# Future Experiments on CP Violation

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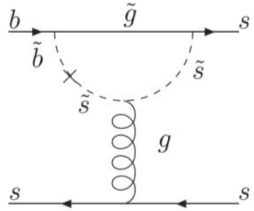
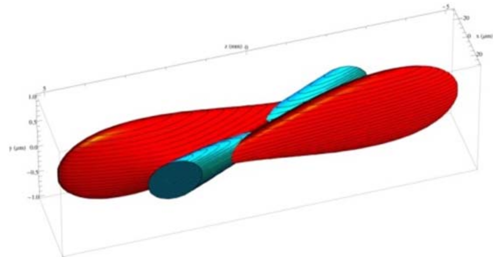
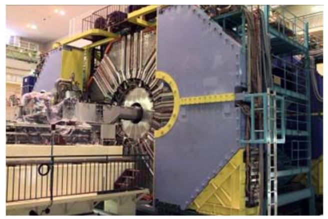
- Physics Motivation




- LHCb Upgrade



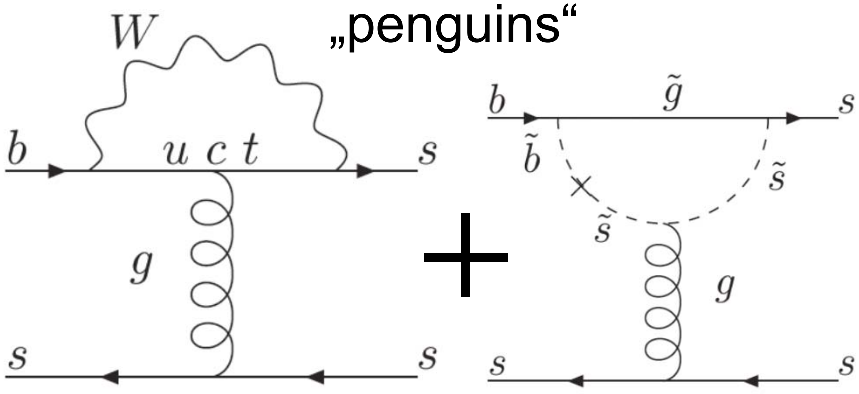
- A new generation of B-Factories: SuperB and SuperKEKB



- Conclusions

# New Physics at the Loop Level ....

„penguins“




SM NP

NP in CPV asymmetries:

$$B \to J/\psi K_S \longleftrightarrow B \to \phi K_S$$

Principle:

Deviation of observable from the SM prediction signals NP

virtual particles in the loop reveal their existence $\longrightarrow \Lambda_{NP}$

Rare Decays of *B* mesons:

| | SM pred. |
|---|---|
| $B \to X_{s,d}\gamma$ | $\mathcal{O}\left(10^{-4}\right)$ |
| $B \to X_{s,d}l^+l^-$ | $\mathcal{O}\left(10^{-6}\right)$ |
| $B \to X_d\nu\overline{\nu}$ | $\mathcal{O}\left(10^{-6}\right)$ |
| $B_s \to l^+l^-$ | $\mathcal{O}\left(10^{-9}\right)$ |

leptons:

$$\left.\begin{array}{l}\tau \to \mu\gamma \\ \tau \to \mu\mu\mu \\ \tau \to \mu\eta\end{array}\right\}$$

NP could make these decays possible

**need precision (statistics) to challenge the SM**

# LHCb vs Super Flavor Factories

**+ LHCb**

large samples (but low efficiencies)

$B_s$ oscillations

$B_c$ , bottom baryons

$B^0_{s,d} \to \mu\mu$

$B \to J/\psi K_S$

$D^0 \to K^+\pi^-, K^+K^-$

**+ Super B Factories**

generally more final states
esp. with photons, missing energy

rare decays, such as

$B^+ \to l^+\nu, B^+ \to K^+\nu\overline{\nu}$

$b \to s\gamma, b \to sl^+l^-$

inclusive processes

$B \to J/\psi\phi, \pi\pi, \rho\pi, \rho\rho, \pi\pi\pi$

$D^0\overline{D}^0$ mixing

LHCb and Super B Fact. will run concurrently. → largely complementary

# Energy reach of the Super Flavor Factories

No flavor structure for NP: $\Lambda_{NP} \geq 100 - 1000 \ \mathrm{TeV}$ „NP flavor problem“

Look for FCNC processes (highly suppressed in SM):

~2 OoM increase

$$\int \mathcal{L} dt = 50 \ \mathrm{ab}^{-1}$$

Assumption on NP flavor sector:
Minimal Flavor Violation (MFV)

Measure, e.g., the decay rates:

$B^0 \rightarrow X_s^0 l^+ l^-$ (inclusive)

$B^0 \rightarrow K^0 l^+ l^-$ (exclusive)

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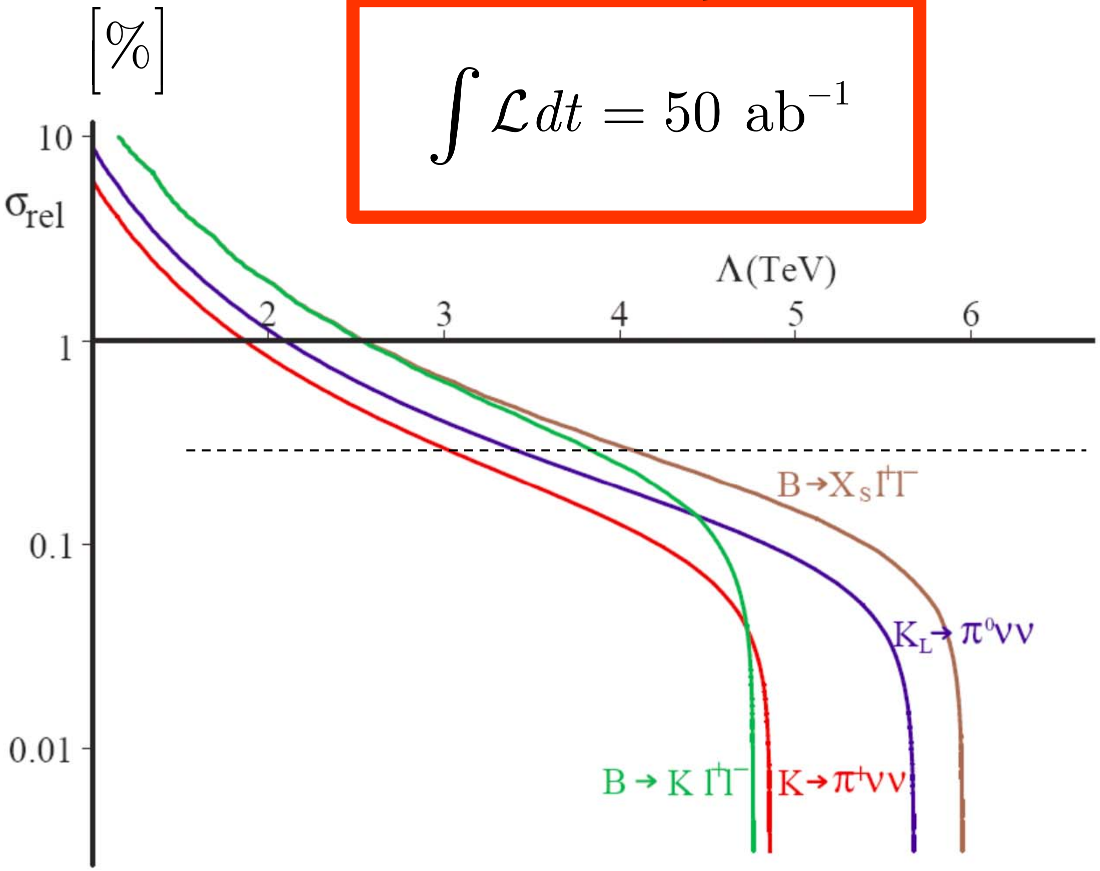
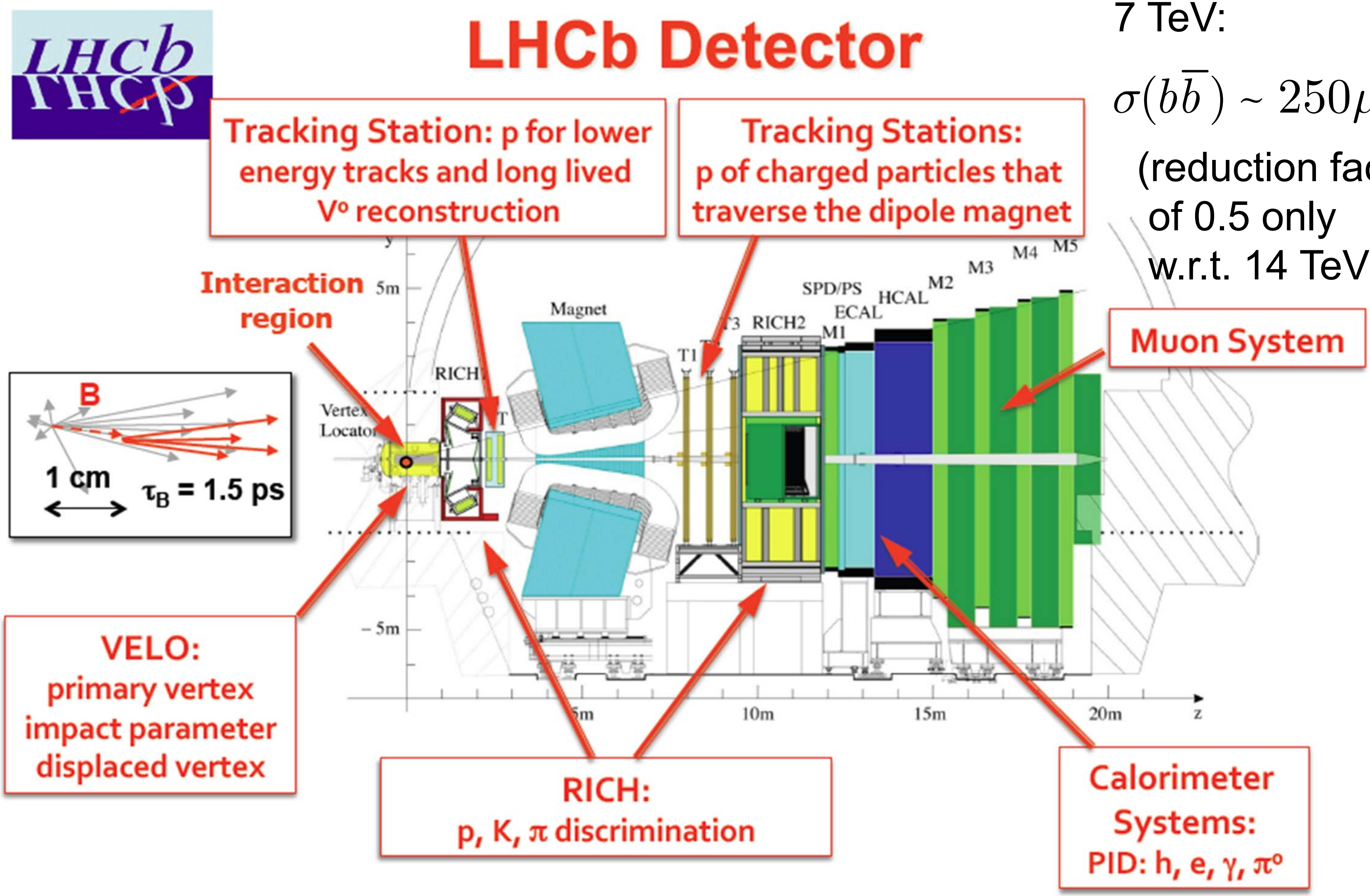


# Upgrade Program for LHCb

7 TeV:

$$\sigma(b\bar{b}) \sim 250\mu b$$

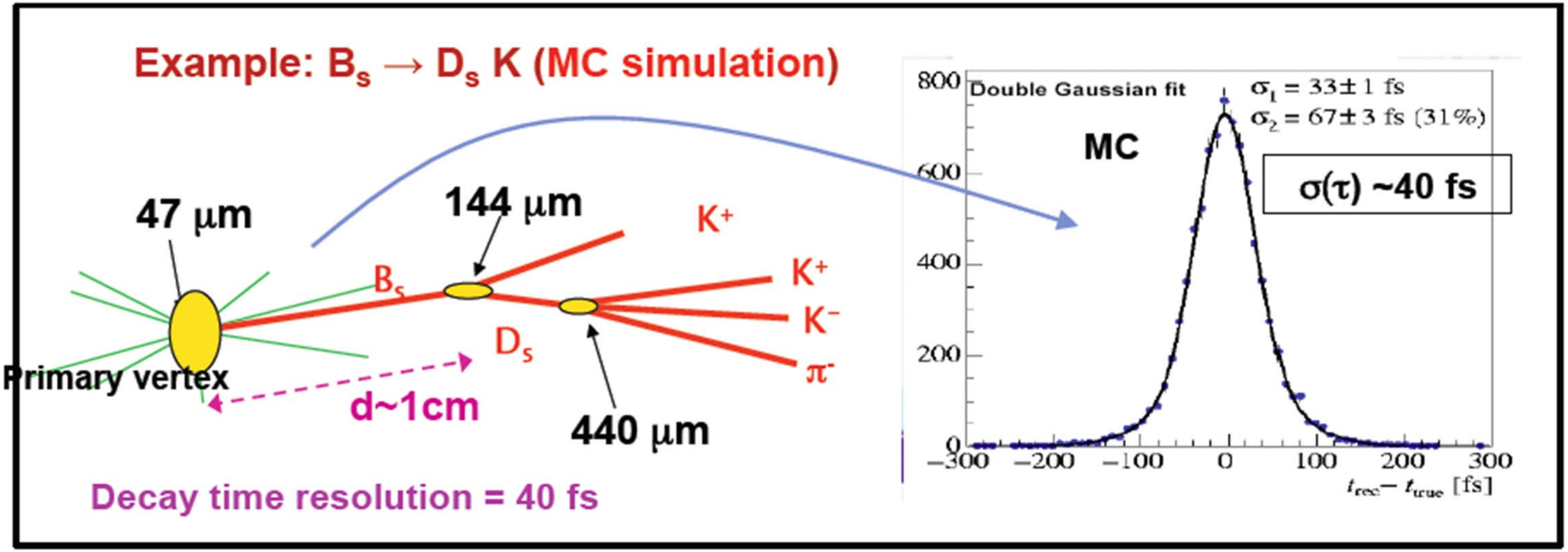
(reduction fact. of 0.5 only w.r.t. 14 TeV)



# LHCb Trigger & DAQ System

Forward spectrometer: huge particle flux even at deliberately reduced lumi @LHCb (operate @ $2x10^{32}$)

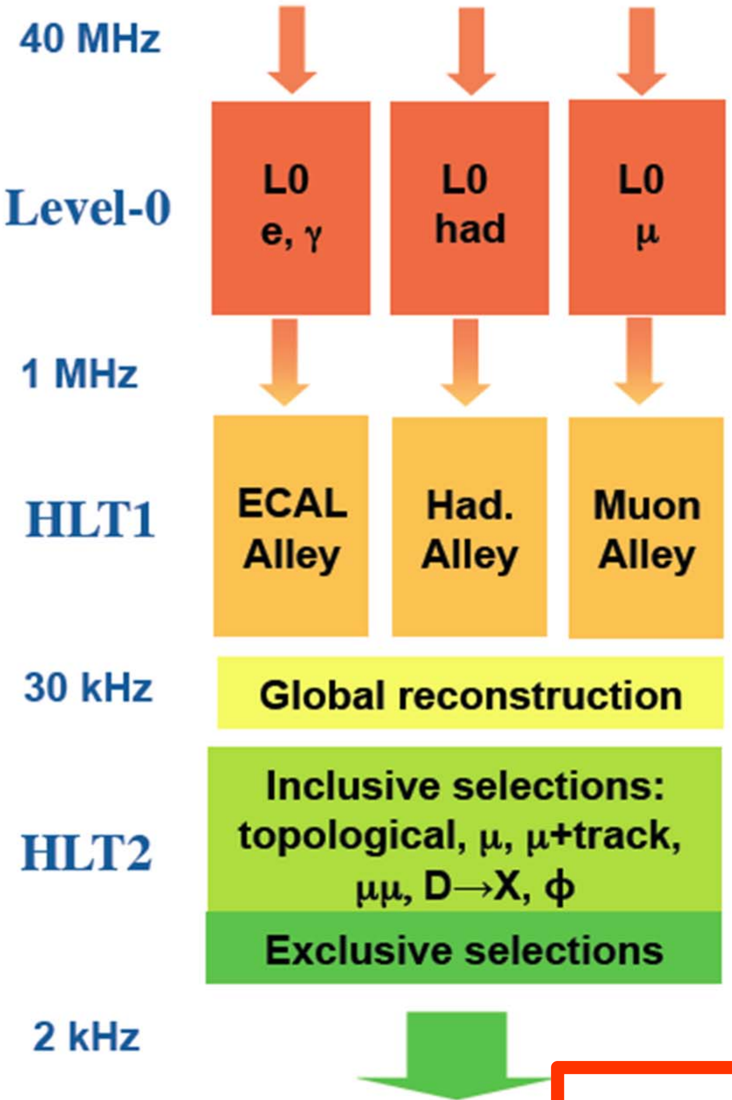
How to survive @ LHC design luminosities:




**Trigger on impact parameter**

**Measurement of decay distance (and then proper decay time)**

# LHCb Trigger & DAQ System Upgrade




Large transverse energy and momentum in calorimeter and muon systems

Associate Level-0 signals with tracks, especially those in VELO displaced from Primary Vertex

Full detector info available for inclusive and exclusive selections

LHC luminosity upgrade planned (2015-2016):

10 x $L_{design}$

Bottlenecks@$2 \times 10^{33}$:

1MHz readout rate, long latency (2.5μs)

Ambitious Solution:

increase R/O to 40MHz, S/W trigger @ 30MHz on CPU farm

Replace VELO & essentially the entire F/E electronics

# Strategies for High Luminosity @ Super BF's

$$\mathcal{L} = \frac{N_+ N_- f}{4\pi\sigma_x\sigma_y} R$$

basic formula for the (instantaneous) luminosity

Accelerator physicists usually like this one better:

stored current

tune shift

$$\mathcal{L} = \frac{\gamma_+}{2er_e}\left(1+\frac{\sigma_y}{\sigma_x}\right)\left(\frac{I_+\xi_{y,+}}{\beta_y}\right)\left(\frac{R}{R_{\xi_y}}\right)$$

vertical beta function at IP

$R_{,\xi}$ : reduction factors (geometrical)

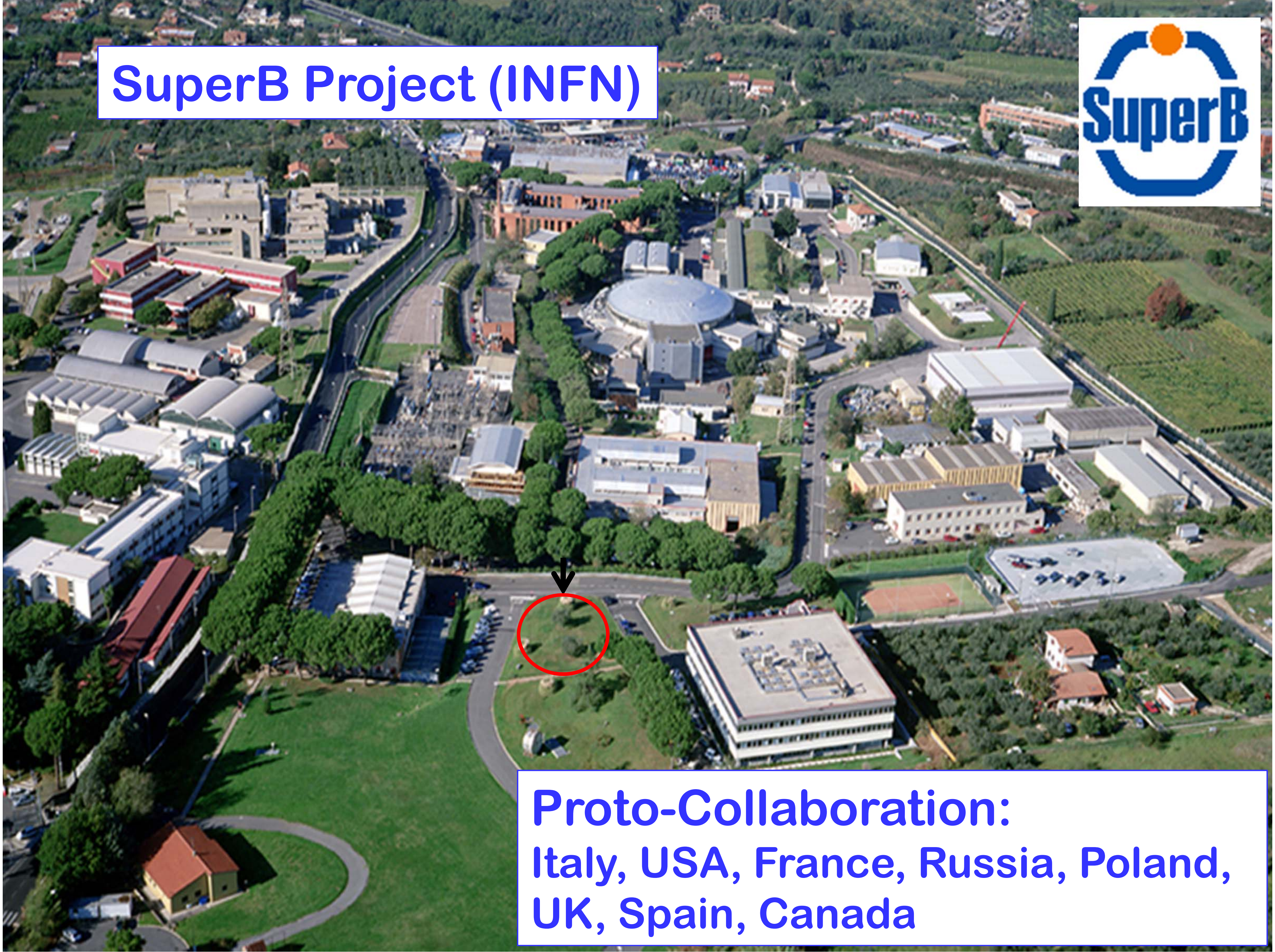
$\sigma_{x,y}$: beam spot size at IP

beam-beam parameter (or tune shift)

$$\xi_{y,+} = \frac{r_e}{2\pi\gamma_+}\left(\frac{\beta_y N_-}{\sigma_x\left(\sigma_x+\sigma_y\right)}\right)R_{\xi_y}$$

$$\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$

beam emittance (need damping ring(s))

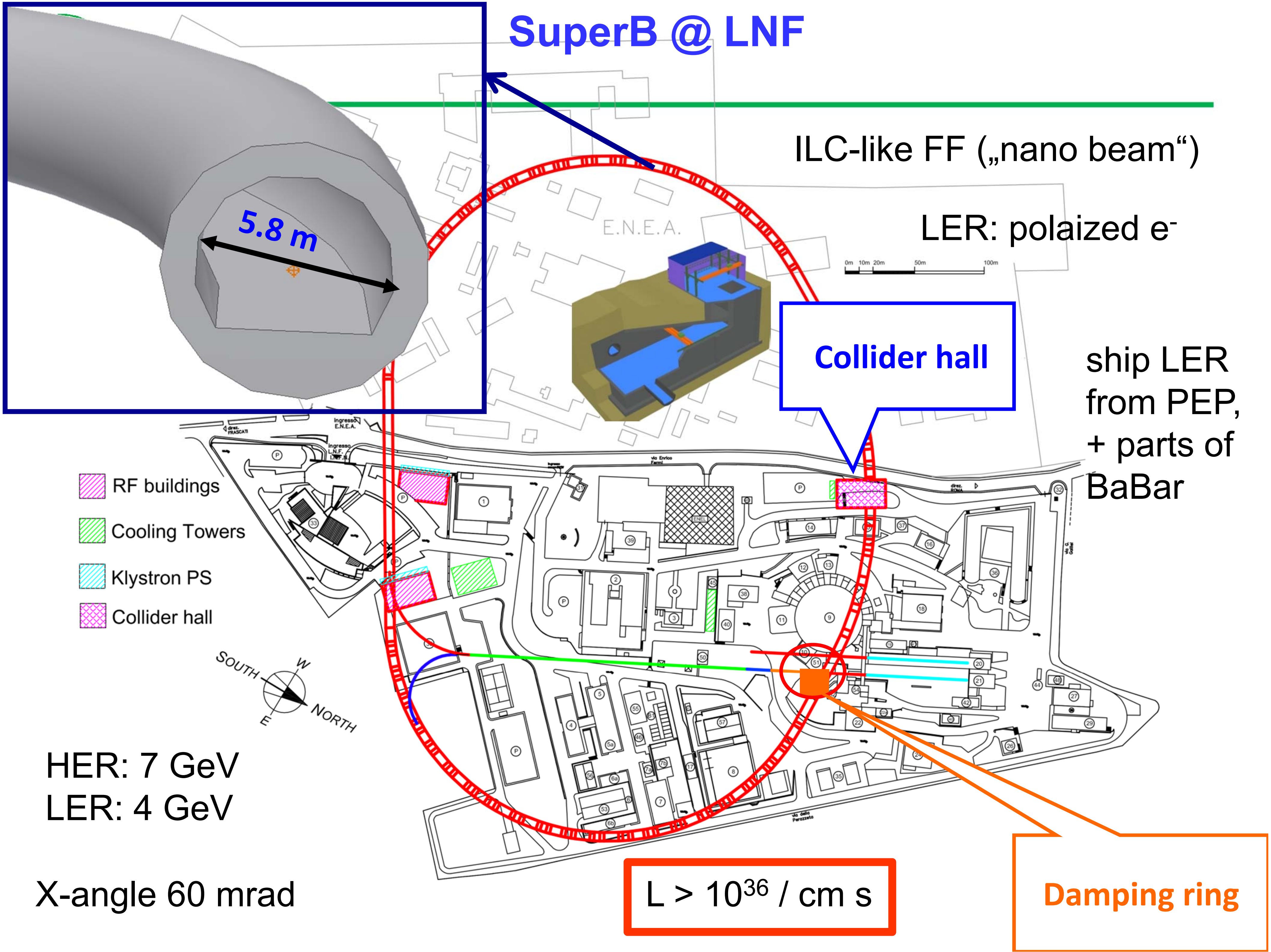

SuperB Project (INFN)
SuperB
Proto-Collaboration:
Italy, USA, France, Russia, Poland,
UK, Spain, Canada

# SuperB @ LNF

ILC-like FF („nano beam“)

LER: polaized e$^-$

ship LER from PEP, + parts of BaBar

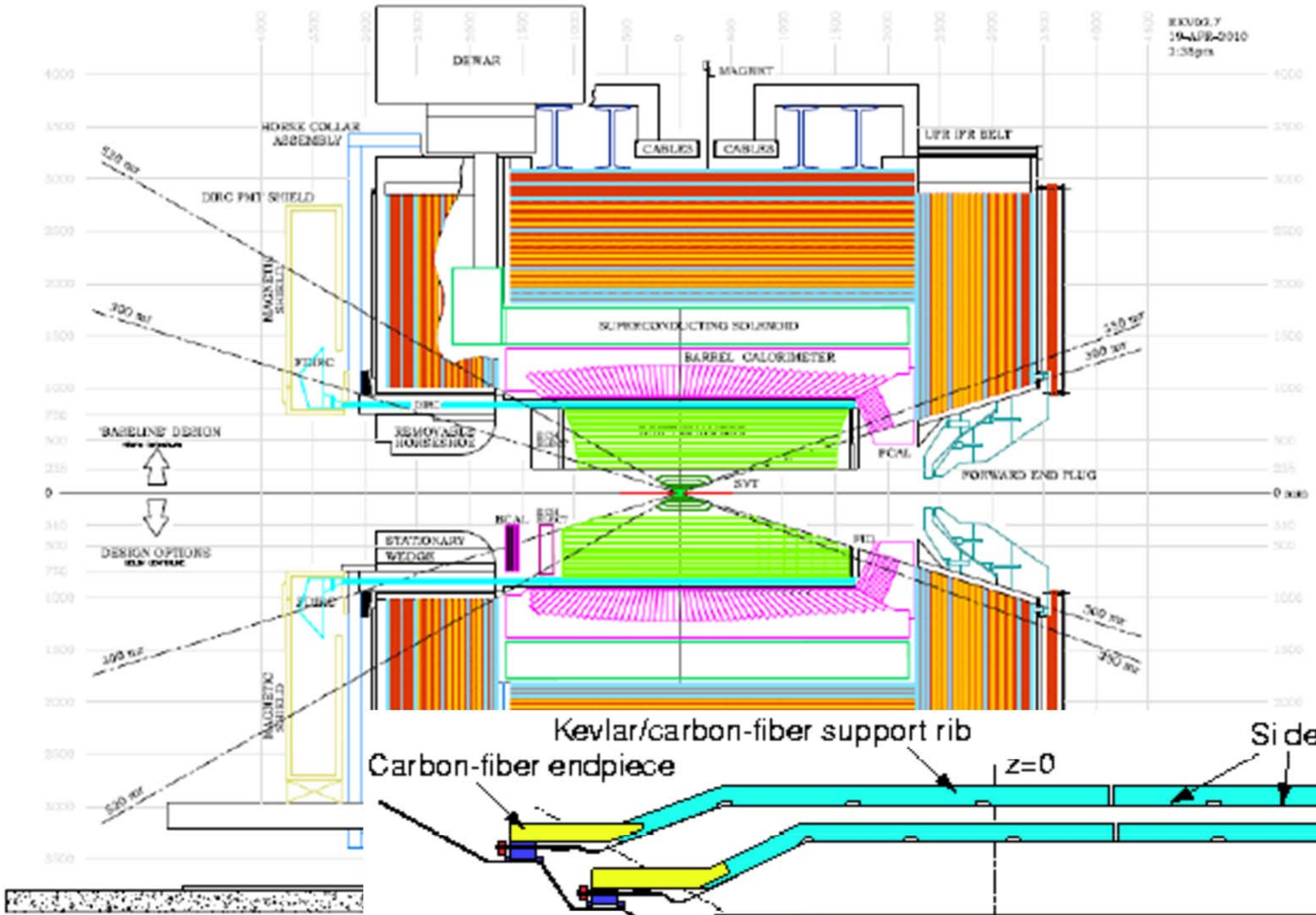



HER: 7 GeV
LER: 4 GeV

X-angle 60 mrad

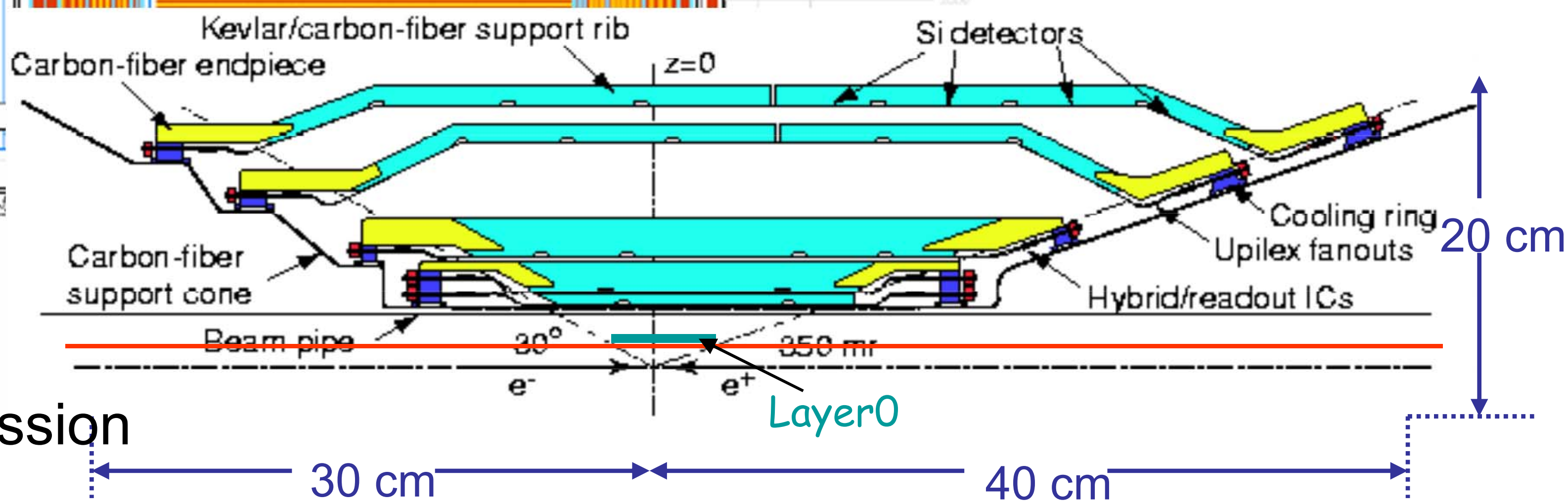
L > $10^{36}$ / cm s

# SuperB Detector




Some main components from BaBar (magnet, yoke ..)

New:
Drift Chamber,
PID (RICH),
EM calorimeter
(Lyso or CsI ?)




New SVT:
5 + 1 layers
L0 under discussion

# SuperB Project Status

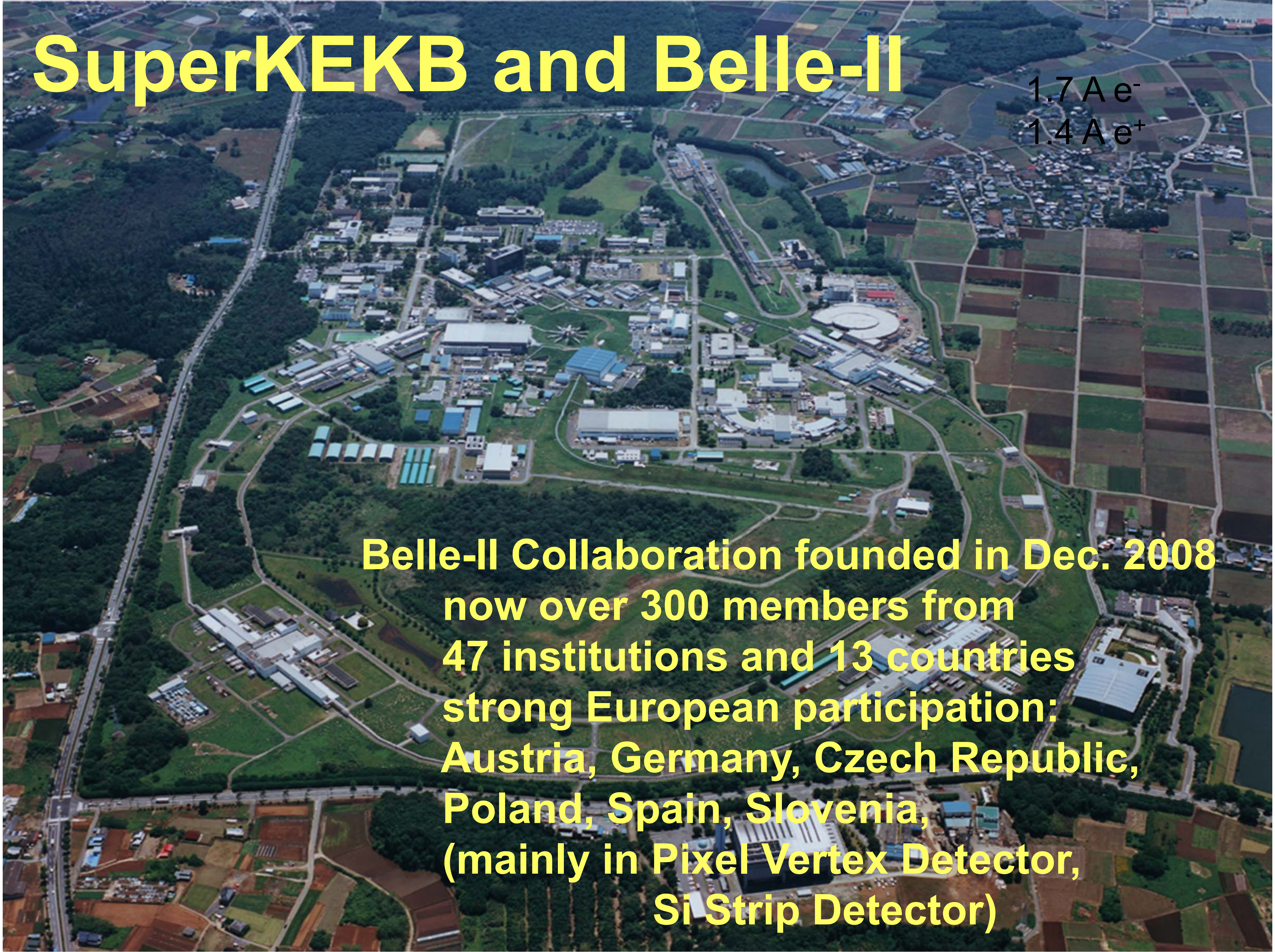
## Toward green light

- The project is the first "flagship project" of the new national research plan
- The project has been mentioned as a reciprocity condition in a russian italian agreement on ignitor (nuclear fusion)

- A formal commitment with INFN for the project with the declaration of some available budget in the current year is expected
- This commitment will set the start of the project

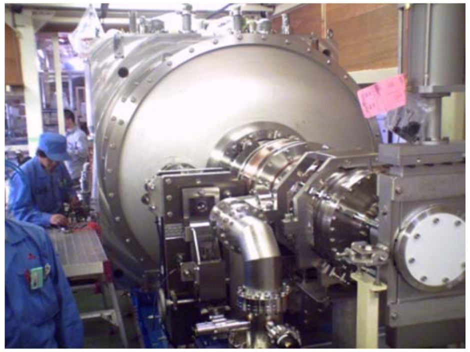
Foil from recent presentation by M. Giorgi

# SuperKEKB and Belle-II



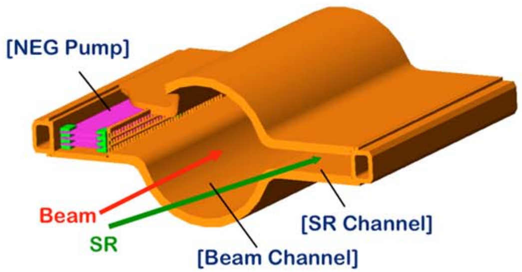

**Belle-II Collaboration founded in Dec. 2008**

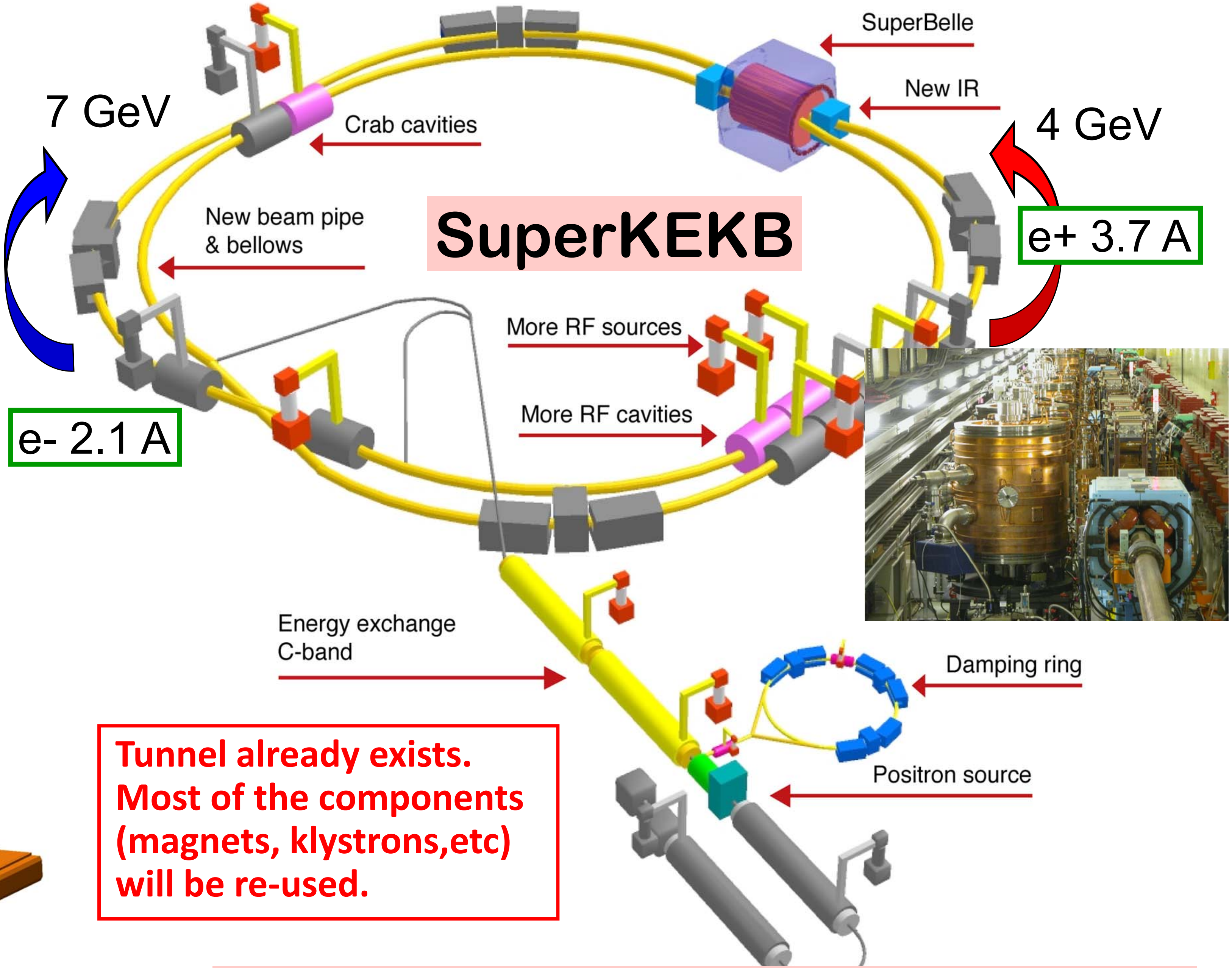
now over 300 members from
47 institutions and 13 countries
strong European participation:
Austria, Germany, Czech Republic,
Poland, Spain, Slovenia,
(mainly in Pixel Vertex Detector,
Si Strip Detector)



Crab cavity (High-Current Option)

Upgrade of superconducting cavities




**Tunnel already exists.**
**Most of the components (magnets, klystrons,etc) will be re-used.**

# Goal: reach > 8 × $10^{35}$ $cm^{-2}s^{-1}$

# Comparison of Options

| | KEKB Design | KEKB Achieved (): with crab | SuperKEKB High-Current Option | SuperKEKB Nano-Beam Option |
|---|---|---|---|---|
| $\beta_y^*$ (mm)(LER/HER) | 10/10 | 6.5/5.9 (5.9/5.9) | 3/6 | 0.21/0.37 |
| $\varepsilon_x$ (nm) | 18/18 | 18/24(15) | 24/18 | 2.8/1.6 |
| $\sigma_y$($\mu$m) | 1.9 | 1.1 (0.84) | 0.85/0.73 | 0.070/0.052 |
| $\xi_y$ | 0.052 | 0.108/0.056 **(0.101/0.096)** | 0.3/0.51 | 0.07/0.07 |
| $\sigma_z$ (mm) | 4 | ~ 7 | 5(LER)/3(HER) | 6 |
| $I_{beam}$ (A) | 2.6/1.1 | 1.8/1.45 (1.62/1.15) | 9.4/4.1 | 3.70/2.13 |
| $N_{bunches}$ | 5000 | 1387 (1585) | 5000 | 2778 |
| Luminosity ($10^{34}$ $cm^{-2}$ $s^{-1}$) | 1 | 1.76 **(2.11)** | 53 | 80 |

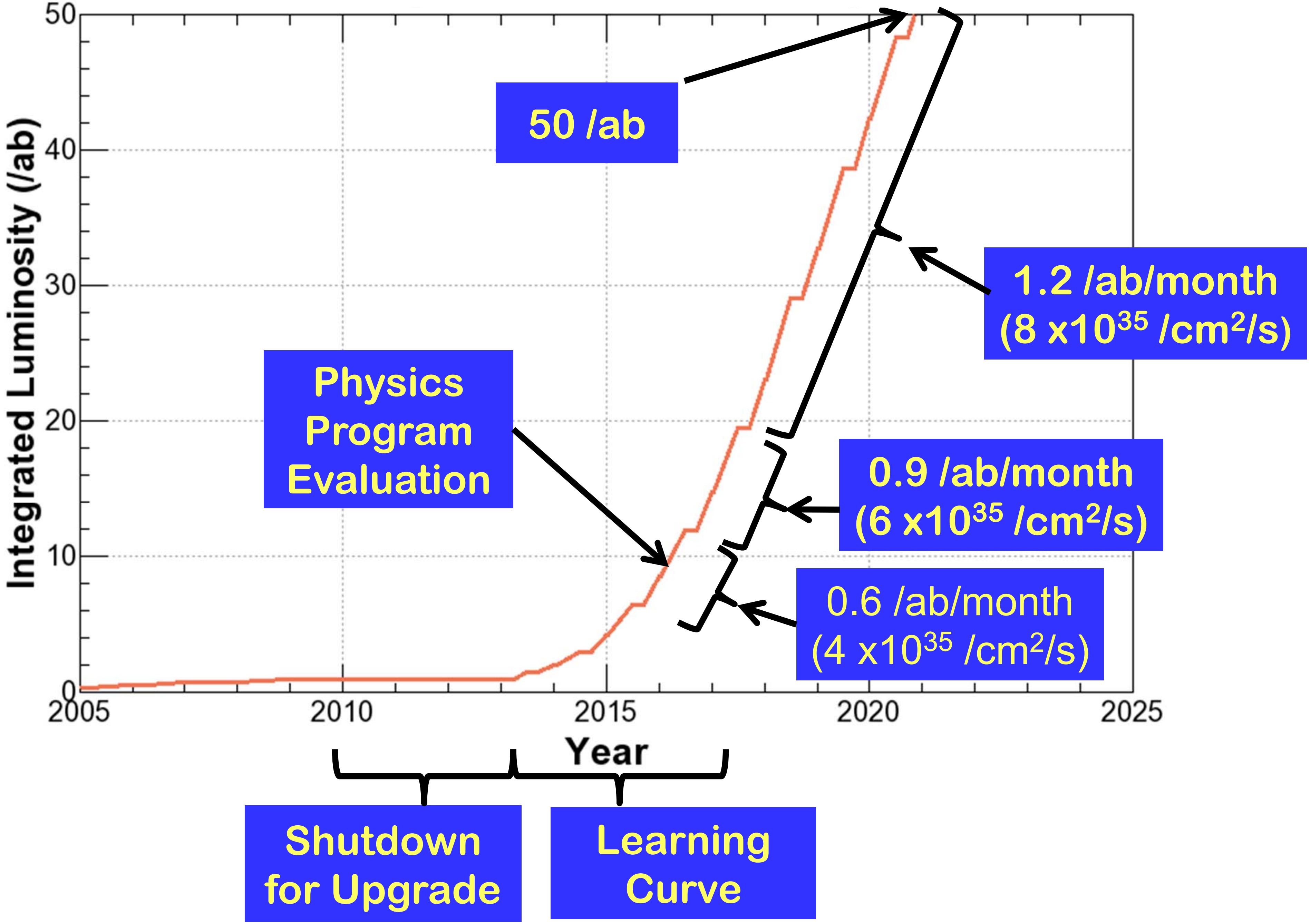
High Current Option includes crab crossing and travelling focus.
Nano-Beam Option does not include crab waist yet

Nano-opt chosen

# Major Machine Components to Upgrade

- New ante-chamber beam pipes for both rings
  - 3km x 2 in total
  - Al/Cu for LER/HER
  - Mitigation techniques for suppression of electron cloud
- New IR optics
  - New superconducting/permanent magnets around IP
  - Optimization of the compensation solenoid
- Additional normal magnets to reduce emittance
  - Replace dipoles & change the wiggler layout for LER
- New HER arc lattice
- More precise magnet setting ⇔ power supplies
- Rearrangement of existing ARES cavities with additional power sources
- New positron damping ring and new positron target
- New RF gun for electrons with reduced emittance

# Expected Luminosity Development



# Funding Situation of the Machine

KEKB upgrade plan has been approved

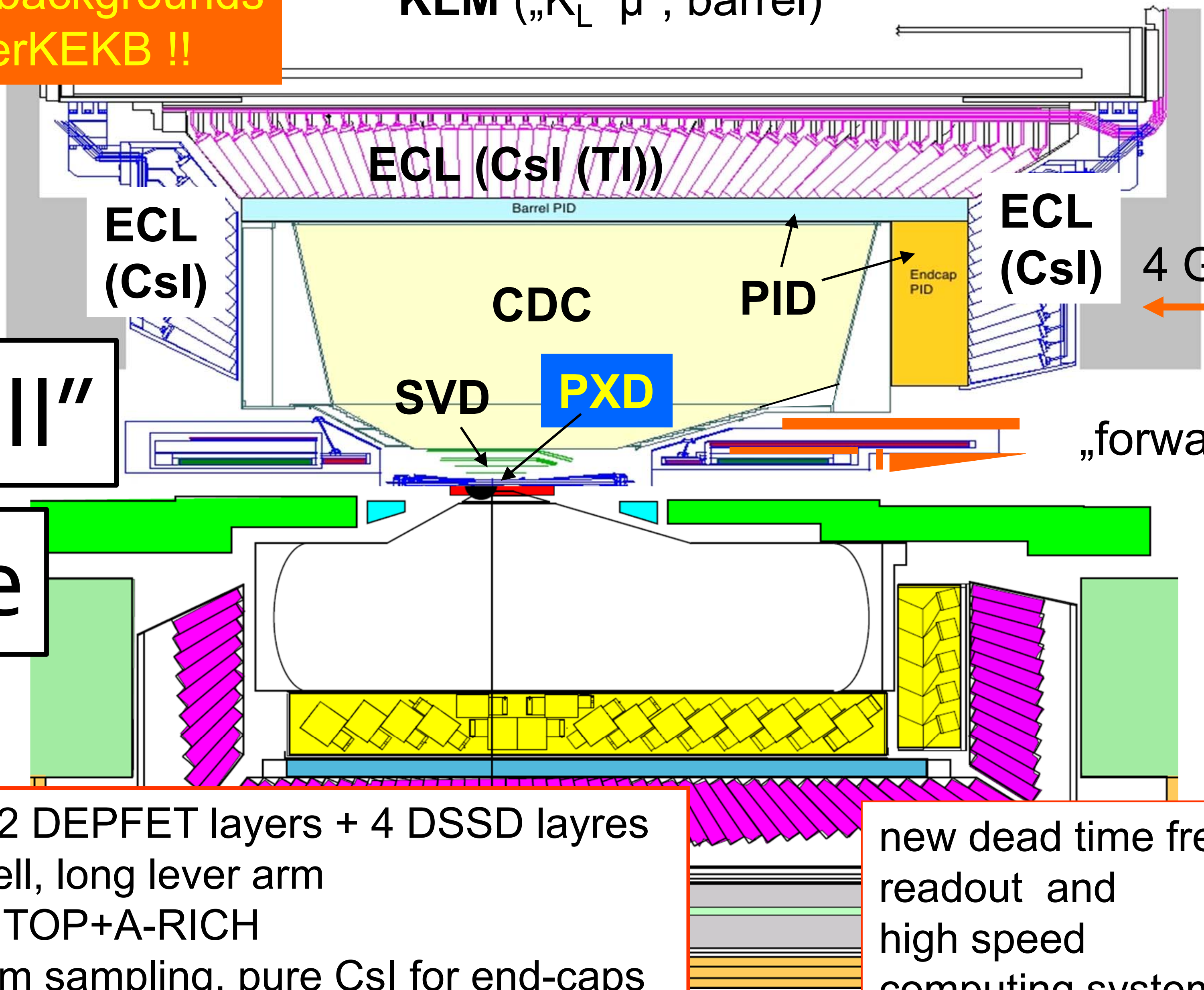
June 23, 2010 High Energy Accelerator Research Organization (KEK)

The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx $110M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new "Very Advanced Research Support Program" of the Japanese government.

"We are delighted to hear this news," says Masanori Yamauchi, former spokesperson for the Belle experiment and currently a deputy director of the Institute of Particle and Nuclear Studies of KEK. "This three- year upgrade plan allows the Belle experiment to study the physics from decays of heavy flavor particles with an unprecedented precision. It means that KEK in Japan is launching a renewed research program in search for new physics by using a technique which is complementary to what is employed at LHC at CERN."

# Detector for SuperKEKB: Belle-II

Much higher backgrounds from SuperKEKB !!

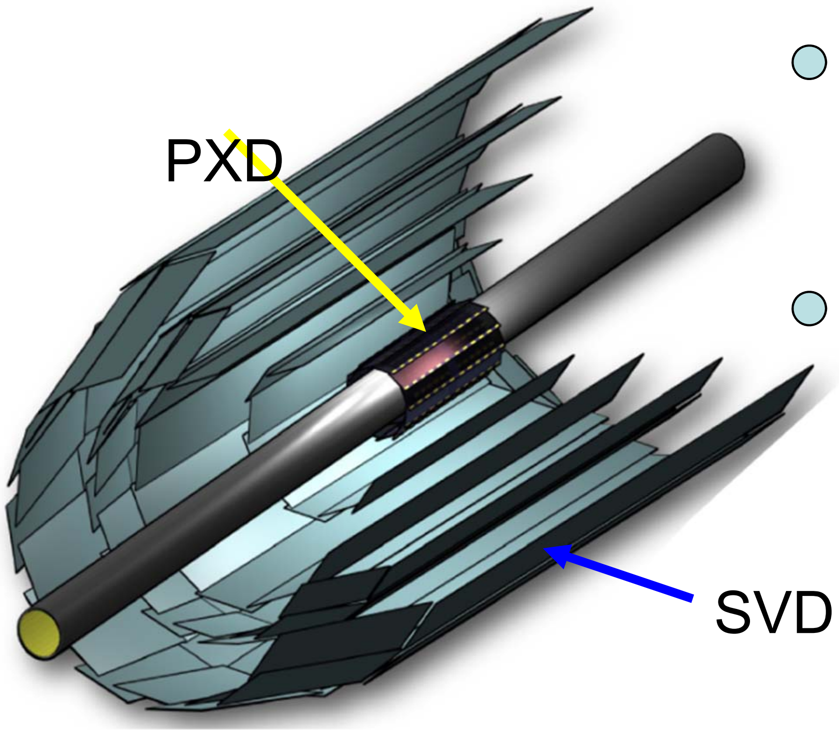



SVD: 4 lyr -> 2 DEPFET layers + 4 DSSD layres
CDC: small cell, long lever arm
ACC+TOF -> TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC -> Scintillator +SiPM (end-caps)

new dead time free readout and high speed computing systems

# Silicon Tracking System @ Belle-II

Nano beam option: 1 cm radius of beam pipe

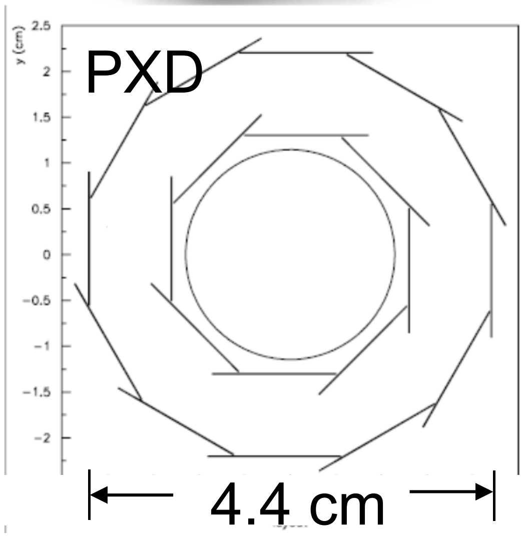



„PXD“

- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 µm (!), pixel size ~50 x 50 µm²

- 4 layer Si strip detector (DSSD) ← „SVD“
  (R = 3.8, 8.0, 11.5, 14.0 cm)

Significant improvement in z-vertex resolution

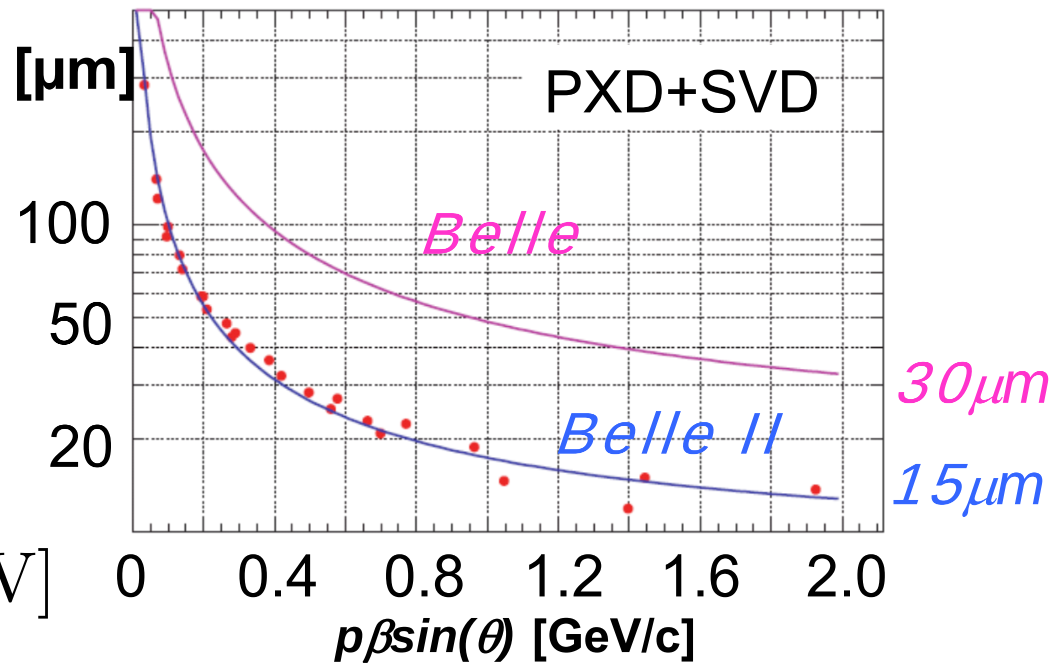



$$\sigma = a + \frac{b}{p\beta \sin^{5/2}\theta}$$

Belle II:

$$a = 8.5\,[\mu m]$$

$$b = 9.6\,[\mu m\,\mathrm{GeV}]$$



# Conclusions

- „New Physics“ needed to explain the observed matter-antimatter asymmetry → new sources of CP violation
- A new generation of B factories planned to search for NP, complementary to the LHC program. LHCb plans for trigger upgrade
- At KEK (Japan), the SuperKEKB project is well under way:
  Strong contribution from Europe (pixel vertex detector)
  Initial funding by Japanes Gorvernment of 100 M$ granted:

  → „Green Light“ for SuperKEKB

- Plan to have machine and detector ready for data taking by early 2014
- SuperB Project in Frascati under discussion using „nano beams“
  (this scheme was also adopted by SuperKEKB)
  initial funding not yet secured
- Excellent prospects for flavor physics during the LHC era

# Backup

# DEPFET Principle

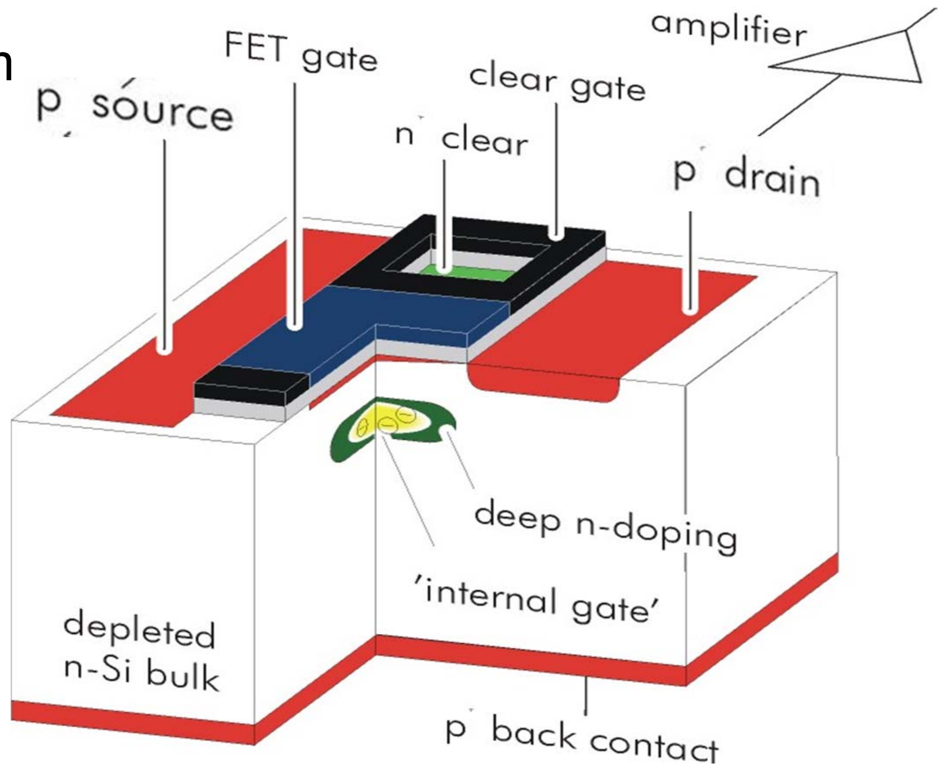
p-channel FET on a completely depleted bulk

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

Complete clear → no reset noise

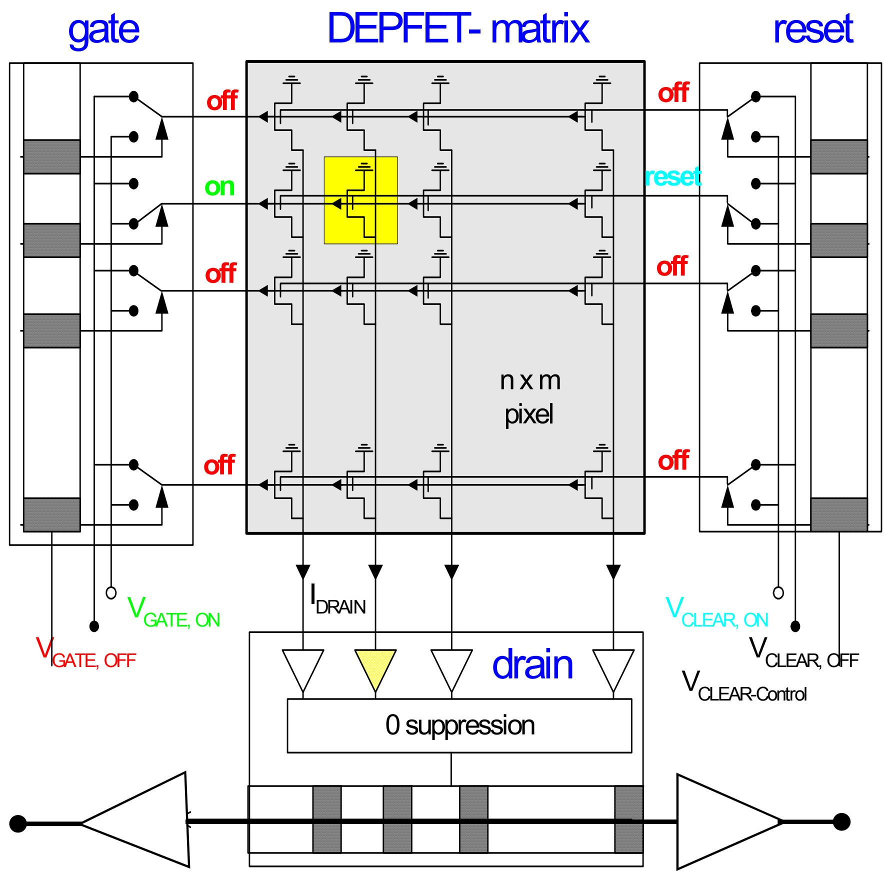
# Array of DEPFETs

**Row wise read-out ("rolling shutter")**

- select row with external gate
  read current,
  clear DEPFET,
  read current again

  → the difference is the signal

- only one row active → low power consumption
- two different auxiliary ASICs needed



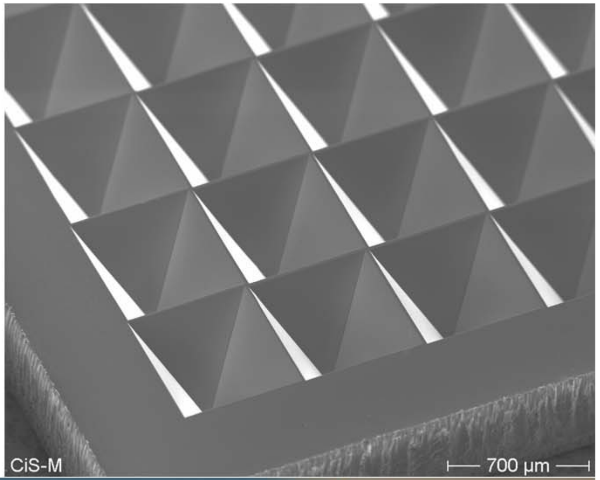

→ Switcher

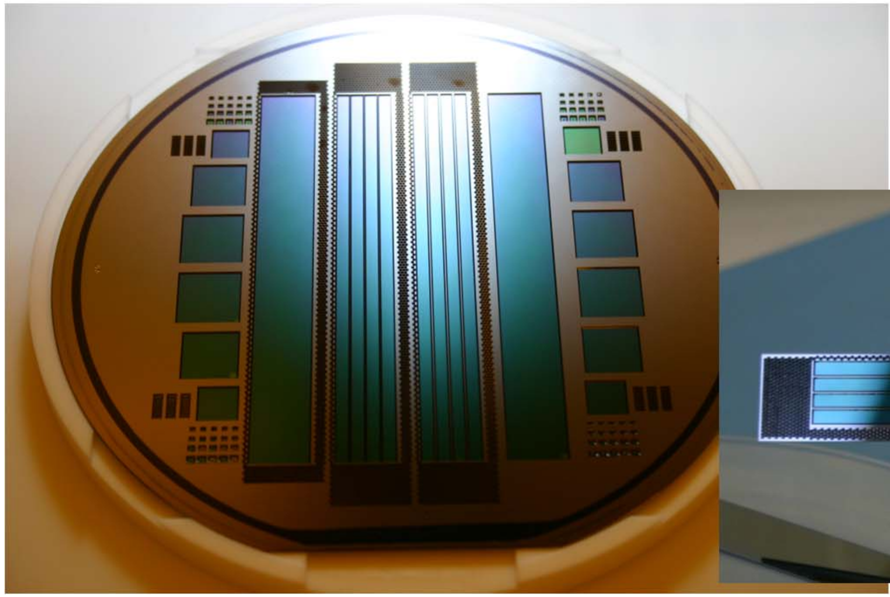
→ DCD (drain current digitizer)

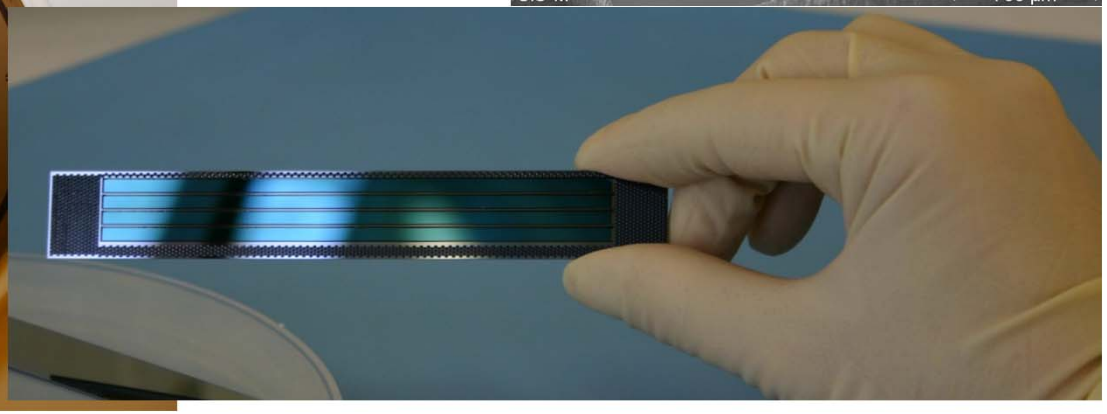
# Thinning Technology


1. implant backside on sensor wafer
2. bond sensor wafer to handle wafer
3. thin sensor side to desired thickness
4. process DEPFETs on top
5. structure resist, etch backside up to oxide/implant

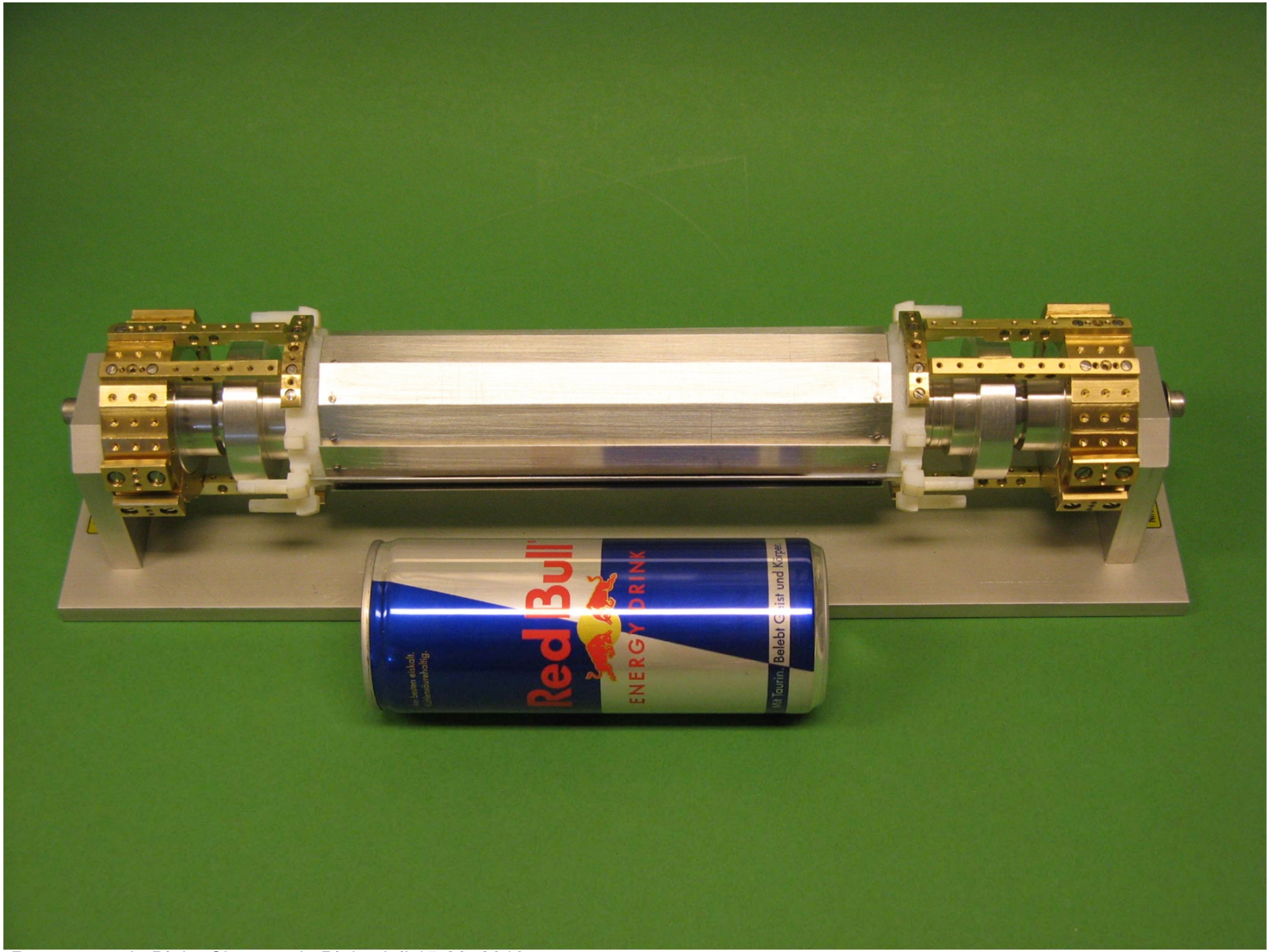
- Sensor wafer bonded on “handle” wafer.
- Rigid frame for handling and mechanical stiffness
- 50 $\mu$m thickness produced
- Samples of 10x1.3 cm$^2$ & frame of 1 & 3 mm width
- Electrical properties ok (diodes)



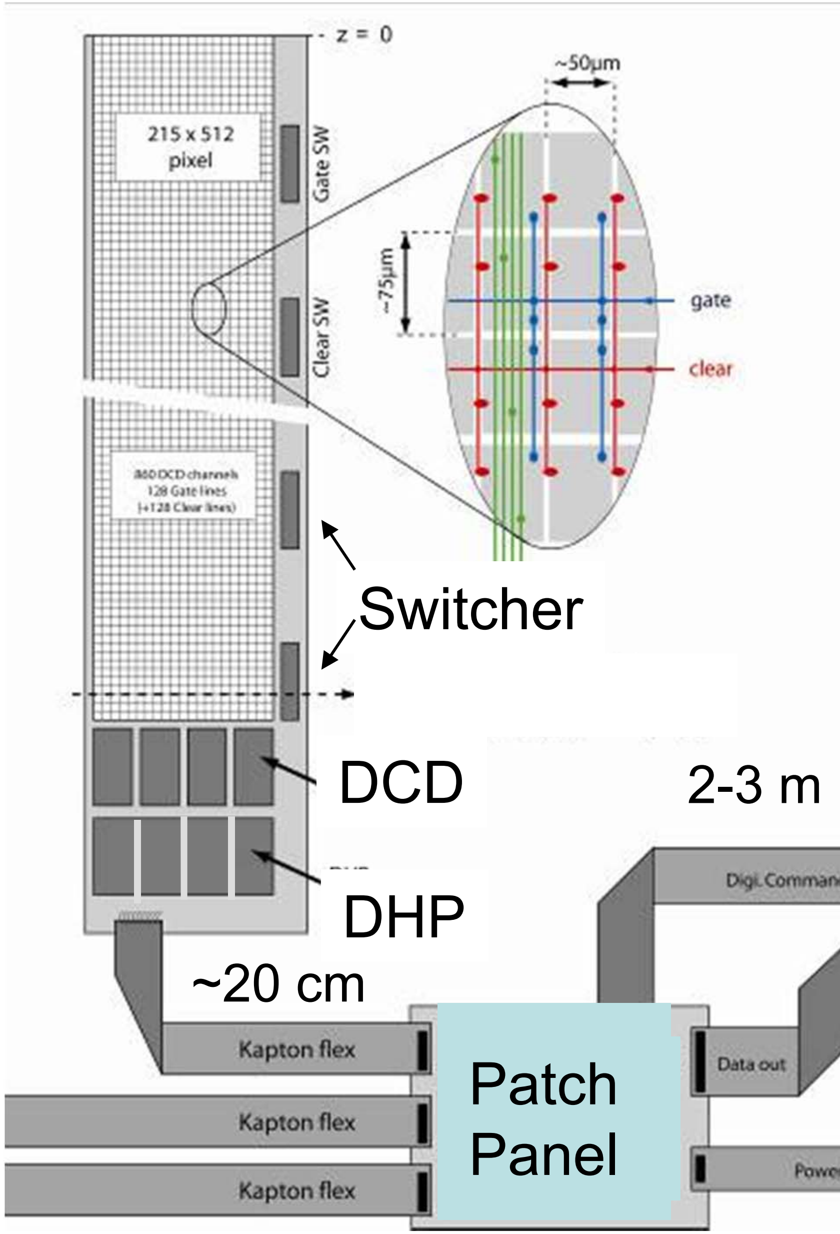


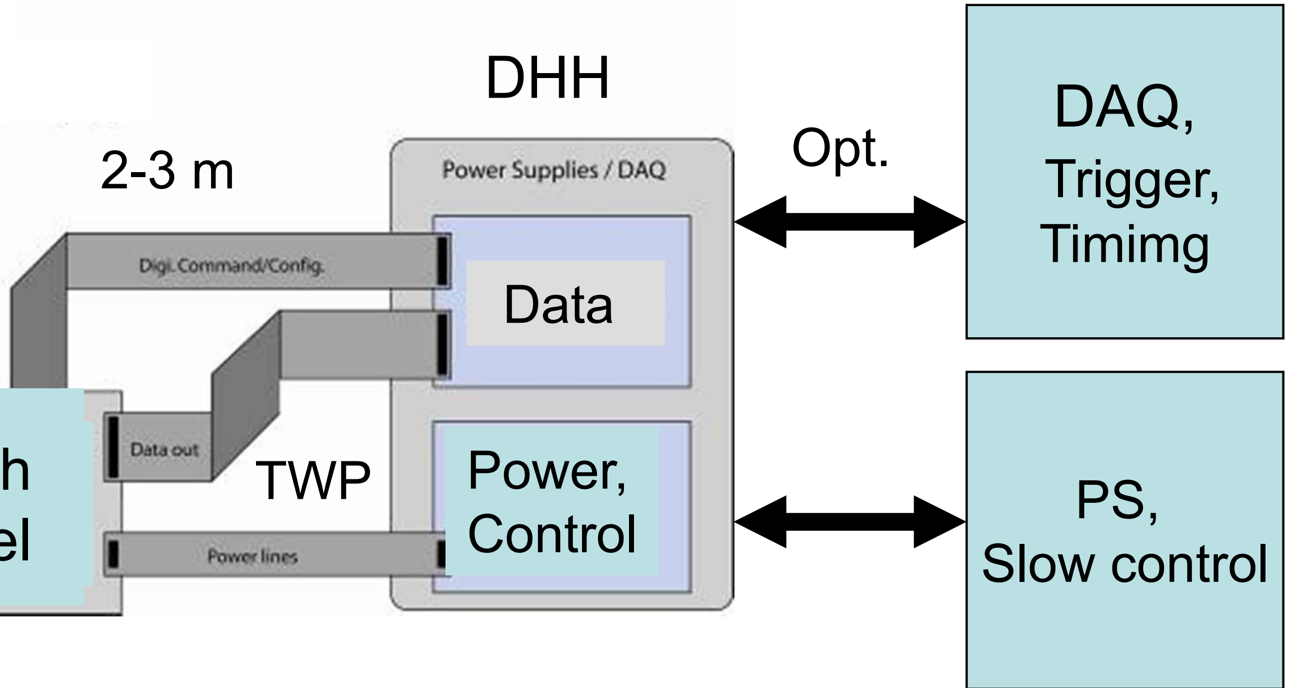
# Support and Cooling Structure: Mockup



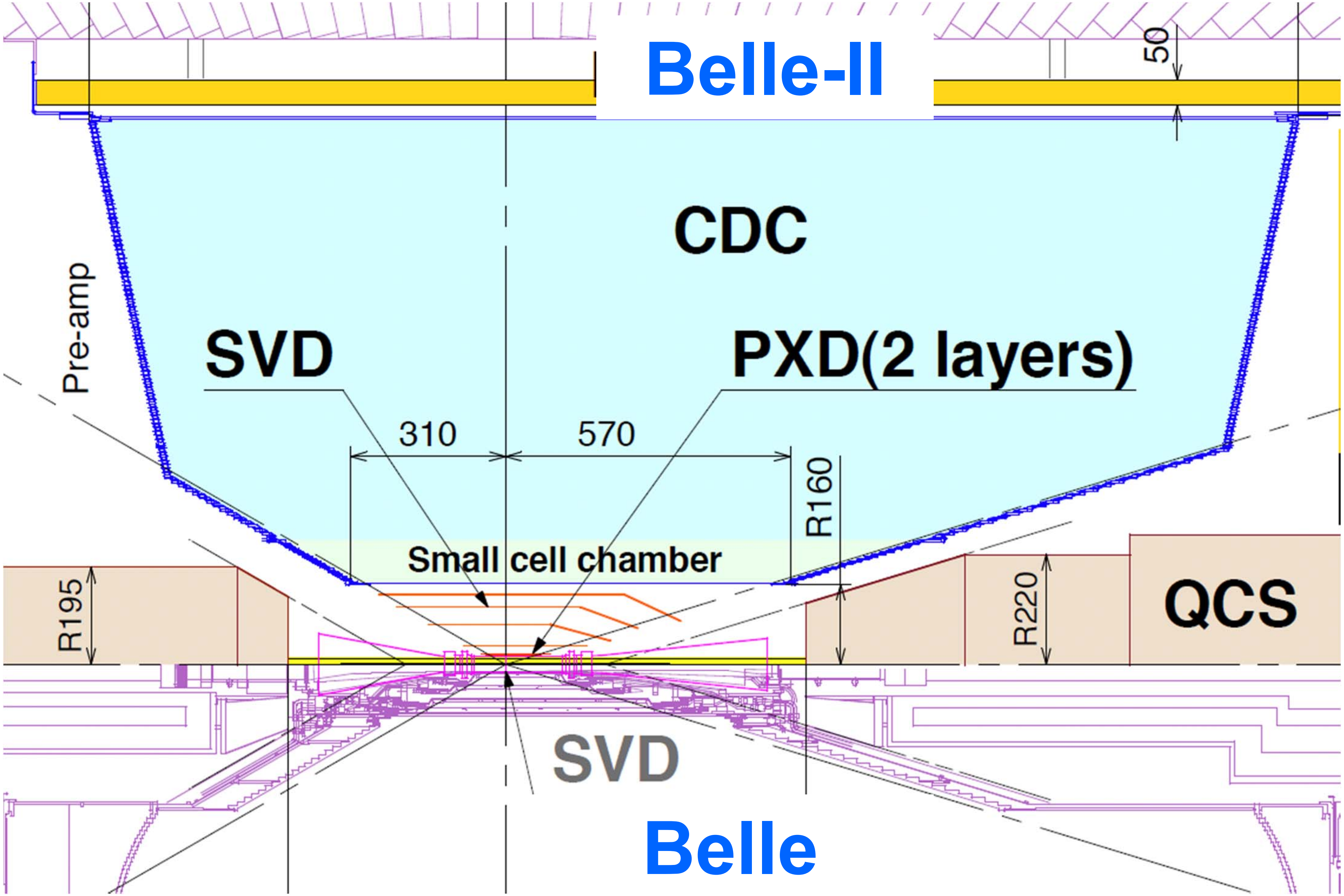
# PXD DAQ Chain

- Kapton cable (from DHP to DHH) cannot be longer than ~ 20-30 cm
- need location for the DHH in low radiation area (FPGAs)
- need to design patch pannel (signal transmission Kapton -> TWP)



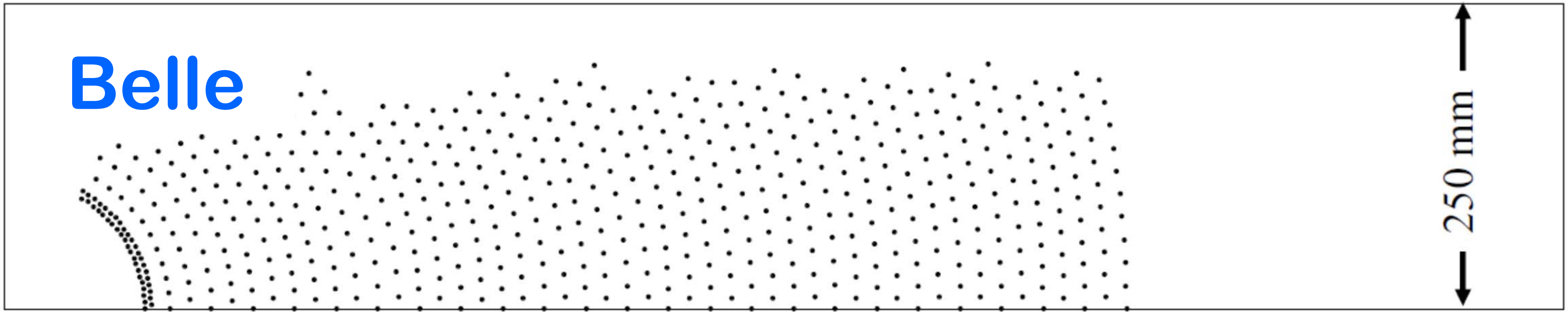
# New Tracking System for Belle-II



# New Central Drift Chamber (CDC)

| | Belle | Belle-II |
|---|---|---|
| Radius of inner boundary (mm) | 77 | 160 |
| Radius of outer boundary (mm) | 880 | 1096 |
| Radius of inner most sense wire (mm) | 88 | 168 |
| Radius of outer most sense wire (mm) | 863 | 1082 |
| Number of layers | 50 | 58 |
| Number of total sense wires | 8400 | 15104 |
| Effective radius of dE/dx measurement (mm) | 752 | 928 |
| Gas | $He\text{-}C_2H_6$ | $He\text{-}C_2H_6$ |
| Diameter of sense wire ($\mu$m) | 30 | 30 |

# New Central Drift Chamber (CDC)

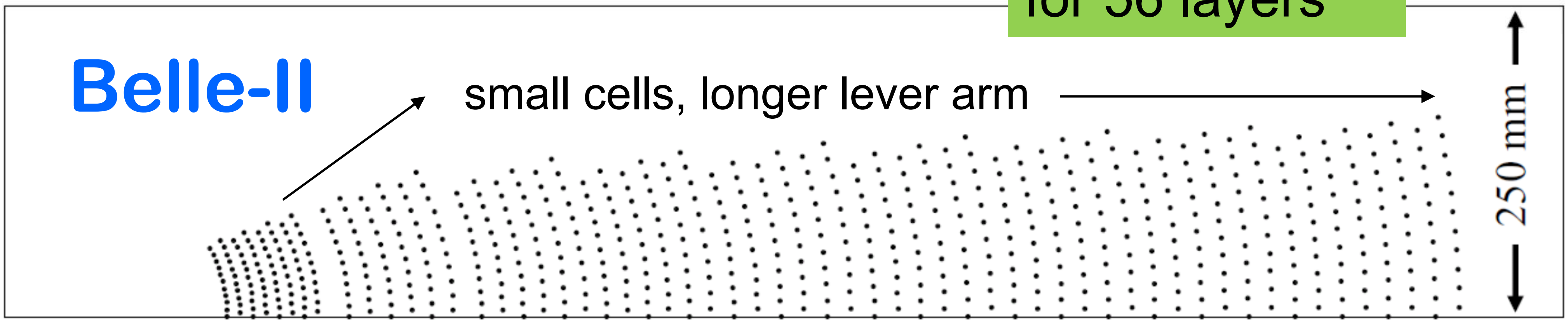



normal cell: 13.3 x 16 mm$^2$

small cell: 5.4 x 5.0 mm$^2$

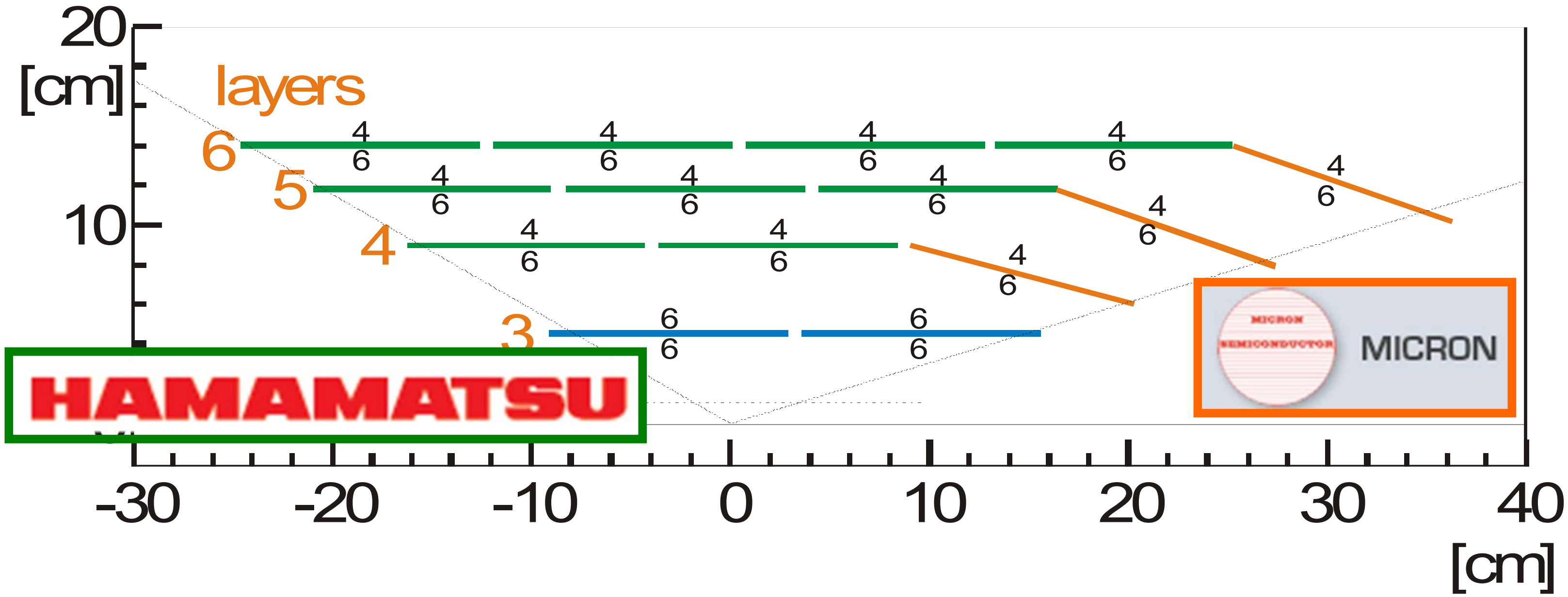
1200 mm

dE/dx: 4.8%
for 56 layers




z-coordinate via standard stereo wire arrangement, charge division planned

# New Si System for Belle-II : SuperSVD



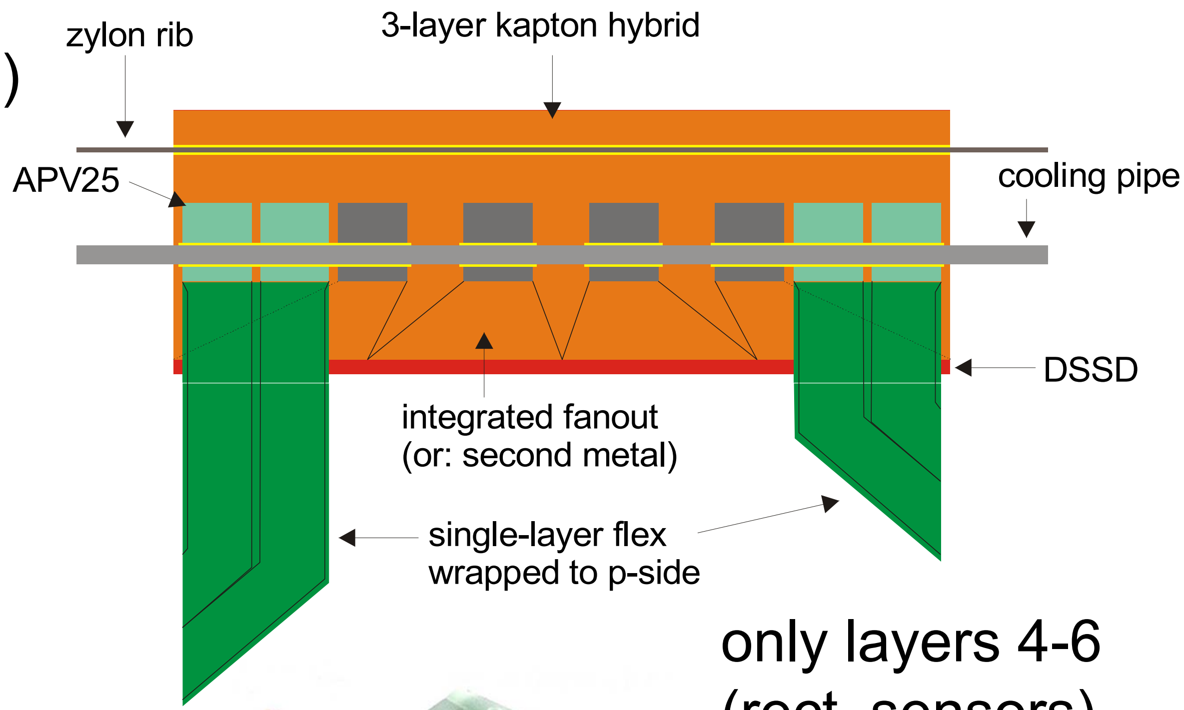

300 µm DSSD

Pitch:
50/160 µm (rect.)
50-75/160 µm (wedge)

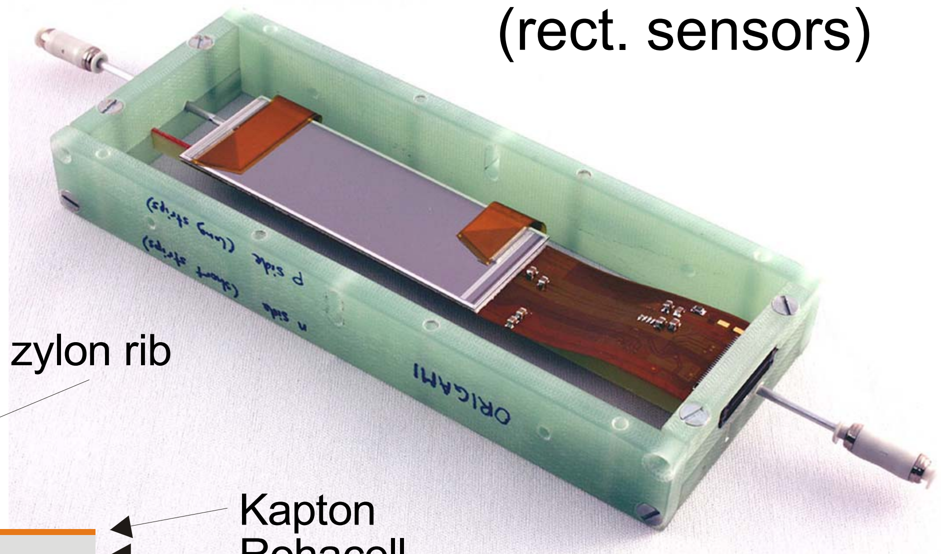
| Layer | # Ladders | Rect. Sensors [50µm] | Rect. Sensors [75µm] | Wedge Sensors | APVs |
|---|---|---|---|---|---|
| 6 | 17 | 0 | 68 | 17 | 850 |
| 5 | 14 | 0 | 42 | 14 | 560 |
| 4 | 10 | 0 | 20 | 10 | 300 |
| 3 | 8 | 16 | 0 | 0 | 192 |
| **Sum:** | **49** | **16** | **130** | **41** | **1902** |

# Chip on Sensor: The Origami Concept (SVD)

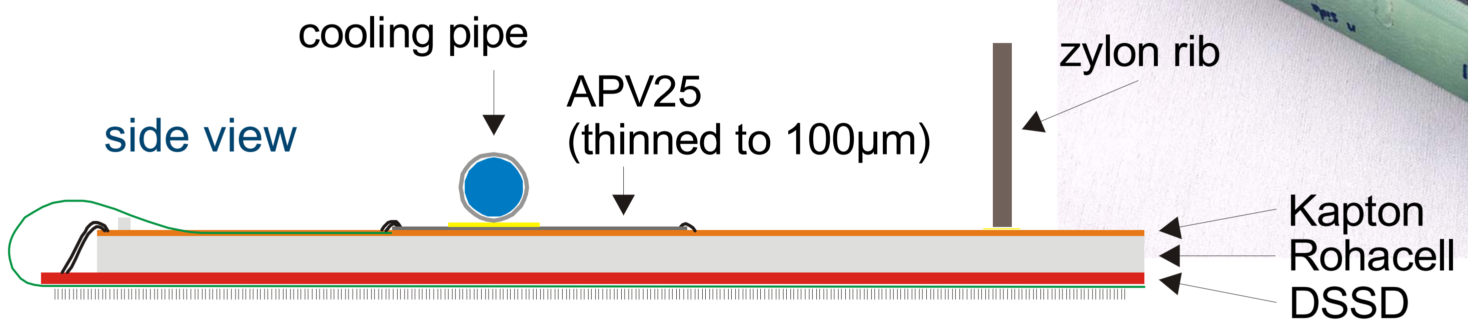
- Thinned readout chips (APV25) on sensor
- Strips of bottom side are connected by flex fanouts wrapped around the edge
- All readout chips are aligned → single cooling pipe
- Shortest possible connections → high signal-to-noise ratio



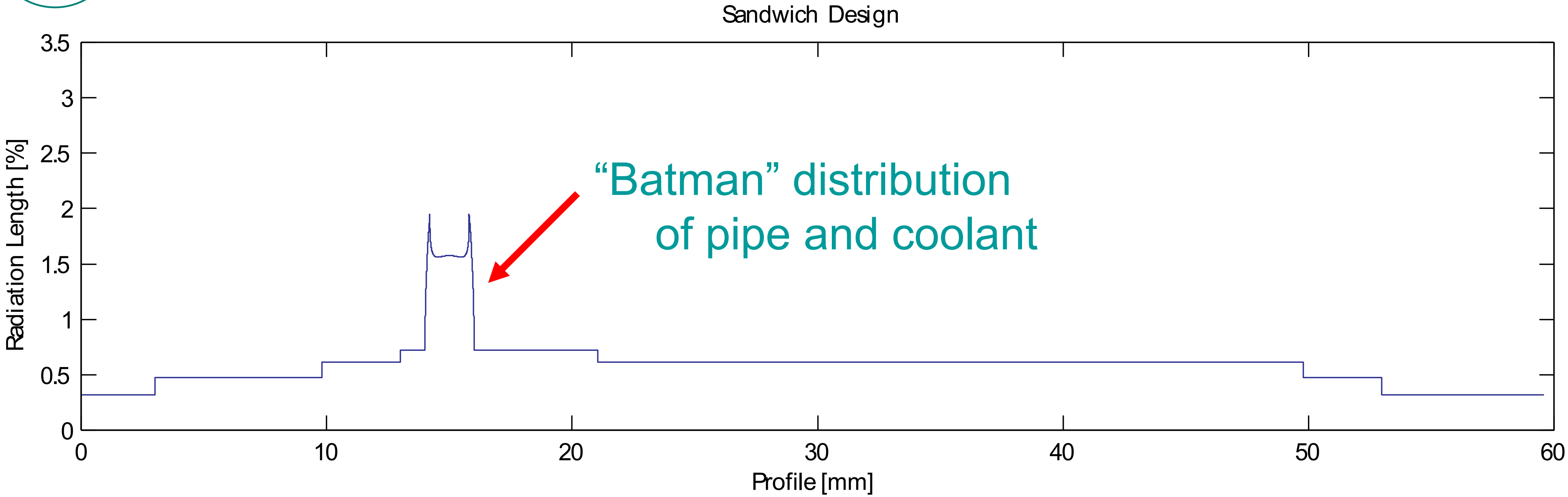

only layers 4-6
(rect. sensors)

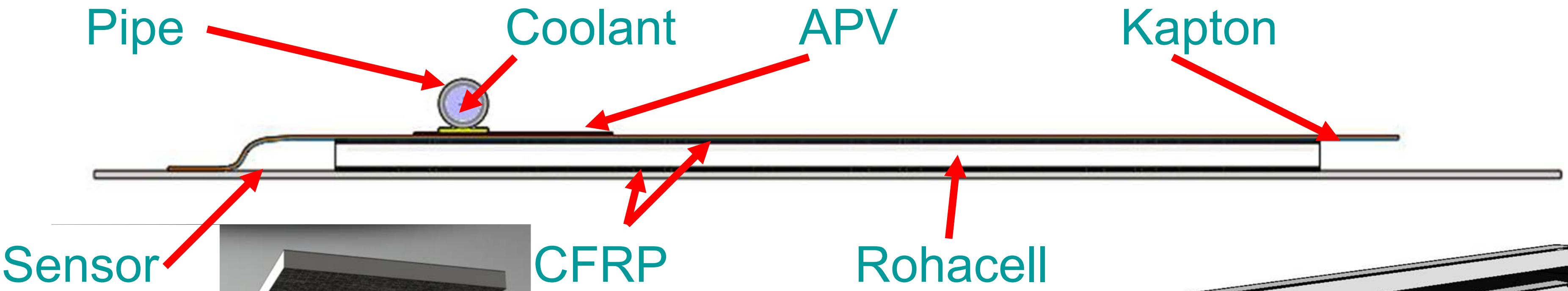


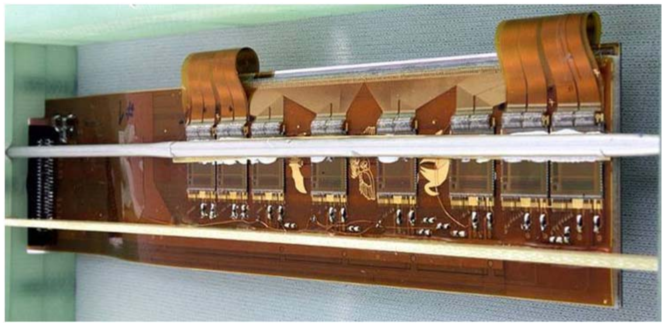

**Total material budget: 0.6% $X_0$**
**(cf. 0.48% for conventional readout)**

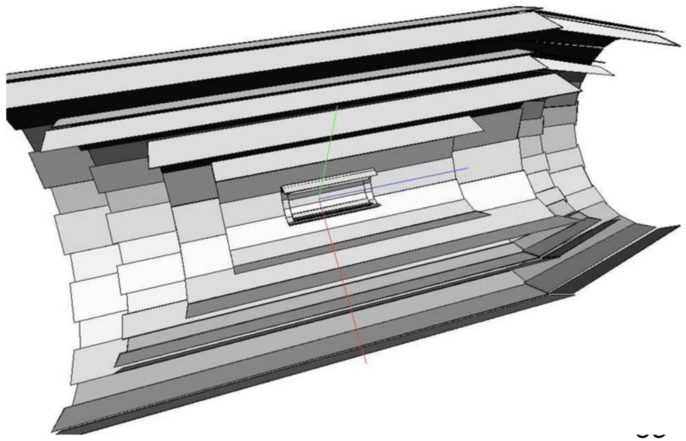


# SVD Mechanics and Material Budget

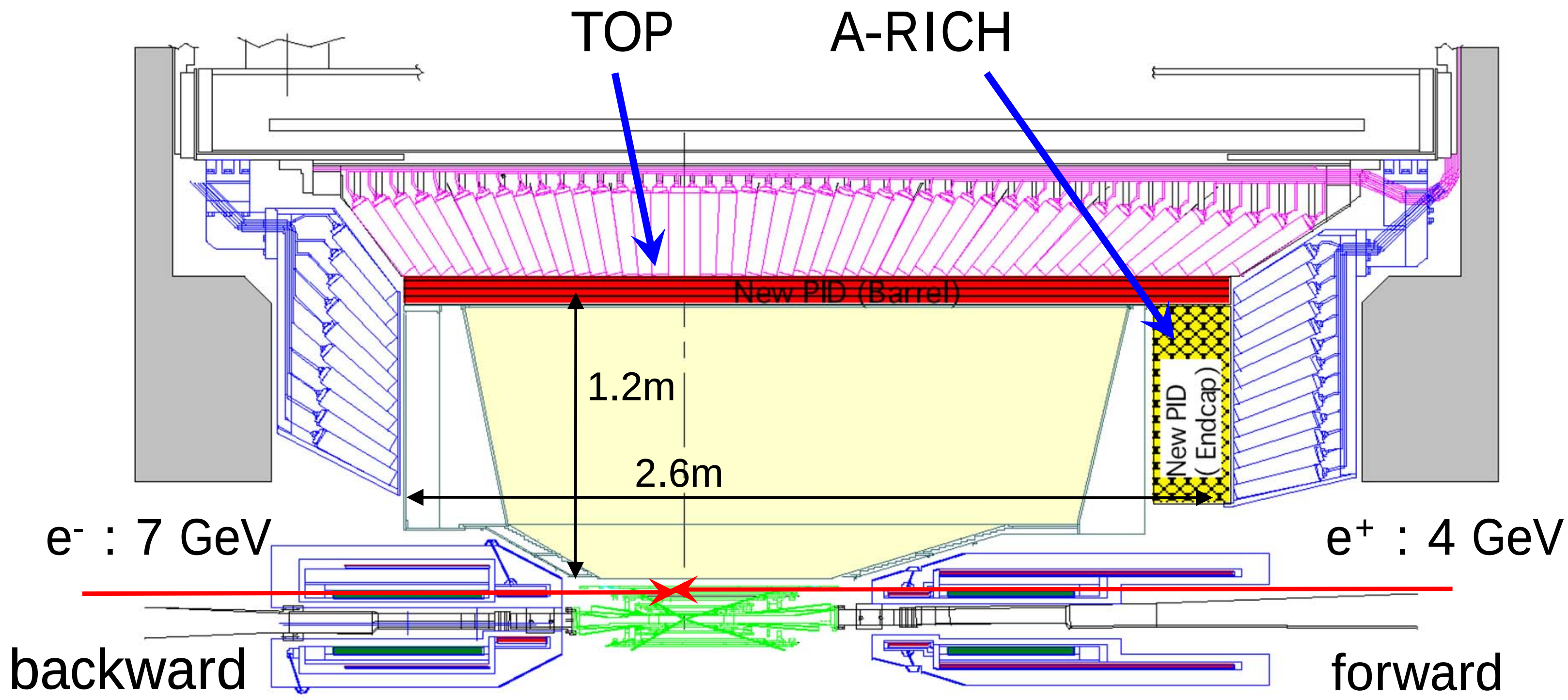


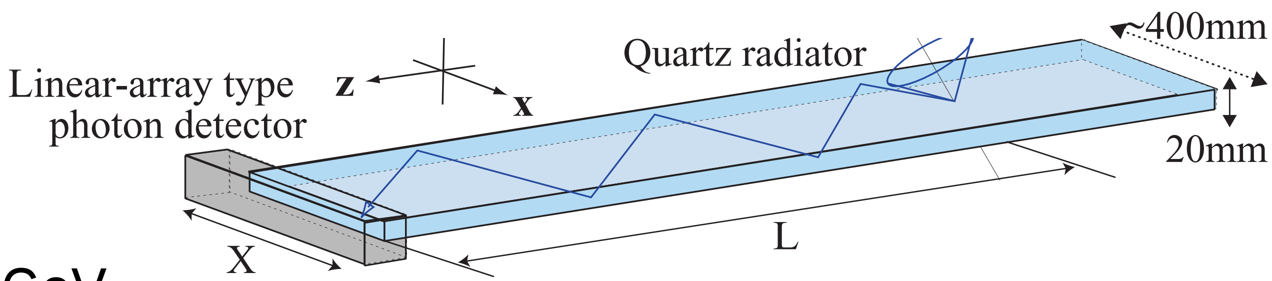





# Upgrade: Particle Identification



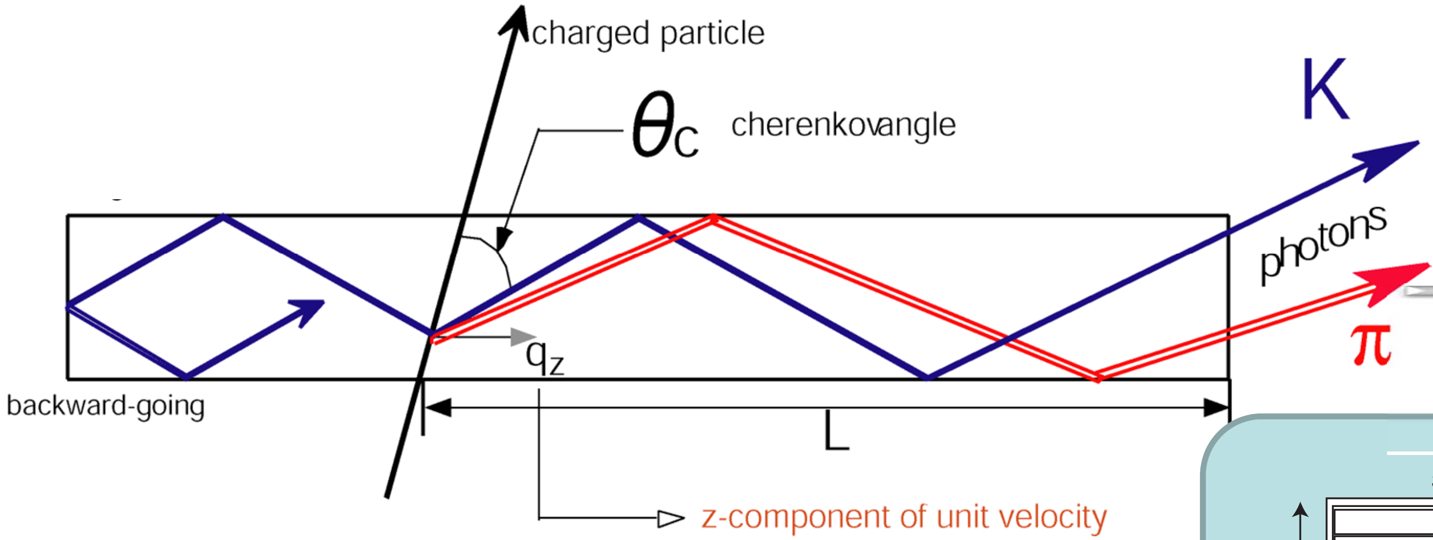




TOP: time of propagation

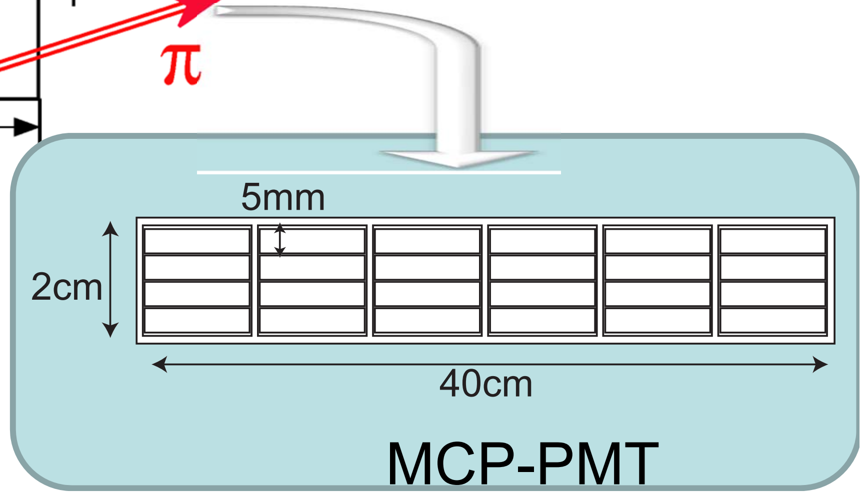
Goal:

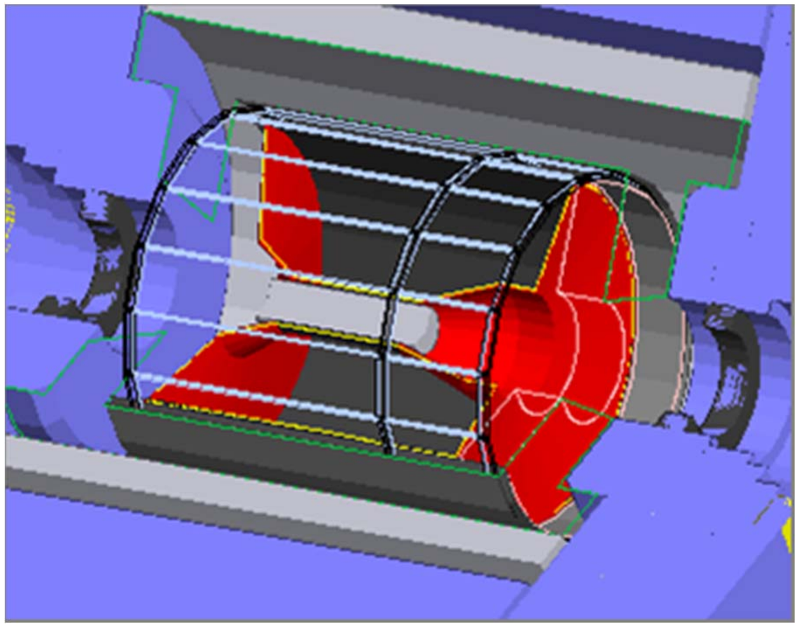
3σ K/pi separation (barrel)
4σ K/pi separation up to 4 GeV
(end caps)

# Baseline Design for Barrel PID (TOP)




TOP =
Time of Propagation



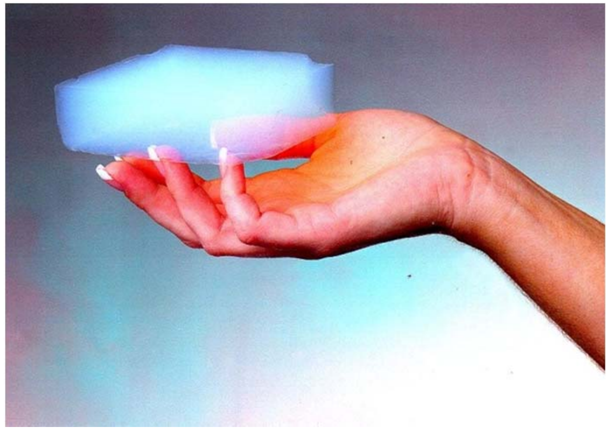
Ring imaging with :

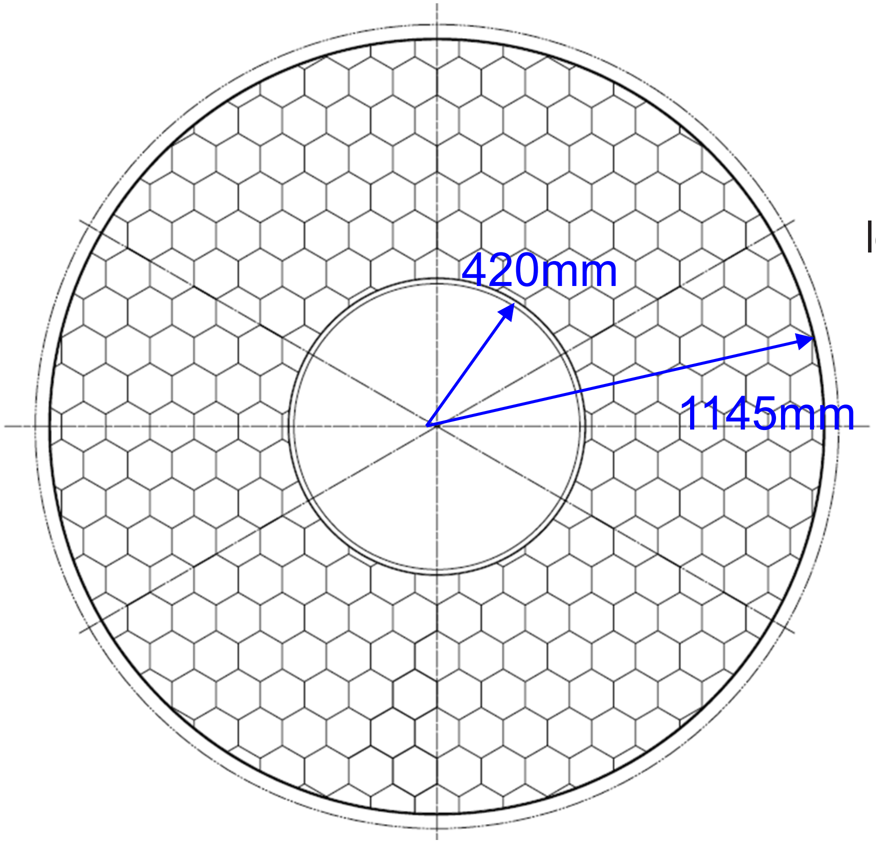
- One coordinate with a few mm precision
- Time-of-arrival

→ Excellent time resolution < ~40ps
required for single photon in 1.5T B field

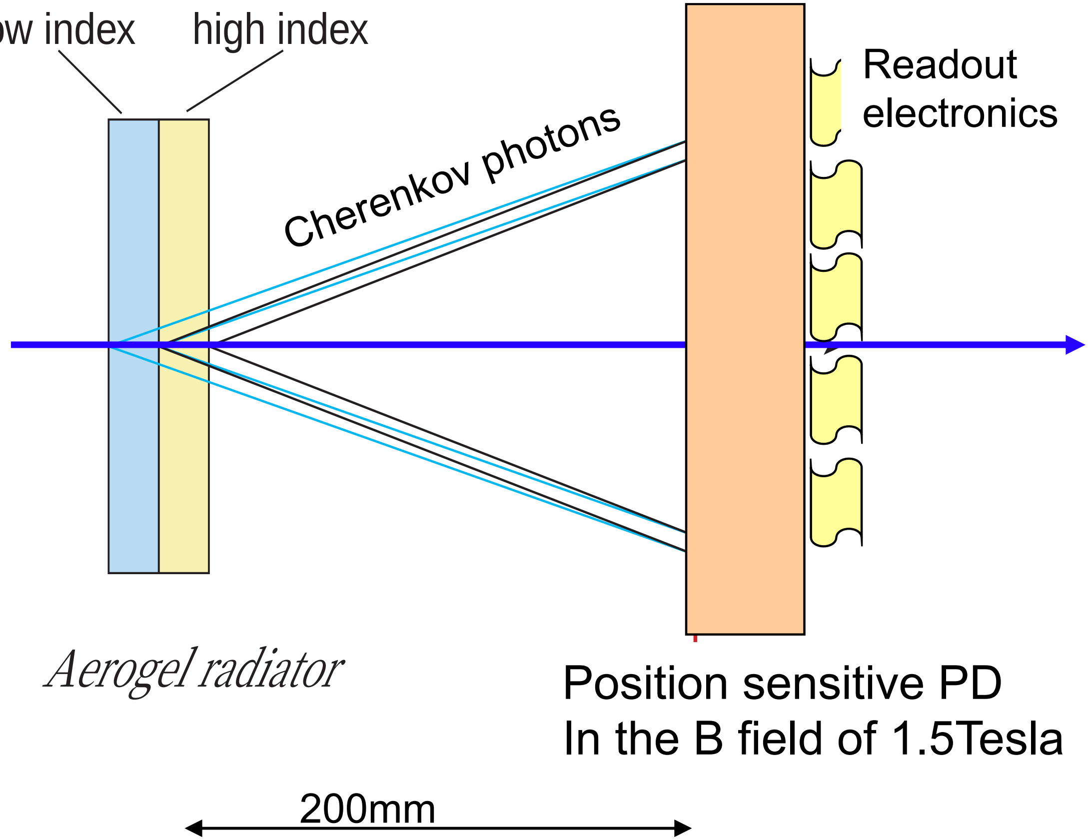
# Baseline Design for Endcap PID (A-RICH)

Proximity focusing RICH with silica aerogel as Cherenkov radiator for new Belle forward PID

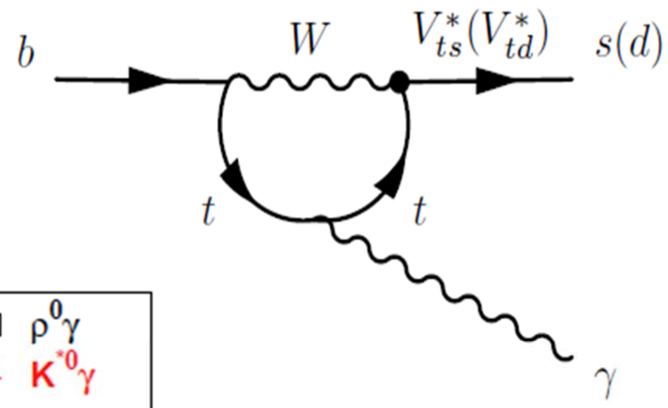




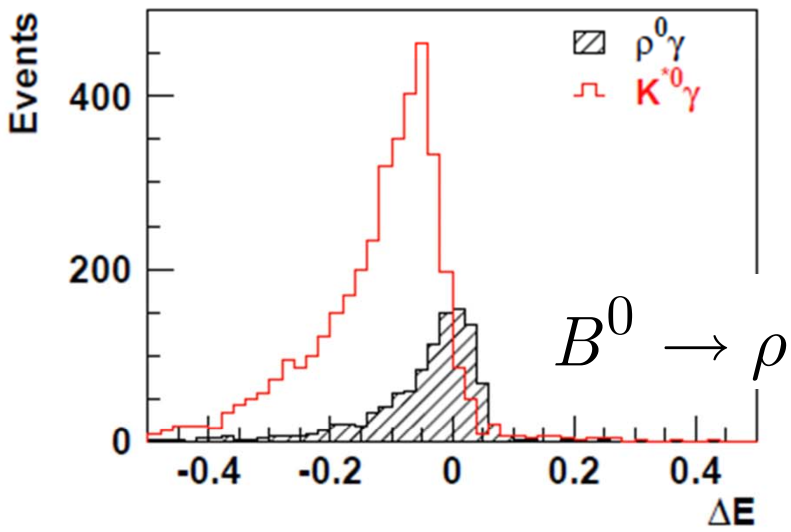

x-y view of forward end-cap



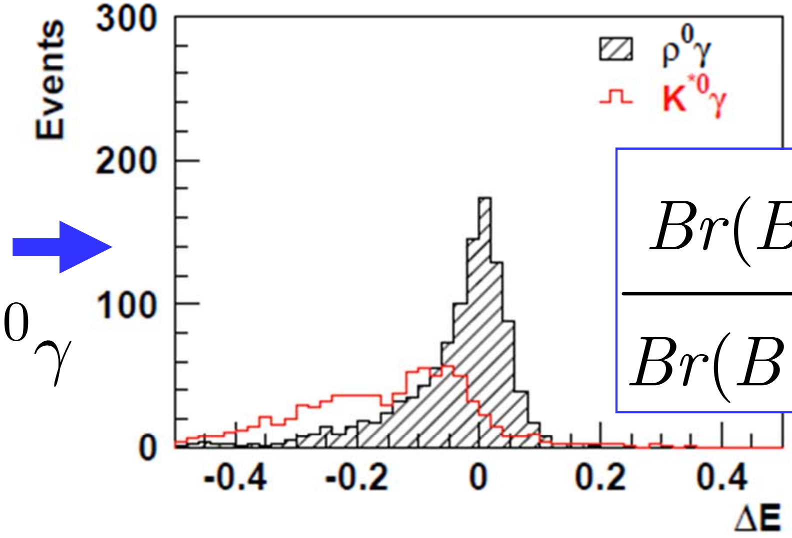
# PID Improvement in Belle-II




**Present Belle PID** | **Belle II PID**

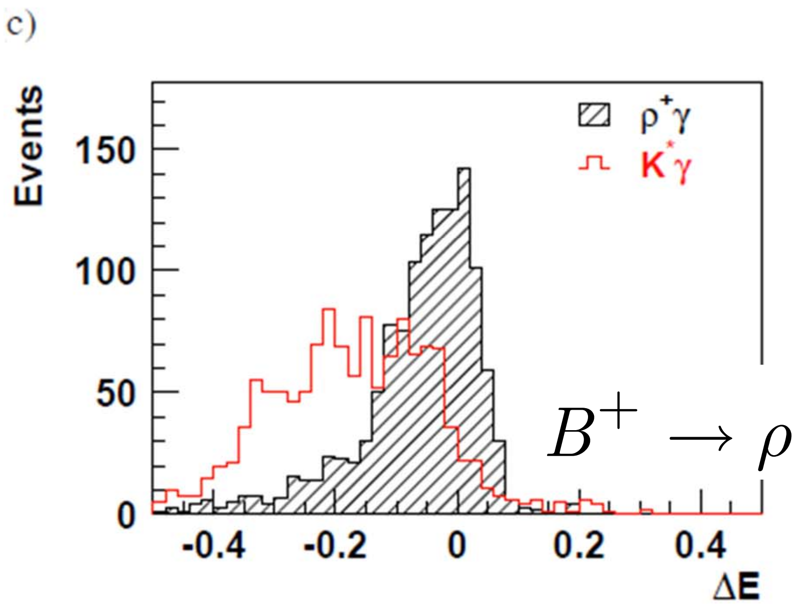



$$B^0 \to \rho^0\gamma$$

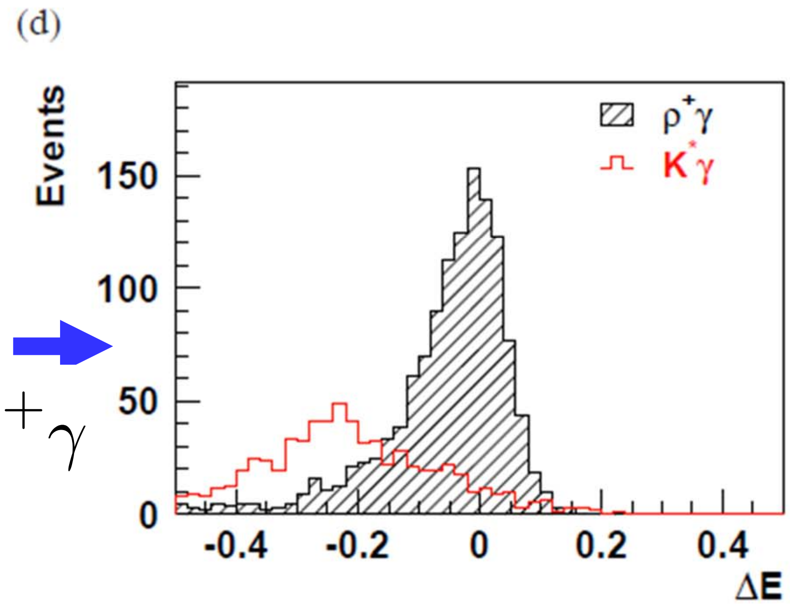



$$\frac{Br(B \to \rho\,\gamma)}{Br(B \to K^*\gamma)} \sim \left|\frac{V_{td}}{V_{ts}}\right|^2$$

$(\sim 1/40)$




$$B^+ \to \rho^+\gamma$$




$B \to \rho\gamma$

difficult because of dominating

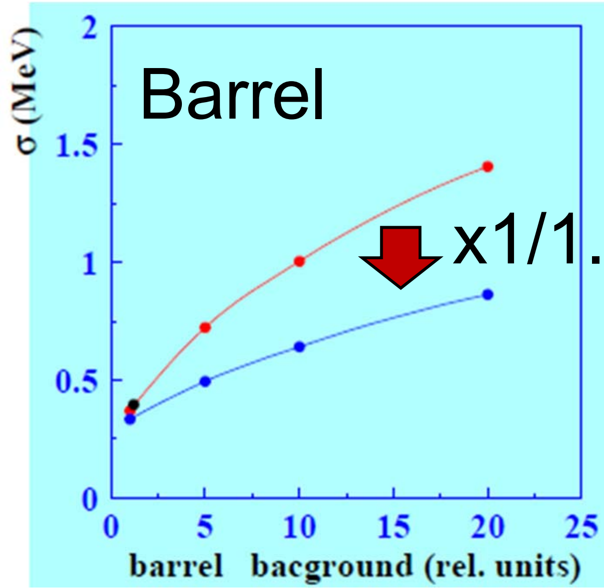
$K^*\gamma$

(Background from K's misident. as π's)

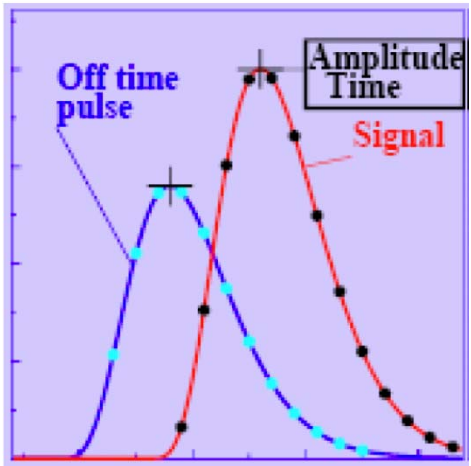
# Calorimeter Upgrade (ECL)

- Increase of dark current due to neutron flux
- Fake clusters & pile-up noise

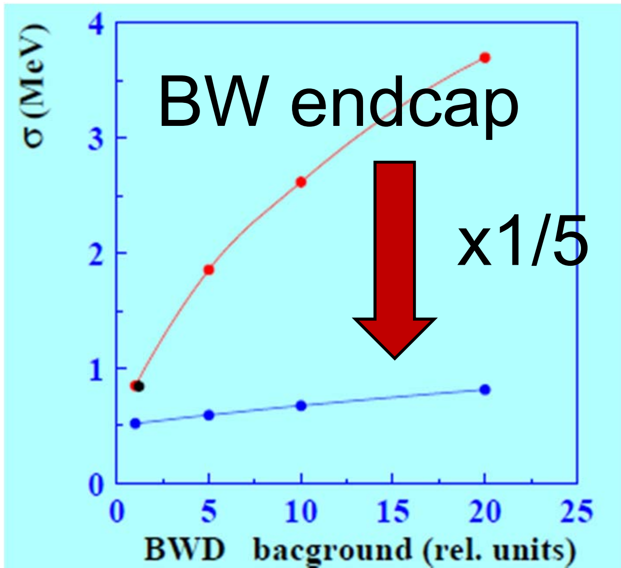
Pileup Reduction:




- Barrel:
  500 ns shaping + 2MHz w.f. sampling.
- Endcap:
  rad. hard crystals with short decay time (e.g. pure CsI) + photopentodes
  30ns shaping + 43MHz w.f. sampling

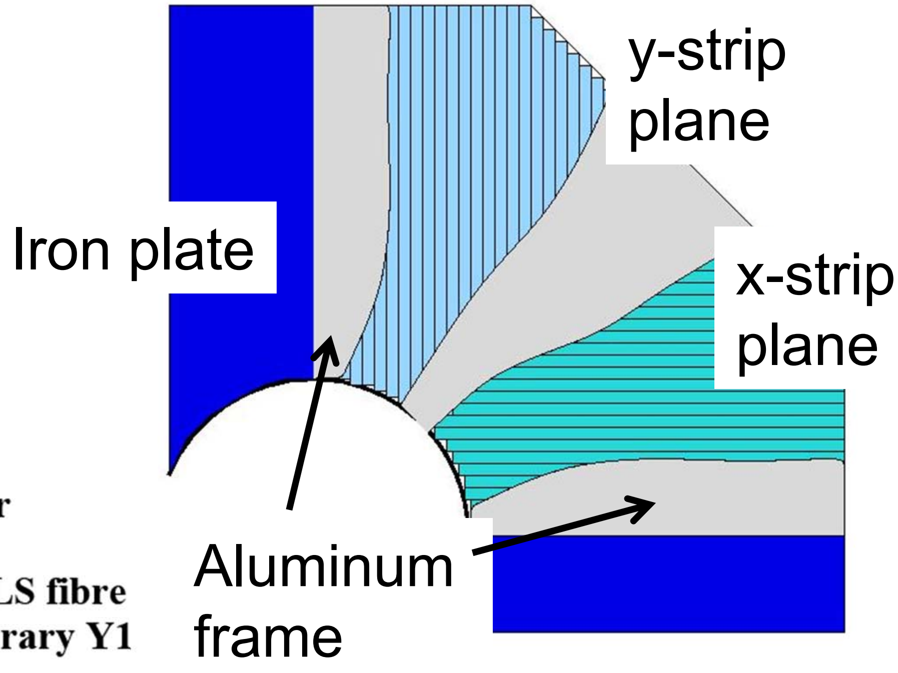


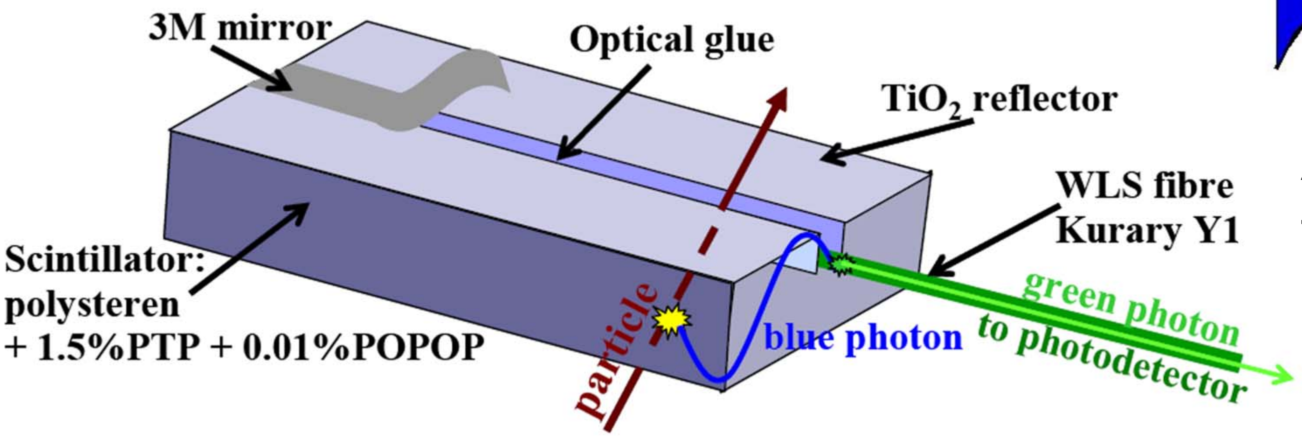

FADC: 16 samples



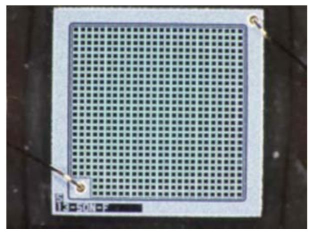
# Upgrade of KLM (Endcaps)

- Two independent (x and y) layers in one superlayer made of orthogonal scintillator strips with WLS read out
- Photo-detector: avalanche photodiode in Geiger mode (SiPM)
- ~120 strips in one 90º sector
  (max L=280cm, w=25mm)
- ~30000 read out channels
- Geometrical acceptance > 99%




676 pixels (20x20μm$^2$)



SiPM, e.g. Hamamatsu 1.3x1.3 mm$^2$