The Belle II Detector

C. Niebuhr, DESY

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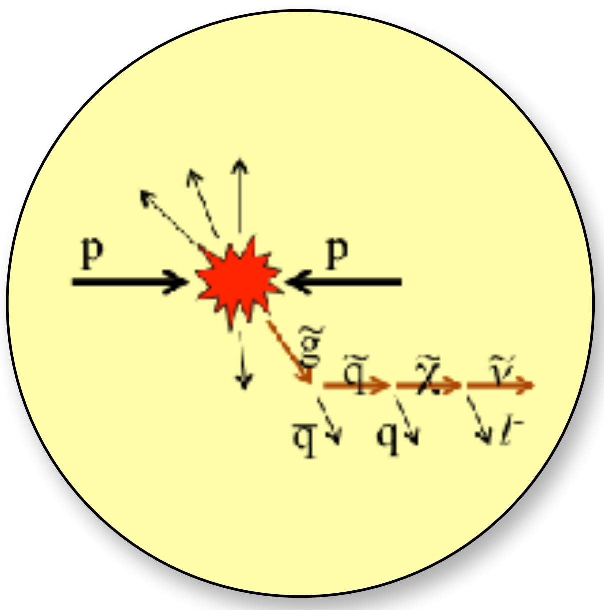
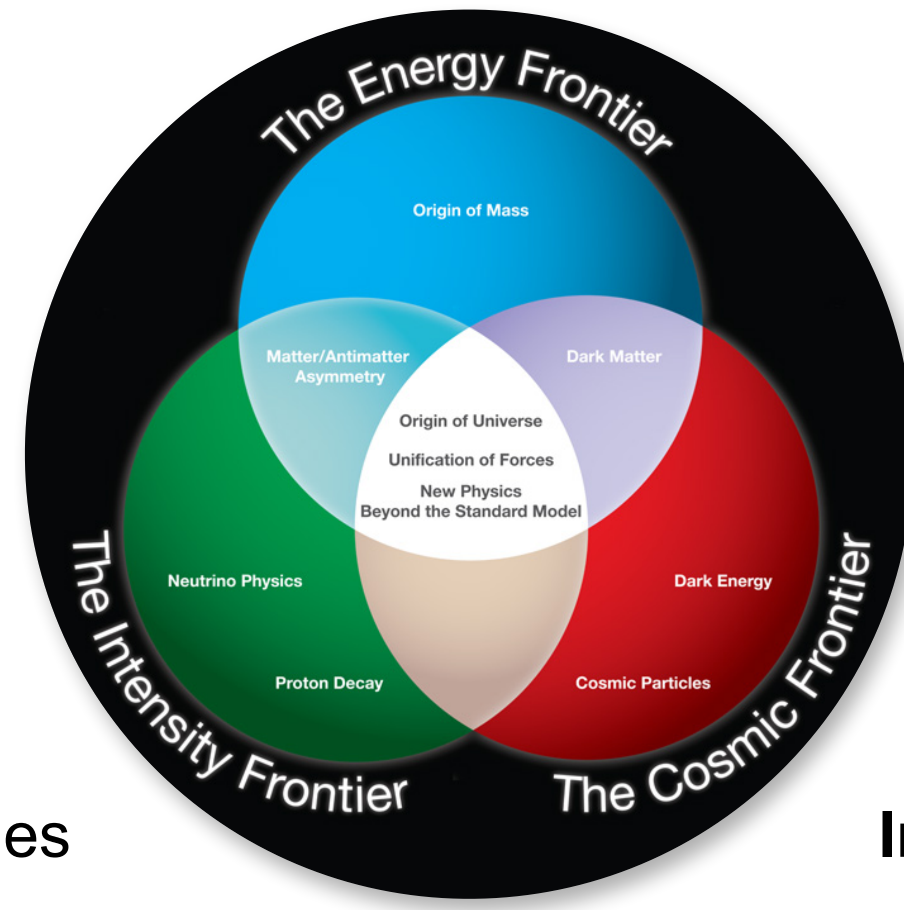
Looking Beyond the Standard Model

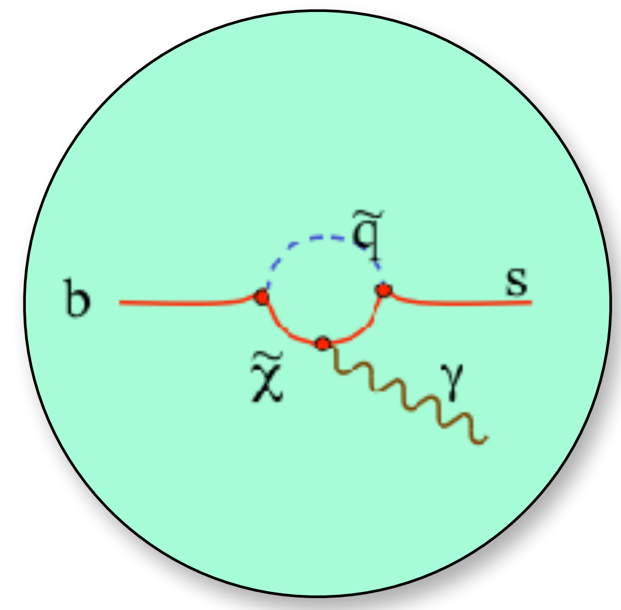
Energy frontier



Direct production of new particles



Intensity frontier

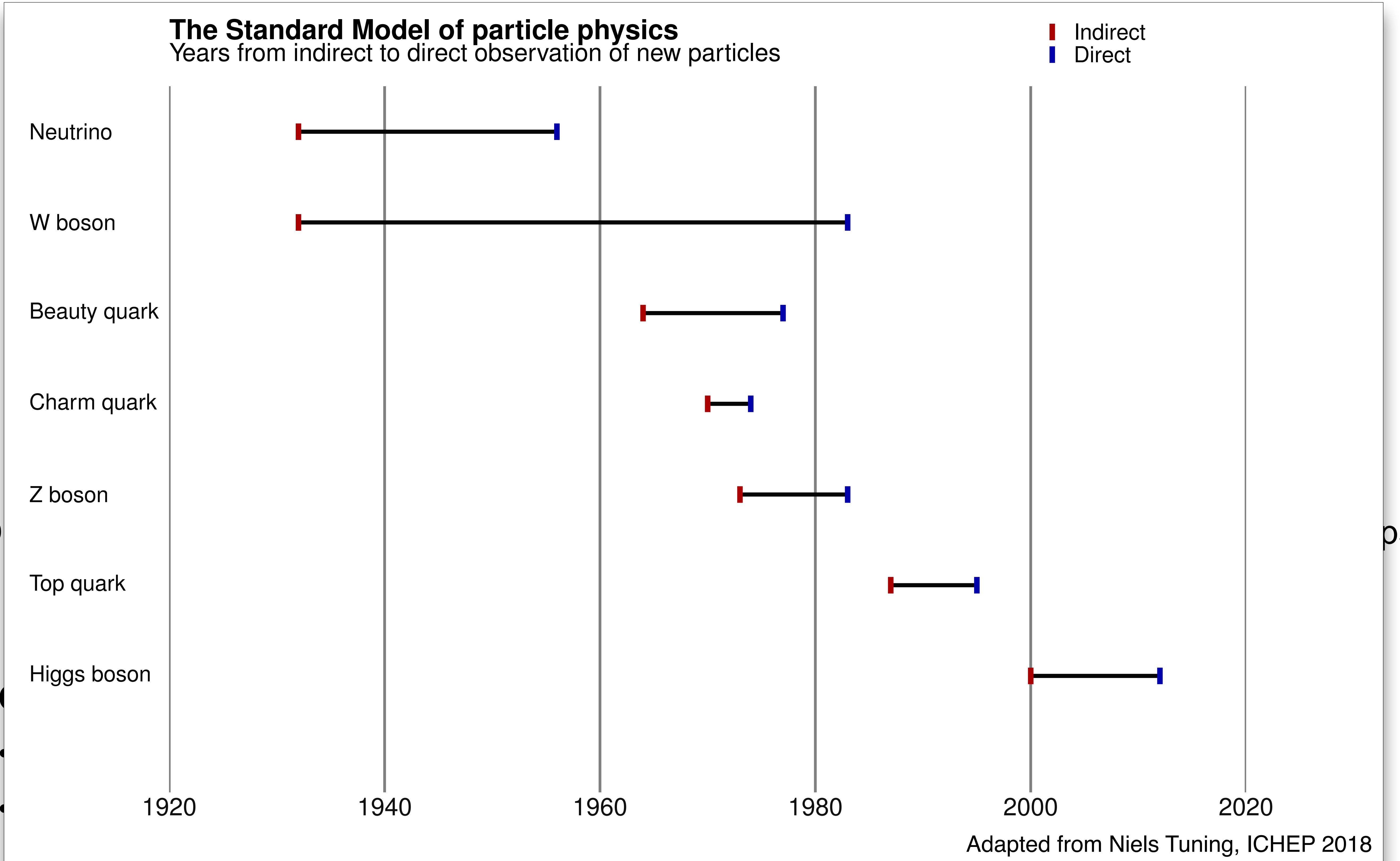


Indirect sensitivity through loops

Current experimental situation

- No clear evidence for Beyond Standard Model (BSM) physics at the high energy frontier
- Intensity frontier offers **indirect** sensitivity to **very high** scales: recent observation of **„Flavour Anomalies“**
- **Direct and indirect searches are complementary and must both be pursued!**

Looking Beyond the Standard Model



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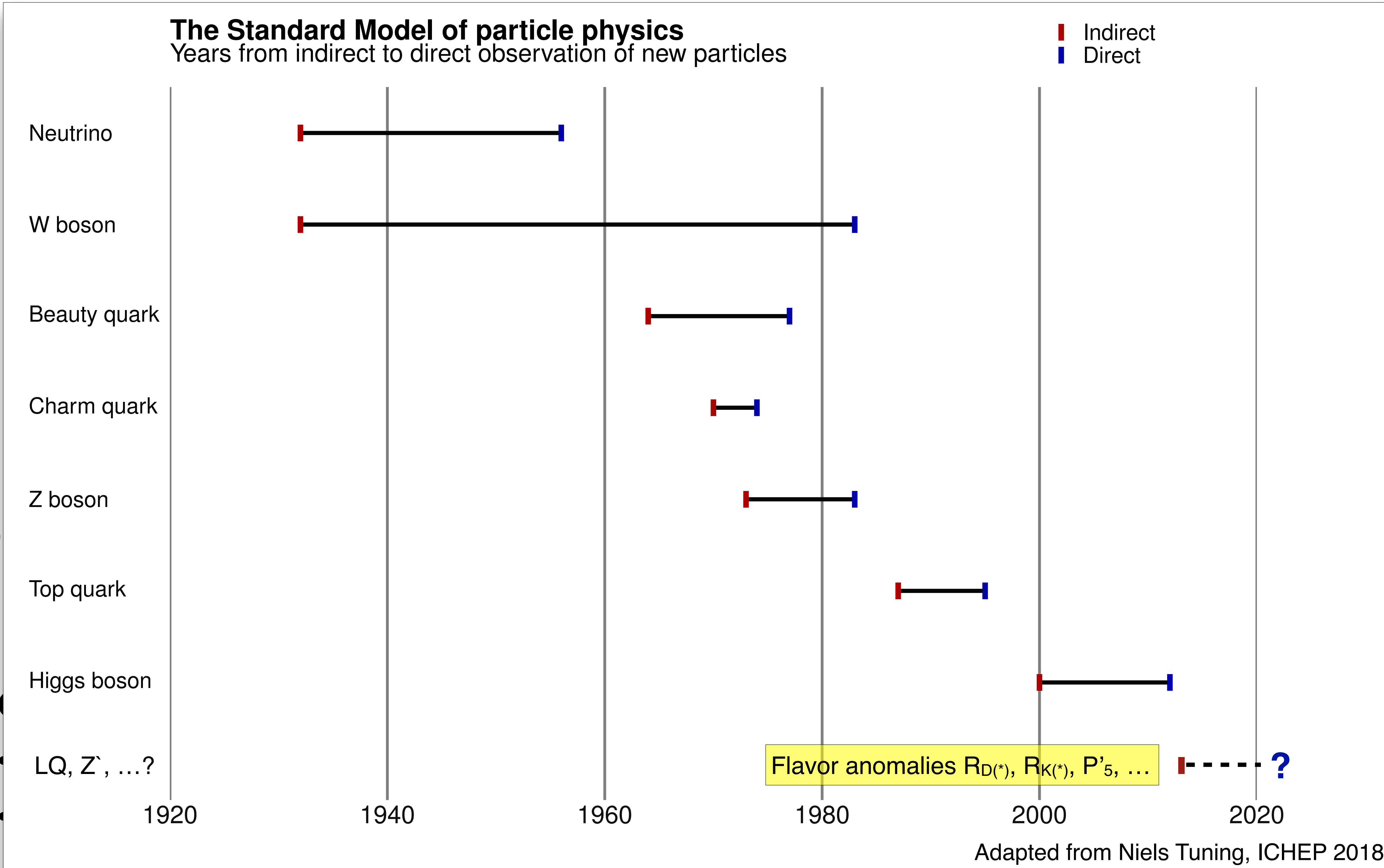

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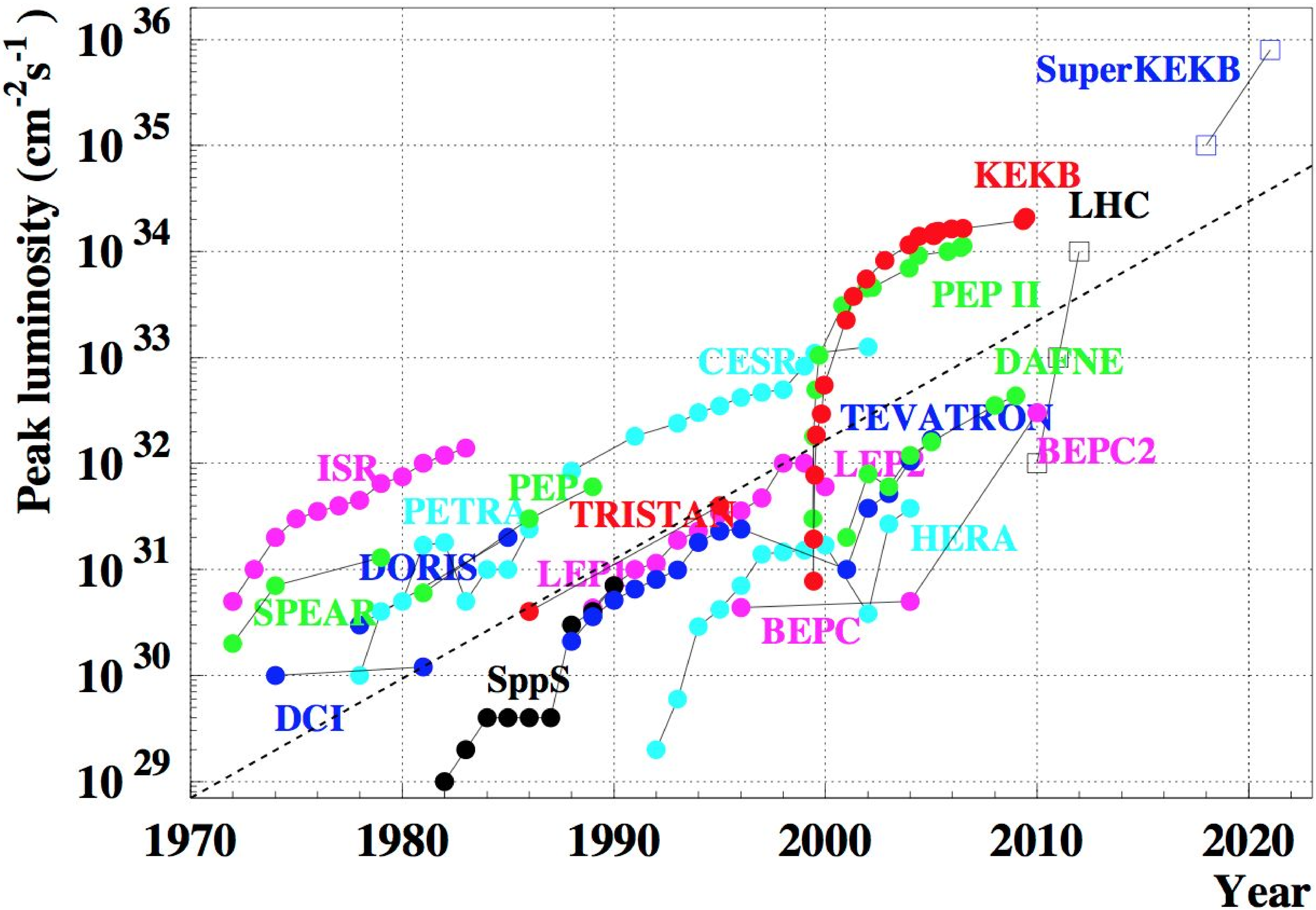
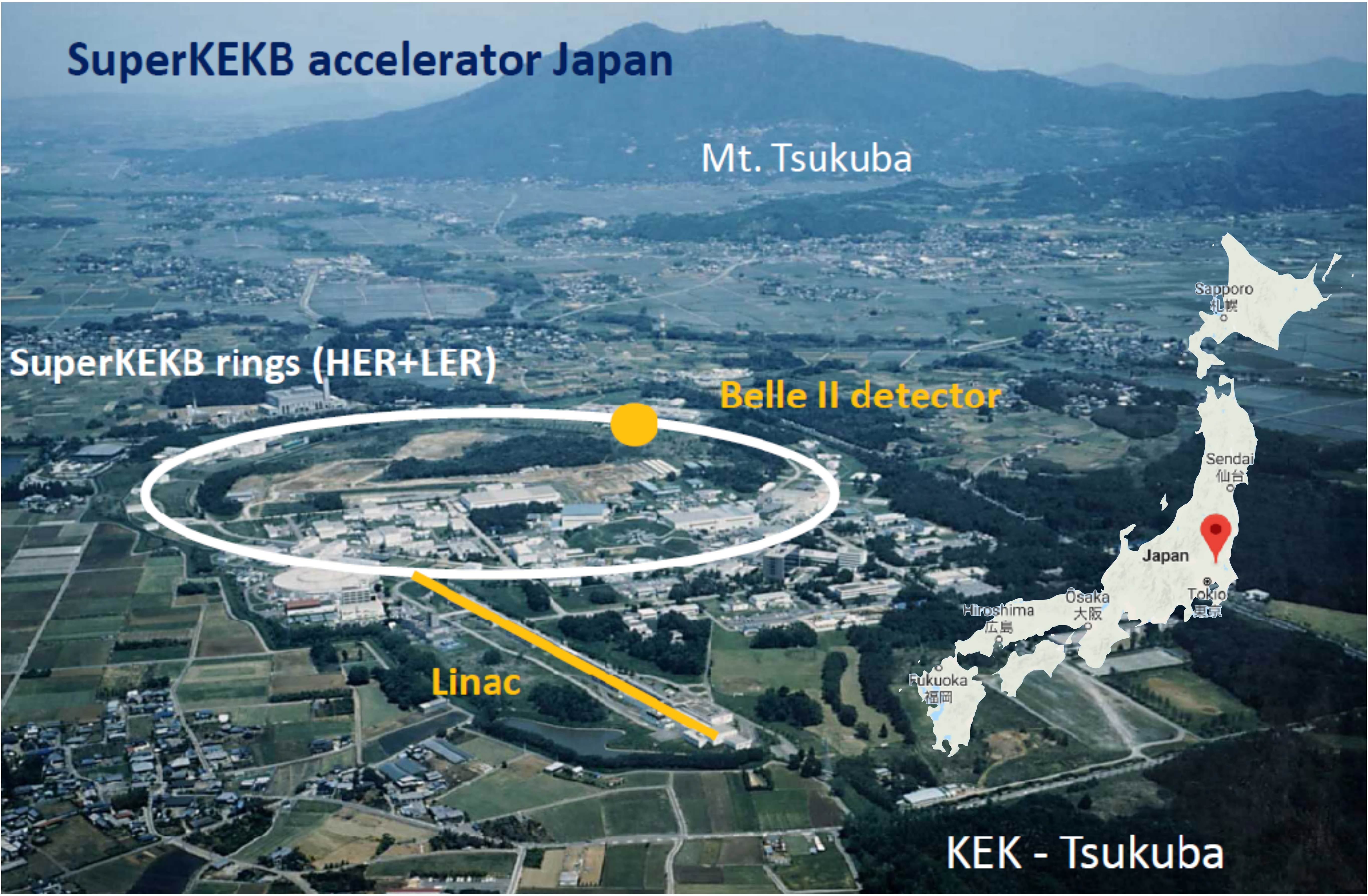
Next Step at Luminosity Frontier: SuperKEKB



KEK @ Tsukuba


SuperKEKB accelerator Japan
Mt. Tsukuba
SuperKEKB rings (HER+LER)
Belle II detector
Linac
Sapporo
札幌
Sendai
仙台
Japan
Tokio
東京
Ōsaka
大阪
Hiroshima
広島
Fukuoka
福岡
KEK - Tsukuba

SuperKEKB and Nano Beam Scheme

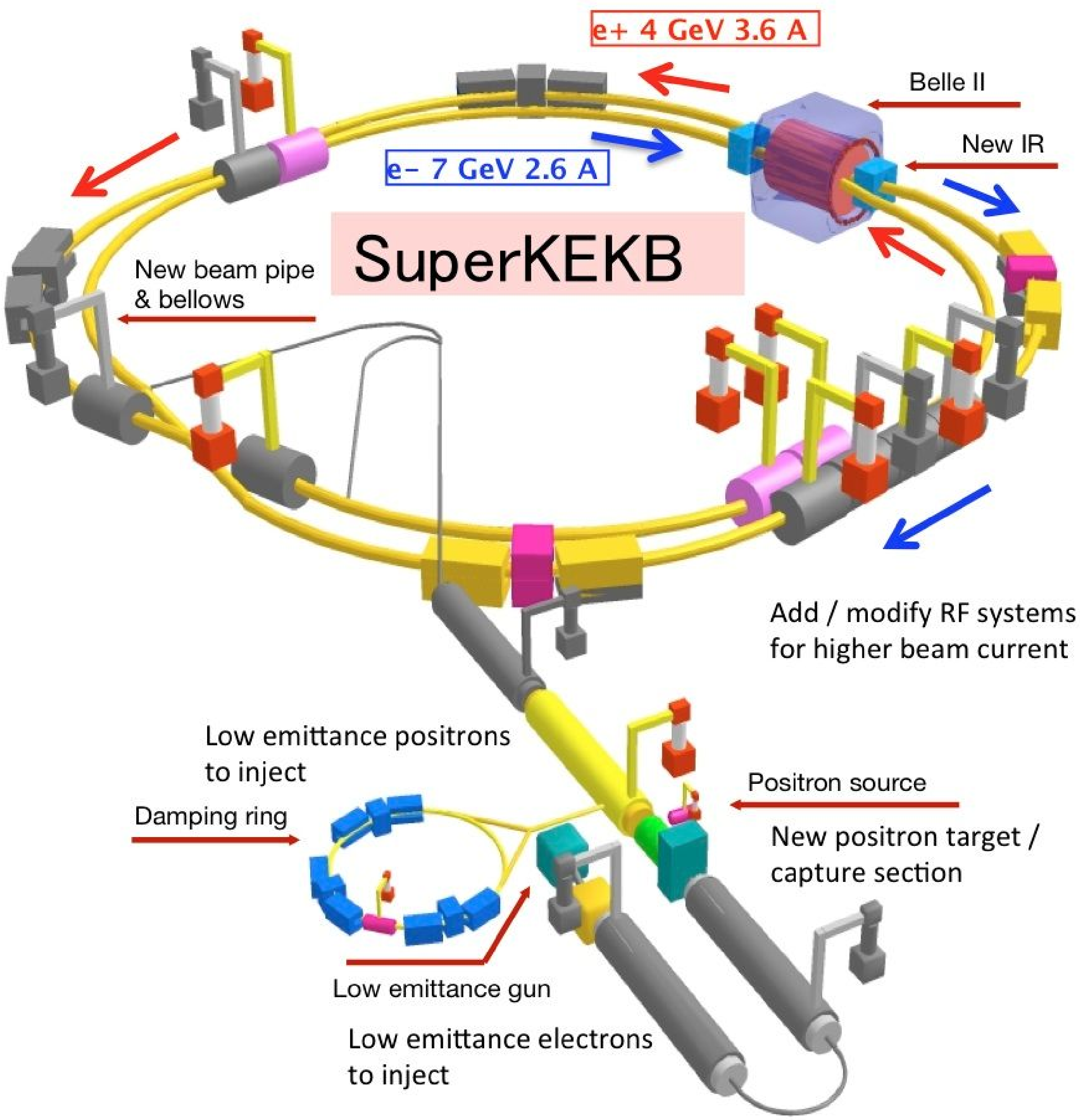
beam current x2

beam-beam param. x1

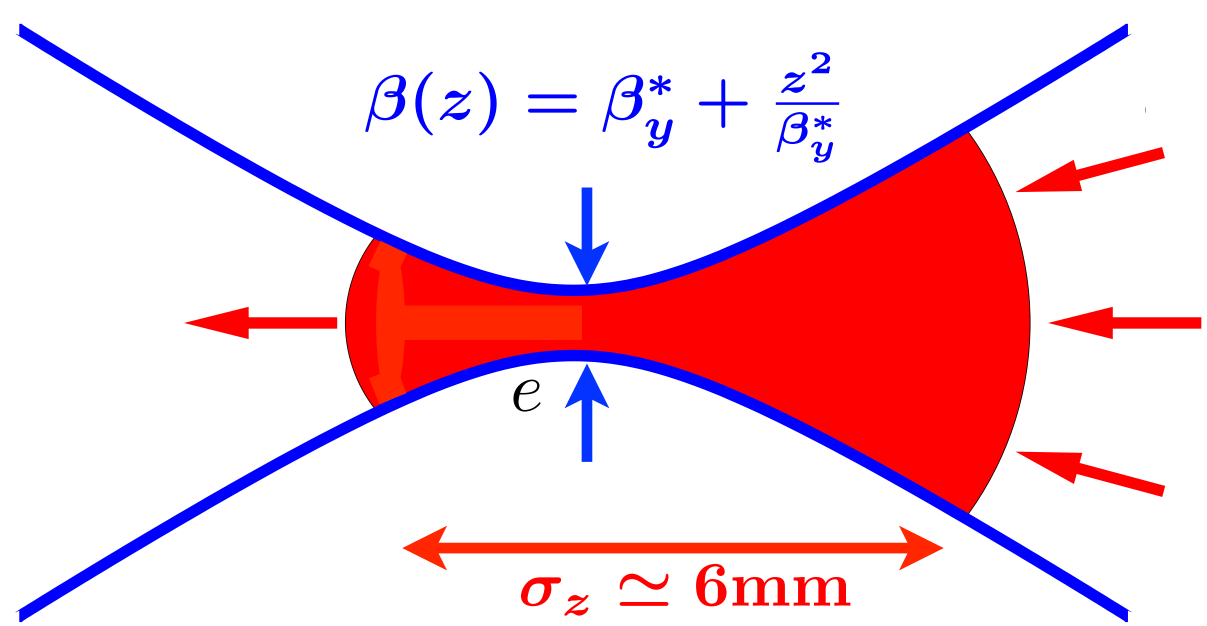
$$L = \frac{\gamma_\pm}{2 e r_r}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{R_L}{R_\xi}\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}$$

vertical beta function x 1/20

LER / HER	KEKB	SuperKEKB	L-Factor
Energy [GeV]	3.5 / 8	4.0 / 7.0	
Crossing angle $2\phi_x$ [mrad]	22	83	
β_y^* [mm]	5.9 / 5.9	0.27 / 0.30	x 20
β_x^* [mm]	1200	32 / 25	
$I_\pm$ [A]	1.64 / 1.19	3.6 / 2.6	x 2
$\varepsilon_x = \sigma_x \times \sigma_{x'}$ [nm]	18 / 24	3.2 / 4.6	
$\varepsilon_y = \sigma_y \times \sigma_{y'}$ [pm]	140 / 140	13 / 16	
$\xi_{y\pm} \sim (\beta_y^*/\varepsilon_y)^{1/2} / \sigma_x^*$	0.129 / 0.09	0.09 / 0.09	x 1
# of bunches	1584	2500	
Luminosity [10^{34} cm^{-2} s^{-1}]	2.1	80	x 40



Hourglass effect



$$\Rightarrow \text{goal} : \sigma_z^{\text{eff}} < \beta_y^*$$

SuperKEKB and Nano Beam Scheme

beam current **x2**

beam-beam param. **x1**

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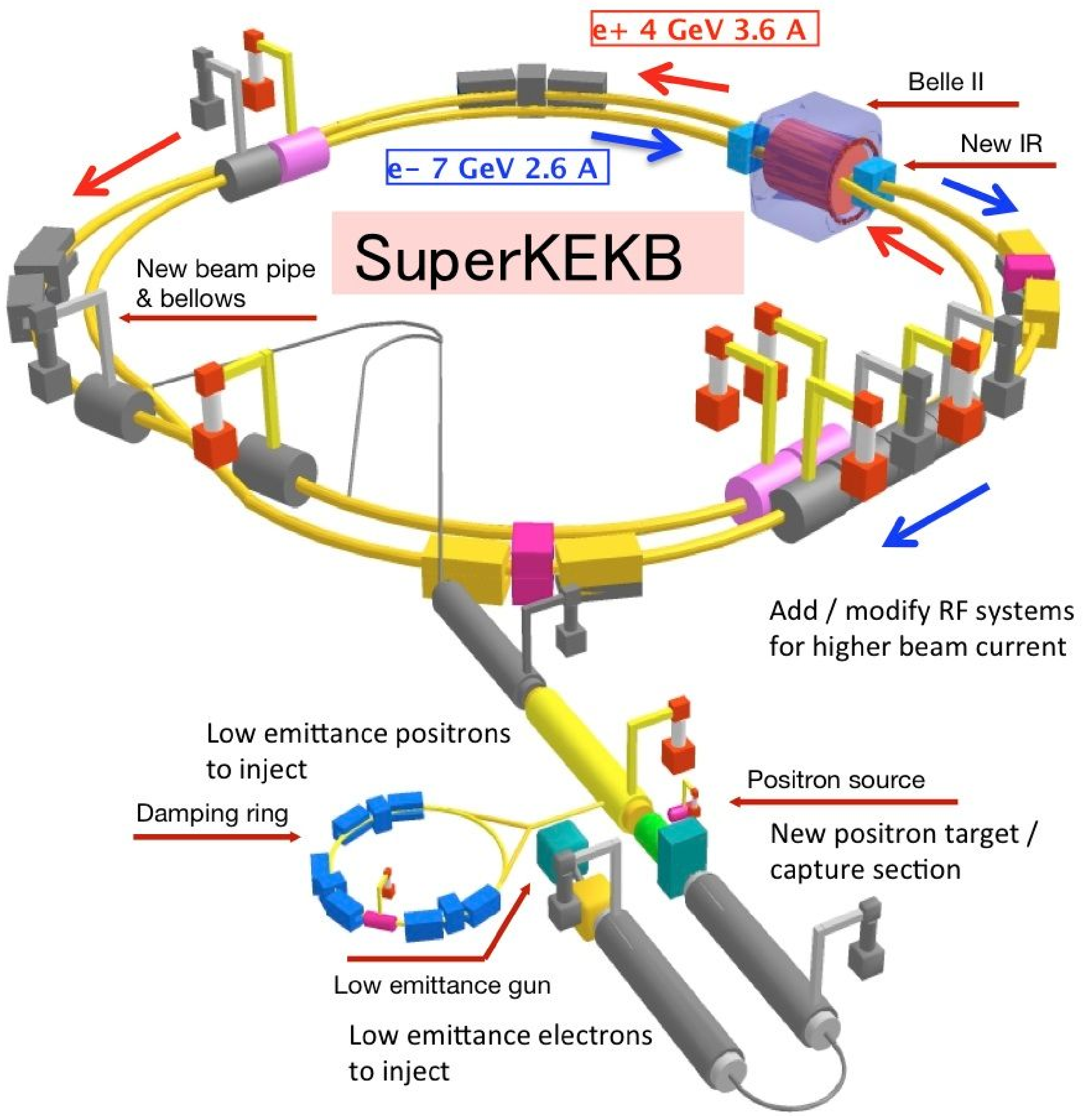
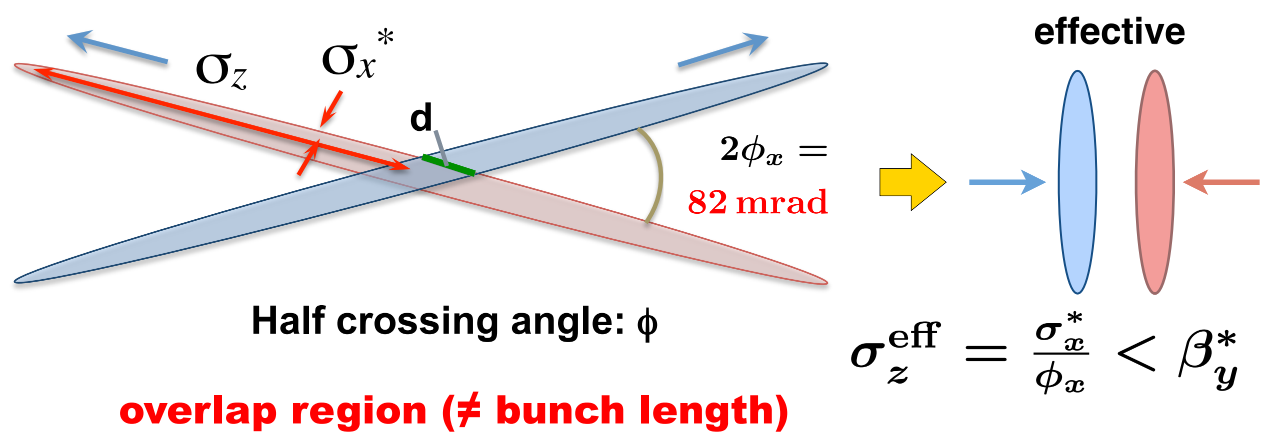


Nano-Beam scheme (P. Raimondi, DAΦNE): Squeeze beta function at the IP (β_x^*,β_y^*) and minimize longitudinal size of overlap region to avoid penalty from hourglass effect.



$$\sigma_z^{\mathrm{eff}} = \frac{\sigma_x^*}{\phi_x} < \beta_y^*$$

Strong focusing of beams down to vertical size of ~ **50nm** requires **low emittance beams** and **large crossing angle** ⇒
Need **sophisticated final focus** system (QCS).

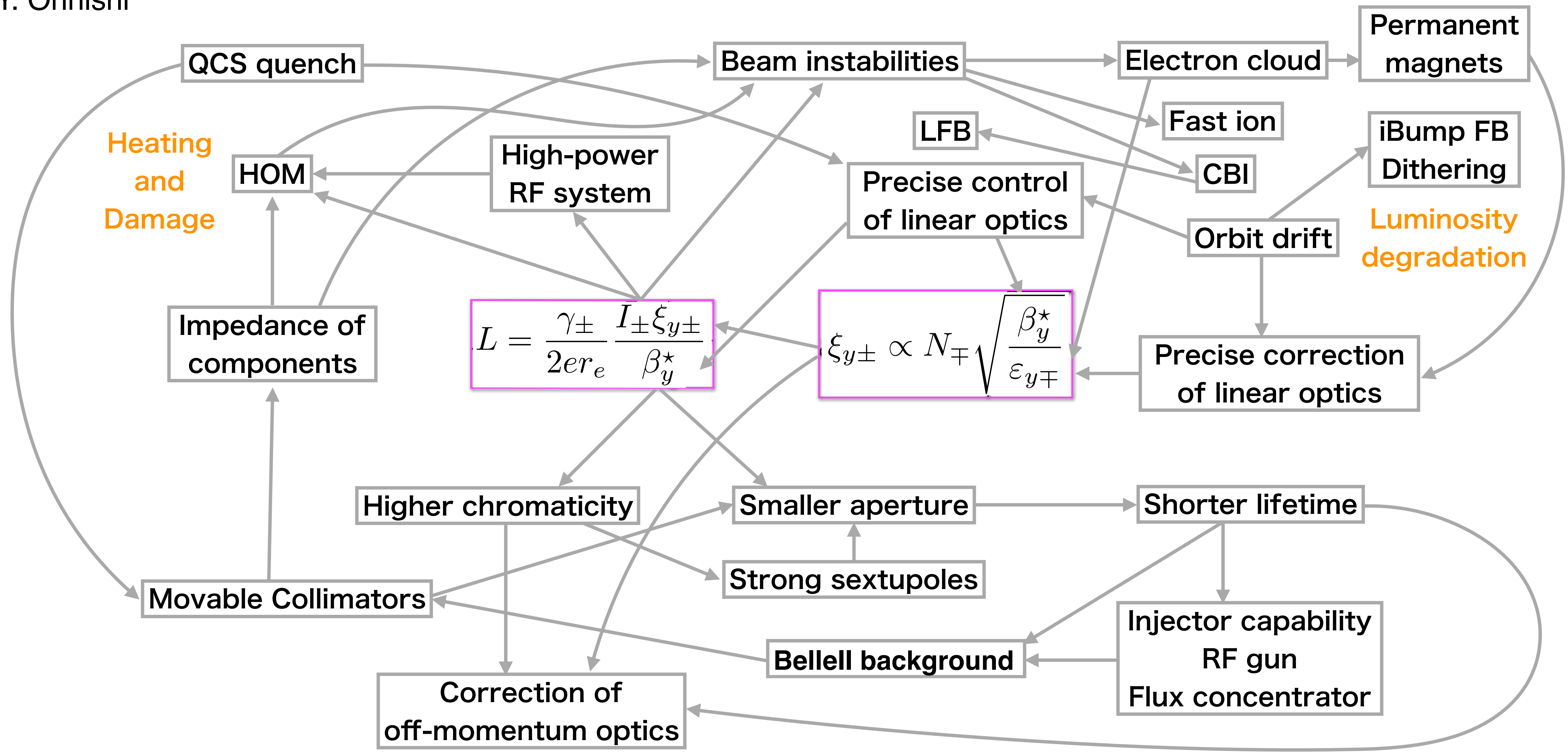
Particle Physicist's View

$$L = \frac{\gamma_{\pm}}{2er_e} \frac{I_{\pm}\xi_{y\pm}}{\beta_y^{\star}} \qquad \xi_{y\pm} \propto N_{\mp}\sqrt{\frac{\beta_y^{\star}}{\varepsilon_{y\mp}}}$$

Once final focus system is in place achieving design luminosity should be rather straightforward

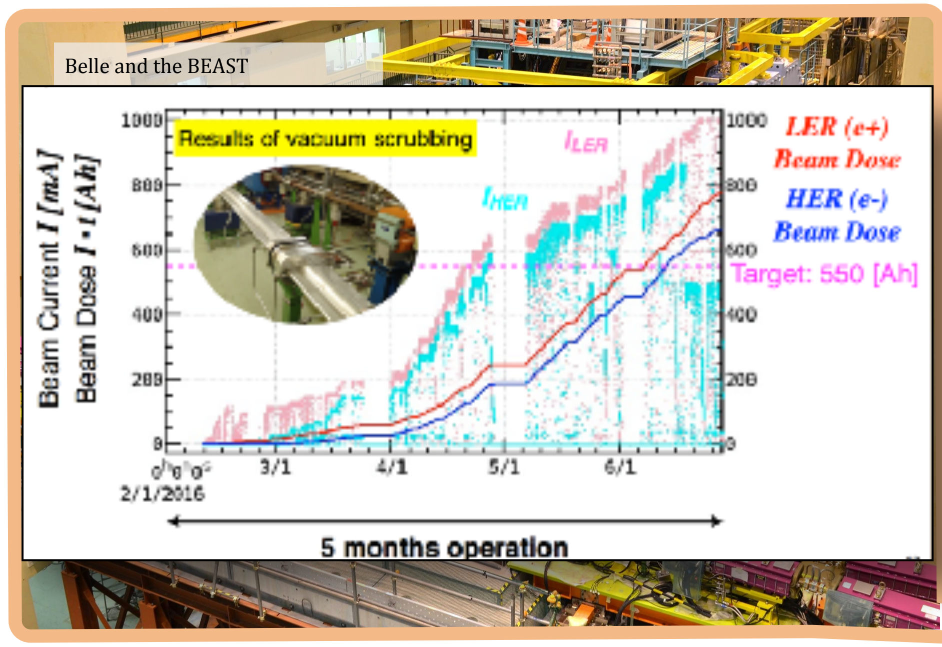
Accelerator Physicist's View

Y. Ohnishi

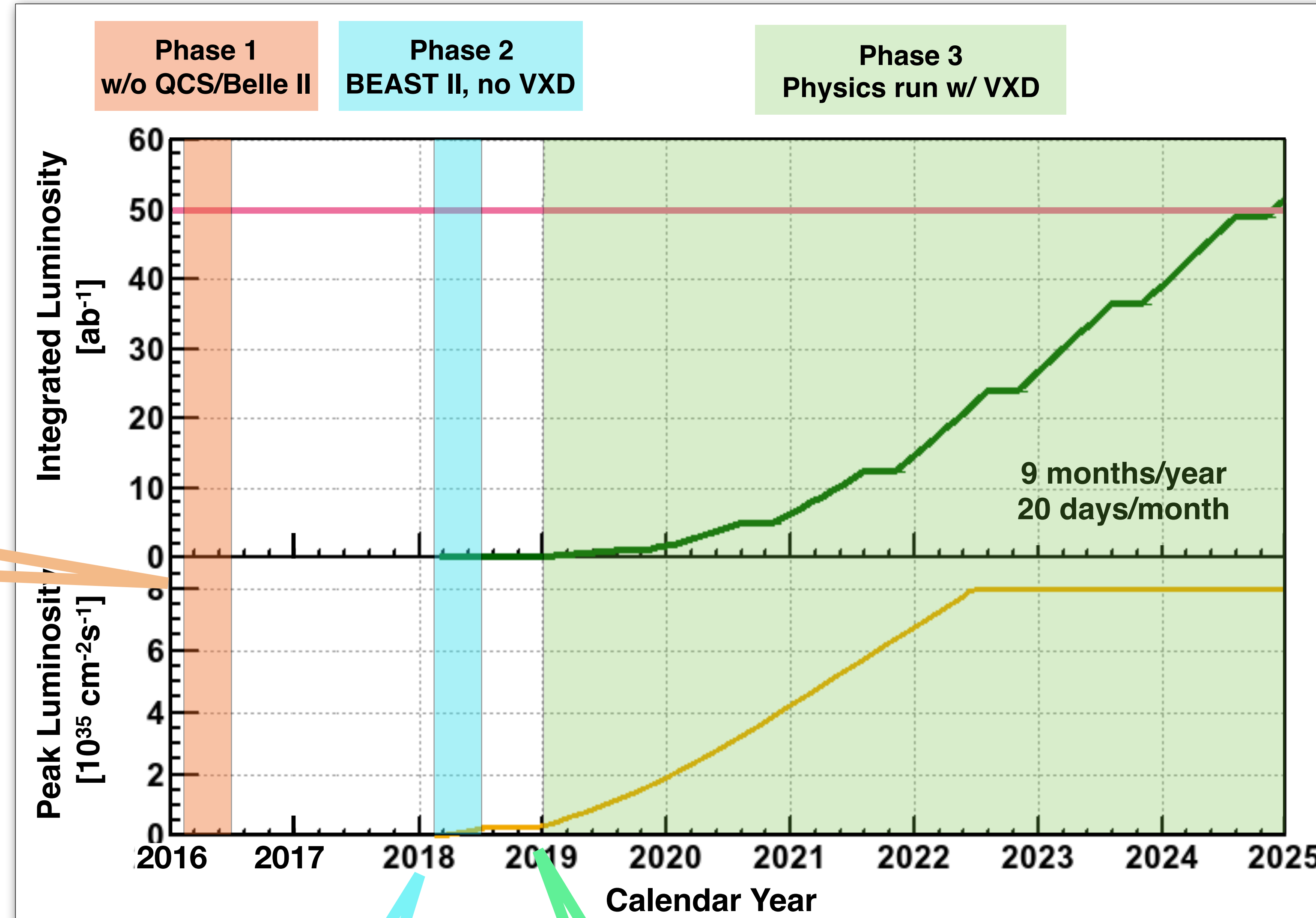


- Achieving maximum luminosity at acceptable detector background is a complex multi-dimensional optimisation task
- Have to simultaneously avoid
  - Electron clouds
  - Beam instability at high beam current operation
  - QCS quenches
  - Collimator damage
  - Detector background
  - …

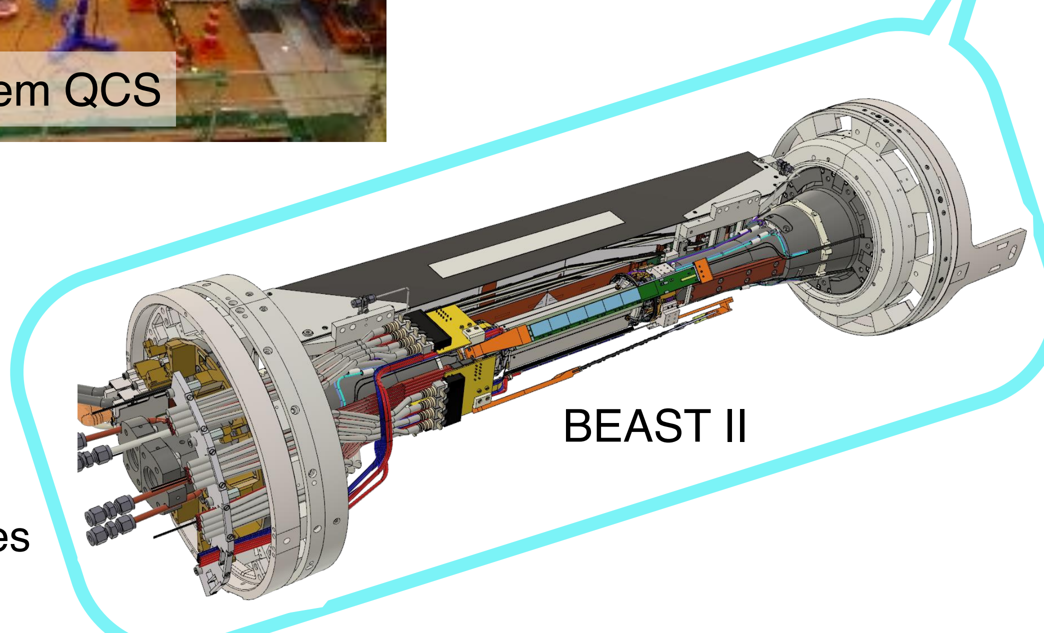
SuperKEKB / Belle II Commissioning

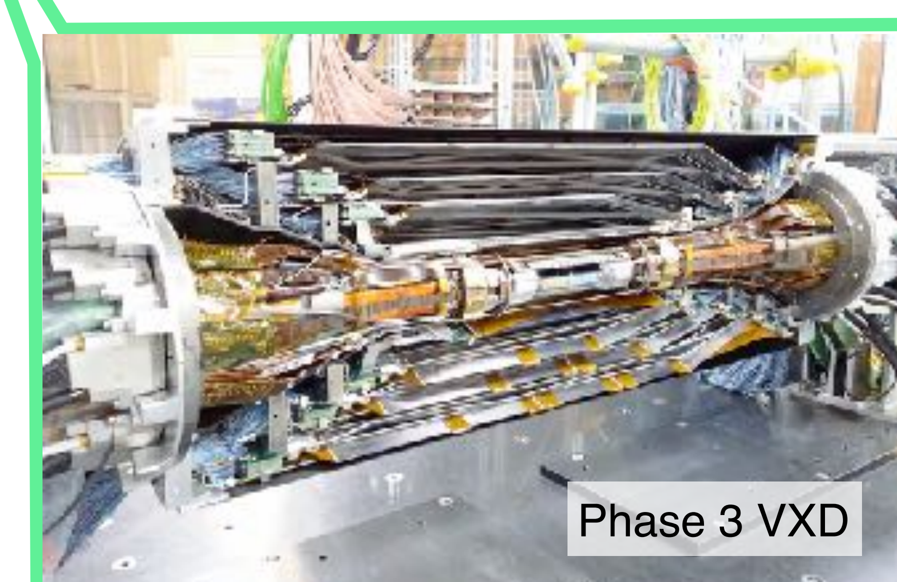


In total 55 individual super conducting magnets

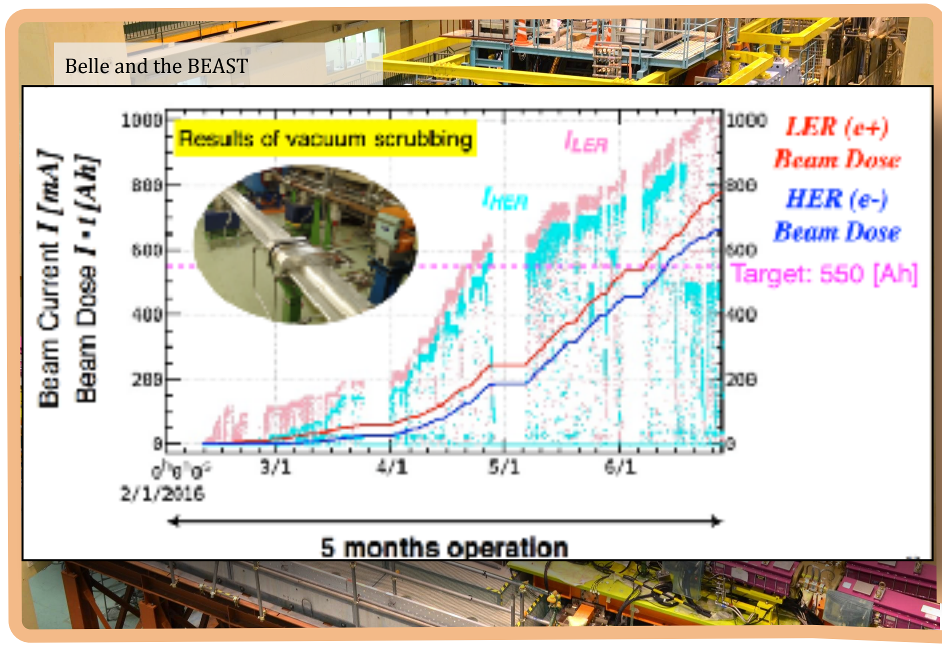


Background studies





SuperKEKB / Belle II Commissioning



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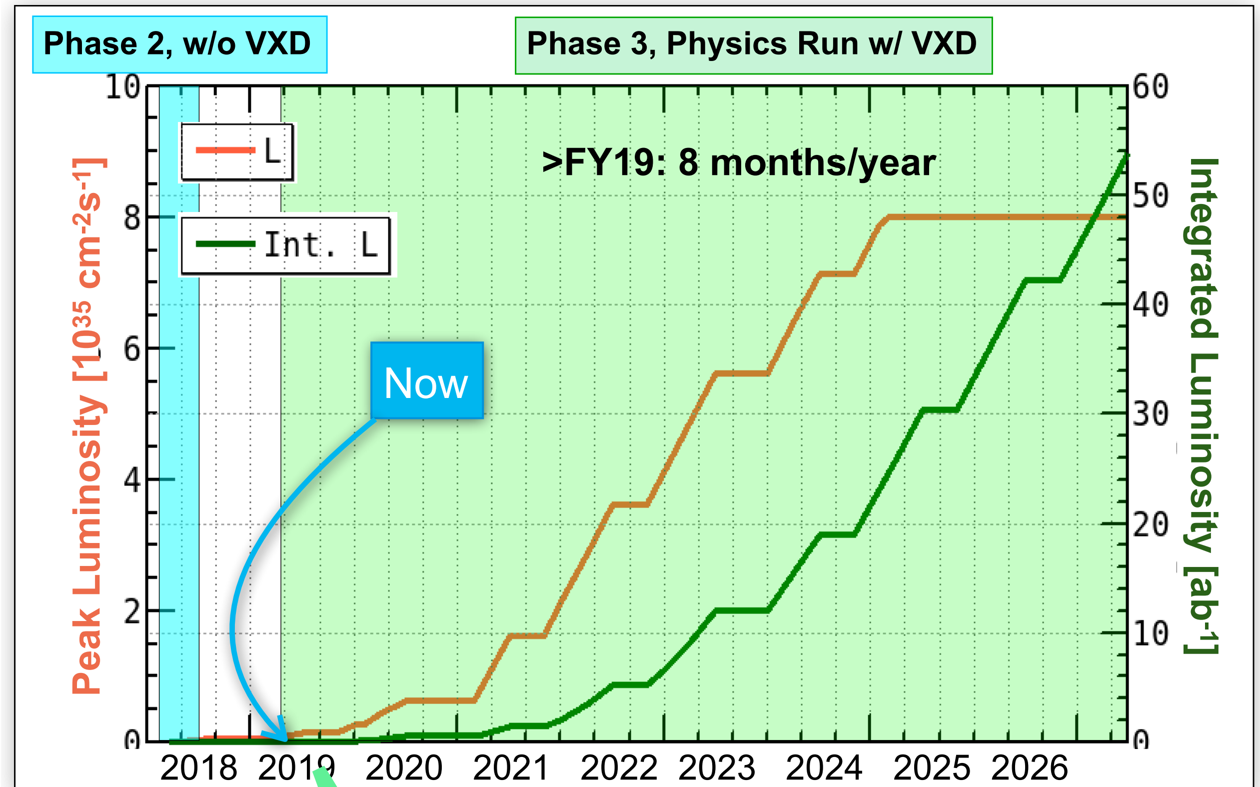
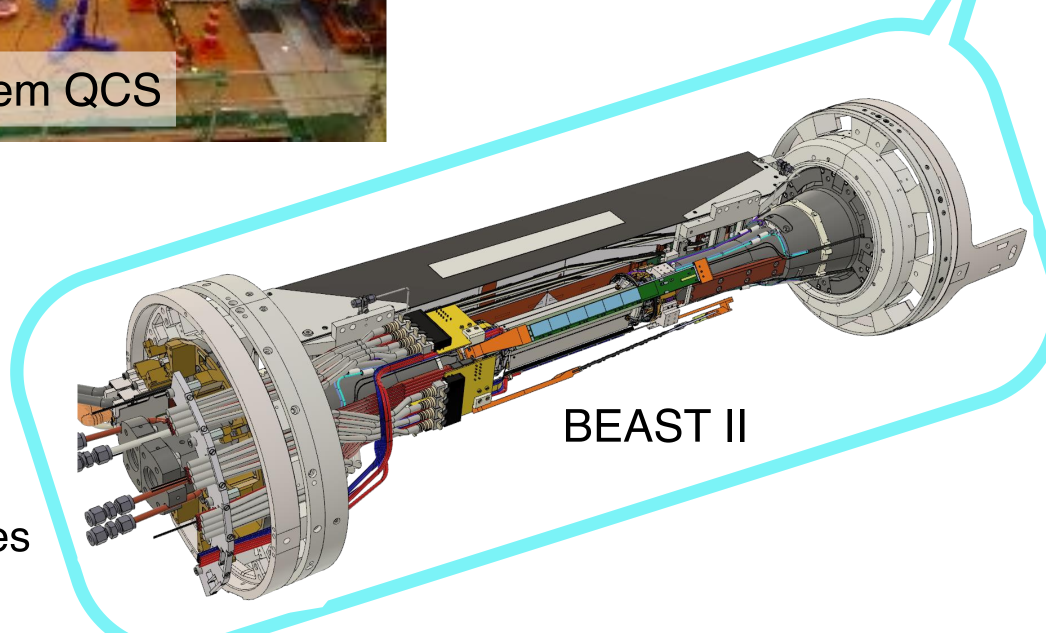
Revised Luminosity Projection after Phase 2





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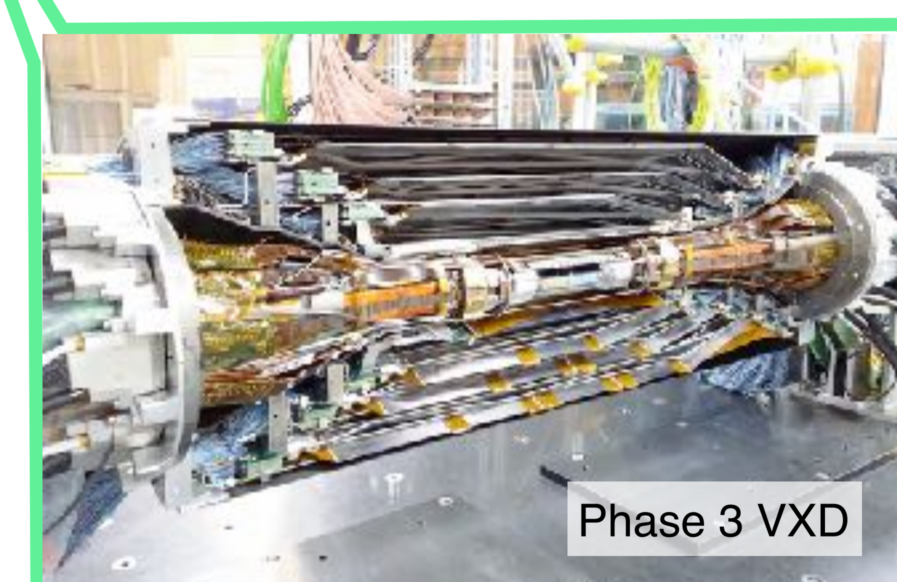
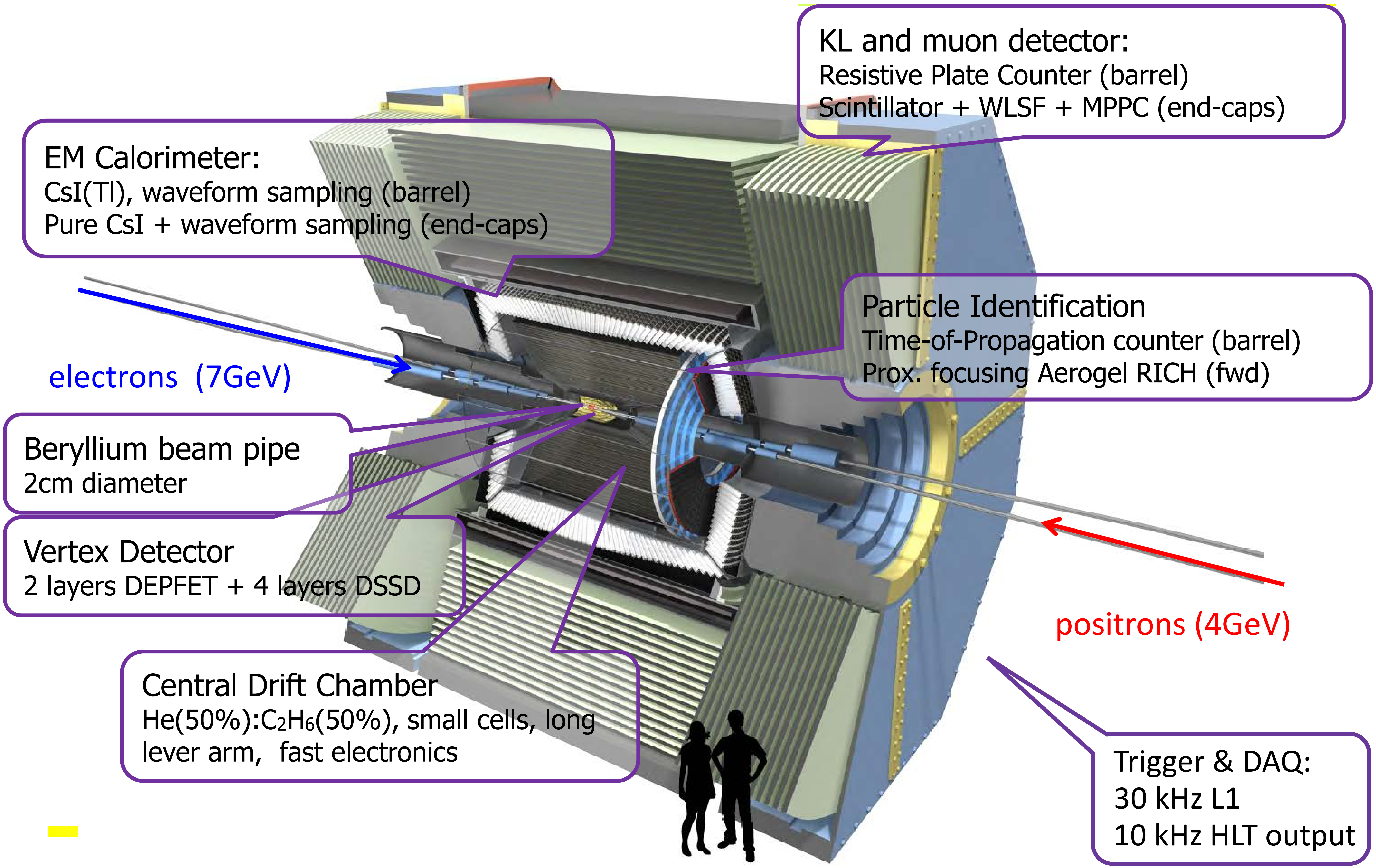
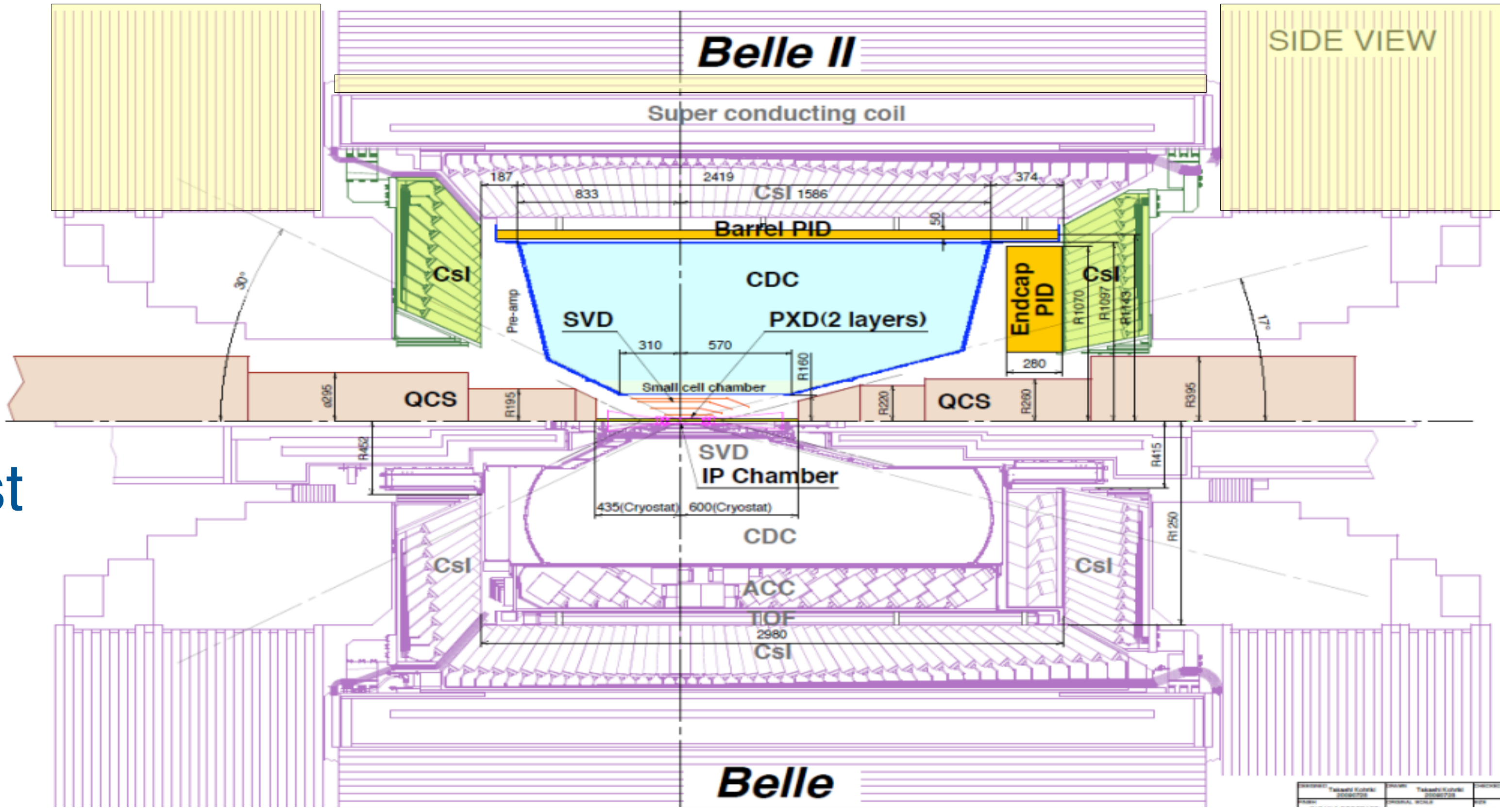


Belle II Detector



Improvements of Belle II versus Belle

- Smaller beam pipe radius (1 cm) allows placement of innermost PXD layer closer to the Interaction point (r = 1.4 cm)
  - significantly improves the vertex resolution (compensate for reduced $\beta\gamma$ by factor 1.5)
- PXD is part of the vertex detector, larger SVD and larger CDC
  - increases K_S efficiency, improves vertex and timing resolution, better flavour tagging
- PID: TOP and ARICH
  - better K/π separation covering the whole momentum range
  - fake rate reduced by factor 2-5
- ECL and KLM consolidation
  - improvements in ECL and KLM to compensate for larger background
- Improved hermeticity
  - due to geometry and reduced boost
- Improved trigger and DAQ
  - 30 kHz L1 rate
  - 10 kHz HLT output rate

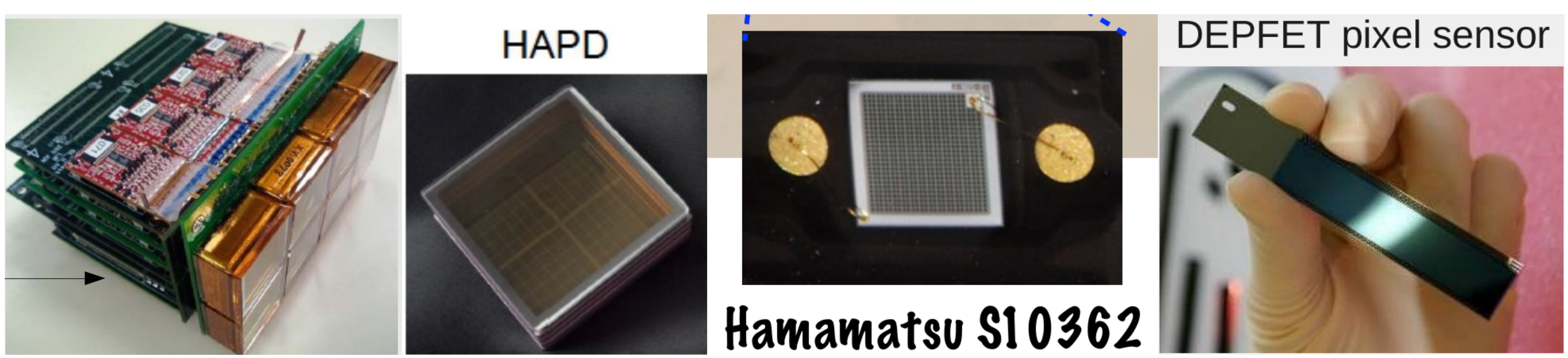


Advanced & Innovative Technologies used in Belle II

- Wide use of pixelated sensors play a central role
  - MCP-PMTs in the TOP
  - HAPDs in the ARICH
  - SiPMs in the KLM
  - DEPFET pixel sensors

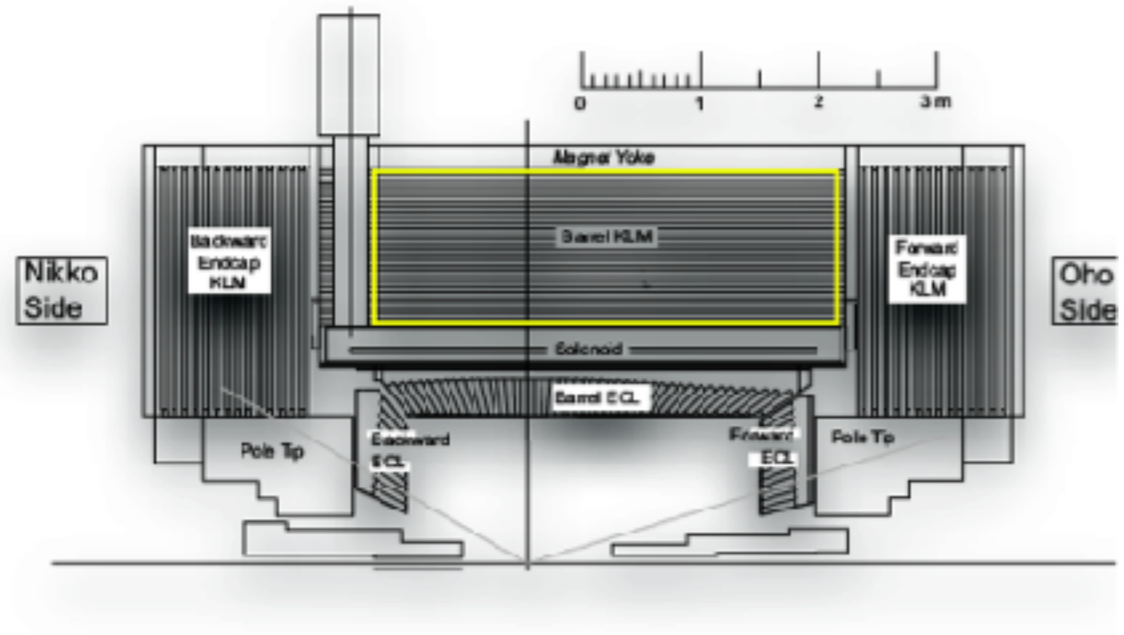
- Waveform sampling with precise timing. Front-end custom ASICs for all subsystems
  - KLM: TARGETX ASIC
  - ECL: New waveform sampling backend with good timing
  - TOP: IRSX ASIC
  - ARICH: KEK custom ASIC
  - CDC: KEK custom ASIC
  - SVD: APV2.5 readout chip adapted from CMS

- DAQ with high performance network switches, large HLT software trigger farm

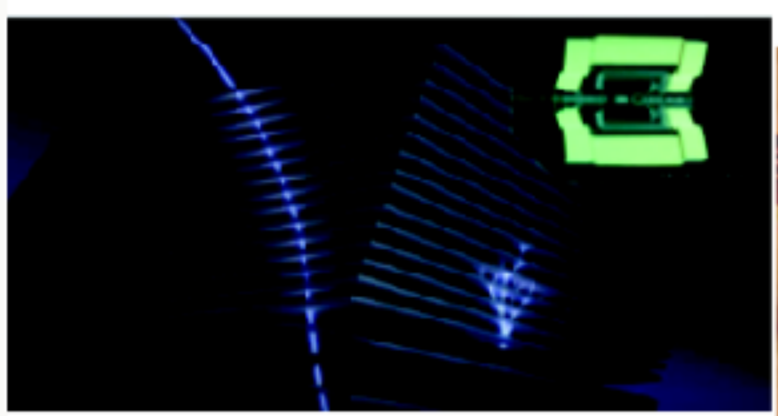


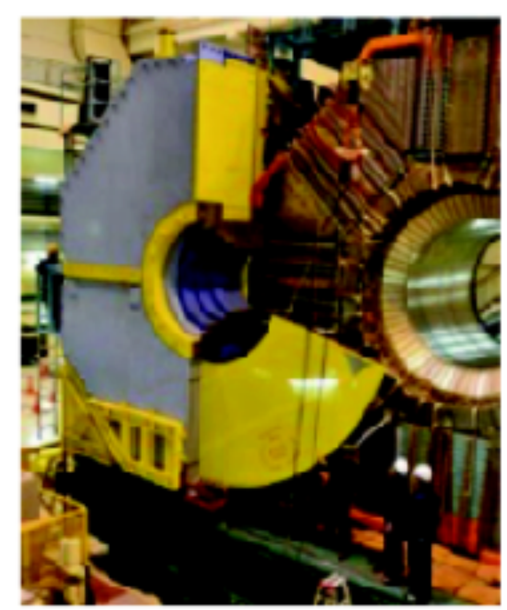
KLM: K_{Long} and Muon Detector

- 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**

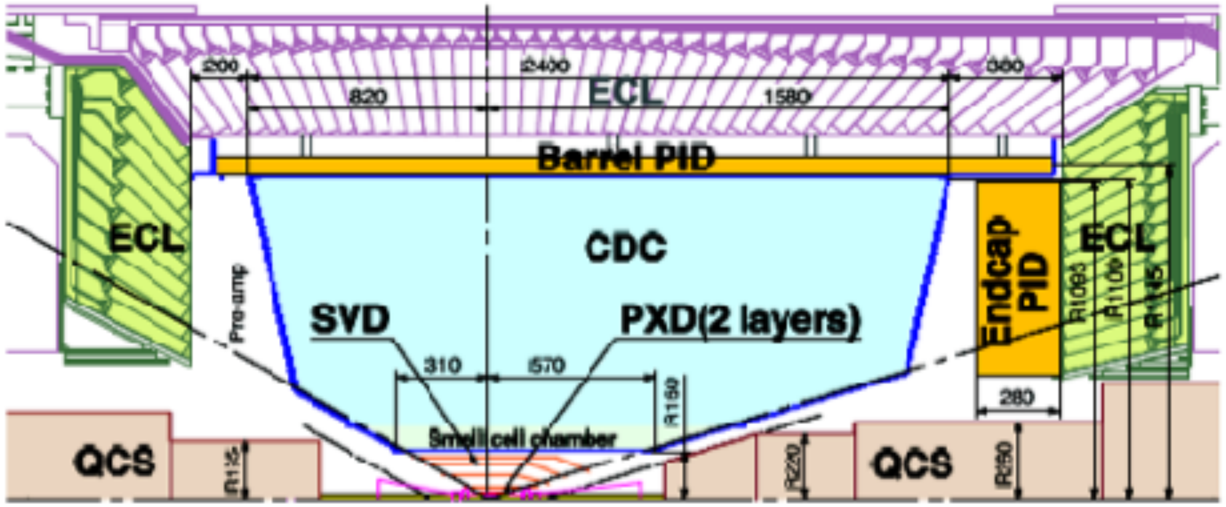


- All endcap active layers + 2 innermost layers in barrel replaced with scintillator strips to resist neutron background
- Installation is complete
- Commissioning with cosmic rays ongoing





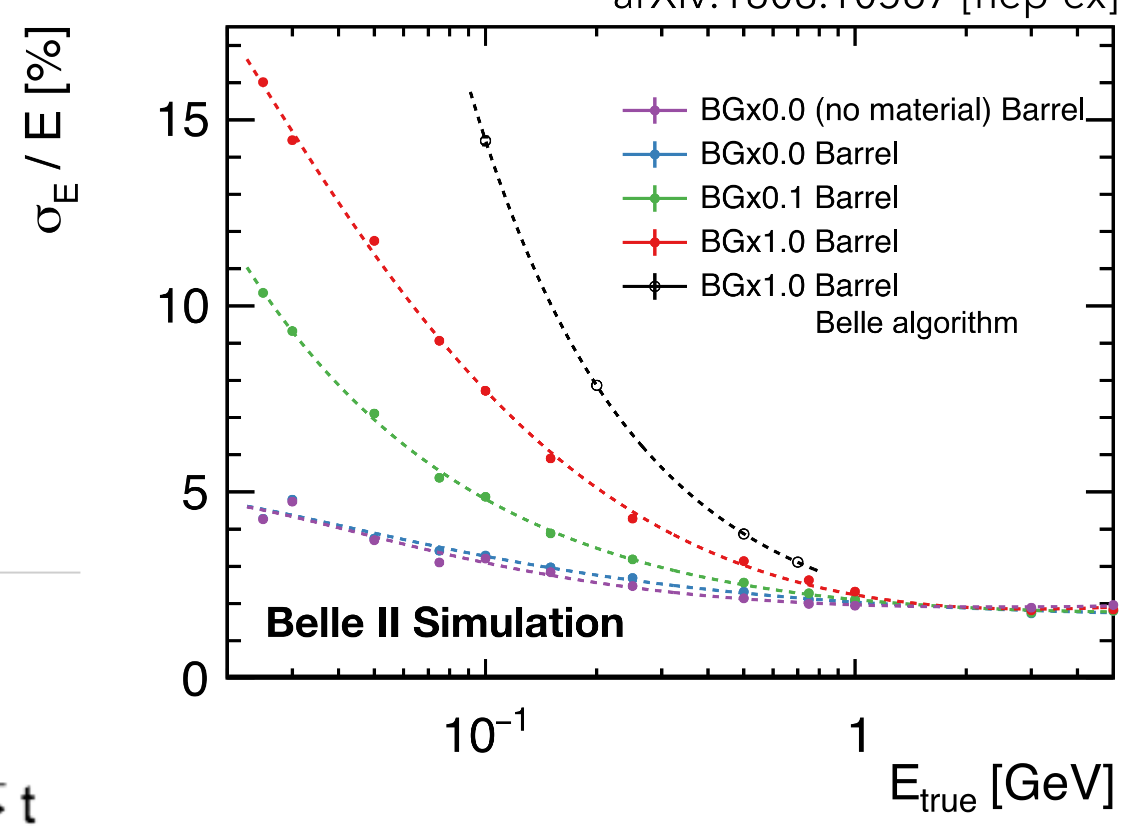
Electromagnetic Calorimeter (ECL)

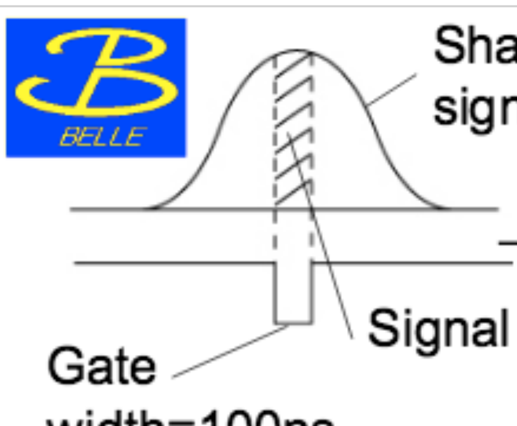


Belle calorimeter: 8736 CsI(Tl) crystals
6624 Barrel
1152 Fwd Endcap
960 Bwd Endcap

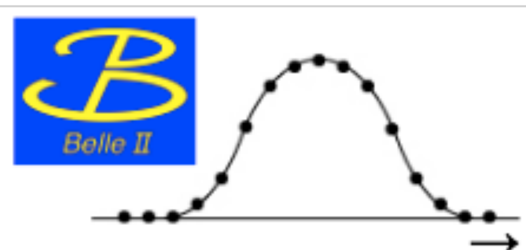
- High rates (machine+physics) ⇒ upgrade of electronics
  - shorter signal shaping (1000ns —> 500ns)
  - the waveform is sampled (~2MHz)
  - waveform fit to extract signal time and amplitude

arXiv:1808.10567 [hep-ex]





Signal charge
↓
Timing (leading/trailing edges) with range information by QtoT converter (MQT300A)
↓
Digitized by TDC



1.76MHz, 18bits digitizer, waveform fit to get energy and timing (i.e. Digital Signal Processing)

Reduction factors;
×7 BG showers
×1.5~2 pileup noise

Belle II ECL trigger efficiency (simulation) compared to Belle ECL efficiency

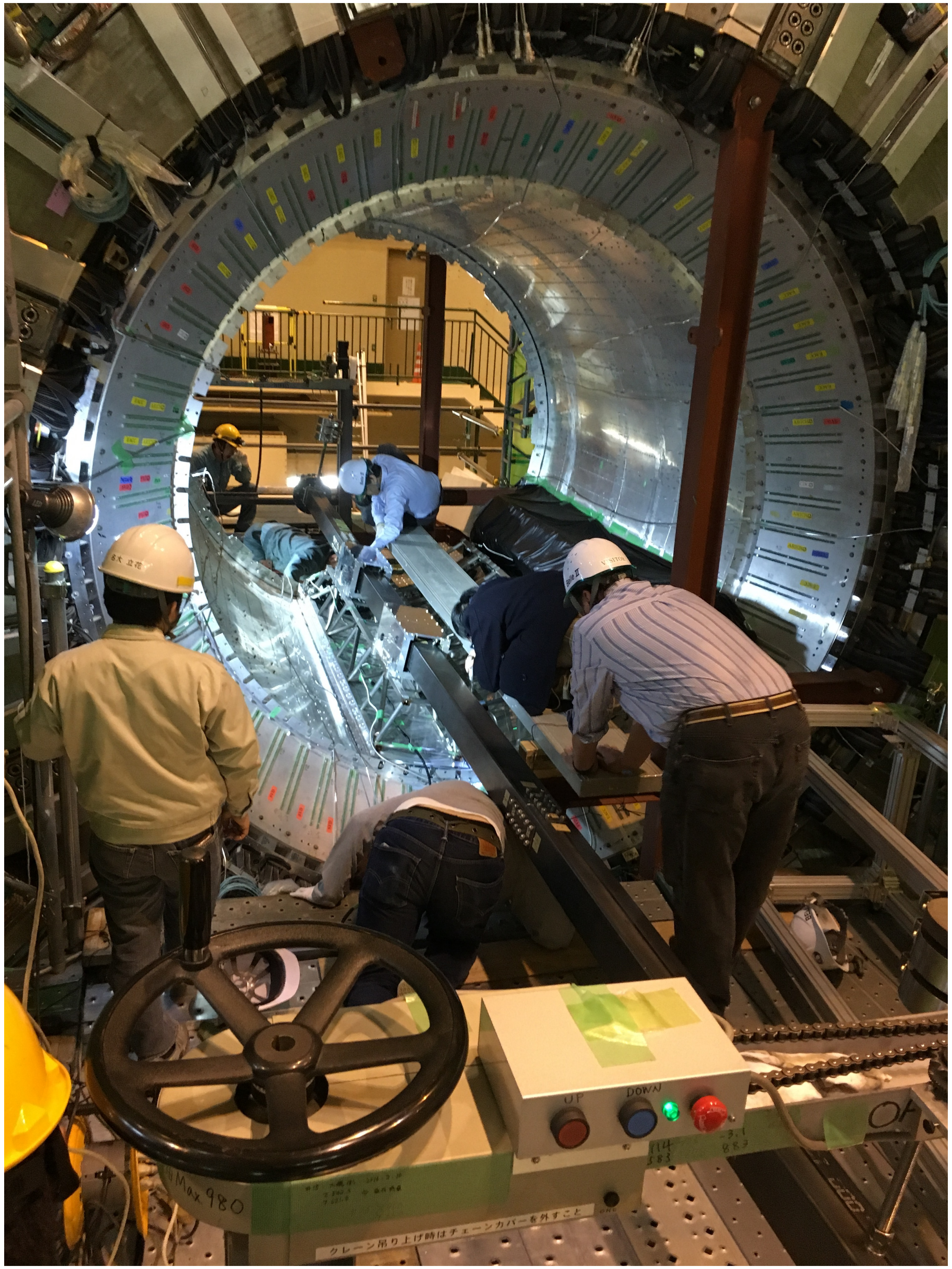
Physics trigger: E_{tot} > 1 GeV

	ε_{phys} (total)	ε_{signal}	ε_{bkg}
Belle	99.42 %	88.70 %	10.72 %
Belle II	99.90 %	99.12 %	0.78 %

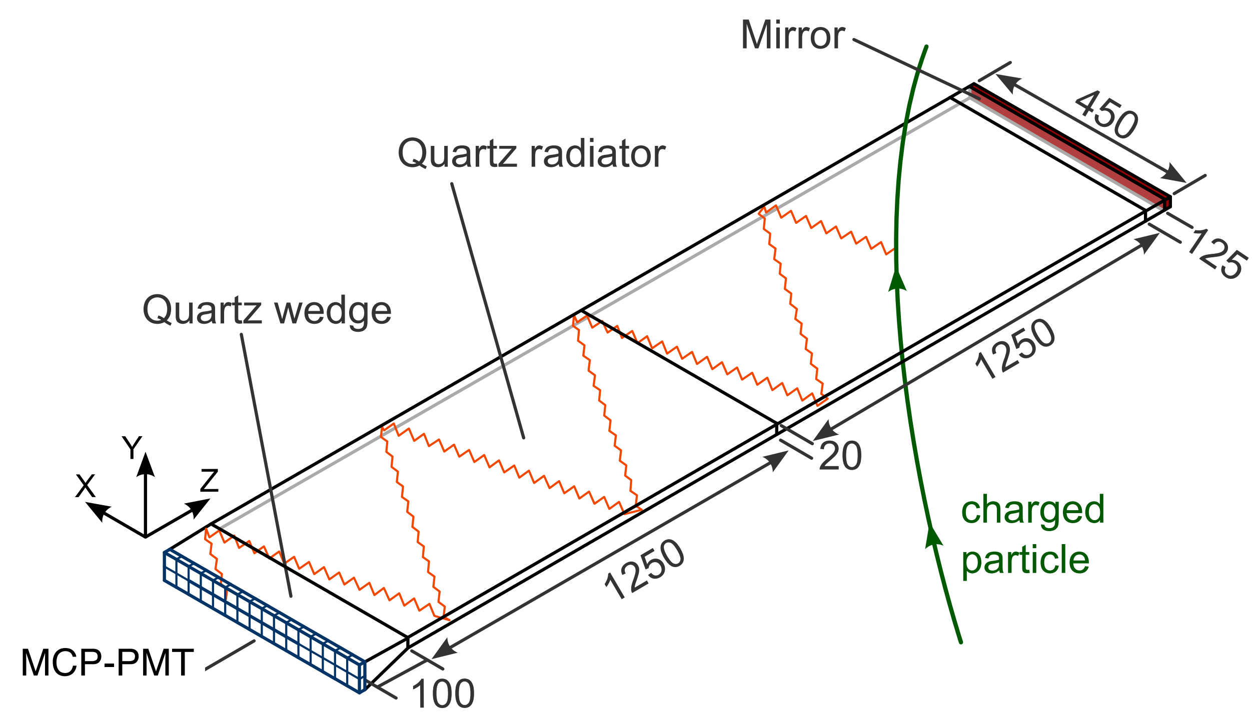
12

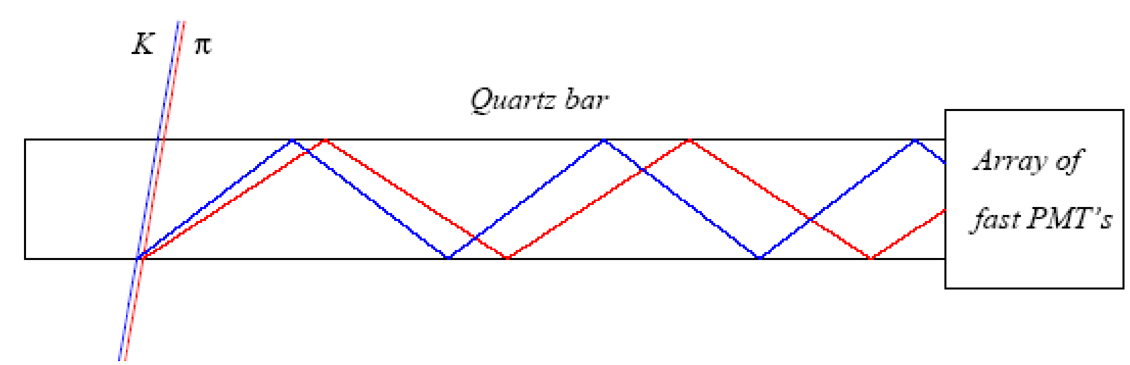
Time Of Propagation Detector TOP

Installation of last TOP module in May 2016



- 16 quartz bars: 2x1.25 m x 0.45 m x 2 cm
- 32 (segmented anode 4x4) Micro-channel plate PMTs Hamamatsu SL-10 MCP PMT





θ_c is reconstructed from hit position (x,y) in the PMT and from time of propagation

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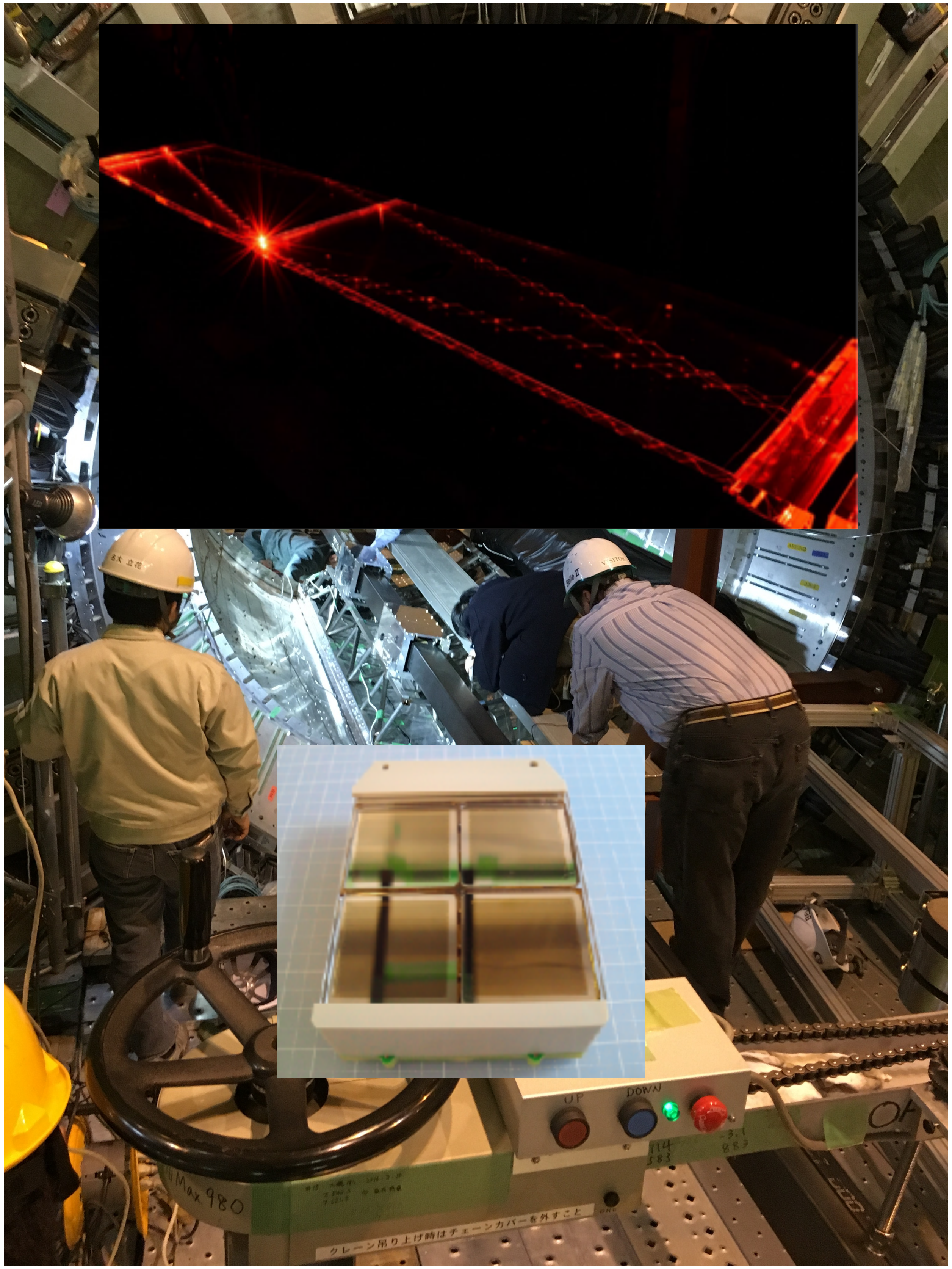

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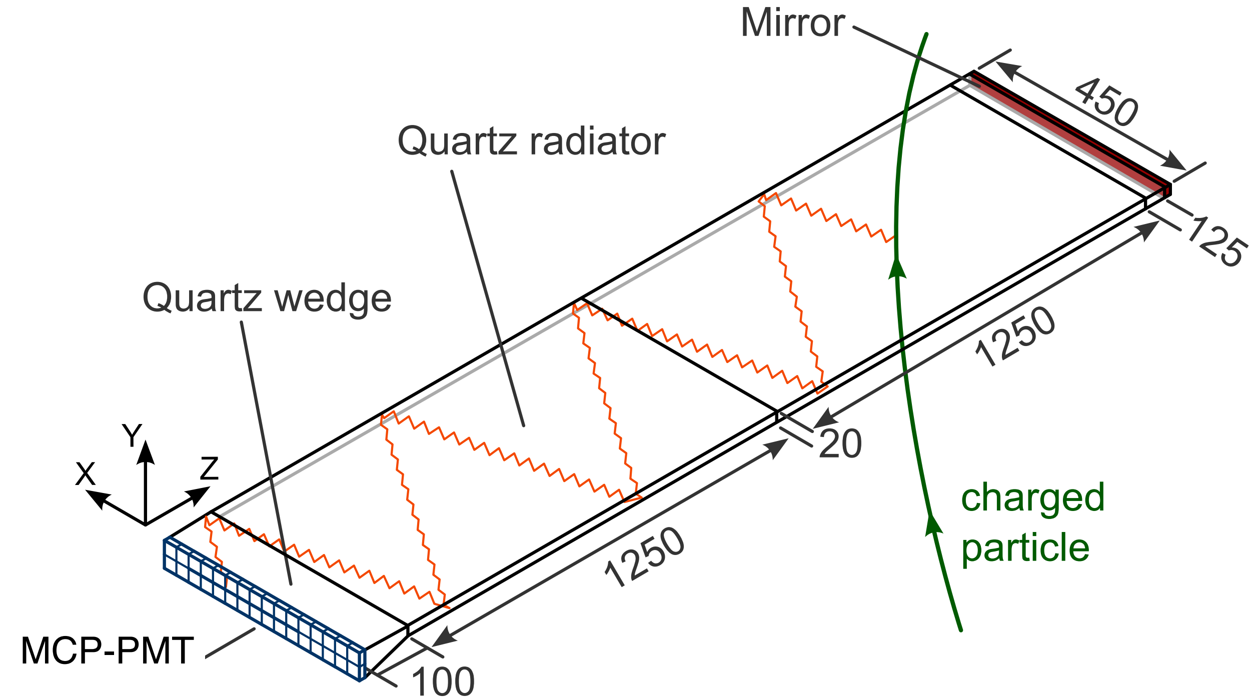

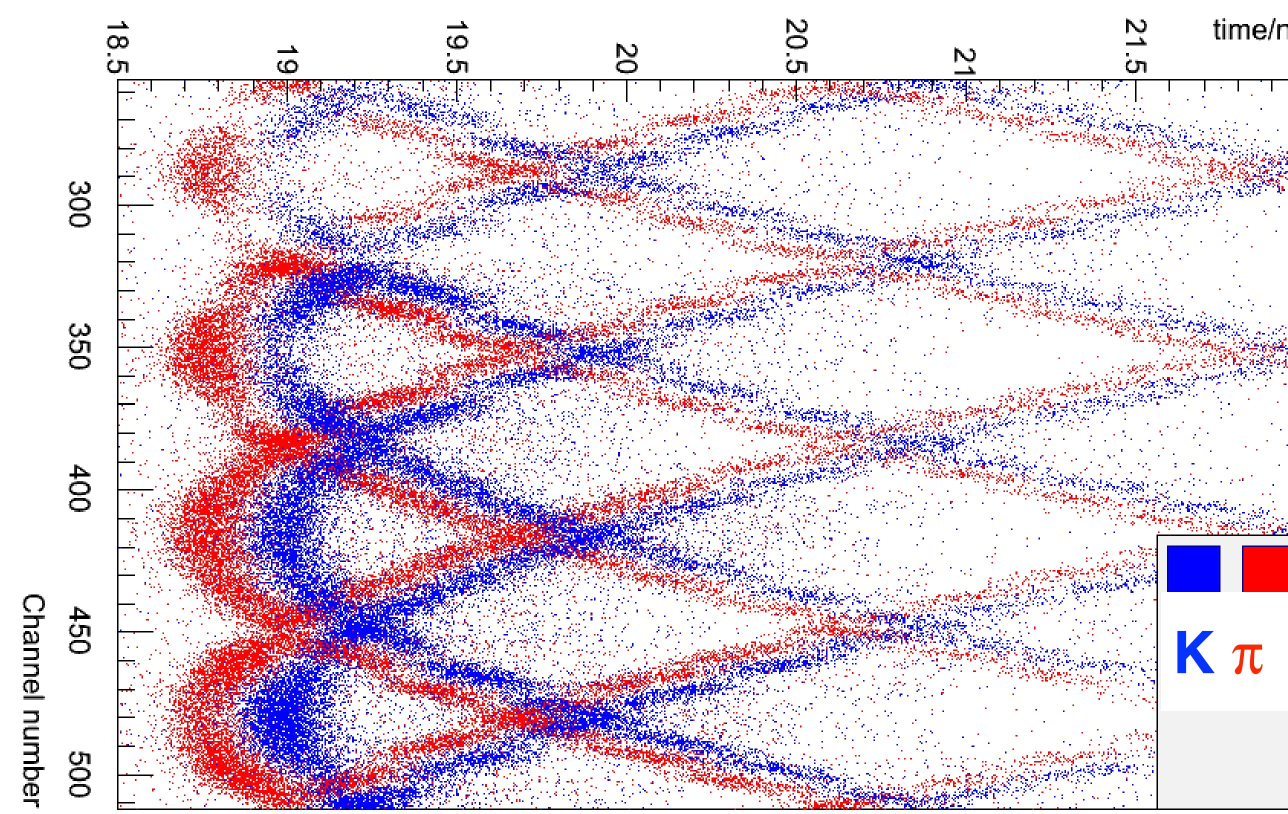

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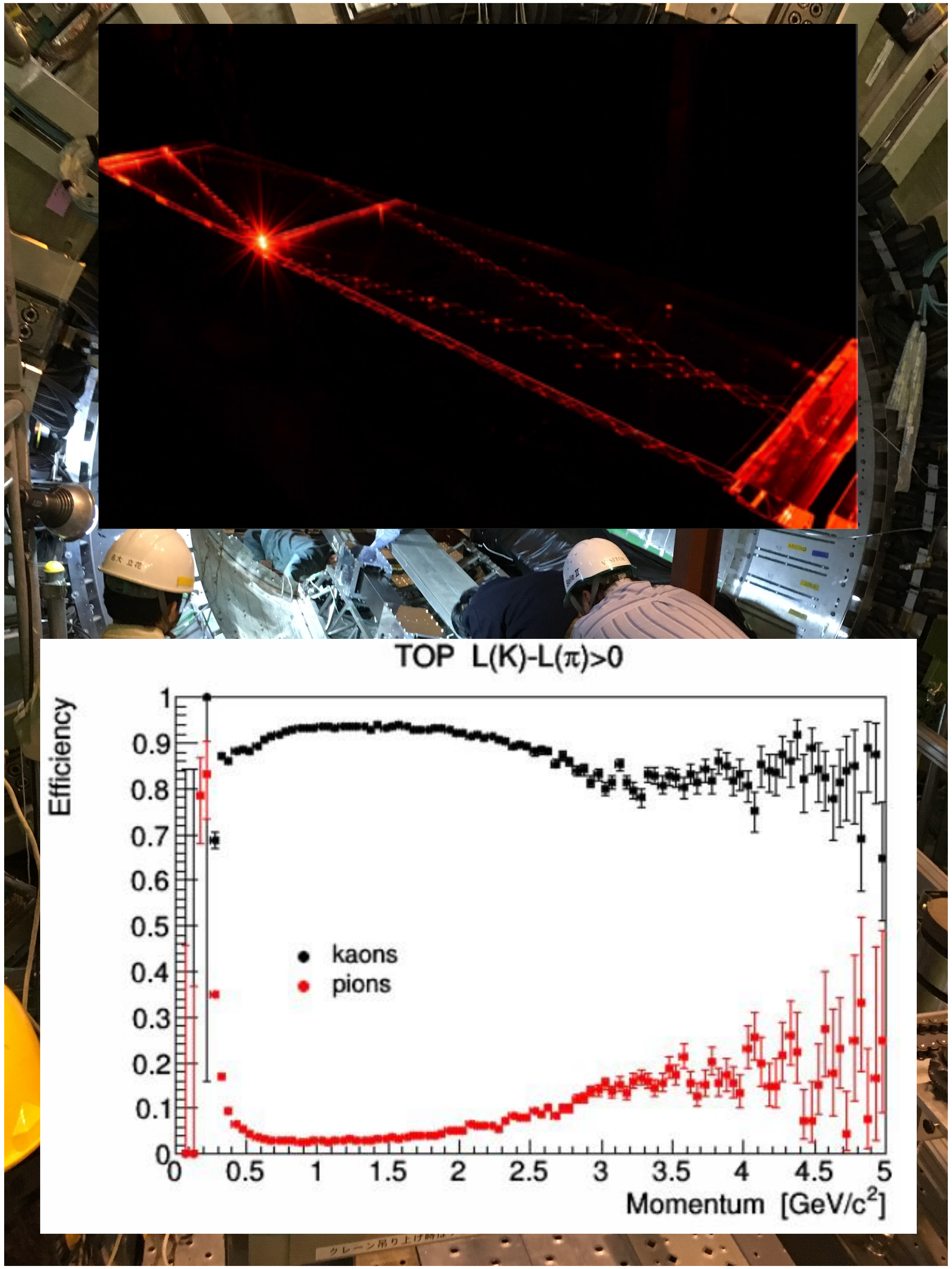

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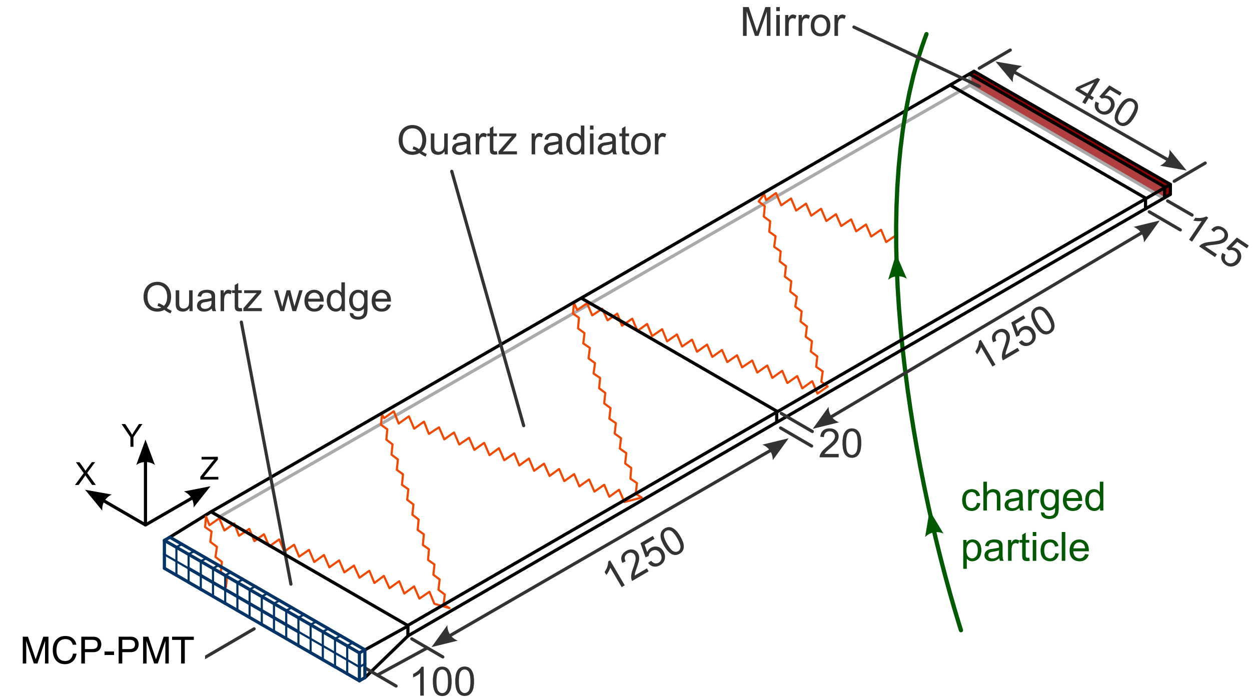
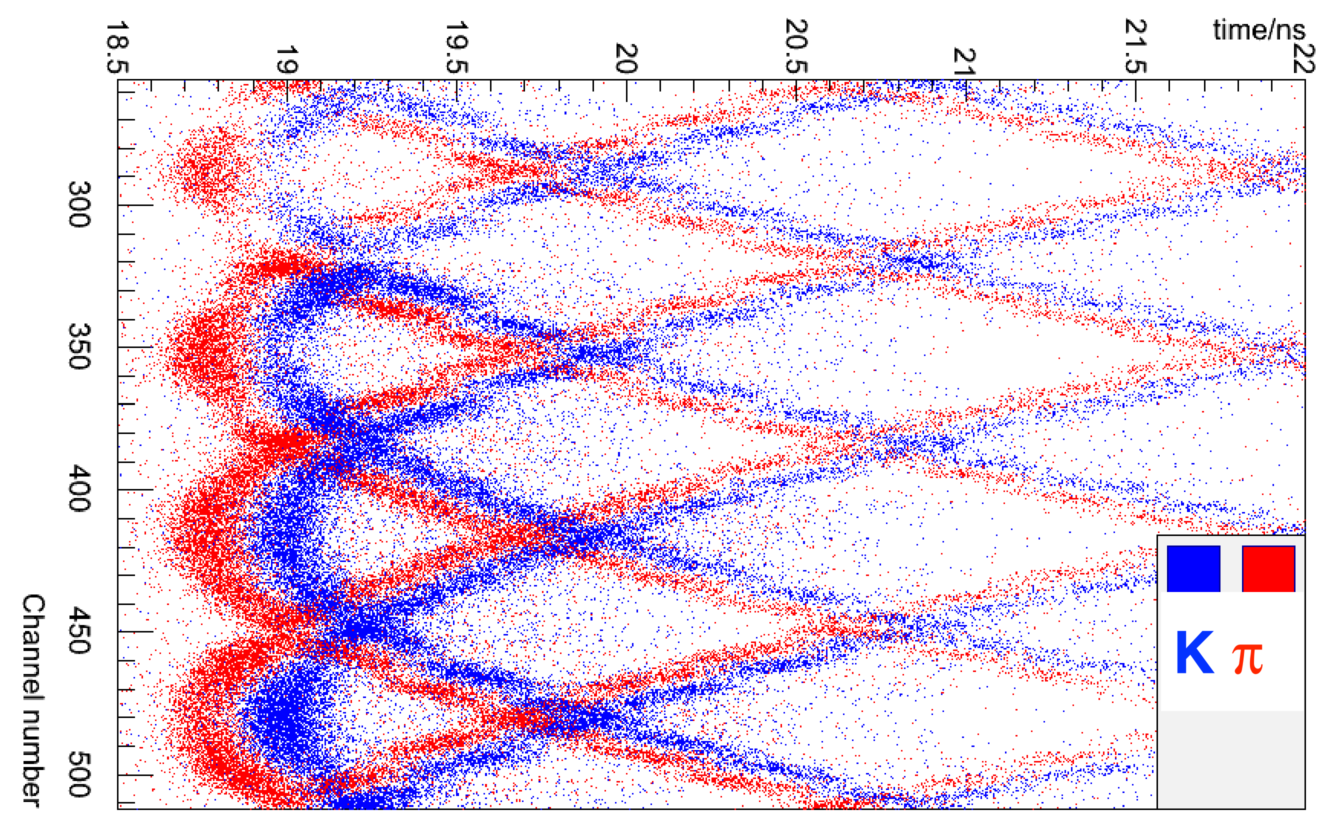
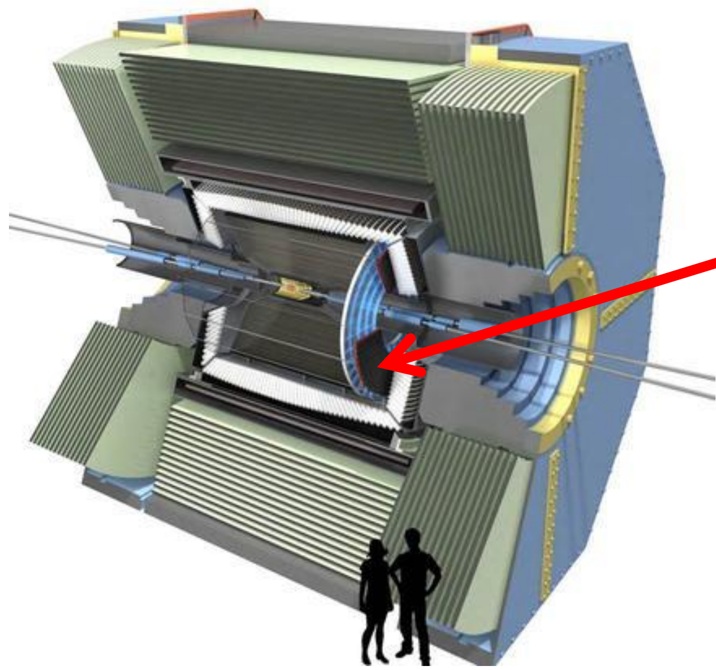
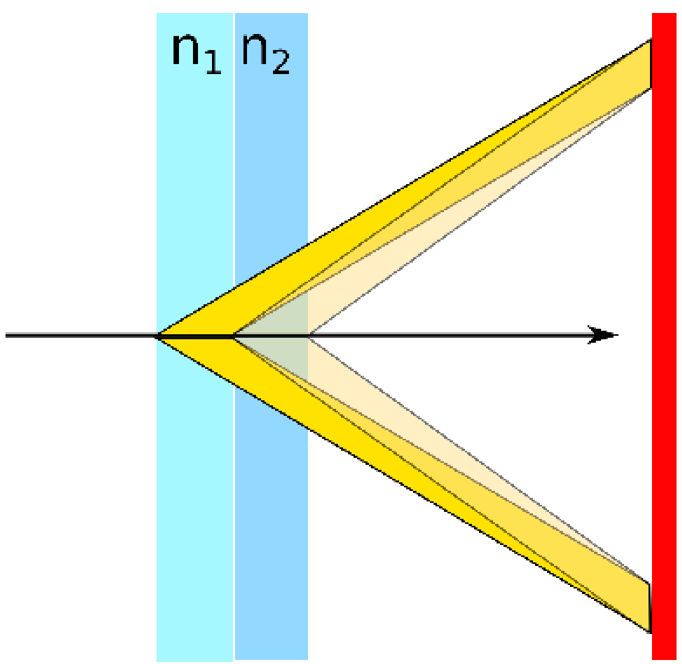


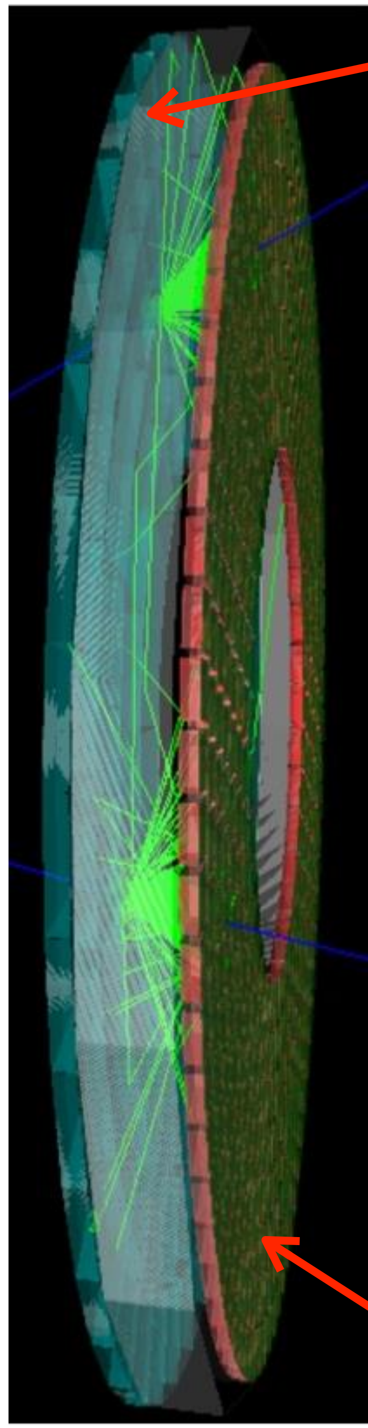


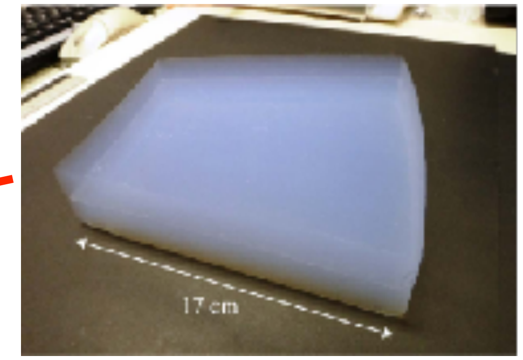
Aerogel RICH: ARICH



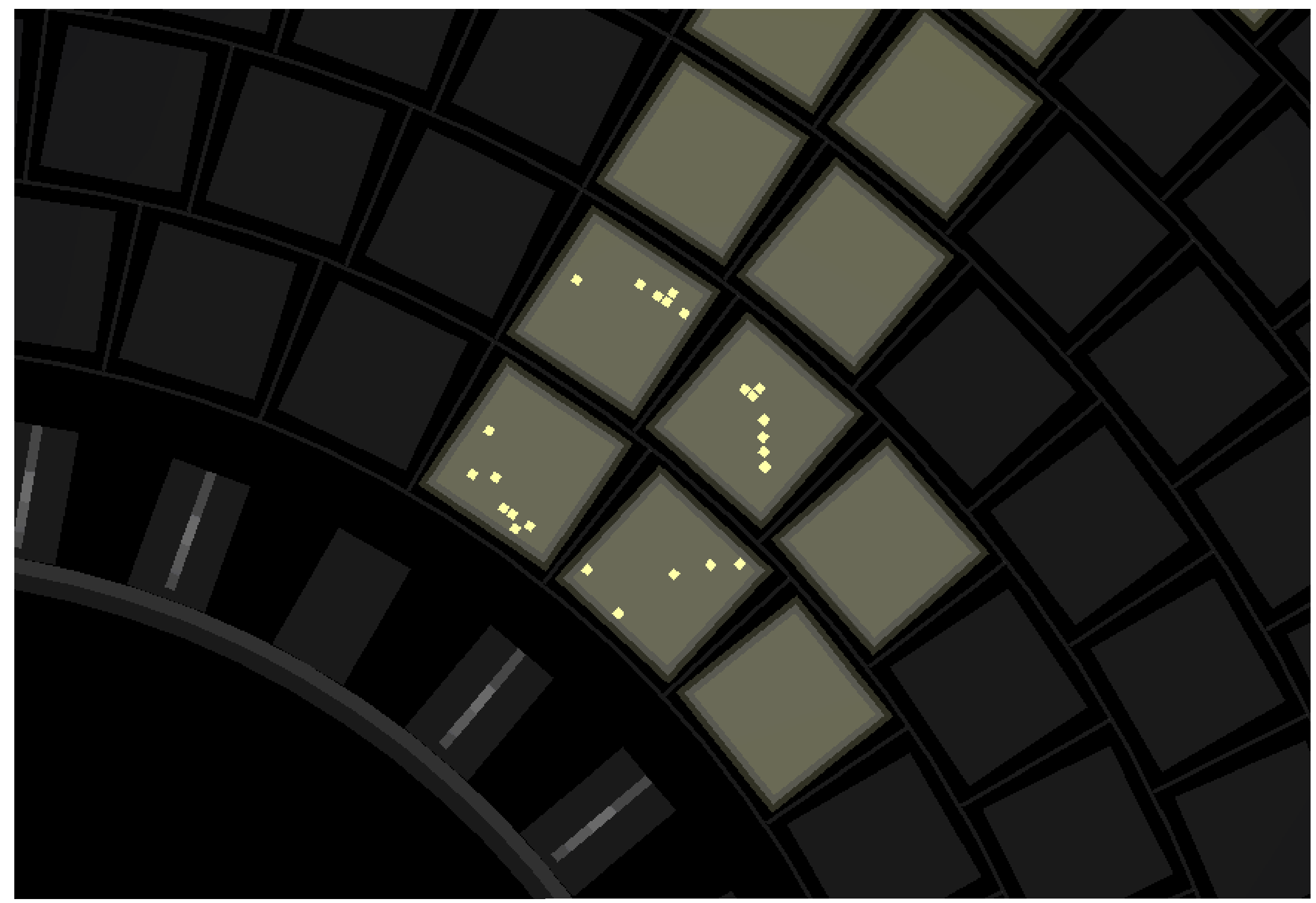


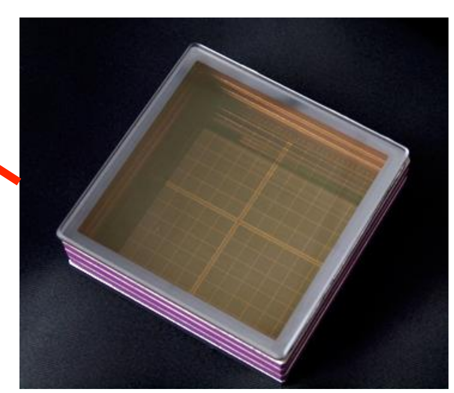
Proximity focussing

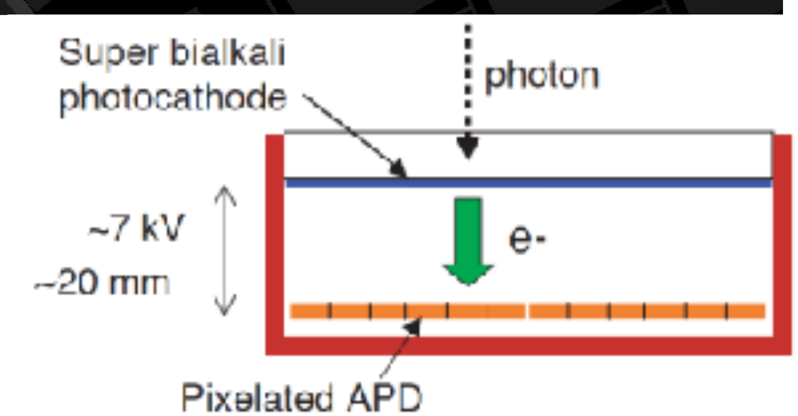




- Radiator
  - Silica Aerogel n = 1.045-1.055
  - transmission length > 40 mm
- Photon detection
  - Hybrid Avalanche Photo Detectors
  - 420 units, 144 channels each, 5 mm pixelated

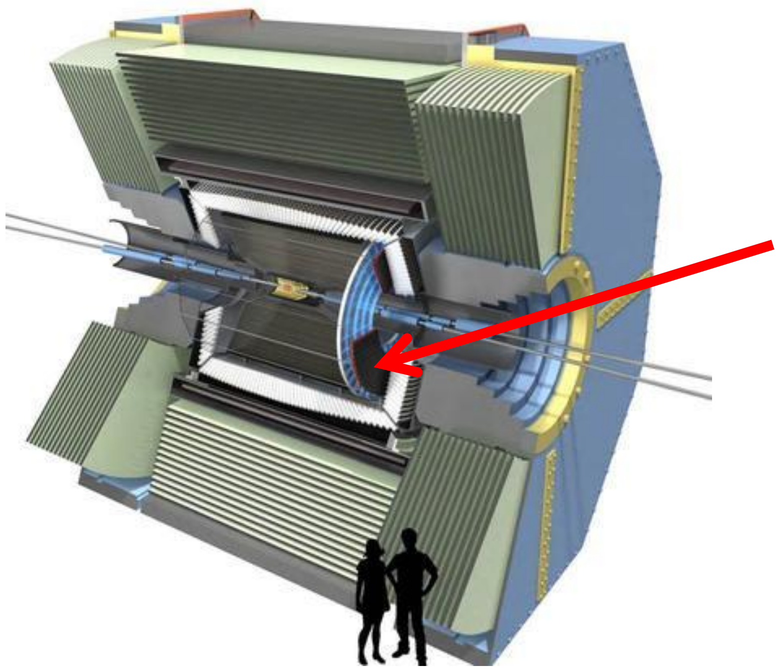


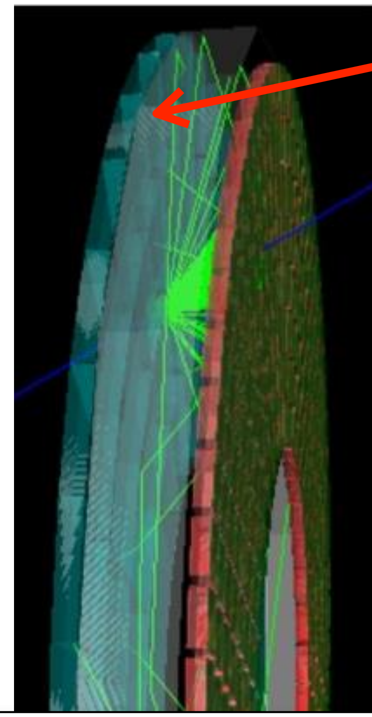


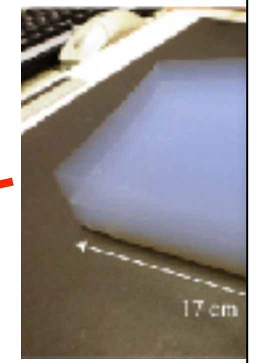


Hybrid Avalanche Photo-Detector

Aerogel RICH: ARICH

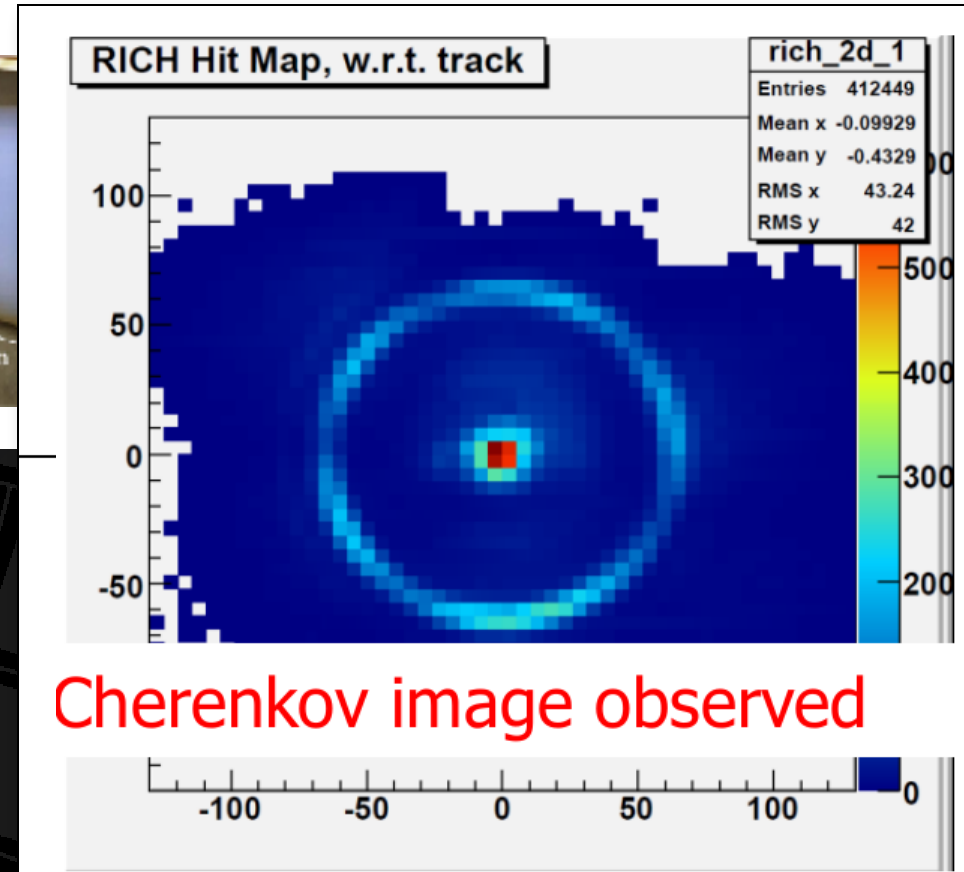


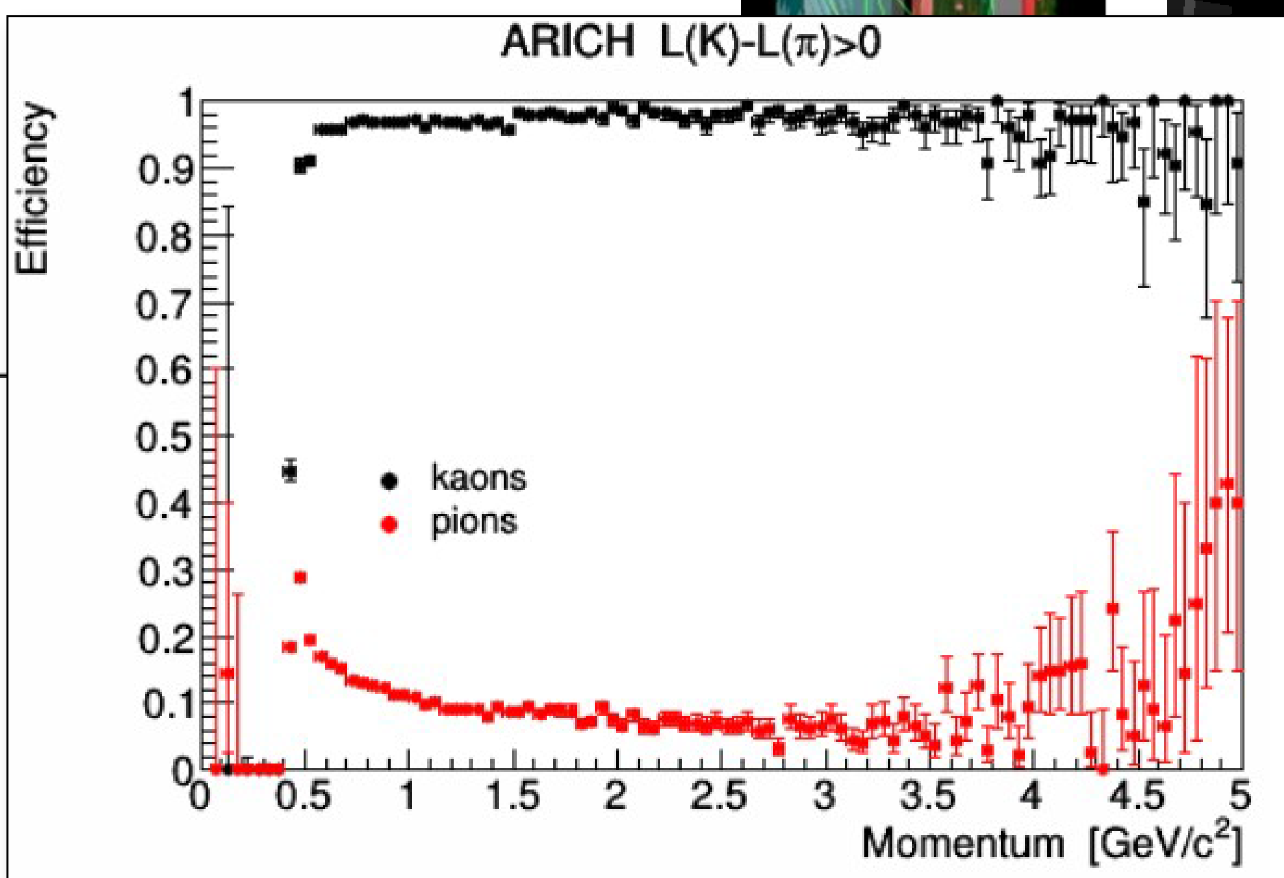


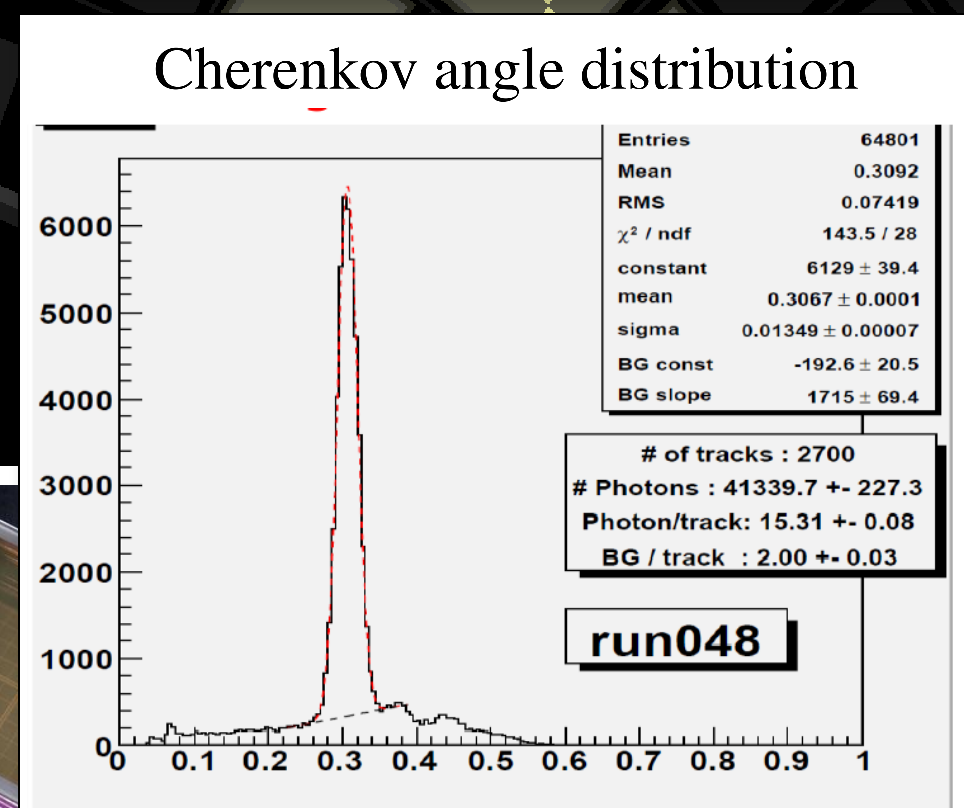


tors

5 mm pixelated



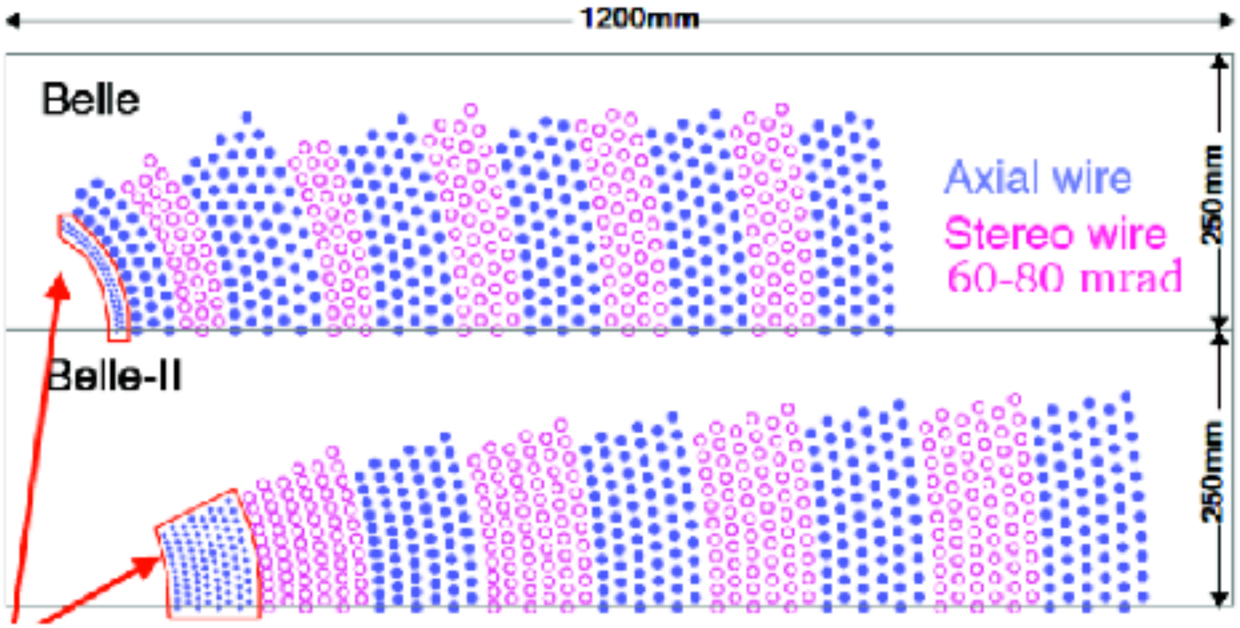




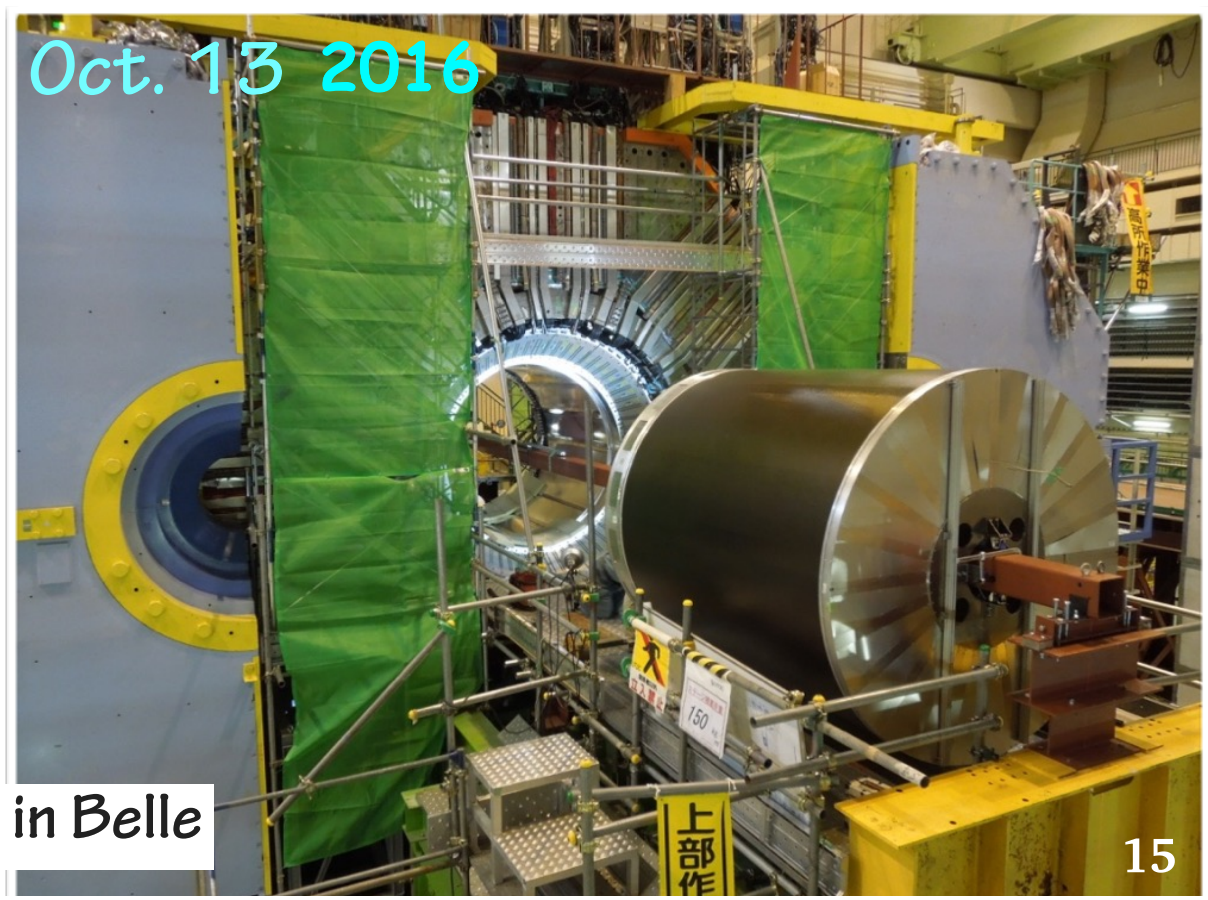
6.6 σ π/K at 4 GeV/c !

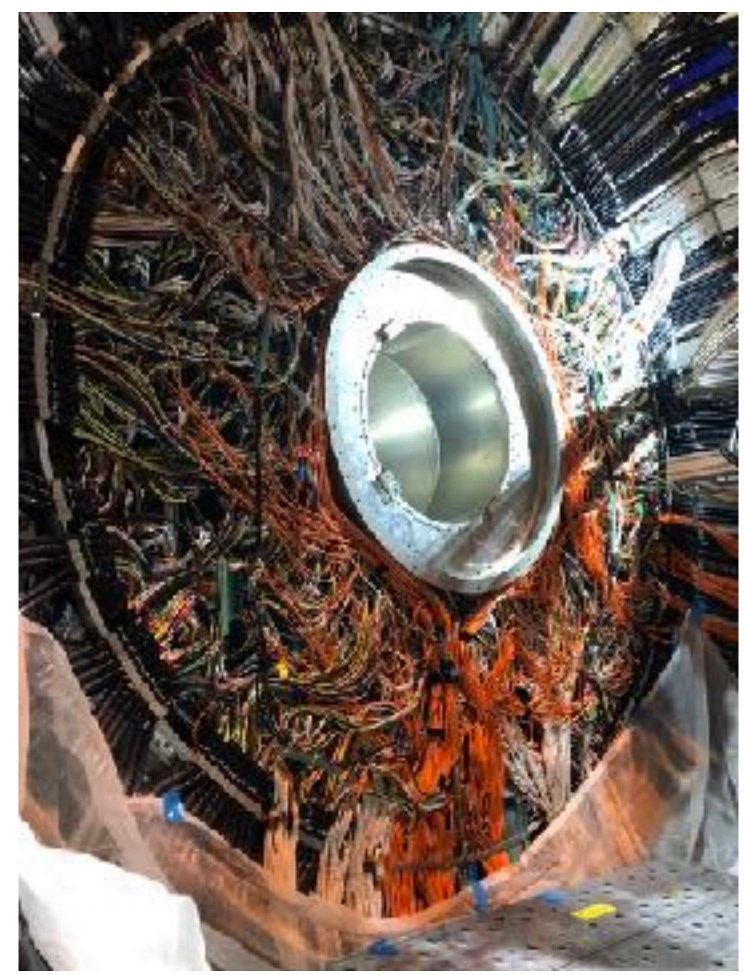
Hybrid Avalanch

Central Drift Chamber CDC

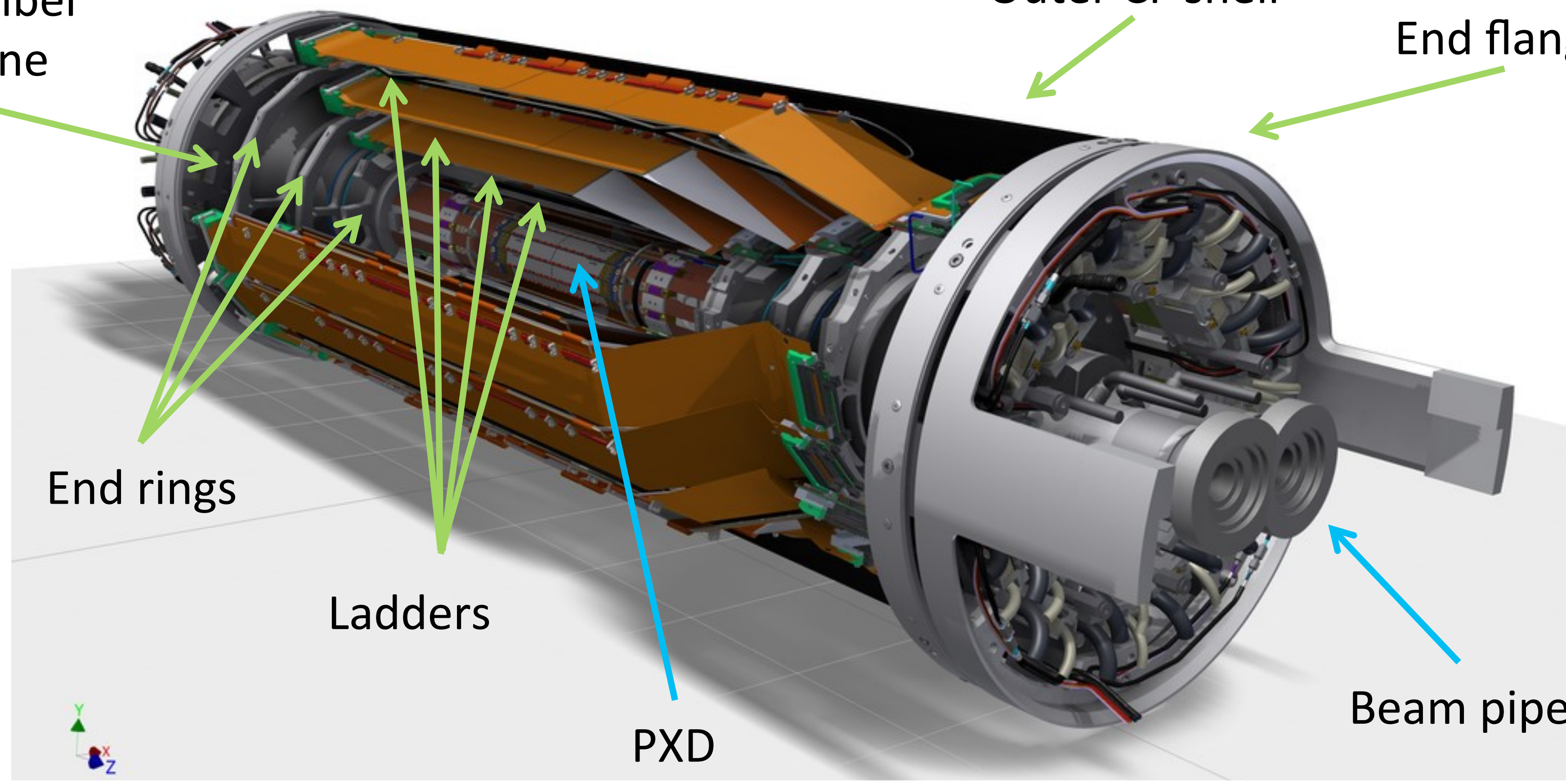


$$\sigma_{r\phi} = 100\ \mu\text{m},\ \sigma_z = 2\ \text{mm}$$
$$\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$$
$$\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}\ \text{(with SVD)}$$

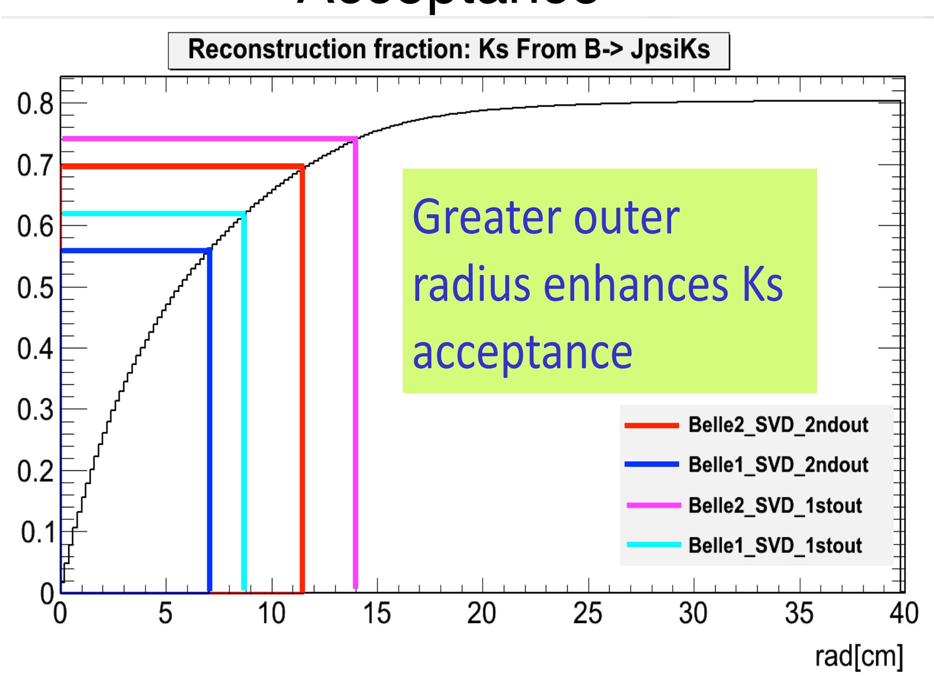




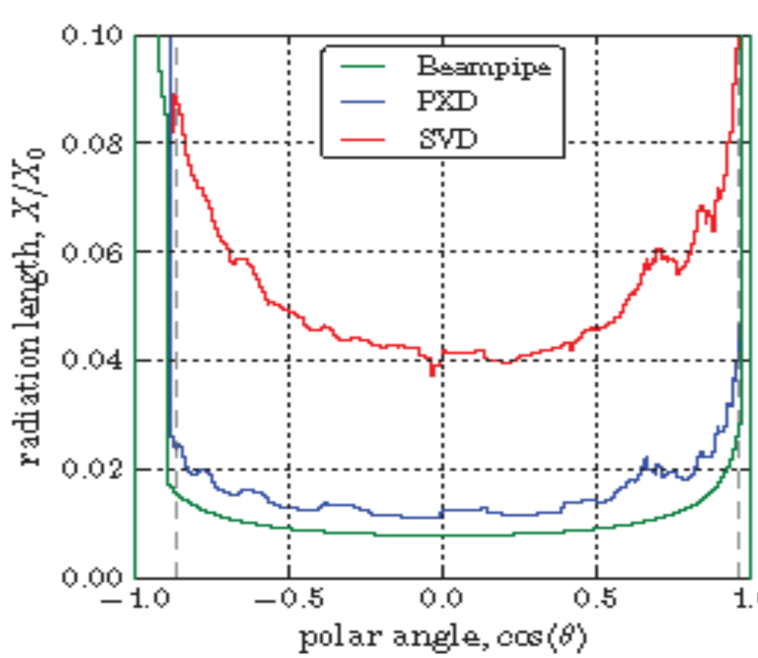
Belle II Vertex Detector VXD



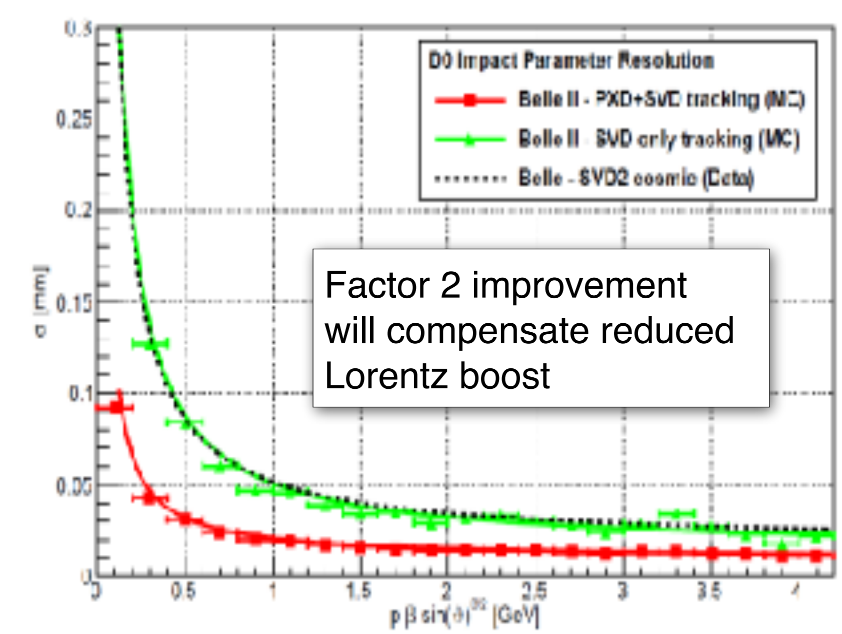
Acceptance



Material budget

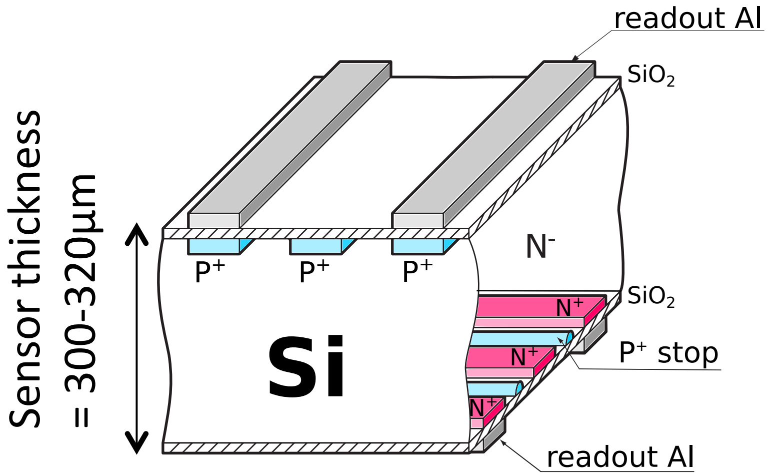


Resolution



SVD Layout

DSSD (Double-sided Si strip detector)

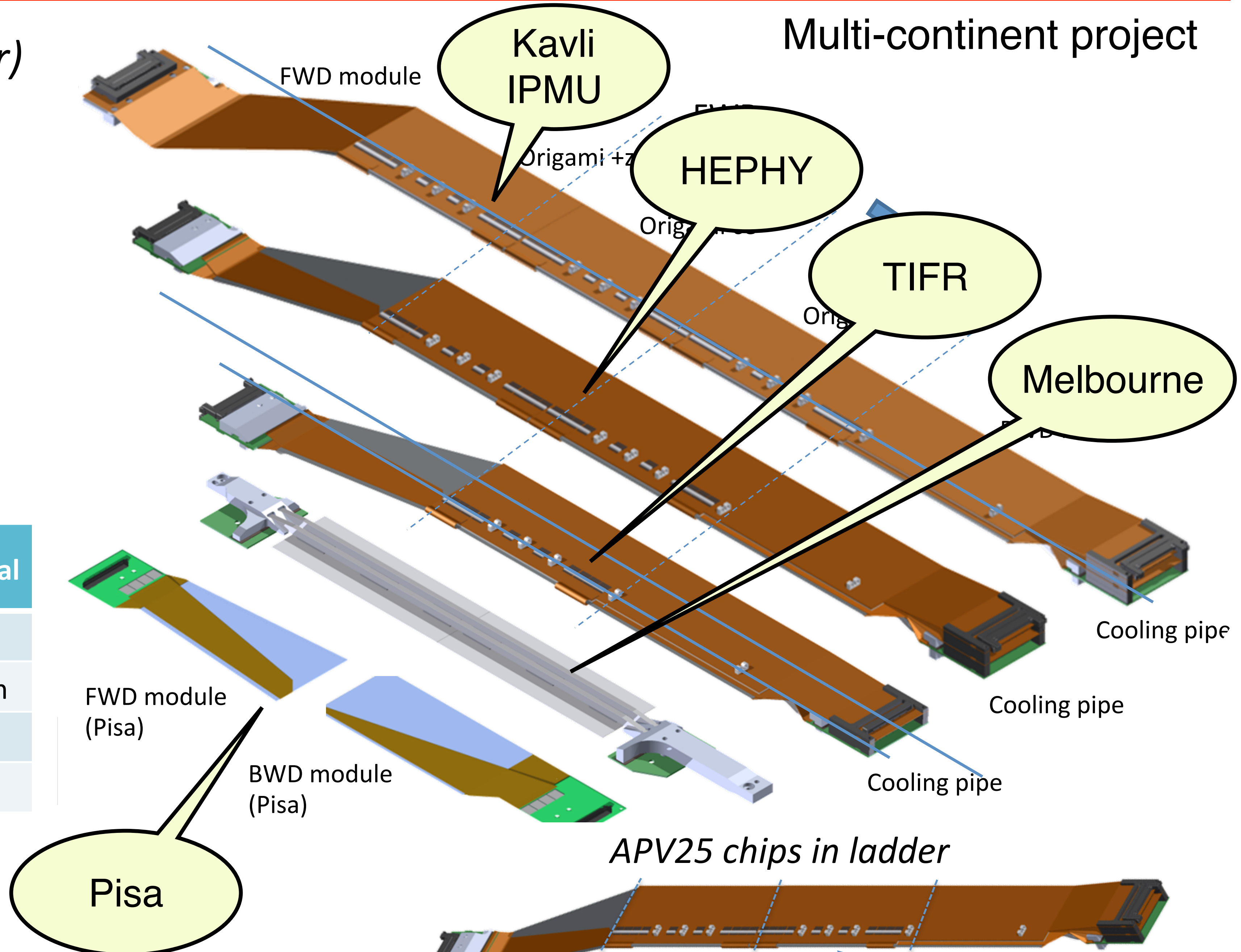


Strip numbers and pitches

- 3 types of DSSD sensors

Sensors	Rectangular (Large)	Rectangular (Small)	Trapezoidal
# of *p*-strips	768	768	768
***p*-strip pitch**	75µm	50µm	50…75µm
# of *n*-strips	512	768	512
***n*-strip pitch**	240µm	160µm	240µm

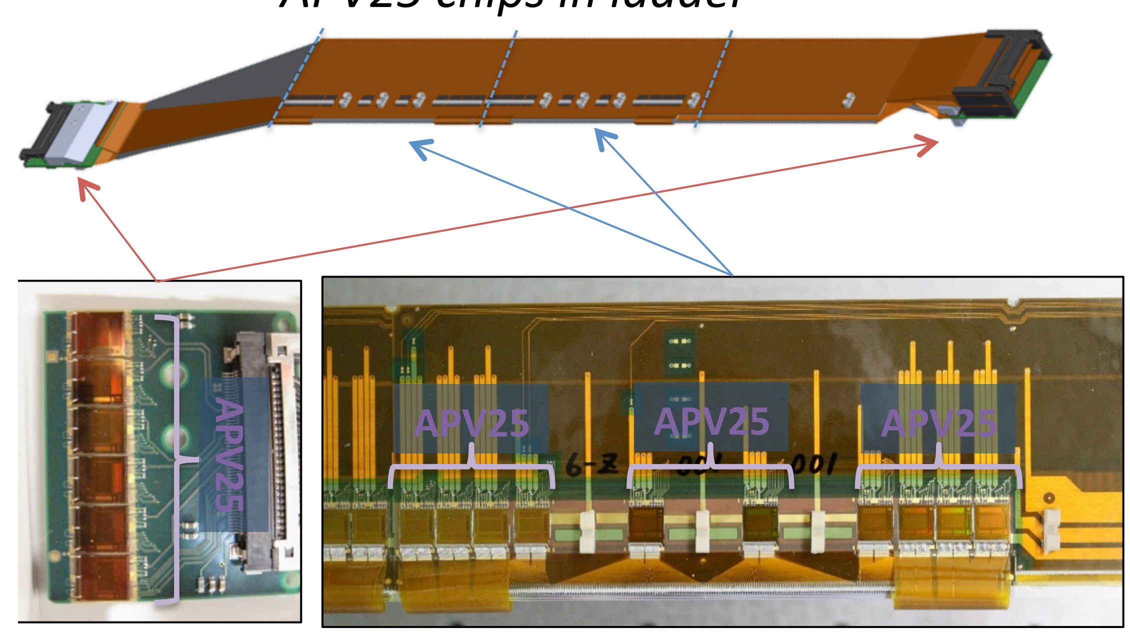
Multi-continent project



APV25 front end readout ASIC

- # of input channels: 128 ch.
- shaping time: 50 ns
- radiation hardness: > 1MGy
- maximum heat dissipation: 0.4W => necessity of CO_2 cooling
- thinned to 100 µm for reduction of the material budget

APV25 chips in ladder

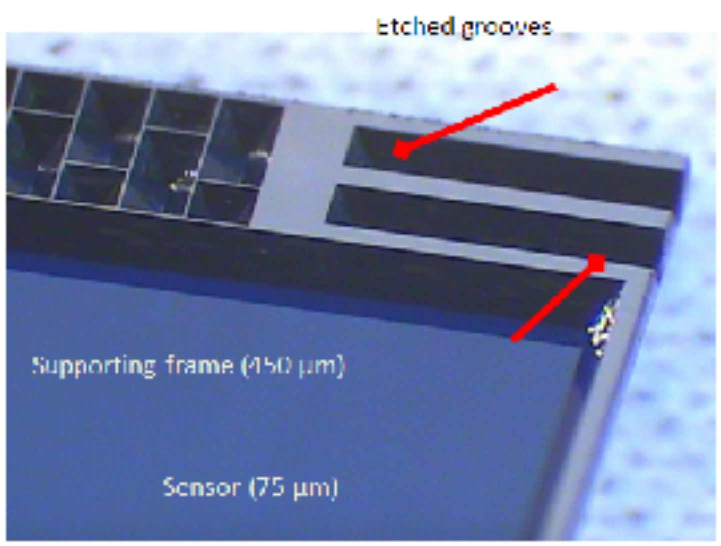


PXD Module based on DEPFET (HLL)

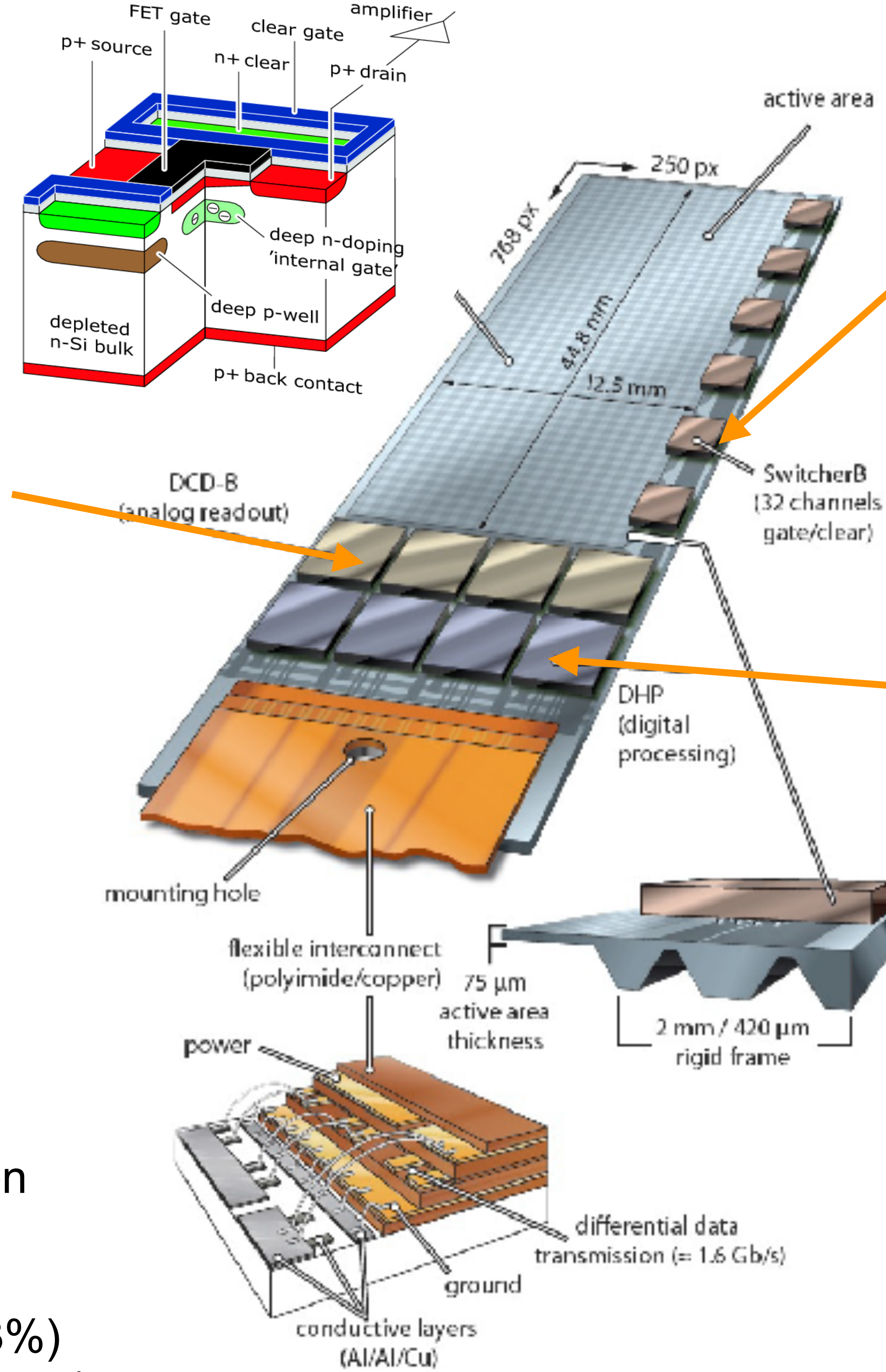
DCDB (Drain Current Digitizer)
Analog front-end

Amplification and digitization of DEPFET signals.

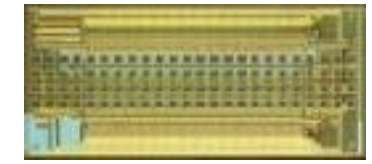
- 256 input channels
- 8-bit ADC per channel
- 92 ns sampling time
- new version w/ 50ns sampling time under test
- UMC 180 nm



Internal amplification
Low noise, low power consumption
2 layers: @1.4(2.2) cm
Pixel size: 50 x 75 µm²
Max. occupancy: 0.5 hits/µm²/s (3%)
Integration time: 20 µs (rolling shutter)
Thickness: **75 µm, 0.21% X_0 per layer**



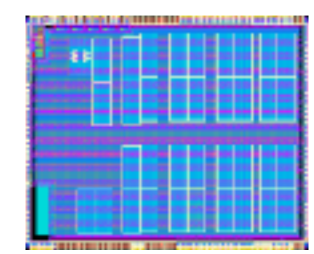
SwitcherB - Row Control



AMS/IBM HVCMOS 180 nm

- Size 3.6 × 1.5 mm²
- Gate and Clear signal
- 32x2 channels
- Fast HV ramp for Clear

DHP (Data Handling Processor)
First data compression

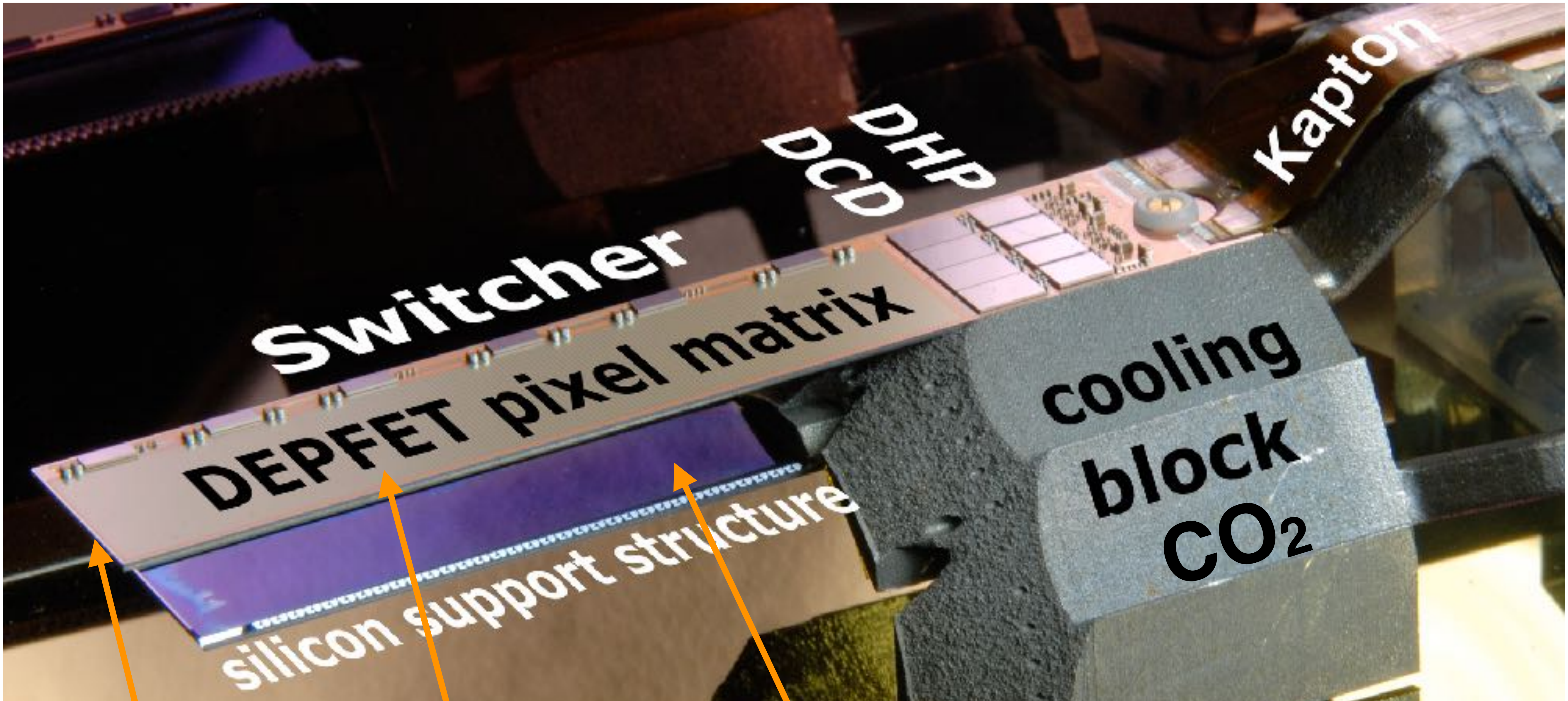


IBM CMOS 90 nm (TSMC 65 nm)

- Size 4.0 × 3.2 mm²
- Stores raw data and pedestals
- CM and pedestal correction
- Data reduction (zero suppression)
- Timing and trigger control
- Drives data link

12 German institutes + contributions from China, Czech Republic, Poland and Spain

Mounted PXD Modules for Phase 2



L2 half-ladder

L1 half-ladder (back side)

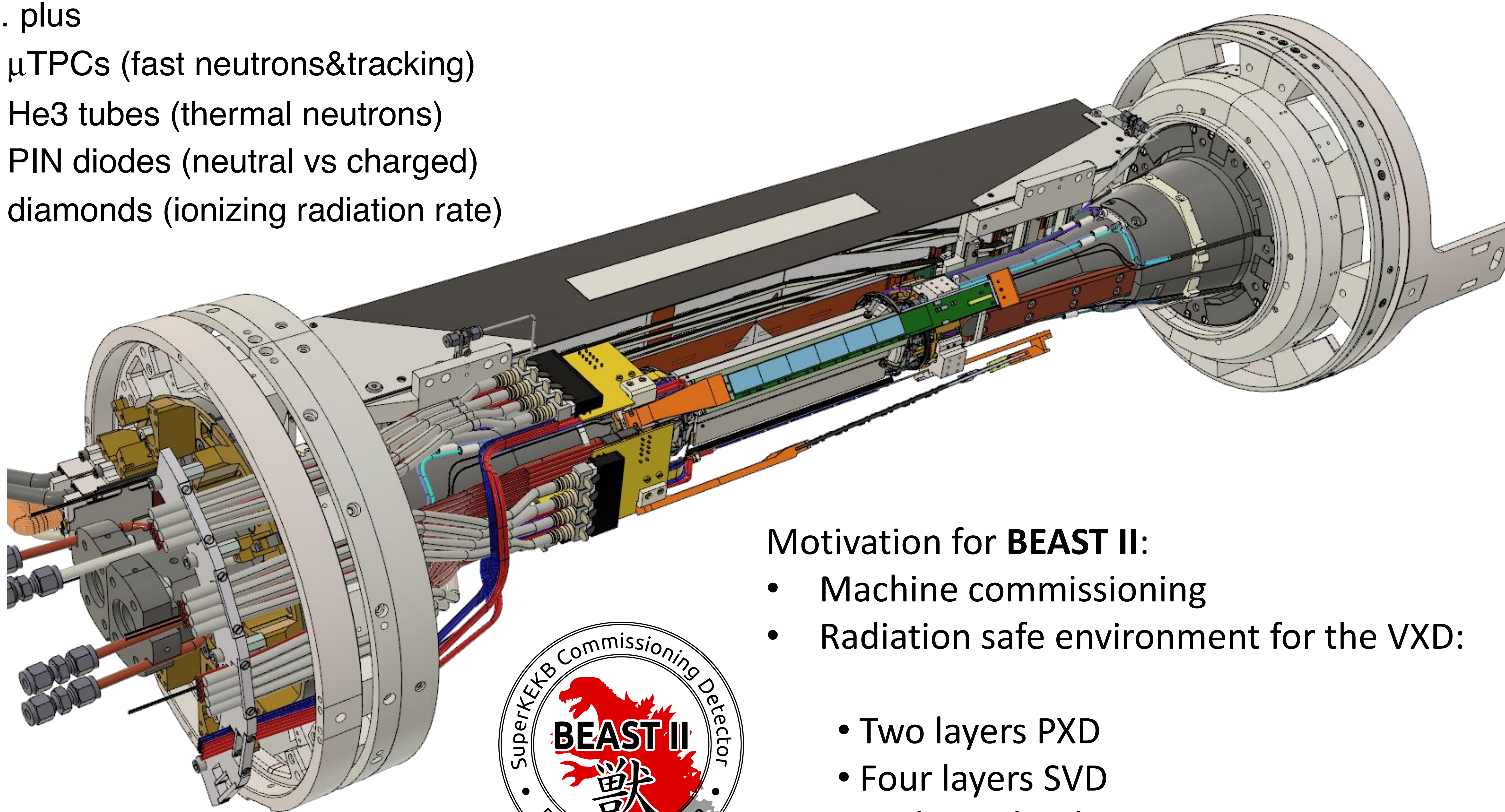
For final PXD ladder: butt-joint of 2 modules

Background Monitoring in Phase 2

Beam **E**xorcism for **A** **S**table Experimen**T**

… plus

- μTPCs (fast neutrons&tracking)
- He3 tubes (thermal neutrons)
- PIN diodes (neutral vs charged)
- diamonds (ionizing radiation rate)



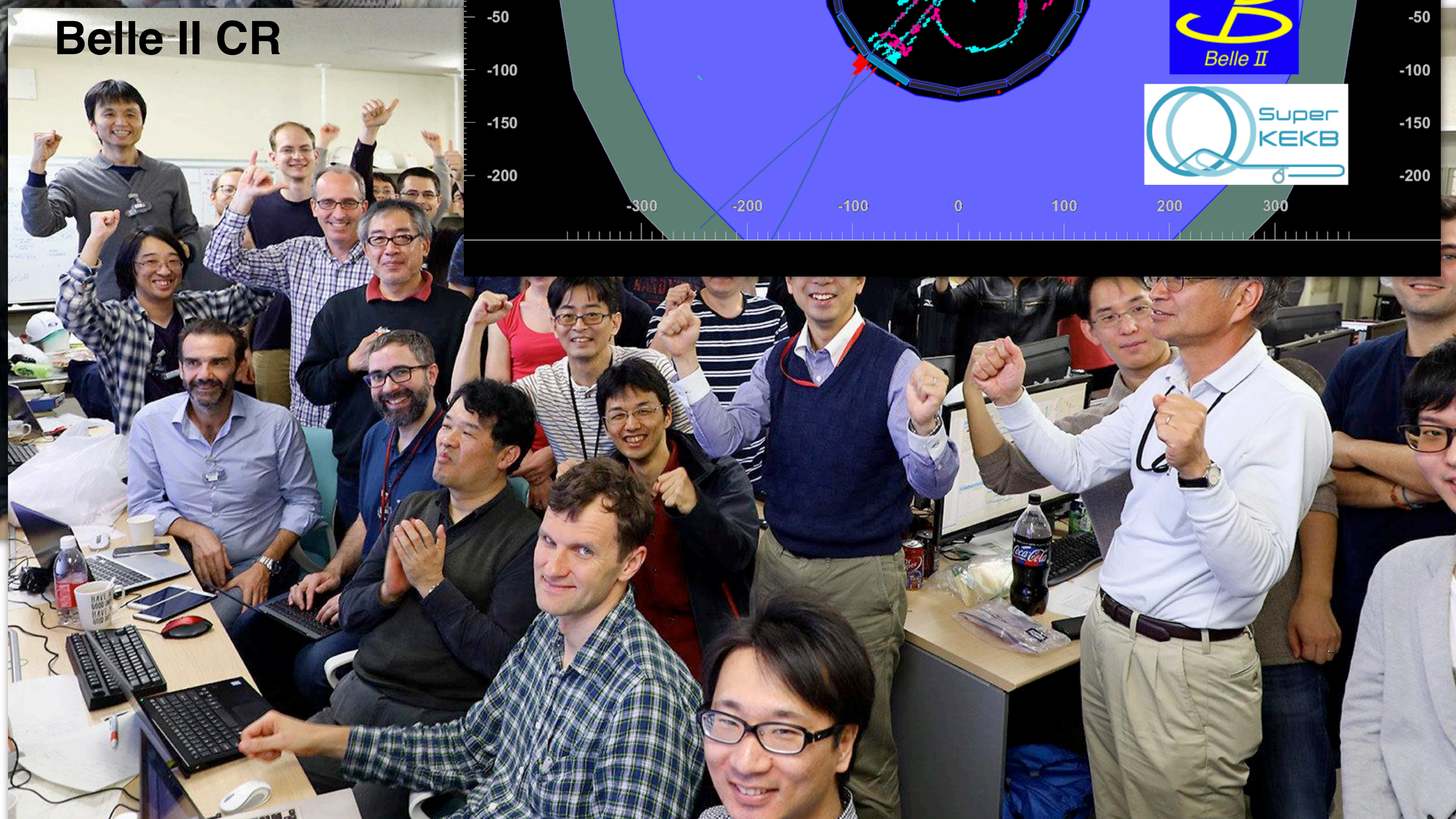
Motivation for **BEAST II**:

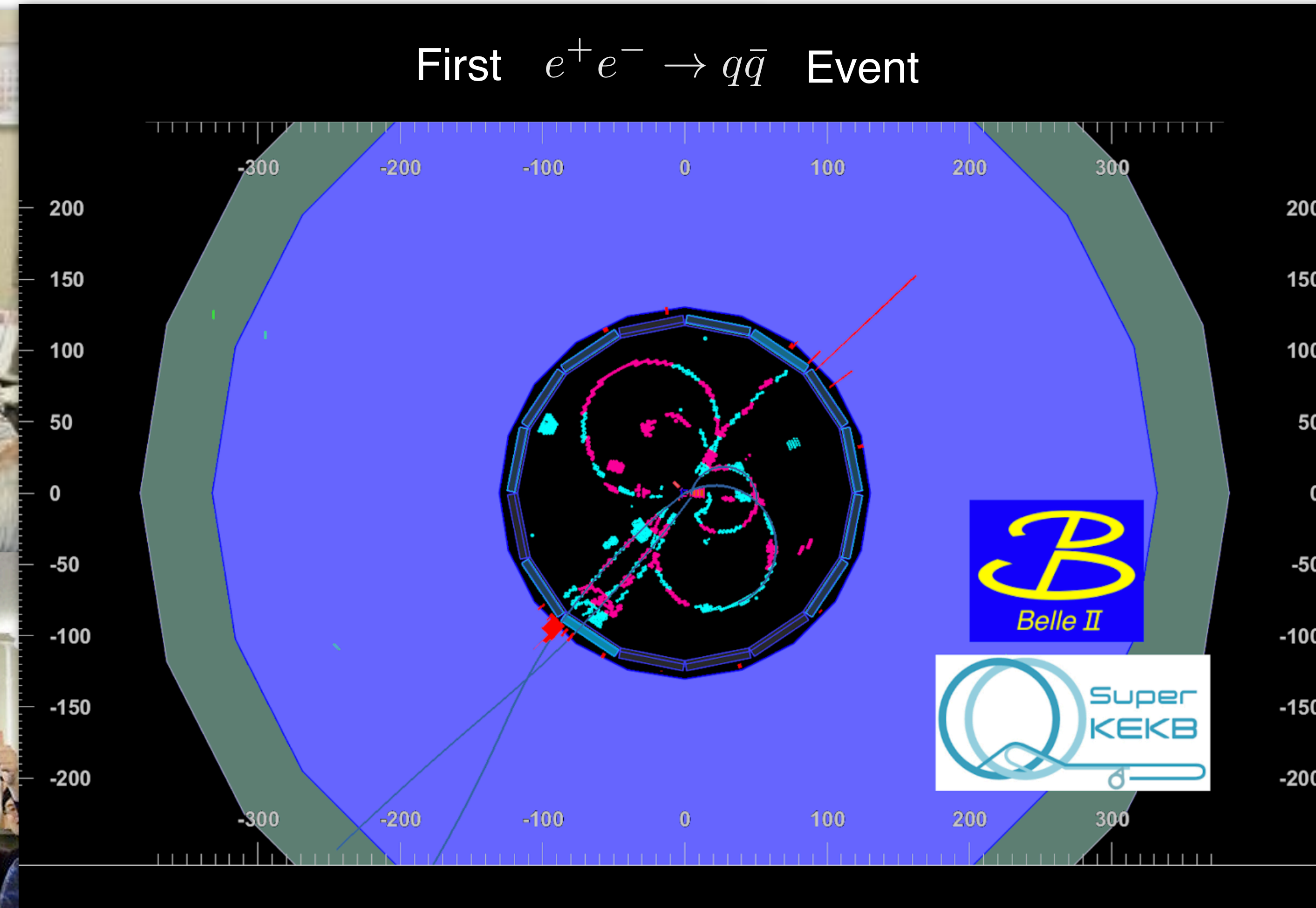
- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors FANGS, CLAWS, PLUME

26. April 2018: First Collisions

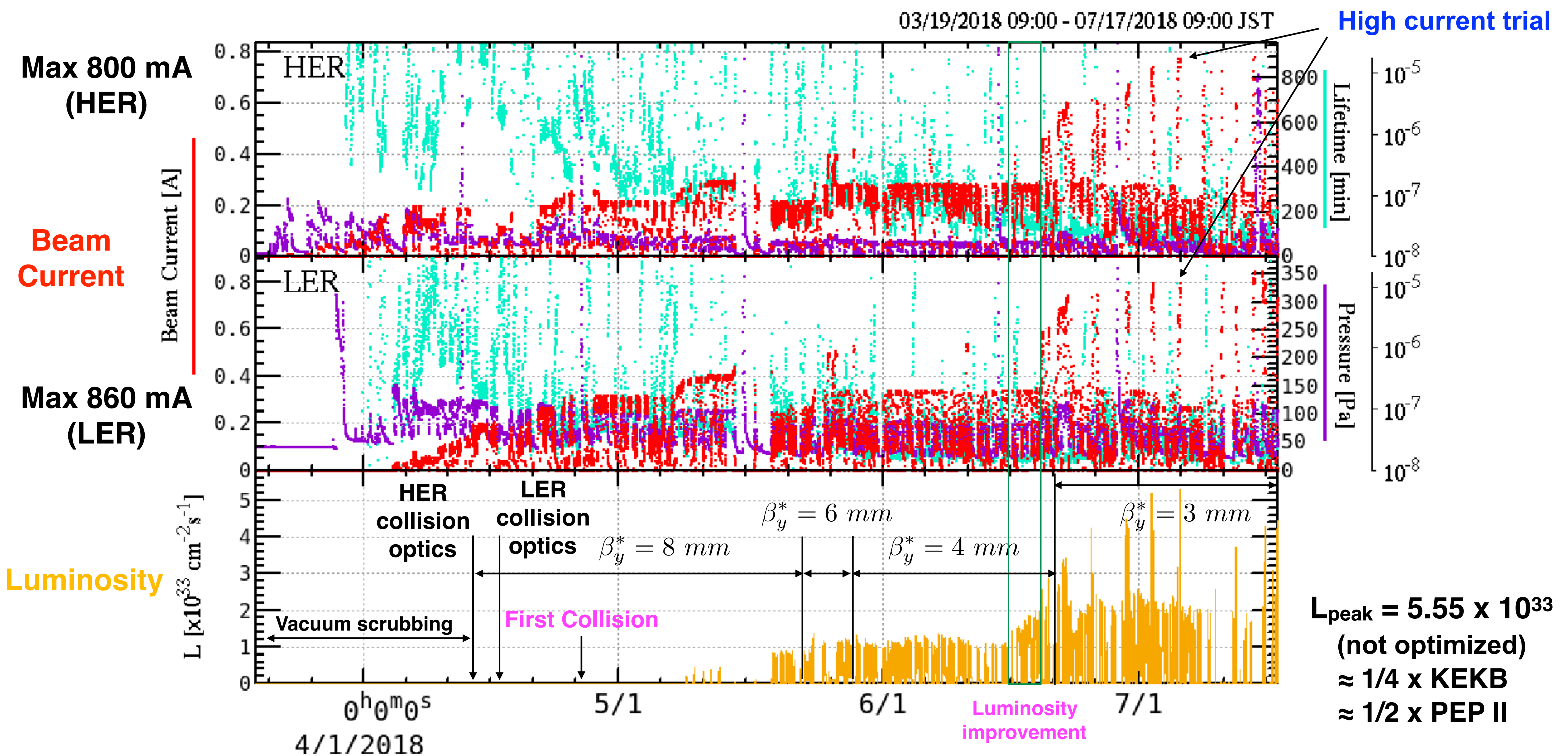
26. April 2018: First Collisions

26. April 2018: First Collisions





Overview Phase 2 Operation



$L_{peak} = 5.55 \times 10^{33}$ (not optimized)
≈ 1/4 x KEKB
≈ 1/2 x PEP II

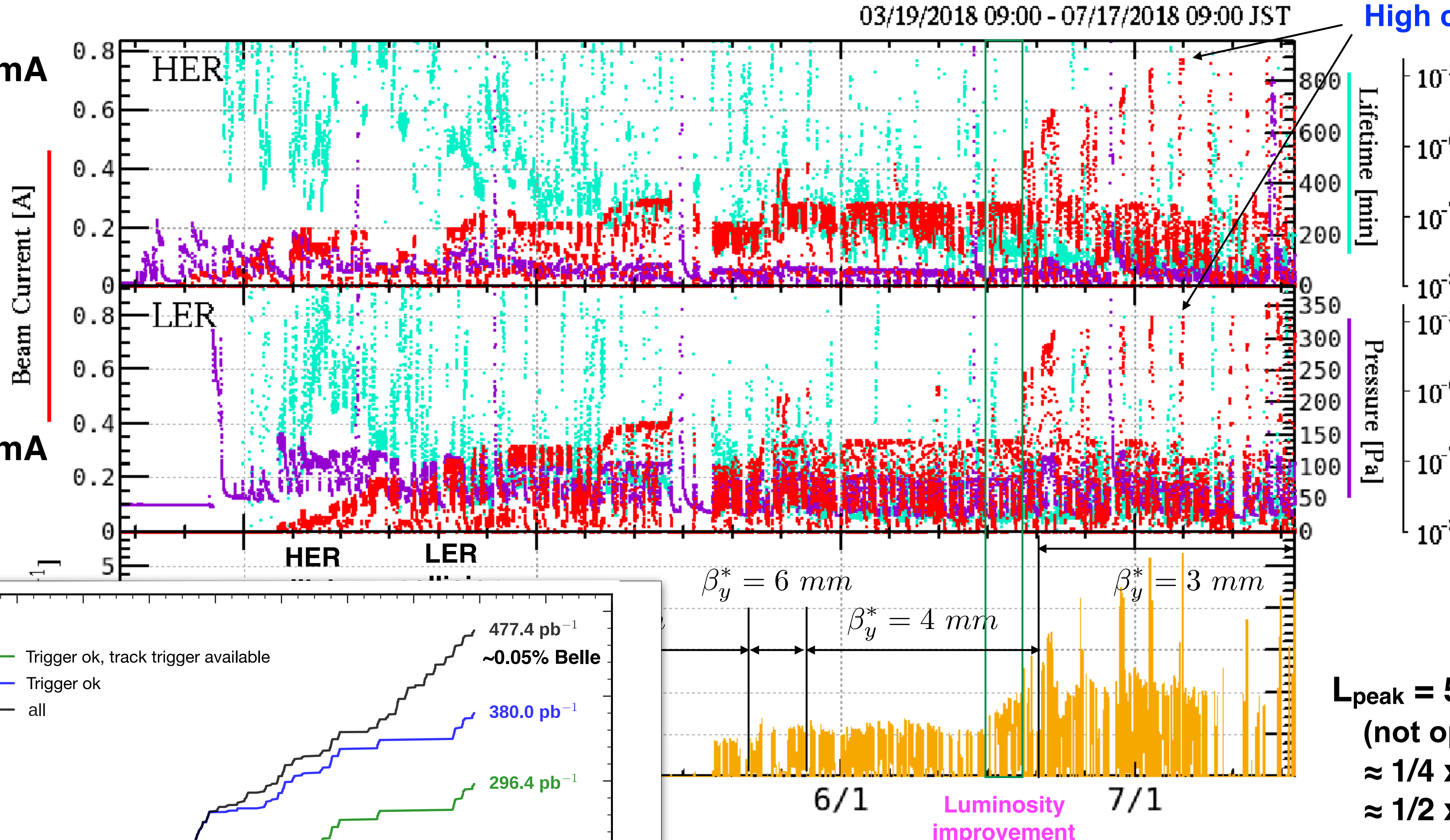
- Priority was given to machine tuning
- Beam currents limited by background
- Still a long way to go to final focus size (one order of magnitude in β^*_y)

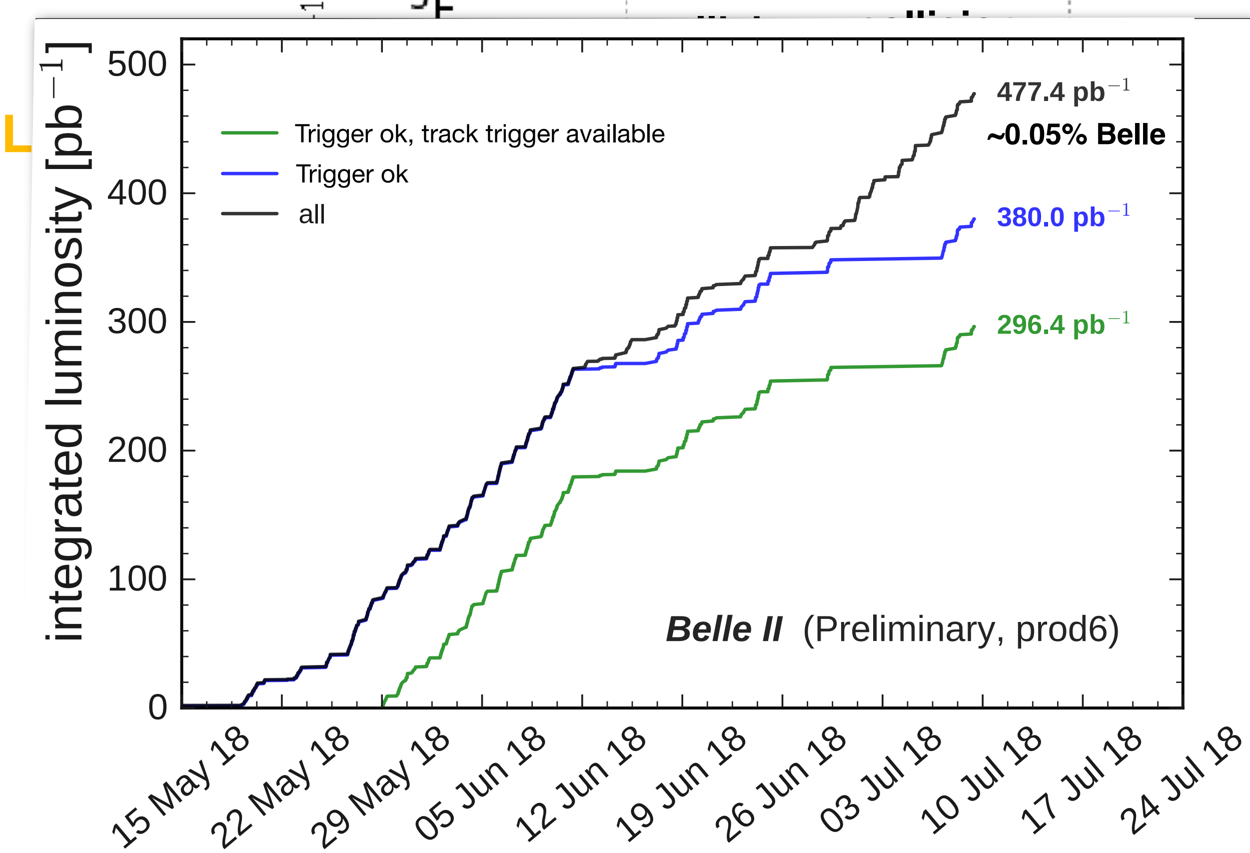
Overview Phase 2 Operation

Max 800 mA (HER)

Beam Current

Max 860 mA (LER)





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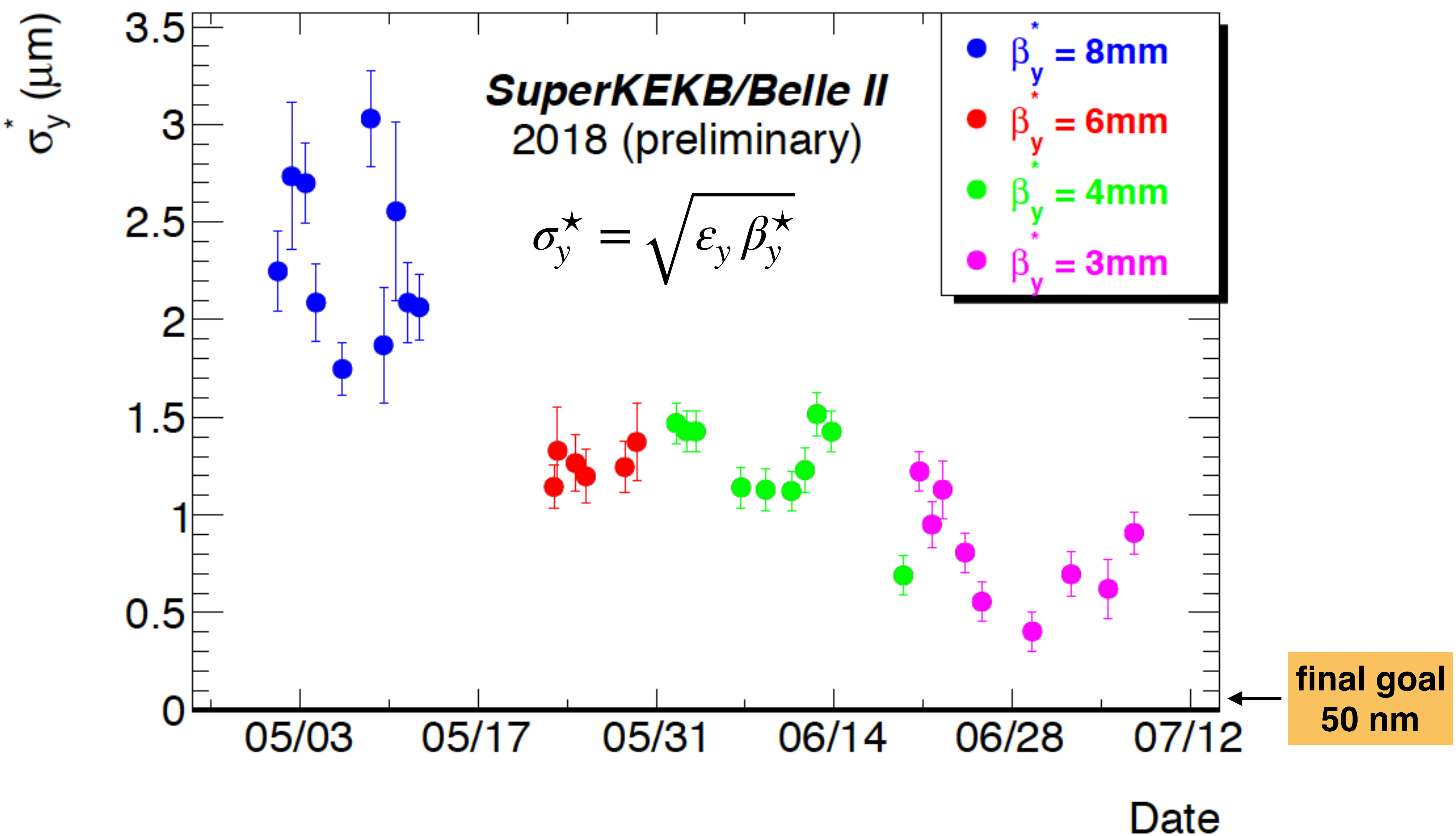
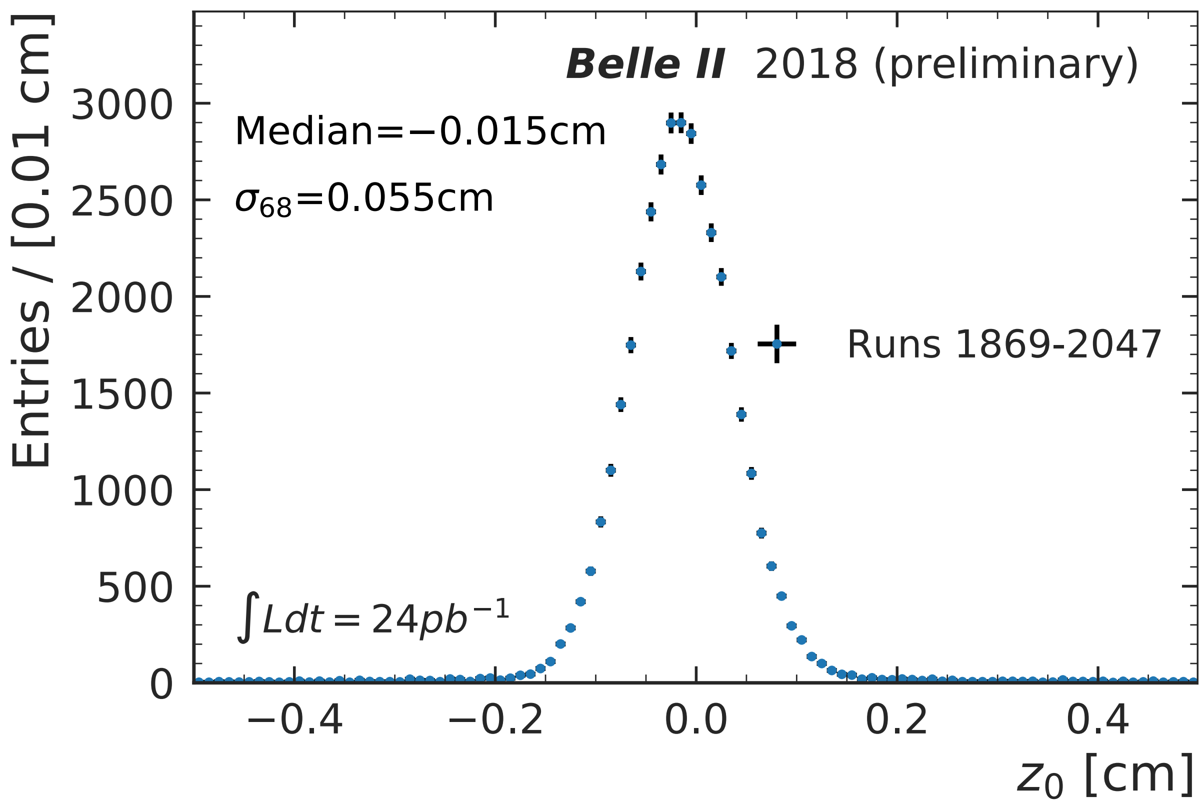
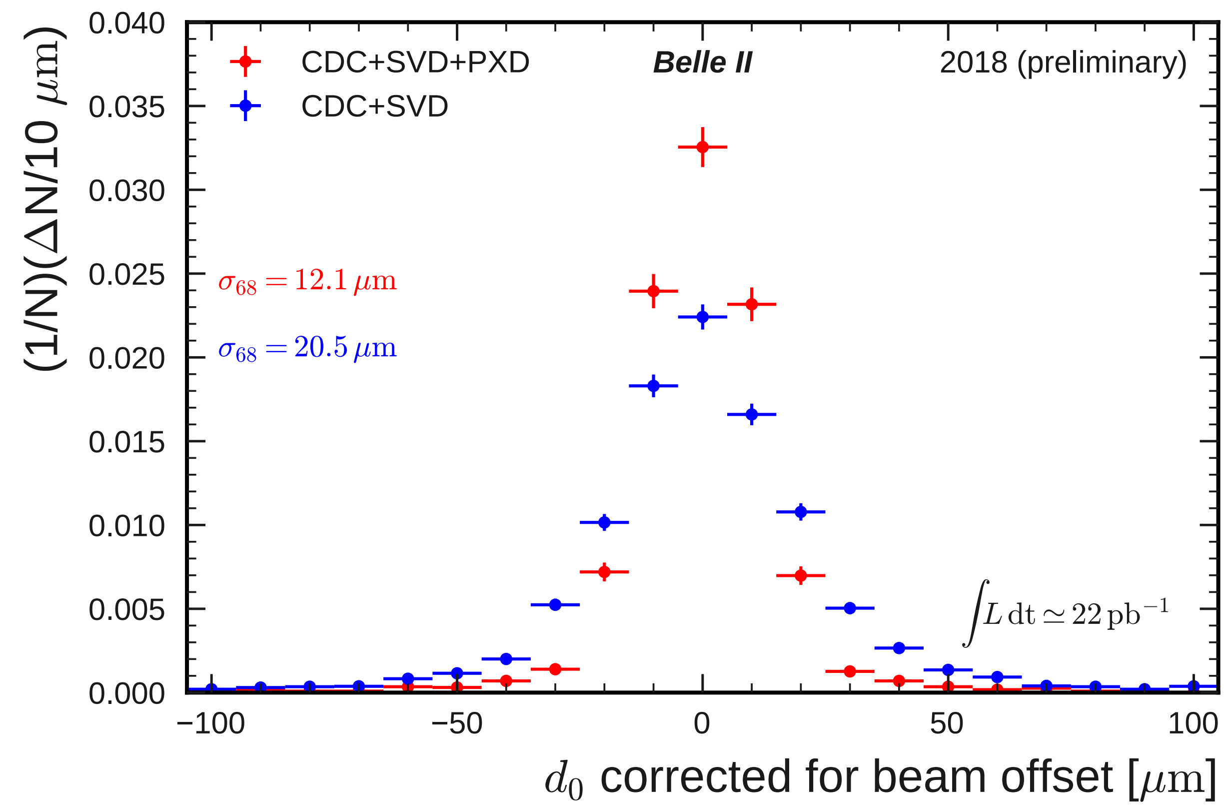
Towards Nano Beams: Vertical Beam Size

Beam size measured with Belle II lumi system using vertical offset scans

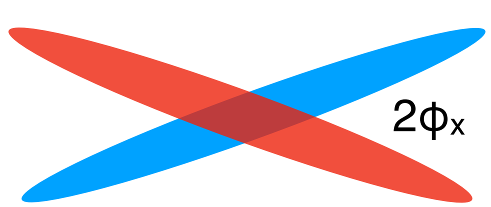


Phase 2 Tracking & Vertexing





- Width of distribution in very good agreement with expectation based on horizontal emittance $\varepsilon_x = 4\times10^{-6}$ mm, $\beta^*_x = 200$ mm, and crossing angle $\phi_x = 41$ mrad

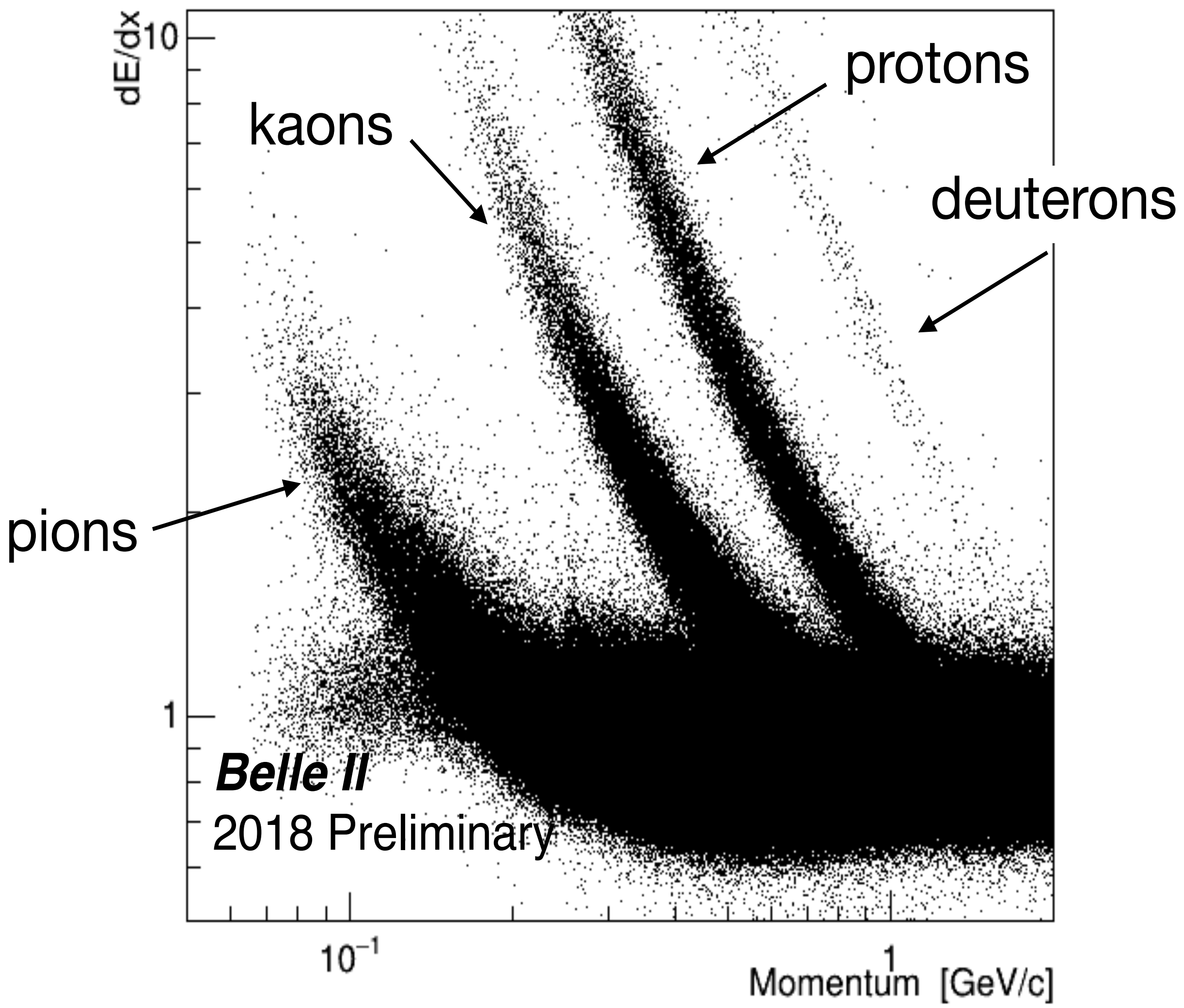


$$\sigma_z^{\text{luminous}} = \frac{\sqrt{\varepsilon_x \beta_x^*}}{\phi_x \sqrt{2}}$$

- Transverse impact parameter resolution estimated from measured vertical beam spot size
  - vertical beam spot size < 2µm i.e. much smaller than expected VXD resolution
  - d_0 resolution of **12 µm** (vs 10 µm expected) with PXD, about twice better than at Belle

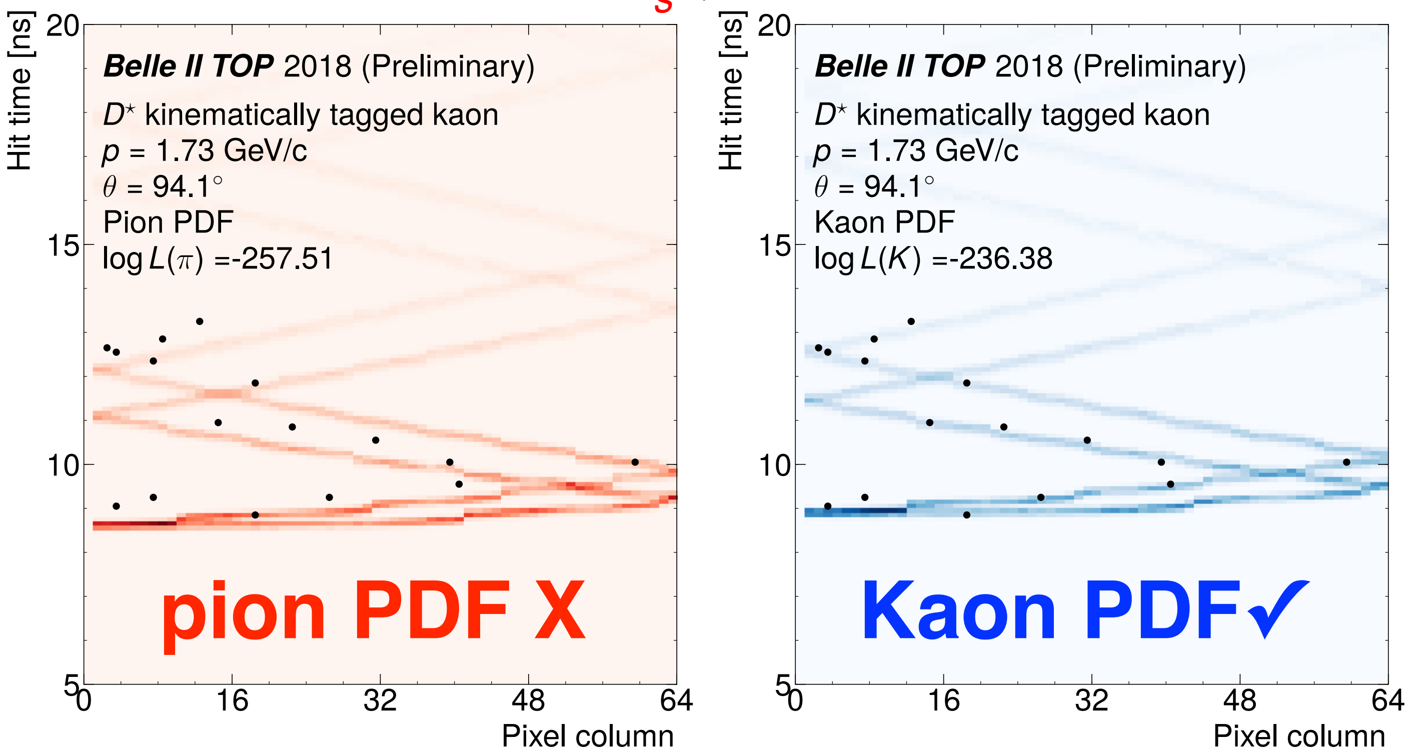
Phase 2 Particle ID

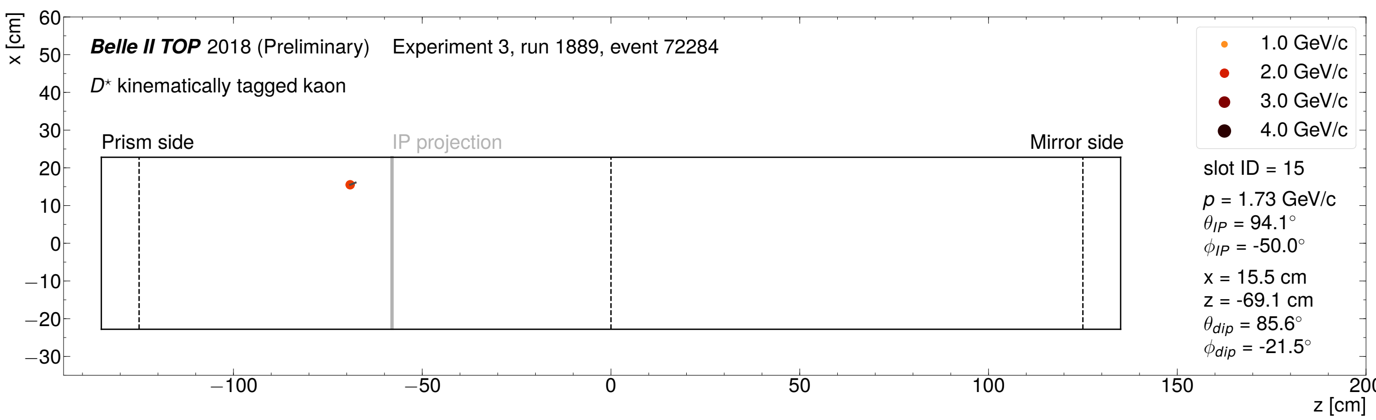
CDC dE/dx



TOP information

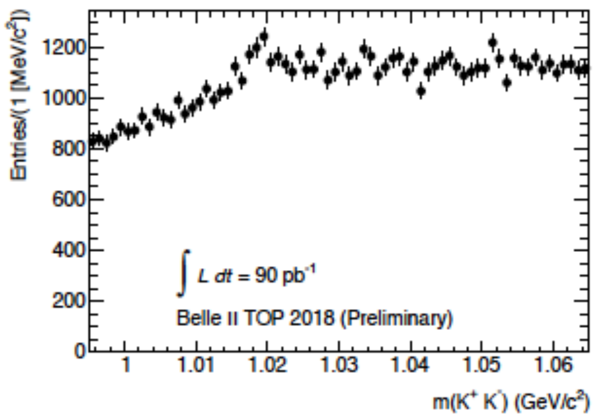
$D^{*+} \rightarrow D^0 \pi_s^+ ; D^0 \rightarrow K^- \pi^+$



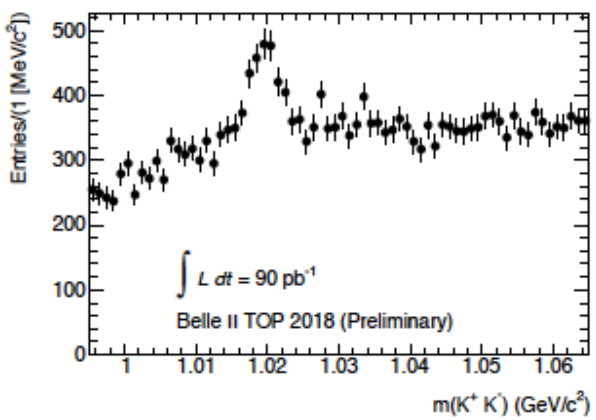


Phase 2 Particle ID

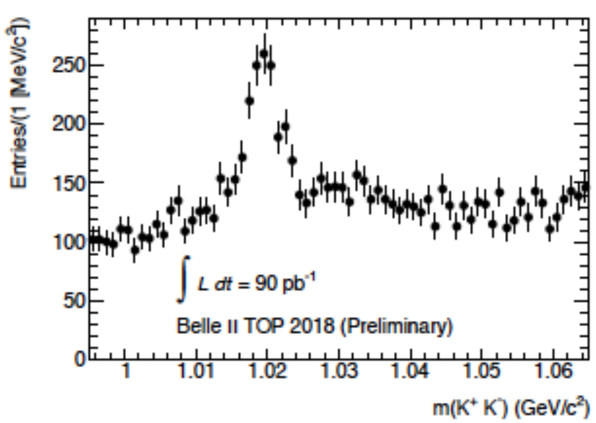
Inclusive $\Phi \rightarrow K^+K^-$ sample



No kaons identified



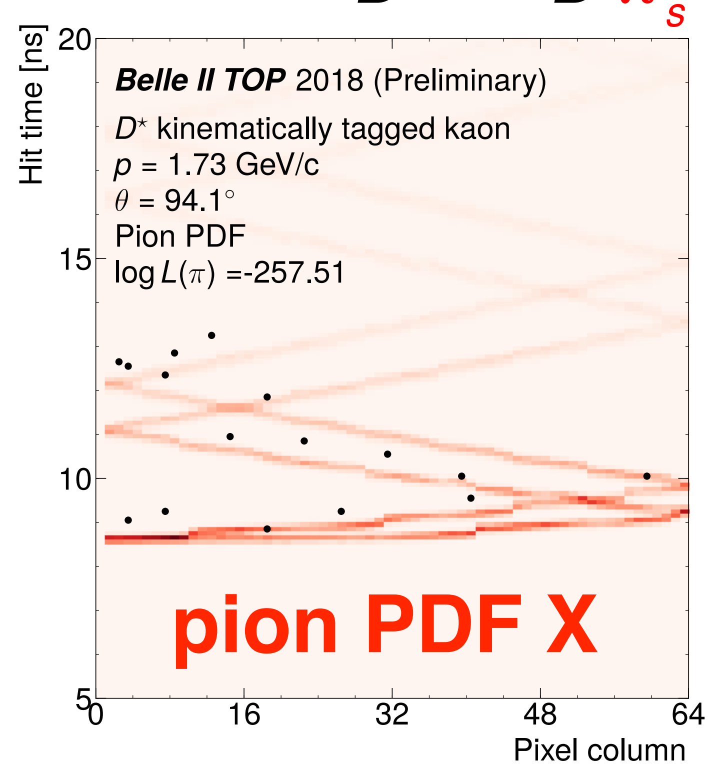
One kaon identified in the TOP.

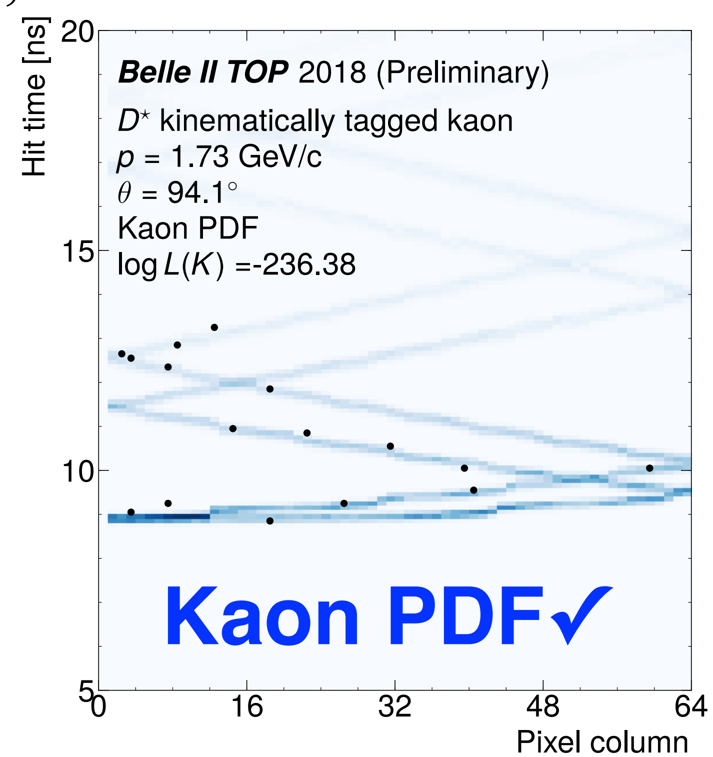


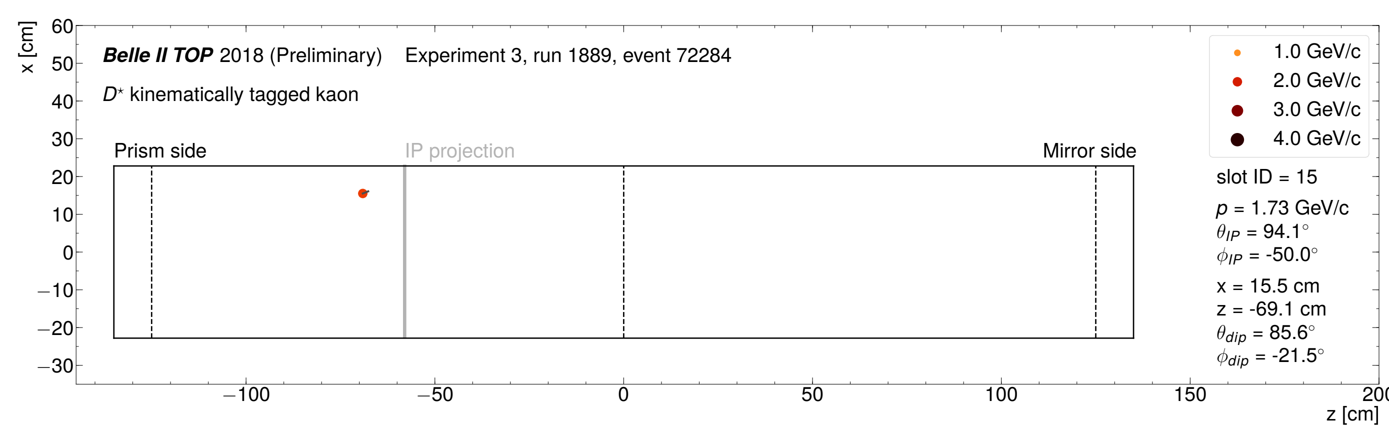
Both kaons identified in the TOP.

TOP information

$D^{*+} \rightarrow D^0\pi_s^+ ; D^0 \rightarrow K^-\pi^+$

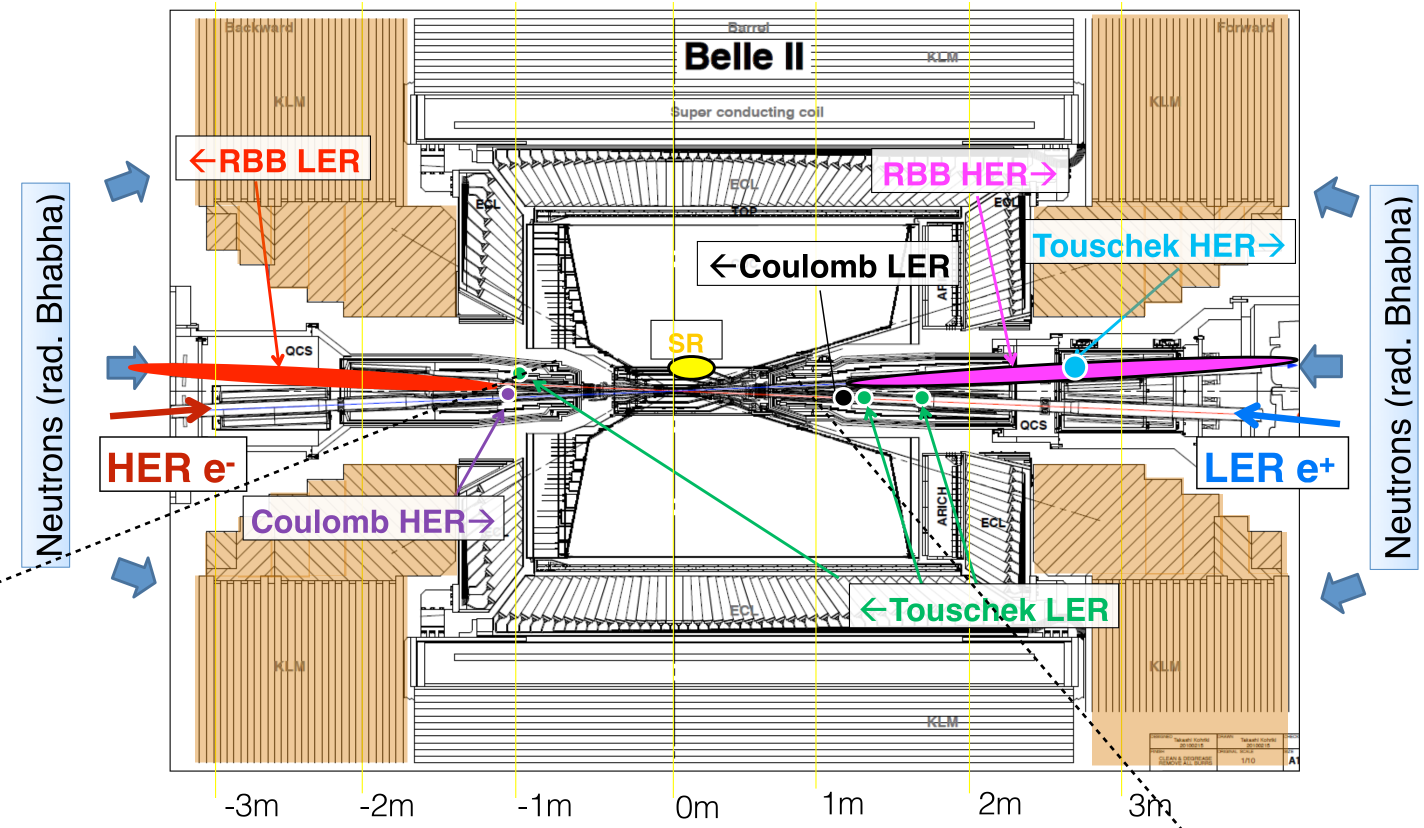


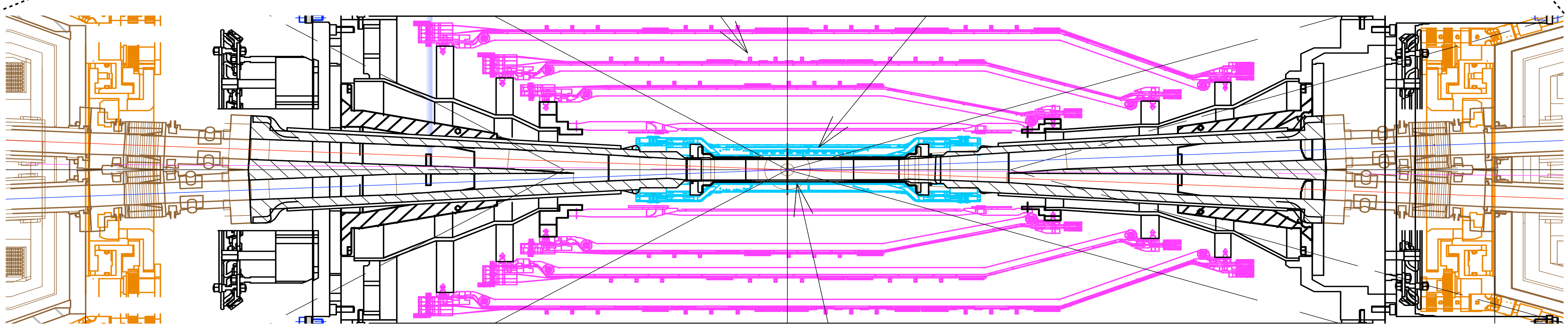




Background in Phase 2

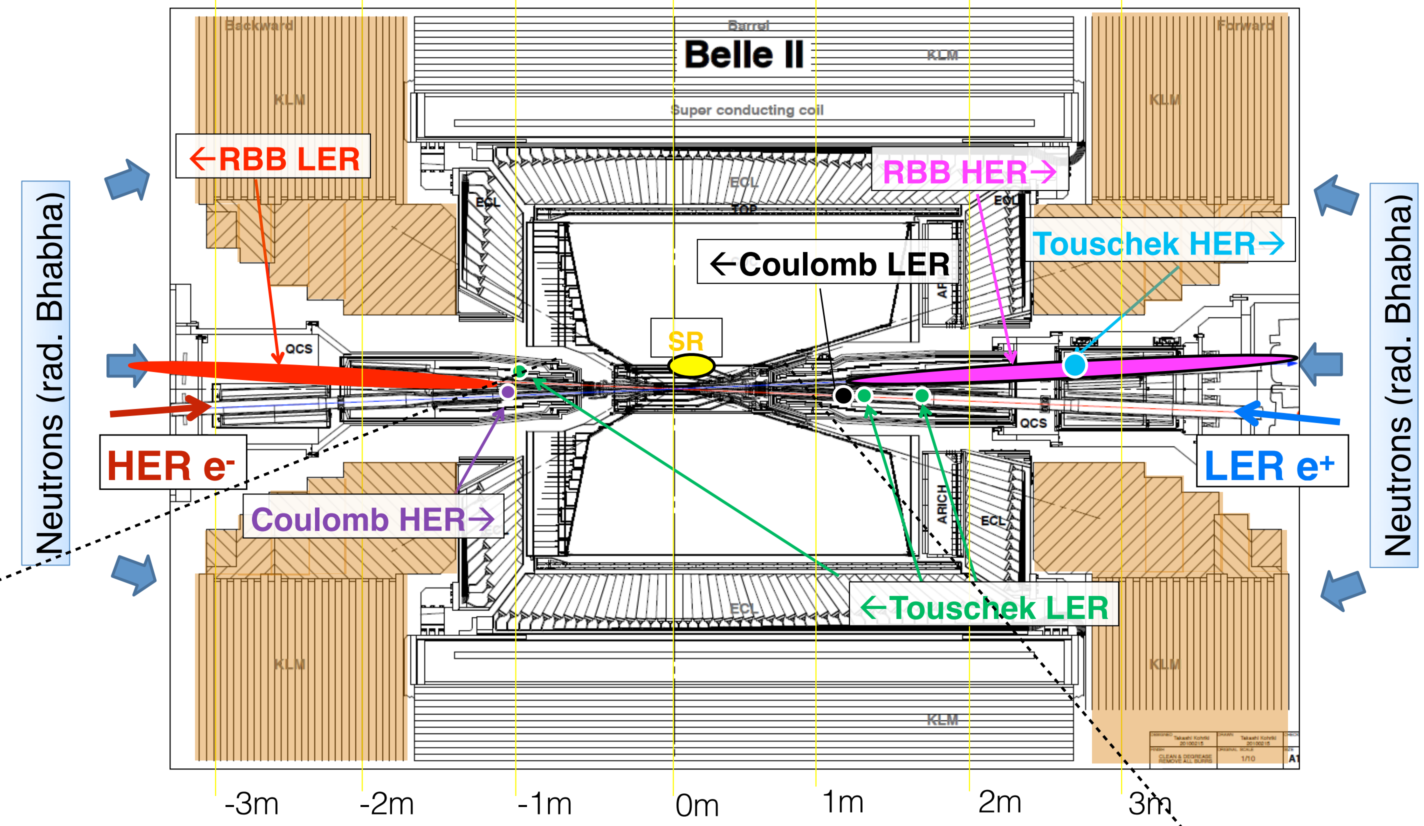
- Multiple background sources expected at SuperKEKB
  - Touschek (intra-beam) scattering will finally limit LER beam lifetime to 10 min
- Observed background significantly higher than simulated
  - ⇒ Beam currents had to be limited to keep background tolerable

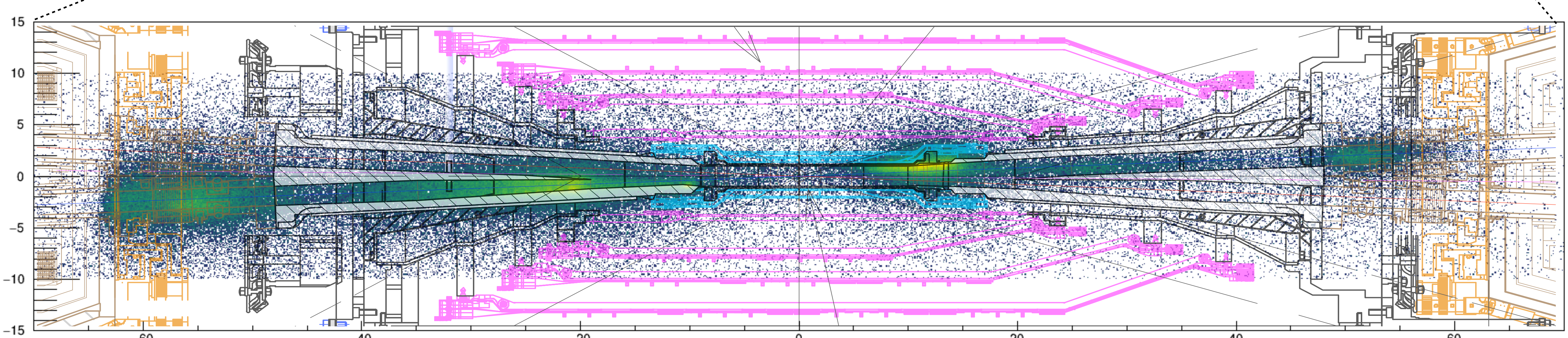




Background in Phase 2

- Multiple background sources expected at SuperKEKB
  - Touschek (intra-beam) scattering will finally limit LER beam lifetime to 10 min
- Observed background significantly higher than simulated
  - $\Rightarrow$ Beam currents had to be limited to keep background tolerable





V0 vertices for runs with HER beam only

Background in Phase 2

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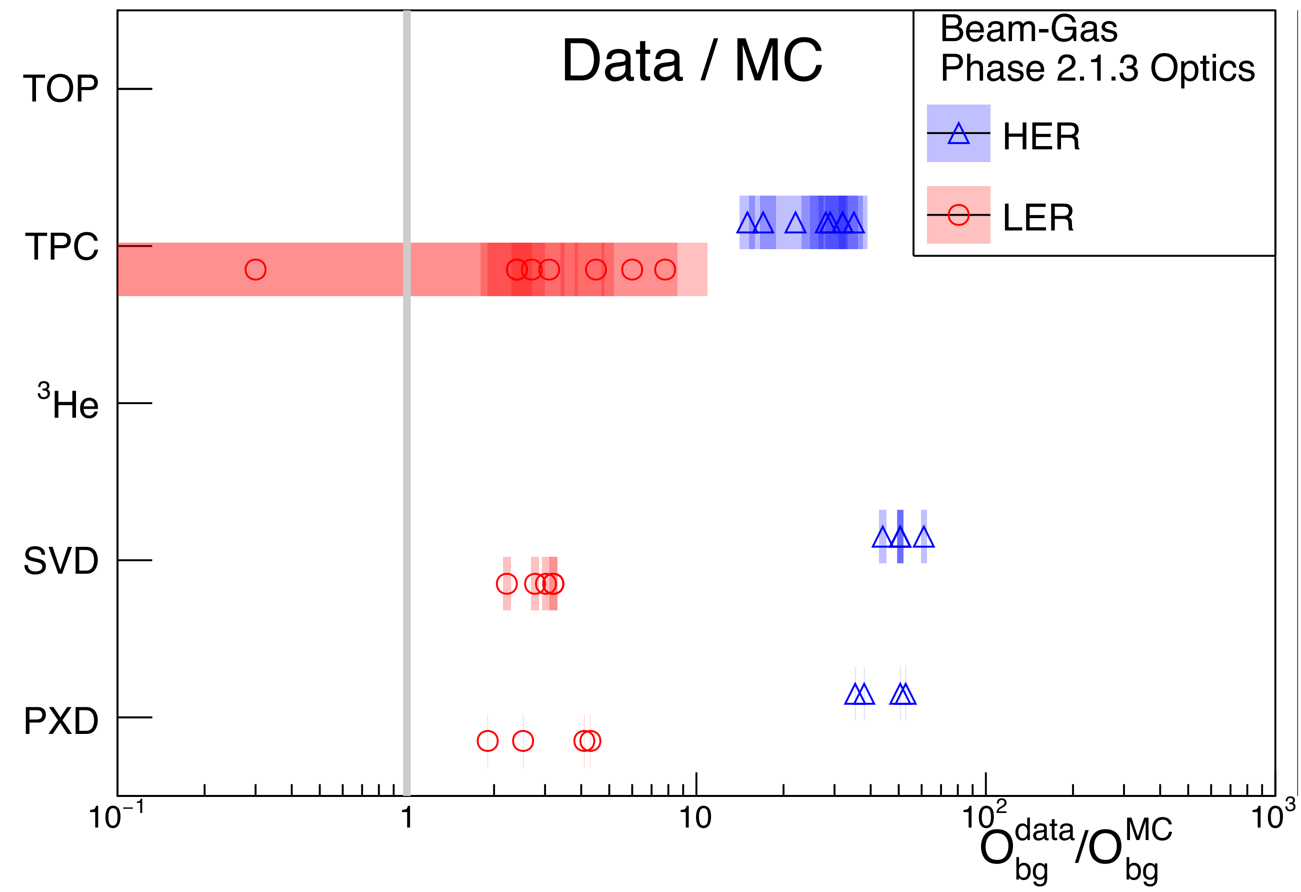
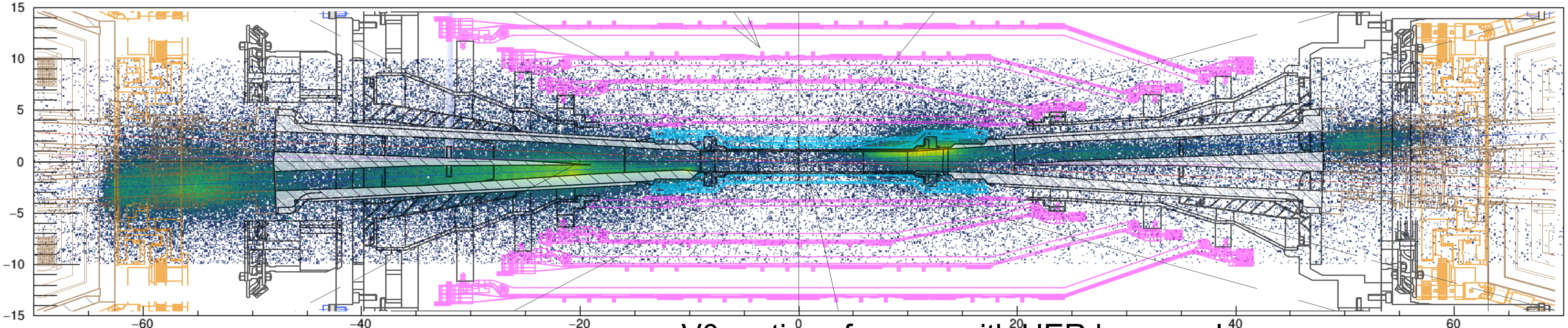
- Extrapolation to final phase 3 conditions has large uncertainties





V0 vertices for runs with HER beam only

Background in Phase 2

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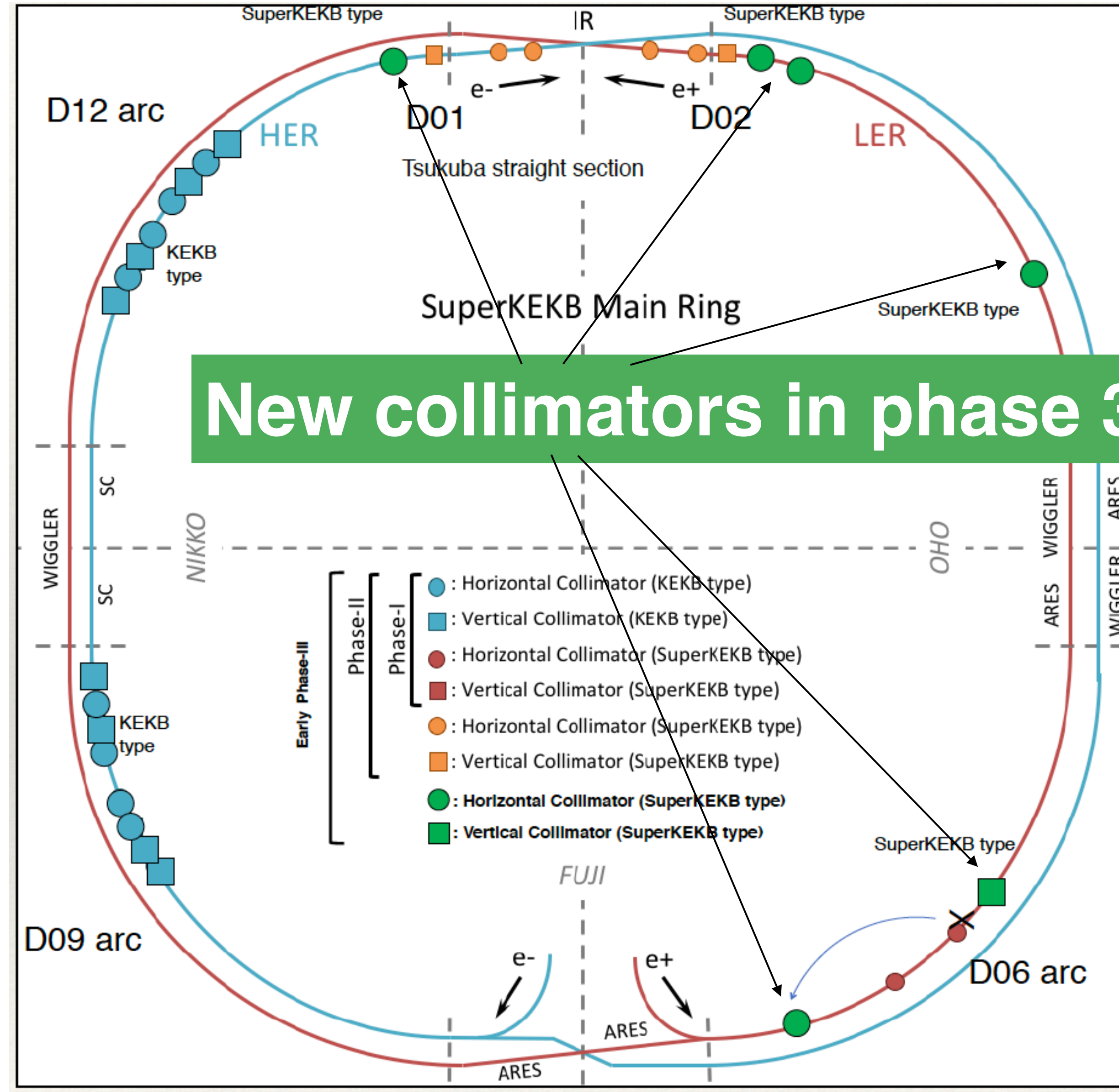
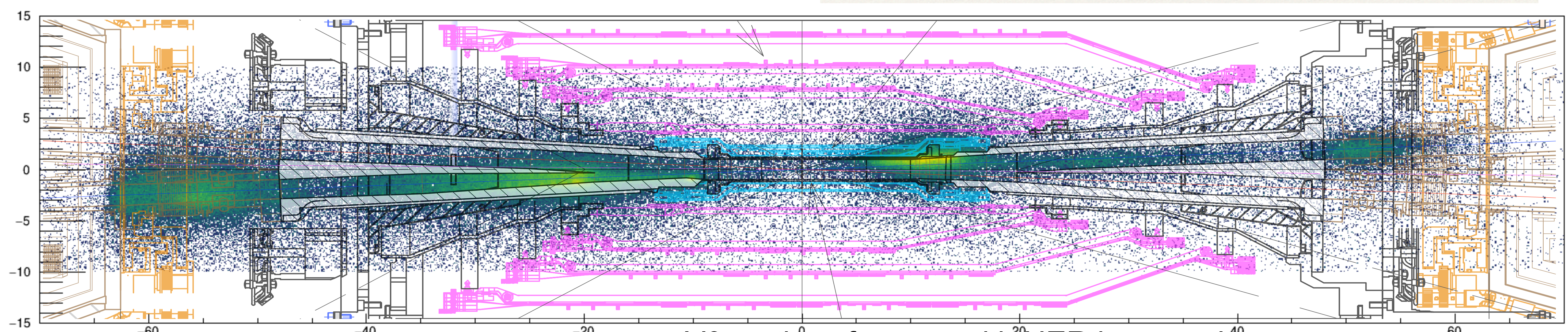
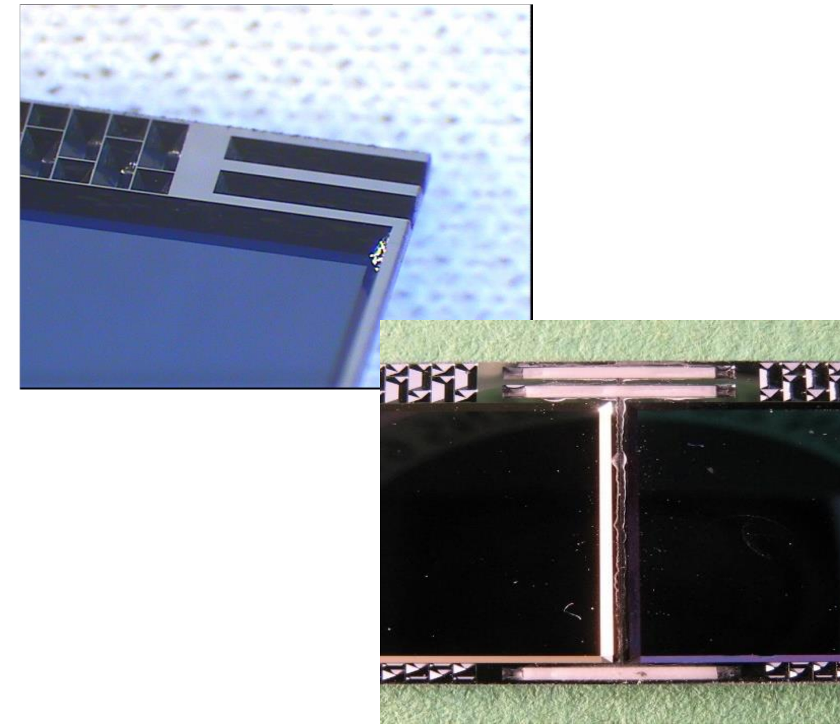
  - Touschek (intra-beam) scattering will finally limit LER beam lifetime to 10 min
- Observed background significantly higher than simulated
  - ⇒ Beam currents had to be limited to keep background tolerable
- Extrapolation to final phase 3 conditions has large uncertainties
- New collimators are expected to reduce background by factor 4 in early phase 3



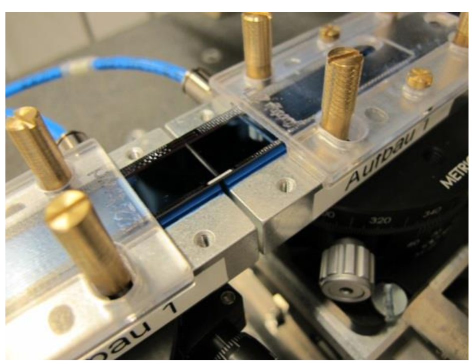


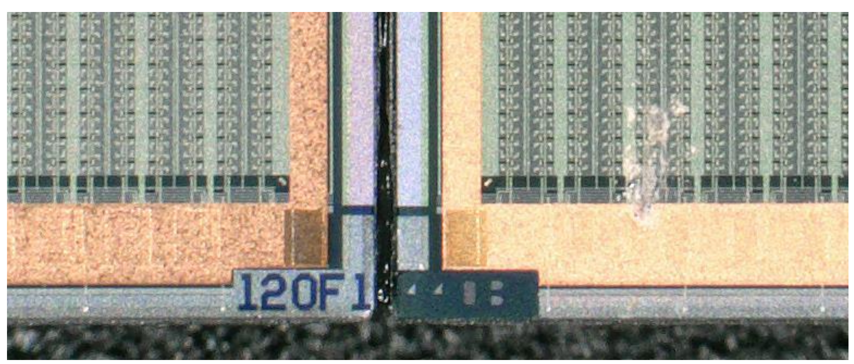
V0 vertices for runs with HER beam only

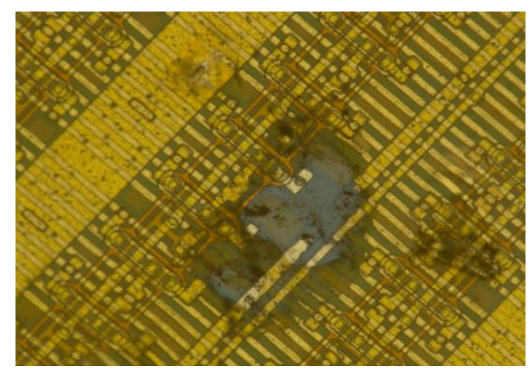
PXD for Phase 3

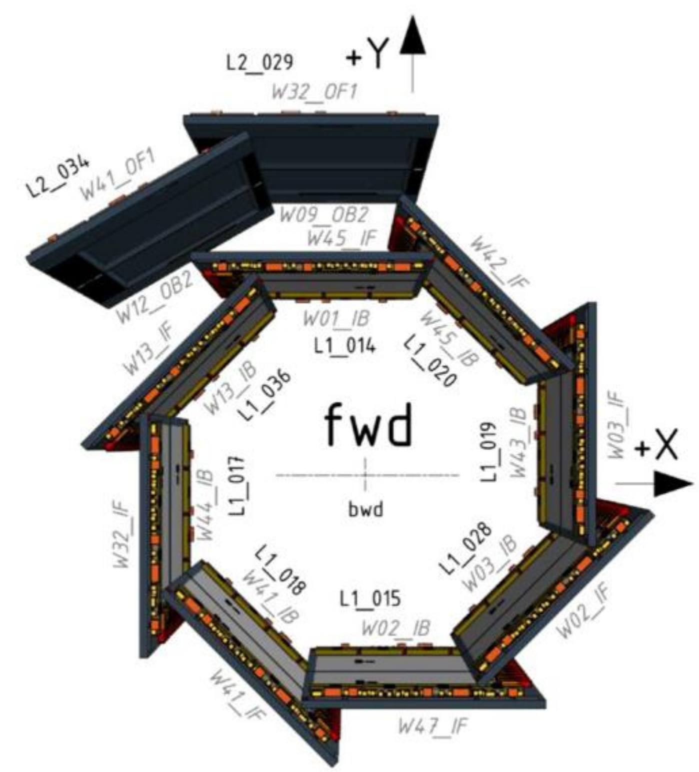


- Join two modules to a ladder by gluing
  - reinforcement of joint by glueing small ceramic inserts into V-grooves on the back side of the modules
- Yield problem: out of 17 assembled ladders, 5 lost due to particles and other issues



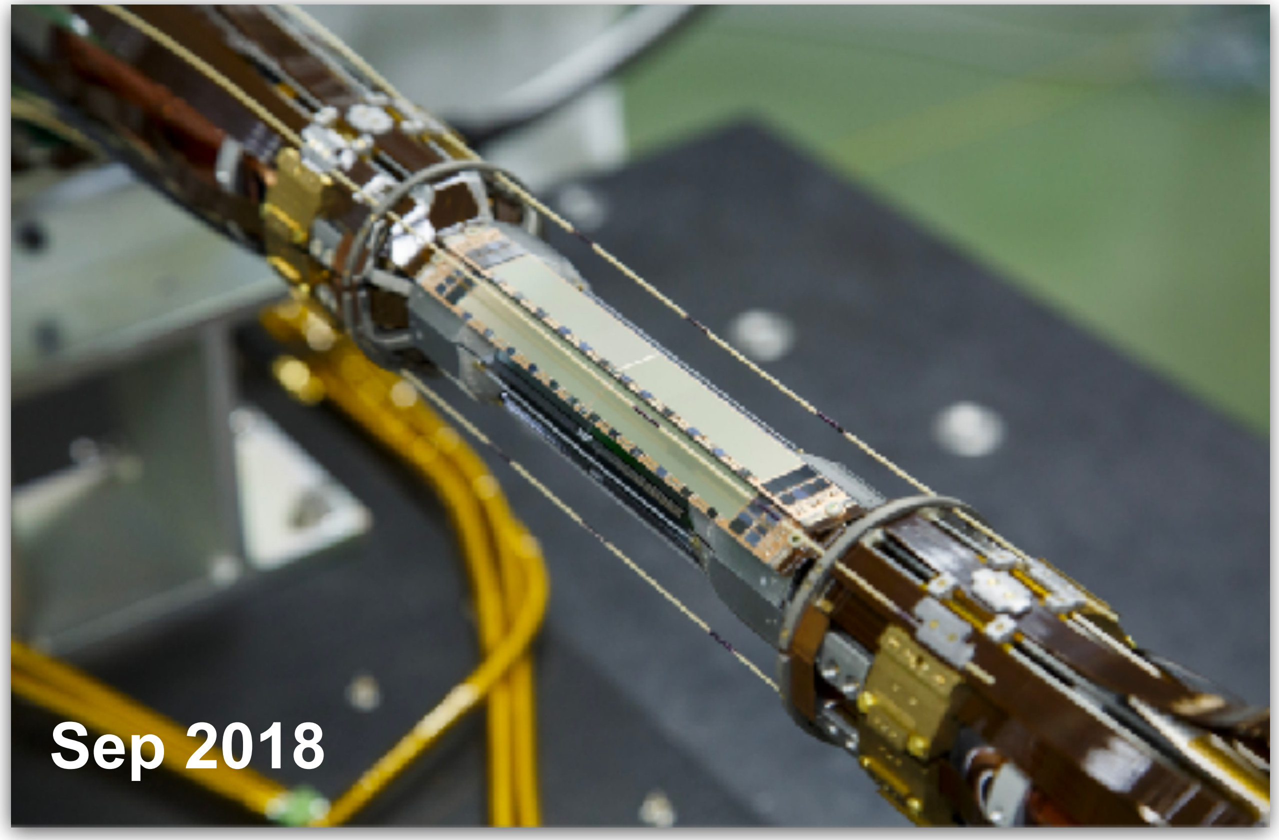


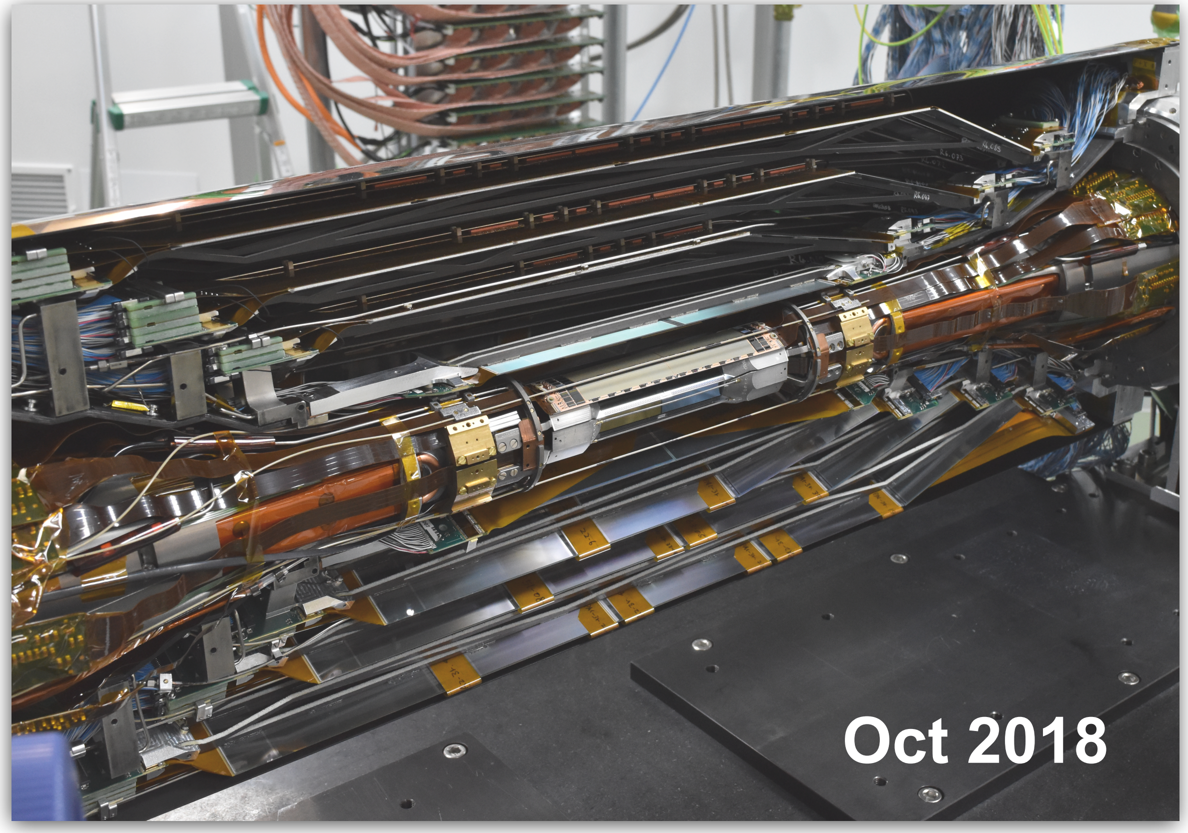


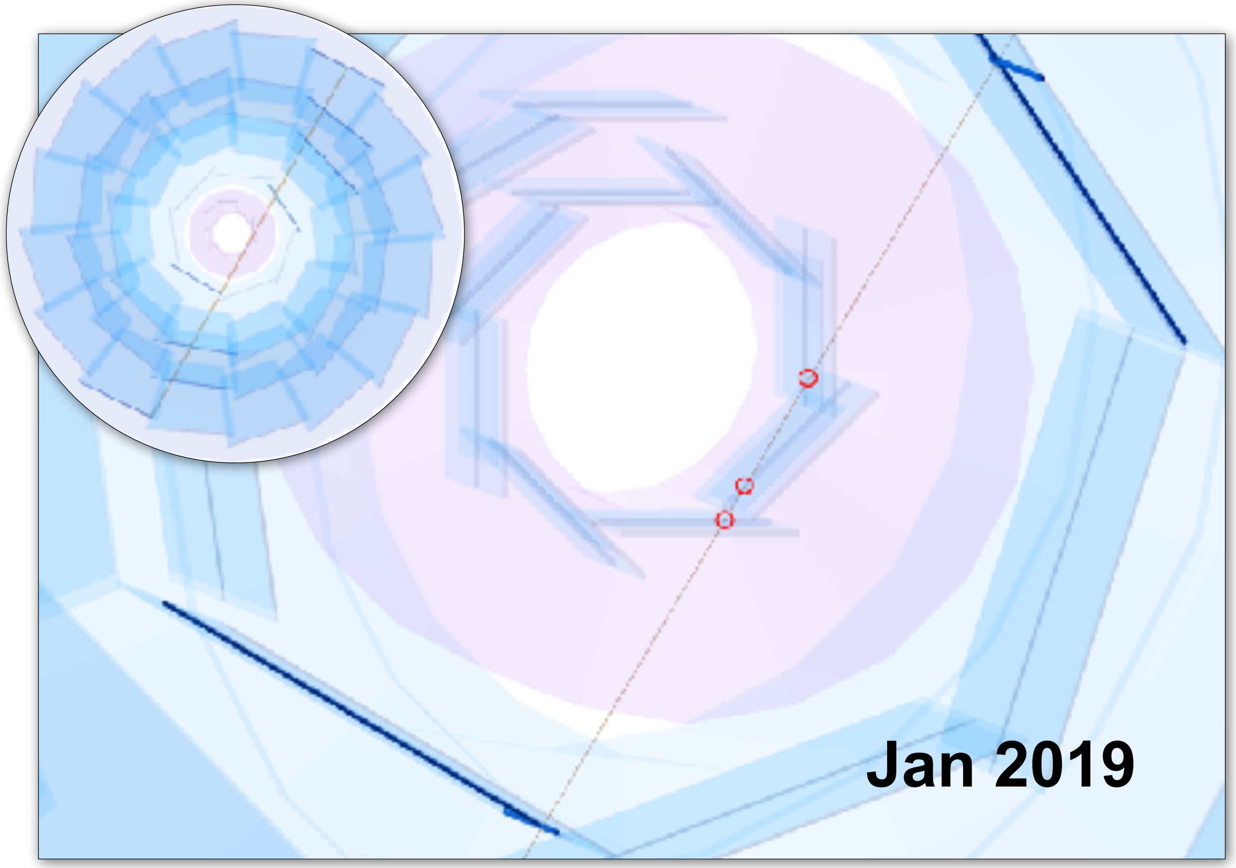


- De-scoped PXD installed to meet schedule for start of phase 3
  - full L1 (8 ladders) and 2 of 12 ladders in L2
- Meanwhile the assembly procedure has been revised
- New PXD wafer production ongoing at HLL
- Installation of complete PXD foreseen in **summer 2020**

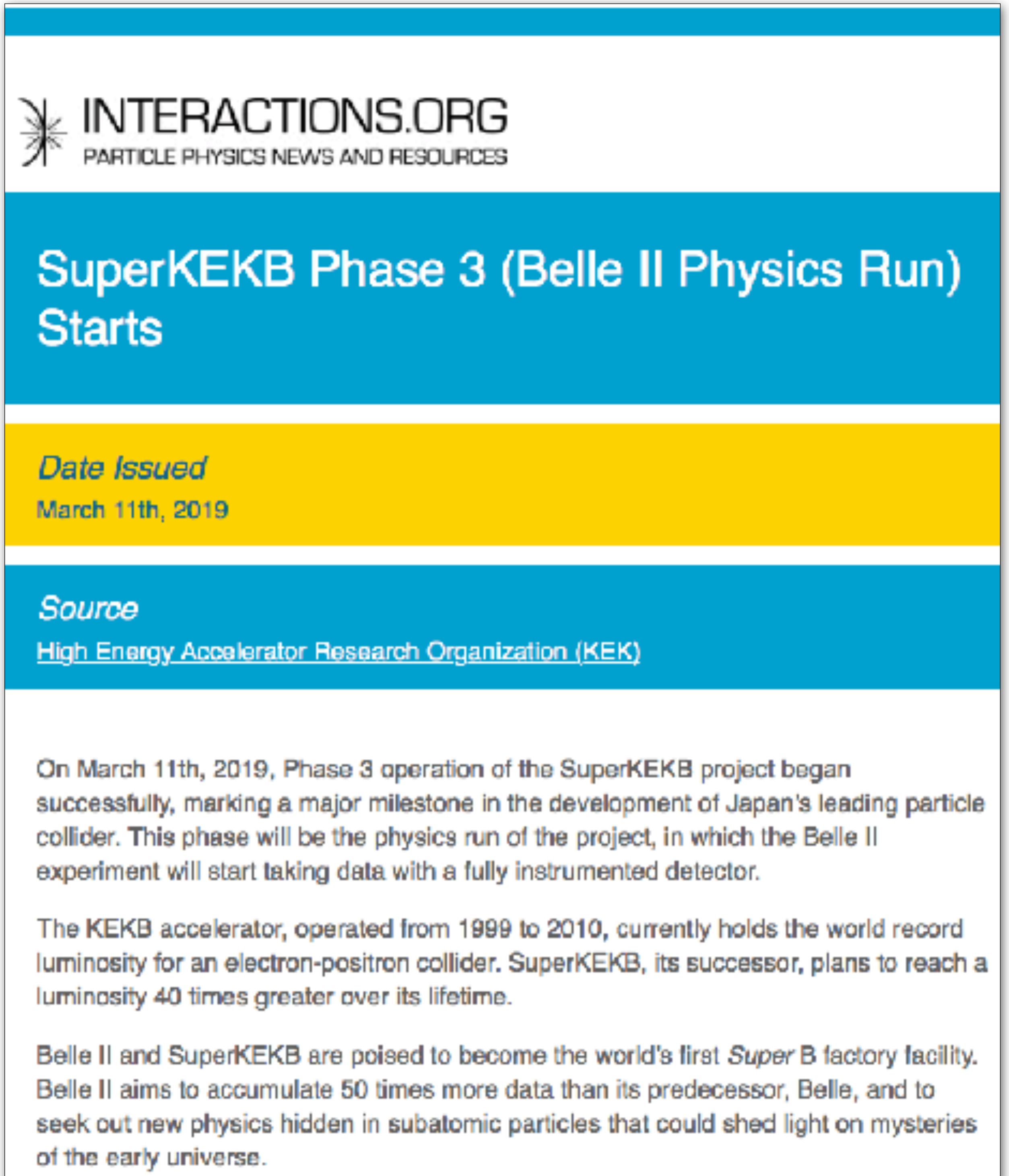
Phase 3 VXD Integration and Commissioning







Phase 3 Operation started this Monday



INTERACTIONS.ORG
PARTICLE PHYSICS NEWS AND RESOURCES

SuperKEKB Phase 3 (Belle II Physics Run) Starts

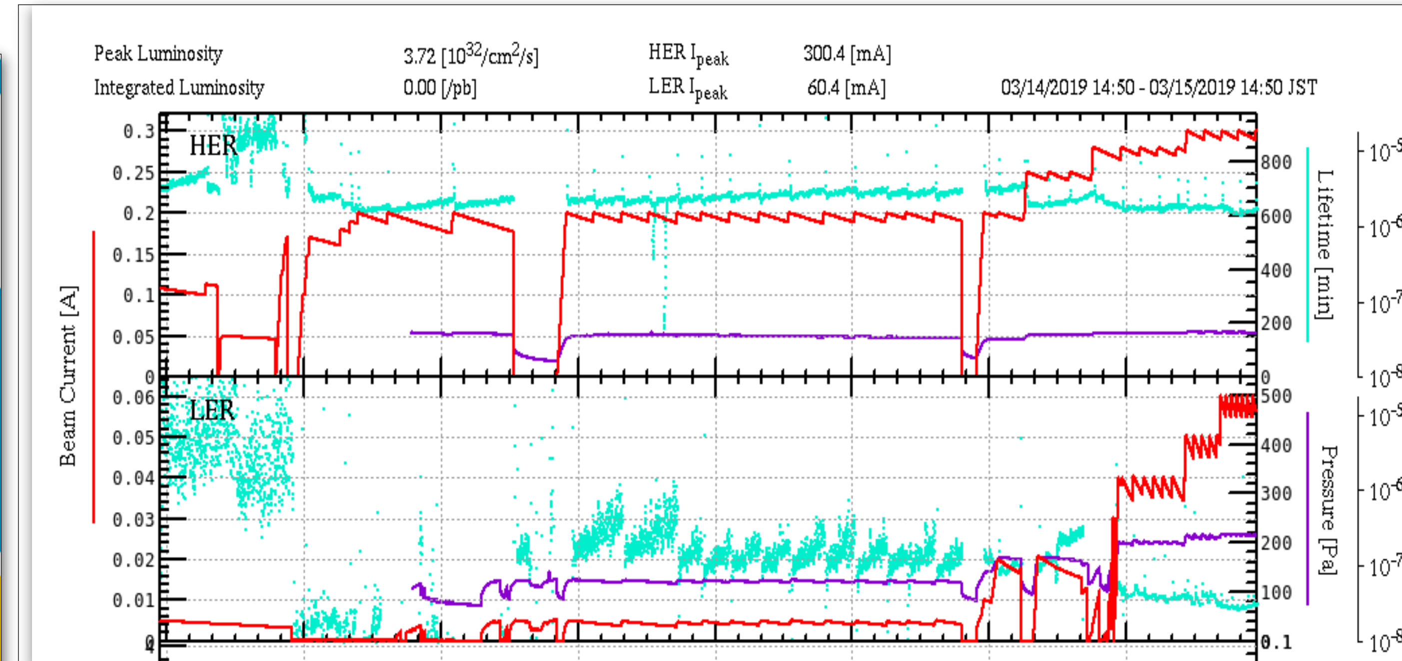
Date Issued
March 11th, 2019

Source
High Energy Accelerator Research Organization (KEK)

On March 11th, 2019, Phase 3 operation of the SuperKEKB project began successfully, marking a major milestone in the development of Japan's leading particle collider. This phase will be the physics run of the project, in which the Belle II experiment will start taking data with a fully instrumented detector.

The KEKB accelerator, operated from 1999 to 2010, currently holds the world record luminosity for an electron-positron collider. SuperKEKB, its successor, plans to reach a luminosity 40 times greater over its lifetime.

Belle II and SuperKEKB are poised to become the world's first *Super* B factory facility. Belle II aims to accumulate 50 times more data than its predecessor, Belle, and to seek out new physics hidden in subatomic particles that could shed light on mysteries of the early universe.



- Plans for first weeks
  - machine check-out
  - vacuum scrubbing
  - beam squeezing to $\beta_y^* = 3$ mm
  - collimator and injection tuning
  - optimise continuos/trickle injection
  - test gated mode operation
- First ~ 2 weeks of April
  - dedicated background studies with all Belle II sub-detectors switched on

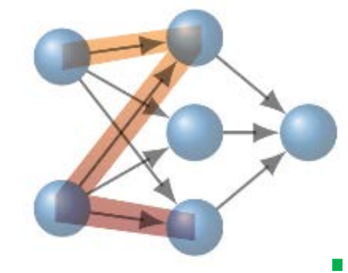
Summary and Conclusions

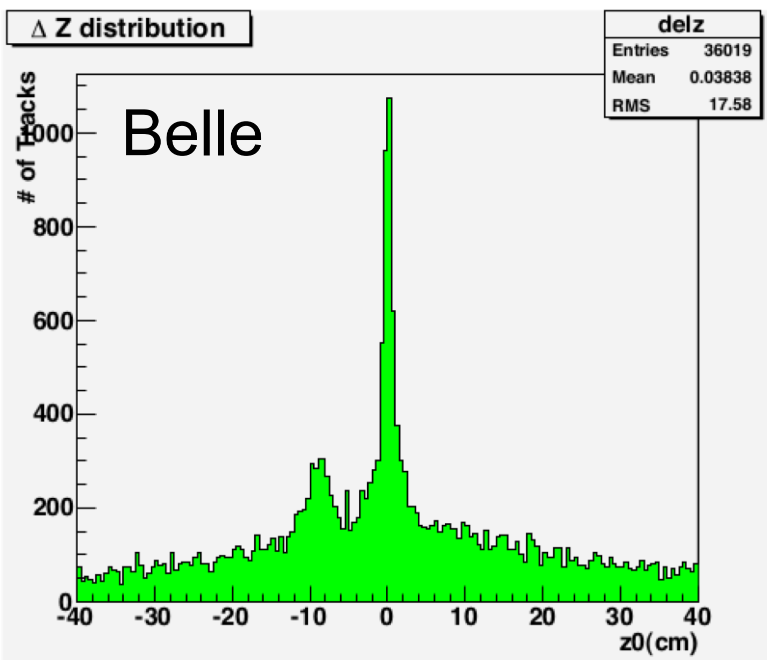
- Belle II and SuperKEKB are very challenging upgrade projects
- Belle II successfully completed initial data taking in 2018 (Phase 2)
  - study machine and backgrounds
  - checkout detector and software
  - collect ~0.5 fb^{-1} for initial physics (dark sector)
- Detector is now complete
  - second layer of PXD to be installed in summer 2020
- Phase 3 operation of SuperKEKB started this week
  - background mitigation high priority item
  - ensure rapid luminosity ramp-up
- Looking forward to shed some light on recently observed flavour anomalies in the coming years

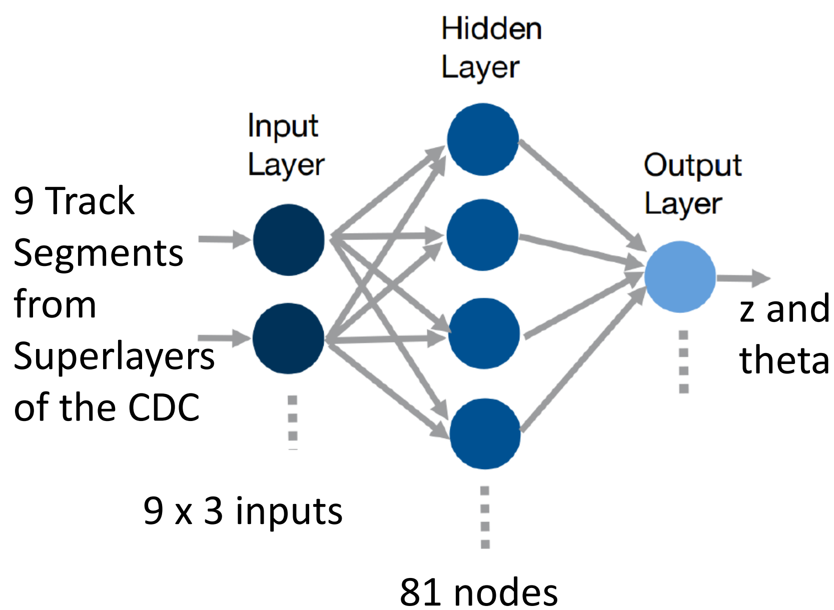
Backup

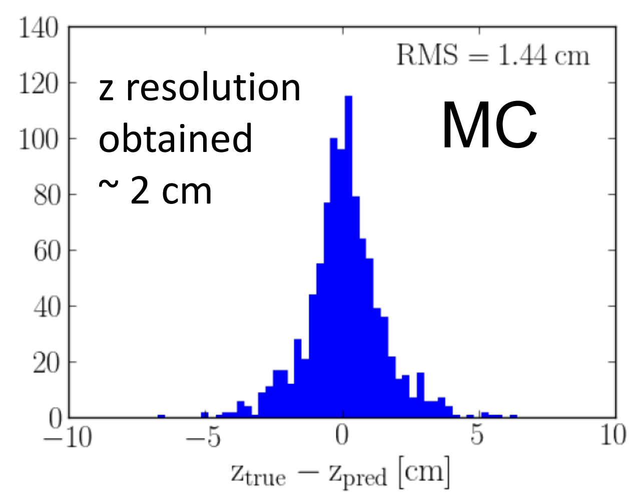
Neural z-Trigger Project

Input from standard 2D trigger → inclusion of stereo wires → Network

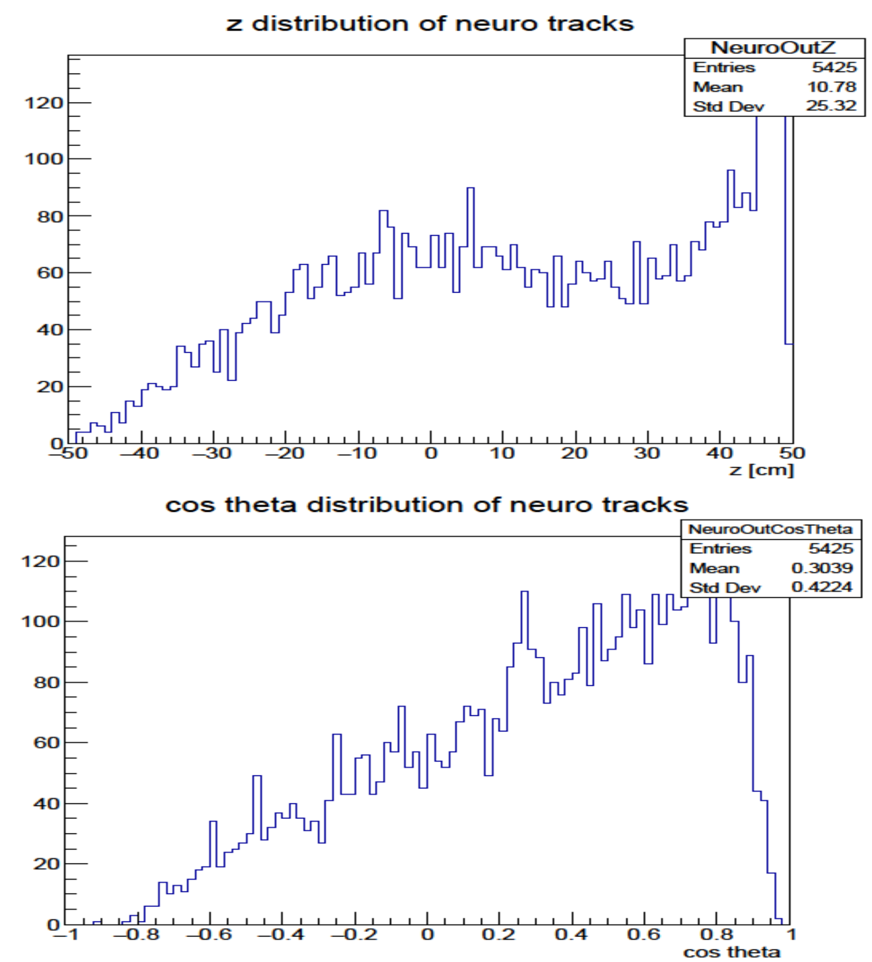








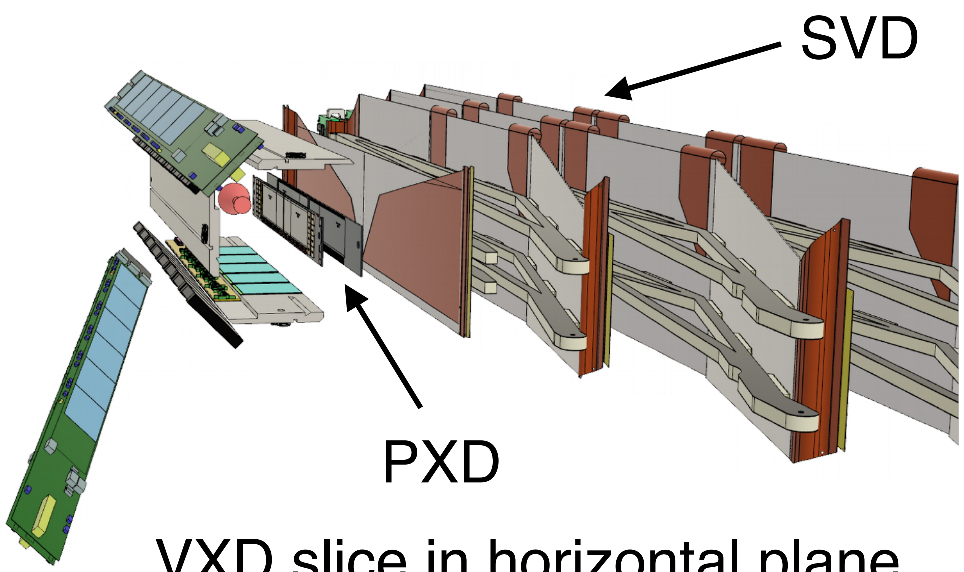
Cosmics triggered by ECL



Neuro – Team:
TUM / MPI : Simulation, training, SC and DQM
KIT : Hardware implementation (VHDL) (done, presently in validation phase)

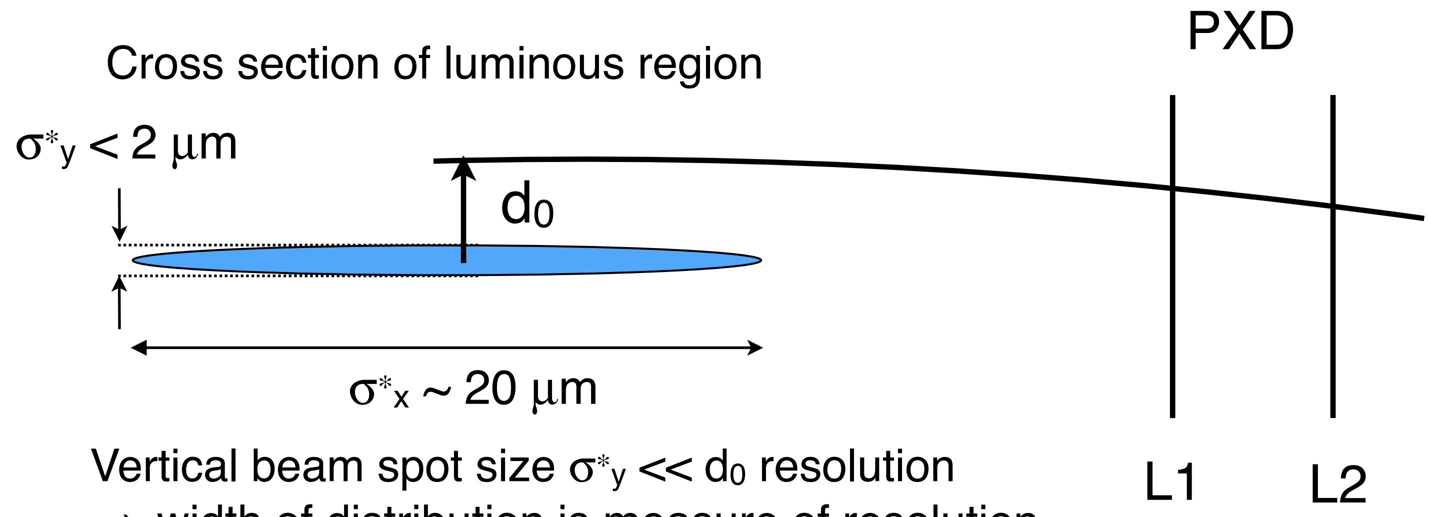
Trigger Boards provided by KEK

Impact Parameter Resolution Study



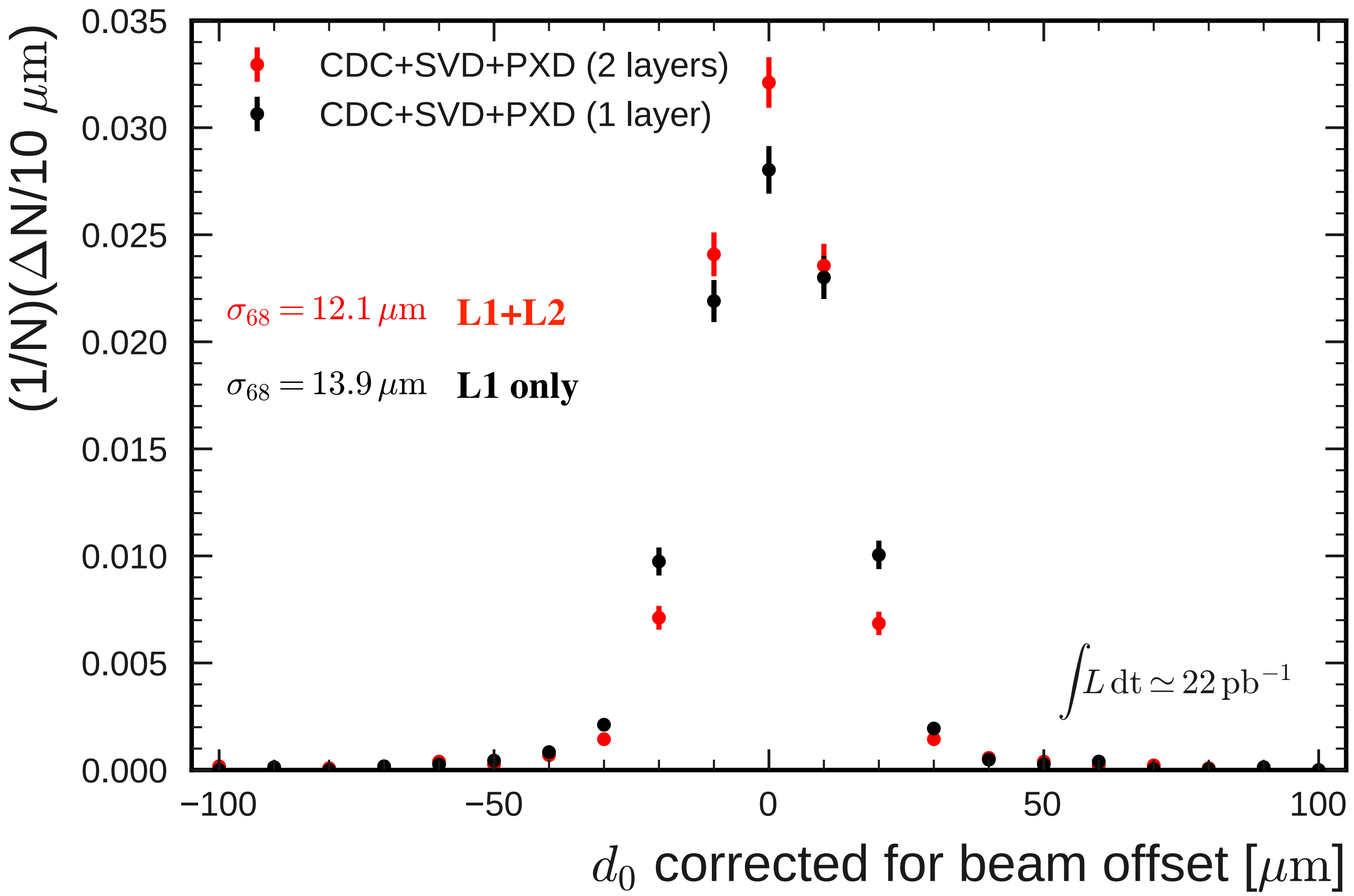
VXD slice in horizontal plane

Transverse impact parameter resolution in phase 2

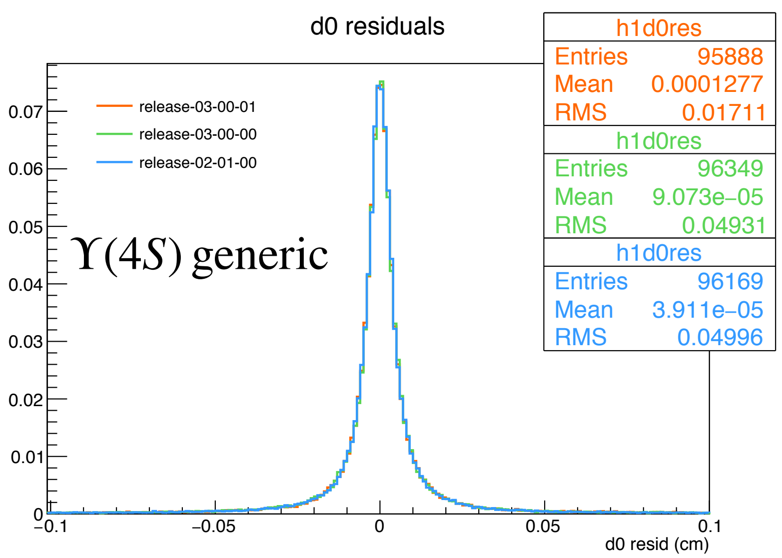


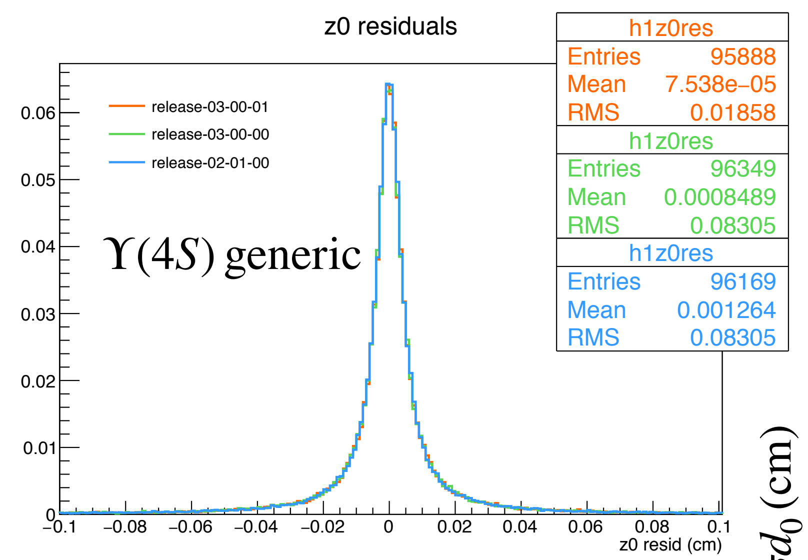
Vertical beam spot size $\sigma^*_y \ll d_0$ resolution

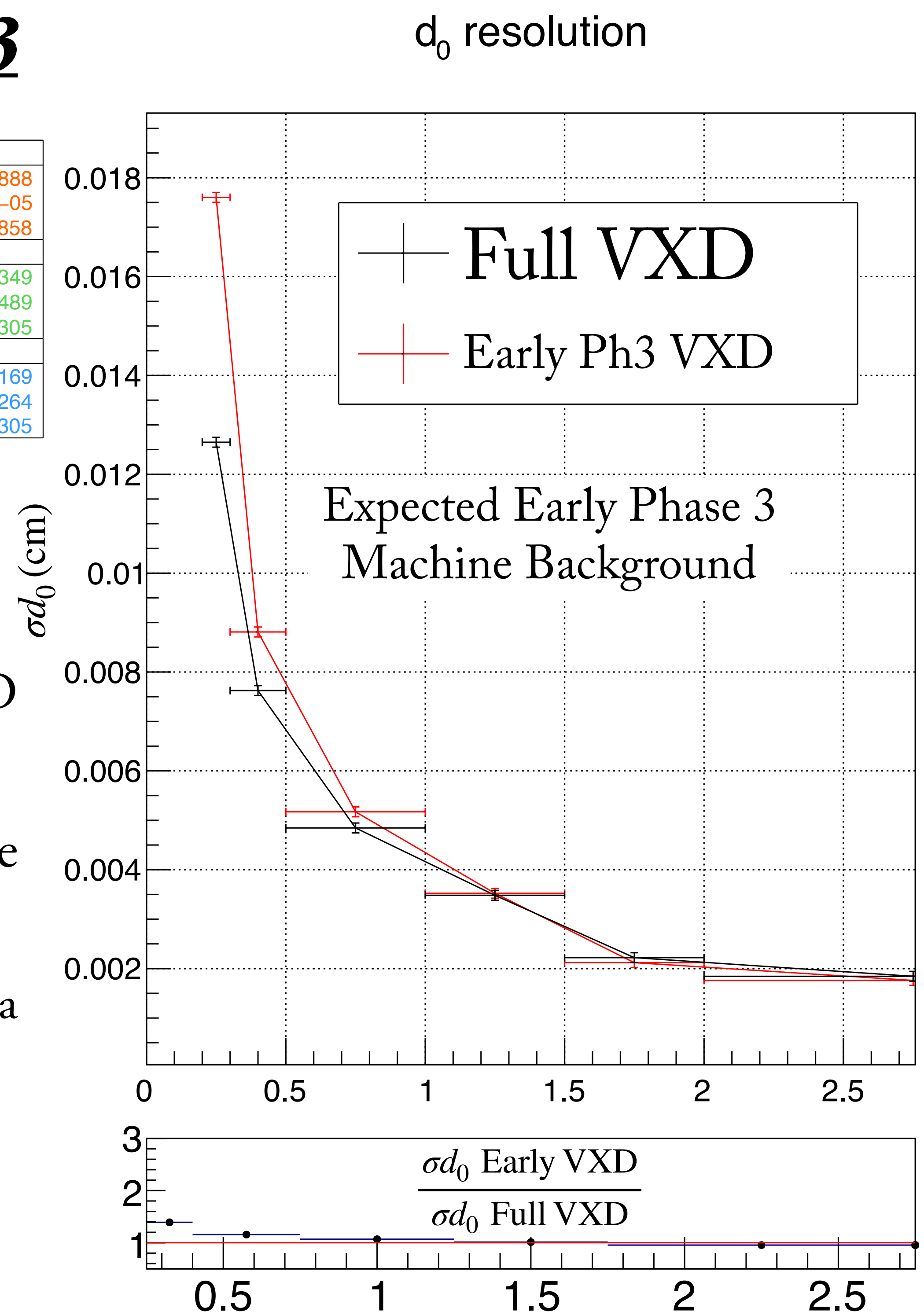
⇒ width of distribution is measure of resolution



PXD Layer2: from Early Phase3 to Phase3



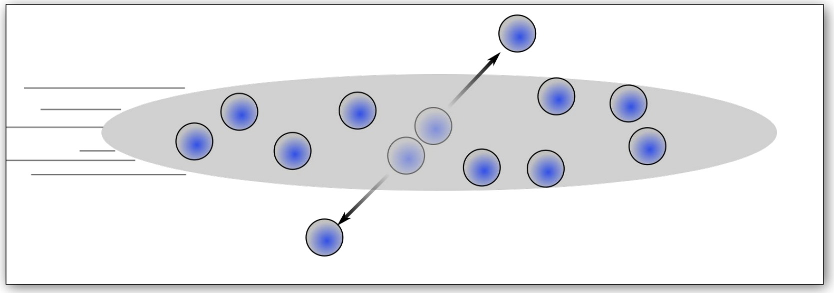




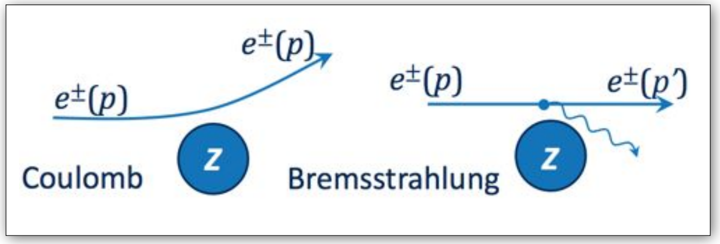
- ✦ The second layer of the PXD is crucial for resolving the PXD pattern in high background
- ✦ Present background simulations suggest a small performance degradation
  - Crucial to check the real performances in the first month of data taking

Background Sources at SuperKEKB

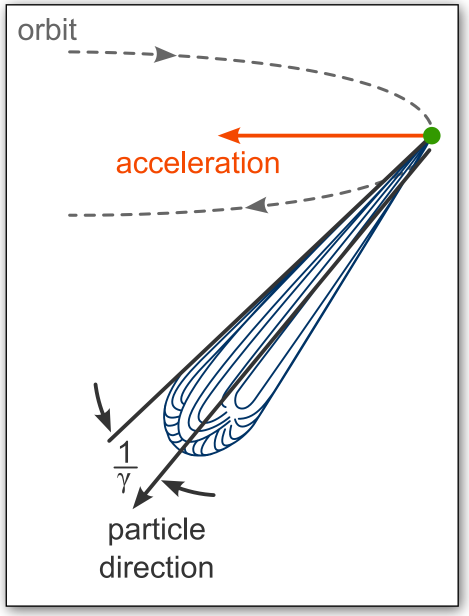
- Single beam (LER and HER)
  - Touschek: intra-bunch Coulomb scattering
    - squeeze beam => increase background
    - $\text{rate} \propto I^2_{\text{beam}} / (n_b \sigma_x \sigma_y E^3_{\text{beam}})$ => reduced energy asymmetry



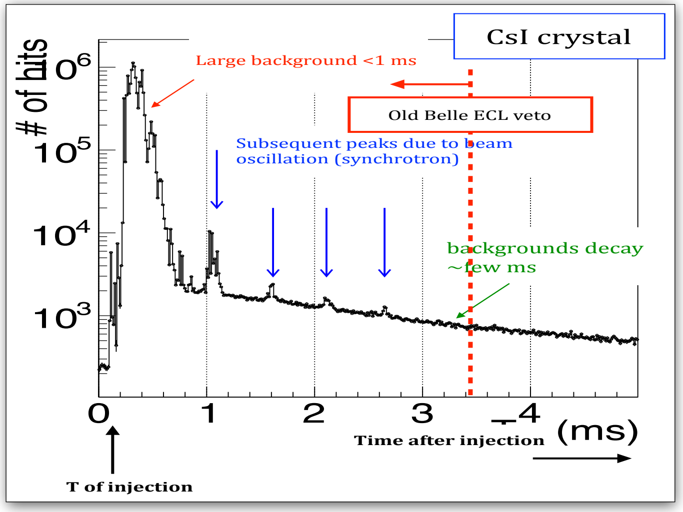
  - beam gas: $\text{rate} \propto I\,p\,Z^2_{eff}\ (\propto I^2)$
    - elastic Coulomb scattering
    - bremsstrahlung



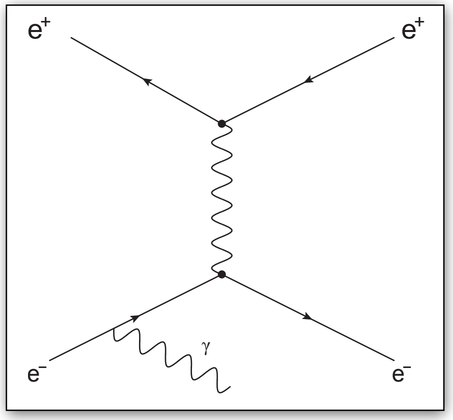
  - synchrotron radiation: $P_\gamma \propto E^4 \rho^{-2}$

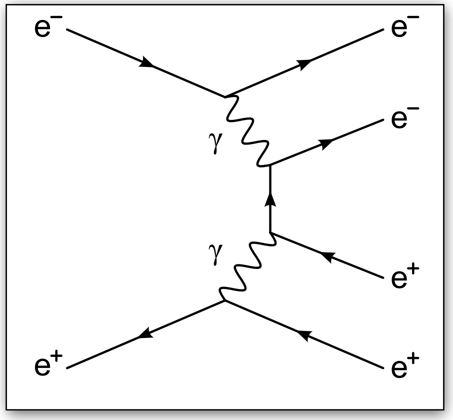


  - injection background (50 Hz)



- Beam-beam: $\text{rate} \propto L$
  - radiative Bhabha: $e^+e^- \to e^+e^-\ (\gamma)$
    - (a) emitted photon (neutrons), (b) spent e+/e-
  - 2-photon process: $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-e^+e^-$

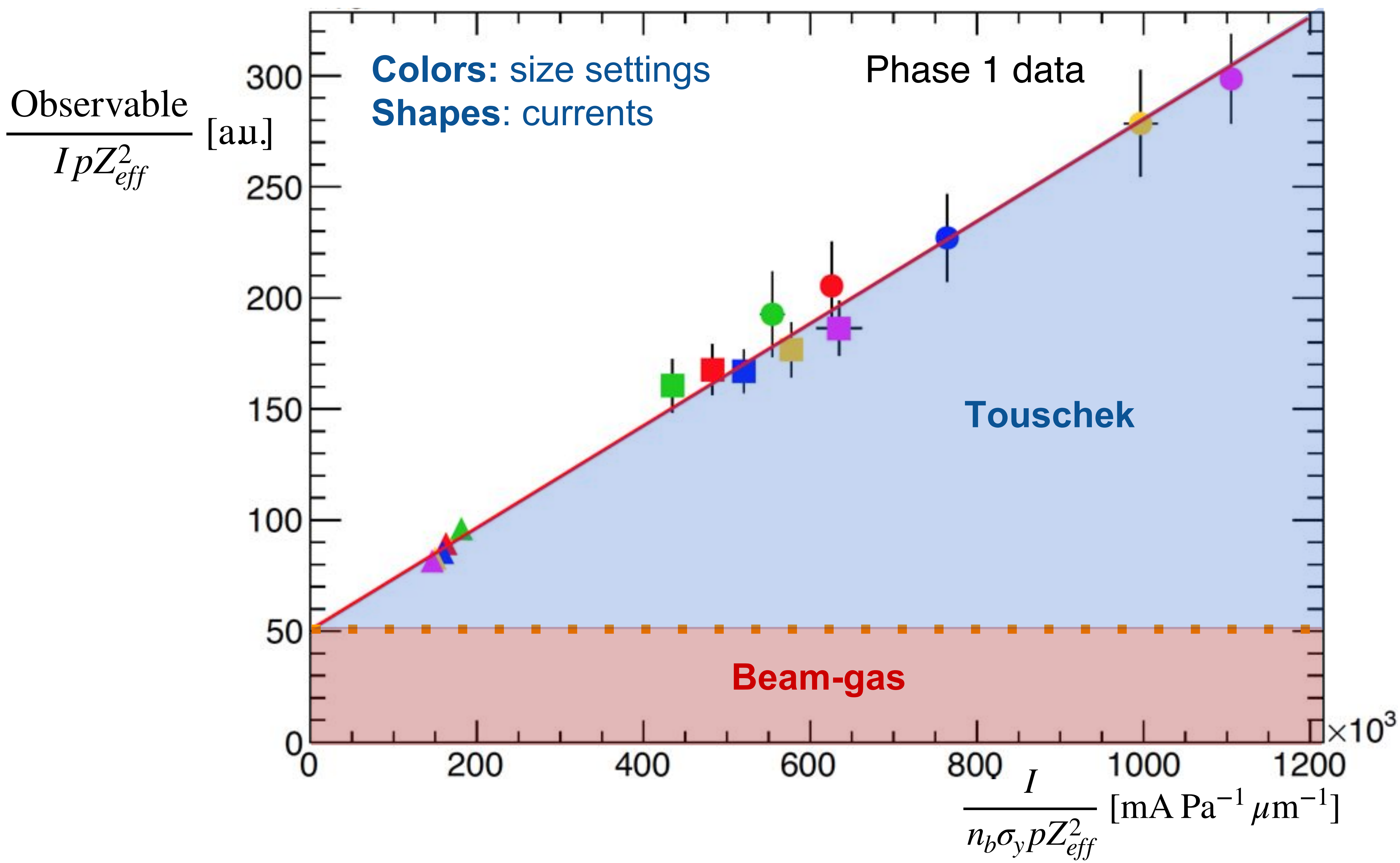




Disentangling Background Sources in Phases 2 and 3

$$\text{Observable} = B \cdot I\, p Z_{eff}^2 + T \cdot \frac{I^2}{n_b\, \sigma_y}$$

Beam gas Touschek

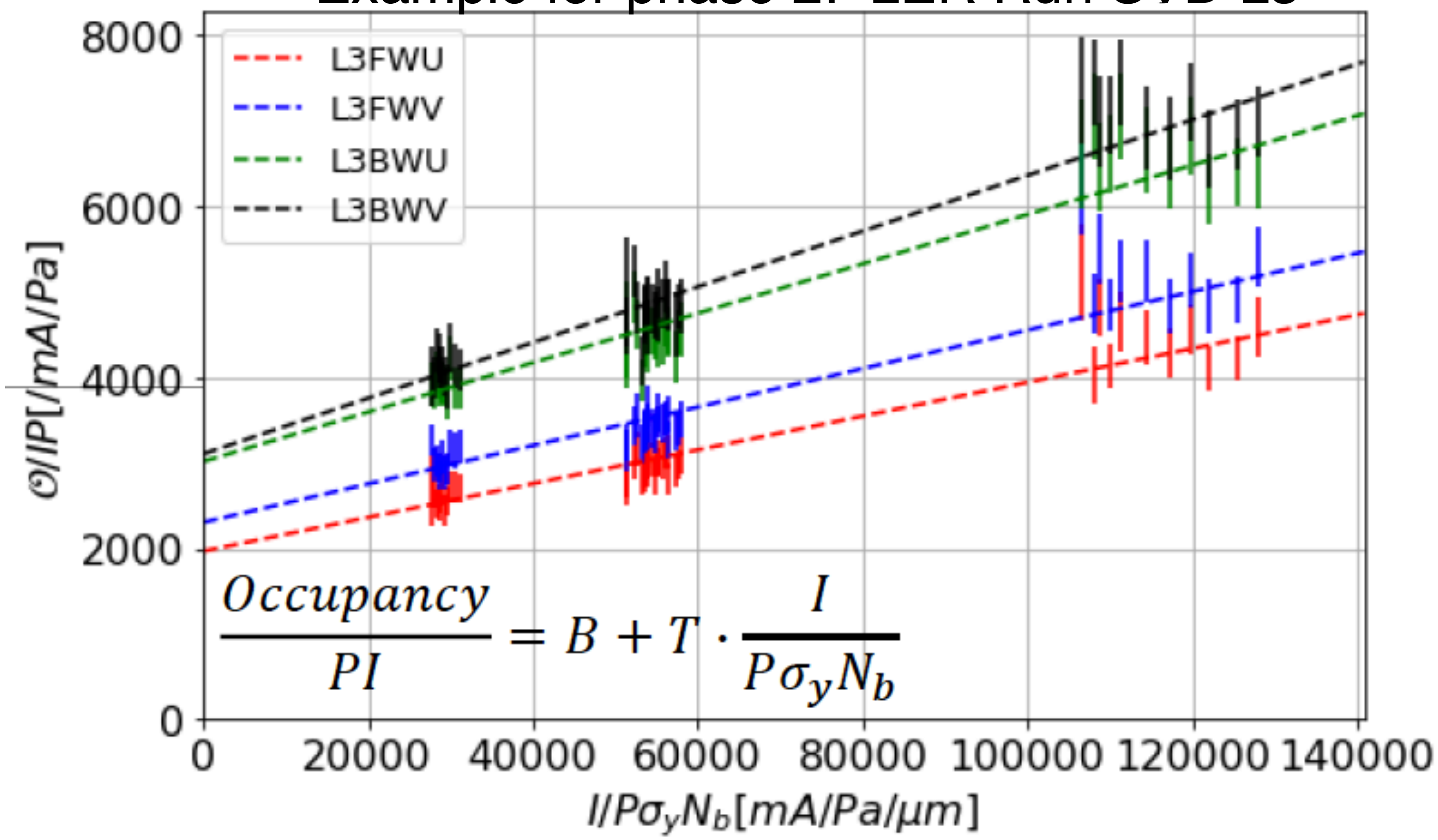


Disentangling Background Sources in Phases 2 and 3

$$\text{Observable} = B \cdot I p Z_{eff}^2 + T \cdot \frac{I^2}{n_b \sigma_y}$$

Beam gas Touschek

Example for phase 2: LER Run SVD L3



Data/MC for L3 sensors *Preliminary*

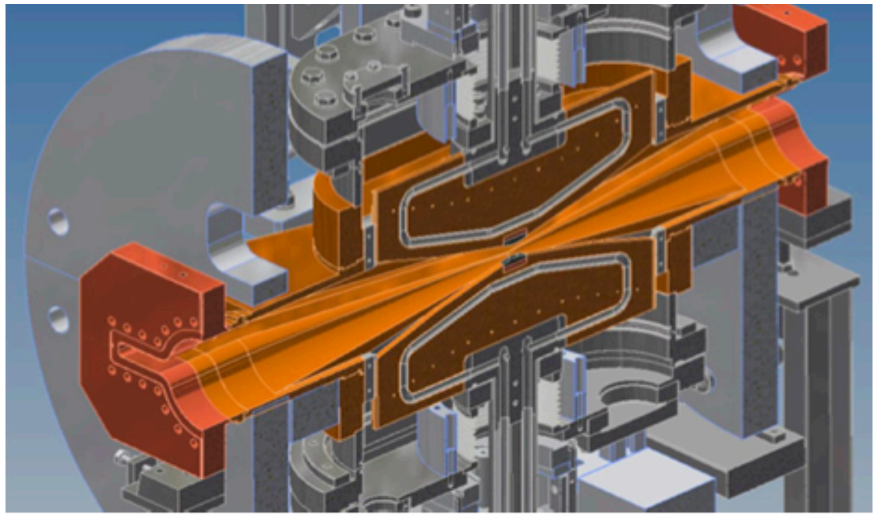
	June 11,12	July 16
HER BeamGas	270-610	230-600
HER Touschek	260-350	850-1700
LER BeamGas	11-13	34-39
LER Touschek	2.3-2.9	3.5-4.6

Use data/MC ratio in phase 2 as scaling factor for phase 3 MC

- Detector occupancy limit: ~2-3% (from tracking)
  - extrapolation to phase 3: will be exceeded
- Radiation dose limits: 10 Mrad (w/o injection)
  - no safety margin for phase 3

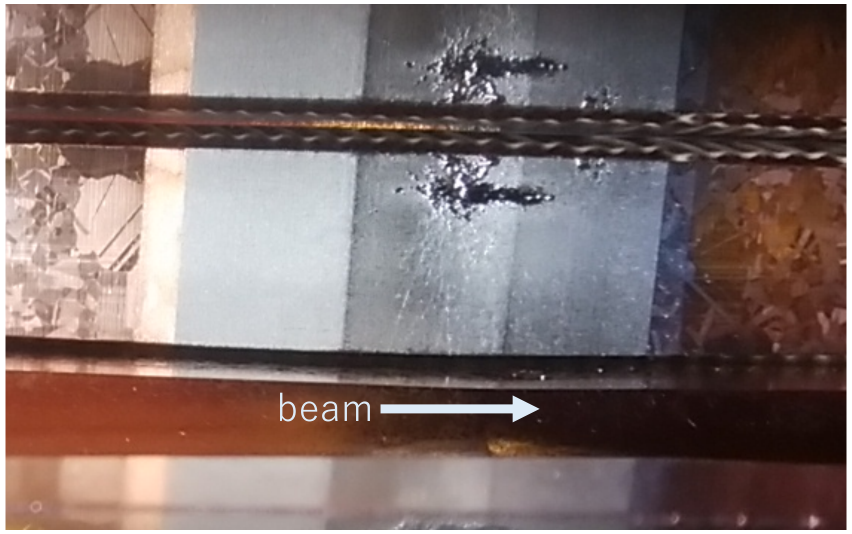
- Need **> factor 2** reduction to operate VXD with good tracking performance in early Phase 3
- Need **> factor 10** improvement in backgrounds for operation at design luminosity

QCS Quenches



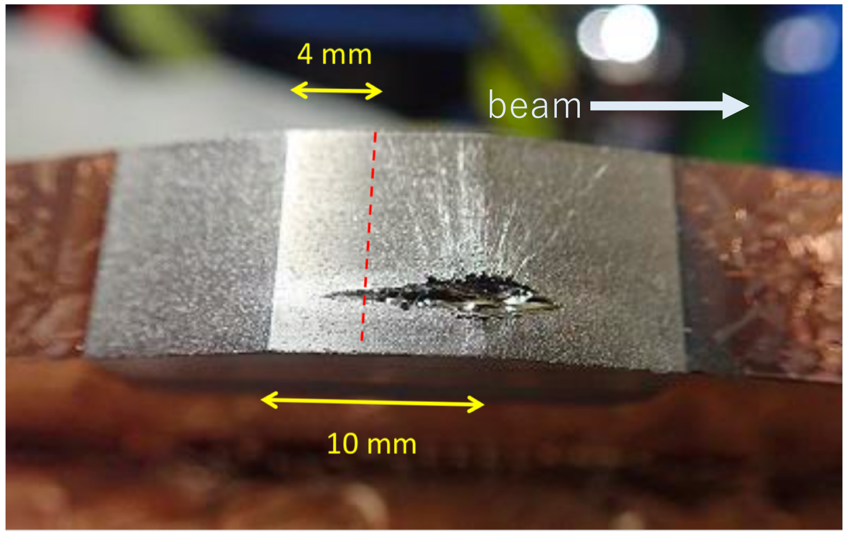
Pressure burst and QCS quench

top jaw

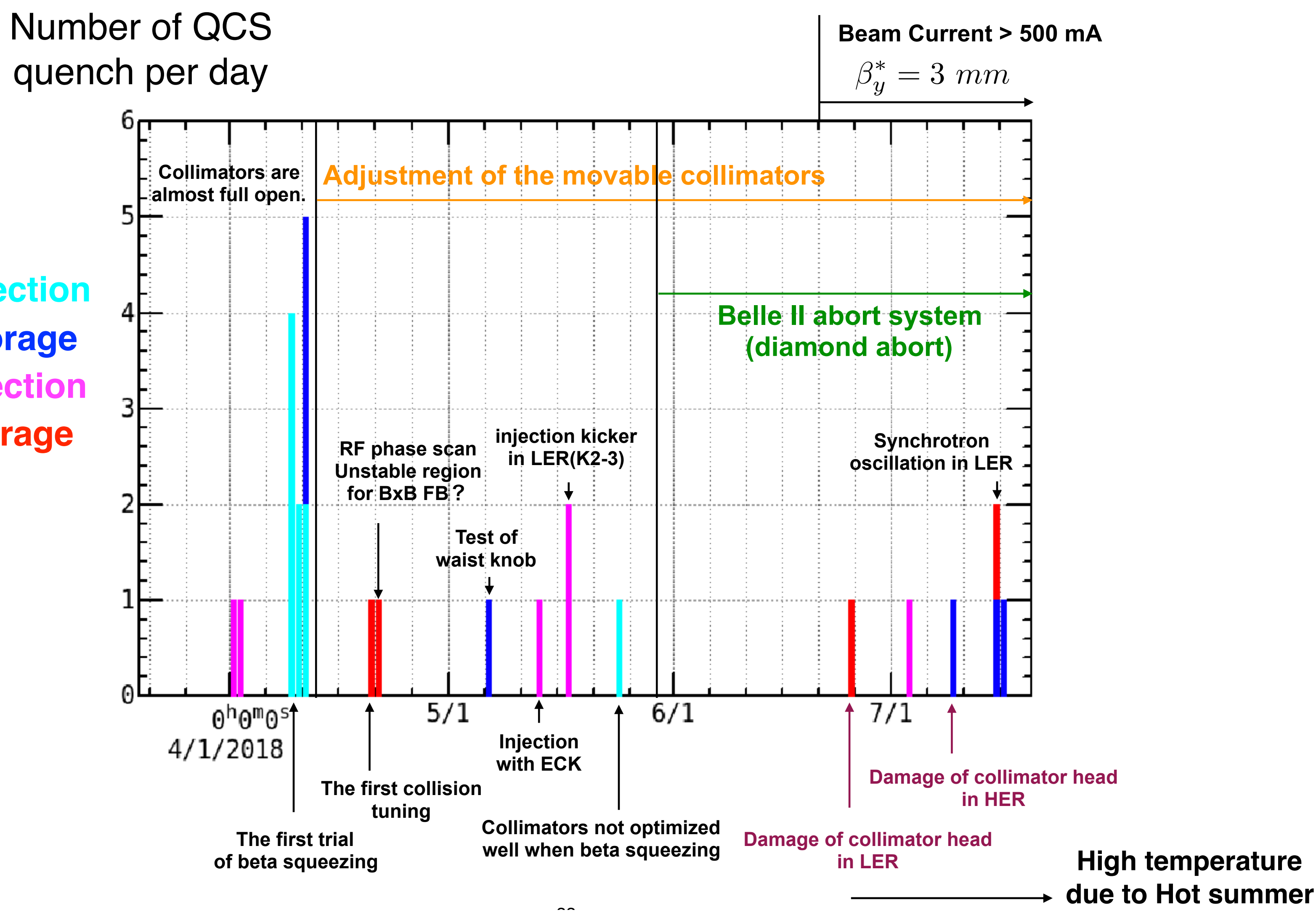


730mA hit D02V1 …

bottom jaw



HER Injection
HER Storage
LER Injection
LER Storage

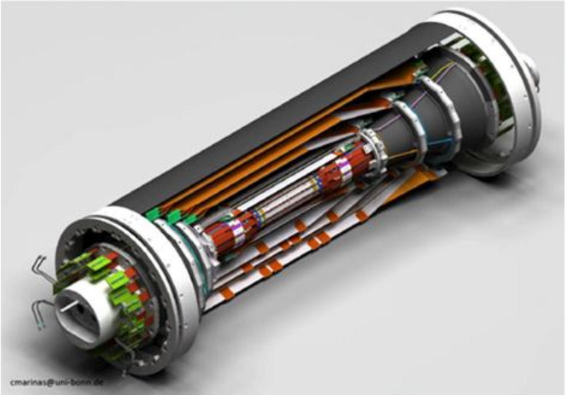


Early Phase 3 Physics

- Luminosity will largely depend on machine and detector performance
- Plausible assumption of about 10 fb^{-1} by summer 2019

Semileptonic
- B→ π l ν and ρ l ν untagged (CLEO saw a signal with 2.66 fb^{-1})

Time Dependent CP Violation/Charm
- D lifetimes (2 fb^{-1})
- Doubly Cabibbo suppressed $D^0 \rightarrow K^+ \pi^-$, $D^0 \rightarrow K^+ \pi^- \pi^0$ (10 fb^{-1})
- B lifetimes (2-10 fb^{-1})
- Time dependent B-anti B mixing (10 fb^{-1})



Demonstrate VXD physics performance

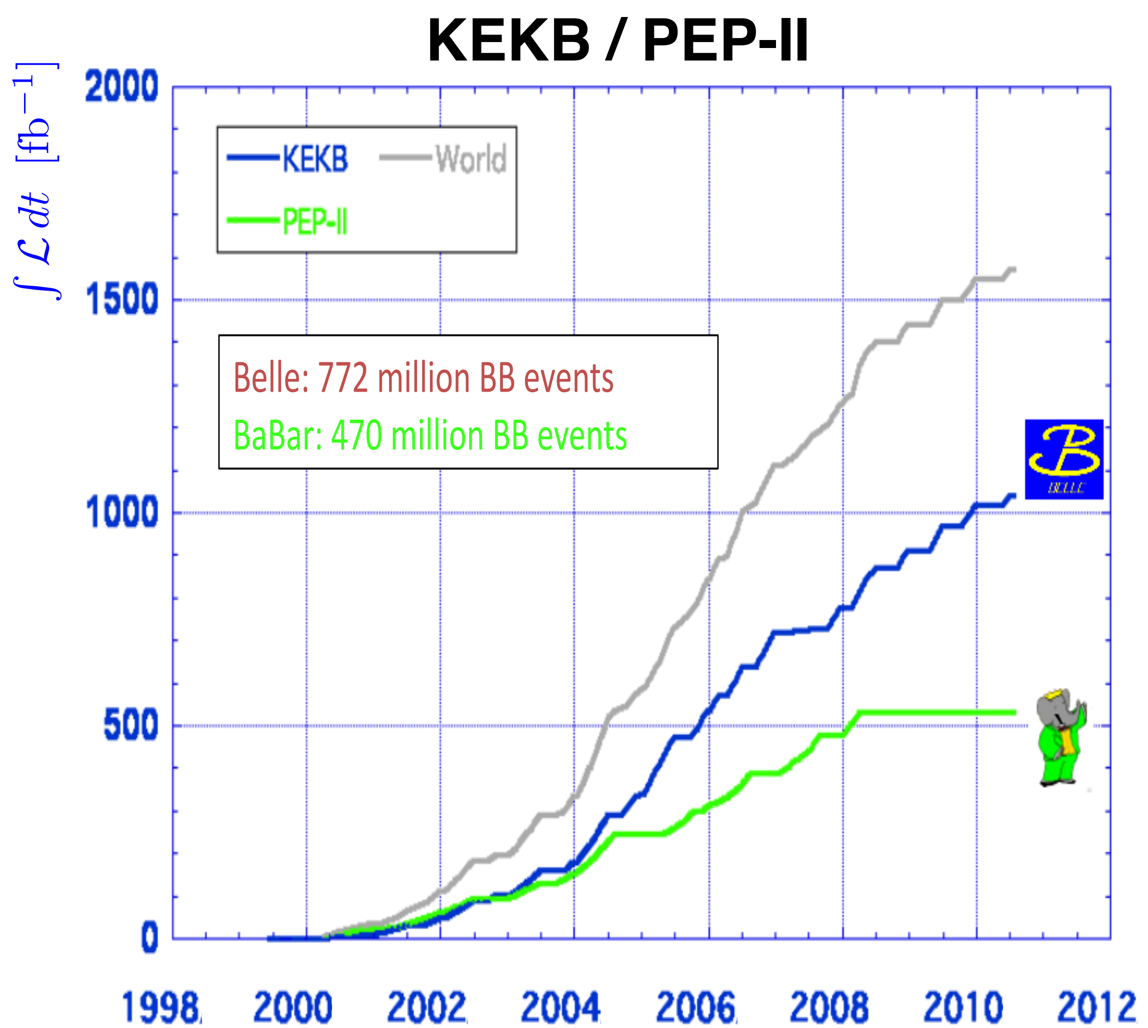
Radiative/Electroweak Penguins
- B→K* γ (b→s) (2 fb^{-1}) rediscover penguins
- B→Xs γ (b→s) (~10 fb^{-1} depending on off-resonance data taking)

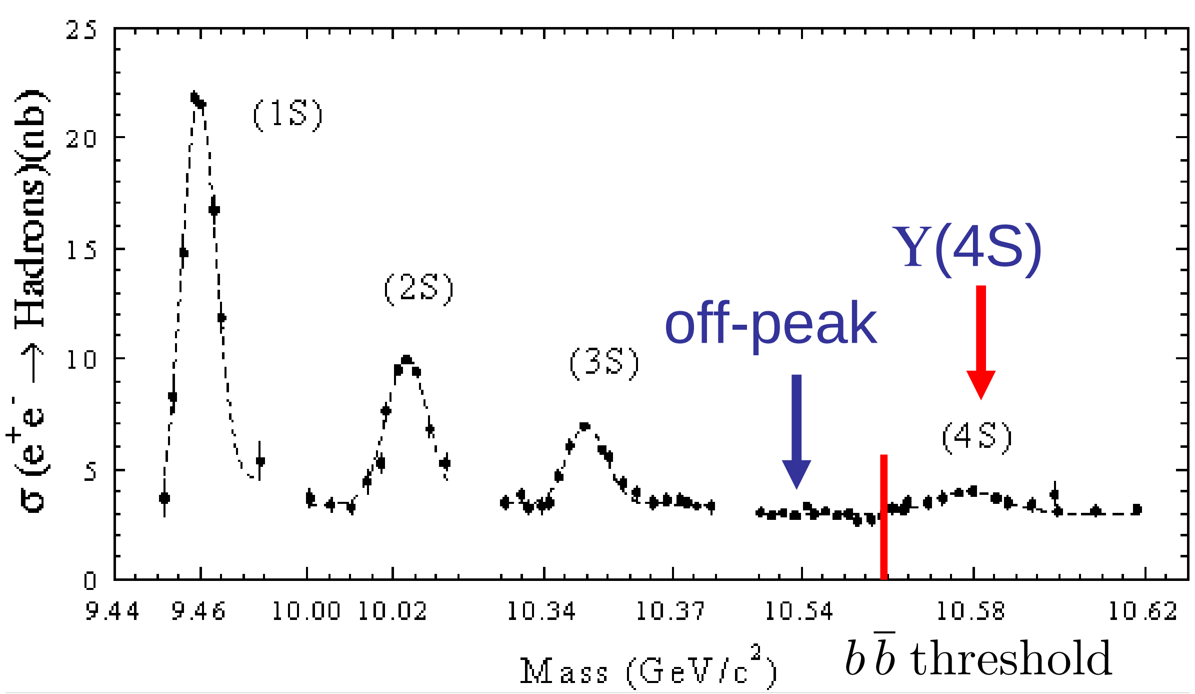
Hadronic B decays (not time dependent)
- B→K π (b→u) (10 fb^{-1})
- B→ Φ K (b→s) (10 fb^{-1})
- B→J/ψ K (with more significance 2-10 fb^{-1})

++ Dark Sector Physics Publications

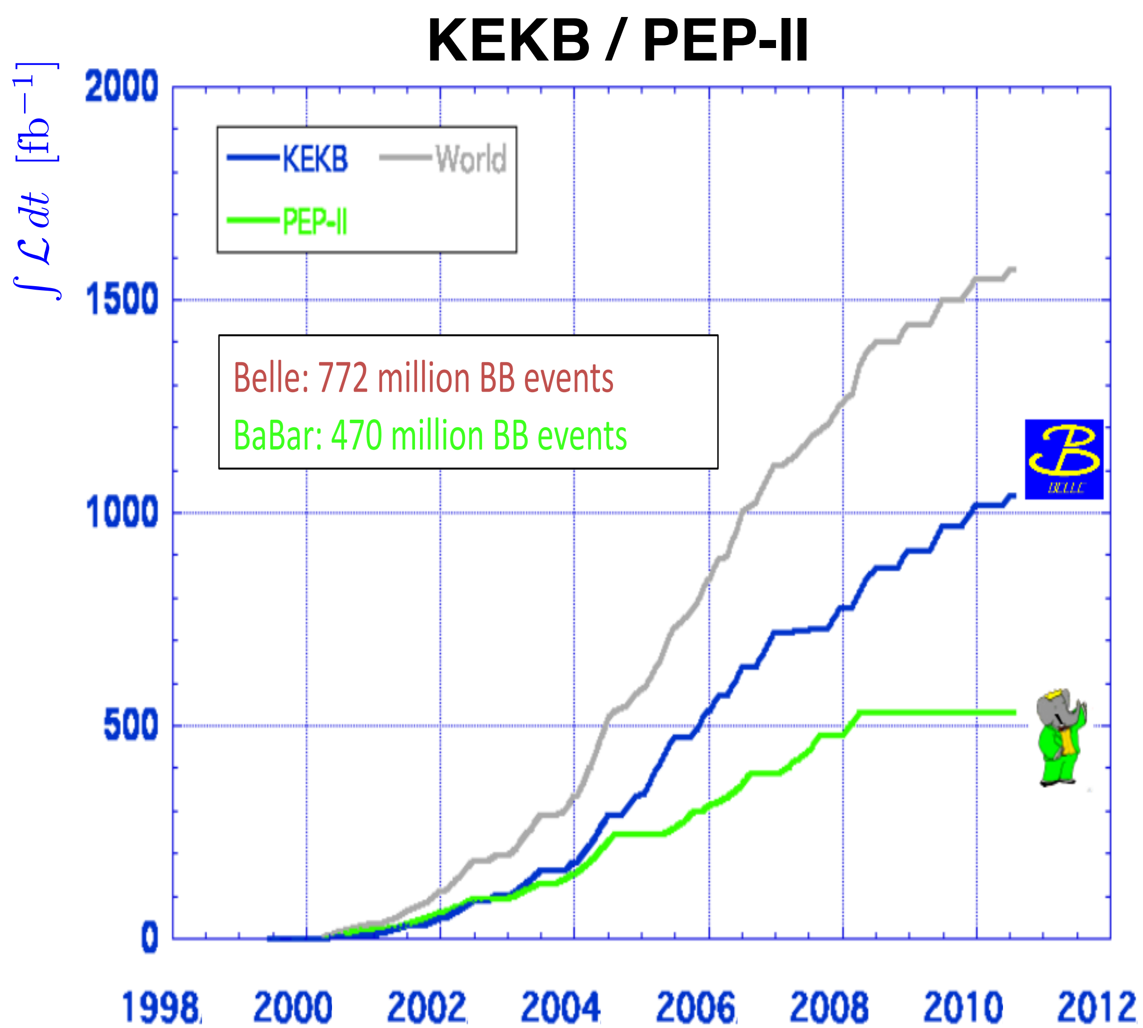
P. Urquijo et al.

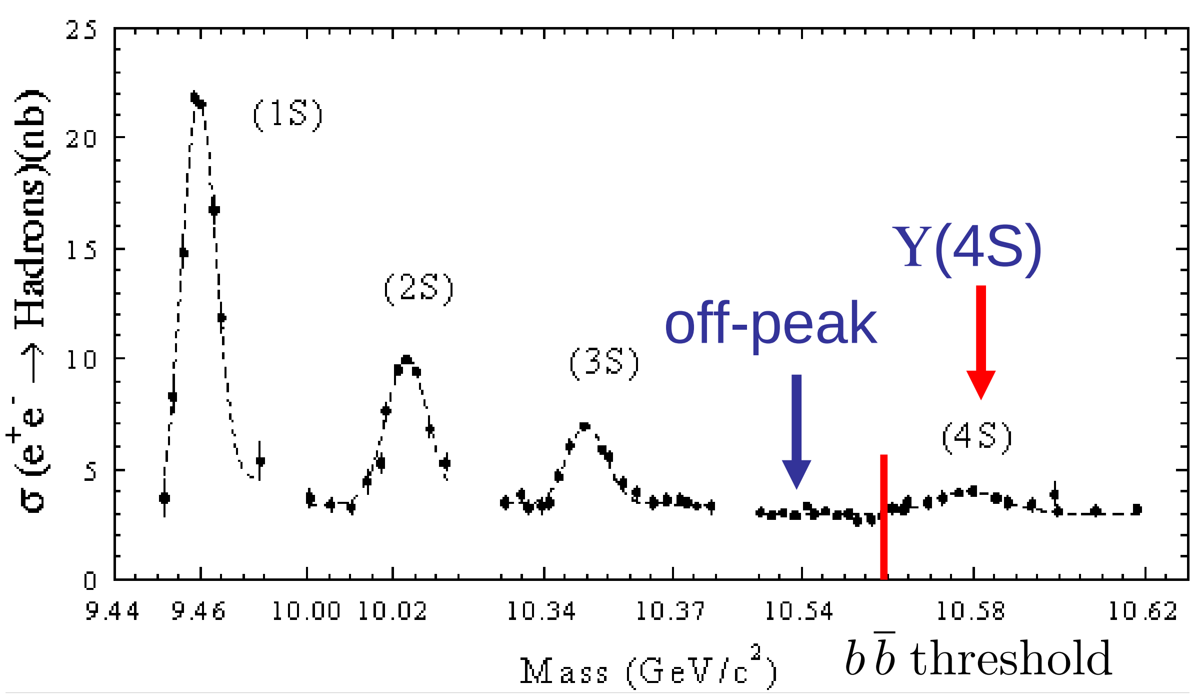
Building on Success of First Generation B-Factories

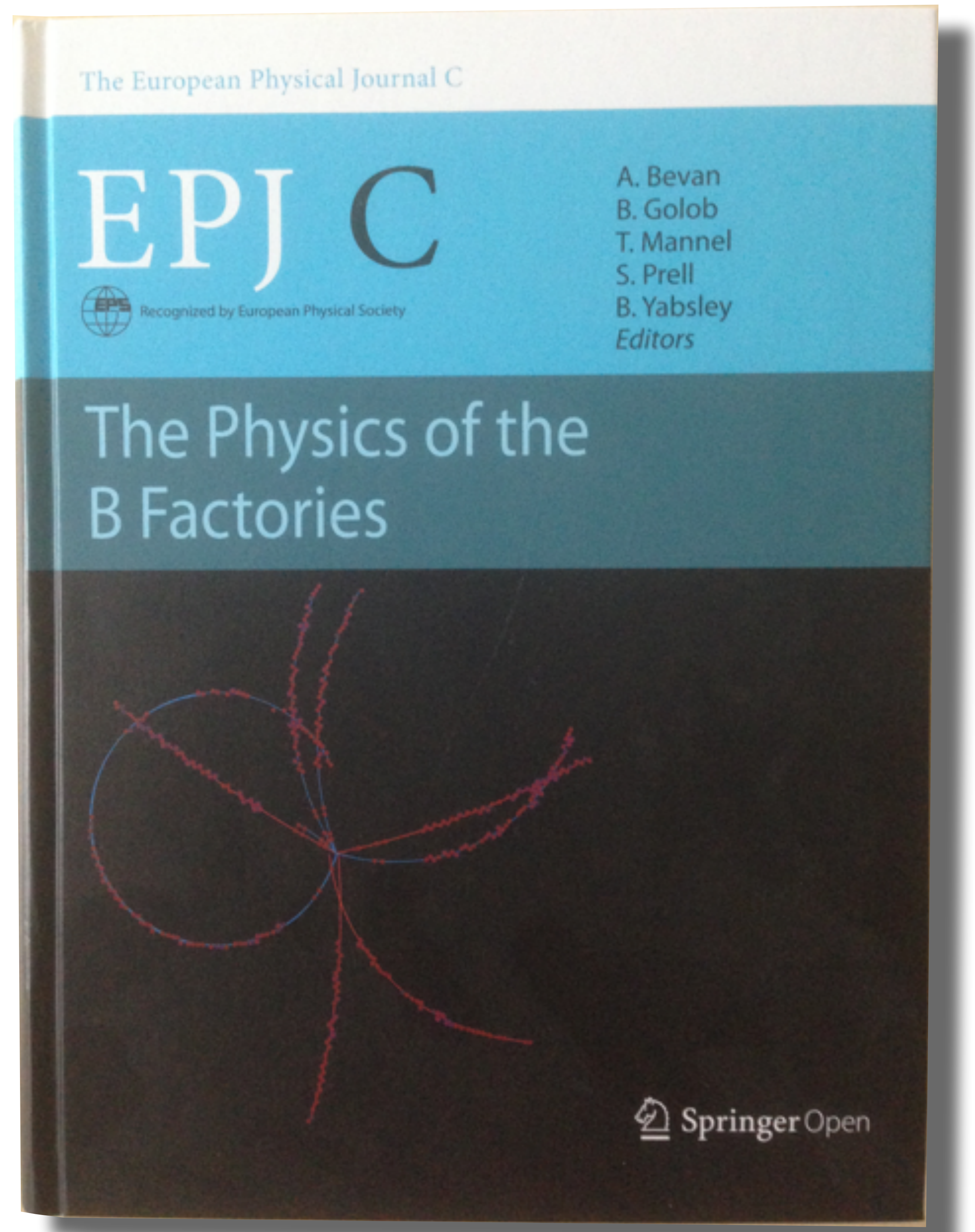




Building on Success of First Generation B-Factories

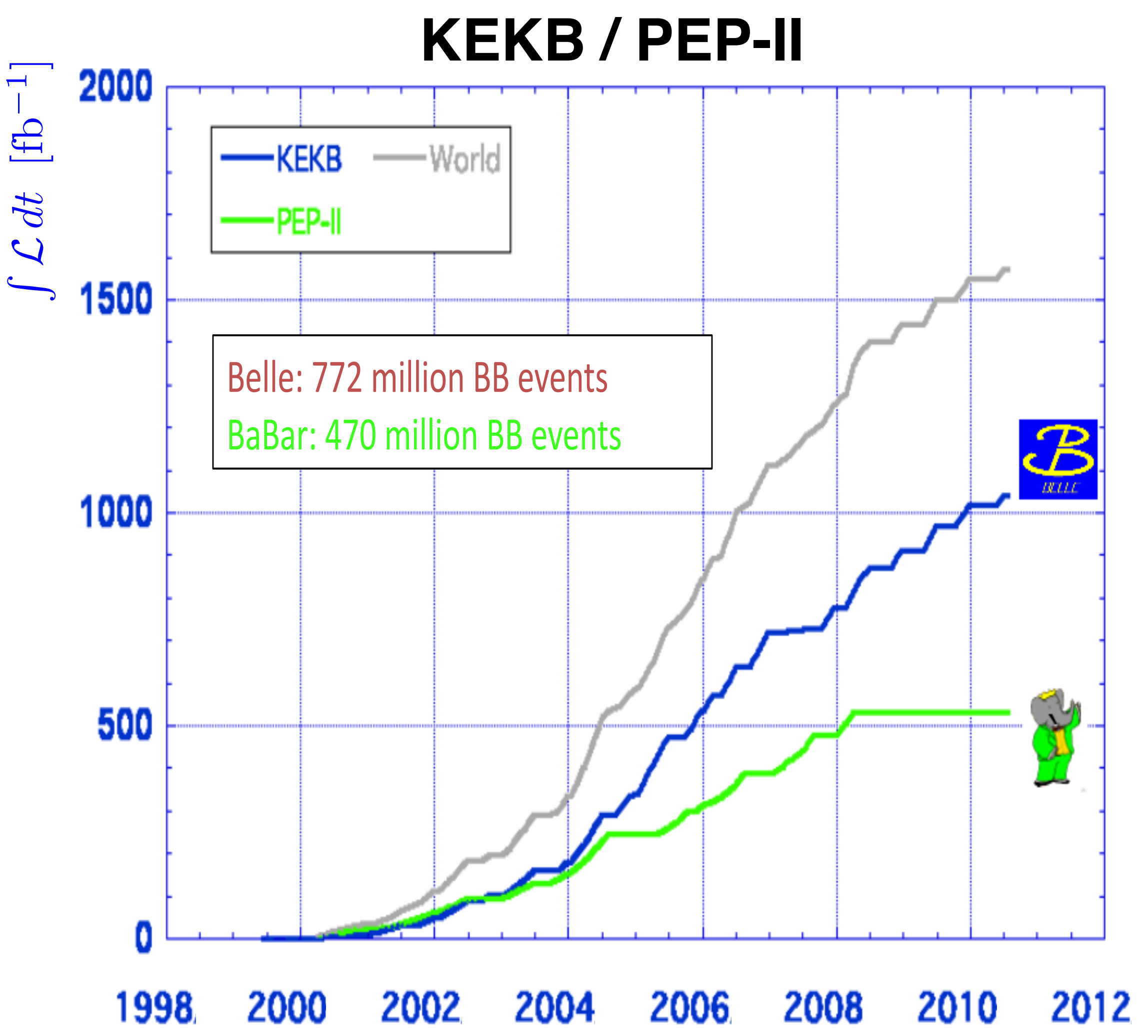


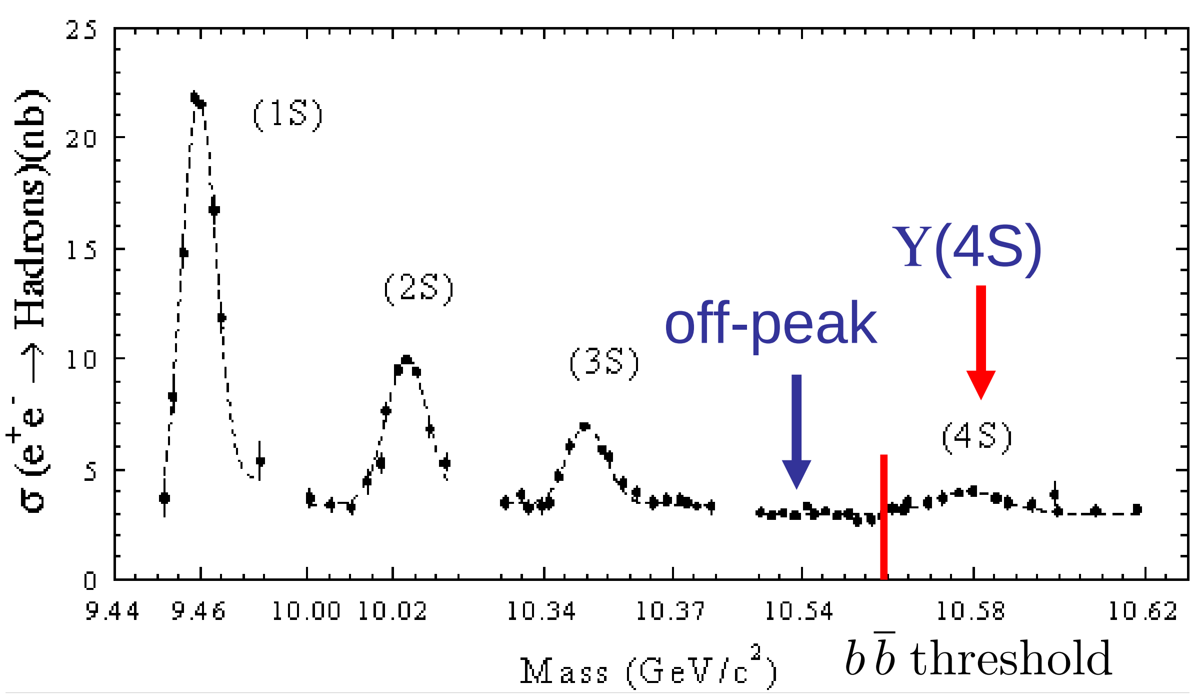


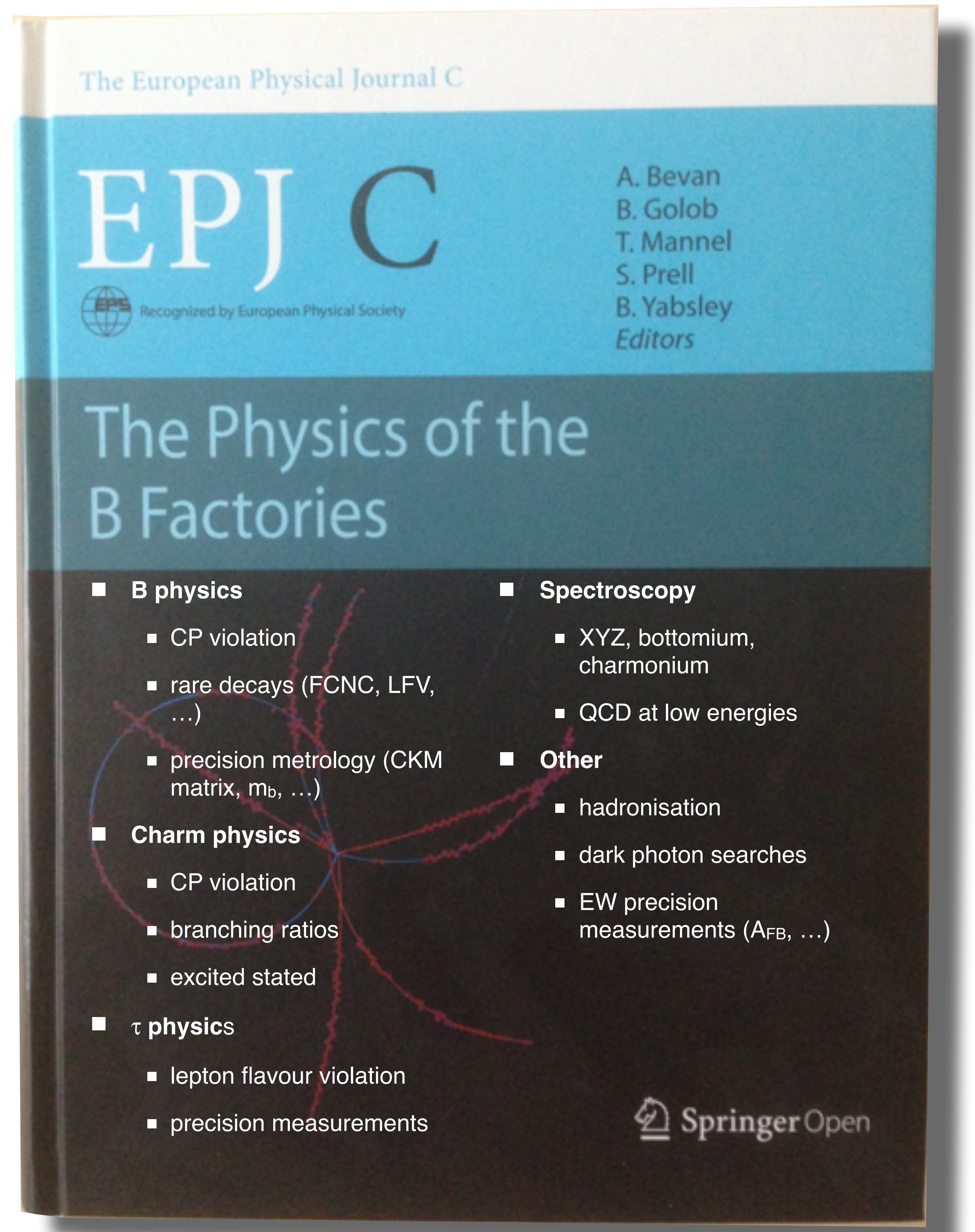


> 900 pages

Building on Success of First Generation B-Factories

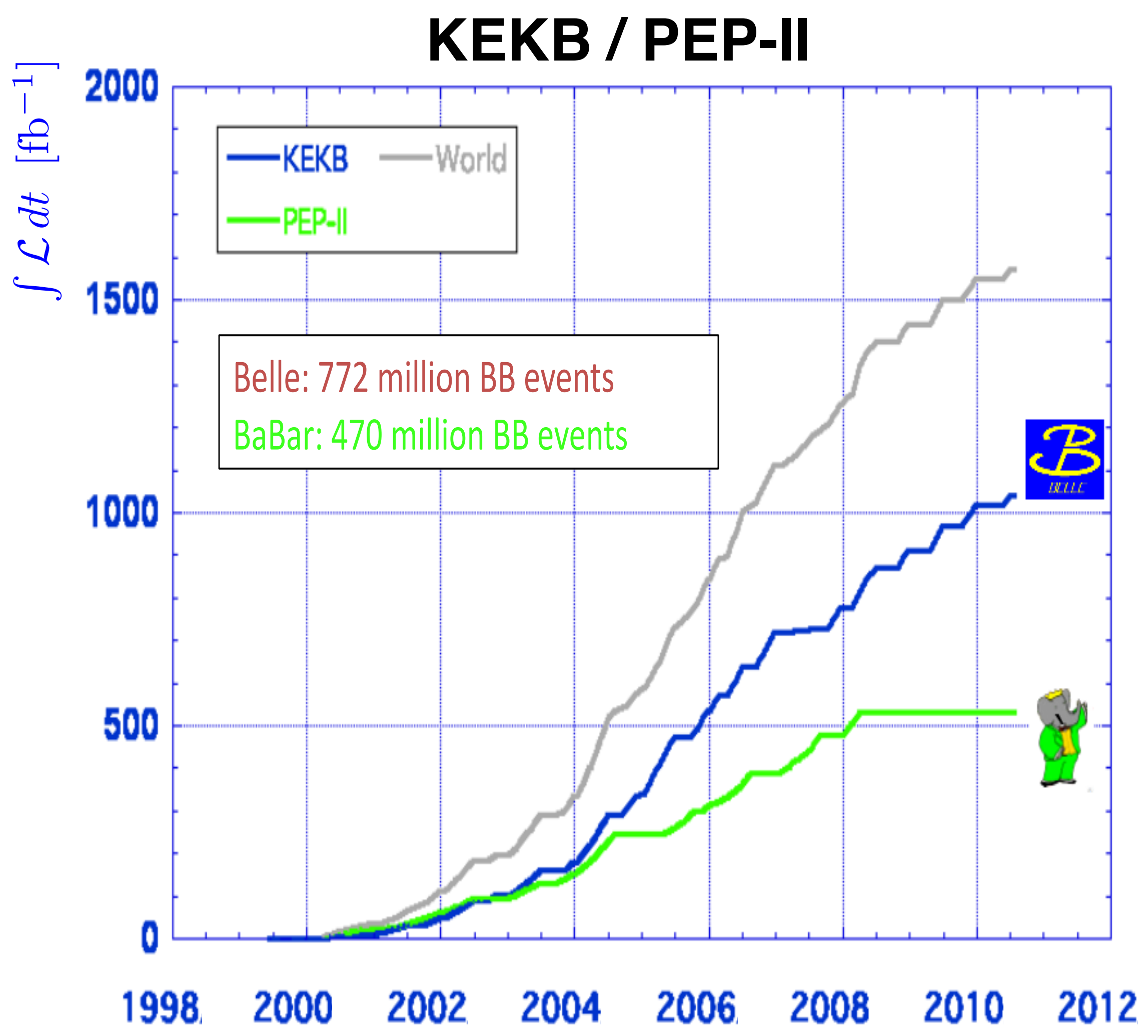


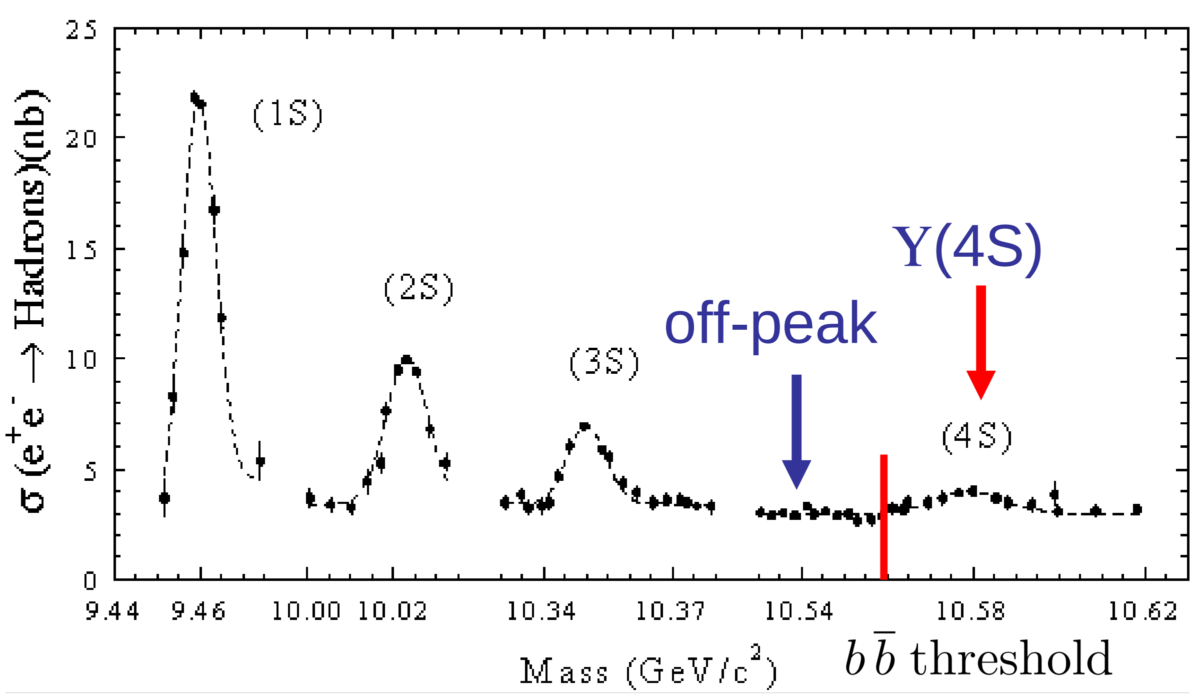




> 900 pages

Building on Success of First Generation B-Factories





KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047

The Belle II Physics Book

Leptonic and Semileptonic B decays
Experiment: G. De Nardo (Naples), A. Zupanc (IJS)
Theory: F. Tackmann (DESY), A. Kronfeld (FNAL, *LQCD*), R. Watanabe (Montreal)

Radiative and Electroweak Penguin B decays
Experiment: A. Ishikawa (Tohoku), J. Yamaoka (PNNL)
Theory: U. Haisch (Oxford), T. Feldmann (Siegen)

Time Dependent CP Violation of B mesons
Experiment: A. Gaz (Nagoya), L. Li Gioi (MPI Munich)
Theory: S. Mishima (Rome/KEK), J. Zupan (Cincinnati)

Determination of the Unitarity Triangle angle ϕ_3
Experiment: J. Libby (IIT Madras)
Theory: Y. Grossman (Cornell), M. Blanke (CERN)

Hadronic B decays and direct CP Violation
Experiment: P. Goldenzweig (KIT)
Theory: M. Beneke (TUM), C-W. Chiang (NCU)

Charm flavour and spectroscopy
Experiment: G. Casarosa (Pisa), A. Schwartz (Cincinnati)
Theory: A. Petrov (Wayne), A. Kagan (Cincinnati)

Quarkonium(like) physics
Experiment: B. Fulsom (PNNL), R. Mizuk (ITEP), R. Mussa (Torino), C-P. Shen (Beihang)
Theory: N. Brambilla (TUM), C. Hanhart (Juelich), Y. Kiyo (Juntendo), A. Polosa (Rome), S. Prelovsek (Ljubljana, *LQCD*)

Tau decays and low-multiplicity physics
Experiment: K. Hayasaka (Nagoya), T. Ferber (DESY)
Theory: E. Passemar (Indiana), J. Hisano (Nagoya)

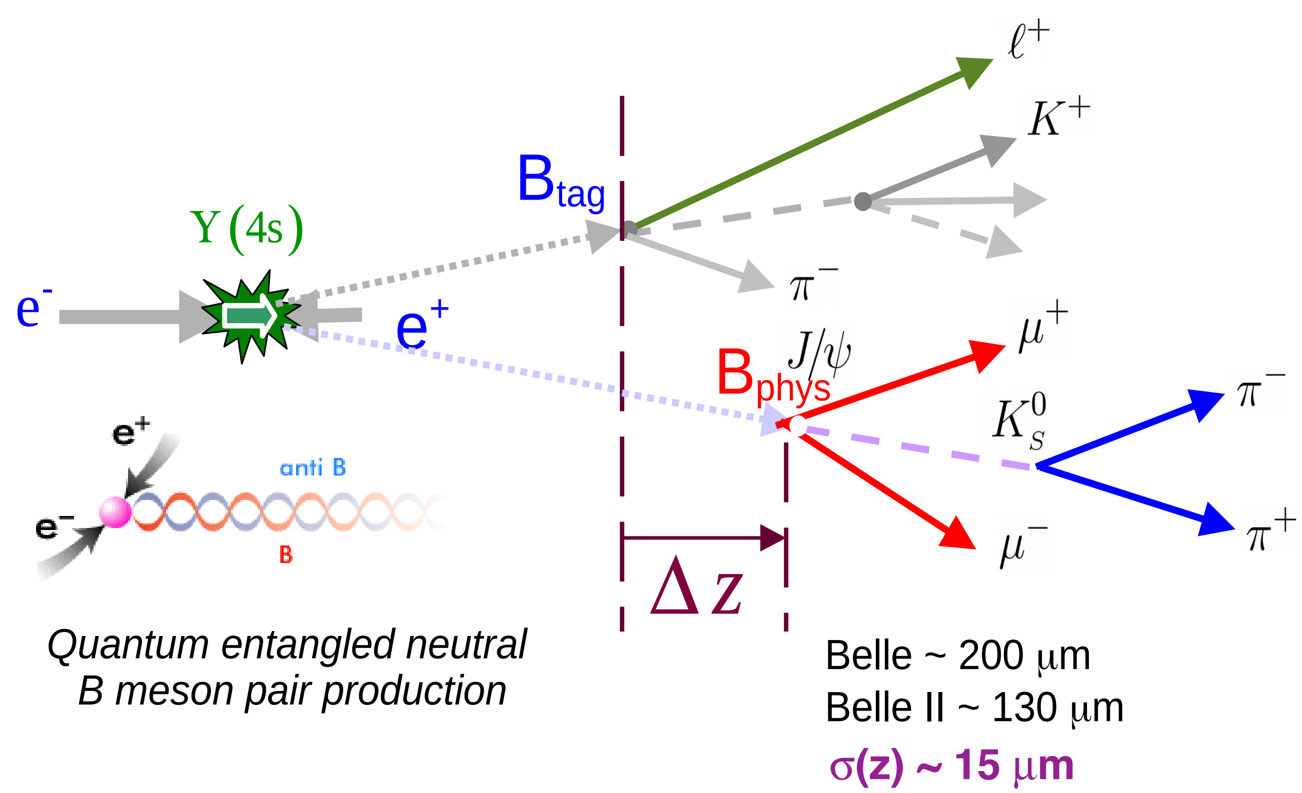
New physics and global analyses
Experiment: F. Bernlochner (Bonn), R. Itoh (KEK)
Theory: J. Kamenik (Ljubljana), U. Nierste (KIT), L. Silvestrini (Rome)

arXiv: 1808.10567 (688p), Submitted to PTEP

B-Factories versus LHCb

Advantages of LHCb

- *O*(mb) vs *O*(nb) b cross section
  - 10^6 times larger (10^5 in acceptance)
- *O*(10^4μm) vs *O*(10^2μm) decay length
  - 10^2 times larger
- multiple scattering less important



Quantum entangled neutral B meson pair production

Advantages of B factories

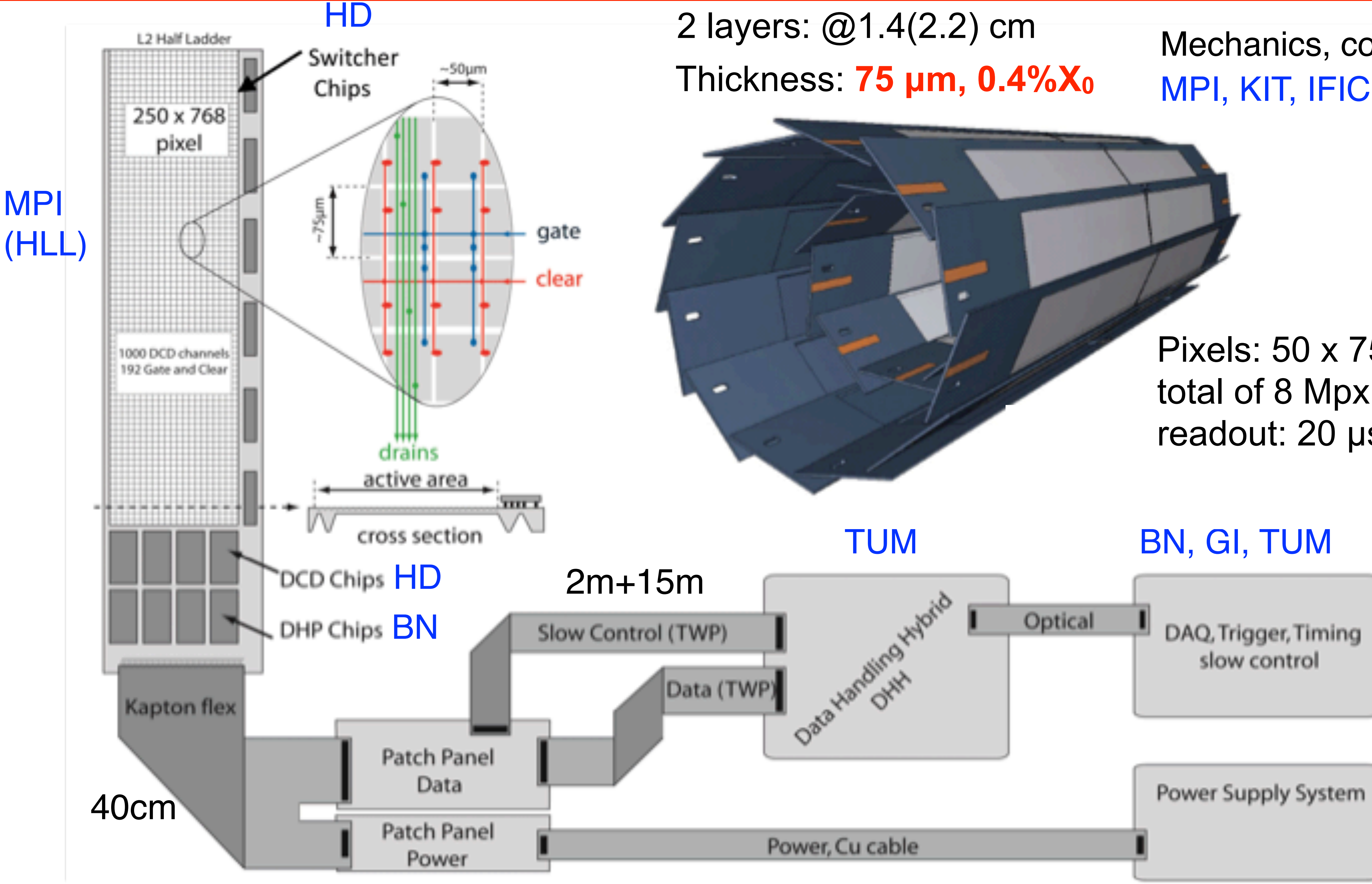
- much higher luminosity (x10^3)
- **low background** allows for the reconstruction of final states containing **photons** from decays of **π⁰, ρ± , η, η′** etc. and **K_L^0** reconstruction
- since the initial state is known, "**missing mass**" analyses can be performed to infer existence of **new particles** via energy/momentum conservation
- ***Full Event Interpretation*** for decays with ν**'s** and **inclusive** measurements
- detection of decay products of one B allows **flavour** of the other B to be **tagged** (time dependent CP violation)
- large samples of τ leptons allowing for measurements of **rare τ decays** and searches for **lepton flavour and lepton number violating** τ decays

PXD System Overview

2 layers: @1.4(2.2) cm

Thickness: **75 µm, 0.4%X_0**

Mechanics, cooling:
MPI, KIT, IFIC, DESY



Pixels: 50 x 75 µm
total of 8 Mpx
readout: 20 µs

Switcher: Gate and Clear signals (rolling shutter mode: 100ns per pixel row)
DCD: Drain Current Digitizer
DHP: Data Handling Processor (common mode rejection, pedestal subtraction, zero-suppression)
DHH: Data Handling Hybrid (FPGA: clock, timming, trigger; conversion to optical; clustering)

DEPFET Principle

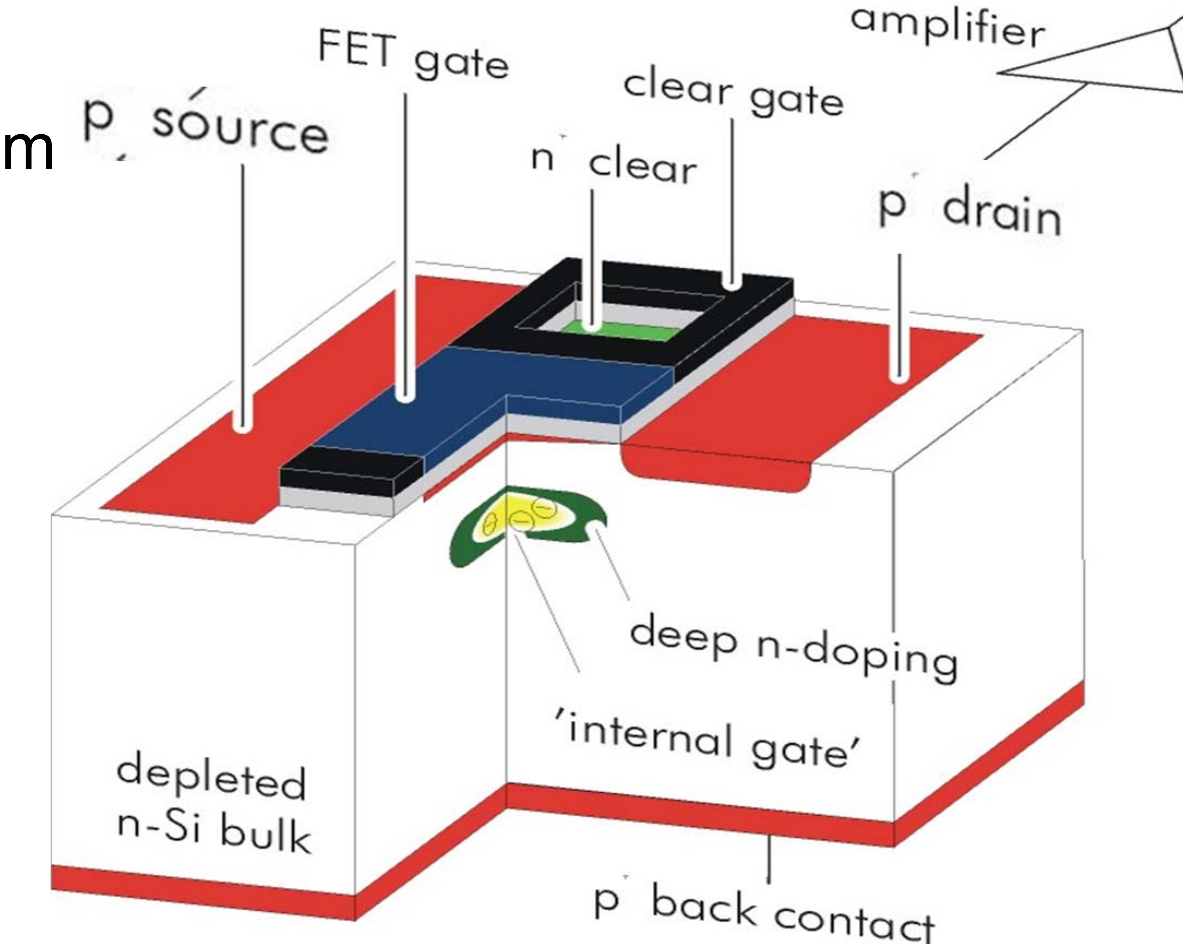
p-channel FET on a completely depleted bulk invented at MPI, produced at HLL

A deep n-implant creates a potential minimum for electrons under the gate (“internal gate”)

Signal electrons accumulate in the internal gate and modulate the transistor current (g_q ~ 400 pA/e^-)

Accumulated charge can be removed by a clear contact (“reset”)

Depleted p-channel FET



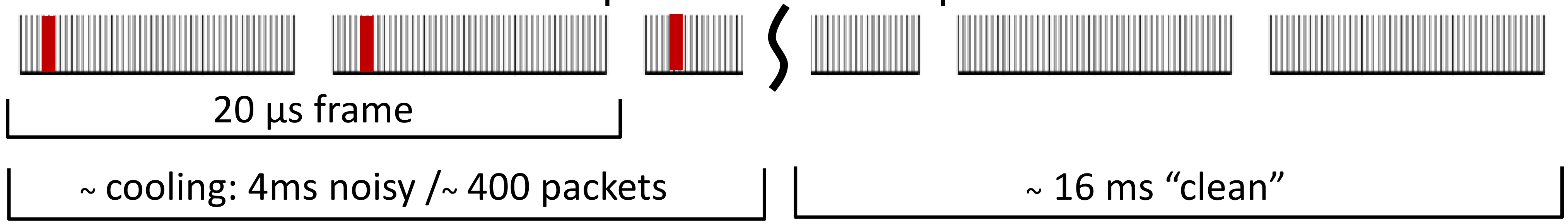
Fully depleted: → large signal, fast signal collection

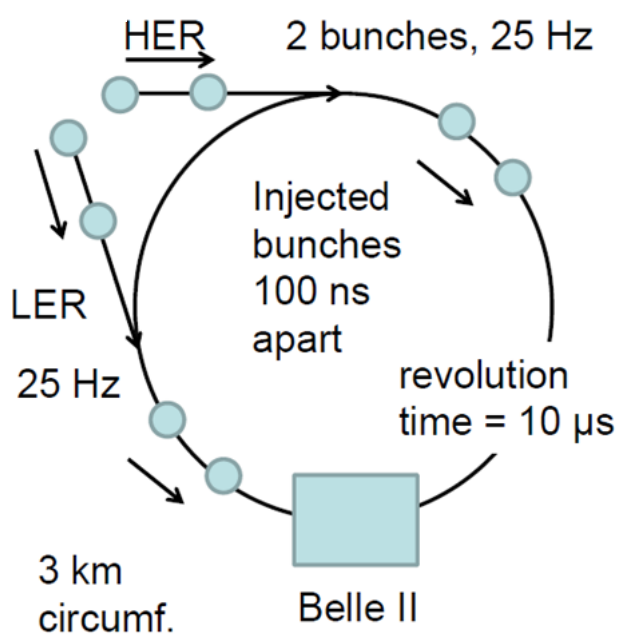
Low capacitance, internal amplification → low noise

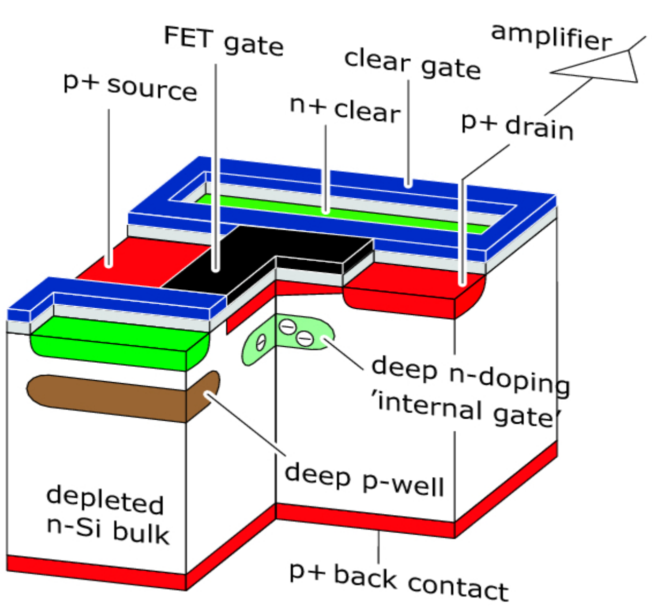
Transistor on only during readout: → low power

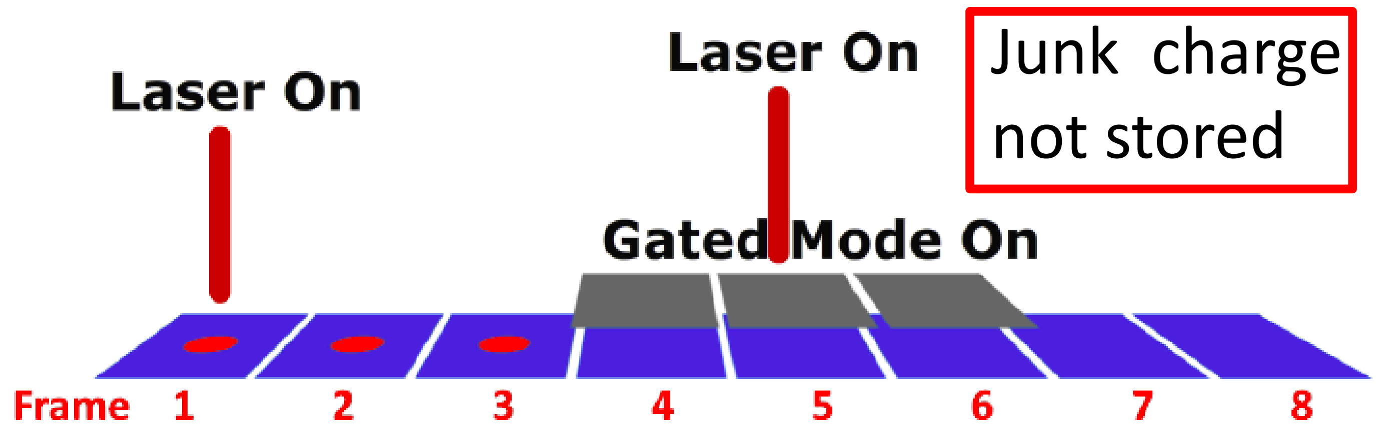
PXD Gated Mode Operation

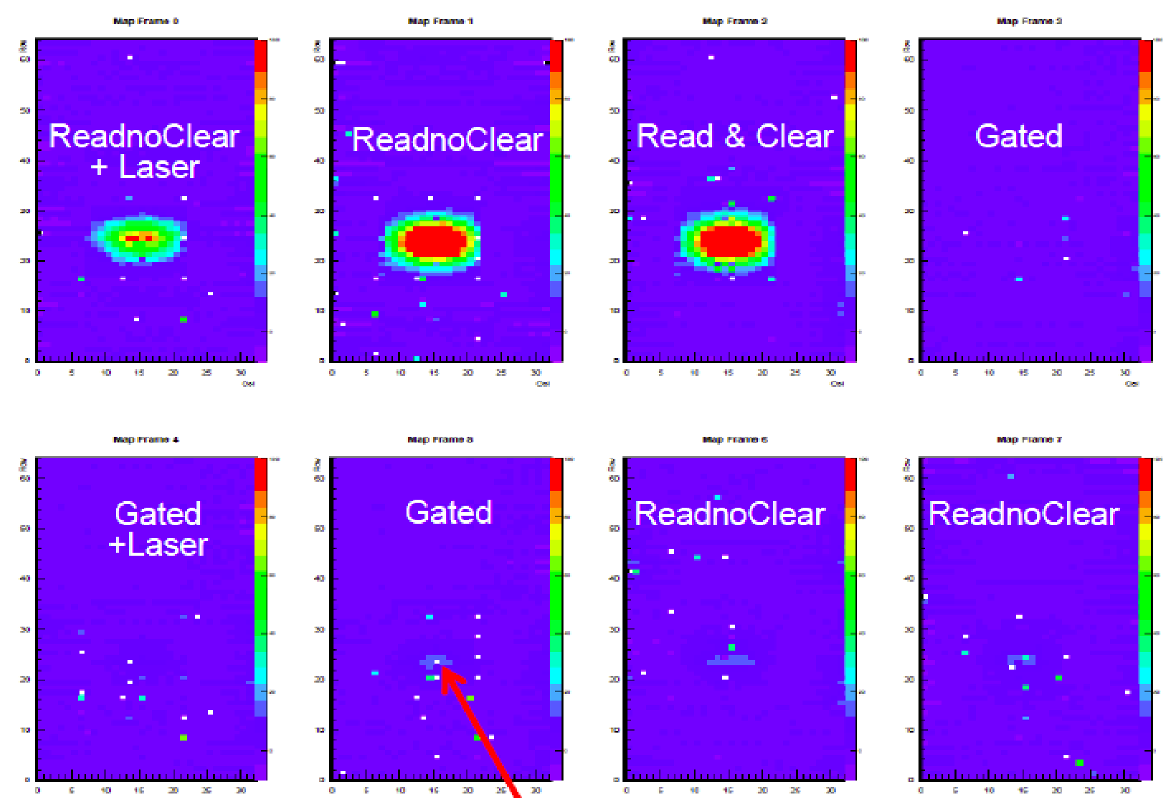
SuperKEKB bunch pattern











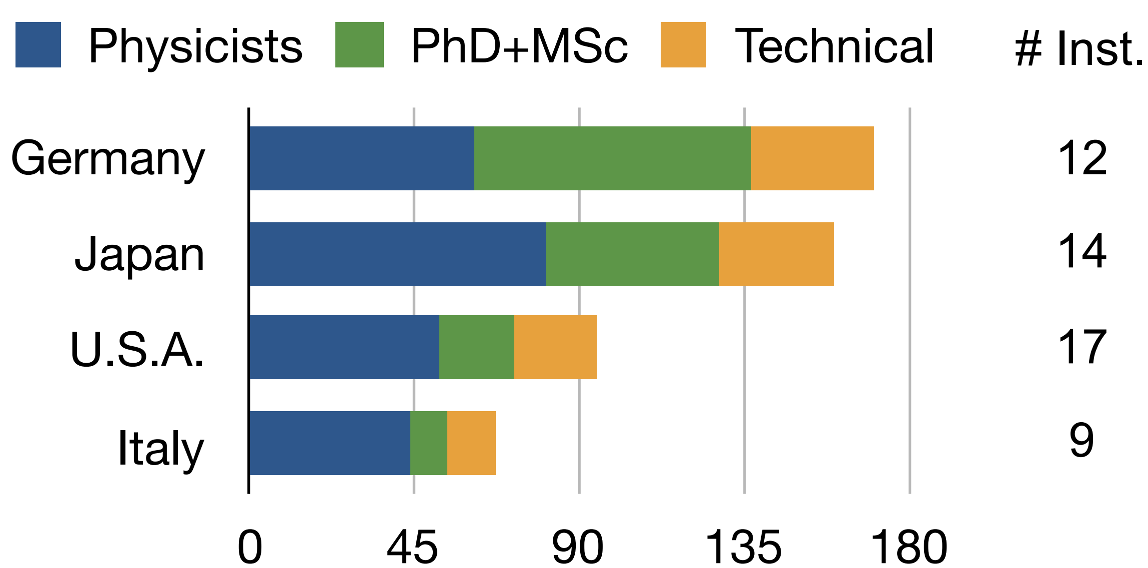
- Laser 1μs, 800mV

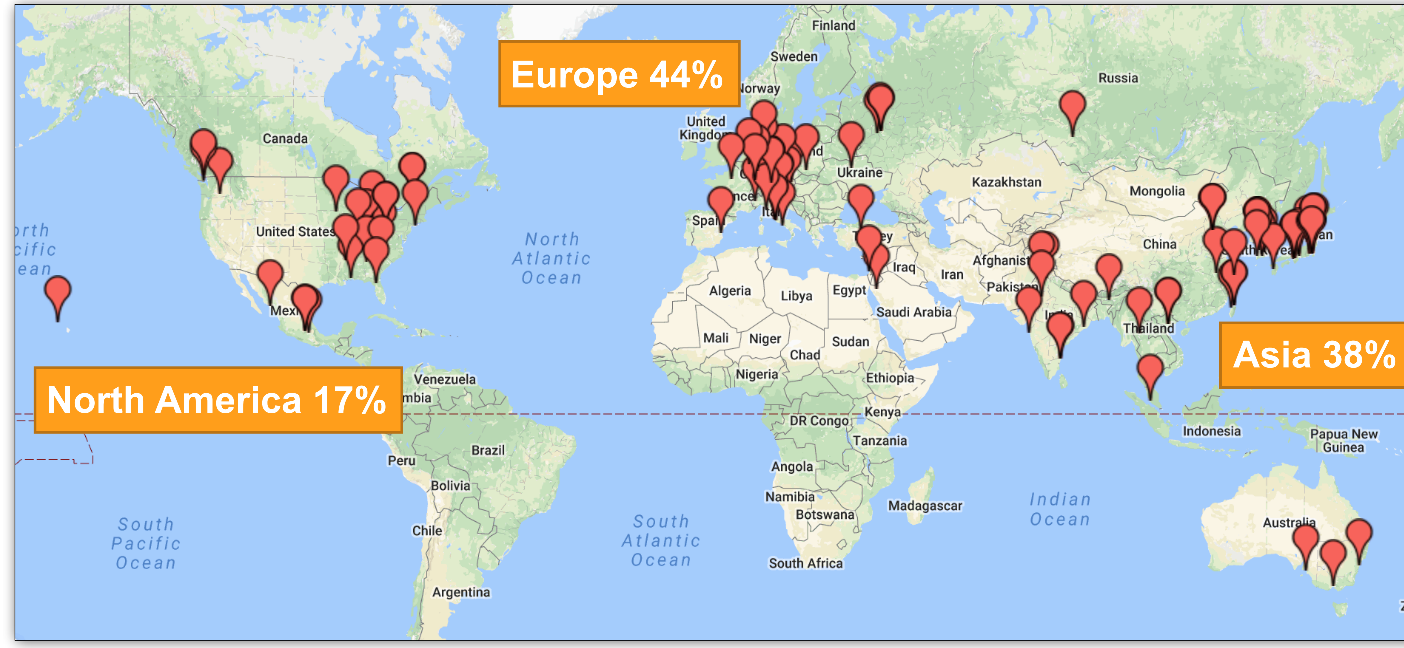
spot contours since rows sensitive for 100ns

Belle II Collaboration

860 members from 113 institutions in 26 countries

Four largest countries by members / institutes





universitätbonn
DESY
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
UNIVERSITÄT HEIDELBERG
MPG HLL
JÜLICH
KIT
LMU
Max-Planck-Institut für Physik
Technical University of Munich TUM

German Belle II institutions

Role of DESY within Germany and beyond

- Facilitating VXD commissioning, installation and integration
  - Test beam facility
  - Helmholtz detector lab (PERSY set-up)
- Acting as computing hub
  - Grid & NAF at DESY
  - 50% of German share as *Raw & Regional Data Center*
  - Migration of Belle II collaborative tools to DESY in 2016/17

Trigger Rates at Design Luminosity 8x10^{35} cm^{-2}s^{-1}

The total cross sections and trigger rates at the goal luminosity of $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for several physical processes of interest are listed in Table 12.1. Samples of Bhabha and $\gamma\gamma$ events will be used to measure the luminosity and to calibrate the detector responses. Since the Bhabha and $\gamma\gamma$ cross sections are very large, these triggers are pre-scaled by a factor of 100 or more; this is straightforward due to their distinct signatures.

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\mathrm{lab}} \geq 17°$)	44	350 $^{(a)}$
$\gamma\gamma$ ($\theta_{\mathrm{lab}} \geq 17°$)	2.4	19 $^{(a)}$
2γ processes ($\theta_{\mathrm{lab}} \geq 17°$, $p_t \geq 0.1\,\mathrm{GeV}/c$)	~ 80	~ 15000
Total	~ 130	~ 20000

$^{(a)}$ rate is pre-scaled by a factor of 1/100

How to increase Luminosity

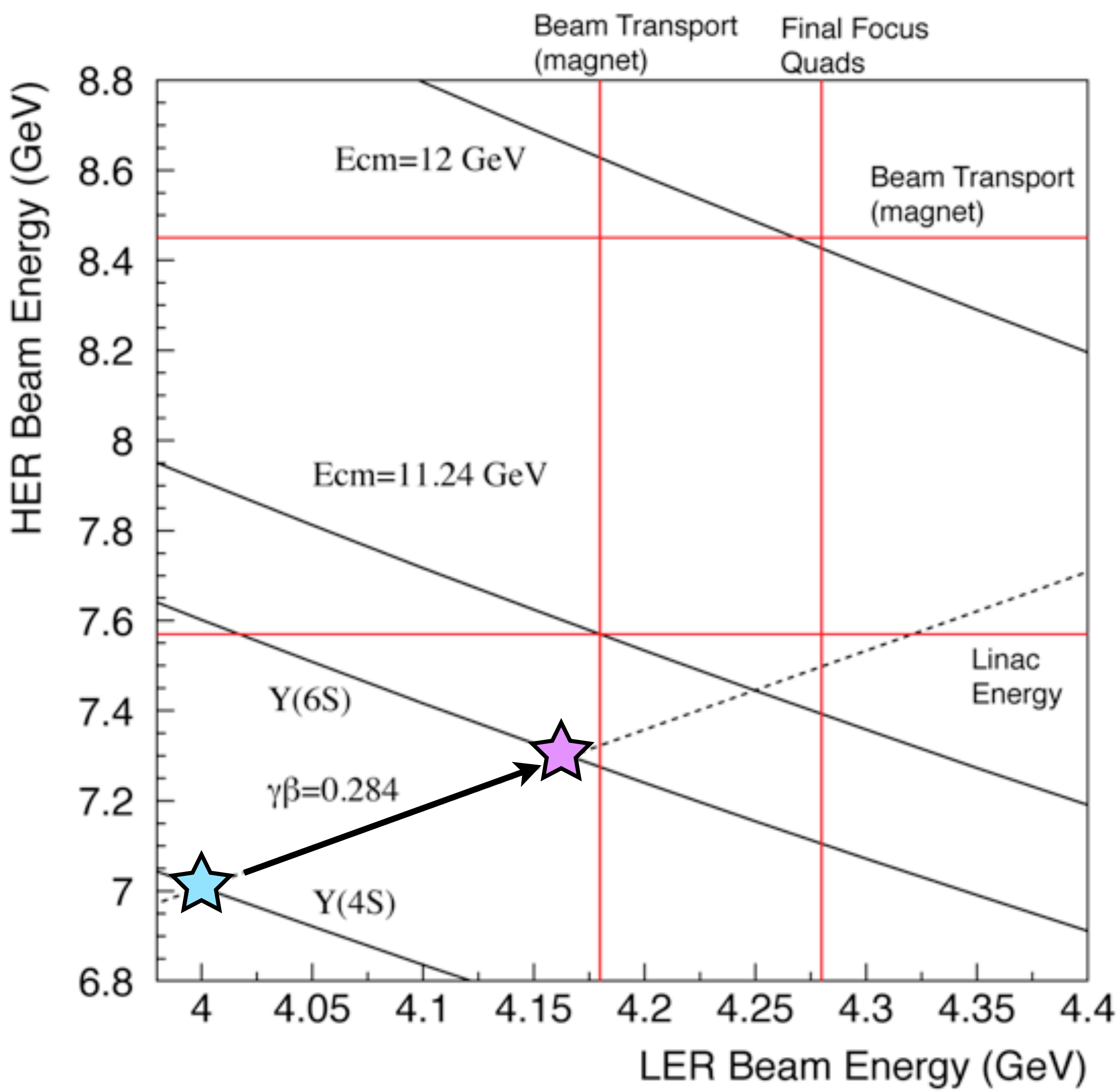
- To keep hourglass limit, we HAVE TO scale…
  - Luminosity: $L \rightarrow N\ L$
  - $\beta_x^* \rightarrow N^{-1}\ \beta_x^*$
  - $\beta_y^* \rightarrow N^{-1}\ \beta_y^*$
  - $\varepsilon_x \rightarrow N^{-1}\ \varepsilon_x$
  - $\varepsilon_y \rightarrow N^{-1}\ \varepsilon_y$

Required to scale $\sigma^*_{z,eff}$

By ε_x scaling, lattice coupling is kept.

- To keep final focus system chromaticity, QCS SHOULD be…
  - Distance from IP $L^* \rightarrow N^{-1}\ L^*$
  - Effective length $L_{eff} \rightarrow N^{-1}\ L_{eff}$
  - Radius $r \rightarrow N^{-1}\ r$ (Typical beam size at QCS)
  - Field gradient $G \rightarrow N^2\ G$
  - Maximum quadrupole field $B_{max} \rightarrow N^1\ B_{max}$
  - Excitation power $nI \rightarrow nI$
  - Current density $nI/A \rightarrow N^2\ nI/A$
  - On beam solenoid field map $Bs(z) \rightarrow Bs(N^1\ z)$

CM Energy Reach



Start from Y(4S) operation at Phase-2

10 fb^{-1} at Y(6S) is requested by Belle II.

~20 days
(80 % efficiency with 8×10^{33})

↕

5 months operation at Phase-2

E_{CM} max with constant γβ=0.284 is ~ 11.1 GeV

Belle II DAQ System