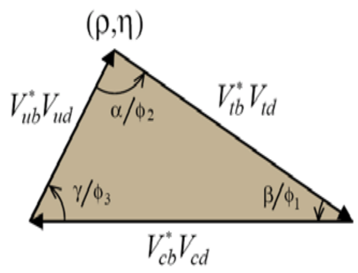
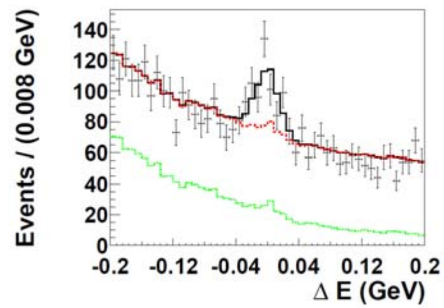
B-Physics with Belle and the Belle-II Detector at SuperKEKB

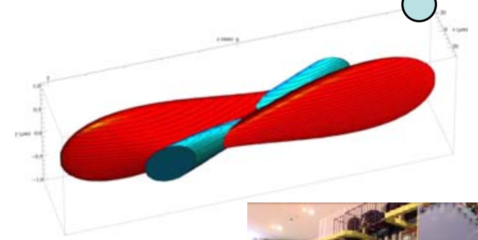
C. Kiesling, MPI Munich

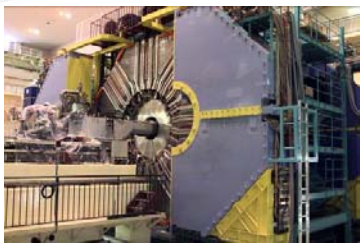


- Physics Motivation
- Towards Novel Analysis Techniques in Belle

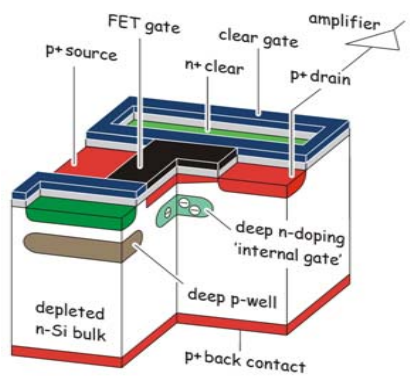


- New Physics at High Luminosity
  The SuperKEKB Collider





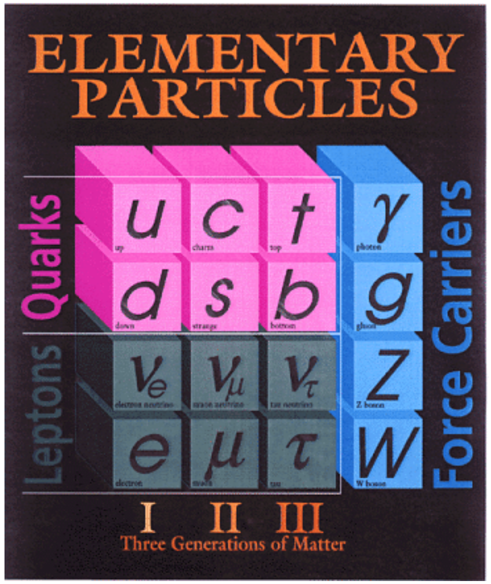
- Belle Upgrade: Belle-II
- Si-Pixel Detector (PXD)



Why is the Physics @ B-Factories interesting ?

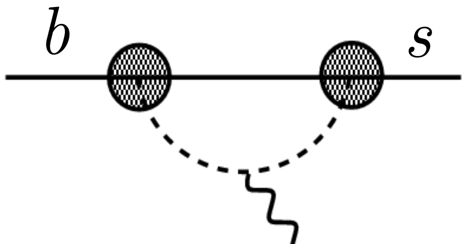
Nobel Prize 2008: Kobayashi & Maskawa

The Standard Model $SU_3 \times SU_2 \times U_1$ (SM) describes all data so far,
yet: cannot be the correct theory, SM only a „low energy“ approximation



Evidence for Physics beyond the Standard Model:

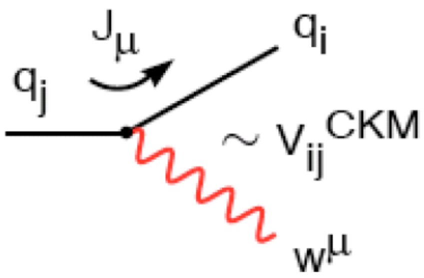
- Dark Matter exists
  (only 4% of the Universe accounted for by SM)
- Neutrinos have mass (Dirac, Majorana?)
- Baryon Asymmetry is too large
  (new sources of $\not{CP}$ needed)



need
very high energy
or **v.h. precision**

High mass scales (multi TeV) reachable
via quantum loop corrorrections to the SM

The CKM Matrix and the Unitarity Triangle(s)



weak decays of hadrons (quarks change flavor) are described in the SM by the (unitary) CKM matrix

Cabibbo, Kobayashi, Maskawa

$$\lambda = \sin\theta_C$$

$$V^{\mathrm{CKM}} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

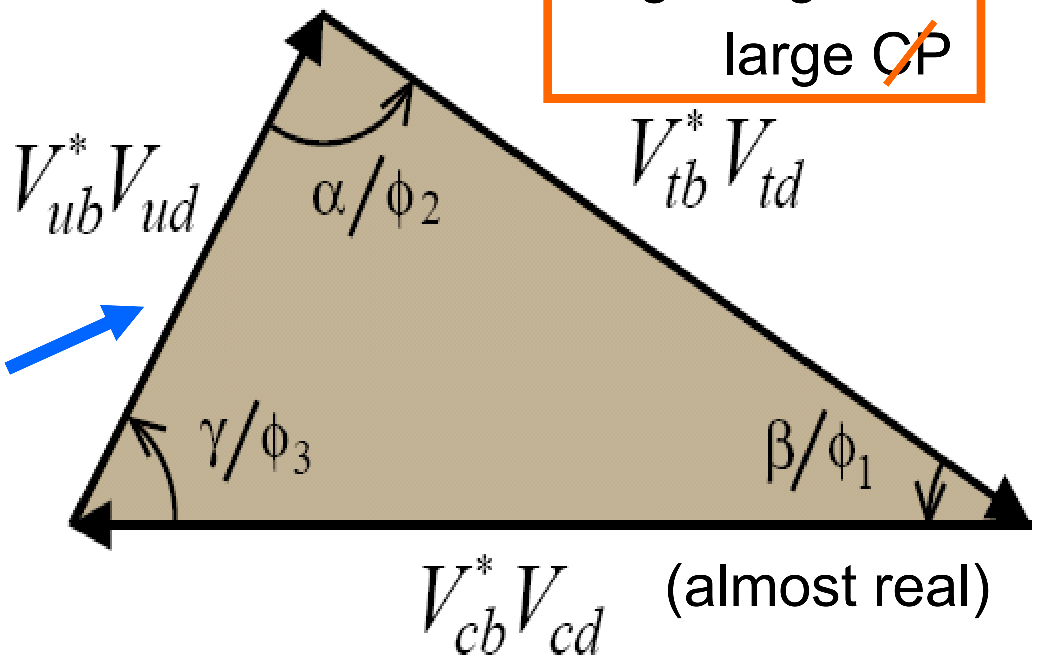
$$V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0$$

Triangle for K mesons

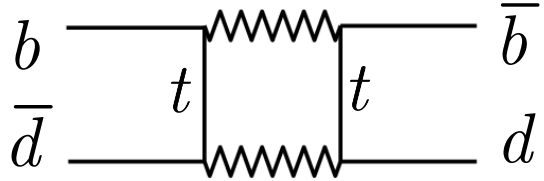
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Triangle for B mesons

large angles = large ~~CP~~



The ~~CP~~ Observables: What do we measure?

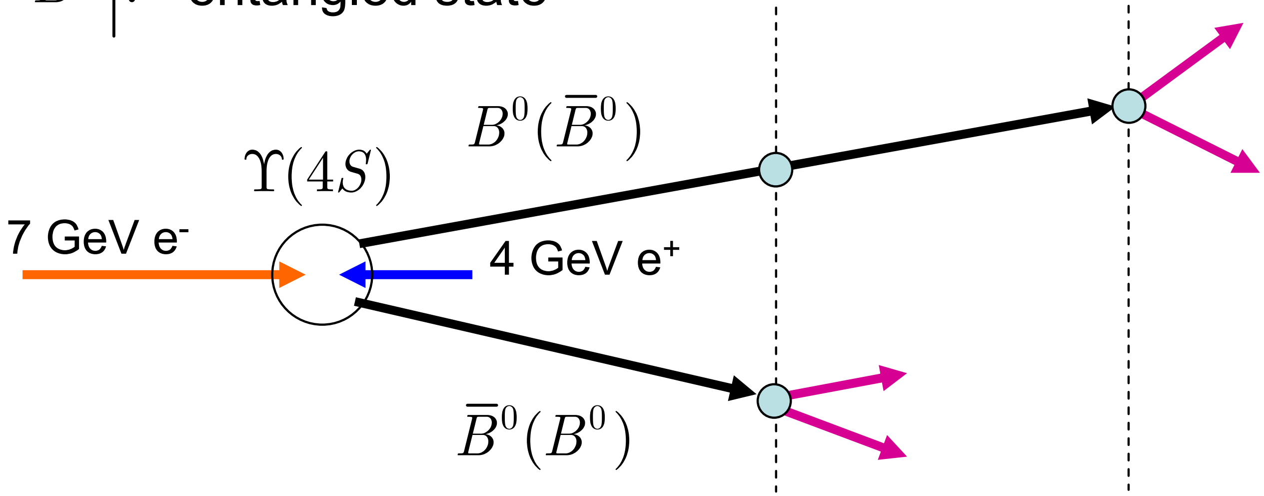


→ time-dependent ~~CP~~ asymmetries

$$\mathcal{A}_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0 \to f_{CP};\Delta t) - \Gamma(B^0 \to f_{CP};\Delta t)}{\Gamma(\bar{B}^0 \to f_{CP};\Delta t) + \Gamma(B^0 \to f_{CP};\Delta t)} = A_f \cos\Delta m\Delta t + S_f \sin\Delta m\Delta t$$

$$\Delta m = M(B_H) - M(B_L)$$

$\langle B^0\bar{B}^0 |$: entangled state



CP eigenstate, e.g.

$J/\psi K_S$

$CP = -1$

select flavor eigenstate

vertex detector essential,
PID important

$$\Delta z = \beta\gamma c\Delta t$$

$$\Delta t \sim 1 \text{ ps}$$

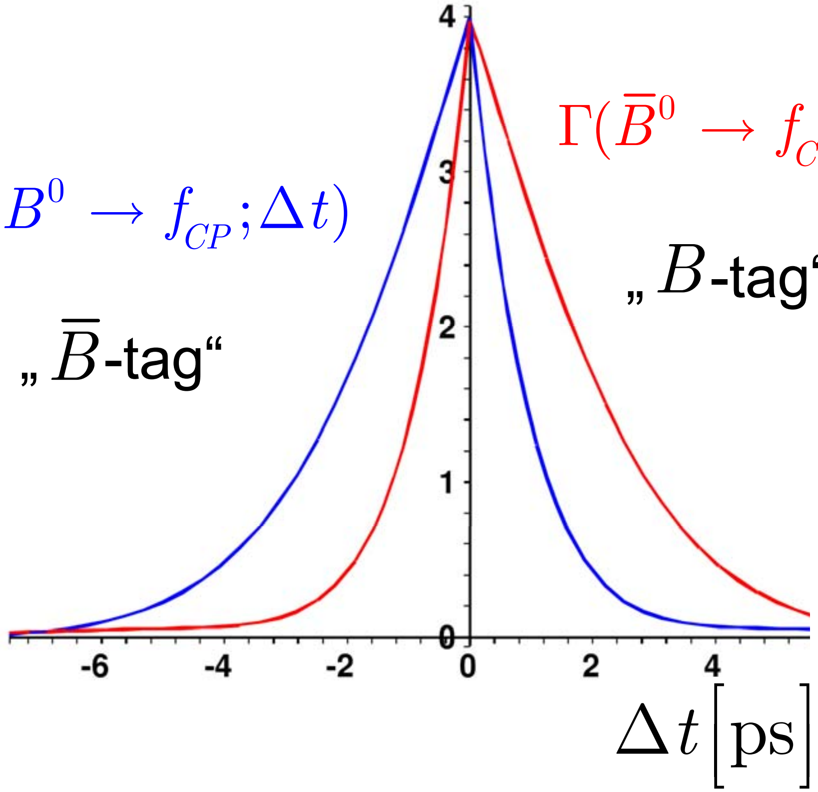
$$\Delta z \sim 150\ \mu\text{m}$$

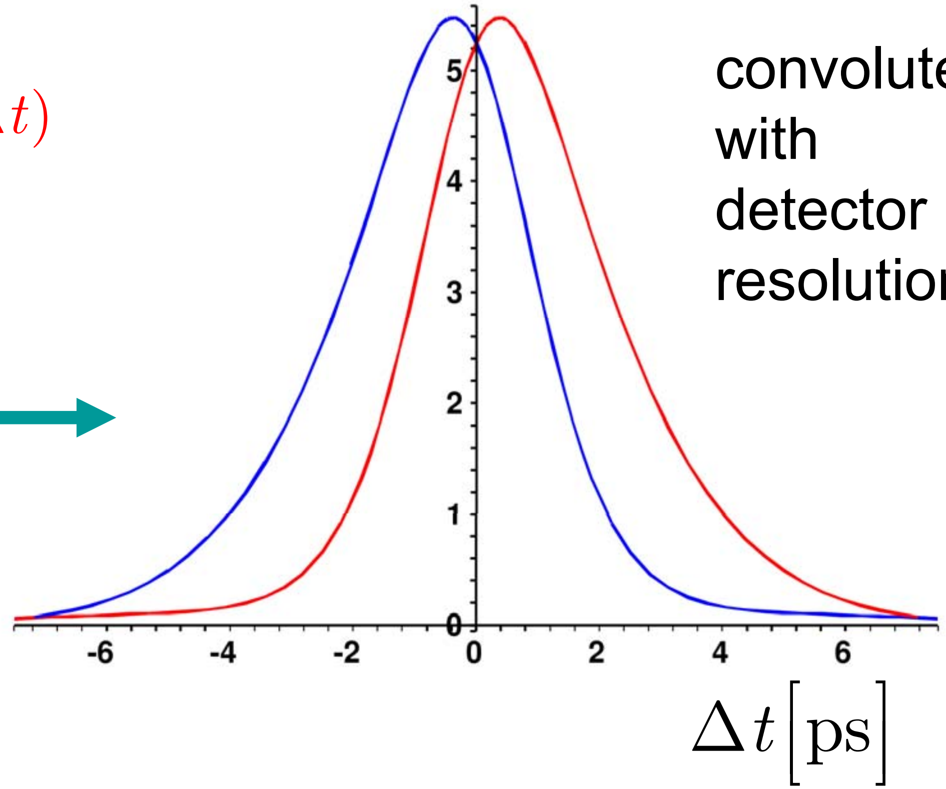
flavor tagging:

$$\bar{b} \to \bar{c}\, l^+ \nu$$

e.g. charge of *l*, *K*, slow *π*

Time Dependent CP-Asymmetries

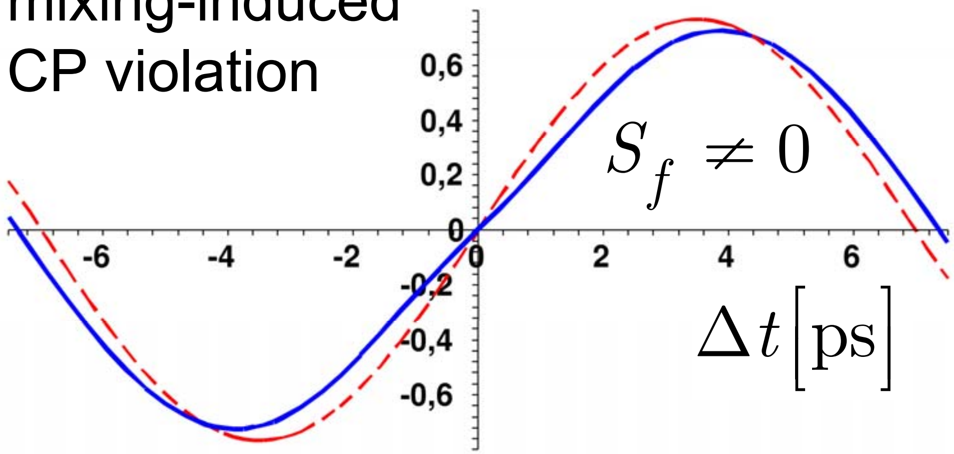




convoluted with detector resolution

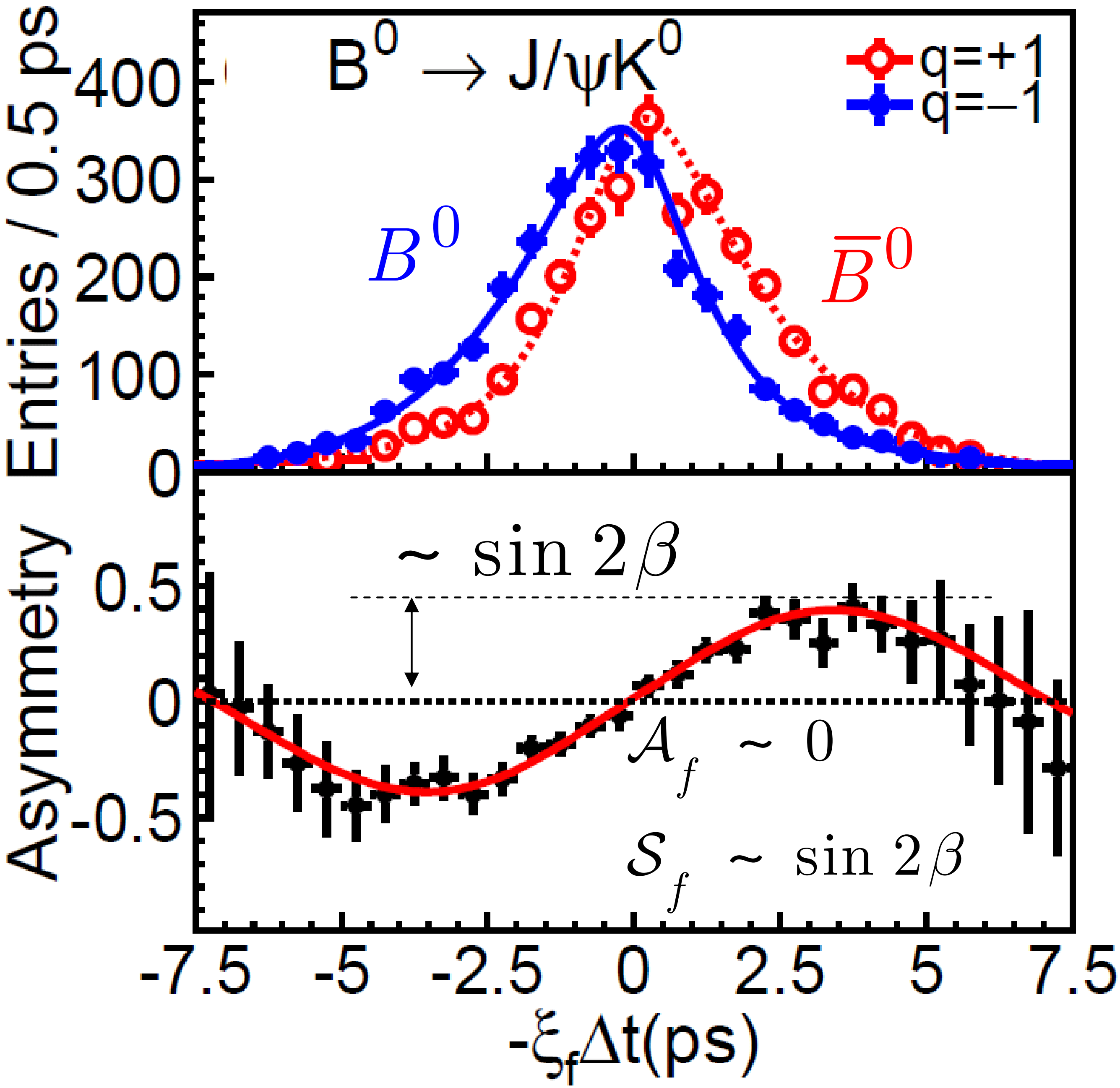
Direct CP violation: $A_f \neq 0$

mixing-induced CP violation



$$\mathcal{A}_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0,\Delta t) - \Gamma(B^0,\Delta t)}{\Gamma(\overline{B}^0,\Delta t) + \Gamma(B^0,\Delta t)}$$
$$= A_f \cos\Delta m\Delta t + S_f \sin\Delta$$

CP-Asymmetry for the „Golden Channel“



data from

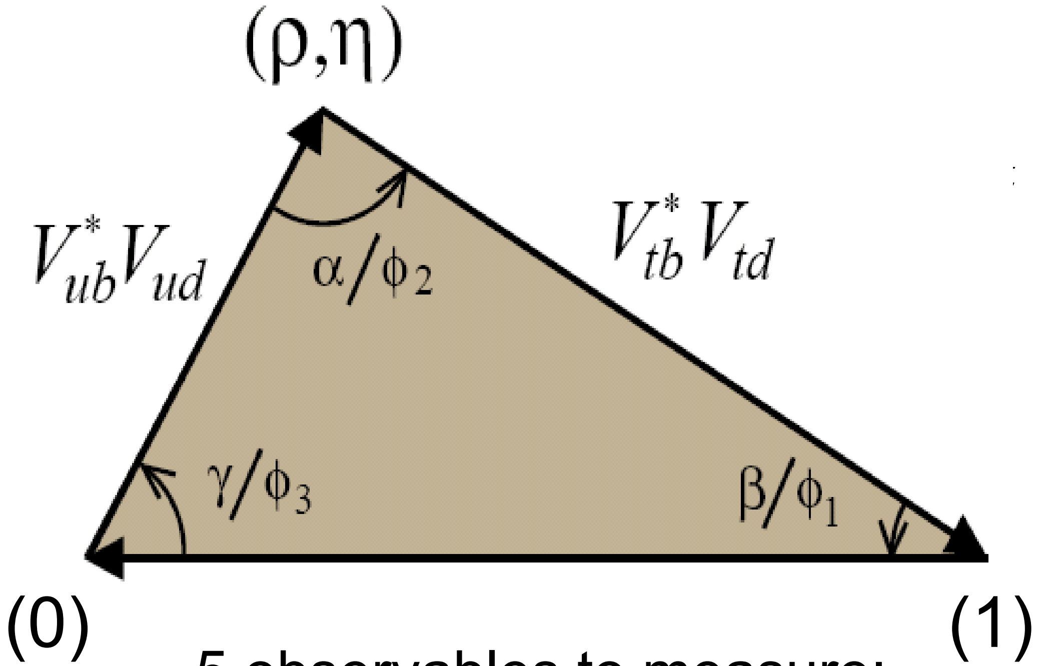
$K^0 \to K_S, K_L$

added

beautiful agreement of the SM with the data

(within the present statistics)

How do we see the New Physics ?



5 observables to measure:
2 sides, 3 angles:
heavily over-determined

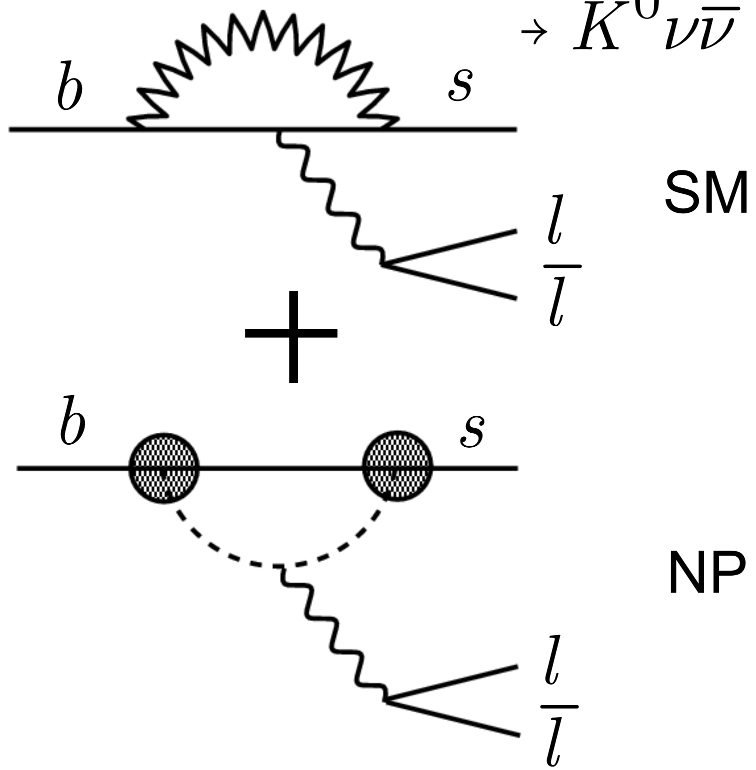
Standard Model: all 5 measurements must give consistency with the triangle

Rare decays, e.g.

$$\overline{B}^0 \rightarrow \overline{K}^0 l^+ l^-$$

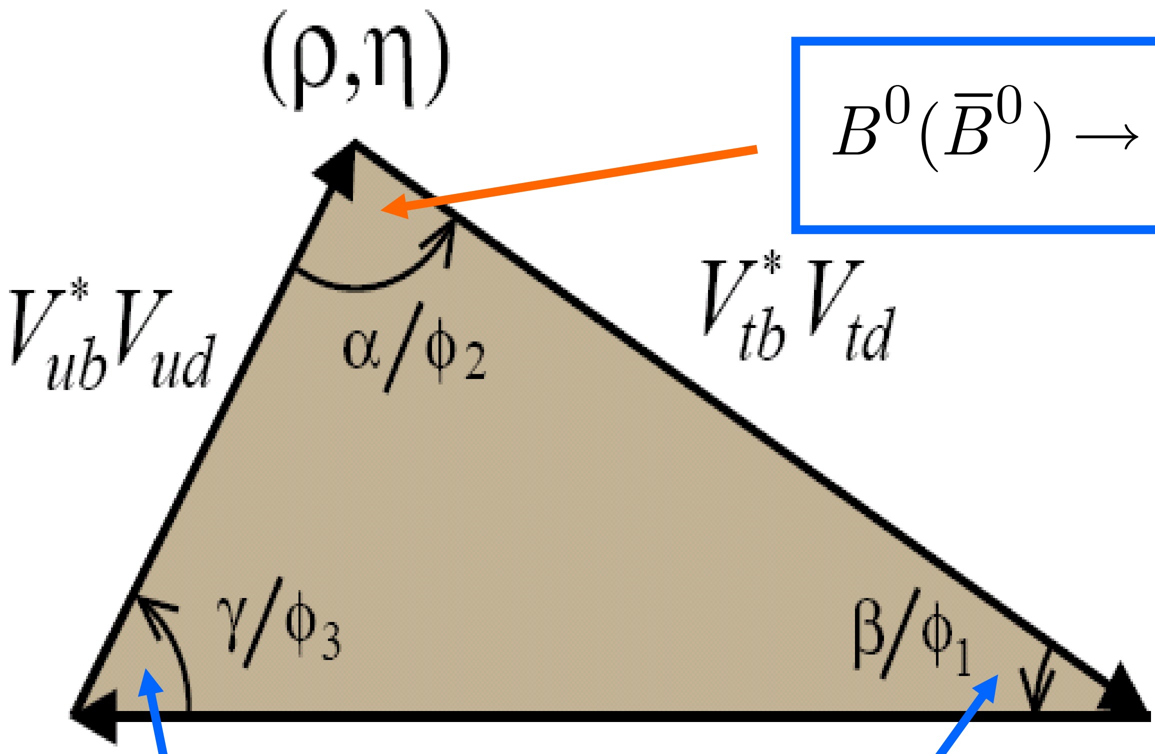
$$\rightarrow \overline{K}^0 \nu \overline{\nu}$$

„Penguin“



If triangle „does not close“ → **New Physics** ← unexpectedly „large“ branching fractions

Measuring the Angles (α,β,γ) (Φ_2,Φ_1,Φ_3)



$$B^0(\bar{B}^0) \to \pi\pi, \rho\rho, \rho\pi, a_1\pi$$

$Br \sim 10^{-6}$

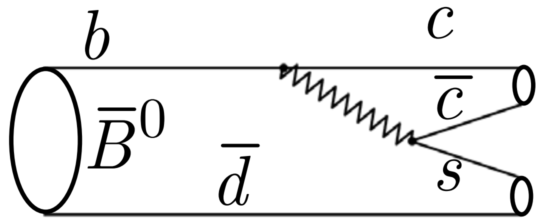
typical branching ratios at tree level

$Br \sim 10^{-4}$

$$B^0(\bar{B}^0) \to D\,K_{S,L}, D^*\pi$$
$$\to K\pi$$

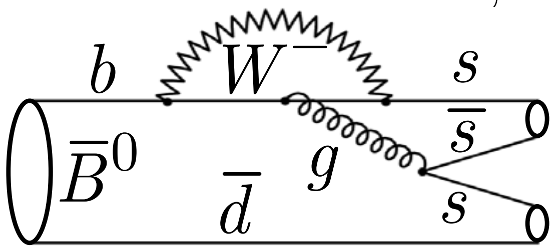
$Br \sim 10^{-5}$

$$B^0(\bar{B}^0) \to J/\psi\,K_{S,L}$$



T

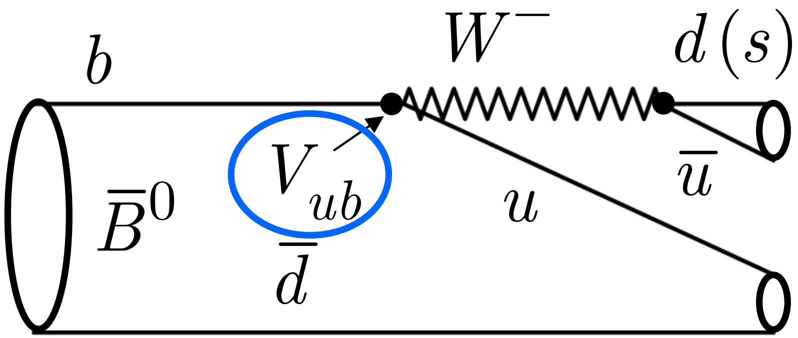
$$\to \phi\,K_{S,L}$$



P

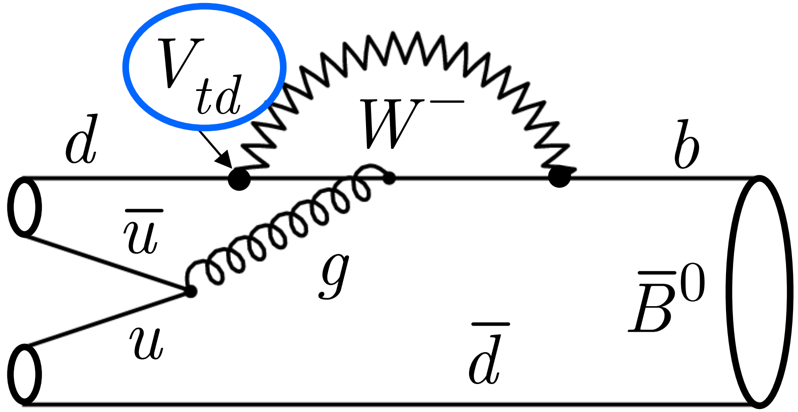
First Project of MPI group: measure α (Φ_2)

$b \to u\bar{u}d$



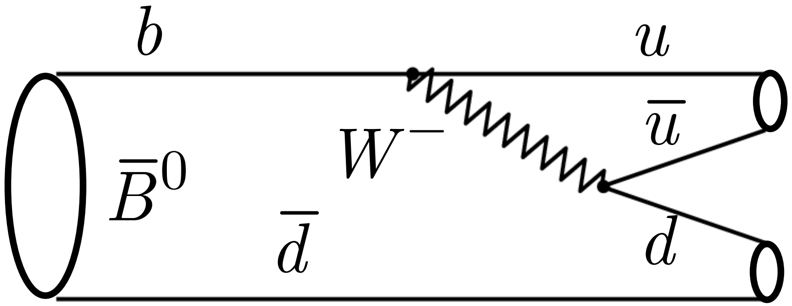
π^-, ρ^-, π^-

π^+, ρ^+, a_1^+



T

P



π^0, ρ^0

π^0, ρ^0

color-suppressed (~1/9)

$B^0 \to \pi^+\pi^-$ Andreas Moll

$\to \rho^+\rho^-$ Kolja Prothmann

$\to \rho^0\rho^0$ Pit Vanhoefer

$\to a_1\pi$ Jeremy Dalseno

Present value of α: 92 ± 7 °

- hope to improve with full Belle data sample + new analysis methods

New Analysis Strategy of MPI group

- $b \to u\bar{u}d$ strongly suppressed by CKM matrix elements (T & P)

  → high background levels (other *B* decays, continuum)

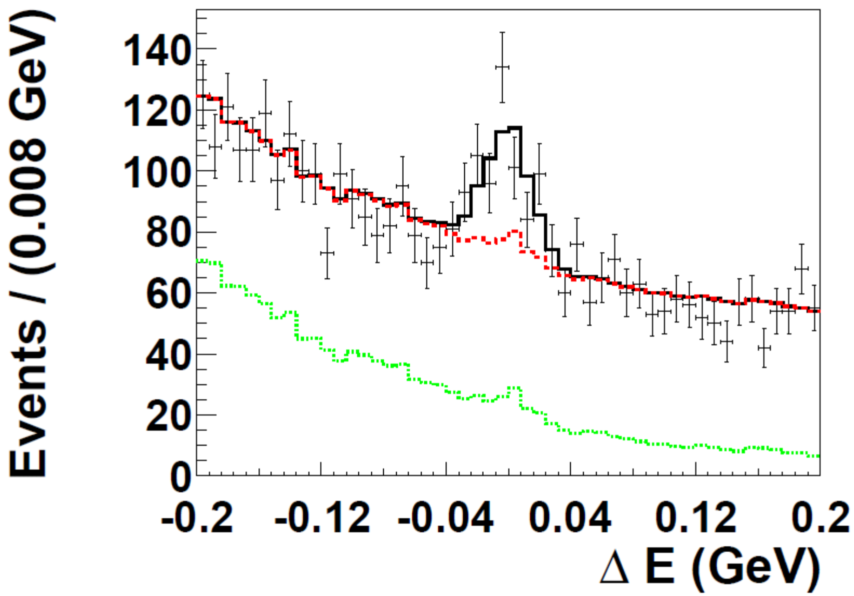
  → construct variables to discriminate signal from continuum $\quad e^+e^- \to q\bar{q},\ q = u,d,s,c$

- Standard Belle procedure: cuts on variables to optimize $S \,/\, \sqrt{S+B}$

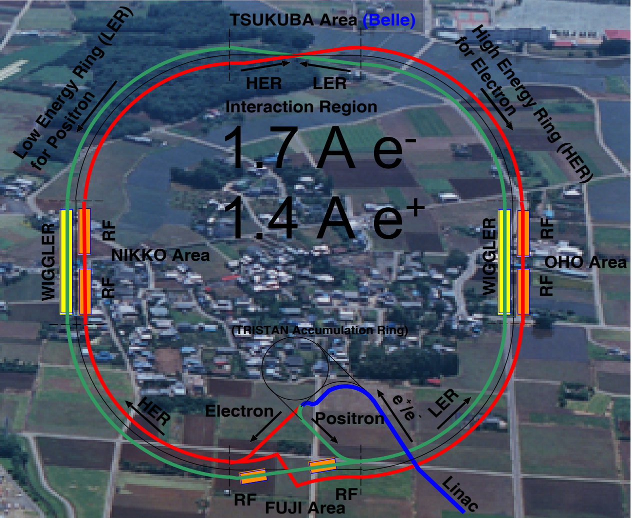
- J. Dalseno et al.: minimize cuts, instead use multi-dimensional fit approach to get best signal sensitivity

Example $B^0 \to a_1(1260)^+\pi^-$

	previously	now	
eff	8.58 %	19.14 %	
BR	13.2 ± 3.0	13.2 ± 1.6	(x 10^{-6})
similarly:			
eff ($\rho^0\rho^0$)	9 %	23 %	(Pit V.)



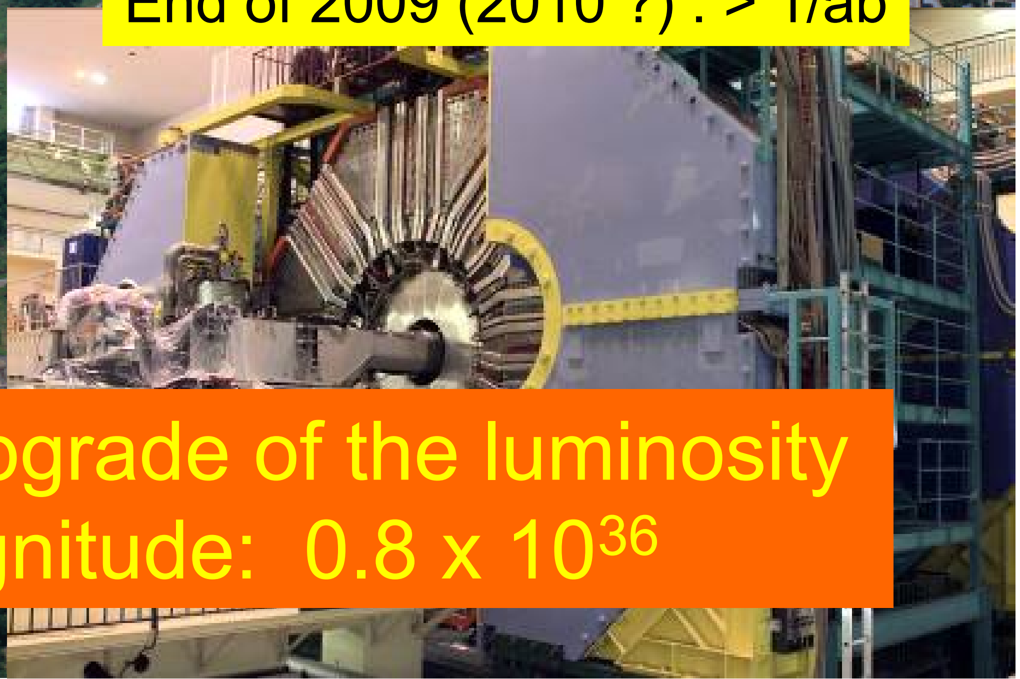
KEKB and Belle



$\mathcal{L} \sim 2 \times 10^{34} \ / \ \mathrm{cm}^2 s$

1 fb^{-1} per day !

Belle is taking data until the End of 2009 (2010 ?) : > 1/ab



The next step: massive upgrade of the luminosity by almost 2 orders of magnitude: 0.8 x 10^{36}

Strategies for Increasing the Luminosity

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

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

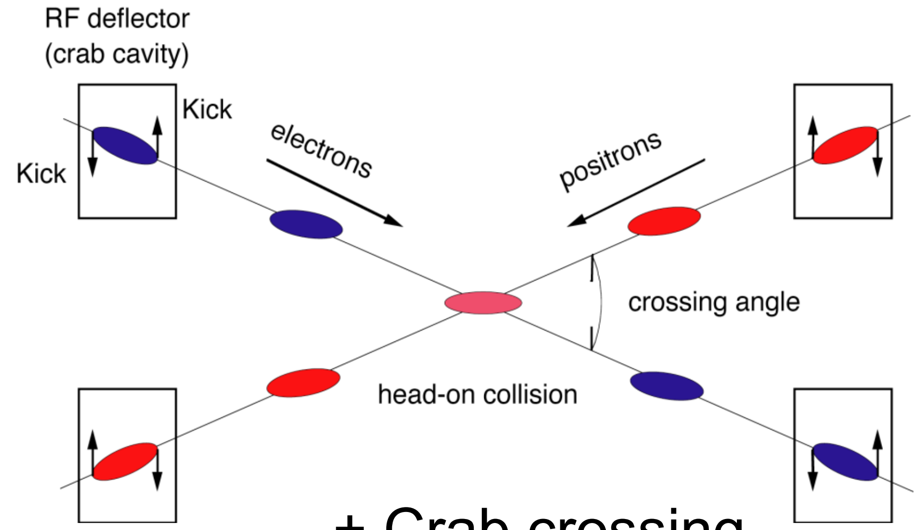
beam-beam parameter (or tune shift)

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

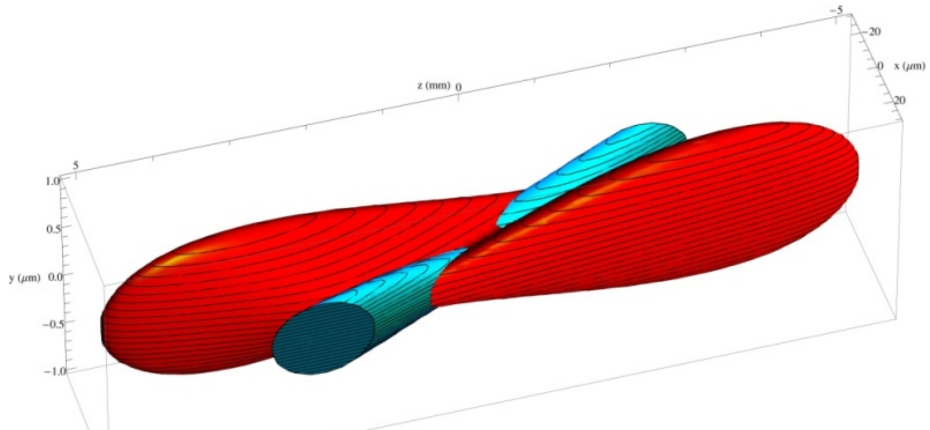
$$\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$

beam emittance

Two Options



+ Crab crossing



+ Crab waist focussing

High Current Option

Extension of current KEKB design,
with much higher beam currents
(9.4 A LER, 4.1 A HER),
and crab crossing.

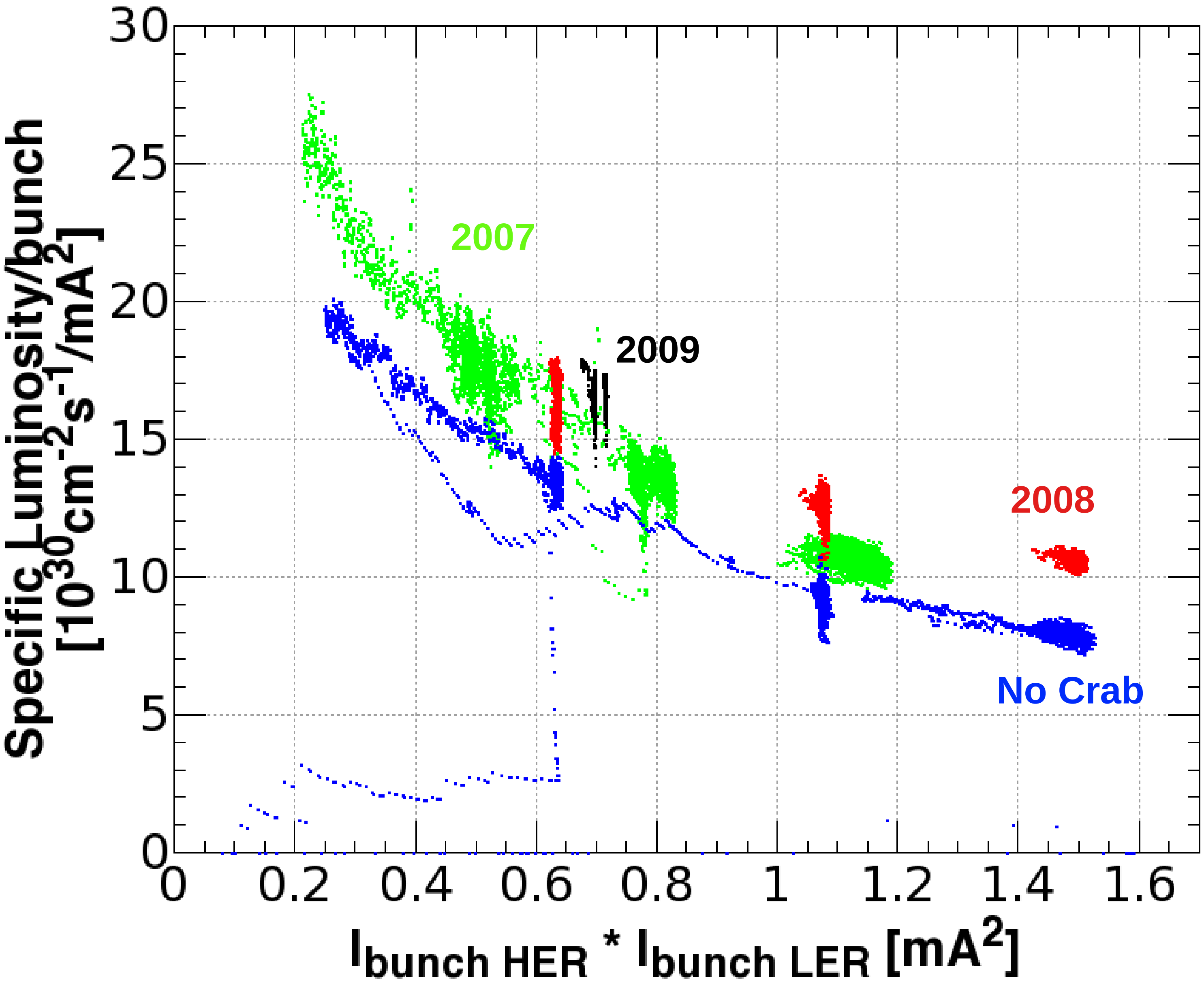
→ large tune shift and short bunches required

Nano Beam Option

Proposal by P. Raimondi *et al.*
for the Italian Super B Factory:
Primarily reduce beam size at the IP.

→ very low emittance beams required, long bunch OK

Crab Crossing: Specific Luminosity



Two problems:

1.
Crab not quite as good as expected from simulations (nevertheless new world record lumi !)

2.
Crab needs short bunches: coherent synchr. radiation (CSR) lengthens bunch

The grass is always greener on the other side of the fence (?)

$$\mathcal{L} = \frac{N_+ N_- f}{4\pi\sigma_x\sigma_y} R \qquad \sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$

Nano beam option produces high lumi by strongly reducing the vertical beta function and the beam emittance

Added value:

no large tune shift required

RF power is reduced

- Preliminary parameter set exists for nano beam option @ KEK (no crab waist yet)
- design can achieve 8 x 10^{35} /cm^{2}s
- will mature within the next few months
- High current nano beam scheme possible with more RF

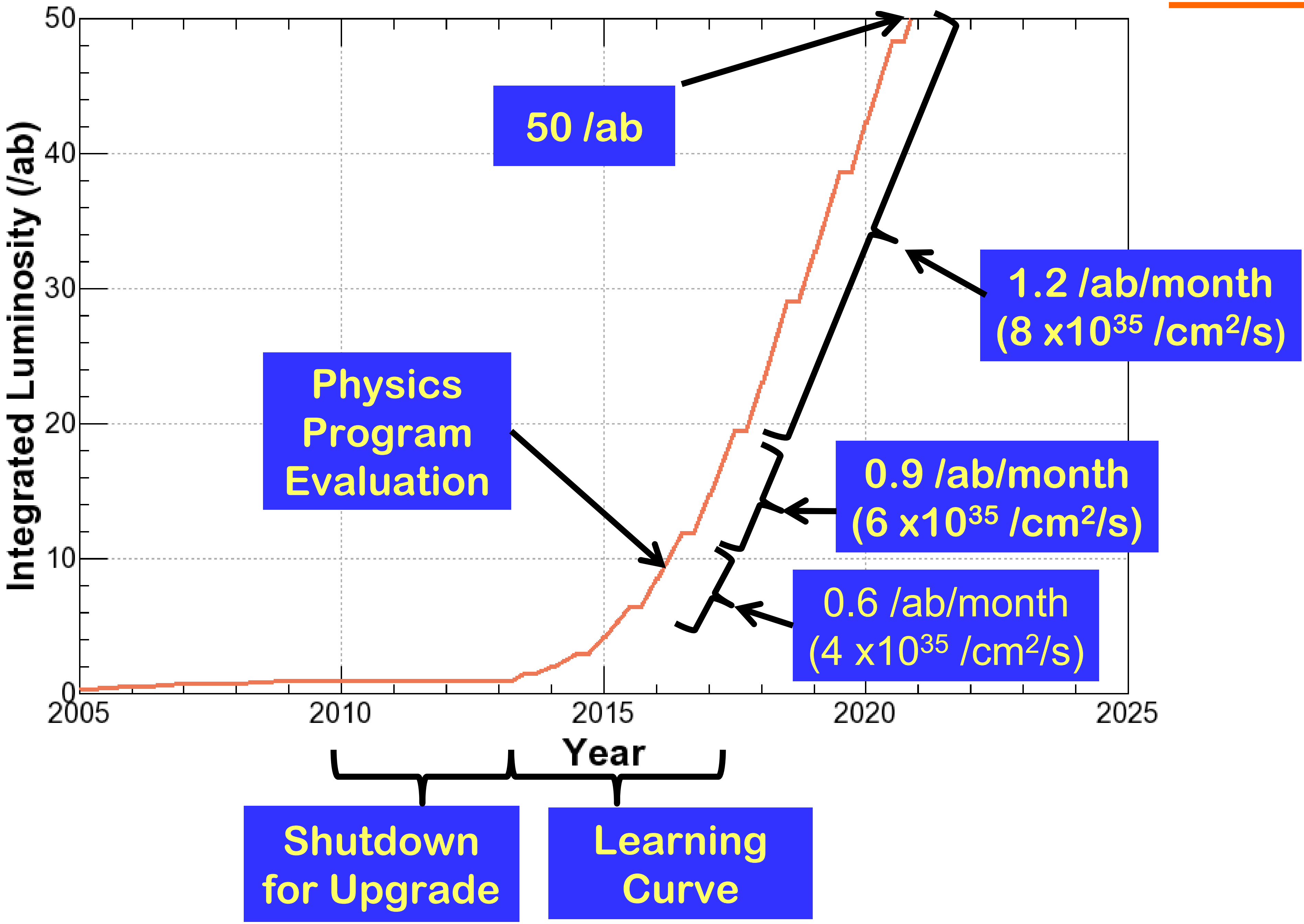
Comparison of Options

	KEKB Design	KEKB Achieved ( ): with crab	SuperKEKB High-Current Option	SuperKEKB Nano-Beam Option
β_y^* (mm)(LER/HER)	10/10	6.5/5.9 (5.9/5.9)	3/6	0.21/0.37
ε_x (nm)	18/18	18/24	24/18	2.8/1.6
σ_y(μm)	1.9	1.1 (0.84)	0.85/0.73	0.070/0.052
ξ_y	0.052	0.108/0.056 **(0.120/0.089)**	0.3/0.51	0.07/0.07
σ_z (mm)	4	~ 7	5(LER)/3(HER)	6
I_{beam} (A)	2.6/1.1	1.8/1.45 (1.60/1.13)	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

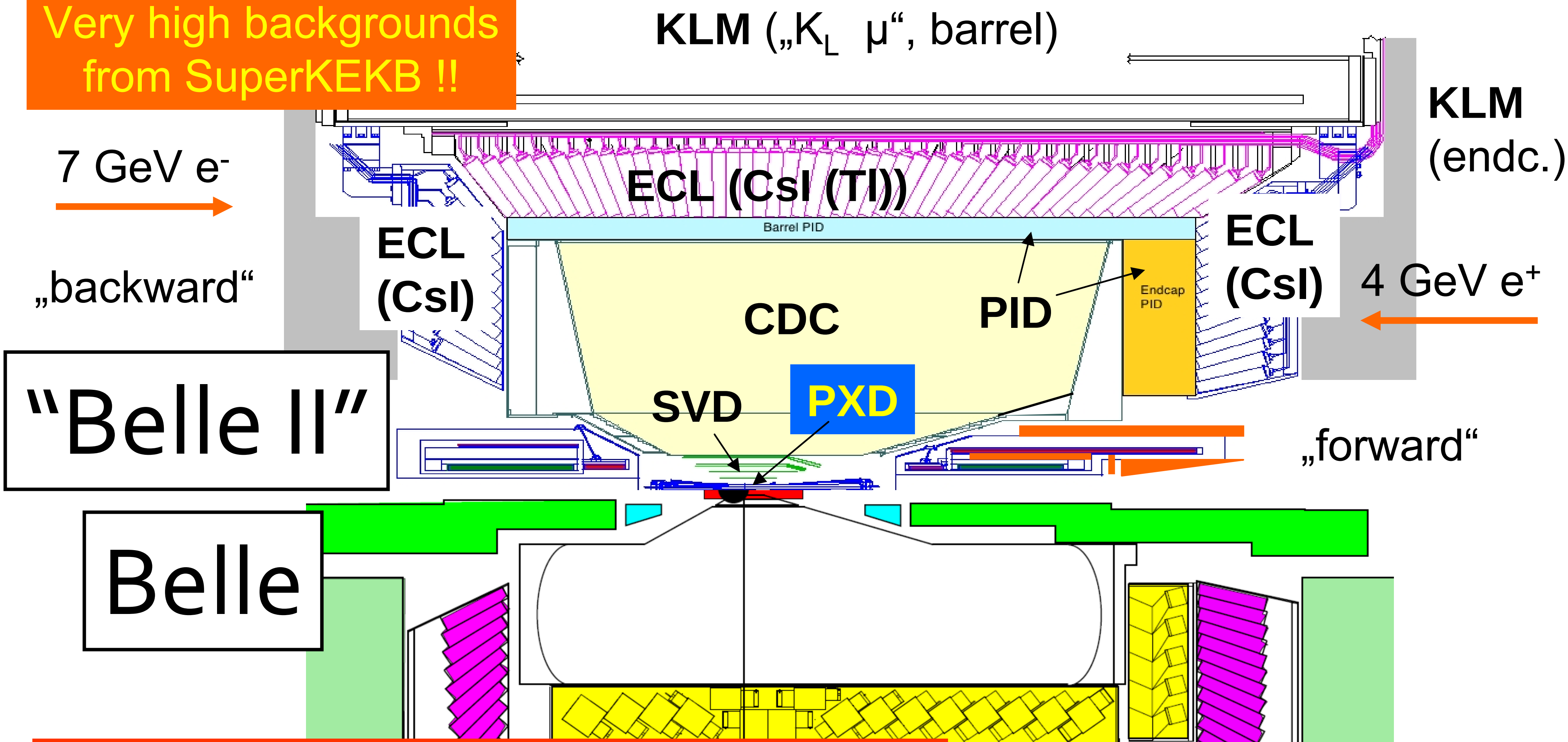
Nano beam was chosen

Expected Luminosity Development



Detector: Baseline Design

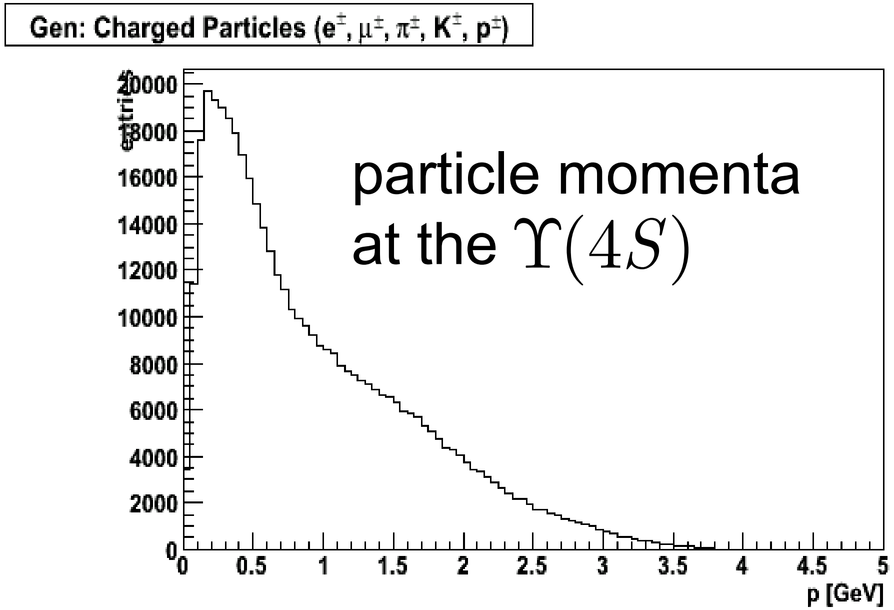
Very high backgrounds from SuperKEKB !!



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

Pixel Detector for Belle-II (PXD)

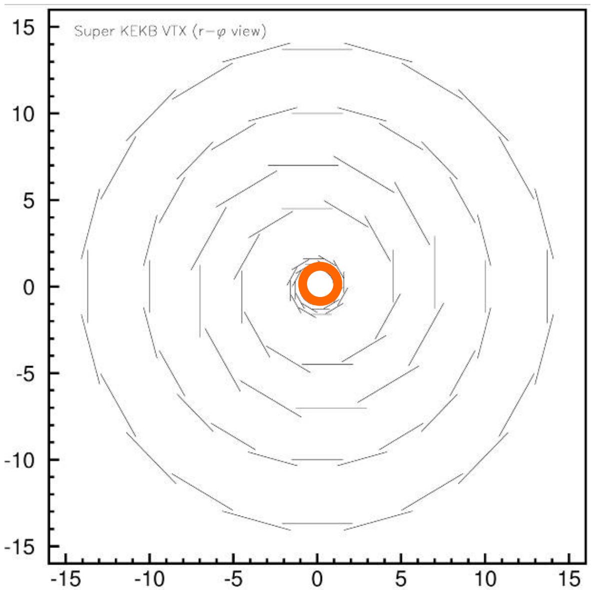


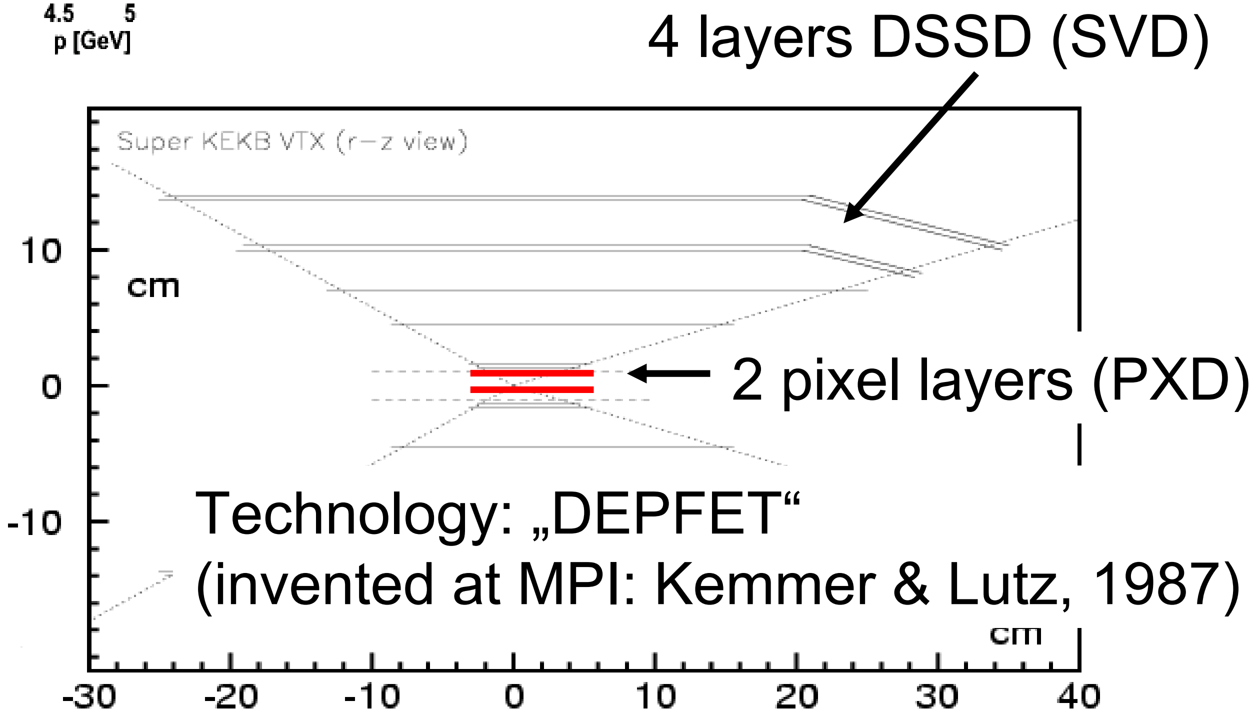
both machine options:
large backgrounds = high occupancy

→ pixels at the innermost (<2cm) radii

→ must be thin, rad. hard, fast readout

→ ready for installation in 2013





Technology: „DEPFET“
(invented at MPI: Kemmer & Lutz, 1987)

DEPFET Principle

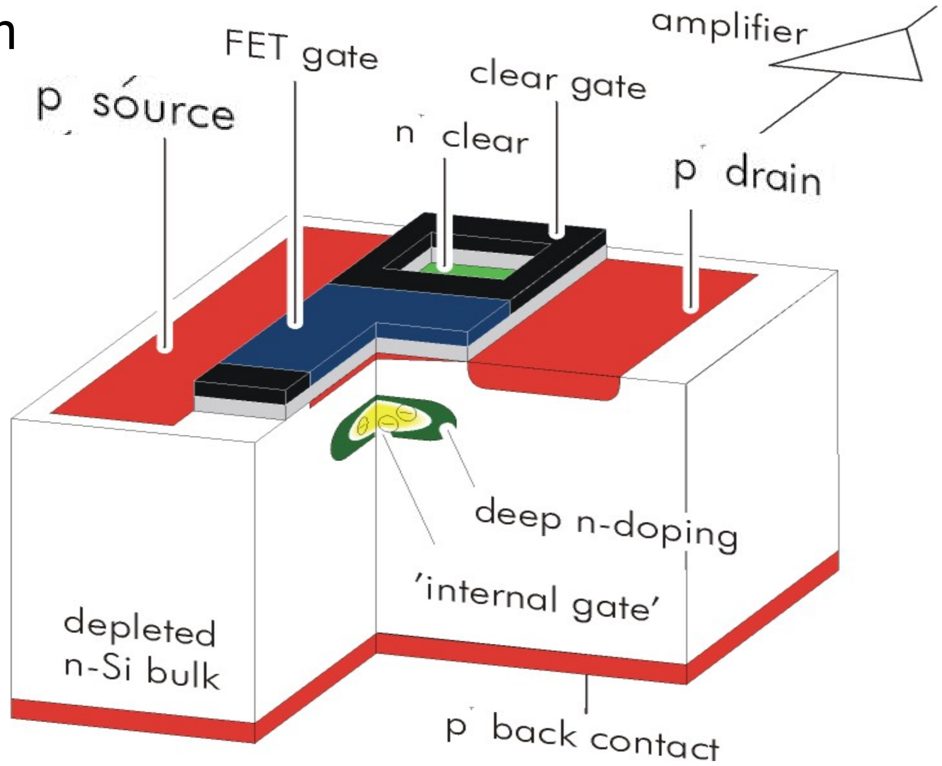
p-channel FET on a completely depleted bulk

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

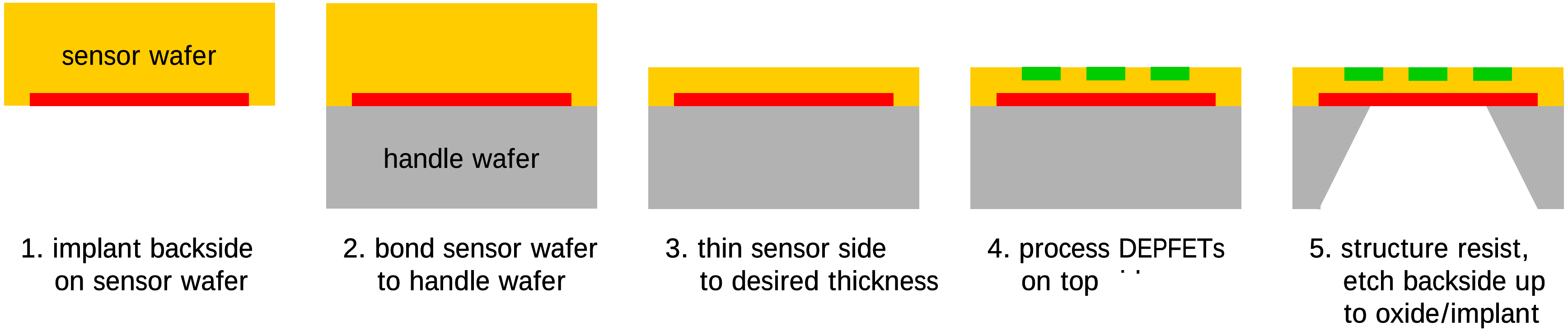


Fully depleted:
→ large signal, fast signal collection

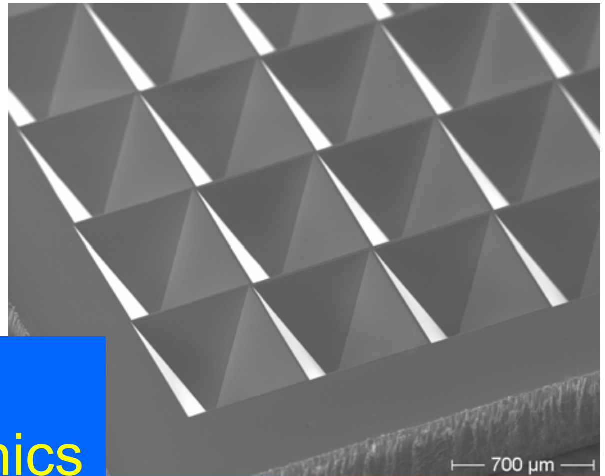
Small capacitance,
internal amplification → low noise

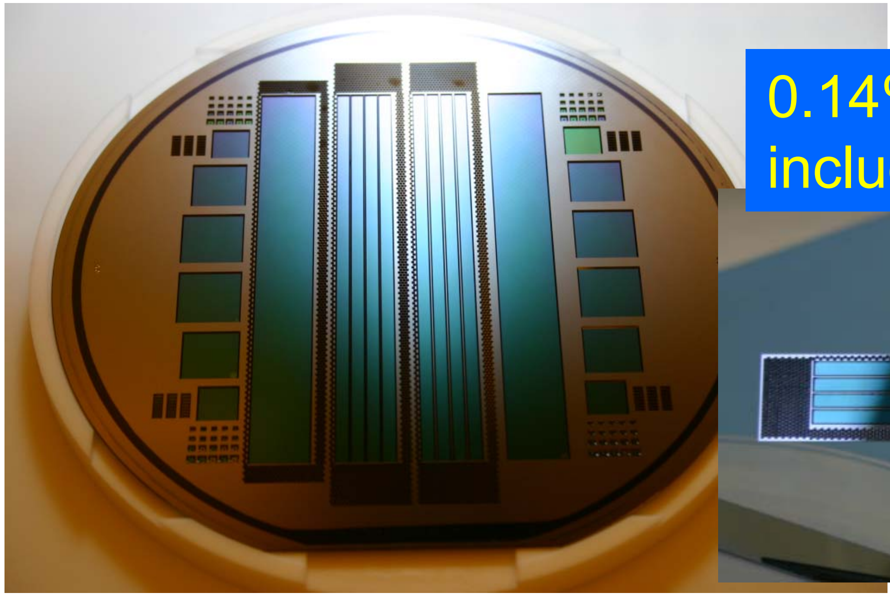
Transistor on only during readout:
→ low power

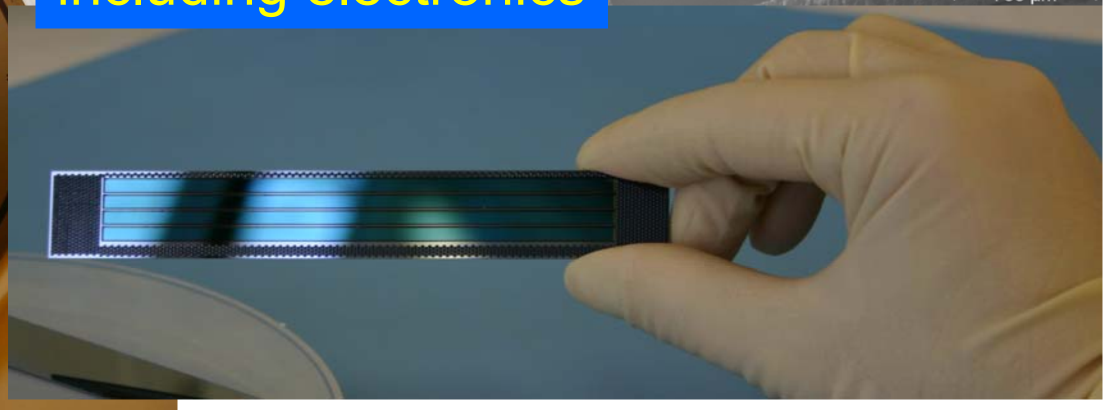
Thinning Technology



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





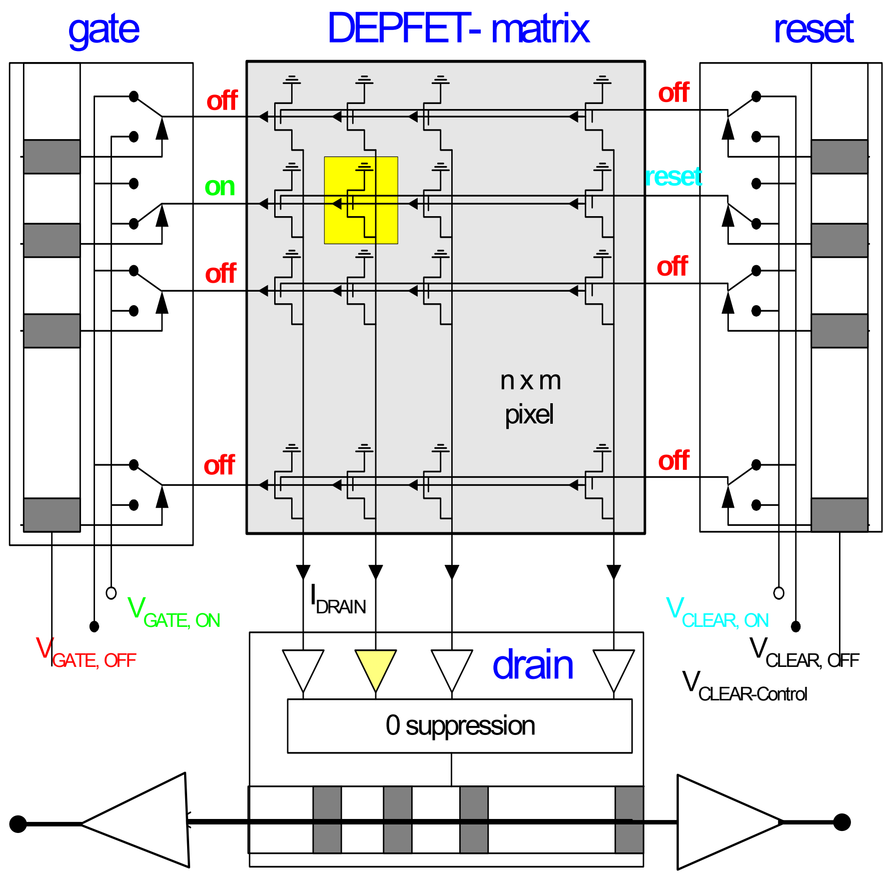


0.14% X_0
including electronics

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

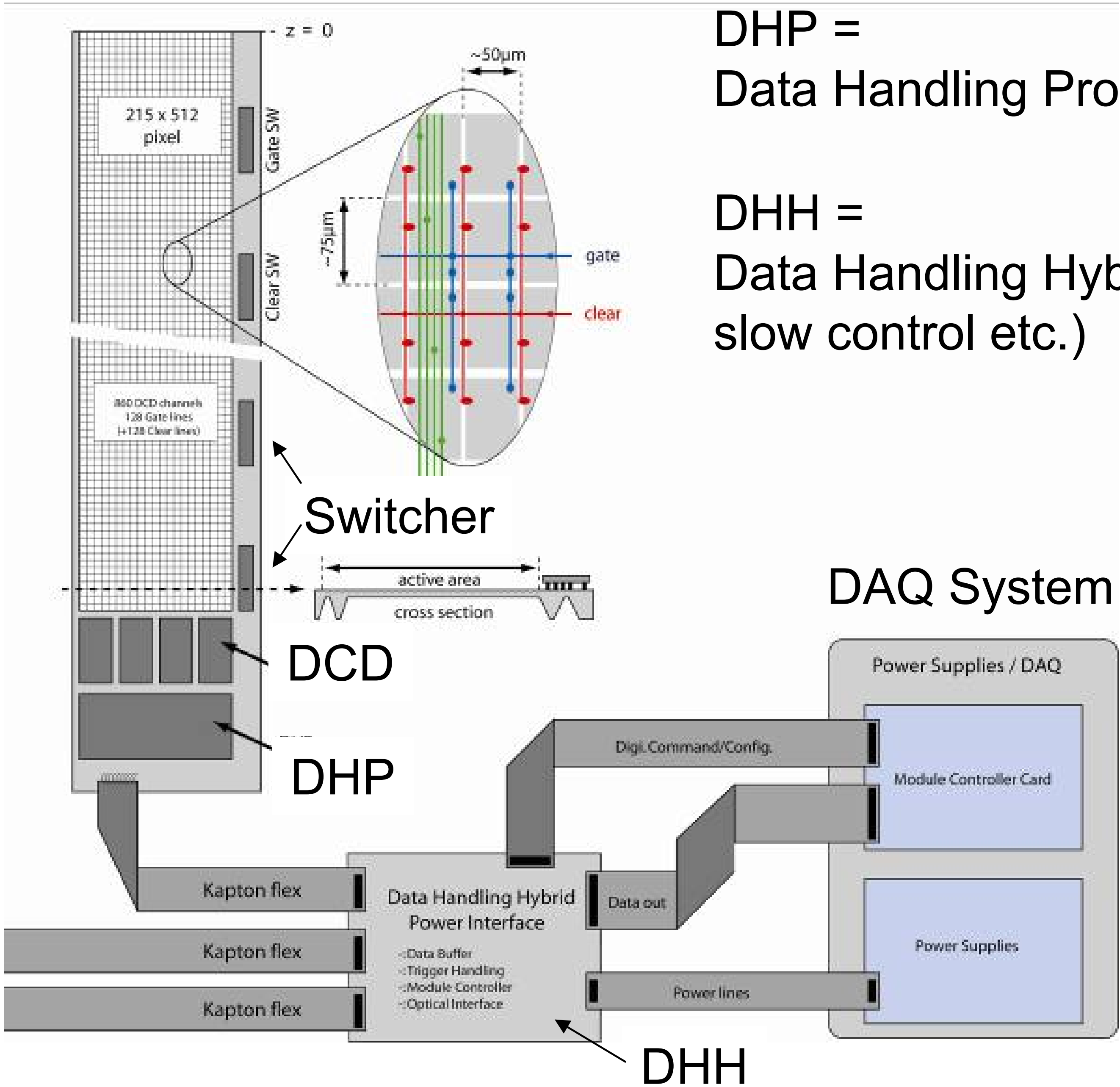
→ Switcher

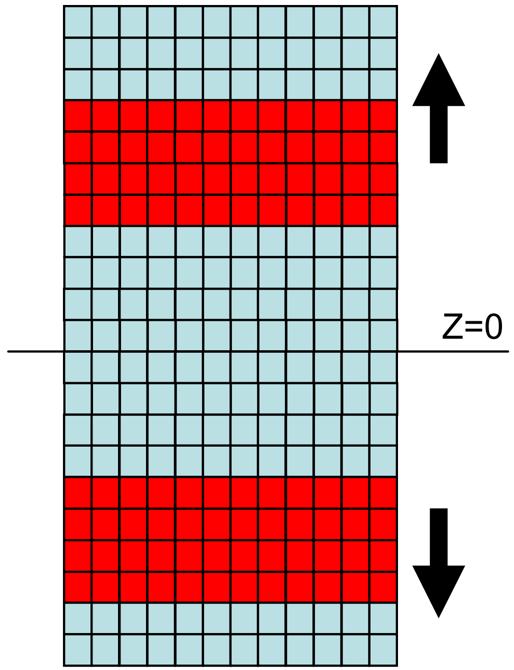
→ DCD (drain current digitizer)

DEPFET Electronics and DAQ

DHP =
Data Handling Processor (zero-suppression)

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





readout speed
80 ns/row

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

with important help from Hawaii, KEK, Vienna

DEPFET@Belle-II

Management:

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

Main Tasks for our Group

Hardware

- Design and production of radiation-hard DEPFET sensors
- Development of test procedures for QC
- Design and construction of the sensor support and the cooling system
- Design and construction of the PXD support on the beam pipe

C. Koffmane
A. Ritter
M. Ritter
P. Müller

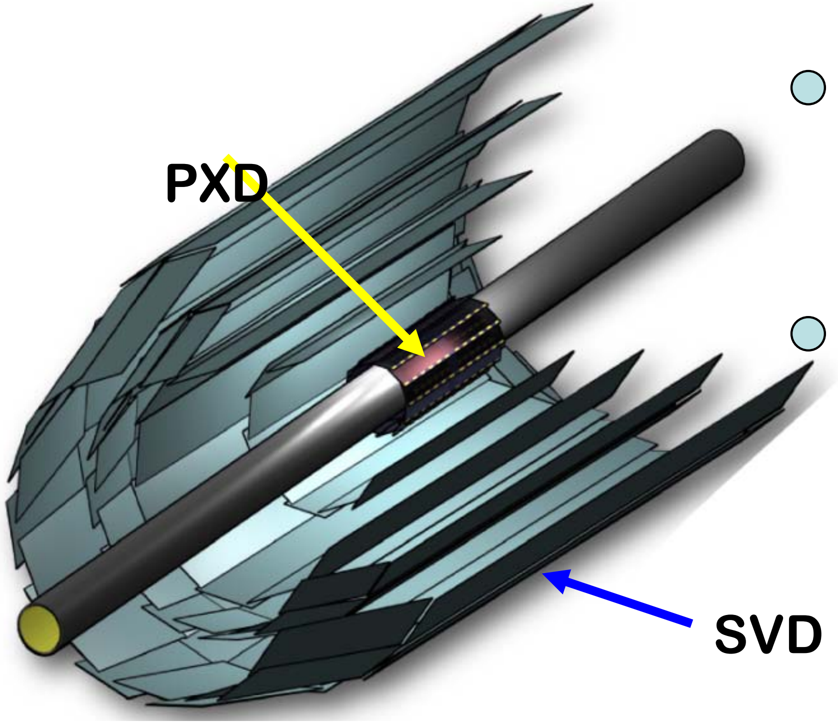
Software

- Optimization of the DEPFET sensors for Belle-II
- Design of algorithms for the PXD data reduction
- Development of simulation/reconstruction framework
- Development of tracking algorithms and PXD alignment

A. Moll
K. Prothmann
M. Ritter
C. Heller

Expected Performance with PXD

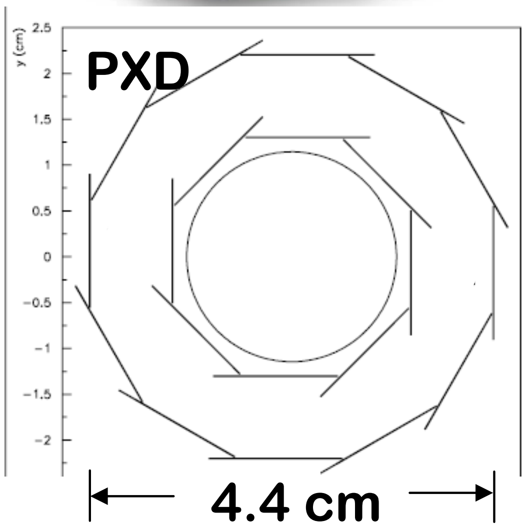
Nano beam option: 1 cm radius of beam pipe



- 2 layer Si pixel detector (DEPFET technology) ← „PXD"
  (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

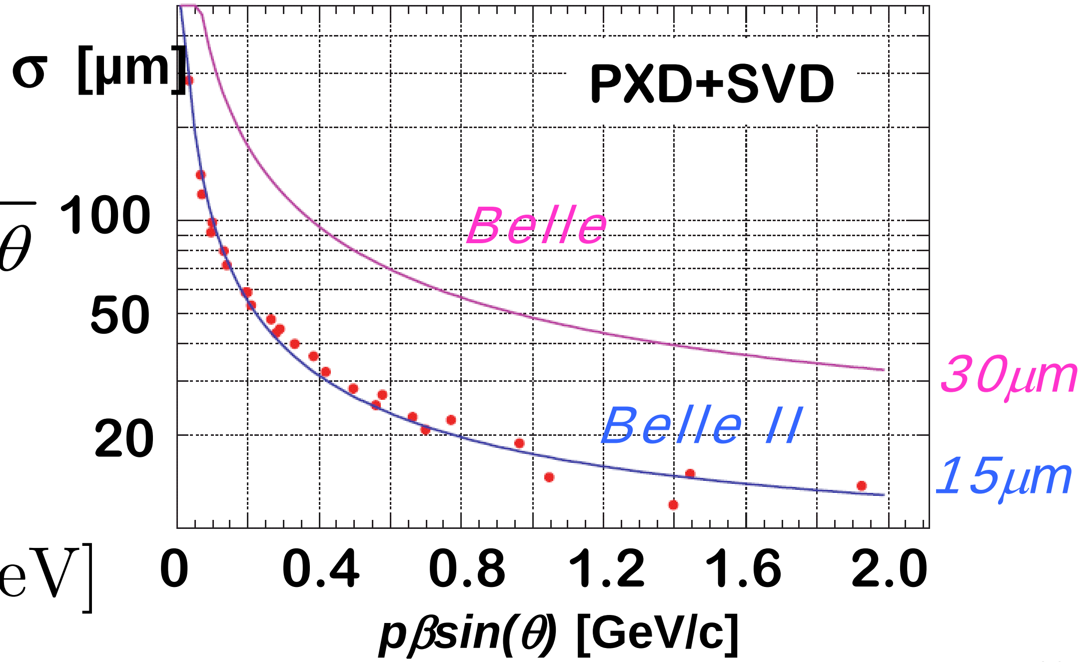


$$\sigma = a + \frac{b}{p\beta \sin^{5/2}\theta}$$

Belle II:

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

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

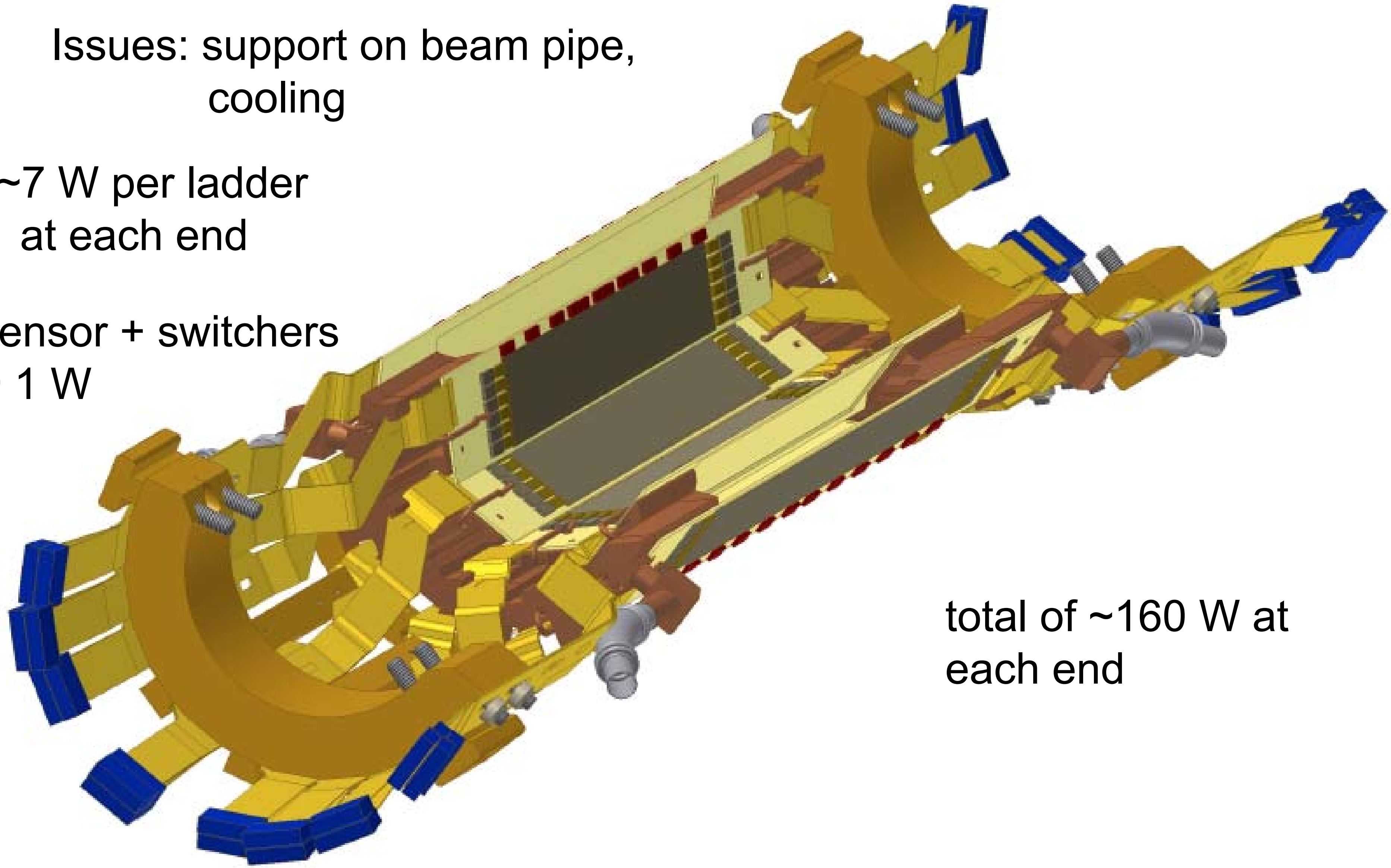


PXD Mechanics, Half Shell

Issues: support on beam pipe, cooling

~7 W per ladder at each end

sensor + switchers ~ 1 W



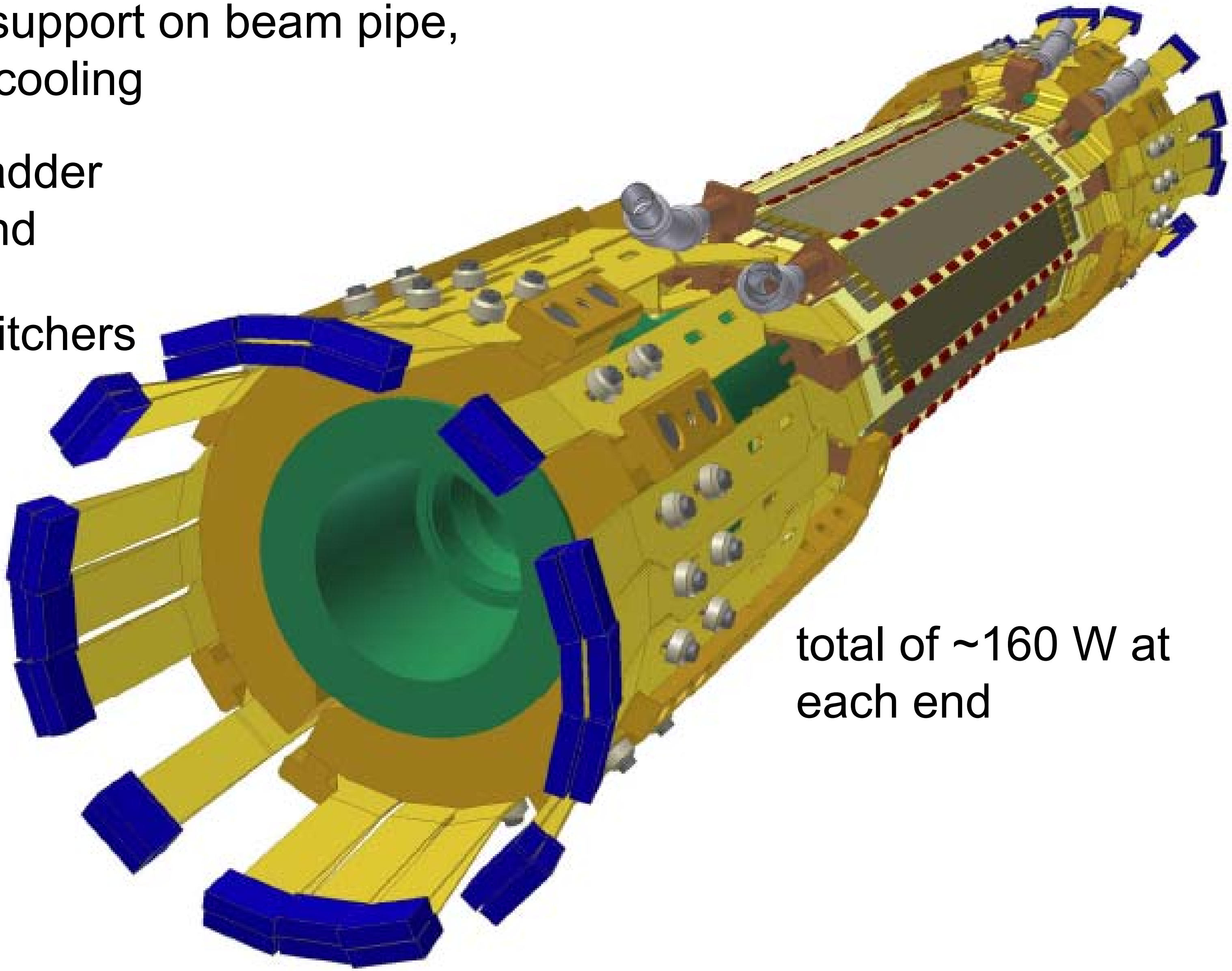
total of ~160 W at each end

PXD Mechanics, Fully Assembled

Issues: support on beam pipe,
cooling

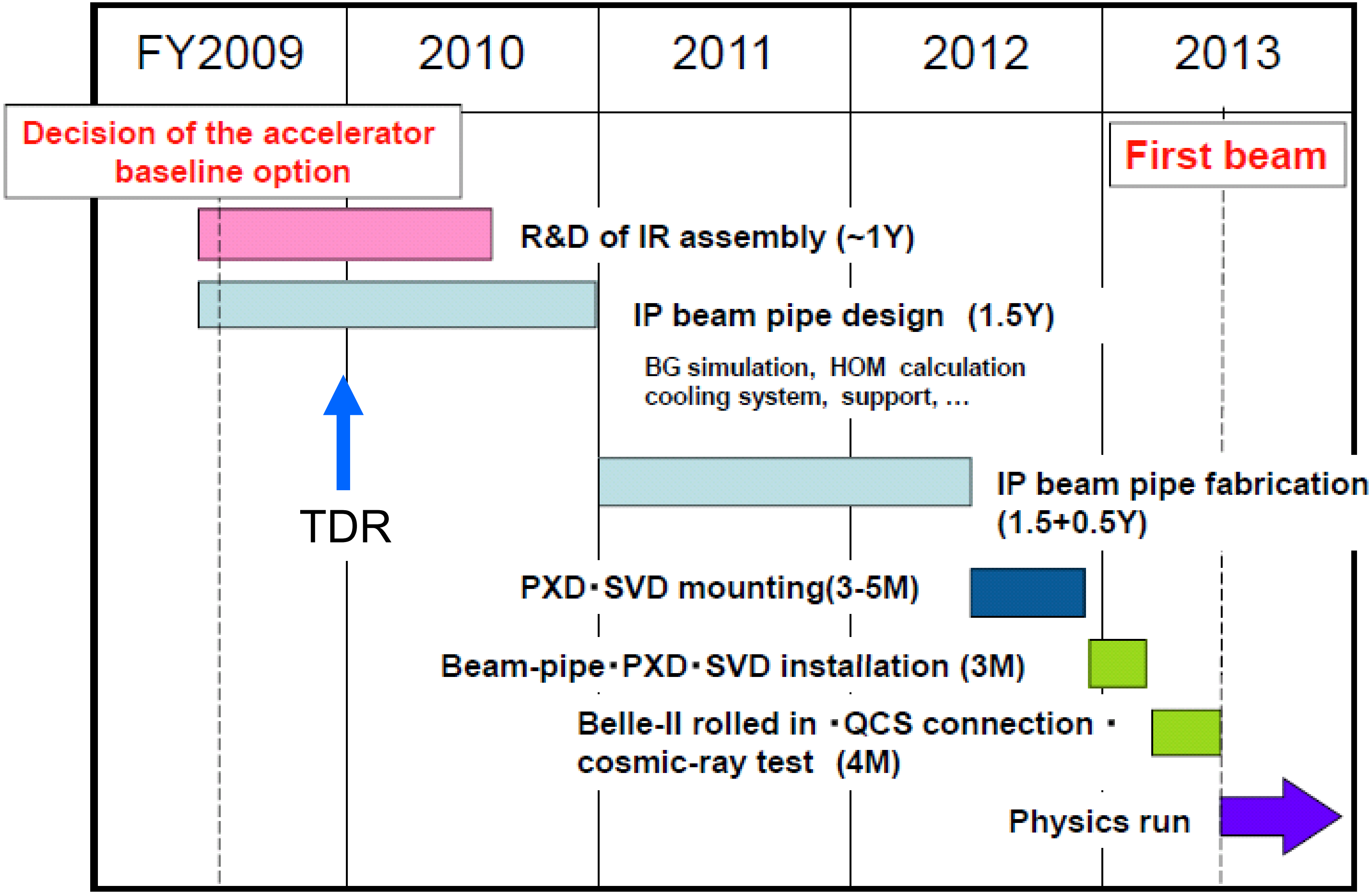
~7 W per ladder
at each end

sensor + switchers
~ 1 W



total of ~160 W at
each end

Project Timetable



The Belle Group at MPI

Staff
Laci Andricek, Christian Kiesling, Hans-Günther Moser,
Rainer Richter, Vladimir Shekelyan
Post Doctoral Scientists
Jeremy Dalseno, Jelena Ninkovic, Burkard Reisert, Frank Simon
PhD Students
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Kolja Prothmann, Andreas Ritter, Martin Ritter
Diploma Students
Claudio Heller, Peter Müller, Pit Vanhoefer
Technical Support
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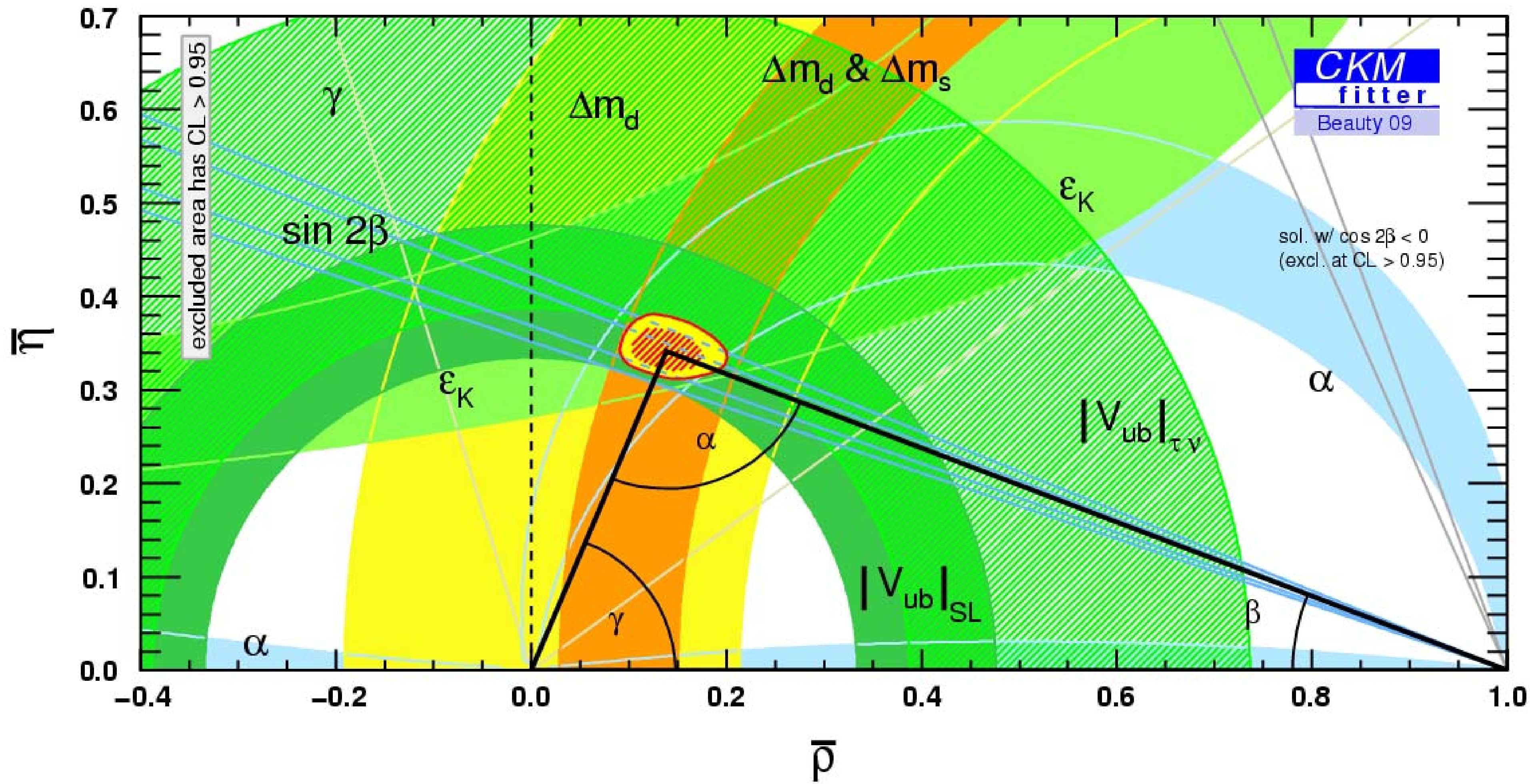
Holger Wetteskind
Technology@HLL
Martina Schnecke, Gerhard Schaller (MPE),Florian Schopper (MPE),
Klaus Heinzinger (PN Sensor), Rouven Eckardt (PN Sensor)

Backup

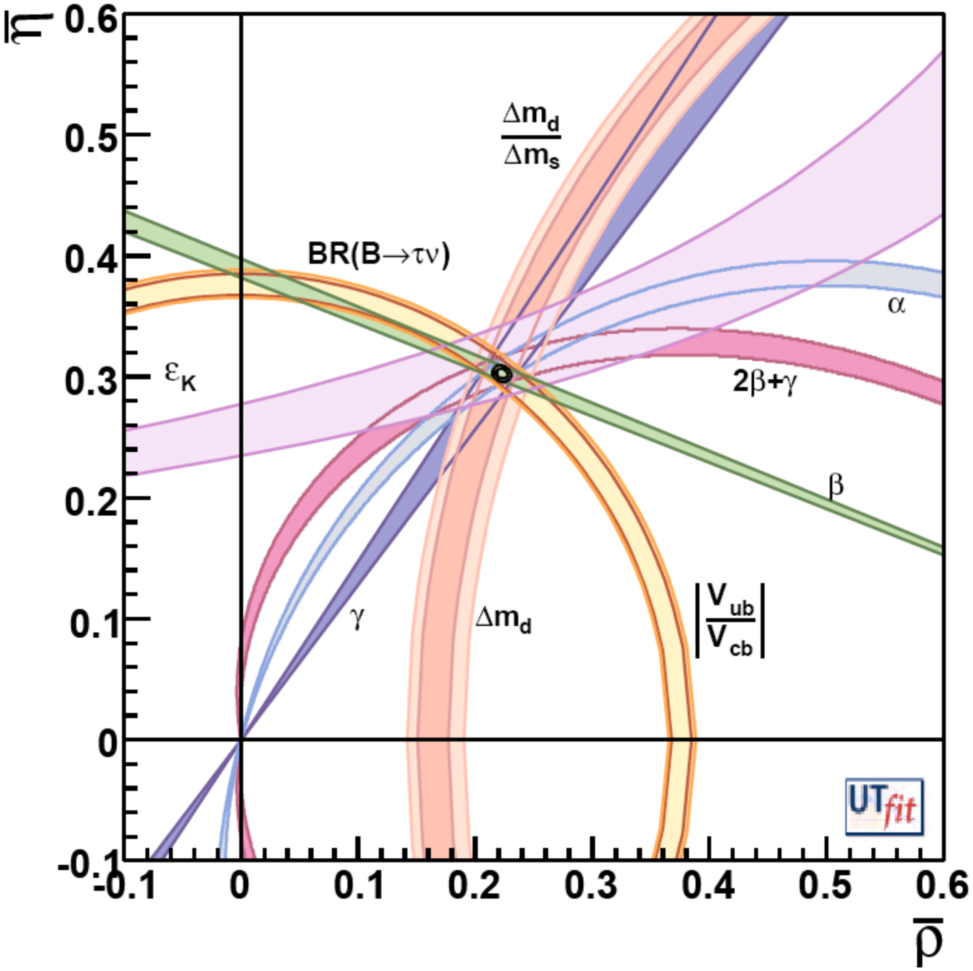
The Unitarity Triangle in the year 2009

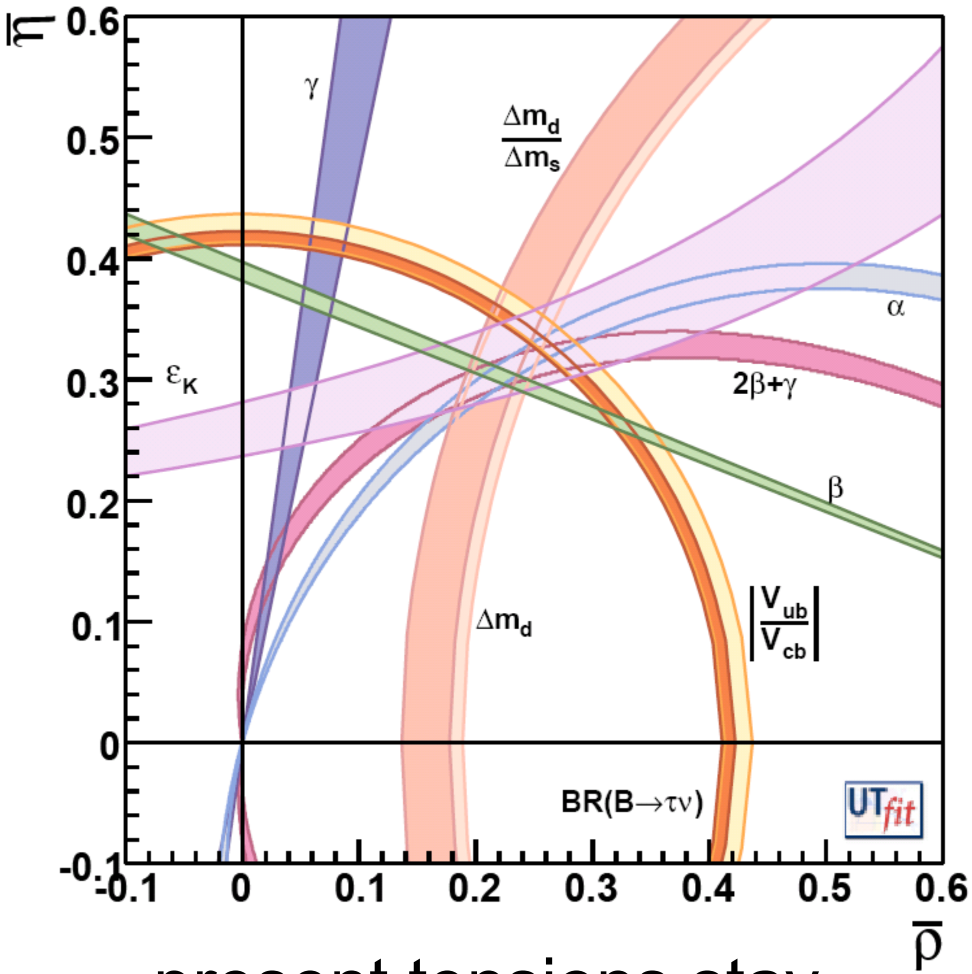


CKM Fitter Group, Beauty 2009 Conference, Heidelberg

The Unitarity Triangle in the year 2020

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





SM correct

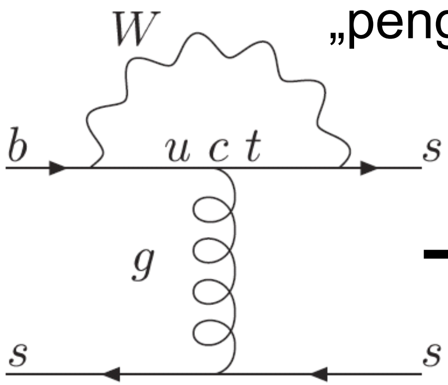
a nightmare …

present tensions stay …

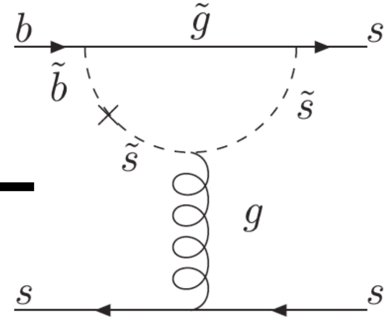
… the dream !

New Physics at the Loop Level ....

„penguins"



+



SM NP

NP in CPV asymmetries:

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

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

leptons:

$$\tau \to \mu\gamma$$
$$\tau \to \mu\mu\mu$$
$$\tau \to \mu\eta$$

NP could make these decays possible

need precision (statistics) to challenge the SM

Energy reach of the SuperKEKB Factory

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

Look for FCNC processes (highly suppressed in SM):

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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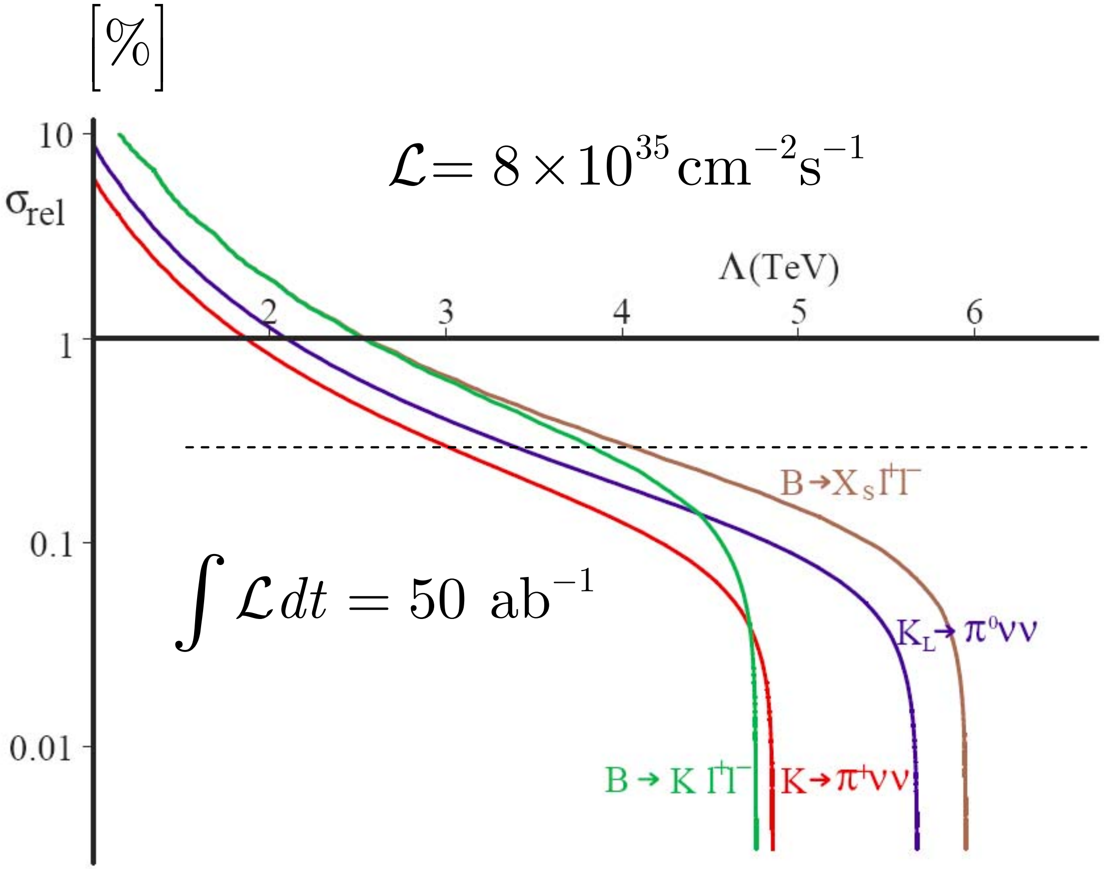


Project Status

- 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.

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

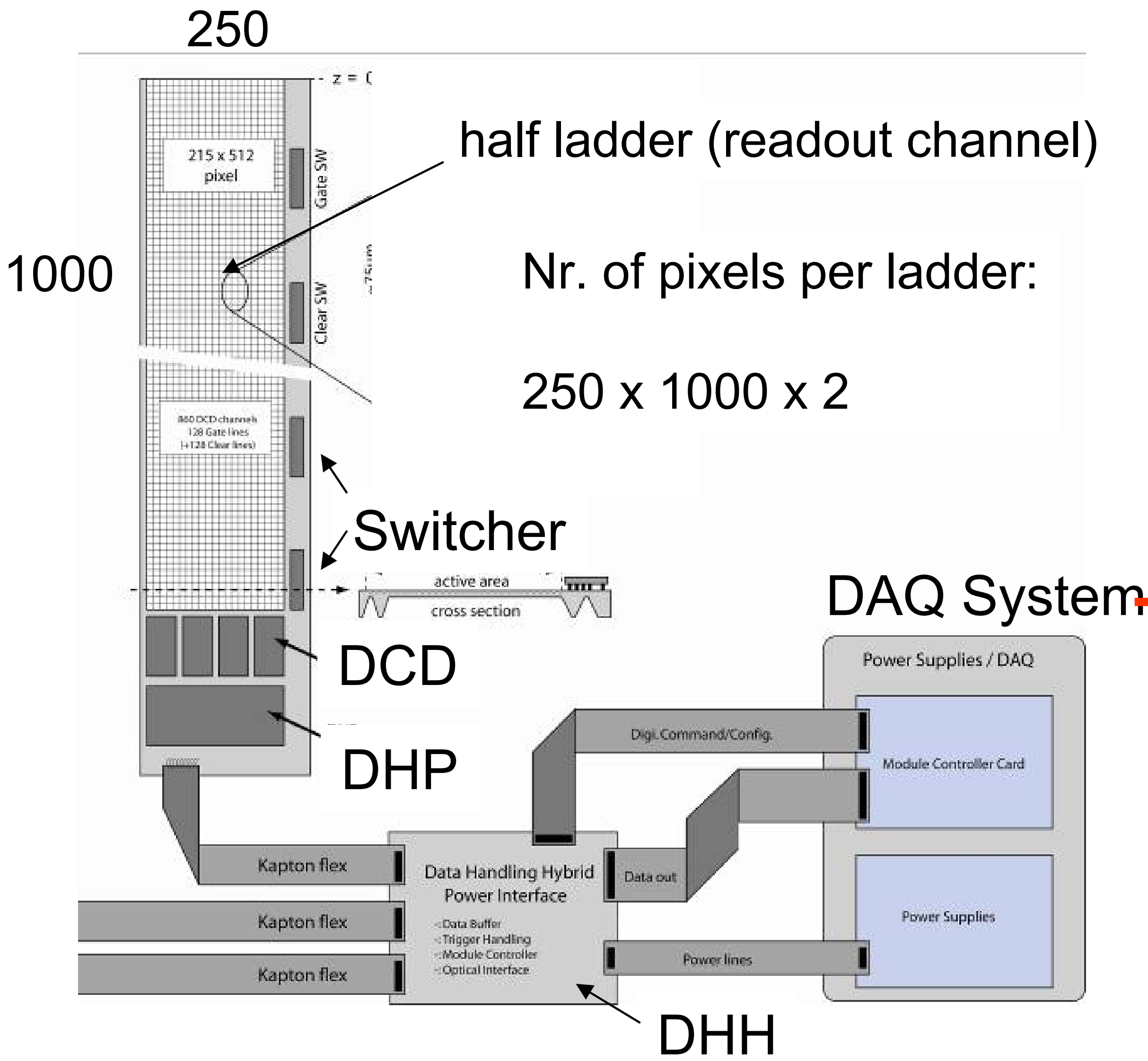
European Participation in Belle-II

- 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

} Members of the DEPFET Collaboration:
+ Heidelberg, Göttingen
+ 5 Spanish groups

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

PXD Data Acquisition



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

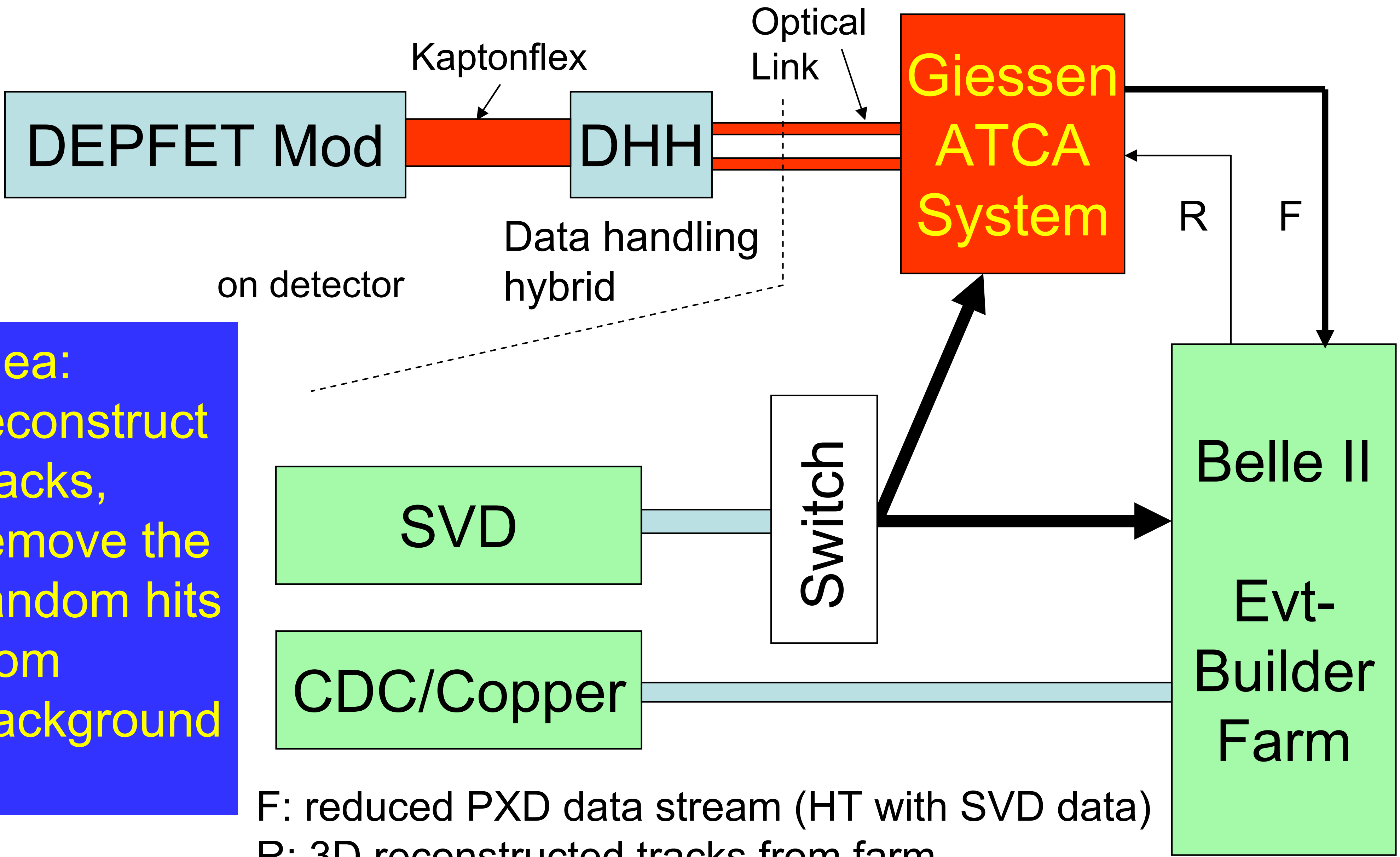
→ 2×10^5 px in each event

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

Total evt size: ~ 1 MByte

Total rate:
200 Gb / sec

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)

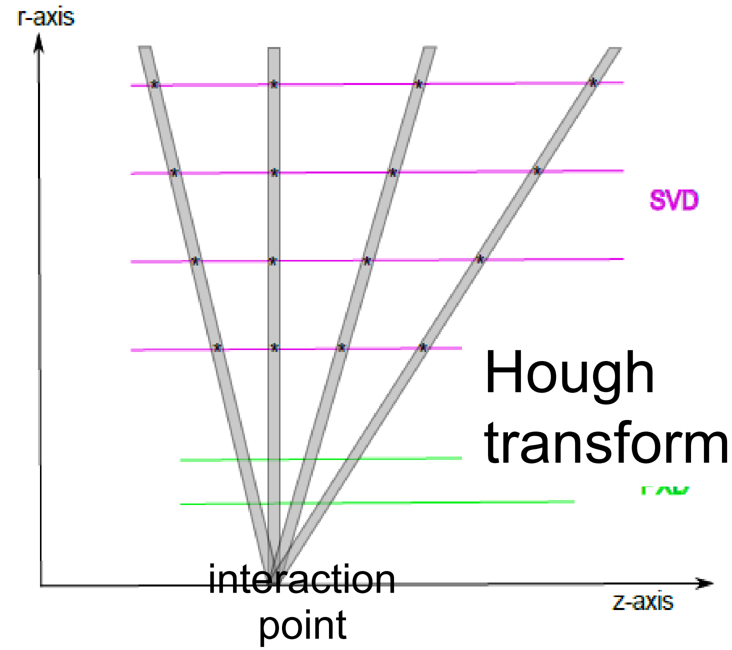
- **debugging ongoing**
  incl. development and testing
  of FPGA-to-FPGA communication
  a.) onboard
  b.) board-to-board
  (via backplane)
- **preparation for beamtime**
  (readout with 1 ATCA shelf)
  at HADES test experiment at GSI
  in 2010

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

Online PXD Data Reduction

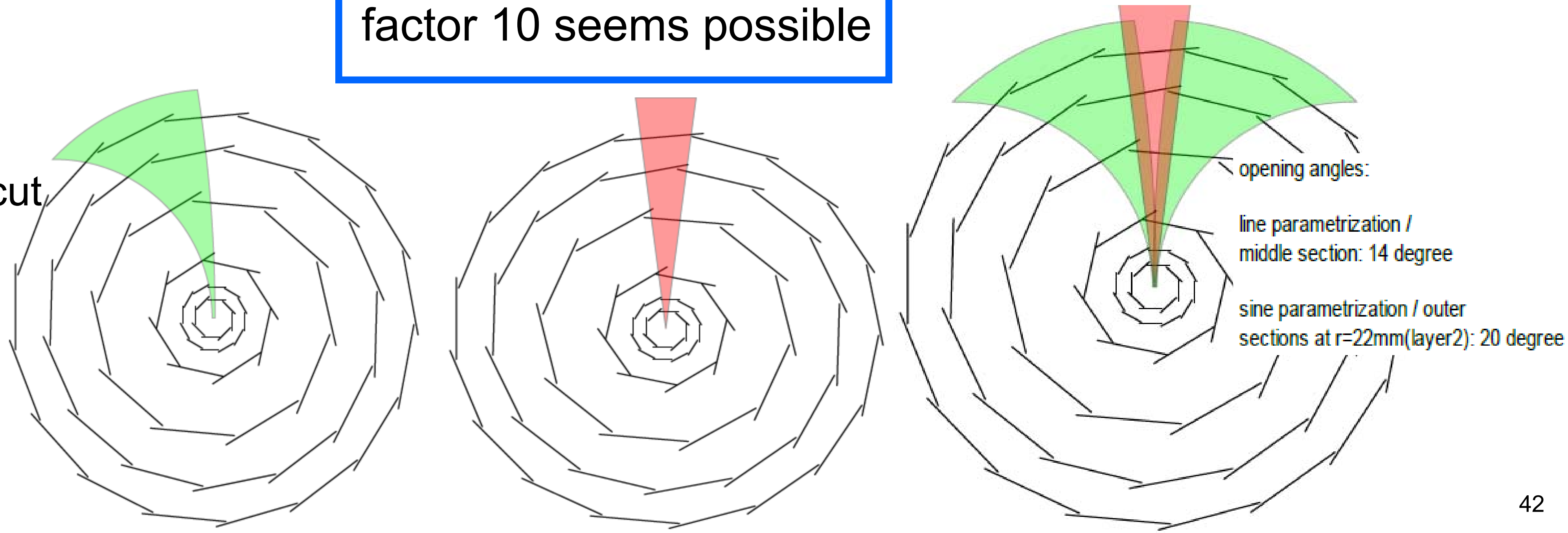
Claudio Heller (MPI)

- 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 $\Delta\Phi=9^{\circ}$
- different shaped sectors for low momentum particles and nearly straight tracks in r-phi-plane



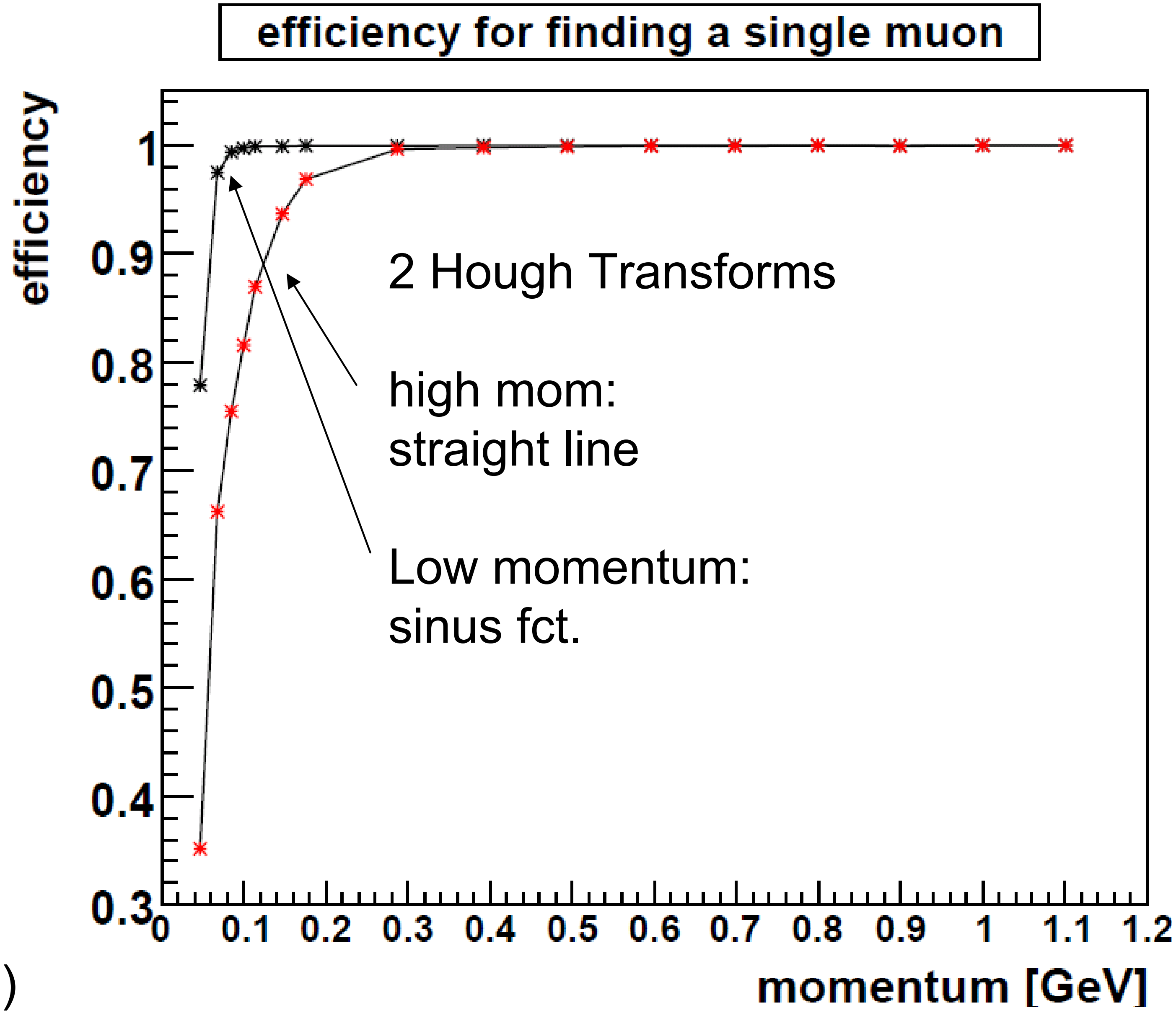
factor 10 seems possible

p_T cut



Online PXD Data Reduction

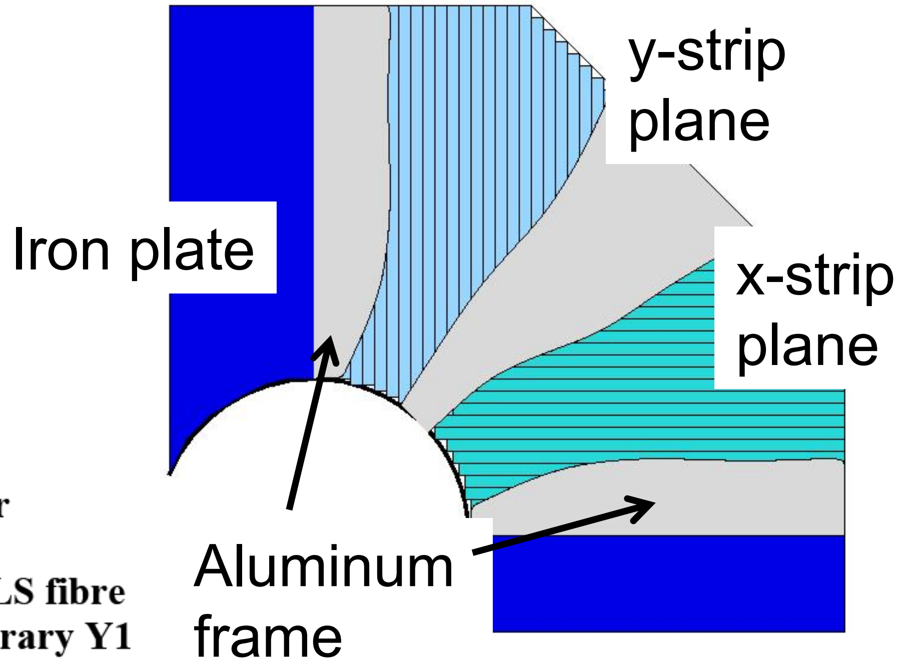
very good eff.
down to very
low momenta

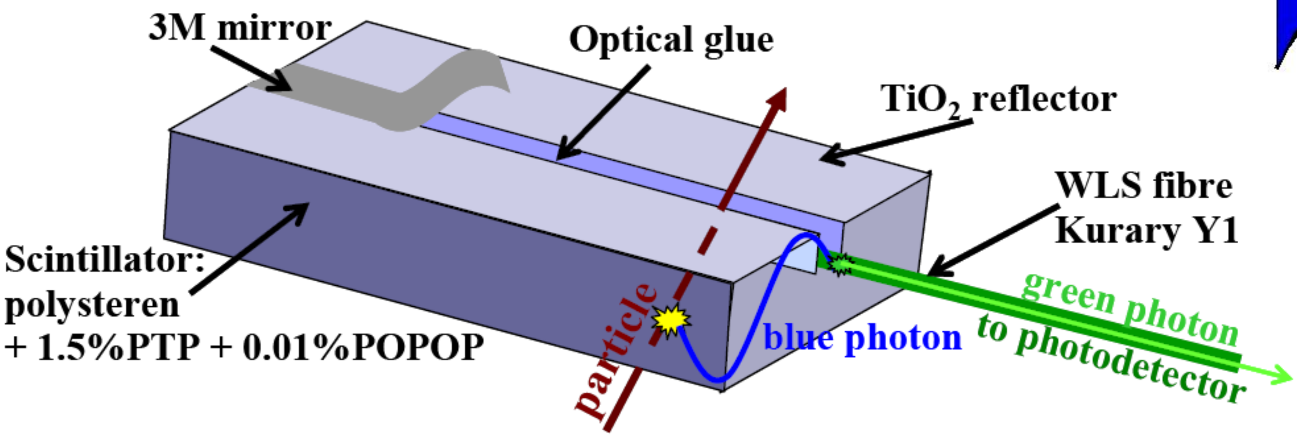


Claudio Heller (MPI)

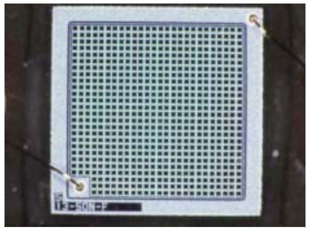
Upgrade of KLM (Endcaps)

- 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 (20x20μm²)



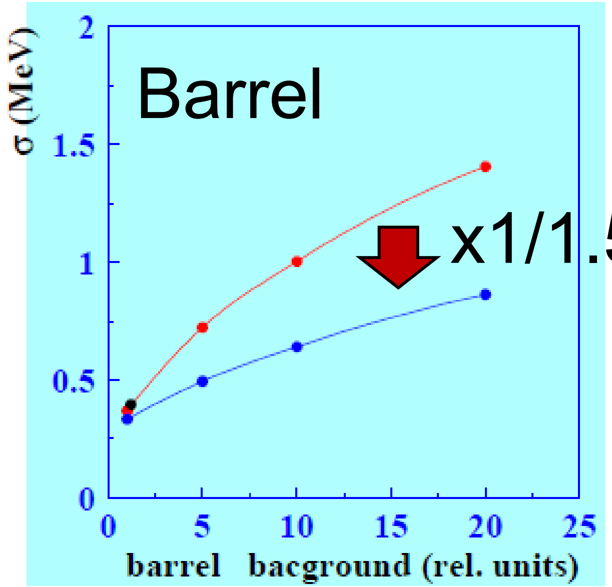
SiPM, e.g. Hamamatsu 1.3x1.3 mm²

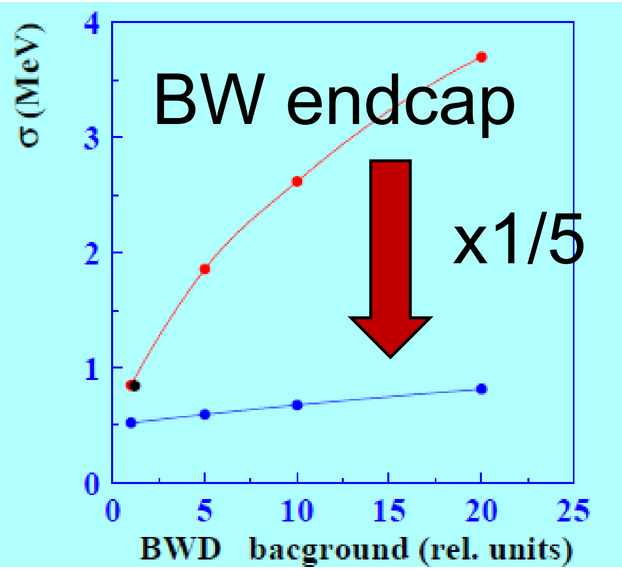
Calorimeter Upgrade (ECL)

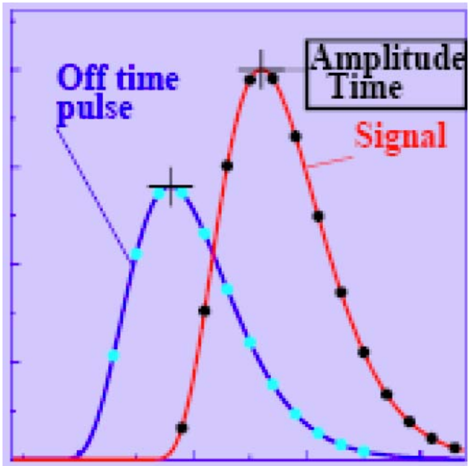
- Increase of dark current due to neutron flux
- Fake clusters & pile-up noise

- 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:

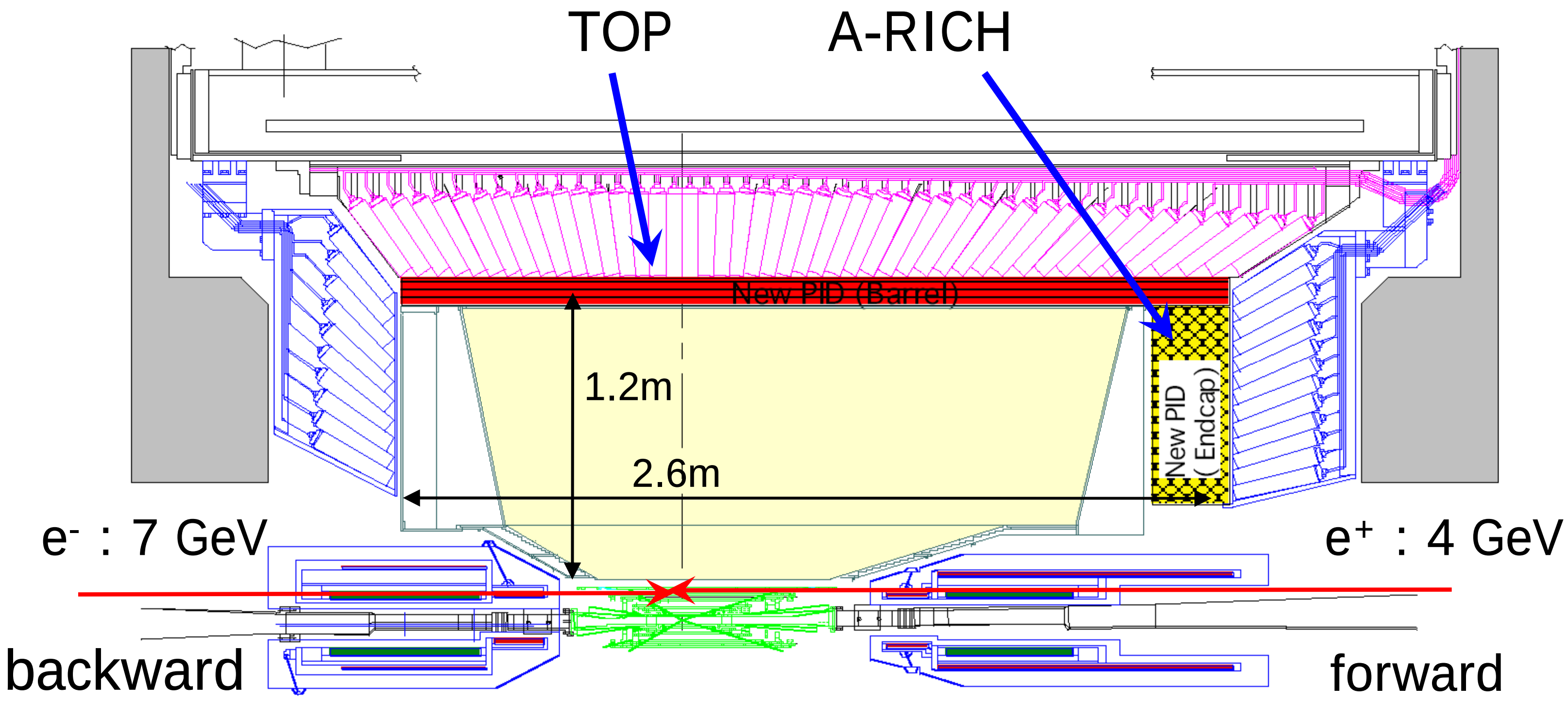






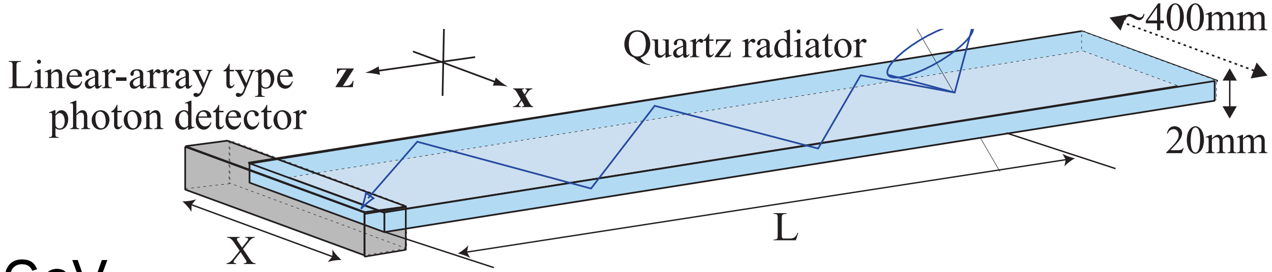
FADC: 16 samples

Upgrade: Particle Identification



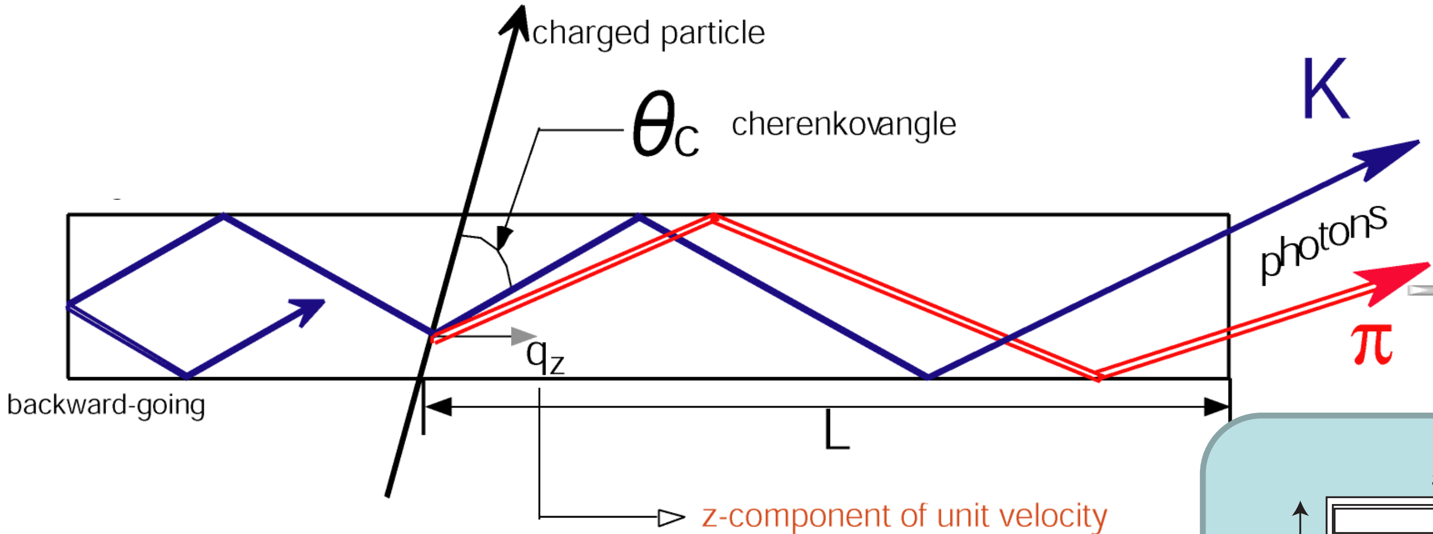
Goal:

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

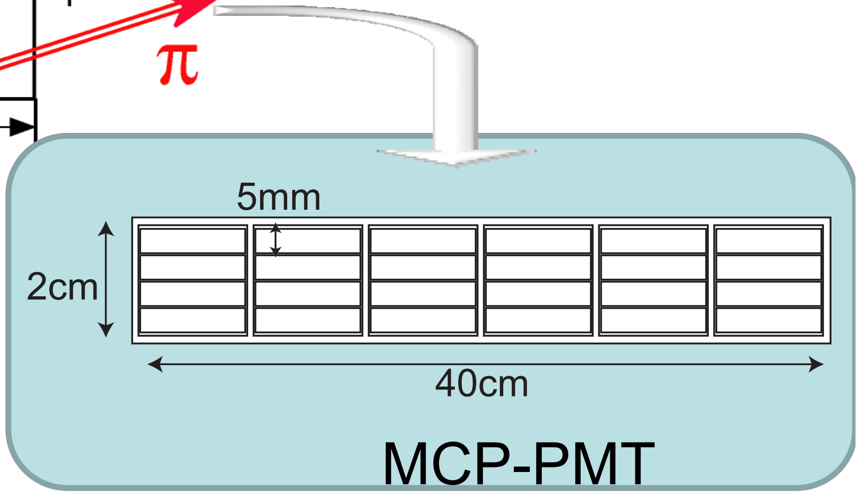


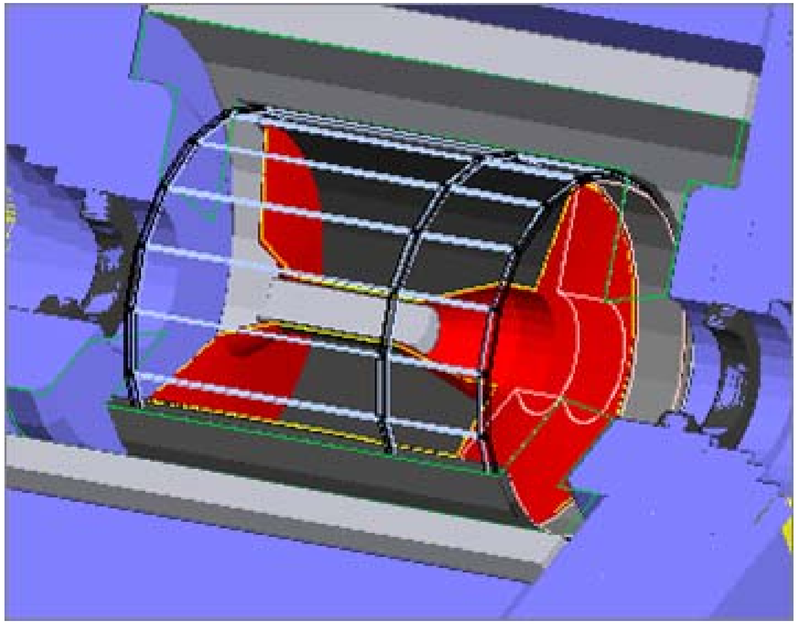
TOP: time of propagation

Baseline Design for Barrel PID



different Cherenkov angle for K and π: also different TOP





Ring imaging with :

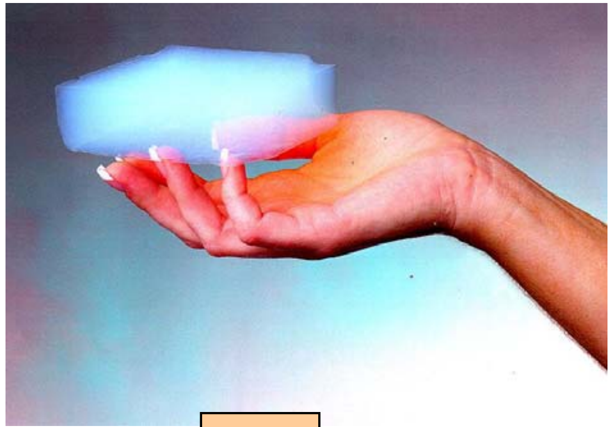
- One coordinate with a few mm precision
- Time-of-arrival

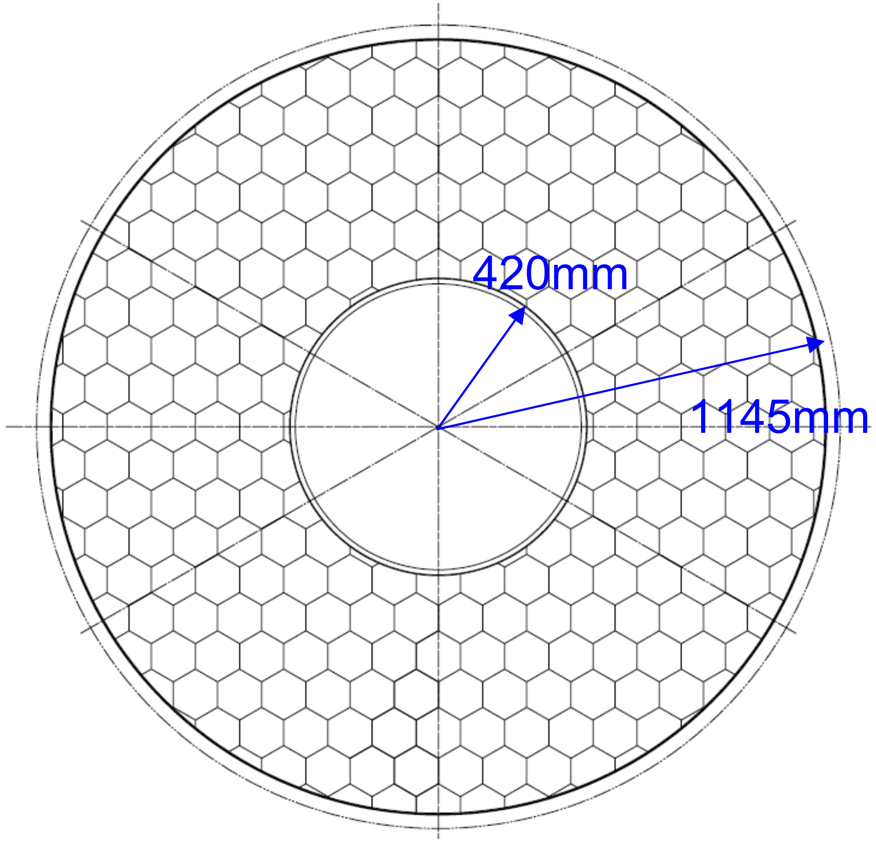
→ Excellent time resolution < ~40ps

efficient single photon detection in 1.5 T field

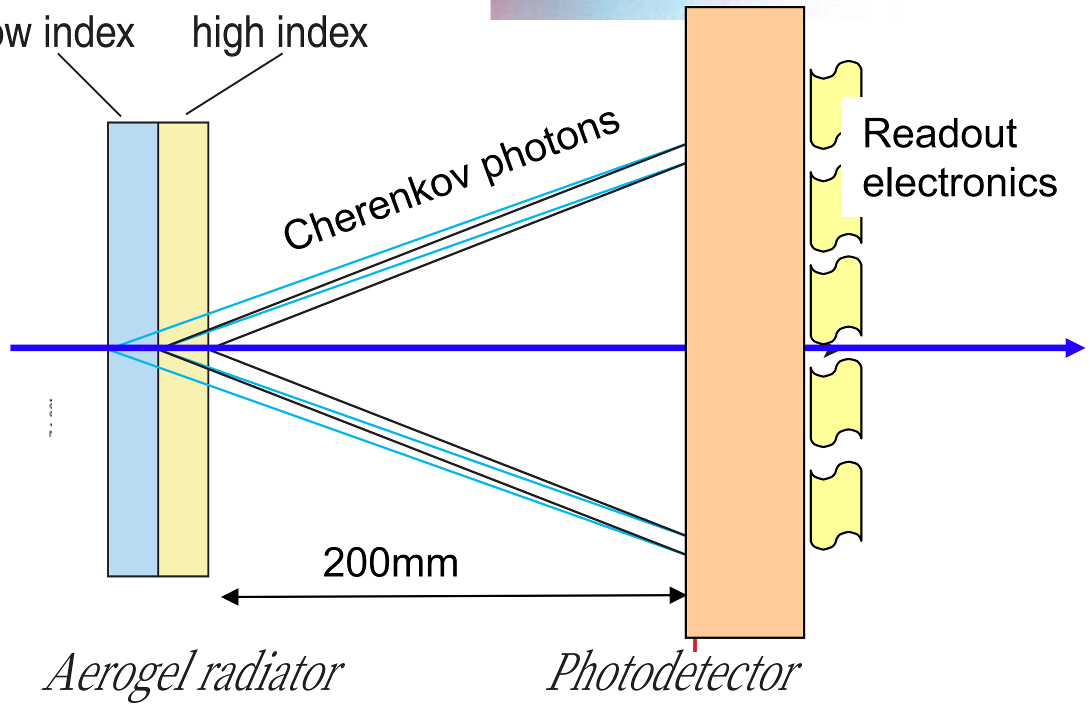
Baseline Design for Endcap PID

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





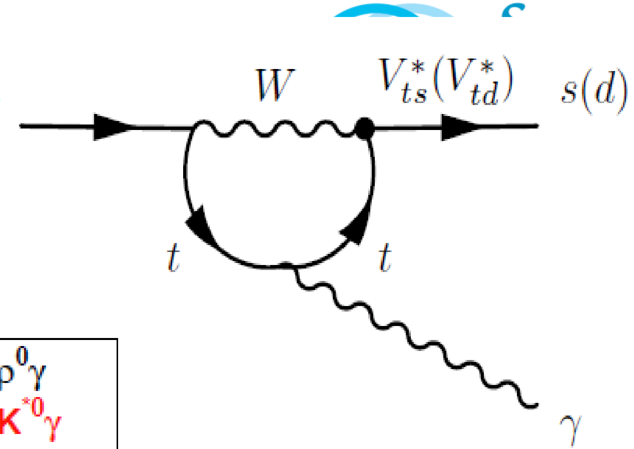
x-y view of forward end-cap



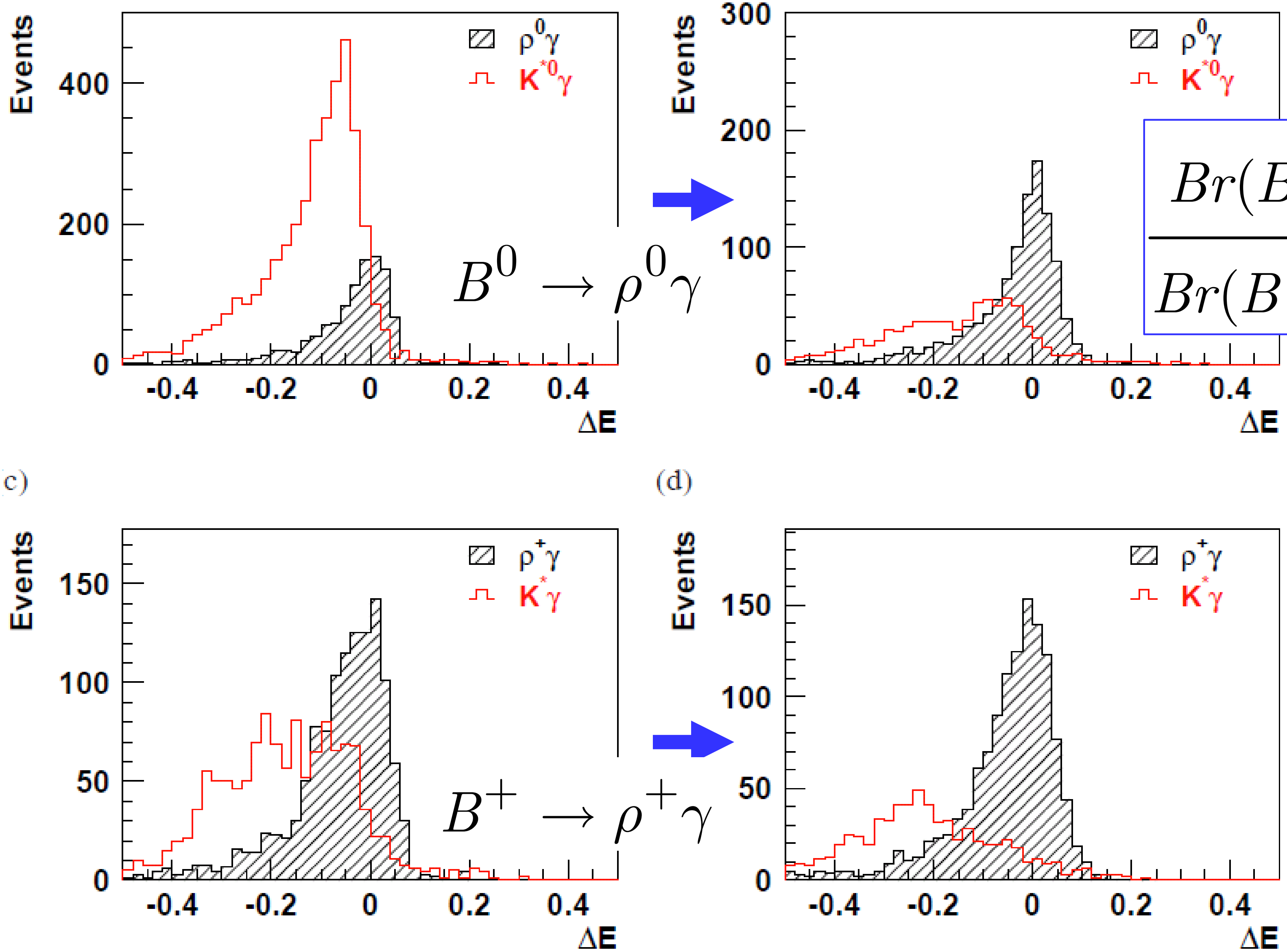
encouraging beam tests: Ch-photons ~ 14/track
angluar res./tr. 4 mrad

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

Expected PID Performance



Present Belle PID | Belle II PID



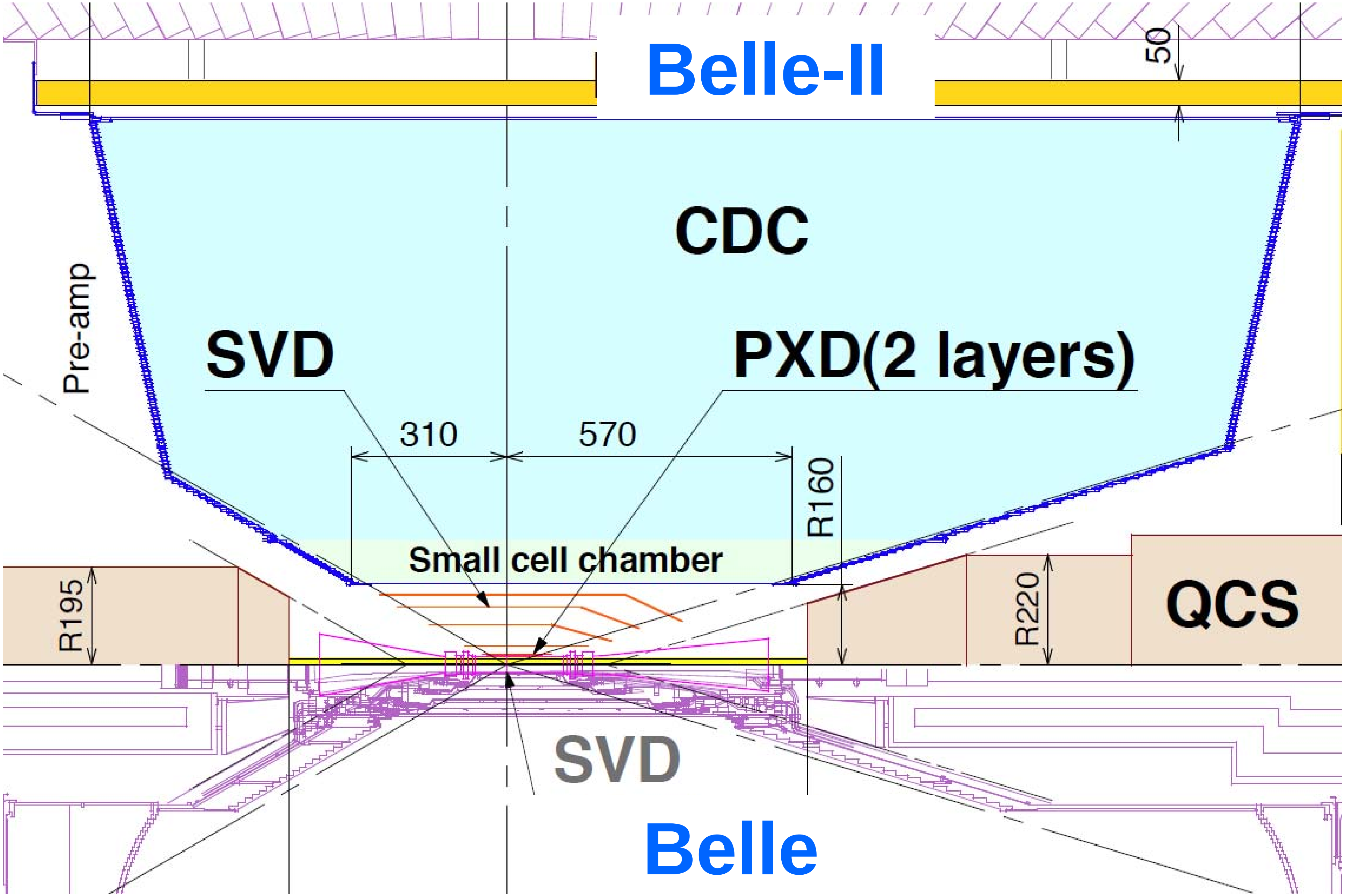
$$\frac{Br(B \to \rho\,\gamma)}{Br(B \to K^*\gamma)} \sim \left|\frac{V_{td}}{V_{ts}}\right|^2$$

$(\sim 1/40)$

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

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

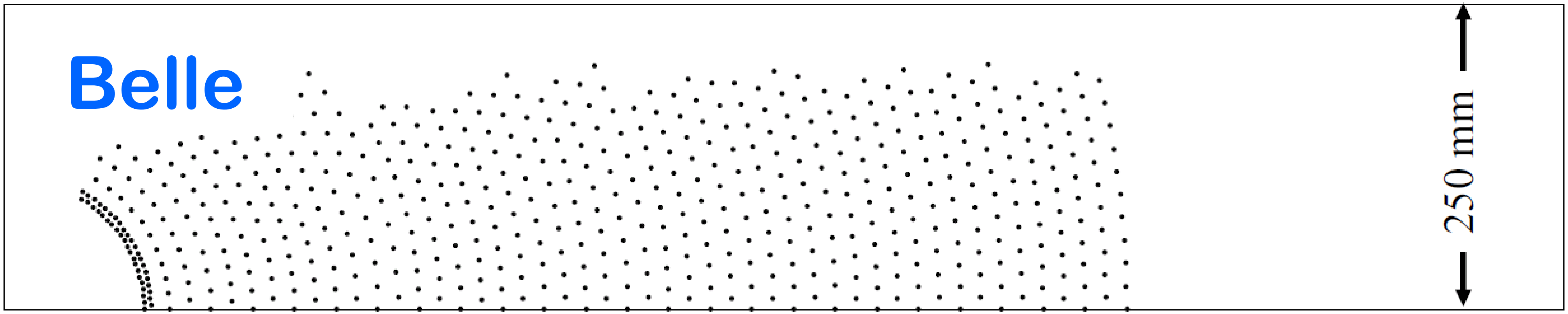
New Tracking System for Belle-II



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	$He\text{-}C_2H_6$	$He\text{-}C_2H_6$
Diameter of sense wire (μm)	30	30

New Central Drift Chamber (CDC)

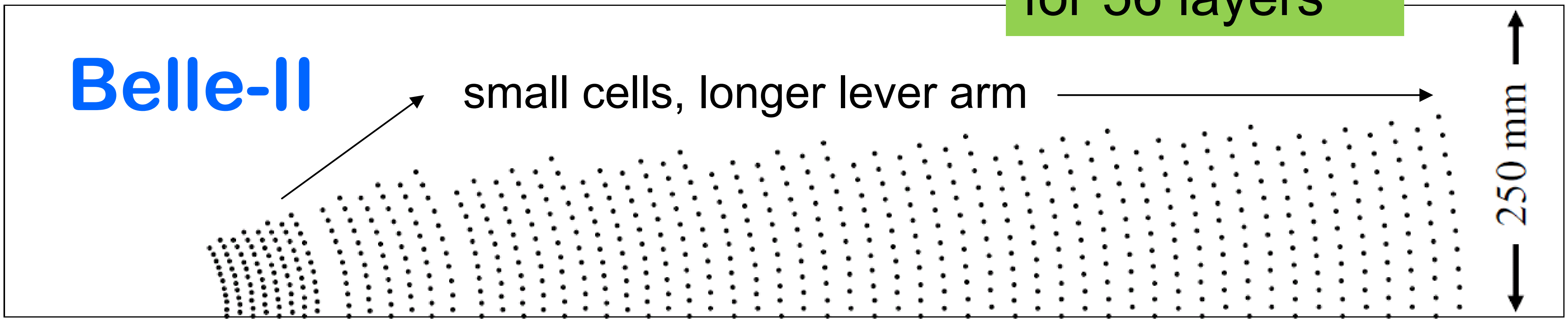


normal cell: 13.3 x 16 mm^2

1200 mm

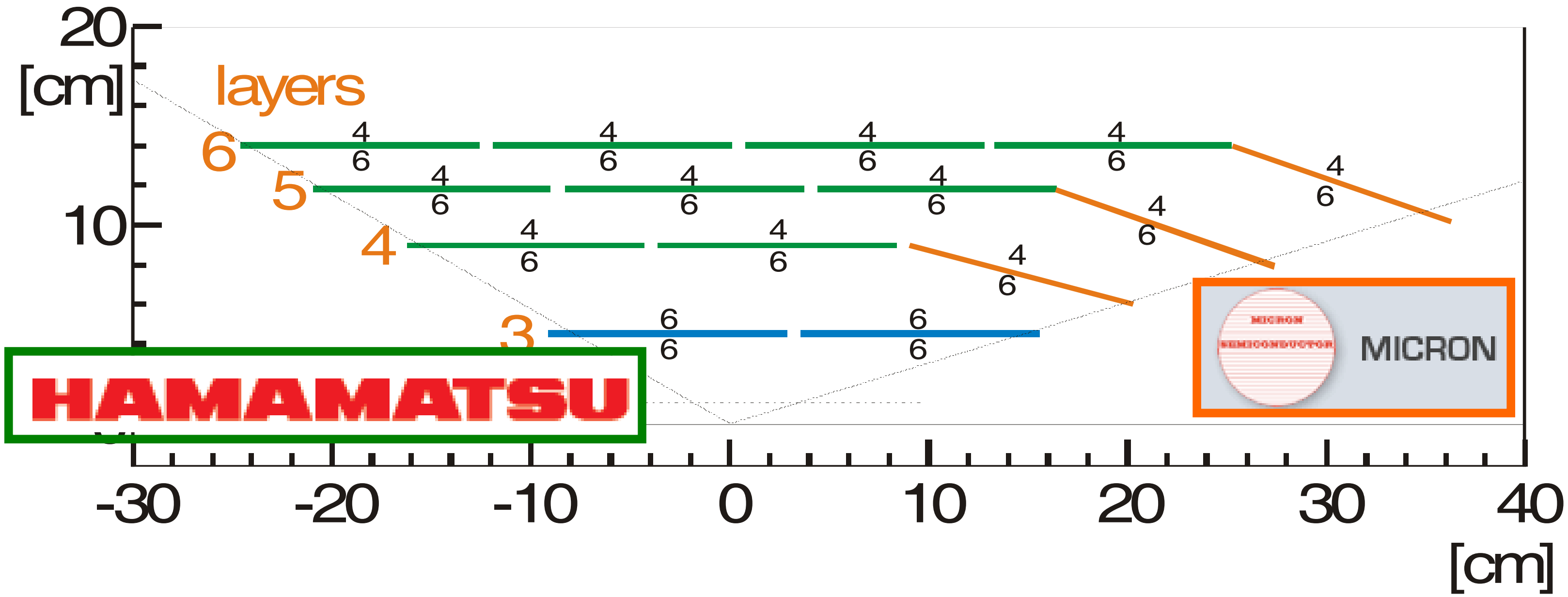
small cell: 5.4 x 5.0 mm^2

dE/dx: 4.8%
for 56 layers



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

New Si System for Belle-II : SuperSVD



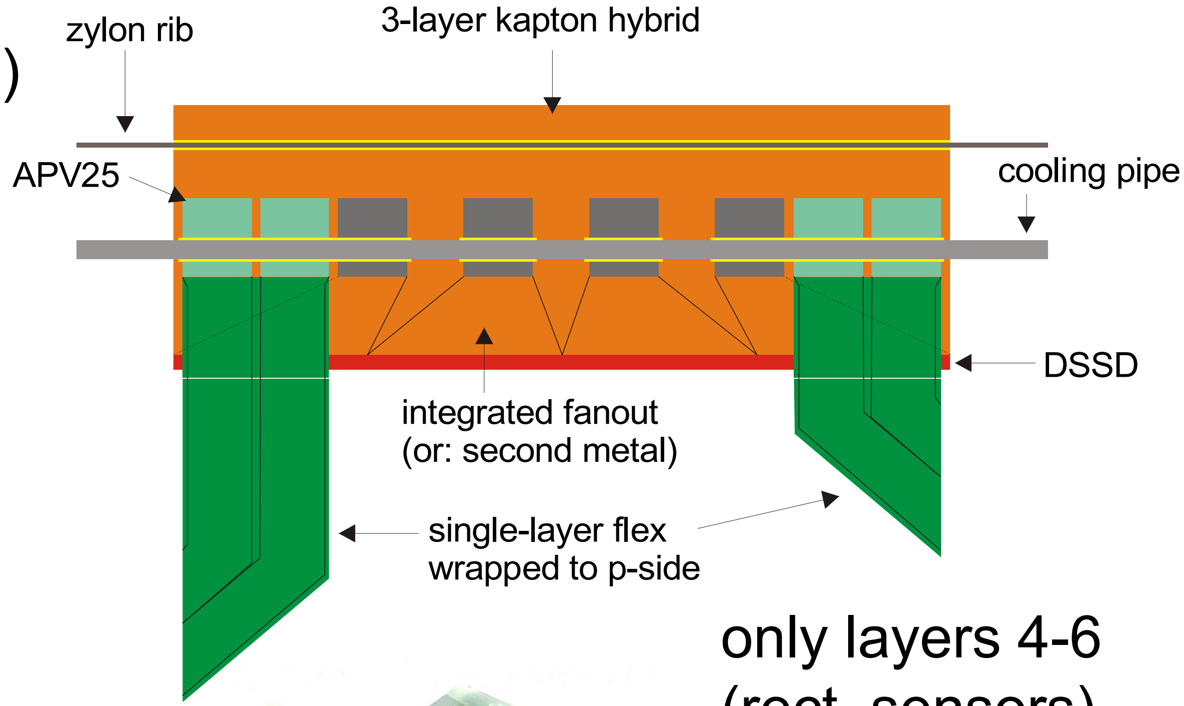
300 µm DSSD

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

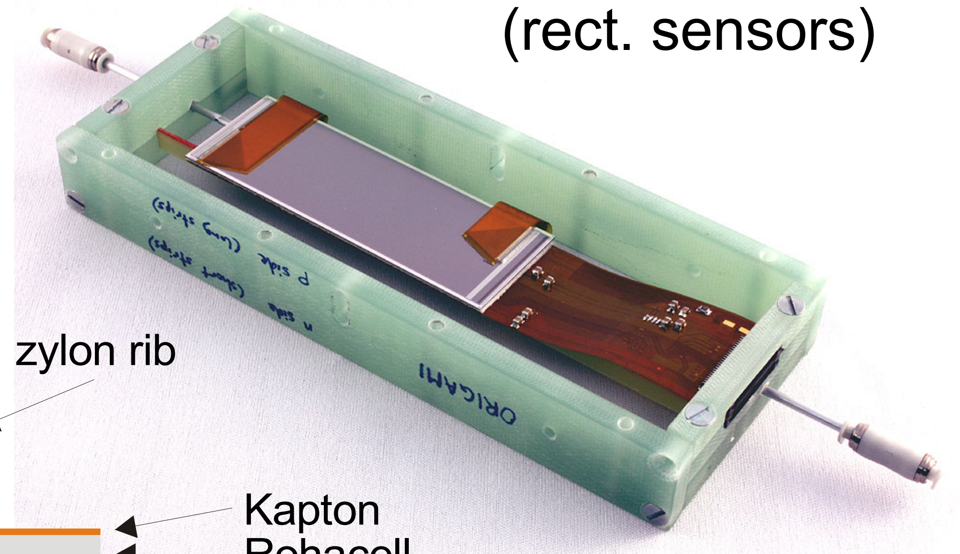
Layer	# Ladders	Rect. Sensors [50 µ m]	Rect. Sensors [75 µ m]	Wedge Sensors	APVs
6	17	0	68	17	850
5	14	0	42	14	560
4	10	0	20	10	300
3	8	16	0	0	192
Sum:	**49**	**16**	**130**	**41**	**1902**

Chip on Sensor: The Origami Concept (SVD)

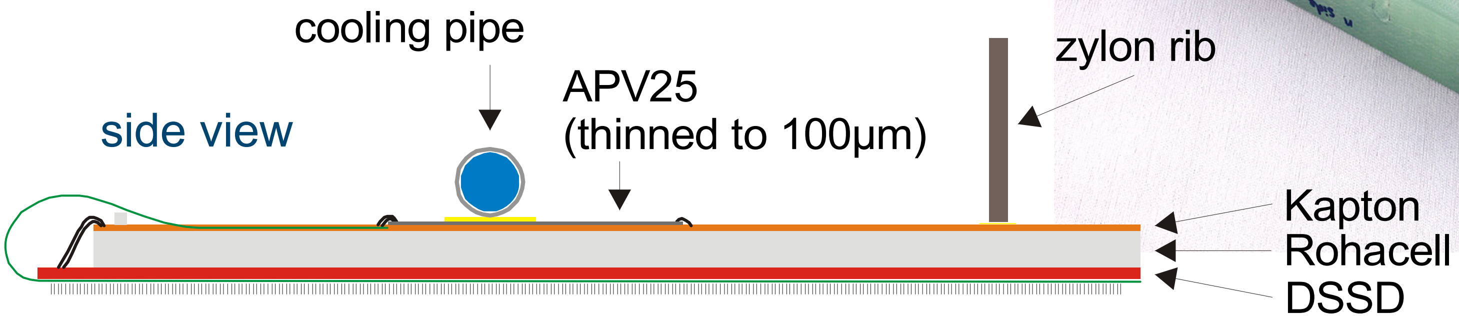
- Thinned readout chips (APV25) on sensor
- Strips of bottom side are connected by flex fanouts wrapped around the edge
- All readout chips are aligned → single cooling pipe
- Shortest possible connections → high signal-to-noise ratio



only layers 4-6
(rect. sensors)



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



SVD Mechanics and Material Budget