A Novel Pixel Vertex Detector for the Belle II Experiment at the SuperKEKB Collider

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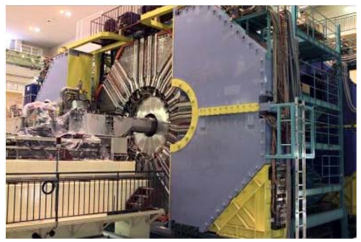
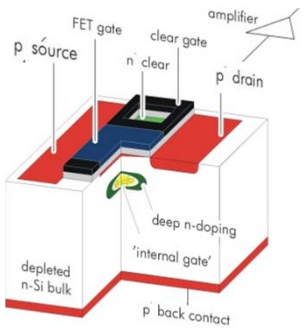
- Motivation: New Physics

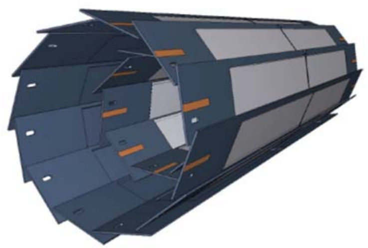
- SuperKEKB and Belle II



- DEPFET Technology



- Pixel Vertex Detector („PXD“)

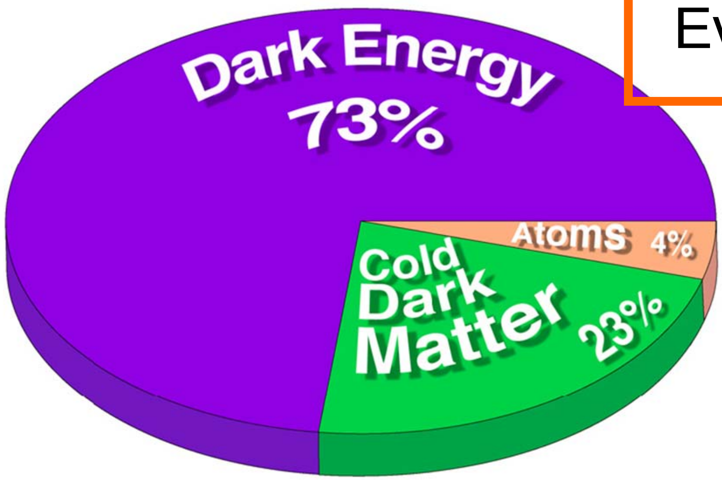


- Conclusion & Next Steps

Why do we Expect New Physics ?

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 in the Universe is
  much too large (by 10 orders of magnitude)

need
very high energy
(LHC) or
v. high precision
(SuperB factories)

At least two of them have to do with CP Violation

$\not{C}\not{P}$: One of the so-called Sakharov-conditions

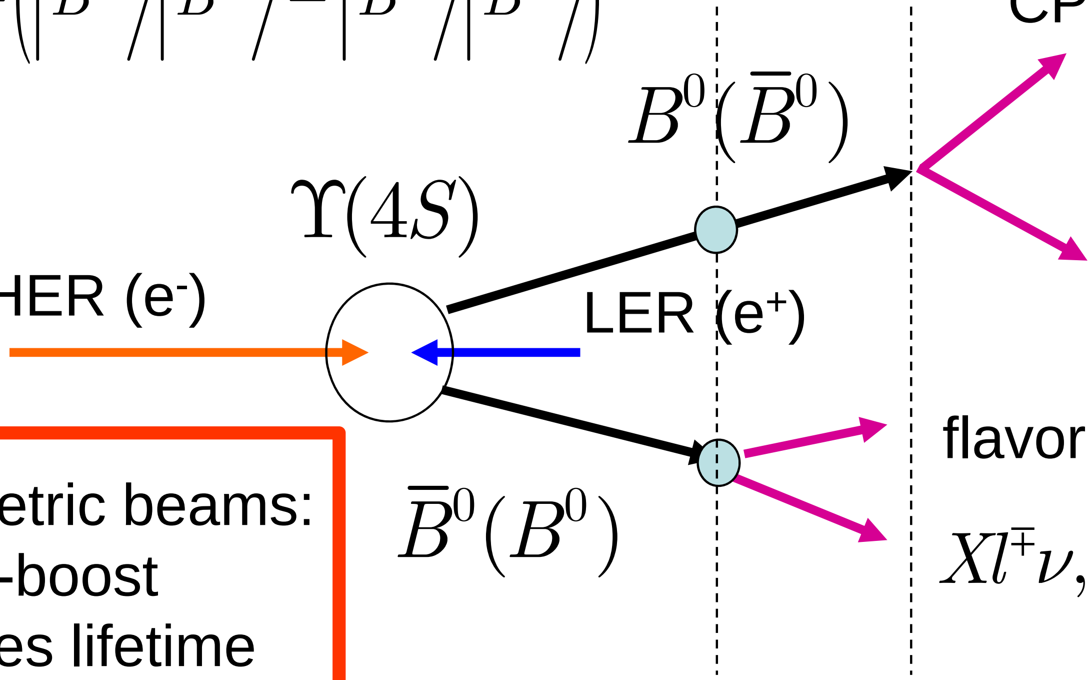
The $\not{C}\not{P}$ Observables: What do we measure?

Quantum-entangled *B*-meson pair:

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\overline{B}^0$$

CME = 10.58 GeV

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle|\overline{B}^0\rangle - |\overline{B}^0\rangle|B^0\rangle\right)$$



some state $f(\overline{f})$ or CP eigenstate, e.g.

$J/\psi K_S$ $CP = -1$ the „Golden" channel

flavor eigenstate

$Xl^{\mp}\nu, D^{*\pm}X$ „flavor tagging"

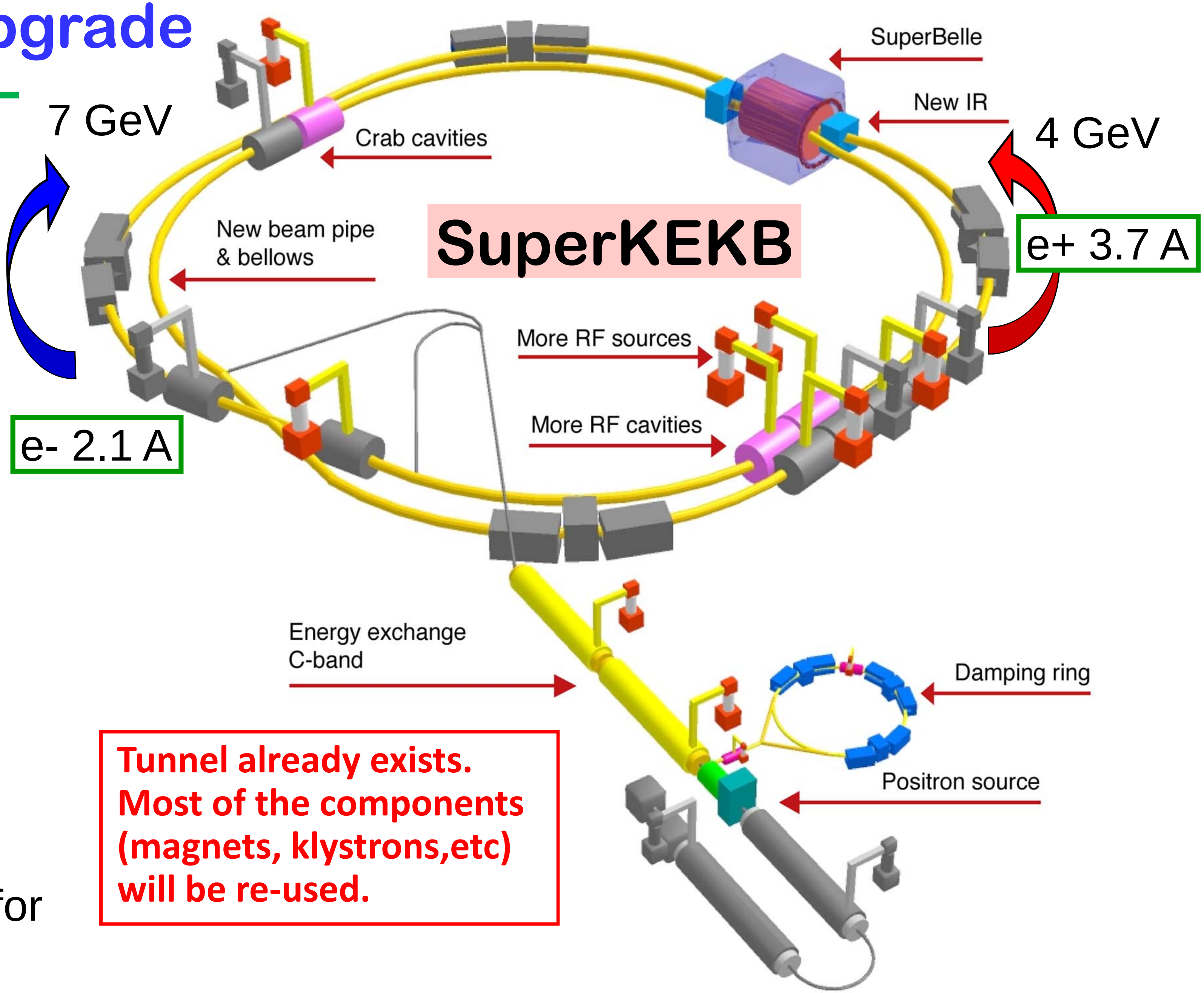
Asymmetric beams: Lorentz-boost translates lifetime to decay length

$$\Delta z = \beta\gamma c\Delta t \sim 150\mu m$$

Precise vertex detectors essential to measure CP violation

Machine Upgrade

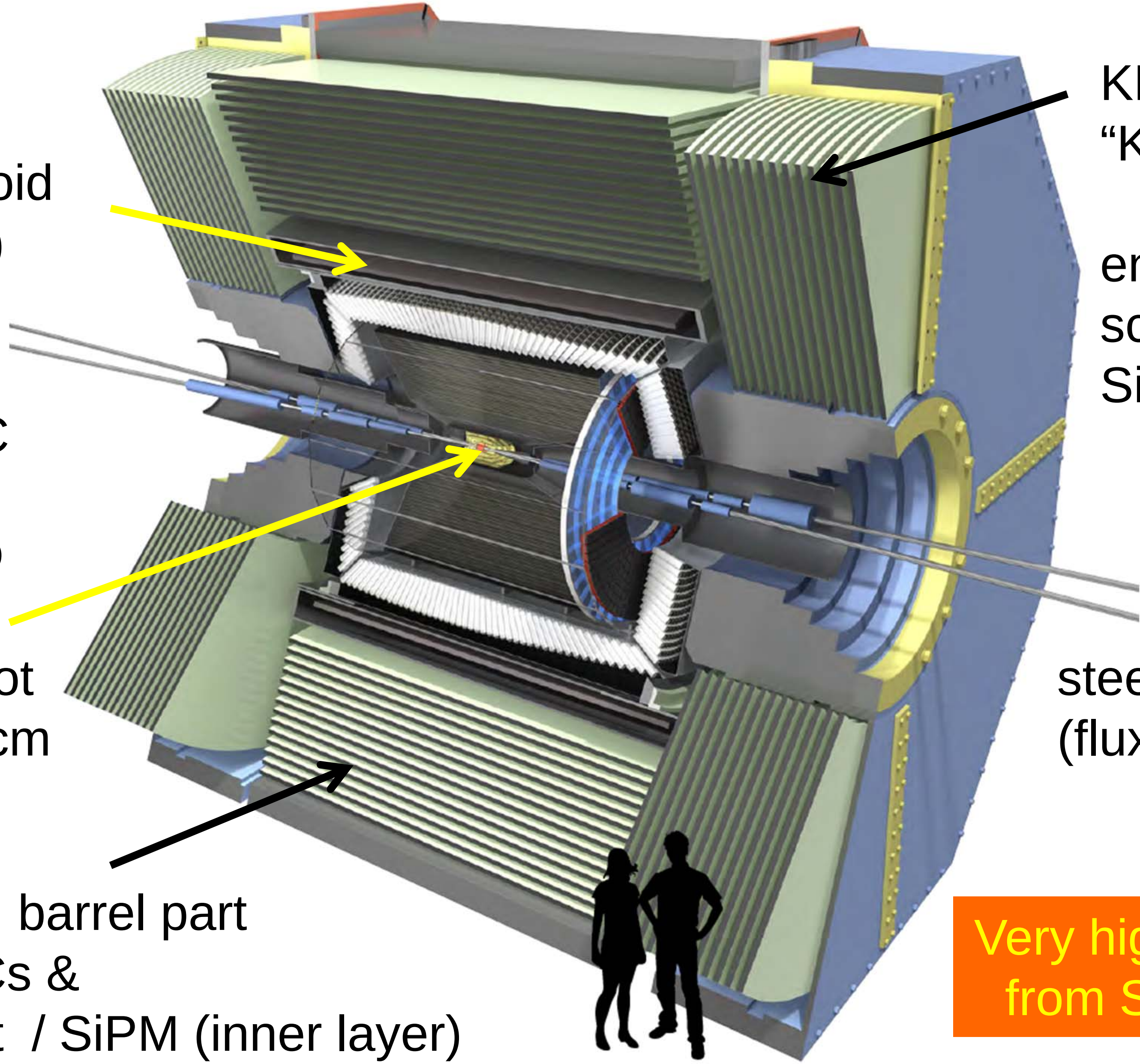
- KEKB has produced world record luminosity: $2x10^{34}$ cm^{-2} s^{-1}
- Upgrade uses "nano-beam" scheme:
- Low emittance electron linac
- Damping ring for positrons



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

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

The Belle II Detector



Very high background from SuperKEKB !!

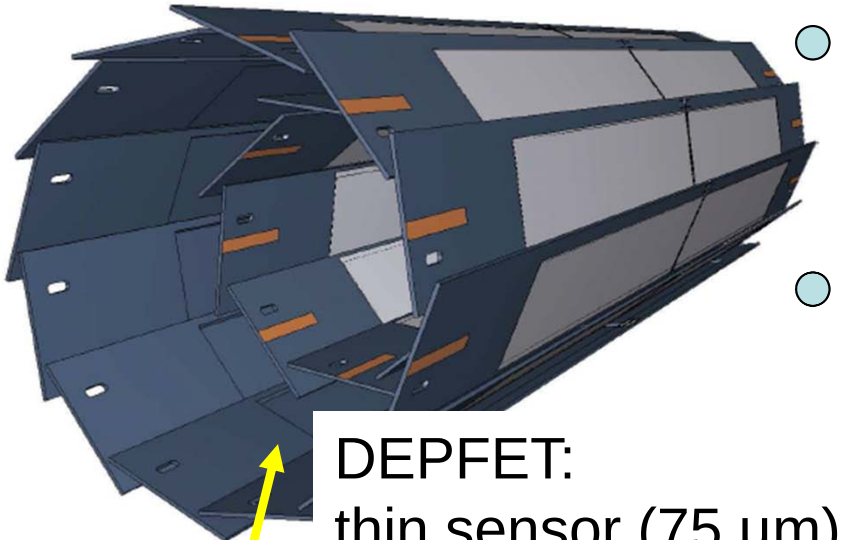
SuperKEKB and Belle-II
The Luminosity Frontier

Belle-II Collaboration founded in Dec. 2008

now over 400 members from
51 institutions and 14 countries
strong European participation:
Austria, Germany, Czech Republic,
Poland, Spain, Slovenia,
(mainly in Pixel Vertex Detector,
Si Strip Detector)

Silicon Tracking System @ Belle II

SuperKEKB: Nano beam option, 1 cm radius of beam pipe

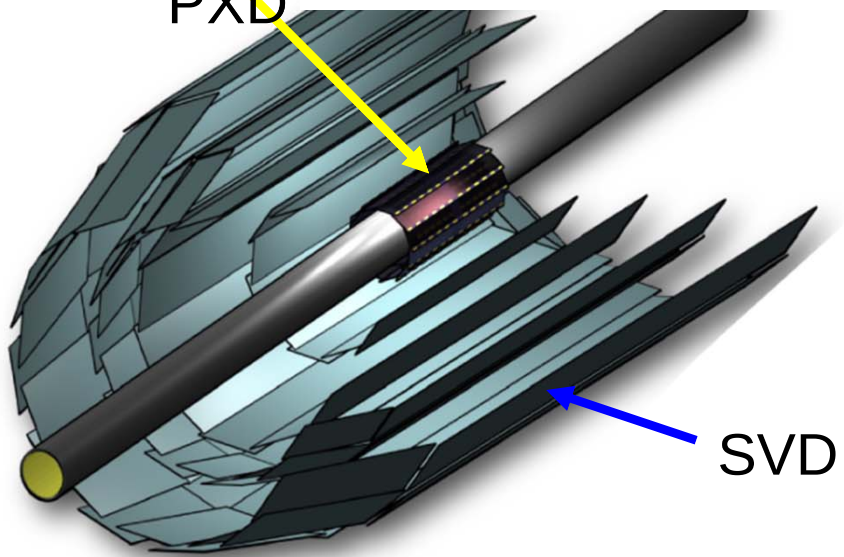


- 2 layer Si pixel detector (DEPFET technology) ← „PXD“
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 µm (!), pixel size ~50 x 50 µm²

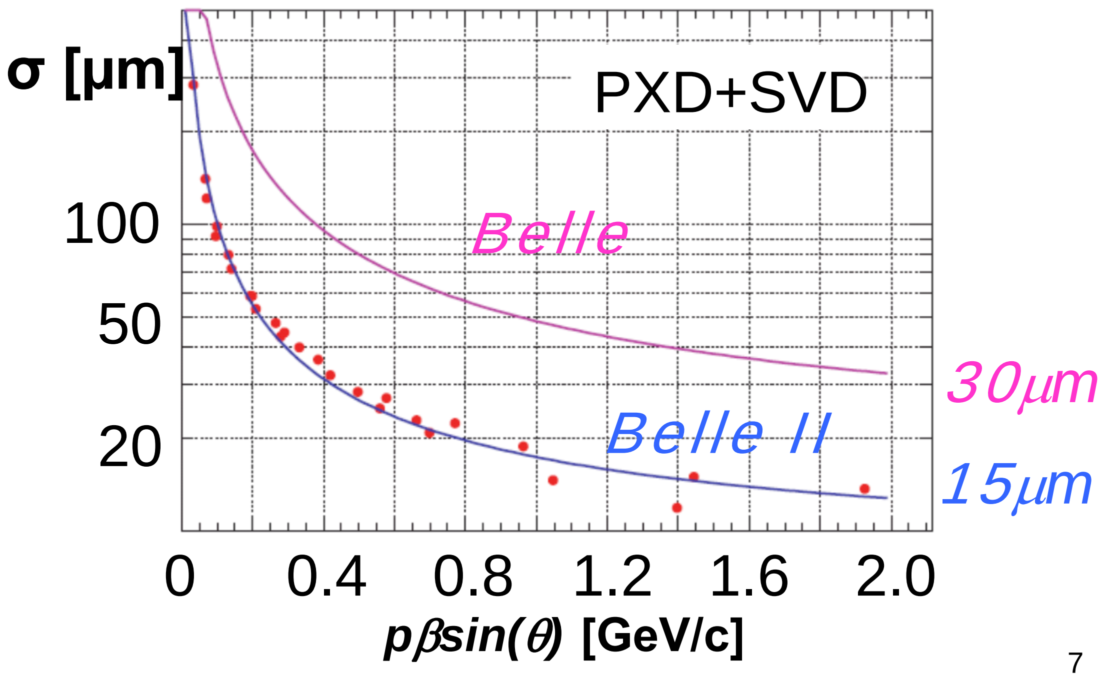
- 4 layer Si strip detector (DSSD) ← „SVD“
  (R = 3.8, 8.0, 11.5, 14.0 cm)

DEPFET:
thin sensor (75 µm)
unique worldwide

PXD



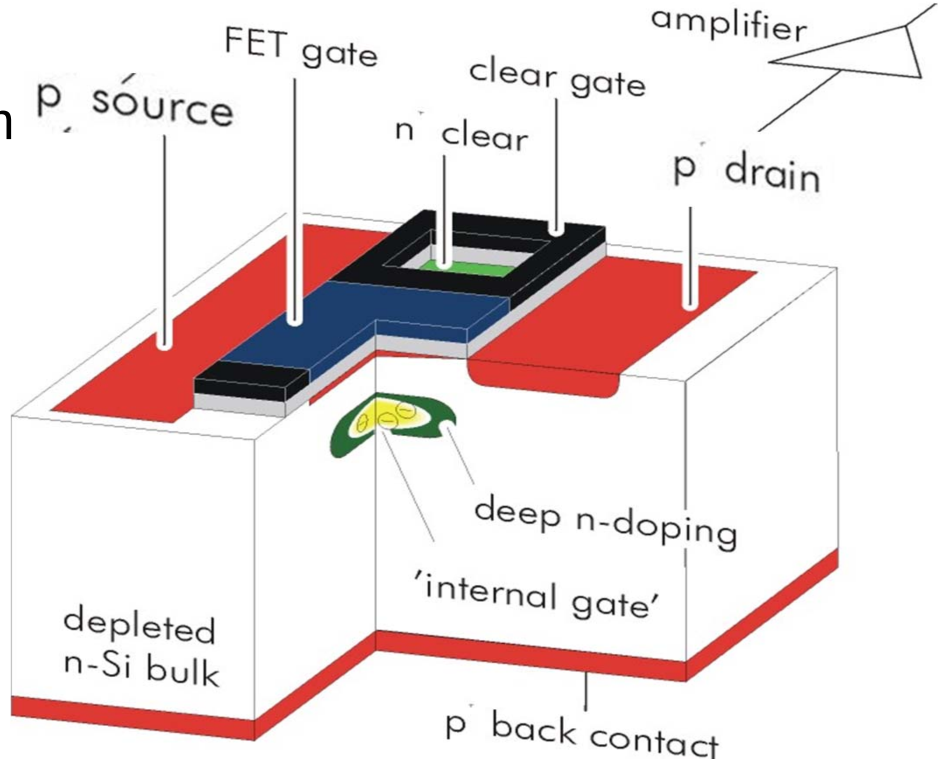
Significant improvement in z-vertex resolution



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

Array of DEPFETs

Row wise read-out

("rolling shutter mode")

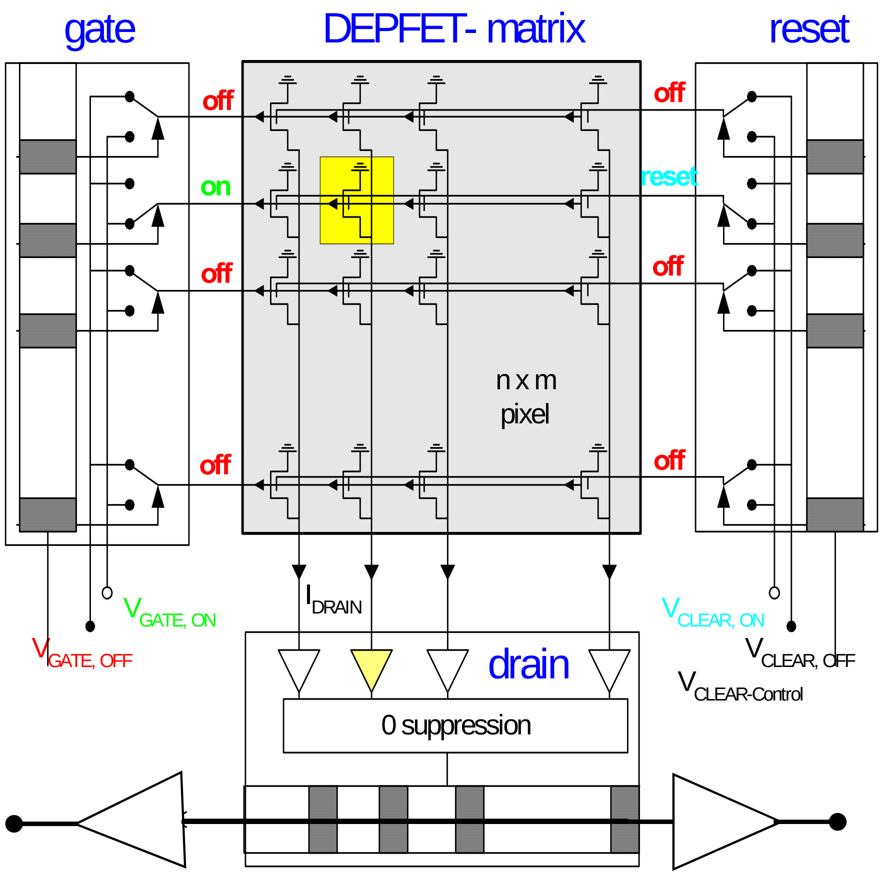
- select row with external gate

  read current,

  clear internal gate,

  read current again

  → the difference is the signal



- readout time of entire PXD in 20 µs (100 ns per row)

- three different auxiliary ASICs needed

  → Switcher

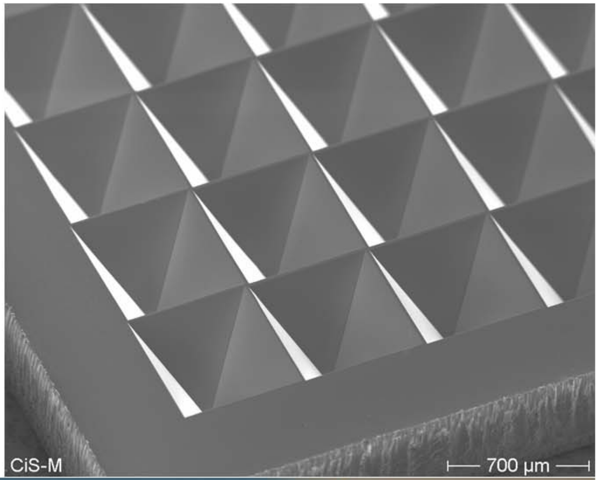
  → DCD (drain current digitizer)

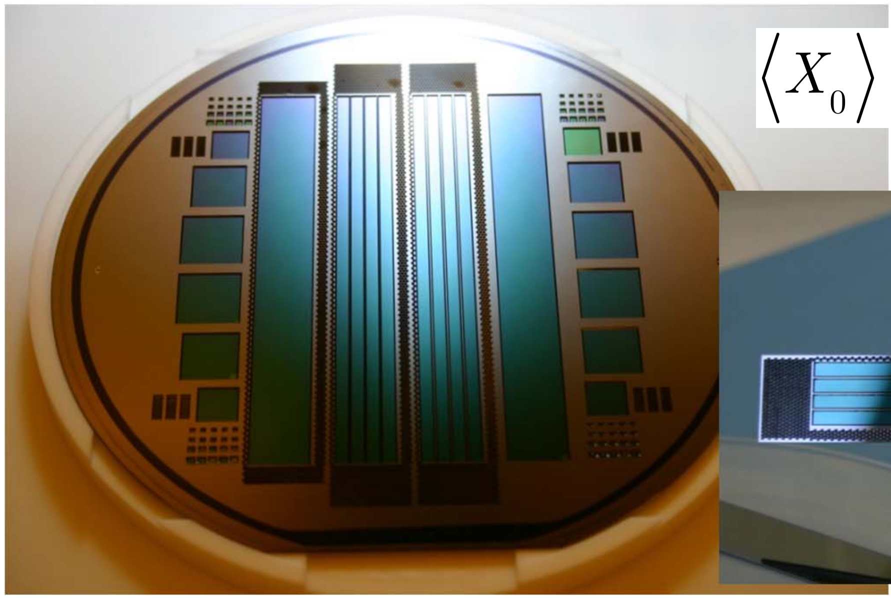
  → DHP (data handling processor)

Thinning Technology

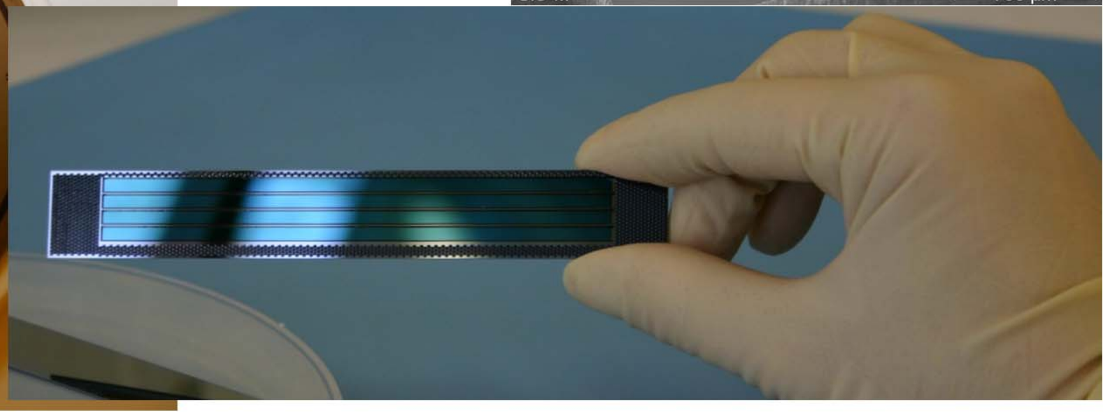
1. implant backside on sensor wafer
2. bond sensor wafer to handle wafer
3. thin sensor side to desired thickness
4. process DEPFETs on top
5. structure resist, etch backside up to oxide/implant

- Sensor wafer bonded on “handle” wafer.
- Rigid frame for handling and mechanical stiffness
- 50 µm thickness produced
- Full-sized Belle II matrices have been produced
- Electrical properties tested successfully

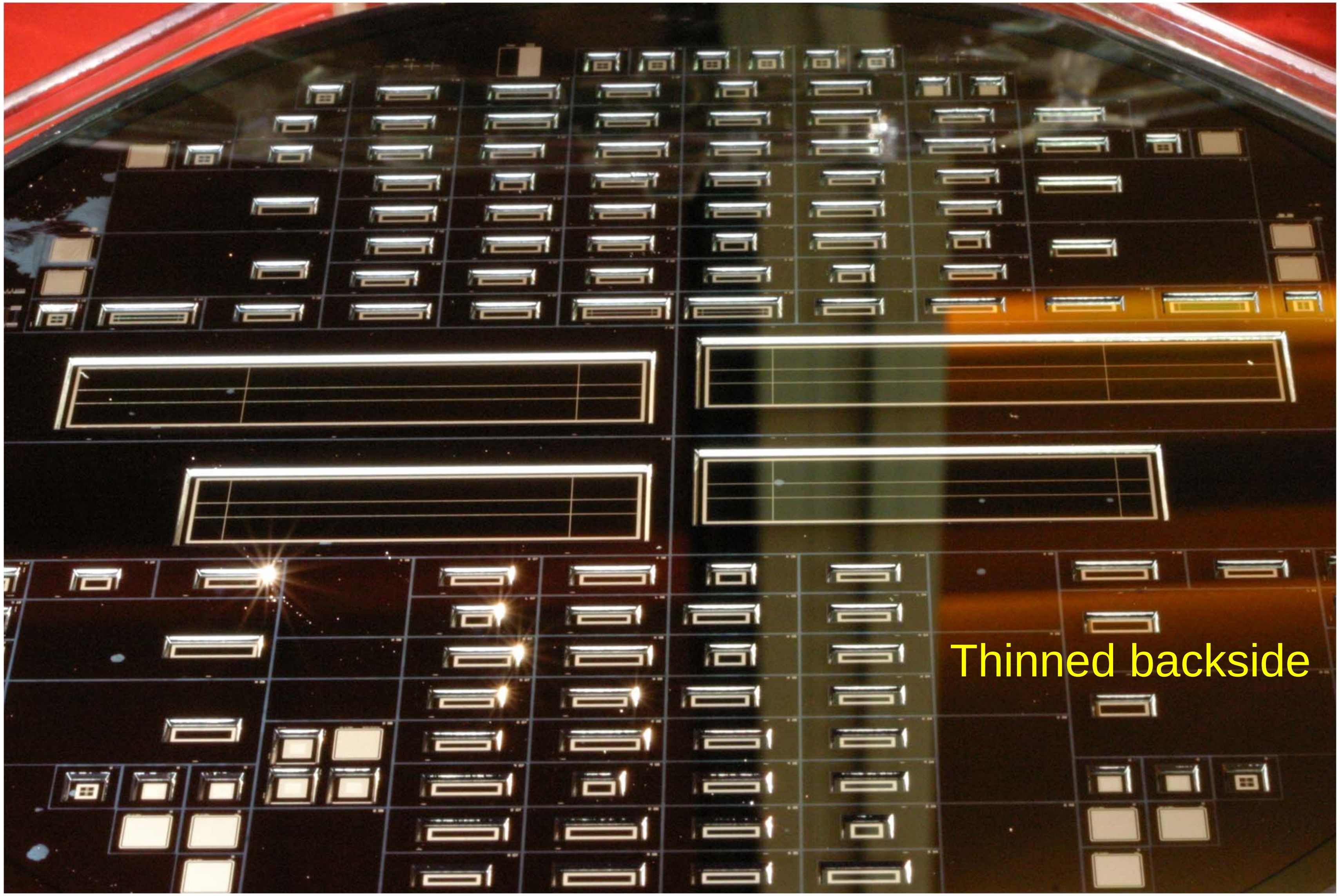




$$\langle X_0 \rangle = 0.18\%$$

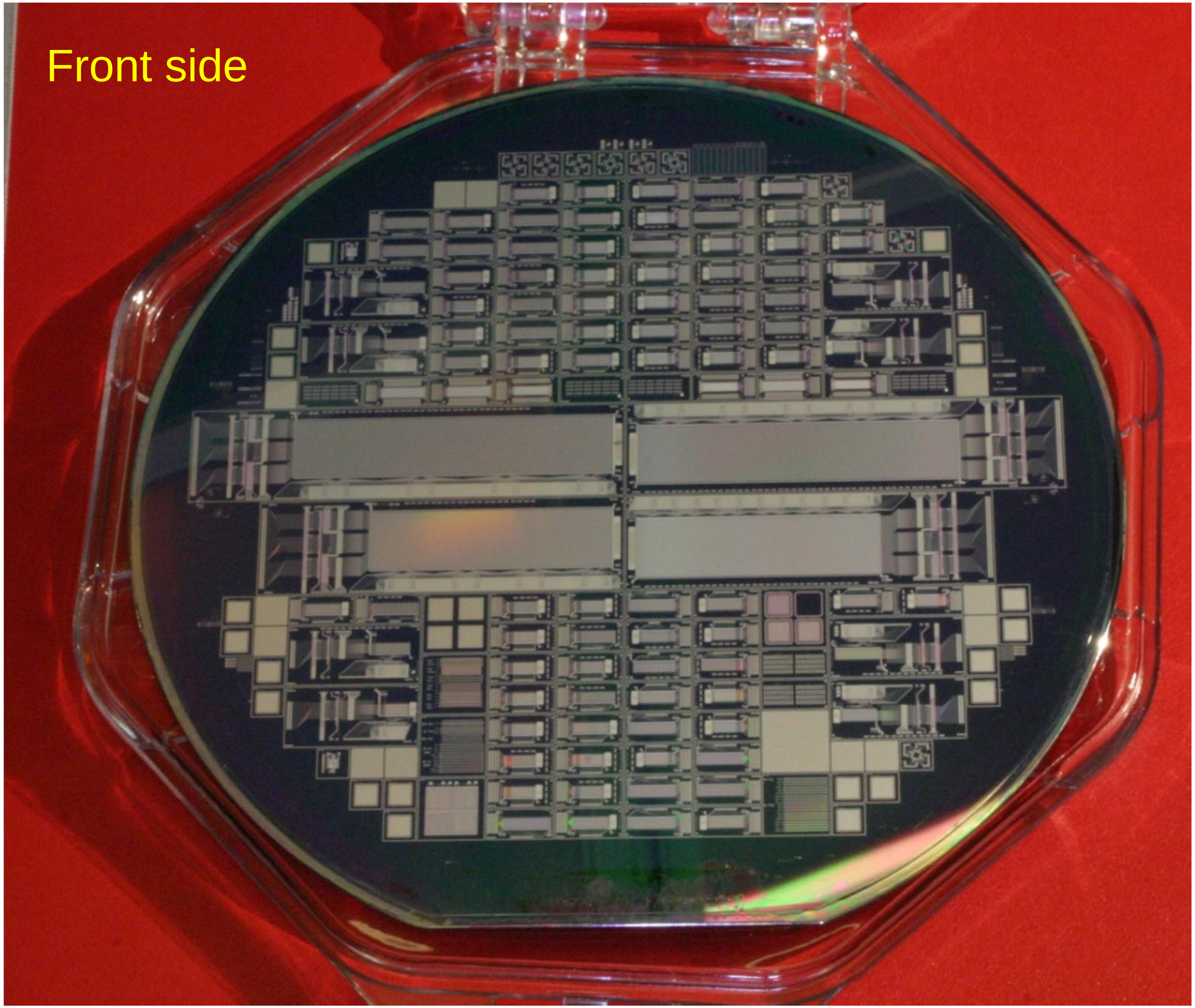


Sensor Test Production

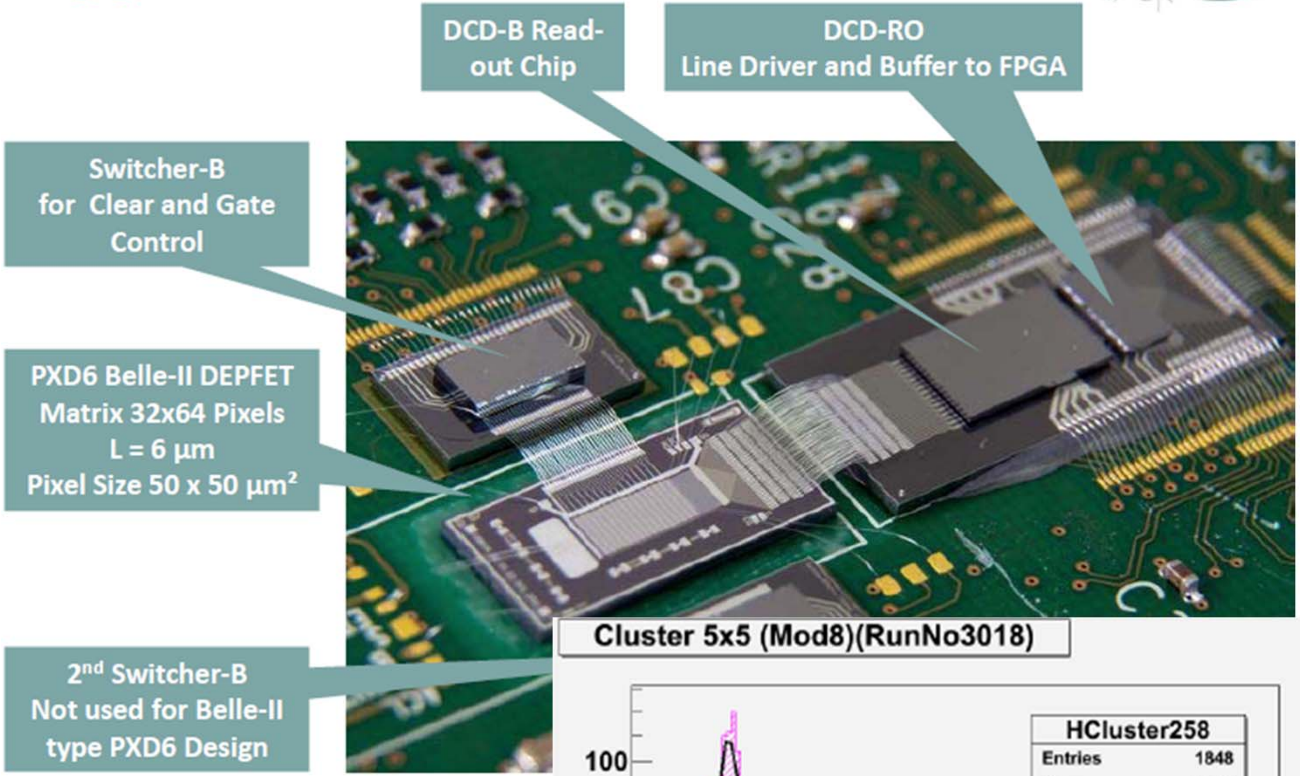


First thinned (50 µm) DEPFETs ever !

Sensor Test Production (cont.)



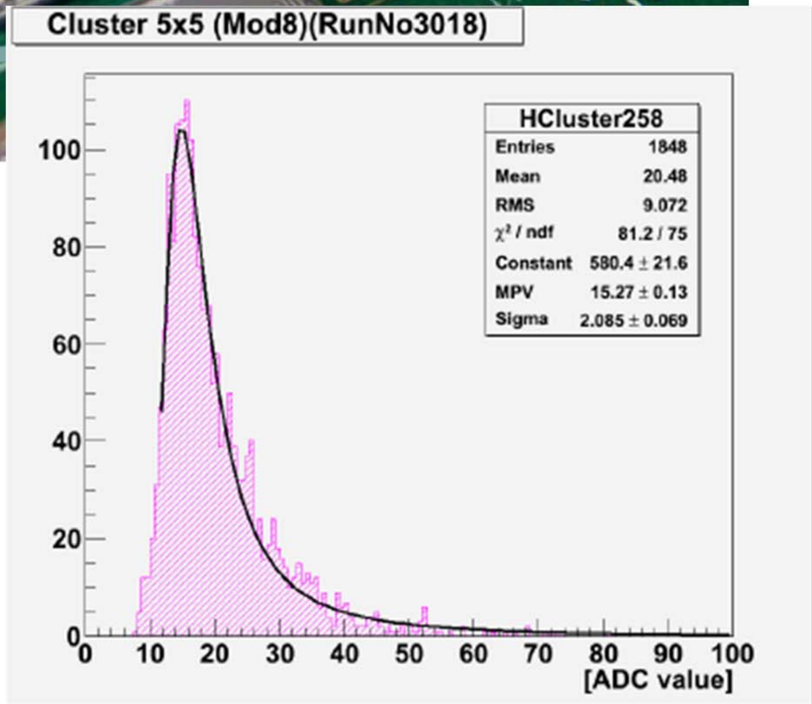
First Tests of Thin DEPFET Sensors („PXD6“)

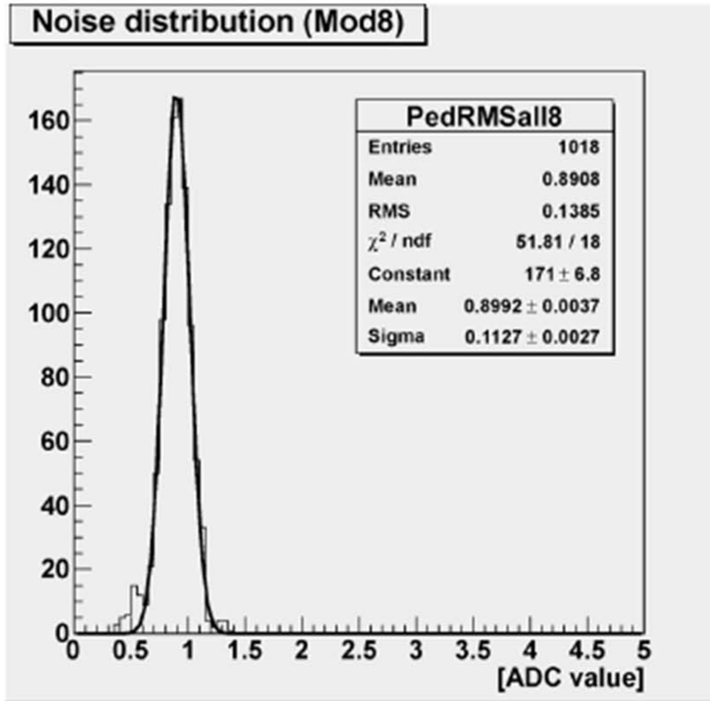


DUT: 32x64 px, Belle II type pixel size 50x50 μm^2

100 ns row read out time
S/N = 17:1 (will improve, not yet optimal bias setting due to current DCD design)

Landau curve from ^{90}Sr source





PXD Project - Layout

2 layers: @1.4(2.2) cm

Pixels: 50 x 50(75) µm

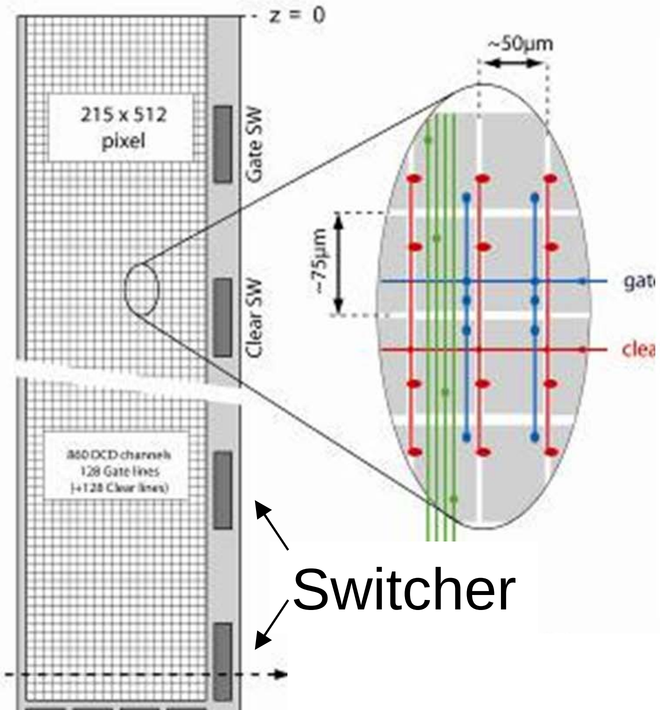
Thickness: 75 µm

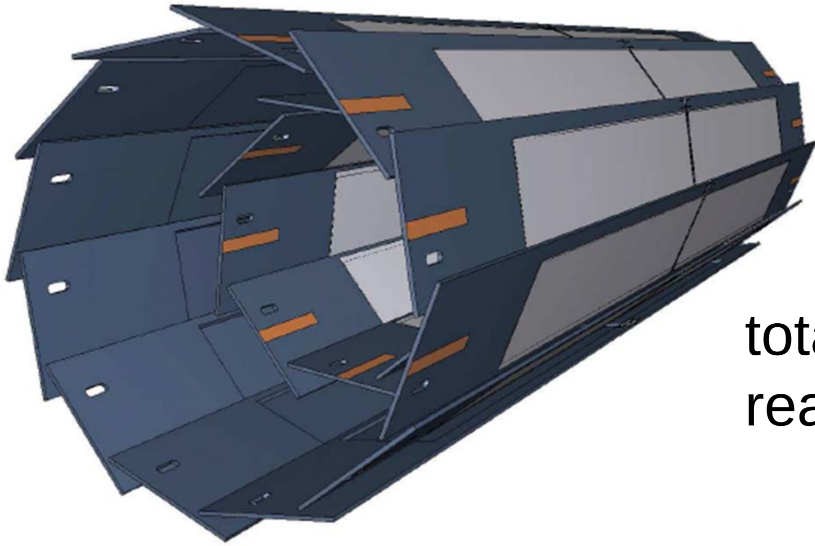
total of 8 Mpx
readout: 20 µs

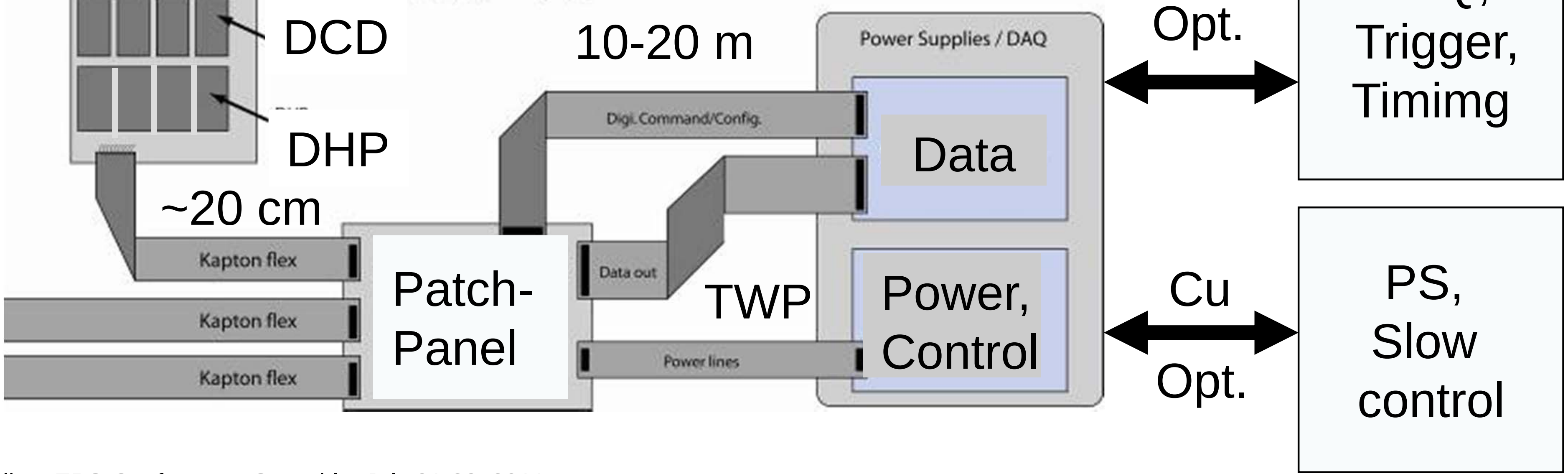
half ladder: 768 rows

250 cols

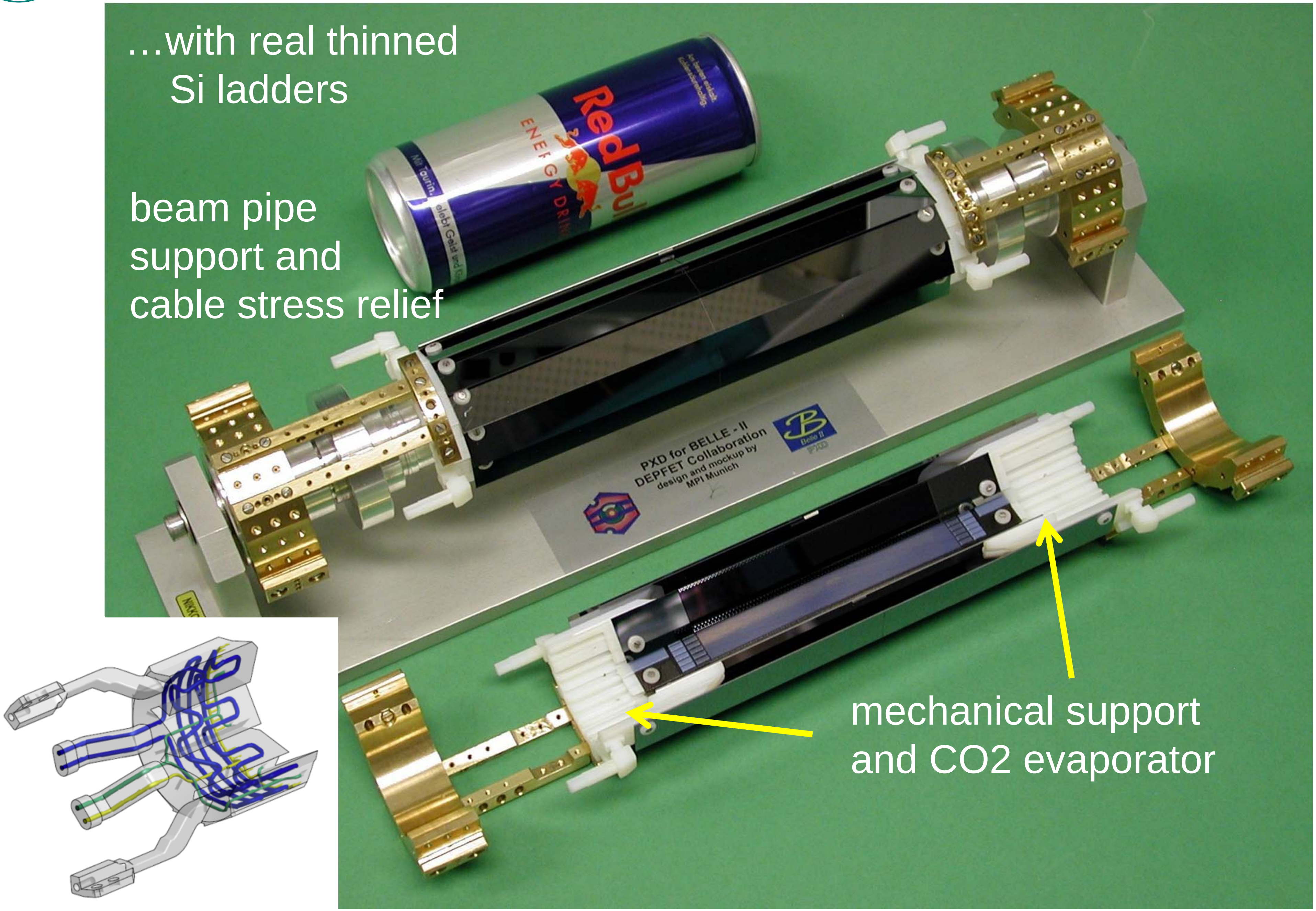
15 x 70 (85) mm







Full-Size Mockup of the PXD

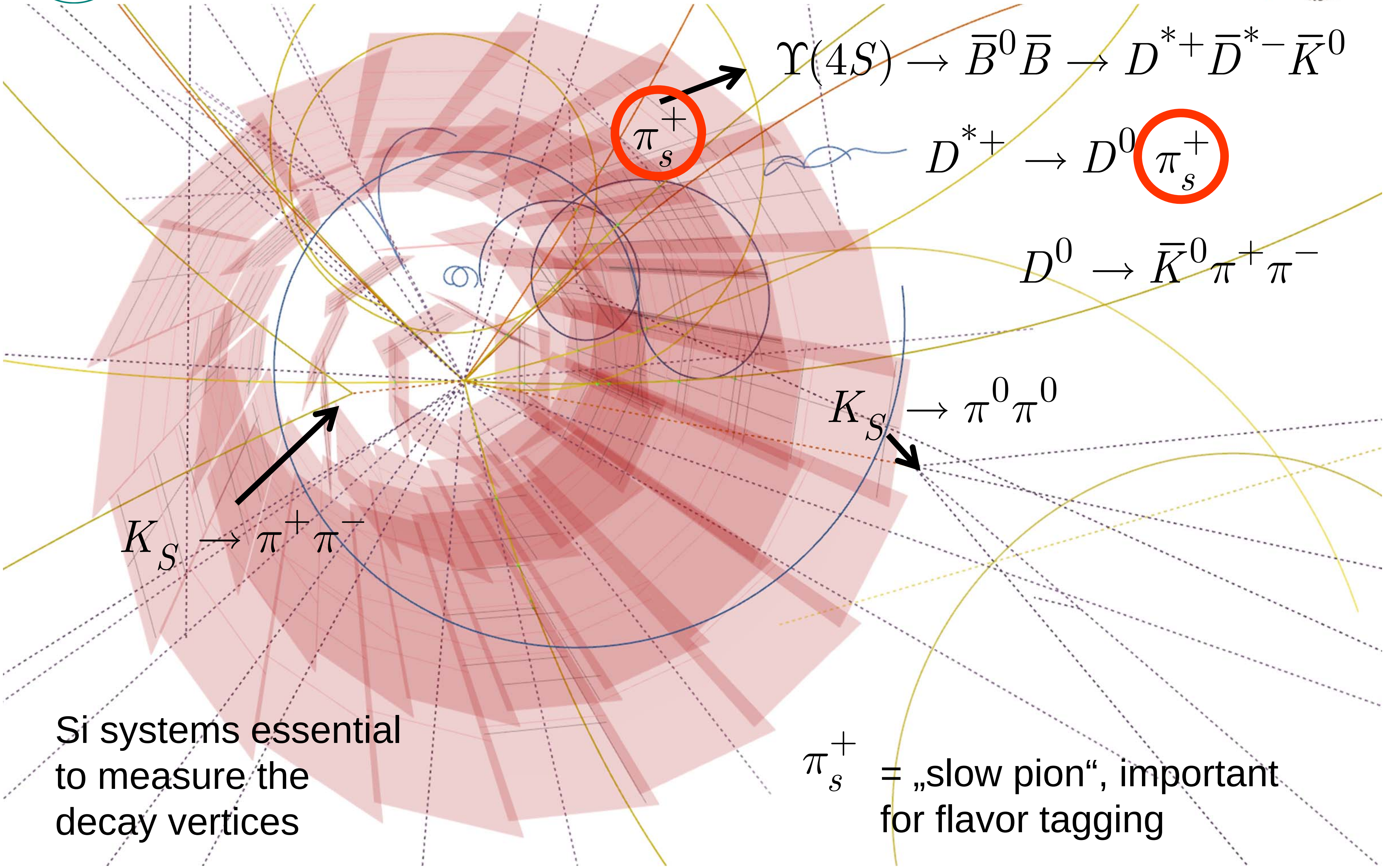


Conclusions & Next Steps

- Vertexing at SuperKEKB essential to measure CP violation
- SuperKEKB will provide very high luminosity, but also high background levels: Si strips not possible close to the beam pipe,
- Low momenta of secondaries need low material budget Silicon
- DEPFET technology will provide monolithic thin (75 µm = 0.18 % of X_0 including electronics) pixel detector (“PXD”) with 100% fill factor
- Design of PXD for Belle II well advanced, ladder support and cooling of electronics outside of acceptance regions solved
- First thin DEPFETs successfully tested, performance as expected
- Some issues still with yield, prototype production is planned
- Schedule: PXD ready for installation by mid of 2015

Backup

An Event in the Silicon Tracking System (Belle)



Si systems essential to measure the decay vertices

π_s^+ = „slow pion“, important for flavor tagging

Improvement of Radiation Hardness

Change in threshold voltage shift due to certain Gate voltages