Development of a Monolithic Active Pixel Detector for a Super-B factory

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On behalf of the Belle Pixel Group

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BELLE

Outline

→ **KEKB and BELLE detector.**

→ **BELLE Silicon Vertex Detector / Super-BELLE perspective.**

→ **Monolithic Active Pixel Sensor (MAPS) for BELLE upgrade.**

→ **Principle of MAPS.**

→ **Results of beam test on prototype MAPS, summer 2004.**

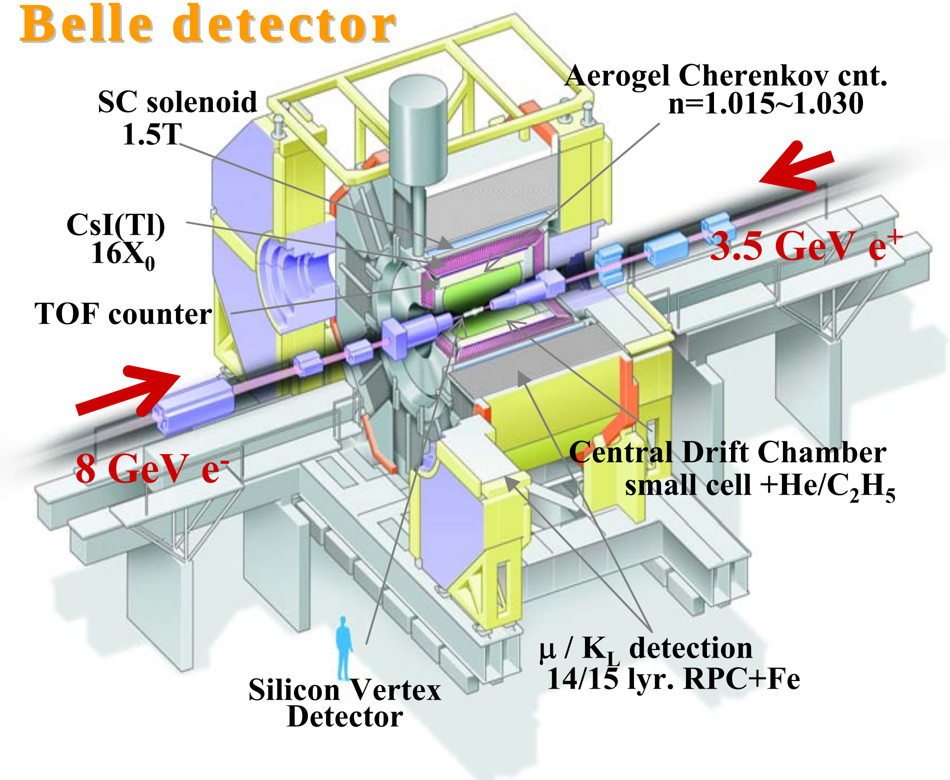
→ **Critical R&D items.**

→ **Plans for the near future.**

→ **Highlights and conclusion.**

BELLE detector at KEKB

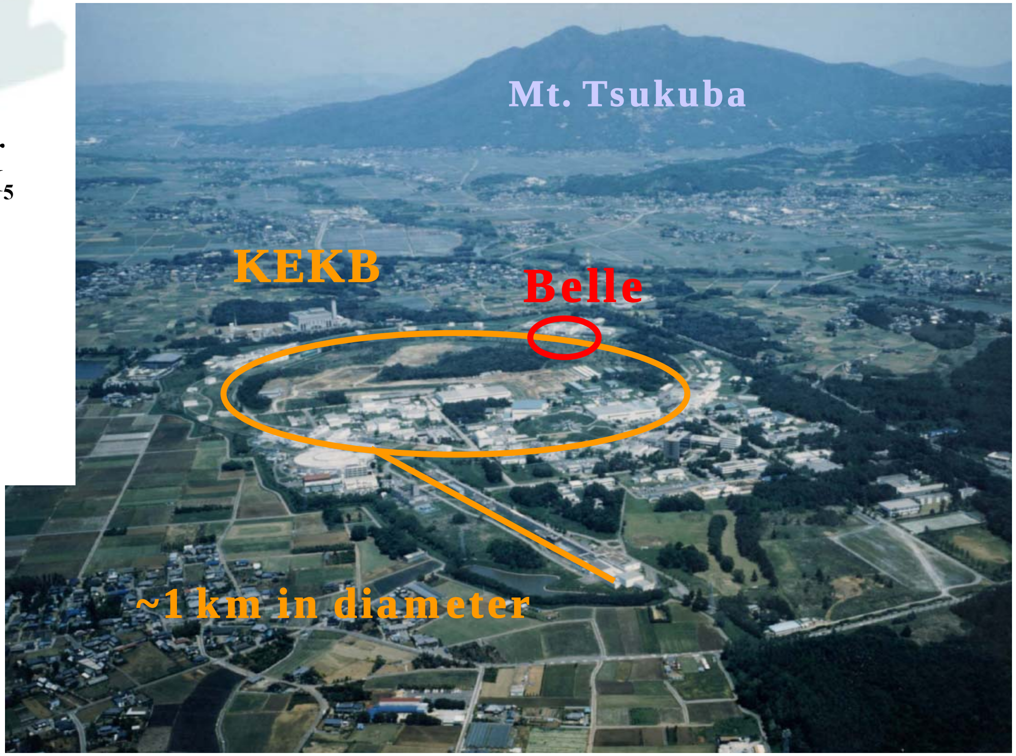
Belle detector



KEKB / Belle started operation in 1999

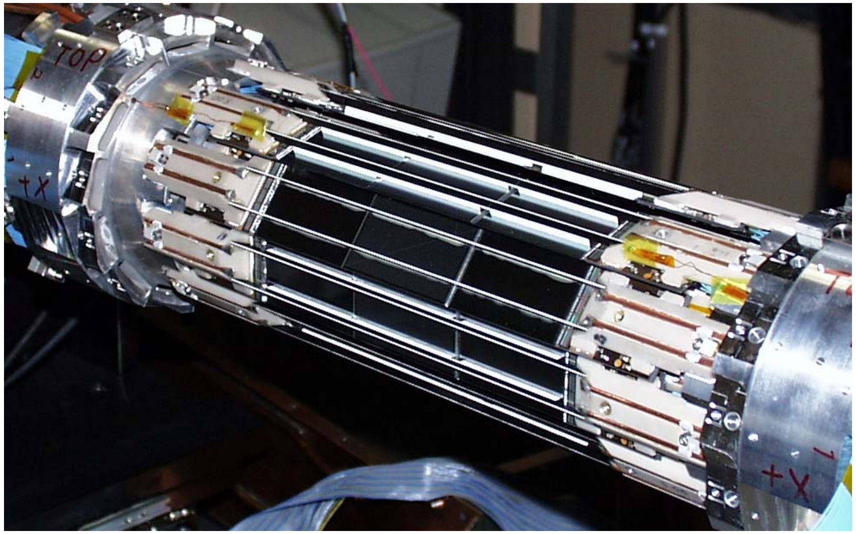
8 GeV e^- x 3.5 GeV e^+

L_{peak} = 1.39×10^{34} $cm^{-2} sec^{-1}$
(highest peak luminosity)

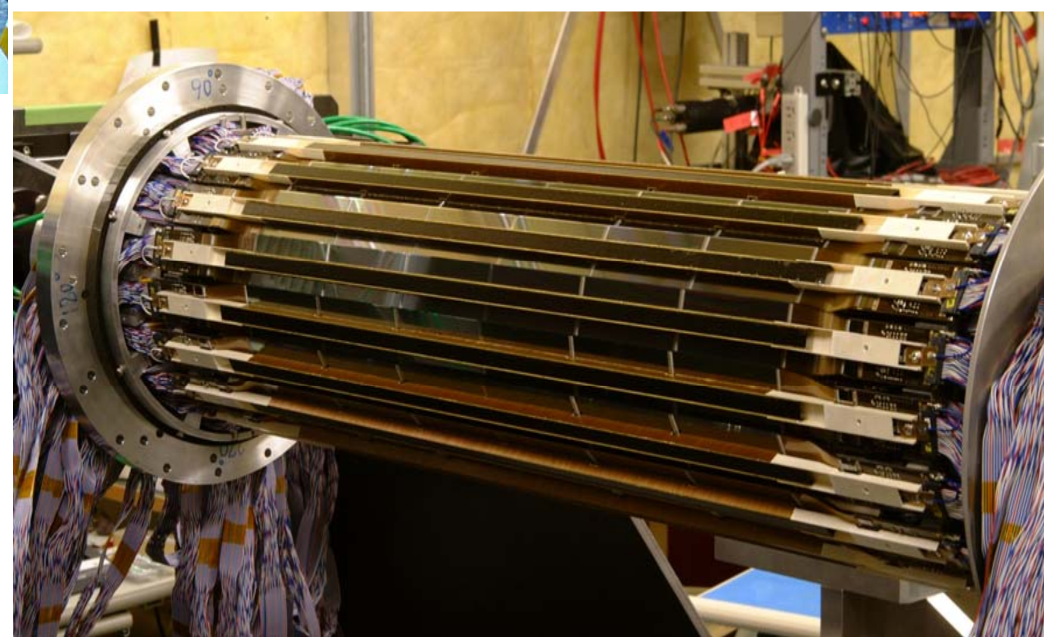


Integrated Luminosity
250 fb^{-1} on-peak so far…
(~274 M. $B\bar{B}$)

BELLE SVD1 → SVD2



1st generation Silicon Vertex Detector (SVD1) → 2nd generation SVD (summer 2003)



Beam pipe radius: 20mm →15mm

3 layers → 4 layers

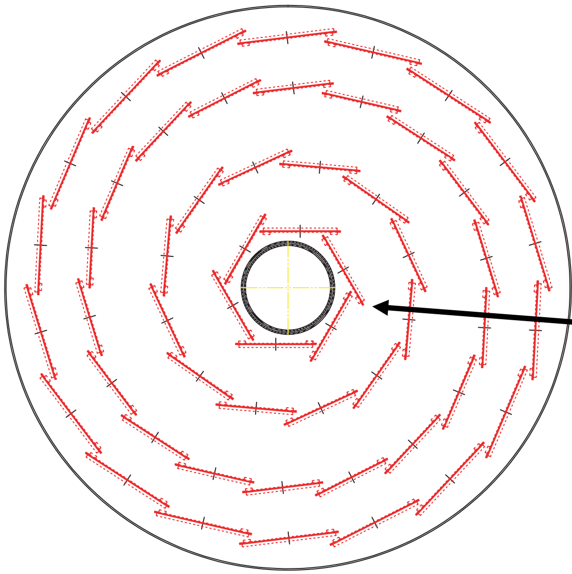
~82K channels → ~110K channels

23° - 139° → 17° - 150° coverage

R=30/45/60 → R=20/43/70/88 (mm)

$\sigma_{r\phi}$ 12μm/ σ_z 20μm

SVD with S-Belle perspective



Present : Belle SVD

~10% occupancy

200 Krad.yr^{-1} cumulated

Upgrade: Super-Belle **L~1.10^{34} → L~5.10^{35} cm^{-2}.s^{-1}**

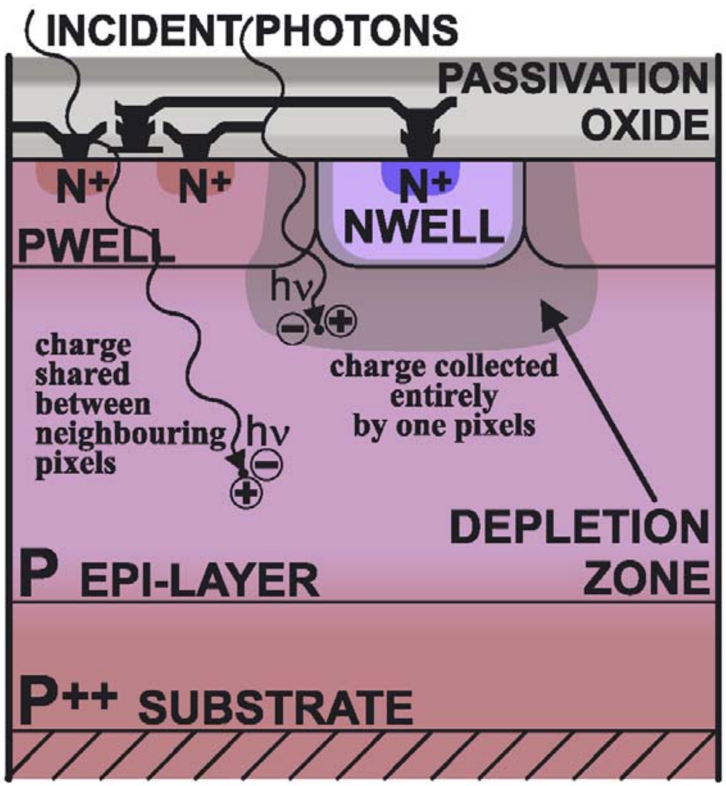
Background increase typ. x50 ! → Occupancy / dose:

Conventional solutions (Si strips) do not work.

Better impact parameter resolution?

MAPS Technology: Standard CMOS

"From digital camera to particle tracking device"



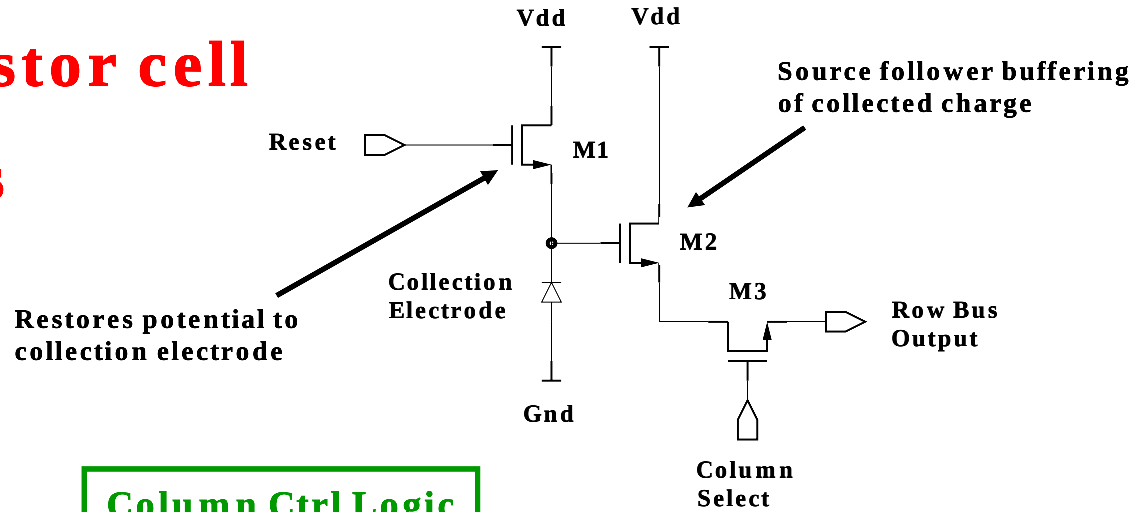
Key Features:

- q collection via thermal diffusion (no HV)
- "System on Chip" possible
- NO bump bonding (not a hybrid pixel detector)
- Could be thinned.
- Standard CMOS: good process control, low cost...

Cont. Acq. Pixels (CAP) 1 Prototype

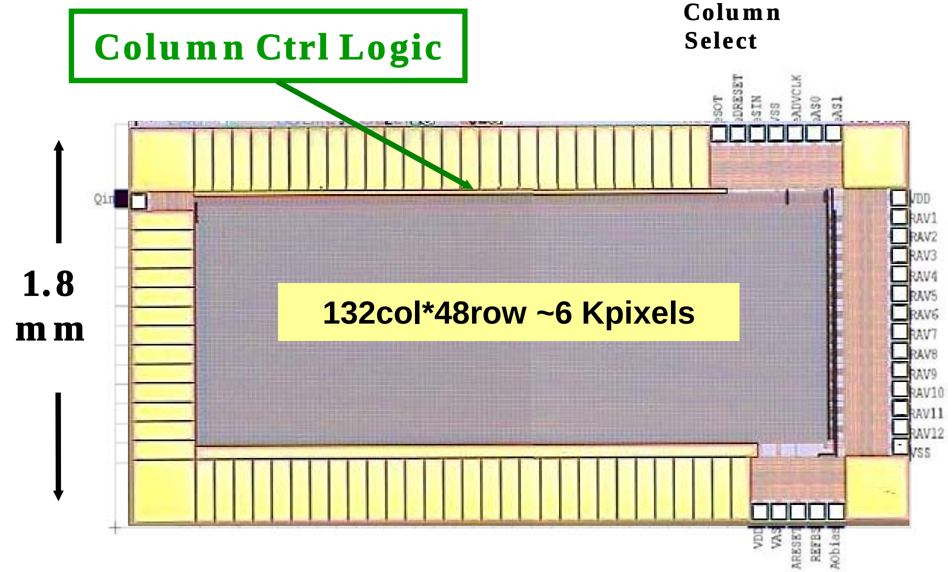
CAP1: simple 3-transistor cell

TSMC 0.35μm Process



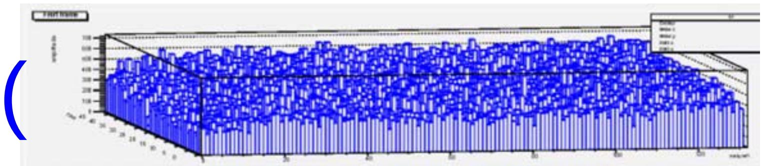
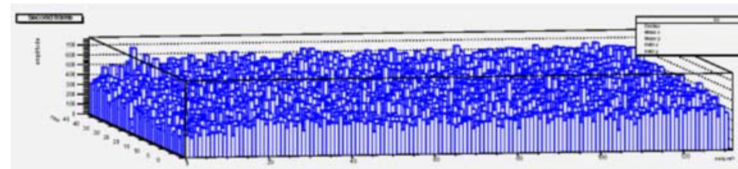
Pixel size:

22.5 μm x 22.5 μm



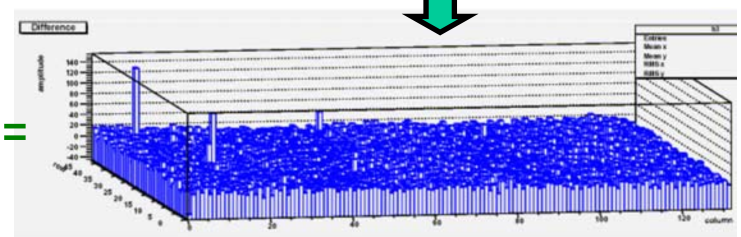
CAPs sample tested: all detectors (>15) function.

Correlated Double Sampling (CDS)

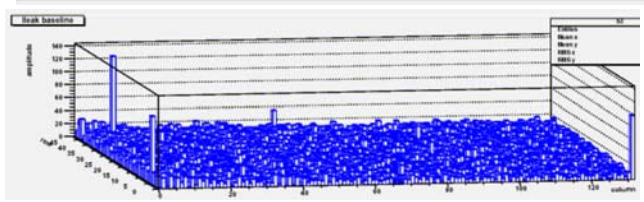
( - )

8ms integration

Frame 1 - Frame 2 =

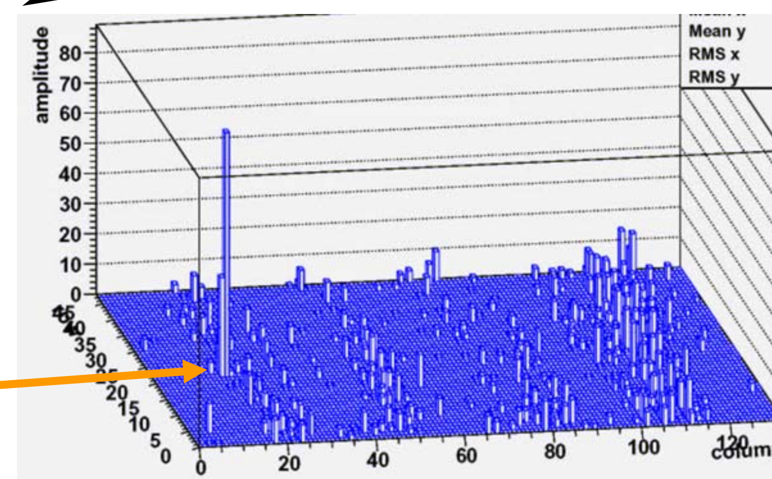


- Leakage current Correction



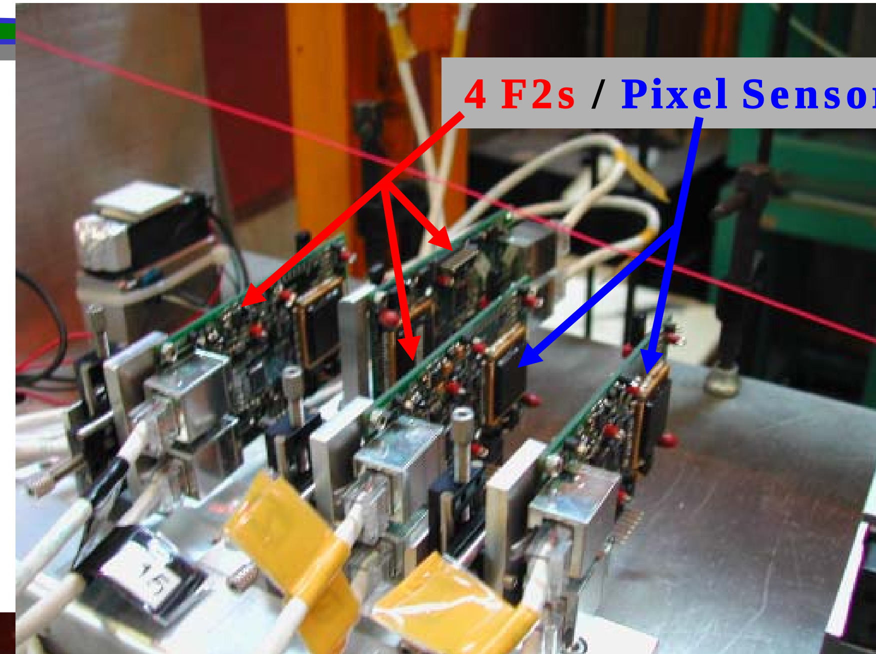
Can readout/process
@ 20Hz ~ 16% live time (CAP1!)
Self-Triggering mode

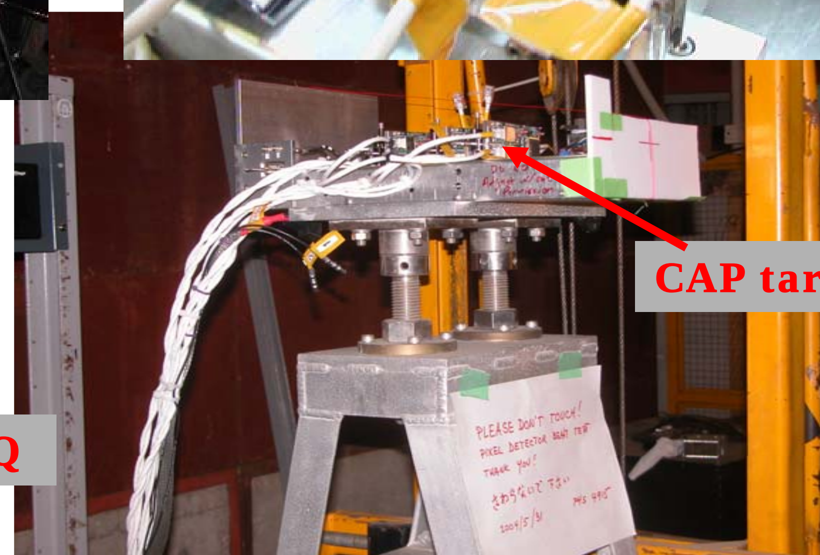
~fA leakage current (typ)
~18fA for hottest pixel shown



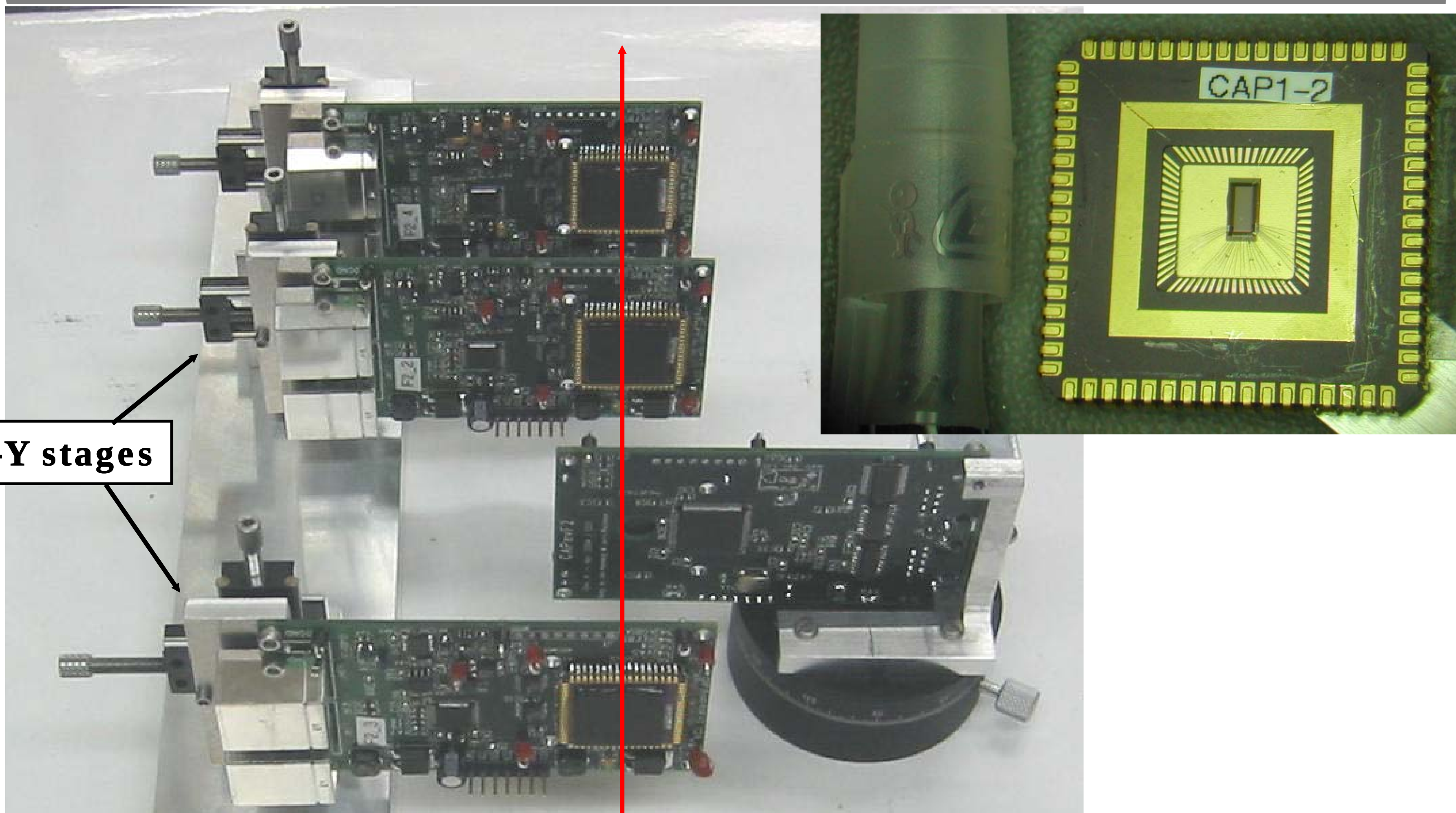
Hit candidate!

Jun.04 KEK Test Beam with pions



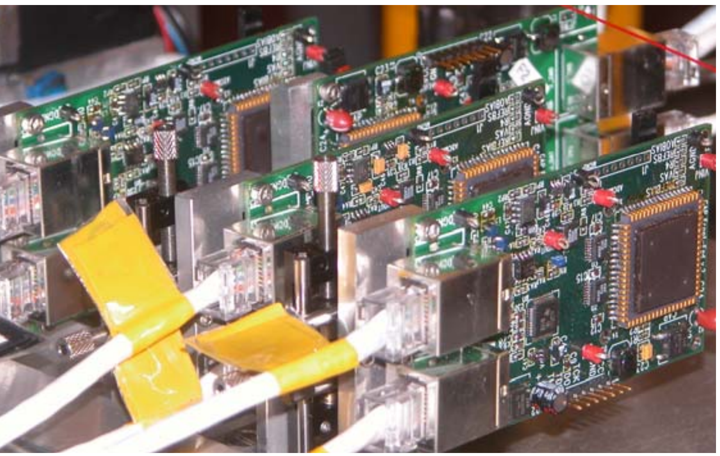


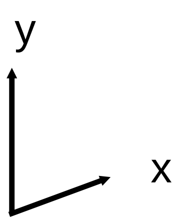
Beam test bench



Initial “by eye”

~1mm x 3mm “rice grain”

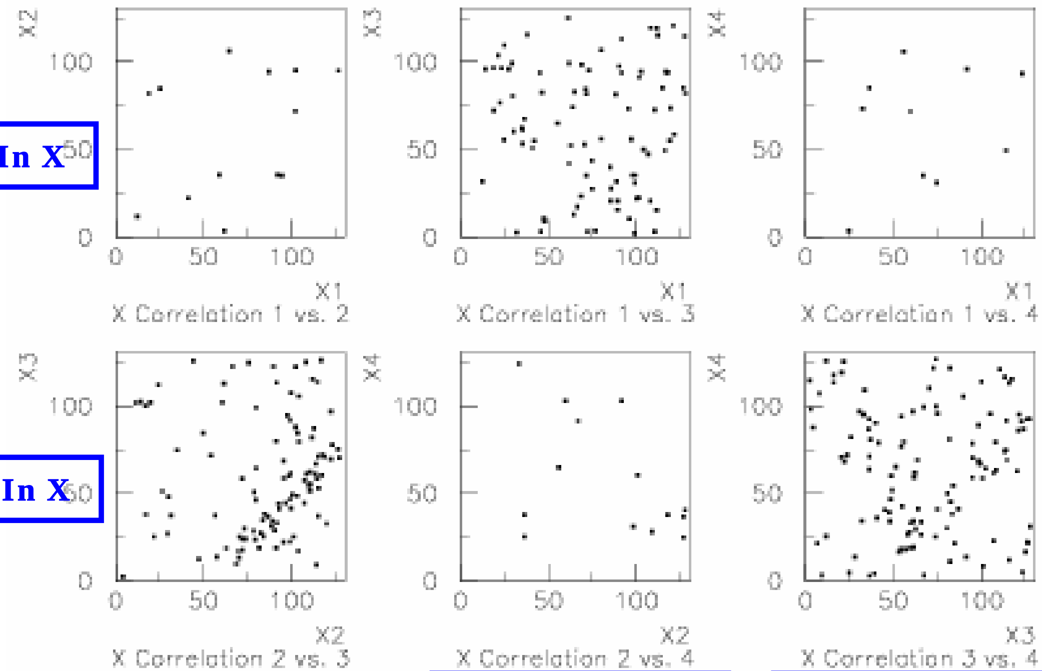




Layer-by-layer correlations

Det.3 vs. Det.1 | **Det.3 vs. Det.2** | **Det.3 vs. Det.4**

In X

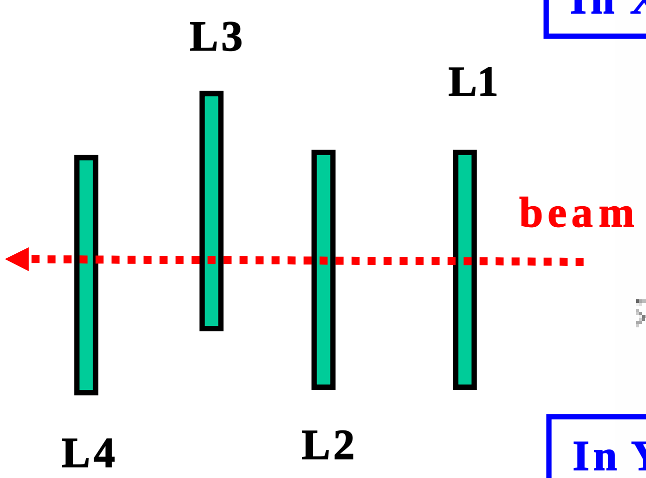


In X

Det.3 vs. Det.2 | **Det.4 vs. Det.2** | **Det.4 vs. Det.3**

And after 4 iterations…

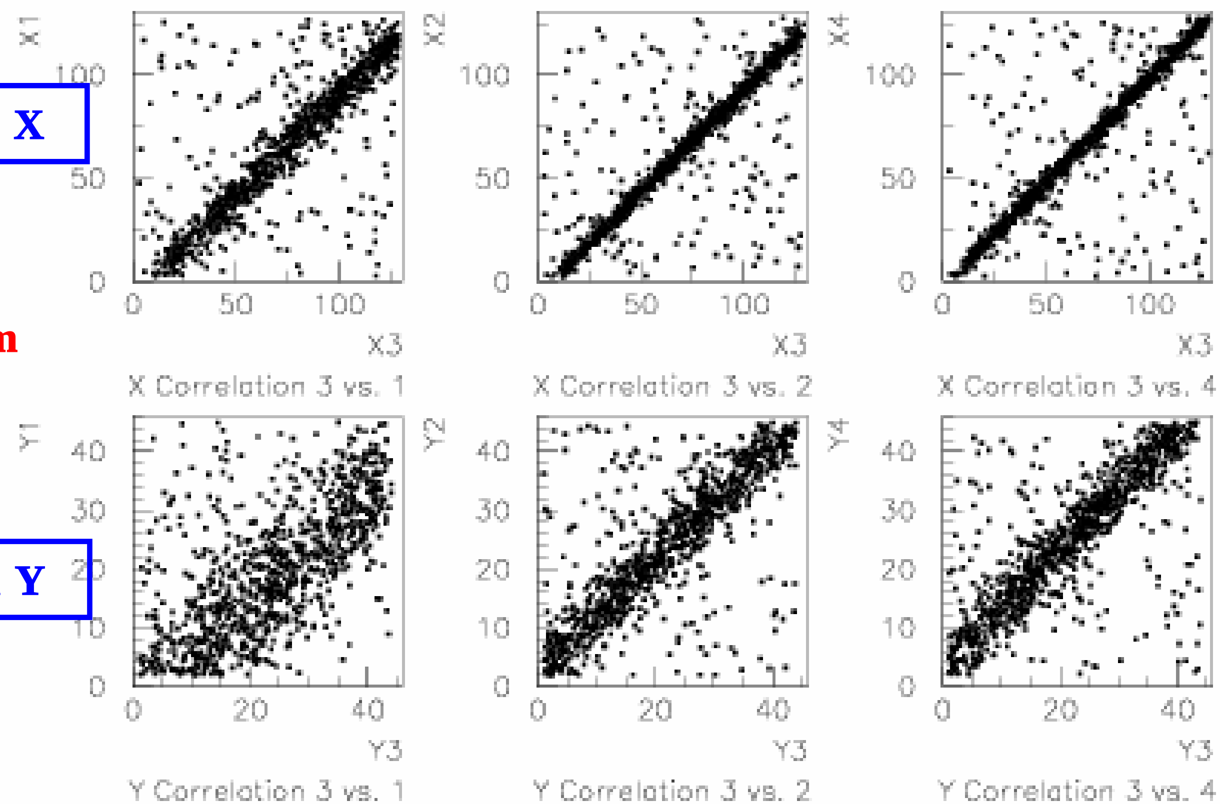
Improved Alignment



Det.3 vs. Det.1 | Det.3 vs. Det.2 | Det.3 vs. Det.4

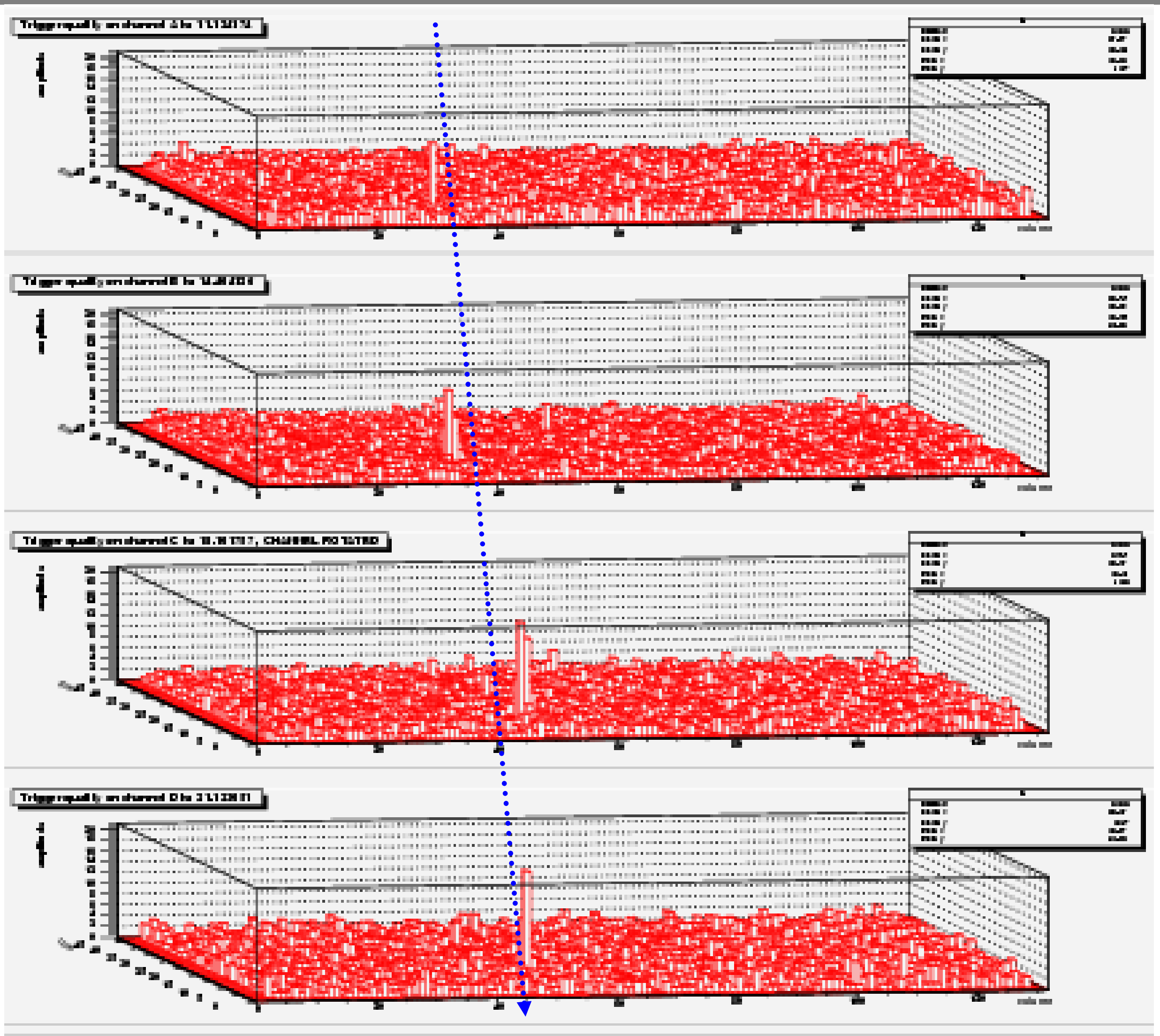
In X

In Y

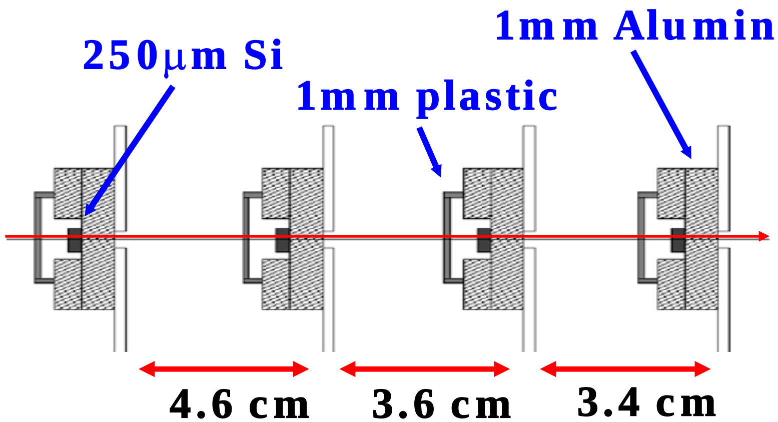


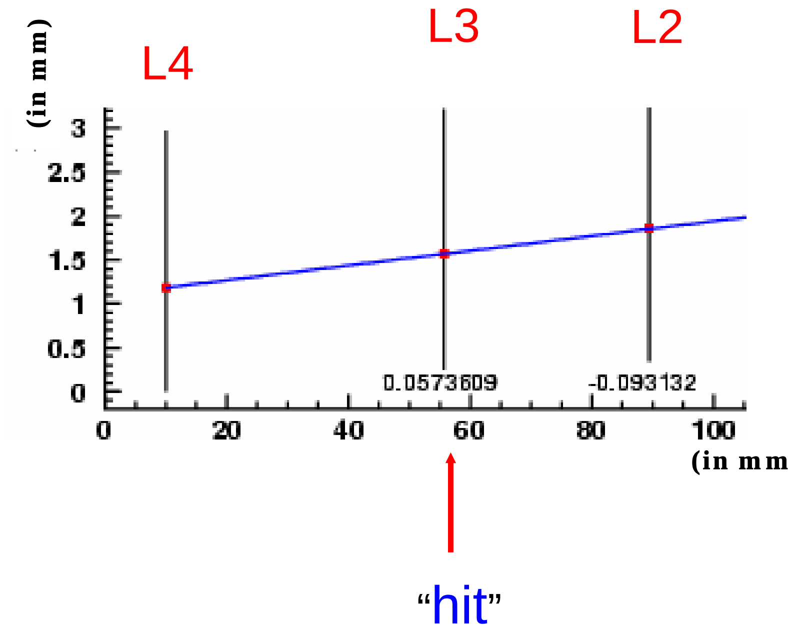
"online" plot

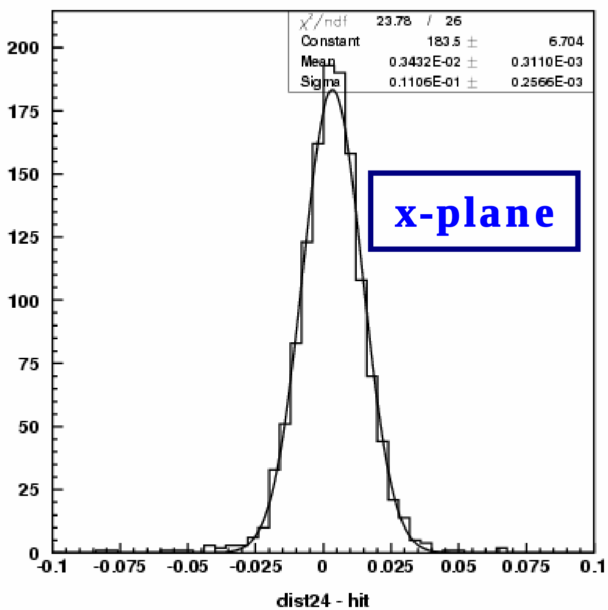
Hits! alignment proof



Hit resolution measurement







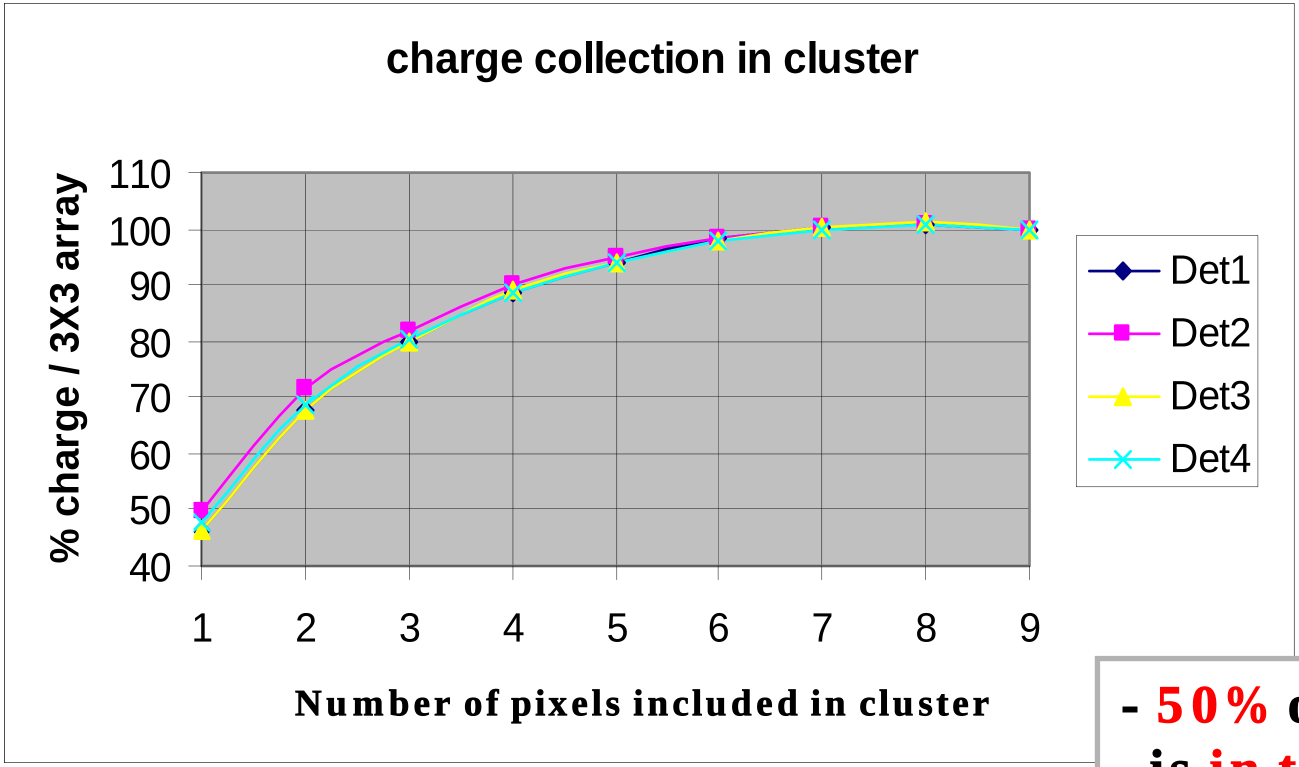
Current Residuals, @ 4GeV:

- **11μm in x plane**
- **14μm in y plane**

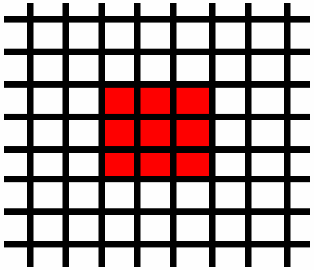
Charge Spread in CAPS

... still June 2004 beam test data...

(MPV of landau fit)



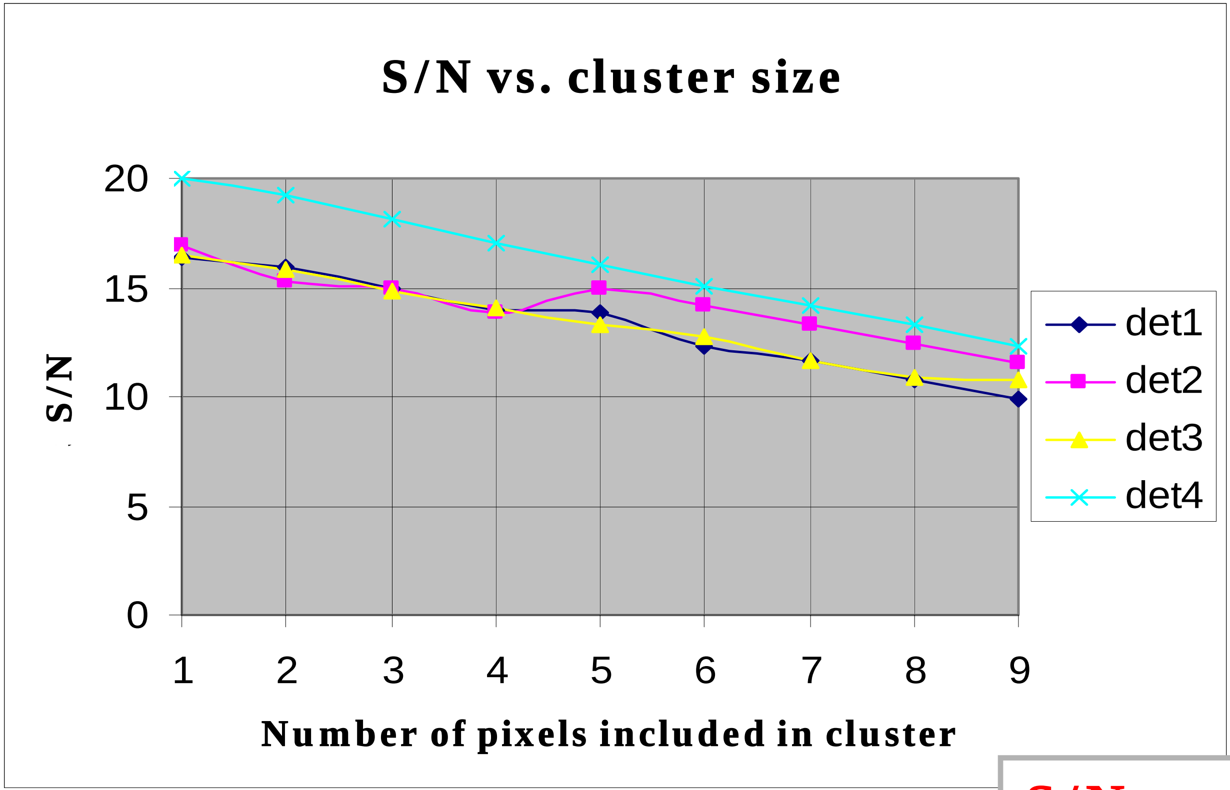
Hyp: charge entirely collected in 3X3 pixel array.

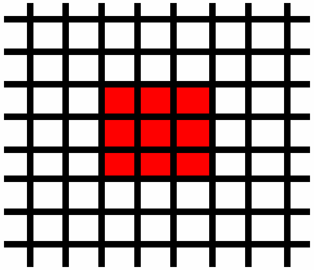


- 50% of the charge is in the peak pixel.
- 90% in the 4 largest.

S/N vs. Cluster Size

... still June 2004 beam test data...





S/N peak signal between 16 and 20.

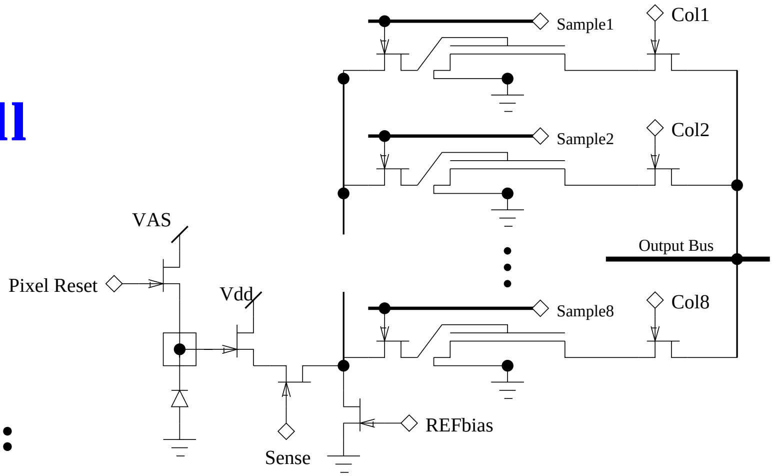
CAP1 / 8ms integration time

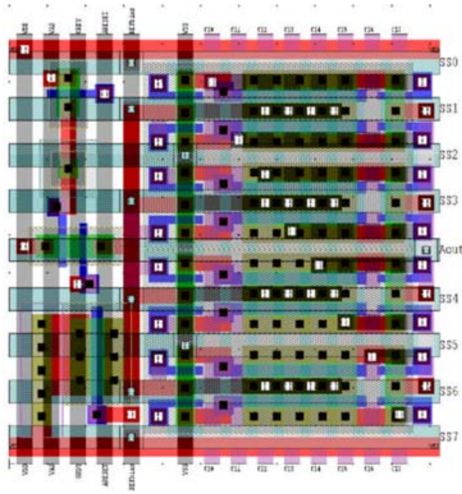
Four Critical R&D Items

1. **Readout Speed**
   1. **Super-B: CAP2, syst. archi., next main R&D topic**
   2. **Elsewhere: STAR phase 1, LC, RAL efforts**
2. **Radiation Hardness**
   1. **Super-B: low E e^-/γ CAP -- results shown next**
   2. **Elsewhere: TESLA, STAR 10^{12} n_{eq}, >100kRad ionizing**
3. **Thin Detector – LBNL**
4. **Full-sized detector – LEPSI**

1. Increased readout speed: CAP2

CAP2: 8x mini-pipeline in each cell



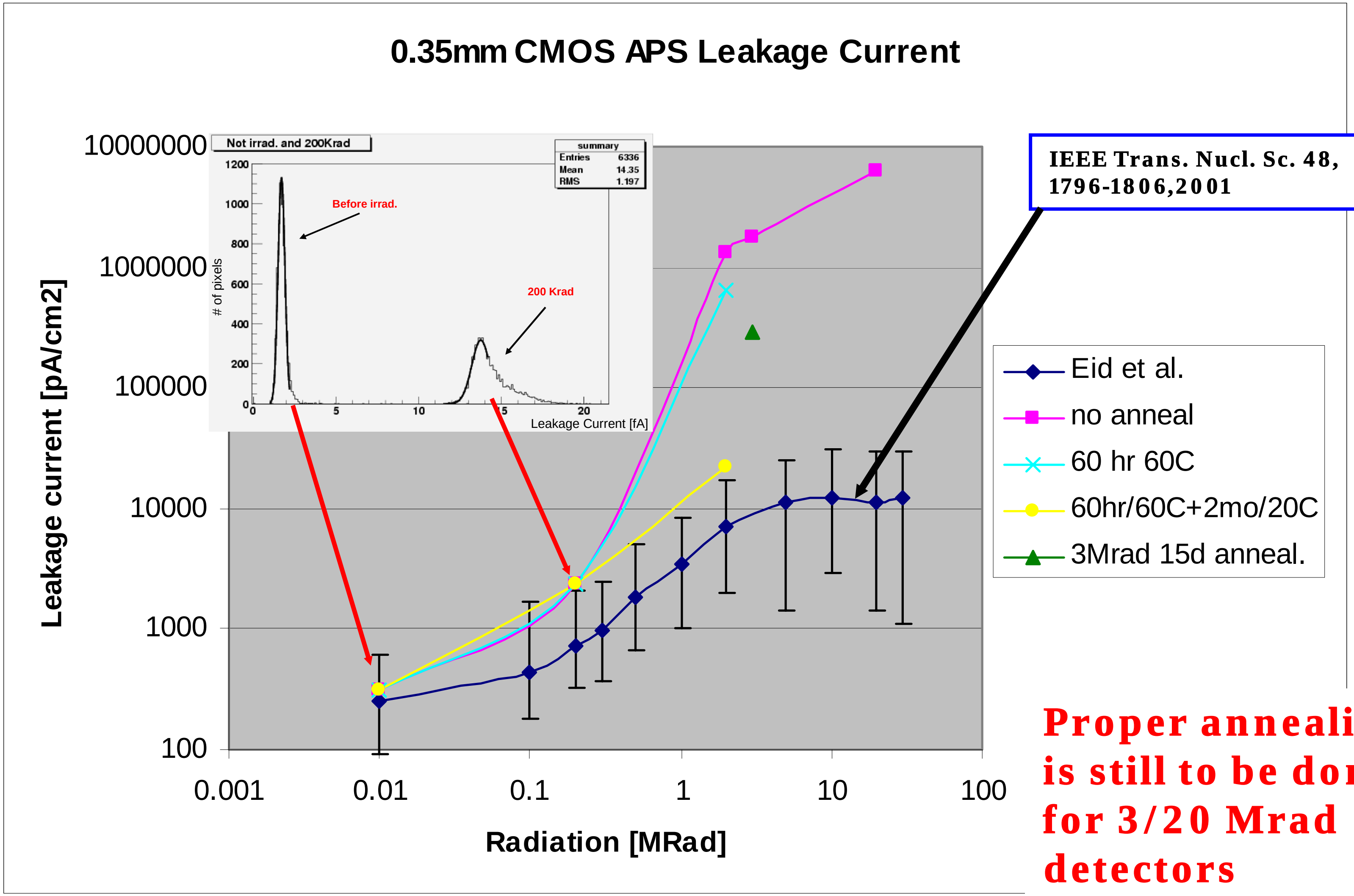


15μs operation of CAP2:

Current status:

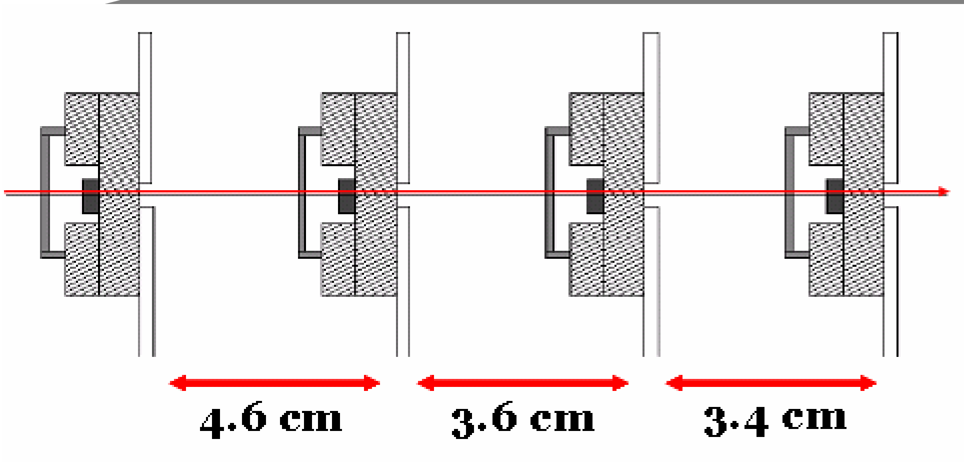
- **Noise higher than what is observed with CAP1/F2/B2 (~30/~35e- vs. 16e-). Related to digital activity? → Shield?**
- **Leakage current under control.**
- **Mini-pipeline output level dispersion rather large. Not a dramatic problem, but can improved (by design). → Modification in pipeline design?**
- **Still more work to be done on CAP2 testing.**

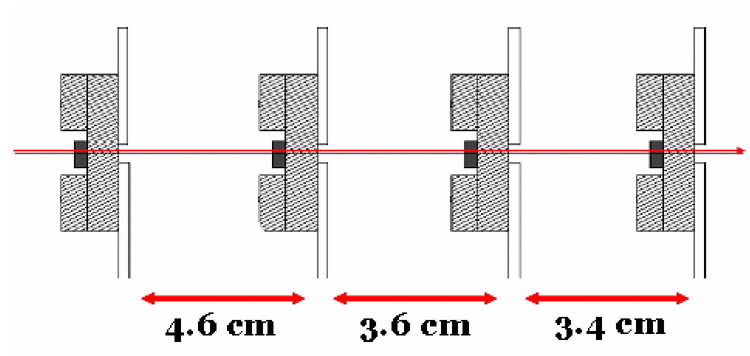
2. Irrad: leakage currents

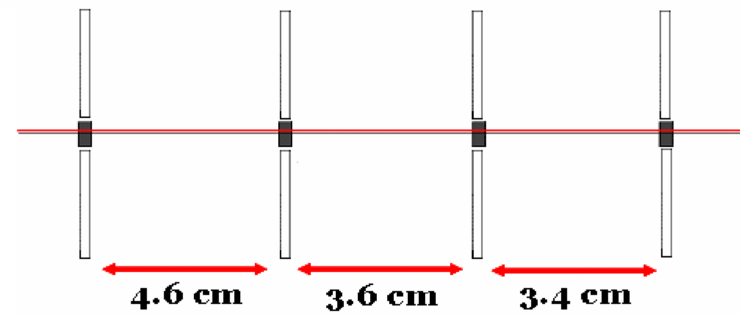


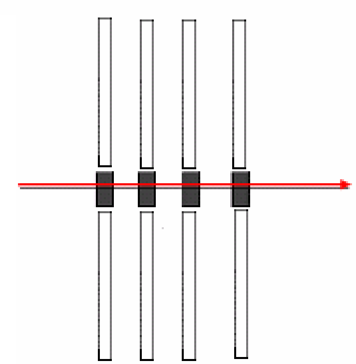
Proper annealing is still to be done for 3/20 Mrad detectors

Improving the UL on resolution?









1- no cover

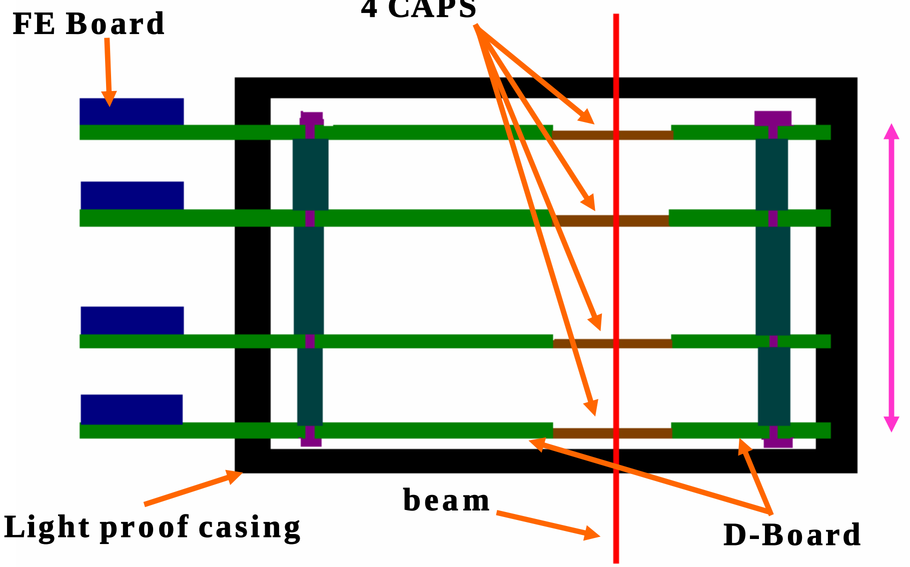
2- no die package behind sensor

3- attach die to board

4- move the boards closer

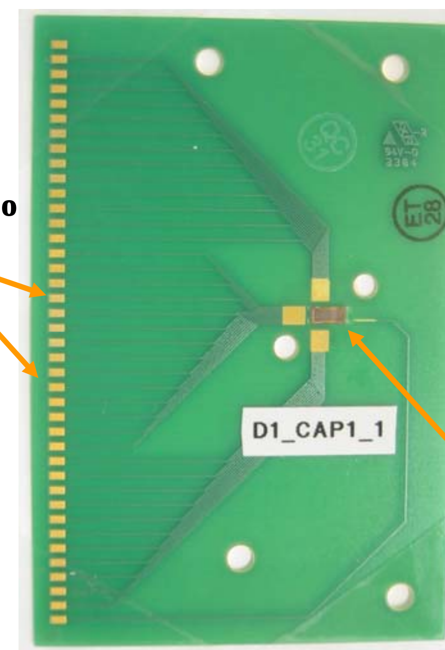
Improving the UL on hit resolution

- **Compact packaging for next beam test:**
  - **Expect a better upper limit on intrinsic resolution**



D-Board view from above

Connections to
F-E Board

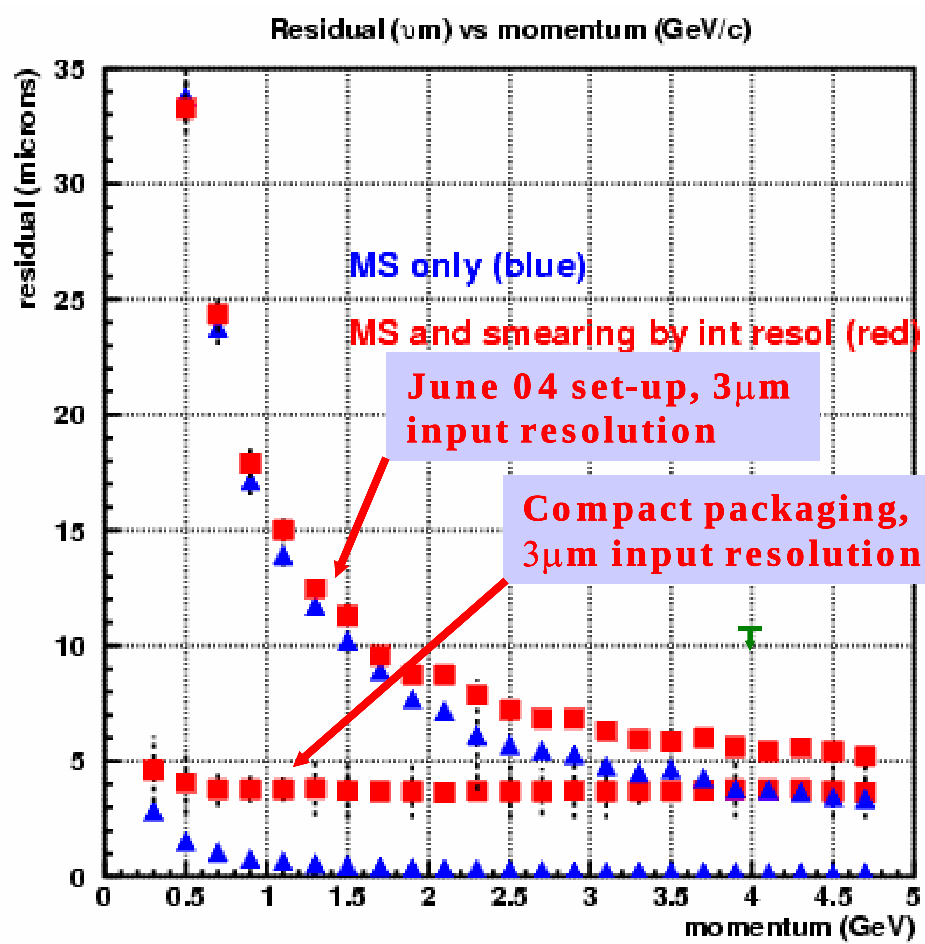


CAPS

Highlights: - **<0.3cm between CAPS.**

- **reduced material**
- **eases alignment.**

Hit resolution (GEANT simulations)



June 04 set-up, 3μm input resolution

Compact packaging, 3μm input resolution

12μm/20μm IR for strips

@ 4GeV, 5-7μm (as in June beam test configuration) → 4μm

Effects of multiple scattering and of distances become negligible!

Looking forward to next beam test

Highlights & Conclusion

MAPS is a promising technology for a Super-B Factory.

- **Successful beam test in June:**
  - **Experience gained / Demonstrate beam test operation.**
  - **UL on IR: 11μm / Charge spread: 90% in 4 pixels.**

- **CAP2 and next iterations:**
  - **Works alright, more work to be done → improvements.**

- **Further Radiation Damage Studies:**
  - **Still a hot topic but positive preliminary studies, we wait for new data points.**
  - **Demonstrate operation with highly irradiated detectors.**

Have started to write down the basis for a future Belle Pixel Vertex Detector 1.0 TDR.