Belle II experiment at SuperKEKB

- Physics goals
- SuperKEKB accelerator
- Belle II detector
- Schedule

Maria Różańska, INP-PAN Kraków
representing the Belle II Collaboration

XXII DIS Workshop,
Warsaw , 28 April - 2 May 2014

Belle II @ SuperKEKB is a new facility at the intensity frontier for searches of physics beyond the stnadard model (new physics) with *B* mesons, charm mesons and τ leptons.

SuperKEKB – major upgrade of the KEKB *B* factory at KEK (Tsukuba)

$$e^+e^- \to \Upsilon(4S) \to \bar{B}B$$

$$L = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

$E(e^+) = 4$ GeV, $E(e^-) = 7$ GeV

Belle II – upgraded Belle detector

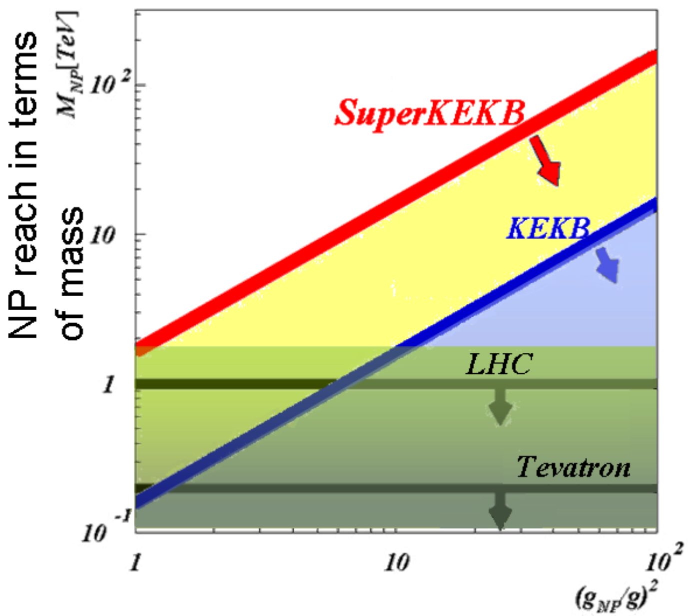
to accumulate $L_{int} \approx 50\ \mathrm{ab^{-1}}$ by 2022

55 billion $B\bar{B}$ pairs, 47 billion $\tau^+\tau^-$ pairs

- **Complementary to direct searches of NP at the energy frontier**:

  - Indirect searches of NP effects in rare processes (suppressed in the SM) allow us to *explore regions of the parameter space that are not covered at LHC;*
  - If the LHC sees direct evidence of new physics, it is plausible to expect NP effects in *B*/*D*/τ decays.
    → Flavour structure of new physics?
    → CP violation in new physics?

Illustrative reach of NP searches

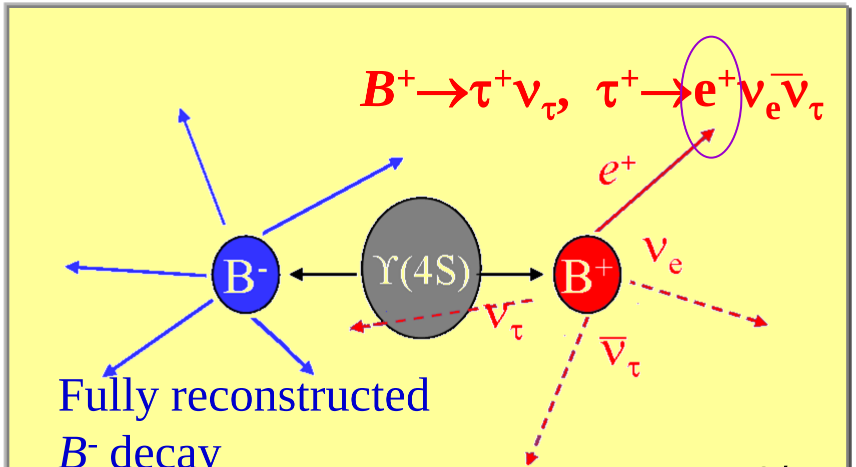


- **Complementarity to indirect NP searches**:

  - ***LHCb*** – huge *B* and charm statistics:
    rare and very rare $B_{(s)}$ decays to clean final states,
    e.g. $B_{s(d)} \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-$,…

  - **Belle II** – well-defined initial state:
    - final states consisting of neutrals, *e.g.* $B \to \pi^0\pi^0$, $B \to K_S\pi^0$, $B \to K_S\pi^0\gamma$, $B \to K_SK_SK_S$ …
    - final states with multiple missing particles (ν's), *e.g.* $B \to \tau\nu_\tau$, $B \to D^{(*)}\tau\nu_\tau$,…
    - inclusive modes, *e.g.* $B \to X_s\gamma$, $B \to X_s l^+l^-$,…

"off-line B meson beam"



Few examples of expected sensitivities @ 50 ab^{-1} for observables sensitive to NP:

Multiple ν's:

$\mathcal{B}(B \to \tau\nu)$ ±3%, $\mathcal{B}(B \to D^{(*)}\tau\nu)$ ±3%

Inclusive:

$\mathcal{B}(B \to X_s\gamma)$ ±6% , $A_{CP}(B \to X_s\gamma)$ ±5 $\cdot 10^{-3}$,

Neutrals:

$S(B \to K_S\pi^0\gamma)$ ±0.03, $S(B \to K_SK_SK_S)$ ±0.04,

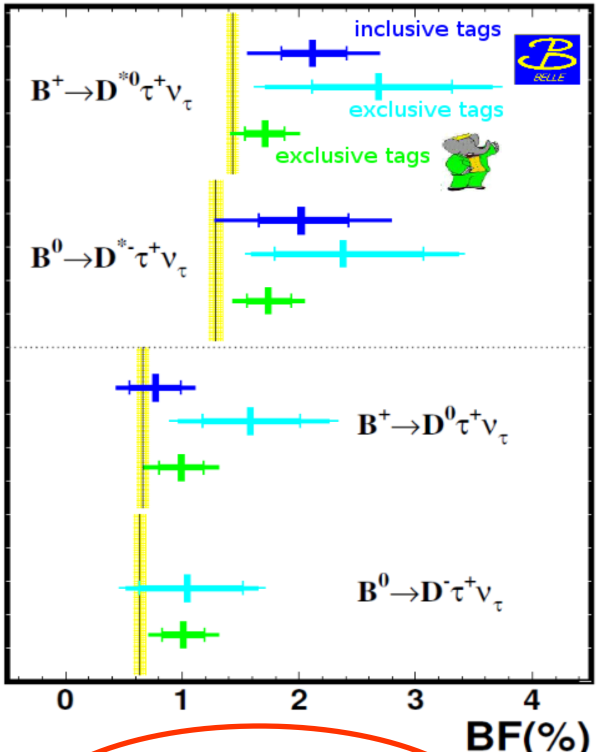
$A_{CP}(B \to K_S\pi^0)$ ± 0.04

$\mathcal{B}(\tau \to \mu\gamma)$ ±3 $\cdot 10^{-9}$ (90% U.L.) (lepton flavour violation)

(from arXiv:1002.5012)

Current measurements of $\mathcal{B}(B \to D^{(*)}\tau\nu)$ are systematically above SM predictions (and disfavour 2HDM II).

Belle: PRL 99 (2007)191807, PRD 82 (2010) 072005, arXiv:0910.4301; BaBar: PRL 109 (2012)101802
SM: M. Tanaka, Y. Watanabe, PRD 82 (2010)034027, S. Fajfer et al., PRD 85 (2012)094025



Tensions between measurements and SM predictions

Puzzling CP violation in $B \to K\pi$ *(Belle, Nature 452 (2008) 332)*

CPV from interference between tree and penguin amplitudes

$$\Delta A \equiv A_{CP}^{B^0 \to K^+\pi^-} - A_{CP}^{B^+ \to K^+\pi^0} = -0.122 \pm 0.022$$ (HFAG 2013)

$\Delta A \approx 0$ in SM, NP (or hadronic effects) can change it

Model independent sume rule to test SM

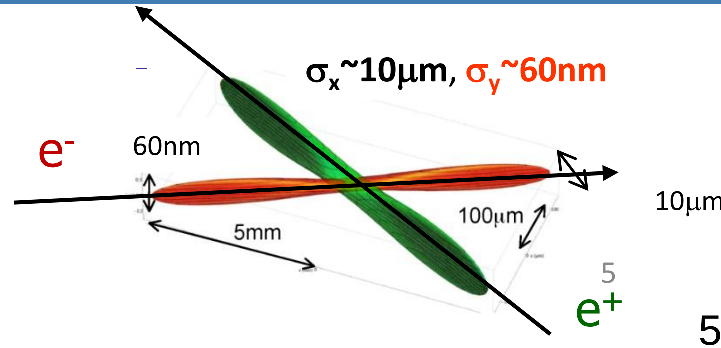
$$A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+} \frac{\mathcal{B}(B^+ \to K^0\pi^+)\tau_{B^0}}{\mathcal{B}(B^0 \to K^+\pi^-)\tau_{B^+}} = A_{CP}^{K^+\pi^0} \frac{2\,\mathcal{B}(B^+ \to K^+\pi^0)\tau_{B^0}}{\mathcal{B}(B^0 \to K^+\pi^-)\tau_{B^+}} + A_{CP}^{K^0\pi^0} \frac{2\,\mathcal{B}(B^0 \to K^0\pi^0)}{\mathcal{B}(B^0 \to K^+\pi^-)}$$

M. Gronau, PLB 627 (2005) 82, D. Atwood, A. Soni, PRD 58 (1998) 036005

SuperKEKB machine parameters

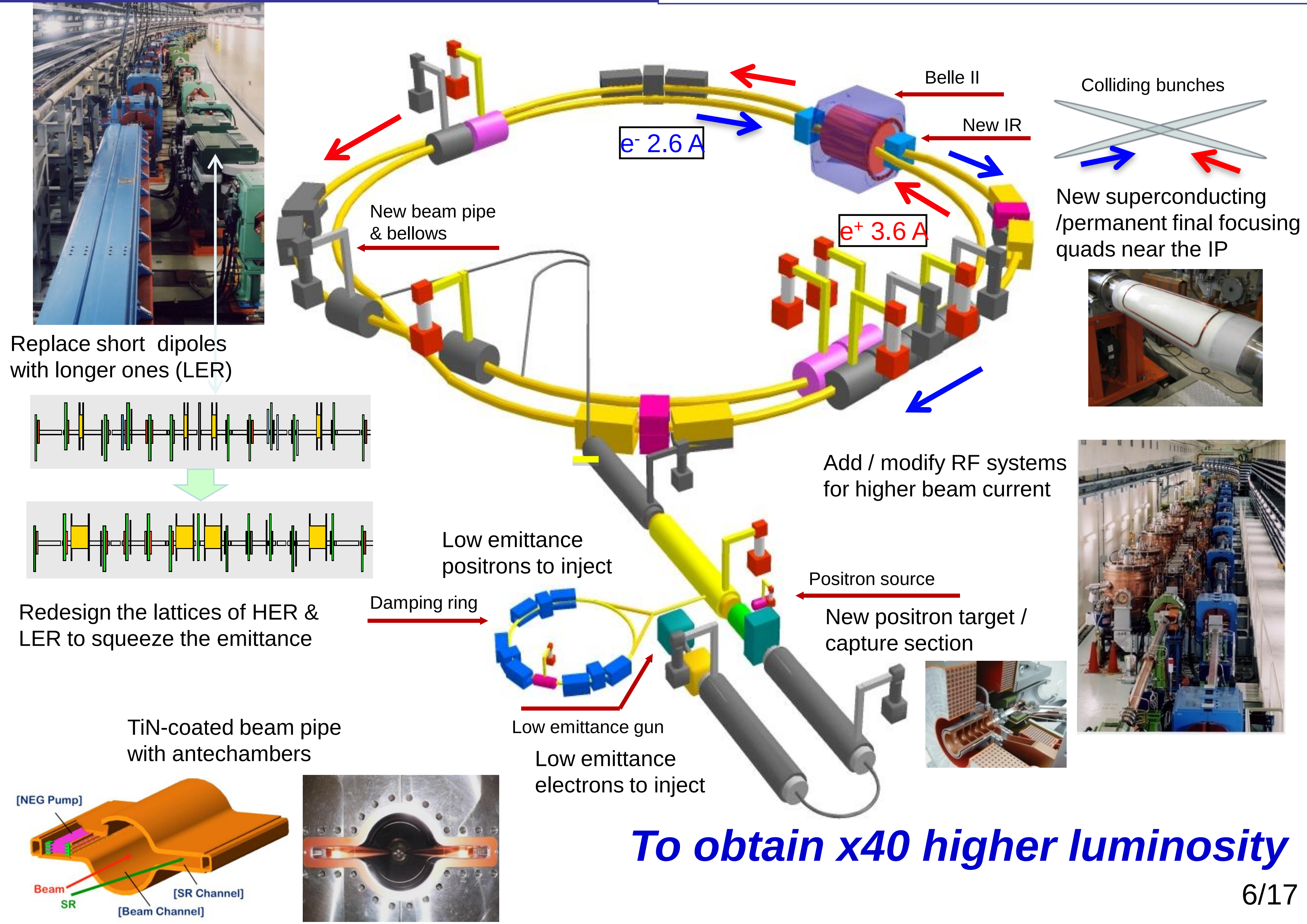
parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

- Small beam size - "nano-beam" (vertical spot size is ~50nm !!)
- ~2 times higher currents
- Smaller boost to improve LER lifetime



From KEKB to SuperKEKB

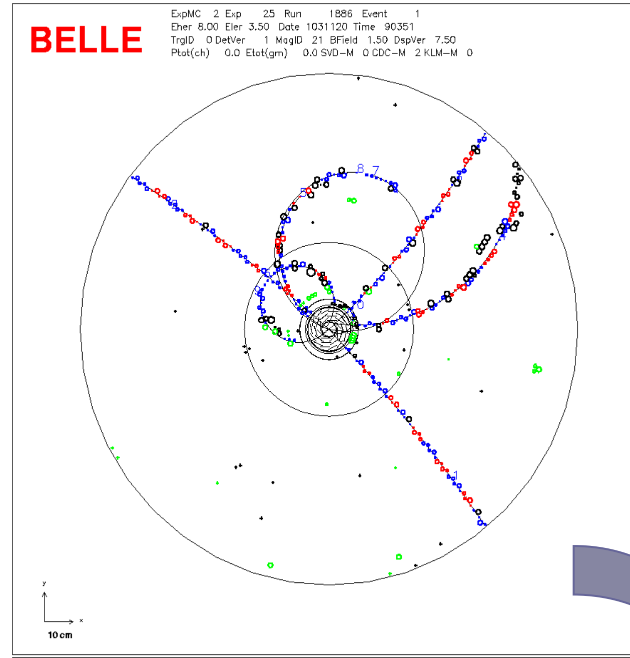
Belle II @ SuperKEKB

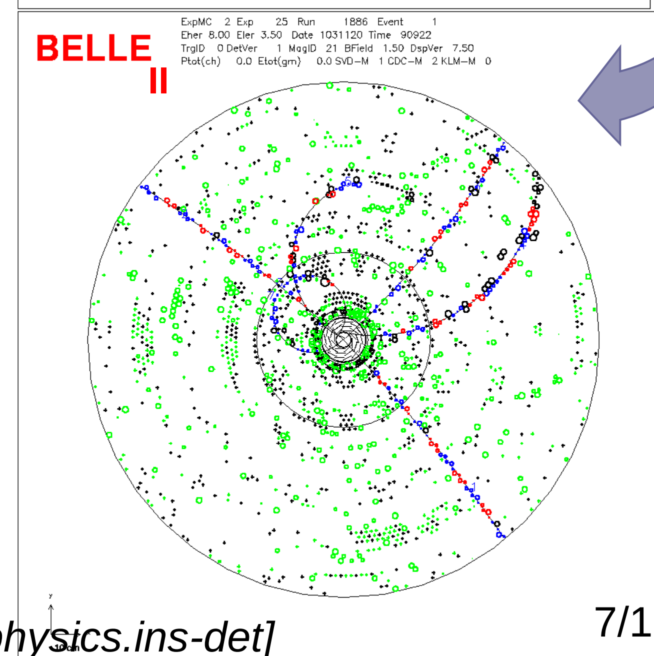


Detector upgrade — Belle II @ SuperKEKB

Critical issues at L= $8\times10^{35}/cm^2/s$:

- Higher background (×10-20)
  - radiation damage and higher occupancy
  - fake hits and pile-up noise in EM calorimeter
- Higher event rates (×10)
  - higher rate trigger (L1 trigg. 0.5→30 kHz)
  - DAQ, computing
- Targeted improvements:
  - increase hermeticity
  - improve IP and secondary vertex resolution
  - improve K_s and π^0 efficiency
  - improve K/π separation
  - add μ-ID and PID in end-caps
  - improve K_s and π^0 efficiency
  - precise timing for neutrals



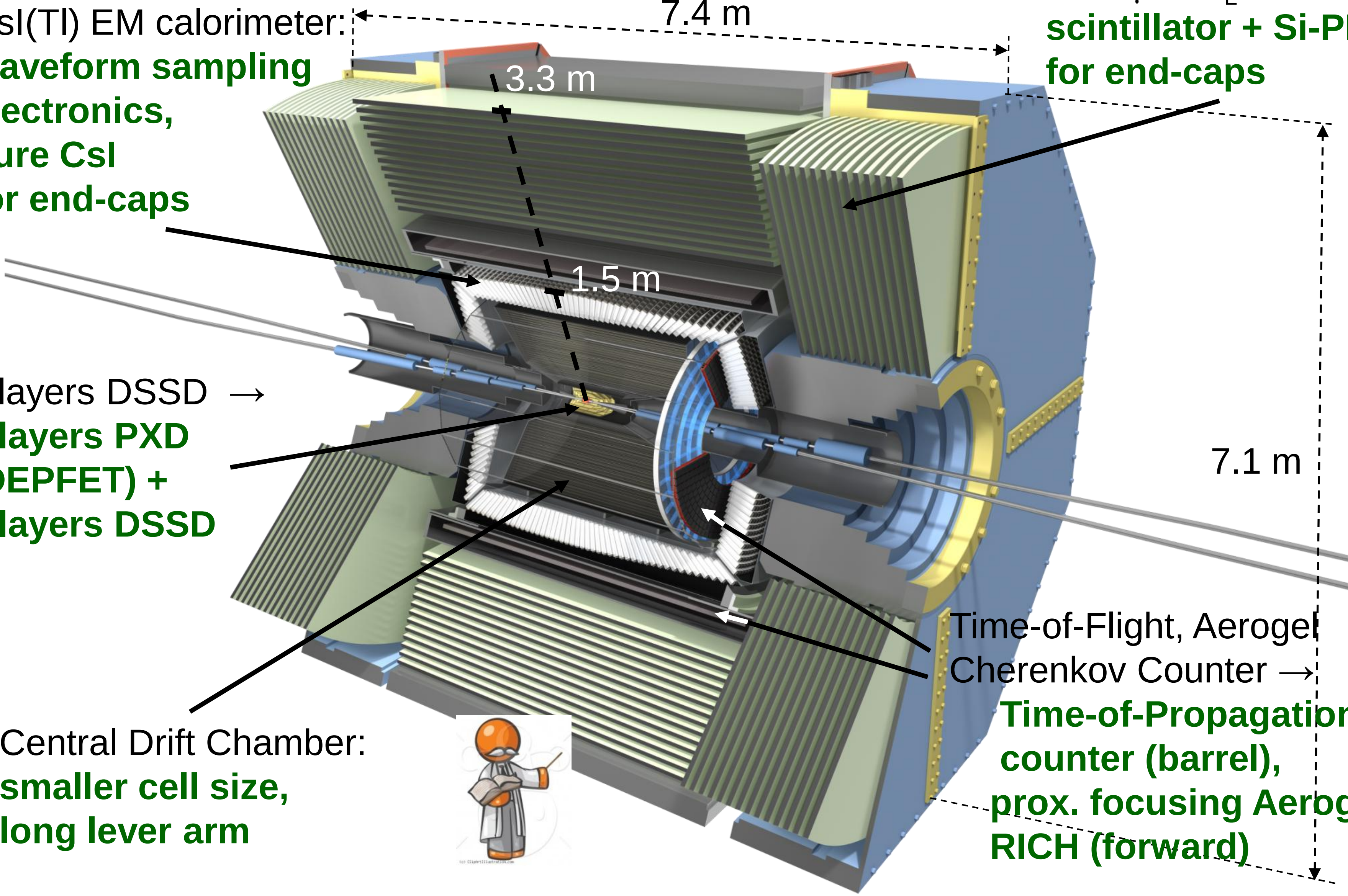


Details in Belle II Technical Design Report, arXiv:1011.03252 [physics.ins-det]

Belle II

CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for end-caps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps



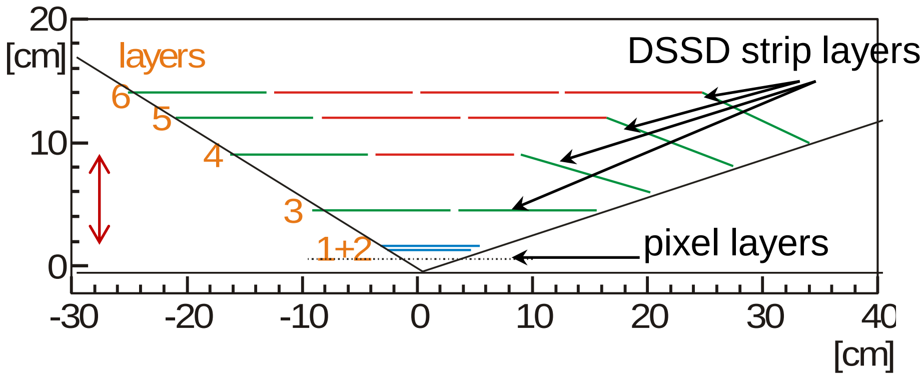
4 layers DSSD →
2 layers PXD (DEPFET) + 4 layers DSSD

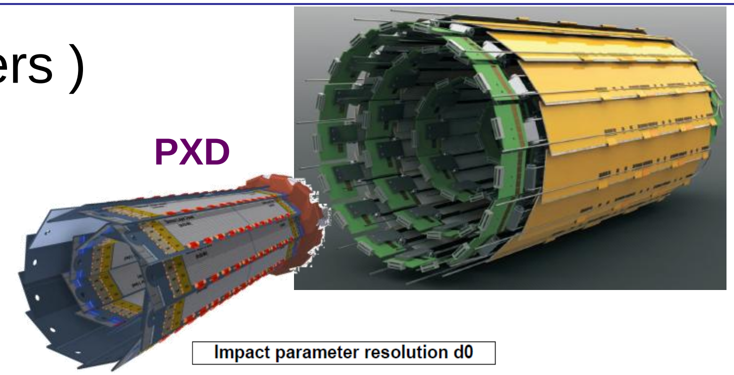
Time-of-Flight, Aerogel Cherenkov Counter →
Time-of-Propagation counter (barrel), prox. focusing Aerogel RICH (forward)

Central Drift Chamber:
smaller cell size, long lever arm

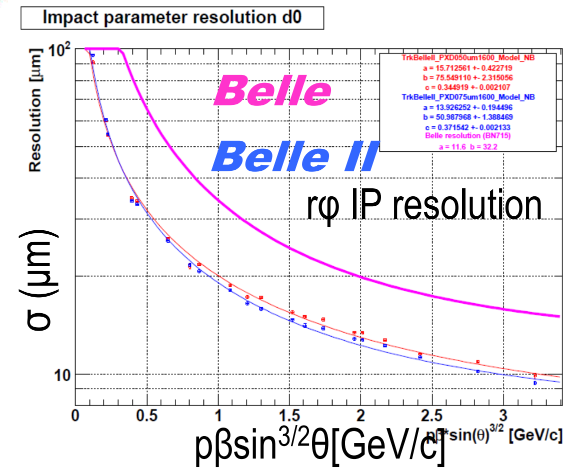
Inner tracking (PXD, SVD)

- PXD + SVD in Belle II (in Belle only strip layers)



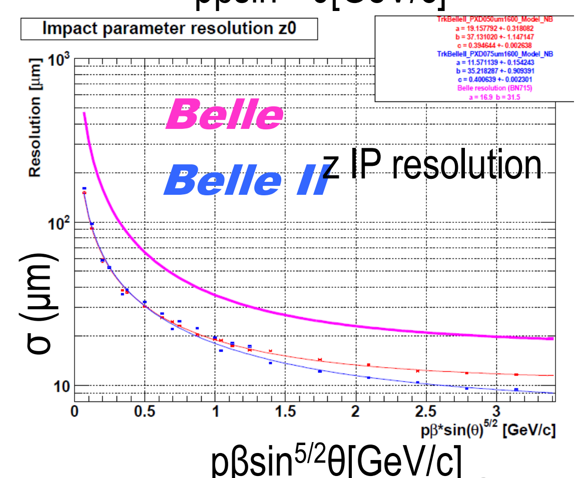


- Pixels in novel DEPFET technology: thin (75μm) sensors give little multiple scattering, close to the IR
- Improved IP resolution and low momentum tracking ($p_T < 100$MeV), 30% larger eff. of $K_S \to \pi^+\pi^-$ with vertex info

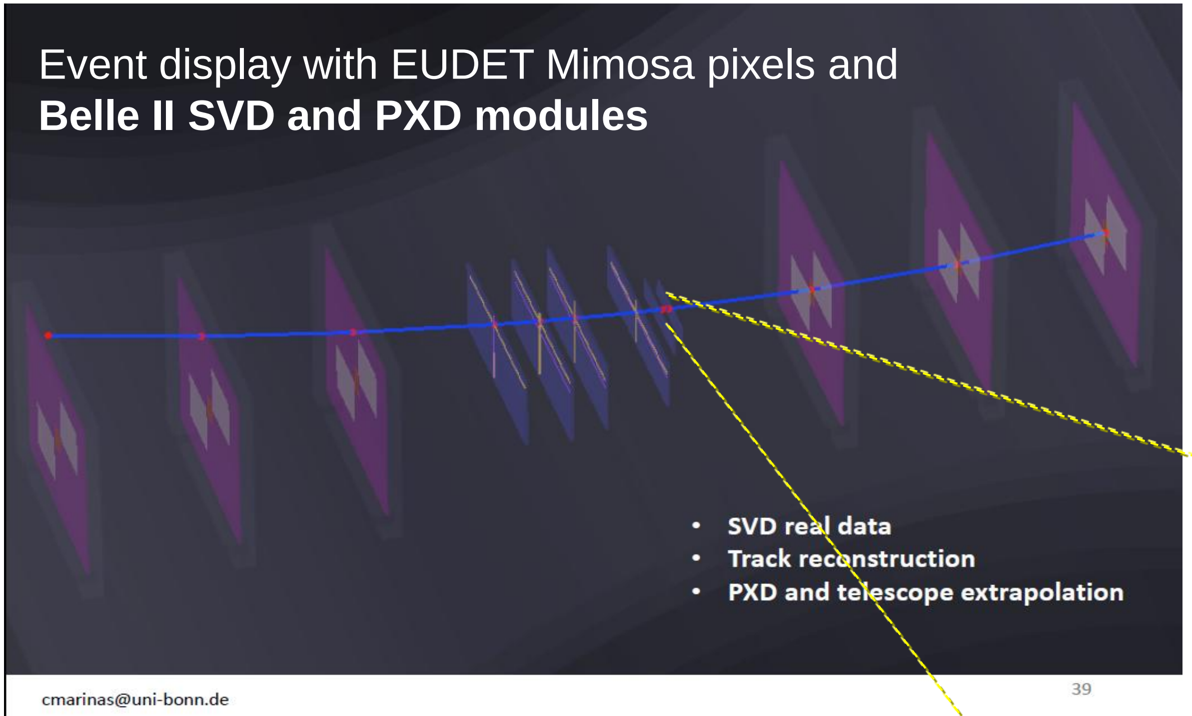


Mechanical mockup of pixel detector

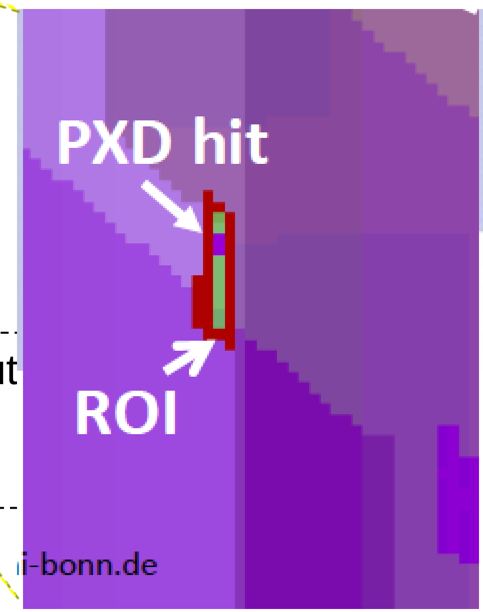
DEPFET sensor



Successful beam tests at DESY, Jan 2014, with prototypes of all components integrated.



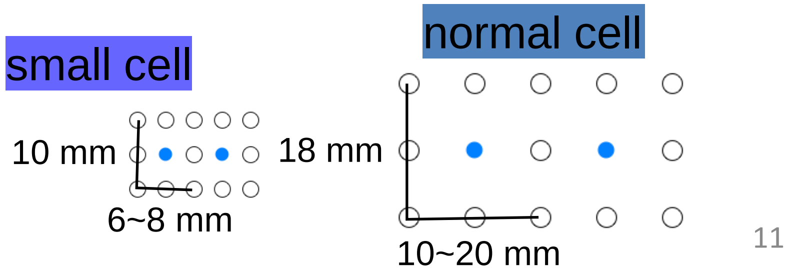
To reduce the Gbit/s data volume from pixels, read out only Regions Of Interest (ROI)'s from projected SVD track segments.

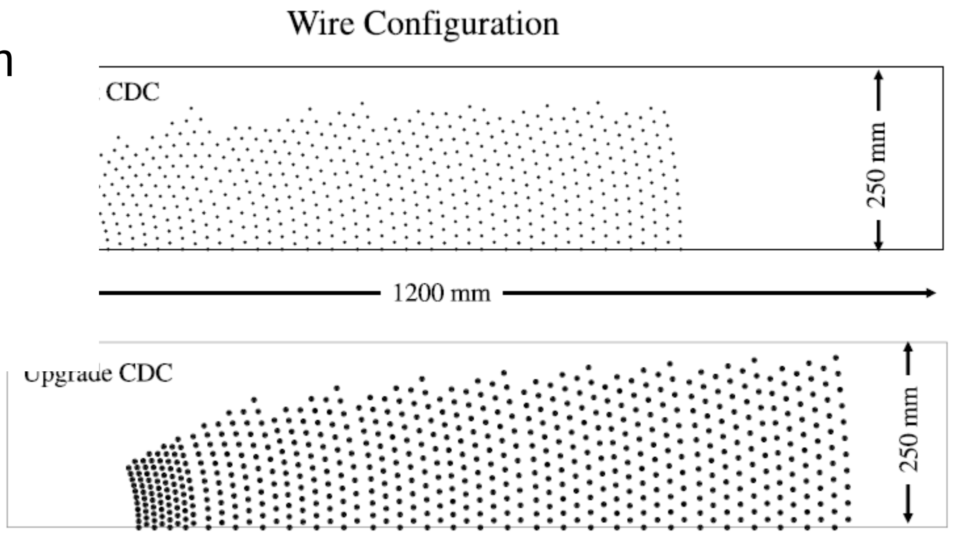


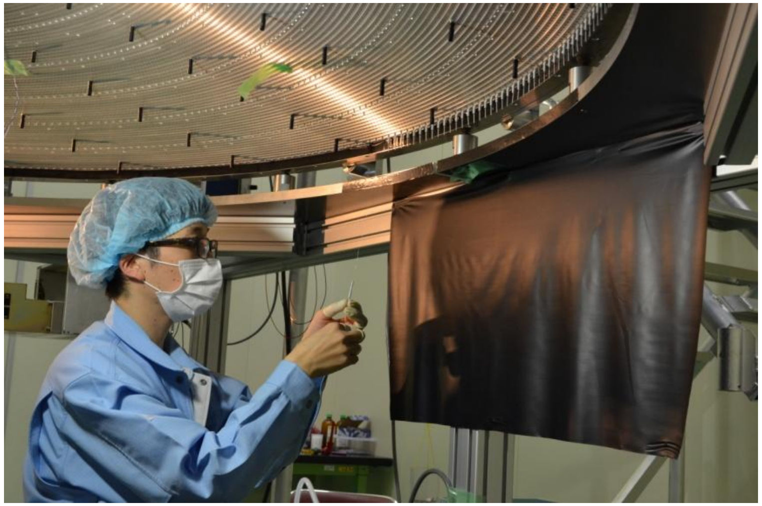
Hit found inside the PXD ROI

Central drift chamber (CDC)

- Extended outer radius, longer lever arm → improved momentum and dE/dx resolutions
- Larger inner radius, smaller cells near beampipe → more background-hard



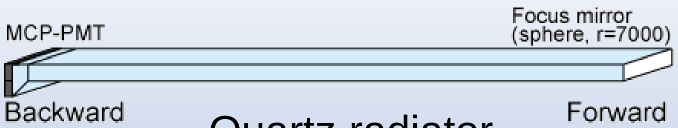




Wire stringing in a clean room in Fuji Hall

CDC wire stringing (~51k wires) is done.

Barrel PID: Time of Propagation Counter

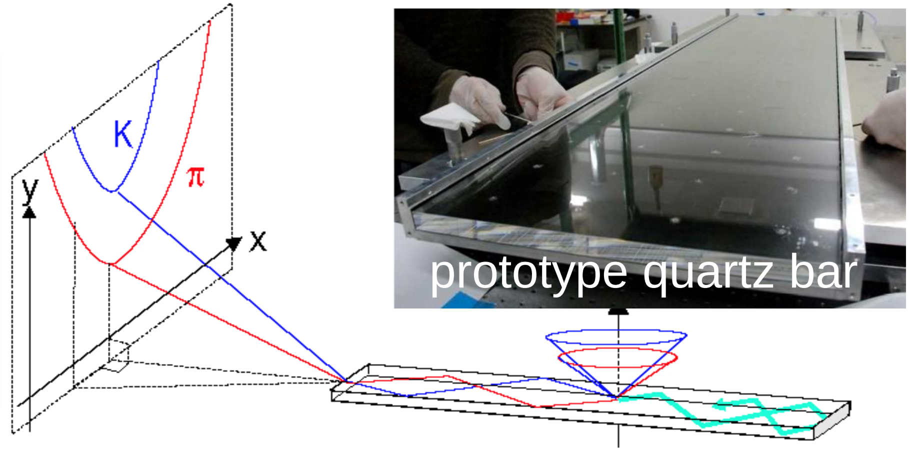


Quartz radiator

Focusing mirror

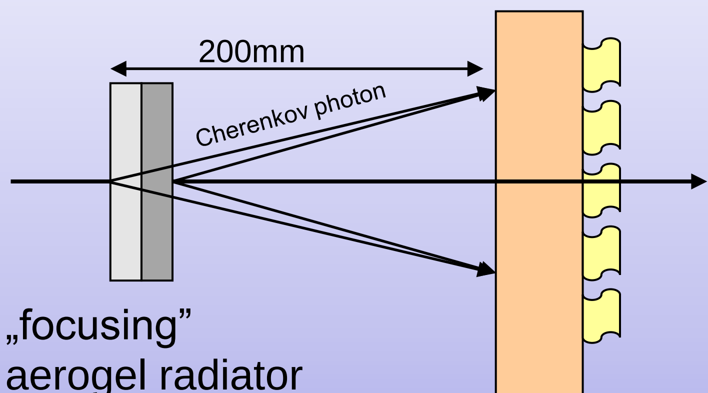
Small expansion block

(ALD) MCP-PMT (measure t, x and y)



iTOP: partial Cherenkov ring reconstruction from x, y and t of propagation using info from PMTs (40 ps resolution)

Endcap PID: Aerogel RICH



„focusing" aerogel radiator

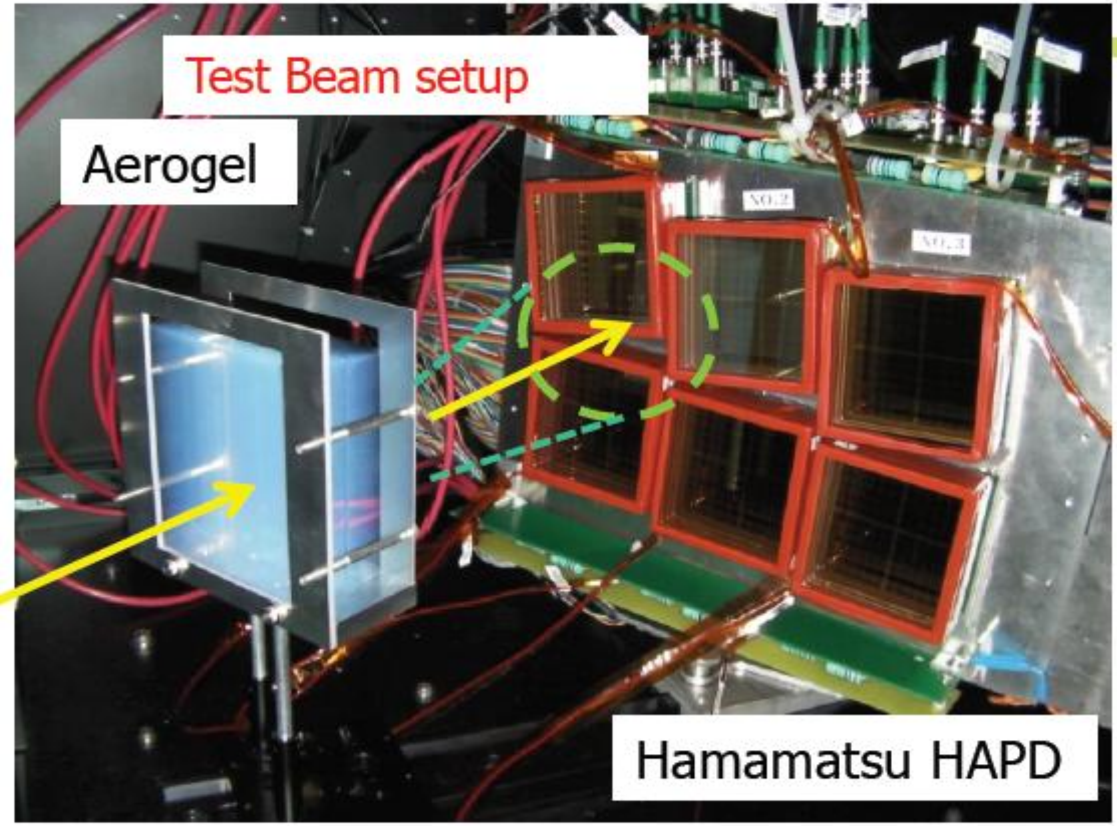
n~1.05

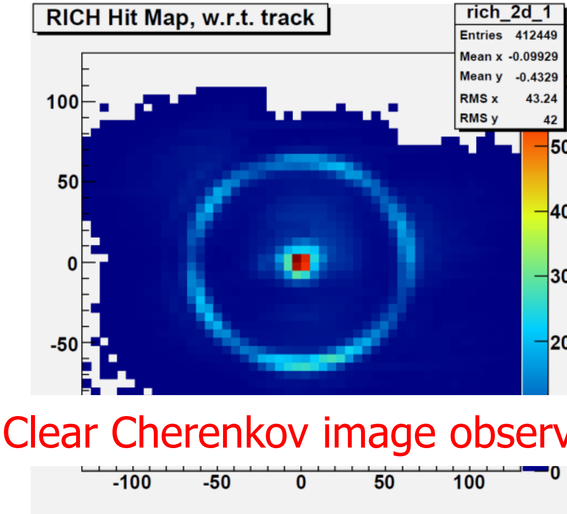
Hamamatsu HAPD + new ASIC

Employ multiple layers with different refractive indices
⇒ Cherenkov images from individual layers overlap on the photon detector; increases the number of photons without degrading the resolution

⇒ Improved K/π separation in wide momentum range

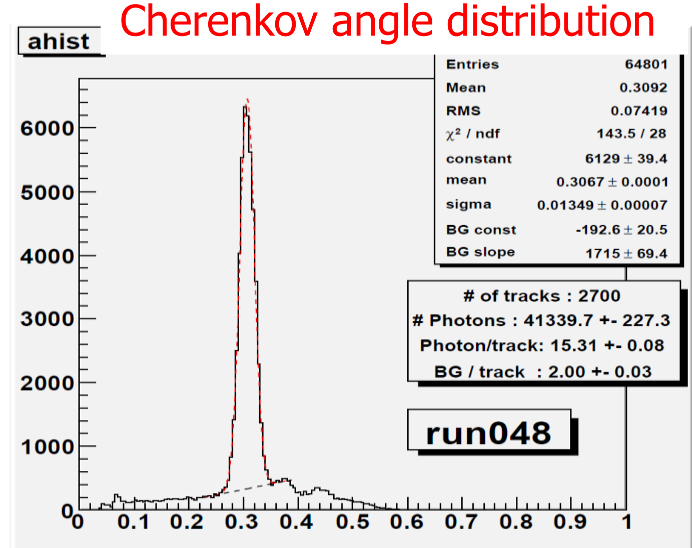
Test beam results for Aerogel RICH





Clear Cherenkov image observed

Cherenkov angle distribution



6.6 σ π/K at 4GeV/c !

EM calorimeter

barrel: new electronics with 2MHz wave form sampling to measure time and amplitude - fake clusters suppressed by factor 7

endcap: pure CsI crystals; faster performance and better rad. hardness than Tl doped CsI (later upgrade)

K_L and muon detector

Resistive Plate Chambers to measure hadronic K_L showers and muon tracks

Background in barrel consistent with cosmic ray flux → no change needed

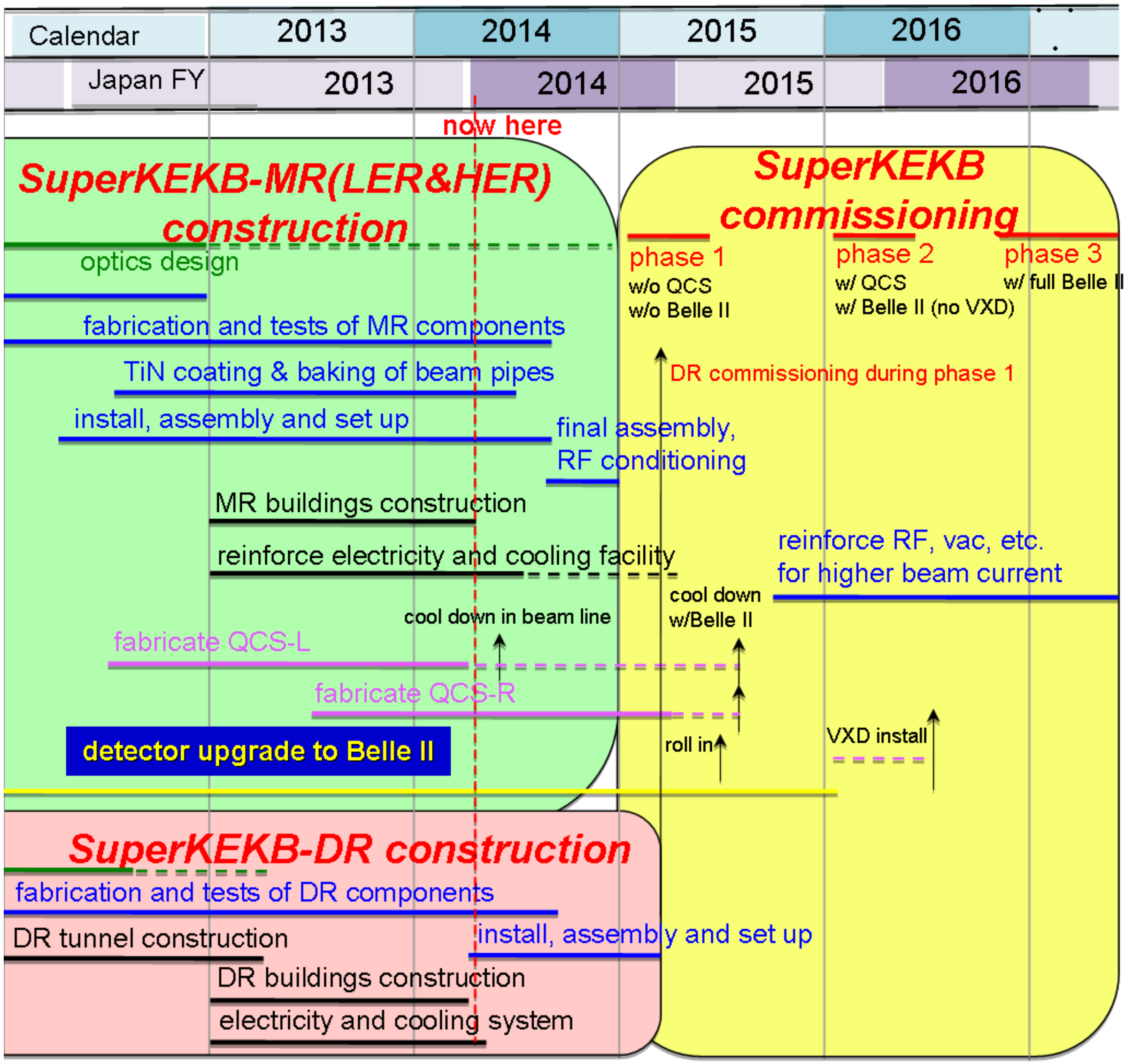
Background increase in endcaps by factor 20-40

(worse shielding of neutrons along beams)

Endcap RPCs will be replaced with scintillator based detectors

→ better beam-background tolerance

SuperKEKB schedule

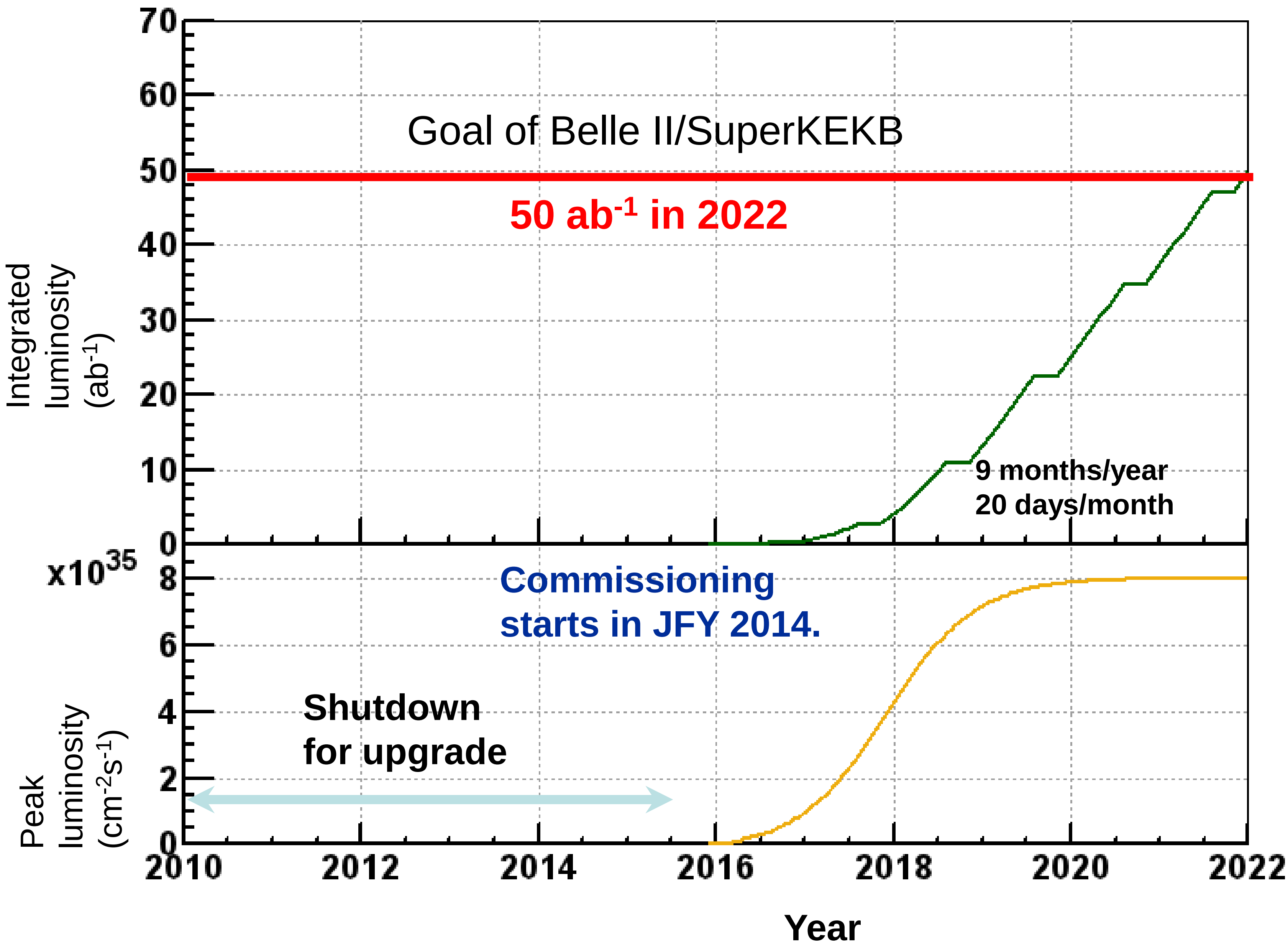


- **Phase 1 (Jan – May 2015)**
  No superconducting IR magnets; no Belle II.

  ➢ Basic tuning, vacuum scrubbing

- **Phase 2 (Feb – June 2016)**
  Full accelerator; Belle II except vertex detector
  ➢ beam collision tuning, background studies

- **Phase 3 (late 2016)**
  First physics, L = 10^{34} $cm^{-2}s^{-1}$
  (1/2 of iTOP will be in place for first physics run. Remainder will be installed in summer 2017).



Goal of Belle II/SuperKEKB
50 ab-1 in 2022
9 months/year
20 days/month
Integrated luminosity (ab-1)
70
60
50
40
30
20
10
0
x10^35
8
6
4
2
0
Commissioning starts in JFY 2014.
Shutdown for upgrade
Peak luminosity (cm-2s-1)
2010
2012
2014
2016
2018
2020
2022
Year

Summary

- B factories have proven to be an excellent tool for flavor physics, with reliable long term operation, and surpassing design values.
- Discovery potential of Belle II is complementary to LHC and to other experiments at intensity frontiers.
- Belle II detector construction and integration is proceeding according to schedule.
- SuperKEKB commissioning starts in Jan 2015, first physics runs in fall 2016
$\Rightarrow$ new exciting time in flavor physics.

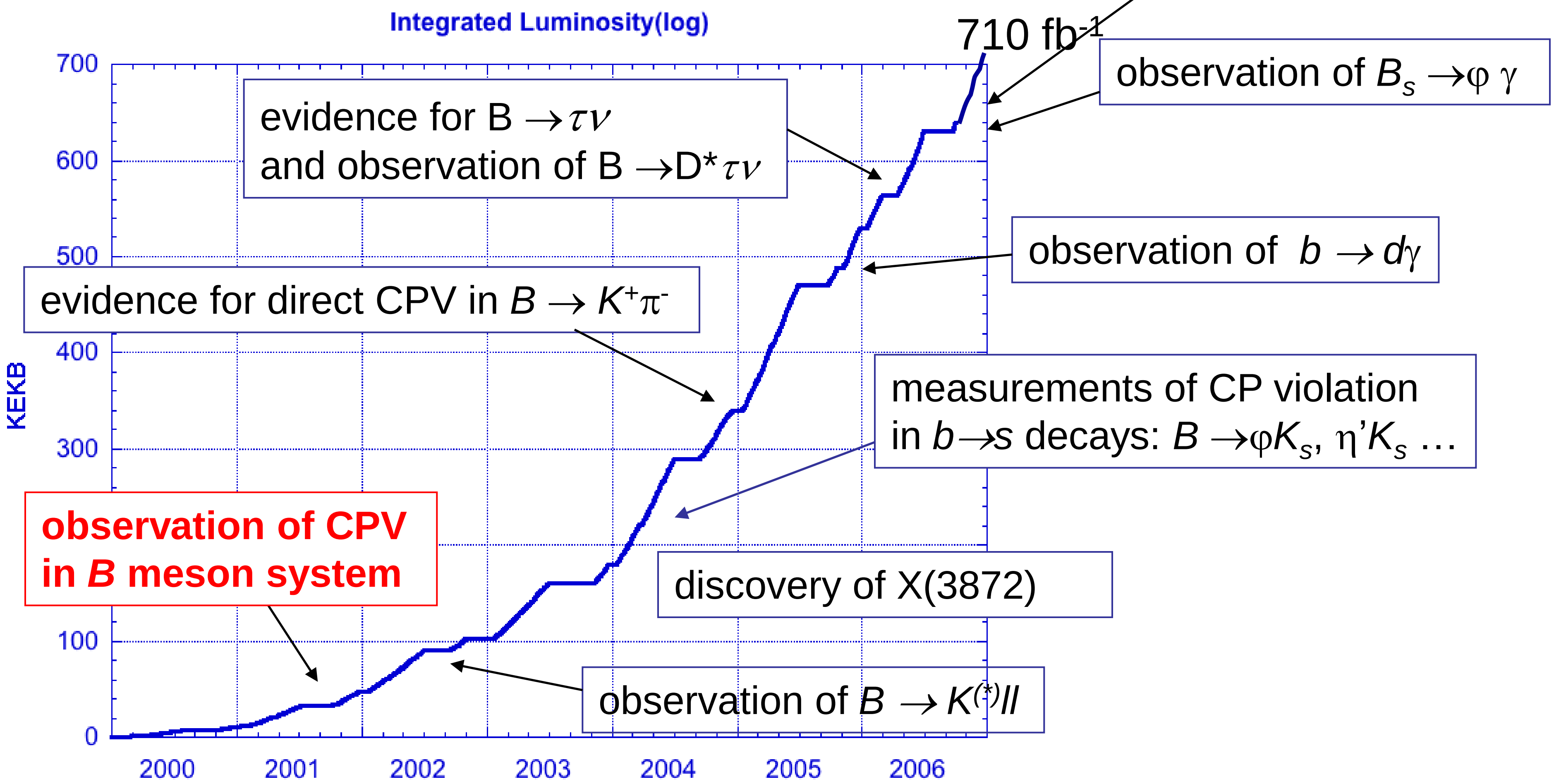
Belle II Collaboration

~600 Collaborators, 97 institutes, 23 countries

Theory interface platform

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

Major achievements at Belle



Wide researche area is possible due to the clean experimental environment
and well defined initial state in the e+e− experiments
as well as high luminosity and general purpose detector

Physics sensitivity at Belle II

Observable	Belle 2006 (~0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	†LHCb (2 fb^{-1})	†LHCb (10 fb^{-1})
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+\nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+\nu)$	†† $< 2.4\mathcal{B}_{SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ $[10^{-9}]$	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ $[10^{-9}]$	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ $[10^{-9}]$	21	3	1	-	-
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	~0.02	~0.01
ϕ_2 $(\pi\pi)$	11°	10°	3°	-	-
ϕ_2 $(\rho\pi)$	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 $(\rho\rho)$	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 $(D^{(*)}K^{(*)})$ (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 $(DK^{(*)})$ (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 $(D^{(*)}\pi)$	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\lvert V_{ub}\rvert$ (inclusive)	6%	5%	3%	-	-
$\lvert V_{ub}\rvert$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

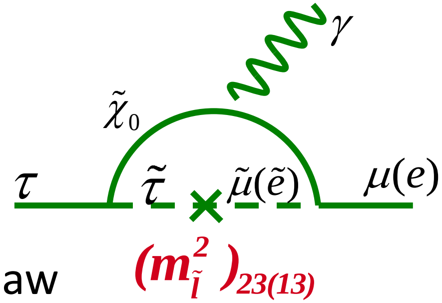
Physics sensitivity at Belle II

Observable	Belle 2006 ($\sim$0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	(50 ab^{-1})	†LHCb (2 fb^{-1})	(10 fb^{-1})
Hadronic $b \to s$ transitions					
$\Delta\mathcal{S}_{\phi K^0}$	0.22	0.073	0.029		0.14
$\Delta\mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta\mathcal{S}_{K_S^0 K_S^0 K_S^0}$	0.33	0.105	0.037	-	-
$\Delta\mathcal{A}_{\pi^0 K_S^0}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
$\phi_1^{eff}(\phi K_S)$ Dalitz		3.3°	1.5°		
Radiative/electroweak $b \to s$ transitions					
$\mathcal{S}_{K_S^0 \pi^0 \gamma}$	0.32	0.10	0.03	-	-
$\mathcal{B}(B \to X_s\gamma)$	13%	7%	6%	-	-
$A_{CP}(B \to X_s\gamma)$	0.058	0.01	0.005	-	-
C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	-	11%	4%		
C_{10} from $A_{FB}(B \to K^*\ell^+\ell^-)$	-	13%	4%		
C_7/C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	-		5%		7%
R_K		0.07	0.02		0.043
$\mathcal{B}(B^+ \to K^+\nu\nu)$	†† $< 3\ \mathcal{B}_{SM}$		30%	-	-
$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$	†† $< 40\ \mathcal{B}_{SM}$		35%	-	-
Radiative/electroweak $b \to d$ transitions					
$\mathcal{S}_{\rho\gamma}$	-	0.3	0.15		
$\mathcal{B}(B \to X_d\gamma)$	-	24% (syst.)		-	-

hep-ex arXiv:1002.5012

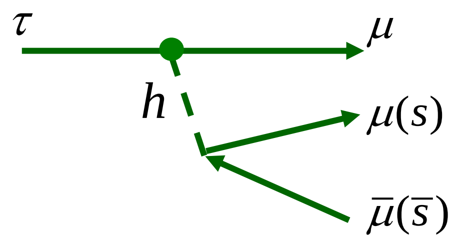
τ lepton flavor violation

$\tau \to l\gamma$



- SUSY + seesaw
- Large LFV

$\tau \to 3l, l\eta$



- Neutral Higgs mediated decay
- Important when M_{SUSY} >> EW scale

mode	Br($\tau \to \mu\gamma$)	Br($\tau \to 3l$)
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-universal Z’	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

Strategy to increase luminosity

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

Lorentz factor

Beam current

Beam-beam parameter

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 - 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 - 2 % (flat beam)

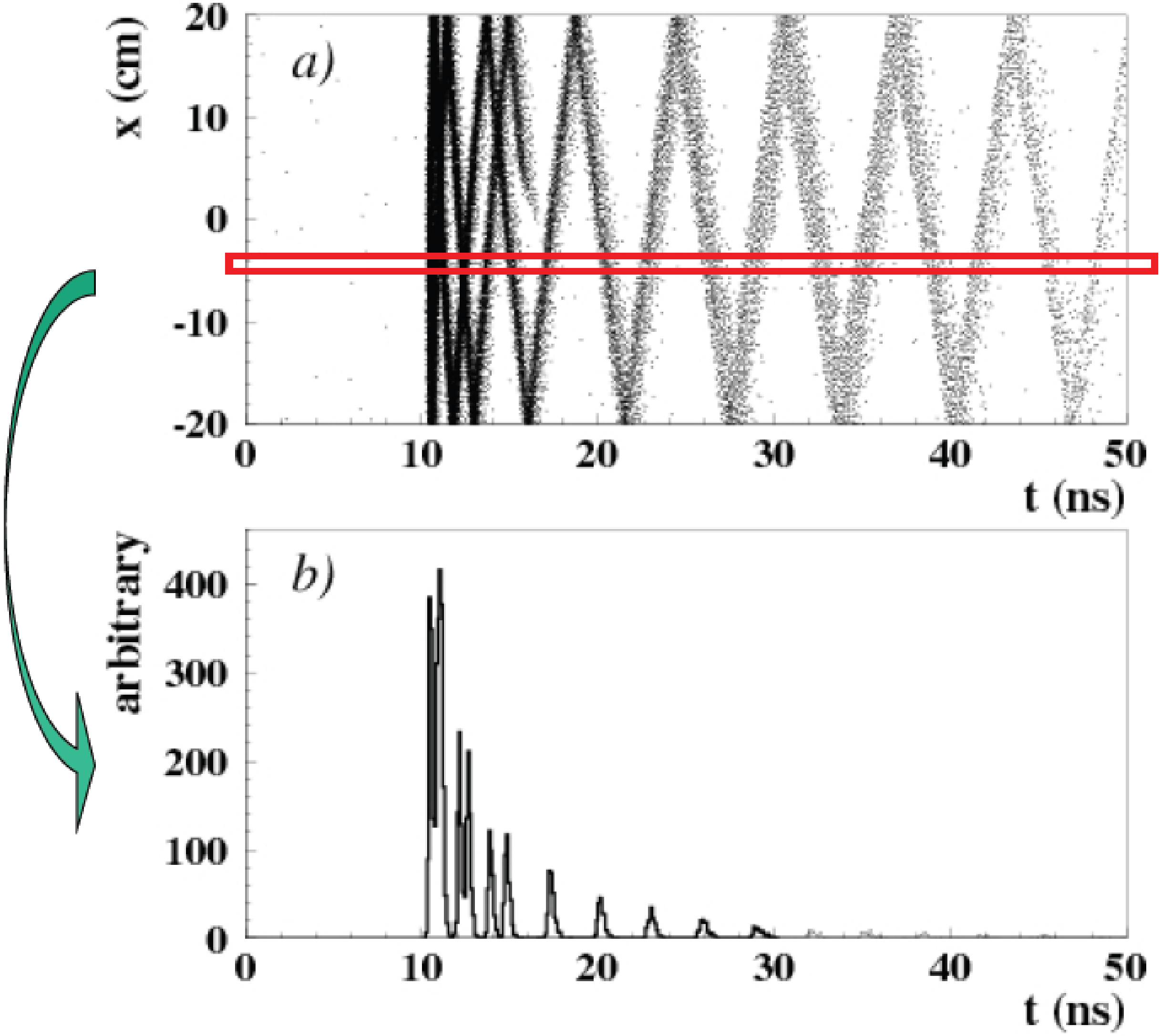
Vertical beta function@IP

(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB iTOP image

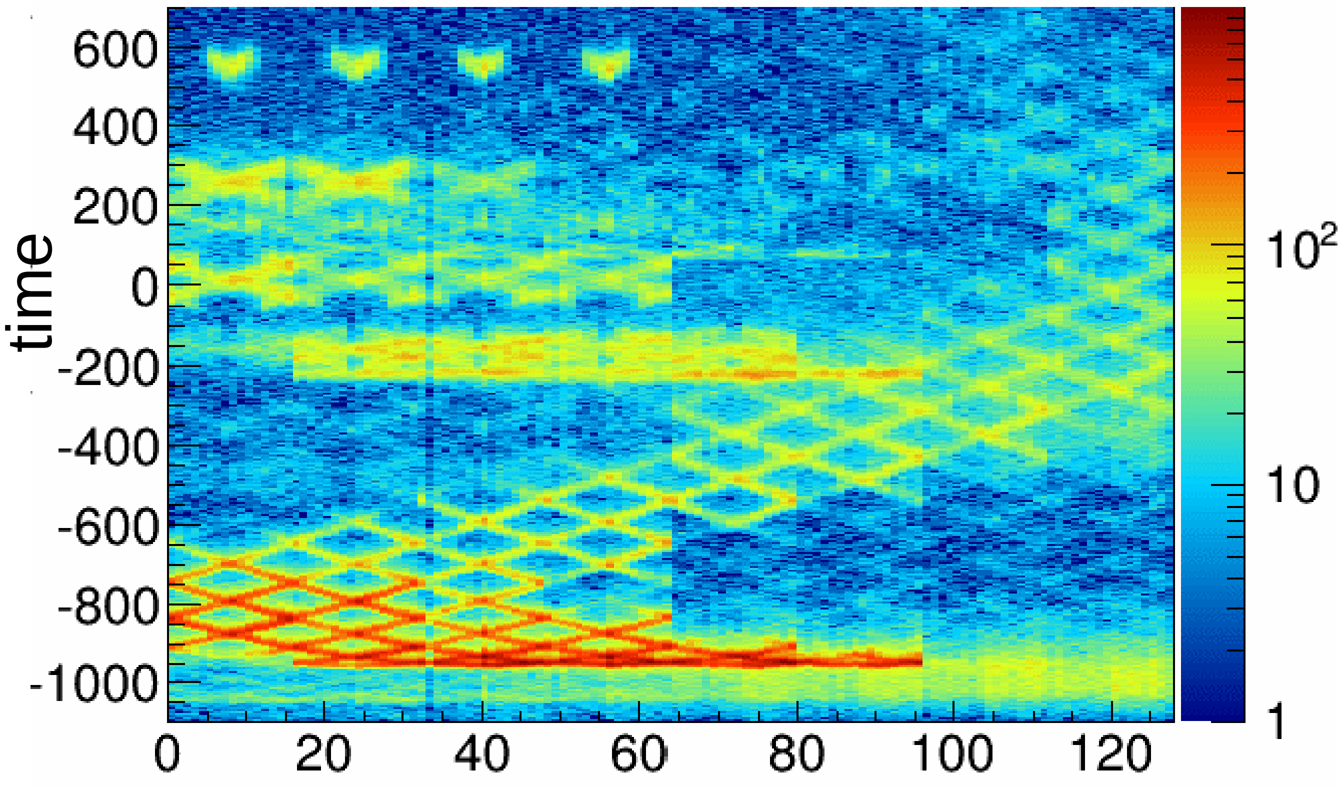


Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

Time distribution of signals recorded by one of the PMT channels: different for π and K (~shifted in time)

Test beam results iTOP

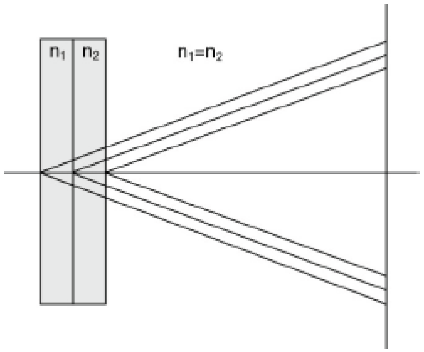
x-t diagram from beam-test

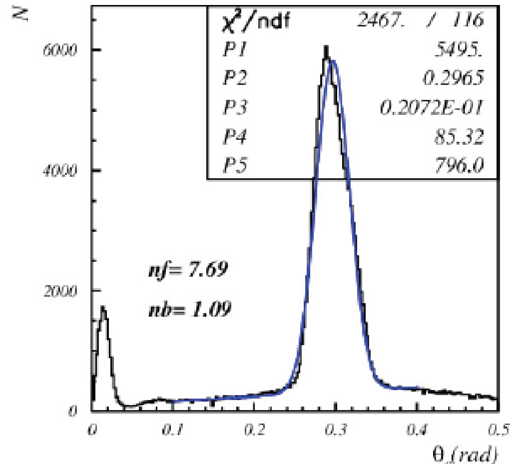


Aerogel RICH with focusing radiator

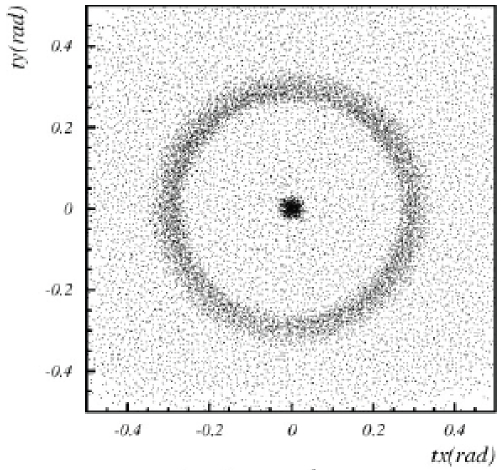
Increases the number of photons without degrading the resolution

4cm aerogel single index



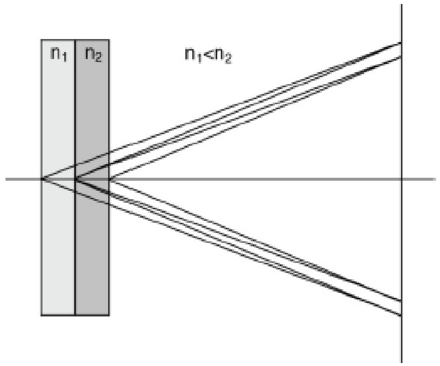


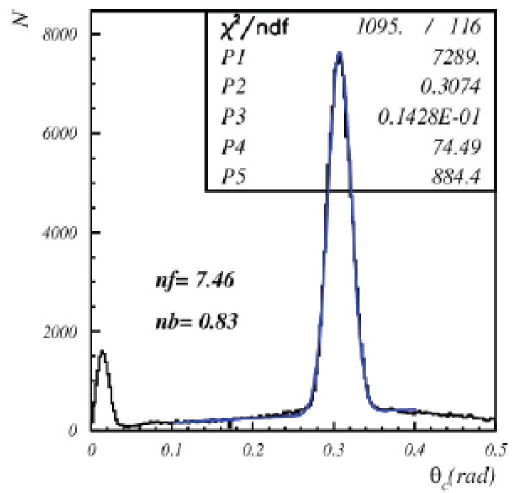
theta cerenkov

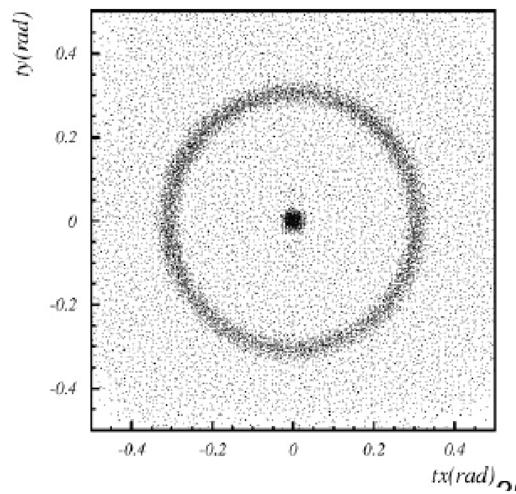


ring in cerenkov space

2+2cm aerogel







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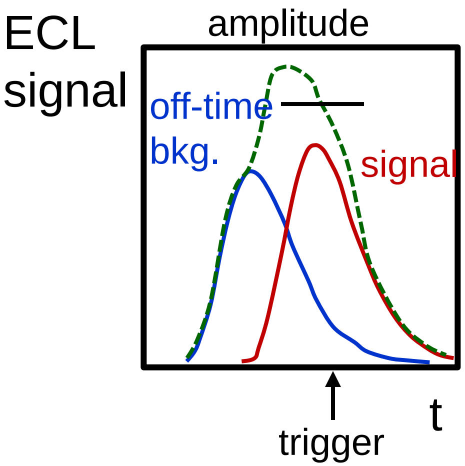
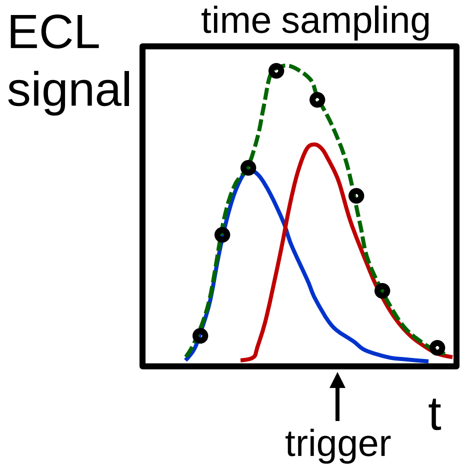
ECL (barrel):

new electronics with
2MHz wave form sampling

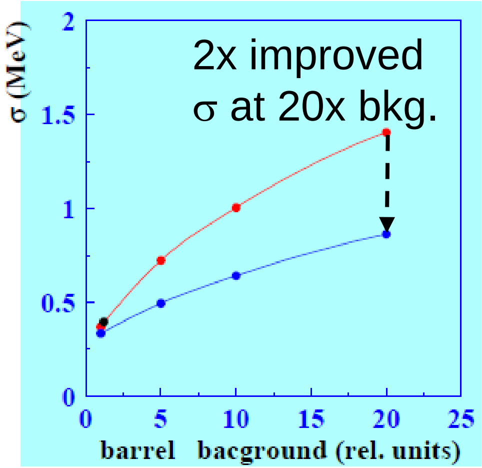




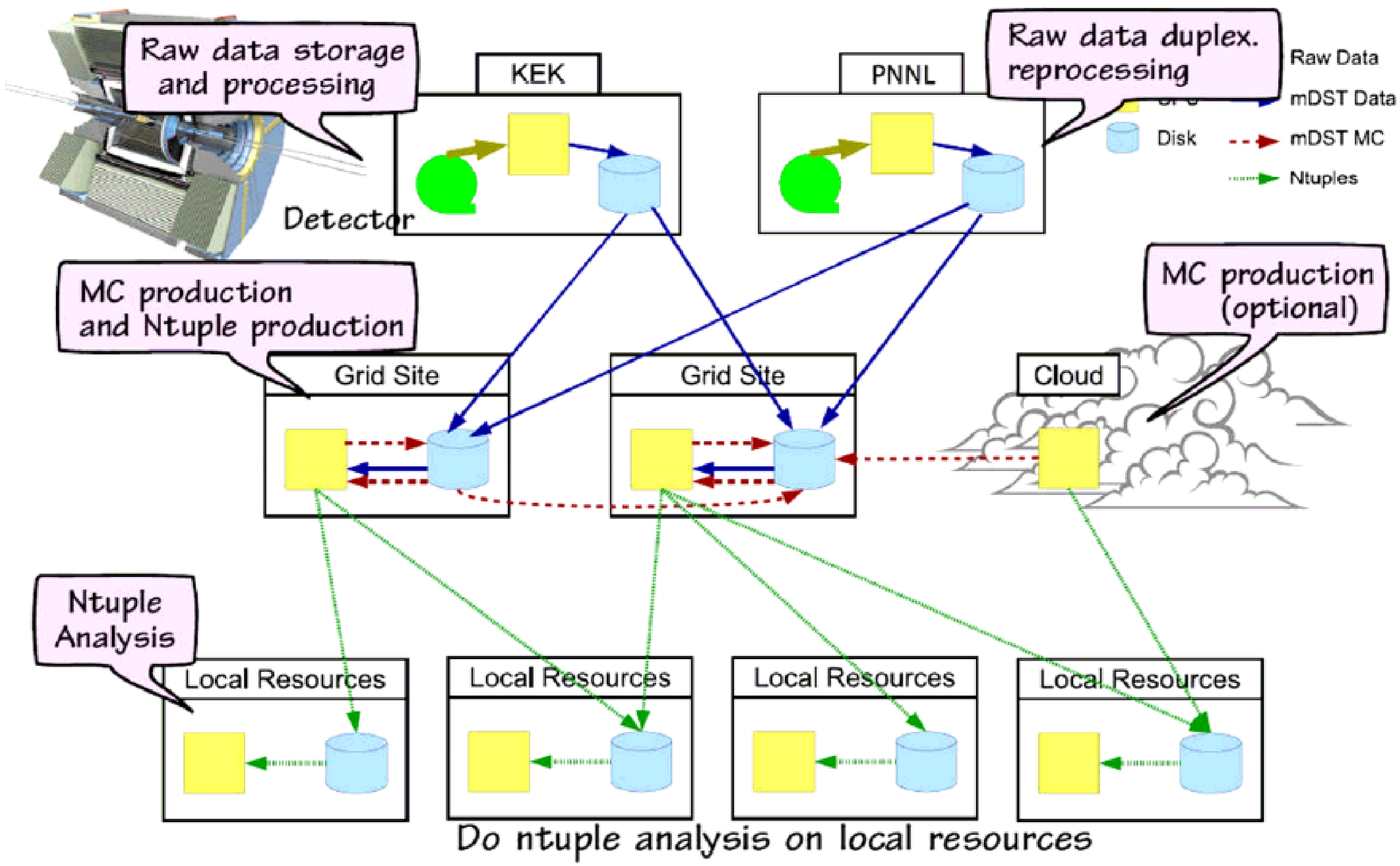
ECL (endcap):

pure CsI crystals;
may be staged;

faster performance and better
rad. hardness than Tl doped CsI



A snapshot of the Belle II computing model



SuperKEKB schedule