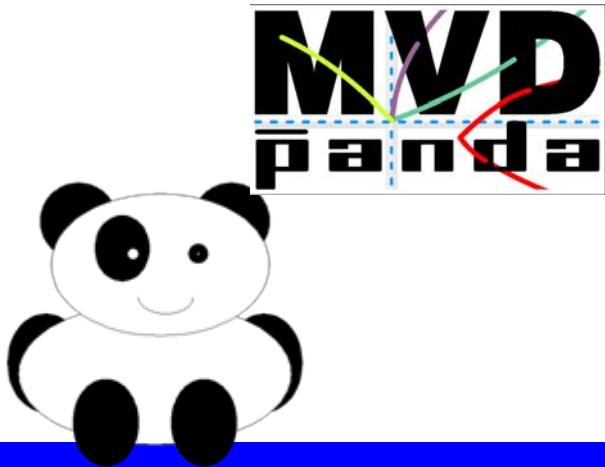


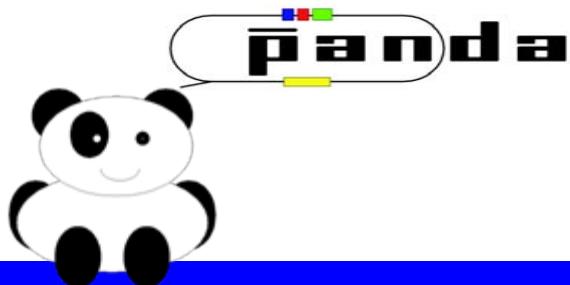
IPRD10, 12th Topical Seminar on Innovative Particle and Radiation Detectors
7-10 June 2010, Siena, Italy



Triggerless and low mass Micro Vertex Detector for the PANDA experiment

Daniela Calvo
on behalf of the PANDA MVD group





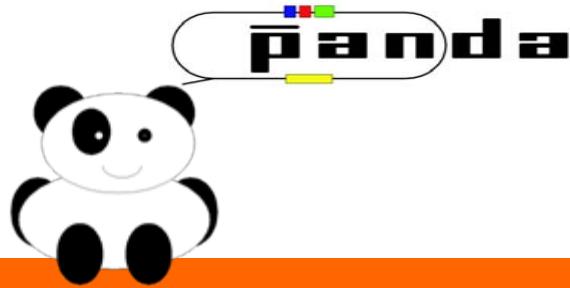
Overview

Introduction

Micro Vertex Detector

- Towards layout optimization
 - First prototype results

Conclusions

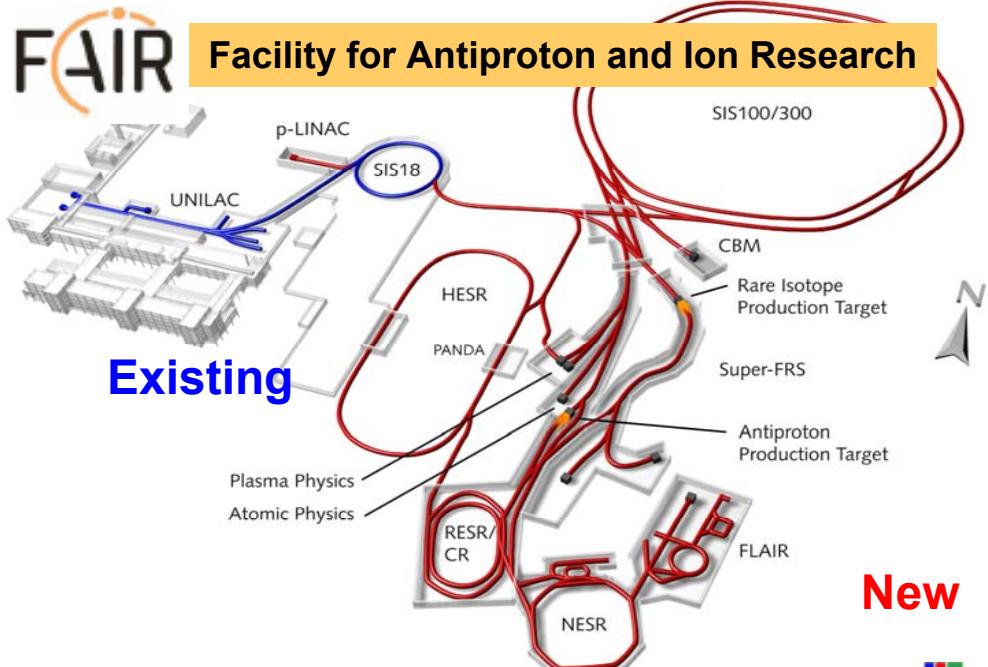


Introduction

FAIR and PANDA

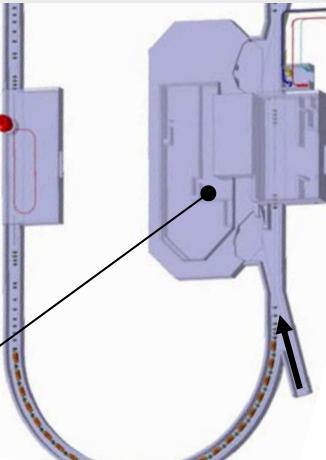


Facility for Antiproton and Ion Research



HESR – High Energy Storage Ring

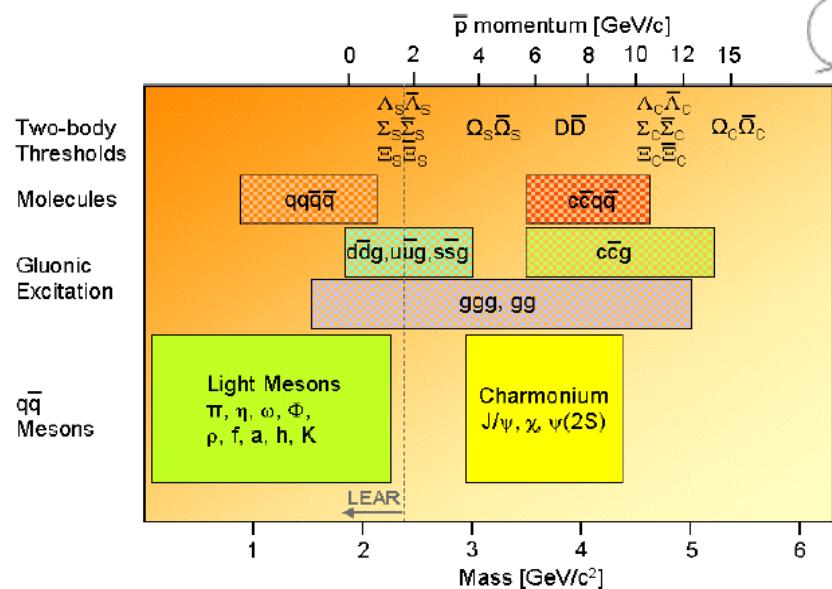
High luminosity: $L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \Leftrightarrow \delta p/p \sim 10^{-4}$
 High resolution: $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \Leftrightarrow \delta p/p \sim 4 \cdot 10^{-5}$



New



Antiproton Annihilations at Darmstadt



Apparatus requirements:

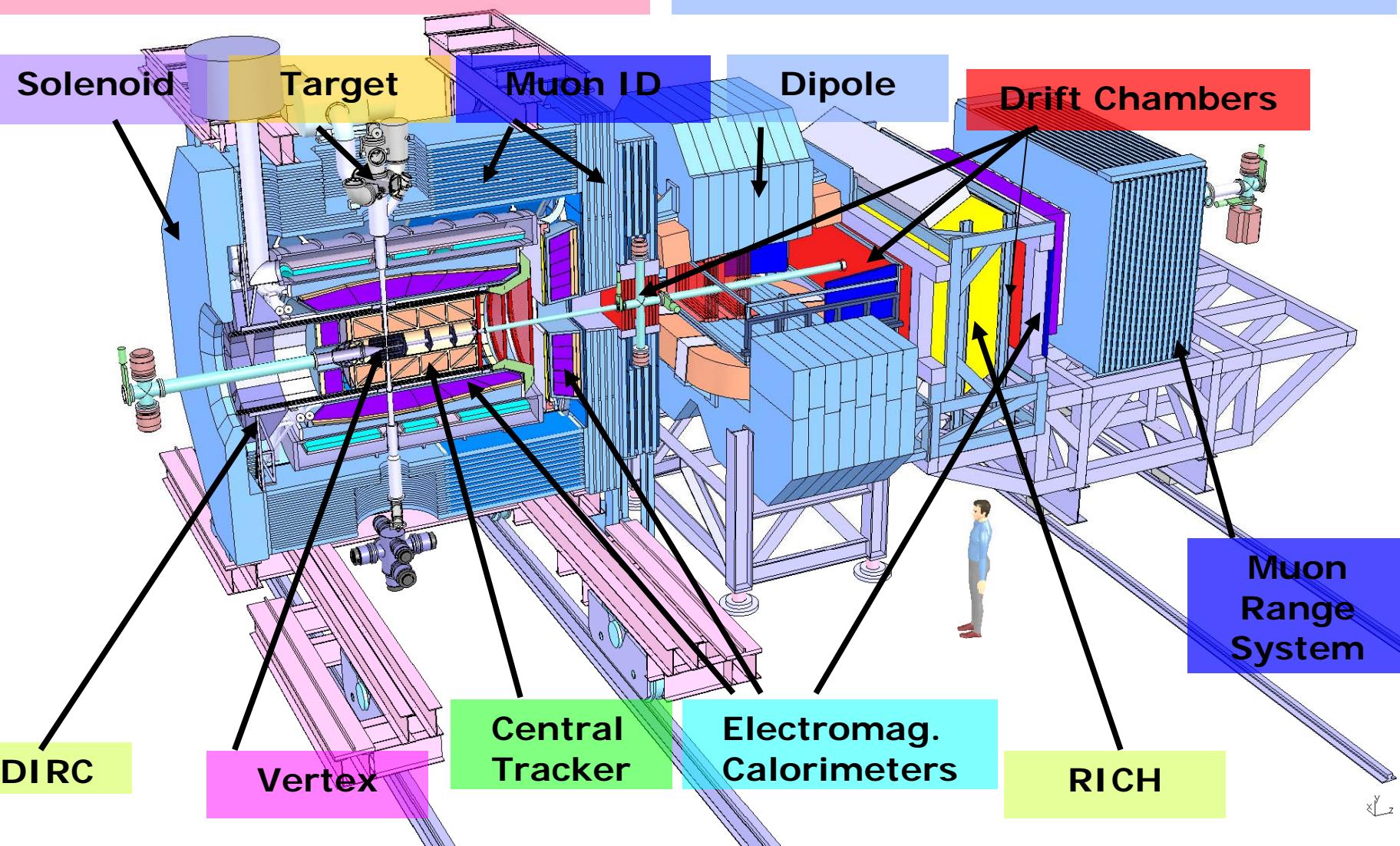
- Nearly 4π acceptance
- High rate capabilities ($2 \cdot 10^7$ pbar-p annihilations /s)
- Continuous readout and efficient event selection
- Momentum resolution (1%)
- Vertex info for D, K^0_s , Λ ($c_\tau = 317 \mu\text{m}$ for D^{+})
 - good tracking
- Good PID (γ , e, μ , π , k, p) with Cherenkov,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

PANDA



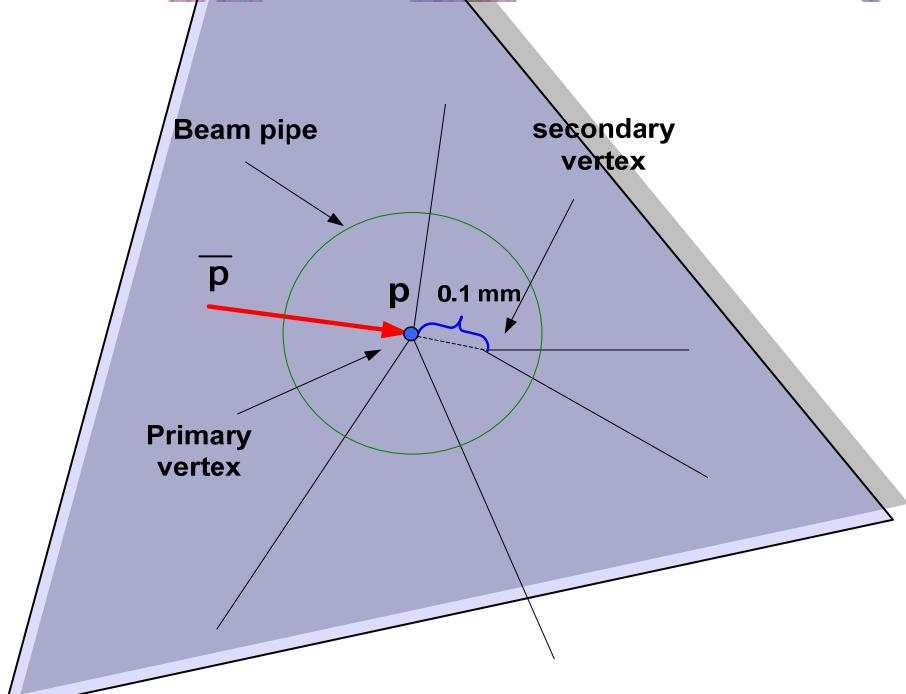
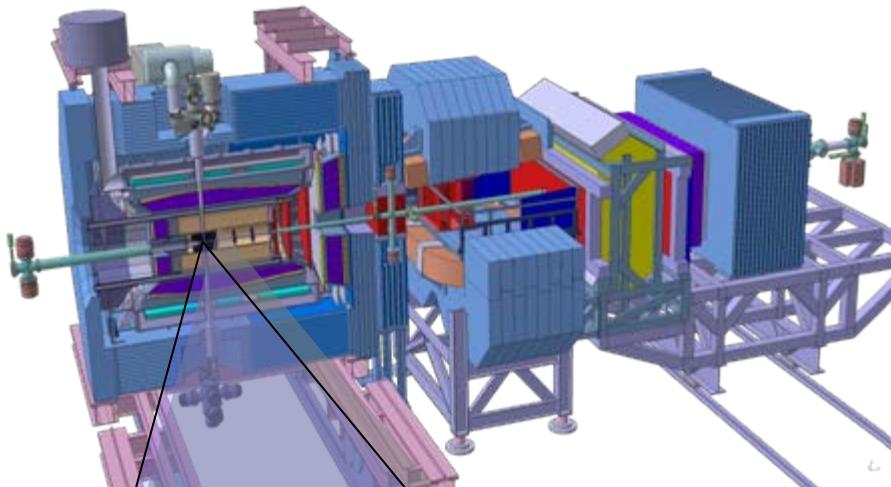
TARGET SPECTROMETER

FORWARD SPECTROMETER



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

Towards the Micro Vertex Detector



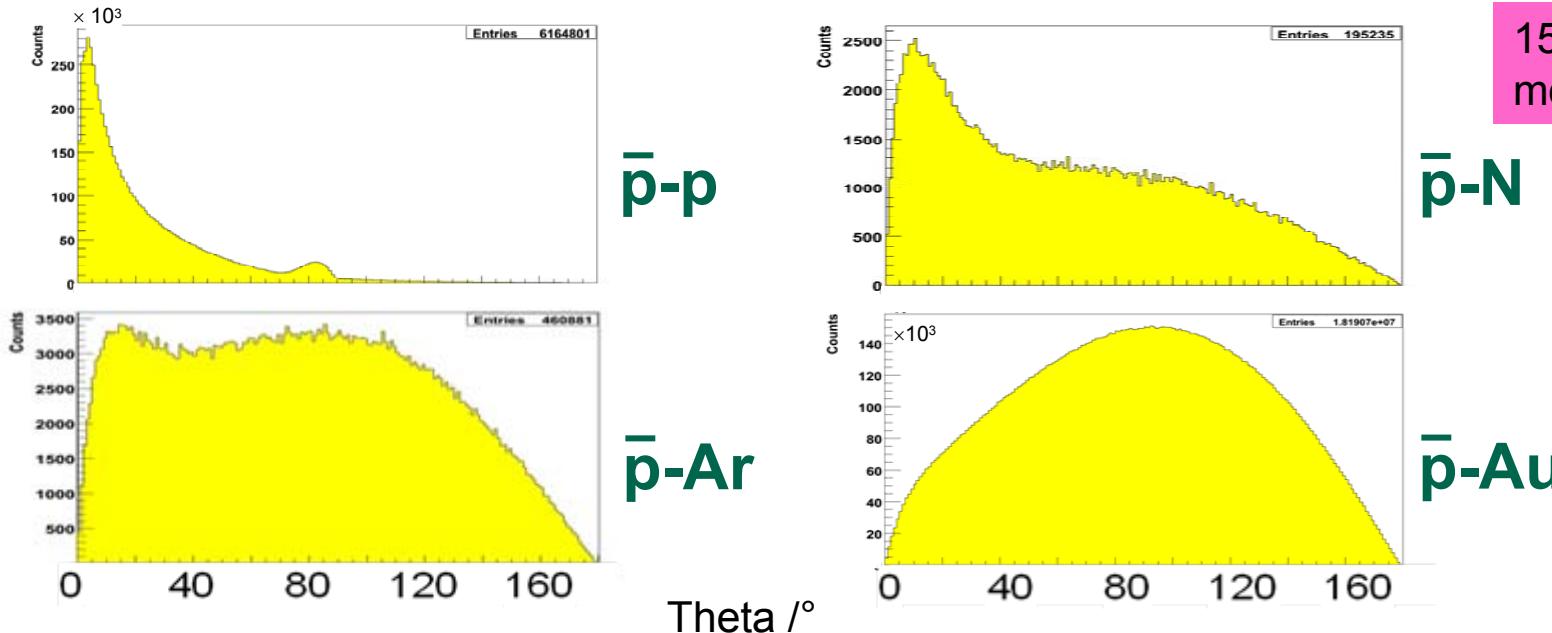
MVD requirements

- Good spatial resolution in r-phi
Momentum measurement of pions from D^* decays
- Good spatial resolution especially in z
Vertexing, D-tagging
- Good time resolution
better than 50 ns with $2 \cdot 10^7$ $\bar{p}p$ annihilations/s
- Triggerless readout
No first level hardware trigger, continuous readout
- Amplitude measurement
 dE/dx measurement to improve particle ID
- Low material budget
low momentum particles (starting from some hundreds of MeV/c) ($< 1\% X_0$ for each layer)
- Radiation hardness: $\sim 4 \cdot 10^{14} n_{1\text{MeV eq}}/\text{cm}^2$ (10 years (50%) of $\bar{p}p$, 15 GeV/c antiproton momentum)
Depends on target material
Different radiation load

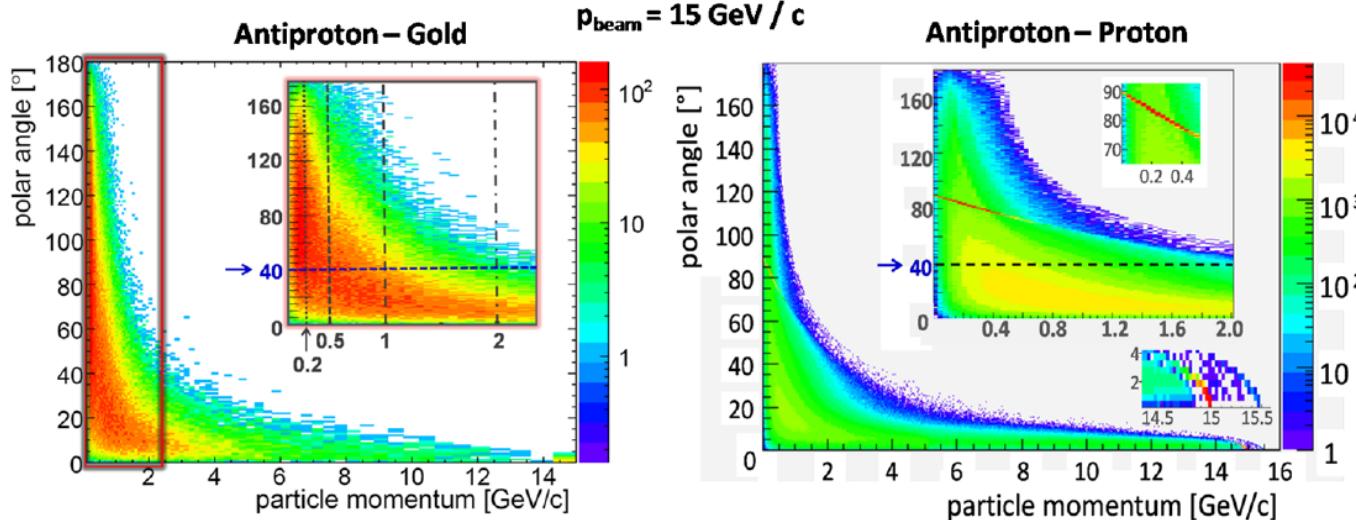
Towards the Micro Vertex Detector



15 GeV/c \bar{p}
momentum



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



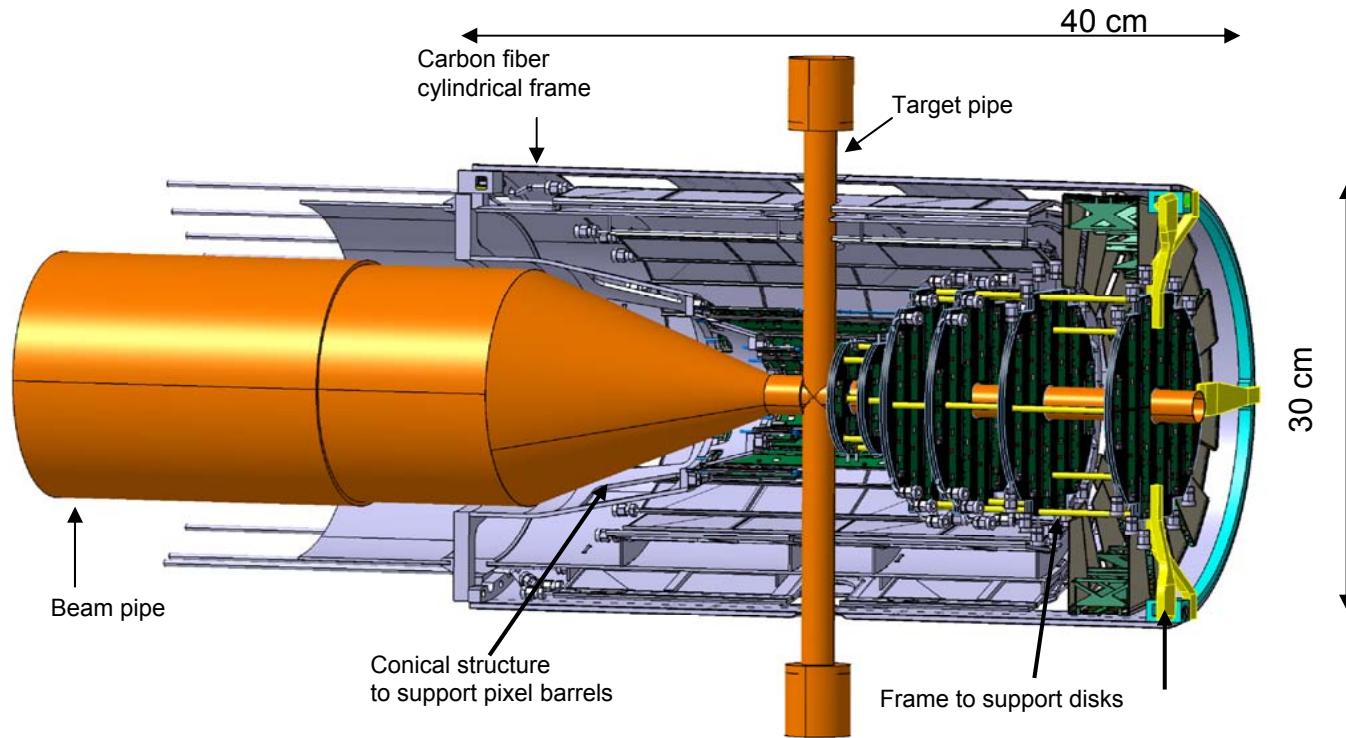


Micro Vertex Detector

D. Calvo



MVD layout



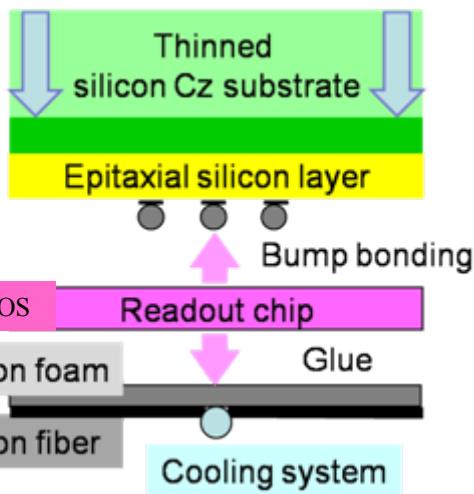
4 barrels
Two *inner layers*:
hybrid pixel detectors
Two *outer layers*:
double sided silicon strip detectors

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

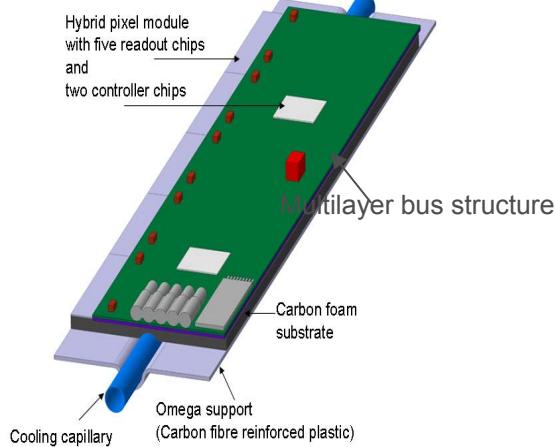
Readout channels:
~ 11 million (pixel)
~ 200.000 (strip)

Hybrid pixel detector

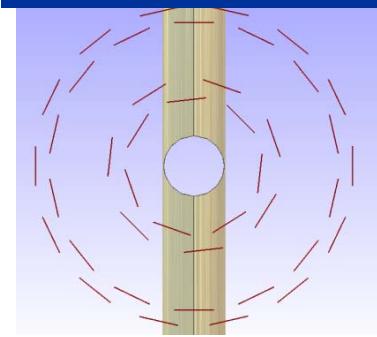
Standard hybrid technology



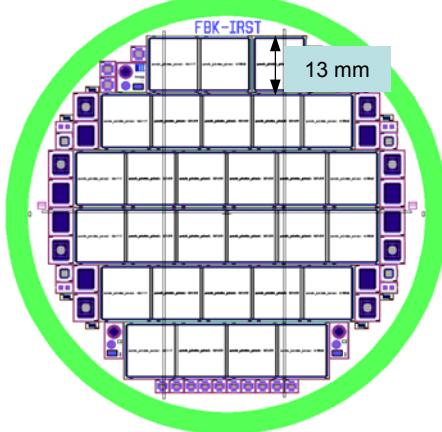
Pixel Module



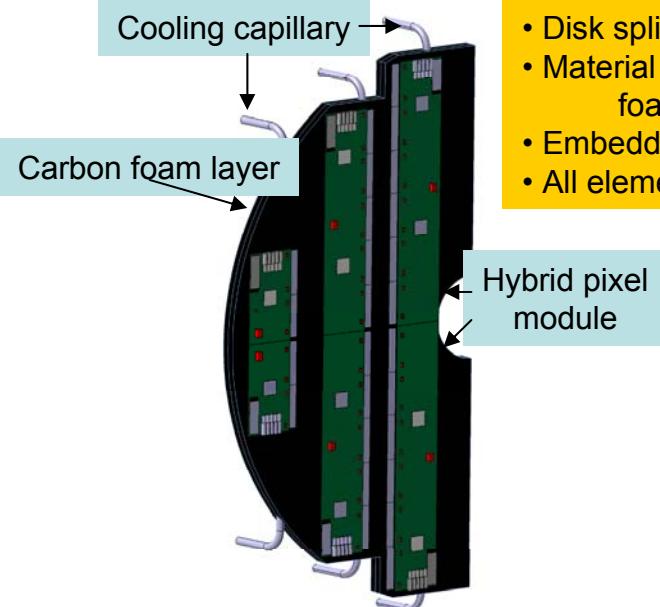
Two pixel barrel section



Pixel sensor size
Pixel cell size $100 \times 100 \mu\text{m}^2$

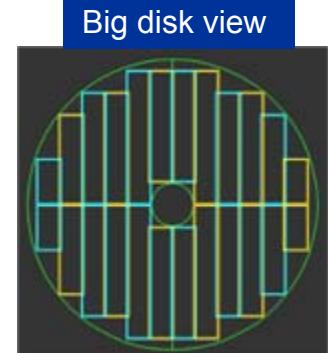


Pixel half-disk – one side



- 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

Big disk view



Double side silicon strips

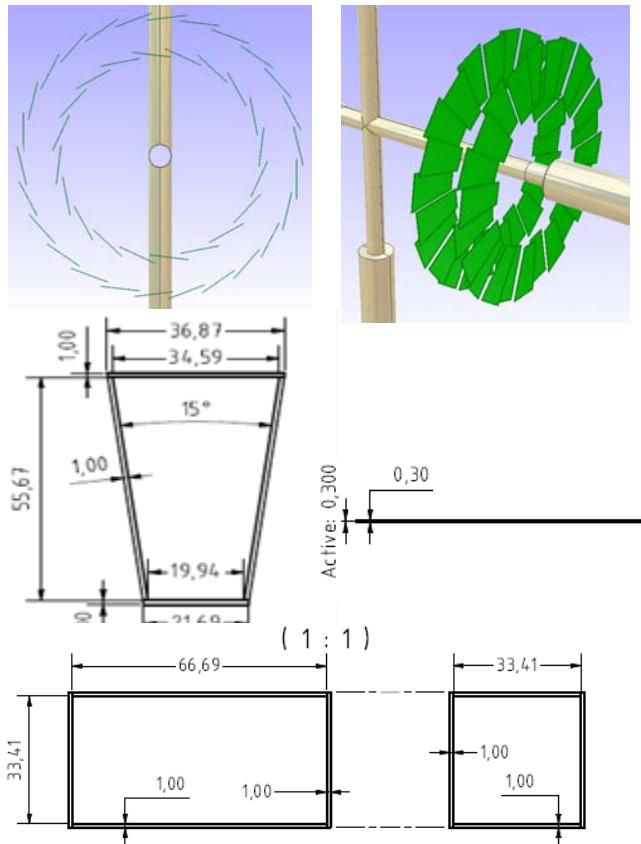
Standard technology

Strip sensor shape

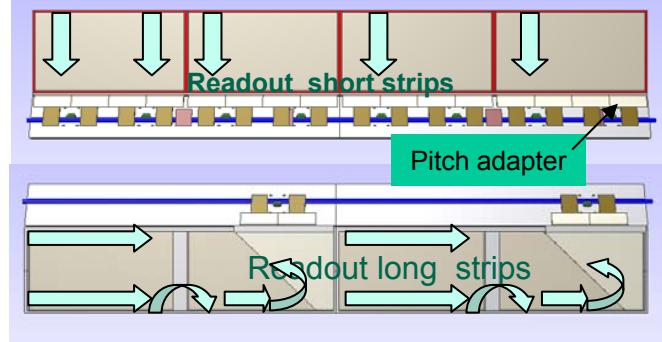
- rectangular for the barrel
- trapezoidal for the disk

Readout: pitch /stereo angle

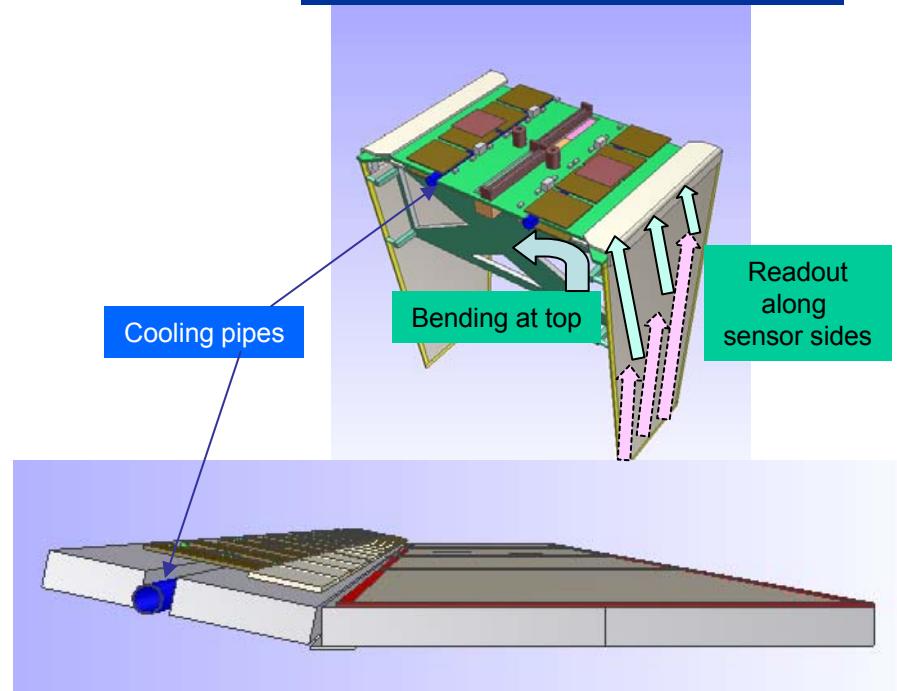
- $130 \mu\text{m} / 90^\circ$ for the barrel
- $70 \mu\text{m} / 15^\circ$ for the disk



Barrel strip super-module



Disk strip super-module



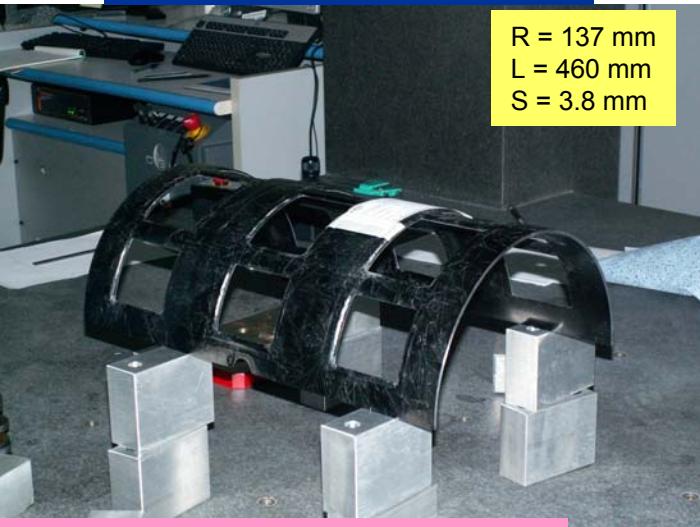


Layout optimization

Light mechanical structures

MVD half support frame

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



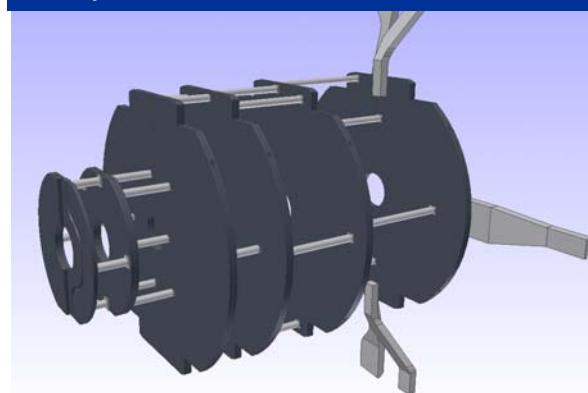
sandwich structure:

1 skin → 4 plies of carbon fibre
M55J/LTM110 (0°, 45°, 90°, 135°)
core → Rohacell 51IG
1 skin → 4 plies of carbon fibre
M55J/LTM110 (0°, 45°, 90°, 135°)
Radiation Length $X_0 \approx 0.4\%$

Upstream cone supporting barrel pixel stave



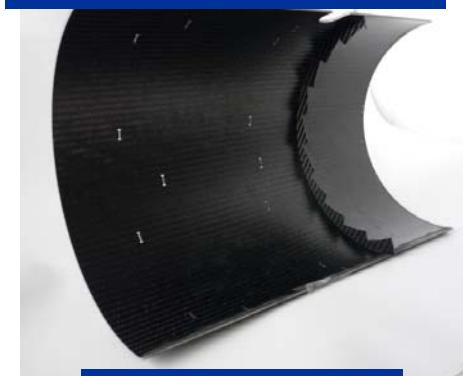
Spacers in between pixel disk
Suspensors for attachment to frame



Foam POCO – HTC pixel half disk



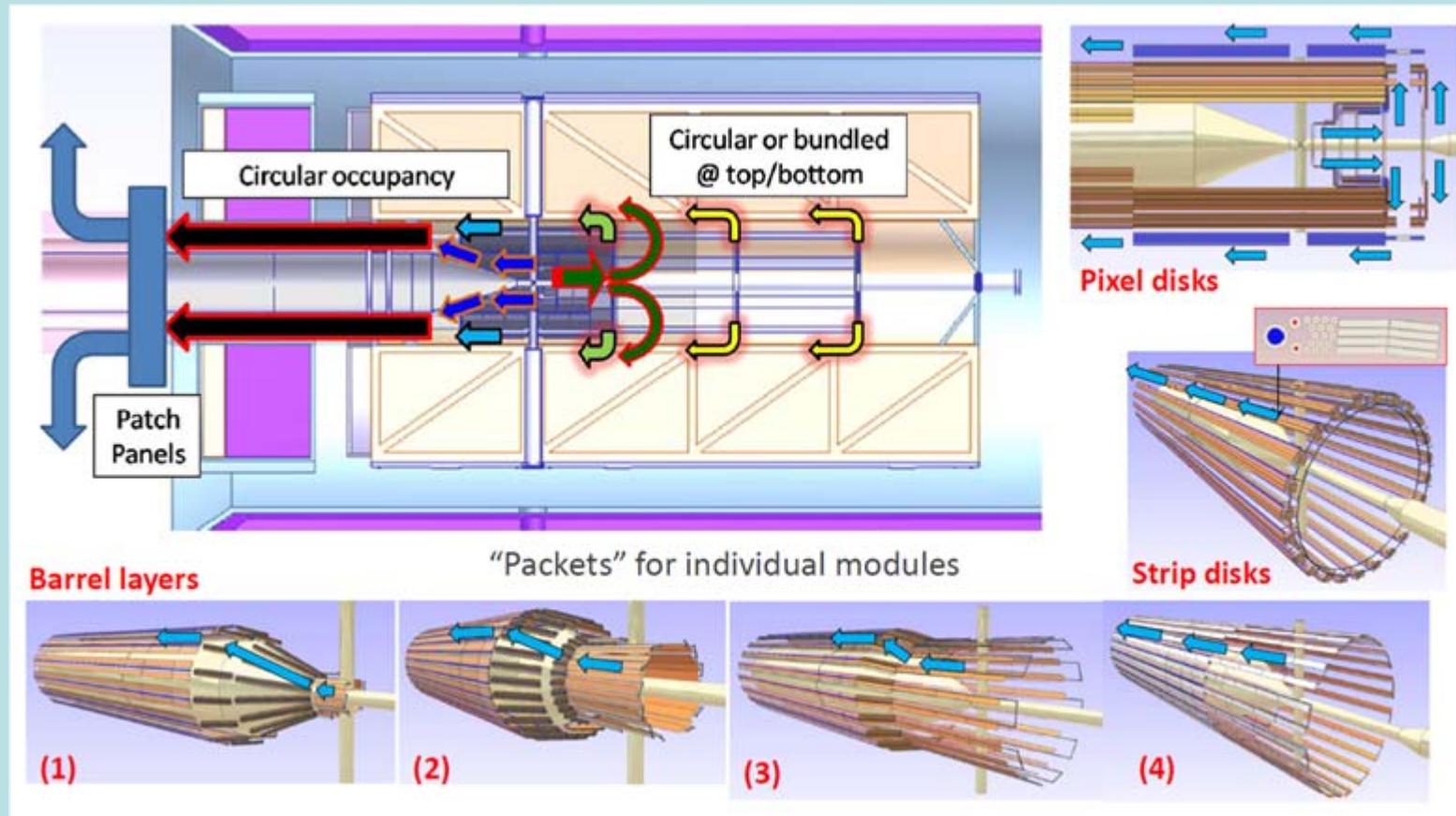
Strip barrel support
Cylinder over full length



Strip support ring



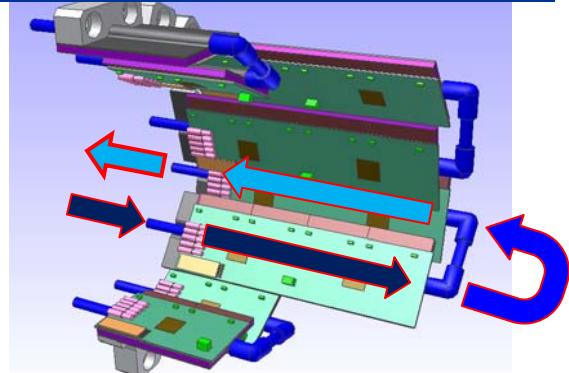
Routing scheme



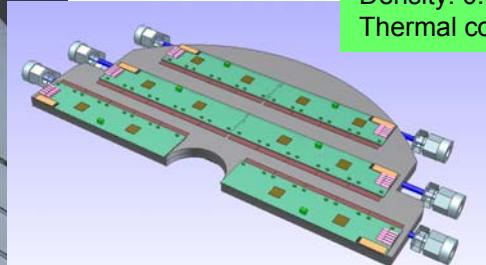
Cooling system

- Cooling fluid: water (input temperature $\sim 18^\circ\text{C}$)
- Cooling system working in depression mode

Cooling concept for barrel staves



HTC foam pixel half disk



Small and partial prototype of a disk
12 resistors (1 W/cm^2 each resistor)
HTC foam support (4 mm thick)
Stainless steel pipes ($\varnothing_e 2\text{mm}$, $\varnothing_i 1.84\text{mm}$)

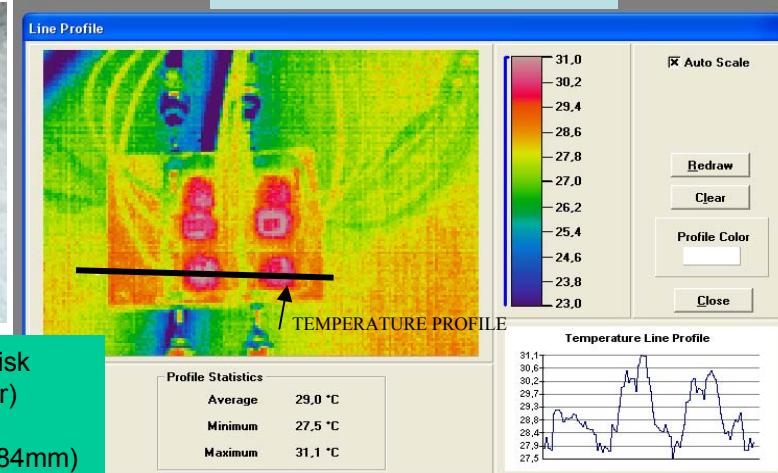
HTC Foam
Density: 0.9 g/cm^3
Thermal conductivity: $245/70/70 \text{ W/m}\cdot\text{K}$

Disk is made by two halves and three pipes embedded (MPN35N Ni-Co alloy; 2 mm external diameter, 1.84 internal diameter).

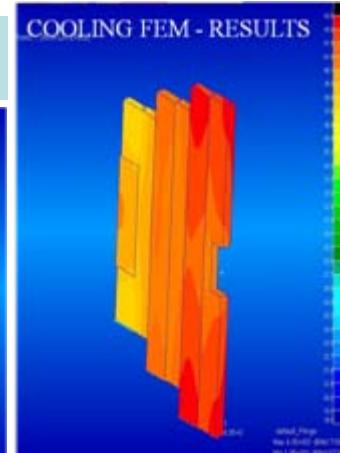
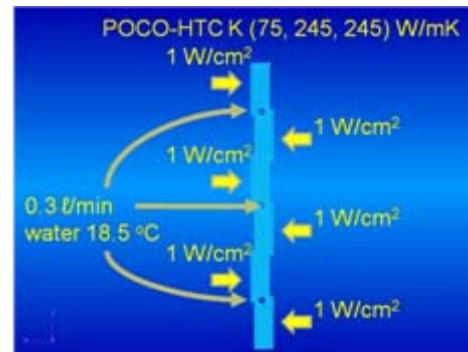
The halves and the pipes are glued with thermal epoxy (EPOTEK H70E)

The surfaces are milling machined to final thickness (4 mm)
Planarity reached $< 20 \mu\text{m}/\text{m}$

Cooling test results – IR image



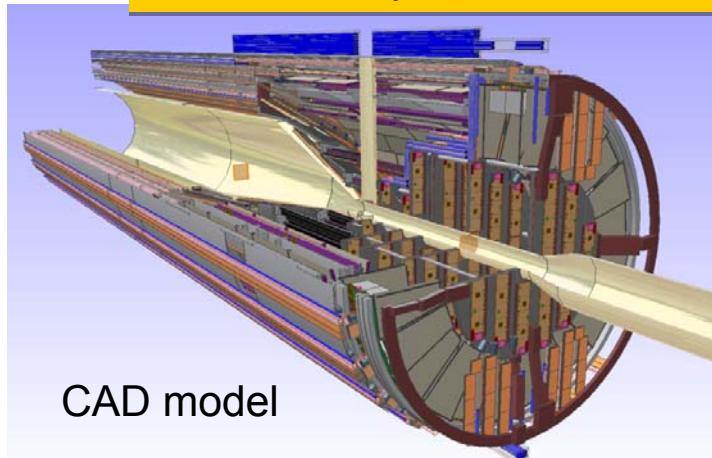
A full half disk is modeled for thermal behavior study.
Thermal flow (with a safety factor > 2) $\rightarrow 1 \text{ W/cm}^2$



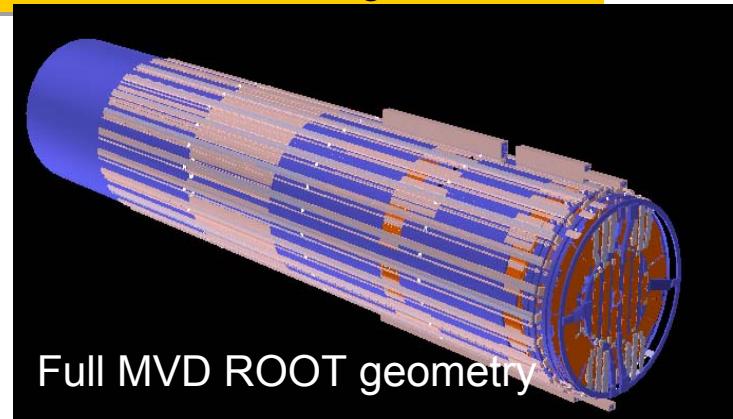
CAD converter → simulations

CAD Converter

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

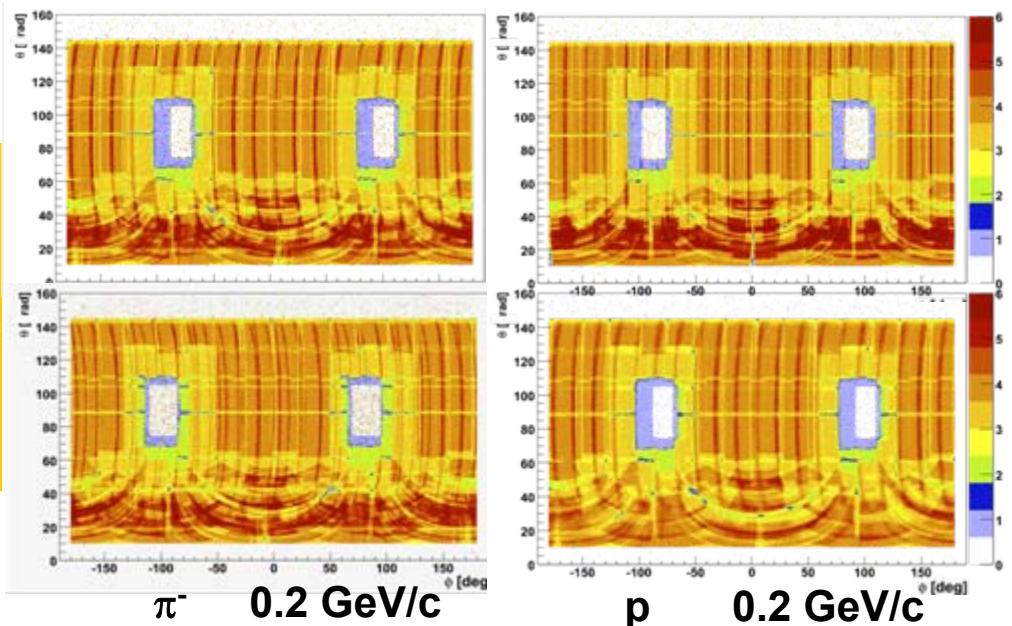


CAD model



Full MVD ROOT geometry

$\pi^+ 0.2 \text{ GeV}/c \rightarrow 1.5 \text{ GeV}/c$



Spatial coverage

2D mapping: Number of MVD points / track

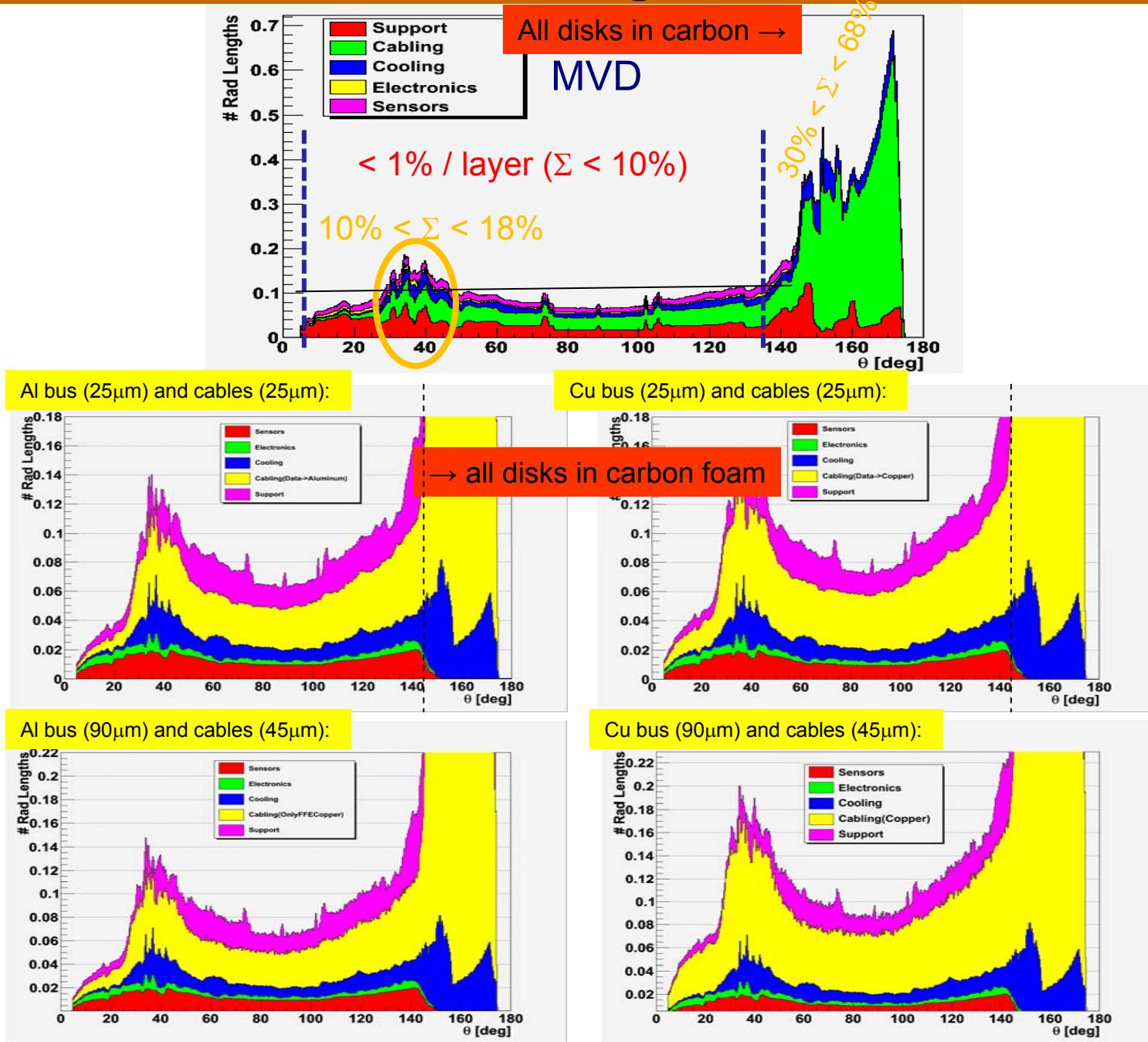
Design optimization for a minimum of 4 track points

No significant effect for particle-antiparticle

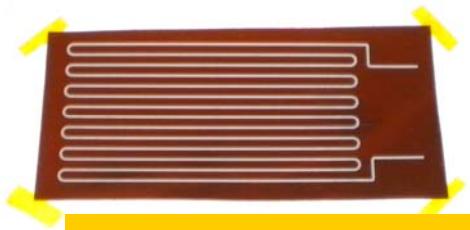
No significant energy dependence

No significant effect for different particle species

Radiation length studies



Cable prototypes



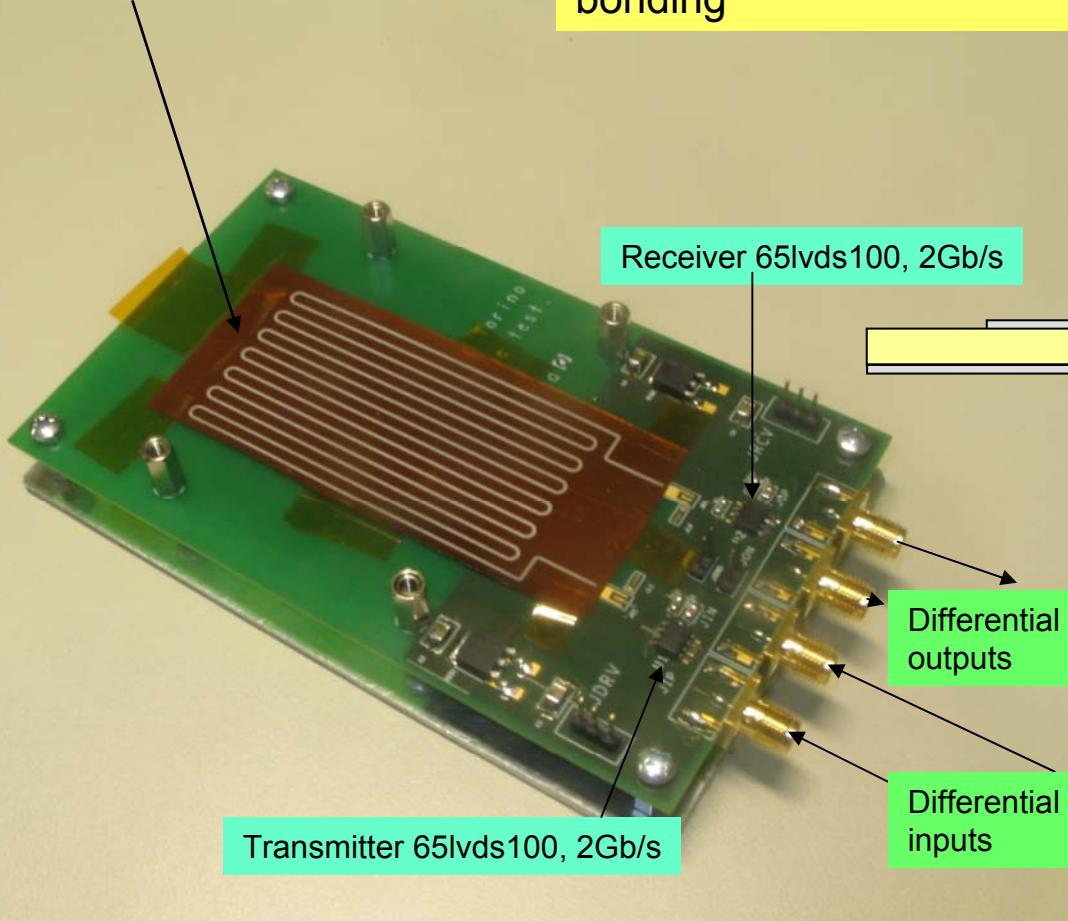
1 m folded differential cable

a) Techfab (Italy)

Technology with aluminum deposition on kapton (or SU8), presently not completely reliable for bonding

b) CERN

Technology with laminated aluminum on kapton, reliable for bonding



a) 5-9 μm thickness
b) 15 μm thickness

Al

Al

Kapton

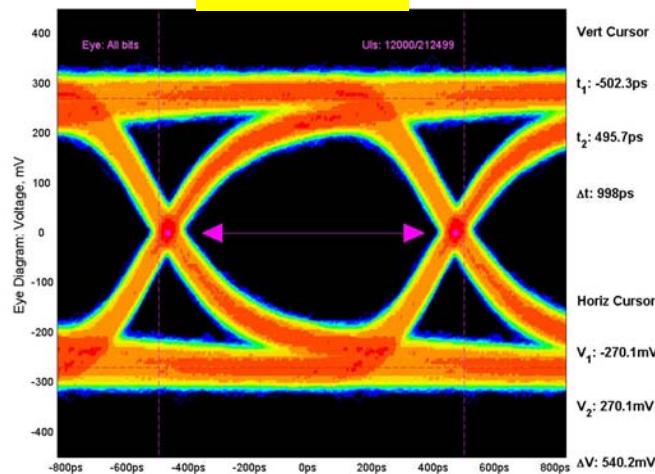
a) 5-9 μm thickness
b) 15 μm thickness

a) 50 μm thickness

b) 65-75 μm thickness (glue+kapton)

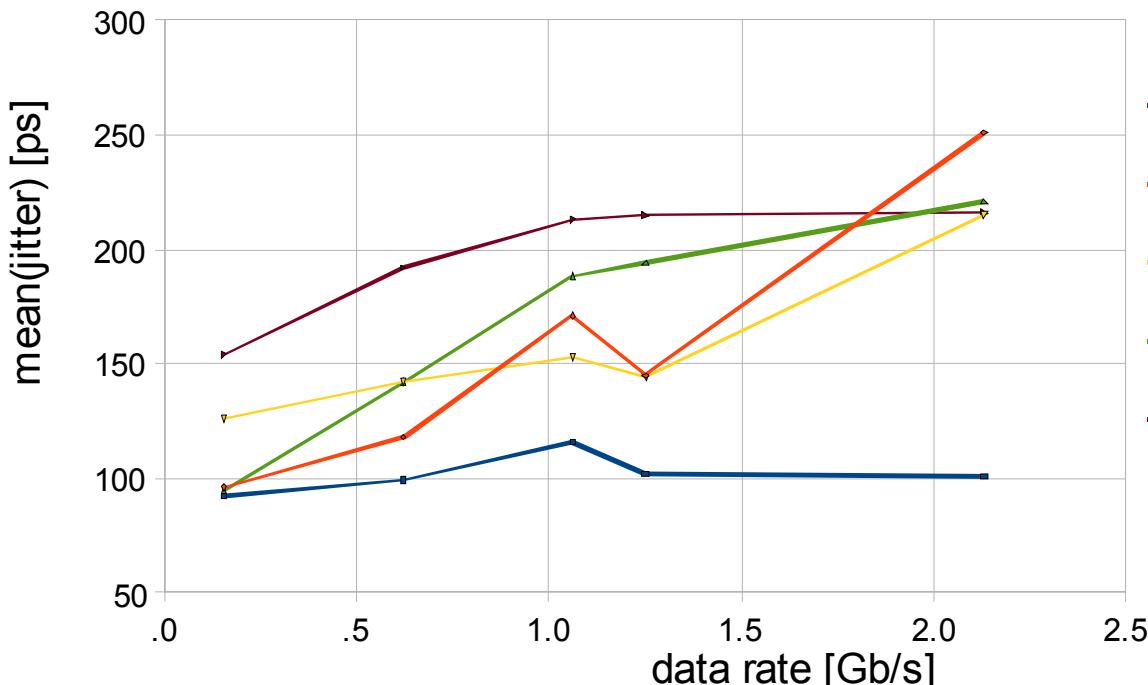
Results from prototypes

From CERN

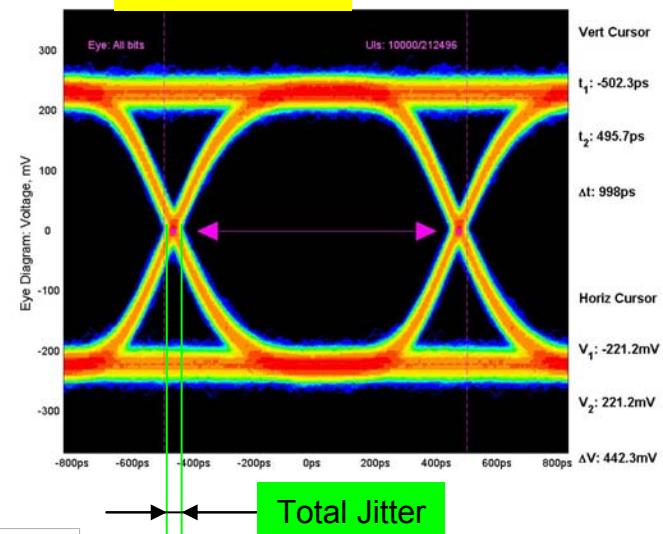


Standard protocol	Data rate [Gb/s]
Optical Carrier 3x	0.156
Optical carrier 12x	0.622
Fiber Channel 1x	1.060
Giga Bit Ethernet	1.250
Fiber Channel 2x	2.130

Total jitter vs data rate.



From Techfab



Total Jitter

- INFN, Cu, 0.570mm, no receiver
- ◆ Techfab, Al, 0.15mm, receiver
- ▼ Techfab, Al, 0.15mm, no receiver
- ▲ Cern, Al, 0.10mm, receiver
- Cern, Al, 0.15mm, no receiver

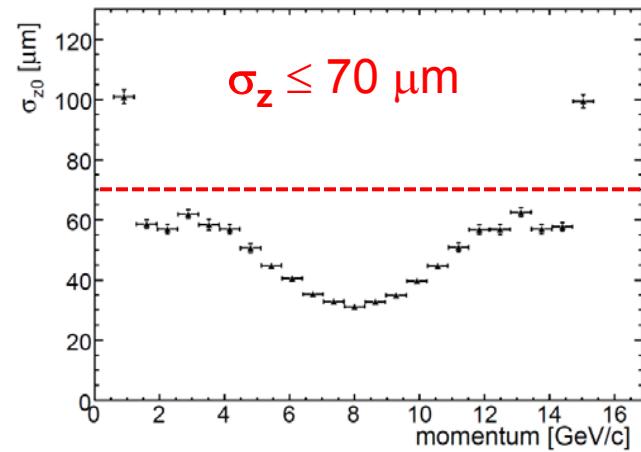
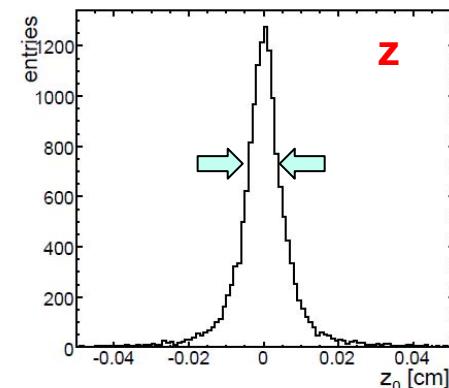
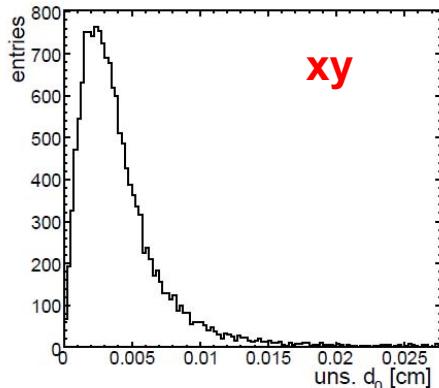
Error bit rate counting: 0

Max. data flow foreseen from MVD: ~100 Gb/s

Performance I

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 GeV/c	vertex resolution [μm]					
	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

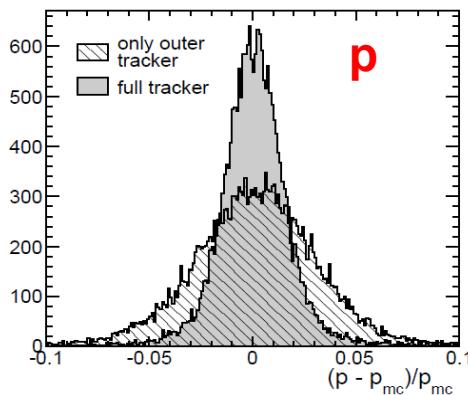
→ Secondary
vertex resolution:

$\sigma_{x,y} \leq 35$ μm

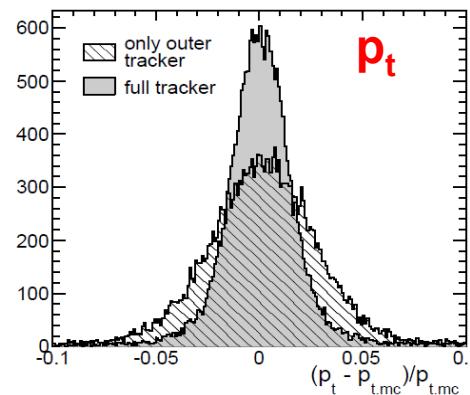
$\sigma_z \leq 100$ μm

Performance II

Momentum resolution



1 GeV/c π



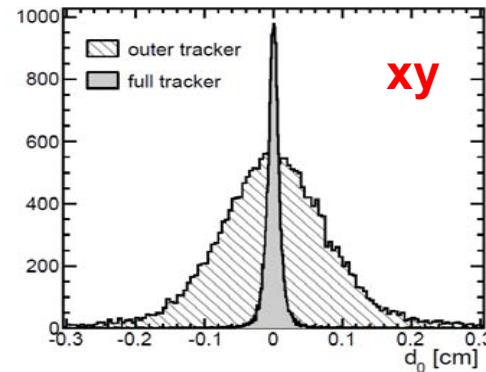
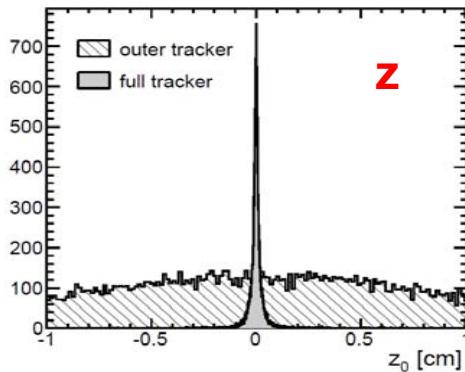
$\sigma(p)$ without MVD = 2.6 %
 $\sigma(p)$ with MVD = 1.4 %

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

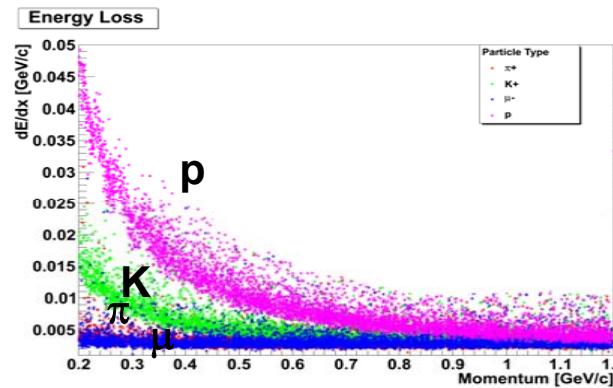
→ Improvement by 50%

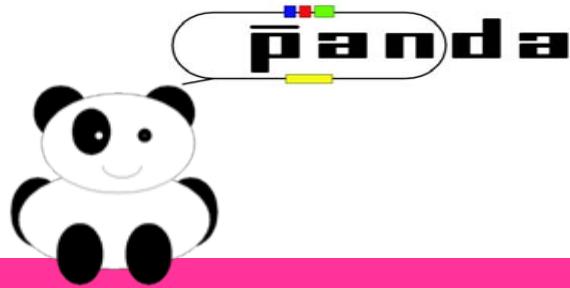
Single track resolution

→ No resolution along z without MVD



Energy loss information (in progress)





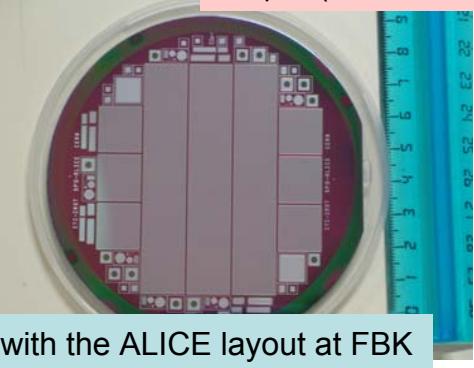
Prototypes

D. Calvo



Hybrid pixel detector I: sensor prototypes

49 μm (4060 $\Omega\cdot\text{cm}$, n/P) + 50 μm Cz substrate (0.01-0.02 $\Omega\cdot\text{cm}$, n⁺/Sb)
74 μm (4570 $\Omega\cdot\text{cm}$, n/P) + 50 μm Cz substrate (0.01-0.02 $\Omega\cdot\text{cm}$, n⁺/Sb)
98 μm (4900 $\Omega\cdot\text{cm}$, n/P) + 50 μm Cz substrate (0.01-0.02 $\Omega\cdot\text{cm}$, n⁺/Sb)



with the ALICE layout at FBK

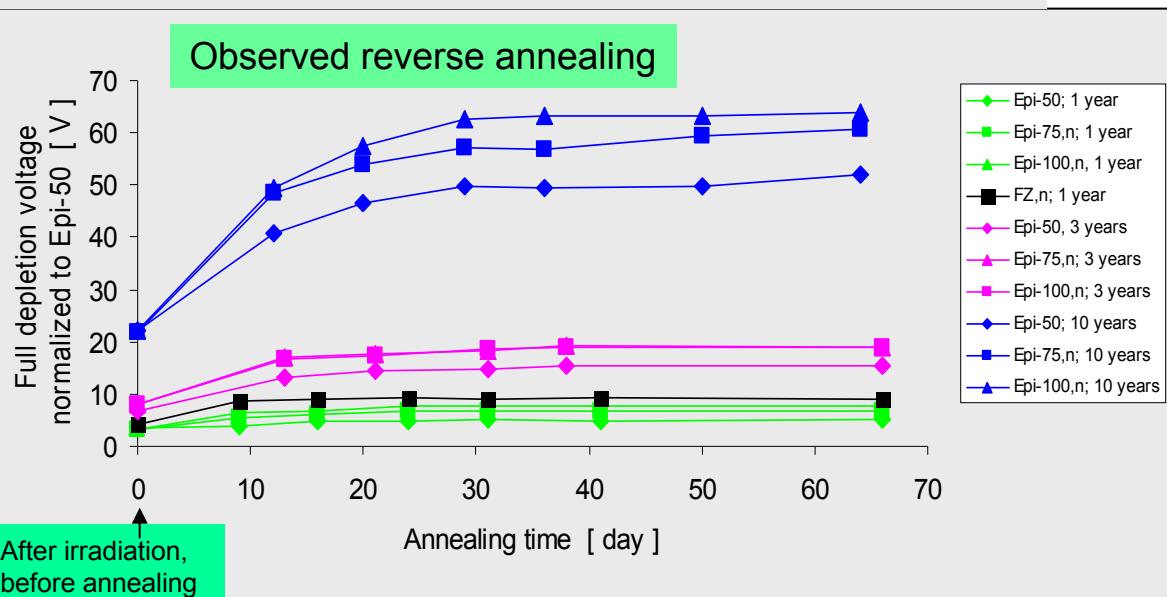
Single chip assembly

- ✓ pixel obtained with the ALICE masks (50 μm x 425 μm)
- ✓ test performed using ALICE pixel readout chip

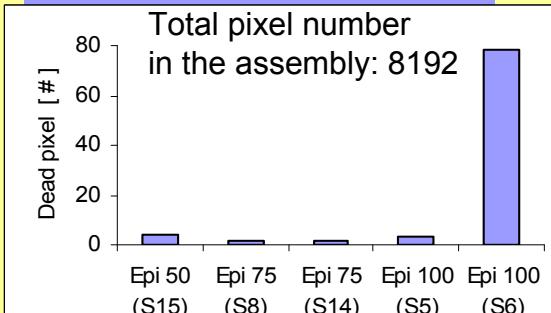
Diodes

Test of radiation damage with neutrons from Pavia nuclear reactor.
Equivalent fluences corresponding to ~ 1, 3 and 10 years of
PANDA lifetime

Observed reverse annealing



NIM A594 (2008) 29-32;
D. Calvo, P. De Remigis, F. Osmic,
P. Riedler, G. Stefanini, R. Wheaton



Dead pixel % $\leq 0.05\%$
 $\leq 1\%$ (worst case)

Leakage current < 50 nA/pixel
(100 μm x100 μm size, 100 μm thick),
immediately after the irradiation,
decrease by a factor 2
after 10 days of annealing at 60°C

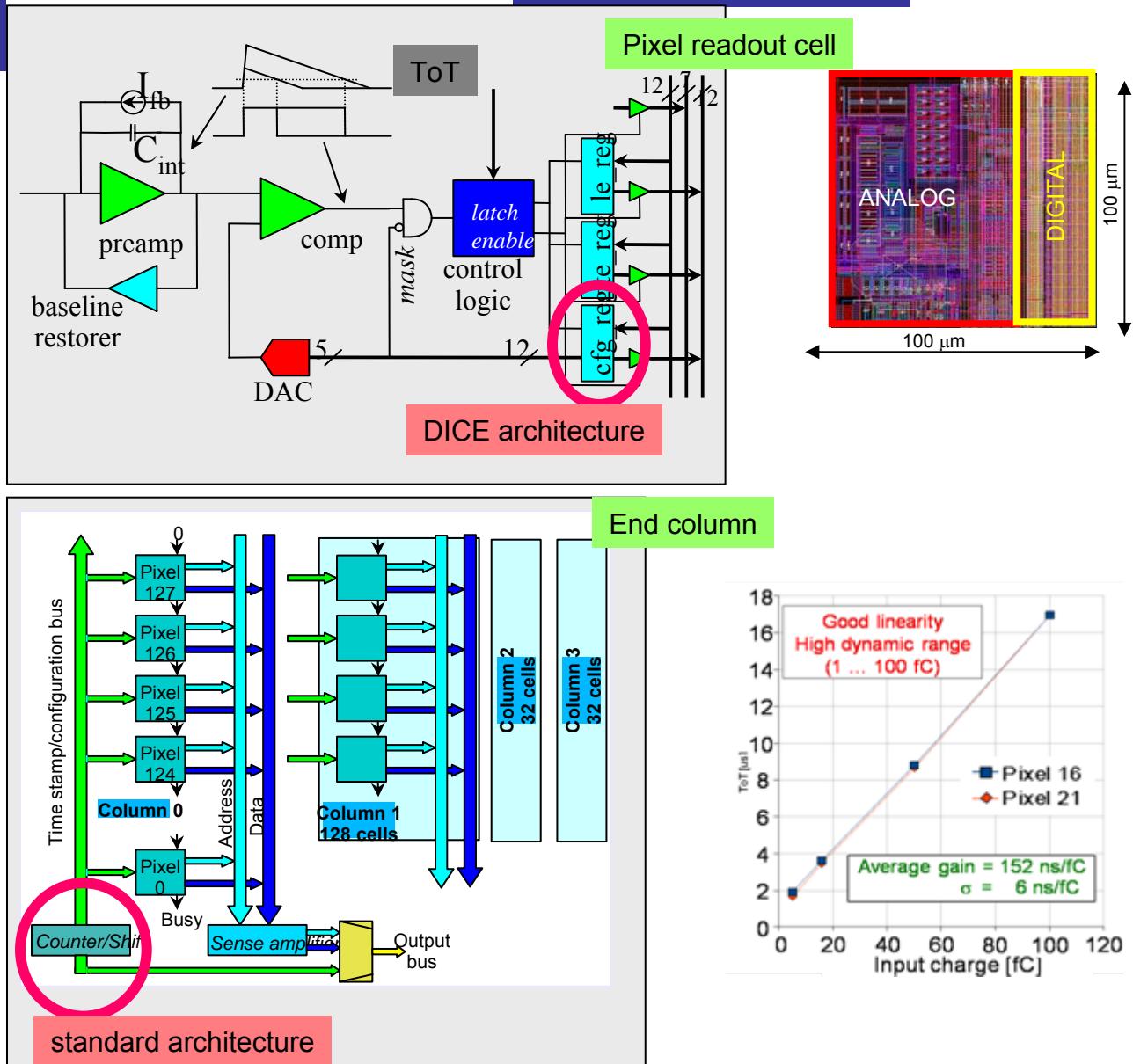
Epitaxial material with lower resistivity
study is in progress

Hybrid pixel detector II: ToPix_v2

ToPix specifications 130nm CMOS technology

Pixel readout size:	$100 \times 100 \mu\text{m}^2$
Chip active area:	$11.4 \times 11.6 \text{ mm}^2$ (116 rows, 110 columns)
dE/dx measurement:	ToT, 12 bits dynamic range
Noise:	< 0.032 fC (200 e ⁻)
Clock frequency:	155 MHz
Time resolution:	6.4 ns (1.85 ns rms)
Power consumption:	<< 500 mW/cm ²
Max. event rate:	(at 2 10^7 pbar-p ann/s): $\sim 12 \cdot 10^6$ hits/ (cm ² s)

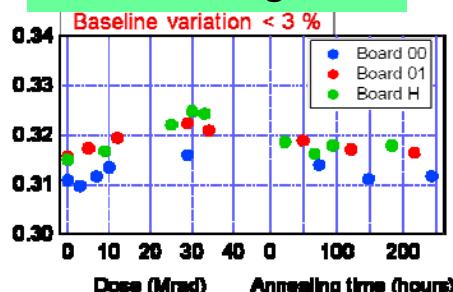
ToPix_v2 prototype



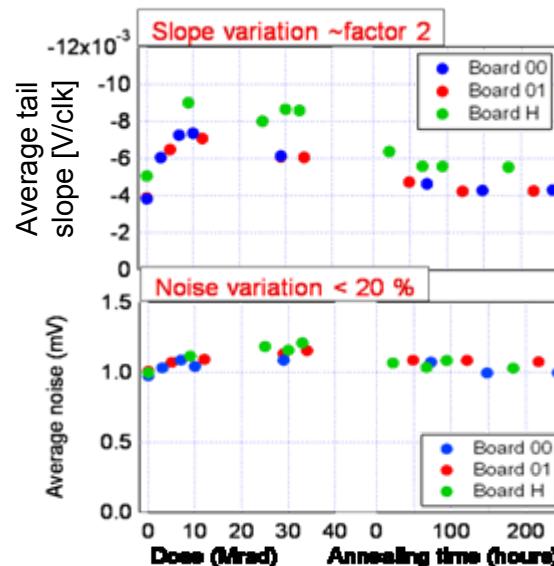
Hybrid pixel detector III: from ToPix_v2 to ToPix_v3

ToPix_v2 prototype

Total Ionizing Dose



The readout chip needs enclosed structures on particular transistors of the constant current discharge circuit



Single event upset

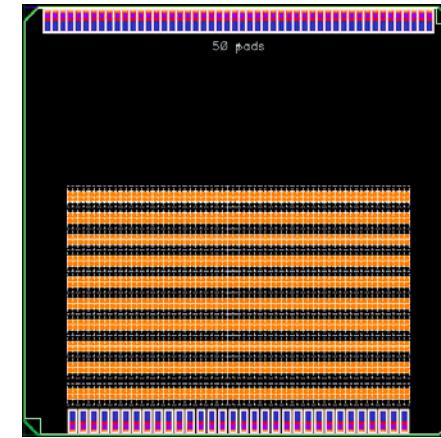
$\sim 6 \cdot 10^{-9}$ SEU bit $^{-1} \cdot \text{sec}^{-1}$ (DICE)
 $\sim 300 \cdot 10^{-9}$ SEU bit $^{-1} \cdot \text{s}^{-1}$ (standard)
with SV: $1 \mu\text{m}^3$,
Threshold Energy: ~ 0.5 MeV (DICE),
0 MeV (standard))

The layout is under design:

4.5 x 4 mm² die area
4 x 128 cells columns
4 x 32 cells columns (for test purposes)
CMOS 130 nm **DM** technology
Enclosed structures (analog part)
Triple redundancy-based SEU protection
End of column logic
320 Mb/s serial output (e-link compatible)
Pads for bump bonding

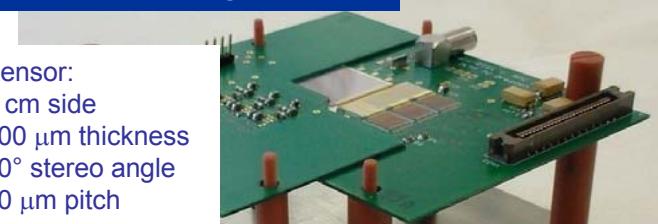
ToPix_v3 prototype

Cell Type	Cell size	comments
Dice	$6 \times 7 \mu\text{m}^2$	ToPix_v2
Triple redundancy	$7 \times 9.6 \mu\text{m}^2$	ToPix_v3 data register
Triple redundancy with self correction	$9 \times 14.4 \mu\text{m}^2$	ToPix_v3 control register

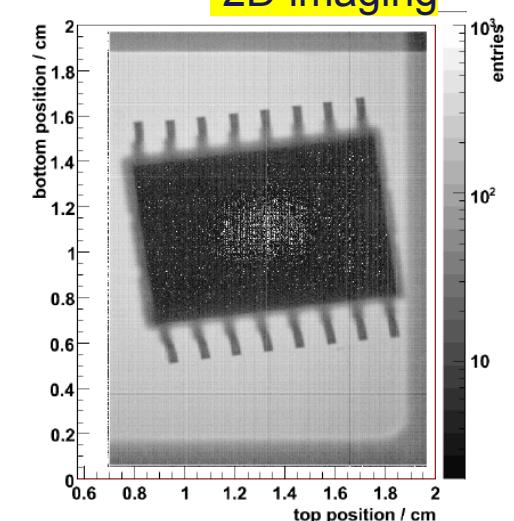
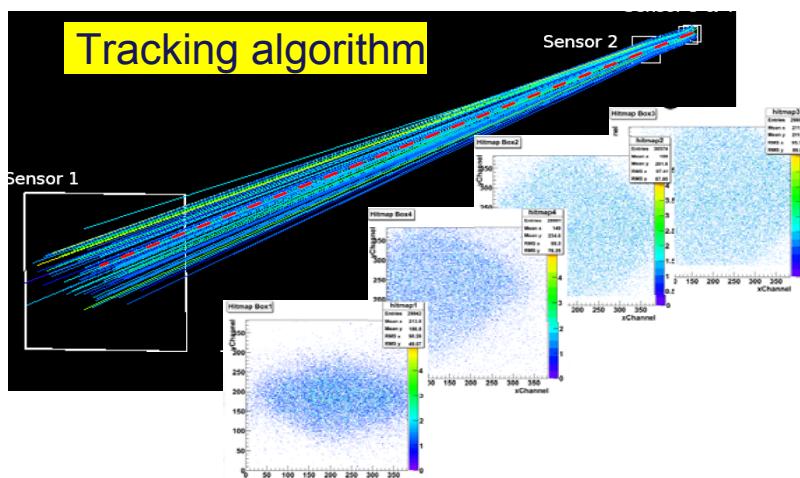


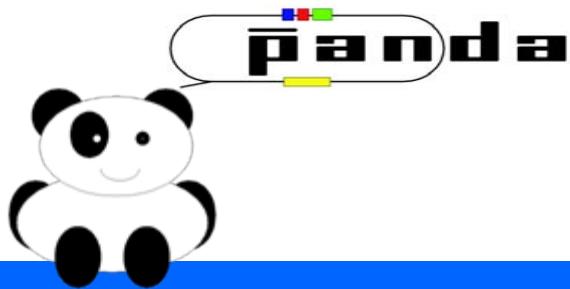
Strip detector

From lab-scale system to tracking station



↑ Tracking Station
at COSY beam time
← Lab setup





Conclusions

MVD design is in progress

Parallel software development to check physics performance

Prototyping phase is started

Still some challenging tasks have to be studied and optimized...

Institutes and members



(INFN-Torino)

K.-Th. Brinkmann, M. Becker, S. Bianco,
R. Jäkel, R. Kliemt, K. Koop, R. Schnell,
P. Vlasov, T. Würschig, H.-G. Zaunick

D. Calvo, S. Coli, P. De Remigis, A. Filippi,
G. Giraudo, G. Mazza, A. Rivetti,
R. Whealon, L. Zotti

F. De Mori, S. Marcello, T. Kugathasan
(Universita' di Fisica -Torino)

T. Stockmanns, L. Atar, D. Grunwald,
H. Kleines, D. Pohl, M. Mertens, J. Ritman



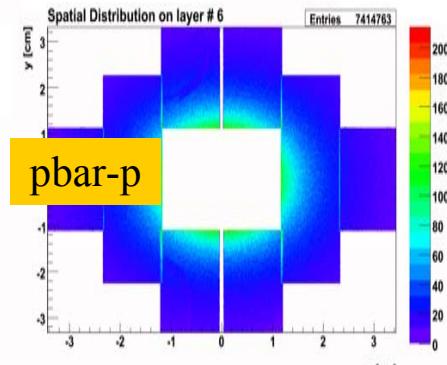
Spare slides

Rates

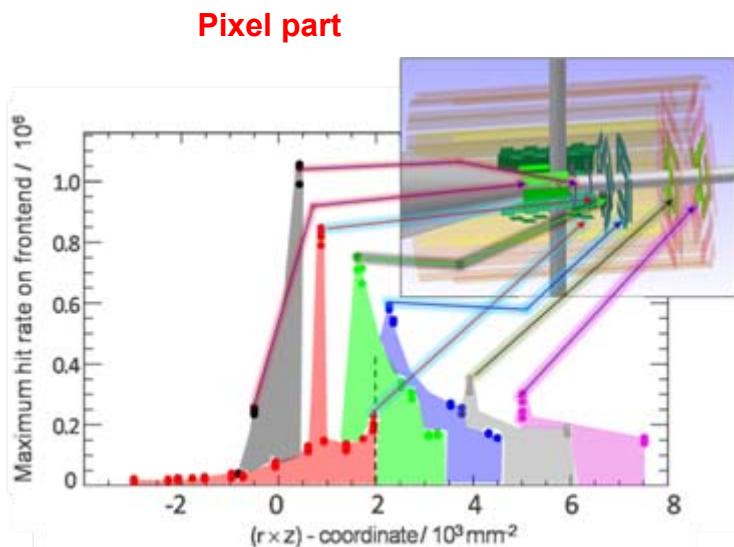
Pixel part

Pbar @15 GeV/c
Proton - $2 \cdot 10^{32}$
Ar - $2.4 \cdot 10^{31}$
Au - $2.2 \cdot 10^{30}$

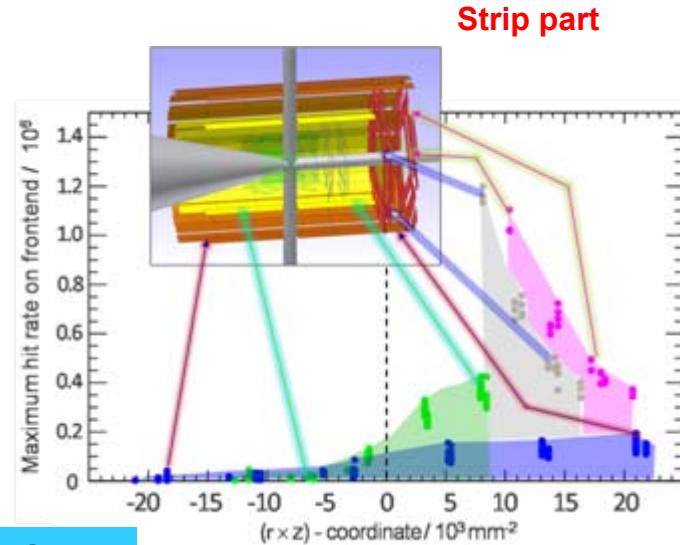
antip-	proton	Ar	Au
Max. average flux [hit/(cm ² ·s)]	$8.24 \cdot 10^5$	$3.30 \cdot 10^5$	$9.47 \cdot 10^4$
Disk number	Disk 6	Disk 5	Disk 4
Max. average flux [hit/(cm ² ·s)]		$2.55 \cdot 10^5$	$1.03 \cdot 10^5$
Barrel 1 stave n.		B1, st 3	B1, st 13
Max. average flux [hit/(cm ² ·s)]		$2.55 \cdot 10^5$	$2.54 \cdot 10^4$
Barrel 2 stave n.		B2, st 19	B2, st 25



pbar-Au



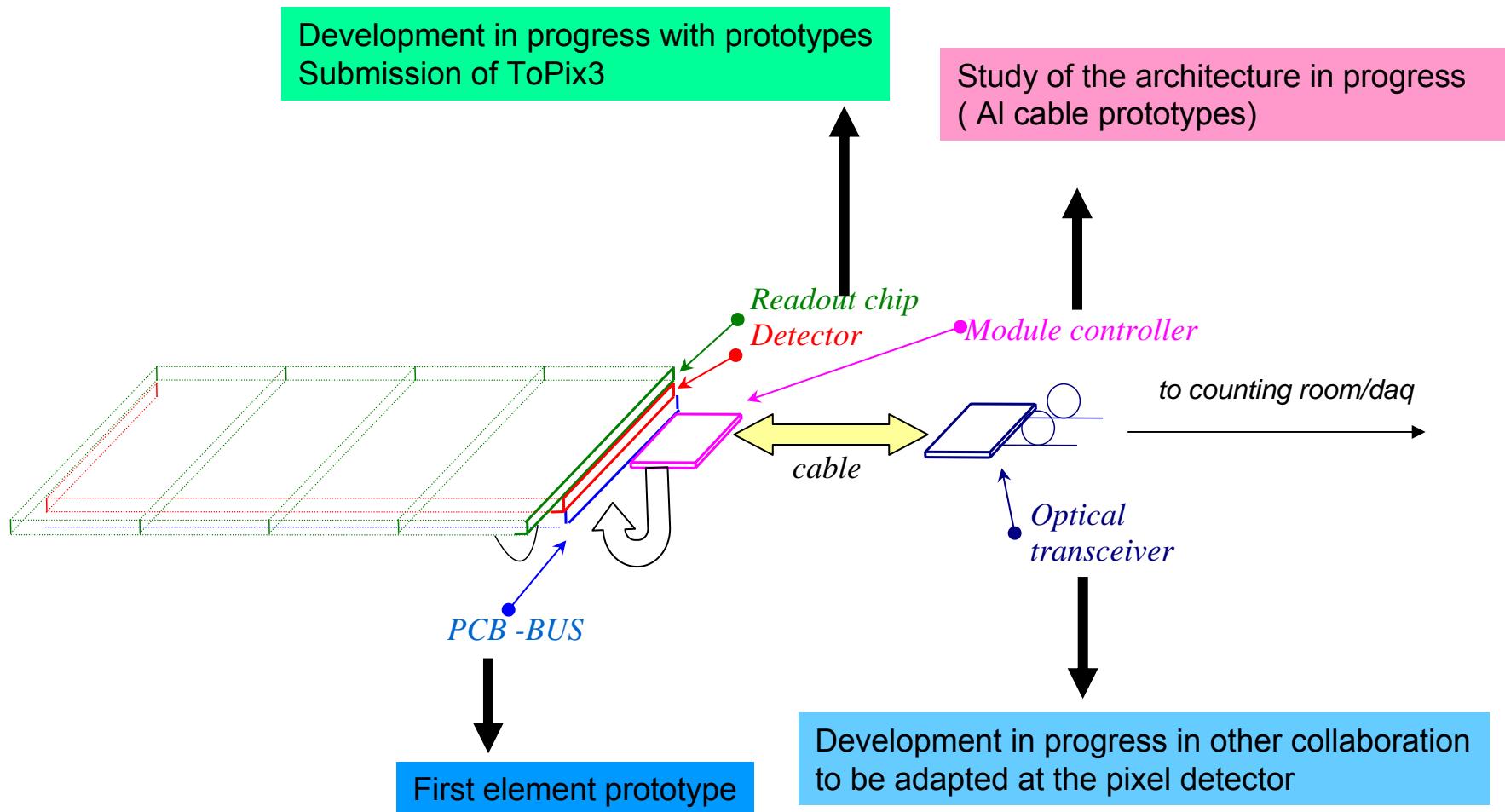
Pixel part



Strip part

Max. data flow foreseen from MVD: ~100 Gb/s

Pixel readout



PANDA DAQ

