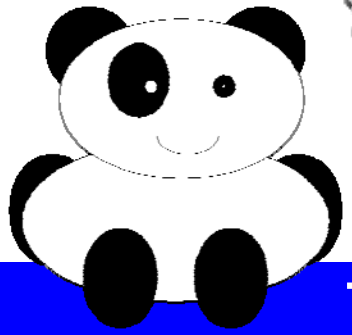
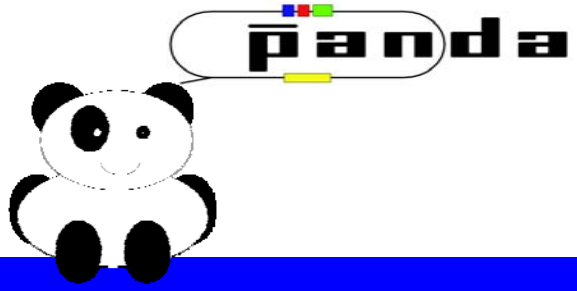


# The silicon Micro Vertex Detector of the PANDA experiment

D. Calvo on behalf of the PANDA collaboration

12° Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba, Italy, May 20-26, 2012




# Overview

Introduction to the
Micro Vertex Detector

- The layout optimization
- Prototype results
- Conclusions

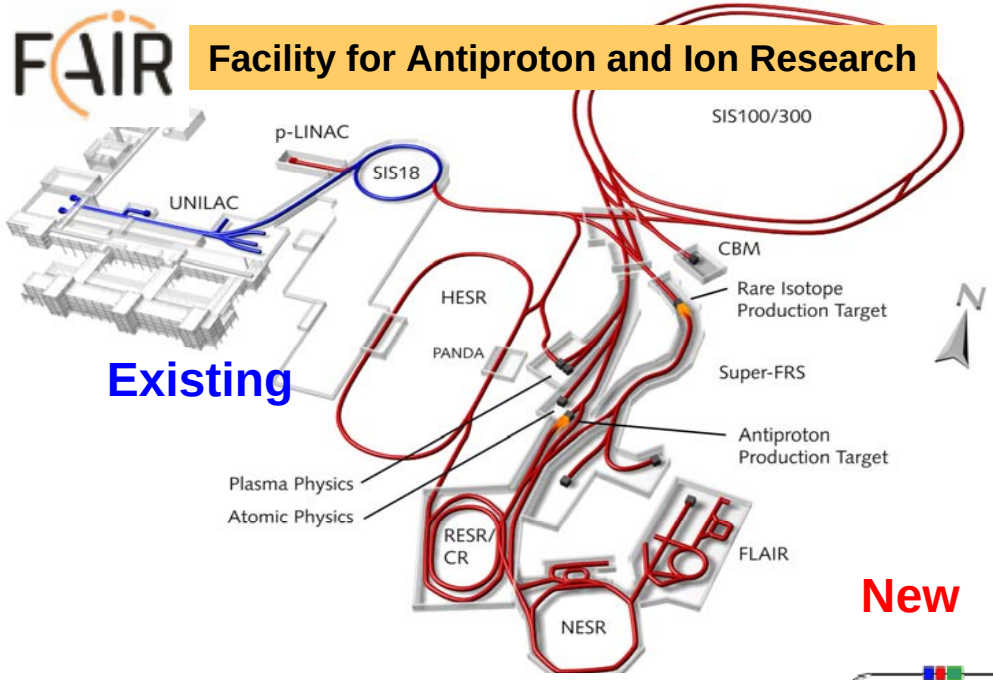
D. Calvo


# Introduction

D. Calvo

# FAIR and PANDA

**Facility for Antiproton and Ion Research**

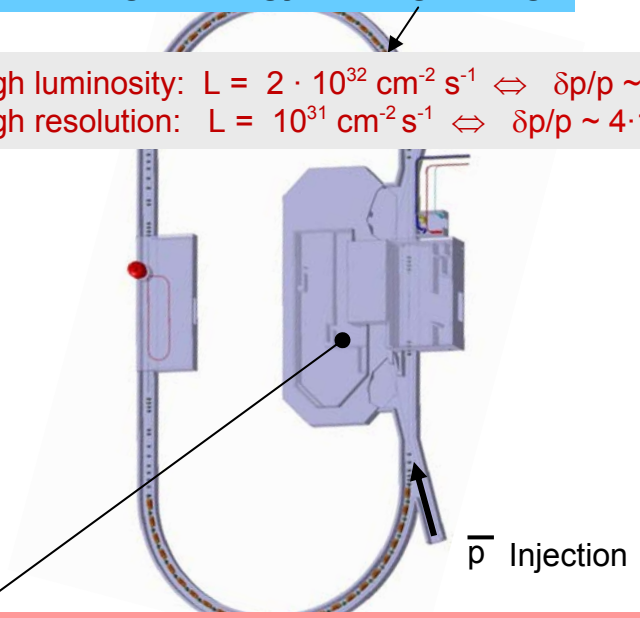



**Existing**

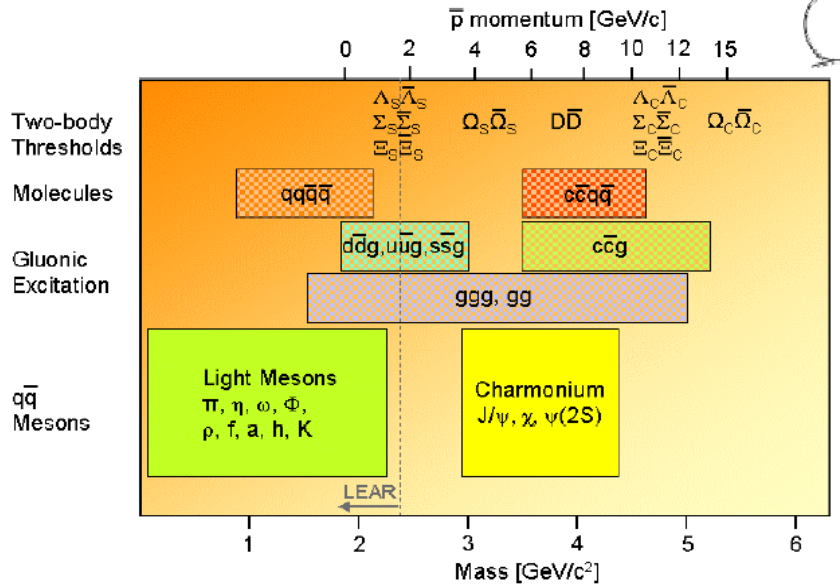
**New**

**HESR – High Energy Storage Ring**

High luminosity: $L = 2 \cdot 10^{32}\ cm^{-2}\ s^{-1} \Leftrightarrow \delta p/p \sim 10^{-4}$
High resolution: $L = 10^{31}\ cm^{-2}\ s^{-1} \Leftrightarrow \delta p/p \sim 4 \cdot 10^{-5}$



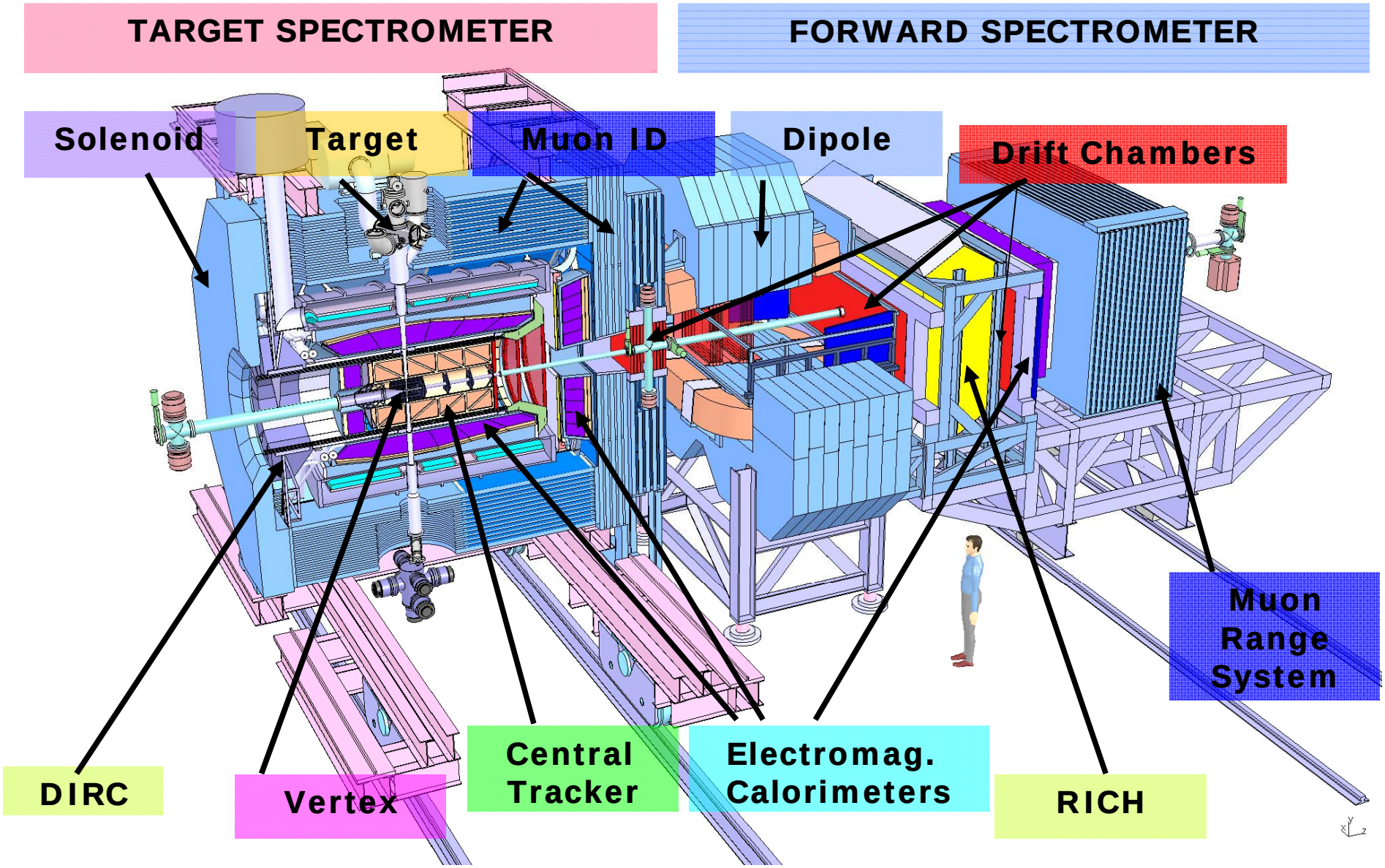

**Antiproton Annihilations at Darmstadt**




**Apparatus requirements**:

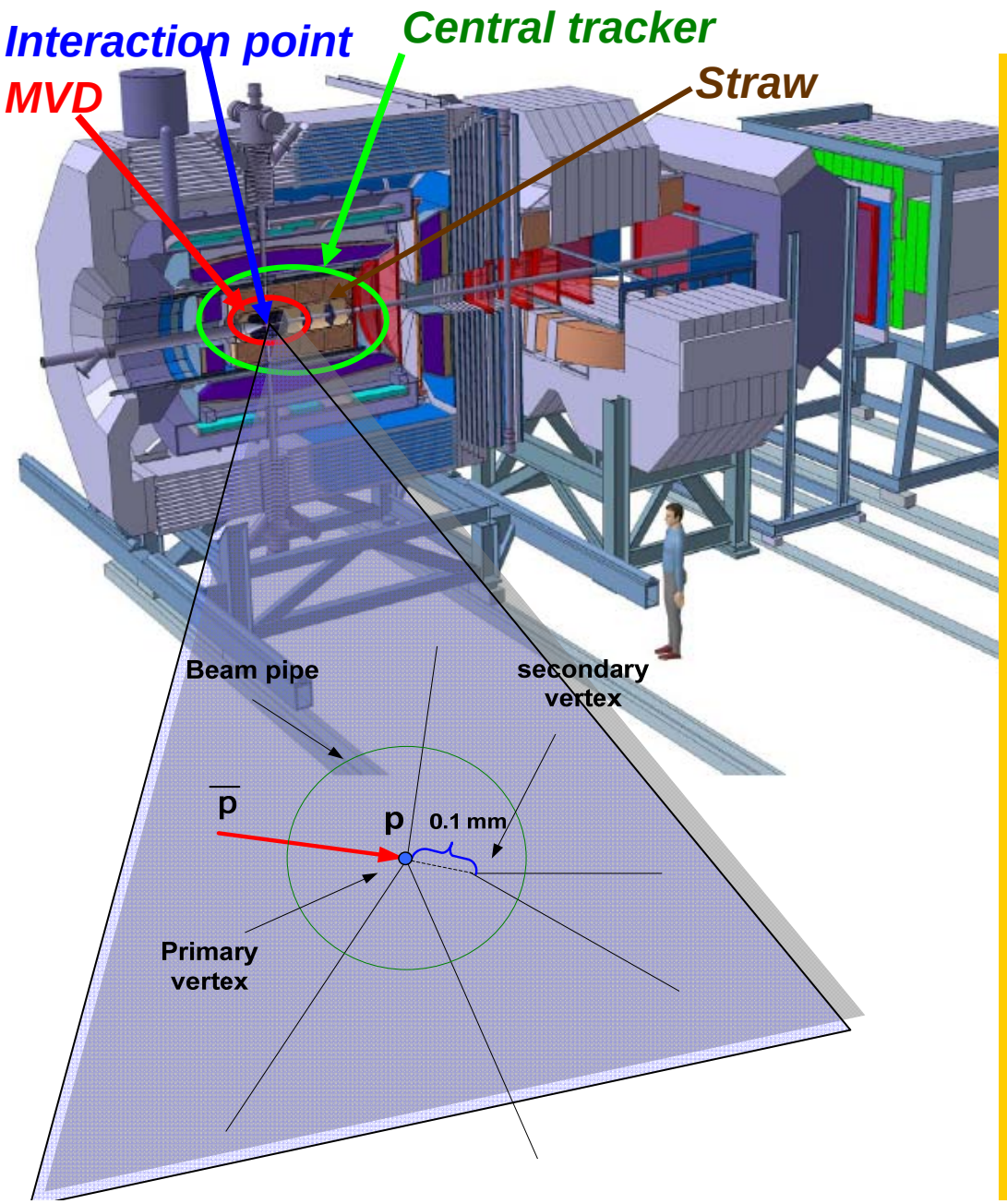
- Nearly 4π acceptance
- High rate capabilities ($2 \cdot 10^7$ pbar-p annihilations /s)
- Continuous readout and efficient event selection
- Momentum resolution (1%)
- Vertex info for D, $K^0_s$, Λ ($c_\tau$ = 317 μm for $D^{+,-}$)
  - good tracking
- Good PID (γ, e, μ, π, k, p) with Cherenkov, TOF, dE/dx
- γ-detection 1 MeV – 10 GeV with Crystal Calorimeter

# PANDA



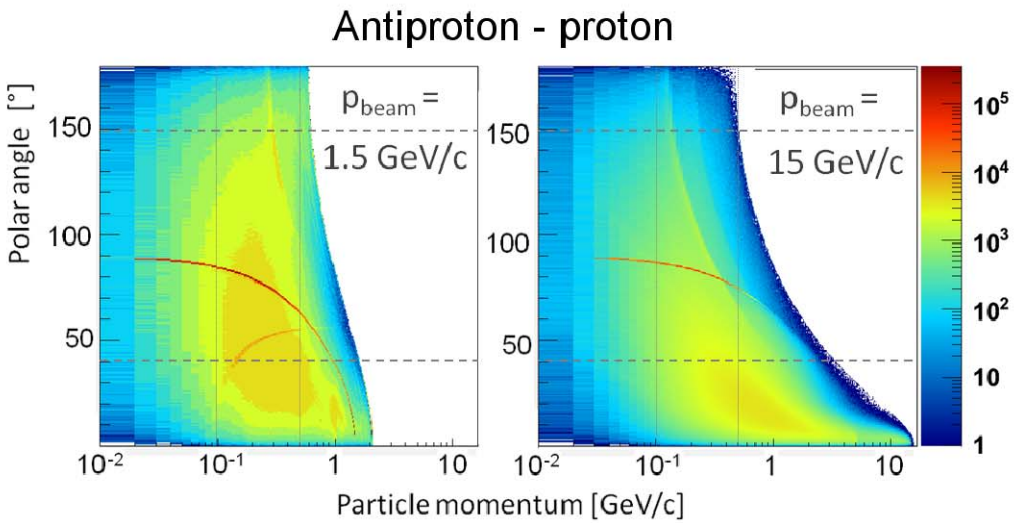

PANDA is a fixed target experiment with frozen hydrogen pellet and heavier nuclear targets (N, Ar…)

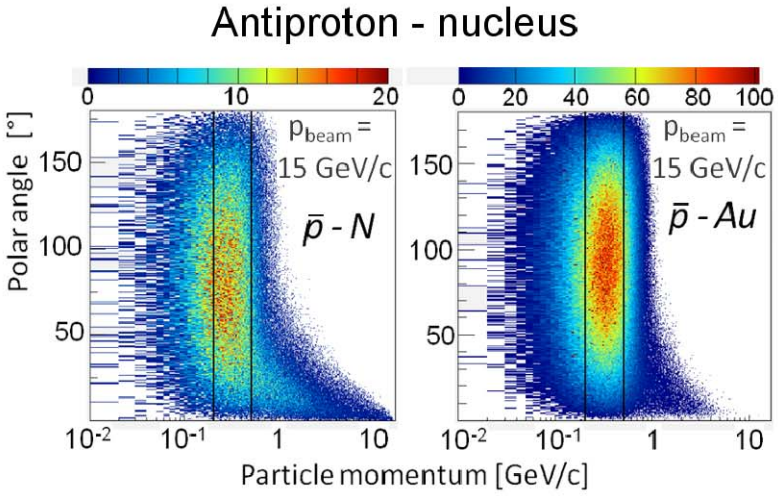
# Towards the Micro Vertex Detector

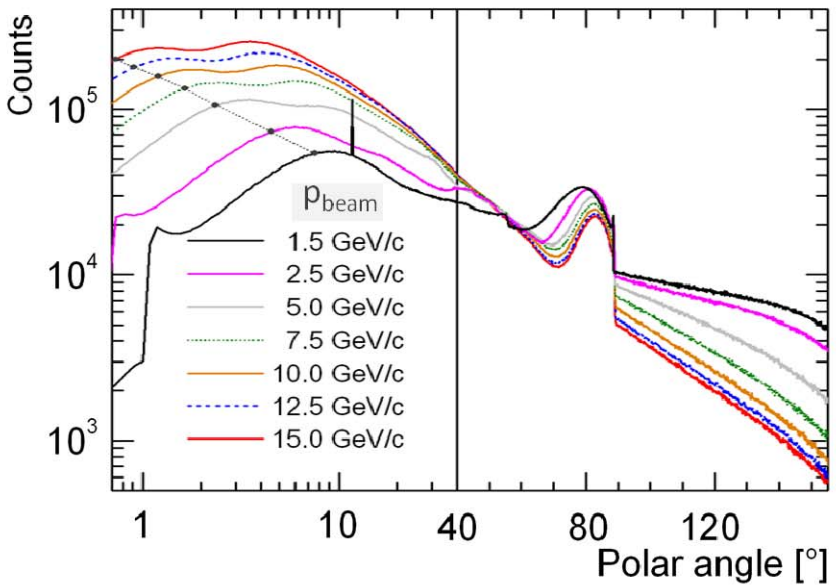


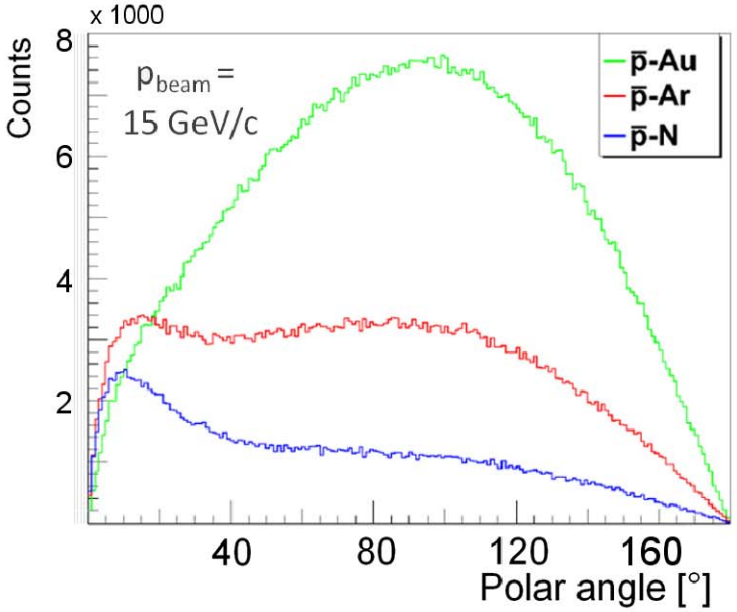

- Good spatial resolution in r-phi
  - Momentum measurement of soft pions from D* decays
- Good spatial resolution especially in z
  - Vertexing, D-tagging
- Good time resolution
  - O(20ns) with $2 \cdot 10^7$ ann/s
- Triggerless readout (155.52 MHz clock)
- Energy loss measurement
  - dE/dx for PID
- Low material budget
  - low momentum of particles (from some hundreds of MeV/c) (<1% $X_0$ for each layer)
- Radiation hardness (O($10^{14}$ n $_{1MeV\ eq}$ /$cm^{2)}$ ) Depends on target
  - Different radiation load

# Towards the Micro Vertex Detector

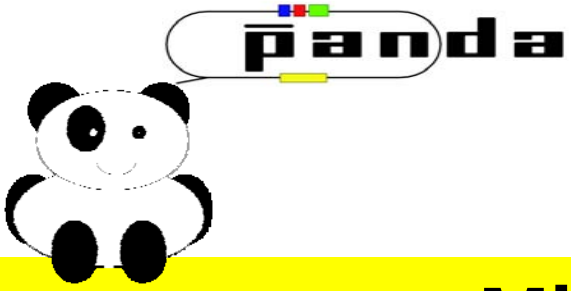



Particle distribution with enhanced emission in forward direction (light target) and low-energetic particles (< 1 GeV/c) in full polar angle




# Micro Vertex Detector

universitätbonn

Fachhochschule
Südwestfalen

INFN
Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DI TORINO

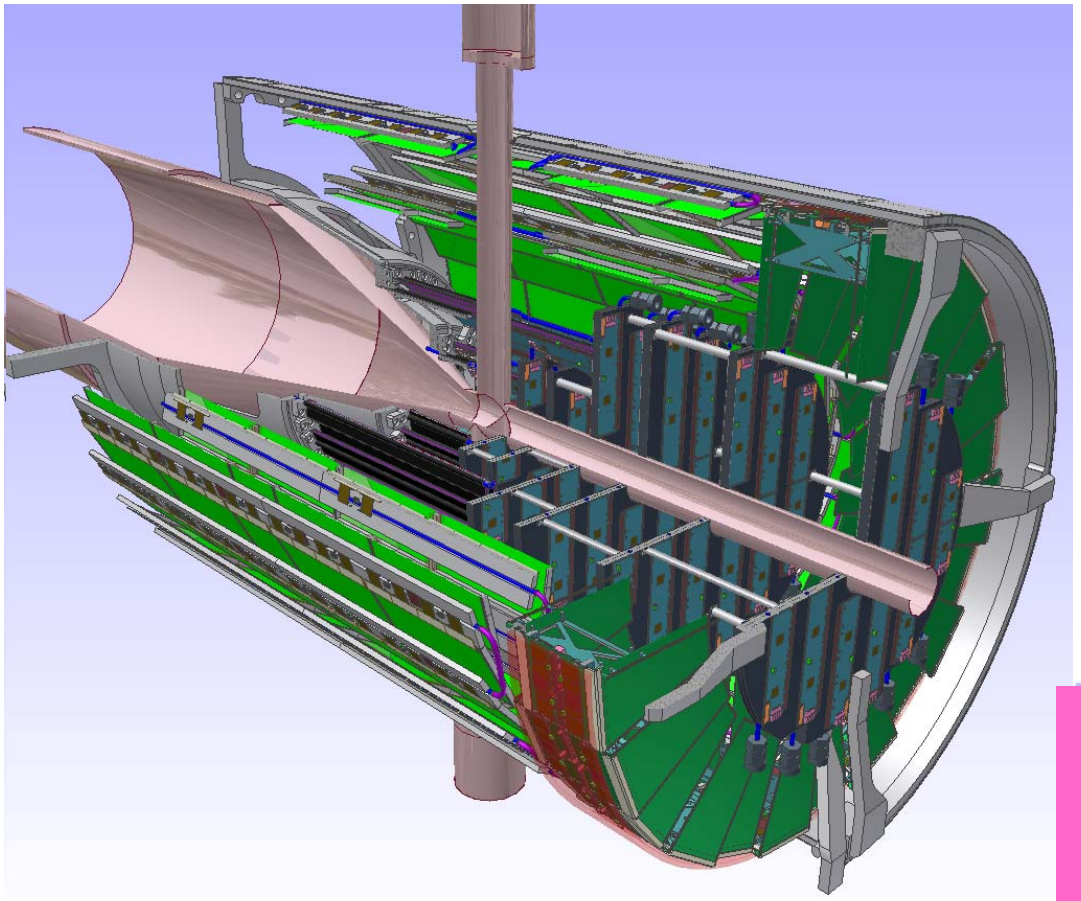
JÜLICH
FORSCHUNGSZENTRUM

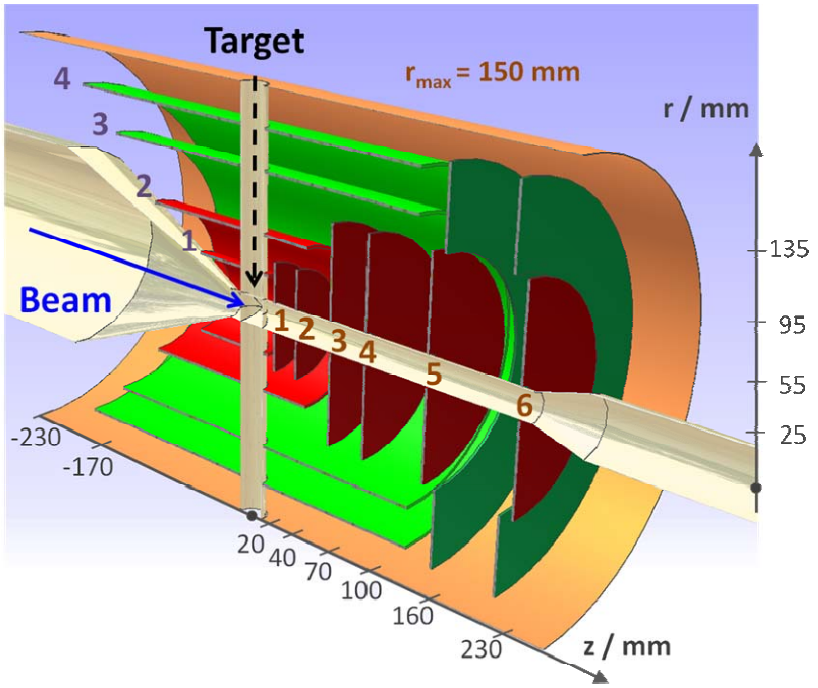
JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

D. Calvo

INFN
ISTITUTO NAZIONALE DI FISICA NUCLEARE

# MVD layout





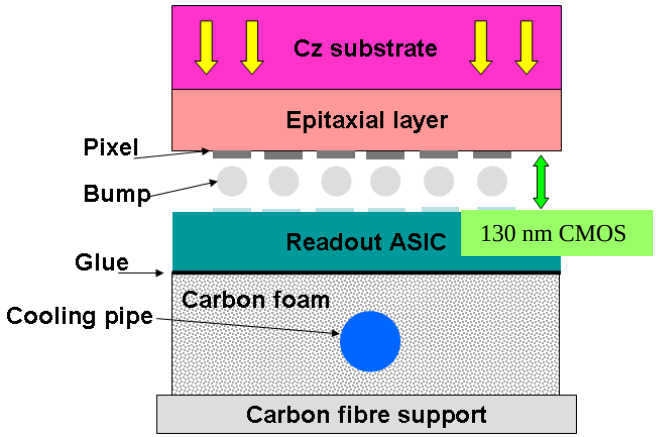

Readout channels:
~ 11 million (pixel)
~ 200.000 (strip)

**4 barrels**
*Two inner layers*:
**hybrid pixel detectors**
*Two outer layers*:
**double side silicon strip detectors**

and **6 forward disks**
*Four disks*:
**hybrid pixel detectors**
*Then two disks*:
**Mixed pixel and strips**

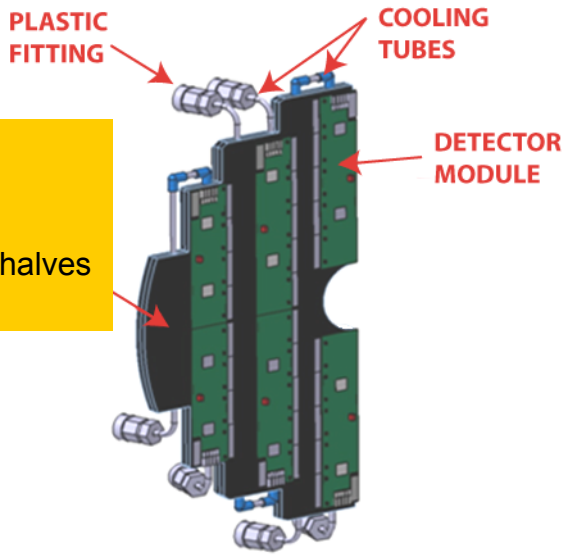
# Hybrid pixel detector

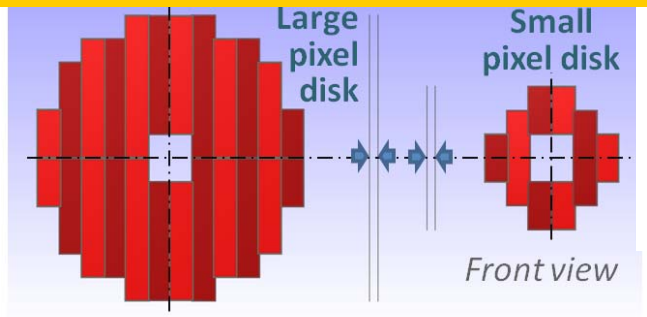
## Standard hybrid technology

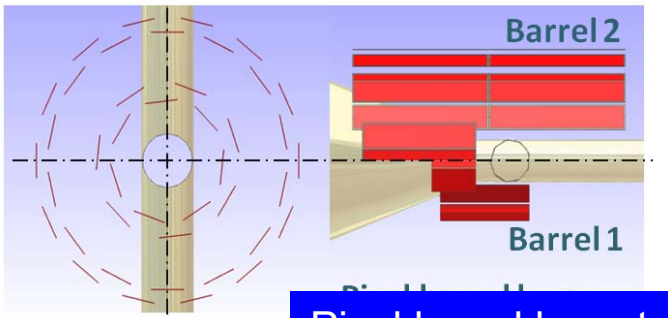



## Pixel disk layout

- Disk split in two halves along the mid-plane
- Material for heat dissipation:
  foam POCO-HTC
- Embedded cooling capillary between the two halves
- All elements glued with thermal glue

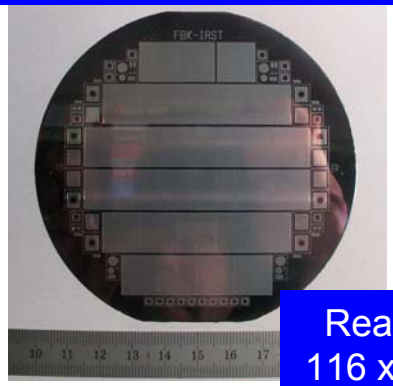


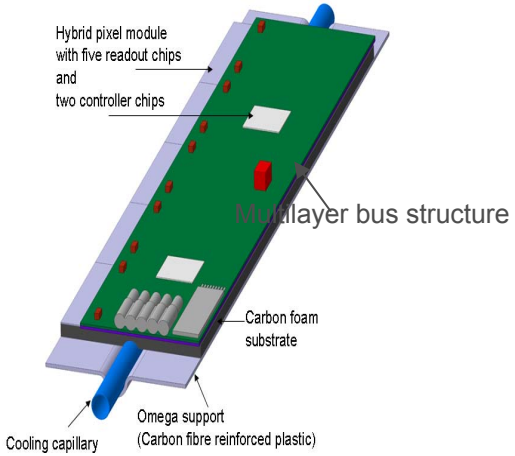




## Pixel barrel layout

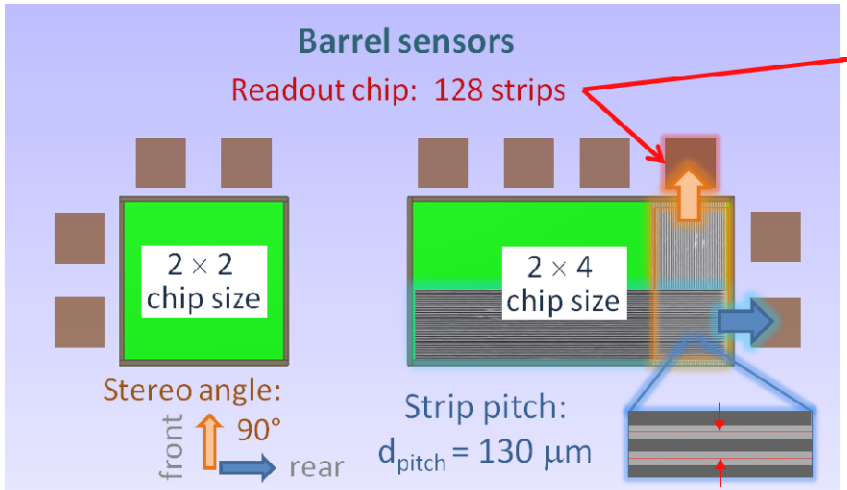
## Pixel sensor size
## Pixel cell size 100 x 100 $\mu m^2$
## 100 $\mu m$ thickness

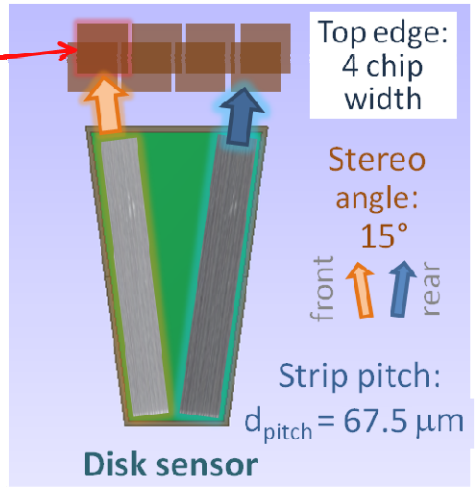


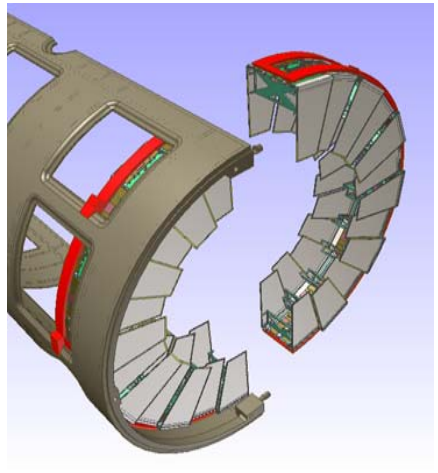
## Readout chip:
## 116 x 110 pixels

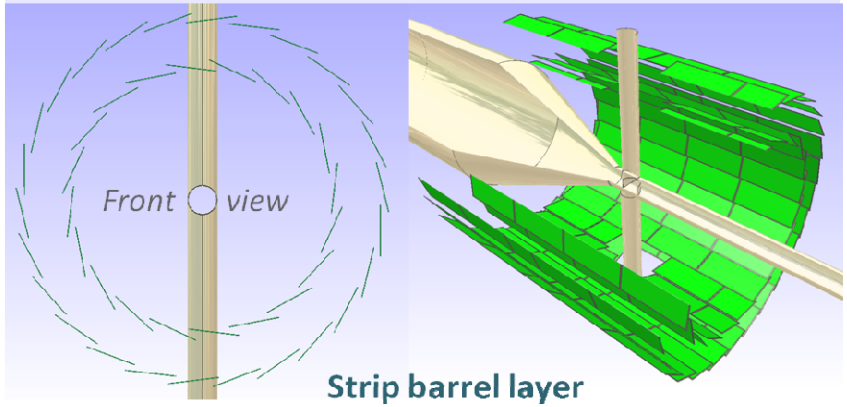


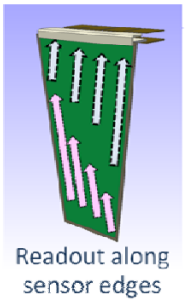
# Double side silicon strips

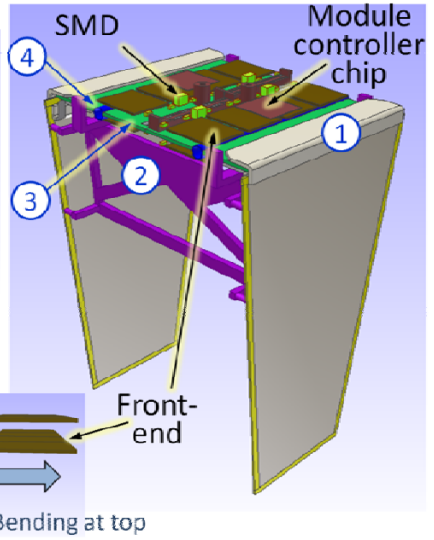


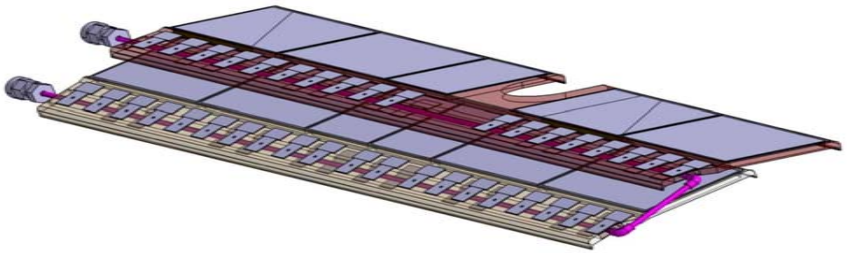





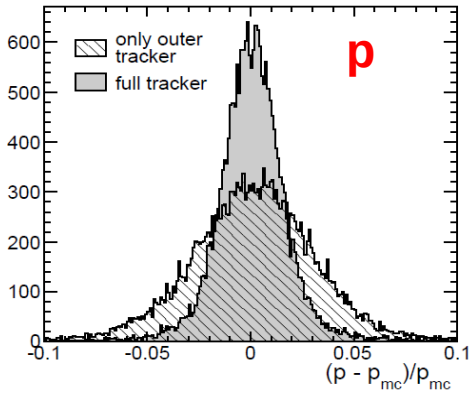



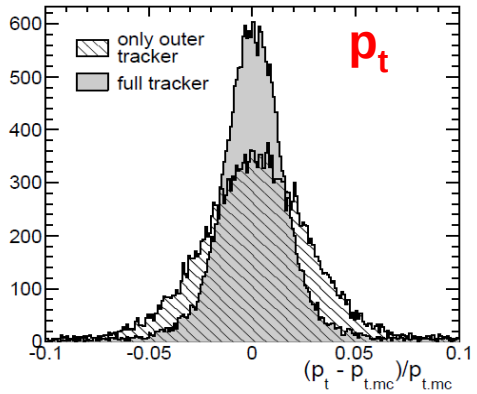



# Performance I

## Momentum resolution

1 GeV/c π



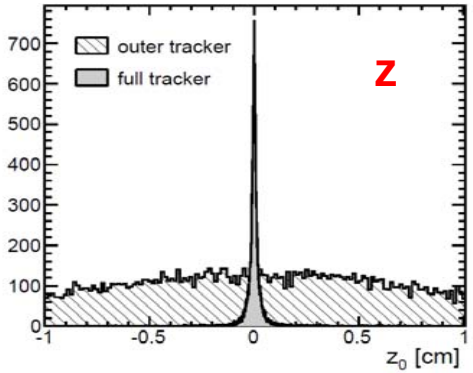

σ(p) without MVD = 2.6 %
σ(p) with MVD = 1.4 %

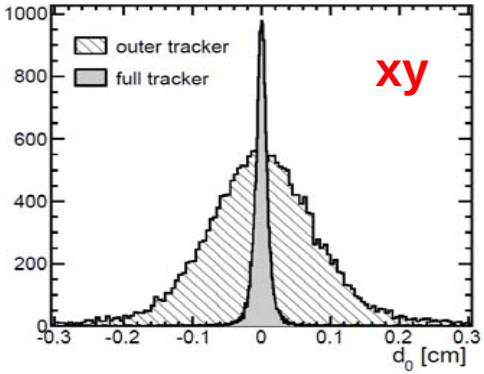
σ($p_t$) without MVD = 2.9 %
σ($p_t$) with MVD = 1.4 %

→ Improvement by 50%

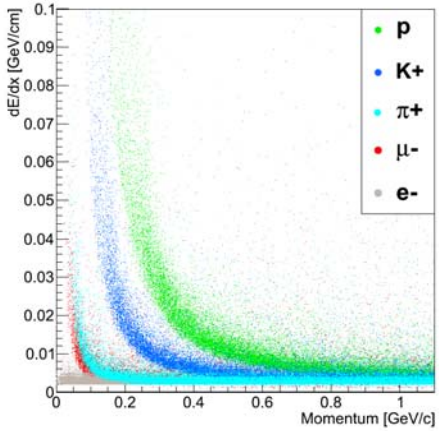
## Single track resolution

→ No resolution along z without MVD



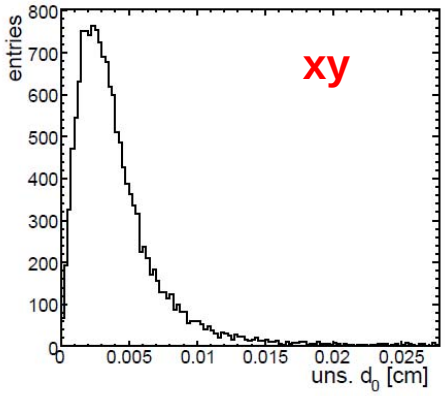



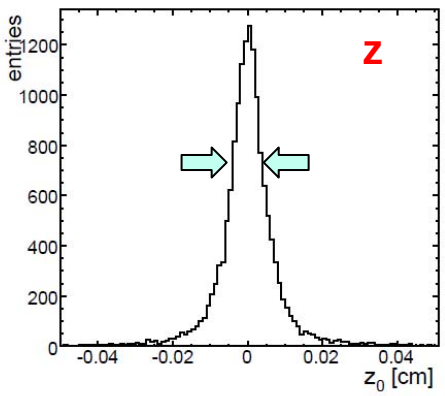

## Energy loss information

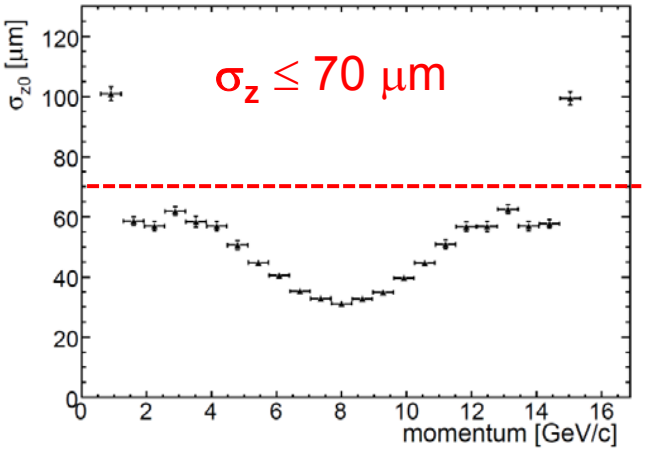


# Performance II

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



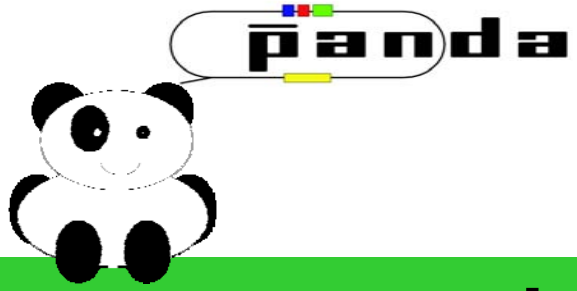

**Vertex resolution** $\bar{p}p \rightarrow D^+D^-$ (6.57 / 7.50 / 8.50) GeV/c

| momentum | vertex resolution [$\mu$m] | | | | | |
|---|---|---|---|---|---|---|
| $GeV/c$ | primary | | | secondary | | |
| | $\sigma_{prim,x}$ | $\sigma_{prim,y}$ | $\sigma_{prim,z}$ | $\sigma_{sec,x}$ | $\sigma_{sec,y}$ | $\sigma_{sec,z}$ |
| 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 |

→ Secondary vertex resolution:

$\sigma_{x,y} \leq 35$ μm

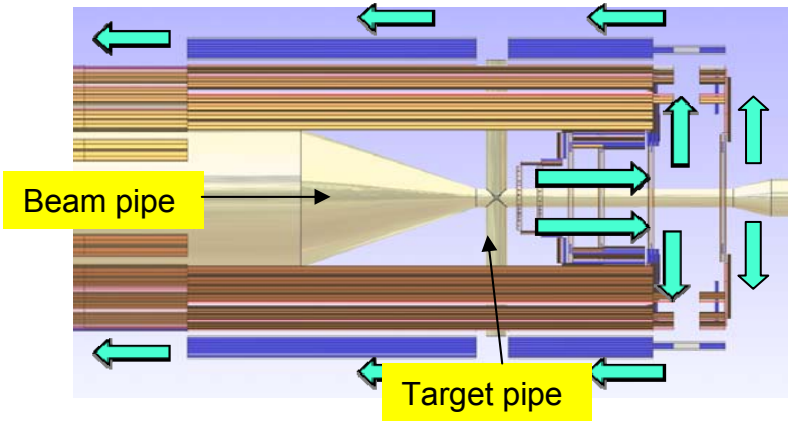
$\sigma_z \leq 100$ μm

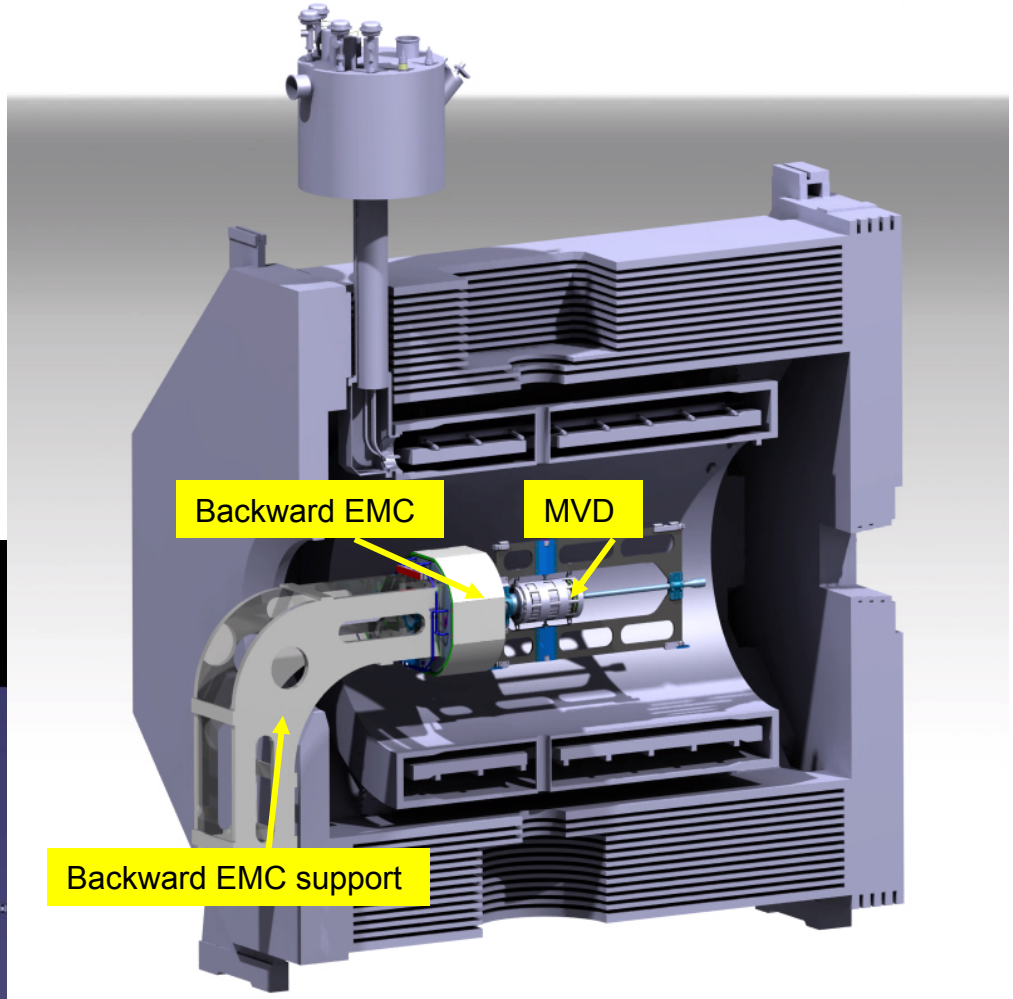


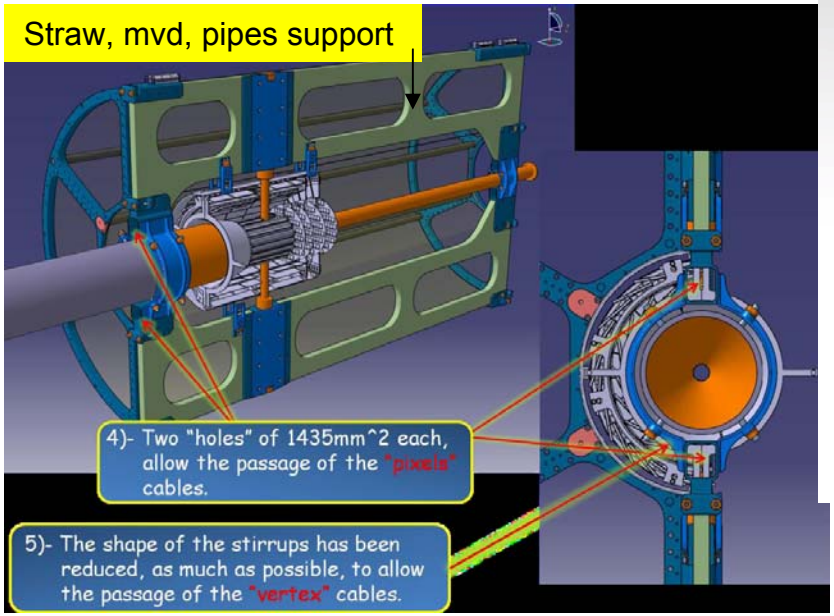

# Layout optimization

D. Calvo

# Layout and routing scheme

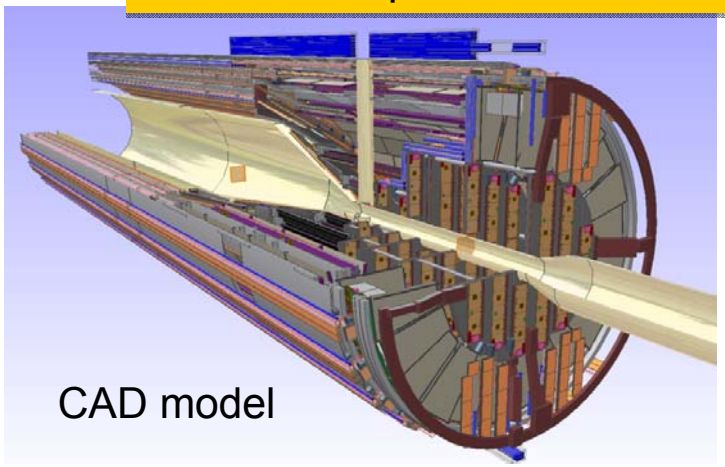


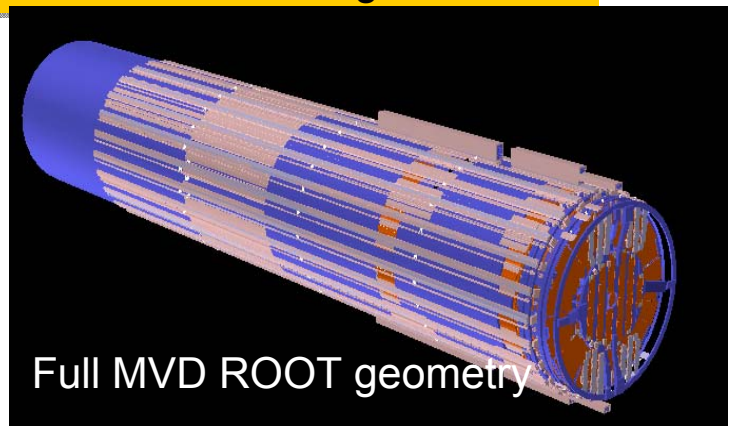



# CAD converter → simulations

**CAD Converter**
translates CAD drawings (STEP-files) into ROOT geometries ➔ access to full pandaROOT simulation with realistic detector design




**Spatial coverage**

2D mapping: Number of MVD points / track

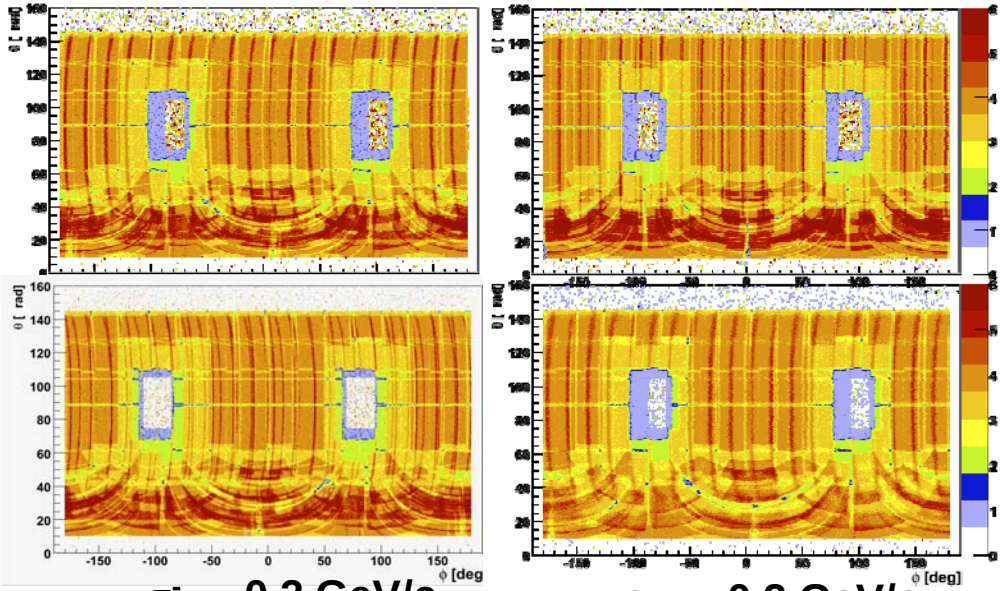
Design optimization for a minimum of 4 track points

No significant effect for particle-antiparticle

No significant energy dependence

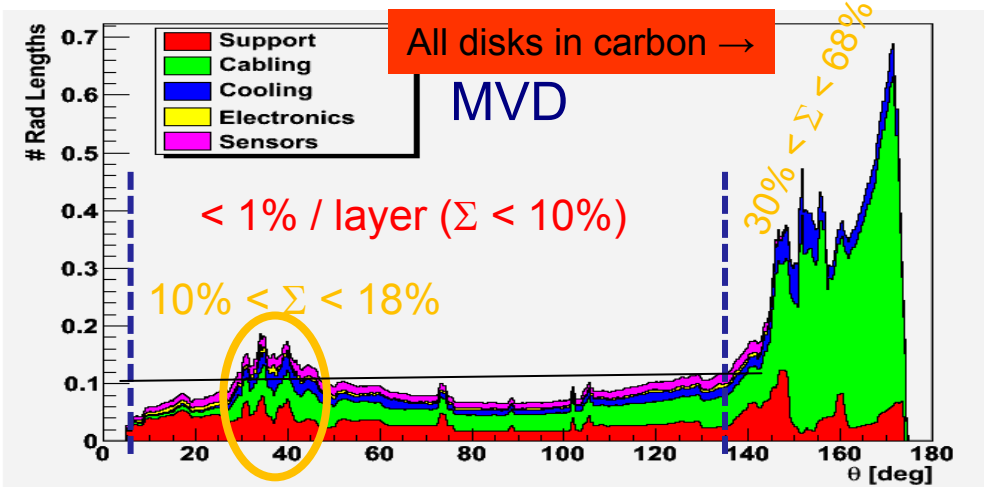
No significant effect for different particle species

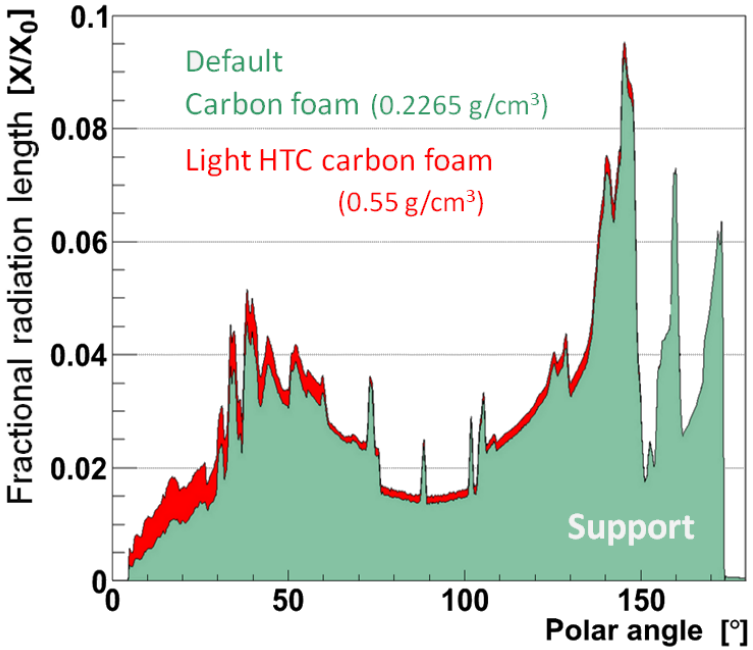
**$\pi^+$ 0.2 GeV/c → 1.5 GeV/c**

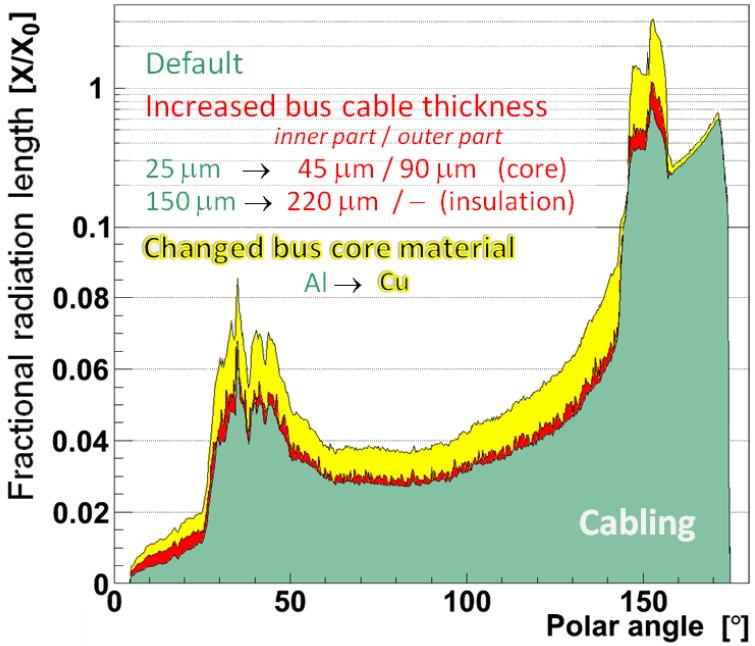



**$\pi^-$ 0.2 GeV/c** **p 0.2 GeV/c**

# Radiation length studies

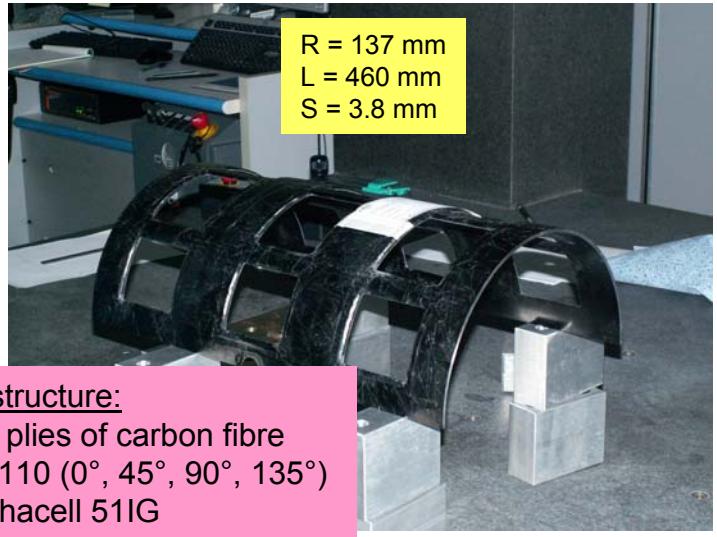


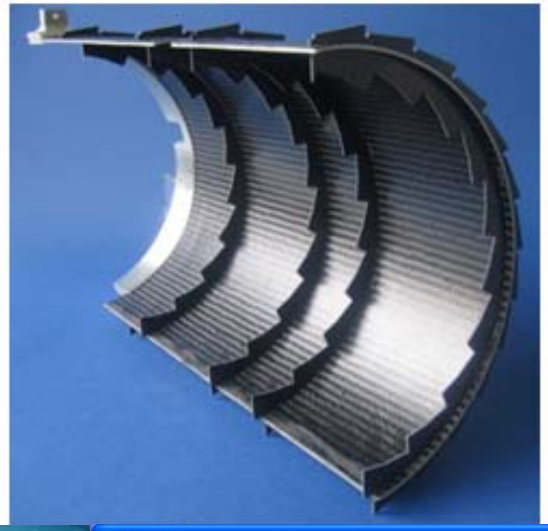
# Light mechanical structures and cooling

## MVD half support frame

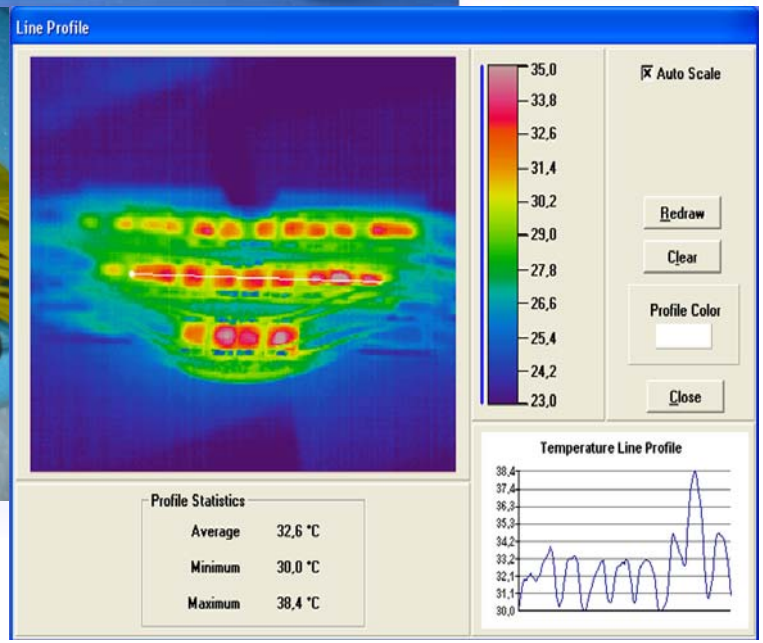



sandwich structure:
2 skin → 4 plies of carbon fibre M55J/LTM110 (0°, 45°, 90°, 135°)
core → Rohacell 51IG
Radiation Length $X_O \approx 0,4\%$

## Strip barrel support Cylinder over full length



HTC foam pixel half disk

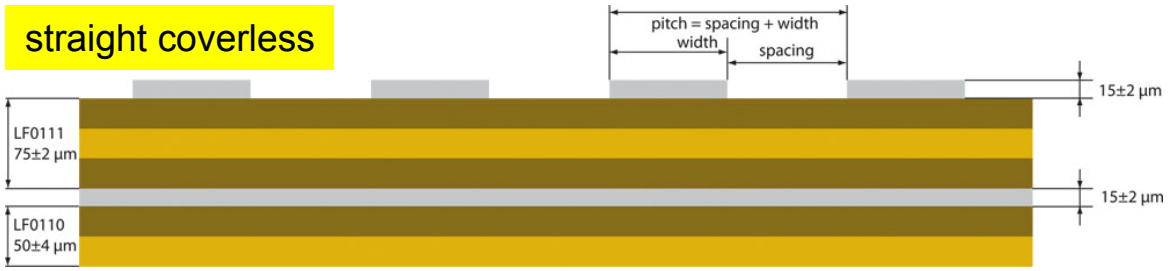


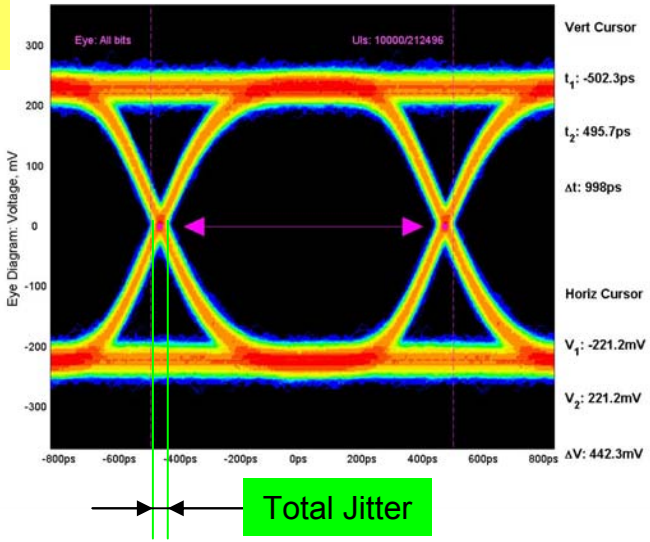

- Total Power 94 W (1,75 W each dummy chip).
- Cooling pipe diameter 2 mm (MPN35N Ni-Co alloy),
- 4 mm carbon foam
- Cooling flow 0,3 lit/min
- Htc therm. conductivity= 50 W/m·K

# 1 m long aluminum strips prototypes

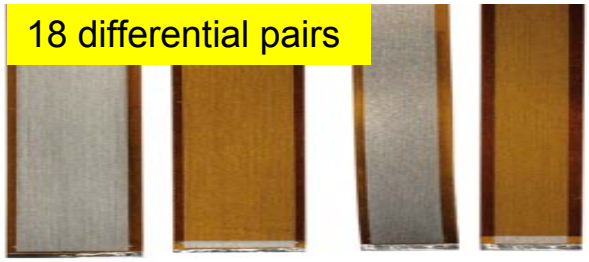
Technology based on laminated aluminum on kapton, reliable for bonding, produced @ CERN according to our design

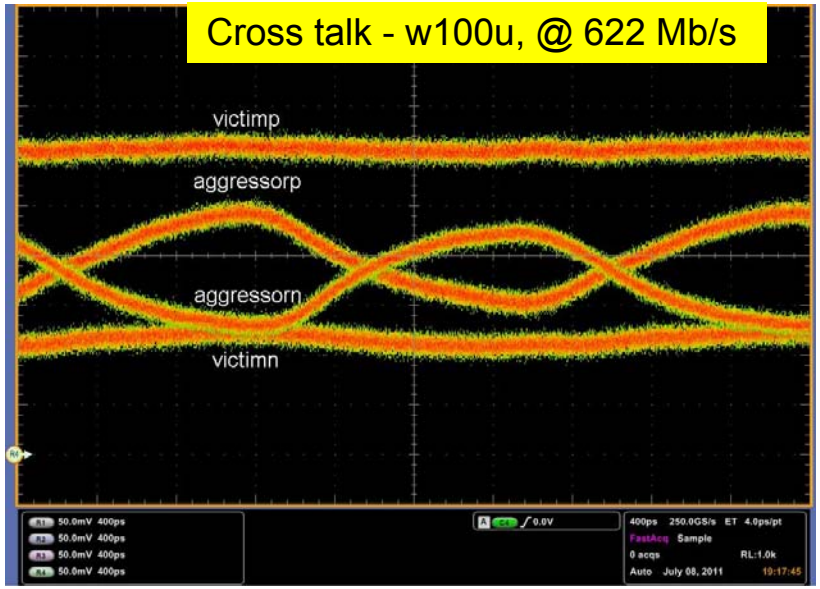
straight coverless

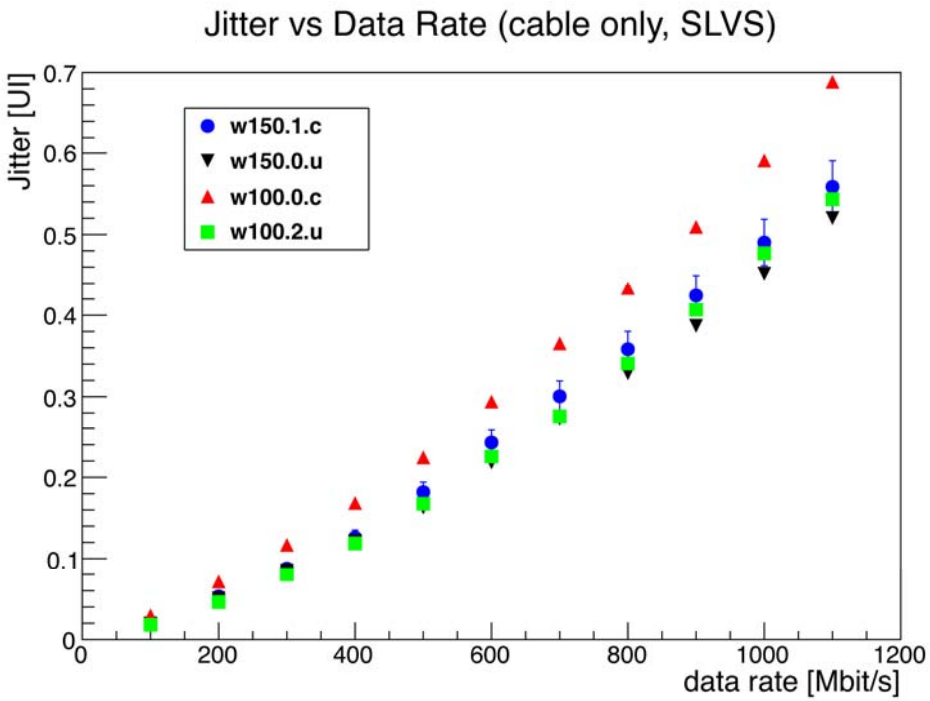


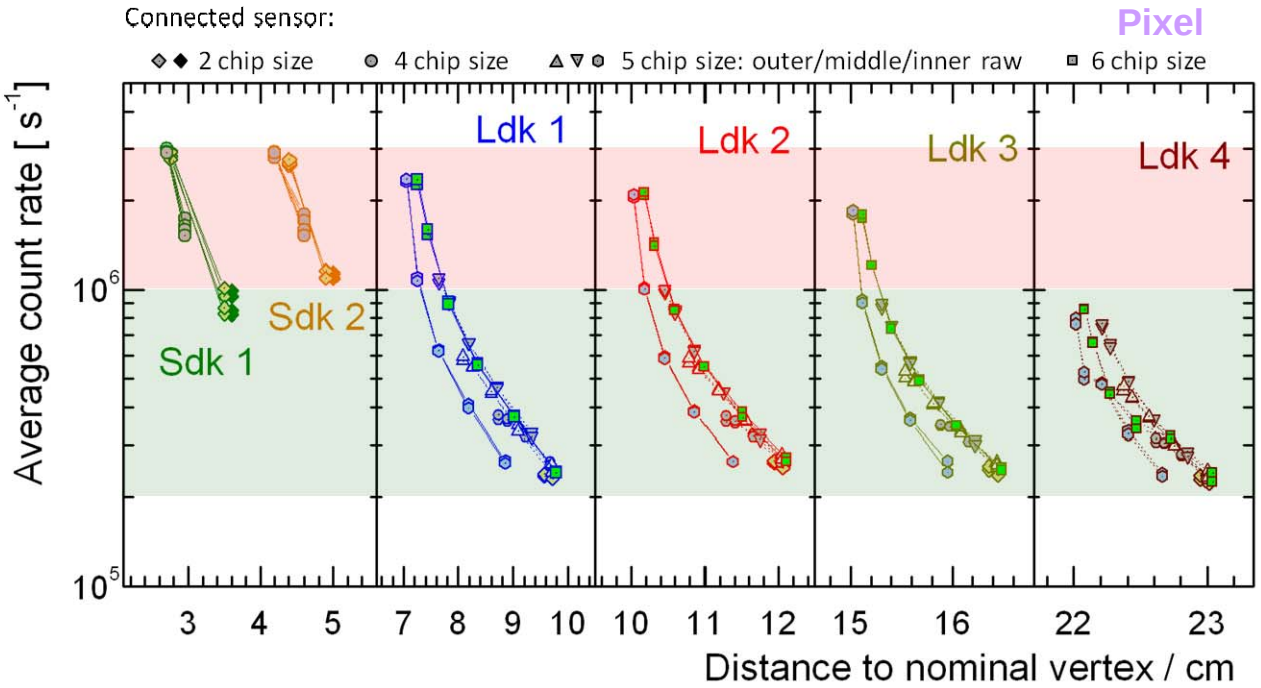

18 differential pairs

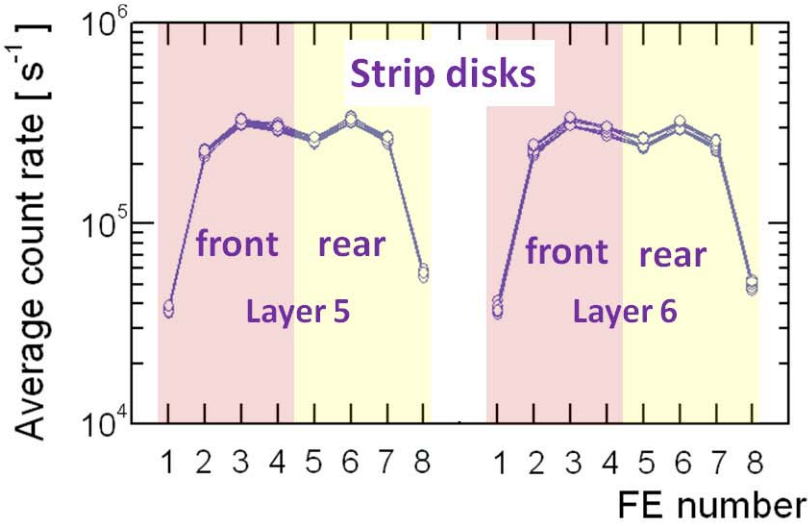


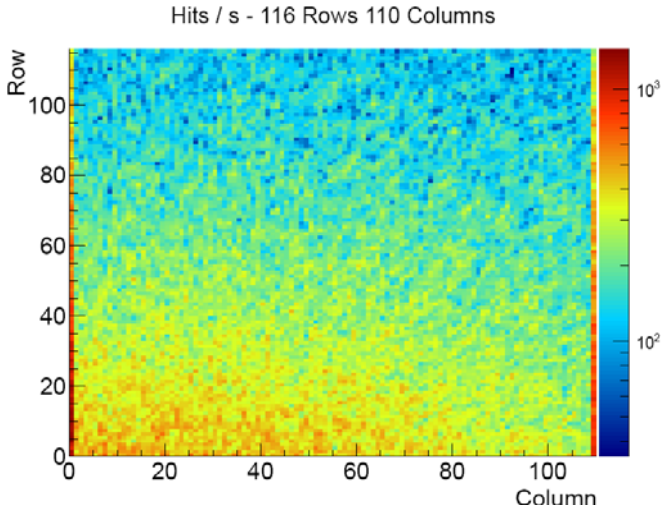


# Data Rate

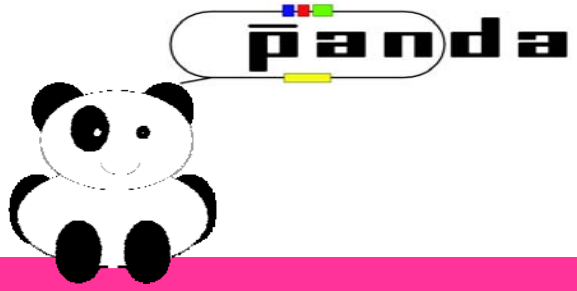



Map of the hits on the hottest pixel readout
( @ $2 \cdot 10^7$ events)

Data load from MVD (@ $2 \cdot 10^7$ ann/s) ~ 38 Gb/s




# Prototypes

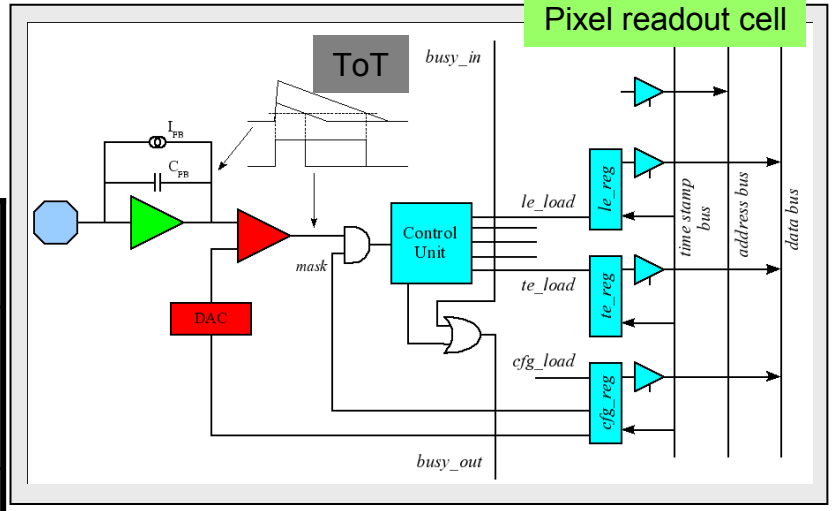
D. Calvo

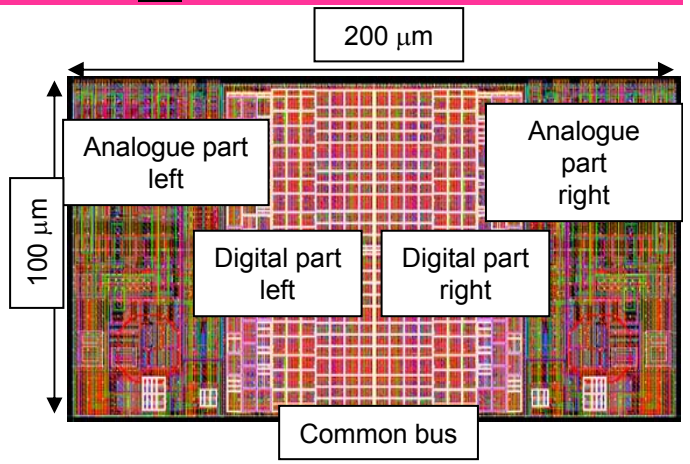
# Hybrid pixel detector I: ToPix_v3

**ToPix Specifications - 130nm CMOS technology**

| |
|---|
| Pixel radout size:<br>100 x 100 μm$^2$ |
| Chip active area:<br>11.4 x 11.6 mm$^2$<br>(116 rows,<br>110 columns) |
| dE/dx measurement:<br>ToT, 12 bits dynamic range (max. Input charge: 50 fC) |
| Noise:<br>< 0.032 fC (200 e$^-$) |
| Clock frequency:<br>155.52 MHz |
| Time resolution:<br>6.4 ns (1.85 ns rms) |
| Power consumption:<br>< 750 mW/cm$^2$ |
| Total ionizing dose:<br>< 100 kGy |
| Max.event rate:<br>(at 2 10$^7$ pbar-p ann/s):<br>~ 3· 10$^6$ hits/ (chip · s) |

Pixel readout cell




CMOS 130 nm **DM technology**

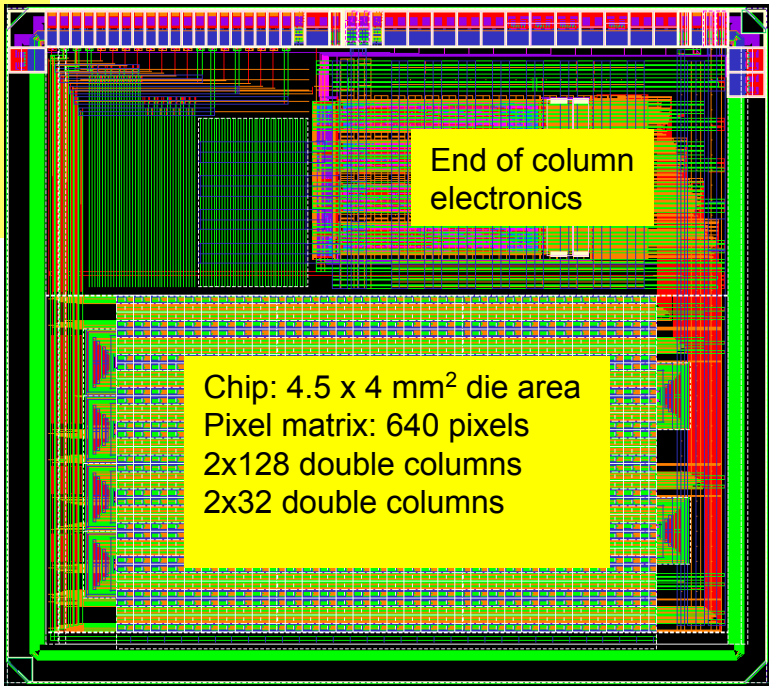
**Triggerless**

**Triple redundancy-based SEU protection (cell)**

**Hamming encoding (EoC)**

**Serial output** (e-link compatible) and SLVS I/O

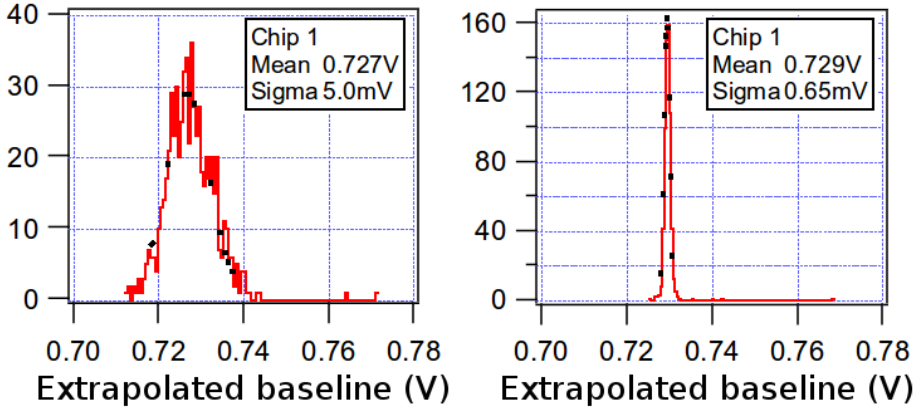
**Pads for bump bonding**

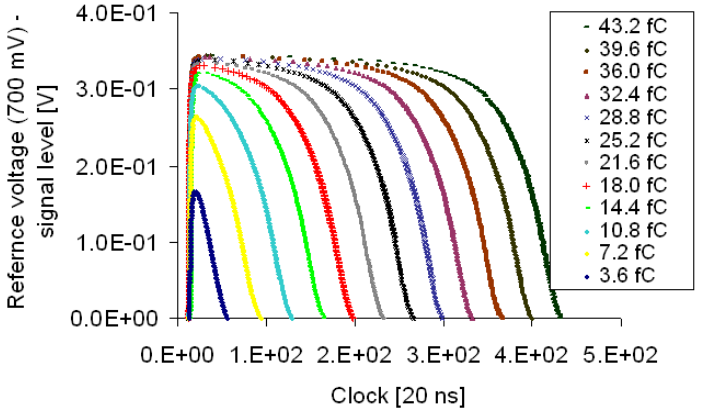


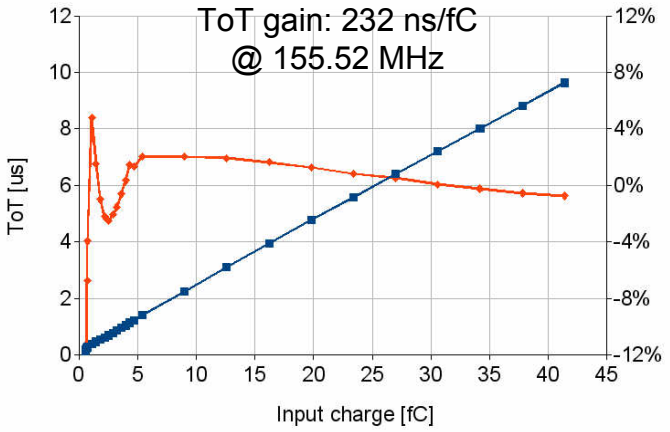
# Hybrid pixel detector II: ToPix_v3

## ToPix_v3 prototype – electrical functionalities

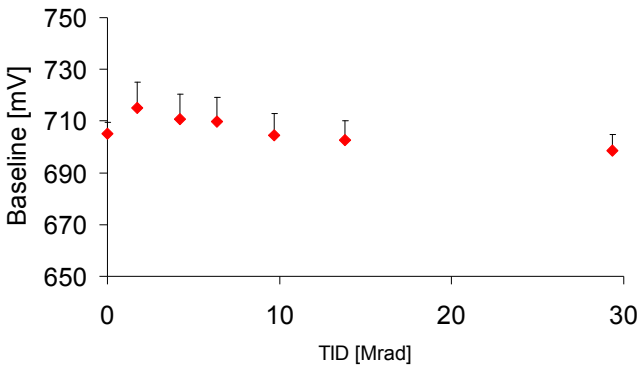
→ The pixel Detector readout ASIC for the Micro Vertex Detector of the PANDA experiment, G. Mazza et al. (Front End, trigger, …**Poster Session**)

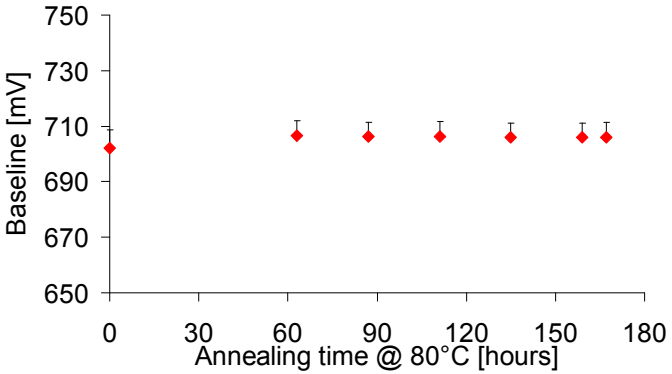



**Total Ionizing Dose (400 rad/s @CERN)**



# Hybrid pixel detector III: sensor prototypes

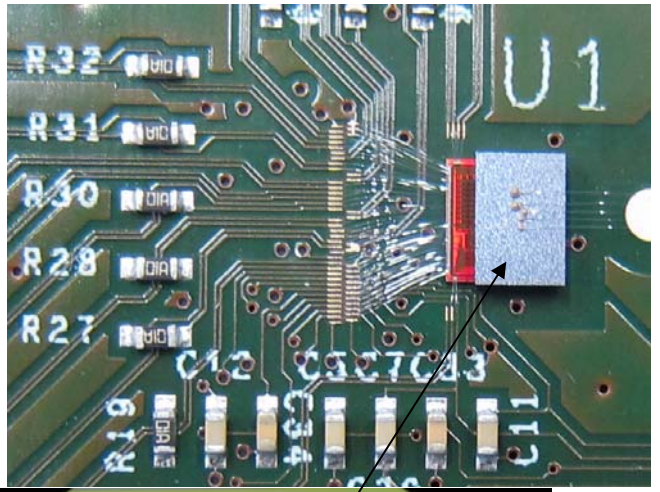
Test of radiation damage with neutrons from Pavia nuclear reactor up to $1.5 \pm 10^{14}$ 1 MeV equivalent neutron/cm$^2$ corresponding to ~ 10 years of PANDA lifetime (DPM 15 GeV/c-NIEL)

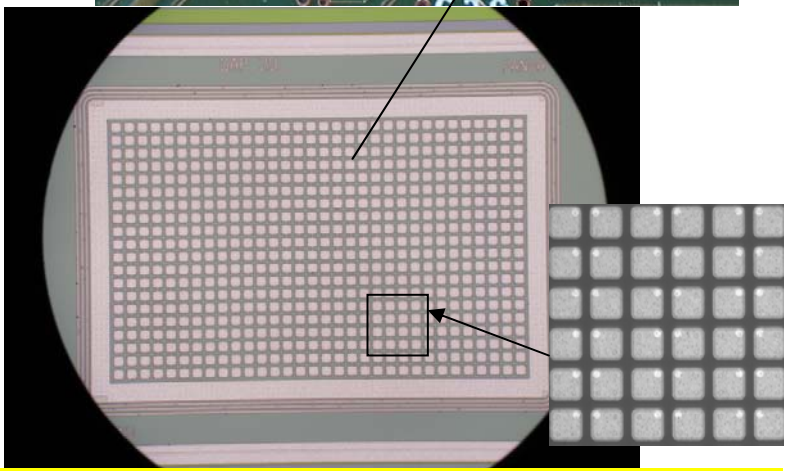
Epi-50, HR: 49 μm (4060 Ω·cm, n/P)
Epi-75, HR: 74 μm (4570 Ω·cm, n/P)
Epi-100, HR: 98 μm (4900 Ω·cm, n/P)
Epi-50, MR: 50 μm (3100 Ω·cm, n/P)
Epi-75, MR: 75 μm (3200 Ω·cm, n/P)
Epi-100, MR: 100 μm (3610 Ω·cm, n/P)
Epi-75, LR: 75 μm (3610 Ω·cm, n/P)
+ Cz substrate (0.01-0.02 Ω·cm, n+/Sb)

Diodes

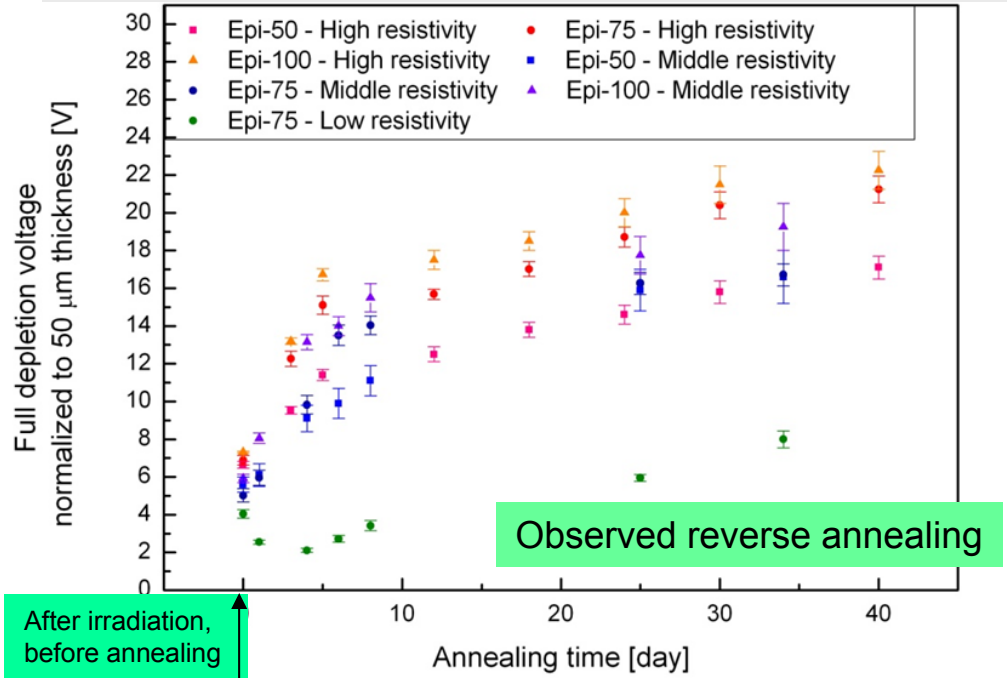
Single chip assembly

- ✓ pixel obtained with Epi-100, MR: 100 μm (3610 Ω·cm, n/P)
- ✓ Readout with ToPix_v3



Leakage current < 20 nA/pixel (100 μmx100μm size, 100 μm thick), immediately after the irradiation. It decreases by a factor 2 after some days of annealing at 60°C



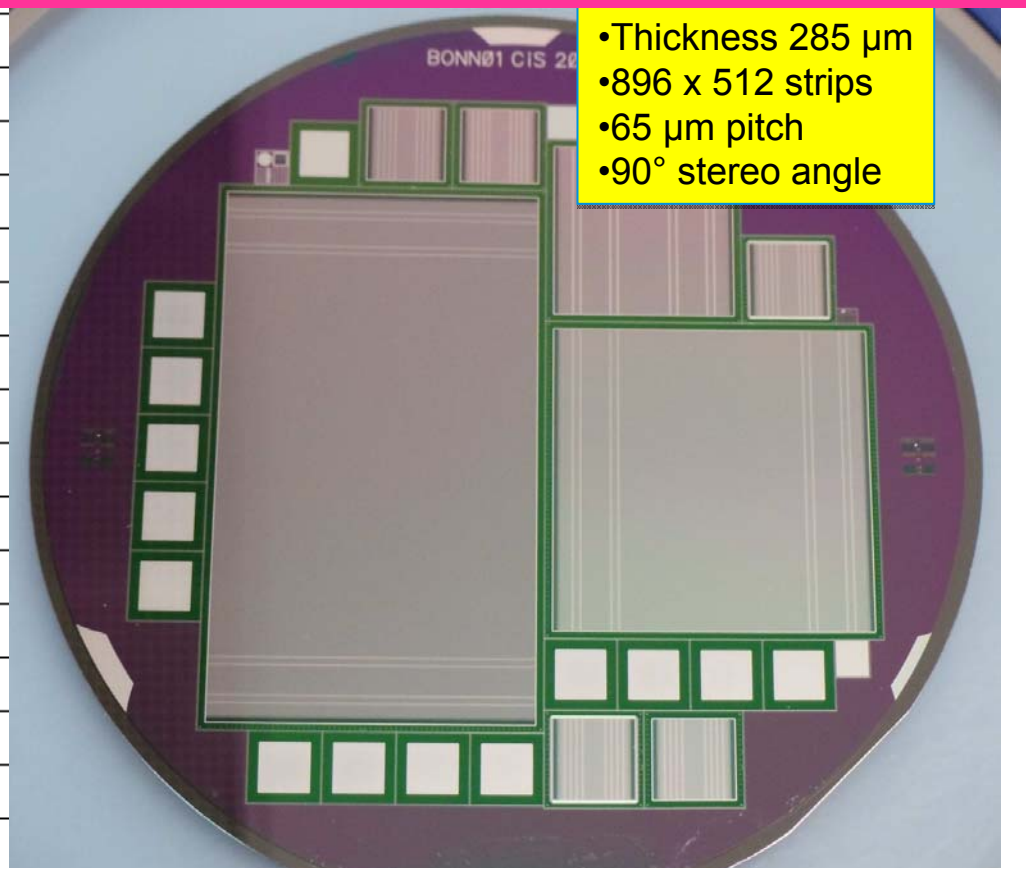

Observed reverse annealing

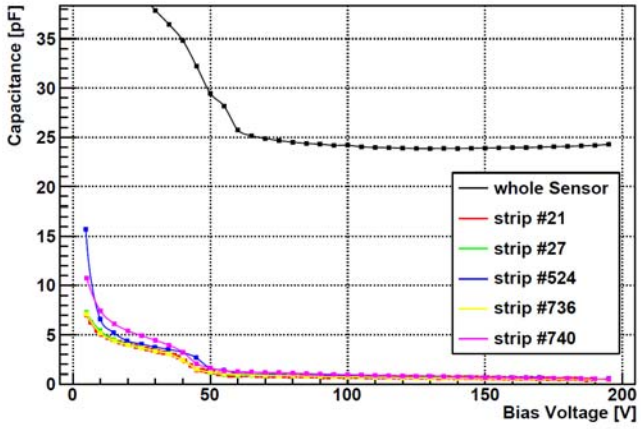
After irradiation, before annealing

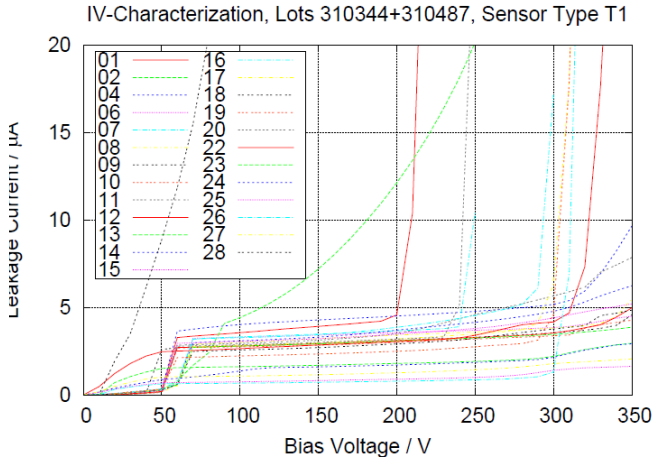
→ Development of thin pixel detectors on epitaxial silicon for HEP experiments, M. Boscardin et al. (Solid State Detectors **Poster Session**)

# Strip detector

| Parameter | adapted ToPix |
|---|---|
| input pad pitch | ≈ 50 µm |
| channels per front-end | 128 |
| dynamical range | 100 fC |
| ENC | 1,000 $e^-$ @ 20 pF |
| peaking time | 6 ns |
| power consumption | 0.8 mW/ch |
| trigger | self-triggering |
| digitisation technique | ToT |
| digitisation resolution | 10 bit |
| time resolution | 1.85 ns @ 155 MHz |
| data interface | e-link - SLVS |
| number of data lines | 1 pair |
| slow control | custom (serial) |
| process | 0.13 µm CMOS |
| radiation hardness | 10 MRad |



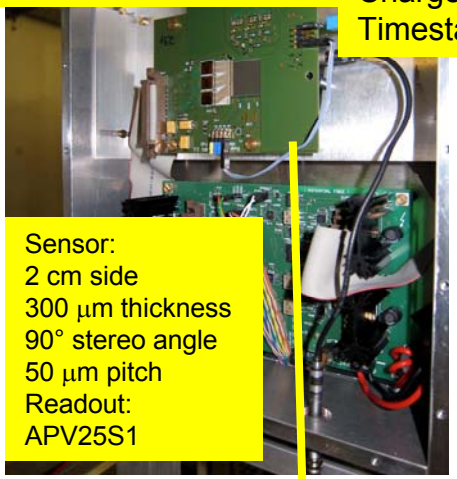



# Tracking station

## Strip plane
## Triggered readout

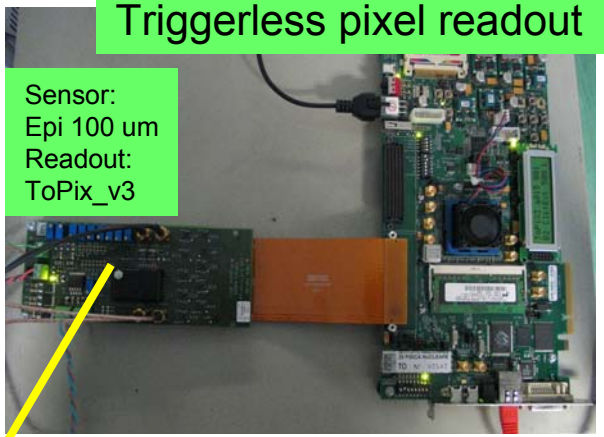
Strip raw data:
Channel
Charge
Timestamp



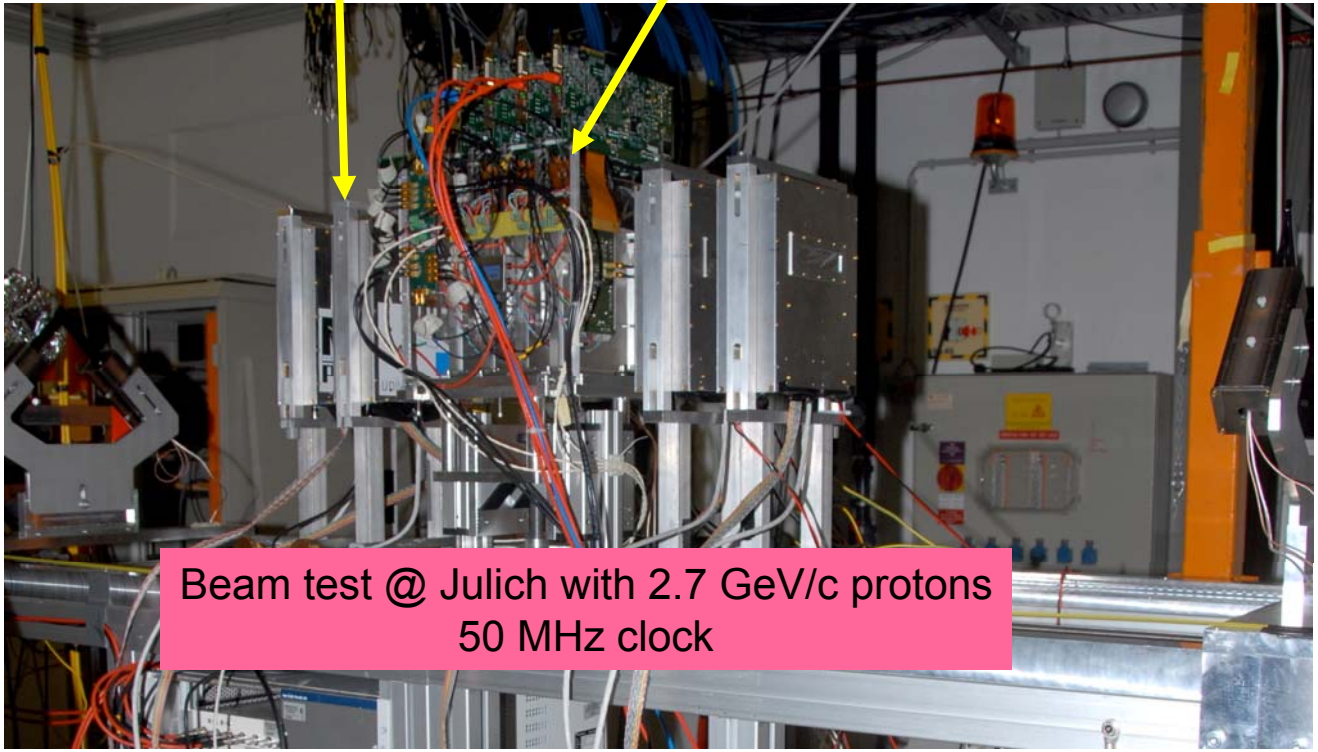
Sensor:
2 cm side
300 μm thickness
90° stereo angle
50 μm pitch
Readout:
APV25S1

## Pixel plane
## Triggerless pixel readout

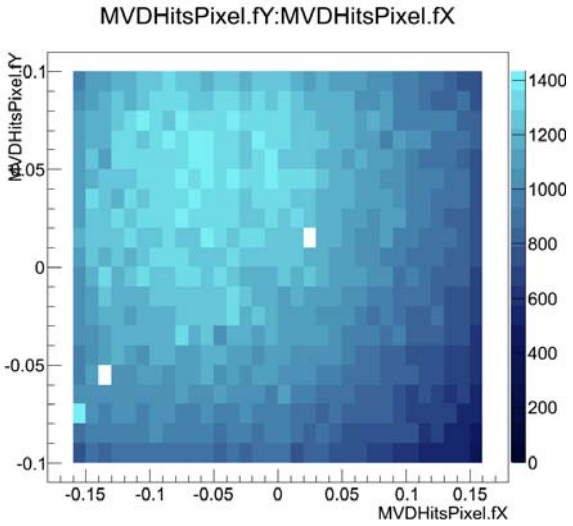
Pixel raw data:
Column & row
Timestamp
Leading &Trailing Edge
(Gray encoded)



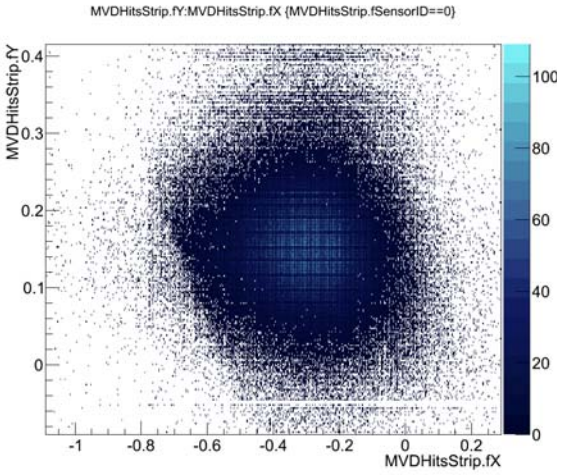
Sensor:
Epi 100 um
Readout:
ToPix_v3



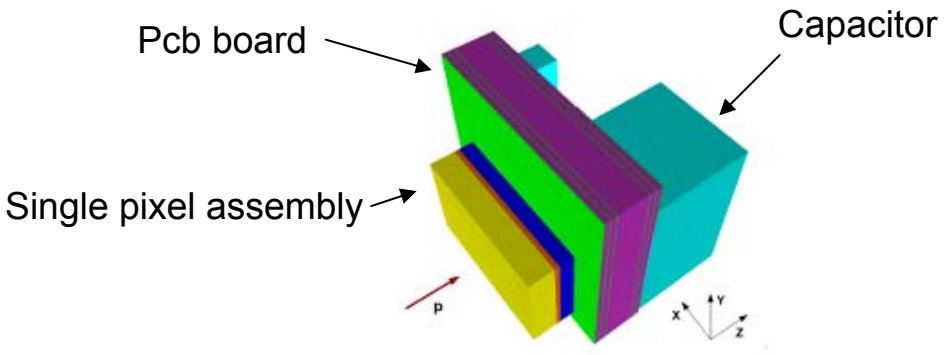
Beam test @ Julich with 2.7 GeV/c protons
50 MHz clock



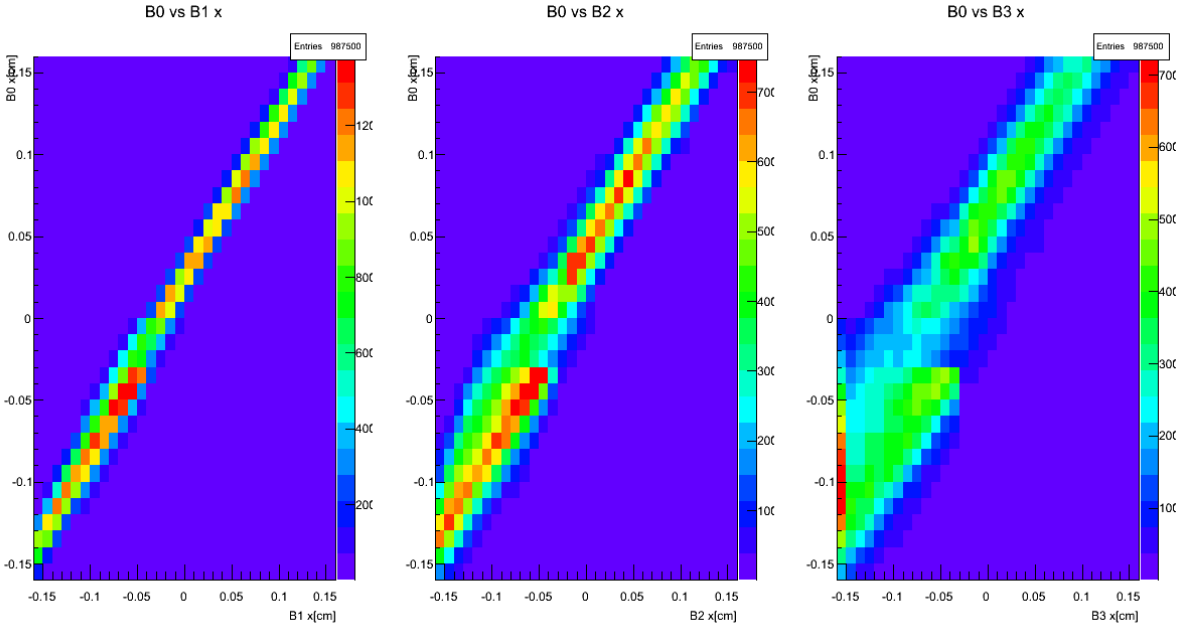

Dead pixel % < 0.08%

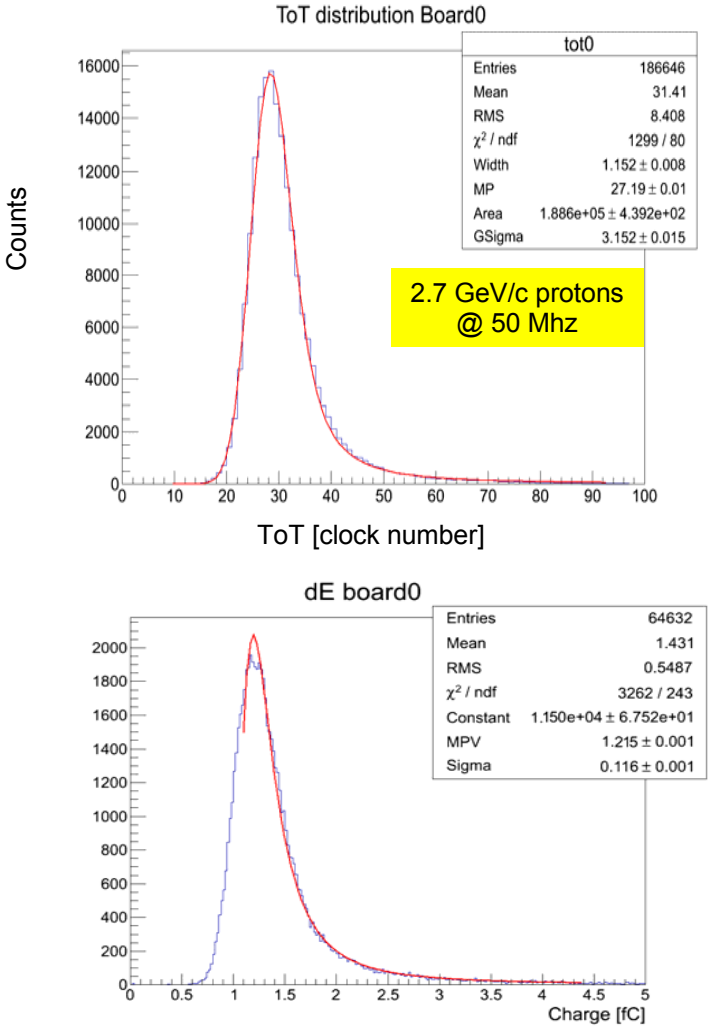


# The material budget and ToT

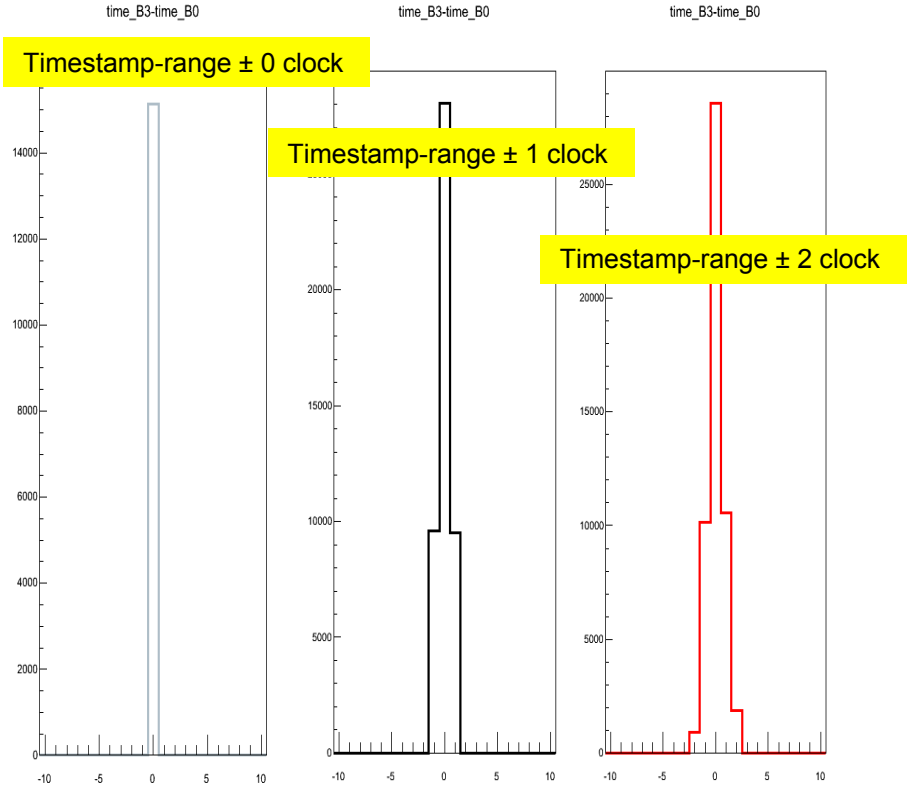



| | $X/X_0$ | |
|---|---|---|
| Number of planes | x>0 | x<0 |
| 1 pixel | ~ 5 % | ~ 6.6 % |
| 4 pixel | ~ 20 % | ~ 26.6 % |
| 1 strip | ~ 0.3 % | |
| 4 strip | ~ 1.3 % | |
| 4 strip + 4 pixel | ~ 21.38 % | ~ 27.91% |

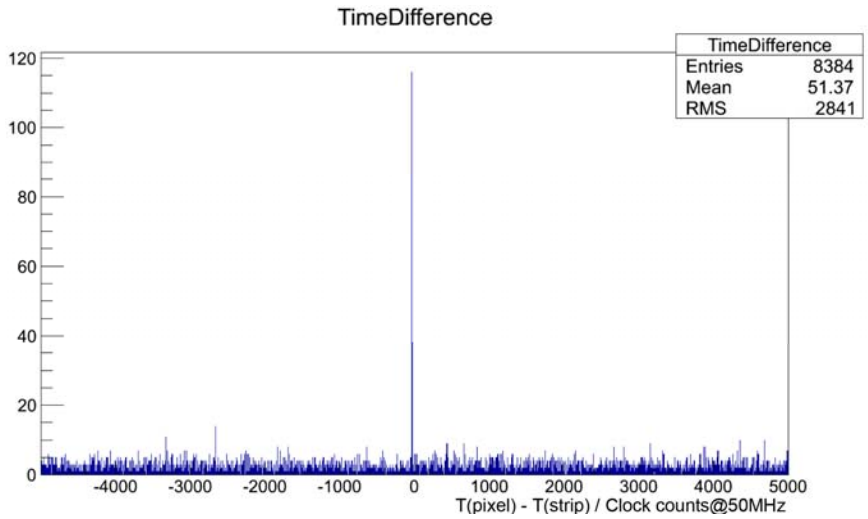


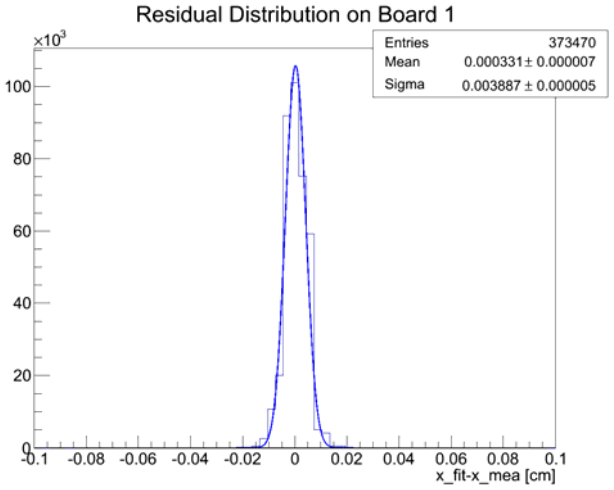



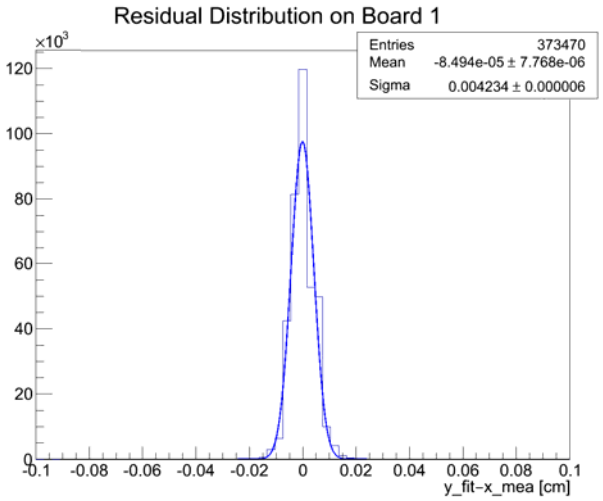
# Timestamp selection and residuals




Timestamp difference between hits measured with the pixel and strip tracking stations

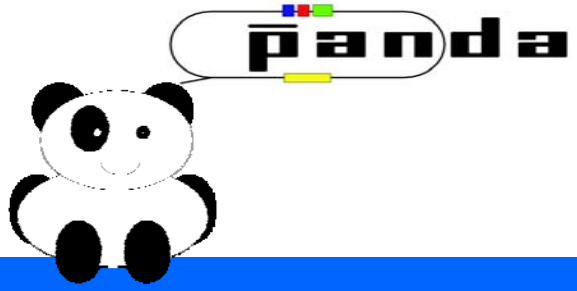



$$\sqrt[4]{\sigma 1_{x,y} * \sigma 2_{x,y} * \sigma 3_{x,y} * \sigma 4_{x,y}}/\sqrt{4}$$

The tracking resolution estimator is ~27 μm




# Conclusions

MVD Technical Design Report has been accepted by the PANDA collaboration and has been submitted to the FAIR committee in December 2011

Tracking station with both triggerless pixel and triggered strips

Software development to check physics performance and prototyping phase are ongoing



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# 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
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati

U & INFN Genova
U Glasgow
U Gießen
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