# The CMS Pixel Detector

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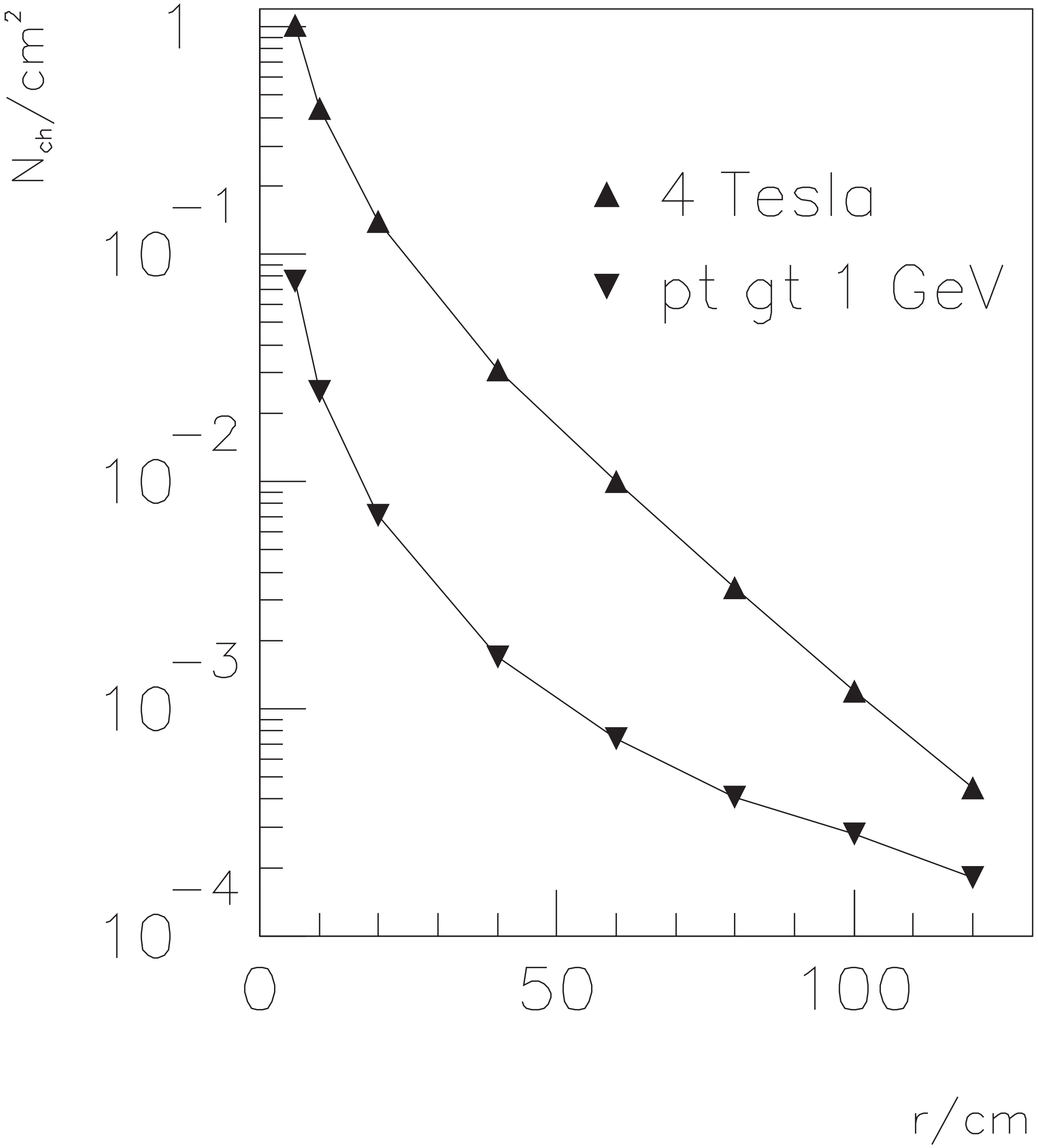
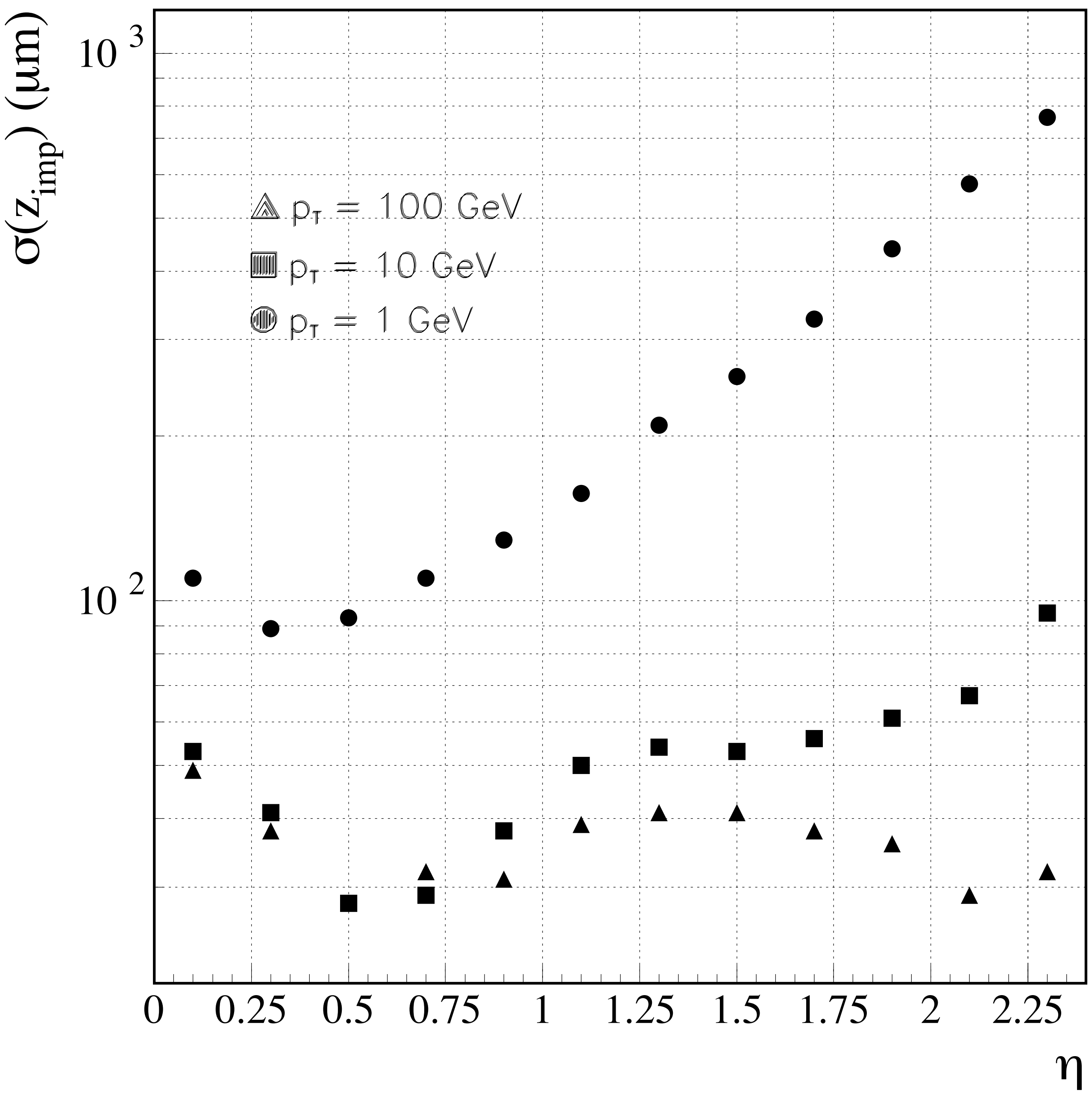
The 11th Vienna Conference on Instrumentation

21 February 2007

# Basic Physics Motivation

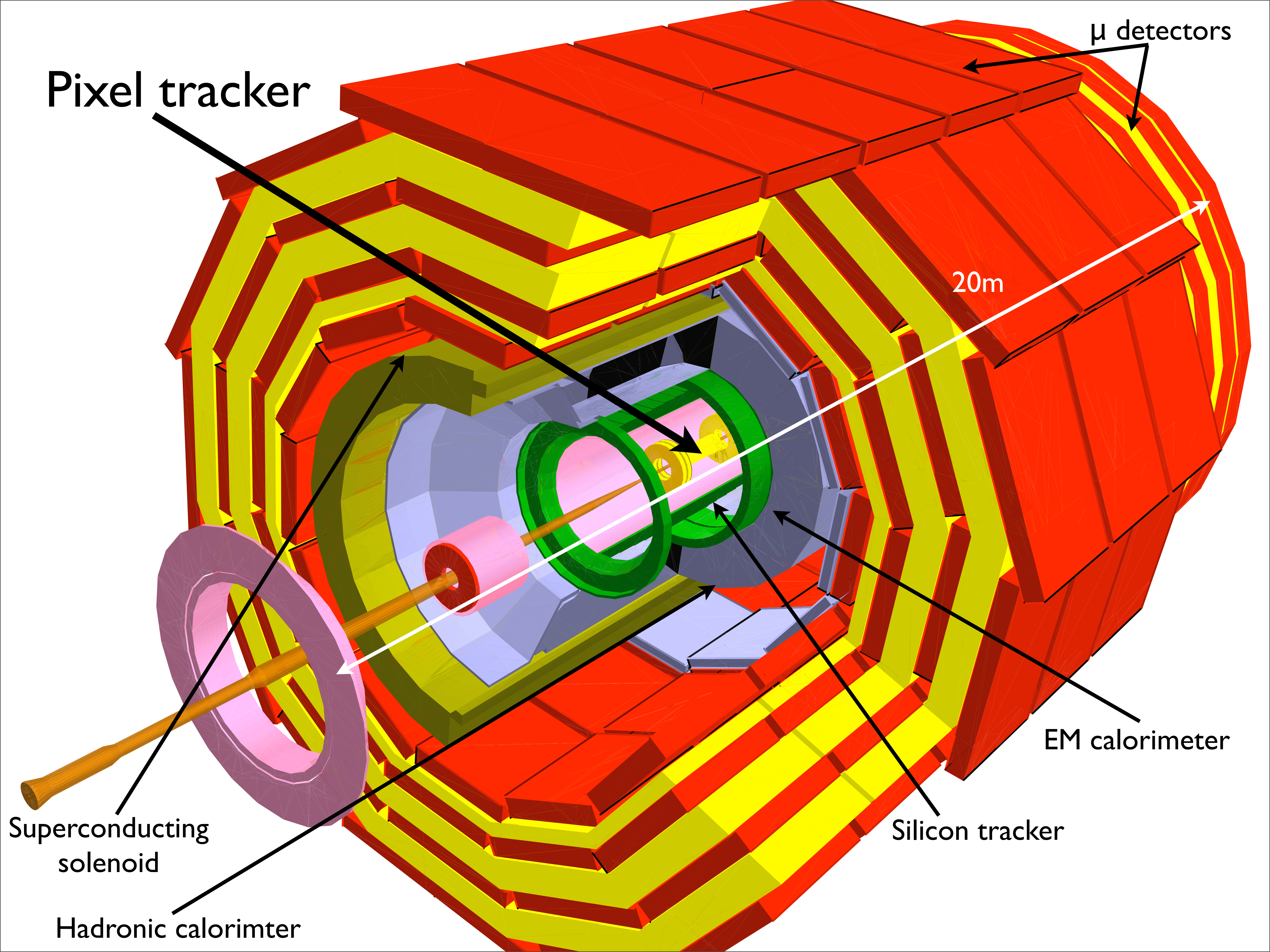



~1% occupancy maximum in all layers

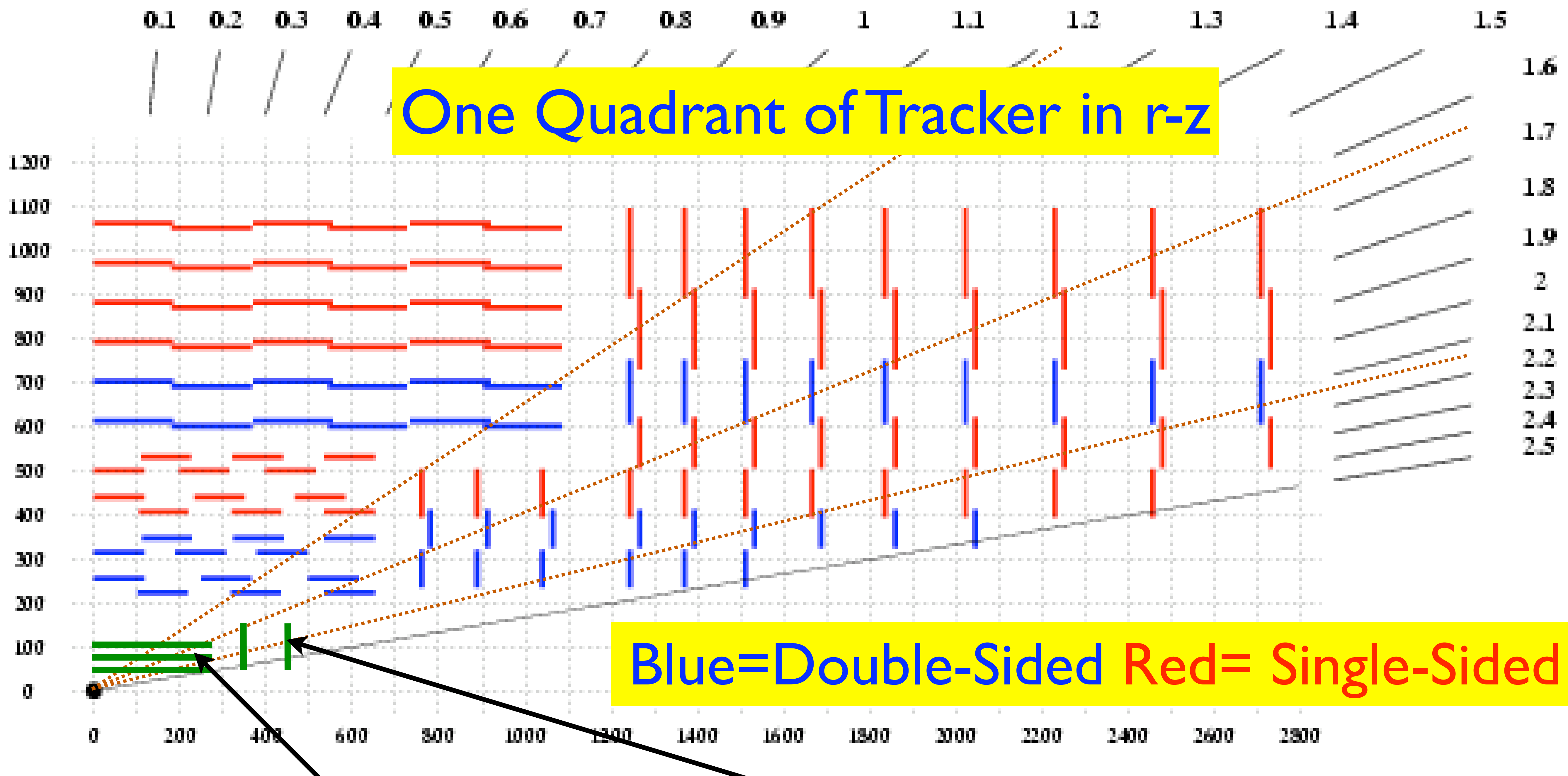
Good impact parameter resolution in rφ & rz

Solution: use small silicon pixels at r=4,7,11cm



Pixel tracker
μ detectors
20m
EM calorimeter
Silicon tracker
Superconducting solenoid
Hadronic calorimter

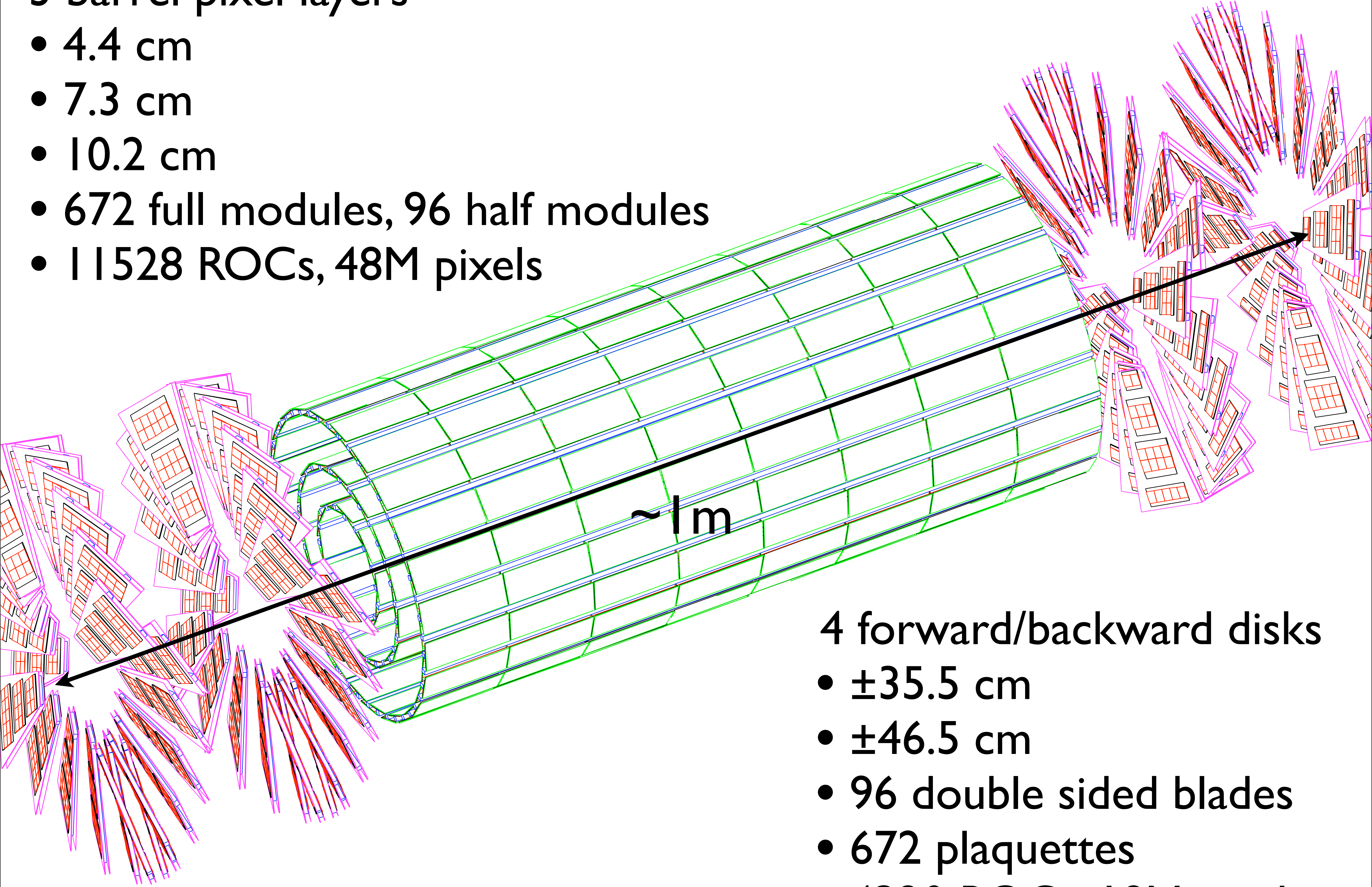
# Pixels part of all Si tracker




- 3 Barrel Pixel Layers, 2 Forward Pixel Disks
- 4 Inner Barrel Layers (TIB), 6 Outer Layers (TOB)
- 3 Forward Inner Disks (TID), 9 Outer Disks (TEC)

3 barrel pixel layers

- 4.4 cm
- 7.3 cm
- 10.2 cm
- 672 full modules, 96 half modules
- 11528 ROCs, 48M pixels

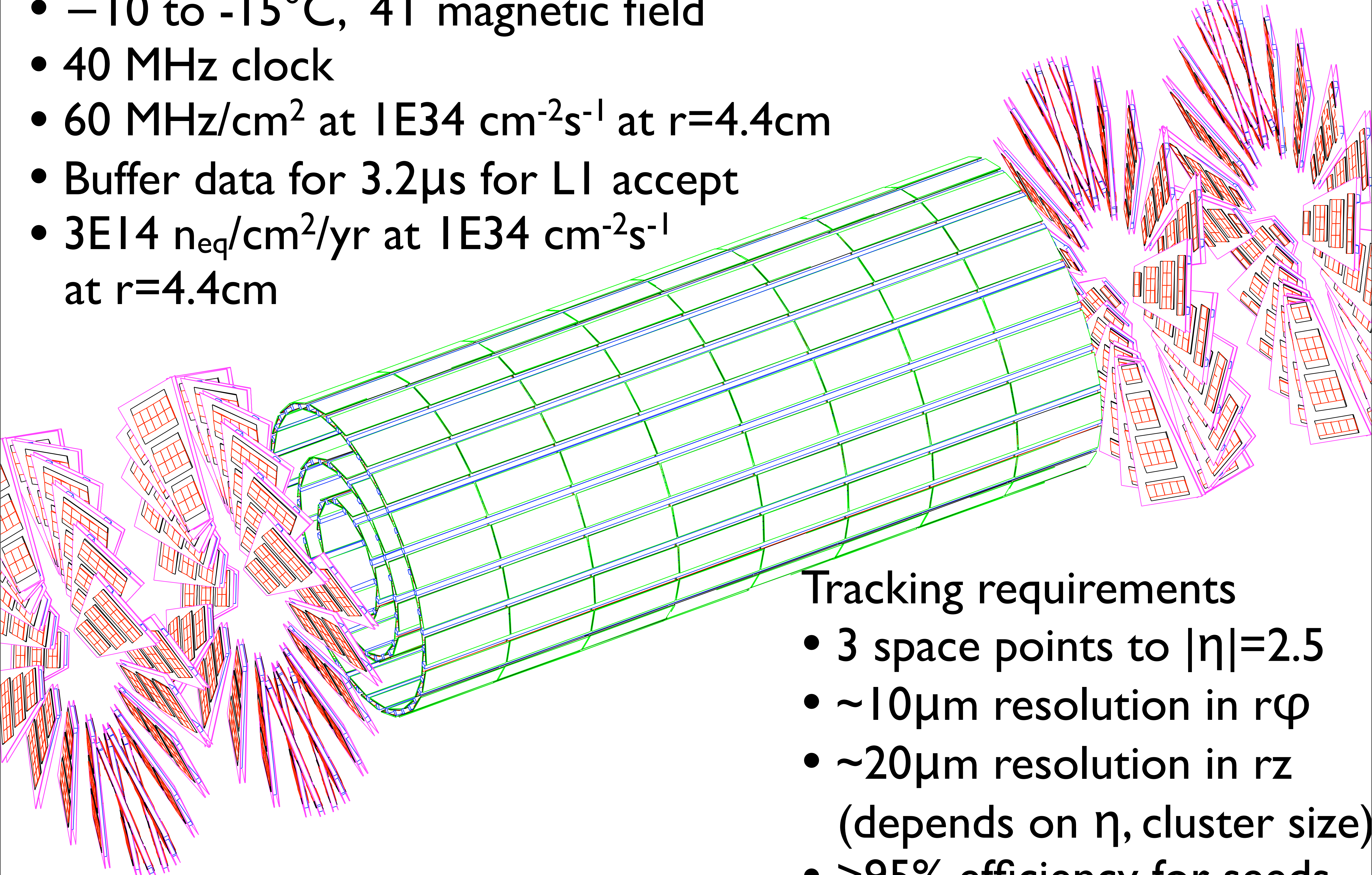



4 forward/backward disks

- ±35.5 cm
- ±46.5 cm
- 96 double sided blades
- 672 plaquettes
- 4320 ROCs, 18M pixels

Operation

- $-10$ to -15°C, 4T magnetic field
- 40 MHz clock
- 60 MHz/cm$^2$ at 1E34 cm$^{-2}$s$^{-1}$ at r=4.4cm
- Buffer data for 3.2μs for L1 accept
- 3E14 $n_{eq}$/cm$^2$/yr at 1E34 cm$^{-2}$s$^{-1}$ at r=4.4cm



Tracking requirements

- 3 space points to |η|=2.5
- ~10μm resolution in rφ
- ~20μm resolution in rz (depends on η, cluster size)
- >95% efficiency for seeds
- Use in HLT standalone

# Tracking Continued...

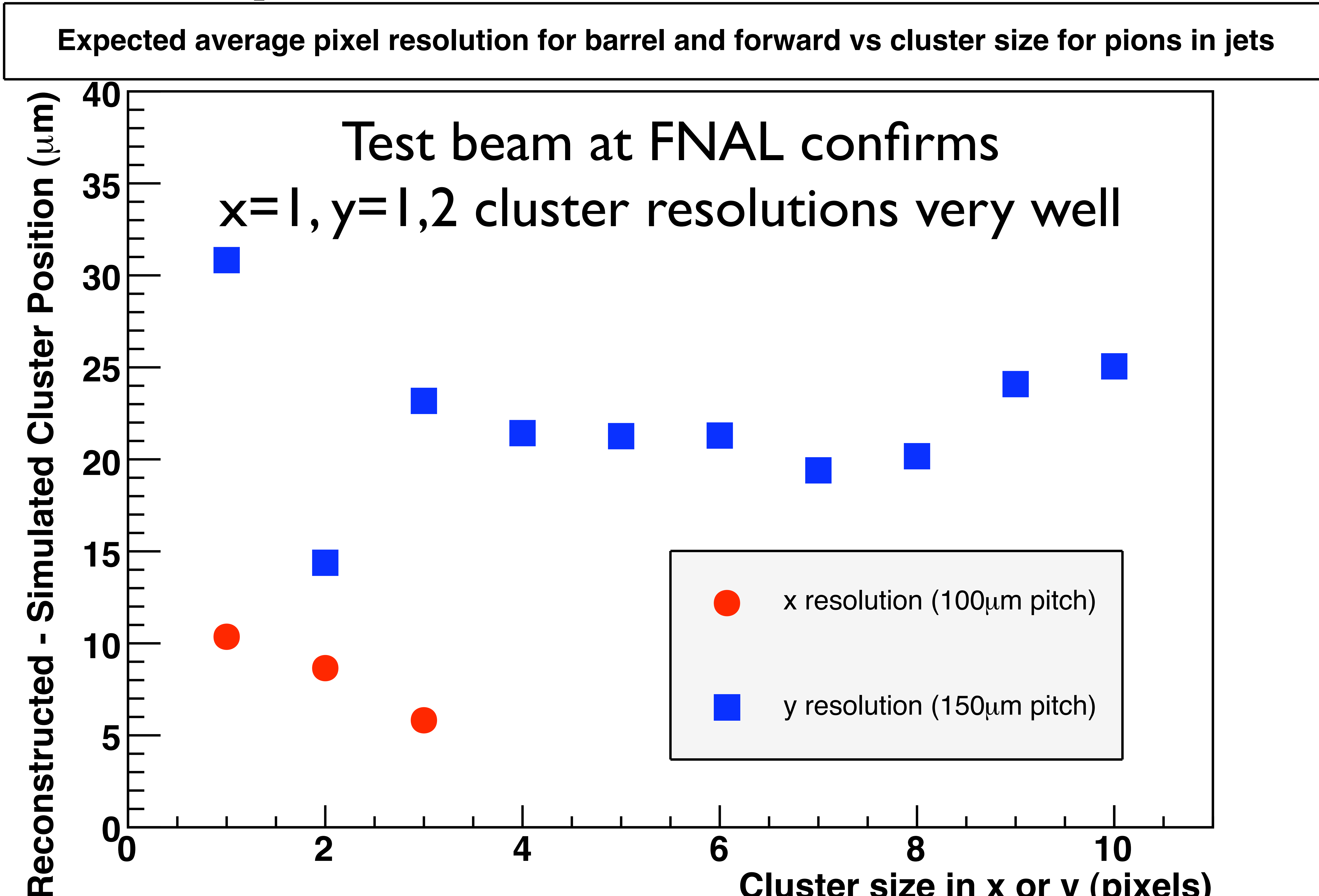
- Need very high segmentation at low radius for low physics occupancy (<1%) → 100, 150 μm pixel size for both barrel & forward
- 4T magnetic field leads to Lorentz drift in rφ improving resolution due to charge sharing
- Forward pixels tilted 20° to improve charge sharing since there is little Lorentz drift
- High signal-to-noise (>30:1) for low fake rate

# Tracking Continued...

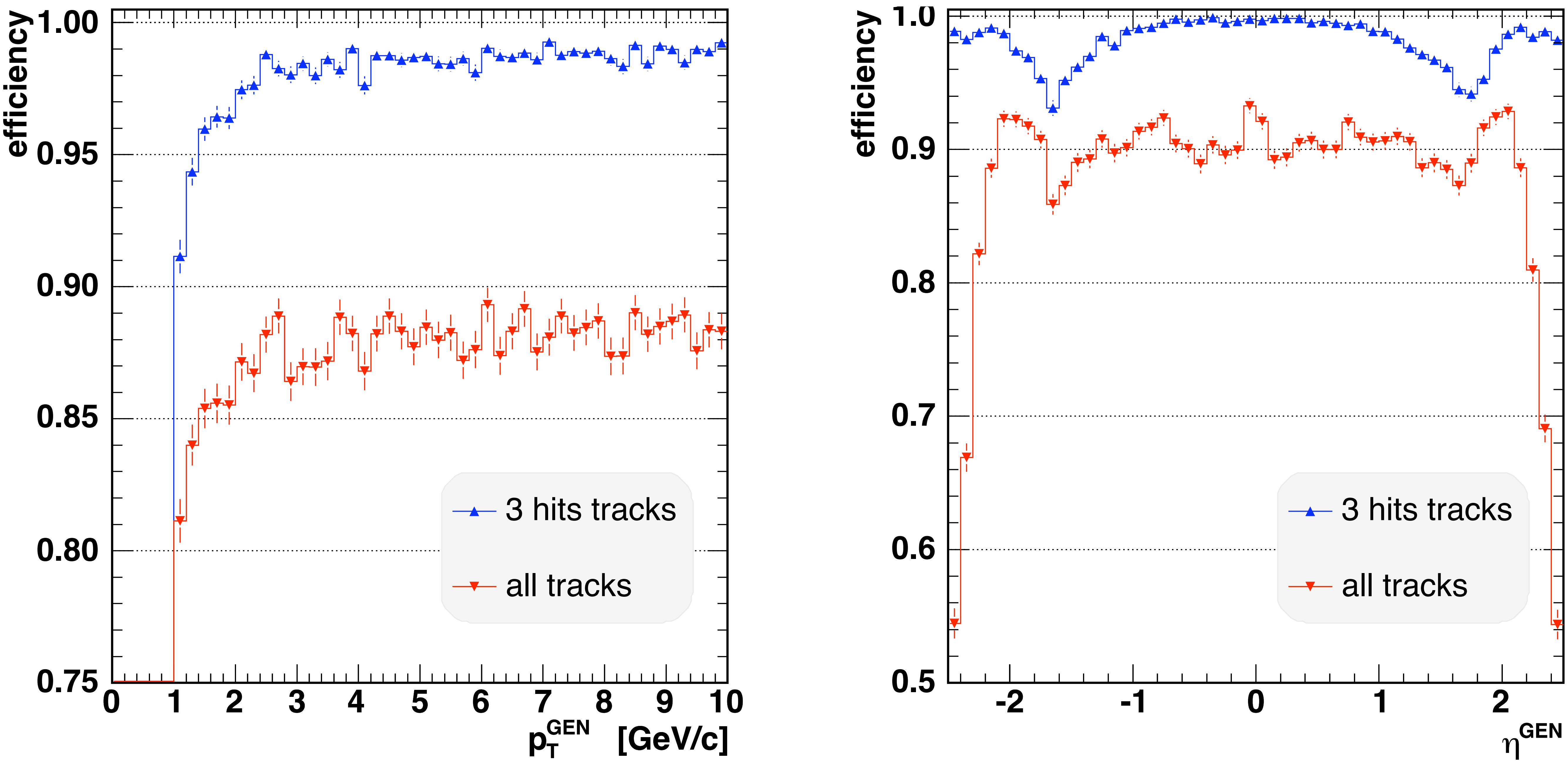
- The 3 pixel hits up to $|\eta|=2.5$ are used for three main purposes:

1. Seeds (in pairs or triplets) for pattern recognition in all silicon tracker
2. Improve vertex resolution near IP
3. Fast tracking/vertexing in (HLT) trigger using only pixel info. Use for b, $\tau$, e, primary vertex & multiple interactions

# Expected Performance

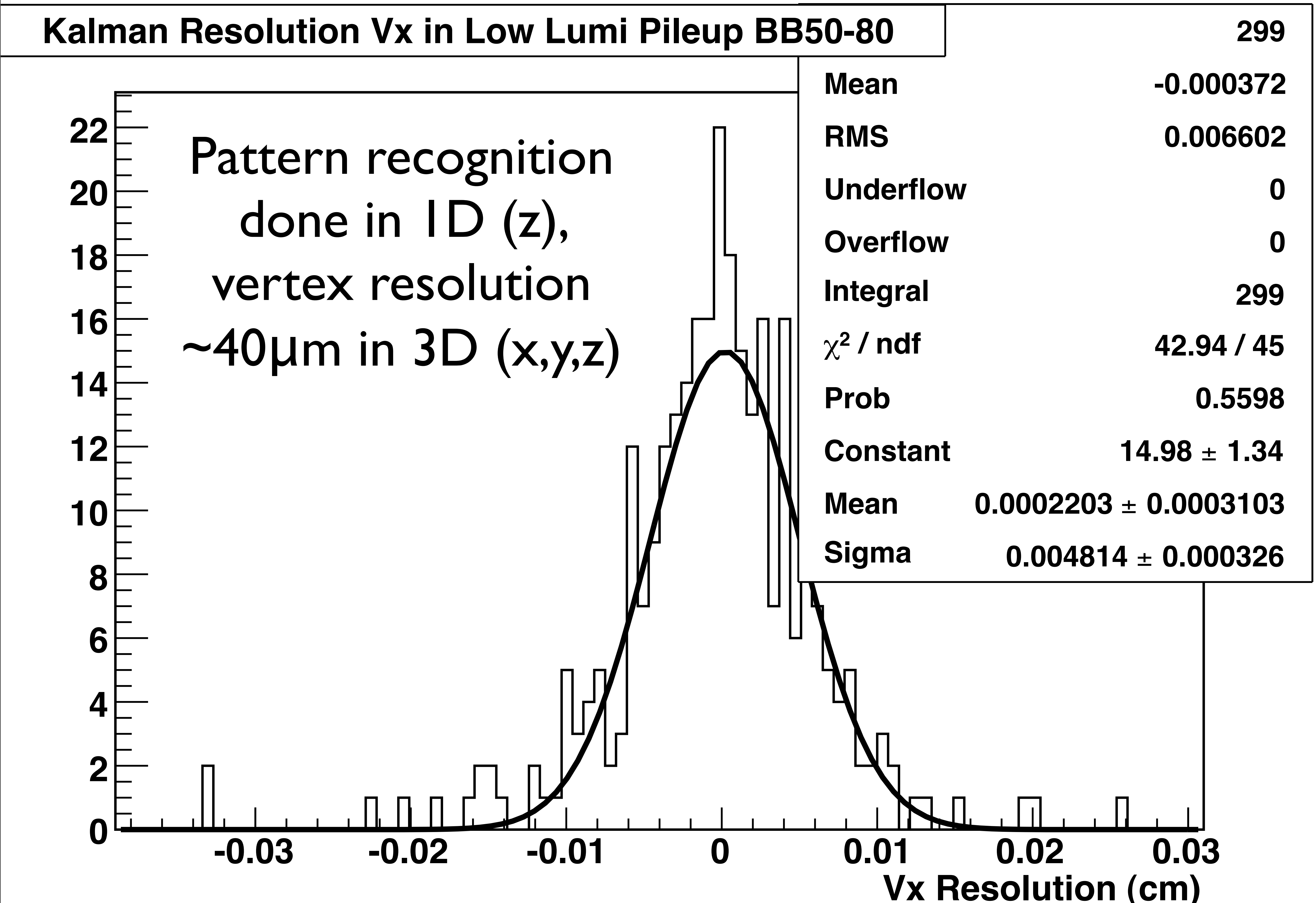


# Standalone Pixel Tracking (HLT & Offline)

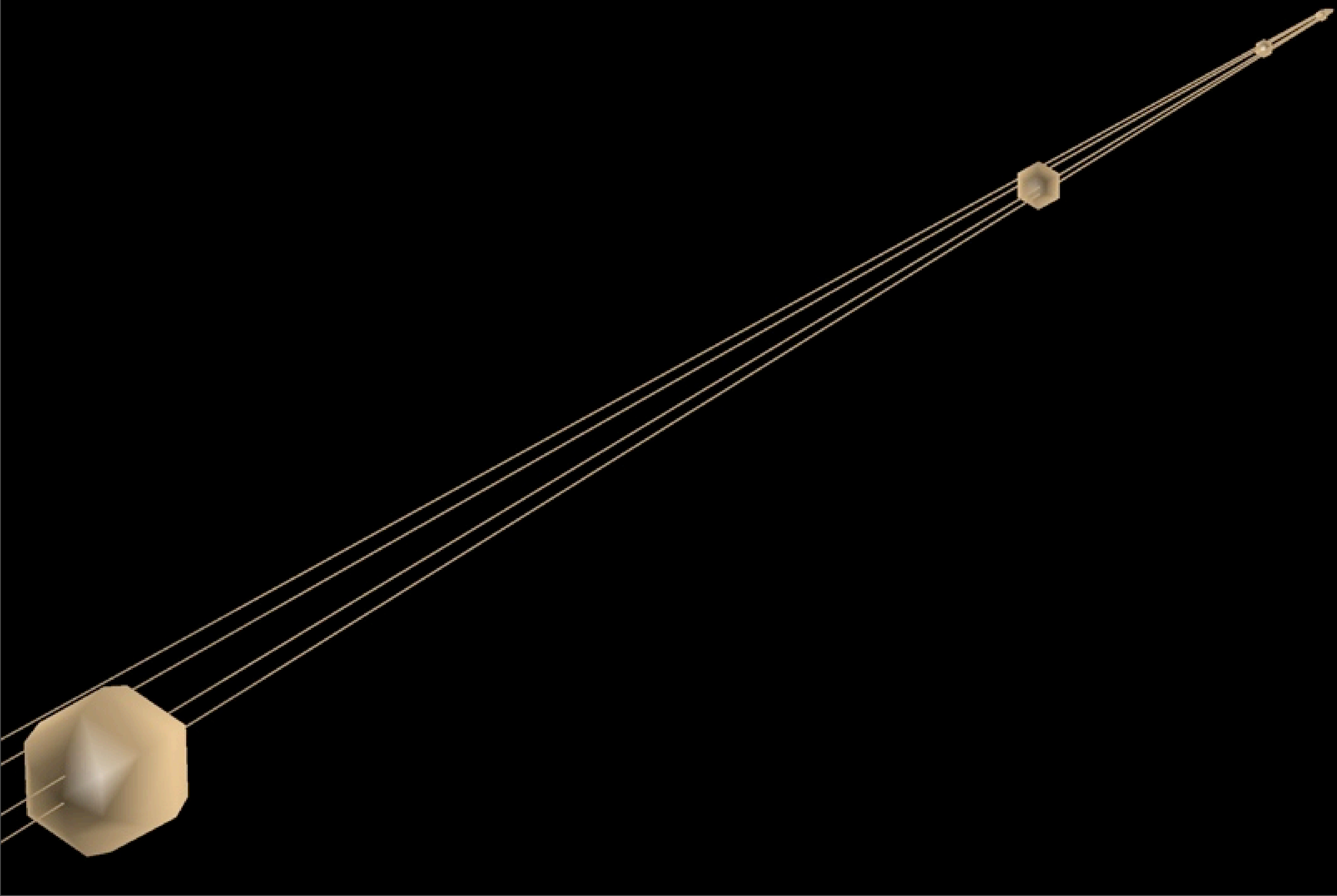


# Standalone Pixel Vertexing (HLT & Offline)

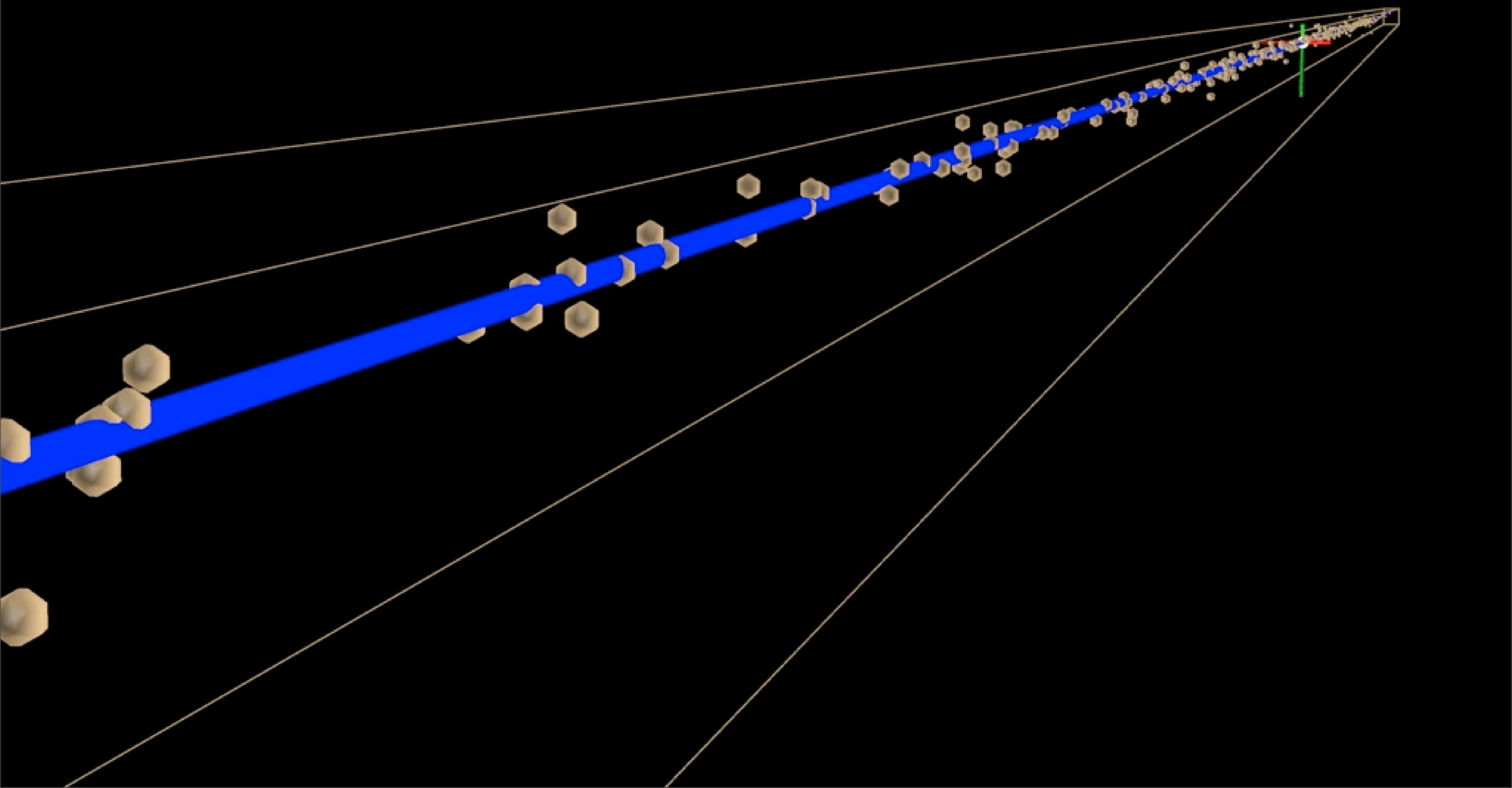
- Using the standalone pixel tracks, we can make a fast 1D pattern recognition for primary vertexes since they are usually well separated in Z (beam spot ~5 cm long)
- 1D pattern recognition is probably good enough for a full 3D (Kalman) fit
- This gives us 3D interaction points online in high level trigger


Kalman Resolution Vx in Low Lumi Pileup BB50-80
299
Mean -0.000372
RMS 0.006602
Underflow 0
Overflow 0
Integral 299
χ² / ndf 42.94 / 45
Prob 0.5598
Constant 14.98 ± 1.34
Mean 0.0002203 ± 0.0003103
Sigma 0.004814 ± 0.000326
Pattern recognition done in 1D (z), vertex resolution ~40μm in 3D (x,y,z)
0
2
4
6
8
10
12
14
16
18
20
22
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
Vx Resolution (cm)

One event with 4 interactions. These are the vertex locations from the Kalman 3D fit



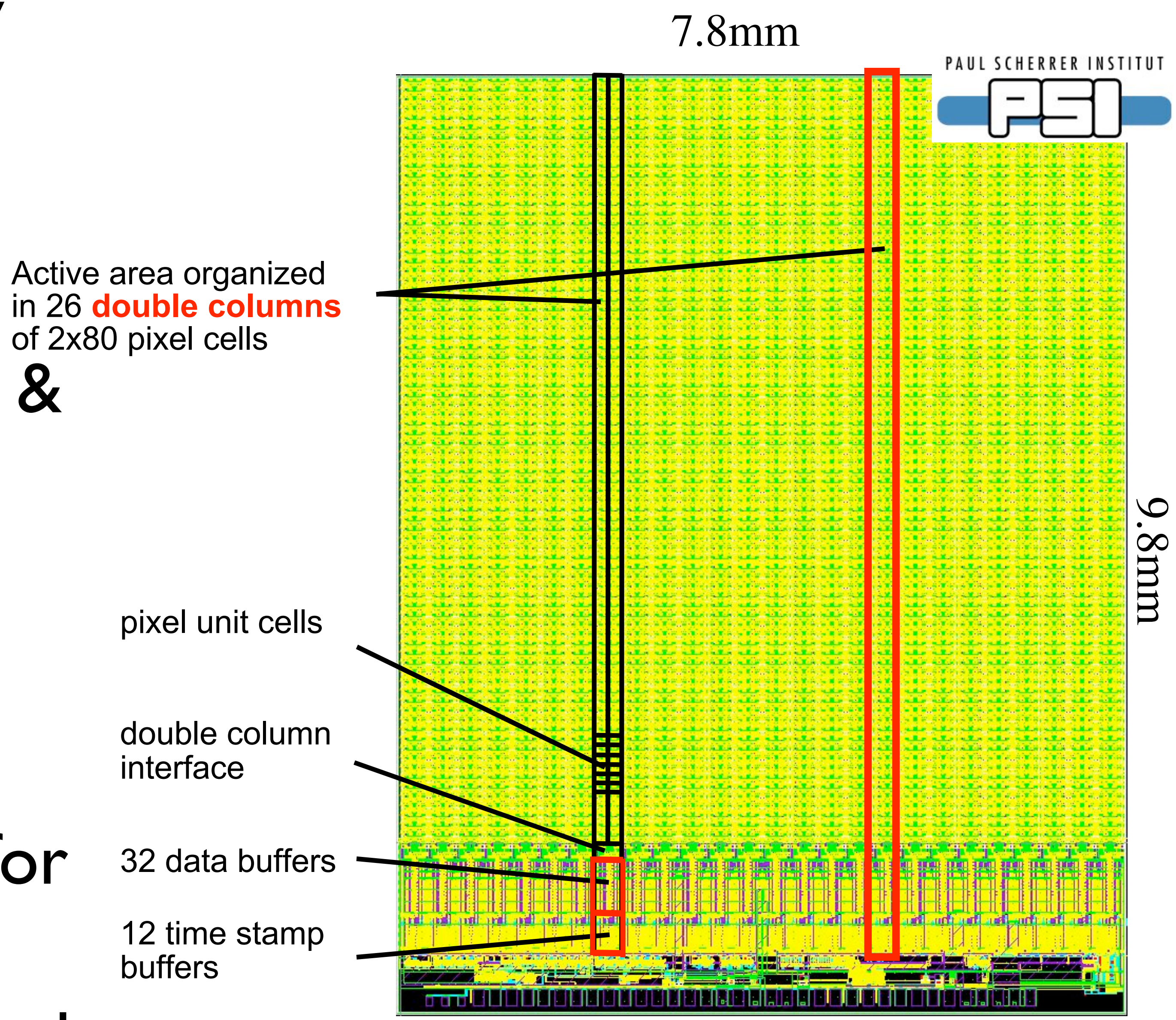
# 300 events of 50-80 GeV BB jets with low luminosity pileup



# Hardware and Current Status

# Readout Chip (ROC)

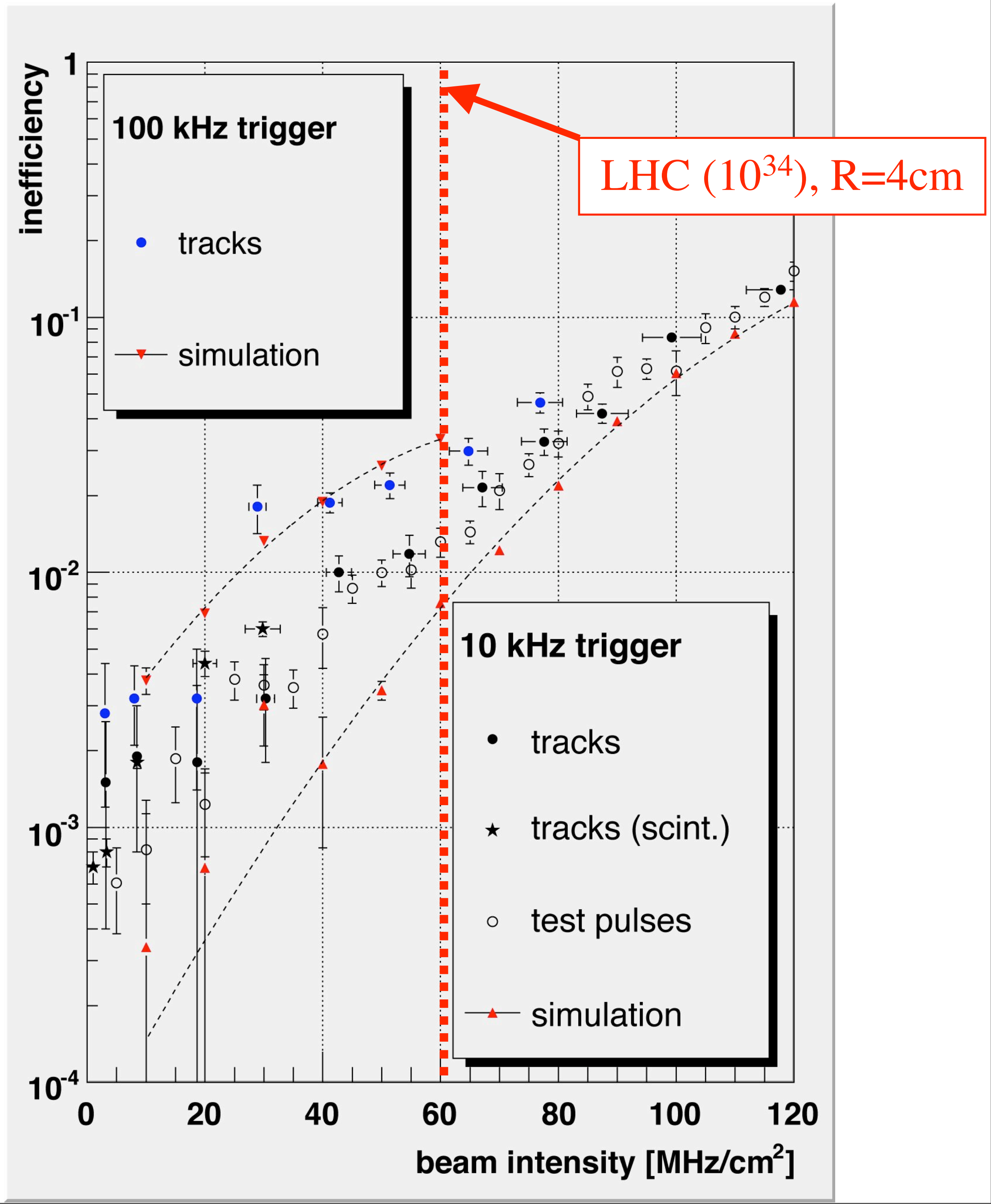
- 0.25µm IBM CMOS technology
- Reads out 100x150µm pixels
- 52x80 array in double columns
- Pixels have amplifier, shaper, discriminator, storage capacitor & charge injection for calibration
- 120 mW/ROC power draw
- Highly tunable (28 DACs)
- Rad hard: noise $100e^- \rightarrow 120e^-$
- 32 data, 12 time stamp buffers for low dead time
- 123 total wafers, yield ~80% good ROCs in ~100 tested so far




Data in 6 analog address levels

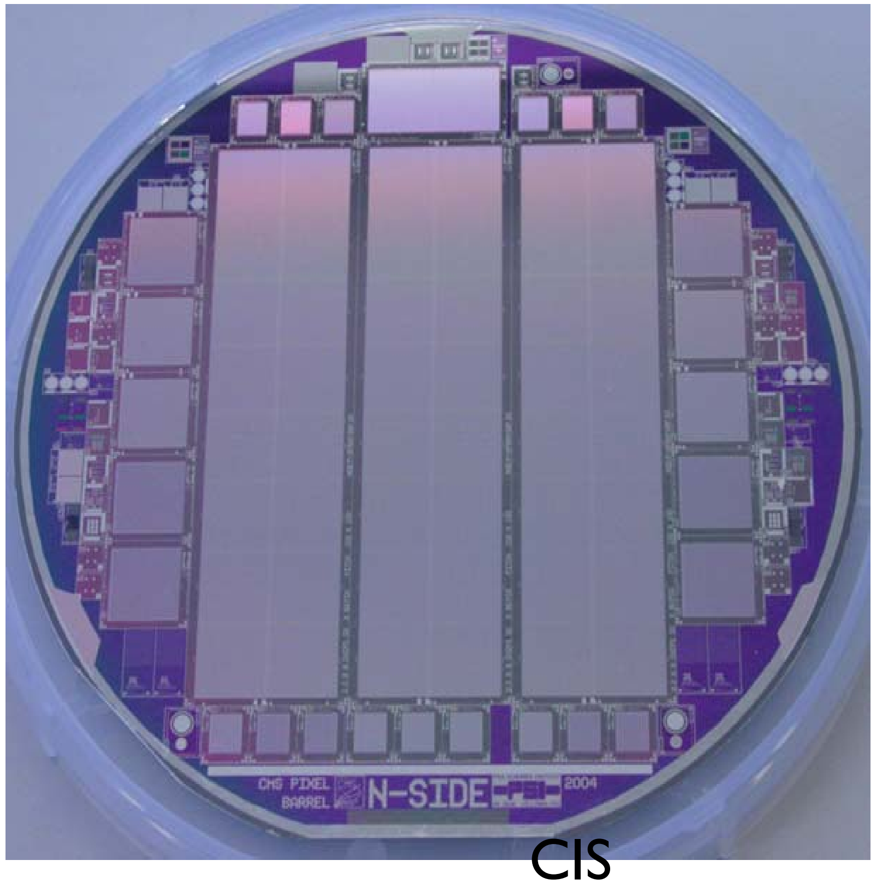
# Data Loss Small and ~Well Understood

- Readout losses possible during high rates
- Measured with 50MHz 300 MeV $\pi^+$ test beam (with scintillator trigger for low rate)
- Also measured with test beam & simultaneous charge injection
- Worst case loss: 0.8%, 1.2%, 3.8% for 11, 7, 4cm at 100kHz L1A

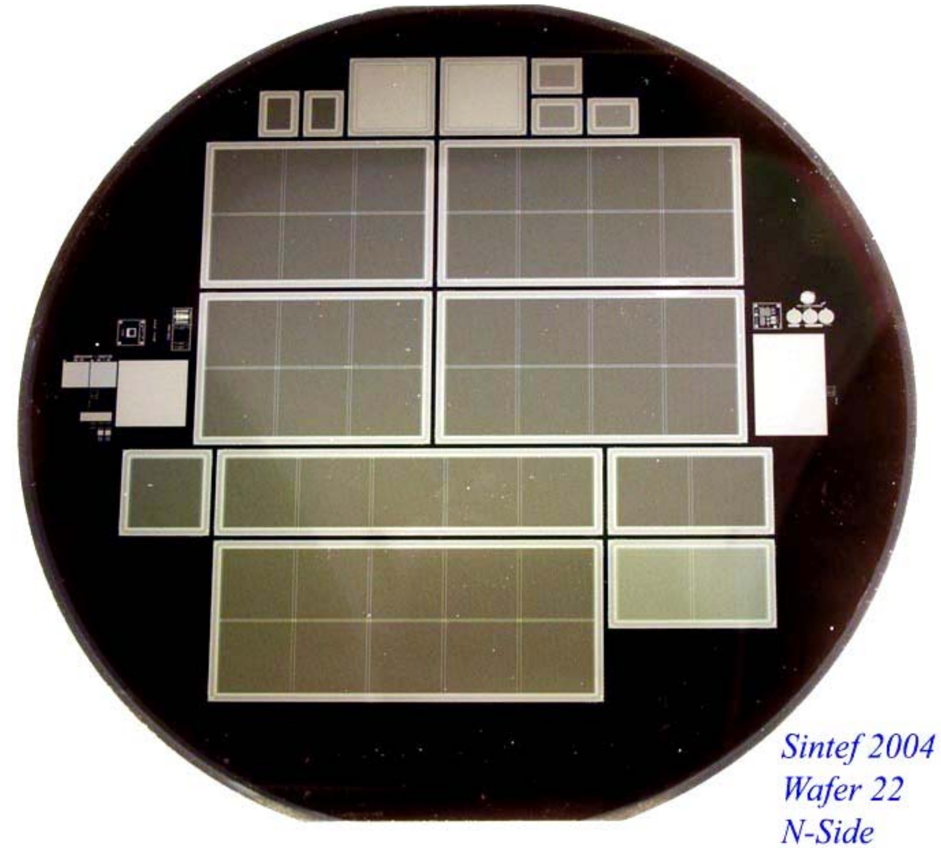


# Sensors: n-on-n

- Barrel sensors use p-spray isolation
- All BPIX sensors in hand from CIS
- Forward sensors use partially open p-stop
- All FPIX sensors in hand from Sintef.
- Irradiation shows FPIX+ROC 98.8% efficient after 8E14 $n_{eq}$/cm
- Irradiation shows BPIX+ROC 99.0% efficient after 6E14 $n_{eq}$/cm
- Expect 6E14 $n_{eq}$/cm at 4cm after 4-5 years of LHC running




CIS

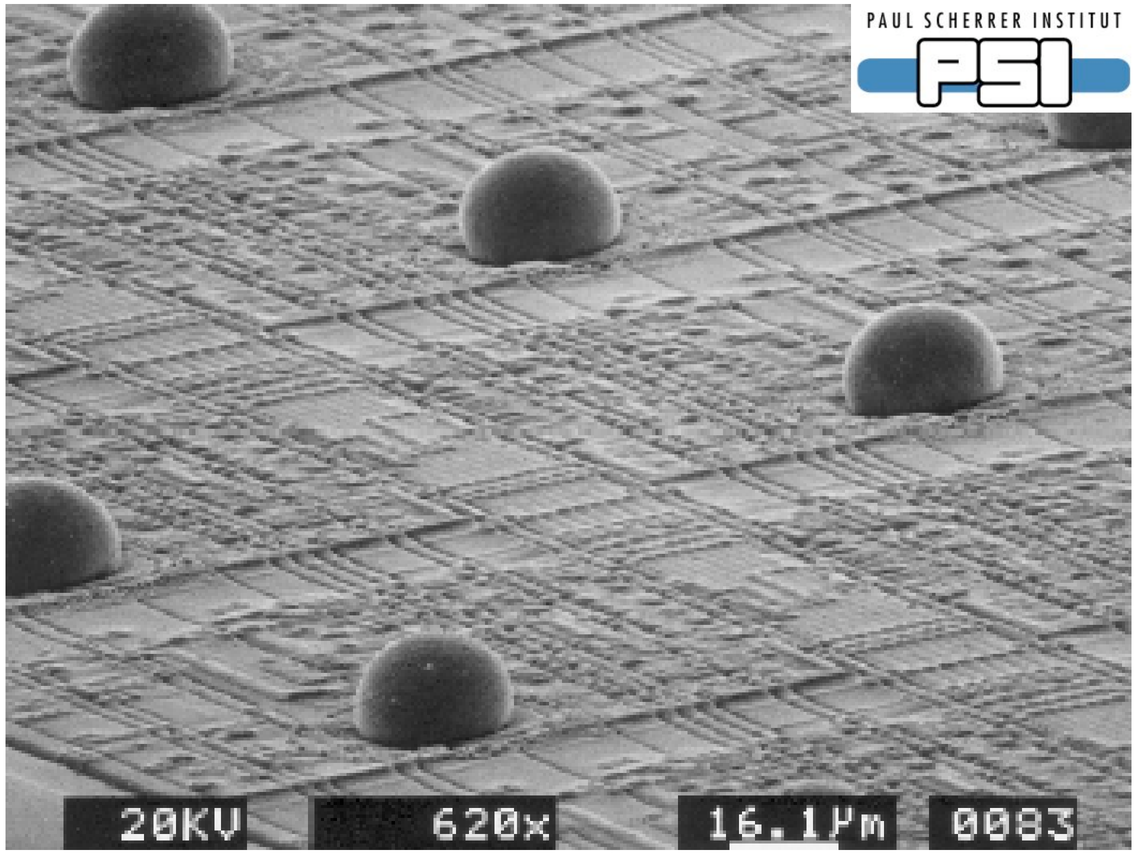


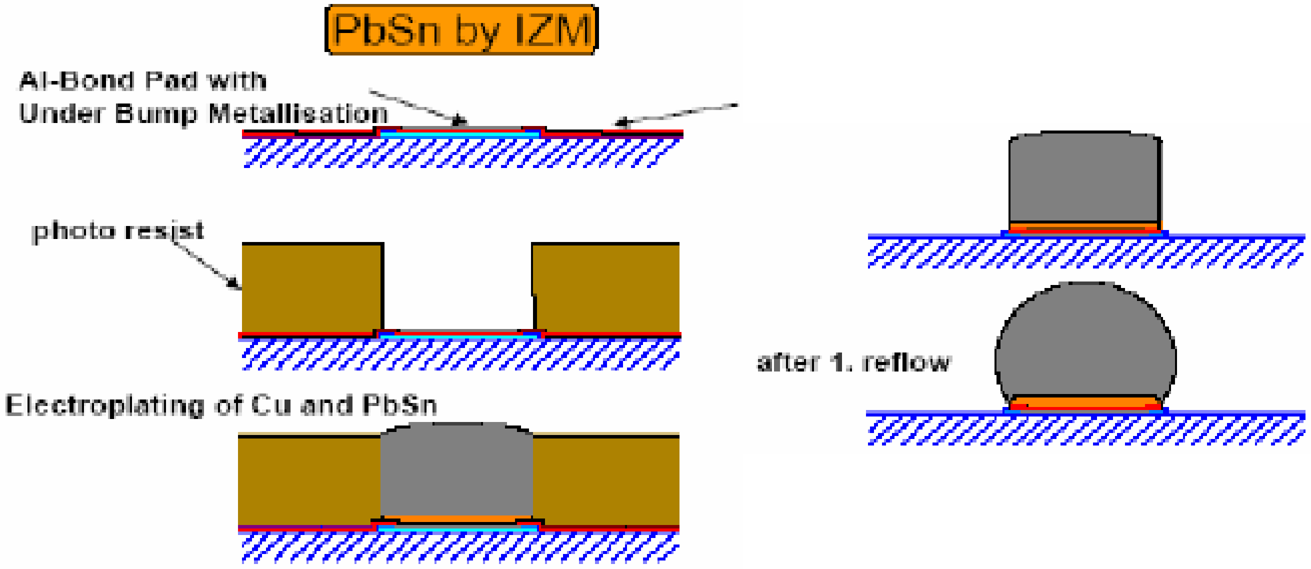
# Bump Bonding

- Barrel pixel sensors have bump deposition in-house at PSI with In (~1.25 hr/ module). Production: 4 modules/day

- Forward pixel sensors are bump bonded at two vendors: RTI (US), IZM (Germany). Production: 80 modules/2wks

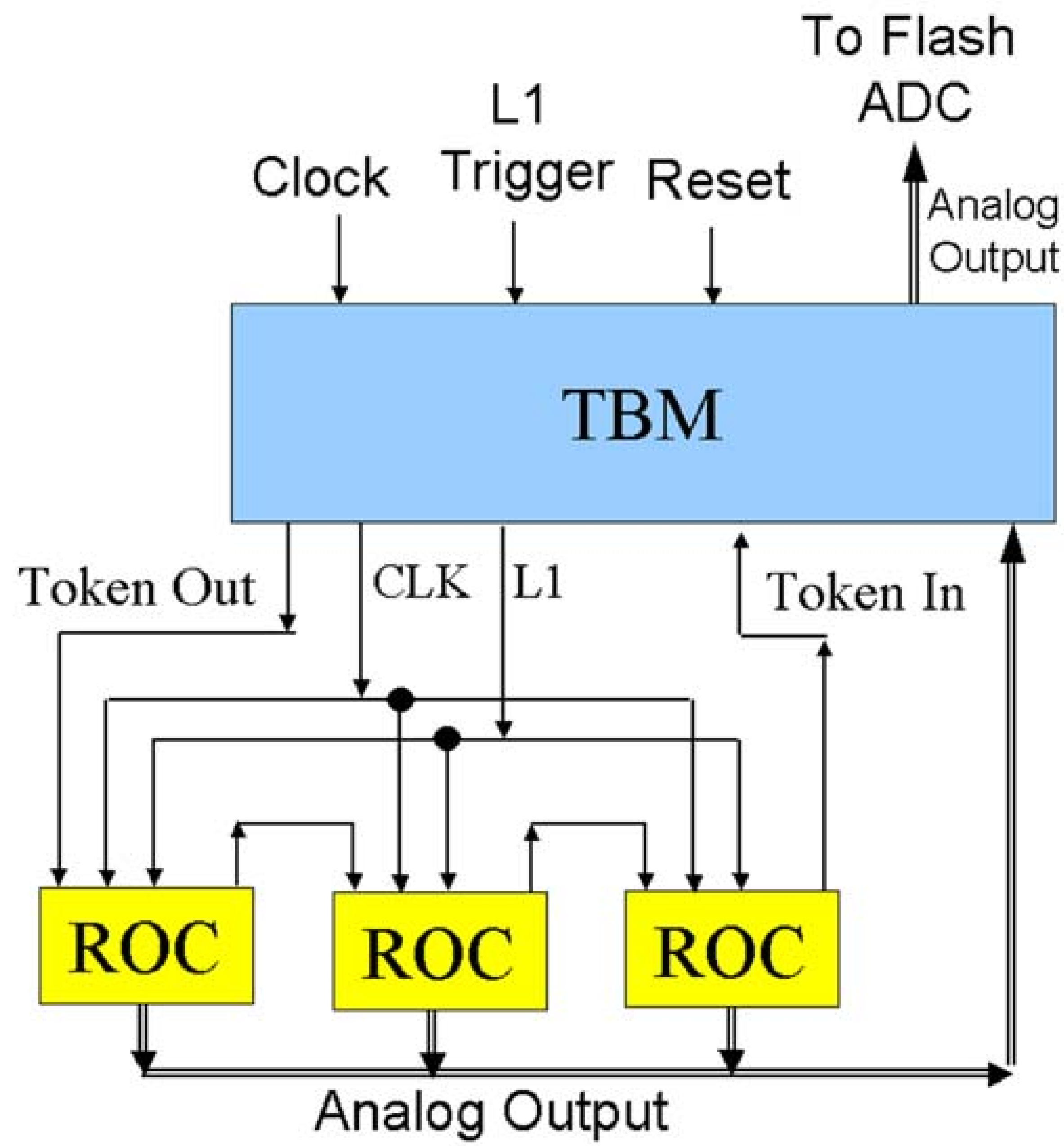
- Yields > 80% after bumping and dicing. Good connectivity: <<1% bad bumps



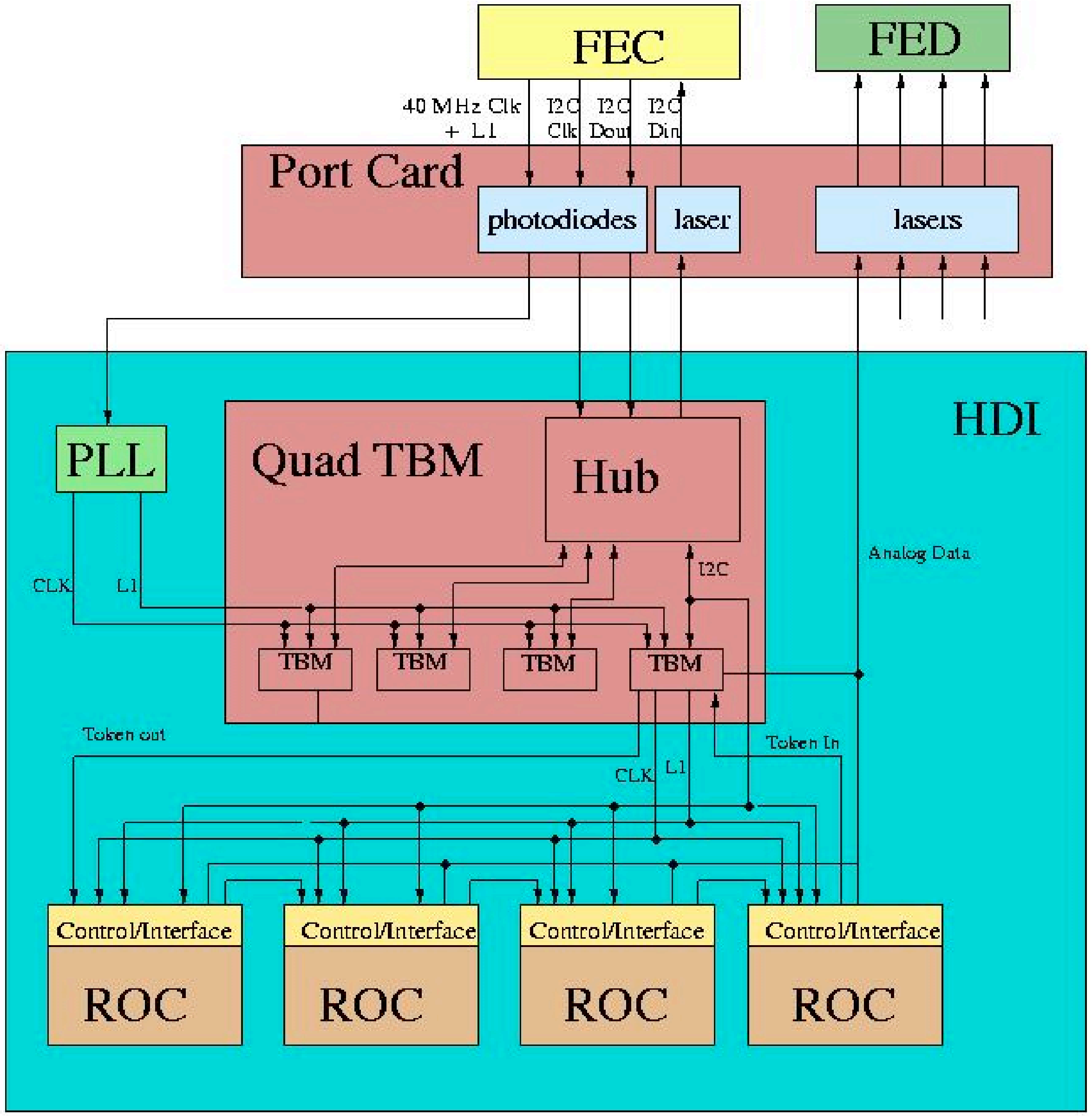



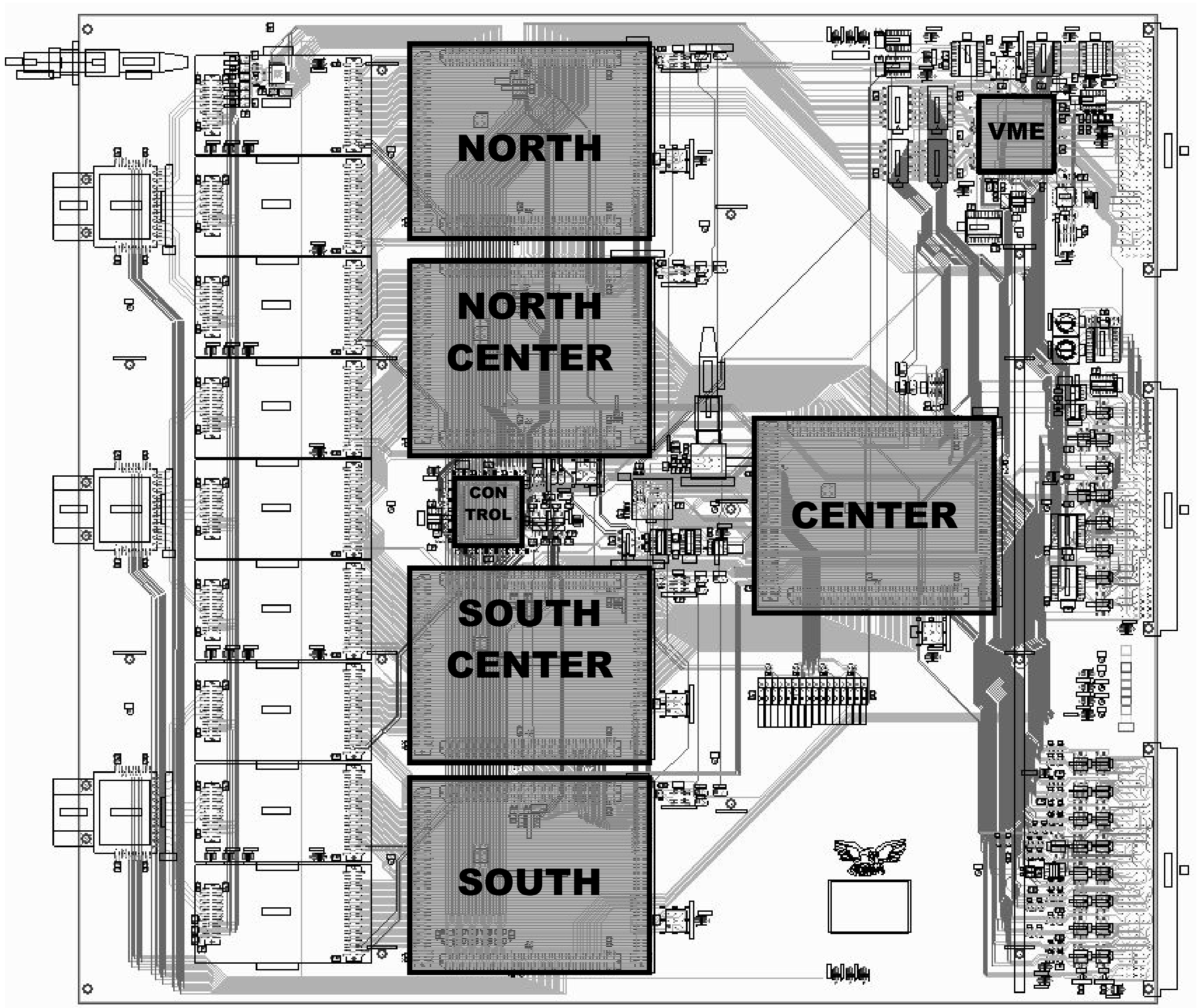
# Token Bit Manager

- The TBM controls the readout of ROCs by initiating a "token pass" for each L1A
- Rad hard 0.25μm process
- Controls between 8-24 ROCs
- Header/trailer words for event number & error status
- Distributes the L1A and clock to ROCs



# PxlFED

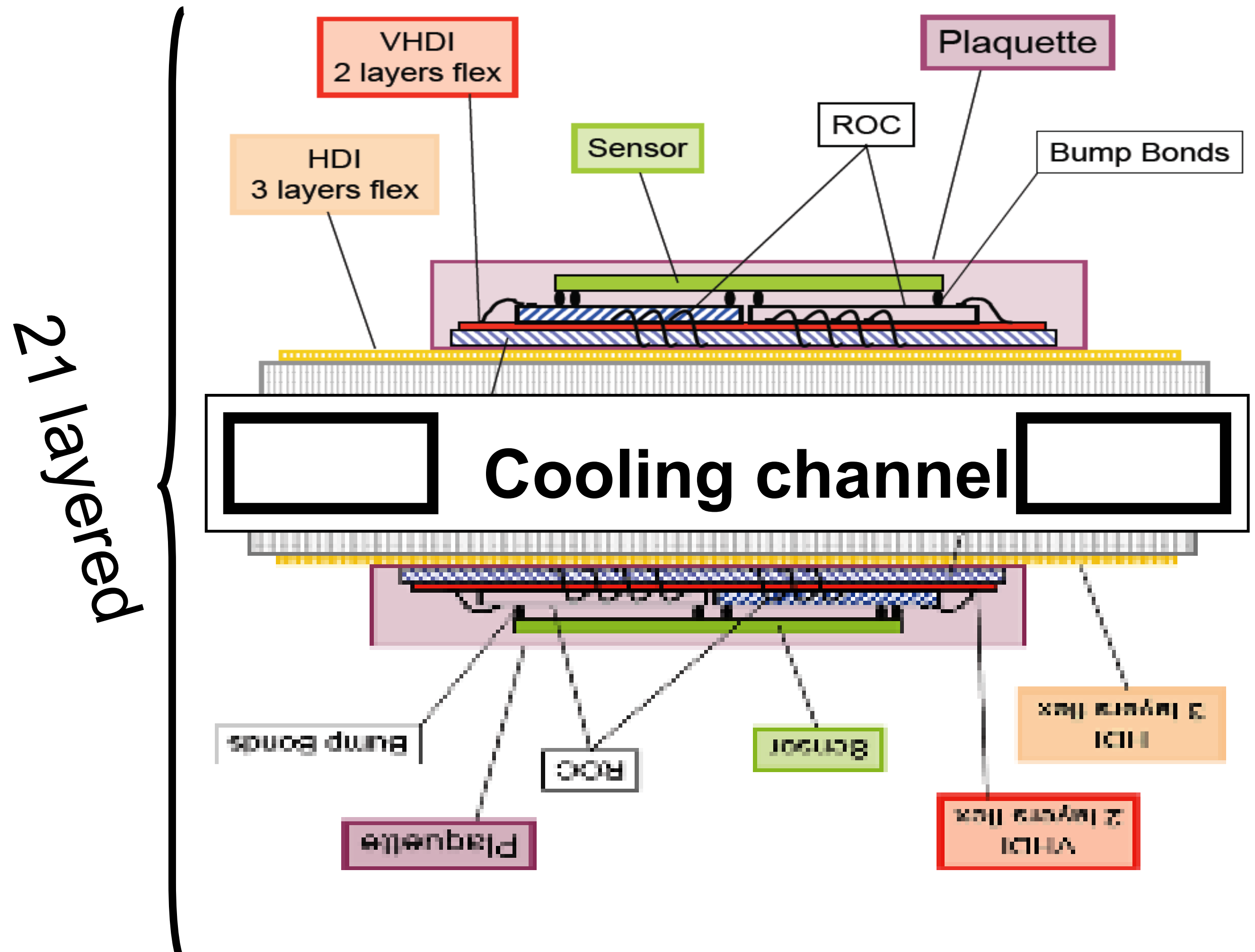



Pixel FED 36 optical channels produced by Vienna (Manfred Pernicka, Helmut Steininger)

# Forward Pixel Modules

- 5 flavors of plaquettes: 1x2, 1x5, 2x3, 2x4, 2x5.
- 3 or 4 plaquettes make a panel. No holes in coverage
- Blade is two panels back-to-back
- Rigorous testing at all stages of production: **see M. Eads' poster**

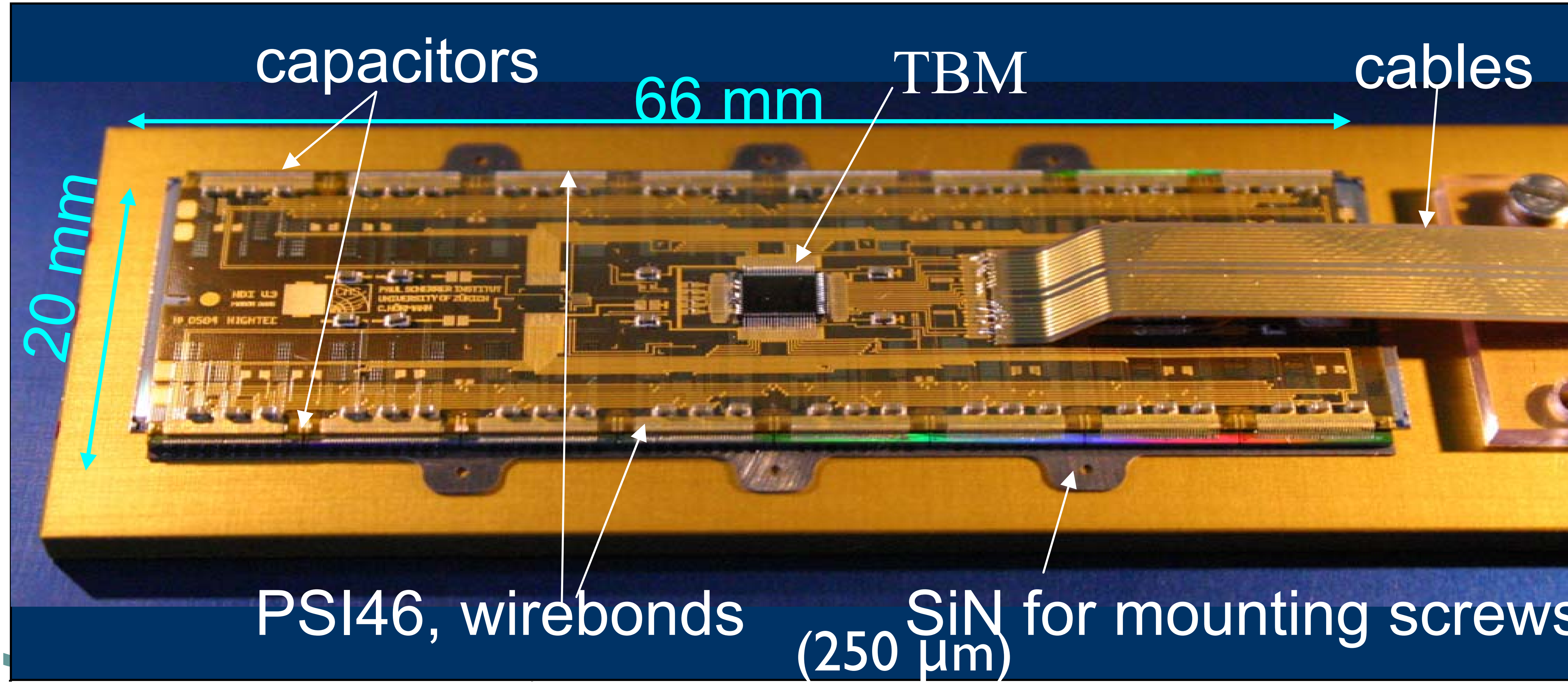



3,4 plaquette panels


Plaquette

Cooling channels

# Barrel Modules



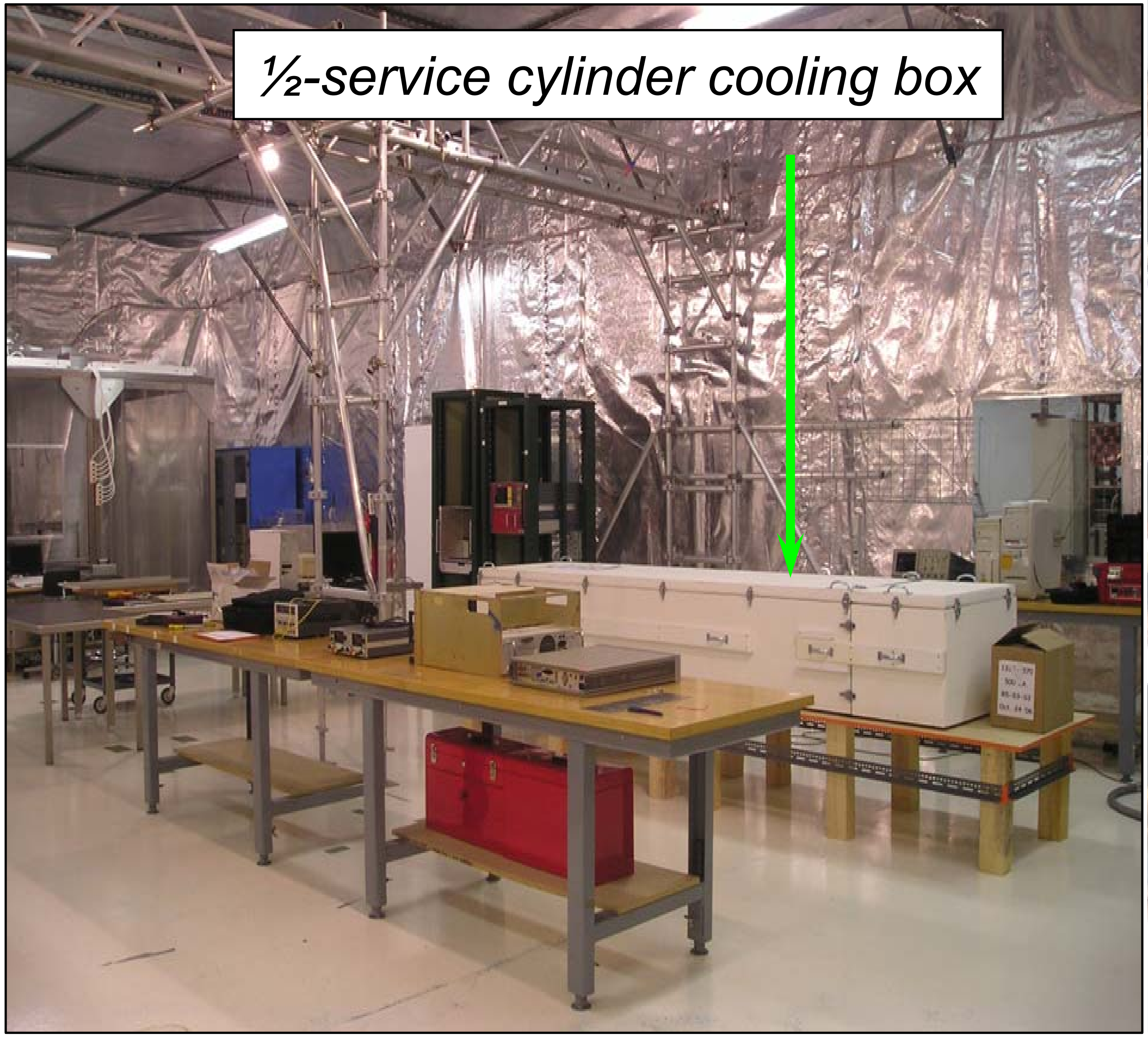

- Power & signals come in on kapton cable
- Flex circuit (HDI) mounts on sensor
- $Si_3N_4$ side strips for support/cooling

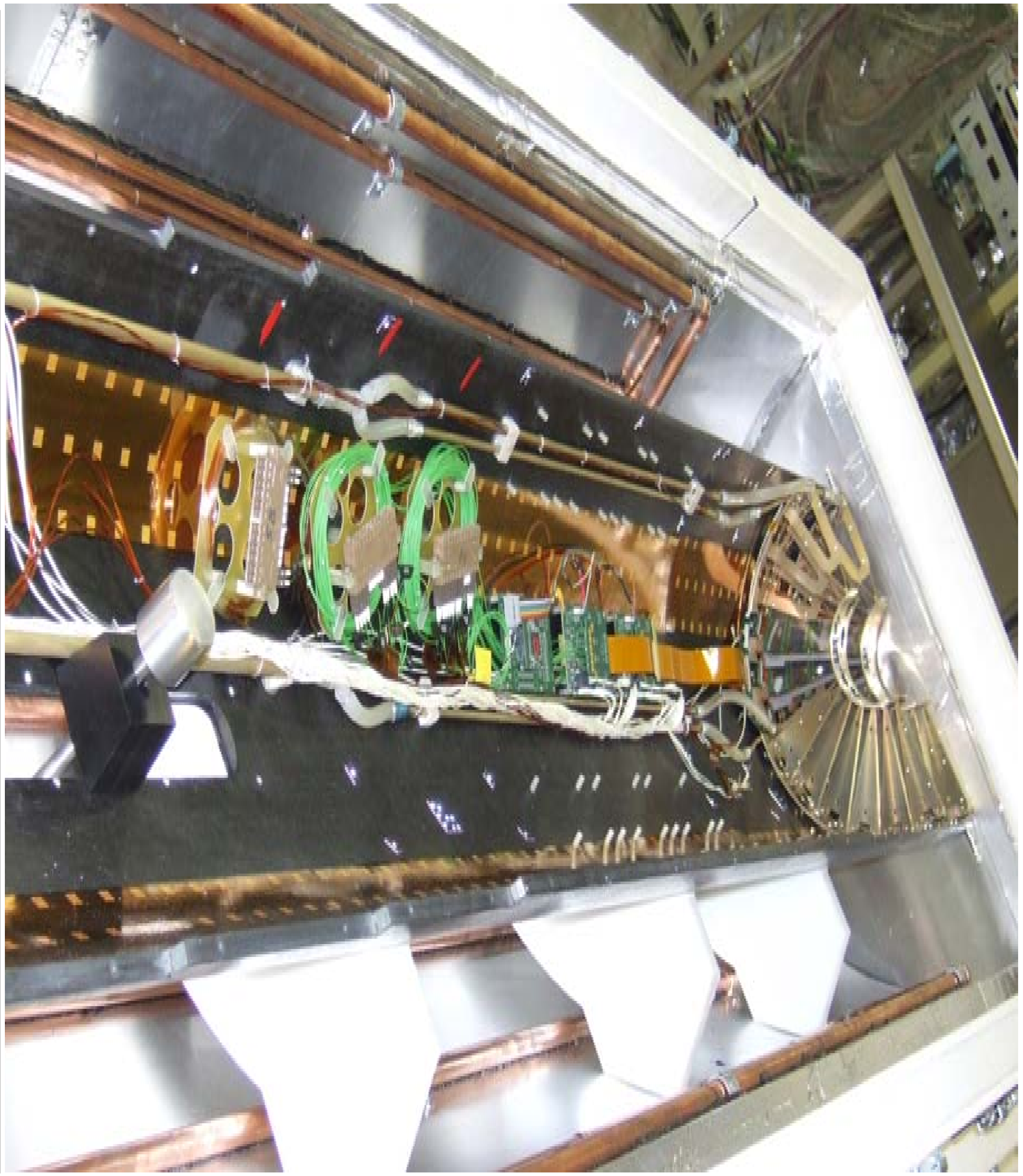
# Current Status

- We are on schedule for installation in CMS for the 2008 physics run
- For 2007 we will run with a single wedge and two forward blades on one side. This is for learning how to run the detector
- We have built over half of the needed plaquettes for the forward detectors
- PSI has built over half the needed production quality modules

# Commissioning at CERN

2007 pilot run detector is being commissioned in "Petal Integration" and "Tracker Integration" facilities



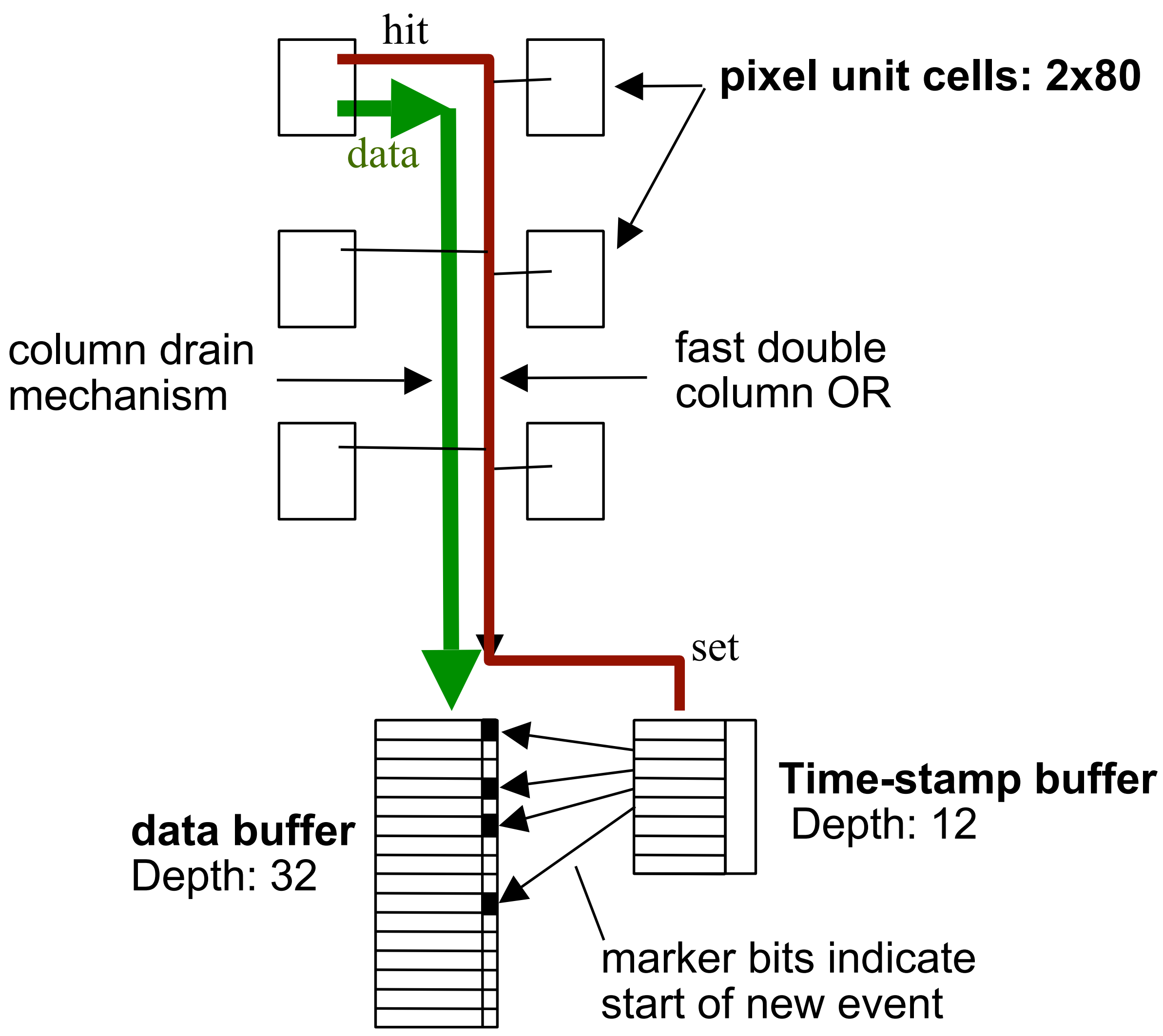
# Conclusions

- 18M forward and 48M barrel pixels are in the active production phase of construction
- Sensors & ROCs perform as expected in test beams and after irradiation
- The detectors are on schedule for installation and running in 2008
- Also looking forward to 2007 pilot run
- We are now thinking of the upgrades (!) needed for 2012 & 2016 since R&D to completion cycle is ~6 years

# Other material

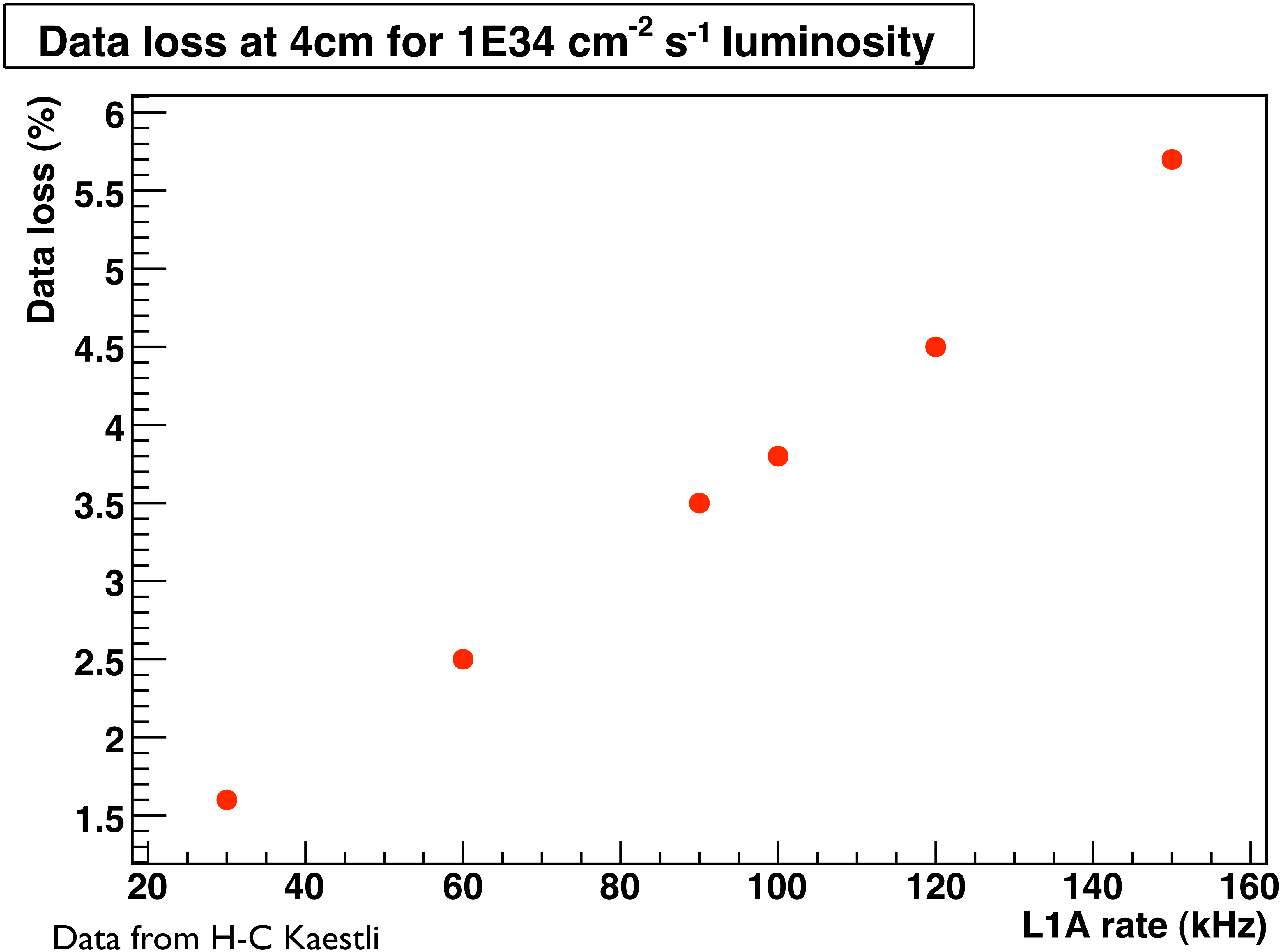
# Column drain architecture

**sketch of a double column**



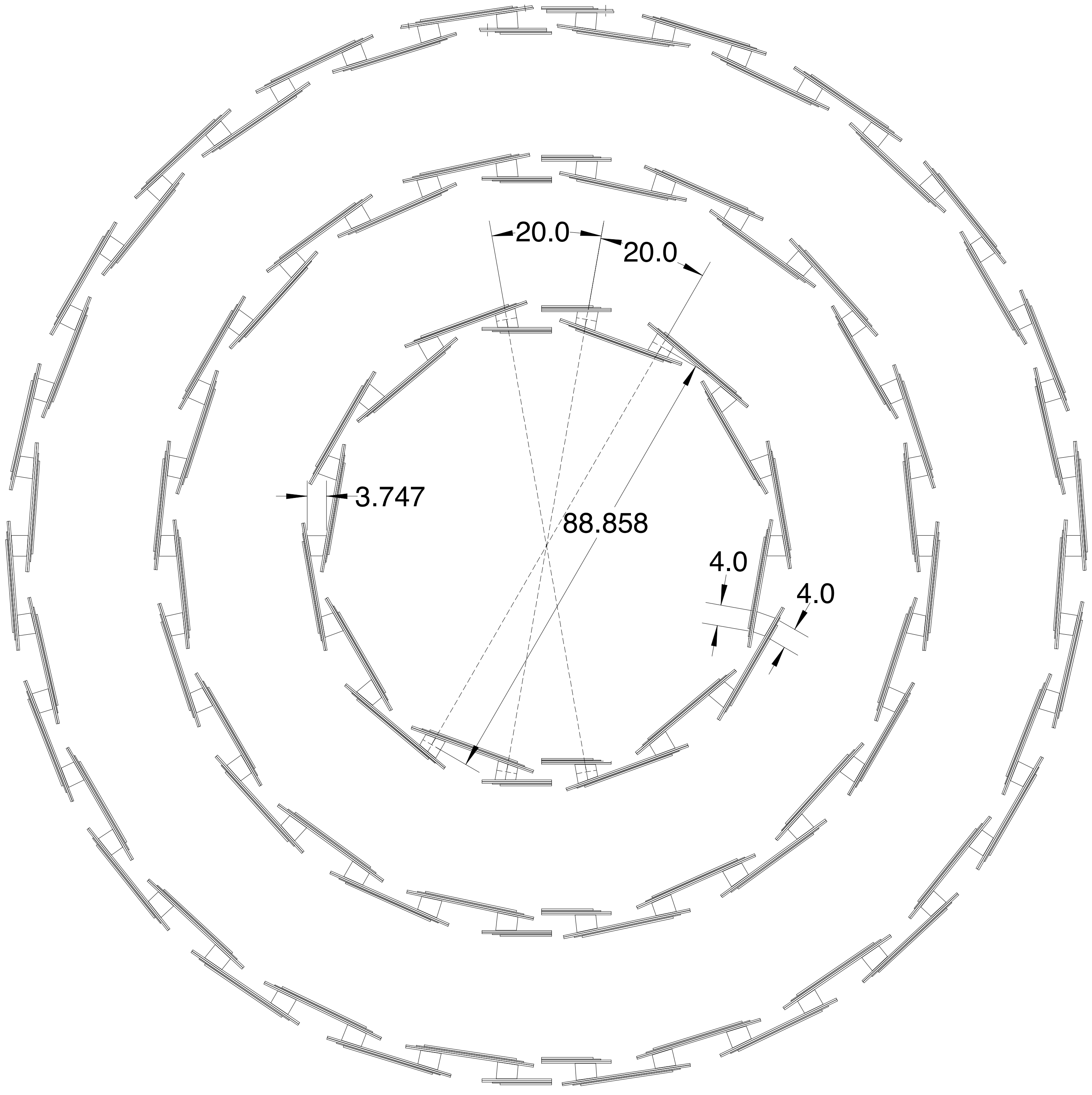

- Zero suppression in pixel cell
- Pixel hit information transferred to time stamp and data buffer
- Kept there during L1 trigger latency
- Double column stops data aquisition when confirmed L1 trigger ⇨ dead time starts
- Double column resets after readout ⇨loosing history (trigger latency)
- Serial readout: 8 (16) ROCs daisy chained. Controlled through readout token

# More on testbeam

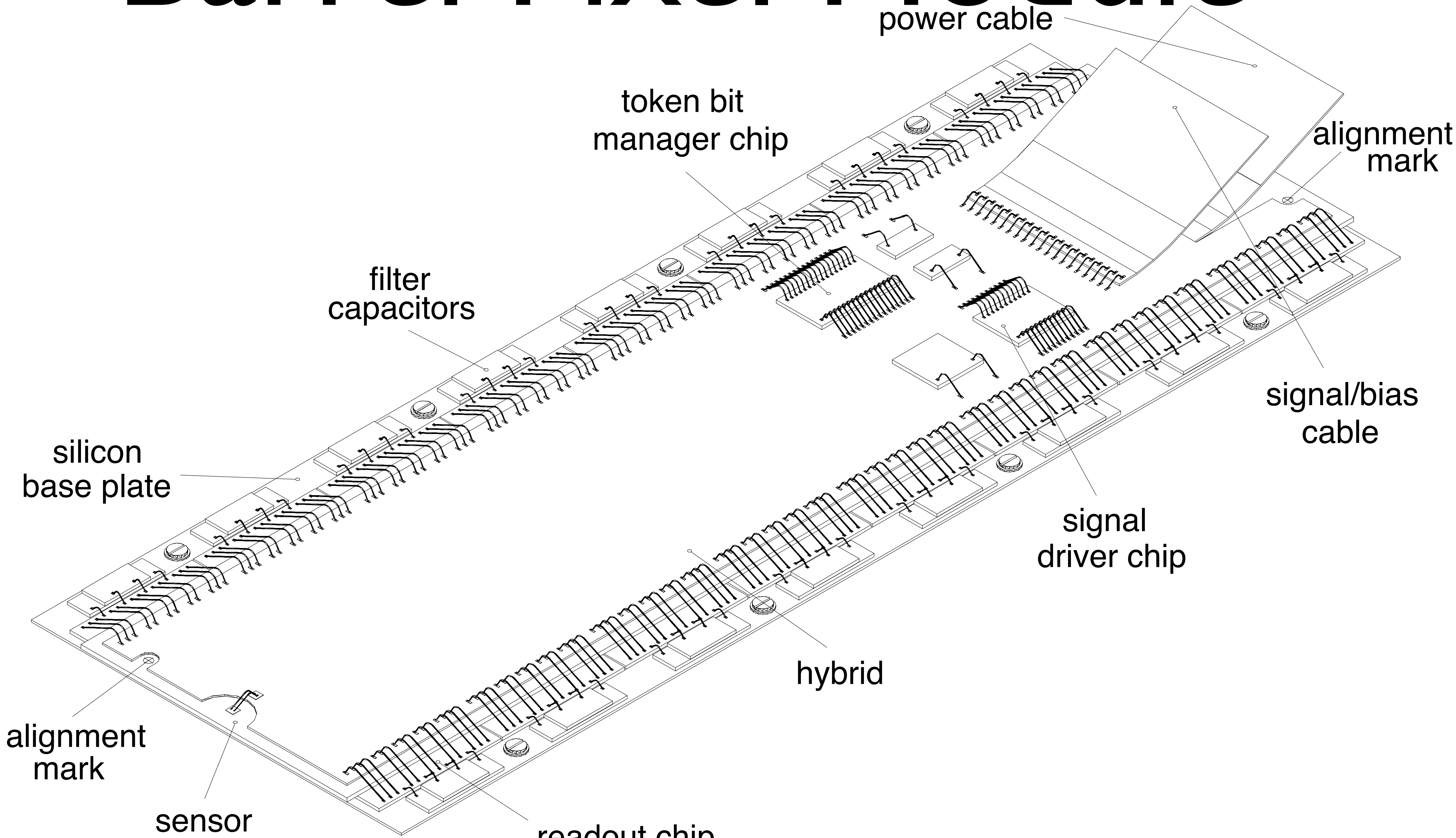


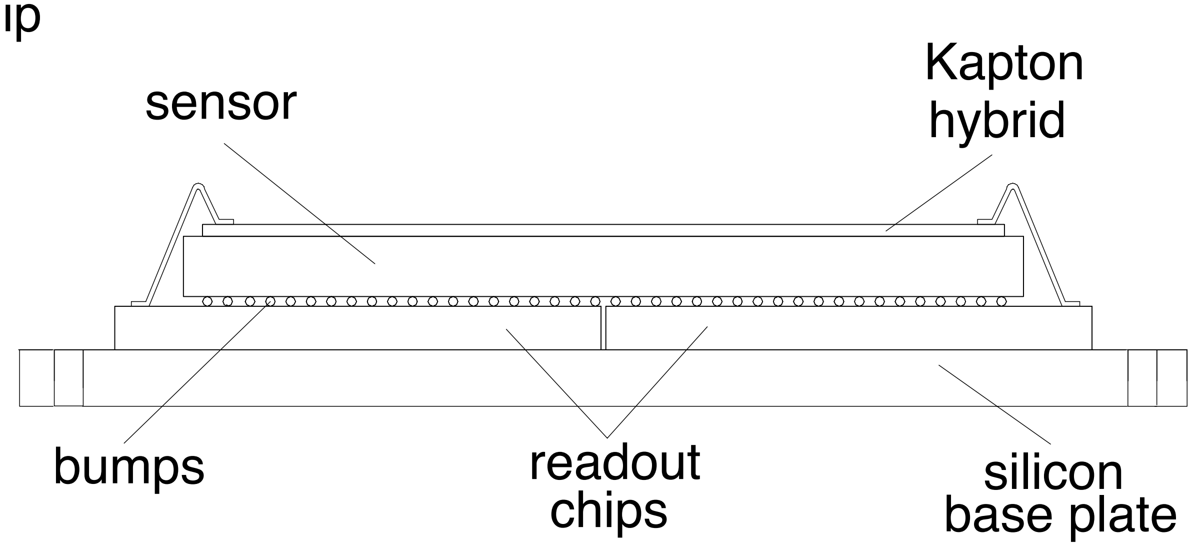

Data from H-C Kaestli

# Barrel Pixel Geometry



# Barrel Pixel Module



# Forward Pixel Schedule