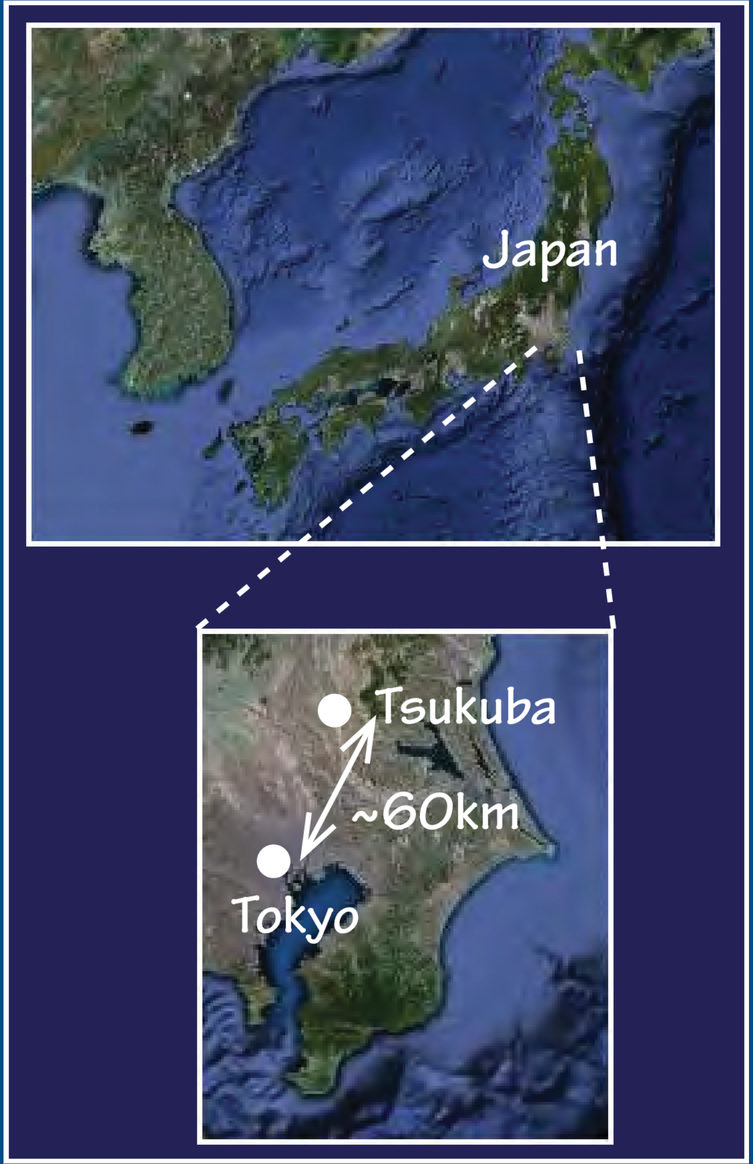
Intensity Frontier Experiment Belle II @ SuperKEKB



Belle II

Vladimir Savinov (University of Pittsburgh) on behalf of the Belle II Collaboration

Some of the Big Questions Everyone Wants to Answer

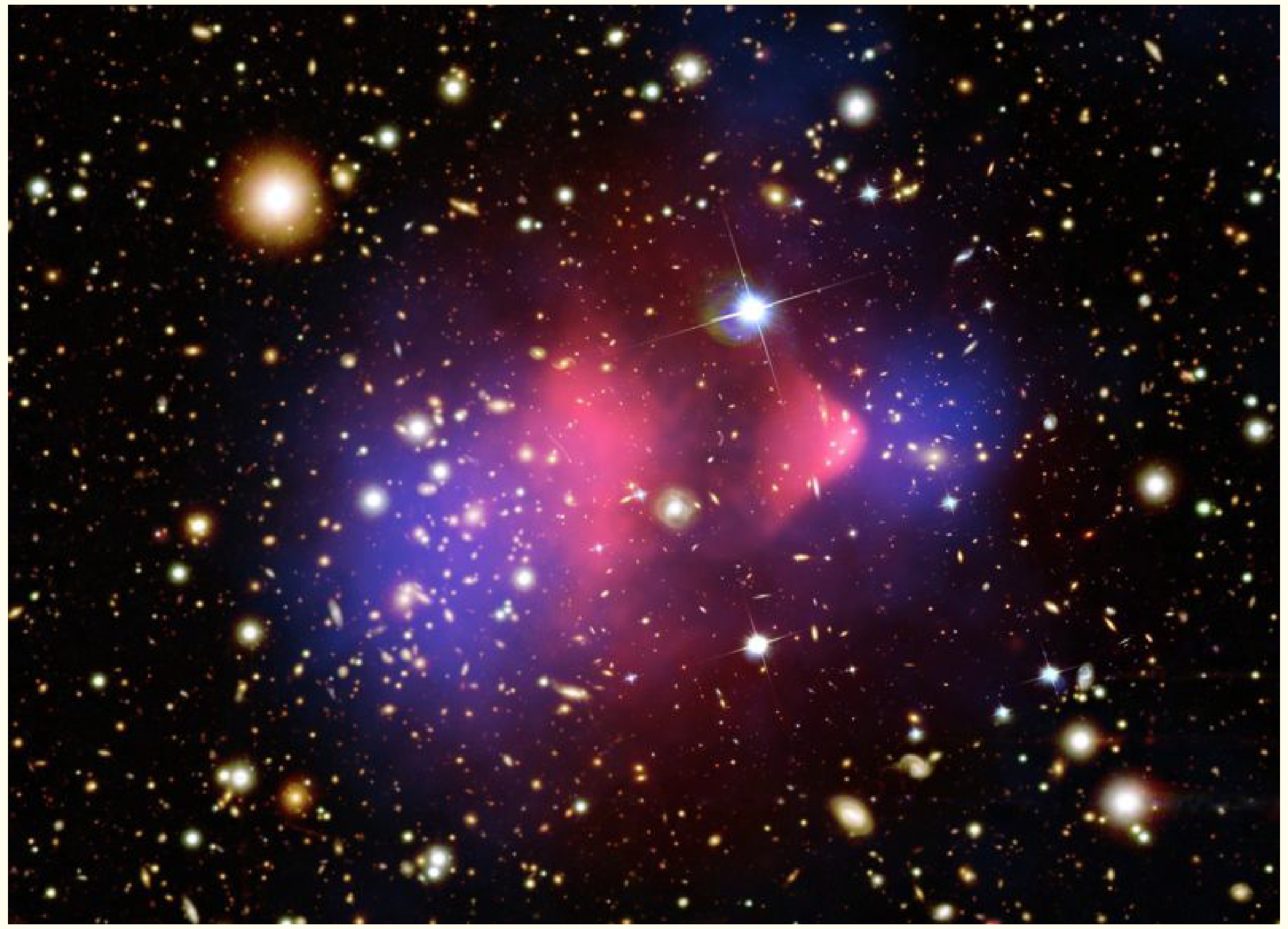
The Baryogenesis (new sources of CPV?)

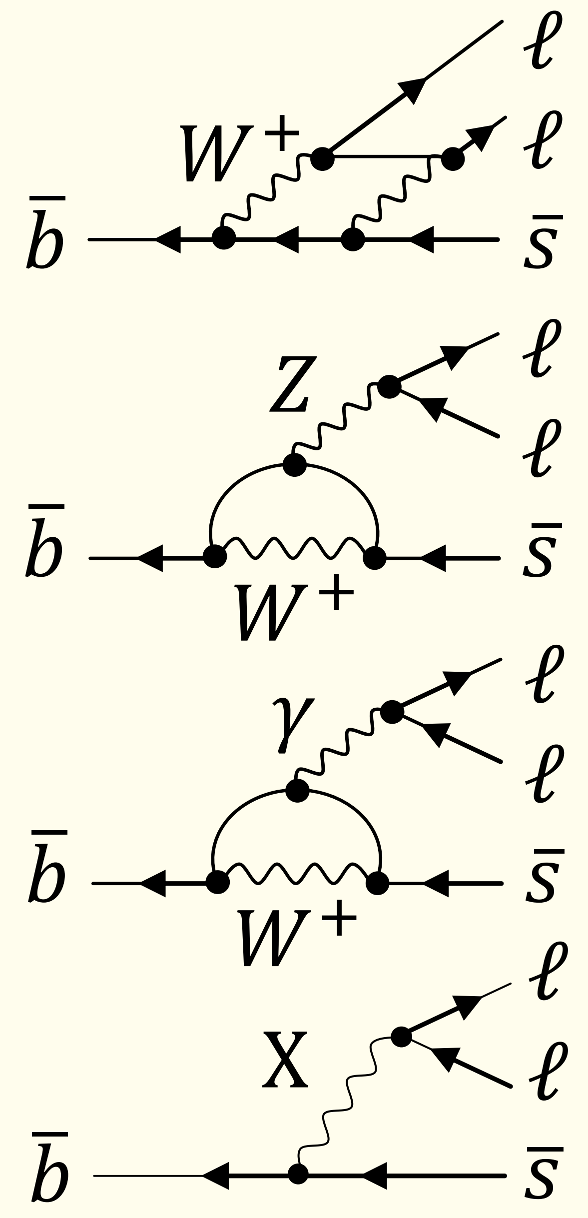
Dark Matter (what / how / where)

Dark Energy / vacuum energy

Neutrino masses (how / etc)

Complementarity of Big and Small
Same questions / different tools





Some "related matters": FCNC, LFV, BNV, new right-handed currents,
how to extract NP / interpret (necessary) QCD
in a model-independent way

The Belle II experiment seeks to provide new information about some of these matters

Belle II: Much More Than the Next Generation B Factory

The next generation B factory (we plan to collect approx. 50 times more statistics than by Belle by ~2026)

but, also

The τ lepton factory (LFV/BNV!)

A window on the dark sector

A program to search for new sources of CP violation

Significant improvement in measuring the CKM angles

A QCD laboratory (hadron spectroscopy (including XYZ states))

Measurements to help improve theoretical estimates of HVP and HLbL for g-2

Hermeticity (even better than @Belle)
Well-understood initial state
Absolute cross sections measurements
Quantum coherence
Flavor tagging

A better machine +
A better detector +
Higher luminosity =>
Larger data set =>
Better NP sensitivity

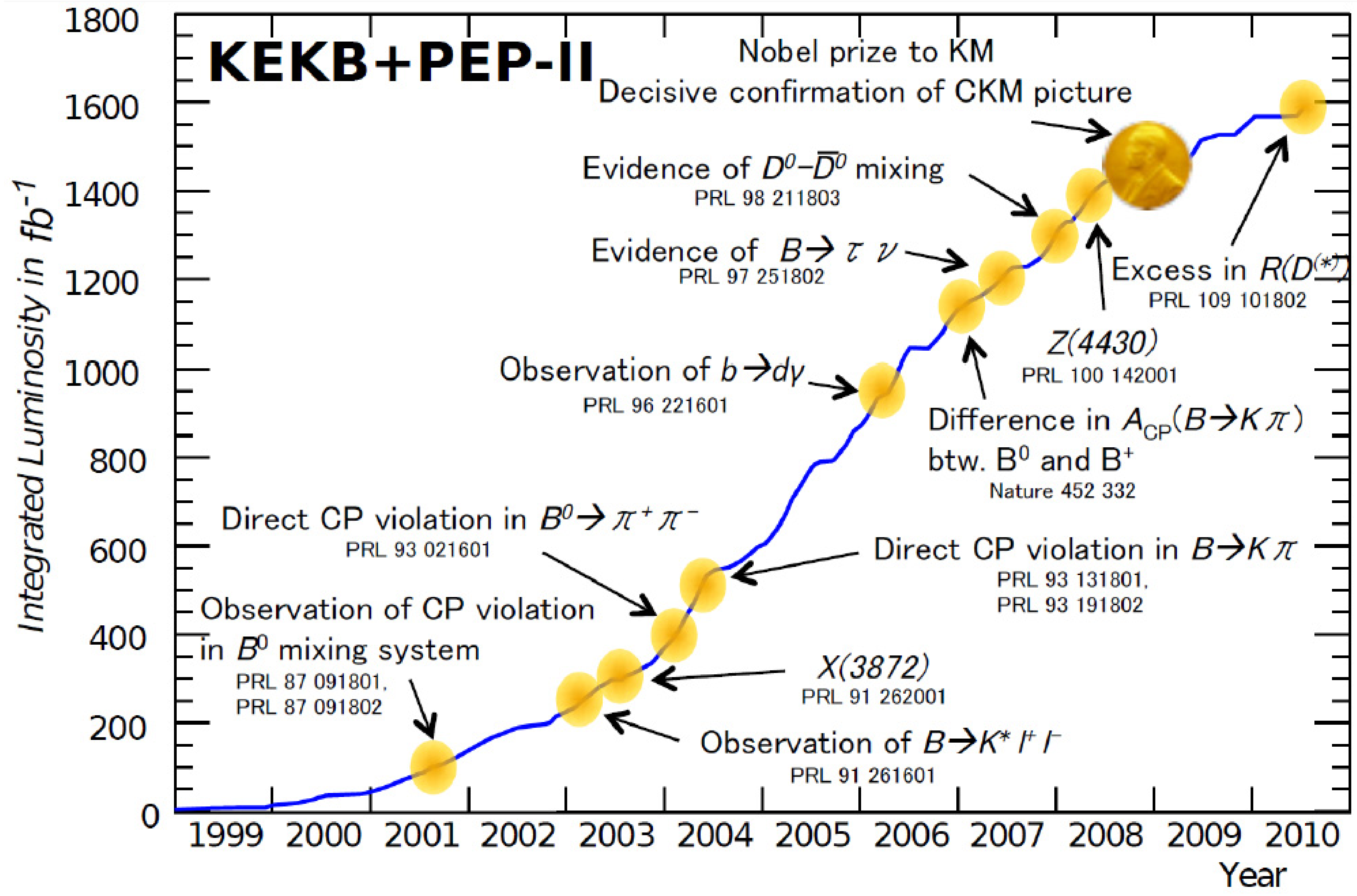
We see Belle II as an indirect NP exploration experiment, besides, there are some very interesting NP scenarios that can be explored directly (e.g. the dark photon)

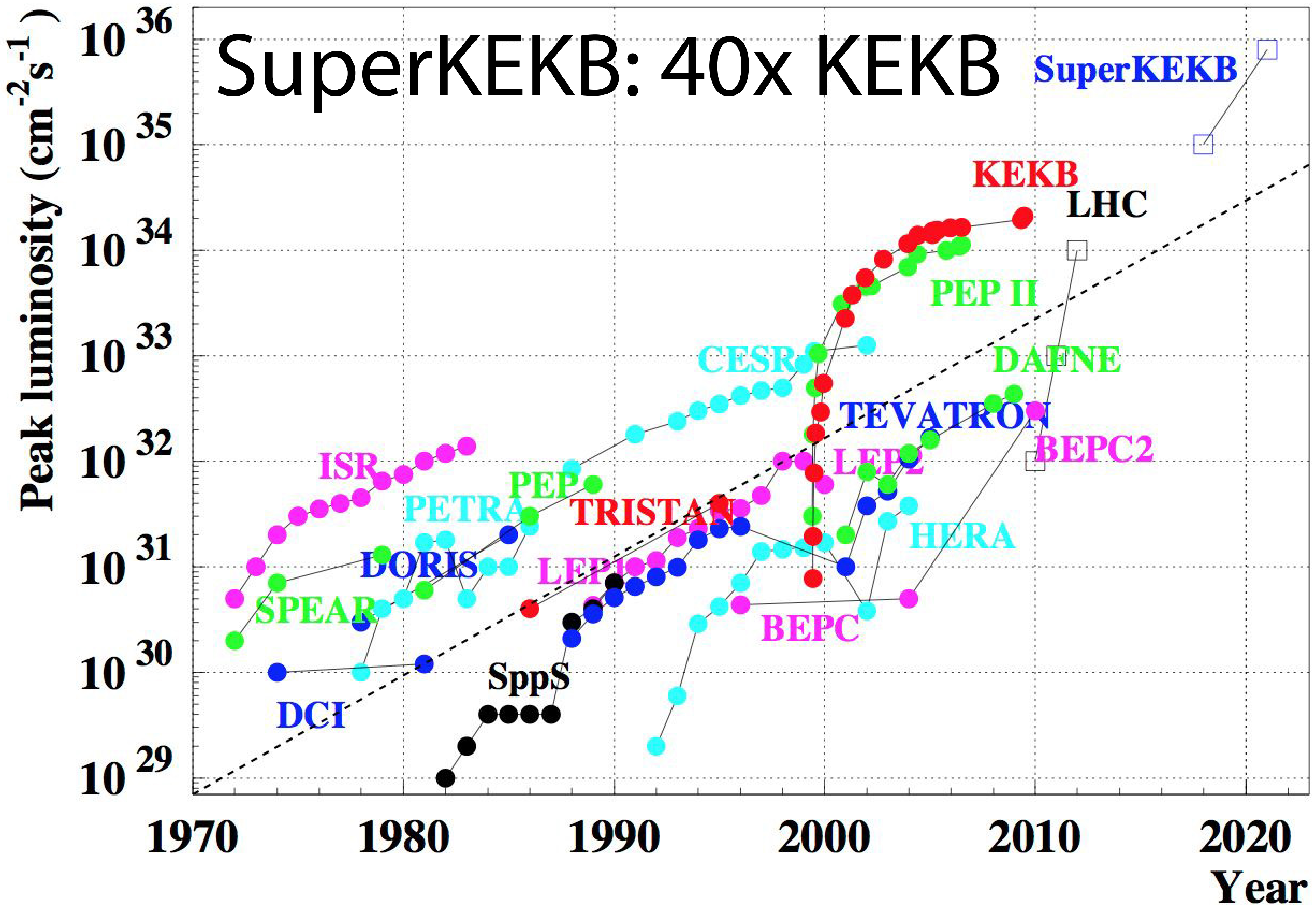
Belle II

Why So Much Confidence in Your Friends and Hardware?

Existing datasets (in inverse fb)

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	Off Res.
CLEO	1.2	1.2	1.2	16	0.1	-	17
BaBar	-	14	30	433	R_b scan		54
Belle	6	25	3	711	121	5.5	100

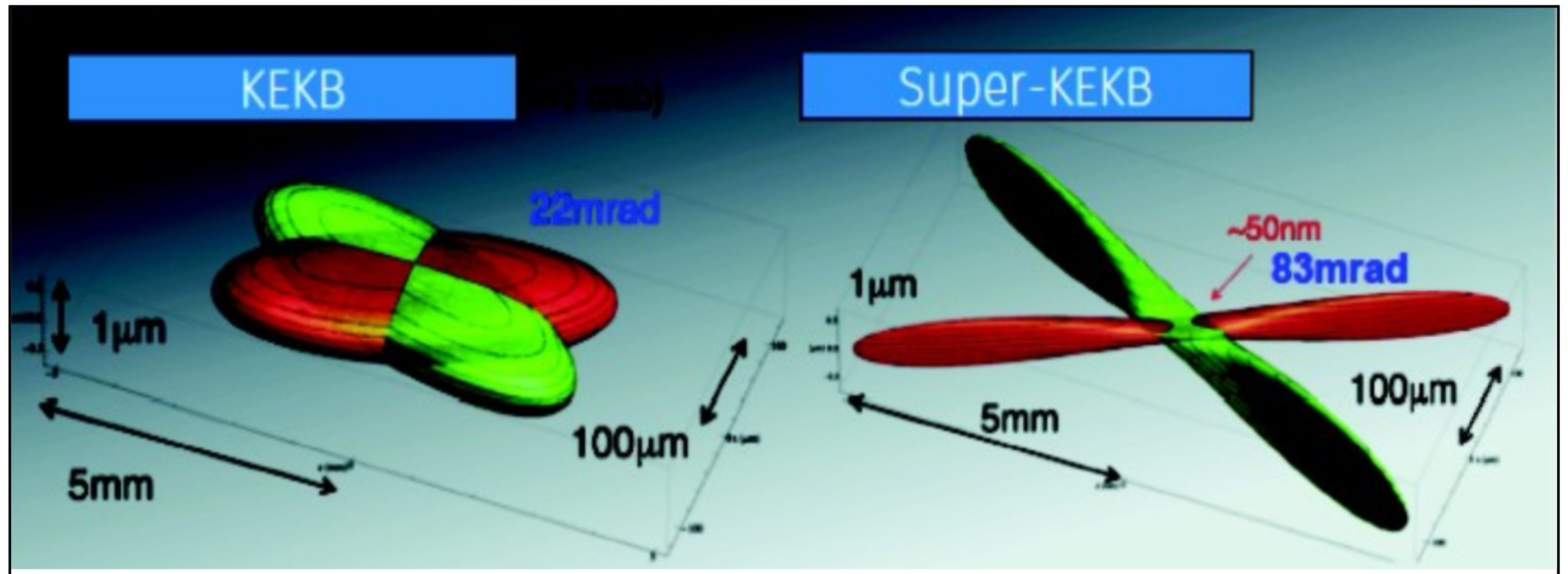




Ingredients for Success: Part 1, The Machine, SuperKEKB

Target: L = $8\times10^{35}/cm^2/s$ = $L_{KEKB}\times40$

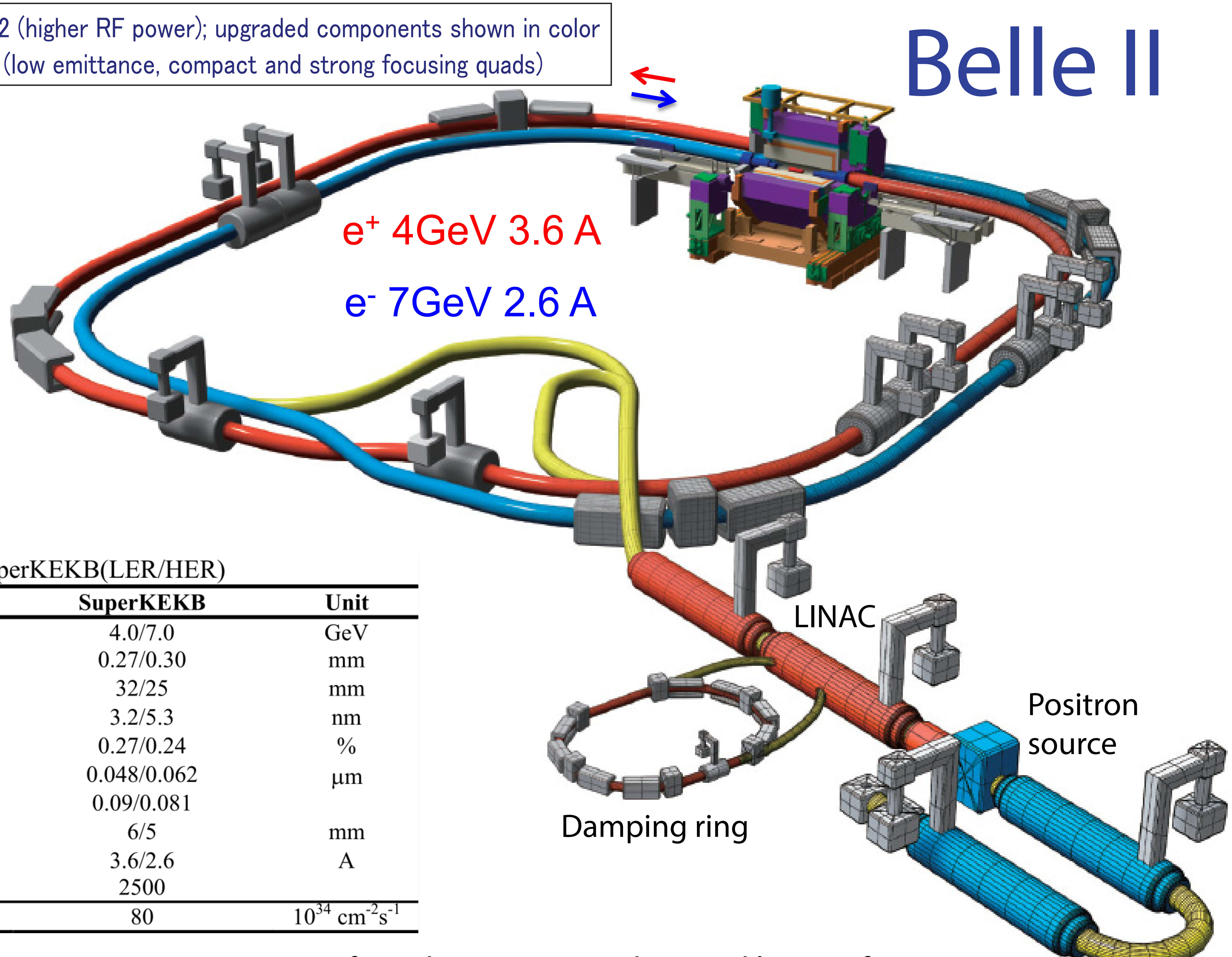
Beam current: ×2 (higher RF power); upgraded components shown in color
Beam size: 1/20 (low emittance, compact and strong focusing quads)



$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{y\pm}}{\beta_{y\pm}^*}\right)\left(\frac{R_L}{R_{\xi y}}\right) \propto \frac{I_\pm\xi_{y\pm}}{\beta_{y\pm}^*}$$

Table 1: Machine parameters of KEKB (LER/HER) and SuperKEKB(LER/HER)

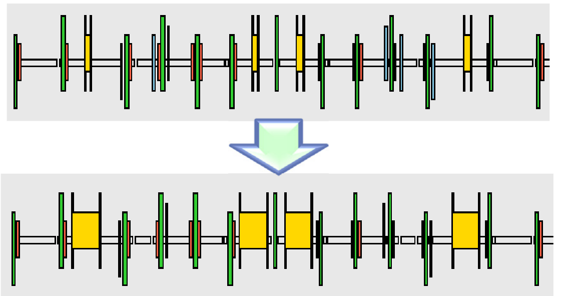
	KEKB design	KEKB Achieved: with crab	SuperKEKB	Unit
Energy	3.5/8.0	3.5/8.0	4.0/7.0	GeV
β_y^*	10/10	5.9/5.9	0.27/0.30	mm
β_x^*	330/330	1200/1200	32/25	mm
ε_x	18/18	18/24	3.2/5.3	nm
x-y coupling ($\varepsilon_y/\varepsilon_x$)	1	0.85/0.64	0.27/0.24	%
σ_y^*	1.9	0.94	0.048/0.062	μm
ξ_y	0.052	0.129/0.090	0.09/0.081	
σ_z	4	6-7	6/5	mm
I	2.6/1.1	1.64/1.19	3.6/2.6	A
N_{bunch}	5000	1584	2500	
Luminosity	1	2.11	80	10^{34} cm^{-2}s^{-1}



Nanobeams (originally proposed by P. Raimondi for SuperB), new positron target, reinforced RF cavities, redesigned lattices for LER & HER,
LER: dipoles magnets replaced by longer ones, TiN-coated LER beampipe with antechambers, new superconducting focusing quadrupole magnets near IP

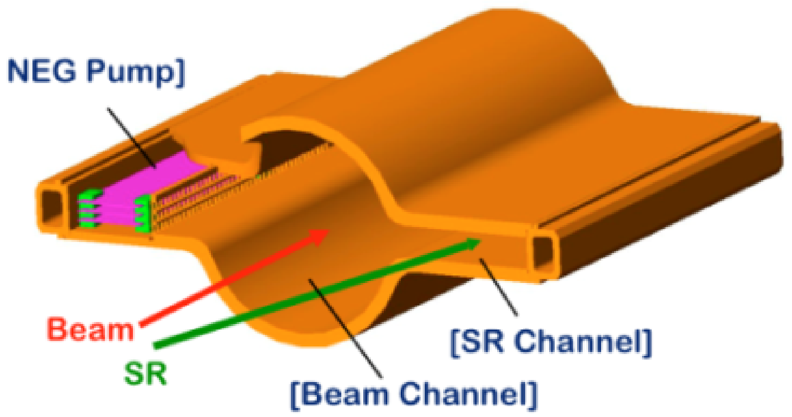
Ingredients for Success: Part 1, The Machine, SuperKEKB

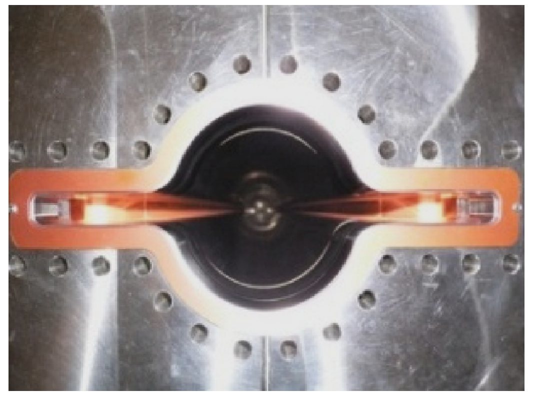
Replace short dipoles with longer ones (LER)

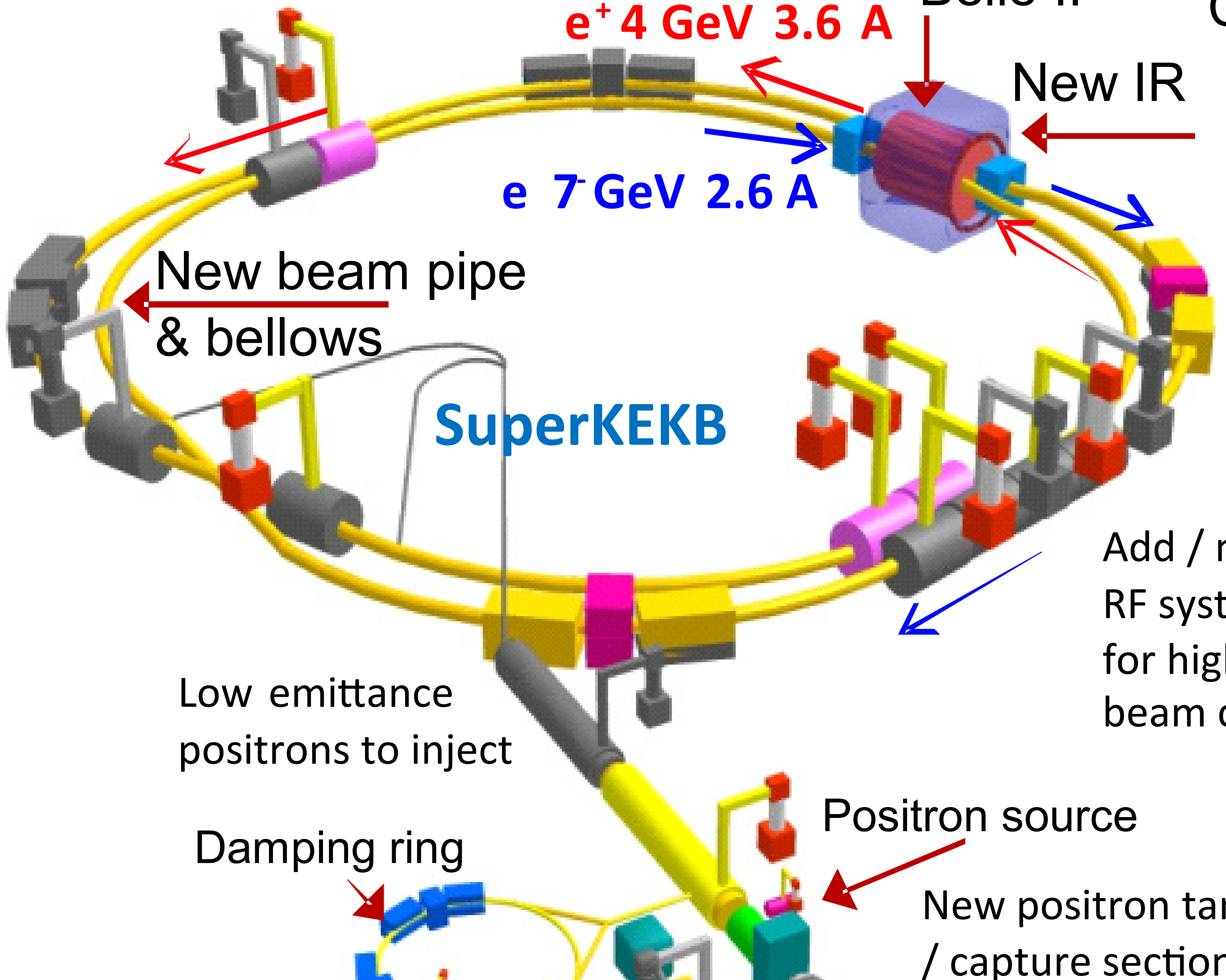


Redesign the lattices of both rings to reduce the emittance

TiN-coated beam pipe with antechambers

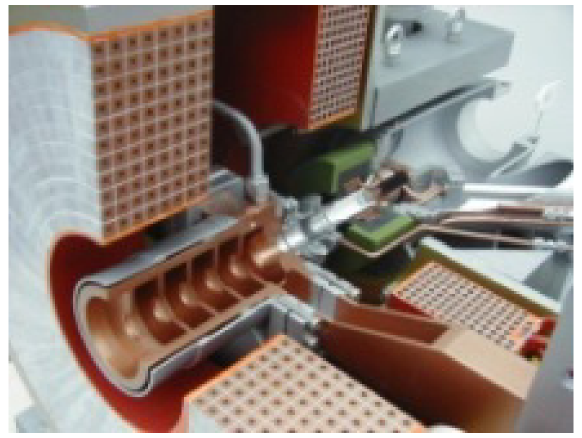




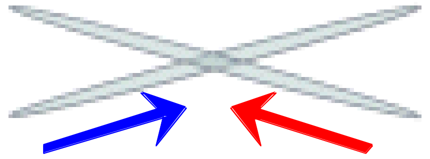


Add / modify RF systems for higher beam current

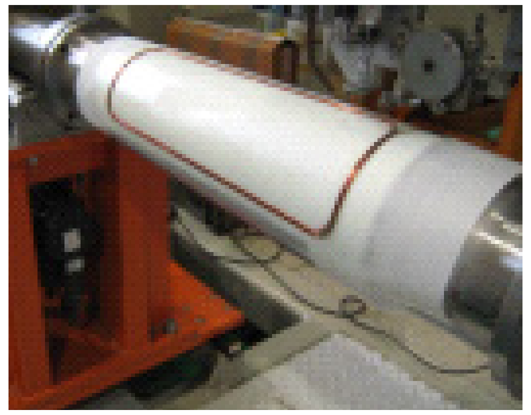
New positron target / capture section



Colliding bunches

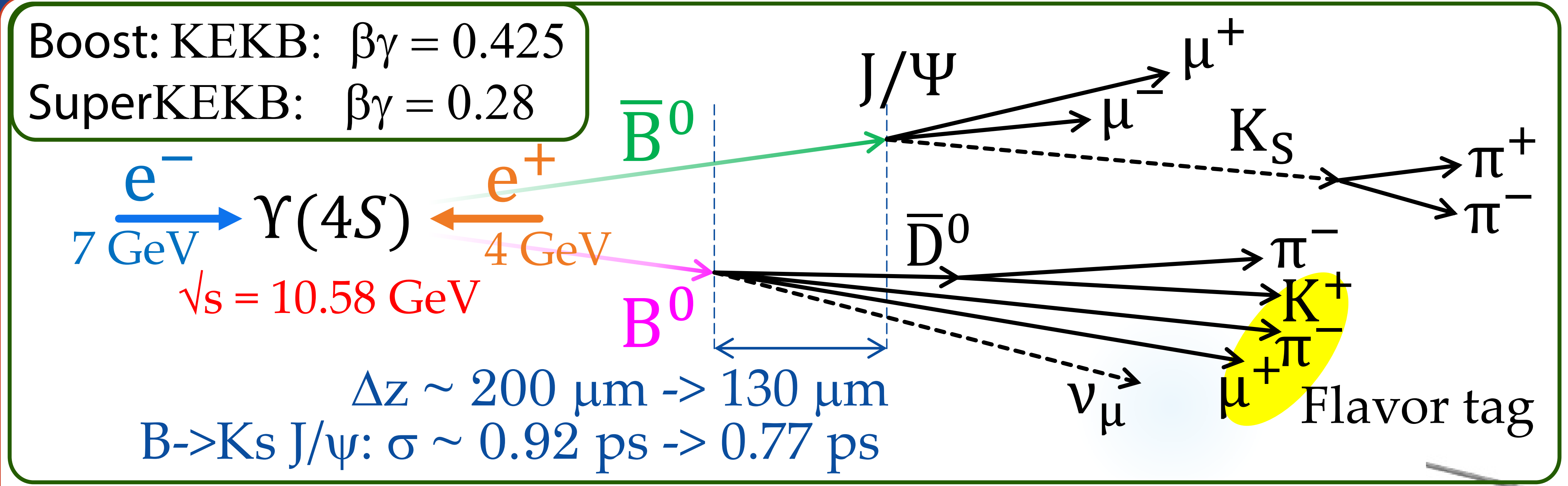


83 mrad crossing angle



New superconducting / permanent final focusing quad magnets near the IP, 1cm radius collision point beryllium beam pipe

Ingredients for Success: Part 2, The Detector, Belle II



Beryllium beam pipe in the interaction region: diameter decreased from 3cm to 2cm

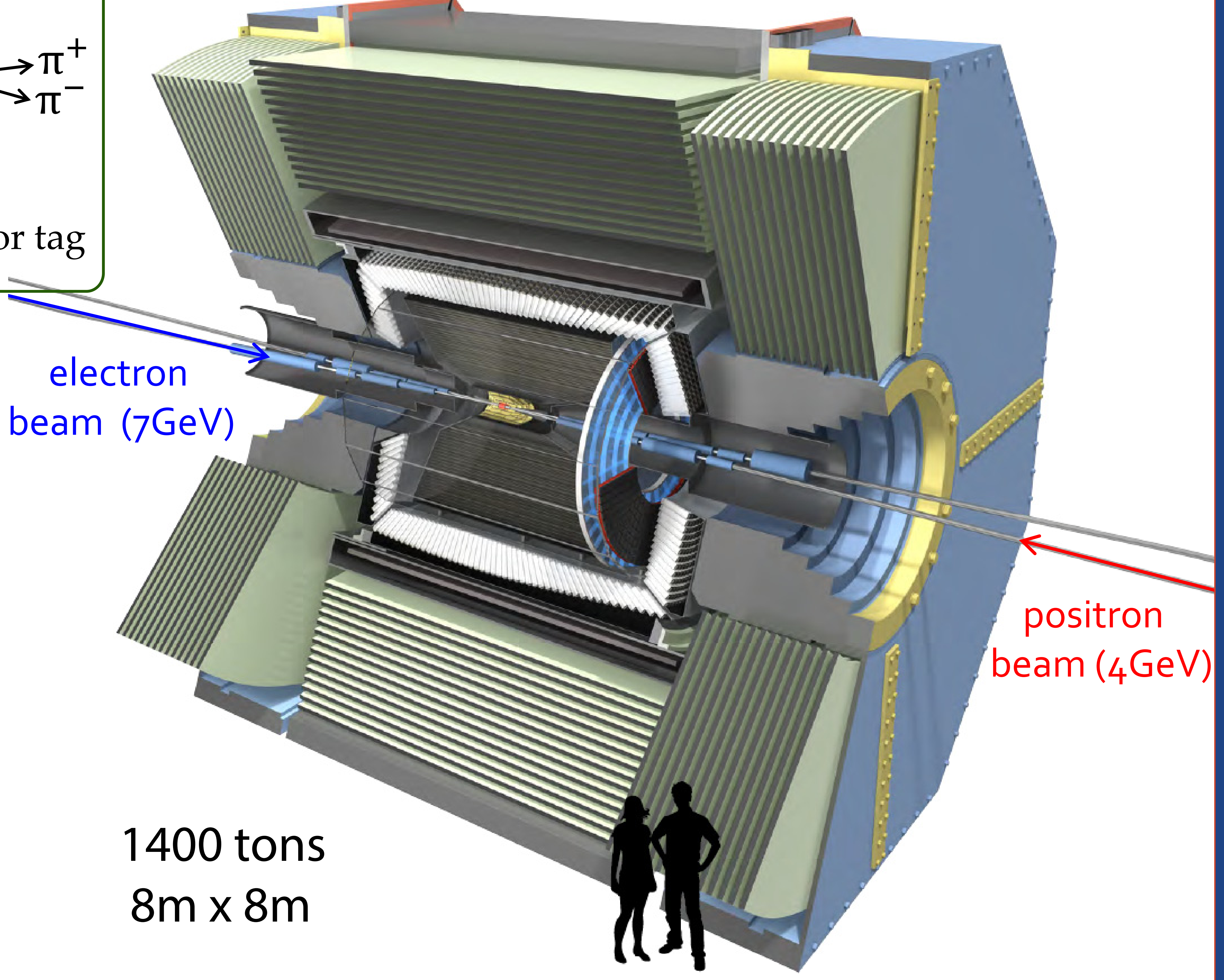
Vertex detector (VXD): two layers of pixels followed by four double-layered silicon strips

Center drift chamber: smaller cells (than @Belle), faster electronics, improved triggering capabilities

PID: compact Time-of-Propagation (TOP) barrel and proximity focusing aerogel endcap Cherenkov detectors

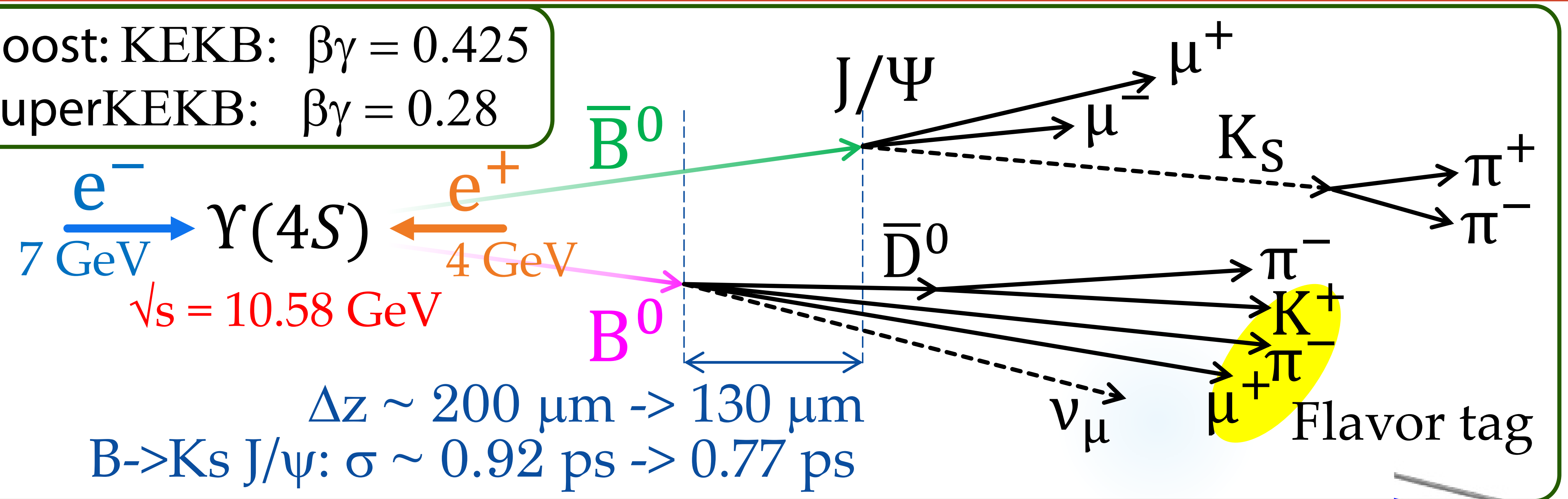
EM calorimeter: Same CsI(TI) crystals, upgraded electronics (shaper based on digital signal processing)

K_L and μ identification: RPCs replaced by scintillators in the endcap and two inner barrel layers, new electronics, triggering



Smaller Boost? Improved Detector? The Implications?

Boost: KEKB: $\beta\gamma = 0.425$
SuperKEKB: $\beta\gamma = 0.28$



Beryllium beam pipe in the interaction region: diameter decreased from 3cm to 2cm

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Center drift chamber: smaller cells (than @Belle), faster electronics, improved triggering capabilities

PID: compact Time-of-Propagation (TOP) barrel and proximity focusing aerogel endcap Cherenkov detector

EM calorimeter: Same CsI(Tl) crystals, upgraded electronics (shaper based on digital signal processing)

K_L and μ identification: RPC replaced by scintillators in the endcap and two inner barrel layers, new electronics, triggering

VXD: beam-related background tolerant

Improved impact parameter resolution

Better z vertex resolution

Approx. 30% better inv. mass resolution

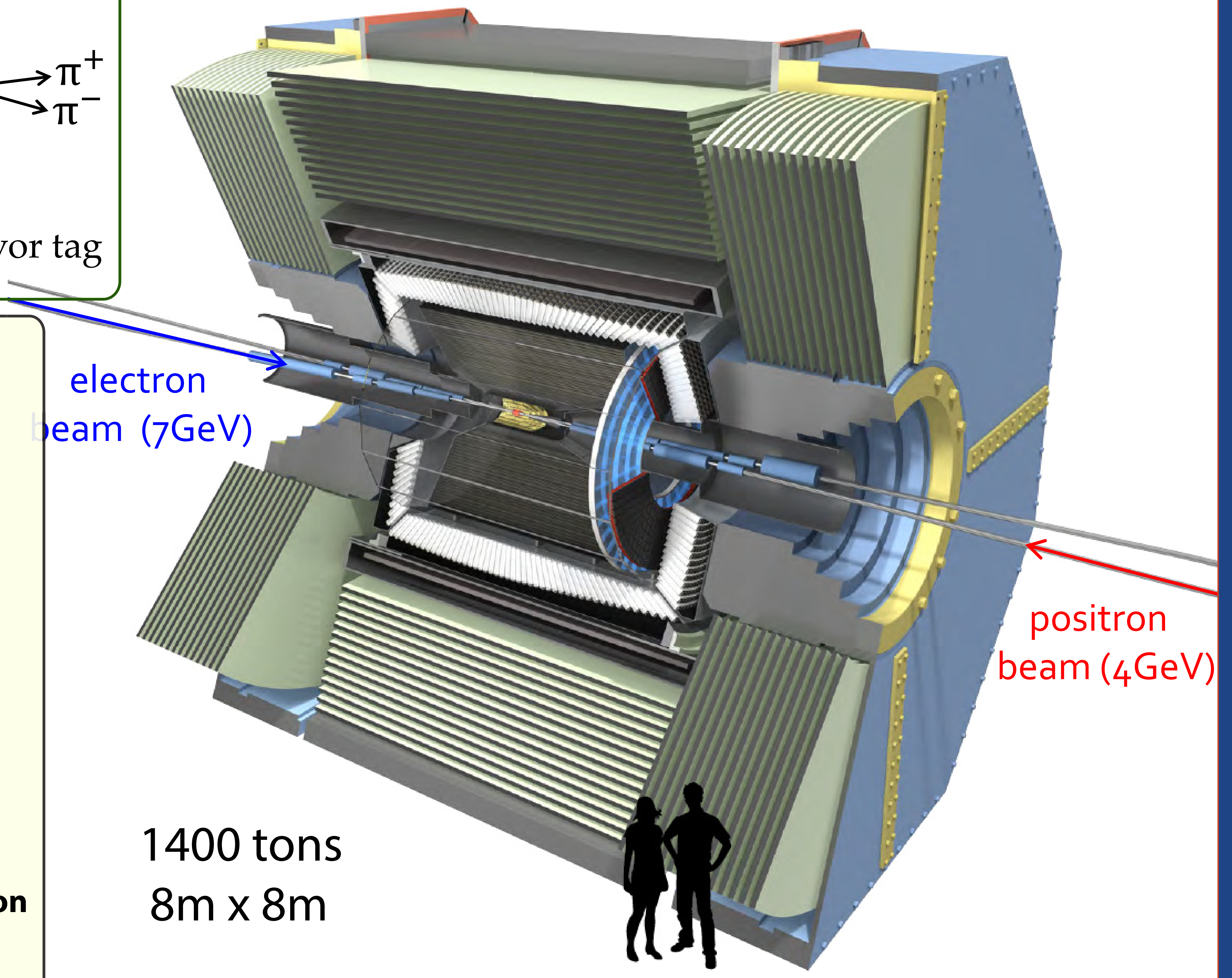
~30% increase in K_S efficiency

Improved K / π separation

Decreased π fake rate by the factor of ~2.5

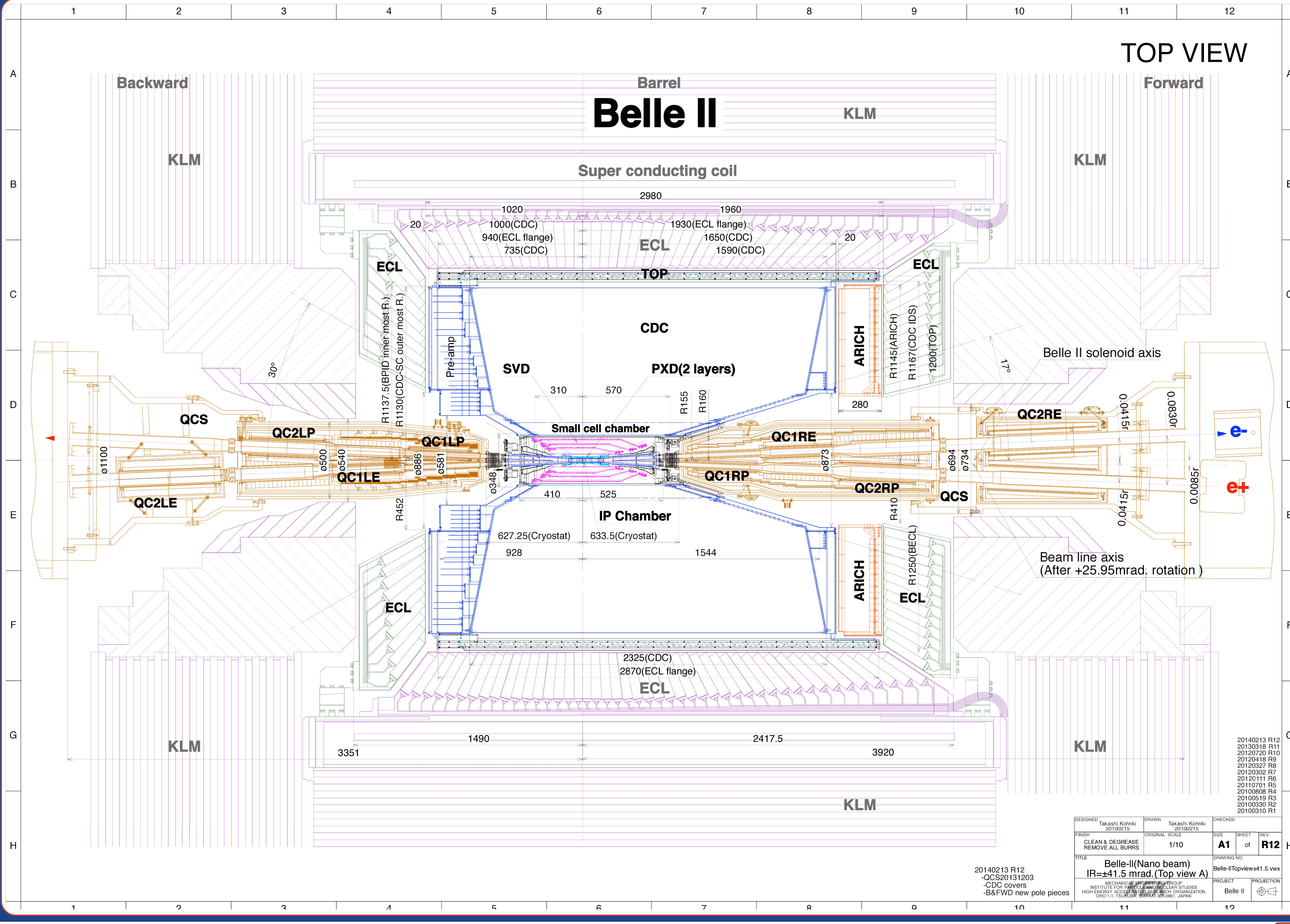
Improved slow (~100MeV/c) π reconstruction

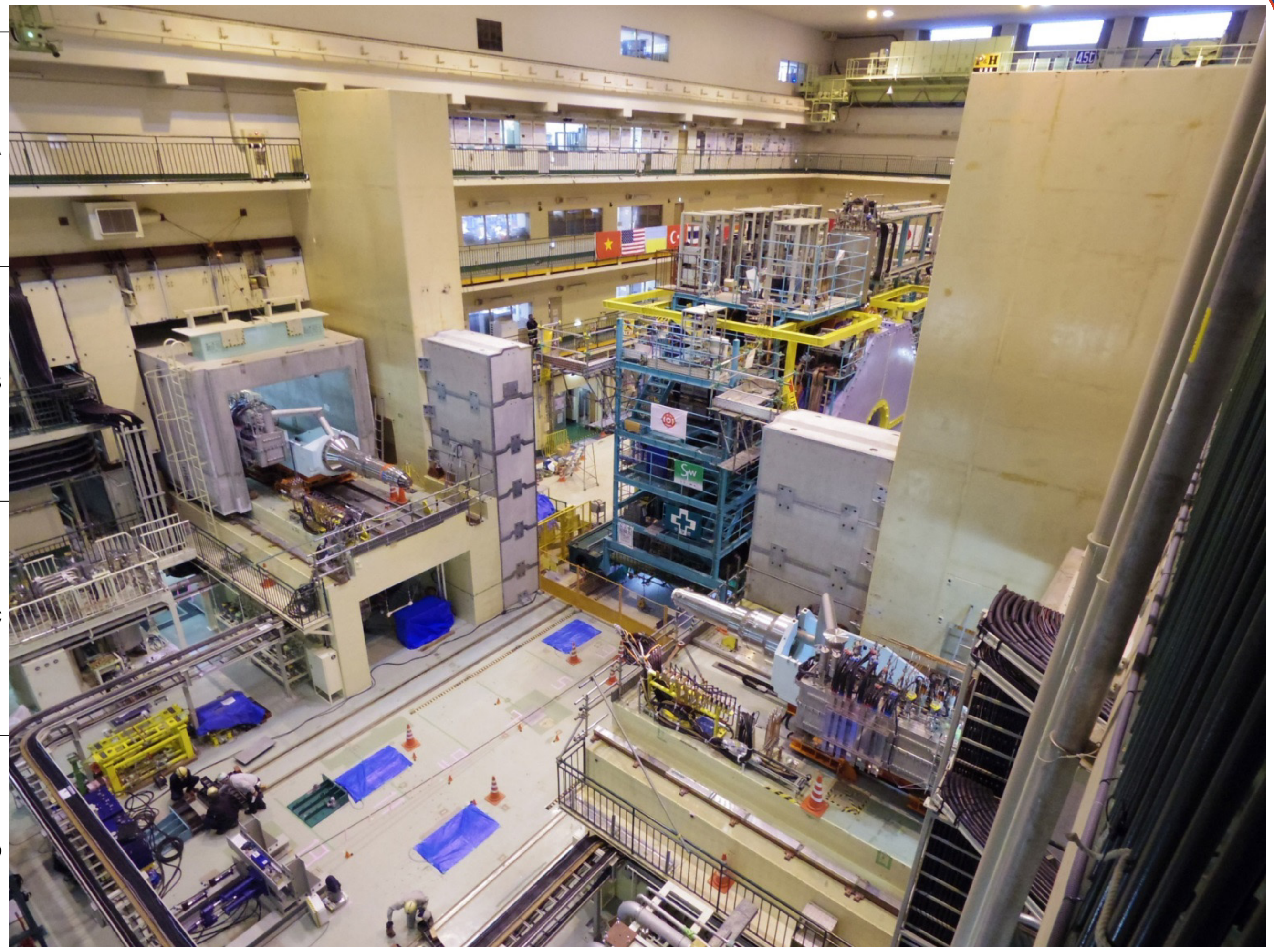
Improved π^0 reconstruction

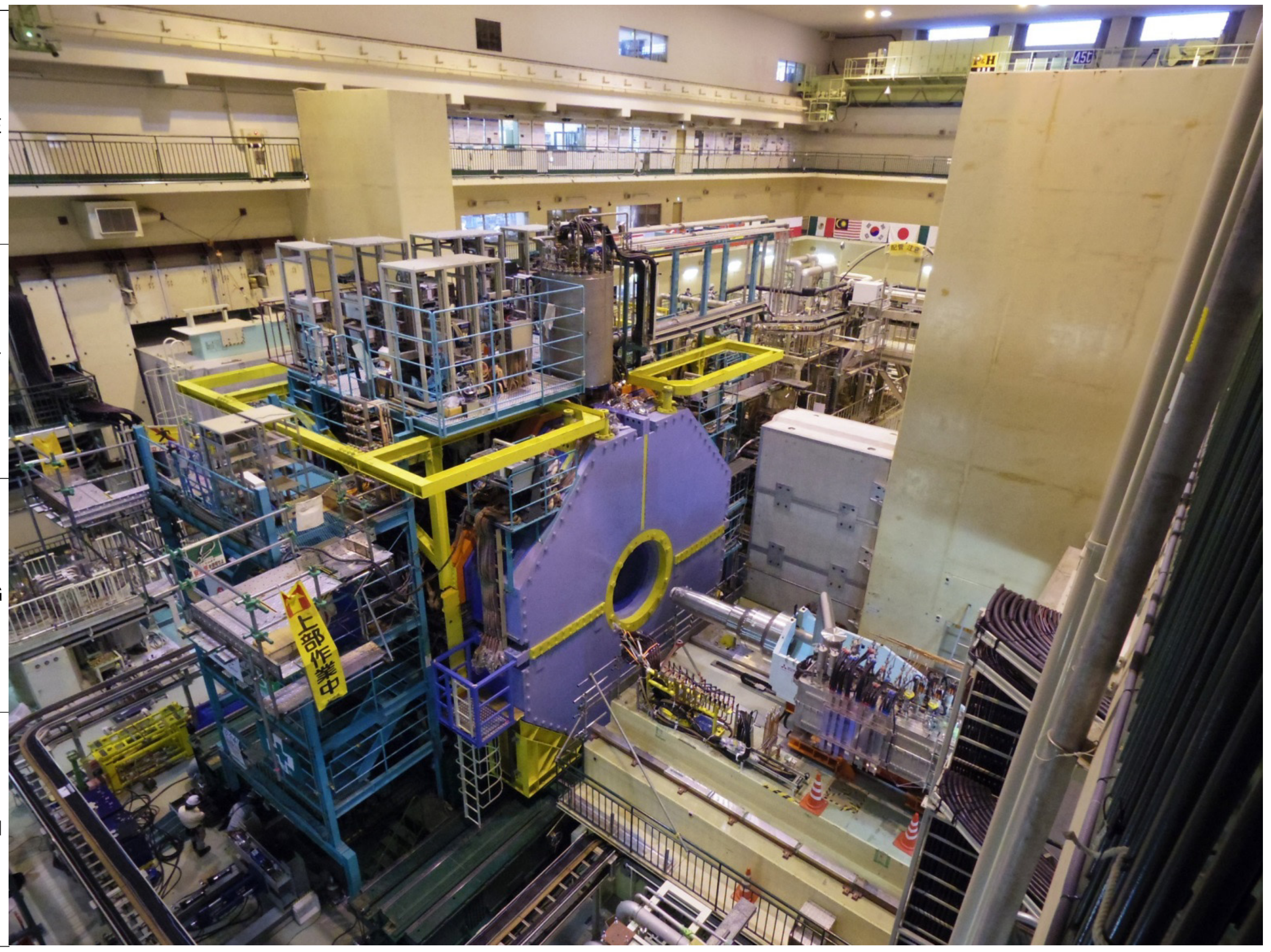


1400 tons
8m x 8m

First data will soon be recorded, but she is not done yet...

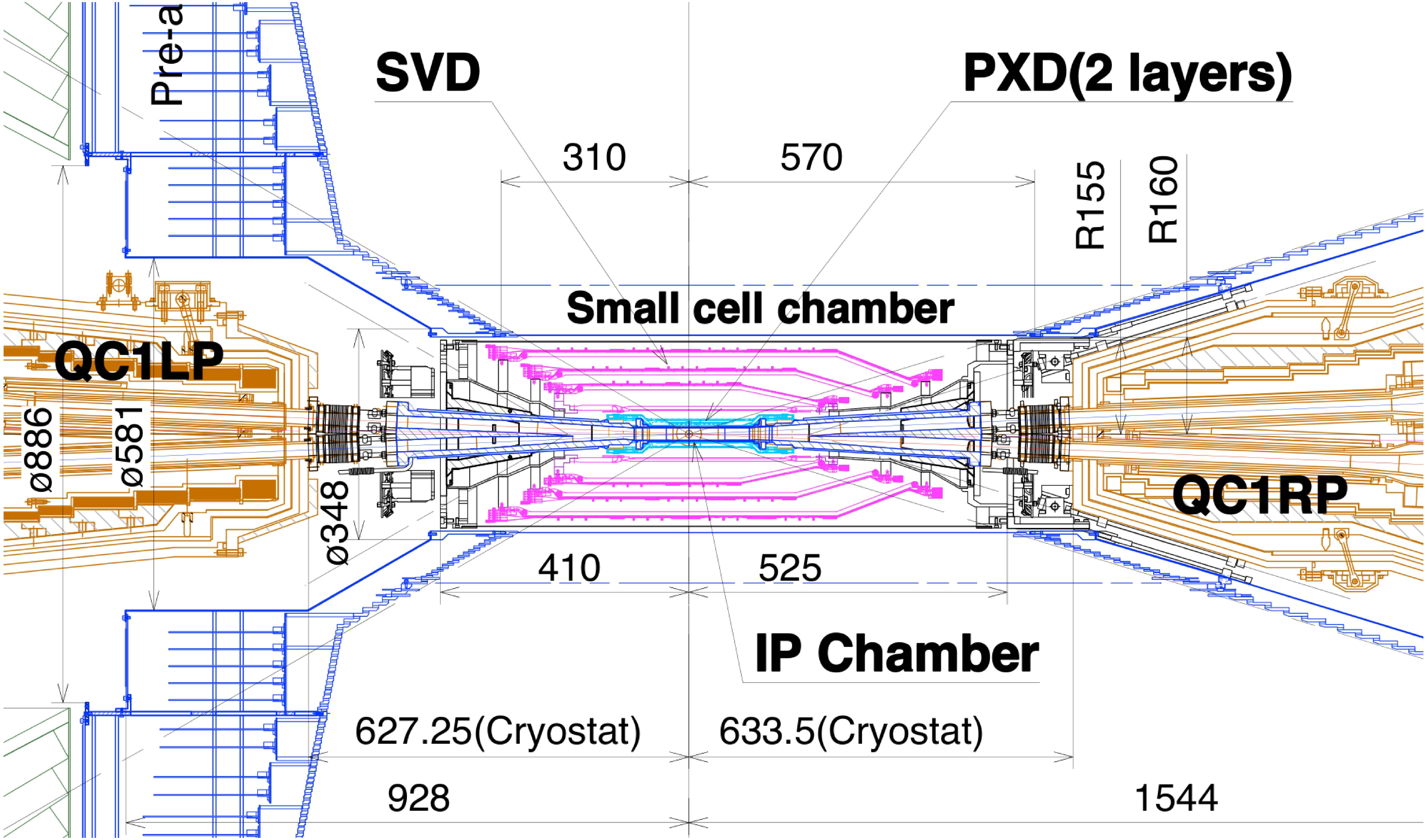






Vladimir Savinov (University of Pittsburgh) on behalf of the Belle II Collaboration

The Place of Future VXD is Currently Occupied by BEAST-II

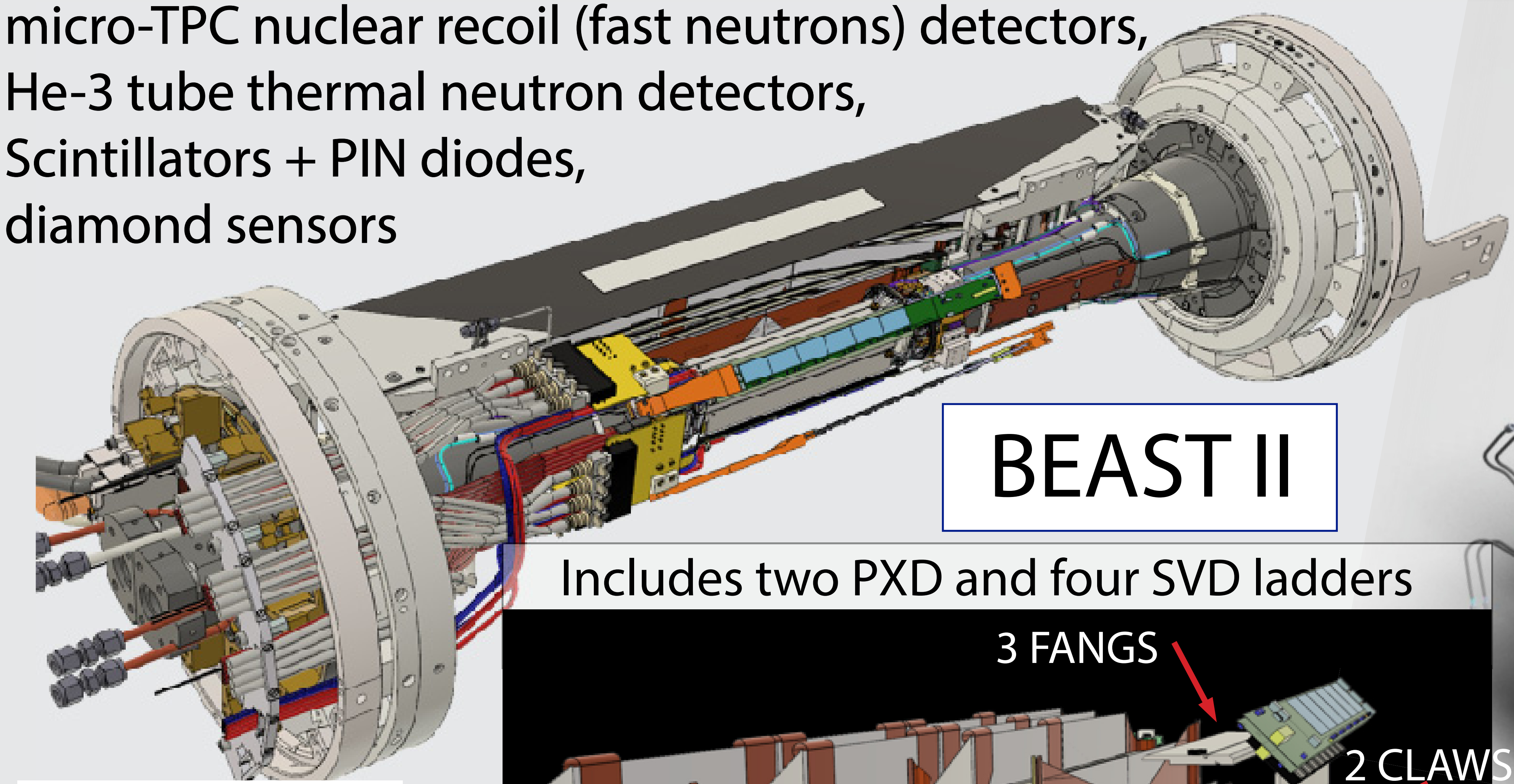


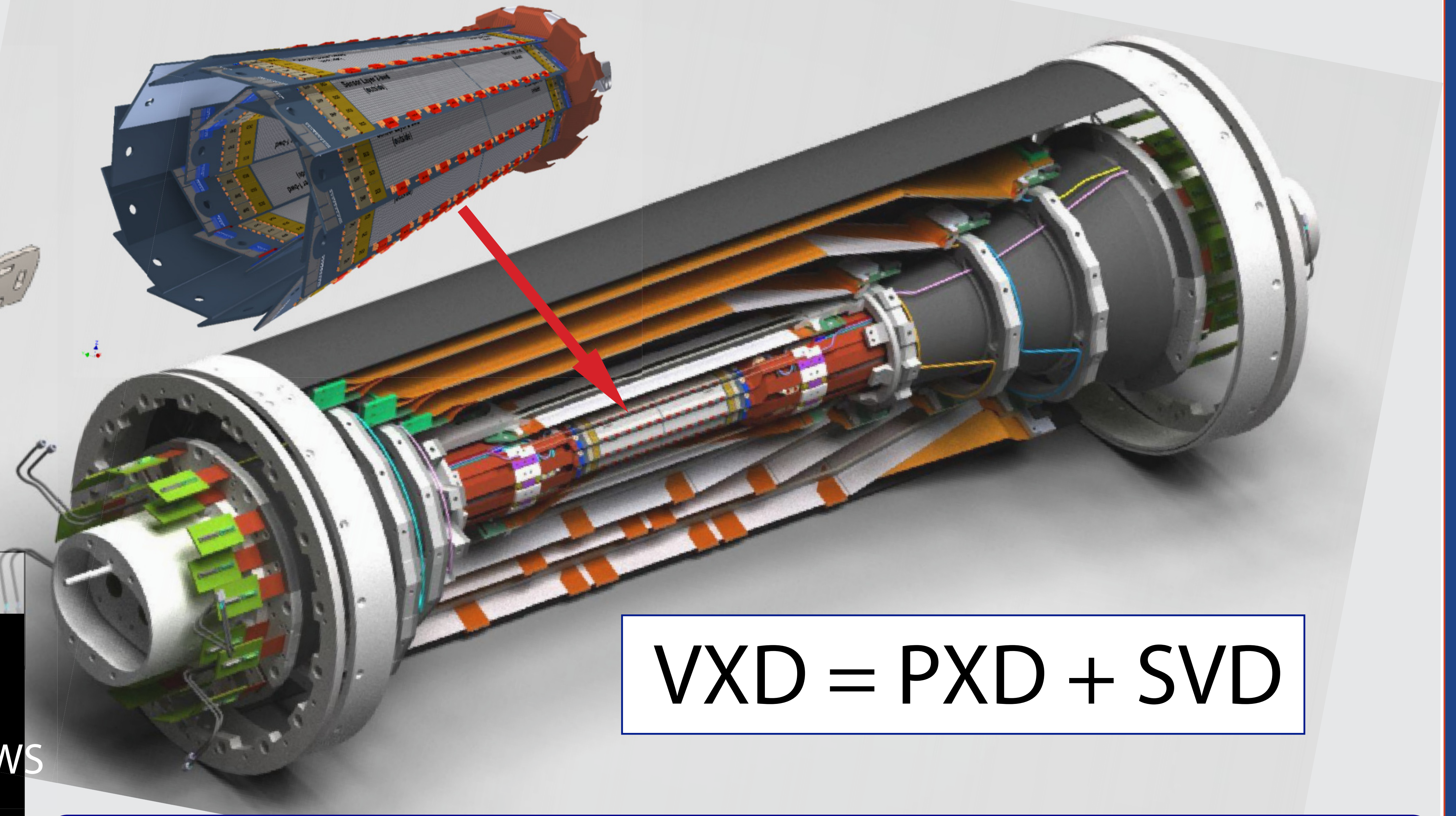
BEAST II (Phase 2 Commissioning Detector inside Belle II)

A system of radiation detectors: beam background monitors, first responders

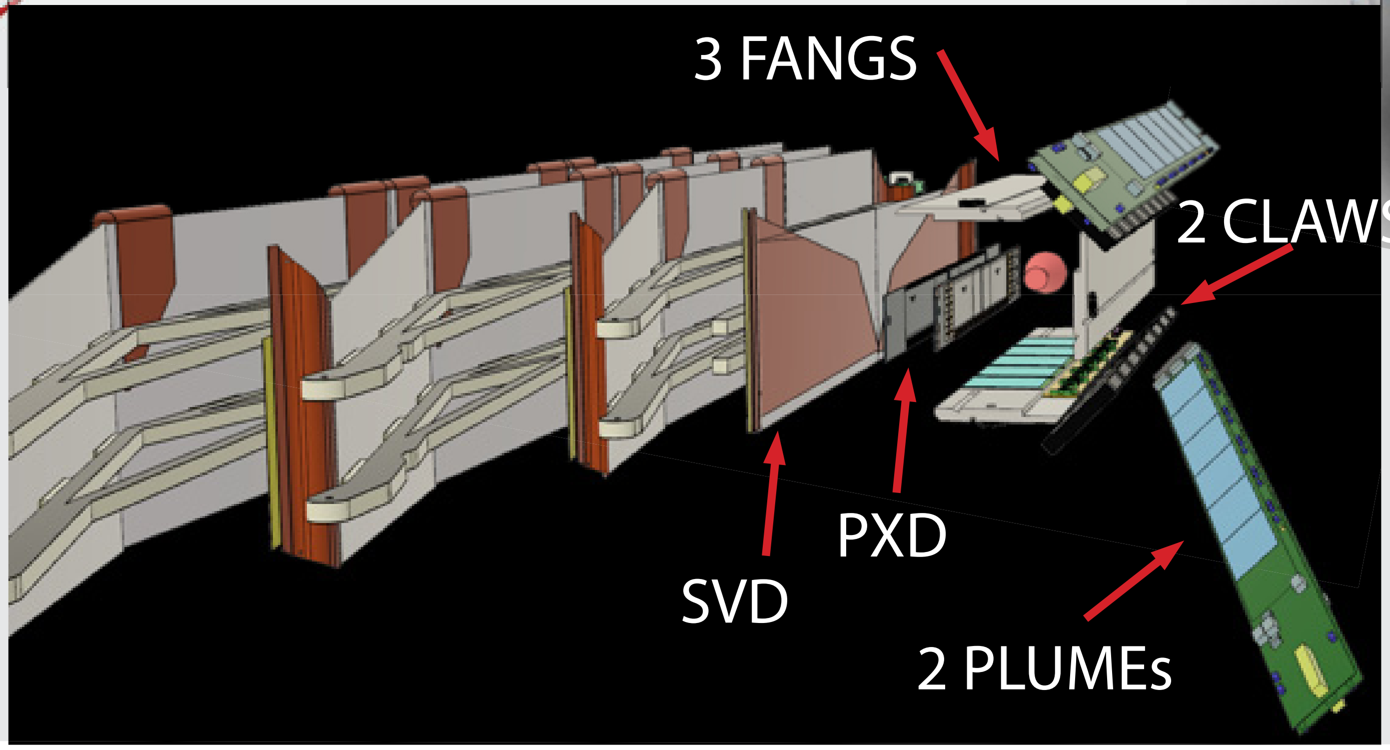
FANGS: "LHC/ATLAS style" silicon pixel sensors,
CLAWS: scintillator tiles read-out by silicon PMTs,
PLUME: "ILC style" MIMOSA silicon pixel sensors,
micro-TPC nuclear recoil (fast neutrons) detectors,
He-3 tube thermal neutron detectors,
Scintillators + PIN diodes,
diamond sensors

Now → End of 2018





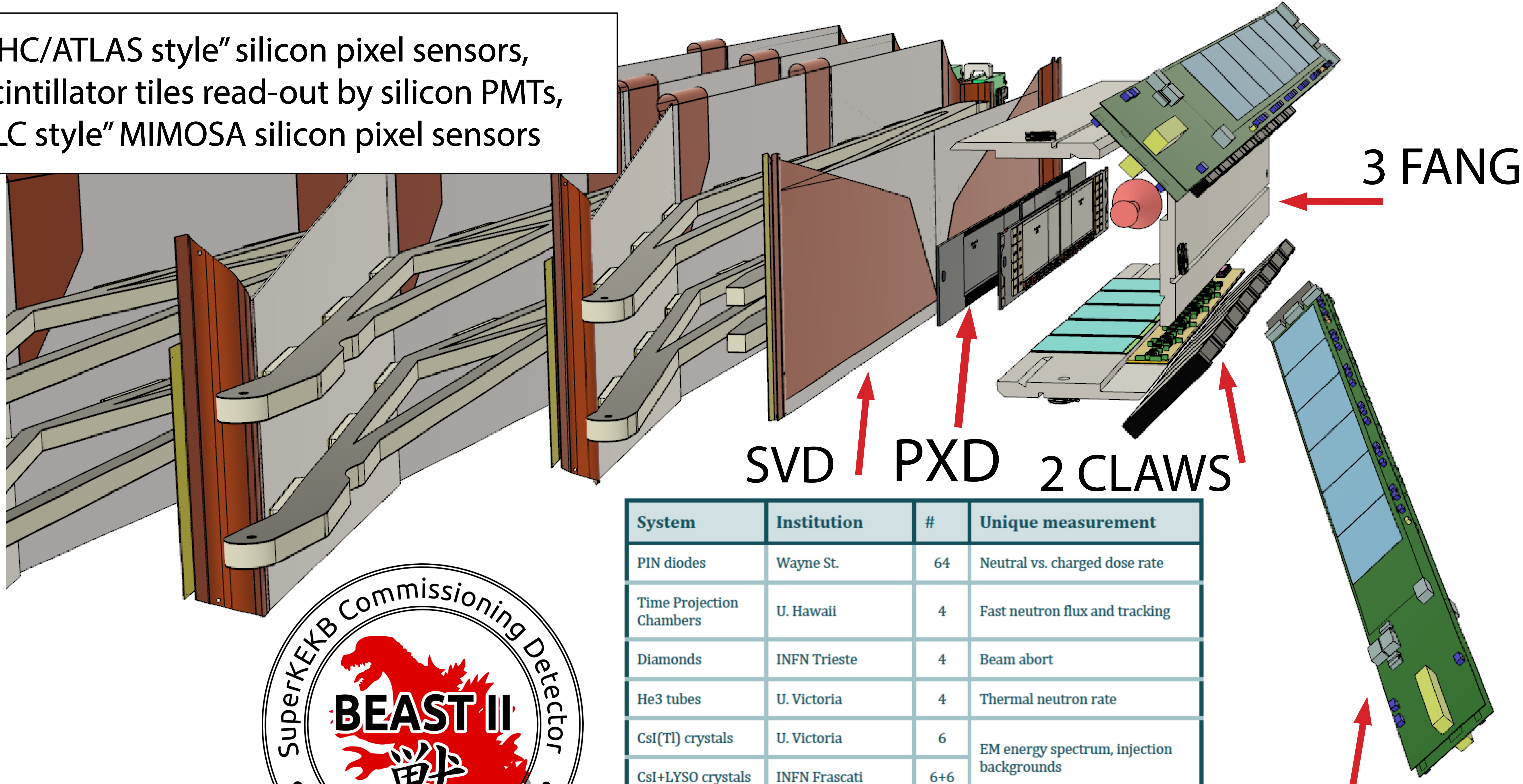
Includes two PXD and four SVD ladders



Understanding beam-related backgrounds (and physics backgrounds!) is of great importance
There is only that much of radiation hardness...

BEAST II, Commissioning Detector, beautiful PLUMEage!

FANGS: "LHC/ATLAS style" silicon pixel sensors,
CLAWS: scintillator tiles read-out by silicon PMTs,
PLUME: "ILC style" MIMOSA silicon pixel sensors

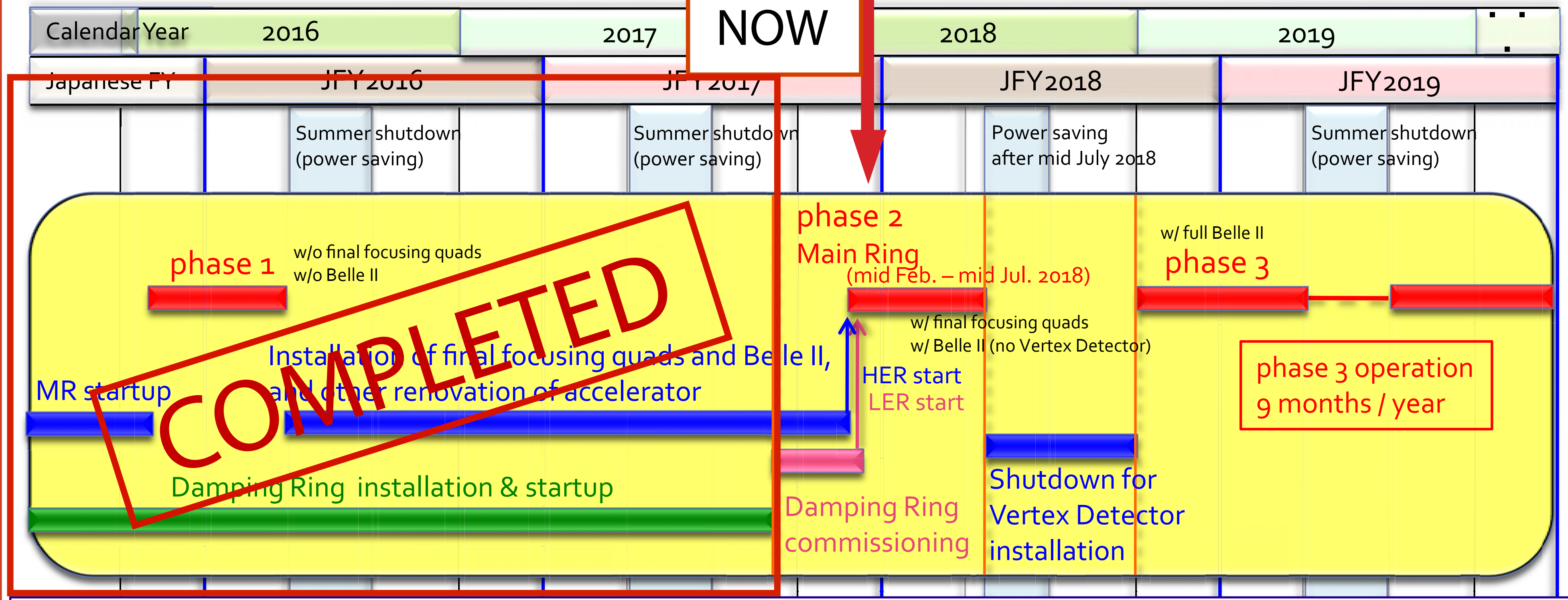


System	Institution	#	Unique measurement
PIN diodes	Wayne St.	64	Neutral vs. charged dose rate
Time Projection Chambers	U. Hawaii	4	Fast neutron flux and tracking
Diamonds	INFN Trieste	4	Beam abort
He3 tubes	U. Victoria	4	Thermal neutron rate
CsI(Tl) crystals	U. Victoria	6	EM energy spectrum, injection backgrounds
CsI+LYSO crystals	INFN Frascati	6+6	
BGO crystals	National Taiwan U.	8	Luminosity and EM rate
CLAWS plastic scintillators	MPI Munich	8	Fast injection backgrounds

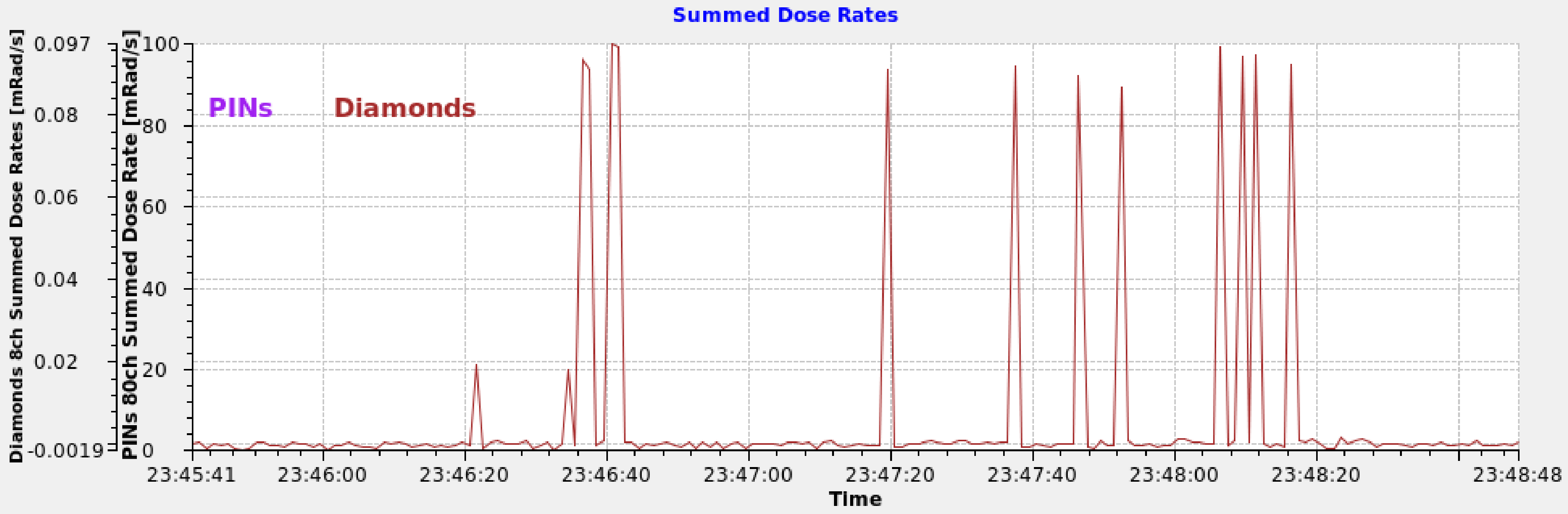
BEAST II (Beam Exorcism for A STable experiment) roars

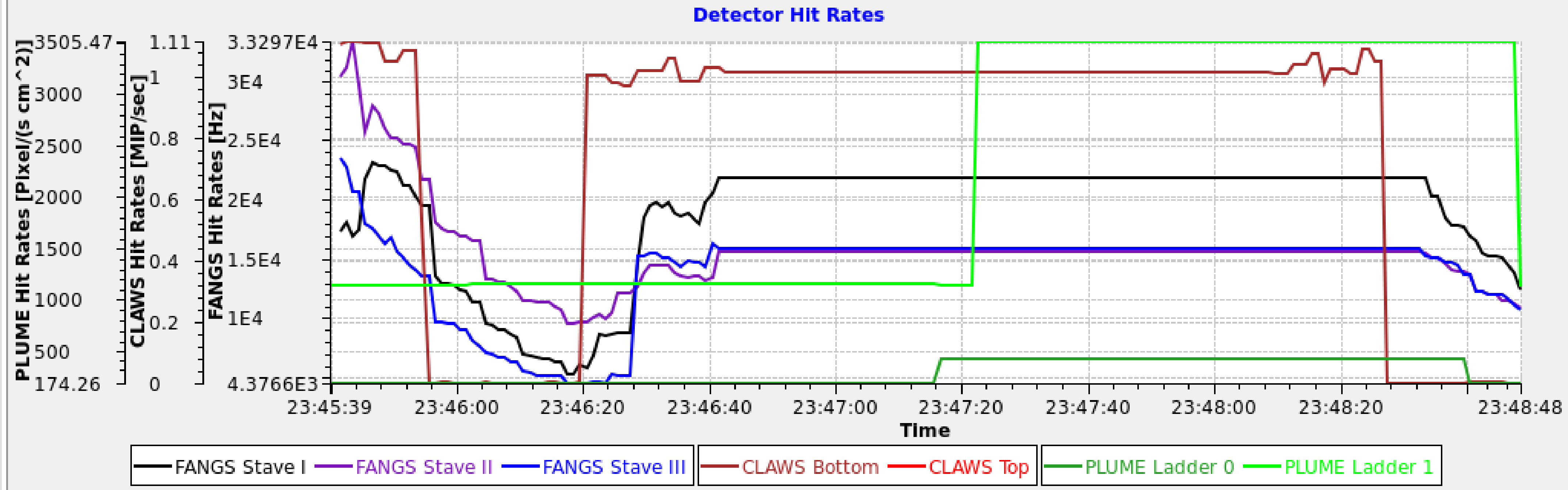
The accelerator group's goal achieved on the first try on March 19, 2018: more than 20 turns with RF off!

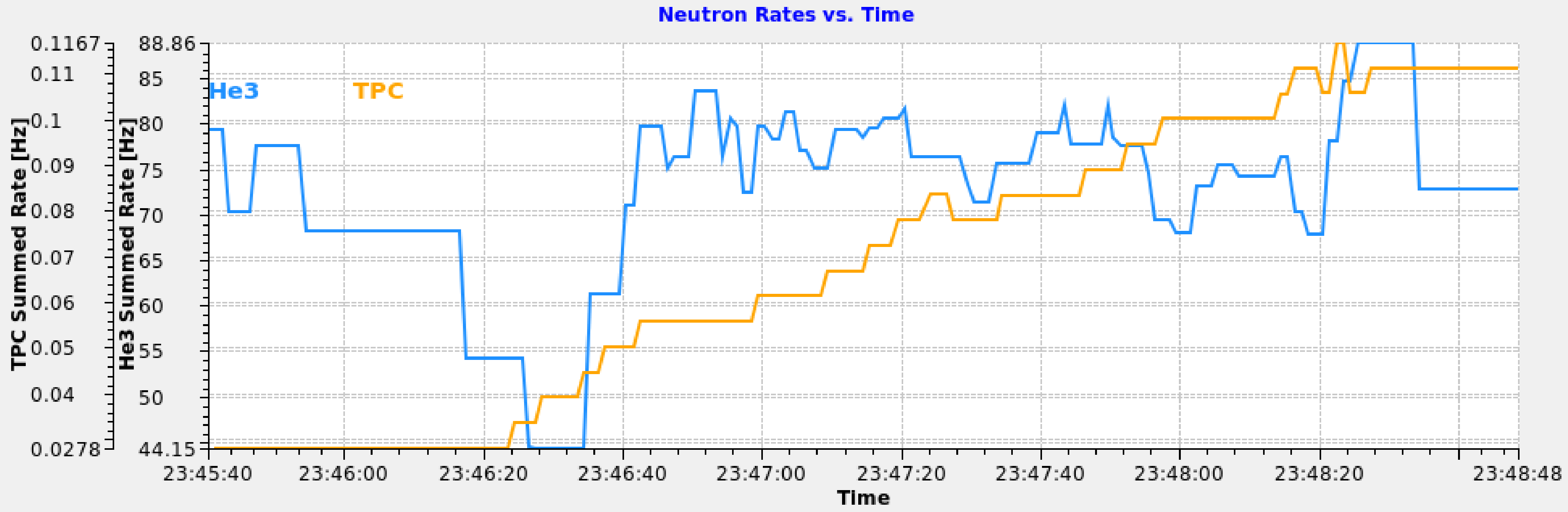
All BEAST detectors (but PIN diodes), i.e. diamonds, FANGS, CLAWS, PLUMEs, He3 and TPCs have seen the first backgrounds



Verification of nano-beam scheme (target $L > 10^{34} cm^{-2} s^{-1}$)
Understanding beam background especially in VXD volume







BEAST II Paper is Out / Beam Backgrounds Measured

First Measurements of Beam Backgrounds at SuperKEKB

P. M. Lewis[f], I. Jaegle[d], H. Nakayama[h], A. Aloisio[q], F. Ameli[k], M. Barrett[v], A. Beaulieu[u], L. Bosisio[t], P. Branchini[l], T. E. Browder[f], A. Budano[l], G. Cautero[c], C. Cecchi[j], Y.-T. Chen[s], K.-N. Chu[s], D. Cinabro[v], P. Cristaudo[t], S. de Jong[u], R. de Sangro[n], G. Finocchiaro[n], J. Flanagan[i], Y. Funakoshi[i], M. Gabriel[o], R. Giordano[q], D. Giuressi[c], M. T. Hedges[f], N. Honkanen[u], H. Ikeda[i], T. Ishibashi[i], H. Kaji[i], K. Kanazawa[i], C. Kiesling[o], S. Koirala[s], P. Križan[m], C. La Licata[t], L. Lanceri[t], J.-J. Liau[s], F.-H. Lin[s], J.-C. Lin[s], Z. Liptak[f], S. Longo[u], E. Manoni[j], C. Marinas[a], K. Miyabayashi[r], E. Mulyani[e], A. Morita[i], M. Nakao[h], M. Nayak[v], Y. Ohnishi[i], A. Passeri[l], P. Poffenberger[u], M. Ritzert[g], J. M. Roney[u], A. Rossi[j], T. Röder[o], R. M. Seddon[p], I. S. Seong[f], J.-G. Shiu[s], F. Simon[o], Y. Soloviev[b], Y. Suetsugu[i], M. Szalay[o], S. Terui[i], G. Tortone[q], S. E. Vahsen[f,*], N. van der Kolk[o], L. Vitale[t], M.-Z. Wang[s], H. Windel[o], S. Yokoyama[r]

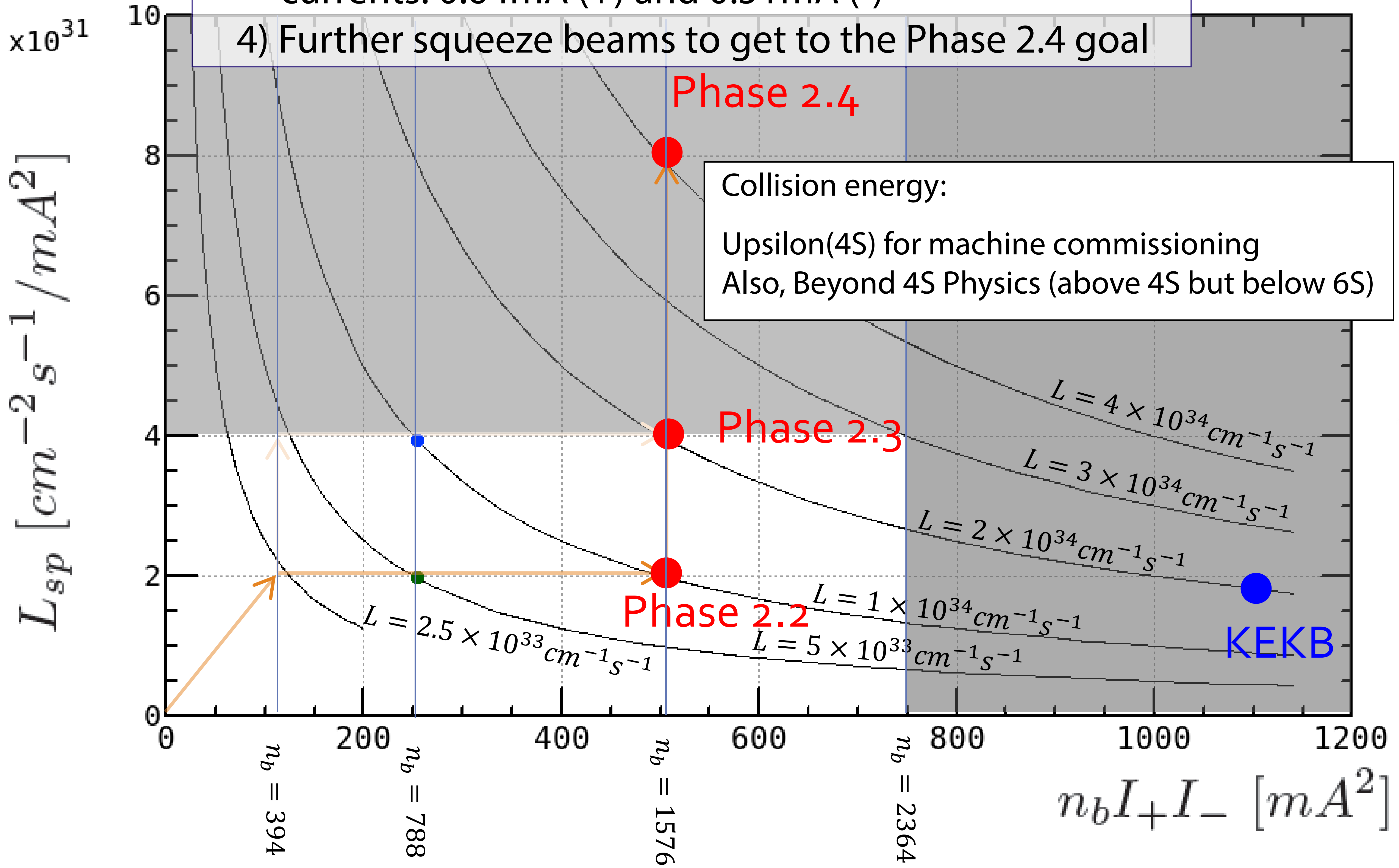
https://arxiv.org/abs/1802.01366

The high design luminosity of the SuperKEKB electron-positron collider is expected to result in challenging levels of beam-induced backgrounds in the interaction region. Properly simulating and mitigating these backgrounds is critical to the success of the Belle II experiment. We report on measurements performed with a suite of dedicated beam background detectors, collectively known as BEAST II, during the so-called Phase 1 commissioning run of SuperKEKB in 2016, which involved operation of both the high energy ring (HER) of 7 GeV electrons as well as the low energy ring (LER) of 4 GeV positrons. We describe the BEAST II detector systems, the simulation of beam backgrounds, and the measurements performed. The measurements include standard ones of dose rates versus accelerator conditions, and more novel investigations, such as bunch-by-bunch measurements of injection backgrounds and measurements sensitive to the energy spectrum and angular distribution of fast neutrons. We observe beam-gas, Touschek, beam-dust, and injection backgrounds. As there is no final focus of the beams in Phase 1, we do not observe significant synchrotron radiation, as expected. Measured LER beam-gas backgrounds and Touschek backgrounds in both rings are slightly elevated, on average three times larger than the levels predicted by simulation. HER beam-gas backgrounds are on on average two orders of magnitude larger than predicted. Systematic uncertainties and channel-to-channel variations are large, so that these excesses constitute only 1-2 sigma level effects. Neutron background rates are higher than predicted and should be studied further. We will measure the remaining beam background processes, due to colliding beams, in the imminent commissioning Phase 2. These backgrounds are expected to be the most critical for Belle II, to the point of necessitating replacement of detector components during the Phase 3 (full-luminosity) operation of SuperKEB.

Phase 2 Commissioning: The Machine Comes First

Preliminary plans for Phase 2 luminosity tuning

1) Start with low current
2) Squeeze beams to achieve specific of ~KEKB
3) Increase the number of bunches from 394 to 1576, currents: 0.64mA (+) and 0.51mA (-)
4) Further squeeze beams to get to the Phase 2.4 goal



Collision energy:

Upsilon(4S) for machine commissioning
Also, Beyond 4S Physics (above 4S but below 6S)

Machine Parameters

SuperKEKB can exceed the peak luminosity of KEKB when we achieve $\xi_y > 0.05$

	Phase 2.2 (8x8)		Phase 2.3 (4x8)		Phase 2.4 (4x4)	
	LER	HER	LER	HER	LER	HER
$I_L \times I_H$, n_b	1000 mA x 800 mA, 1576 bunches (3-bucket spacing)					
β_x^* [mm]	256	200	128	100	128	100
β_y^* [mm]	2.16	2.40	2.16	2.40	1.08	1.20
$\varepsilon_y/\varepsilon_x$ [%]	5.0		1.4		0.7*	
ξ_x	0.0104	0.0041	0.0053	0.0021	0.0053	0.0021
ξ_y	0.0257	0.0265	0.0484	0.0500	0.0496	0.0505
I_{bunch} [mA]	0.64	0.51	0.64	0.51	0.64	0.51
L [$cm^{-2}s^{-1}$]	1×10^{34} (tentative target)		2×10^{34}		4×10^{34}	
L_{sp} [$cm^{-2}s^{-1}/mA^2$]	1.97×10^{31}		3.94×10^{31}		7.88×10^{31}	

* conserve β_y^*/ε_y

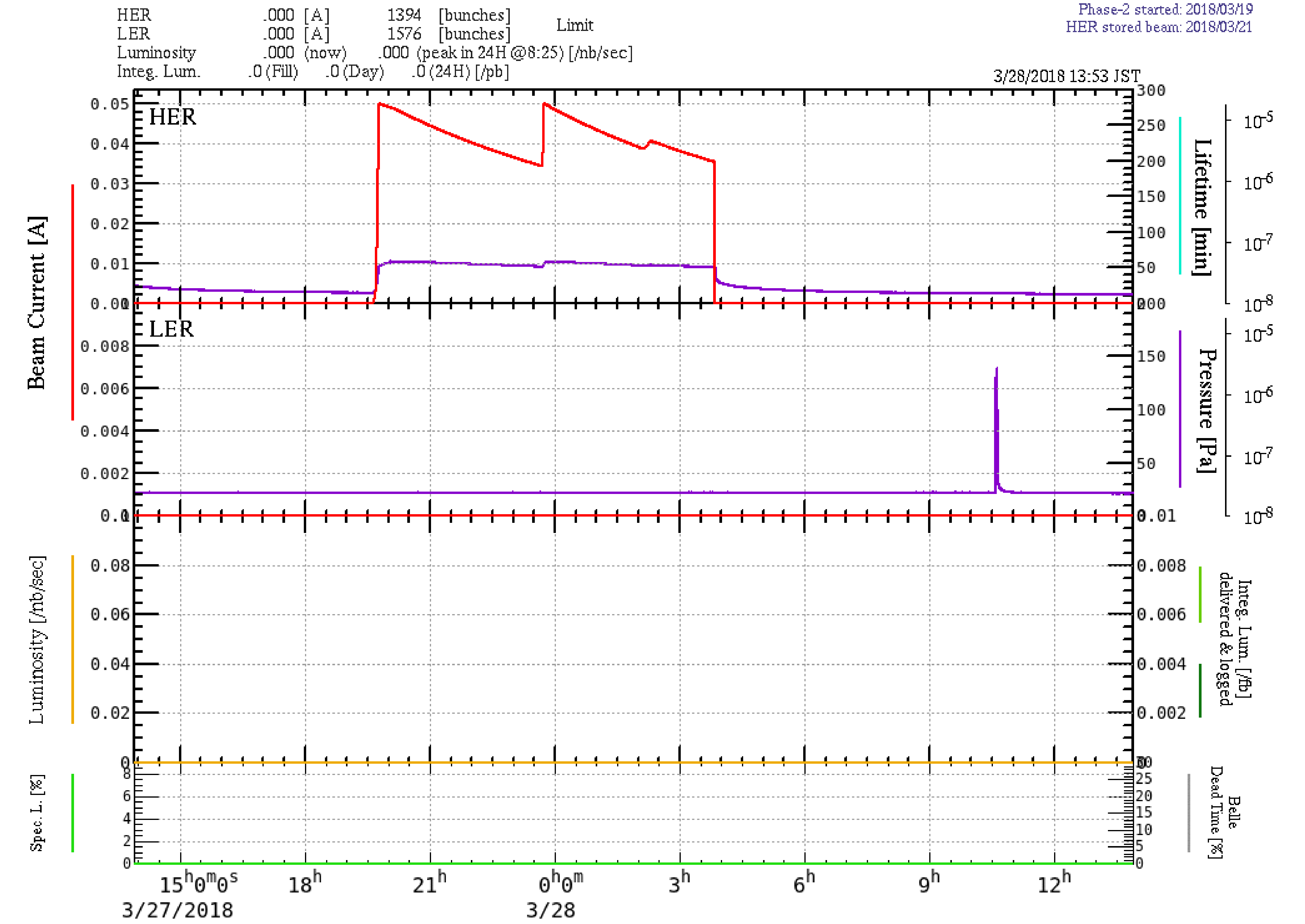
Dedicated beam background studies during phase 2

Study	Purpose
Beam-size scan	Measure Touschek BG component
Vacuum bump study	Measure Beam-gas BG component
Collimator study	Find optimal setting
Injection study	Measure injection BG time structure, improve injection efficiency
Luminosity scan	Measure luminosity BG component

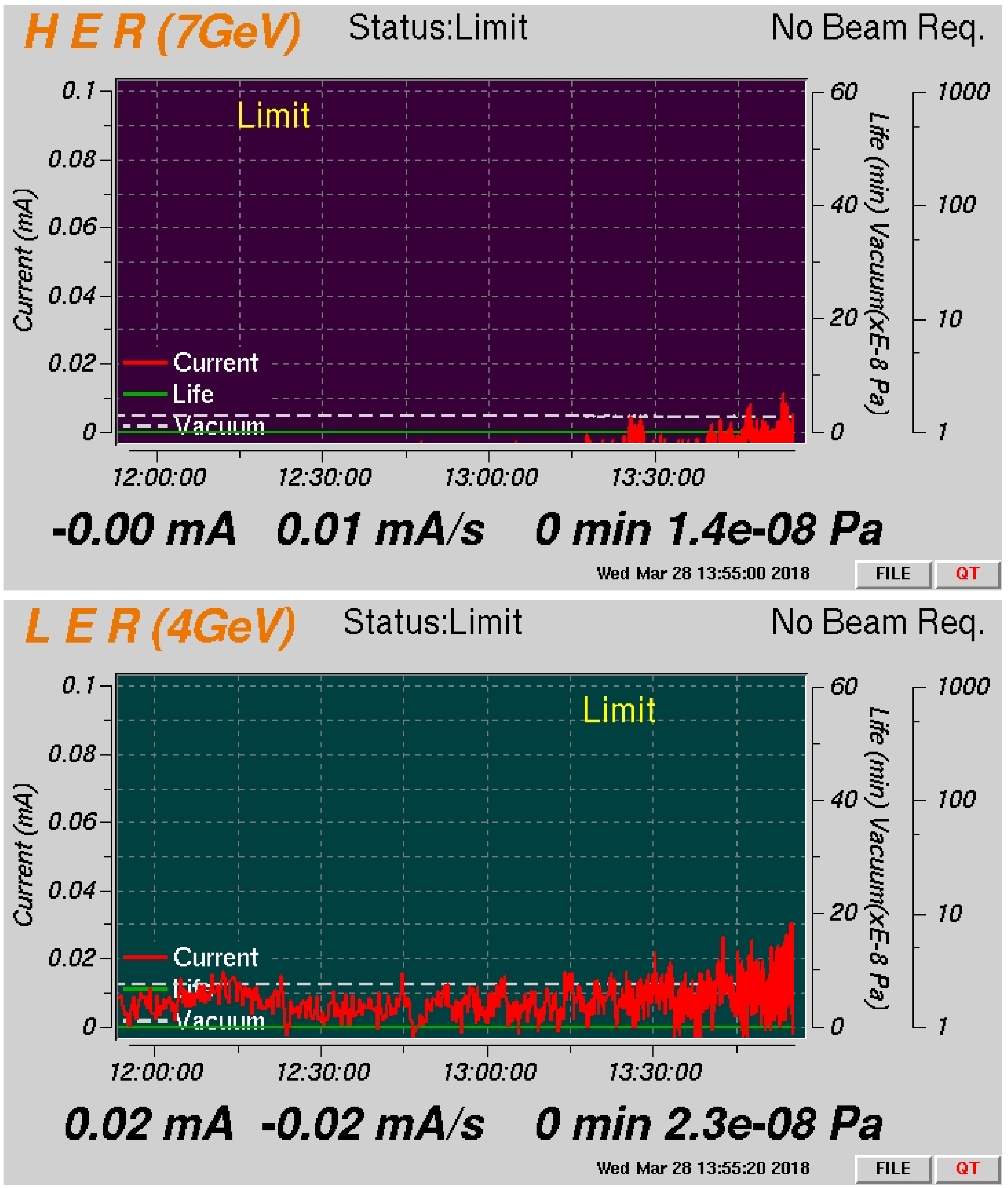
Preliminary

Welcome to the Machine

http://www-superkekb.kek.jp/operation.html



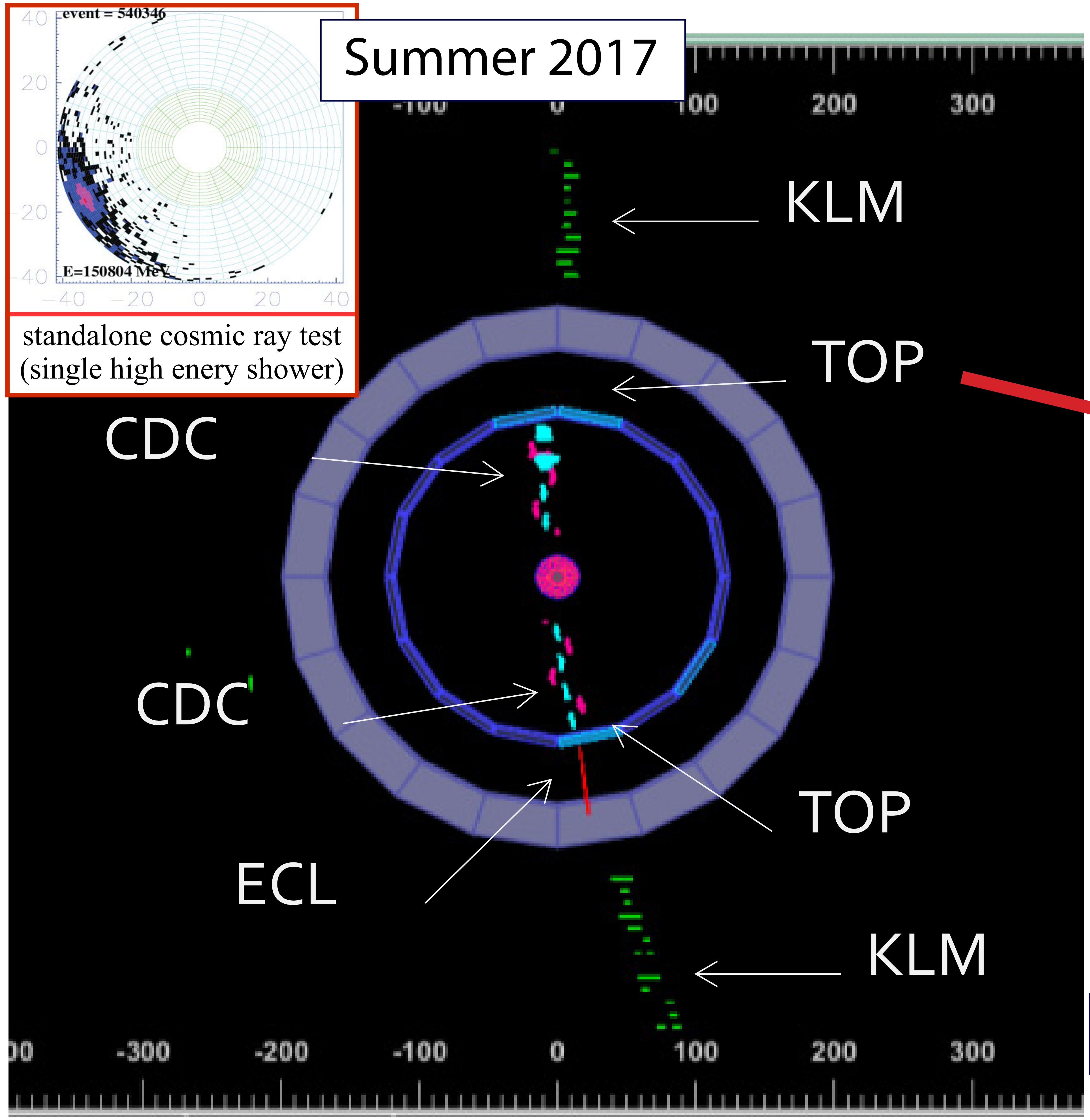
SuperKEKB 24-Hour Operation Summary

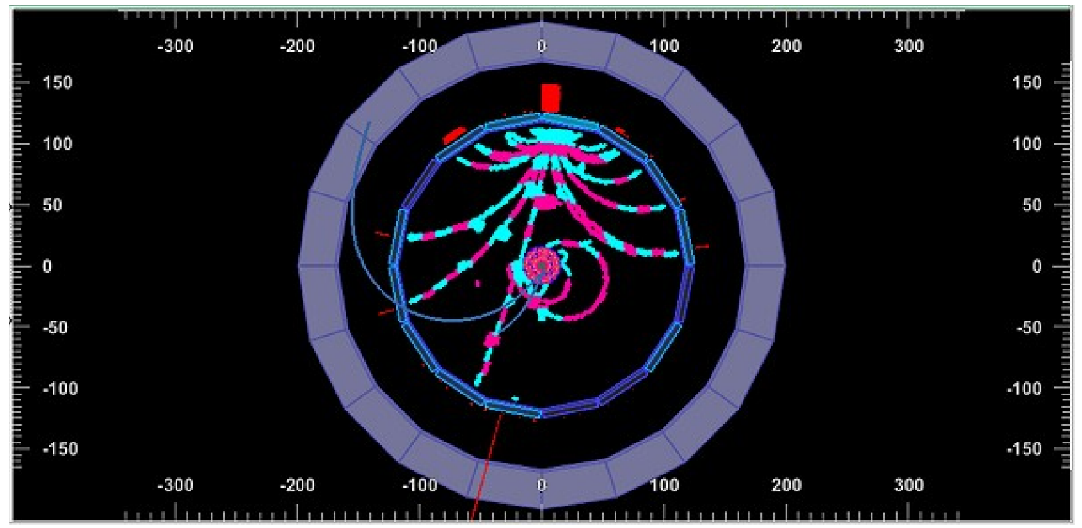


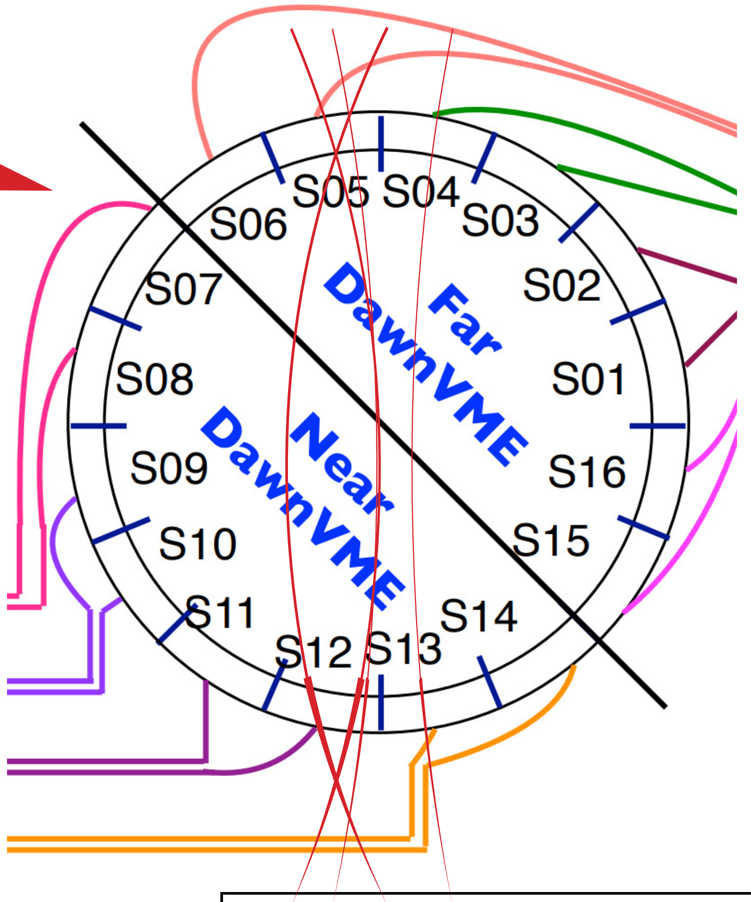
SuperKEKB 2-Hour Operation Summary

In Phase 1 the LER (positron) current reached 1010 mA and the HER (electron) current reached 870 mA. After optics corrections, the emittances of the two beams were near or below design values. Since there was no superconducting final focus, only single beam studies were possible

Belle II Had Been Recording Cosmic Events Until Recently

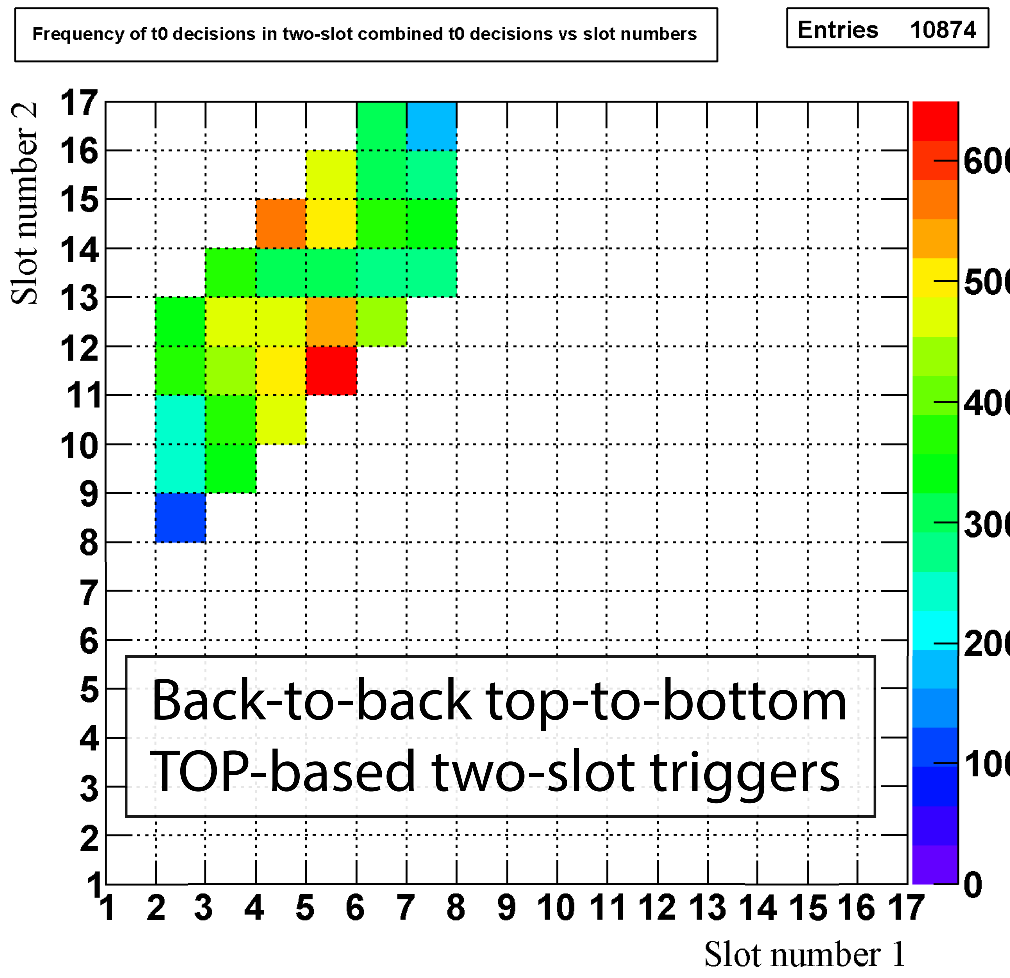


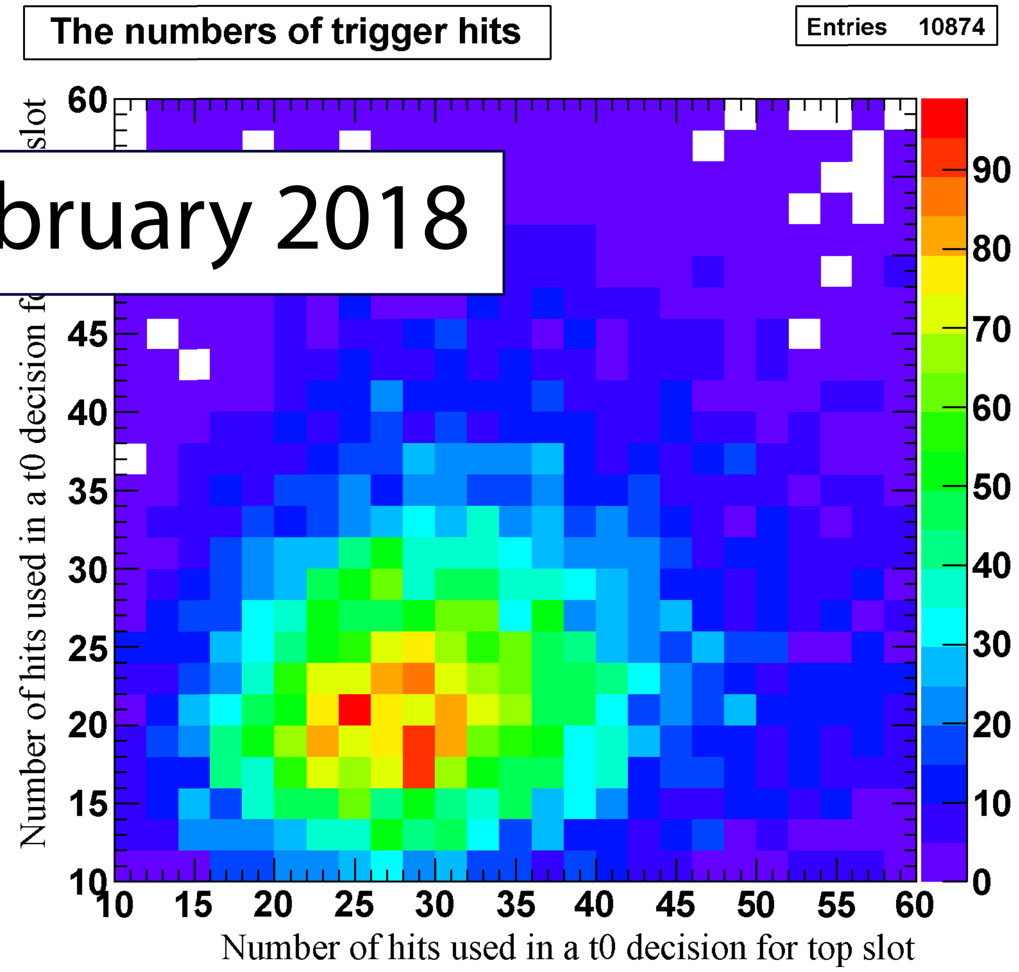




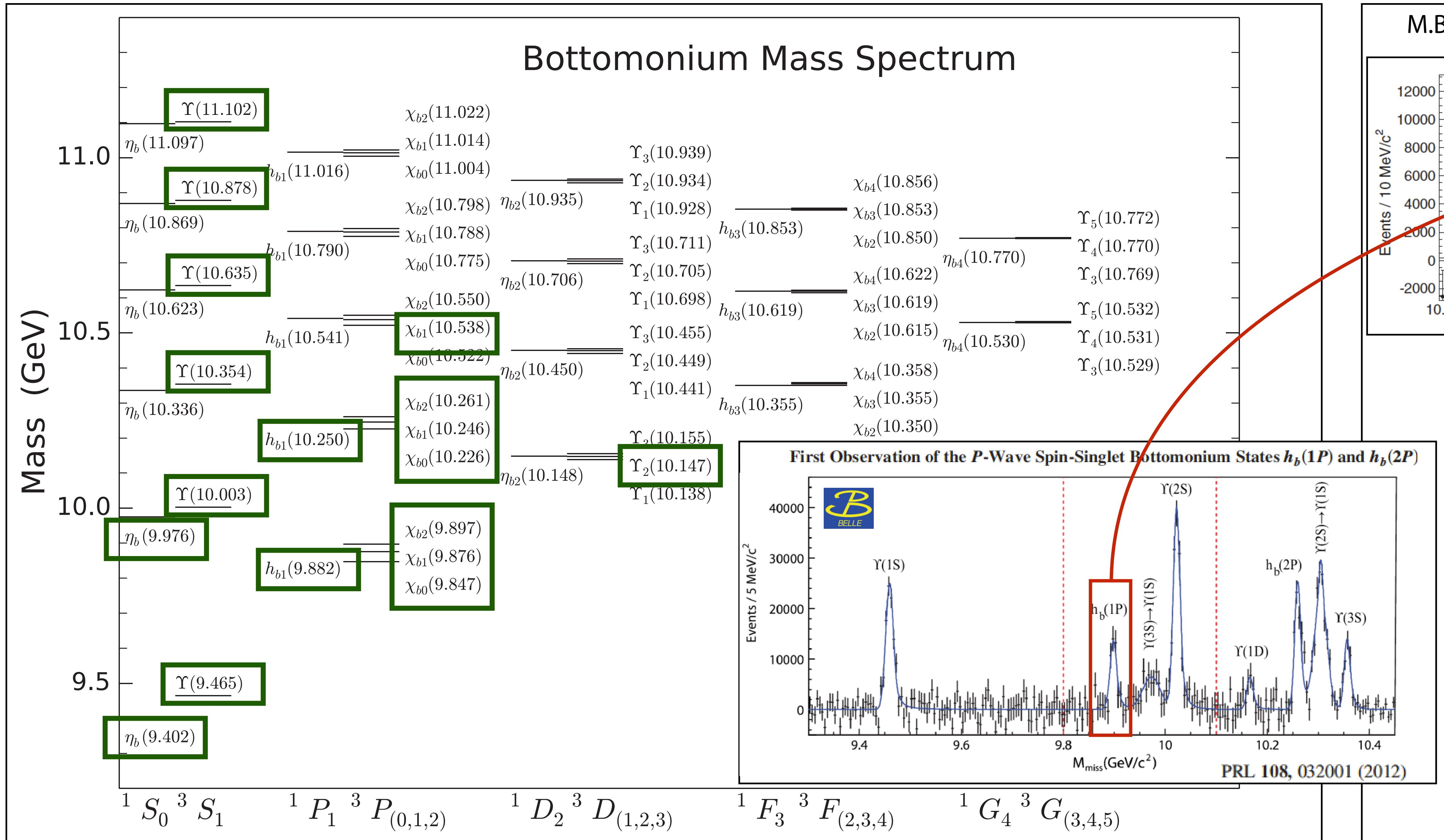
Beam view layout of 16 TOP slots

Clean standalone TOP triggering on cosmic muons





Belle II Phase 2 / Early Phase 3 Physics (possibly with VXD)

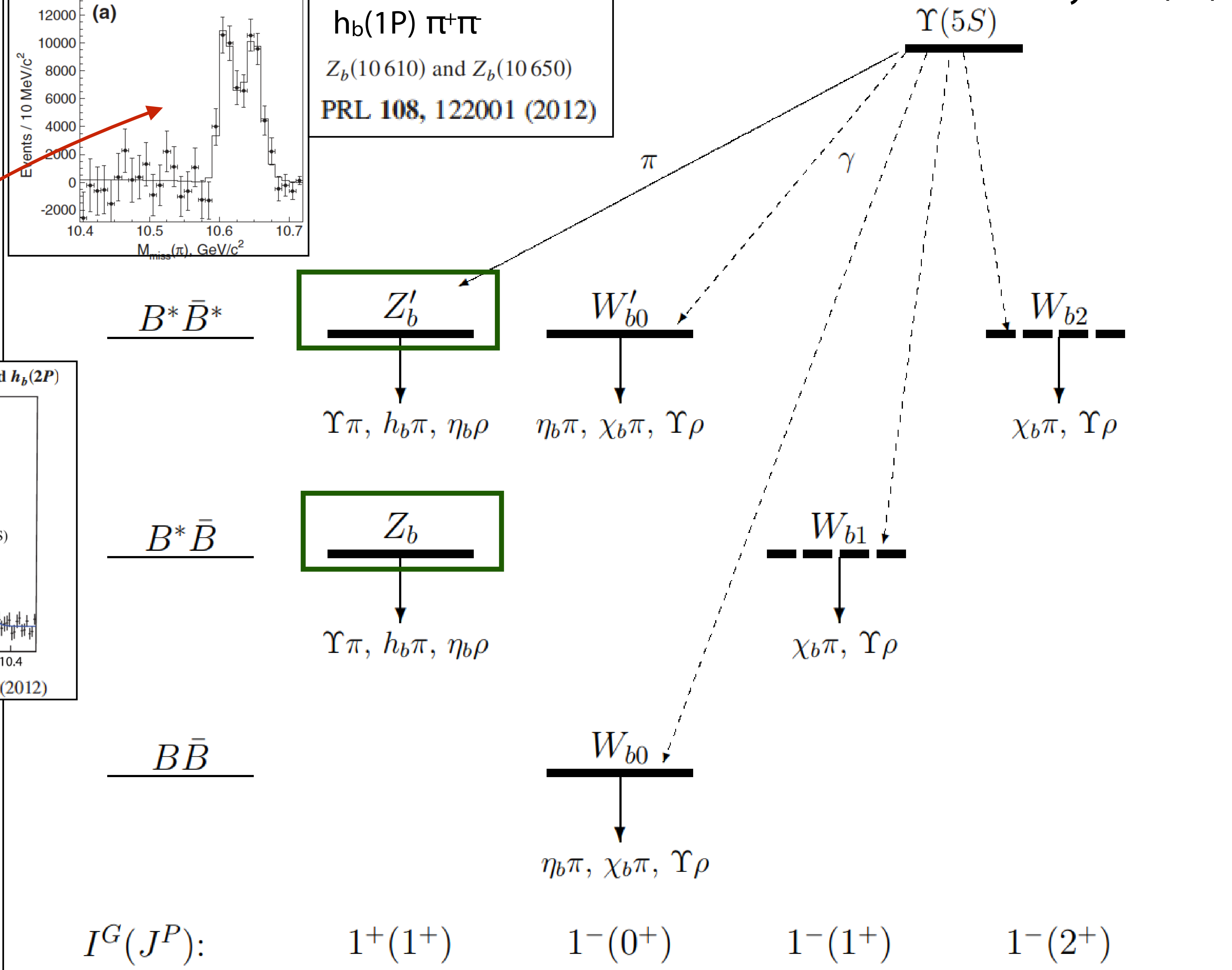


S. Godfrey and K. Moats, Bottomonium mesons and strategies for their observation, Phys. Rev. D 92, 054034 (2015)
S. Godfrey and N. Isgur, Mesons in a relativized quark model with chromodynamics, Phys. Rev. D 32, 189 (1985).

> Many of these states have been observed
>
> Many more have not been discovered yet
>
> Low-energy hadronic physics is important

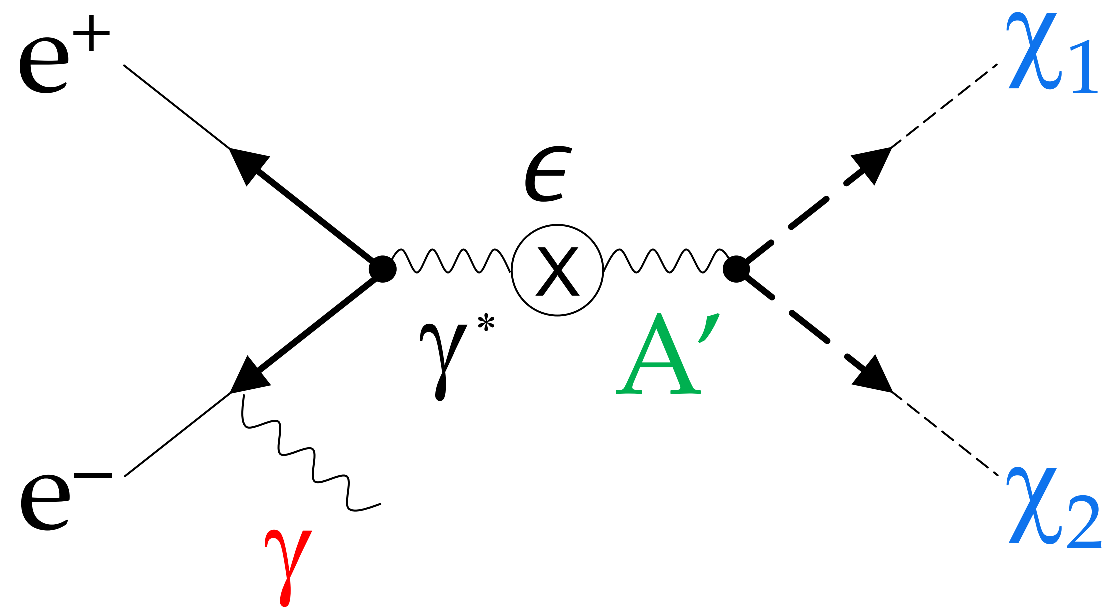
M.B. Voloshin, Radiative transitions from Υ(5S) to molecular bottomonium, Phys. Rev. D 84, 031502(R) (2011)

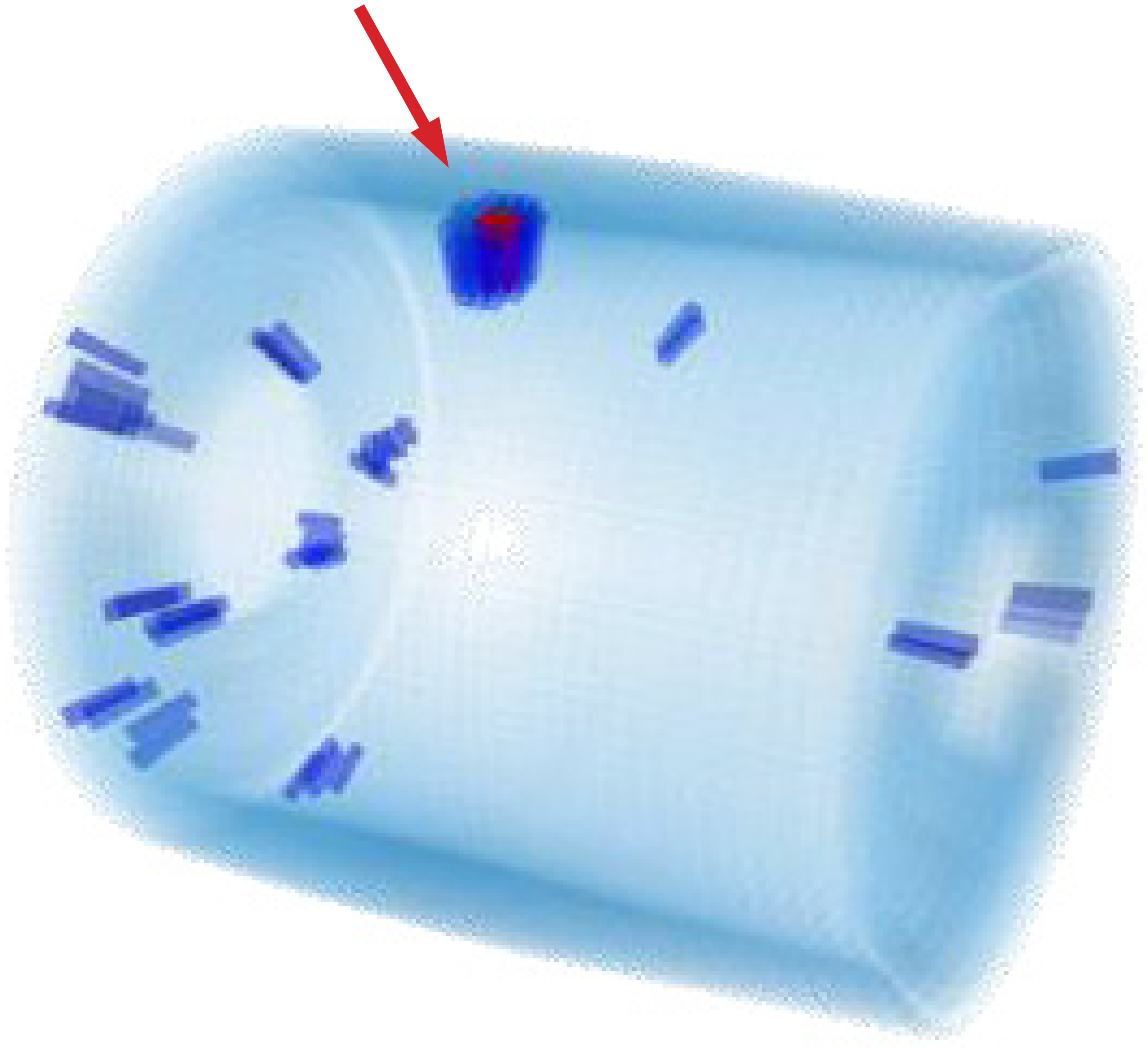
The real interest is actually to Υ(6S)

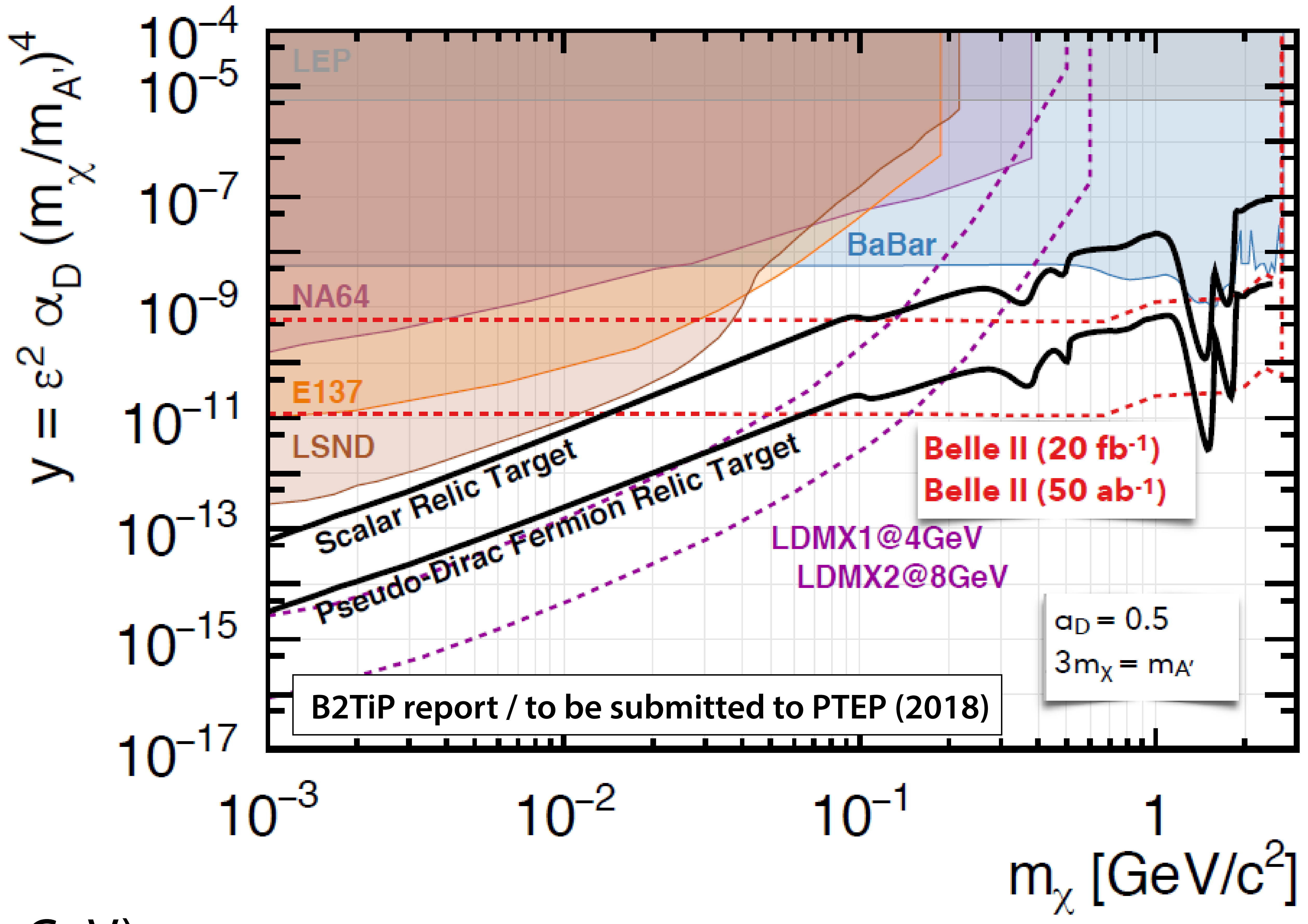


The heavy quark spin symmetry implies that in addition to the recently observed $Z(10610)$ and $Z(10650)$ molecular resonances with $I^G = 1^+$, there should exist two or four molecular bottomonium-like states with $I^G = 1^-$. Properties of these G-odd states are considered, including their production in the radiative transitions from $\Upsilon(5S)$, by applying the same symmetry to the $\Upsilon(5S)$ resonance and the transition amplitudes. The considered radiative processes can provide a realistic option for observing the yet hypothetical states.

QCD creates no good vibrations? Then Dark Matters must!





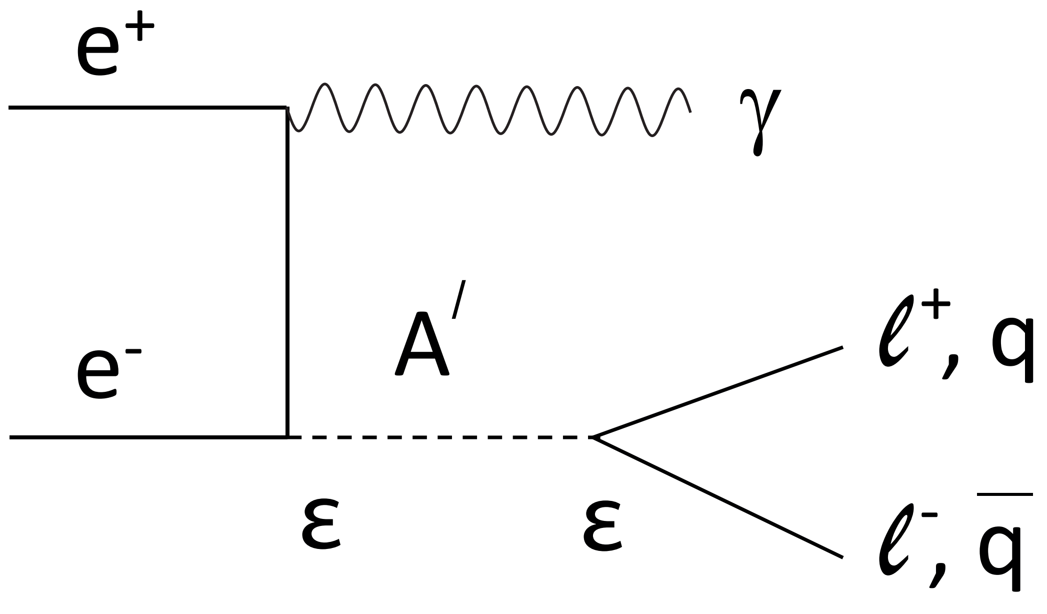


Single-photon events, ECL trigger (~GeV)

Dark matter is unexpectedly absent from the galaxy NGC1052–DF2

Nature, March 28, https://www.sciencenews.org/article/dark-matter-mia-strange-galaxy

Different Portals to Dark Sector Will Be Explored at Belle II



ISR (and two-photon processes) will also allow to search for ALPs

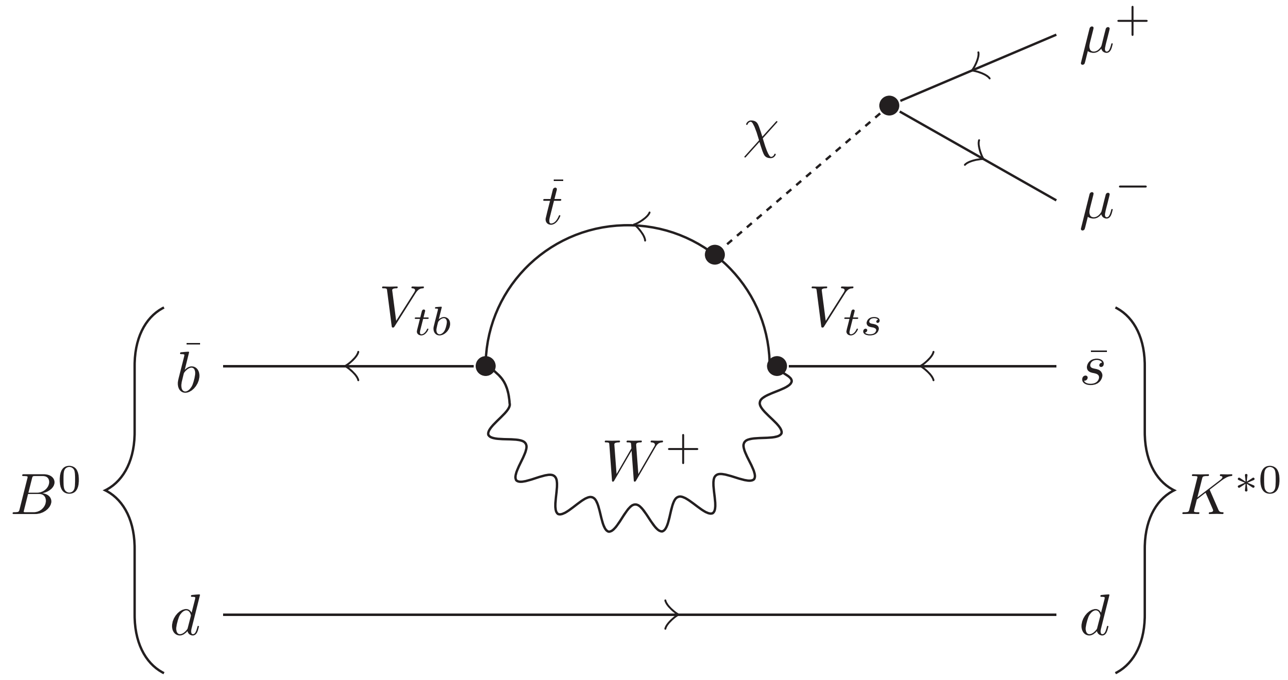
$$e^+e^- \to \gamma\, A'(\to \chi\bar{\chi}) \qquad e^+e^- \to \gamma\, A'(\to \ell^+\ell^-)$$

$$e^+e^- \to \Upsilon(nS) \to \gamma A^0$$

$$e^+e^- \to h'(\to A'A')A' \ \text{ with } A' \to \ell^+\ell^-$$

Multilepton signatures of a hidden sector in rare *B* decays, Batell, Pospelov, Ritz, PRD 83, 054005 (2011)

We explore the sensitivity of flavor-changing $b \to s$ transitions to a (sub-) GeV hidden sector with generic couplings to the standard model through the Higgs, vector, and axion portals. The underlying two-body decays of B mesons, $B \to X_s\mathcal{S}$, and $B^0 \to \mathcal{S}\mathcal{S}$, where $\mathcal{S}$ denotes a generic new GeV-scale particle, may significantly enhance the yield of monochromatic lepton pairs in the final state via prompt $\mathcal{S} \to l\bar{l}$ decays. Existing measurements of the charged lepton spectrum in neutral-current semileptonic B decays provide bounds on the parameters of the light sector that are significantly more stringent than the requirements of naturalness. New search modes, such as $B \to X_s + n(l\bar{l})$ and $B^0 \to n(l\bar{l})$ with $n \geq 2$, can provide additional sensitivity to scenarios in which both the Higgs and vector portals are active, and are accessible to (super-) B factories and hadron colliders.



$$B \to SS \to 2(\ell^+\ell^-)$$

$$B \to K^{(*)}S \to K^{(*)}\ell^+\ell^-$$

$$B \to K^{(*)}A'(\to \ell^+\ell^-)$$

$$B \to K^{(*)}h' \ \text{ with } h' \to A'A' \to 2(\ell^+\ell^-)$$

$$B \to 2h' \to 4A' \to 4(\ell^+\ell^-)$$

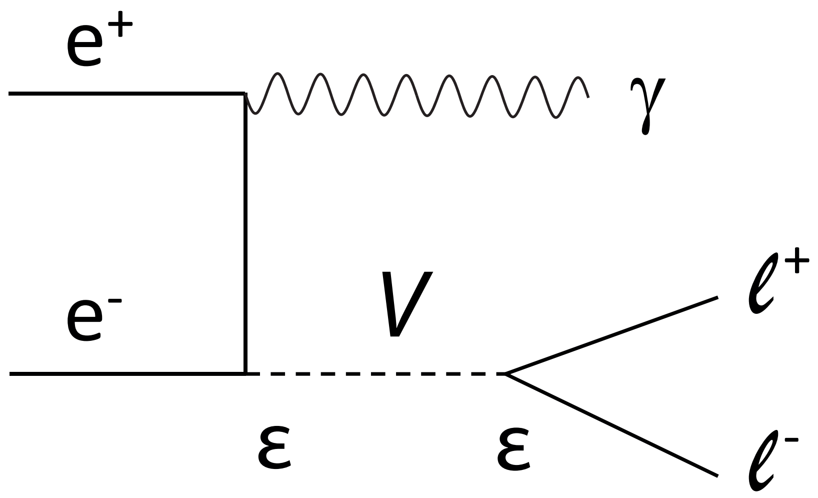
$$B \to A'A' \to 2(\ell^+\ell^-) \ \text{ through off-shell } h - h' \text{ mixing}$$

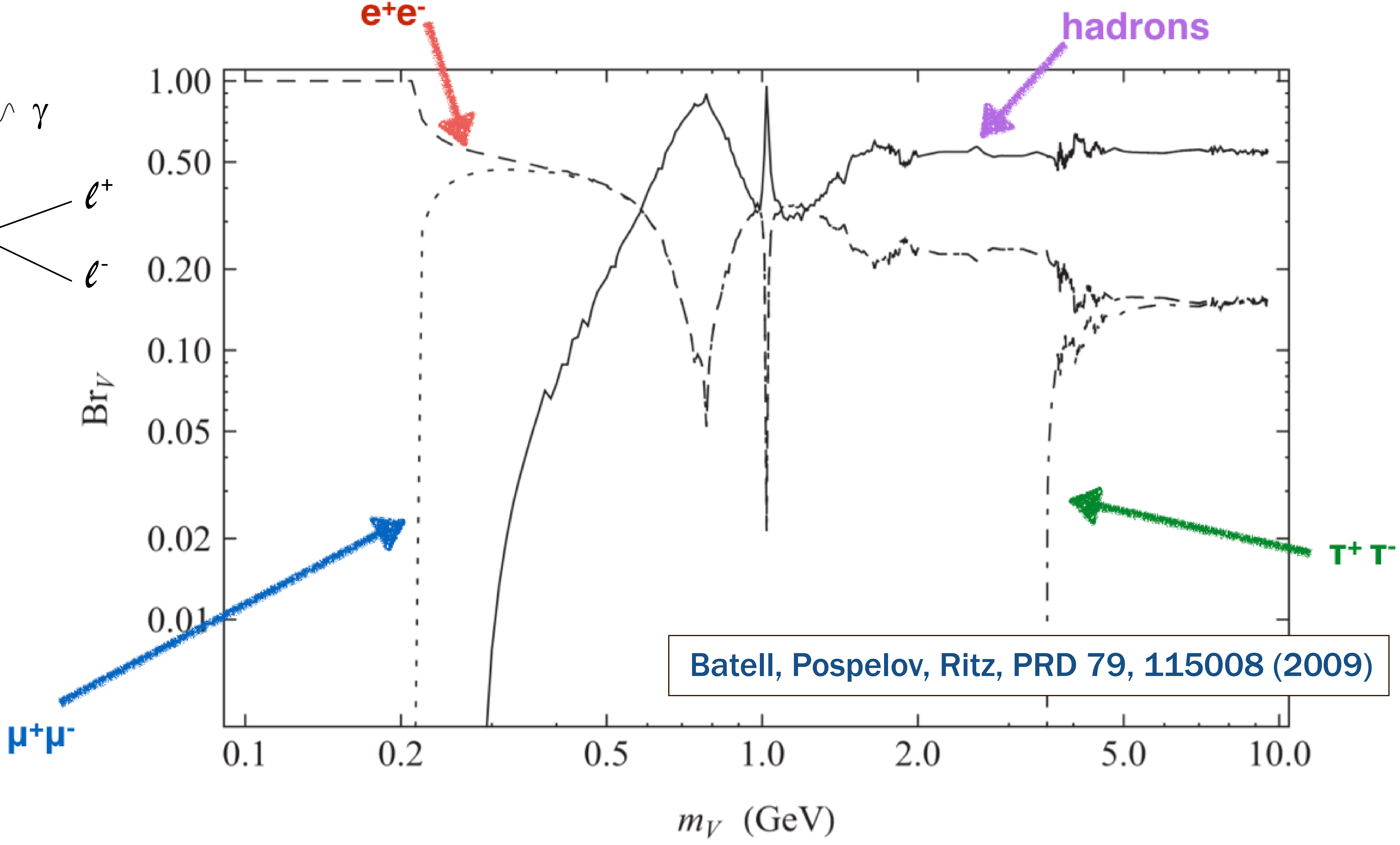
Another interesting portal to invisibles is provided by dipion transitions of Y(nS) to nothing (visible)

h′ is a Higgs and *A′* is an intermediate vector boson of an additional $U(1)_s$ gauge group

Different Portals to Dark Sector Will Be Explored at Belle II

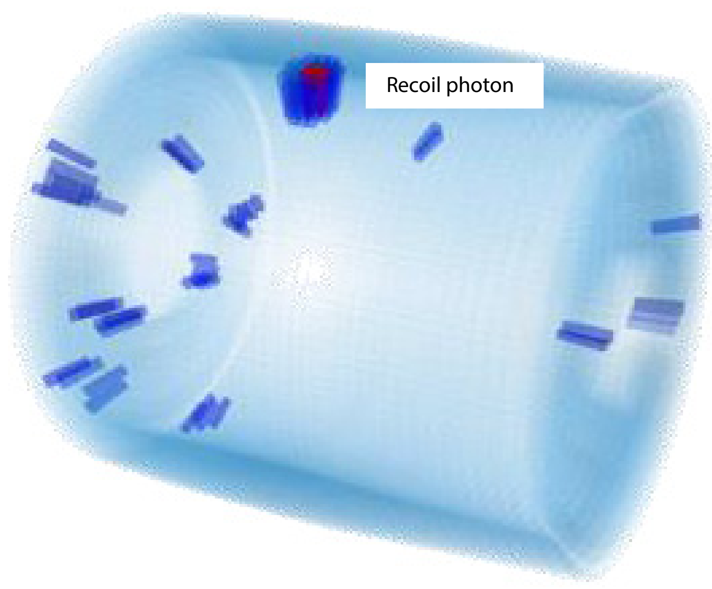
Probing a secluded U(1) at *B* factories via Higgsstrahlung in the secluded sector

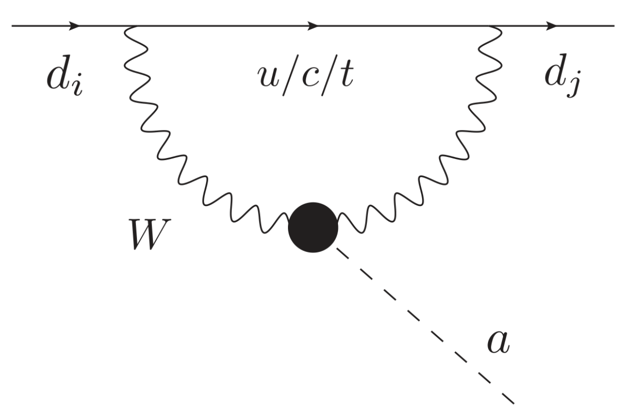




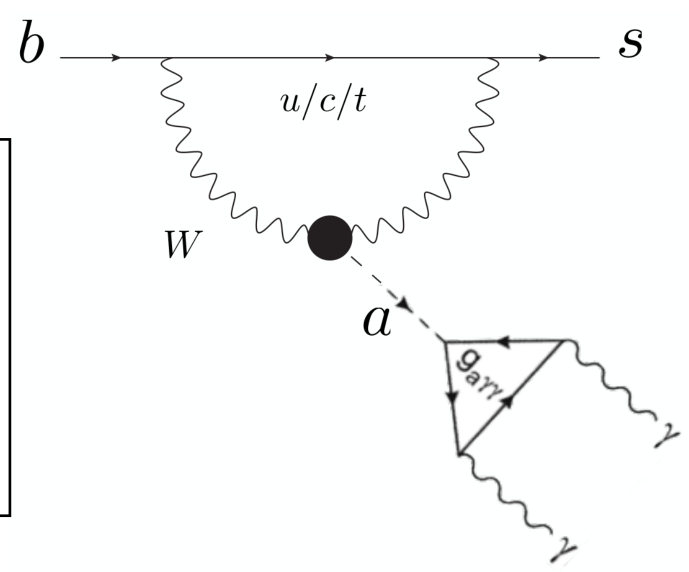
Batell, Pospelov, Ritz, PRD 79, 115008 (2009)

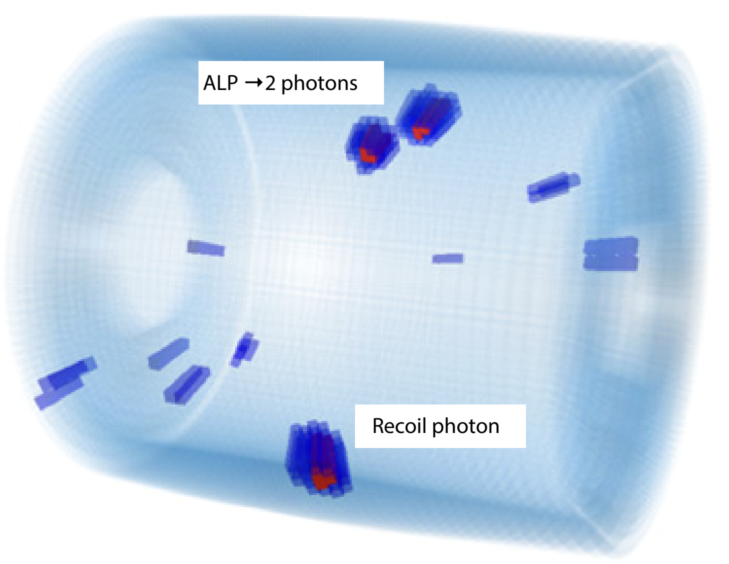
Different Portals to Dark Sector Will Be Explored at Belle II



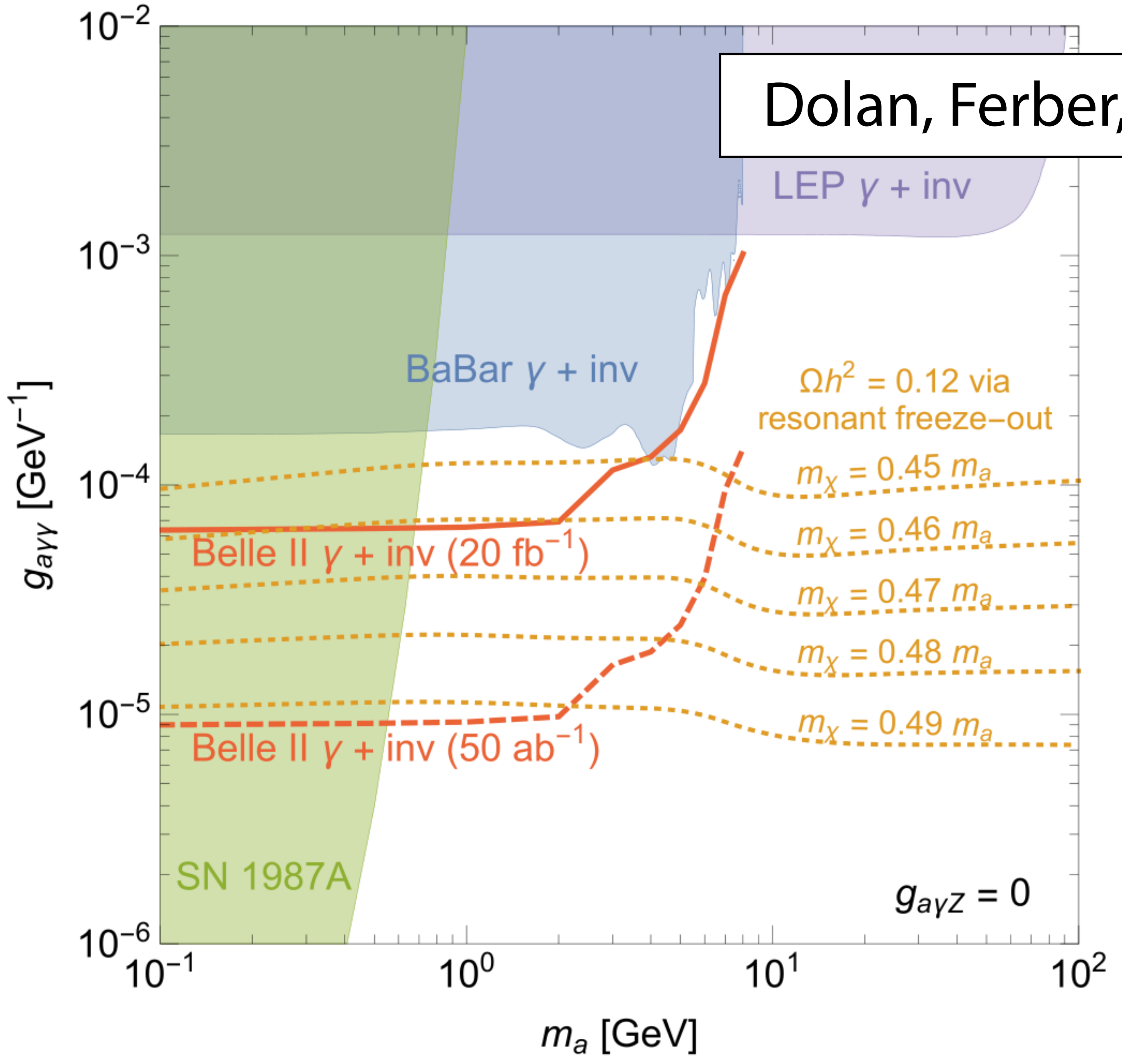


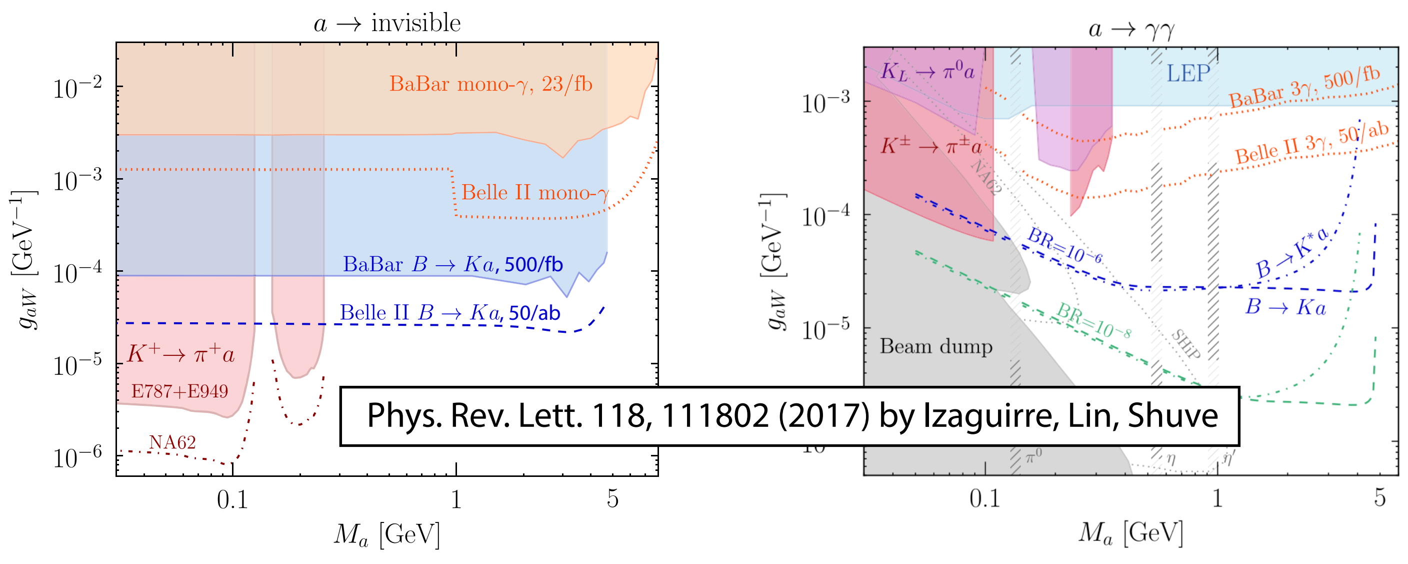
Searches for ALPs (axion-like particles)





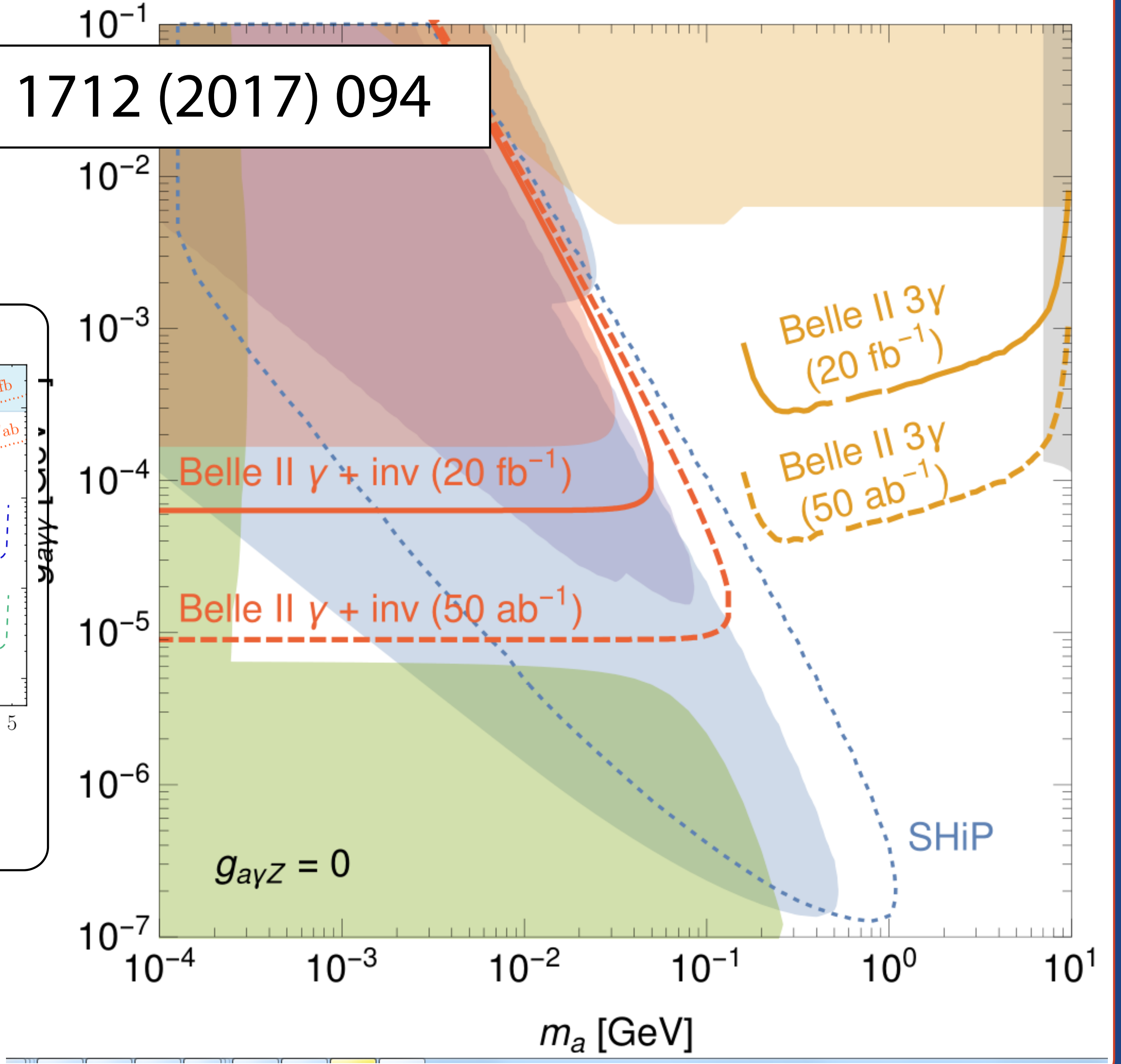
Dolan, Ferber, Hearty, Kahlhoefer, Schmidt-Hoberg, JHEP 1712 (2017) 094



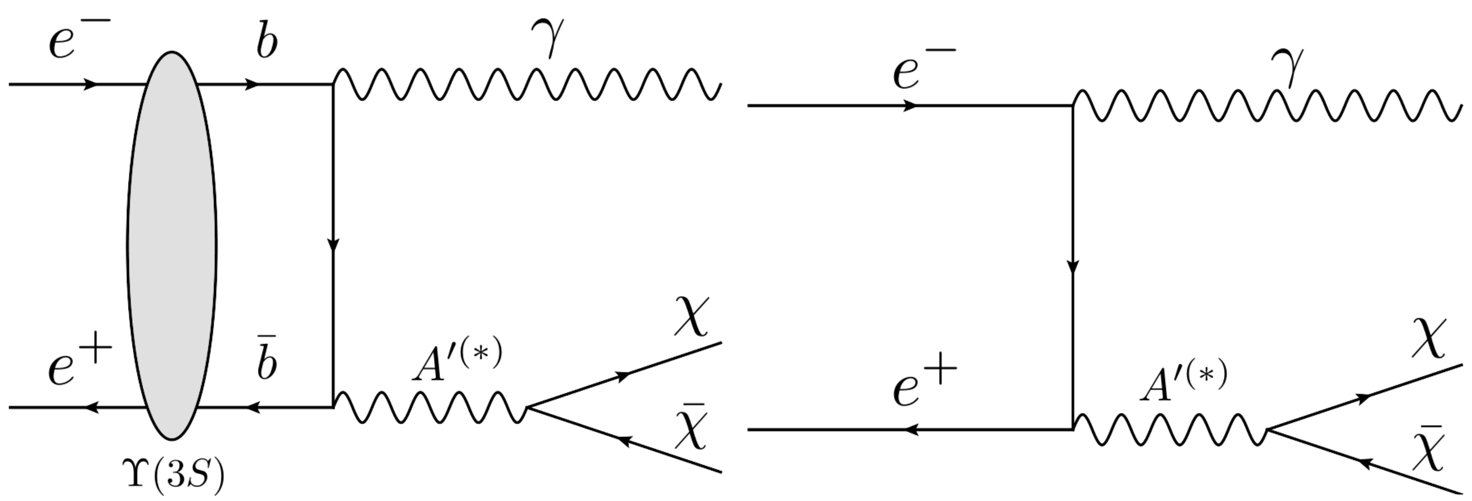


Phys. Rev. Lett. 118, 111802 (2017) by Izaguirre, Lin, Shuve

(a different, non-Belle-II analysis)



Different Portals to Dark Sector Will Be Explored at Belle II



Thanks to Rouven for repeatedly emphasizing the importance of low-multiplicity trigger

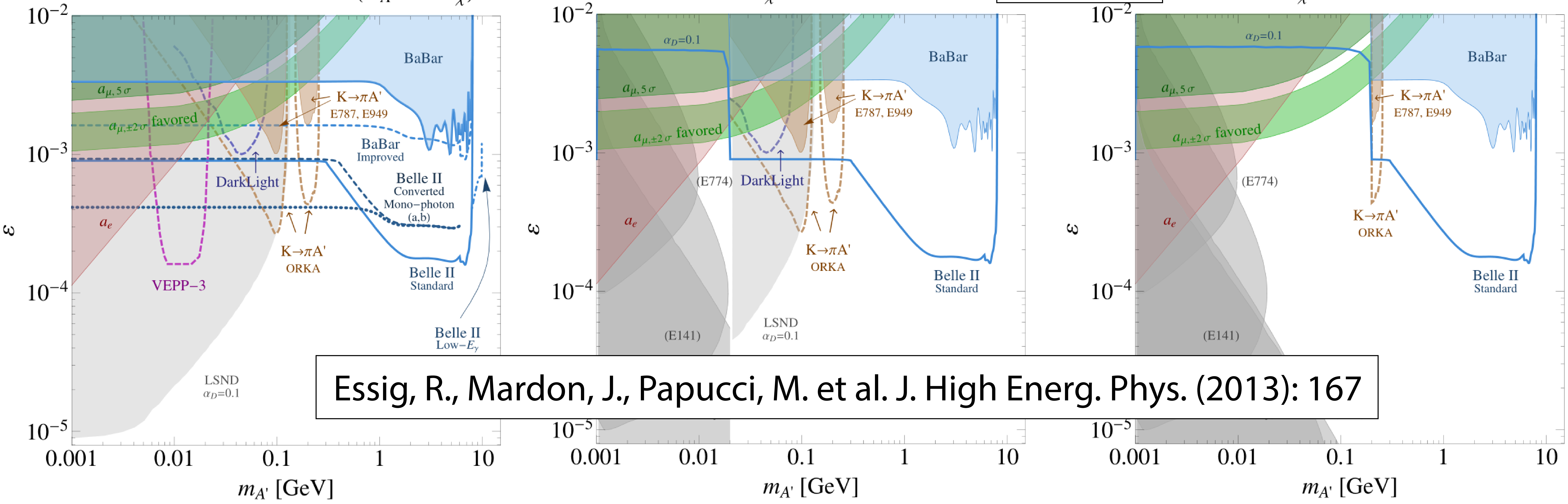
"Standard" Belle II search: single-photon events, statistics assumed: 50 / ab

Hidden Photon → invisible ($m_{A'} > 2\, m_\chi$)

Hidden Photon (invisible and visible) $m_\chi = 10$ MeV

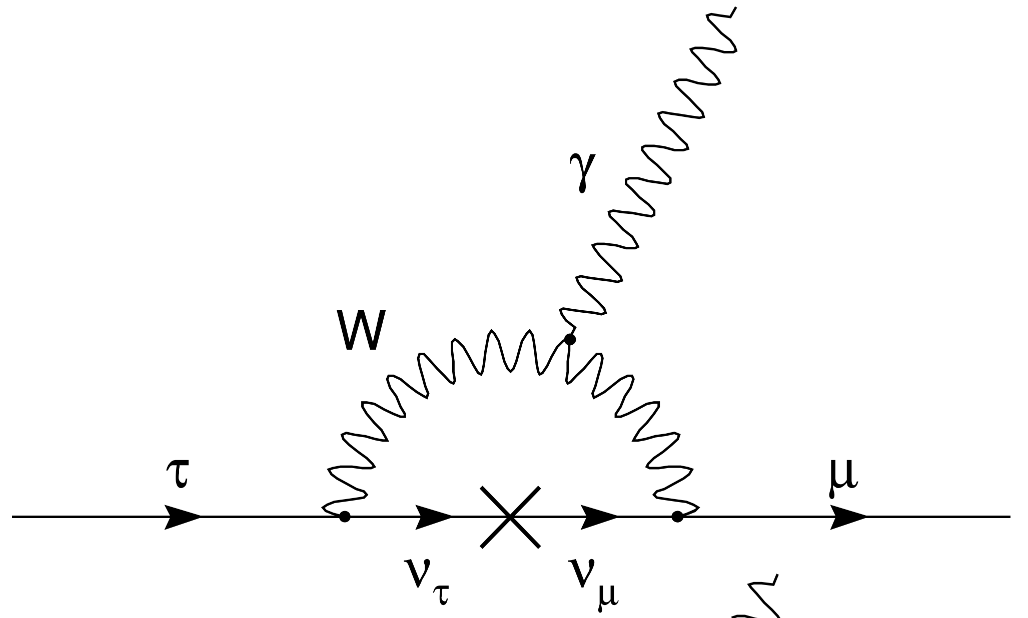
($m_{A'} < 2\, m_\chi$)

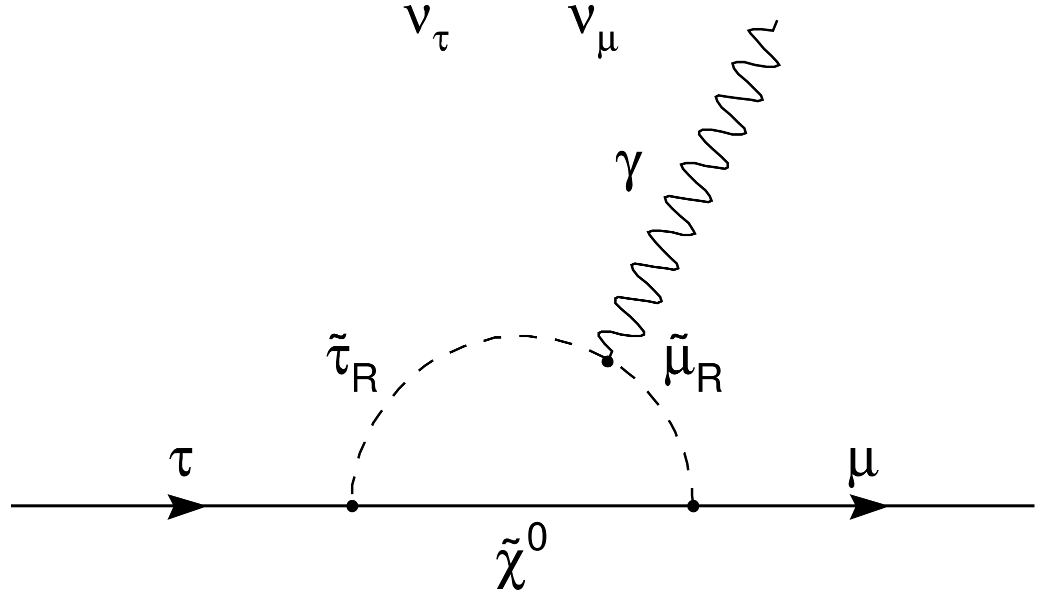
Hidden Photon (invisible and visible) $m_\chi = 100$ MeV

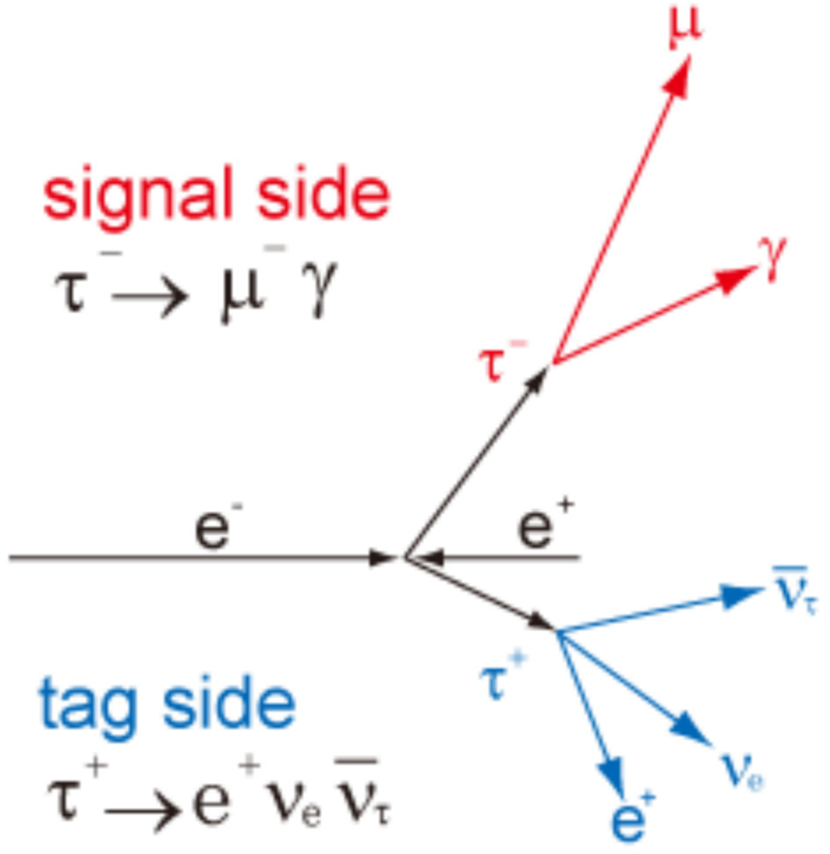


Essig, R., Mardon, J., Papucci, M. et al. J. High Energ. Phys. (2013): 167

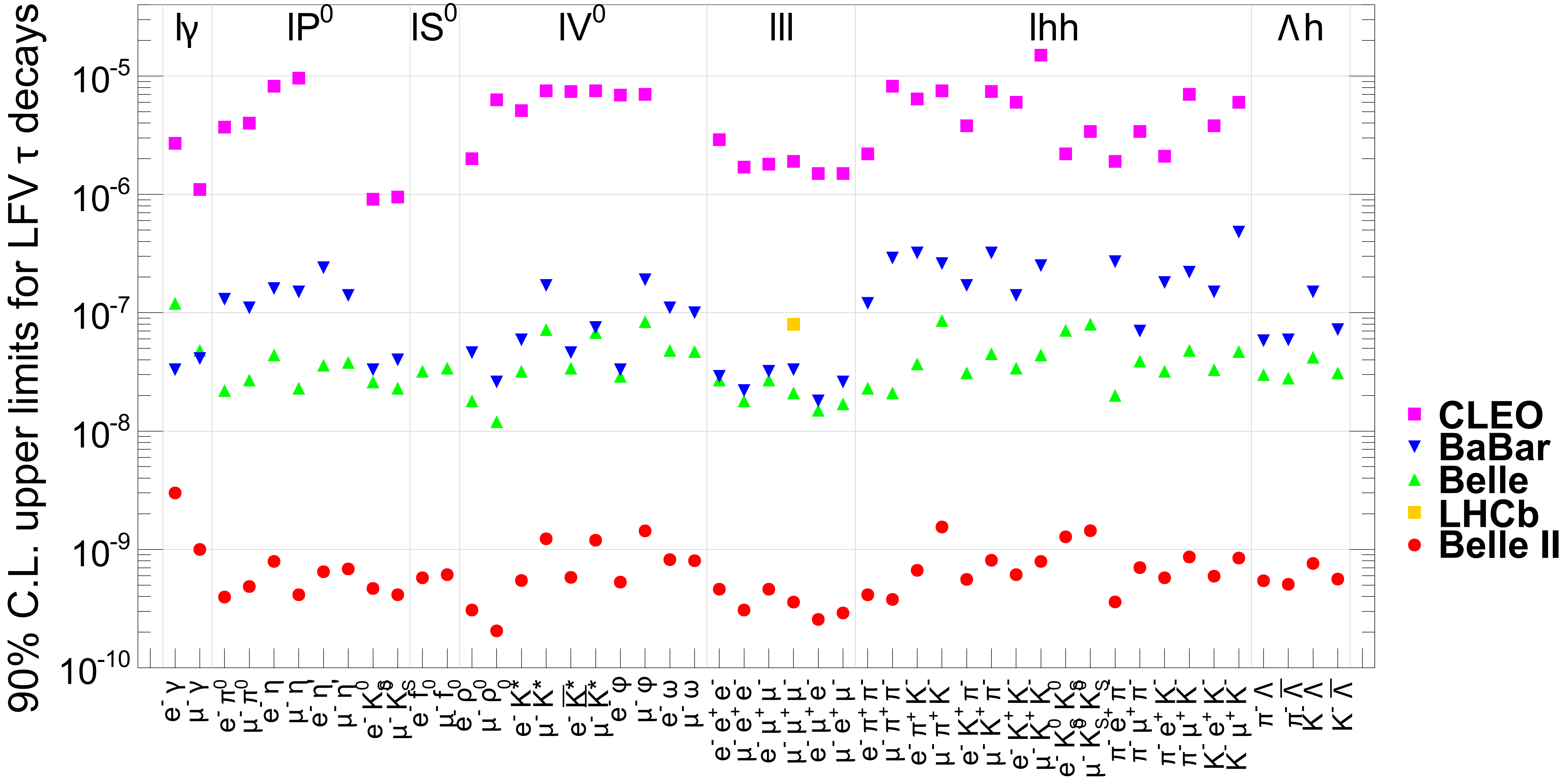
τ Leptons Provide a Unique Laboratory to Search for LFV





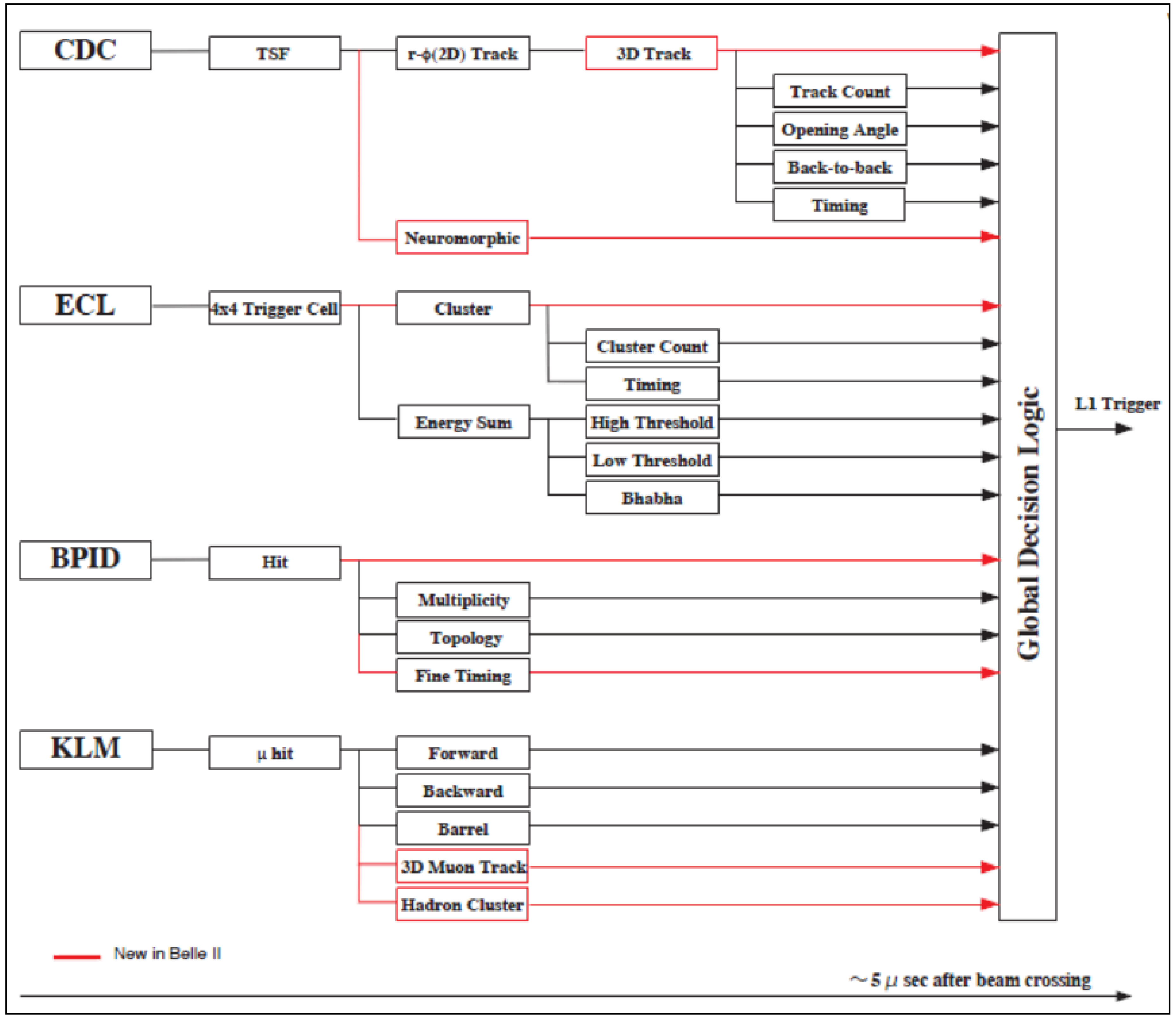


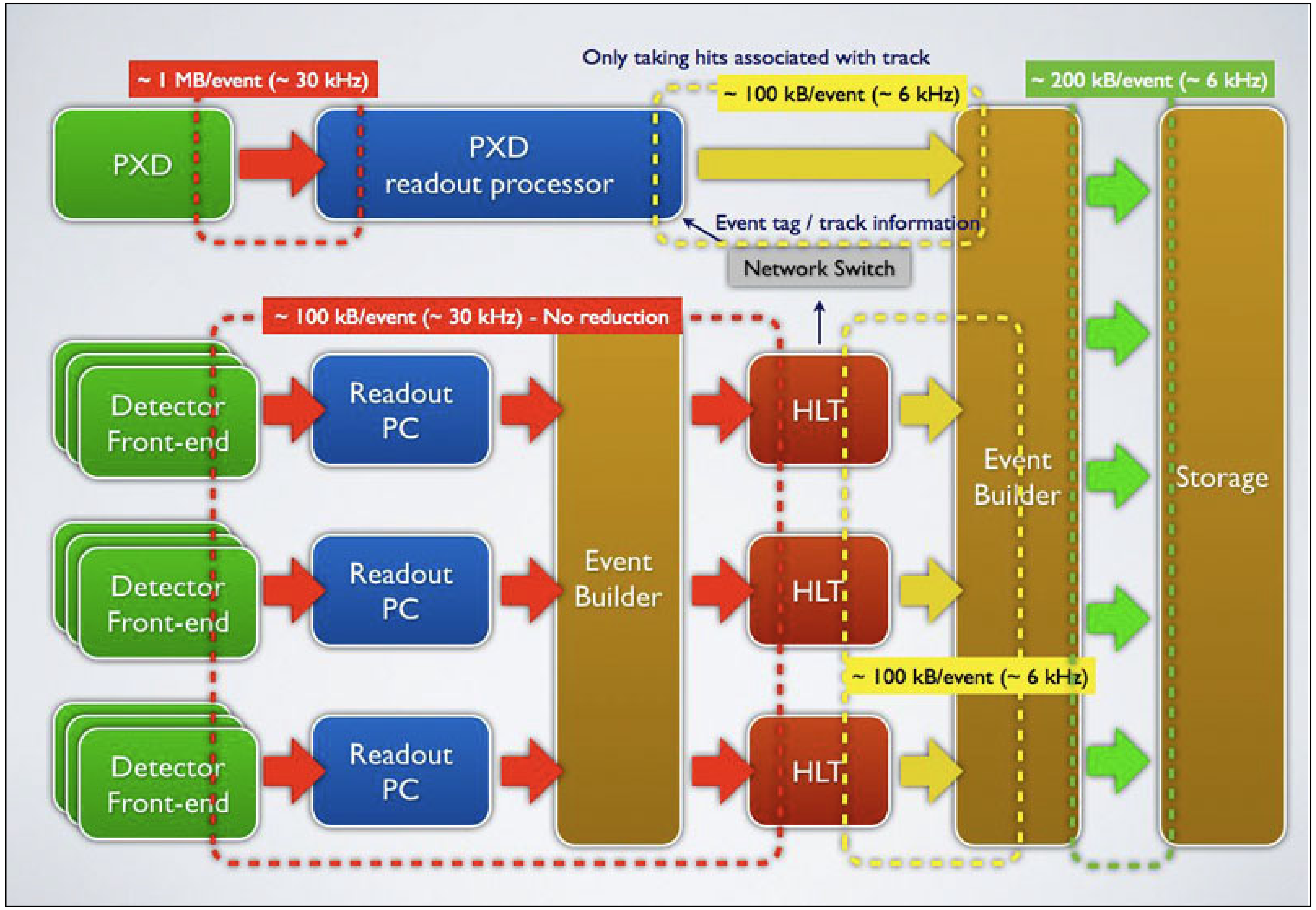
Upper limits for LFV τ decays with the full 50 ab^{-1} data sample at Belle II



B2TiP report / to be submitted to PTEP (2018)

Belle II L1 and High Level Trigger (HLT)





L1 and HLT trigger menus are being developed to allow for triggering on low-multiplicity events

Belle II L1 and High Level Trigger (HLT)

ECL trigger objects

nClust	ECL clusters
n300MeV	Clusters with E > 300 MeV
n2GeV	Clusters with E*>2 GeV
n2GeV414	Clusters with E*>2 GeV and ThetaID in [4,14]
n2GeV231516	Clusters with E*>2 GeV and ThetaID = 2, 3, 15 or 16
n2GeV117	Clusters with E*>2 GeV and ThetaID = 1 or 17
n1GeV415	Clusters with E*>1 GeV and ThetaID in [4,15]
n1GeV2316	Clusters with E*>1 GeV and ThetaID = 2, 3, or 16
n1GeV117	Clusters with E*>1 GeV and ThetaID = 1 or 17
nPhiPairHigh	Pairs of clusters back-to-back in ϕ*, both clusters >250 MeV
nPhiPairLow	Pairs of clusters back-to-back in ϕ*, at least 1 cluster <250 MeV
n3DPair	Pairs of clusters back-to-back in ϕ* and θ*
nECLBhabha	Bhabhas or $\gamma\gamma$ selected using ECL only
iBhabha1	Index of 1st cluster in ELCBhabha
iBhabha2	Index of 2nd cluster in ELCBhabha

Number of clusters with different energy thresholds.

Back-to-back clusters

CDC trigger objects

nTrk2D	Tracks (2D)
nTrk3D	Tracks (3D)
nTrkZ25	Tracks with |Z0| < 25 cm
nTrkZ10	Tracks with |Z0| < 10 cm

Number of tracks

ECL+CDC trigger objects

nTrkBhabha	Bhabhas selected using ECL and CDC
nSameHem1Trk	Clusters in the same hemisphere as the track, 1 track event
nOppHem1Trk	Clusters in the opposite hemisphere as the track, 1 track event

Tracks matched to clusters.

	Bit	Phase 2 and 2019	Prescale Phase 2	Changes for 2020	Prescale 2020
	0	3 or more 3D tracks			
$\Upsilon(3S)\to\pi\pi\Upsilon(1S)$, $Z'\to$Invisible	1	2 3D tracks, ≥1 within 25 cm, not a trkBhabha		2 3D tracks, ≥1 within 10 cm, not a trkBhabha	
	2	2 3D tracks, not a trkBhabha	20		20
	3	2 3D tracks, trkBhabha			2
	4	1 track, <25cm, clust same hemi, no 2 GeV clust		1 track, <10cm, clust same hemi, no 2 GeV clust	
$\tau\tau$	5	1 track, <25cm, clust opp hemi, no 2 GeV clust		1 track, <10cm, clust opp hemi, no 2 GeV clust	
	6	≥3 clusters inc. ≥1 300 MeV, not an eclBhabha		≥3 clusters inc. ≥2 300 MeV, not an eclBhabha	
ISR, ALPs	7	2 GeV E* in [4,14], not a trkBhabha			
	8	2 GeV E* in [4,14], trkBhabha			2
	9	2 GeV E* in 2,3,15,16, not eclBhabha			
low mass ALPs	10	2 GeV E* in 2,3,15 or 16, eclBhabha			
	11	2 GeV E* in 1 or 17, not eclBhabha	10		20
	12	2 GeV E* in 1 or 17, eclBhabha	10		20
A $\to$Invisible	13	exactly 1 E*>1 GeV and 1 E>300 MeV, in [4,15]			
	14	exactly 1 E*>1 GeV and 1 E>300 MeV, in 2,3 or 16			5
	15	clusters back-to-back in phi, both >250 MeV, no 2 GeV			
ALPs from $\gamma\gamma$ fusion	16	clusters back-to-back in phi, 1 <250 MeV, no 2 GeV		clust back-to-back in phi, <250 MeV, no 2 GeV, no trk>25cm	3
Endcap muons	17	clusters back-to-back in 3D, no 2 GeV			5

Tracks only

Tracks and clusters

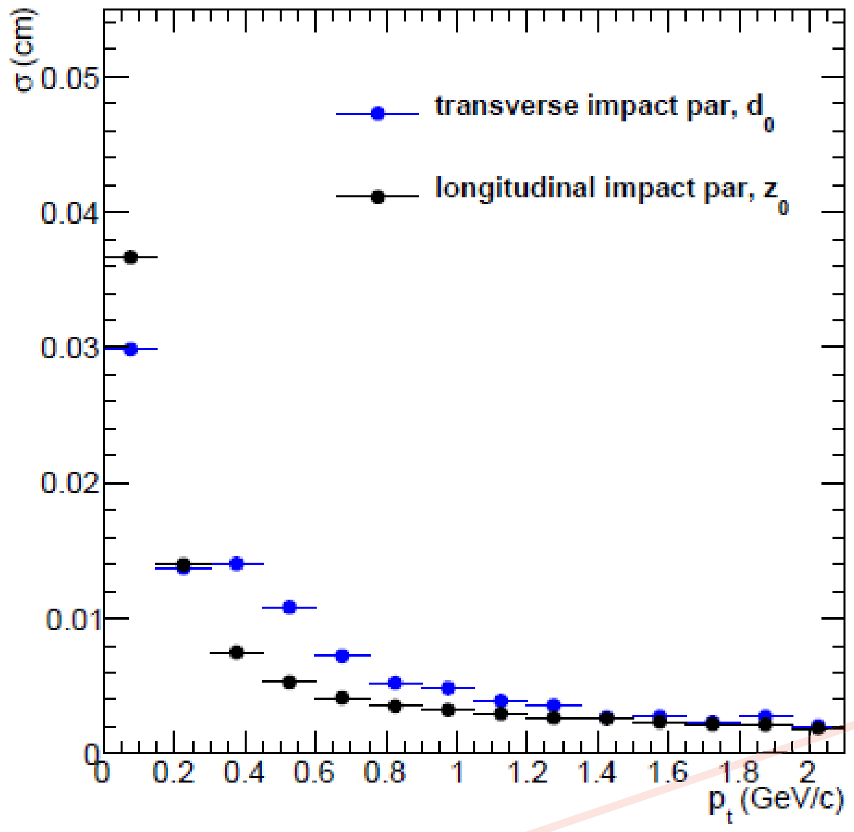
Clusters

HLT trigger logic is being developed with focus on low multiplicity final states and orthogonal trigger lines (similar philosophy as for L1)

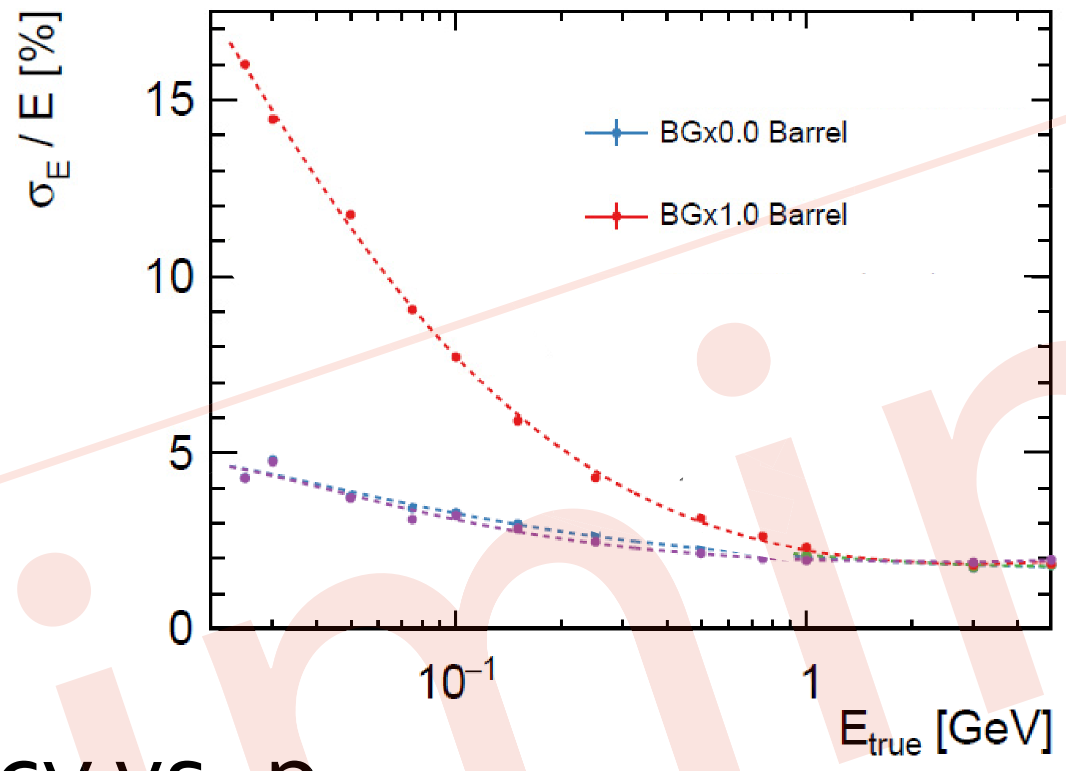
An ability to trigger on low-multiplicity final states is an important conceptual development at Belle II

Expected Performance of Belle II (full MC)

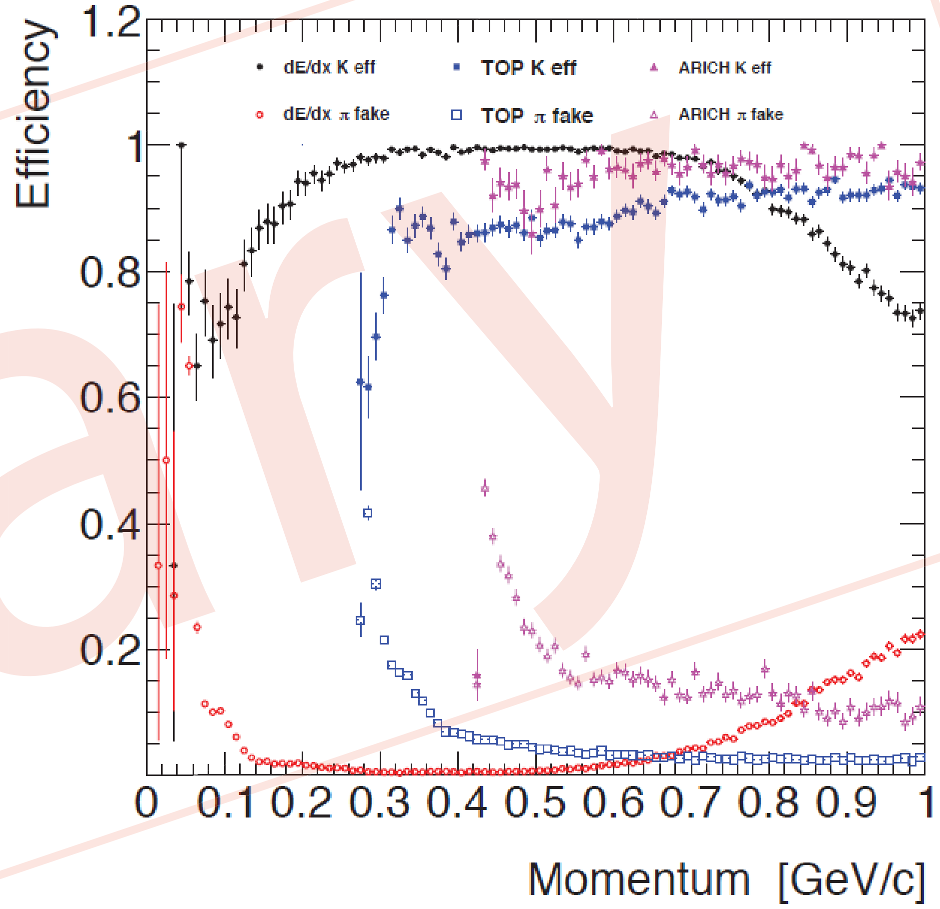
IP resolution



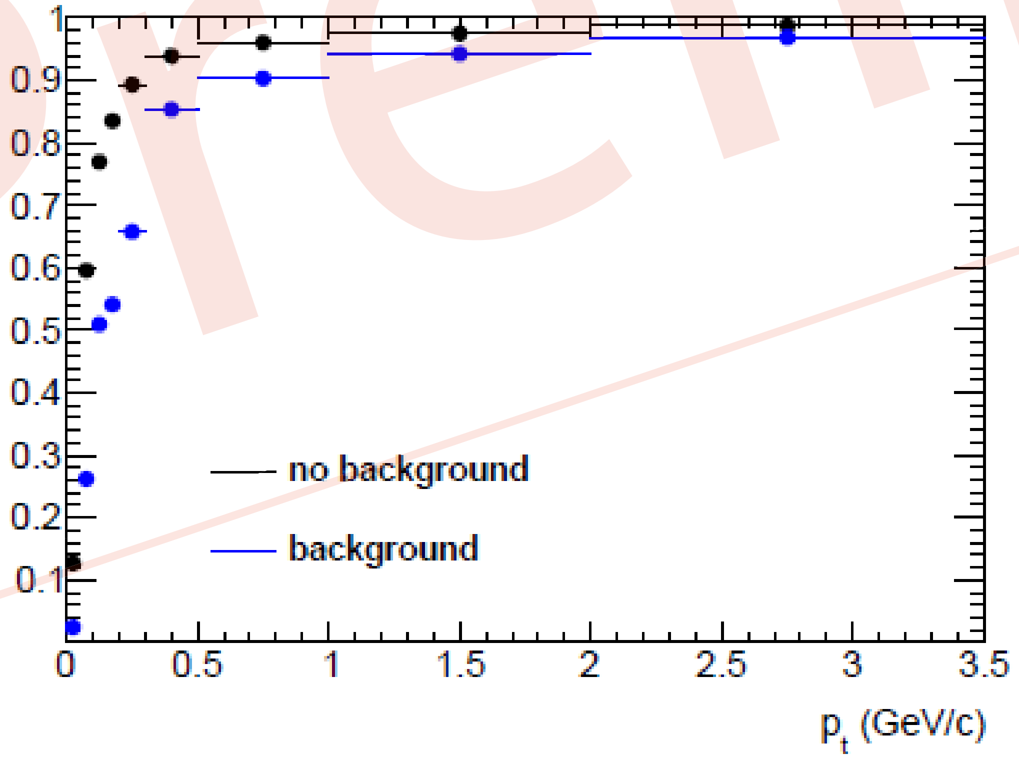
Energy resolution
with and without background



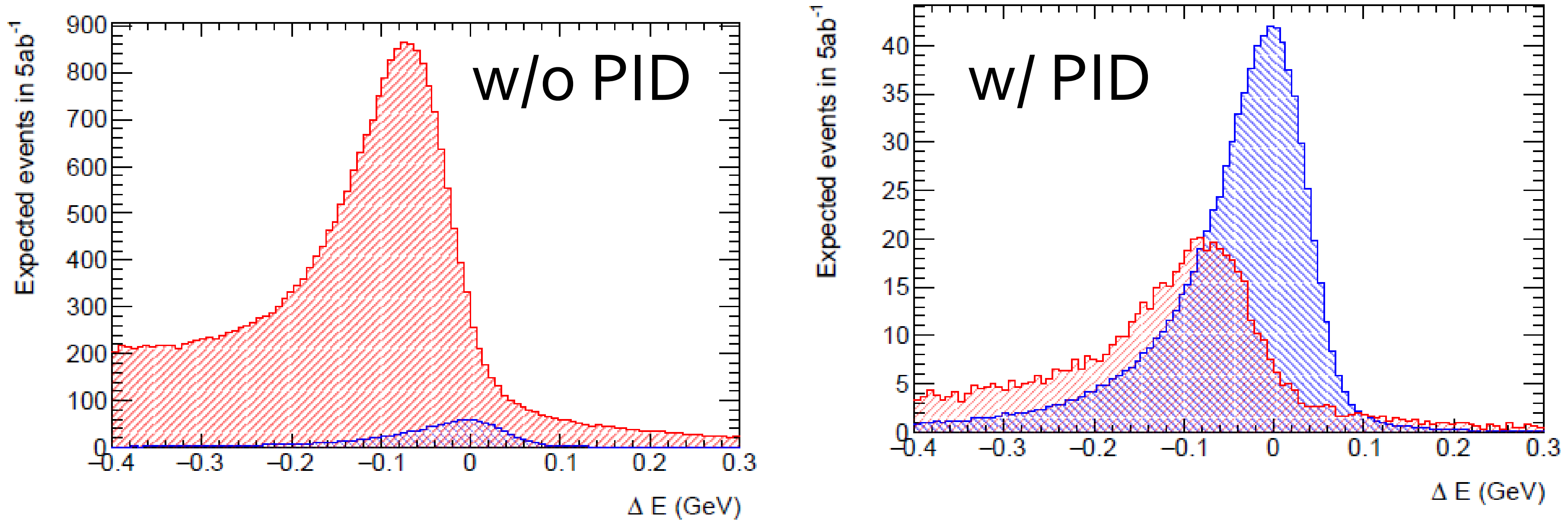
K/π PID



Tracking efficiency vs. p_t



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



We expect Belle II to perform similarly or better than Belle despite of ~20 times higher beam background

Expected Uncertainties on Select Observables

	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
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
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$ [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.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\text{ex.}} \pm 2.7\%_{\text{th.}})$ [10]	1.8%	1.4%
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$ [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%

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Improved estimates have been obtained by recently in the framework of
Belle II Theory Interface Platform: https://confluence.desy.de/display/BI/B2TiP+WebHome
B2TiP report (Belle II Physics Program) will soon be submitted to PTEP

Expected Uncertainties on Select Observables

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
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%
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ $[10^{-6}]$	< 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%
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7 [40]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2 [42]‡	–

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Expected Uncertainties on Select Observables

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
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
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm {}^{4}_{5}$ [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

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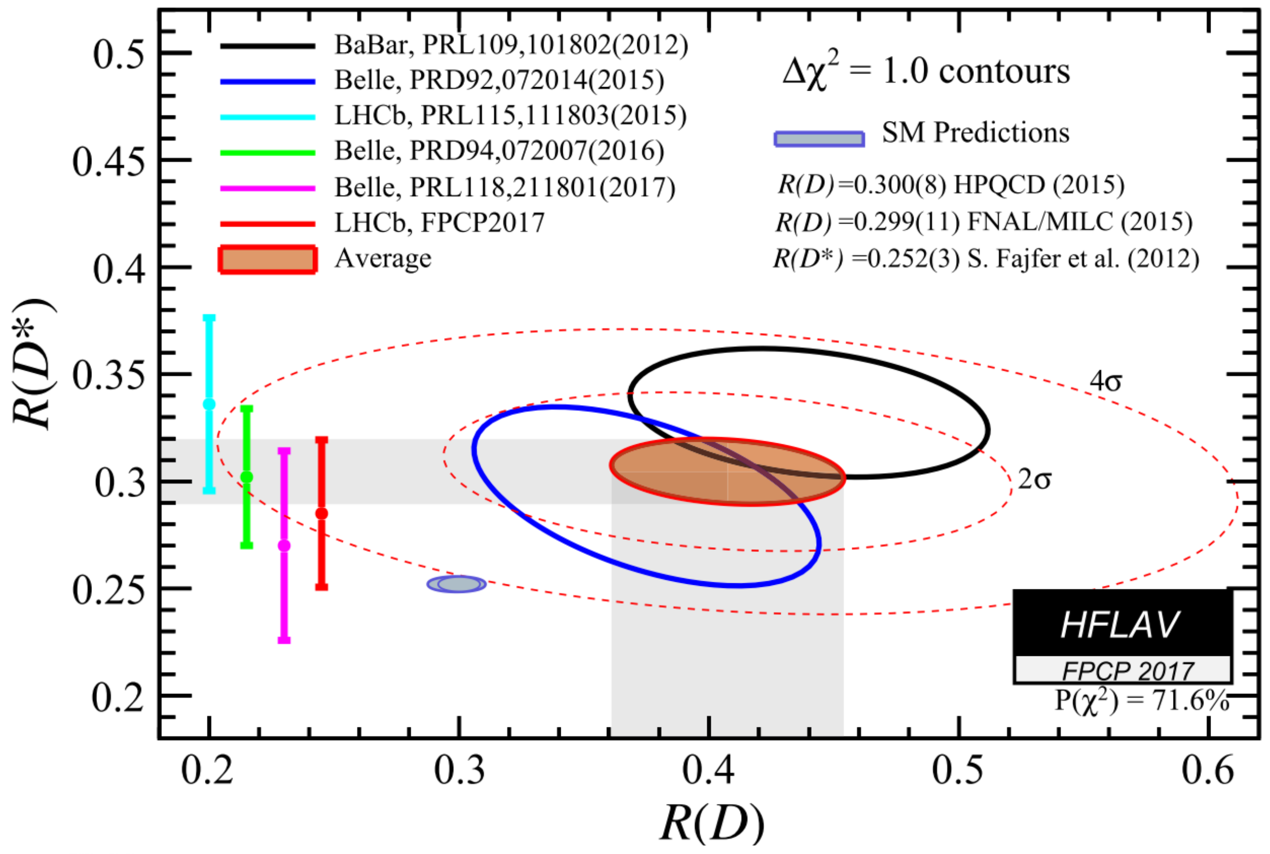
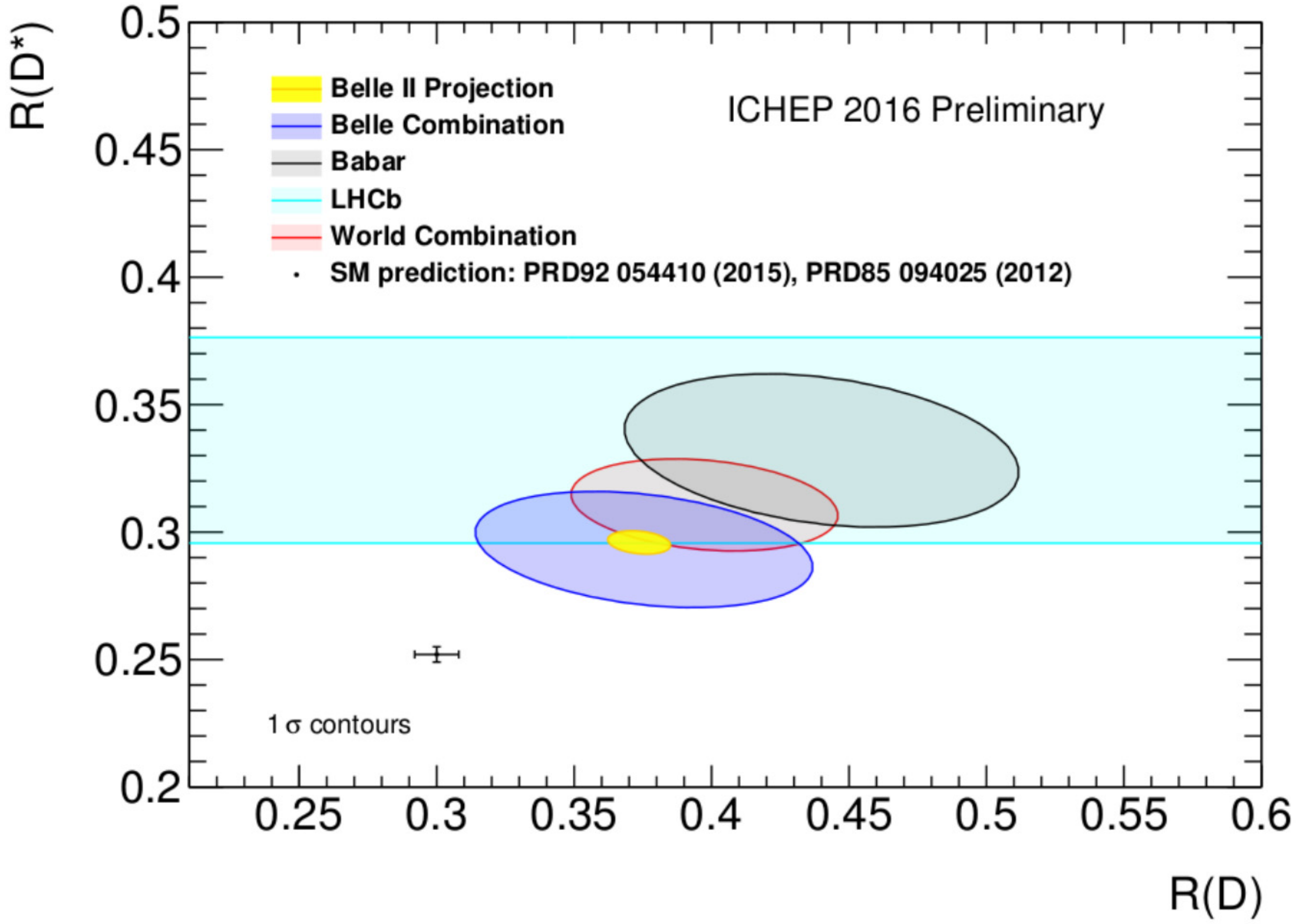
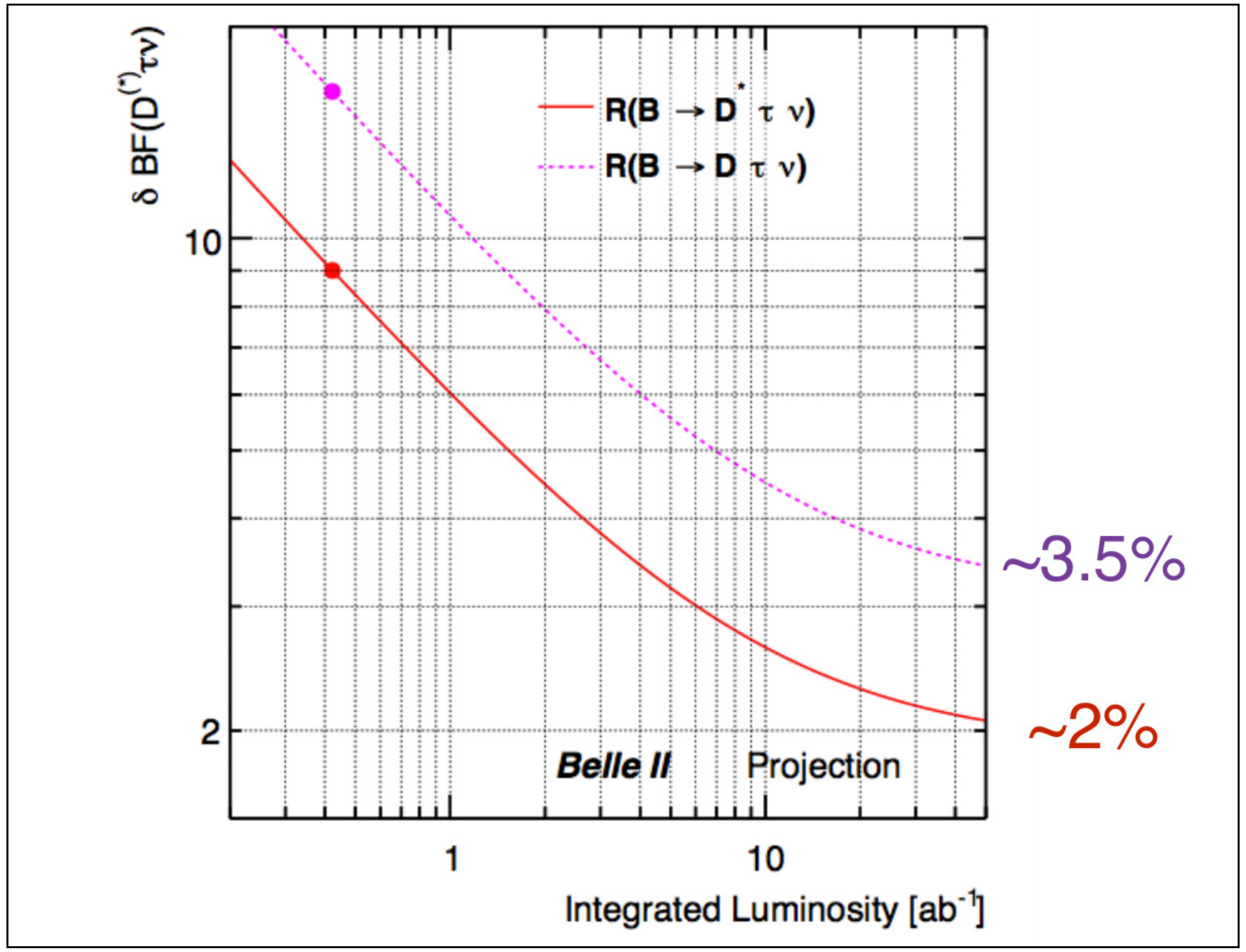
Flavor Anomaly in R(D) and R(D*)



$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)} \quad (\ell = e, \mu)$$

[τ helicity provides a handle to investigate the new (virtual) particle (if confirmed)]

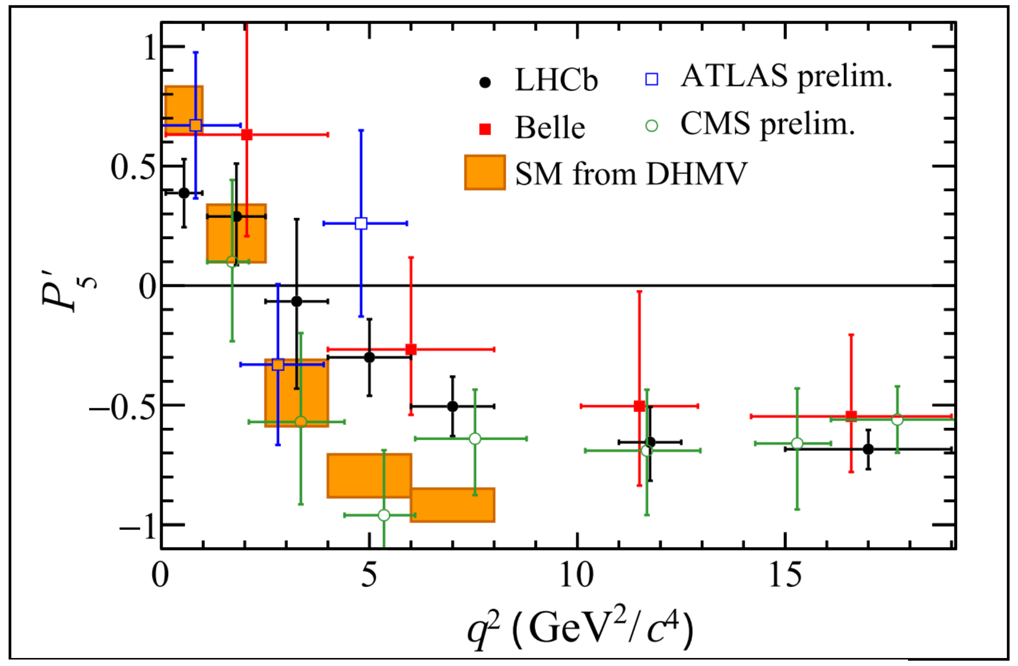




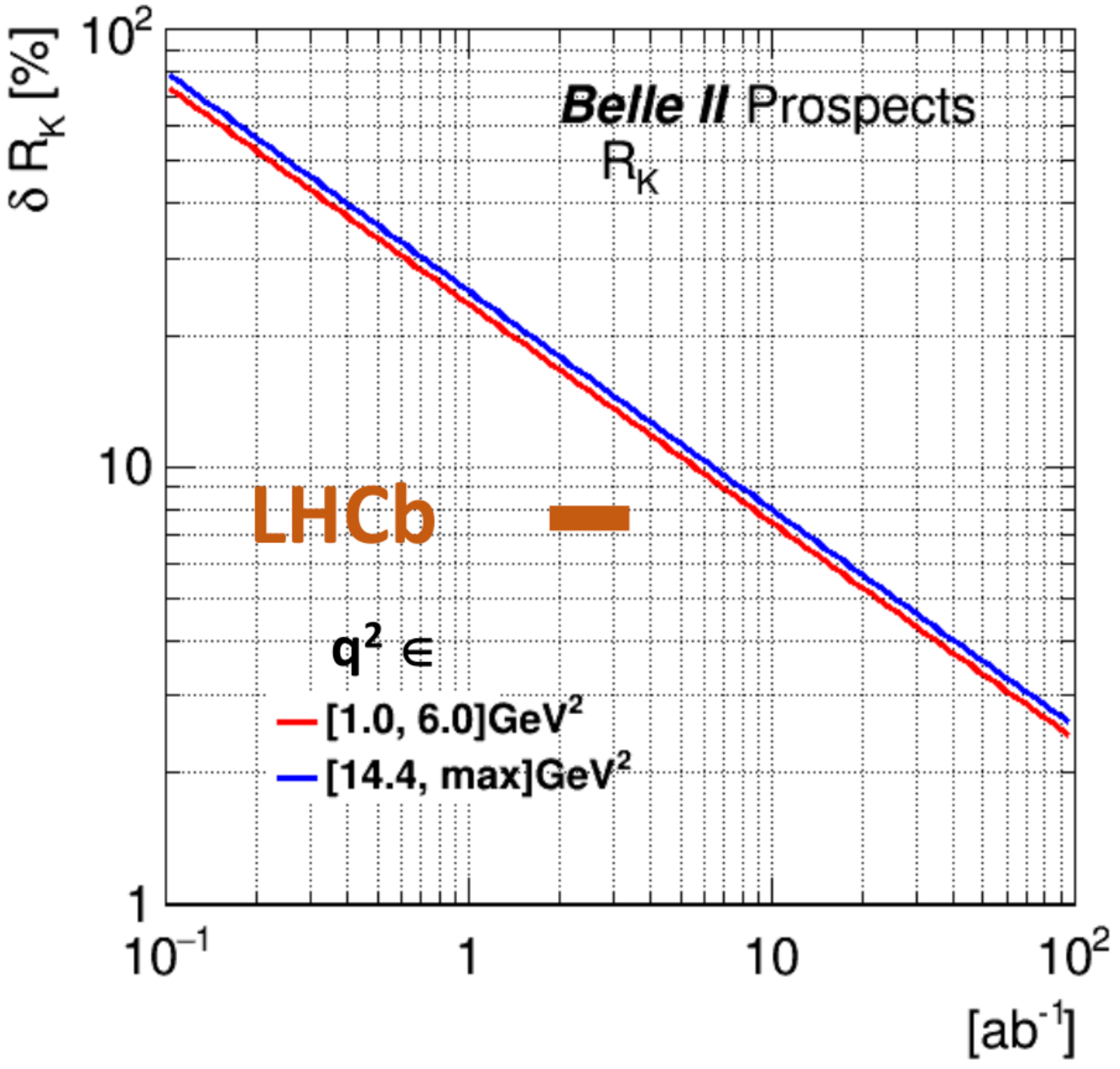
If the current 4.1σ deviation is real, Belle II should be able to make a discovery with 5/ab (i.e. around 2021)

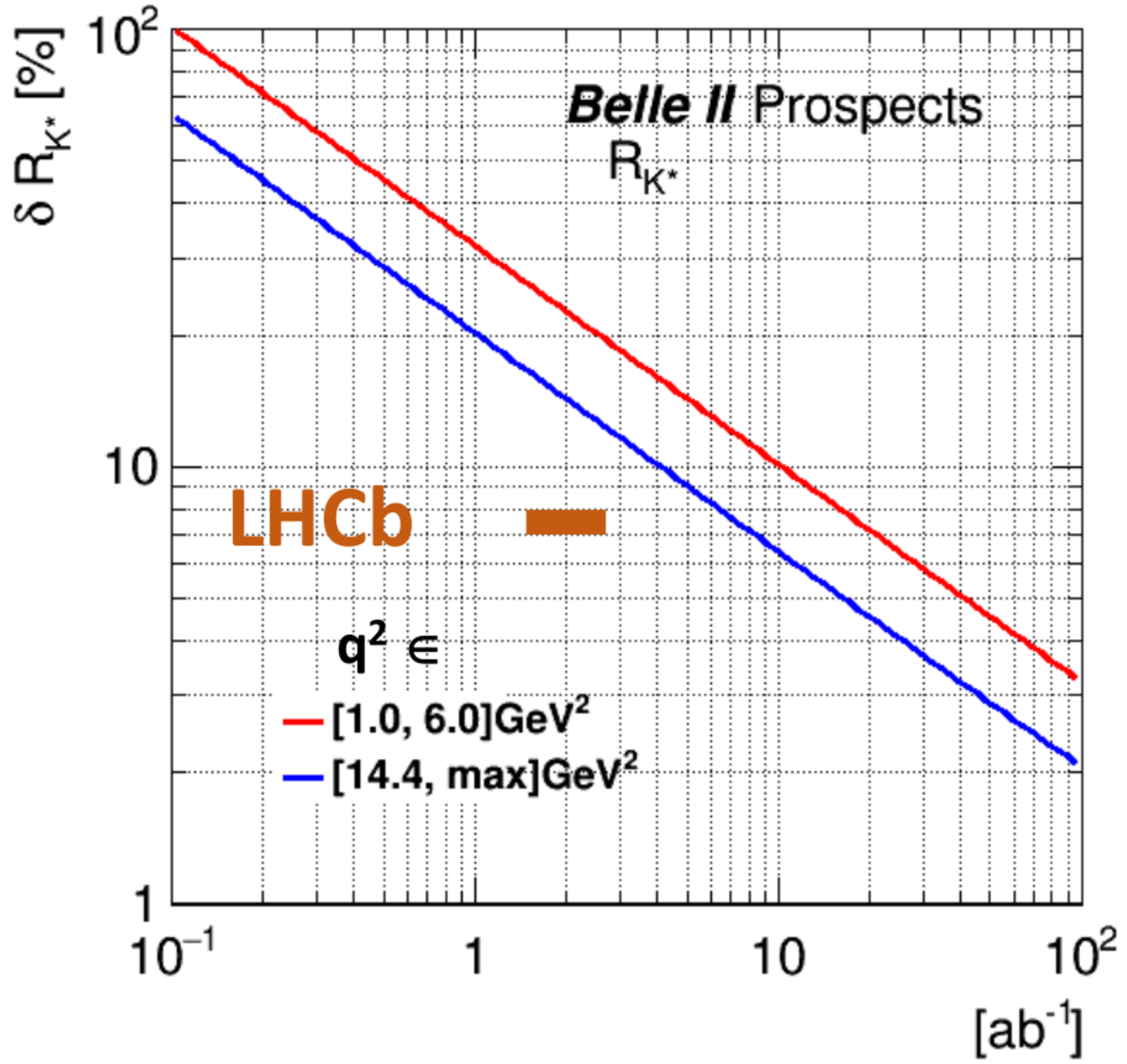
Lepton Universality in B Decays, R(K), R(K*), R(X_s)

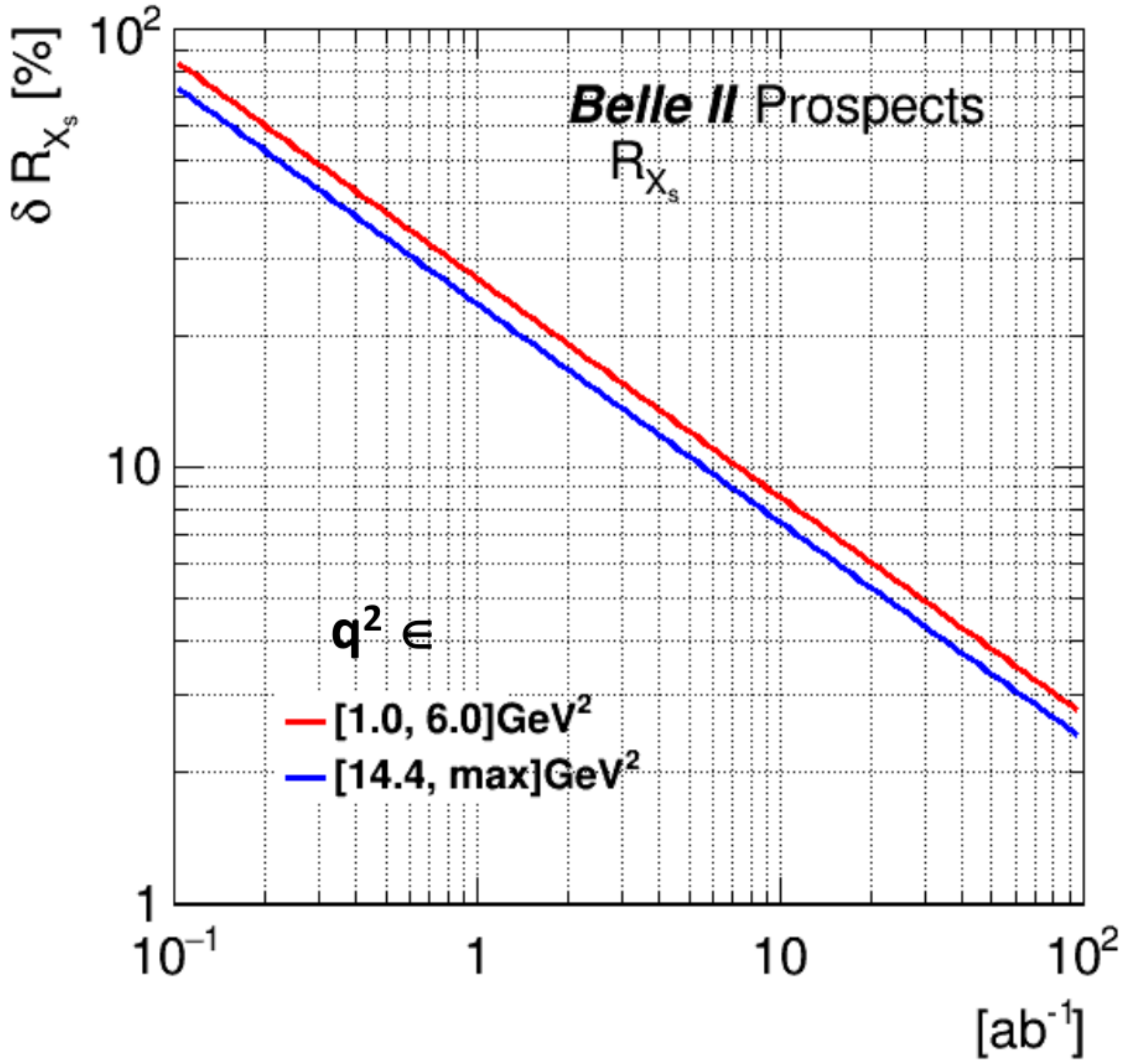
$$R_{K(*)} = \mathcal{B}(B \rightarrow K^{(*)}\mu\mu)/\mathcal{B}(B \rightarrow K^{(*)}ee)$$
$$= 1 \pm \mathcal{O}(10^{-3})\ (\mathrm{SM})$$



2.6σ deviation from the SM (PRL 113, 151601 (2014) / LHCb)







If 2.6σ deviation is real, Belle II should be able to make a discovery by ~2024

Conclusions, References and Acknowledgements

SuperKEKB+Belle II commissioning continues

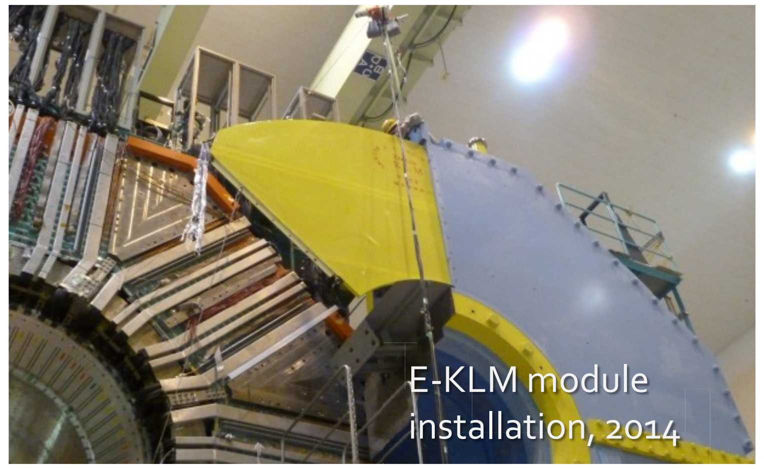
BEAST II is roaring

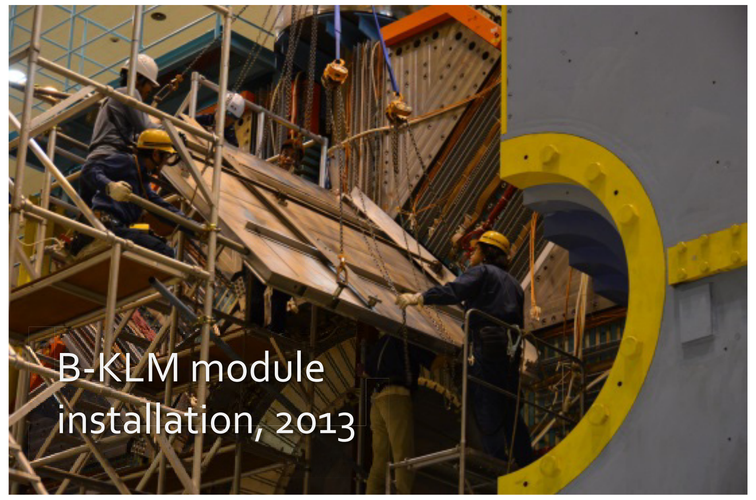
Belle II will soon be ready to take data

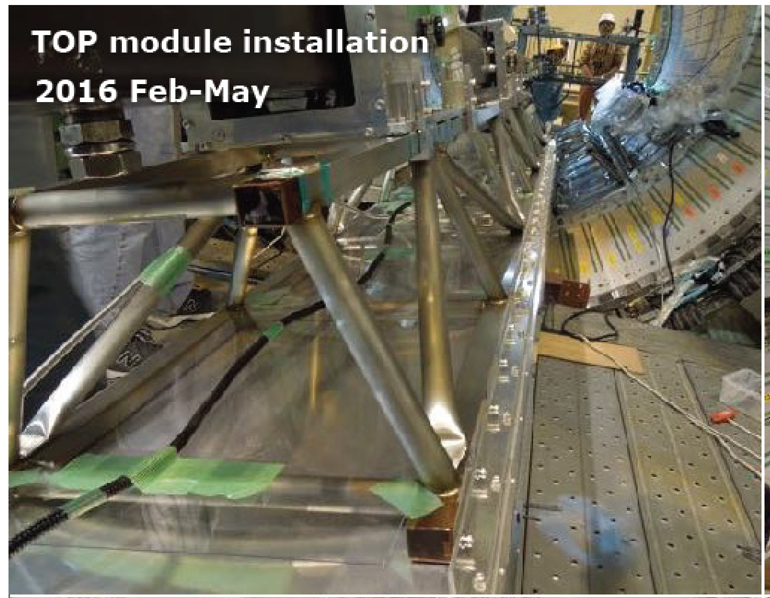
VXD is coming (starting on July 17, 2018)

Physics results will start coming soon

The next decade will be very exciting!







References (besides http://belle2.jp/ and https://www.belle2.org):

Belle II Theory Interface Platform (B2TIP)
(https://confluence.desy.de/display/BI/B2TiP+WebHome)

6th Belle II Theory Interface Platform (B2TiP) Workshop, KEK
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Physics prospects at the Belle II experiment, P. Urquijo,
Nuclear and Particle Physics Proceedings, 263-264 (2015) 15-23

A large number of very capable and talented physicists, engineers and technicians made it possible

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