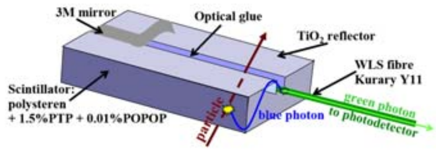
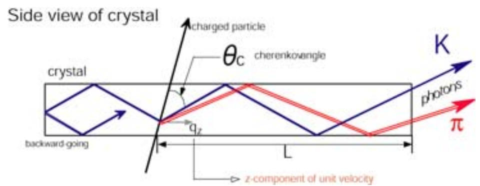
The Belle II Detector at SuperKEKB

C. Kiesling, MPI Munich

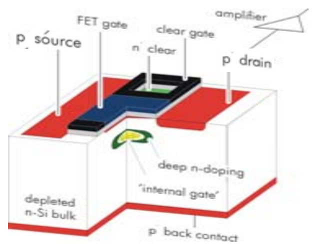
- General Overview
- K_L detector (KLM)
  Electromagnetic Calorimeter (ECL)



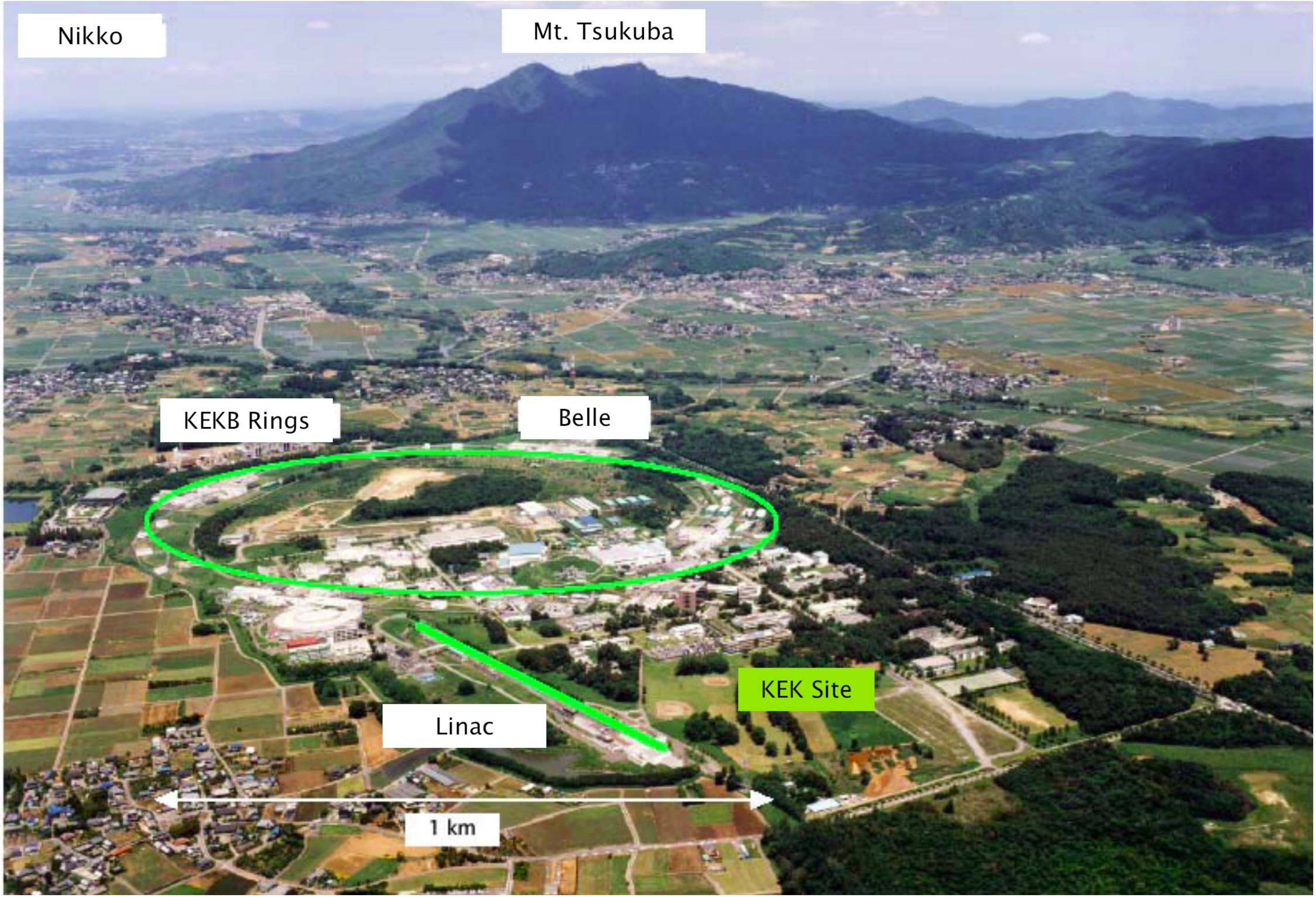
- Particle ID System (PID)
  Central Drift Chamber (CDC)



- Silicon Strip detector (SVD)
  Si-Pixel Detector (PXD)

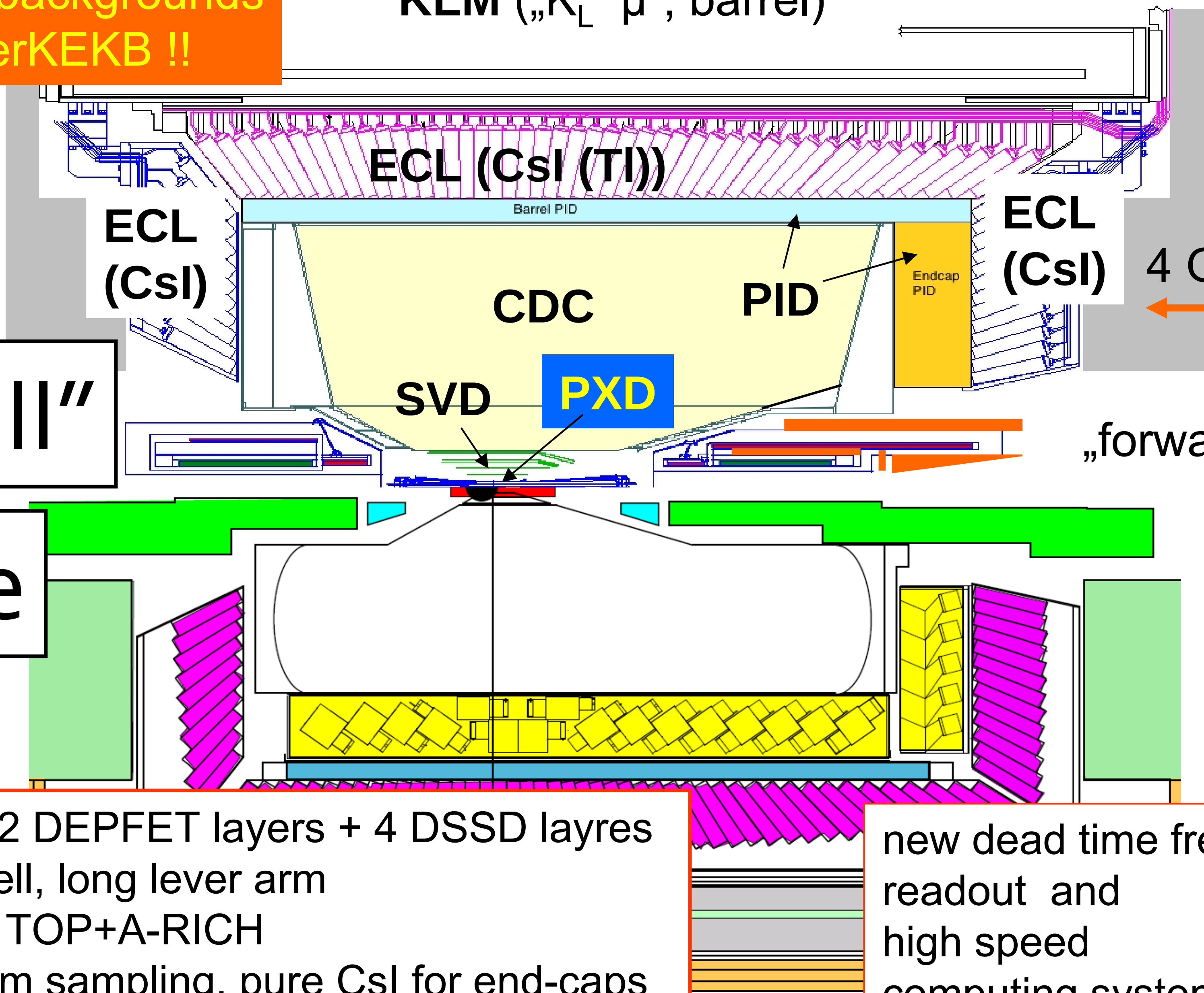


- Summary & Conclusions


Nikko
Mt. Tsukuba
KEKB Rings
Belle
KEK Site
Linac
1 km

Detector: Baseline Design

Much higher backgrounds from SuperKEKB !!



7 GeV e^-

„backward“

4 GeV e^+

„forward“

“Belle II”

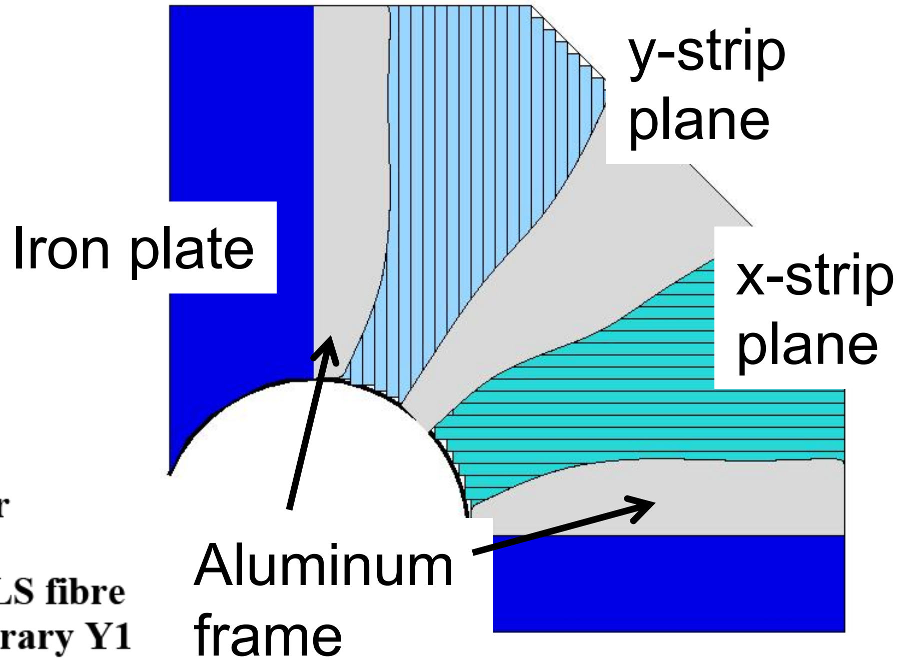
Belle

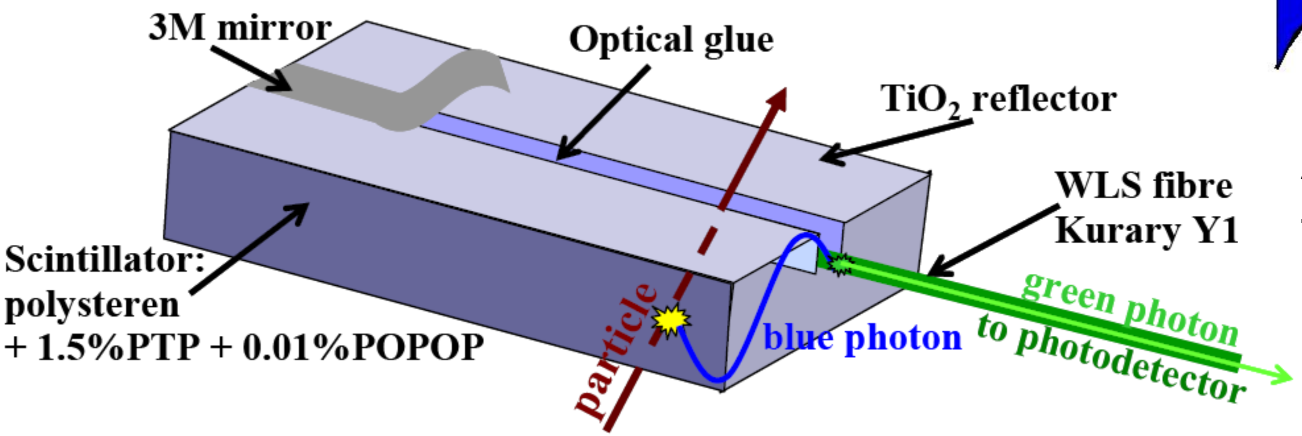
SVD: 4 lyr -> 2 DEPFET layers + 4 DSSD layres
CDC: small cell, long lever arm
ACC+TOF -> TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC -> Scintillator +SiPM (end-caps)

new dead time free readout and high speed computing systems

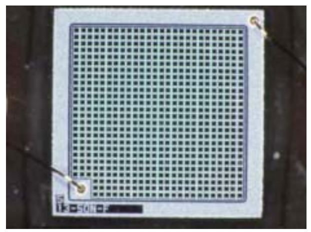
Upgrade of KLM (Endcaps)

- 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)



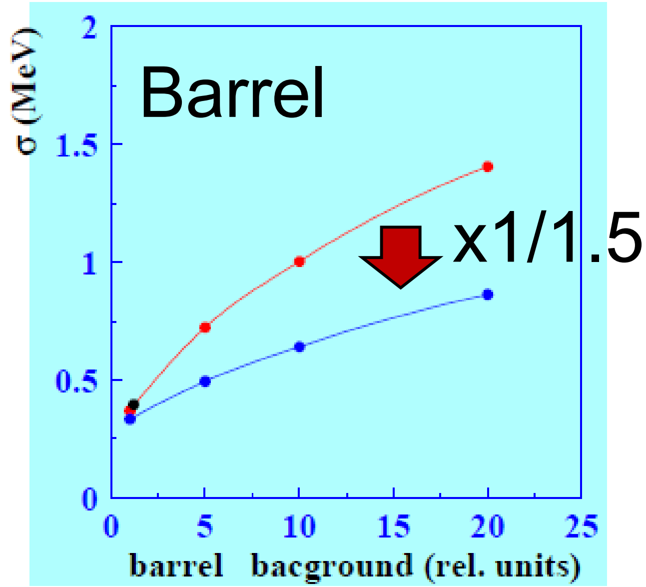
SiPM, e.g. Hamamatsu 1.3x1.3 mm^2

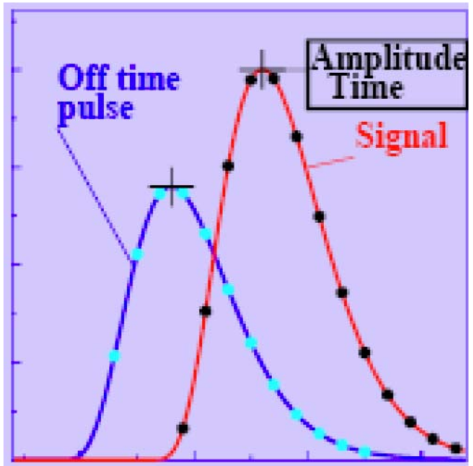
Calorimeter Upgrade (ECL)

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

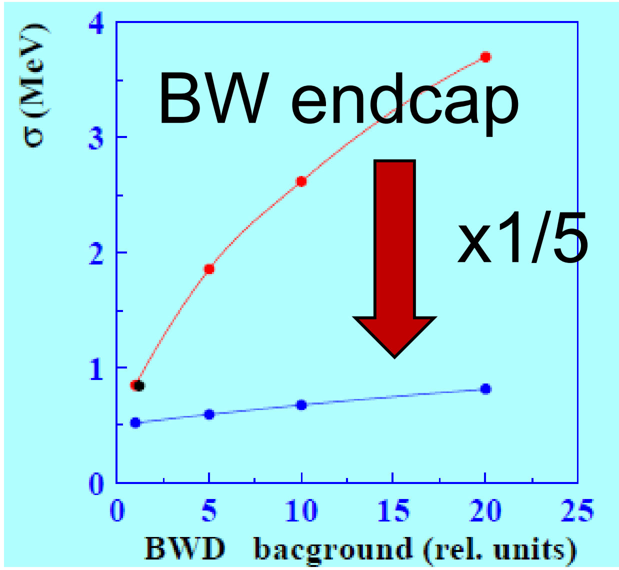
- Barrel:
  500 ns shaping + 2MHz w.f. sampling.
- Endcap:
  rad. hard crystals with short decay time (e.g. pure CsI) + photopentodes
  30ns shaping + 43MHz w.f. sampling

Pileup Reduction:

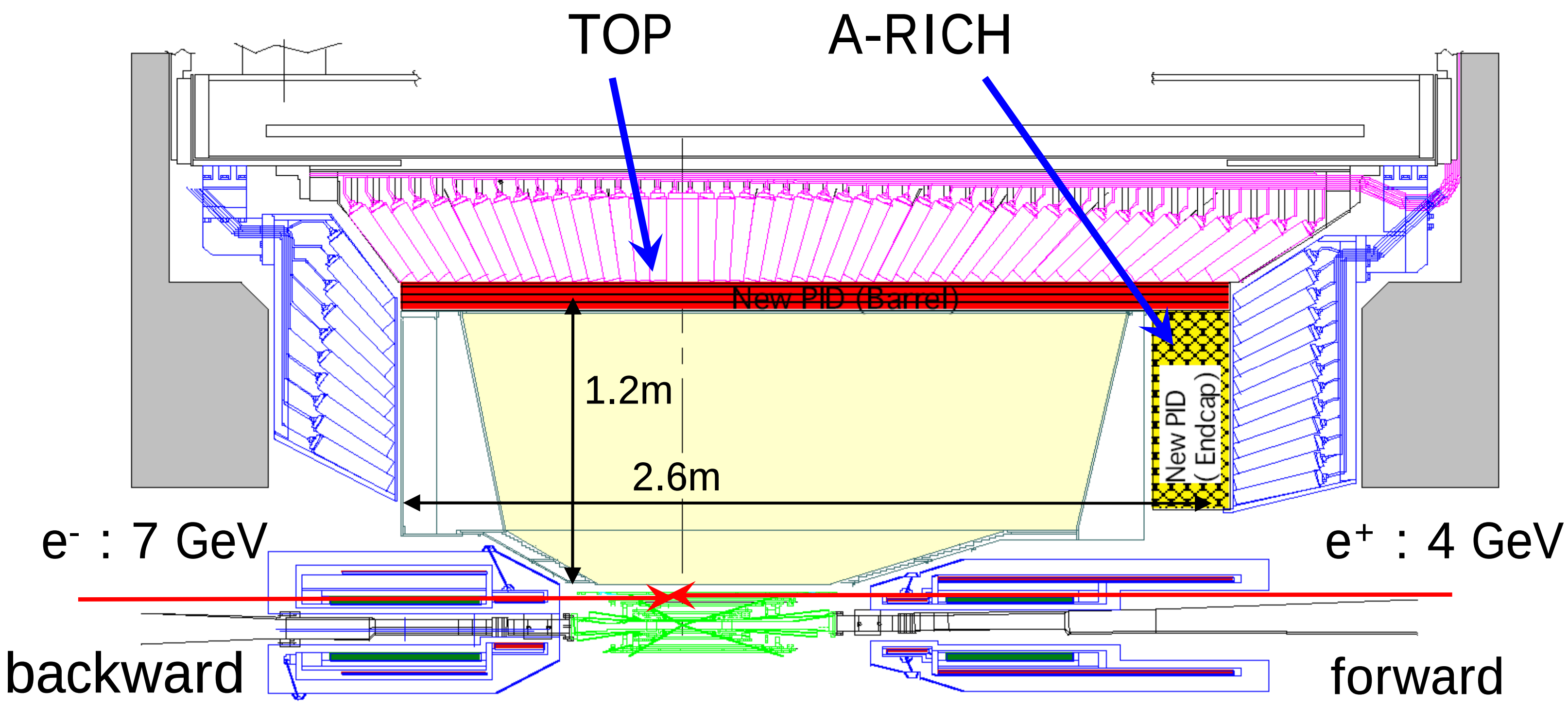




FADC: 16 samples



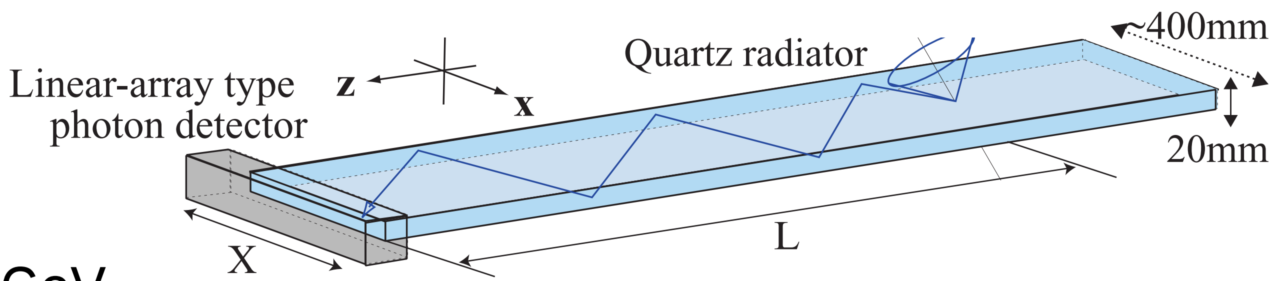
Upgrade: Particle Identification



Goal:

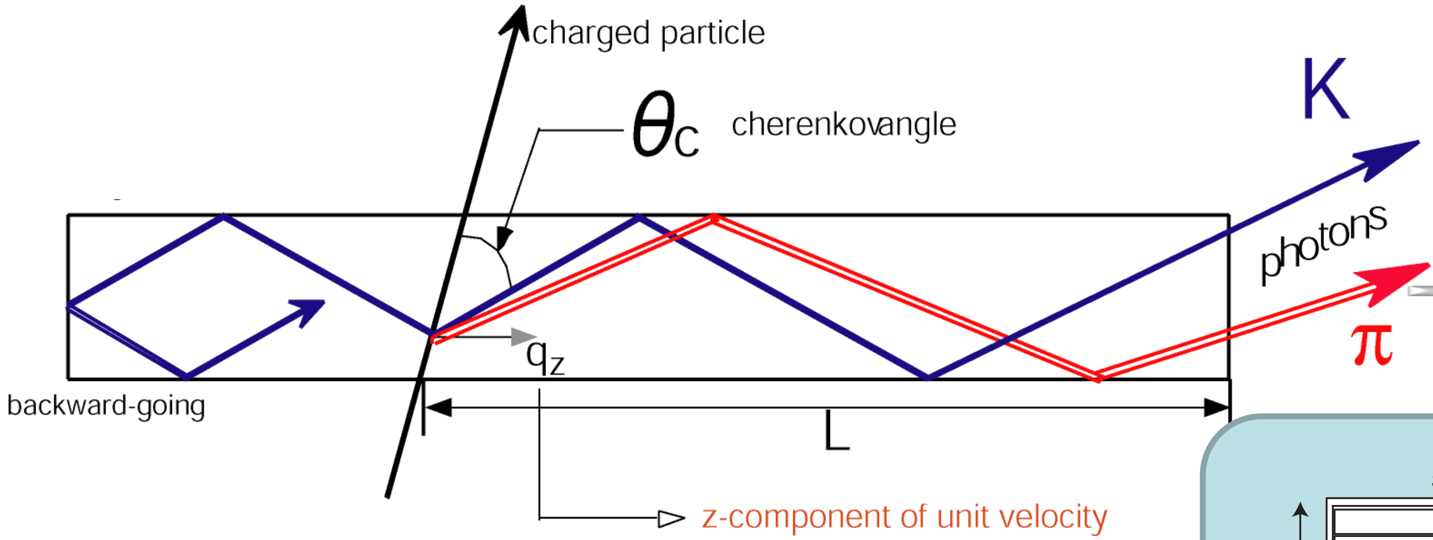
3s K/pi separation (barrel)

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

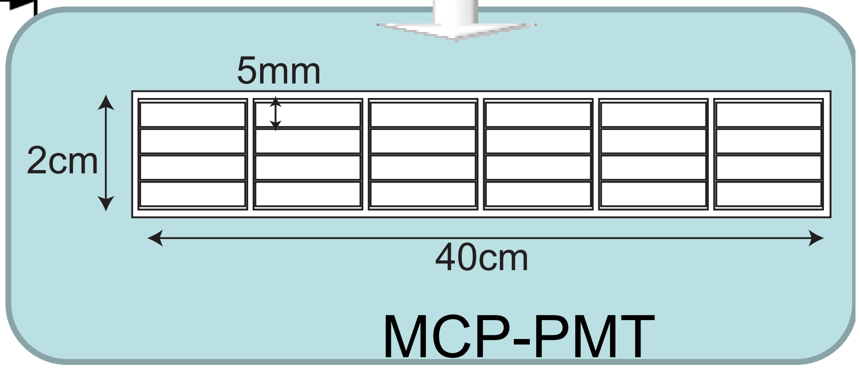


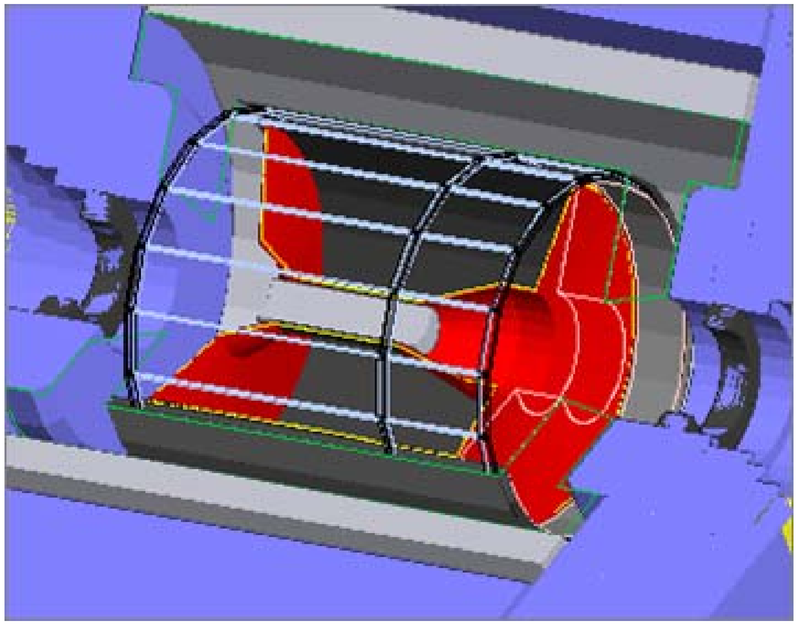
TOP: time of propagation

Baseline Design for Barrel PID



different Cherenkov angle for K and π: also different TOP





Ring imaging with :

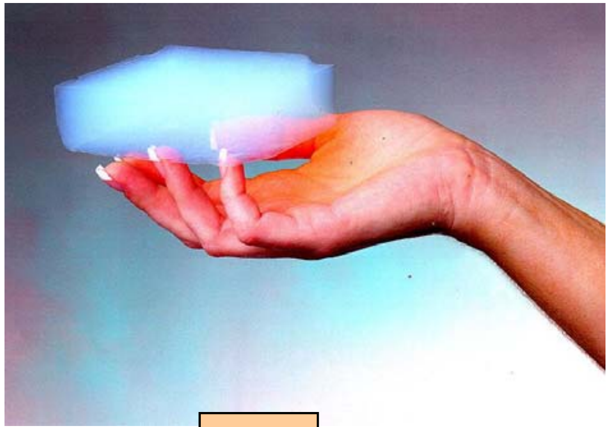
- One coordinate with a few mm precision
- Time-of-arrival

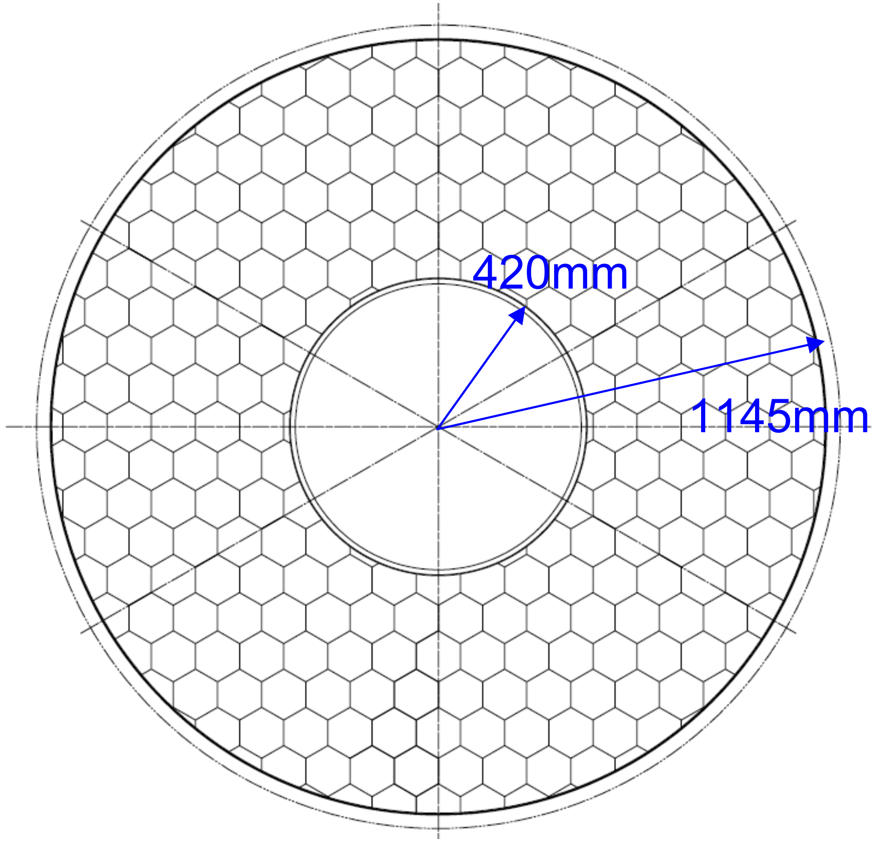
→ Excellent time resolution < ~40ps

efficient single photon detection in 1.5 T field

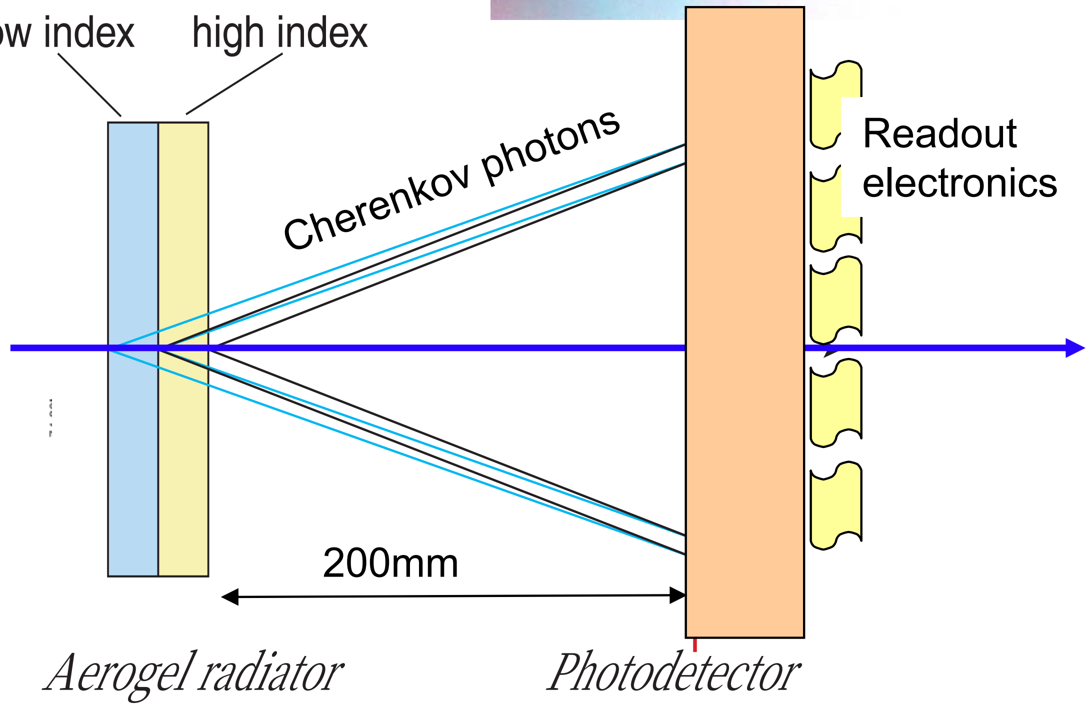
Baseline Design for Endcap PID

Proximity focusing RICH with silica aerogel as Cherenkov radiator for the Belle-II forward PID





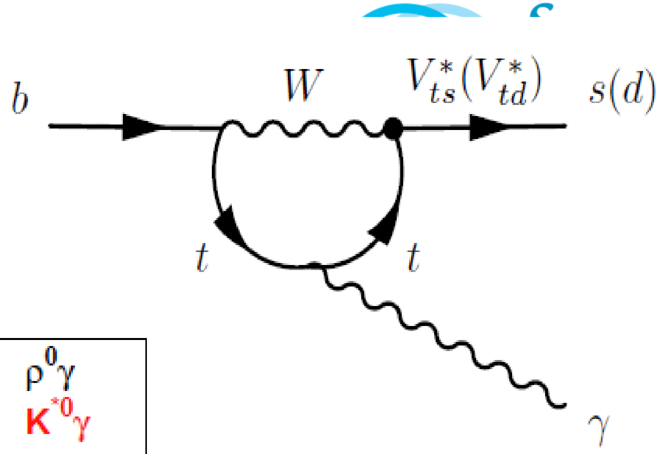
x-y view of forward end-cap



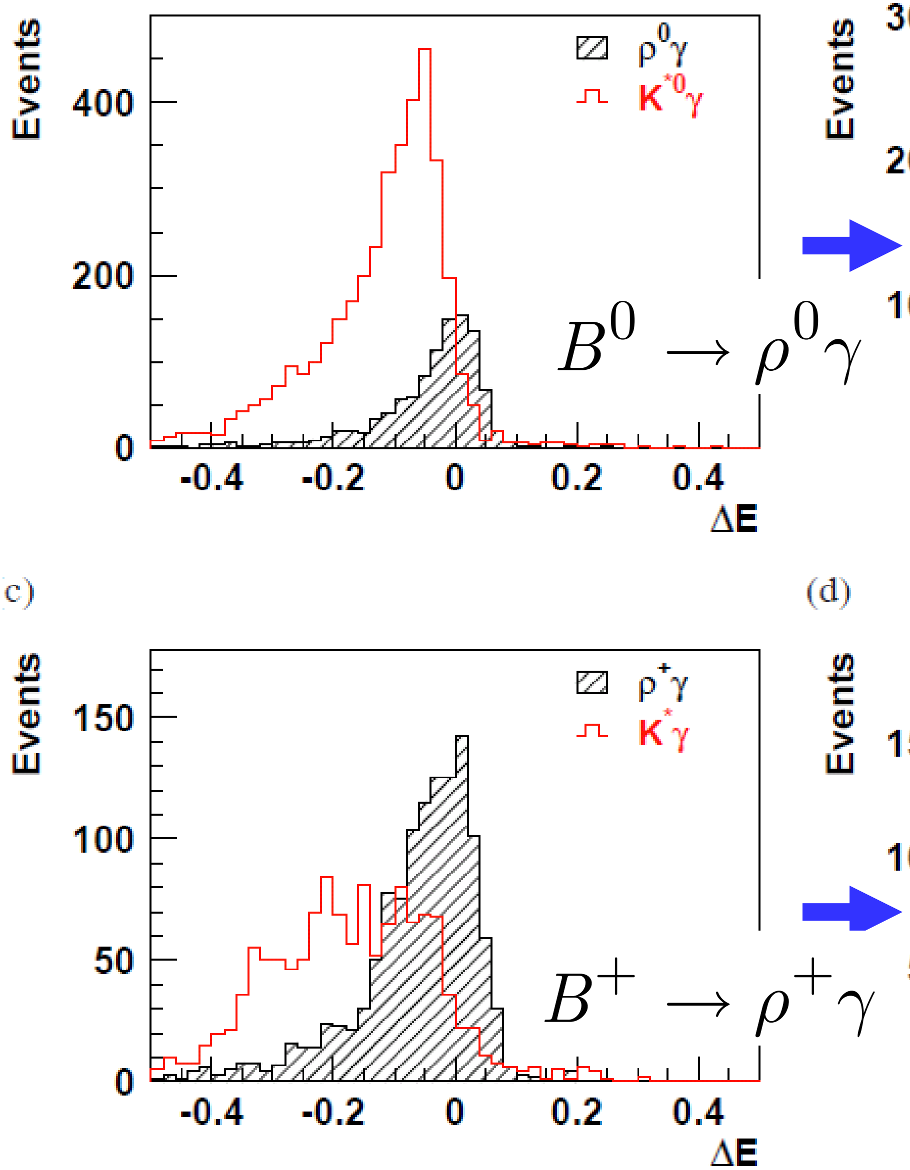
encouraging beam tests: Ch-photons ~ 14/track
angluar res./tr. 4 mrad

Position sensitive PD
In the B field of 1.5Tesla
(HAPD's or SiPM's)

Expected PID Performance



Present Belle PID | Belle II PID



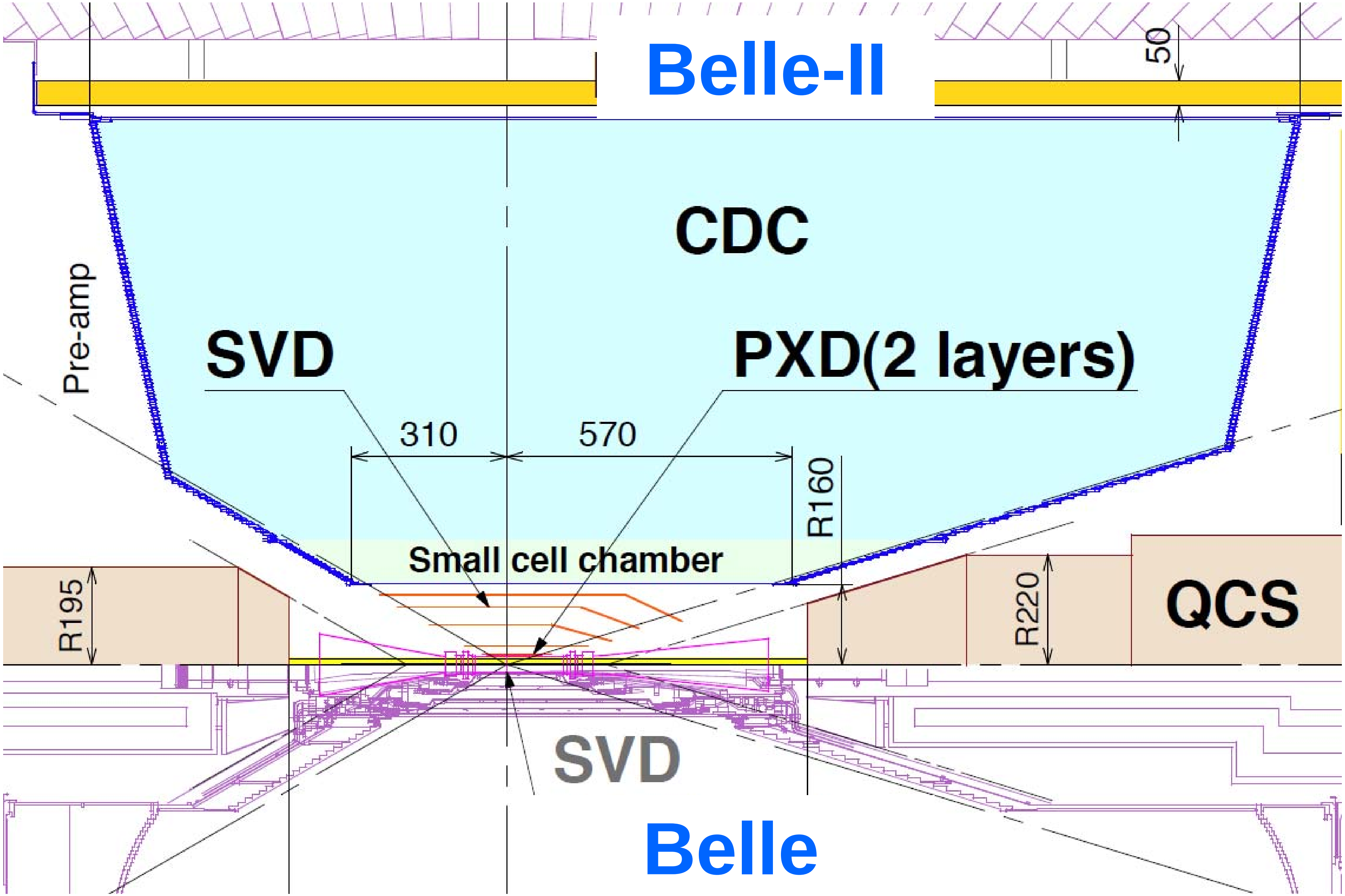
$$\frac{Br(B \to \rho\,\gamma)}{Br(B \to K^*\gamma)} \sim \left|\frac{V_{td}}{V_{ts}}\right|^2$$

$(\sim 1/40)$

$B \to \rho\gamma$ difficult because of dominating $K^*\gamma$

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

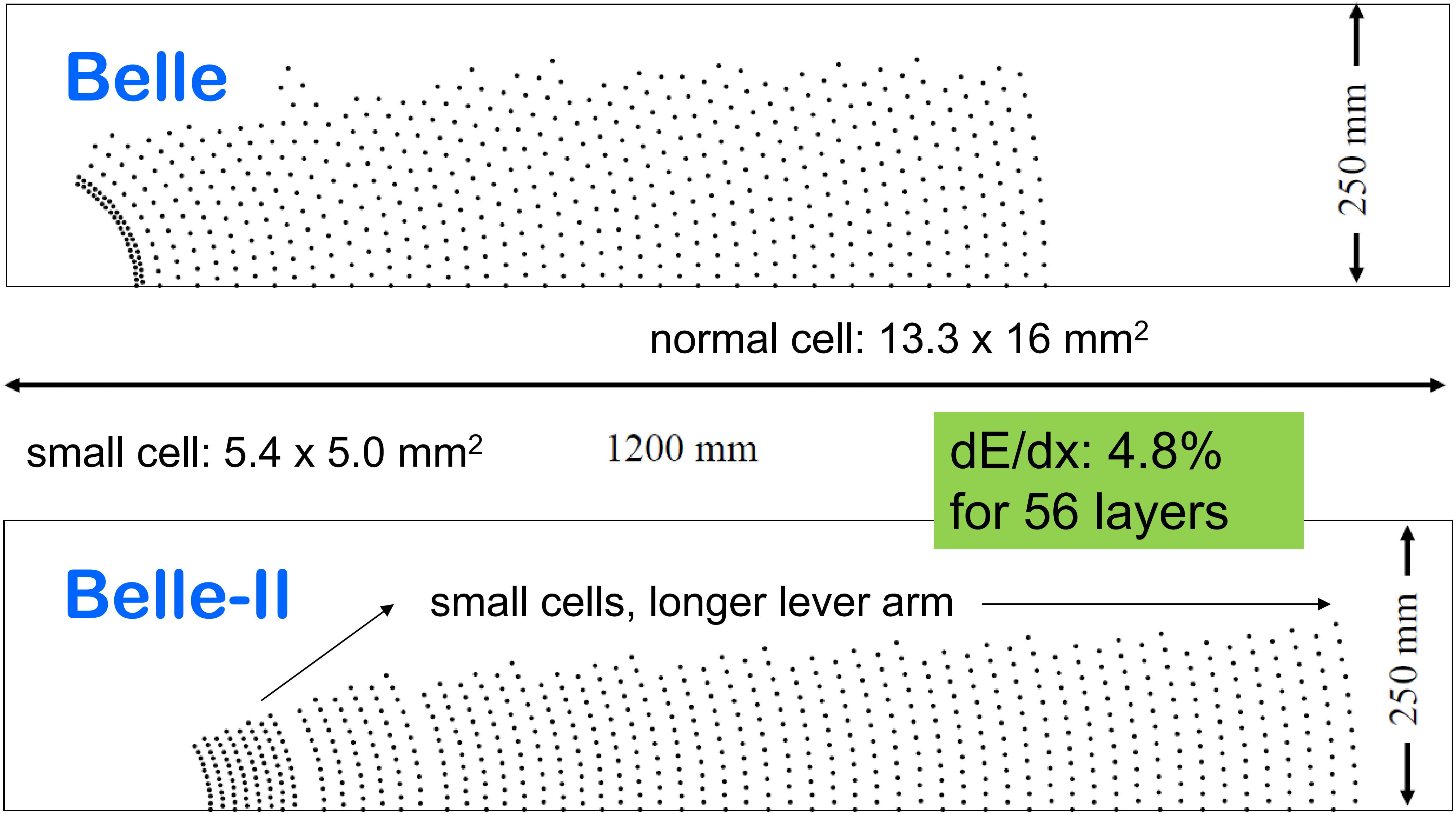
New Tracking System for Belle-II



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-C_2H_6	He-C_2H_6
Diameter of sense wire (μm)	30	30

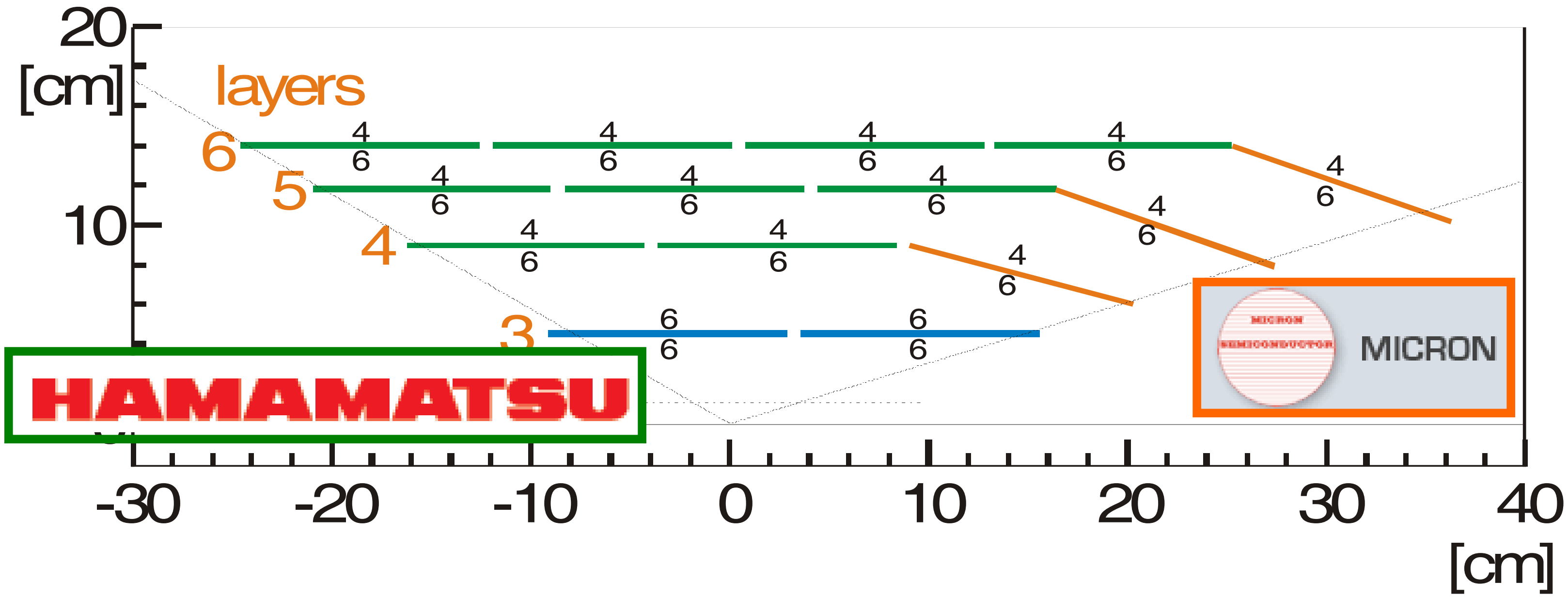
New Central Drift Chamber (CDC)



dE/dx: 4.8%
for 56 layers

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

New Si System for Belle-II : SuperSVD



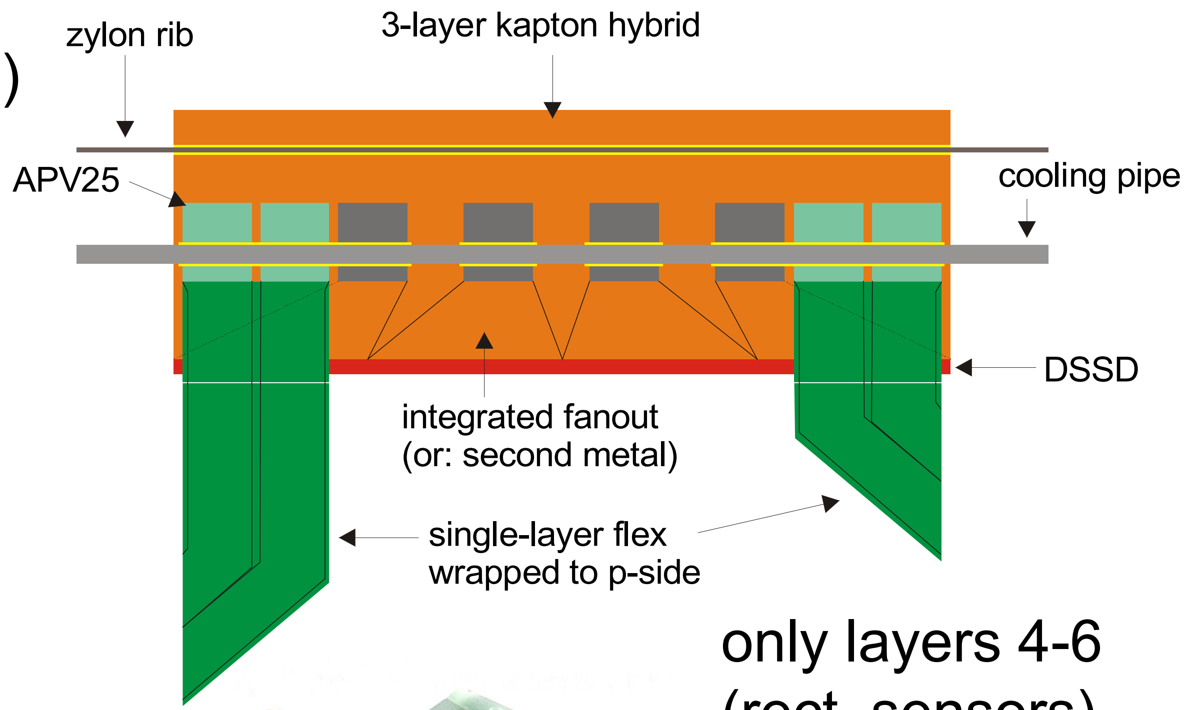
300 μm DSSD

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

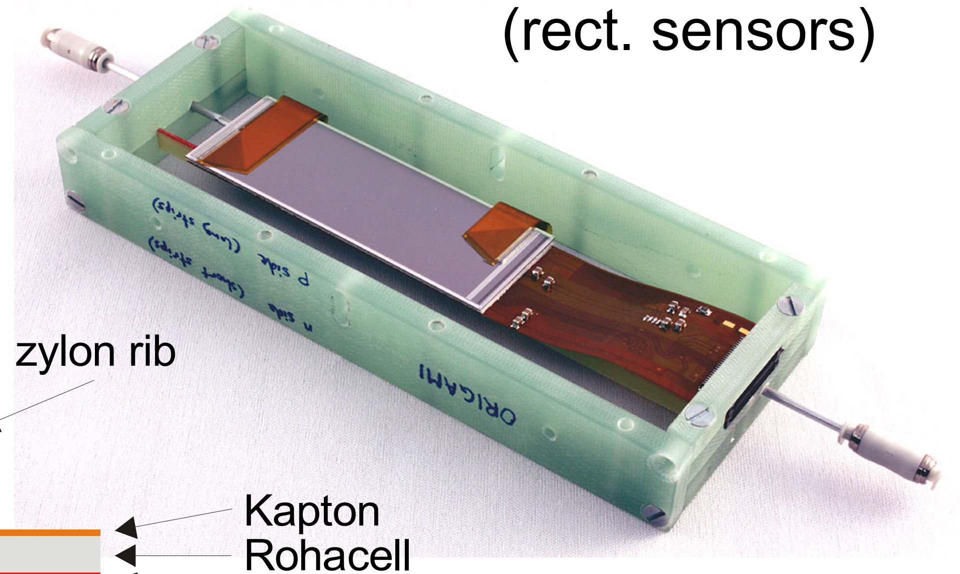
Layer	# Ladders	Rect. Sensors [50μm]	Rect. Sensors [75μm]	Wedge Sensors	APVs
6	17	0	68	17	850
5	14	0	42	14	560
4	10	0	20	10	300
3	8	16	0	0	192
Sum:	**49**	**16**	**130**	**41**	**1902**

Chip on Sensor: The Origami Concept (SVD)

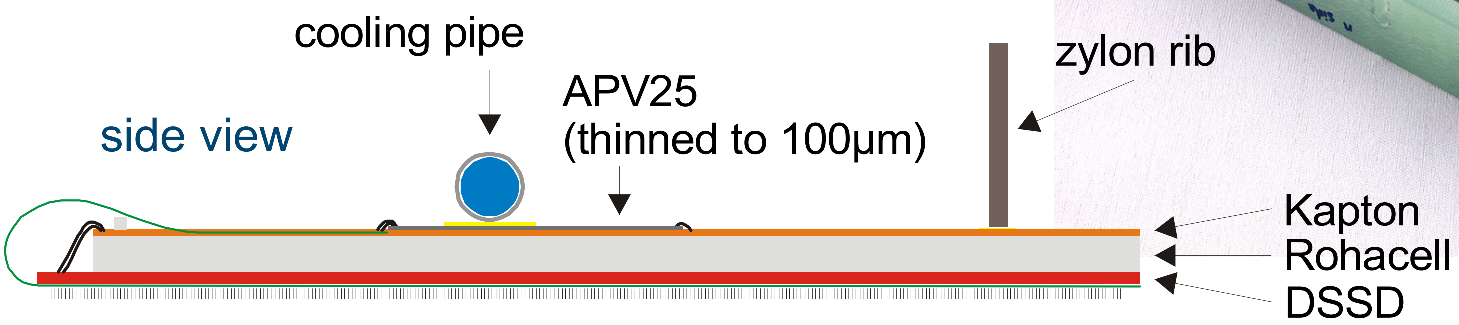
- Thinned readout chips (APV25) on sensor
- Strips of bottom side are connected by flex fanouts wrapped around the edge
- All readout chips are aligned → single cooling pipe
- Shortest possible connections → high signal-to-noise ratio



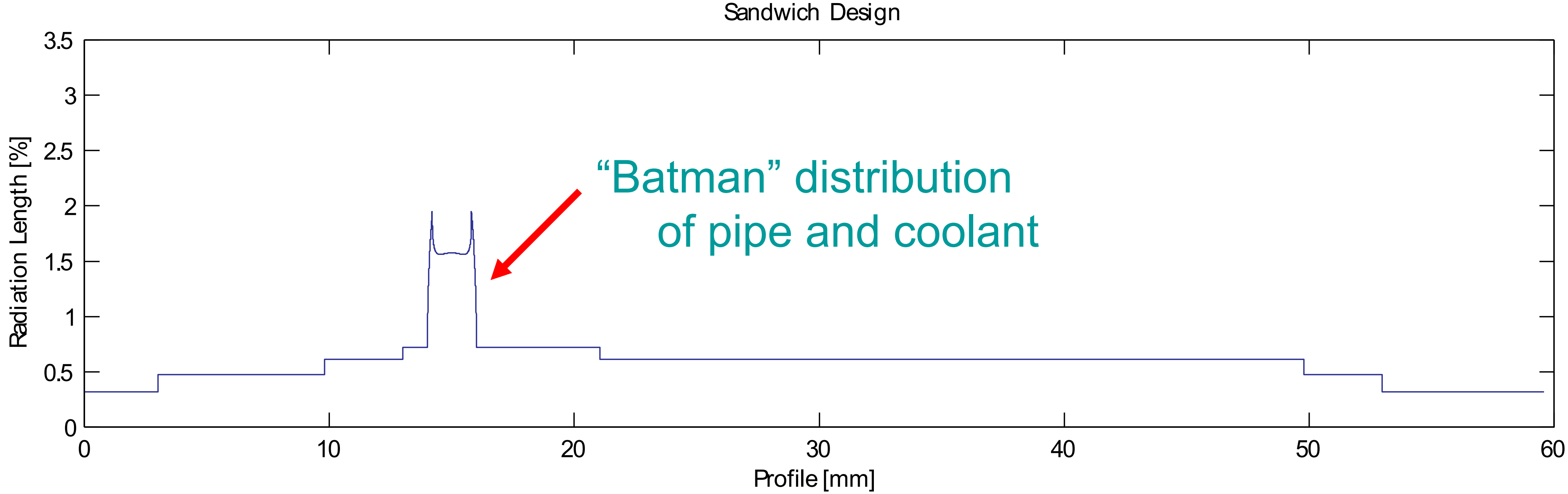
only layers 4-6
(rect. sensors)

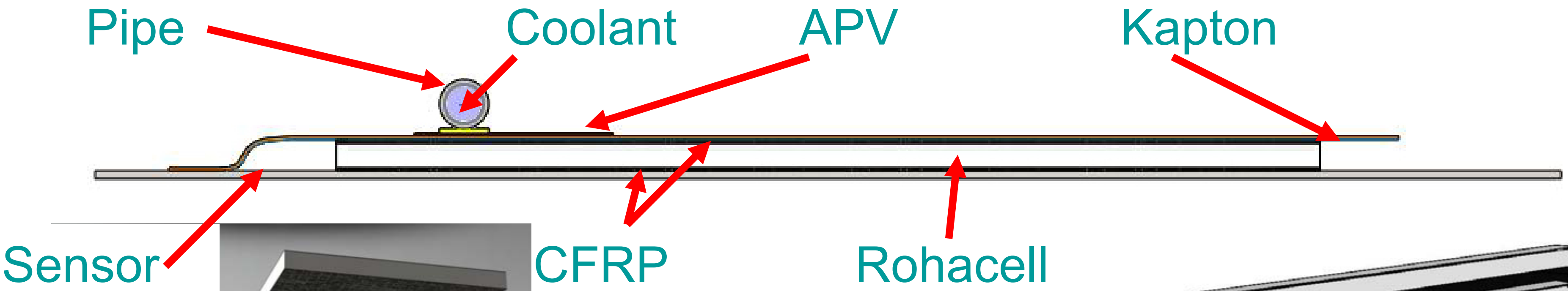


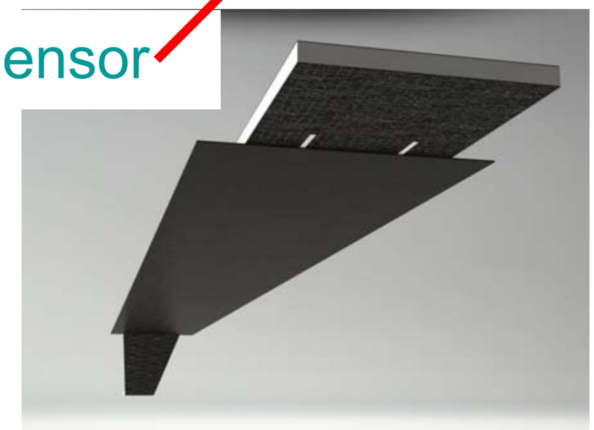
Total material budget: 0.6% X_0
(cf. 0.48% for conventional readout)

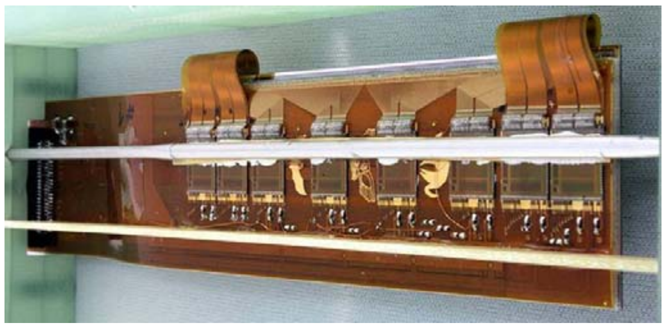


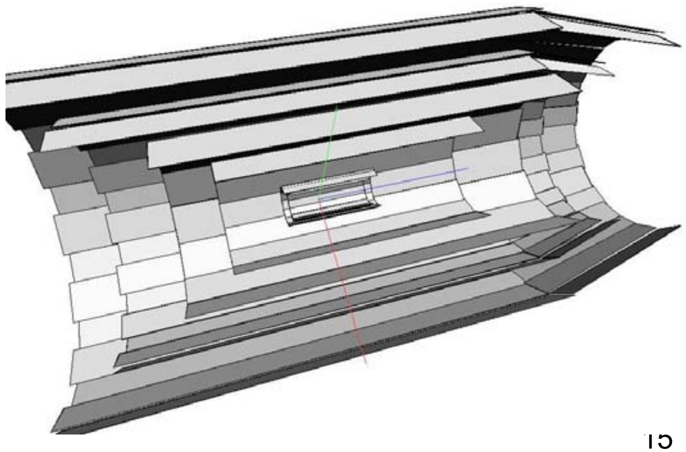
SVD Mechanics and Material Budget



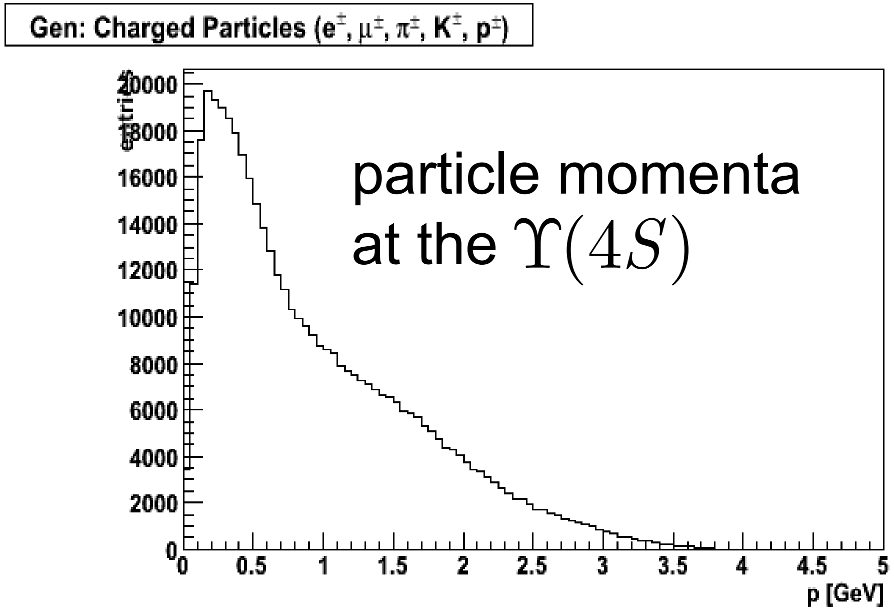








Pixel Detector for Belle-II (PXD)

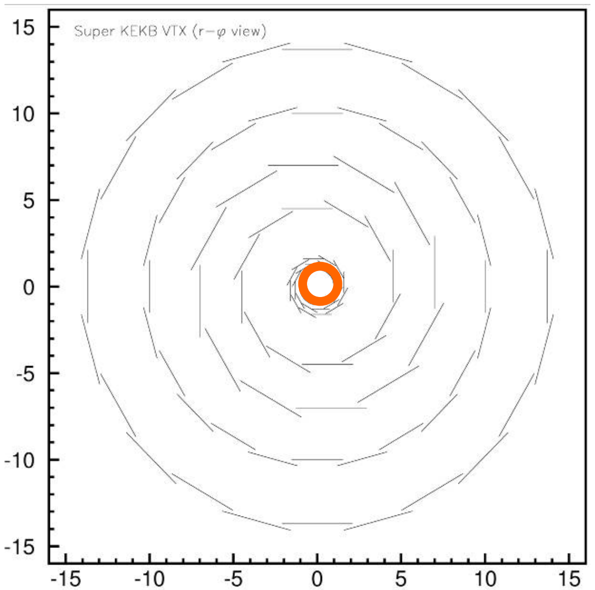


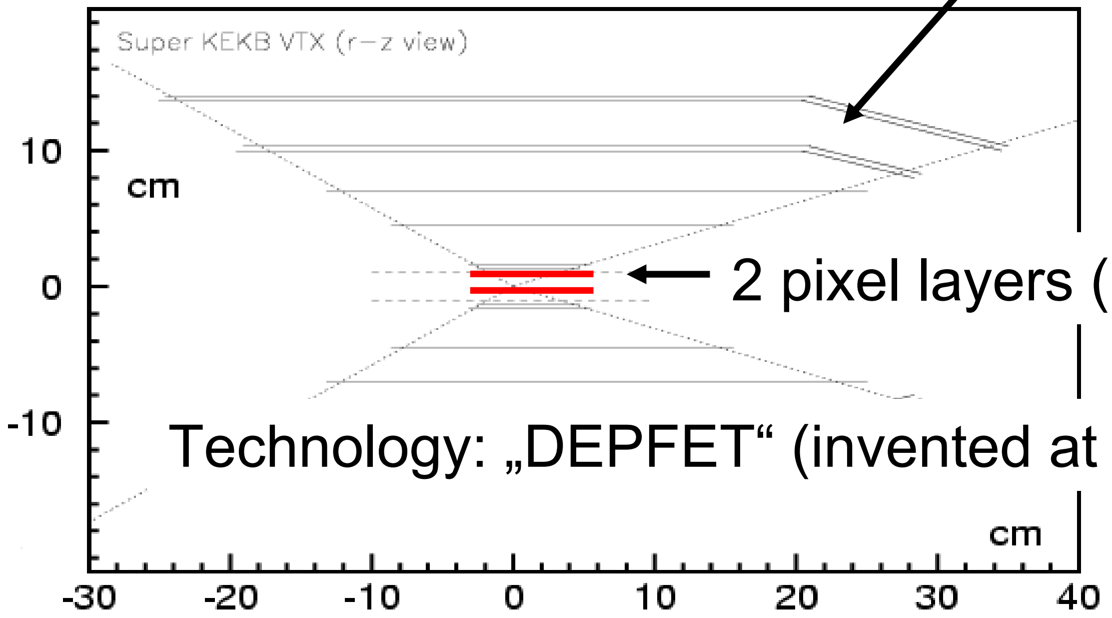
both machine options:
large backgrounds = high occupancy

→ pixels at the innermost (<2cm) radii

→ must be thin, rad. hard, fast readout

→ ready for installation in 2013





Technology: „DEPFET" (invented at MPI)

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”)

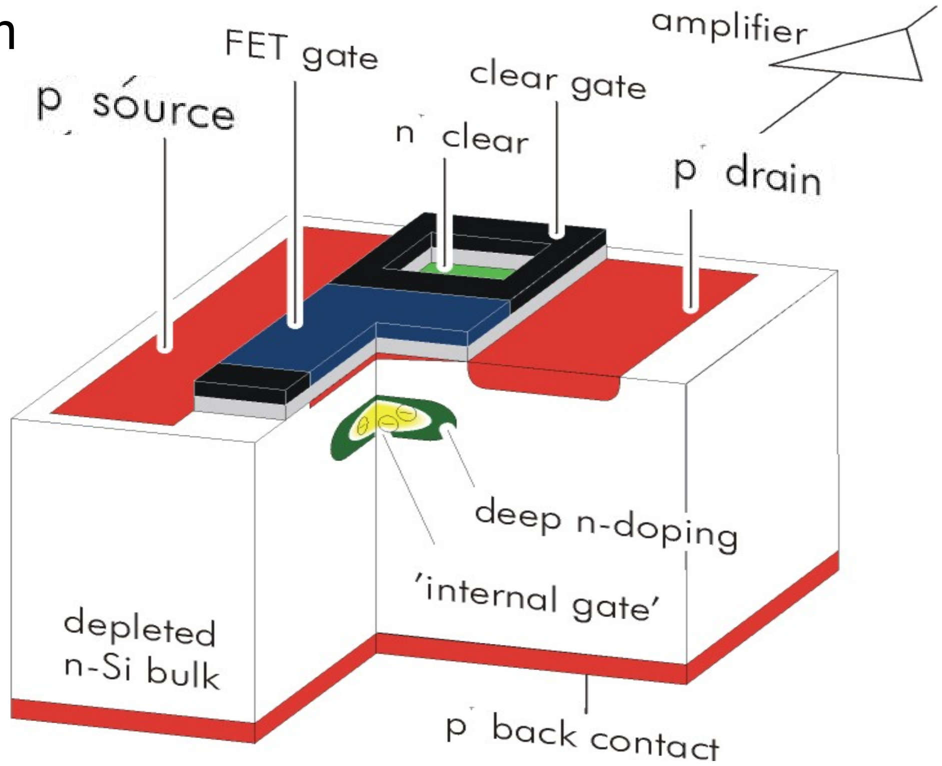
Signal electrons accumulate in the internal gate and modulate the transistor current (g_q ~ 400 pA/e^-)

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

Fully depleted:
→ large signal, fast signal collection

Small capacitance, internal amplification → low noise

Depleted p-channel FET

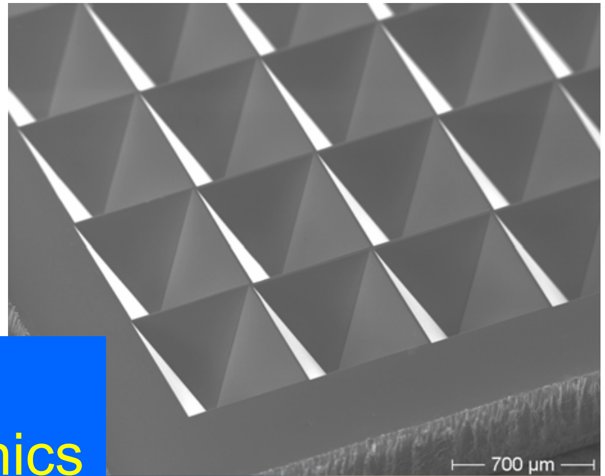


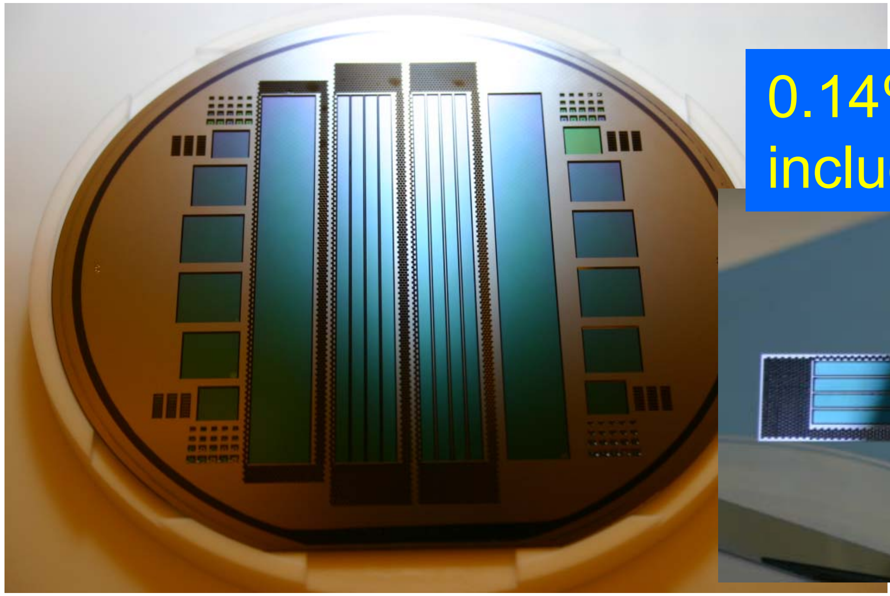
Transistor on only during readout:
→ low power

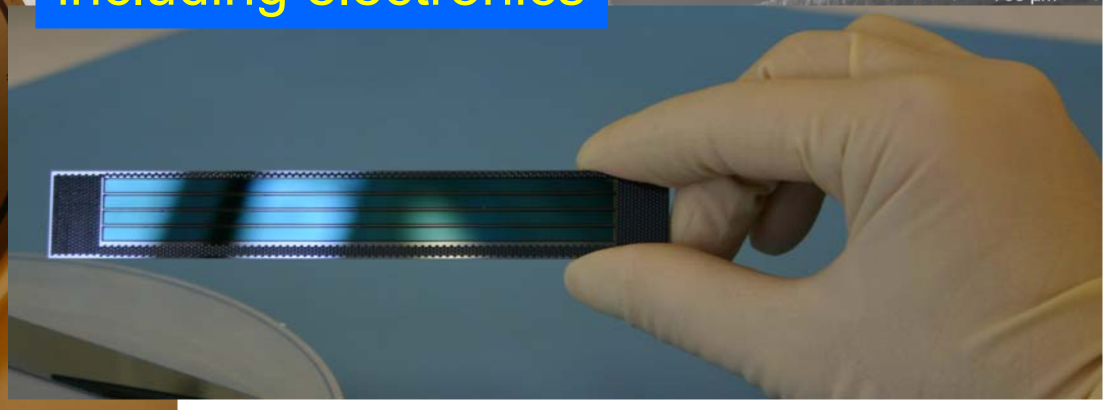
Thinning Technology

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 μm thickness has been produced
- Samples of 10x1.3 cm² & frame of 1 & 3 mm width
- Electrical properties OK (diodes)







0.14% X_0
including electronics

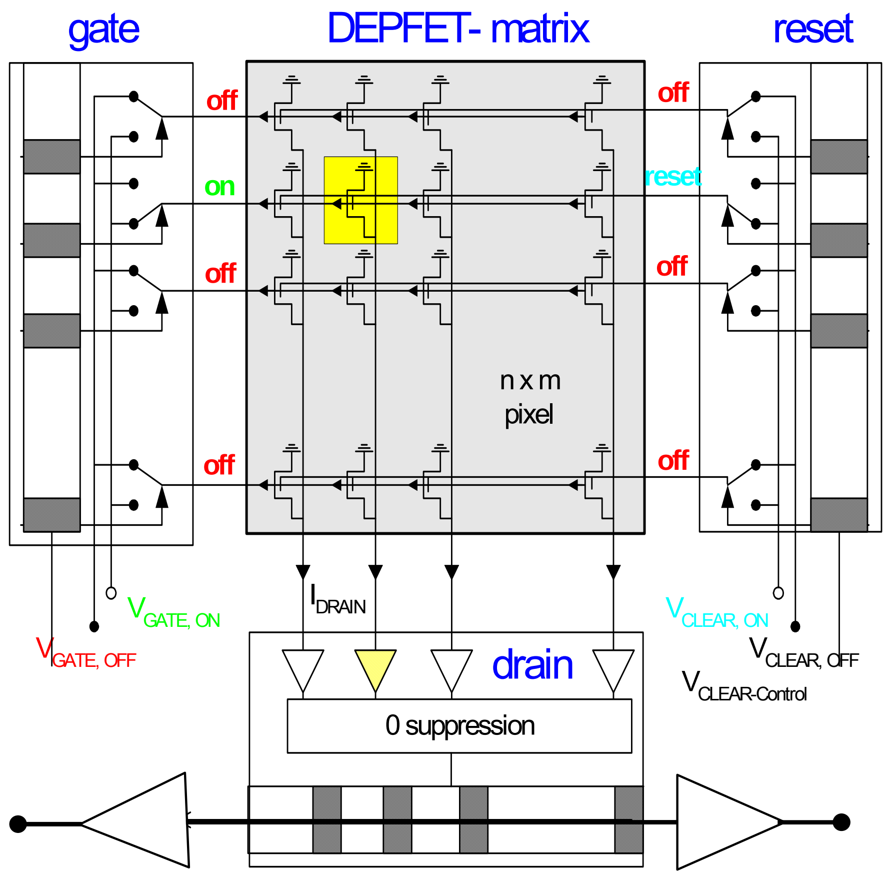
Array of DEPFETs

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



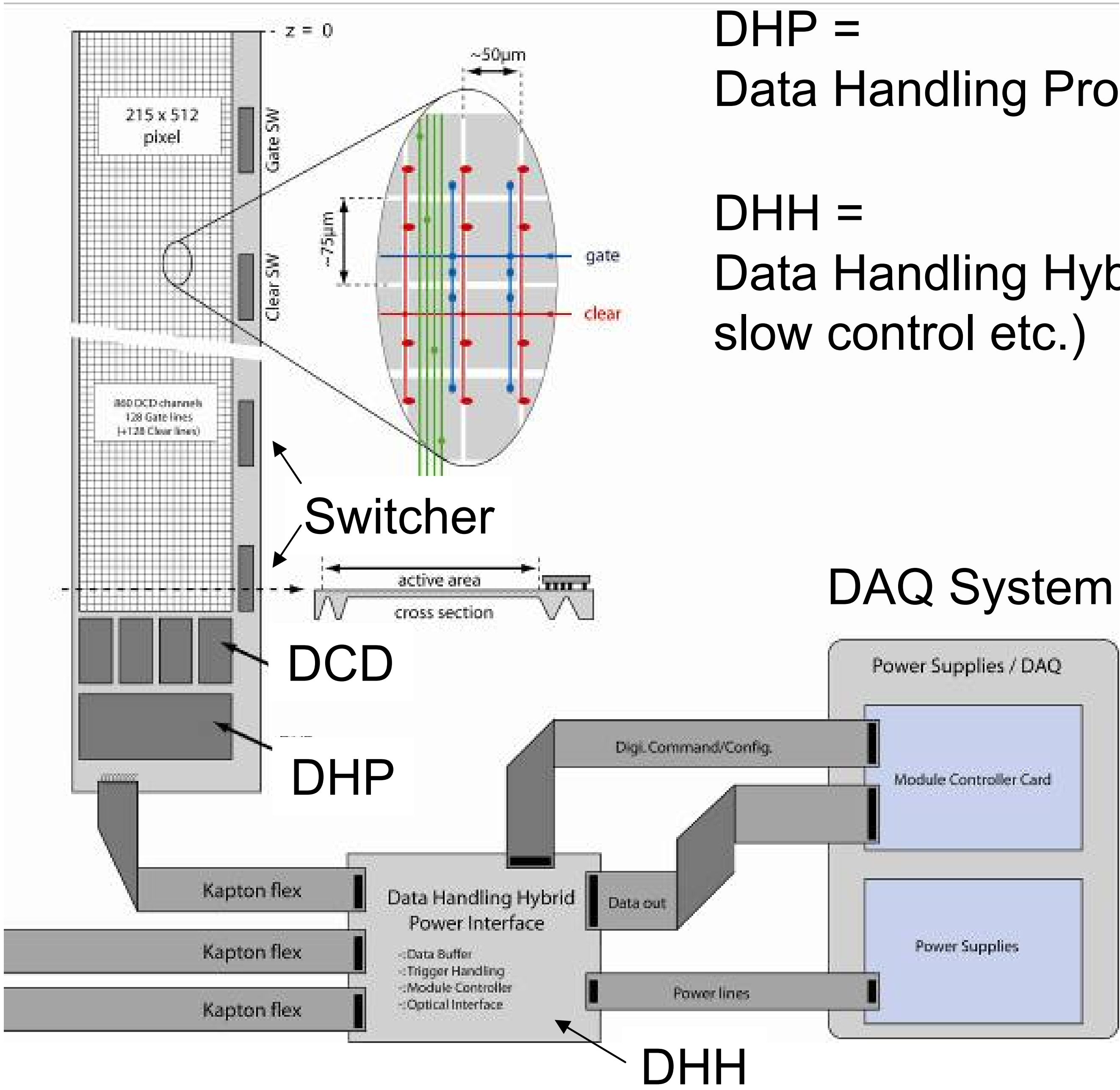
→ Switcher

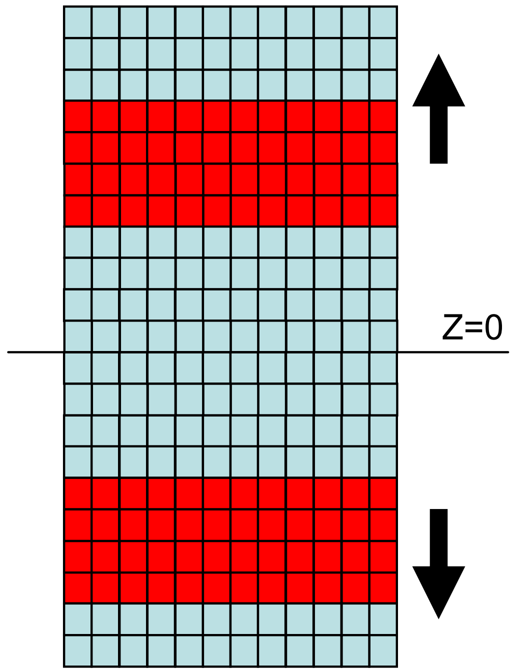
→ DCD (drain current digitizer)

DEPFET Electronics and DAQ

DHP =
Data Handling Processor (zero-suppression)

DHH =
Data Handling Hybrid (buffer readout, slow control etc.)





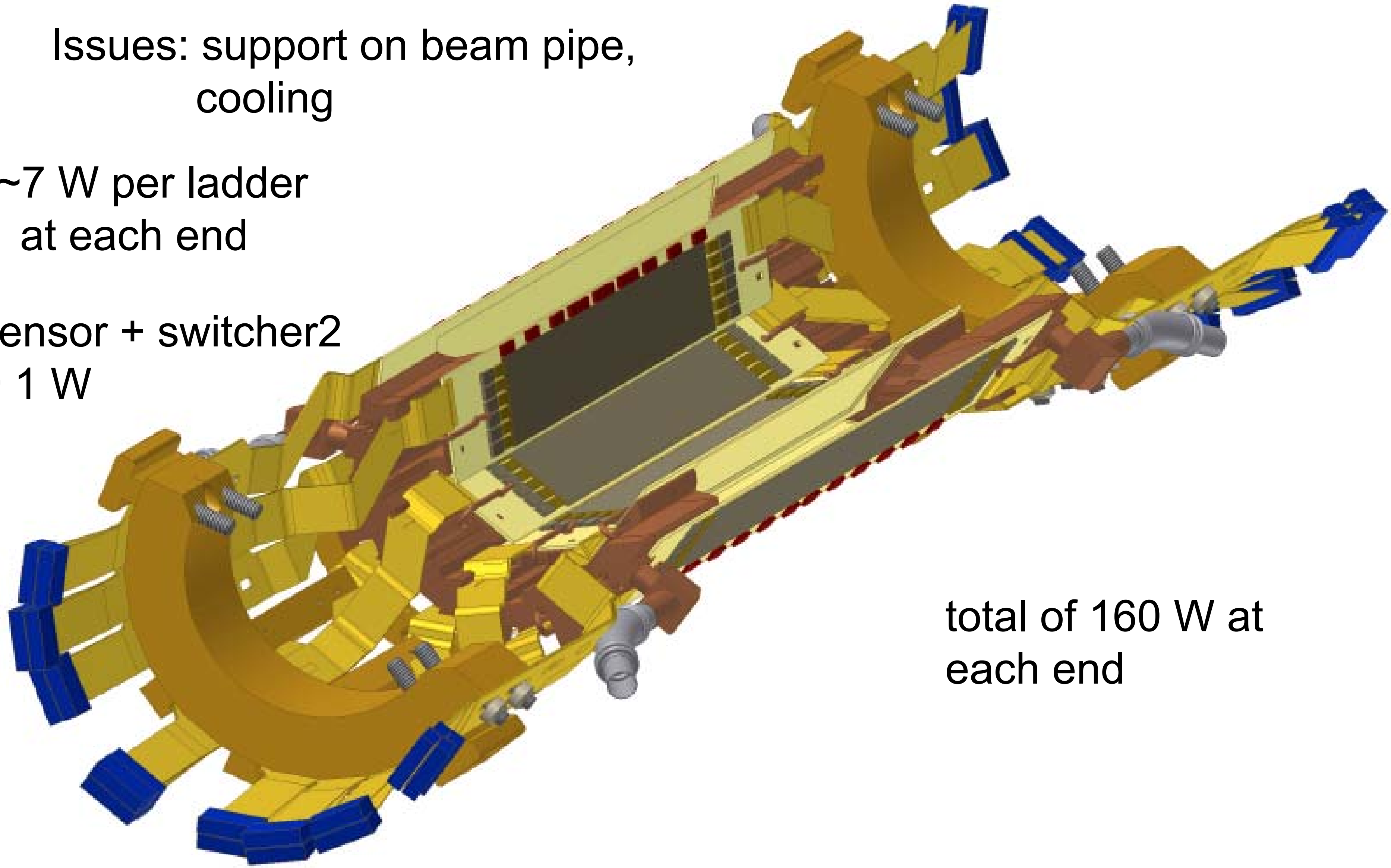
readout speed
80 ns/row

PXD Mechanics, Inner Layer

Issues: support on beam pipe, cooling

~7 W per ladder at each end

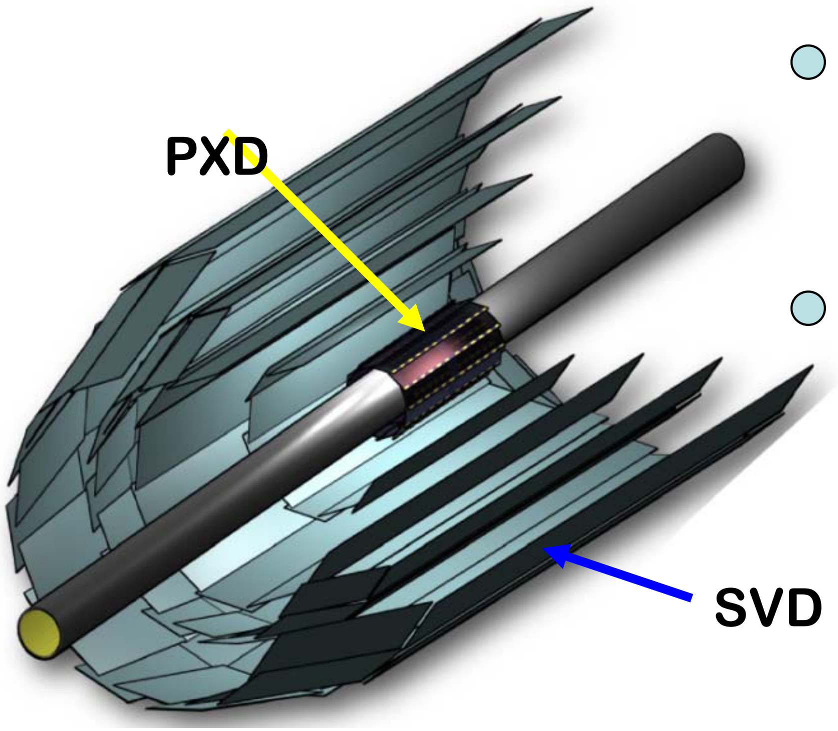
sensor + switcher2 ~ 1 W



total of 160 W at each end

Expected Performance with PXD

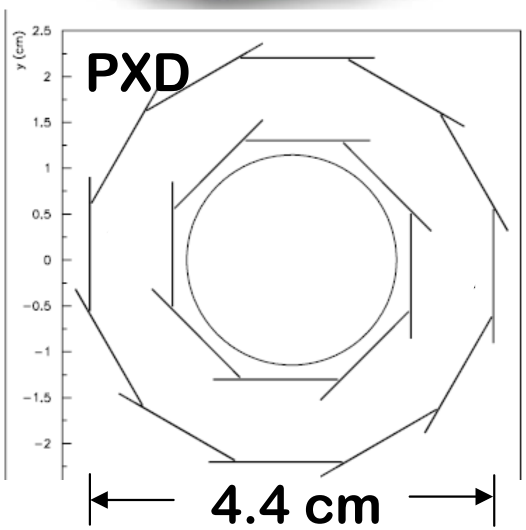
Nano beam option: 1 cm radius of beam pipe



„PXD“

- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.3, 2.2 cm) monolithic sensor
  thickness 50 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

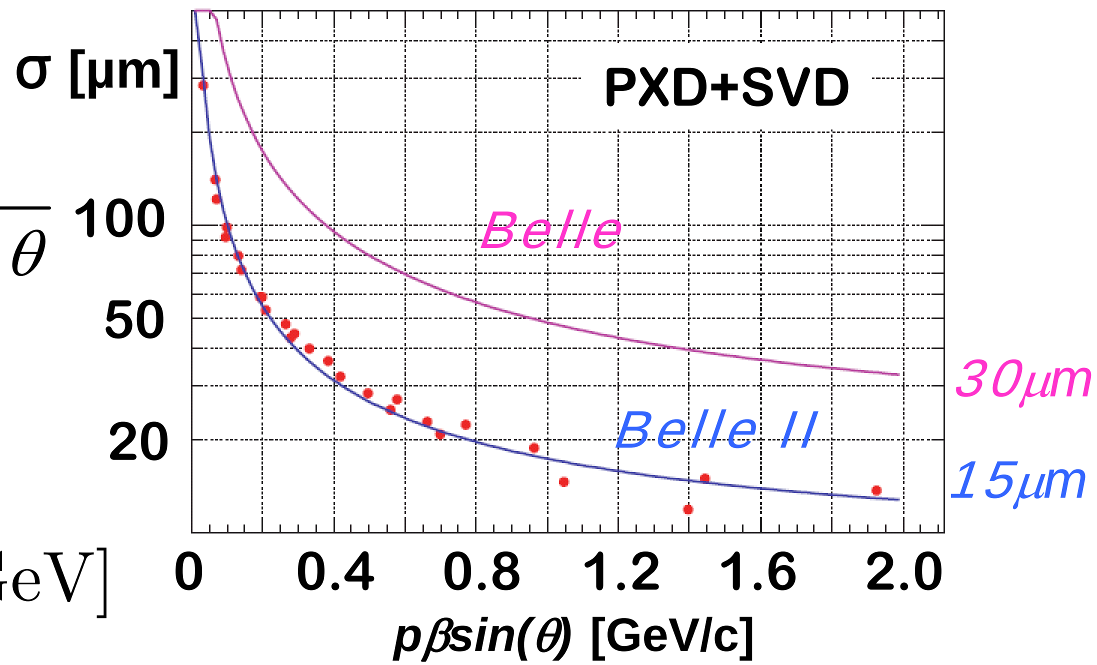


$$\sigma = a + \frac{b}{p\beta \sin^{5/2}\theta}$$

Belle II:

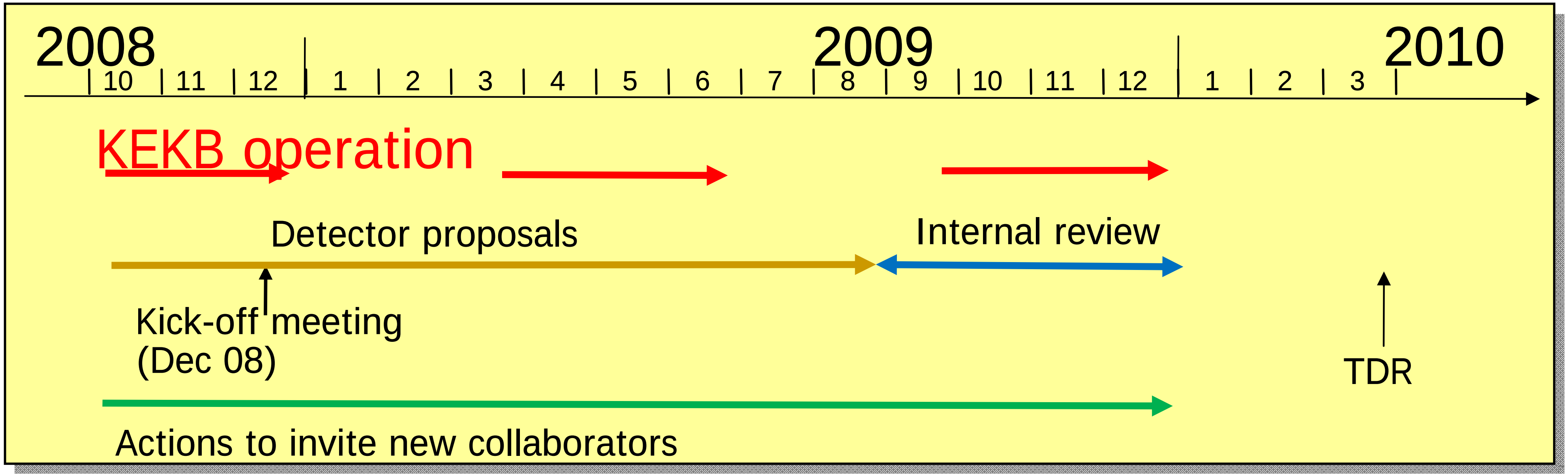
$$a = 8.5\,[\mu m]$$

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

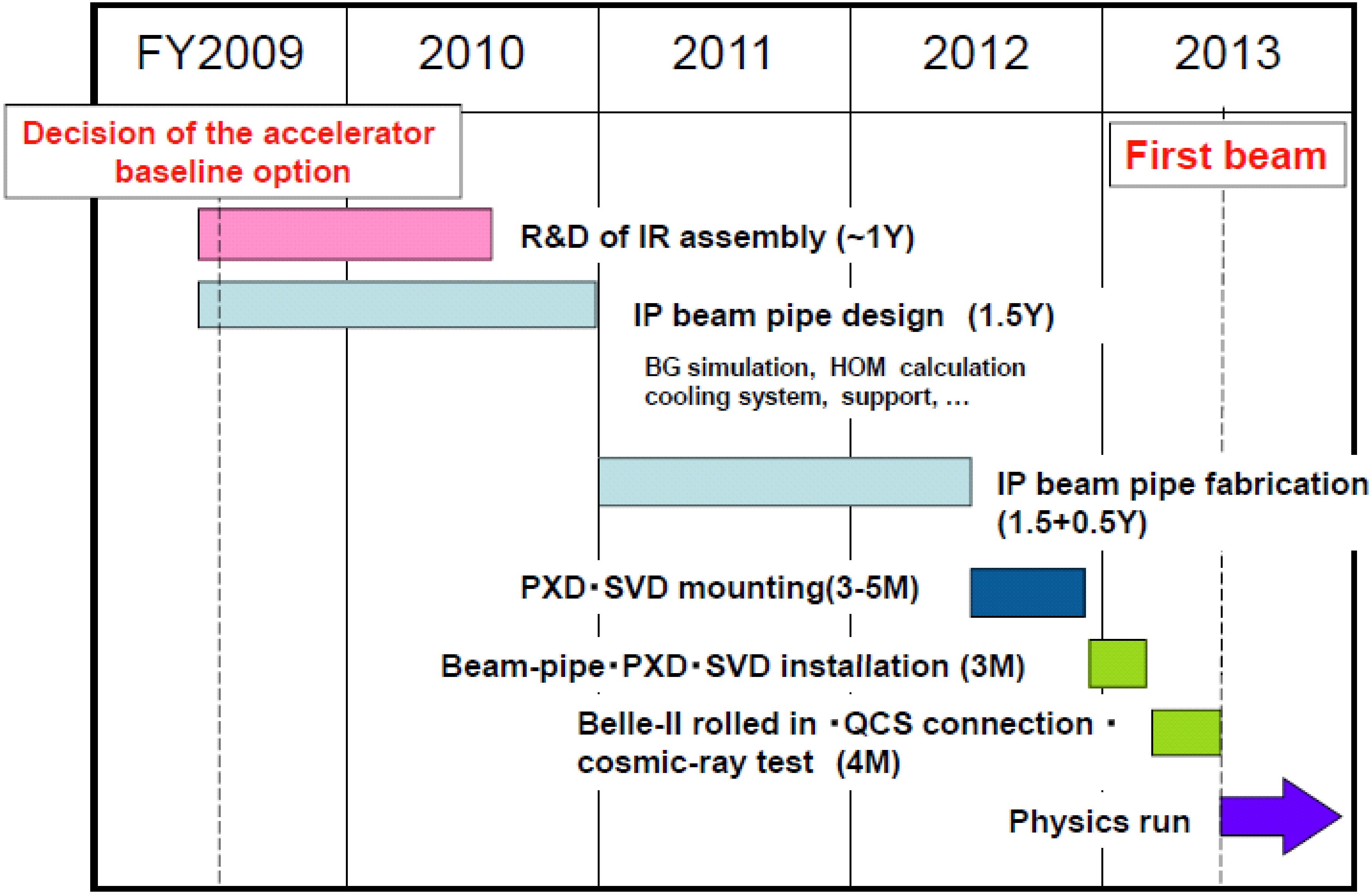


Project Timetable

- Near-term plan
  - Detector proposals (by Dec. 2009)
  - Decisions on technology choices (Barrel PID configuration/photon detector, ECL endcap crystalls and photosensors)
  - TDR by March 2010



Project Timetable (cont.)



Belle-II Collaboration

2004.06: LoI for SuperKEKB
2008.01: KEK Roadmap → identified as high priority project at KEK
2008.12: New collaboration (Belle-II) officially formed

- 13 countries/region, 43 institutes, ~300 members

Organization:

Executive Board (Chair: H. Aihara)

Spokesperson: P. Križan
Project manager: M. Yamauchi

Institutional Board (Chair: L. Piilonen)

Physics coordinator: B. Golob

Technical coordinator: Y. Ushiroda

Software /computing coordinators: T. Hara / T. Kuhr

2009.11: 4th Open Collaboration Meeting

European Participation in Belle-II

- Austria: HEPHY (Vienna)
- Czech republic: Charles University in Prague
- Germany: U. Bonn, KIT Karlsruhe, MPI Munich, U. Giessen
- Poland: INP Krakow
- Russia: ITEP (Moscow), BINP (Novosibirsk),
- Slovenia: J. Stefan Institute, U. Ljubljana, U. Maribor, U. Nova Gorica

(Czech republic, Germany and Poland:) Members of the DEPFET Collaboration:
+ Heidelberg, Göttingen
+ 5 Spanish groups

Sizeable fraction of the collaboration: in total 100 collaborators out of 287!

Project Status

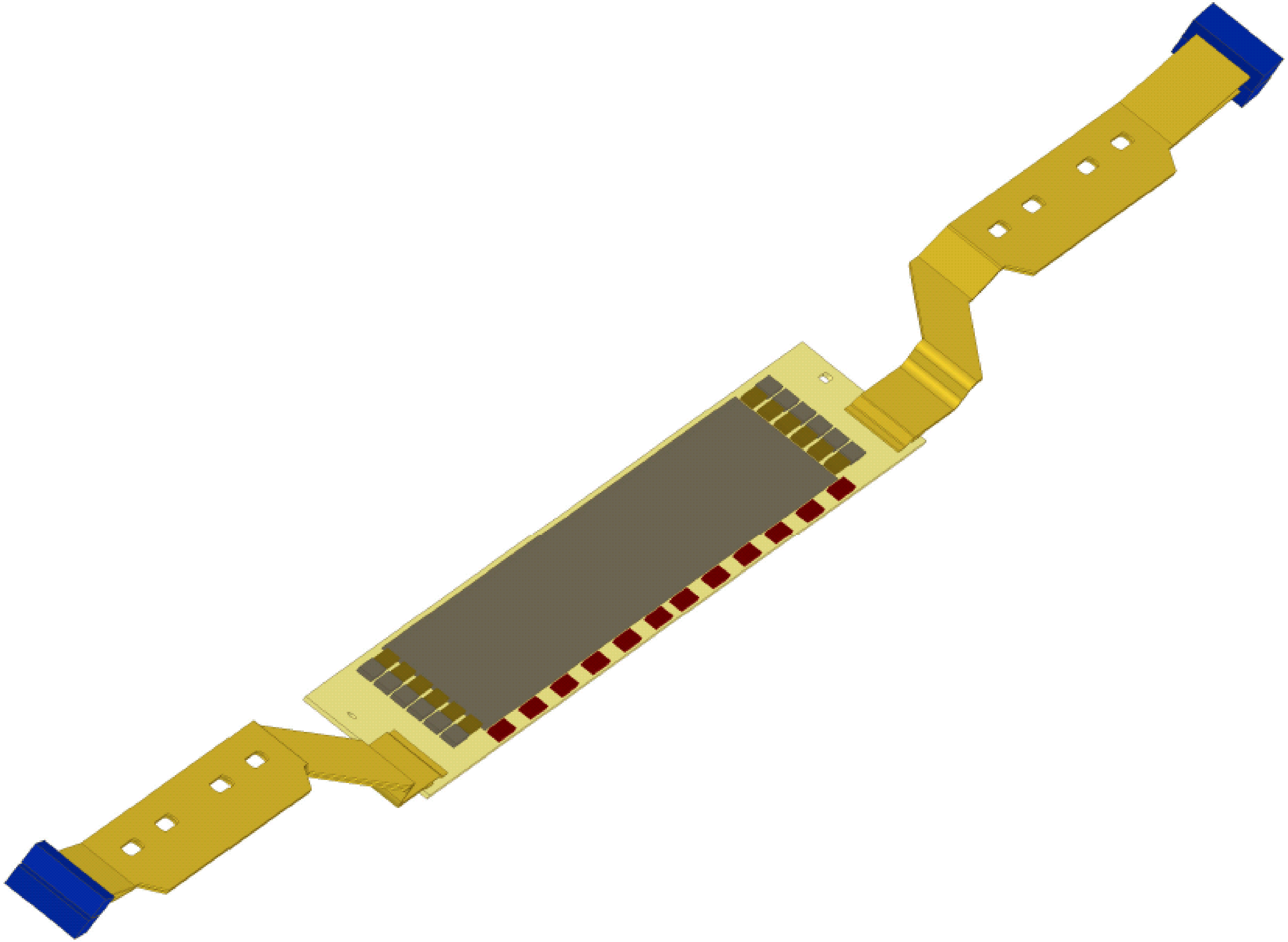
- SuperKEKB and Belle-II are priorities of KEK
- The Japanese government has allocated 32 oku-yen (32 M$) for upgrade R&D in FY 2009, as a part of its economic stimulus package. This is considered as a very important sign in Japan.
- KEK has submitted to the Ministry of education, science, and technology (MEXT) a budget request for FY 2010 and beyond for 350 M$ for the construction of SuperKEKB. MEXT submitted a request for the upgrade budget to the Ministry of finance.
- The Japanese government is currently reviewing all major projects. The decision concerning SuperKEKB and Belle-II is expected by the end of this year.
- Several non-Japanese funding agencies have already allocated sizable funds for the upgrade.

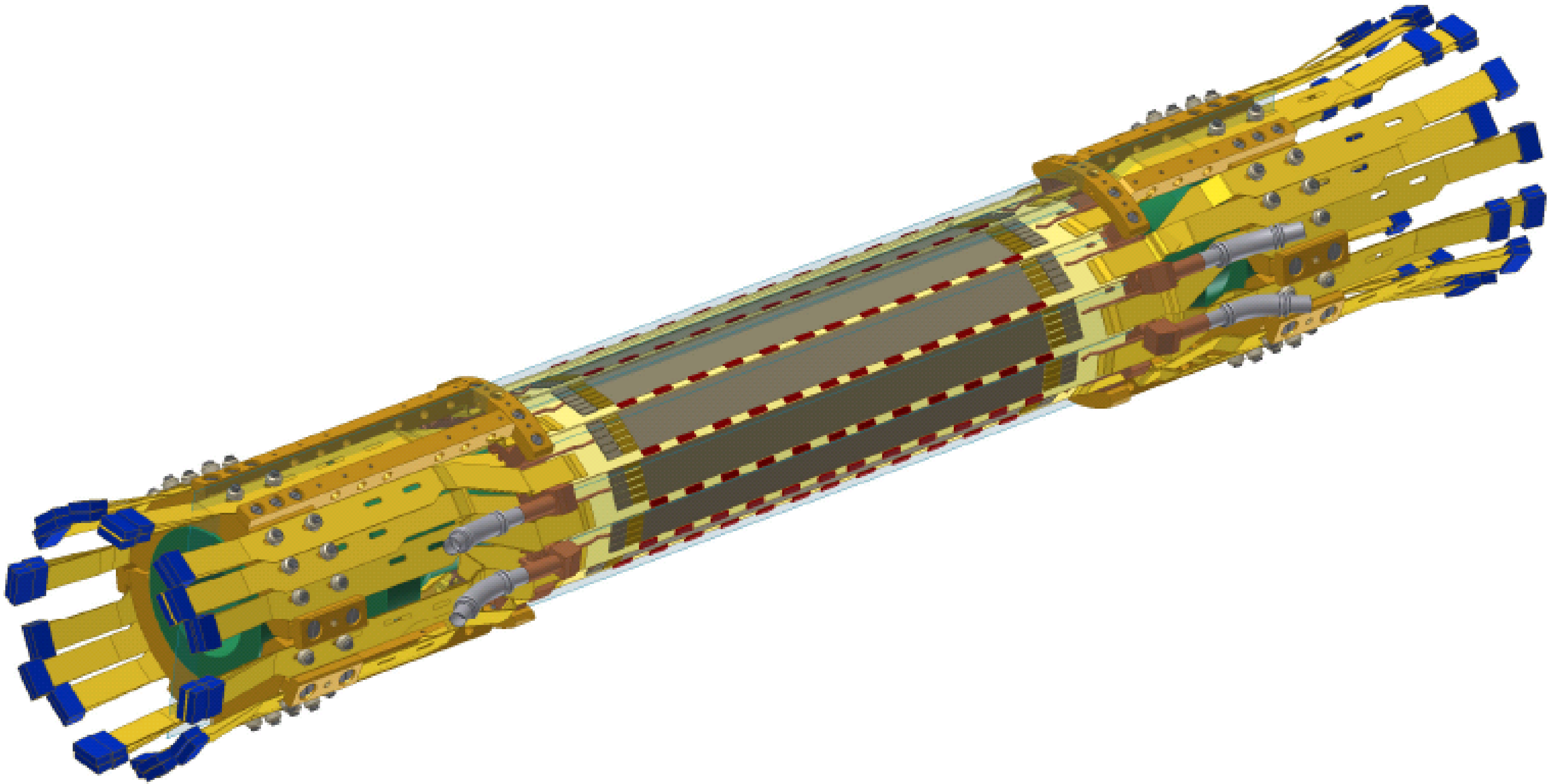
Summary & Conclusions

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance.
- Major upgrade at KEK in 2010-13 → Super B factory, L x 40
- The Belle-II detector is essentially a new project, all components have to be replaced, options to be frozen in the next few months
- The project has a strong European participation (about 1/3!)
- A physics reach update is being prepared – to be made public soon
- Expect a new, exciting era of discoveries, complementary to LHC

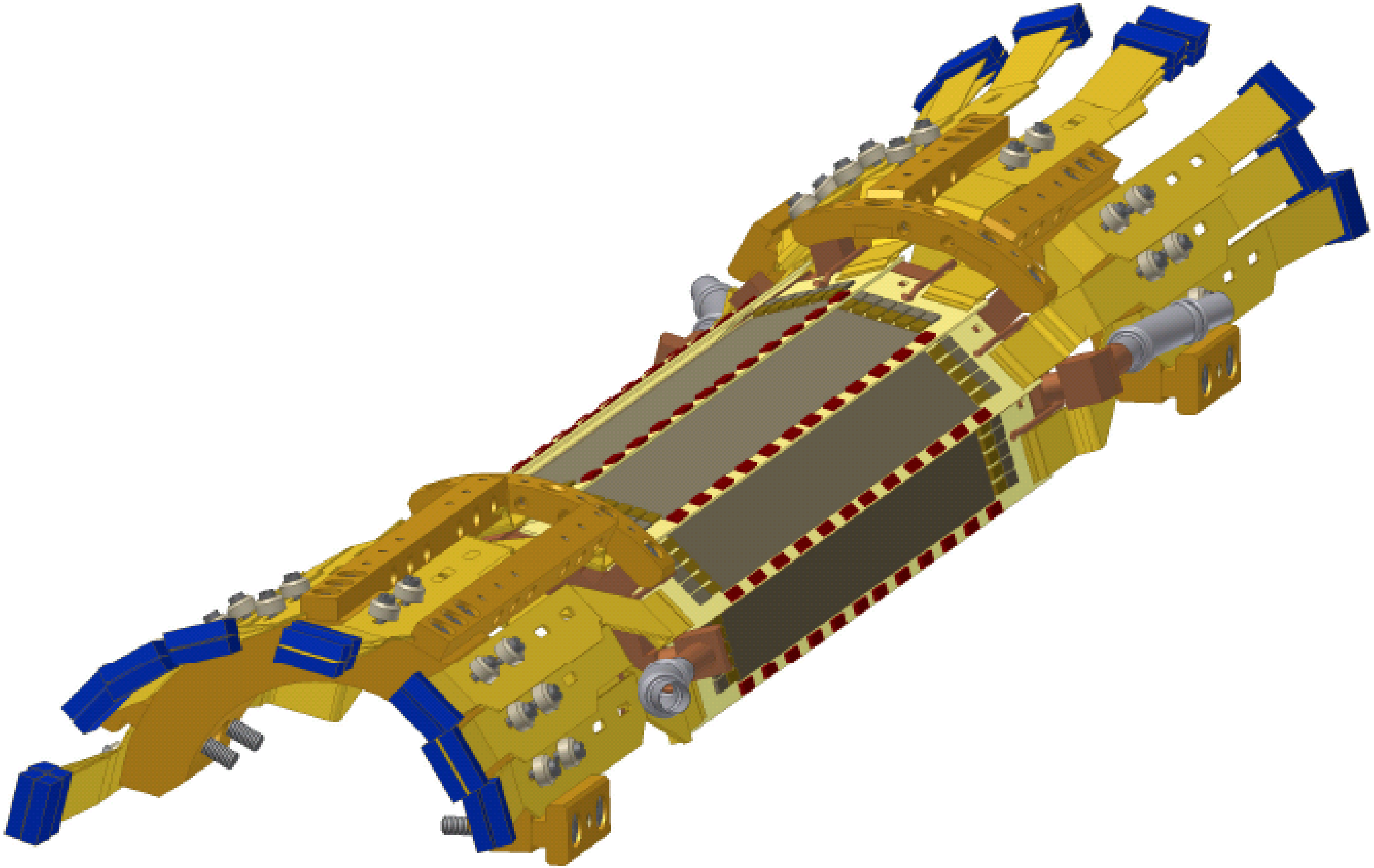
Backup

PXD Sensor & Kapton Cable





PXD Mechanics, Outer Layer



DEPFET-Collab. @ Belle-II

Original Collaboration: DEPFET pixel detector @ ILC (since 2002)
now: Unite efforts to deliver a REAL PXD by 2013 for Belle-II

University of Barcelona, Spain
CNM, Barcelona, Spain
Universitat Ramon Llull, Barcelona, Spain
Bonn University, Germany
Heidelberg University, Germany
Giessen University, Germany
Goettingen University, Germany
Karlsruhe University, Germany
IFJ PAN, Krakow, Poland
MPI Munich, Germany
Charles University, Prague, Czech Republic
University of Santiago de Compostela, Spain
IFIC, Valencia, Spain

DEPFET@Belle-II

Management:

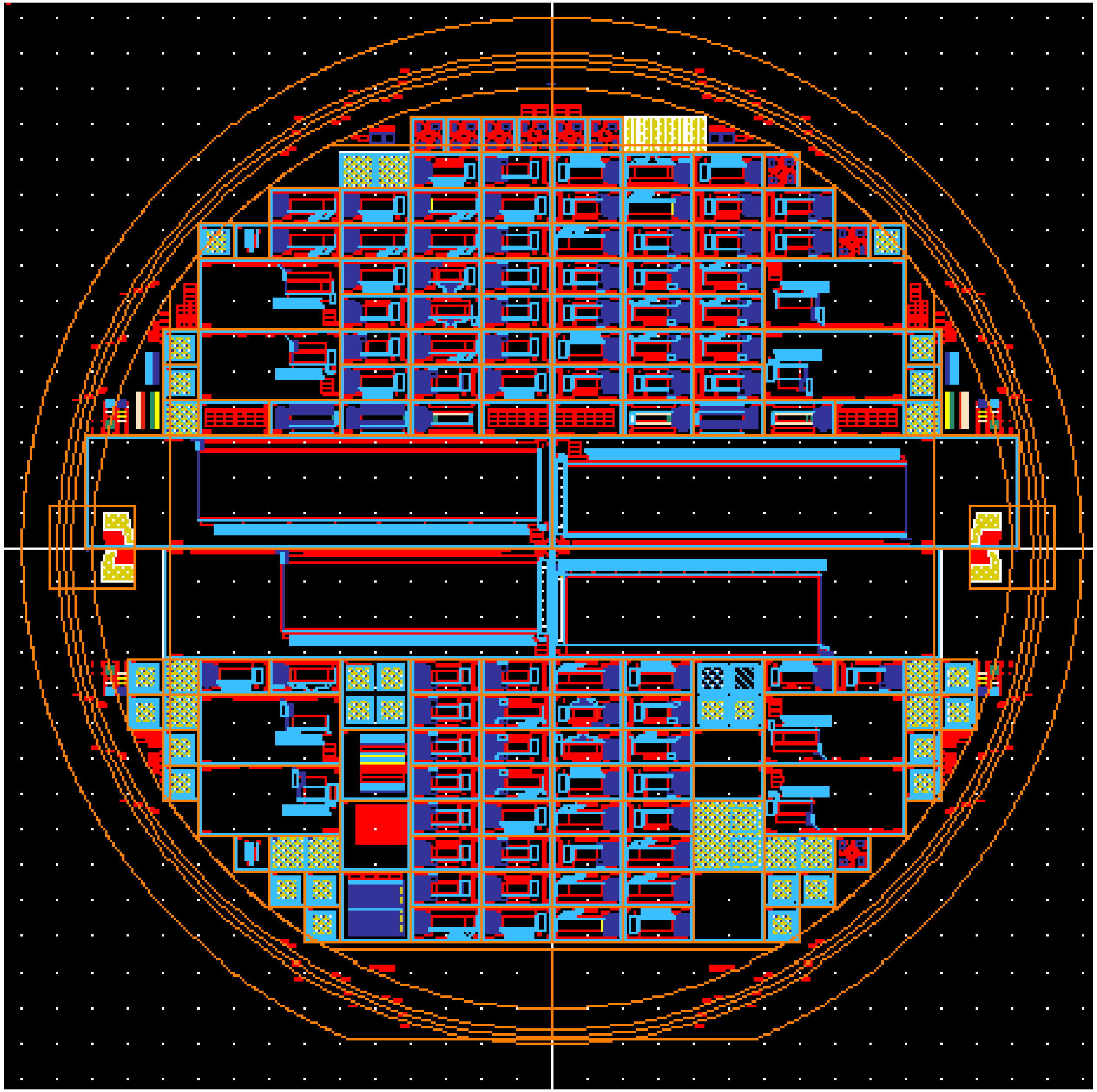
- IB- Board
- Project Leader
  C. Kiesling
- Technical Coord.
  H.-G. Moser
- Integration Coordinator
  Shuji Tanaka (KEK)

with important help from Hawaii, KEK, Vienna

Main PXD R&D Issues

Sensors:	pixel geometry -> parameter studies prototyping, radiation hardness inter-connections, thinning technology
Read-out ASICs:	Drain Current Digitizer chip (DCD): prototyping Switcher: rad-hard design
DHP & DHH: :	Zero-suppr: 400 Gpx/s -> 2 Gpx/s (trigger, occ) -> 1.6 Gb/s per half module
DAQ:	~200 Gb/s total (zero-suppressed!)
Mechanics, Cooling:	Mounting, thermal coupling, alignment …,
Test Procedures:	System / beam tests

Prototype Sensors for PXD



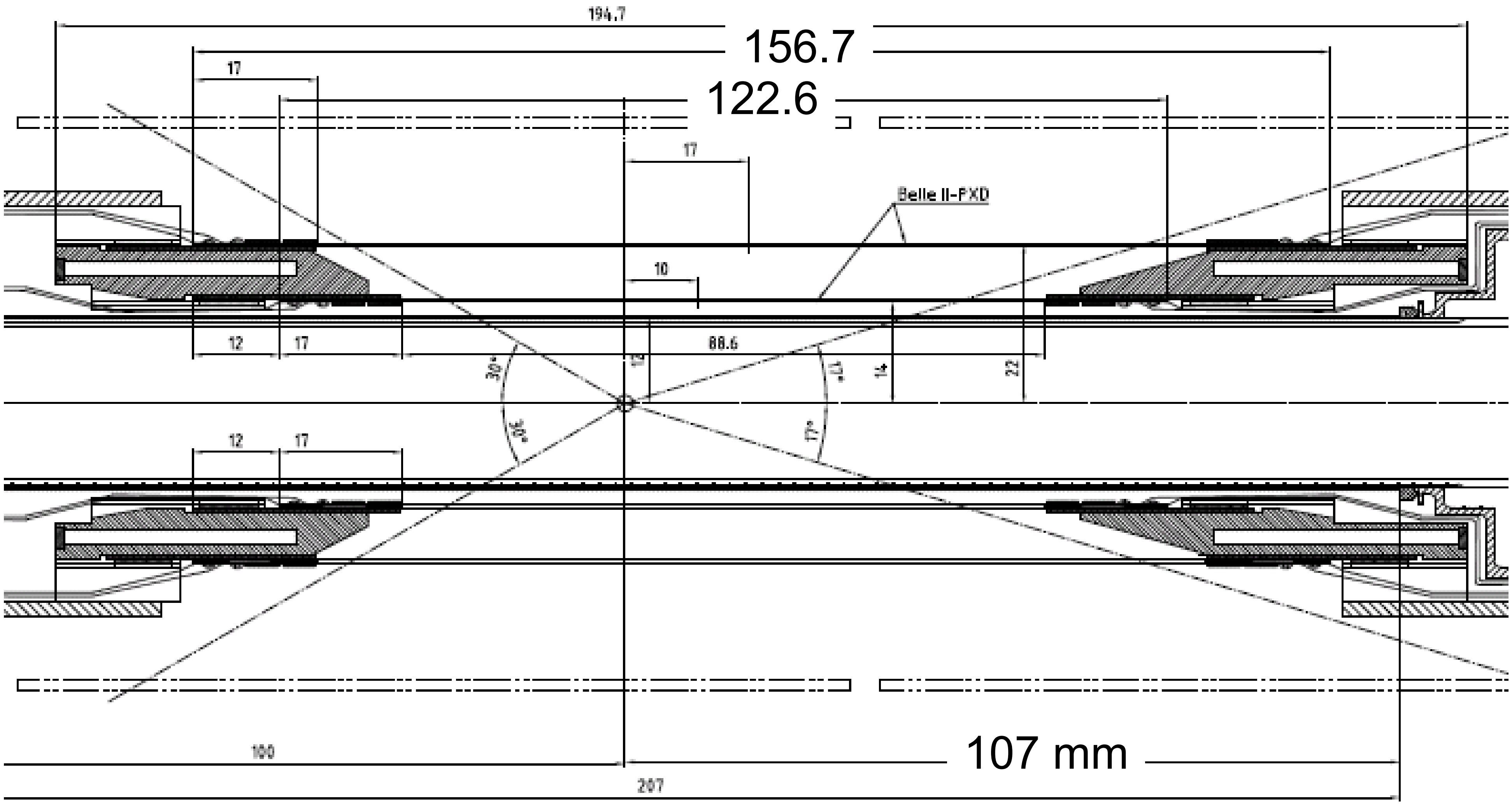
4 big chips
half modules
bump bonded
4 different design options
2 inner
2 outer

8 standard BB (128 x 16)
same design options as for
the big chips (2 of each)

85 standard WireBonded
(128 x 8 or 16)
8 of them on thin oxide
6 ILC (128x128)
2 of them on thin oxide
9 mini matrices
2 of them on thin oxide
4 single trans. Chips
24 DEPFET pairs with varied
channel and clear gate geometry

Test structures

Ladder Mechanics



outer sensor must be in two parts (limitation of wafer size)

Data Acquisition

Update: Nano beam option

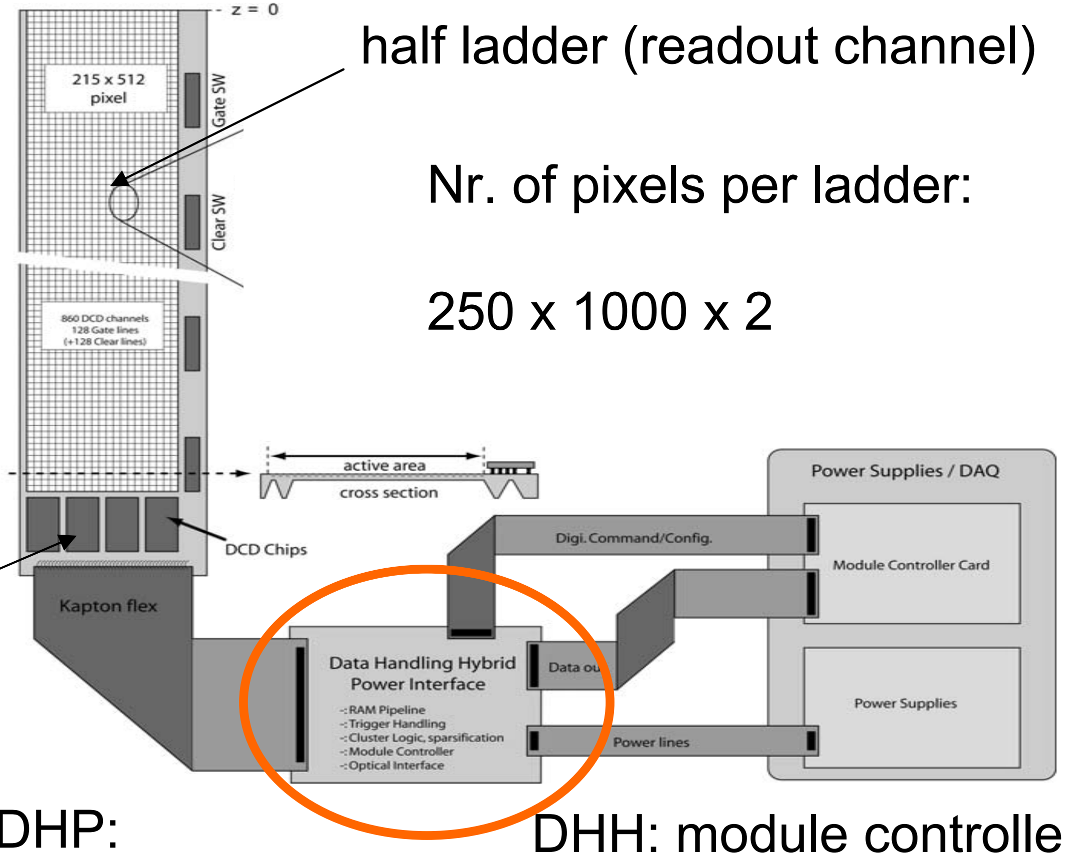
250

1000

half ladder (readout channel)

Nr. of pixels per ladder:

250 x 1000 x 2



- 40 half ladders:
  10 Million pixels (px)
- 1-2% occupancy (?)
- 200 kpx on at any time

→ 2×10^5 px in each event

- 4 bytes per px (pos + ADC)
- 800 kB/event

DHP:
zero-suppression
readout buffers (10 MByte)
slow control …

DHH: module controller
data link

Digitzation (DCD)

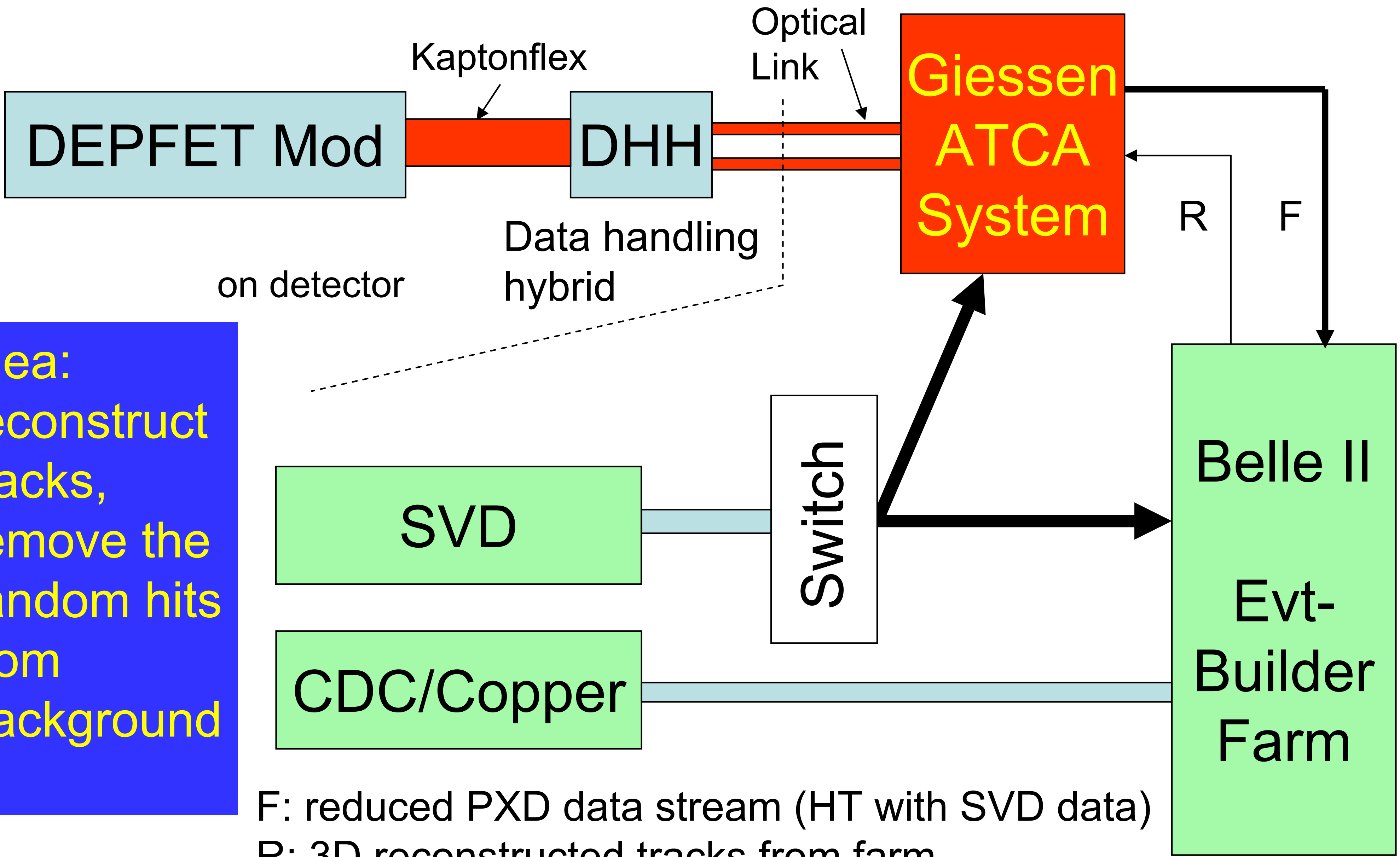
Total evt size: ~ 1 MByte

Data Compression (clustering):

→ ½

C. Kiesling, XIth Meeting SuperB Project, INFN, Frascati, Dec. 1-5, 2009

Data Acquisition



Idea: reconstruct tracks, remove the random hits from background

F: reduced PXD data stream (HT with SVD data)
R: 3D reconstructed tracks from farm

DAQ Scheme (Proposal)

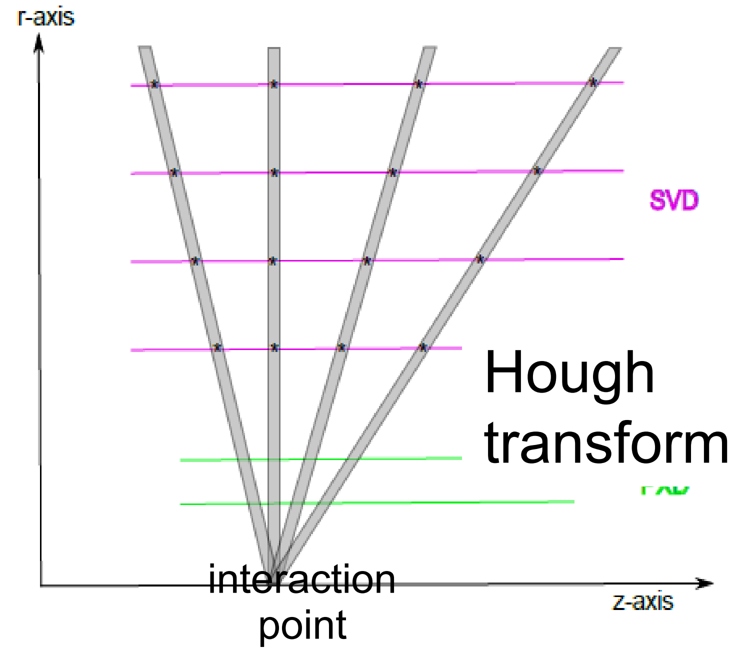
- **debugging ongoing**
  incl. development and testing
  of FPGA-to-FPGA communication
  a.) onboard
  b.) board-to-board
  (via backplane)
- **preparation for beamtime**
  (readout with 1 ATCA shelf)
  at HADES test experiment at GSI
  in 2010

- **main priority right now:**
  trigger and event builder
  algorithms for HADES

Online PXD Data Reduction

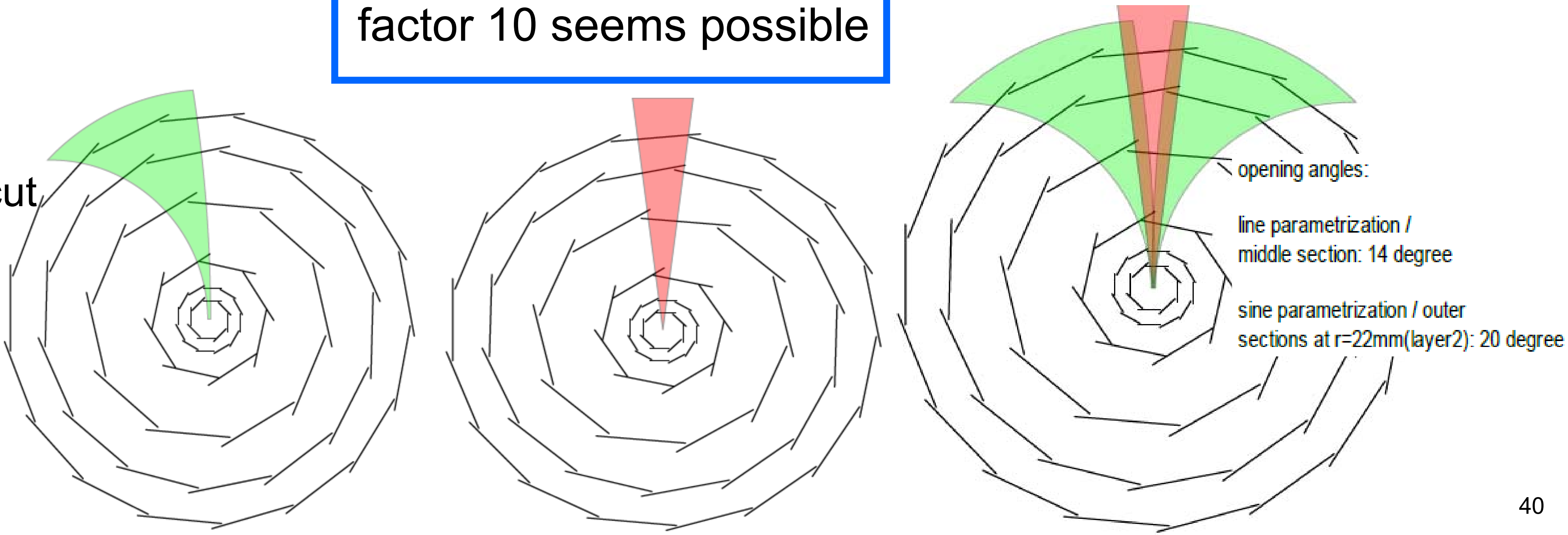
Claudio Heller (MPI)

- 2D pattern recognition in z-r-plane using SVD data: Hough-transform with fast peak finding algorithm
- SVD hits are divided into 3 x 40 overlapping sectors in r-phi rotated with ΔΦ=9°
- different shaped sectors for low momentum particles and nearly straight tracks in r-phi-plane



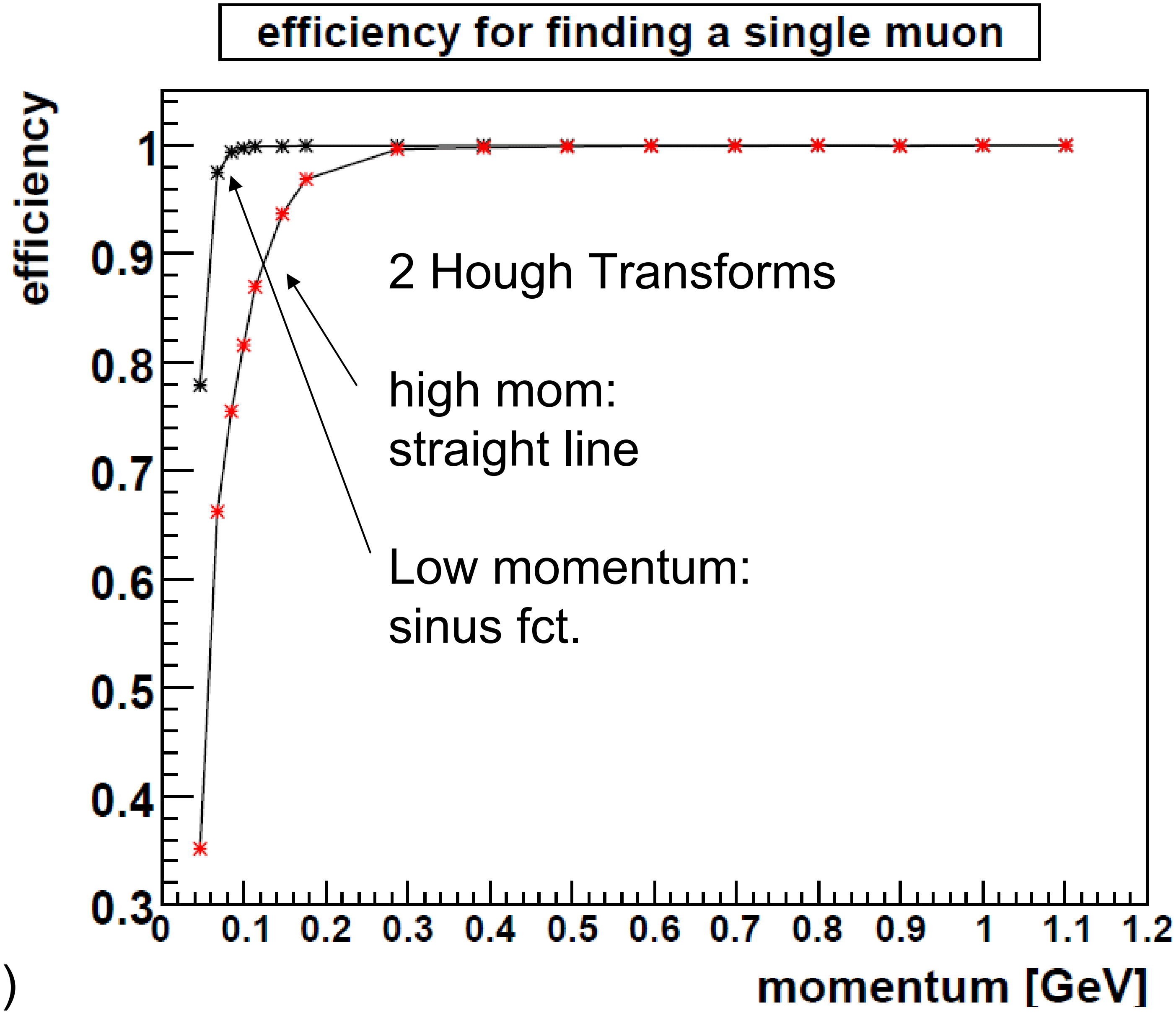
factor 10 seems possible

p_T cut



Online PXD Data Reduction

very good eff.
down to very
low momenta



Claudio Heller (MPI)