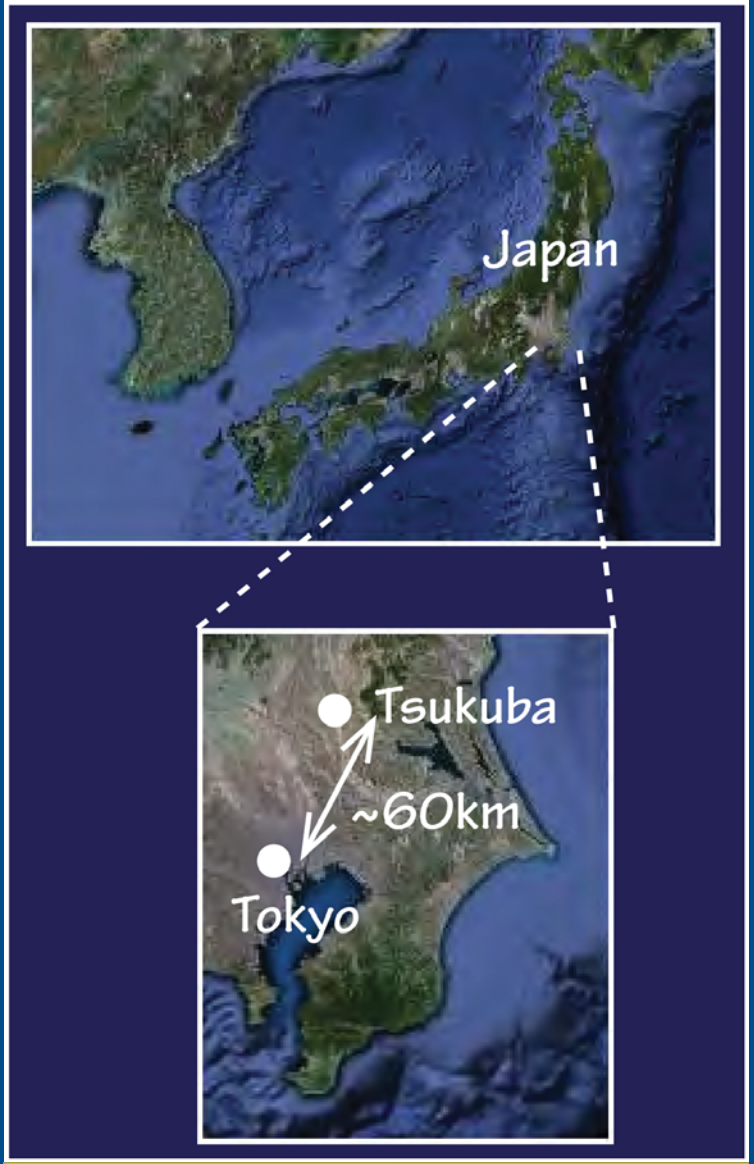
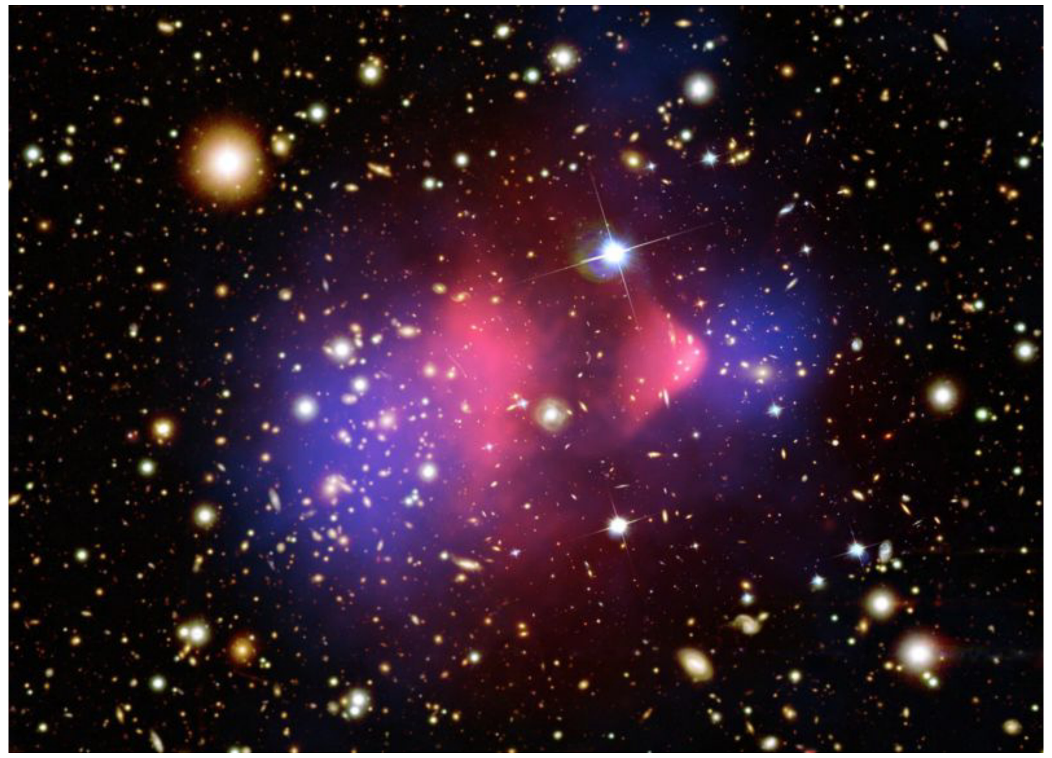
Electroweak Penguin Physics Prospects at Belle II



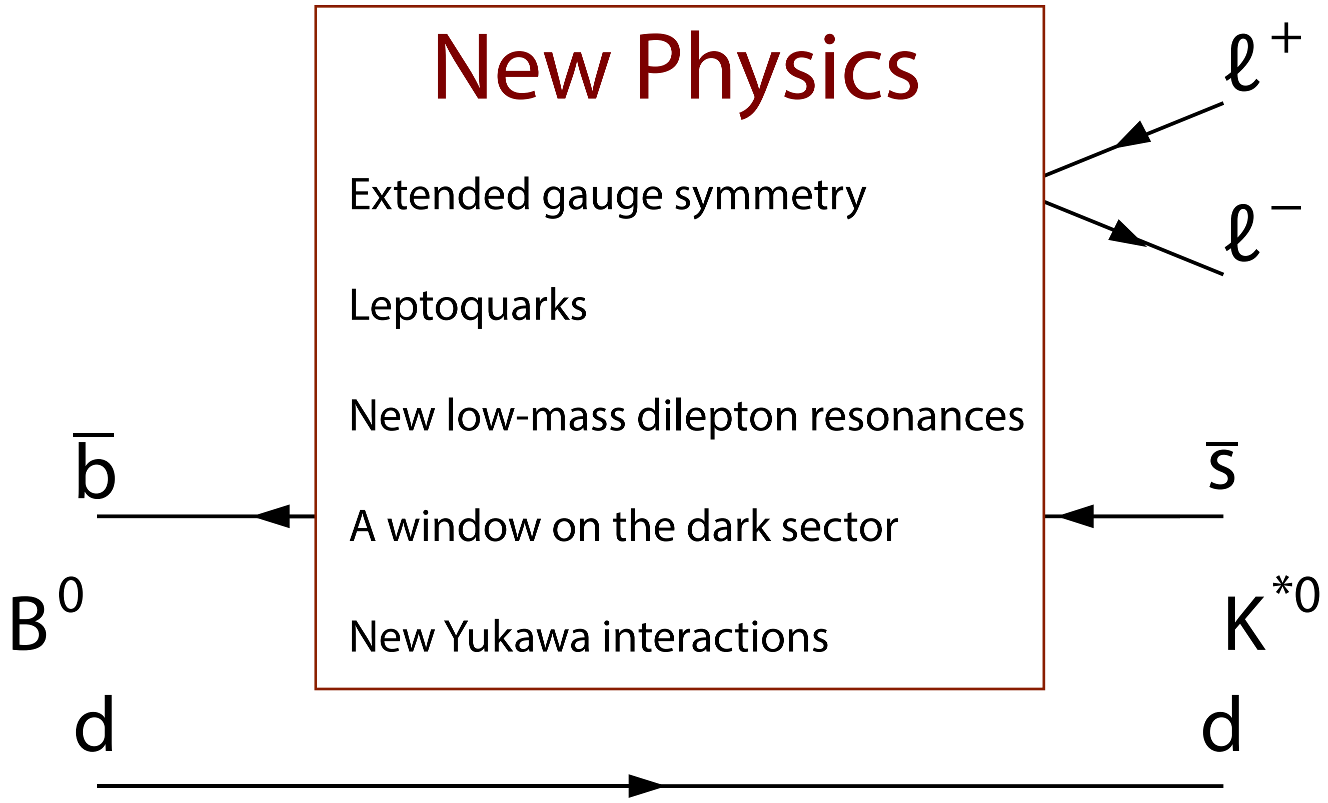
Vladimir Savinov (University of Pittsburgh) on behalf of the Belle II Collaboration

Electroweak Penguins and Other Birds of a Feather

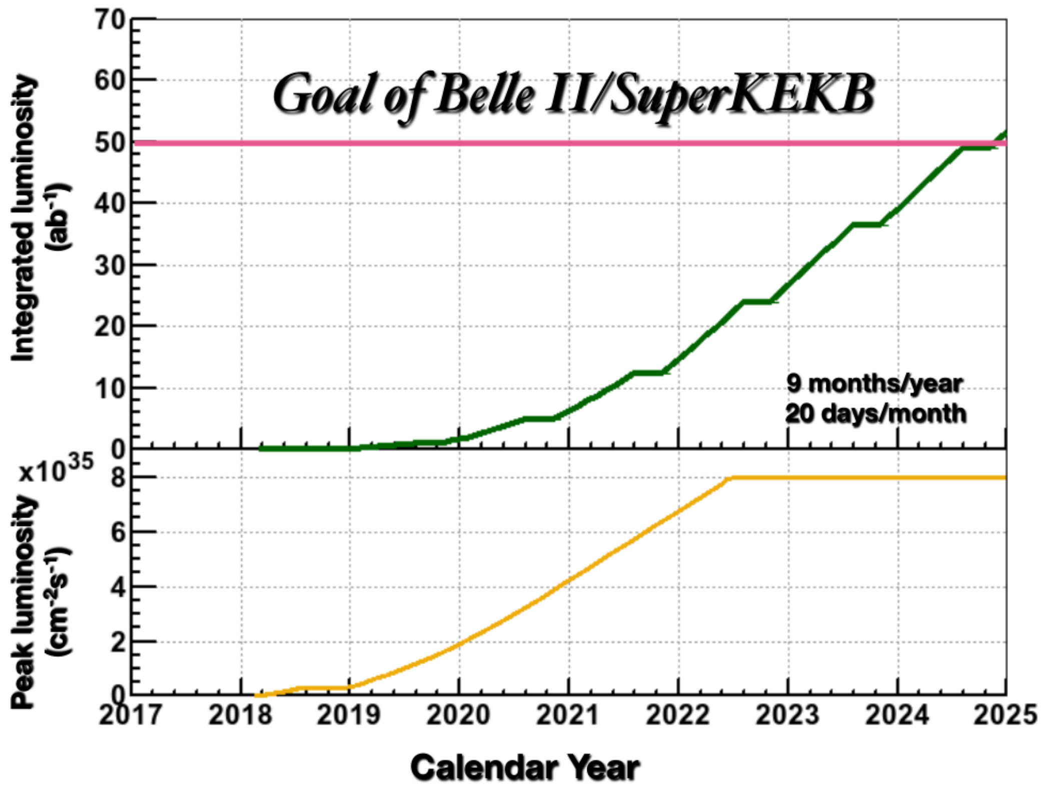
Complementarity of Big and Small
Same questions / different tools



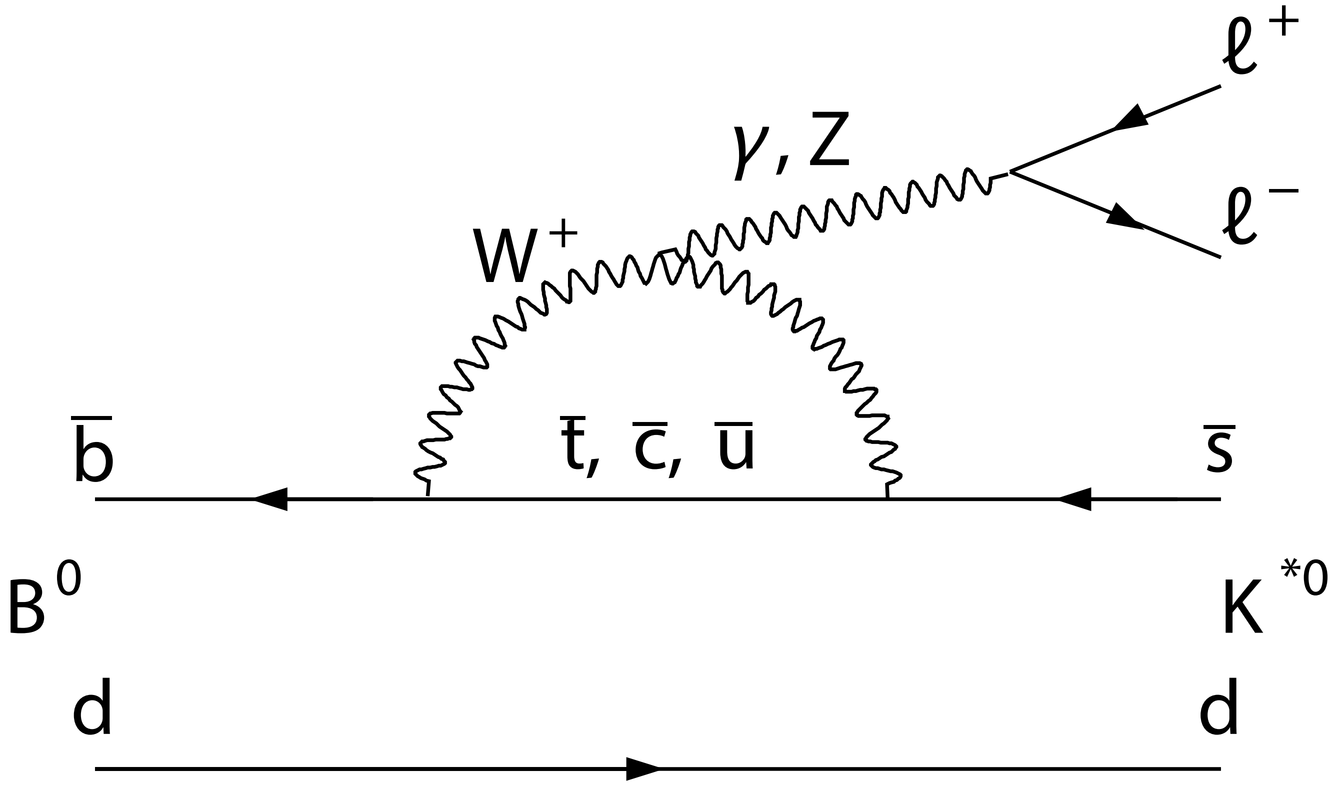
Belle II is an indirect NP exploration experiment

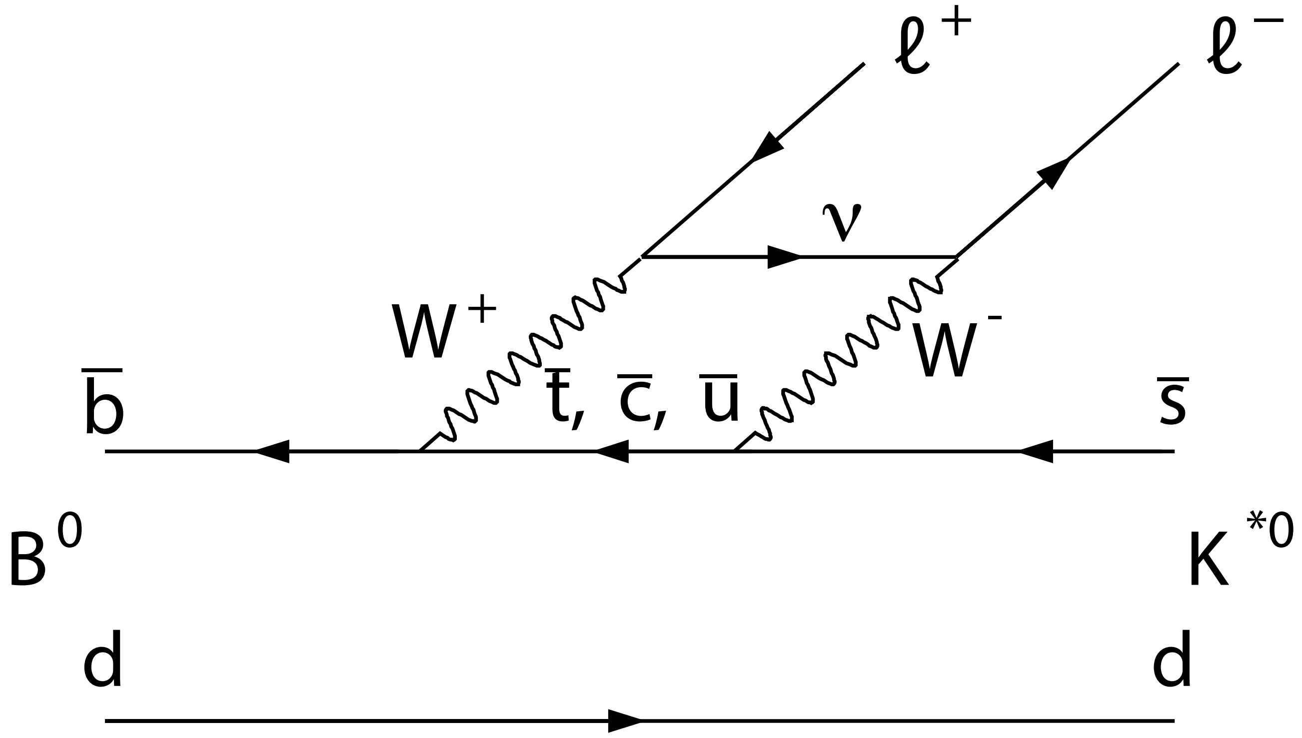


SuperKEKB luminosity projection



Flavor-Changing Neutral Currents in the Standard Model



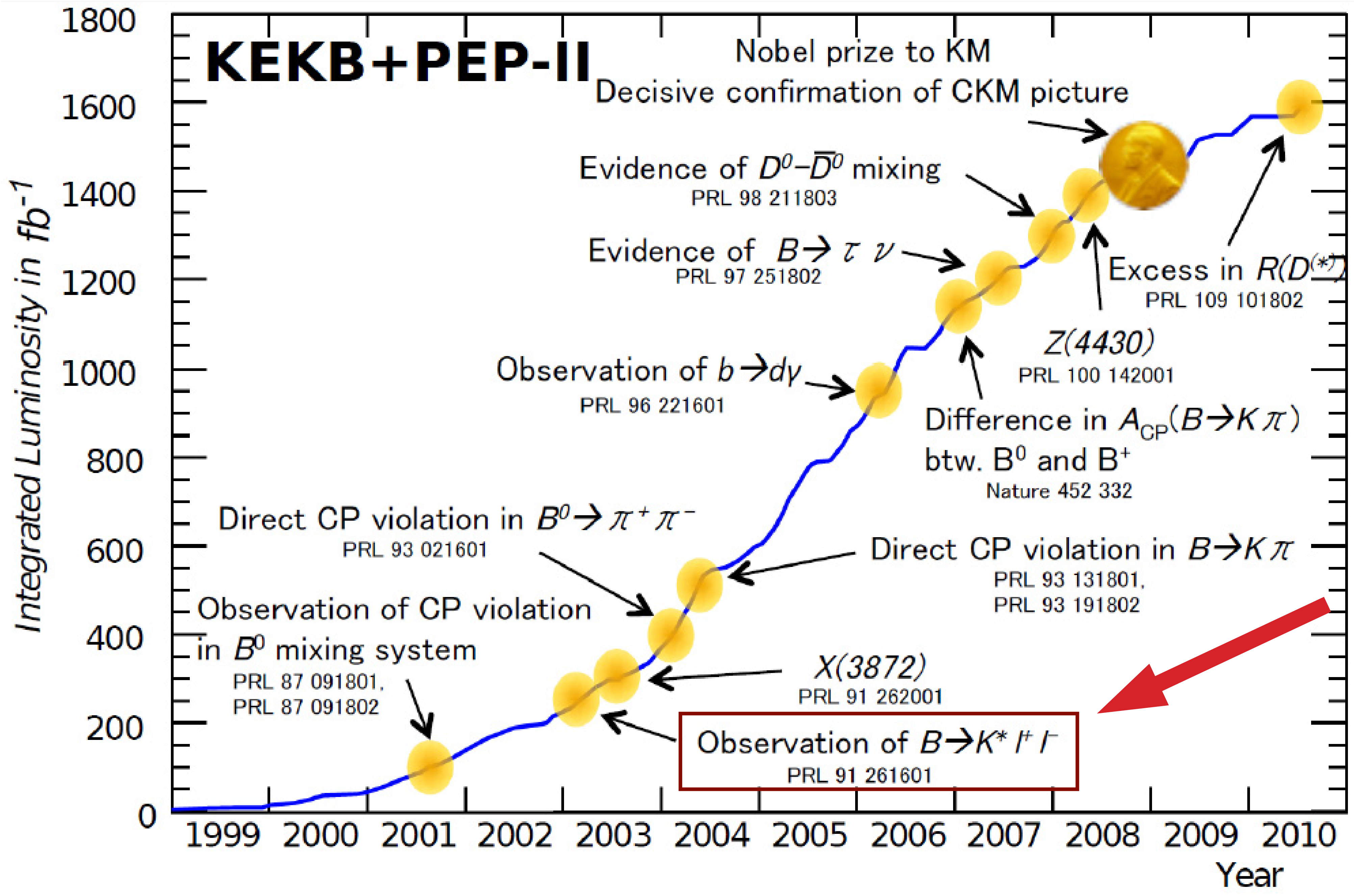


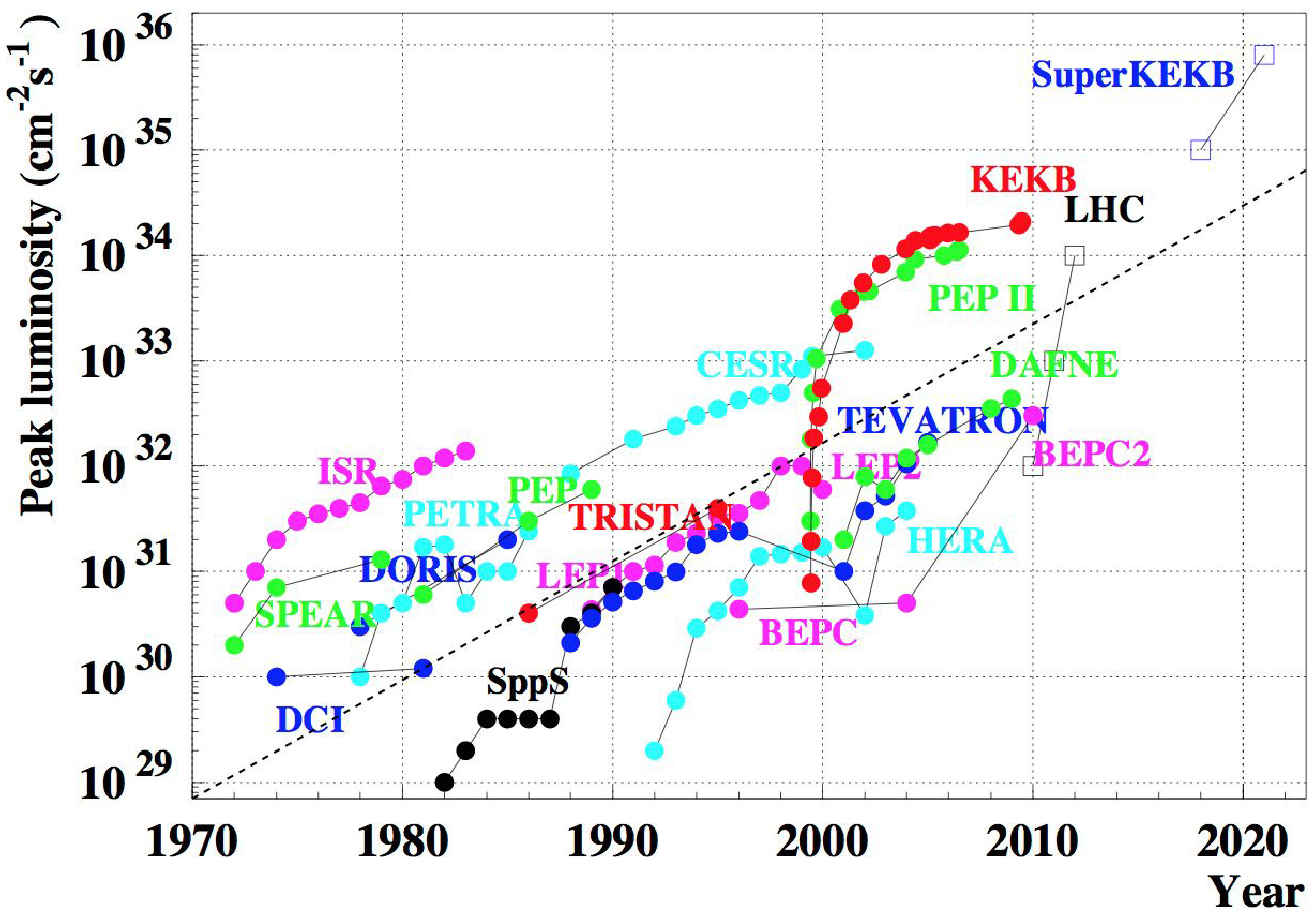
Are (NP) Discoveries Possible With ~70 Times More Data?

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

~50 /ab by ~2025





Belle's Radiative and Electroweak Penguin Legacy (select)

VOLUME 88, NUMBER 2 — PHYSICAL REVIEW LETTERS — 14 JANUARY 2002

021801

Observation of the Decay $B \to K l^+ l^-$

VOLUME 91, NUMBER 26 — PHYSICAL REVIEW LETTERS — week ending 31 DECEMBER 2003

261601

Observation of $B \to K^* \ell^+ \ell^-$

VOLUME 90, NUMBER 2 — PHYSICAL REVIEW LETTERS — week ending 17 JANUARY 2003

021801

Measurement of the Electroweak Penguin Process $B \to X_s \ell^+ \ell^-$

PRL **96,** 251801 (2006) — PHYSICAL REVIEW LETTERS — week ending 30 JUNE 2006

Measurement of Forward-Backward Asymmetry and Wilson Coefficients in $B \to K^* l^+ l^-$

PRL **96,** 221601 (2006) — PHYSICAL REVIEW LETTERS — week ending 9 JUNE 2006

Observation of $b \to d\gamma$ and Determination of $|V_{td}/V_{ts}|$

PRL **103,** 241801 (2009) — PHYSICAL REVIEW LETTERS — week ending 11 DECEMBER 2009

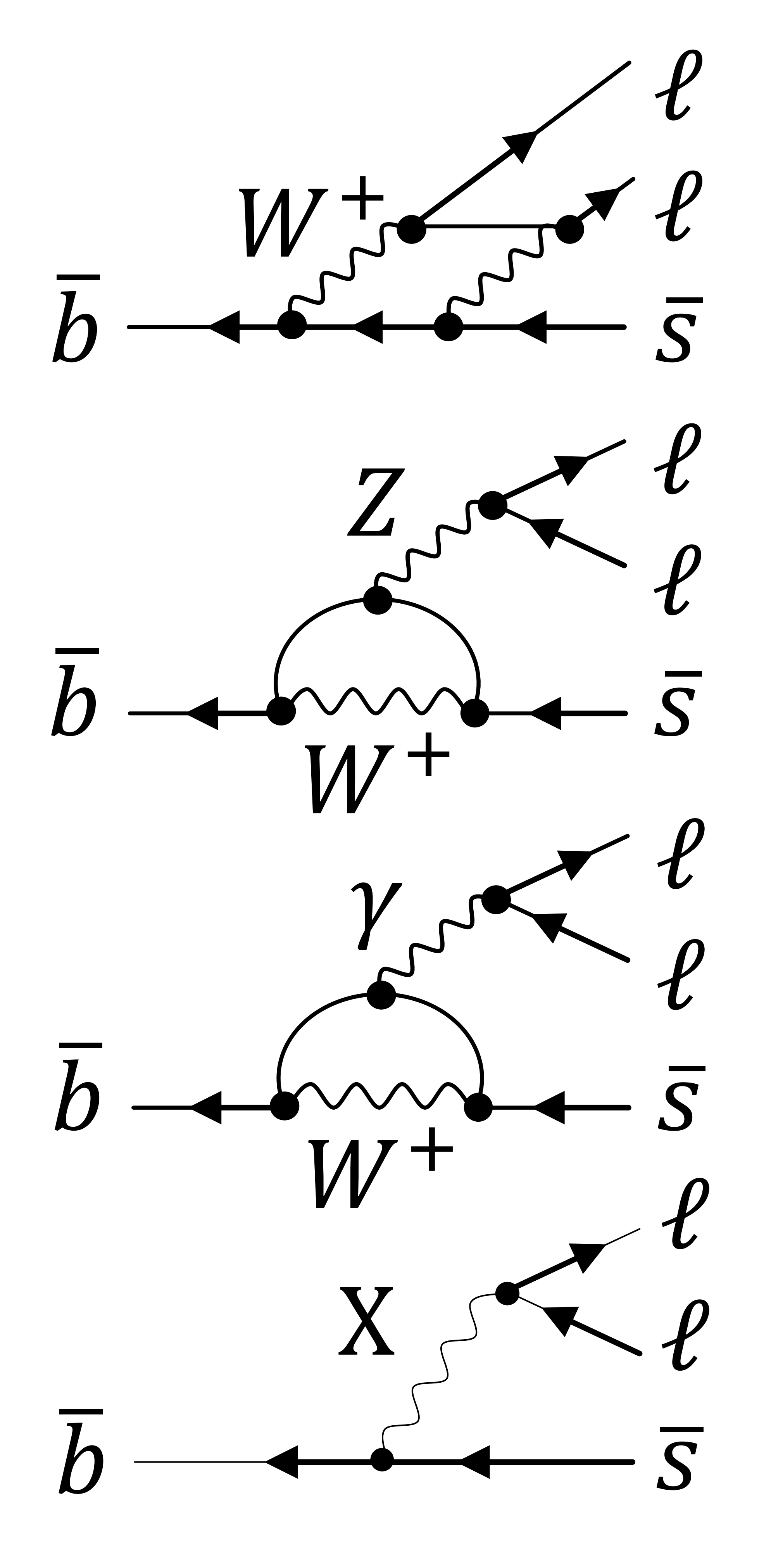
Measurement of Inclusive Radiative B-Meson Decays with a Photon Energy Threshold of 1.7 GeV

PRL **105,** 091801 (2010) — PHYSICAL REVIEW LETTERS — week ending 27 AUGUST 2010

Search for a Low Mass Particle Decaying into $\mu^+\mu^-$ in $B^0 \to K^{*0} X$ and $B^0 \to \rho^0 X$ at Belle

PRL **118,** 111801 (2017) — PHYSICAL REVIEW LETTERS — week ending 17 MARCH 2017

Lepton-Flavor-Dependent Angular Analysis of $B \to K^* \ell^+ \ell^-$



Penguin Physics is not Yo' Mama's Banana Pudding!

Implications of B Physics Anomalies

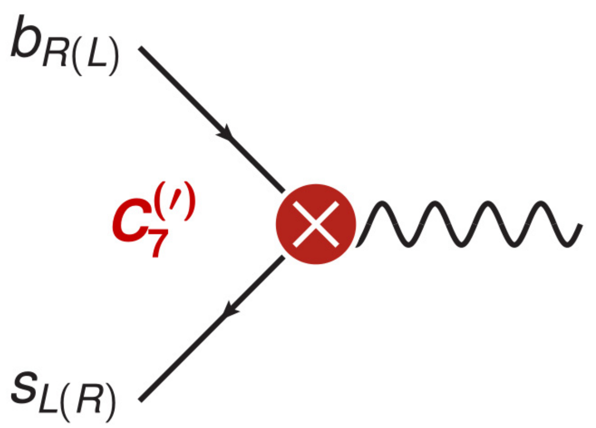
Aspen Winter Conference
"The Particle Frontier"
Aspen, March 25 - 31, 2018

FROM SLIDES OF

Wolfgang Altmannshofer
altmanwg@ucmail.uc.edu
UNIVERSITY OF Cincinnati

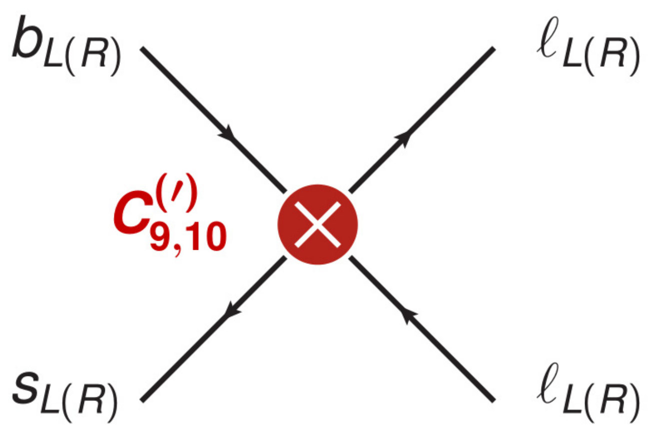
$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right)$$

magnetic dipole operators



$C_7^{(\prime)} (\bar{s}\sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$

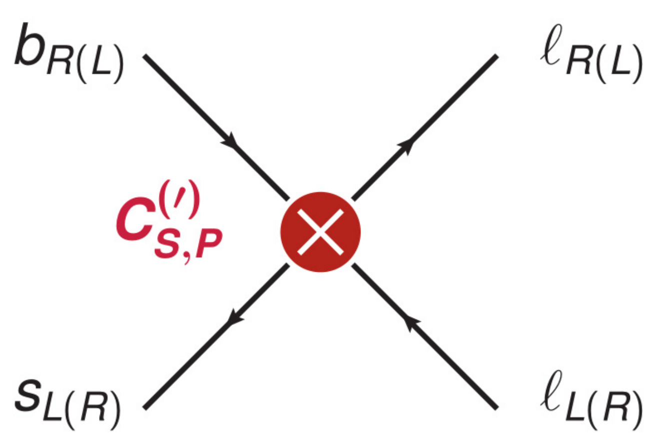
semileptonic operators



$C_9^{(\prime)} (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell)$

$C_{10}^{(\prime)} (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$

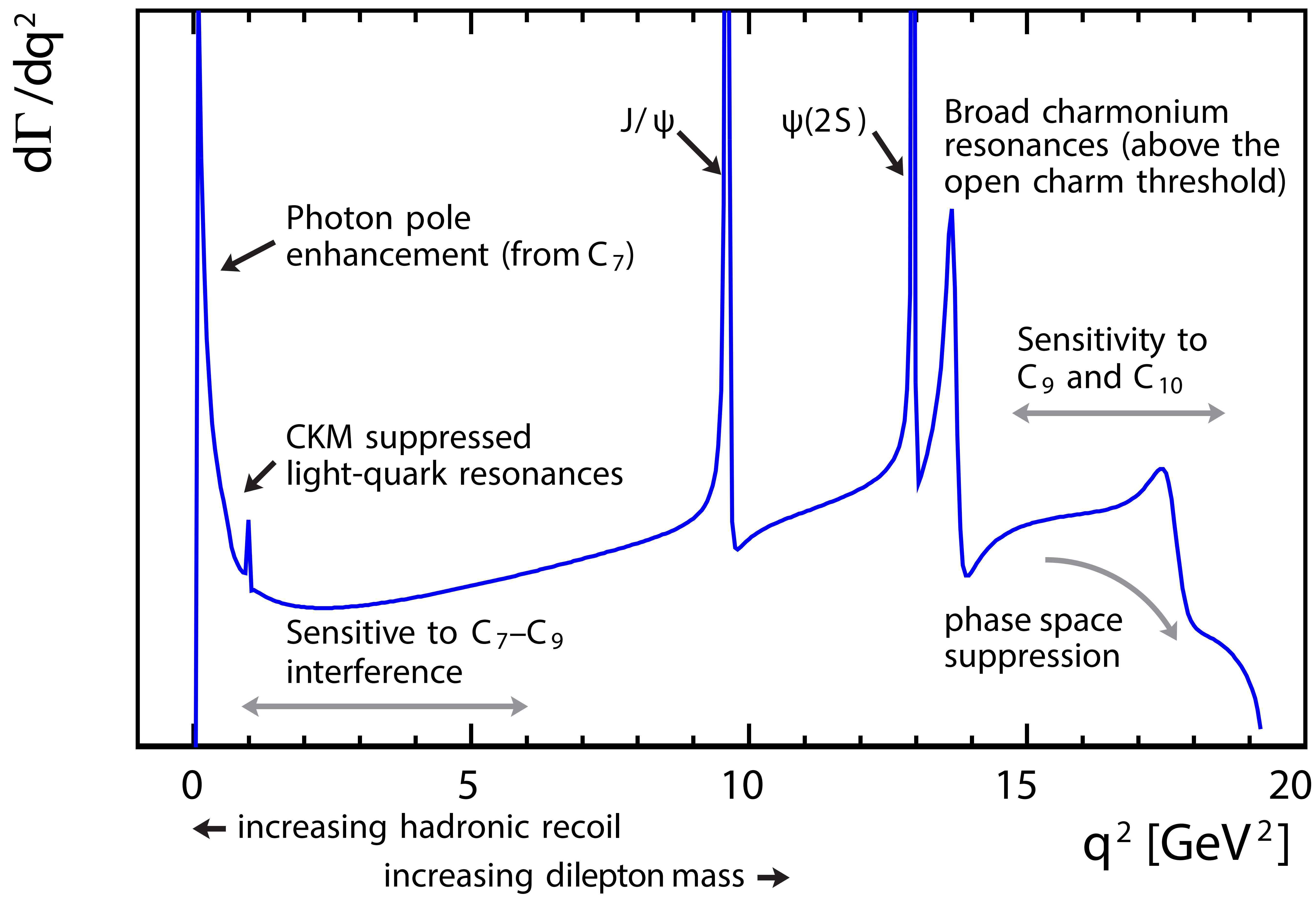
scalar operators

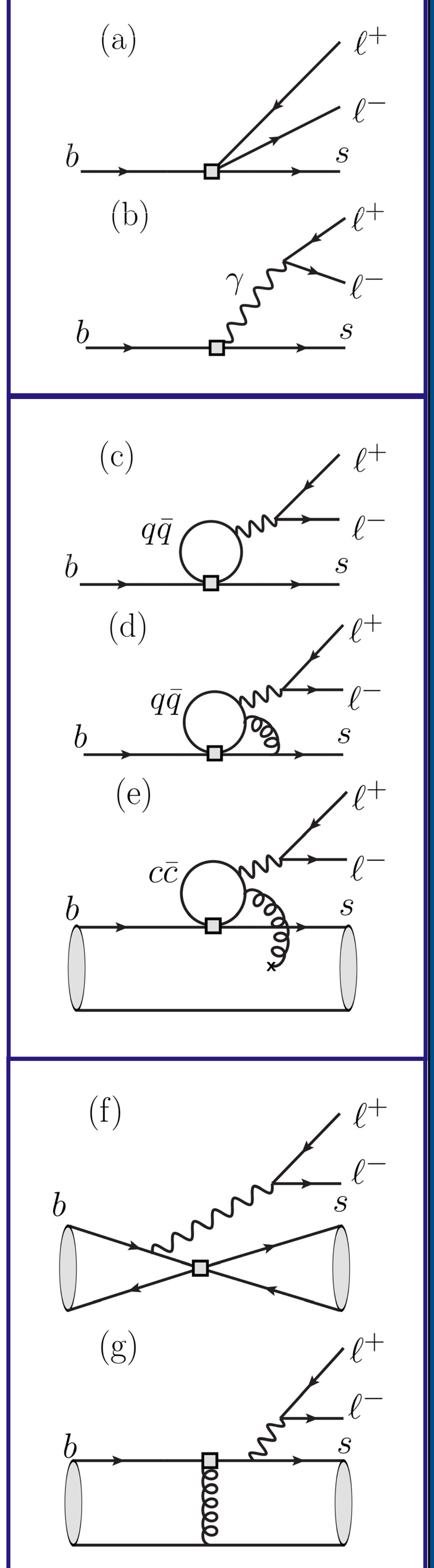


$C_S^{(\prime)} (\bar{s} P_{R(L)} b)(\bar{\ell} P_{L(R)} \ell)$

Blake, T., Lanfranchi, G., Straub, D. M. & Rare, B. Decays as tests of the standard model. Prog. Part. Nucl. Phys. 92, 50–91 (2017)

$d\Gamma/dq^2$ for $B \to K^*\ell^+\ell^-$





"There are more ways of killing a cat than choking it with cream"

(an old British saying, sometimes, for wrong reasons, mistakenly attributed to Erwin Schrödinger)

$$R_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} = 1 \pm \mathcal{O}(10^{-2})$$

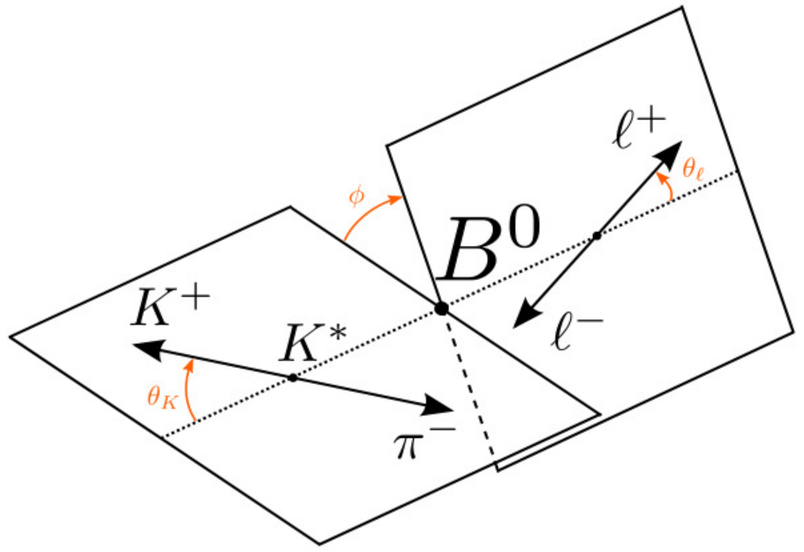
(for q^2 approx. above dimuon threshold)

The ratio of these two R's is also very valuable:

G. Hiller, M. Schmaltz, arXiv:1411.4773, JHEP02(2015)055:
The new *right-handed* quark currents result in *anti-correlation* between R_K and R_{K^*}, meanwhile *left-handed* quark currents produce a *correlated* change in R_K and R_{K^*}.

Full angular analysis gives even more information:

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$-F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi$$



Optimal observables

CP-averaged and CP-violating observables can also be constructed from observables $S_i(q^2)$ and $F_L(q^2)$.

These include forward-backward asymmetry A_{FB} and CP-averaged observables P_i' which are largely insensitive to form-factor uncertainties

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

JHEP 05 (2013) 137
S. Descotes-Genon, T. Hurth, J. Matias, and J. Virto

Transverse polarization asymmetry

$$A_T^{(2)} = 2S_3/(1-F_L)$$

Tests of Lepton Universality (R_K, R_{K^*} and R_{X_s})

PRL 103, 171801 (2009) PHYSICAL REVIEW LETTERS week ending 23 OCTOBER 2009

Measurement of the Differential Branching Fraction and Forward-Backward Asymmetry for $B \to K^{(*)} l^+ l^-$

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08 \text{ and } R_K = 1.03 \pm 0.19 \pm 0.06$$

Belle's results (85% of full sample, an update is in progress)

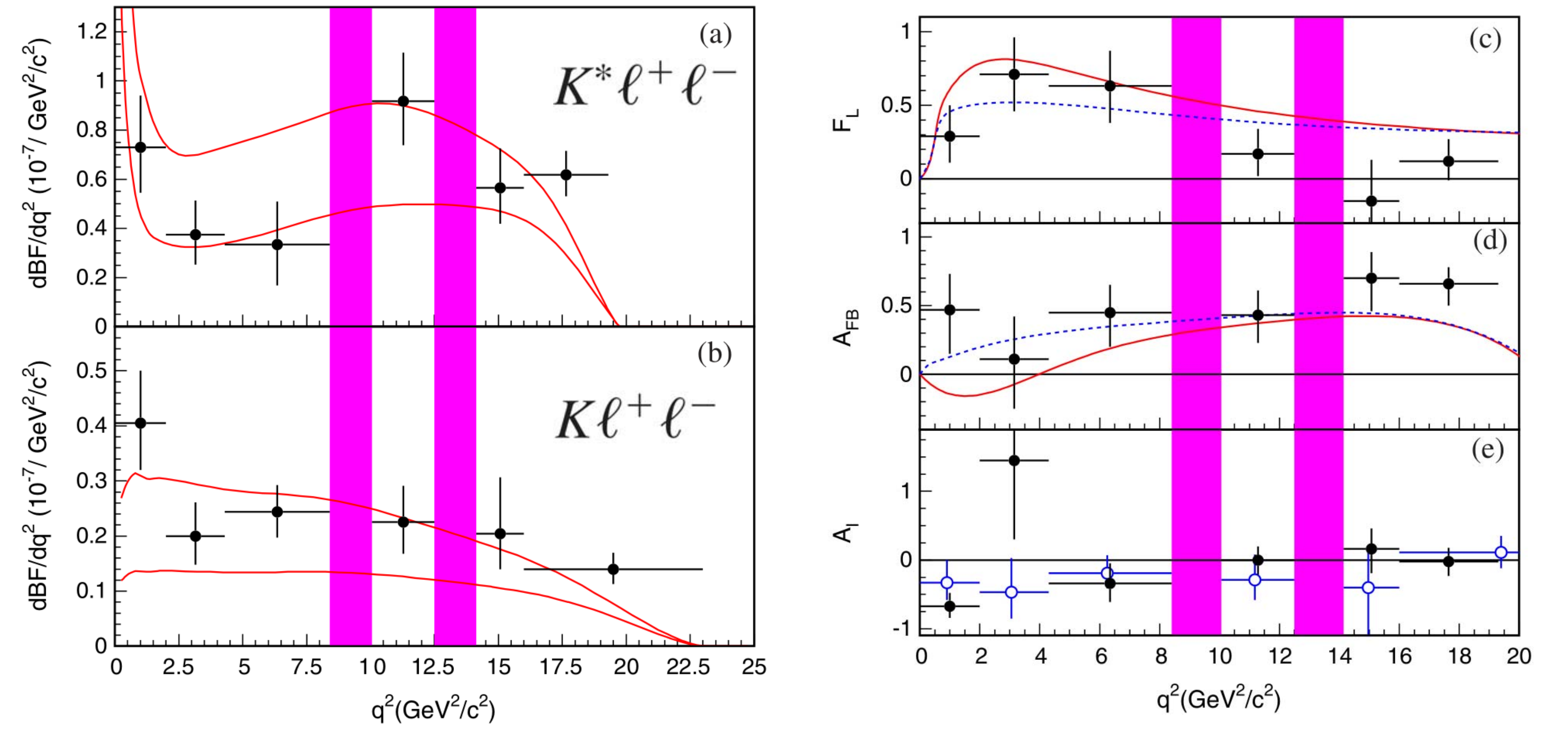
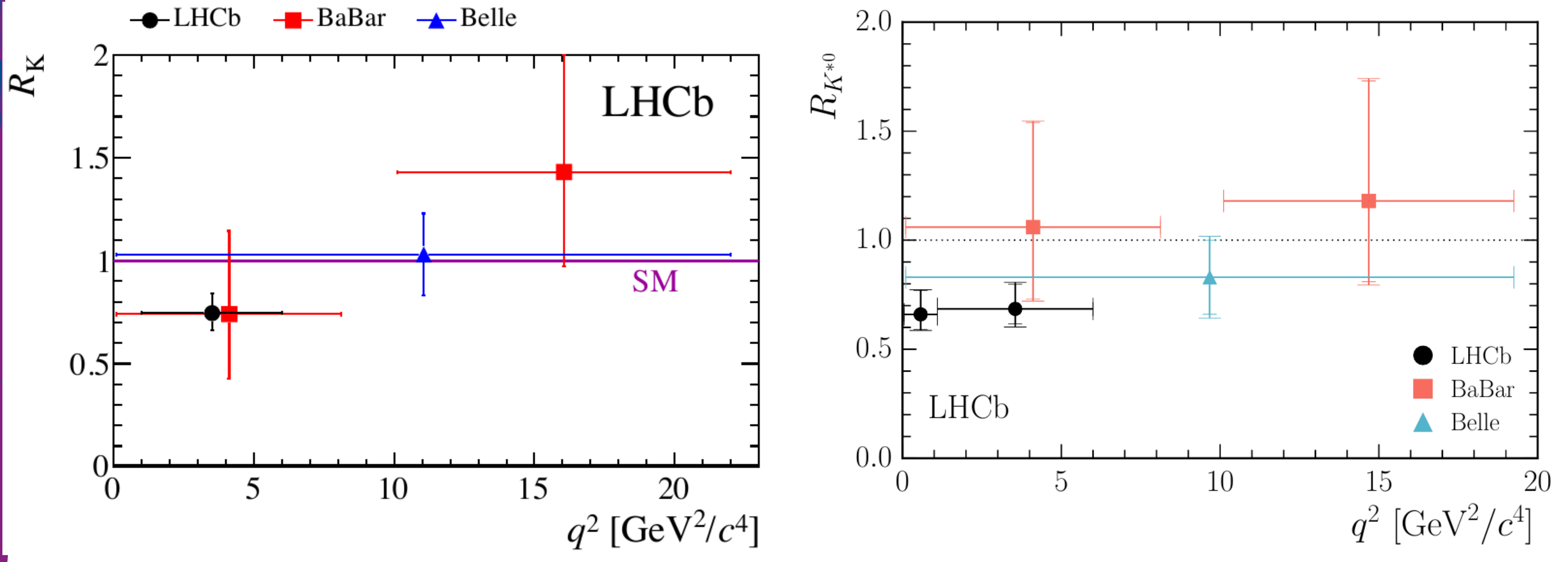


FIG. 1 (color online). Differential branching fractions for the (a) $K^*\ell^+\ell^-$ and (b) $K\ell^+\ell^-$ modes as a function of q^2. The two shaded regions are veto windows to reject $J/\psi(\psi')X$ events. The solid curves show the SM theoretical predictions with the minimum and maximum allowed form factors [16]. (c) and (d) show the fit results for F_L and A_{FB} in $K^*\ell^+\ell^-$ as a function of q^2, together with the solid (dotted) curve representing the SM ($C_7 = -C_7^{SM}$) prediction [16]. (e) is the A_I asymmetry as a function of q^2 for the $K^*\ell^+\ell^-$ (filled circles) and $K\ell^+\ell^-$ (open circles) modes.



Belle / Belle II Advantages

- Can study both electron and muon channels
- Both *low* and *high* q^2 regions could be measured
- M_{BC} resolutions for electron and muon channels are similar
- Only lepton ID systematics do not fully cancel in the ratios

Tests of Lepton Universality (R_K, R_{K^*} and R_{X_s})

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

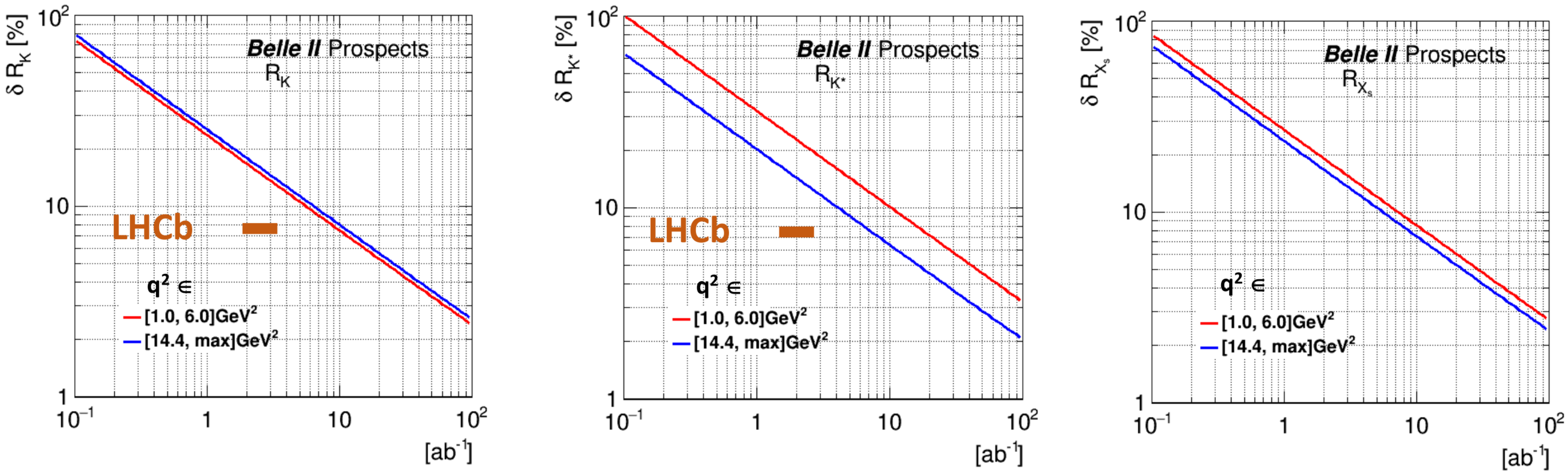
6th Belle II Theory Interface Platform (B2TiP) Workshop, KEK
https://kds.kek.jp/indico/event/27330/

Radiative and Electroweak Penguin B Decays

A. Ishikawa[1], U. Haisch[2], T. Feldmann[3], and J. Yamaoka[4]

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
R_K $(1 < q^2 < 6$ GeV$^2)$	28%	11%	3.6%
R_K $(q^2 > 14.4$ GeV$^2)$	30%	12%	3.6%
R_{K^*} $(1 < q^2 < 6$ GeV$^2)$	26%	10%	3.2%
R_{K^*} $(q^2 > 14.4$ GeV$^2)$	24%	9.2%	2.8%
R_{X_s} $(1 < q^2 < 6$ GeV$^2)$	32%	12%	4.0%
R_{X_s} $(q^2 > 14.4$ GeV$^2)$	28%	11%	3.4%

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 5σ discovery with 20/ab

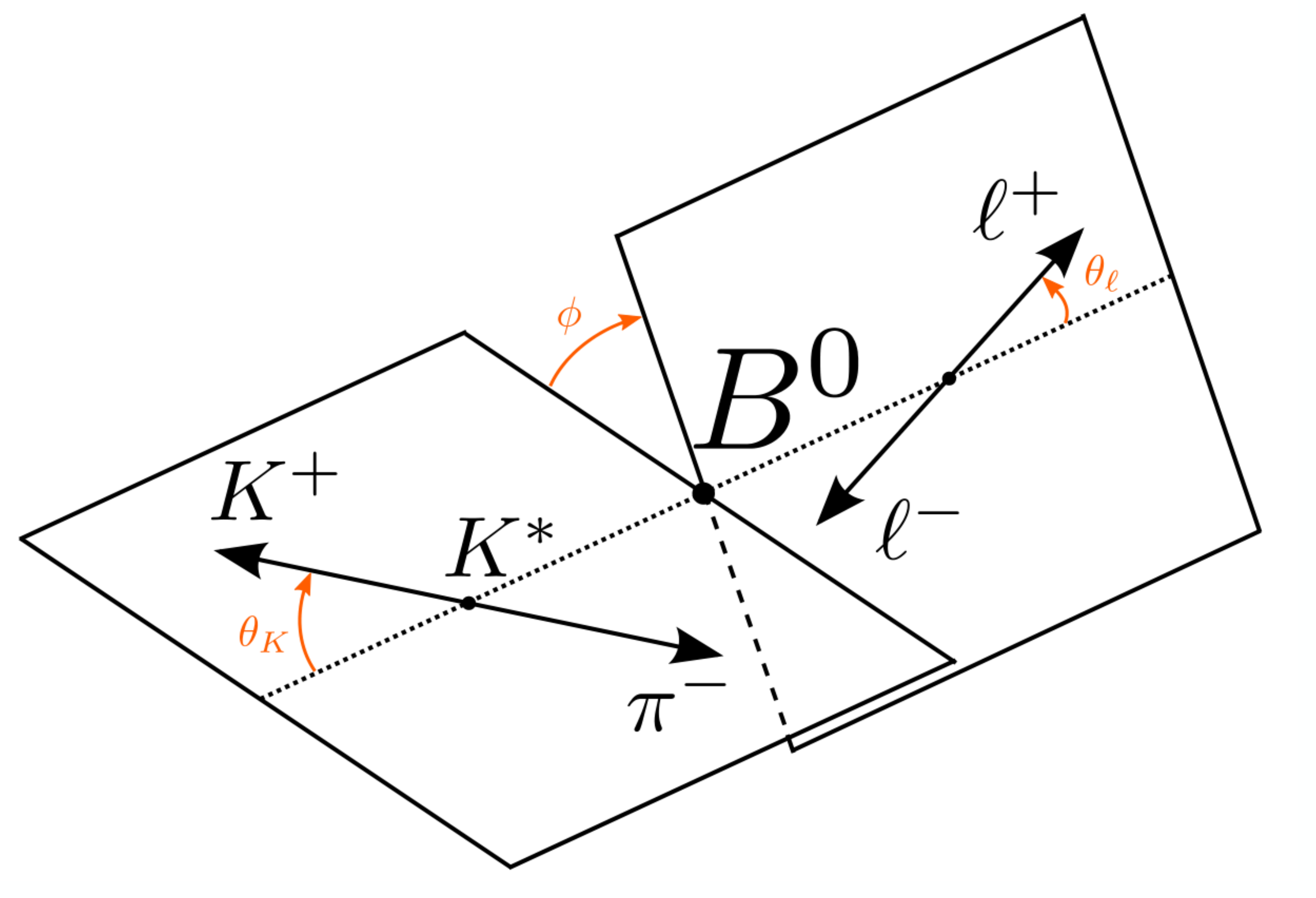
Lepton-Flavor-Dependent Angular Analysis of $B \to K^* \ell^+ \ell^-$

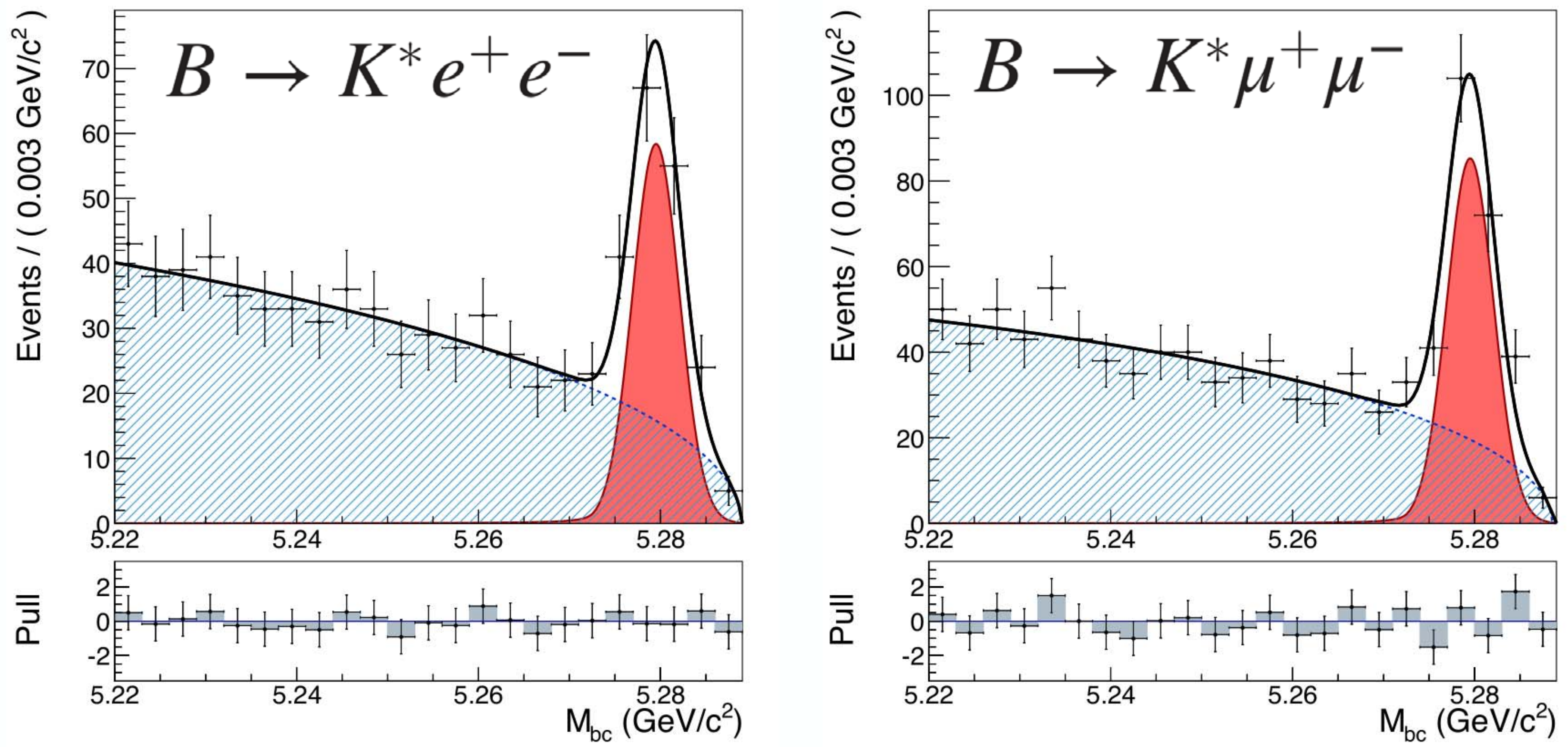
PRL **118**, 111801 (2017) PHYSICAL REVIEW LETTERS week ending 17 MARCH 2017

Belle

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$
$$+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

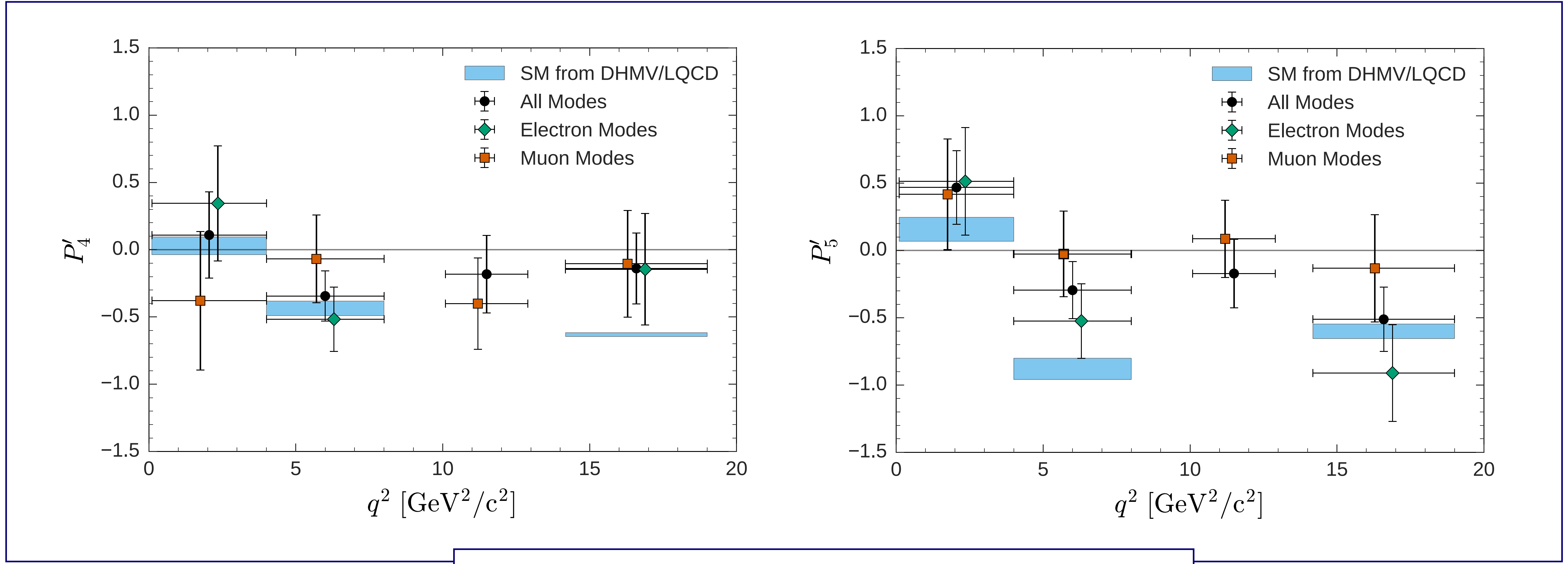
$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$



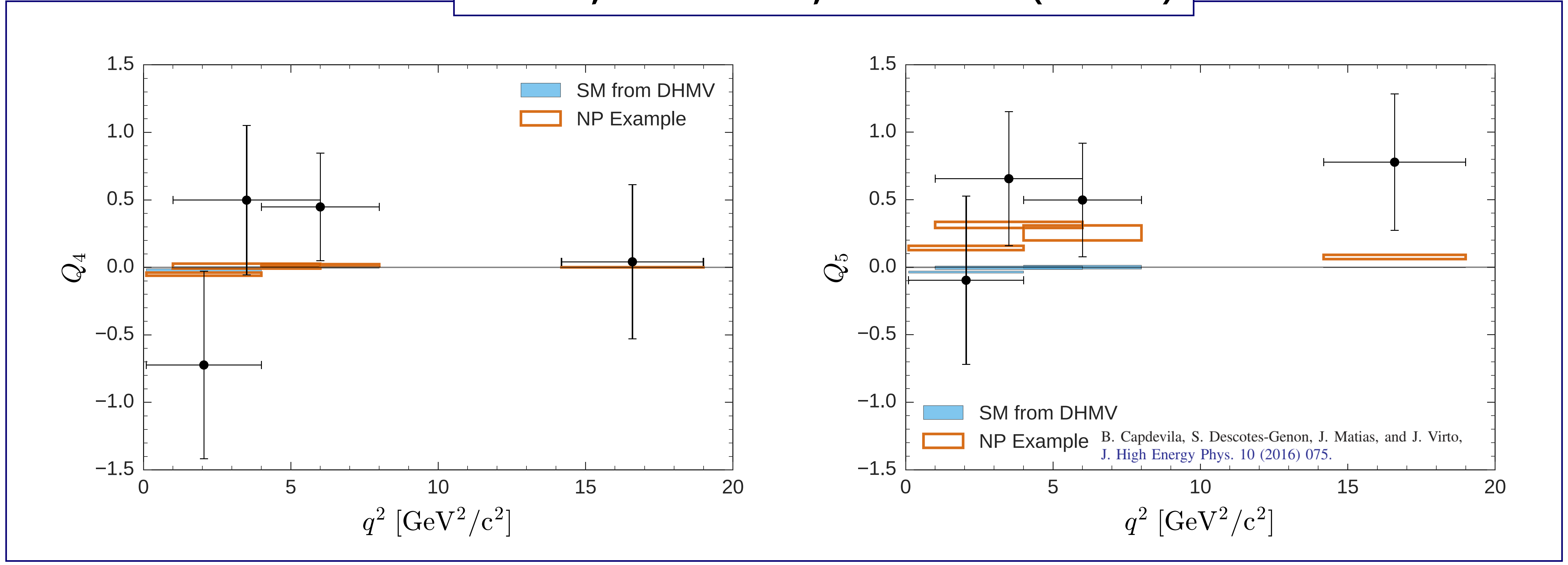


$N_{\rm sig} = 127 \pm 15$ $N_{\rm sig} = 185 \pm 17$

Lepton-Flavor-Dependent Angular Analysis of $B \to K^* \ell^+ \ell^-$



Belle, PRL **118**, 111801 (2017)



$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

Largest deviation from the SM: 2.5σ is observed in P'_5 for the muon mode in the region $4\ \mathrm{GeV}/c^2 < q^2 < 8\ \mathrm{GeV}^2/c^2$

In the same q^2 region, the electron modes deviate from the SM by 1.3σ

$$Q_i = P'^{\,\mu}_i - P'^{\,e}_i$$

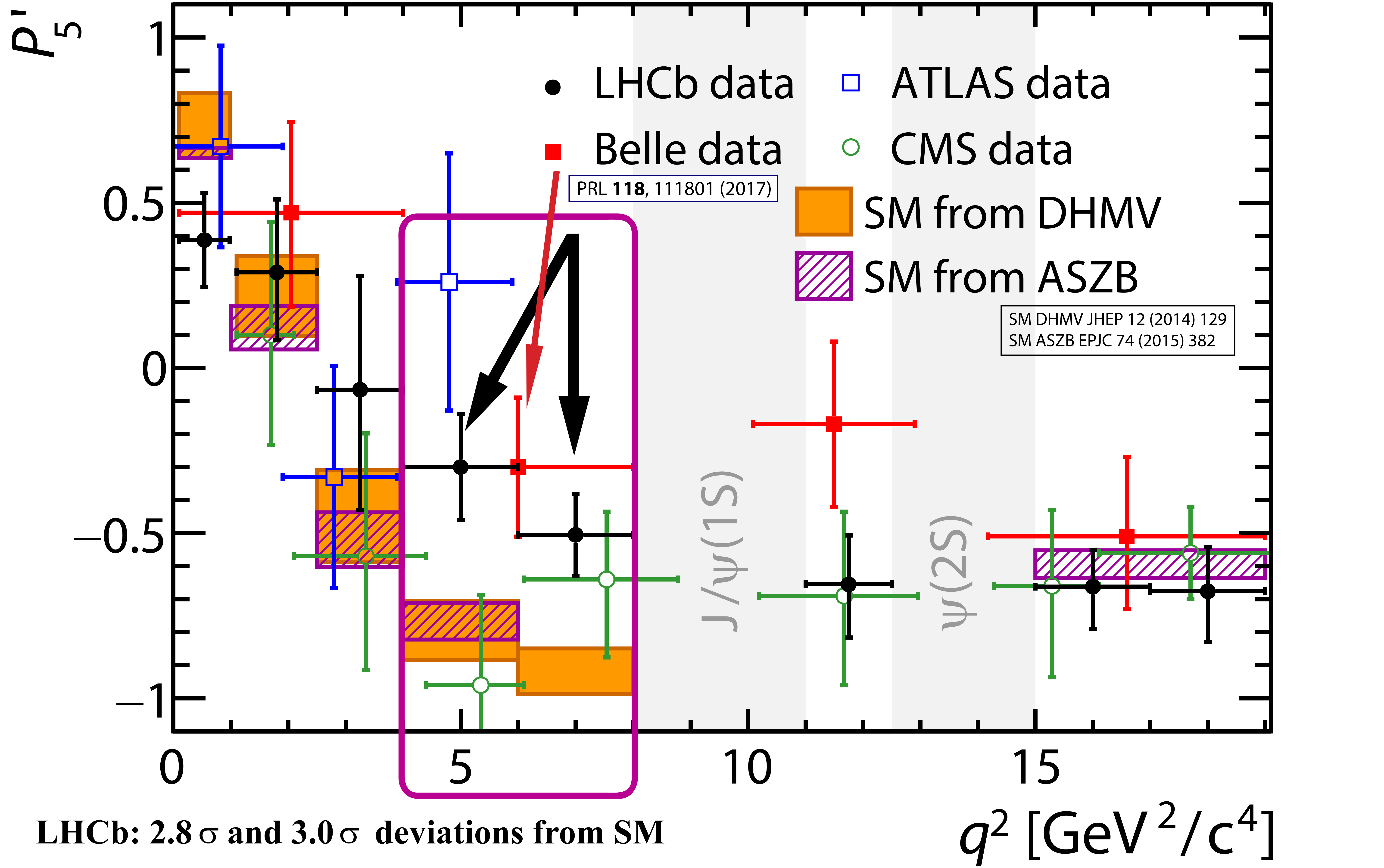
Deviation from zero would be a sign of NP

SM predictions from

S. Descotes-Genon, L. Hofer, J. Matias, and J. Virto, J. High Energy Phys. 12 (2014) 125.
R. R. Horgan, Z. Liu, S. Meinel, and M. Wingate, *Proc. Sci.*, LATTICE2014 (2015) 372.

B. Capdevila, S. Descotes-Genon, J. Matias, and J. Virto, J. High Energy Phys. 10 (2016) 075.

Summary of P_5' Results (electron and muon modes, where applicable)



LHCb: 2.8 σ and 3.0 σ deviations from SM

Belle II Projected Sensitivity to (some of) Angular Observables

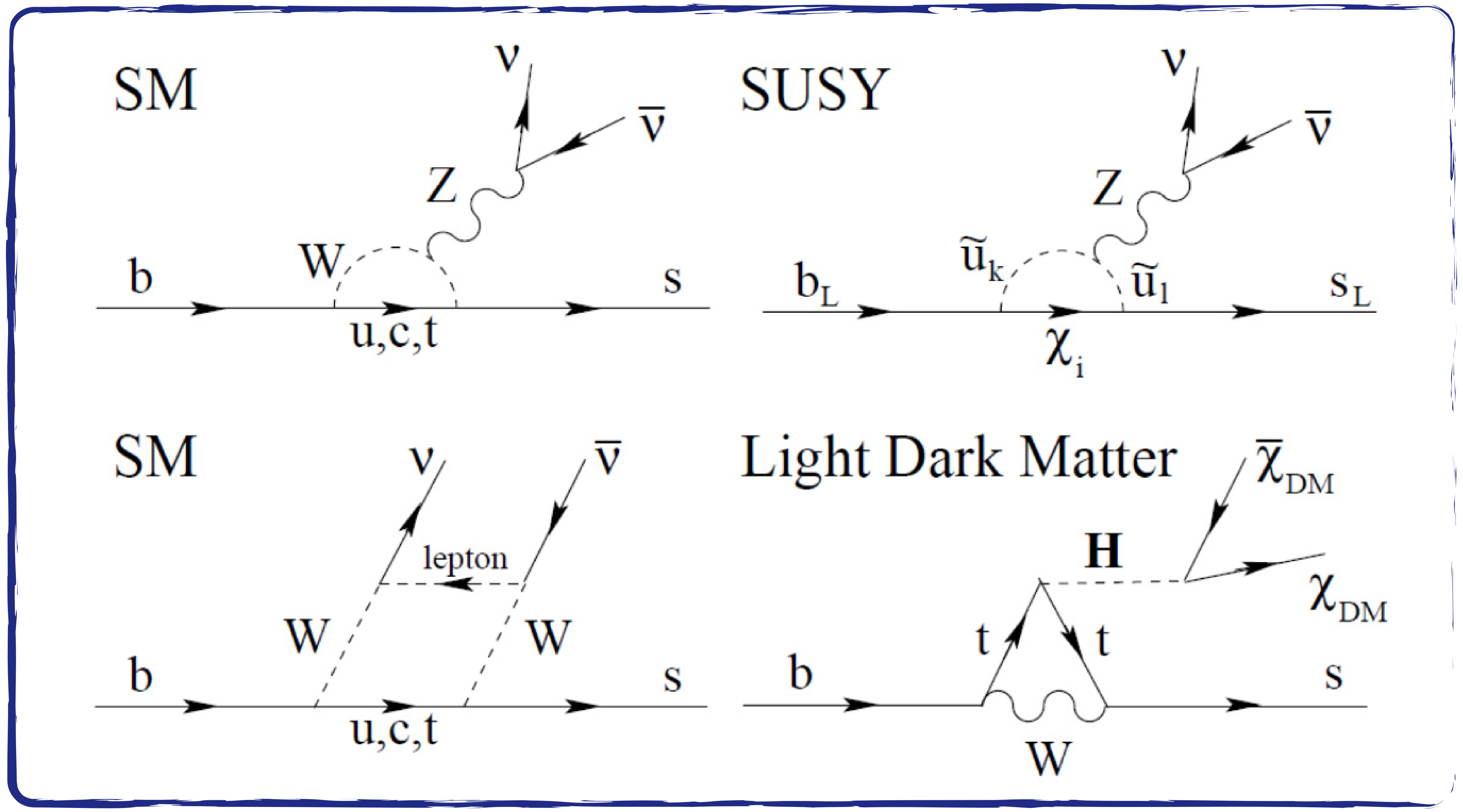
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
F_L $(1 < q^2 < 2.5\ \text{GeV}^2)$	0.19	0.063	0.025
F_L $(2.5 < q^2 < 4\ \text{GeV}^2)$	0.17	0.057	0.022
F_L $(4 < q^2 < 6\ \text{GeV}^2)$	0.14	0.046	0.018
F_L $(q^2 > 14.2\ \text{GeV}^2)$	0.088	0.027	0.009
P_5' $(1 < q^2 < 2.5\ \text{GeV}^2)$	0.47	0.17	0.054
P_5' $(2.5 < q^2 < 4\ \text{GeV}^2)$	0.42	0.15	0.049
P_5' $(4 < q^2 < 6\ \text{GeV}^2)$	0.34	0.12	0.040
P_5' $(q^2 > 14.2\ \text{GeV}^2)$	0.23	0.088	0.027

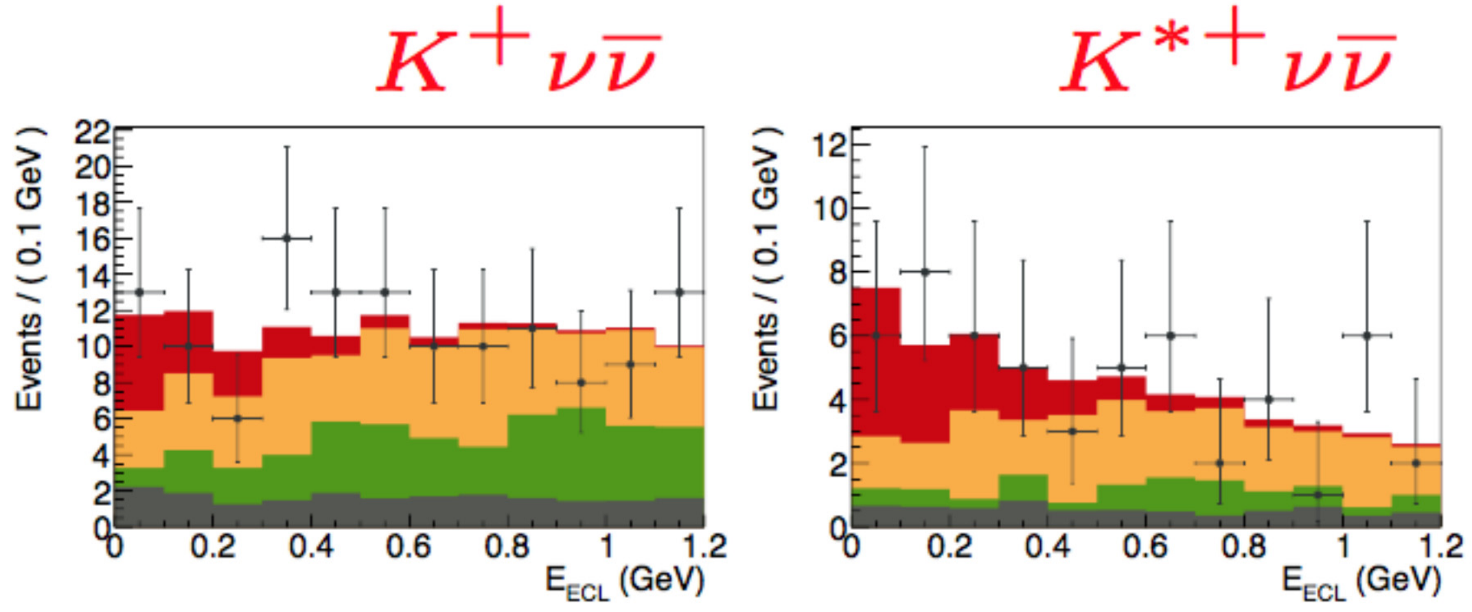
Belle II Theory Interface Platform (B2TIP)
(https://confluence.desy.de/display/BI/B2TiP+WebHome)

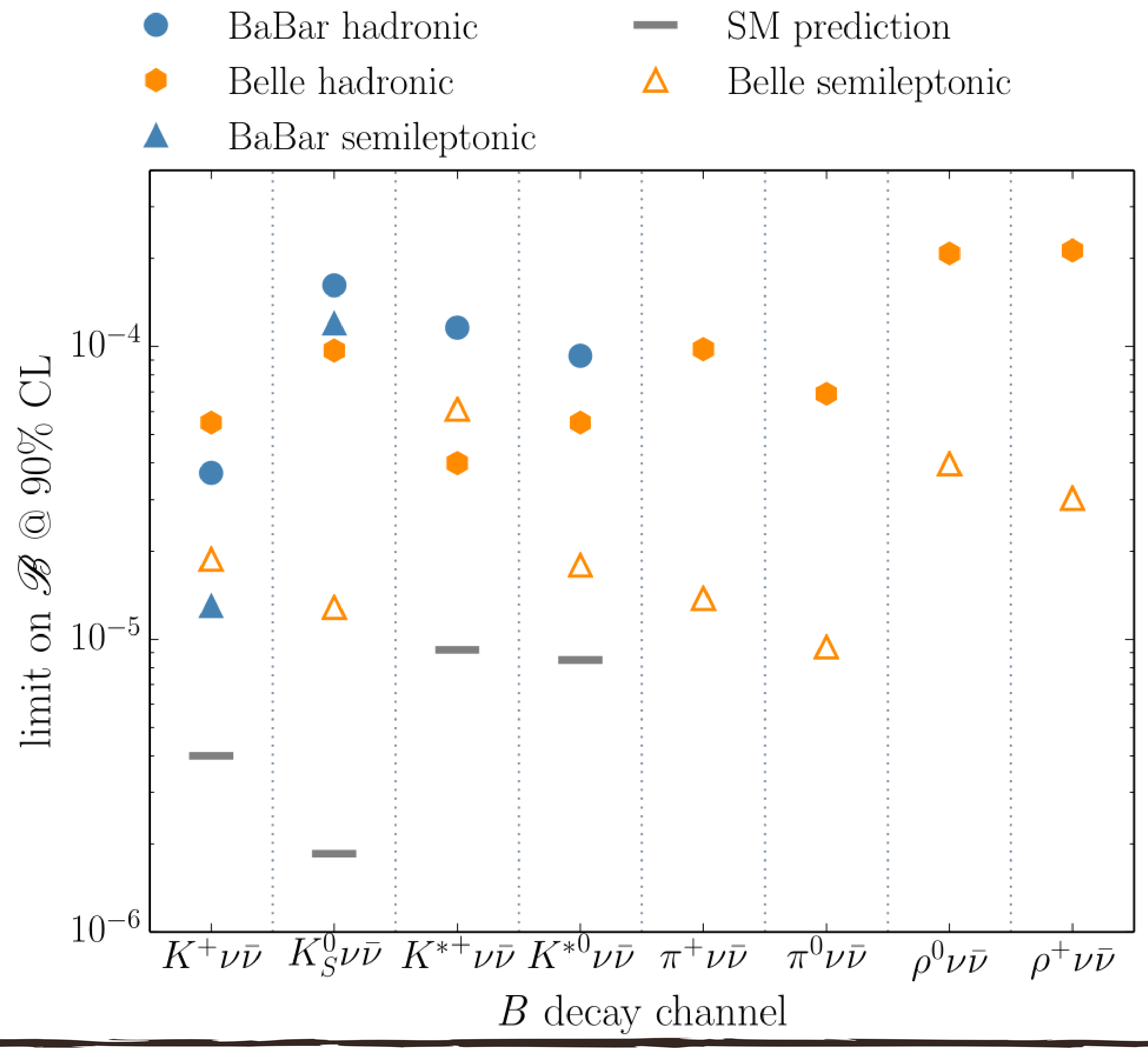
6th Belle II Theory Interface Platform (B2TiP) Workshop, KEK
https://kds.kek.jp/indico/event/27330/

PHYSICAL REVIEW D **96,** 091101(R) (2017)

Search for $B \to h\nu\bar{\nu}$ decays with semileptonic tagging at Belle







Belle II Prospects for Neutrino Electroweak Penguin Decays

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	25%	9.3%
$F_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	–	0.079
$F_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	–	0.077
$\mathrm{Br}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5
$\mathrm{Br}(B_s \to \nu\bar{\nu}) \times 10^5$	< 9.7	< 1.1	–

Tauonic Electroweak Penguin Modes (we all wish / if only)

τ: the heaviest lepton, NP sensitivity could improve by $|m_\tau/m_\mu|^2 \sim 300$

but
$$\mathrm{Br}^{\mathrm{SM}}_{K^{*+}\tau^+\tau^-} = (0.99 \pm 0.12) \cdot 10^{-7}$$
$$\mathrm{Br}^{\mathrm{SM}}_{K^{*0}\tau^+\tau^-} = (0.91 \pm 0.11) \cdot 10^{-7}$$

Some models, however, predict
$$\mathcal{B}(B \to K\tau^-\tau^+)^{MLFV} < 2 \times 10^{-4}$$
Alonso, R., Grinstein, B. & Camalich, J.M. J. High Energ. Phys. (2015) 2015

BaBar established a limit: $\mathcal{B}(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ at 90% C.L.

Belle can do a little bit better (only MC estimates are available)

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-) \cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B^0_s \to \tau^+\tau^-) \cdot 10^4$	< 70	< 8.1	–
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	$--$	$--$	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	$--$	$--$	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp) \cdot 10^5$	$--$	$--$	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp) \cdot 10^5$	$--$	$--$	< 1.3

Inclusive Penguin Decays $B \to X_s l^+ l^-$

Complementary to exclusive modes

Hadronic uncertainties are reduced

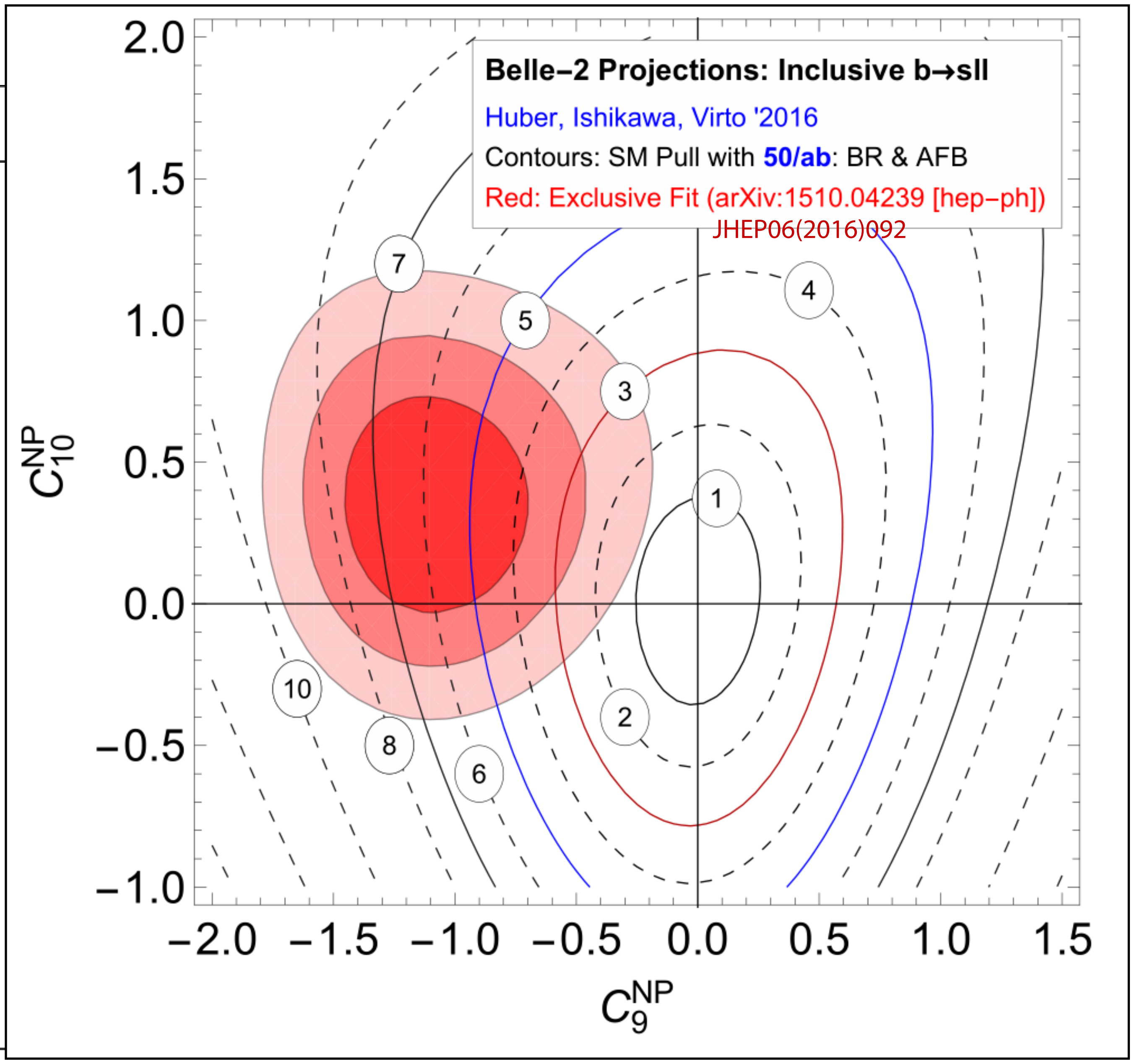
Could be quite challenging (if done inclusively, subject to huge $b \to c$ background)

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

6th Belle II Theory Interface Platform (B2TiP) Workshop, KEK https://kds.kek.jp/indico/event/27330/

However, inclusive channels alone have potential for NP discovery

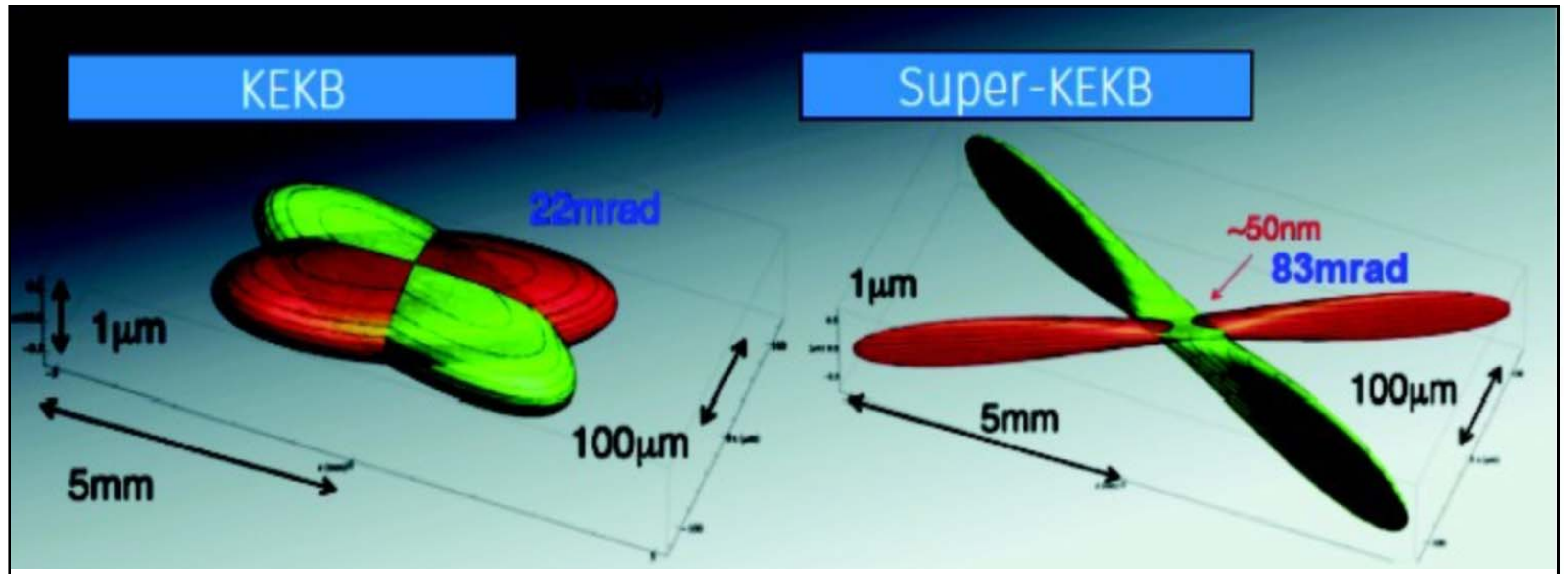
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 3.5$ GeV$^2)$	29%	13%	6.6%
$B(B \to X_s \ell^+ \ell^-)$ $(3.5 < q^2 < 6.0$ GeV$^2)$	24%	11%	6.4%
$B(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4$ GeV$^2)$	23%	10%	4.7%
$A_{CP}(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 3.5$ GeV$^2)$	26%	9.7 %	3.1 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ $(3.5 < q^2 < 6.0$ GeV$^2)$	21%	7.9 %	2.6 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4$ GeV$^2)$	21%	8.1 %	2.6 %
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 3.5$ GeV$^2)$	26%	9.7%	3.1%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(3.5 < q^2 < 6.0$ GeV$^2)$	21%	7.9%	2.6%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4$ GeV$^2)$	19%	7.3%	2.4%
$\Delta_{CP}(A_{FB})$ $(1.0 < q^2 < 3.5$ GeV$^2)$	52%	19%	6.1%
$\Delta_{CP}(A_{FB})$ $(3.5 < q^2 < 6.0$ GeV$^2)$	42%	16%	5.2%
$\Delta_{CP}(A_{FB})$ $(q^2 > 14.4$ GeV$^2)$	38%	15%	4.8%



Ingredients for Success: Part 1, The Machine, SuperKEKB

Target: L = 8x10^{35}/cm^2/s = L_{KEKB}x40

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



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

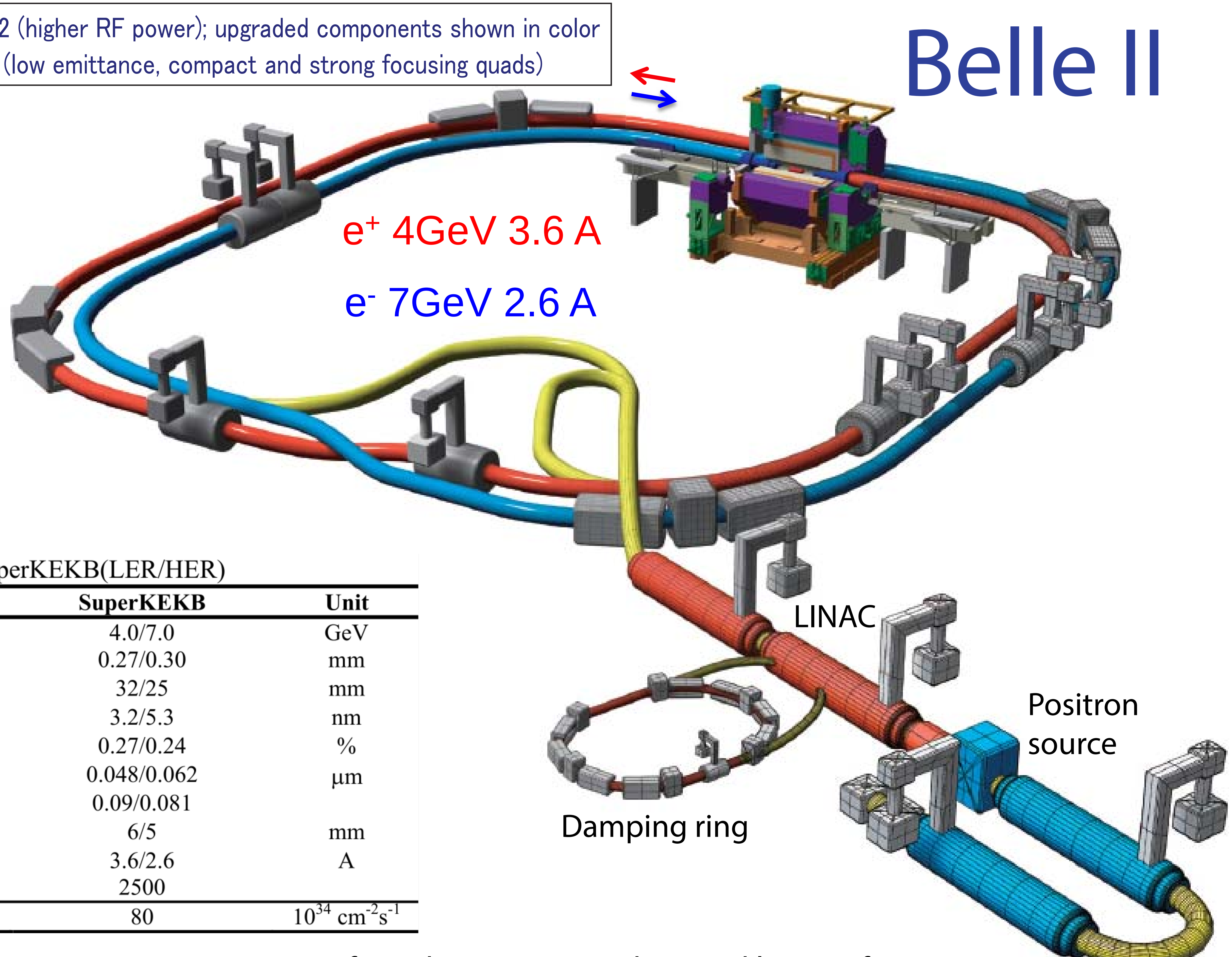


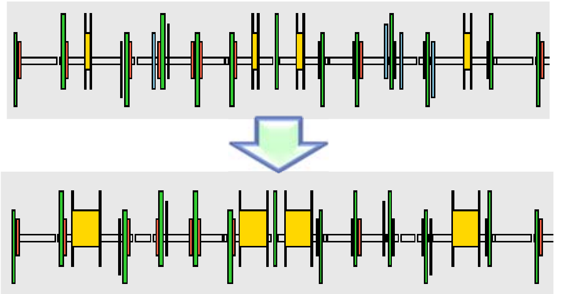
Table 1: Machine parameters of KEKB (LER/HER) and SuperKEKB(LER/HER)

	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 (ϵ_y/ϵ_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

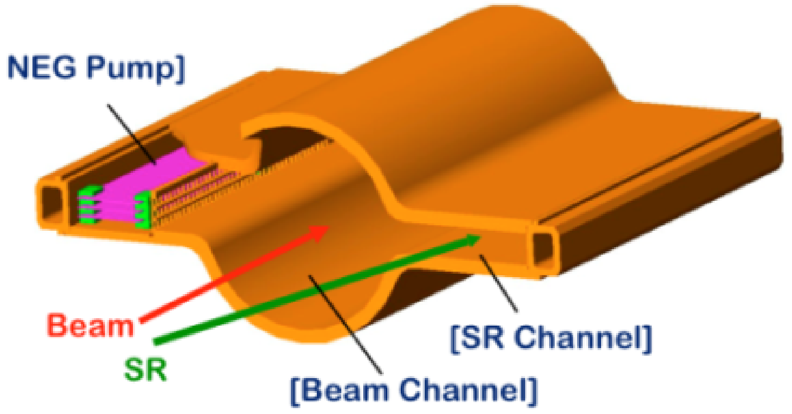
Ingredients for Success: Part 1, The Machine, SuperKEKB

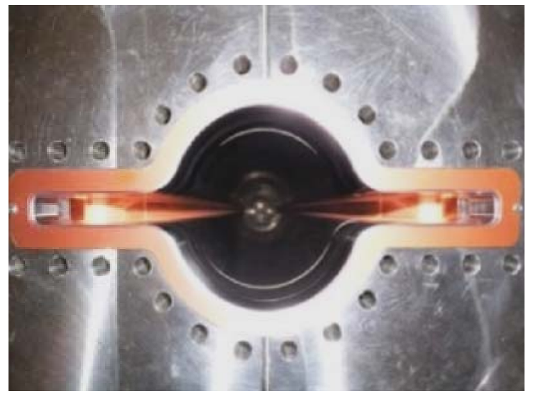
Replace short dipoles with longer ones (LER)

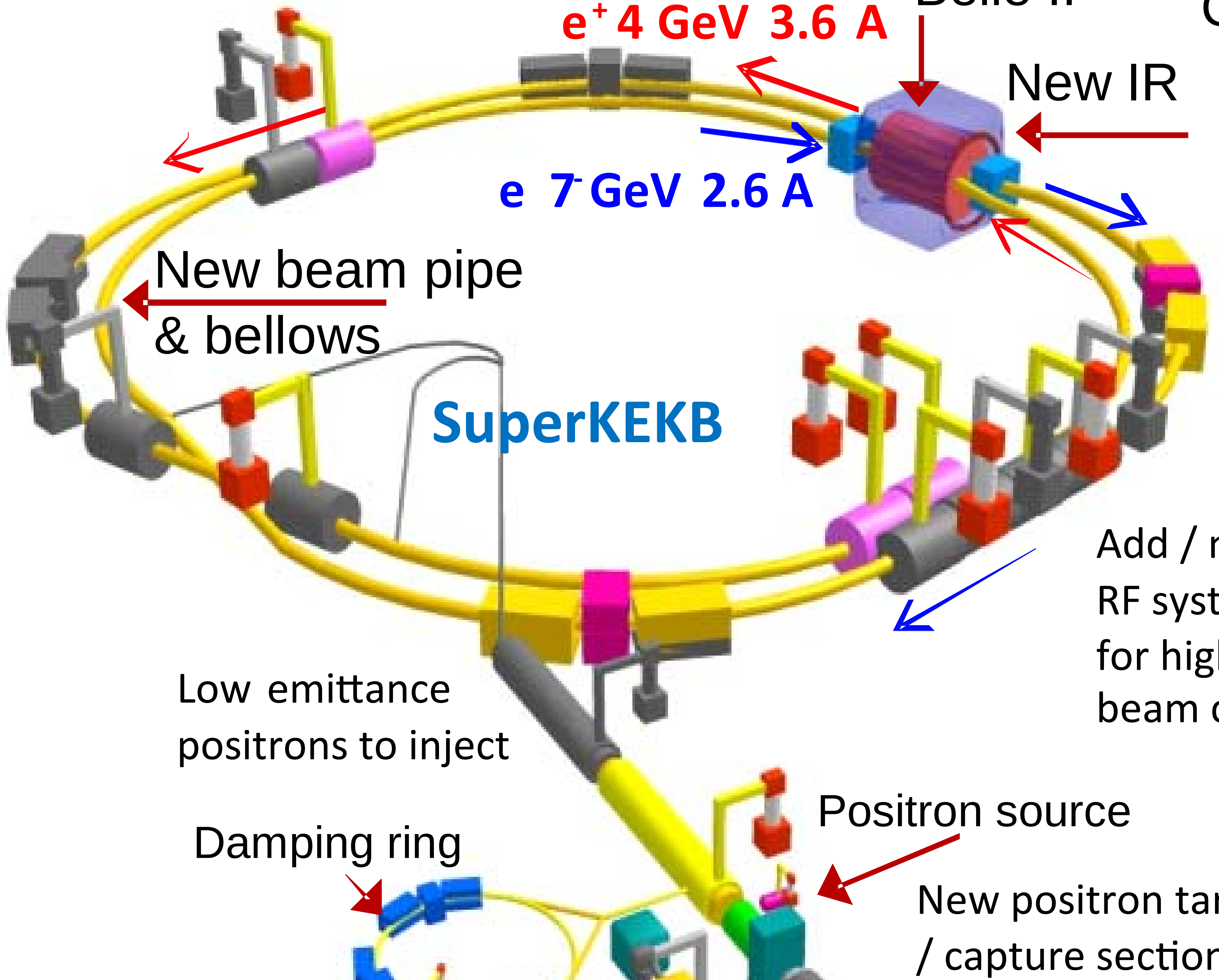


Redesign the lattices of both rings to reduce the emittance

TiN-coated beam pipe with antechambers







e^+ 4 GeV 3.6 A

Belle II

New IR

e^- 7 GeV 2.6 A

New beam pipe & bellows

Add / modify RF systems for higher beam current

Low emittance positrons to inject

Positron source

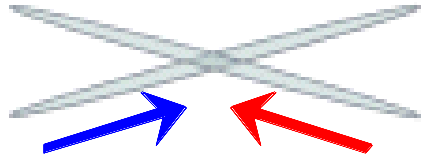
Damping ring

New positron target / capture section

Low emittance gun

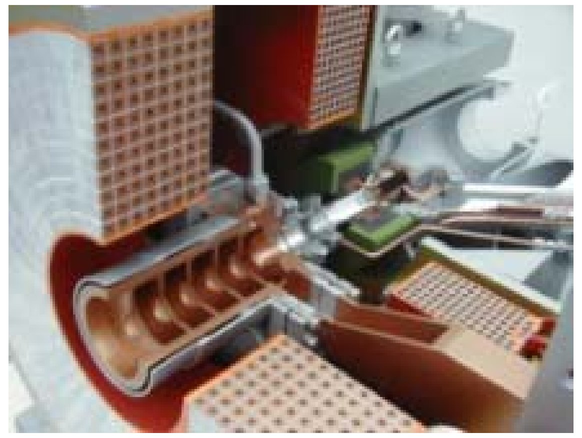
Low emittance electrons to inject

Colliding bunches

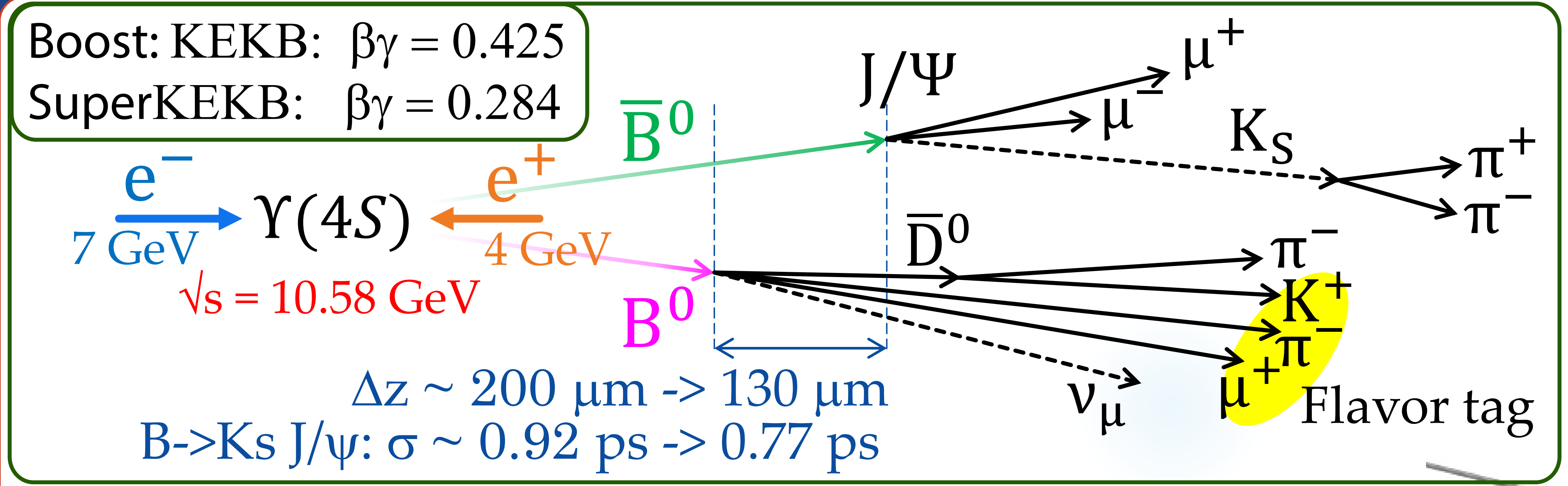


83 mrad crossing angle

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

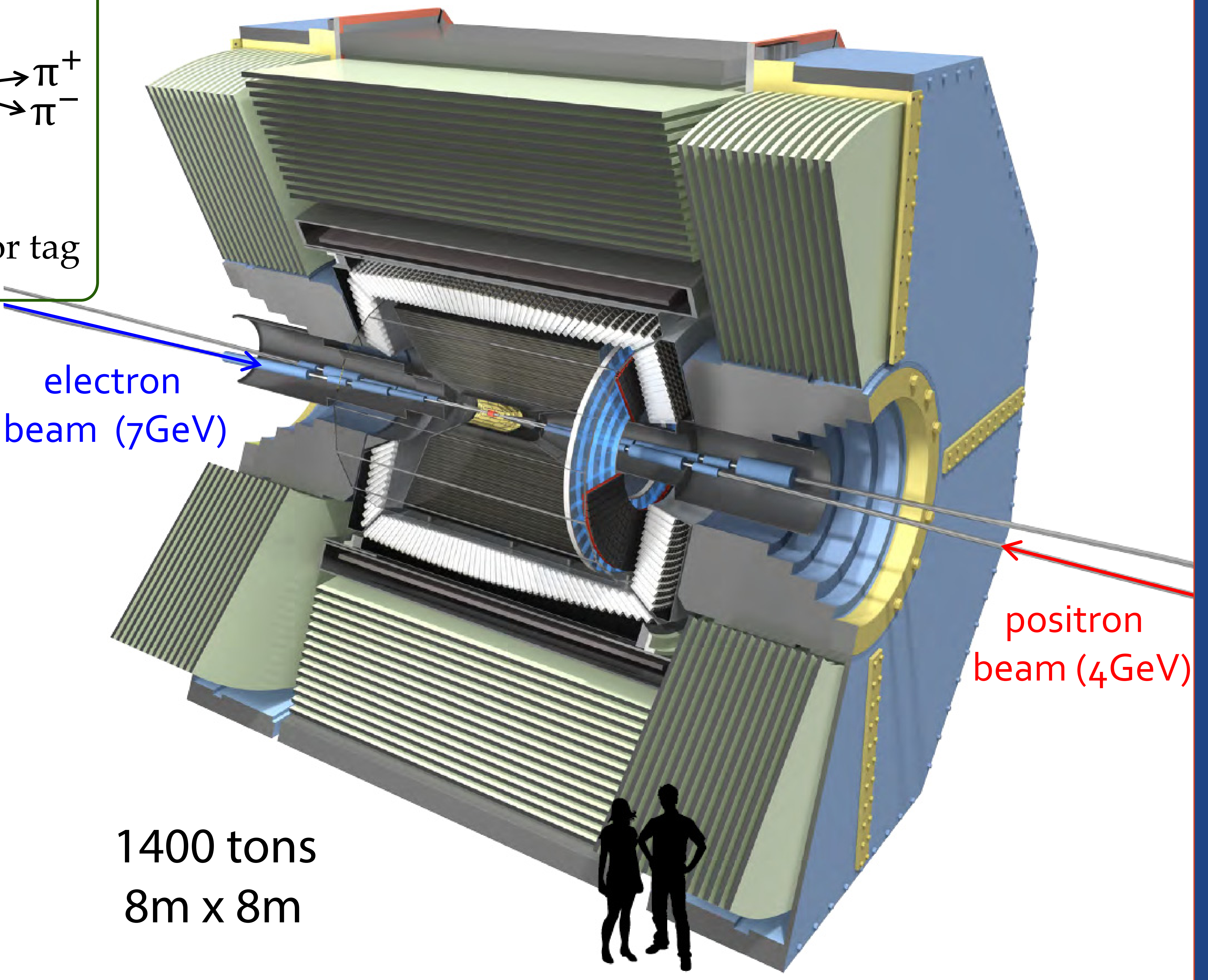
Vertex detector (VXD): two layers of pixels followed by four double-layered silicon strips

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(Tl) crystals, upgraded electronics (shaper based on digital signal processing)

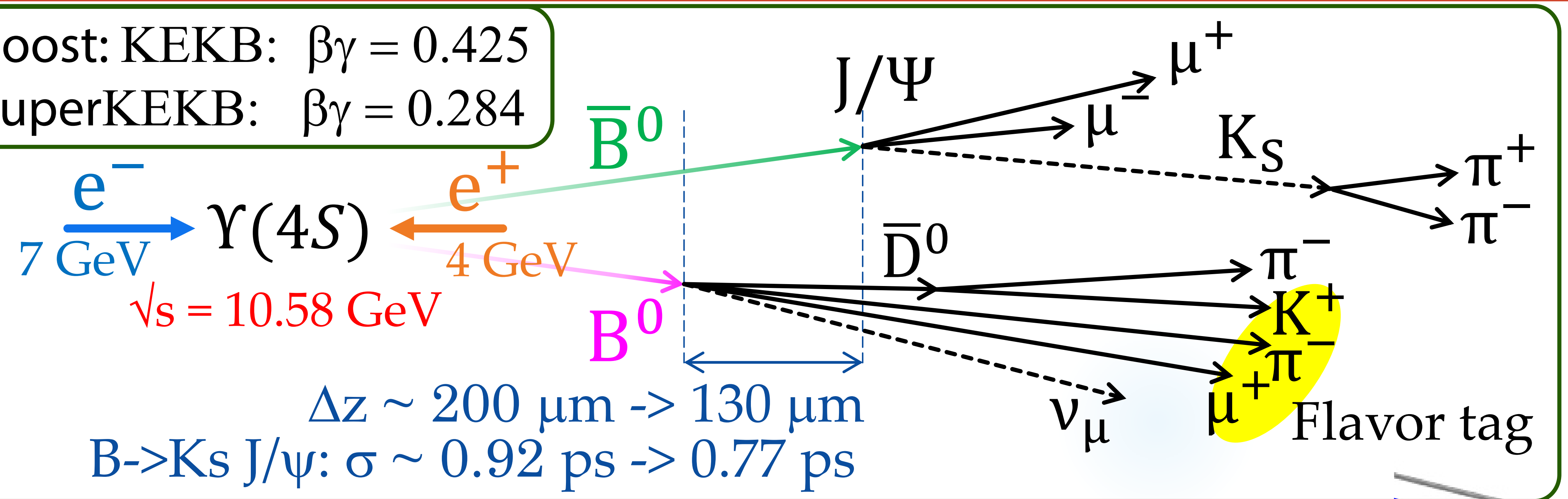
***K_L* and μ identification:** RPCs replaced by scintillators in the endcap and two inner barrel layers, new electronics, triggering



1400 tons
8m x 8m

Smaller Boost? Improved Detector? The Implications?

Boost: KEKB: $\beta\gamma = 0.425$
SuperKEKB: $\beta\gamma = 0.284$



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(Tl) 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

VXD: beam-related background tolerant

Improved impact parameter resolution

Better z vertex resolution

Approx. 30% better inv. mass resolution

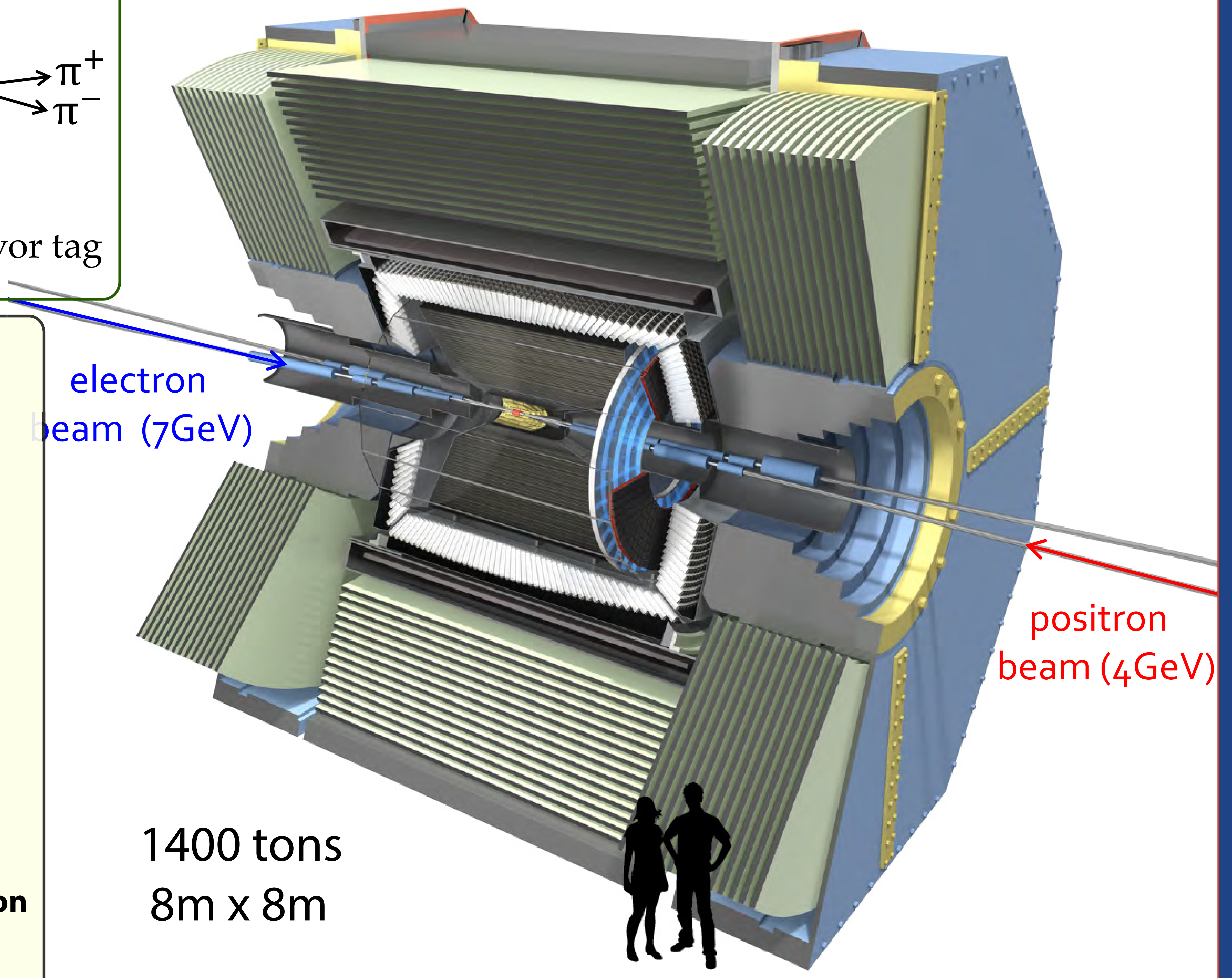
~30% increase in K_S efficiency

Improved K / π separation

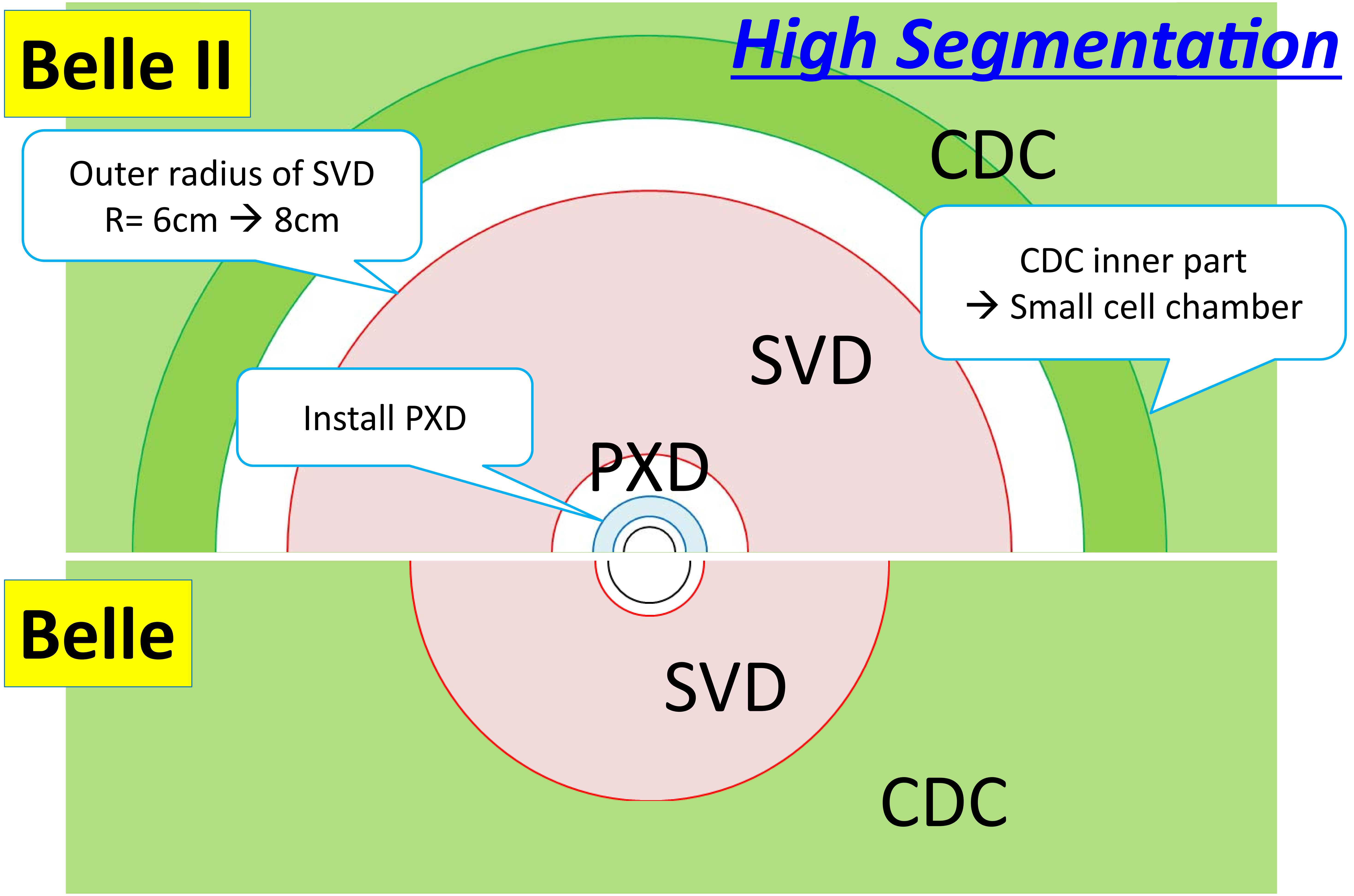
Decreased π fake rate by the factor of ~2.5

Improved slow (~100MeV/c) π reconstruction

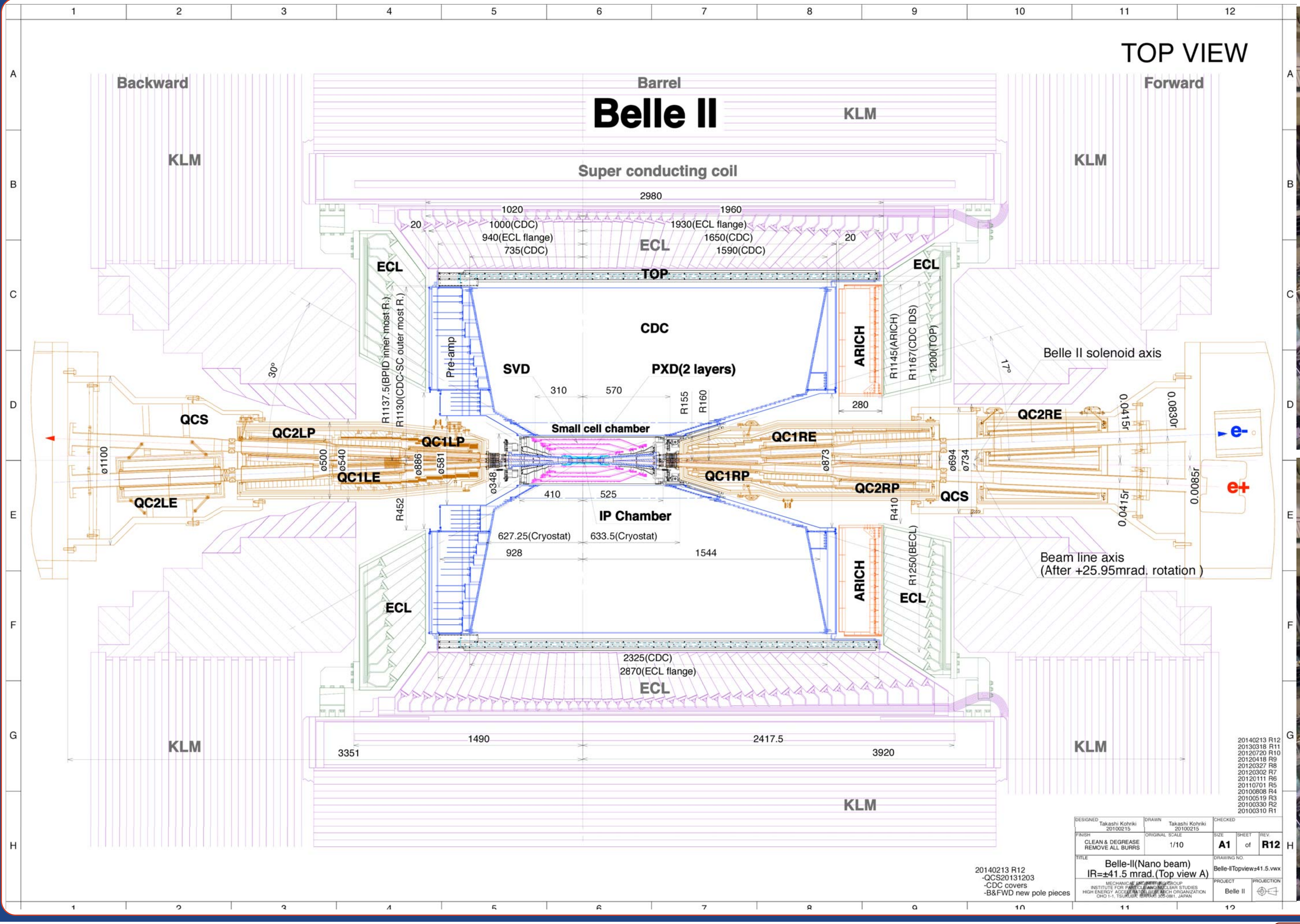
Improved π^0 reconstruction

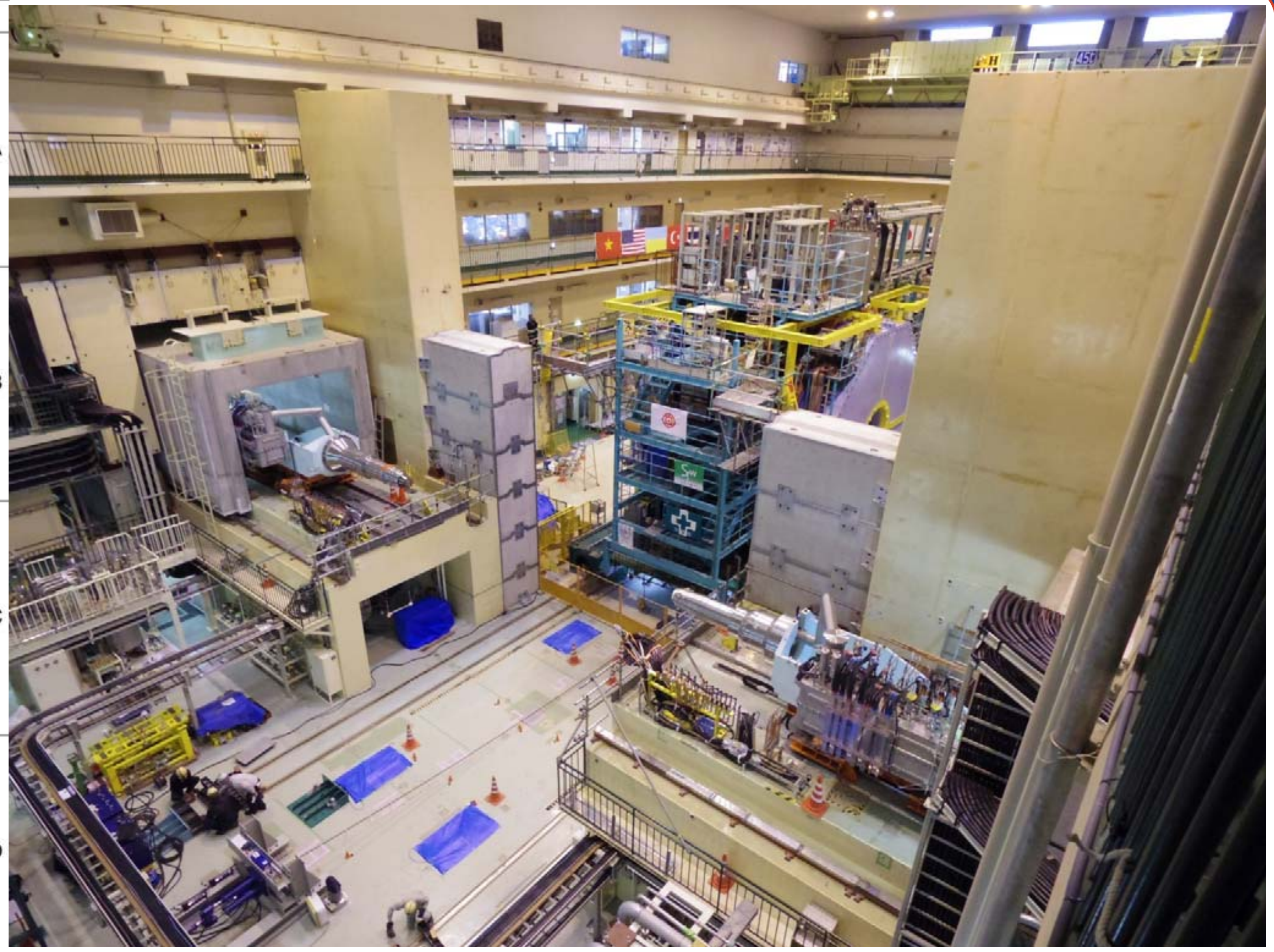


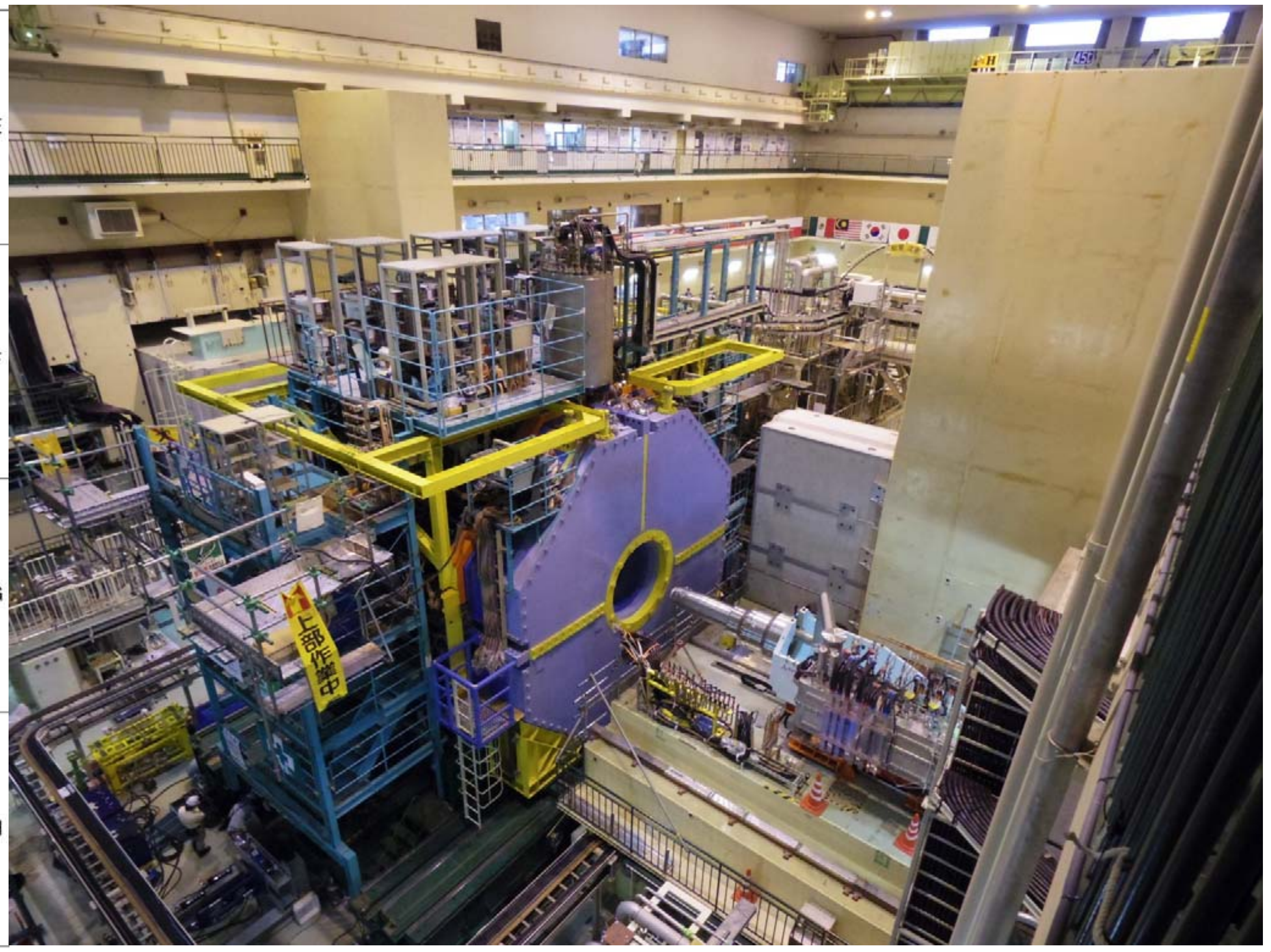
Belle vs Belle II Made Simple



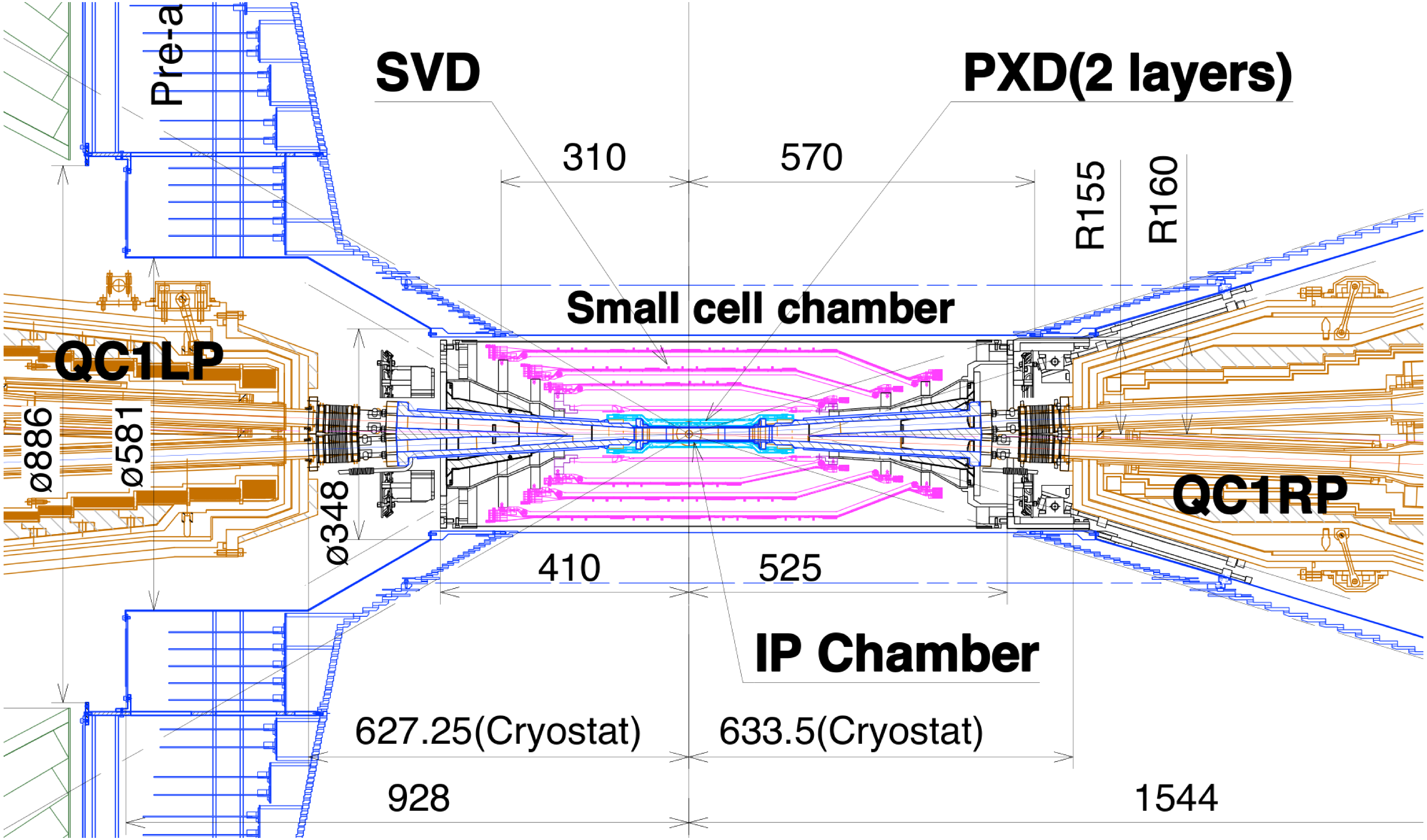
First data are already being recorded! But she is not done yet!







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

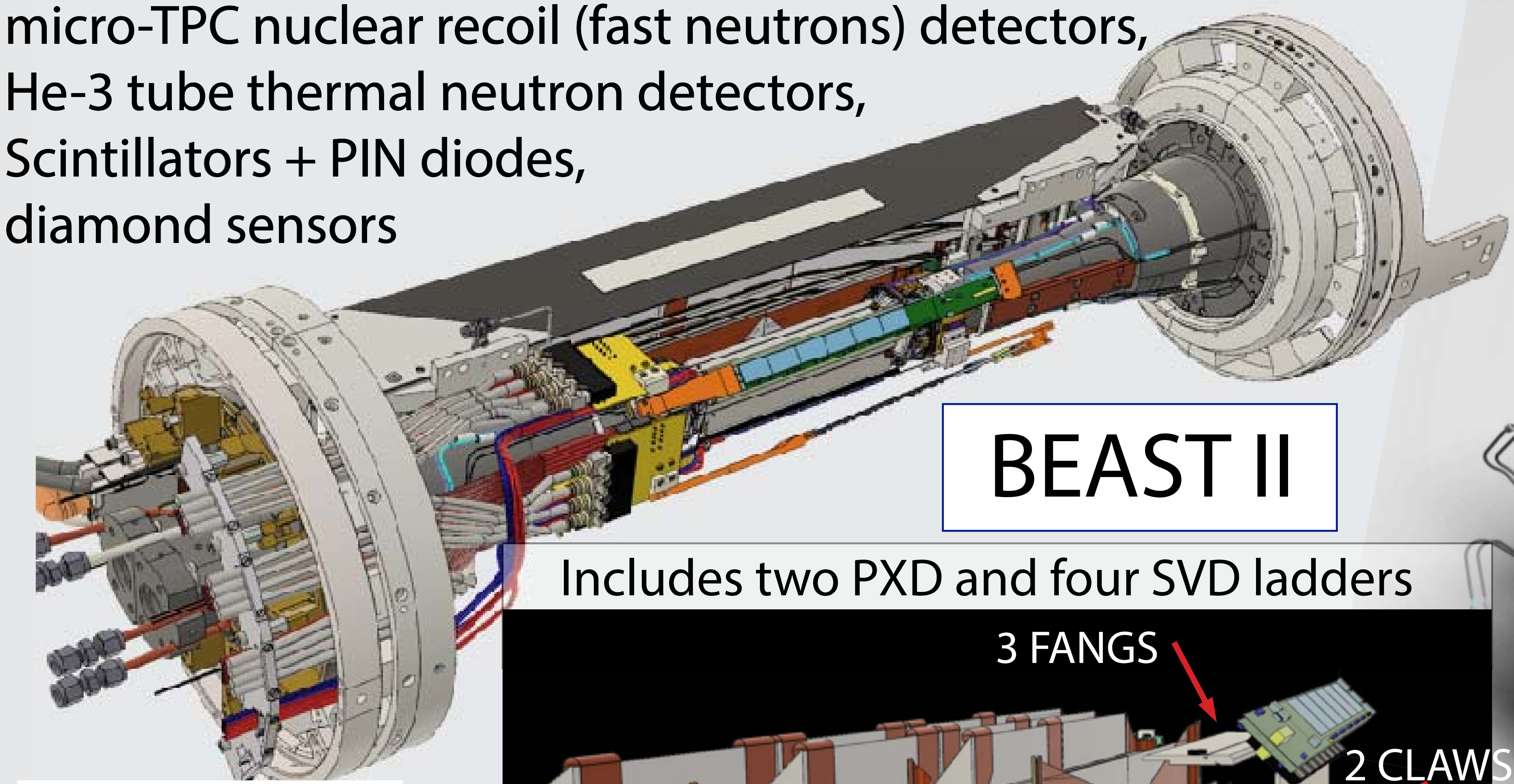


BEAST II (Phase 2 Commissioning Detector inside Belle II)

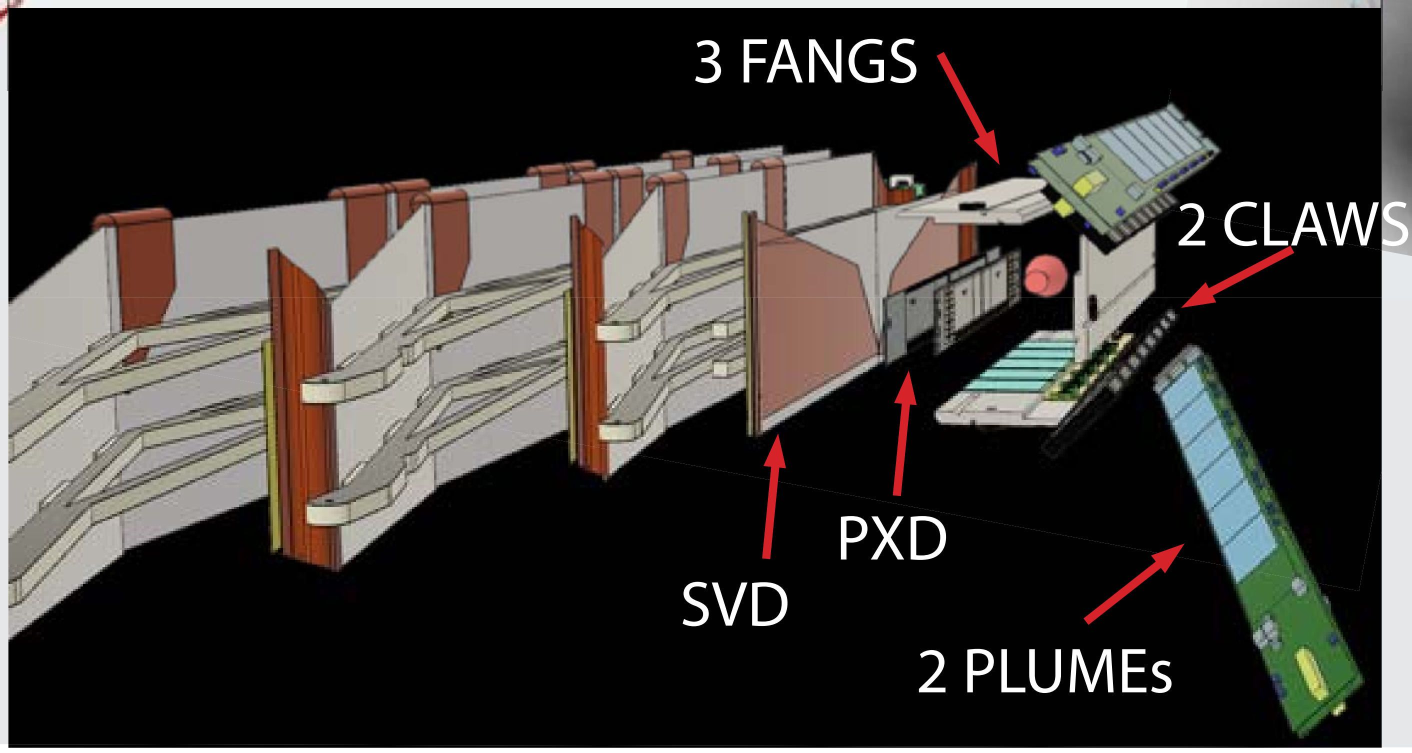
A system of radiation detectors: beam background monitors, first responders

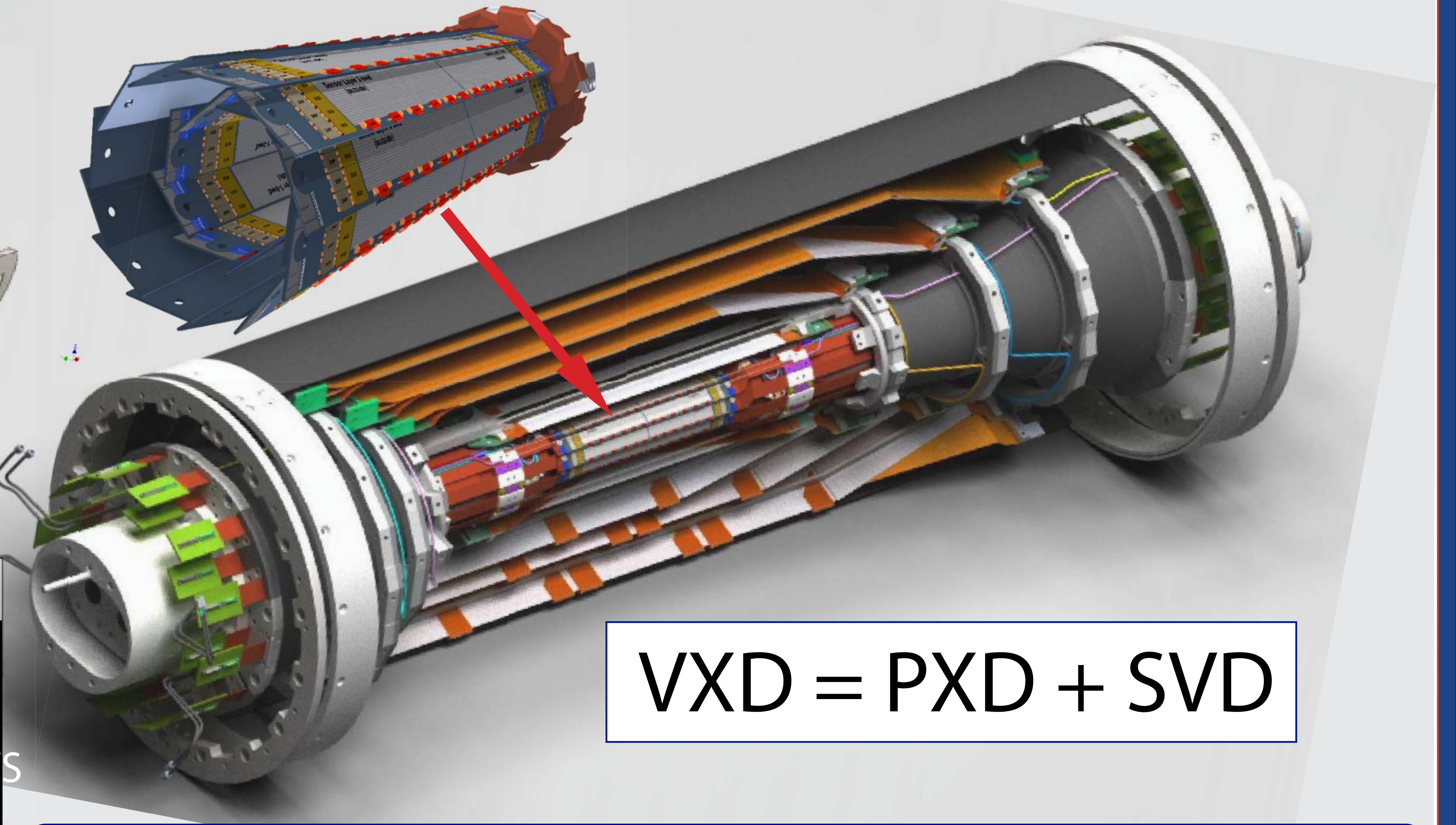
FANGS: "LHC/ATLAS style" silicon pixel sensors,
CLAWS: scintillator tiles read-out by silicon PMTs,
PLUME: "ILC style" MIMOSA silicon pixel sensors,
micro-TPC nuclear recoil (fast neutrons) detectors,
He-3 tube thermal neutron detectors,
Scintillators + PIN diodes,
diamond sensors

Now → End of 2018



Includes two PXD and four SVD ladders

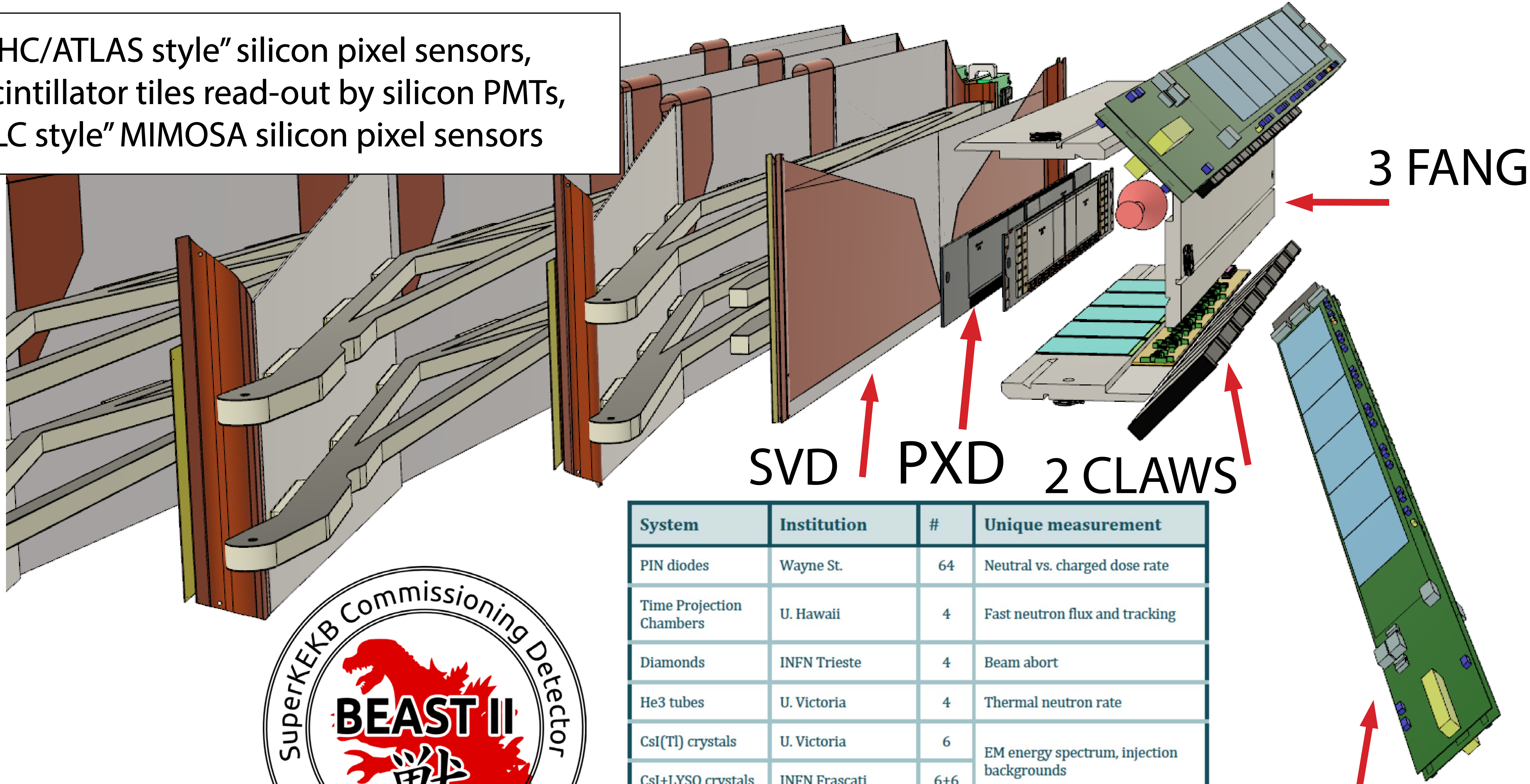




Understanding beam-related backgrounds (and physics backgrounds!) is of great importance
There is only that much of radiation hardness...

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

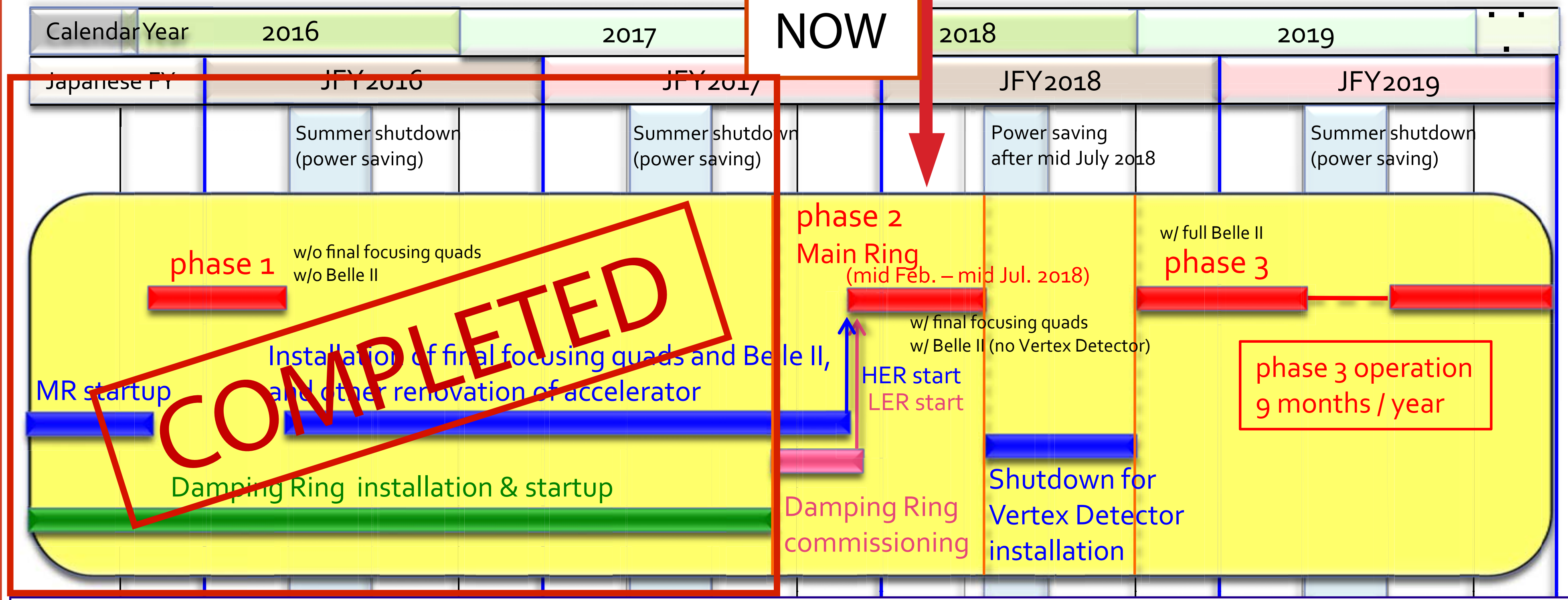
on the first try on March 19, 2018:

more than 20 turns with RF off!

All BEAST detectors (but PIN diodes), i.e.

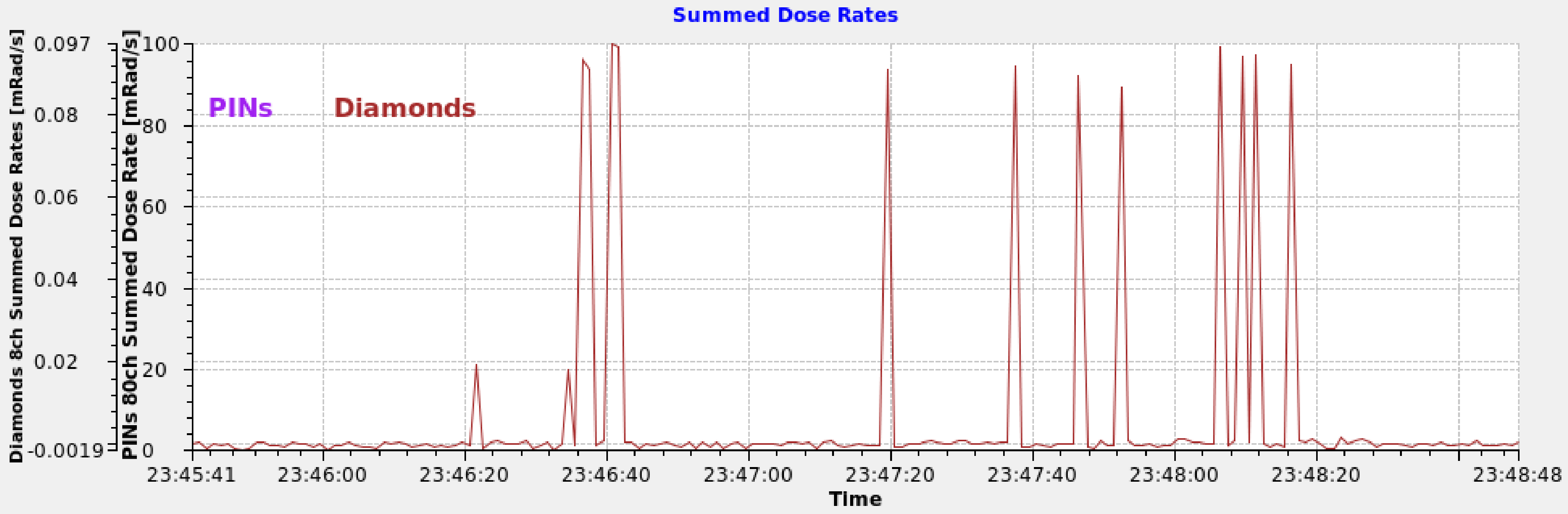
diamonds, FANGS, CLAWS, PLUMEs, He3

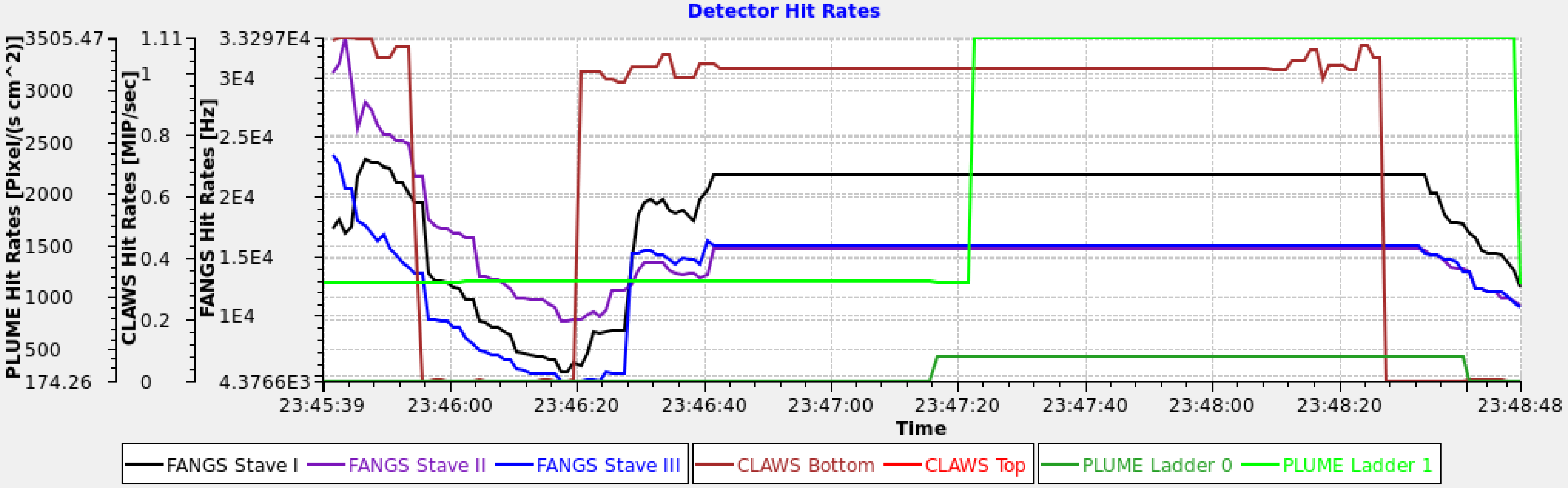
and TPCs have seen the first backgrounds

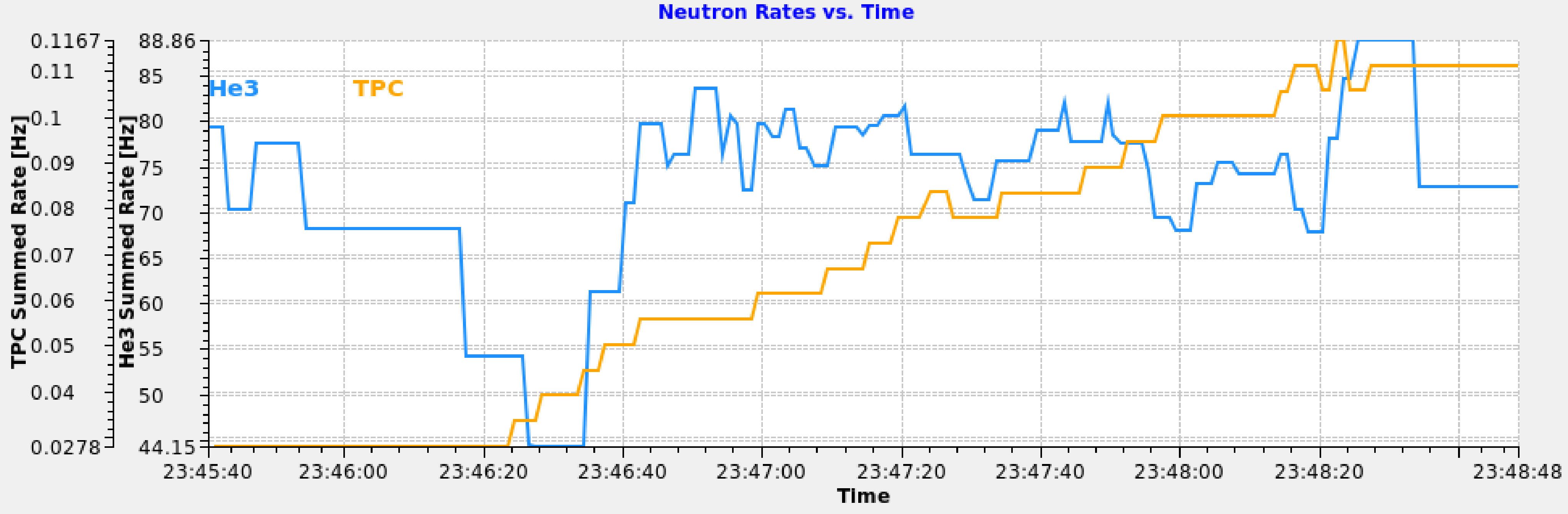


Verification of nano-beam scheme (target $L > 10^{34}\,cm^{-2}s^{-1}$)

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]

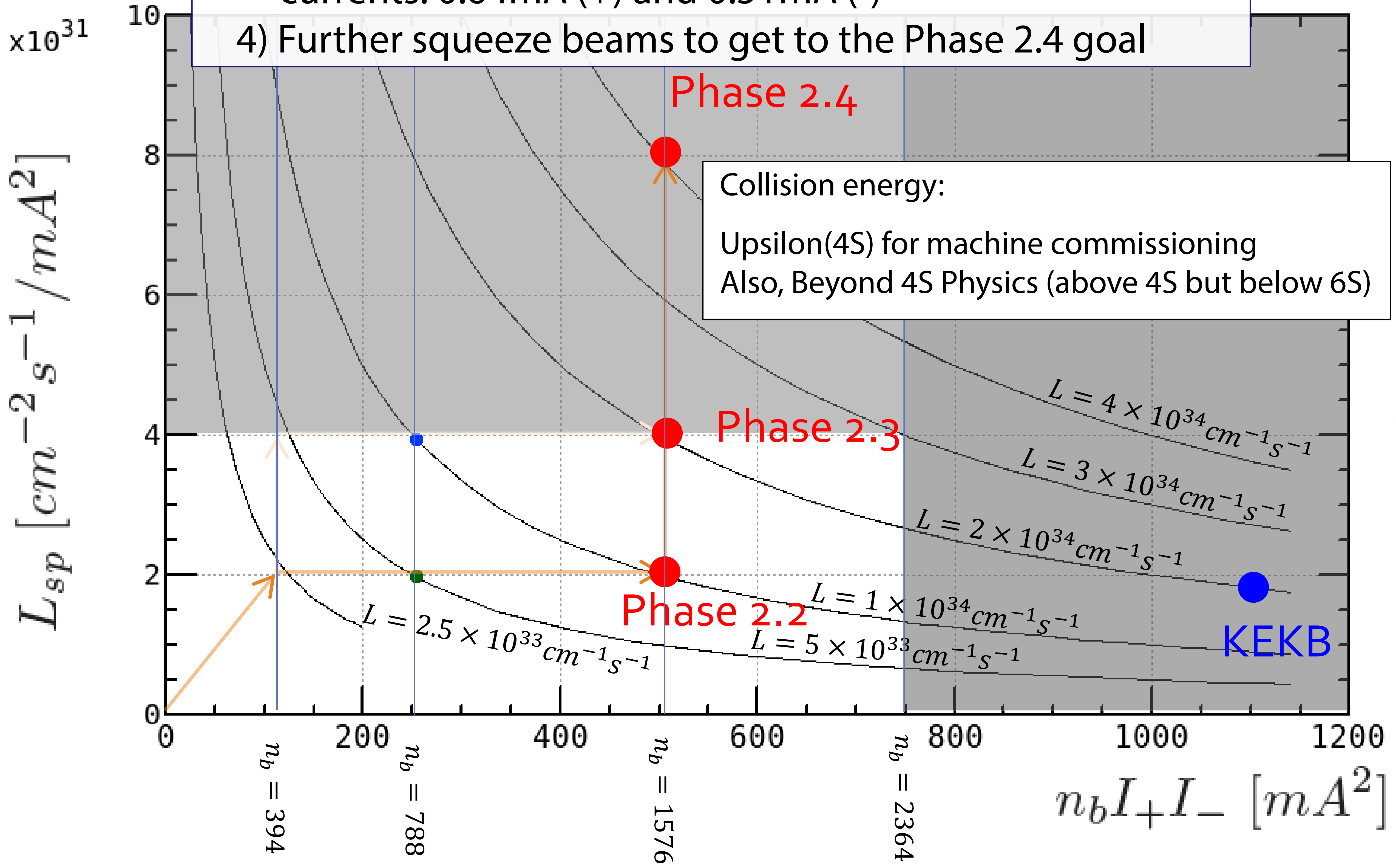
https://arxiv.org/abs/1802.01366

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 luminosity 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)

SuperKEKB — 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

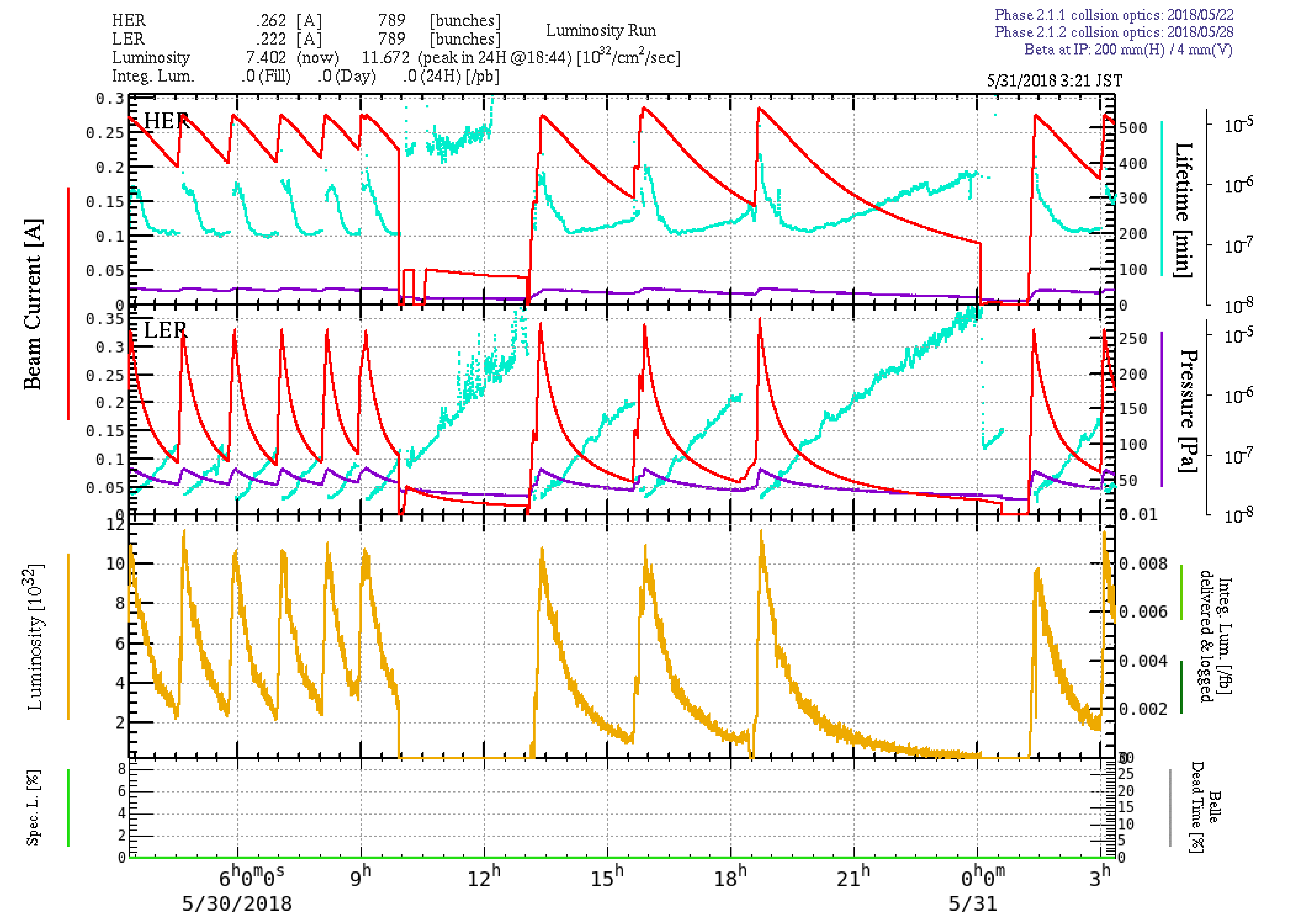
Dedicated beam background studies during phase 2

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

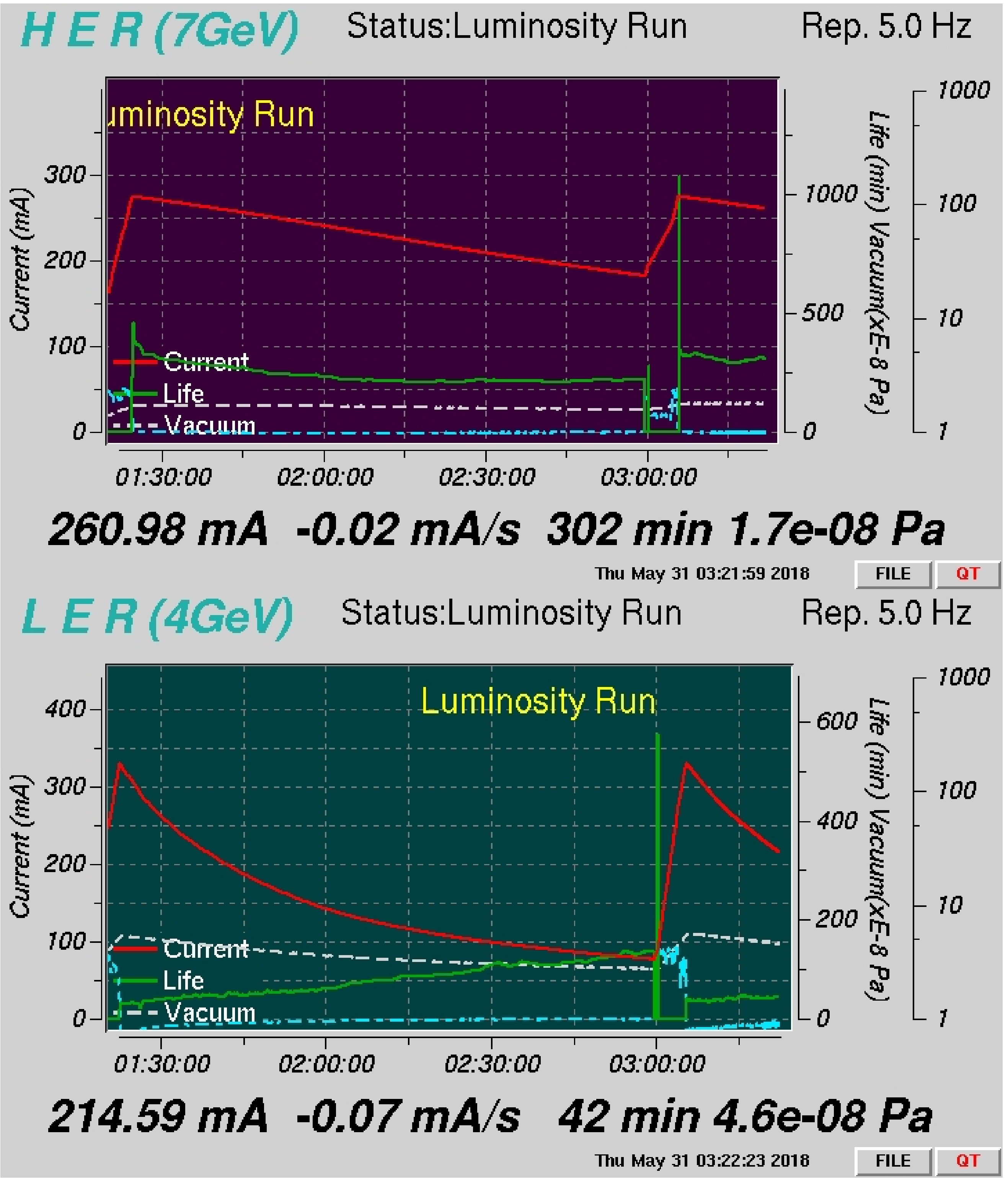
Preliminary

Welcome to the Machine

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



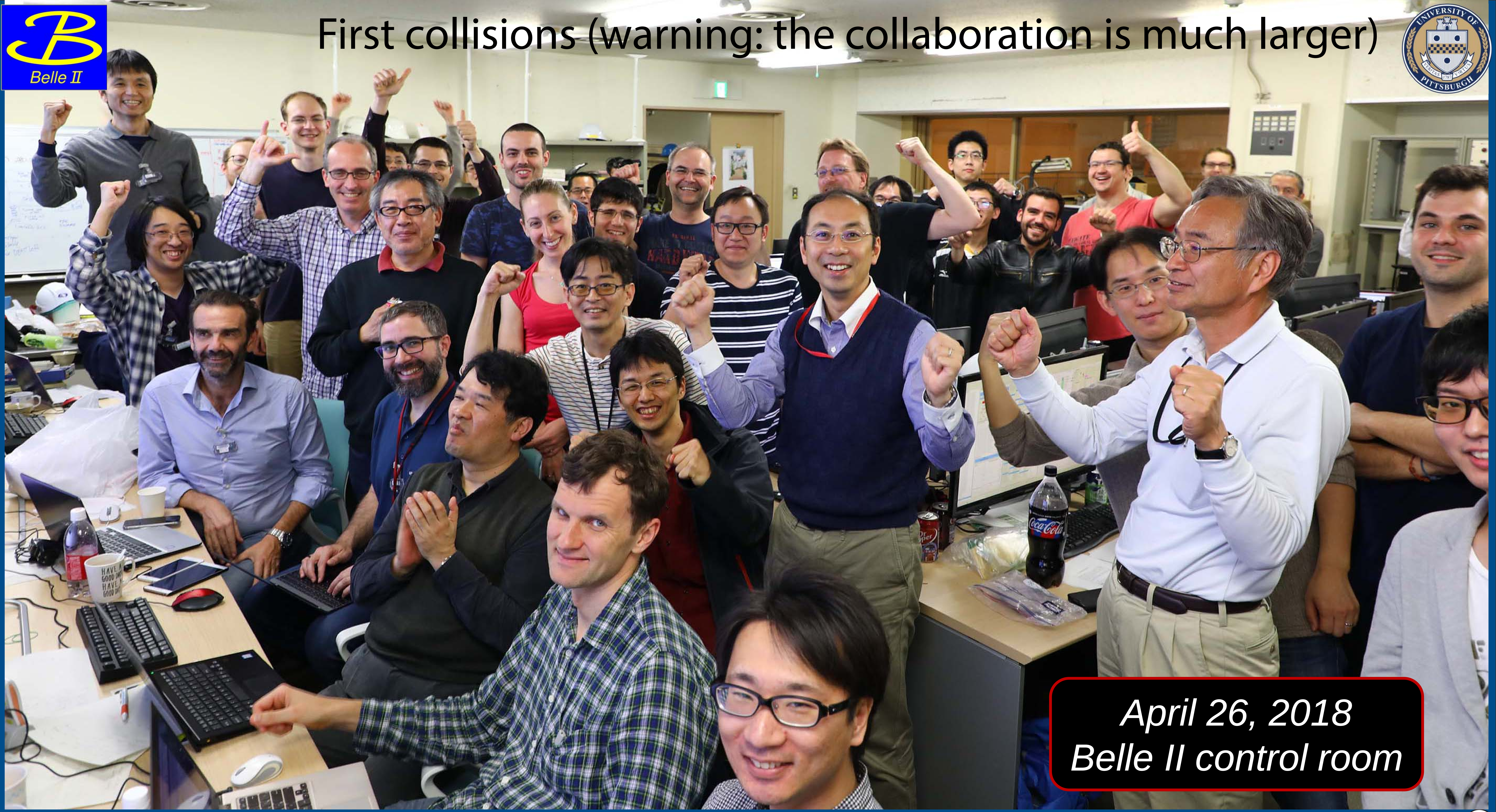
SuperKEKB 24-Hour Operation Summary



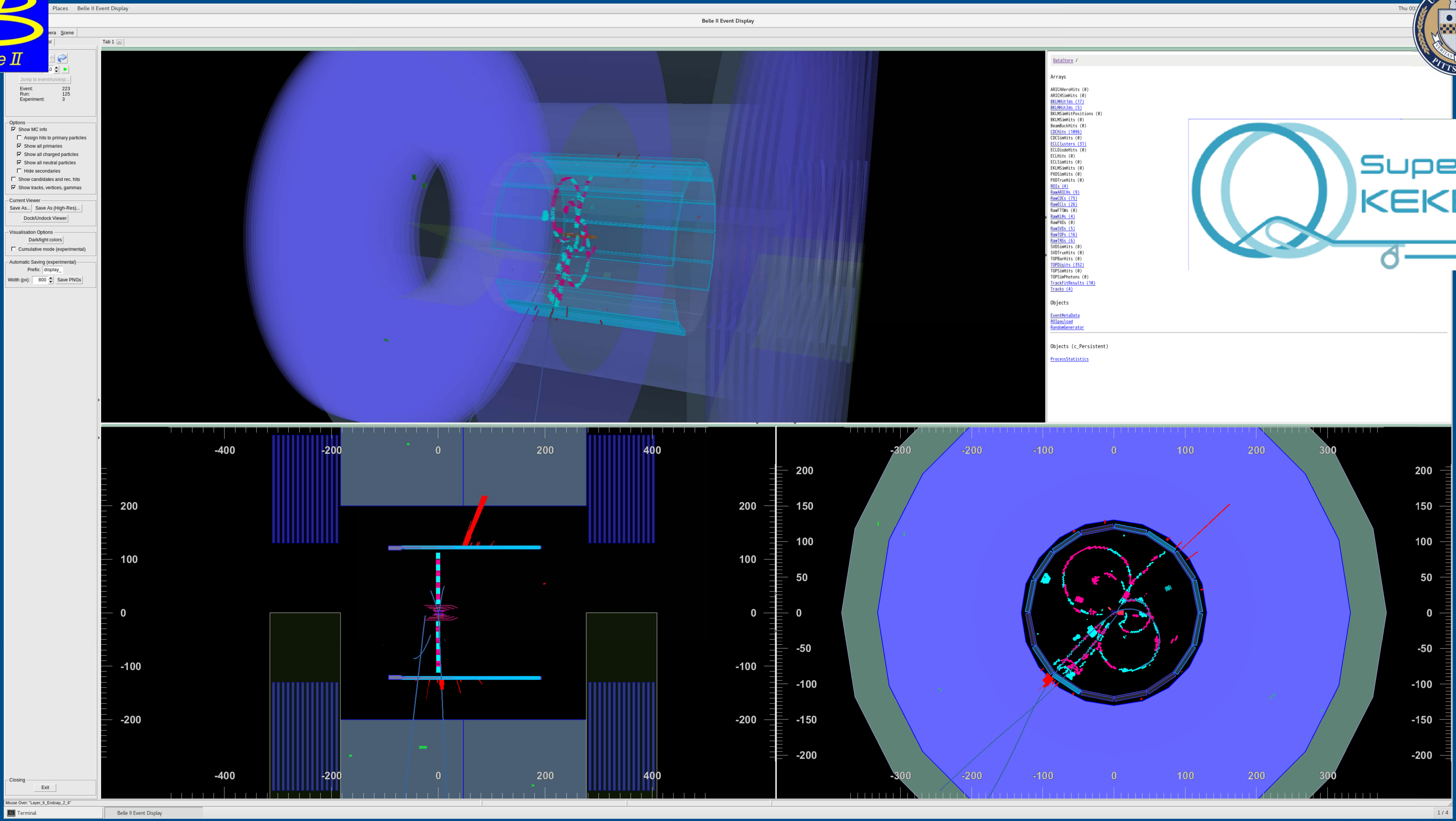
SuperKEKB 2-Hour Operation Summary

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

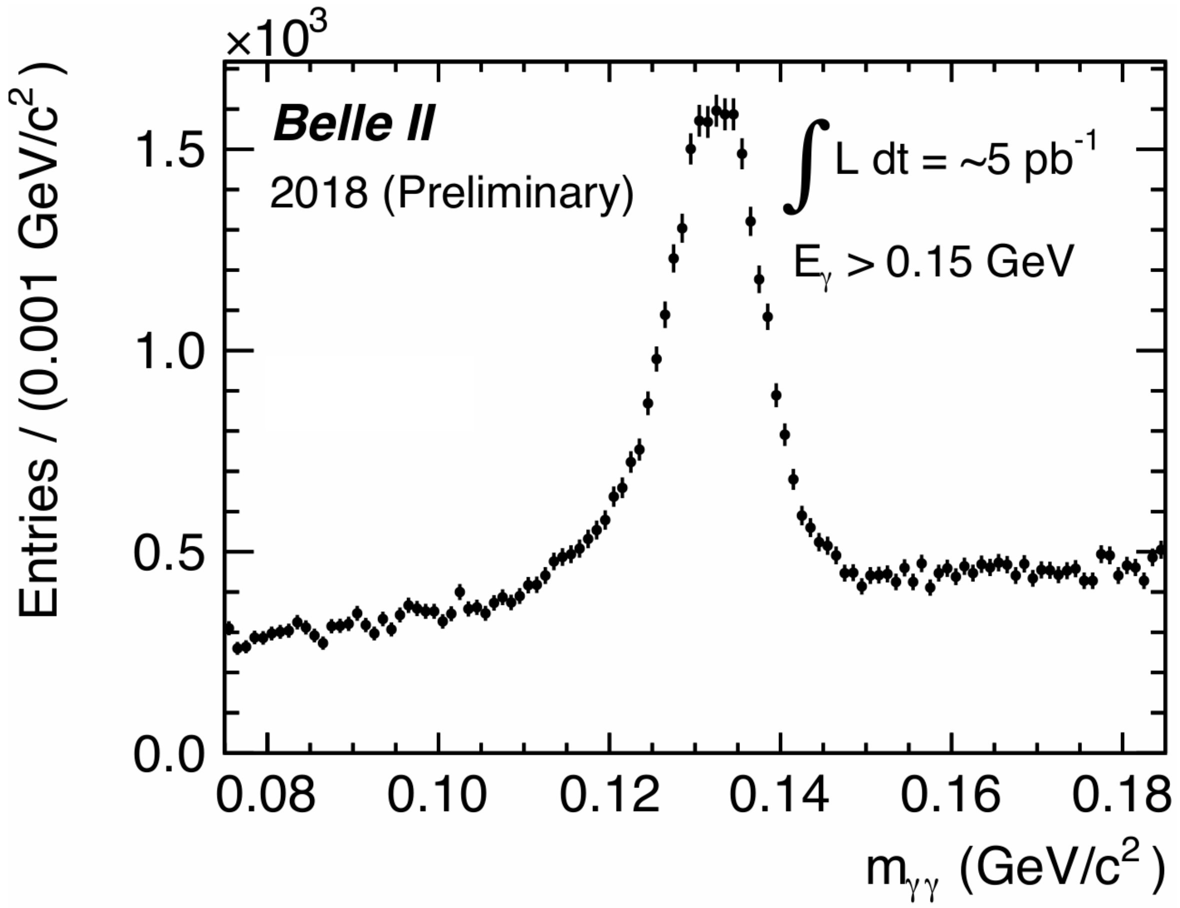
First collisions (warning: the collaboration is much larger)

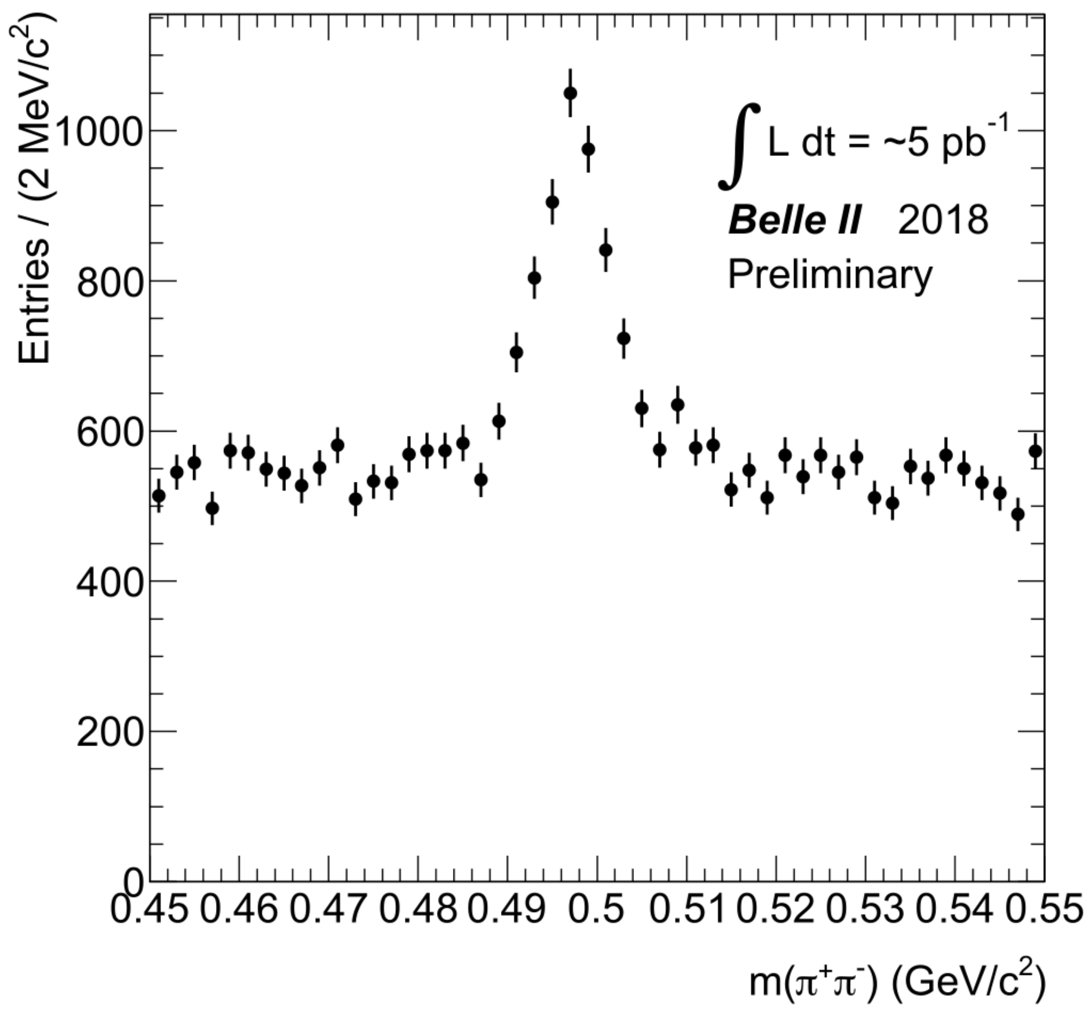


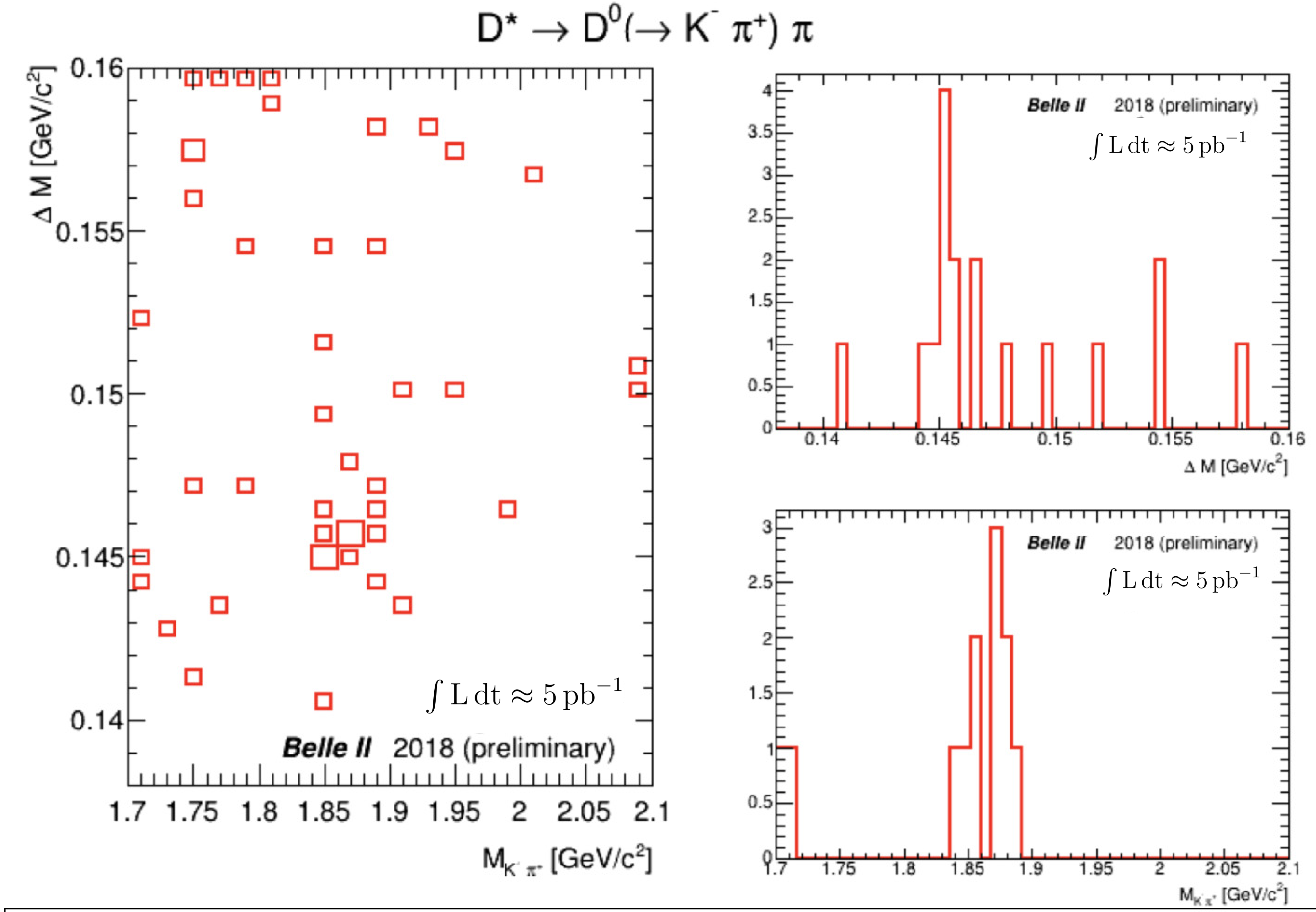
April 26, 2018
Belle II control room


Places
Belle II Event Display
Belle II Event Display
Tab 1
Event: 223
Run: 125
Experiment: 3
Options
Show MC info
Assign hits to primary particles
Show all primaries
Show all charged particles
Show all neutral particles
Hide secondaries
Show candidates and rec. hits
Show tracks, vertices, gammas
Current Viewer
Save As...
Save As (High-Res)...
Dock/Undock Viewer
Visualisation Options
Dark/light colors
Cumulative mode (experimental)
Automatic Saving (experimental)
Prefix: display_
Width (px): 800
Save PNGs
Closing
Exit
DataStore /
Arrays
Objects
Objects (c_Persistent)
ProcessStatistics
Terminal
Belle II Event Display

Some Recent Distributions from Belle II Commissioning Data







https://docs.belle2.org/collection/Belle%20II%20Notes%20%3A%20Plots?ln=en

Conclusions, References and Acknowledgements

SuperKEKB+Belle II commissioning continues

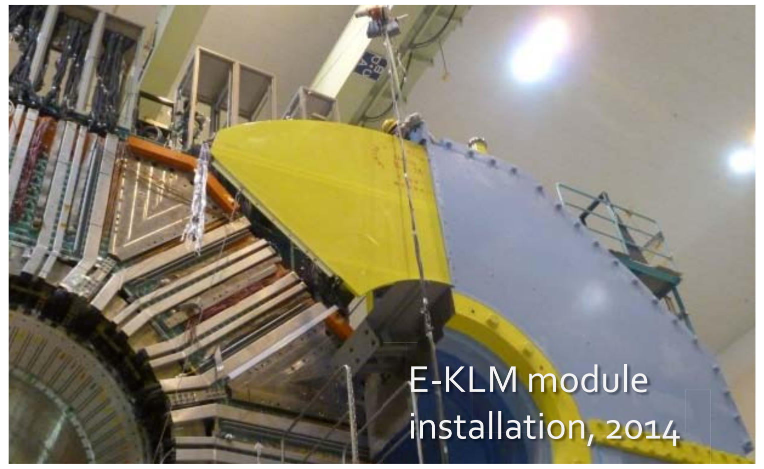
BEAST II is roaring

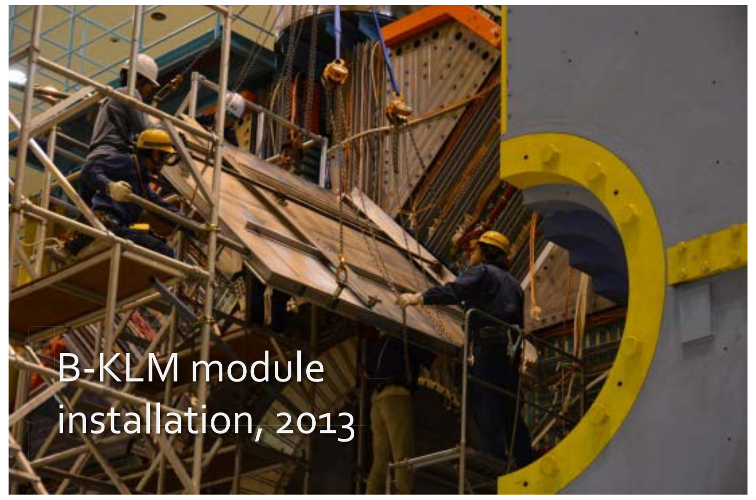
Belle II is taking commissioning data!

VXD is coming (starting on July 17, 2018)

Physics results will start coming soon

The next decade will be very exciting!


E-KLM module installation, 2014


B-KLM module installation, 2013


TOP module installation 2016 Feb-May


B field measurement by CERN mapper 2016 June-July


CDC installation 2016 Oct-Dec

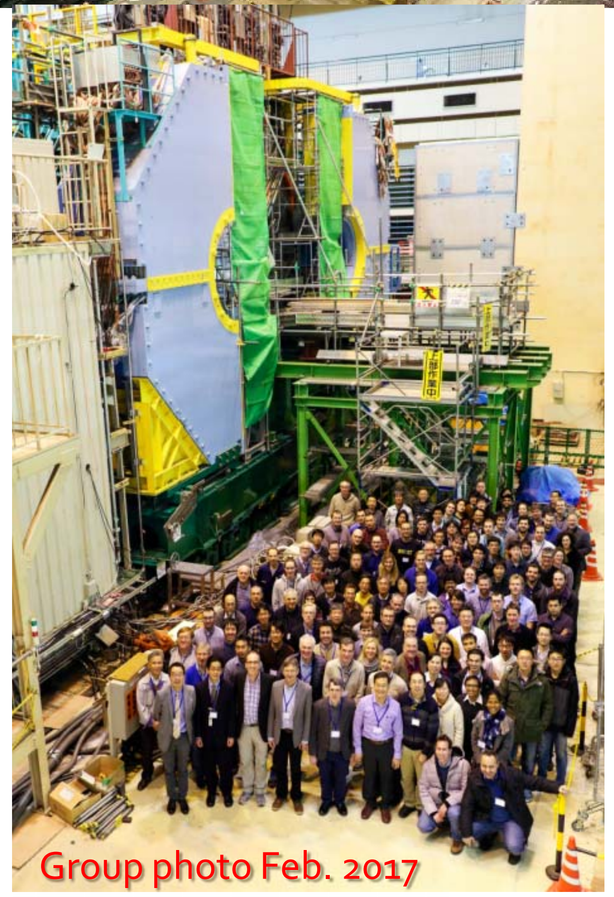

BWD end-cap installation 2017 Jan-Feb

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
https://kds.kek.jp/indico/event/27330/


Group photo Apr. 2017


Group photo Feb. 2017

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

I would like to thank them all: SuperKEKB, Belle II, theoretical community involved in B2TiP, everyone