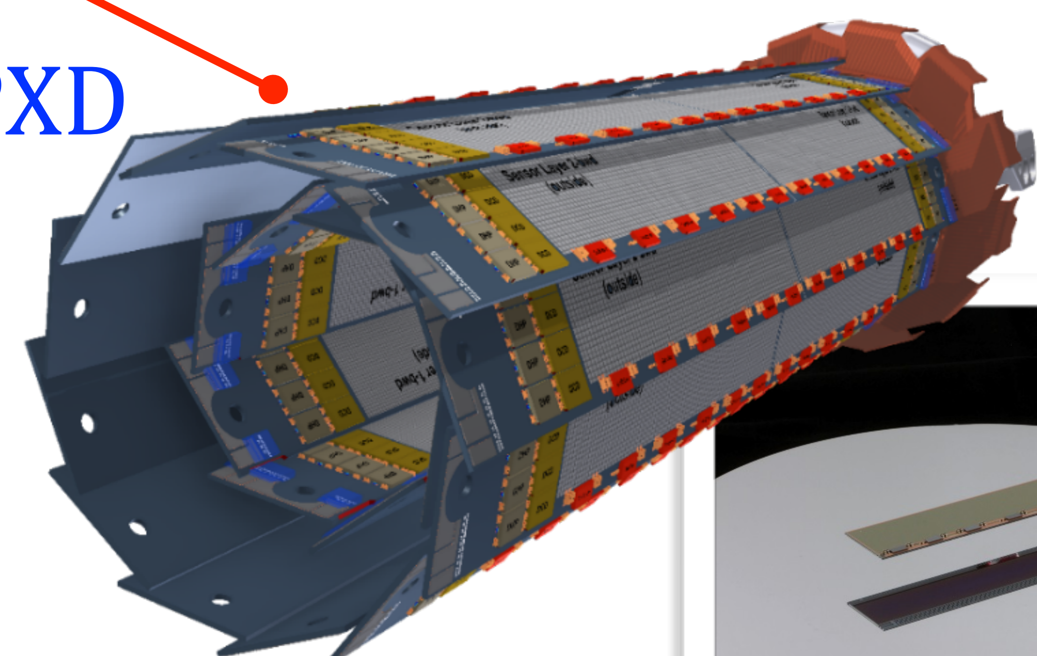
Vertex Detector

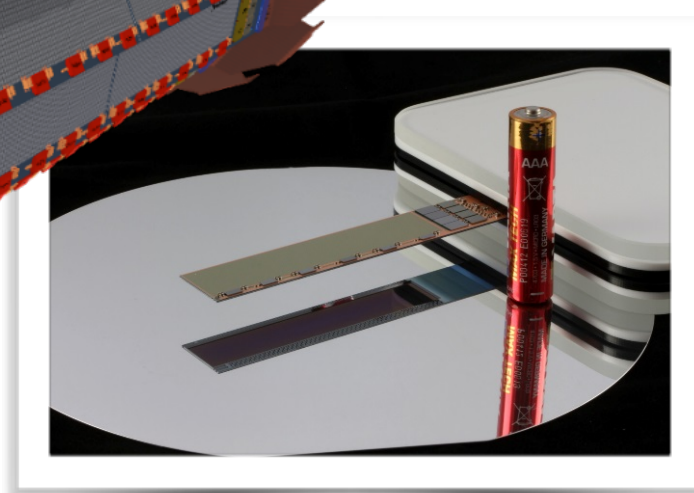
- Vertex detector (VXD)
  - Pixel Detector (PXD): 2 layers of DEPFET pixels
  - Silicon Vertex Detector (SVD): 4 layers of double-sided silicon detectors
- Larger outer SVD radius: significant improvement (x2) expected with respect to Belle in vertex resolution
- Installation: **summer 2018 ⇒ Phase 3**

$$\langle\beta\gamma\rangle^{\text{Belle II}} = 28/44\cdot\langle\beta\gamma\rangle^{\text{Belle}}$$

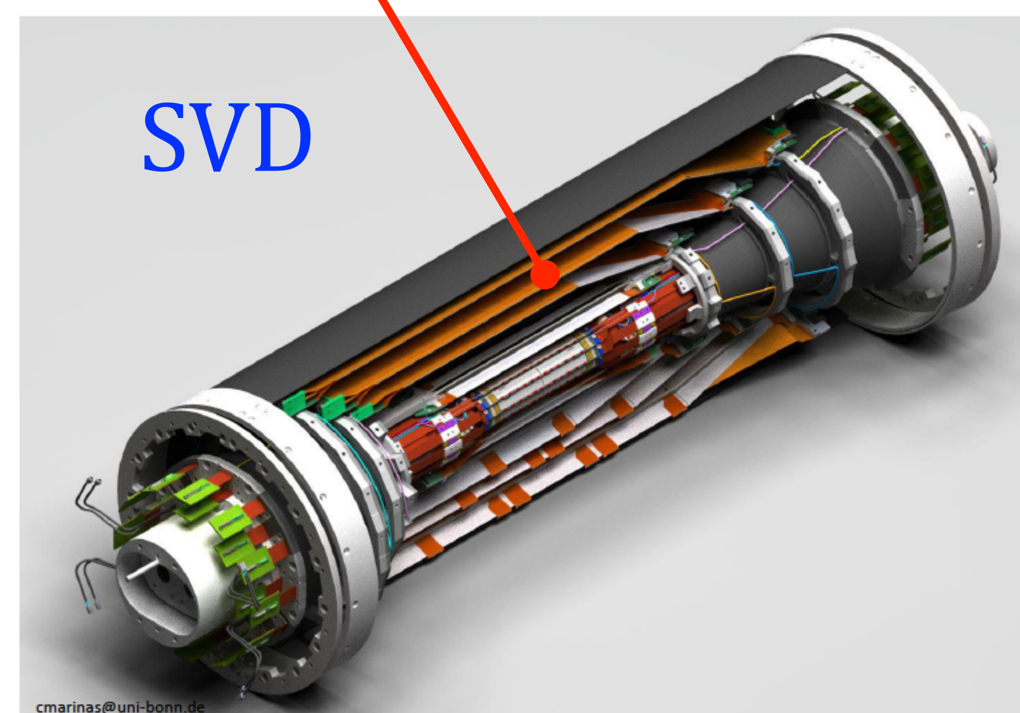
$$\sigma_{\Delta_t}^{\text{Belle II}} \sim \frac{3}{4}\sigma_{\Delta t}^{\text{Belle}}$$

PXD



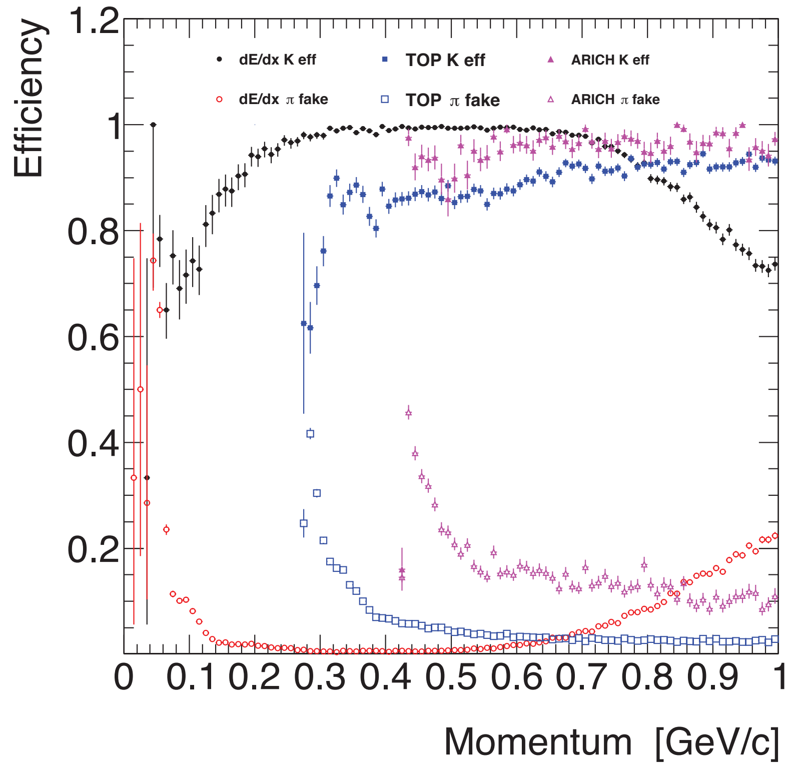


SVD



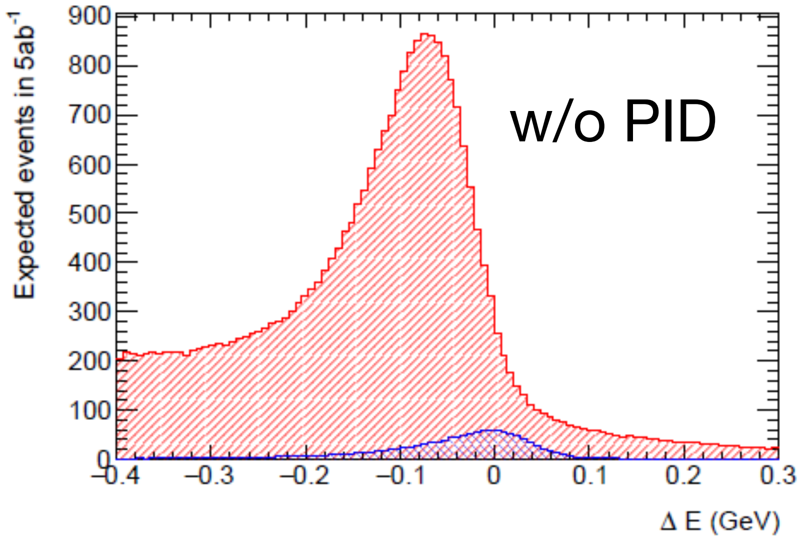
Reconstruction performance

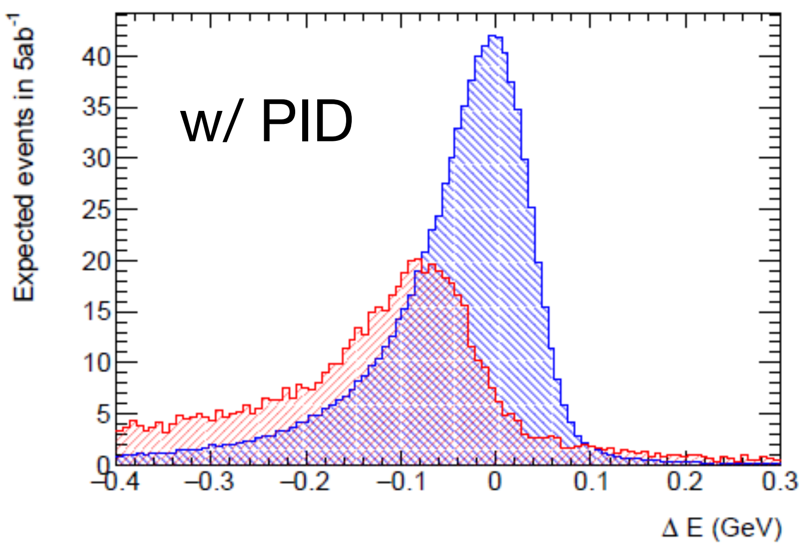
PID performance



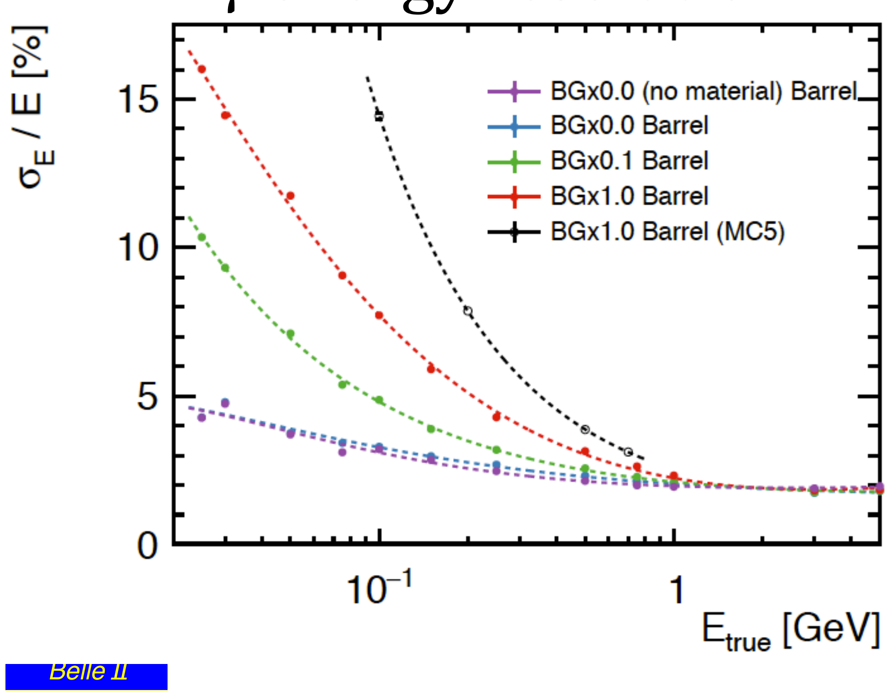
Belle II works similar to or better than Belle despite ~20 times higher beam background!

$B^0 \to \rho^0\gamma$ vs. $K^{*0}\gamma$

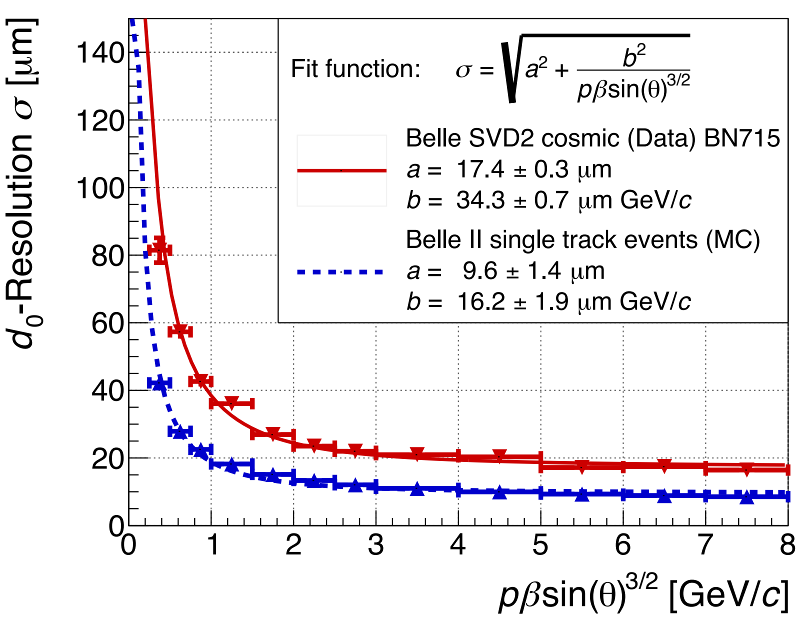


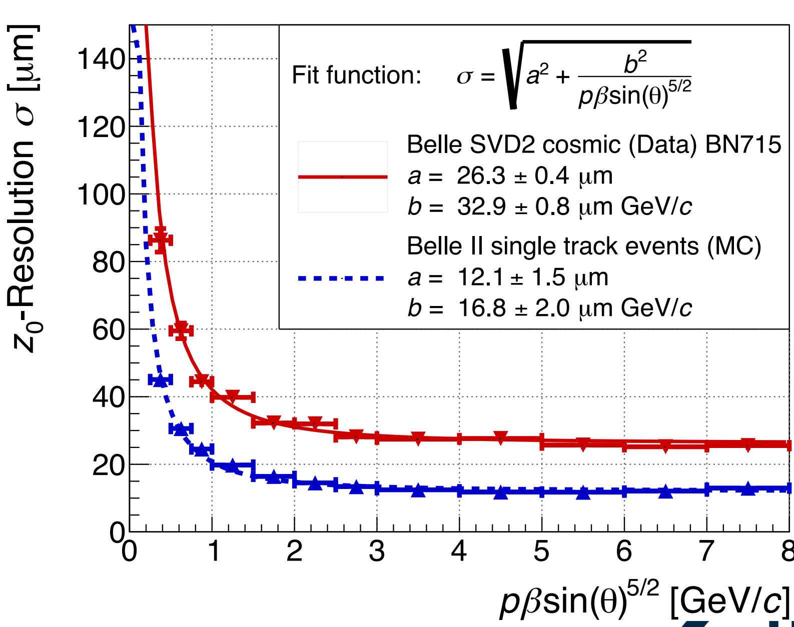


γ energy resolution



Vertex resolution: Belle II x2 better than Belle!





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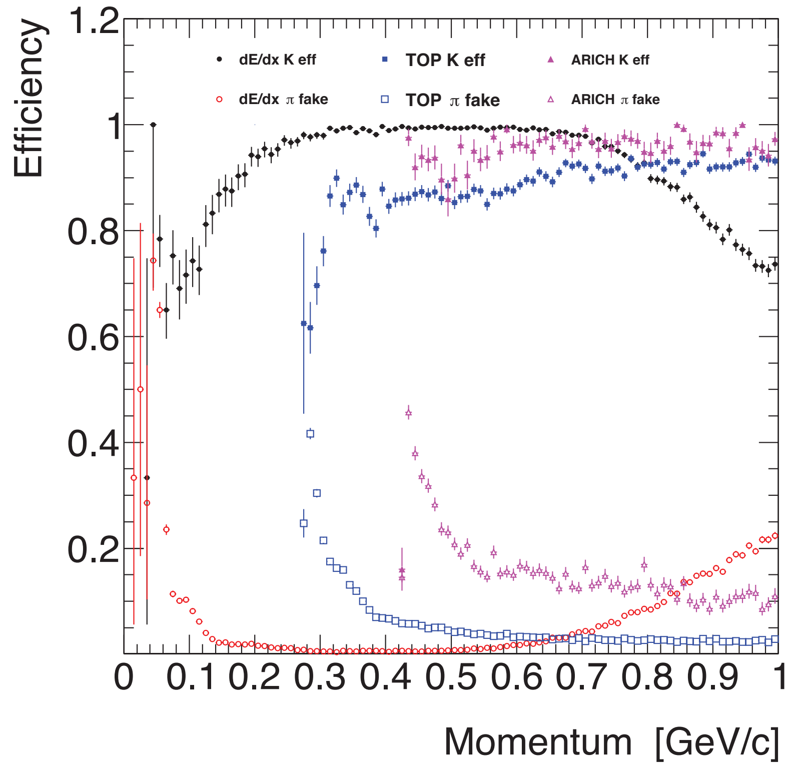

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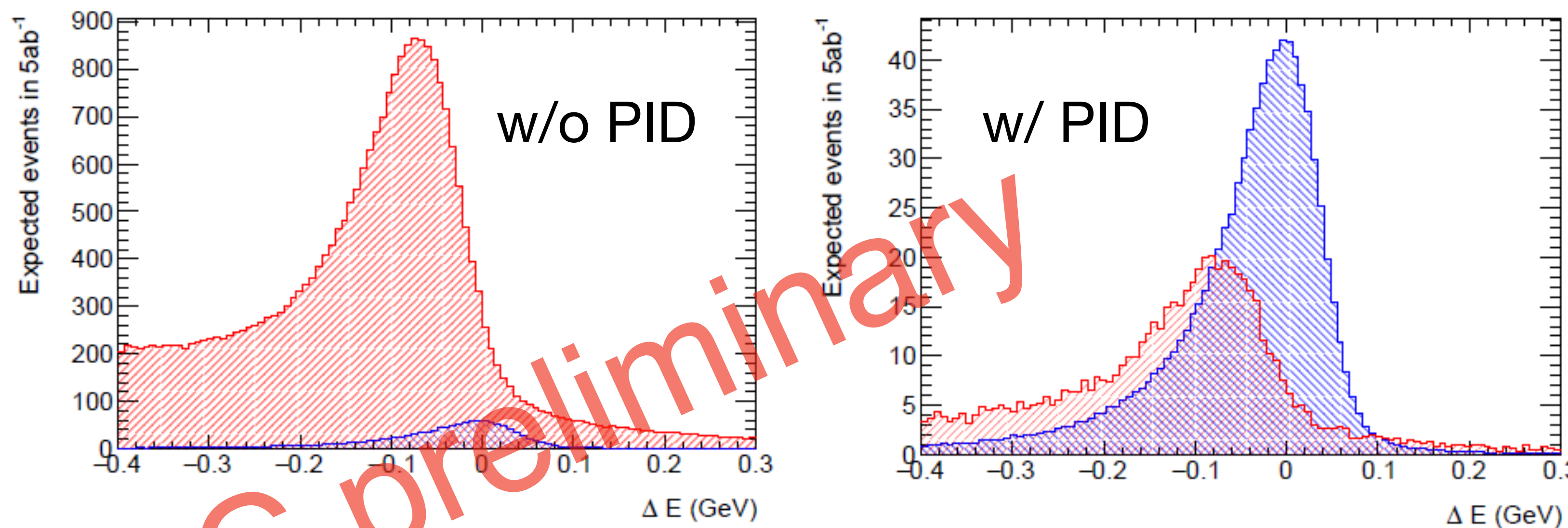

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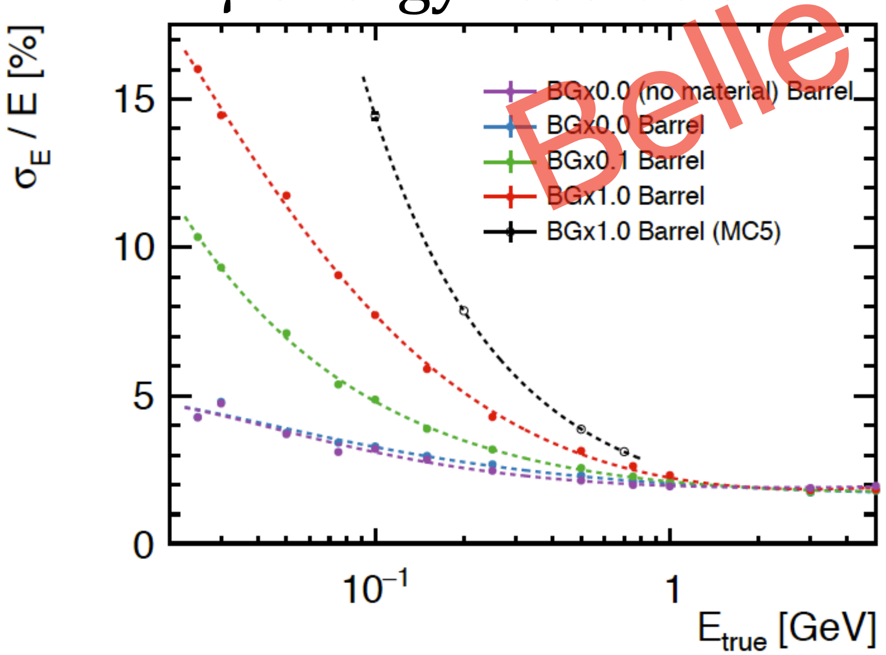

Belle II

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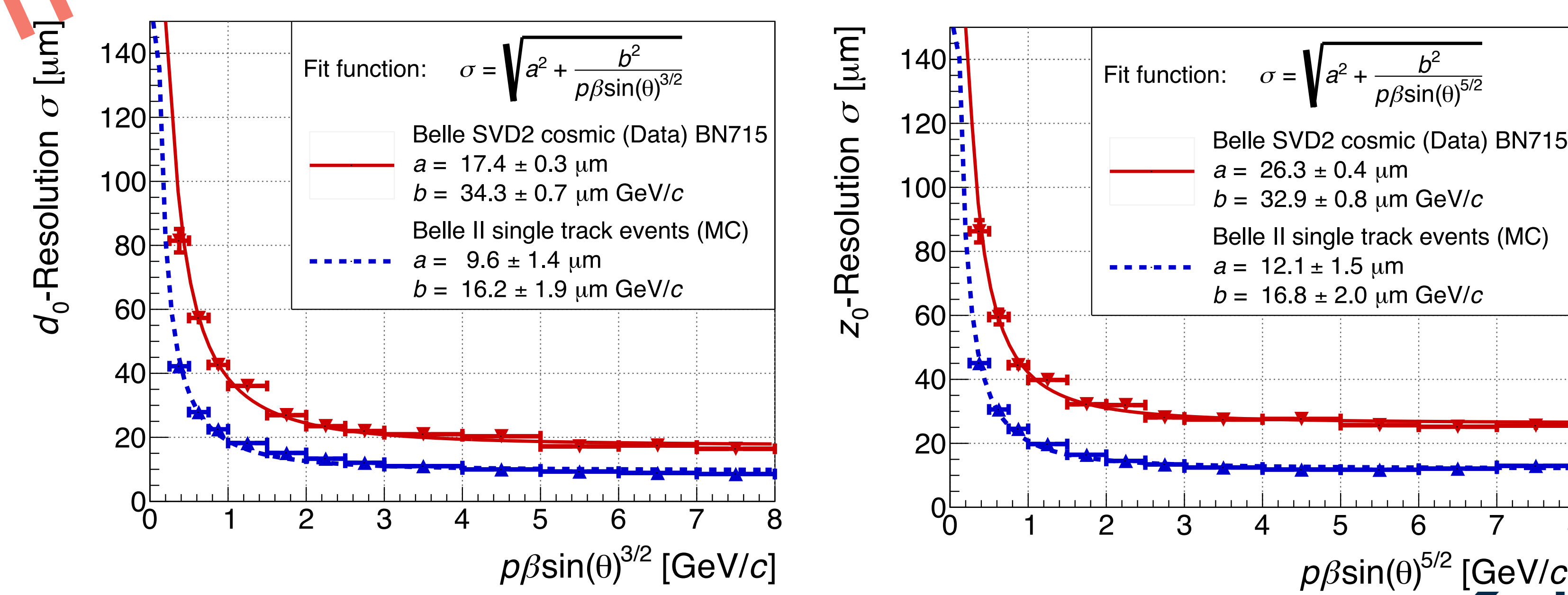


Belle II Physics: Flavour Observables

- Rich physics program, competitive and complementary to LHCb
- Belle II strong in missing energy modes, time dependent CPV, very strong in precision CKM
- There is much more
  - QCD physics, quarkonia and exotic states
  - Dark matter searches
  - …

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [56]	0.012	0.008	
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1	
	γ [°]	68 ± 14 [13]	6	1.5	LHCb
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018	
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [57]	0.028	0.011	
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033	
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [58]	0.07	0.04	
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%		
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{ex.} \pm 2.7\%_{th.})$ [10]	1.8%	1.4%	
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{ex.} \pm 2.5\%_{th.})$ [5]	3.4%	3.0%	
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 9.5\%)$ [7]	4.4%	2.3%	LHCb
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	5%	
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [59]	20%	7%	
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.2%	3.4%	
	$R(B \to D^* \tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	2.9%	2.1%	LHCb
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40 [31]	< 15	20%	
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55 [31]	< 21	30%	
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%	
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$ [60]	1	0.5	
	$S(B \to K_S^0 \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$[20]	0.11	0.035	
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07	
	C_7/C_9 ($B \to X_s \ell\ell$)	~20% [37]	10%	5%	LHCb
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [40]	0.3	–	
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [42]‡	–	
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [44]	2.9%	0.9%	
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [44]	3.5%	3.6%	
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5 [47]	30%	25%	
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$ [61]	0.11	0.06	
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$ [62]	0.29	0.09	
	$A_{CP}(D^0 \to K_S^0\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [62]	0.08	0.03	
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$ [50]	0.14	0.11	
	$y(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$ [50]	0.08	0.05	
	$\lvert q/p \rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$ [50]	0.10	0.07	
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$ [50]	6	4	
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45 [63]	< 14.7	< 4.7	
	$\tau \to e\gamma$ [10^{-9}]	< 120 [63]	< 39	< 12	
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0 [64]	< 3.0	< 0.3	LHCb

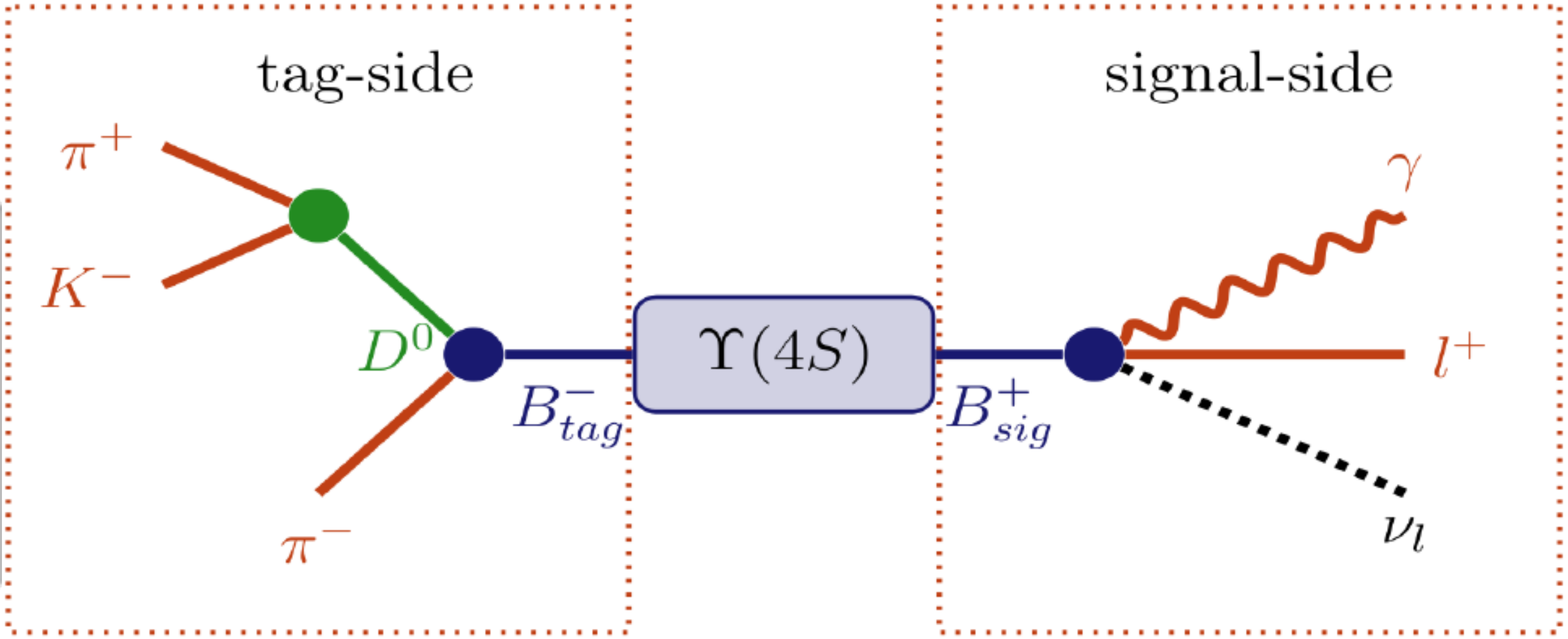
P. Urquijo / Nuclear and Particle Physics Proceedings 263–264 (2015) 15–23

Full reconstruction tagging

- A powerful benefit of physics at B factories: fully reconstruct one B to tag the flavour of the other B, determine its momentum, isolate tracks of signal side

Full reconstruction:
($\varepsilon \approx 0.3$ - 1.5%)

Signal side
$B \to X\ell\nu$ - Precise meas. of $|V_{ub}|$
$B \to \tau\nu$ - Search for NP
$B \to K\nu\nu$ - Search for NP

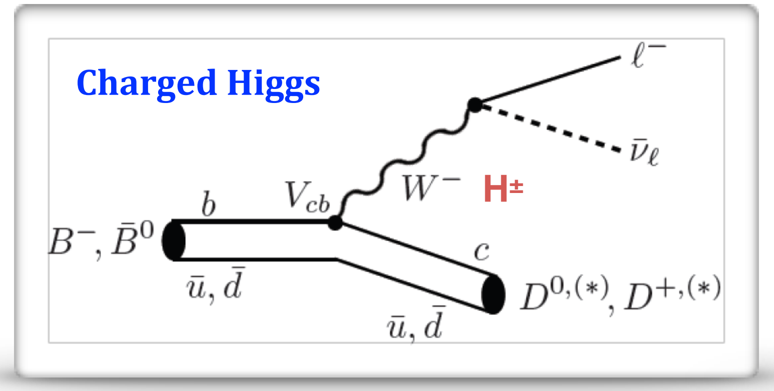


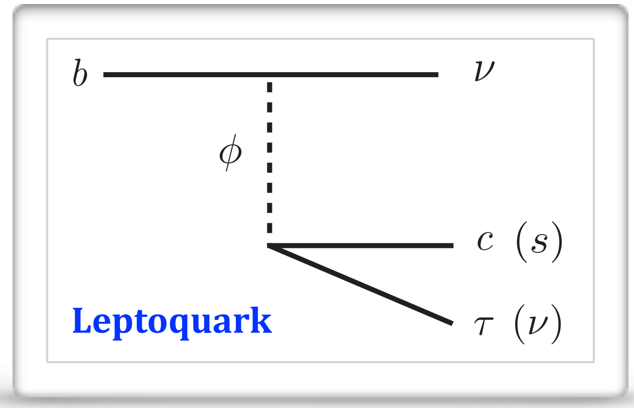
- Excellent tool for missing energy, missing mass analyses!

Flavour anomaly in R(D) and R(D*)

Observable:

$$R(D^*) = \frac{BF(B \to D^* \tau \nu)}{BF(B \to D^* \mu \nu)} \overset{SM}{=} 0.252 \pm 0.003$$





PRL 116, 141802 (2016)

- Proceed via first-order electroweak interactions (mediated by W)
- Decays involving electrons and muons insensitive to non-SM contributions ⟹ measure CKM elements $|V_{cb}|$ and $|V_{ub}|$
- Decays involving tau also sensitive to additional amplitudes ⟹ search for NP

Flavour anomaly in R(D) and R(D*)

Observable:

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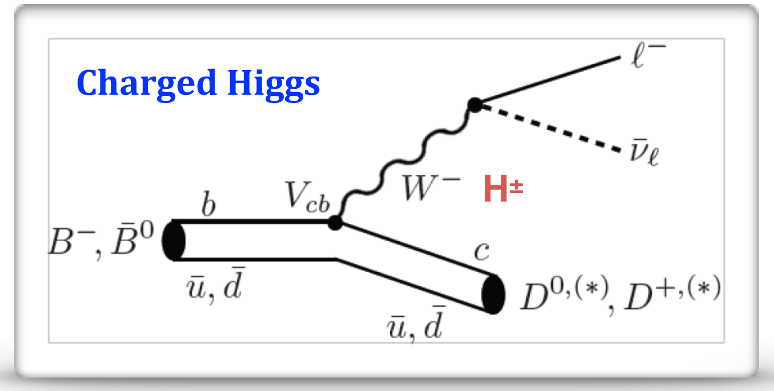

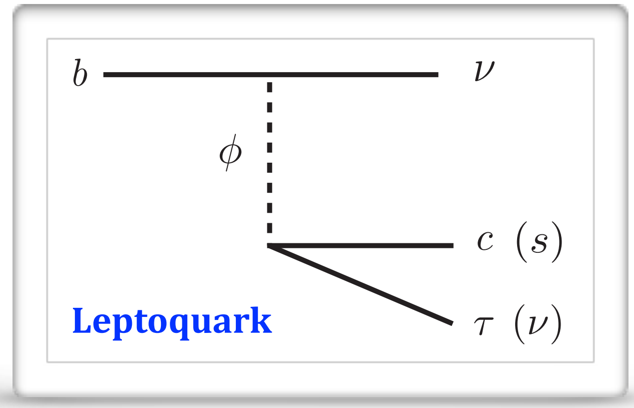

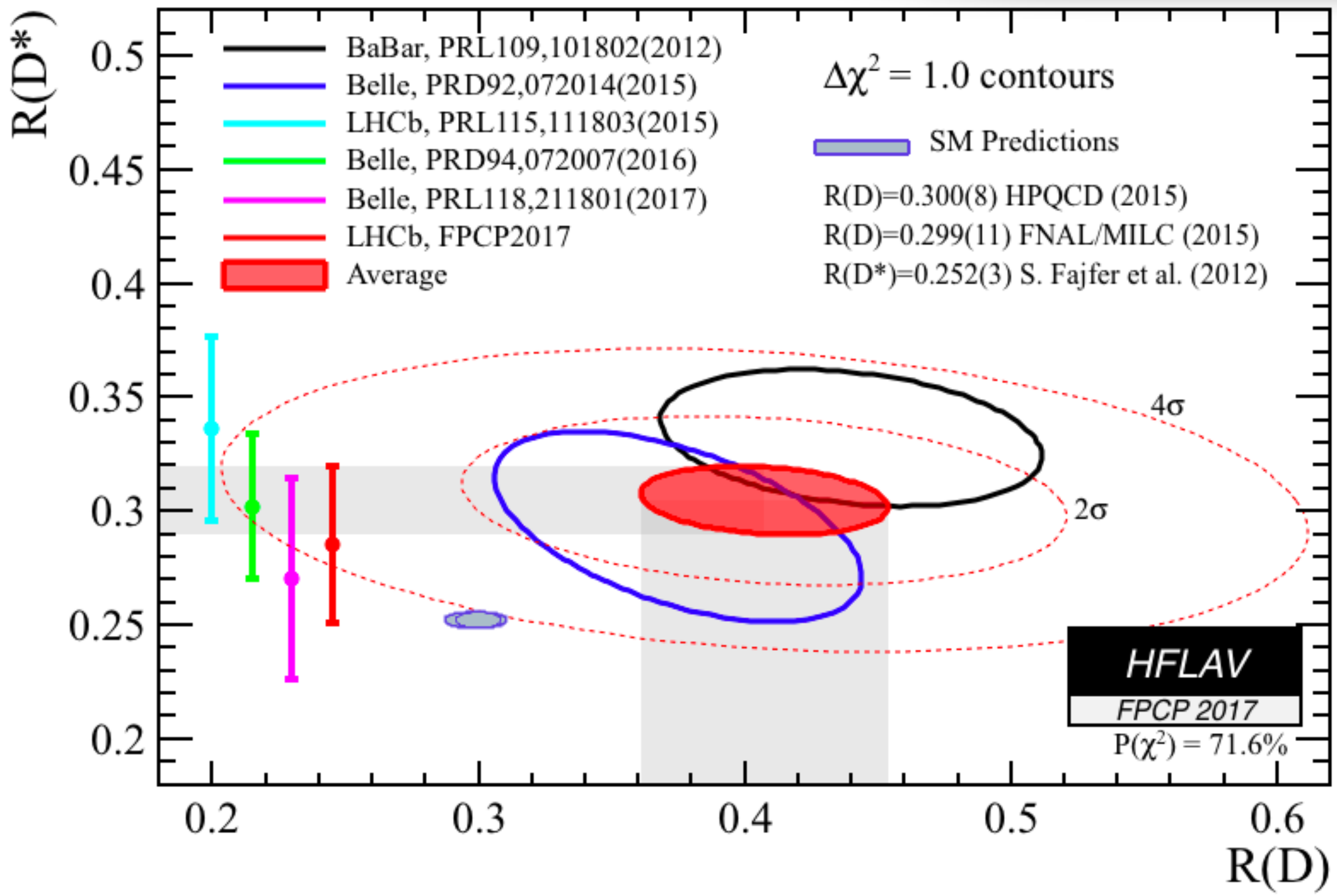

PRL 116, 141802 (2016)

- Combined significance of 4.1σ disagreement with SM
- Not compatible with type II 2HDM, could be accommodated by more general charged Higgs or NP

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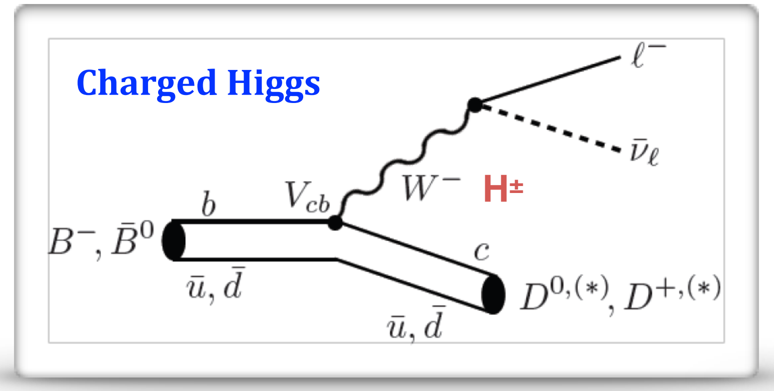
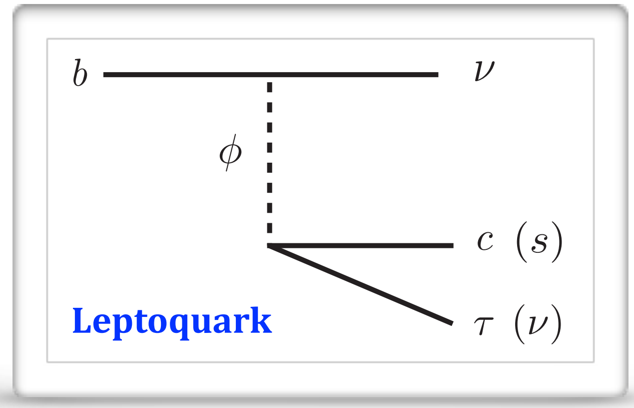
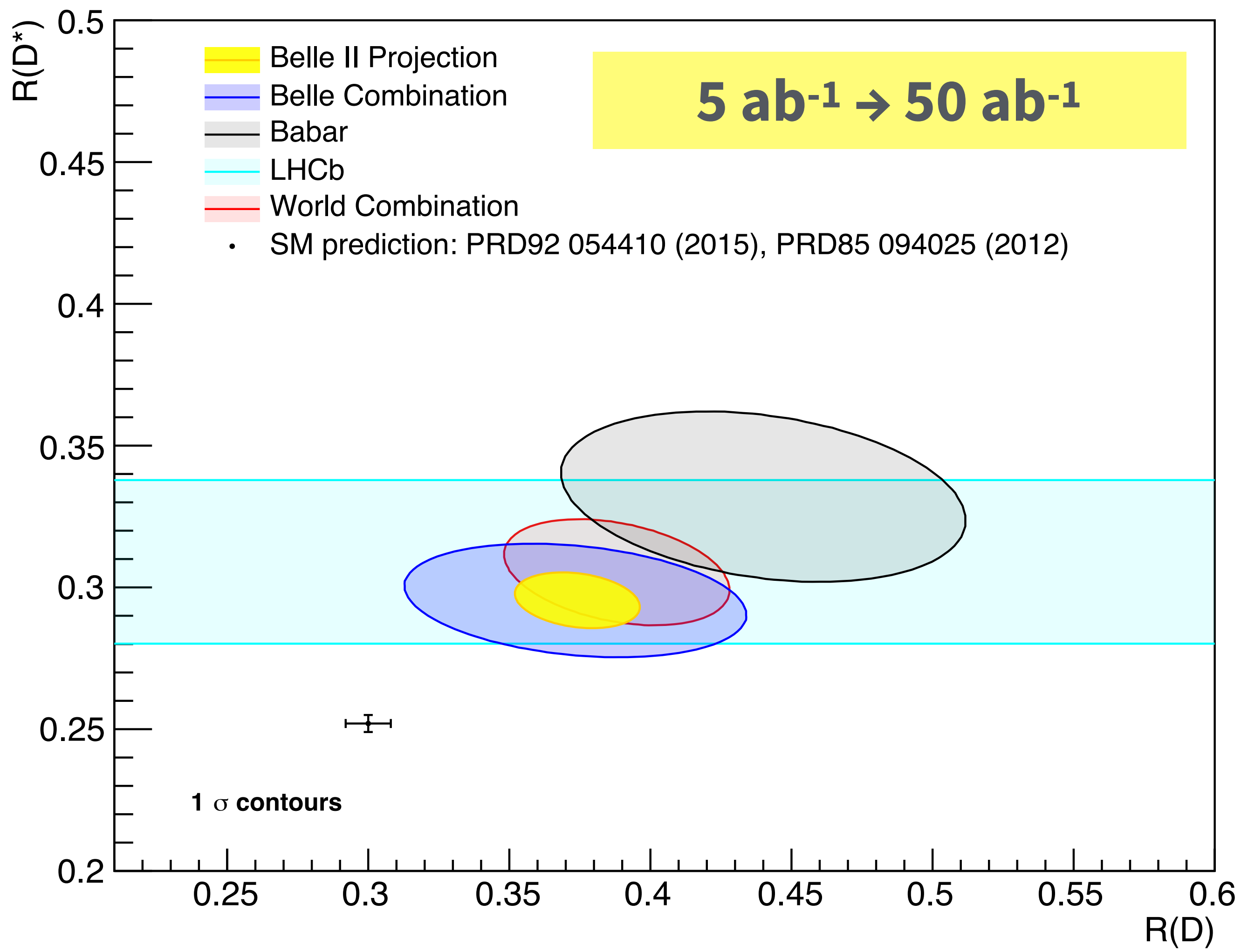




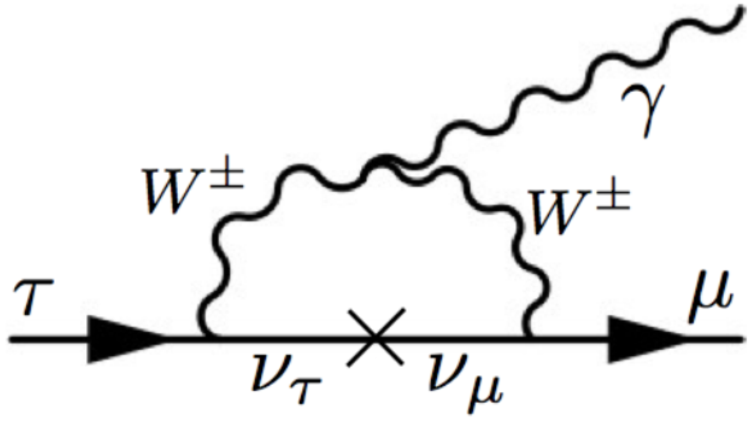
PRL 116, 141802 (2016)



- Combined significance of 4.1σ disagreement with SM
- Not compatible with type II 2HDM, could be accommodated by more general charged Higgs or NP

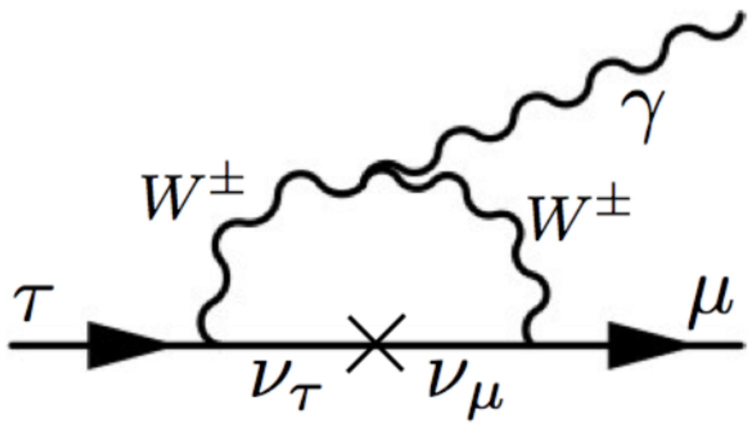
Belle II should be able to confirm the excess with ~5 ab^{-1}

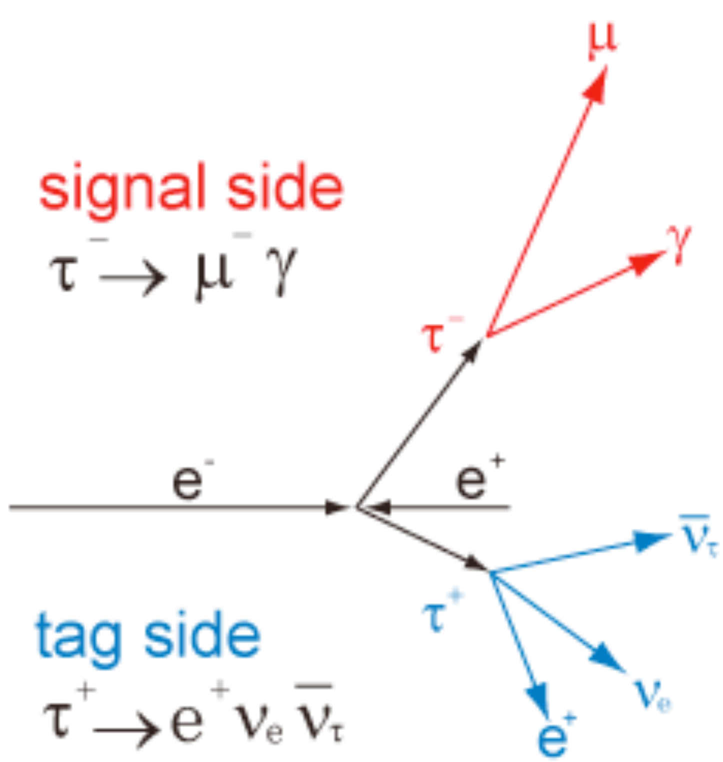
Lepton Flavour Violation

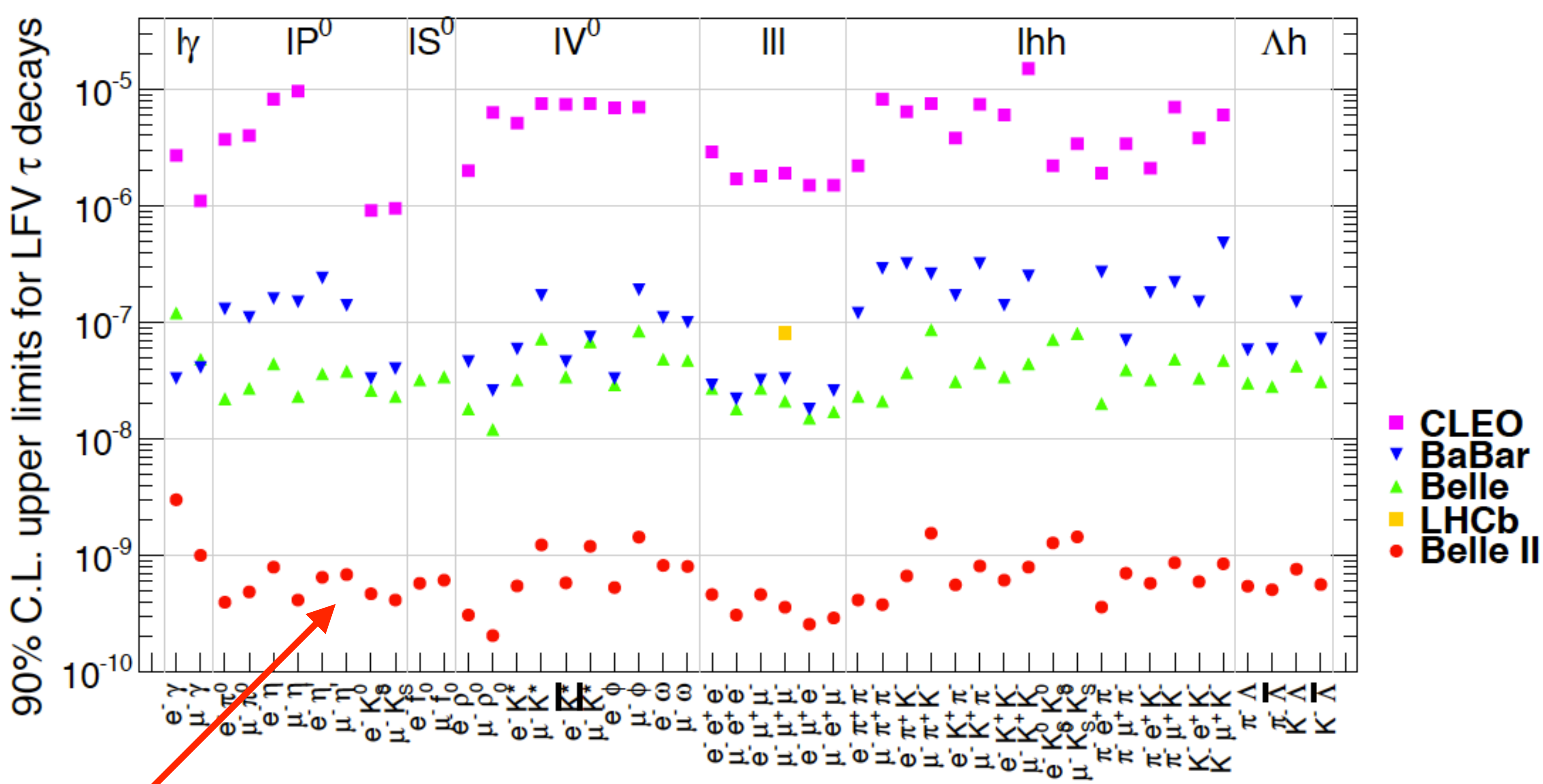


- Highly suppressed in the SM
  - BF on the order of 10^{-40} ($\tau \to \ell\gamma$) to 10^{-54} ($\tau \to \ell\ell\ell$)
- Clean probes for NP effects
- τ decays uniquely studied at B-factories
  - Hadron machines not competitive - trigger and track p_T limiting

Lepton Flavour Violation



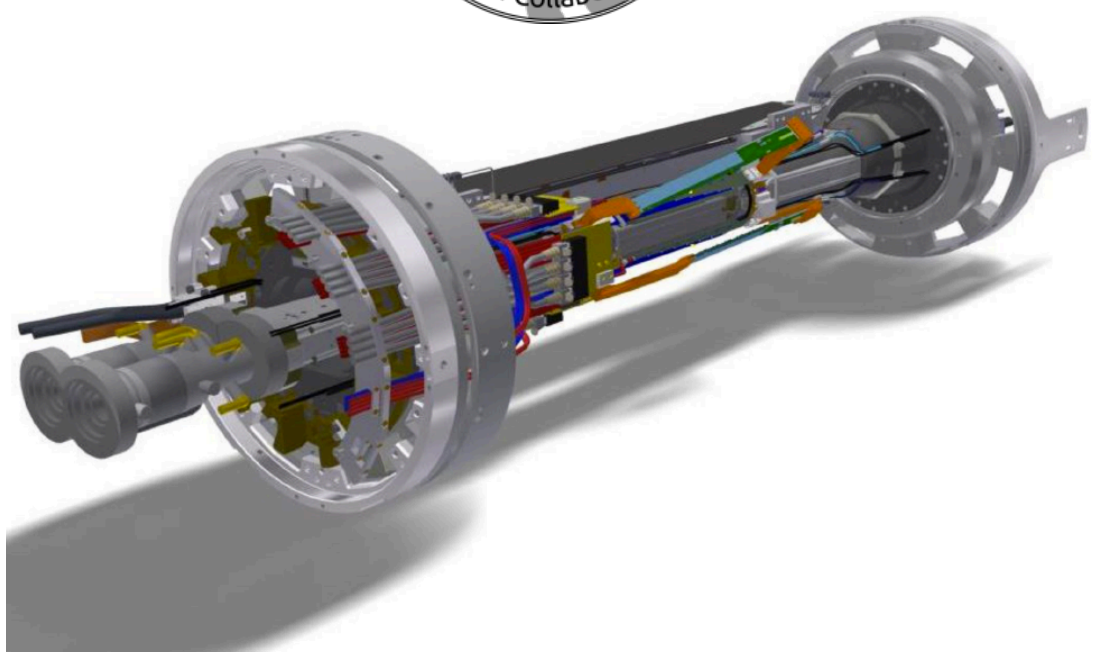




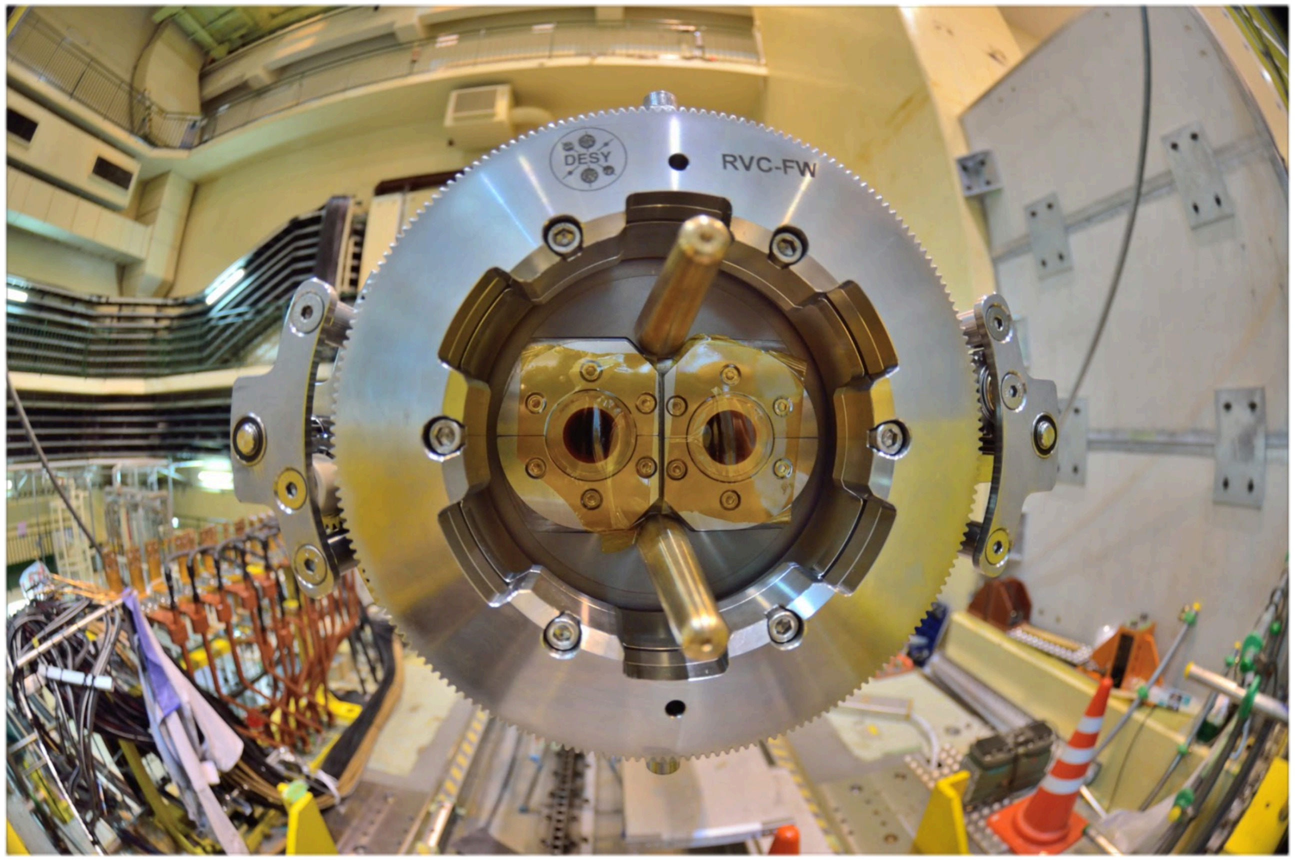
Belle II can access LFV decay rates more than an order of magnitude smaller than Belle!

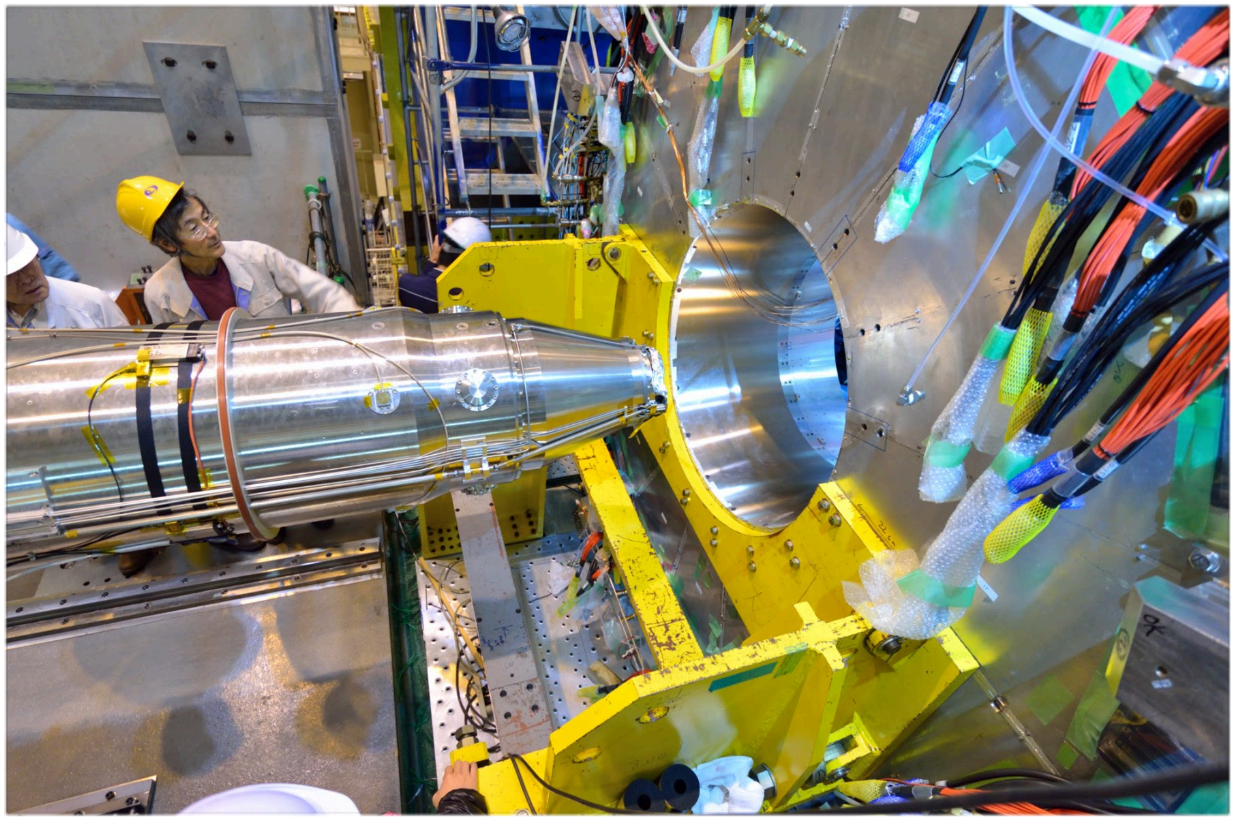
Phase II Goals

- Run from February to middle of July 2018
  - Reduce backgrounds for Belle II
  - Commission HER/LER rings with Belle II solenoid and final focus QCS
  - Reduce beam emittance and beam size, reach beam-beam parameter $\xi_y \geq 0.05$
  - Collide beams at $\sqrt{s}=\Upsilon(4S)$ to reach a peak luminosity $L \geq 10^{34}$ $cm^{-2}s^{-1}$ at the end of run
- Belle II could get ~10÷20 fb^{-1} of integrated luminosity before the end of the run
- No vertex detector ⇒ BEAST II instead



Both QCS Installed!





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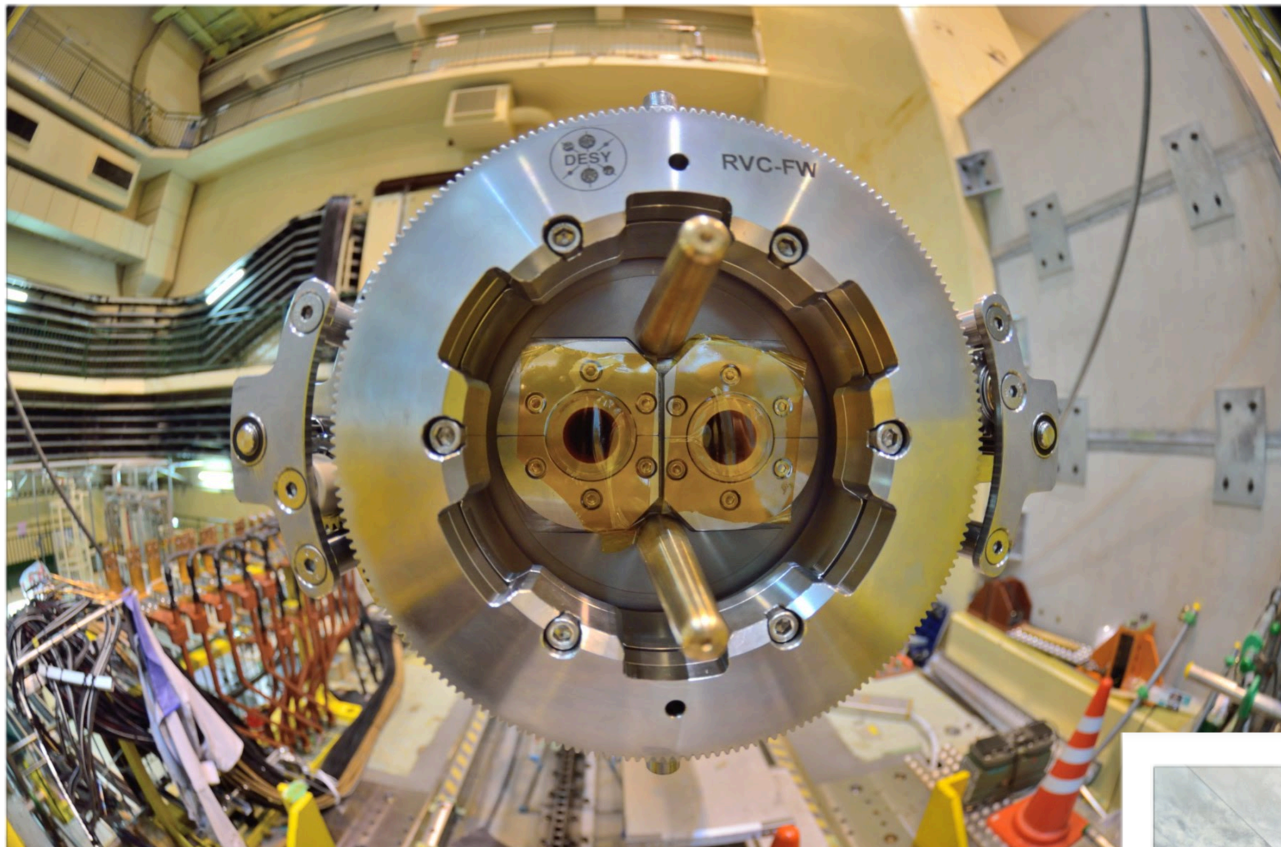
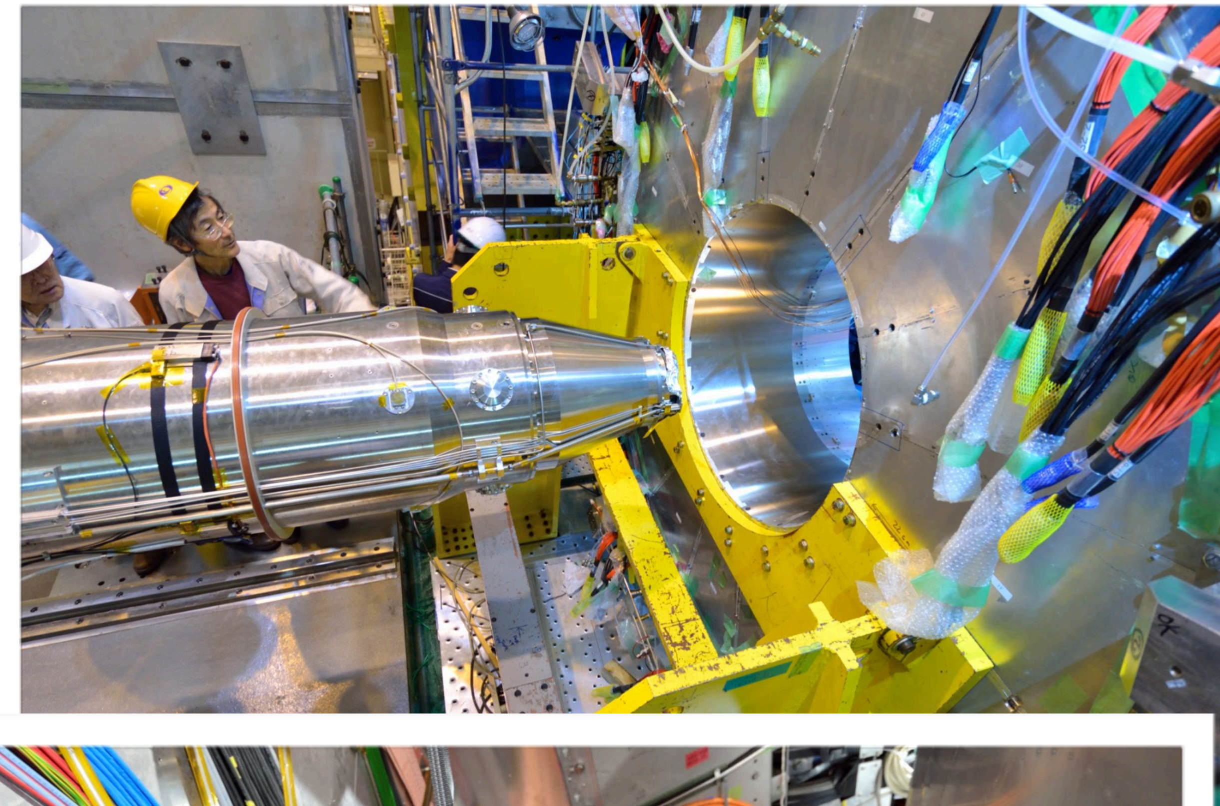
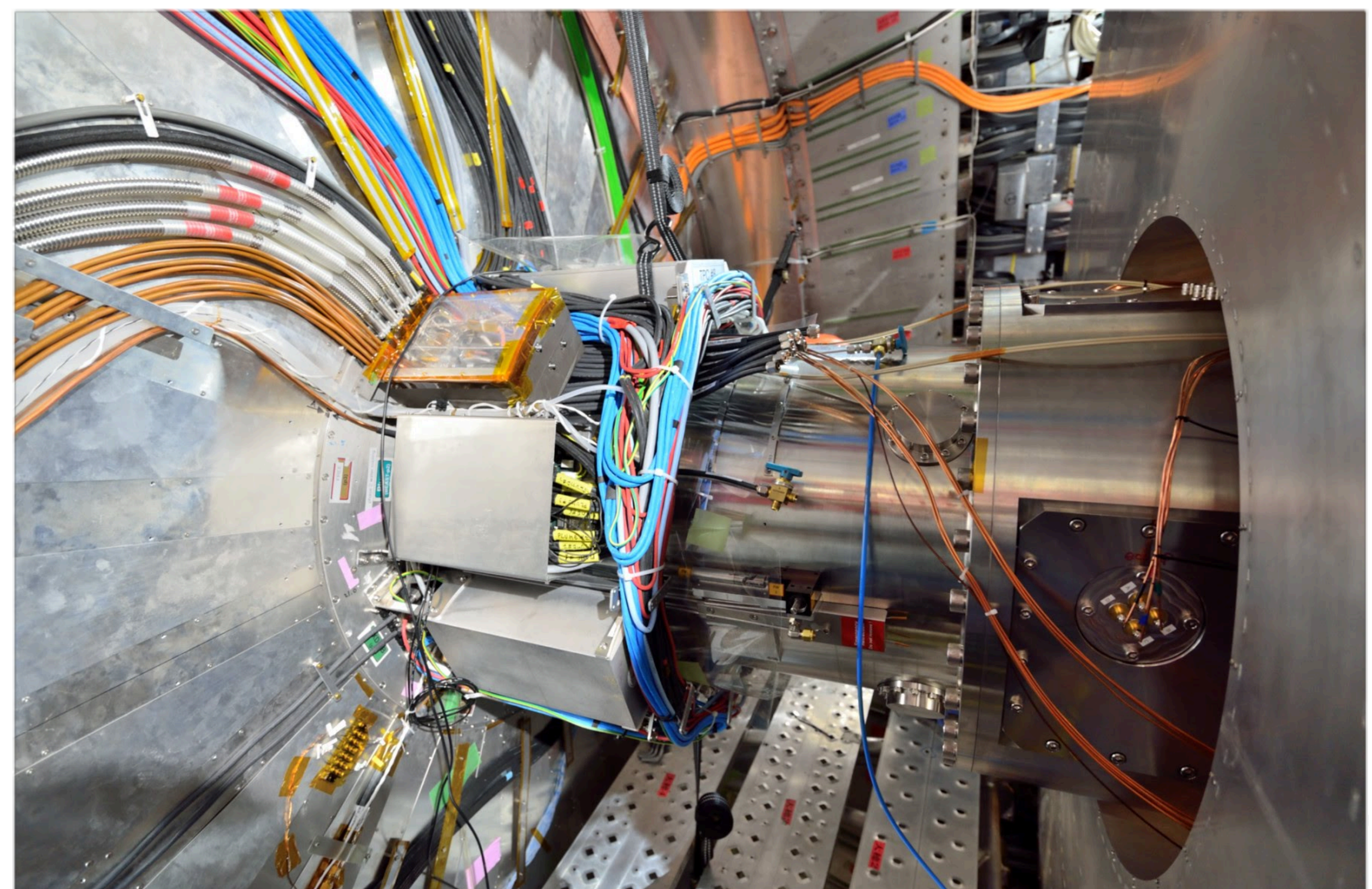
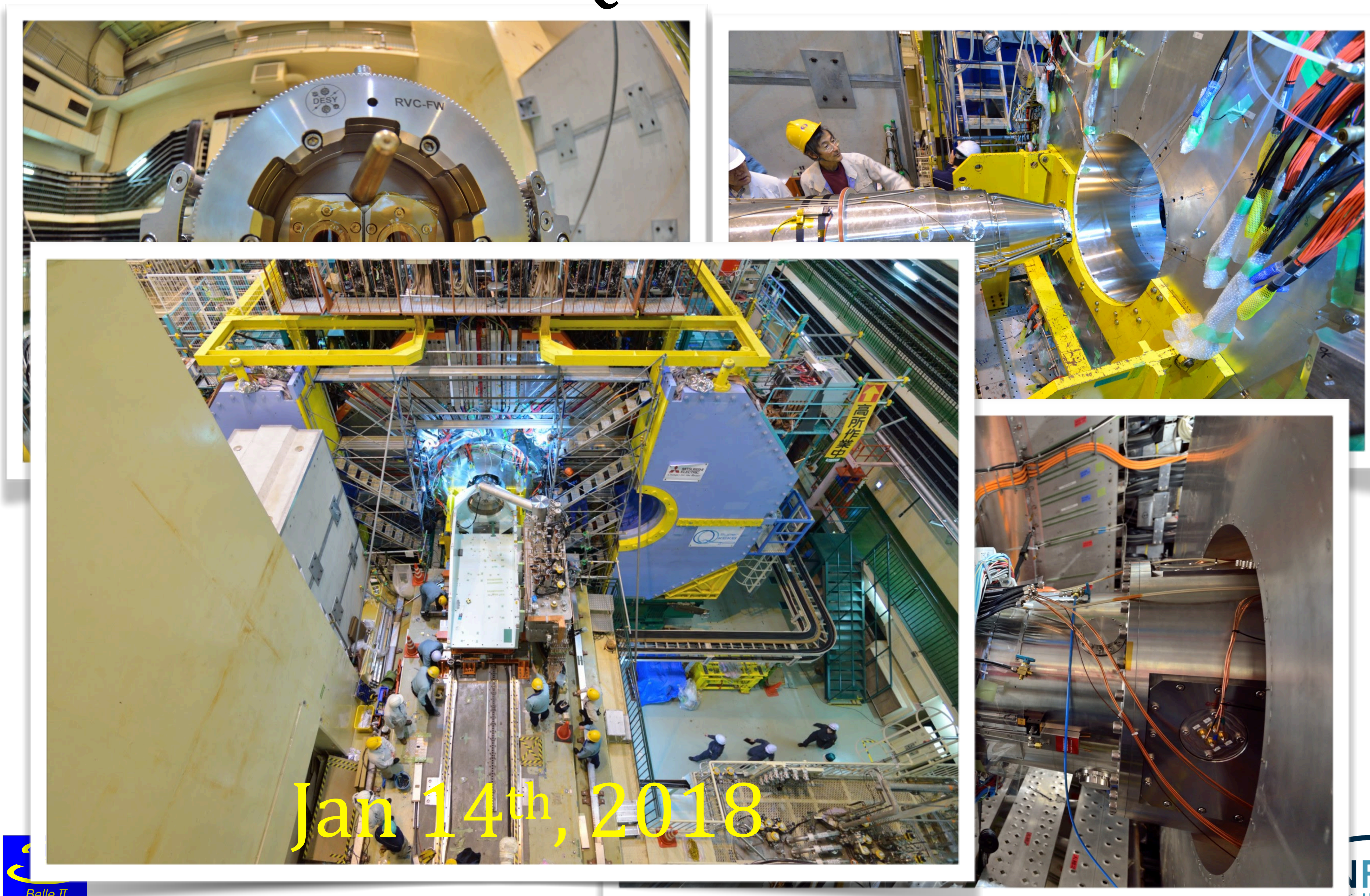






Both QCS Installed!

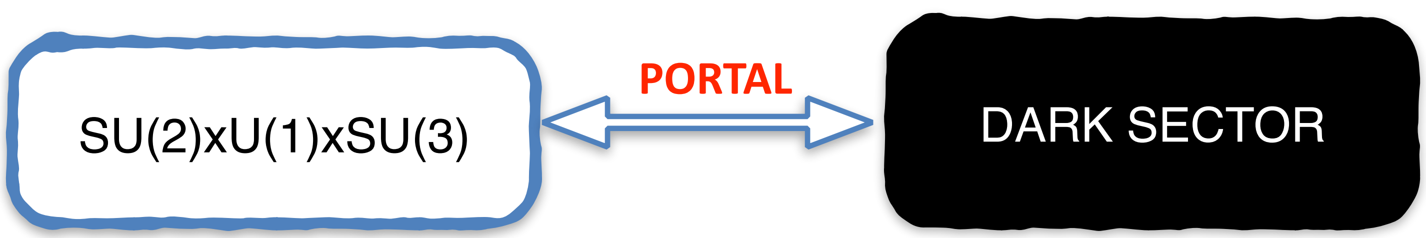


Dark matter searches

Phase II

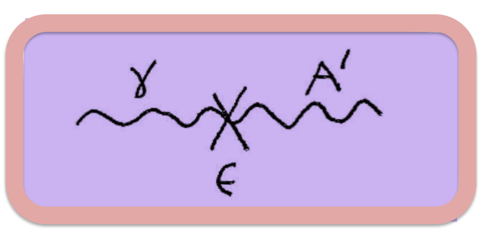
- Dark Matter and Dark Energy implied by cosmological observations
- A minimal DM model introduces a DM particle χ and a new scalar or gauge boson A′ ("dark photon")
  - The hidden (or secluded, or dark) sector could be accessed from the standard world through a "portal"

Phys. Rev. D 80, 015003 (2009); arXiv:1311.0029v1 [hep-ph]



  - A′ could be coupled to the standard photon via "kinetic mixing"

Phys. Lett. B 166 (1986) 196



$$\Delta\mathcal{L} = \varepsilon\ F^{\mu\nu}\ F'_{\mu\nu}$$

$\varepsilon \equiv \sqrt{\frac{\alpha'}{\alpha}}$ is the **A′**-γ coupling strength

  - A′ decays to
    - SM particles if $m_\chi > m_{A'}/2$ (visible decay)
    - $\chi\bar{\chi}$ if $m_\chi < m_{A'}/2$ (invisible decay)

Free parameters *(to be measured)*:

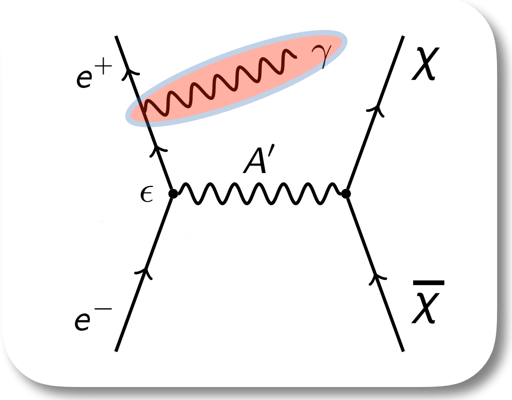
ε (strength of the mixing)

m_A (mass of the dark photon)

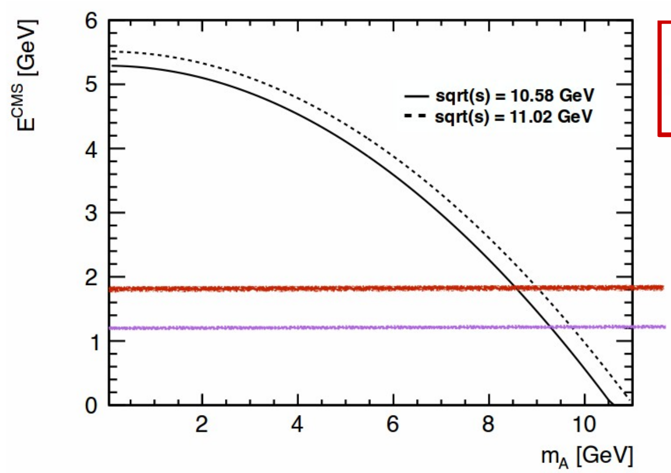
Dark matter searches

Phase II

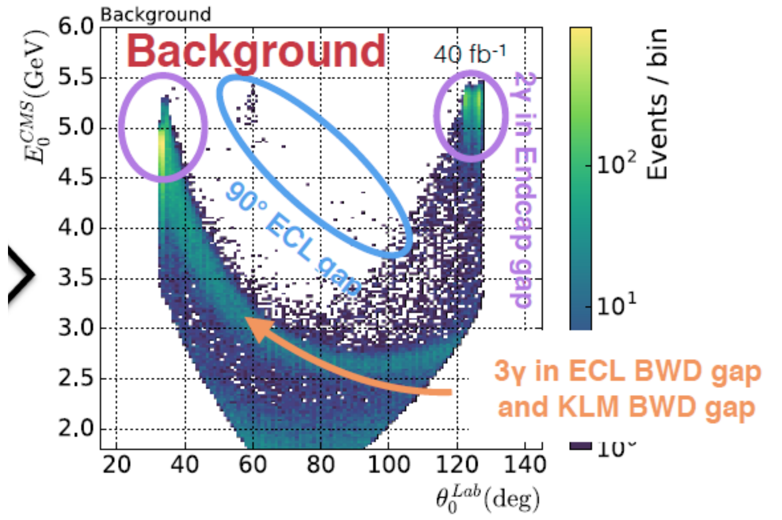
A′ → invisible



- Signature is a single photon - search for a bump in the recoil mass
  - requires efficient single photon trigger
    - two level-1 single photon triggers (1 GeV, 2 GeV) being developed for Belle II (MC preliminary ε~95%)
  - main backgrounds are e+e−(γ) and γγ(γ), when all but 1 γ escape detection
    - require hermetic detector, control over machine background
    - use KLM detector as a veto to ECL gaps
  - Preliminary unoptimised selection has signal efficiency ~ 30-40%

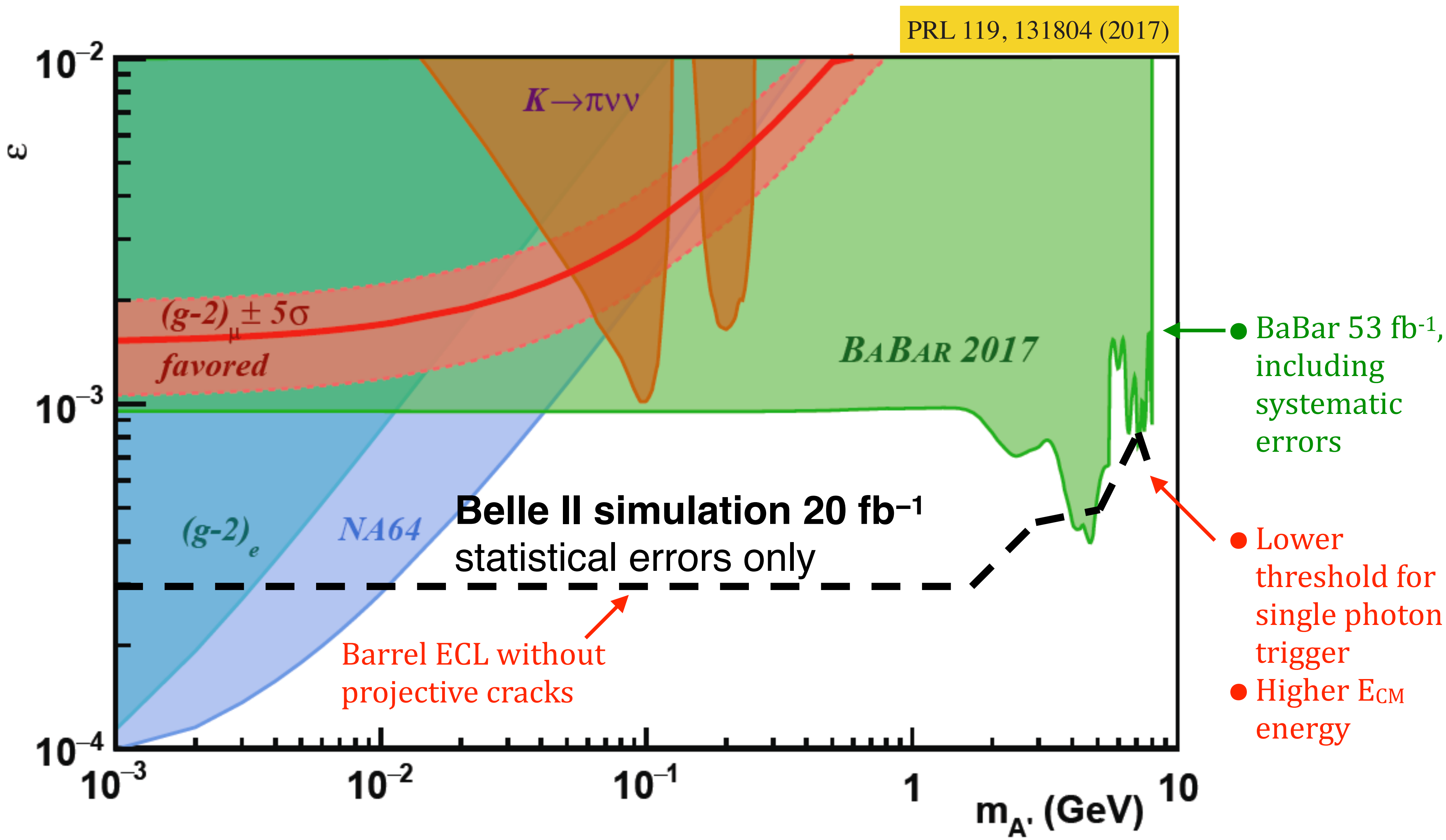


$$E_\gamma = \frac{s - M_{A'}^2}{2\sqrt{s}}$$



A' → invisible

Phase II



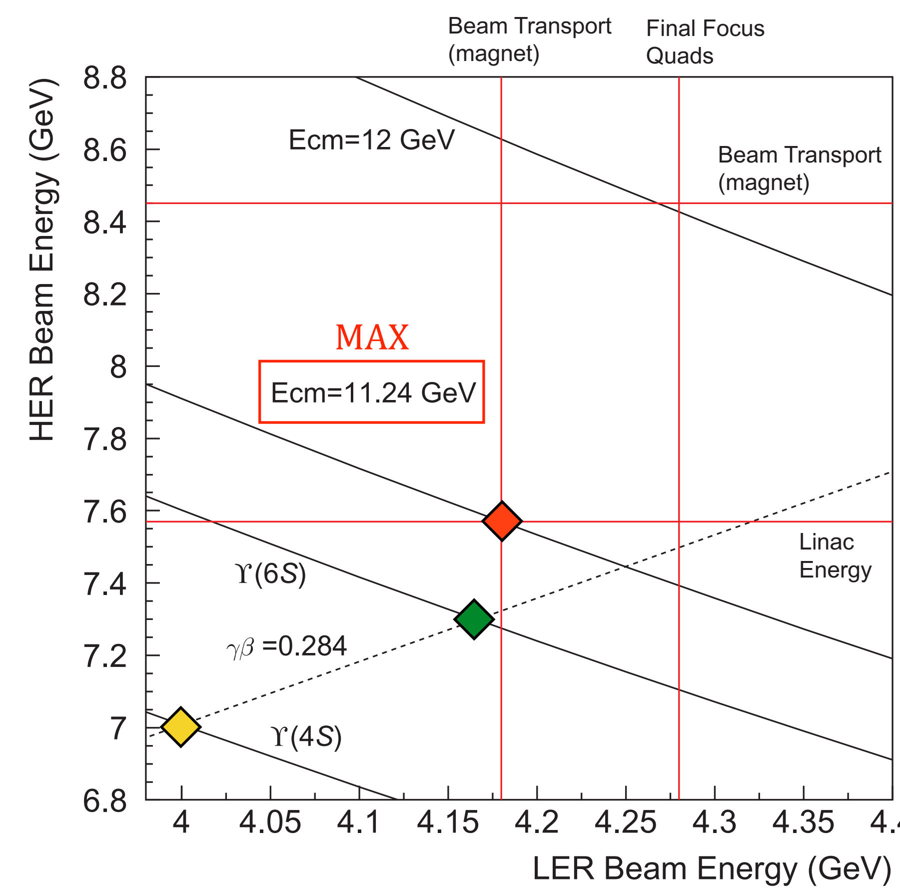
Extrapolation to full luminosity affected by sustainability of single photon trigger with increased backgrounds.

Phase II: Non-$\Upsilon(4S)$ running

Quarkonia spectroscopy

Energy	Outcome	Lumi (fb^{-1})	Comments
Υ(1S) On	N/A	60+	-No interest identified -Low energy
Υ(2S) On	New physics searches	20+	-Requires special trigger
Υ(1D) Scan	Particle discovery	10-20	-Already accessible in B Factories?
Υ(3S) On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 3
Υ(3S) Scan	Precision QED	~10	-Understanding of beam conditions needed
Υ(2D) Scan	Particle discovery	10-20	-Unknown mass
>Υ(4S) On	Particle discovery?	10+?	-Energy to be determined
Υ(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

SuperKEKB limitations



Experiment	Scans Off. Res.	$\Upsilon(6S)$ fb^{-1}	$\Upsilon(5S)$ fb^{-1}	$\Upsilon(5S)$ 10^6	$\Upsilon(4S)$ fb^{-1}	$\Upsilon(4S)$ 10^6	$\Upsilon(3S)$ fb^{-1}	$\Upsilon(3S)$ 10^6	$\Upsilon(2S)$ fb^{-1}	$\Upsilon(2S)$ 10^6	$\Upsilon(1S)$ fb^{-1}	$\Upsilon(1S)$ 10^6
CLEO	17.1	-	0.1	0.4	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan			433	471	30	122	14	99	–	
Belle	100	~ 5.5	36	121	711	772	3	12	25	158	6	102

Scan above the $\Upsilon(4S)$

Phase II

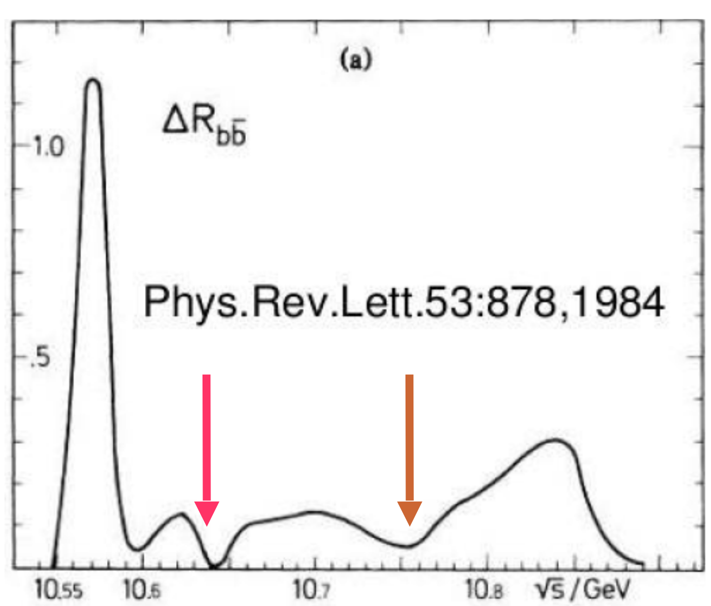
Where to run for $\int L dt \sim 10\ fb^{-1}$?

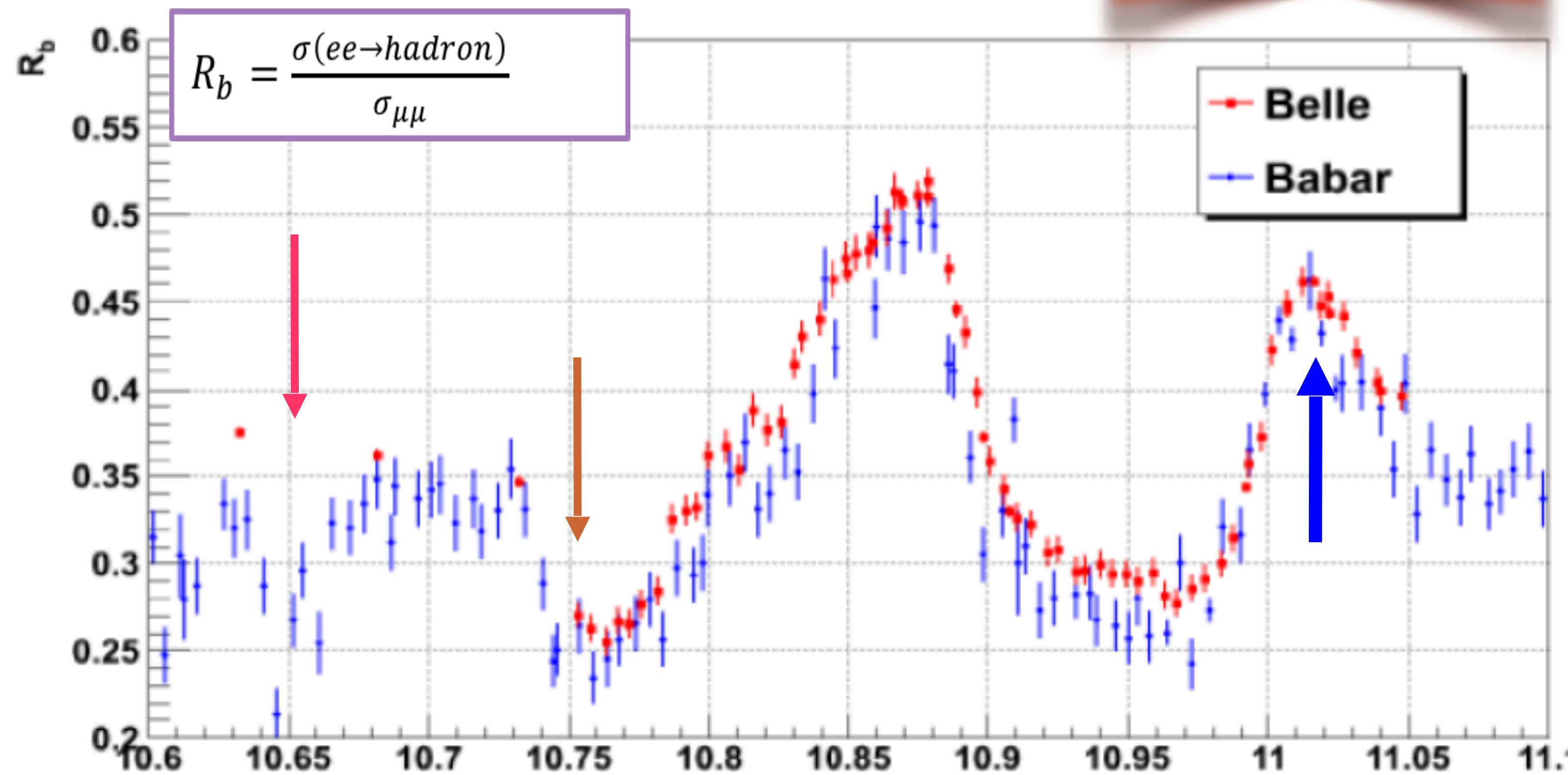
⇒ E = **10.65** GeV
Dip in R_b , just on B*B* threshold

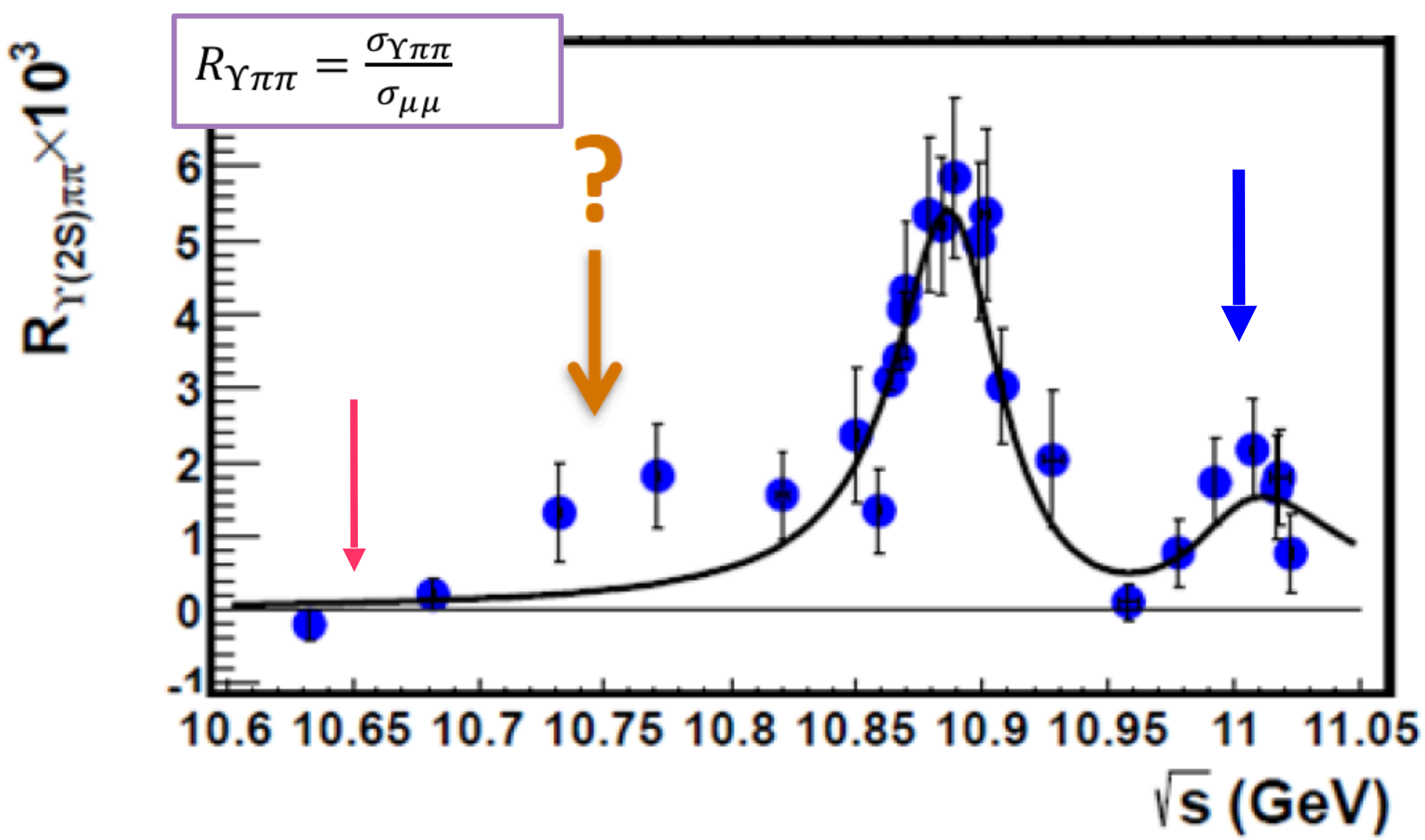
⇒ E = **10.75** GeV
On the first $Z_b\pi$ threshold, above R_b drop at 10.74 where a bump is observed in R_Υ

⇒ E = **11.02** GeV
$\Upsilon(6S)$ peak. (A 6 point scan (1 fb^{-1} each) taken by Belle-I)

Note: features predicted by theory (coupled channel model)







Summary

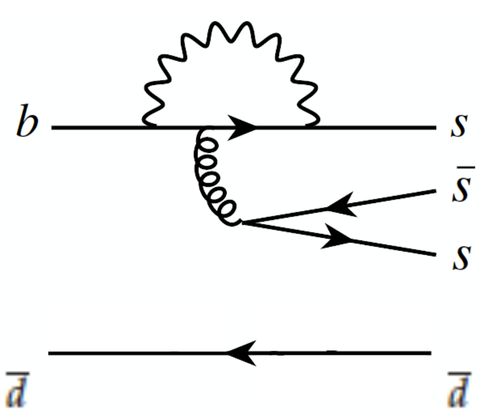
- After a successful phase I operation in 2016, phase II of SuperKEKB commissioning is fast approaching
  - Machine parameters will be tuned to obtain the first collisions in Spring of 2018
  - The Belle II detector commissioning is also well under way to be ready to exploit the first delivered luminosity during phase II
  - Even without the vertex detector and a small expected integrated luminosity in phase II, Belle II will be in a position to produce significant first physics results, possibly on searches for dark matter invisible decays and quarkonia spectroscopy
- Following the installation of the vertex detector in summer 2018, the complete Belle II detector will ready for the first physics run to start in fall 2018 at the $\Upsilon(4S)$ energy
- The Belle II Collaboration is looking forward to the next 10 years to carry out a rich physics program, complementary to existing experiments, and to significantly contribute to the quest for new physics beyond the Standard Model

Backup Slides

New sources of CPV?

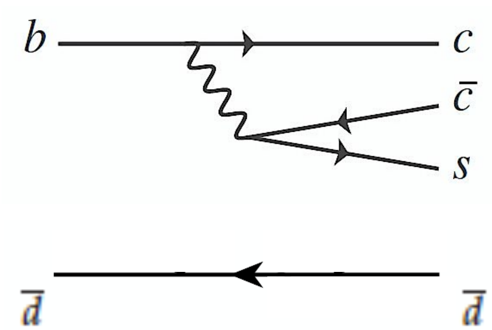
- Most theories involving NP include additional CP-violating phases
  - Some allow large deviations from SM predictions for B meson decays
- Search for new sources of CPV by comparing mixing-induced CP asymmetries in penguin transitions with tree-dominated modes
- Time-dependent CPV in b → s decays such as B → φK^0, η'K^0, K^{0}K^{0}K^0

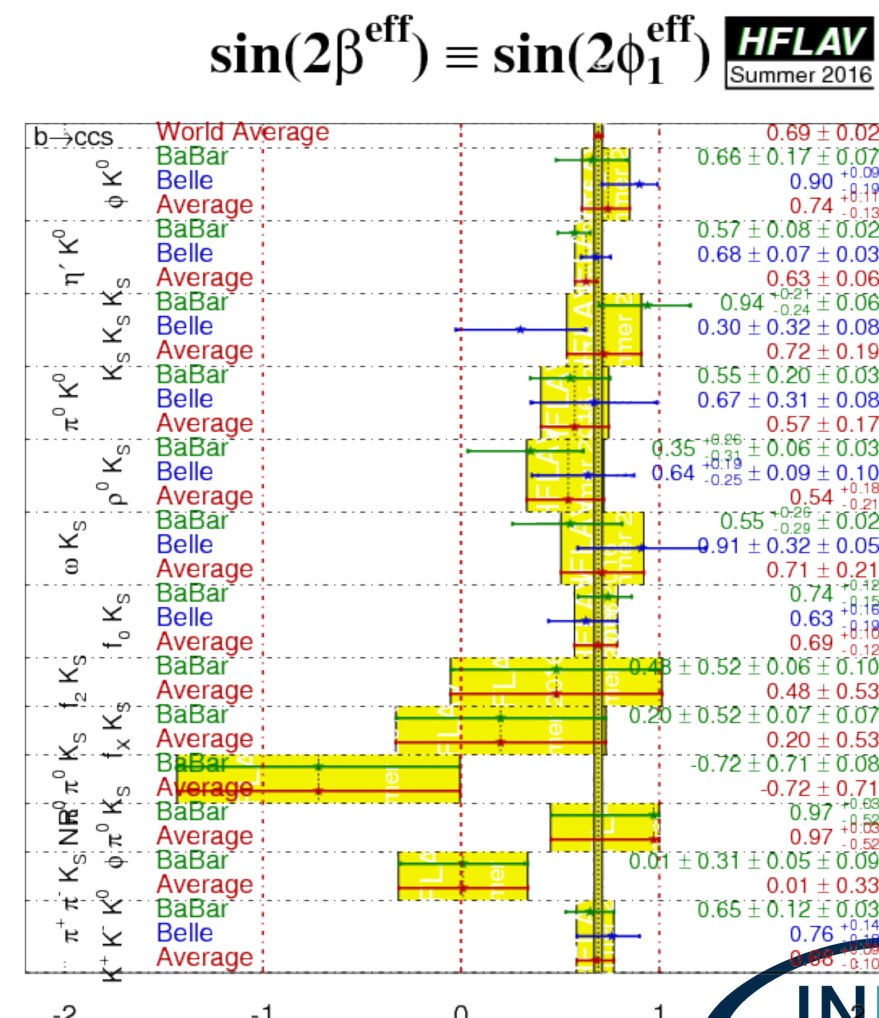
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left\{1 + q \cdot \left[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)\right]\right\}$$



SM:
$|S_{b\to c} - S_{b\to s}| \simeq 0$

NP in loop:
$|S_{b\to c} - S_{b\to s}| > 0$





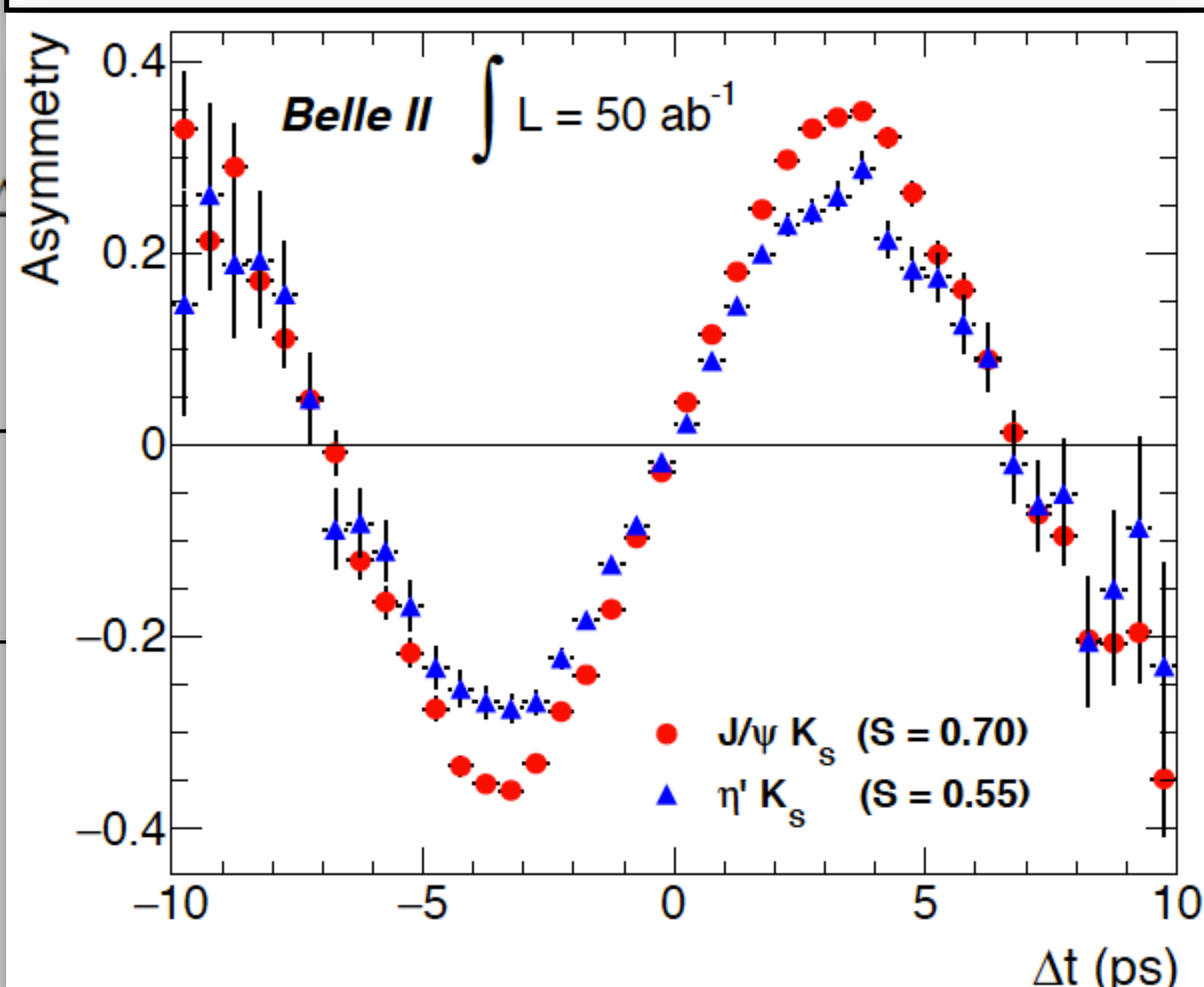
- Discrepancies with respect to J/ψ K^0 could provide evidence for NP

New sources of CPV?

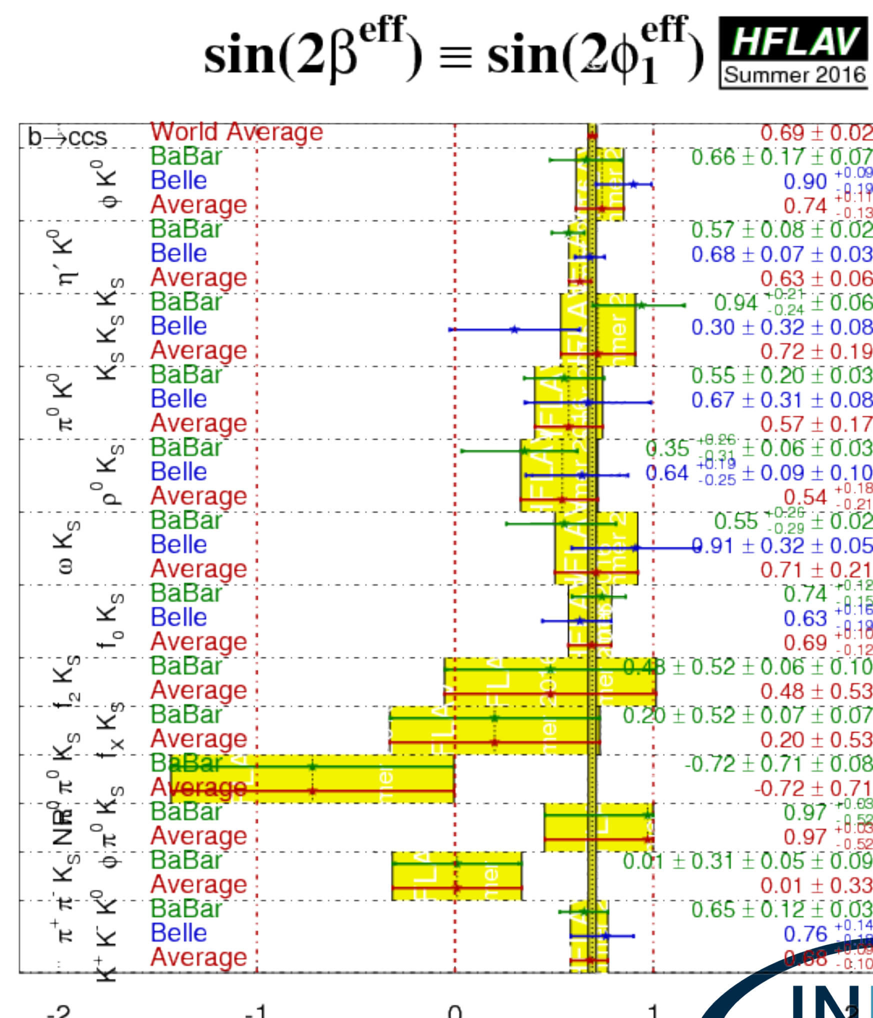
- Most theories involving NP include additional CP-violating phases
  - Some allow large deviations from SM predictions for B meson decays
- Search for new sources of CPV by comparing mixing-induced CP … ee-dominated modes
- … s B → φK⁰, η'K⁰, K⁰K⁰K⁰

$\mathcal{P}(\Delta$ … $\Delta t)]\}$

Unambiguous sign of New Physics, easily detectable at Belle II

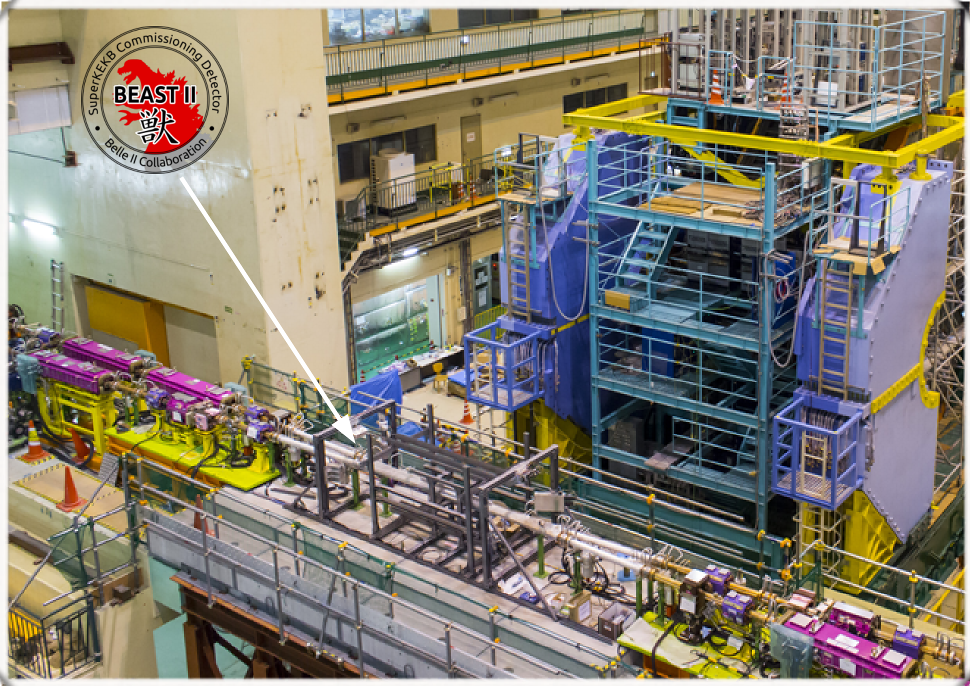


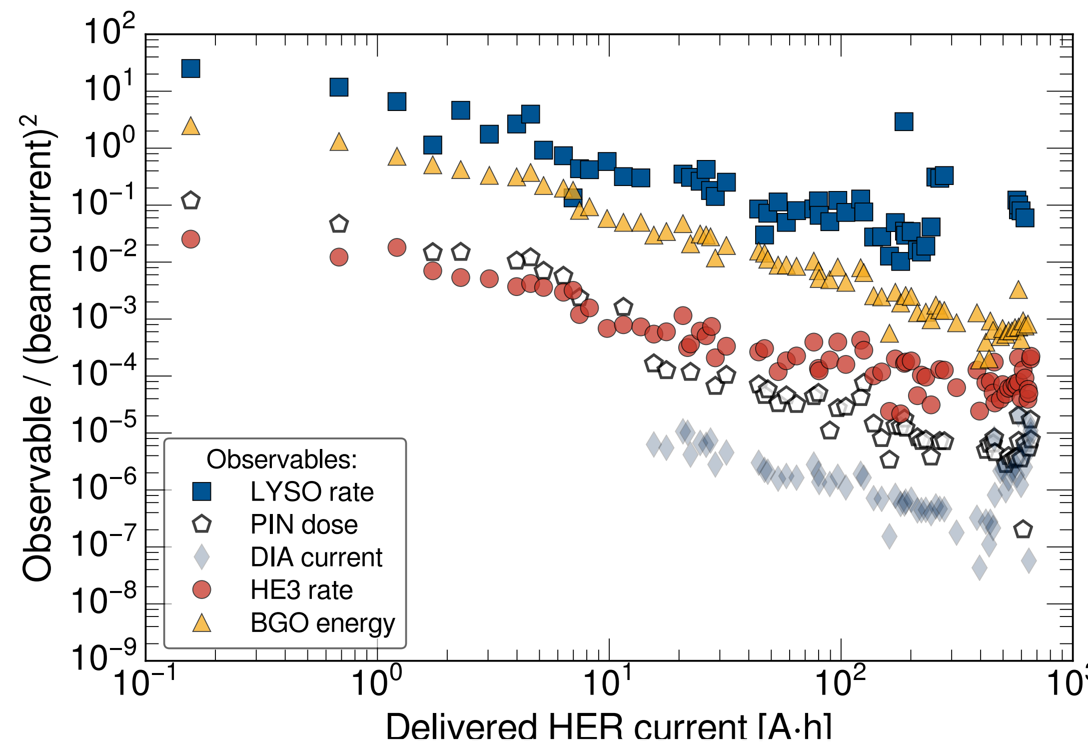
b
$\bar{d}$
c
$\bar{c}$
s
$\bar{d}$



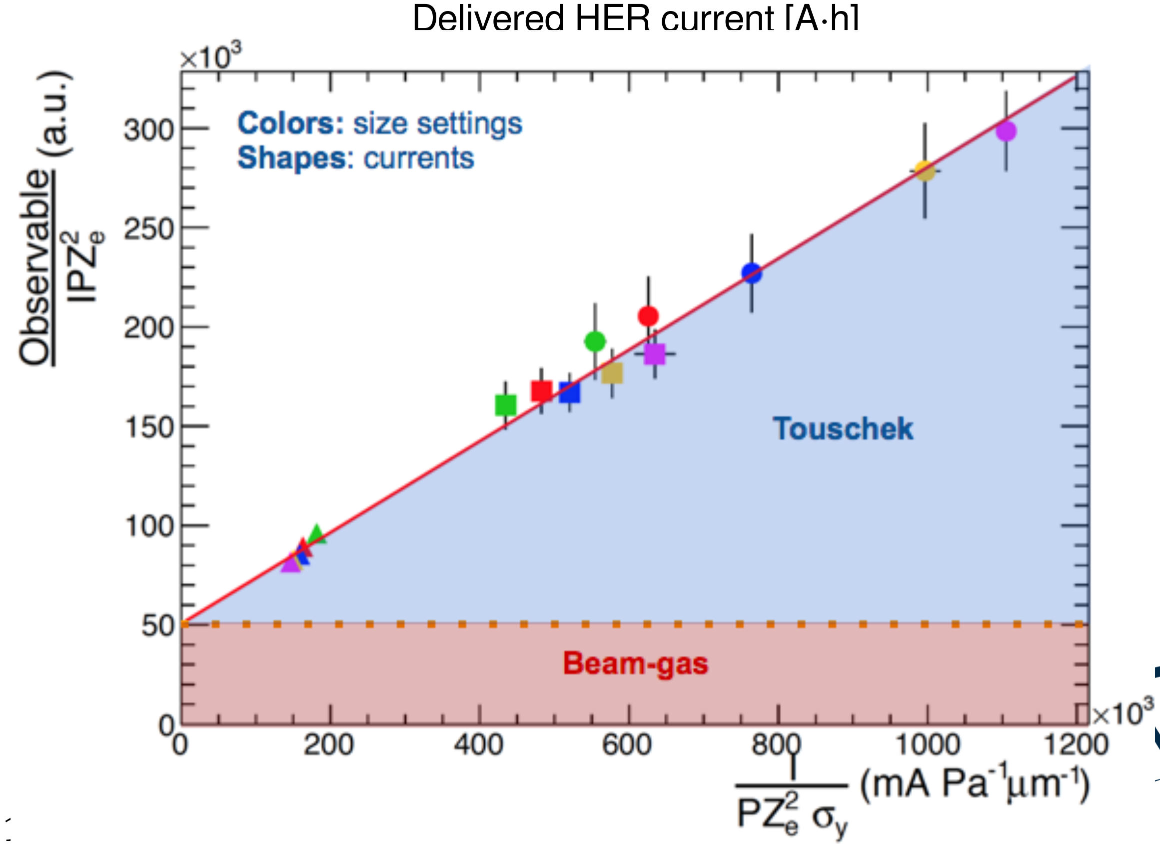
BEAST II - Phase 1

Beam **E**xorcisms for **A St**able Belle II Experiment



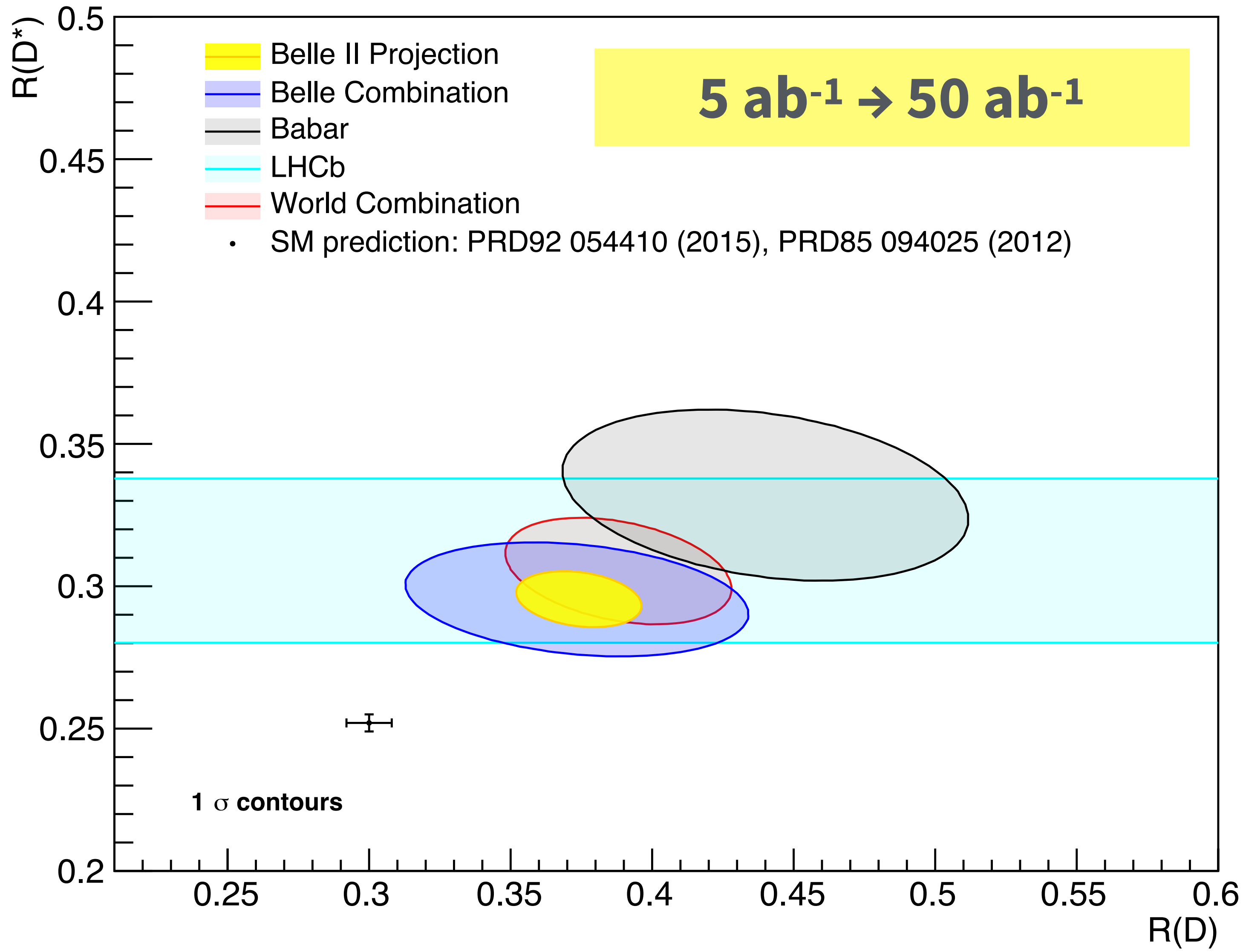


⇒ Rings vacuum scrubbing



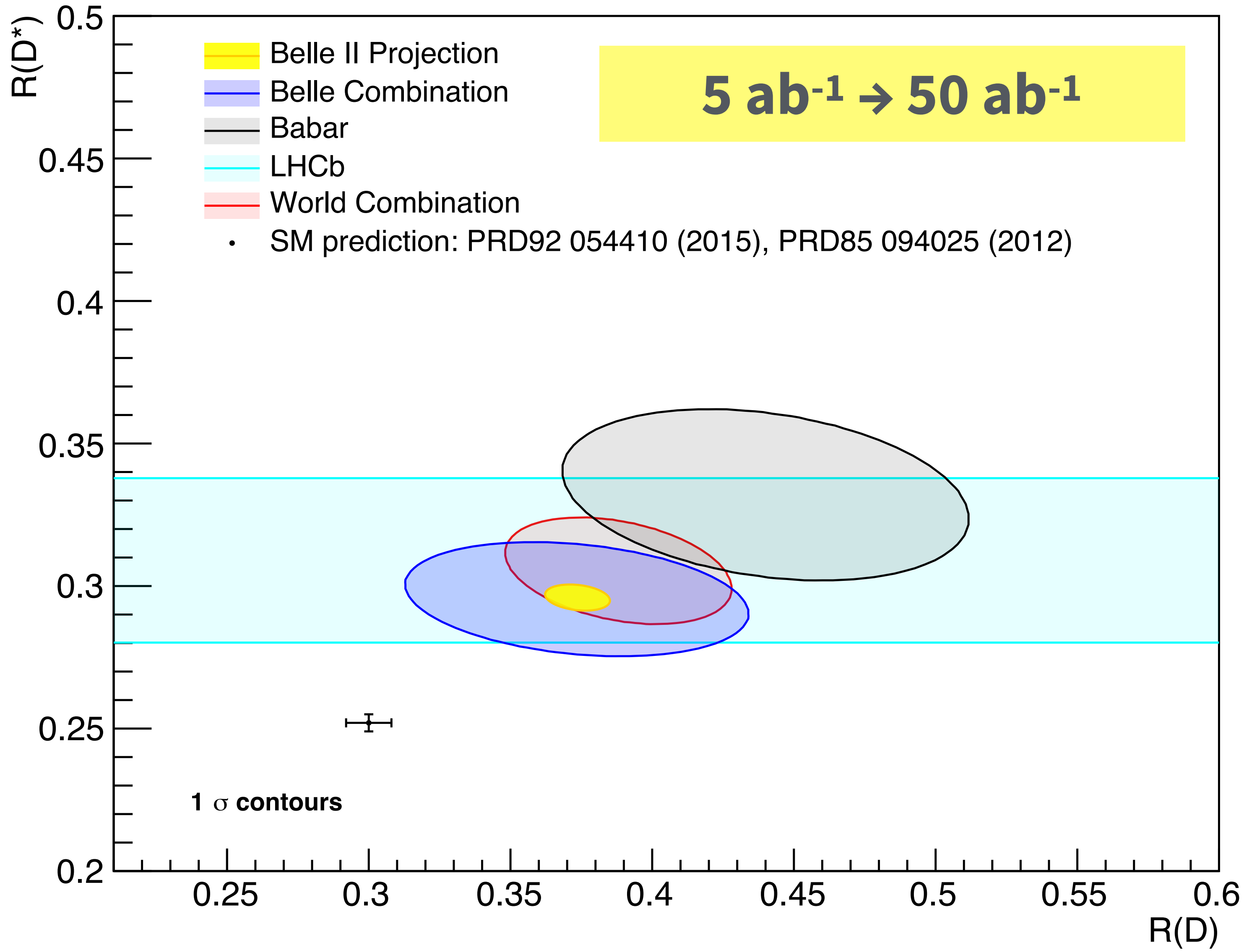
⇒ Touschek & beam-gas

Flavour anomaly in R(D) and R(D*)



Belle II should be able to confirm the excess with ~5 ab^{-1}

Flavour anomaly in R(D) and R(D*)



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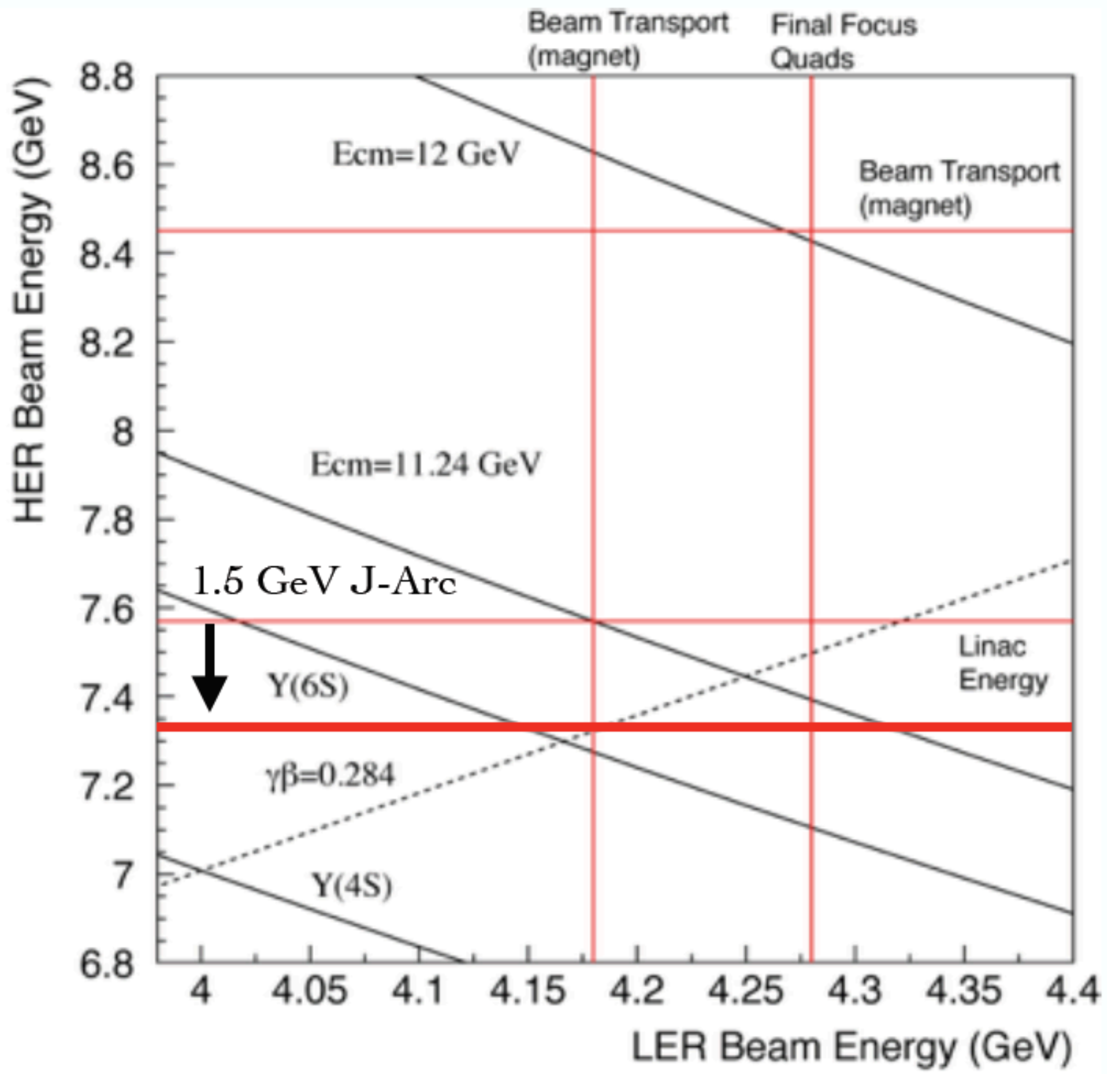
Super KEKB limitations



Y(4S)
HER: 7 GeV
LER: 4 GeV

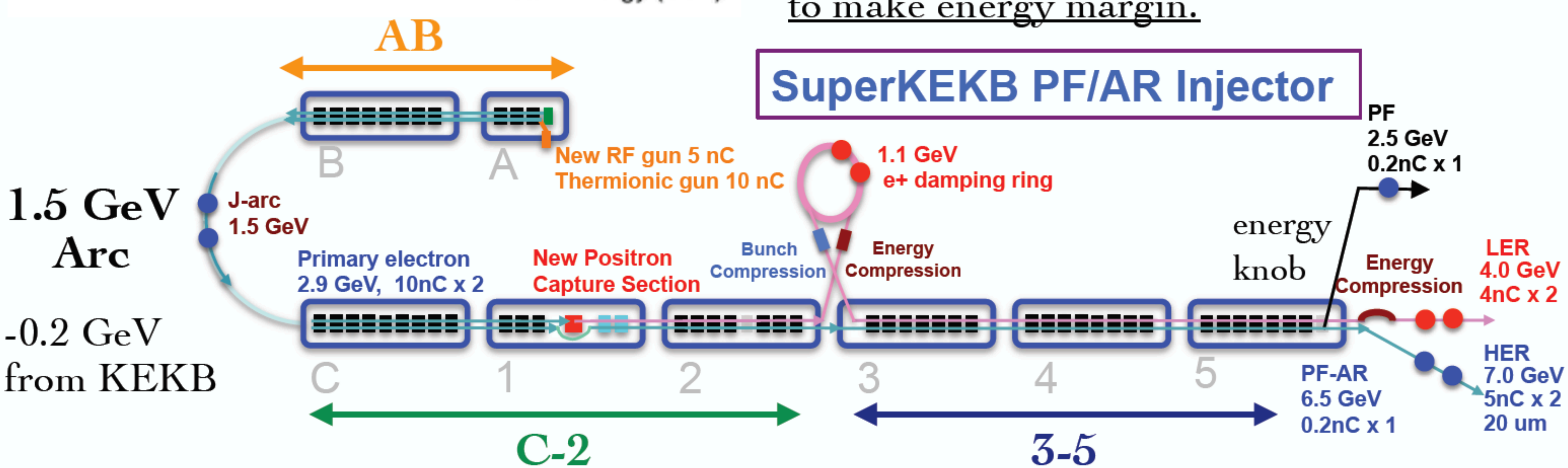
A - B sector : 1 backup unit
C - 2 sector: 1 backup unit
3 - 5 sector: 1 backup unit
(1 unit = 160 MeV)

C - 2 → 2 backup units in Phase 3

Y(6S)
HER: 7.30 GeV
no backup unit in C - 5 sector(max 7.35 GeV)
LER: 4.16 GeV
no backup unit in 3 - 5 sector(max 4.18 GeV)

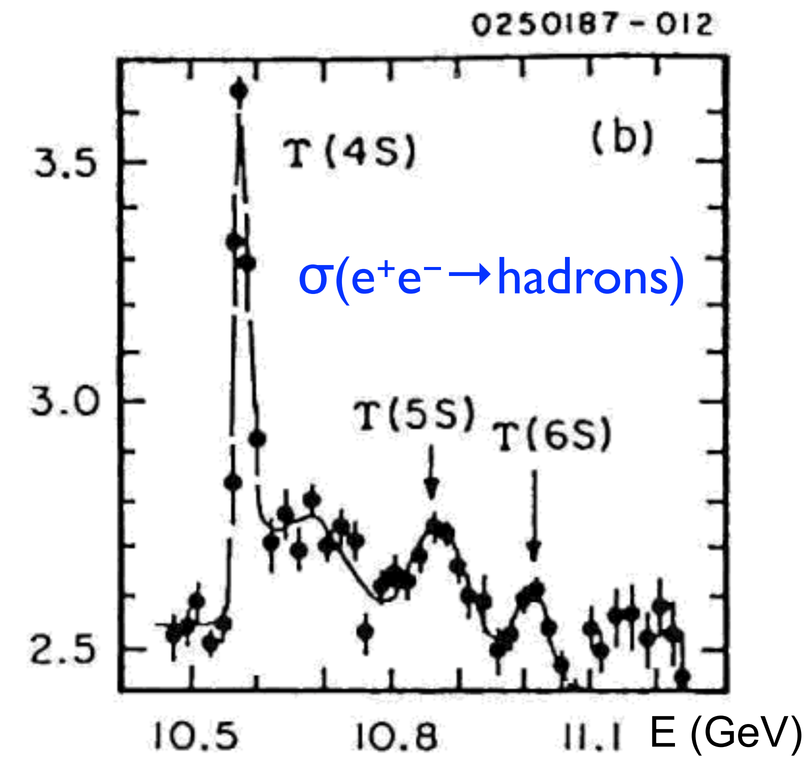
Risk at higher beam energy

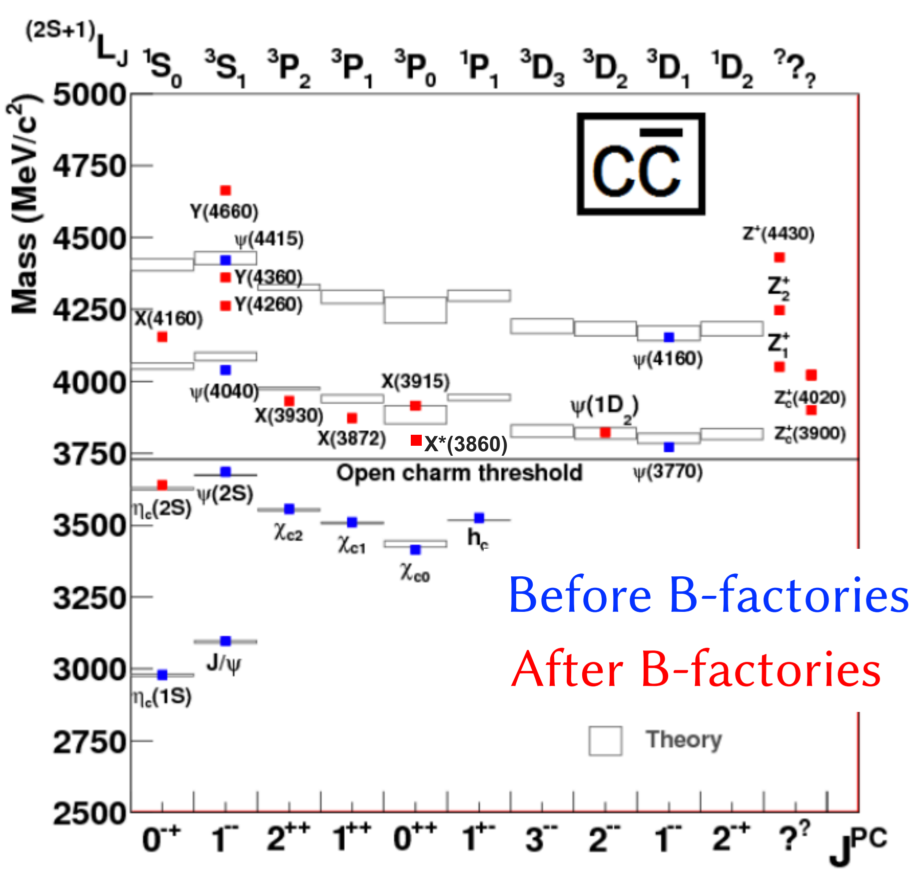
The old accelerating structures should be replaced to make energy margin.

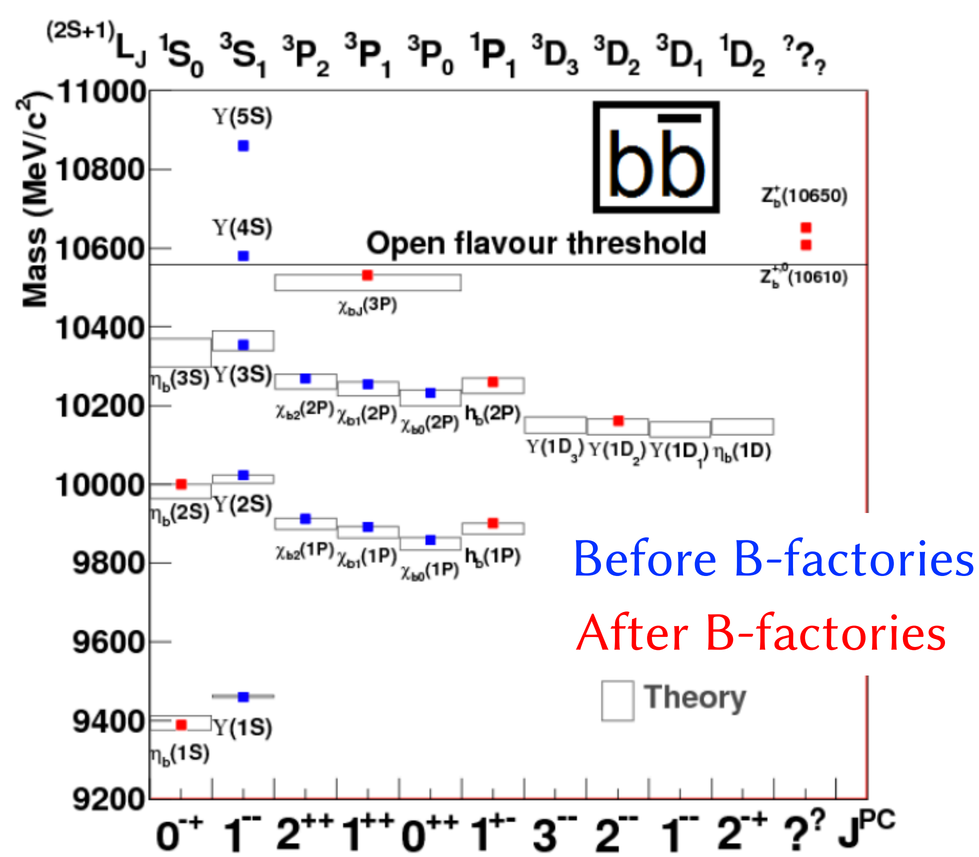


Quarkonia Spectroscopy

- Heavy quarkonia are bound states of *cc-bar* and *bb-bar* quarks
  - Heavy quark mass ⇒ NRQCD potential models predict spectra
  - Test perturbative and non-perturbative QCD



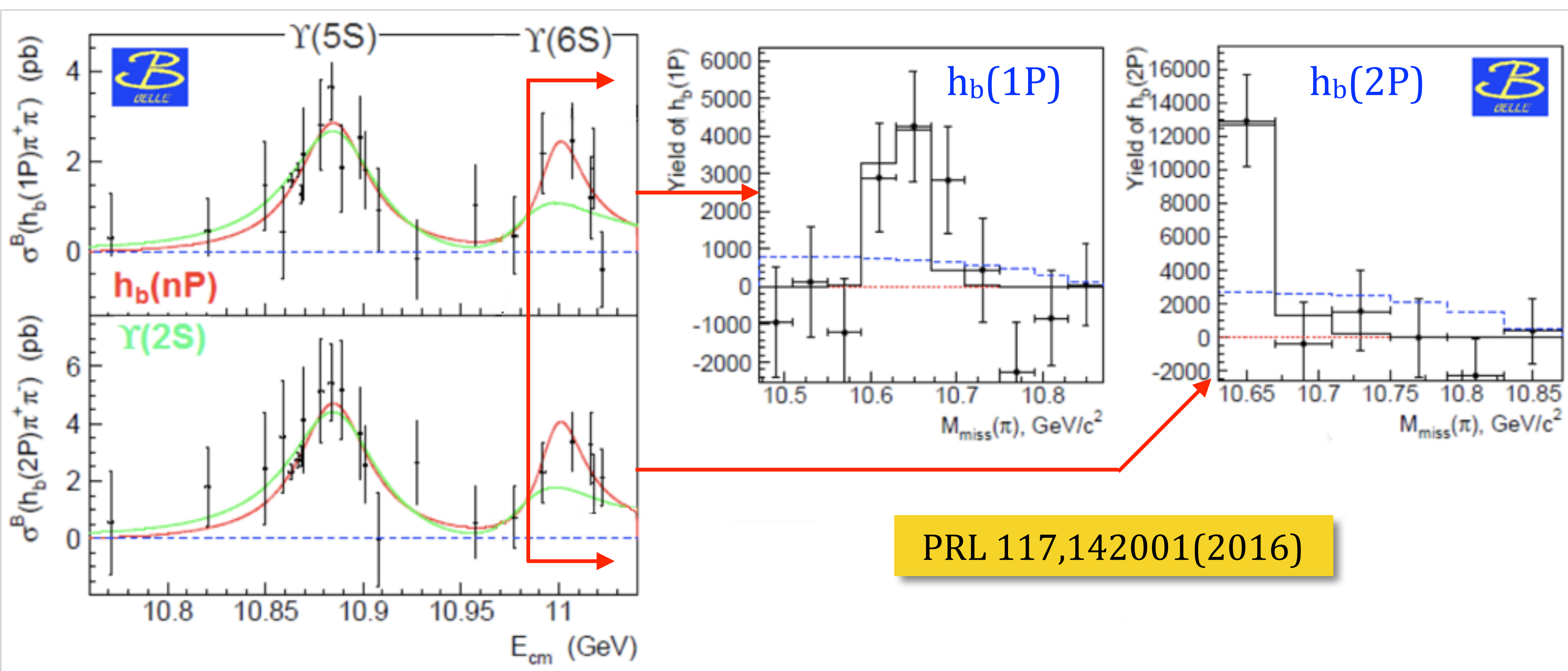




Study the Z_b at the $\Upsilon(6S)$

Phase II

- Evidence of $\Upsilon(6S) \rightarrow h_b(nP)\pi^+\pi^-$ transitions via π $Z_b(10610)$/ $Z_b(10650)$ decays obtained in Belle data
  - Resonance structure of decay could not be resolved
  - ~10 fb^{-1} at $\Upsilon(6S)$ would be sufficient to separate the $Z_b(10610)/Z_b(10650)$ contributions



PRL 117,142001(2016)

Missing $b\bar{b}$ states below threshold

Below threshold

* **3S**: η_b**(3S)** not yet observed by anyone, maybe reachable from **h_b(3P)**?

* **3P**: χ_b**(3P)** discovered at LHC, not yet resolved, can we see them from 4S?

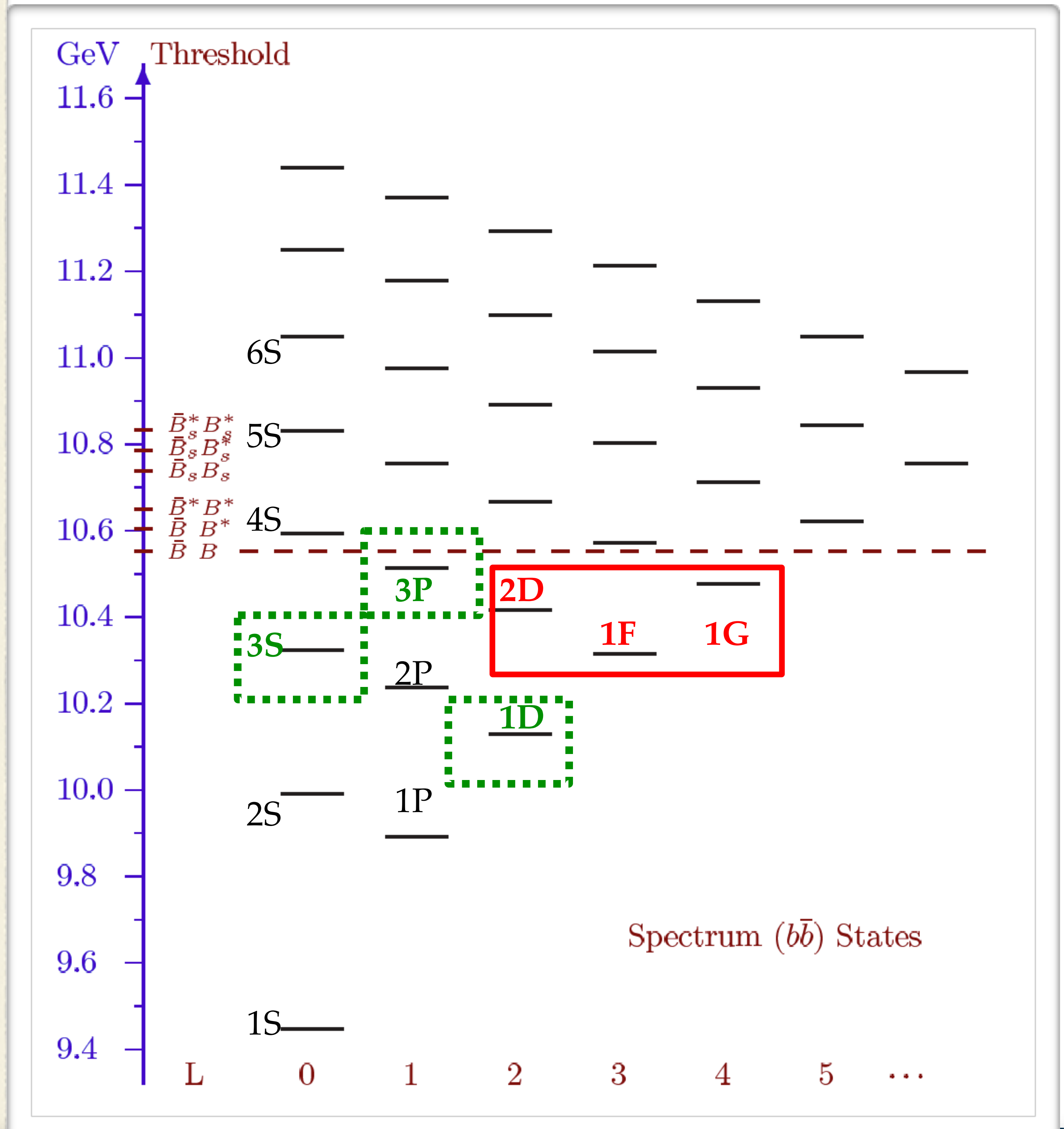
h_b(3P): too high to be reached from 5S via Z_b, maybe from 6S? How?

* **1D** states: triplet states best studied from 3S, singlet (2^{-+}) *maybe* reachable from h_b(2P). We plan to scan the 1^{--} region.

* **2D, 1F, 1G**: totally unknown

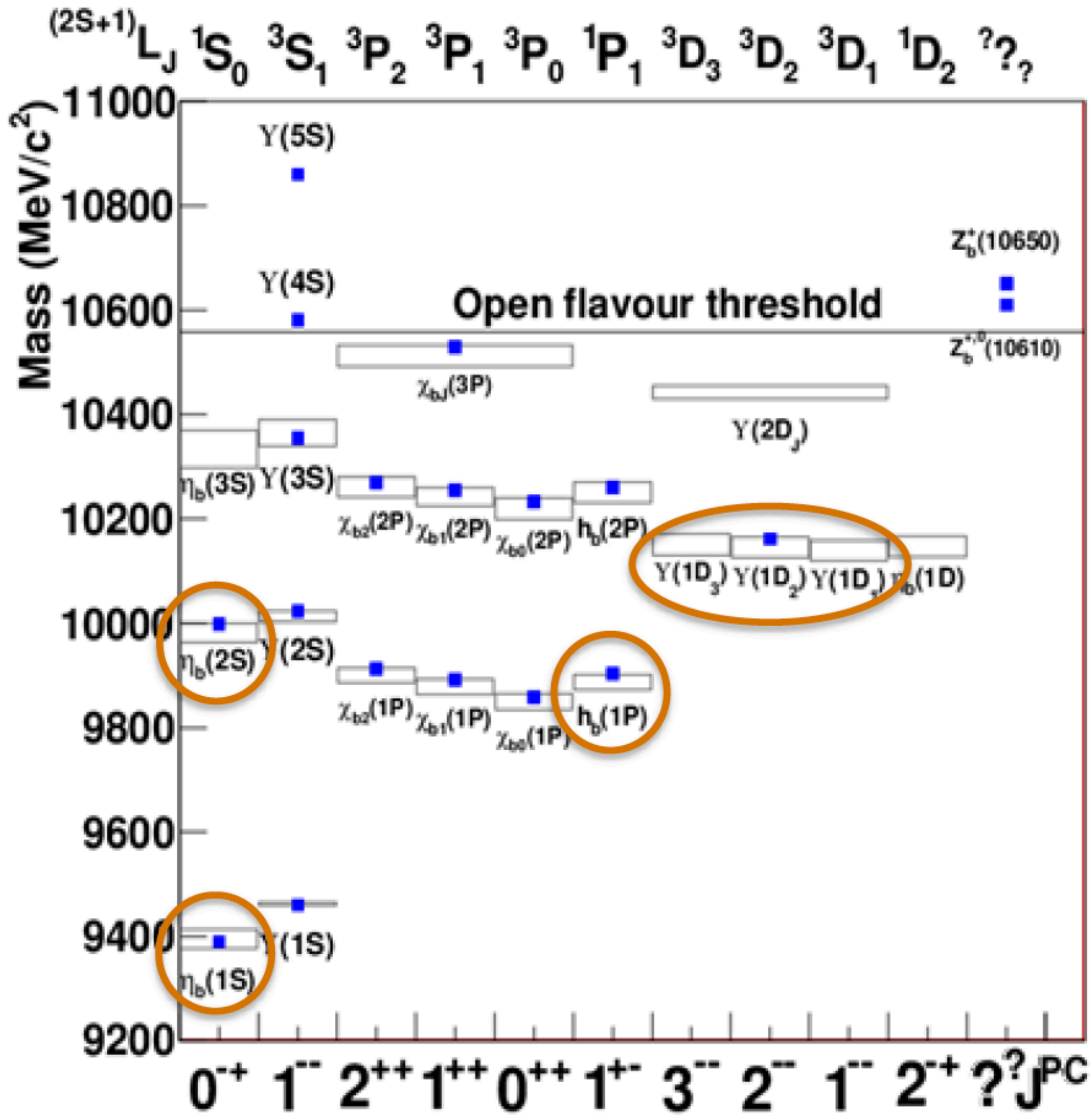
We propose to search for the lowest member of the 2D triplet with a scan. The others *may* be reached from 6S.

The **1F** triplet $2,3,4^{++}$ is very close in mass to Υ(3S), but may be reached from the 2D triplet via E1 radiative transitions.



A rich physics program at Υ(3S)

- **200fb^{-1} ~7xBaBar (Phase 3+)**
- $\Upsilon(1^3D_J)$ triplet
  - J=1,3 yet to be discovered
  - Pathways: 4γ, 2γ2π, incl. γ
- η_b(1S,2S)
  - Confirm m(η_b(1S,2S))
  - $\Upsilon(3S) \rightarrow \gamma\ \eta_b(2S)$
  - $\chi_{b0}(2P) \rightarrow \eta\ \eta_b(1S)$
- Hadronic ($\pi^o,\pi^+\pi^-,\eta,\omega$) decays
  - $\Upsilon(3S) \rightarrow \pi^o h_b(1P)$, $\eta\Upsilon(1S)$
  - $\Upsilon(1D) \rightarrow \eta\Upsilon(1S)$
  - $\chi_b(2P)$: $\omega\Upsilon(1S)$, $\pi^+\pi^-\chi_{bJ}(1P)$
- Radiative transitions



Bottomonium samples

Needs to fulfill the bottomonium program

100 fb^{-1} @ Υ(6S) +
300 fb^{-1} @ Υ(3S) +
400 fb^{-1} @ Υ(5S)-Υ(6S) scan +

0.8 ab^{-1} for bottomonium only (1.6% of BelleII dataset)

1 ab^{-1} @ Υ(5S) (for Bs also) =

1.8 ab^{-1} for bottomonium + Bs (3.6 % of BelleII dataset)

Minimum needs to produce new results

60 fb^{-1} @ Υ(3S) Not enough lumi in PhaseII

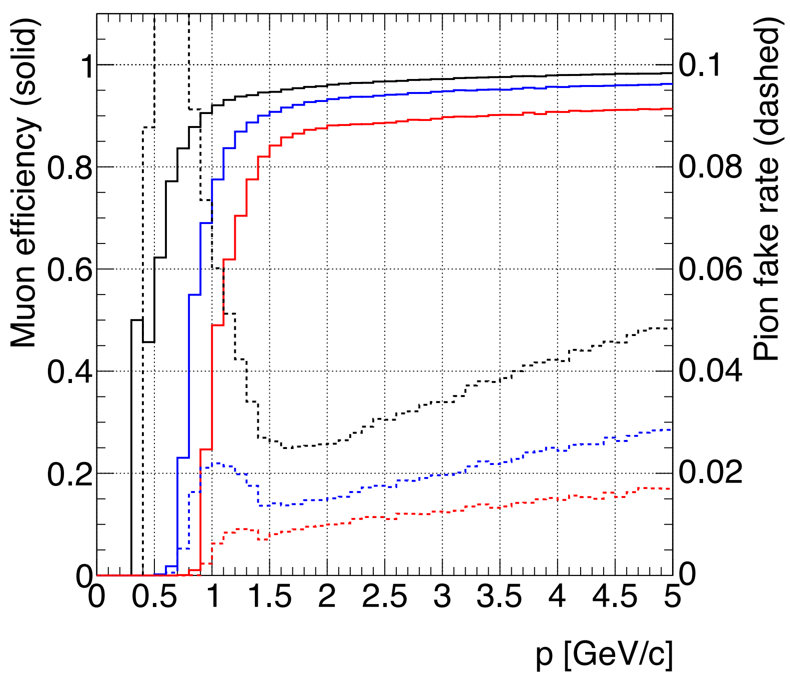
200 fb^{-1} @ Υ(5S) Not enough lumi in PhaseII

10 fb^{-1} @ Υ(6S) sqrt(s) too high for PhaseII

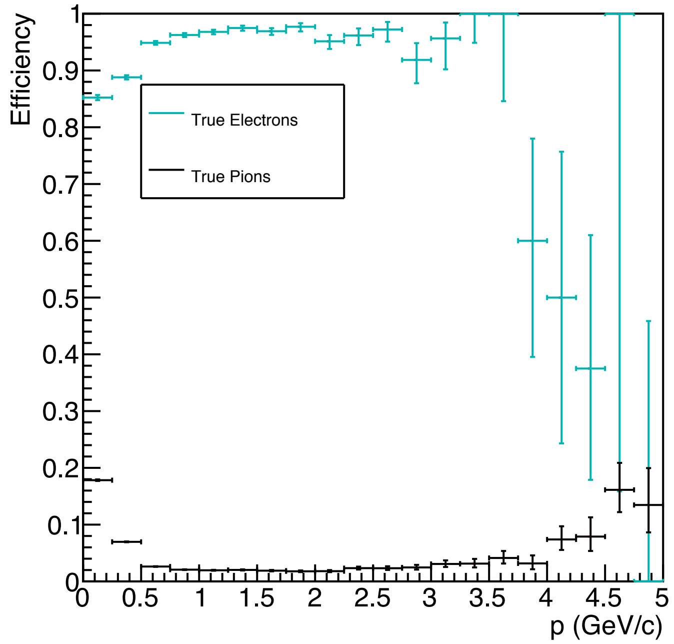
10-20 fb^{-1} @ 10.7 → 10.8 GeV mini-scan Doable?

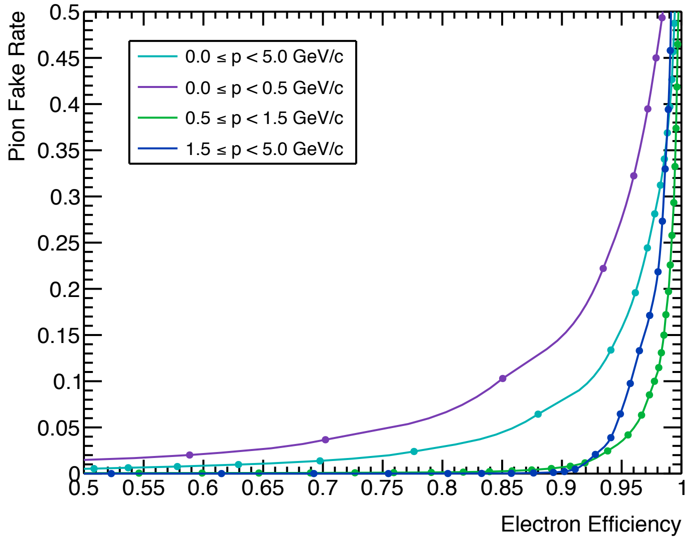
Belle II - PID

muon ID



electron ID

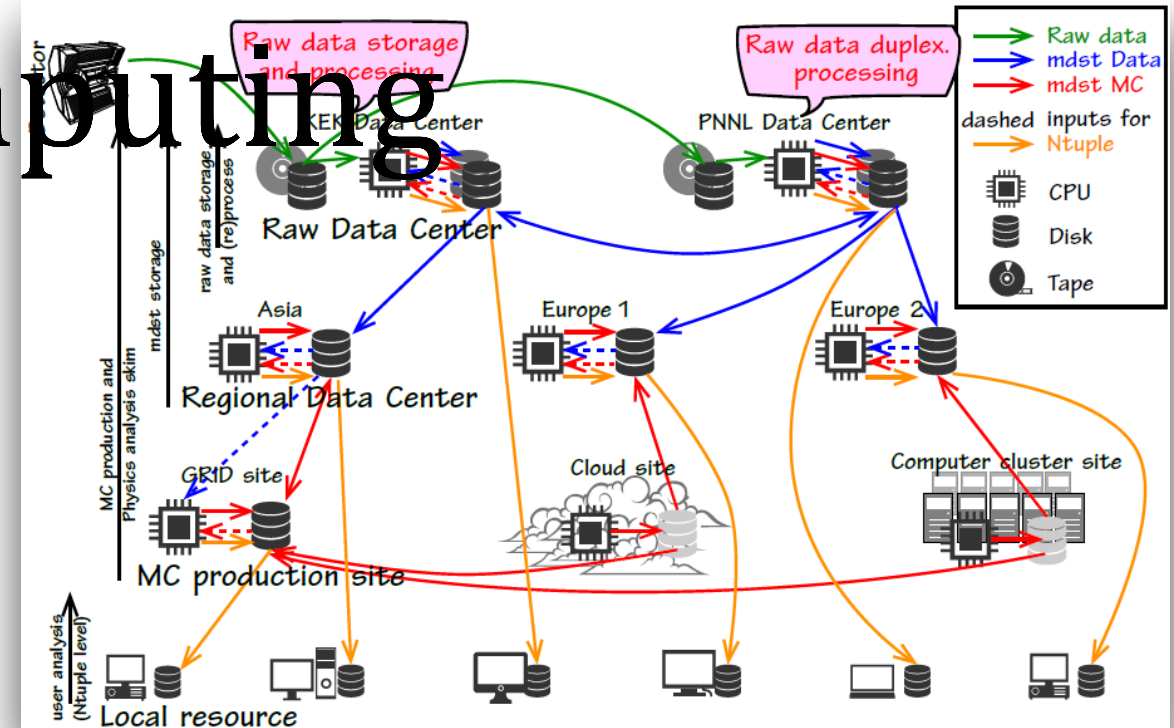


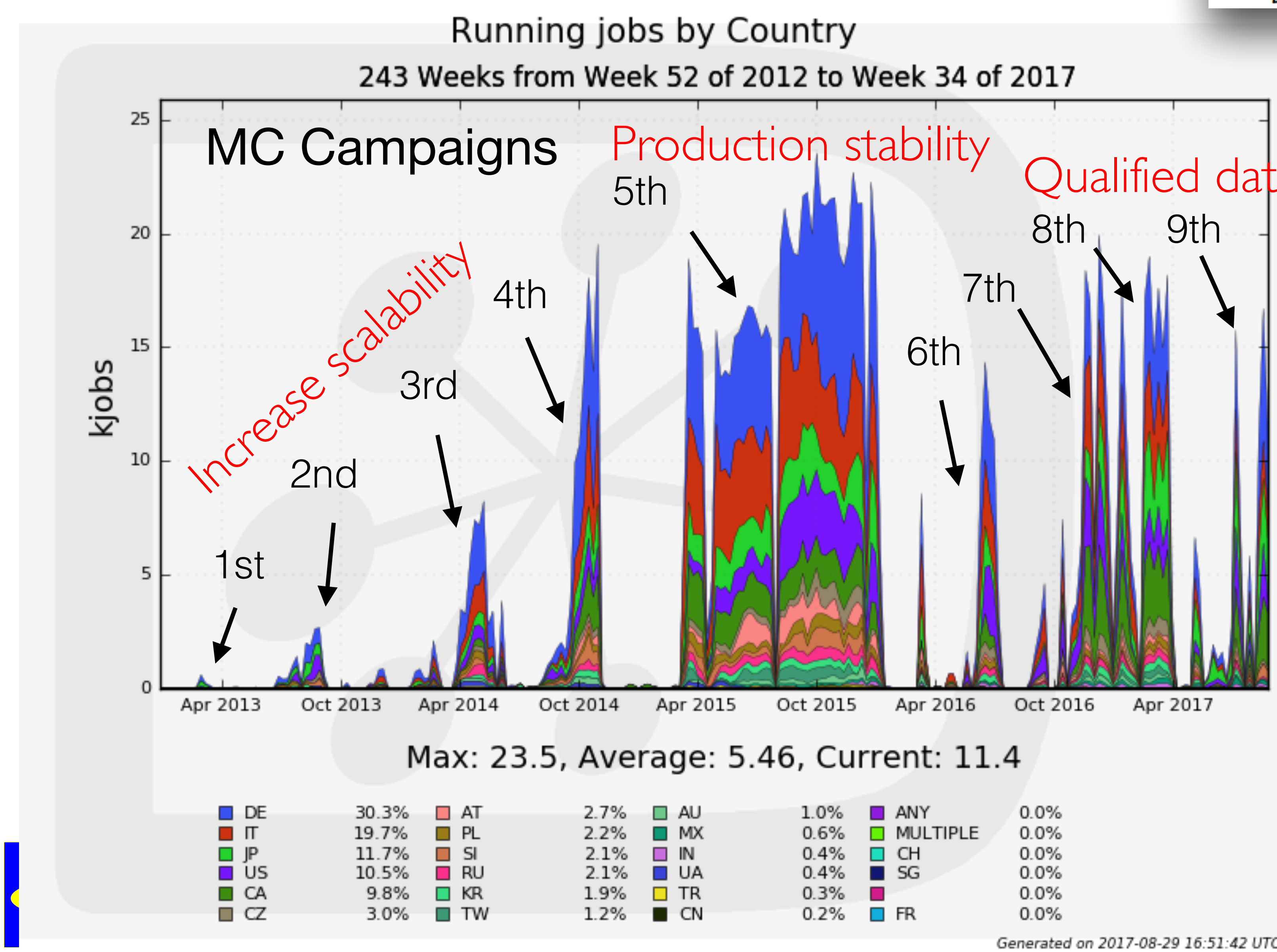


Offline computing

Distributed computing following the LHC model

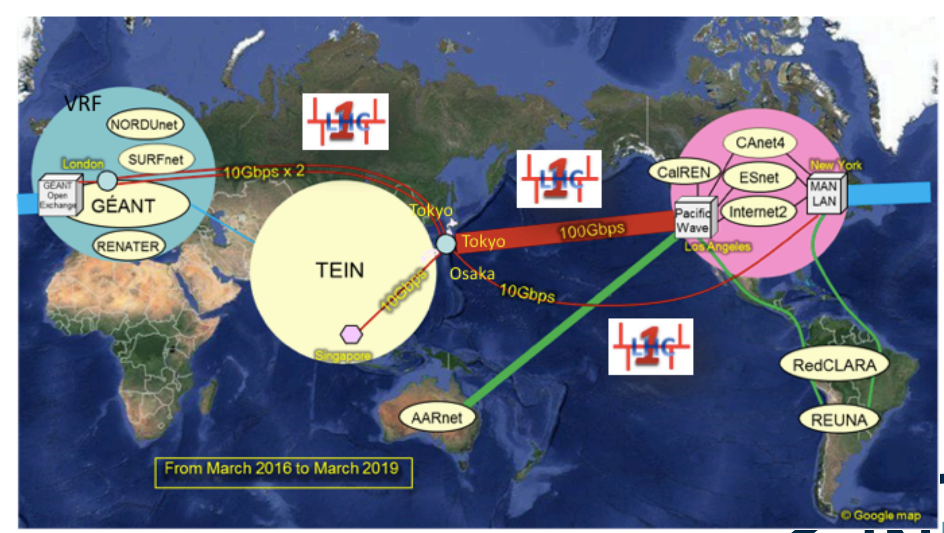
- Manage the processing of massive data sets
- Production of large MC samples
- Many concurrent user analysis jobs





High speed networking data challenge in 2016:

- Belle II networking requirements are satisfied



Simulated Background Rates in Belle 2

Table 22: Beam background types (12th background campaign).

type	source	rate [MHz]
radiative Bhabha	HER	1320
radiative Bhabha	LER	1294
radiative Bhabha (wide angle)	HER	40
radiative Bhabha (wide angle)	LER	85
Touschek scattering	HER	31
Touschek scattering	LER	83
beam-gas interactions	HER	1
beam-gas interactions	LER	156
two-photon QED	-	206

← Total rates from simulation

Total number of hits per event in each sub-detector ↓

component	background	generic $B\overline{B}$
PXD	10000 (580)*	23
SVD	284 (134)	108
CDC	654	810
TOP	150	205
ARICH	191	188
ECL	3470	510
BKLM	484	33
EKLM	142	34

* in parentheses numbers without 2-γ QED

Backgrounds are ~ x20 Belle

CKM & CPV

$\sin(2\beta/\Phi_1)$

Table 26: Expected uncertainties on the S and A parameters for the channels sensitive to $\sin(2\phi_1)$ discussed in this chapter for an integrated luminosity of 5 and 50 ab^{-1}. The present (2017) World Average [1] errors are also reported.

	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK_S^0	0.21	0.14	0.08	0.06	0.024	0.020
$K_S^0\pi^0\gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K_S^0\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

CKM & CPV

α/Φ_2

Table 21: Branching fractions, fractions of longitudinally polarised events and CP asymmetry parameters entering in the isospin analysis of the $B \to \rho\rho$ system: Belle measurements at 0.8 ab^{-1} and 0.08 ab^{-1}, BaBar measurements at 0.5 ab^{-1} and expected Belle II sensitivity at 50 ab^{-1}.

$B^0 \to \rho\rho$

	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [78]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [84]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm 1.5 \pm 1.5$ [78]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm 0.30 \pm 0.15$ [84]	$\pm 0.04 \pm 0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm 0.10 \pm 0.06$ [78]	$\pm 0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm 0.15 \pm 0.05$ [78]	$\pm 0.02 \pm 0.01$
	Value	0.08 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm 0.11 \pm 0.02$ [69]	$\pm 0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm 7.1 \pm 5.3$ [69]	$\pm 0.3 \pm 0.5$
	Value	0.5 ab^{-1}	50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm 0.8 \pm 0.3$ [68]	$\pm 0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm 0.7 \pm 0.2$ [68]	$\pm 0.07 \pm 0.01$

Evaluation of systematic errors

- Extrapolate from Belle/BaBar
  - reducible systematics: scaled with luminosity
  - total systematics: reducible $\oplus$ irreducible

CKM & CPV

Table 20: Branching fractions and CP asymmetry parameters entering in the isospin analysis of the $B \to \pi\pi$ system: Belle measurements at 0.8 ab^{-1} together with the expected Belle II sensitivity at 50 ab^{-1}.

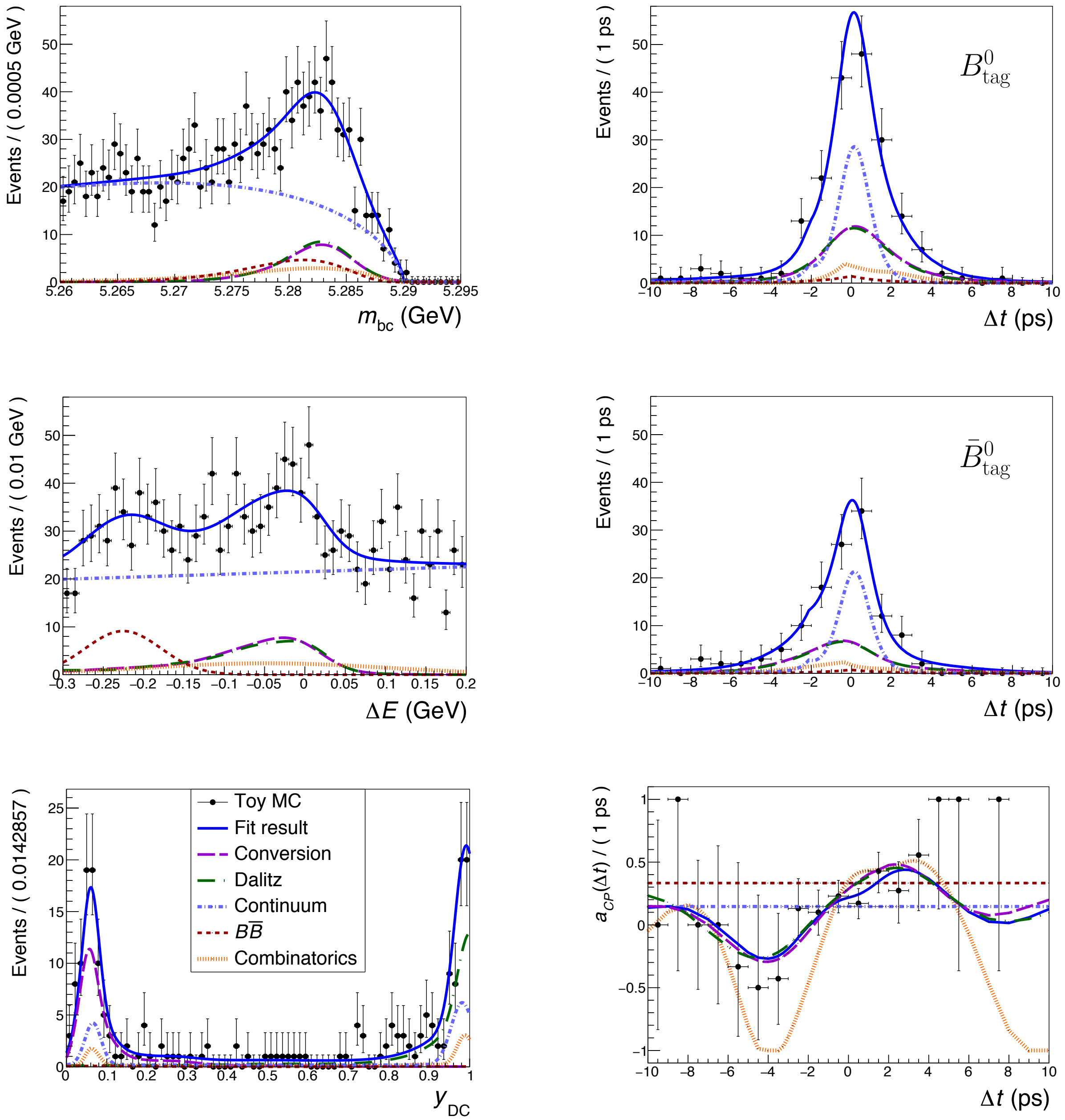
$B^0 \to \pi\pi$

	Value	0.8 ab^{-1}	50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm 0.21 \pm 0.18$ [82]	$\pm 0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm 0.19 \pm 0.18$ [81]	$\pm 0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm 0.26 \pm 0.38$ [82]	$\pm 0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm 0.06 \pm 0.03$ [83]	$\pm 0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm 0.08 \pm 0.03$ [83]	$\pm 0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm 0.36 \pm 0.12$ [81]	$\pm 0.03 \pm 0.01$

α/Φ_2

Full MC Sensitivity Study - $B^0 \to \pi^0\pi^0$

α/Φ_2



in 50 ab^{-1}

270 evt $B^0 \to \pi^0$_dalitz π^0

50 evt $B^0 \to \pi^0$(conv)π^0

Table 18: Fraction of generated events in the acceptance n^{acc}_{gen}/n_{gen}, reconstruction efficiency n_{rec}/n^{acc}_{gen} and efficiency after final selection $n^{FS}_{rec}/n^{acc}_{gen}$ (the efficiencies are normalised to the number of generated events in the acceptance n^{acc}_{gen}). Events with converted photons and Dalitz π^0s (first and second rows) were reconstructed as $B^0_{sig} \to \pi^0_{dal}\ \pi^0_{\gamma\gamma}$. The highlighted row corresponds to the whole set used for time dependent CP-analysis.

Decay. Channel	n^{acc}_{gen}/n_{gen} [%]	n_{rec}/n^{acc}_{gen} [%]	$n^{FS}_{rec}/n^{acc}_{gen}$ [%]
$B^0 \to \pi^0_{dal}\ \pi^0_{\gamma\gamma}$	2.0	52.0	7.2
$B^0 \to \pi^0_{\gamma_c\gamma}\ \pi^0_{\gamma\gamma}$	3.0	48.8	4.2
Dal + Conv	5.0	50.1	5.4
$B^0 \to \pi^0_{\gamma\gamma}\ \pi^0_{\gamma\gamma}$	76.2	86.0	19.2

Table 19: Purity and fraction $\frac{n_{combin}}{n_{sig}+n_{comb}}$ of wrongly reconstructed signal events (combinatorial background) after the final selection.

Decay Channel	Purity [%]	$n_{combin}/n_{sig} + n_{comb}$ [%]
Dal + Conv	17.6	1.1
$B^0 \to \pi^0_{\gamma\gamma}\ \pi^0_{\gamma\gamma}$	15.8	1.0

$B^0 \to \pi\pi$ α/Φ_2 $B^0 \to \rho\rho$

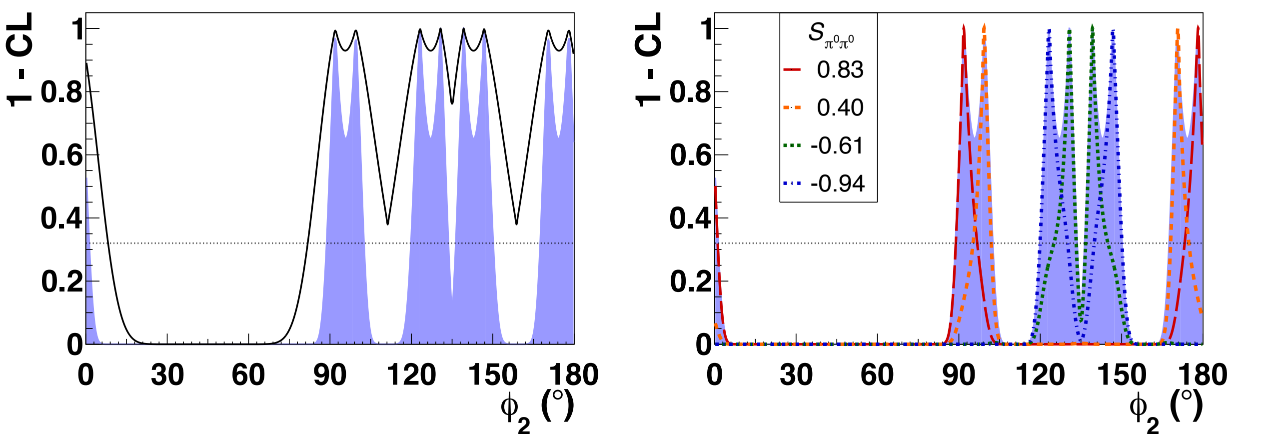


Fig. 18: Scan of the confidence for ϕ_2 performing isospin analysis of the $B \to \pi\pi$ system. The black solid line (left) shows the result of the scan using data from Belle measurements (S. Table 20). The blue shaded area in both plots shows the projection for Belle II. Results of the scan adding the $S_{\pi^0\pi^0}$ constraint (right): Each line shows the result for a different $S_{\pi^0\pi^0}$ value. The dotted horizontal lines correspond to one σ.

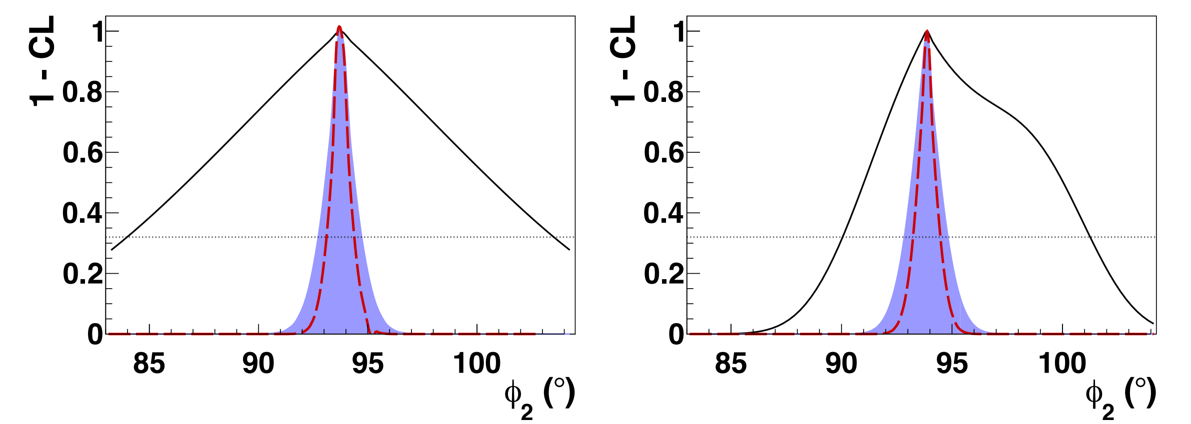


Fig. 20: Scans of the confidence for ϕ_2 performing an isospin analysis of the $B \to \rho\rho$ system (left) and combining the isospin analyses of the $B \to \pi\pi$ and the $B \to \rho\rho$ systems (right). The black solid lines show the results of the scans using data from measurements at current precision (S. Tables 21 and 20). The blue shaded areas show the projections for Belle II. The red long dashed lines show the results of the scans adding the S_{00} constraints: $S_{\rho^0\rho^0} = -0.14$ and $S_{\pi^0\pi^0} = 0.75$. The dotted horizontal lines correspond to one σ.

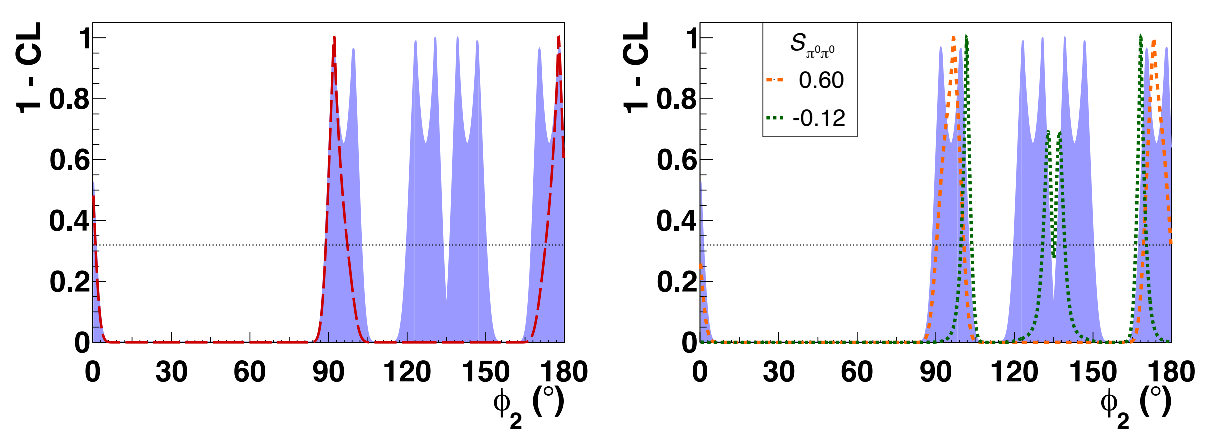


Fig. 19: Scan of the confidence for ϕ_2 performing isospin analysis of the $B \to \pi\pi$ system. The blue shaded area in both plots shows the projection of the Belle measurements (S. Fig. 18) for Belle II. Results of the scan with additional $S_{\pi^0\pi^0}$ constraints are shown by dashed lines. Each line correspond to different input $S_{\pi^0\pi^0}$ values. The red long dashed line on the left figure shows the result for $S_{\pi^0\pi^0} = 0.83$. The dotted horizontal line correspond to one σ.

Table 27: Current world average error [2] and expected uncertainties on the determination of ϕ_2 performing isospin analyses of the decay systems $B \to \pi\pi$ and $B \to \rho\rho$ together with a combined isospin analysis of these two systems. For the current world average error, also the decay system $B \to \rho\pi$ was considered.

Channel	$\Delta\phi_2$ [°]
Current world average	$^{+4.4}_{-4.0}$
$B \to \pi\pi$	4.0
$B \to \rho\rho$	0.7
$B \to \pi\pi$ and $B \to \rho\rho$ Combined	0.6

π^0 Transition Form Factor

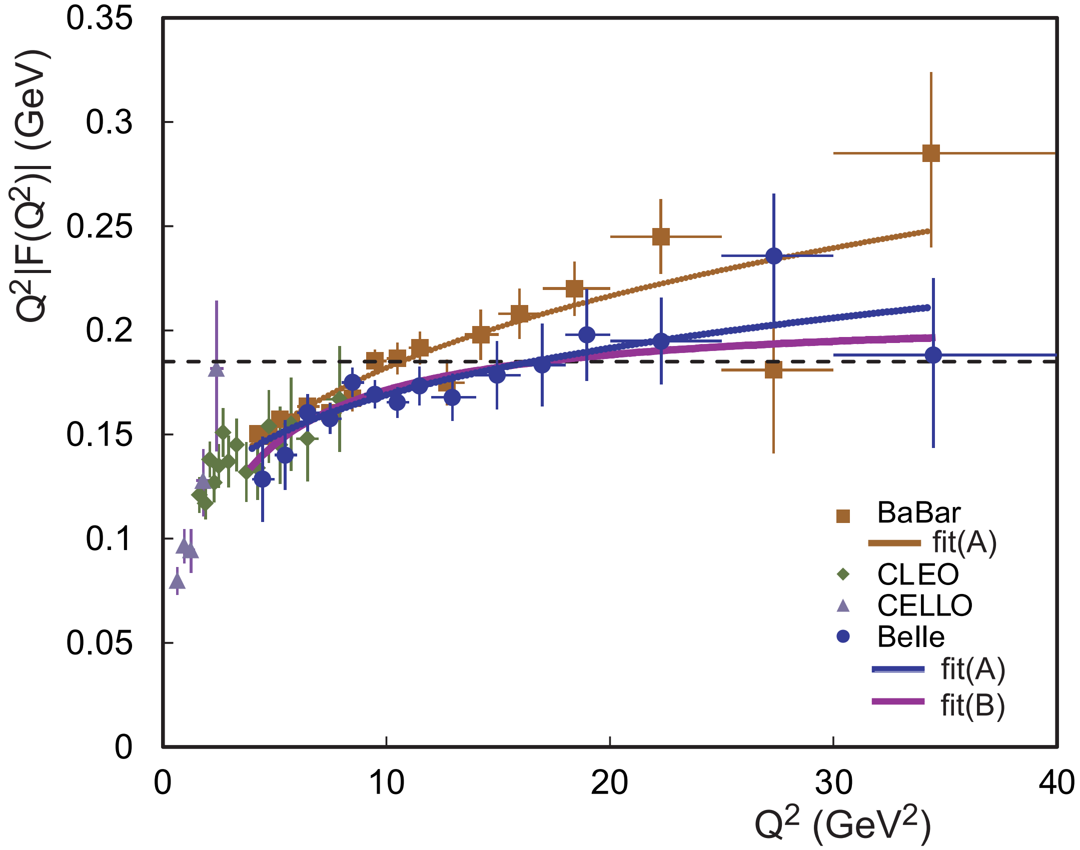


FIG. 24: Comparison of the results for the product $Q^2|F(Q^2)|$ for the π^0 from different experiments. The error bars are a quadratic sum of statistical and systematic uncertainties. For the Belle and BaBar results, only a Q^2-dependent systematic-error component is included. The two curves denoted fit(A) use the BaBar parameterization while the curve denoted fit(B) uses Eq.(23) (see the text). The dashed line shows the asymptotic prediction from pQCD (~ 0.185 GeV).

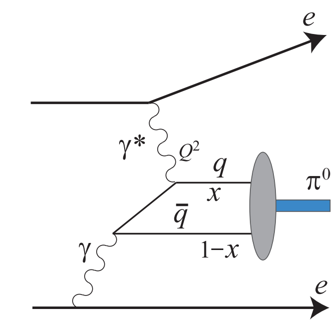


FIG. 1: A Feynman diagram for $\gamma\gamma^* \to q\bar{q} \to \pi^0$ in e^+e^- collisions

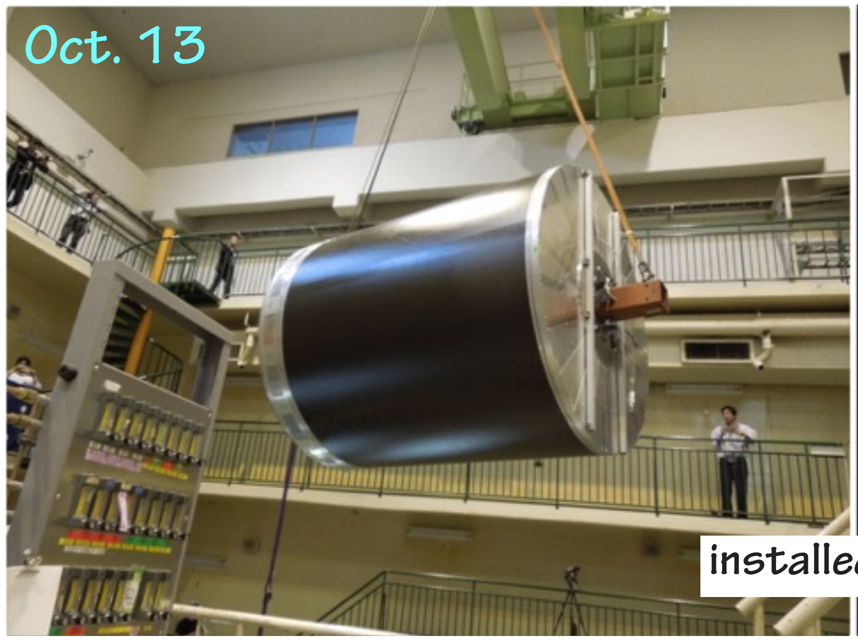
2-γ process

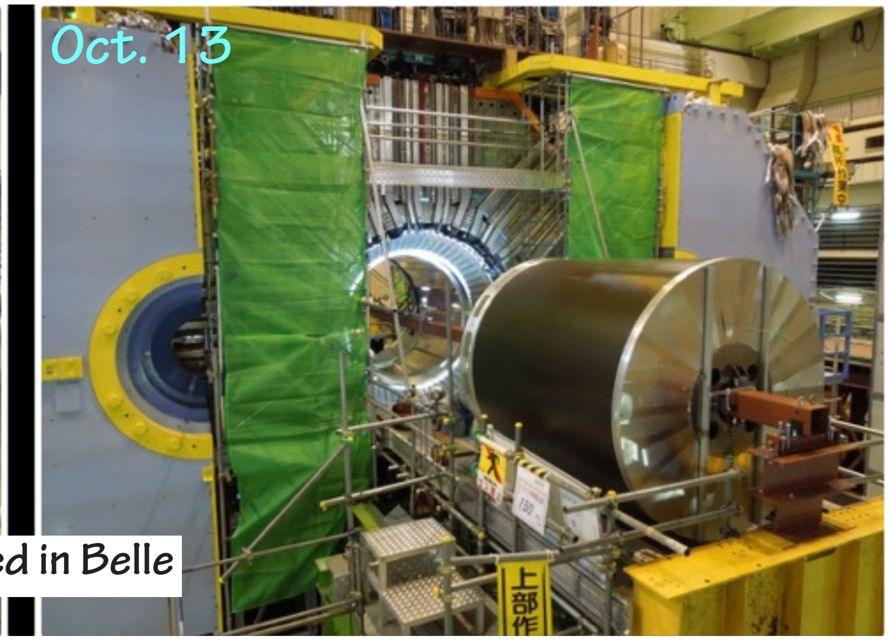
Belle, 2012, 759 fb^{-1}

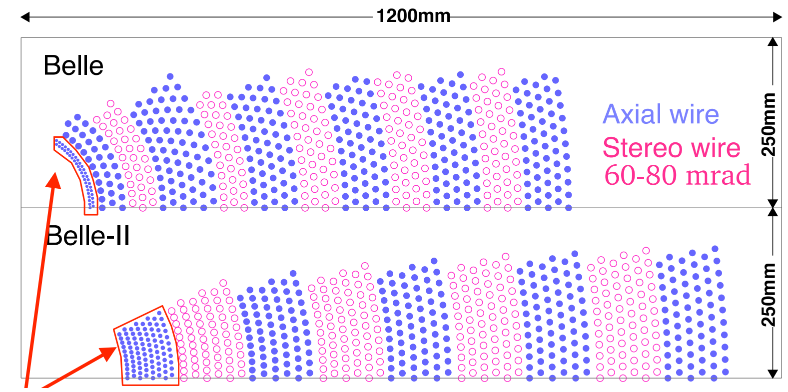
TABLE III: $e^+e^- \to (e)e\pi^0$ differential cross section combined for the p- and e-tags with systematic uncertainties ($\epsilon_{\rm sys}$) and the transition form factor $Q^2|F(Q^2)|$. The first and second uncertainties for $Q^2|F(Q^2)|$ are statistical and systematic, respectively.

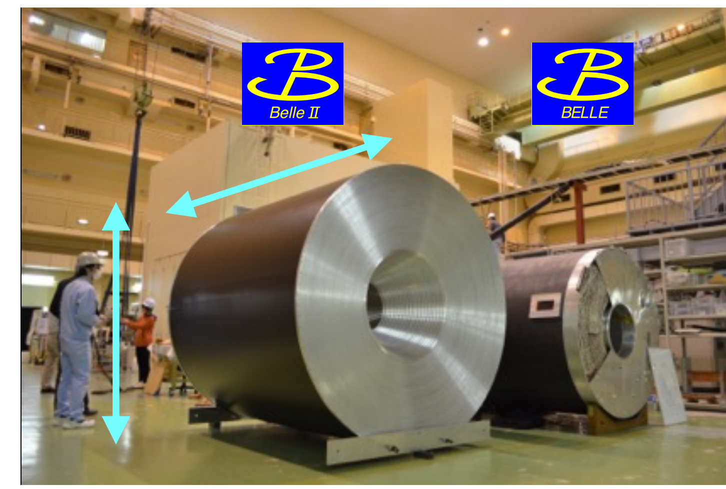
Q^2 (GeV^2)	$d\sigma/dQ^2$ (fb/GeV^2)	$\epsilon_{\rm sys}$ (%)	$Q^2\lvert F(Q^2)\rvert$ (GeV)
4.46	75.0 ± 22.3	10	$0.129 \pm 0.020 \pm 0.006$
5.47	43.3 ± 9.6	9	$0.140 \pm 0.016 \pm 0.007$
6.47	31.15 ± 2.64	10	$0.161 \pm 0.007 \pm 0.008$
7.47	17.86 ± 1.38	8	$0.158 \pm 0.006 \pm 0.007$
8.48	13.88 ± 0.85	8	$0.175 \pm 0.005 \pm 0.007$
9.48	8.62 ± 0.55	8	$0.169 \pm 0.005 \pm 0.007$
10.48	5.68 ± 0.42	8	$0.165 \pm 0.006 \pm 0.007$
11.48	4.44 ± 0.41	9	$0.173 \pm 0.008 \pm 0.007$
12.94	2.65 ± 0.23	12	$0.168 \pm 0.007 \pm 0.010$
14.95	1.73 ± 0.22	14	$0.179 \pm 0.012 \pm 0.013$
16.96	1.123 ± 0.208	13	$0.183 \pm 0.017 \pm 0.012$
18.96	0.845 ± 0.160	13	$0.198 \pm 0.019 \pm 0.013$
22.29	0.431 ± 0.074	14	$0.195 \pm 0.017 \pm 0.013$
27.33	0.275 ± 0.064	14	$0.236^{+0.026}_{-0.029} \pm 0.016$
34.46	0.066 ± 0.027	14	$0.188^{+0.035}_{-0.043} \pm 0.013$

The Central Drift Chamber (CDC)

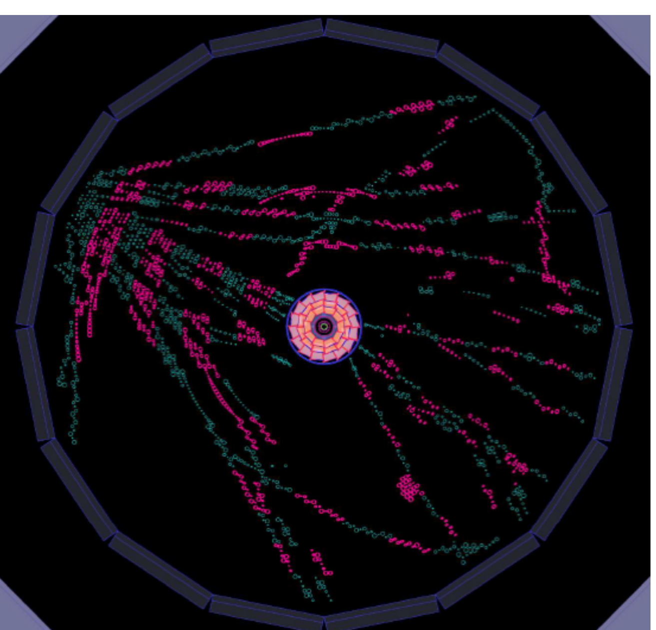


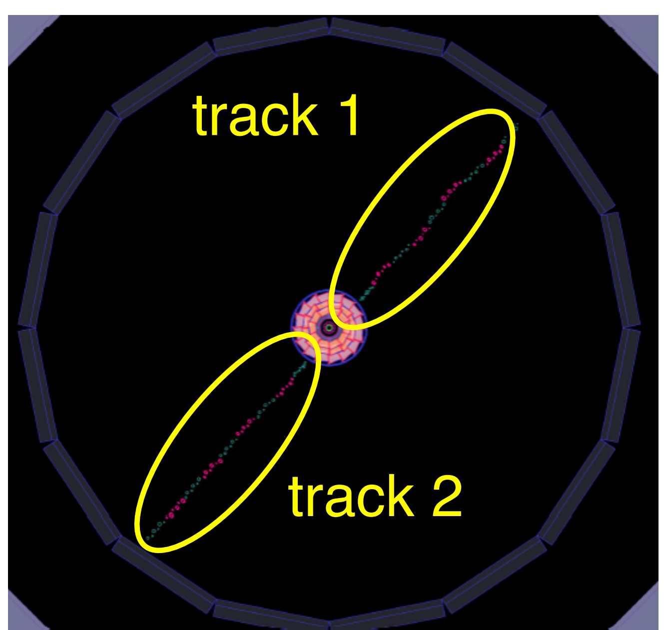


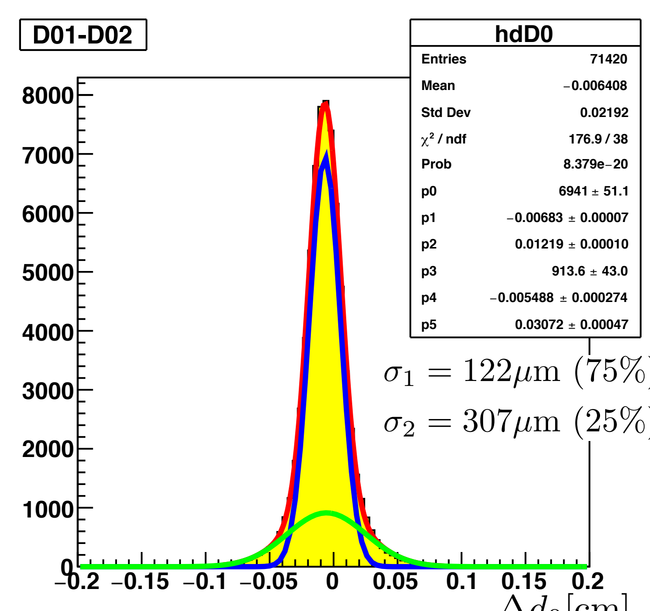


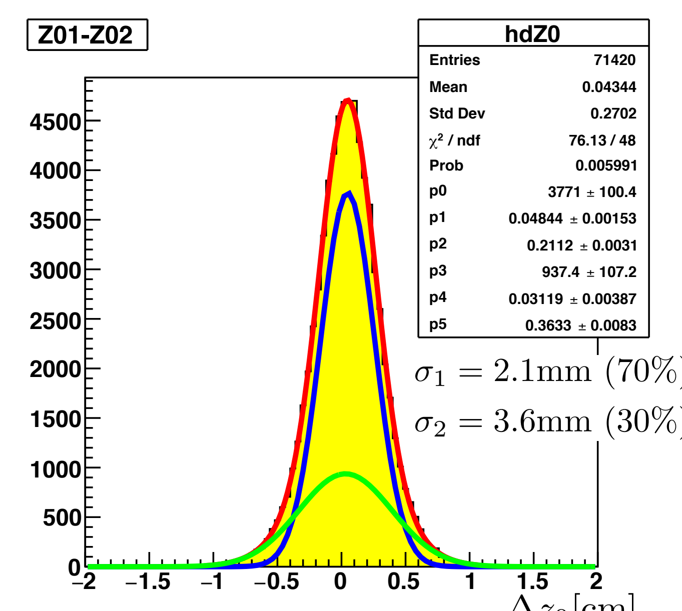


- Installed on Oct, 2016
- Commissioning with cosmic ray tracks is ongoing





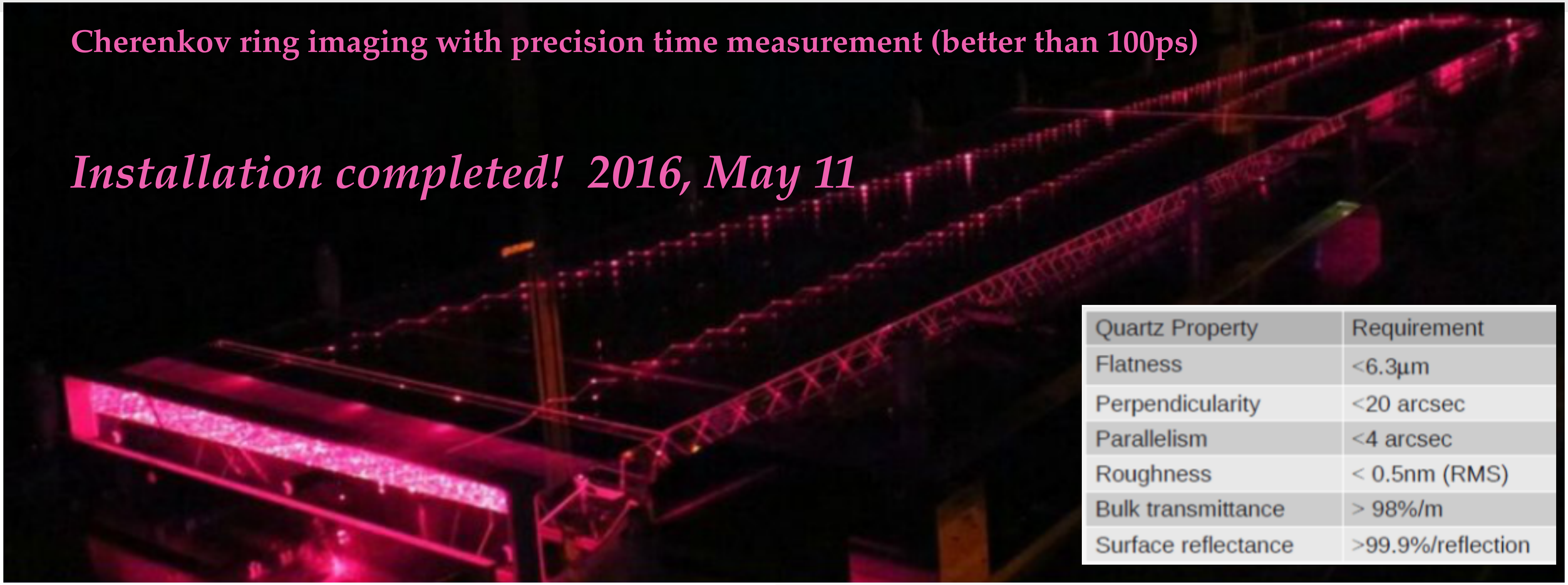




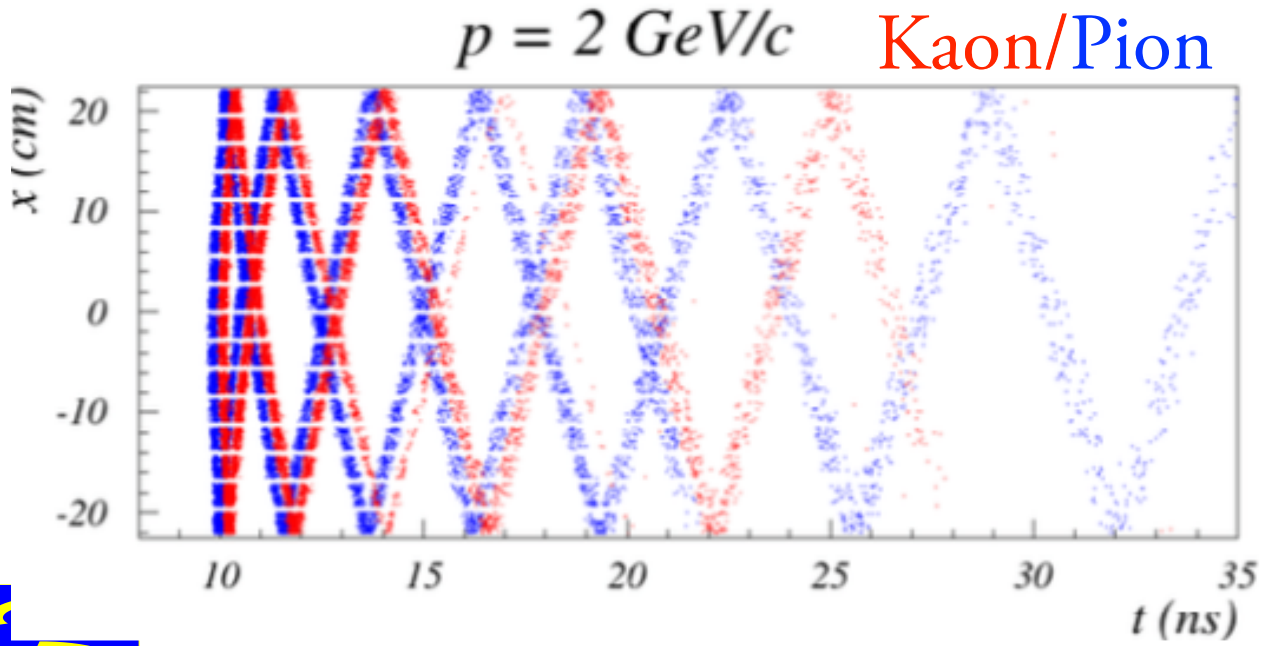
Barrel PID: Time Of Propagation

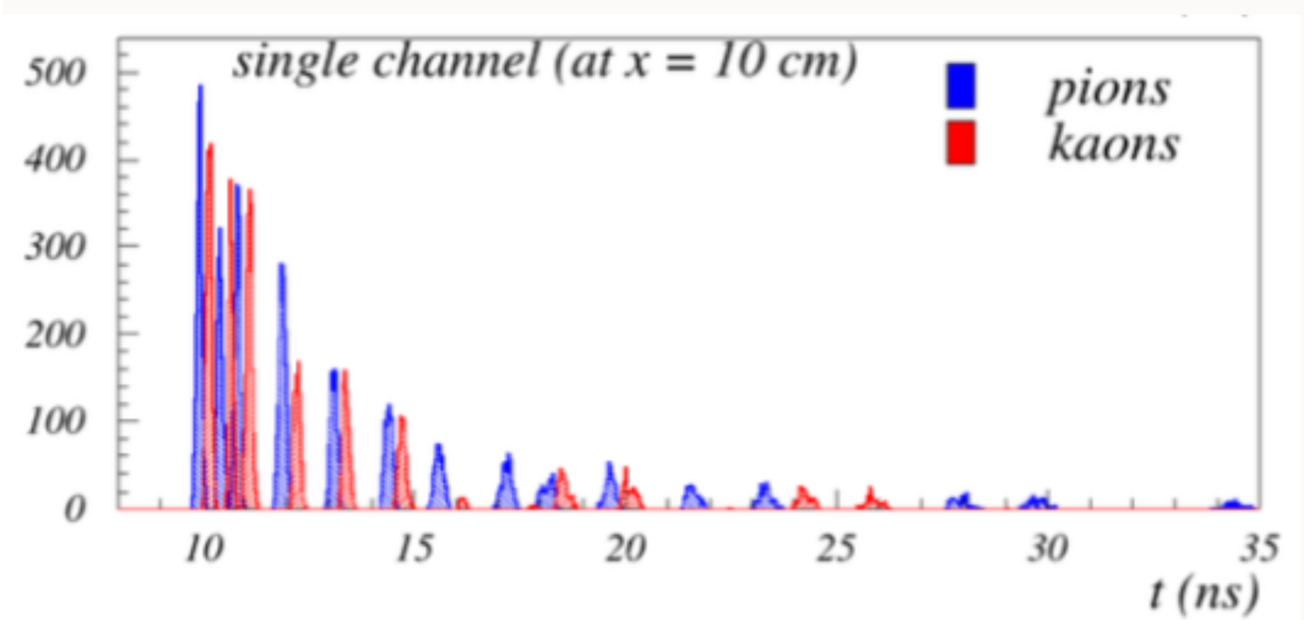
Cherenkov ring imaging with precision time measurement (better than 100ps)

Installation completed! 2016, May 11



Quartz Property	Requirement
Flatness	<6.3µm
Perpendicularity	<20 arcsec
Parallelism	<4 arcsec
Roughness	< 0.5nm (RMS)
Bulk transmittance	> 98%/m
Surface reflectance	>99.9%/reflection

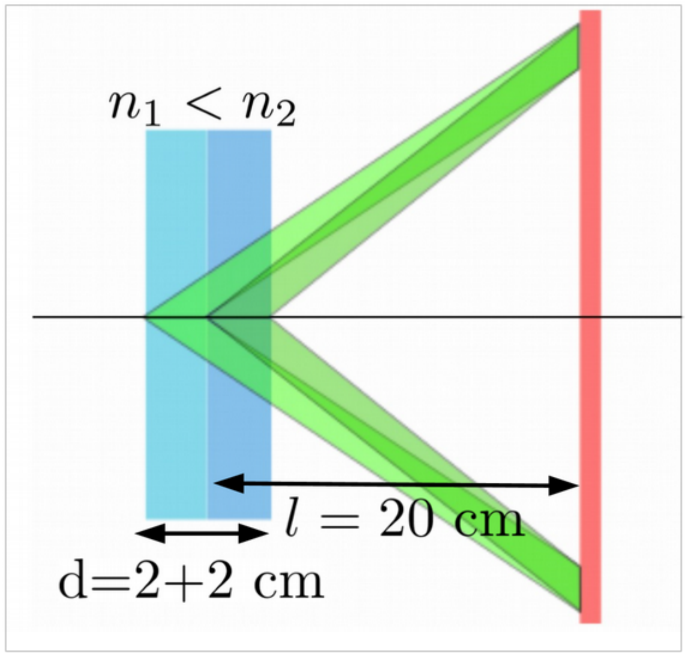




Forward PID: the Aerogel RICH

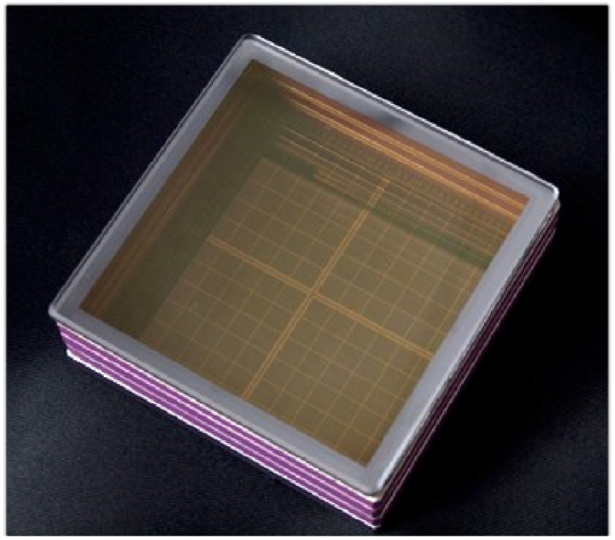
Use two aerogel layers in focusing configuration to increase n. of photons without resolution degradation

$n_1 = 1.045, \; n_2 = 1.055$



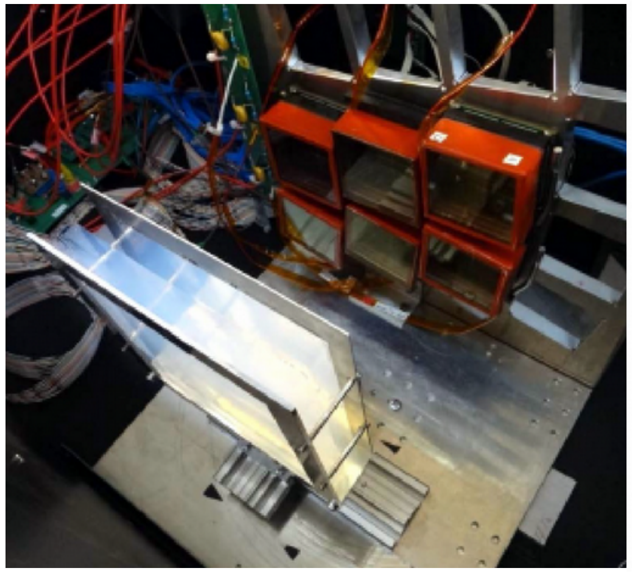
HAPD – Hybrid Avalanche Photo-Detector

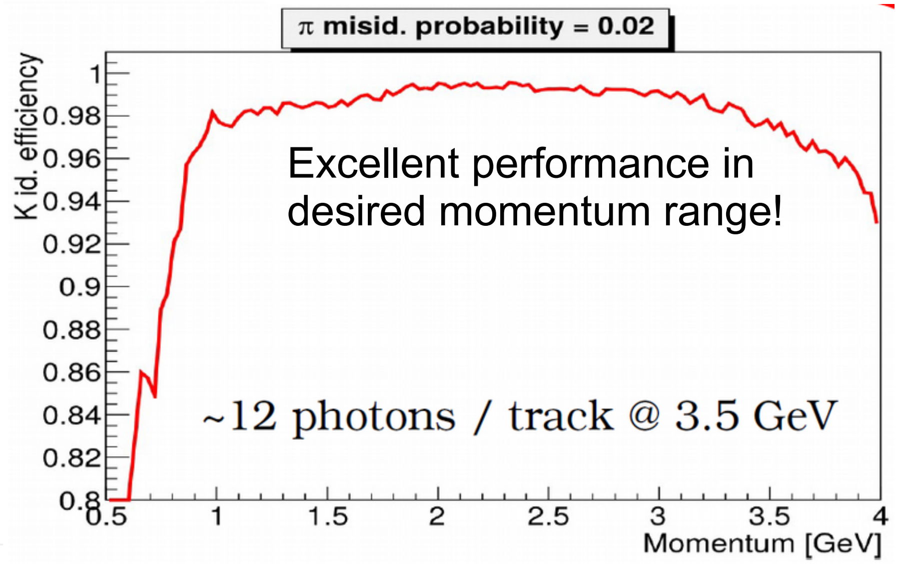
- Developed in collaboration with Hamamatsu photonics
- Basic requirements: - 1.5 T - n,γ tolerance ($10^{12}\ n/\mathrm{cm}^2$)



- position resolution
- large coverage (3.5 m^2)

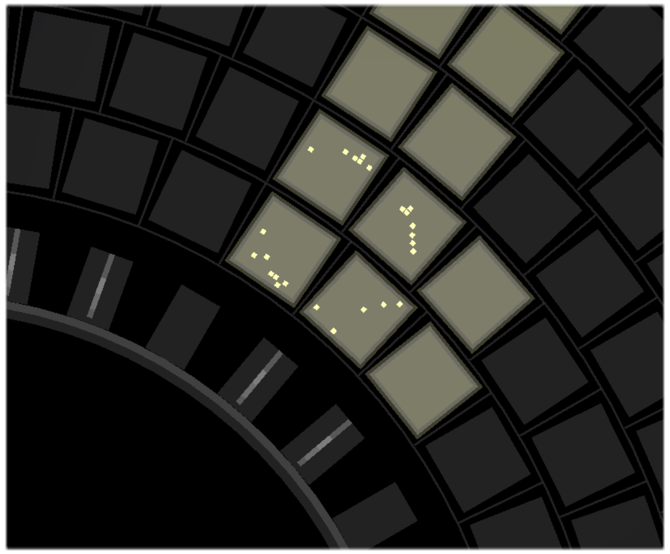
Beam test measurements

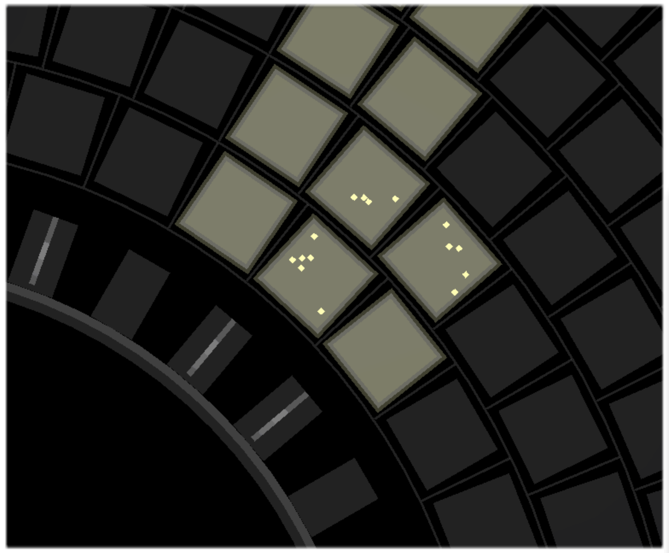




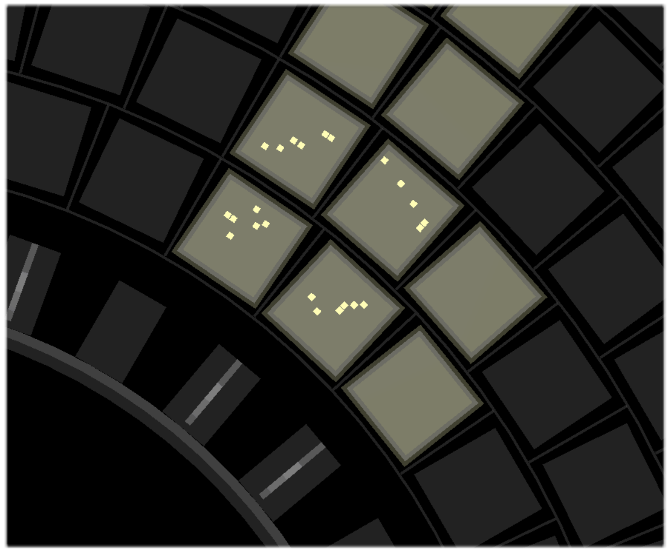
ARICH Rings from cosmic ray muons

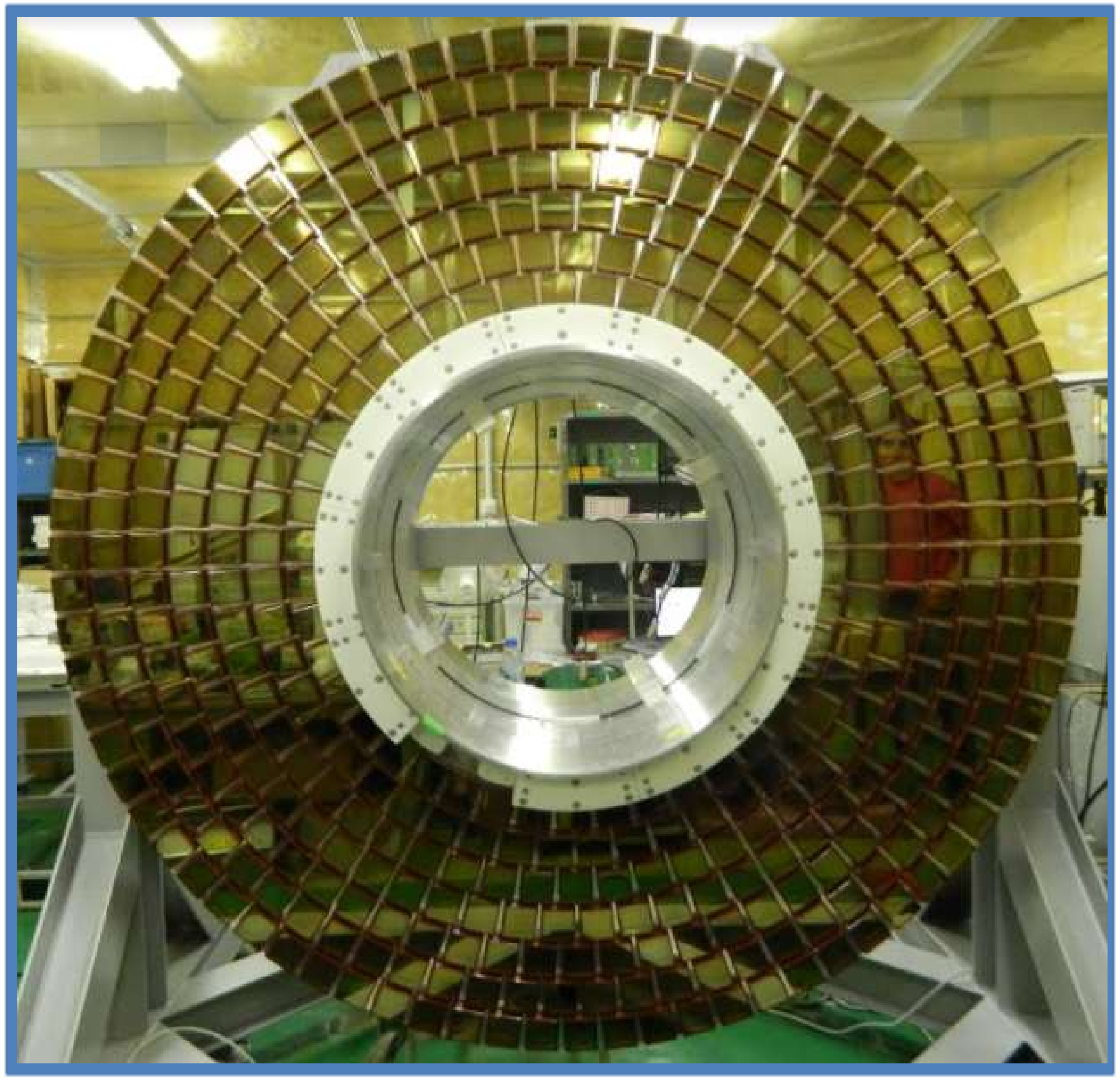
- First events from CR tracks recorded in a partially instrumented sector of the ARICH



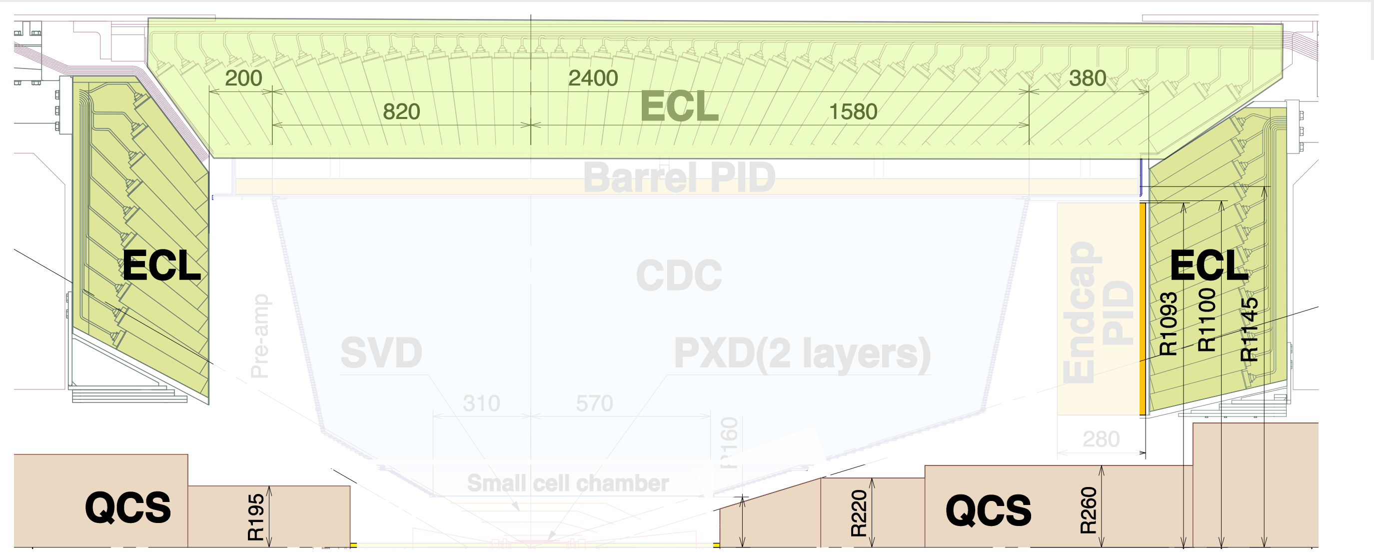


- Production of aerogel tiles and HAPDs is finished.
- Installation on the structure complete!
- Install in Belle II in September.





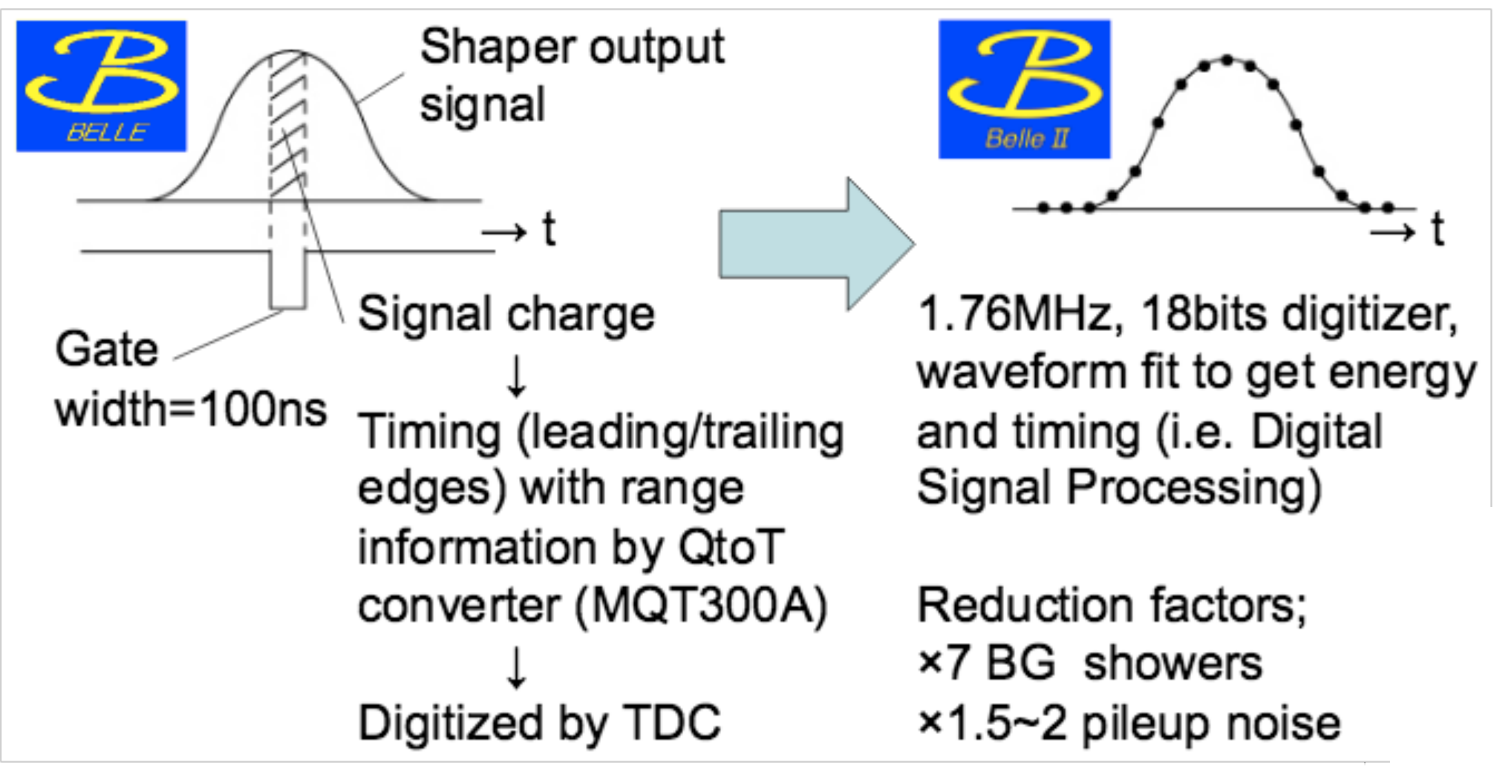
E.M. Calorimeter (ECL)



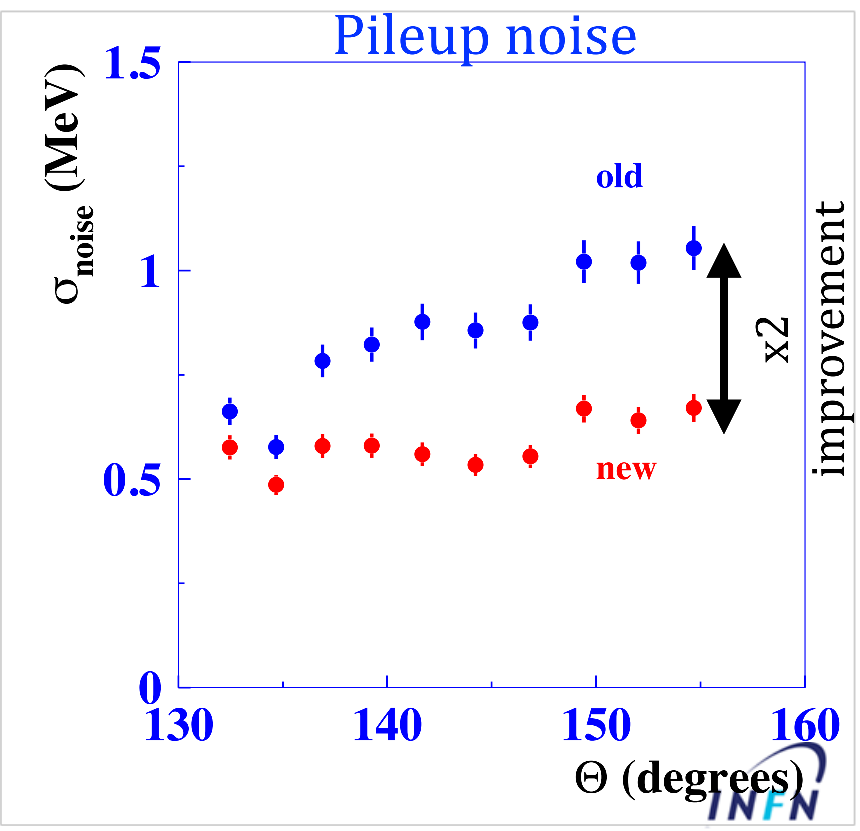
Belle calorimeter

- 8736 CsI(Tl) crystals
- 6624 Barrel
- 1152 Fwd Endcap
- 960 Bwd Endcap

- High rates (machine+physics) ⇒ upgrade of electronics
  - shorter signal shaping
  - waveform fit to extract signal time and amplitude

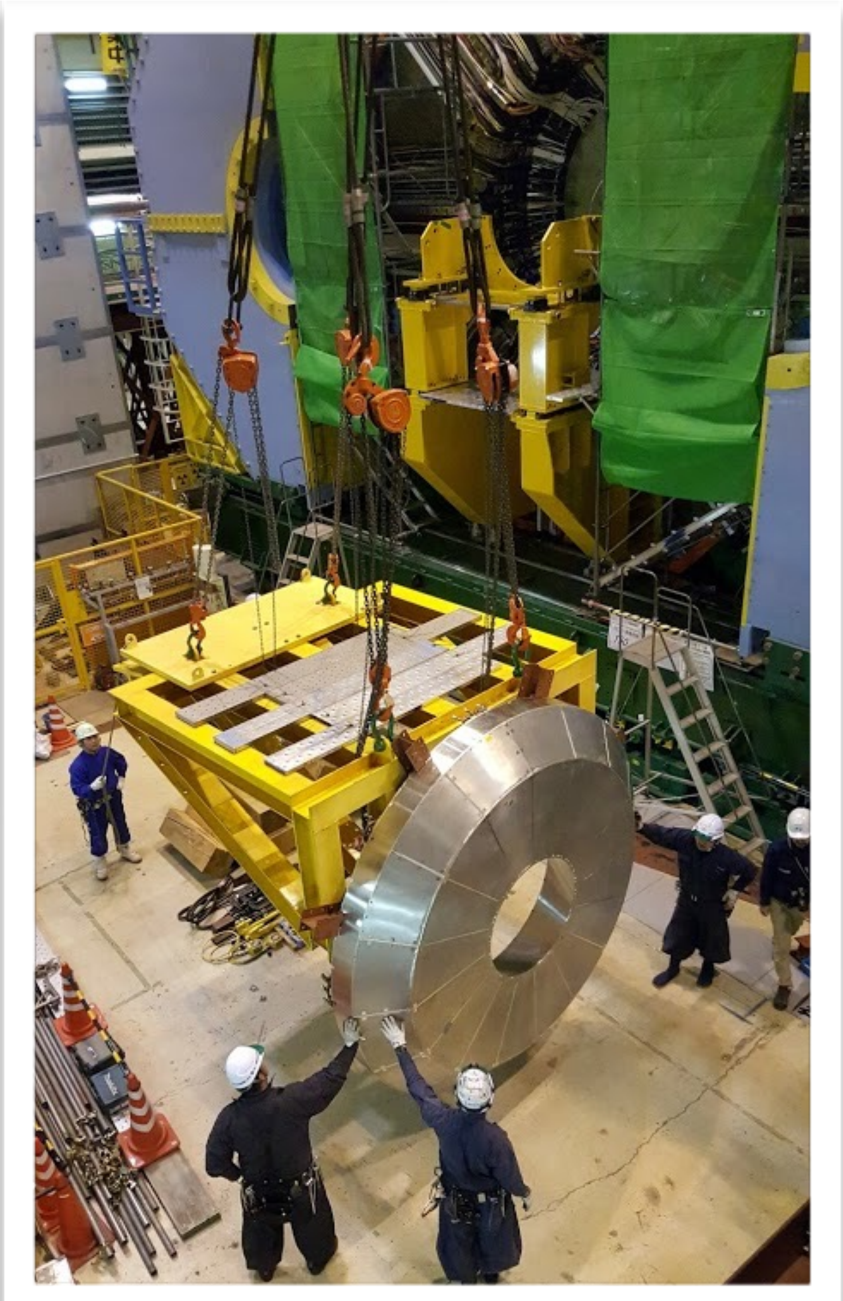


Early prototype tested at Belle

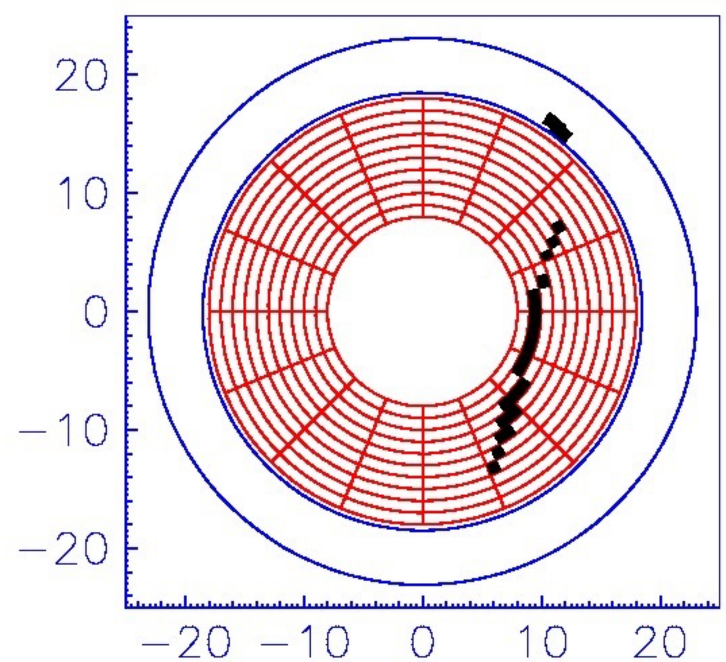


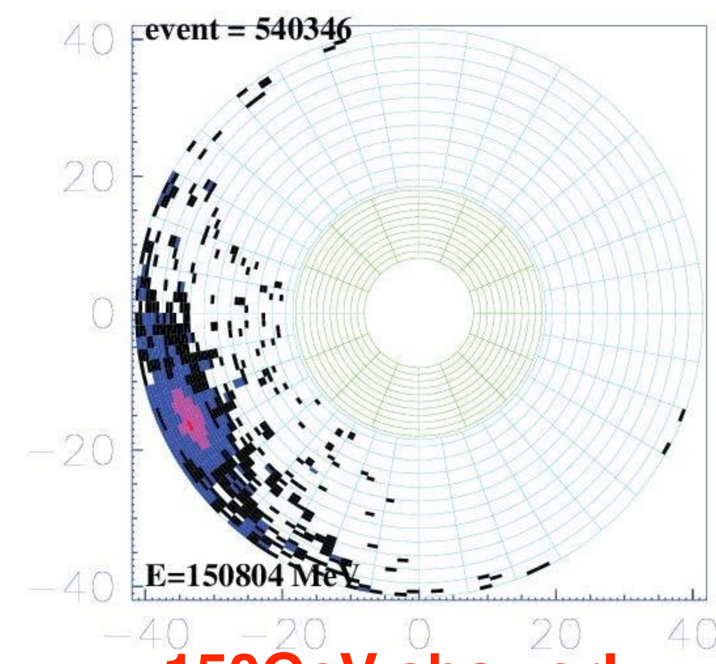
ECL commissioning

BWD endcap installation
January 2017



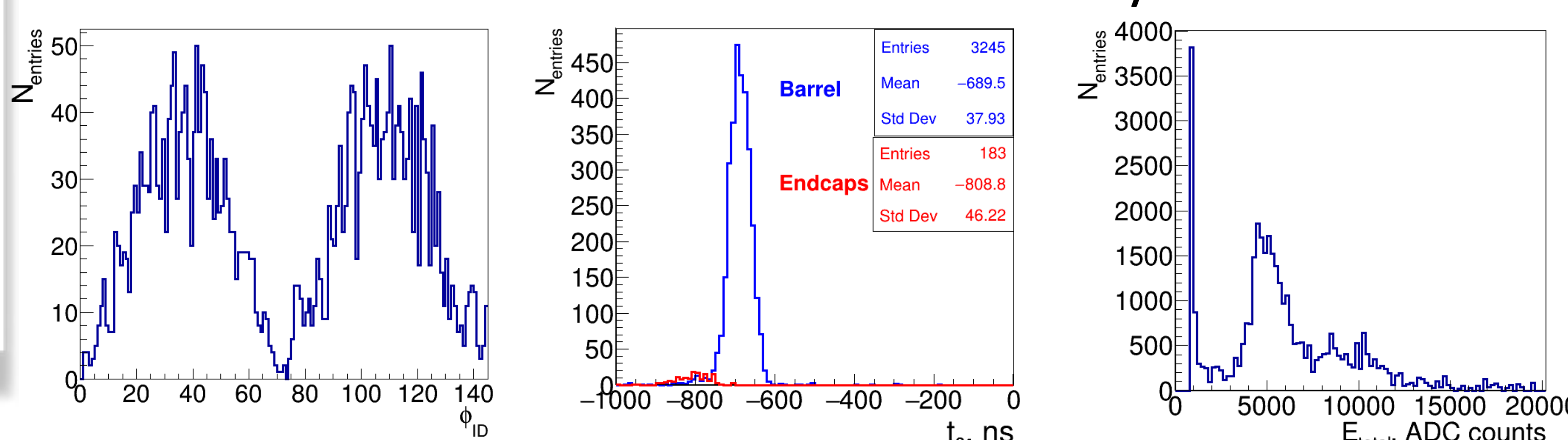
- Barrel ECL under CR test since 2015
- Endcap calorimeter CR test ongoing





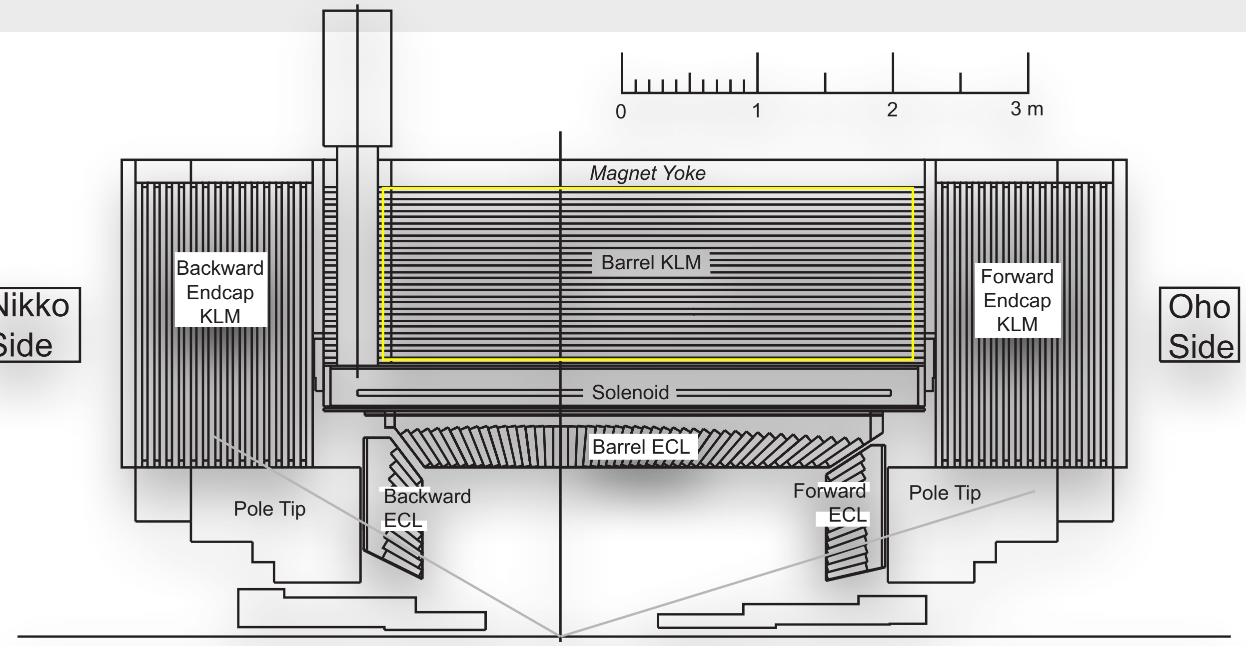
150GeV shower!

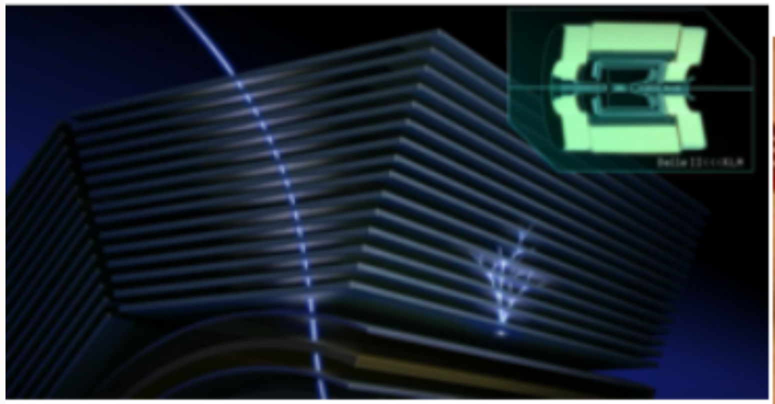
Combined CDC-ECL cosmic ray test

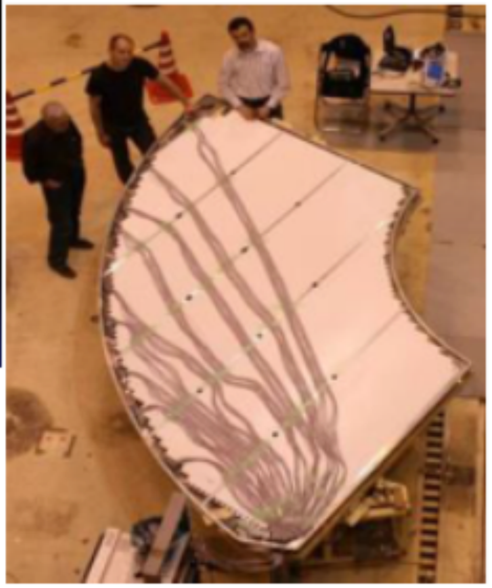


The KLong and Muon detector KLM

- 14 iron layers 4.7cm thick
- 15 barrel active layers
  - ✓ 2 x [scintillator strips + WLS + SiPM] ⇐ **NEW**
  - ✓ 13 x [double glass RPC + 5 cm orthogonal phi, z strips]
- 14 endcap active layers
  - ✓ 14 x [scintillator strips + WLS + SiPM] ⇐ **NEW**







- All endcap glass RPC + 2 in the innermost layers of the barrel replaced with scintillator strips to resist higher backgrounds
- Installation is complete
- Commissioning with cosmic rays ongoing