The PANDA apparatus

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on behalf of the PANDA Collaboration

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Outline

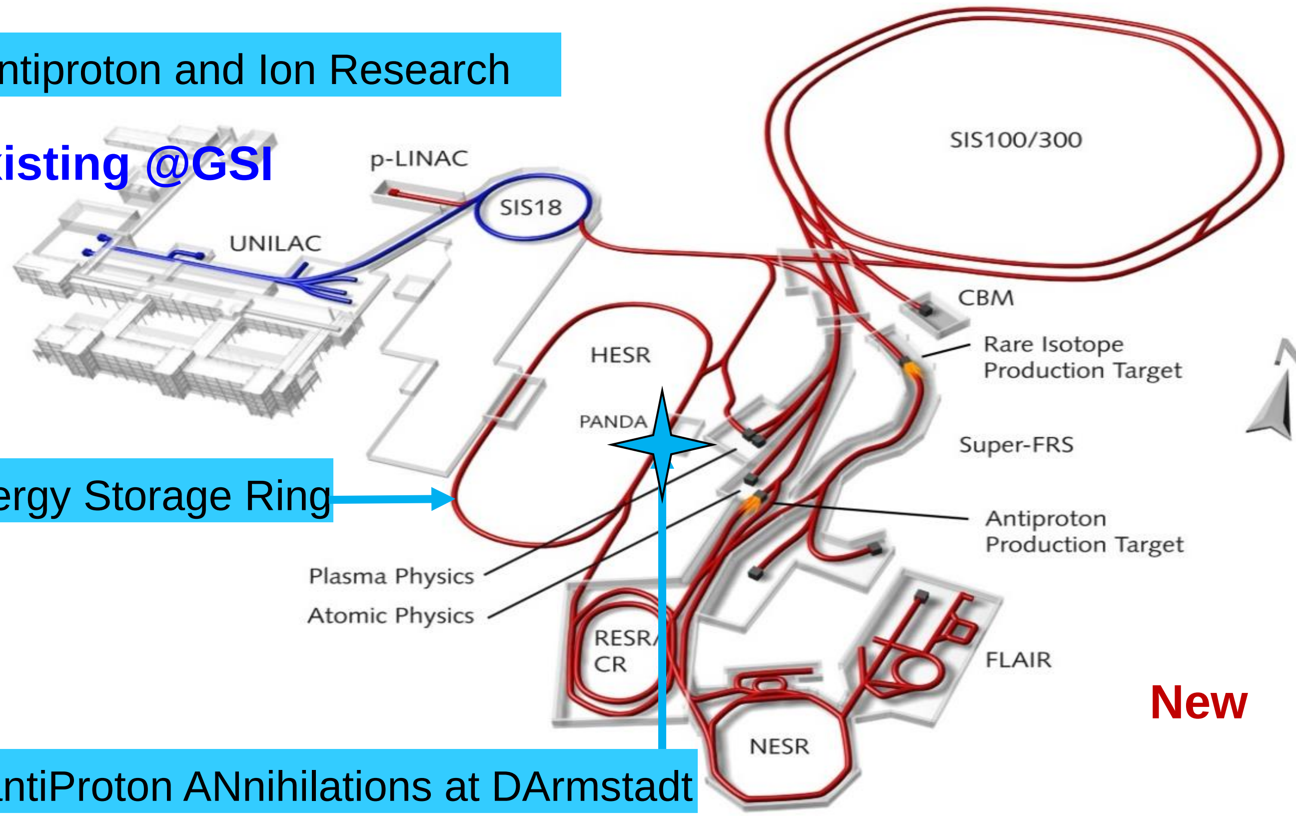
- Introduction to PANDA
- The target system and the luminosity monitor
- The Micro Vertex Detector
- The Tracking System
- The Particle Identification
- The Calorimetry
- The DAQ
- Conclusion

PANDA @ FAIR

HESR – High Energy Storage Ring

FAIR Facility for Antiproton and Ion Research

Existing @GSI



HESR High Energy Storage Ring

New

panda antiProton ANnihilations at DArmstadt

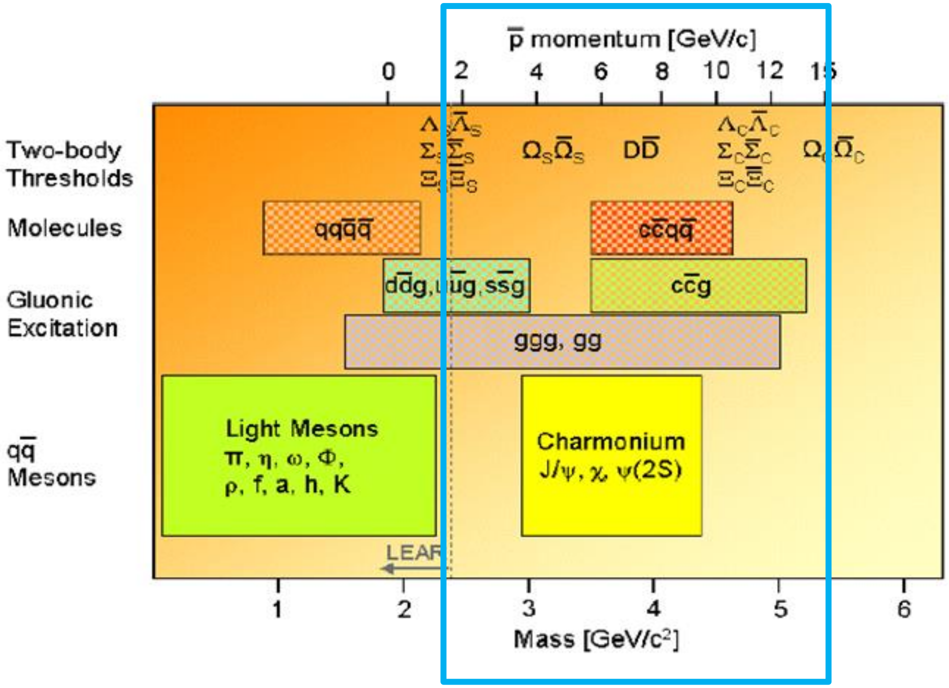
High luminosity mode

- $L \sim 2 \cdot 10^{32}\ cm^{-2}\ s^{-1}$
- $\delta p/p \sim 10^{-4}$
- 1.5÷15 GeV/c antiproton momentum

High resolution mode

- $\delta p/p \sim 4 \cdot 10^{-5}$
- $L \sim 2 \cdot 10^{31}\ cm^{-2}\ s^{-1}$,
- 1.5÷8.9 GeV/c antiproton momentum

Physics @ PANDA



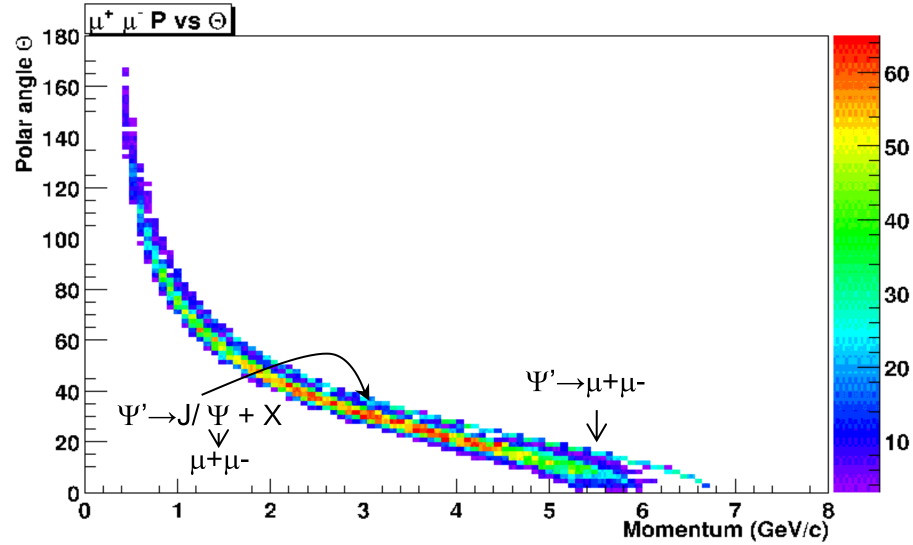
- Meson spectroscopy
- Baryon-antibaryon production
- Baryon spectroscopy
- Search for gluonic excitations
- Hadrons properties in the nuclear matter
- Hypernuclear physics
- Electromagnetic processes

PANDA is designed as a multipurpose apparatus
Efficient event selection

- All detectors have to handle a continuous data transmission at the interaction rate of $\sim 2 \cdot 10^{7}$ s^{-1}
- Syncronization with a precise time stamp distribution (experiment clock: 155.52 MHz)

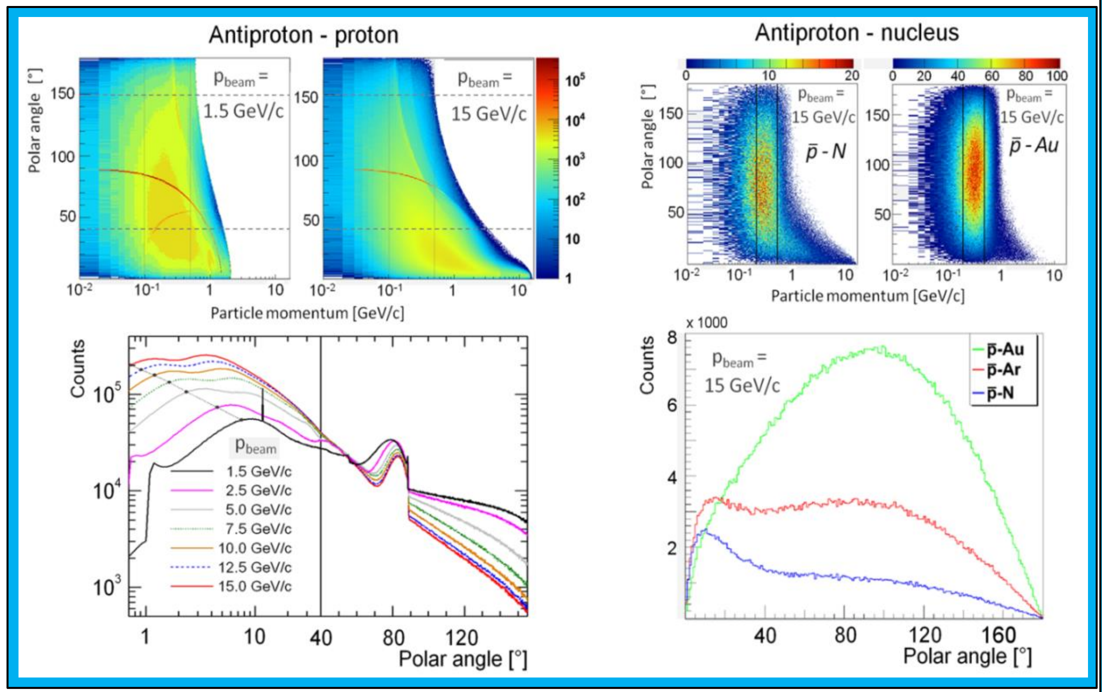
Apparatus requirements

- Momentum resolution ~ 1%
- Vertex info for D, K^0_s, Λ
  (cτ of some hundreds of μm)
- Good tracking
- Good PID (e, μ, π, k, p)
- γ-detection ~ 1 MeV ÷ 10 GeV
- nearly 4π solid angle acceptance

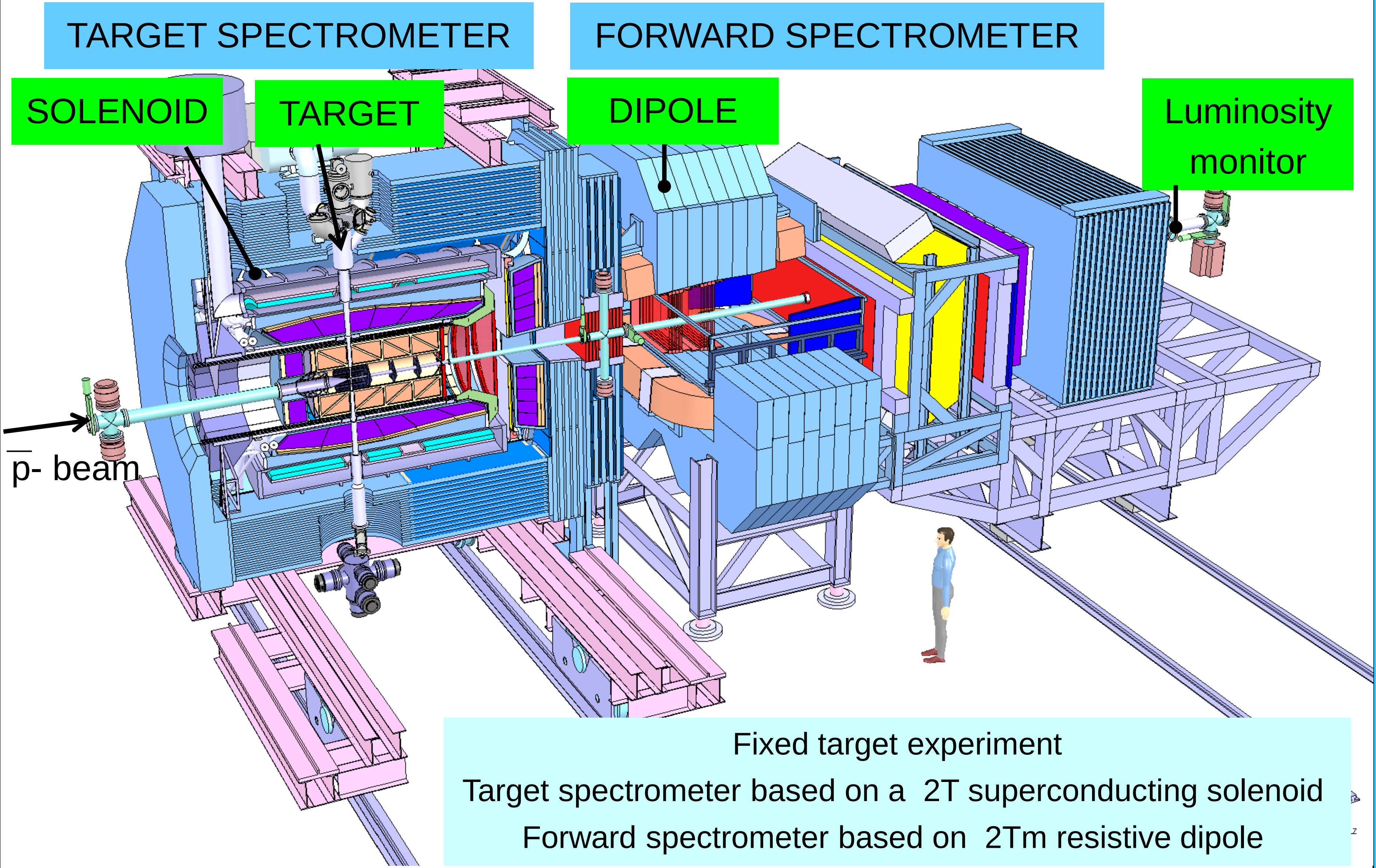


Emitted particle distributions

- forward peaked in pbar-p annihiliations
- feature enhancements at high polar angles in pbar-nucleus interactions



PANDA apparatus

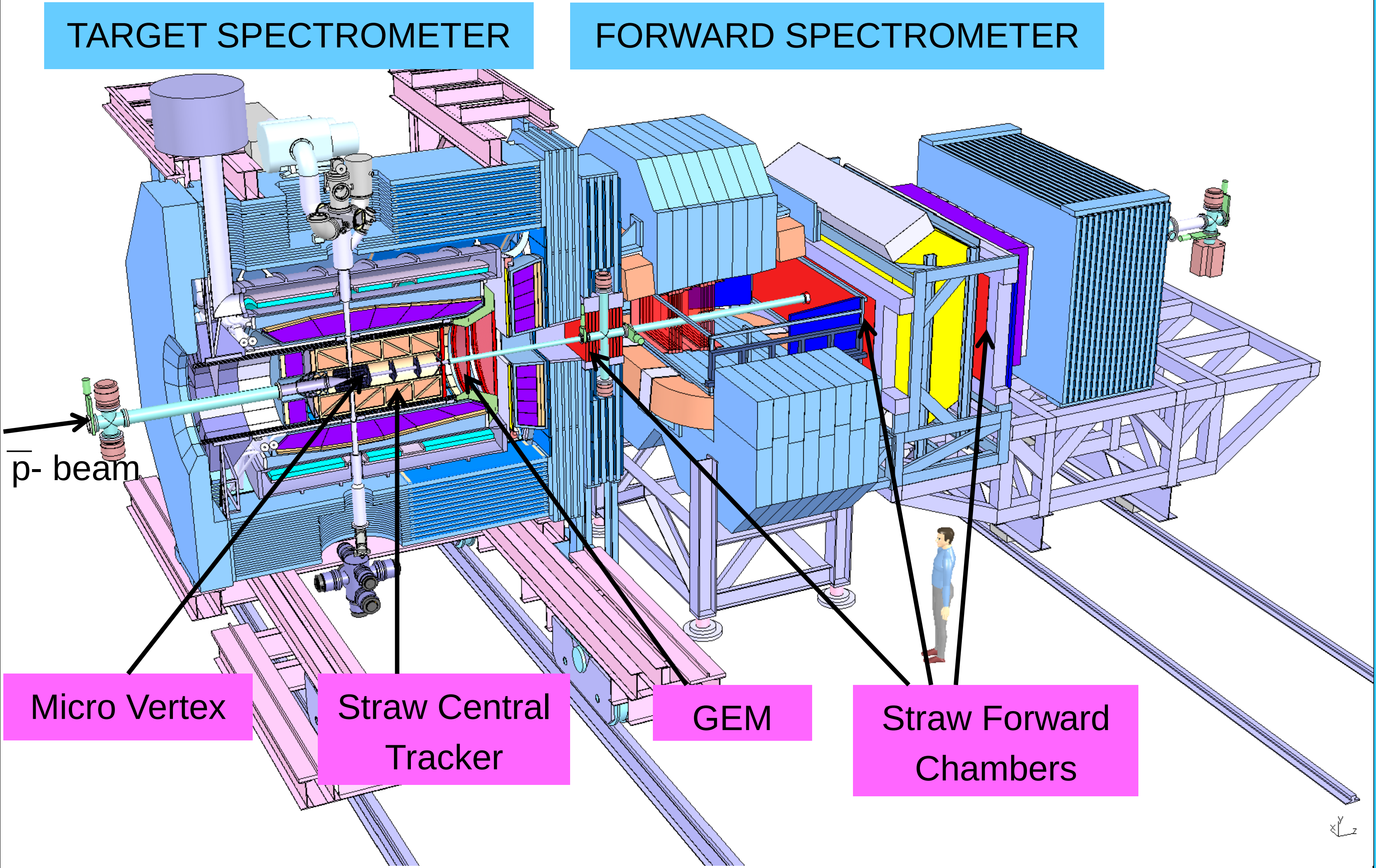


Fixed target experiment

Target spectrometer based on a 2T superconducting solenoid

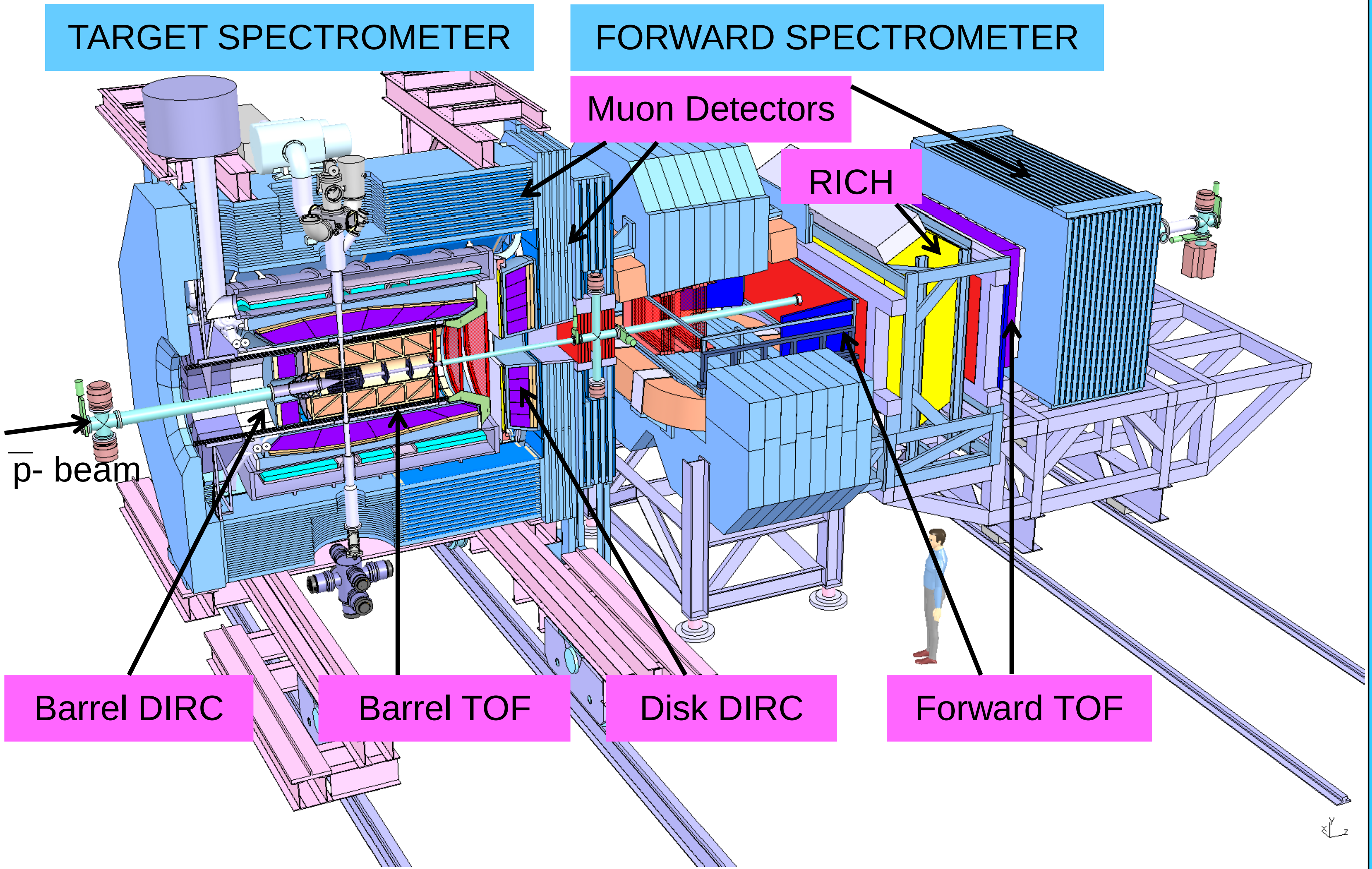
Forward spectrometer based on 2Tm resistive dipole

Tracking

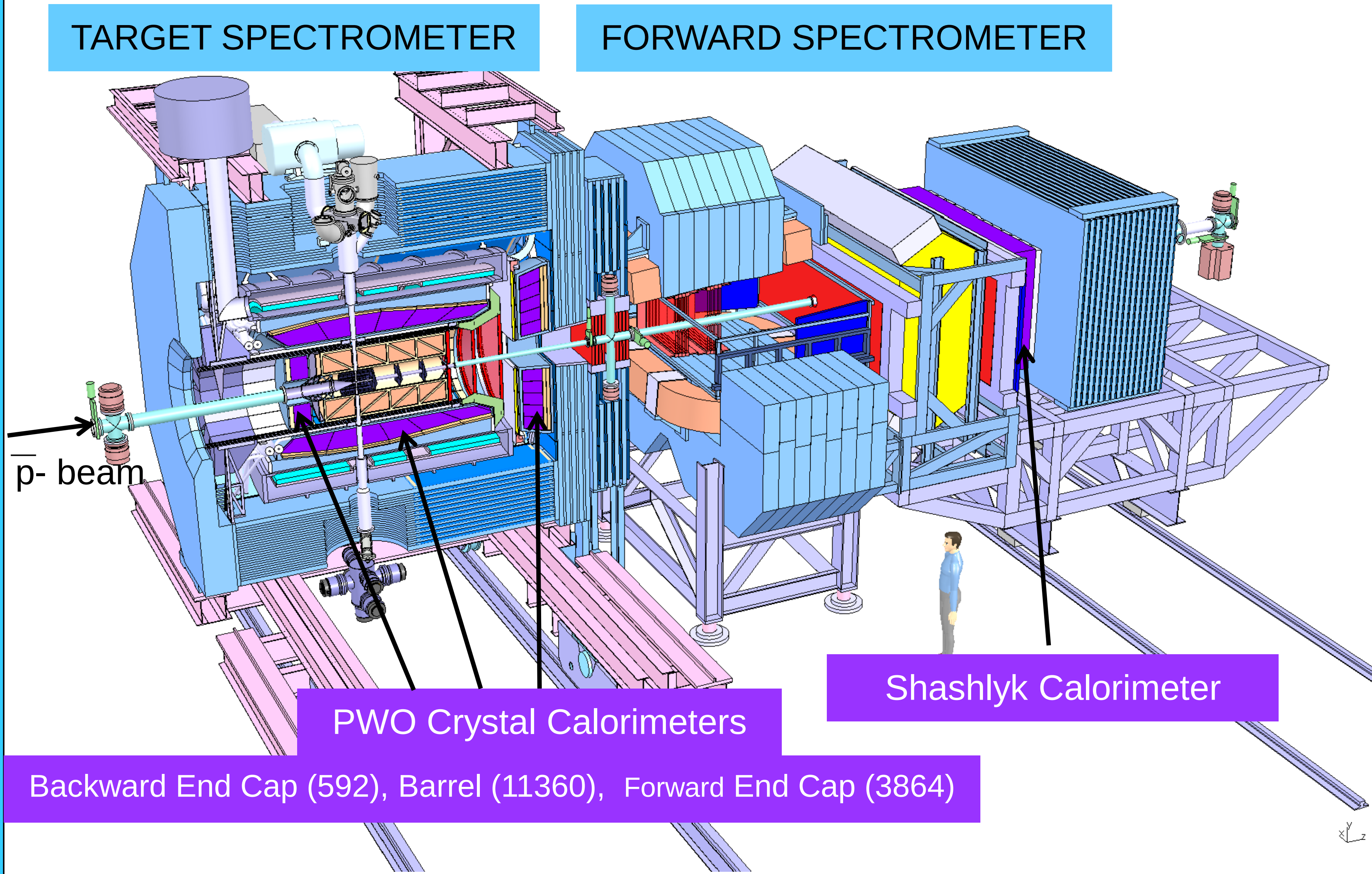


TARGET SPECTROMETER
FORWARD SPECTROMETER
$\bar{p}$- beam
Micro Vertex
Straw Central Tracker
GEM
Straw Forward Chambers

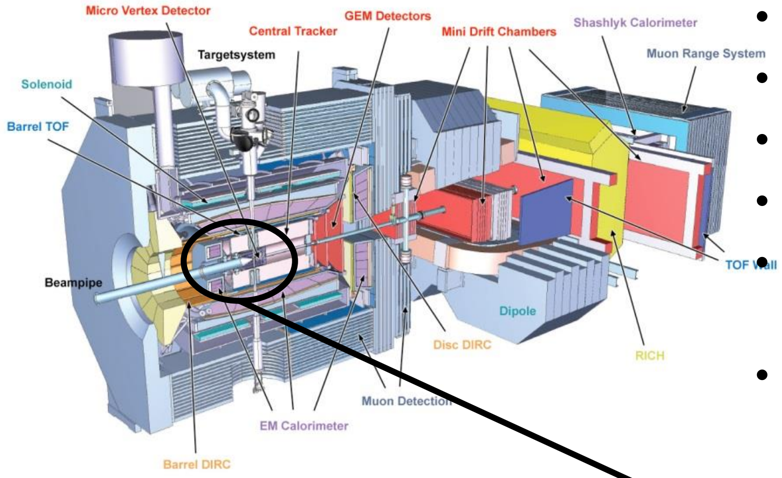
Particle identification



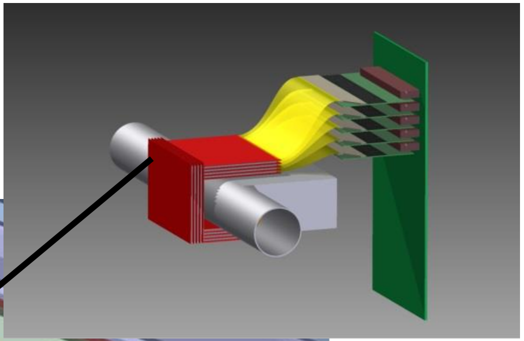
Calorimetry

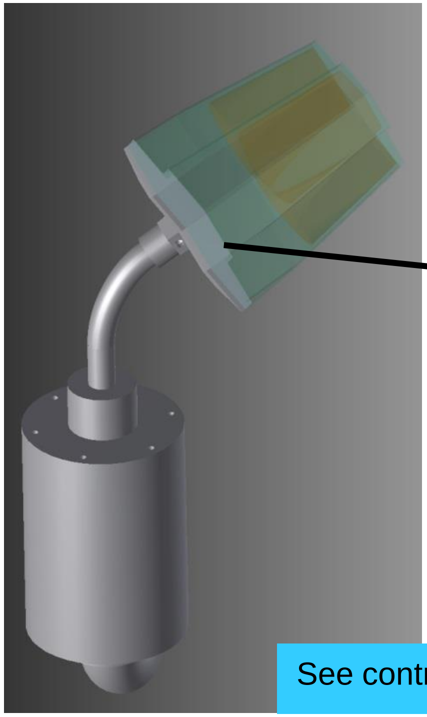


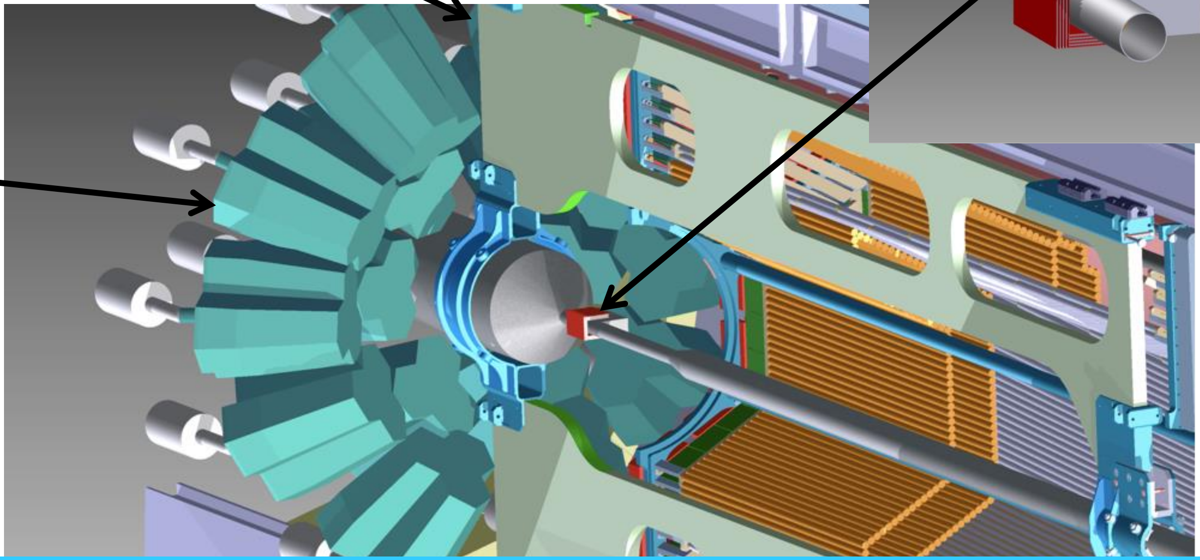
Hypernuclear setup



- $\Lambda\Lambda$ hypernuclei study: $\bar{p} + {}^{12}C \Rightarrow \Xi^{-} + \bar{\Xi}$
- Backward End Cap EMC and MVD will be removed
- Dedicated beam pipe system
- Wire target into the beam pipe
- Secondary active target (Si strips + Be,B,C absorbers)
- HPGe encapsulated crystal attached to the X-Cooler







See contribution: Hypernuclear Physics studies of the PANDA experiment at FAIR, Alicia Sanchez Lorente

Target

Target requirement: ~ 10^{15} atoms/cm^2 at the interaction point

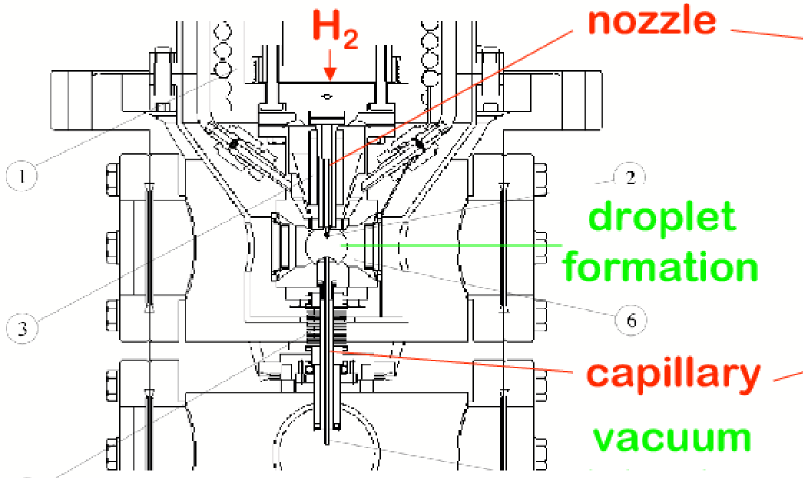
- ✓ Pellet Target (frozen microspheres of hydrogen…)
- ✓ Cluster jet target (hydrogen and deuterium…)

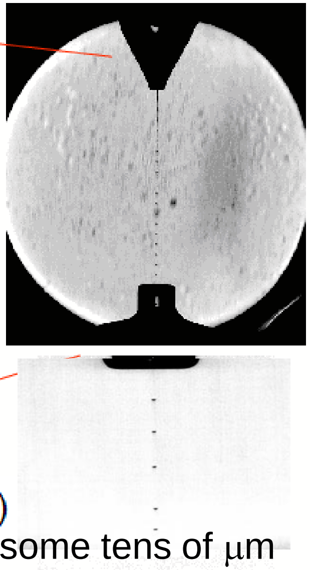
(Distance of ~ 2.1 m of the target source from the interaction point)

See contribution: Pellet tracking system for hadron physics experiments, Andrze Pyszniak

- ✓ Wires (nuclear target)

Prototypes

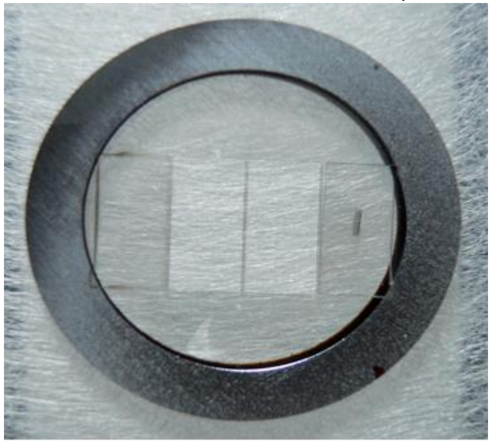




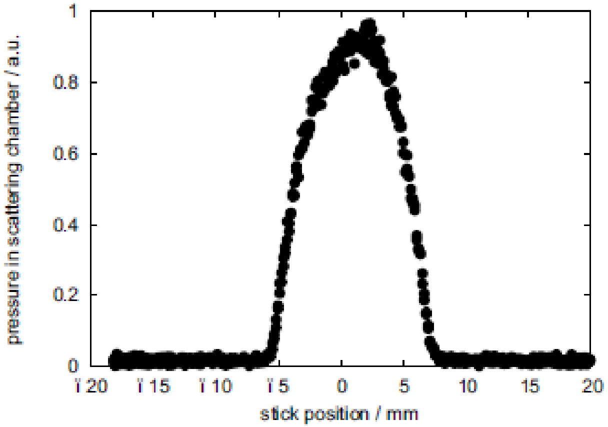
Pellet target: O. Nordhage (GSI/Uppsala)

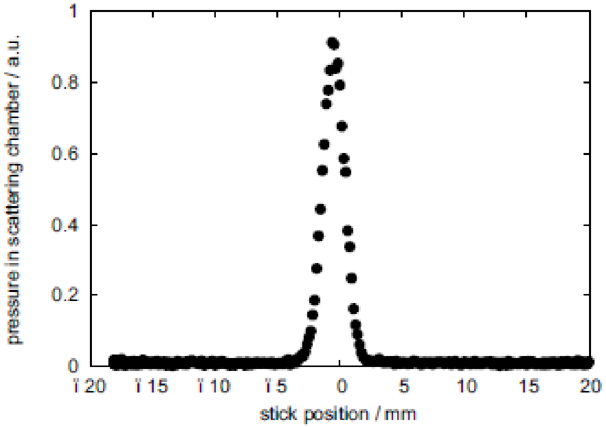
Diameter: some tens of μm

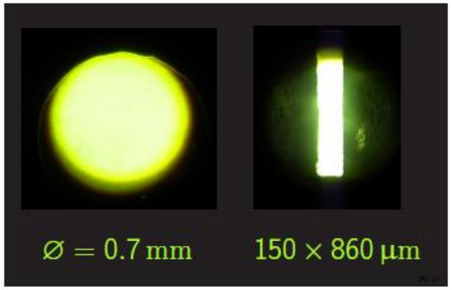
Diamond **wire target (Politecnico di Torino and INFN)**
Si ring outer f =15 mm
Si ring inner f = 11 mm
Diamond width: 100 μm
Diamond thickness = 3 μm



Cluster Jet target (University of Muenster)
Cluster beam profiles with use of a collimator: round opening (left) and slit (right)
Study to reduce the influence of the cluster beam on the vacuum of HESR





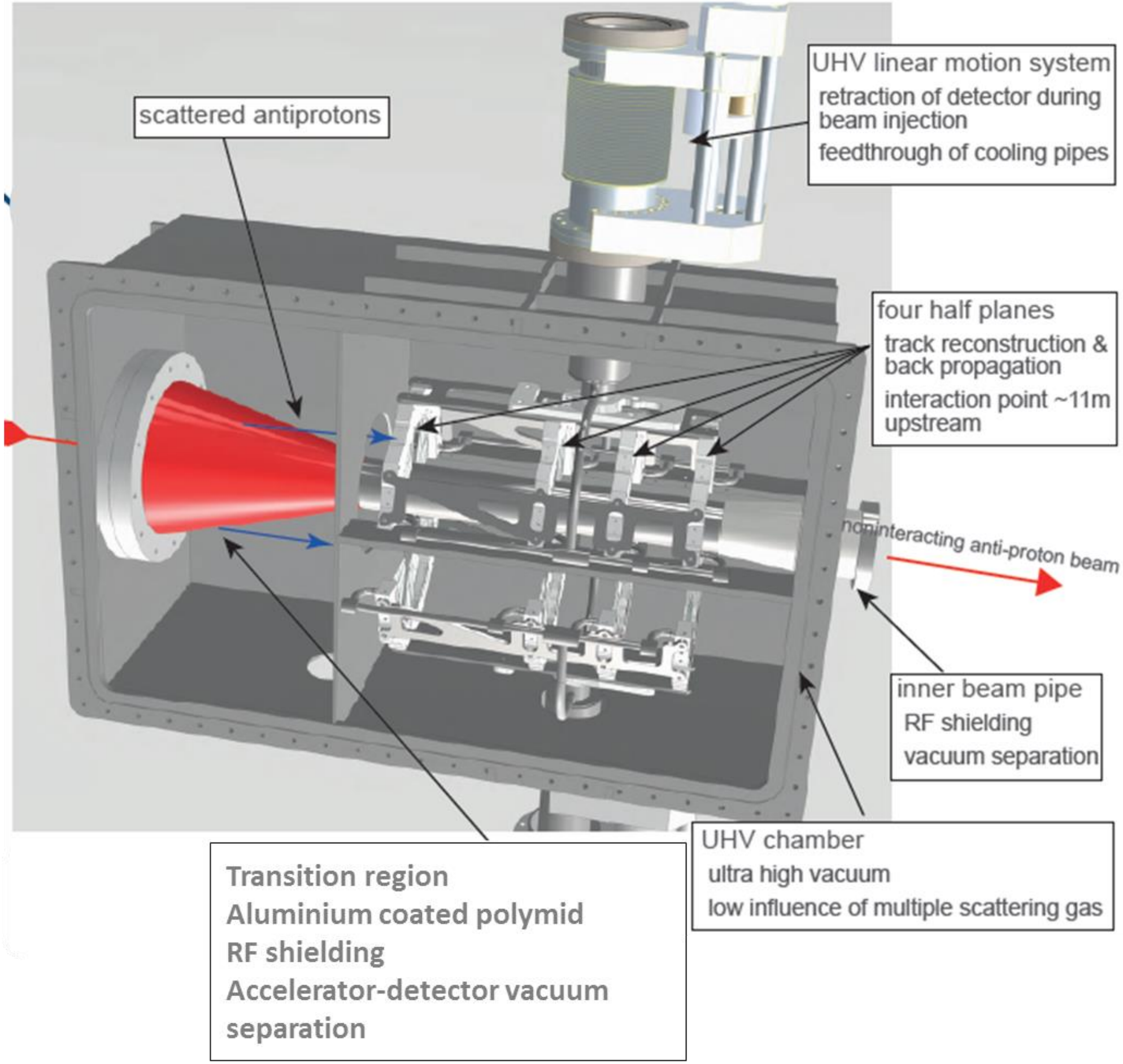


Luminosity monitor

Precise knowledge of the beam luminosity to determine absolute cross sections

Downstream the dipole → Track direction measurement

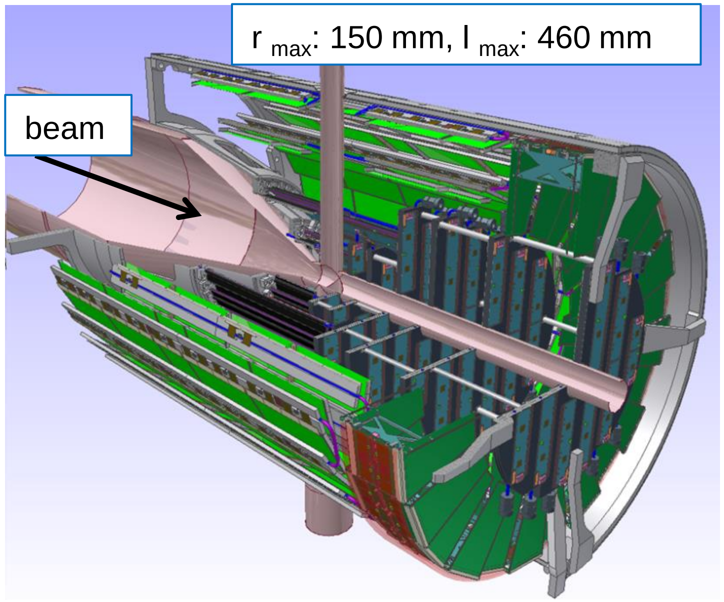
- HV-MAPS
- active area: 20 x 20 mm^2
- 50 μm sensor thickness
- 14 μm depletion zone
- low noise and radiation hardness
- 5 HV-MAPS glued on each side of cooled diamond wafer



Micro Vertex Detector

- ✓ Primary vertex reconstruction and Identification of the secondary
- ✓ Improvement in momentum resolution
- ✓ Support PID of low momentum particles by energy loss measurement

- Good space resolution (some tents in $\rho\phi$, better than 100 μm along z)
- Accurate time-tagging (time resolution: < 5 ns rms)
- At least four hits per track
- Limited material budget
- Radiation fluence of 10^{14} n [1MeVeq] /cm^2
- Room temperature operation
- Routing and Services only in the backward region



- Inner layers: hybrid pixel detectors
- Outer layers: **double sided silicon micro strips**

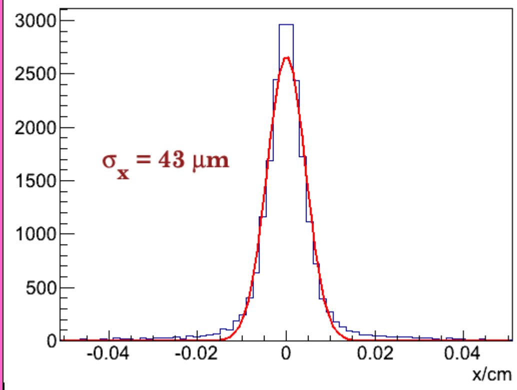
~ 10.5 x 10^6 pixels, ~ 2 x 10^5 strips

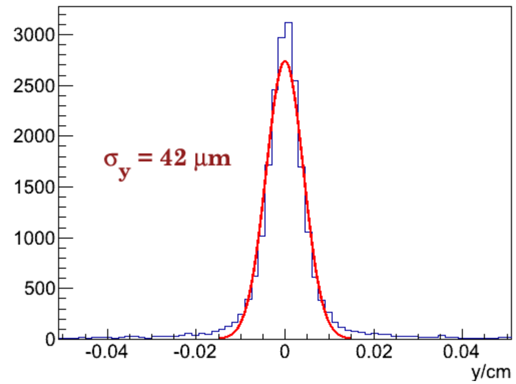
Performances

Benchmark Channel:
$\overline{p}p \rightarrow \psi(2S) \rightarrow J/\psi\pi^+\pi^-$

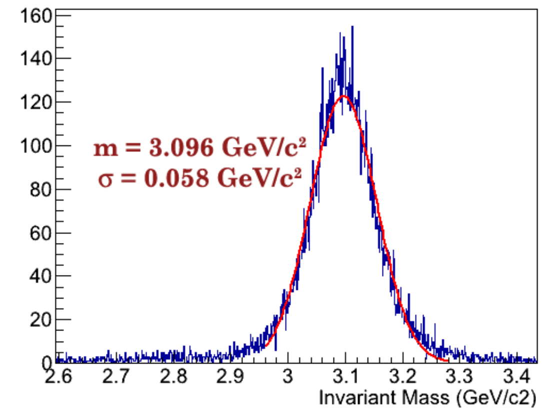
$J/\psi \rightarrow \mu^+\mu^-$

Distributions of the J/ψ vertices reconstructed from their decay in the nominal interaction point



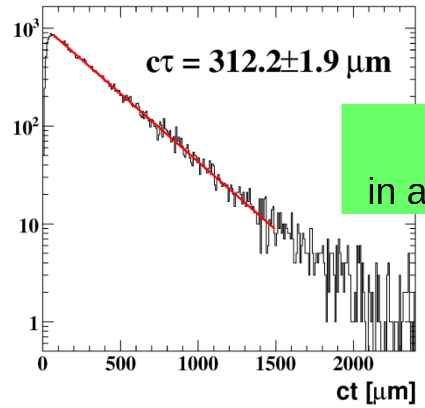


Mass distribution of J/ψ ,
in agreement with the expected value



Benchmark Channel: D **mesons**

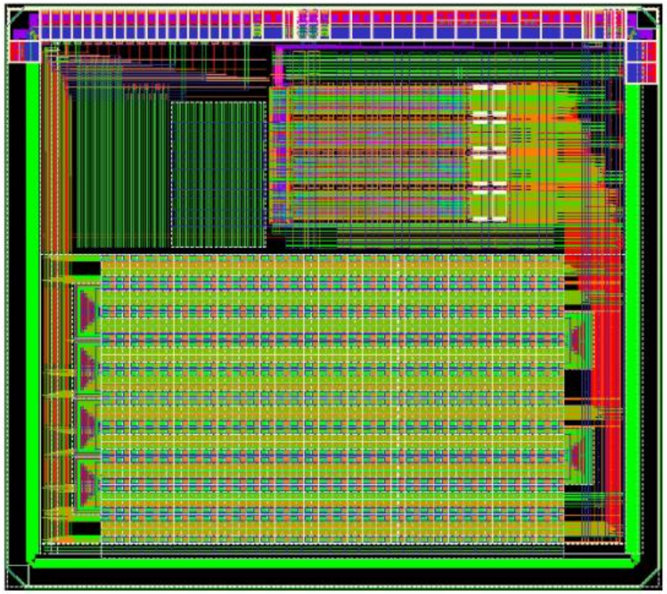
$\overline{p}p \rightarrow D^+D^- \rightarrow K^-\pi^+\pi^+K^+\pi^-\pi^-$



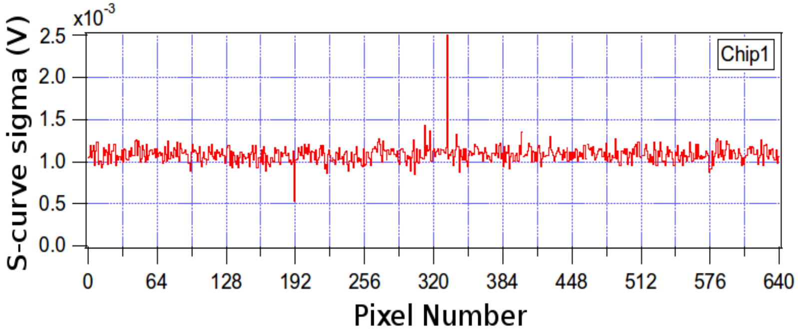
Decay length of the $D^{\pm}$'s
in agreement with the DPG value (311.8)

Triggerless pixel readout prototype

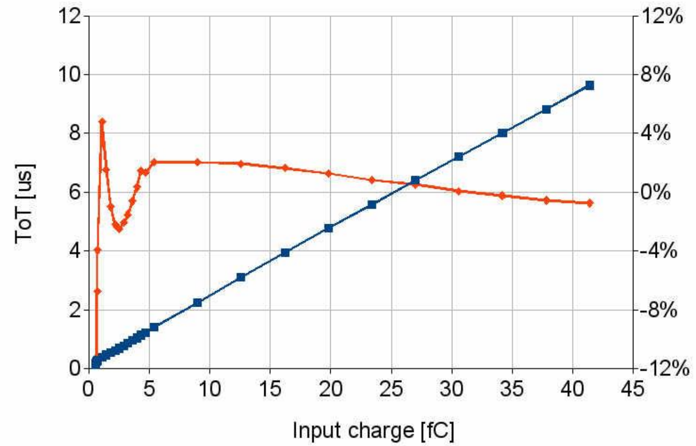
- ✓ produced with a MPW
- ✓ in 130 nm CMOS technology
- ✓ The third generation contains all the relevant features:
  - Triggerless
  - Charge encoding with ToT technique
  - Folded columns (128 pixels)
  - Double column readout
  - Common time reference
  - Triple redundancy-based SEU protection (register)
  - End of column buffering, serial ouput and SLVS I/O



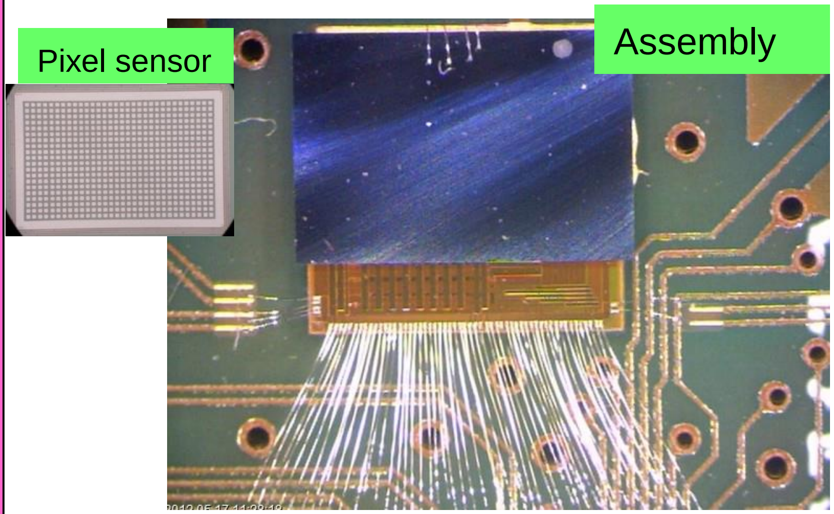
ENC = 110 electrons rms (@ 12 μW/pixel)



ToT Gain

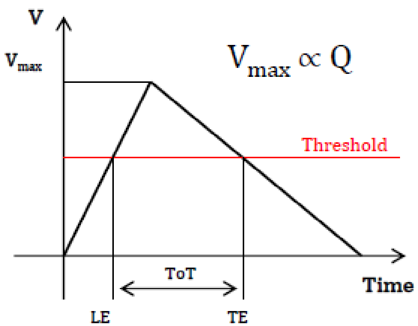


First triggerless single chip pixel assembly



ToPix_3 prototype + custom epitaxial sensor

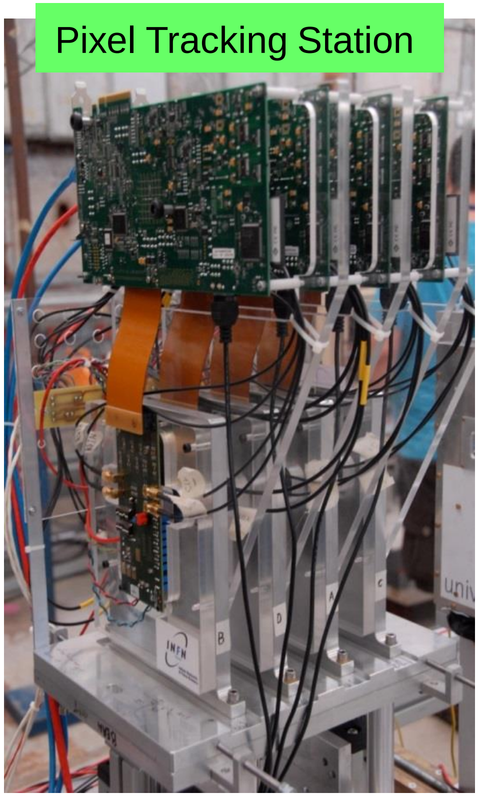
- 640 pixel matrix, pixel size: 100 x 100 μm^2, 100 μm
- epitaxial thickness
- Raw Epi wafer provided by ITME (Varsaw),
- pixel obtained at FBK (Trento), Cz thinning +
- Bump bonding @ IZM (Berlin) using Sn-Pb bumps
- Yield of the tested assemblies : ~ 99.5 %



Pixel raw data:

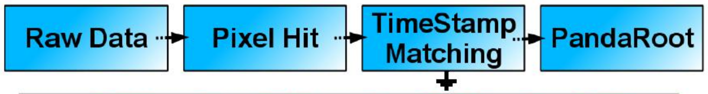
- ❑ Column & row information
- ❑ Timestamp
- ❑ (Leading Edge) + Trailing Edge (Gray encoded)

each hit

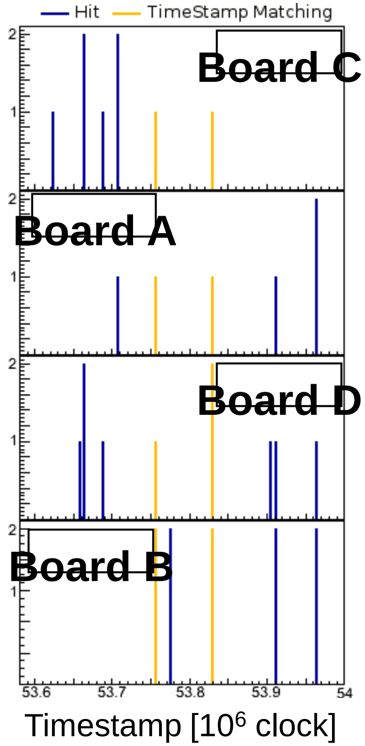


BEAM

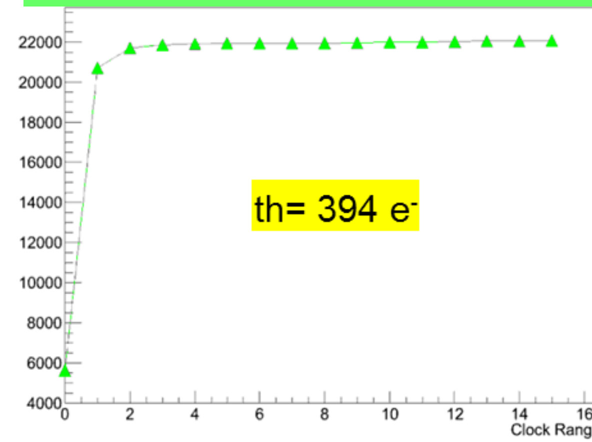
Prototype results

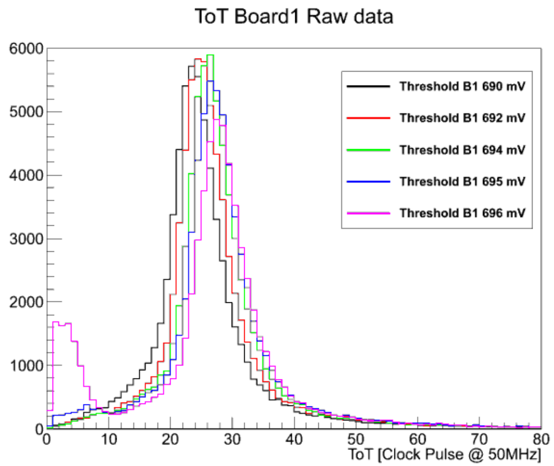


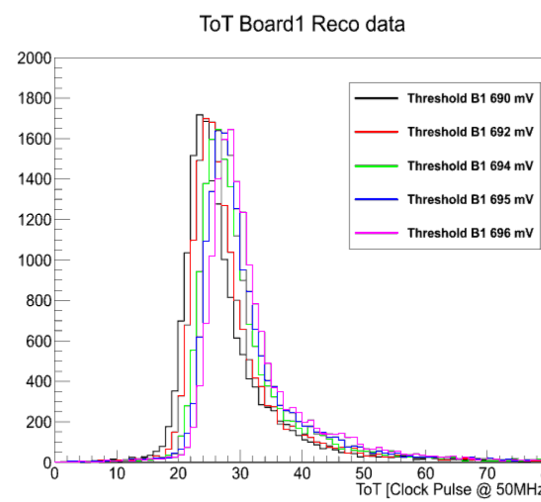
BOARD0		BOARD1		BOARD2		BOARD3	
Row	fTimeStam	Row	fTimeStam	Row	fTimeStam	Row	fTimeStam
210	537020249	150	558724657	190	546305718	155	558729325
211	546462082	151	558730152	191	546305718	156	558730152
212	558710073	152	558733717	192	546305718	157	558732955
213	558724656	153	558739485	193	558704130	158	558733716
214	558730152	154	558748899	194	558730151	159	558738431
215	558742175	155	558749613	195	558732954	160	558738432
216	558749612	156	558755429	196	558733718	161	558739485
217	558749615	157	558762802	197	558733720	162	558743179
218	558755430	158	558765329	198	558738431	163	558745417
219	558762802	159	558766188	199	558739485	164	558748900
220	558765330	160	558766254	200	558748900	165	558749612
221	558766189	161	558766528	201	558749612	166	558754553
222	558766253	162	558766529	202	558753162	167	558755429
223	558766674	163	558768586	203	558754310	168	558762802
224	558770175	164	558770174	204	558755429	169	558765330
225	558770402	165	558770174	205	558762802	170	558766188
226	558770904	166	558770402	206	558765330	171	558766254
227	558775489	167	558770903	207	558766188	172	558766419
228	558781647	168	558775489	208	558766253	173	558768586
229	558781648	169	558781647	209	558766528	174	558769056
230	558786946	170	558781649	210	558766531	175	558770174
231	559024129	171	558786945	211	558768586	176	558770904
232	559028535	172	559024127	212	558770174	177	558775489
233	559031646	173	559028535	213	558770904	178	558781015
234	559032975	174	559028891	214	558770904	179	558781225



Reconstructed event number vs the time window in clock unit (clock @ 50 MHz)



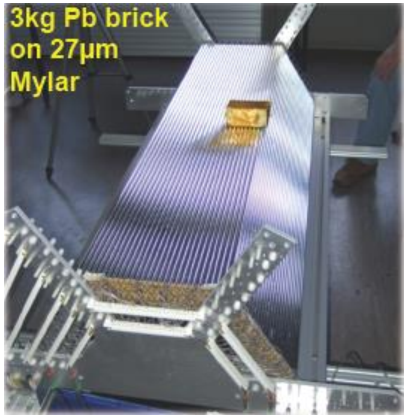




Tracking System

Straw Tube Central Tracker

- 4636 straws
- Skew angle 2.9°
- 30 μm Al-mylar tube, 1 cm diameter, l= 1.4m
- Rin= 16 cm, Rout= 42 cm
- Self supporting straw, at 1 bar overpressure (Ar/CO2)
- Light detector : X/Xo= 4.4 x 10^{-4} /tube
- Spatial resolution: 150 μm
- High rate capability (drift time of 200 ns)
- $\sigma_{\rho\phi}$ 100-150 μm, σ_z 2-3 mm (single hit)



See contribution: The Central Straw Tube Tracker in the PANDA Experiment, Peter Wintz

GEM

- 3 stations with circular + radial strips
  - 10-150 pF strips capacitance
  - Up to 10 KHz/strip
  - Resolution: 150 μm
  - Pitch: 400 μm, L: 80 cm
  - Time resolution : 5ns
  - Low power consumption < 10mW/channel

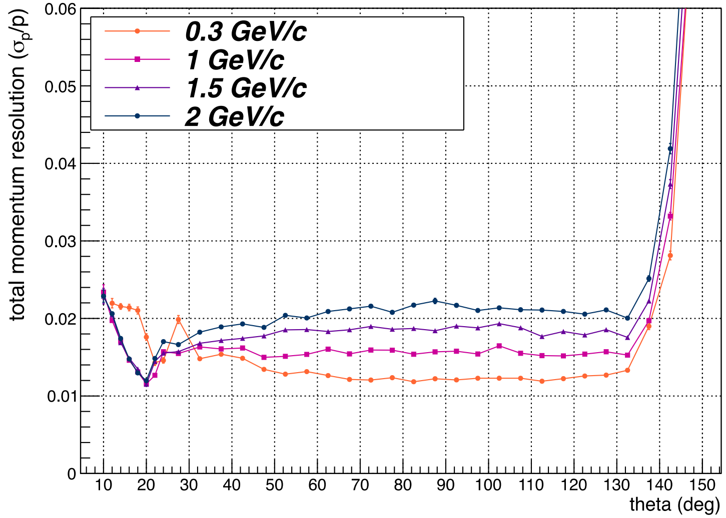
Forward Tracker

- 6 tracking stations with vertical and ±5° tilted straw double layers each
- Angular acceptance: ±5º vertically, ±10º horizontally
- Momentum acceptance down to ~2% of p_{beam}
- Momentum resolution: ~0.5%

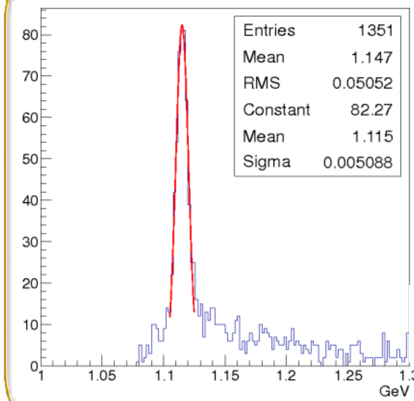
See contribution: Study of resolution of the PANDA GEM detector with Garfield, Dmytro Melnychuk

Tracking system

STT + MVD + GEM Pattern Recognition



Λ/Λbar Invariant Mass

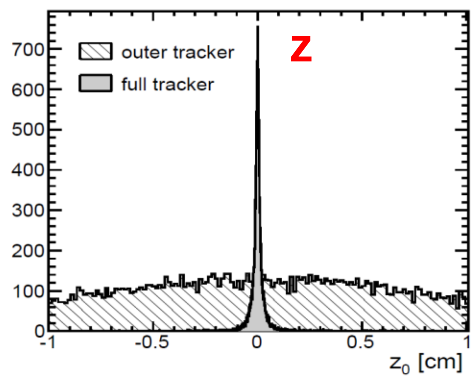


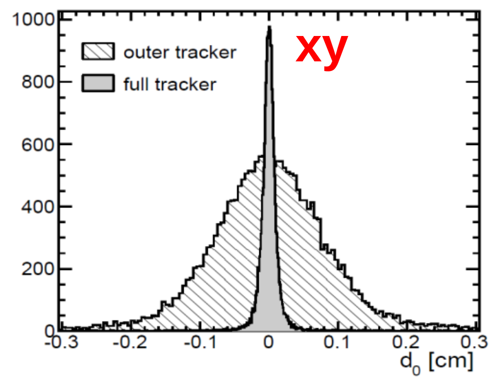
STT capabilities

- The peak is in the correct position
- from a very rough fit the sigma is around 5.1 MeV.

Single track resolution

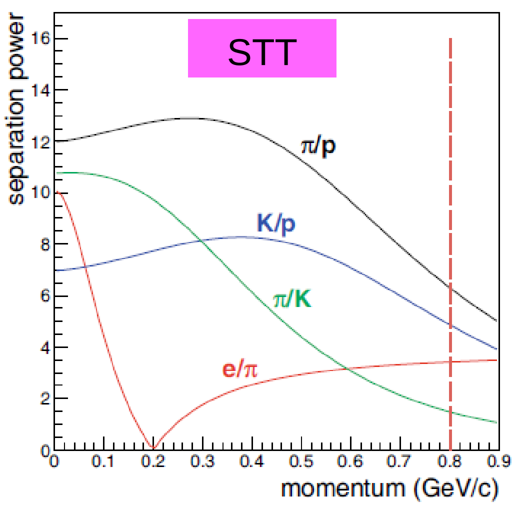
No resolution along z without MVD

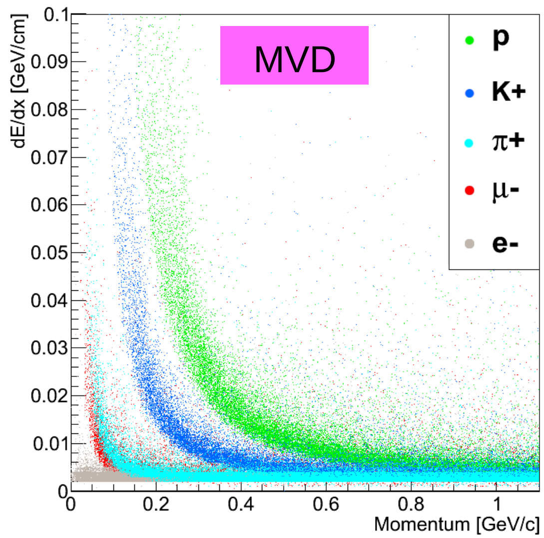


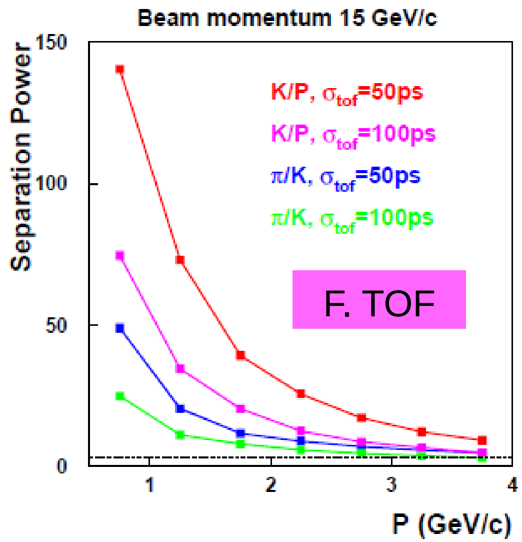


PID in PANDA

- Cherenkov radiation : above ~ 0.8 GeV/c
- Energy loss measurements: below ~ 0.8 GeV/c
- Time of flight
- Muon detectors: primary muons selection from pions and decay muons
- EMC: electromagnetic showers for e and γ

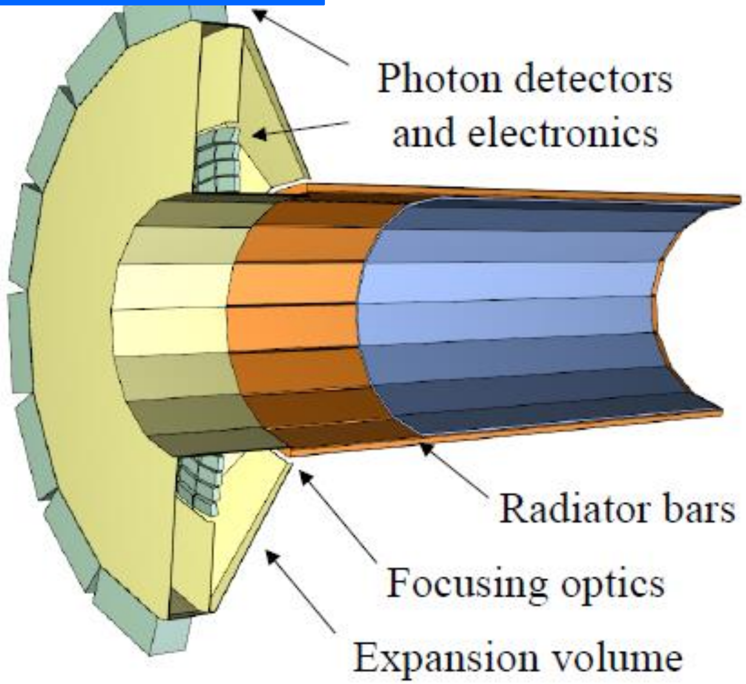






Barrel and Disk DIRCs

Barrel DIRC

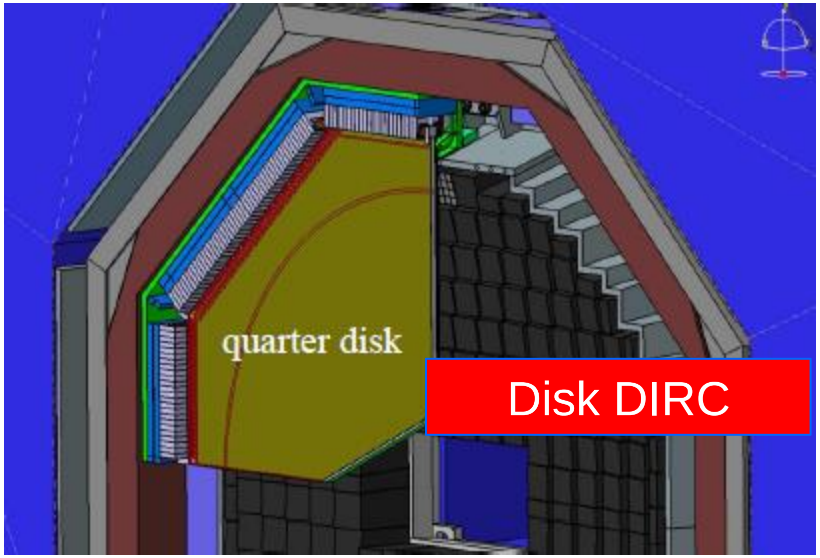


- 22° - 140 ° polar angle
- 80 radiator bars, syntetic fused silica 1.7x3.3x250 cm^3
- Double lens system
- 30 cm oil-filled
- ~ 15 kchannels MCP-PMTs

Single photon Cherenkov angle resolution: 8-9 mrad

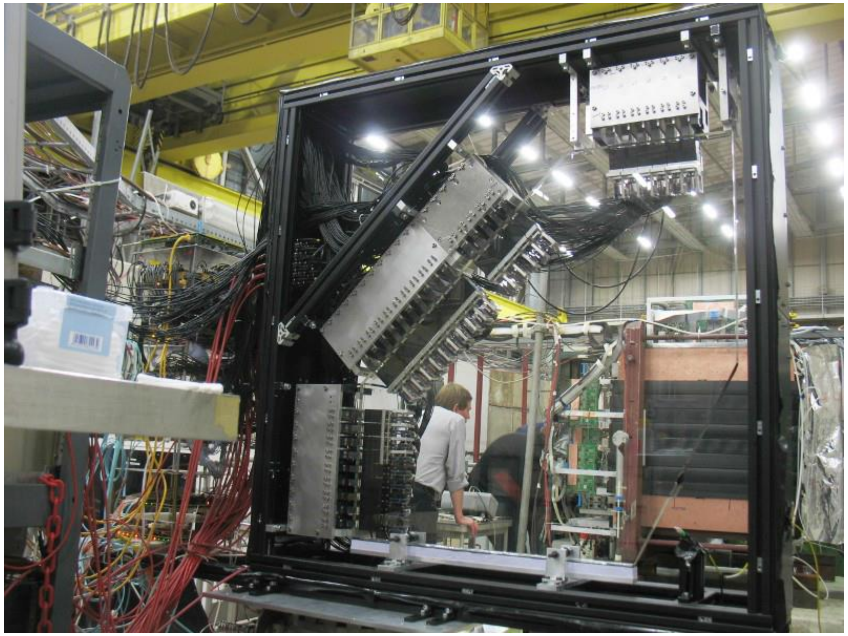
Number of photoelectrons per track > 20

- 5°-22°
- Octagonal disk, 2 m diameter, 2 cm thick
- Four identical pieces with polished and reflecting sides
- Dichroic mirrors on rim
- 432 small focusing guides image photons on digital SiPM or MCP PMTs



Disk DIRC

DISC DIRC – 80% scale prototype



Borofloat glass radiator plate fitting 84x84x2 cm2

Quarter section of final octagonal disc (80% of the final size)

Bottom face mirrored by BC630 optical grease

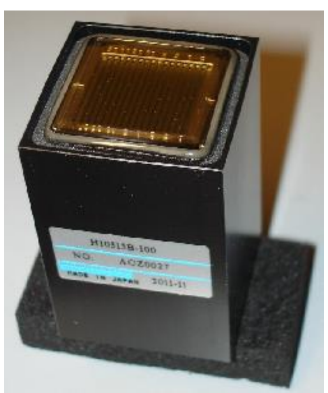
Diagonal face covered by black tape

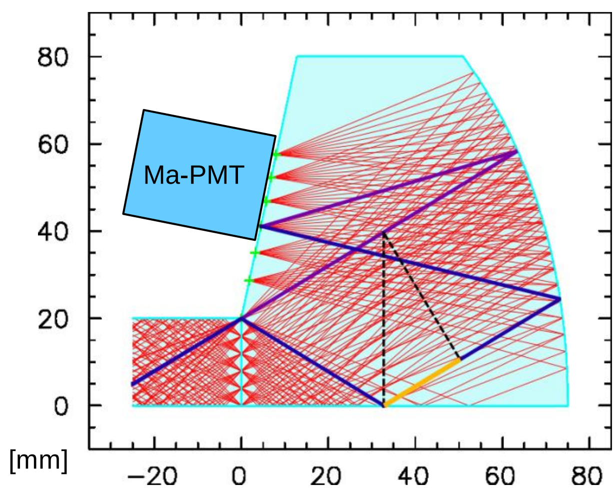
Vertical face unchanged

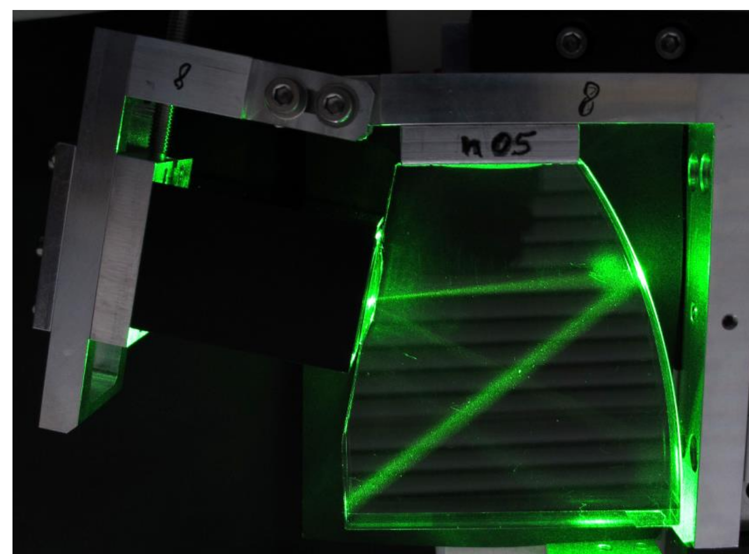
Focussing Light Guide (FLG) is coupled with optical grease to the multianode PMT

30 Hamatsu H10515B100 multi-anode PMTs

16x 1x16 mm ^{2}

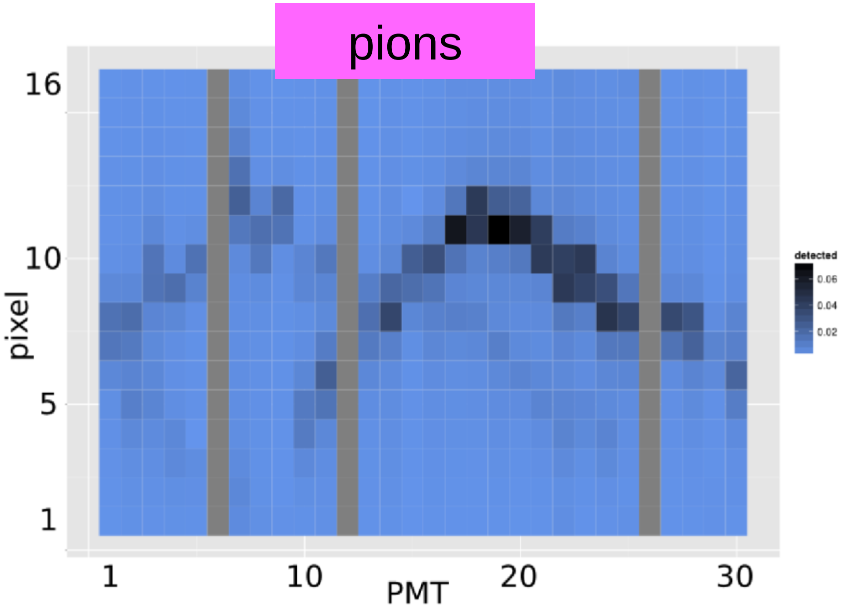


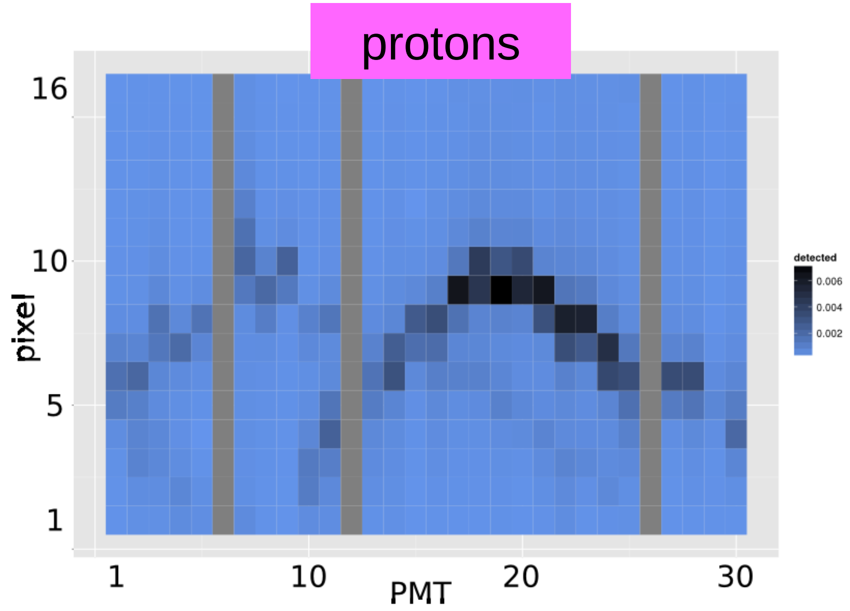


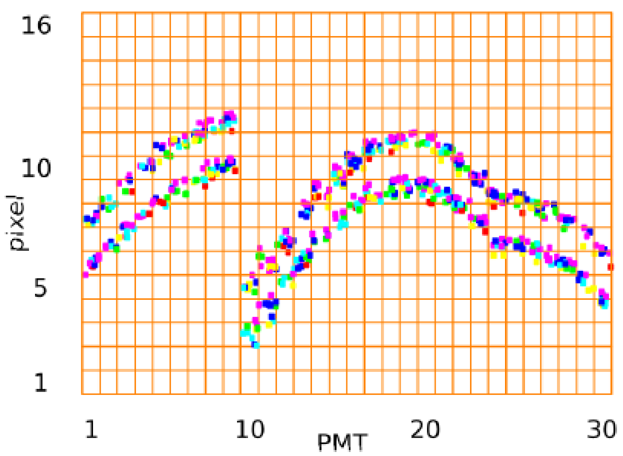


D. Calvo, LEAP 2013, Uppsala, June 13, 2013

Demonstrator results

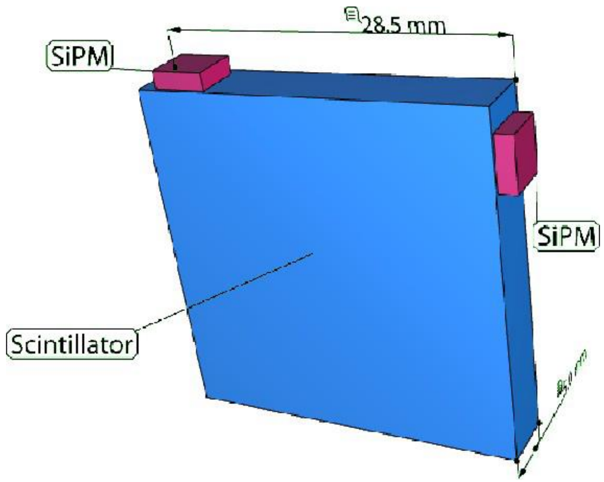


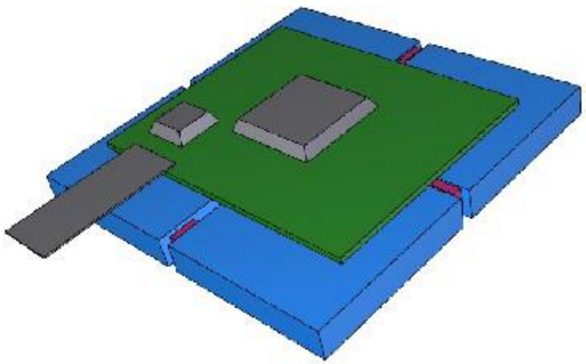




- 3.5 GeV/c beam @ CERN
- Beam incident angle of 3°
- Simulated hit patterns showing the photons on direct path: the pions patterns are above the proton patterns
- Cumulative hit patterns. Intensity is counts per trigger.

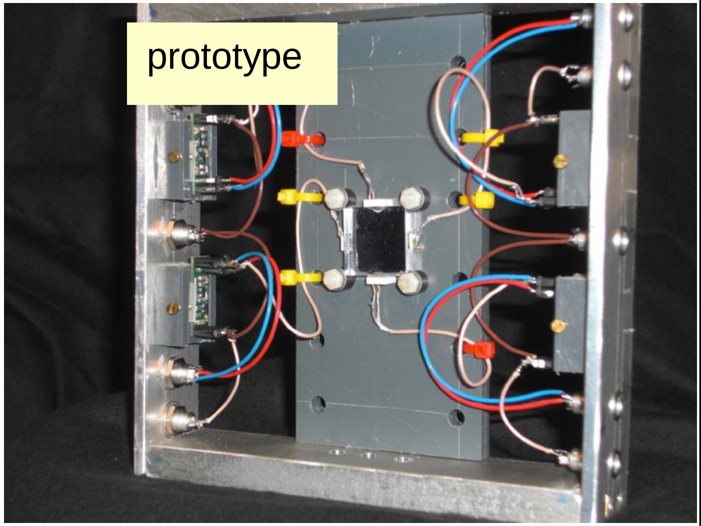
SciTil





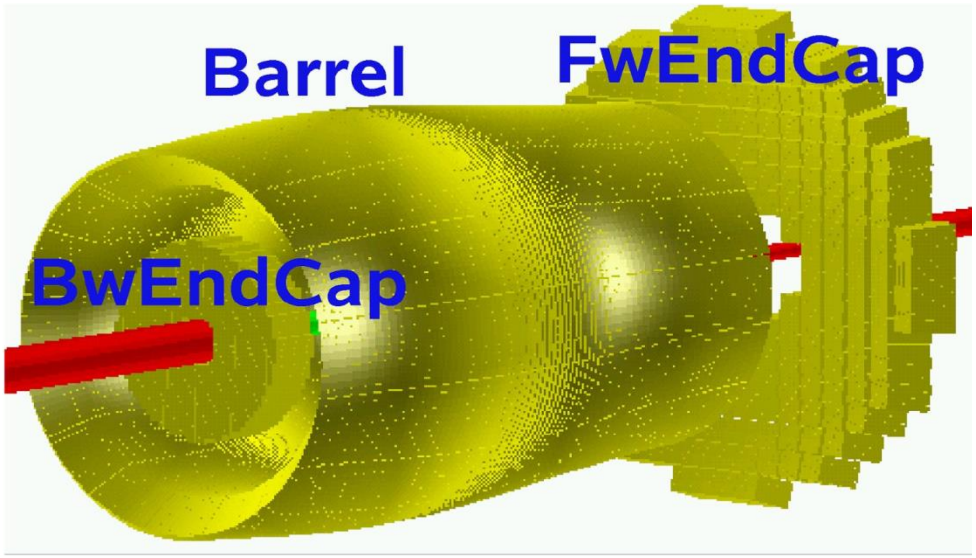
- 5760 scintillation tiles (BC408)
- Expected time resolution σ 100ps
- Detection of γ-conversions in front of EMC
- Readout at two positions : more photons, less light path fluctuations, larger detection efficiency
- 3x3 mm^3 SiPm, high yield at 1 GeV (MIP): 50-100 photons, and 8 ch ASIC, IC data transfer

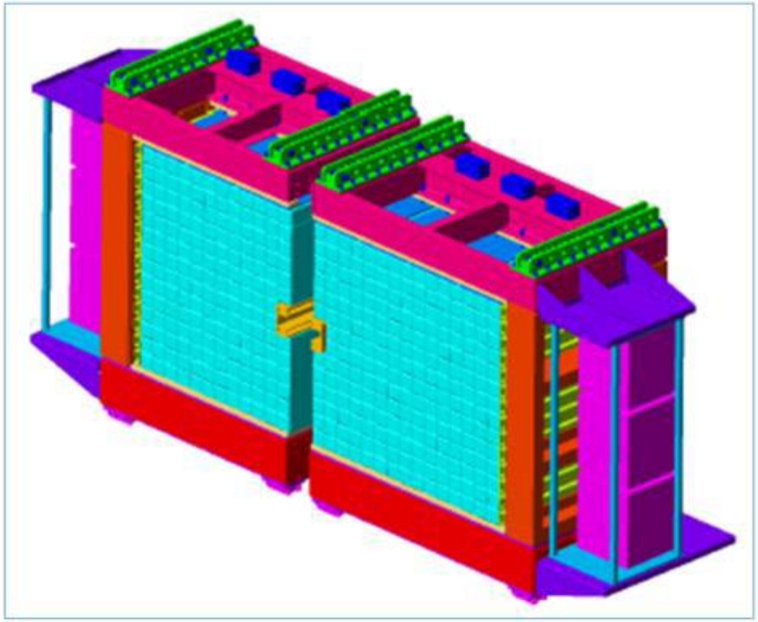
  - BC408, 20 x 20 x 5 mm^3
  - Hamamatsu SiPm, S10931-050P, S10362-33-050C
  - Photonique Fast amplifier 611
  - Readout NINO + Hades TRB



prototype

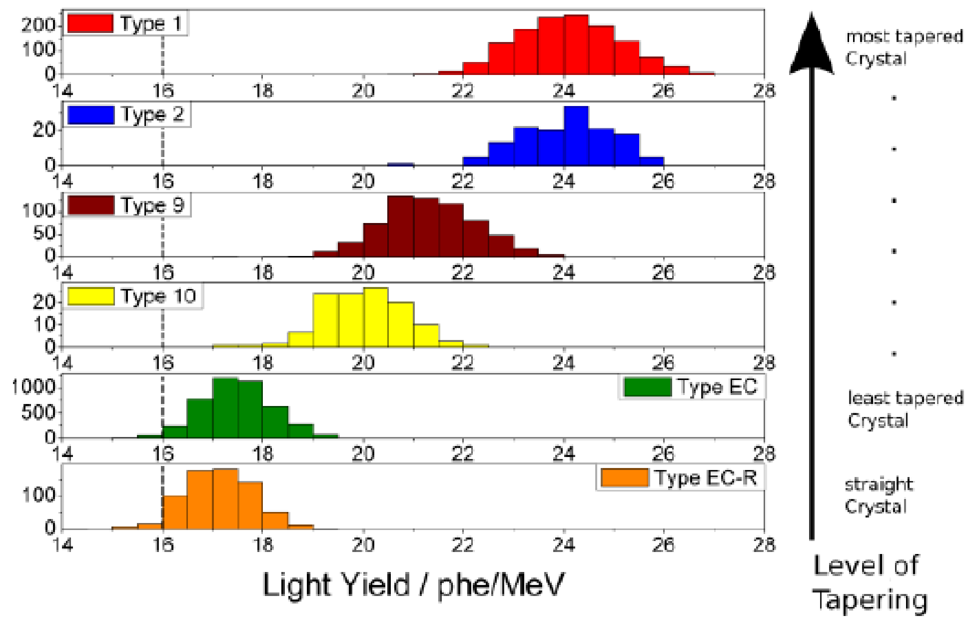
Calorimeters

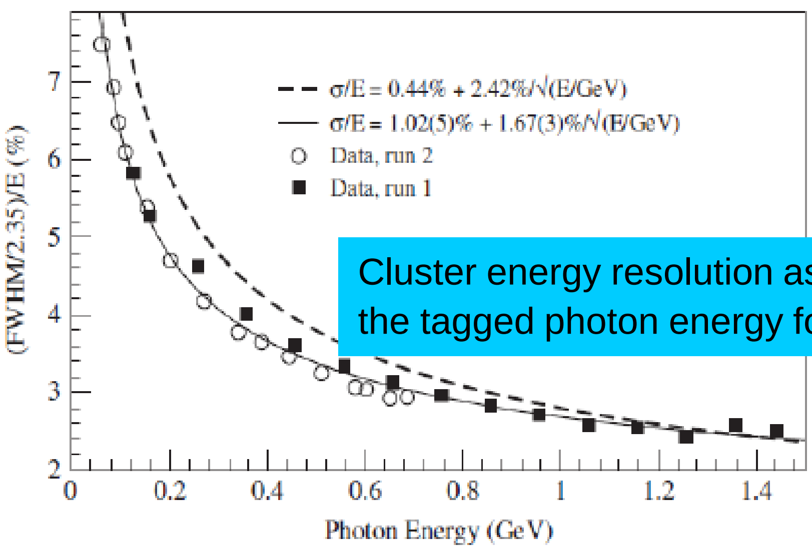




PWO Crystal Calorimeters

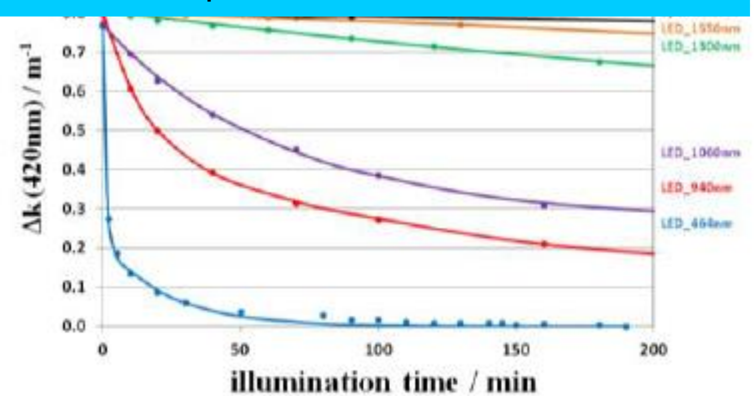
- 15552 tapered PWO-II crystals (light yield: 2xCMS)
- cooled down to -25°C (light yield: 4xT=25°C)
- inner radius of barrel 57 cm
- 200 mm length
- thickness: 22Xo
- energy resolution: 1.54%/ √E[GeV]+0.3%
- Photosensors:
    - Large Area Avalanche Photodiodes (LAAPDs) (barrel), two each cristal
    - Vacuum Photo-Triodes (VPTs) (end-cap)





Cluster energy resolution as a function of the tagged photon energy for a 3x3 matrix

Recovery of a PWO-II crystal after irradiation with 30 Gy at room temperature

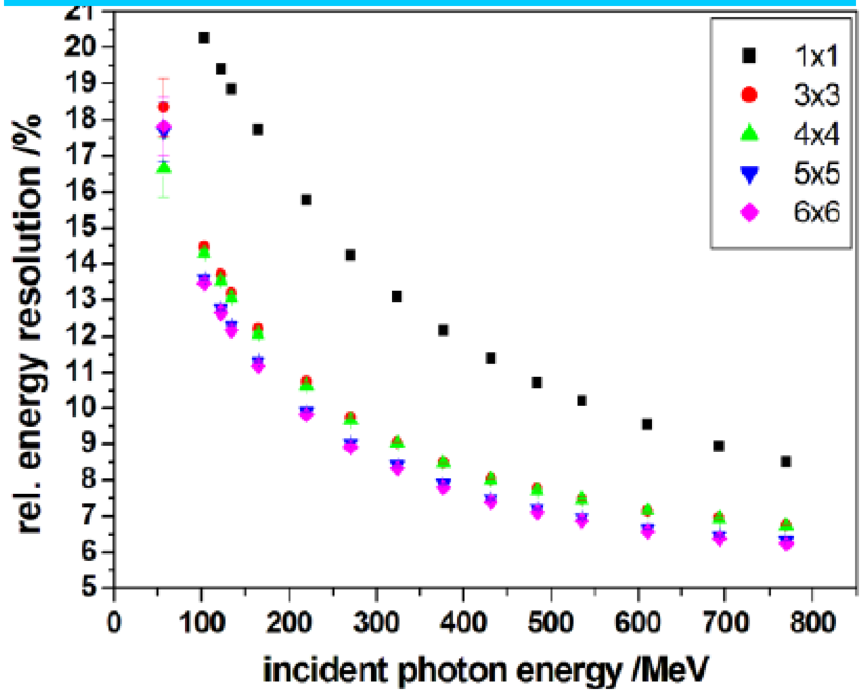


See contribution: The response of PWO scintillators for the PANDA emc at low energy…, Makonyi Karoly

Shashlyk calorimeter

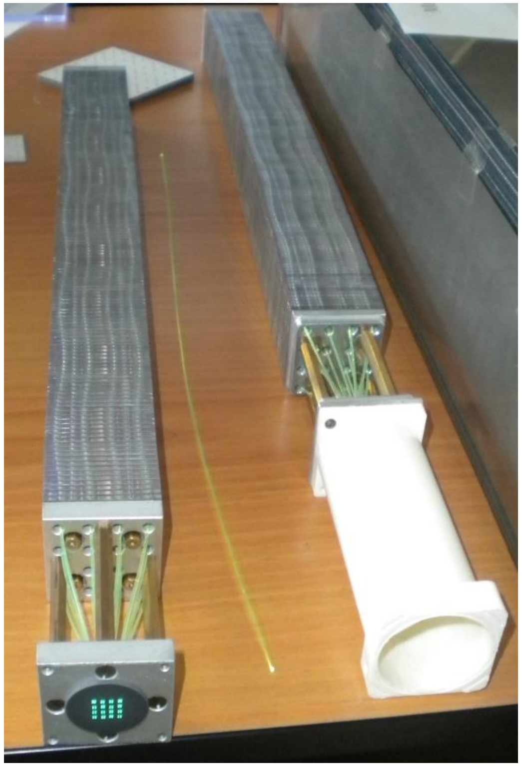
- 7 m from the interaction point
- active area: ~ 4.5 m^2
- supermodule number: 374
- 4 modules in a supermodule
- Energy resolution: $\sigma E/E = 3.5/E + 2.4/\sqrt{E} + 1.3[\%]$, E in GeV

Energy resolution of Shashlyk prototypes (different module clusters)



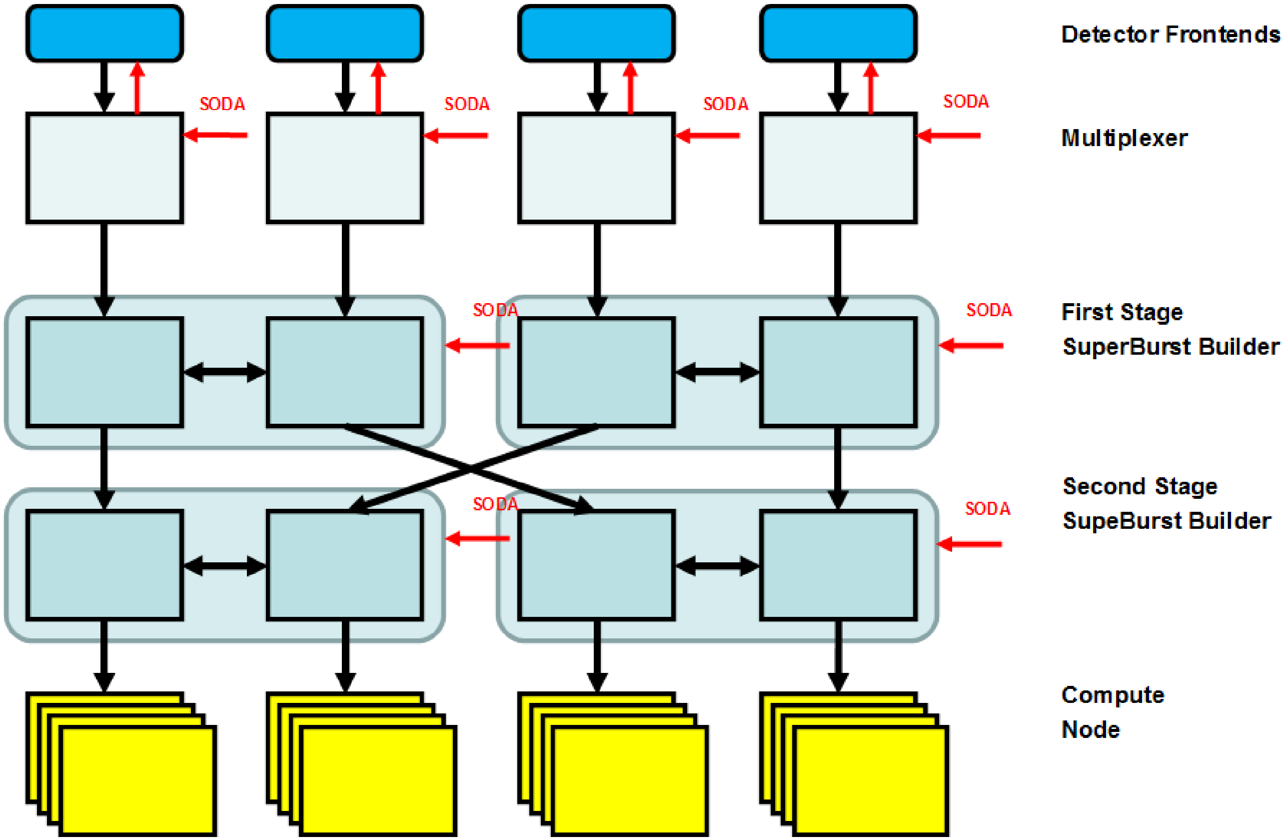
MODULE

- 380 layers of 0.3mm lead and 1.5 mm scintillator
- 55mm x 55mm transverse size
- total lenght: 684mm
- total radiation length: 19.6 Xo
- Moliere radius: 59 mm
- light collection: 18 WLS fibers (BC91, 1 mm diameter)
- photodetector: PMT (XP1912, R7899)



DAQ

- No hardware trigger
- Autonomous recording frontends
- Time stamp syncronization
- Event selection in compute nodes



FEE-Data Concentrator

Feature extraction:

Time, Amplitude, Clusterization, Zero suppression

Burst builder

Combines data:

One burst-one data block

Compute nodes,

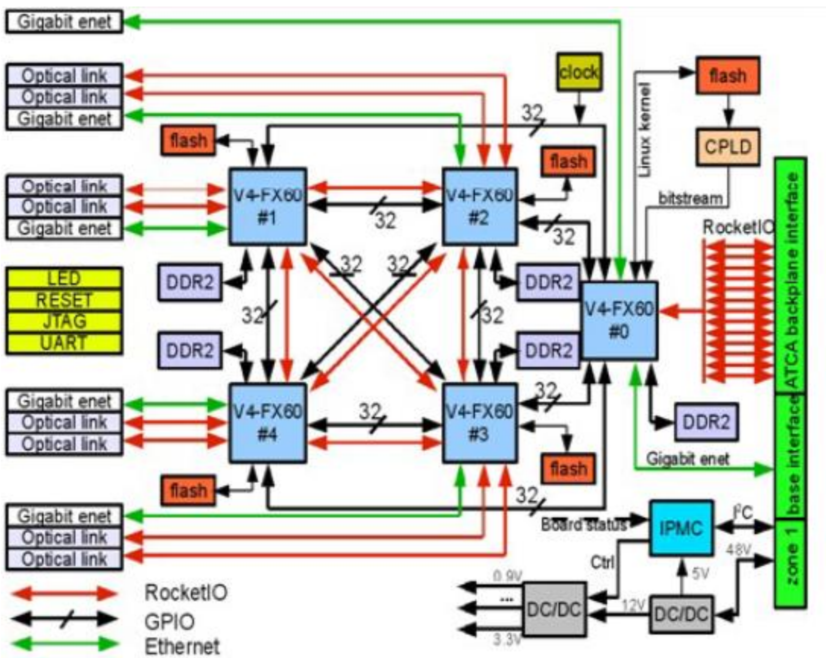
Computer farms

Online data processing

Accept/reject decision

Compute node

- Data rate after fee pre-processing (event size of 4÷10 kB): 80÷200 GB/s
- Universal high performance platform (for multiple applications)
- ATCA standard (Full Mesh topology in backplane) and FPGA-based



5 x Virtex-4 Fx60-10/-11 FPGA

5 x 2 GB 400 MHz DDR2 DRAM

5 x Gigabit Ethernet port

8 x 2-6.25 Gbps Optical Links for data input

13 x 2-3.125 Gbps to backplane for interconnection

Conclusions

PANDA is a multipurpose apparatus for extending our knowledge of physics using antiproton beams with momentum in the 1.5 ÷ 15 GeV/c range

- Large acceptance
- Tracking and vertexing capabilities
- Particle identification and calorimetry
- Modular detectors
- Triggerless readout

Novel techniques in detector and readout design developments

Conclusions

Physics Book, arXiv: 0907.0169

Technical Design Reports written and ongoing

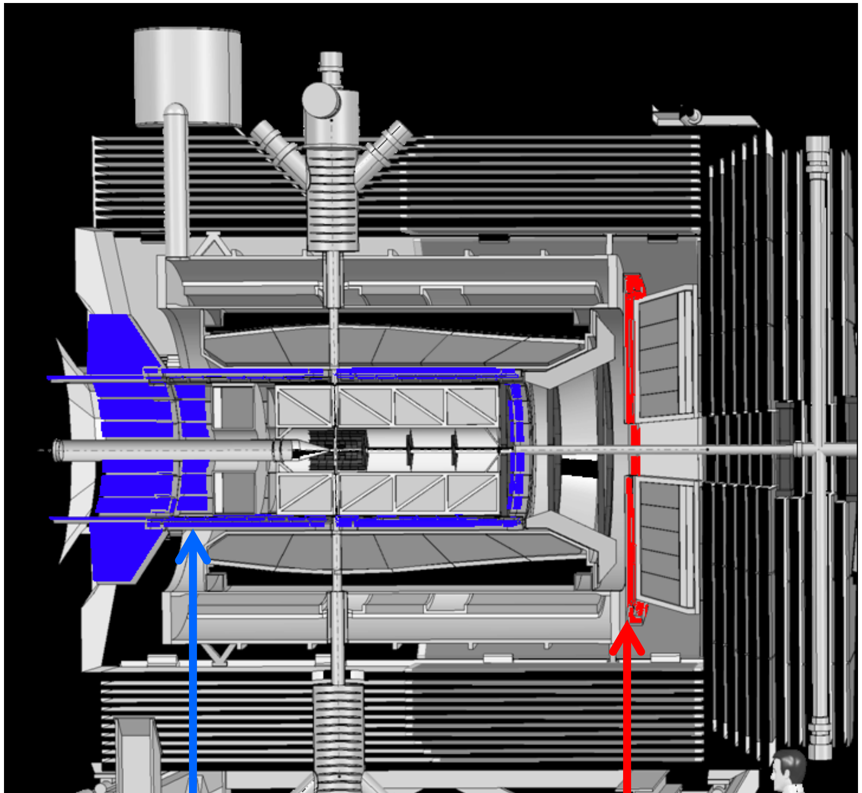
- EMC Technical Design Report, arXiv: 0810.1216v1
- Magnets Technical Design Report, arXiv: 0907.0169
- Micro Vertex Detector Report, arXiv: 1207.6581v2
- Straw Tube Tracker Technical Design Report: 1205.5441v2
- Muon Range System TDR submitted to FAIR
- Target Technical Design Report submitted to FAIR

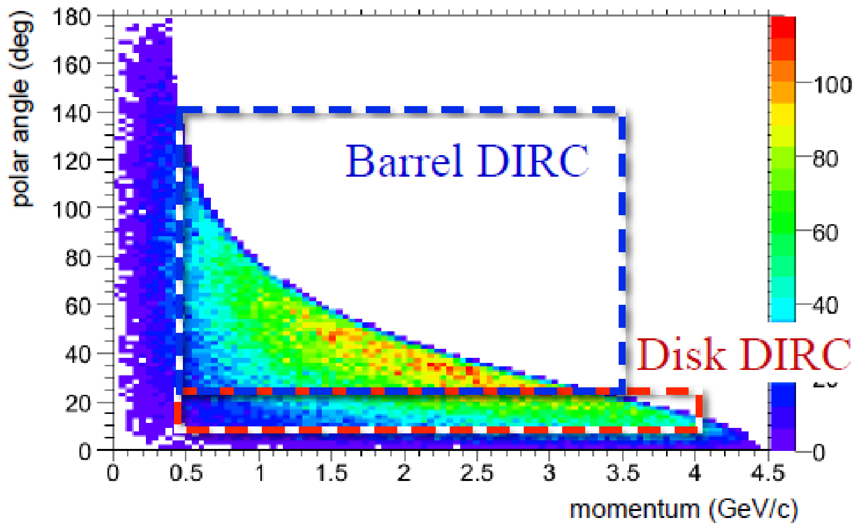
Data taking scheduled in 2018

More than 400 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN 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
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk
IPN Orsay
U & INFN Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

DIRC (Detection of Internally Reflected Cherenkov Light)





Kaon distribution of the radiative decay

$J/\psi \rightarrow K^+K^-\gamma$

(search of glue balls)

Barrel DIRC

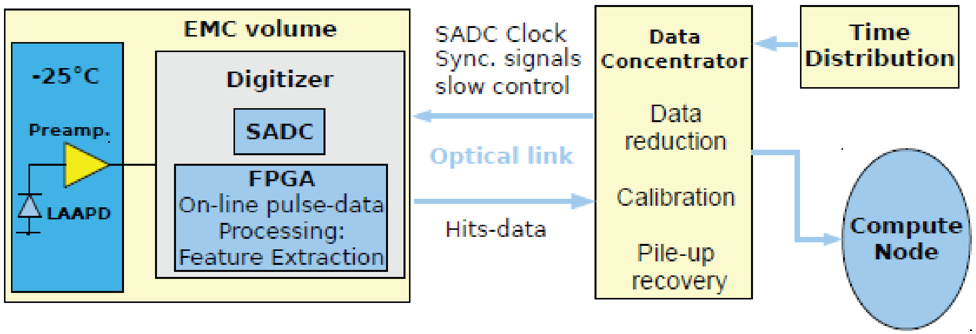
(22°-140°)

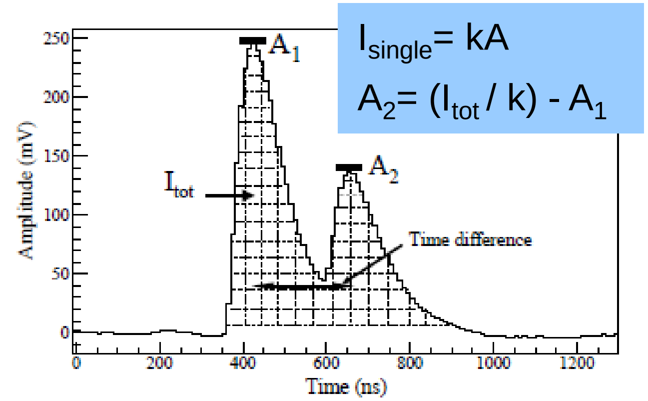
Endcap Disk DIRC

(5°-22°)

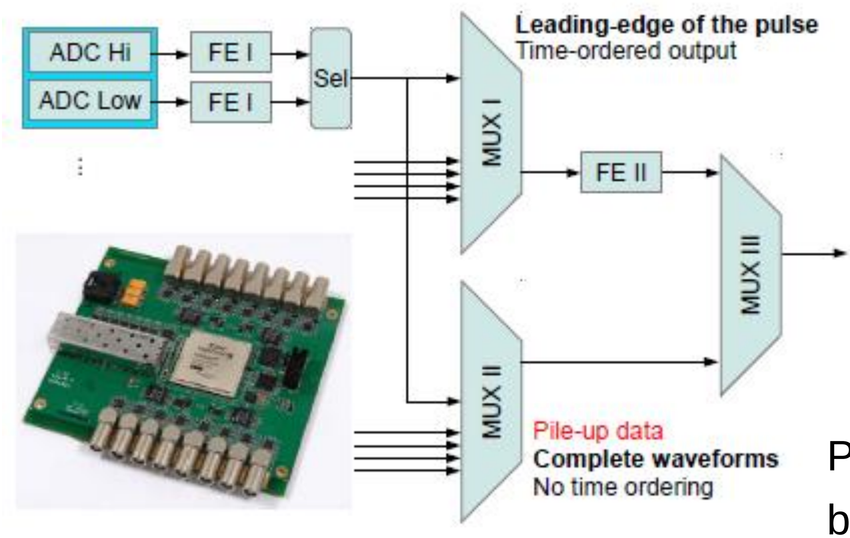
D. Calvo, LEAP 2013, Uppsala, June 13, 2013

Triggerless readout with pulse pile-up recovery for EMC

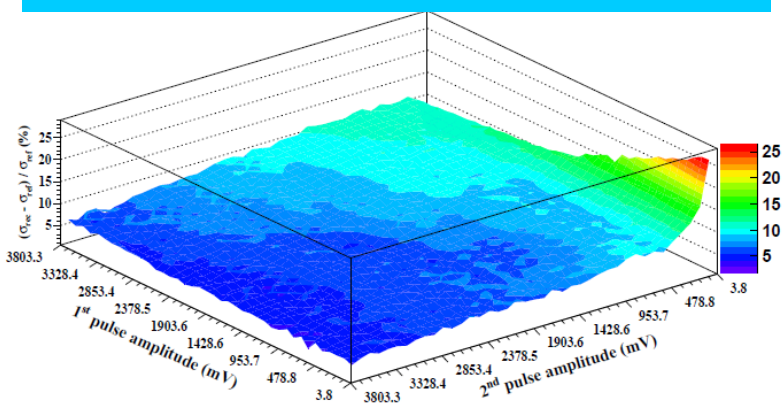




- 16 channel 14 bit 125 MHz SADC
- Implemented feature-extraction firmware



Relative difference between the recovered and reference energy resolution vs the first and second pulse amplitude



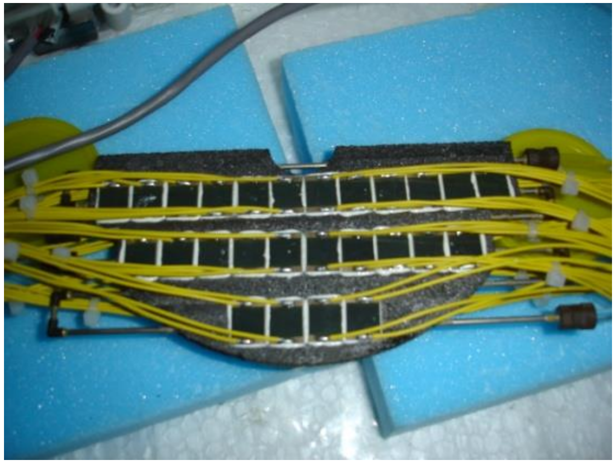
Pile-up reduction from 13 % to 2.4 %

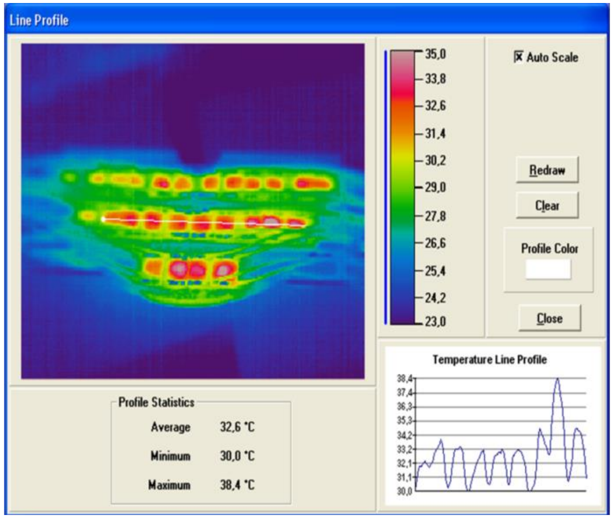
by applying the recovery method at the 500 kHz hit rate

Prototypes

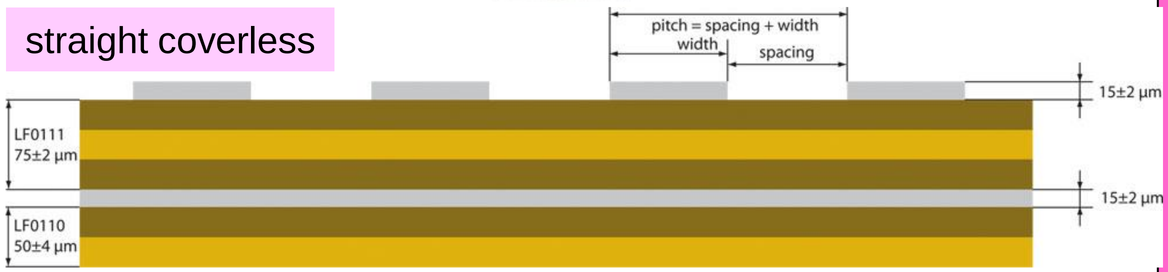
- Total power 94 W
- Cooling pipe diameter 2 mm (MPN35N Ni-Co alloy)
- 4 mm carbon foam
- Cooling flow 0,3 l/m, inlet temperature: 18.5 °C
- HTC thermal conductivity = 50 W/m·K

1 m long aluminum strips prototypes
18 differential pairs





straight coverless



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