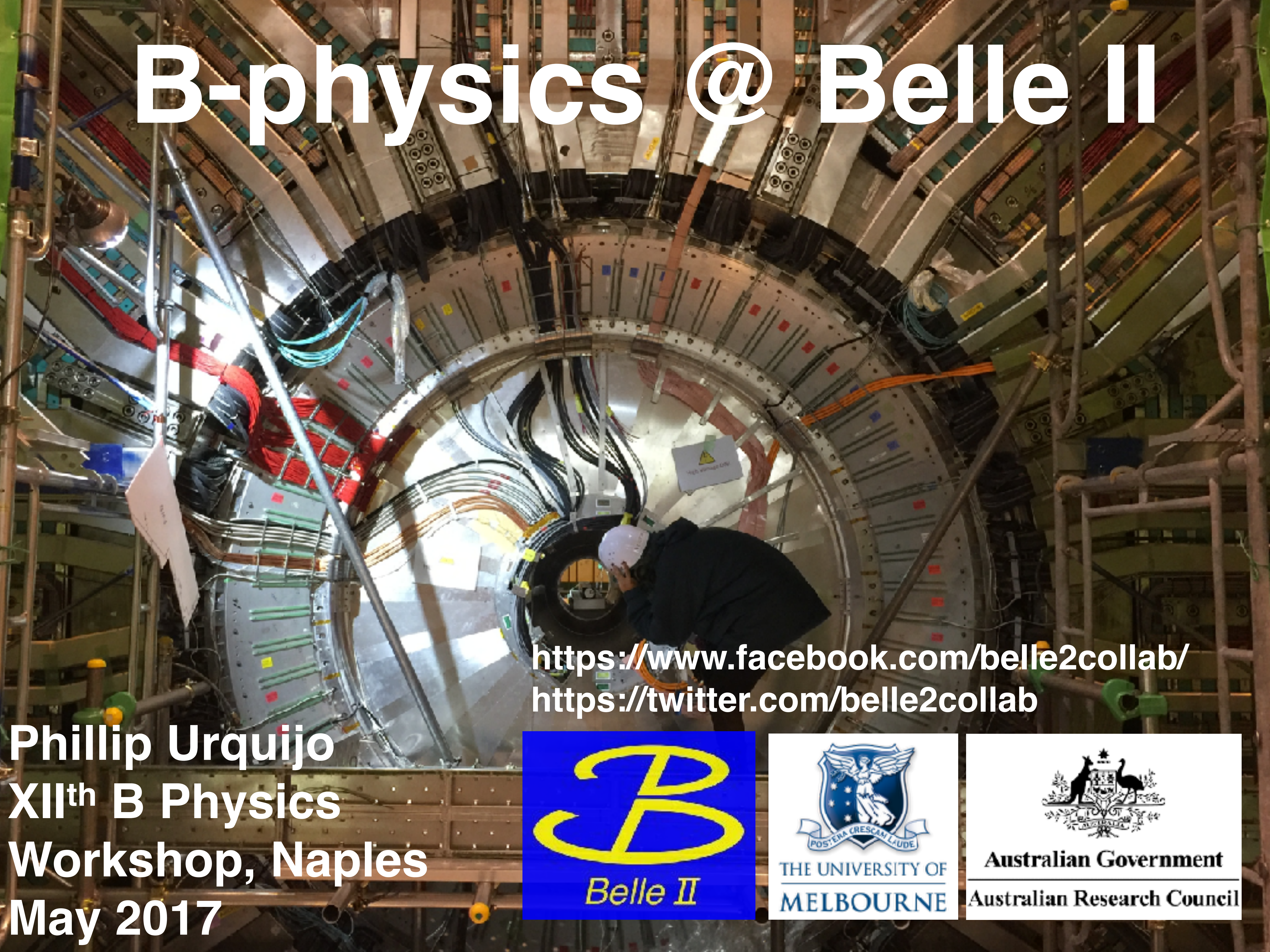


B-physics @ Belle II

https://www.facebook.com/belle2collab/
https://twitter.com/belle2collab

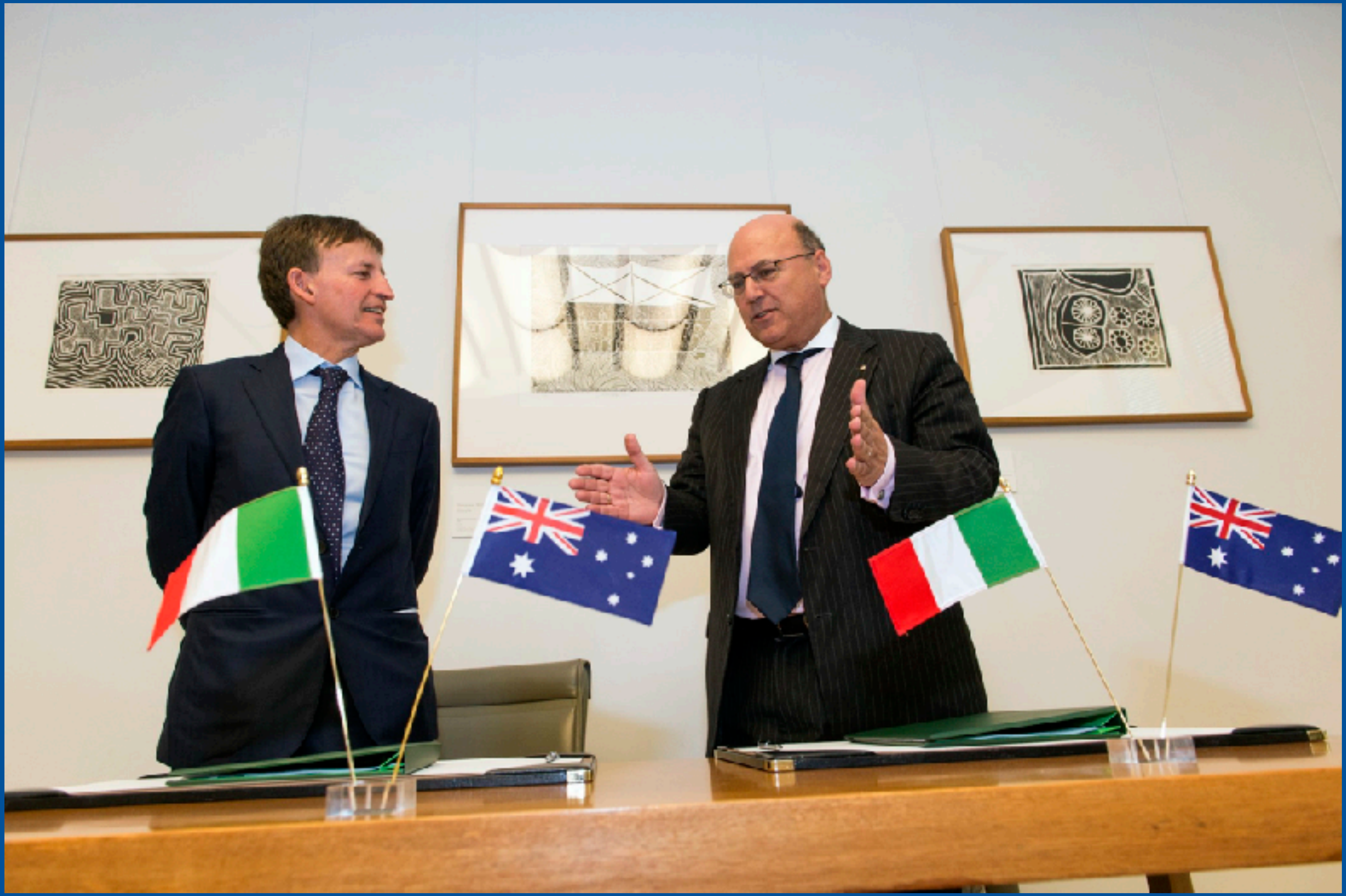
Phillip Urquijo

XIIth B Physics Workshop, Naples
May 2017

Belle II

THE UNIVERSITY OF MELBOURNE

Australian Government
Australian Research Council



Senator Arthur Sinodinos AO, Ambassador H. E Pier Francesco Zazo

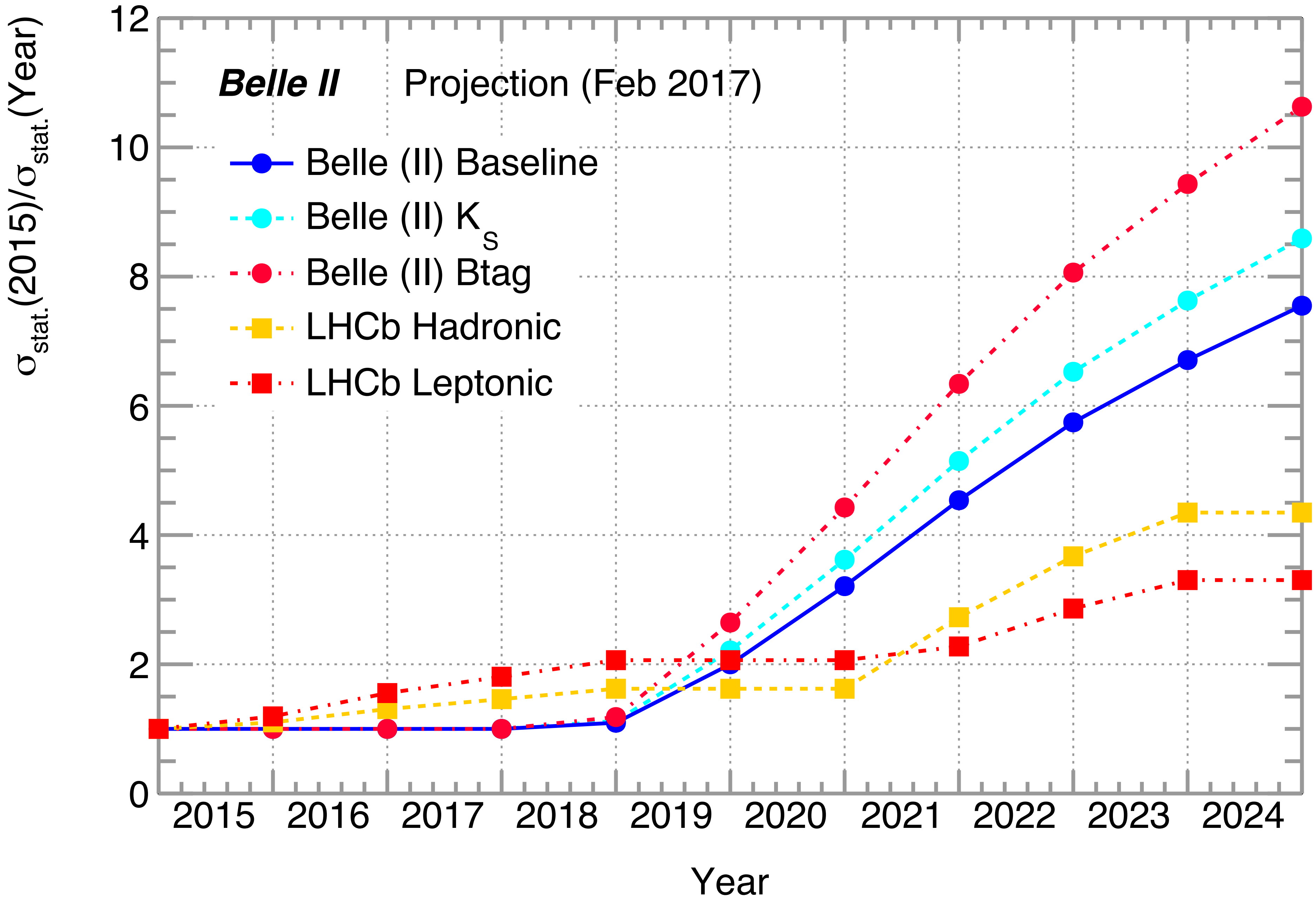
Australia strengthens science and innovation ties with Italy, 22 May 2017

Australia and Italy have signed an agreement that will further strengthen scientific, technological and innovation co-operation between both nations.

Present: Prof. Enrico Cappellaro INAF, Prof. Antonio Masiero INFN etc.

Outline

1. **Belle II Status**
2. **Anomalies**
   $b \to sll$, $b \to c\tau\nu$
3. Time Dep. CP Violation
4. UT Precision Tests
5. Early physics in 2018



The case for new physics manifesting in Belle II

Issues (addressable at a Flavour factory)

- Baryon asymmetry in cosmology
  → New sources of CPV in quarks and charged leptons
- Quark and Lepton flavour & mass hierarchy
  → L-R symmetry, extended gauge sector, charged Higgs
- Finite neutrino masses
  → Tau LFV.
- 19 free parameters
  → Extensions of SM relate some, (GUTs)

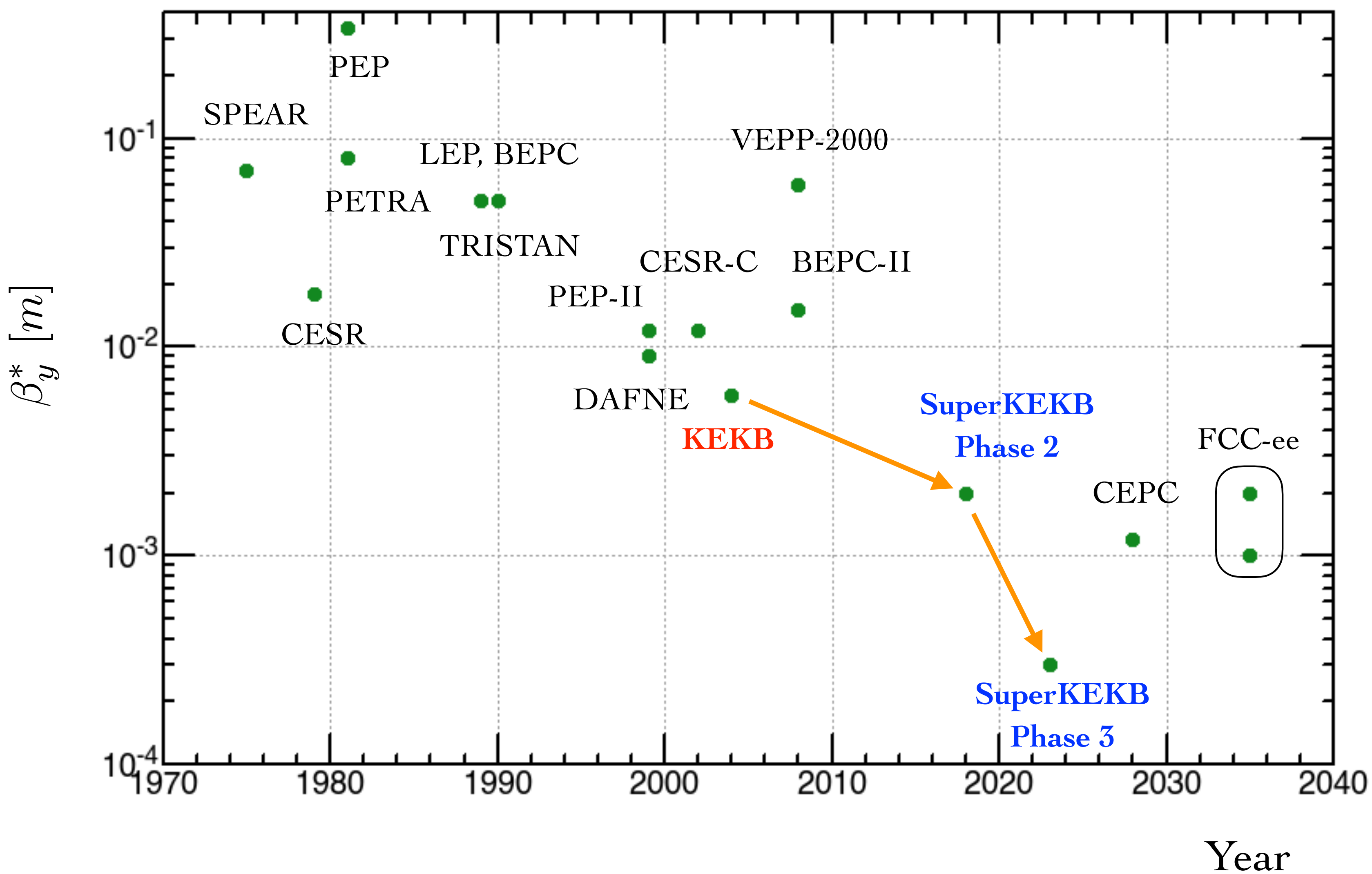
- Puzzling nature of exotic “new” QCD states.
- The hidden universe (dark matter)

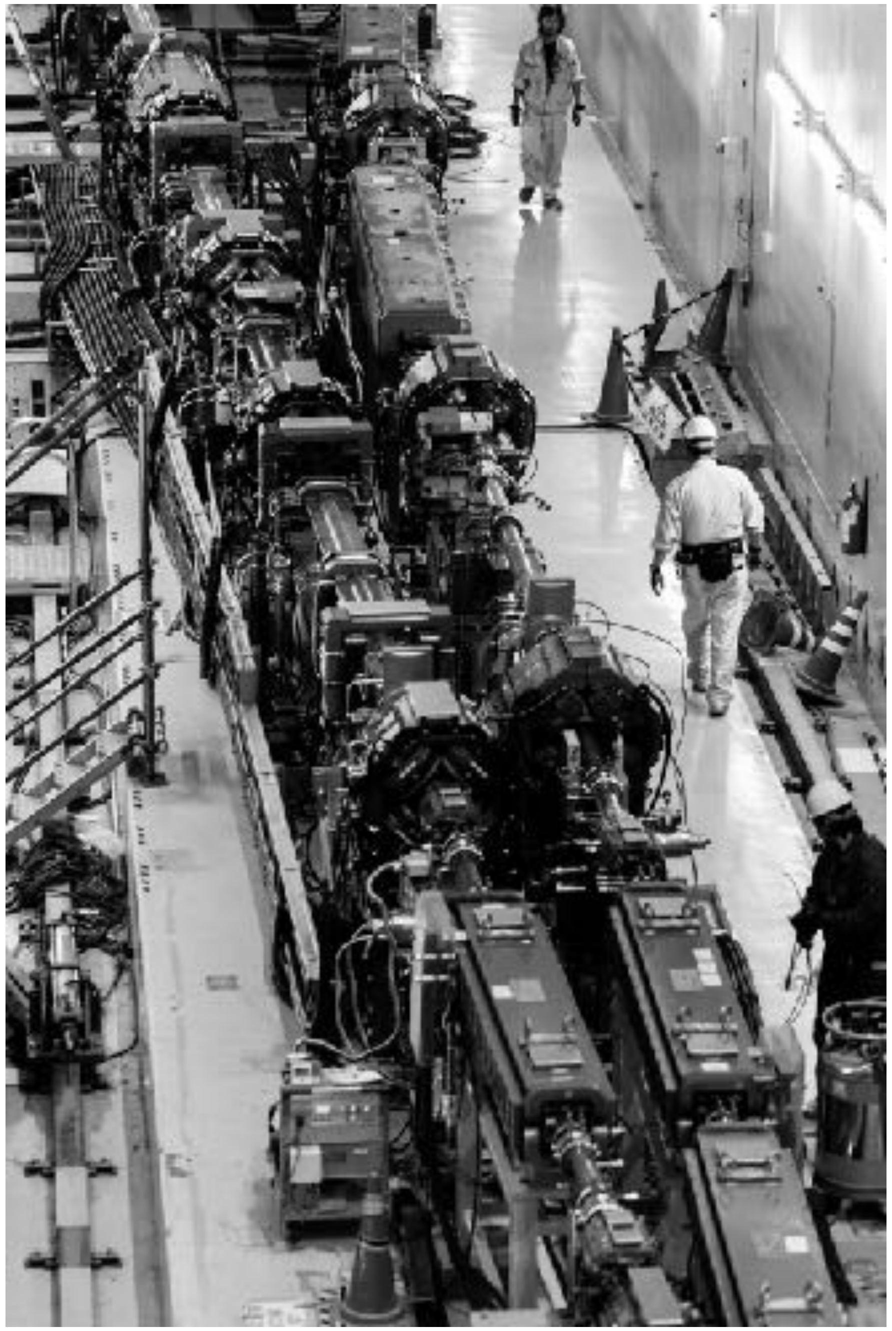
B-physics @ Belle II

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

Accelerator & Detector status

SuperKEKB





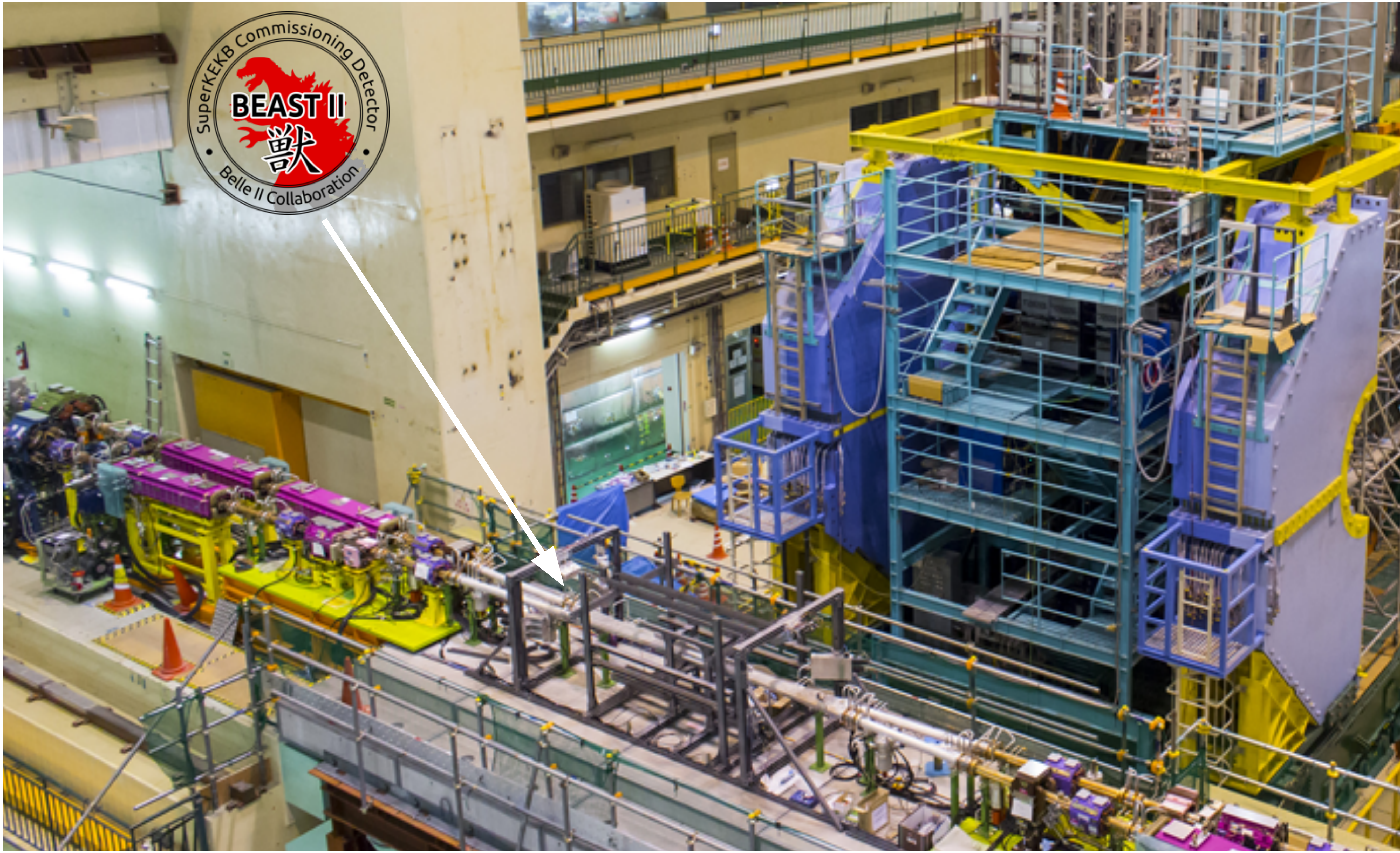
$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \, \zeta_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Lorentz factor; beam current; beam-beam parameter; beam size aspect ratio; vertical β function; geometric factors

- Compared to KEKB
  - 20x smaller vertical beam size
  - 2x current

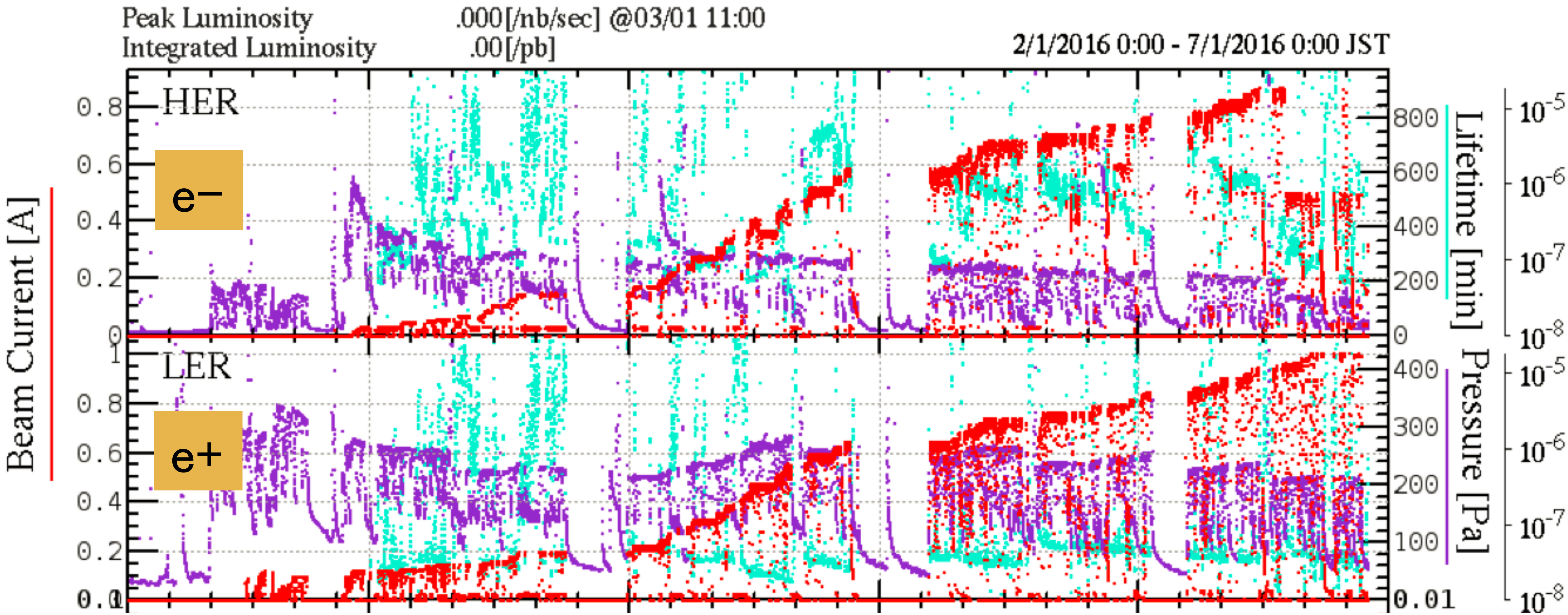
7

BEAST II, Phase I commissioning



First operation of SuperKEKB (4 GeV e+'s & 7 GeV e-'s)

Feb 16 2016 Start



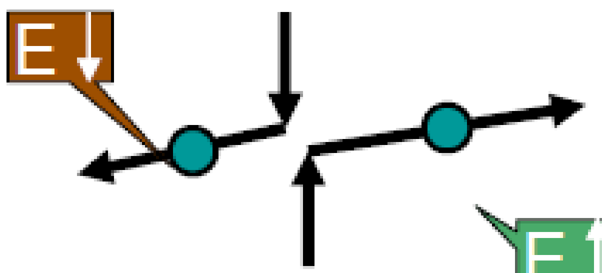
Red: total beam current
Purple: vacuum pressure

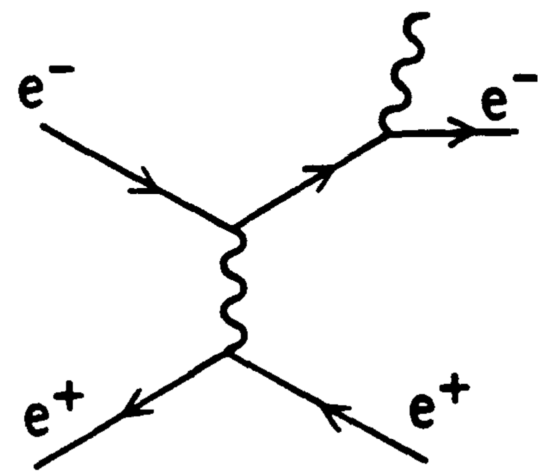
LER: 1010 mA, HER 870 mA

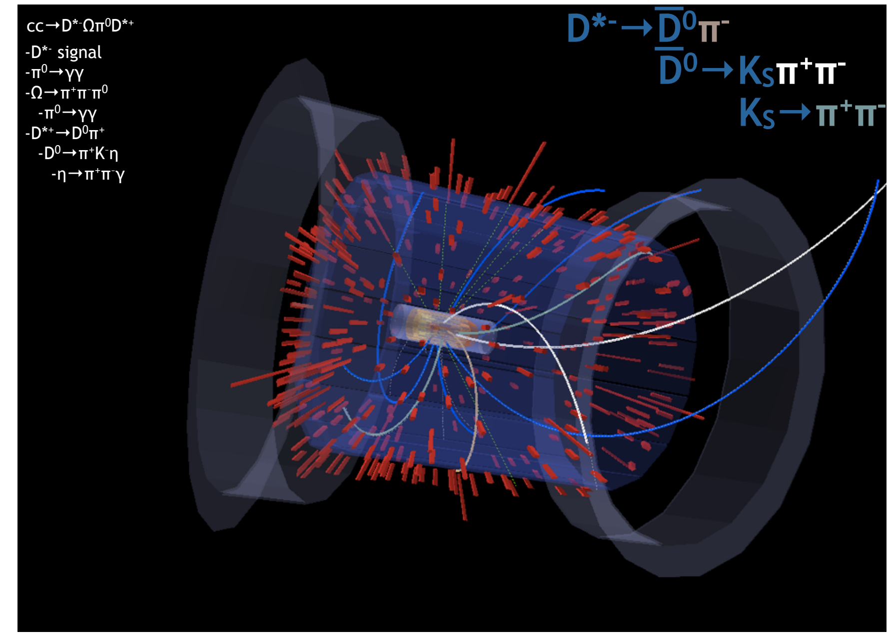
5 Months operation

Beam background (Simulation)

- Increases occupancy in inner Si layers - can degrade tracking.
- Increases off-time energy deposition in the calorimeter.







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

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

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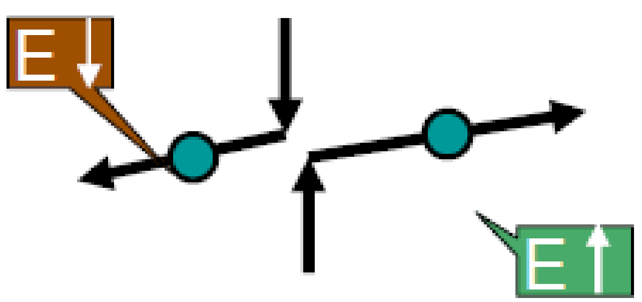

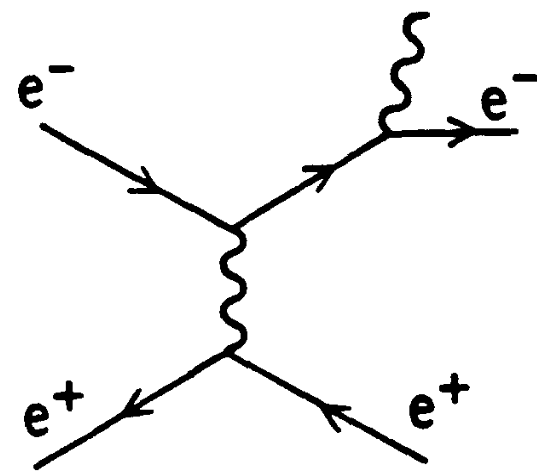

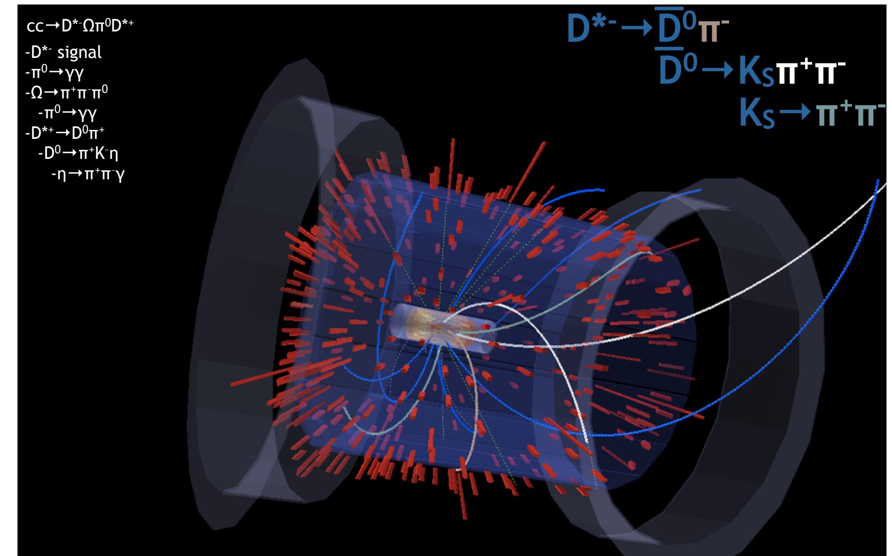

Figure does not include ECL timing or energy threshold requirements

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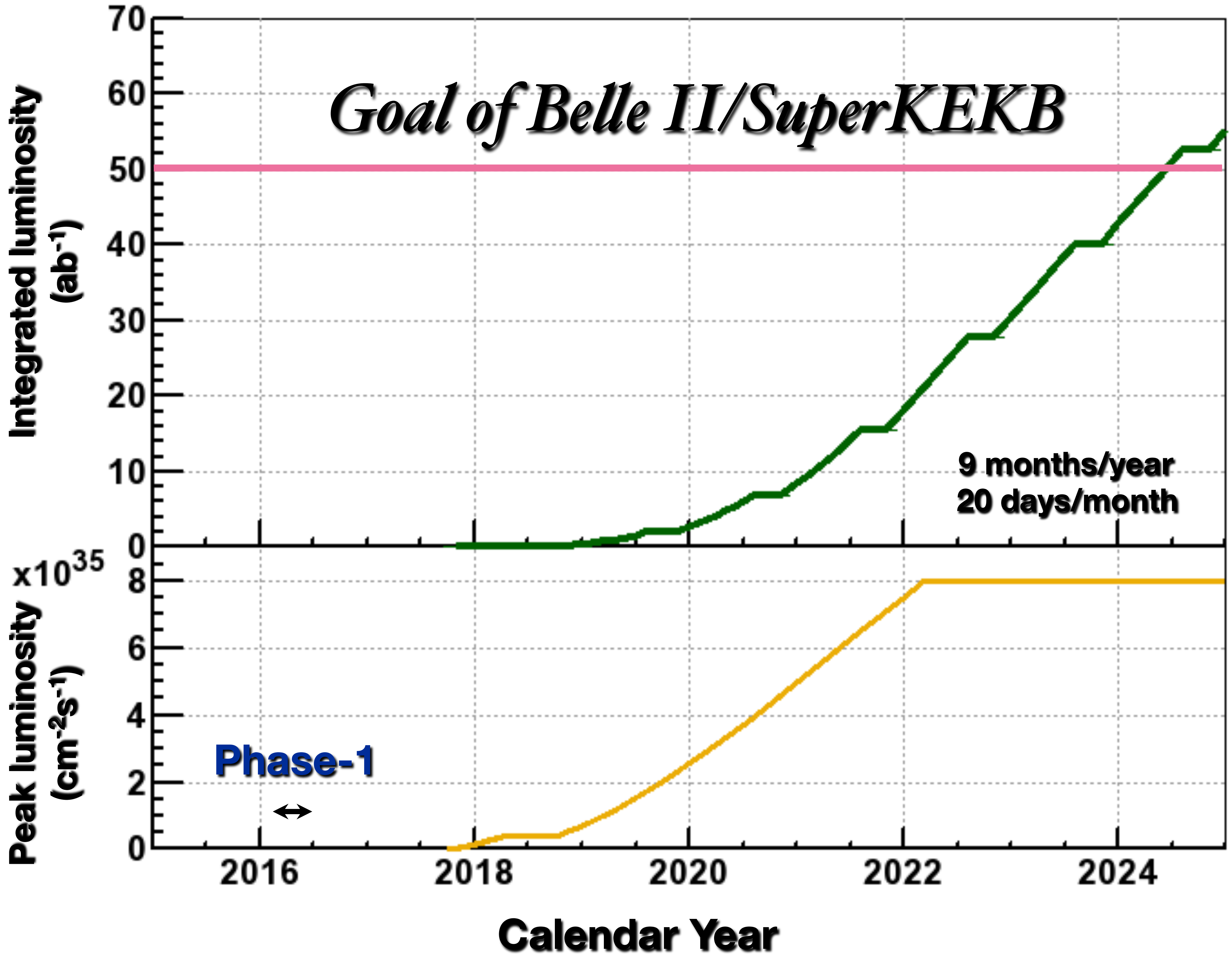
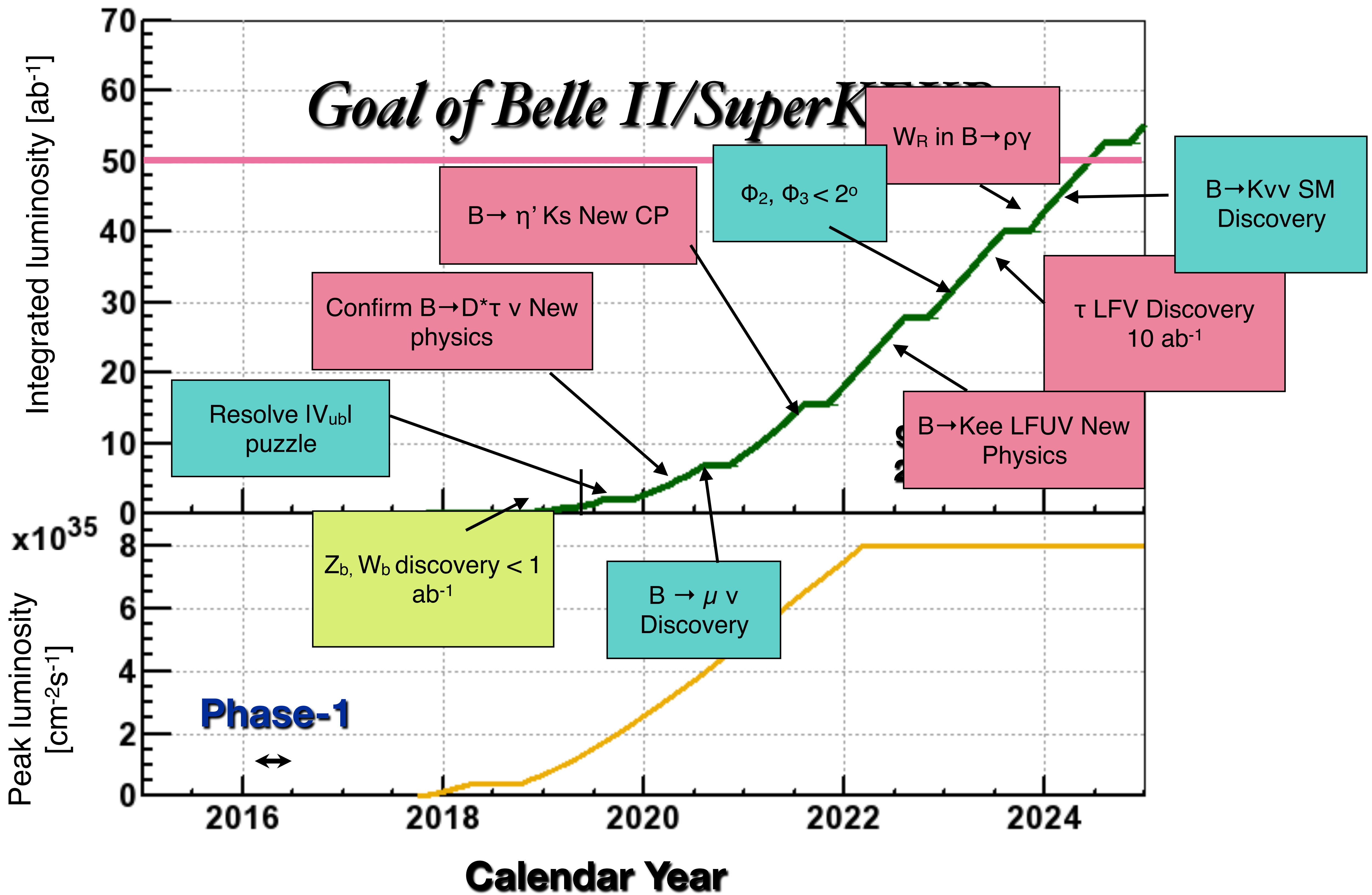
Latest SuperKEKB Luminosity Profile

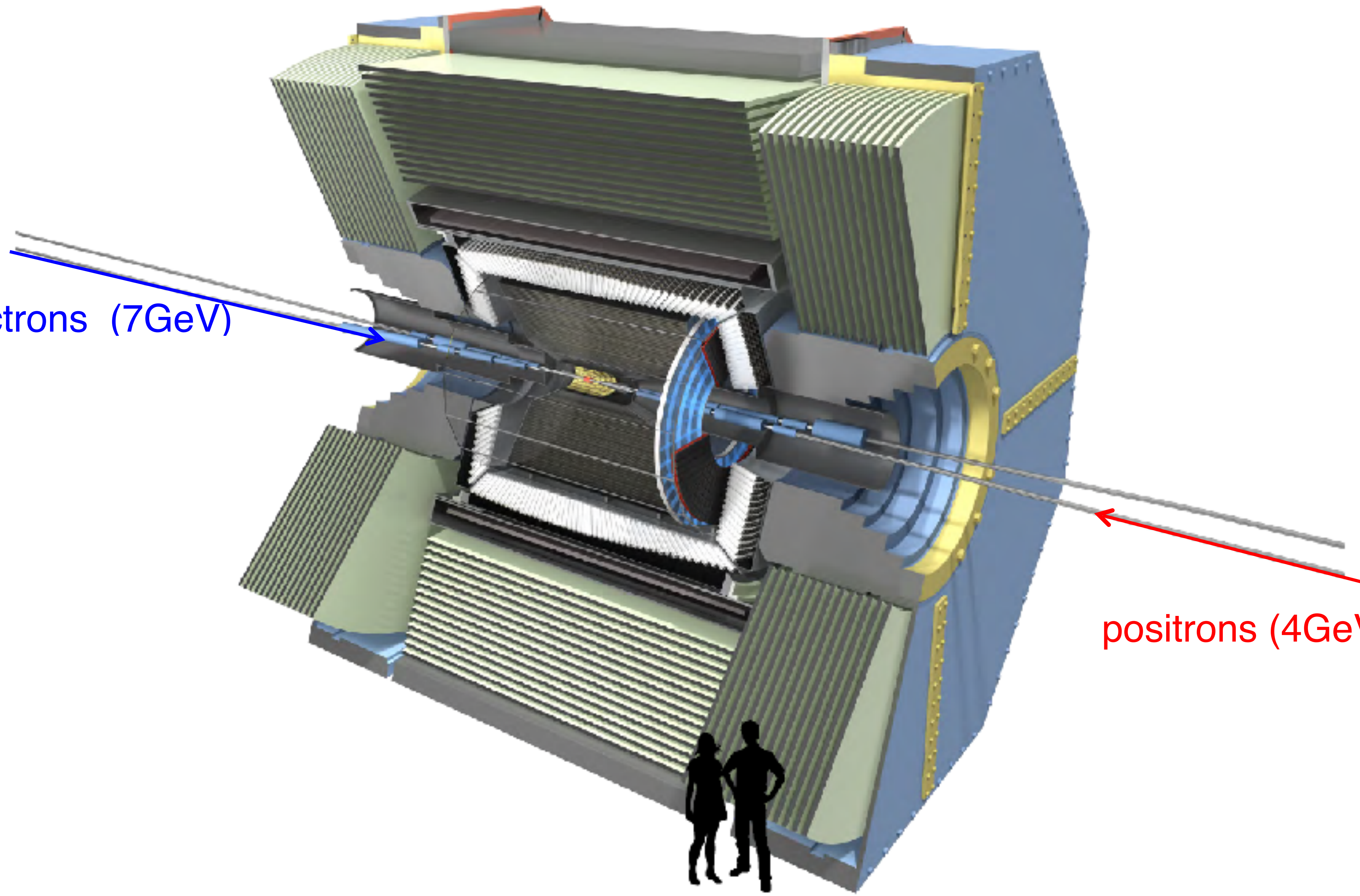


Latest SuperKEKB Luminosity Profile



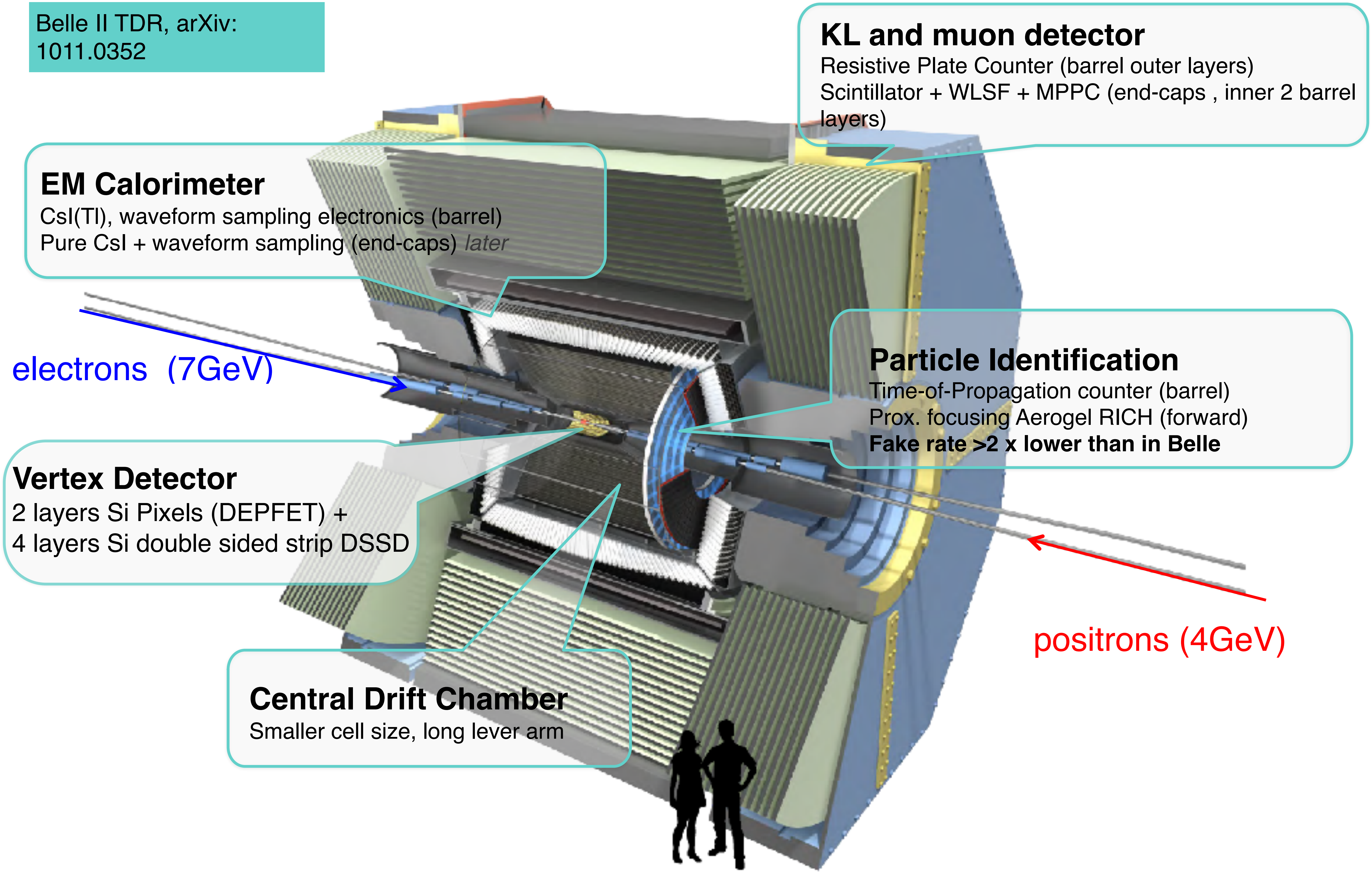
Belle II Detector [735 collaborators, 101 institutes, 23 nations]

Belle II TDR, arXiv: 1011.0352



Belle II Detector [735 collaborators, 101 institutes, 23 nations]

Belle II TDR, arXiv: 1011.0352

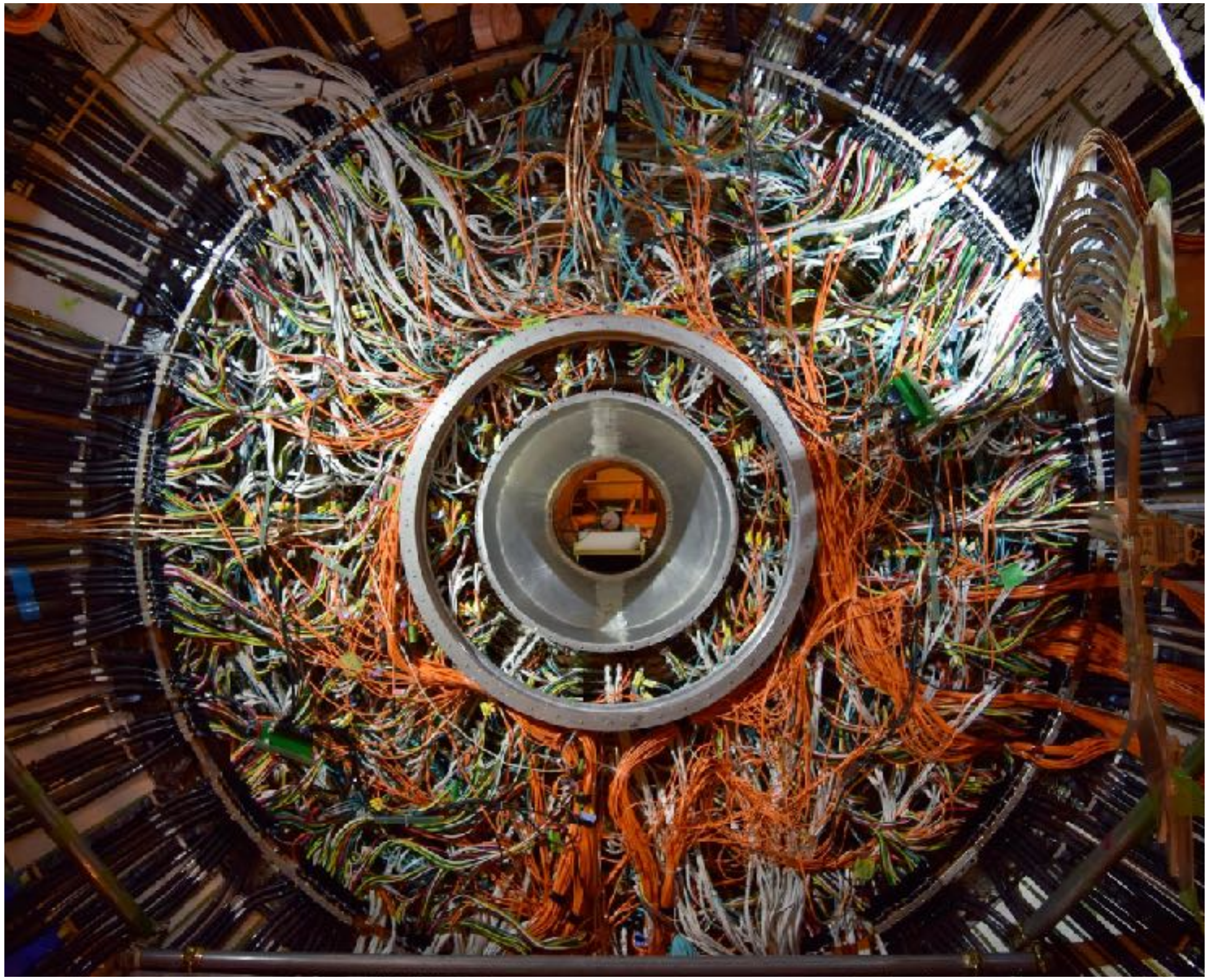


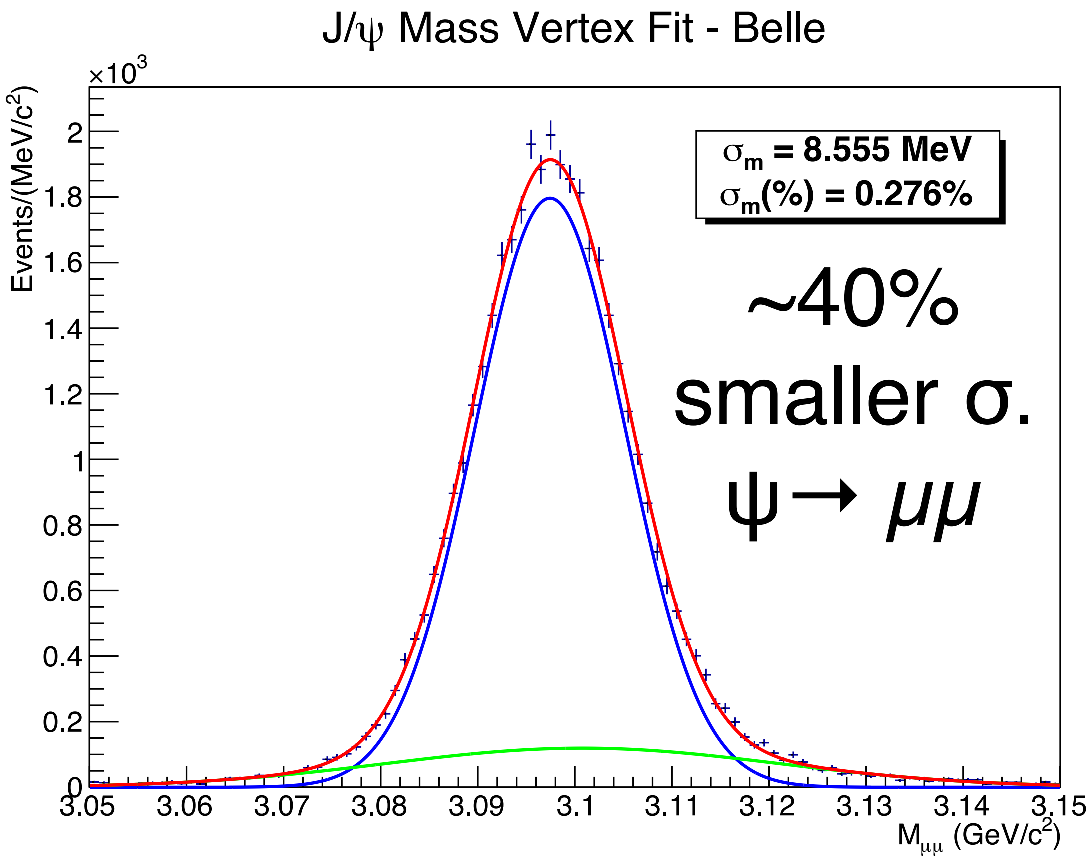
Electromagnetic Calorimeter (ECL) endcap installation

Electromagnetic Calorimeter (ECL) endcap installation

CDC fully instrumented

- CDC backward view on Jan 10th, 2017. After all cables, cooling pipe and dry air are connected.
- Smaller segments → better mass resolution.





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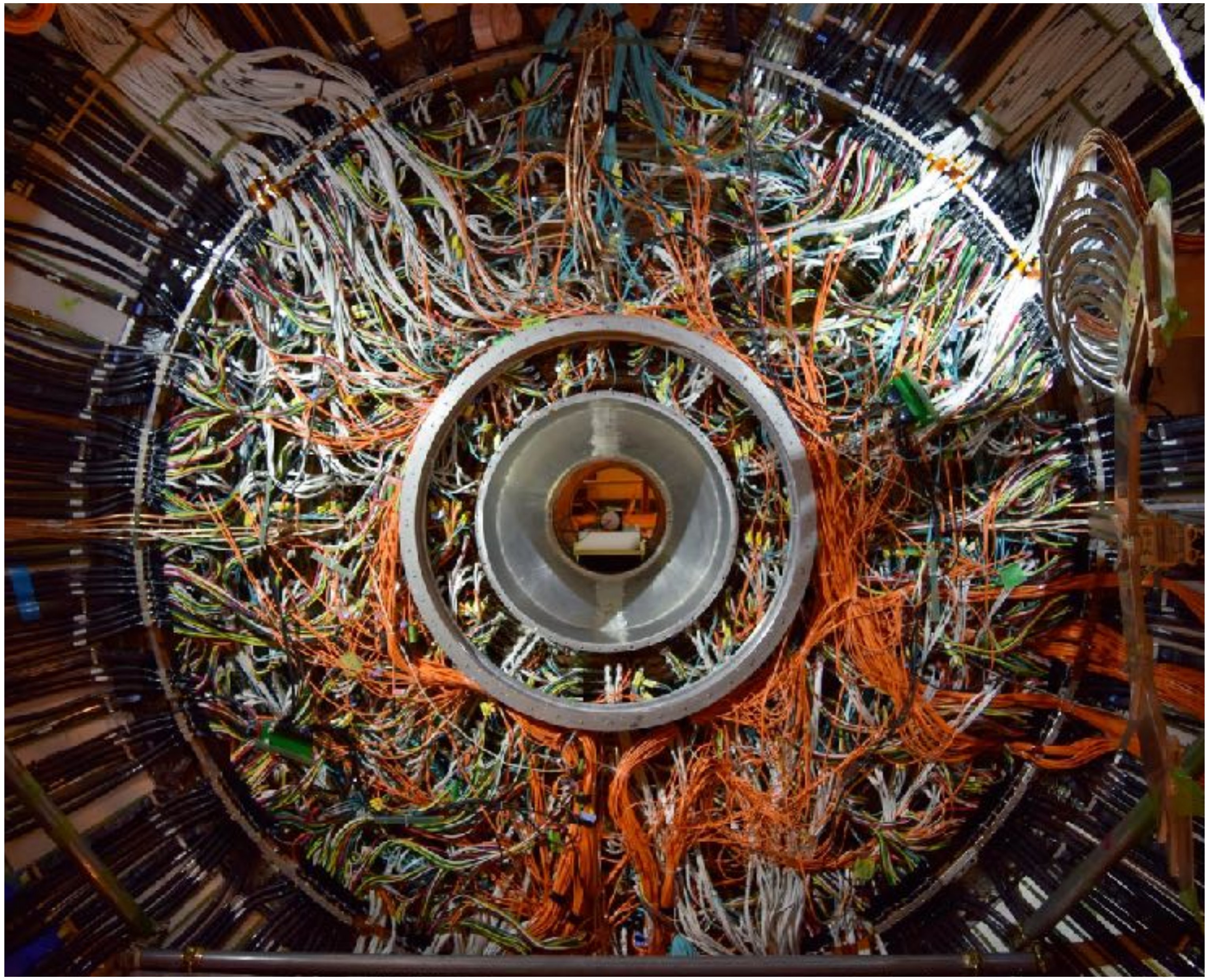
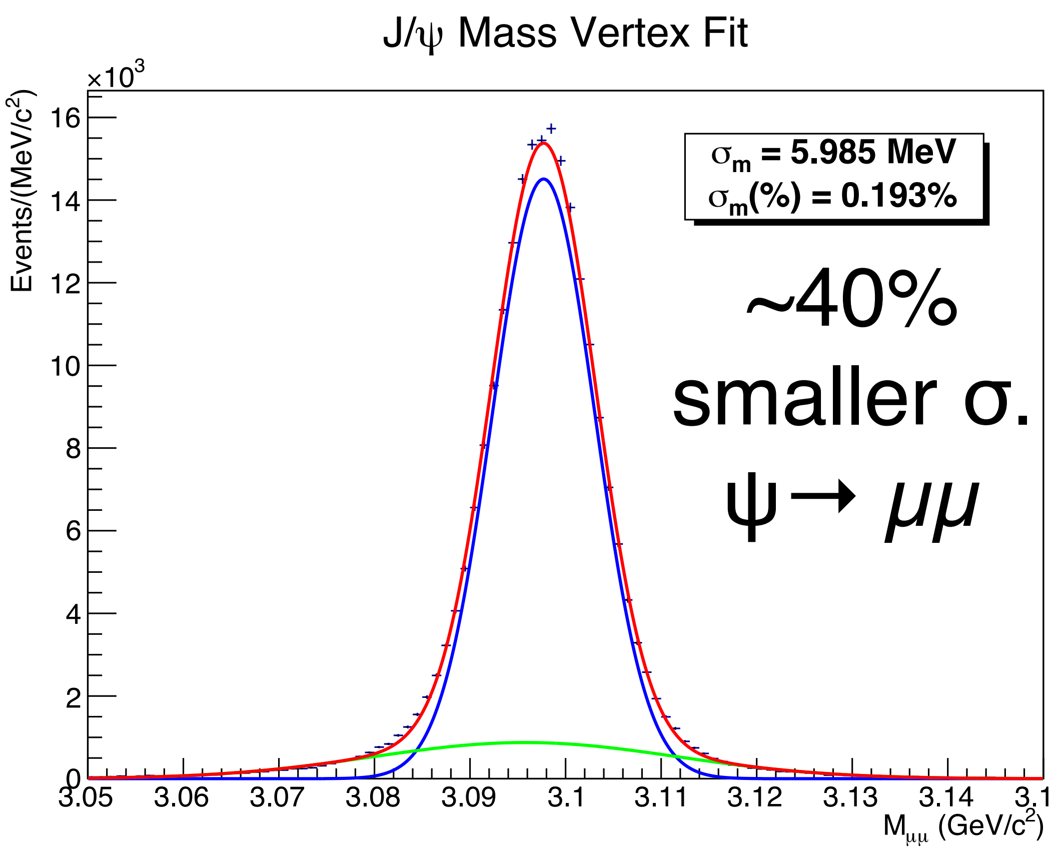
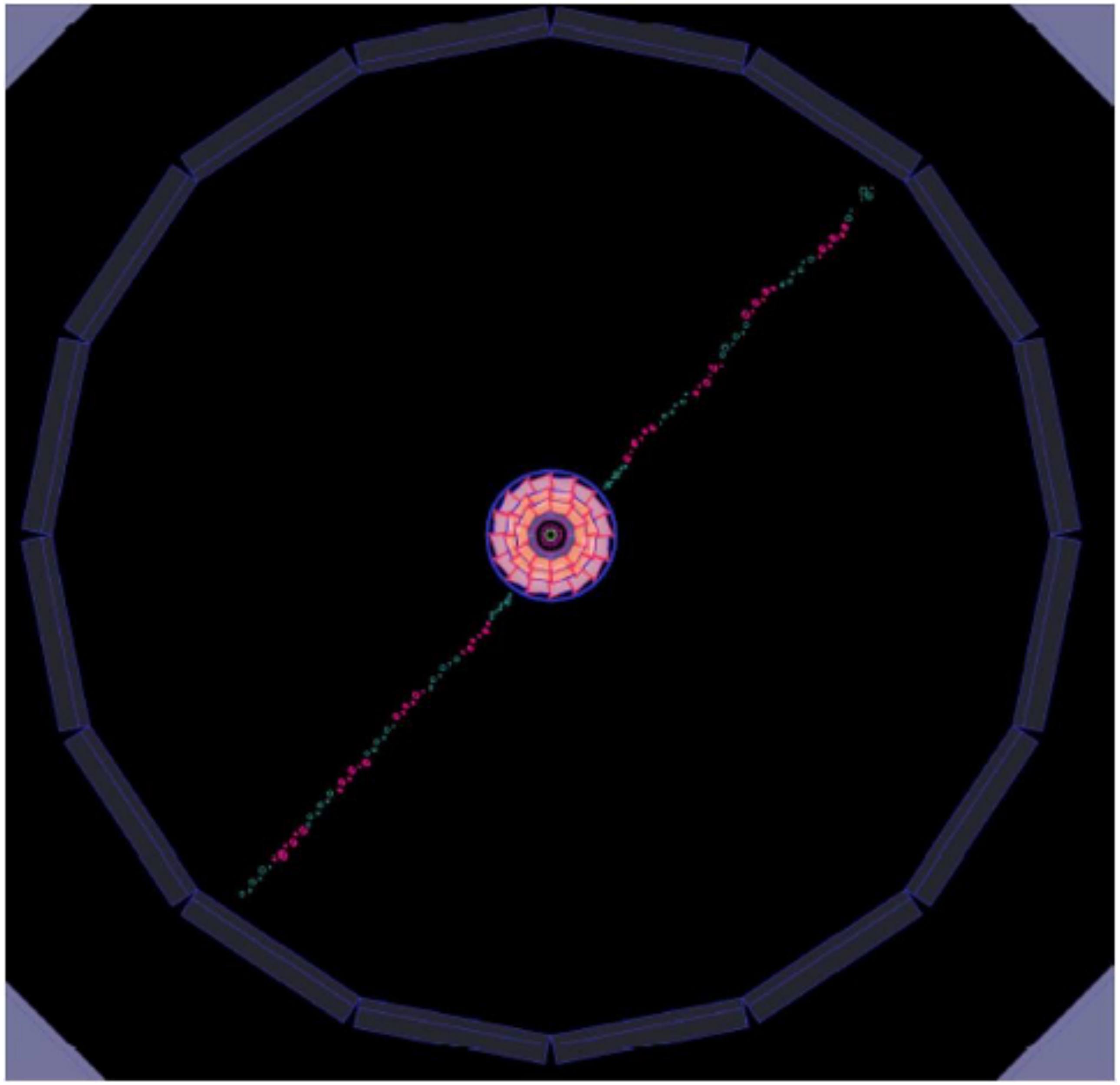




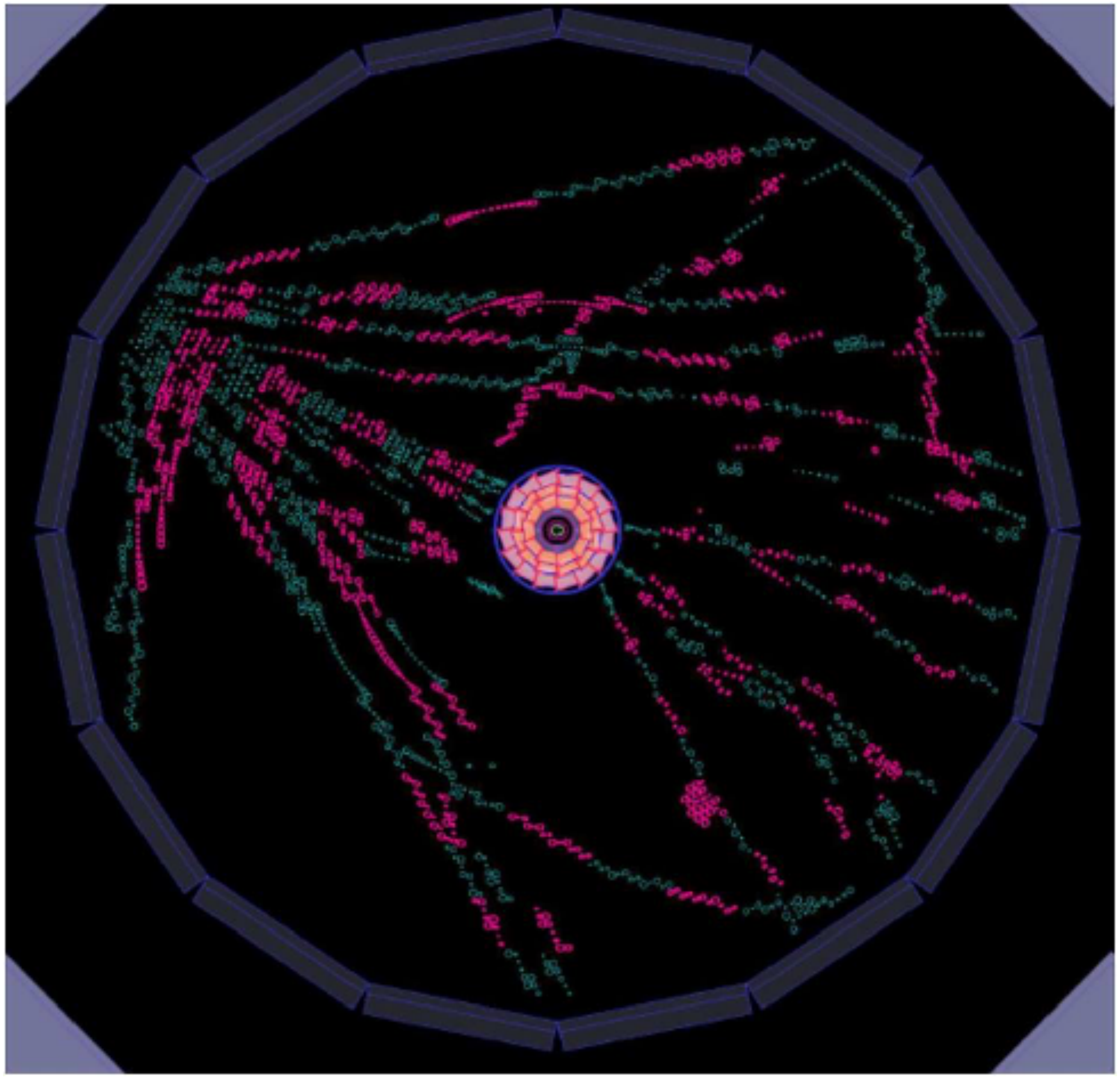
CDC (Central Drift Chamber) Fully instrumented

- Cosmic run (Feb 7, 2017)

Single cosmic ray track

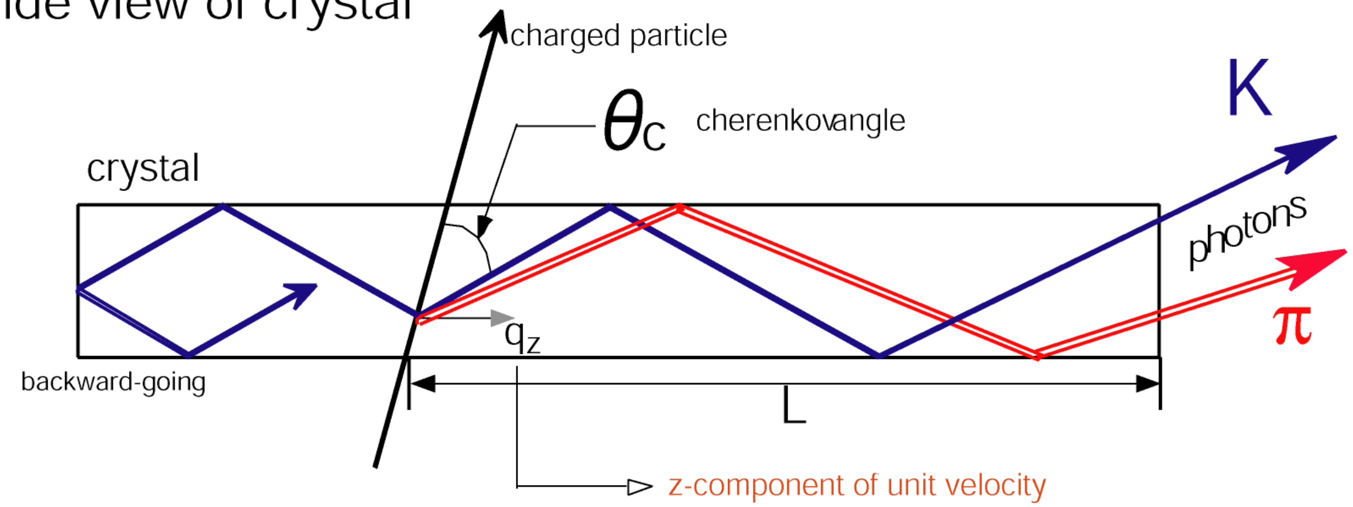


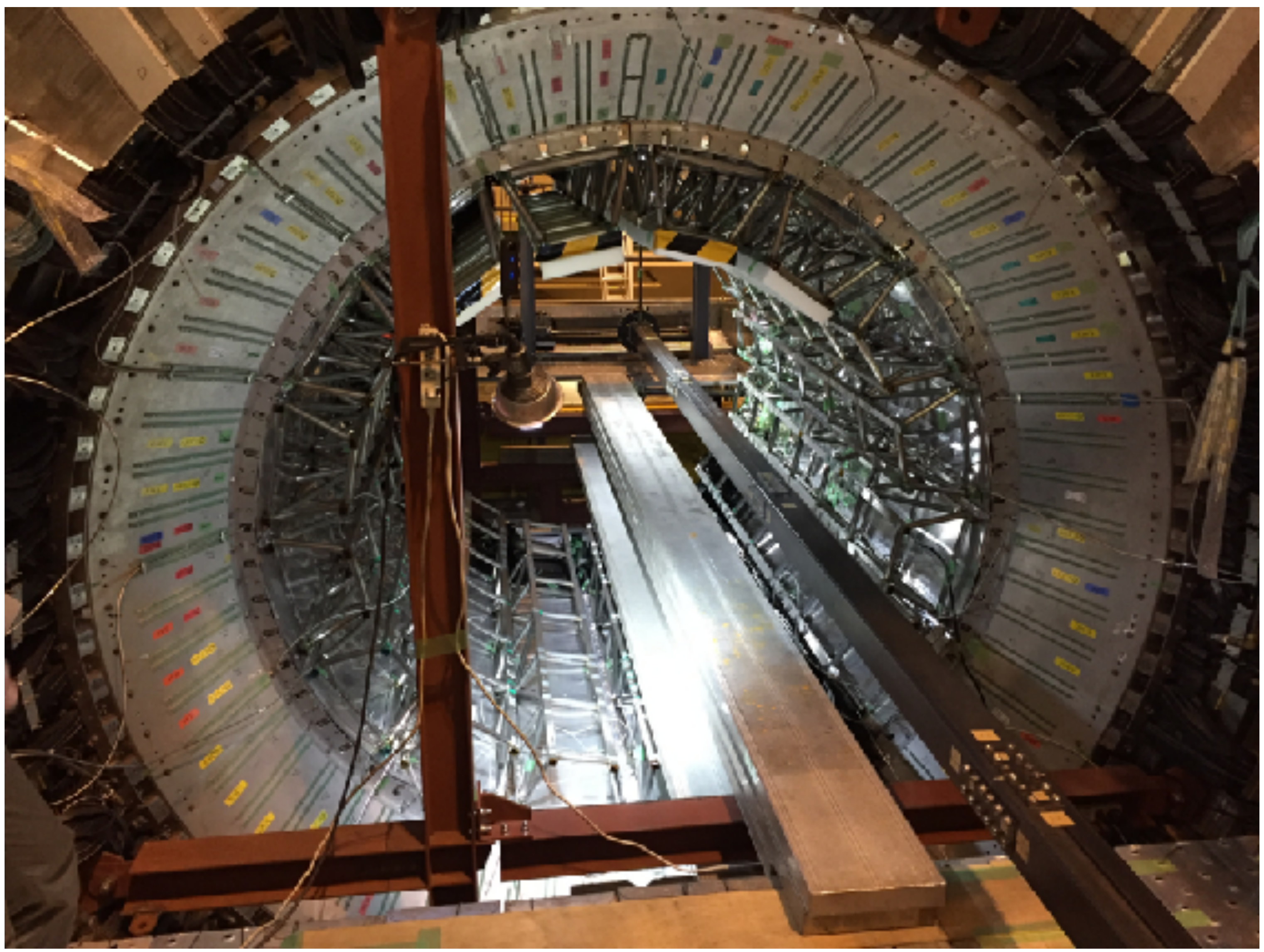
Multiple tracks
(showering cosmic ray event)

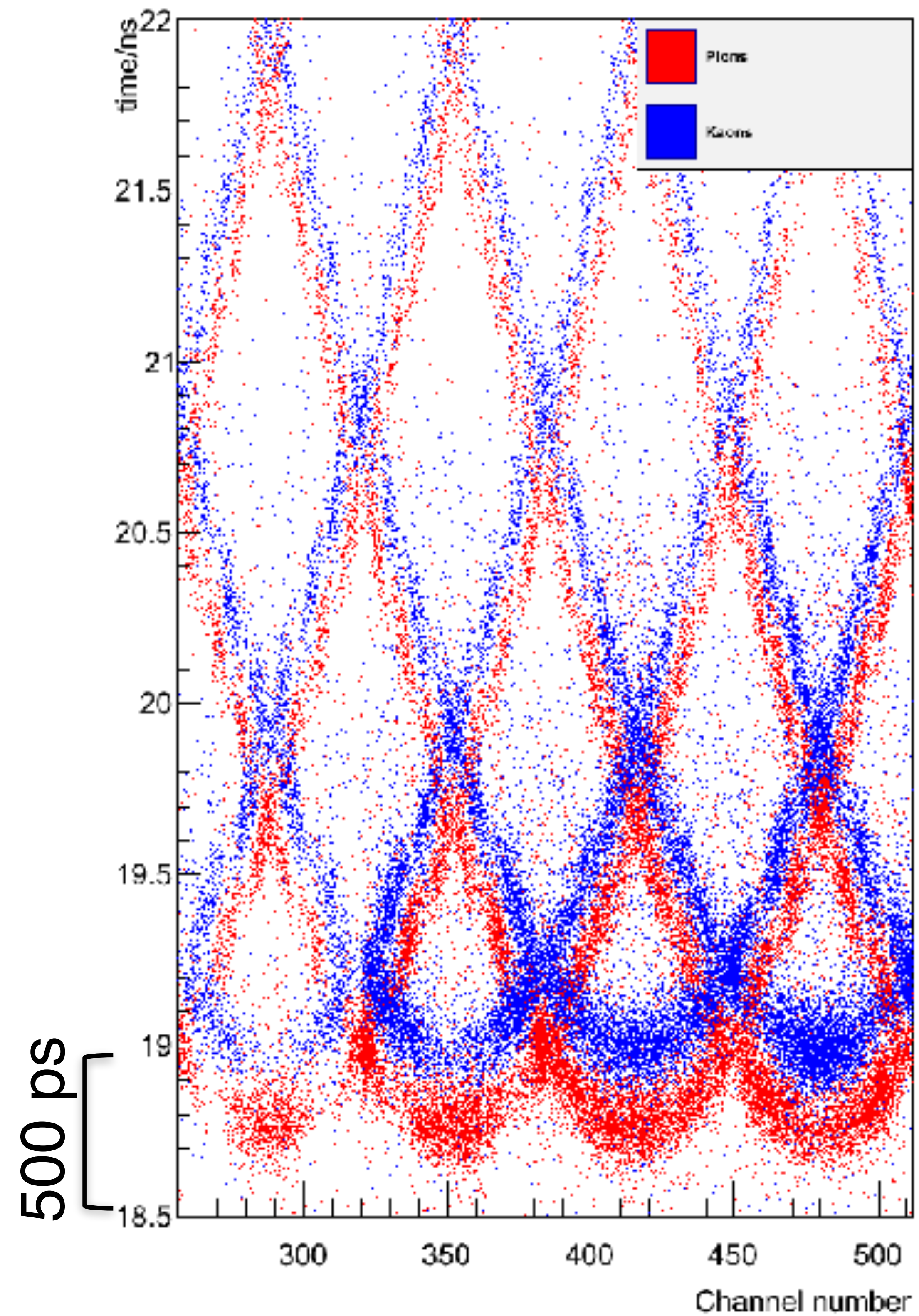


Time-of-Propagation Cherenkov Detector

Side view of crystal

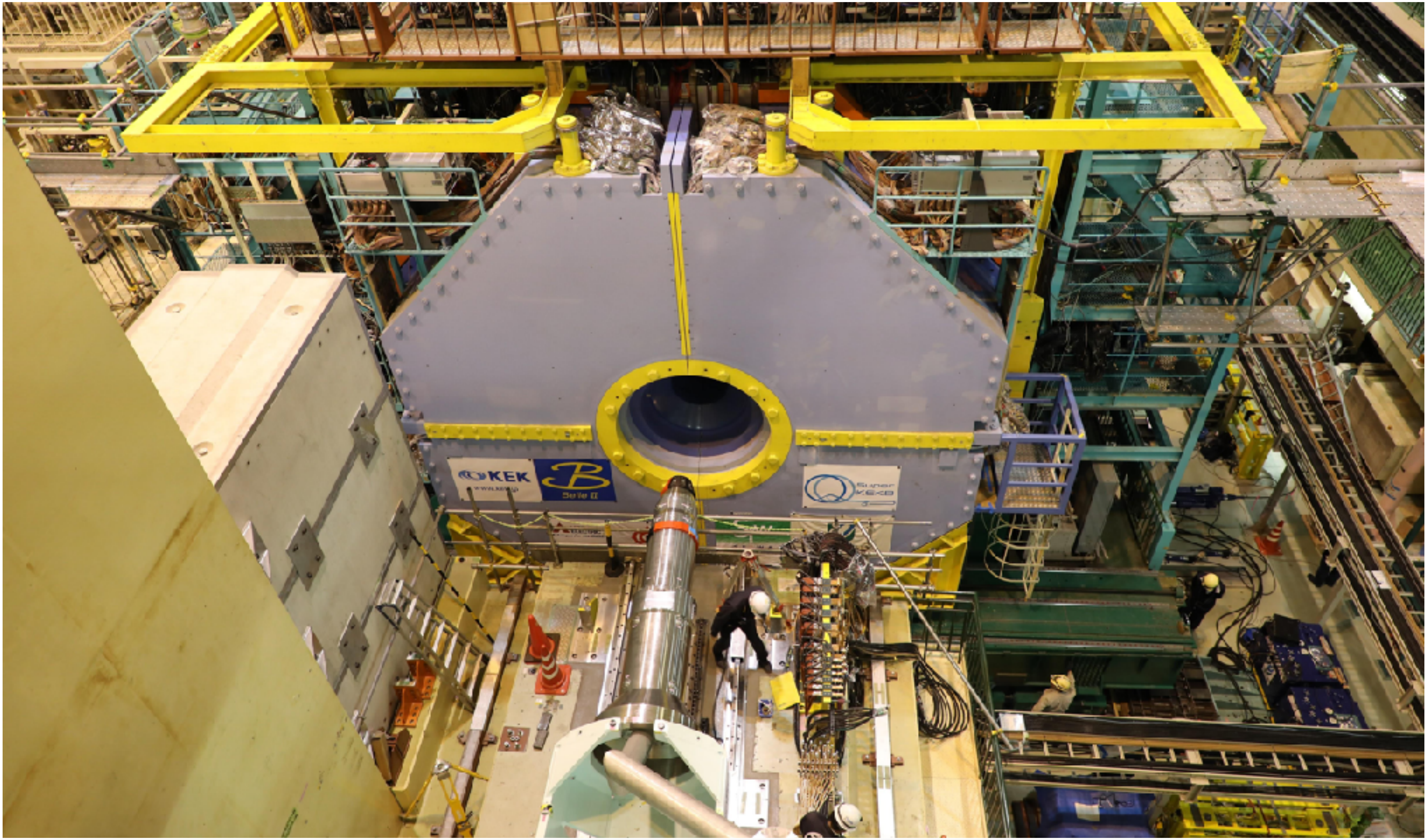






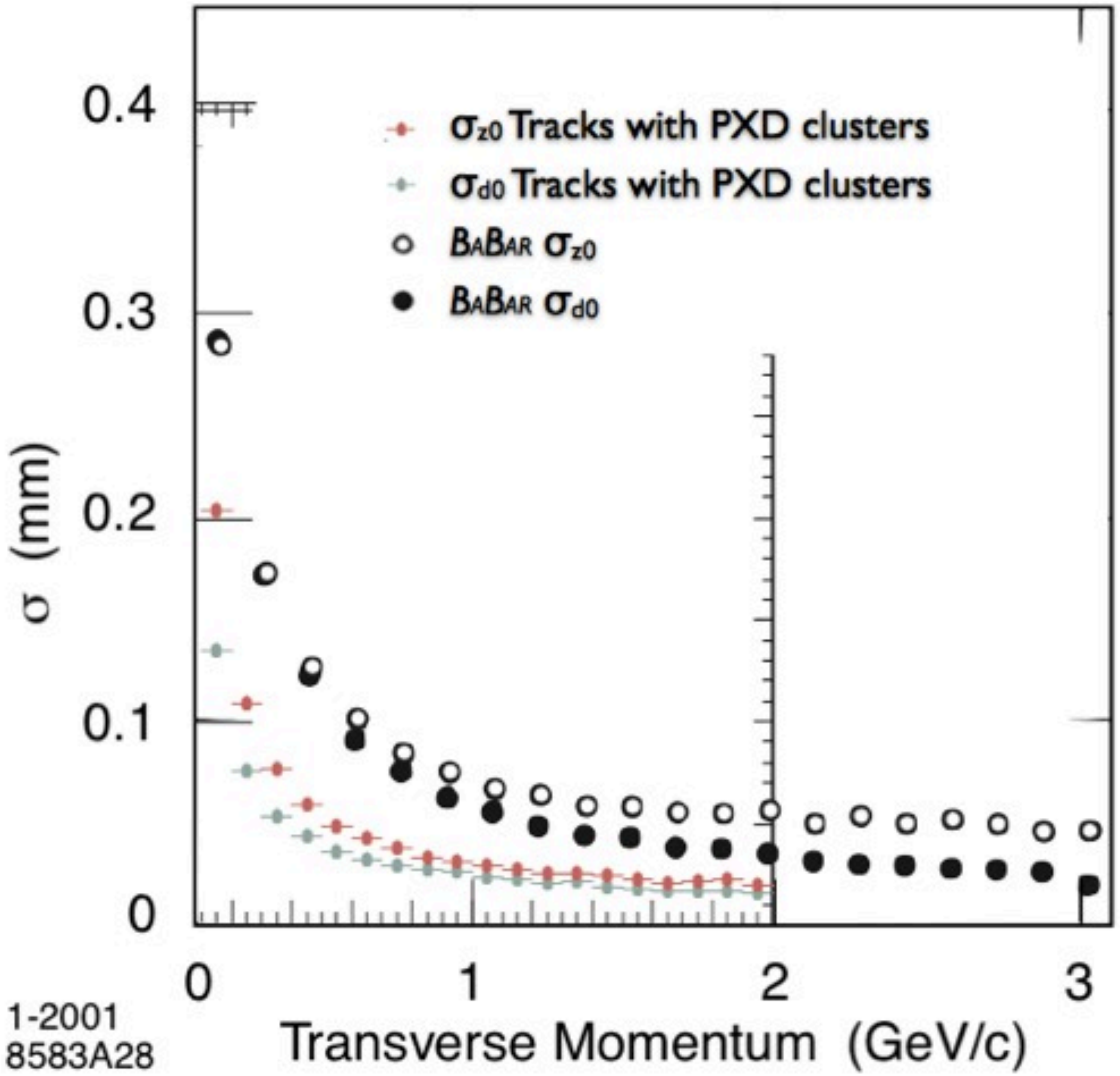
Belle II in place

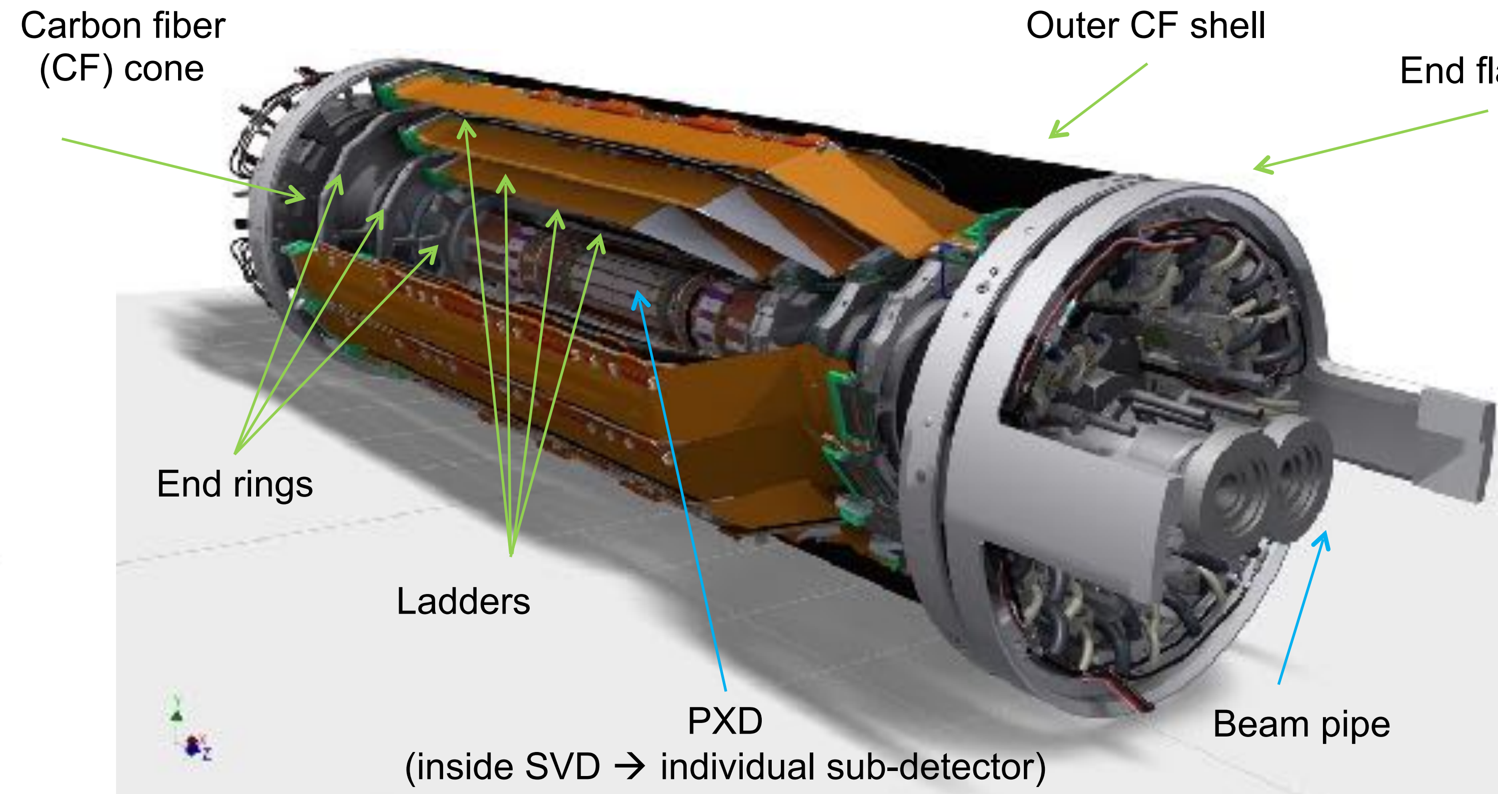
April 1, Belle II "roll-in"

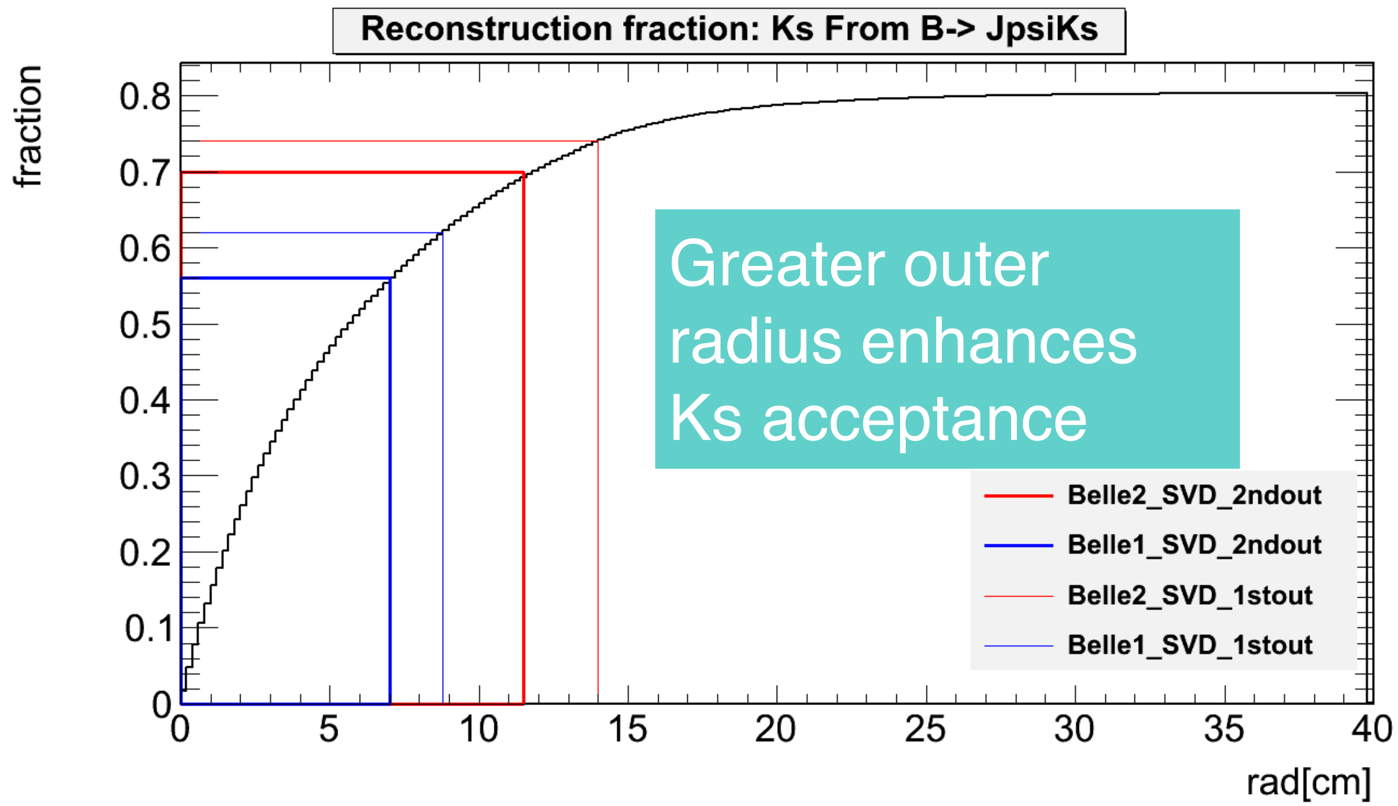


Vertex Detector

IP resolution much better than Belle & Babar → much better vertexing

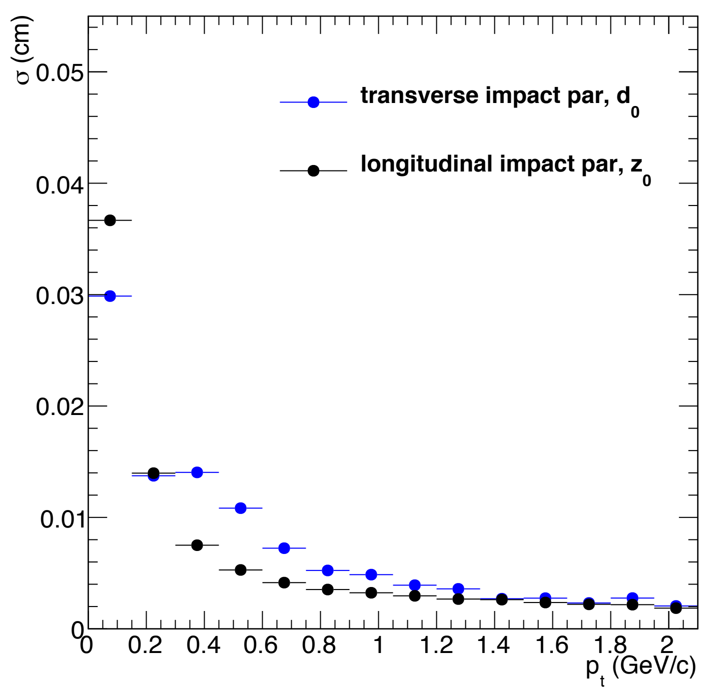




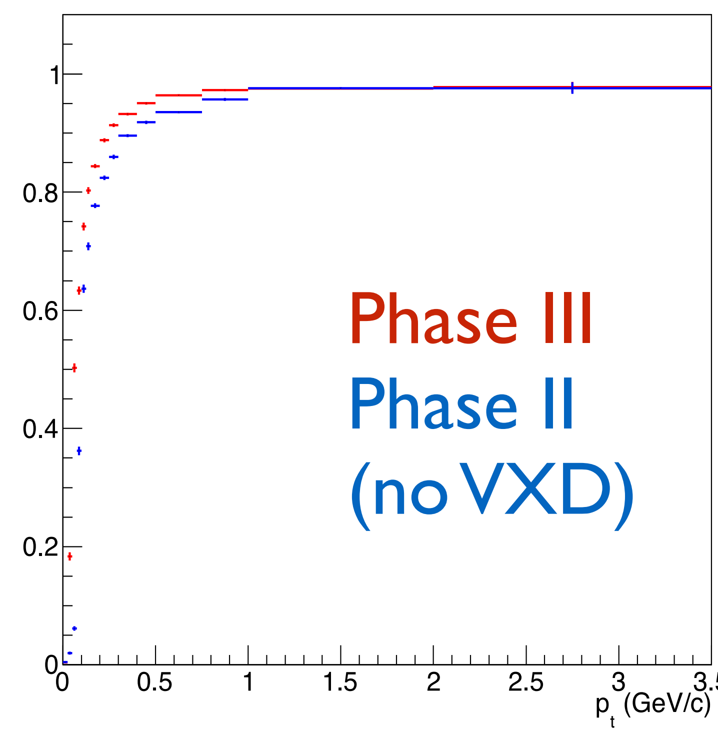


Performance Snapshot: Reconstructed Particles

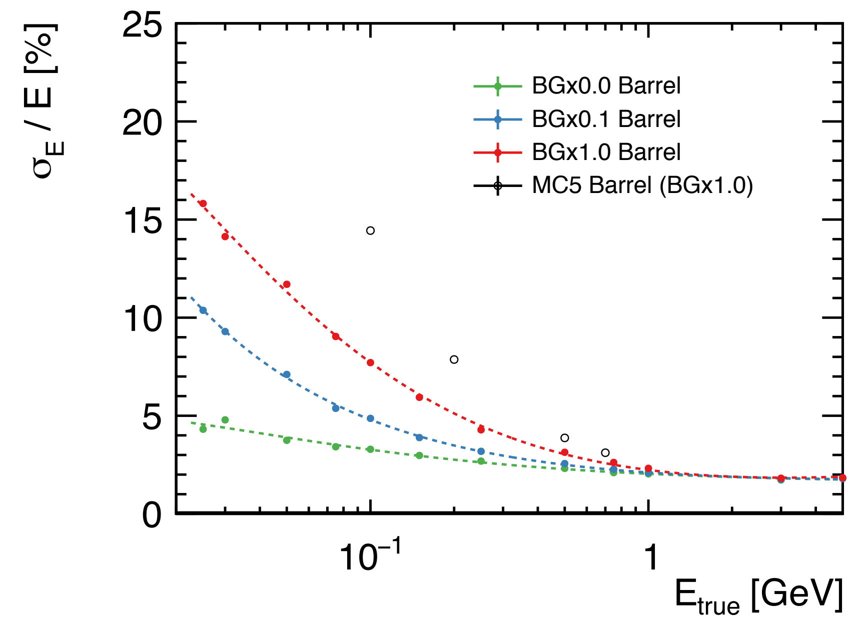
Tracking IP resolution, Rel7



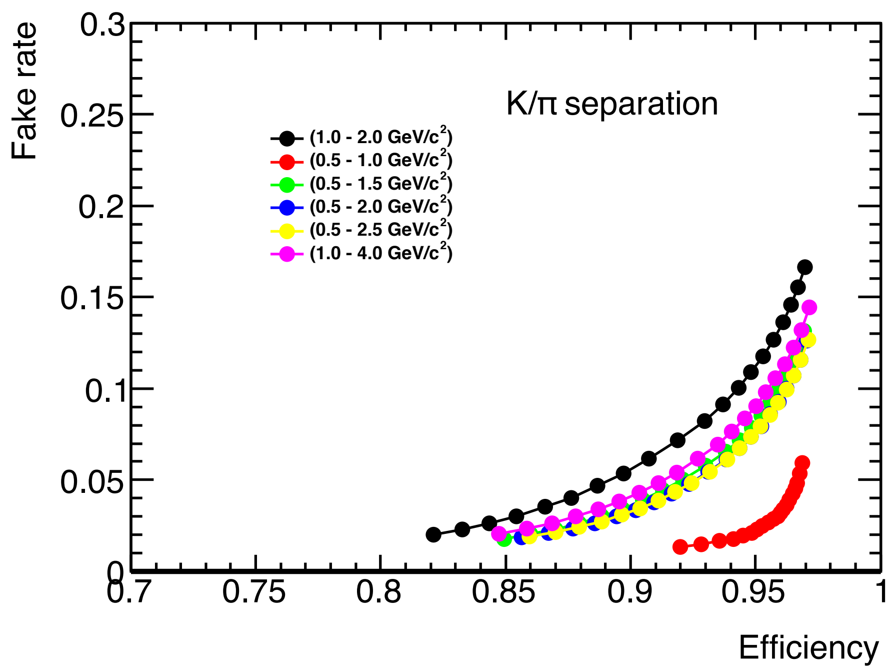
Tracking efficiency vs Pt, Rel7



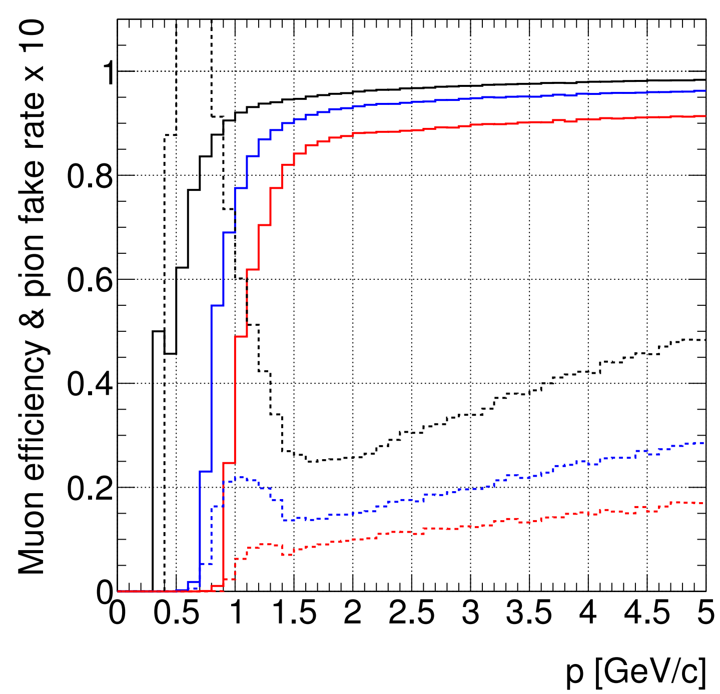
Photon energy resolution, Rel7



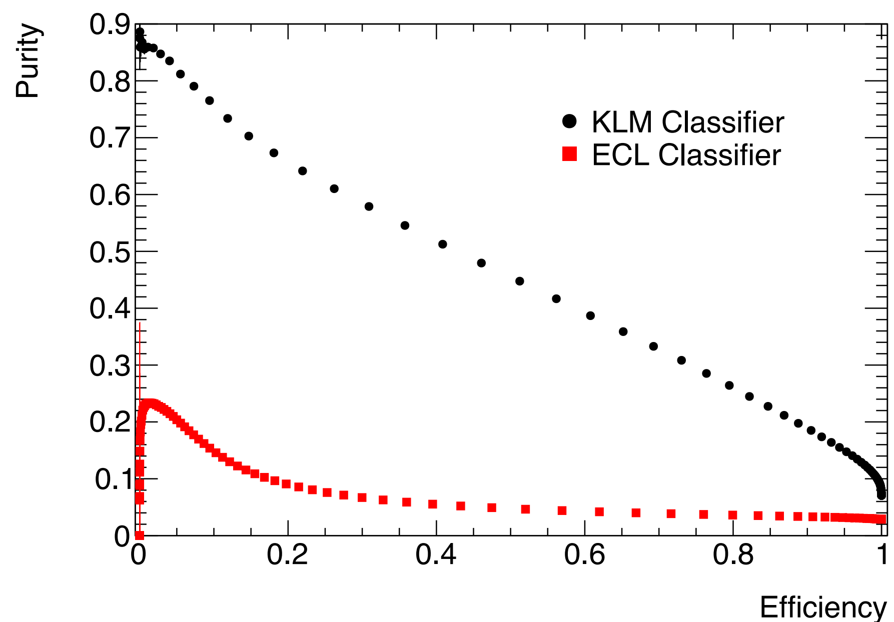
K/π separation ROC, Rel7



Muon ID efficiency, Rel7



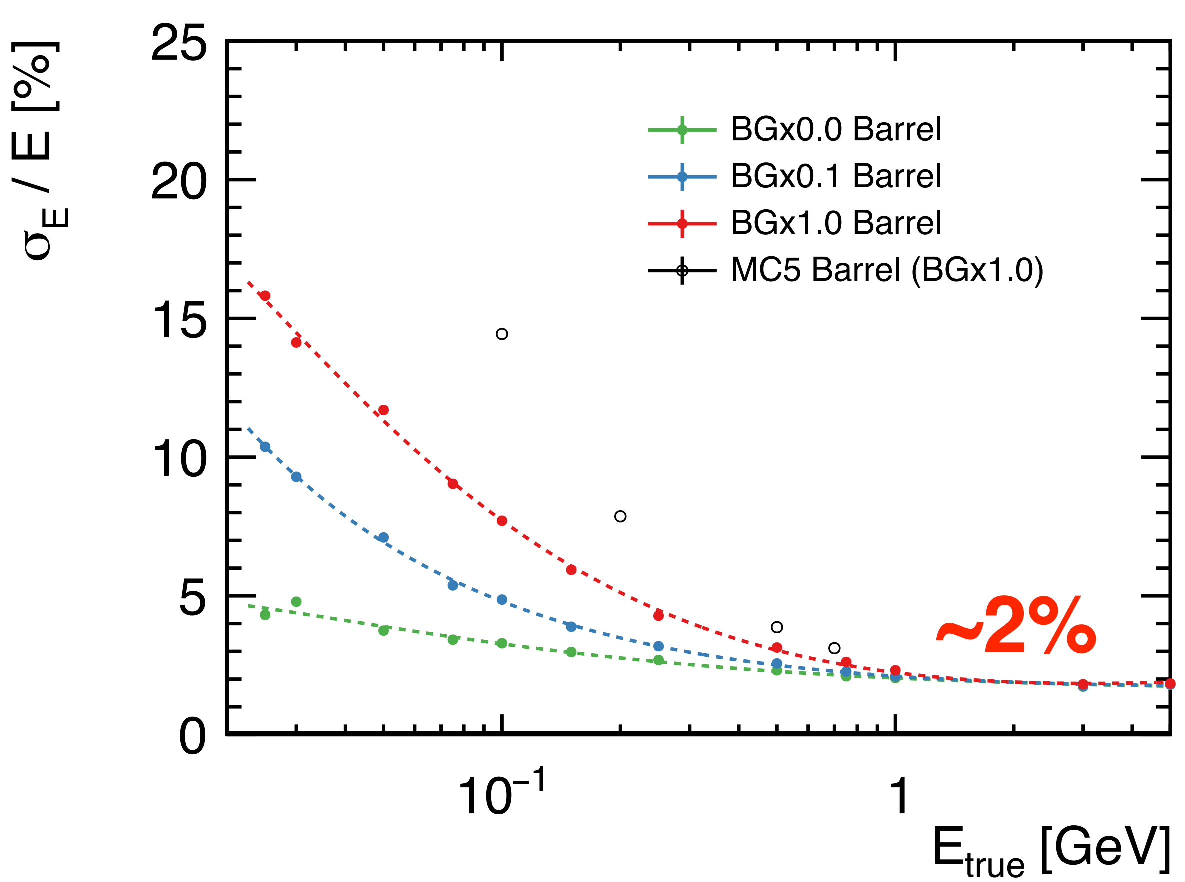
K_L ID ROC, Rel7



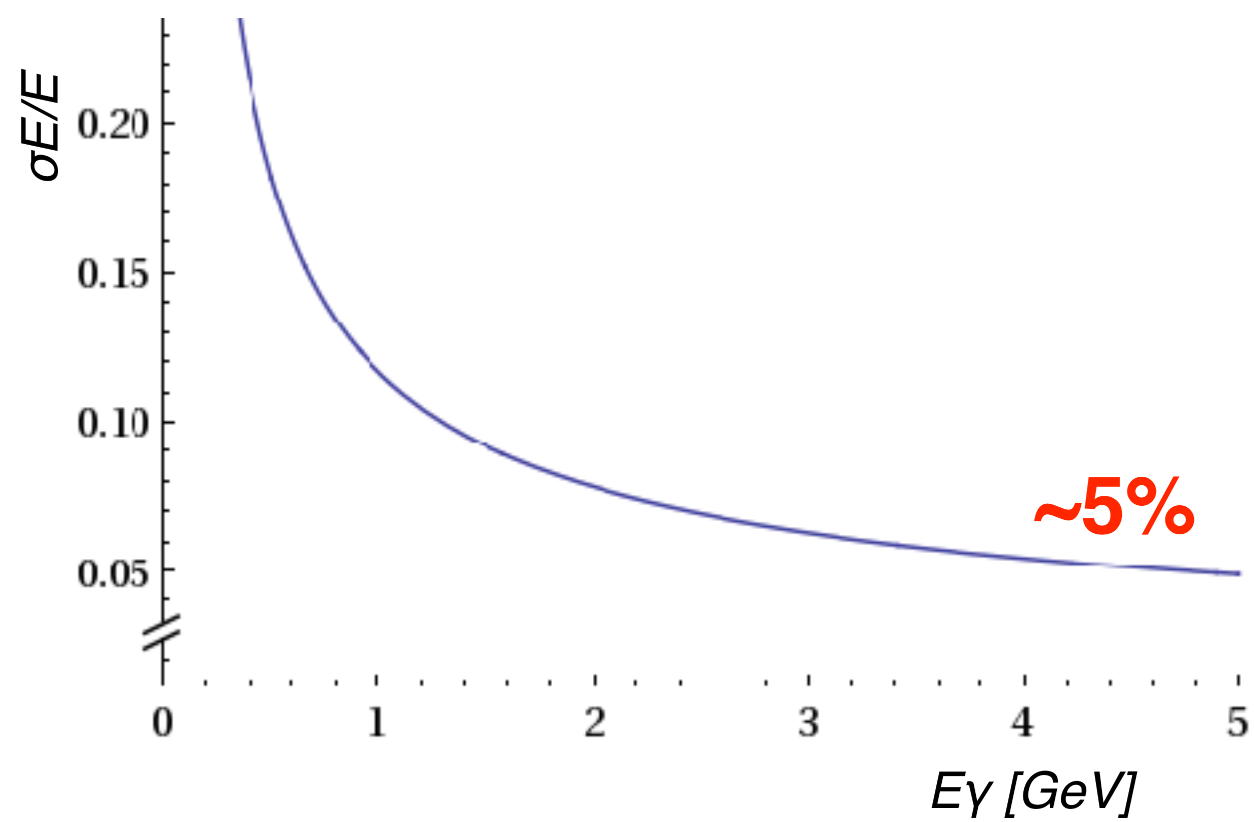
Electromagnetic interactions

- Far fewer background & pileup photons than hadron collider
- Higher performance calorimeter
- Much less material in front (important for electrons)

Photon energy resolution, Rel7



LHCb upgrade full simulation (parametrisation)



So when do we start Belle II ?

BEAST PHASE I:
Feb-June 2016
(Belle II roll-in in March 2017).

PHASE II Operation: Starts in ~Jan 2018 [Begin with damping ring commissioning; First collisions; *limited physics without vertex detectors*]

Phase III: Belle II Physics Running: late 2018 [vertex detectors in]

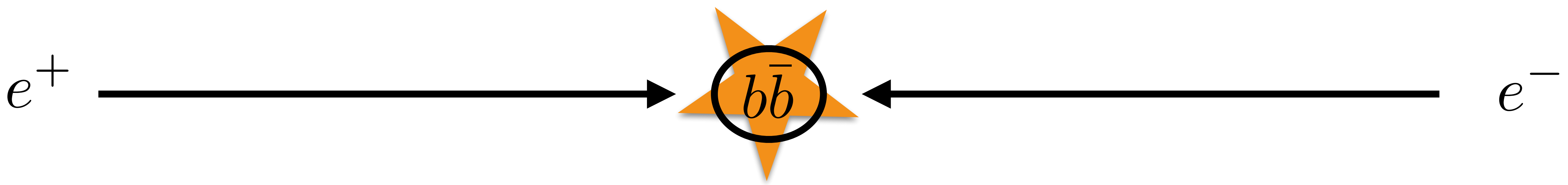
QCSL at the IP, Aug 2016

Anomalies in $b \to s\, l\, l$ & $b \to c\, \tau\, \nu$

Missing energy decays an e+e- collider

BDT based hadronic+semileptonic tag reconstruction implemented.

Missing energy decays an e+e- collider



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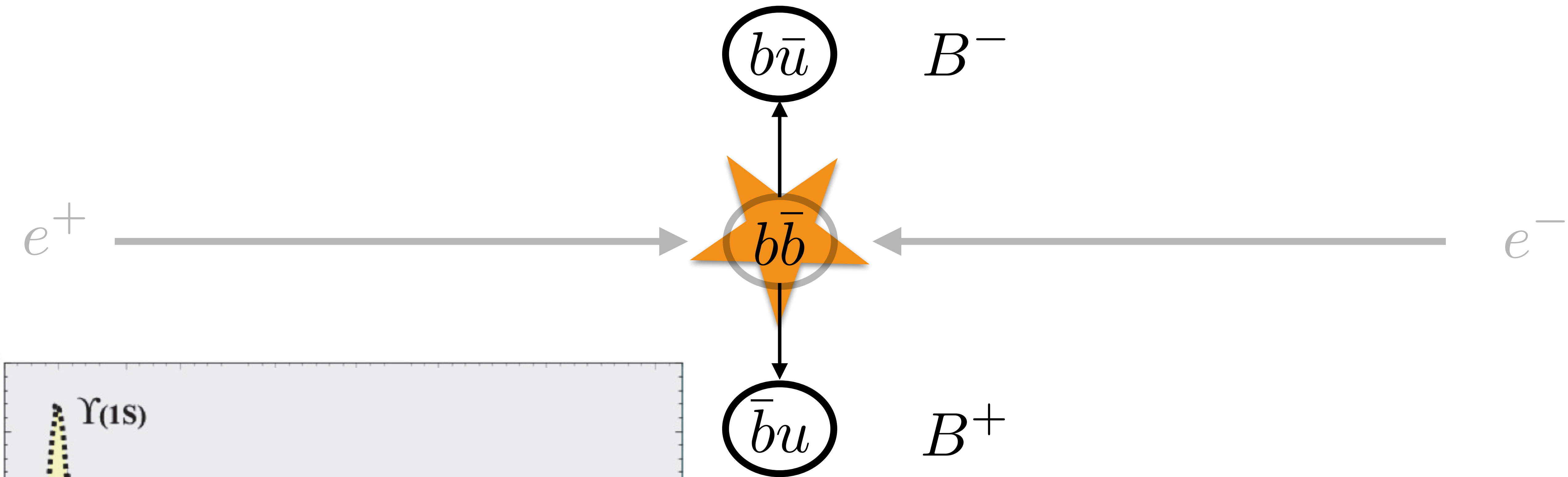
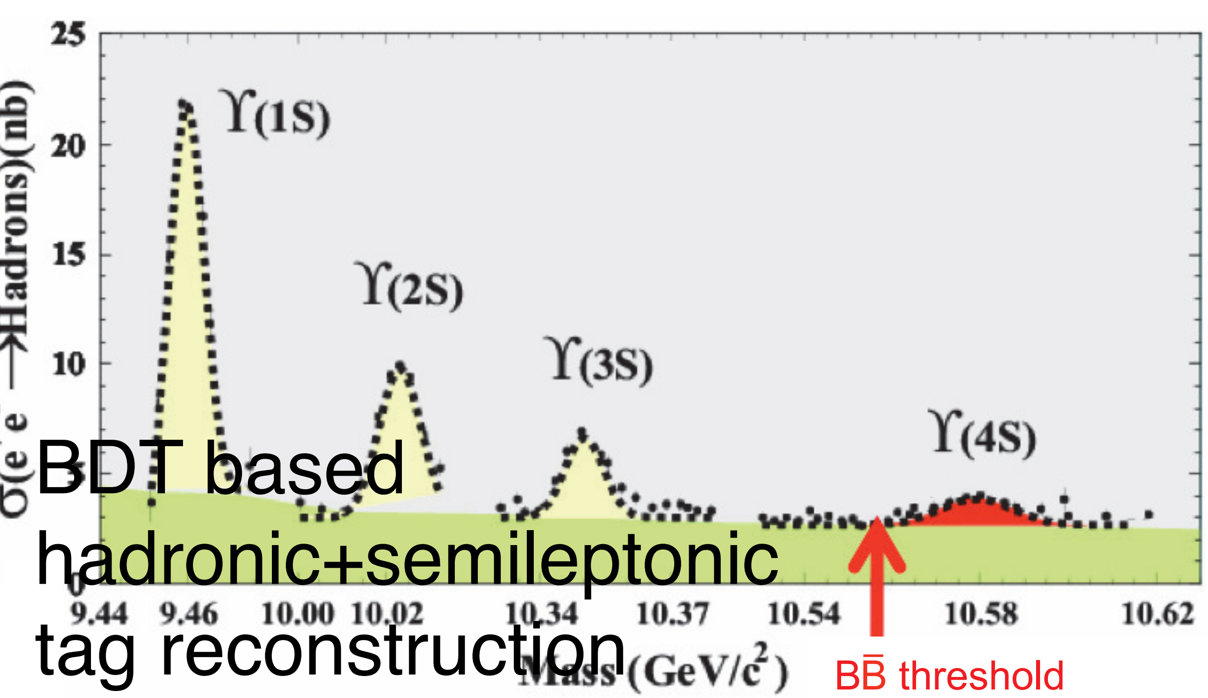


$$\Upsilon(1S) = \langle b\bar{b} \rangle$$

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



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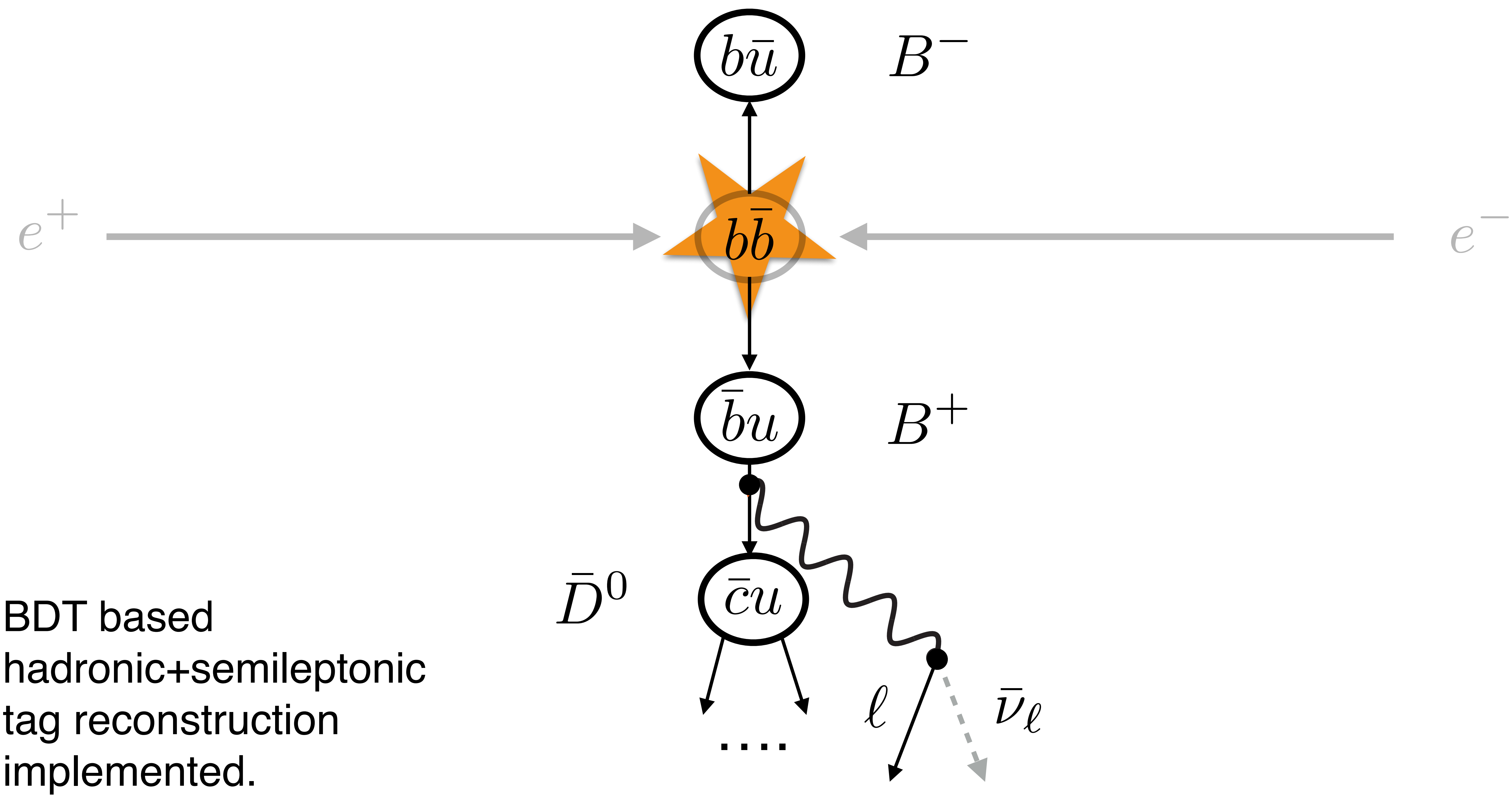

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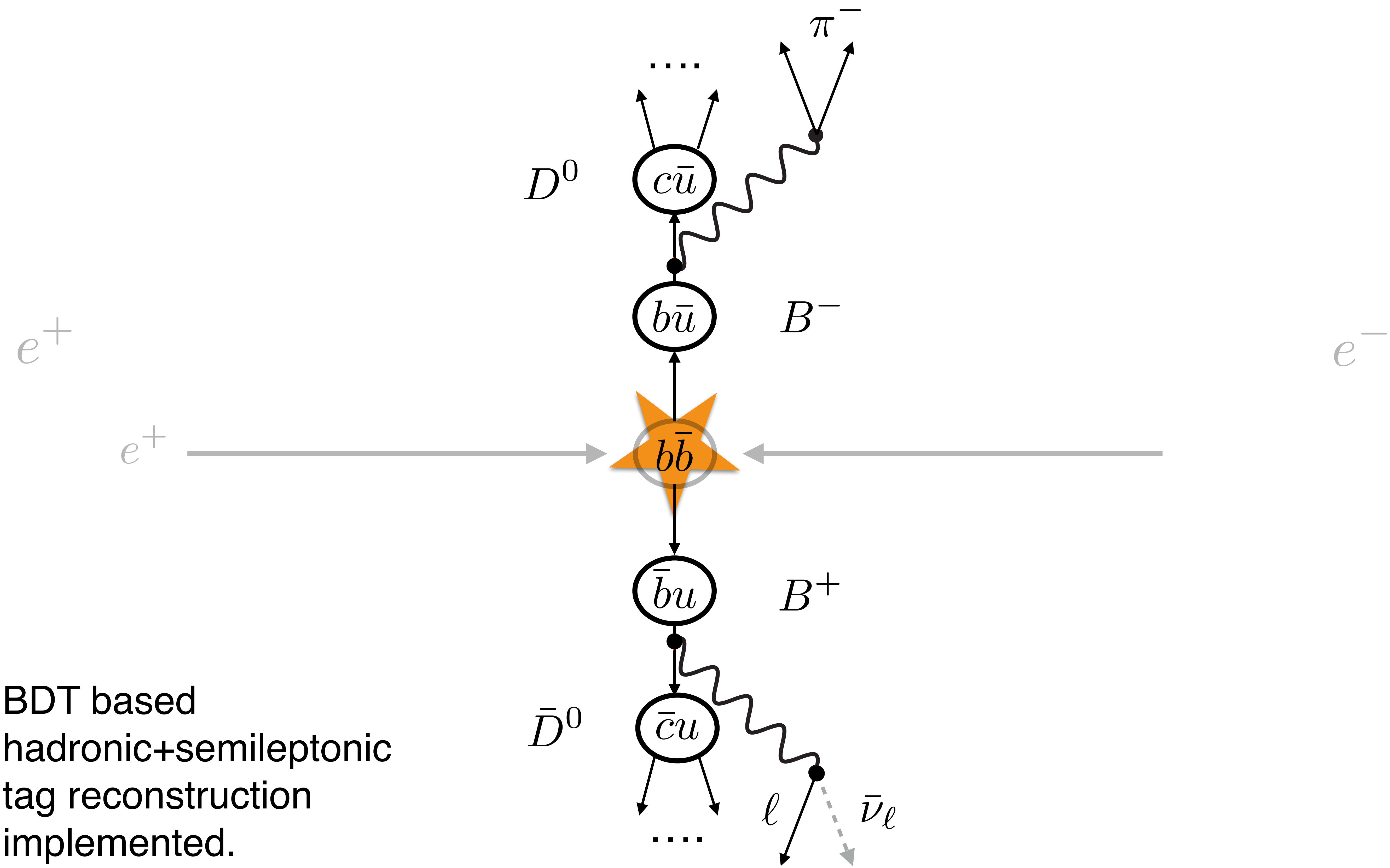

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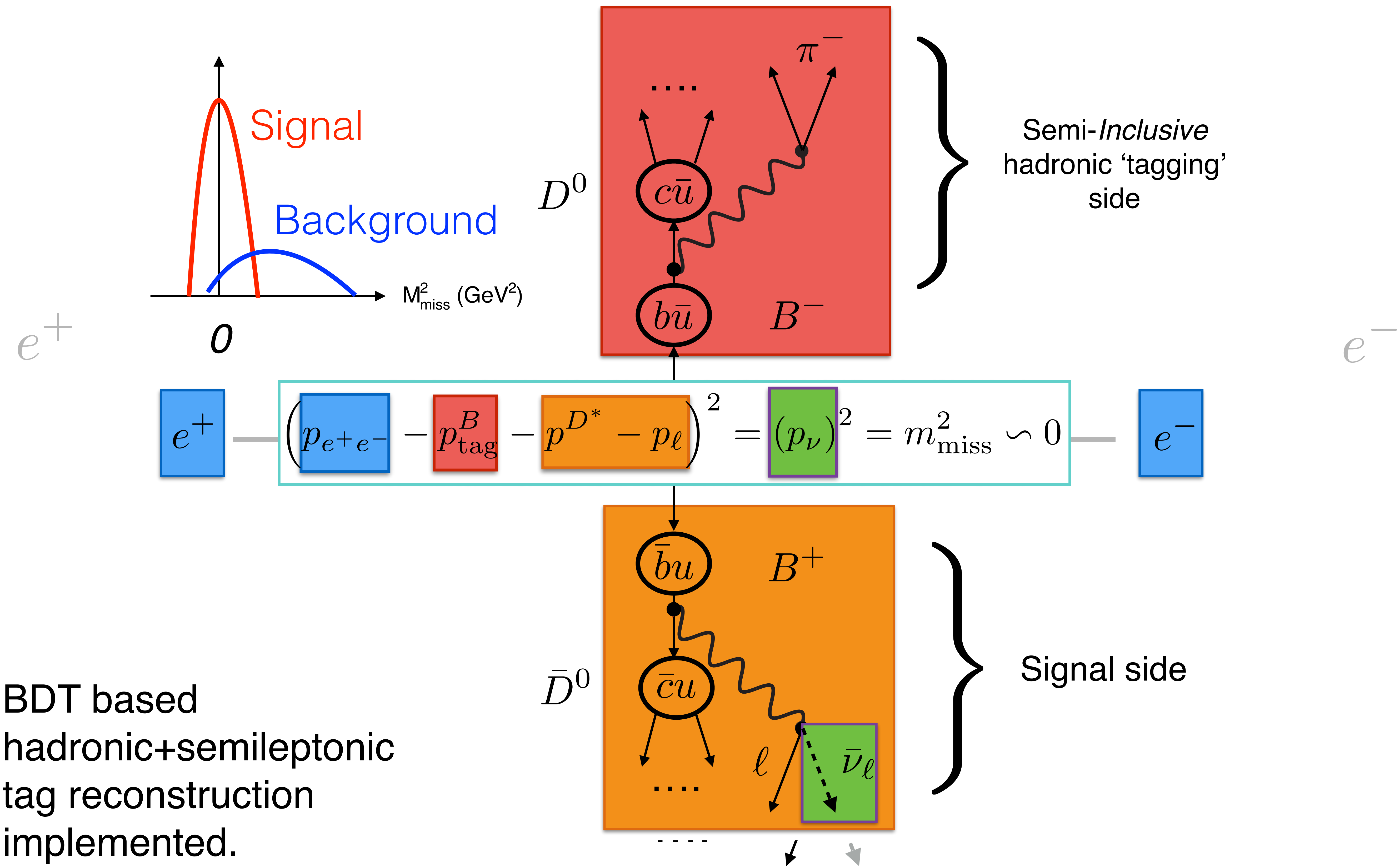


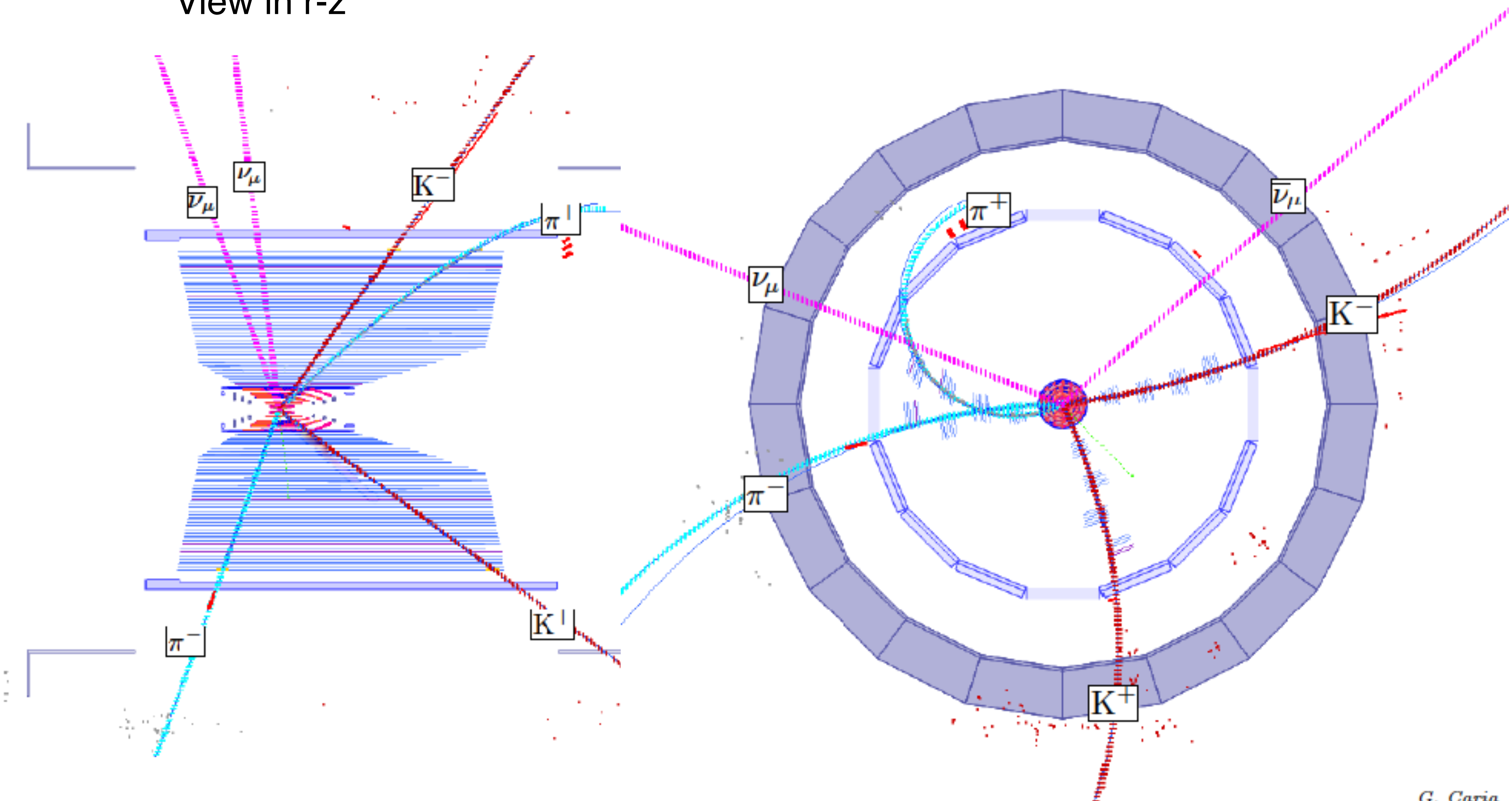
BDT based hadronic+semileptonic tag reconstruction implemented.

“Missing Energy Decay” in a Belle II GEANT4 simulation

Signal B→ K ν ν   tag mode: B→ Dπ; D→ Kπ

View in r-z

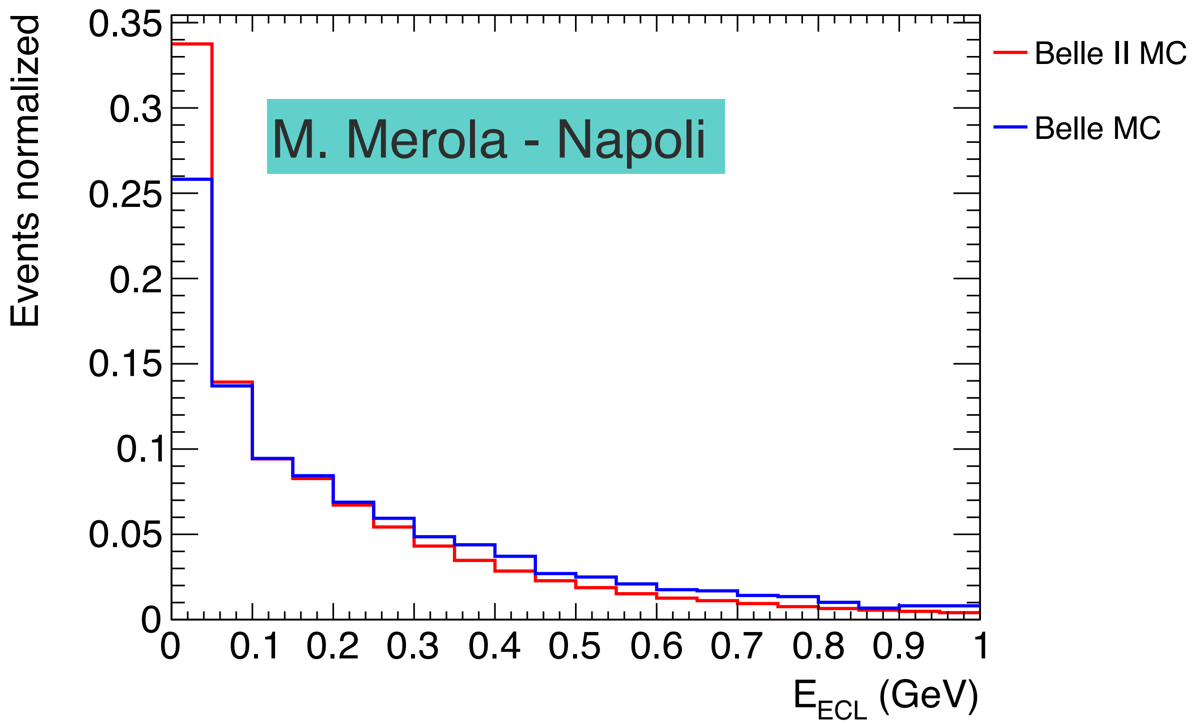
Zoomed view of the vertex region in r--phi

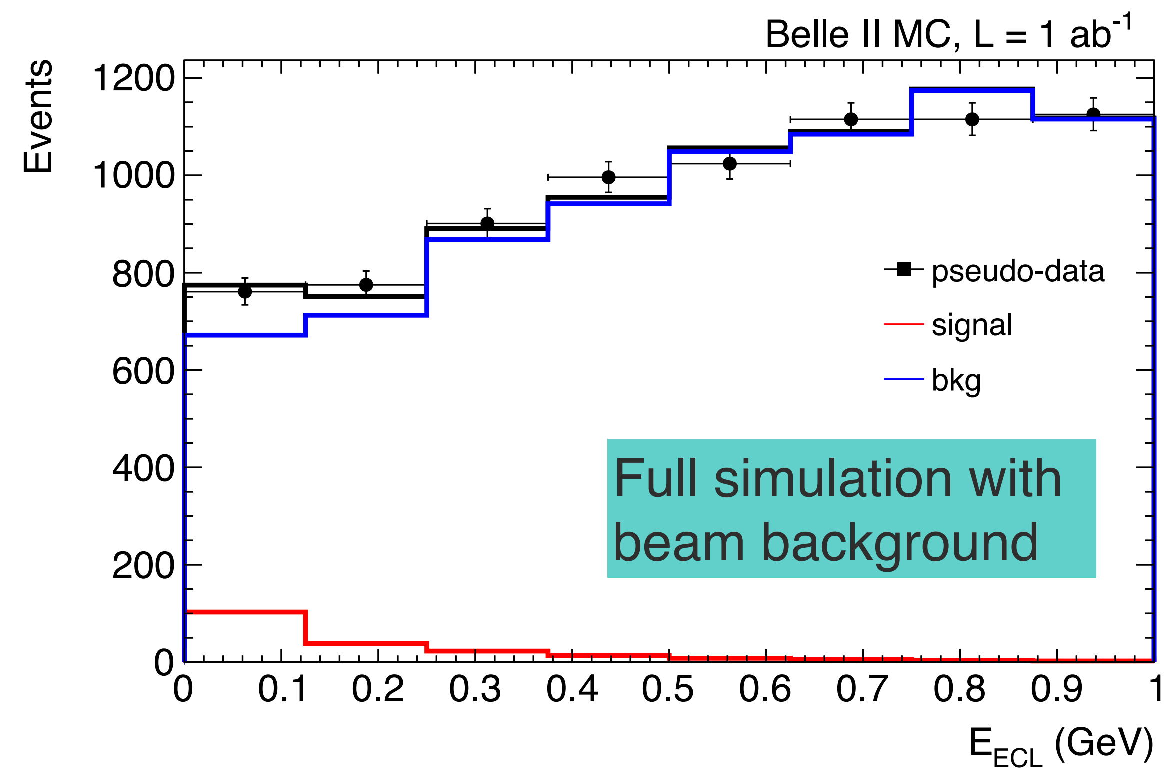


B → τ (→ l ν ν) ν with FEI

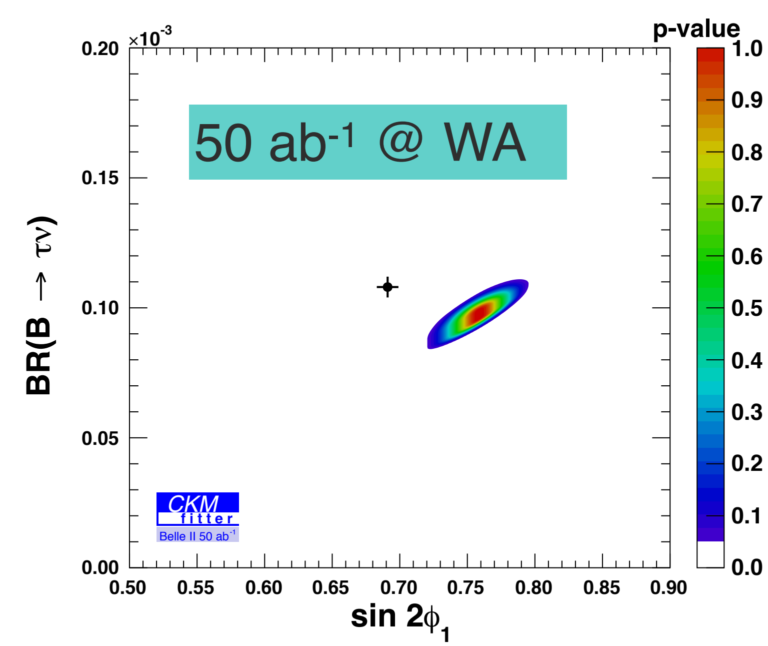
- MC6, BDT Signal optimisation,
- Even with nominal beam background sensitivity comparable to Belle.

$E_{extra} < 1$ GeV	Babar PRD 88, 031102 (2013)	Belle PRL 110, 131801 (2013)	Belle II (this analysis)
Signal Efficiency (‰)	0.72	1.1	2.2





ab^{-1}	1		5		50	
	Had	**SL**	**Had**	**SL**	**Had**	**SL**
Stat [%]	**29**	19	13	9	4	3
Sys[%]	13	18	**7**	9	5	5
Total[%]	32	26	15	12	**6**	**5**

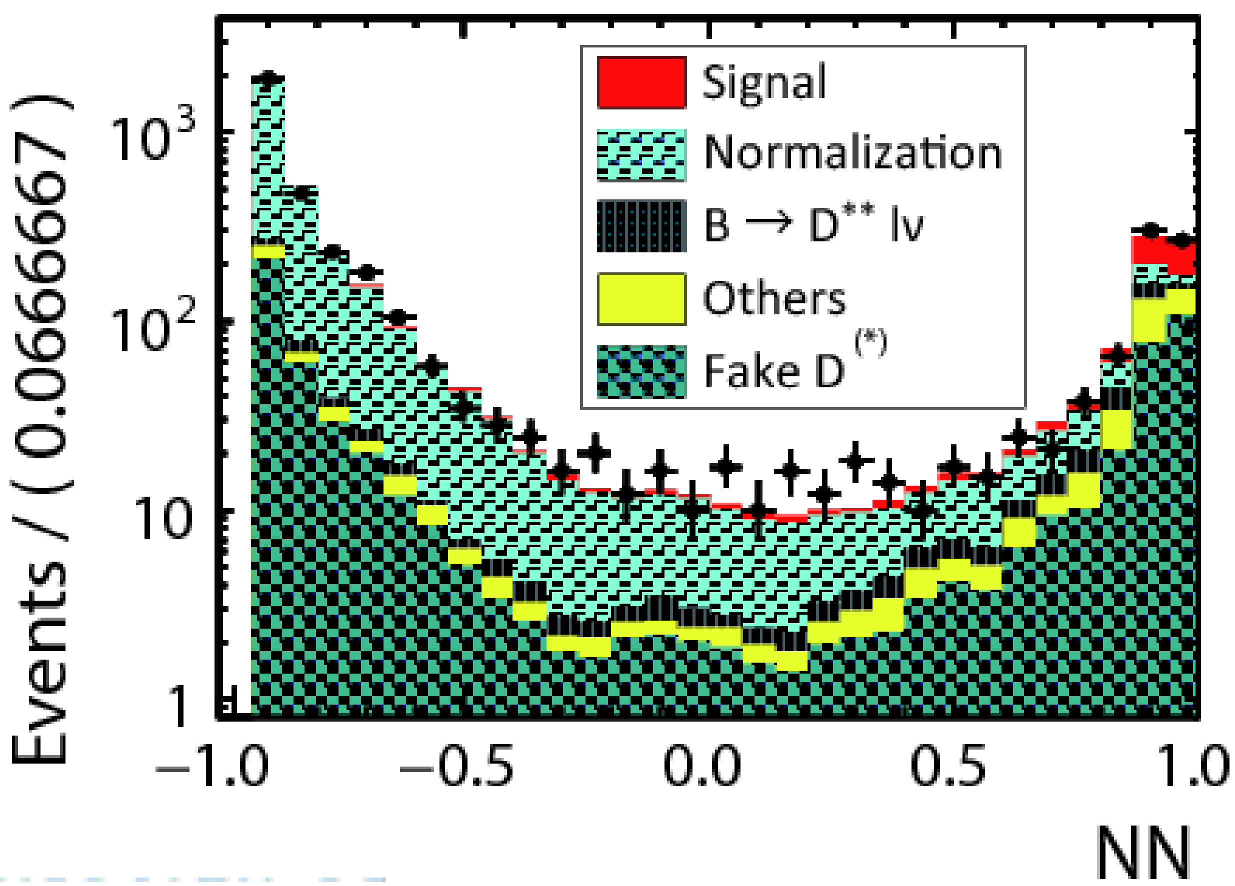


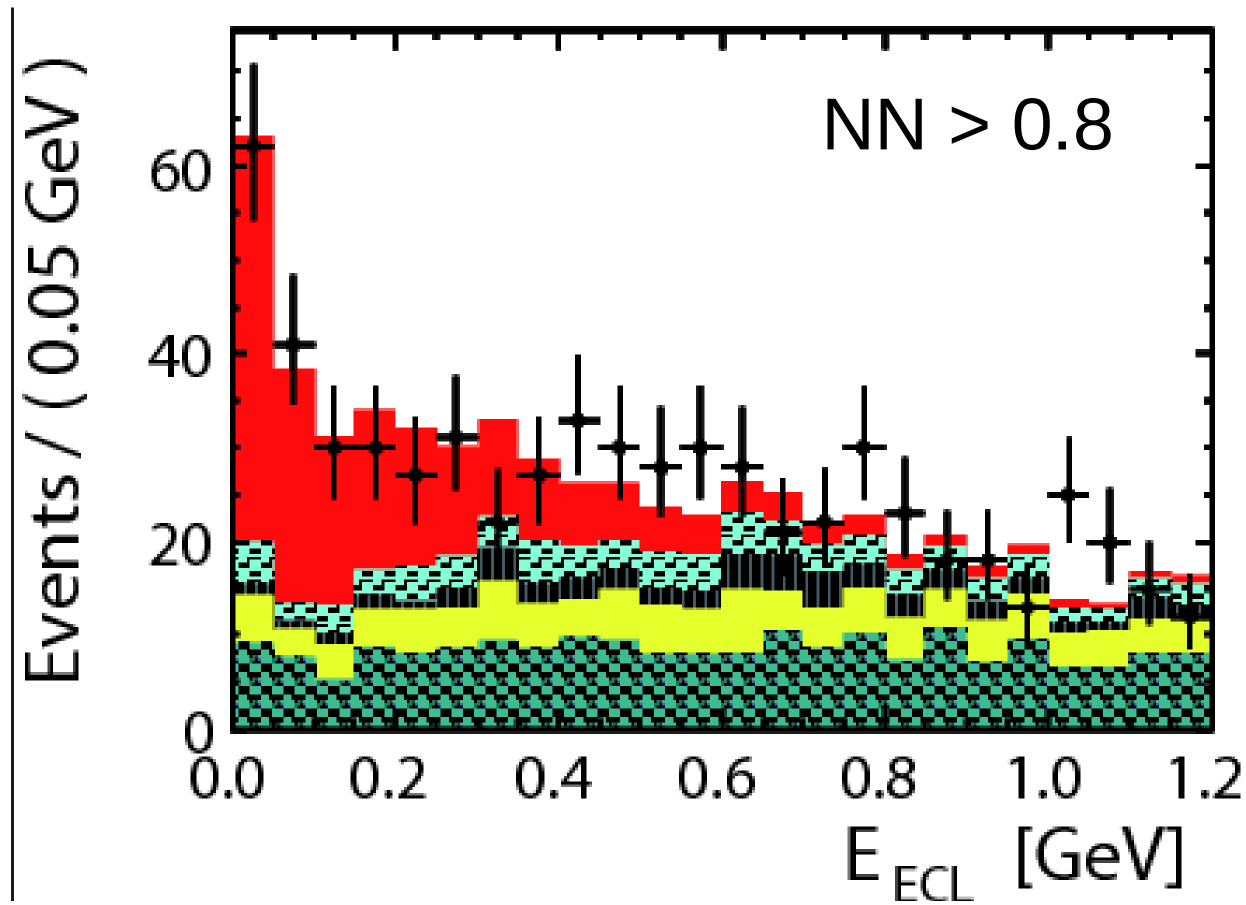
B→ D(*) τ ν

Belle, Phys.Rev.D 92, 072014 (2015)
Belle, Phys.Rev.D 94, 072007 (2016)
Belle, arXiv:1612.00529 (to PRL)

- Belle has 4 approaches
  - τ → l ν ν [had tag, SL tag, untagged]
  - τ → h ν [had tag]
- First application of semileptonic tagging for B →D(*)τν

R(D*) = 0.302 ± 0.030 ± 0.011

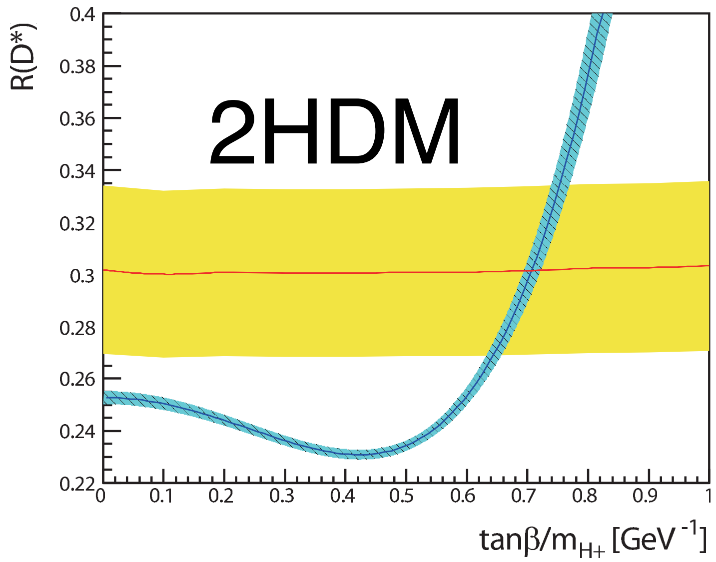


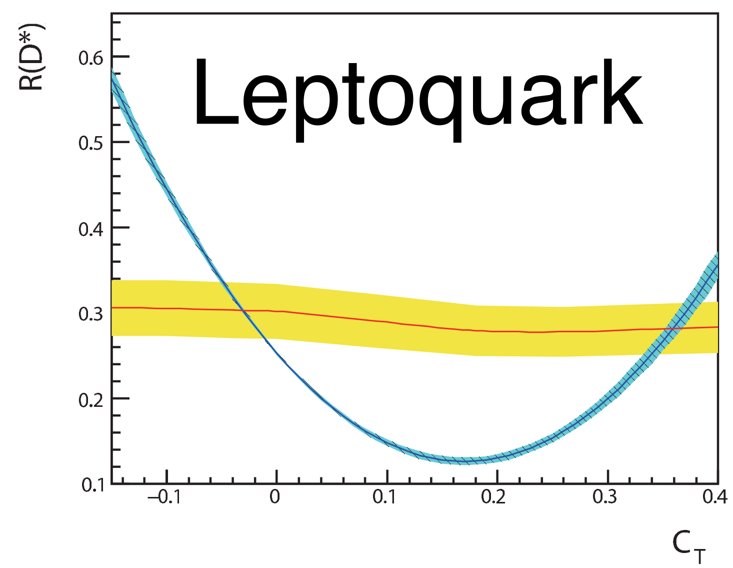


Limits on Type II 2HDM From Belle

Belle, Phys.Rev.D 94, 072007 (2016)

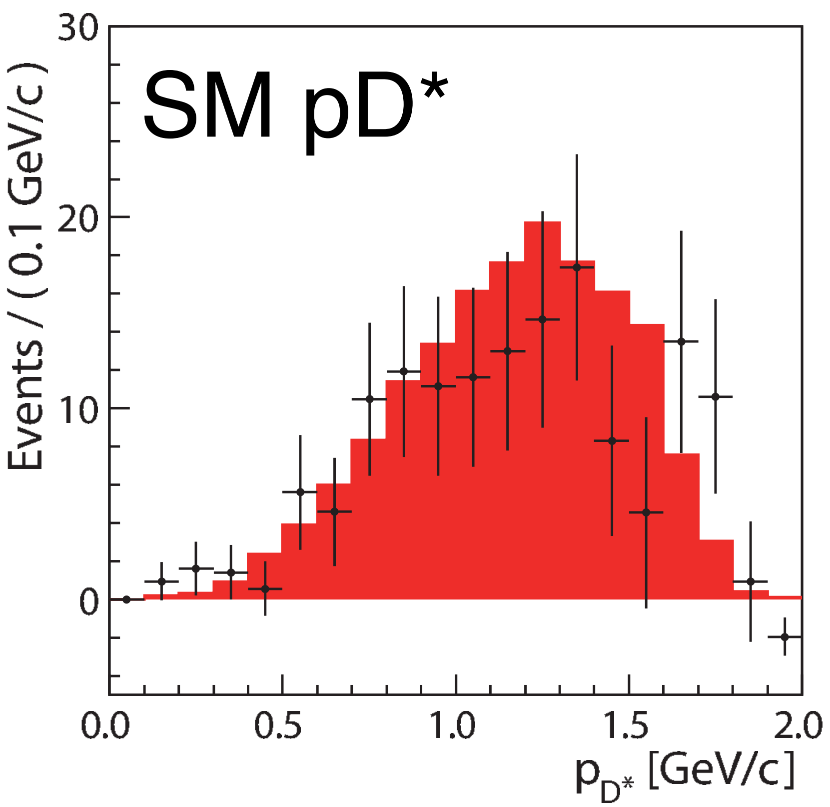
$B \to D^* \tau \nu$

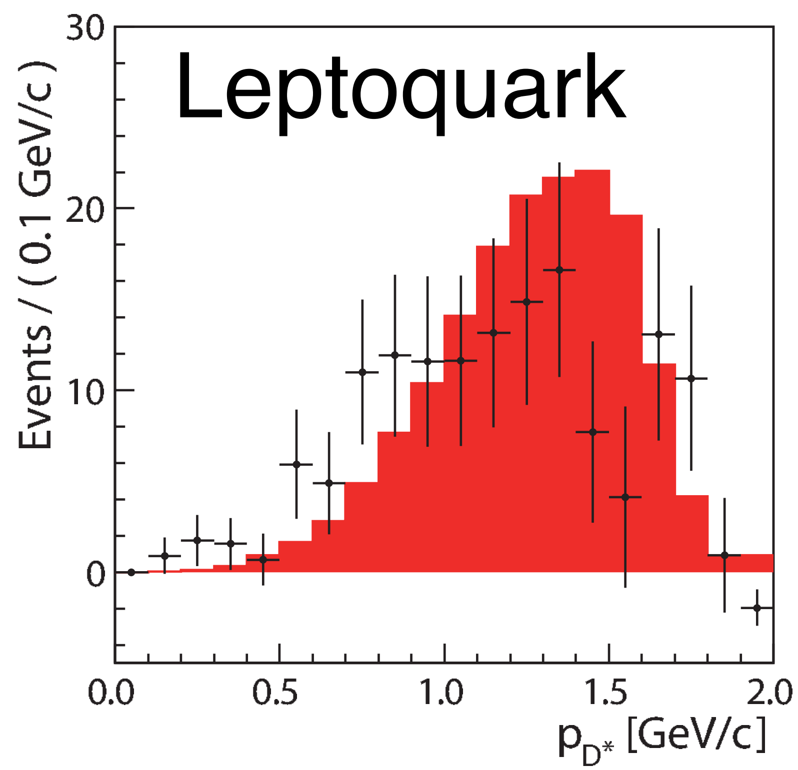




χ^2/ndf = 20.3/19, p = 37.6 %

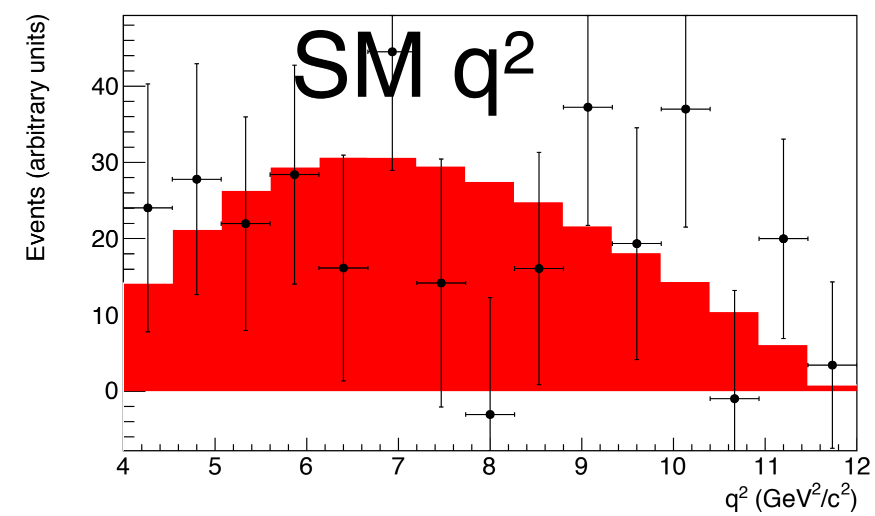
χ^2/ndf = 35.1/19, p = 1.4 %

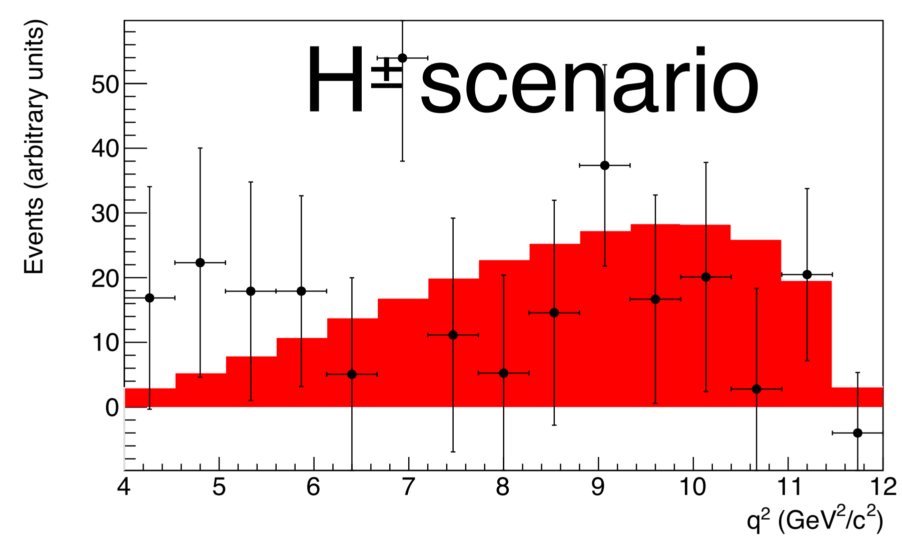




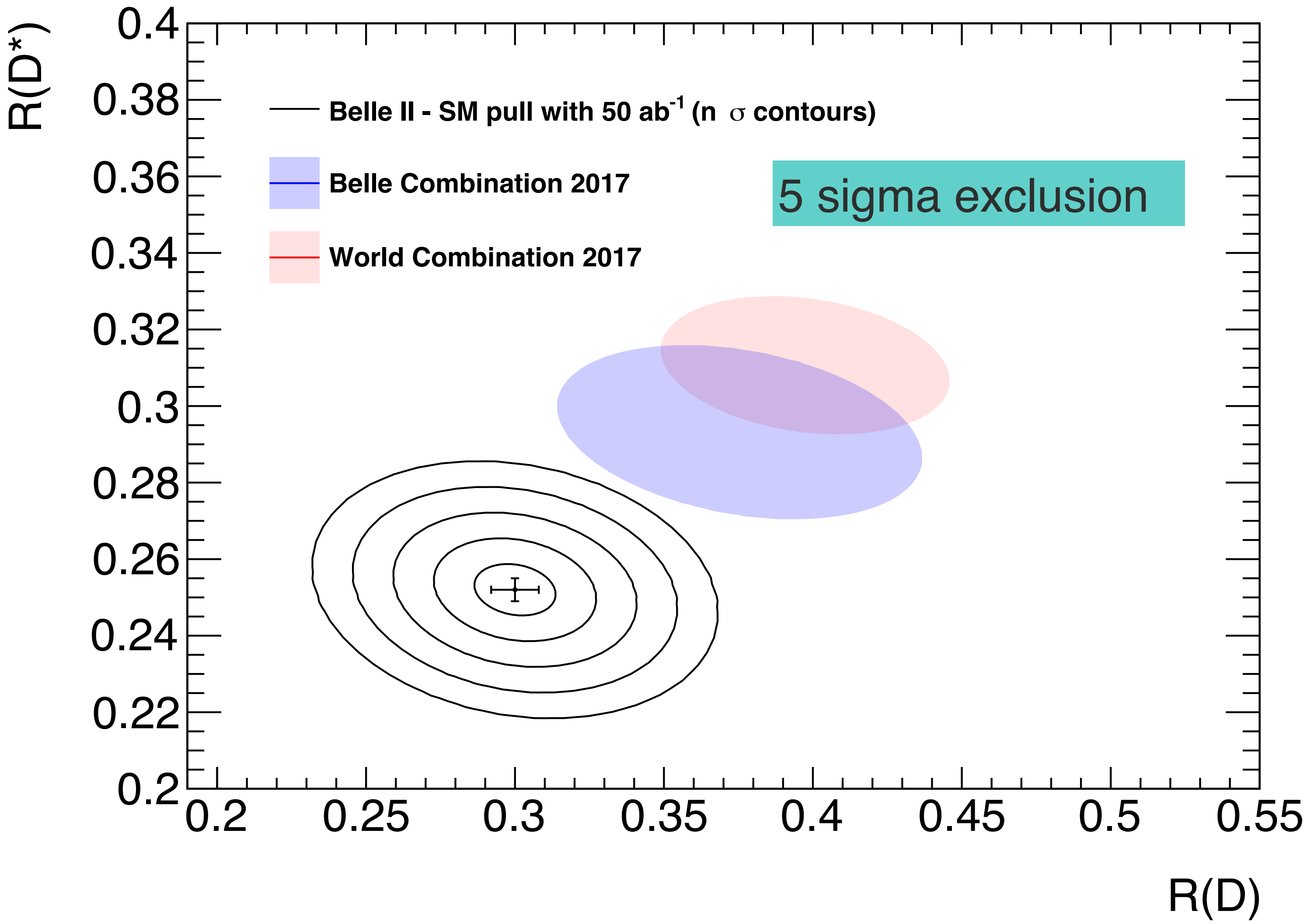
Belle, Phys.Rev.D 92, 072014 (2015)

$B \to D \tau \nu$

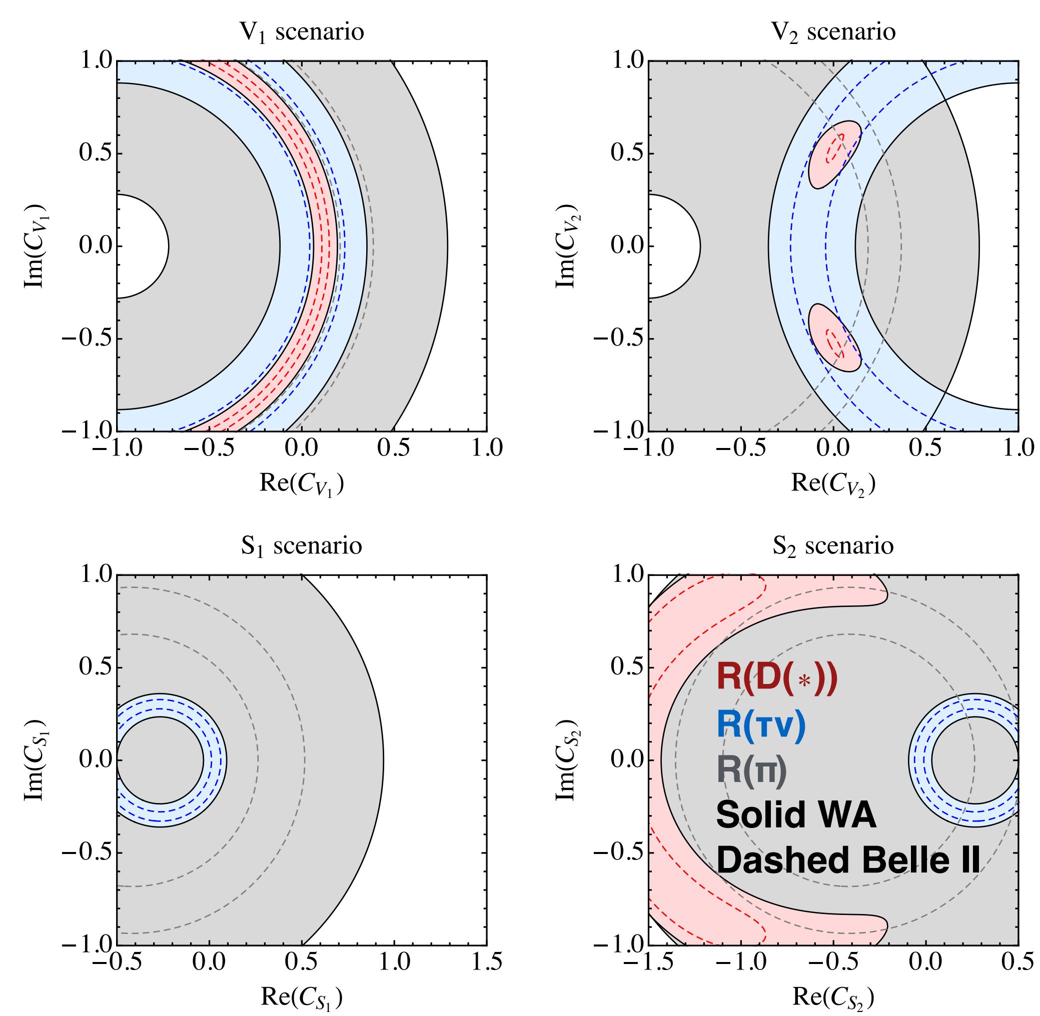




$B \to D^{(*)} \tau \nu$



$$\mathcal{O}_{V_1}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\ell)\,,$$
$$\mathcal{O}_{V_2}^{(q,\nu_\ell)} = (\bar{q}\gamma^\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\ell)\,,$$
$$\mathcal{O}_{S_1}^{(q,\nu_\ell)} = (\bar{q} P_R b)(\bar{\tau} P_L \nu_\ell)\,,$$
$$\mathcal{O}_{S_2}^{(q,\nu_\ell)} = (\bar{q} P_L b)(\bar{\tau} P_L \nu_\ell)\,,$$
$$\mathcal{O}_{T}^{(q,\nu_\ell)} = (\bar{q}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\ell)\,,$$



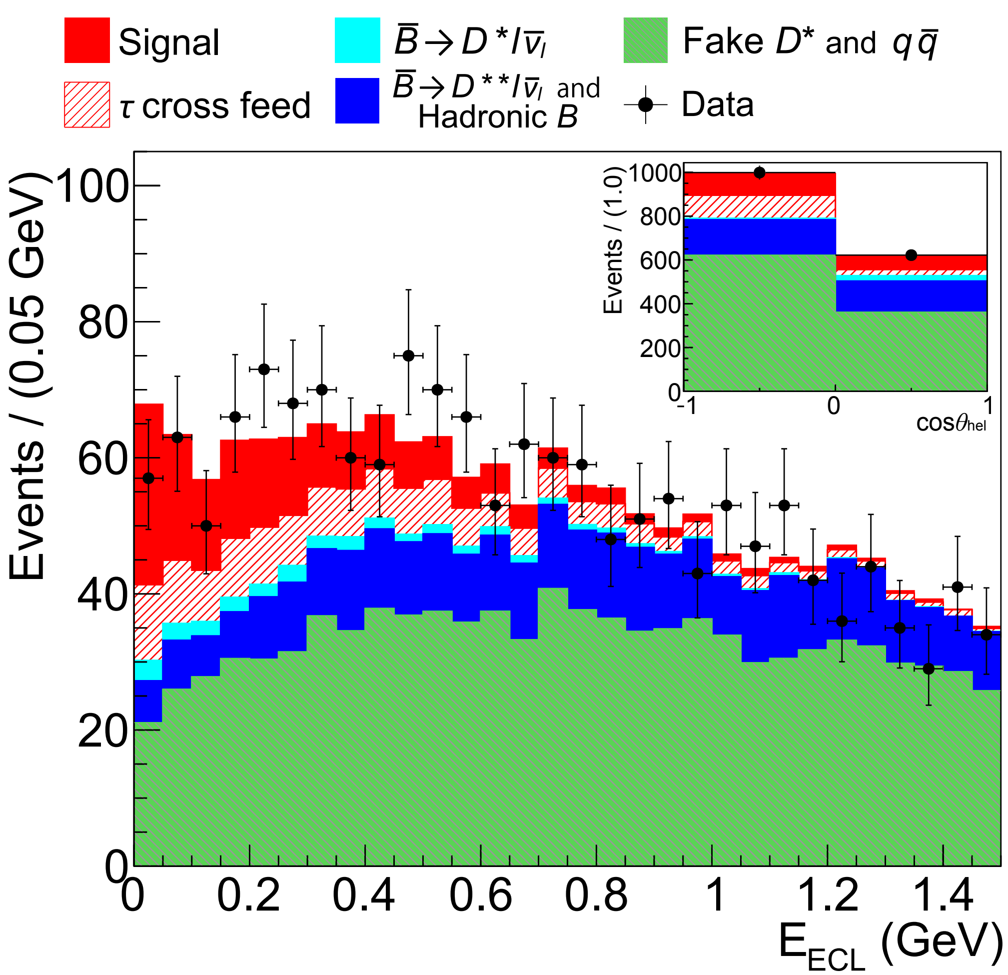
- Reaching this goal needs focus on $B \to D^{**} l \nu$ background. See: https://agenda.hepl.phys.nagoya-u.ac.jp/indico/conferenceDisplay.py?confId=702

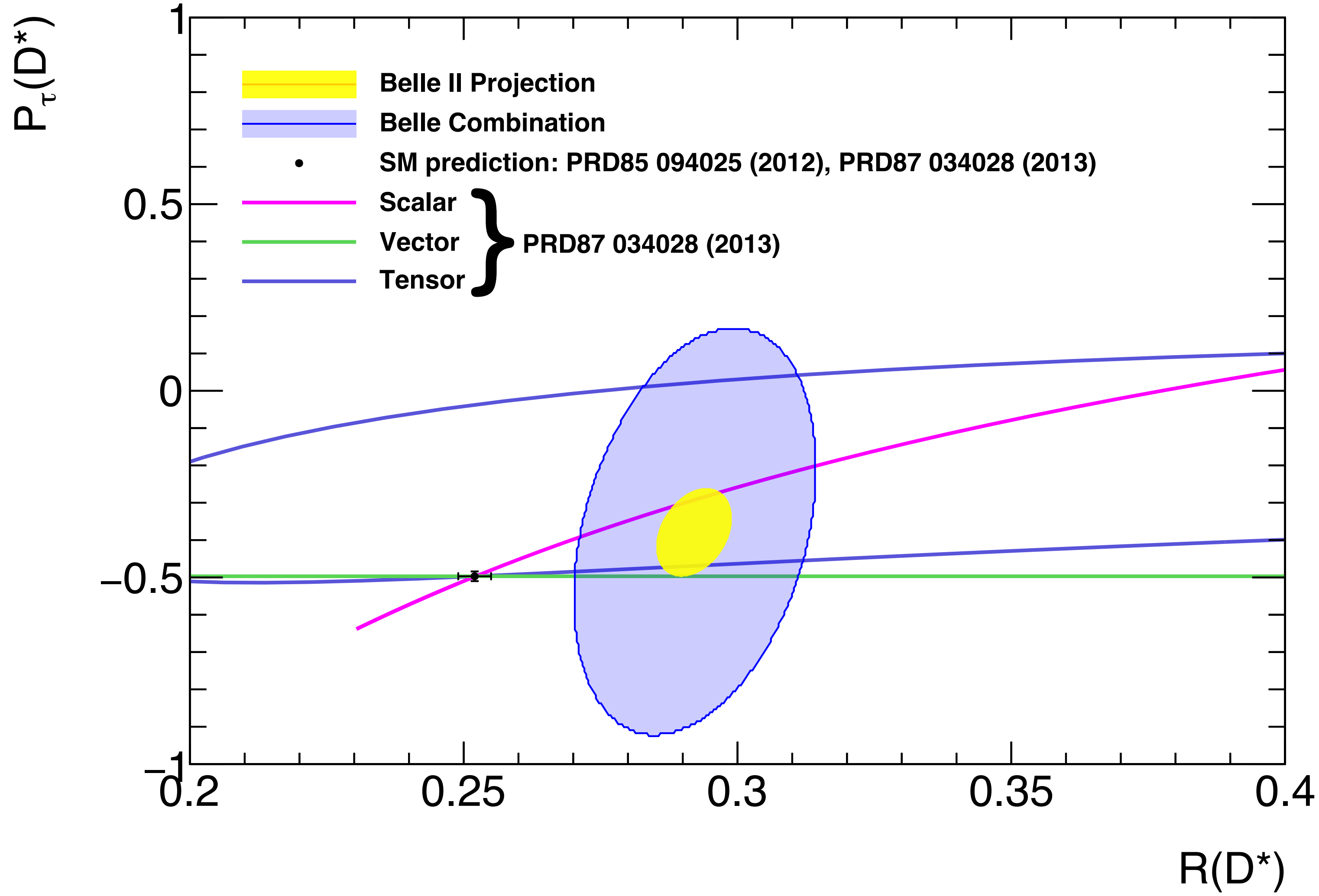
Polarisation

Belle arXiv: 1612.00529 (accepted in PRL)

- P(τ) measured.
  - Strongly stat. limited. & only done in hadronic tag.
- P(D*) possible too

$$R(D^*) = 0.270 \pm 0.035(\text{stat.})\,^{+0.028}_{-0.025}(\text{syst.})$$
$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})\,^{+0.21}_{-0.16}(\text{syst.})$$

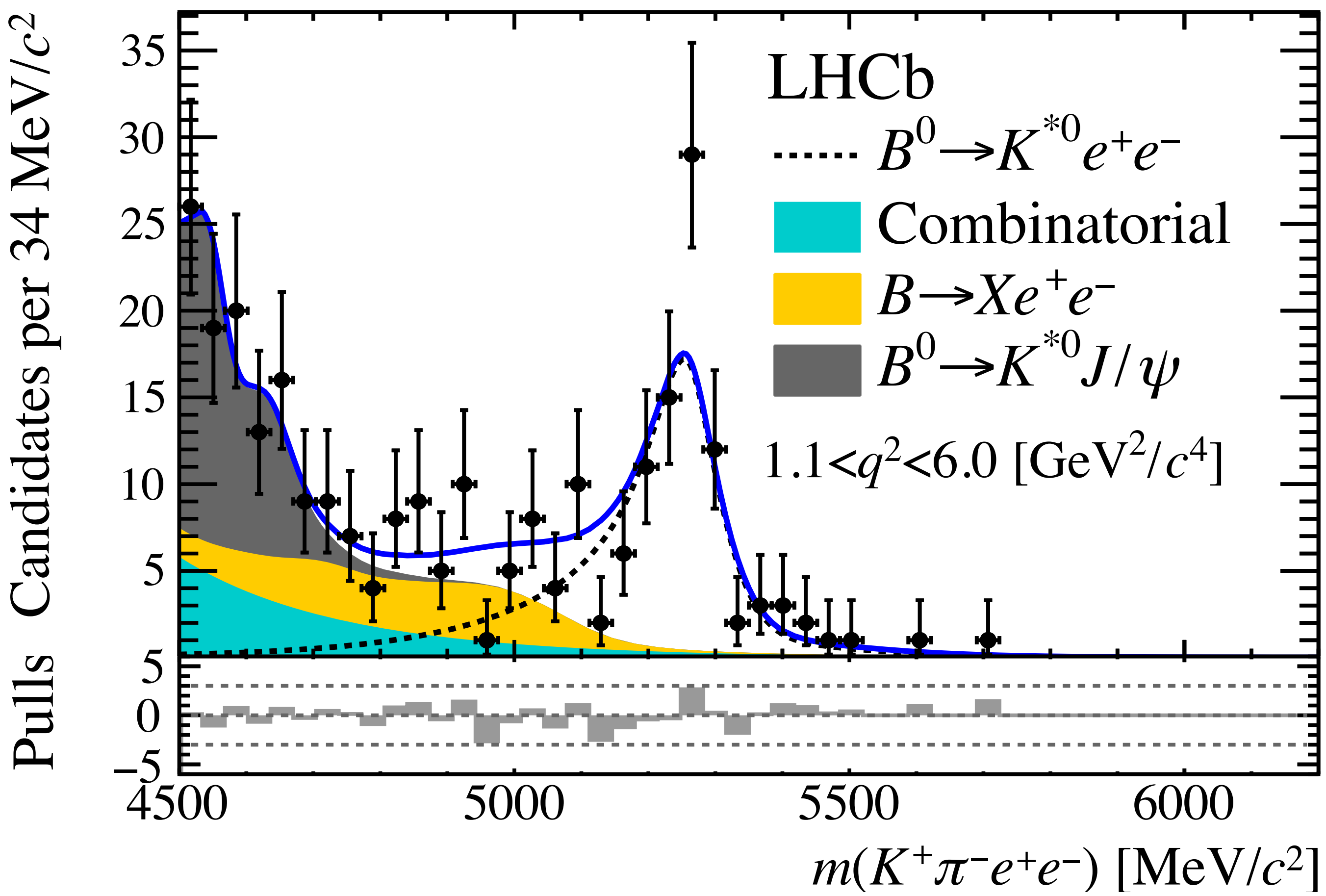


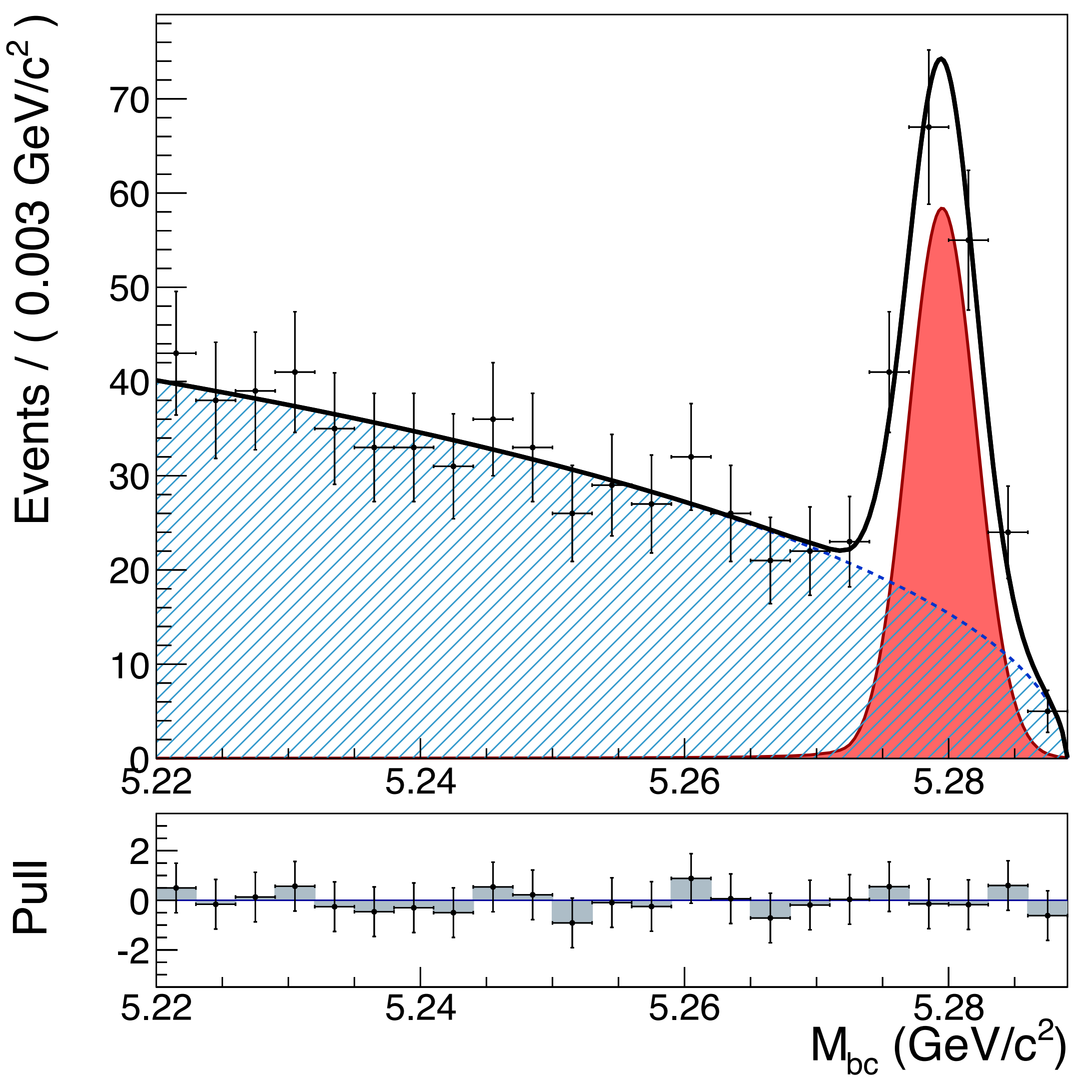


$B \to K^* e^+ e^-$

Belle PRL. 118 (2017) no.11, 111801
LHCb, arXiv:1705.05802
LHCb, PRL 113, 151601 (2014)

Belle (II) Electron reconstruction is minimally affected by material effects and pile-up

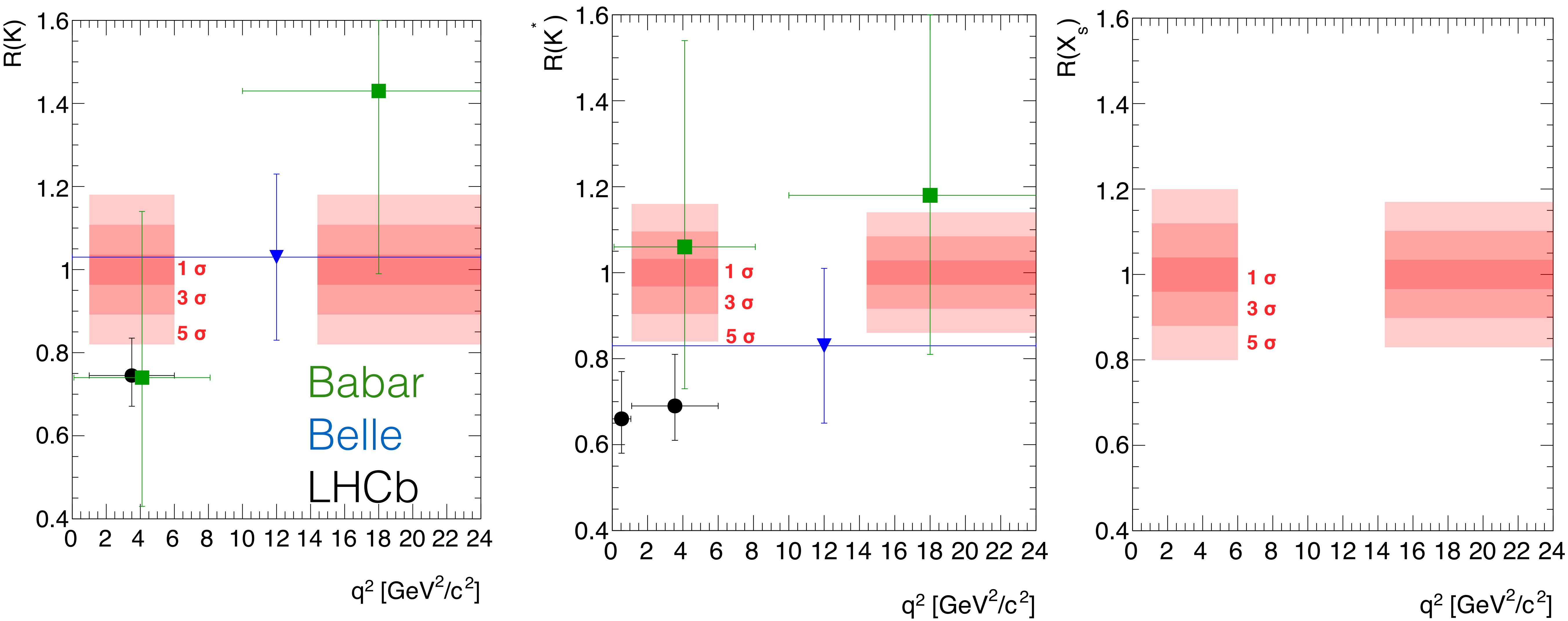




Lepton Flavour Universality Violation

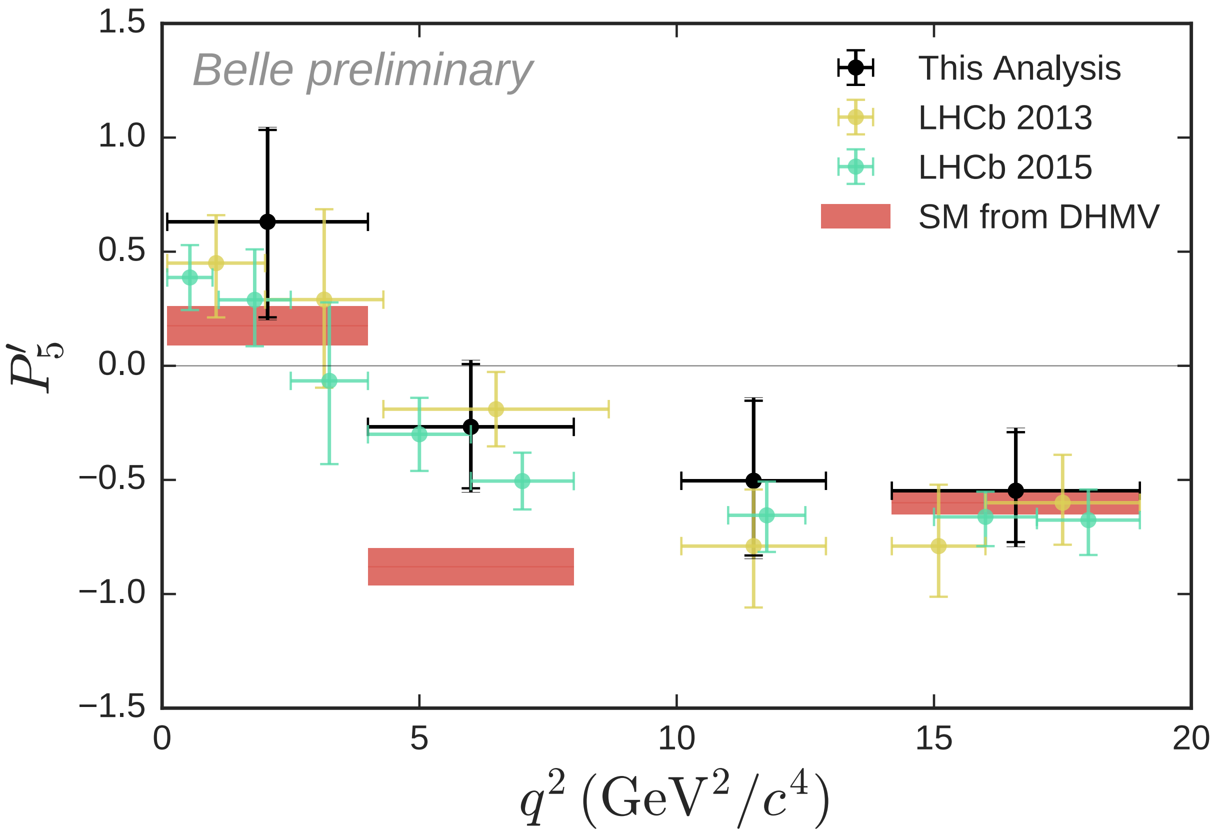
B2TiP Study

- R {K,K*,Xs}: Expect 3-4% precision in each bin.

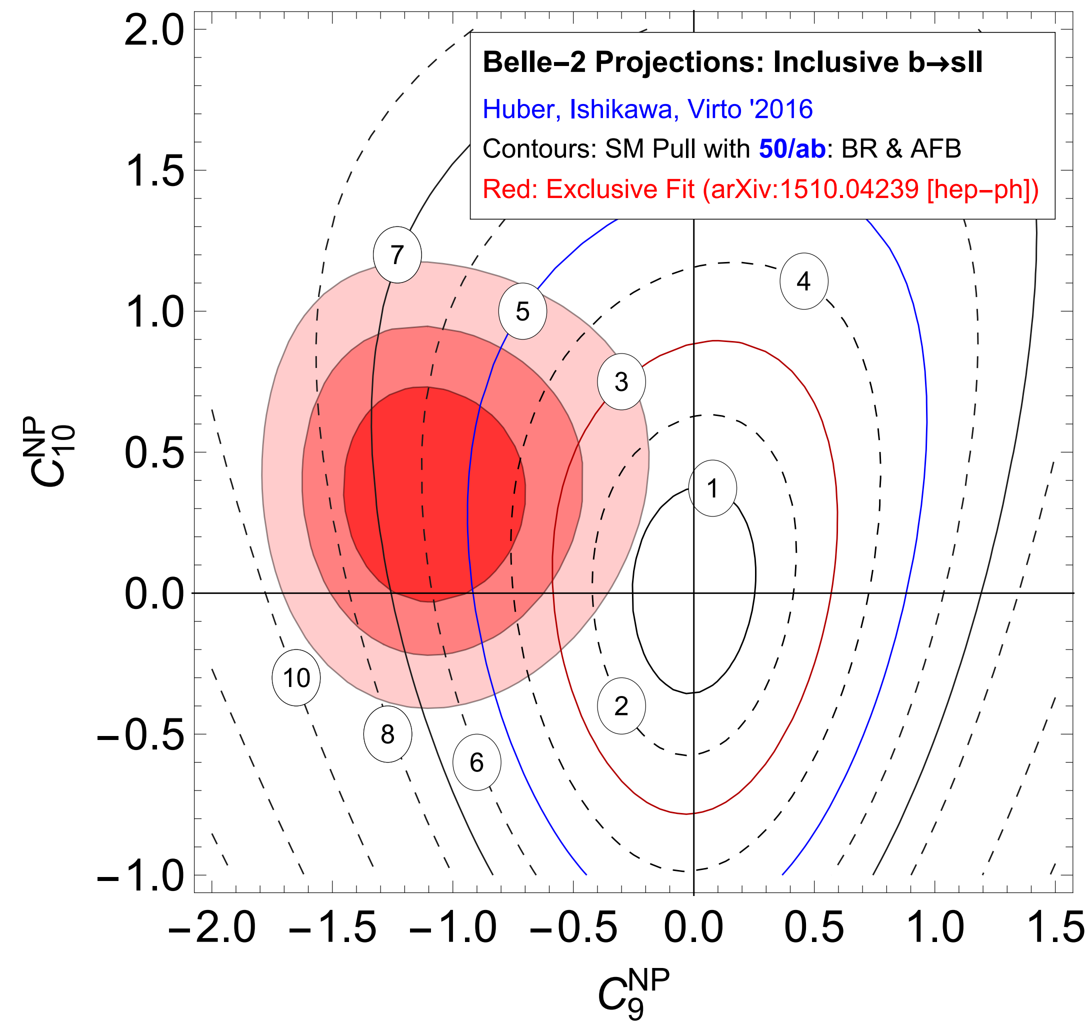


LHCb & Belle results on $B \to K^* l^+ l^-$ (q^2)

$$P_5' = \sqrt{2}\frac{\mathrm{Re}\left(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*}\right)}{\sqrt{\left(|A_0^L|^2 + |A_0^R|^2\right)\left(|A_\parallel^L|^2 + |A_\parallel^R|^2 + |A_\perp^L|^2 + |A_\perp^R|^2\right)}}$$



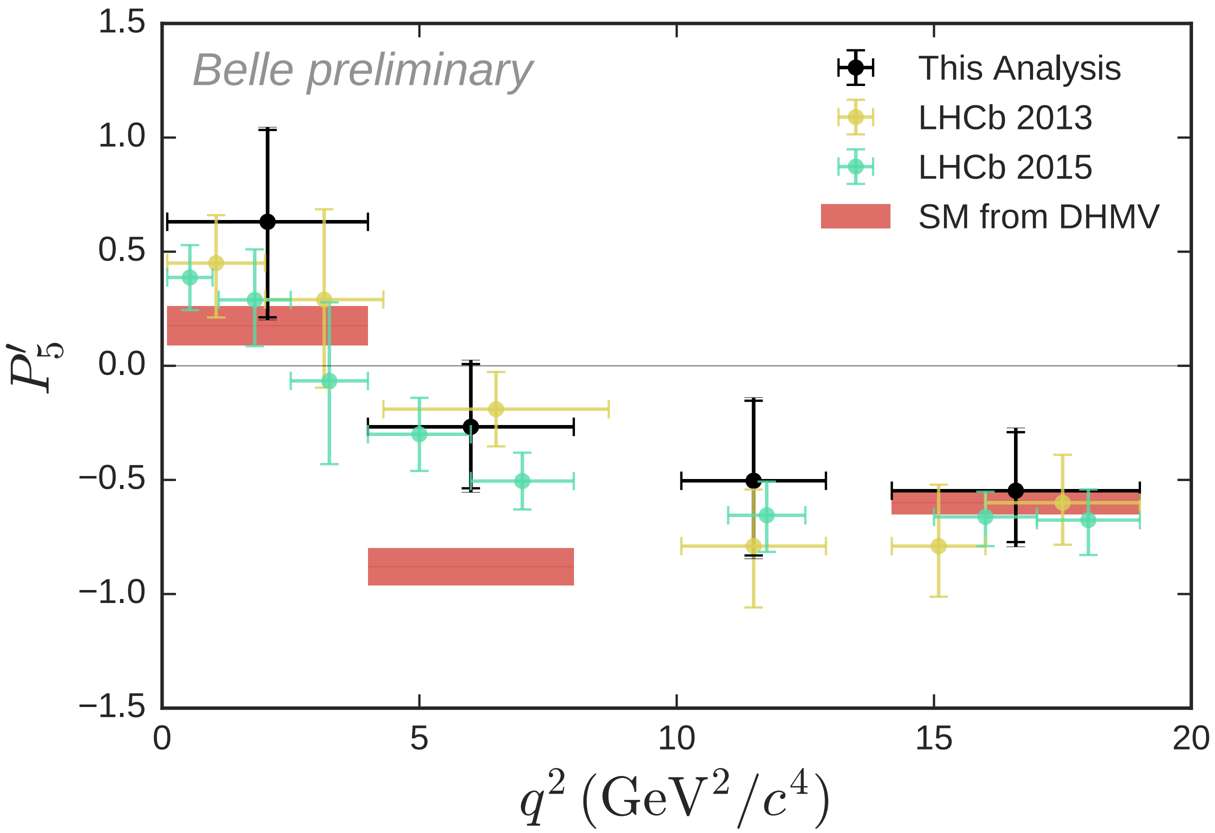
Belle PRL. 118 (2017) no.11, 111801



q^2 GeV^2/c^2	Belle	LHCb 3fb^{-1}	Belle II 50 ab^{-1}
0.1-4	0.416	0.109	-
4.00-8.00	0.277	0.099	**0.024**
10.09-12.0	0.344	0.155	-
14.18-19.00	0.248	0.092	**0.027**

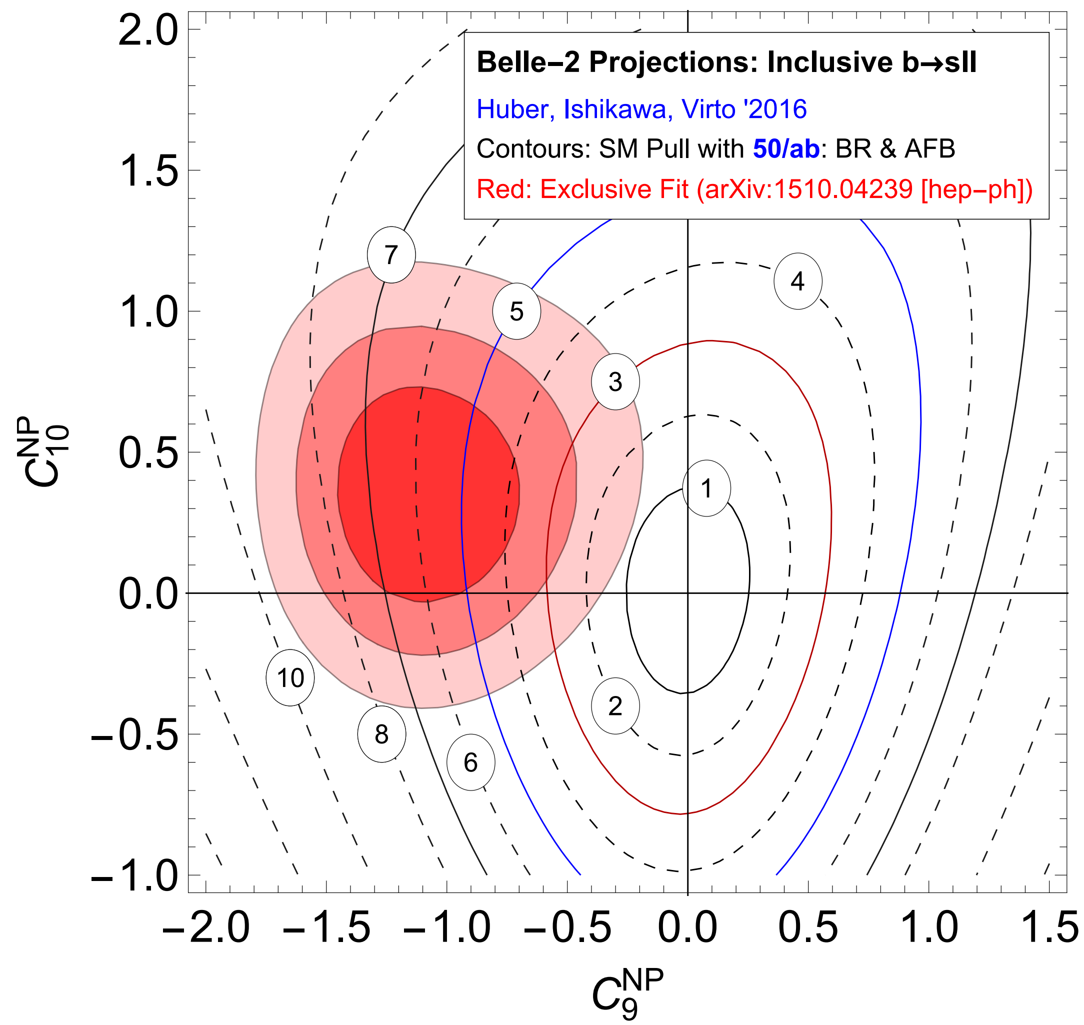
LHCb & Belle results on B→ K* l+l- (q²)

$$P_5' = \sqrt{2}\frac{\mathrm{Re}\left(A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*}\right)}{\sqrt{\left(|A_0^L|^2 + |A_0^R|^2\right)\left(|A_\parallel^L|^2 + |A_\parallel^R|^2 + |A_\perp^L|^2 + |A_\perp^R|^2\right)}}$$



Belle PRL. 118 (2017) no.11, 111801

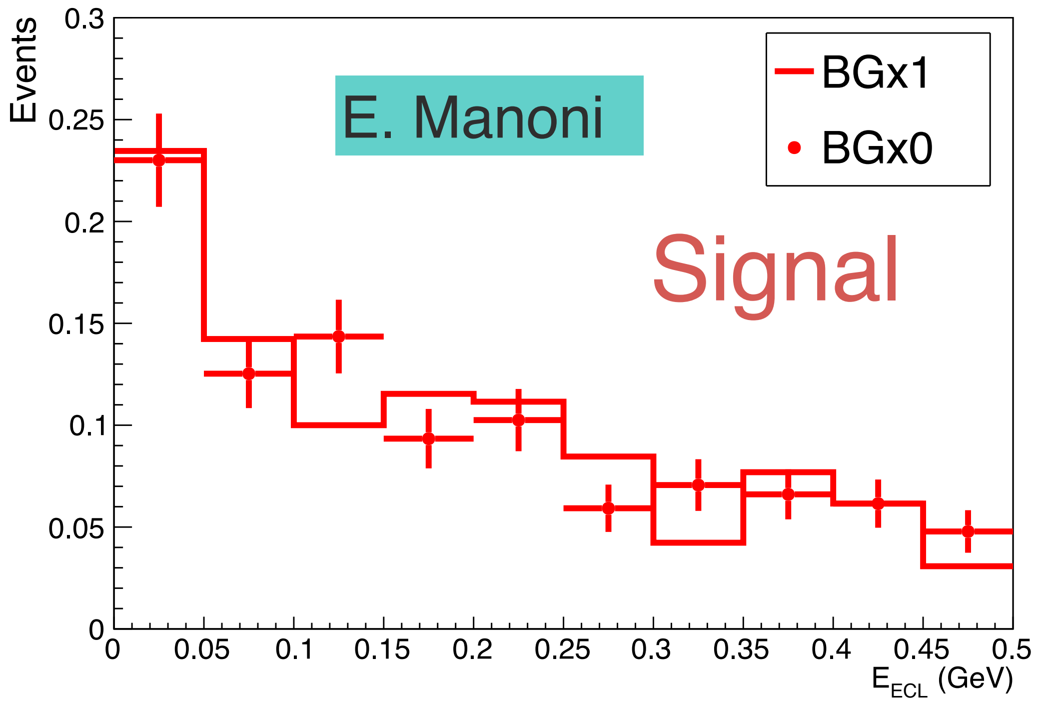
→ Belle II will also study inclusive

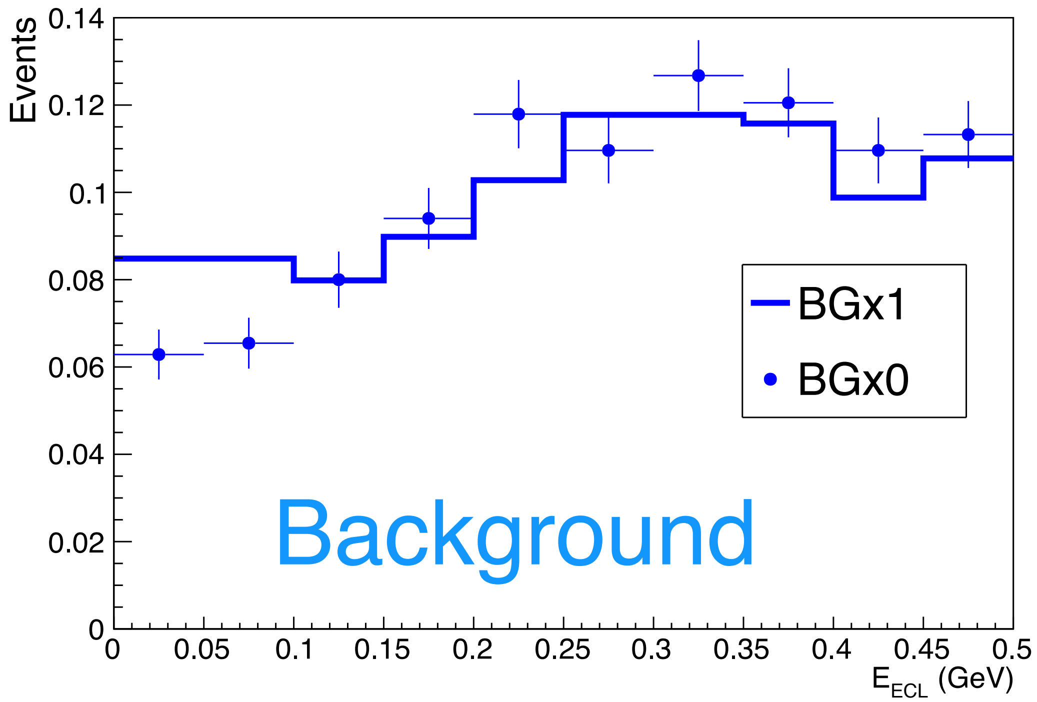


q² GeV²/c²	Belle	LHCb 3fb⁻¹	Belle II 50 ab⁻¹
0.1-4	0.416	0.109	-
4.00-8.00	0.277	0.099	**0.024**
10.09-12.0	0.344	0.155	-
14.18-19.00	0.248	0.092	**0.027**

B → K ν ν

Belle II Full Simulation

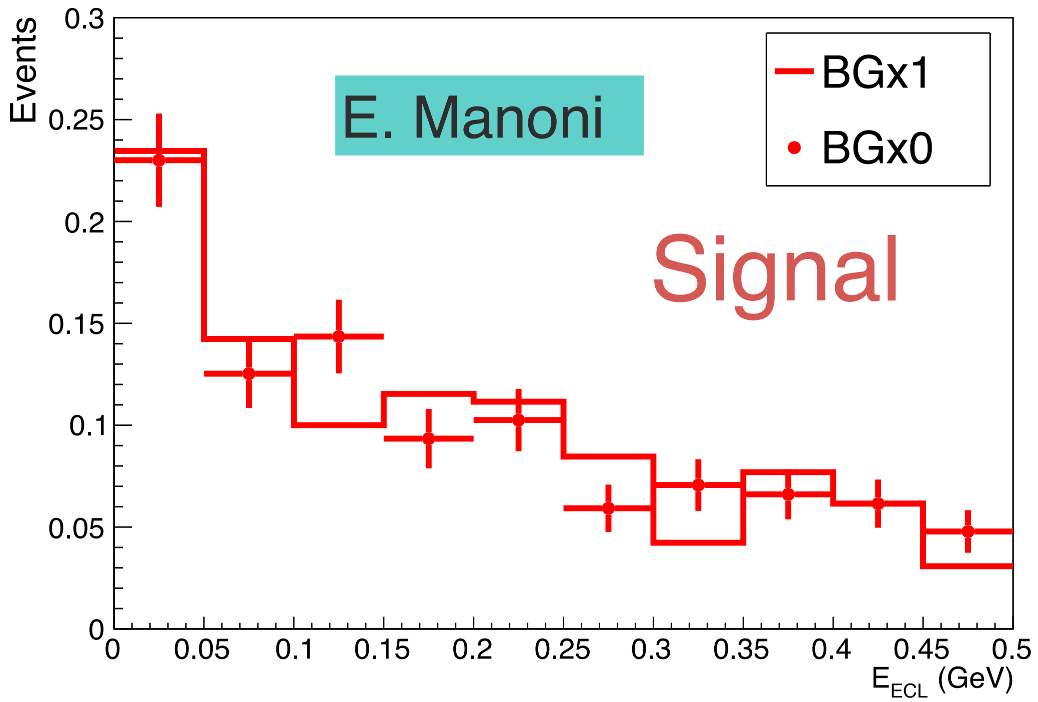


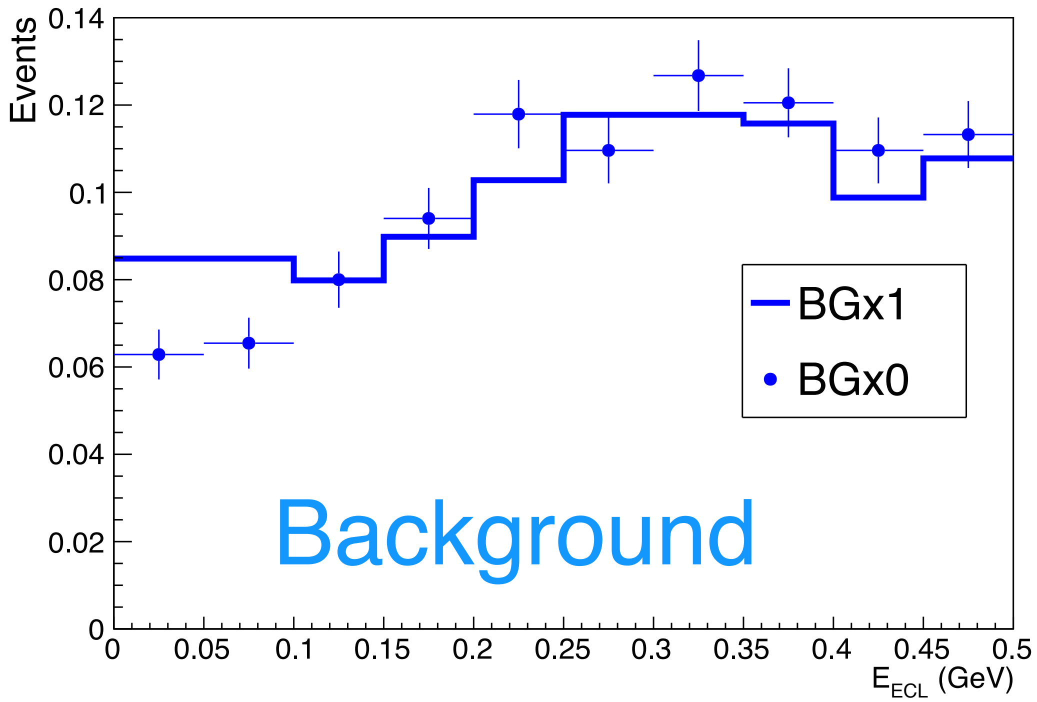


Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B^+ \to K^+ \nu\bar{\nu})$	$< 450\%$	38%	12%
$B(B^0 \to K^{*0} \nu\bar{\nu})$	$< 180\%$	35%	11%
$F_L(B^0 \to K^{*0} \nu\bar{\nu})$	–	–	0.11
$B(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5
$B(B^+ \to K^+ \tau^+ \tau^-) \times 10^5$	< 32	< 6.5	< 2.0
$B(B^0 \to \tau^+ \tau^-) \times 10^5$	< 140	< 30	< 9.6

Belle II Full Simulation

B→K ν ν: Do not expect large loss of resolution in E_{ECL} with background.





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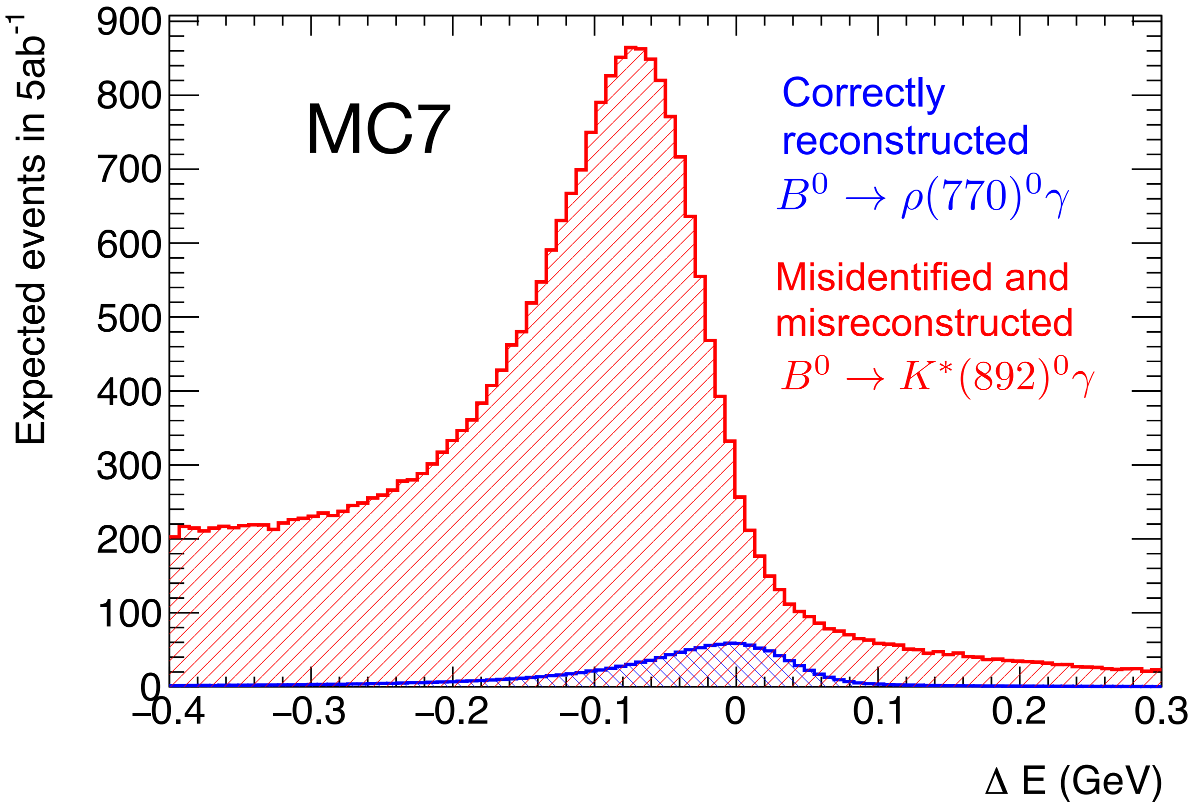
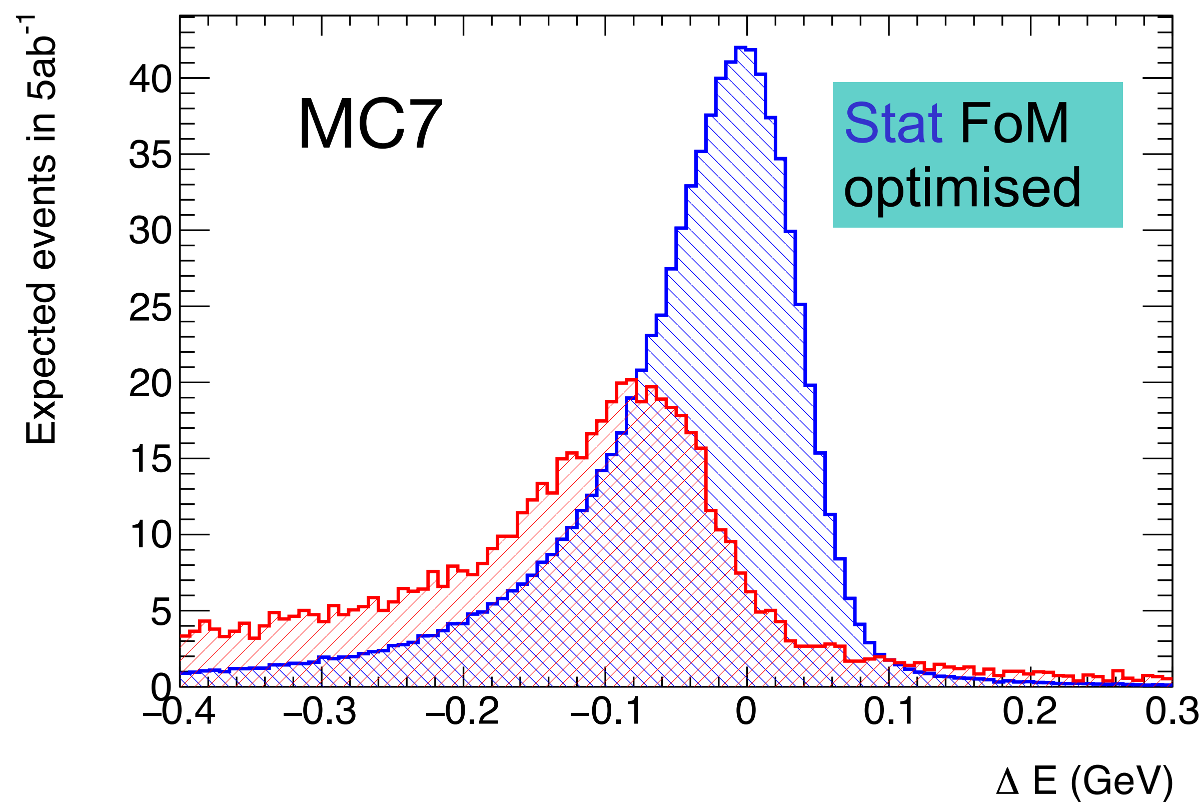
$B(B^0 \to \tau^+ \tau^-) \times 10^5$	< 140	< 30	< 9.6

b→d couplings: B→ ργ

Belle II Full Simulation & B2TiP study

- Without K/π ID
- Belle II K/π ID





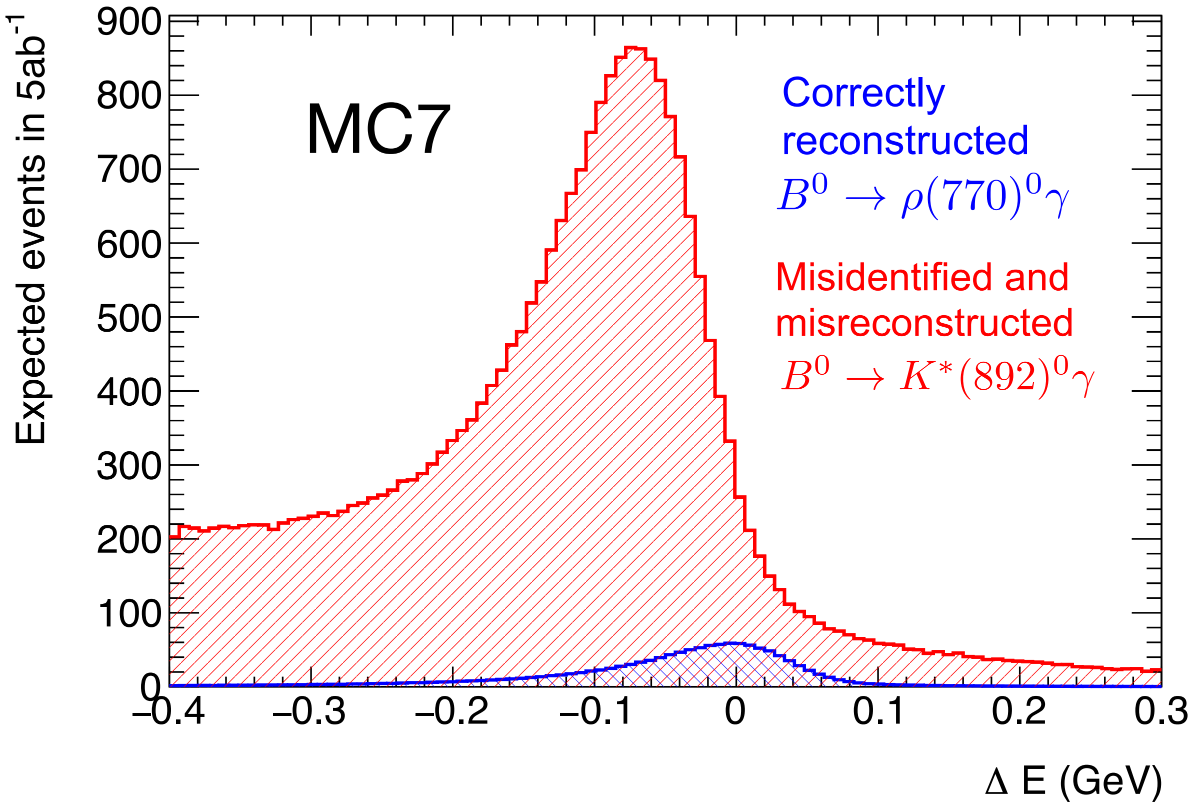
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\Delta_{0+}(B \to \rho\gamma)$	39%	12%	3.9%
$A_{CP}(B^+ \to \rho^+\gamma)$	30%	9.6%	3.0%
$S_{CP}(B^0 \to \rho^0\gamma)$	63%	19%	6.4%
$A_{CP}(B^0 \to \rho^0\gamma)$	44%	12%	3.8%
$\Delta A_{CP}(B \to \rho\gamma)$	77%	16%	4.8%

b→d couplings: B→ ργ

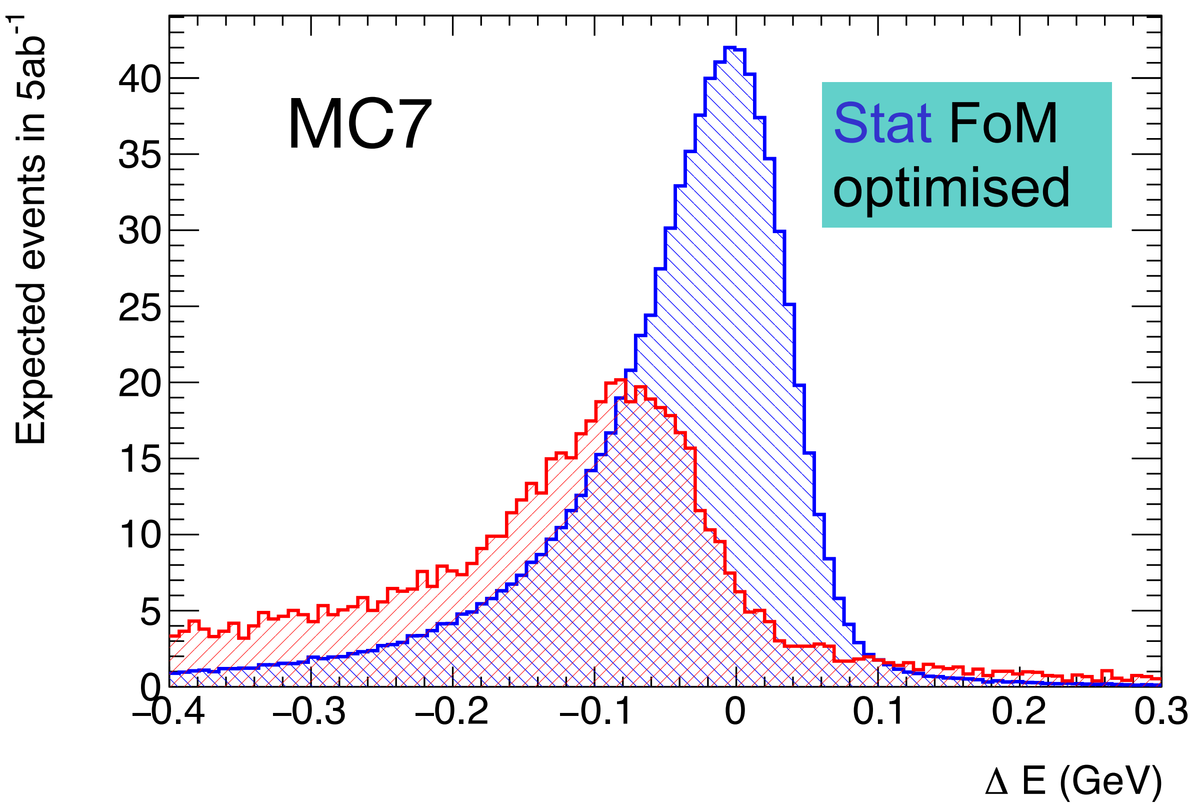
Belle II Full Simulation & B2TiP study

K/π fake rates < 2x smaller in Belle II: separates b→ d from b→ s

- Without K/π ID



- Belle II K/π ID



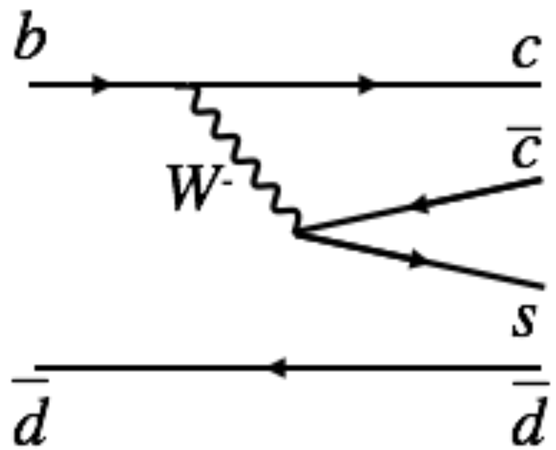
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\Delta_{0+}(B \to \rho\gamma)$	39%	12%	3.9%
$A_{CP}(B^+ \to \rho^+\gamma)$	30%	9.6%	3.0%
$S_{CP}(B^0 \to \rho^0\gamma)$	63%	19%	6.4%
$A_{CP}(B^0 \to \rho^0\gamma)$	44%	12%	3.8%
$\Delta A_{CP}(B \to \rho\gamma)$	77%	16%	4.8%

Time dependent CP violation

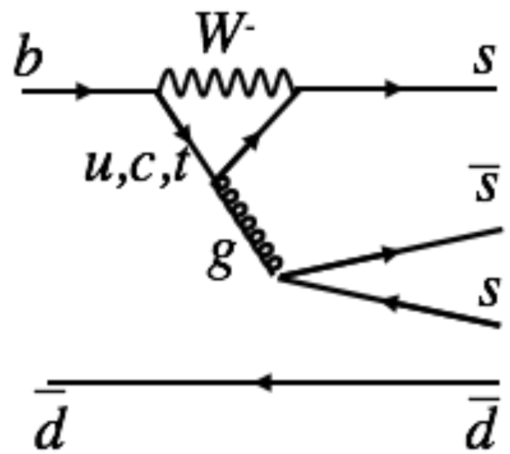
Belle II Analysis

Belle II Full Simulation

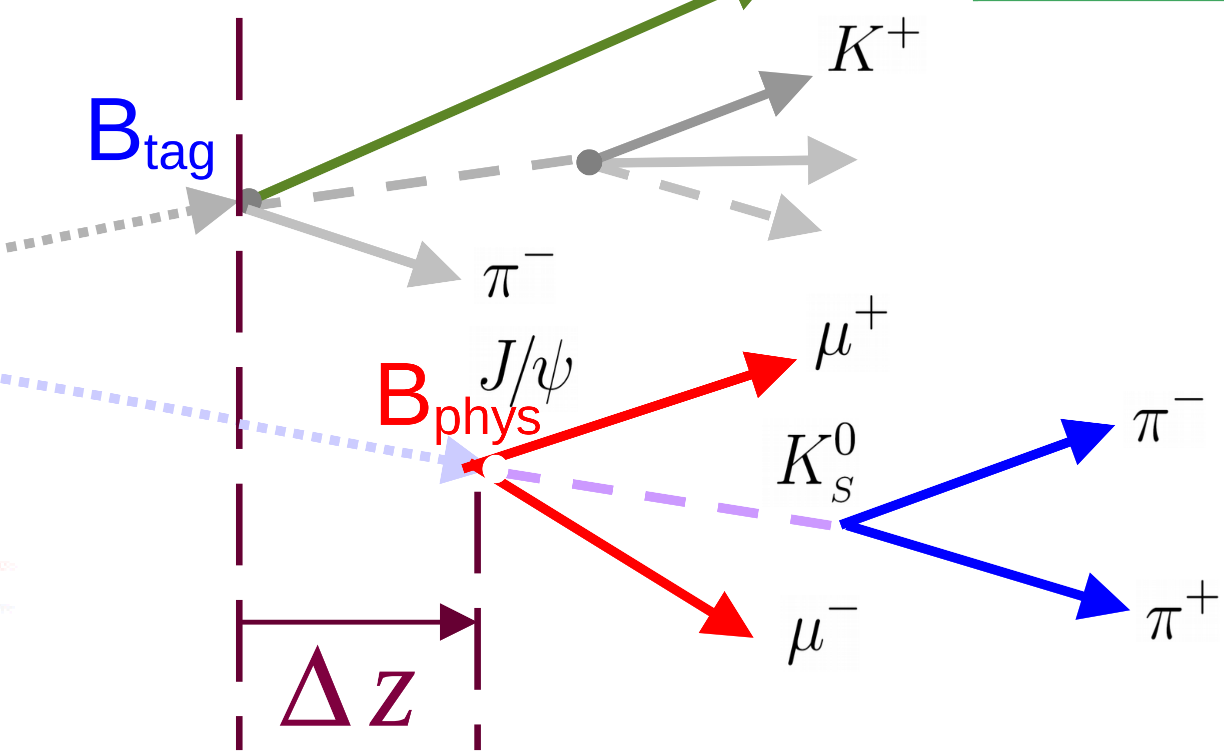
- Tree

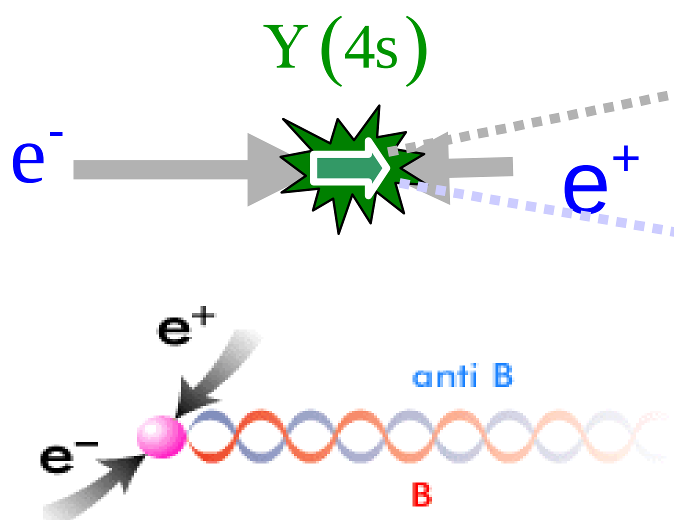


- Gluonic Penguin (NP sensitive)



B→J/ψ Ks	B_{CP} μm	B_{tag} μm	Δt ps
Belle II	22	52	0.71
Belle	63	89	0.92



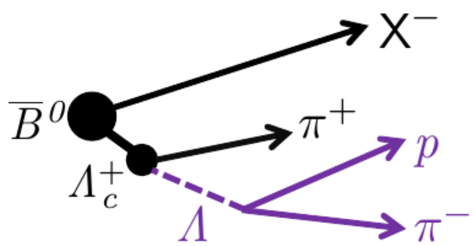


Coherent B meson pair production

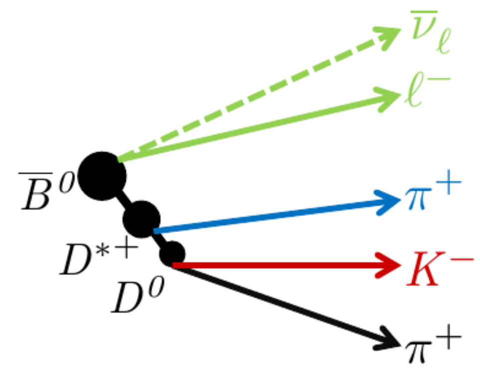
Belle ~ 200 μm
Belle II ~ 130 μm

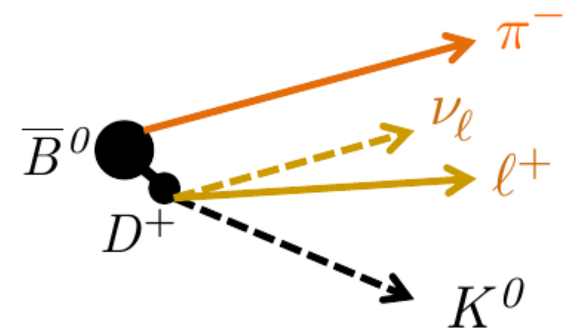
Flavour Tagging

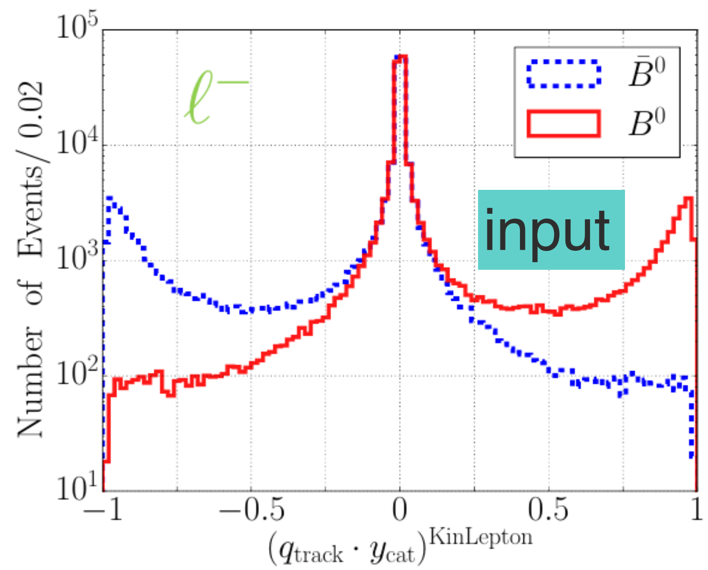
- Categories based on different signatures

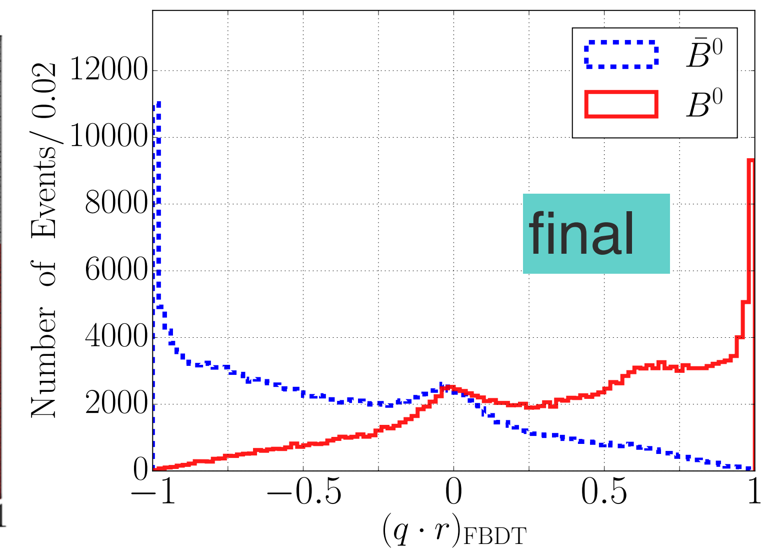


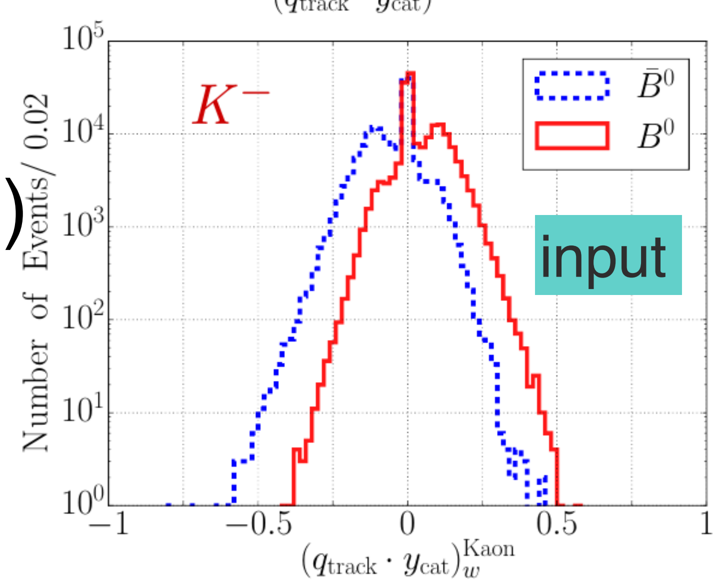
Categories	$\varepsilon_{\text{eff}}(\%)$	$\Delta\varepsilon_{\text{eff}}(\%)$
Electron	5.26	−0.05
IntermediateElectron	1.06	−0.02
Muon	5.55	−0.02
IntermediateMuon	0.17	−0.01
KinLepton	10.86	−0.07
IntermediateKinLepton	0.98	−0.04
Kaon	21.83	−1.72
KaonPion	15.12	−0.87
SlowPion	7.96	−0.23
FSC	13.11	−0.33
MaximumPstar	13.24	0.39
FastPion	2.58	−0.06
Lambda	1.98	0.36

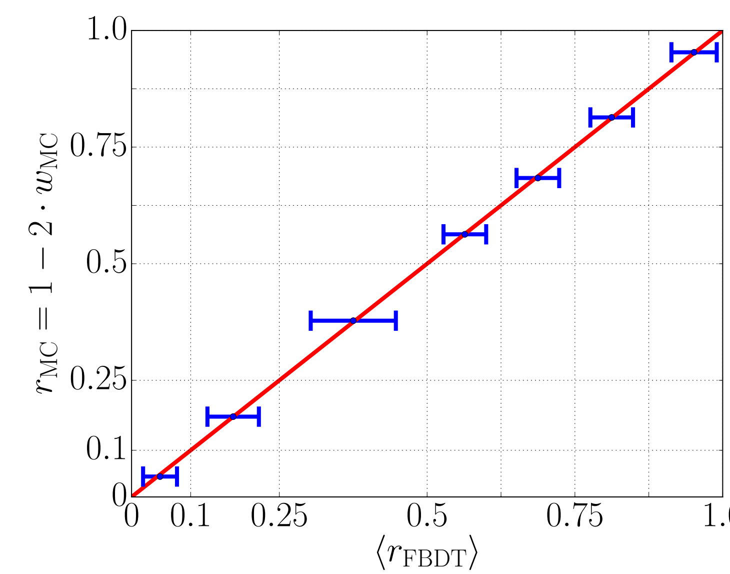










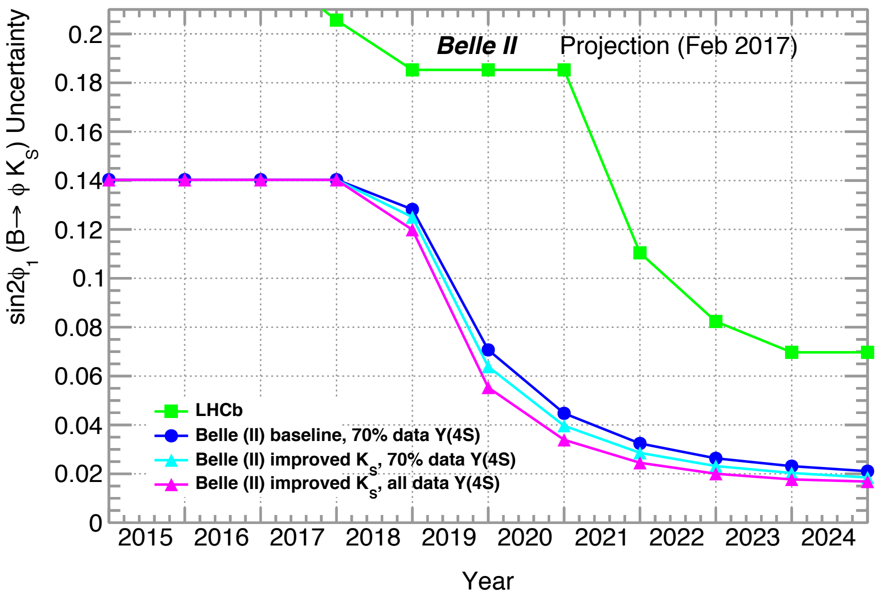


- Belle II: 35% (varies with release)
  - few% less w/ beam bkg
- Belle (this algo): 32%
- Belle (old algo):29%

Time dependent CP Violation with Penguins

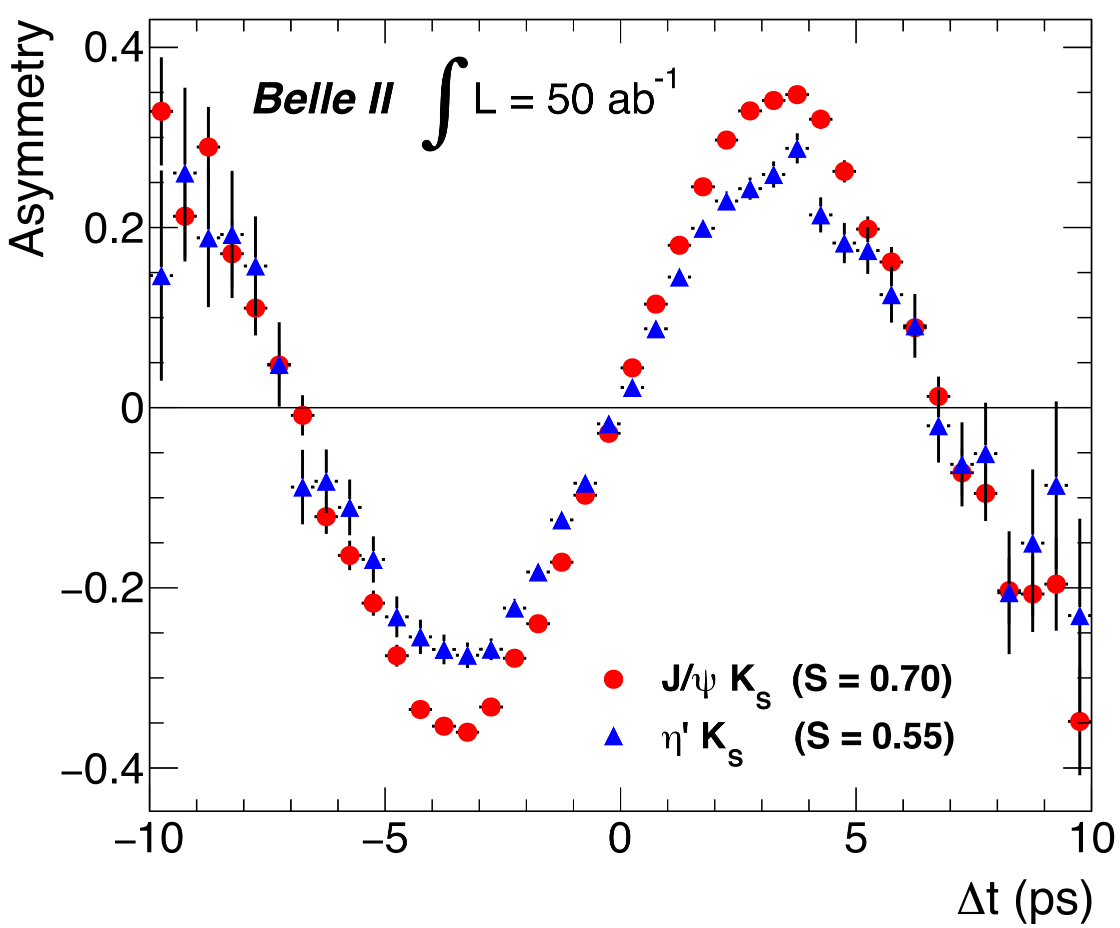
Belle II Full Simulation
B2TiP Theory

Channel	$\int \mathcal{L}$	Event yield	$\sigma(S)$	$\sigma(S)_{2017}$	$\sigma(A)$	$\sigma(A)_{2017}$
$J/\psi K^0$	50 ab^{-1}	$1.4 \cdot 10^6$	0.0052	0.022	0.0050	0.021
ϕK^0	5 ab^{-1}	5590	0.048	0.12	0.035	0.14
$\eta' K^0$	5 ab^{-1}	27200	0.027	0.06	0.020	0.04
ωK_S^0	5 ab^{-1}	1670	0.08	0.21	0.06	0.14
$K_S \pi^0 \gamma$	5 ab^{-1}	1400	0.10	0.20	0.07	0.12
$K_S \pi^0$	5 ab^{-1}	5699	0.09	0.17	0.06	0.10



Error on sin(2β) from B → J/ψ Ks	tot.
LHCb 22/fb	**0.014**
Belle II 50/ab	**0.007**

Mode	QCDF [27]	QCDF (scan) [27]	$SU(3)$	Data
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$[0.02, 0.15]$	$[-0.11, 0.12]$ [41]	$-0.11^{+0.17}_{-0.17}$
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$		$-0.14^{+0.18}_{-0.21}$
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	$[0.00, 0.03]$	$(0 \pm 0.36) \times 2\cos(\phi_1)\sin\gamma$ [42]	-0.05 ± 0.06
ηK_S	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$		—
ϕK_S	$0.02^{+0.01}_{-0.01}$	$[0.01, 0.05]$	$(0 \pm 0.25) \times 2\cos(\phi_1)\sin\gamma$ [42]	$0.06^{+0.11}_{-0.13}$
ωK_S	$0.13^{+0.08}_{-0.08}$	$[0.01, 0.21]$		$0.03^{+0.21}_{-0.21}$



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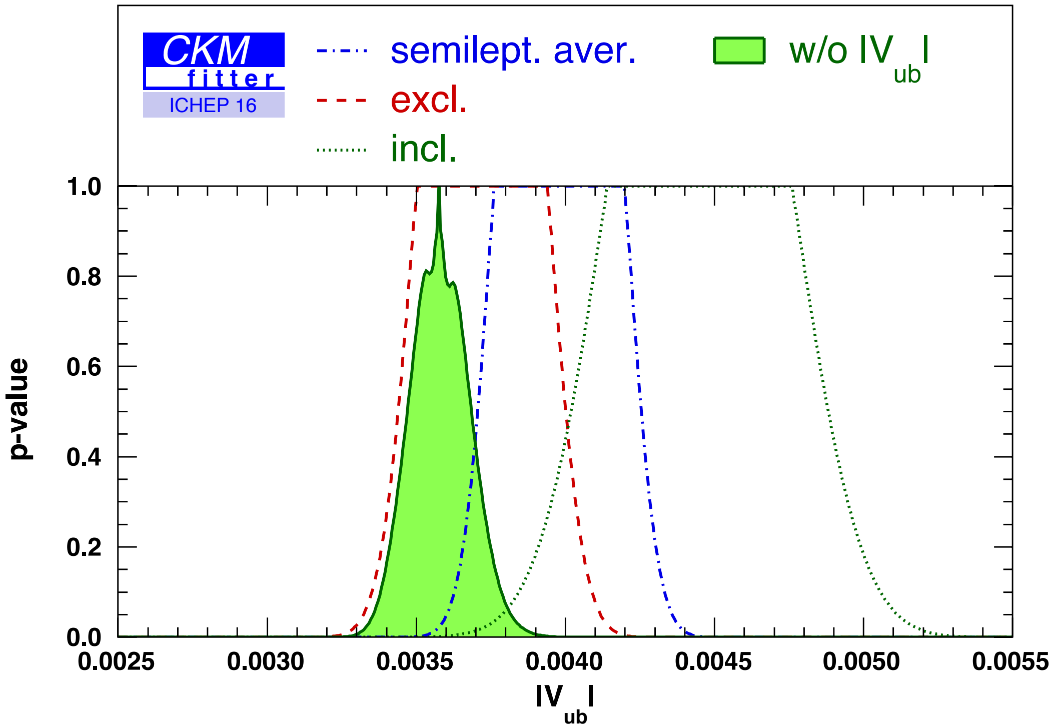
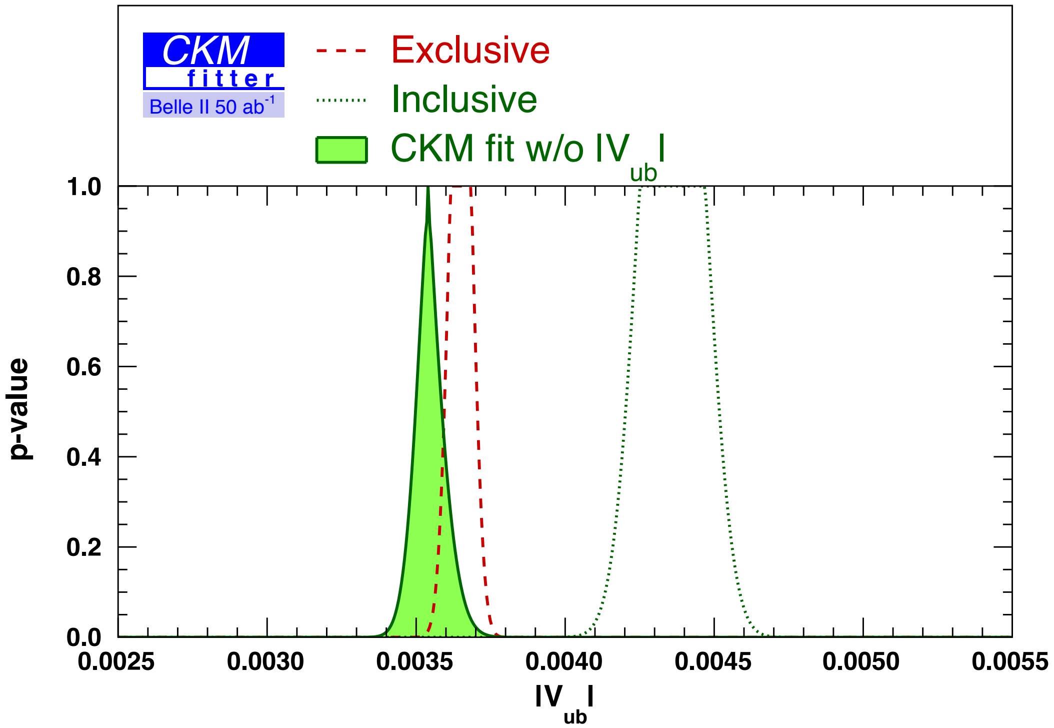
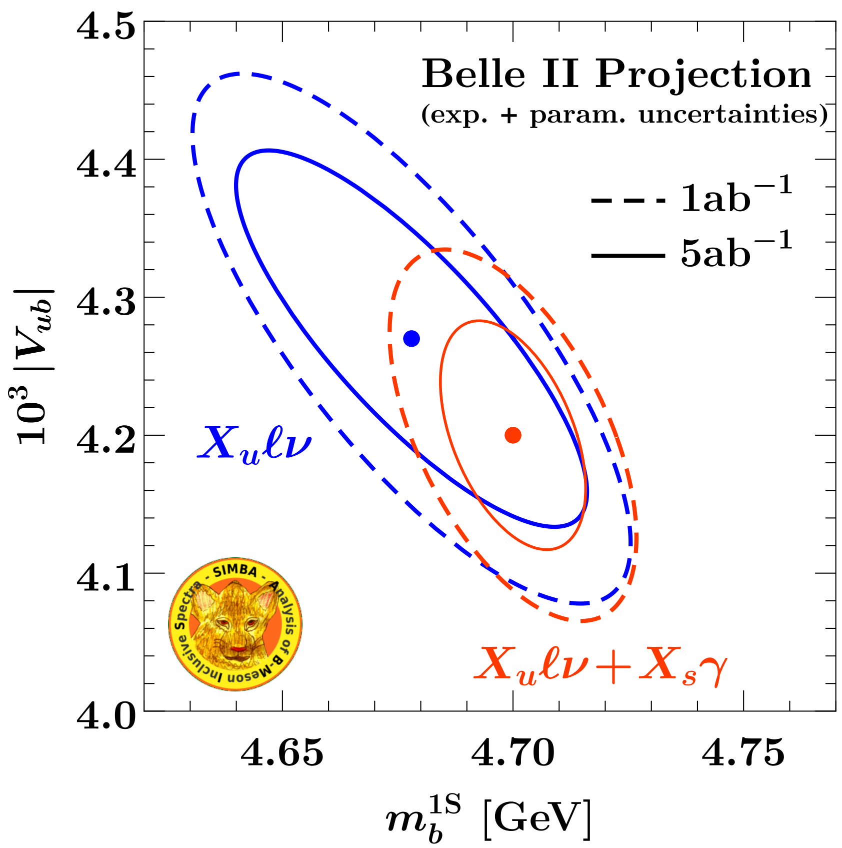
UT Precision Tests

The |V_{ub}| puzzle



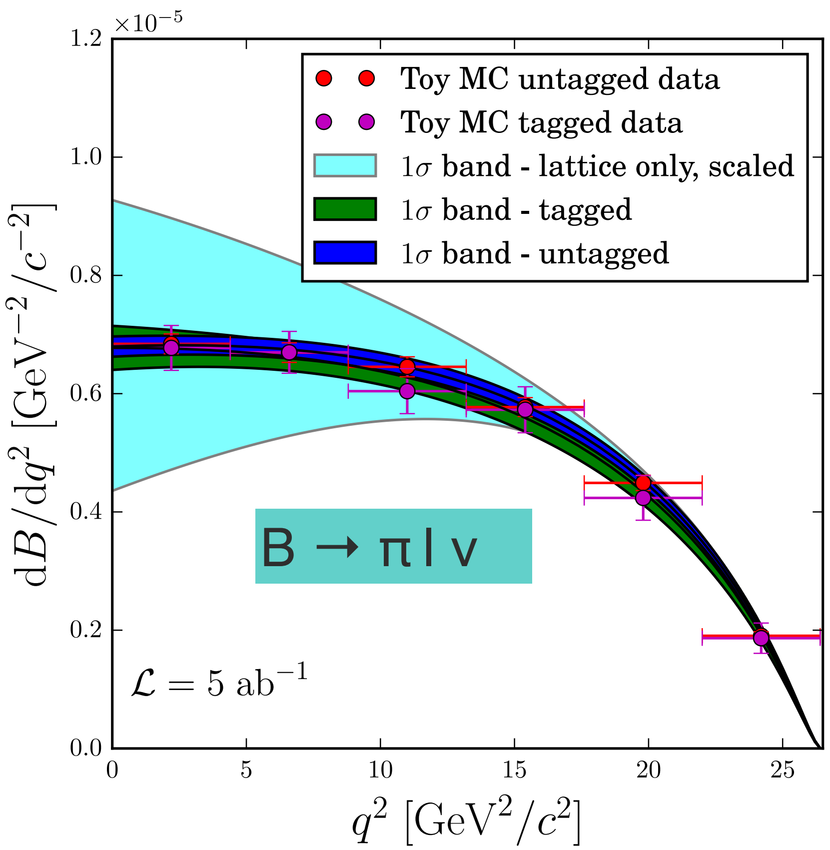


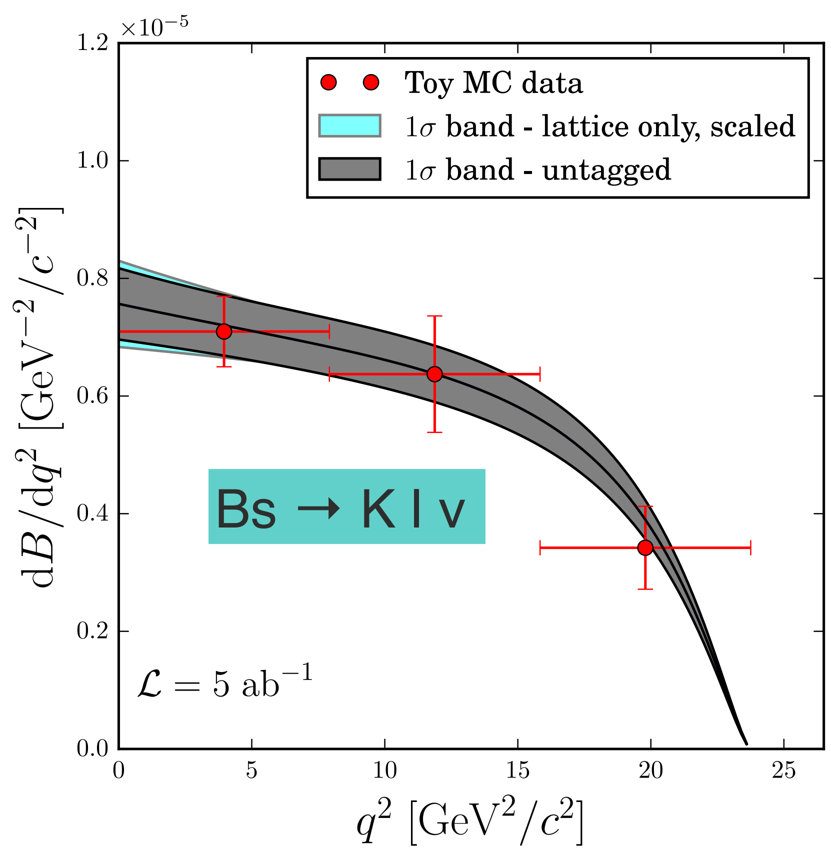
- Critical input on inclusive B→ Xu l v comes from
  - M_X^2 fit for $m_b/\mu_\pi^2/V_{ub}$
  - Fitting for fragmentation of X_u
  - Δ~3%

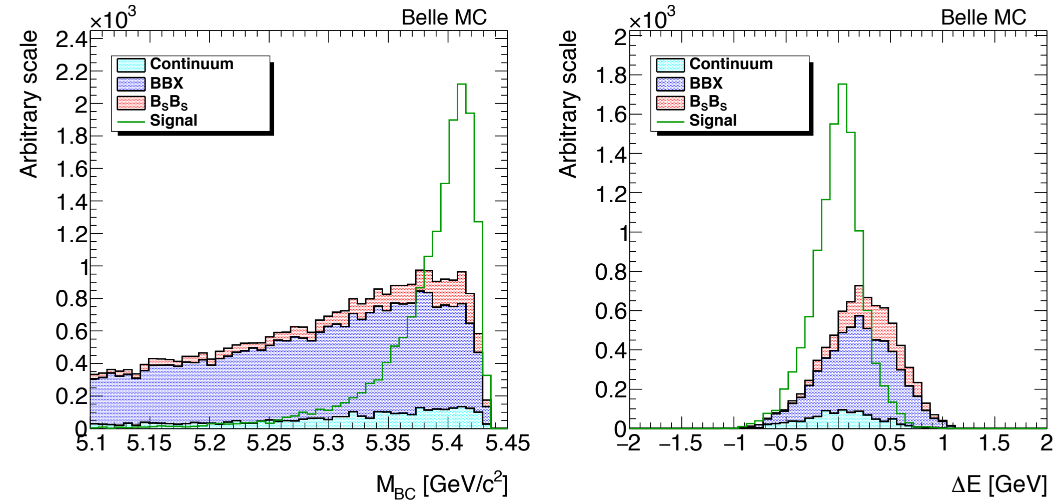


$|V_{ub}|$ Exclusive

Belle II Full Simulation and B2TiP Lattice





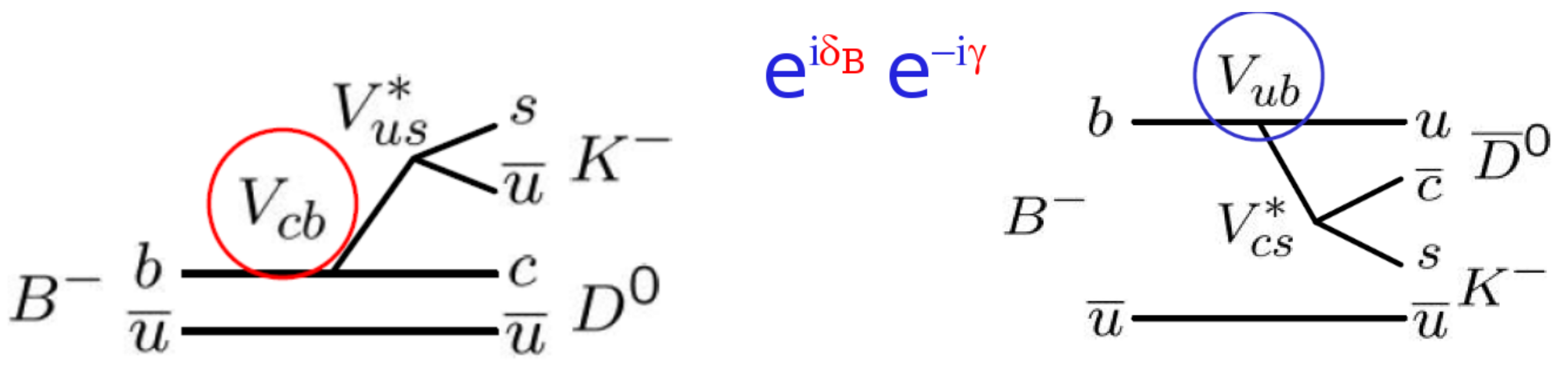


$\mathcal{L}$ [ab^{-1}]		$\sigma_{\mathcal{B}}$ (stat±sys)	$\sigma_{LQCD}^{forecast}$	$\sigma_{V_{ub}}$
1	tagged	3.6 ± 4.4	current	6.2
	untagged	1.3 ± 3.6		3.6
5		1.6 ± 2.7	in 5 yrs	3.2
		0.6 ± 2.2		2.1
10		1.2 ± 2.4	in 5 yrs	2.7
		0.4 ± 1.9		1.9
50		0.5 ± 2.1	in 10 yrs	1.7
		0.2 ± 1.7		1.3

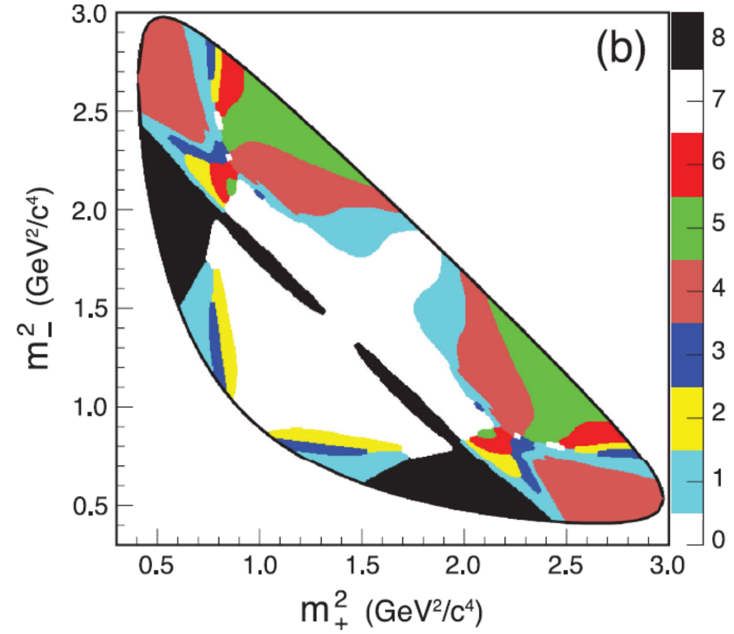
$\mathcal{L}$ [ab^{-1}]	$\sigma_{\mathcal{B}}$ (stat±sys)	$\sigma_{LQCD}^{forecast}$	$\sigma_{V_{ub}}$
1	6.5 ± 3.6	current	6.5
5	2.9 ± 2.2	in 5 yrs	4.7

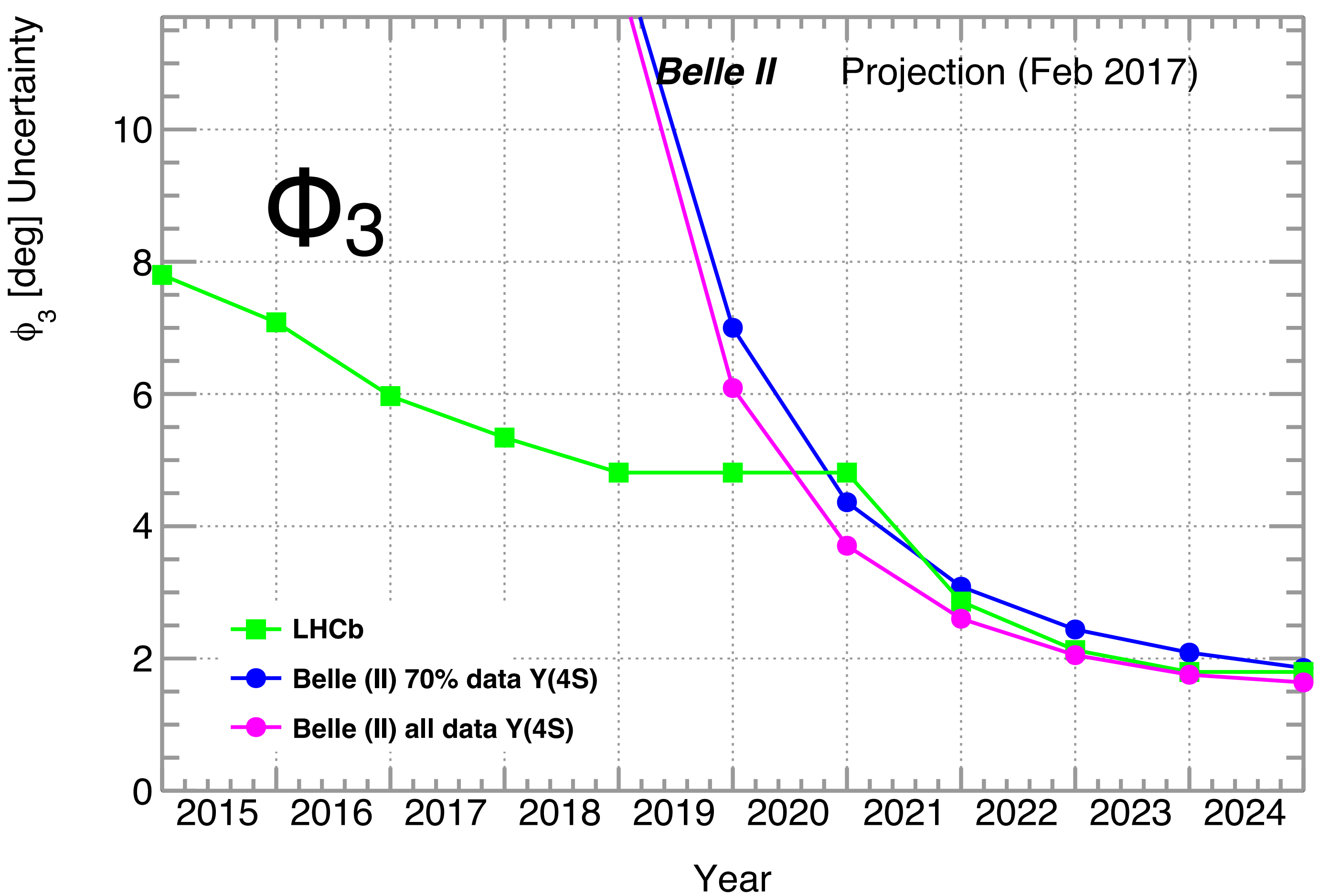
Φ_3 from B → DK

- Phase between b→u and b→c



Strong phase differences can be measured at a charm factory





Φ_3 Belle = $(73\ ^{+13}_{-15})^o$

Φ_3 WA = $(72.2\ ^{+5.3}_{-5.8})^o$

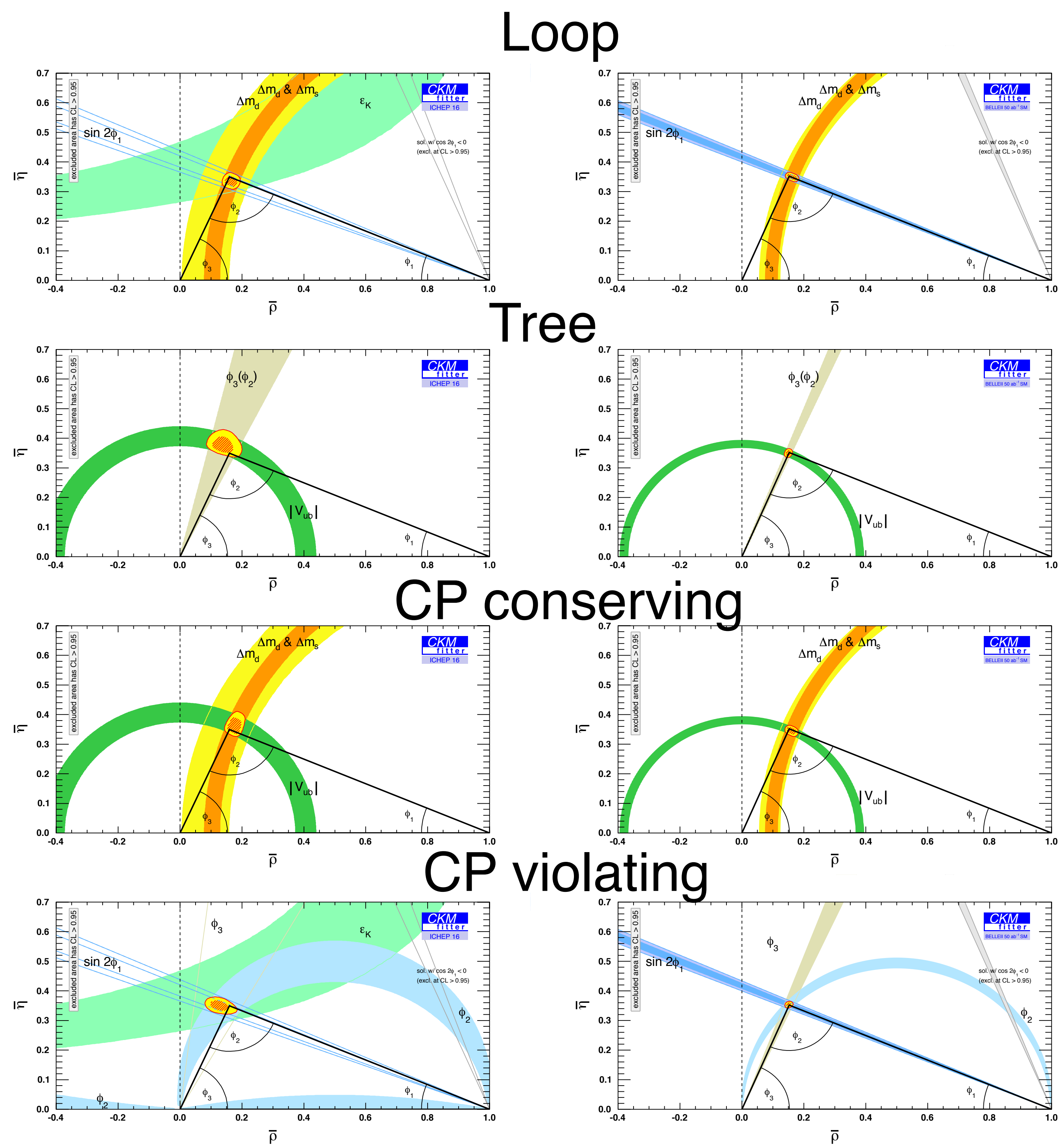
- 1.6^o expected at Belle II
- Include neutral D modes
- Assume BES III collects 10 fb^{-1}

CKMFitter: 2016 Vs 2025

B2TiP Book, CKMFitter

Input	World average 2016	Belle II (+LHCb) 2025
$\|V_{ub}\|(\text{semileptonic})[10^{-3}]$	$4.01 \pm 0.08 \pm 0.22$	± 0.10
$\|V_{cb}\|(\text{semileptonic})[10^{-3}]$	$41.00 \pm 0.33 \pm 0.74$	± 0.57
$\mathcal{B}(B \to \tau\nu)$	1.08 ± 0.21	± 0.04
$\sin 2\beta$	0.691 ± 0.017	± 0.008
$\gamma[^\circ]$	$73.2^{+6.3}_{-7.0}$	± 1.5 (± 1.0)
$\alpha[^\circ]$	$87.6^{+3.5}_{-3.3}$	± 1.0
Δm_d	0.510 ± 0.003	-
Δm_s	17.757 ± 0.021	-
$\mathcal{B}(B_s \to \mu\mu)$	$2.8^{+0.7}_{-0.6}$	(± 0.5)
f_{B_s}	$0.224 \pm 0.001 \pm 0.002$	0.001
B_{B_s}	$1.320 \pm 0.016 \pm 0.030$	0.010
f_{B_s}/f_{B_d}	$1.205 \pm 0.003 \pm 0.006$	0.005
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$	0.005

Expect substantial improvements to tree constraints!



Phys. Rev. D 89, 033016 (2014)

By Stage II,

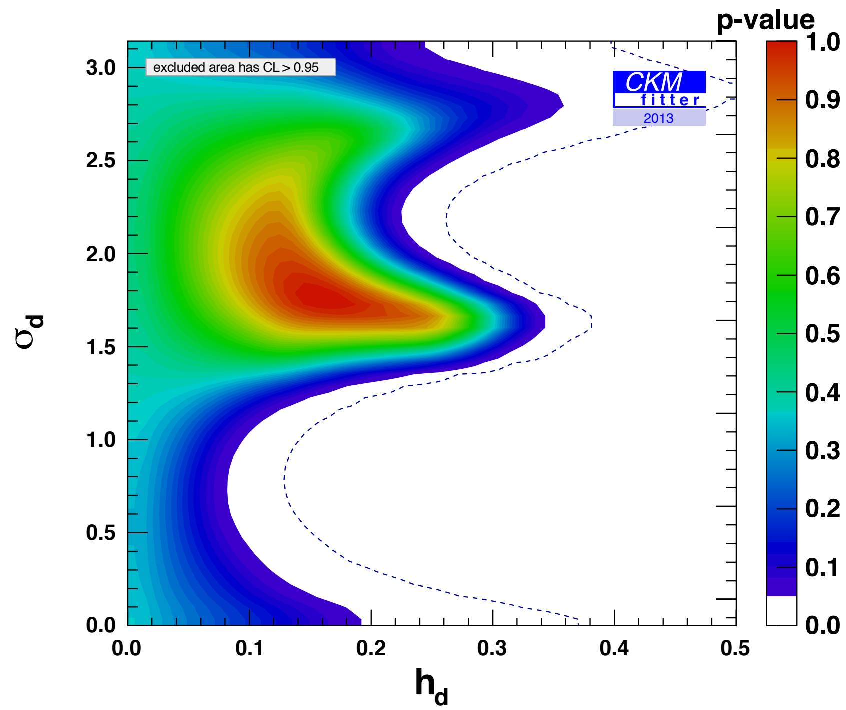
- $\Lambda \sim$ 20 TeV (**tree**)
- Mixing
- $\Lambda \sim$ 2 TeV (**loop**)

$$i\frac{d}{dt}\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(M^q - \frac{i}{2}\Gamma^q\right)\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$$

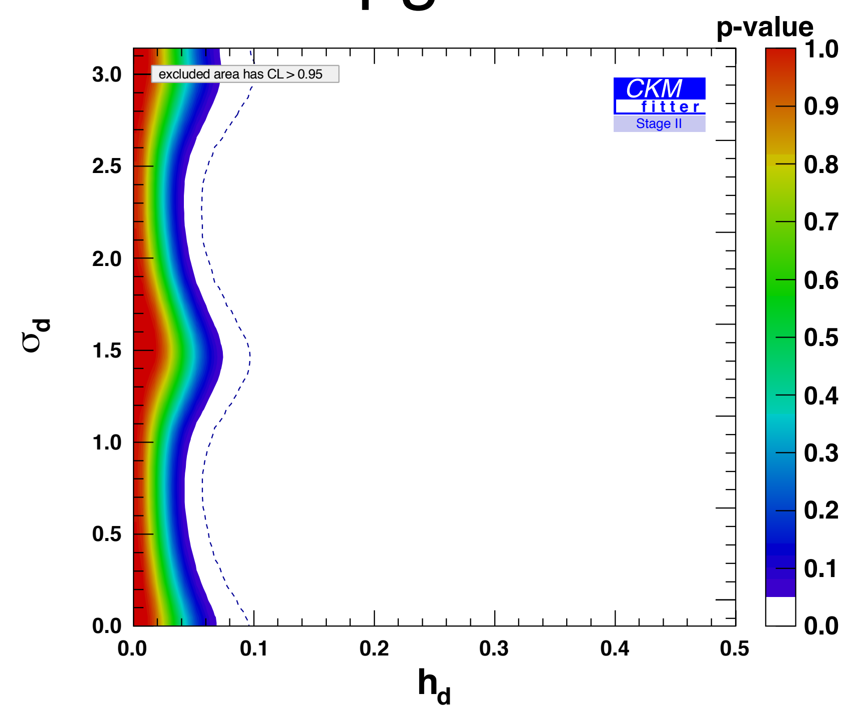
- Parameterise NP.

$$M_{12} = M_{12}^{SM} \times \left(1 + he^{2i\sigma}\right)$$

2013



LHCb Upg.+ Belle II



- 95% CL, NP$\lesssim$(many × SM) $\Longrightarrow$ NP$\lesssim$(0.05 × SM)

$$h \simeq 1.5\frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2}\frac{(4\pi)^2}{G_F\Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2}\left(\frac{4.5\text{ TeV}}{\Lambda}\right)^2$$

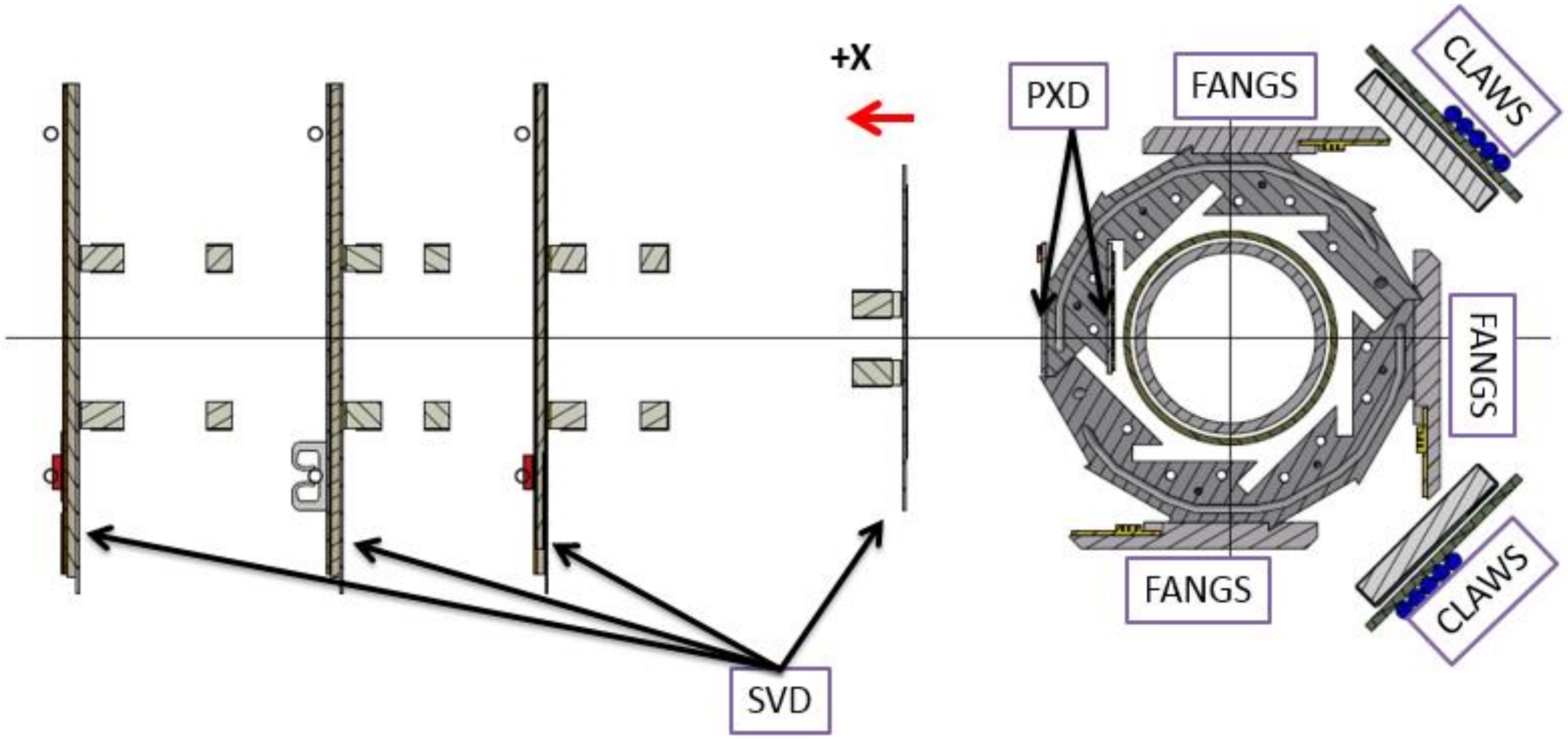
$$\sigma = \arg(C_{ij}\lambda_{ij}^{t*})$$

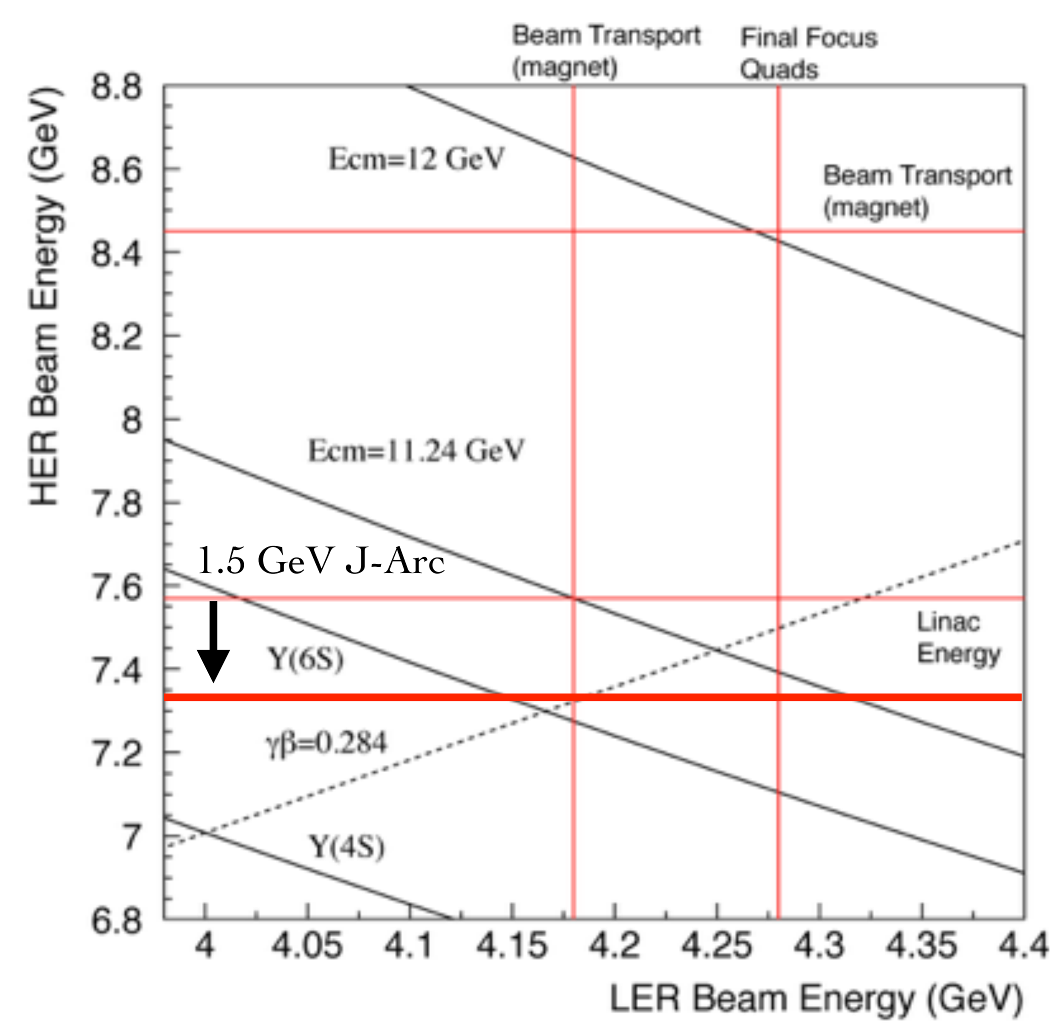
Physics in 2018

Phase II: First collision Run, Feb-Jun 2018

Phase 1 2016	"BEAST"/SuperKEKB & cosmics
Phase 2 Feb 2018- July 2018	Belle II no VXD, commissioning data
Full physics Dec 2018-	Vertex detectors in

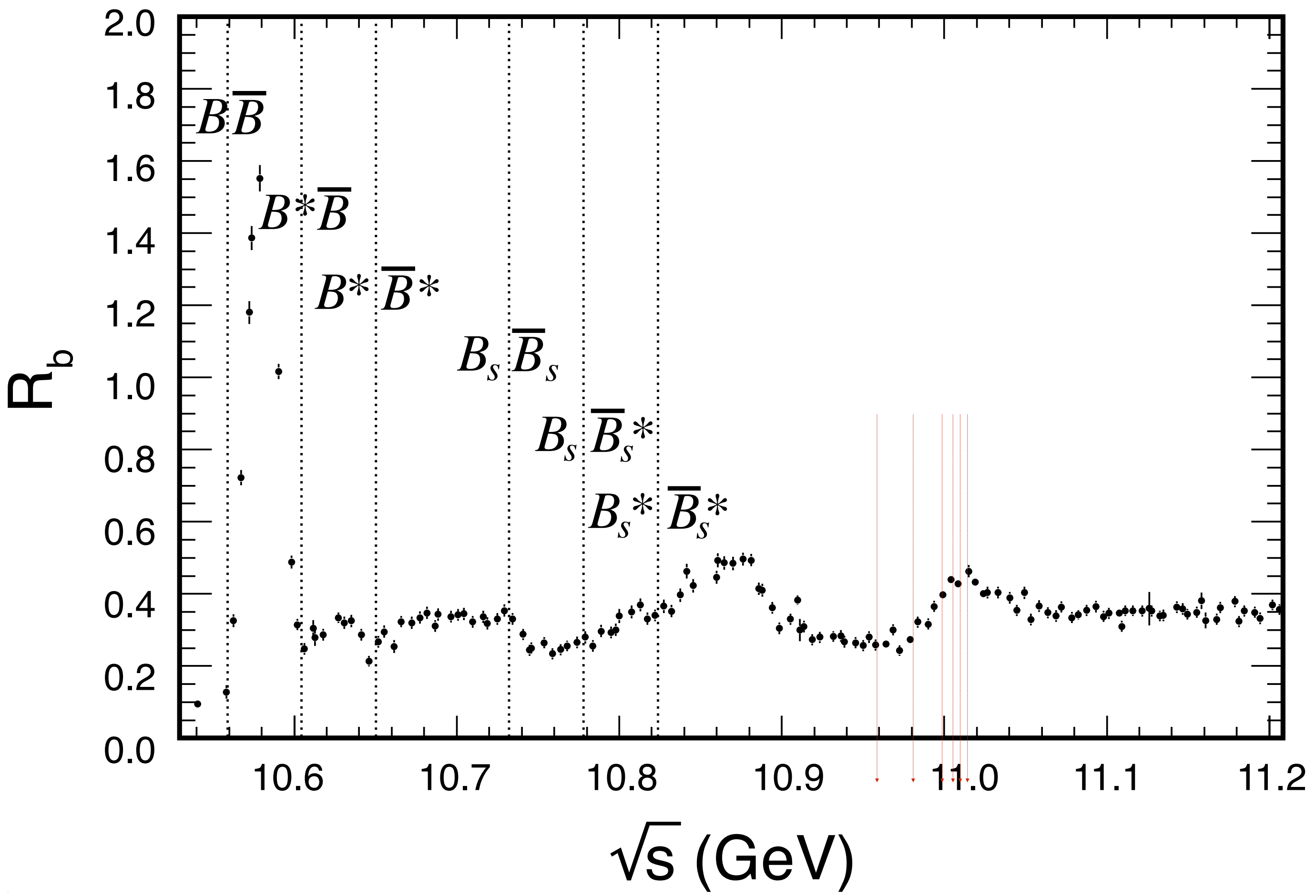
- 4-5 months of machine study, 1~2 months may contain usable data.
- Target luminosity 1 x 10^{34} $cm^{-2}s^{-1}$





Phase II Unique data sets

- **Only ~20-40 fb^{-1} in Phase II**
  - Unique E_{CM} , e.g. Y(6S) for bottomonium - strong interaction studies
  - New trigger menu to greatly enhance low multiplicity & dark sector physics



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

Exotic 4-quark States

Belle arXiv:1508.06562

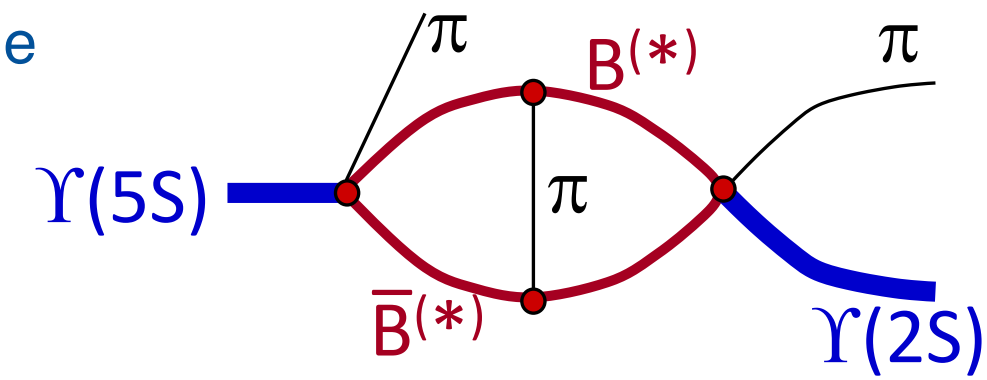
Bottomonium - atomic-like bound bb states

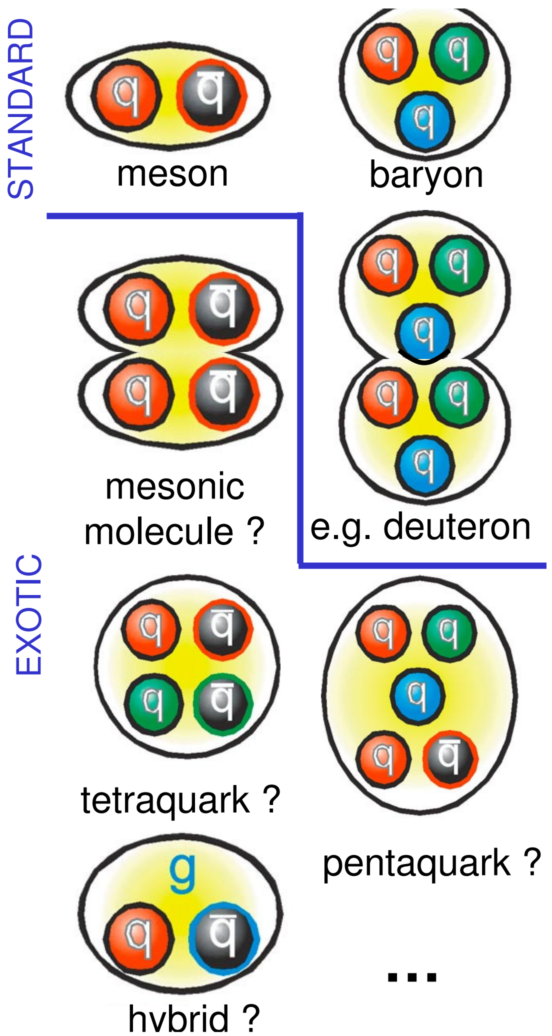
Bottomonium-like - additional quark pair

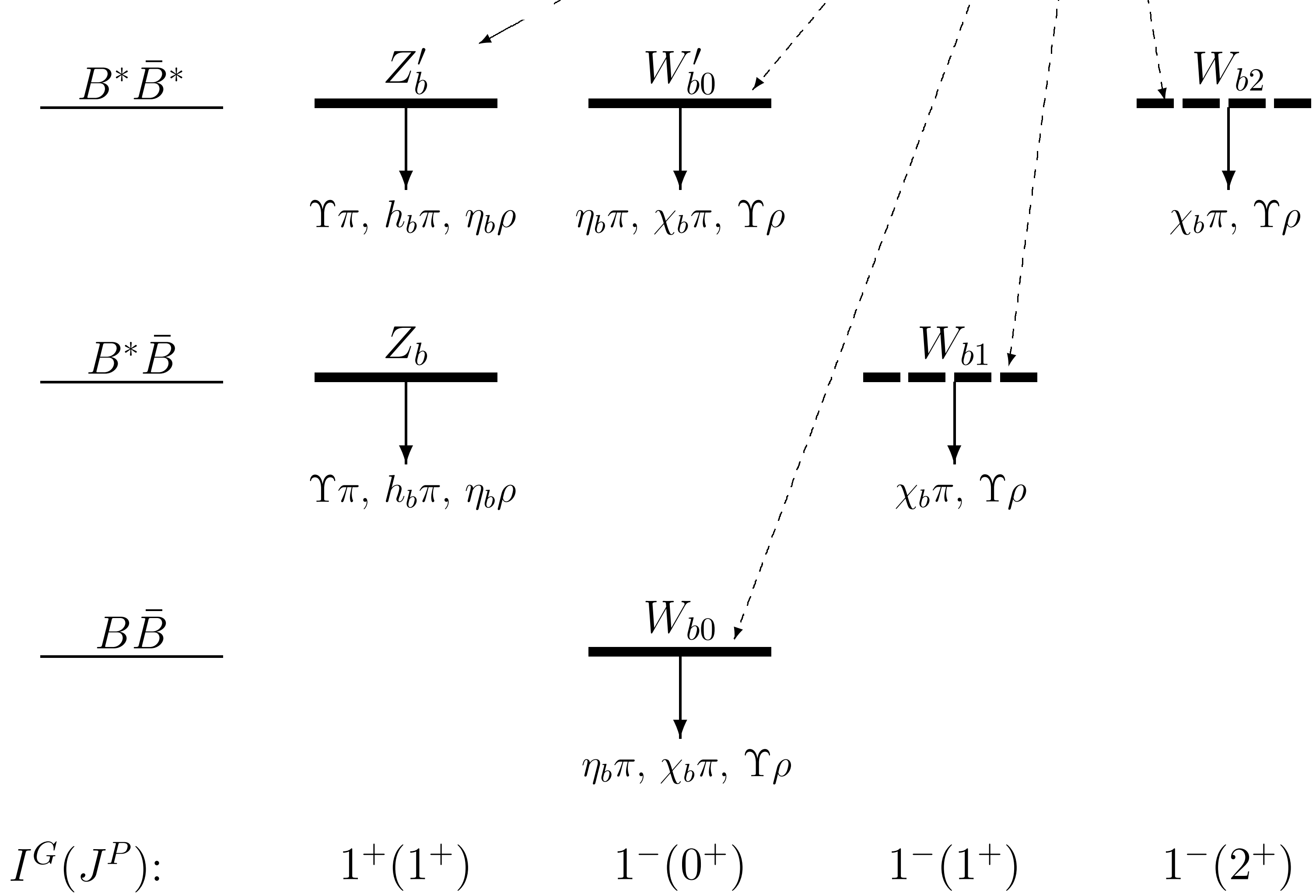
Z_b, W_{bx} — postulated states

Deuteron-like molecule

π, ρ , ω, σ exchange



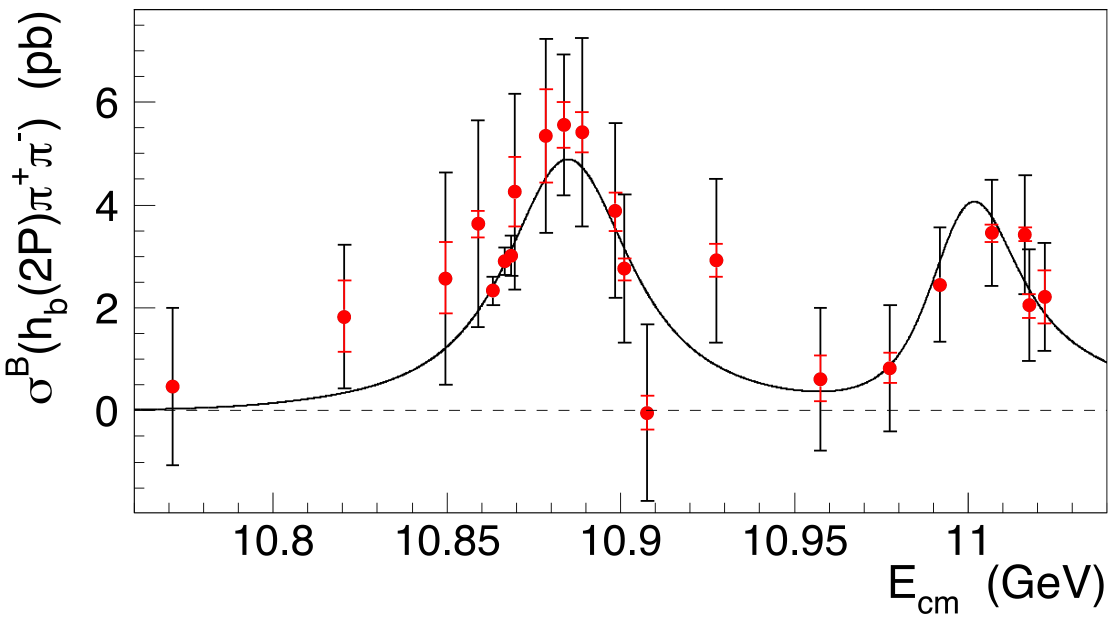


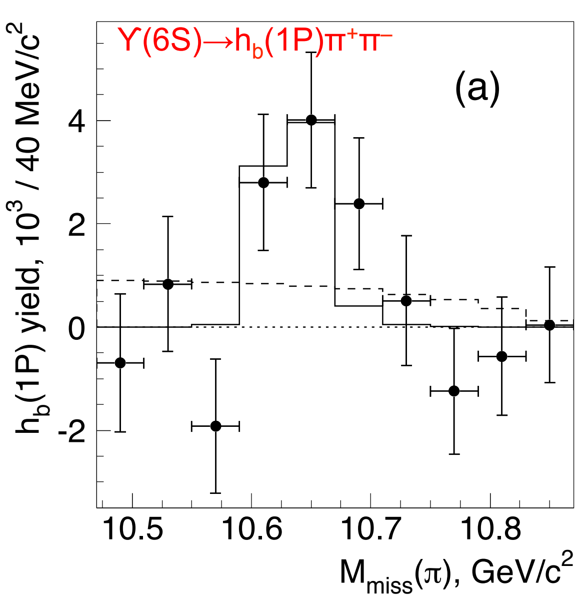


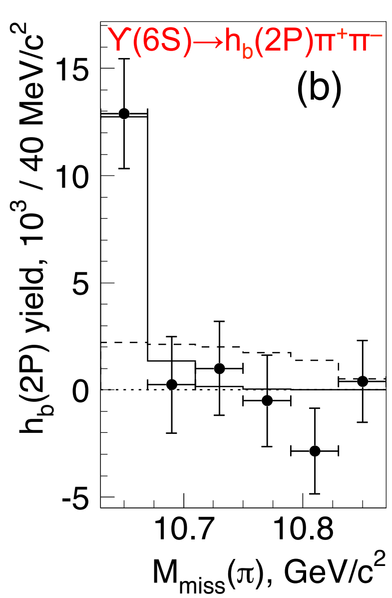
Bottomonium-like resonances above open B threshold

- $\Upsilon(6S) \rightarrow h_b(mP)\pi\pi$ vs CMS energy, evidence for $Z_b \rightarrow h_b\,\pi$,
- $\pi\pi$ tagged, analyse missing mass

Belle PRL 117, 142001 (2016)

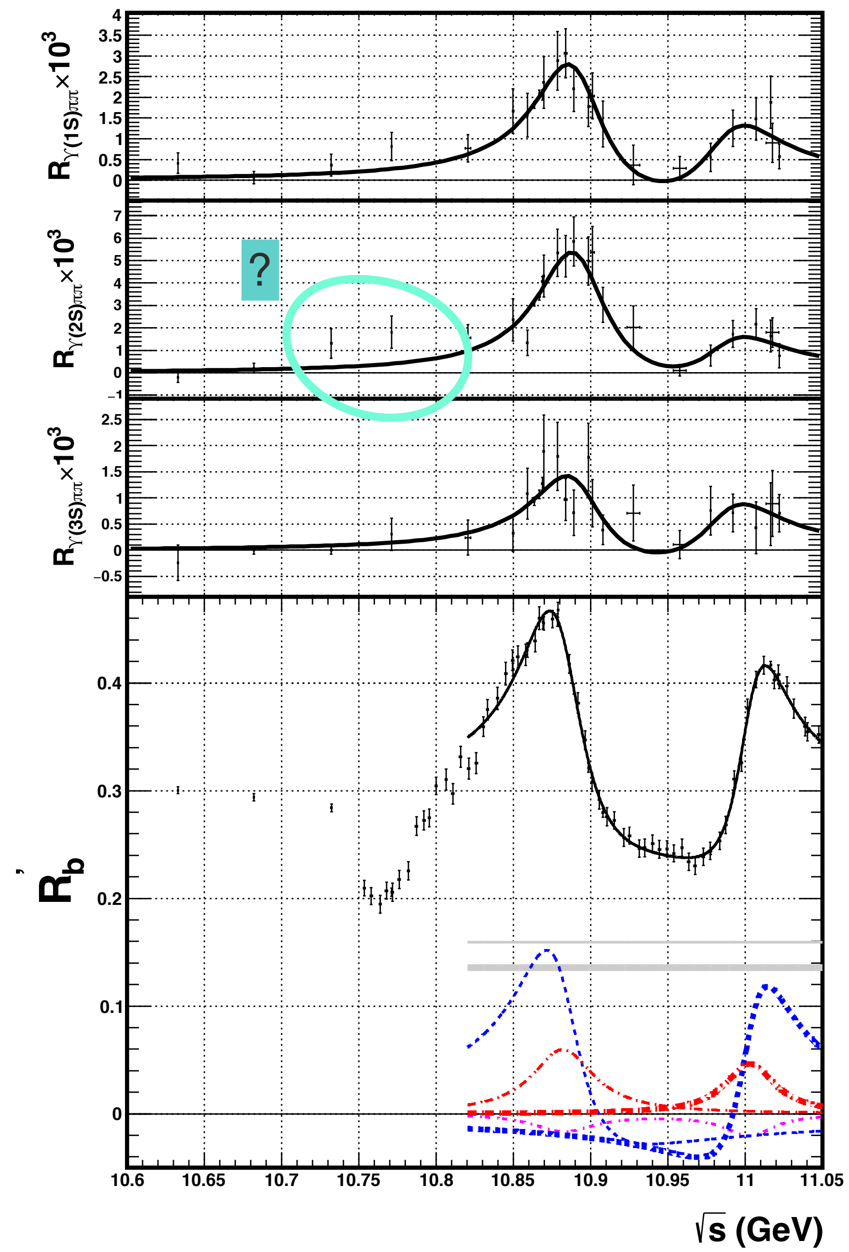






- $\sigma(\Upsilon(nS)\pi\pi)$, $\sigma(bb)$ vs CMS

Belle PRD 93, 011101 (2016)

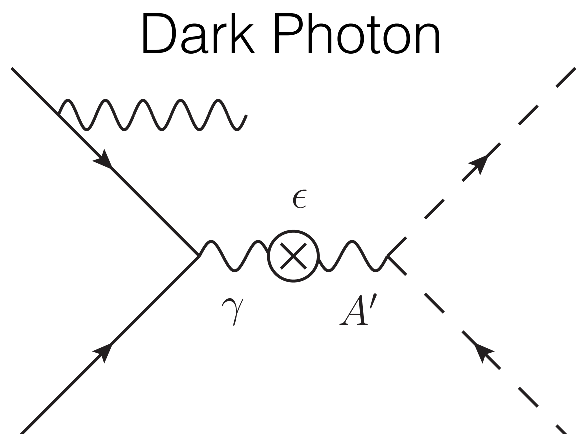


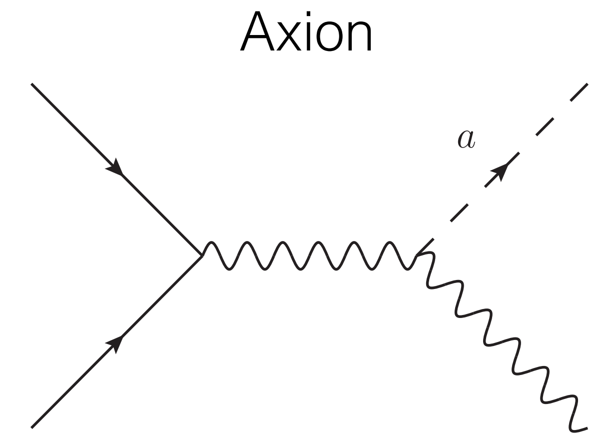
Need to study dipion kinematics near Zb π treshold

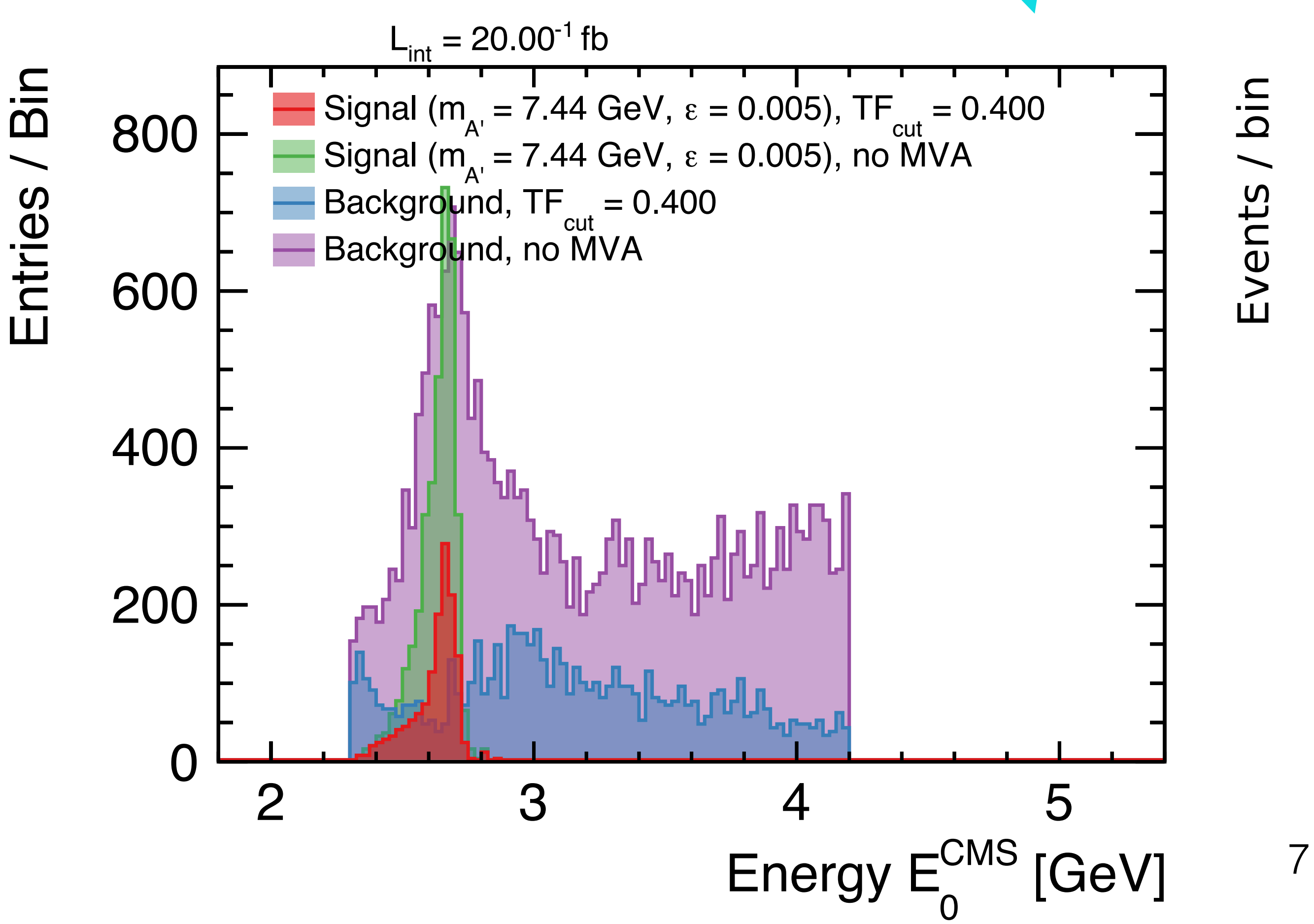
Dark Sector in phase II

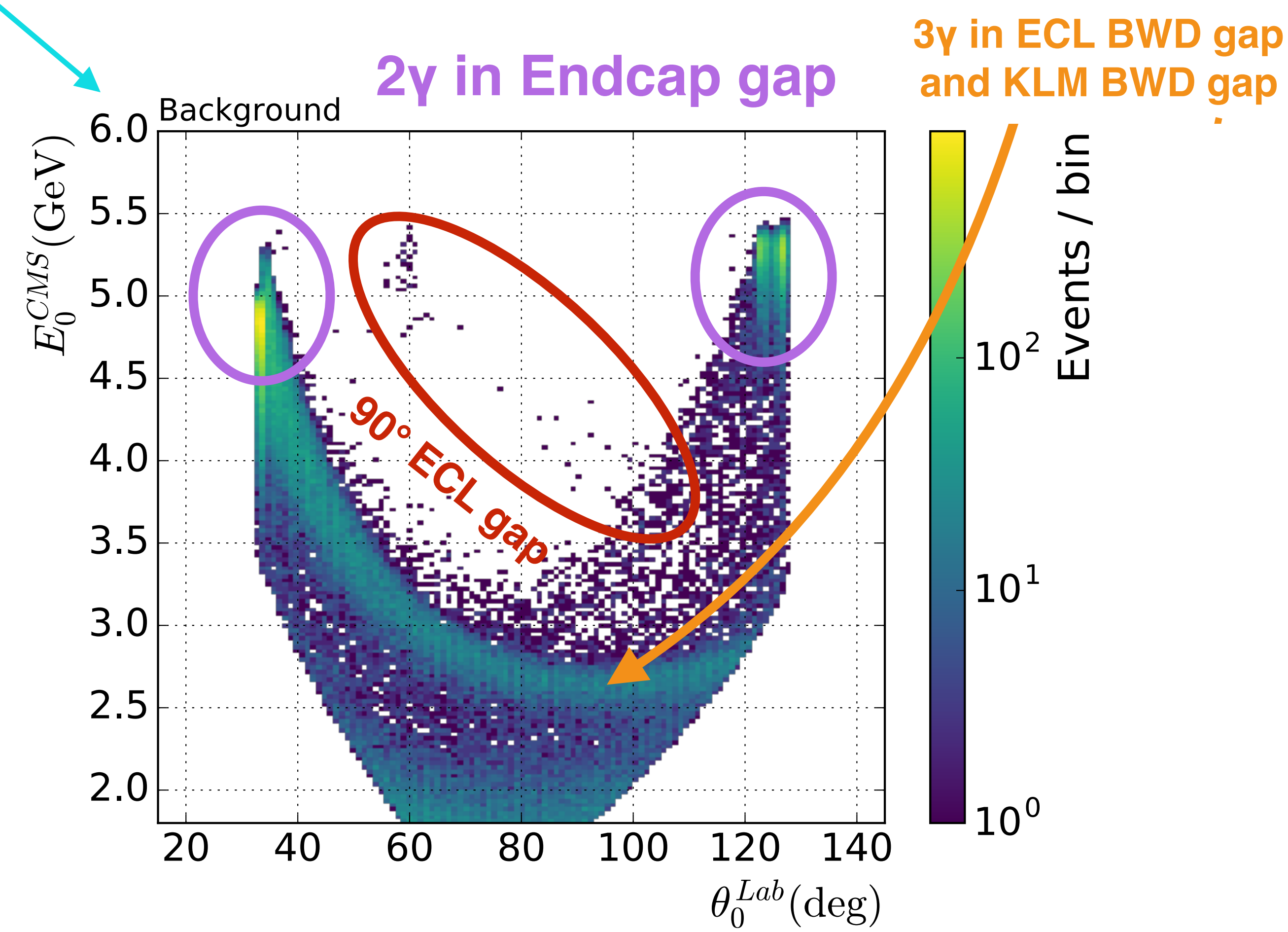
Belle II Full Simulation

- Dark photon search with NN.
- ee → γ a [a→ γ γ] *New*









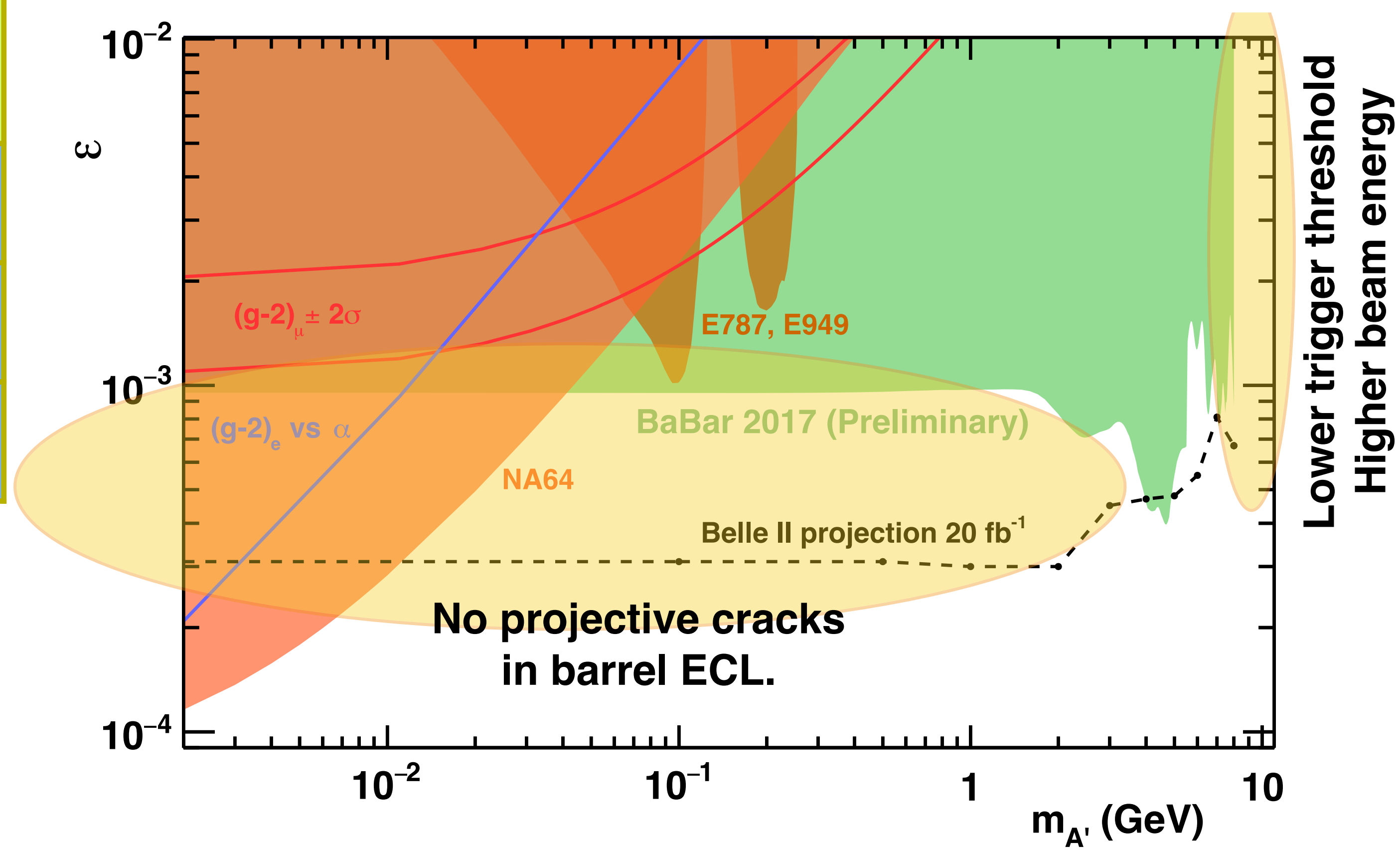
Triggering dark sector physics

- 2 stage trigger: **Hardware** (L1) then **Software**.

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\text{lab}} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\text{lab}} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.
[b] $\theta_{\text{lab}} \geq 17°$, $p_t \geq 0.1\text{GeV}/c$

	Hardware Trigger accept	Physics output rate	Raw event size
Belle	500 Hz	90 Hz	
Belle II	30 kHz	3-10kHz	~200 kB
ATLAS	100 kHz	1 kHz	1.6MB



Summary

- SuperKEKB has been brought to life.
- Phase II collisions start January 2018, Phase III Late 2018

- **Rich physics program at SuperKEKB/Belle II**
  - New sources of CPV, New gauge bosons, Lepton Flavour Violation, Dark Sectors.
  - **Numerous anomalies to probe with the first 5 ab^{-1}**

- **Strong case for phase II physics.**

- **The Belle II physics book to be published in 2017 (ed. PU & E. Kou)**

Backup

Belle II Physics Book

- B2TiP Report (600p)
  - https://confluence.desy.de/display/BI/B2TiP+ReportStatus
- To be published in PTEP / Oxford University Press & printed.
  - Belle II Detector, Simulation, Reconstruction, Analysis tools
  - Physics working groups
  - New physics prospects and global fit code

PTEP

Prog. Theor. Exp. Phys. **2015**, 00000 (319 pages)
DOI: 10.1093/ptep/0000000000

The Belle II Physics Book

Emi Kou[1], Phillip Urquijo[2], The Belle II collaboration[3], and The B2TiP theory community[4]

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The report of the Belle II Theory Interface Platform is presented in this document.

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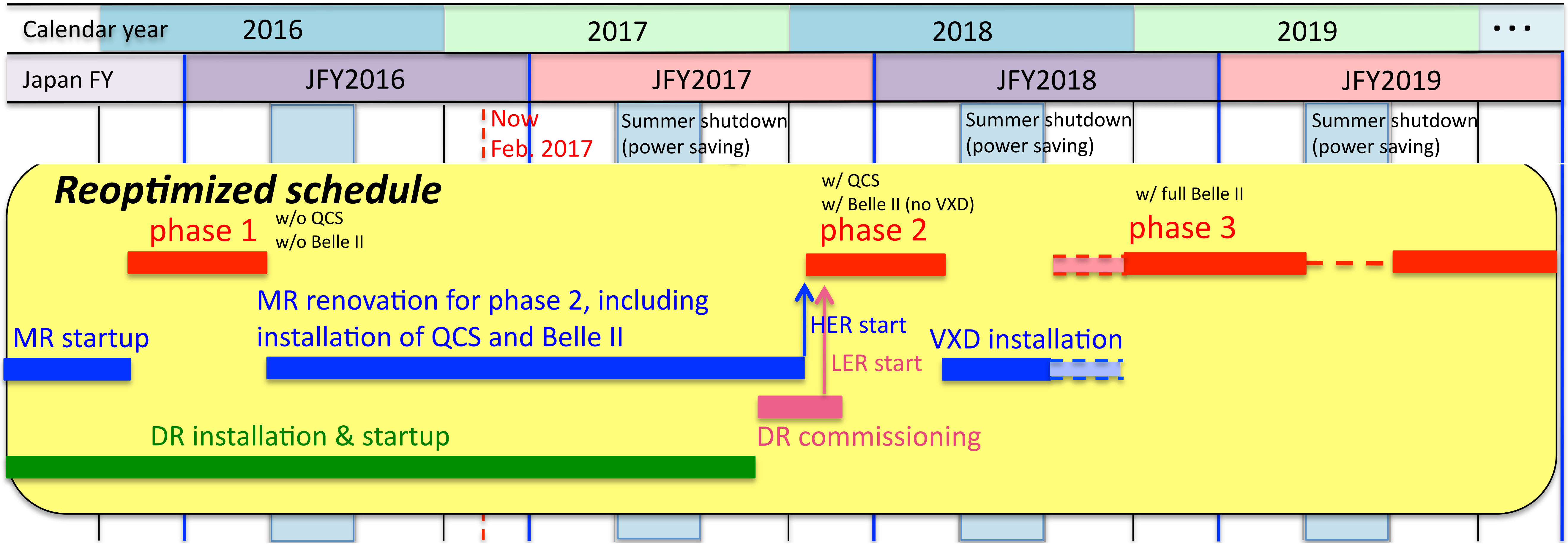
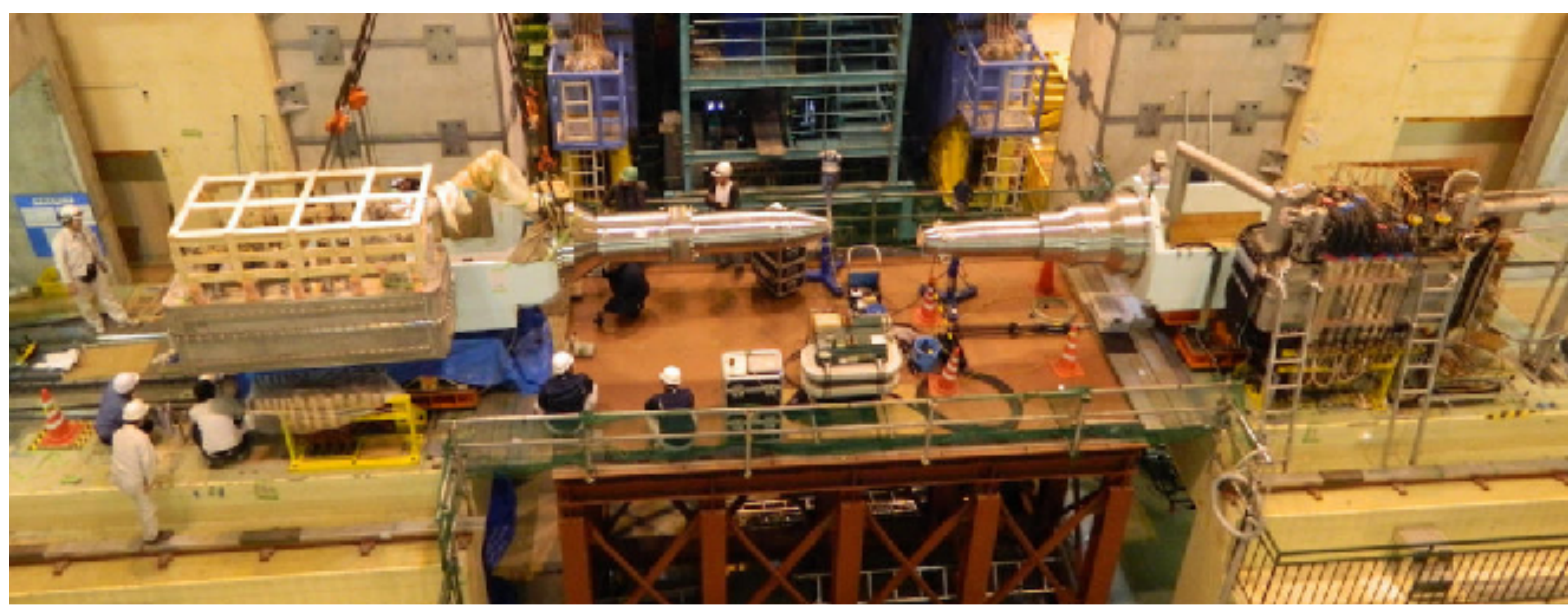


February 13, QCSR arrived in Tsukuba Hall



Φ_1

$B^0 \to J/\psi\ K_S$	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0035	0.0035	0.0060
syst. reducible	0.0012	0.0012	0.0012
syst. irreducible	0.0082	0.0044	0.0040
A (50 ab^{-1})			
stat.	0.0025	0.0025	0.0043
syst. reducible	0.0007	0.0007	0.0007
syst. irreducible	$^{+0.043}_{-0.022}$	$^{+0.042}_{-0.011}$	0.011

$b \to c\bar{c}s$	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
A (50 ab^{-1})			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

- $\sin(2\Phi_1)$ will remain the most precise measurement in the UT
- In Belle II the measurement will be dominated by systematics
- Dominated by vertex related uncertainties.

Error on $\sin(2\beta)$ from $B \to J/\psi\ K_s$	tot.
LHCb 22/fb	**0.014**
Belle II 50/ab	**0.007**