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An Overview of the High Rate Low Radiation Length Micro-Vertex-Detector

for the PANDA Experiment

6. September 2010 | Tobias Stockmanns

Main Physics Program

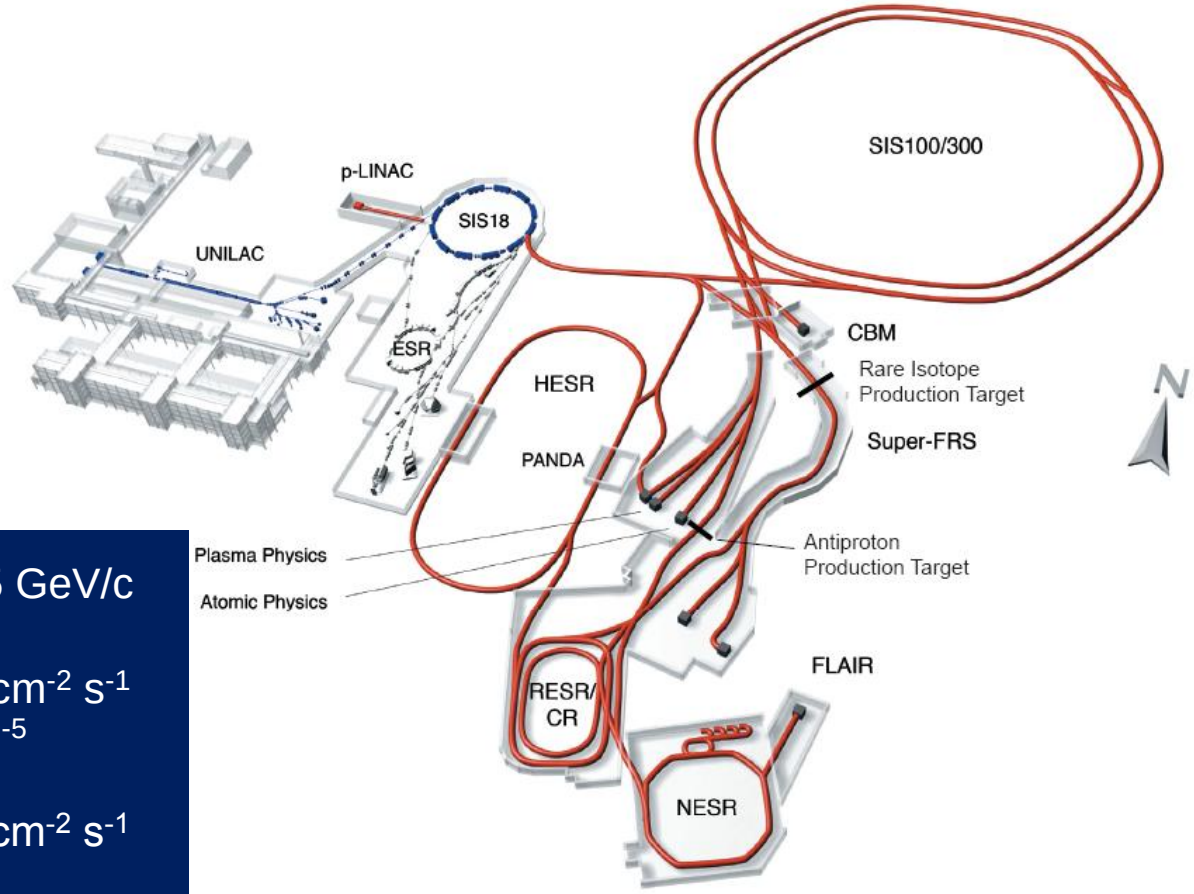
$\bar{P}$ANDA – Anti**P**roton **An**nihilations at **Da**rmstadt

Cooled antiproton beam up to 15 GeV/c on a fixed target

- $q\bar{q}$ potential in the charmonium system
  - precision measurements of $c\bar{c}$-states (not only $J^{PC} = 1^{--}$)
  - $c\bar{c}$ above $D\bar{D}$-threshold ➔ D-meson tagging essential
- Spectroscopy of new charm states
- Search for Hybrids $q\bar{q}g$ and/or Glueballs gg
- Charmed and multi-strange baryon spectroscopy
- Electromagnetic processes ($p\bar{p} \rightarrow e^+e^-$, $p\bar{p} \rightarrow \gamma\gamma$, Drell-Yan)
- Properties of single and double hypernuclei
- Properties of hadrons in nuclear matter

FAIR Facility for Antiproton and Ion Research

http://www.gsi.de/fair/index.html



antiprotons at 1.5 - 15 GeV/c

High resolution:

$L = 10^{31}\ cm^{-2}\ s^{-1}$

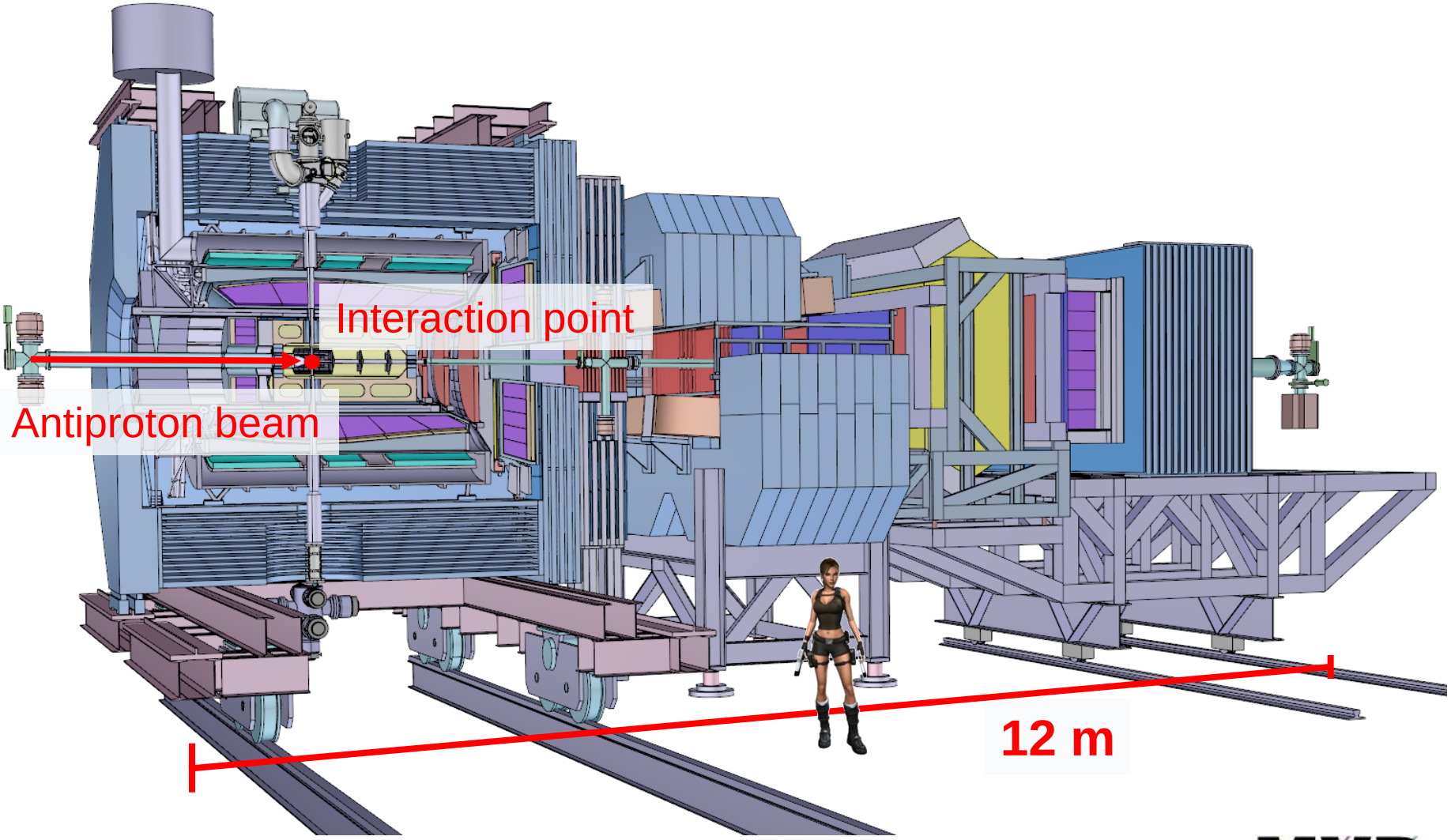
$\delta p/p < 4 \times 10^{-5}$

High luminosity:

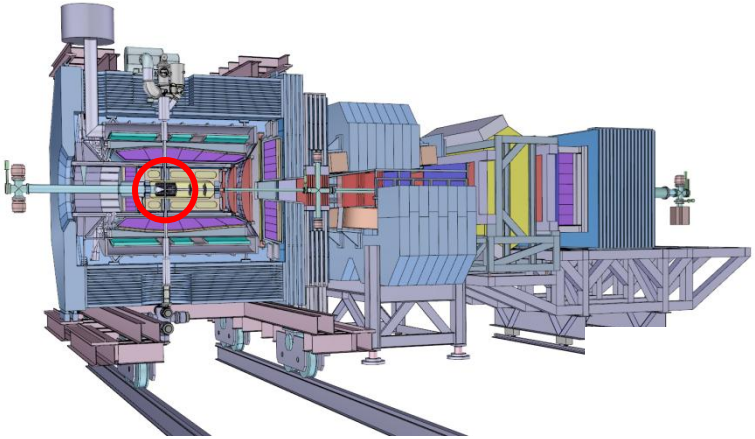
$L = 2 \cdot 10^{32}\ cm^{-2}\ s^{-1}$

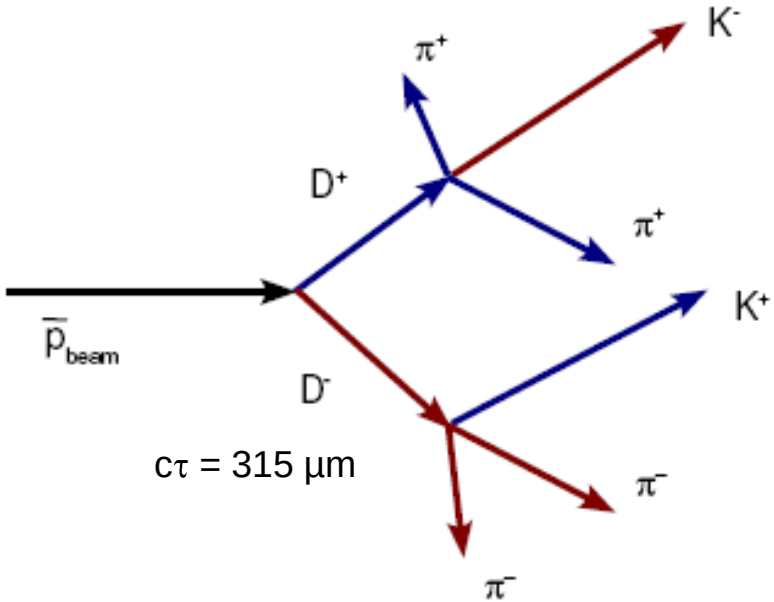
$\delta p/p < 10^{-4}$

$\bar{P}$ANDA Spectrometer



Micro-Vertex-Detector

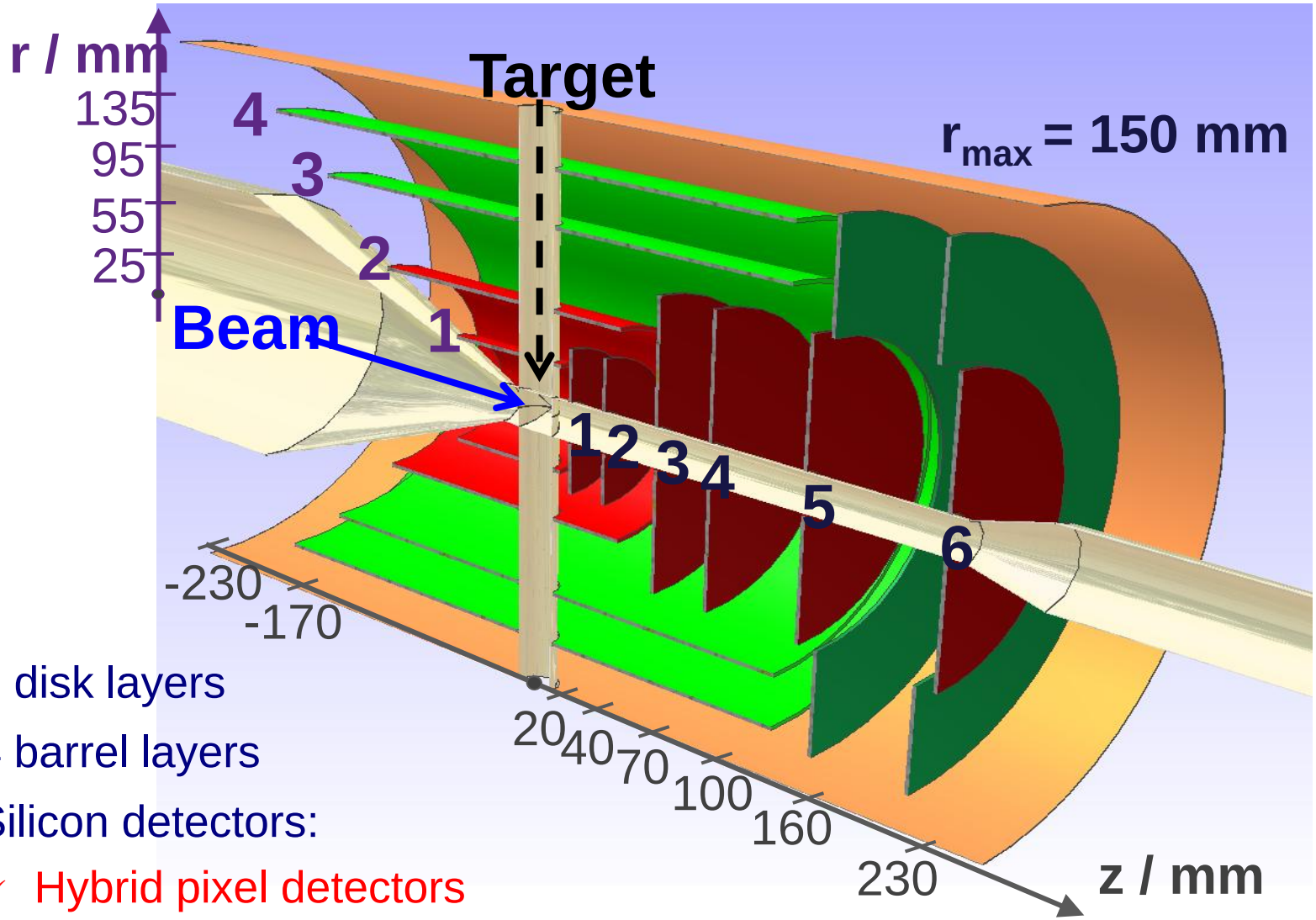




Requirements MVD

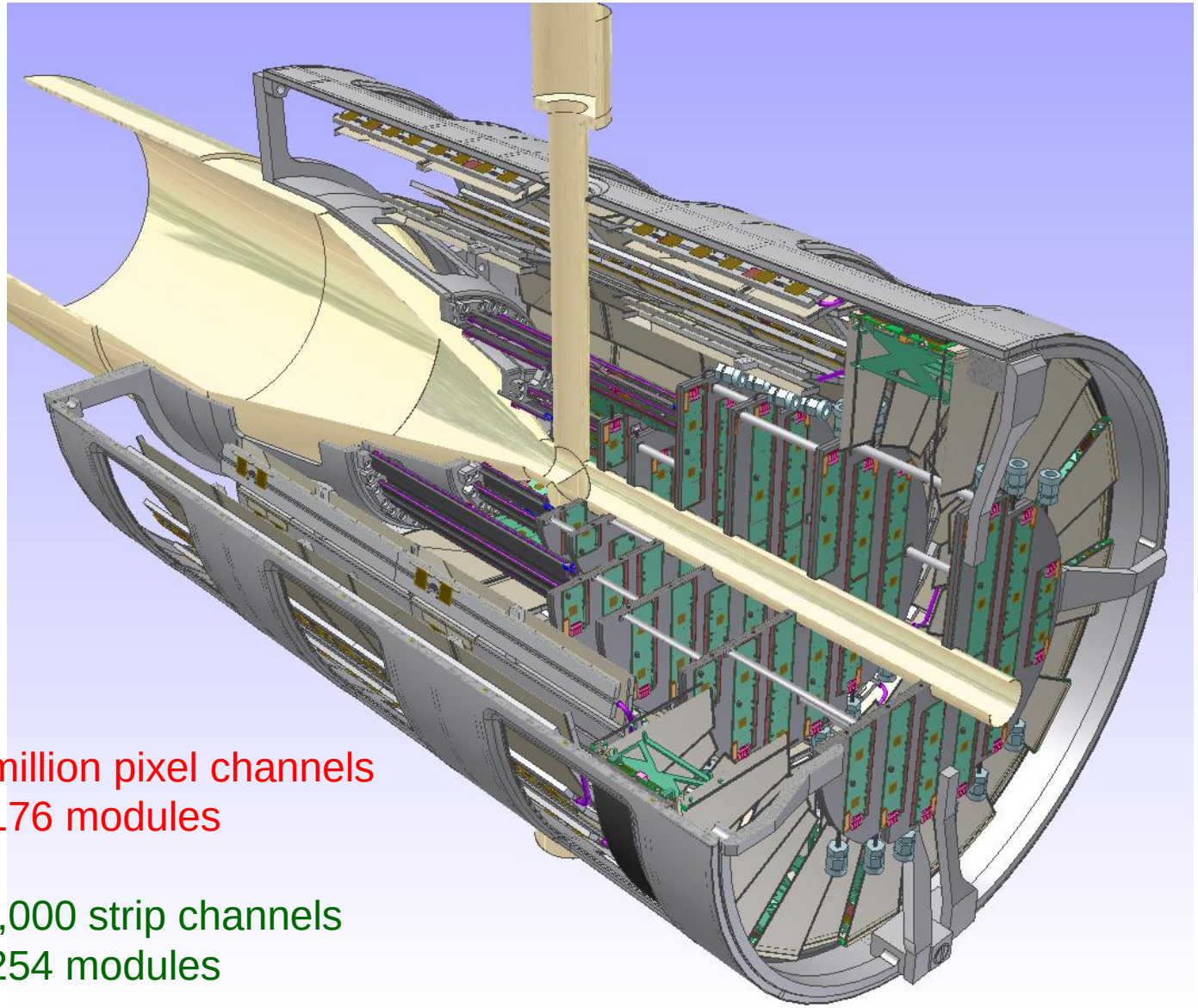
- Good spatial resolution in r-phi ➔ momentum measurement of soft pions from D* decays
- Good spatial resolution specially in z ➔ vertexing, D-tagging
- Good time resolution (O(10 ns)) ➔ 'DC'-beam (2 10^7 events/s)
- Amplitude measurement ➔ improvement of resolution dE/dx to improve particle ID
- Modest radiation hardness (O(10^{14} n_{eq} / cm^2)) ➔ depends on target material
- Triggerless readout ➔ no first level hardware trigger
- Low material budget ➔ low momentum particles energy resolution calorimeter

Schematic view of MVD



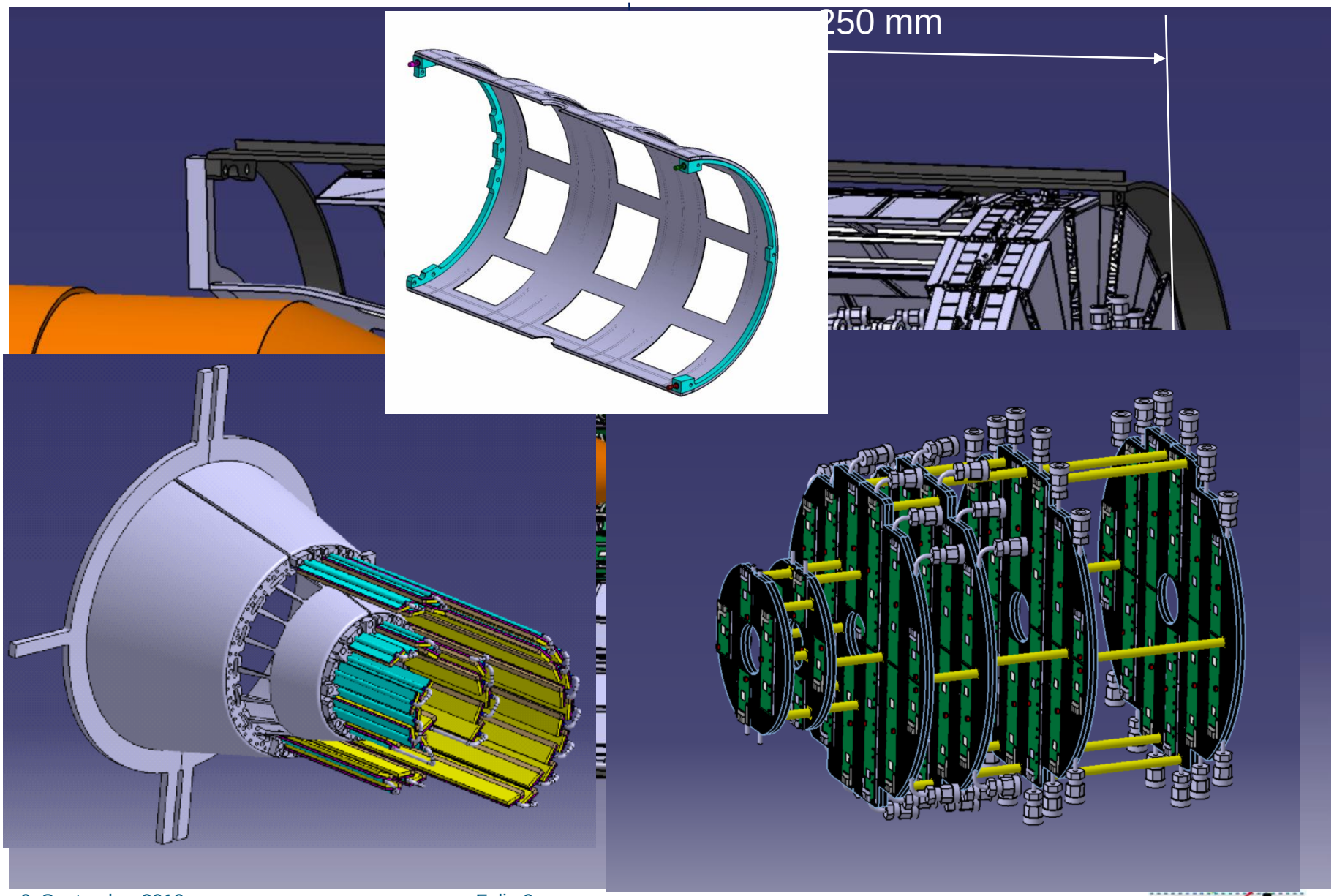
- 6 disk layers
- 4 barrel layers
- Silicon detectors:
  - ✓ Hybrid pixel detectors
  - ✓ Double-sided microstrip detectors

Detailed CAD Design



- 10 million pixel channels on 176 modules
- 200,000 strip channels on 254 modules

Pixel Support Structures

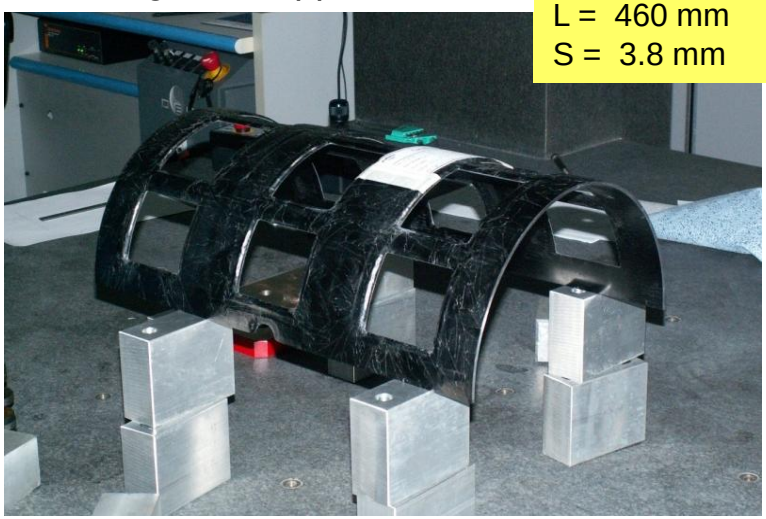


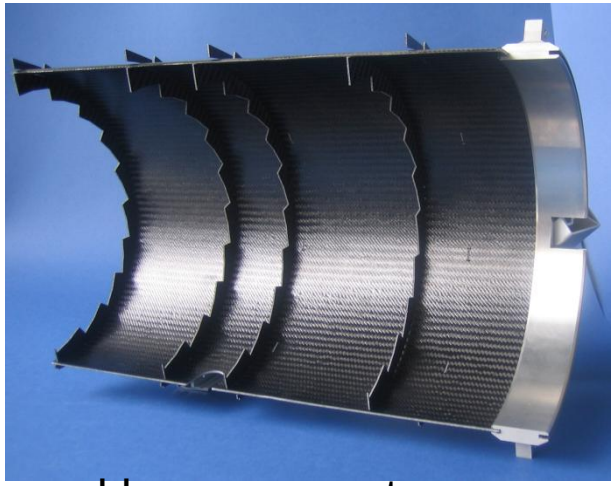
Mechanics

- Lightweight support structures

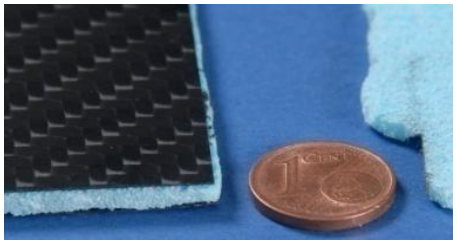
MVD global support frame

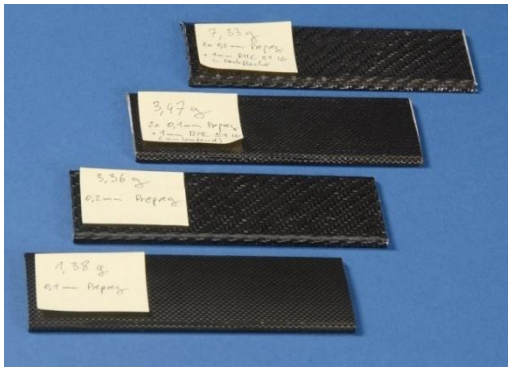
R = 137 mm
L = 460 mm
S = 3.8 mm

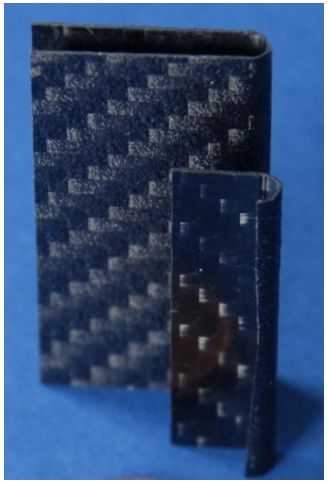




Strip barrel layer support



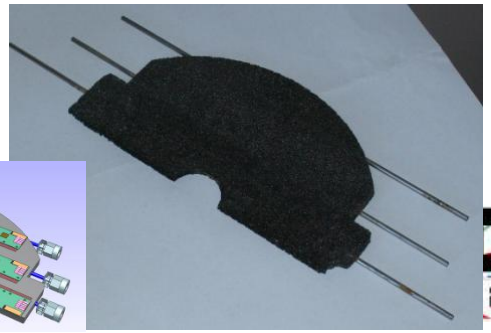


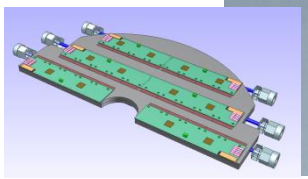


Local support
(barrel modules)

- Sandwich structure:
  (Carbon – Rohacell® – Carbon)
- 2 - 4 layers of carbon fibre (400 μm)
- < 0.17 – 0.26 % X/Xo

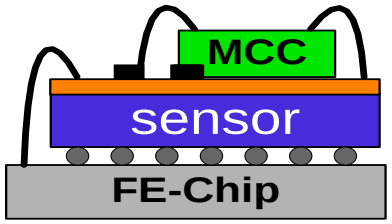
HTC foam half disk embedding cooling pipes

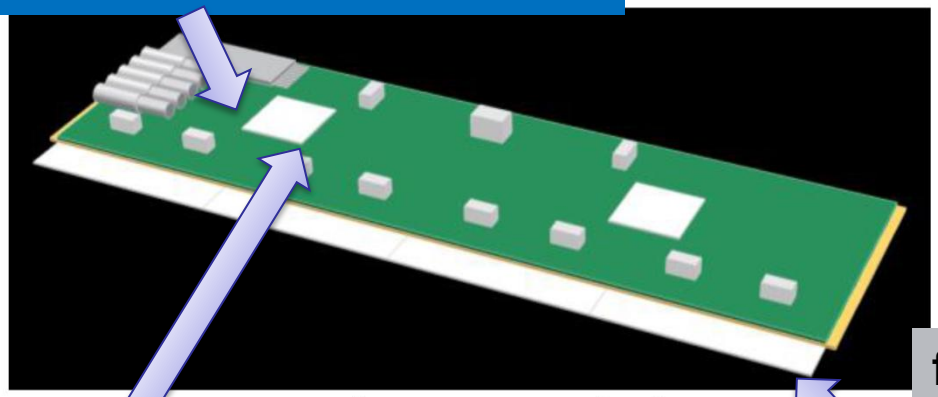




Hybrid Pixel Module

sensor:
- epi-Silicon
  - 50, 75, 100 µm thick epi-Layer on CZ substrate
  - thinned down to 100 – 150 µm
- alt. oxygen enriched silicon
  - thinned down to 150 – 200 µm



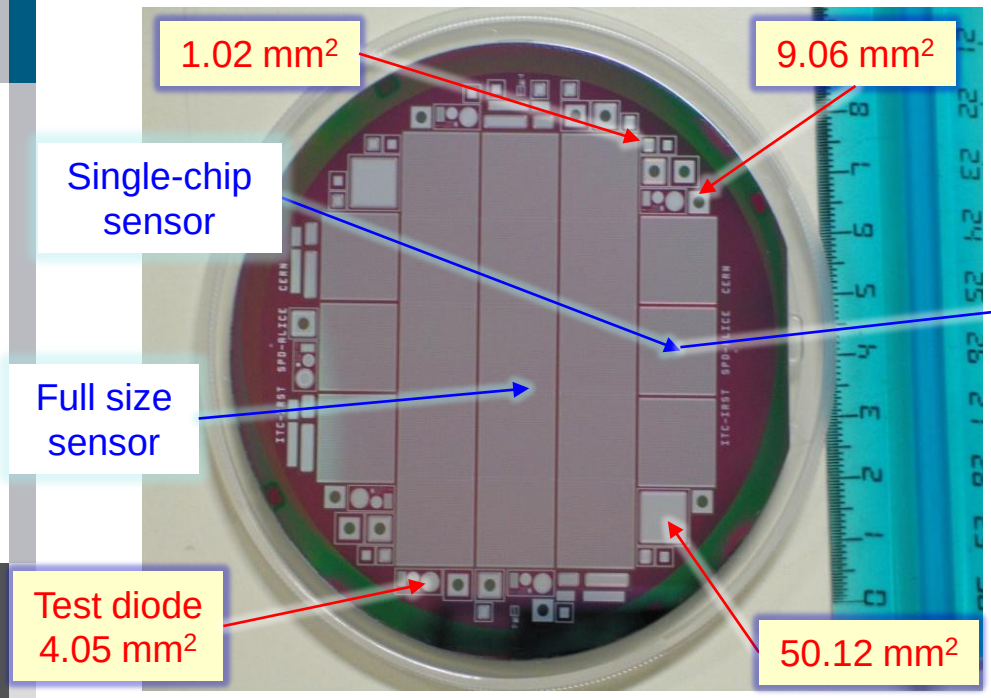


4-chip module

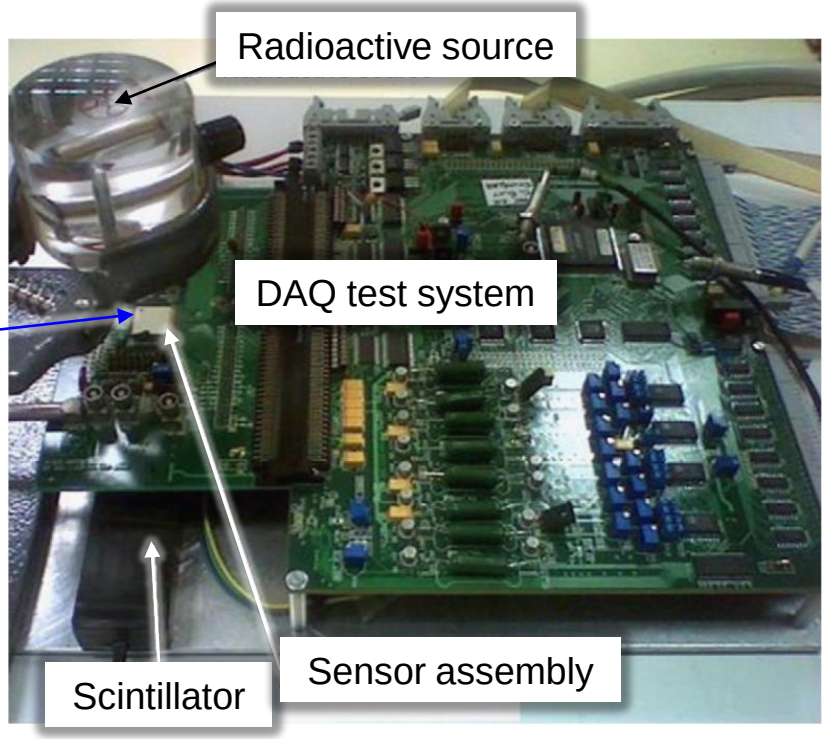
front-end chip:
- custom development (ToPix)
  - $(100\ \mu m)^2$ pixels
  - 110 x 116 pixel matrix
  - untriggered readout
  - 130 nm IBM process

readout:
- Buffer Chip

Pixel Sensors



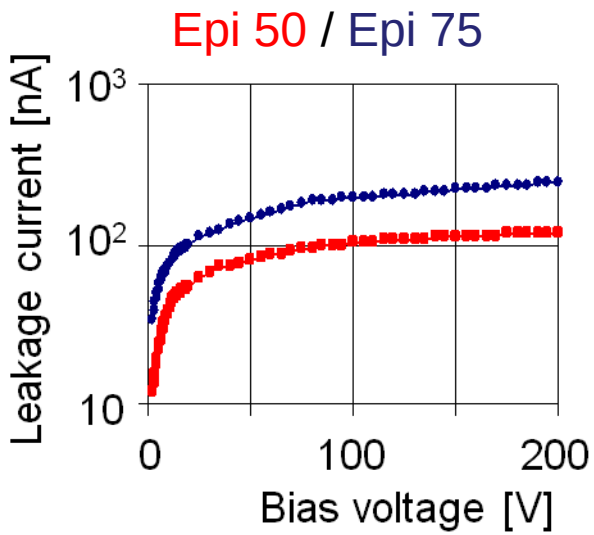
Single Chip Sensor on ALICE pixel chip

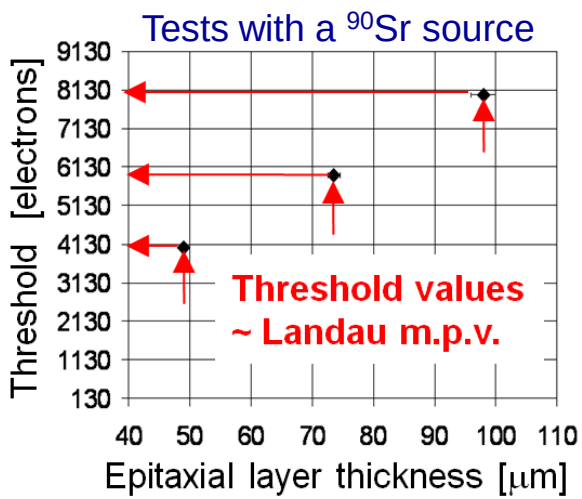


Epitaxial Silicon Sensors with 50, 75, 100 µm epi layer thickness, total sensor thickness 100 – 150 µm

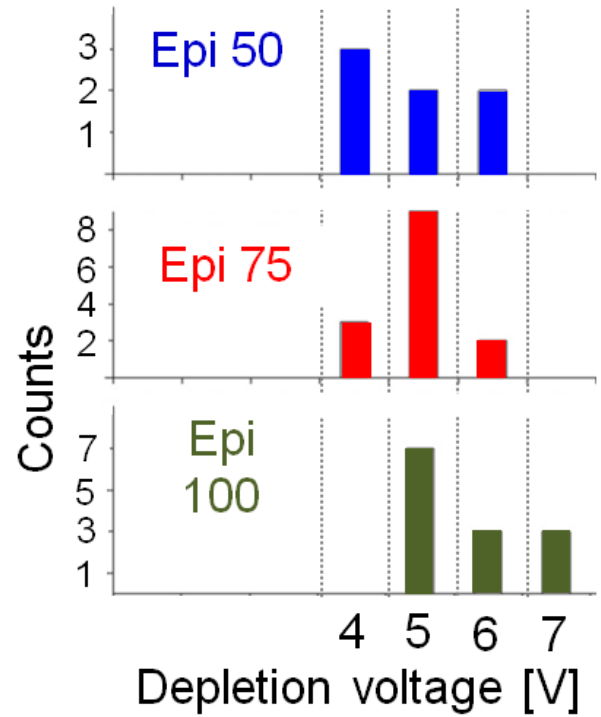
Epi Sensors

Single Chip



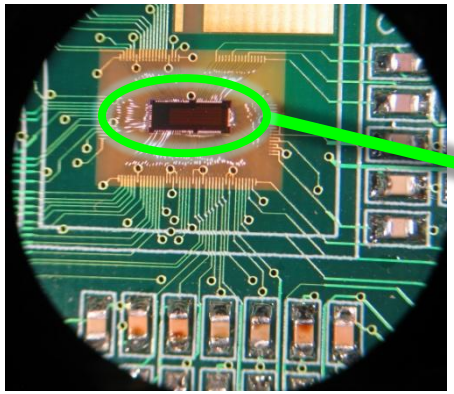


Diodes measured on probestation

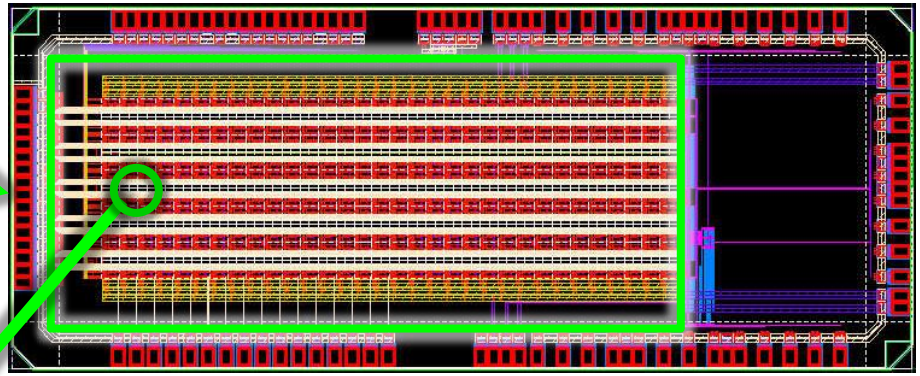


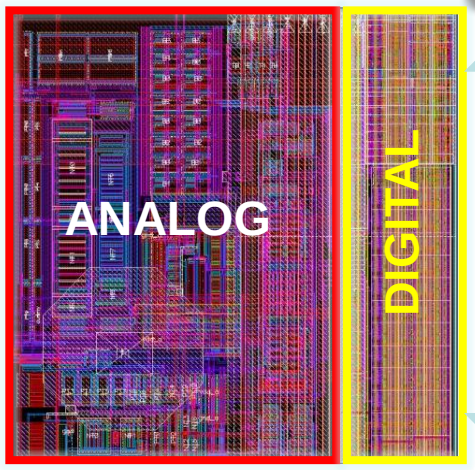
Front-End Electronics ToPix2 Testchip

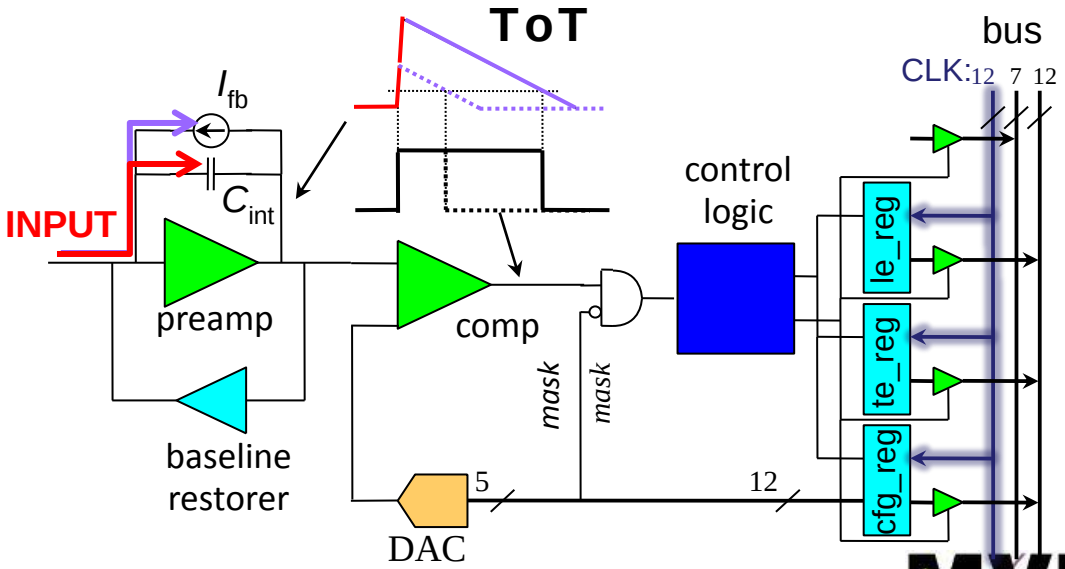
ToPix: Custom made pixel readout chip



Prototype: 320 cells

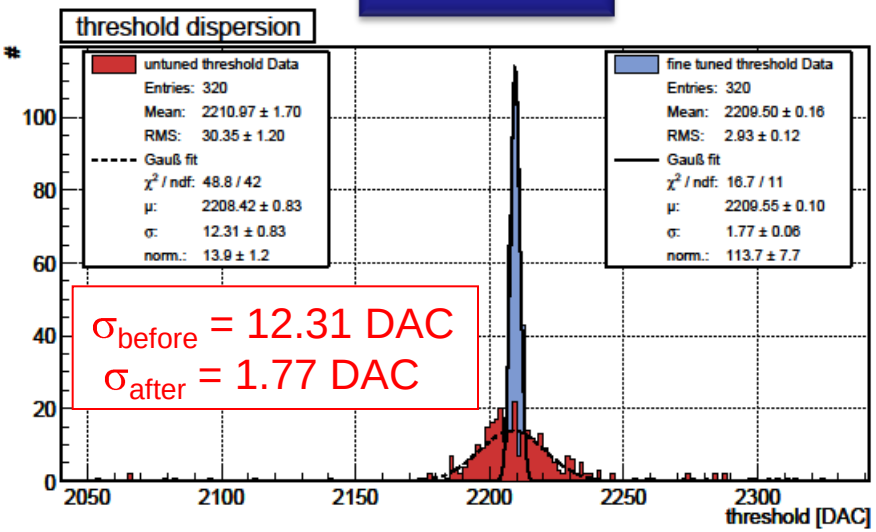




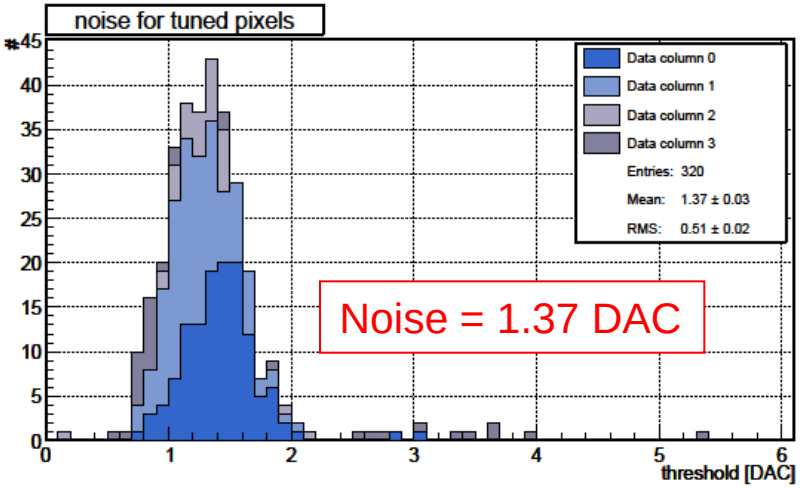


Characterization of ToPix 2

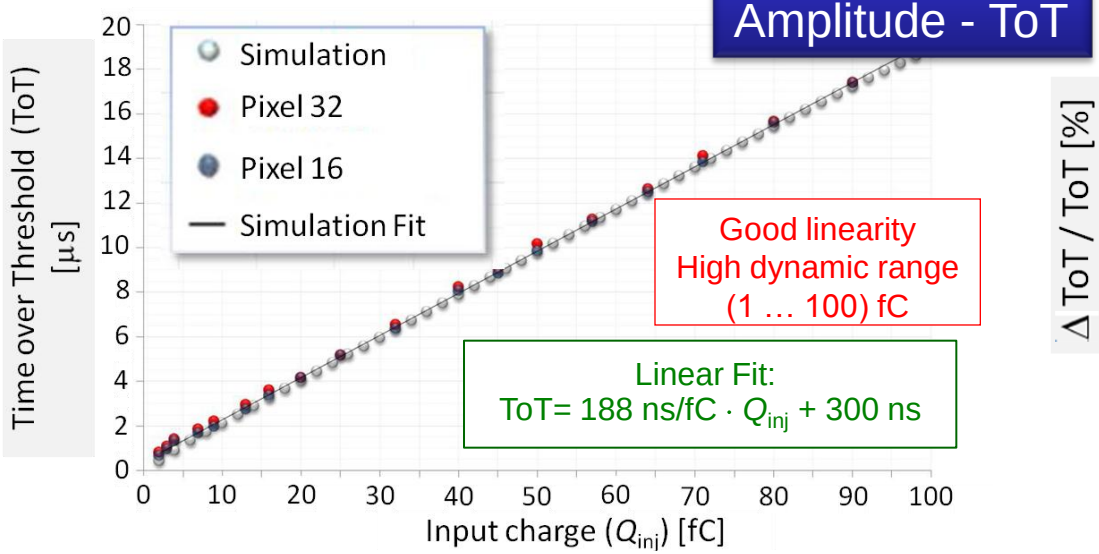
Threshold

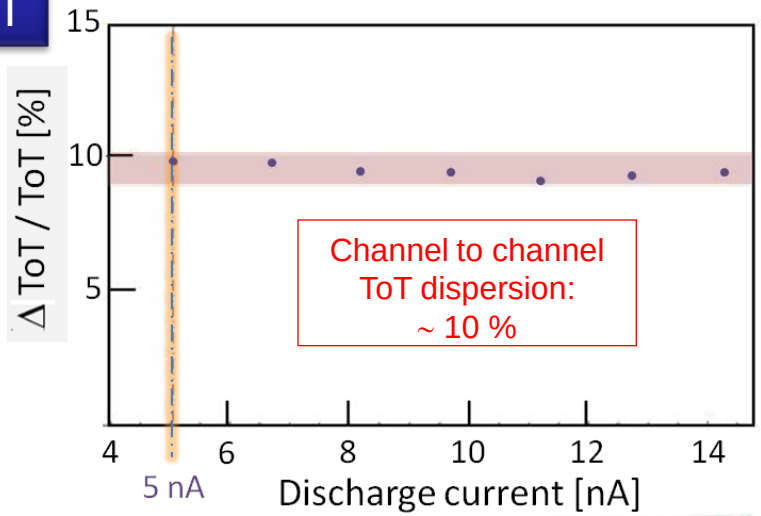


Noise

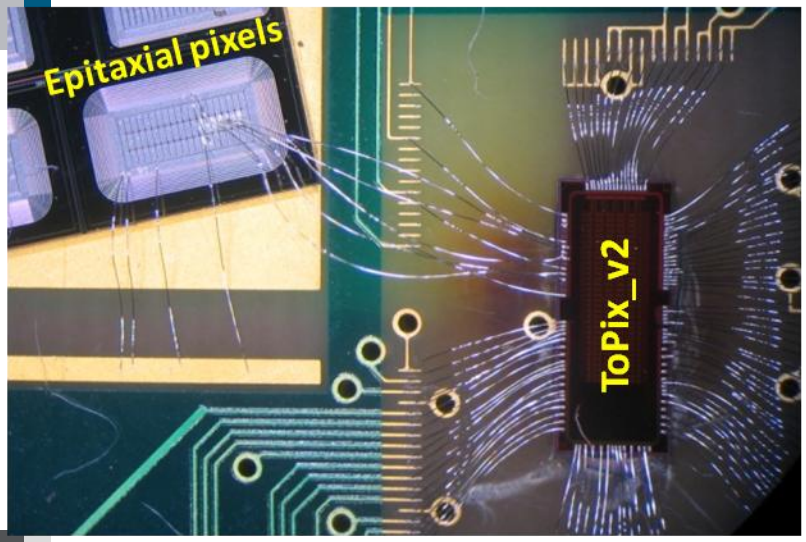


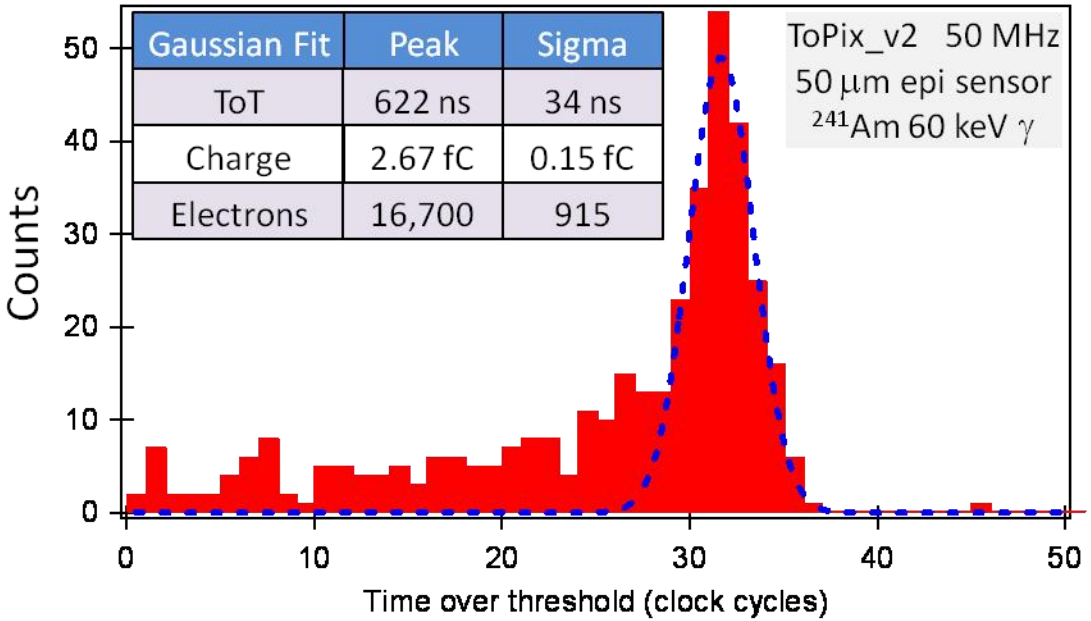
Amplitude - ToT





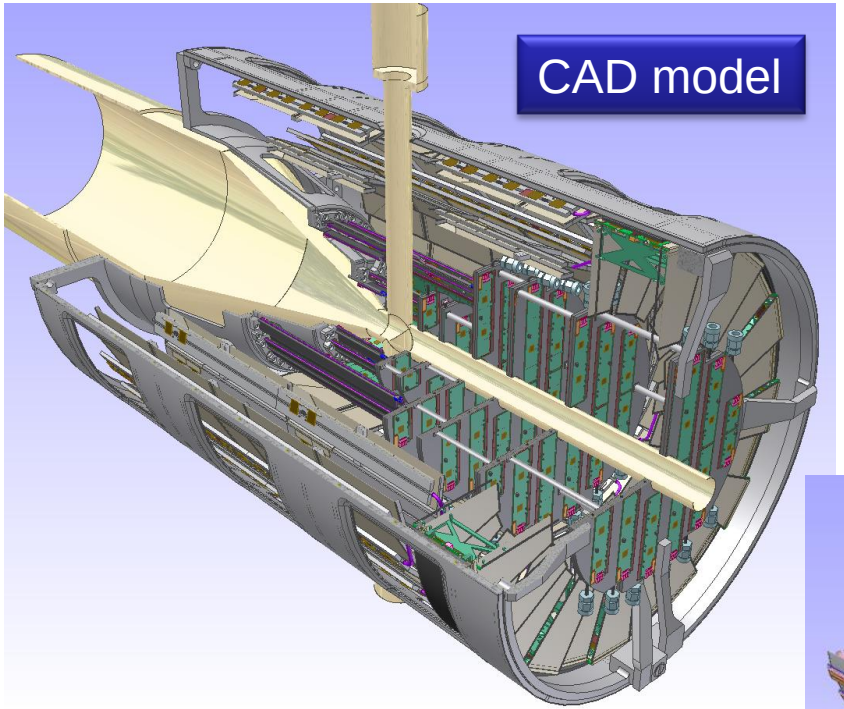
Pixel sensor prototypes with ToPix readout





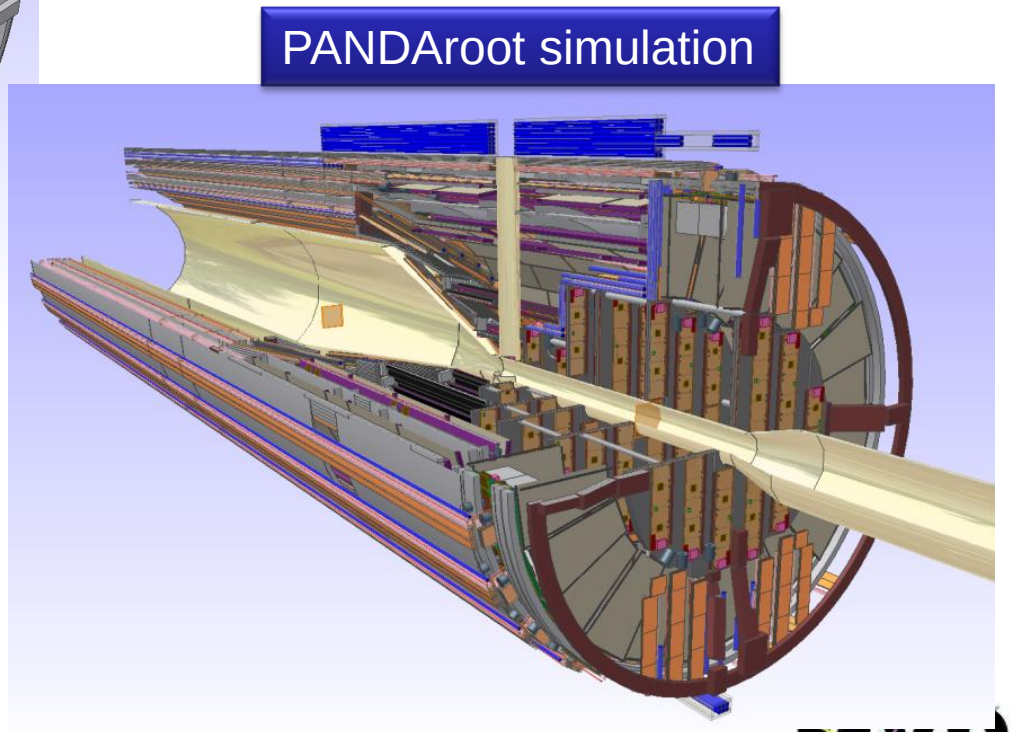
Gaussian Fit	Peak	Sigma
ToT	622 ns	34 ns
Charge	2.67 fC	0.15 fC
Electrons	16,700	915

CAD Converter



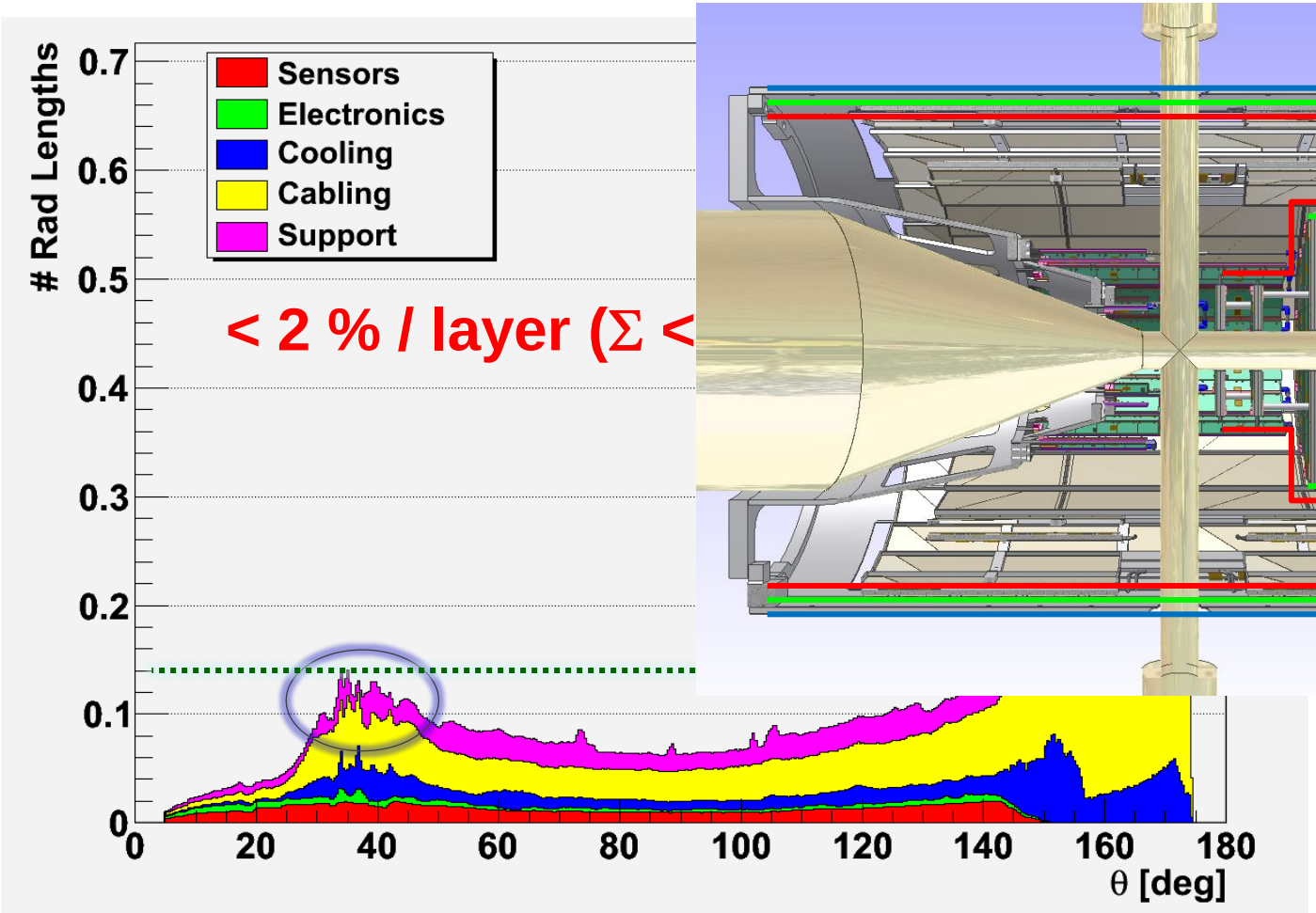
Simulation model includes:

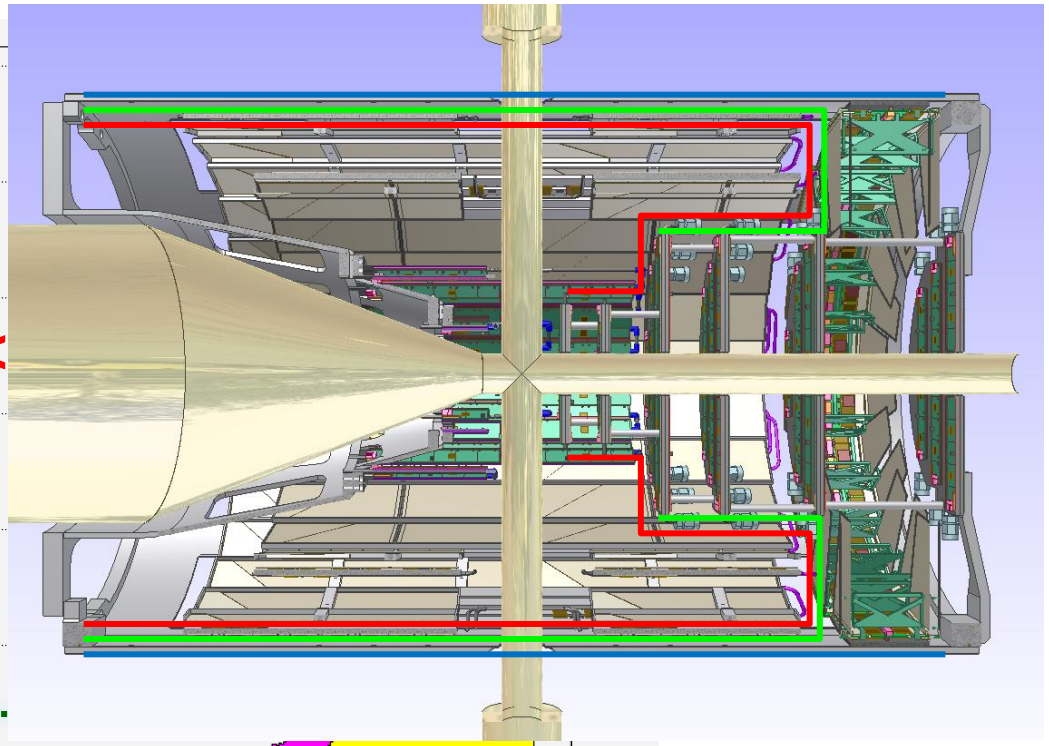
- all silicon components
- support structures
- cooling tubes
- cables, capacitors, resistors
- ...



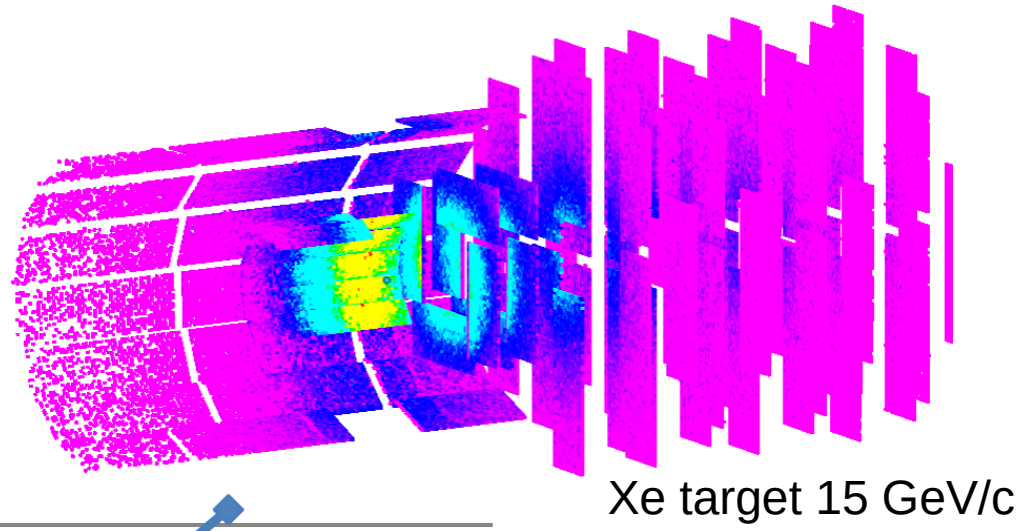
Conversion done with semi-automatic CAD converter

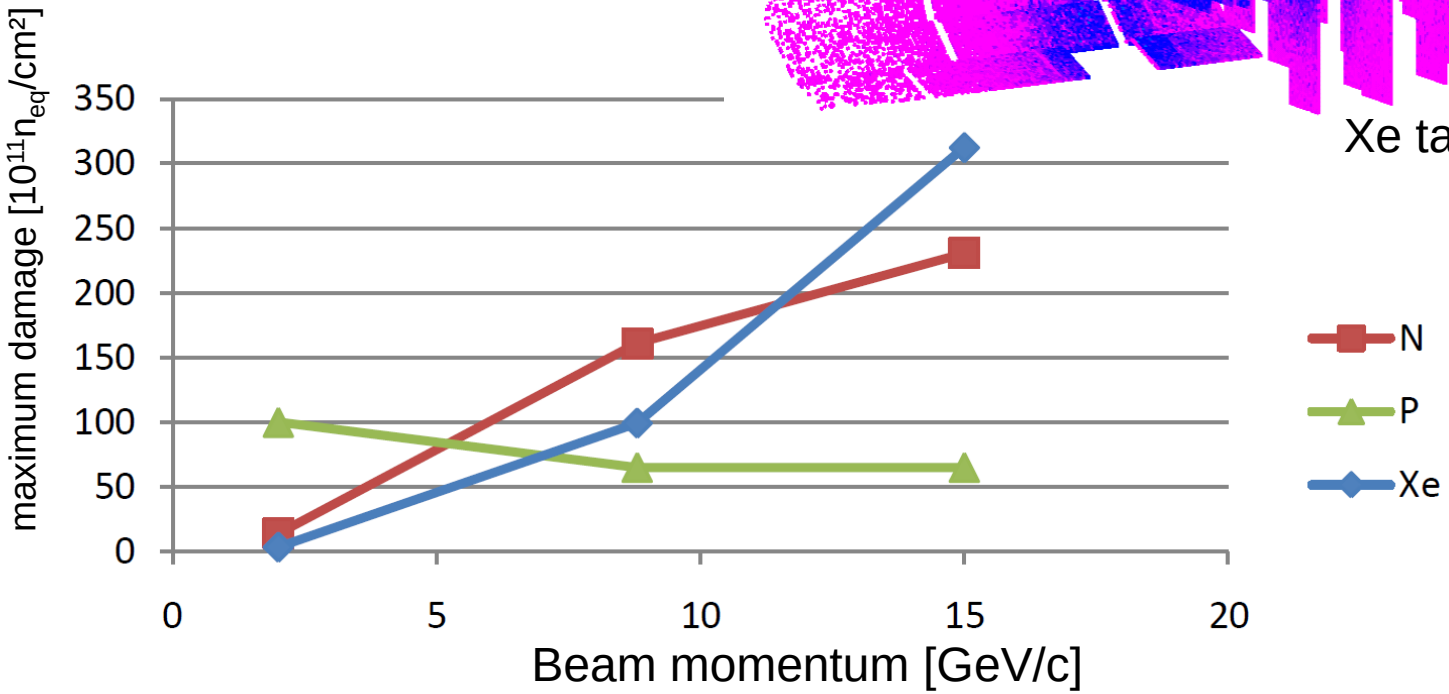
MVD Material Budget





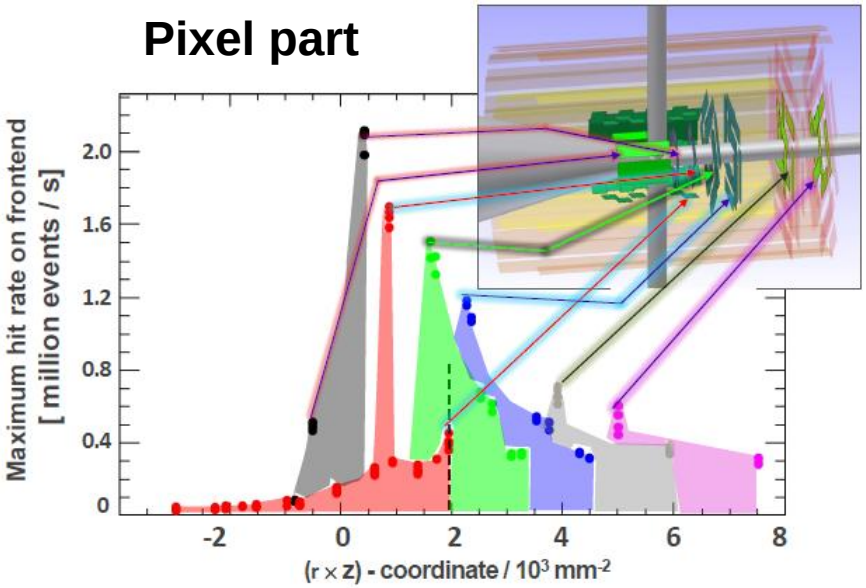
Radiation damage per operation year

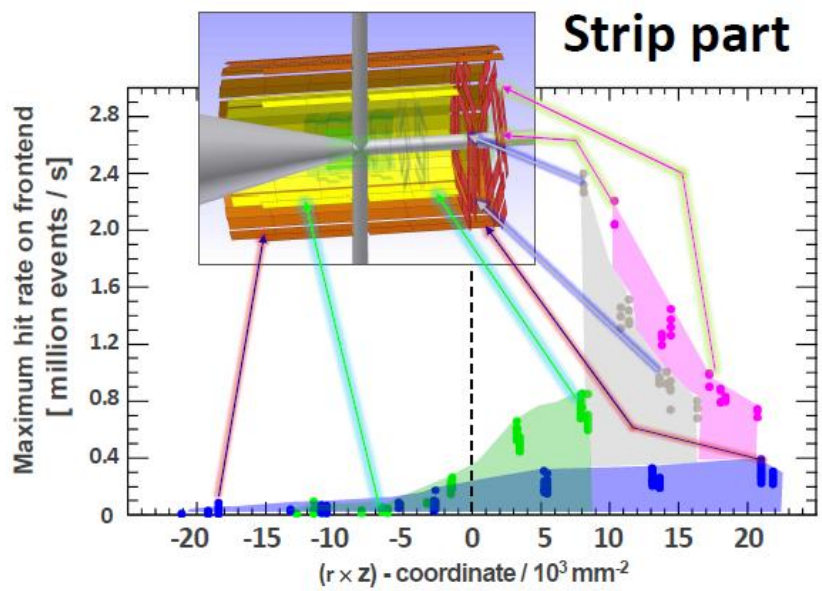




Count rates

15 GeV/c antiproton on proton





- Maximu evts / s
- Integrate / s
- Integrate / s

with 50 bit per hit we have:

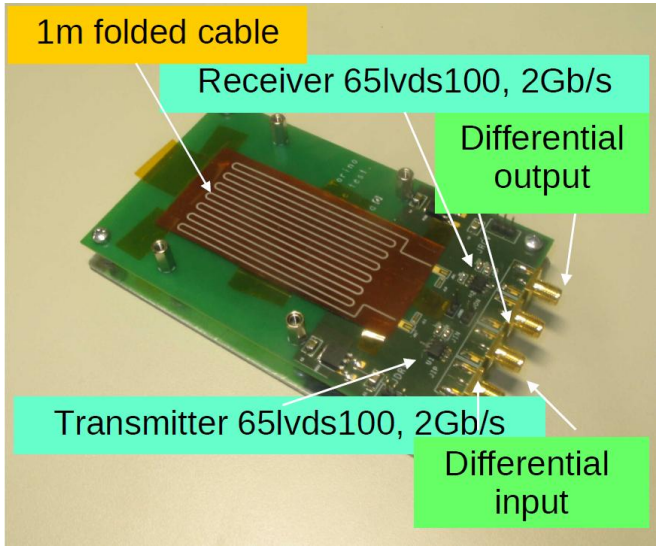
- **500 MBit /s at maximum per FE**
- **150 GBit / s for full MVD**

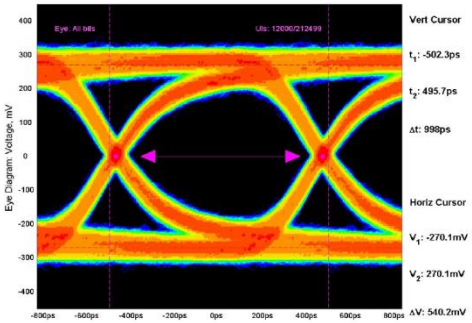
→ Full MVD: 3.0 Gevts / s

Data transmission

- 2 – 3 * 300 MBit/s serial links per FE
- 1 – 2 load balancing chips on each module with 1 GBit/s data transmission
- Aluminium cables with up to 2 GBit / s under study

- Detailed time ordered simulations ongoing



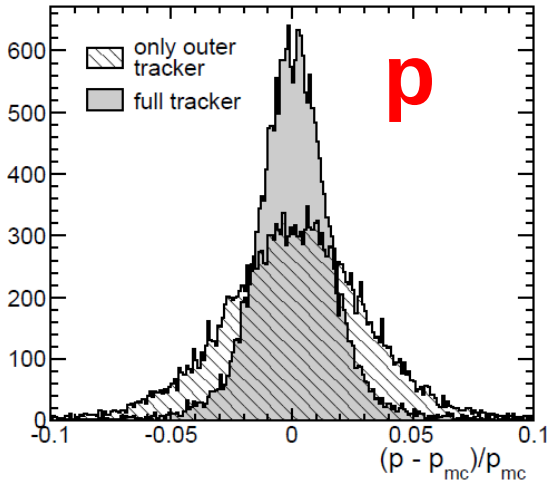


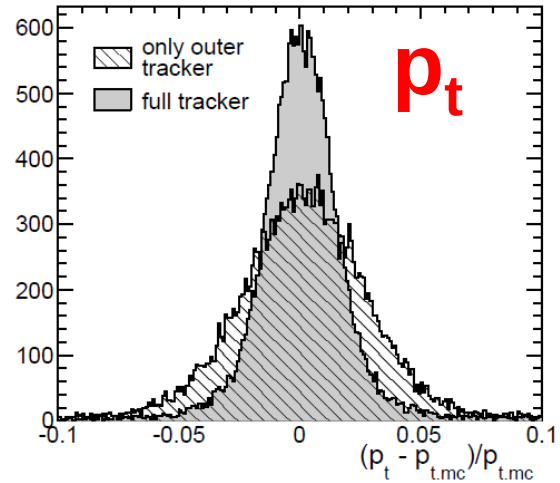
Techfab: 7µm Al on 50 µm Kapton
CERN: 15 µm Al on 70 µm Kapton

Momentum and Track Resolution

Momentum resolution

1 GeV/c pions (0;0;0)





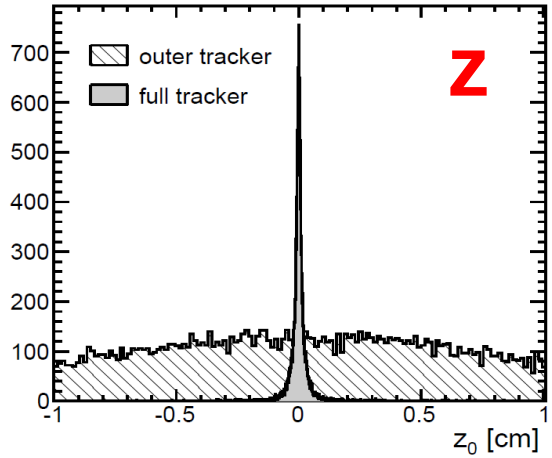
$\sigma(p)$ without MVD = 2.6 %
$\sigma(p)$ with MVD = 1.4 %

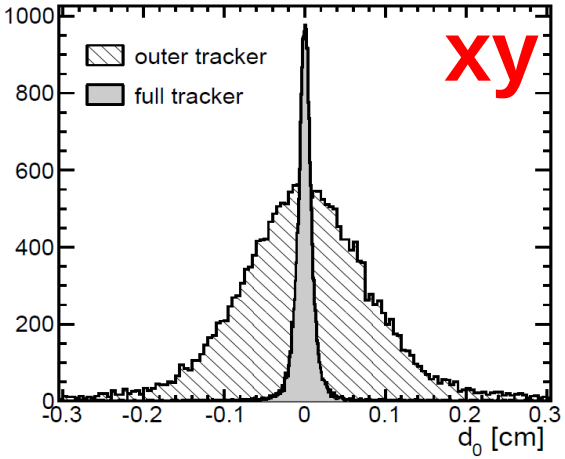
$\sigma(p_t)$ without MVD = 2.9 %
$\sigma(p_t)$ with MVD = 1.4 %

→ Improvement by 50%

Single track resolution

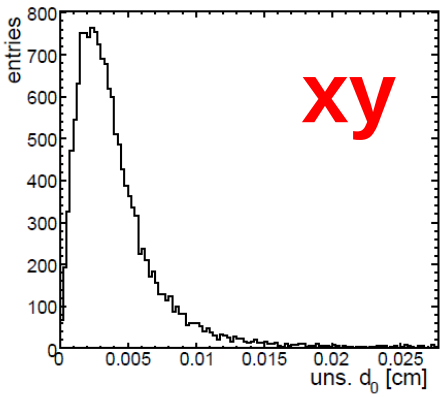
→ No resolution along z without MVD

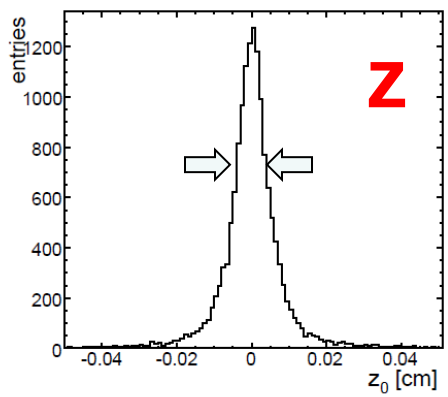


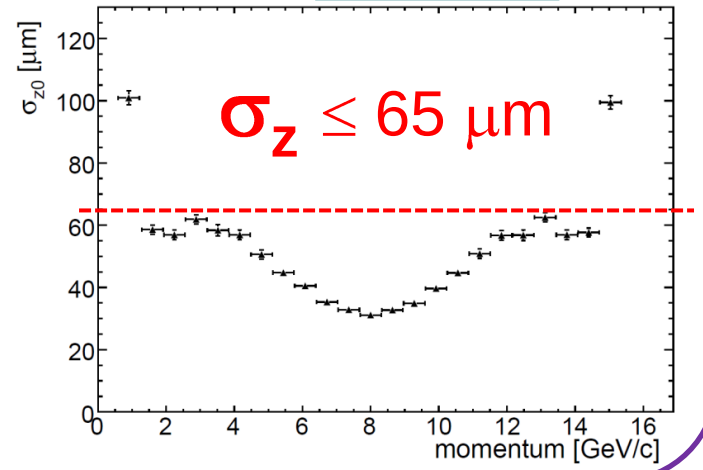


Vertex resolution

Primary vertex resolution $\bar{p}p \longrightarrow \pi^+\pi^-$ 15 GeV/c







Vertex resolution $\bar{p}p \longrightarrow D^+D^-$ (6.57 / 7.50 / 8.50) GeV/c

momentum GeV/c	vertex resolution [μm] primary $\sigma_{prim,x}$	$\sigma_{prim,y}$	$\sigma_{prim,z}$	secondary $\sigma_{sec,x}$	$\sigma_{sec,y}$	$\sigma_{sec,z}$
6.57	30.7	30.7	493.6	35.4	35.2	77.1
7.50	30.4	30.3	208.5	37.1	36.4	84.0
8.50	30.0	29.0	157.4	36.7	36.2	92.4

→ Primary and secondary vertex resolution:

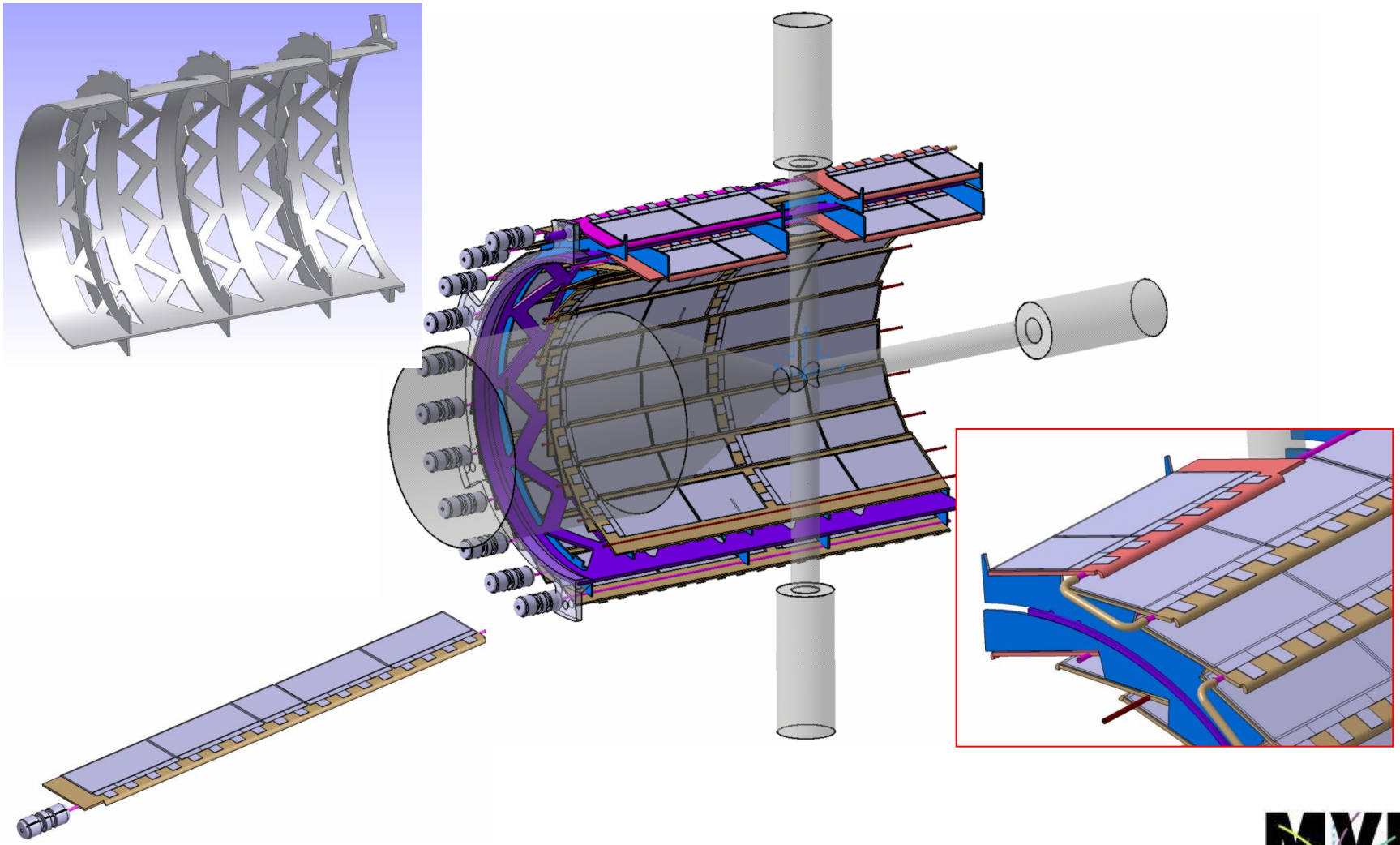
$\sigma_{x,y} \leq 35$ µm

$\sigma_z \leq 100$ µm

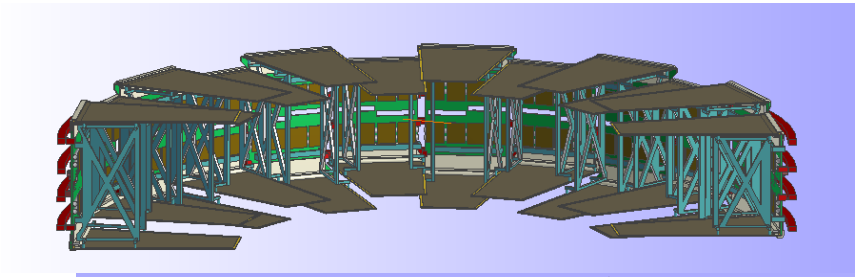
Summary

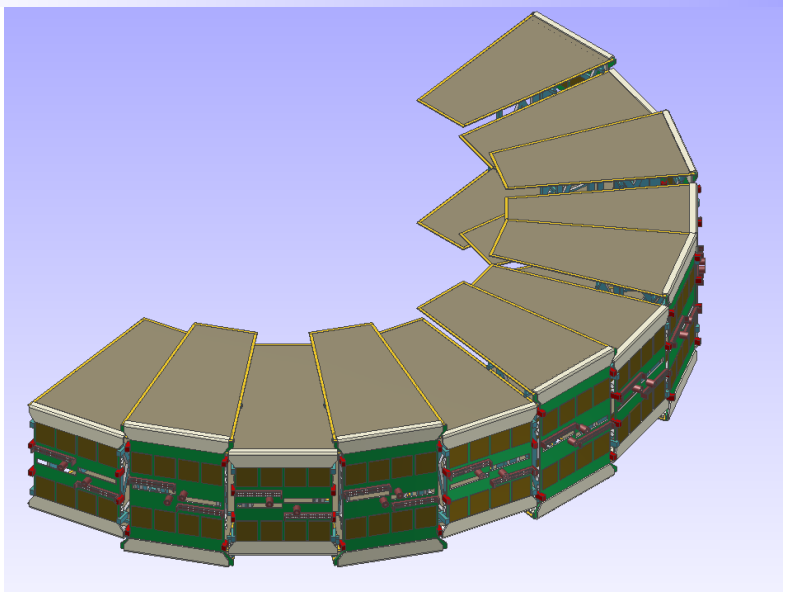
- The Micro-Vertex-Detector is one of the most challenging subdetectors within PANDA
- It faces the highest radiation load, highest hit rates, very stringent requirements on the radiation length and by far the highest number of readout channels
- In the course of the PANDA project a very sophisticated simulation software was (and is still) developed which allows us to optimize all different design parameters of the detector and do realistic simulations of the physics performance
- The hardware development is on a good track and we think that we have the necessary technologies at hand which allows us to build this detector. Nevertheless there is still a lot of work ahead of us

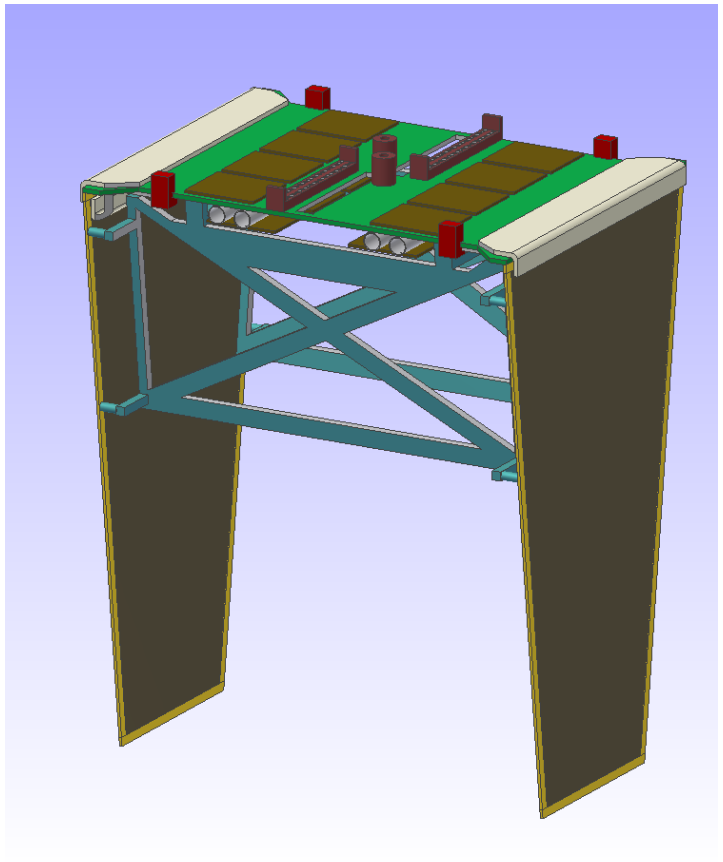
Support Structures Strips - Barrel



Support Structures Strips - Disks

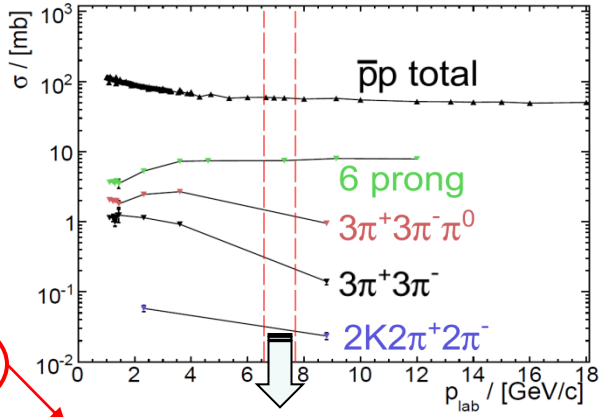






Physics analysis

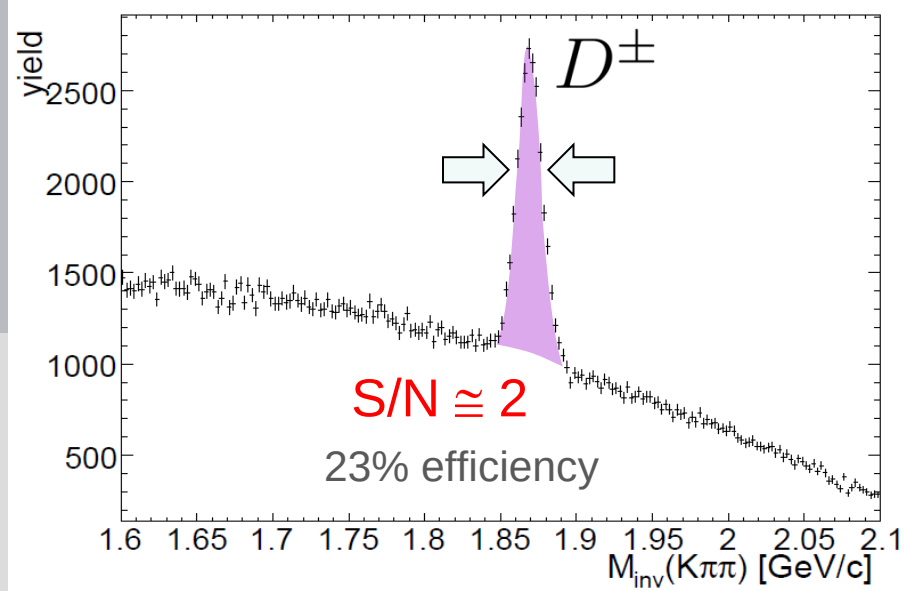
- Physics analysis $\bar{p}p \rightarrow D^+D^-$
  - Reconstruction: $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$

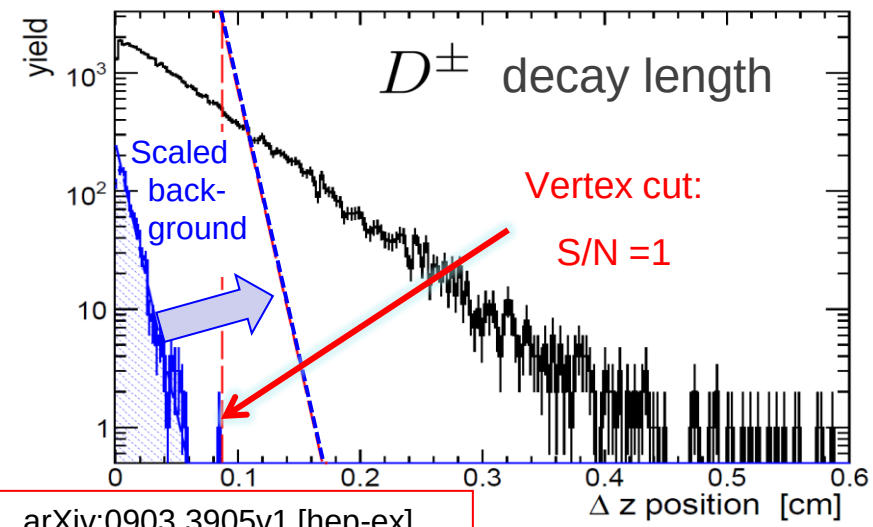


Conservative estimate

$$R = \frac{\sigma(\bar{p}p \rightarrow D^+D^-)}{\sigma(\bar{p}p \rightarrow X)} = \frac{2.83nb \cdot (0.092)^2}{60mb} = 4.0 \cdot 10^{-10}$$

6 orders of magnitude lower

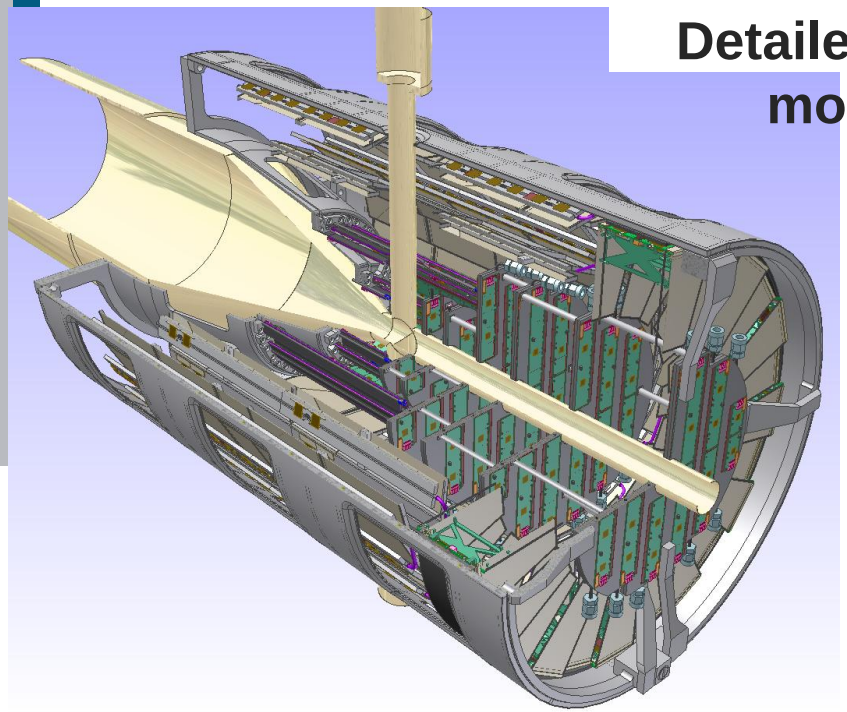


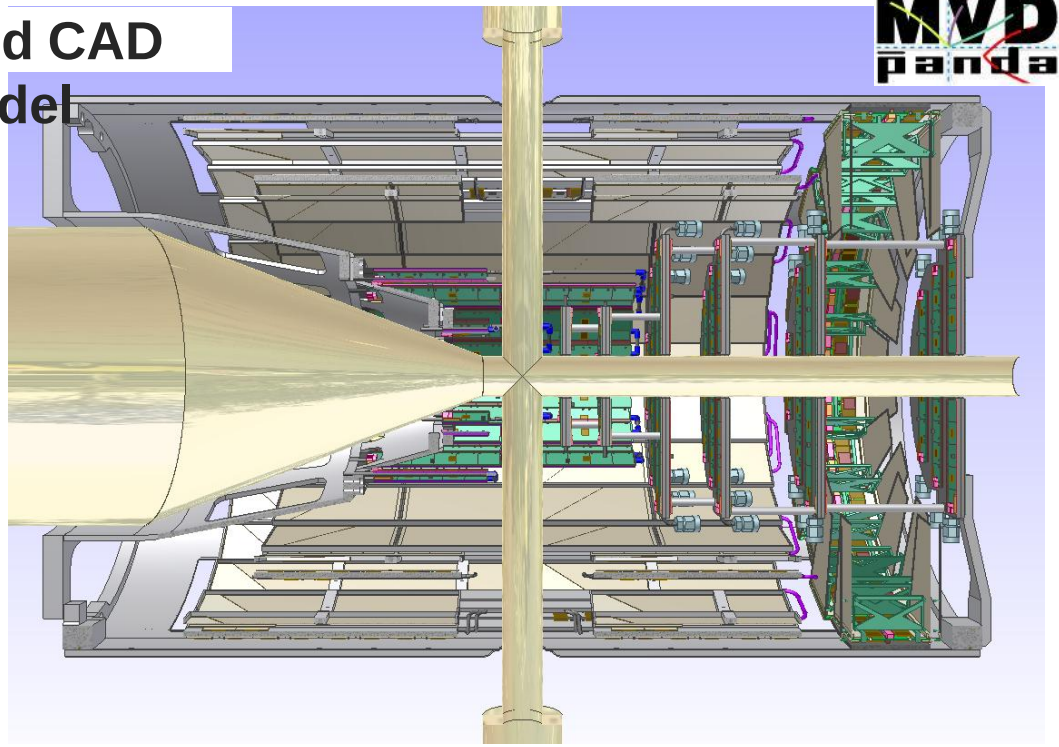


arXiv:0903.3905v1 [hep-ex]

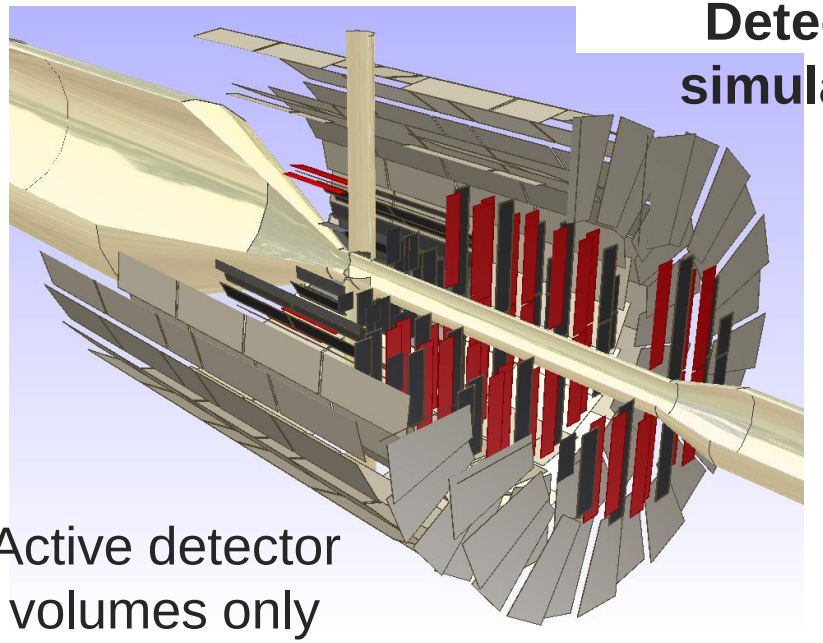
→ Background suppression for open charm channels impossible without MVD

Detailed CAD model

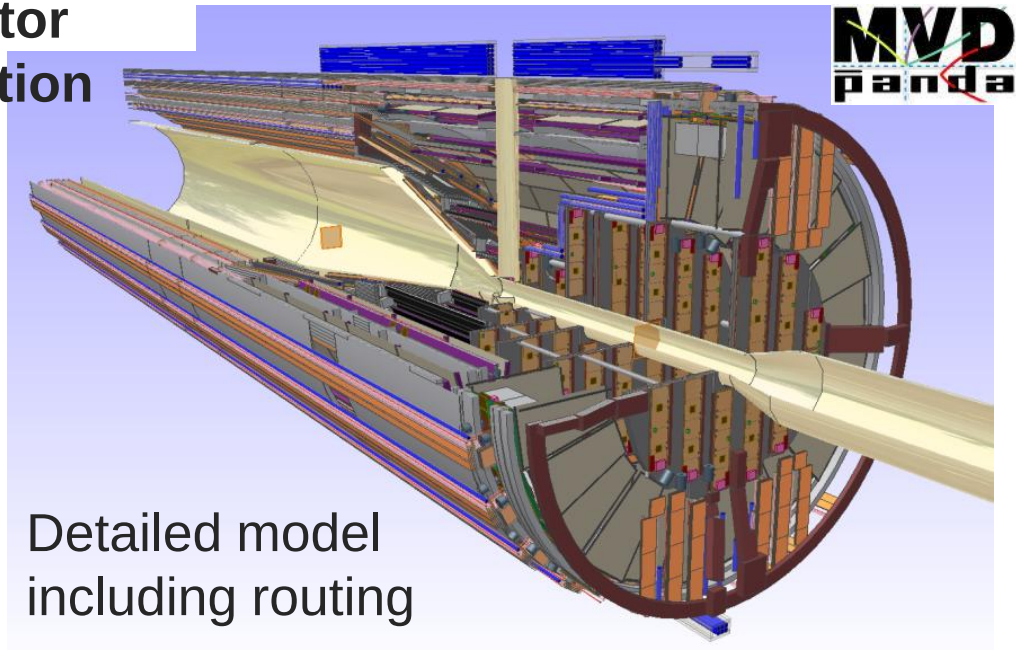




Detector simulation

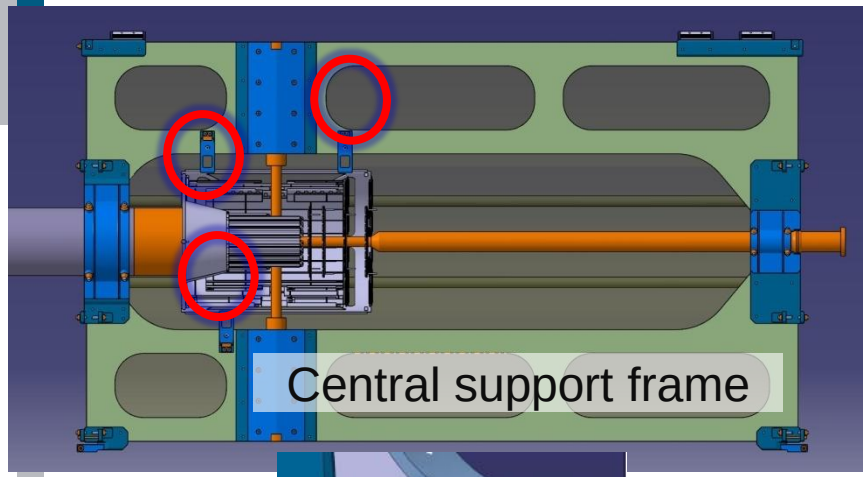


Active detector volumes only



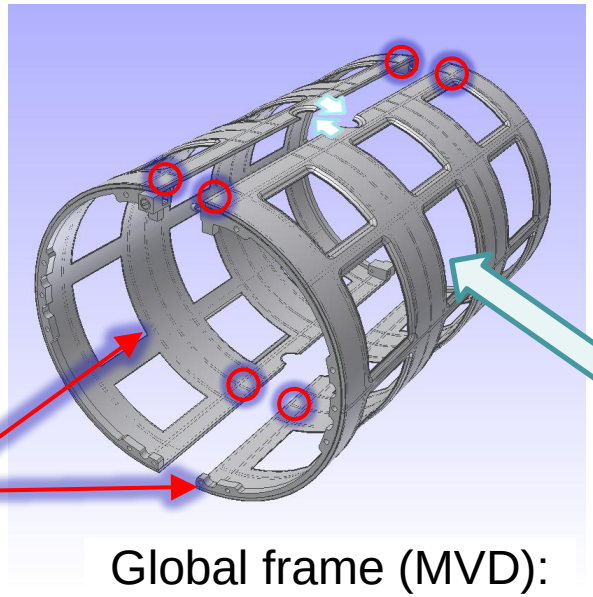
Detailed model including routing

Overall detector integration



3 point fixation

MVD attachment



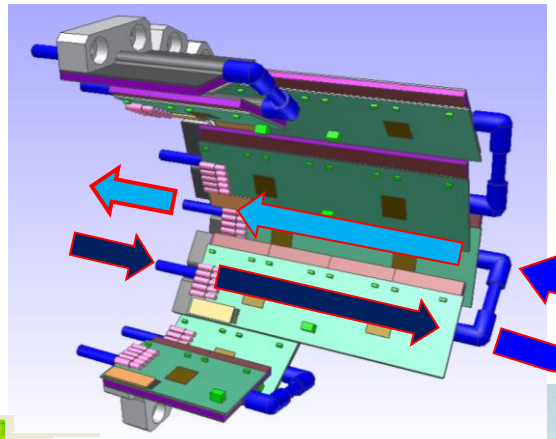
Global frame (MVD): 2 halves

Main MVD parts

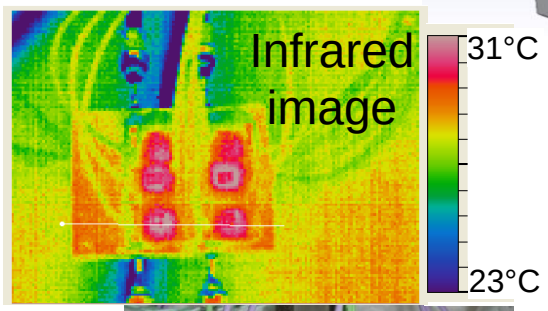
- 2 pixel half-barrels
- 2 strip half-barrels
- 6 pixel half-disks
- 2 strip half-disks

Cooling

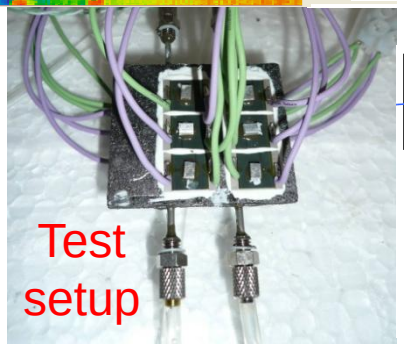
- Cooling concept
  - Coolant: Water (18°C)
  - Vacuum-operated mode using hydrostatic pressure
  - Active part: $\varnothing_{ext}$ 2 mm pipe (Ni-Co alloy)
  - Upstream routing: $\varnothing_{ext}$ 4 mm flexible plastic pipes



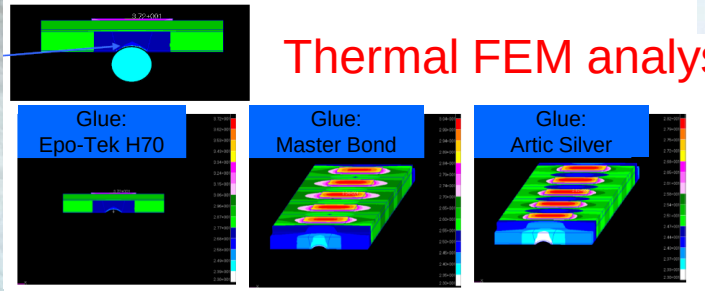
Barrel layer



Micro fittings: Thermoplastic resin

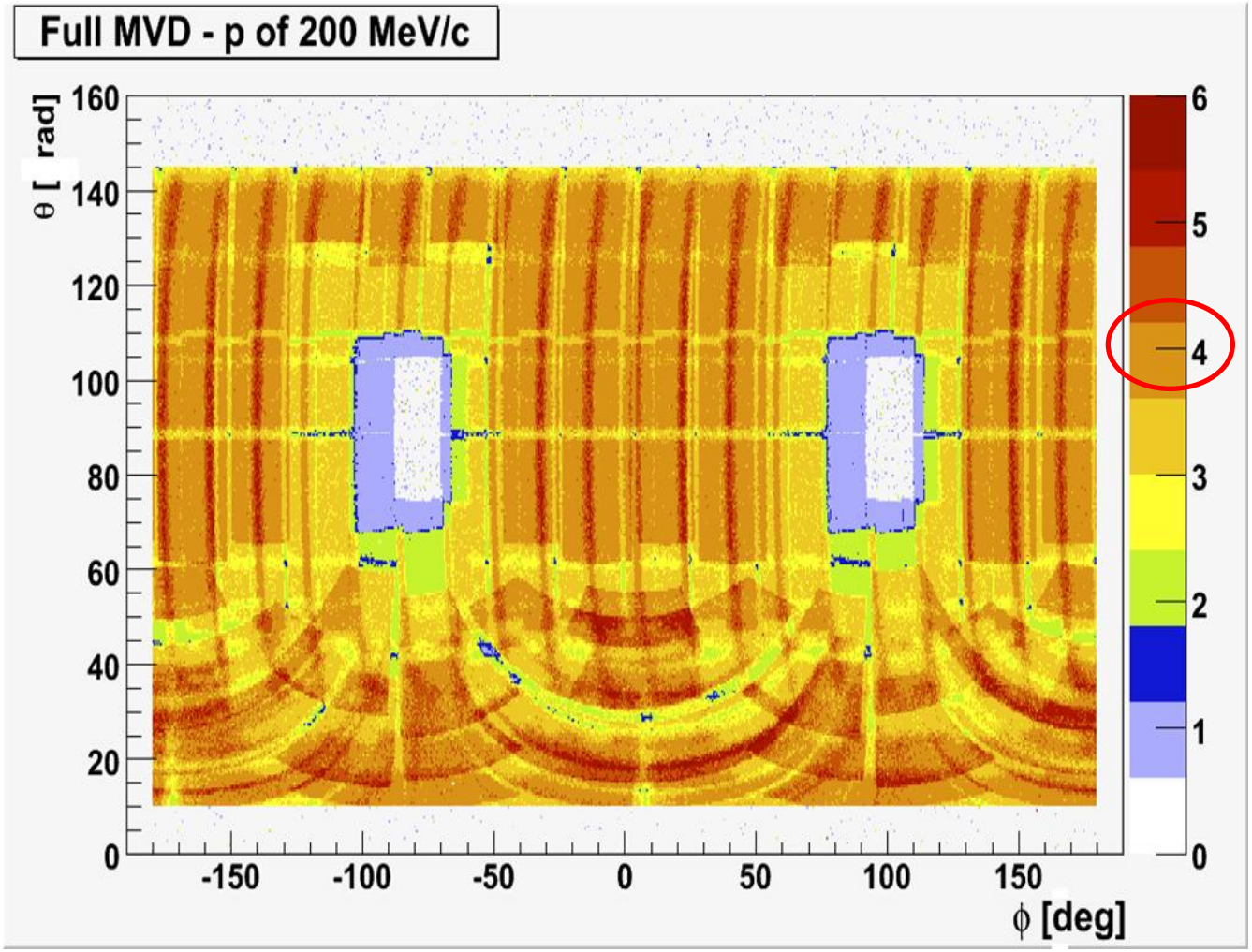


Test setup



Thermal FEM analysis

MVD Coverage



Aim is to have on average 4 hit points per track to do independent tracking

The PANDA Collaboration

More than 400 physicists from 55 institutions in 17 countries

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IHEP Beijing
U Bochum
U Bonn
U & INFN Brescia
U & INFN Catania
U Cracow
GSI Darmstadt
TU Dresden
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