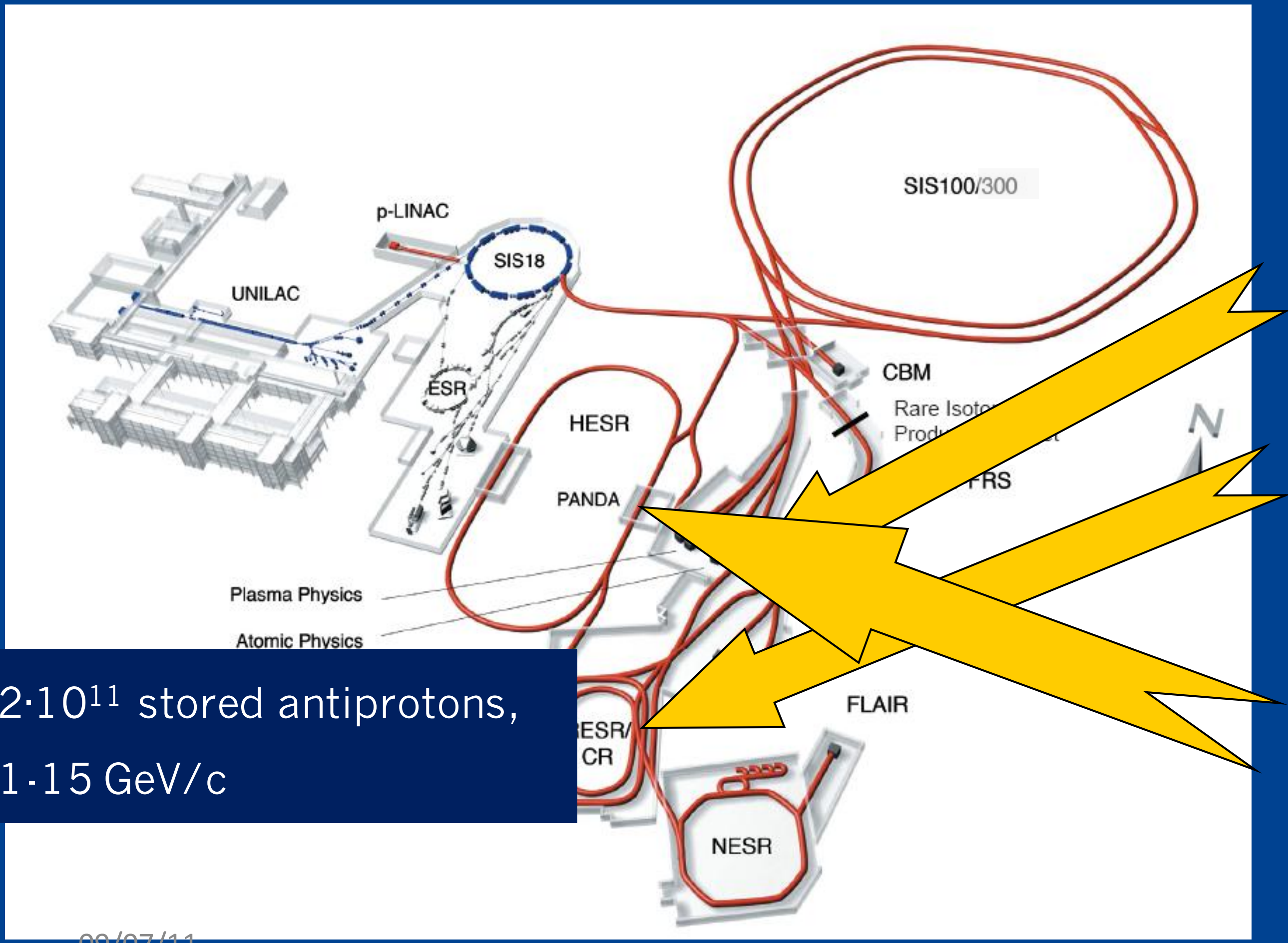
The P̄ANDA Micro-Vertex-Detector

et al.

Kai-Thomas Brinkmann, Mont Sainte-Odile 09/2011

http://www.fair-center.com/



2·10^{11} stored antiprotons,

1-15 GeV/c

antiprotons

production
(30 GeV p on Cu)

collection and
preparation

acceleration and
preparation

experiments

antiProton ANnihilations at DArmstadt

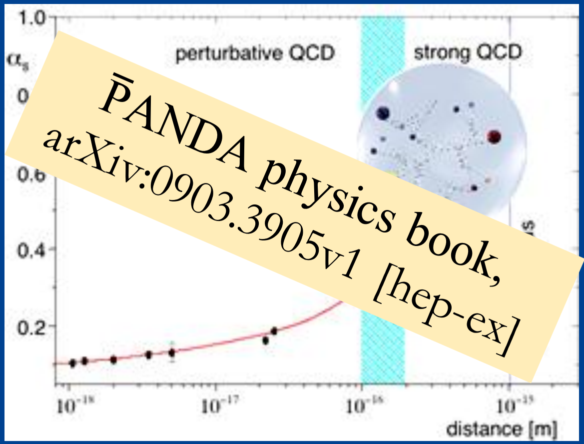
High Energy Storage Ring

10^{11} stored antiprotons, momentum range 1.5 to 15 GeV/c

Luminosity at peak intensity: $\mathcal{L} = 2 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\delta p/p = 10^{-4}$
(stochastic cooling) interaction rate $2 \cdot 10^{7}\ \mathrm{s}^{-1}$

Luminosity for highest resolution: $\mathcal{L} = 2 \cdot 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\delta p/p < 4 \cdot 10^{-5}$
(electron cooling)

$\bar{P}$ANDA Physics



- Many open questions in strong (non-perturbative) QCD

- charmonium - hybrids, glueballs and exotics - open charm

- Chiral symmetry in SU(3) and hadron mass modifications

  - hadrons in the nuclear medium

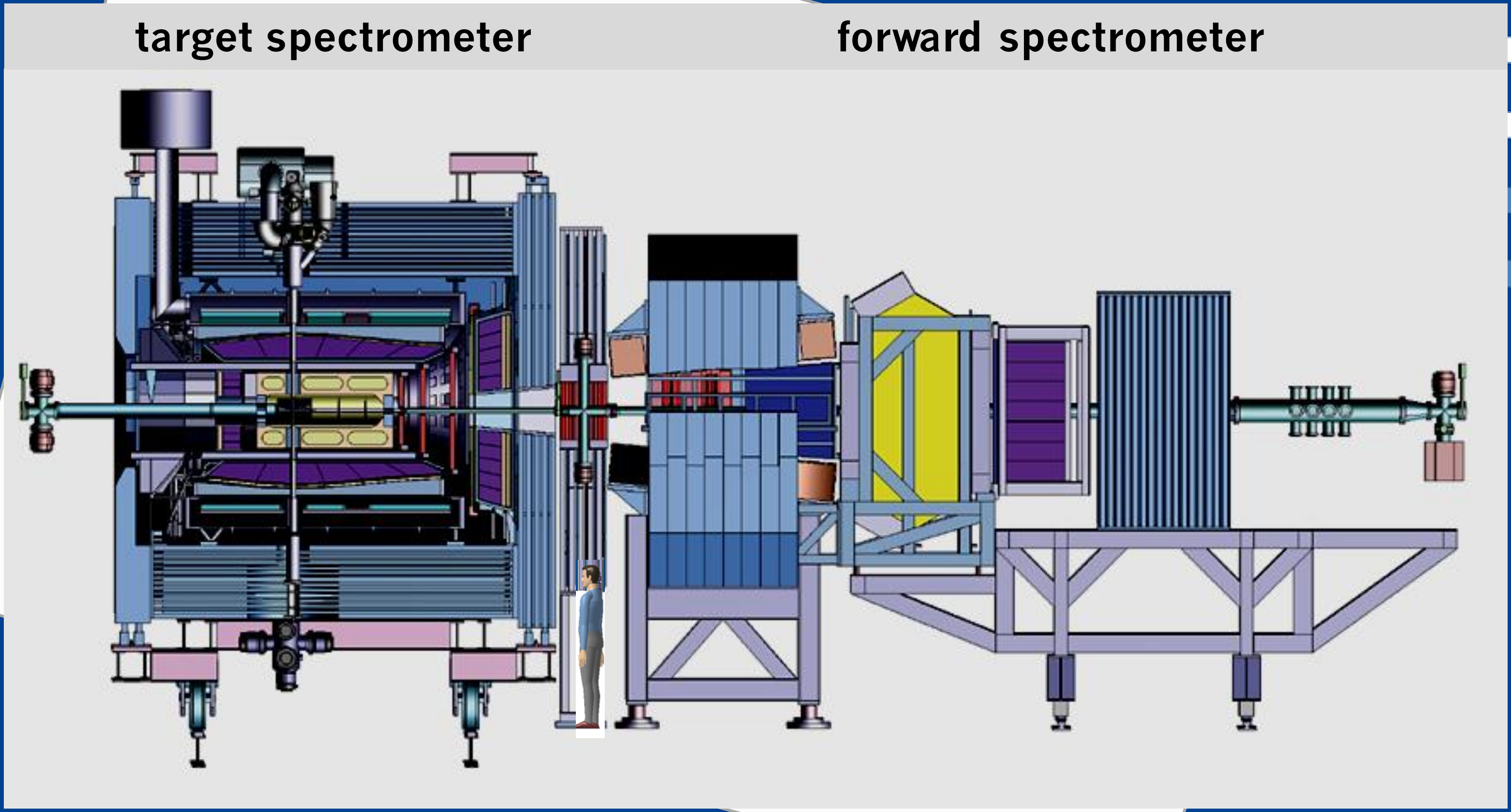
- Hypernuclei: “3rd dimension“ of the chart of nuclides

- Electromagnetic channels and processes

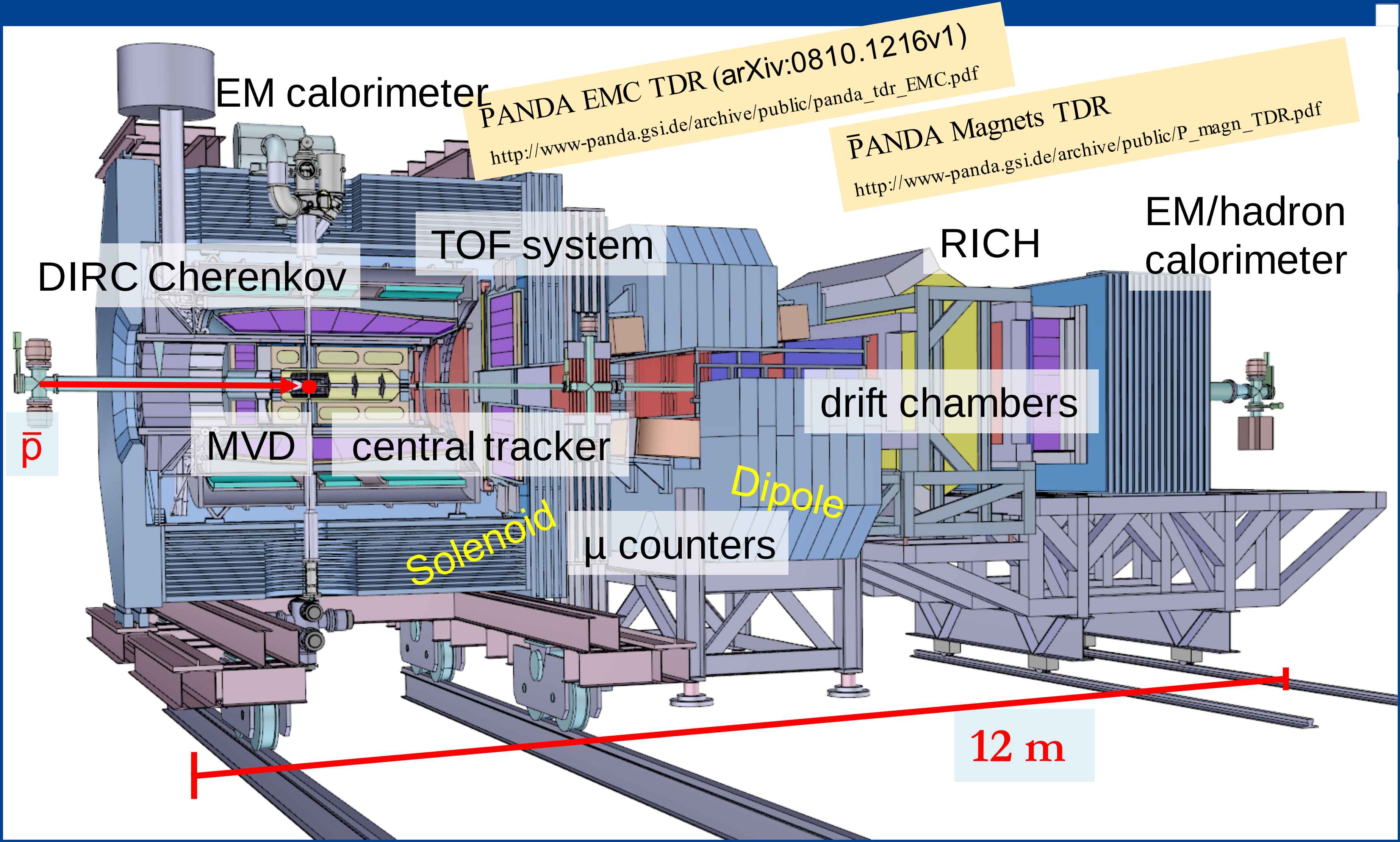
(generalized parton distributions, e-m formfactor of the proton in the time-like regime , virtual Compton scattering, Drell-Yan)

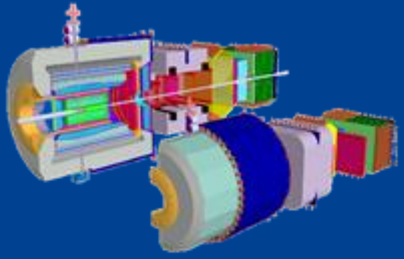
baryon spectroscopy, mixing/CP violation in the charm sector, rare decays, antiproton physics at low energies

antiProton ANnihilations at DArmstadt



antiP̄roton ANnihilations at DArmstadt





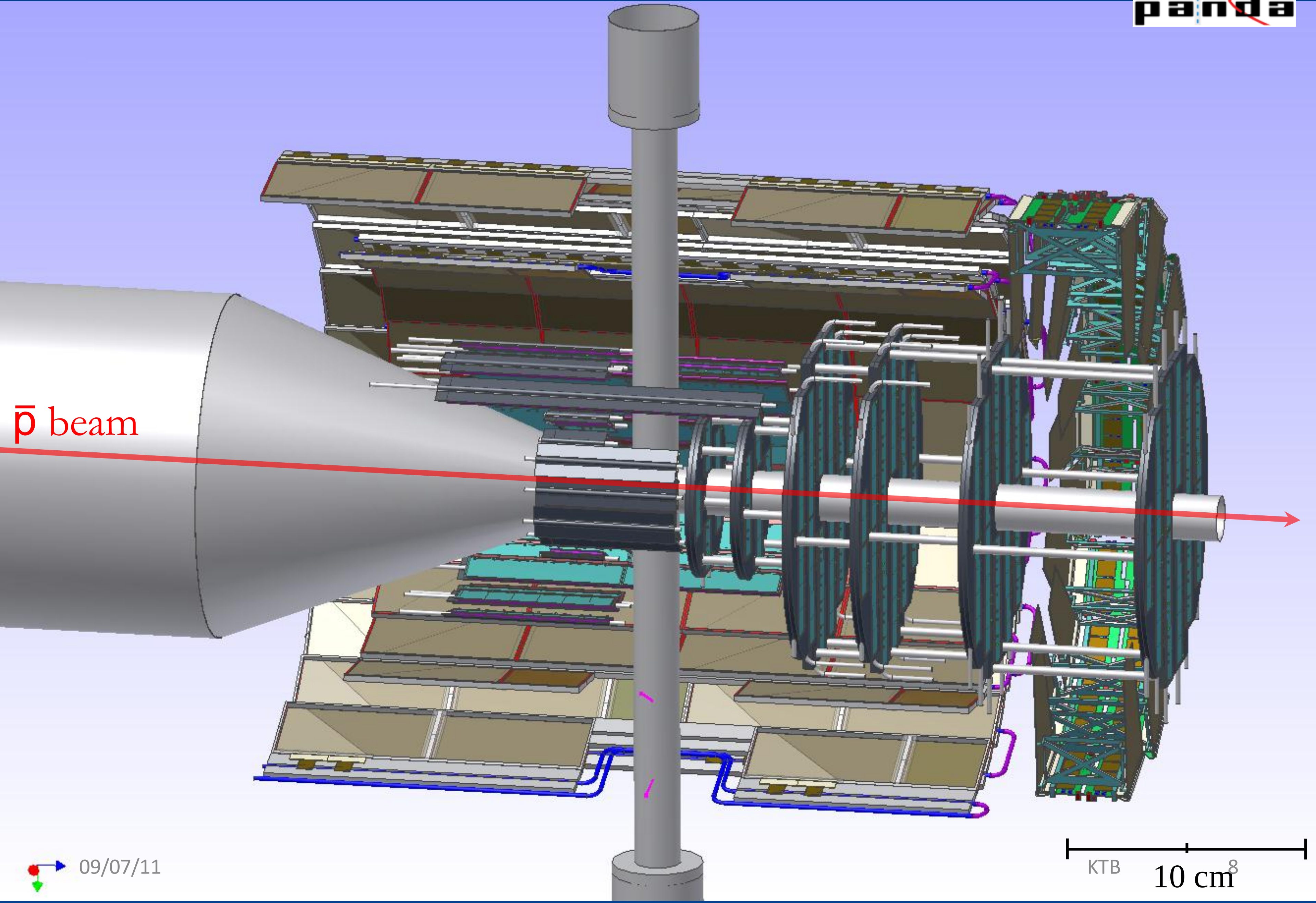
The $\bar{\text{P}}$ANDA Detector

$\bar{\text{P}}$ANDA Technical Status Report,
http://http://www-panda.gsi.de/

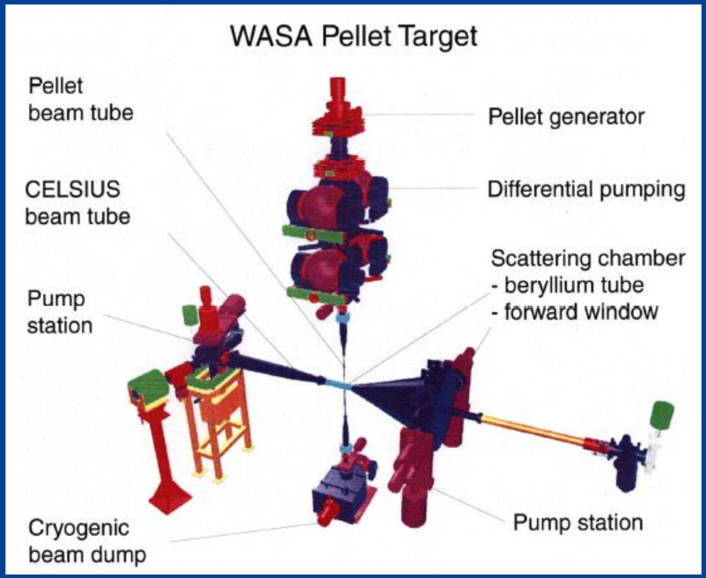
$\bar{\text{P}}$ANDA is a modular multi-purpose device:

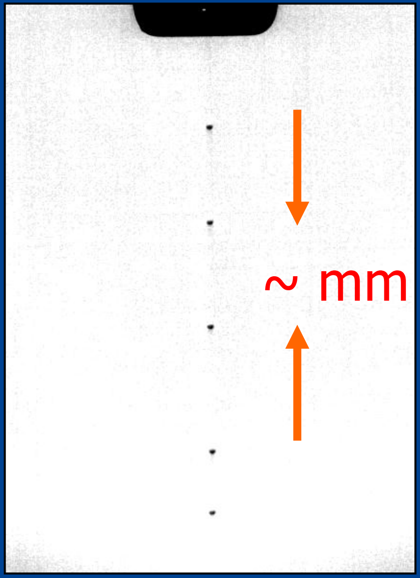
- Excellent forward acceptance and resolution
- (Moderate) backward acceptance
- Wide dynamic range: particle momenta 0.1 - 8 GeV/c
- Momentum measurements in magnetic fields ($\Delta p/p \approx 1\%$)
- Particle ID in wide momentum range $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, p, \ldots$
- Electromagnetic calorimeter: γ, π^0, η ... ($e^{\pm}$)
- High-resolution vertex detection: $D^{\pm}, D^0$ / $K_s, \Lambda, \Sigma, \Omega$ ...
- High interaction rate beyond $2 \cdot 10^7\ s^{-1}$
- Intelligent trigger design for parallel data acquisition at high rates and small branching fractions

hydrogen pellet or cluster jet target



P̄ANDA Targets

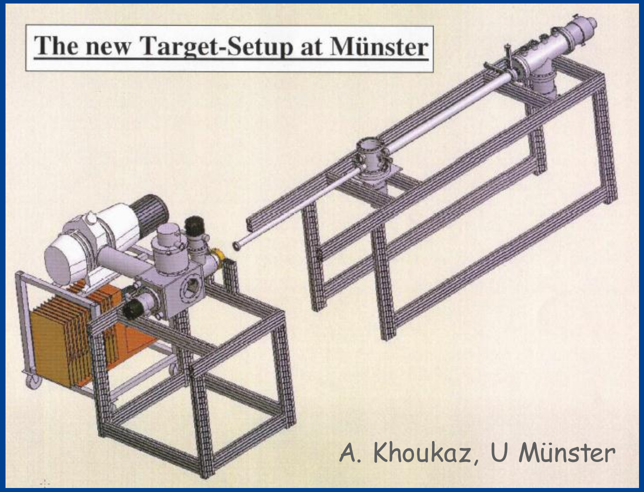




pellet target

10^{16} atoms/cm^2

20-40 µm diameter
mm interspacing



cluster jet target

up to 10^{15} atoms/cm^2

a few mm long in interaction region

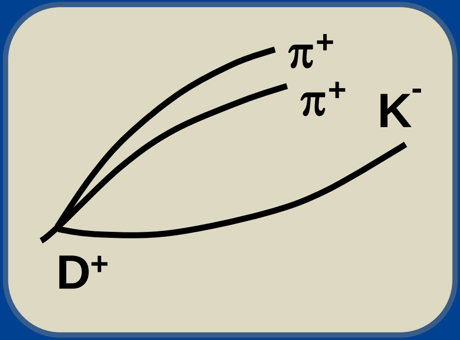
heavy targets: heavy gases, wires, and foils

The $\bar{\mathrm{P}}$ANDA MVD

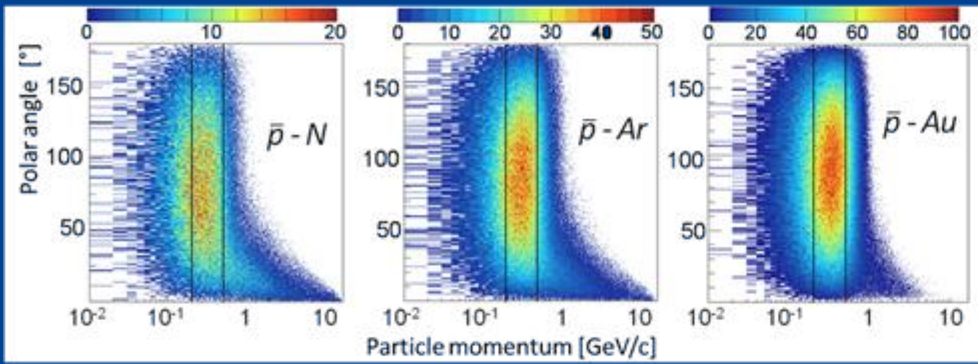
Design adopts state-of-the-art silicon sensor techniques

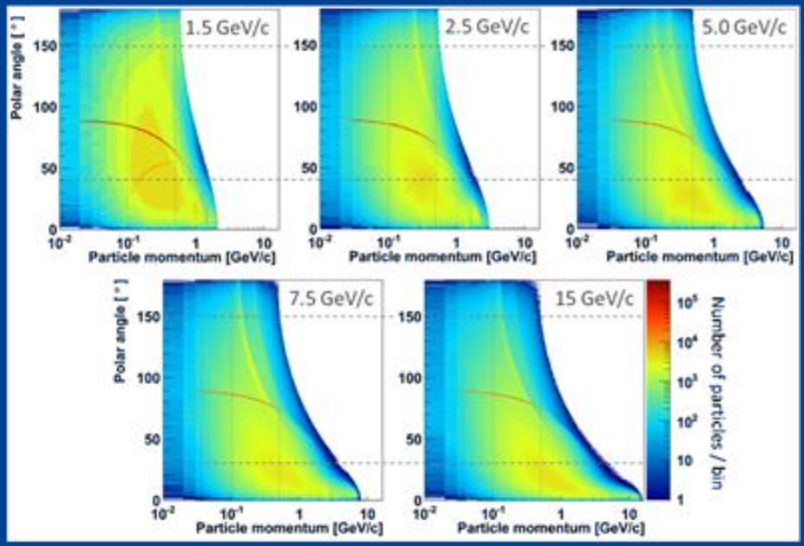
Focus on $\bar{\mathrm{P}}$ANDA specific issues:

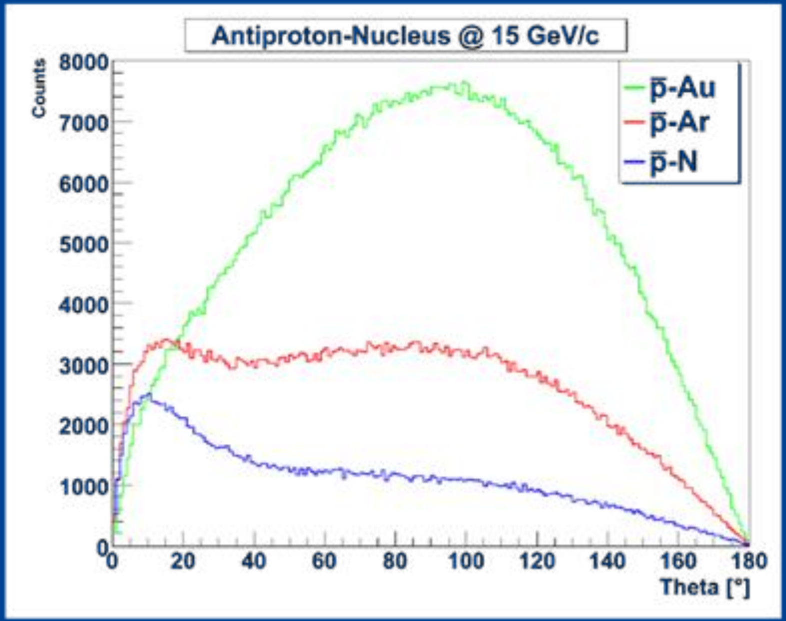
- High and asynchronous interaction rate
- Strongly asymmetric angular distributions
- Versatile experimental requirements
- D meson ID ($c\tau\beta\gamma \sim 500$ μm typical)
- Minimum mass budget

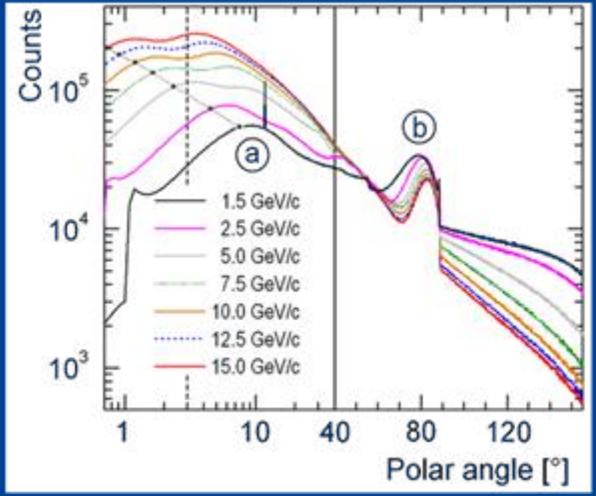


P̄ANDA Physics ☞ MVD









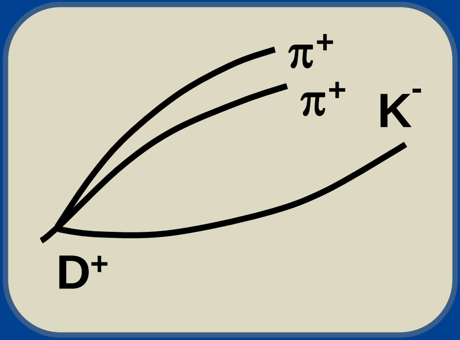
Physics with the MVD

Secondary vertices from delayed decays:

- D meson reconstruction

$$D^0:\ c\tau = 123.7\,\mu\text{m} \quad \begin{array}{l} (56\pm5)\%\,K^{\pm} + anything \\ (42\pm5)\%\,K^0/\overline{K}^0 + anything \end{array}$$

$$D^{\pm}:\ c\tau = 315\,\mu\text{m} \quad \begin{array}{l} (30\pm4)\%\,K^{\pm} + anything \\ (59\pm7)\%\,K^0/\overline{K}^0 + anything \end{array}$$



$(c\bar{c})$ also have considerable branching ratios involving $K\overline{K}$

- Hyperons (e.g. (excited) Ω´s) and kaons (K_S)
- Heavy baryons (e.g. Λ_c)
- Slow charged pions and kaons

The P̄ANDA MVD

Design adopts state-of-the-art silicon sensor techniques

Focus on P̄ANDA specific issues:

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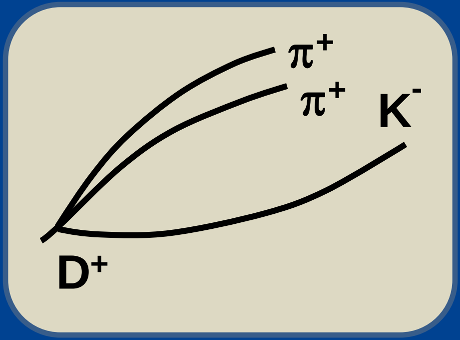
- Versatile experimental requirements
- D meson ID ($c\tau\beta\gamma \sim 500$ μm typical)
- Minimum mass budget



Solutions:

- Heterogeneous design (pixel and strip sensors)
- Very compact design
- Limited number of space points / layers (default 4)
- Novel readout electronics (non-triggered readout)
- Tracklets real-time (fast on-line processing)

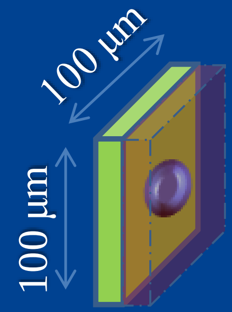
The $\bar{\text{P}}$ANDA MVD Project

Silicon pixel sensors

Small pixel cells – 100 x 100 μm^2

Specialized custom hybrid ☞ ToPix

Features:
- .13 µ technology
- ToT to retain (some) energy information
- fast handling for high data rates
- “untriggered” readout of data
- rad hard within “typical” limits
- minimum material load ⬄ sensor technology



Silicon strip sensors

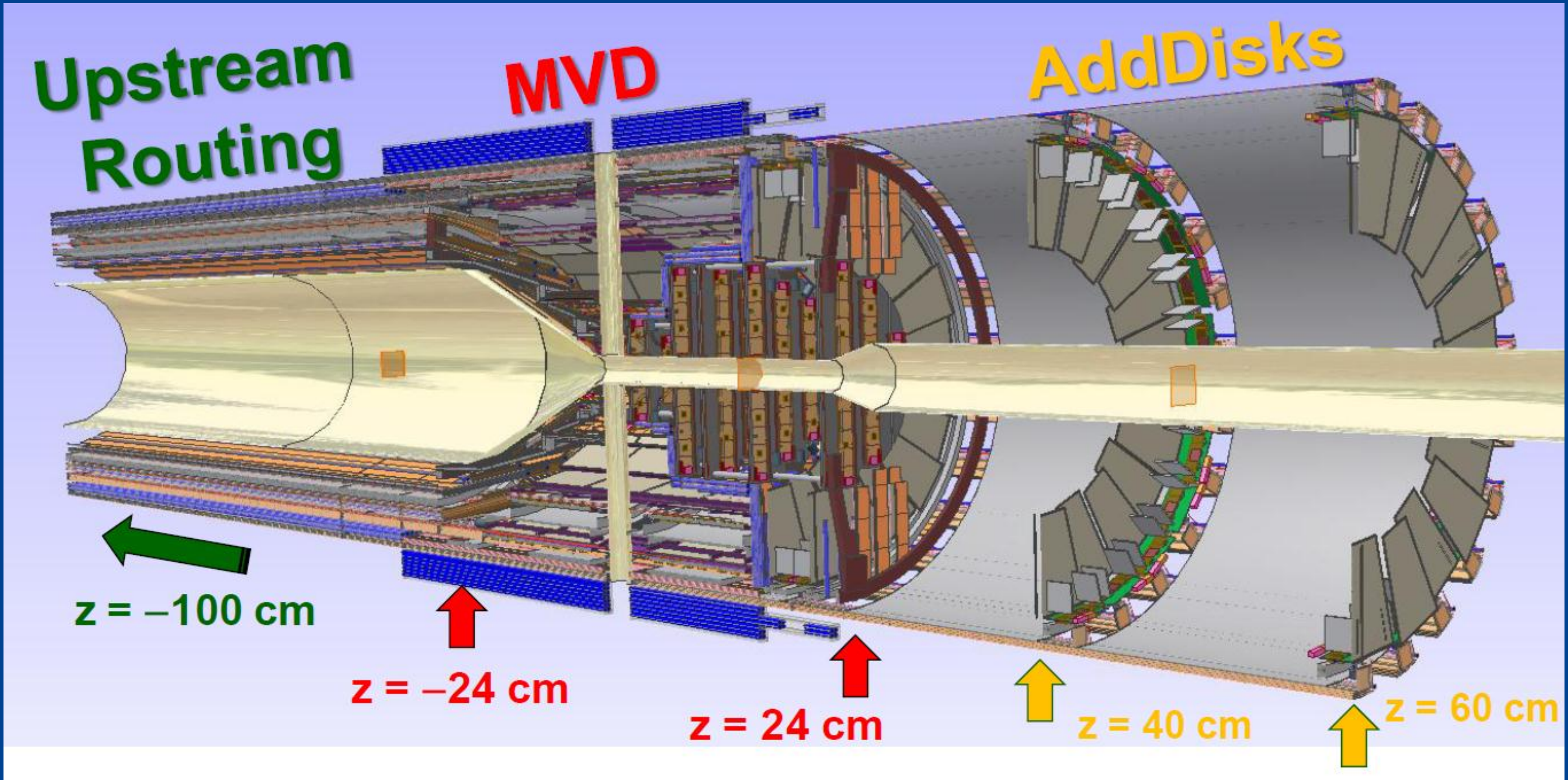
Less traversed material than pixels, smaller number of channels

Features:
- pitch of 50 – 150 µm
- double-sided sensors, 200 µm thick
- specialized solution for front-end

The P̄ANDA MVD Project

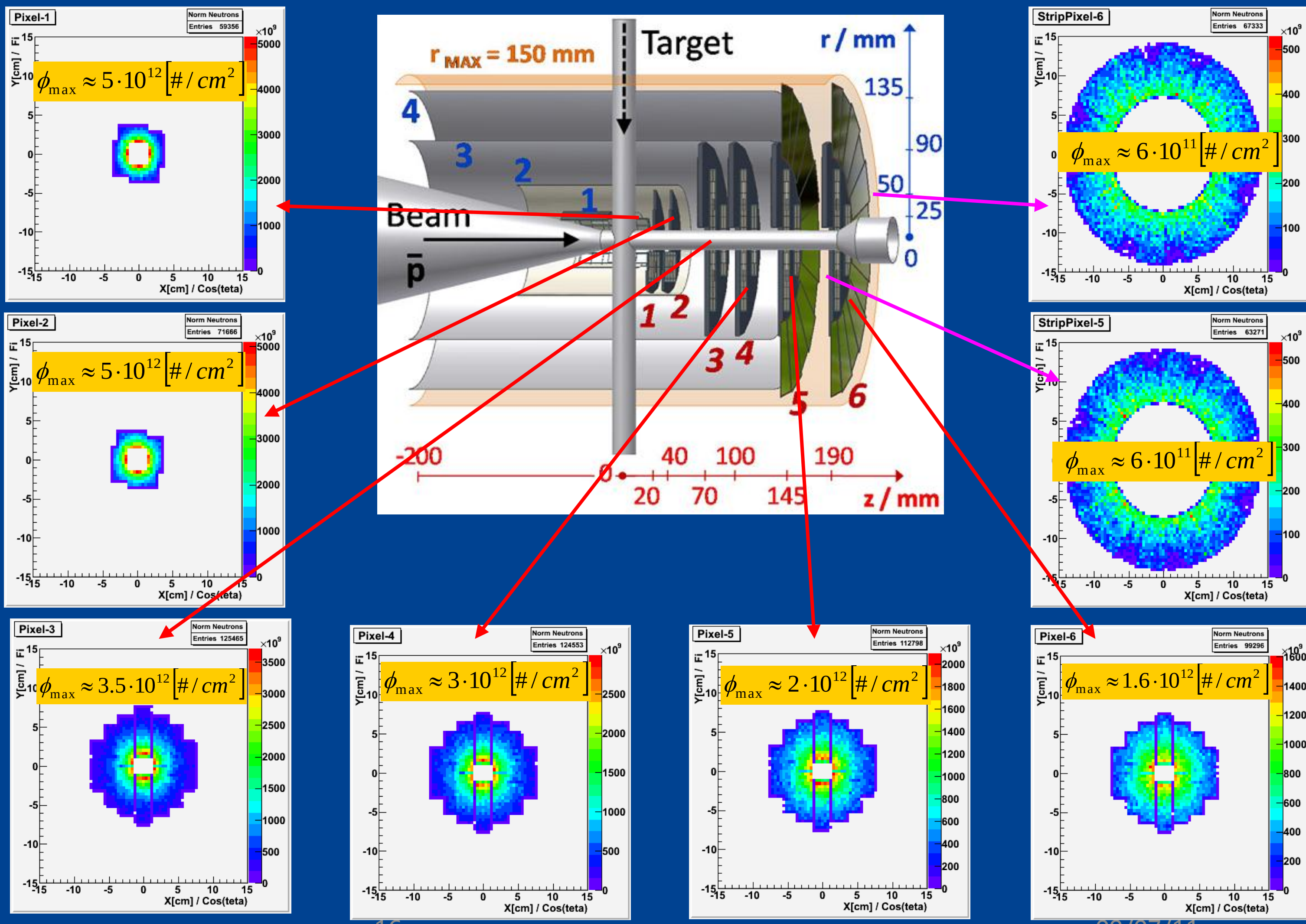
Technical detector layout “v1.0“

- all components specified



Design

- Simulation of properties and performance



Perfor-mance study by simulation:

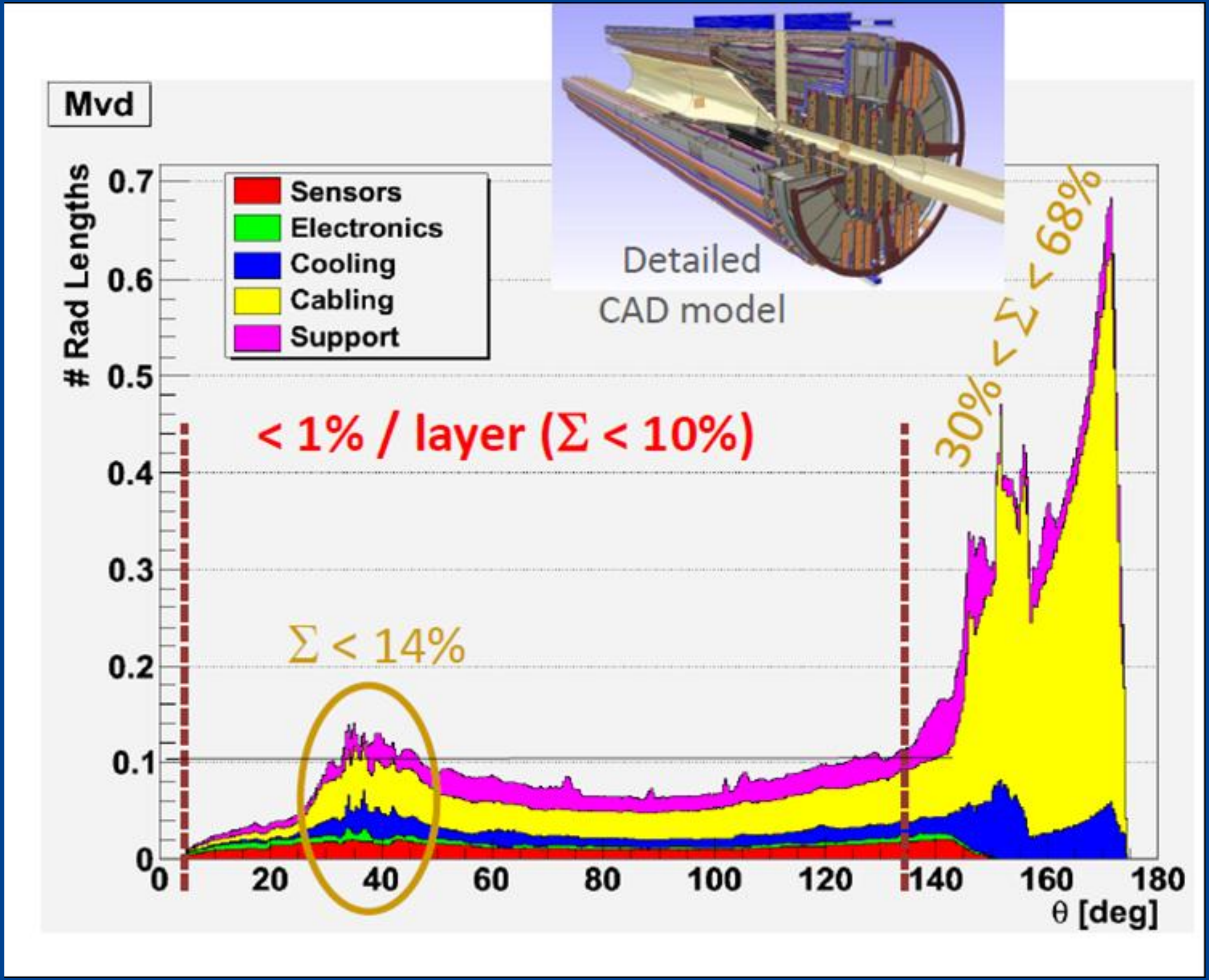
- **rad load**

(max. $10^{13}/cm^2$ per ½ a)

- **rate load**

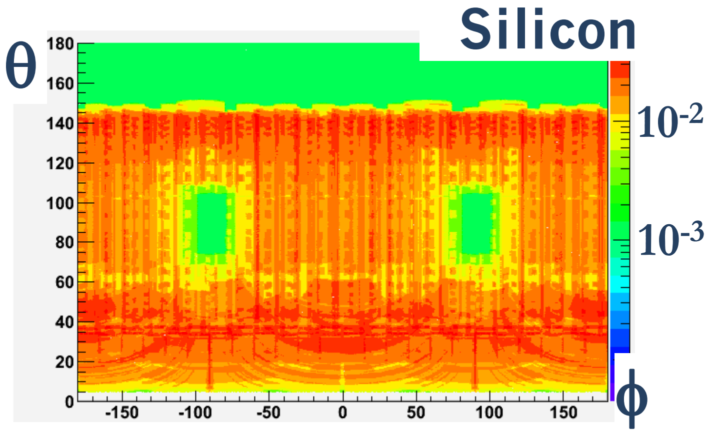
Design

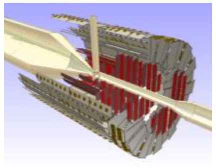
Simulations

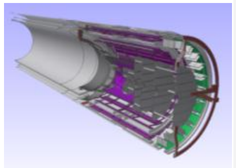


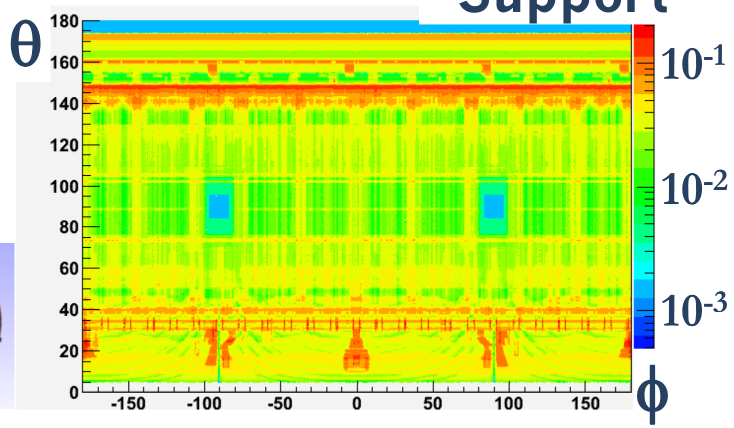
Design

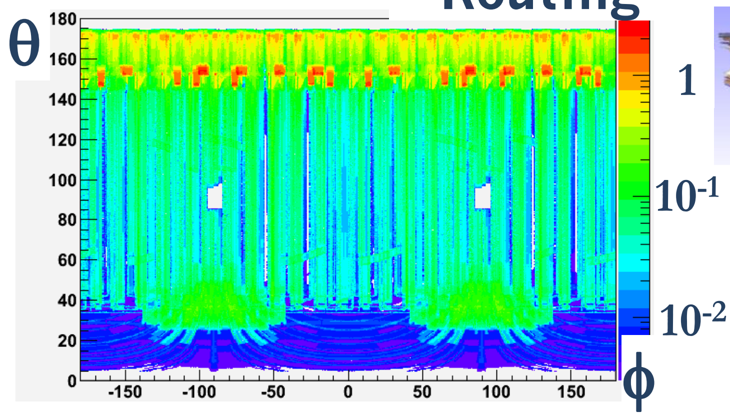
Simulations: component thickness

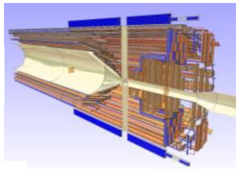


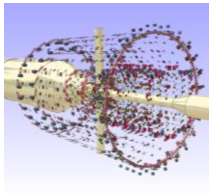


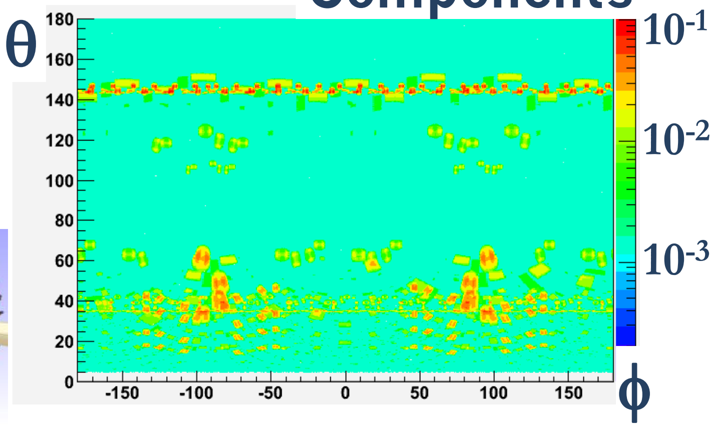




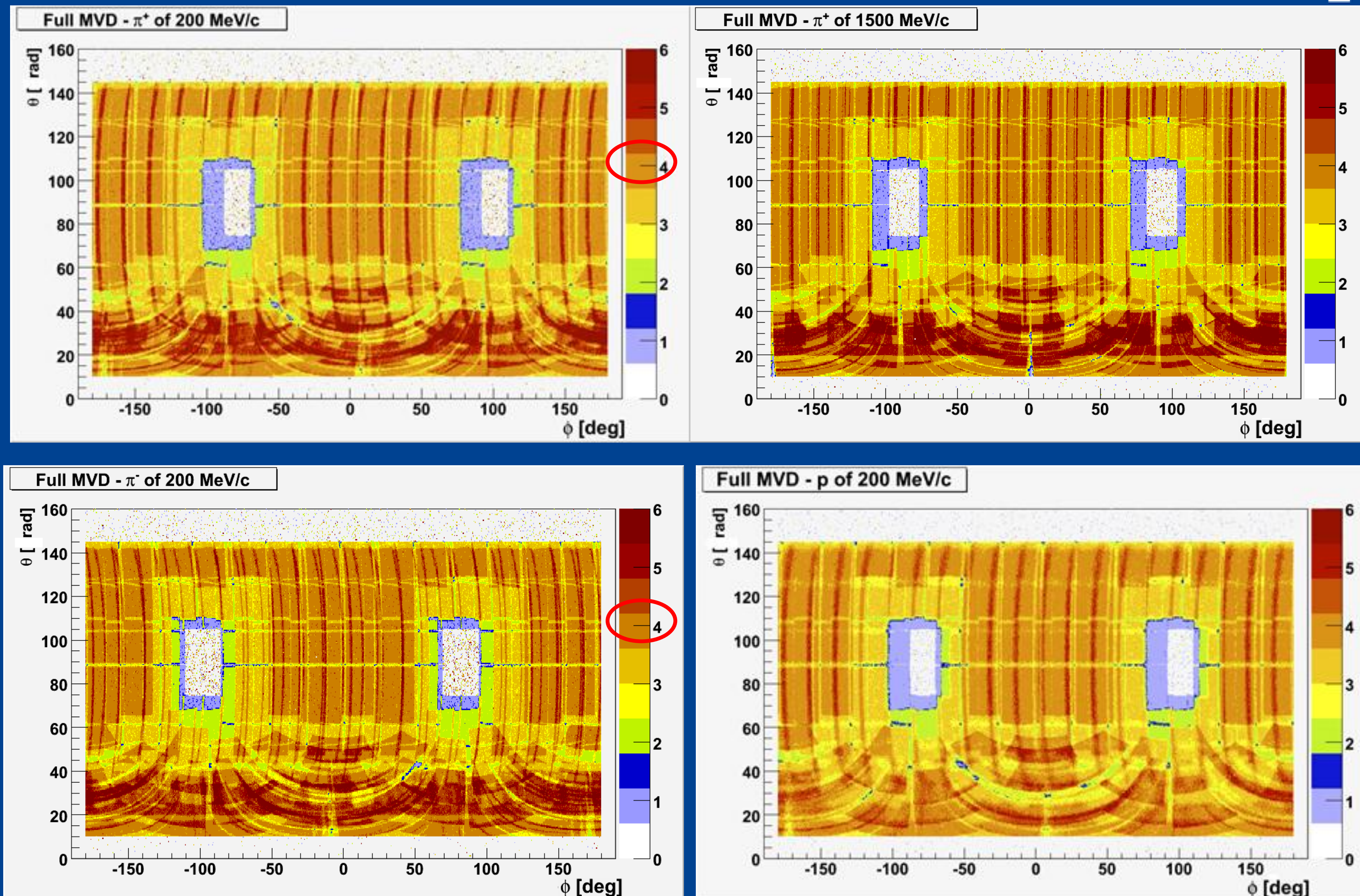




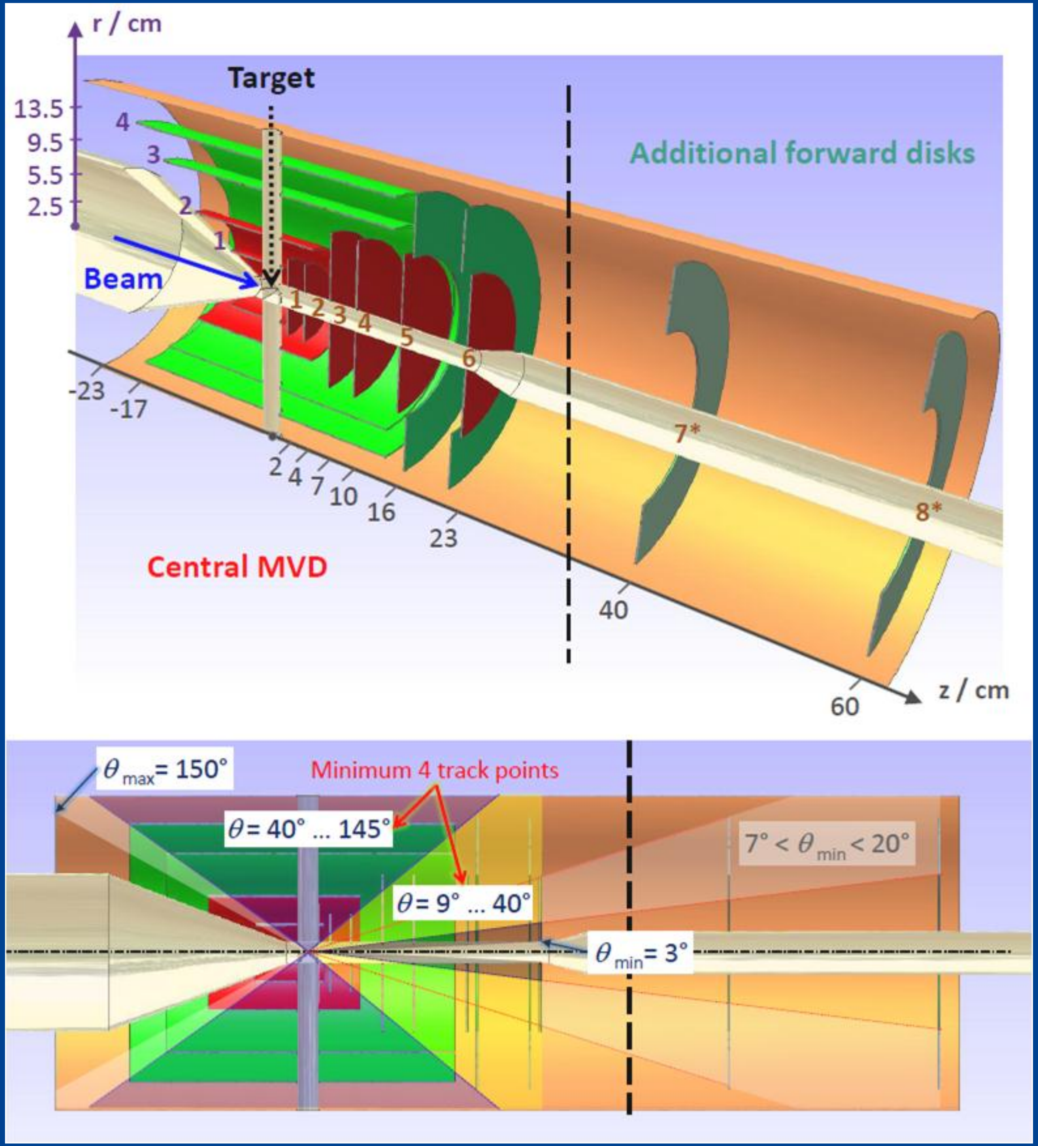




Simulation: Number of Track Points



Design



4 barrels:

- 2 inner layers: pixels
- 2 outer layers: strips

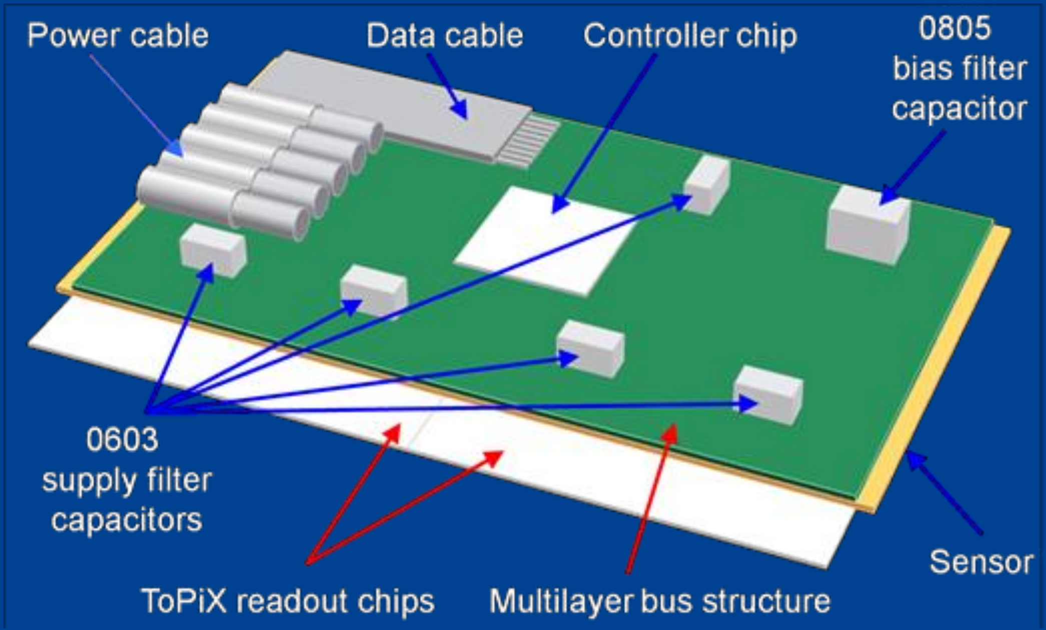
6 forward disks:

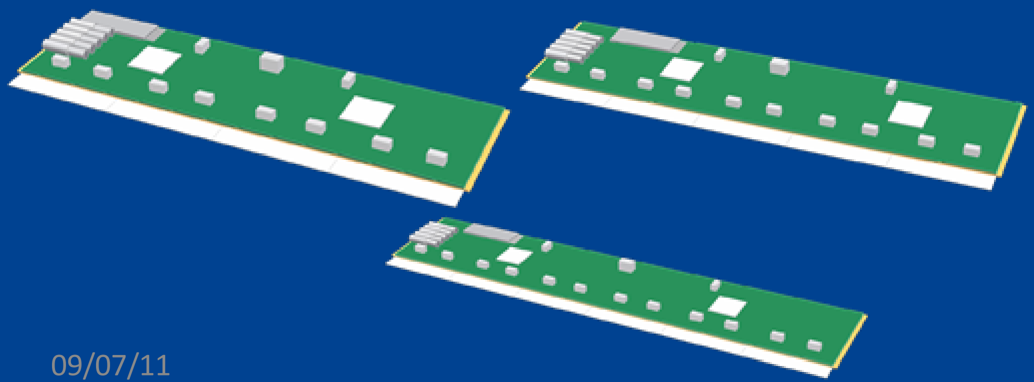
- 4 pixels
- 2 mixed disks

Pixels :
11M channels, 0.13 m^2
Strips :
200k channels, 0.5 m^2

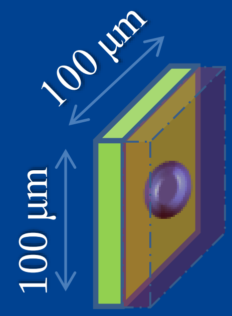
Design: Pixels

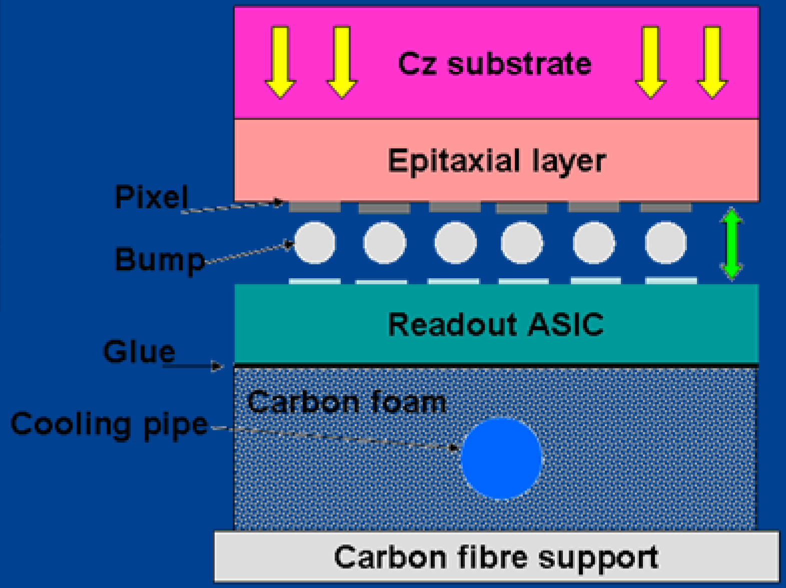
Pixel module



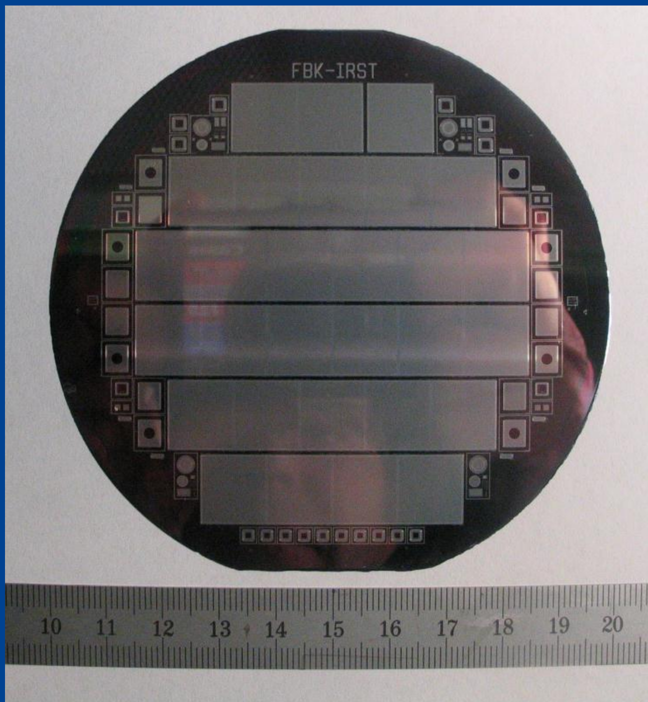


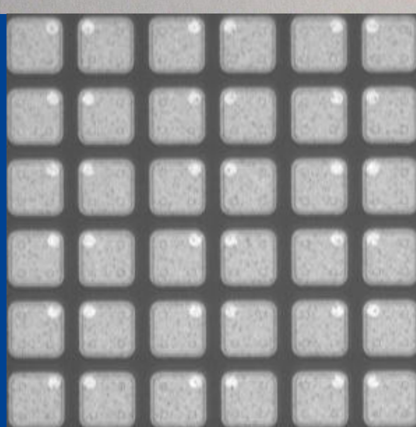
hybrid technology



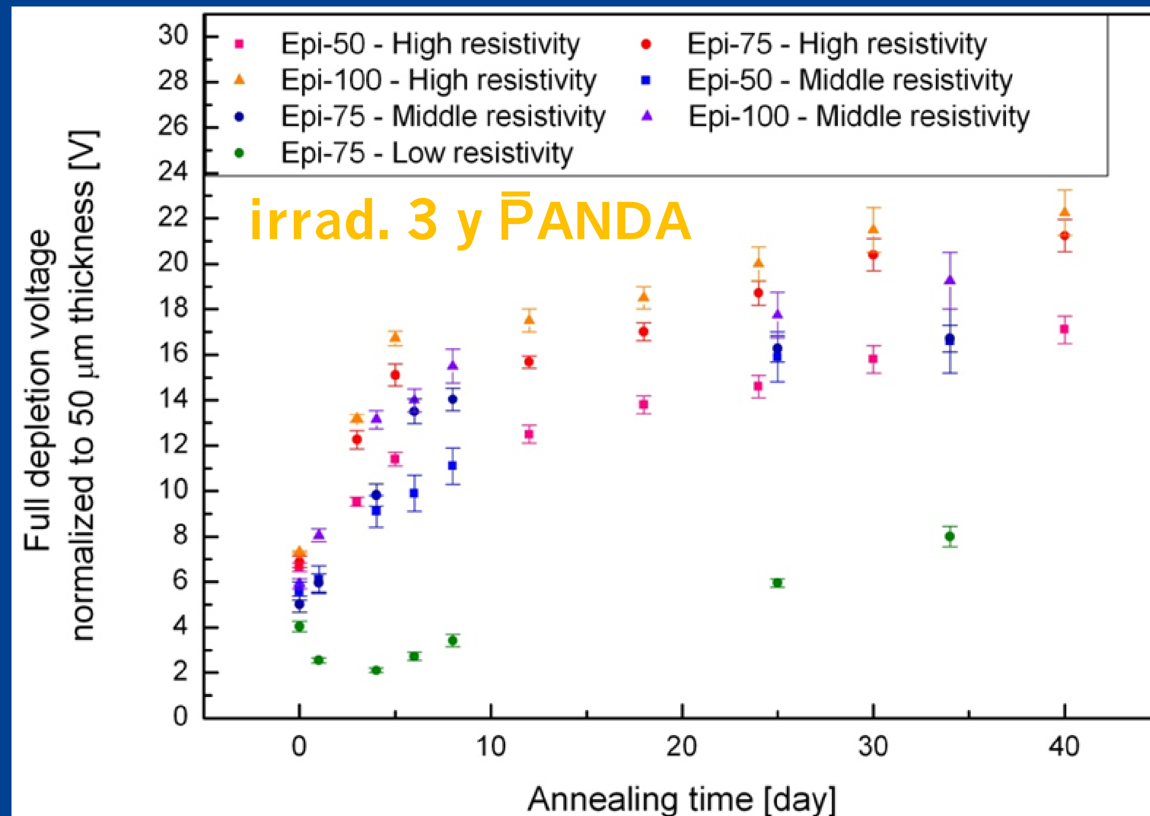


EPI Sensor Tests



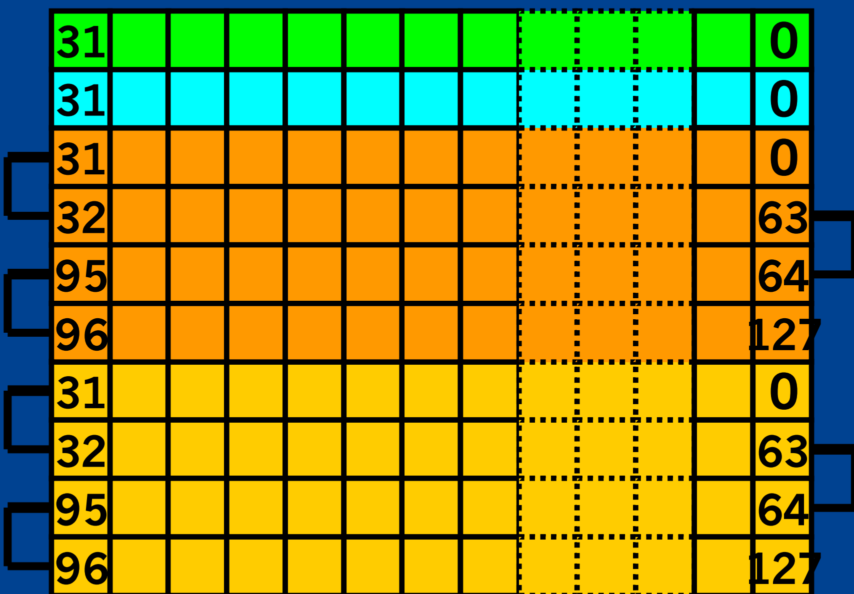


n-epitaxial layers deposited on standard Czochralski (Cz) substrate



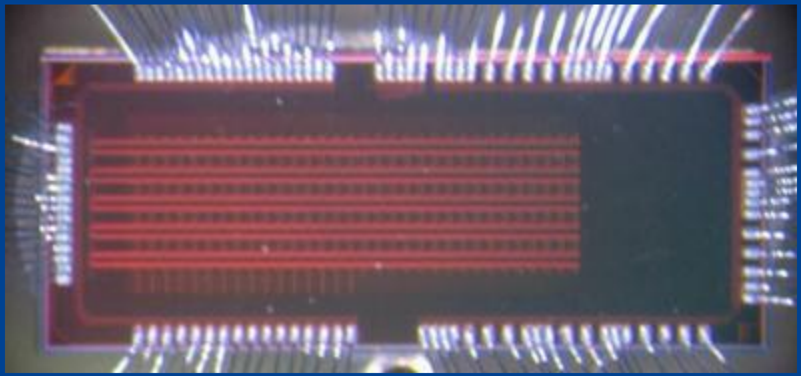
Pixel Readout

ToPix 2.0:
- Reduced scale prototype.
- Designed in CMOS 0.13 μm technology



128 pixel column: 12.8 mm.

320 pixel cells in four columns:
- 2 short c's with 32 pixels
- 2 folded c's with 128 pixels
- Simplified end-of-column logic
- 16 pixels with wire bonding pads

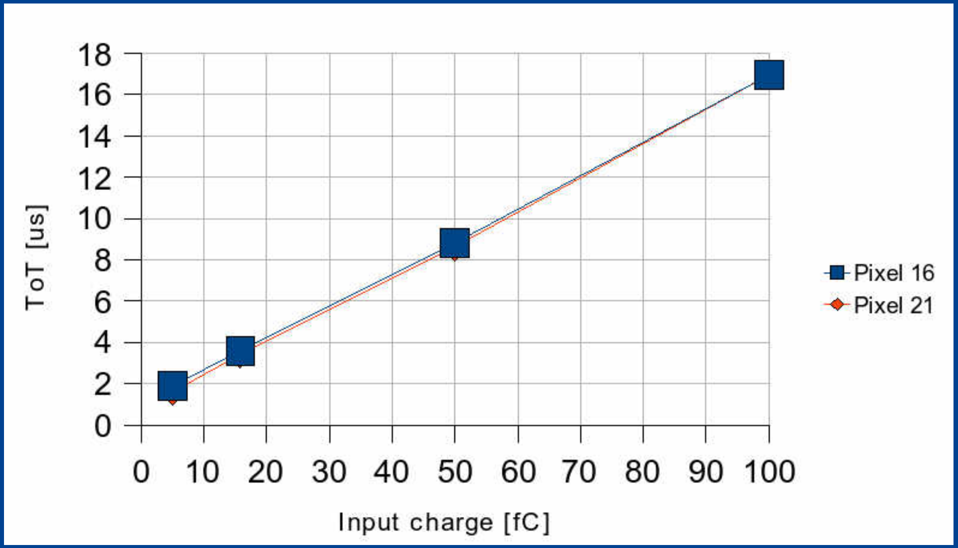


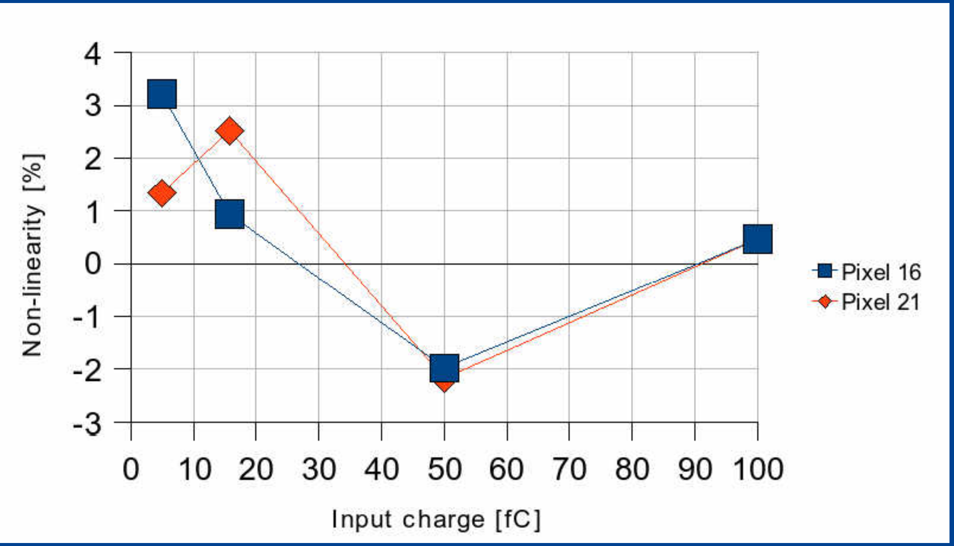
Final ToPix:
- Matrix of 116x110 cells, pixel size 100x100 μm^2
- 1.28 cm^2 active area.

Pixel Readout: Tests

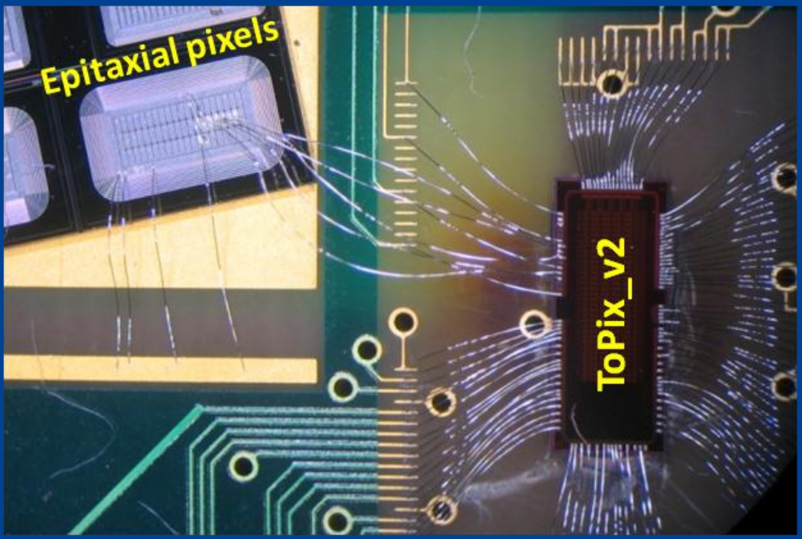
ToPix 2.0:

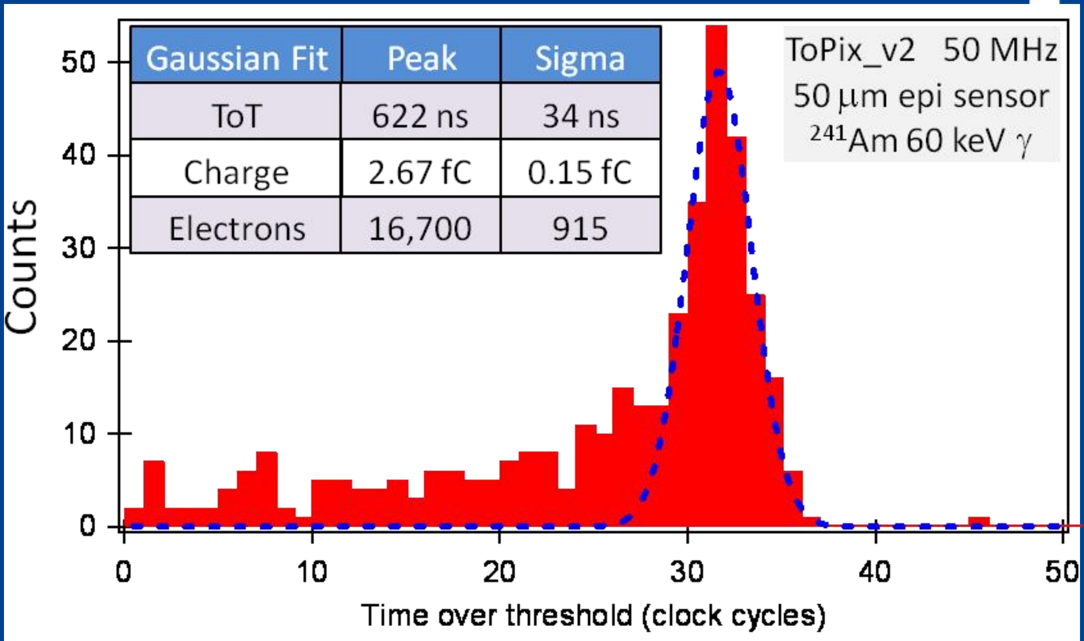
ToT performance
I/O

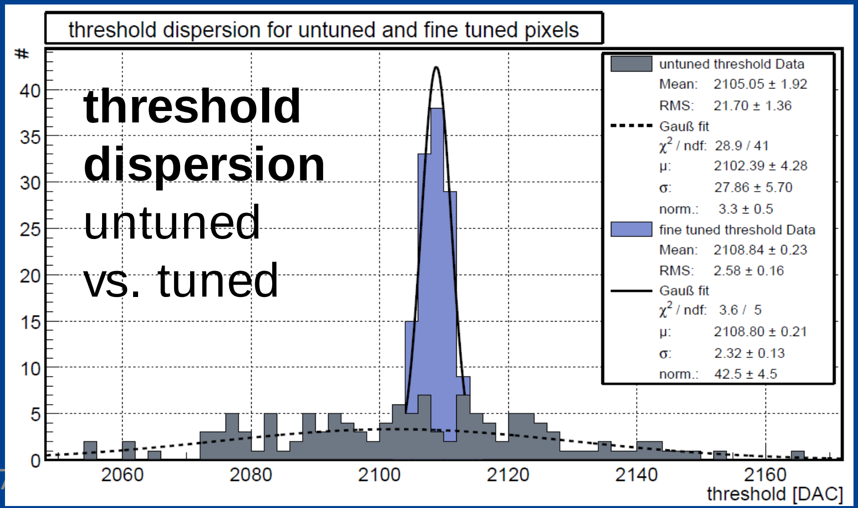


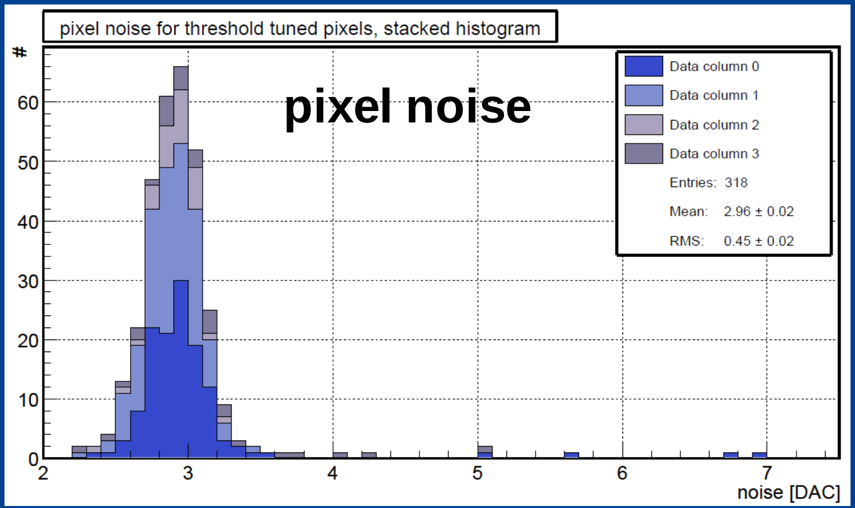


Pixel Readout: Tests



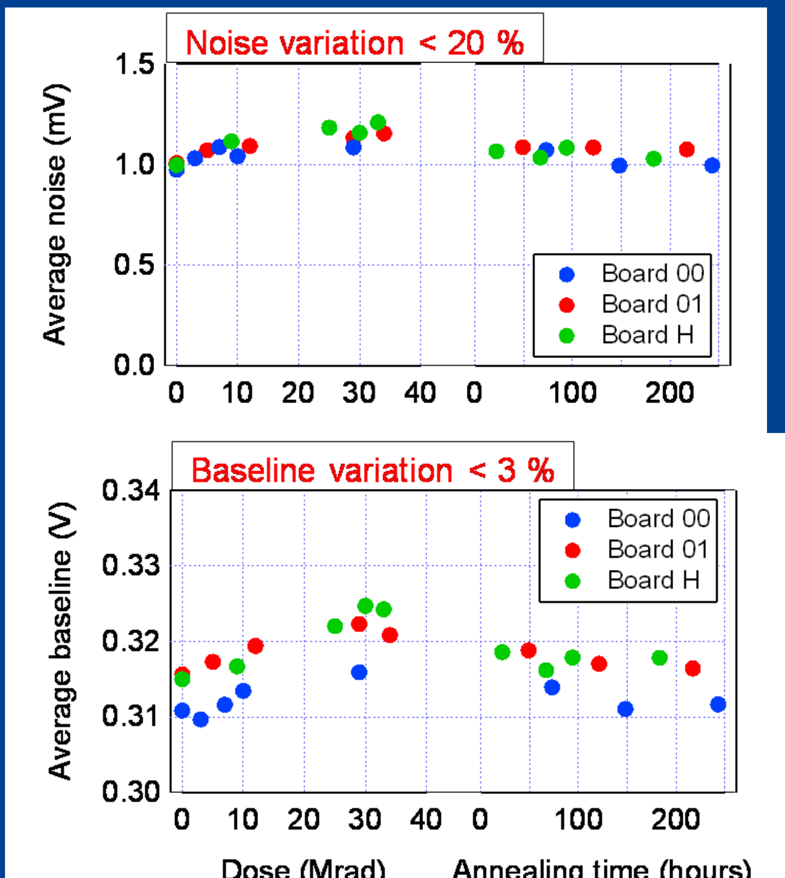




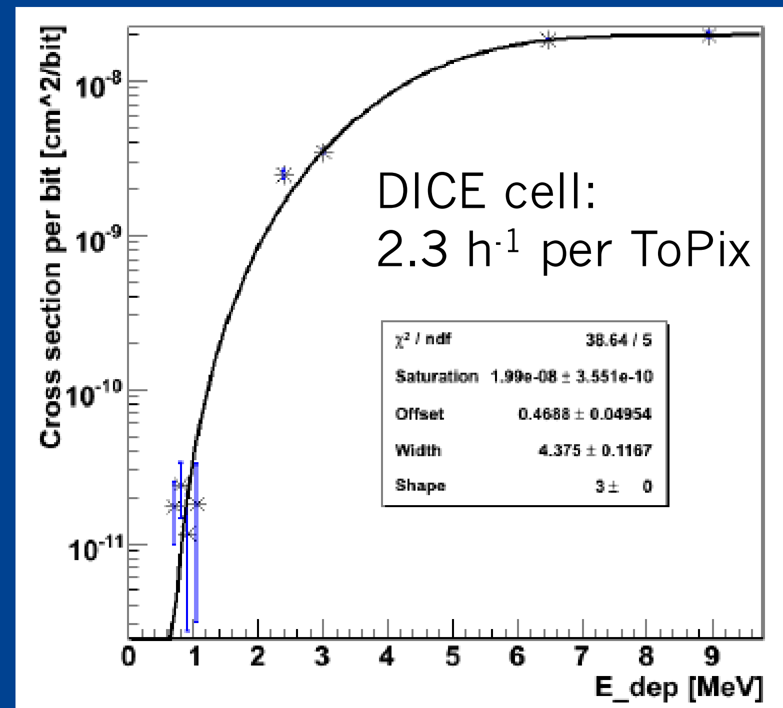


ToPix v2: TID and SEU

Irradiation



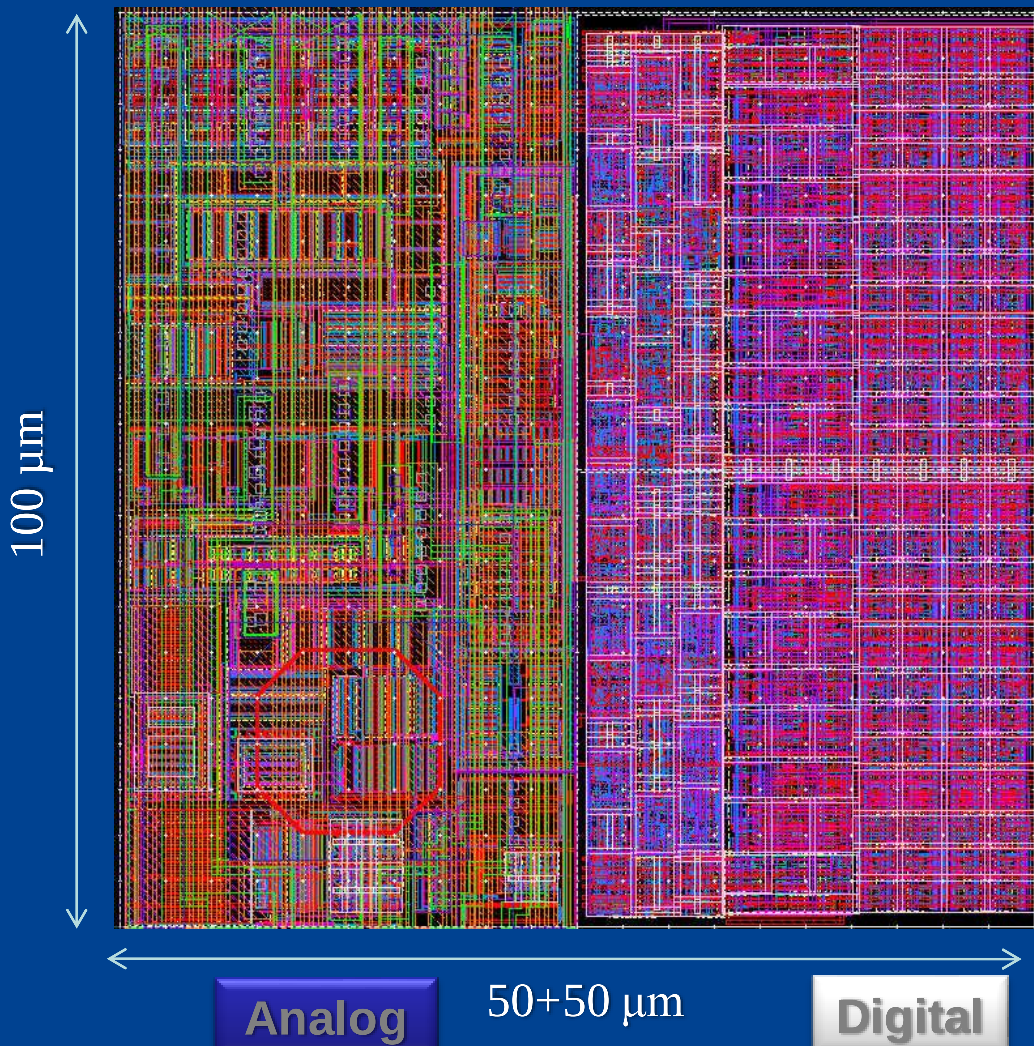
Single Event Upset



☞ **next prototype with triple redundancy SEU protection**

Pixel Readout

Pixel cell layout, ToPiX v3



Per cell:

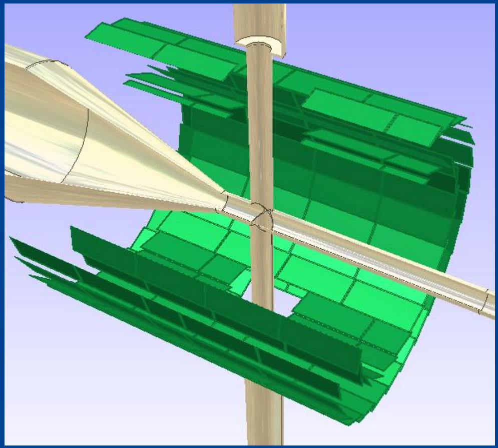
- preamplifier
- Leakage compensation
- 5 bit DACs (threshold tuning)
- Comparator
- 12 bit configuration register
- One register for leading edge
- One register for trailing edge

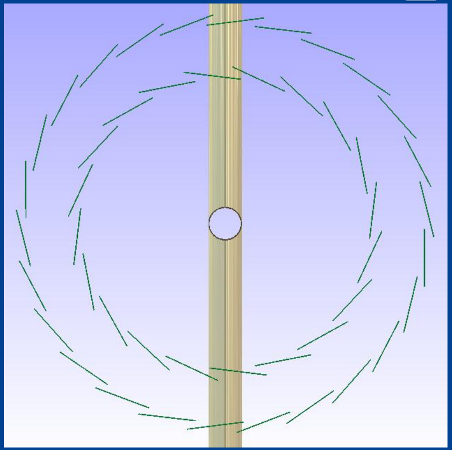
Pixel size	*100 × 100 µm^2*
Chip active area	*11.4 × 11.6 mm^2 (116 rows, 110 cols)*
dE/dx measurement	*ToT, 12 bits dynamic range*
Max input charge	*50 fC*
Noise floor	*<32 aC (200 e$^-$)*
Clock frequency	*155.52 MHz*
Time resolution	*6.45 ns (1.9 ns r.m.s.)*
Power consumption	*< 750 mW/cm^2*
Max event rate	*6 · 10^6*
Total ionizing dose	*< 100 kGy*

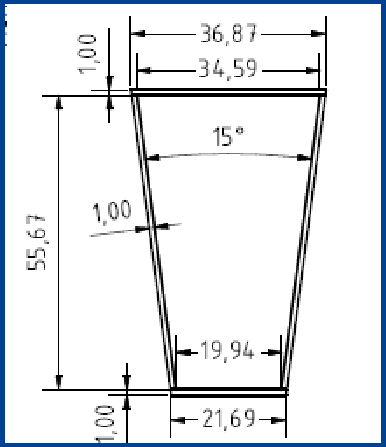
Design: Strips

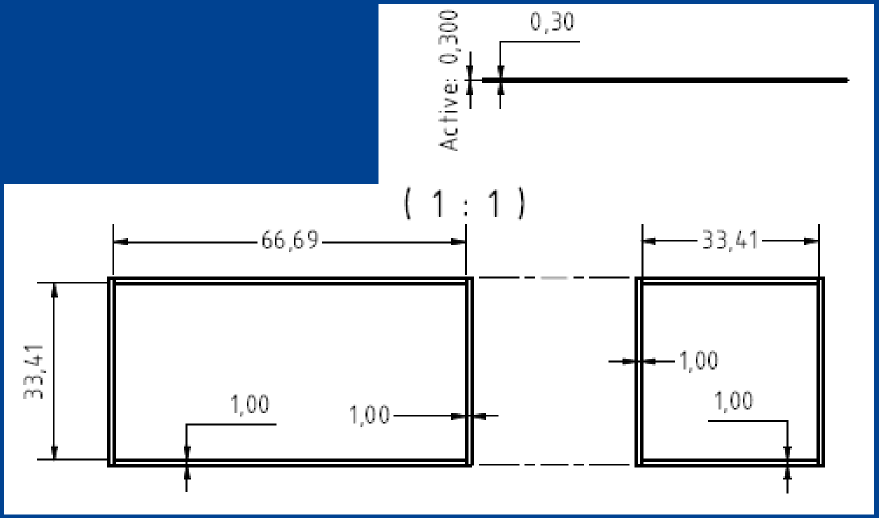
- **Strip sensors**
- trapezoidal (disk) , 70 µm, 15°

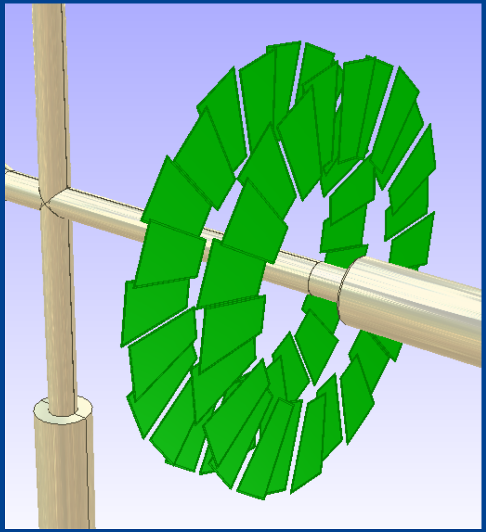
rectangular (barrel) , 130 µm, 90°









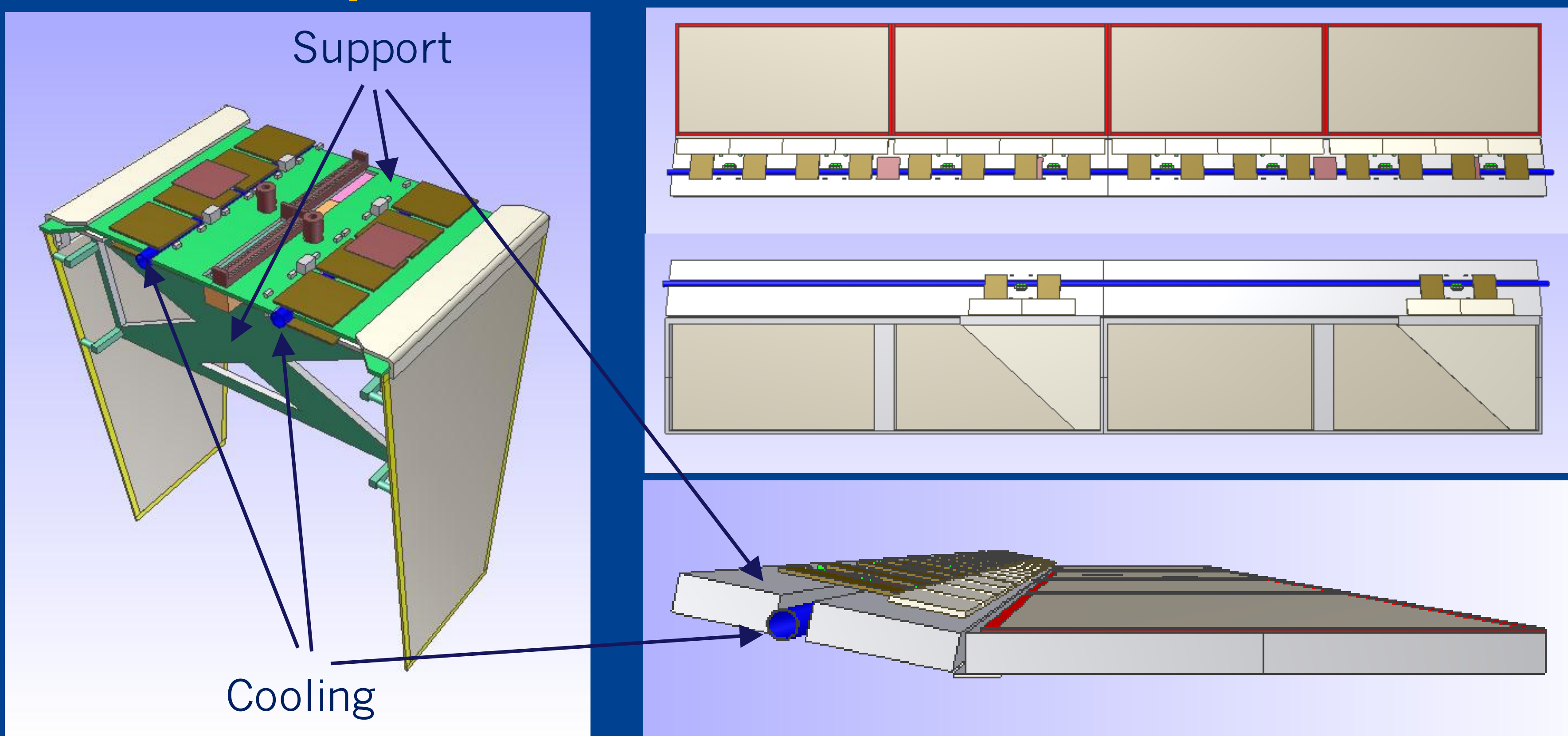


Design: Strips

Strip super-module r/o and cooling

Disk part

Barrel part



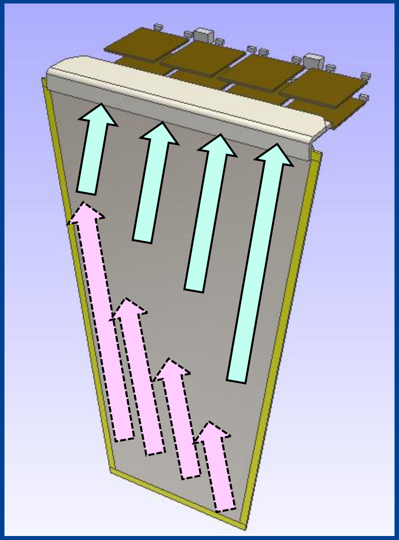
Design: Strips

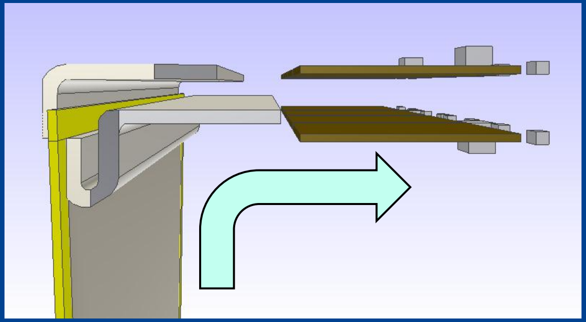
Hybridization: Strip module readout

Disk part

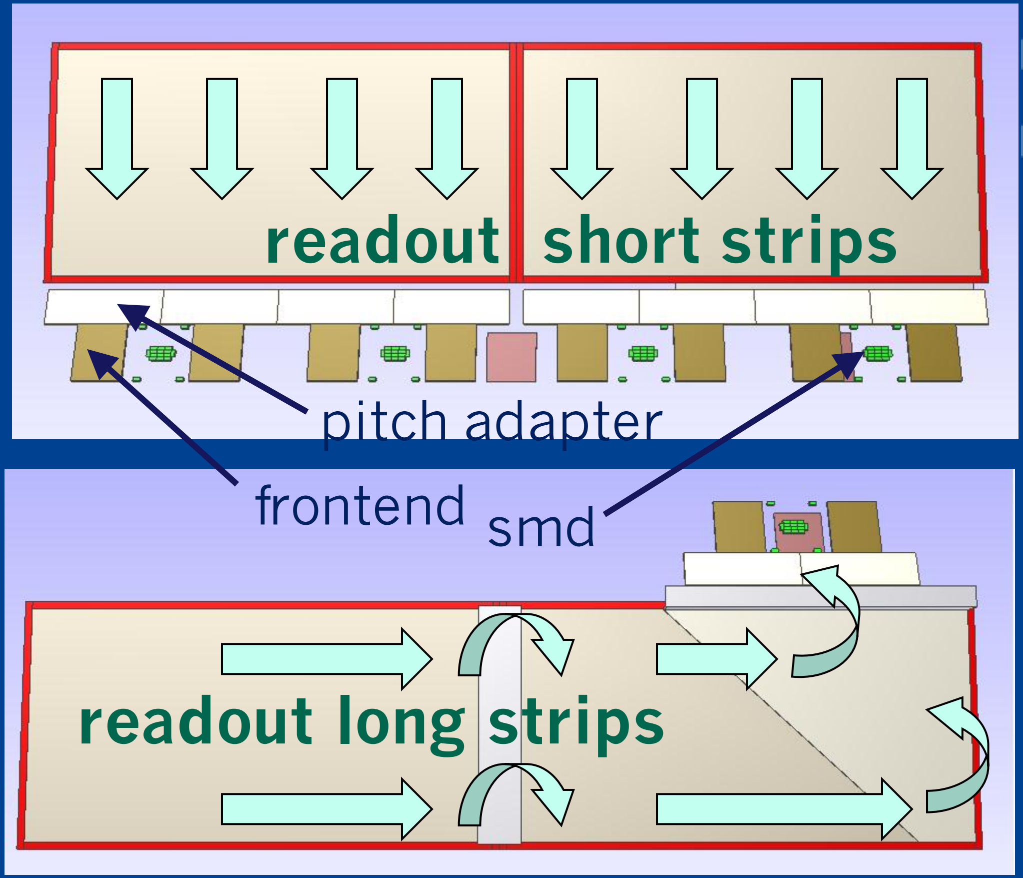
readout along sensor sides

90° bend at top





Barrel part



Towards P̄ANDA MVD Strips

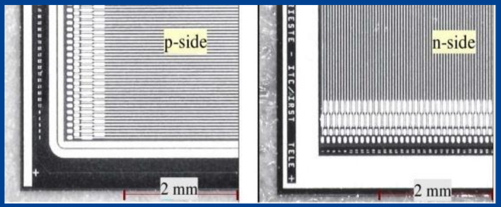
- Hardware

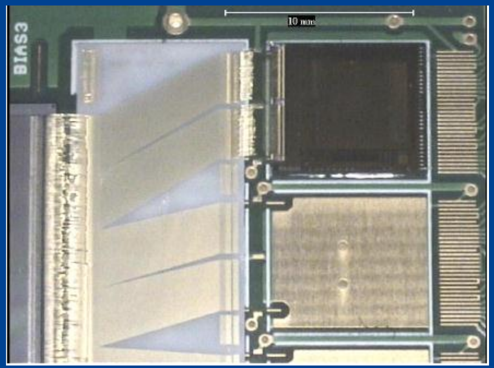
Test Station for sensor tests, readout and electronics development

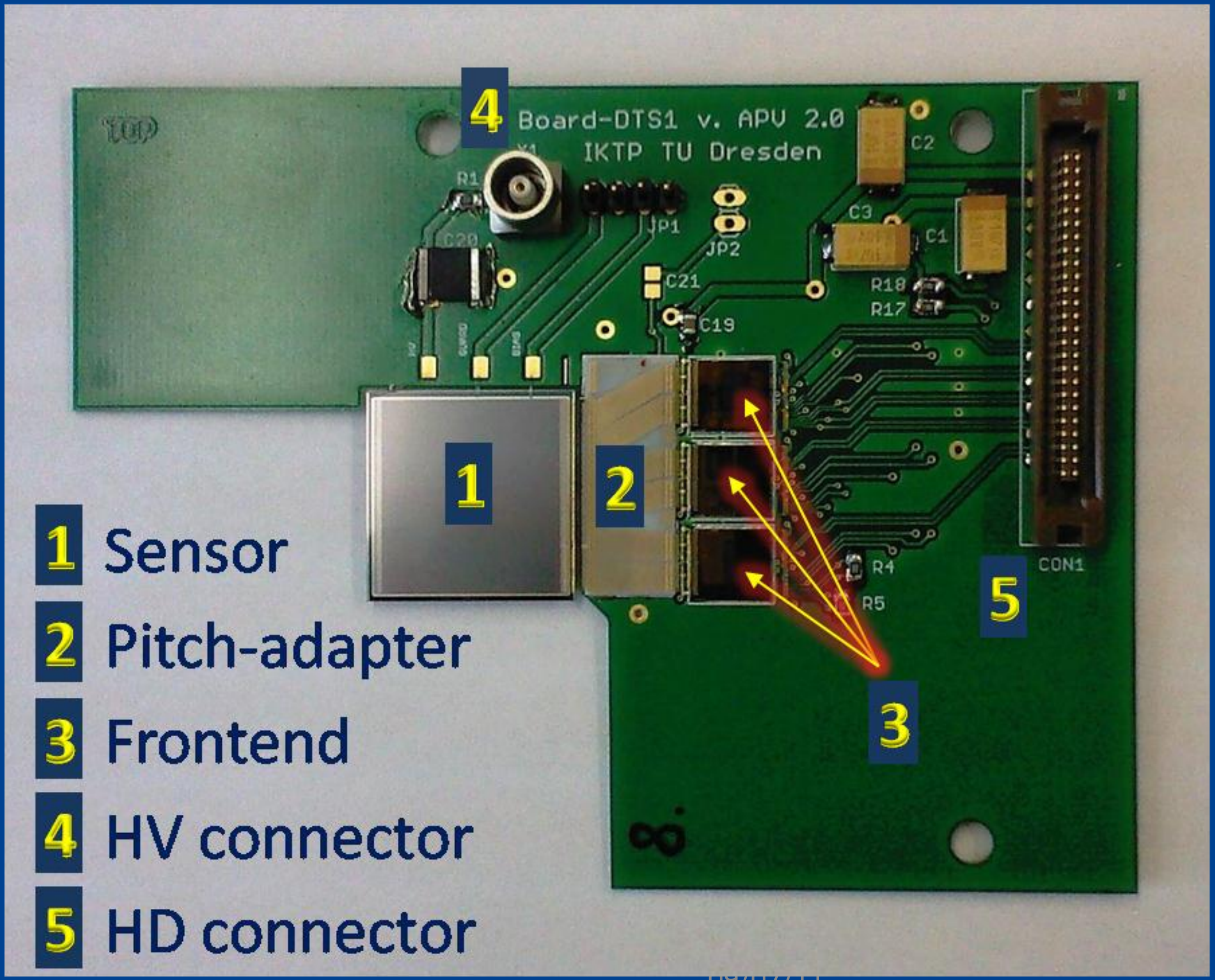
sensor “telescope”

20x20 mm^2

50 µm pitch

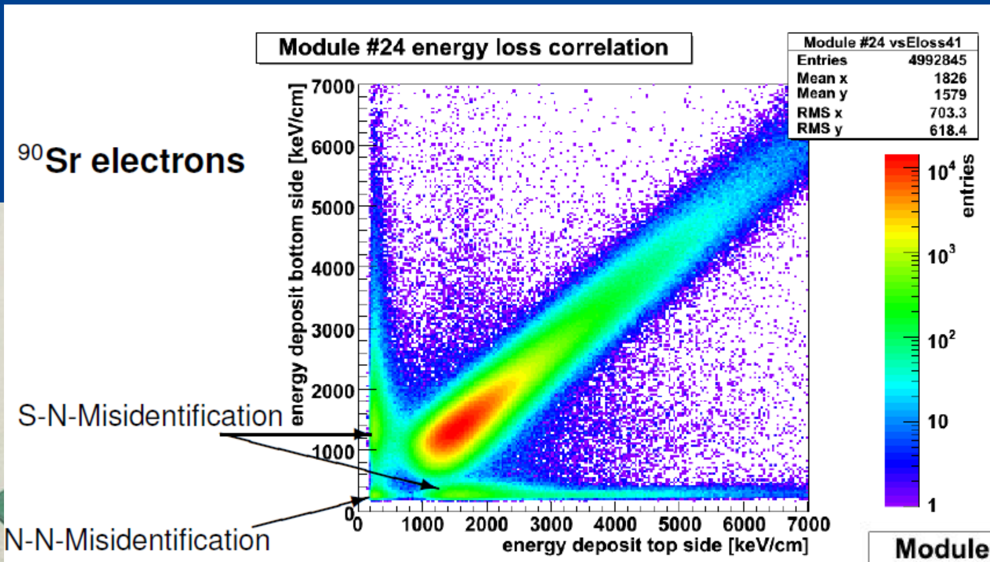


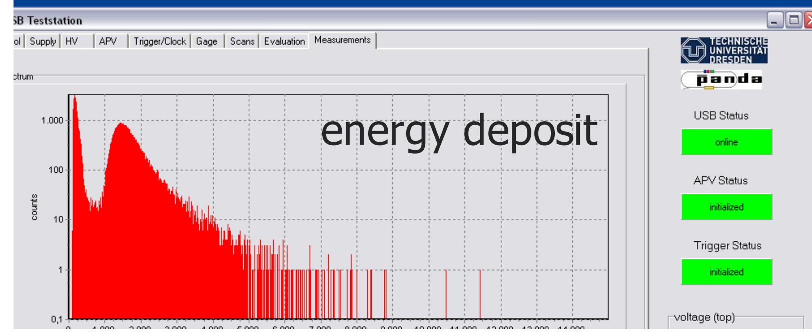


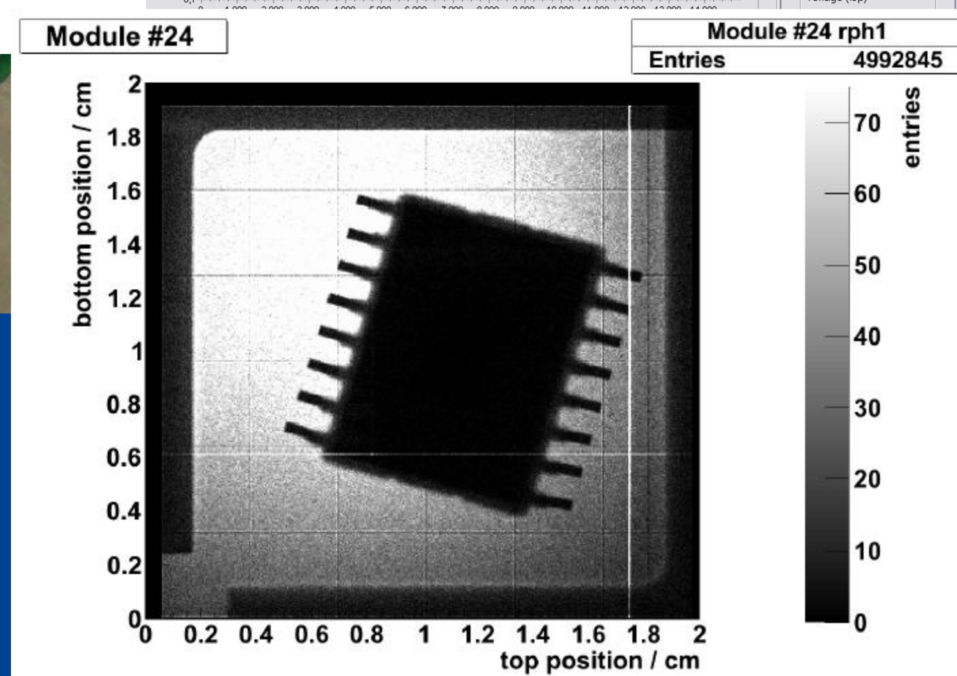


Towards P̄ANDA MVD Strips

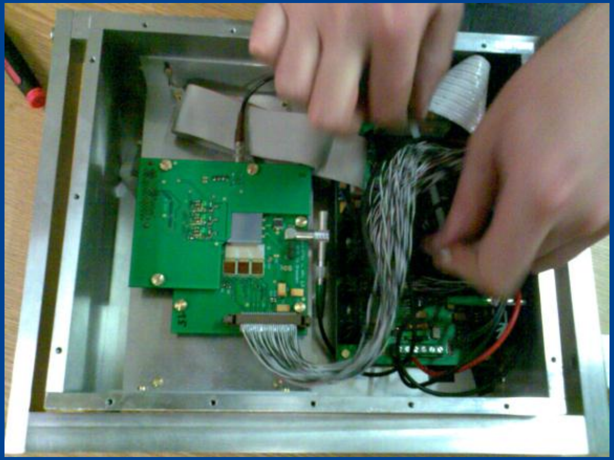
r sensor tests, readout
s development DTS-1







Strip Sensor Tests



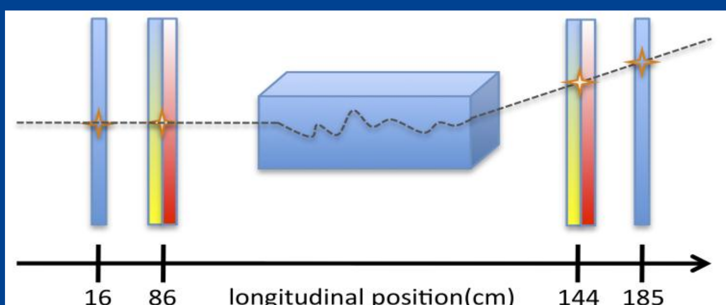
- Protons @ COSY (Jülich) .8 GeV/c and 2.95 GeV/c
- Photons and electrons @ ELSA (Bonn) up to 3.2 GeV/c
- Electrons @ DESY (Hamburg) 1 to 5 GeV/c

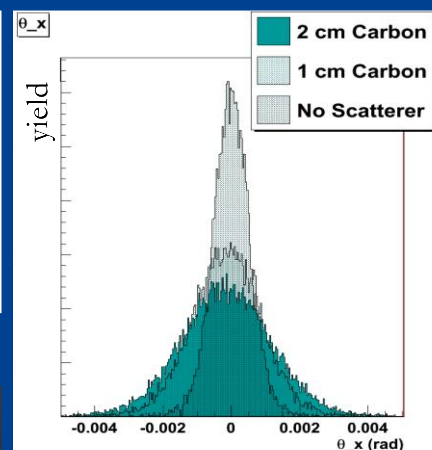
- **Tracking and scattering in station and DuT (sensors, frames)**
- **Fast cluster recognition (next: track recognition)**
- **Validation of simulations**

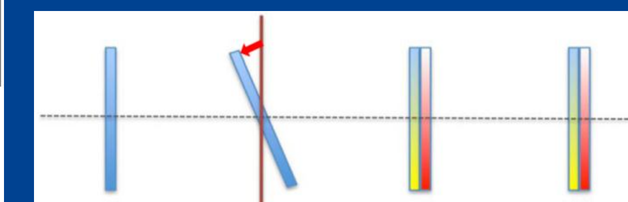
Strip Sensor Tests

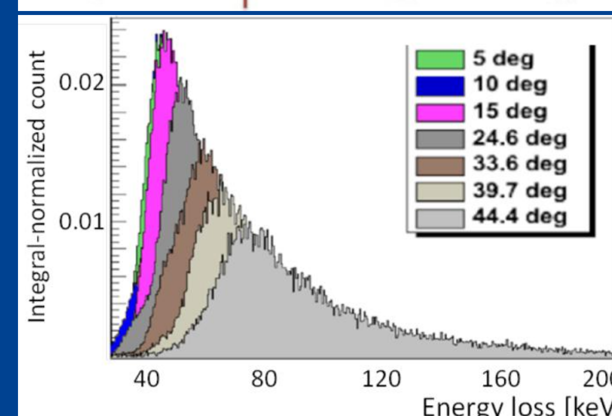
- Beam tests: p at COSY; e at DESY, ELSA

Tracking station

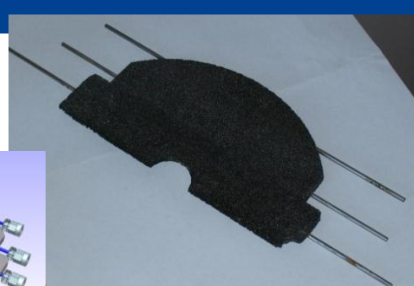


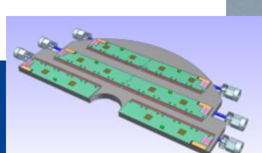




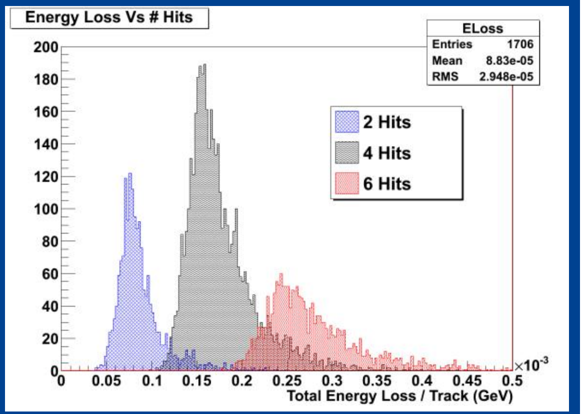


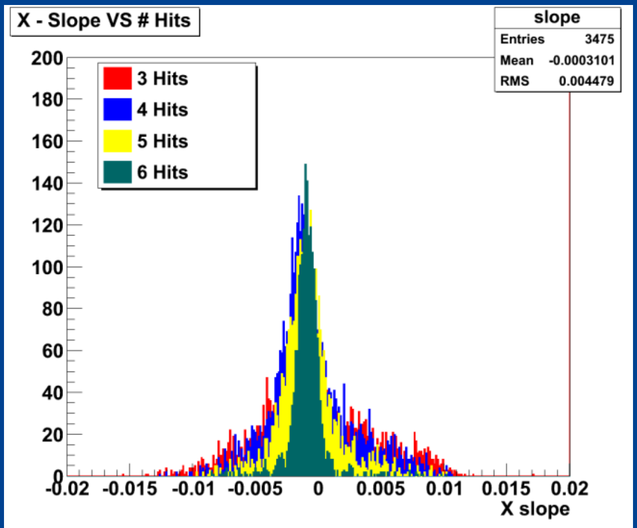
HTC foam half disk embedded cooling pipes



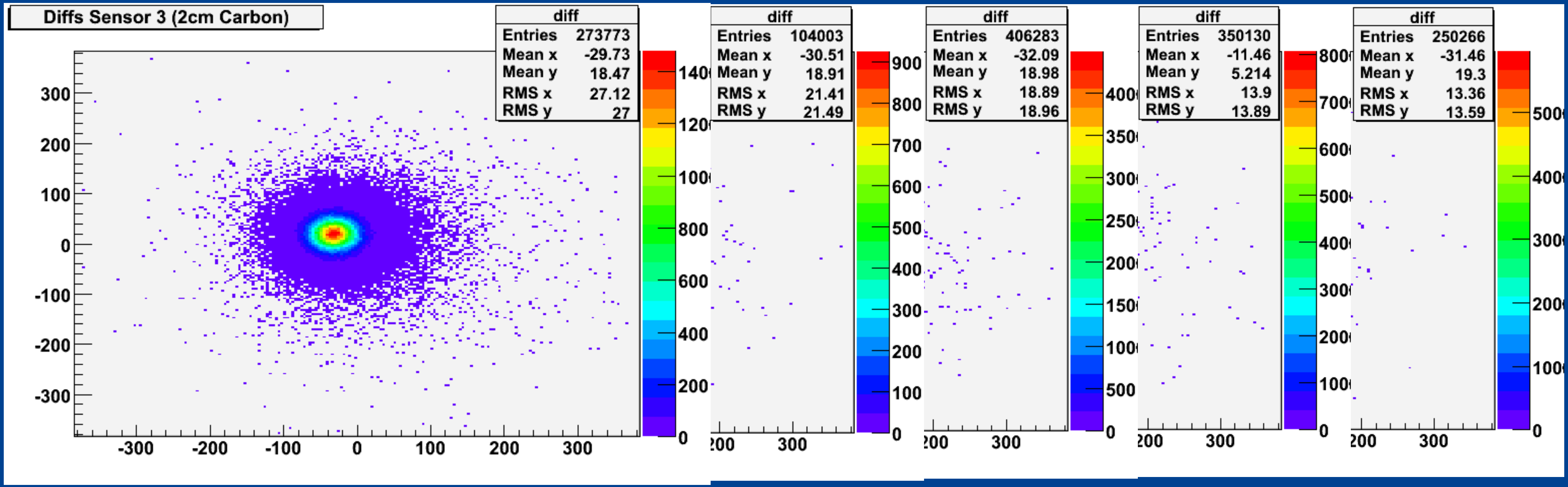


Tracking and Scattering





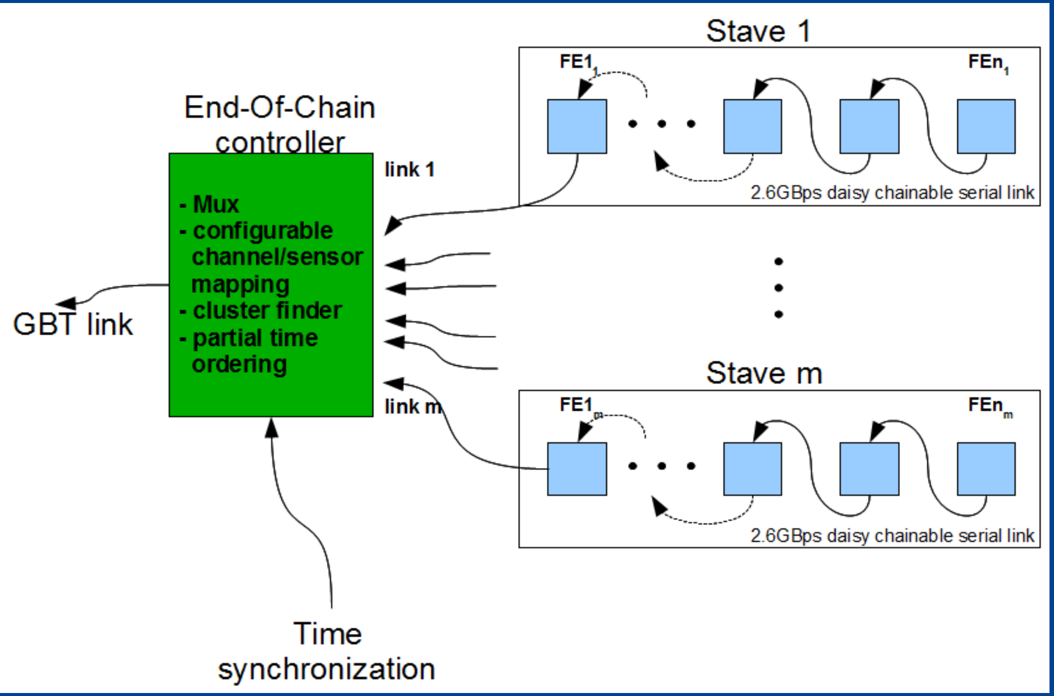
Development of a fast readout chain with data manipulation capacity



Strip Sensor Readout

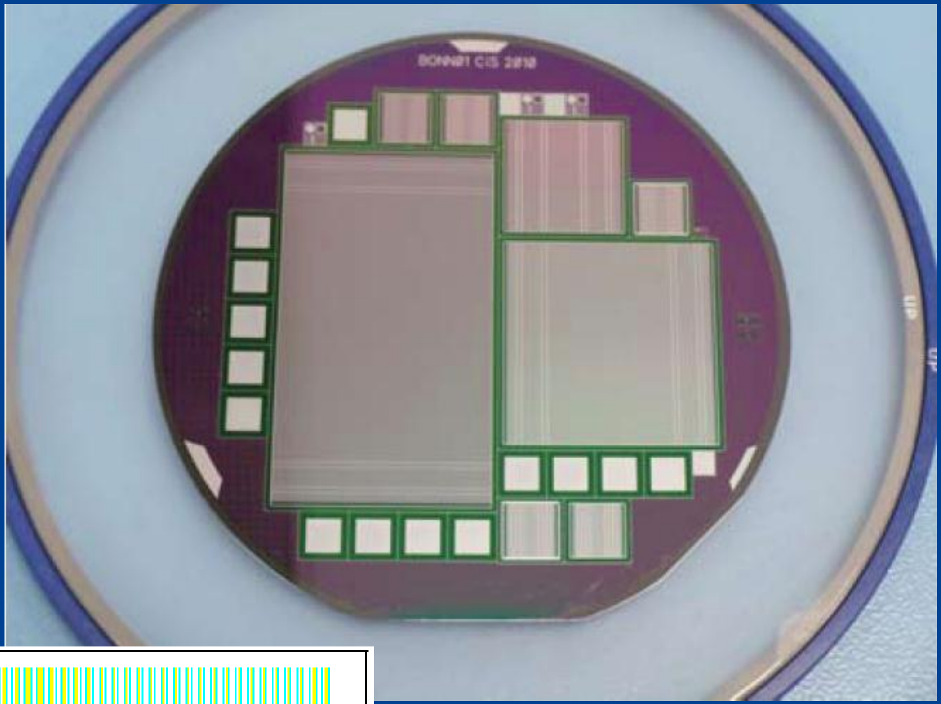
P̄ANDA readout schematics

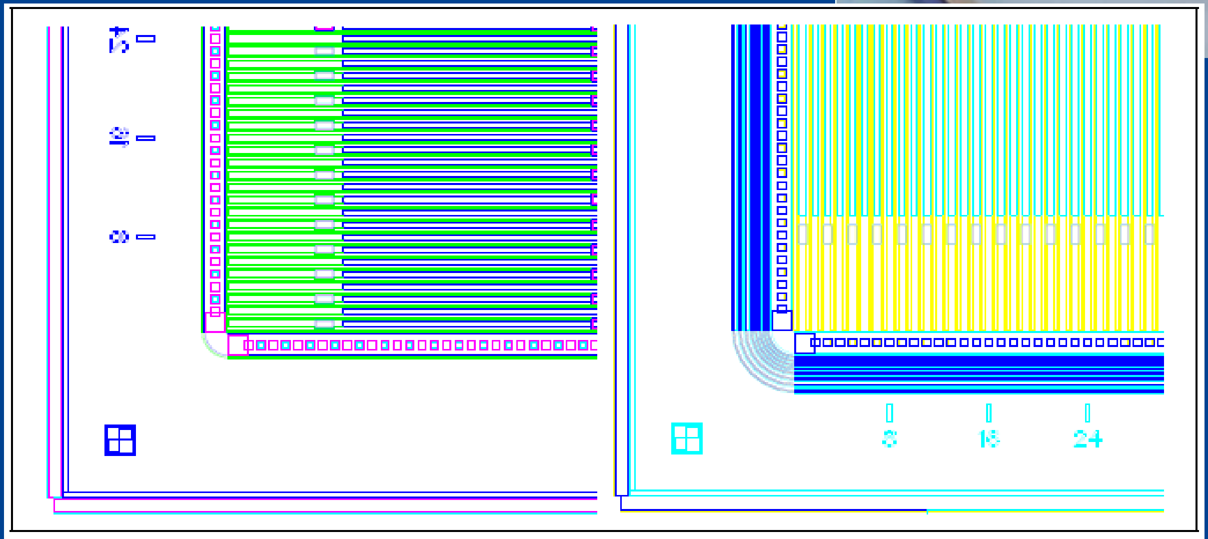
- Several frontends on one link depending on occupancy
- EoC reads up to 4 (8) FE chains, reduces amount of data (clustering, priority matching) and buffers
- Multiplexed output sends data optically



Strip Sensors

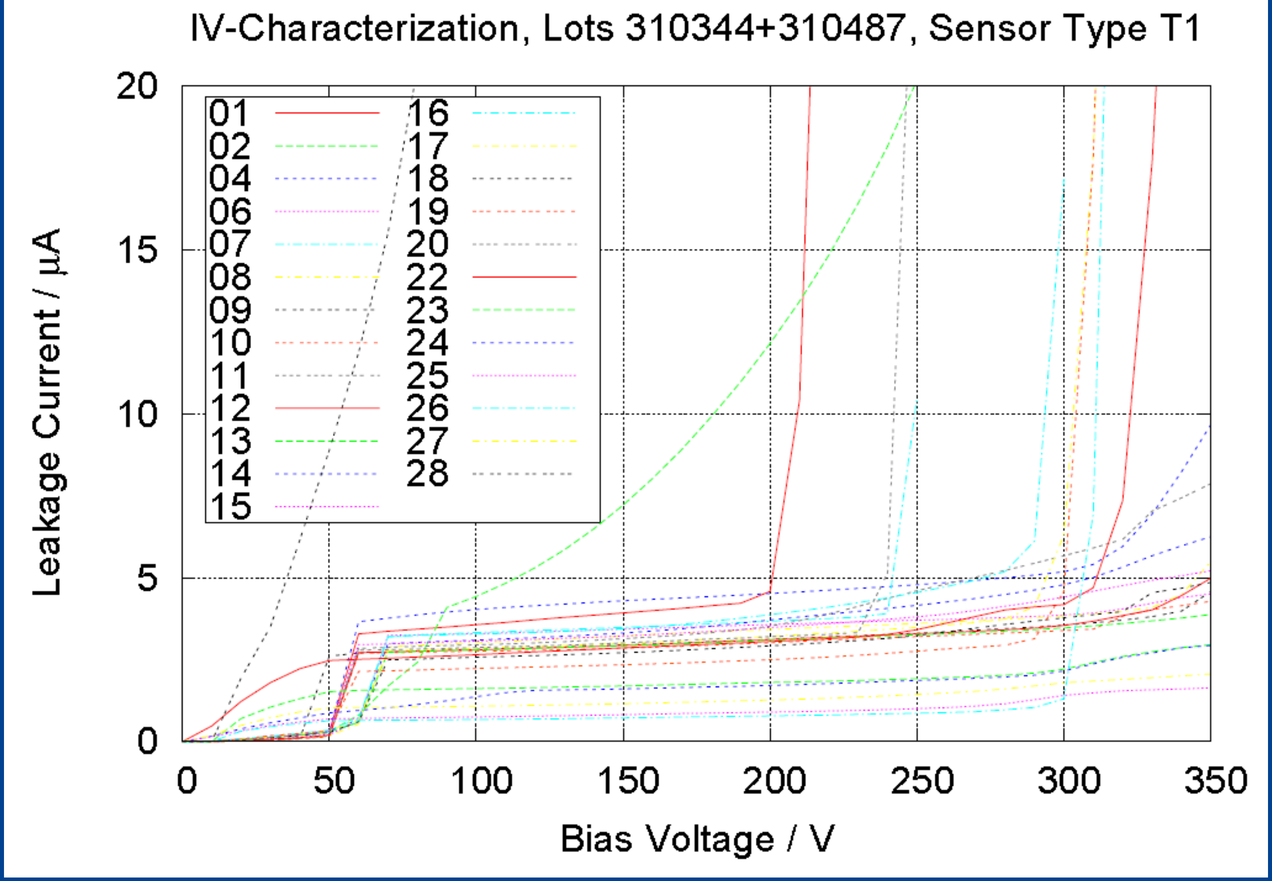
P̄ANDA
full-size prototypes
(with CIS, Erfurt)

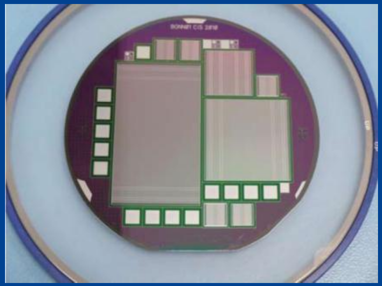


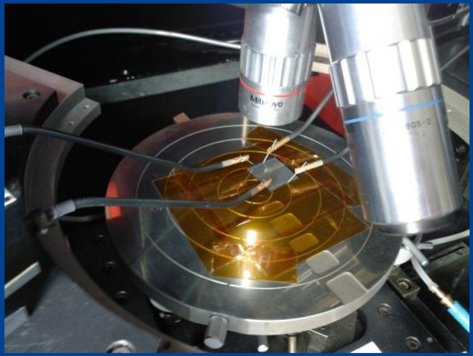


Strip Sensors

Prototype characterization







Strip Sensor Readout Options

$\bar{P}$ANDA specific requirements:

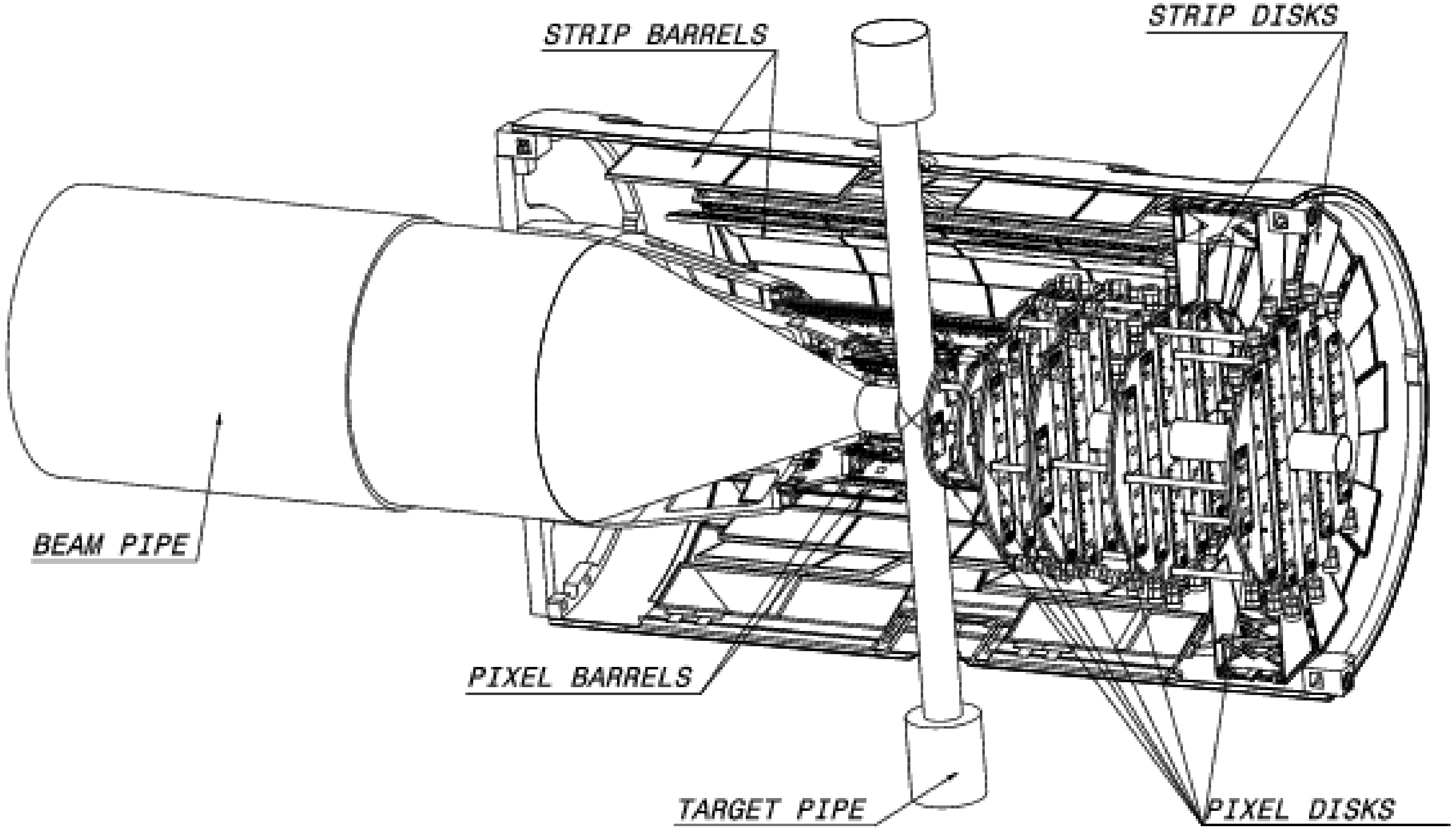
- self triggering
- precise time resolution
- fully digital hit information

=> not many front-ends available that comply with these requirements

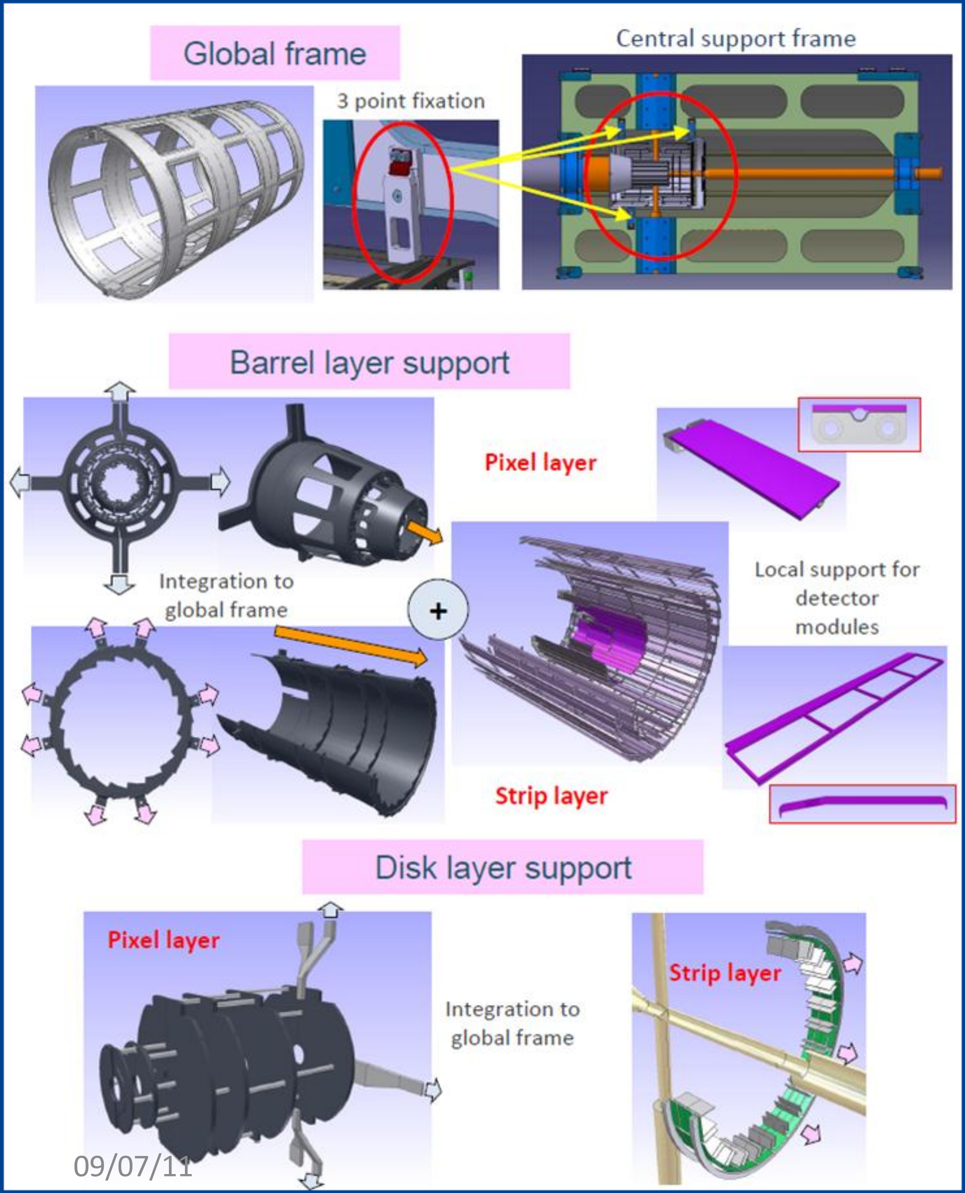
$\bar{P}$ANDA frontend options:

- adapted ToPix3
- STS-XYTER
- (modified) FSSR2
- channel-wise ADC

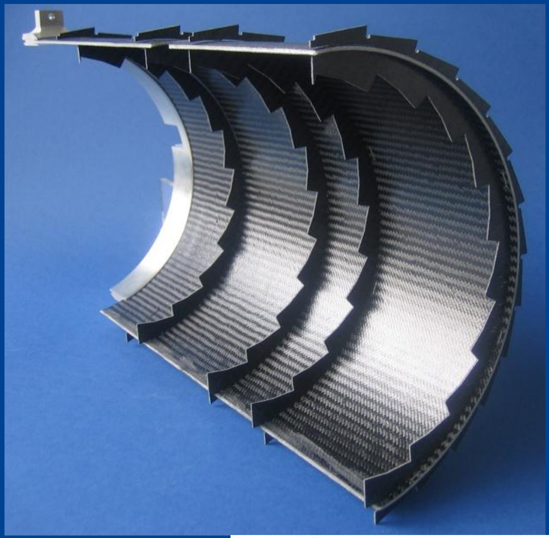
Mechanics


STRIP BARRELS
STRIP DISKS
BEAM PIPE
PIXEL BARRELS
TARGET PIPE
PIXEL DISKS

Design: Mechanics

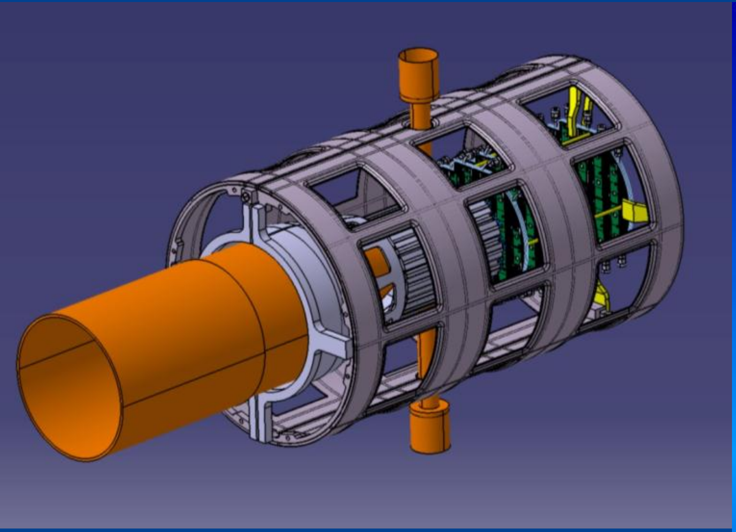


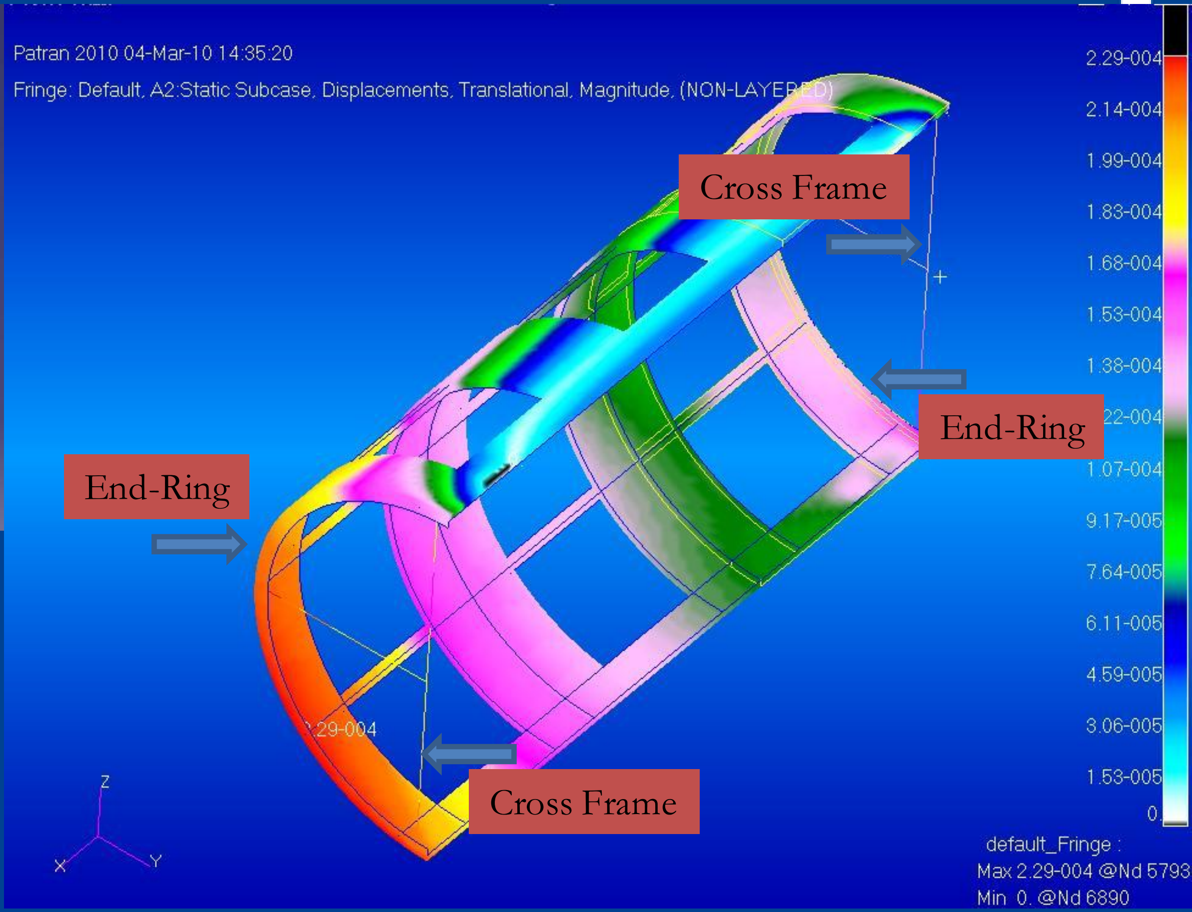
- Light-carbon support structures
- Overall integration concept
- Tests and prototypes



Mechanics

Detector support





Simulation of end rings and cross frame

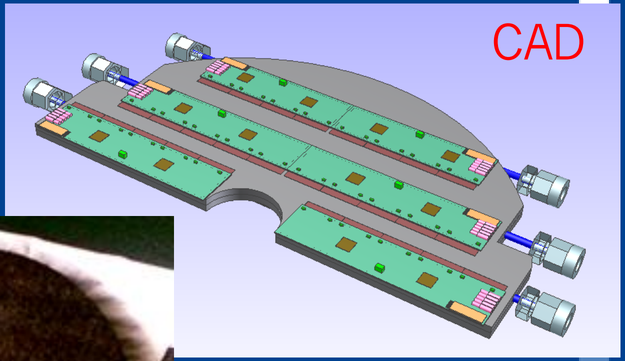
asymmetric displacement
safety factor of 2 included

Mechanics

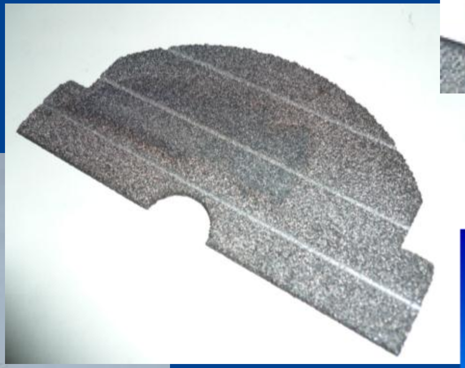
Cooling concept

- Coolant: water (18°C)
- Under-pressure mode using hydrostatic pressure

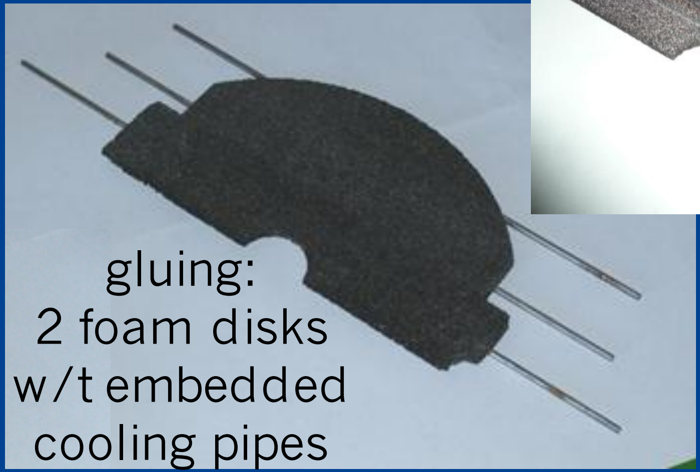
disk layer



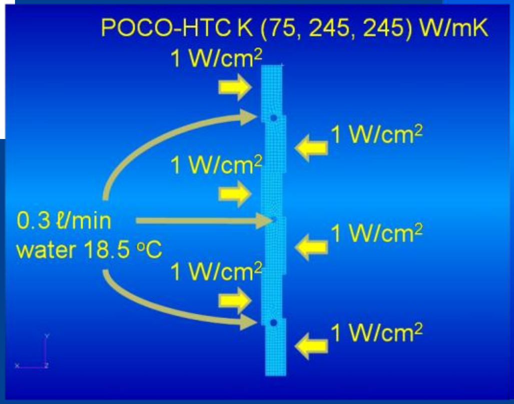
carbon foam cutting

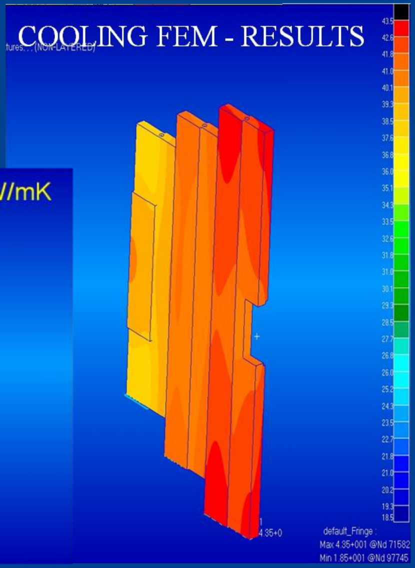


drilling and baking



gluing:
2 foam disks
w/t embedded
cooling pipes

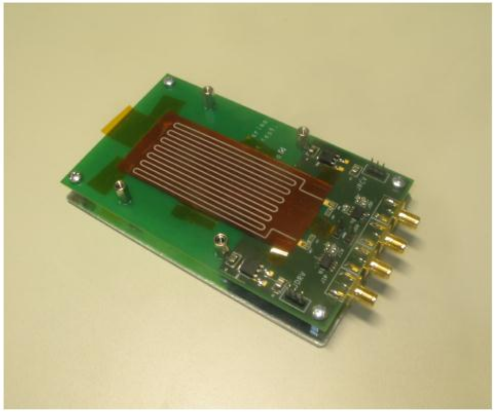


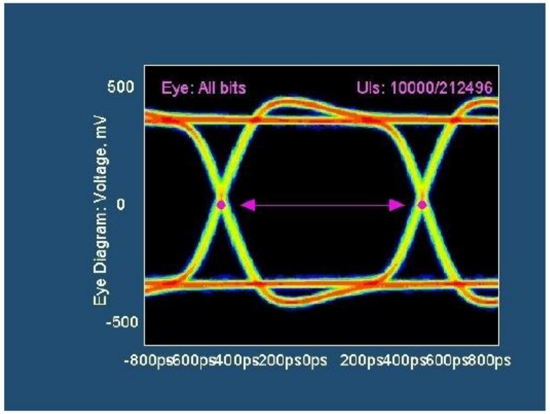


Hardware

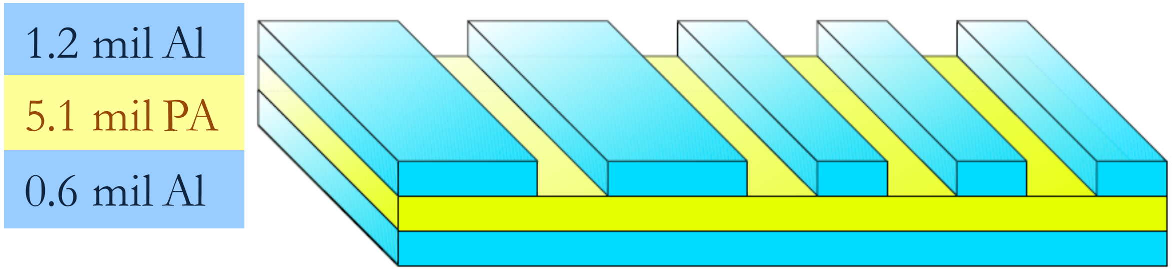
Low-mass cables

- Al cables on thin dielectric
- High-bandwidth data transmission
- 1m prototypes under study





total jitter T_j=171ps @ s=1.06Gb/s



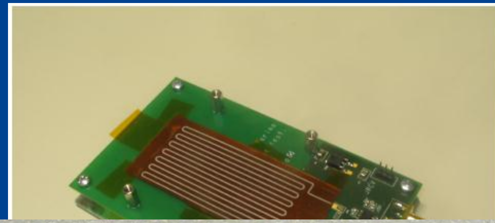
	Subclass Name	Type	Material	Thickness (MIL)	Conductivity (mho/cm)	Dielectric Constant	Loss Tangent	Negative Artwork	Shield	Width (MIL)	Impedance (ohm)
1		SURFACE	AIR			4.500000	0				
2	TOP	CONDUCTOR	ALUMINUM	1.18	350000	4.500000	0	☐		6.0	68.115
3		DIELECTRIC	POLYIMIDE_FILM	5.12	0	3.500000	0				
4	BOTTOM	PLANE	ALUMINUM	0.55	350000	4.500000	0	☐	☒		
5		SURFACE	AIR			4.500000	0				

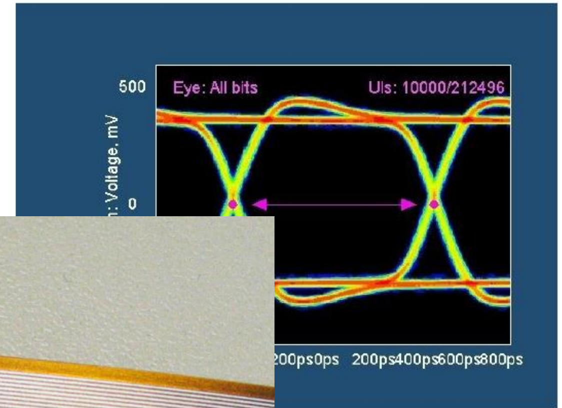
	Subclass Name	Type	Thickness (MIL)	Dielectric Constant	Loss Tangent	Shield	Width (MIL)	Impedance (ohm)	Coupling Type	Spacing (MIL)	DiffZ0 (ohm)
1		SURFACE		4.500000	0						
2	TOP	CONDUCTOR	1.16	4.500000	0		6.0	66.115	EDGE	6.0	114.63
3		DIELECTRIC	5.12	3.500000	0						
4	BOTTOM	PLANE	0.55	4.500000	0	☒					
5		SURFACE		4.500000	0						

Hardware

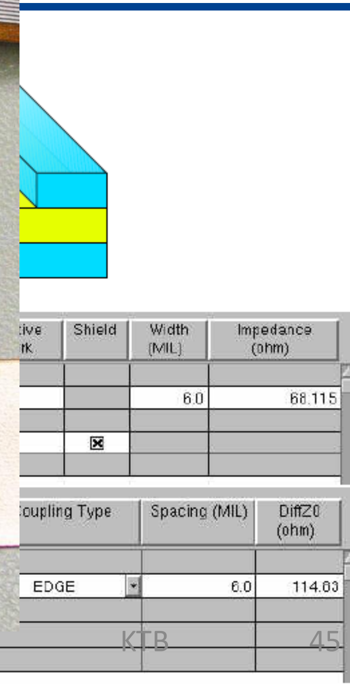
Low-mass cables

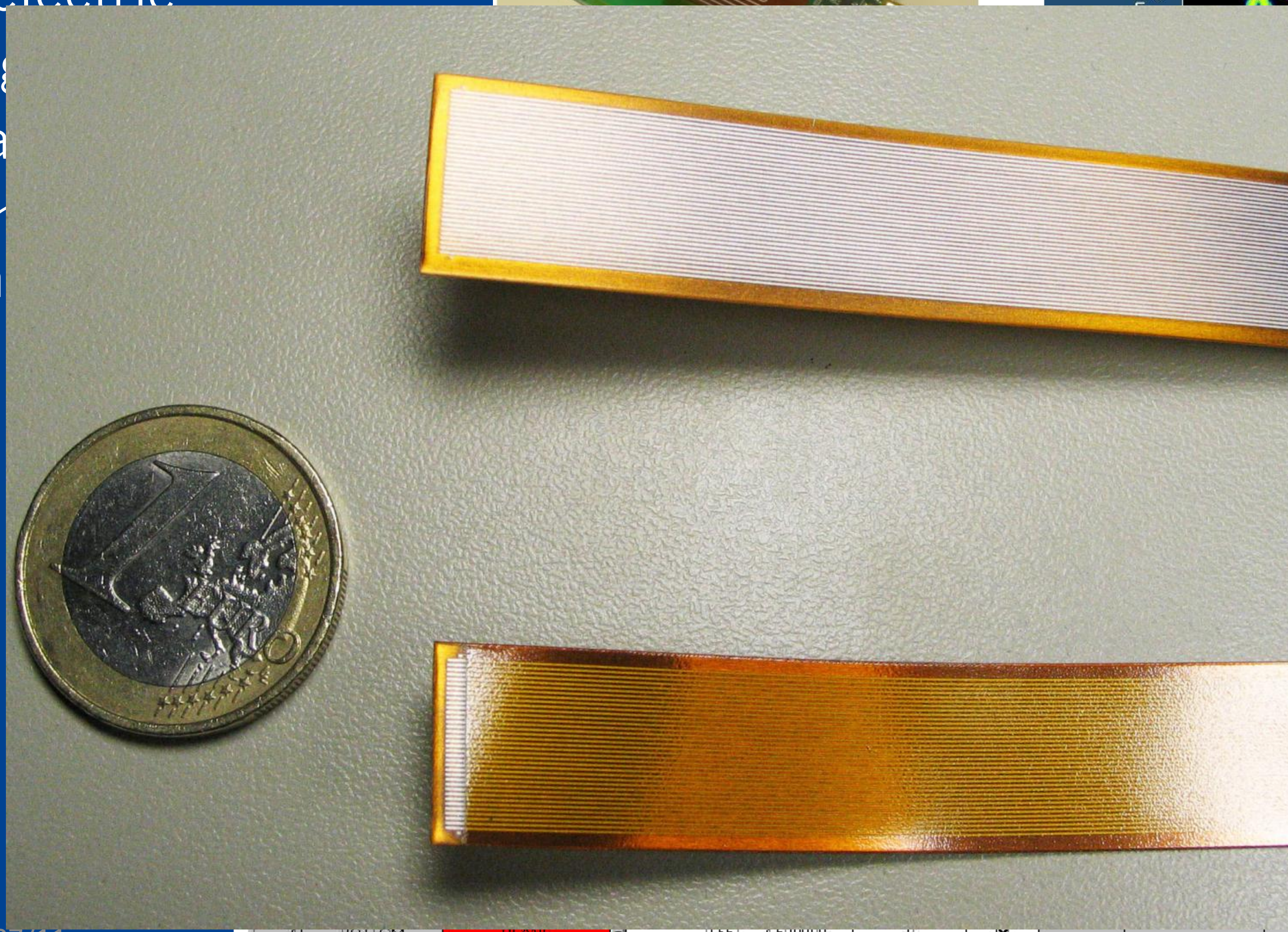
- Al cables on thin dielectric
-Hi…
tra…
- 1r…
un…





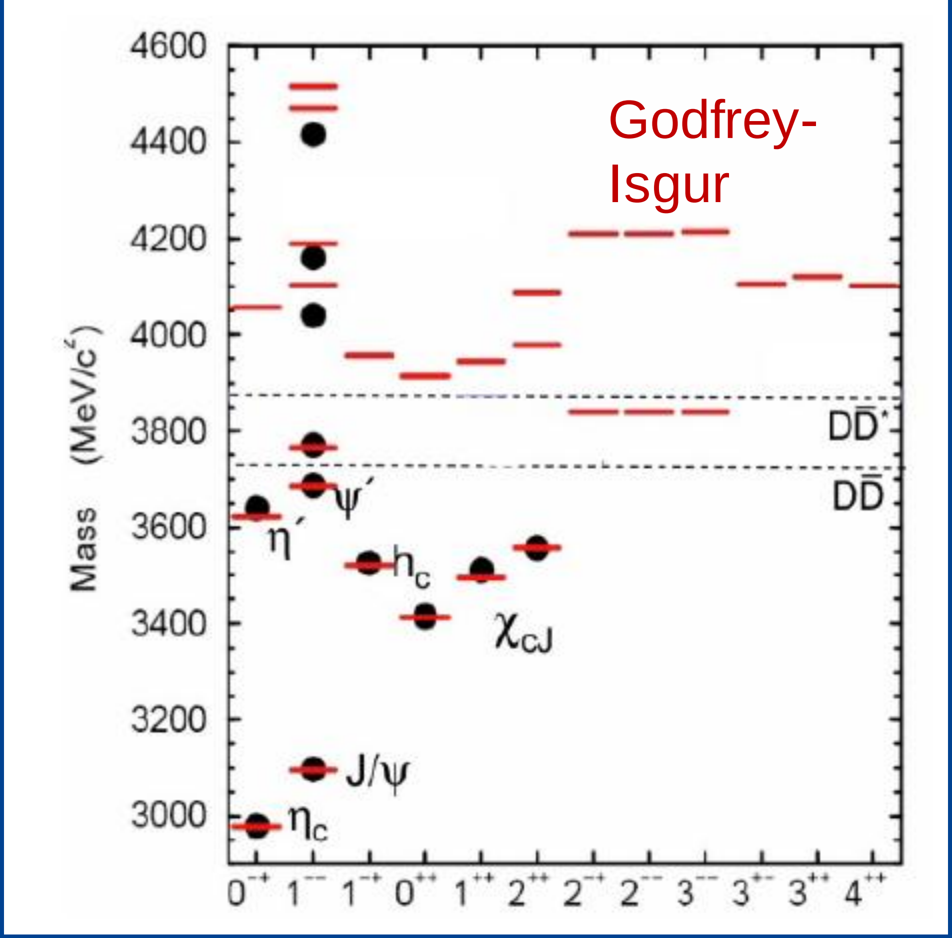
…ps @ s=1.06Gb/s



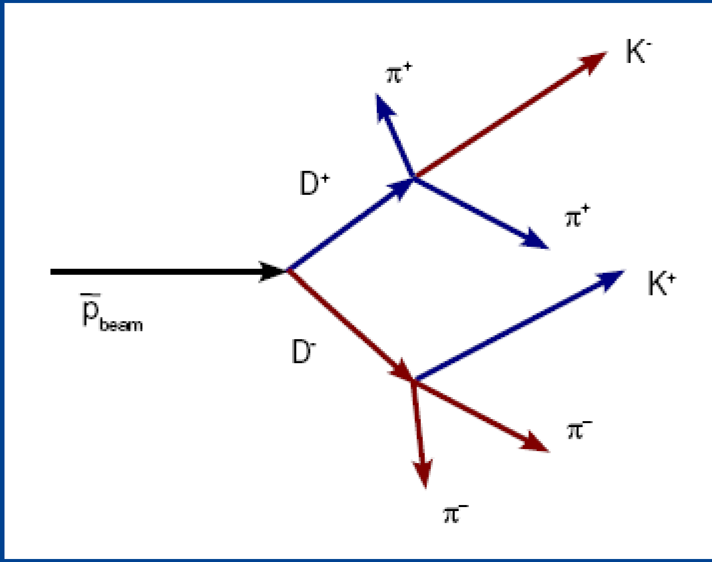


The P̄ANDA MVD Project

- Physics simulations: Charmonium States



Observation of states above DD̄ threshold in DD̄!



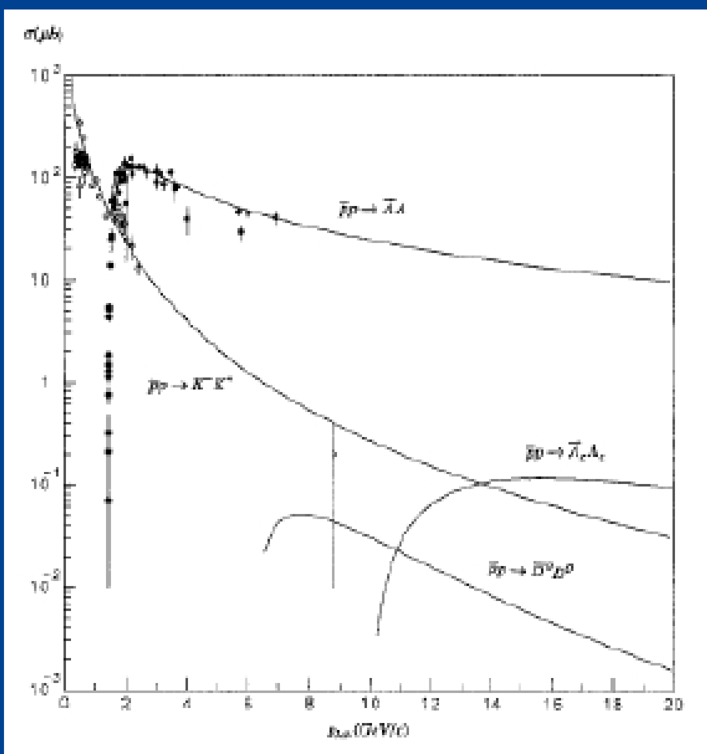
Charmonium States

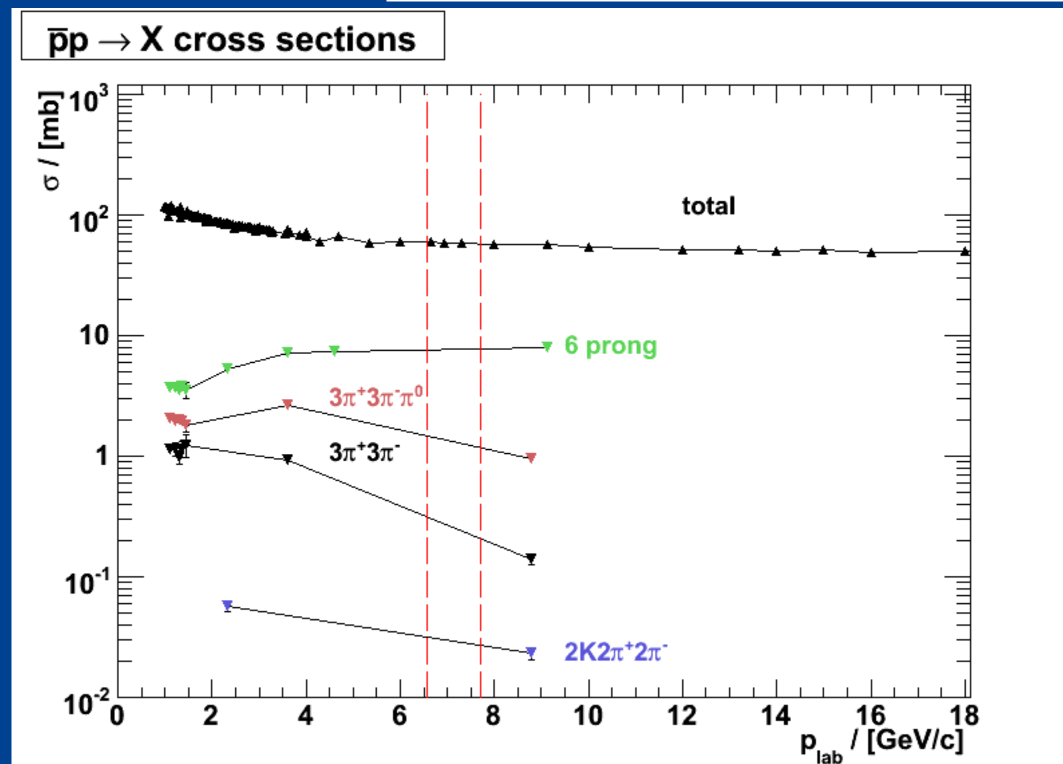
D$\bar{\text{D}}$: huge background from less charming channels!

$$\bar{p}p \longrightarrow D^+ D^-$$

channel	D^+D^-	$D^{*+}D^{*-}$
decay	$D^\pm \to K^\mp \pi^\pm \pi^\pm$ (9.2 %)	$D^{*+} \to D^0 \pi^+$ (67.7 %) $D^0 \to K^- \pi^+$ (3.8 %)
R	4×10^{-10}	1×10^{-11}

Kaidalov , Volkovitsky, Z. Phys. C 63, 517(1994)

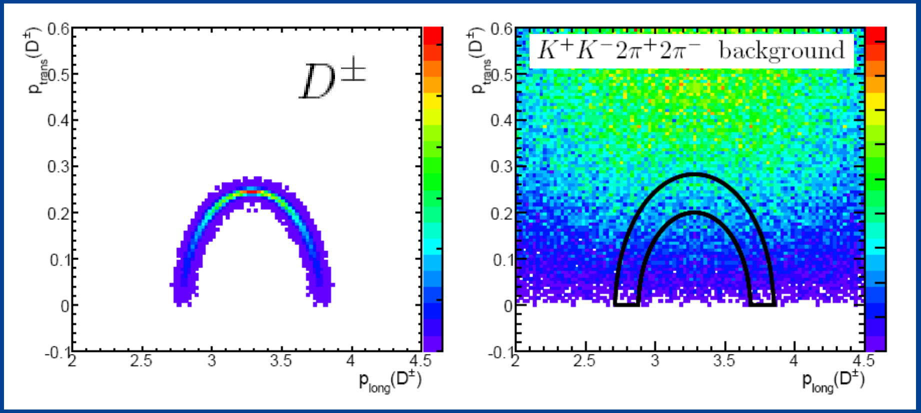


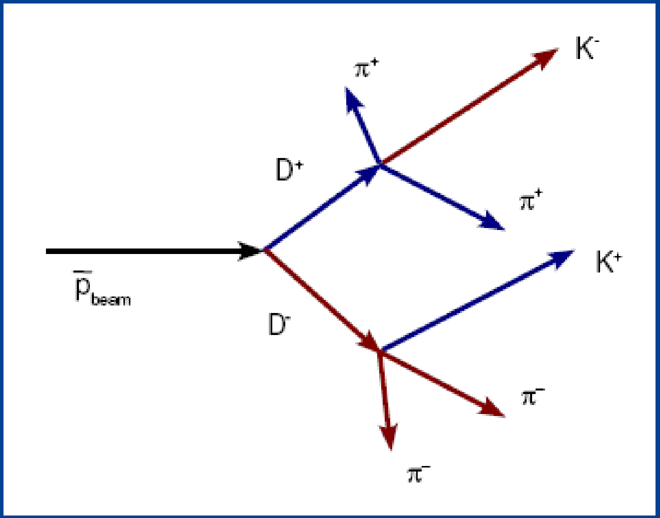


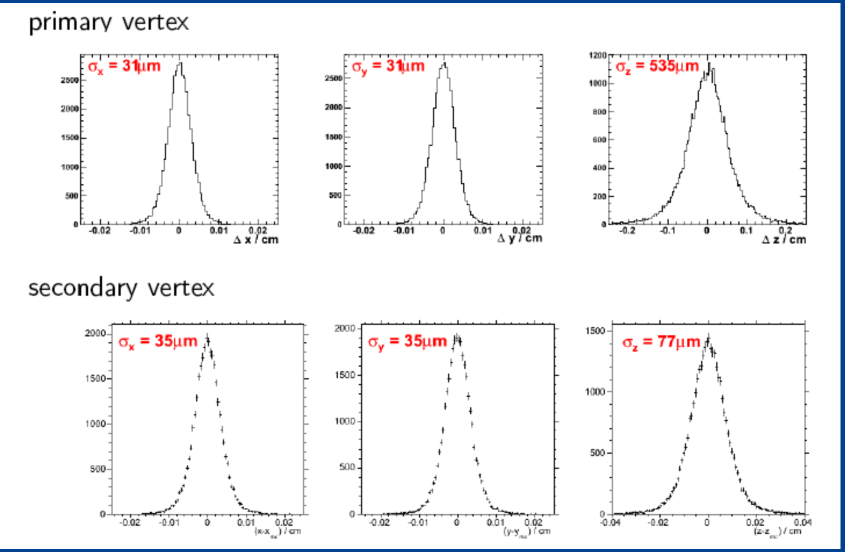
Charmonium States

$D\bar{D}$: huge background from less charming channels!

$$\bar{p}p \longrightarrow D^+D^-$$

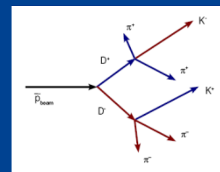




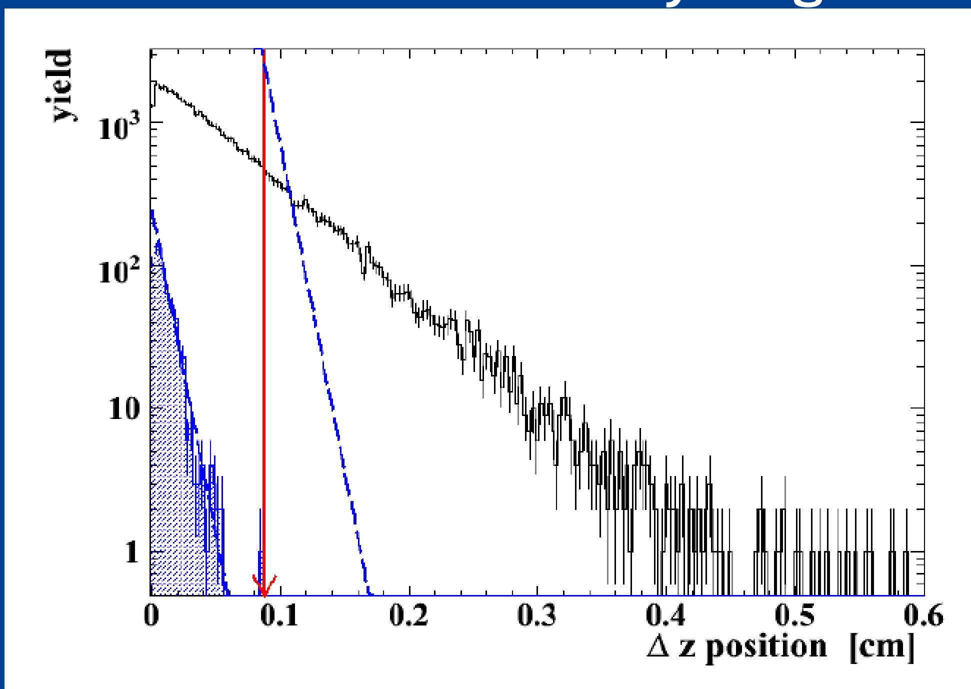


Charmonium States

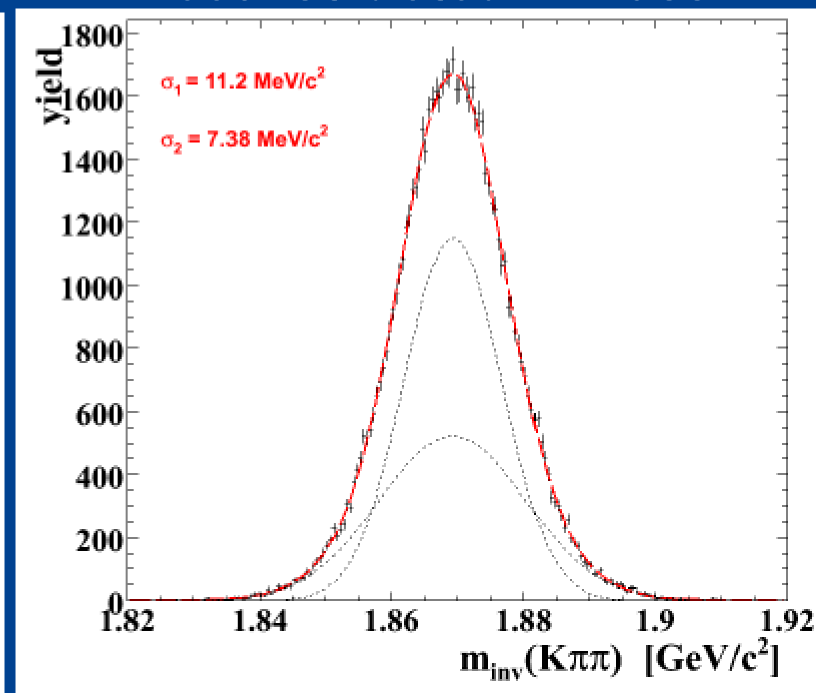
$$\bar{p}p \longrightarrow D^+ D^-$$



reconstructed decay length



reconstructed D mass

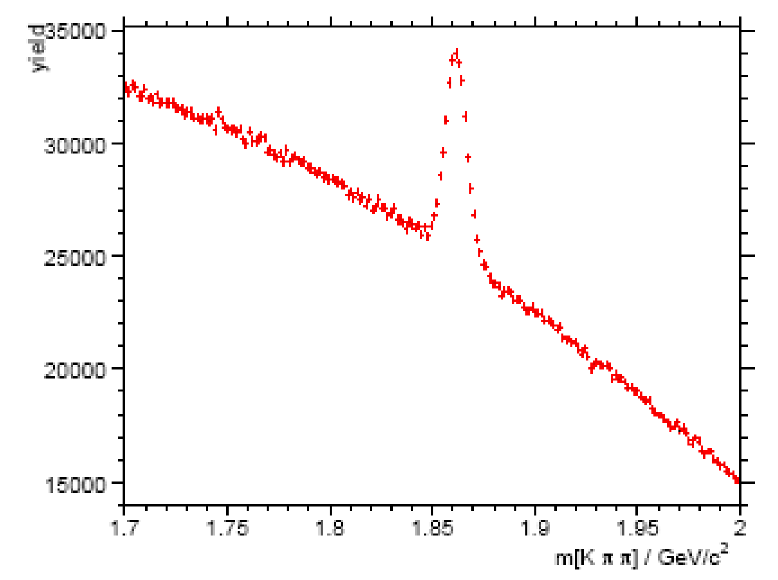


Charmonium States

$\bar{p}p \rightarrow D^+D^-$

channel	D^+D^-	$D^{*+}D^{*-}$
	number of events [$\times 10^6$]	
DPM	24	-
$3\pi^+3\pi^-\pi^0$	50	40
$3\pi^+3\pi^-$	10	70
$2K^\mp 4\pi^\pm$	1	10

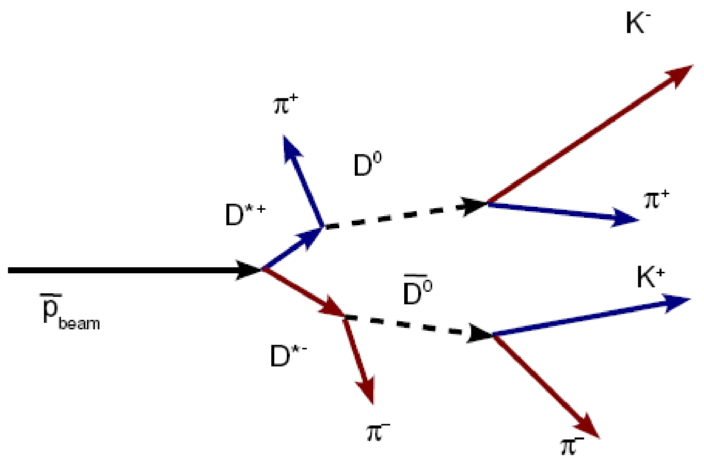
reaction	cross section [mb]	fraction to $p\bar{p}$	fraction to D^+D^-
$3\pi^+3\pi^-\pi^0$	1.5	$2.5 \cdot 10^{-2}$	$6.25 \cdot 10^7$
$3\pi^+3\pi^-$	0.32	$5.0 \cdot 10^{-3}$	$1.25 \cdot 10^7$
$2K^\mp 4\pi^\pm$	0.033	$5.0 \cdot 10^{-4}$	$1.25 \cdot 10^6$



ε ≈ 40%
> 5·10^4 events per $\overline{\text{P}}$ANDA **year**

selection	efficiency			signal/background	
selection	D^+D^-	$3\pi^+3\pi^-$	$3\pi^+3\pi^-\pi^0$	$\frac{D^+D^-}{3\pi^+3\pi^-}$	$\frac{D^+D^-}{3\pi^+3\pi^-\pi^0}$
preselection	0.43	$5.4 \cdot 10^{-3}$	$9.6 \cdot 10^{-4}$	-	-
4C-fit	0.40	$1.4 \cdot 10^{-6}$	$4.2 \cdot 10^{-7}$	0.02	0.015
$D^\pm$ momentum	0.40	$< 1.1 \cdot 10^{-8}$	$< 3.6 \cdot 10^{-9}$	> 2.7	> 1.8
K LH > 0.3	0.23	$< 1.8 \cdot 10^{-9}$	$< 1.7 \cdot 10^{-9}$	> 6.4	> 2.9

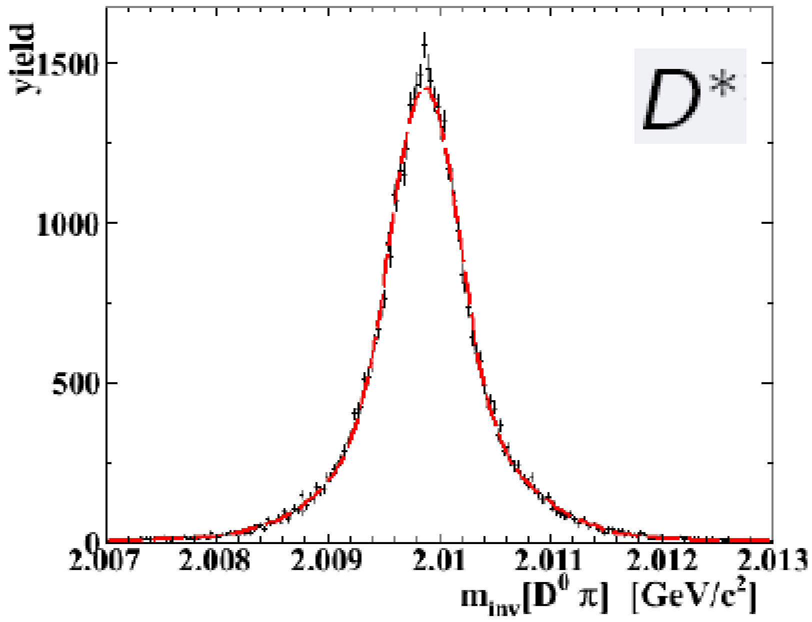
Charmonium States

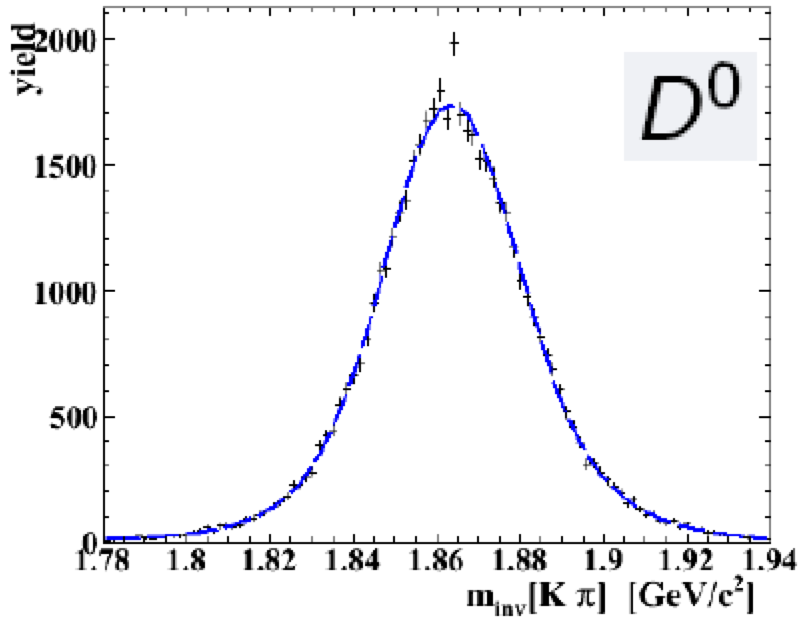


$$p\bar{p} \longrightarrow D^{*+}D^{*-}$$

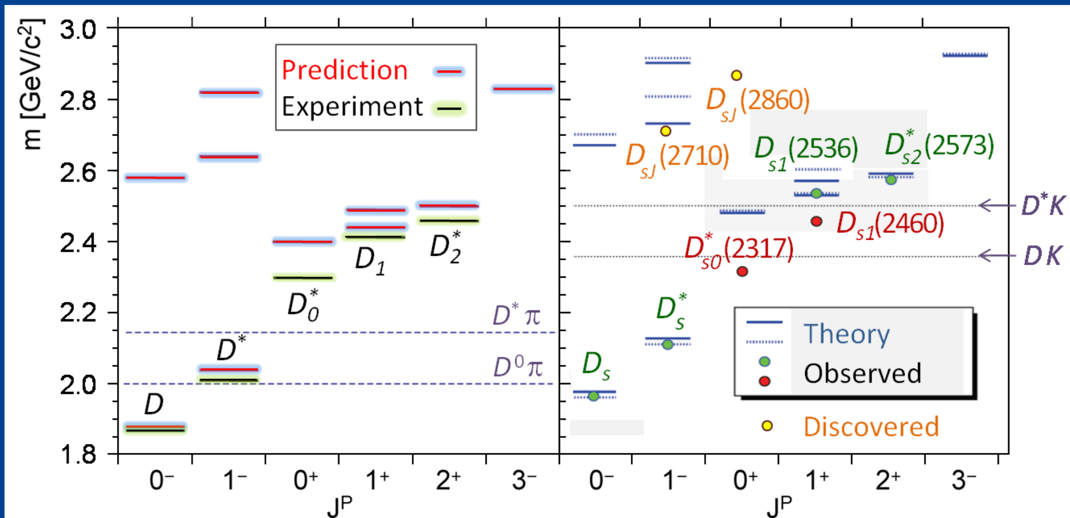
$\varepsilon \approx 25\%$

> 10^3 events per P̄ANDA year





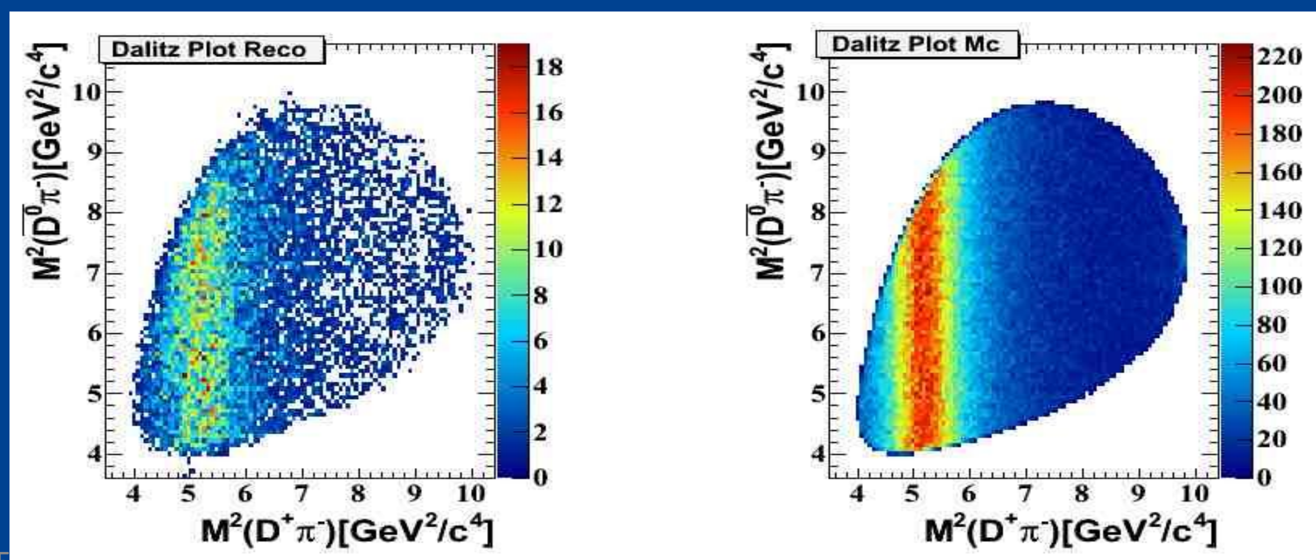
Open Charm

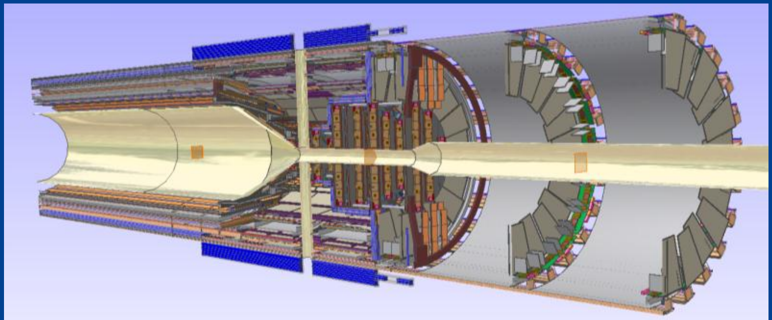


$$\bar{p} + p \rightarrow D_0^{\ *} + \bar{D}_0$$

P̄ANDA performance:

- >10% acceptance,
- flat coverage





Summary

The MVD concept

- needs continued R&D.
- has to undergo add‘l iterations with simulation.
- has reached a technical level.
- meets the design specifications.

R&D on components ongoing

TDR will go public before the end of 2011

Realisation of the $\bar{\text{P}}$ANDA MVD in sight