2017 ICFA Seminar

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Shaw Centre, Ottawa, Ontario, Canada

Status and Prospects for SuperKEKB and Belle II

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Belle II

Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

November 7, 2017

Super KEKB

SuperKEKB/Belle II

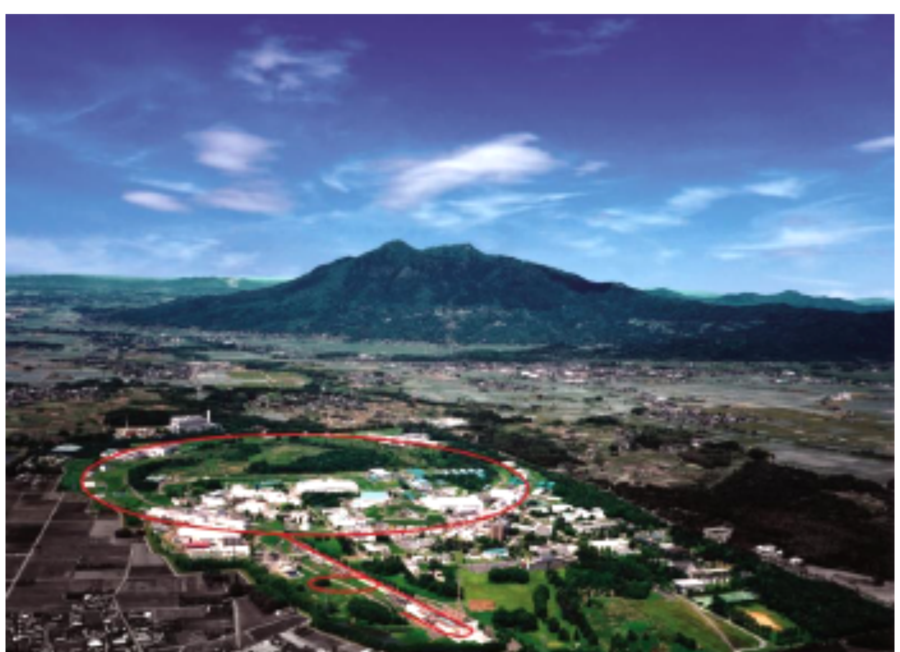
New intensity frontier facility at KEK

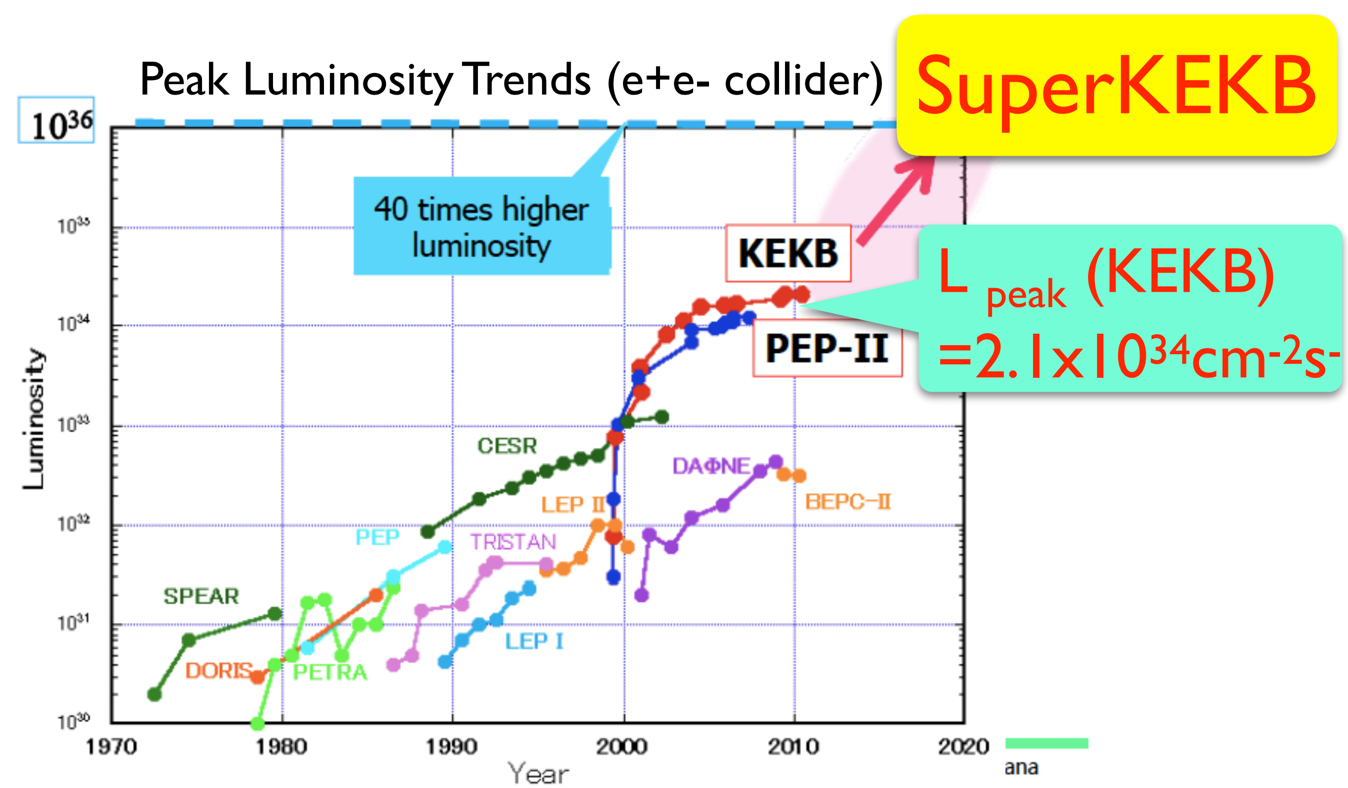
- Target luminosity ; $L_{peak} = 8 \times 10^{35} cm^{-2}s^{-1}$

  $\Rightarrow \sim 10^{10}\ B\bar{B}, \tau^+\tau^-$ 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

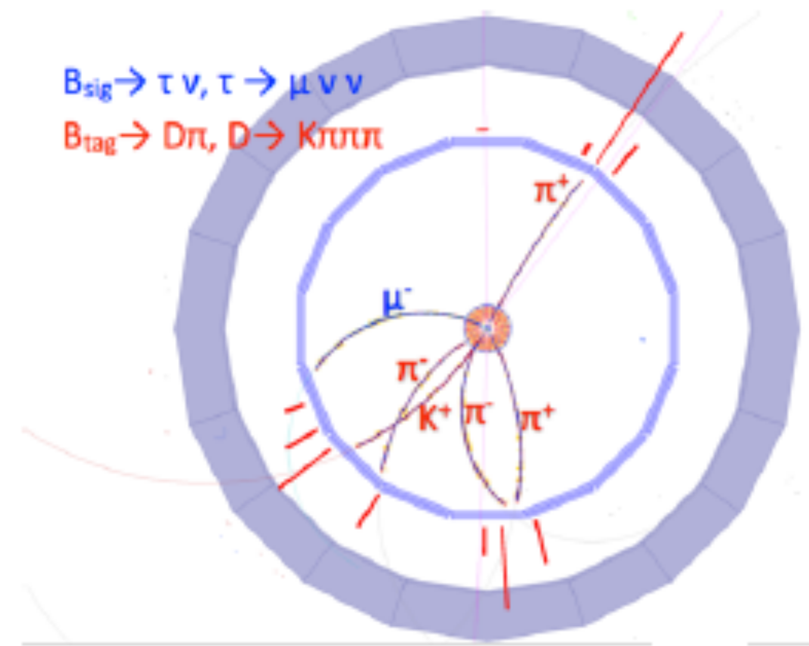




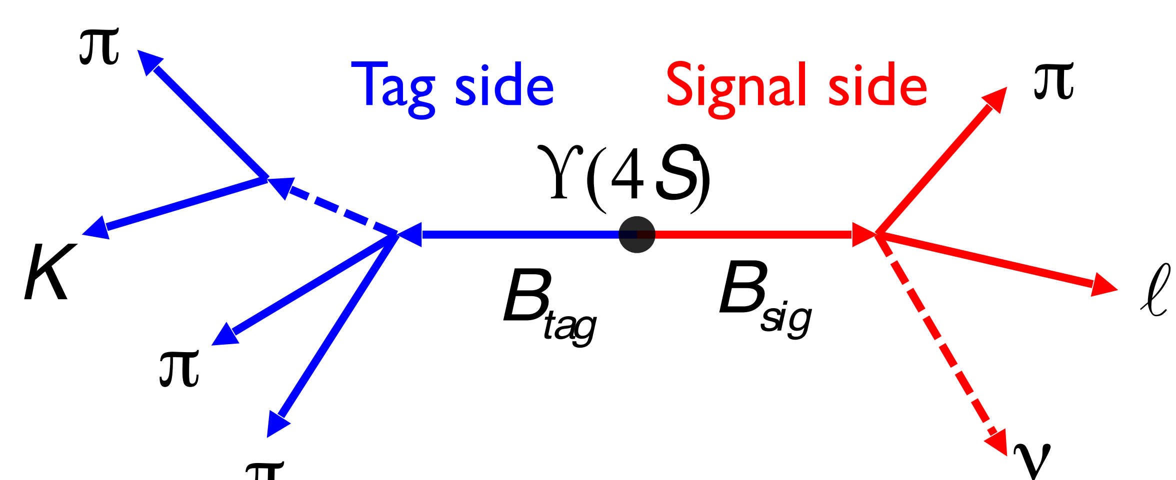
The first particle collider after the LHC !

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



$B \to \pi\, l\, \nu$

$B \to \tau\, \nu,\ D\, \tau\, \nu$

$B \to K\, \nu\, \nu$

SuperKEKB Accelerator

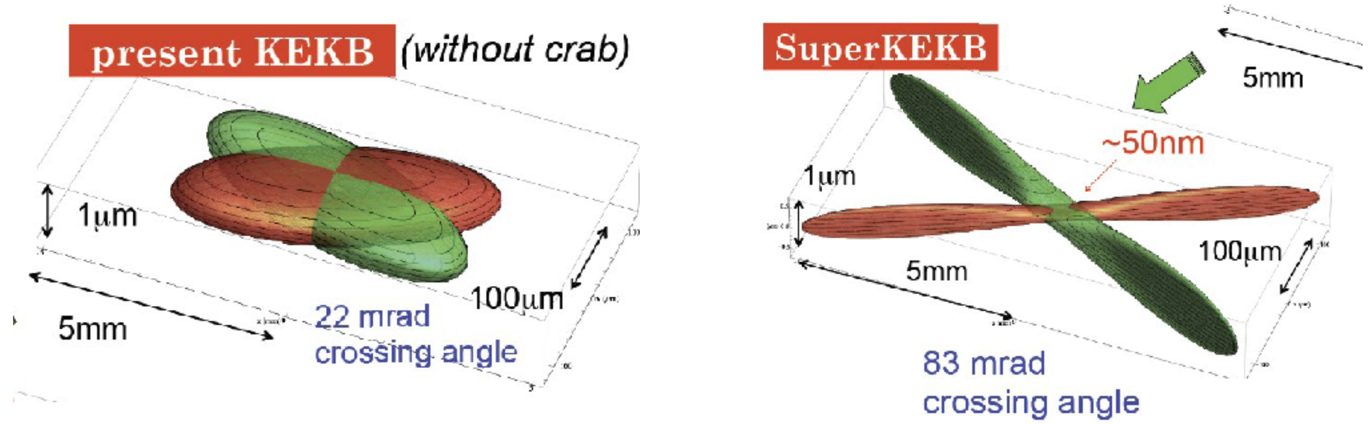
- Low emittance (“nano-beam”) scheme employed (originally proposed by P. Raimondi)

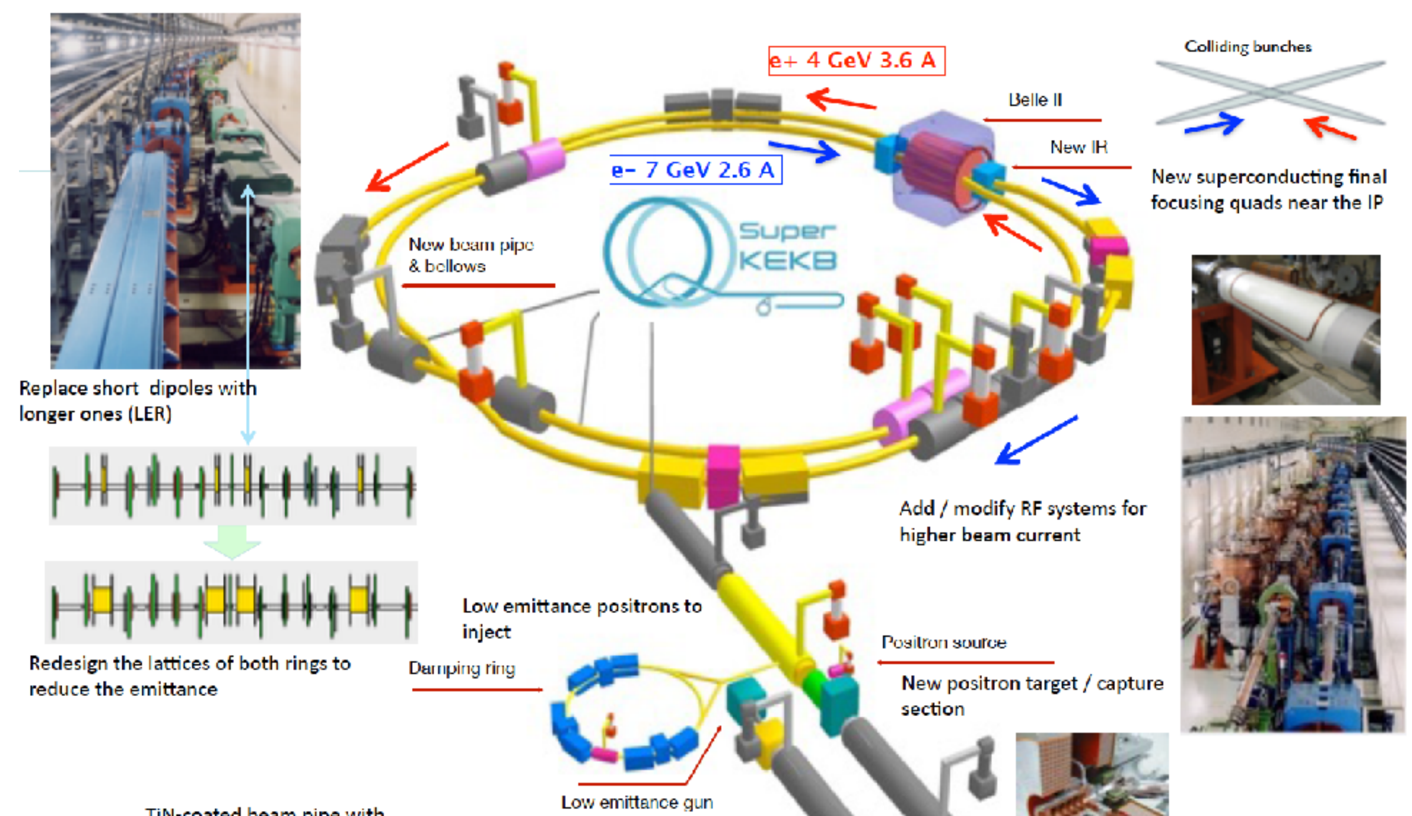
Machine parameters

	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

x2



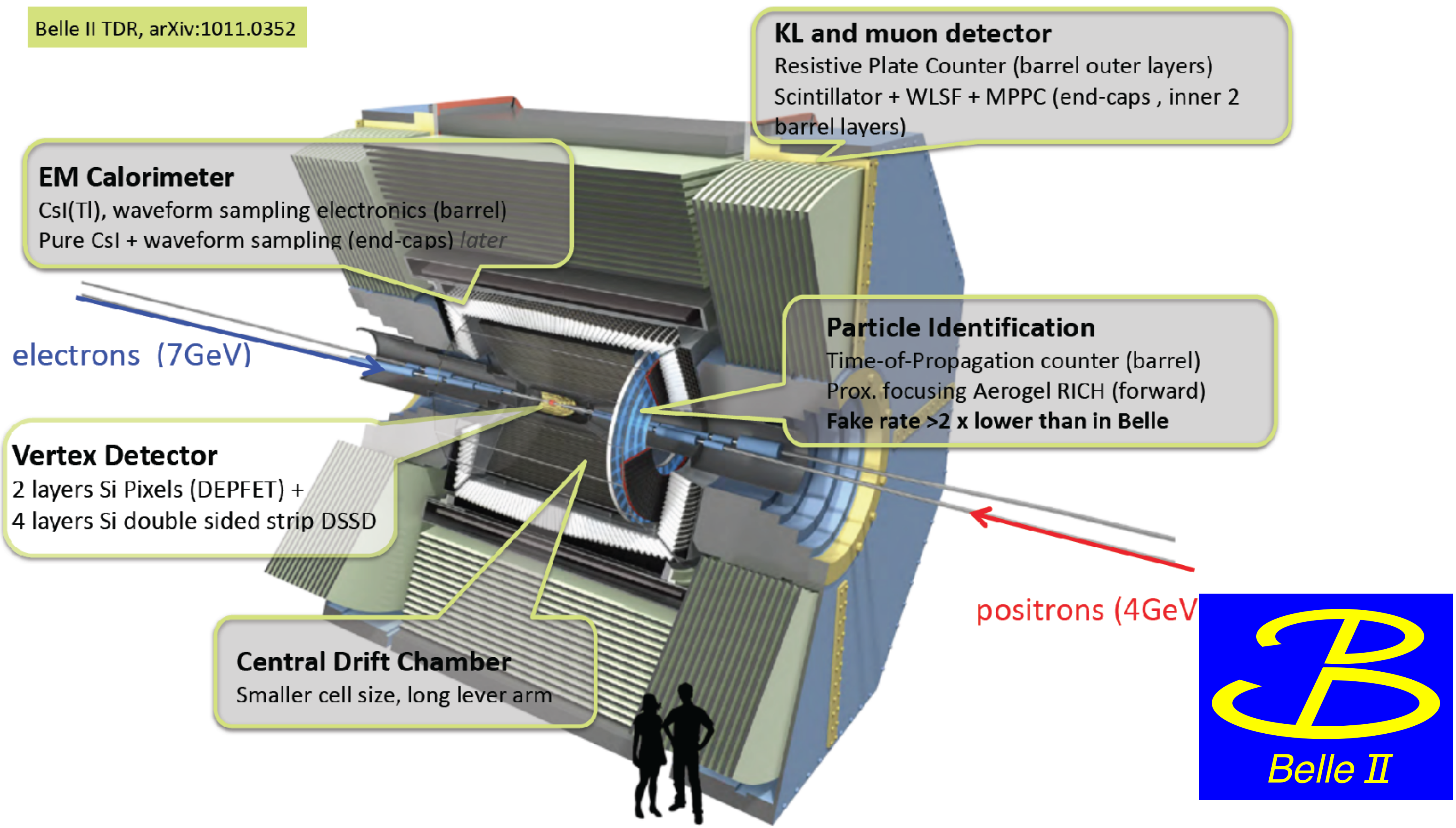


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

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 Collaboration

As of Oct. 2017

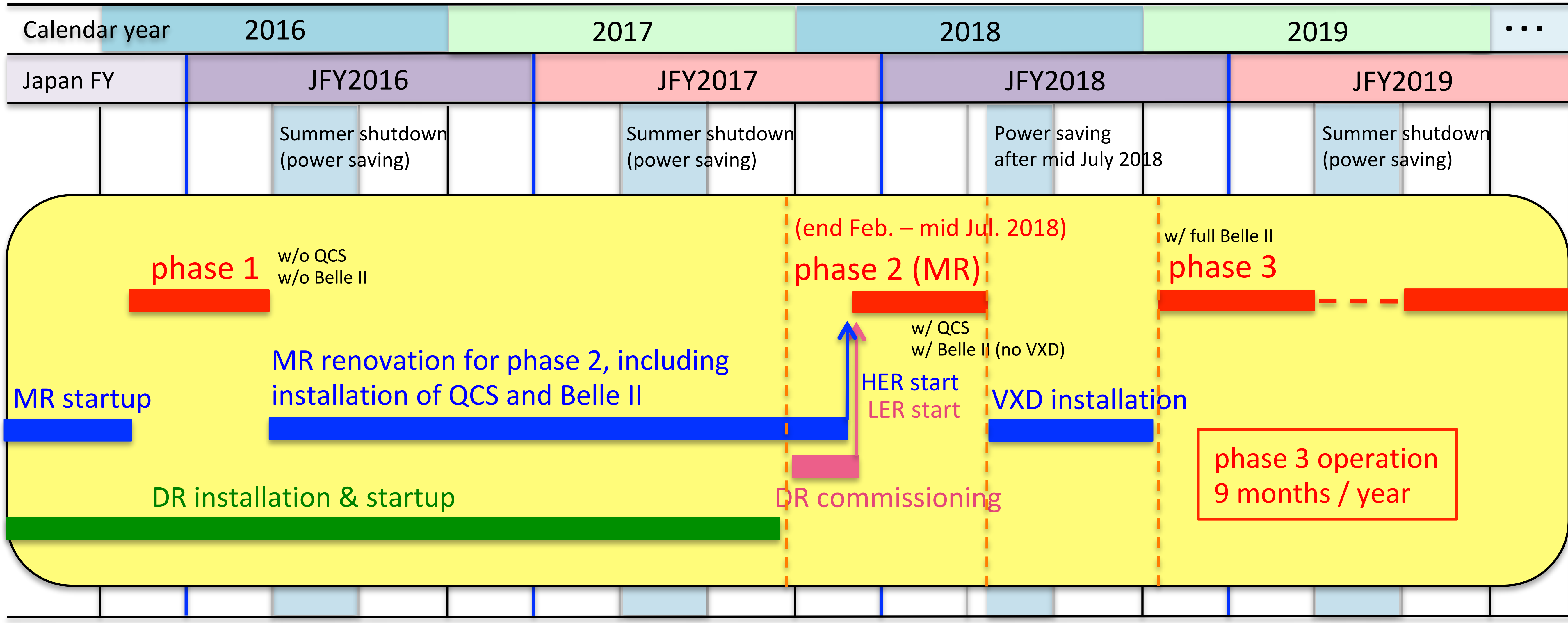
25countries/regions
105 institutions
~750 researchers

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	Korea	43
Australia	33	Malaysia	6
China	33	Vietnam	3
India	44	Taiwan	28
Japan	150	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

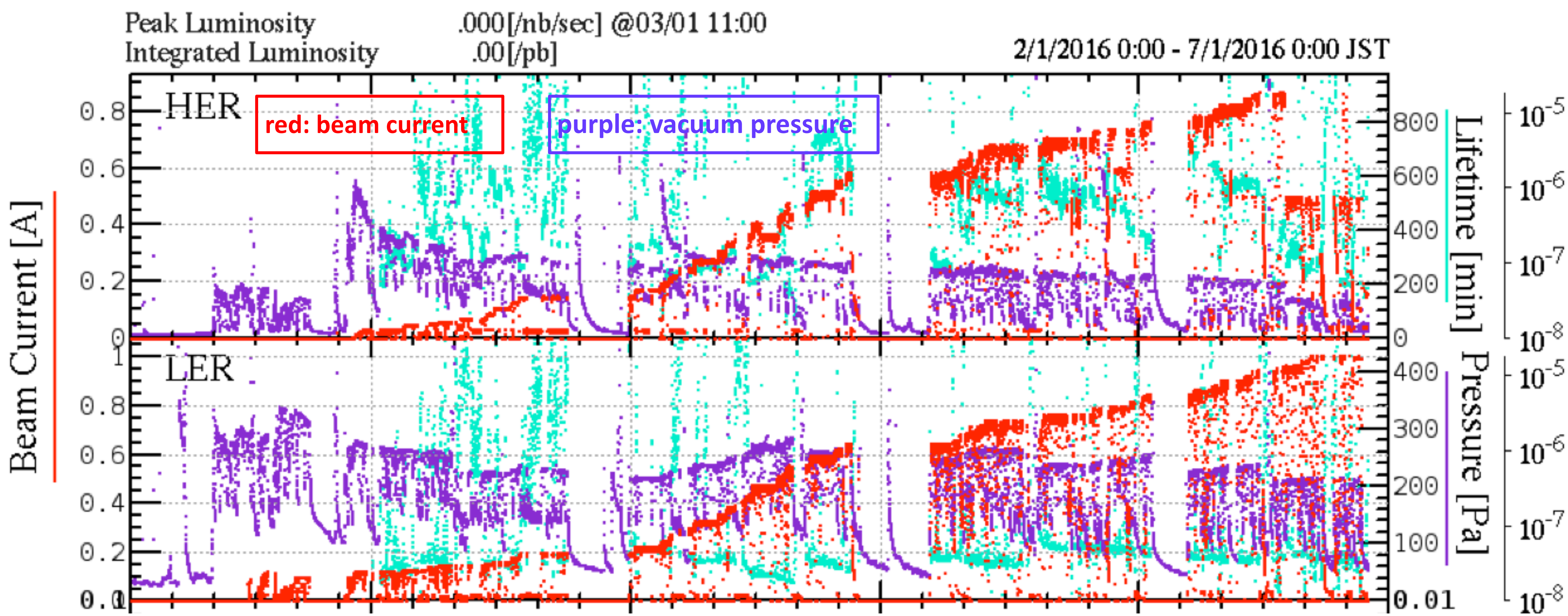
Phase 1 Commissioning

Feb. - June 2016

Phase 1 milestones (in 2016)

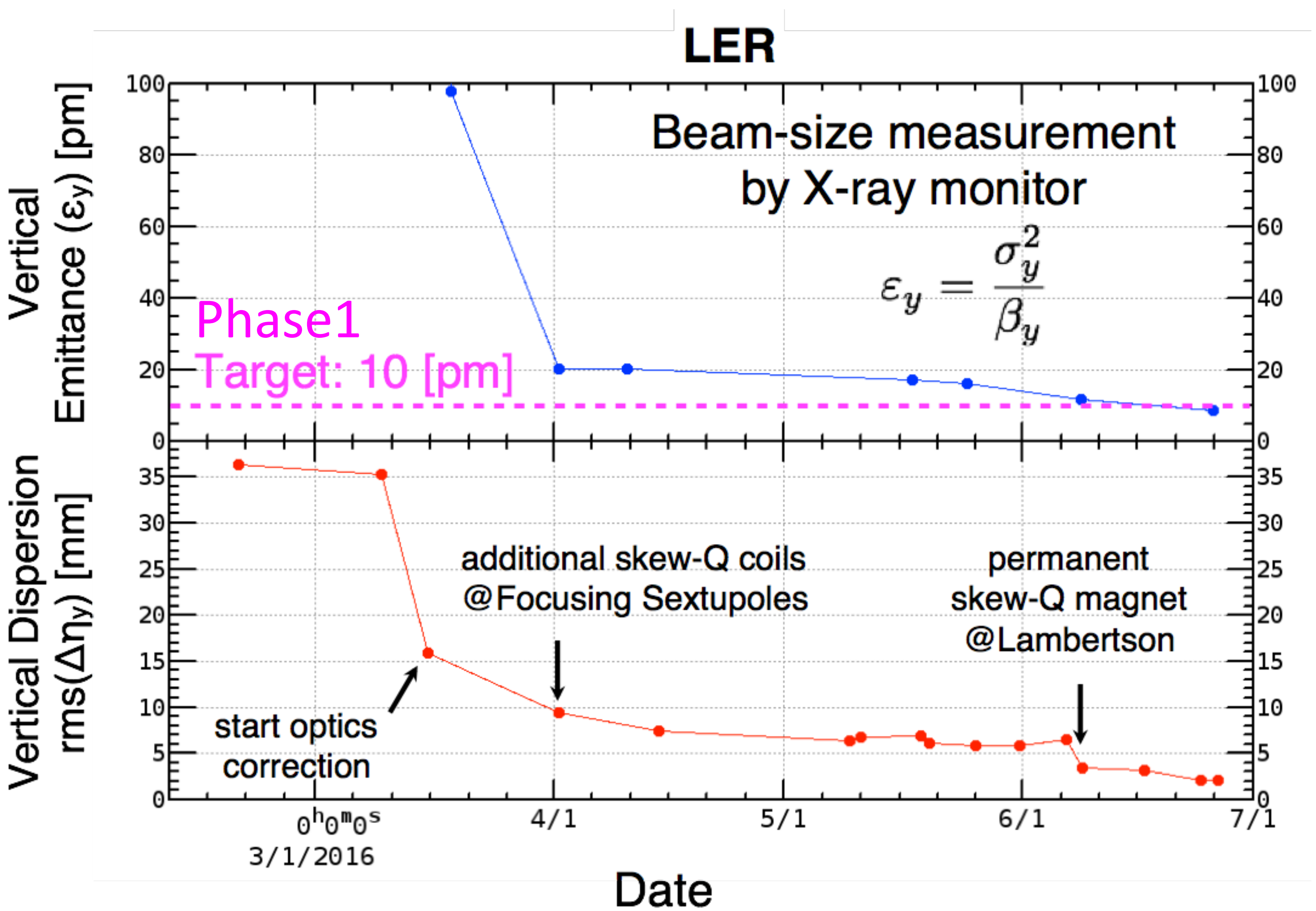
- Feb. 1: BT tuning started
- Feb. 8: LER injection tuning started
- Feb. 10: beam storage in LER
- Feb. 22: HER injection tuning started
- Feb. 26: beam storage in HER

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

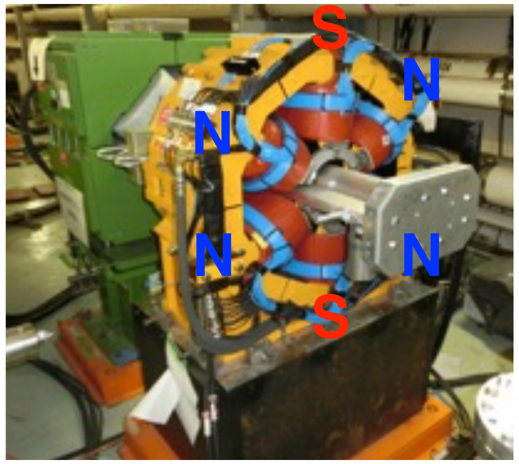


Low Emittance Tuning

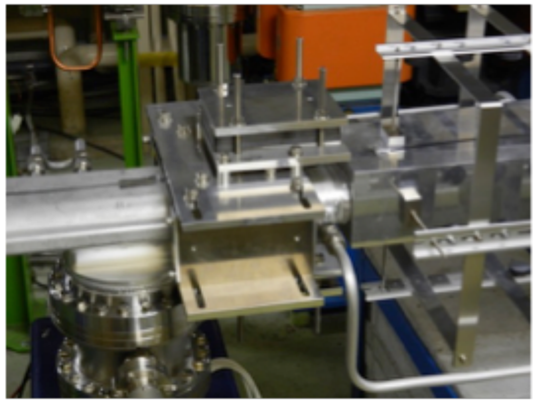
- Optics corrections have been worked successfully in both rings.
- Phase I target of vertical emittance has been achieved in LER.
- More calibration of X-ray monitor in HER needed in Phase 2.



skew-Q corrector coil on sextupole

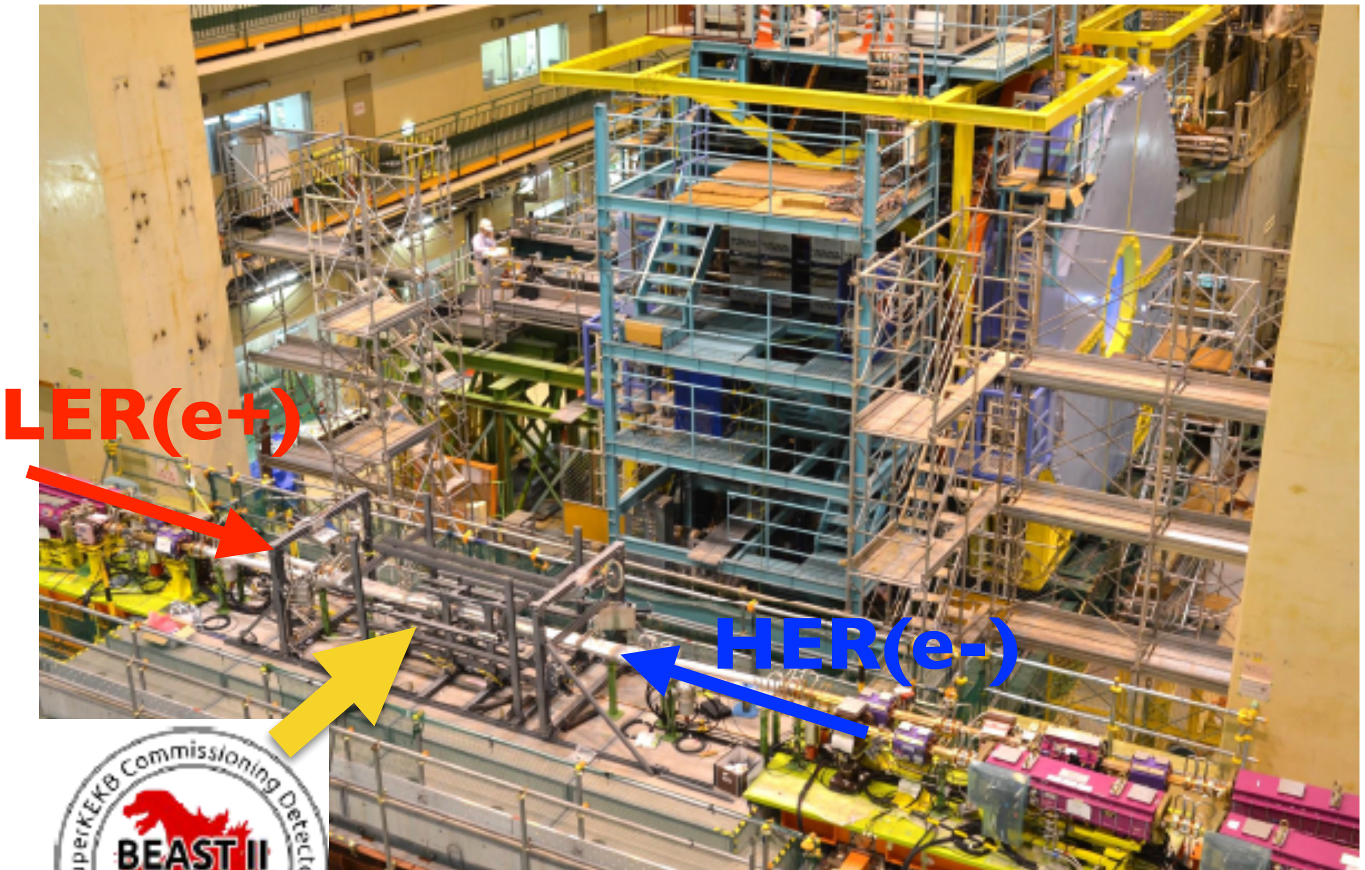


permanent skew-Q to correct error field of Lambertson



Phase 1 Beam Background Study

Interaction region during Phase 1



Beam **E**xorcism for **A** **S**table Experimen**T**
Dedicated Background Monitors

Phase 1 Beam Background Study

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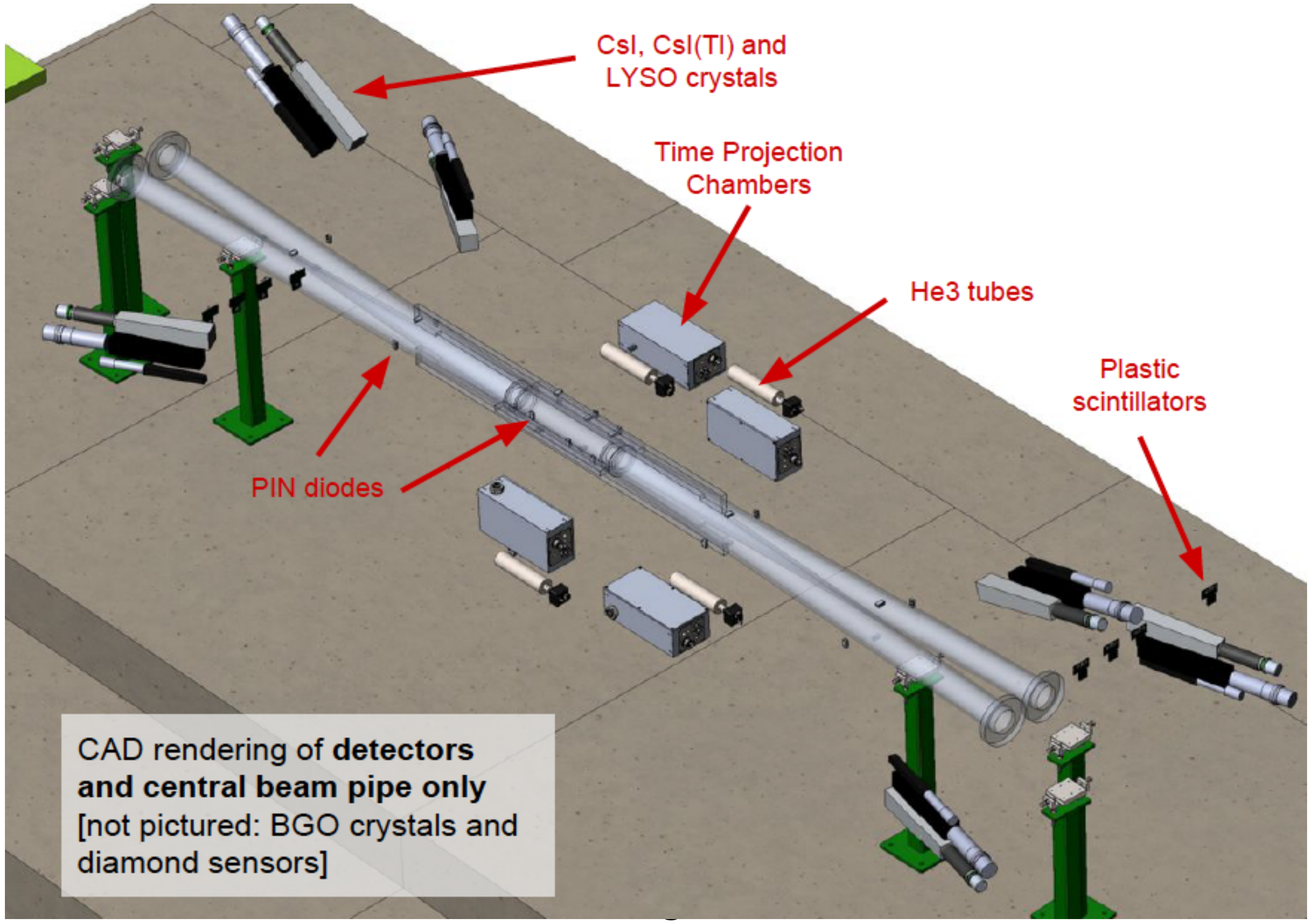
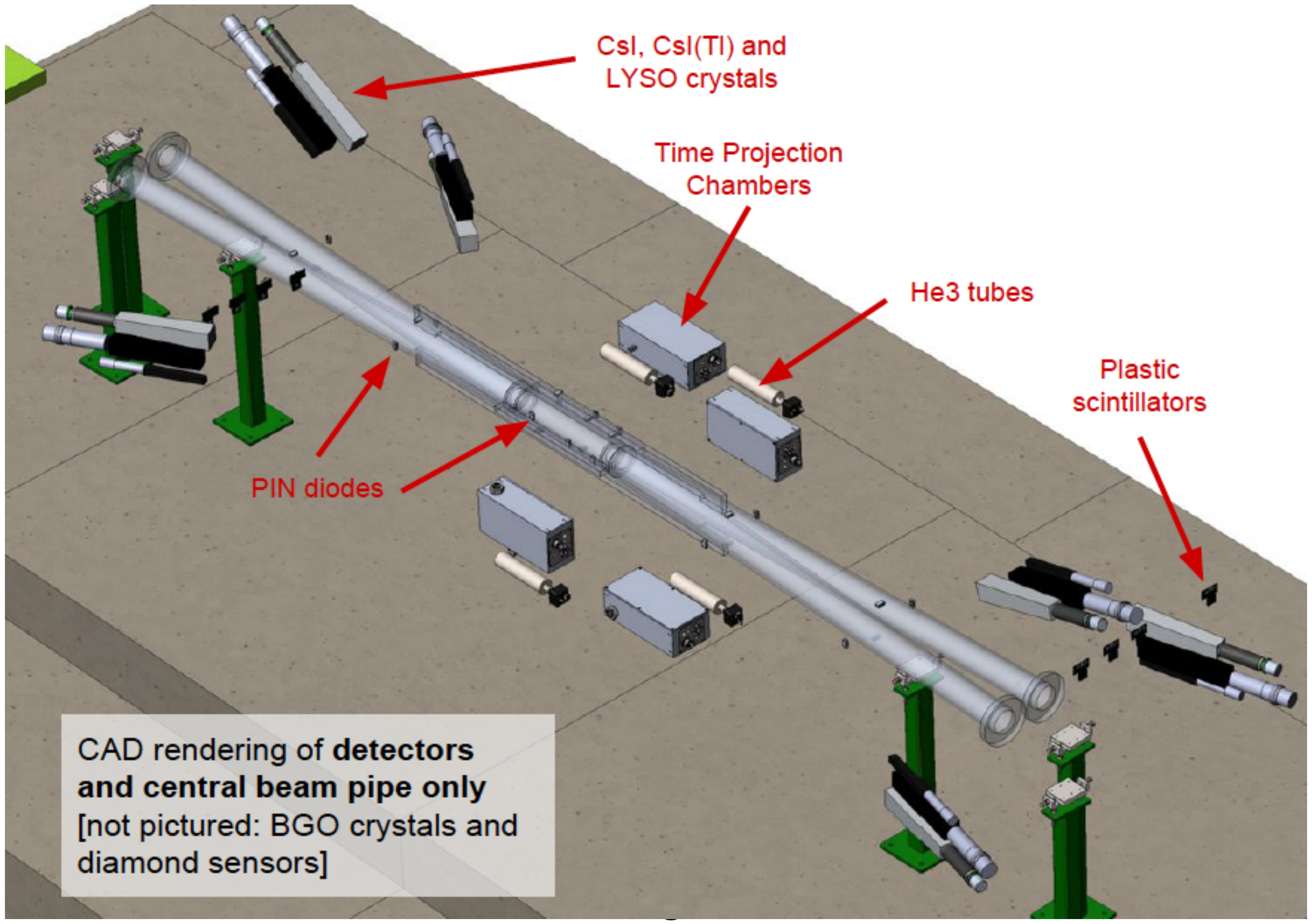


7- detector system providing :

- Thermal neutron rate
- Fast neutron tracking
- Neutral and charged dose rates
- EM spectrum and dose
- Bunch-by-bunch injection background
- More…

Phase 1 Beam Background Study

Interaction region during Phase 1



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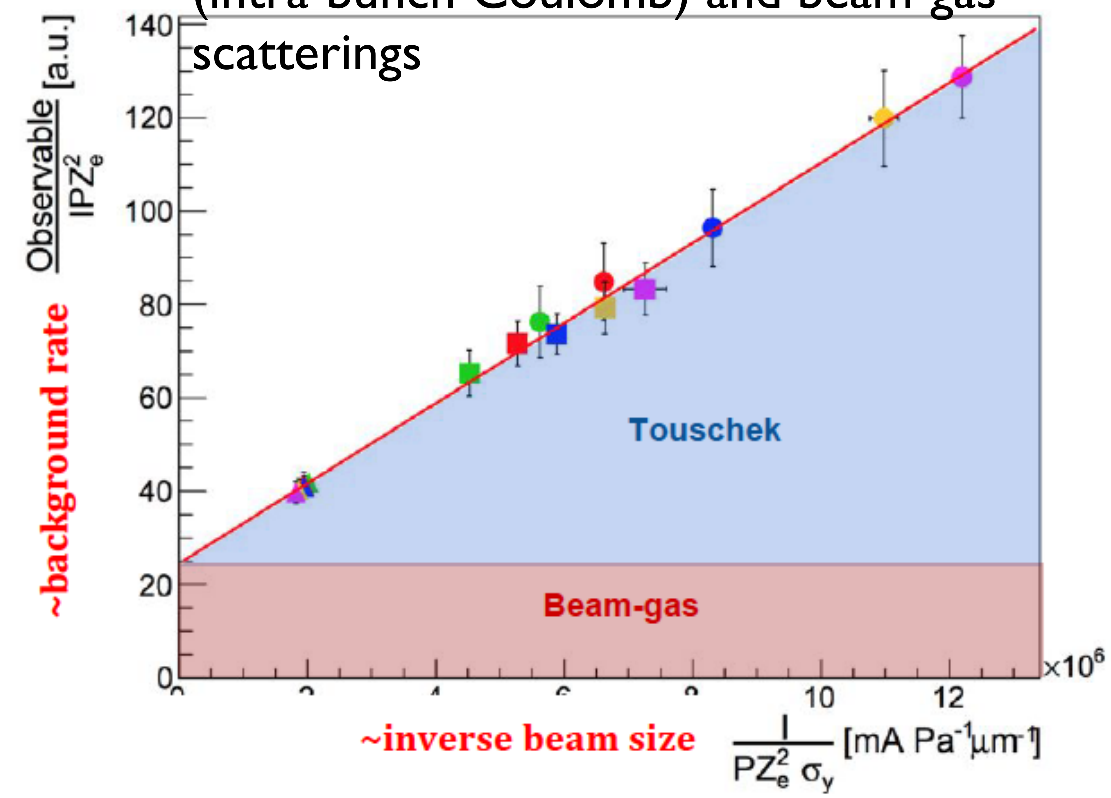
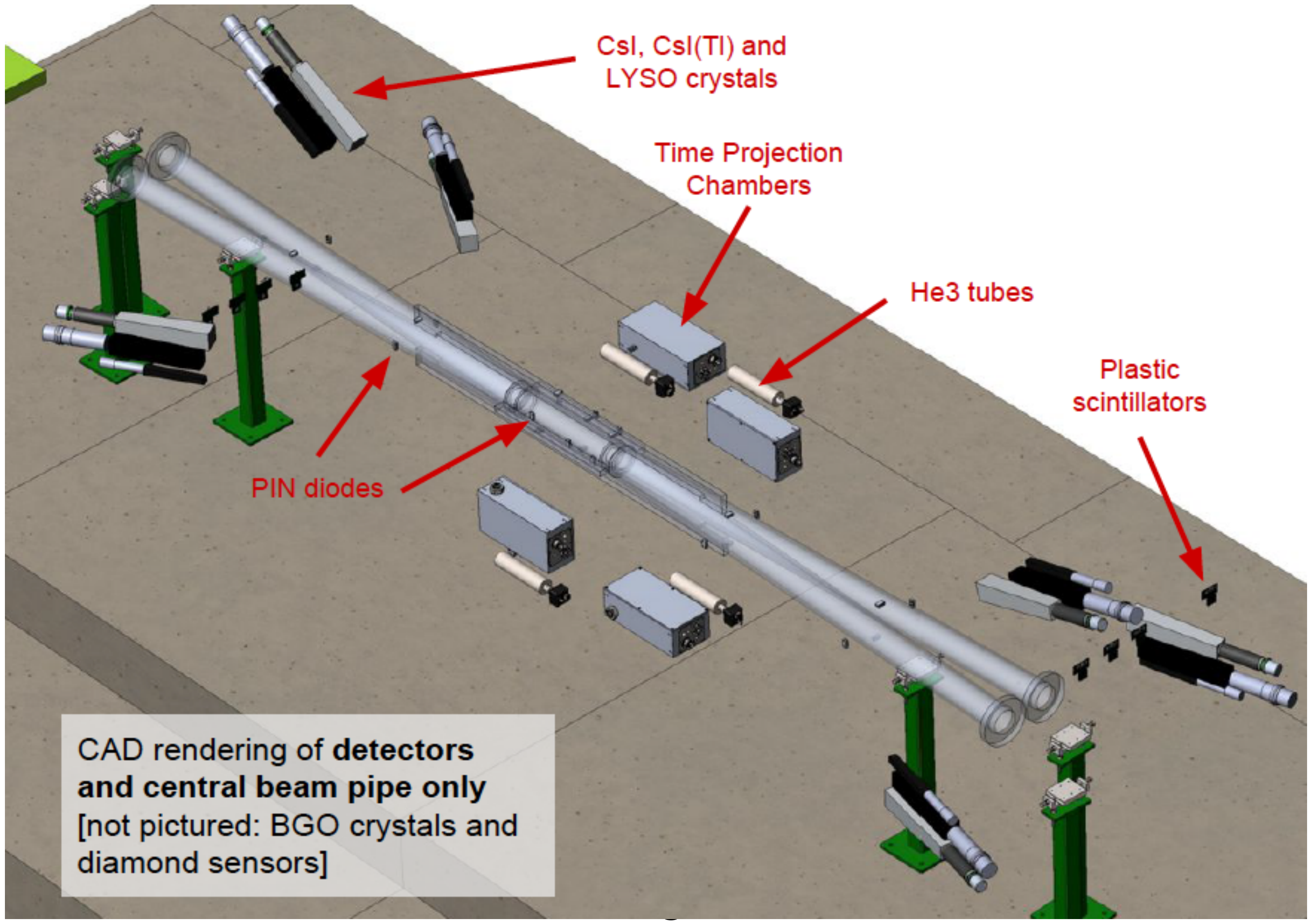
Beam background

Change beam size to decompose Touschek (intra-bunch Coulomb) and beam-gas scatterings



Phase I Beam Background Study

Interaction region during Phase I



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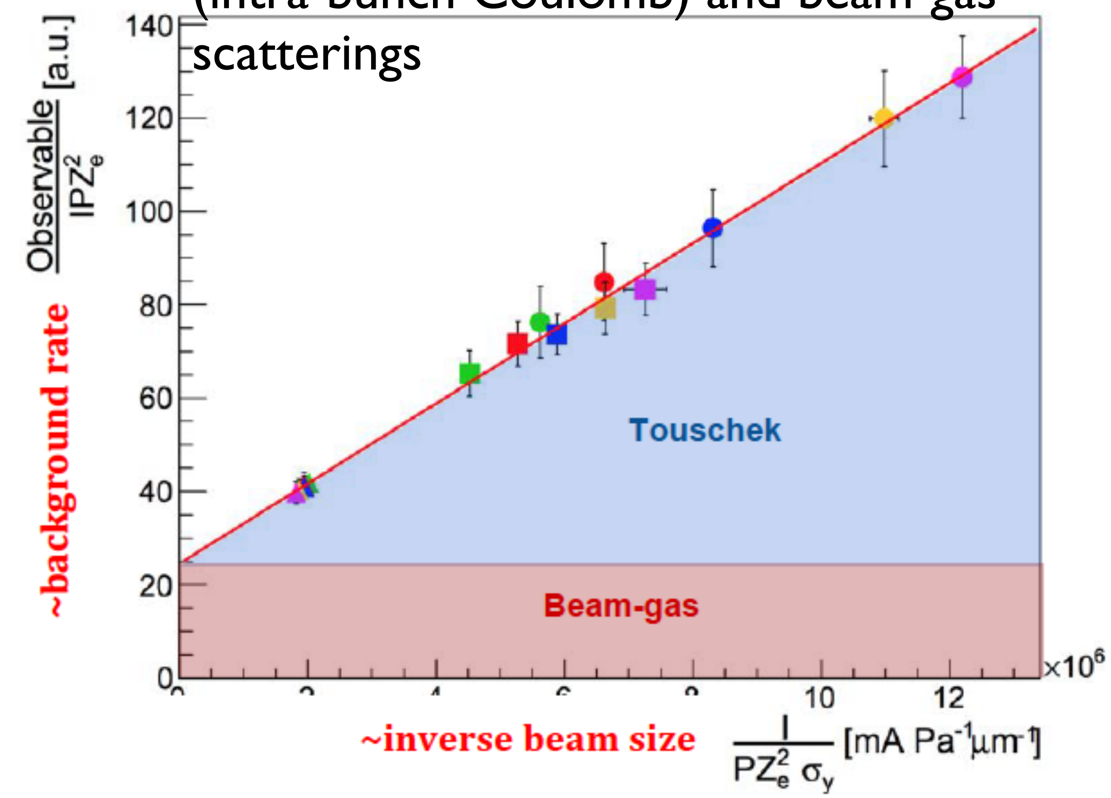
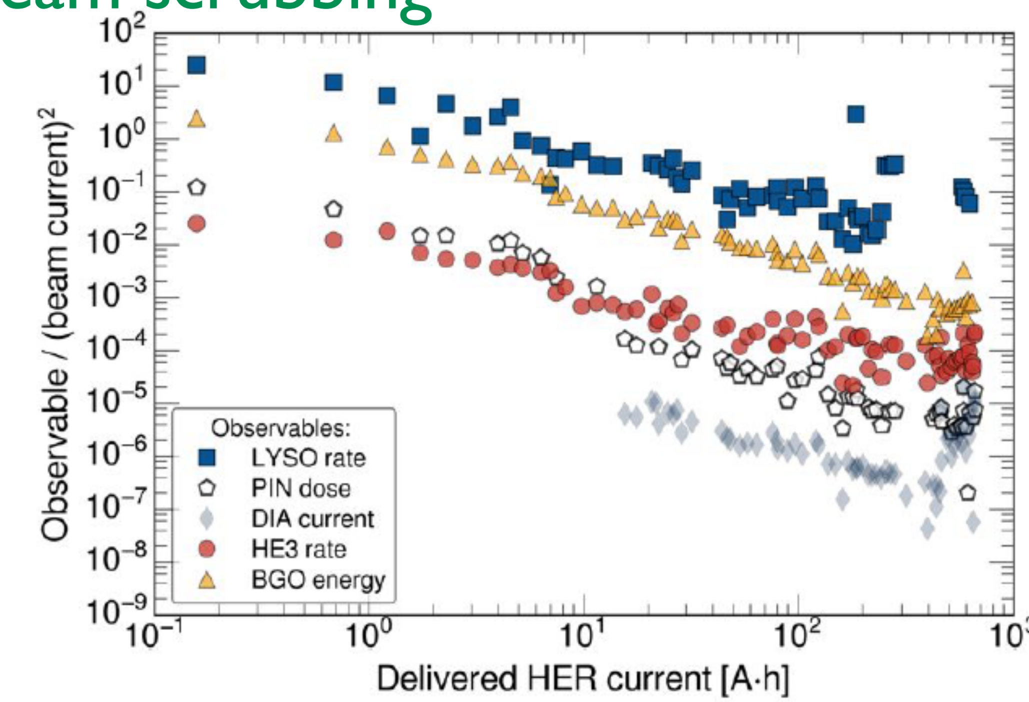


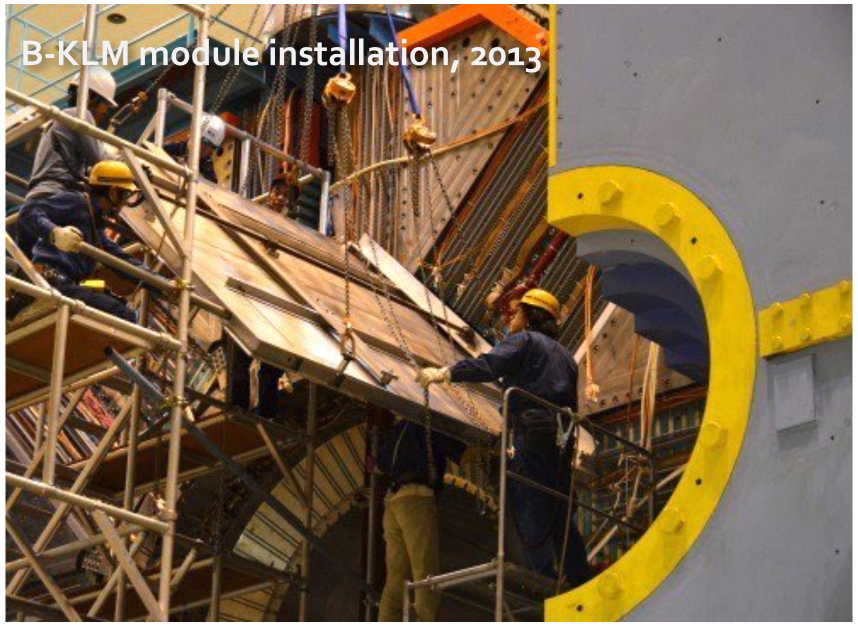
Beam scrubbing



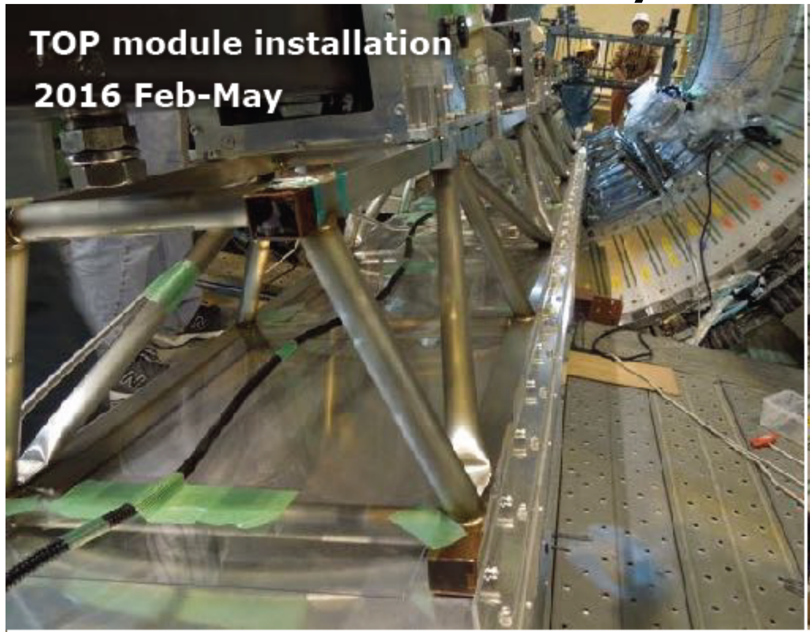
Belle II Integration

2013 - 2017 Feb. at roll-out position

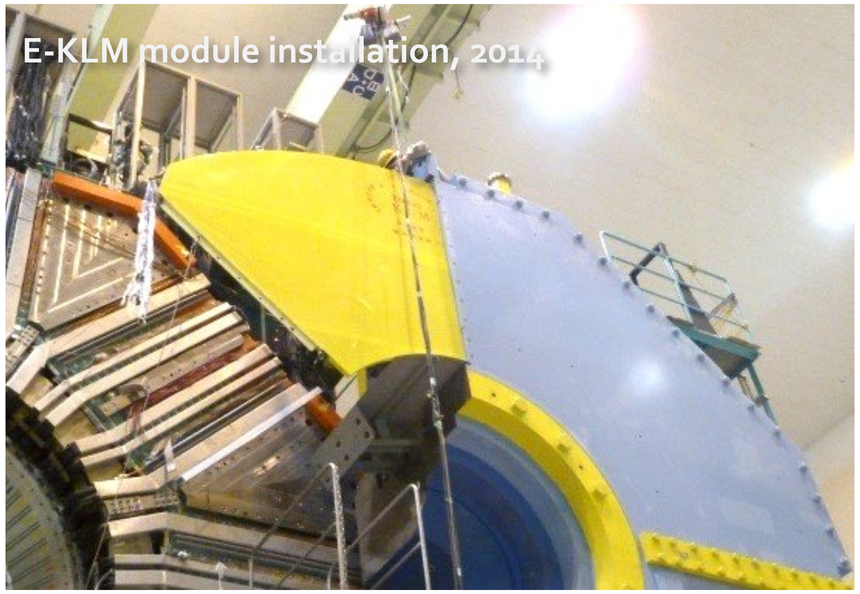
B-KLM, 2013



TOP, 2016 Feb-May



B field meas., 2016 Jun-July



E-KLM, 2014

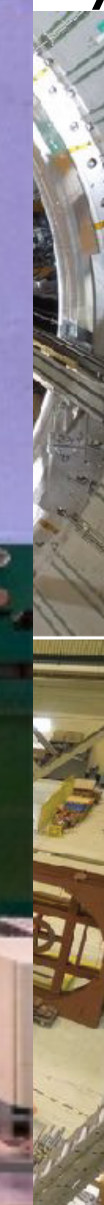
CDC 2016 Oct-Dec

BW endcap, 2017 Jan-Feb

Belle II Integration

2013 - 2017 Feb. at roll-out position

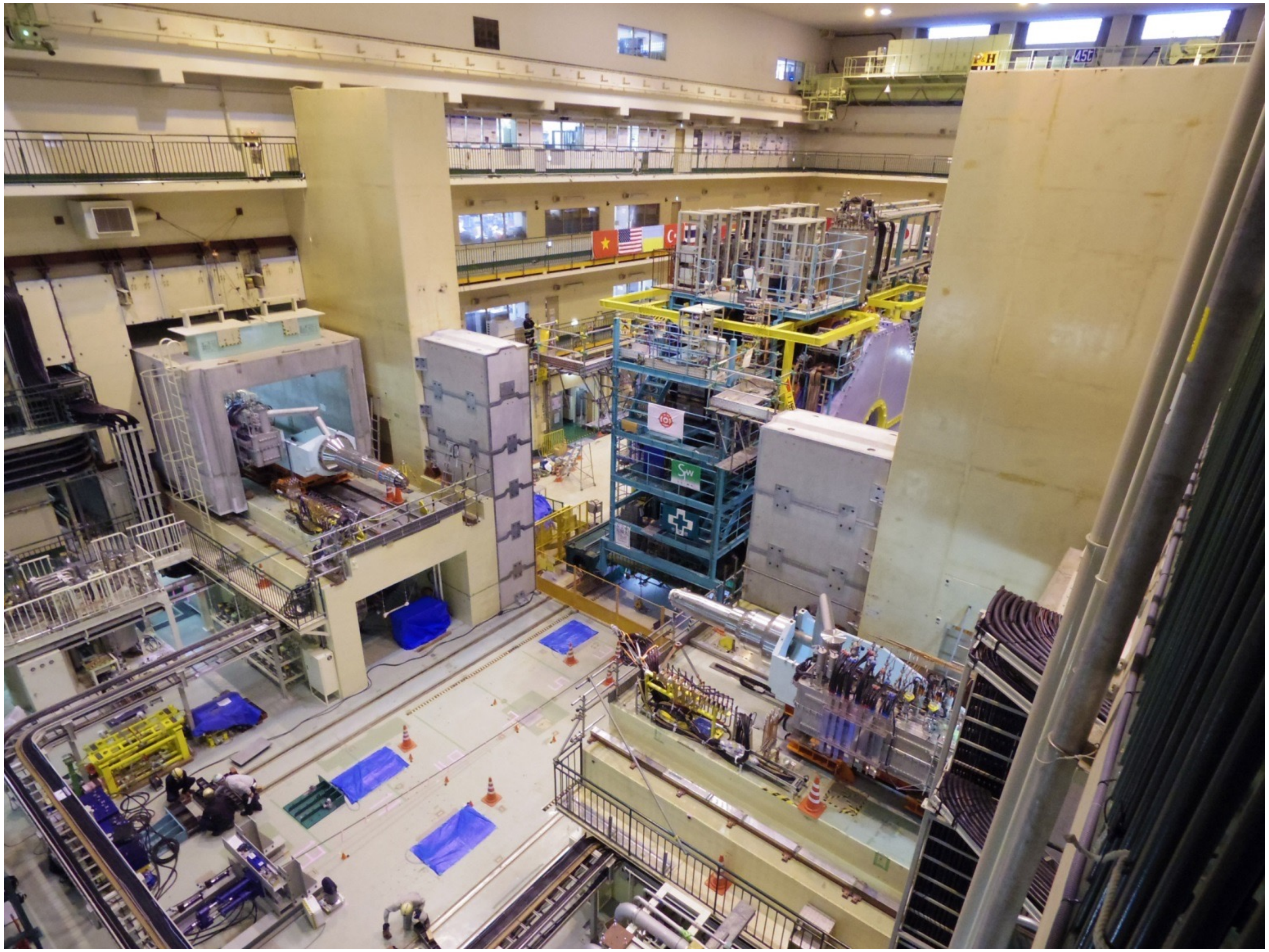
uly



eb

Belle II Roll-In

April 11, 2017



Belle II rolled-in to the beam line on April 11th, 2017
One of the most significant milestones in the construction phase

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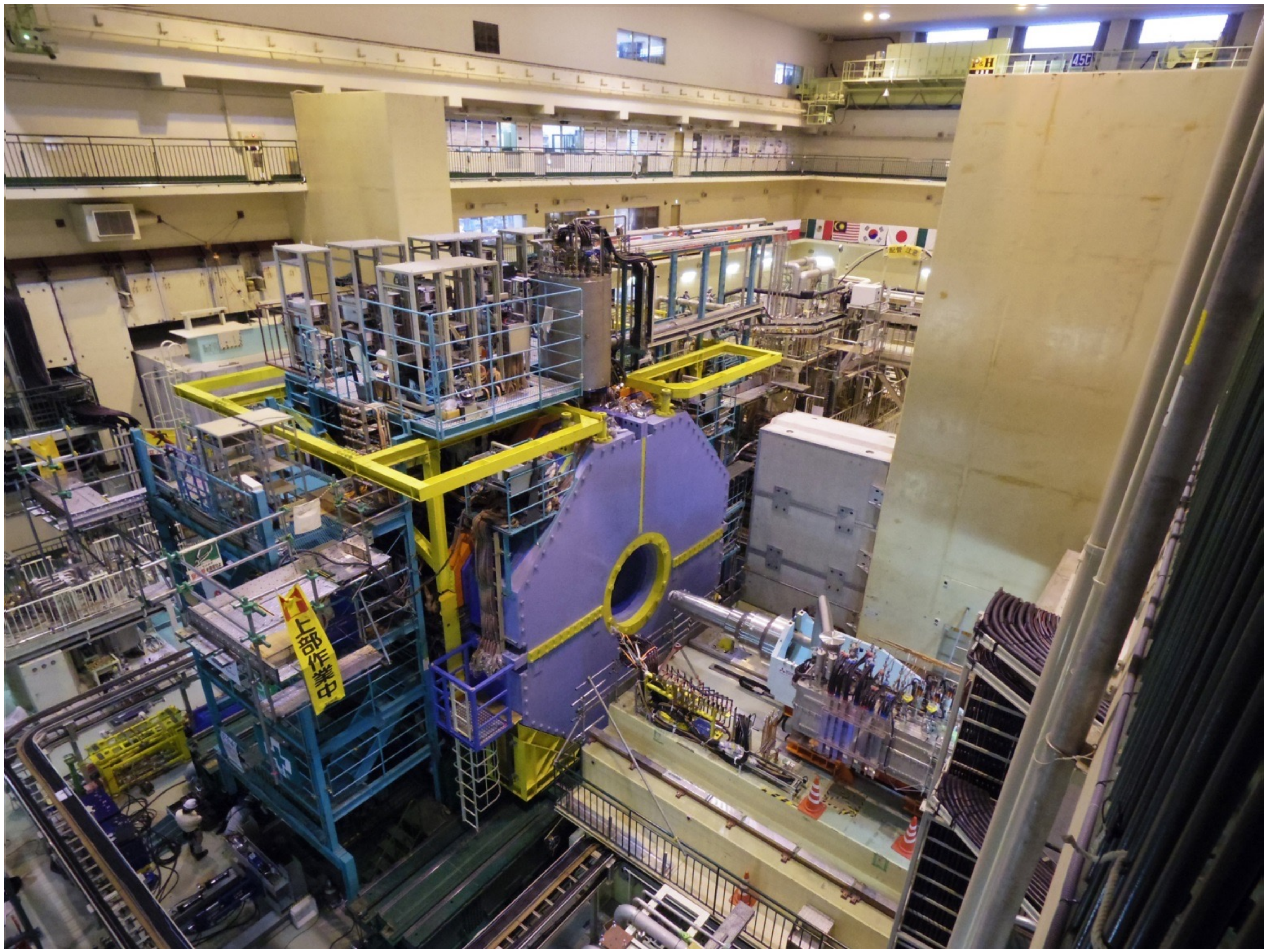

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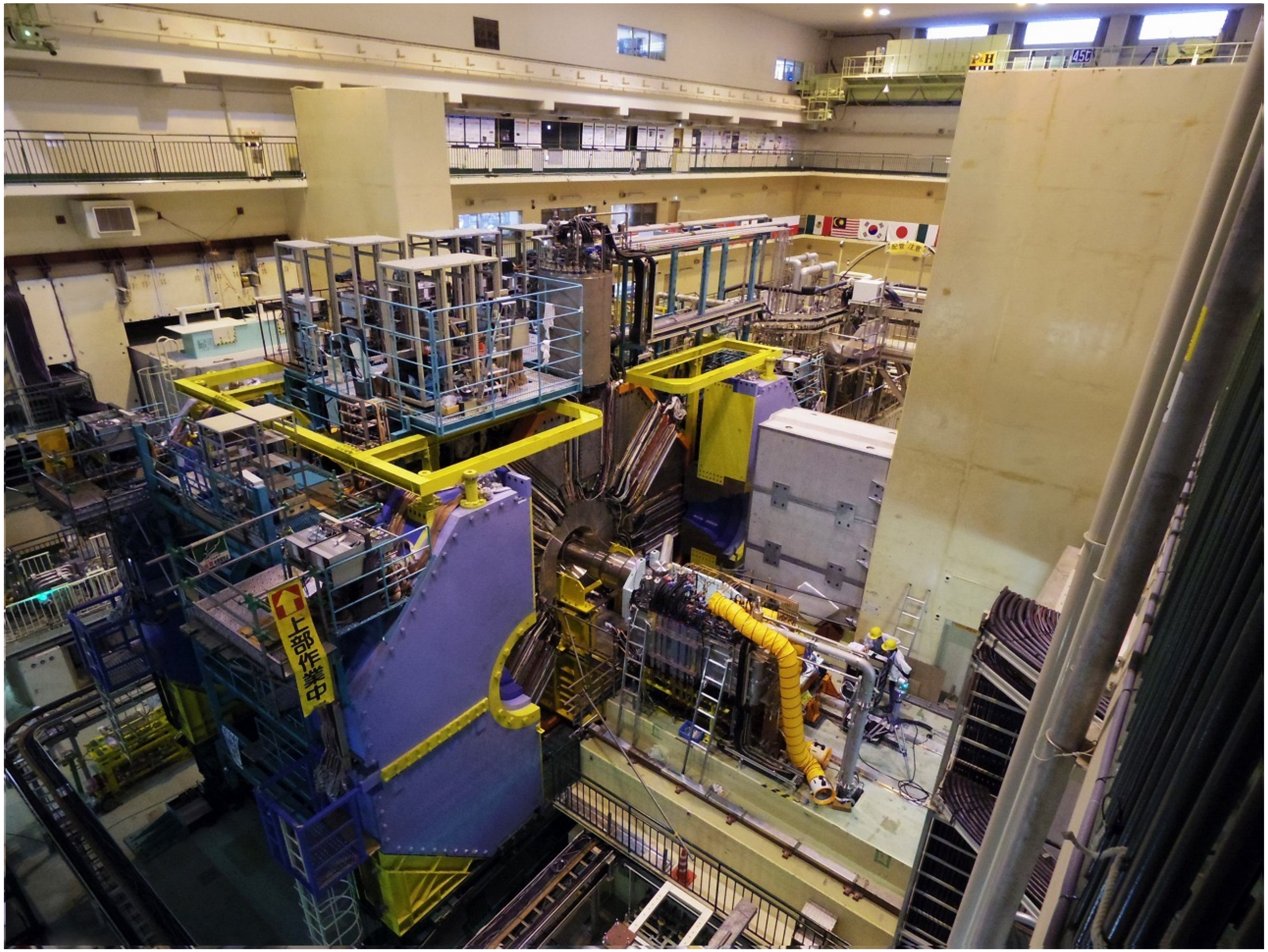
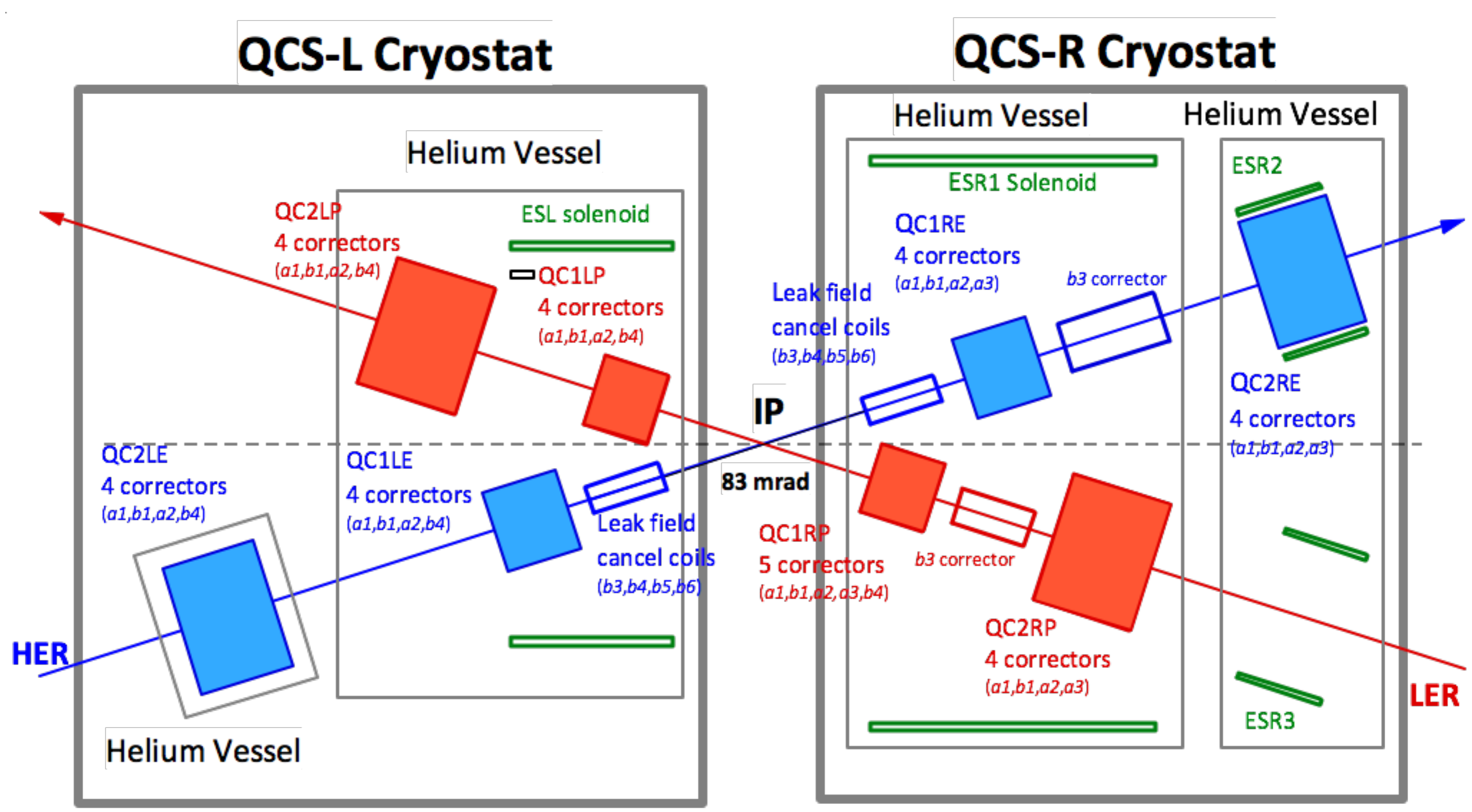
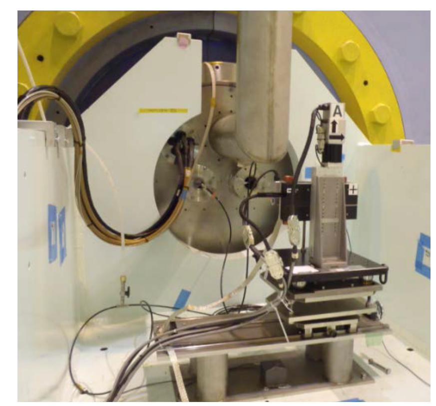


Belle II rolled-in to the beam line on April 11th, 2017
One of the most significant milestones in the construction phase

Field Measurement of QCS + Solenoid

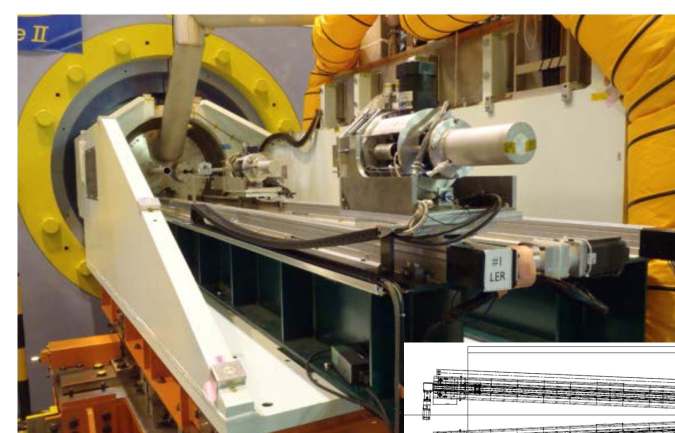
- The QCS system is the key ingredient of the nano-beam collisions.
  - 55 superconducting coils in 2 cryostats
- Performance test of the QCS system carried out May - August, 2017.
  - Cool-down and excitation together with the Belle II solenoid at 1.5 T.
  - Careful magnetic field measurements with Single Stretched Wire (SSW), Harmonic coils and hall probe.

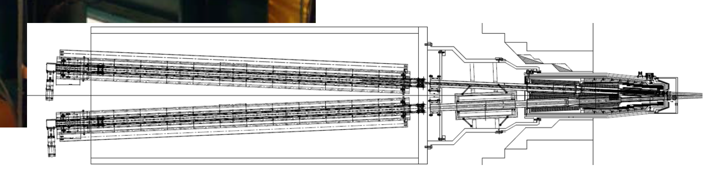




SSW

A Φ0.1mm BeCu wire stretched on the beam line through the two cryostats, moved in the field to measure the center and angle from induced voltage. (collaboration with Fermilab)





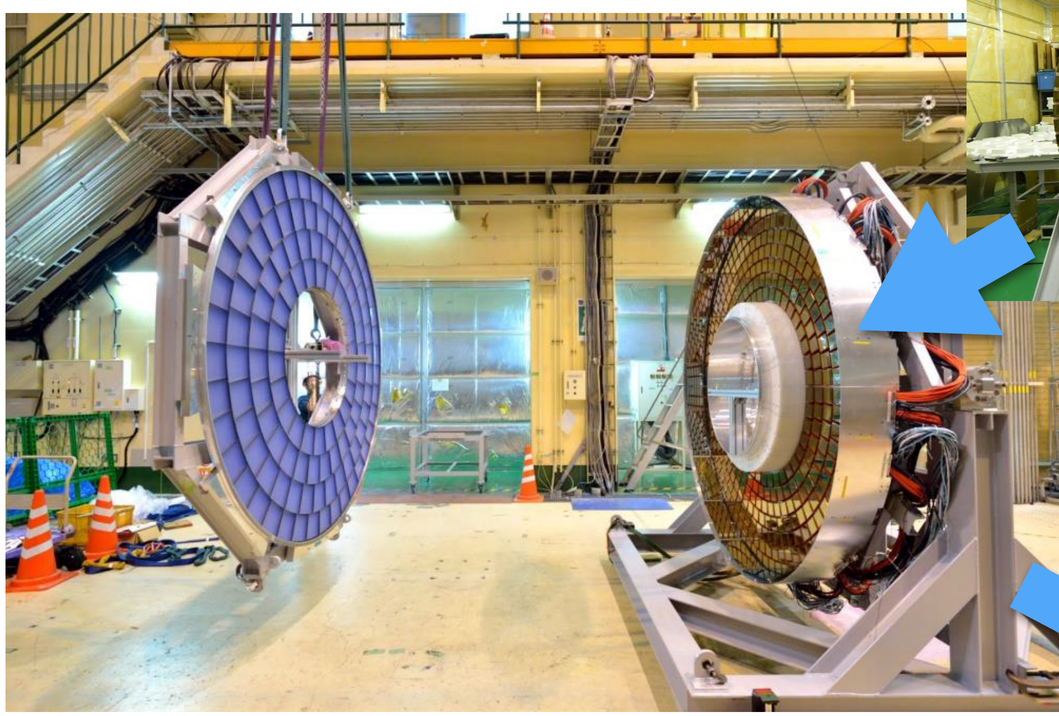
Harmonic coils

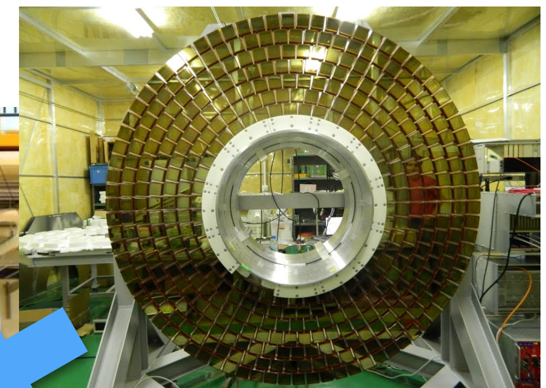
The multipole field components as the error components were measured with the 6 harmonic coils.

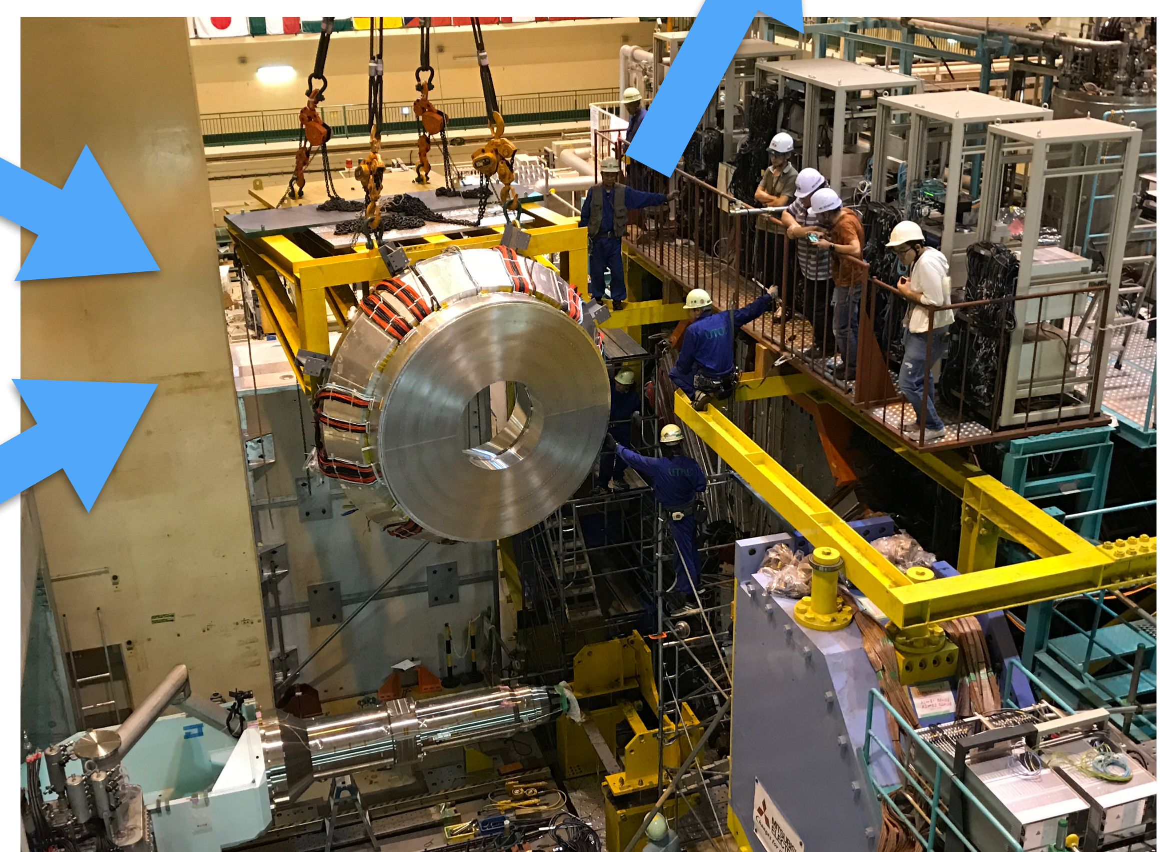
Forward End-cap Installation

Sep.-Oct., 2017

- Two sub-detectors (A-RICH + FW ECL) are combined and installed into Belle II.

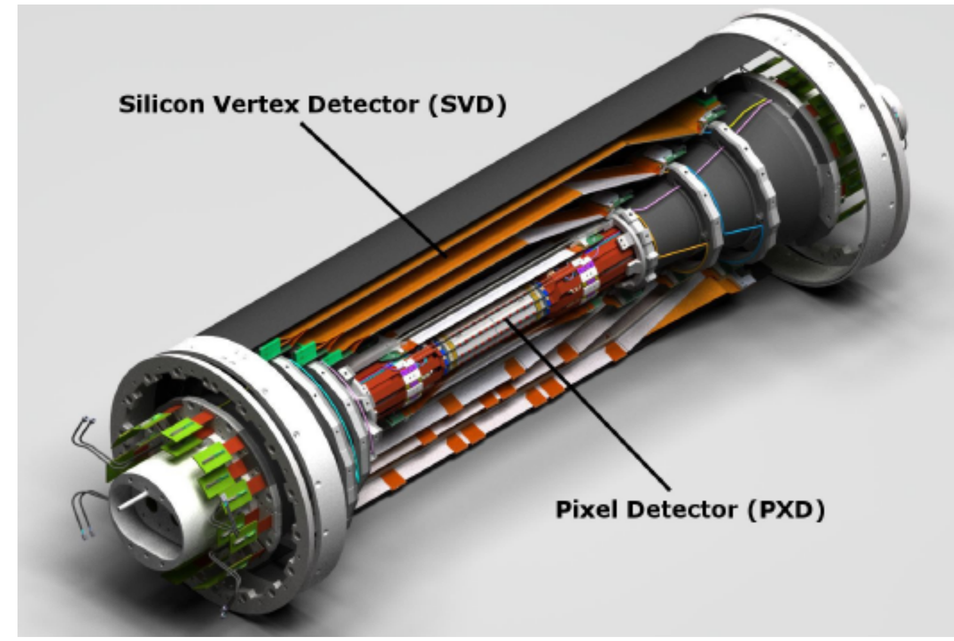


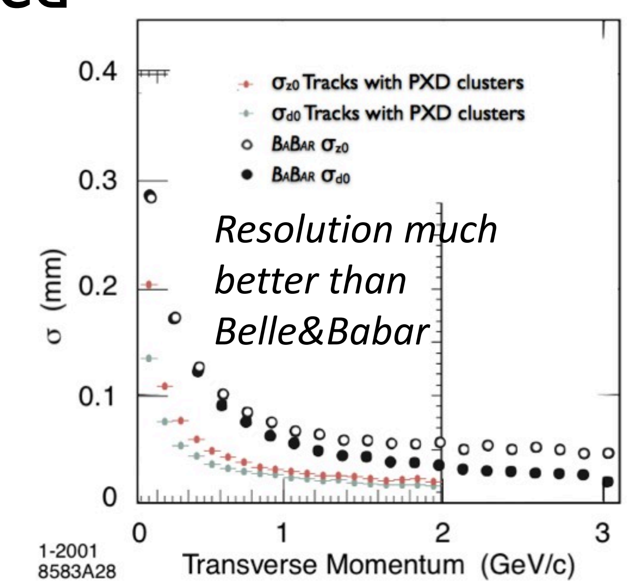


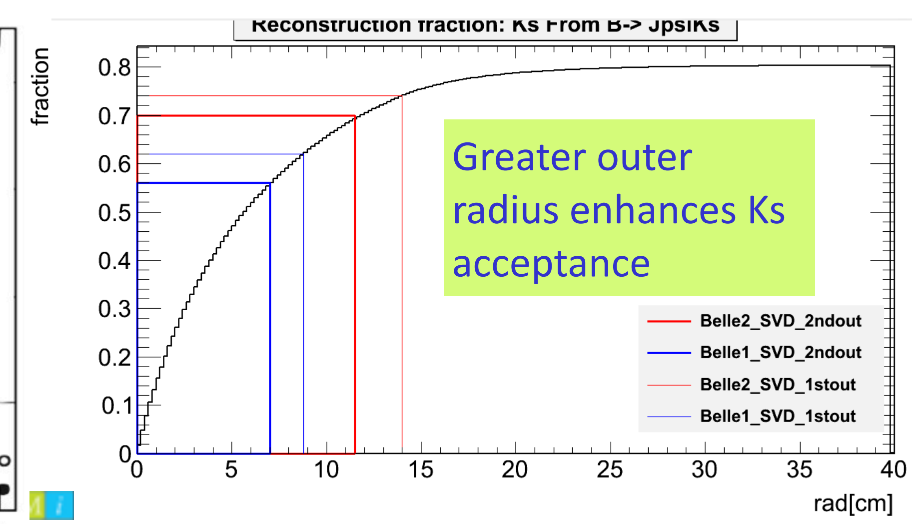


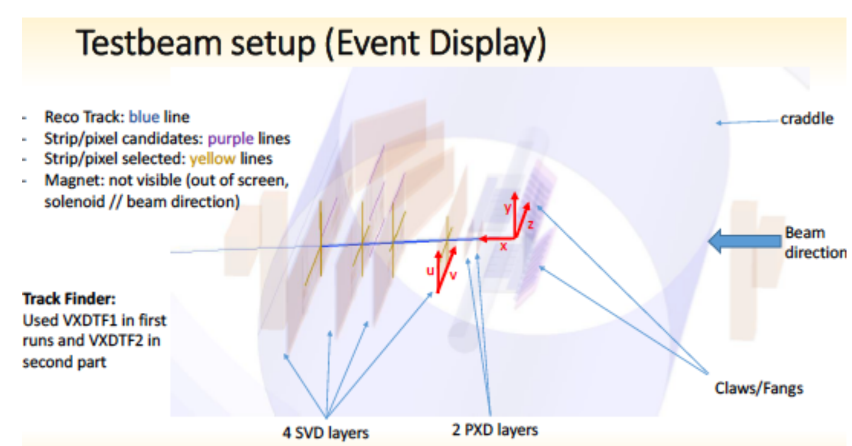
Belle II Vertex Detector

- Critical component for CPV measurements
- New vertex detectors:
  - PXD: 2-layer pixel detector based on DEPFET (Depleted P-channel Field Effect Transistor) technology.
  - SVD: 4-layer DSSD (Double Sided Silicon Detector).
- Smaller beam pipe radius
  - =1cm (2cm → 1.5cm @ Belle)
- Larger outer radius
  - Improved Ks acceptance
- Excellent performance (position resolution, efficiency) confirmed in beam test at DESY.







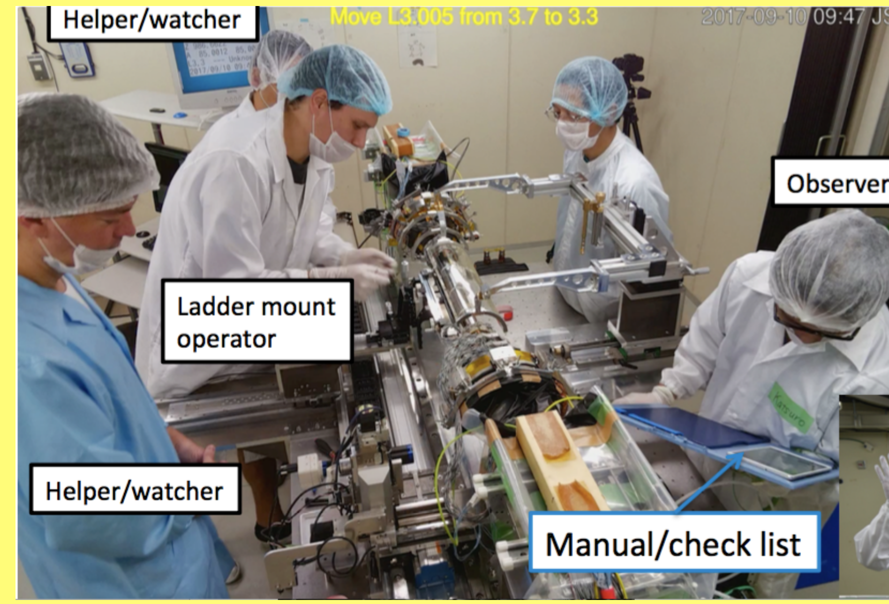


Status of VXD production

SVD

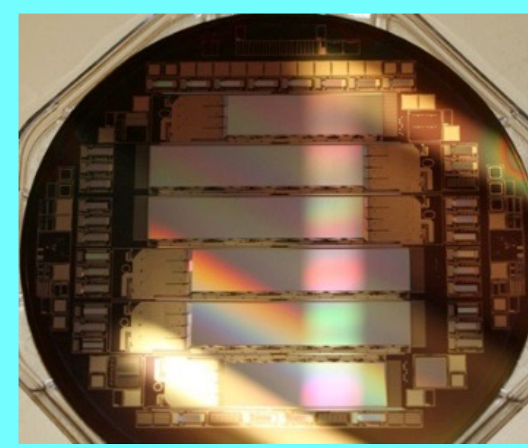
- Ladder production: completed at 3 out of 5 sites.
  - will be finished by Feb. 2018.
- Ladder mount started (Sep.7, 2017)
  - L3 mount completed (Sep.19, 2017)
  - Completion of the 1st half shell (Dec. 2017)
  - Completion of the 2nd half shell (Apr. 2018)

Ladder mount tools and procedures have undergone a series of technical reviews and were finally approved on Sep 5, 2017

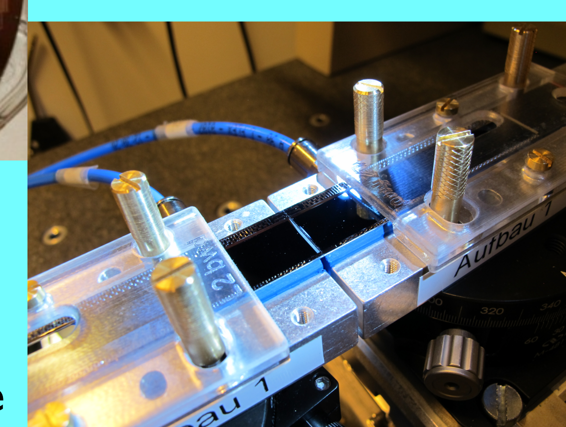


PXD

- Almost twice the required number of prime grade sensors
  - 40 sensors are required.
- Module assembly has started
  - Module assembly yield is ~100% so far
- Arrival of the assembled PXD at KEK: mid. of April, 2018



DEPFET sensor wafer produced at MPG-HLL (Munich)

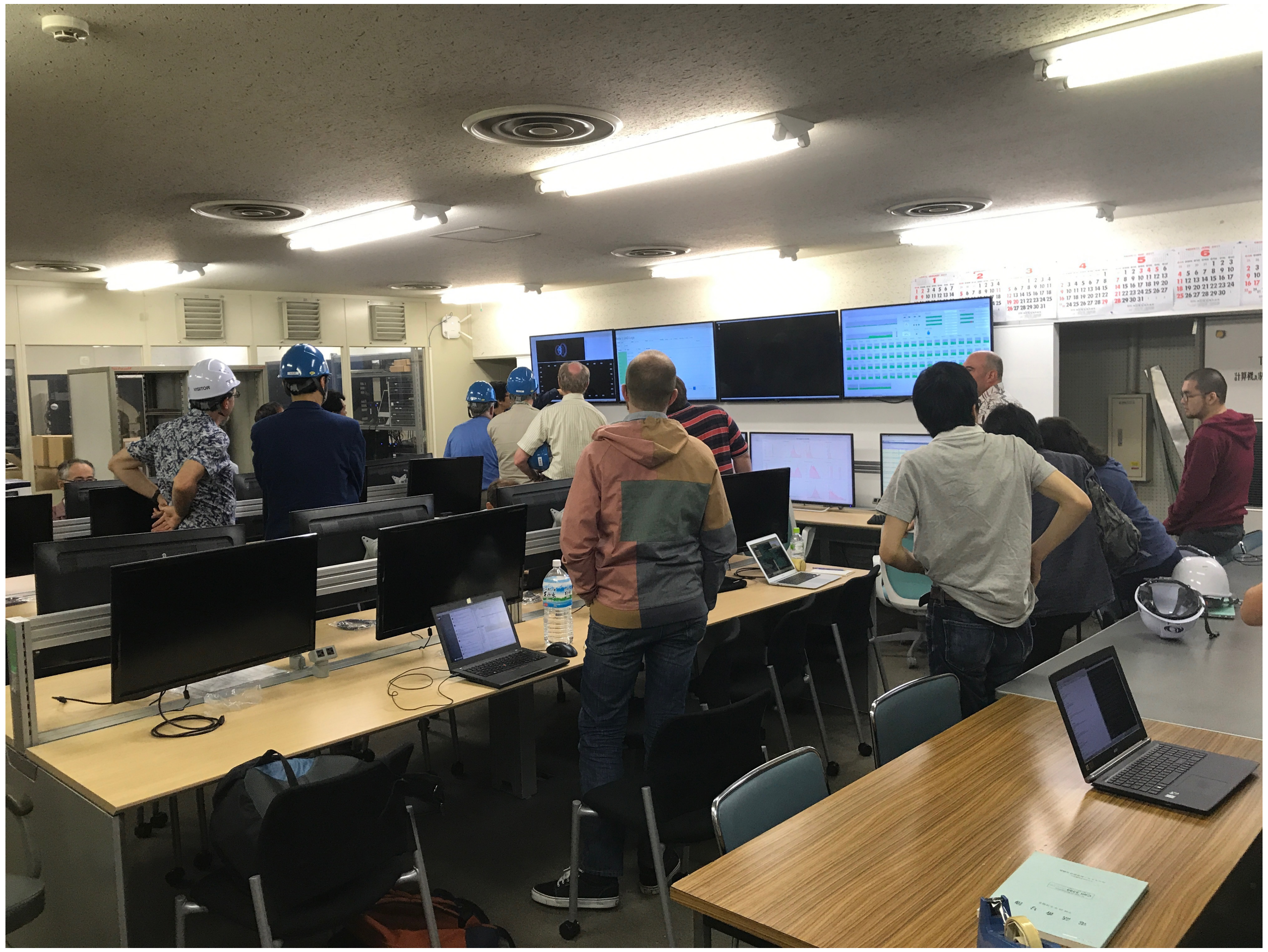


Two PXD sensor glued together to make a module

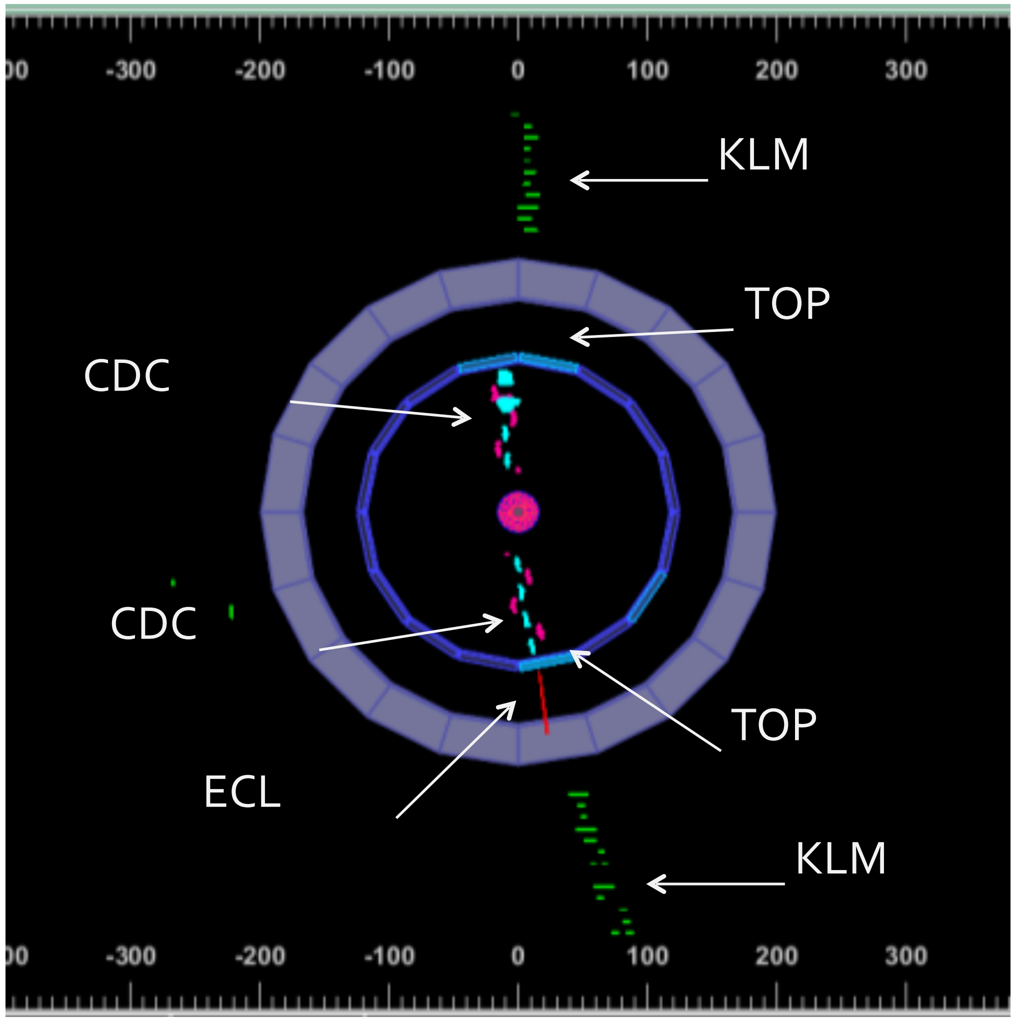
Readout Integration

- Readout integration of installed sub-detectors and central DAQ is in progress.
- Global cosmic ray runs with B=1.5 Tesla in July and August, 2017.
  - Trigger rate at ~100Hz → plan to do stress test up to 30kHz

Belle II control room



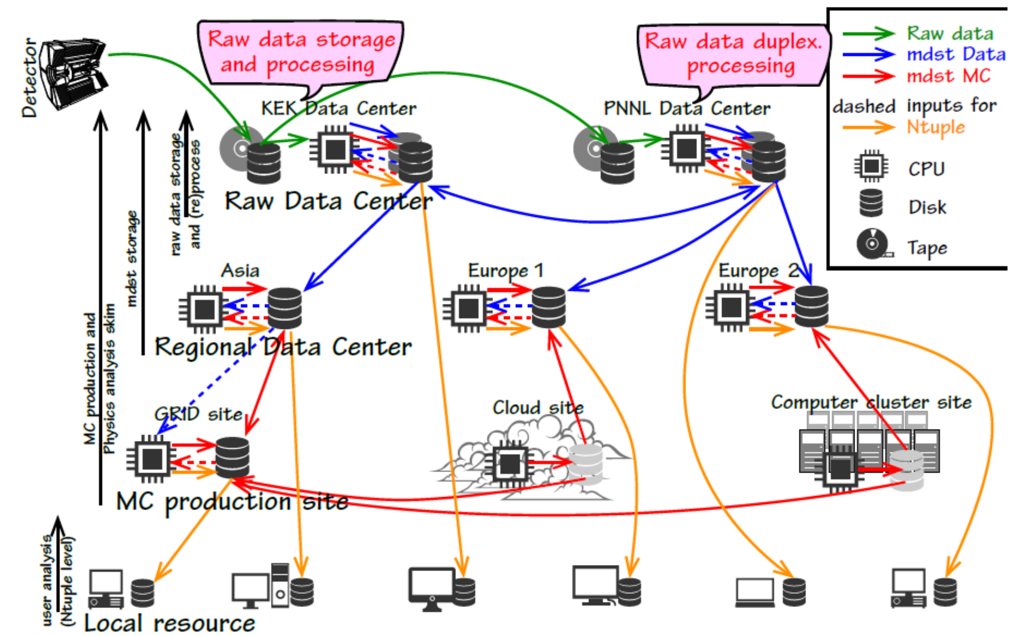
Typical cosmic ray event

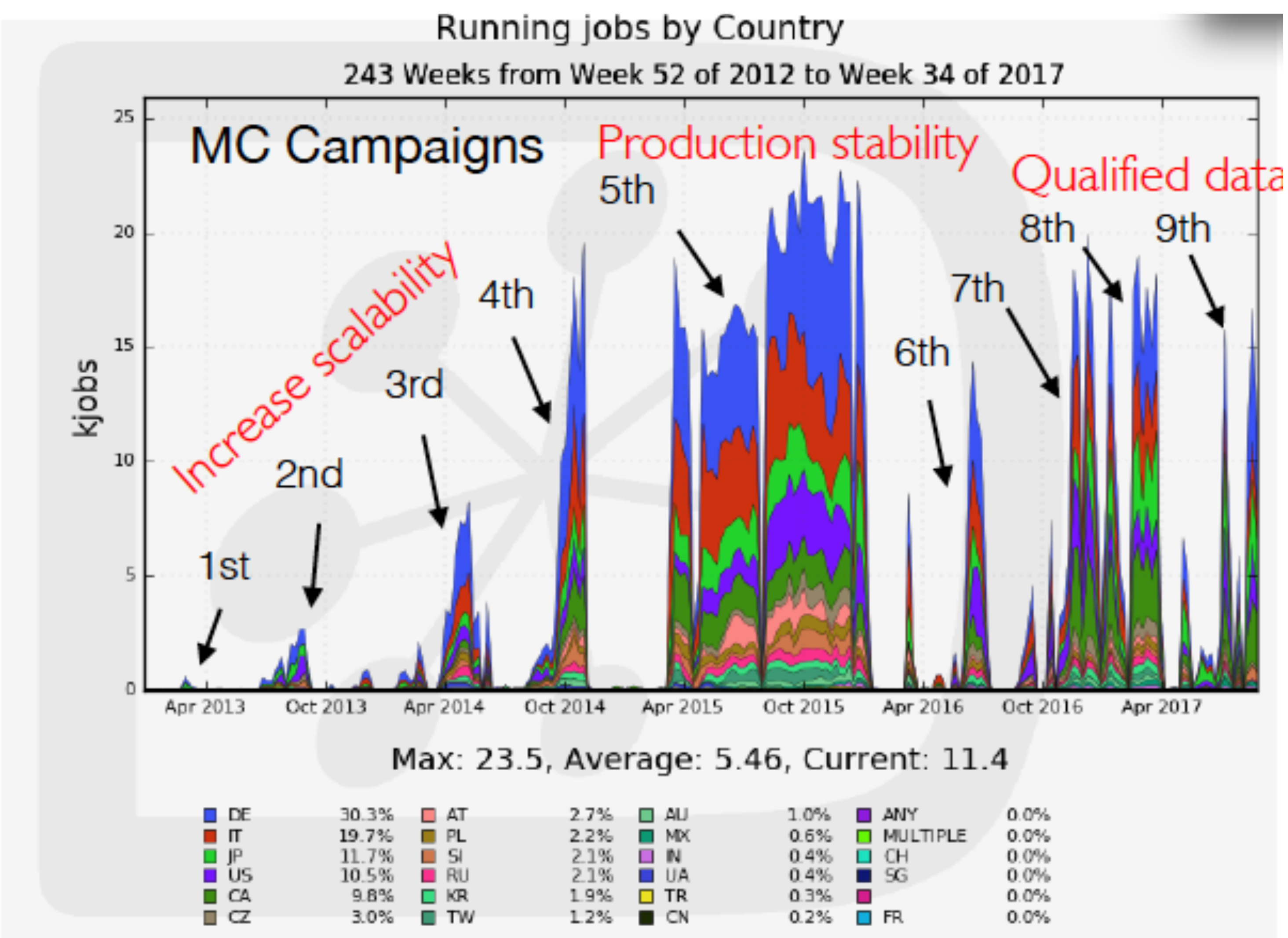


Belle II Computing

Distributed computing following the LHC model

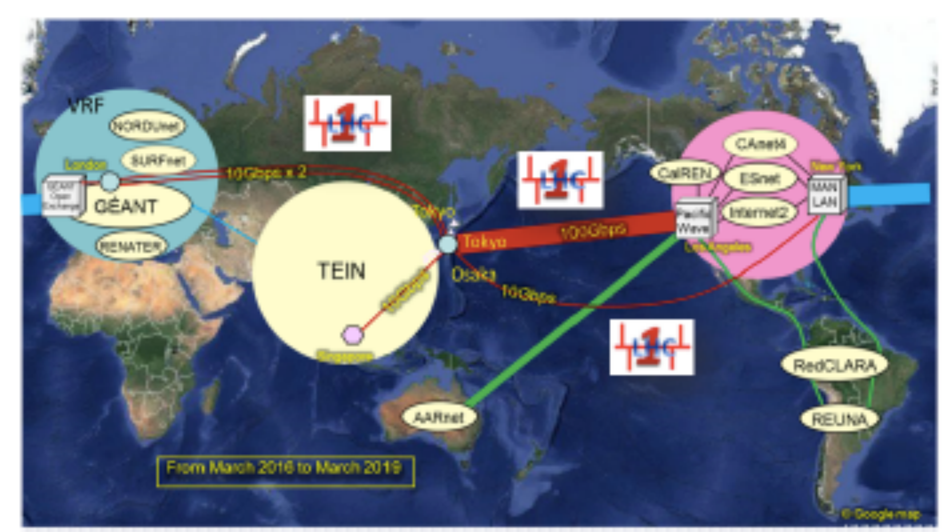
- Manage the processing of massive data sets
- Production of large MC samples
- Many concurrent user analysis jobs



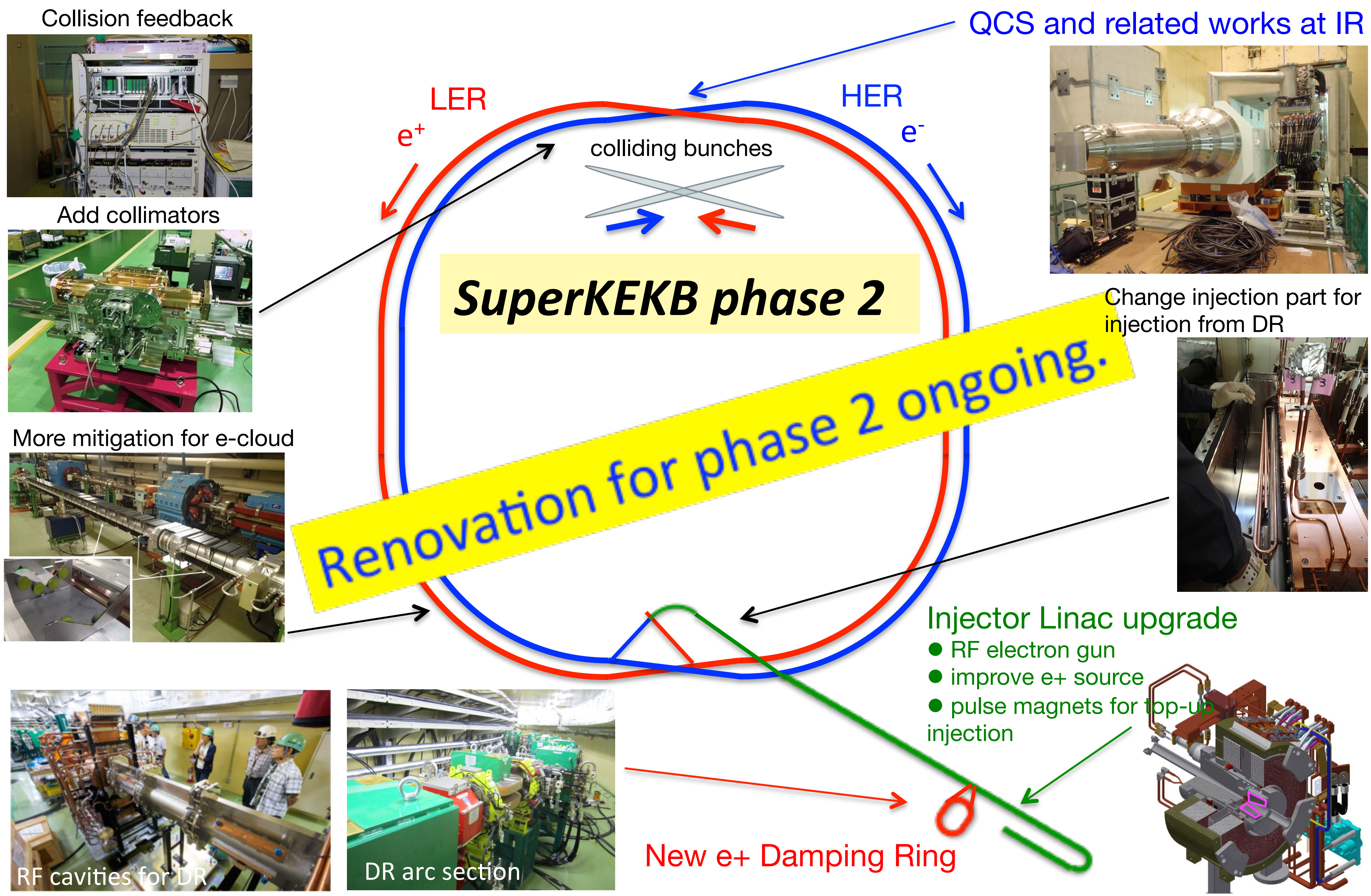


High speed networking data challenge in 2016:

- Belle II networking requirements are satisfied



Machine Preparation for Phase 2



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 $8\times10^{31}/cm^2/s/mA^2$

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

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2. Squeeze beams to achieve specific Luminosity
   $L_{sp} = L/(I_+ I_- n_b) = 2\times10^{31}/\mathrm{cm}^2/\mathrm{s}/\mathrm{mA}^2$
   cf. $L_{sp}=1.7\times10^{31}/\mathrm{cm}^2/\mathrm{s}/\mathrm{mA}^2$ @KEKB
3. Increase number of bunches (n_b) from 394 to 1576, keeping bunch current constant:
   $I_+ = 0.64\mathrm{mA}$, $I_- = 0.51\mathrm{mA}$
4. Further squeeze beam to achieve $L_{sp} = 4\times10^{31}/\mathrm{cm}^2/\mathrm{s}/\mathrm{mA}^2$, and even $8\times10^{31}/\mathrm{cm}^2/\mathrm{s}/\mathrm{mA}^2$

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 [$\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	1×10^{34} (tentative target)		2×10^{34}		4×10^{34}	
L_{sp} [$\mathrm{cm}^{-2}\mathrm{s}^{-1}/\mathrm{mA}^2$]	1.97×10^{31}		3.94×10^{31}		7.88×10^{31}	

* conserve β_y^*/ε_y

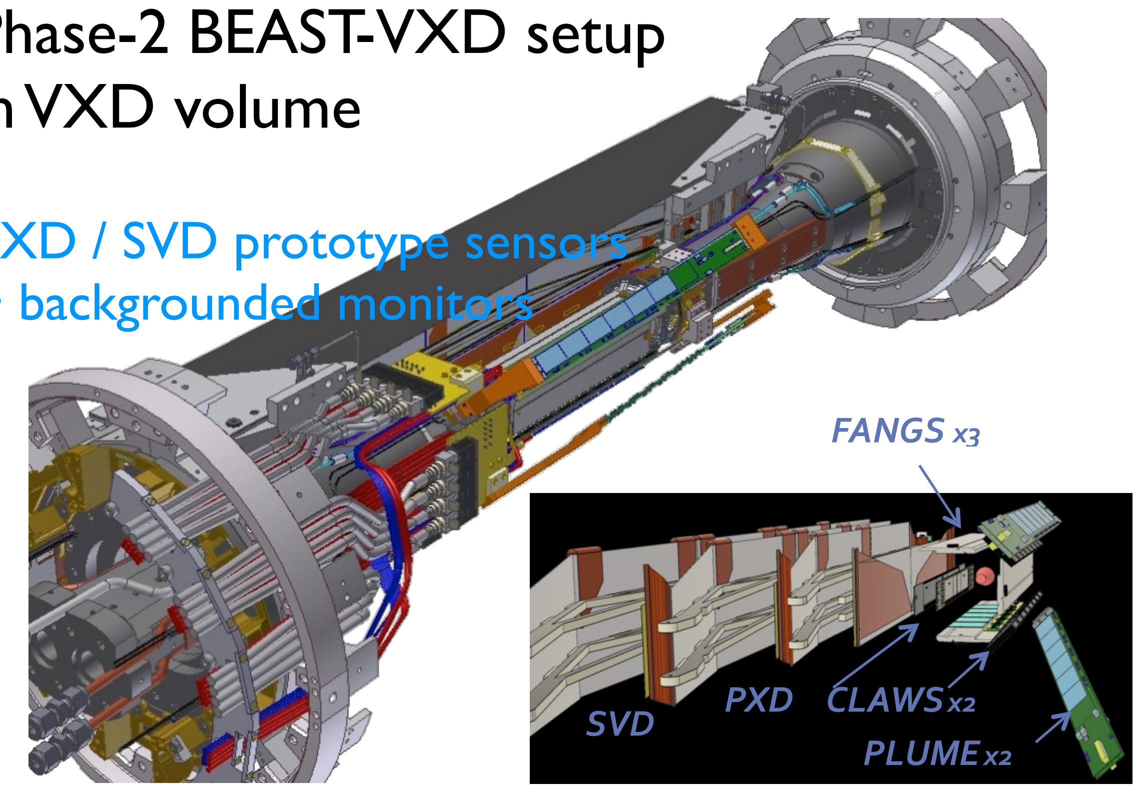
21

Beam background study

Study	Purpose
Beam-size scan	Measure Touschek BG component
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 BEAST-VXD setup in VXD volume

PXD / SVD prototype sensors
+ backgrounded monitors



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:
   $I_+ = 0.64 mA, I_- = 0.51 mA$
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

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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}	

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21

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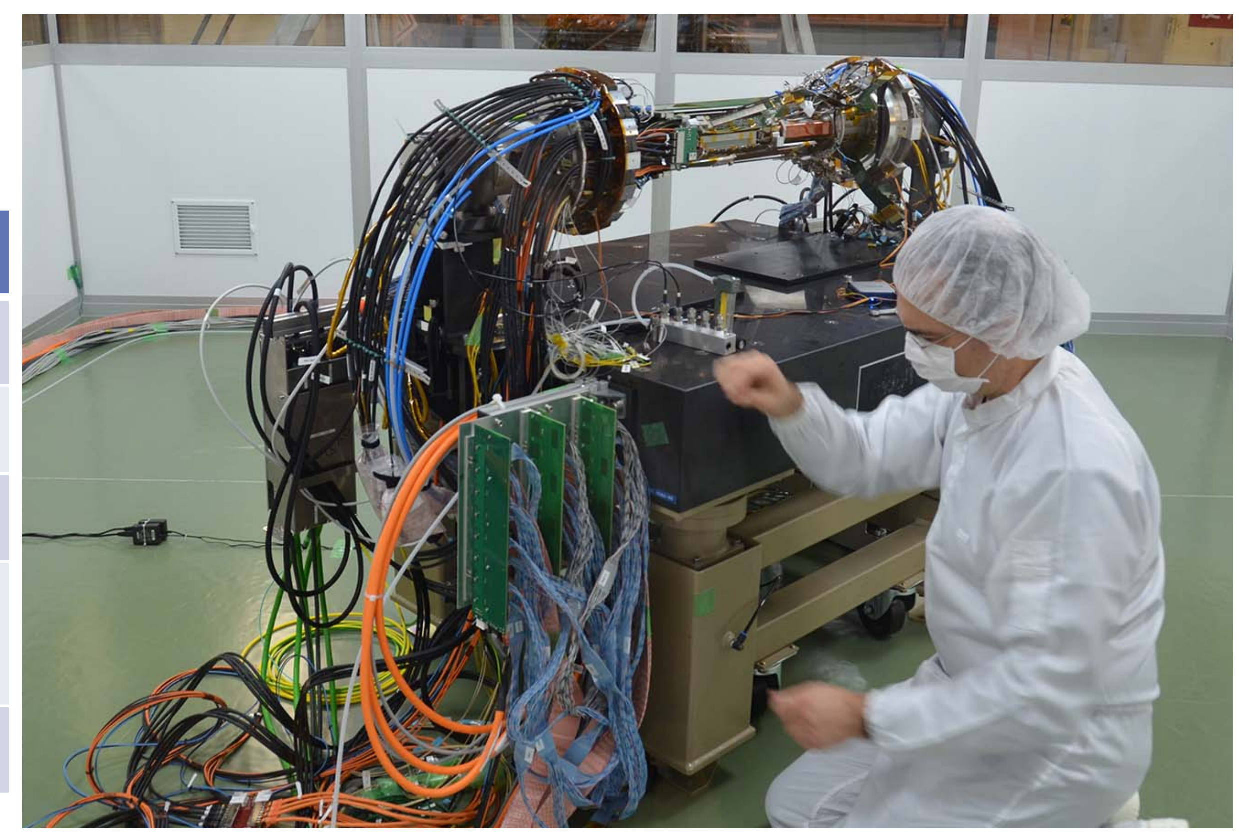


Phase 2 Physics

Plan for 4-5 months of machine studies → 1-2 months may contain useful data, w/ L ~ $1\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ → 20-40 fb^{-1}

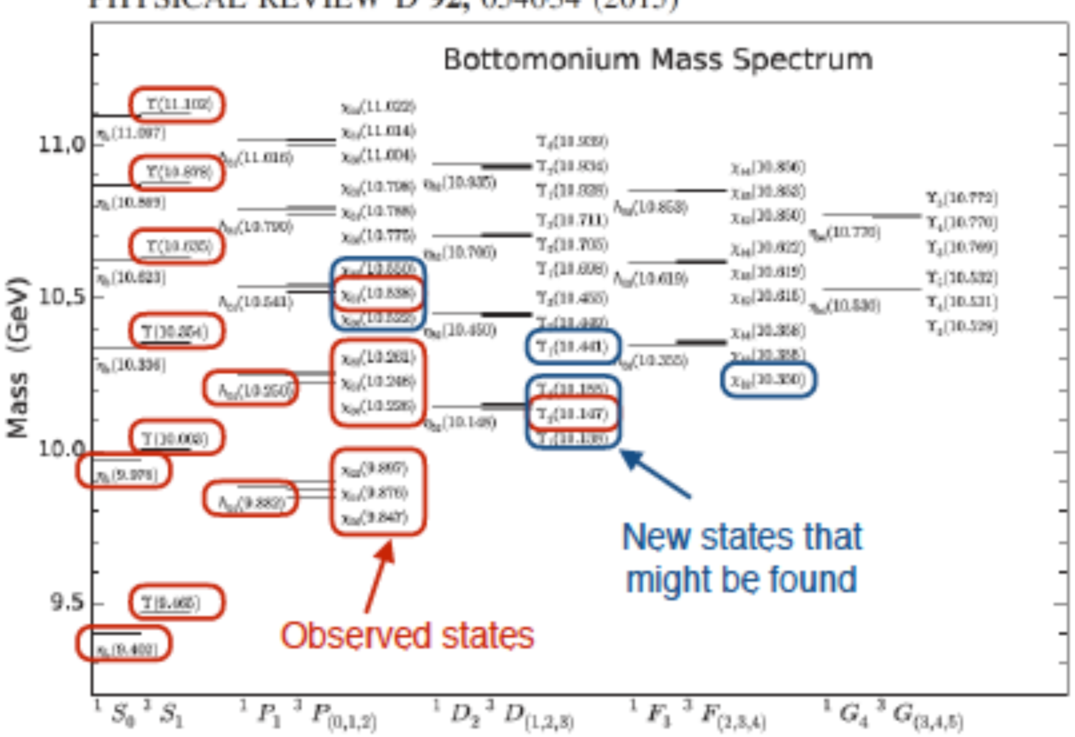
- Runs on unique E_{CM}, e.g. $\Upsilon(6S)$

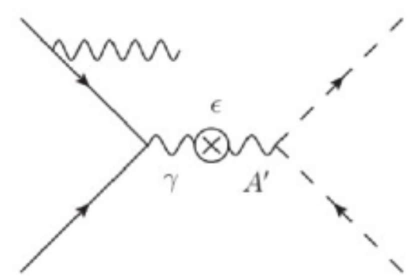
Experiment	Scans Off. Res.	$\Upsilon(6S)$ fb^{-1}	$\Upsilon(5S)$ fb^{-1}	$\Upsilon(5S)$ 10^6	$\Upsilon(4S)$ fb^{-1}	$\Upsilon(4S)$ 10^6	$\Upsilon(3S)$ fb^{-1}	$\Upsilon(3S)$ 10^6	$\Upsilon(2S)$ fb^{-1}	$\Upsilon(2S)$ 10^6	$\Upsilon(1S)$ fb^{-1}	$\Upsilon(1S)$ 10^6
CLEO	17.1	-	0.1	0.4	16	17.1	1.2	5	1.2	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

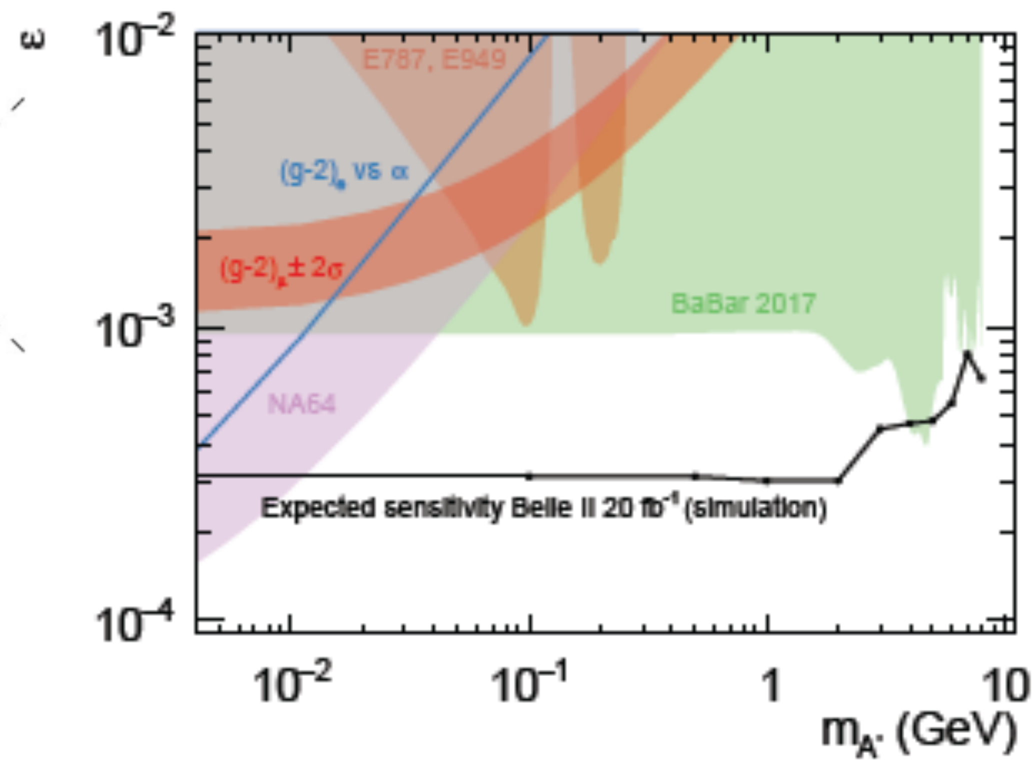
- Bottomonium (-like) physics
- Light DM search w/ 20fb^{-1}

dark photon: A' → γ + invisible

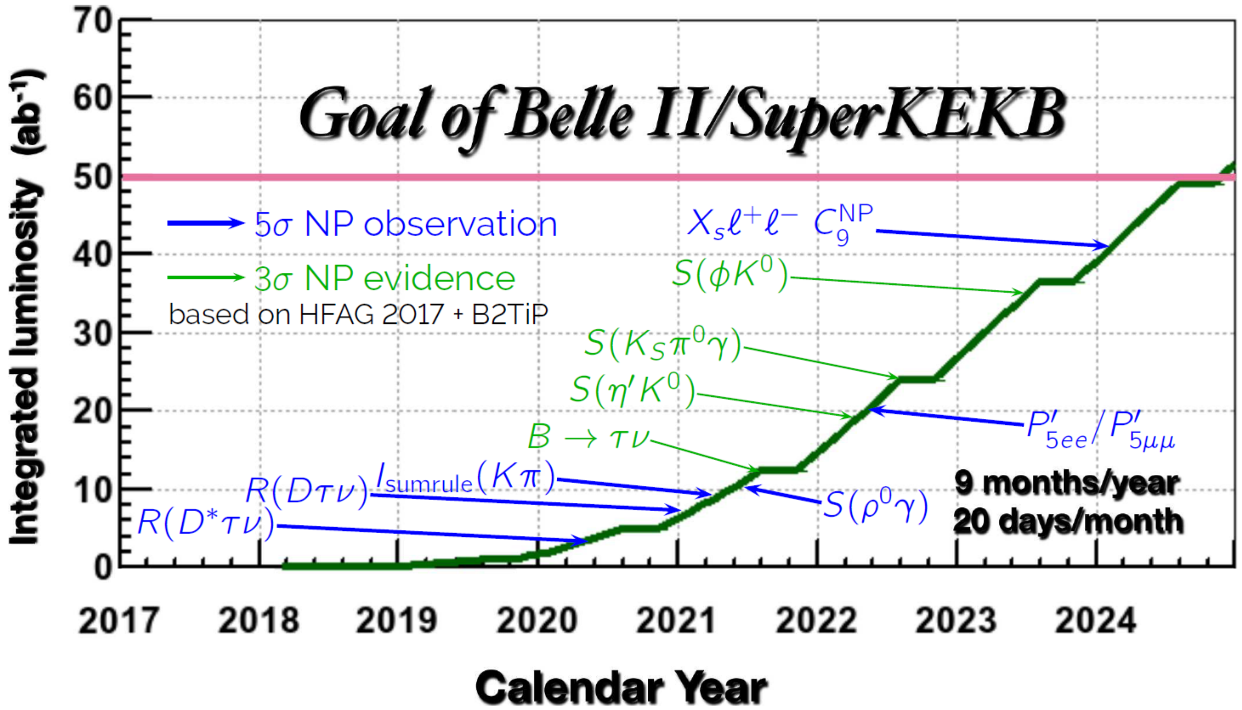
PHYSICAL REVIEW D 92, 054034 (2015)



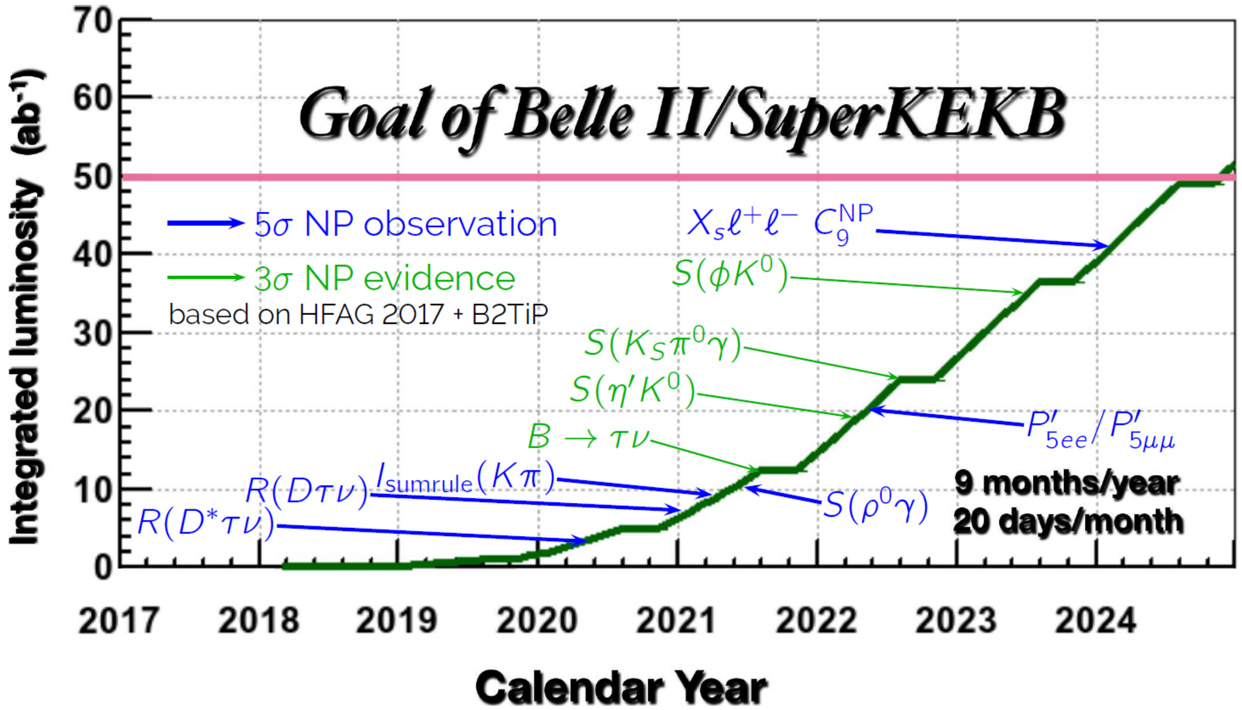


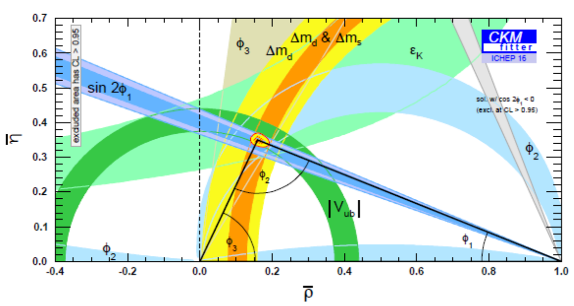


Physics Prospects (Phase 3)



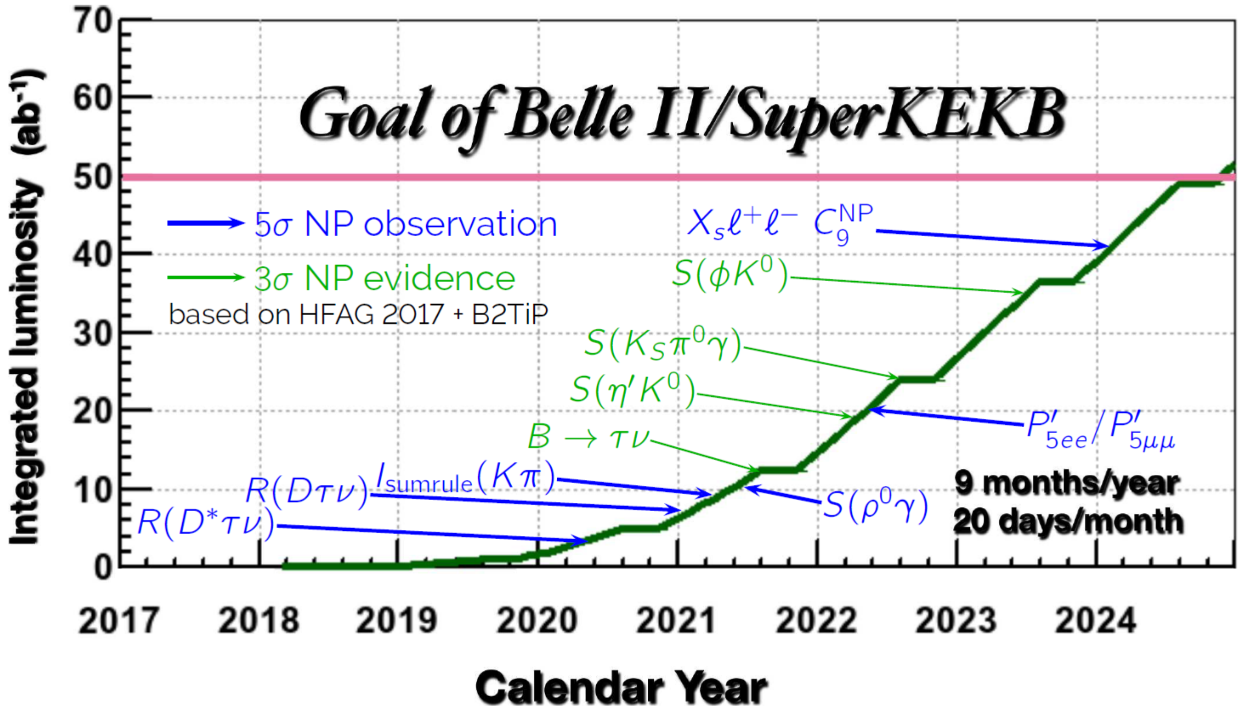
Physics Prospects (Phase 3)





CKM

Physics Prospects (Phase 3)



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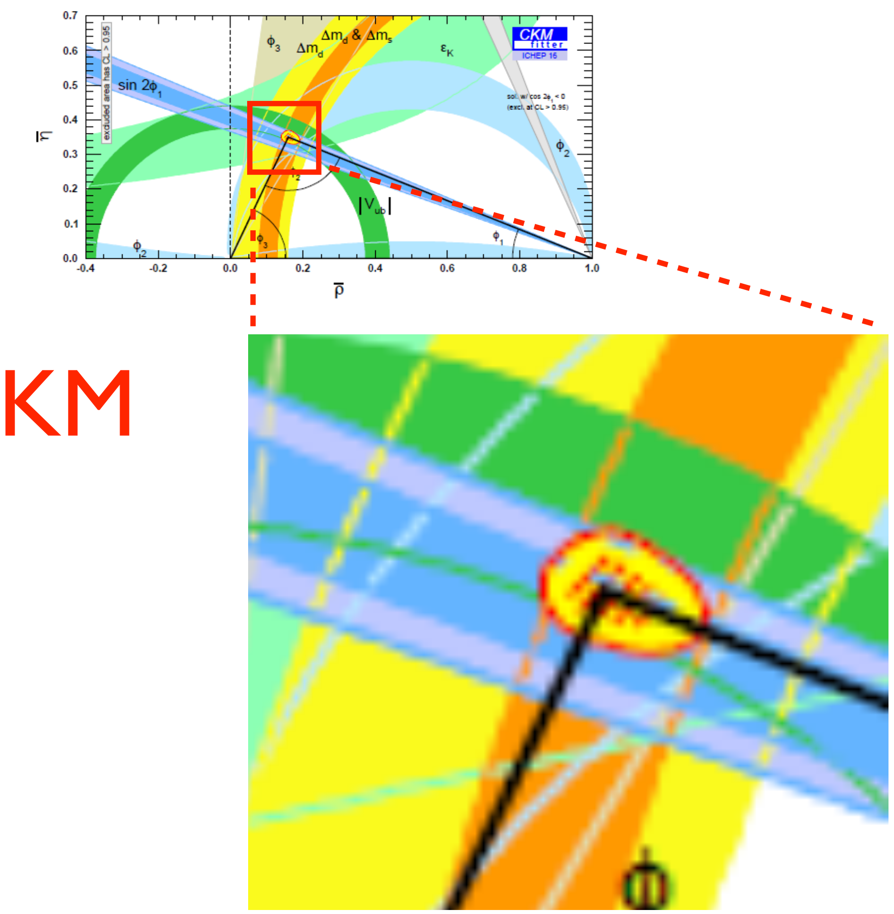
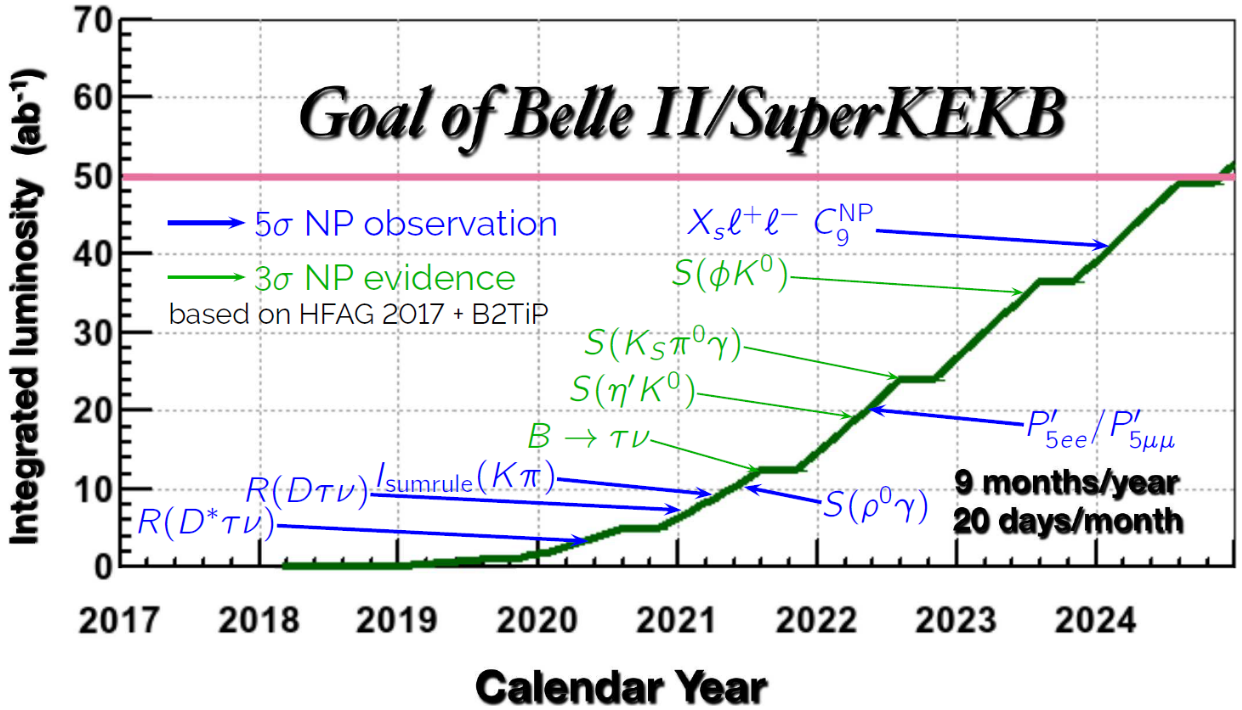


Physics Prospects (Phase 3)



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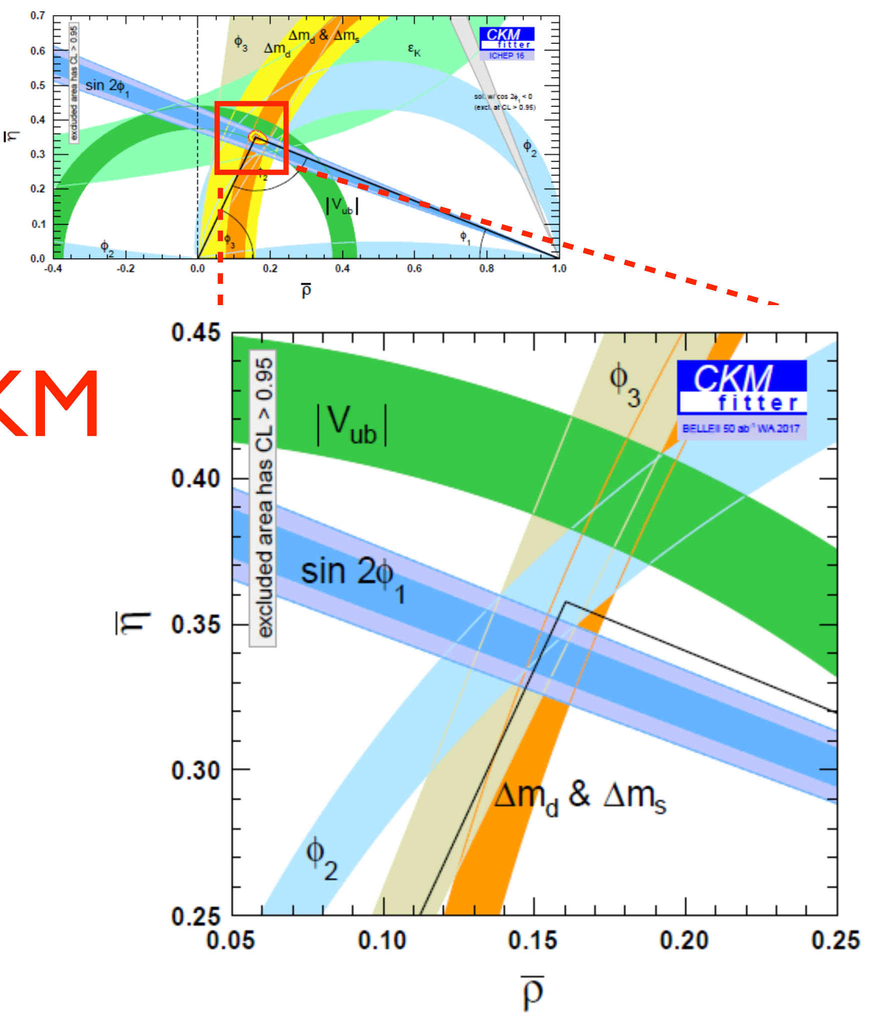
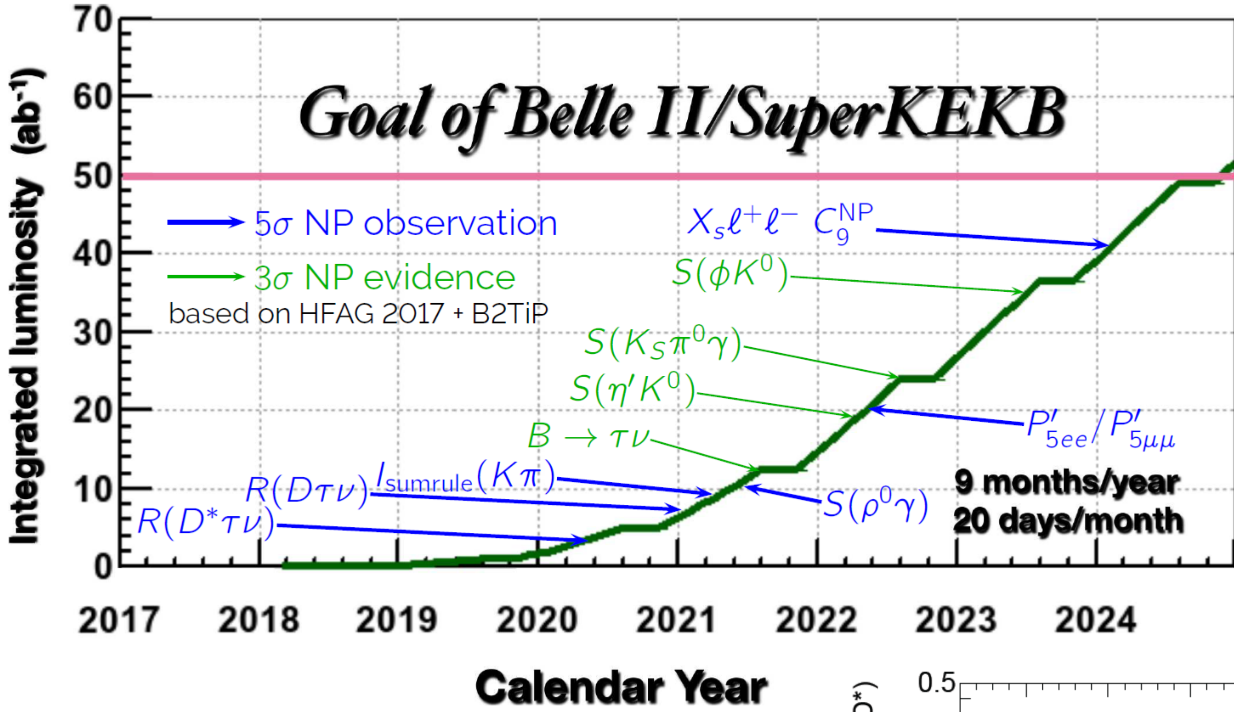


Physics Prospects (Phase 3)



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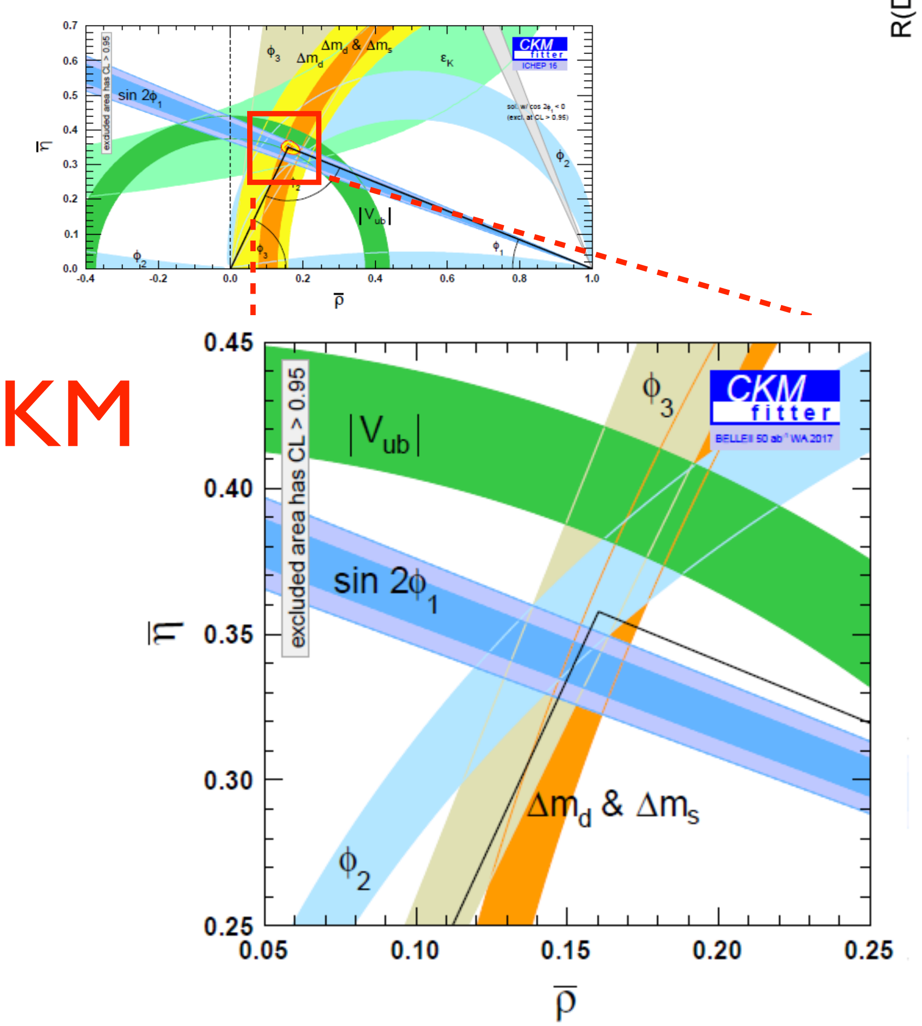
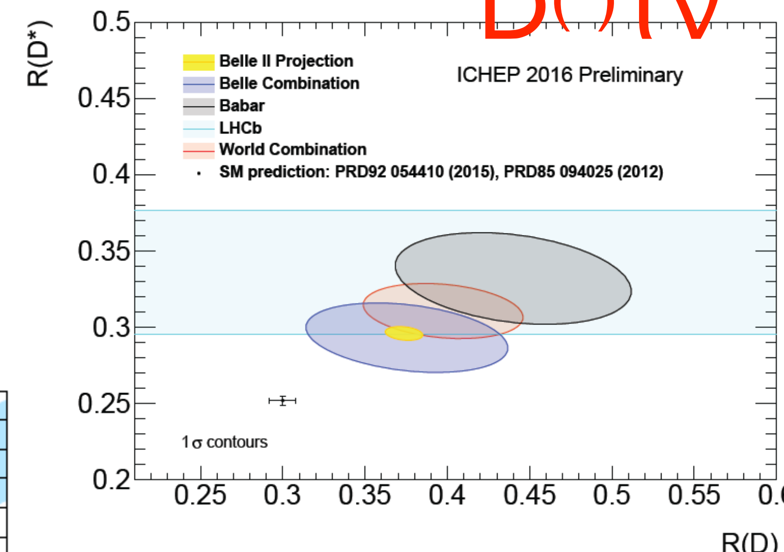
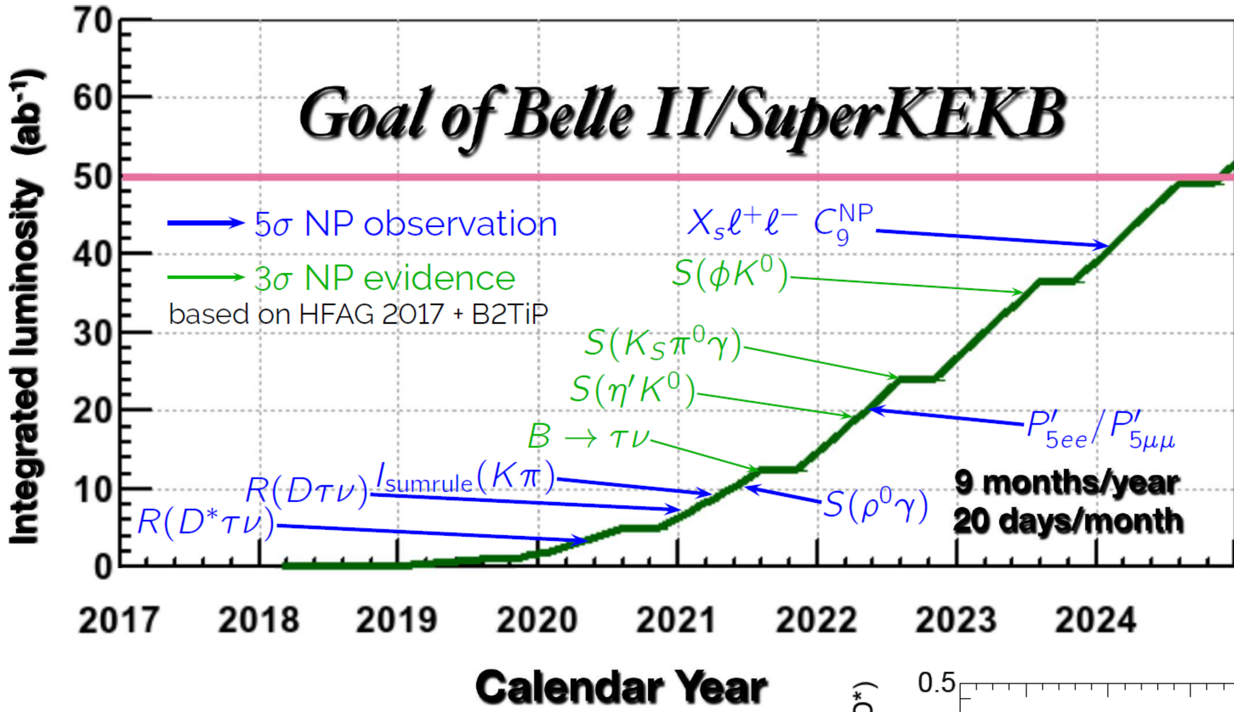


D(*)τν



Physics Prospects (Phase 3)



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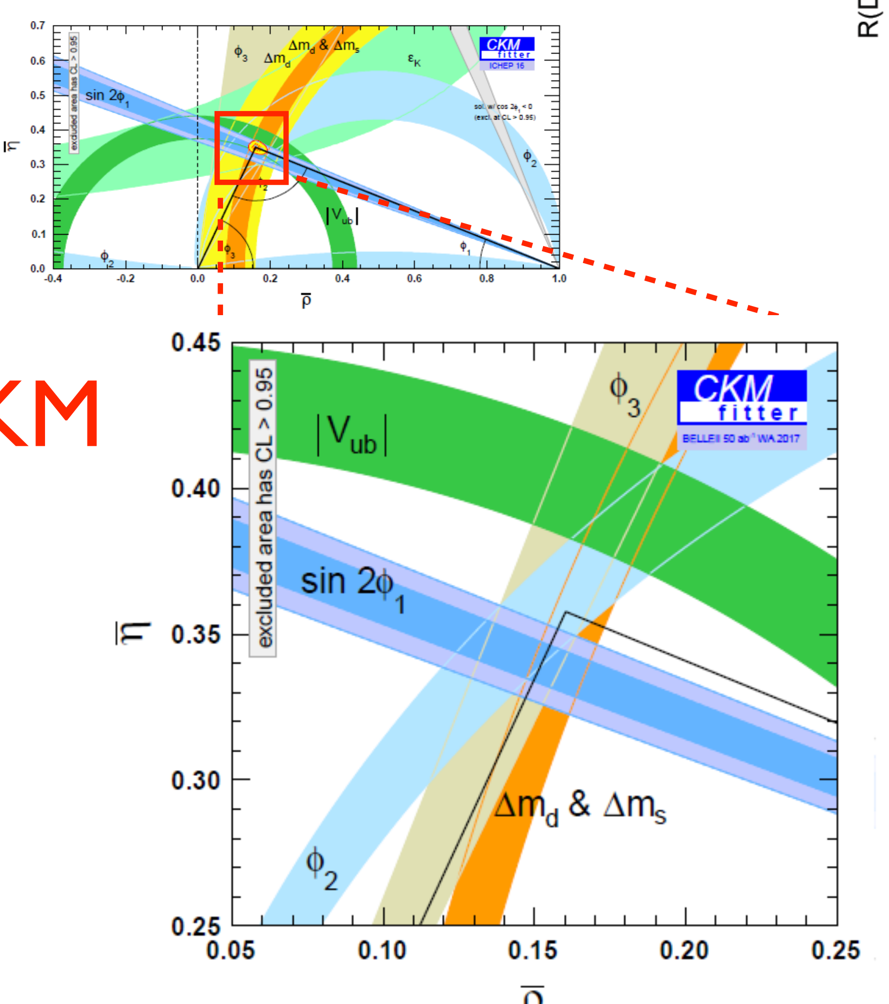
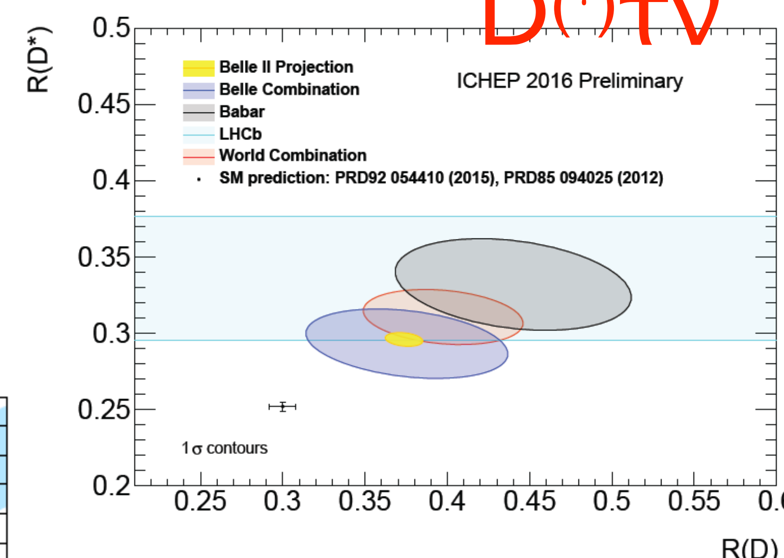


D(*)τν



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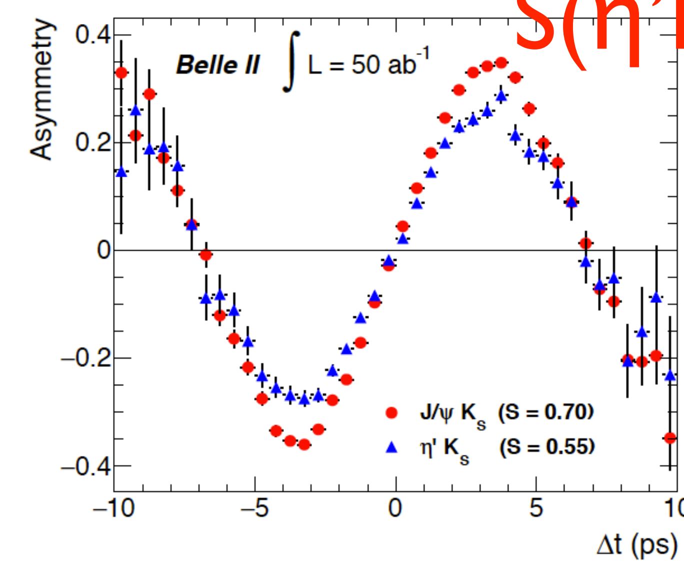
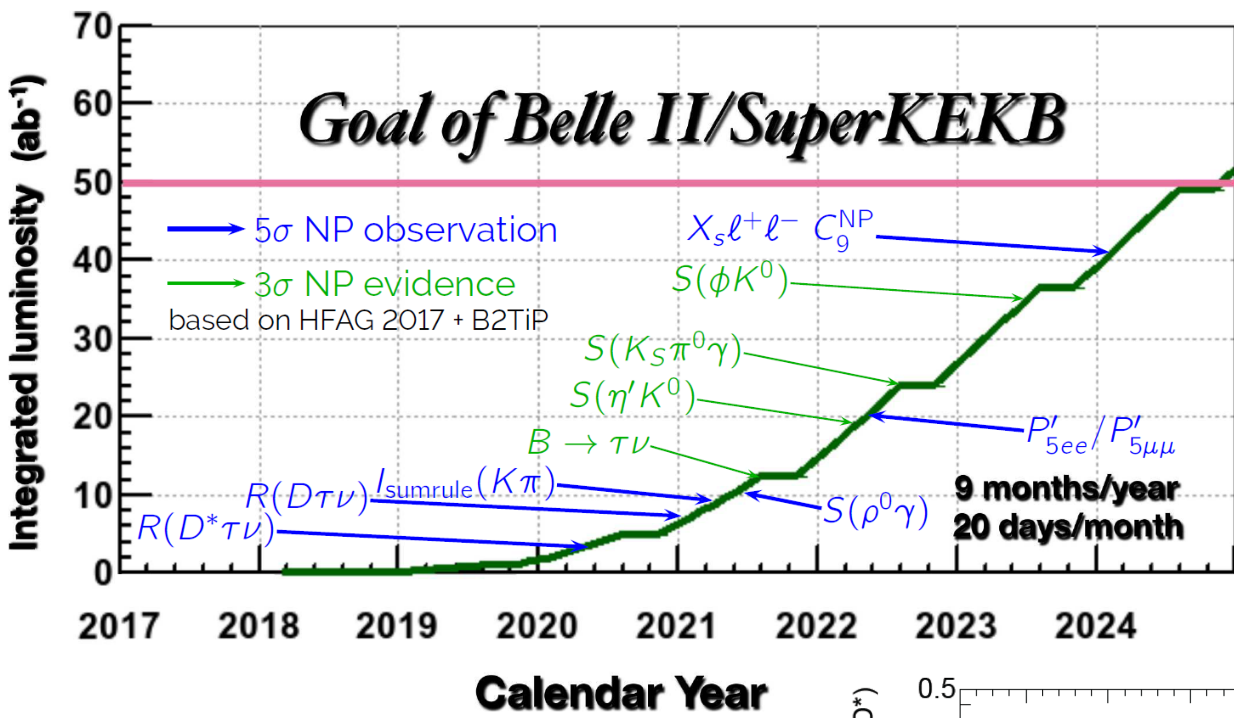
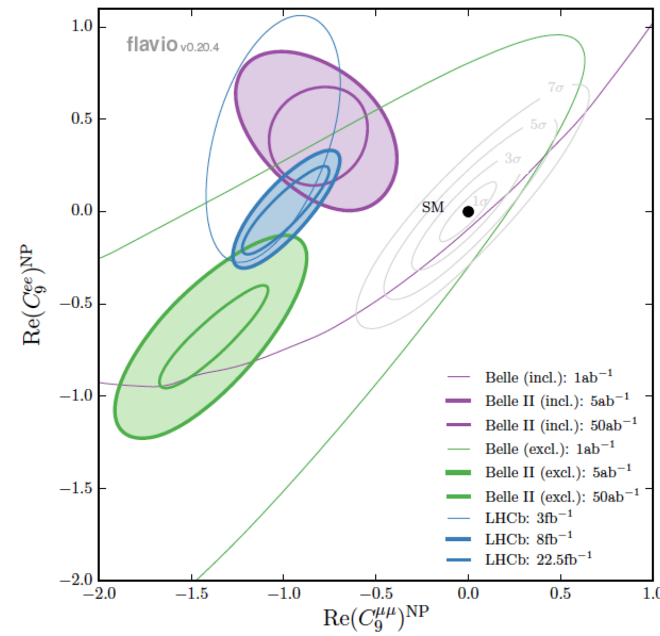


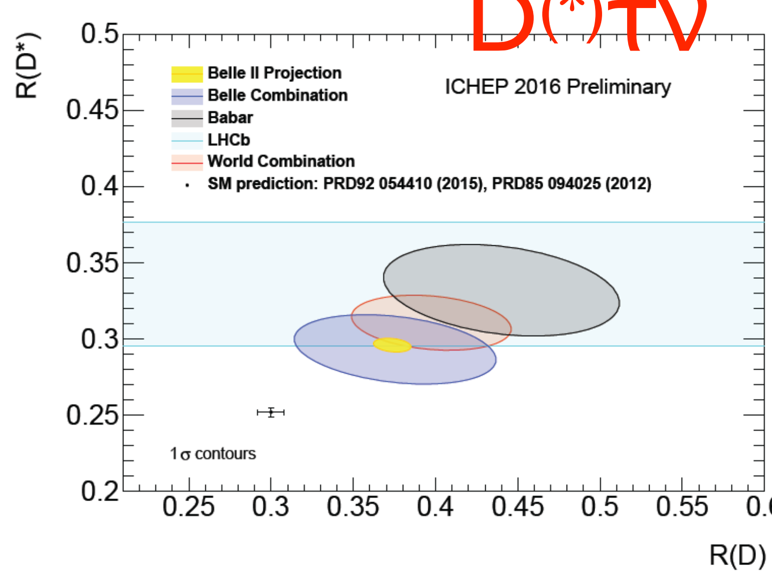
Physics Prospects (Phase 3)





K(*) ll
Xs ll

D(*)τν



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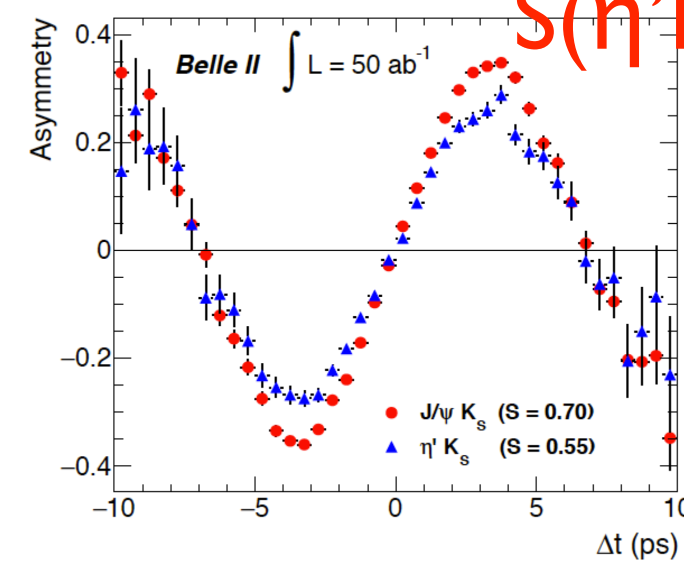

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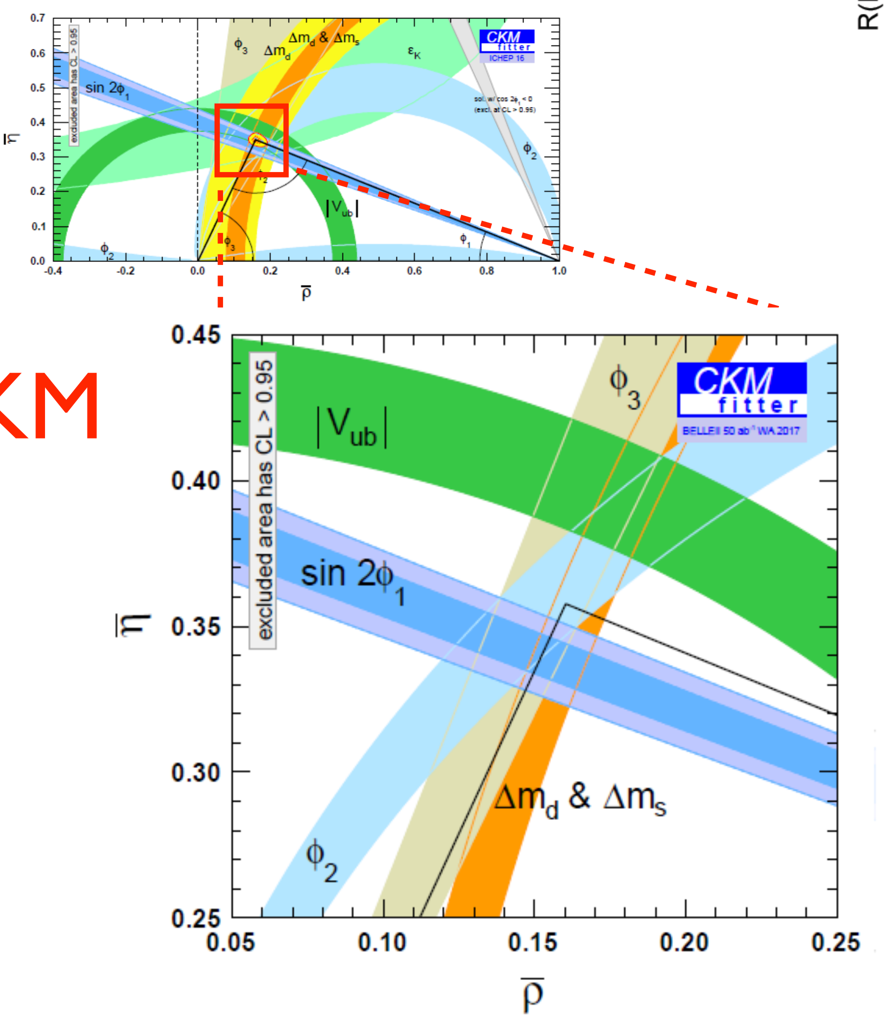

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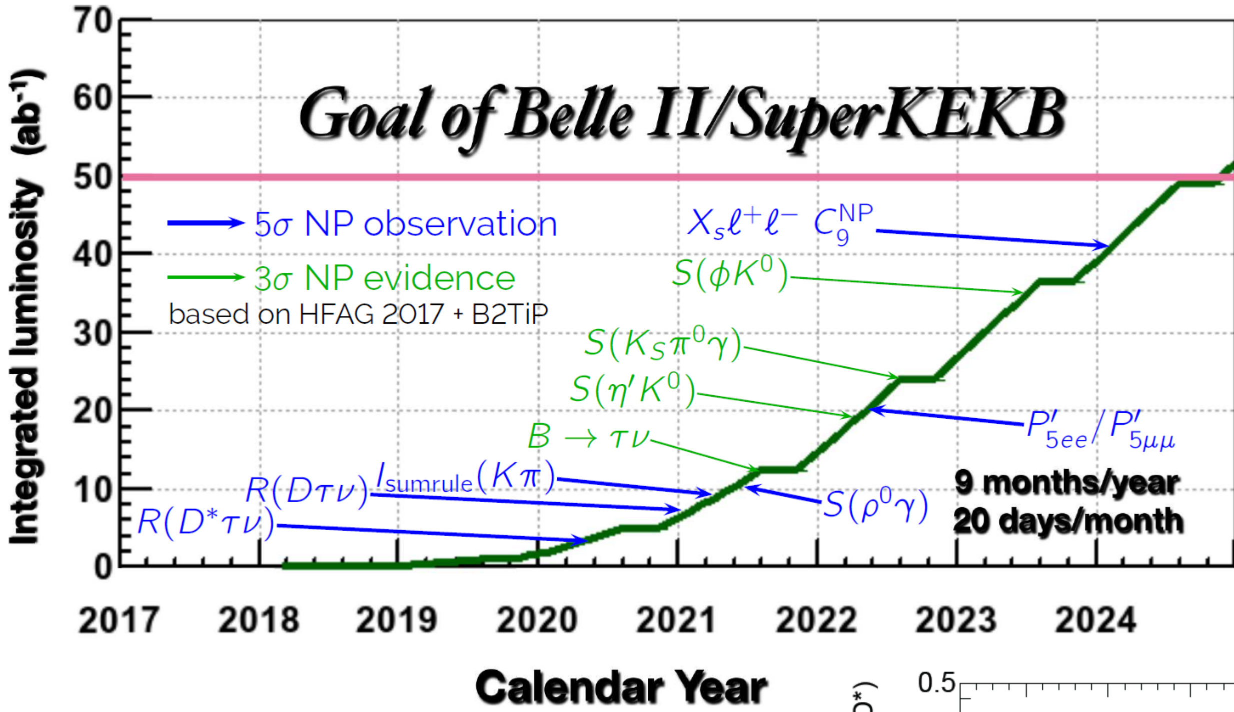
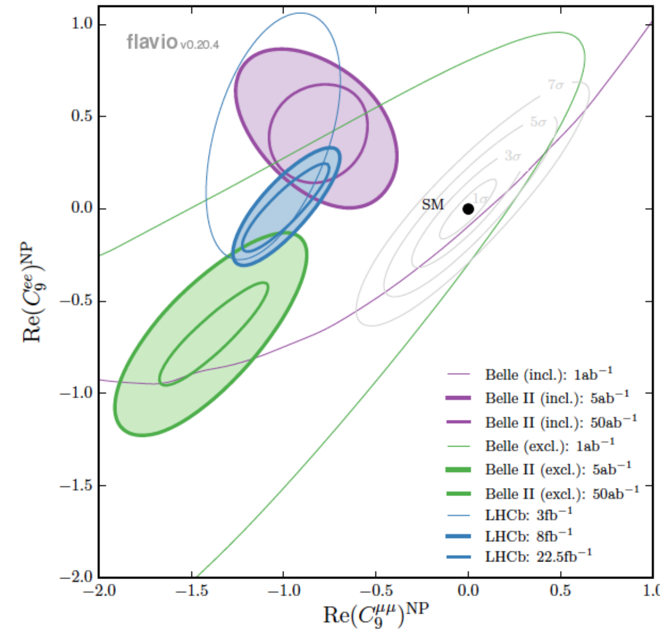
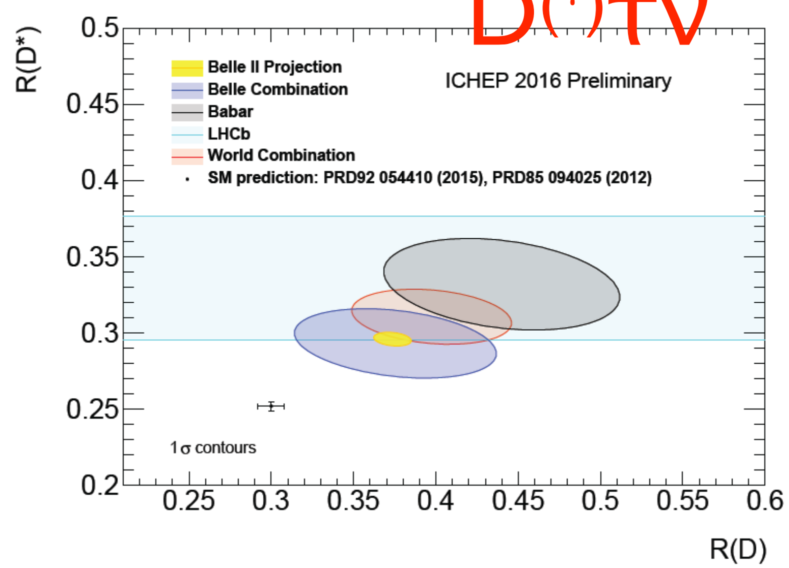




K(*) ll

Xs ll

D(*)τν



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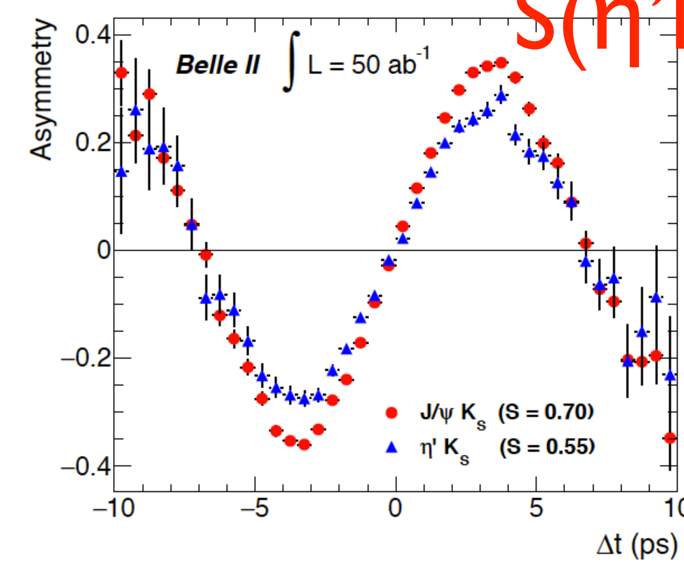

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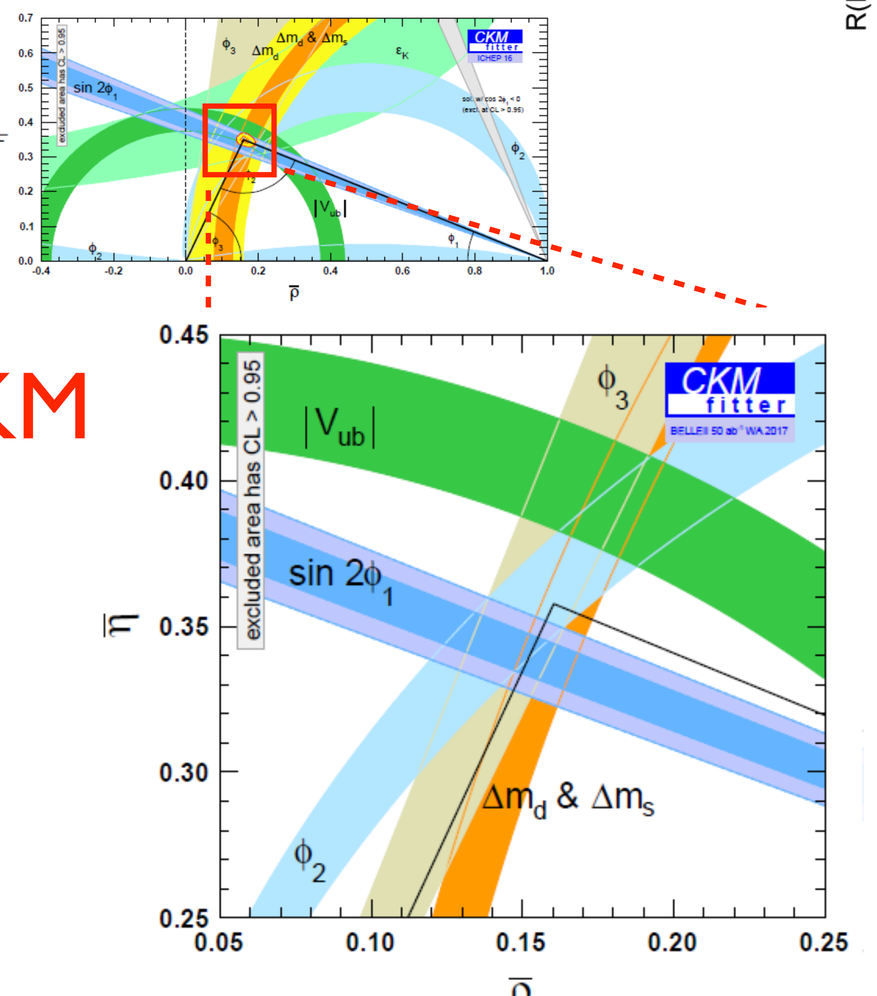
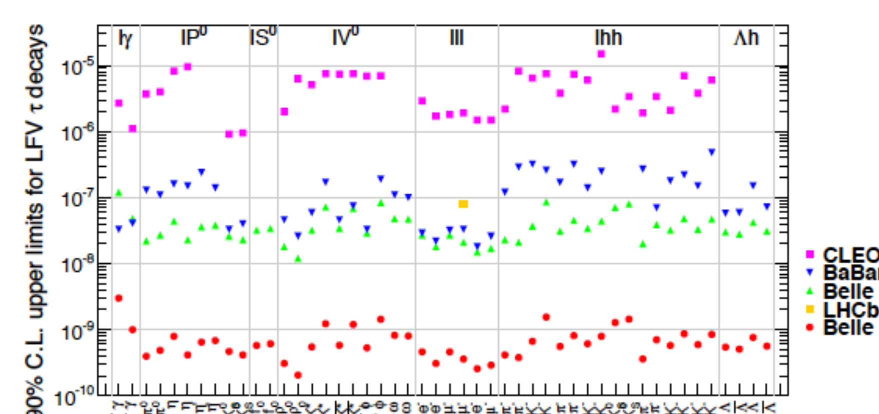


τ LFV

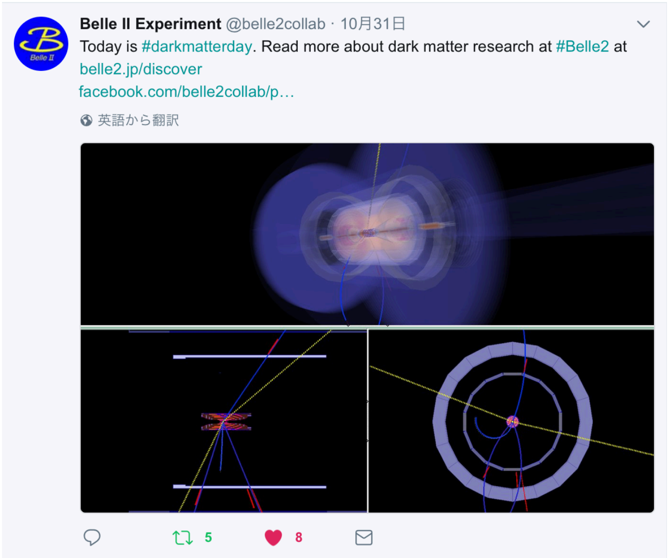


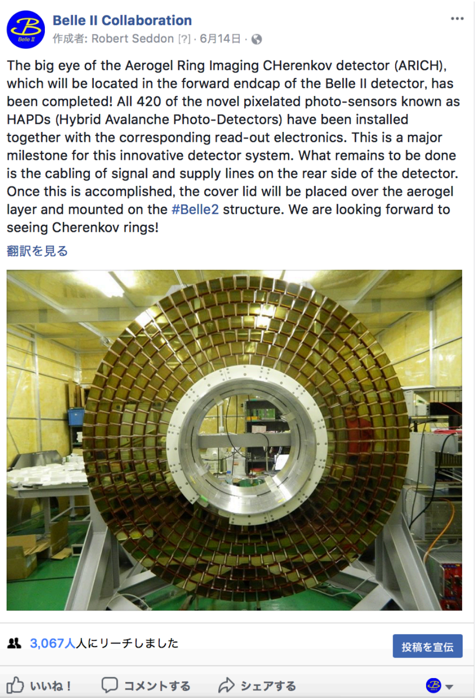
Summary

- Phase 1 commissioning in 2016 was successful.
- Phase 2 preparation in progress
  - All sub-detectors except for VXD have been installed.
  - Global cosmic ray runs with B field in Summer 2017.
  - Damping ring starts in Dec.2017, Main ring in Feb.2018.
  - Plan for background study and physics programs under discussion.
- Vertex detectors (SVD+PXD) construction in full swing. They will be installed after phase 2
- Phase 3 will start in late JFY2018.

Rich physics results will come soon !

Belle II Outreach





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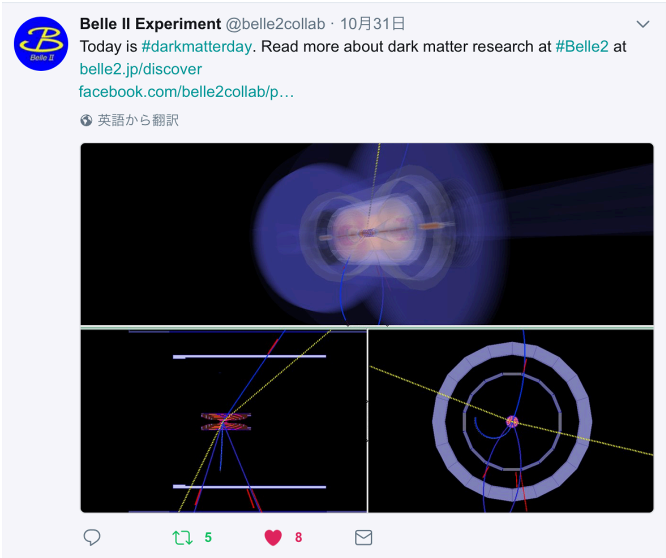
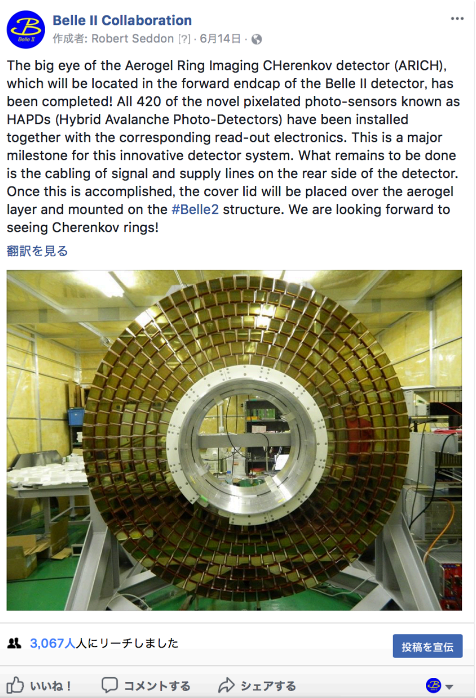
Belle II Outreach





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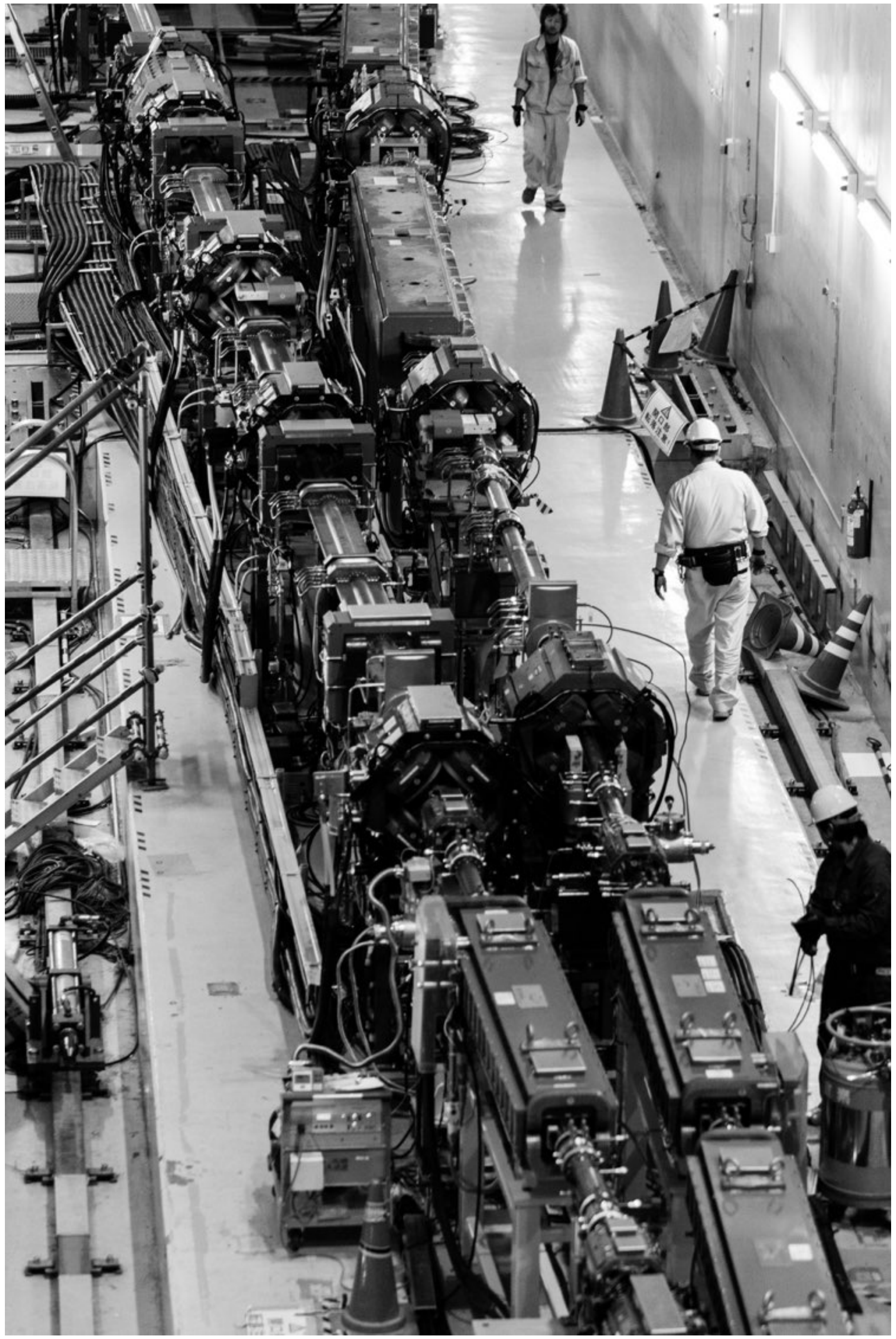
Thank you !

Backup Slides

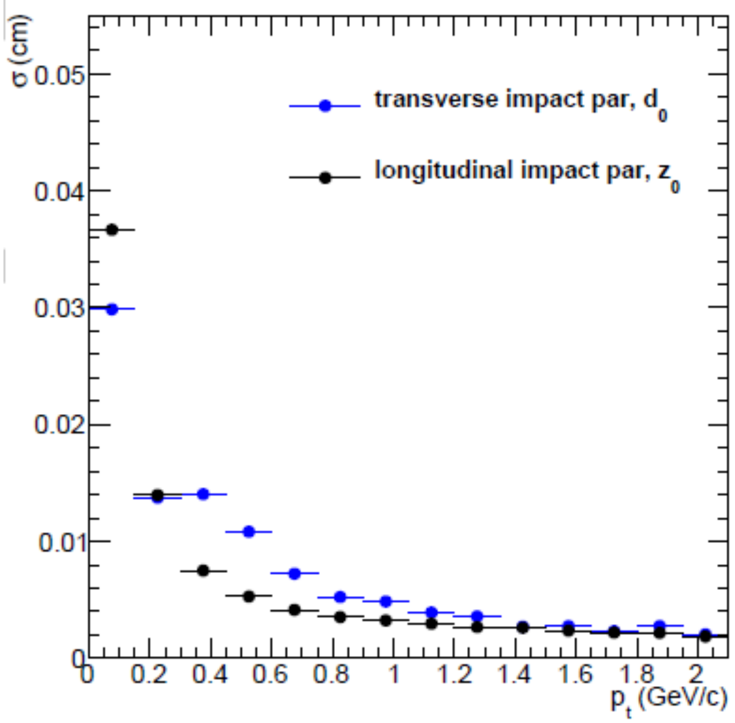


Parameter

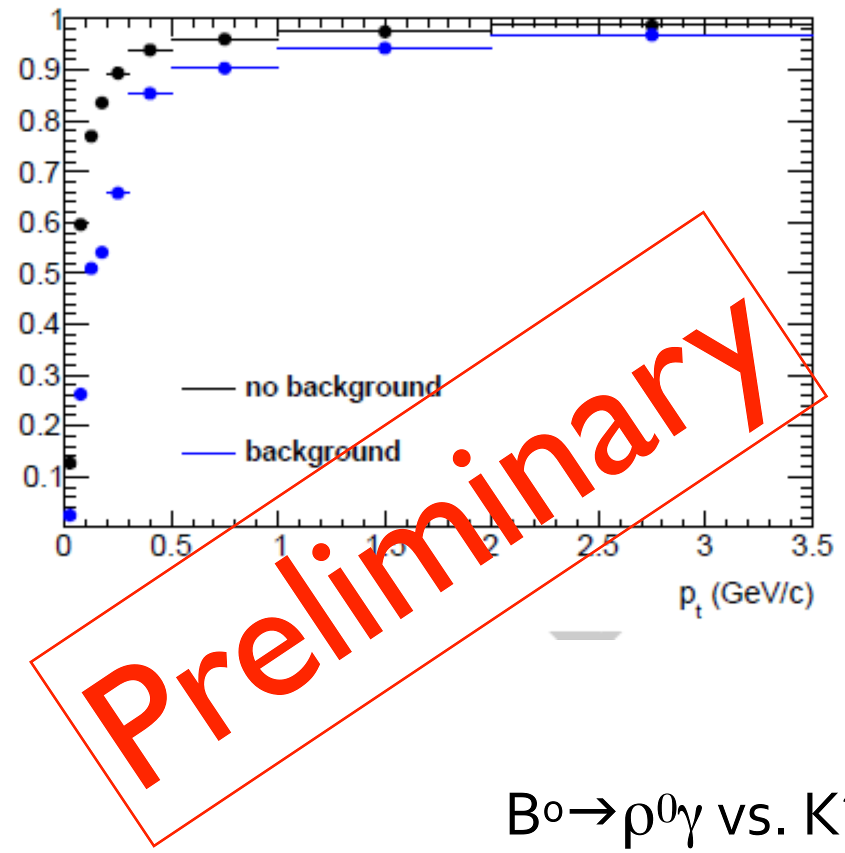
	KEKB LER /HER	Phase 1	Phase 2 4x8	Phase 3
β_x^* (mm)	1200 / 1200	/	128 / 100	32 / 25
β_y^* (mm)	5.9 / 5.9	/	2.16 / 2.4	0.27 / 0.30
ε_x (nm)	18 / 24	2.0 / 4.6	2.1 / 4.6	3.2 / 4.6
ε_y (pm) , coupling	1498 / 1598	~ 10 / -	29.4 / 64.4, 1.4% (105 / 230, 5.0%)	8.64 / 12.9 (0.27% / 0.28%)
ξ_y	0.129 / 0.090	-	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

Belle II Expected Performance

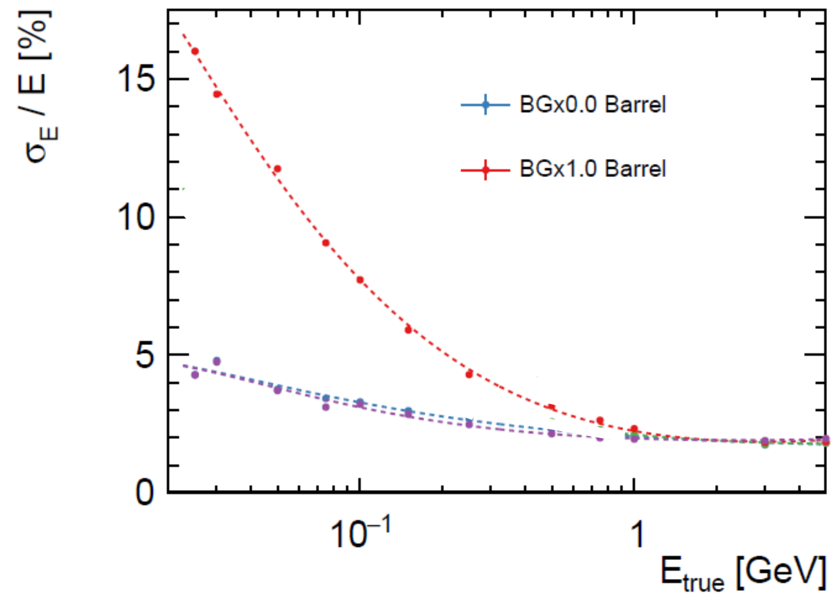
IP resolution



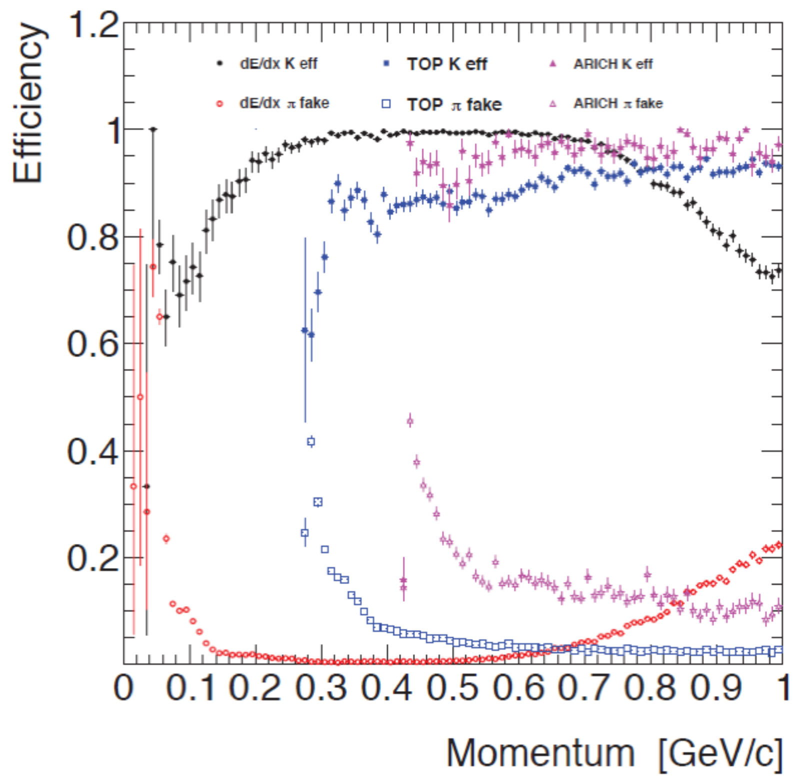
Tracking efficiency vs. p_t



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



K/π PID



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