



The Belle II upgrade



B factories

- motivation for upgrade

SuperKEB

Belle II

- detector overview

- closer look: PXD

The DEPFET sensor

- principle & properties

- Belle II DEPFET module

- test beams
- radiation hardness
- material
- gated operation

- System aspects

Conclusions

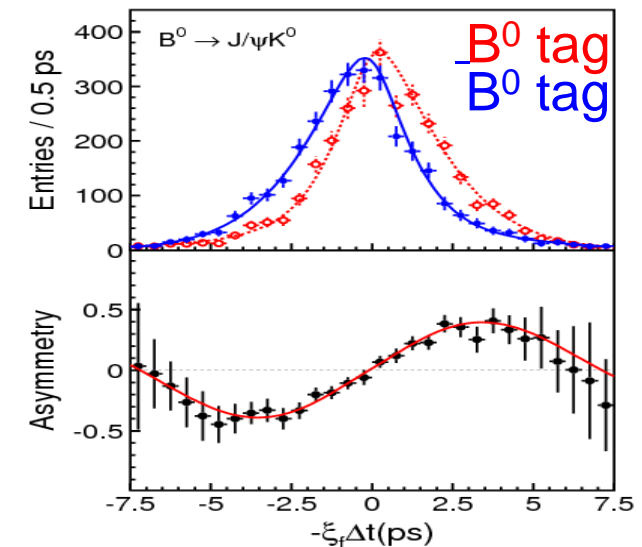
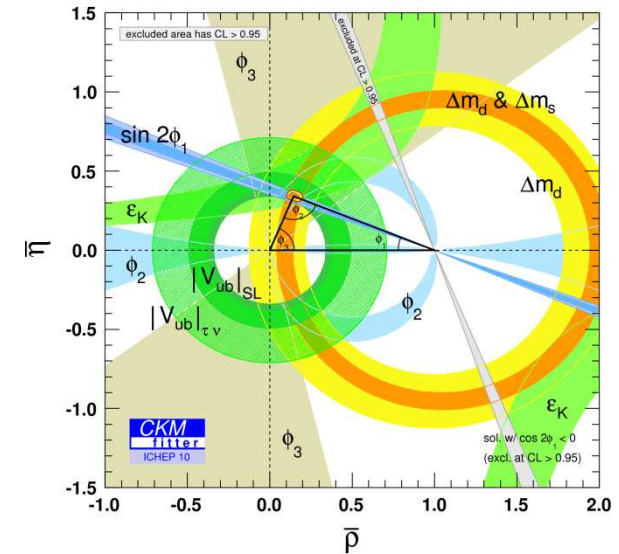




B-factory Detectors – a huge success!

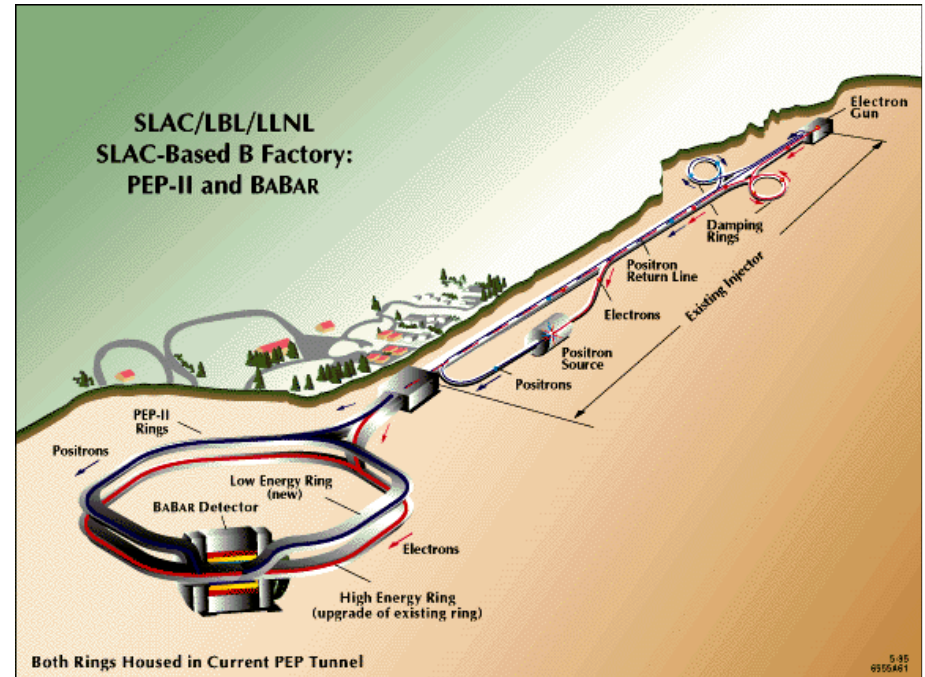
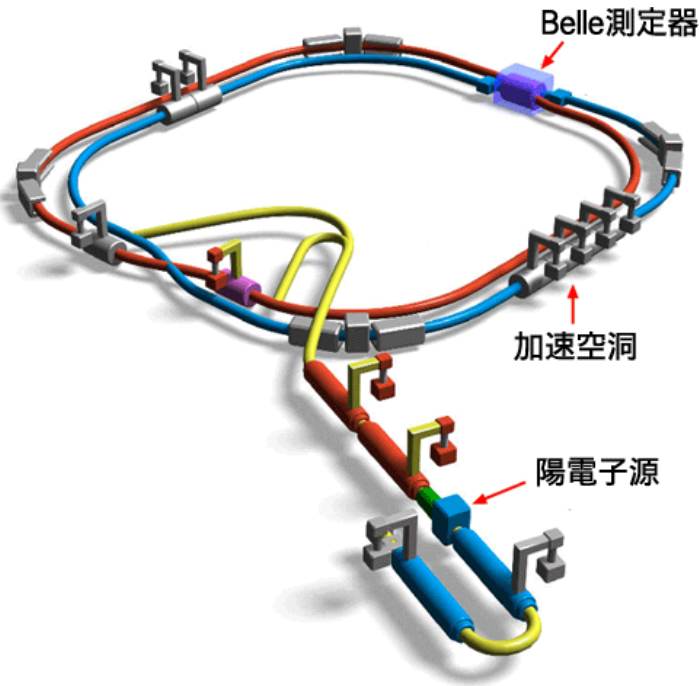


- » Measurements of CKM matrix elements and angles of the unitarity triangle
- » Observation of direct CP violation in B decays
- » Measurements of rare decays (e.g., $B \rightarrow \tau \nu$, $D \tau \nu$)
- » $b \rightarrow s$ transitions: probe for new sources of CPV and constraints from the $b \rightarrow s \gamma$ branching fraction
- » Forward-backward asymmetry (A_{FB}) in $b \rightarrow s l l$ has become a powerful tool to search for physics beyond SM.
- » Observation of D mixing
- » Searches for rare τ decays
- » Observation of new hadrons

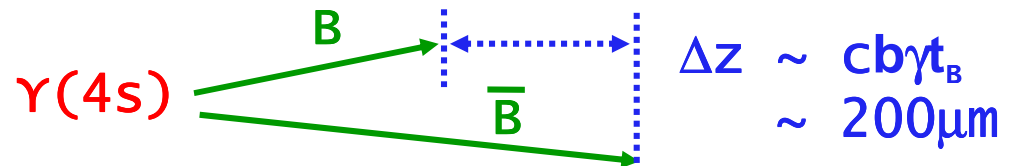
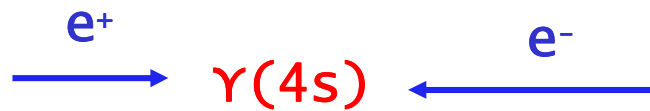




Asymmetric B factories



$$\sqrt{s} = 10.58 \text{ GeV}$$



BaBar	$p(e^-) = 9 \text{ GeV}$	$p(e^+) = 3.1 \text{ GeV}$
Belle	$p(e^-) = 8 \text{ GeV}$	$p(e^+) = 3.5 \text{ GeV}$

$$\beta\gamma = 0.56$$

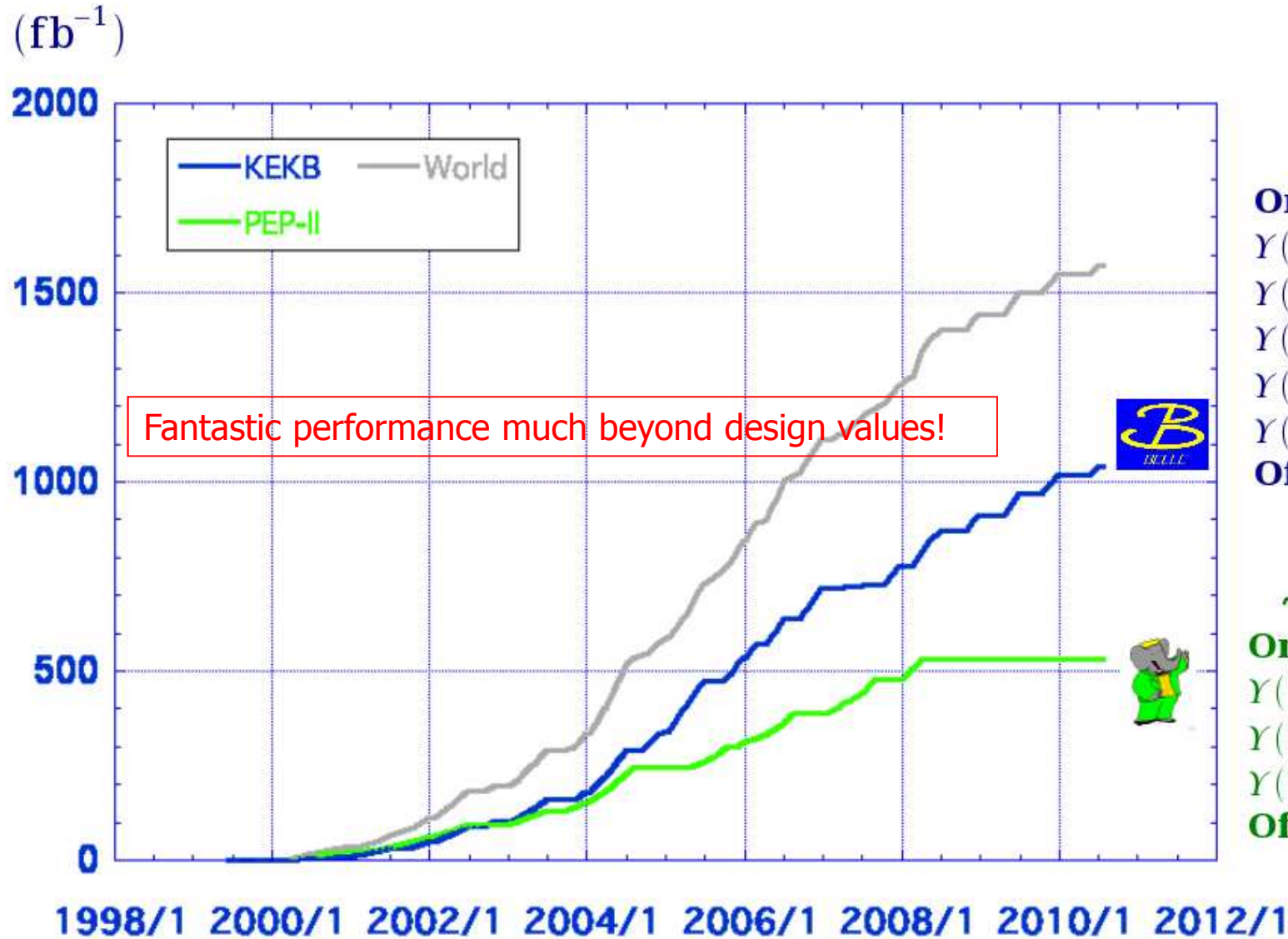
$$\beta\gamma = 0.42$$

Belle II	$p(e^-) = 7 \text{ GeV}$	$p(e^+) = 4 \text{ GeV}$
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$$\beta\gamma = 0.28$$



Luminosity at the B Factories

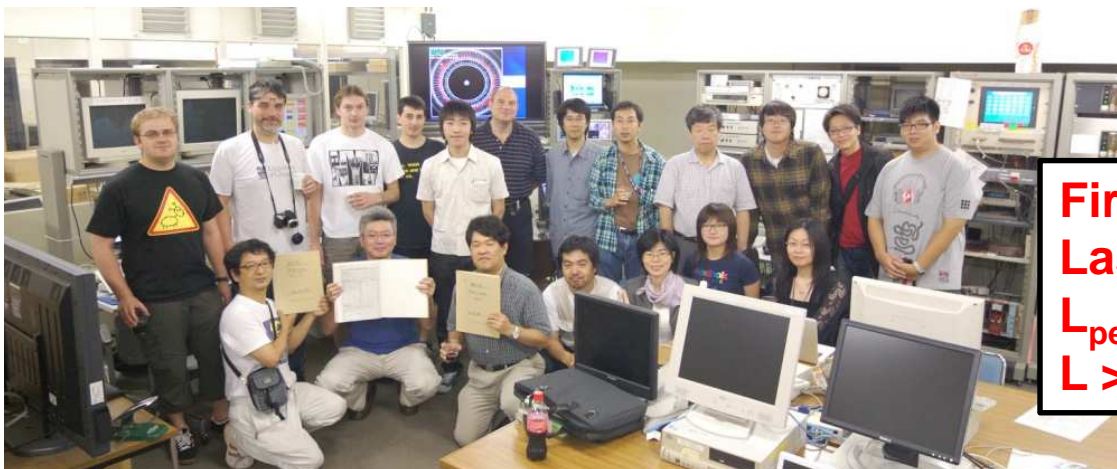


> 1 ab⁻¹
On resonance:
Y(5S): 121 fb⁻¹
Y(4S): 711 fb⁻¹
Y(3S): 3 fb⁻¹
Y(2S): 24 fb⁻¹
Y(1S): 6 fb⁻¹
Off reson./scan:
~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
Y(4S): 433 fb⁻¹
Y(3S): 30 fb⁻¹
Y(2S): 14 fb⁻¹
Off resonance:
~ 54 fb⁻¹



Last KEKB beam abort: June 30, 2010



First physics run on June 2, 1999
Last physics run on June 30, 2010
 $L_{\text{peak}} = 2.1 \times 10^{34} / \text{cm}^2 / \text{s}$
 $L > 1 \text{ ab}^{-1}$



Nobel Prize in Physics 2008



The 2008 Nobel Prize in Physics: What is the Kobayashi-Maskawa Theory?

Q What is a quark?

The protons and neutrons which make up a nucleus are themselves made of even smaller constituents, or elementary particles. These are the u (up) and d (down) quarks (Fig. 1). We now know that, in addition to u and d , there exist four other types, or "flavors," of quark. The six flavors of quarks are sorted into unlike-charge pairs, forming three "generations" of quark doublets (Figure 2).



Fig. 1

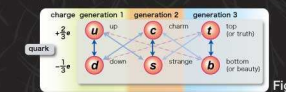


Fig. 2

Q What is an anti-particle?

Elementary particles such as quarks and electrons have corresponding anti-particles. While a particle and its anti-particle are opposite in most identifying characteristics, such as electric charge, their masses are the same. For example, the electron has negative electric charge and its anti-particle, the positron, carries a positive electric charge of equal magnitude. A particle and its anti-particle are created in pairs and can recombine to annihilate and become pure energy. Each of the flavors of quarks has its corresponding anti-quark, and mesons are particles that consist of a quark (q) and an anti-quark (\bar{q}). The mesons that exhibit violation of CP symmetry are known as the K and B mesons (Figure 3).



Fig. 3

Long-Anticipated Results: Proof from the B-factories

Q How do we know the KM theory is correct?
All theories must be verified experimentally. By 1994, advances in accelerator-based technologies had resulted in the discovery of six flavors of quarks. Finally in 2001, 30 years after its introduction, the Kobayashi-Maskawa theory was validated when examinations of over 10 million B meson pairs by two "B-factory" experiments yielded evidence for the violation of CP symmetry in the B meson.

Q What is a B-factory?

It is a facility for generating large quantities of B mesons (hence the term "factory"), investigating their properties, and measuring violation of CP symmetry. Based on the Kobayashi-Maskawa theory, it was predicted in 1980 that a large violation of CP symmetry occurs in B meson decay. To measure it, however, would require the detection of 100 mesons a many B mesons as were available at the time. The B-factories were built between 1994 and 1999 at the High Energy Accelerator Research Organization (KEK, Tsukuba-shi, Ibaraki, Japan; photo) and at the Stanford Linear Accelerator Center (Stanford, California, USA).



Q Tell me about the KEK B-factory.

The B-factory at KEK consists of the KEKB accelerator ($L = 3$ km circumference) and the 1.600-ton Belle detector (~ 8 m each dimension). KEKB accelerates electrons to energies of 8 billion electron volts (8 GeV) (proton masses equivalent) and positrons to 3.5 GeV, colliding them nearly head-on to produce a $B + \text{anti-B}$ meson pair. KEKB, with the world's highest rate of any colliding beam facility, produces about 18 B meson pairs per second. The role of the Belle experiment is to investigate the properties of B mesons in detail. The Belle detector includes about 200,000 precision sensors, which measure parameters such as position, time, and energy as particles pass through. About 360 researchers participated in building and operating the experiment and in analyzing the river of data coming out of the apparatus. The quantity of accumulated digital data is so far greater than 1 petabyte (1 million GB).



This poster has been created by the Belle experimental group to celebrate the Nobel Prize awarded to Prof. Kobayashi and Masakawa and to describe the ongoing work of the B-factory experiments. The illustration depicts the Belle detector at the collaboration of the long-awaited confirming result to Prof. Kobayashi and Masakawa.

Q What is CP violation? Why is it important?

Conservation of CP symmetry stipulates that the physical laws in the world of particles are identical to those in the world of anti-particles. Physicists believed initially that CP symmetry is respected in all phenomena. The discovery in 1964 by Cronin, Fitch and others that CP symmetry is slightly broken in the K meson was thus a great surprise. Interestingly, the existence of anti-matter was not known before the discovery of positrons in the 1930s. The universe today consists overwhelmingly of particles rather than anti-particles, and there has been no evidence for astronomical objects composed of anti-matter. Considering that we believe equal numbers of particles and anti-particles were created in the Big Bang, this is a major puzzle regarding the creation and evolution of the universe. An important key to this puzzle is the small difference between particles and anti-particles, the "violation of CP symmetry."

Q What is the Kobayashi-Maskawa theory?

In 1973 Drs. Kobayashi and Maskawa proposed that, if there were to exist six quark flavors paired into three generations, the existence of CP violation could be explained. At the time, only three flavors of quarks were known to exist, so the introduction of three additional ones was a revolutionary idea. Soon thereafter, the c-quark was discovered (in 1974), then later the b-quark (1977), and the t-quark (1994), establishing the existence of six quark flavors. Still, to confirm this theory would require the experimental verification of CP-asymmetry in the B meson, which contains a b-quark.

Q Why do we need six flavors of quarks?

If the number of flavors were odd (three or five), the rate of transformation between different flavors would be much higher than indicated by the experimental facts. With four flavors in two generations, there are not enough different transformations to leave room for a variable called the complex phase, which breaks CP symmetry. For these reasons it was concluded that at least six flavors of quarks are necessary.

Q How has CP violation been measured?

In KEKB, the B and anti-B meson pairs are created moving with known speed along the direction of the electron beam and proceed briefly before decaying as the b-quark is transformed into a c, s, u, or d quark, and throwing many particles into the Belle detector. The average time between creation and decay is $\sim 10^{-12}$ seconds (1.5 trillionths of a second), but in that brief instant they move about 0.3 mm (Fig. 4). Specific B decay patterns are identified in data, and precise path reconstruction locates decay positions so that the difference in position between B and its pair partner gives the difference in decay times. The frequency of such occurrences are plotted in bins of the decay time difference (blue dots in the figure). The same measurement is repeated with anti-B rather than B mesons (red dots). If CP symmetry is not broken, the red and blue dots should coincide. The figure shows clearly that there is a difference between the two measurements (Figure 5).

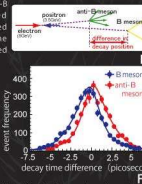


Fig. 4

Fig. 5

Q Can the KM theory explain everything?

Regrettably, it can not. Vigorous research continues, in pursuit of answers to the many things not yet fully understood in elementary particle physics in Japan, which has a long and distinguished history in particle theory, world-class results are now being achieved in the experimental arena as well as experiments such as the B-factory and Super Kamiokande. With the breakthrough by Kobayashi and Maskawa as a starting point, we now propose to seek the source of a much greater violation of CP symmetry that is believed to have occurred when the universe was created about 13.7 billion years ago and resulted in its matter dominance, through the Super KEKB Super Belle experimental project. You are invited to participate.

Q What chance does an individual have to demonstrate originality in a large experiment?

Big accelerators and experiments are built based on the collected wisdom of many researchers. Even though you as an individual may take on a small operational role, you become part of a community that shares your interest in fundamental and exciting questions, such as "How was the universe created?" There are many opportunities for individuals to pursue creative solutions that are essential to the success of the experiment.



K M T H E O R Y P I T C H E S T R U T H
B F A C T O R I E S H I T H O M E R U N

KEKB B-factory Collaborating Institutions

- BNP - IMSC Chennai - Chiba U - U of Cincinnati
- Osaka Women's U - Pwlin Catholic U - U of Gießen
- Gyeongang National U - Harbin U - U of Hawaii
- Hiroshima Tech - IHEP Beijing - IHEP Moscow
- IHEP Vienna - IT - Gwangju - FEP - Kanagawa U
- U Karlsruhe - KEK - Korea U
- Krakow Inst. of Nuclear Physics - Kyoto U
- Kyungpook National U - EPF Lausanne
- Joze Stefan Institute - U of Ljubljana - U of Maribor
- U of Melbourne - Nagoya U - Nara Women's U
- National Central U - National Taiwan U
- National United U - Nagoya U - Nippon Dental U
- Nova Gorka - Osaka U - Osaka City U - Parag U
- Peking U - U Pittsburgh - Princeton U - Riken
- Saga U - SUTG - Seoul National U - Shizuoka U
- Sungkyunkwan U - U of Sydney - Yeda Institute
- Tohoku U - Tohoku U - Tohoku Gakuin U - U of Tokyo
- Tokyo Institute of Technology - Tokyo Metropolitan U
- Tokyo U of Agriculture and Technology
- INFN Torino - Toyama National College - VPI
- Wayne State U - Yonsei U



Poster Designed by T. Iijima, Y. Iwasaki, S. Katsuka, N. Katayama, K. Miyabayashi
English version by K. Kimoshita

Confirmation by Babar and Belle



Are we done yet ?





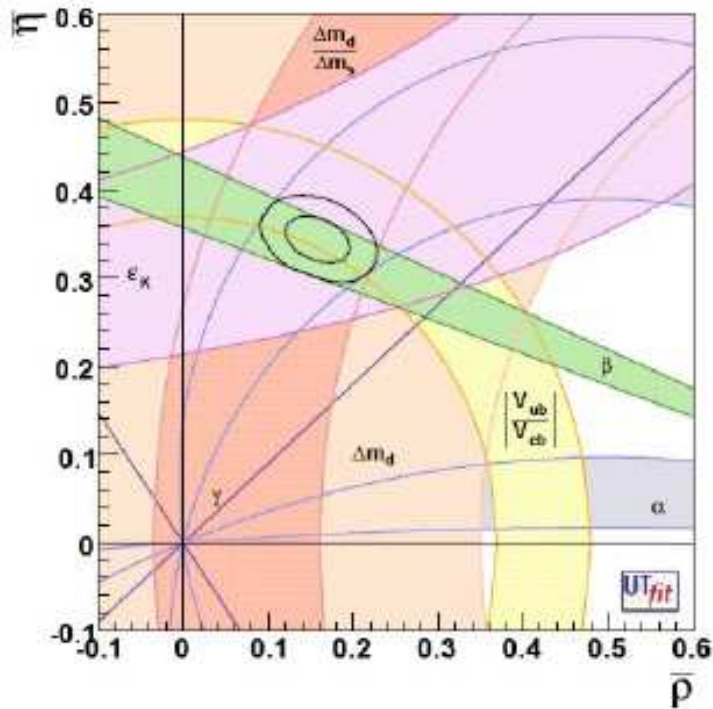
Motivation for Upgrade



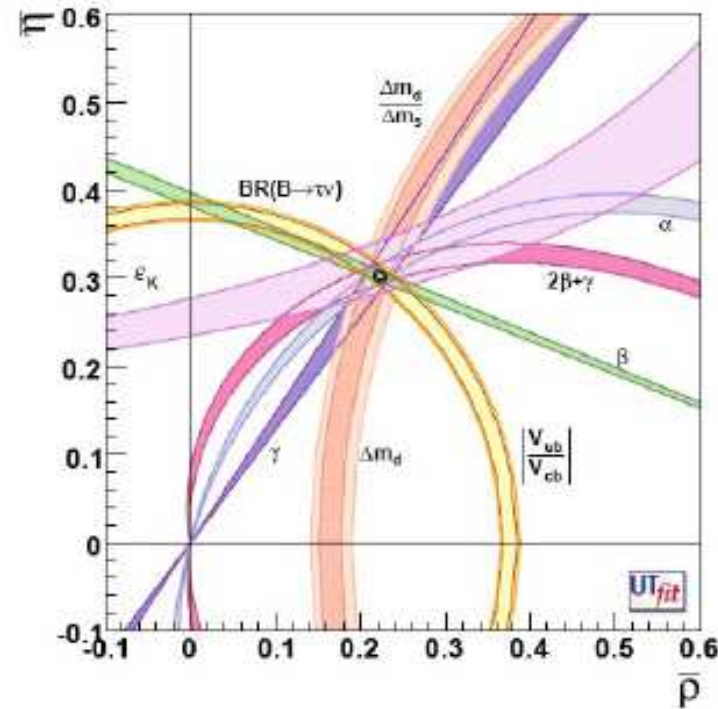
Measure CKM elements as precisely as possible
 Overconstrain unitarity triangle
 Look for deviations from SM

$$\begin{aligned} \Phi_1/\beta &= (21. \pm 1 \ 0.9)^\circ \\ \Phi_2/\alpha &= (88.4 \pm 5.6)^\circ \\ \Phi_3/\gamma &= (70 \pm 29)^\circ \end{aligned}$$

=> Need about 50 ab⁻¹



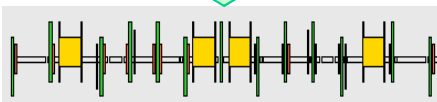
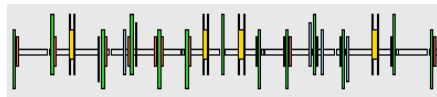
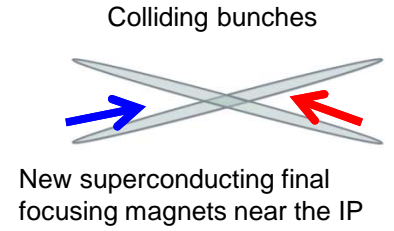
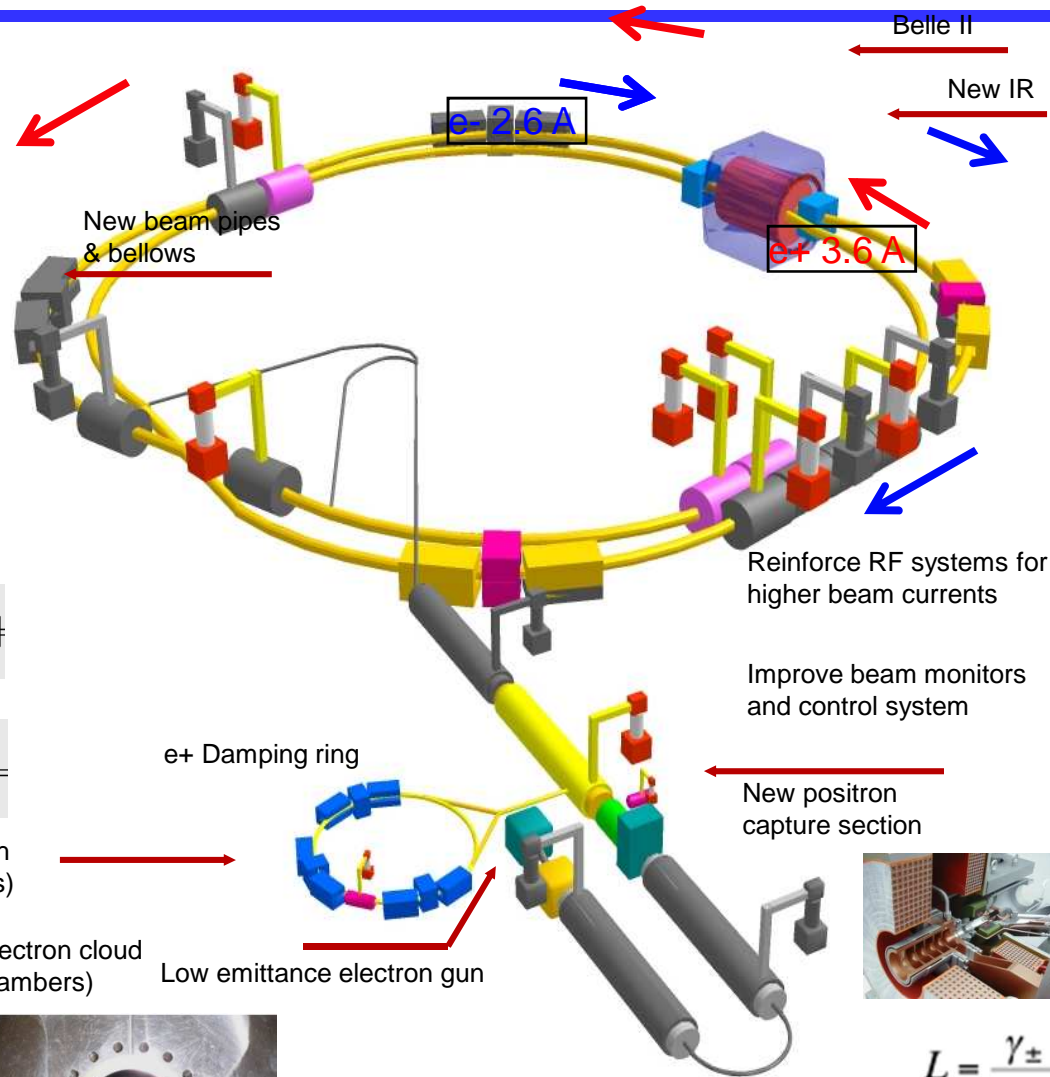
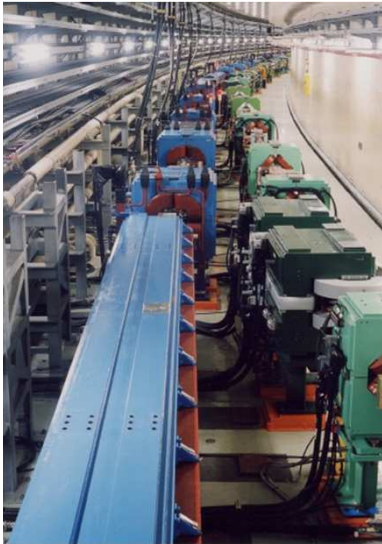
Babar/Belle



With 50 ab⁻¹ (same central values)

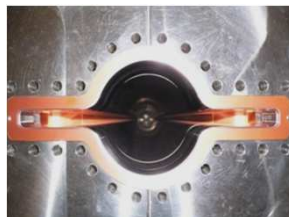
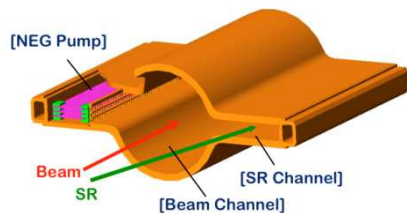


KEKB to SuperKEKB



redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)

Replace beam pipes to suppress electron cloud (TiN-coated beam pipe with antechambers)



$$L = \frac{\gamma_{\pm}}{2e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \frac{I_{\pm} \xi_{\pm y}}{\beta_y^*} \frac{R_L}{R_y} \right)$$

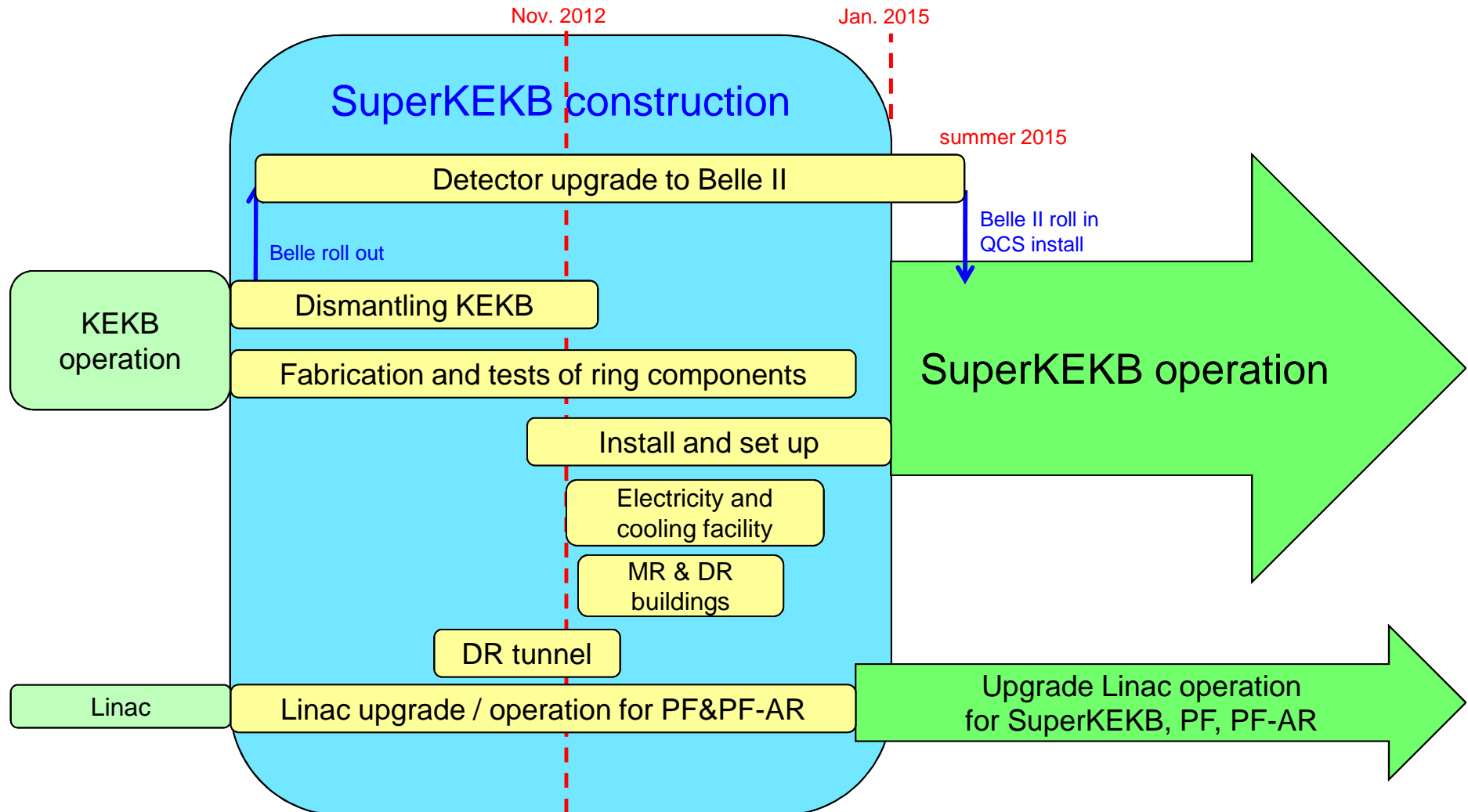
To get x40 higher luminosity



SuperKEKB Schedule

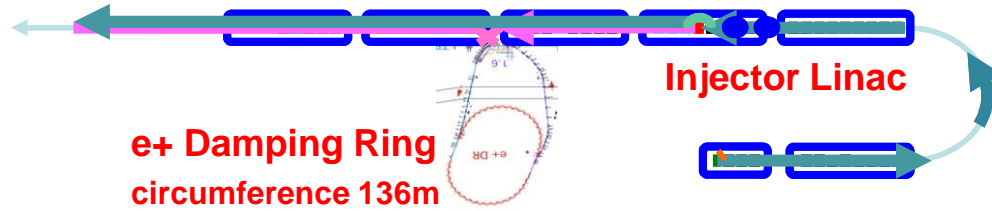


Calendar	2010	2011	2012	2013	2014	2015	2016	2017	...
Japan FY	2010	2011	2012	2013	2014	2015	2016	2017	..





superKEKB construction



beam pipes after baking and TiN coating. They are temporary stocked until moved to tunnel



Tunnel construction for new bending ring

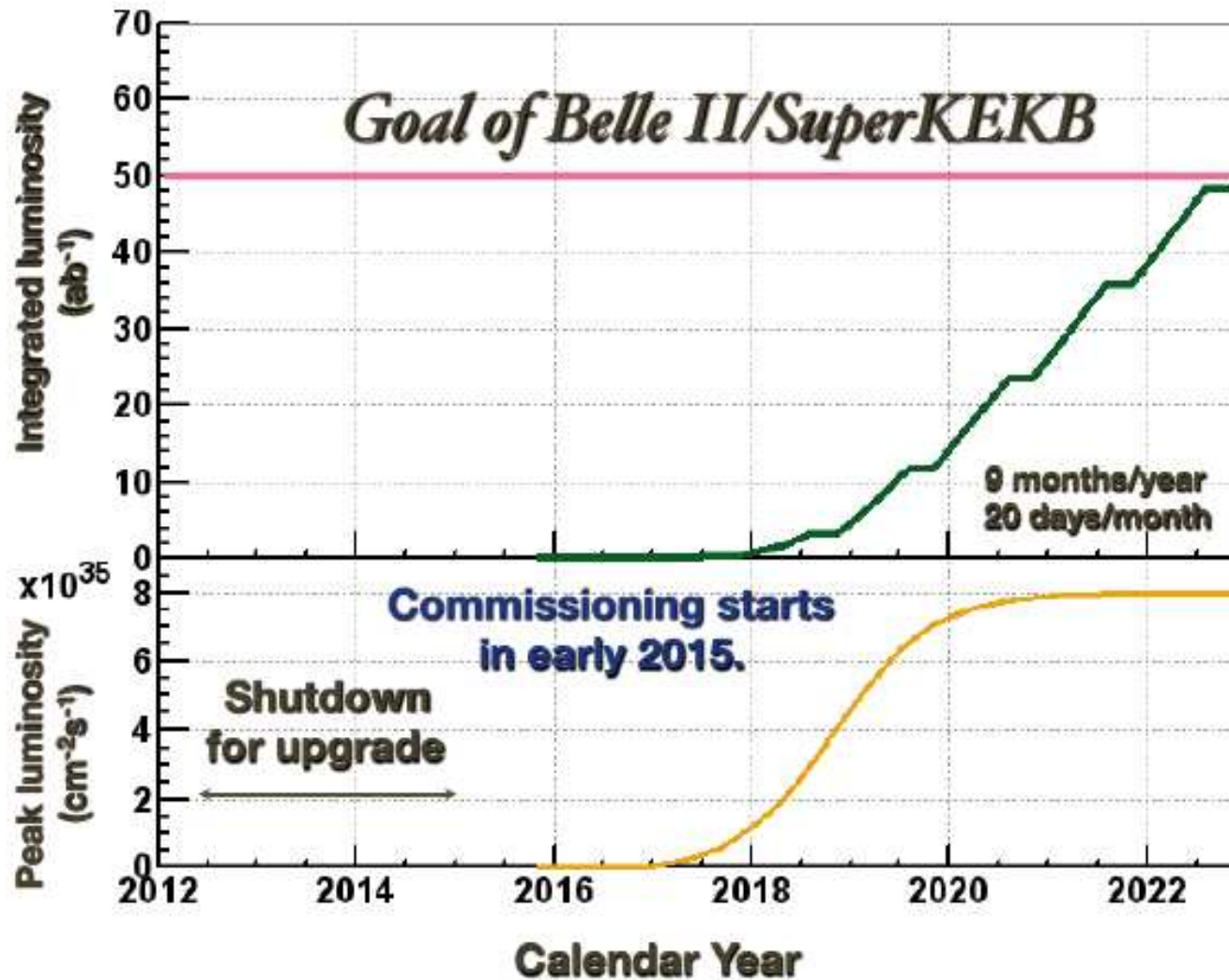


100 new bending pipes are installed

Machine upgrade on schedule



SuperKEKB luminosity profile





Requirements for the Belle II detector



Critical issues at $L = 8 \times 10^{35}/\text{cm}^2/\text{sec}$

► Higher background ($\times 10\text{-}20$)

- radiation damage and occupancy
- fake hits and pile-up noise in the EM Calorimeter

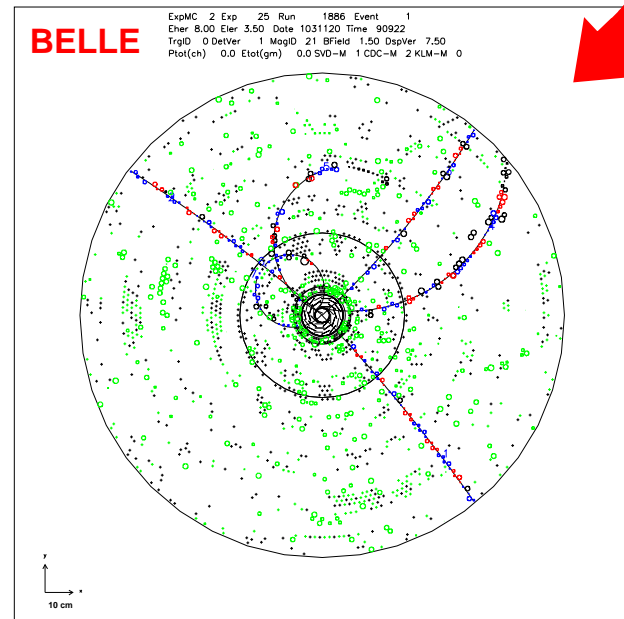
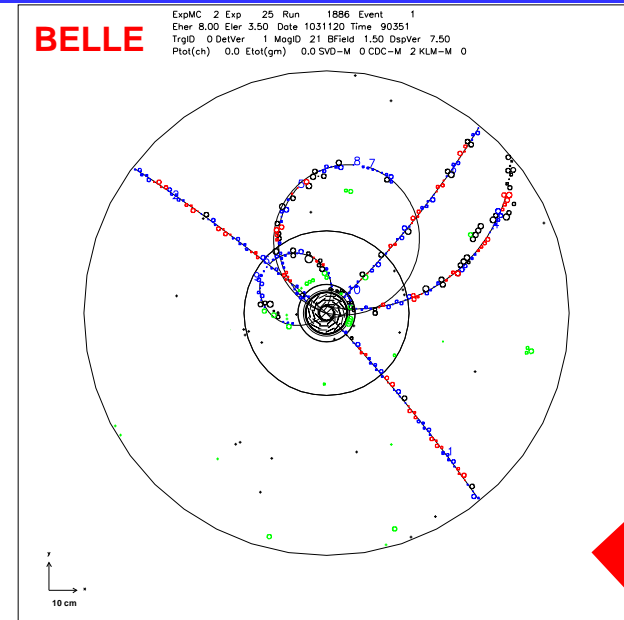
► Higher event rate ($\times 10$)

- higher rate trigger, DAQ and computing

► Special features required

- $\gamma\beta$ reduced by a factor of 2:
compensated by improved vertexing

Result: significant upgrade





Belle II: design concept



CsI(Tl) EM calorimeter:
waveform sampling
electronics, pure CsI
for end-caps

7.4 m

RPC μ & K_L counter:
scintillator + Si-PM
for end-caps

4 layers DS Si Vertex
Detector \rightarrow
2 layers PXD (DEPFET),
4 layers DSSD

5.0 m

Central Drift Chamber:
smaller cell size,
long lever arm

Time-of-Flight, Aerogel
Cherenkov Counter \rightarrow
Time-of-Propagation counter
(barrel),
prox. focusing Aerogel RICH
(forward)

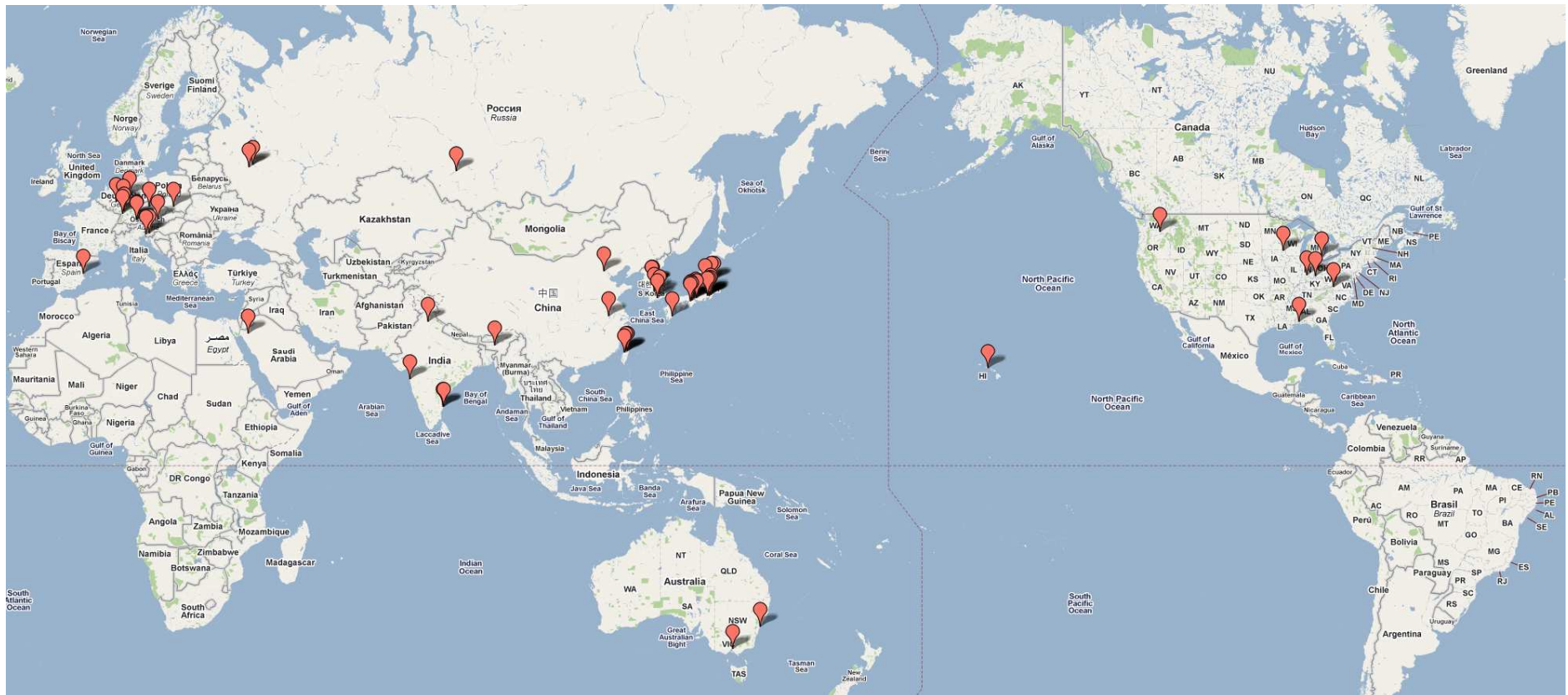


Belle II Collaboration



15 countries,
~60 institutions (9 German)

~400 collaborators





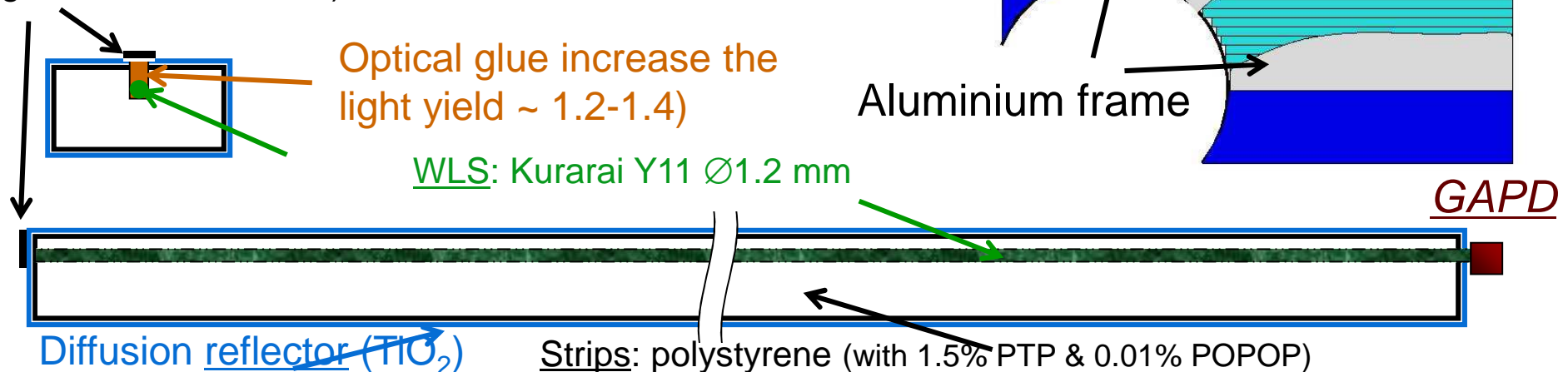
Endcap KLM upgrade



Replace RPCs with Scintillator-based approach

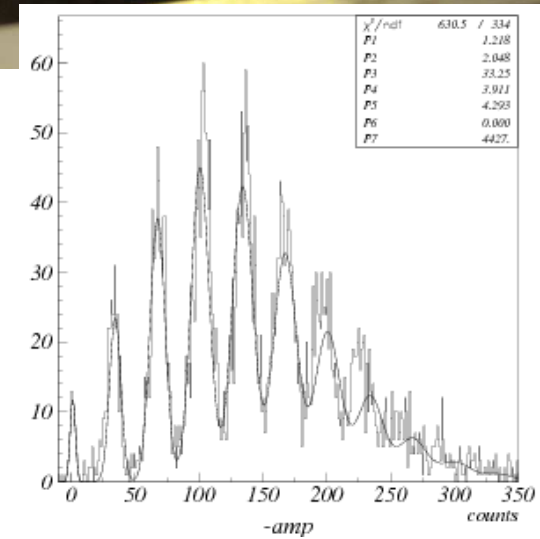
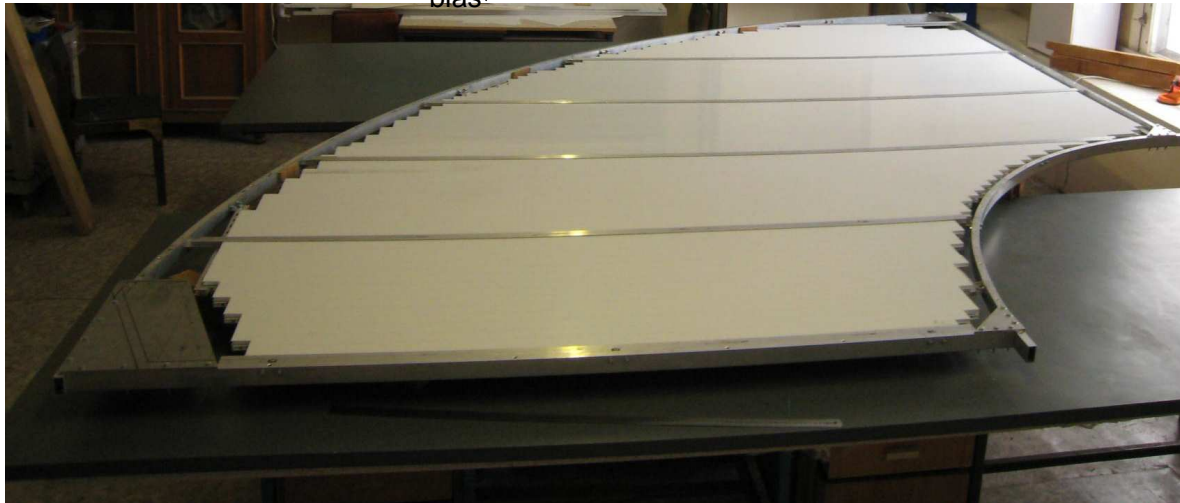
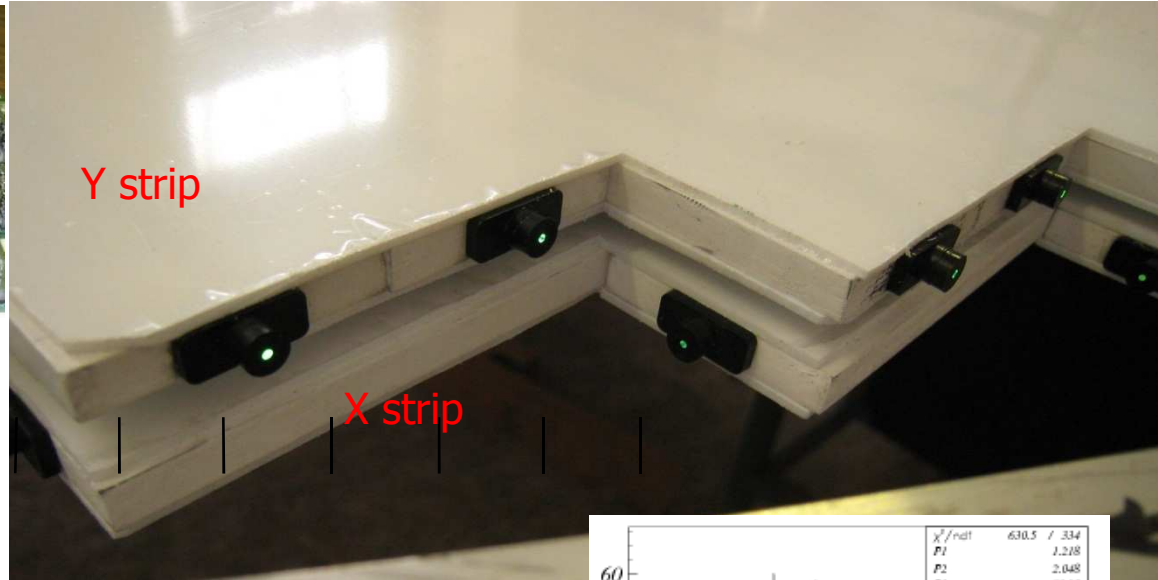
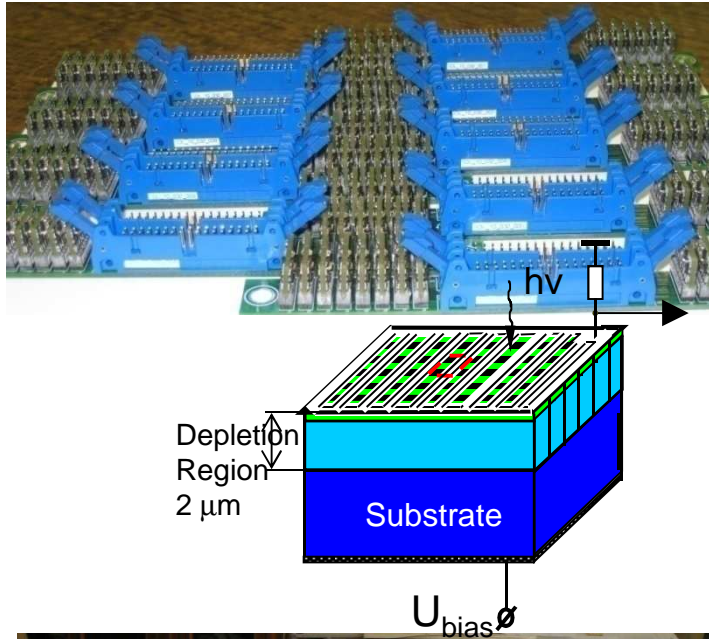
- » Two independent (x and y) layers per superlayer made of orthogonal strips with WLS read out
- » Photo-detector = avalanche photodiode in Geiger mode (SiPM)
- » ~150 strips in one 90° sector
(max L=280cm, w=25mm)
- » ~16800 read out channels
- » Geometrical acceptance > 99%

Mirror 3M (above groove & at fiber end)





Endcap KLM upgrade



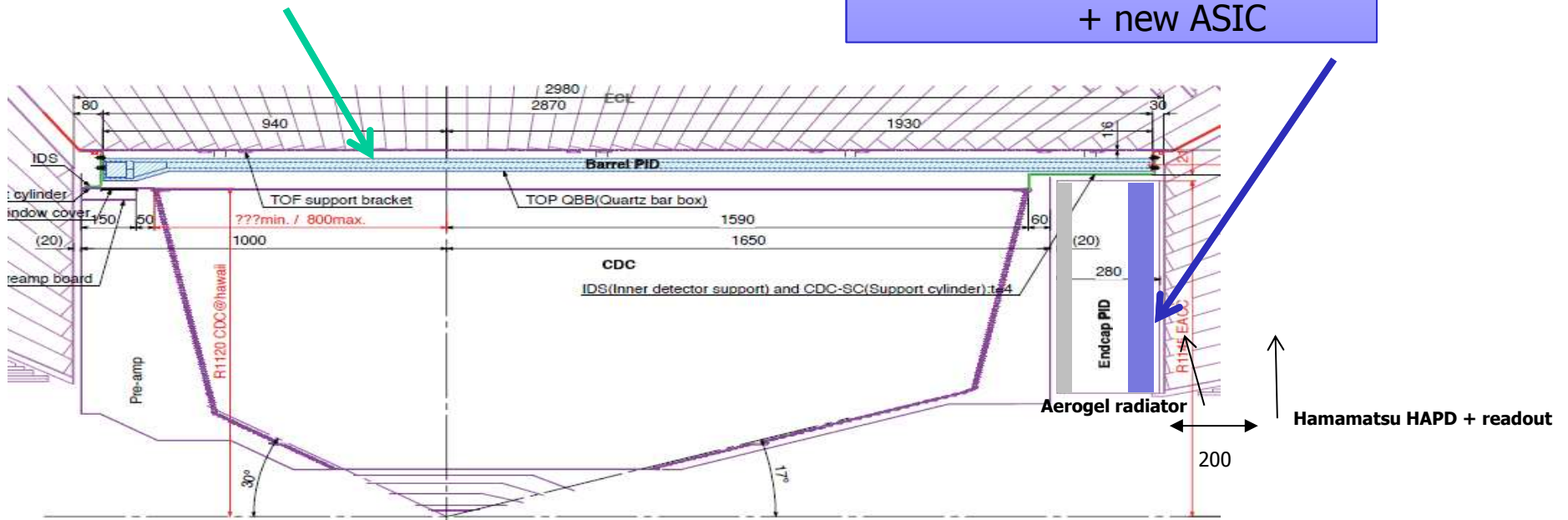
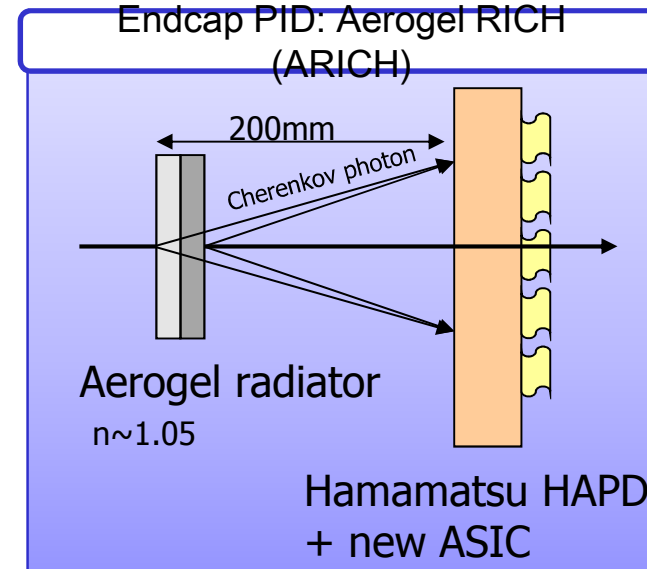
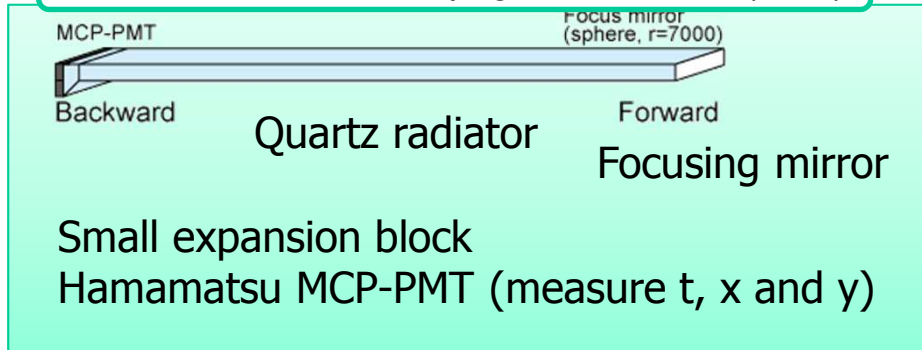
Single p.e. resolution with TARGET WFS ASIC readout



Particle Identification



Barrel PID: Time of Propagation Counter (TOP)





TOP (Barrel PID)



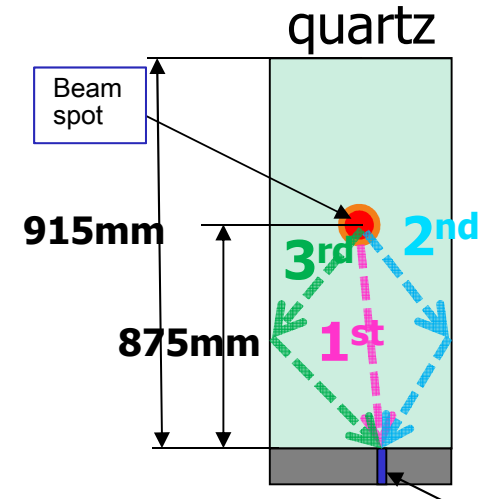
» Quartz radiator

- $2.6\text{m}^L \times 45\text{cm}^W \times 2\text{cm}^T$
- Excellent surface accuracy

» MCP-PMT

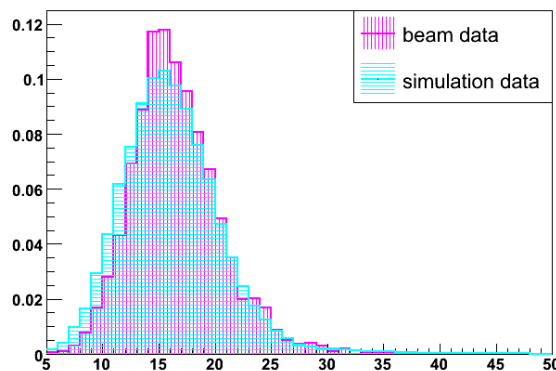
- Hamamatsu 16ch MCP-PMT
 - Good TTS (<35ps) & lifetime
 - Multialkali photo-cathode → SBA

SL10 MCP-PMT

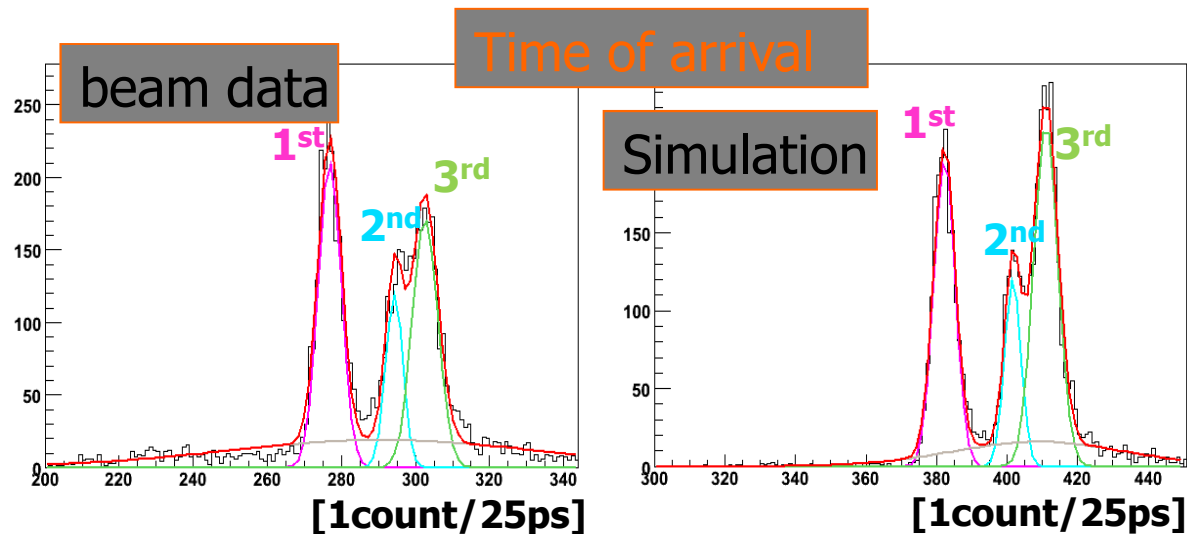


» Beam test in 2009

- # of photons consistent
- Good time resolution



of photons

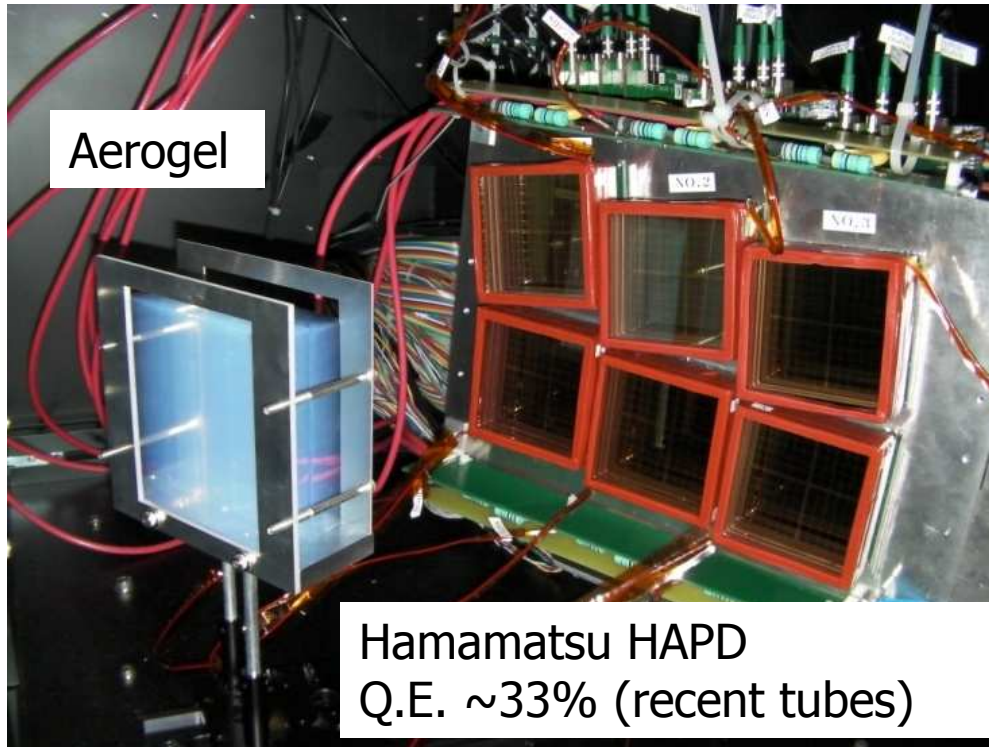




Aerogel RICH (endcap PID)

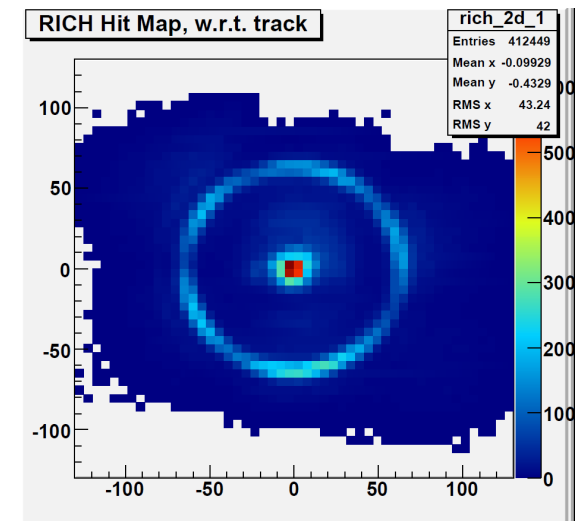
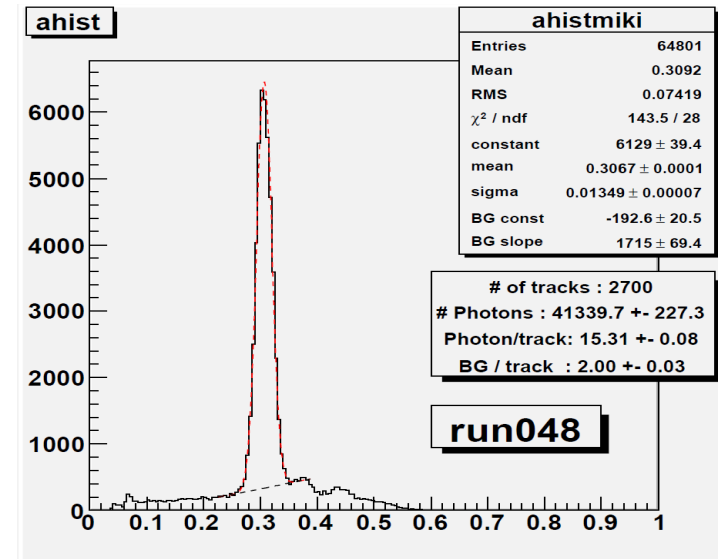


Test Beam setup



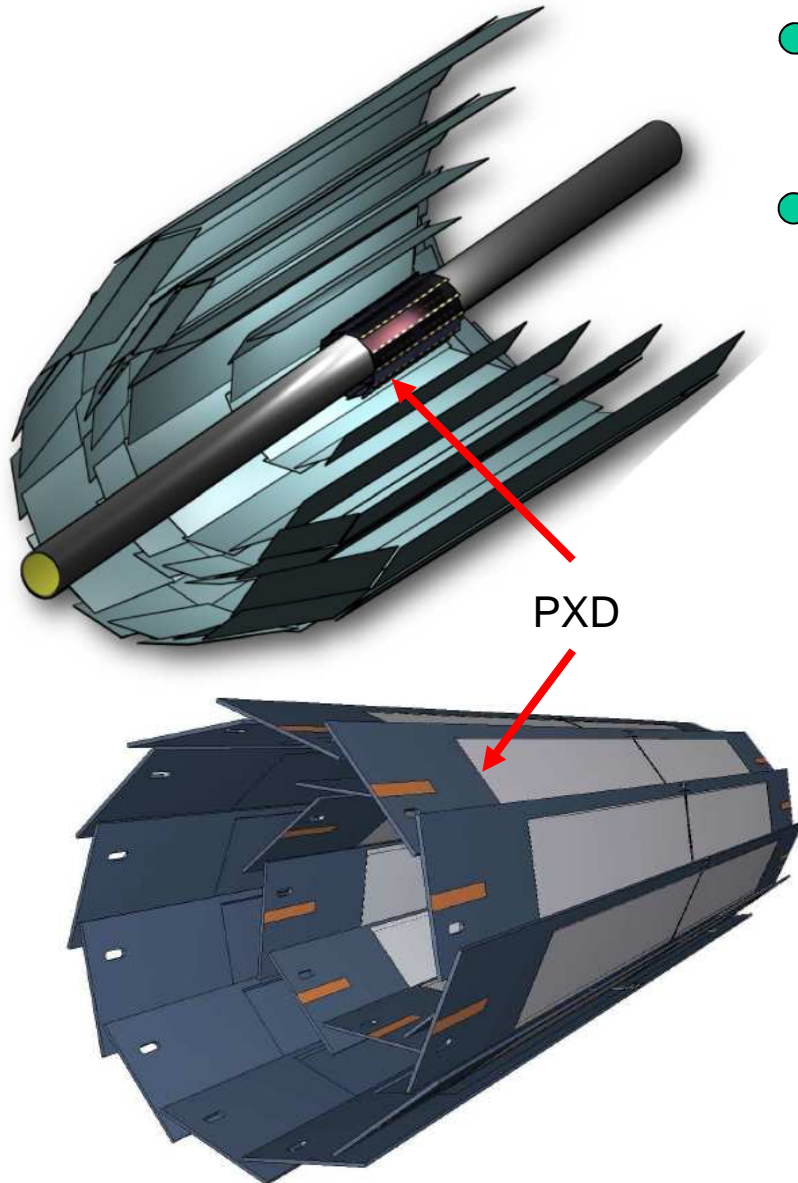
6.6σ p/K at 4GeV/c !

Cherenkov angle distribution



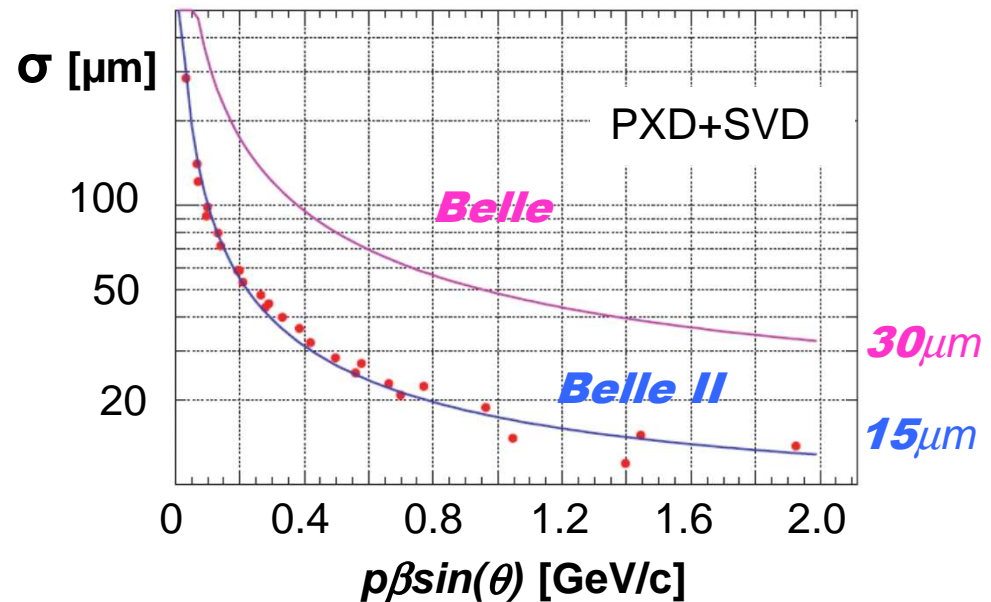


Silicon Tracking System @ Belle II



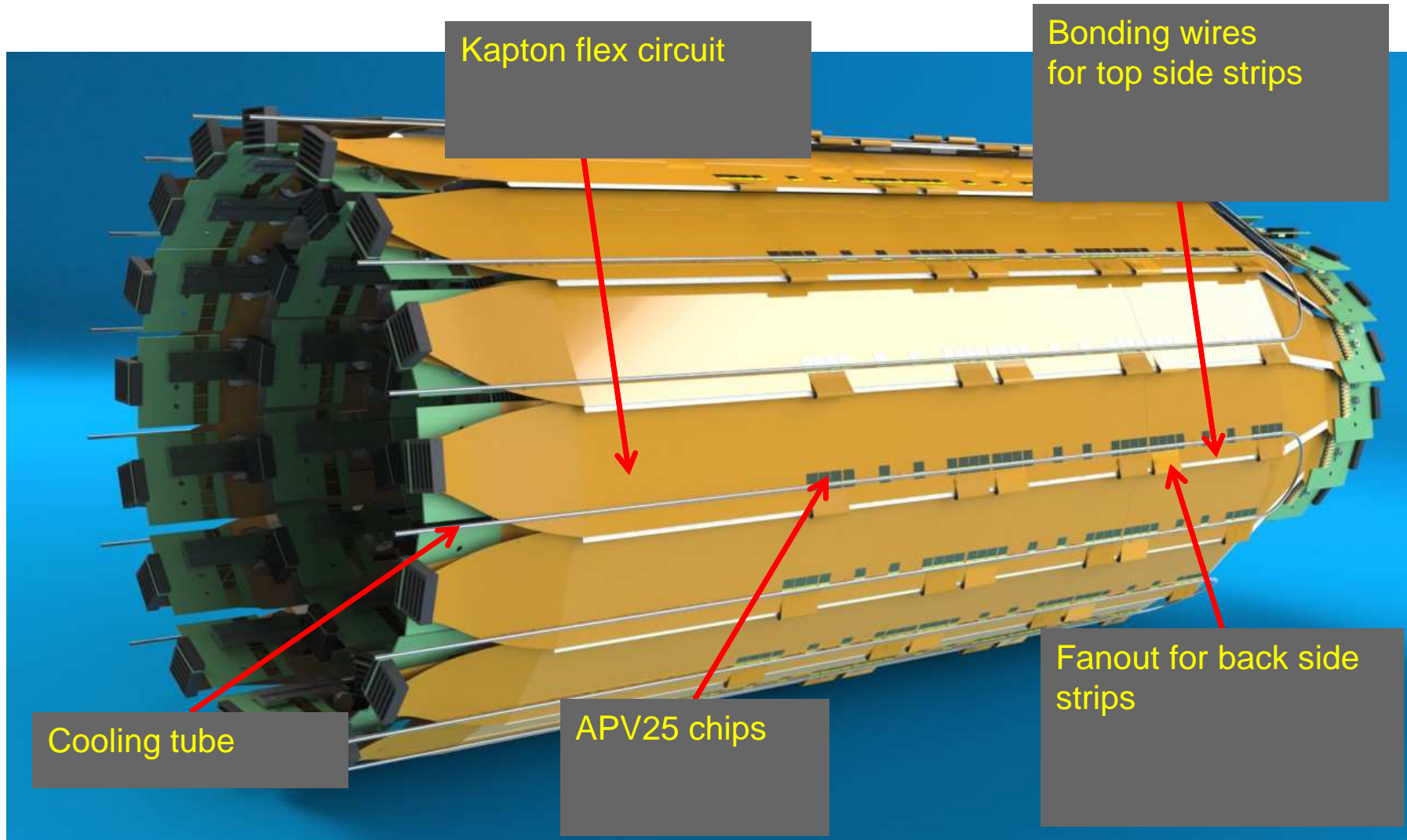
- SVD: 4 layer Si strip detector (DSSD)
($R = 3.8, 8.0, 11.5, 14.0$ cm)
- PXD: 2 layer Si pixel detector (DEPFET technology)
($R = 1.4, 2.2$ cm)
monolithic sensor
thickness $75 \mu\text{m}$ (!),
pixel size $50 \times 55 \mu\text{m}^2$ to $50 \times 85 \mu\text{m}^2$ (depending on layer and z)

Significant improvement in z-vertex resolution





Silicon Vertex Detector



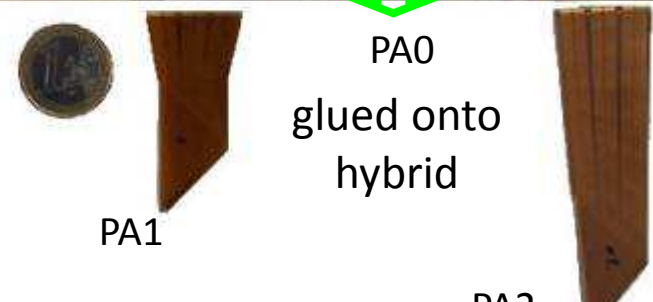


APV25 readout chip adapted to Belle-II



Origami PCB

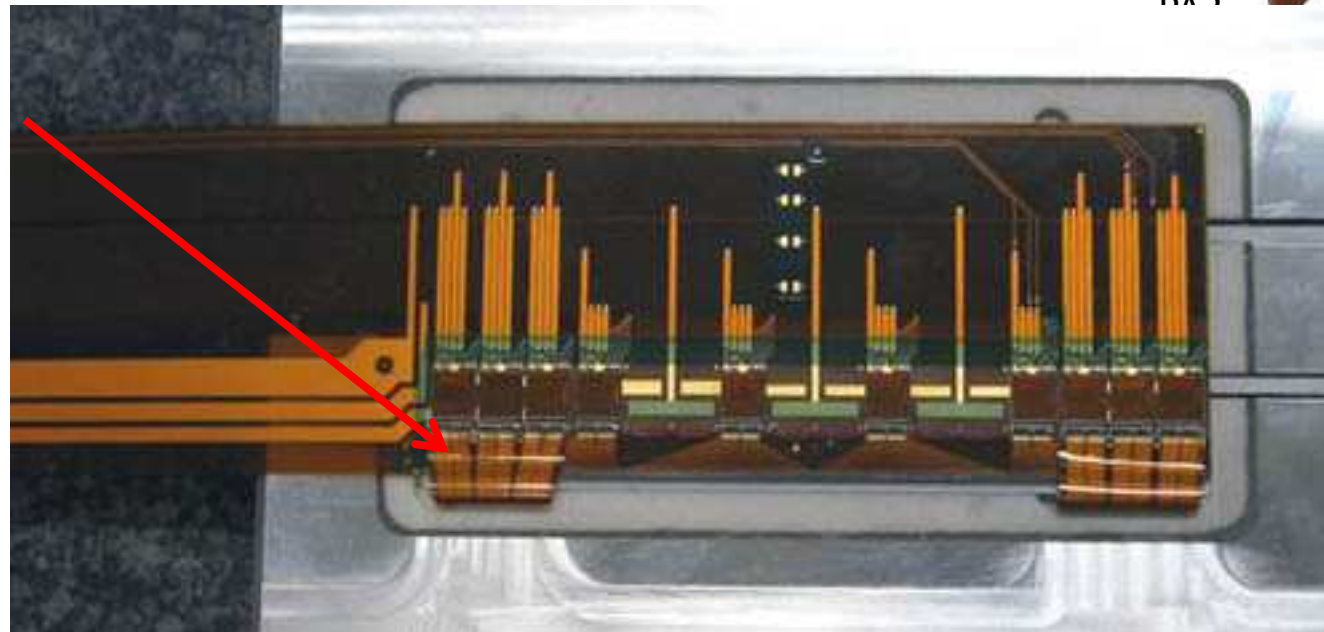
- Origami PCB
 - 3-layer design
 - 237μm thick (nominal)
- PA0, PA1 and PA2
 - 2-layer design
 - 145μm thick (nominal)



PA0
glued onto
hybrid

Thinned APV25
(300μm → ~100μm)

~0.55% X_0 /layer





DEPFET



Each pixel is a 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 ($g_m \sim 400 \text{ pA/e}^-$)

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

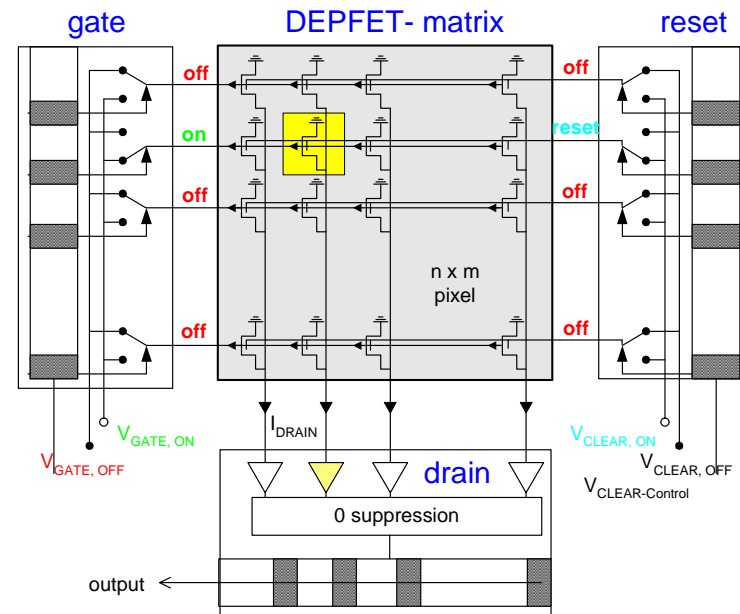
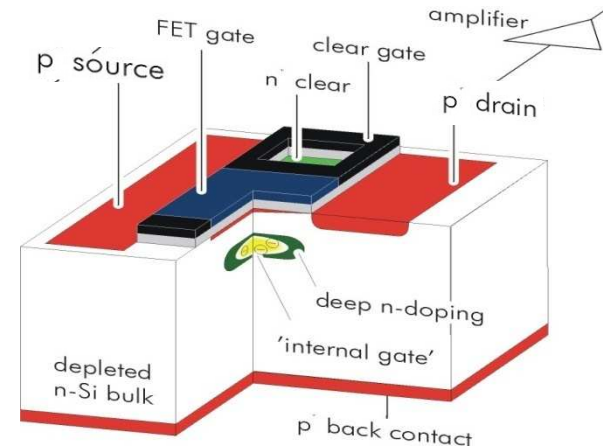
Fully depleted:
⇒ large signal, fast signal collection

Low capacitance,
internal amplification: ⇒ low noise

High S/N even for thin sensors

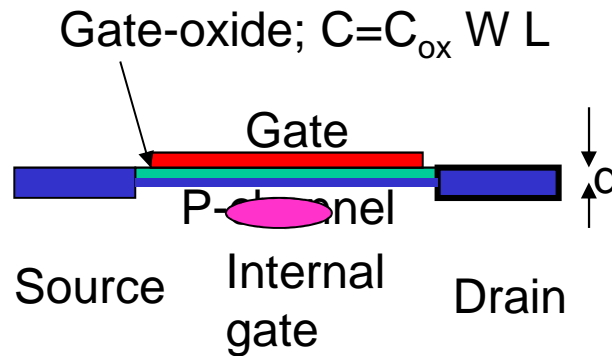
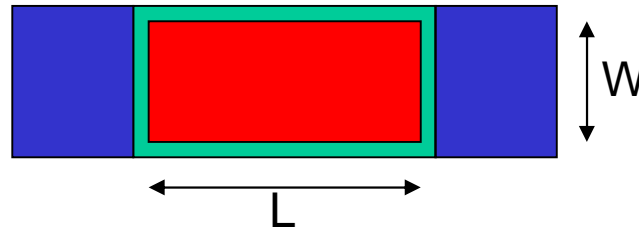
Rolling shutter mode (column parallel) for matrix operation

⇒ 20 μs frame readout time
⇒ Low power (only few lines powered),





How does it work?



A charge q in the internal gate influences a mirror charge αq in the channel ($\alpha < 1$, for stray capacitance)
 This mirror charge is equivalent to a change of the gate voltage:

$$\Delta V = \alpha q / C = \alpha q / (C_{ox} W L)$$

FET in saturation:

$$I_d = \frac{W}{2L} \mu C_{ox} \left(\frac{W}{2L} \mu C_{ox} \left(V_G + \frac{\alpha q_s}{C_{ox} W L} - V_{th} \right)^2 \right)^2$$

- I_d : source-drain current
- C_{ox} : sheet capacitance of gate oxide
- μ : mobility (p-channel: holes)
- V_g : gate voltage
- V_{th} : threshold voltage

Transconductance:

$$g_q = \frac{dI_d}{dq_s} = \frac{dI_d}{dV_G} \frac{dV_G}{dq_s} = \frac{W}{L} \mu C_{ox} \left(\frac{W}{2L} \mu C_{ox} \left(V_G + \frac{\alpha q_s}{C_{ox} W L} - V_{th} \right) \right) = \alpha \sqrt{2 \frac{I_d \mu}{L^3 W C_{ox}}}$$

$$g_q = \alpha \sqrt{\frac{W \mu C_{ox} I_d}{W L C_{ox} L}} = \alpha \frac{g_m}{C}$$



Gain and Noise

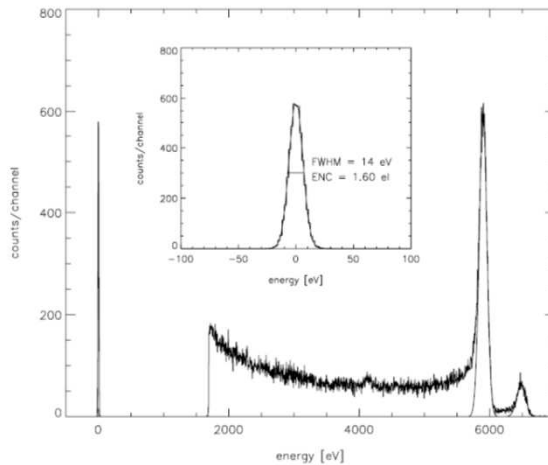
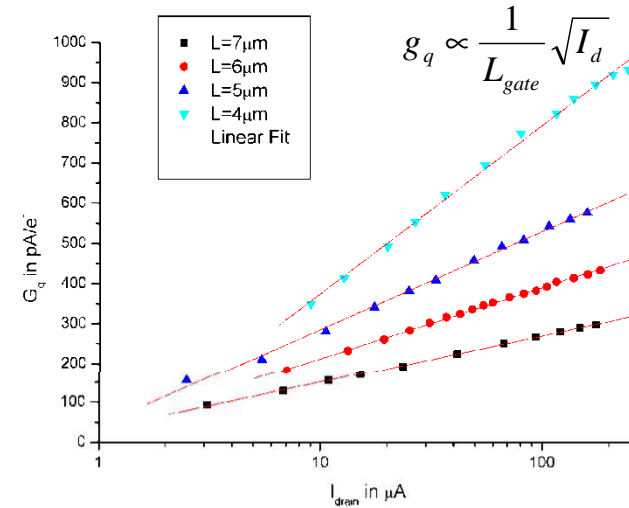


Measurements in good agreement
Typical values:

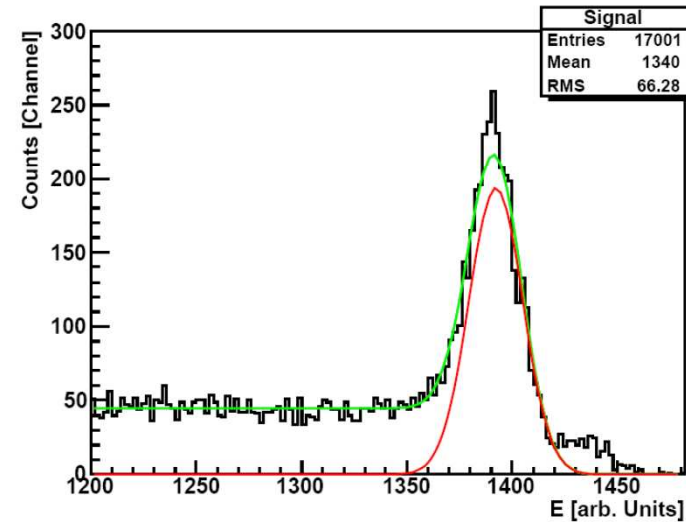
$g_q \sim 400 \text{ pA/e}$ (for $L = 6 \mu\text{m}$)

Could be pushed up to 1 nA/e

$$ENC = \sqrt{\alpha \frac{8kTg_m}{3g_q^2} \frac{1}{\tau} + 2\pi a_f C_{tot}^2 + qI_{Leak}\tau}$$



1.6 e ENC at $\tau=10 \mu\text{s}$



40 e ENC at $\tau=20\text{ns}$ (50MHz)

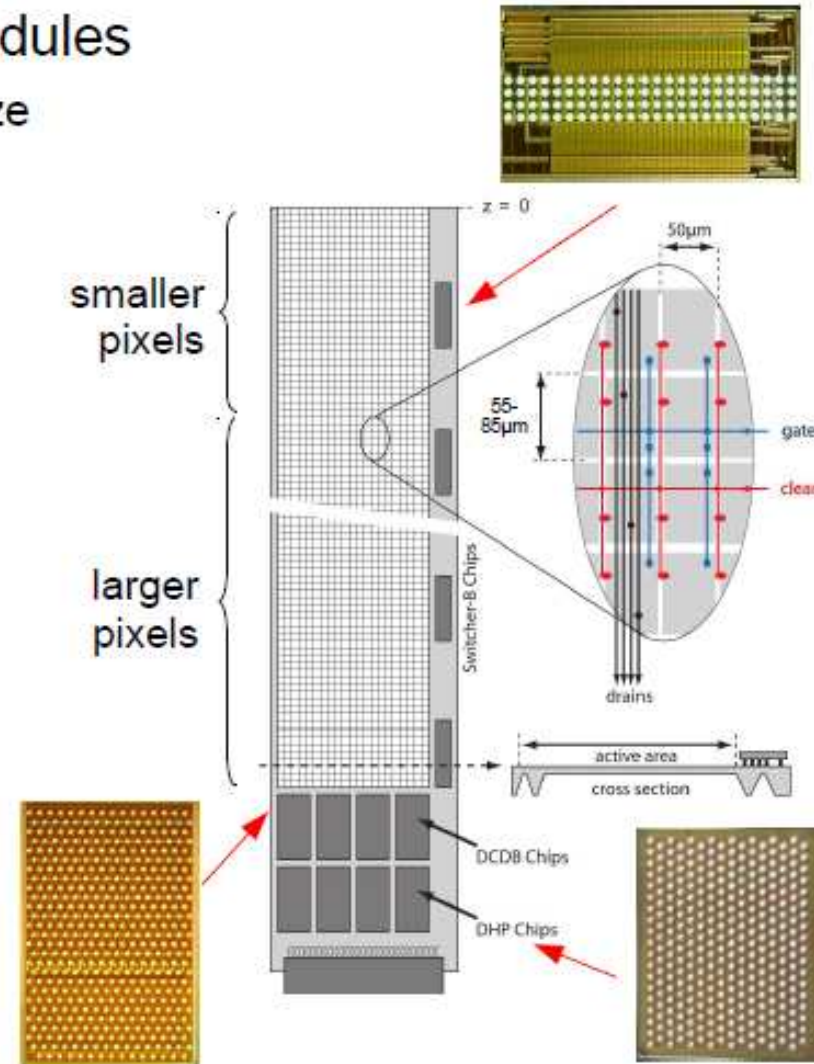


Sensor Module/Ladder



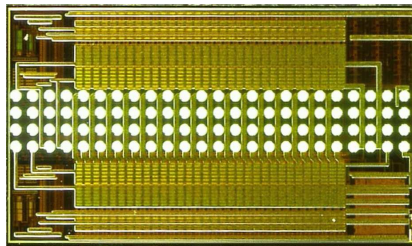
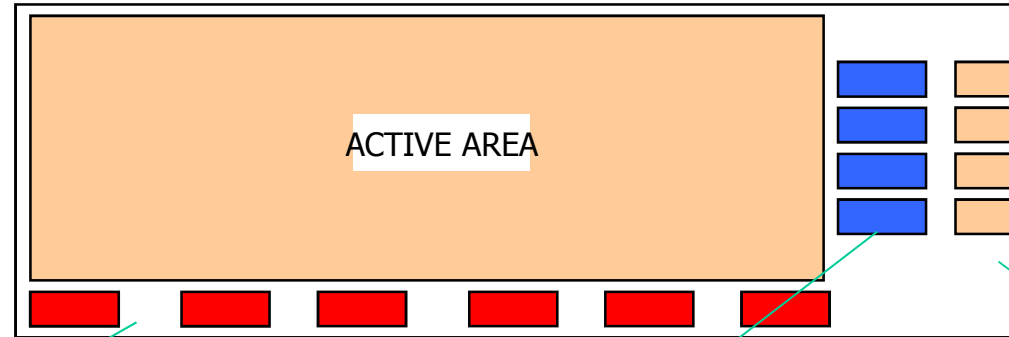
- PXD ladder is built of two half modules
 - module length restricted by wafer size
 - yield considerations

Half Module	Inner layer	Outer layer
# (half) modules	8 (16)	12 (24)
Radius	14 mm	22 mm
Pixel size	50x55 μm^2 50x60 μm^2	50x70 μm^2 50x85 μm^2
Thickness	75 μm	75 μm
# pixels	1536(z) x 250(R- ϕ)	1536(z) x 250(R- ϕ)
Size	15x68 mm^2	15x85 mm^2



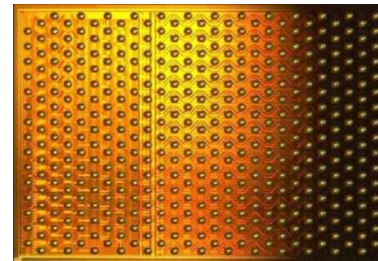


ASICs for control and readout



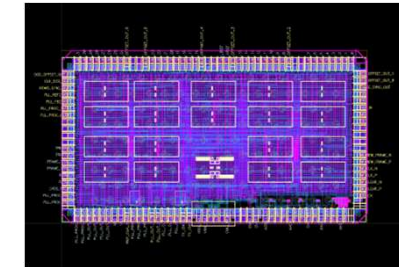
Switcher

Control of gate and clear
32 x 2 channels
Switches up to 30V
AMS 0.18 μm HV technology
Tested up to 36 Mrad



DCDB

Amplification and digitization of DEPFET signals
256 input channels
8-bit ADC per channel
92 ns sampling time
UMC 189nm
Rad hard design



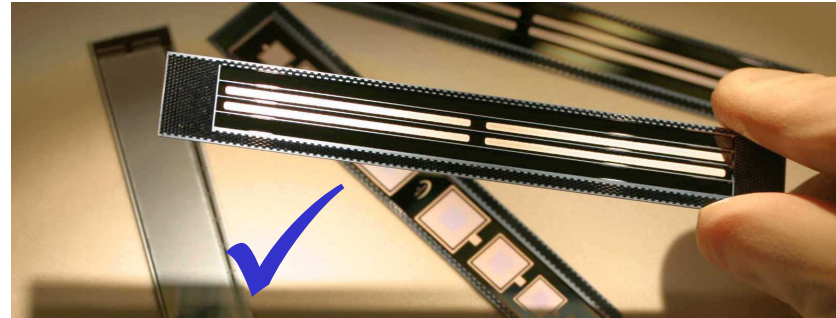
DHP

Signal processor
Common mode correction
Pedestal subtraction
0-suppression
Timing and trigger control
IBM 90 nm
Rad hard design
Convert to TSMC 65nm

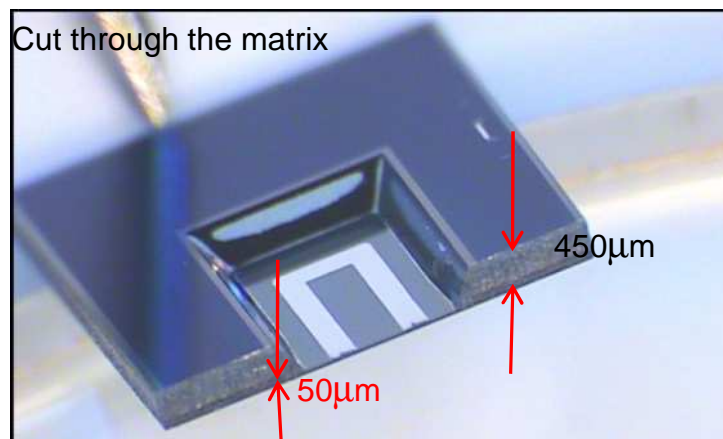
All three chips fabricated and tested



Sensor Thinning



Need thin (50 μ m-75 μ m) self supporting all silicon module

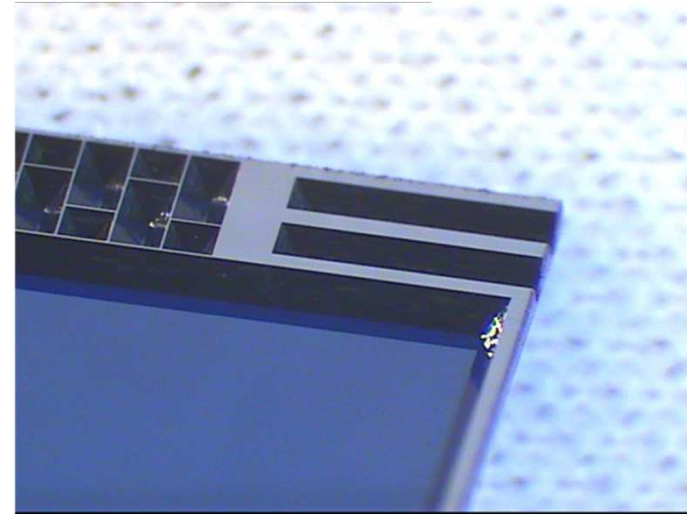




μ -joint between half-ladders

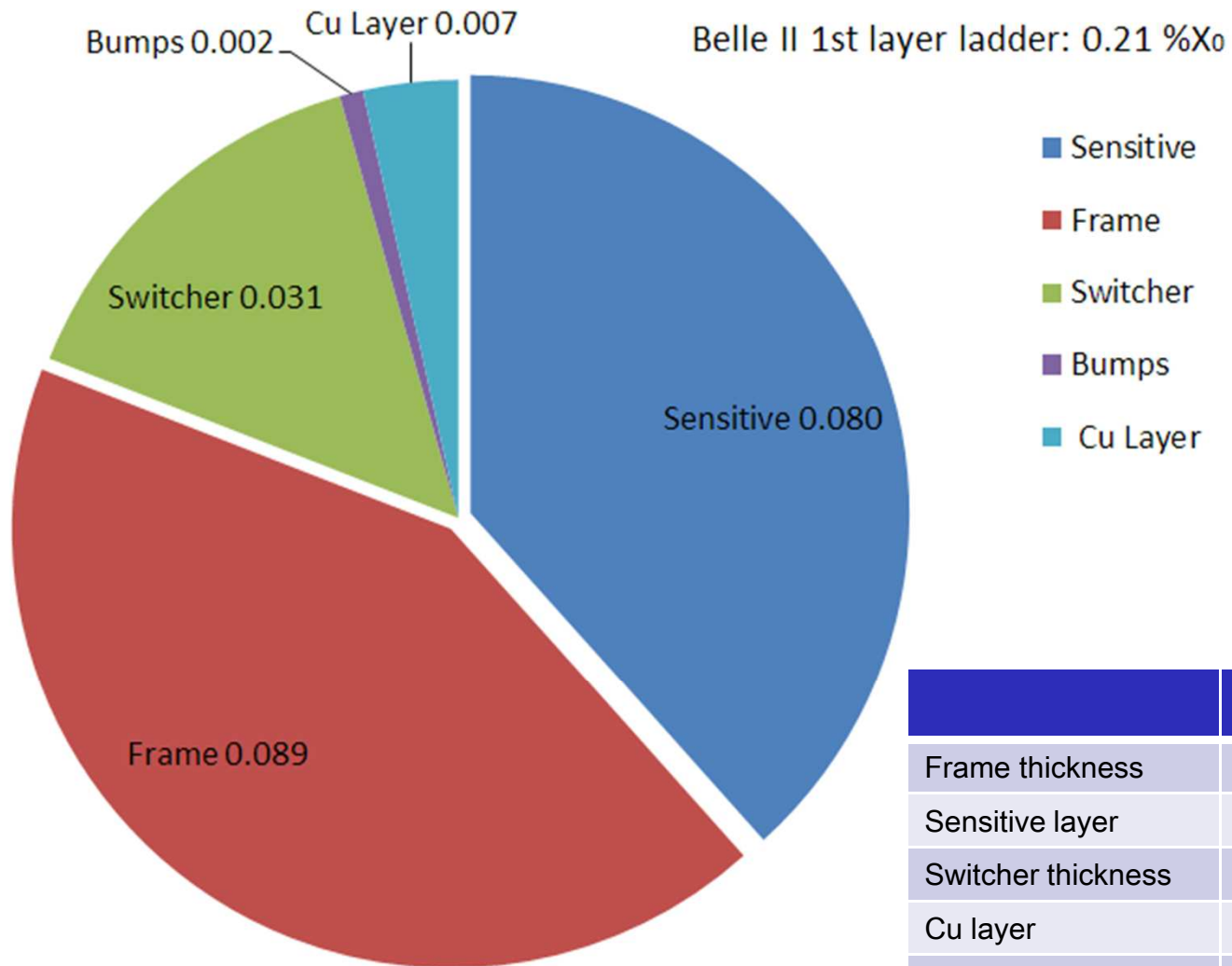


- » v-grooves in support silicon
- » butt-joint between two half-ladders
- » reinforced with 3 ceramic inserts
- » 2x300 μ m dead area per ladder
- » mechanical tests \rightarrow remarkably robust!!
- » bowing: up to 1 mm sag (over 10 cm)
- » tension: 40 to 60 N, then the Si broke





All-silicon module – material budget (single layer)



	Belle II
Frame thickness	525 μm
Sensitive layer	75 μm
Switcher thickness	500 μm
Cu layer	only on periphery
Total	0.21 %X ₀

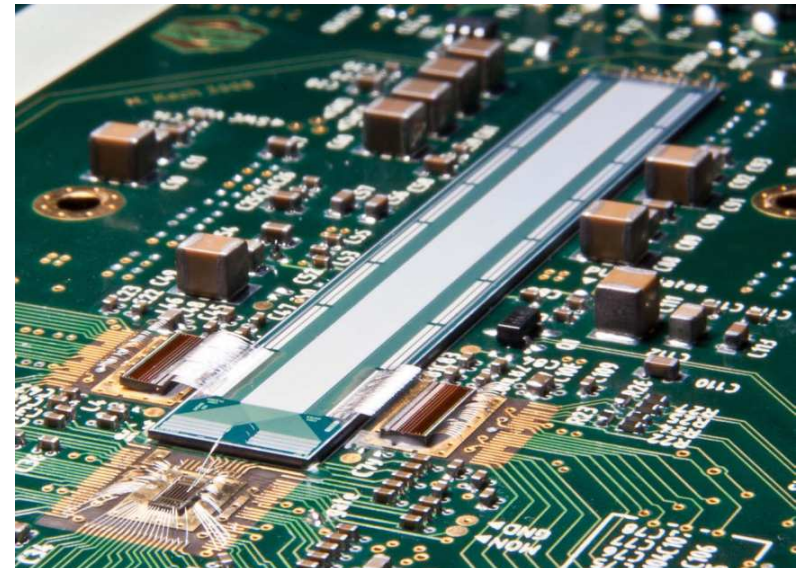
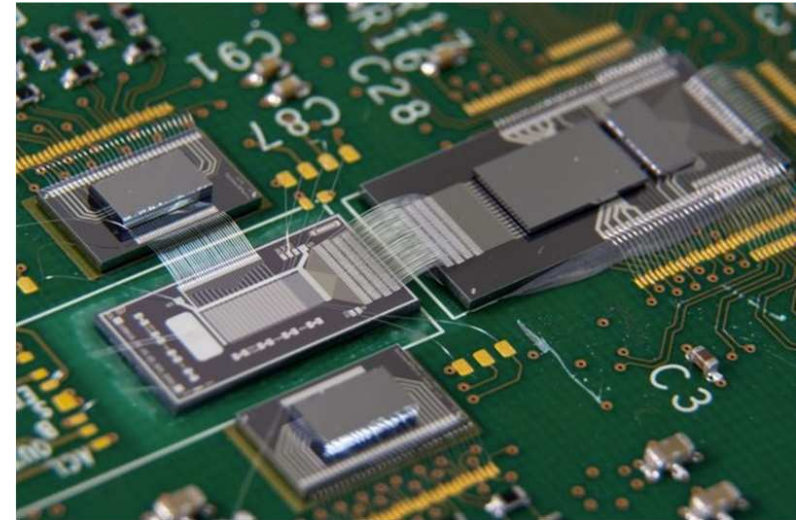
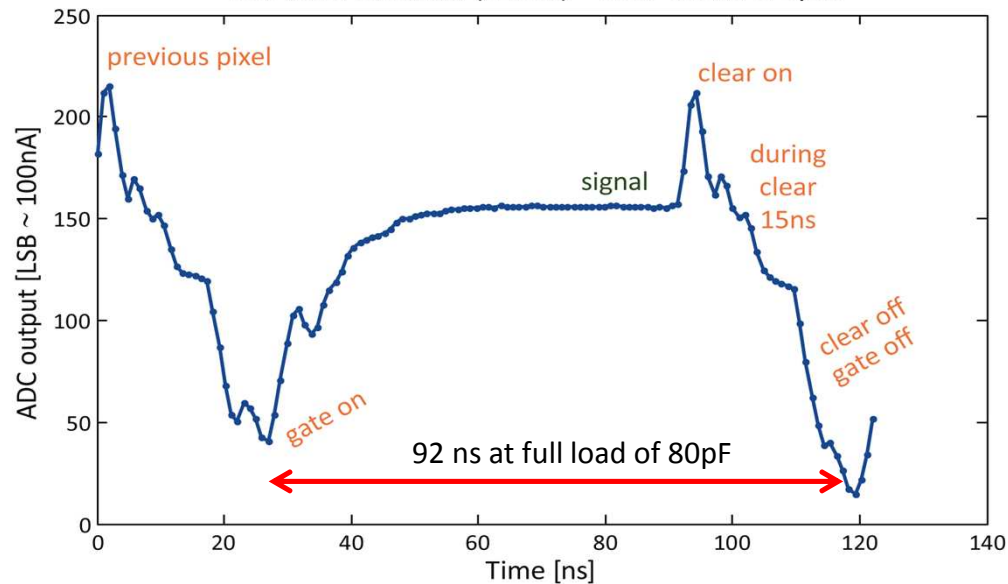


PXD6 testing in the lab



- » bench tests in the lab
 - ↳ determine best operating point (Clear, ClearGate, Drift..)
 - ↳ in-pixel studies with laser
 - ↳ radioactive source tests
 - ↳ **read-out speed...**
- » goal @Belle II
 - » 320 MHz system clock
 - » 50 kHz frame rate (20 μ s r/o time per frame)
 - » 768 rows, 4-fold r/o \rightarrow **~100 ns per row**

single pixel DEPFET (COCG LE) current output as seen by DCD
row-rate 10.83MHz (92.3ns) -- clear at end of cycle





Test Beam



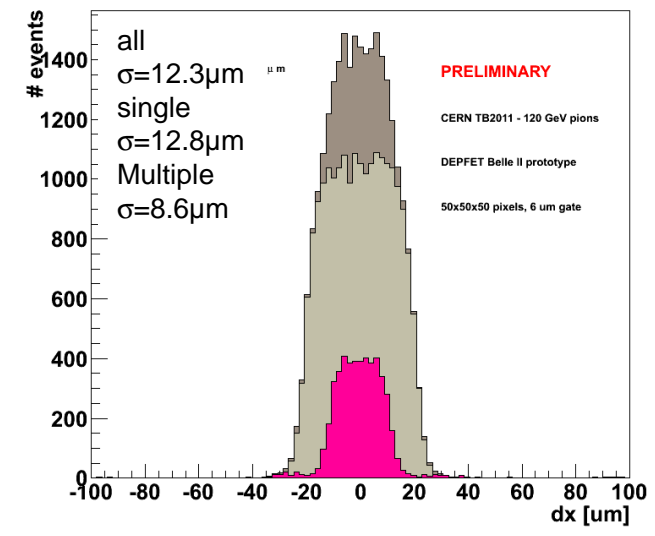
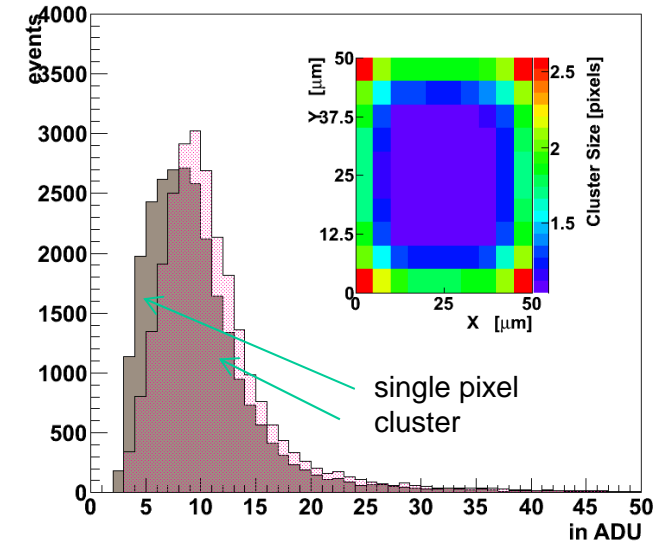
Test beam at CERN, October 2011

- a) PXD6, 50 μm , L=4 μm , standard ox: S/N ~ 40
- b) PXD6, 50 μm , L=6 μm , thin ox: S/N ~ 20

thin oxide not yet optimized => smaller S/N
DCD V1 does not allow optimal I_{drain}
final sensors are 50% thicker

=> S/N > 40 expected for optimal settings

Readout speed up to 320 MHz (100ns readout time)

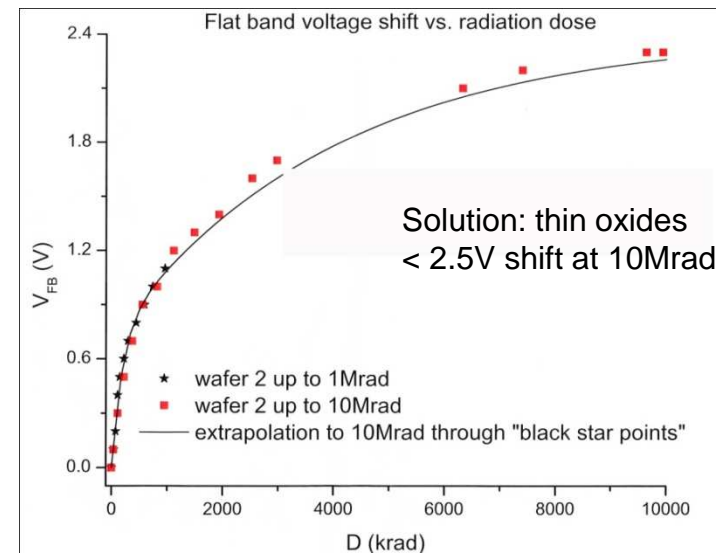
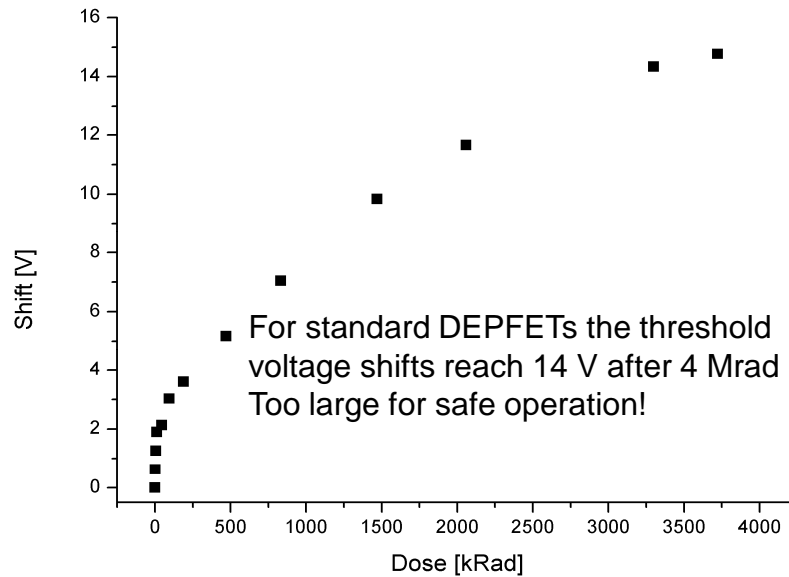
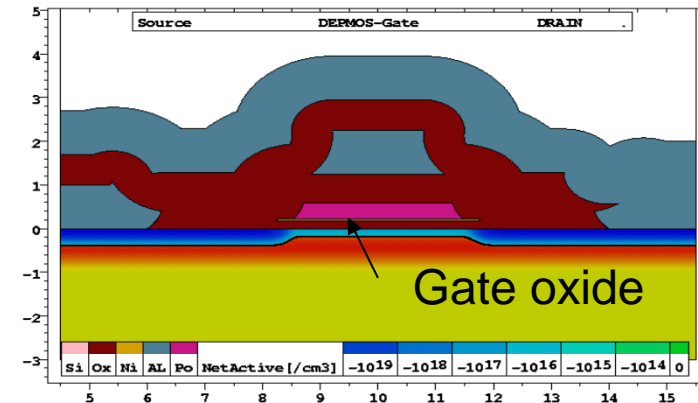




Radiation Hardness

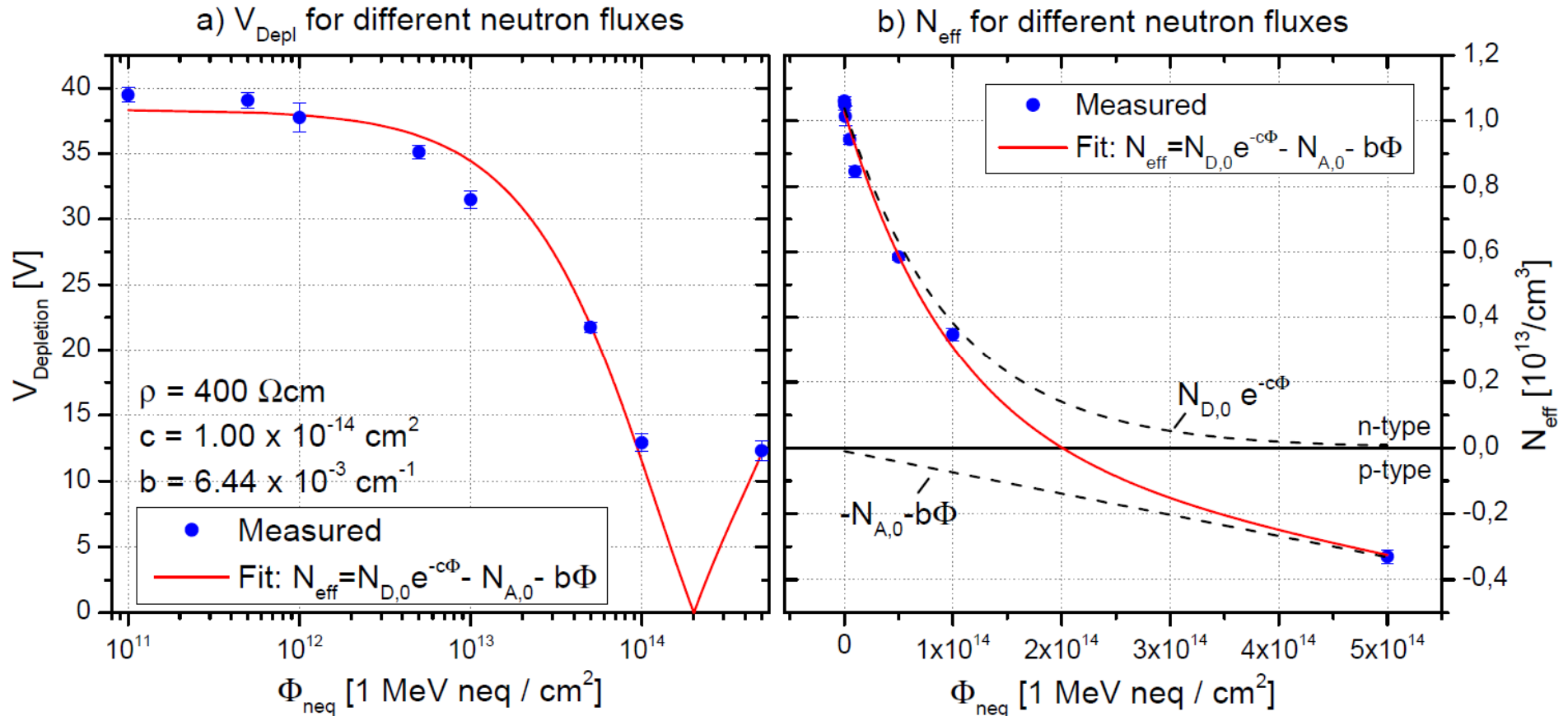


DEPFET based on a MOS structure
 problem with ionising radiation:
 Creation of fixed (positive) charges in the oxide layer
 and at the interface
 Attracts electrons at the Si/SiO₂ interface
 Need more negative gate voltages to compensate
 => Shift of transistor threshold





Neutron irradiations



- Type Inversion at an equivalent neutron flux of approximately $2 \times 10^{14} \text{ neq/cm}^2$
 → No Type Inversion expected during BELLE II operations

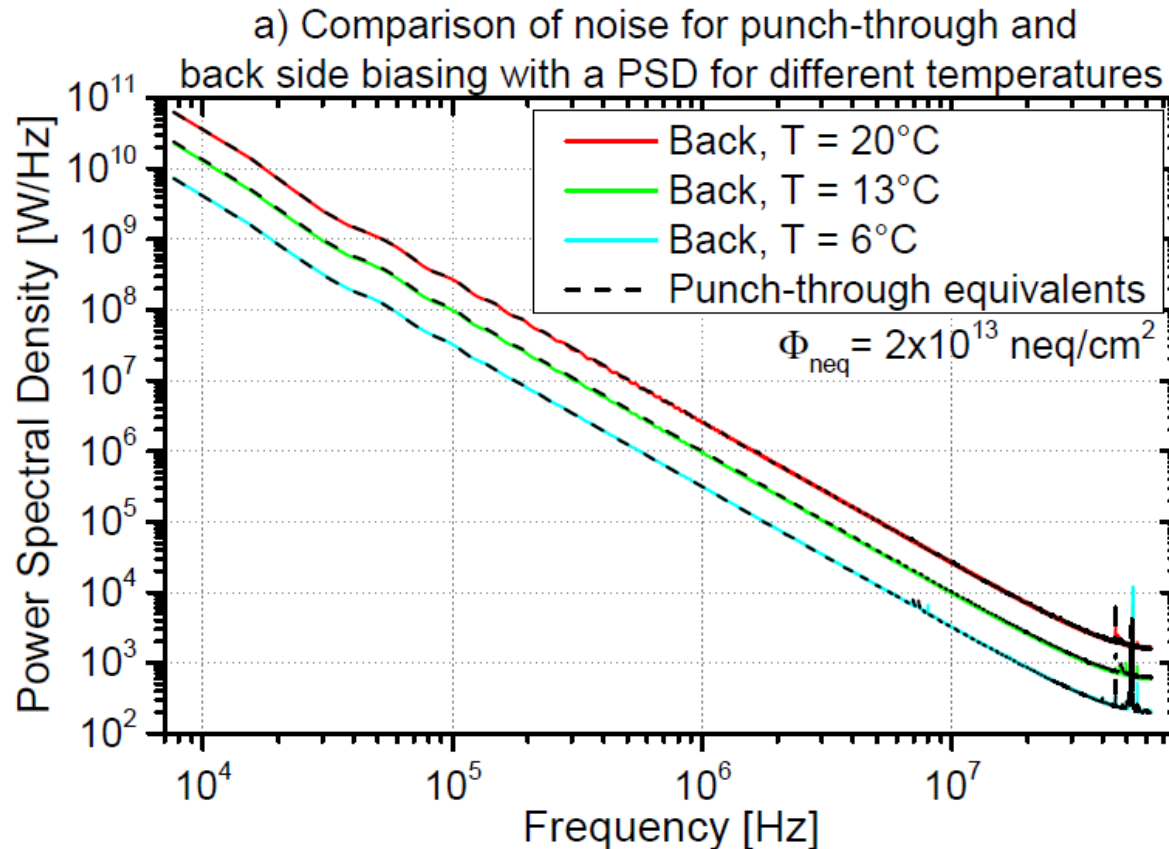
- Measured leakage current after a neutron flux of $2 \times 10^{14} \text{ neq/cm}^2$ was roughly $6 \times 10^{-4} \text{ A/cm}^3$



Punch Through Bias



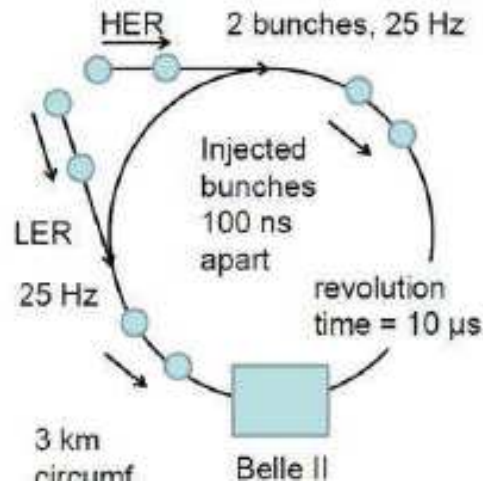
Punch through mechanism allows to bias the backside from a contact on the front side.
No electrical connections on backside needed
However, CDF observed excess noise in punch through biased strip detectors



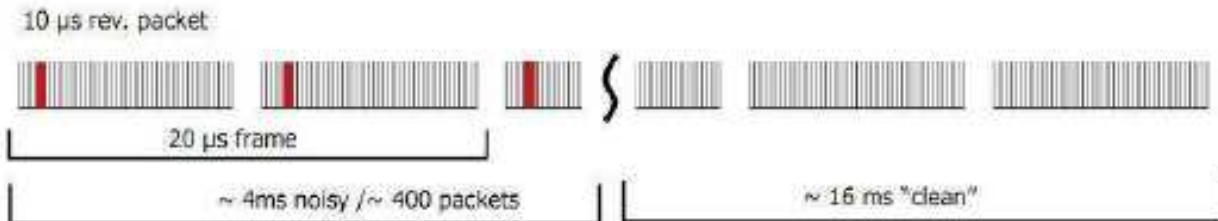
- Punch-through biasing mechanism still in tact after high neutron fluxes
- No increase of punch-through noise after irradiation up to $1 \times 10^{14} \text{ neq/cm}^2$ detectable (measured through various methods)



Injection Noise & Gating



10 μs packets with 2503 bunches, 200 ns gap in-between (TDR)



Sensor filled with hits from freshly injected bunches => ~ 20% dead time

Gating : Sensor is made blind for a short time during high background (noisy bunch)
Signals detected in the clean period before are preserved

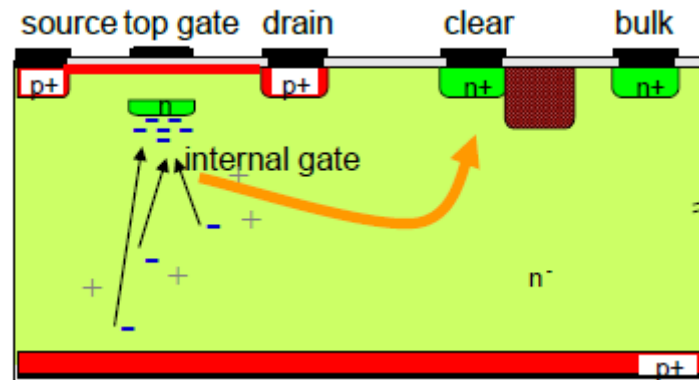
Simulations, lab tests with lasers and particle beams demonstrate feasibility of gating



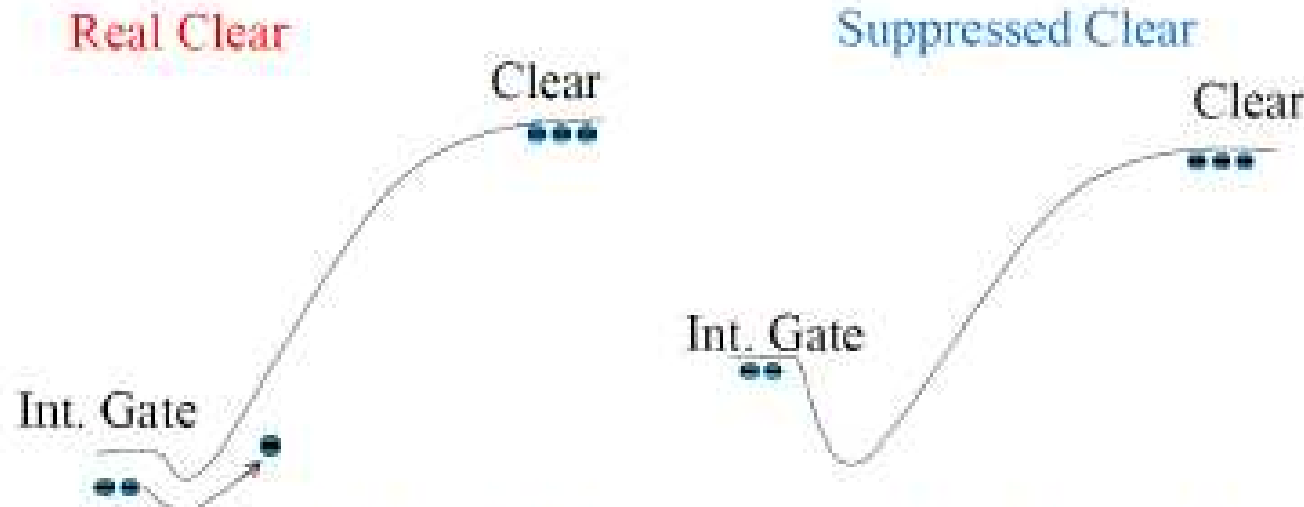
Gated Operation



In normal clear operation
 the gate is pulsed
 negatively
 (repels electrons)
 The clear is pulsed
 positively
 (attracts electrons from
 internal gate and bulk
 underneath)



In gated mode the gate is
 not pulsed,
 Remains attractive for
 electrons
 The clear is pulsed
 positively,
 Attracte electrons fro,
 bulk underneath



Selectivity of the Clear Process [R. Richter]



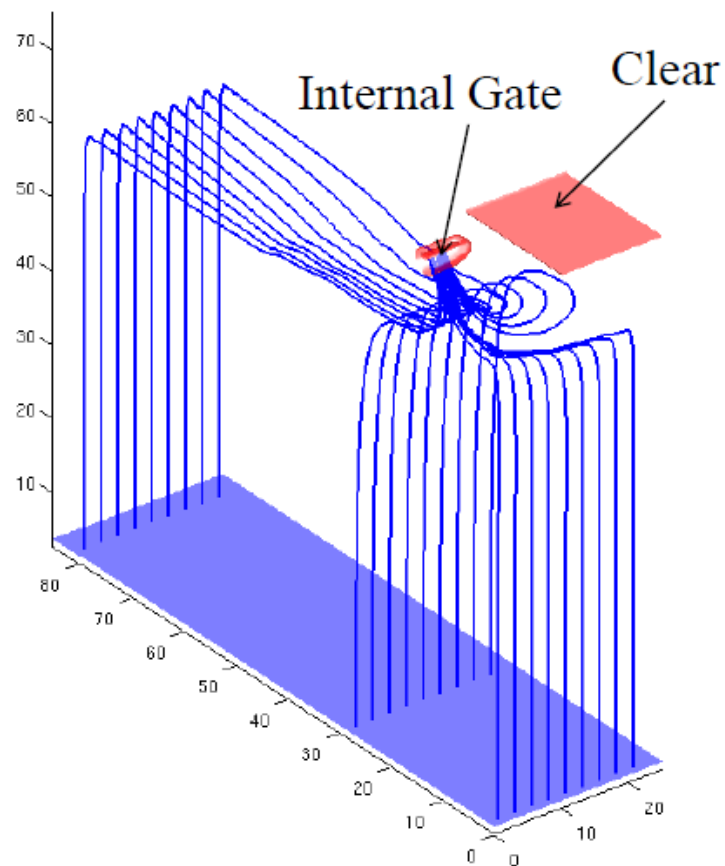
Electron drift directions



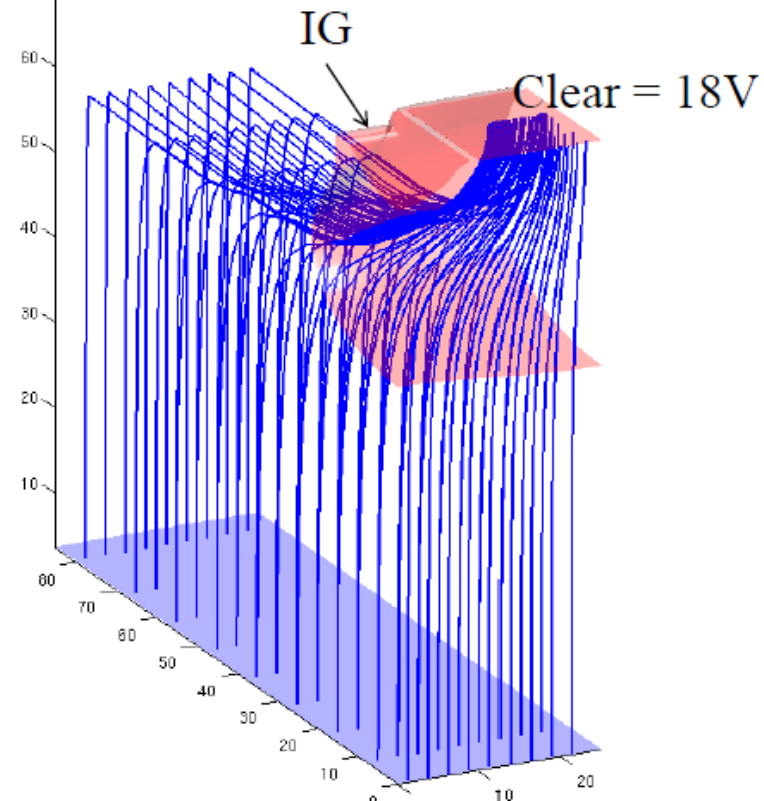
Normal operation:
Signal charge drifts into internal gate

Gated Mode
Charges from background drift directly to clear gate

Signal already stored in internal gate is protected



Huge clear region compared to Internal Gate
- good for electron dumping



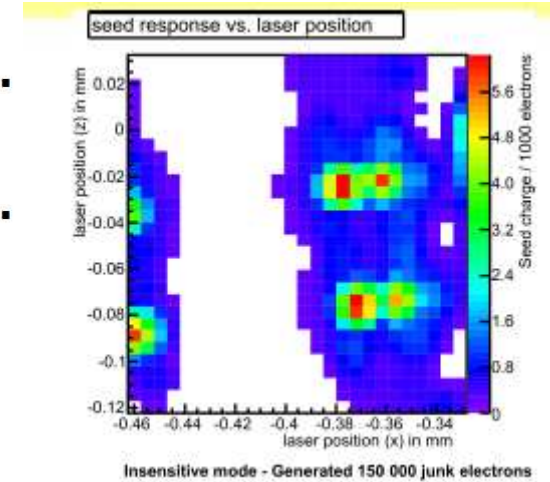
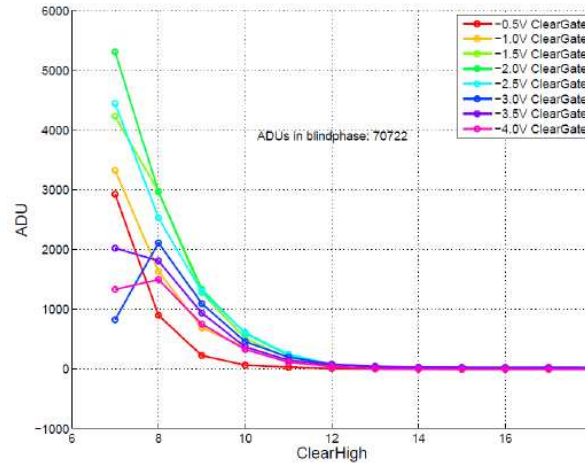


Lab test with laser



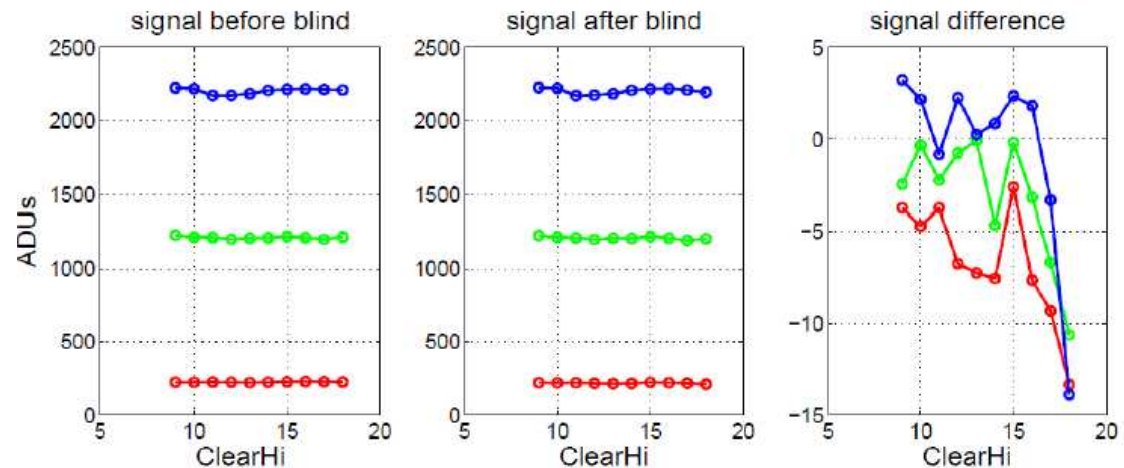
Inject (using a laser) 180k electrons
(MIP: 6k electrons)

scan clear voltage
=> 12V needed for complete shield



Test storage capacity during gating
Measure injected signal before and after gate

=> No losses up to 14V clear voltage



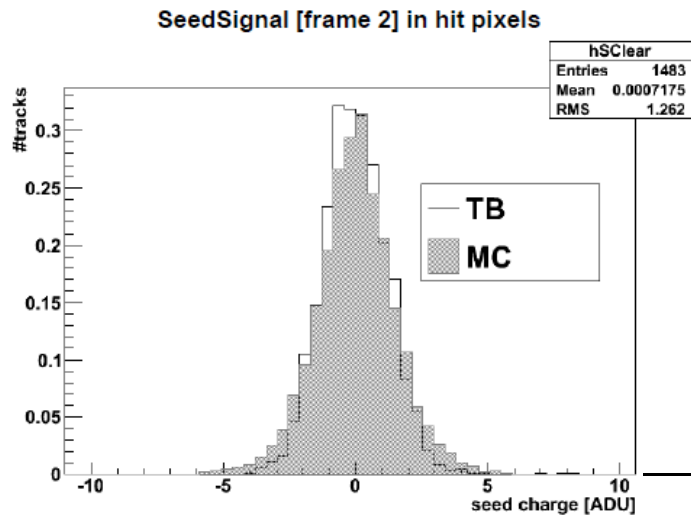
- three different amounts of electrons have been created (red, green, blue curve)
- shielding of the internal gate works for all studied ClearHi voltages



Tests with beam



Gated mode successfully tested in the lab (laser) and test beam

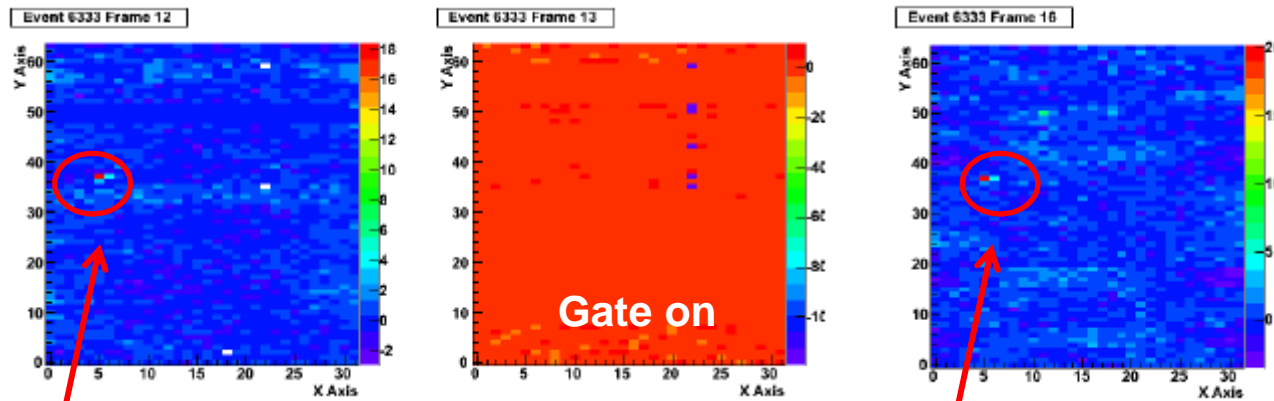


TB: Signal distribution of pixels which have been hit by a track when gating was on (from track extrapolation)
MC: normal noise distribution

A real signal should be here



Protection: the signal of a real hit is still present after gating:

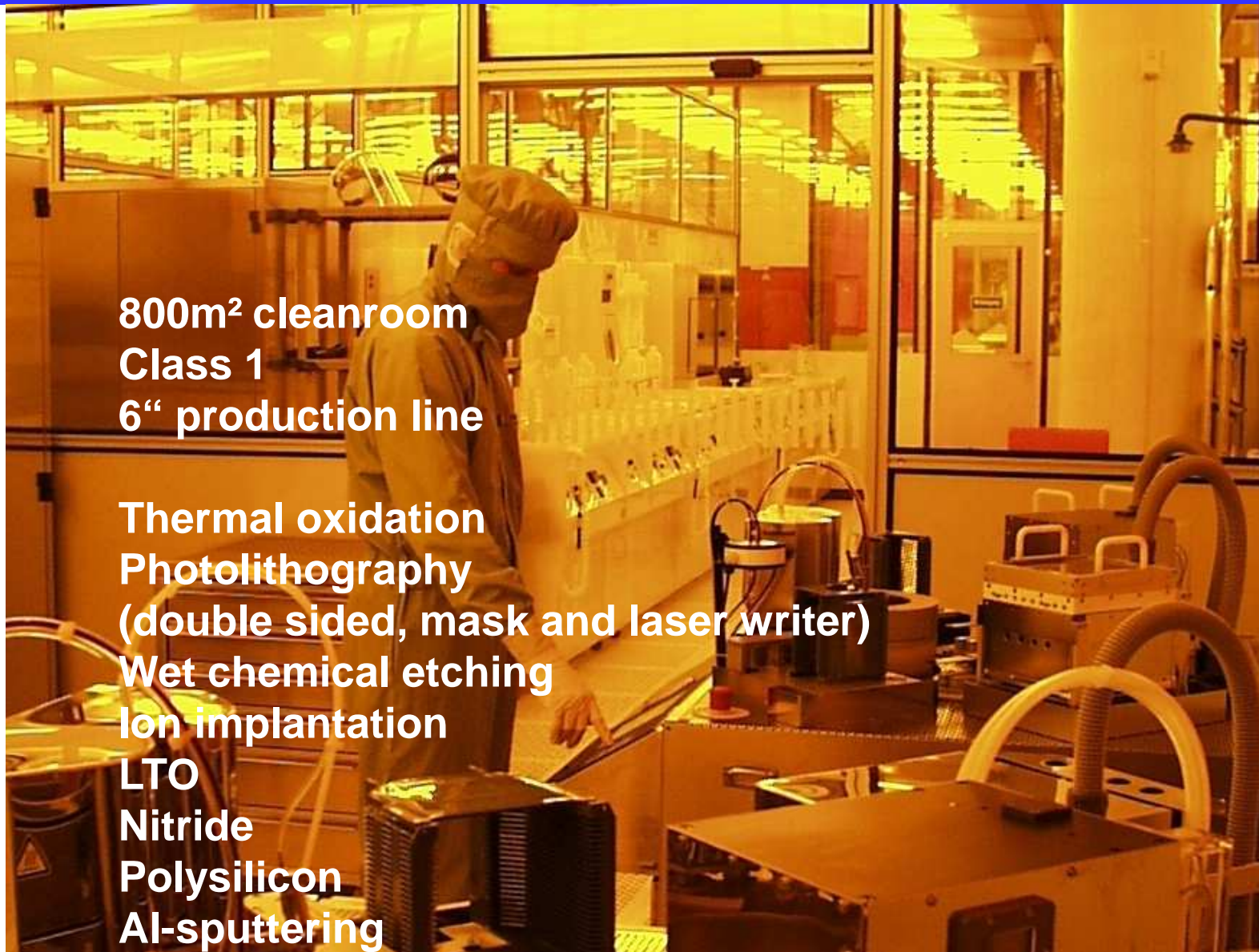


Signal before gate (not cleared)

Signal after gate



Production Facilities



800m² cleanroom
Class 1
6" production line

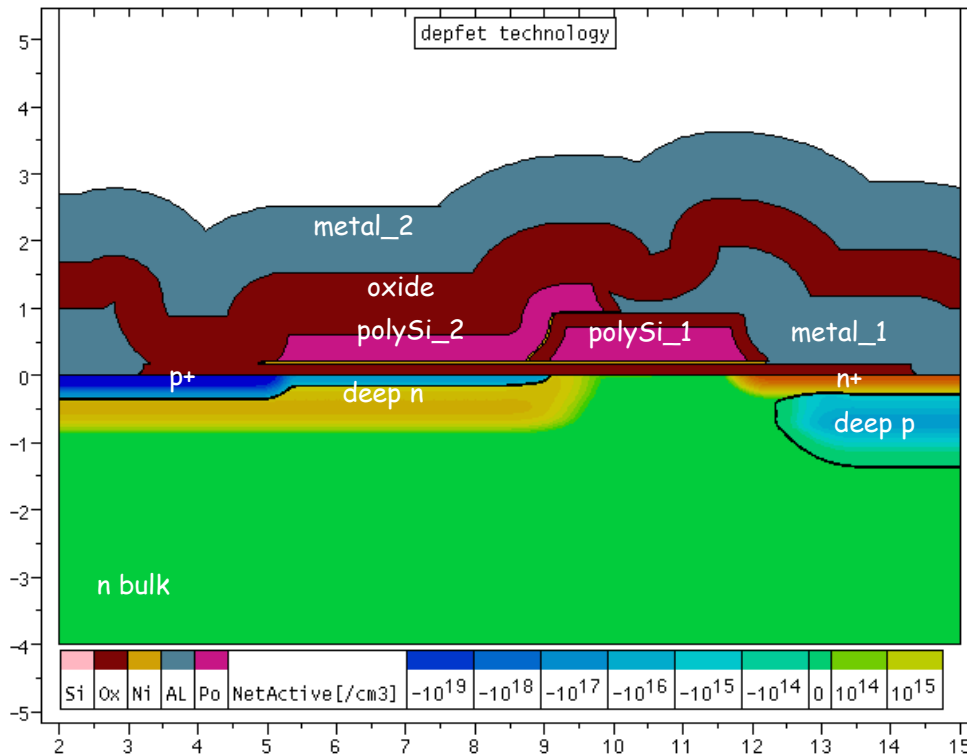
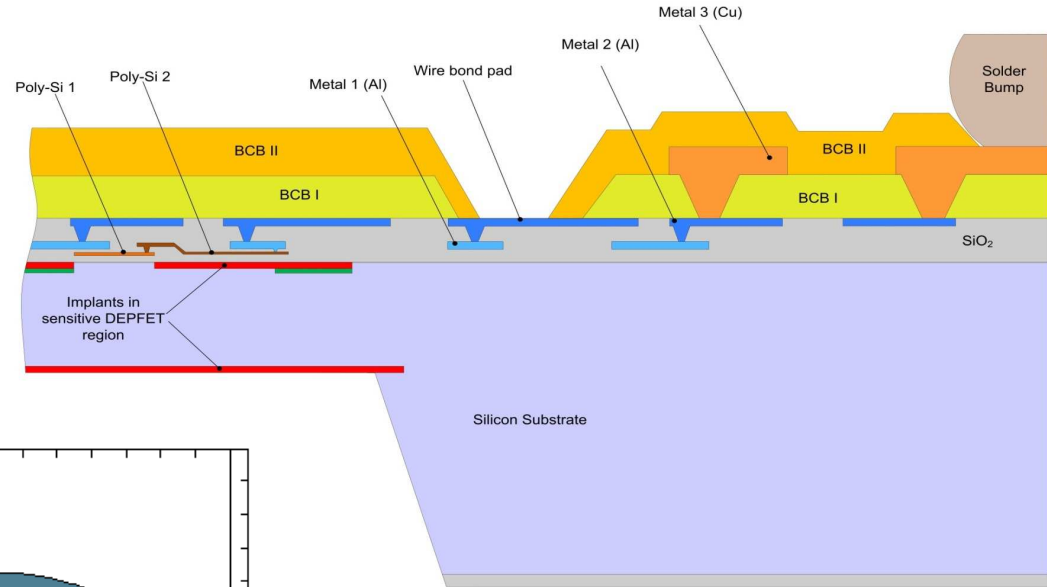
Thermal oxidation
Photolithography
(double sided, mask and laser writer)
Wet chemical etching
Ion implantation
LTO
Nitride
Polysilicon
Al-sputtering



DEPFET production



BCB passivation
Copper layer (power and UBM)
BCB insulation



Poly I (transistor gate)
Poly II (clear gate, contact)
Alu I (contacts)
Alu II (contacts)

In total: 93 processing steps
~ 2 years processing time



DEPFET Production



First production batch with 13 wafers started in HLL in July

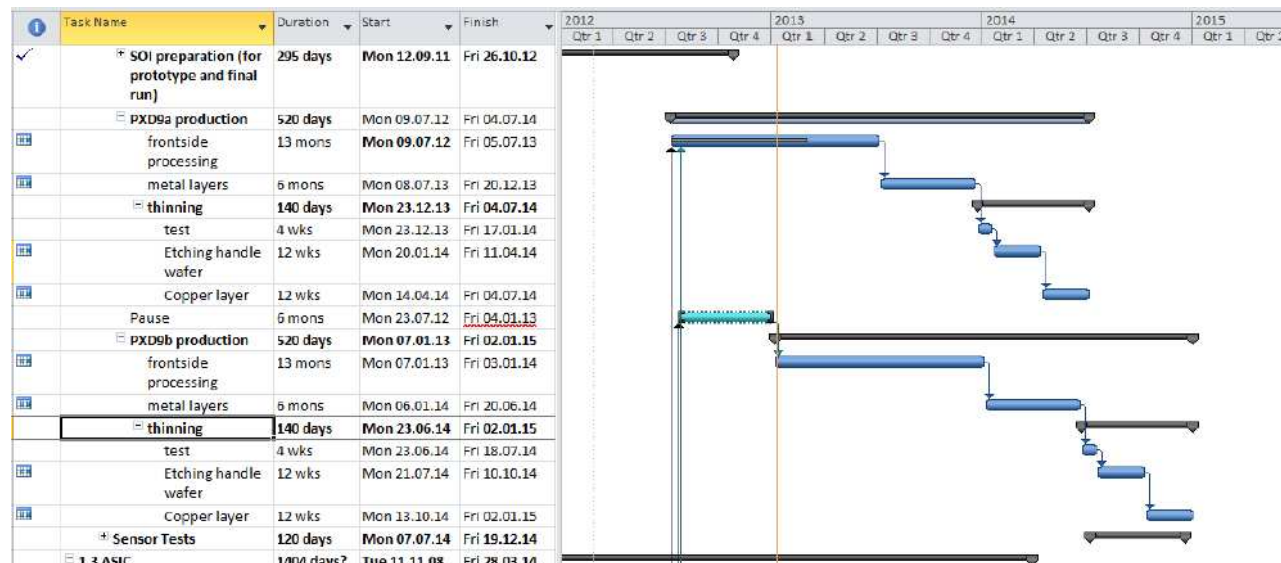
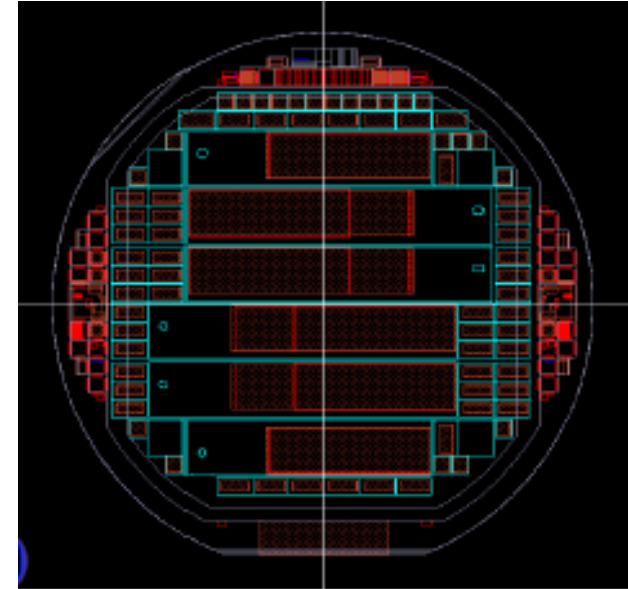
- one wafer has sensors for 1 inner and 2 outer ladders

Nominal processing time (including thinning): 2 years

Processing runs smoothly, ahead of schedule

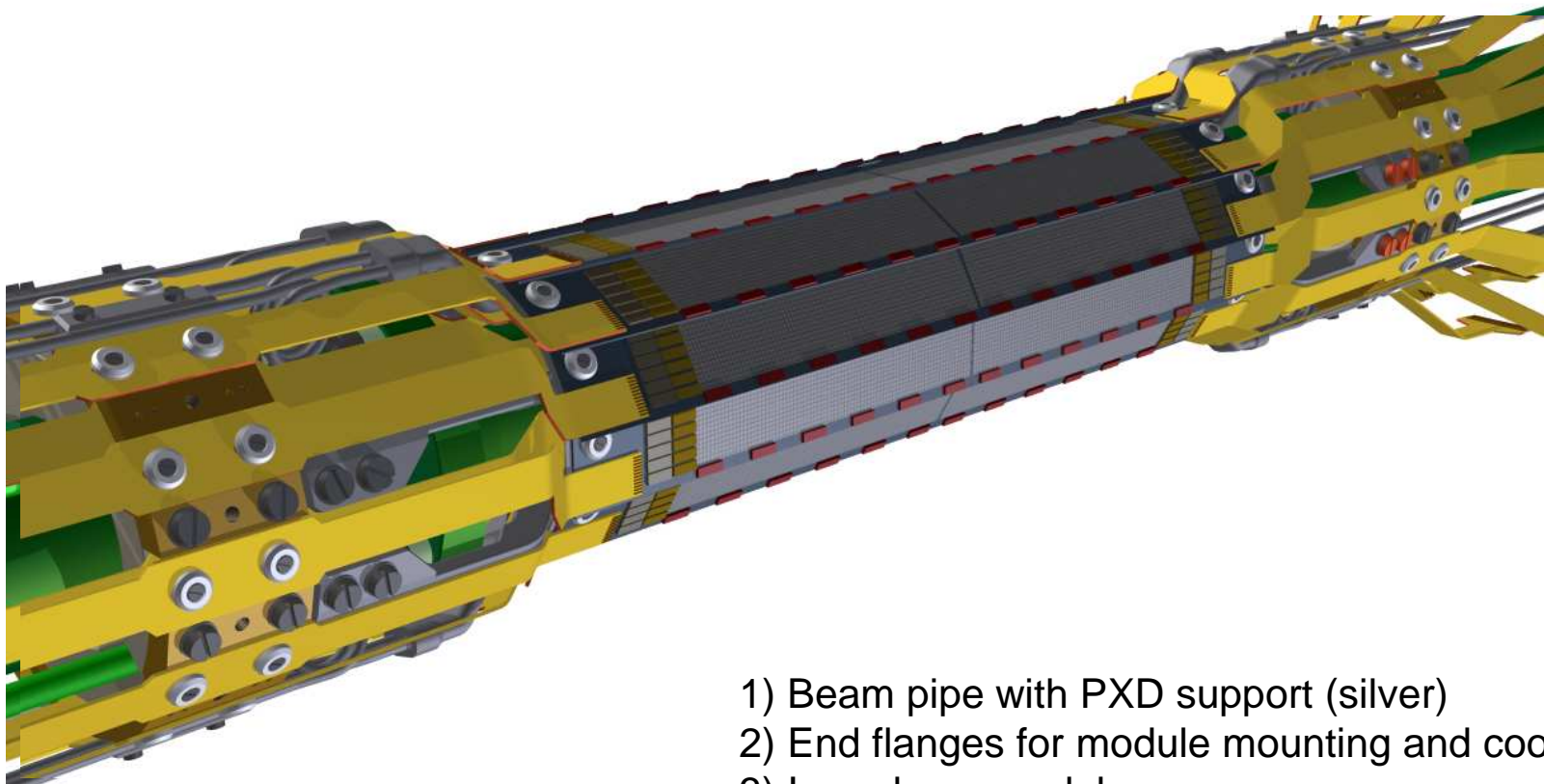
Second batch with 18 wafers will follow soon

Yield requirements: 20% for outer layer
27% for inner layer





Support



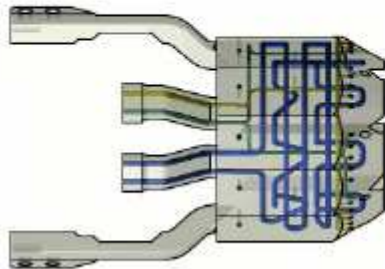
- 1) Beam pipe with PXD support (silver)
- 2) End flanges for module mounting and cooling
- 3) Inner layer modules
- 4) Outer layer modules



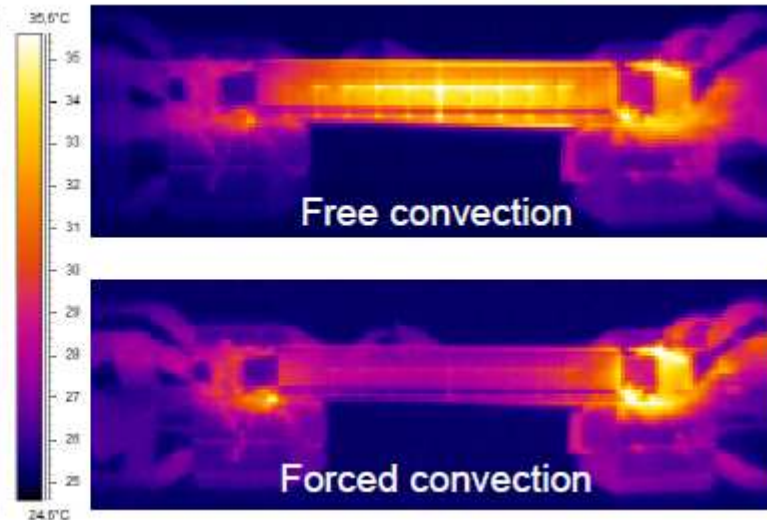
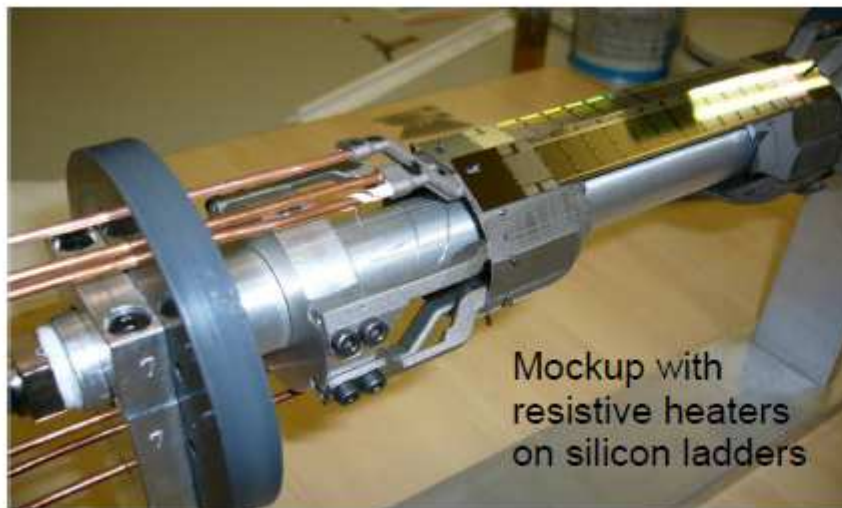
End Flange - Cooling Block



- Cooling system outside acceptance
- Closed CO2 cooling system for readout electronics (320W)
- Cold dry air for steering chips and DEPFET pixels (40W) 150mW/cm²



- Stainless steel
- Fast sintering
- Blue: CO2 channels
- Yellow: Air channels

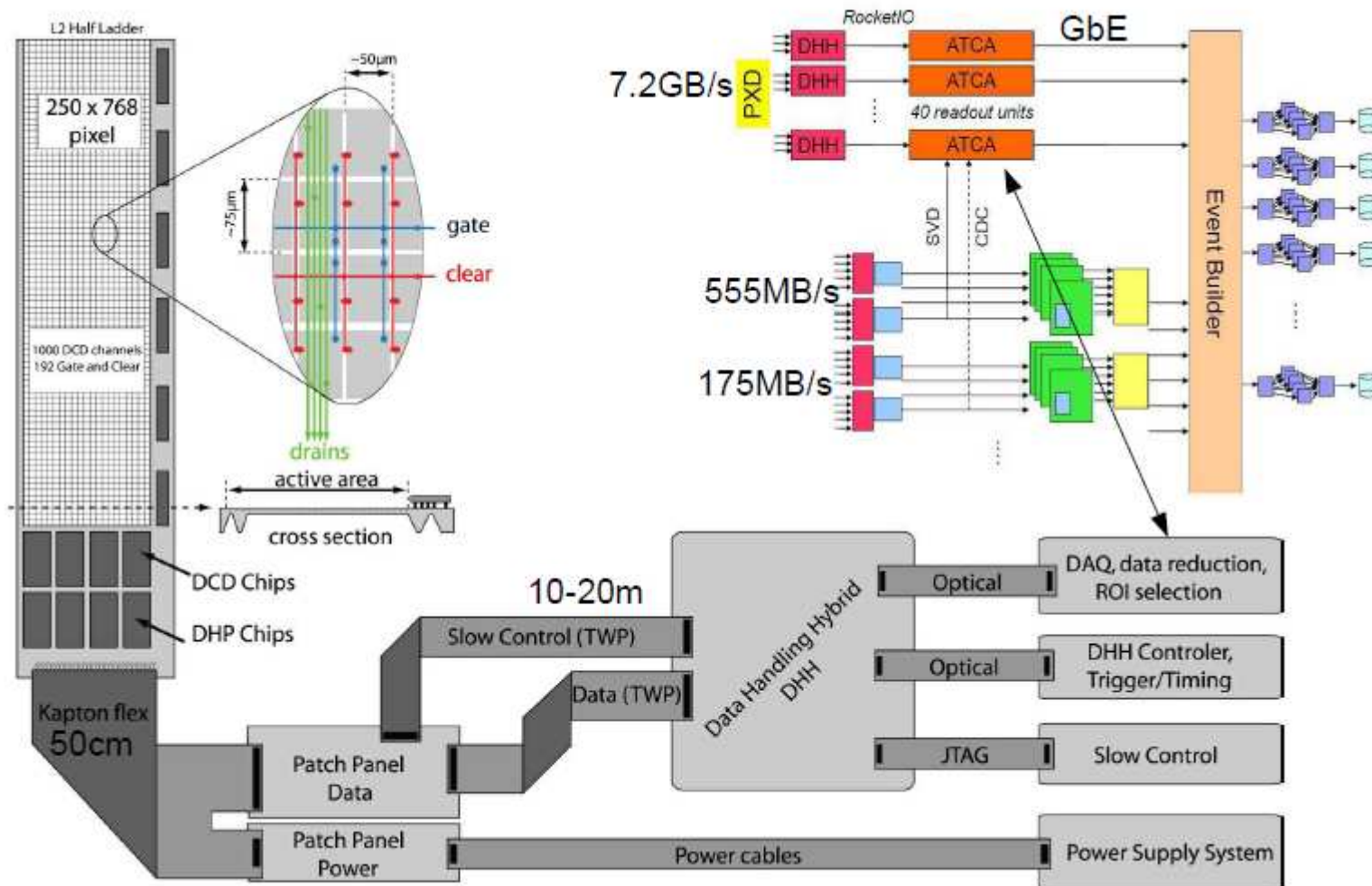




DAQ



Max data rate: 20 GB/s @ 3% occupancy (expected: 0.8%)
Data reduction (ROI selection): ~ 700 MB/s





Conclusions



SuperKEKB upgrade progressing well

-> machine commissioning starts beginning of 2015

Major upgrade of Belle II detector underway (inner detector, PID, KLM)

Pixel Detector:

- DEPFET sensors thinned to $75\mu\text{m}$
- low mass self supporting, air cooled module: 0.21% X_0
- S/N, resolution, readout speed and radiation hardness tested
- production of final sensors started
- CO_2 cooling for ASICs (and SVD)
- mounting blocks with integrated cooling channels (3D printing)

Installation of PXD/SVD: September 2015

Physics start: mid 2016



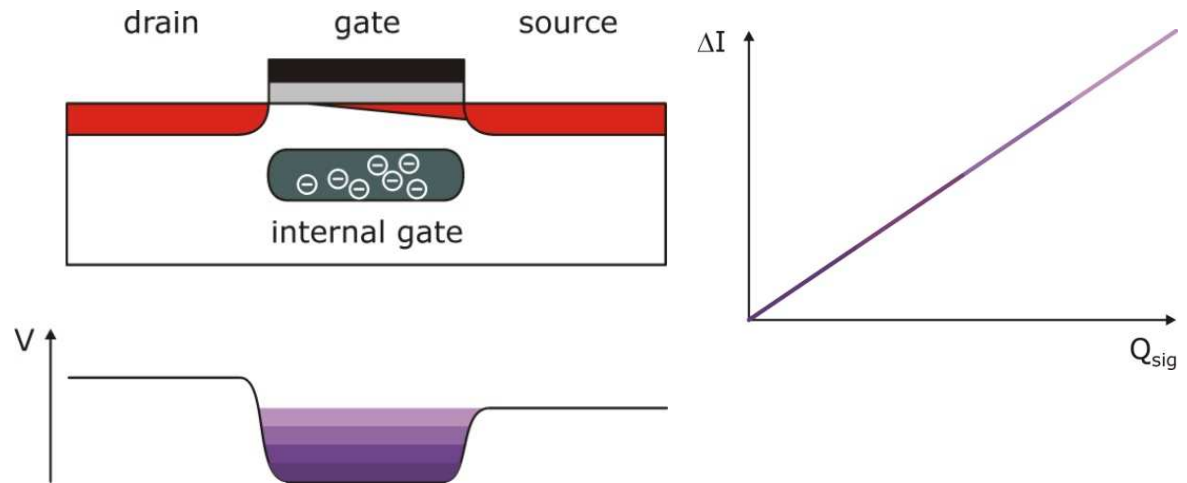
DSSC DEPFET Principle



J. Kemmer and G. Lutz, "New semiconductor concept," *NIM. A*, 1987

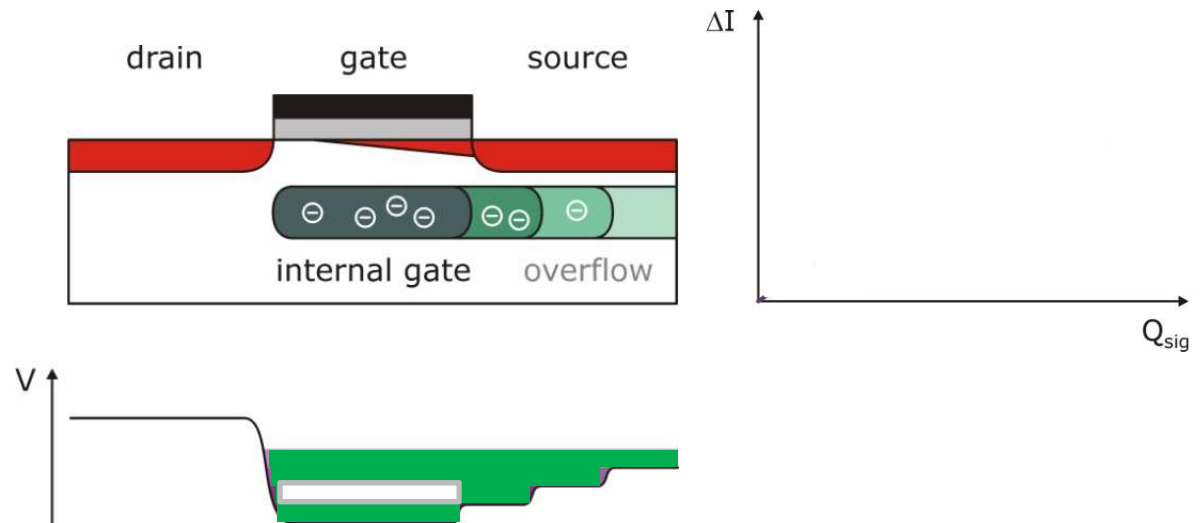
Standard DEPFET principle

- p-FET on depleted n-bulk
 - ↳ All signal charge collected in potential minimum below FET channel
 - "internal gate"**
 - ↳ all signal charges cause an equal effect on the FET current
 - ↳ **linear $\Delta I/Q_{sig}$ characteristics**
- reset via ClearFET
- low capacitance & noise



DSSC adaptation

- ↳ signal charges at high levels also stored under source
- ↳ less/no effect on FET current
- ↳ **non-linear $\Delta I/Q_{sig}$ characteristics**
- ↳ gain curve engineering by dose & geometry of implantations





Need O(100x) more data → Next generation B-factories



10³⁶

