北京航空航天大學
BEIHANG UNIVERSITY

Charm Physics Prospects at Belle II

Chengping Shen

BESIII-BELLE-LHCb粲强子物理联合研讨会

http://indico.ihep.ac.cn/event/7195/

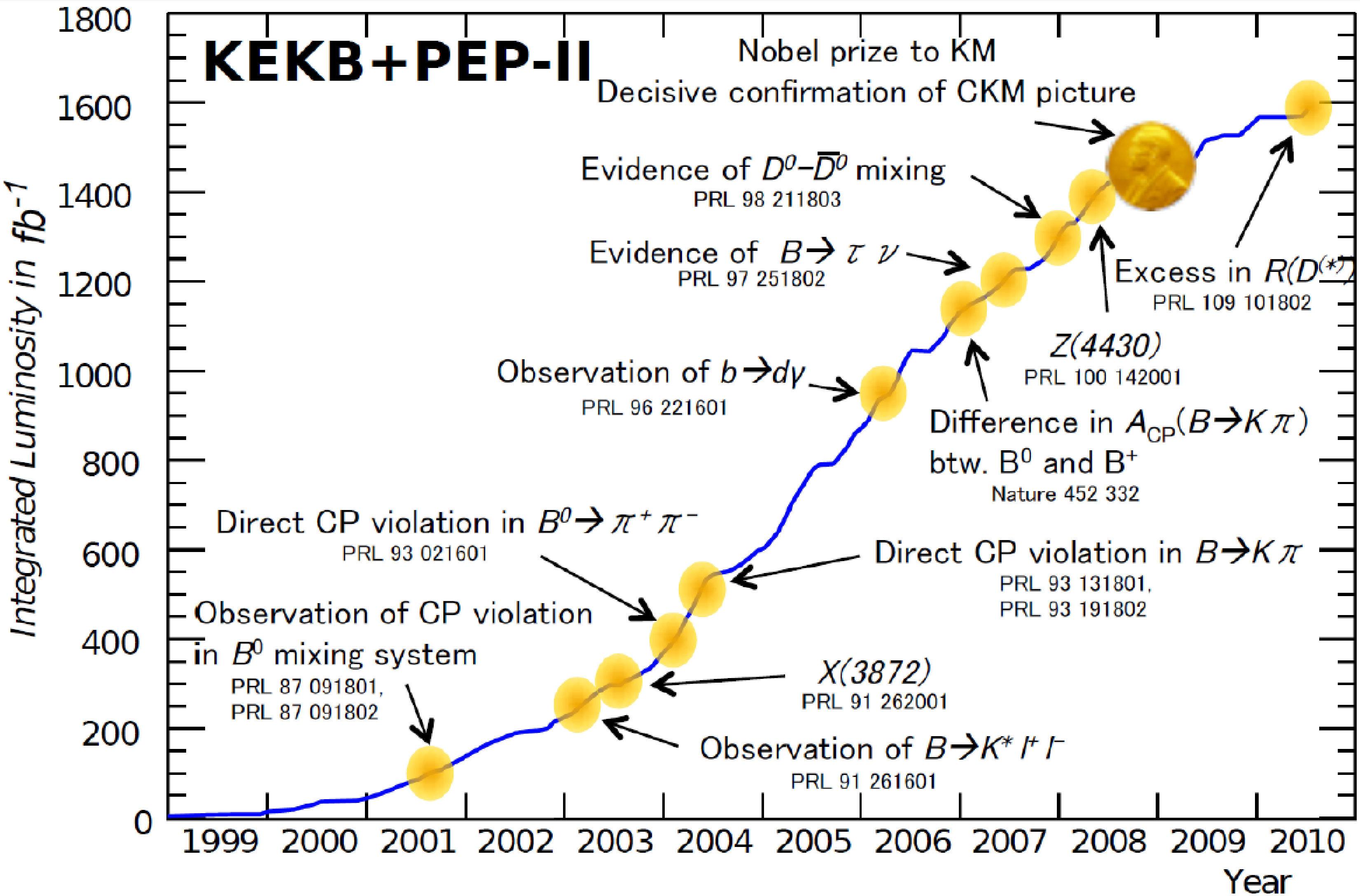
2017年9月23-24日

Outline

- The Belle II experiment
- Charm mixing and CP violation
- Leptonic charm decays
- Rare charm decays
- Summary

The Belle II experiment

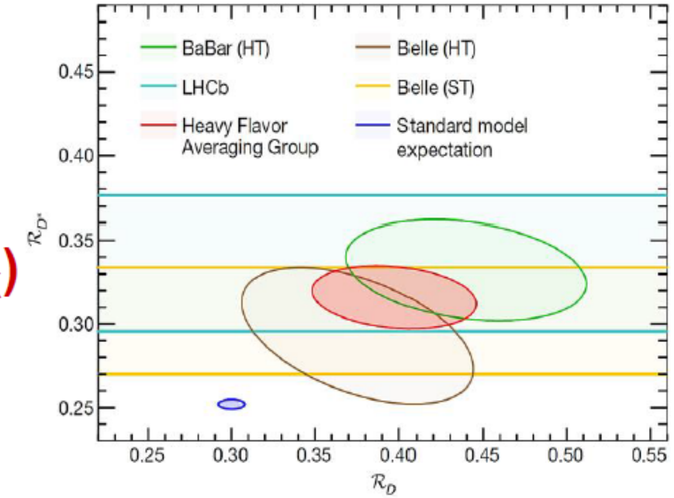
The B Factory Legacy



- Next Generation SuperKEKB+ Belle II with > 50 ab^{-1}

  ➔ Discover (or constrain) new physics!

Physics at Belle II



- Good chance to see/confirm new phenomena:
  - **CPV from the new physics (non KM).**
  - **lepton universality in B decays (R_D, R_{D^*}, R_K)**
  - **$B \rightarrow \tau\nu$ to probe charged Higgs.**
  - **Lepton flavor violations in τ decays.**
- Will help to diagnose (if found) or constrain (if not found) NP.
- **Physics motivation independent of LHC.**
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the >TeV scale physics.
- Many more topics: CPV in charm, new hadrons, …

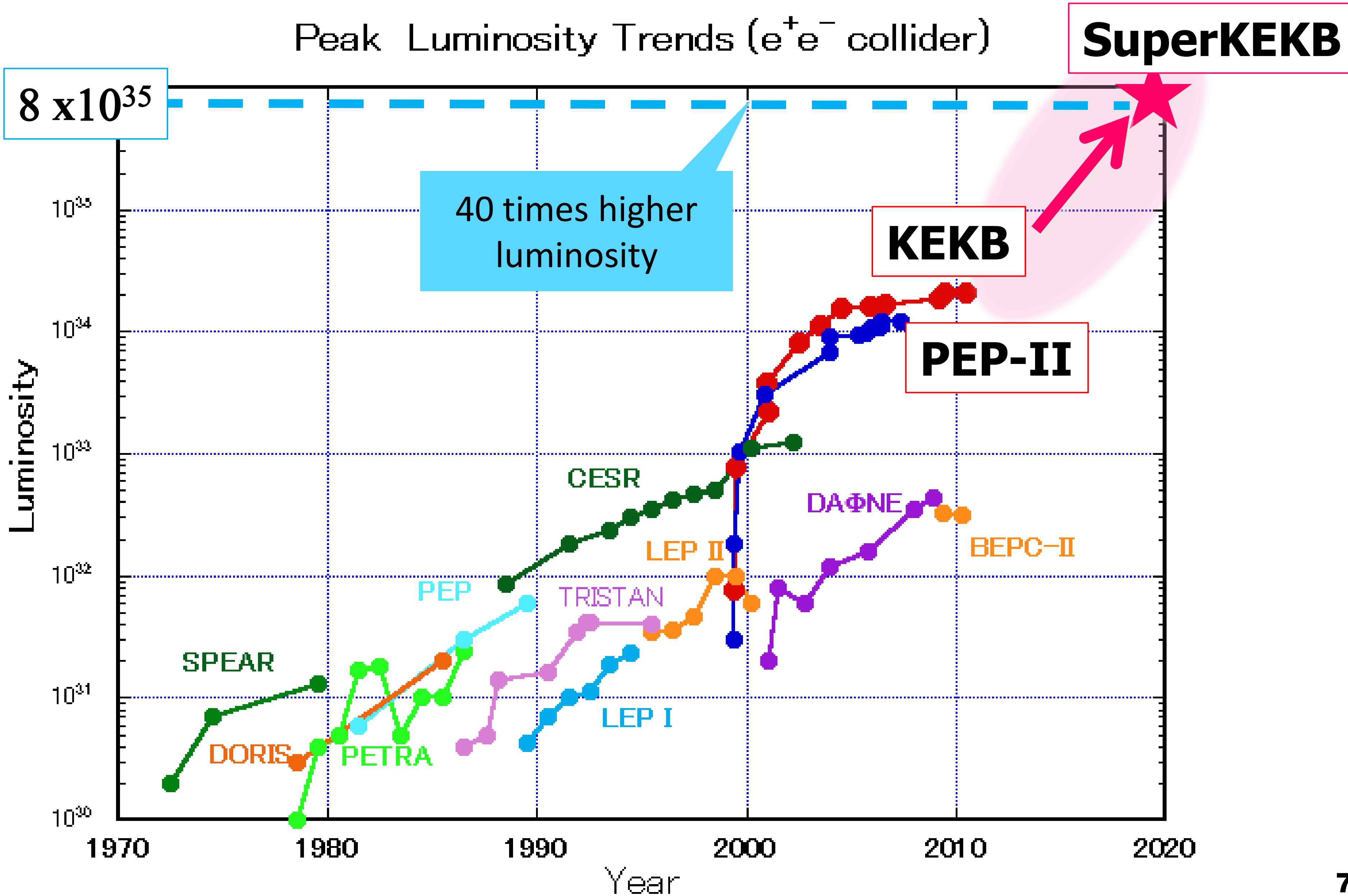
Physics reach with 50 ab^{-1} (75 ab^{-1}):

1. Physics at Super B Factory (Belle II authors + guests) > arXiv:1002.5012
2. SuperB Progress Reports: Physics (SuperB authors + guests) > arXiv:1008.1541
3. B2TIP report: confluence.desy.de/display/BI/B2TiP+WebHome: > PTEP soon

5


WE NEED
YOU
Belle II
Belle II

Need O(100x) more data →Next generation B-factories



High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathscr{L} = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$ (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

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

Lorentz factor; beam current; beam-beam parameter; geometrical reduction factors; beam aspect ratio at the IP; vertical beta-function at the IP

parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1x10		8×10^{35}		$\mathrm{cm^{-2}s^{-1}}$

High-Luminosity Asymmetric B Factory

- ➡ Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- ➡ Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @

Lorentz factor

beam

beam-beam

beam aspect

at the IP

vertical beta-function at the IP

reduced CM boost

- reduced vertex separation, Δt resolution
- increased detector hermeticity

squeezed beams @ IP

- greatly improved constraint for decay chain vertex fitting

paramet				SuperKEK		units
		LER	H	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	βγ	0.425		0.28		
h				41.5		mrad
ho			24	3.2	4.6	nm
			0.66	37	0.40	%
b			5.9	32/0.27	25/0.30	mm
			1.19	3.6	2.6	A
bea			90	0.0881	0.0807	
			2	10/0.059		μm
			0	8x10^{35}		cm^{-2}s^{-1}

x40 luminosity

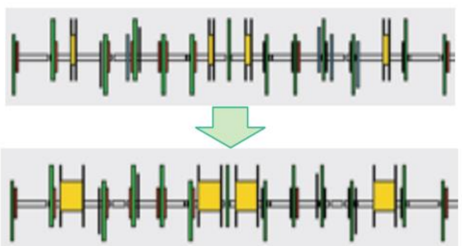
- higher background rates (~10-20x)
  - detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- x40 produced signal events

SuperKEKB Status

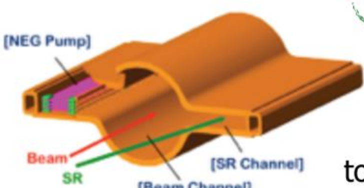
Longer LER dipoles magnets installed

increase wiggler cycles

Redesign the lattices of HER & LER to squeeze the emittance

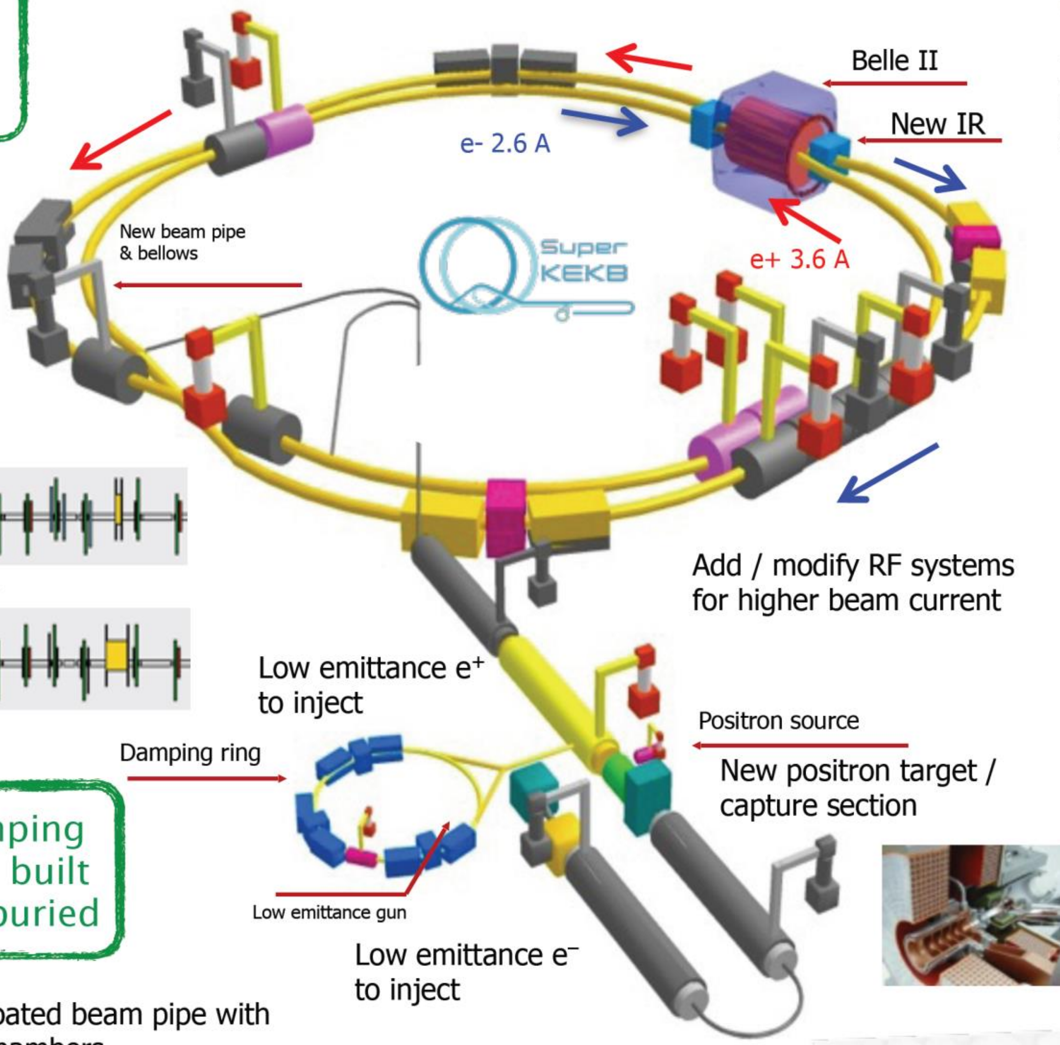


Damping Ring built and buried



TiN-coated beam pipe with antechambers

to reduce Synchrotron radiation

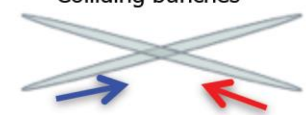


Add / modify RF systems for higher beam current

Low emittance e^+ to inject

New positron target / capture section

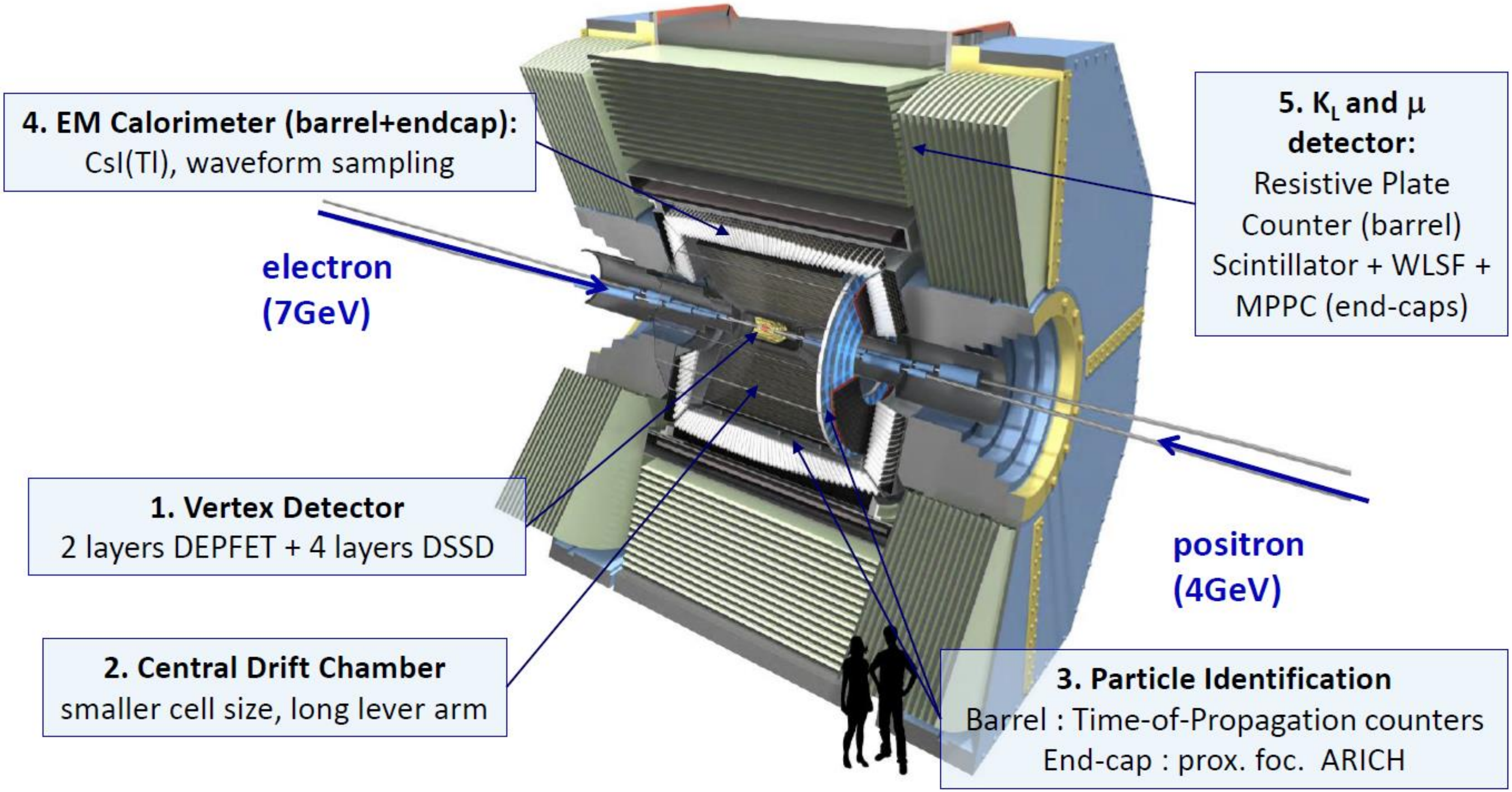
Low emittance e^- to inject



New superconducting / permanent final focusing quads near the IP

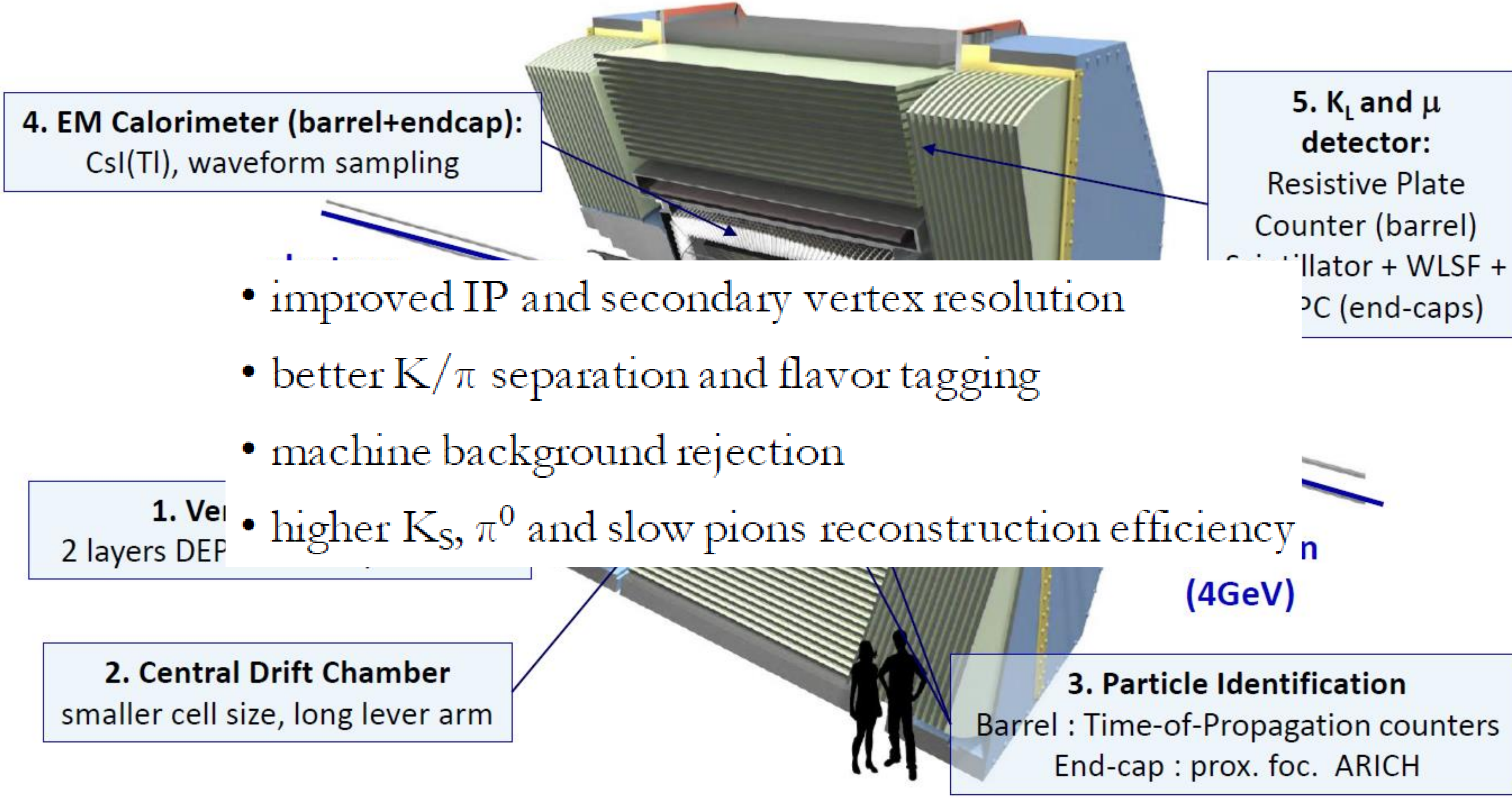
New LER & HER wiggler cavities installed

Belle II Detector



- All sub-detectors are upgraded from Belle II:
    - Except for ECL crystals and a part of Barrel KLM

Belle II Detector

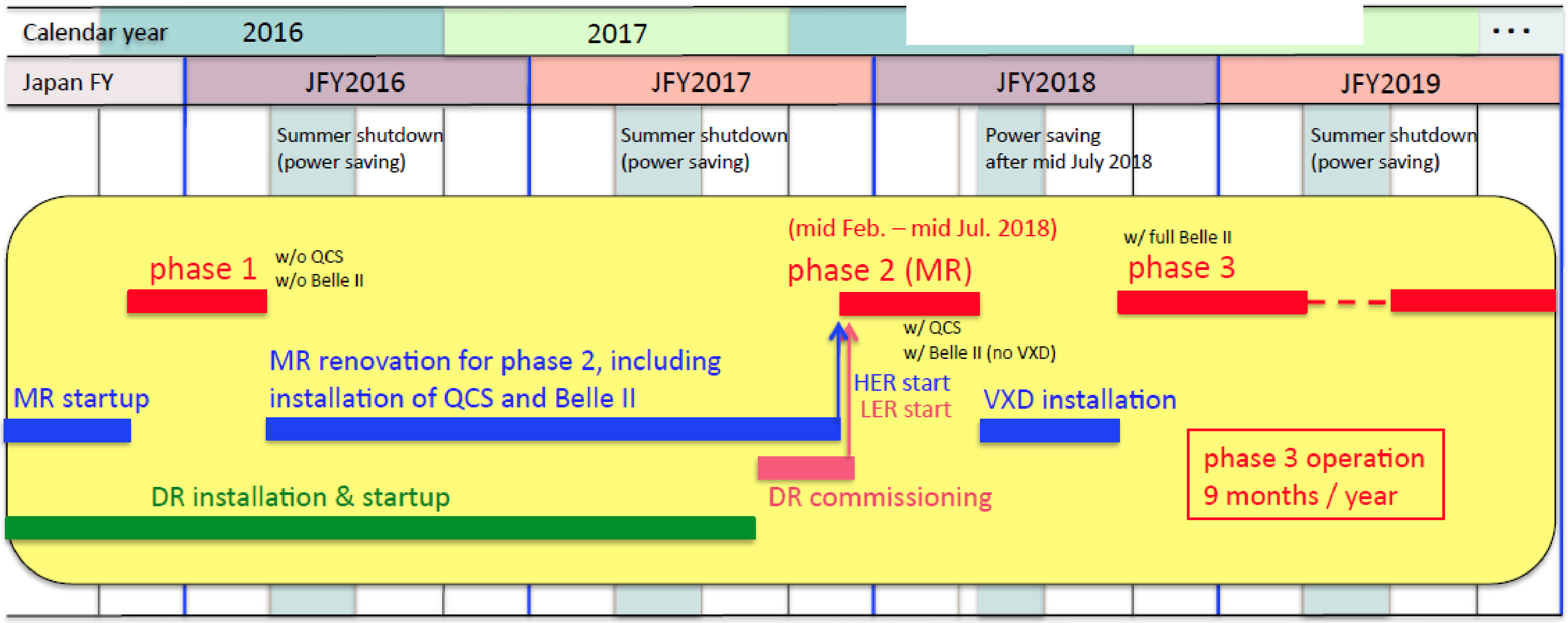


- improved IP and secondary vertex resolution
- better K/π separation and flavor tagging
- machine background rejection
- higher K_S, π^0 and slow pions reconstruction efficiency

- All sub-detectors are upgraded from Belle II:
  - Except for ECL crystals and a part of Barrel KLM

SuperKEKB / Belle II schedule

last B2GM (Feb. 2017)



Phase 1 –
- commisioning of the main ring
- Installation of outer detectors
- Vacuum scrubbing & beam background studies with BEASTII

Phase 2 – Start of the collisions, detector commissioning (Nov 2017 – spring 2018) **without vertex detector. First physics runs on Y(4S) and Y(6S)! ~20±20 fb -1**

Phase 3 - full detector operation by the end 2018


QUIET PLEASE BOARD MEETING in progress
It's settled. We put out a press release saying we can't remember what we decided.
Nicholson 25 April '09

Phase 1 commissioning results

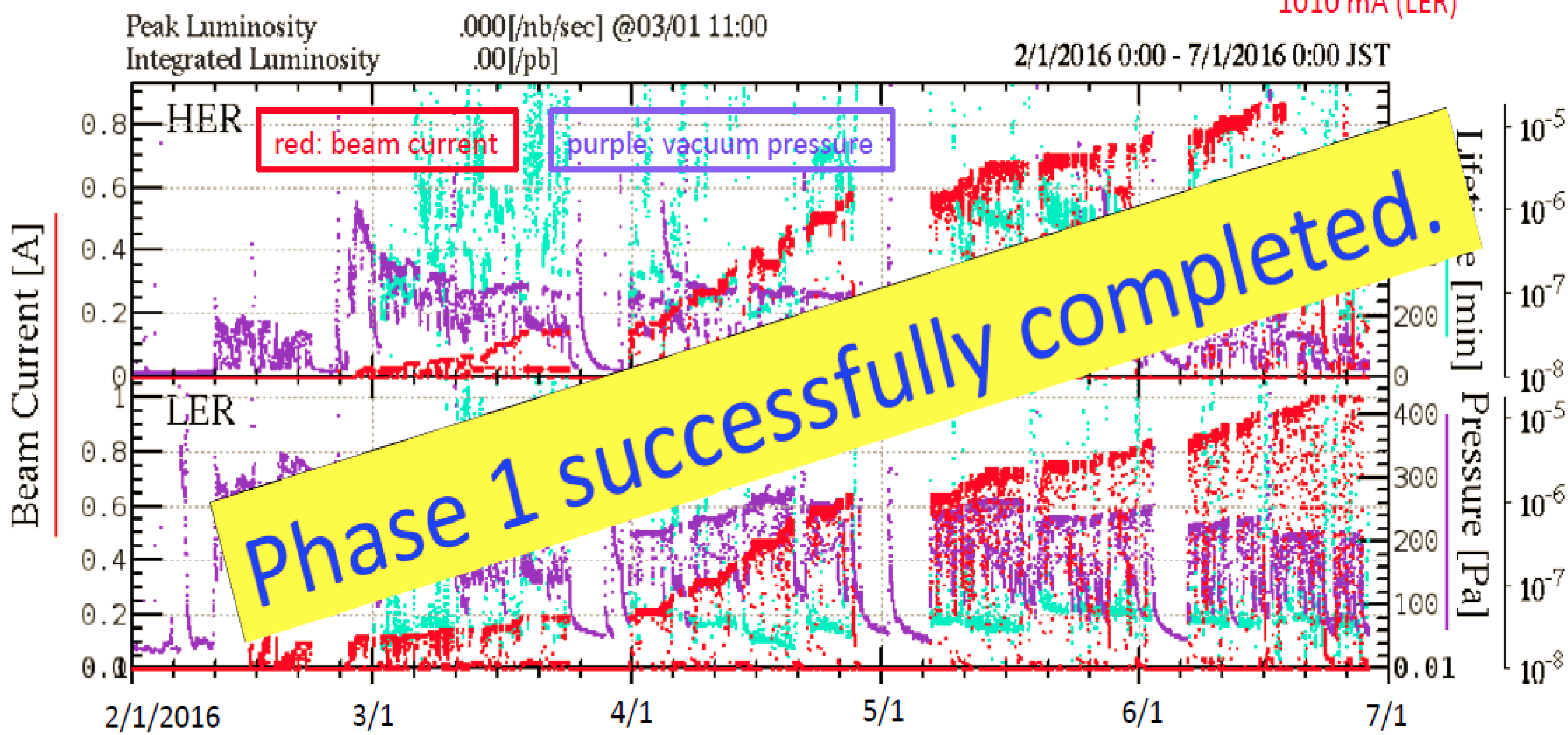
Phase 1 milestones

- 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

Tasks during phase 1 operation

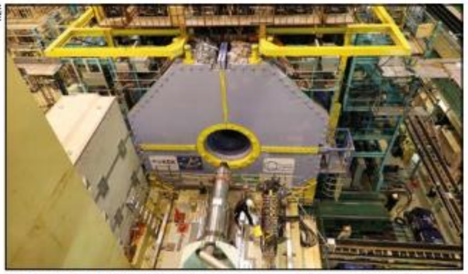
- Basic machine tuning
- Low emittance beam tuning
- Vacuum scrubbing
- Machine studies including Beast studies

Achieved beam current
870 mA (HER)
1010 mA (LER)



Belle II Status

Belle II Roll-In completed April 11, 2017



INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERNCOURIER

VOLUME 57 NUMBER 5 JUNE 2017

FACILITIES

Belle II rolls in

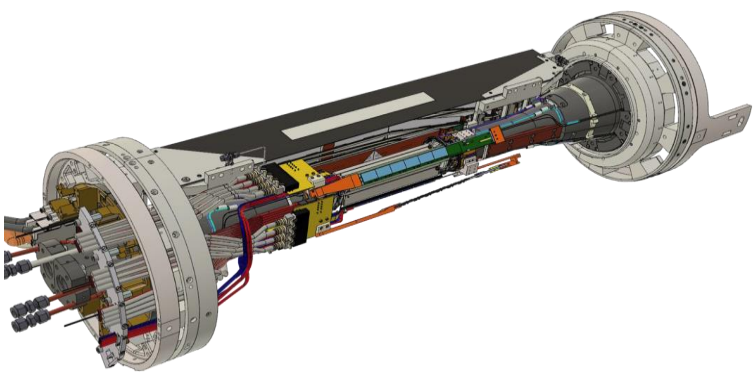
On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron–positron collisions. It will analyse copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (*CERN Courier* September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400 tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to install the complex focusing magnets around the Belle II interaction point. SuperKEKB achieved its first turns in February 2016, with operation of the main rings scheduled for early spring and phase-III "physics" operation by the end of 2018.

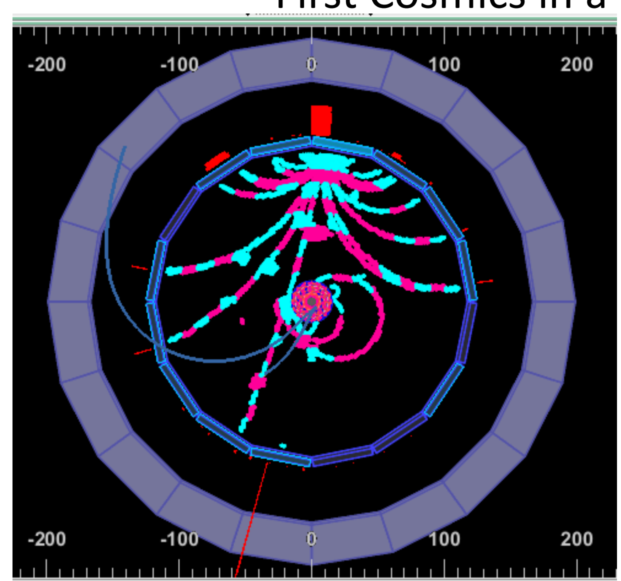
Compared to the previous Belle experiment, and thanks to major upgrades made to the former KEKB collider, Belle II will allow much larger data samples to be collected with much improved precision. "After six years of gruelling work with many unexpected twists and turns, it was a moving and gratifying experience for everyone on the team to watch the Belle II detector move to the interaction point," says Belle II spokesperson Tom Browder. "Flavour physics is now the focus of much attention and interest in the community and Belle II will play a critical role in the years to come."

KEK

The Belle II detector is now in place at the SuperKEKB facility in Japan.



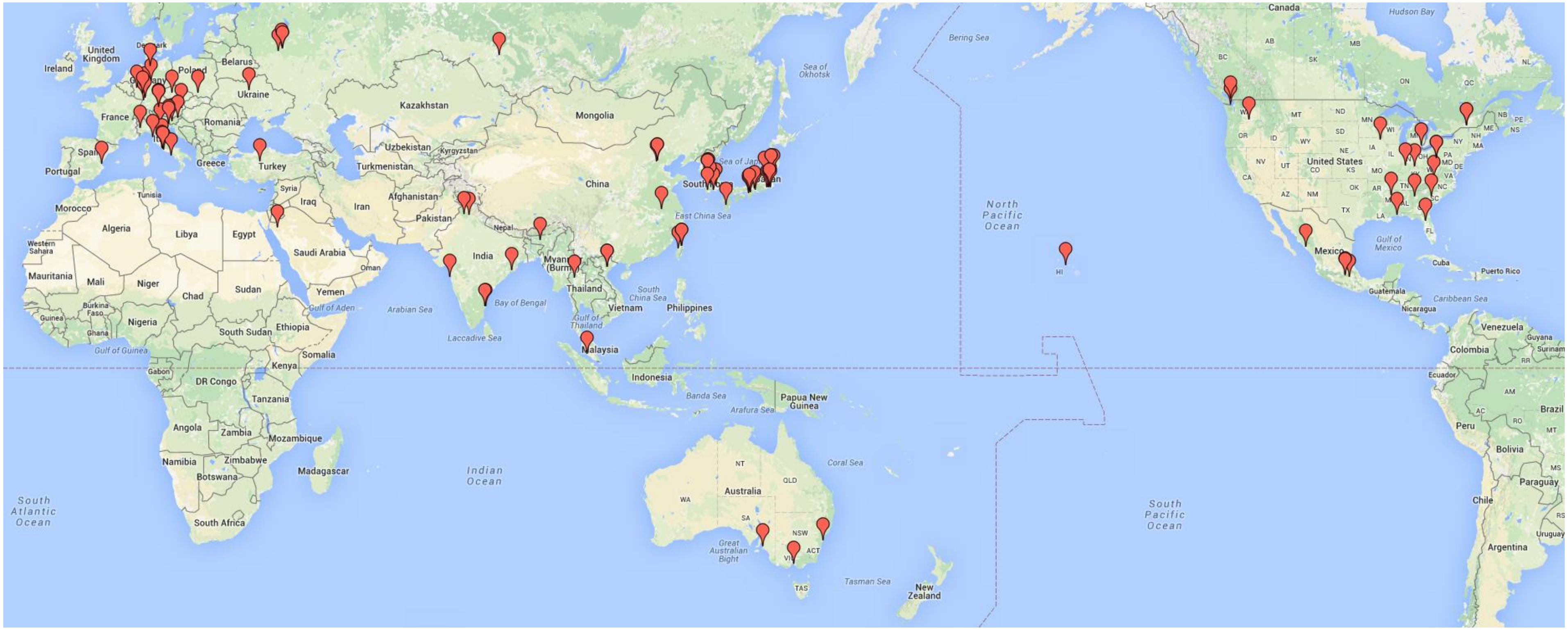
First Cosmics in a B field:



Motivation for **BEAST II**:

- Machine commissioning
- Radiation safe environment for the VXD

Belle II Collaboration

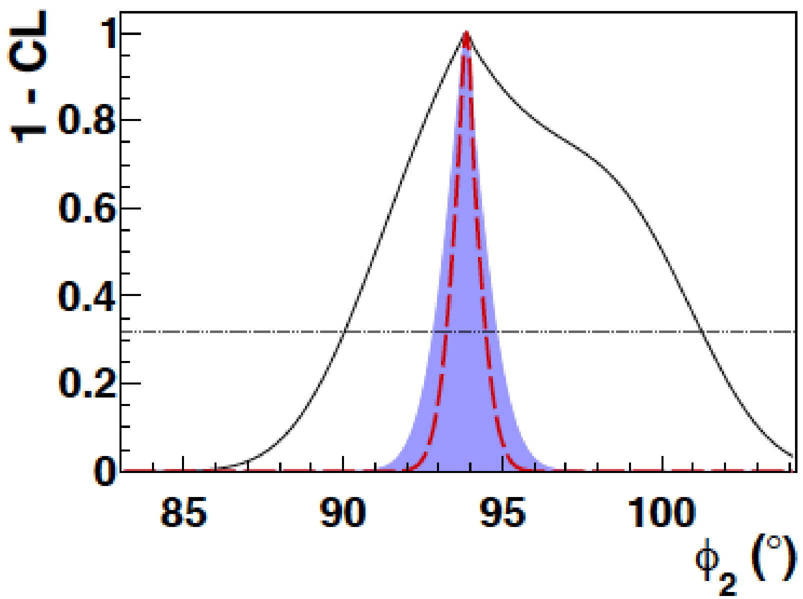


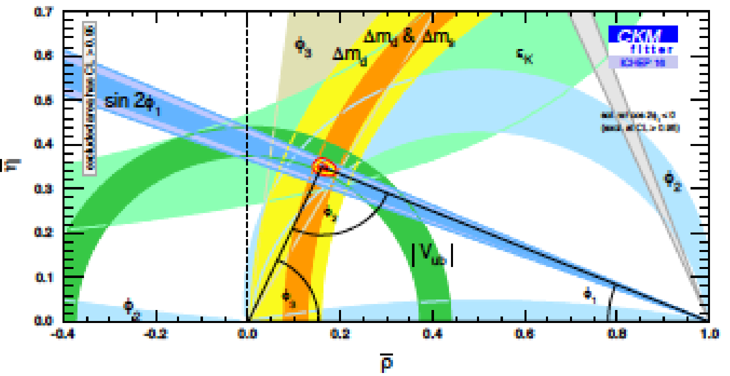
750 colleagues, 101 institutions, 23 countries/regions

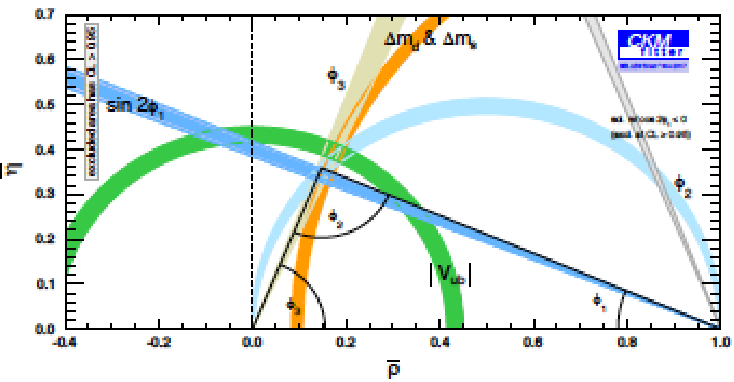
Status of Belle II Physics Book

- Belle II physics book (630p), to be printed by PTEP / Oxford University Press
  https://confluence.desy.de/display/BI/B2TiP+ReportStatus
- A few small unfinished areas, but otherwise close to complete and ready for review to commence.
- Await formation of Belle II publication committee to conduct collaboration wide review and form full collaboration author list ASAP.

Recent highlight $S_{CP}(B \to \pi^0\pi^0)$ & Φ_2: F. Abudinen







Charm mixing and CP violation

Mixing and CP violation

- Open-flavor neutral meson transforms to anti-meson:

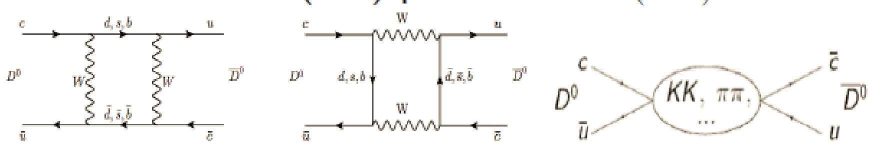
$$K^0 \Leftrightarrow \overline{K^0},\ B_d^0 \Leftrightarrow \overline{B_d^0},\ B_s^0 \Leftrightarrow \overline{B_s^0},\ D^0 \Leftrightarrow \overline{D^0}$$

- Flavor eigenstate ($|D^0\rangle$, $|\overline{D^0}\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$)

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D^0}\rangle \text{ (CPT: } p^2+q^2=1)$$

- Mixing parameters: $\mathbf{x} \equiv 2\frac{M_1 - M_2}{\Gamma_1 + \Gamma_2}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$

- Unique system: only up-type meson for mixing
- Standard Model(SM) predicts: $\sim \mathcal{O}(1\%)$



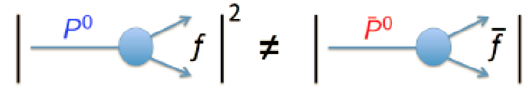
(1) short distance ($< 0.1\%$) (2) long distance ($\sim 1\%$)

- Precise measurement of x, y: effectively limit the New Physics(NP) modes; and search for NP, eg: $|x| \gg |y|$

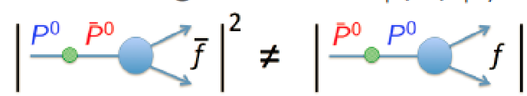
▶ Three types of Charged-conjugated-Parity combined symmetry Violation (CPV):

$$A^f_{CP} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})} = a^f_d + a^f_m + a^f_i$$

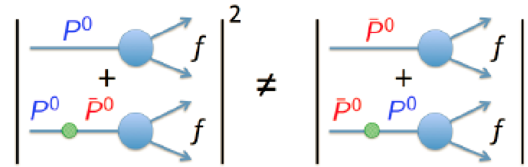
- a^f_d: (direct CPV) CPV in decay $|\bar{A}_{\bar{f}}/A_f| \neq 1$



- a^f_m: CPV in mixing with $r_m = |q/p| \neq 1$



- a^f_i: CPV in interference with $\arg(q/p) \neq 0$

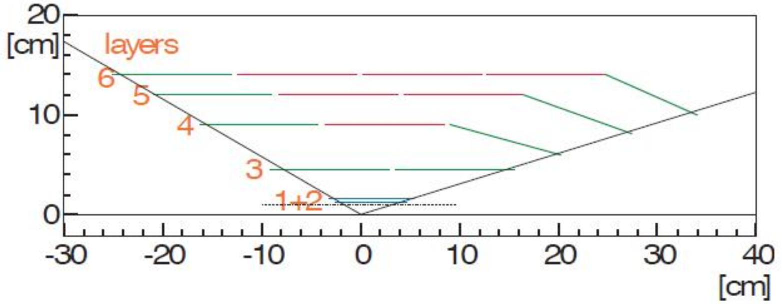


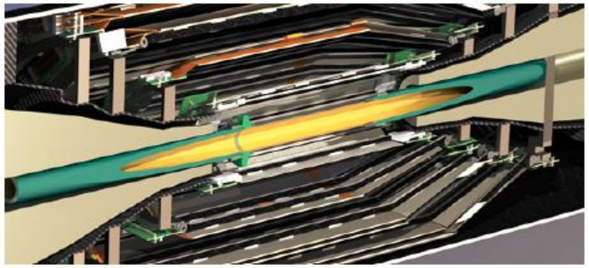
- SM with only a source: the phase in CKM
- in charm sector, it's predicted at $\sim \mathcal{O}(10^{-3})$
- $\sim 1\%$ exp. sensitivity to observe CPV→NP

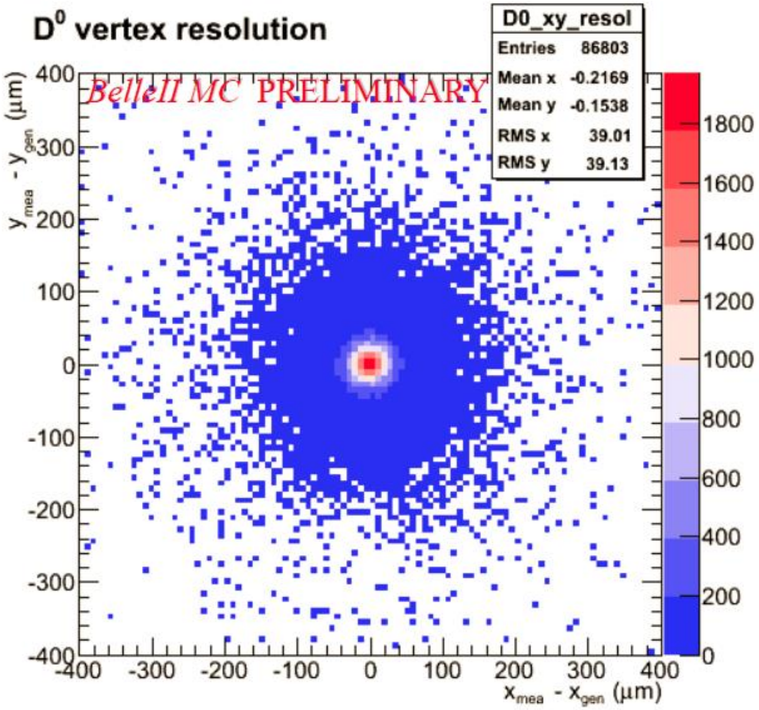
D^0-$\overline{D^0}$ mixing observation in more channels, and CPV searches are two of most important physical goals for Charm WG at our Belle II experiment.

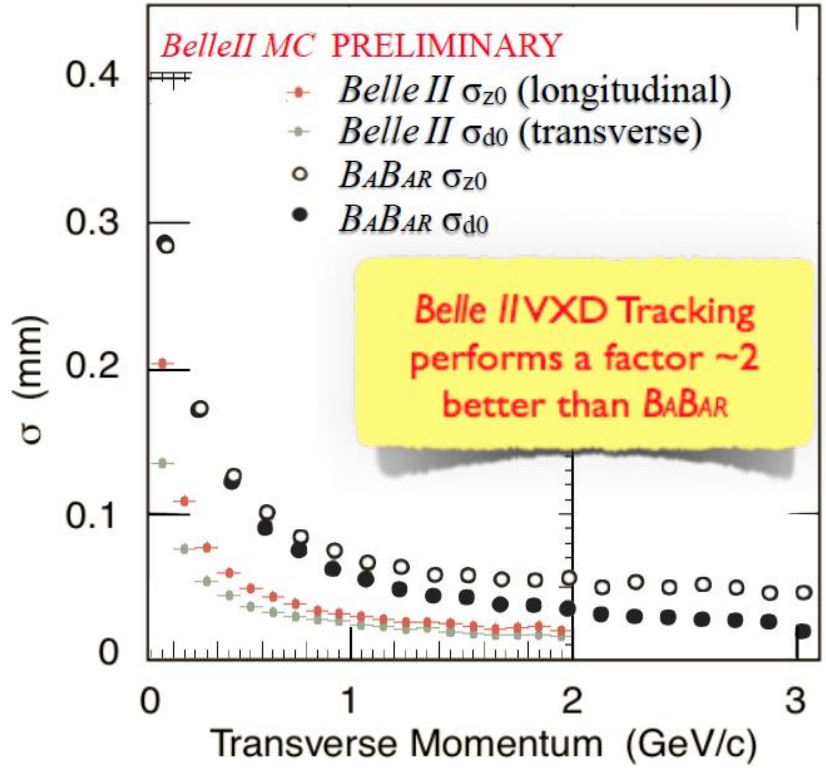
Belle II Vertex Detector Upgrade

Vertex detector:
double layer of DEPFET pixels + 4 layers DS Si strips









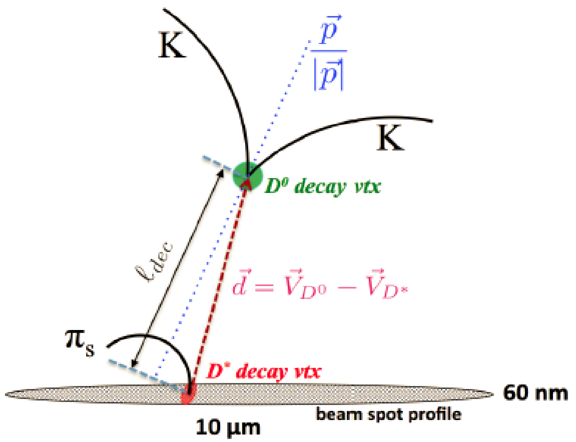
Belle II:
$\sigma \approx 40\ \mu m$

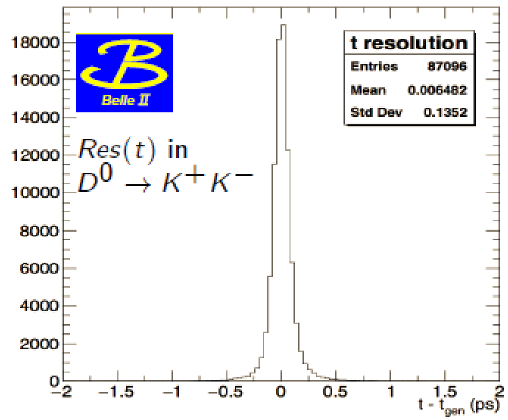
$D^0 \to K^+K^-$ Decay Time Resolution

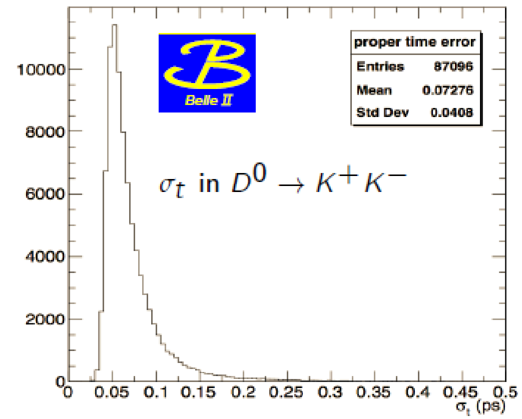
- Time-dependent amplitude of $D^0 \to f$ (here $t[\tau_{D^0}]$ and $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$):

$$\Gamma(D^0(t) \to f) \propto |\mathcal{A}_f|^2 e^{-t}\left(\frac{1+|\lambda_f|^2}{2}\cosh(yt) - \mathrm{Re}(\lambda_f)\sinh(yt)\frac{1-|\lambda_f|^2}{2}\cos(xt) + \mathrm{Im}(\lambda_f)\sin(xt)\right) \otimes_t Res(t)$$

- Time resolution $Res(t)$ is essential in t-dept. measurements of D^0-$\overline{D^0}$ mixing and CPV
- Determine D^0 proper time: $t = \frac{\ell_{dec}}{c\beta\gamma} = \frac{m_D}{cp}\vec{d}\cdot\frac{\vec{p}}{p}$ and its uncertainty σ_t





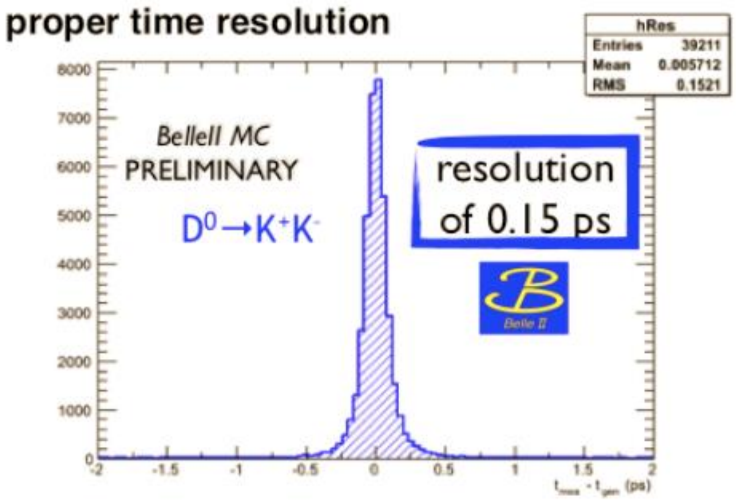


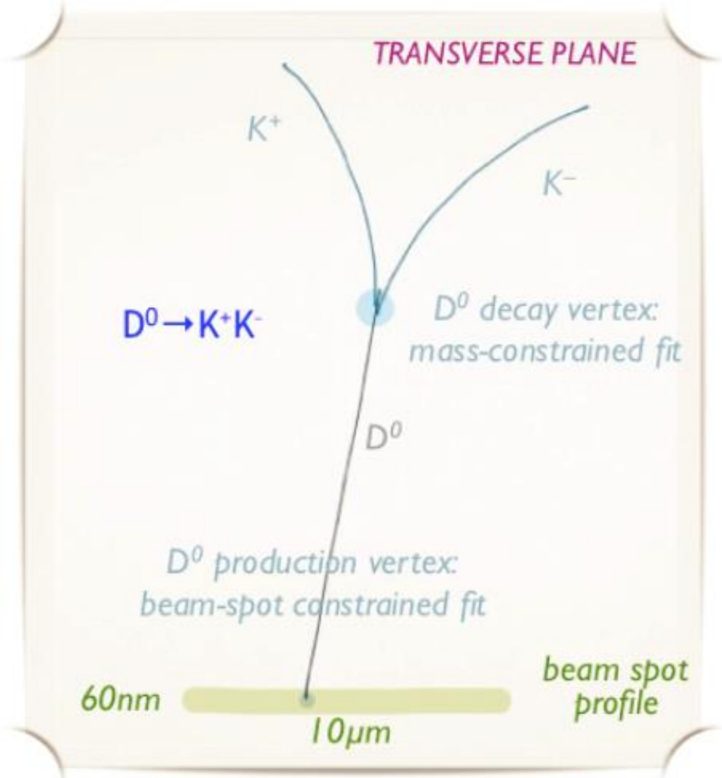
- Based on MC study, time resolution = 140 fs: 2× better than BaBar (270 fs)
- Time error σ_t: factor 3 improvement; and RMS(σ_t): reduced by a factor 2.
  - $Res = Gauss(\mu, k\sigma_t)$, so reduced RMS($\sigma_t$) (higher weight in the fit) results in an increased statistics

$D^0 \to K^+K^-$ Decay Time Resolution (prompt)

$$t = \frac{\ell}{\beta\gamma c} = \frac{\ell}{c}\frac{m_D}{|\vec{p}|}$$

$e^+e^- \to \bar{D}^0 D^0$,
$D^0 \to K^+K^-$





⇒ *decay time resolution of prompt D^0 = 0.15 ps (also excellent)*

Mixing/CPV precision for $D^0 \to K^+\pi^-$

- *generate $D^0 \to K^+\pi$- decays with mixing* (study II: + CPV)
- *smear decay time according to resolution $\sigma = 0.14$ ps*
- *generate and fit ensembles of 1000 experiments corresponding to 5, 20, 50 ab^{-1} of data)*

Toy MC study #1: no CPV

- *fit decay time distribution for R_D, x'^2, y'*
- *use same PDF for D^0 and D^0bar (convolved with Gaussian resolution function)*

$$\frac{dN(D^0 \to f)}{dt} \propto e^{-\overline{\Gamma} t}\left\{R_D + \sqrt{R_D}\, y'(\overline{\Gamma} t) + \frac{(x'^2 + y'^2)}{4}(\overline{\Gamma}\, t)^2\right\}$$

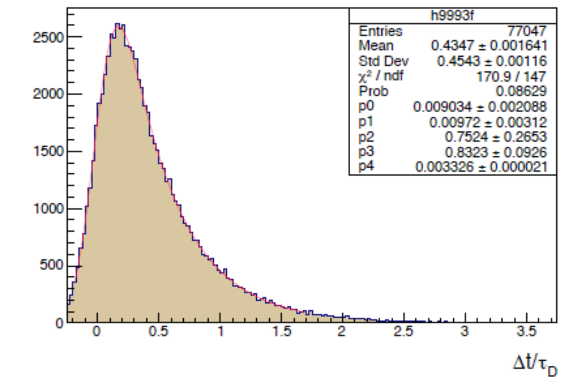
Toy MC study #2: include CPV

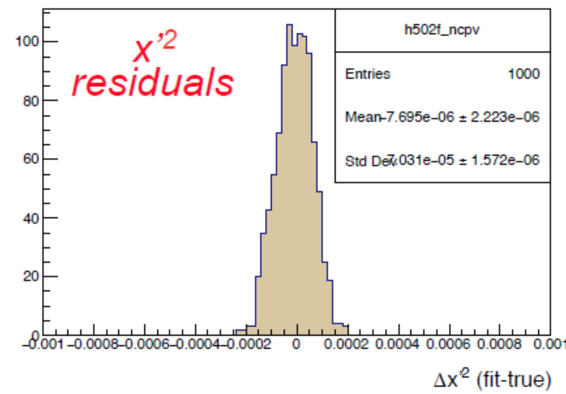
- *fit decay time distribution for R_D, x', y', $|q/p|$, ϕ (note: sensitive to sign of x)*
- *use different PDFs for D^0 and D^0bar (convolved with the same Gaussian resolution function)*

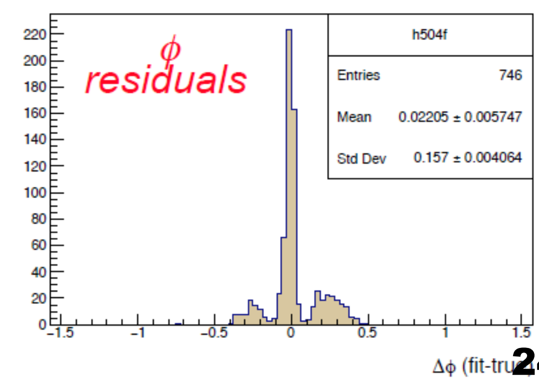
$$D^0(t) \propto \left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\phi - x'\sin\phi)(\overline{\Gamma} t) + \left|\frac{q}{p}\right|^2 \frac{(x'^2 + y'^2)}{4}(\overline{\Gamma}\, t)^2\right\}$$

$$\overline{D}^0(t) \propto \left\{\overline{R}_D + \left|\frac{p}{q}\right|\sqrt{\overline{R}_D}(y'\cos\phi + x'\sin\phi)(\overline{\Gamma} t) + \left|\frac{p}{q}\right|^2 \frac{(x'^2 + y'^2)}{4}(\overline{\Gamma}\, t)^2\right\}$$

Preliminary







Effect upon Mixing and CPV Precision

Toy MC no CPV results *(preliminary)*:

	5 ab^{-1}		20 ab^{-1}		50 ab^{-1}	
x'^2 (x 10^{-5}) x' (%)	14.4	0.72	7.0	0.35	4.4	0.22
y' (%)	0.156		0.075		0.047	

LHCb 3 fb^{-1}

4.3

0.08

competitive for y'?

Toy MC allowing for CPV results *(preliminary)*:

	5 ab^{-1}	20 ab^{-1}	50 ab^{-1}
x' (%)	0.37	0.23	0.15
y' (%)	0.26	0.17	0.10
$\lvert q/p \rvert$	0.197	0.089	0.051
ϕ (deg)	15.5	9.2	5.7

Mixing/CPV Precision for $D^0 \to K_S \pi^+\pi^-$:

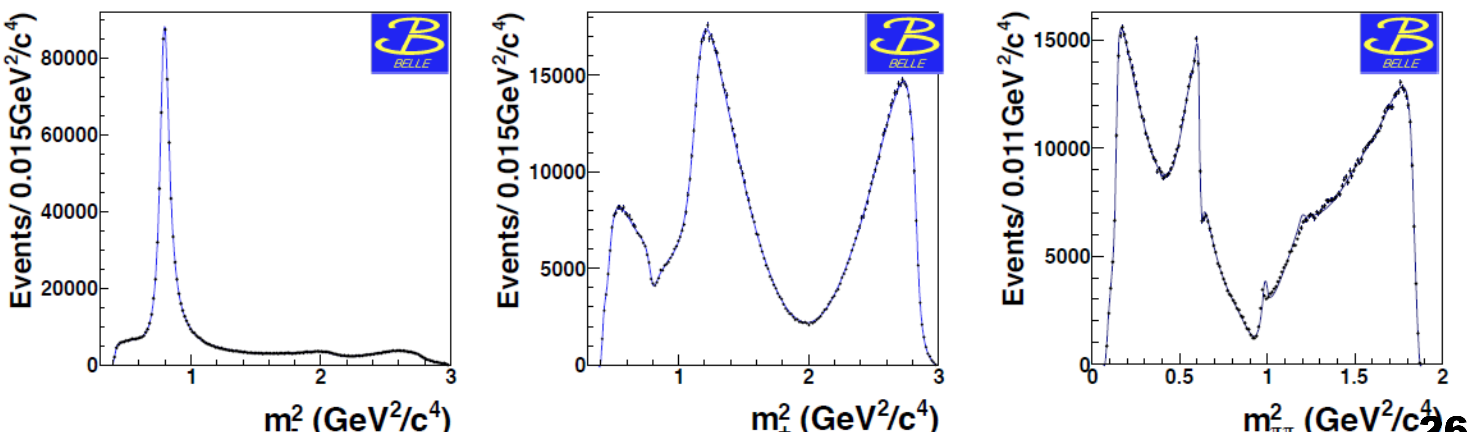
PRD 89, 091103(R) (2014)

Fitting the time-dependent Dalitz plot yields x, y, $|q/p|$ and $\phi = Arg(q/p)$

- Signal yield determined from 2-dim. fit to $M_{K\pi\pi}$ and $\Delta M = M_{K\pi\pi\pi} - M_{K\pi\pi}$. Yield is 1.2 x 10^6 events with a purity of 96%.
- For events in signal region, do unbinned ML fit to $m^+ = M(K\pi^+)^2$, $m^- = M(K\pi^-)^2$, and decay time t. Fit parameters are x, y, τ, resolution function parameters (2-3 Gaussians), and decay model: magnitudes and phases of 13 intermediate resonances.
- Do fit separately (+ simultaneously) for D^0 and D^0bar samples to obtain $|q/p|$, ϕ.

Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.590 ± 0.003	131.8 ± 0.2	0.6045
$K_0^*(1430)^-$	2.059 ± 0.010	-194.6 ± 1.7	0.0702
$K_2^*(1430)^-$	1.150 ± 0.009	-41.5 ± 0.4	0.0221
$K^*(1410)^-$	0.496 ± 0.011	83.4 ± 0.9	0.0026
$K^*(1680)^-$	1.556 ± 0.097	-83.2 ± 1.2	0.0016
$K^*(892)^+$	0.139 ± 0.002	-42.1 ± 0.7	0.0046
$K_0^*(1430)^+$	0.176 ± 0.007	-102.3 ± 2.1	0.0005
$K_2^*(1430)^+$	0.077 ± 0.007	-32.2 ± 4.7	0.0001
$K^*(1410)^+$	0.248 ± 0.010	-145.7 ± 2.9	0.0007
$K^*(1680)^+$	1.407 ± 0.053	86.1 ± 2.7	0.0013
$\rho(770)$	1 (fixed)	0 (fixed)	0.2000
$\omega(782)$	0.0370 ± 0.0004	114.9 ± 0.6	0.0057
$f_2(1270)$	1.300 ± 0.013	-31.6 ± 0.5	0.0141
$\rho(1450)$	0.532 ± 0.027	80.8 ± 2.1	0.0012

Fit projections: (fitted function describes the data well)



Mixing/CPV Precision for $D^0 \to K_S\, \pi^+\pi^-$

$$\sigma_{\text{Belle II}} = \sqrt{(\sigma^2_{\text{stat}} + \sigma^2_{\text{syst}}) \cdot \frac{\mathcal{L}_{\text{Belle}}}{50\ \text{ab}^{-1}} + \sigma^2_{\text{irred}}}$$

	Observable	Statistical	Systematic red.	Systematic irred.	Total	LHCb 3 fb^{-1} (arXiv:1208.3355)	LHCb 1 fb^{-1} (JHEP 1604, 033)
x	$x^{K_S\pi^+\pi^-}$ $[10^{-2}]$					0.2	0.6
	976 fb^{-1}	0.19	0.06	0.11	0.20		
	50 ab^{-1}	0.03	0.01	0.11	0.11		
$\lvert q/p\rvert$	$\lvert q/p\rvert^{K_S\pi^+\pi^-}$ $[10^{-2}]$					20	-
	976 fb^{-1}	15.5	5.2-5.6	7.0-6.7	17.8		
	50 ab^{-1}	2.2	0.7-0.8	7.0-6.7	7.0-7.4		
y	$y^{K_S\pi^+\pi^-}$ $[10^{-2}]$					0.2	0.5
	976 fb^{-1}	0.15	0.06	0.04	0.16		
	50 ab^{-1}	0.02	0.01	0.04	0.05		
ϕ	$\phi^{K_S\pi^+\pi^-}$ $[°]$					15	-
	976 fb^{-1}	10.7	4.4-4.5	3.8-3.7	12.2		
	50 ab^{-1}	1.5	0.6	3.8-3.7	4.0-4.2		

- *irreducible systematics related to Dalitz plot model; this will improve with model-independent approach (using BESIII binned phases)*
- *improvement in proper time resolution not included here*

Mixing/CPV Precision for $D^0 \to K^+ \pi^- \pi^0$

- Time-dependent Dalitz plot(TDDP) provides an essential tool in studying D^0-$\overline{D^0}$ mixing.
- Only method: sensitive to linear order in both mixing parameters, especially self-conjugated decays like $K_S^0 hh$ (not rotated by an unknown δ)

- TDDP fit on $D^0 \to K^+\pi^-\pi^0$ WS decays to extract mixing par. $(x''/r_0,\, y''/r_0)$

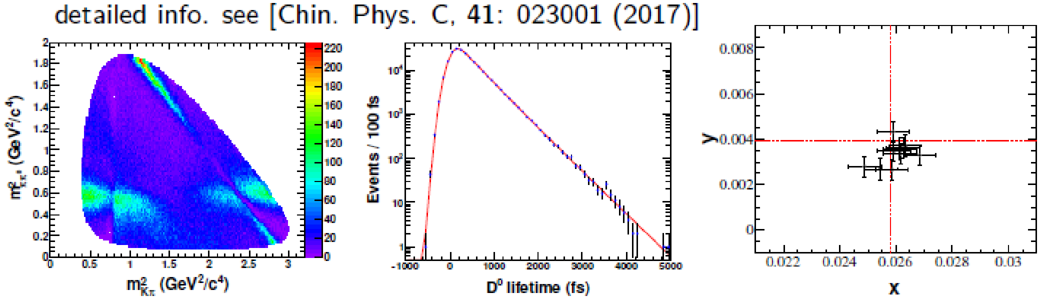
$$|\mathcal{A}_{\bar f}|^2 = \left[|\mathcal{A}_{\bar f}^{DCS}|^2 e^{-\Gamma t} + \frac{(x^2+y^2)}{4r_0^2}|\bar{\mathcal{A}}_{\bar f}^{CF}|^2(\Gamma t)^2 e^{-\Gamma t} + \left(\frac{y''}{r_0}\mathrm{Re}[\mathcal{A}_{\bar f}^{DCS}\bar{\mathcal{A}}^{*CF}_{\bar f}] + \frac{x''}{r_0}\mathrm{Im}[\mathcal{A}_{\bar f}^{DCS}\bar{\mathcal{A}}^{*CF}_{\bar f}]\right)(\Gamma t)e^{-\Gamma t}\right] \otimes_t Res(t)$$

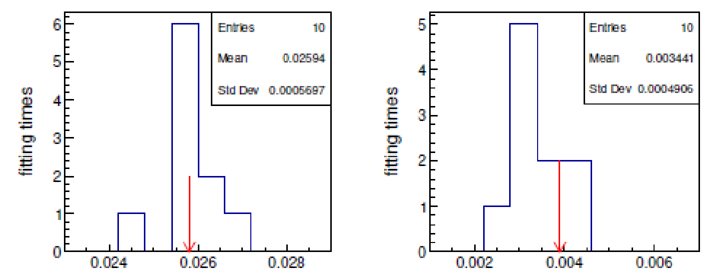
$$x'' = x\cos\delta_{K\rho} + y\sin\delta_{K\rho},\; y'' = y\cos\delta_{K\rho} - x\sin\delta_{K\rho},\; r_0 = |A^{CF}|/|A^{DCS}|$$

- BaBar: the evidence (3.2σ) with 384 fb^{-1}: $\sigma(x'', y'') = (^{+0.57}_{-0.68}, ^{+0.55}_{-0.64})\%$ [PRL **103**, 211801 (2009)]

- ToyMC: smear lifetime with Gauss(σ=140 fs); without considering bkg effects.
- Sensitivity estimation: one order of magnitude improvement than BaBar

detailed info. see [Chin. Phys. C, **41**: 023001 (2017)]





$\sigma_x = 0.060\%$, $\sigma_y = 0.049\%$

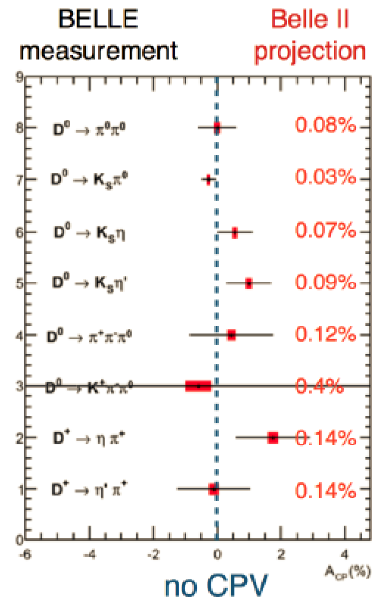
Direct CP Asymmetries

- Time-integrated *CP* asymmetries are measured based on partial decay rates:

$$A^f_{CP} = \frac{\Gamma(D\to f) - \Gamma(\overline{D}\to \overline{f})}{\Gamma(D\to f) + \Gamma(\overline{D}\to \overline{f})} = a^f_d + a^f_{ind} \quad \text{e.g: in } D^0 \to K^0_S h^+, \text{ measured asym.: } A_{raw} = A_{CP} + A_{FB} + A^{h^+}_{\epsilon} + A^{K^0}_{CP}$$

- Several measurements are performed at Belle

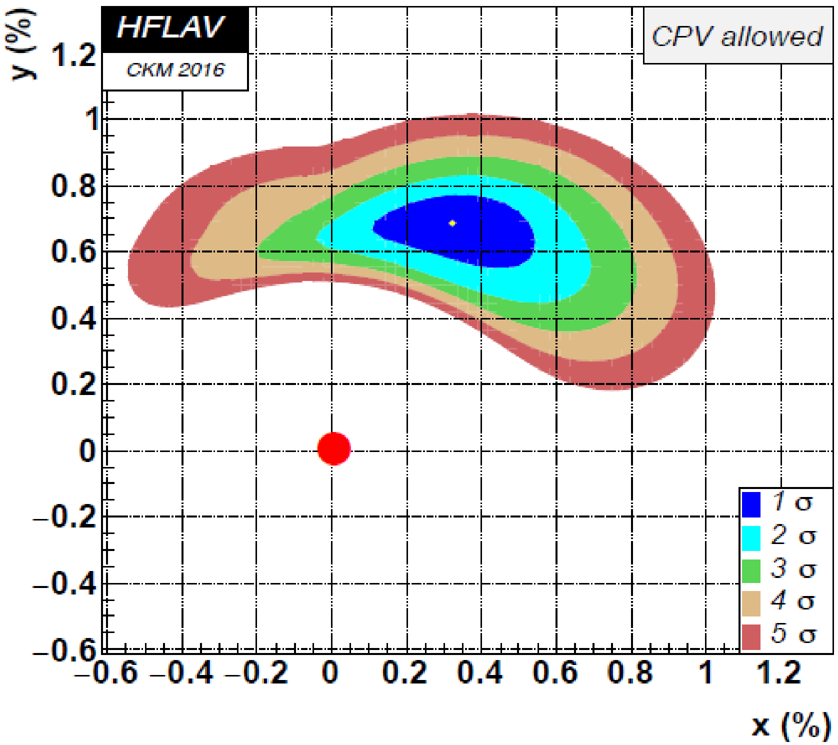
Channel	$\mathcal{L}$(/fb)	Current measurement value(%)	References	Belle II 50 ab^{-1}(%)	LHCb 50 fb^{-1}(%)
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.05	± 0.03
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.03	± 0.03
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	PRL **112**, 211601 (2014)	± 0.09	
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.17$	arXiv:1705.05966	± 0.20	
$D^0 \to K^0_S \pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	PRL **112**, 211601 (2014)	± 0.03	
$D^0 \to K^0_S \eta$	791	$+0.54 \pm 0.51 \pm 0.16$	PRL **106**, 211801 (2011)	± 0.07	
$D^0 \to K^0_S \eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	PRL **106**, 211801 (2011)	± 0.09	
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 0.41 \pm 1.23$	PLB **662**, 102 (2008)	± 0.13	
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	PRL **95**, 231801 (2005)	± 0.40	
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	$+0.43 \pm 1.30$	PRL **95**, 231801 (2005)	± 0.33	
$D^+ \to \pi^0\pi^+$	921	$+0.89 \pm 1.98 \pm 0.22$	Belle Preliminary	± 0.40	
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	PRL **108**, 071801 (2012)	± 0.04	
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	PRL **107**, 221801 (2011)	± 0.14	± 0.01
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	PRL **107**, 221801 (2011)	± 0.14	
$D^+ \to K^0_S\pi^+$	977	$-0.363 \pm 0.094 \pm 0.067$	PRL **109**, 021601 (2012)	± 0.03	± 0.03
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	JHEP **02** (2013) 098	± 0.05	
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	PRL **104**, 181602 (2010)	± 0.29	± 0.03
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	PRL **104**, 181602 (2010)	± 0.05	



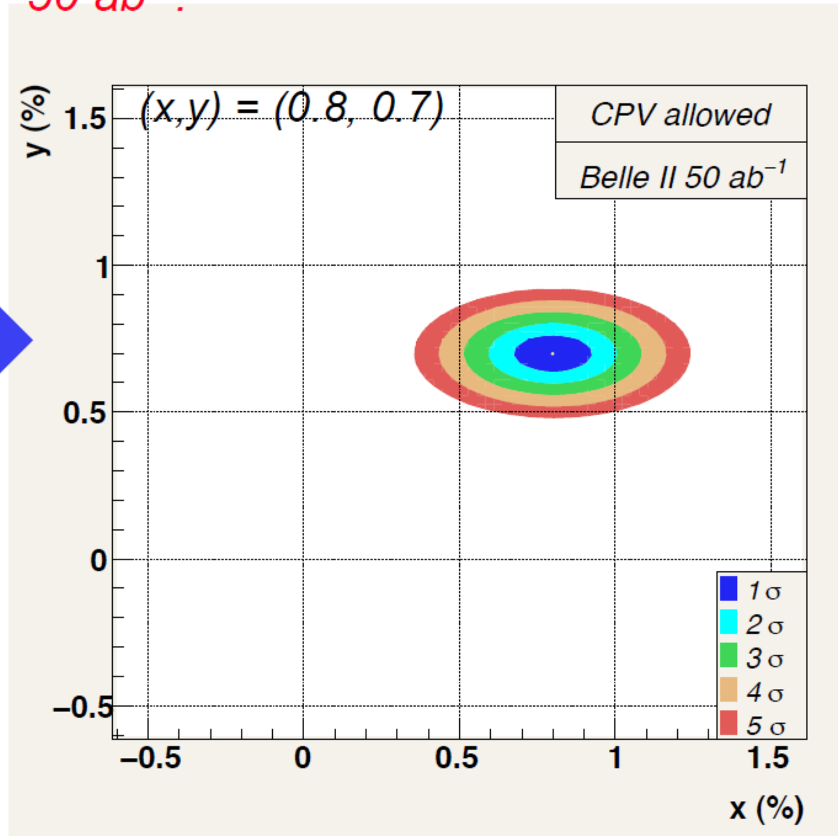
- Belle II: precision of $\mathcal{O}(0.01\%)$ (down to SM level). $\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{syst}) \cdot (\mathcal{L}_{Belle}/50\ \text{ab}^{-1}) + \sigma^2_{irred}}$
- With respect to LHCb, Belle II has advantages of excellent γ and π^0 reconstruction.

Mixing Constraints in the D^0-$\bar{D}^0$ system

Now:



50 ab^{-1}:

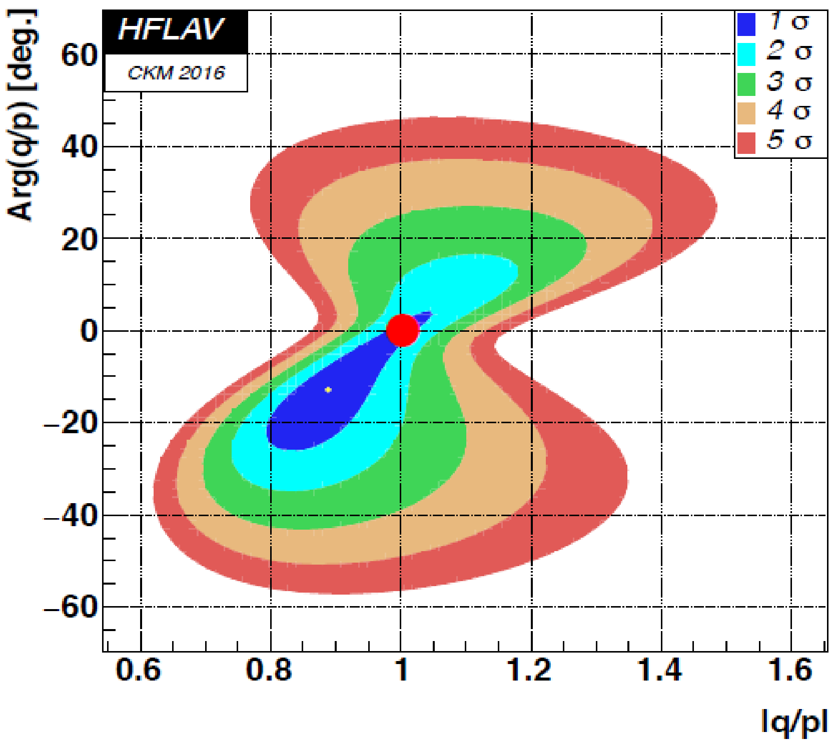


Current measurements of x, y give many constraints on NP models
[see Golowich et al., PRD76, 095009 (2007); 21 models considered, e.g., 2-Higgs doublets, left-right models, little Higgs, extra dimensions, of which 17 give constraints]

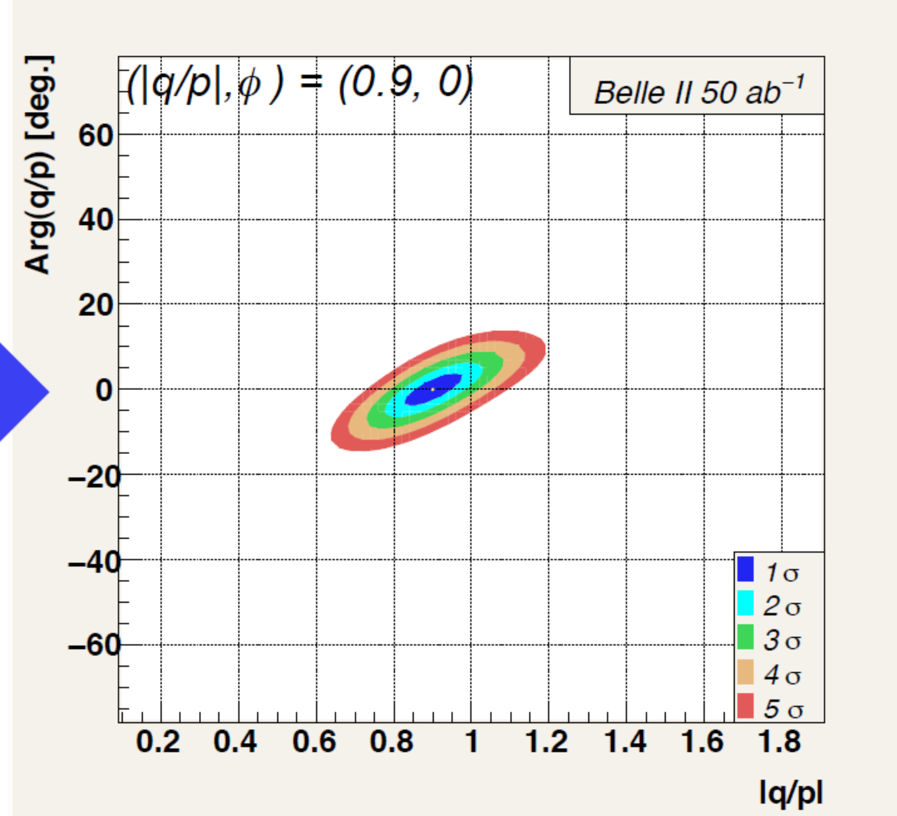
- $\gg 11.5\sigma$ to exclude no mixing (x,y)=(0,0) with CPV-allowed

CPV Constraints in the D^0-$\bar{D}^0$ system

Now:



50 ab^{-1}:



Note: *LHCb will dominate most of these measurements, but Belle II should be competitive in y_{CP} and possibly in x'^2, y', $|q/p|$, ϕ (see Staric, KEK FFW14). If LHCb sees new physics, it would be important for Belle II to independently confirm.*

- No hints for indirect CPV ⇐ no direct CPV $(|q/p|,\phi)=(1,0)$ at C.L=40%
- No clear evidence of direct CPV ⇐ no CPV at C.L=9.3%

Leptonic charm decays

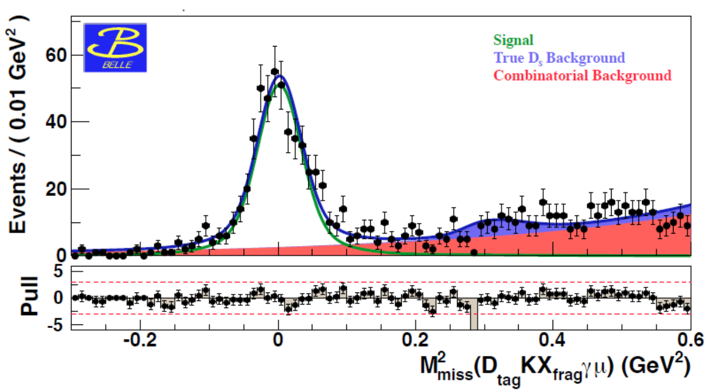
$D_{(s)}$ (semi-)leptonic decays

- (Semi-)Leptoinc charm decays involve both well-understood weak interactions physics and non-perturbative strong-interaction effects $\Rightarrow$ test lattice QCD or measure $|V_{cd}|$ and $|V_{cs}|$.
  - leptonic decays are used to extract $|V_{cd}|f_D$ or $|V_{cs}|f_{D_s}$
  - semileptonic decays are used to extract $|V_{cd}|f_+^{\pi}(q^2=0)$ or $|V_{cs}|f_+^{K}(q^2=0)$

Leptonic Decay $D_s^+ \to \mu^+\nu$

$e^+e^- \to D_{tag} X_{frag} K D_s^{*+} \to D_s^+ \gamma$

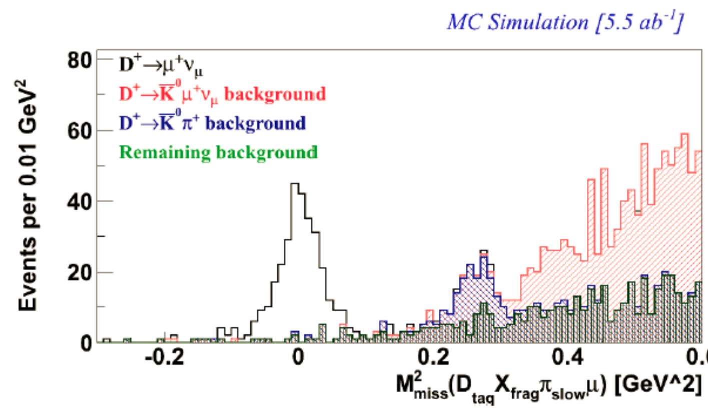
Fit to $D_{tag} X_{frag} K \mu^+ \gamma$ missing mass



Leptonic Decay $D^+ \to \mu^+\nu$

$e^+e^- \to D_{tag} X_{frag} K D^{*+} \to D^+ \pi^0$

Fit to $D_{tag} X_{frag} \mu^+ \pi^0$ missing mass



- Leptonic decays yields estimation at Belle II with 50 ab^{-1}

Mode	$D_s^- \to \mu^-\bar{\nu}$	$D^0 \to \nu\bar{\nu}$	$D^- \to \mu^-\bar{\nu}$	$D \to \pi\ell^+\nu$
Belle	0.91 ab^{-1} 492±26	0.92 ab^{-1} $(695\pm1)\times10^3$		0.28 ab^{-1} 126±12
Belle II	27000	38×10^6	1250	7.0×10^5
Sensitivity	improve $\lvert V_{cs}\rvert_{best}$	$7\times$ better	$<2\%$ $\lvert V_{cd}\rvert$	comparable to BESIII

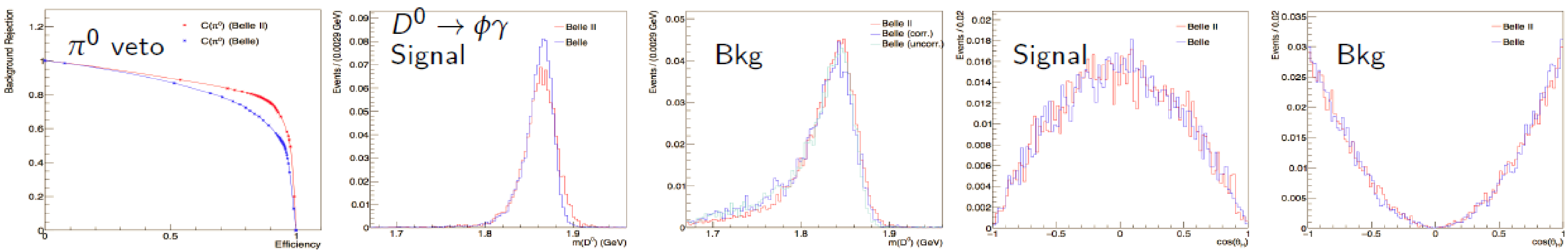
Rare Charm decays

D^0 Mode	BEST (90% C.L.)	BESIII (20 fb^{-1})	Belle II (50 ab^{-1})
$\gamma\gamma$	2.2×10^{-6}	5×10^{-8}	2×10^{-7}
$\mu^+\mu^-$	6.2×10^{-9}	1.7×10^{-7}	1.6×10^{-8}
μ^+e^-	2.6×10^{-7}	4.3×10^{-8}	3.0×10^{-8}
e^+e^-	7.9×10^{-8}	2.4×10^{-8}	1.0×10^{-9}
$\pi^0\mu^+\mu^-$	1.8×10^{-4}	1.2×10^{-7}	1.6×10^{-6}
$\pi^0e^+e^-$	4.5×10^{-5}	7.9×10^{-8}	3.5×10^{-9}
$\pi^0\mu^+e^-$	8.6×10^{-5}	9.7×10^{-8}	7.5×10^{-7}
$K^0\mu^+\mu^-$	2.6×10^{-4}	1.1×10^{-7}	5.9×10^{-6}
$K^0e^+e^-$	1.1×10^{-4}	7.5×10^{-8}	8.5×10^{-9}
$K^0\mu^+e^-$	1.0×10^{-4}	9.6×10^{-8}	7.7×10^{-9}
$\eta\mu^+\mu^-$	5.3×10^{-4}	1.0×10^{-7}	4.1×10^{-8}
ηe^+e^-	1.1×10^{-4}	1.0×10^{-7}	8.5×10^{-9}
$\eta\mu^+e^-$	1.0×10^{-4}	1.0×10^{-7}	7.7×10^{-9}

D^+ Mode	BEST (90% C.L.)	BESIII (20 fb^{-1})	Belle II (50 ab^{-1})
$\pi^+e^+e^-$	1.1×10^{-6}	5.6×10^{-8}	9.6×10^{-8}
$\pi^+\mu^+\mu^-$	7.3×10^{-8}	8.7×10^{-8}	5.7×10^{-7}
$\pi^+\mu^+e^-$	2.8×10^{-6}	8.3×10^{-8}	2.3×10^{-7}
$\pi^-e^+e^+$	1.1×10^{-6}	5.6×10^{-8}	1.7×10^{-7}
$\pi^-\mu^+\mu^+$	2.2×10^{-8}	8.7×10^{-8}	1.7×10^{-7}
$\pi^-\mu^+e^+$	2.0×10^{-6}	5.9×10^{-8}	1.7×10^{-7}
$K^+e^+e^-$	1.0×10^{-6}	6.7×10^{-8}	8.8×10^{-8}
$K^+\mu^+\mu^-$	4.3×10^{-6}	1.1×10^{-7}	3.8×10^{-7}
$K^+\mu^+e^-$	2.8×10^{-6}	8.3×10^{-8}	2.5×10^{-7}
$K^-e^+e^+$	9.0×10^{-7}	6.7×10^{-8}	7.9×10^{-8}
$K^-\mu^+\mu^+$	1.0×10^{-5}	1.1×10^{-7}	8.8×10^{-7}
$K^-\mu^+e^+$	1.9×10^{-6}	8.3×10^{-8}	1.7×10^{-7}

$D^0 \to \gamma$ V rare radiative decays

- Radiative decays of $D^0 \to V\gamma$: dominated by long-range contribution ($\sim 10^{-5}$, whereas short-range at 10^{-8} level); direct CPV can be enhanced to exceed 1% in NP. [PRL 109,17801(2012)]
- BR measurement to test SM; observing $A_{CP}^{V\gamma} > 3\%$ is a signal of NP. [PRL 109,17801(2012)]
- Belle II sensitivity estimation for A_{CP} based on MC study:
  - similar performance of π^0 veto and resolution of signal or bkg
  - similar signal-to-bkg btw Belle and Belle II $\Rightarrow$ scaling luminosity



- Belle II: statistical $\sigma_{A_{CP}}$ at $1-2\%$ level with 50 ab^{-1}.

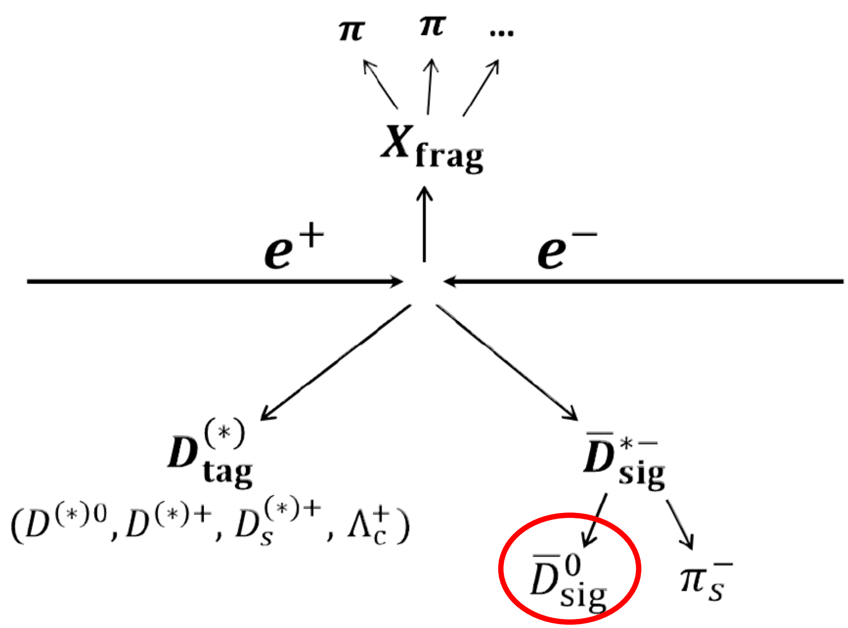
radiative decays	Belle A_{CP} results [1] 976 fb^{-1}	Belle II uncertainty 5 ab^{-1}	15 ab^{-1}	50 ab^{-1}
$D^0 \to \rho^0\gamma$	$+0.056 \pm 0.152 \pm 0.006$	± 0.07	± 0.04	± 0.02
$D^0 \to \phi\gamma$	$-0.094 \pm 0.066 \pm 0.001$	± 0.03	± 0.02	± 0.01
$D^0 \to \bar{K}^{*0}\gamma$	$-0.003 \pm 0.020 \pm 0.000$	± 0.01	± 0.005	± 0.003

[1] T. Nanut *et al.*(Belle Collaboration), Phys. Rev. Lett. **118**, 051801 (2017)

$D^0 \to$ invisible final states

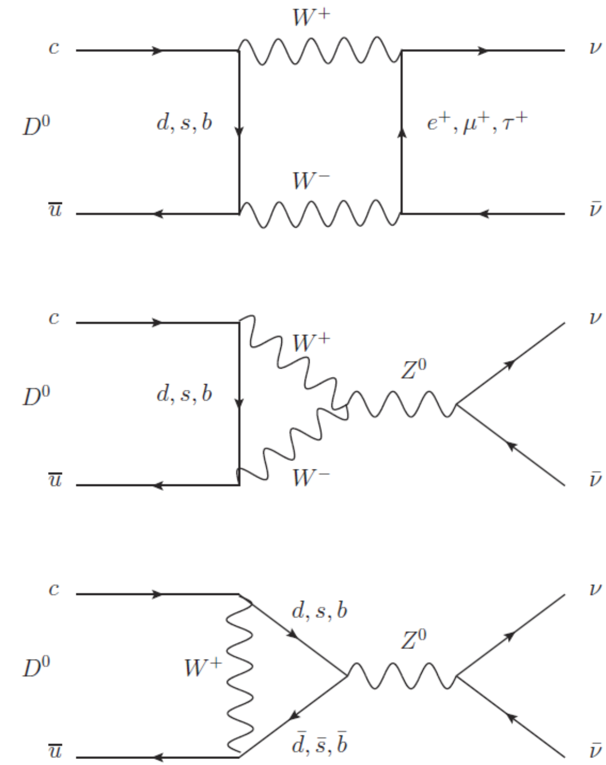
- D meson to $\nu\bar{\nu}$ is helicity suppressed in SM with Br~1.1×10^{-30}
- Under different DM models the Br can reach $O(10^{-15})$
  PLB651, 374(2007); Phys.Rept.117,75(1985)
- Use charm tagger method to select an inclusive D^0 sample which allows the identification of D^0 invisible decays

$$e^+e^- \to c\bar{c} \to D^{(*)}_{\rm tag} X_{\rm frag} \bar{D}^{*-}_{\rm sig}$$



An illustration of the charm tagger method.

$$M_{D^0} \equiv M_{\rm miss}(D^{(*)}_{\rm tag} X_{\rm frag} \pi_s^-)$$

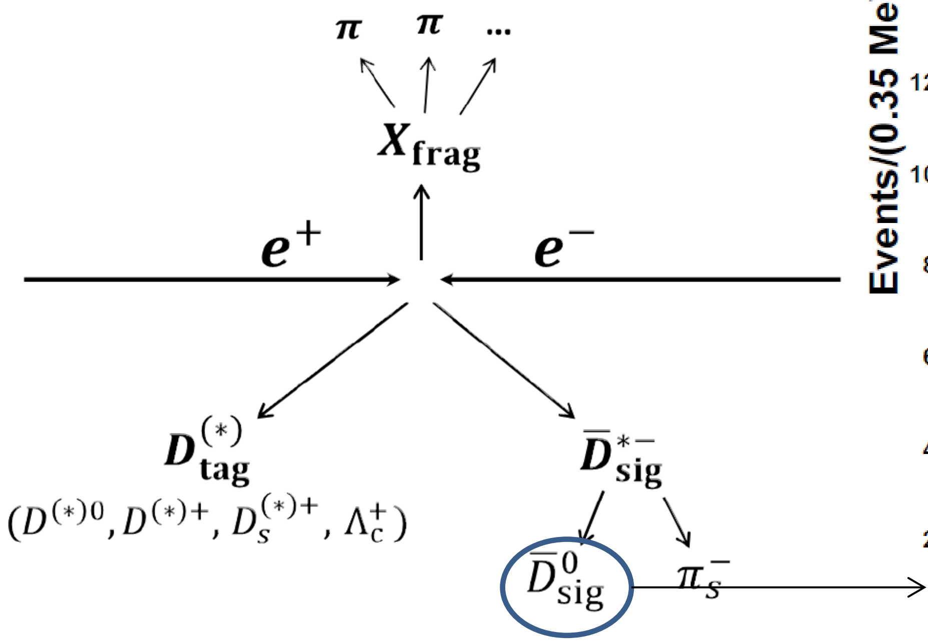


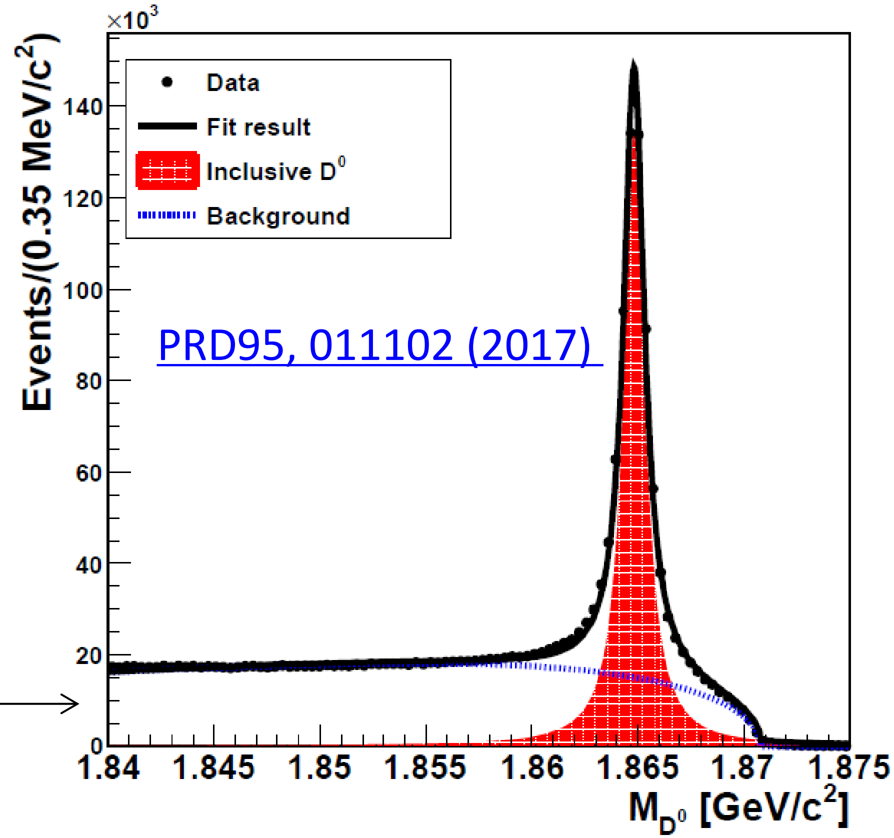
Decay diagrams of $D^0 \to \nu\bar{\nu}$.

- $X_{\rm frag}$: a few unflavored mesons
- Four types of $D_{\rm tag}$ are reconstructed using 23 decay modes
- $D^*_{\rm tag}$ are reconstructed in five decay modes: $D^0\pi^+$, $D^+\pi^0$, $D^0\pi^0$, $D^0\gamma$, $D_s^+\gamma$

$D^0 \to$ invisible final states

$$e^+e^- \to c\bar{c} \to D^{(*)}_{\rm tag} X_{\rm frag} \bar{D}^{*-}_{\rm sig}$$





$$M_{D^0} \equiv M_{\rm miss}(D^{(*)}_{\rm tag} X_{\rm frag} \pi^-_s)$$

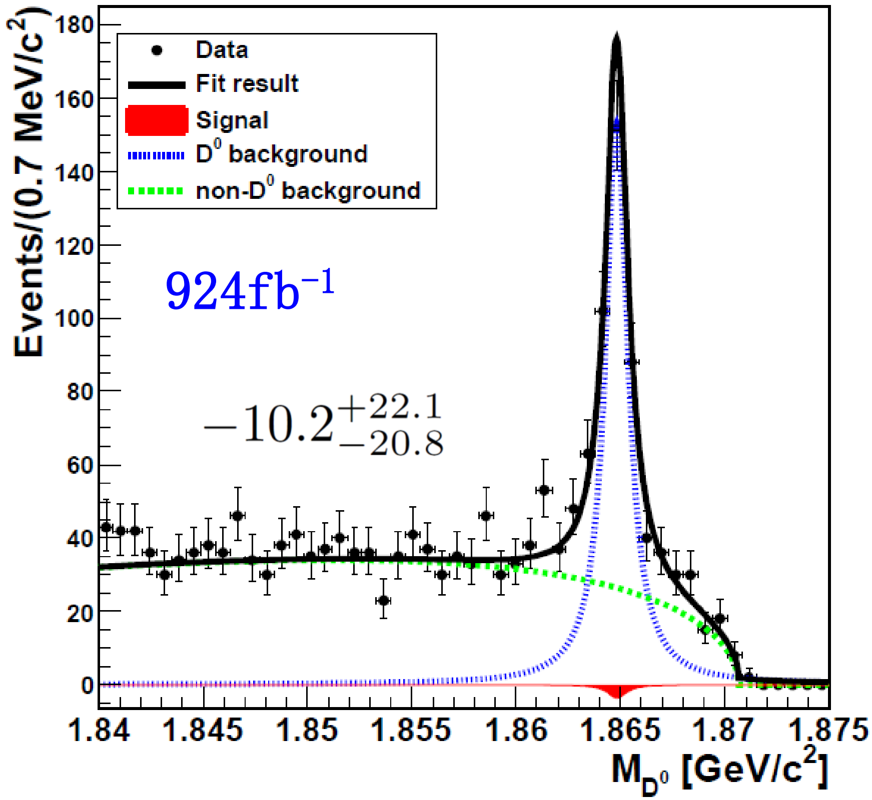
694505^{+1030}_{-1472} inclusive D^0 decays.

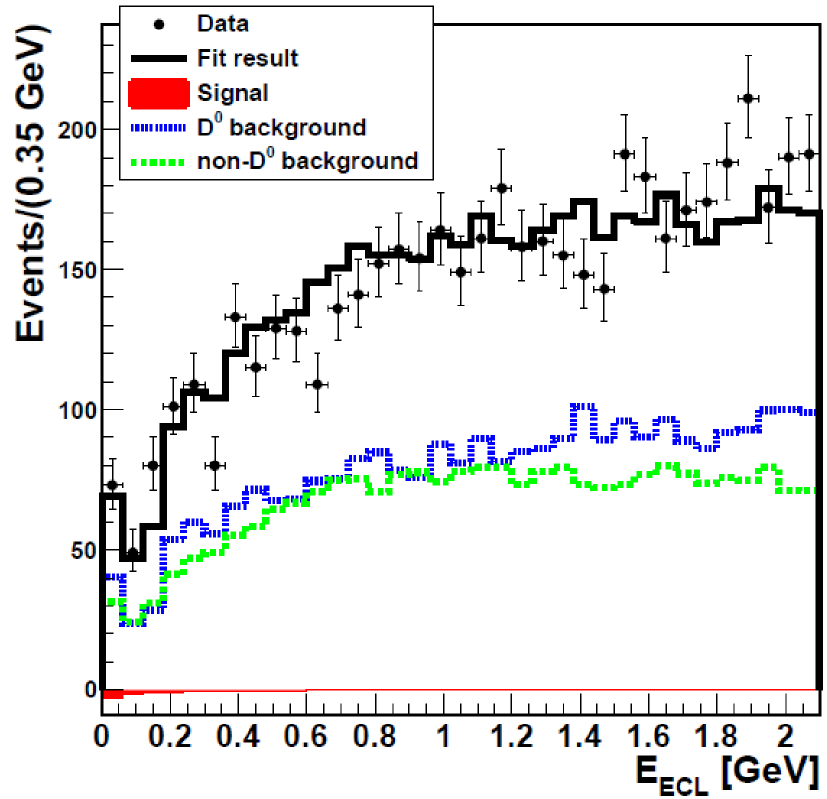
- $D^0 \to$invisible decays are selected by requiring no remaining final states associated with $\overline{D^0}_{\rm tag}$
- The residual energy in the ECL, E_{ECL}, is used to extract signal events
- 2D fit: $M(D^0)$, E_{ECL}

$D^0 \to$ invisible final states

- 2D fit: M(D^0), E_{ECL}

PRD95, 011102 (2017)





·No significant signal yield is found

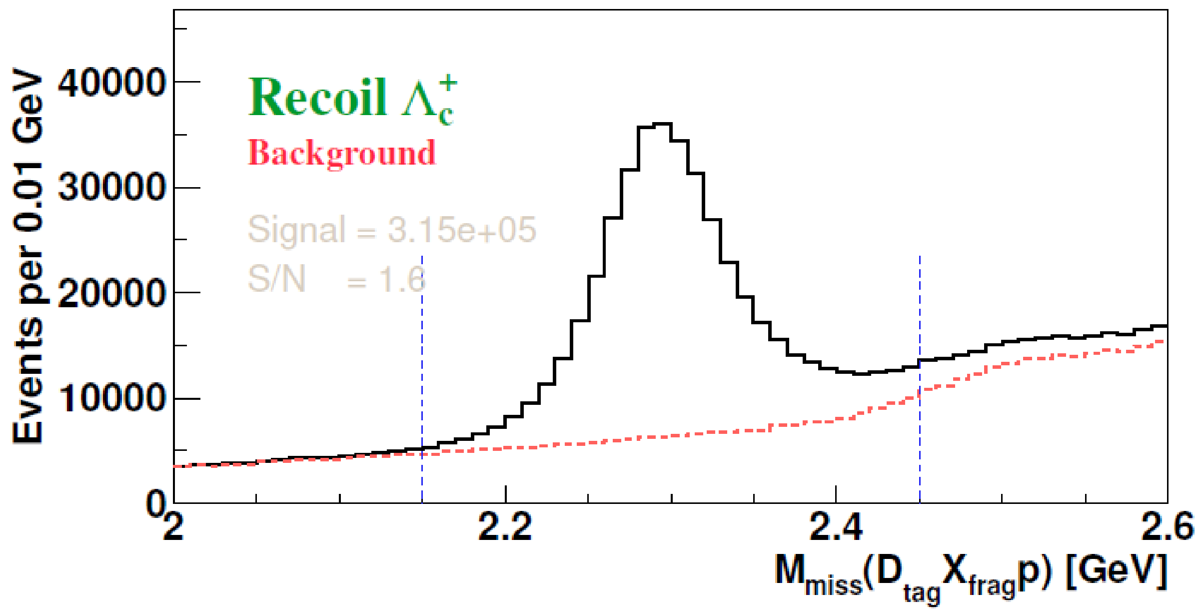
·Br($D^0 \to$invisible decays)<8.8×10^{-5} @ 90%C.L. with sys errors included

⇒ *Belle II yield in 50 ab^{-1}:* ***38 x 10^6 inclusive D^0 decays***

Inclusive $\Lambda_c^+ \to X$

$e^+e^- \to D_{tag} X_{frag}\, p\, \Lambda_c^+$

MC Simulation [5.5 ab^{-1}]



⇒ *Belle II yield in 50 ab^{-1}:* ***2.8 x 10^6 inclusive***

Unique sample:

- *allows measurement of Λ_c absolute branching fractions*
- *allows measurement of semileptonic Λ_c decays*
- *allows searches for Λ_c rare decays with missing energy*

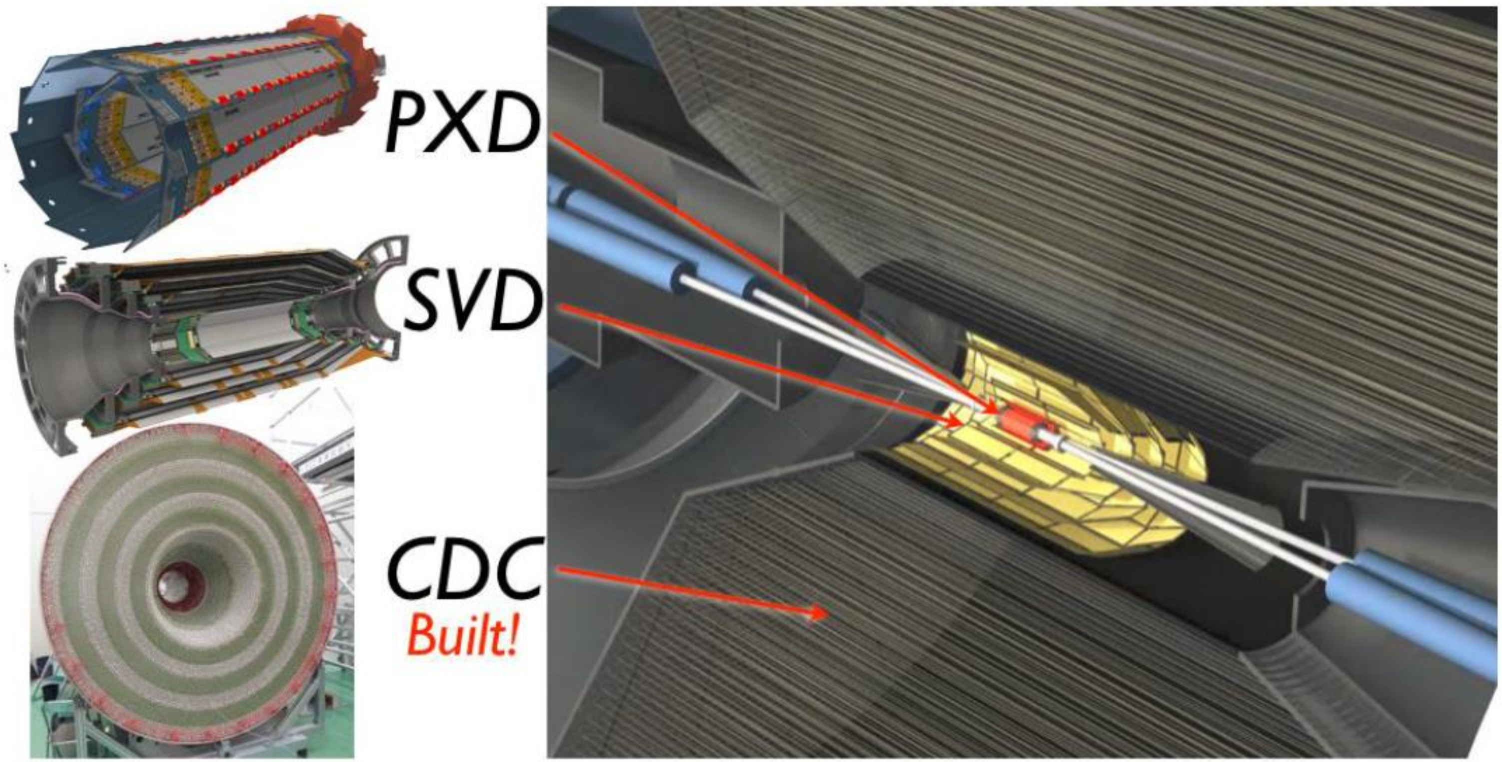
Summary

- Belle II at SuperKEKB which aims to achieve luminosity of 8.0×10^{35} $cm^{-2}s^{-1}$, will collect 50 ab^{-1} of dataset, which gives us a rich program for charm physics study.
- Many impacts on charm physics at Belle II with the large dataset are presented, benefiting from the improved tracking efficiency and vertex reconstruction,
  - D^0-$\overline{D}^0$ mixing and CP violation measurement with much more precision
  - more precise and exciting results for CP asymmetries
  - competitive in searches of several rare charm decays
- Belle II will achieve more precise measurements (mostly one order of magnitude improvement) of charm observables in the next decade, improving our knowledge of charm physics and searching for new physics beyond the Standard Model.

Let's look forwards to the charming news of charm physics from Belle II.

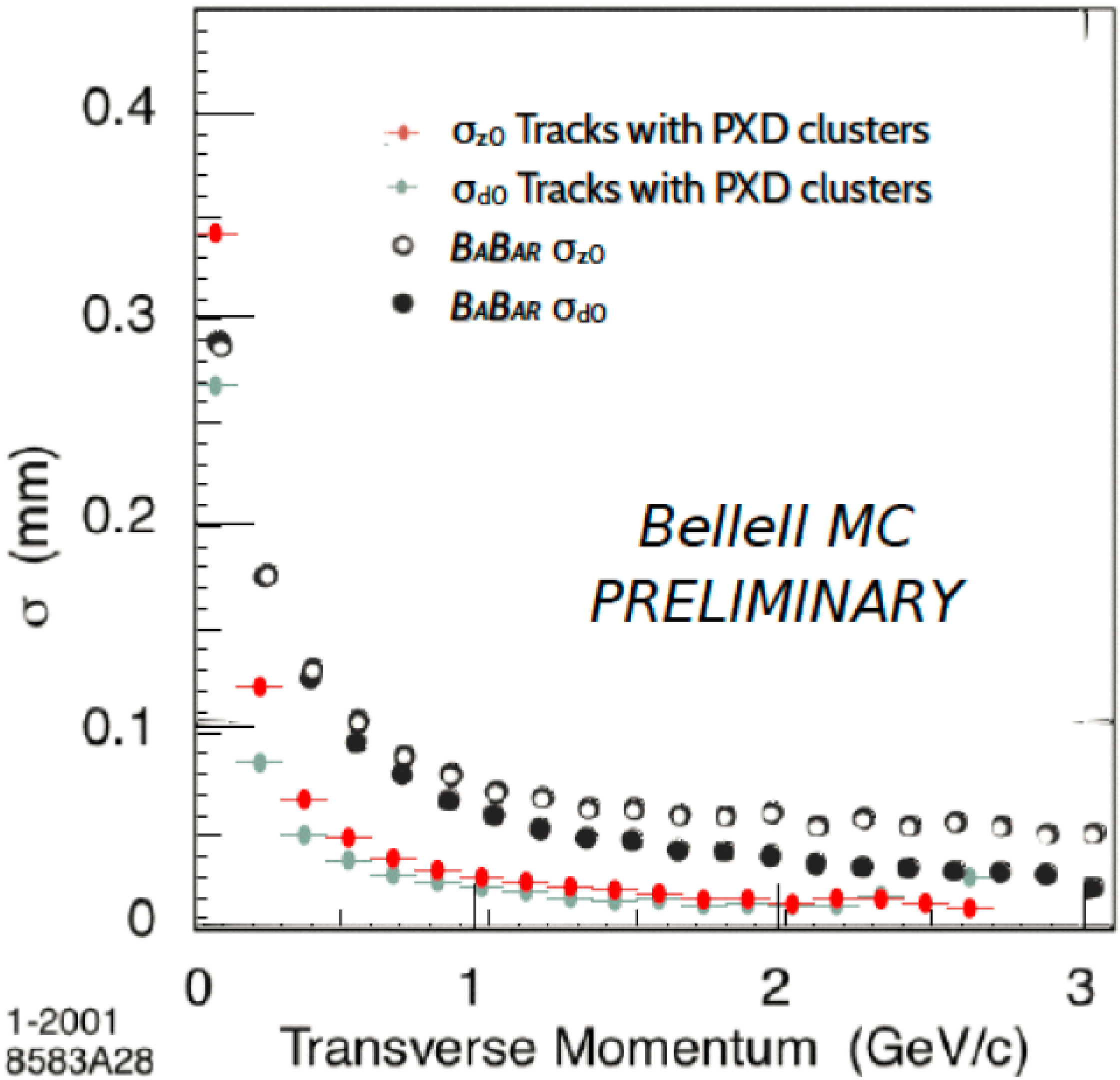
Thank you

The tracking system



Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

Improvements of vertex detector



- Extrapolations of detector performance confirmed after beam-test results, and realistic software implementation
- Currently, in spite of

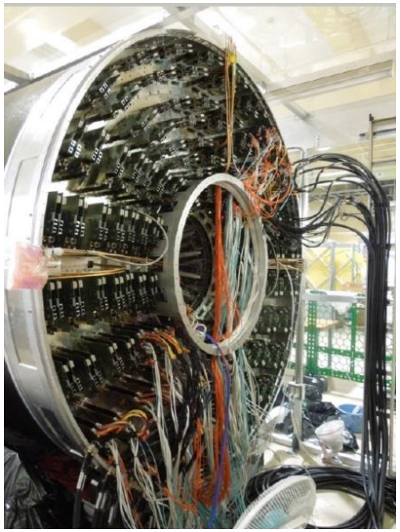
$$\langle\beta\gamma\rangle^{\text{Belle II}} = 28/44\cdot\langle\beta\gamma\rangle^{\text{Belle}}$$

$$\sigma_{\Delta_t}^{\text{Belle II}} \sim \frac{3}{4}\sigma_{\Delta t}^{\text{Belle}}$$

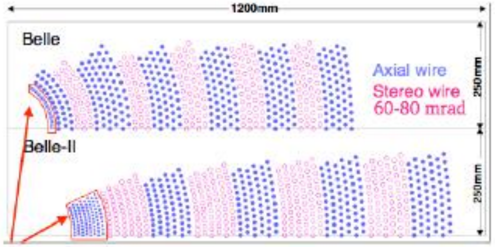
CDC

- Belle II Central Drift Chamber (CDC) is larger than that of Belle.
- Smaller drift cells with sense wires and more layers allow better charged track reconstruction and dE/dx measurement compared to Belle.
- Faster readout electronics

	Belle	Belle II
Radius of inner boundary (mm)	88	168
Radius of outer boundary (mm)	863	1111
Number of layers	50	56
Number of sense wires	8400	14336
Gas	HeC_2H_6	HeC_2H_6
Diameter of a sense wire (µm)	30	30



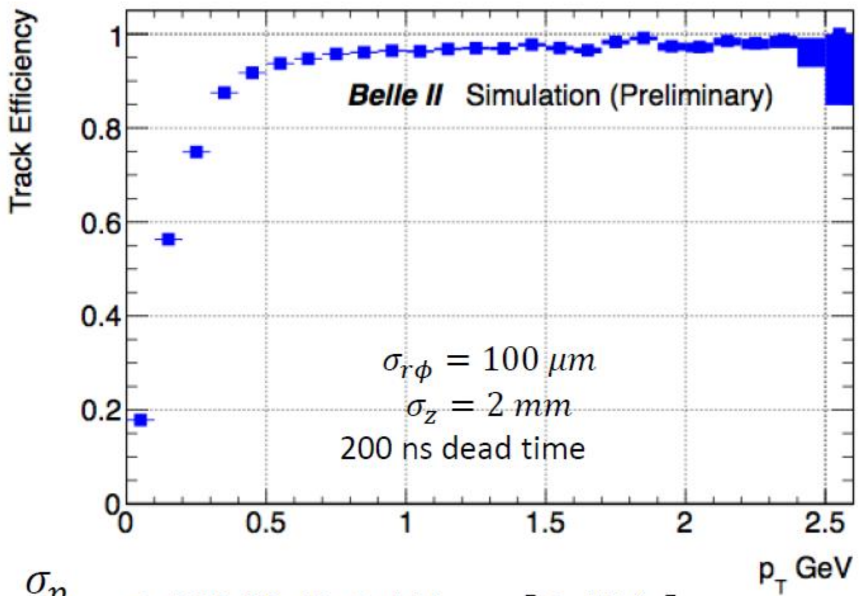
- Key roles:
  1. Reconstruct charged tracks with precision momentum measurements.
  2. Particle identification using measurements of $\frac{dE}{dx}$.
  3. Trigger for charged particles.

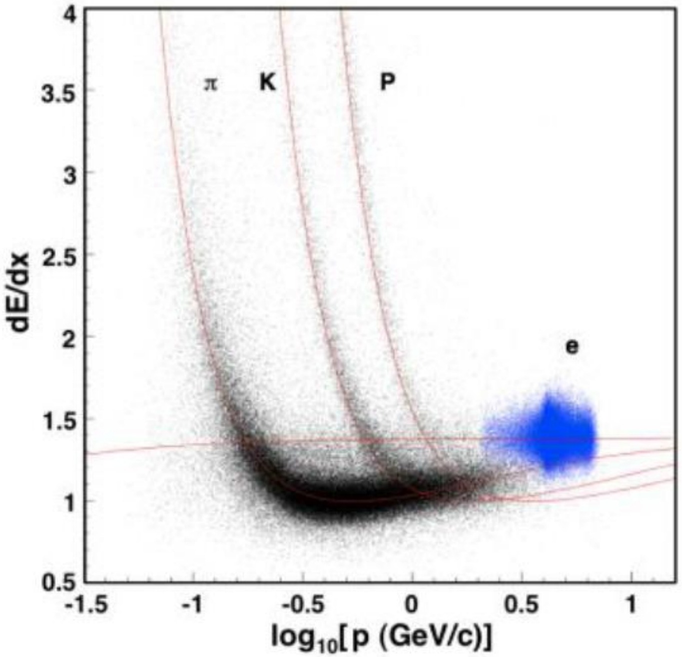


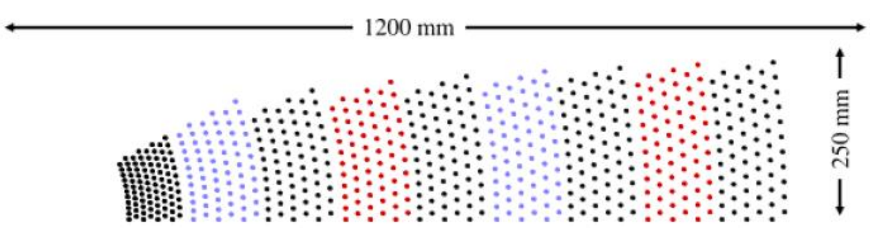
Central Drift Chamber (CDC)

Three important roles:

- Track reconstruction and momentum determination
- Particle identification via dE/dx
- Trigger for background rejection







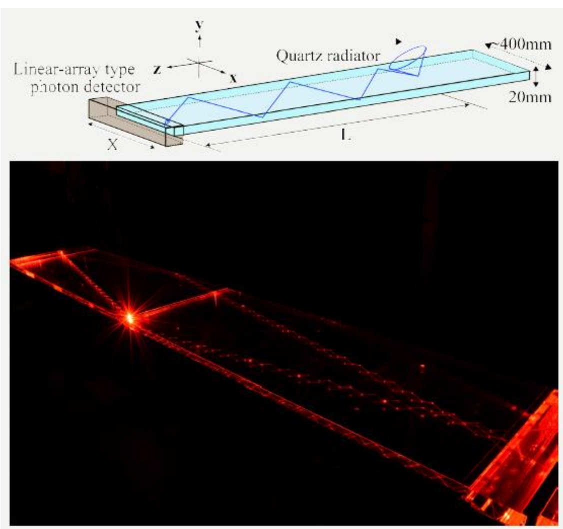
$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

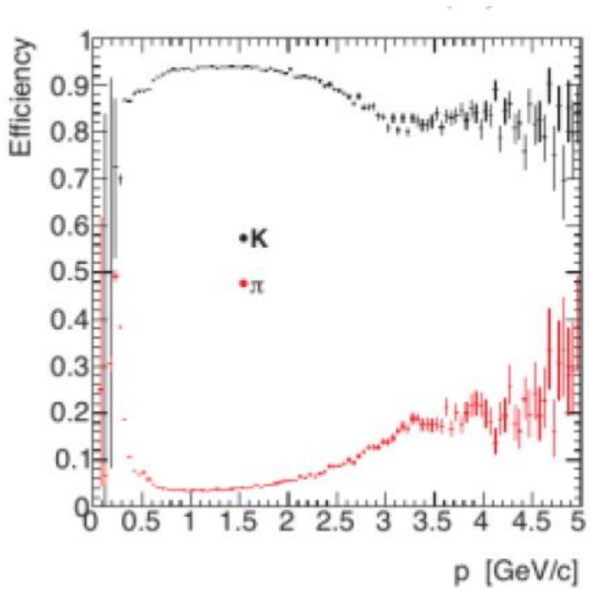
$$\sigma\left(\frac{dE}{dx}\right)\Big|_{\mathrm{MIP}} \sim 5\%$$

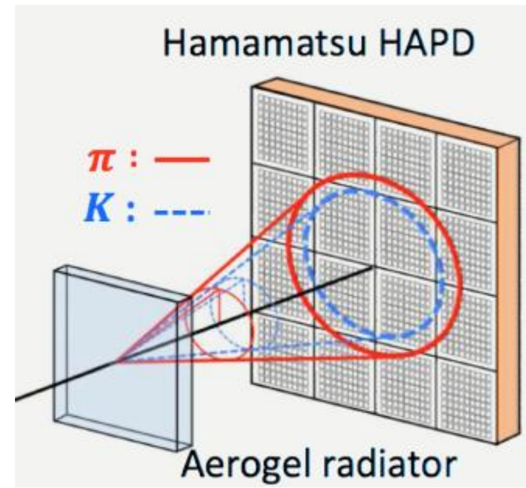
PID=TOP+ARICH

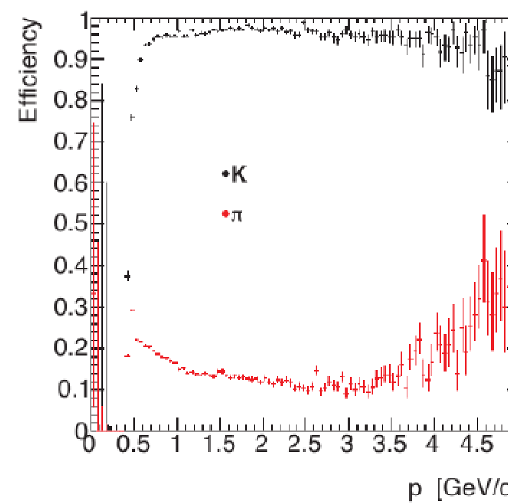
Two Cherenkov detectors for particle identification (mainly Kion and Pion)

- Barrel: Time of Propogation (TOP)
- Endcap: Aerogel Ring-Imaging Chernkov









Electromagnetic Calorimeter (ECL)

E.M. Calorimeter to measure:

Energy and angle of electrons/photons

Luminosity

Need upgrade due to high backgrounds:

- Barrel:

CsI(Tl) crystals reused

16.1 X_0 (30 cm)

New electronics 2 MHz waveform sampling

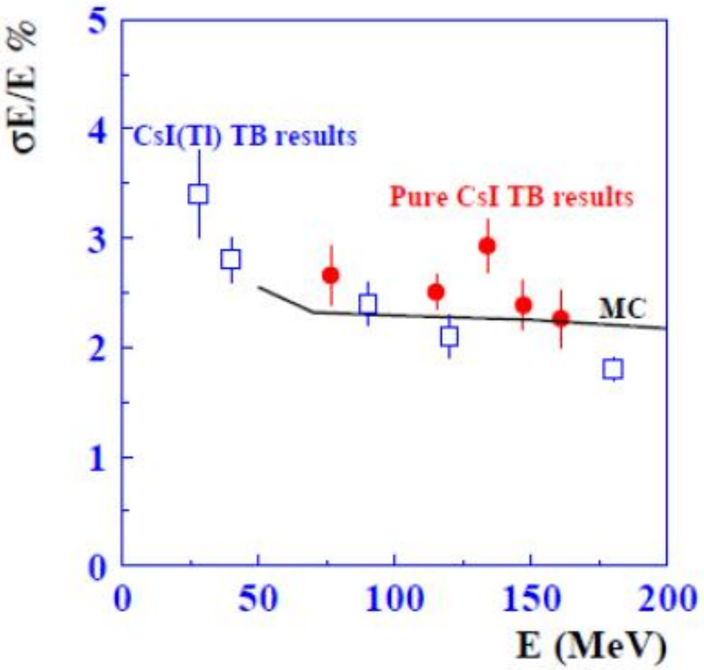
- Endcaps:

CsI(Tl), crystals reused

16.1 X_0 (30 cm)

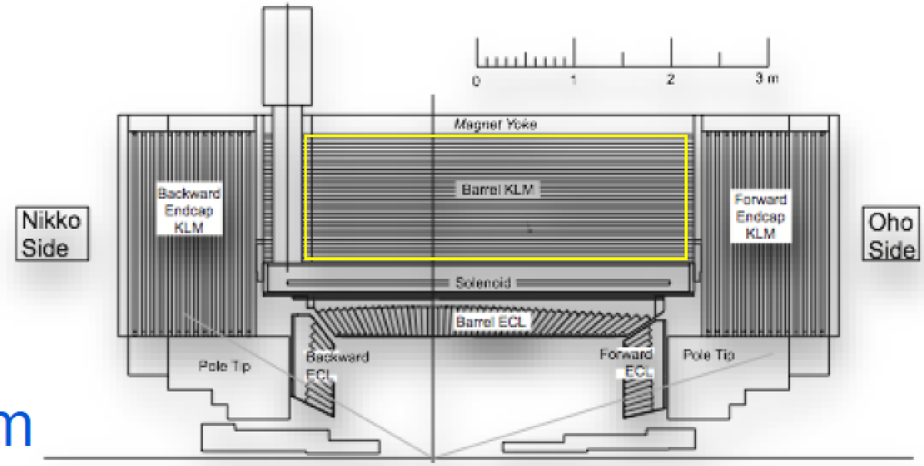
Replacement with pure CsI in future (under study)

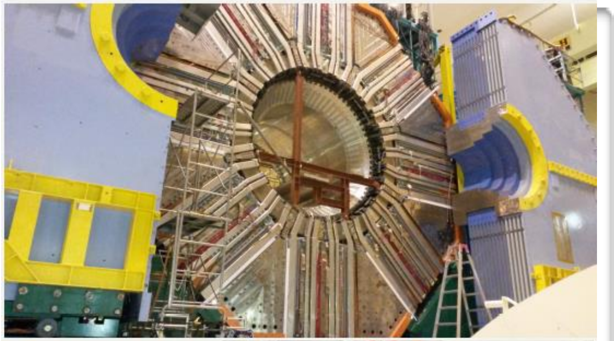
Time constant (shaping) 30 ns

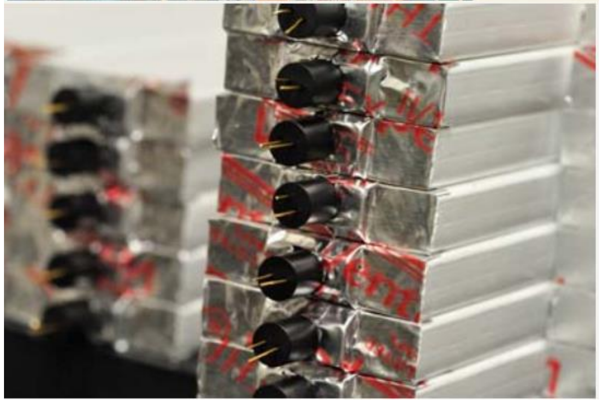


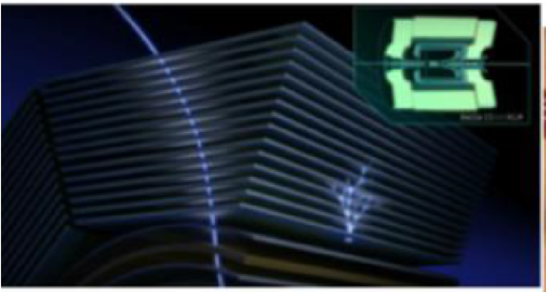
The KLong and Muon detector KLM

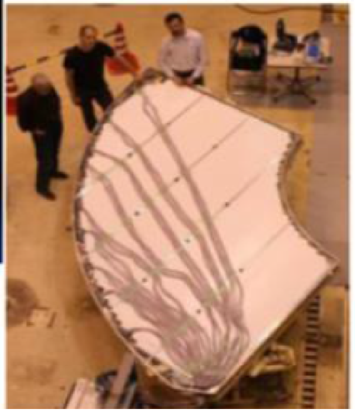
- 14 iron layers 4.7cm thick
- 15 barrel active layers
  - ✓2 x [scintillator strips + WLS + SiPM] ⇐ NEW
  - ✓13 x [double glass RPC + 5 cm orthogonal phi, z strips]
- 14 endcap active layers
  - ✓14 x [scintillator strips + WLS + SiPM] ⇐ NEW









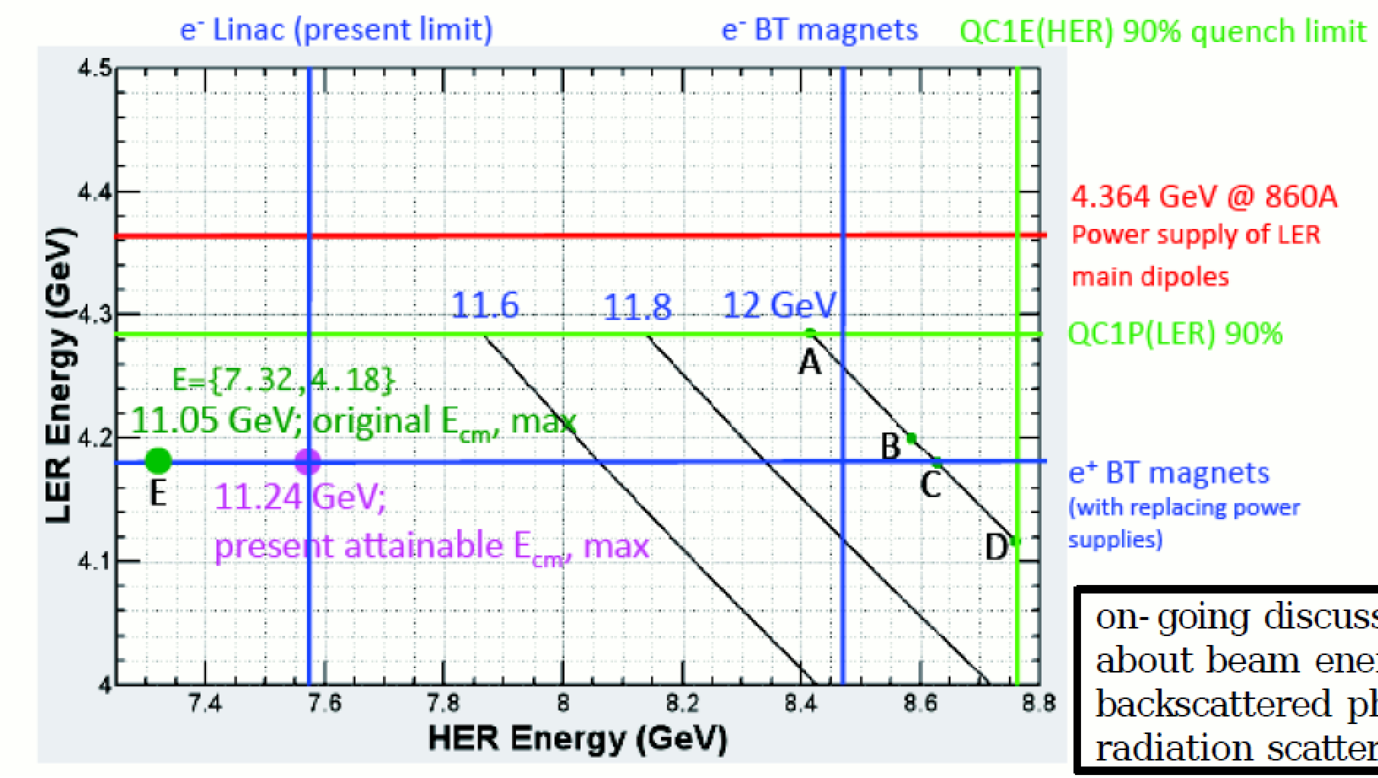


Higher energy run

from K. Akai,
BPAC Feb 2012

- Design: original design maximum energy is 11.05 GeV at $\Upsilon(6S)$
- Possible higher energy run (11.5 GeV – 12 GeV)?
  - If any, higher energy run will be after several years running at $\Upsilon(4S) \sim \Upsilon(6S)$
  - **present max E_{cm} is 11.24 GeV**, limited by e^- Linac and e^+ BT magnets
  - In order to inject the electron beam to HER at the required energy for 12 GeV operation, there must be huge reinforcement of Linac (replacement of S-band with C-band, 7.571 → 8.6 GeV

11.24 GeV region: $\Lambda_b \overline{\Lambda}_b$ threshold



e.g. [arXiv:1211.0103]

on-going discussion with SuperKEKB people about beam energy measurement using backscattered photons produced by laser radiation scattered head-on the beams