$R(D^{(*)})$

Status at Belle & Outlook for Belle II

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Belle II

SuperKEKB

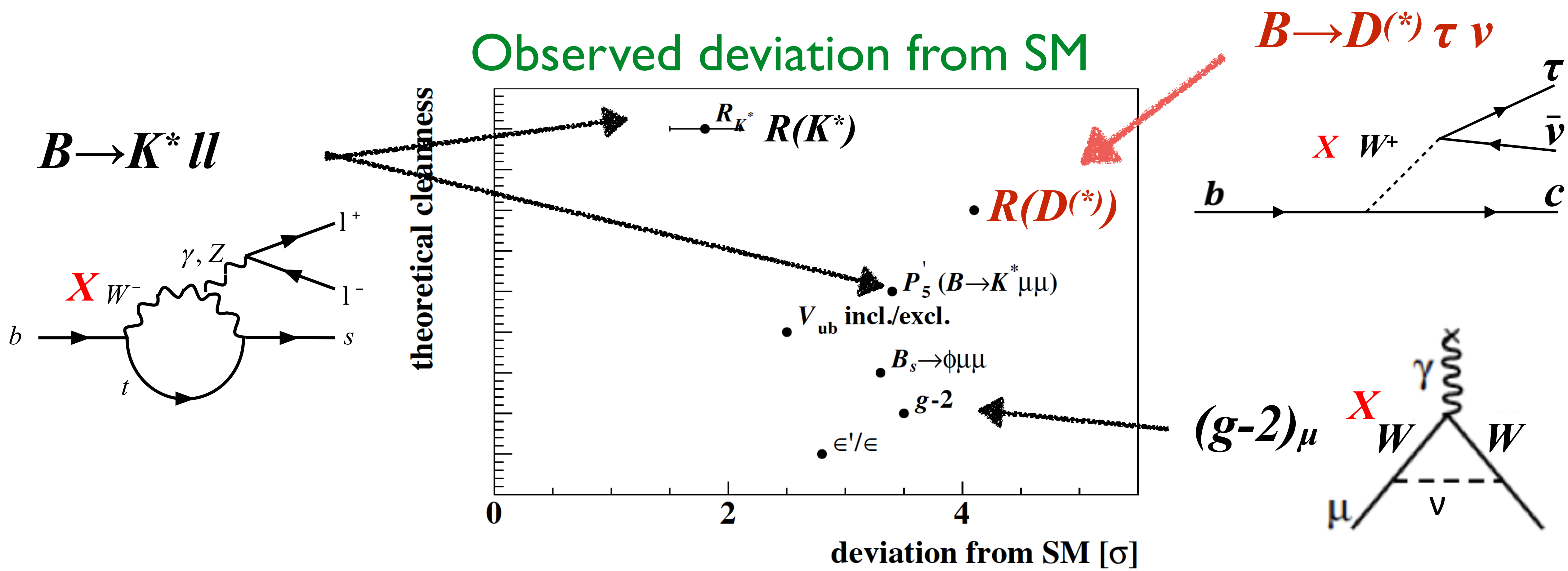
May 31, 2018

Exotic Hadrons and Flavor Physics

Stony Brook

Role of Flavor Physics

- Search for New Physics through processes sensitive to presence of virtual heavy particles.
- Complementary to direct search at LHC high P_T programs.
- Becoming more and more important, since no NP signal at LHC at this moment.



SuperKEKB/Belle II

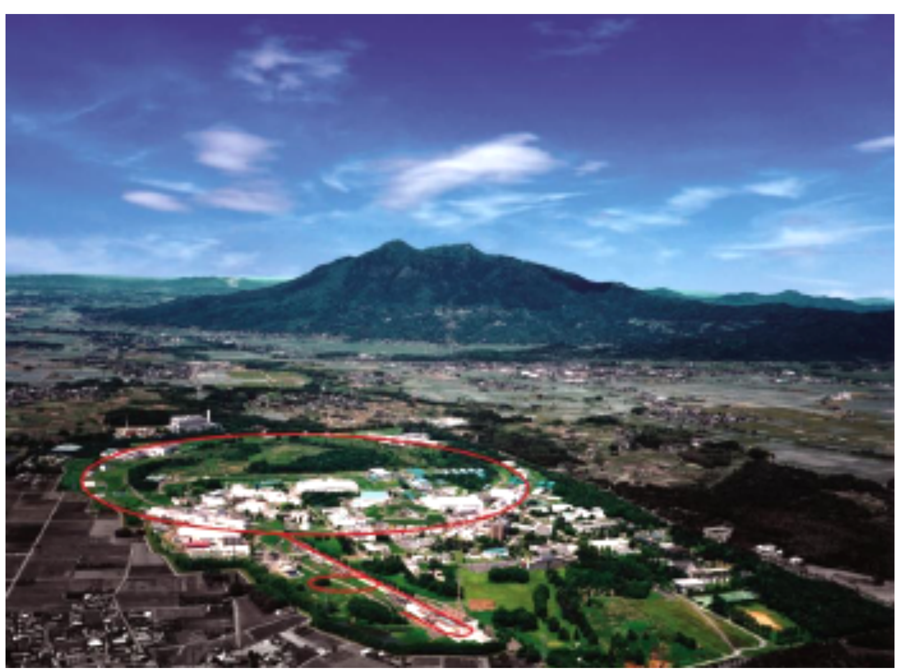
New intensity frontier facility at KEK

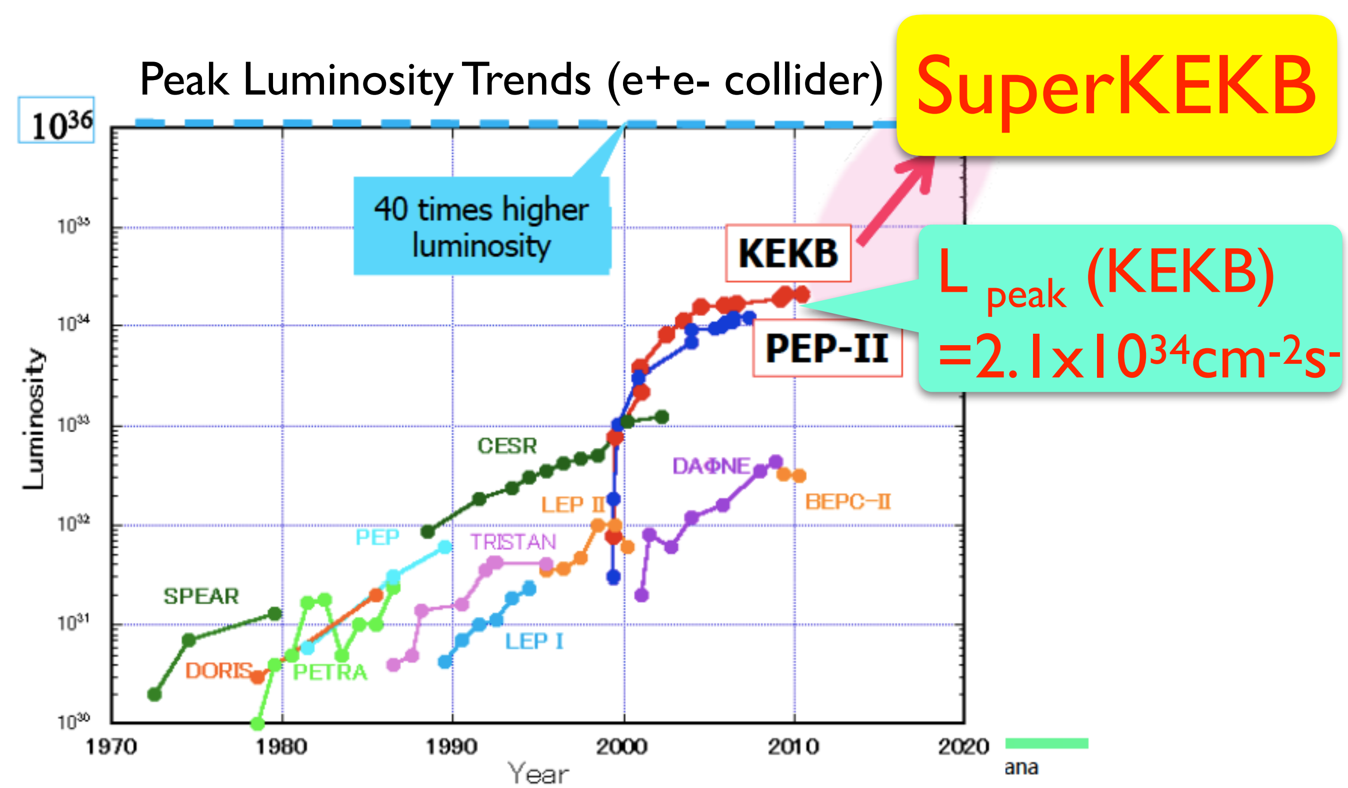
- Target luminosity ; $L_{peak} = 8 \times 10^{35} cm^{-2} s^{-1}$

  $\Rightarrow \sim 10^{10}\ B\bar{B}, \tau^+\tau^-$ and charms per year !

  $L_{int} > 50\ ab^{-1}$

- Rich physics program
  - Search for New Physics through processes sensitive to virtual heavy particles.
  - New QCD phenomena (XYZ, new states including heavy flavors) + more

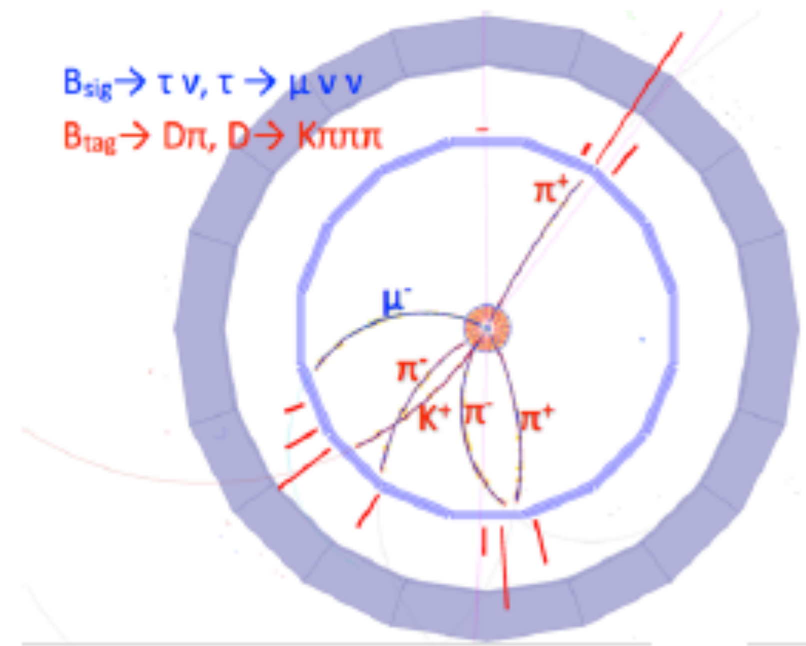




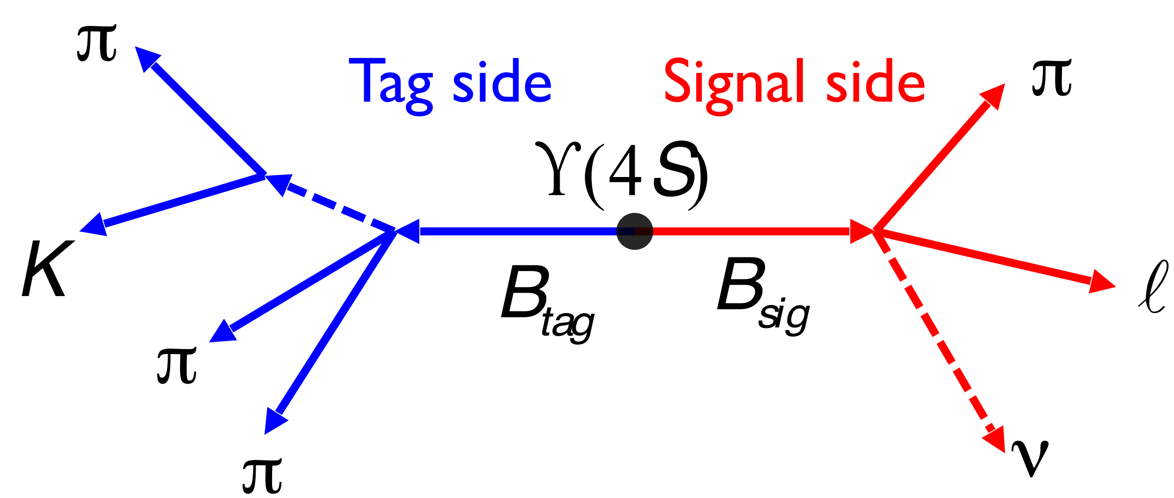
The first particle collider after the LHC !

Advantage of e^+e^- Flavor Factory

- Clean environment
  - Efficient detection of neutrals (γ, π^0, η, …)
- Quantum correlated $B^0\overline{B}^0$ pairs
  - High effective flavor tagging efficiency : ~34%(Belle II) ⟷ ~3% (LHCb)
- Large sample of τ leptons
  - Search for LFV τ decays at $O(10^{-9})$



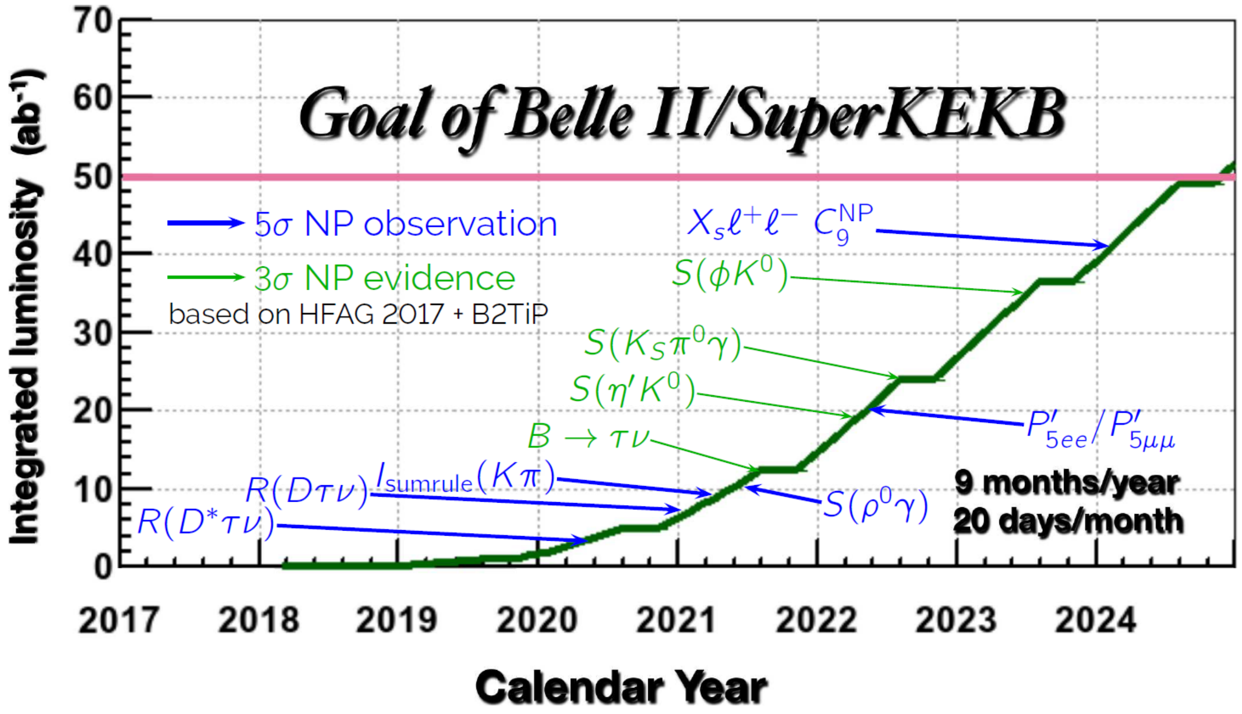
- Full reconstruction tagging possible
  - A powerful tool to measure;
    - b→u semileptonic decays (CKM)
    - decays with large missing energy



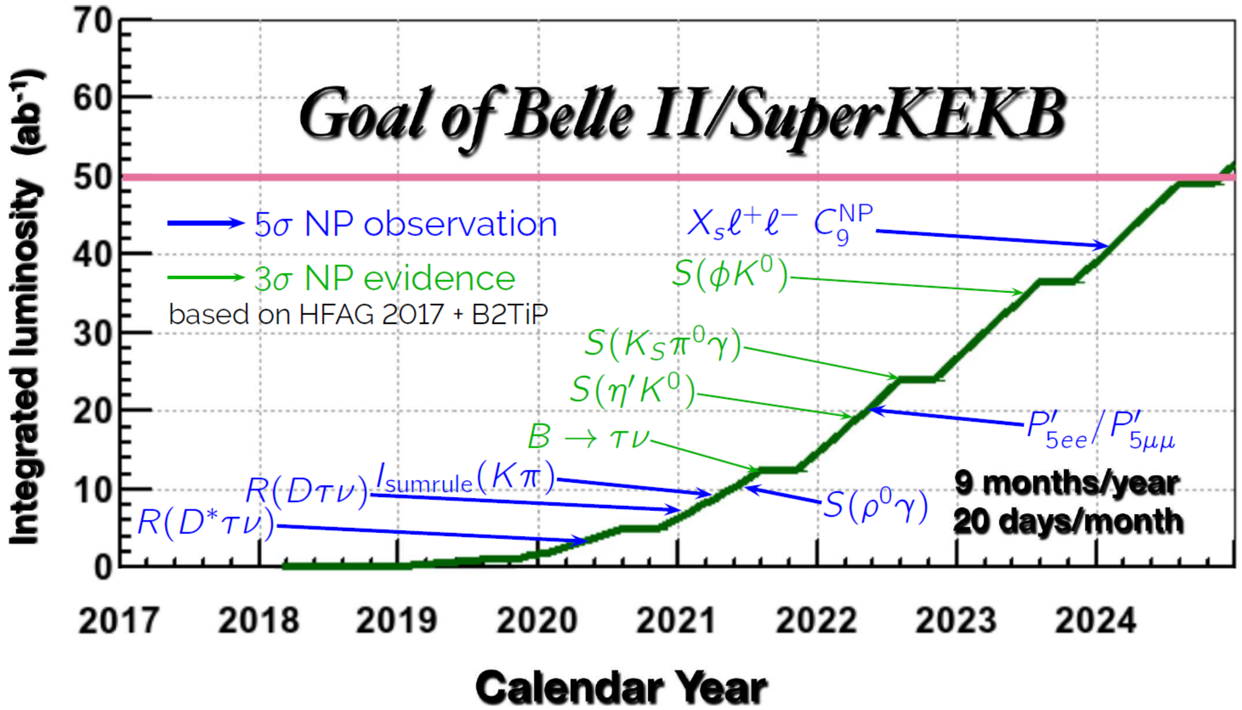
- Systematics different from LHCb
  - Two experiments are required to establish NP

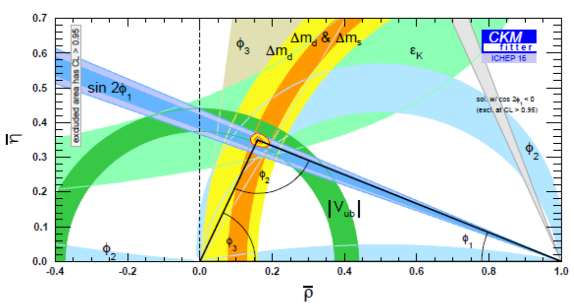
$B \to \pi l \nu$
$B \to \tau \nu, D \tau \nu$
$B \to K \nu \nu$

Belle II Physics Prospects



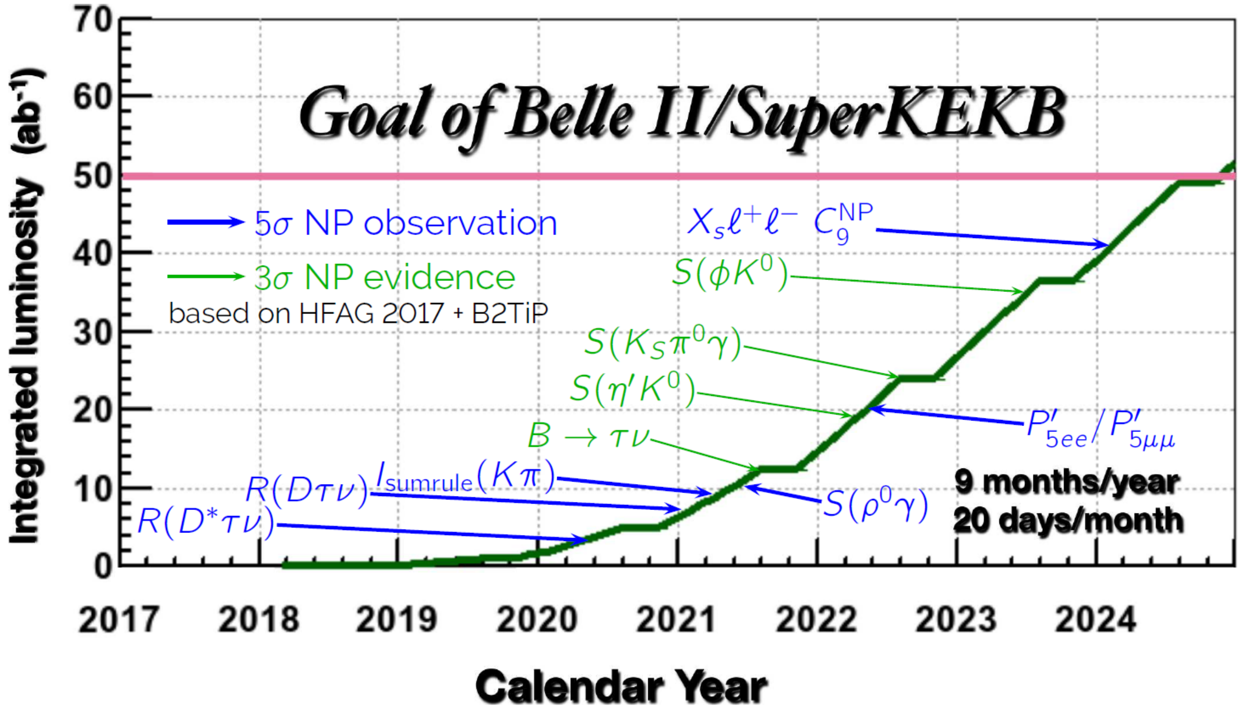
Belle II Physics Prospects



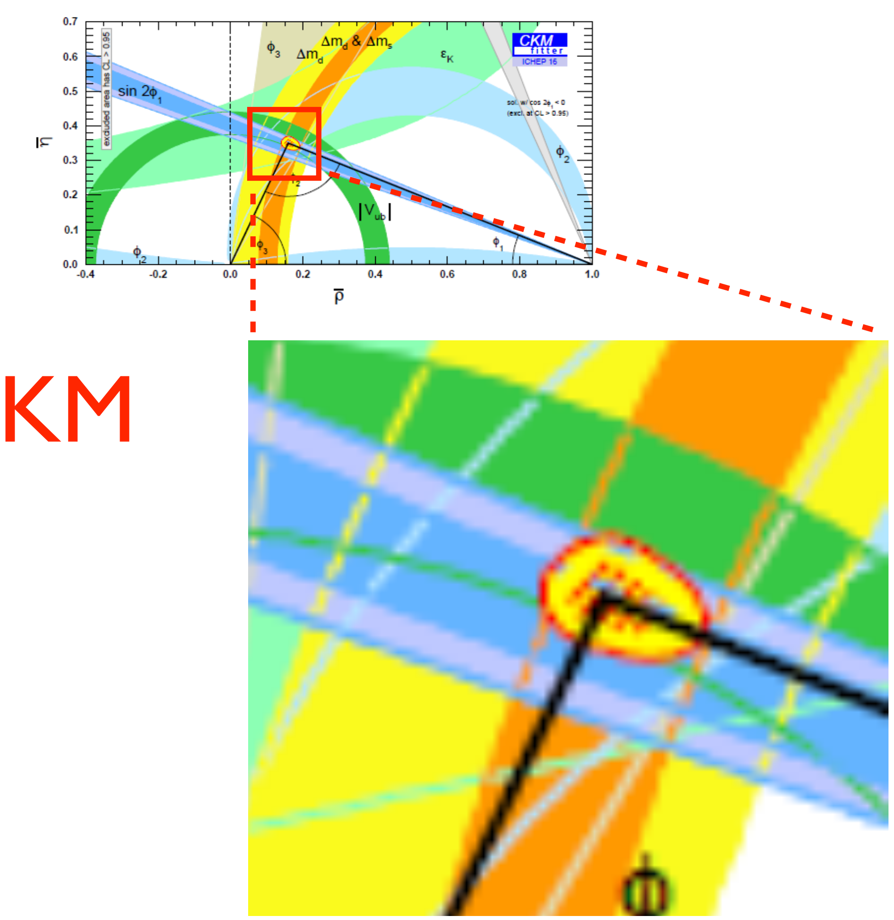


CKM

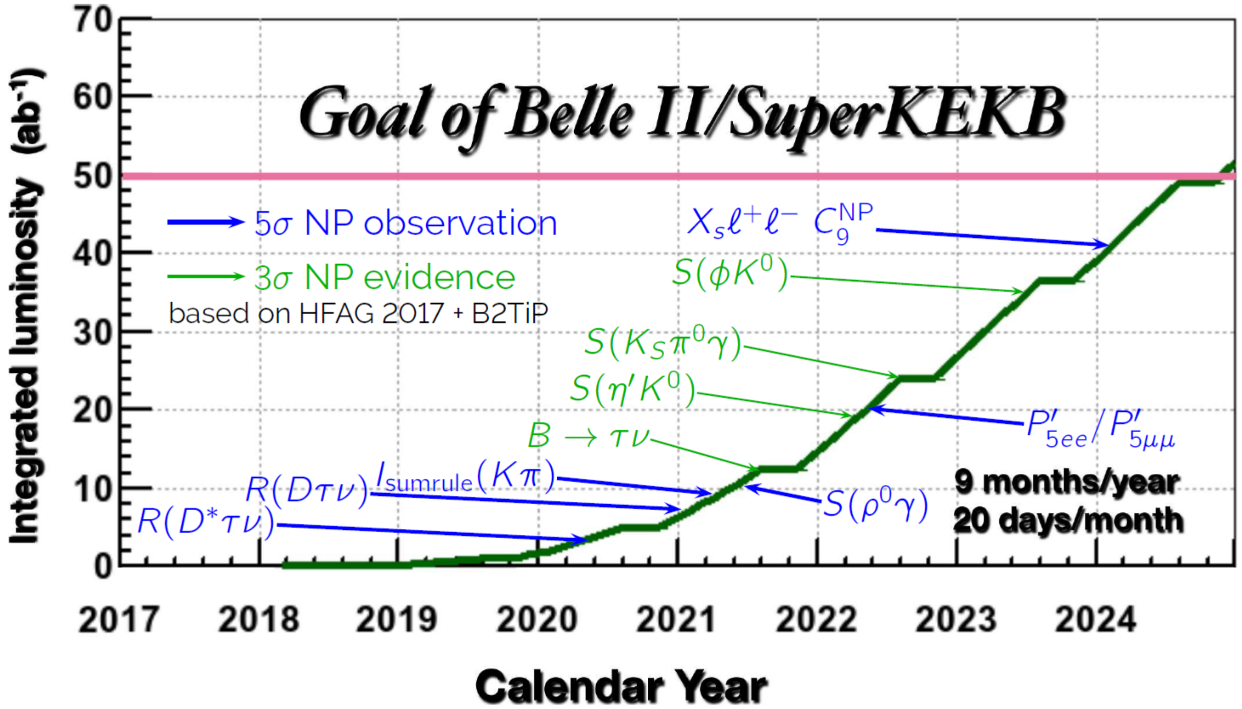
Belle II Physics Prospects



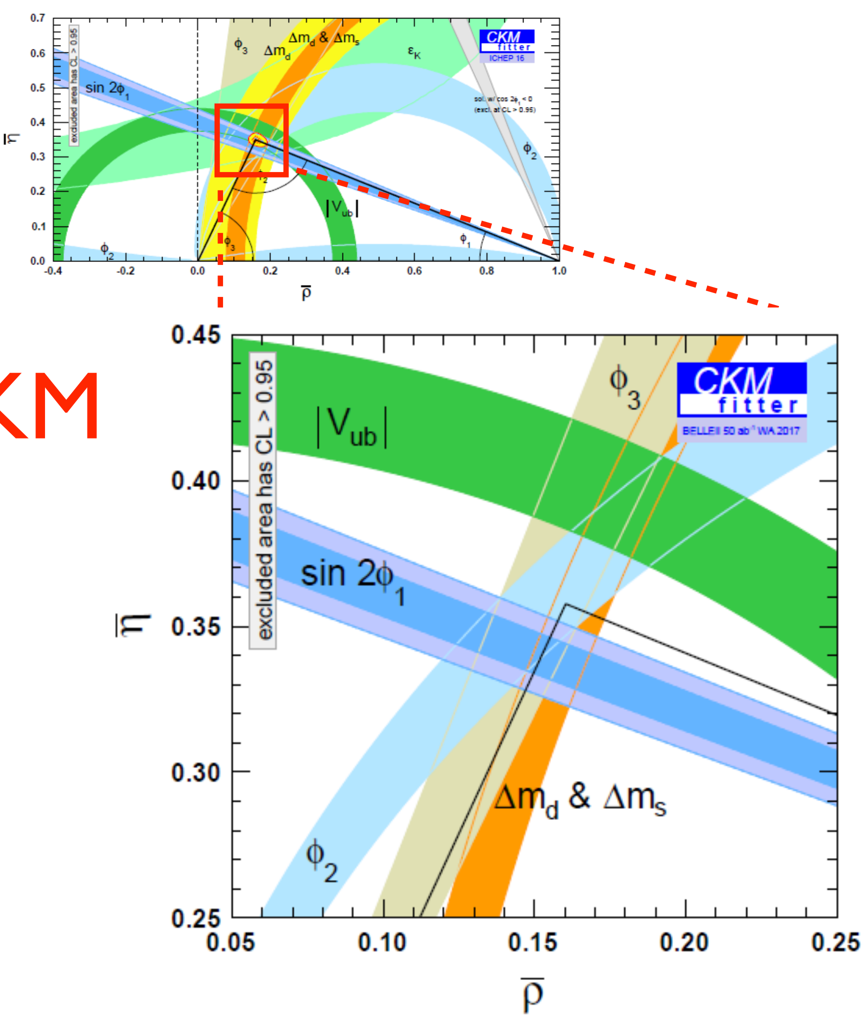
CKM



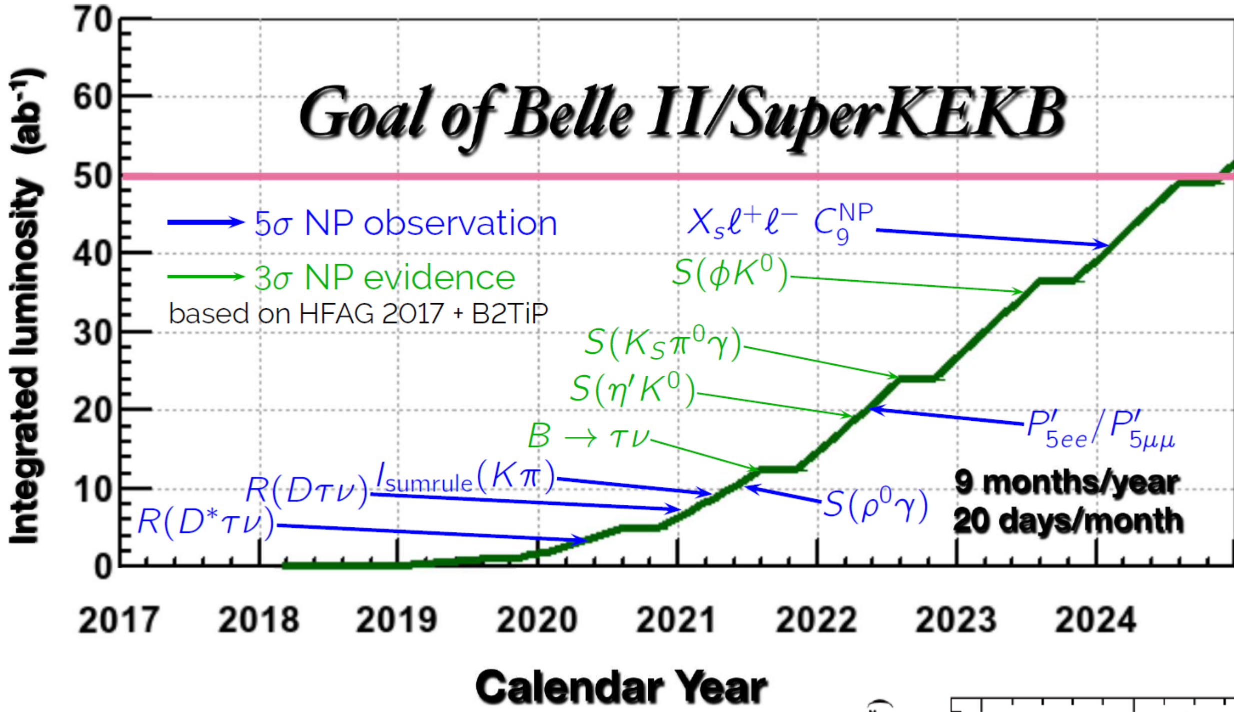
Belle II Physics Prospects



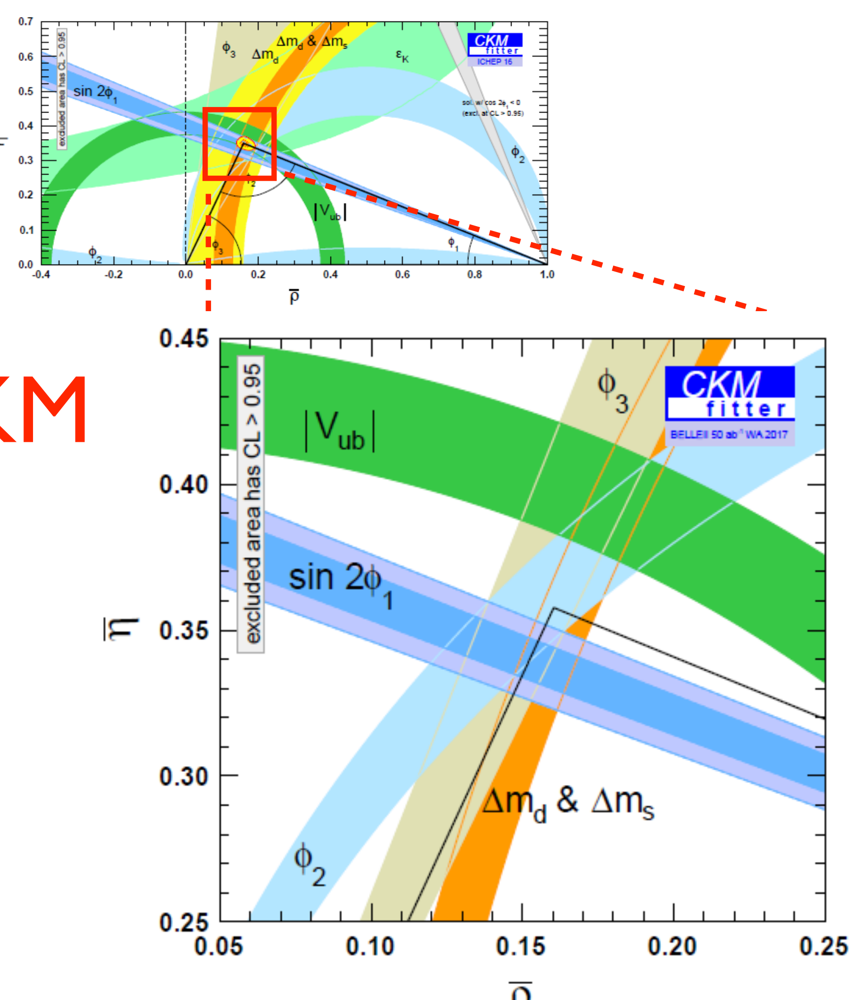
CKM



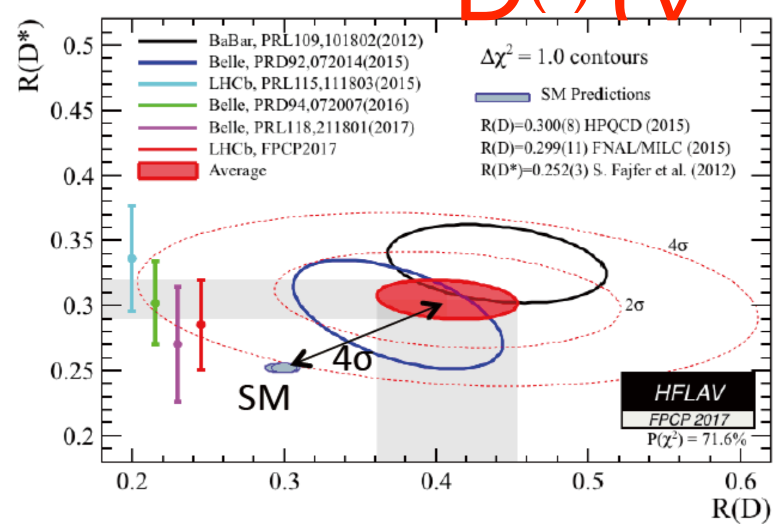
Belle II Physics Prospects



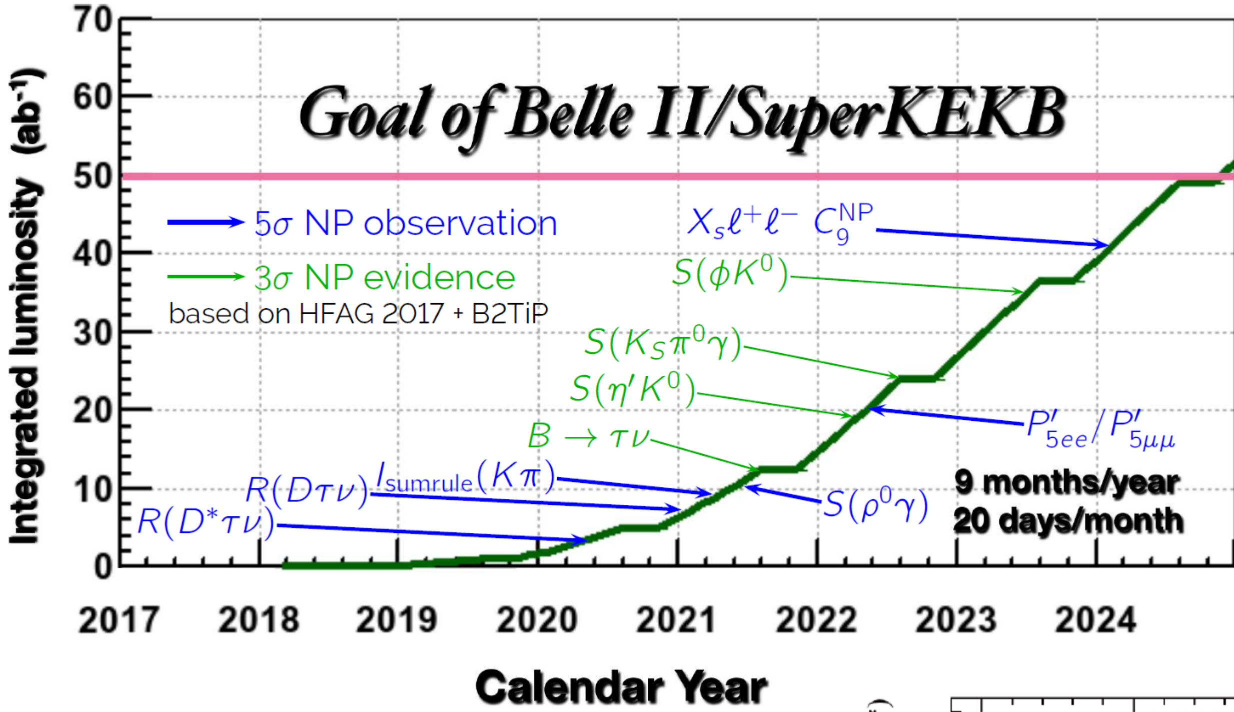
CKM



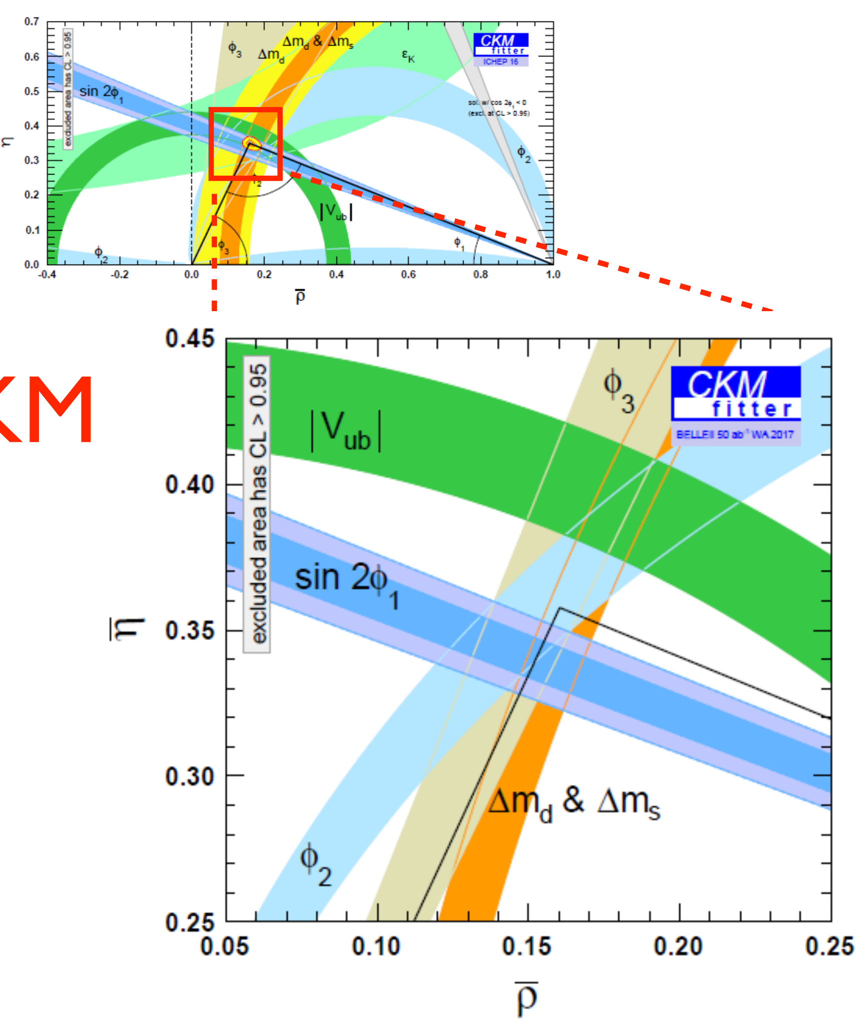
$D^{(*)}\tau\nu$



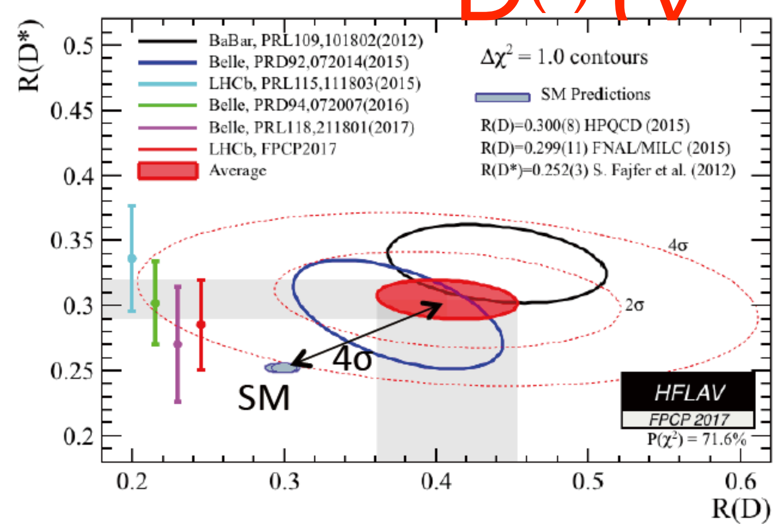
Belle II Physics Prospects



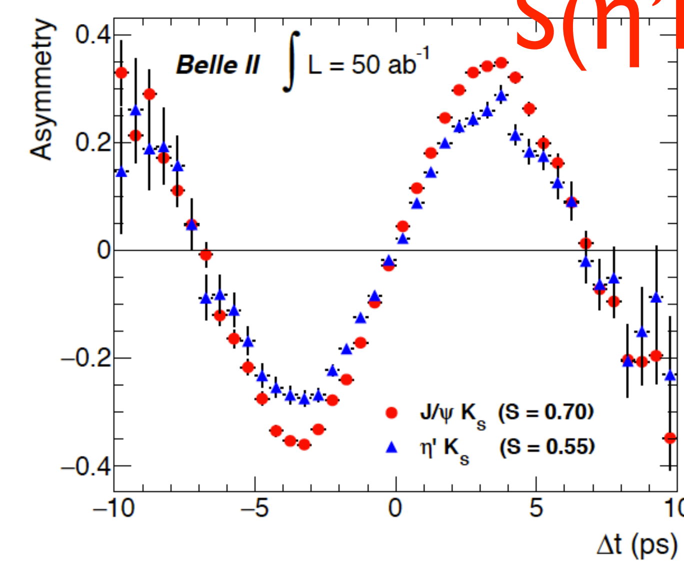
CKM



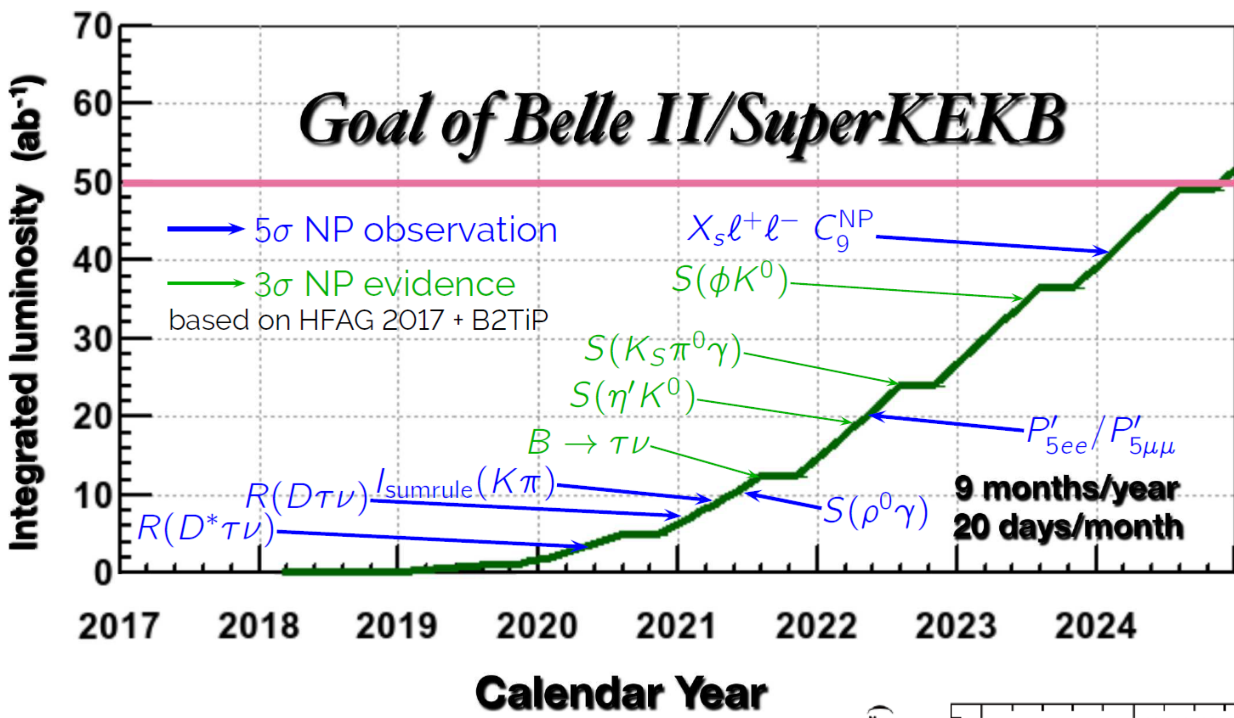
D(*)τν

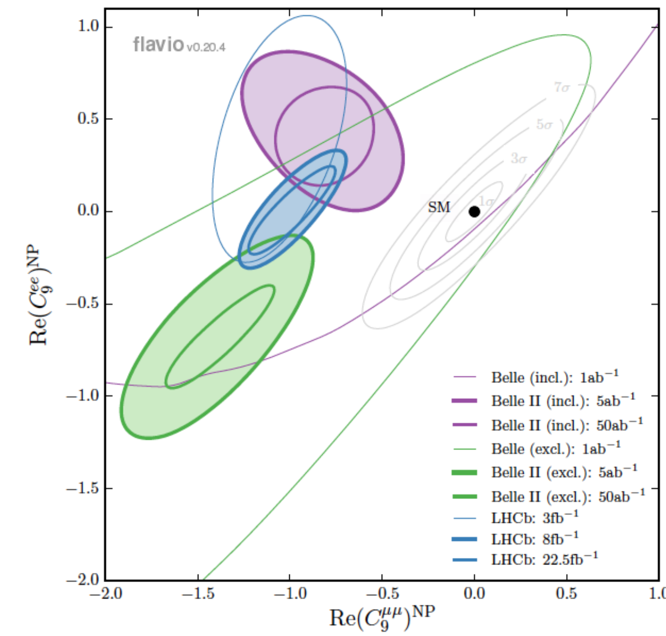


S(η'Ks)



Belle II Physics Prospects

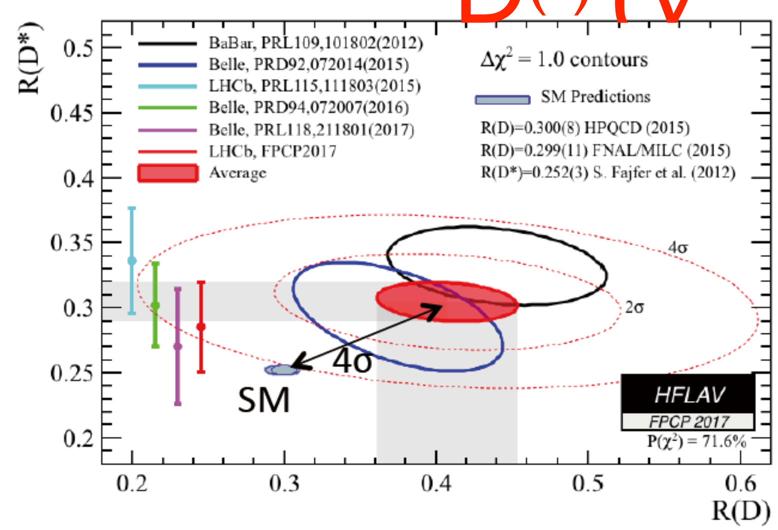




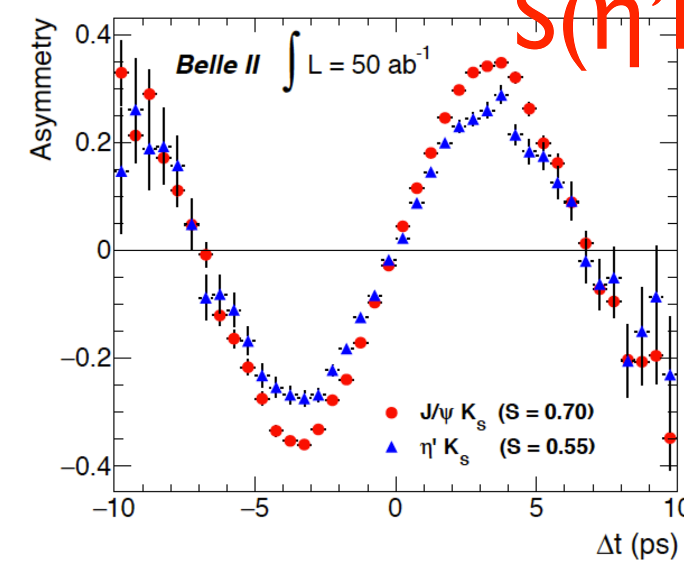
K(*) ll

Xs ll

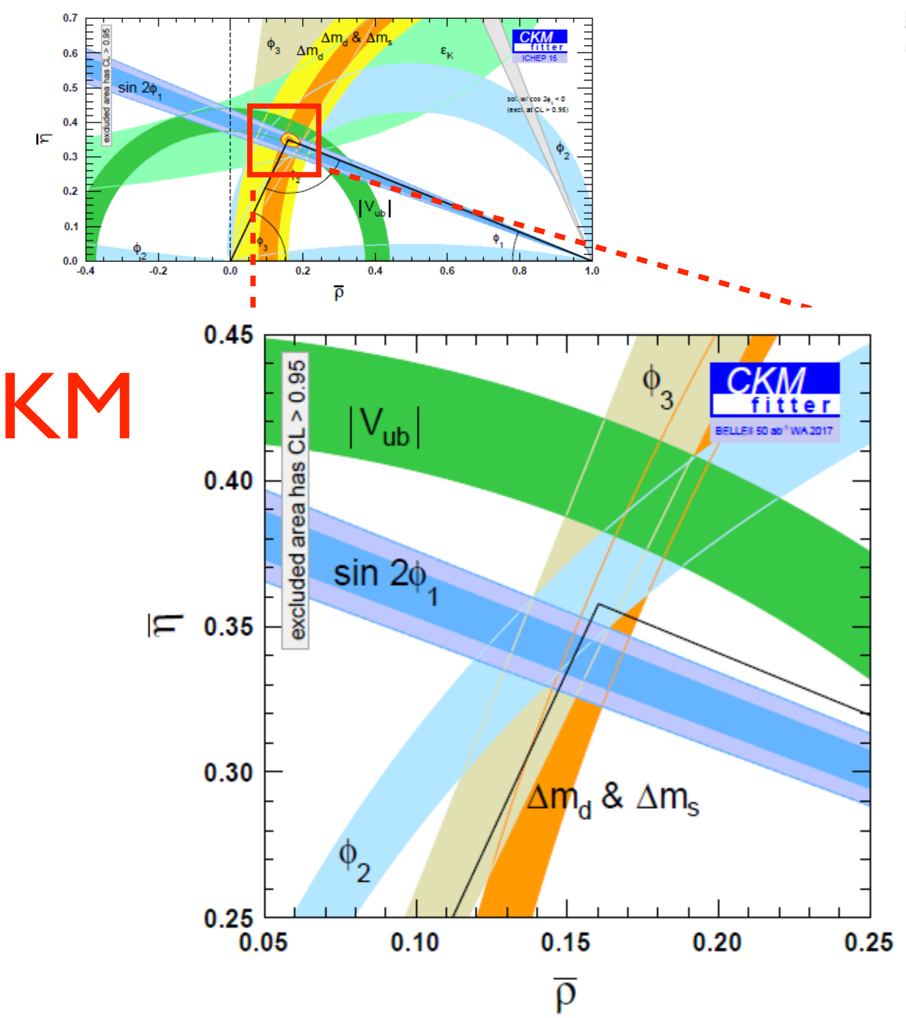
D(*)τν



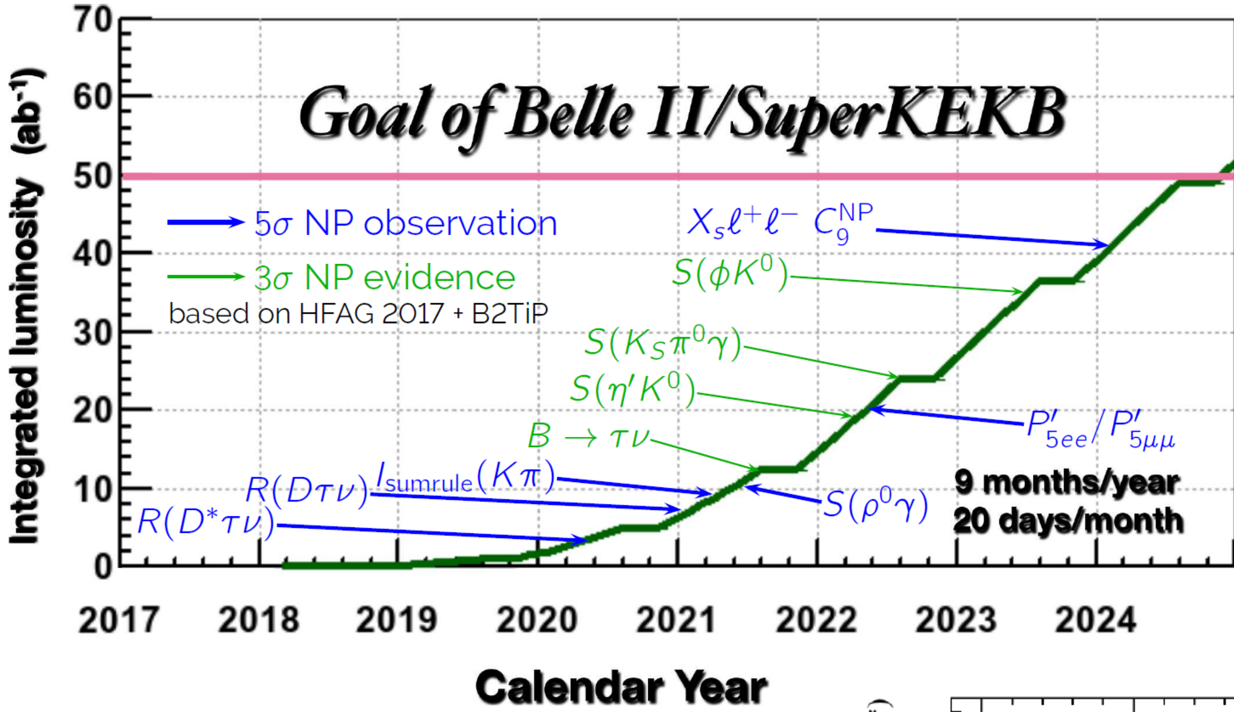
S(η'Ks)

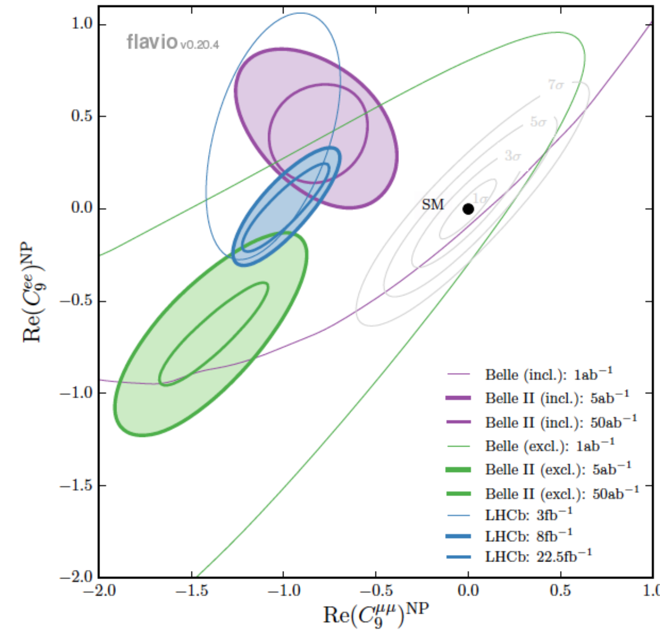


CKM



Belle II Physics Prospects

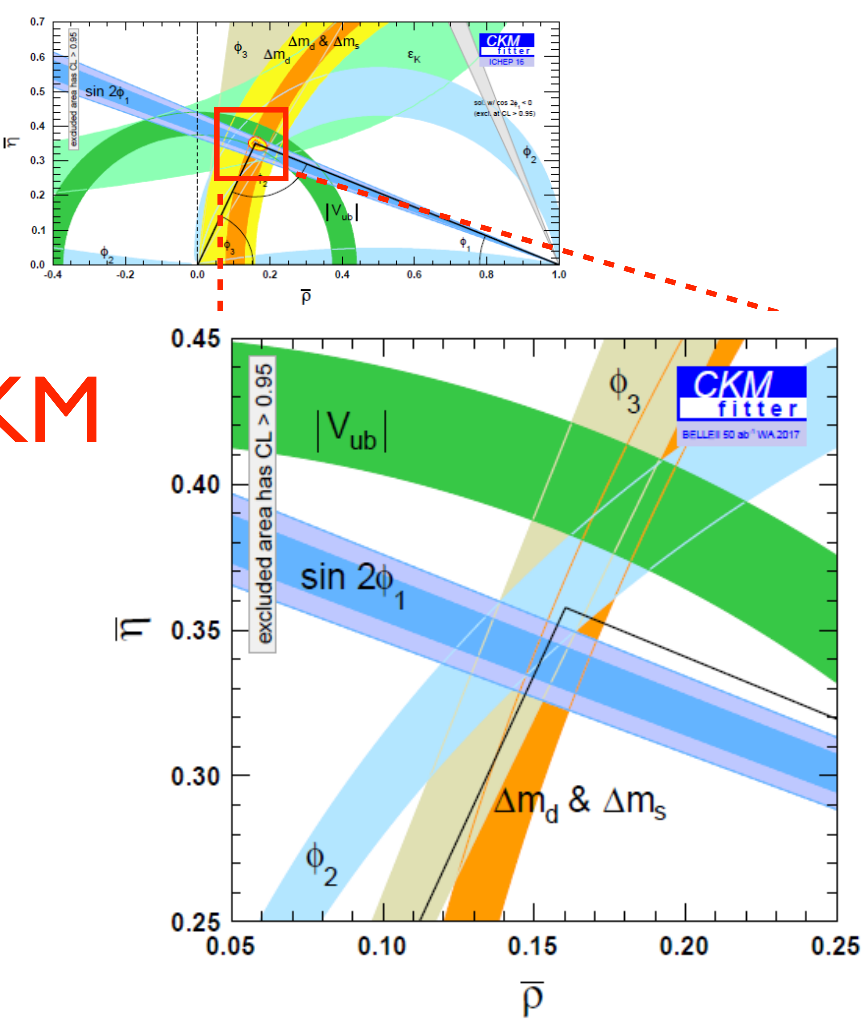




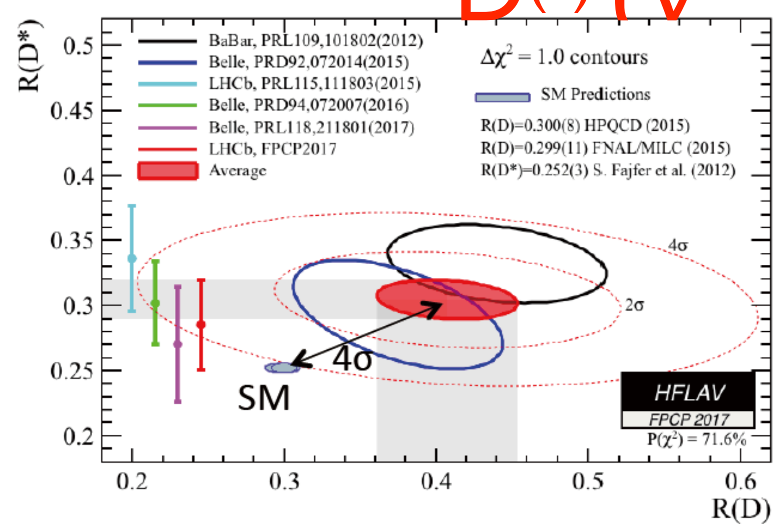
K(*) ll

Xs ll

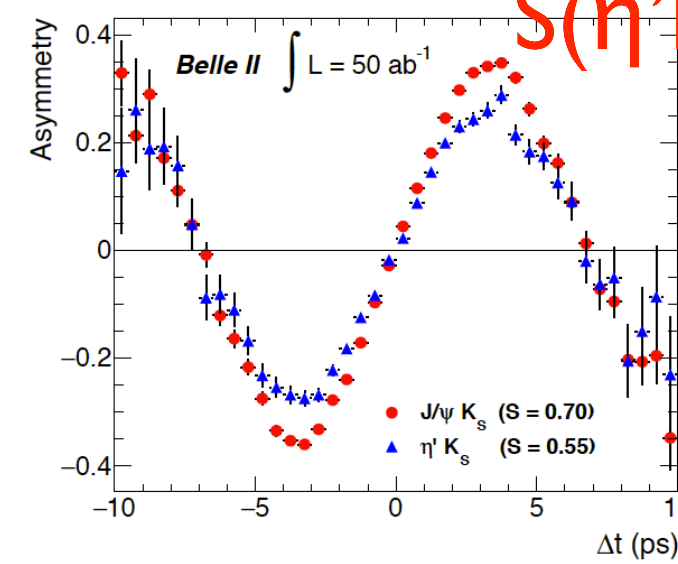
CKM



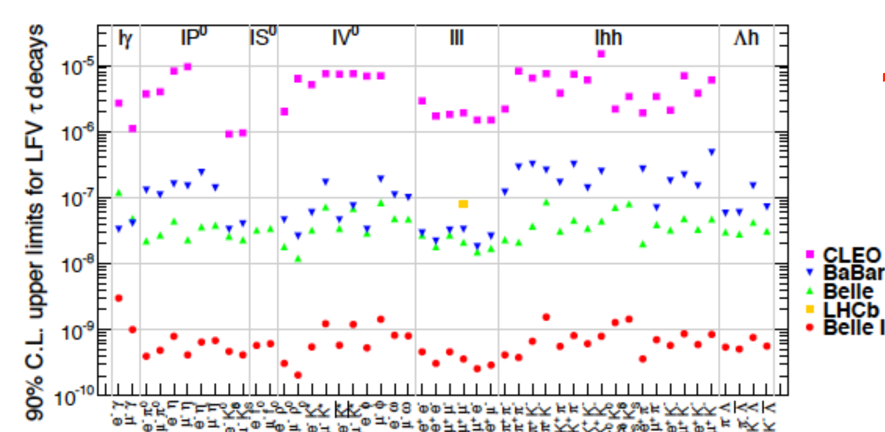
D(*)τν



S(η'Ks)

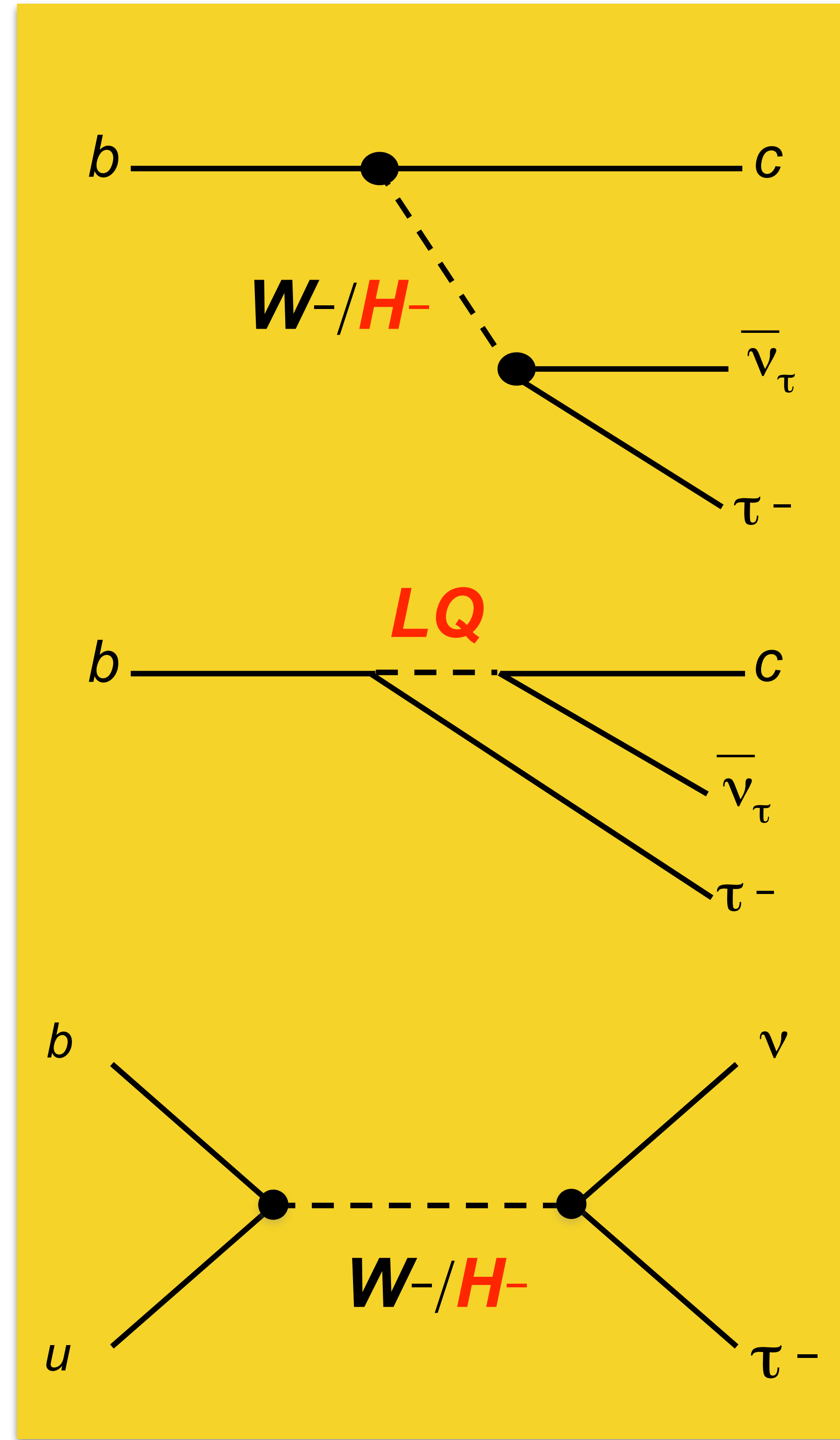


τ LFV



Tauonic B Decays

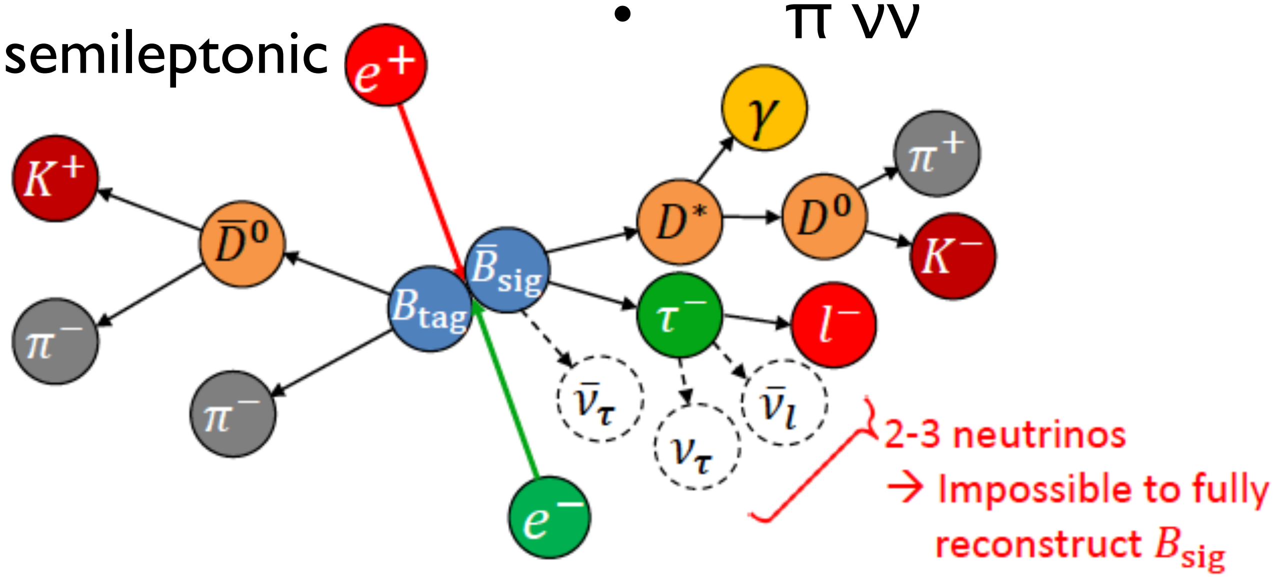
- New Physics may appear in tree level.
- 3rd generation quark (b) and lepton (τ) involved.
  - large masses → sensitivity to NP
  - Charged Higgs, Leptoquark, …
- $B \to D^{(*)} \tau \nu$ and $B \to \tau \nu$ are complementary
- Quantities of interest
  - Lepton Flavor Universality :
    - R(D), R(D*)
  - Polarization: P_τ, P_{D^*}
  - q^2 distribution etc.



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

Tag side
- inclusive
- hadronic
- semileptonic

Signal side
- $\tau \to l \nu\nu$
- $\pi \nu\nu$



$$R(D^{(*)}) \equiv \frac{BF(B \to D^{(*)}\tau^-\bar{\nu}_\tau)}{BF(B \to D^{(*)}l^-\bar{\nu}_l)}$$

$$(l^- = e^-, \mu^-)$$

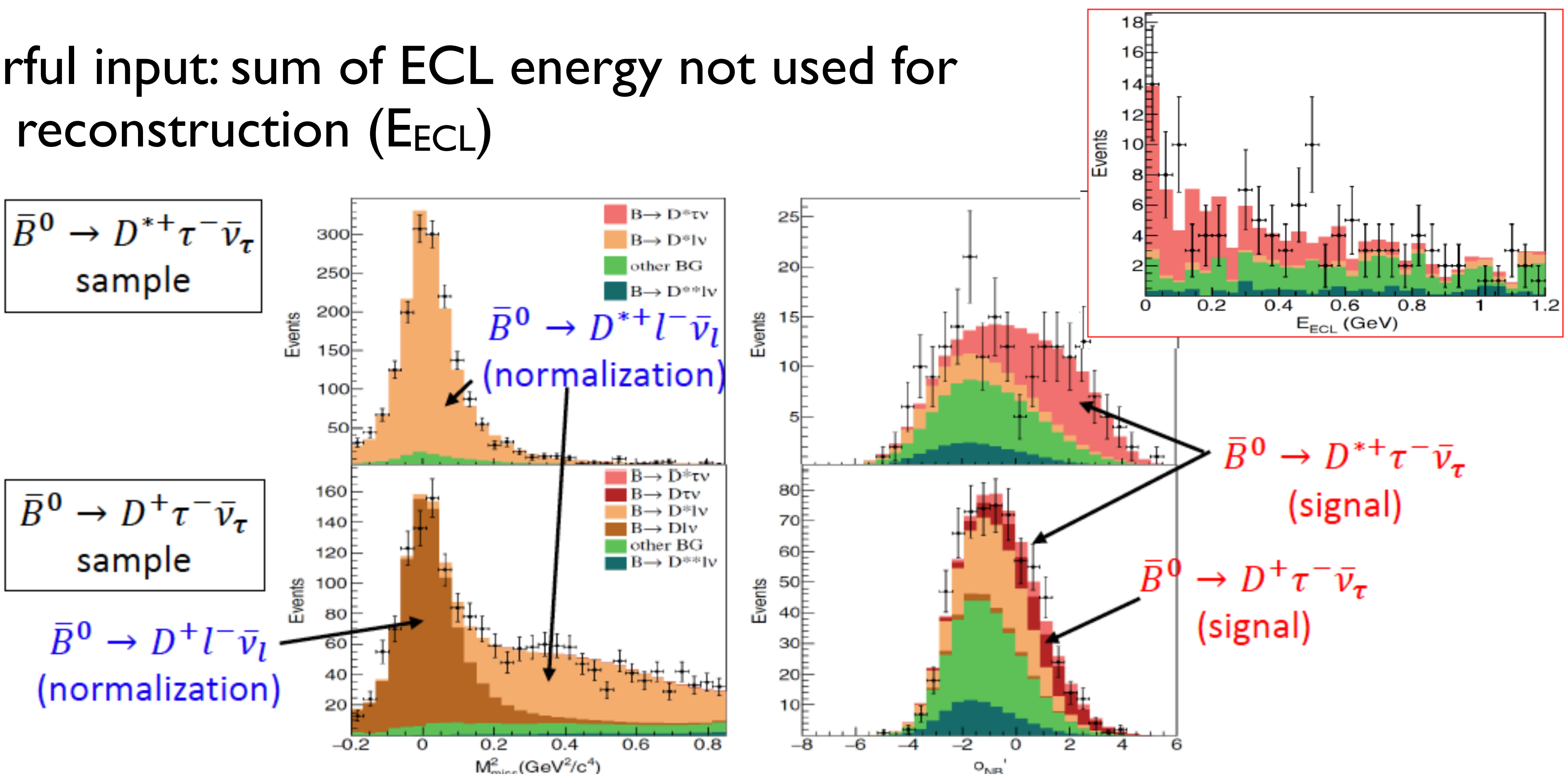
year	tag	τ mode	R(D)	R(D*)	Ref.
2007	incl.	πν, lνν	0.38±0.11	0.34±0.08	PRL99, 191807 (2007)
2010	incl.	πν, lνν			PRD82, 072005 (2010)
2015	had.	lνν	0.375±0.064±0.026	0.293±0.038±0.015	PRD92, 072014 (2015)
2016	s.l.	lνν	IN PROGRESS	0.302±0.030±0.011	PRD94, 072007 (2016)
2017	had.	πν,ρν		0.270±0.035±0.027	PRL118, 211801 (2017), PRD97, 012004 (2018)

~20% (stat) ~7%(syst) ~10-13% (stat) ~3.6-10%(syst)

$B \to D^{(*)} \tau \nu$ w/ $\tau \to l \nu \nu$ & had. tag

PRD92, 072014 (2015)

- M^2_{miss} to measure $B \to D^{(*)} l \nu$
  - $M^2_{miss} = [\, p(e^+e^-) - p(B_{tag}) - p(D^{(*)}) - p(l) \,]^2$
- Transformed neural network output (O'_{NB}) to measure $B \to D^{(*)} \tau \nu$
  - Powerful input: sum of ECL energy not used for signal reconstruction (E_{ECL})

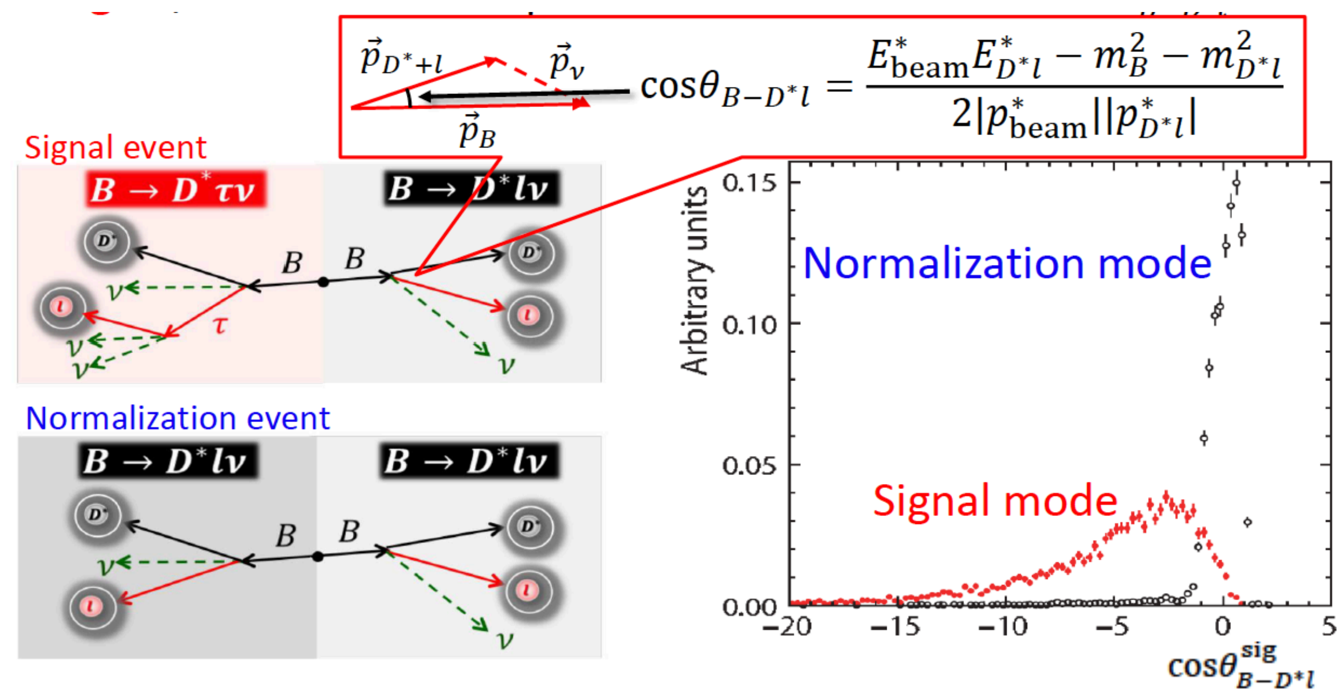


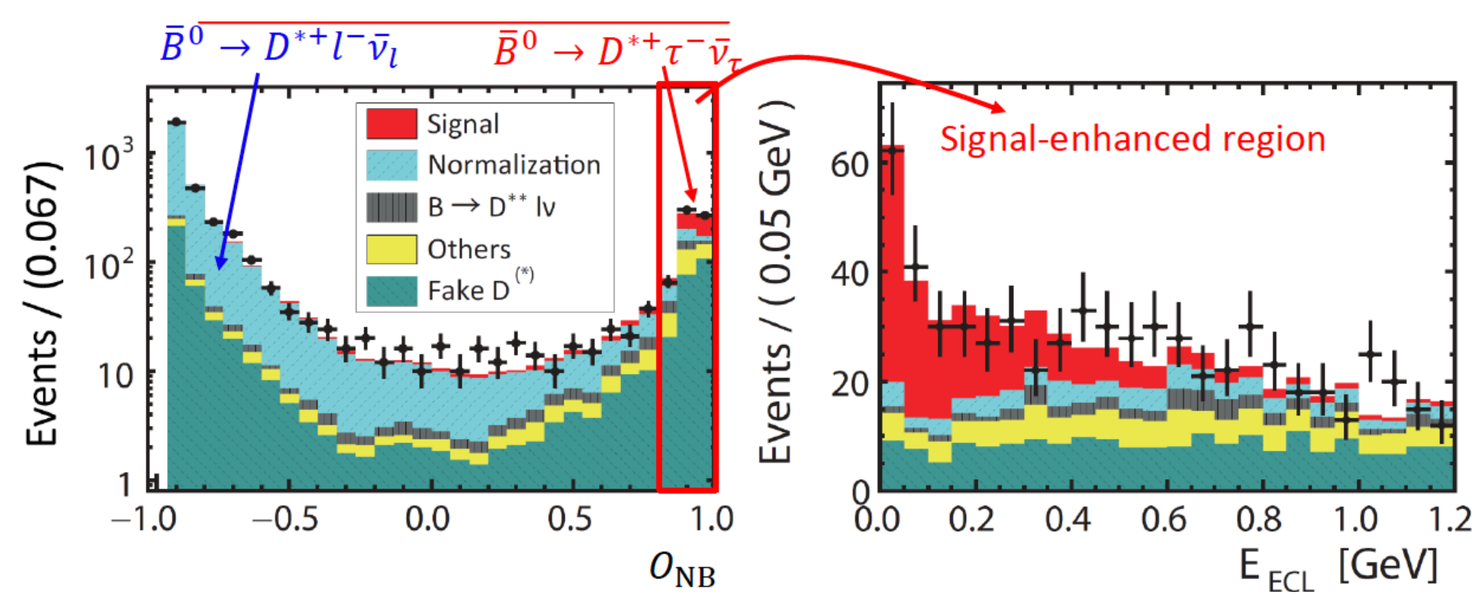
$$R(D) = 0.375 \pm 0.064(\text{stat.}) \pm 0.026(\text{syst.})$$
$$R(D^*) = 0.293 \pm 0.038(\text{stat.}) \pm 0.015(\text{syst.})$$

$B \to D^* \tau \nu$ w/ $\tau \to l\nu\nu$ & s.l. tag

PRD94, 072007 (2016)

- More background due to additional ν
- Signal/normalization modes are separated by $\cos\theta_{B\text{-}D^*l}$
- Two dimensional fit to neural network output (O_{NB}) and E_{ECL}
- The first measurement of $B \to D^* l \nu$ with s.l. tagging technique





$$R(D^*) = 0.302 \pm 0.030\,(\text{stat.}) \pm 0.011\,(\text{syst.})$$

$B \to D^* \tau \nu$ w/ $\tau \to \pi/\rho\nu$ & had. tag

PRL118, 211801 (2017), PRD97, 012004 (2018)

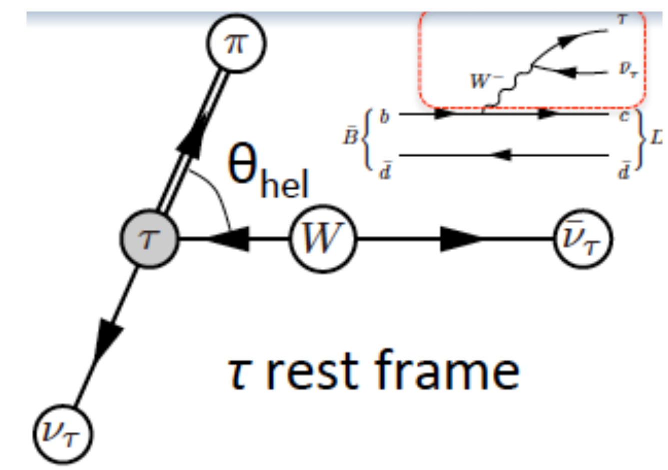
Analysis w/ τ hadronic decays
→ τ polarization

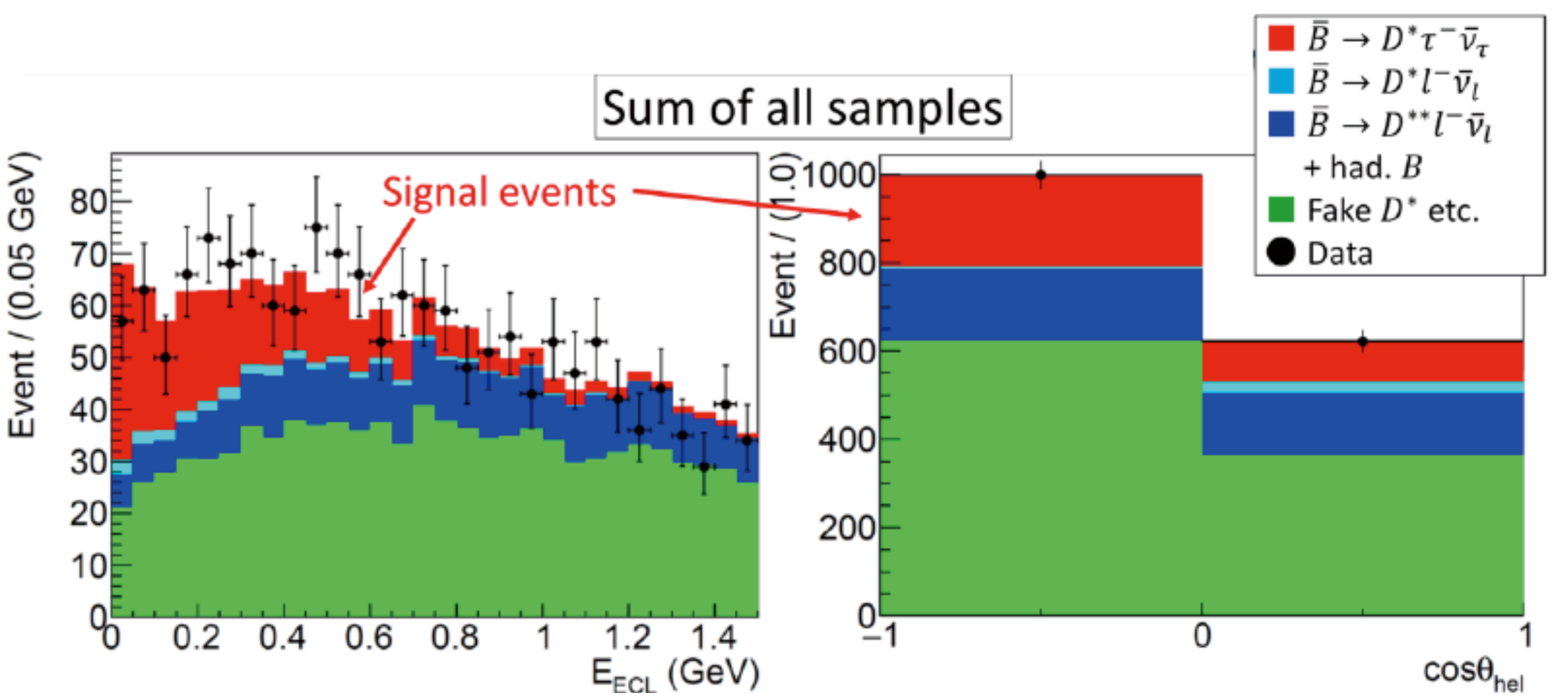
$P_\tau(D^*) = -0.497 \pm 0.013$

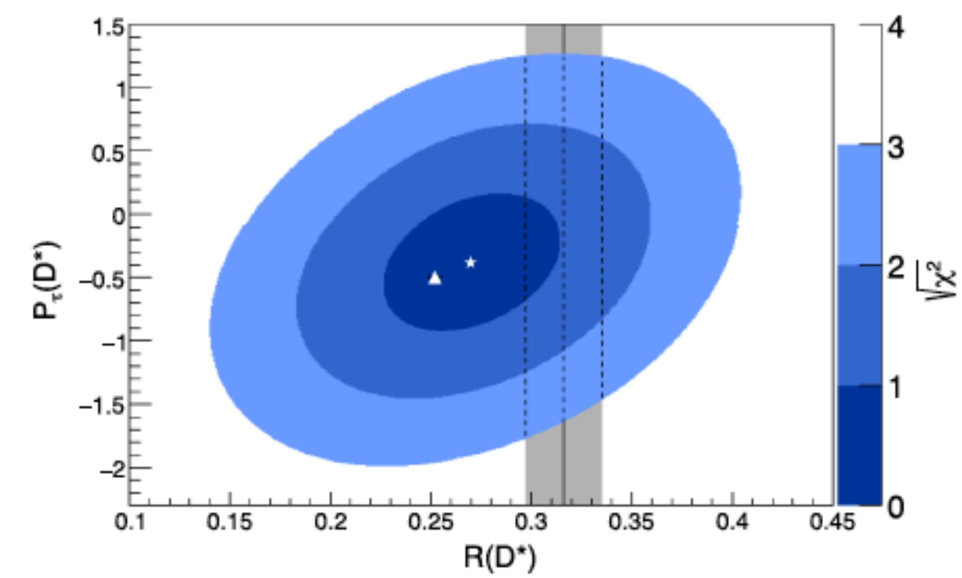
$$\frac{1}{\Gamma(D^{(*)})}\frac{d\Gamma(D^{(*)})}{d\cos\theta_{\rm hel}} = \frac{1}{2}\left[1+\alpha P_\tau(D^{(*)})\cos\theta_{\rm hel}\right]$$

$\tau \to \pi\nu$: $\alpha = 1.0$, $\tau \to \rho\nu$: $\alpha = 0.449$

$$P_\tau(D^*) = \frac{2}{\alpha}\frac{N_{\rm sig}(\cos\theta_{\rm hel}>0) - N_{\rm sig}(\cos\theta_{\rm hel}<0)}{N_{\rm sig}(\cos\theta_{\rm hel}>0) + N_{\rm sig}(\cos\theta_{\rm hel}<0)}$$







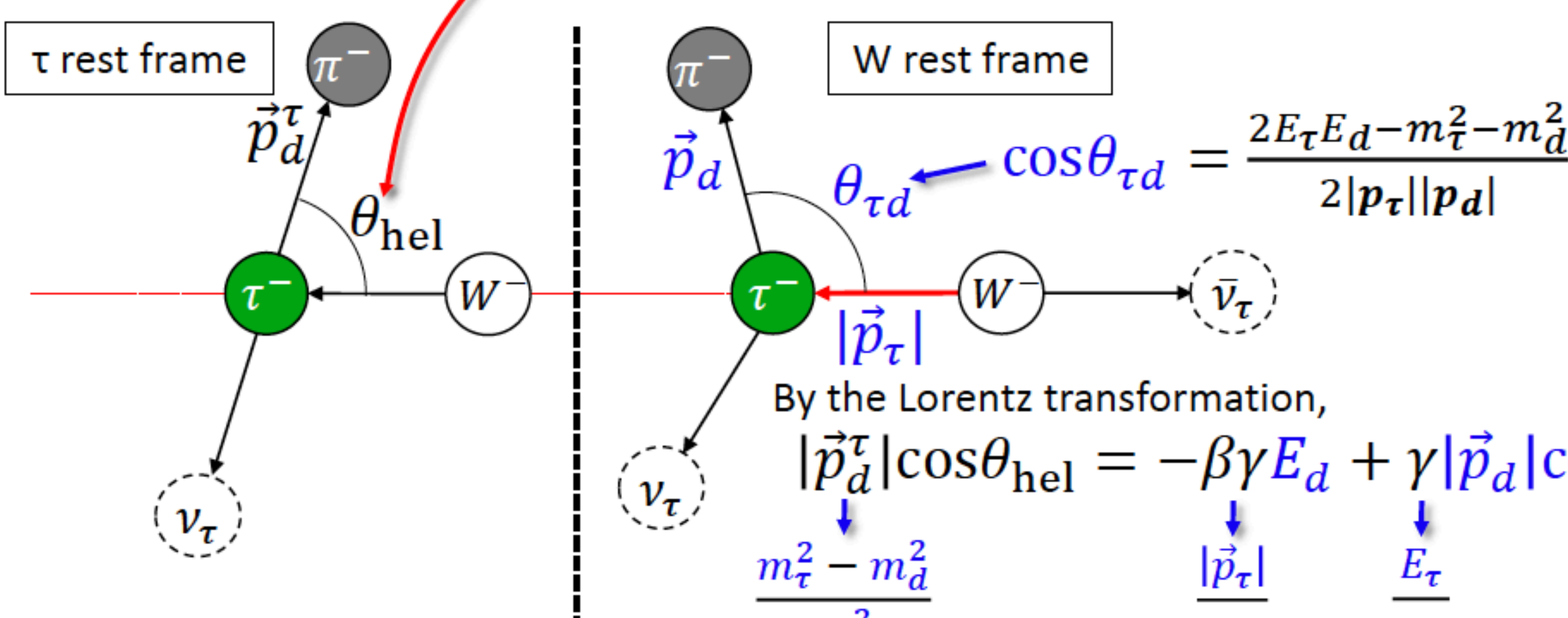
$$R(D^*) = 0.270 \pm 0.035(\text{stat.})\,^{+0.028}_{-0.025}(\text{syst.})$$
$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})\,^{+0.21}_{-0.16}(\text{syst.})$$

The first measurement of $P_\tau(D^*)$: < +0.5 (90% C.L.)

Measurement of τ polarization

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\mathrm{hel}}} = \frac{1}{2}\left(1 + \alpha P_\tau(D^*)\cos\theta_{\mathrm{hel}}\right)$$

$$\alpha = \begin{cases} 1 & \text{for } \tau^- \to \pi^- \nu_\tau \\ \sim 0.45 & \text{for } \tau^- \to \rho^- \nu_\tau \end{cases}$$



$$\cos\theta_{\tau d} = \frac{2E_\tau E_d - m_\tau^2 - m_d^2}{2|\boldsymbol{p}_\tau||\boldsymbol{p}_d|}$$

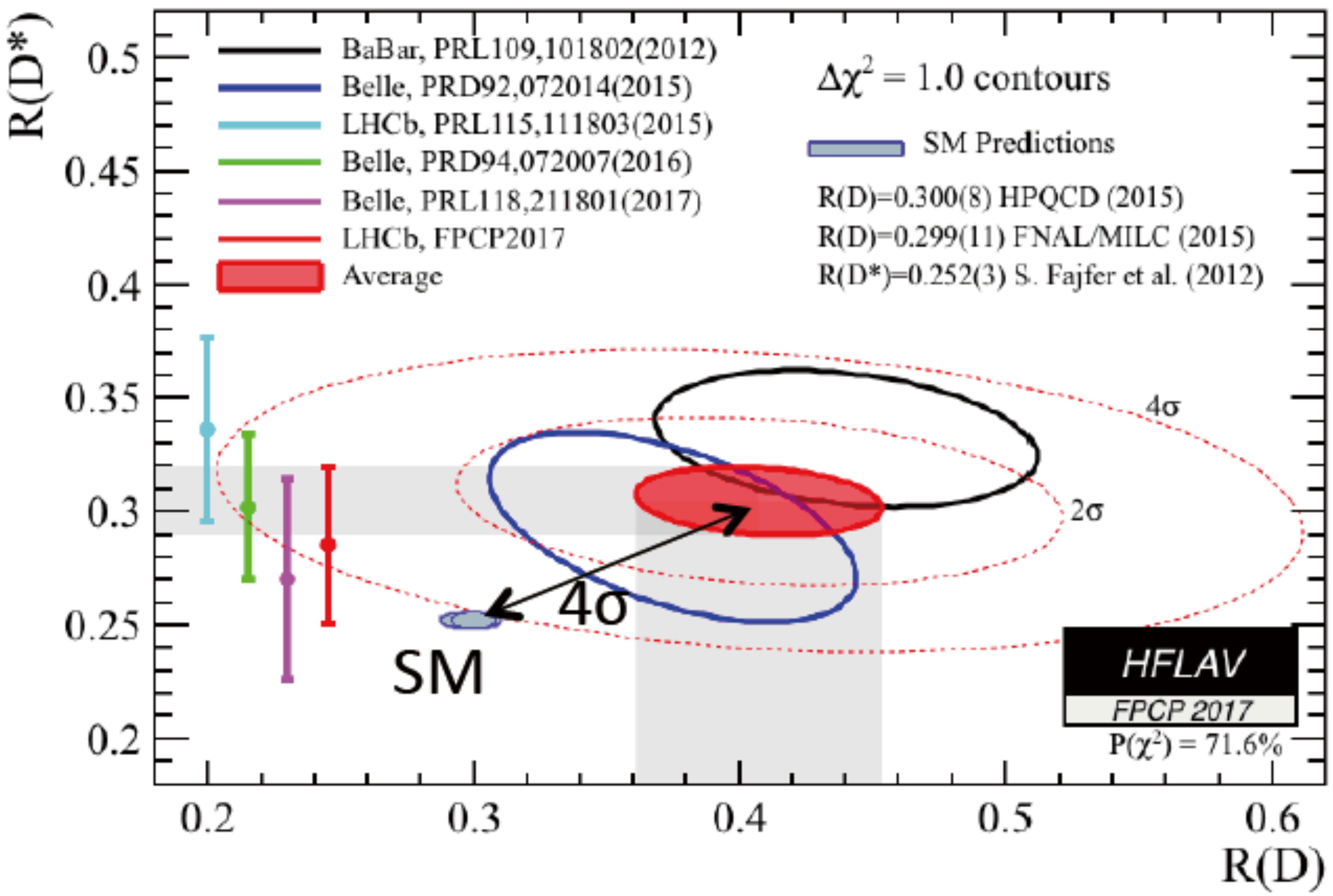
By the Lorentz transformation,

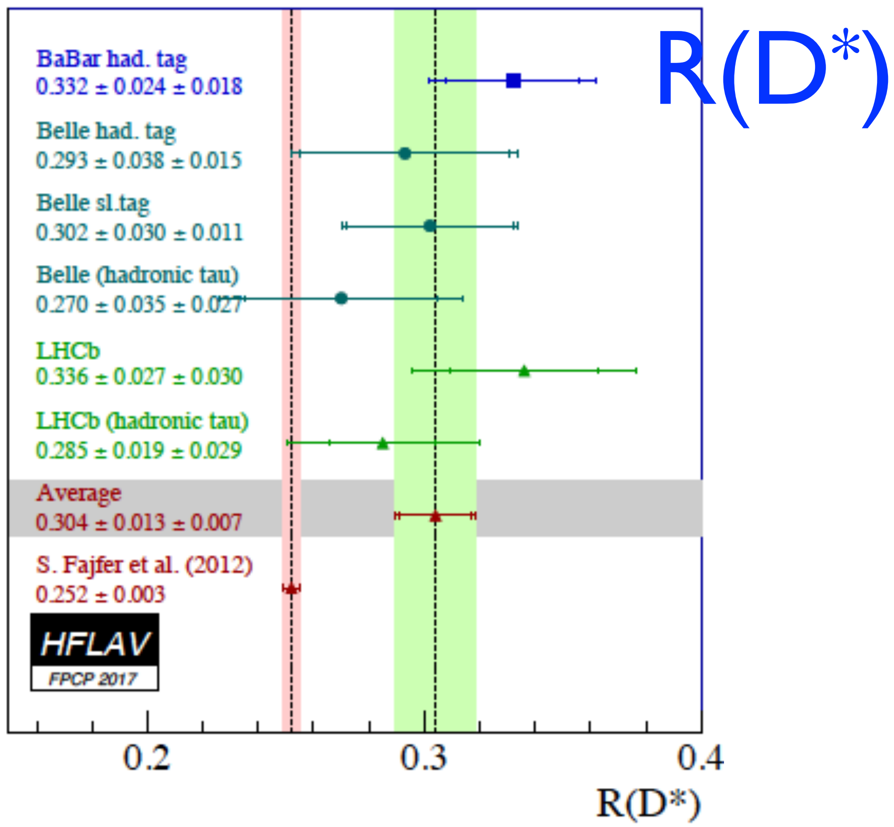
$$|\vec{p}_d^{\,\tau}|\cos\theta_{\mathrm{hel}} = -\beta\gamma E_d + \gamma|\vec{p}_d|\cos\theta_{\tau d}$$

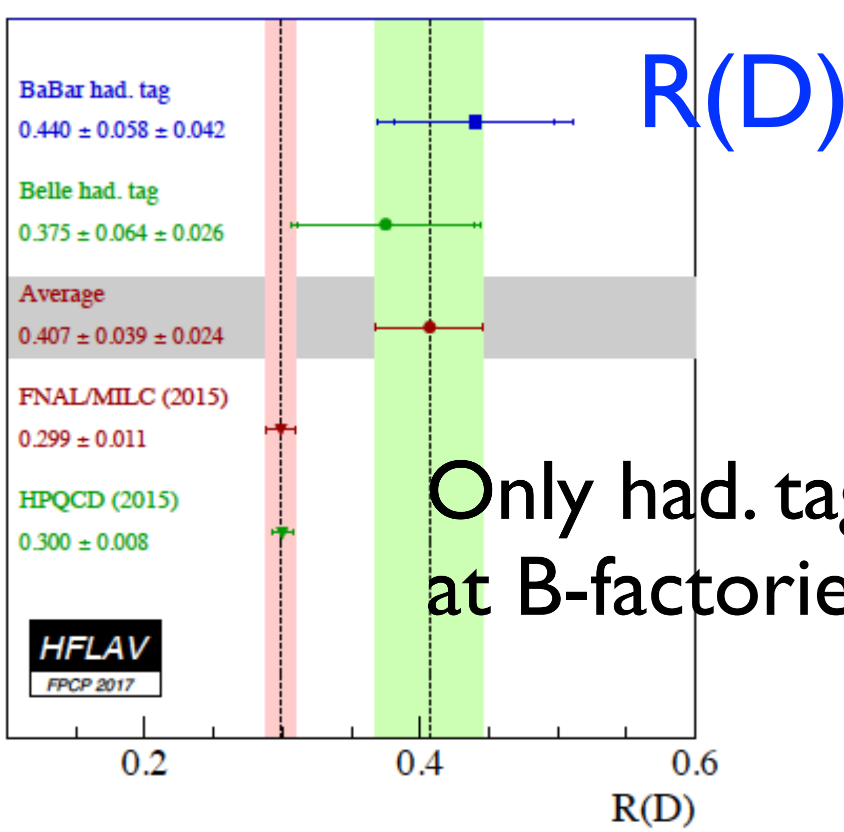
$$|\vec{p}_d^{\,\tau}| \to \frac{m_\tau^2 - m_d^2}{m_\tau^2}, \quad \beta\gamma \to \frac{|\vec{p}_\tau|}{m_\tau}, \quad \gamma \to \frac{E_\tau}{m_\tau}$$

Solving the equation, $\cos\theta_{\mathrm{hel}}$ is obtained!

Summary of present R(D$^{(*)}$) Results







Only had. tag.
at B-factories

R(D) = 0.300±0.008 HPQCD (2015)
0.299±0.011 FNAL/MILC (2015)
0.299±0.003 P. Gambino, D. Bigi (2016)
LQCD+f(B→Dlv) from BaBar/Belle

R(D*) = 0.252±0.003 S.Fajfer, J.F.Kamenik, and I.Nisandzic (2012)

Expected resolution at Belle II

- Simple extrapolation by luminosity allows measurements with statistical errors;
  - R(D) : ~ 7.5% (2.4%) at 5 (50) ab^{-1}
  - R(D*): ~ 4.9% (1.5%) at 5 (50) ab^{-1}

for hadronic tag + $\tau \to l \nu\nu$

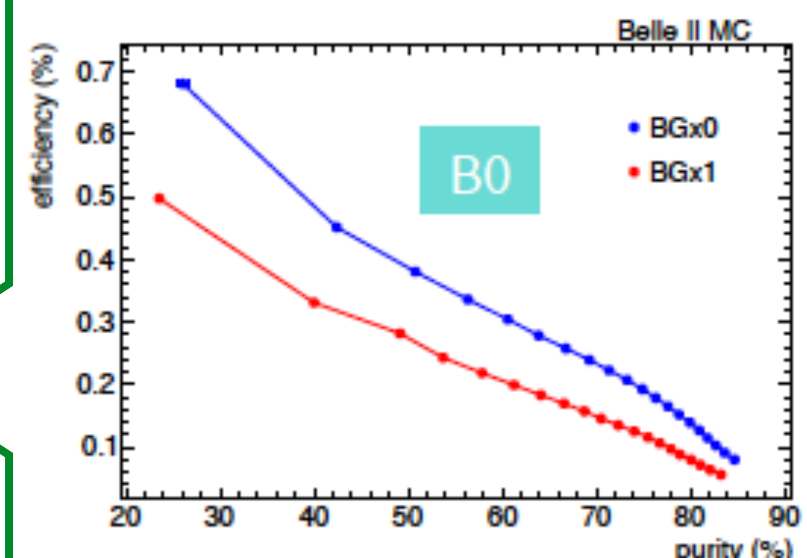
- Statistical error will be further reduced by improved tagging with;
  - Fast BDT
  - More decay modes

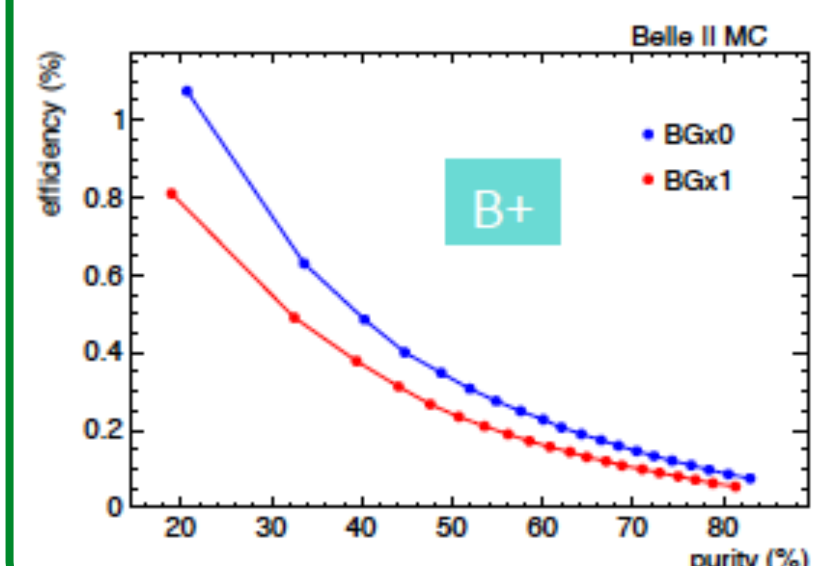
Tag algorithm date	MVA	Efficiency	Purity
Belle v1 (2004)	Cut-based (Vcb)	-	-
Belle v3 (2007)	Cut-based	0.1	0.25
Belle NB (2011)	**Neurobayes**	**0.2**	**0.25**
Belle II FEI (2017)	Fast BoostedDecisionTree	0.5	0.25

- Will soon hit the systematic limit !

Number of decay modes used in tagging (Belle → Belle II)

- B^+ : 17 → 29
- B^0 : 14→26
- $D^+/D^{*+}/D_s^+$: 18 → 26
- D^0/D^{*0} : 12 → 17





Leading Systematic Uncertainties (Belle)

- Uncertainty in D^{**} composition
- Uncertainty in modeling of $B \rightarrow D^{**} l \nu$ kinematics
- Uncertainty in hadronic B decays as well (for measurements with τ hadronic decays)

Phillip Urquijo @ LHCb semitauonic workshp at LAL (Nov.2017)

	Experiment	Error profile*	SL tag R_{D^*}	Had tag R_{D^*}, $\tau \to h \nu$	Had tag R_{D^*}, $\tau \to l \nu \nu$	Had tag R_D, $\tau \to l \nu \nu$
1	MC statistics	Gauss	2.2	3.5	-	-
2	**B → D** l ν modelling**	**Uniform**	**+1, -1.7**	**2.4**	**1.5**	**4.2**
3	B → D* l ν	Gauss	+1.3, -0.2	2.3	-	-
4	**D** decay modes**	**Uniform**	**(in 2)**	**(in 2)**	**1.3**	**3.0**
5	**Hadronic B decays**	**Mixed**	**1.1**	**7.3**	**-**	**-**
6	**B → D** τ ν**	**Uniform**	**(in 2)**	**(in 2)**	**-**	**-**
7	Fake $D^{(*)}$	Gauss	1.4	0.2	0.3	0.5
8	Fake lepton	Gauss	-	-	0.6	0.5
9	Lepton ID	Gauss	1.2	1.8	0.5	0.5
10	τ Br	Gauss	0.2	0.3	0.2	0.2
11	Other	Gauss	-	2.3	-	-
	Total		3.5	9.9	5.2	7.1

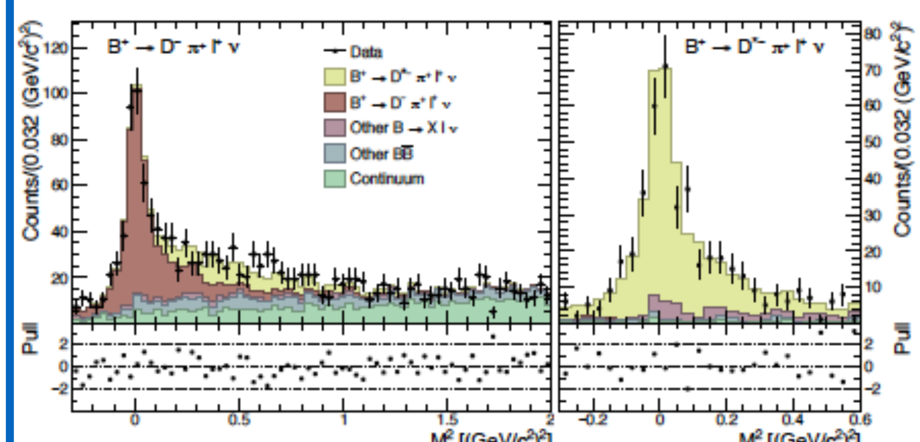
* Gauss = data driven or PDG, Uniform = nominal central value is arbitrary

Belle, arXiv: 1803.06444

New hadronic tag analysis

- $B^+ \rightarrow D^{(*)} \pi^+ l \nu$ (1.4k signal)
- $B^0 \rightarrow D^{(*)} \pi^+ l \nu$ (1.1k signal)

- $\mathcal{B}(B^+ \to D^- \pi^+ \ell^+ \nu) = [4.55 \pm 0.27 \text{ (stat.)} \pm 0.39 \text{ (syst.)}] \times 10^{-3}$,
- $\mathcal{B}(B^0 \to \bar{D}^0 \pi^- \ell^+ \nu) = [4.05 \pm 0.36 \text{ (stat.)} \pm 0.41 \text{ (syst.)}] \times 10^{-3}$,
- $\mathcal{B}(B^+ \to D^{*-} \pi^+ \ell^+ \nu) = [6.03 \pm 0.43 \text{ (stat.)} \pm 0.38 \text{ (syst.)}] \times 10^{-3}$,
- $\mathcal{B}(B^0 \to \bar{D}^{*0} \pi^- \ell^+ \nu) = [6.46 \pm 0.53 \text{ (stat.)} \pm 0.52 \text{ (syst.)}] \times 10^{-3}$.



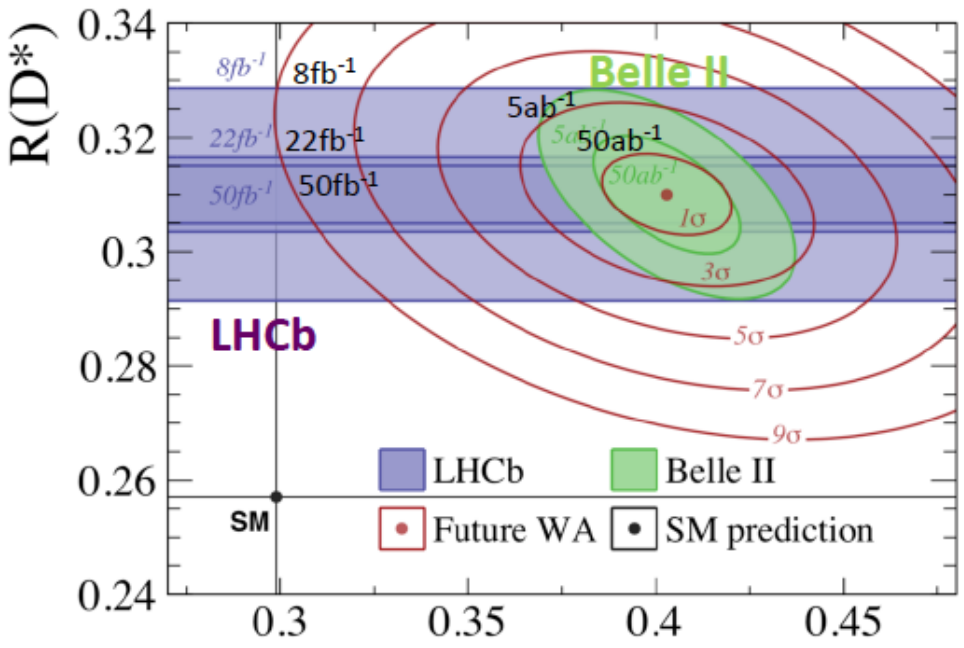
Belle II will provide much more information

- Differential distribution of narrow and broad components
- More complete study of D^{**} decay width m2miss studies and hadronic modes

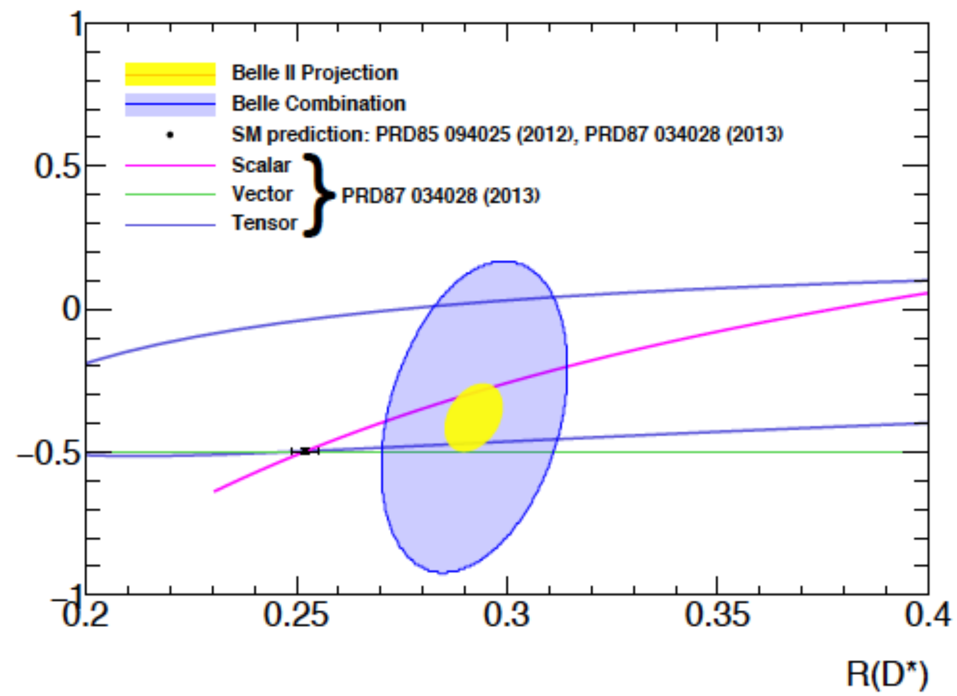
O(10) more tags expected.

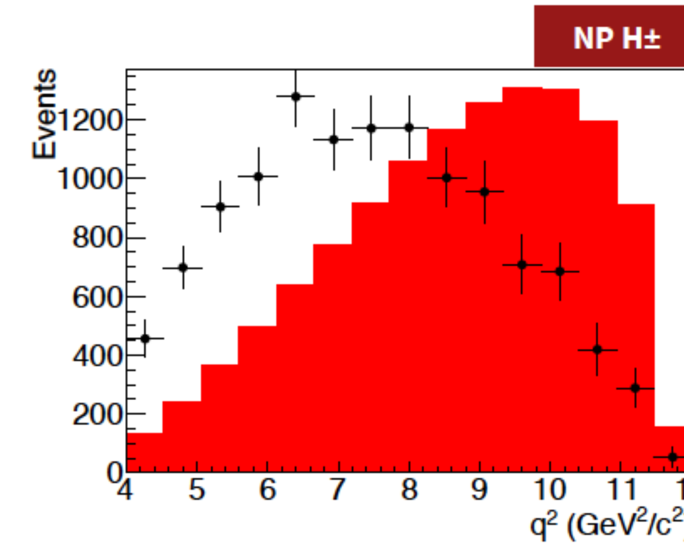
Belle II Projections

- Lepton universality violation may be established even with 5ab-1 (2020).
- High statistics data will provide more detailed information, such as τ polarization, q2 distribution, to discriminate type of NP.



arXiv:1709.10308





50 ab-1 projection of the subtracted q^2 spectrum in $B \to D^* \tau \nu$ (HT)

	ΔR(D) [%]			ΔR(D*) [%]		
	Stat	Sys	Total	Stat	Sys	Total
Belle 0.7 ab^{-1}	14	6	16	6	3	7
Belle II 5 ab^{-1}	5	3	6	2	2	3
Belle II 50 ab^{-1}	2	3	3	1	2	2

- More observables (distributions) !
  - P(τ), P(D*)
  - $d\Gamma/dq^2$, $d\Gamma/dp_{D(*)}$, $d\Gamma/dp_e$, …
- More modes !
  - $B \to \pi \tau \nu$,
  - $B_s \to D_s \tau \nu$ (at 5S runs) , …

SuperKEKB Accelerator

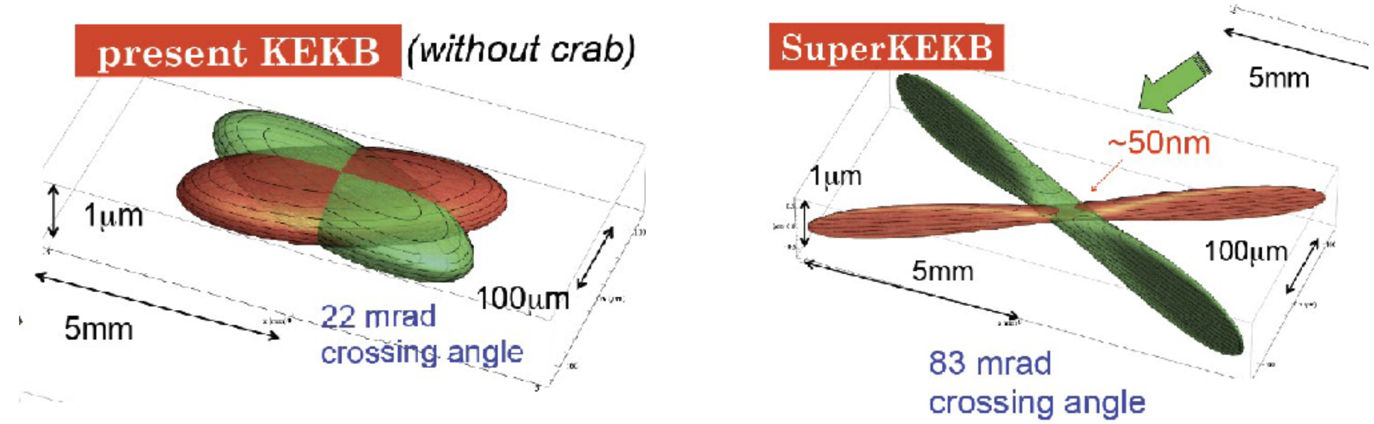
- Low emittance ("nano-beam") scheme employed (originally proposed by P. Raimondi)

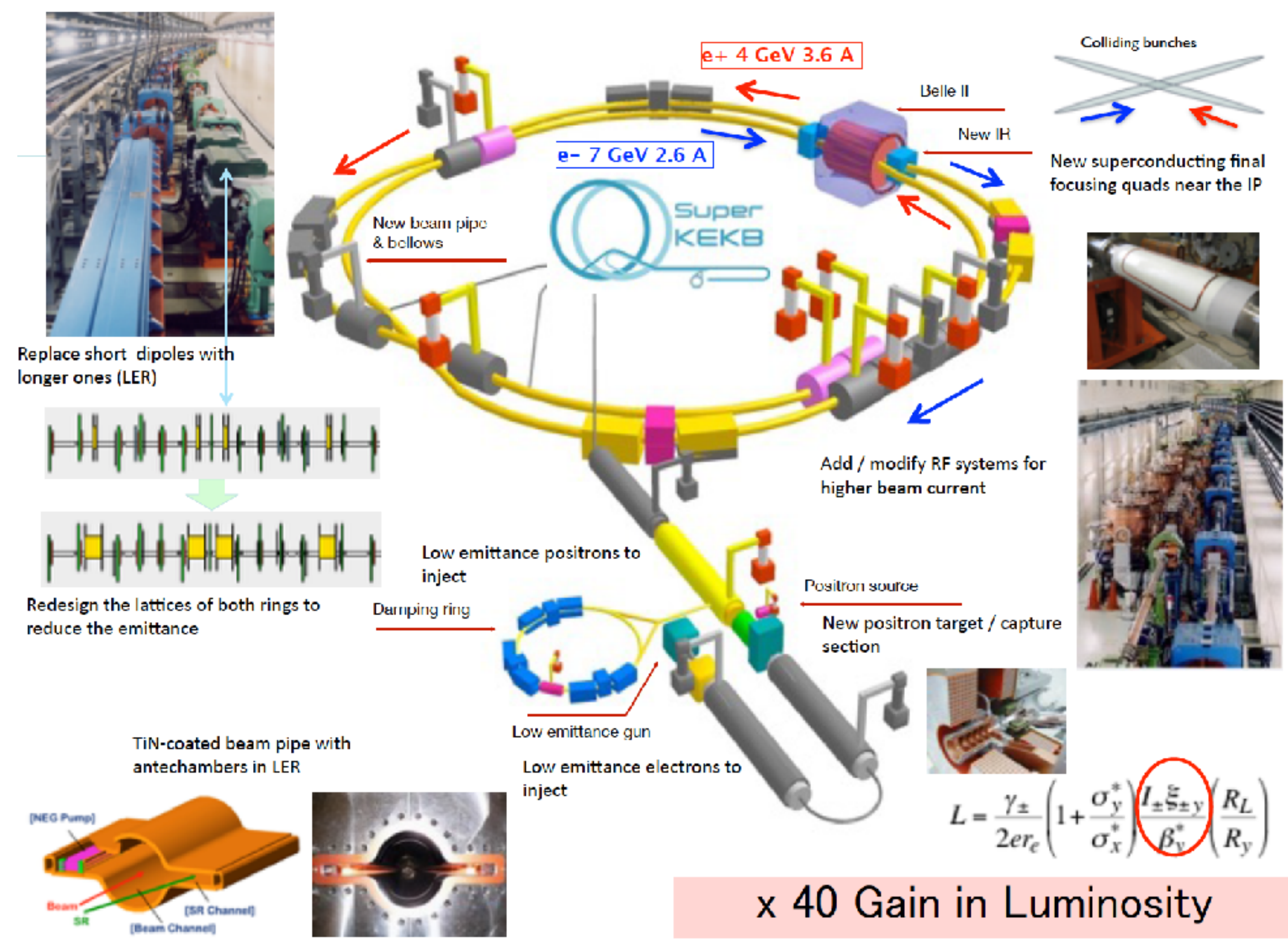
Machine parameters

	SuperKEKB LER/HER	KEKB LER/HER
E(GeV)	4.0/7.0	3.5/8.0
ε_x (nm)	3.2/4.6	18/24
β_y at IP(mm)	0.27/0.30	5.9/5.9
β_x at IP(mm)	32/25	120/120
Half crossing angle(mrad)	41.5	11
I(A)	3.6/2.6	1.6/1.2
Lifetime	~10min	130min/200min
L($cm^{-2}s^{-1}$)	80×10^{34}	2.1×10^{34}

x20 (β_y at IP)

x2 (I(A))





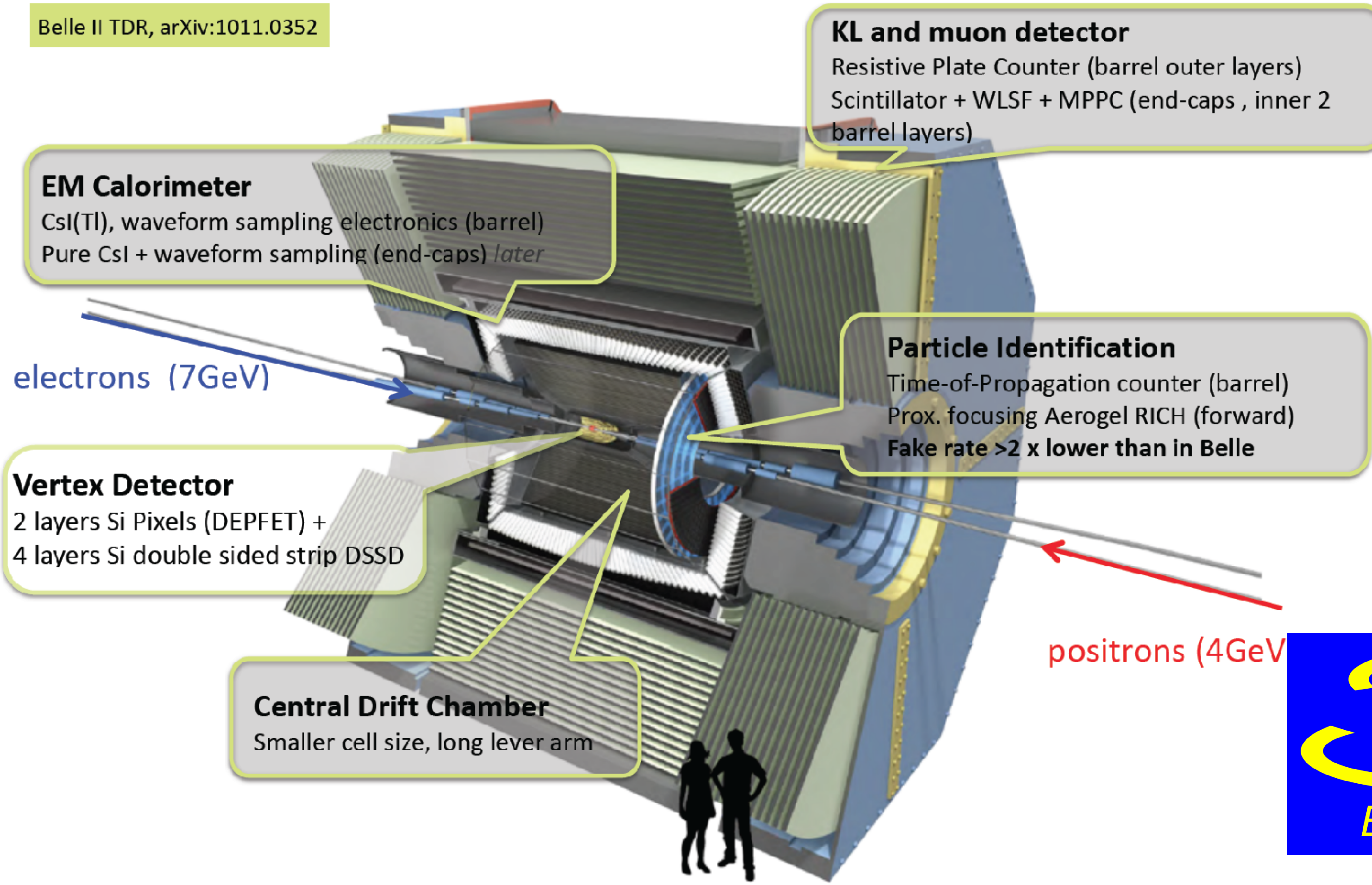
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

x 40 Gain in Luminosity

Belle II Detector

- Deal with higher background (10-20×), radiation damage, higher occupancy, higher event rates (L1 trigg. 0.5→30 kHz)
- Improved performance and hermeticity

Belle II TDR, arXiv:1011.0352



Belle II Collaboration

As of Oct. 2017

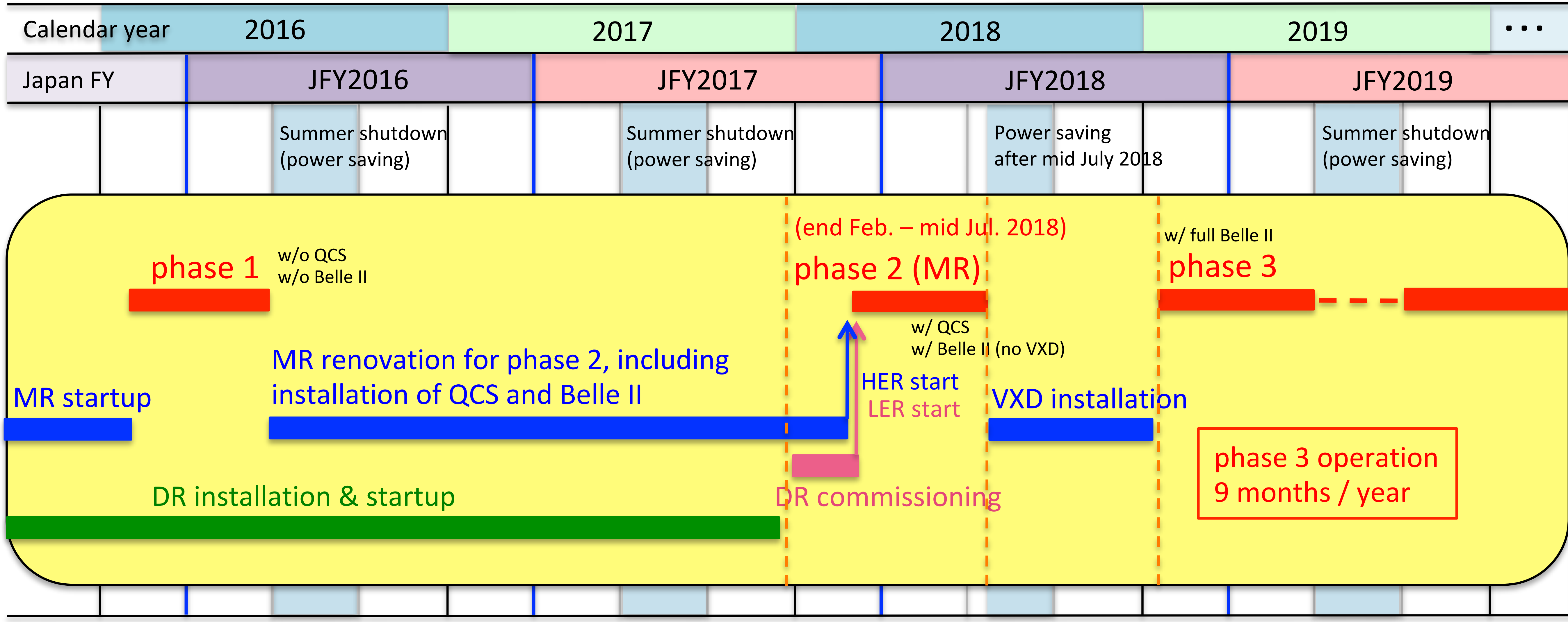
25countries/regions
105 institutions
~750 researchers

Europe	300
Austria	13
Czechia	6
France	14
Germany	110
Israel	3
Italy	76
Poland	13
Russia	42
Slovenia	16
Spain	4
Ukraine	3

Asia	346
Saudi Arabia	1
Australia	33
China	33
India	44
Japan	150
Korea	43
Malaysia	6
Vietnam	3
Taiwan	28
Thailand	2
Turkey	3

America	129
Canada	28
Mexico	12
USA	89

SuperKEKB/Belle II Schedule



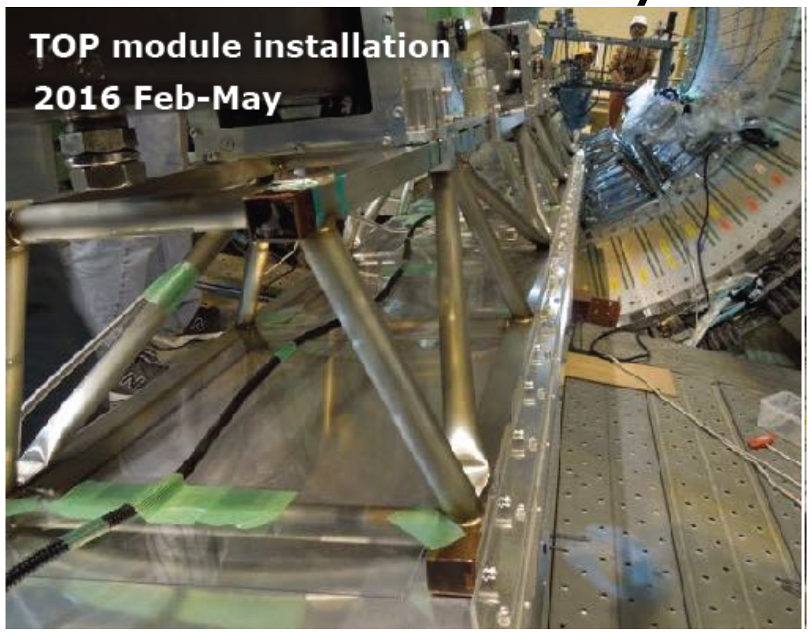
Phase 1 (w/o final focusing Q, w/o Belle II):
- Accelerator system test and basic tuning,
- **Vacuum scrubbing**,
- **Low emittance tuning**, and
- **Beam background studies**

Phase 2 (w/ final focusing Q, w/Belle II but background monitors instead of vertex detectors)
- **Verification of nano-beam scheme**
  target: $L>10^{34}$ $cm^{-2}s^{-1}$
- Understand **beam background** especially in vertex detector volume

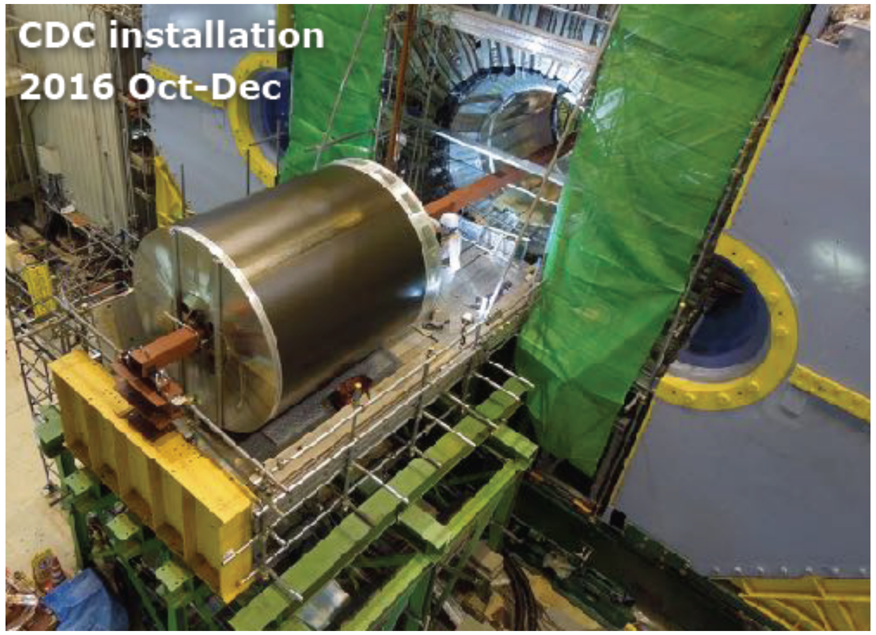
Belle II Integration

B-KLM, 2013

TOP, 2016 Feb-May



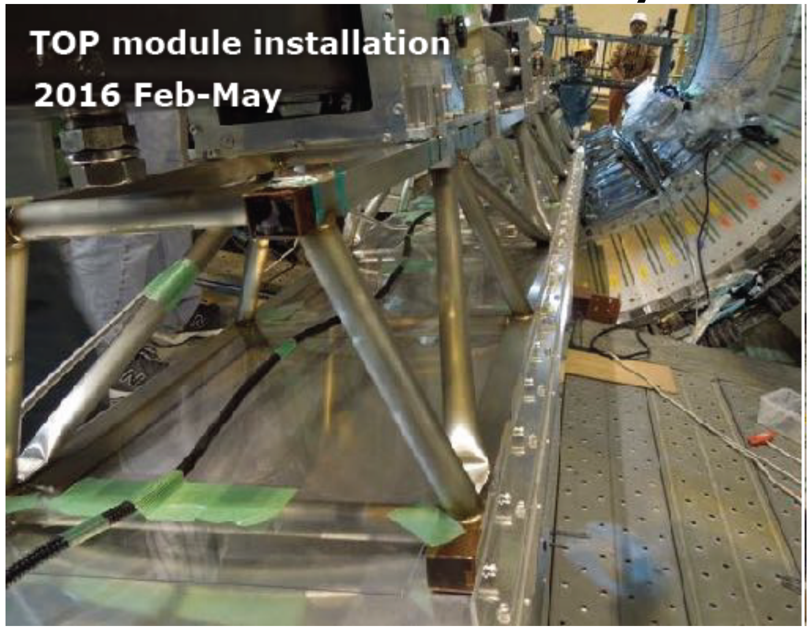
CDC 2016 Oct-Dec



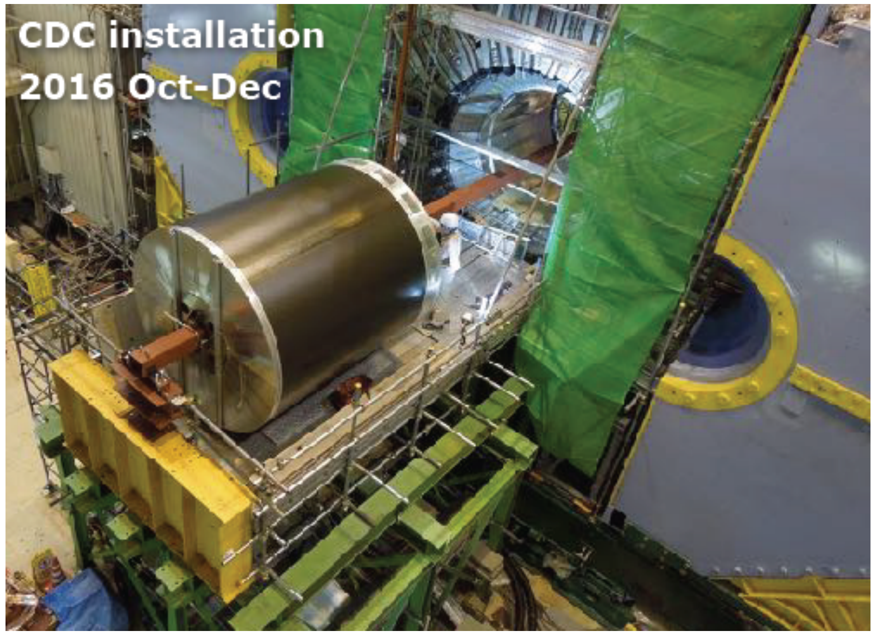
Belle II Integration

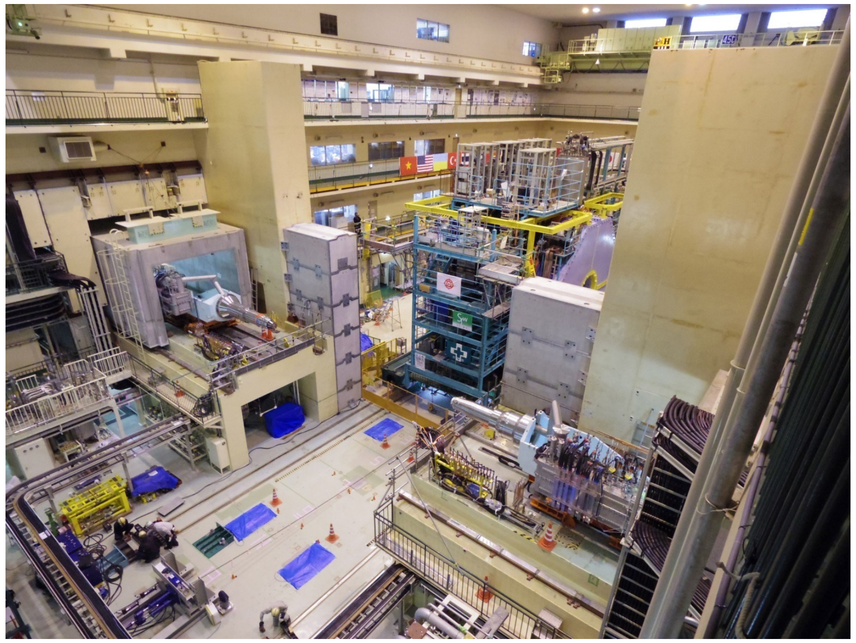
B-KLM, 2013

TOP, 2016 Feb-May



CDC 2016 Oct-Dec



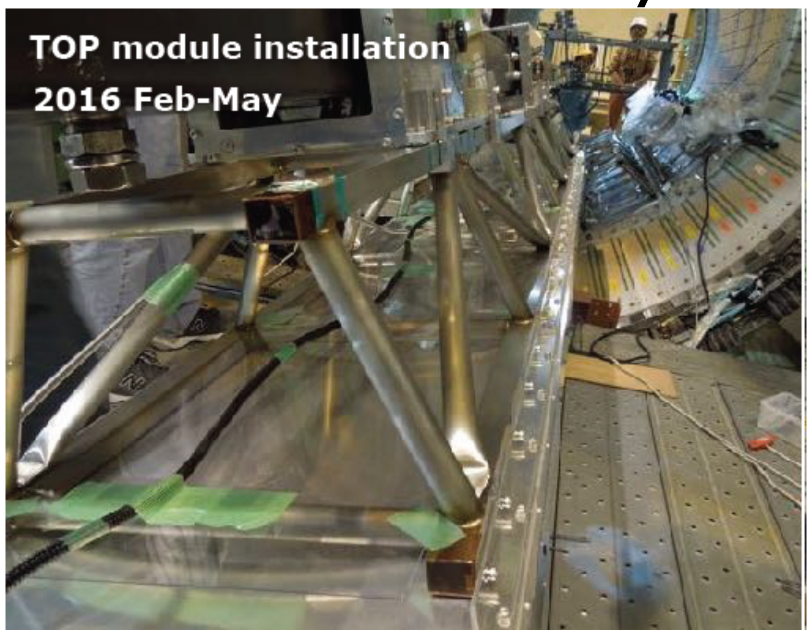


Roll-In 2017 Apr.

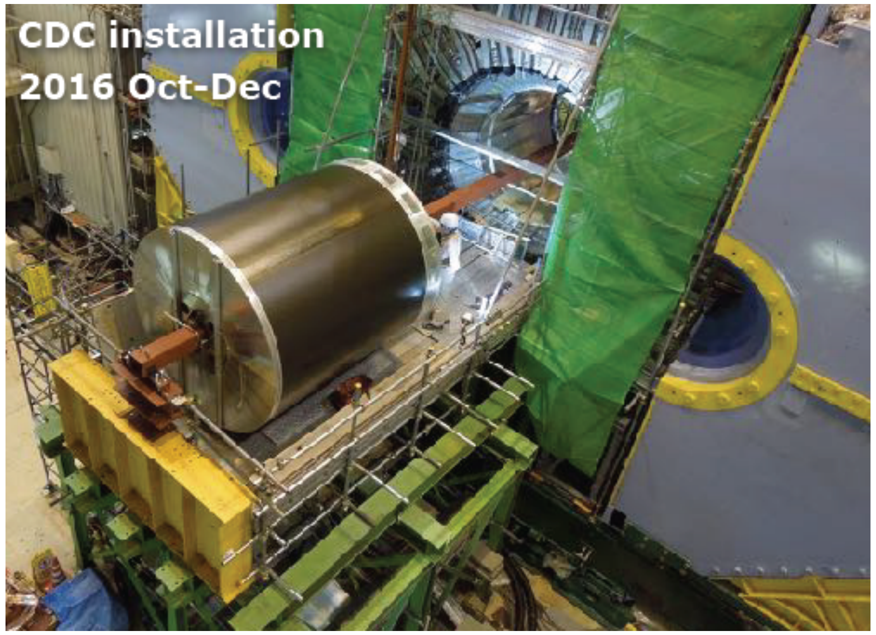
Belle II Integration

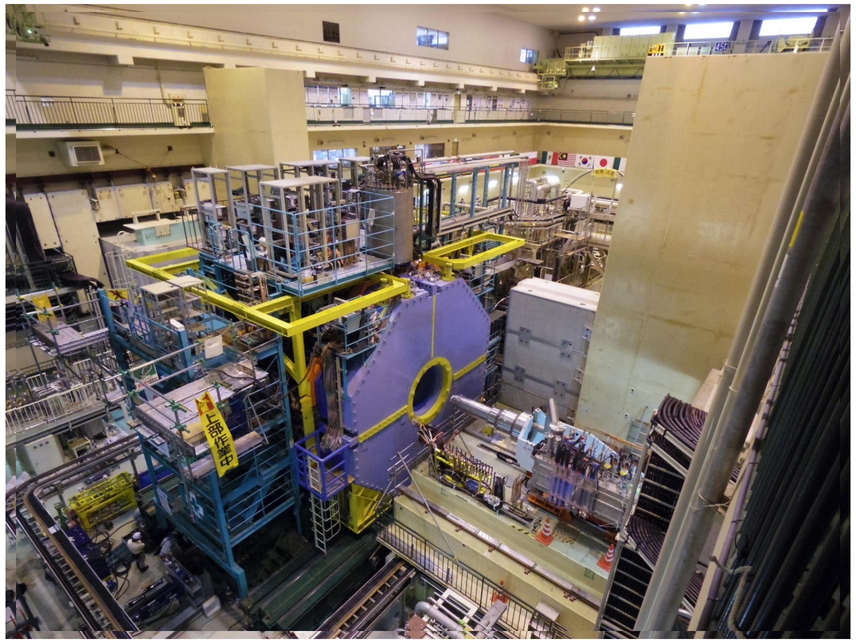
B-KLM, 2013

TOP, 2016 Feb-May



CDC 2016 Oct-Dec





Roll-In 2017 Apr.

Belle II Integration

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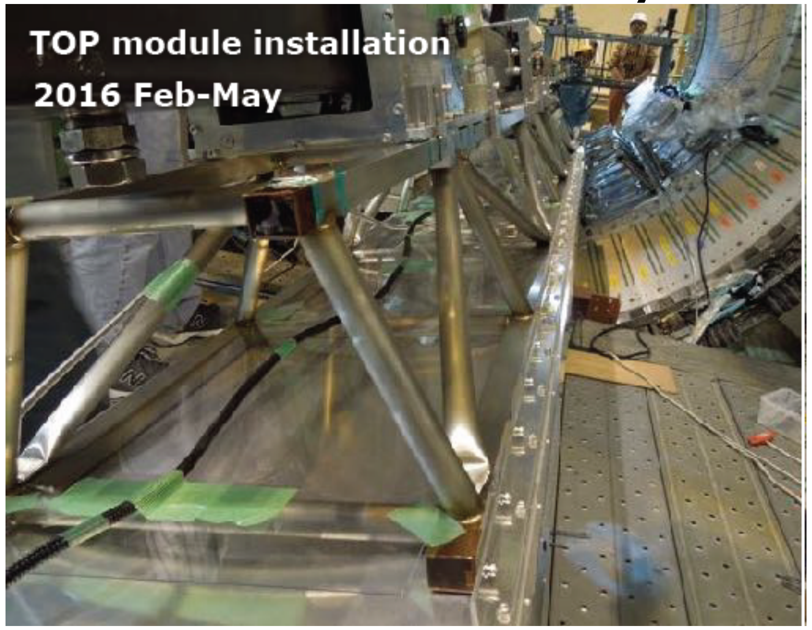

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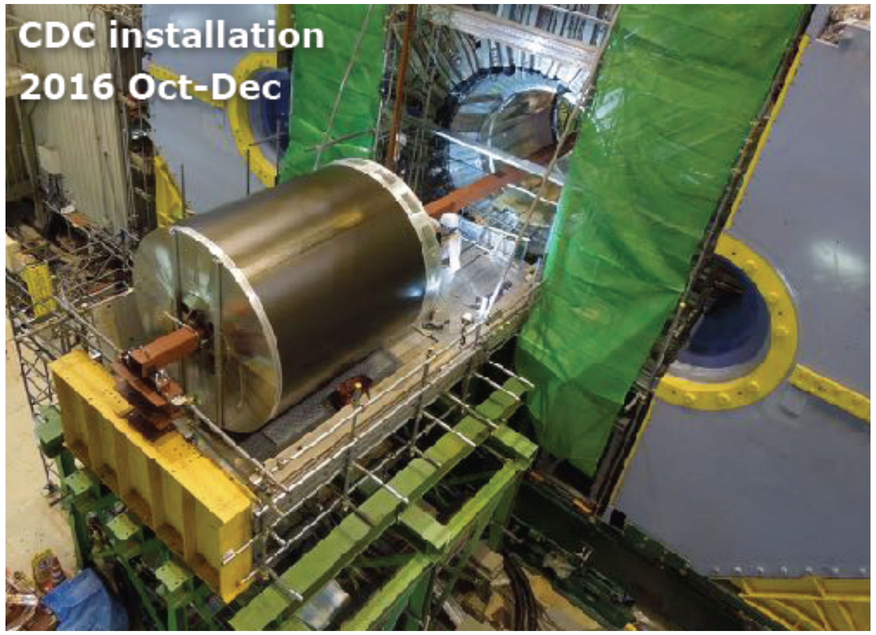
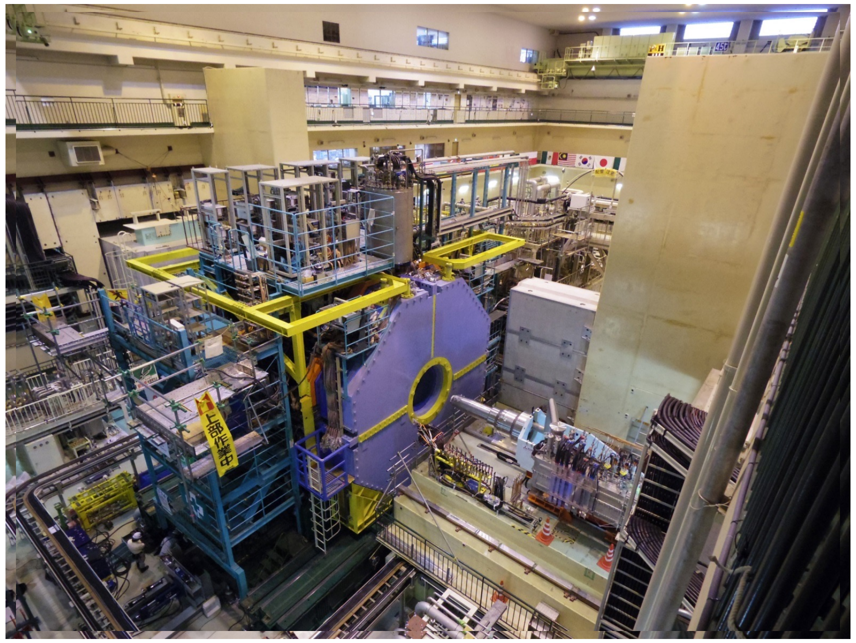
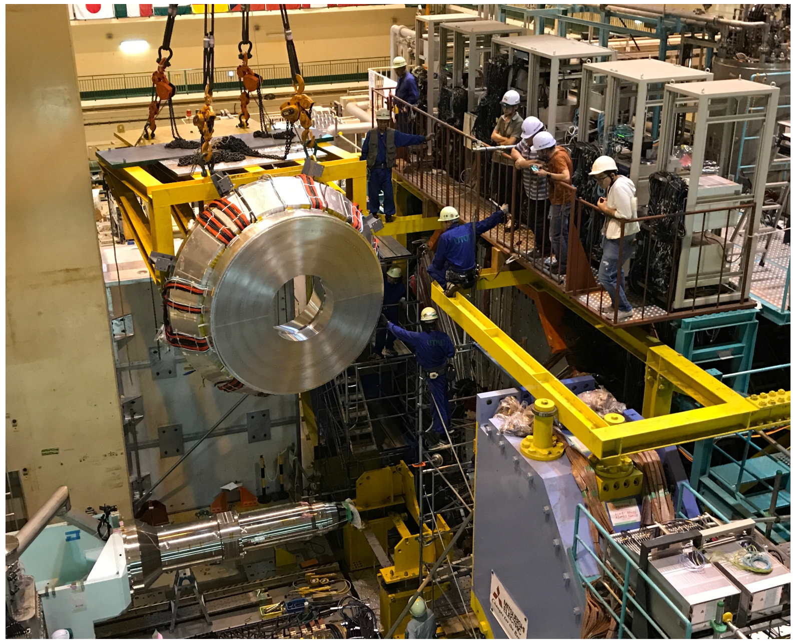




Roll-In 2017 Apr.

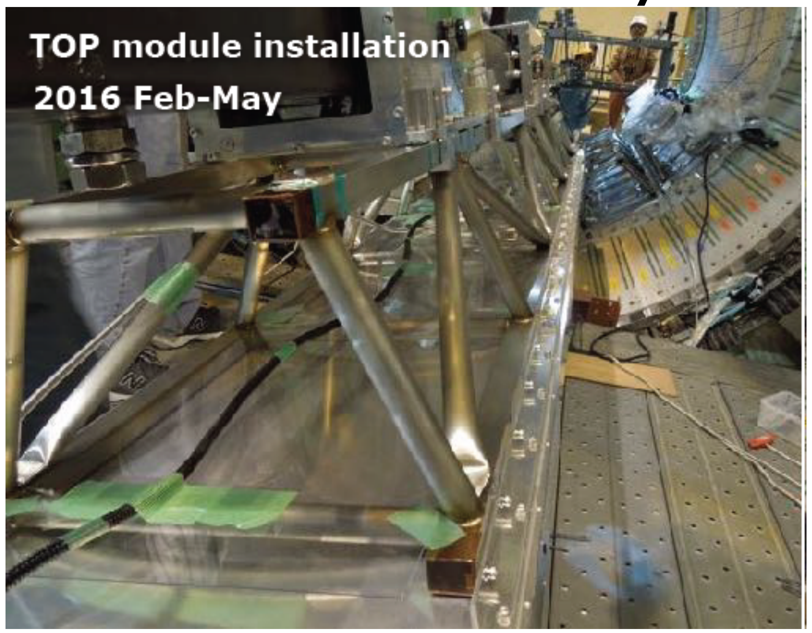


A-RICH+FW-ECL
2017 Oct.

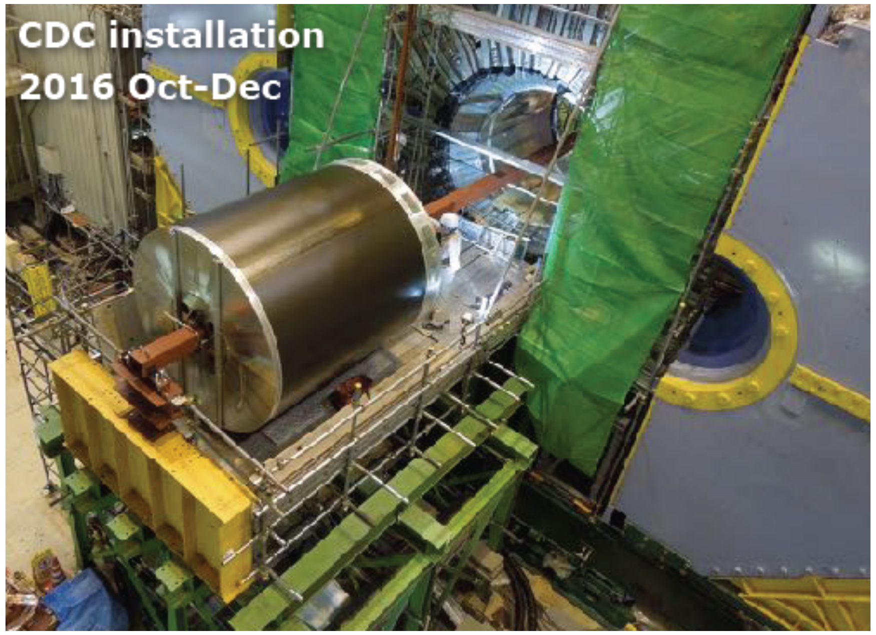
Belle II Integration

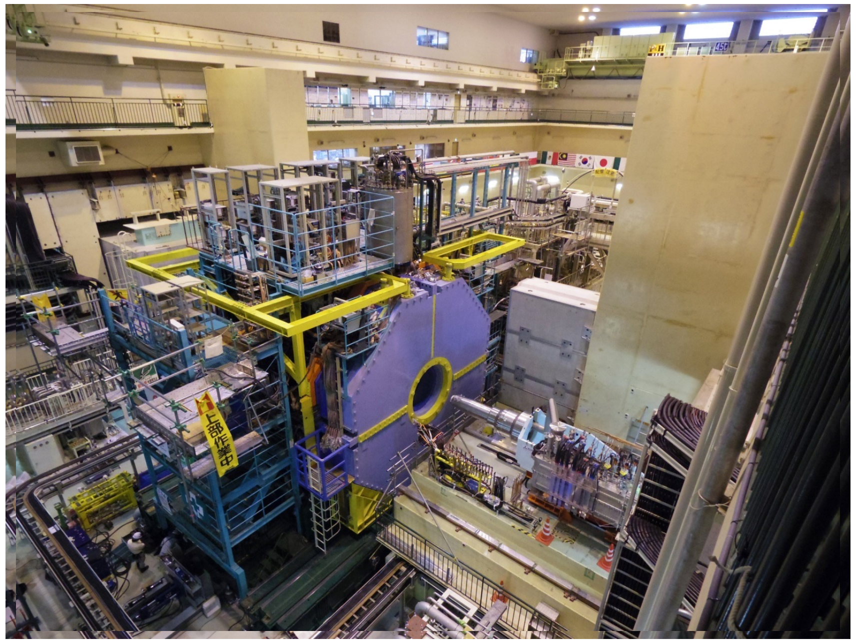
B-KLM, 2013

TOP, 2016 Feb-May

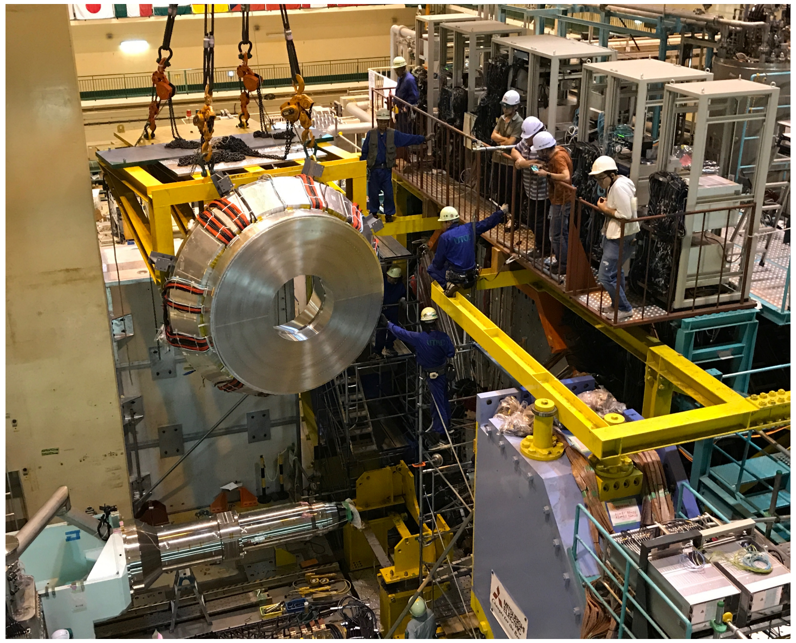


CDC 2016 Oct-Dec

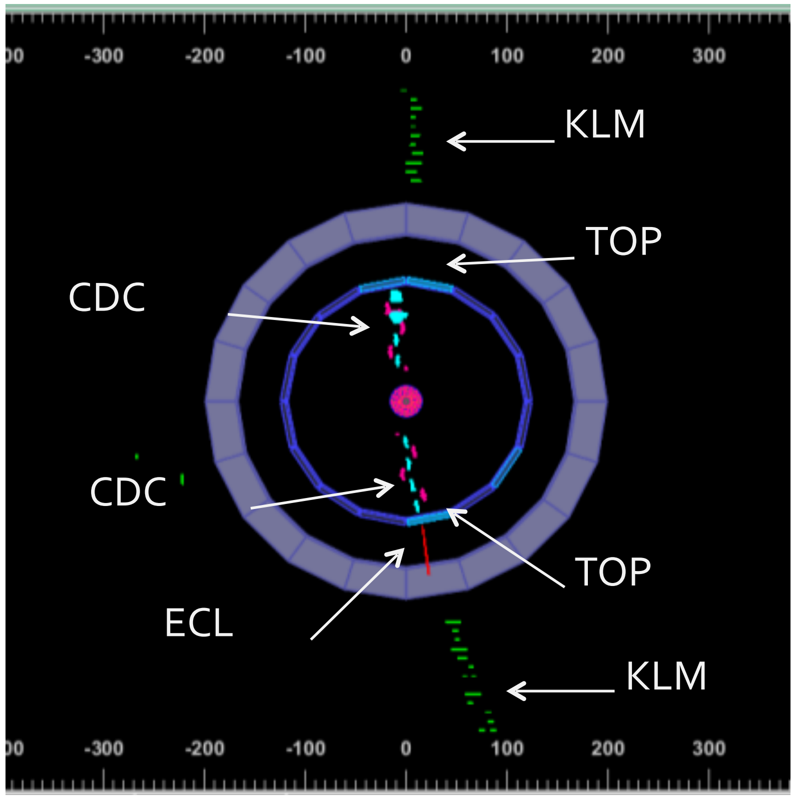




Roll-In 2017 Apr.



A-RICH+FW-ECL
2017 Oct.



Global Cosmic Ray Run
2017 Nov. -

Phase 2 Commissioning

Machine commissioning strategy

1. Start with low beam current
2. Squeeze beams to achieve specific Luminosity

   $L_{sp} = L/(I_+ I_- n_b) = 2\times10^{31}/cm^2/s/mA^2$

   cf. $L_{sp}=1.7\times10^{31}/cm^2/s/mA^2$ @KEKB
3. Increase number of bunches (n_b) from 394 to 1576, keeping bunch current constant:

   $I_+ = 0.64mA, I_- = 0.51mA$
4. Further squeeze beam to achieve $L_{sp} = 4\times10^{31}/cm^2/s/mA^2$, and even $8\times10^{31}/cm^2/s/mA^2$

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

21

Phase 2 Commissioning

Machine commissioning strategy

1. Start with low beam current
2. Squeeze beams to achieve specific Luminosity

   $L_{sp} = L/(I_+ I_- n_b) = 2\times10^{31}/cm^2/s/mA^2$

   cf. $L_{sp}=1.7\times10^{31}/cm^2/s/mA^2$ @KEKB
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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 x 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*	
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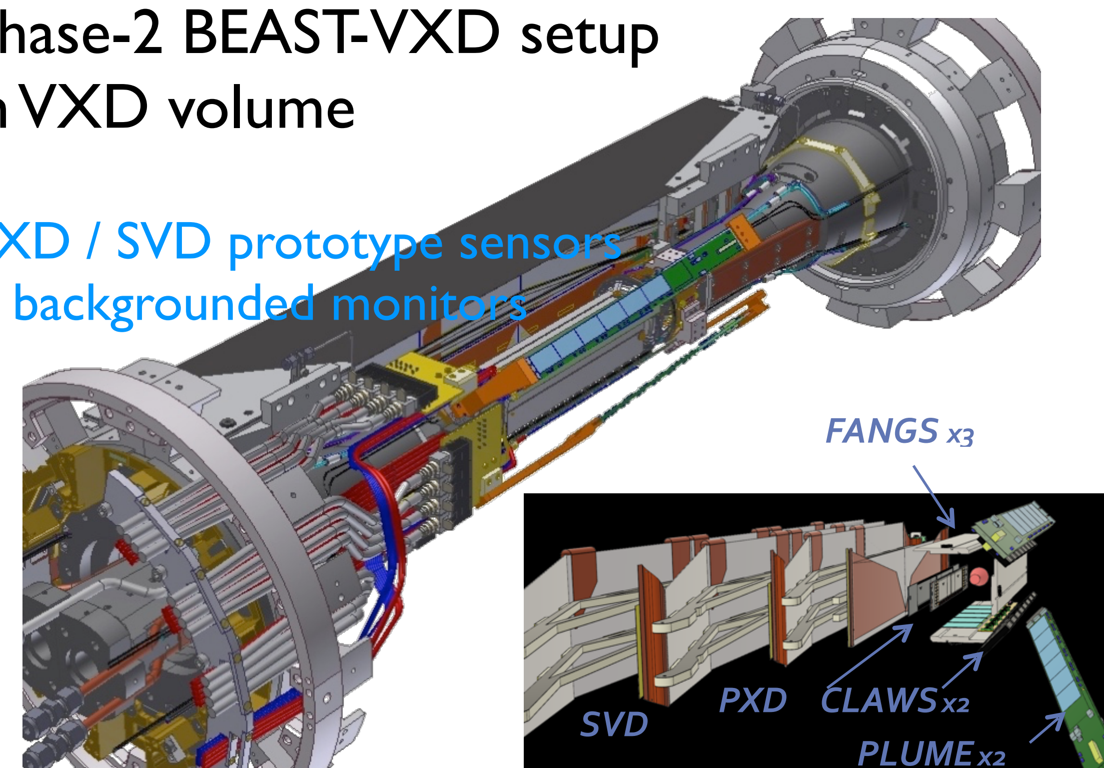
L_{sp} [$cm^{-2}s^{-1}/mA^2$]	1.97×10^{31}		3.94×10^{31}		7.88×10^{31}	

* conserve β_y^*/ε_y

21

Phase-2 BEAST-VXD setup in VXD volume

PXD / SVD prototype sensors + backgrounded monitors



Beam background study

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 lumi. BG component

Phase 2 Commissioning

Machine commissioning strategy

1. Start with low beam current
2. Squeeze beams to achieve specific Luminosity

   $L_{sp} = L/(I_+ I_- n_b) = 2\times10^{31}/cm^2/s/mA^2$

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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 x 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

21

Beam background study

Study	Purpose
Beam-size scan	Measure Touschek BG component
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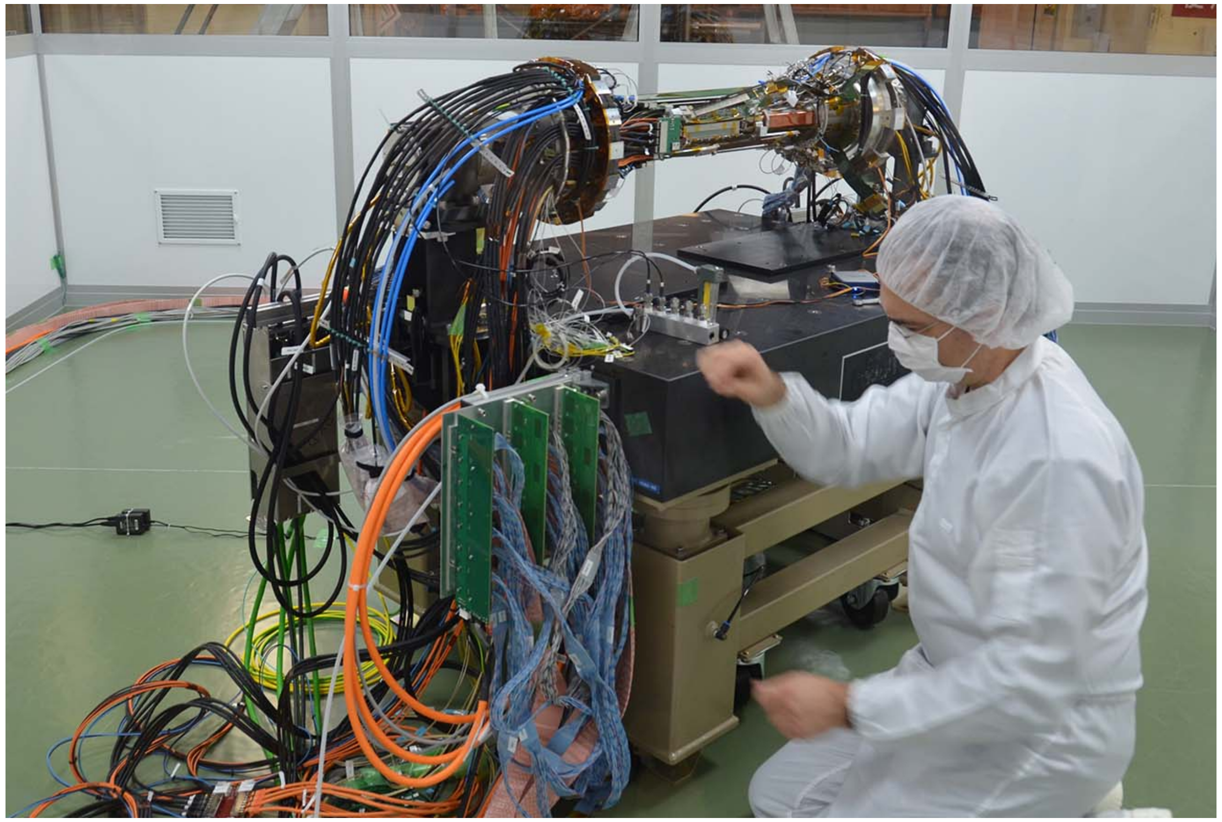
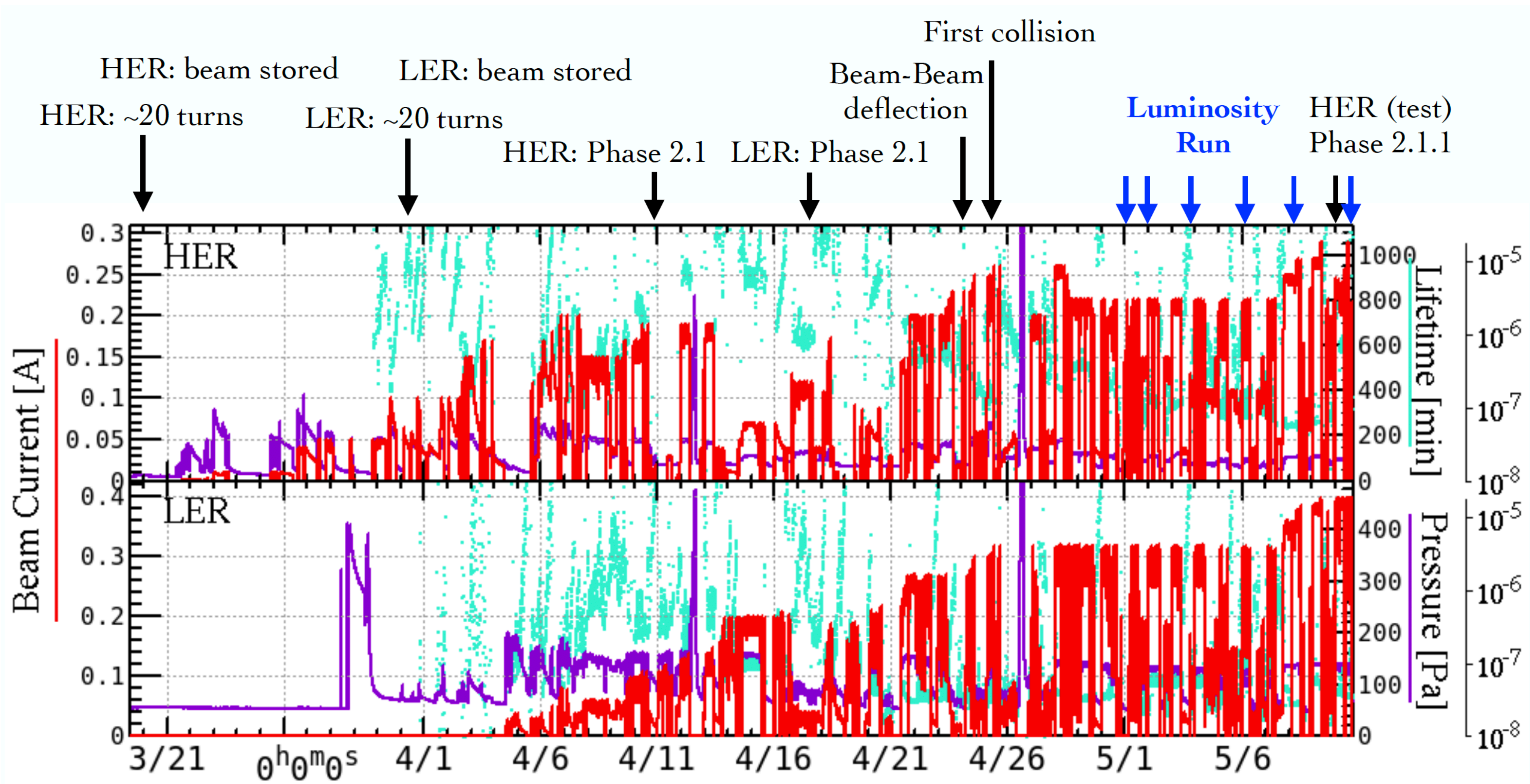
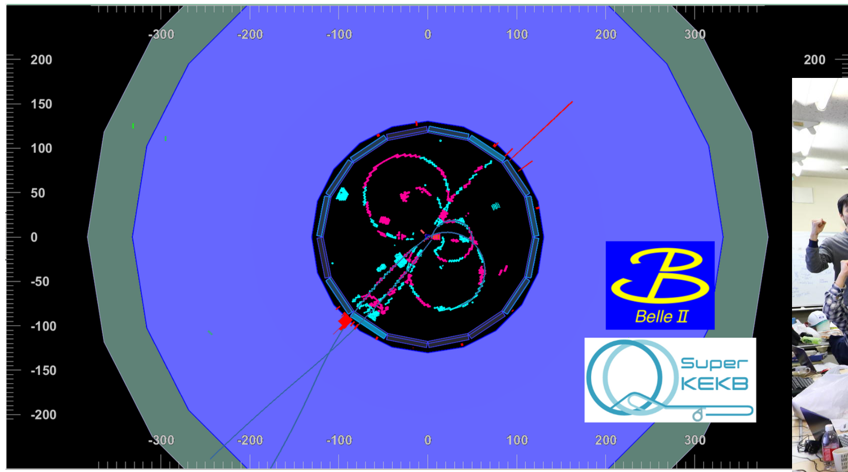
Collimator study	Find optimal setting
Injection study	Measure injection BG time structure, improve injection efficiency
Luminosity scan	Measure lumi. BG component

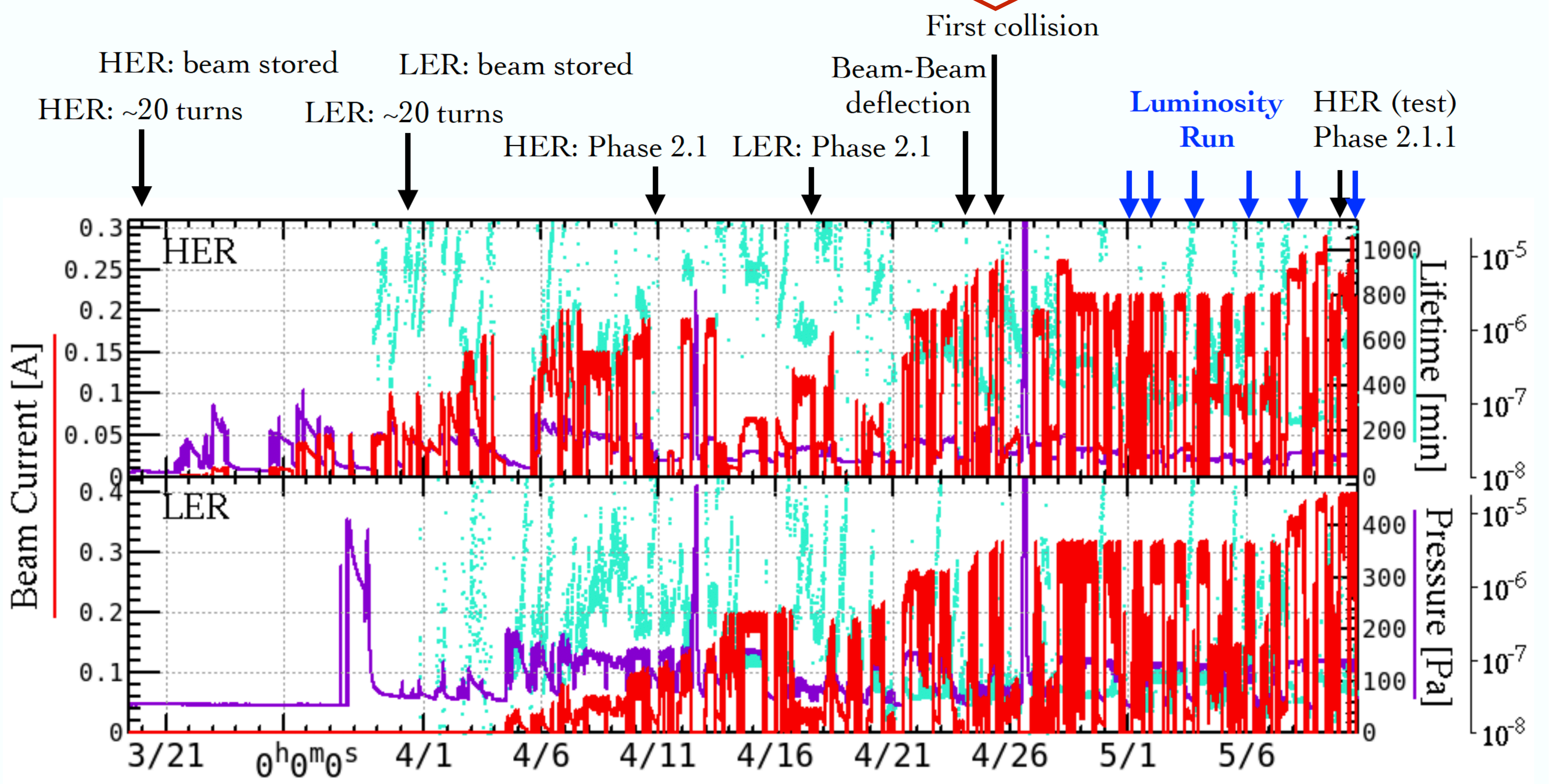


Phase 2 Commissioning

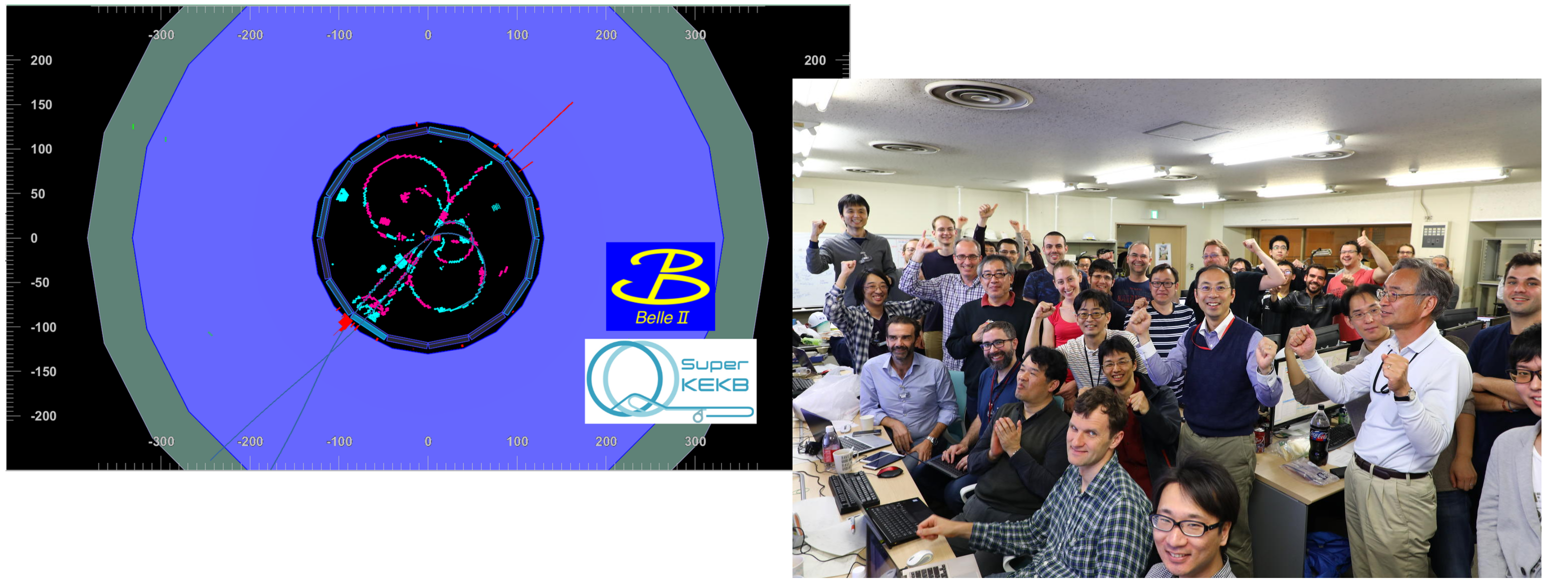


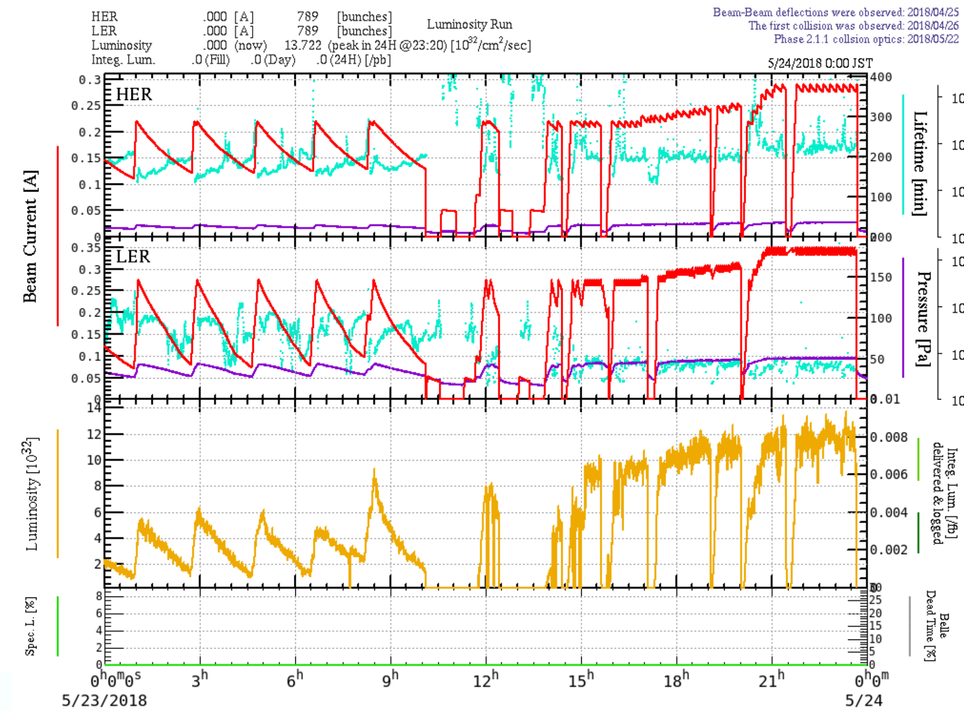
Phase 2 Commissioning

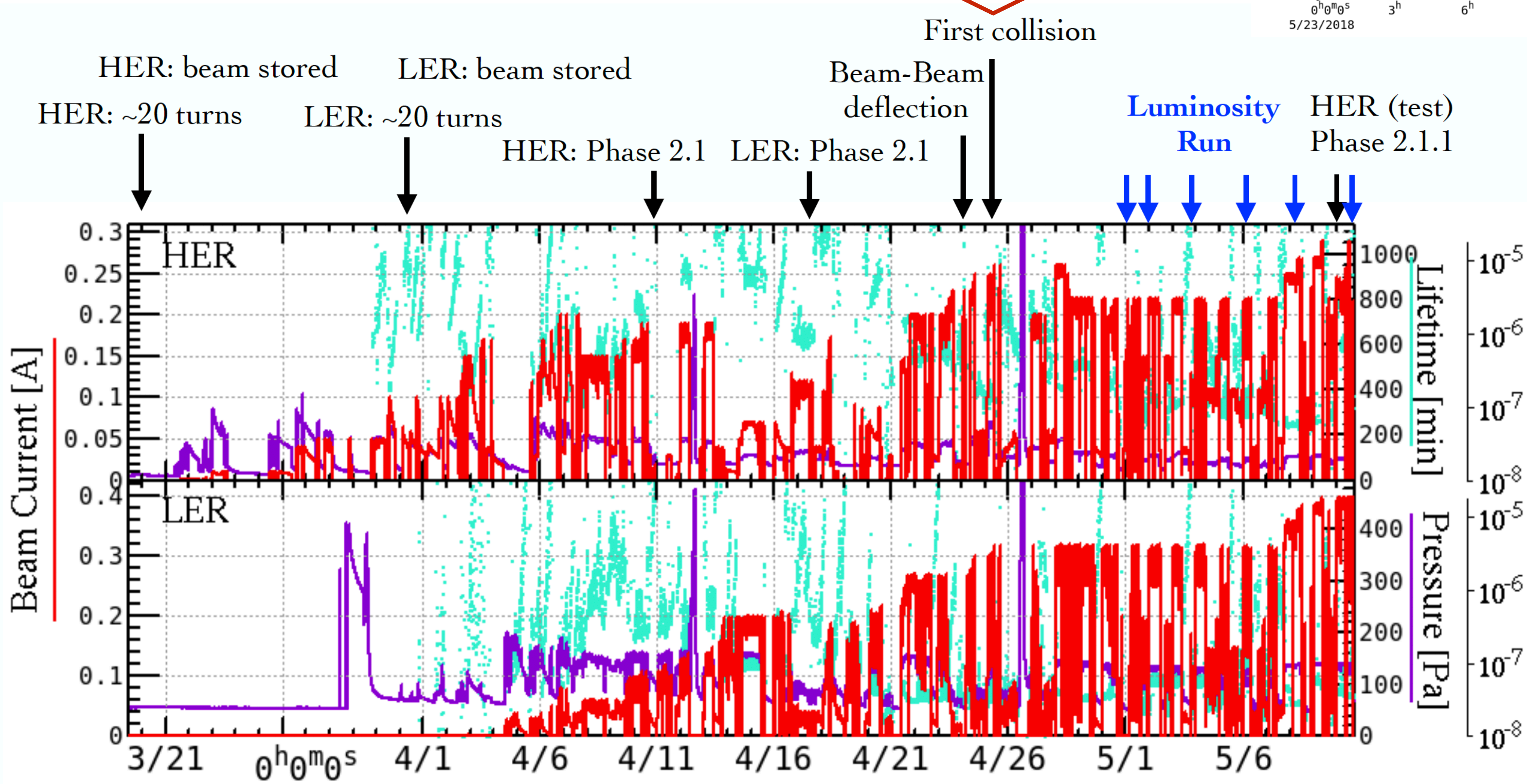




Phase 2 Commissioning





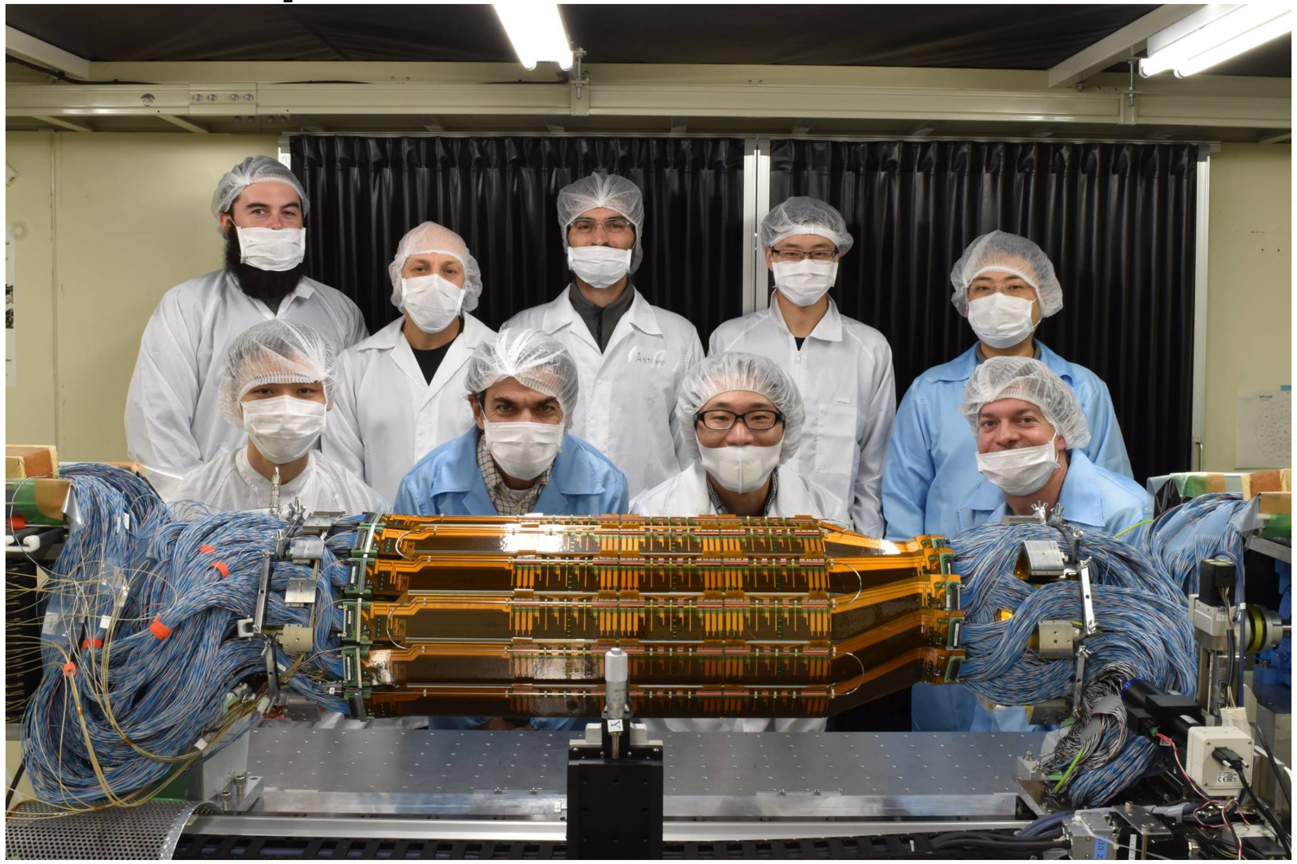


Luminosity > $1\times10^{33}cm^{-2}s^{-1}$

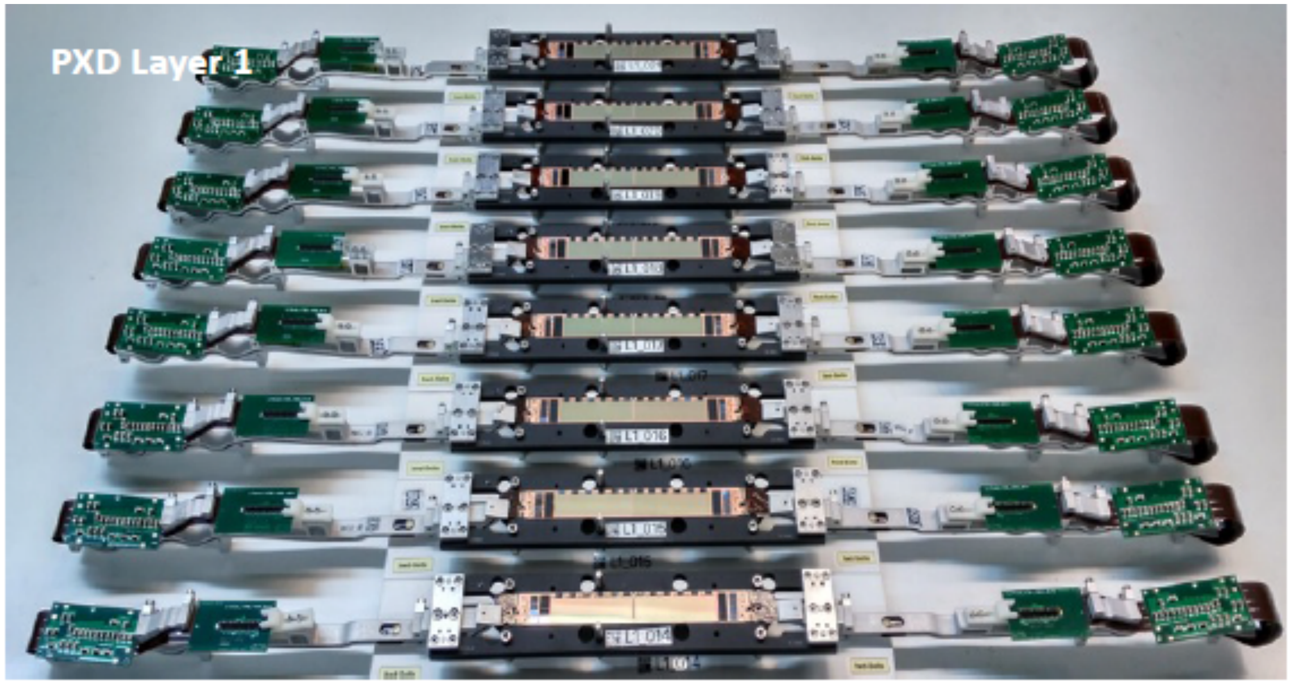
Construction of Vertex Detector

- Construction of the vertex detector is also in progress.
    - 4 layers of strip (SVD) + 2 layers of pixel (PXD) semiconductor sensors.
- They will be installed in summer 2018, after test collision run.

Completion of SVD half shell



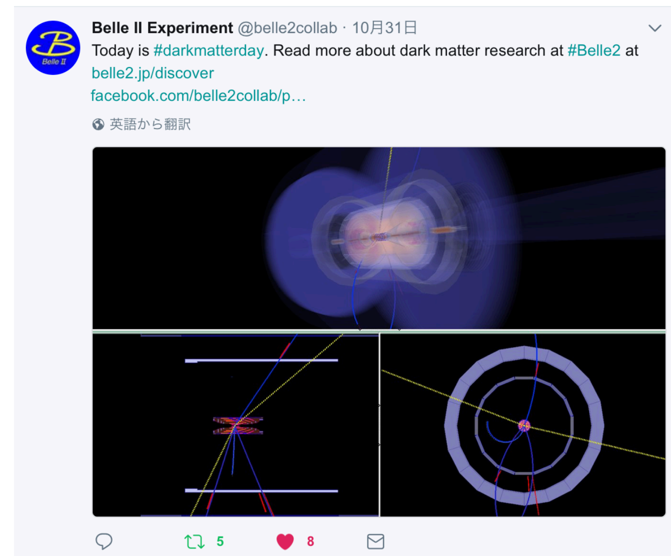
PXD layer 1

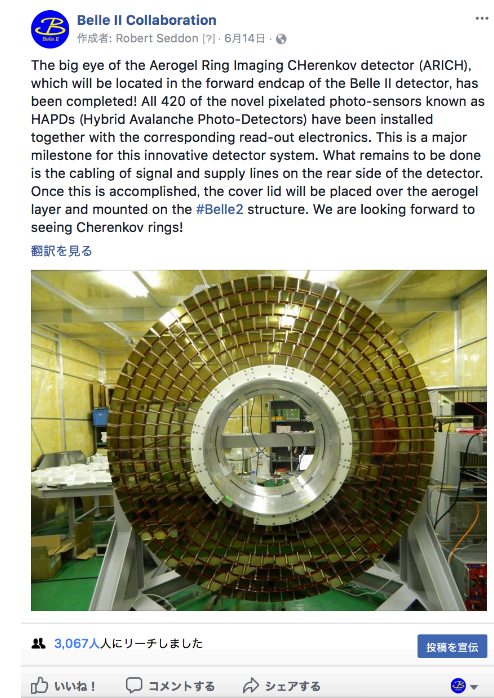


Summary

- Measurements of $B \to D^* \tau \nu$ is one of highlights in the Belle II physics analyses.
  - If confirmed both at Belle II and LHCb, it would be a breakthrough in particle physics !
  - Deviation may be established even with $\sim 5 ab^{-1}$
- Many improvements are expected;
  - Improved efficiency
  - More observables (τ polarization, q^2 dist., etc.)
- Measurements at Belle II will be systematic error limited. Need parallel efforts to understand B semileptonic and hadronic decays with excited D* states.

Belle II Outreach





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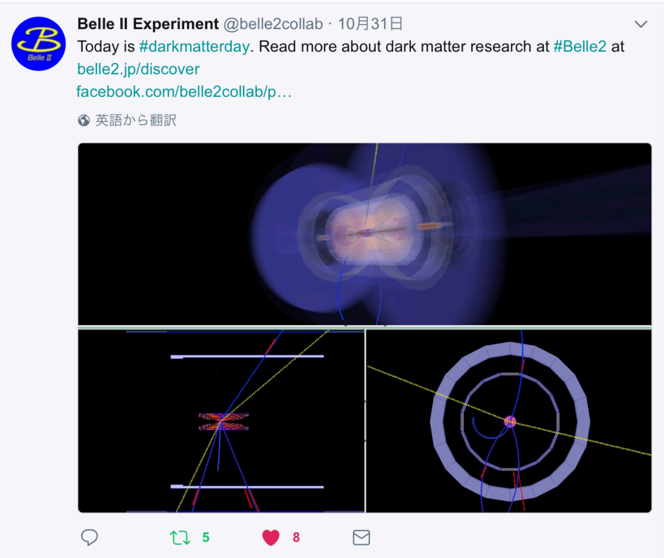
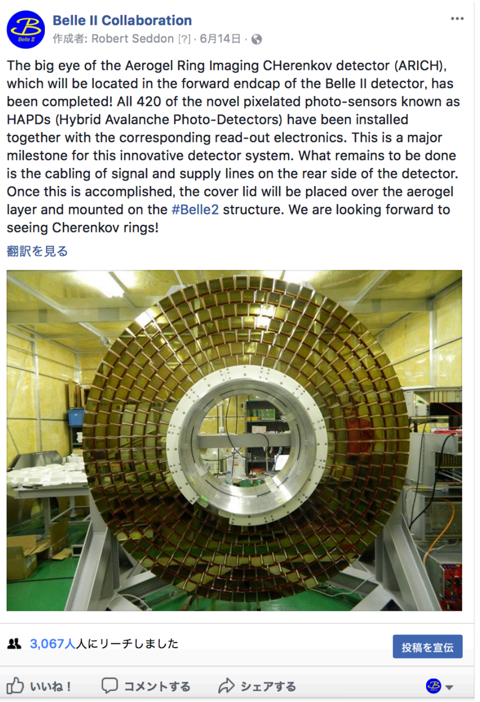
Belle II Outreach



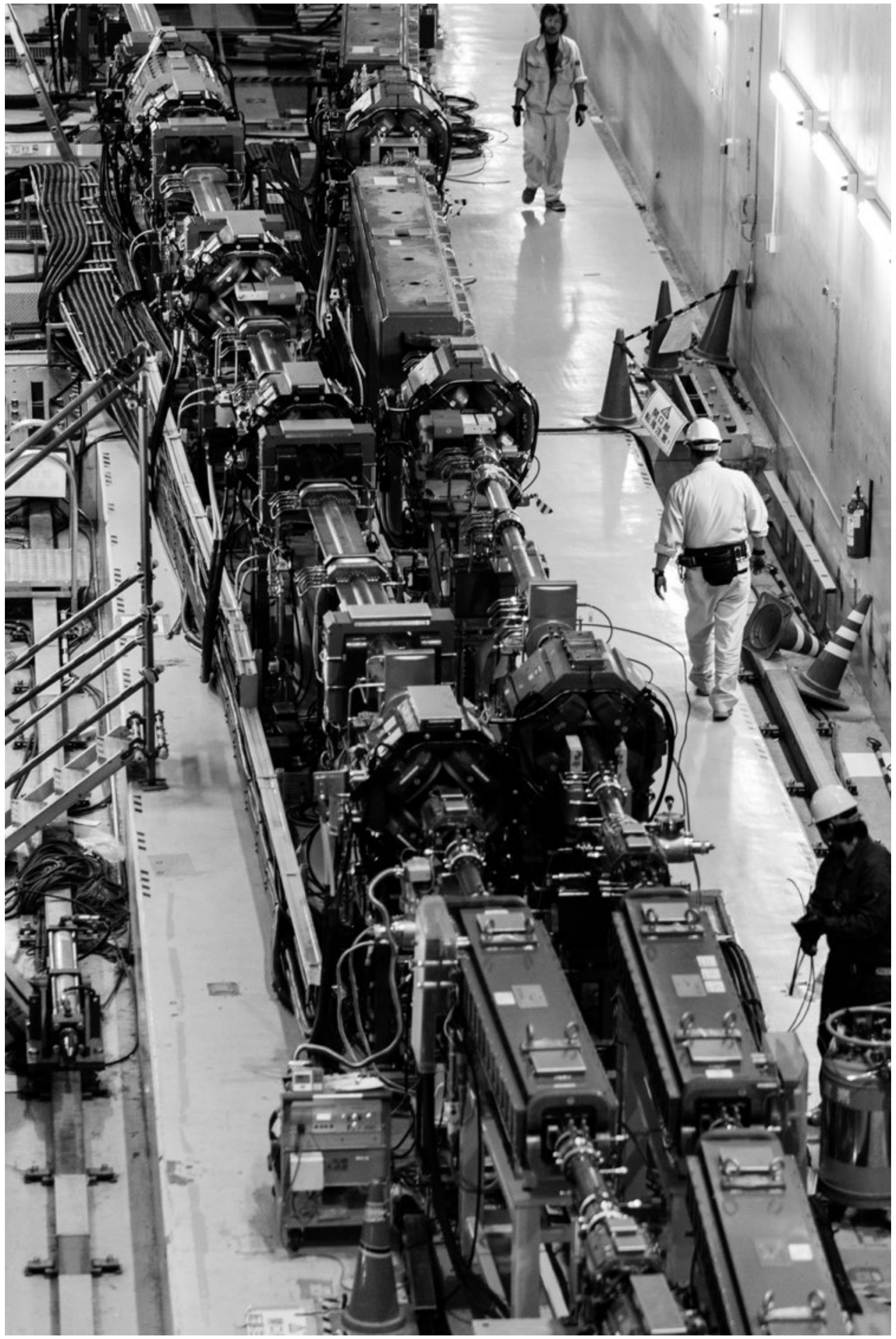


Follow Us & Like Us @Belle2collab

Also public HP: belle2.jp

Thank you !

Backup Slides



Systematic Tables at Belle

TABLE IV. Overview of relative systematic uncertainties in percent. The last column gives the correlation between $R(D)$ and $R(D^*)$.

	$R(D)[\%]$	$R(D^*)[\%]$	Correlation
$D^{(*(*))}\ell\nu$ shapes	4.2	1.5	0.04
D^{**} composition	1.3	3.0	−0.63
Fake D yield	0.5	0.3	0.13
Fake ℓ yield	0.5	0.6	−0.66
D_s yield	0.1	0.1	−0.85
Rest yield	0.1	0.0	−0.70
Efficiency ratio f^{D^+}	2.5	0.7	−0.98
Efficiency ratio f^{D^0}	1.8	0.4	0.86
Efficiency ratio $f_{\rm eff}^{D^{*+}}$	1.3	2.5	−0.99
Efficiency ratio $f_{\rm eff}^{D^{*0}}$	0.7	1.1	0.94
CF double ratio g^+	2.2	2.0	−1.00
CF double ratio g^0	1.7	1.0	−1.00
Efficiency ratio $f_{\rm wc}$	0.0	0.0	0.84
$M^2_{\rm miss}$ shape	0.6	1.0	0.00
$o'_{\rm NB}$ shape	3.2	0.8	0.00
Lepton PID efficiency	0.5	0.5	1.00
Total	7.1	5.2	−0.32

TABLE I. Summary of the systematic uncertainties on $\mathcal{R}(D^*)$ for electron and muon modes combined and separated. The uncertainties are relative and are given in percent.

	$\mathcal{R}(D^*)$ (%)		
Sources	$\ell^{\rm sig} = e, \mu$	$\ell^{\rm sig} = e$	$\ell^{\rm sig} = \mu$
MC size for each PDF shape	2.2	2.5	3.9
PDF shape of the normalization in $\cos\theta_{B-D^*\ell}$	$^{+1.1}_{-0.0}$	$^{+2.1}_{-0.0}$	$^{+2.8}_{-0.0}$
PDF shape of $B \to D^{**}\ell\nu_\ell$	$^{+1.0}_{-1.7}$	$^{+0.7}_{-1.3}$	$^{+2.2}_{-3.3}$
PDF shape and yields of fake $D^{(*)}$	1.4	1.6	1.6
PDF shape and yields of $B \to X_c D^*$	1.1	1.2	1.1
Reconstruction efficiency ratio $\varepsilon_{\rm norm}/\varepsilon_{\rm sig}$	1.2	1.5	1.9
Modeling of semileptonic decay	0.2	0.2	0.3
$\mathcal{B}(\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau)$	0.2	0.2	0.2
Total systematic uncertainty	$^{+3.4}_{-3.5}$	$^{+4.1}_{-3.7}$	$^{+5.9}_{-5.8}$

TABLE II. The systematic uncertainties in $R(D^*)$ and $P_\tau(D^*)$, where the values for $R(D^*)$ are relative errors. The group "common sources" identifies the common systematic uncertainty sources in the signal and the normalization modes, which cancel to a good extent in the ratio of these samples. The reason for the incomplete cancellation is described in the text.

Source	$R(D^*)$	$P_\tau(D^*)$
Hadronic B composition	$^{+7.7\%}_{-6.9\%}$	$^{+0.134}_{-0.103}$
MC statistics for PDF shape	$^{+4.0\%}_{-2.8\%}$	$^{+0.146}_{-0.108}$
Fake D^*	3.4%	0.018
$\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$	2.4%	0.048
$\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau$	1.1%	0.001
$\bar{B} \to D^*\ell^-\bar{\nu}_\ell$	2.3%	0.007
τ daughter and ℓ^- efficiency	1.9%	0.019
MC statistics for efficiency estimation	1.0%	0.019
$\mathcal{B}(\tau^- \to \pi^-\nu_\tau, \rho^-\nu_\tau)$	0.3%	0.002
$P_\tau(D^*)$ correction function	0.0%	0.010
Common sources		
Tagging efficiency correction	1.6%	0.018
D^* reconstruction	1.4%	0.006
Branching fractions of the D meson	0.8%	0.007
Number of $B\bar{B}$ and $\mathcal{B}(\Upsilon(4S) \to B^+B^-$ or $B^0\bar{B}^0)$	0.5%	0.006
Total systematic uncertainty	$^{+10.4\%}_{-9.4\%}$	$^{+0.21}_{-0.16}$

Parameter

	KEKB LER /HER	**Phase 1**	**Phase 2 4x8**	**Phase 3**
β_x^* (mm)	1200 / 1200	/	128 / 100	32 / 25
β_y^* (mm)	5.9 / 5.9	/	2.16 / 2.4	0.27 / 0.30
ε_x (nm)	18 / 24	2.0 / 4.6	2.1 / 4.6	3.2 / 4.6
ε_y (pm) , coupling	1498 / 1598	~ 10 / -	29.4 / 64.4, 1.4% (105 / 230, 5.0%)	8.64 / 12.9 (0.27% / 0.28%)
ξ_y	0.129 / 0.090	-	0.0484 / 0.0500 (0.0257 / 0.0265)	0.088/0.081
σ_y^* (μm)	0.94 / 0.94	-	0.25 / 0.39 (0.48 / 0.74)	0.048/0.062
I_{beam} (A)	1.64/1.19	1.01/0.87	1.0/0.8	3.6/2.6
$N_{bunches}$	1584	1576	1576	2500
Luminosity (10^{34} cm^{-2} s^{-1})	2.1	-	2 (1)	80

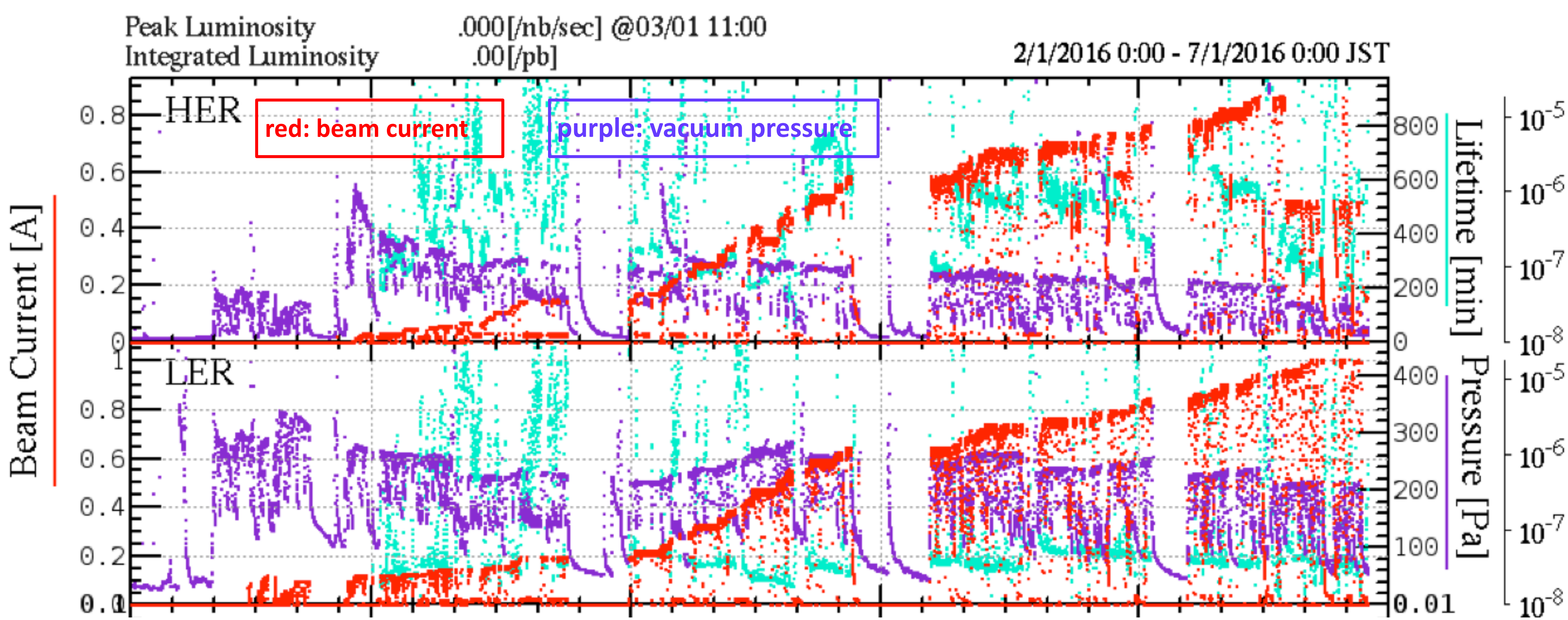
Phase 1 Commissioning

Feb. - June 2016

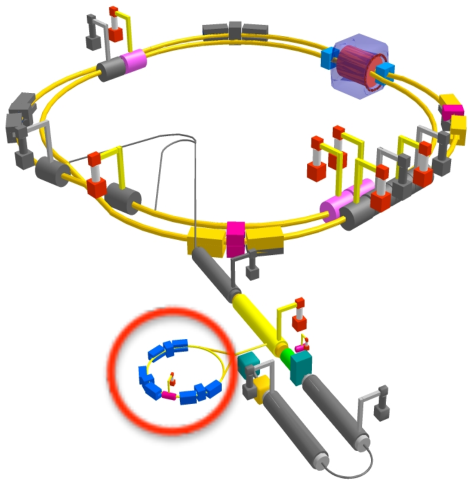
Phase 1 milestones (in 2016)

- Feb. 1: BT tuning started
- Feb. 8: LER injection tuning started
- Feb. 10: beam storage in LER
- Feb. 22: HER injection tuning started
- Feb. 26: beam storage in HER

	HER	LER
Max. current [mA]	870	1010
Integrated current [Ah]	660	780
Avg. pressure [Pa]	~2 x 10^{-7}	~1 x 10^{-6}
Lifetime [min.]	~ 400	~ 70

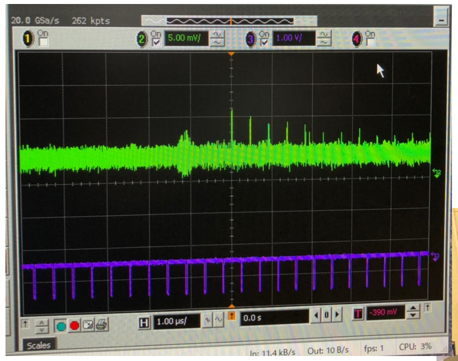


DR → Phase II



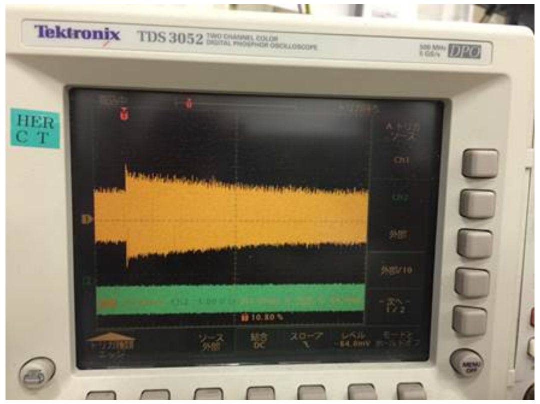
Commissioning of the Positron Dumping Ring (DR)

- First turn on Feb. 8
- Successful storage on Mar. 9



Commissioning of the Main Rings (MR)

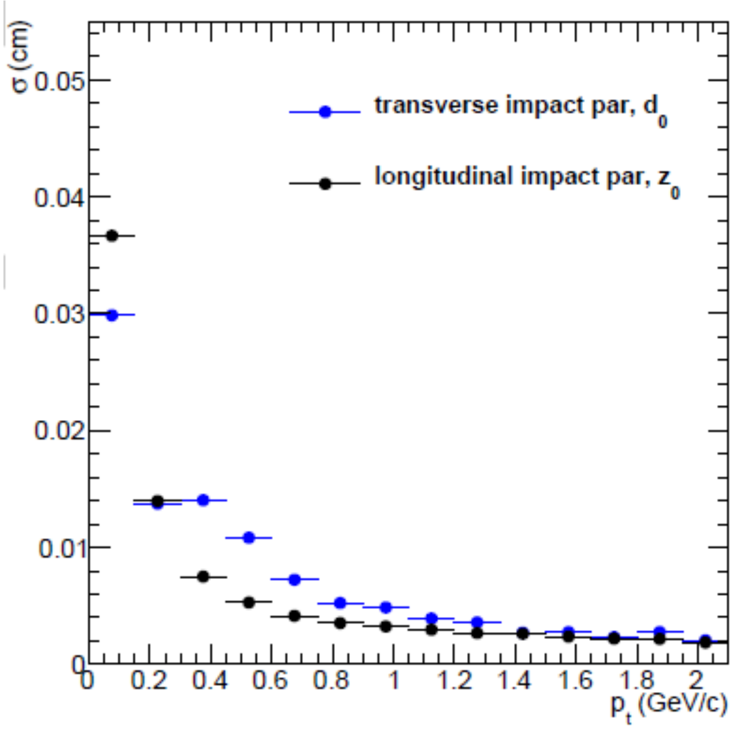
- HER storage on Mar.20
- LER storage on Mar.31



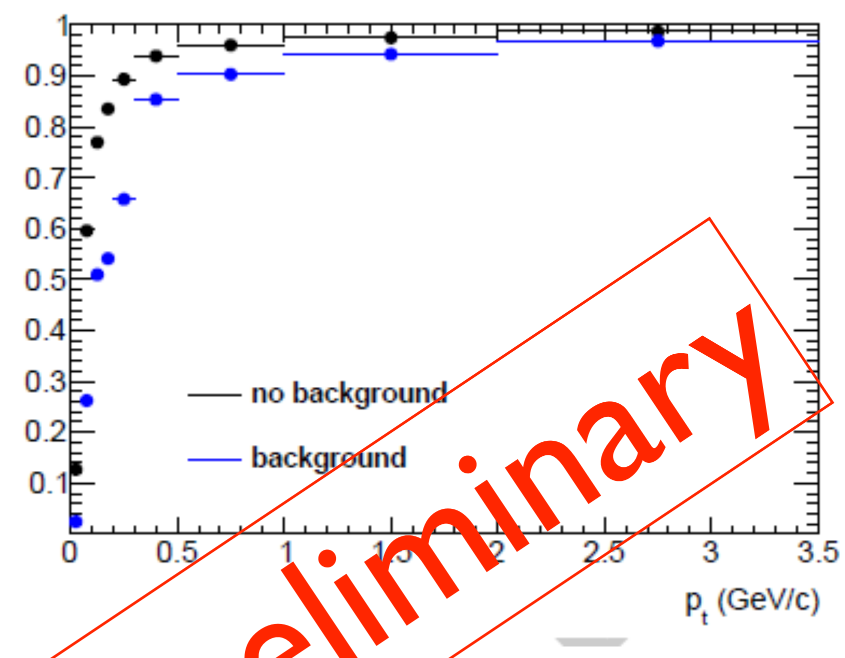
Preparation for collision started in April

Belle II Expected Performance

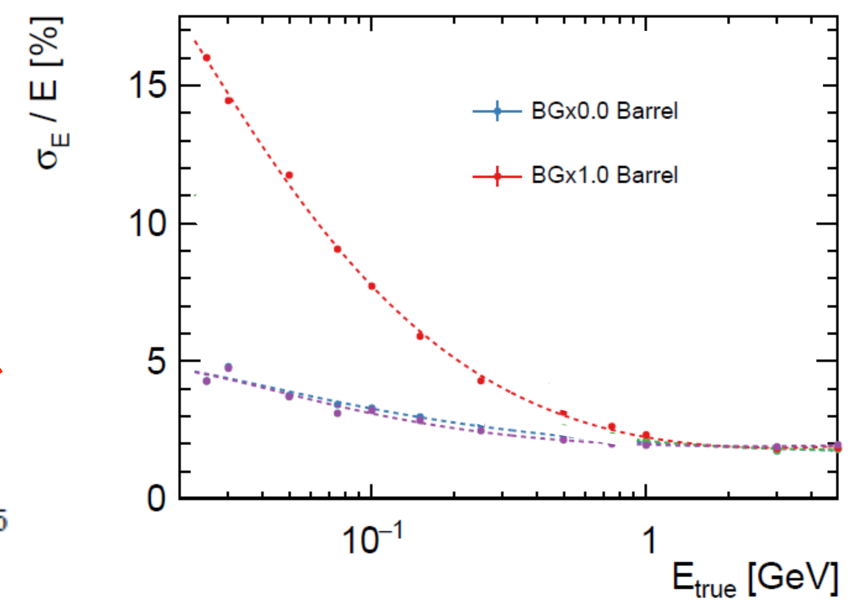
IP resolution



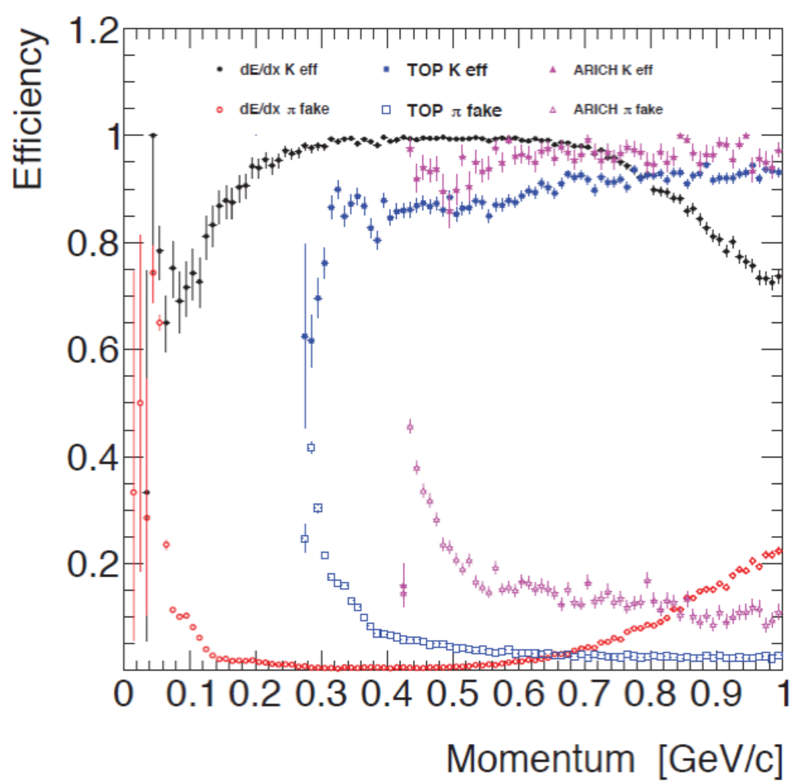
Tracking efficiency vs. p_t



Energy resolution
Better w/ no background,
worse w/ background



K/π PID



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