PANDA detector R&D study

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On behalf of the PANDA collaboration

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FAIR: Facility for Antiproton and Ion Research

GSI, Darmstadt

German National Lab for Heavy Ion Research

Highlights:

- Heavy ion physics
- Nuclear physics
- Atomic & plasma physics
- Cancer research

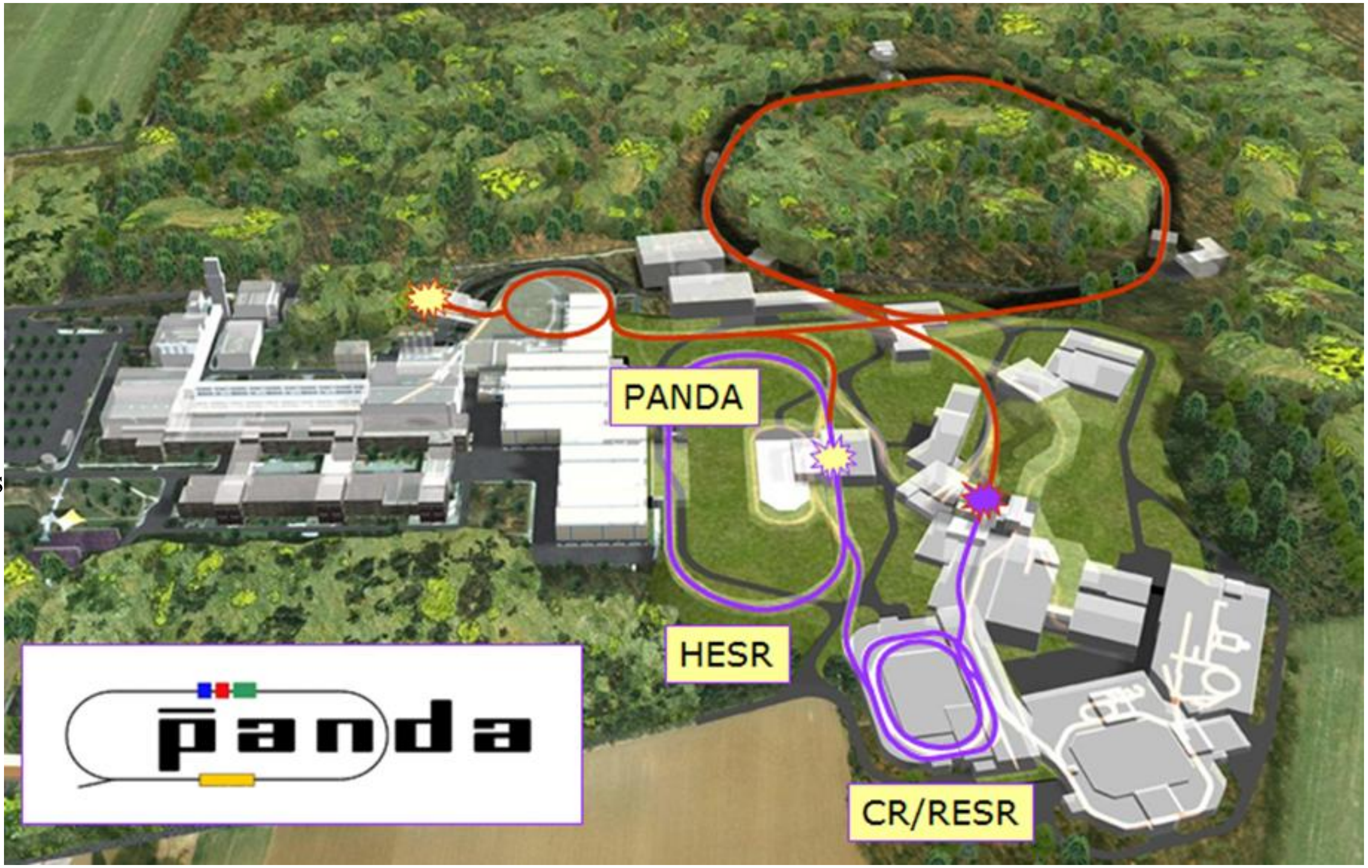
FAIR: New facility

Rare Isotope Beams

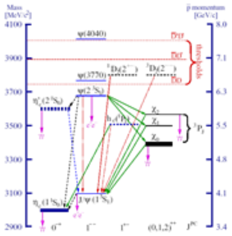
Heavy ions

→ higher intensities & energies

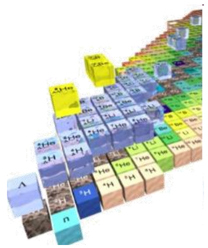
Antiprotons



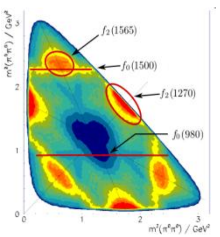
PANDA Physics



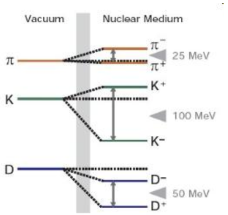
Charmonium Spectroscopy



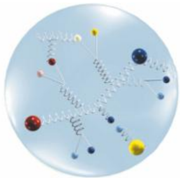
S=2 Hypernuclei



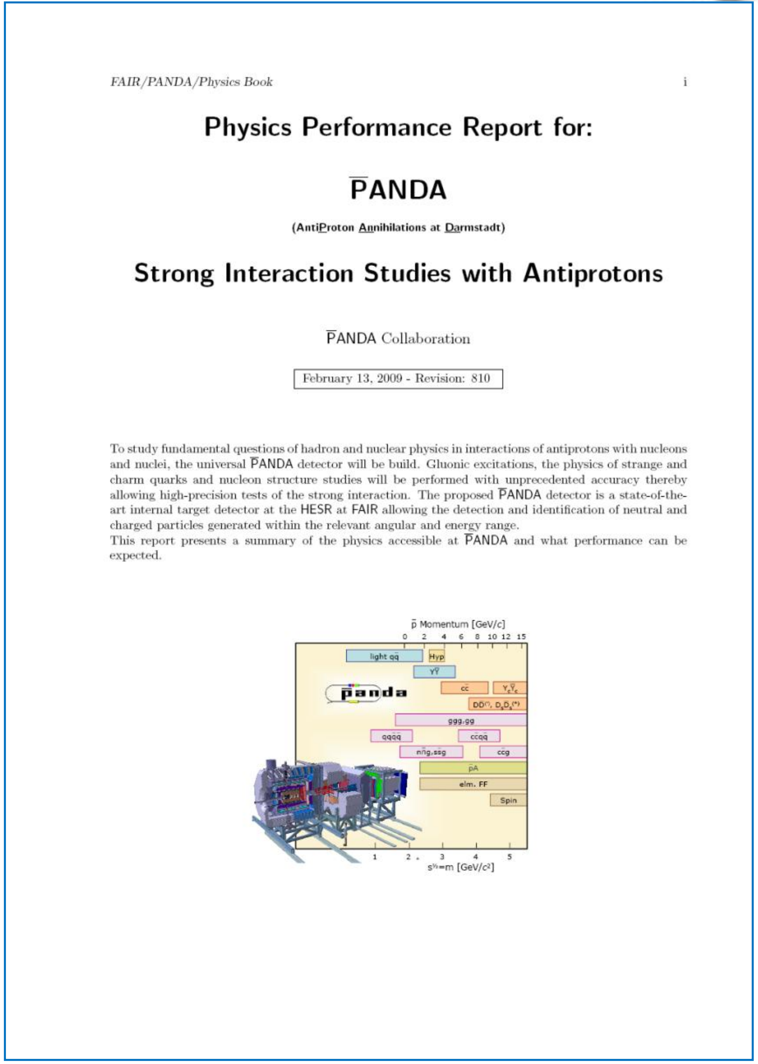
Search for Exotics



Charm in Medium



Nucleon Structure



FAIR/PANDA/Physics Book i

Physics Performance Report for:

$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

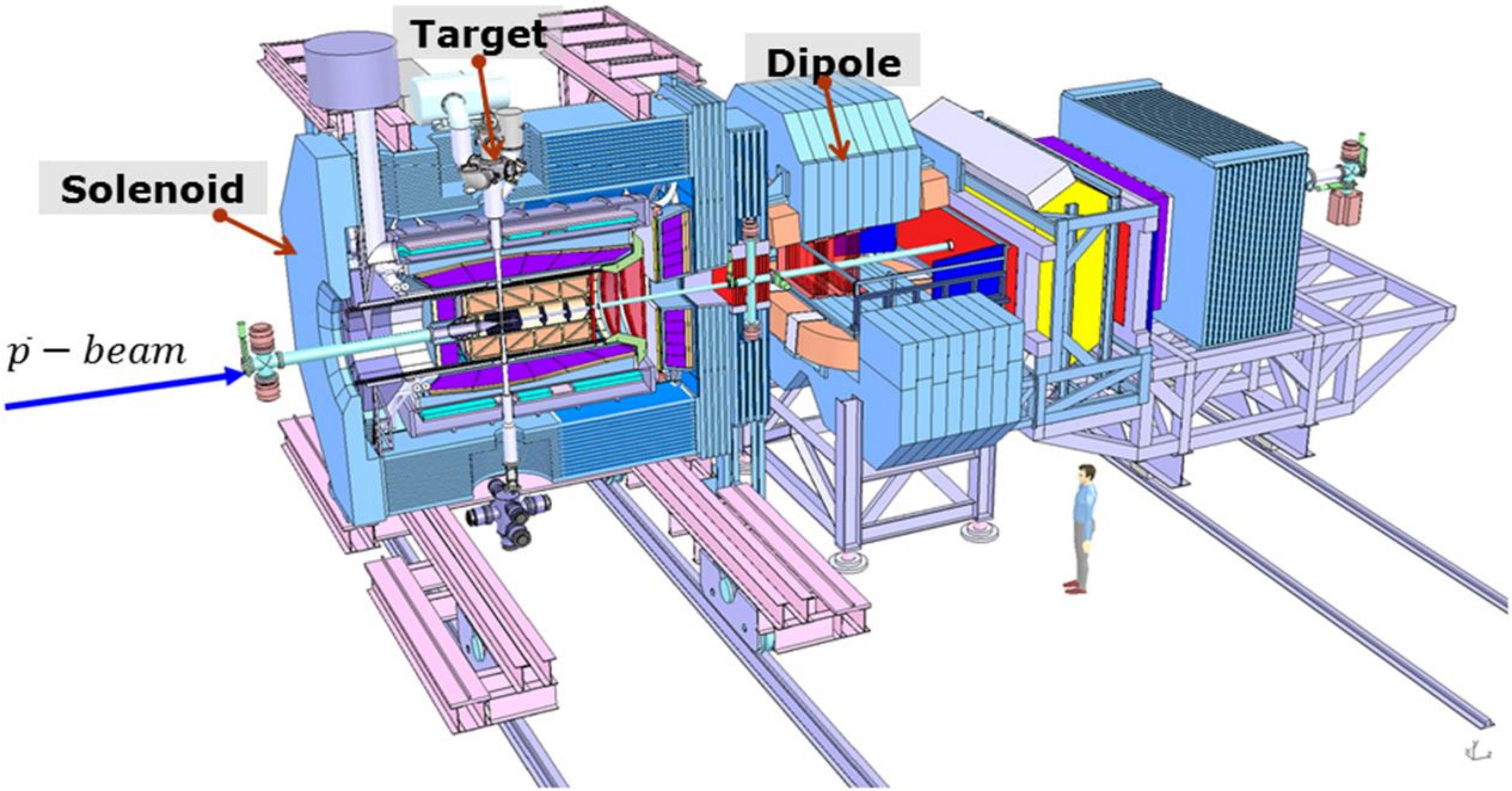
Strong Interaction Studies with Antiprotons

$\overline{\text{P}}$ANDA Collaboration

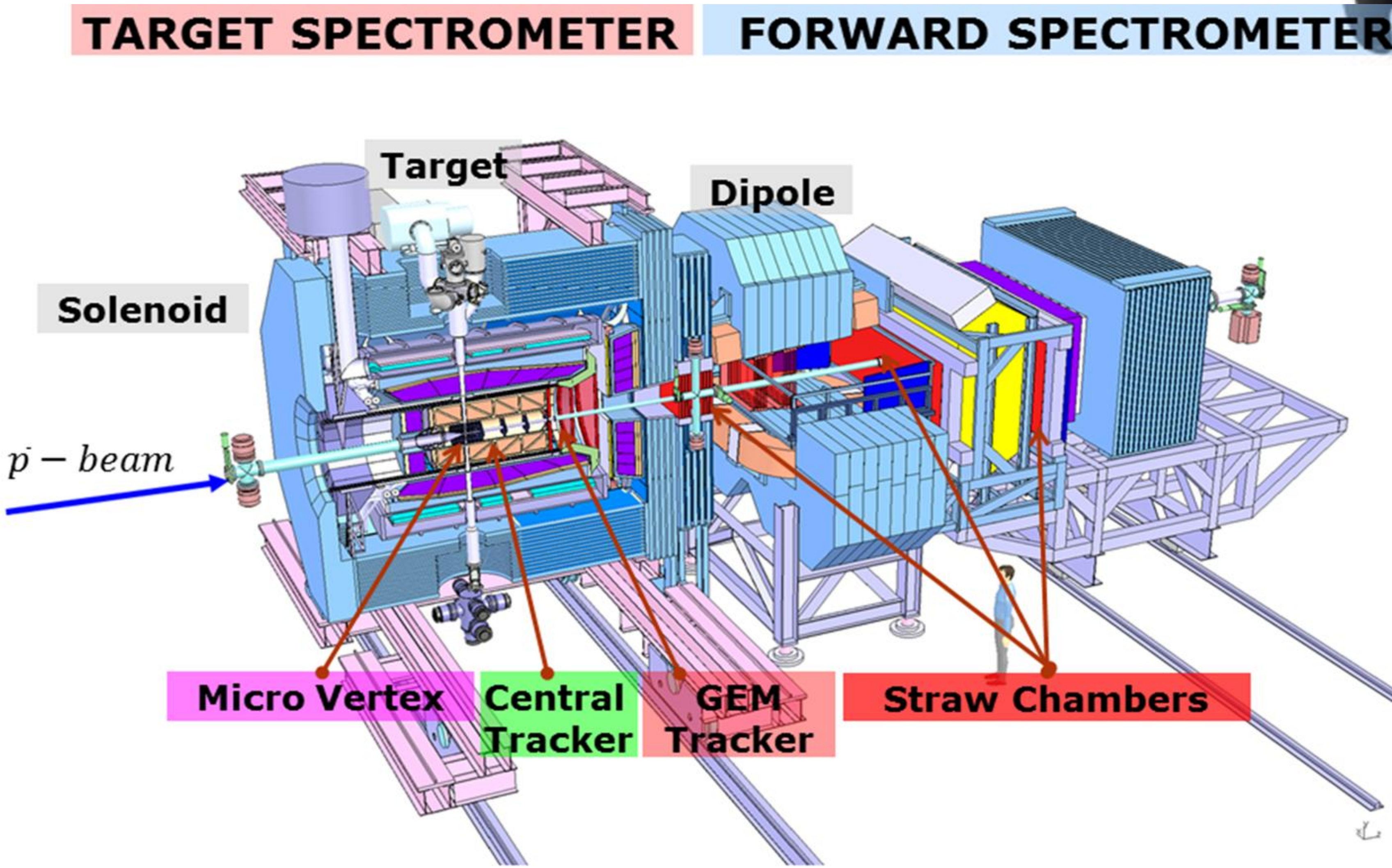
February 13, 2009 - Revision: 810

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\text{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\overline{\text{P}}$ANDA and what performance can be expected.

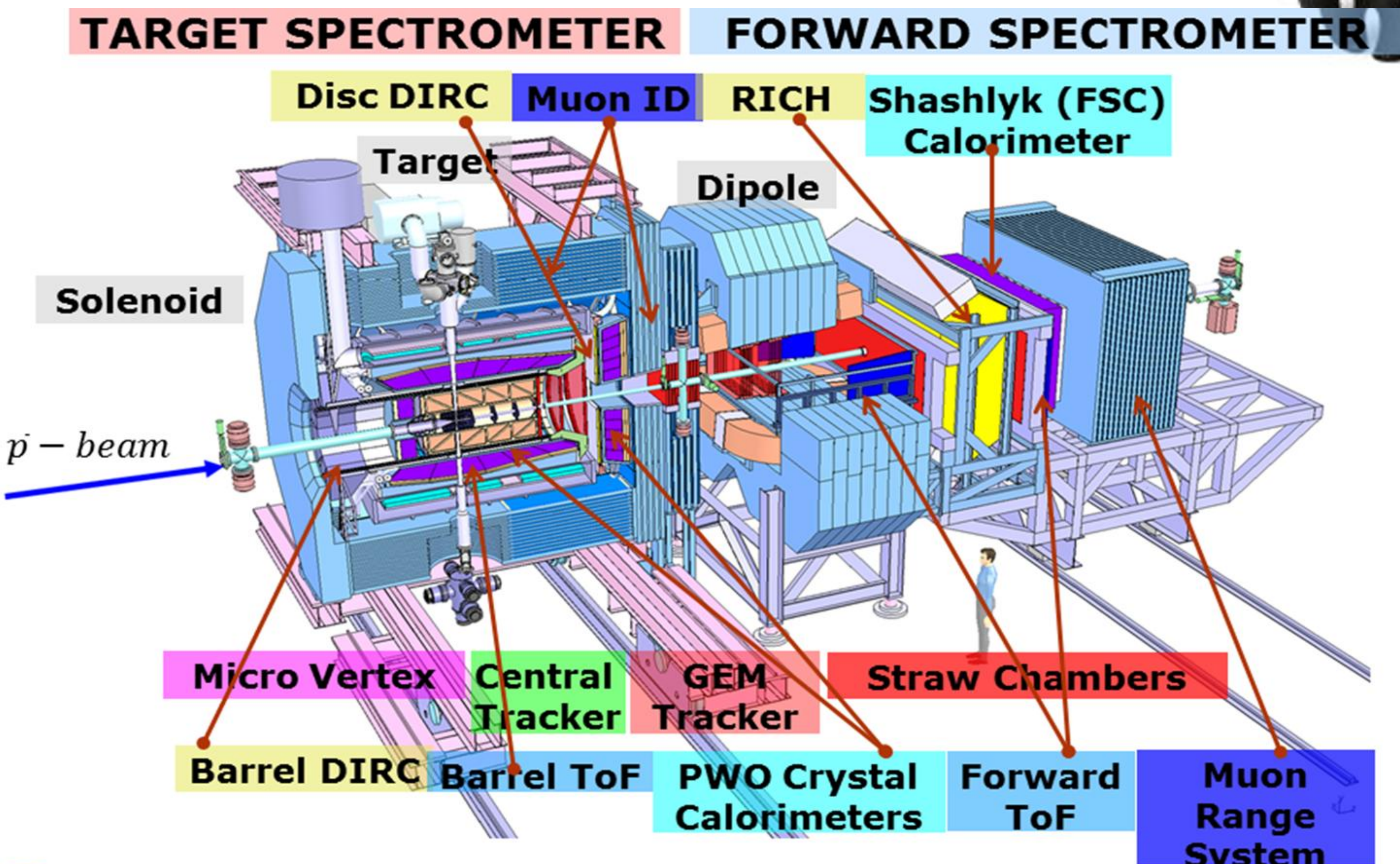
PANDA Detector



PANDA Detector



PANDA Detector



Target Spectrometer EMC

Barrel Calorimeter

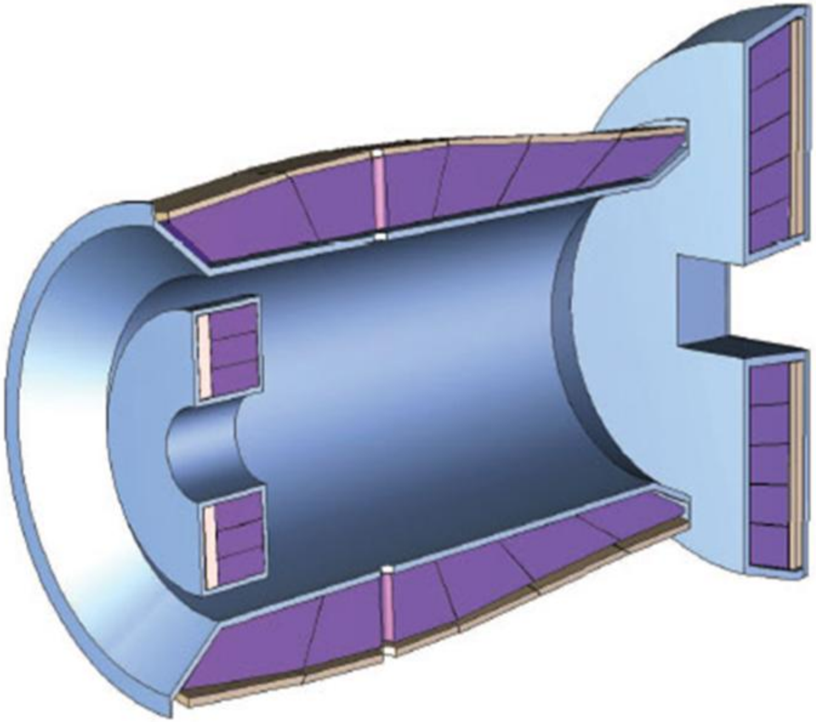
- 11360 PWO Crystals
- LAAPD readout, 2x1cm^2

Forward EndCap

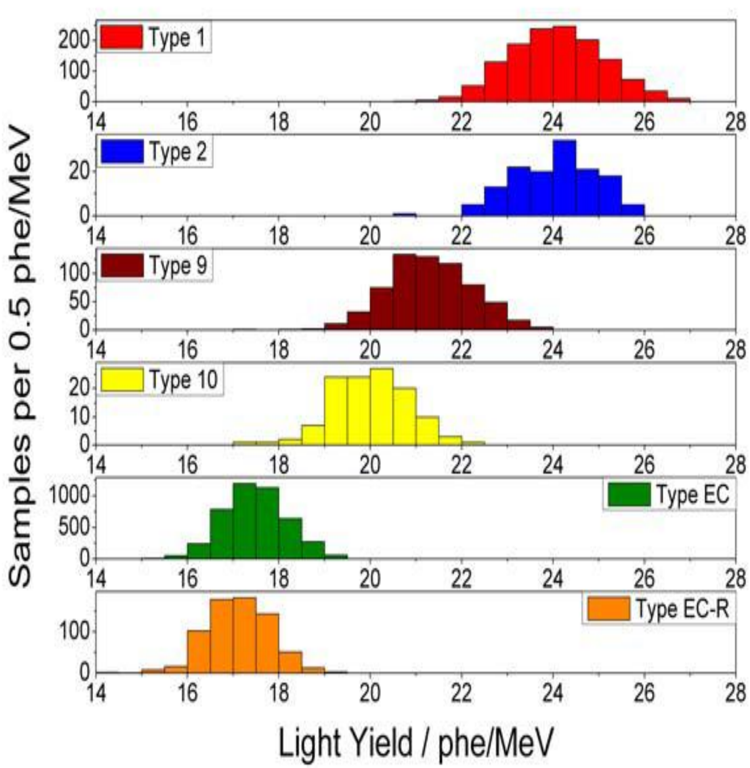
- 4000 PWO crystals
- High occupancy in center
- LA APD or VPT

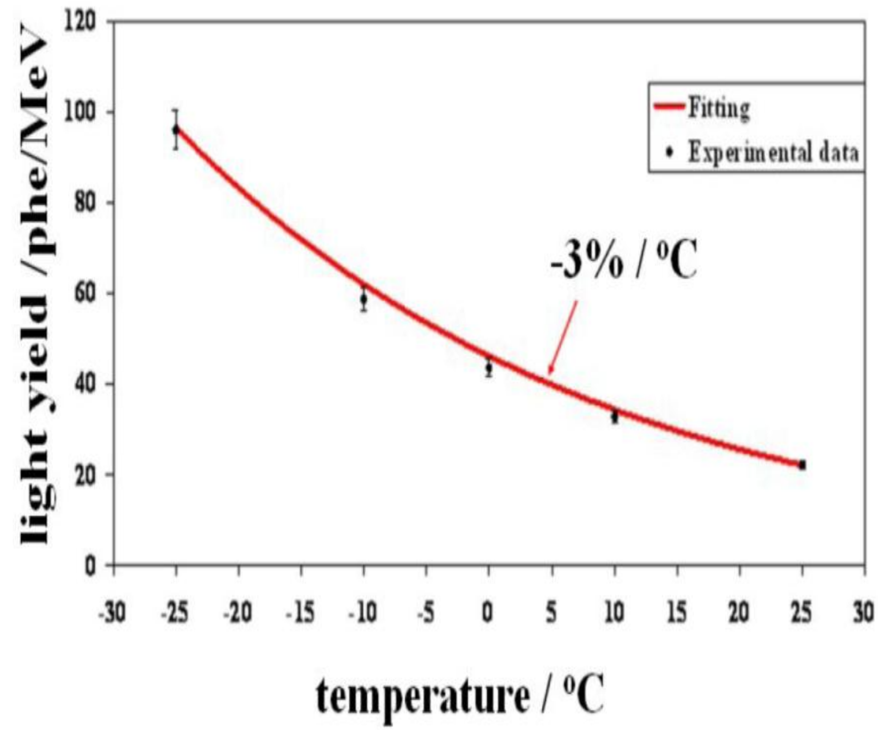
Backward EndCap

for hermeticity, 560 PWO crystals



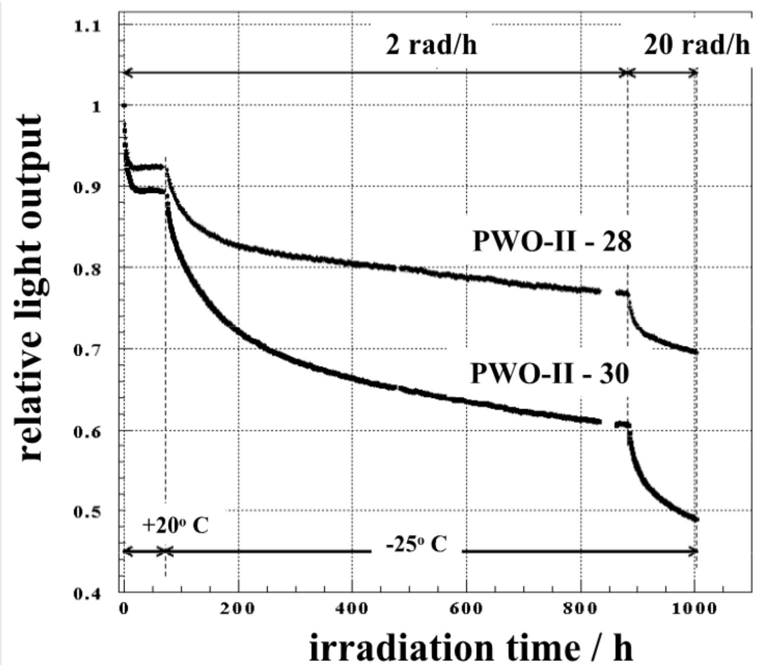
PWO-II light yield

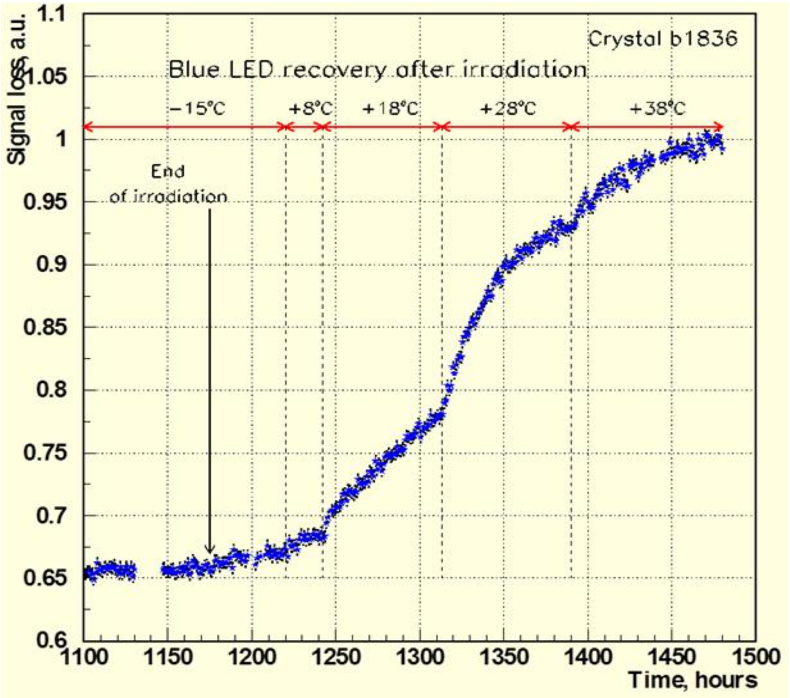




PWO-II has two times more light yield than CERN (CMS type) crystals
Temperature gives additional factor of 4 in light yield (total factor 8).

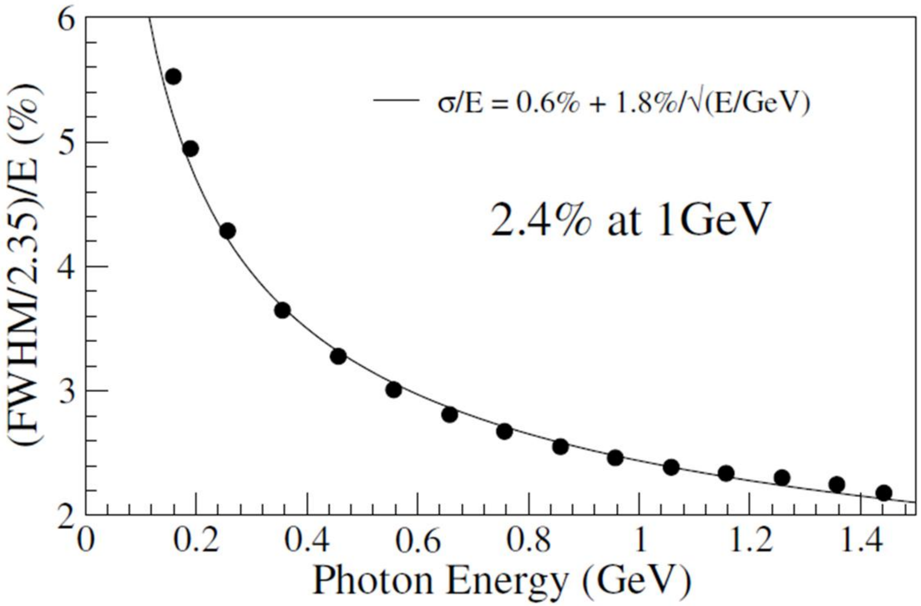
Signal loss after irradiation

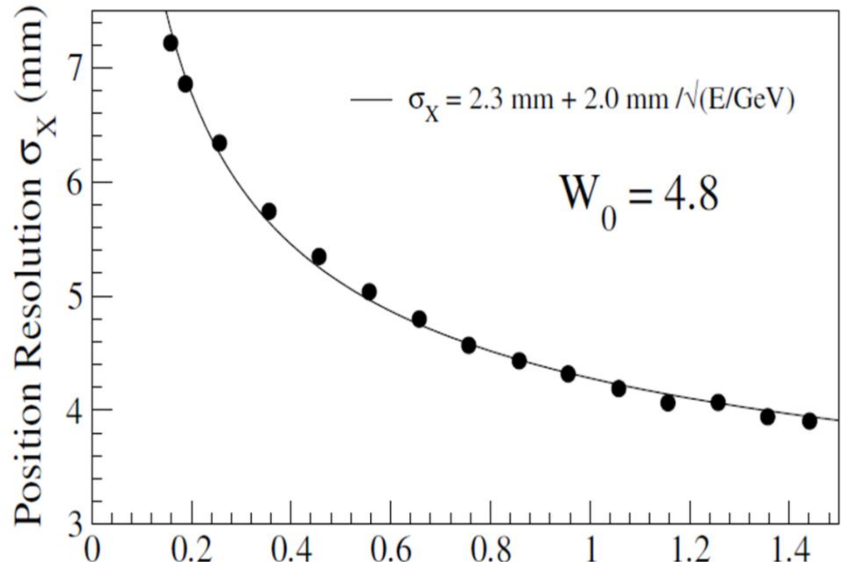




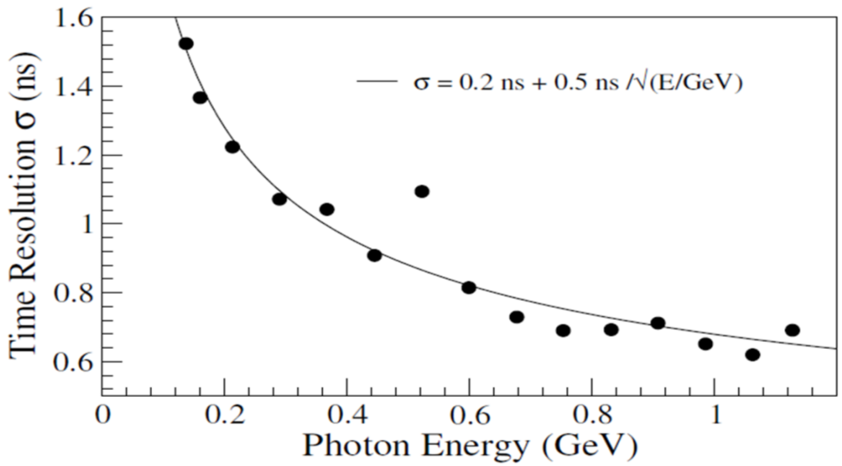
- PWO crystals lose the transparency under irradiation
  - Good monitoring and calibration is required
- BUT – temperature recovery works,
  - Recovery by stimulation with infrared light is under study

Target Spectrometer EMC performance

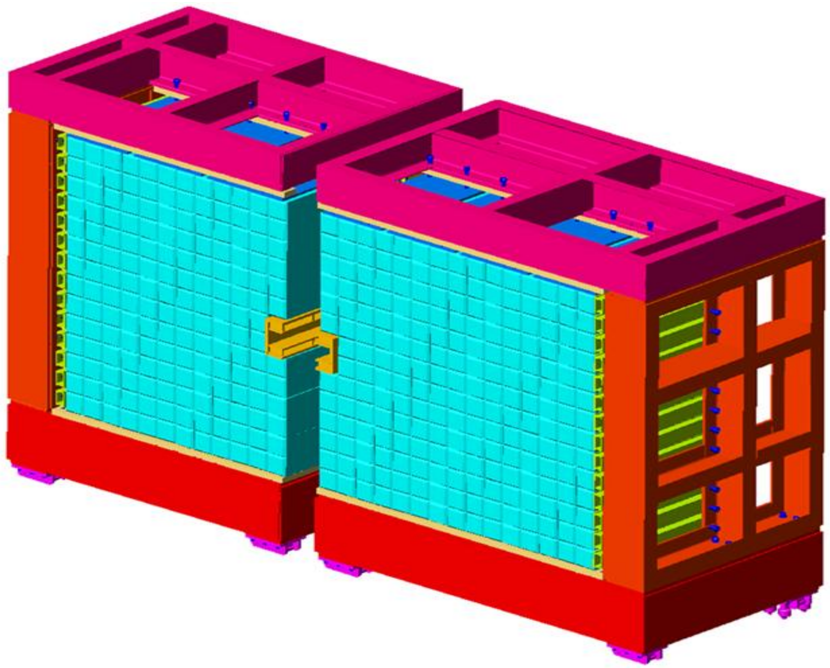




Module threshold is 0.75 *MeV*.



FSC construction



Detector size: ~3,6m x 2,2 m (54x28 cells)

- 380 layers of 0.3-mm lead and 1.5-mm scintillator, total length 680 mm
- Transverse size 55x55 mm^2
- Light collection: 36 fibers BCF-91A (∅1.0 mm)
- PMT as a photodetector
- LED for each module as a light monitoring system
- Optical fiber for each cell for a precise PMT gain monitoring

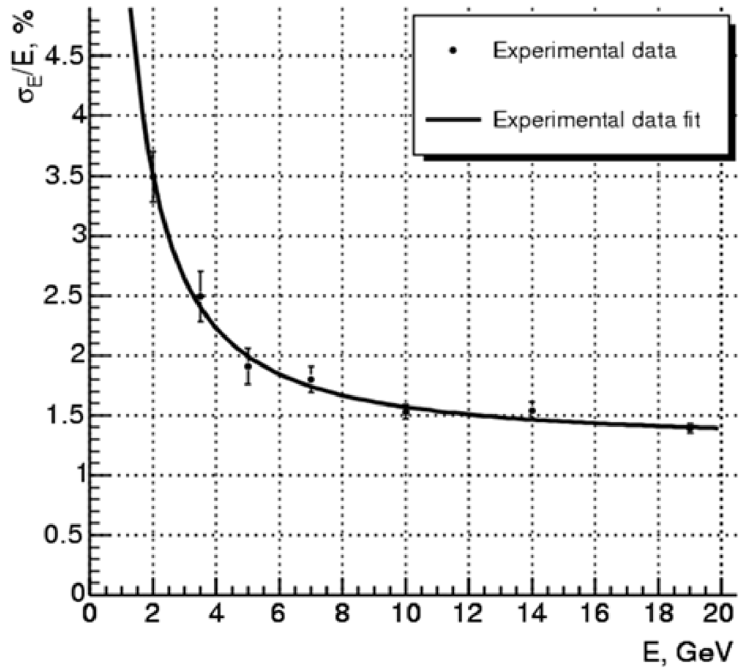
FSC performance

Energy resolution

- stochastic term 2.4%
- constant term 1.3 %

Position resolution at 19 GeV (measured with e- beam)

- 3 mm at cell center
- 1.5 mm at cell edge



Detection energy threshold and performance at low energies to be measured at Mainz this Fall

FSC performance

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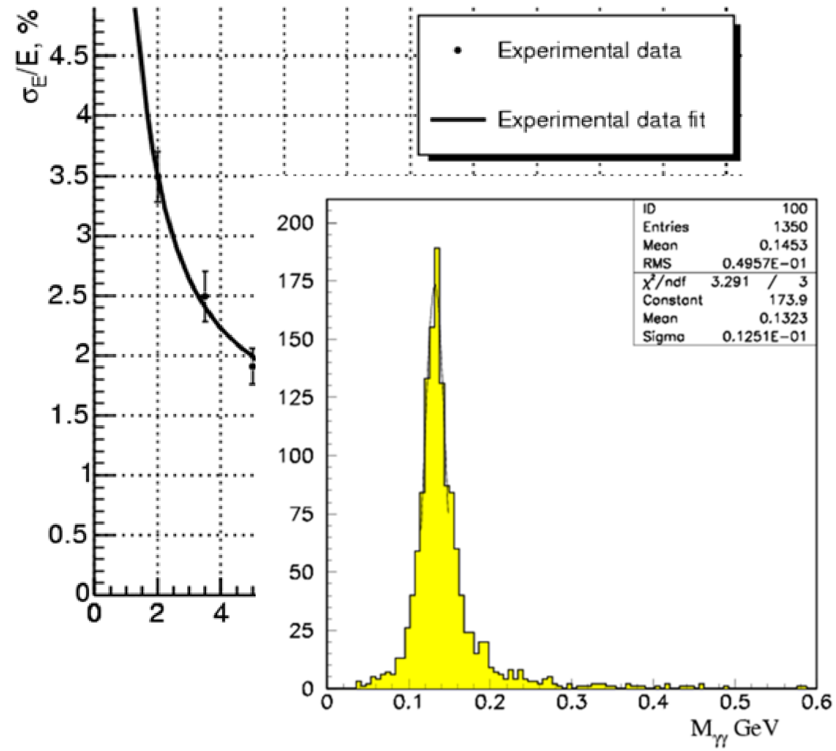
Detection energy threshold and performance at low energies to be measured at Mainz this Fall



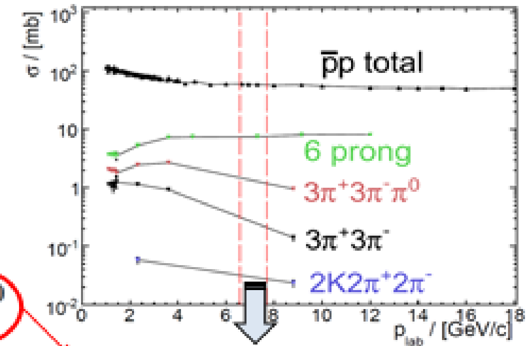
π^0 1-2 GeV, σ_m 12.5 MeV

MVD physics – open charm

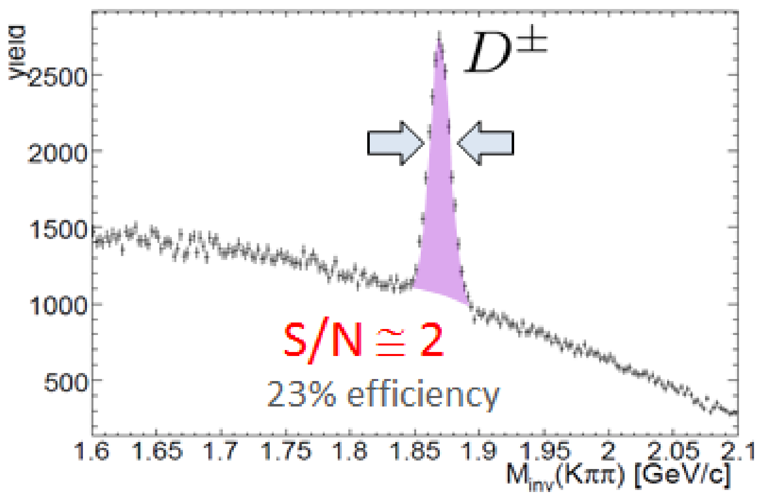
- **Physics analysis** $\bar{p}p \rightarrow D^+D^-$
  - Reconstruction: $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$

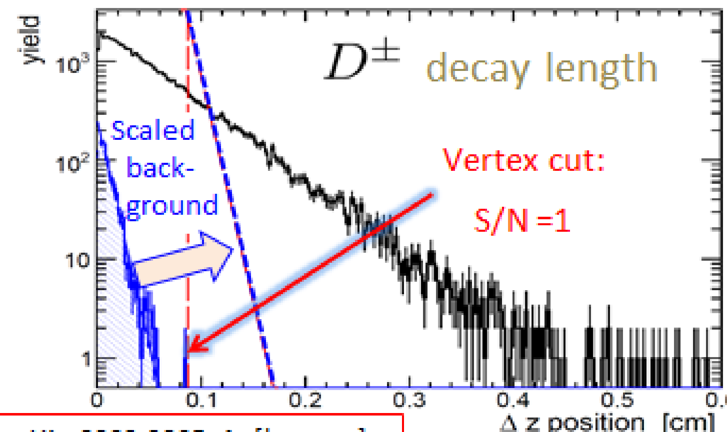
Conservative estimate

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



6 orders of magnitude lower





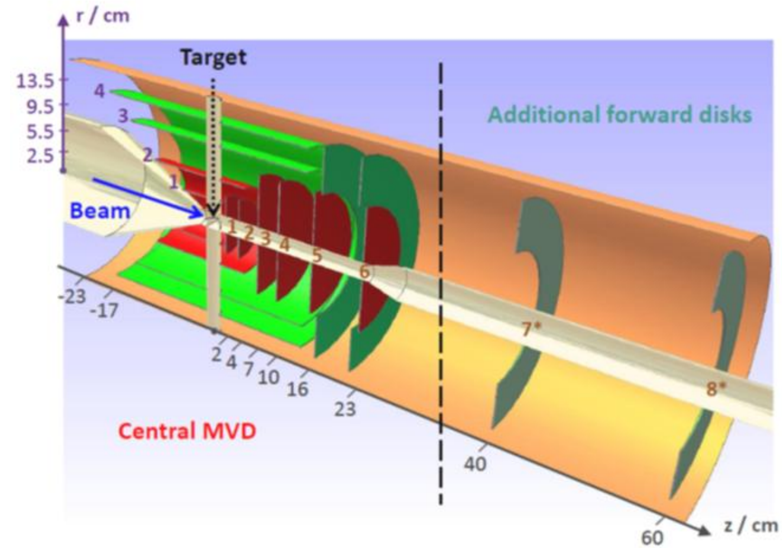
arXiv:0903.3905v1 [hep-ex]

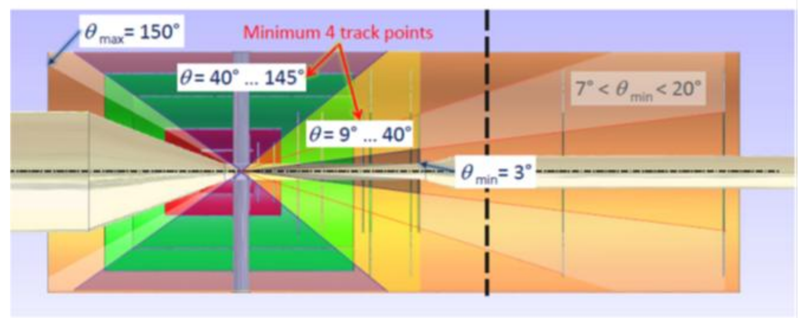
- Background suppression for open charm channels impossible without MVD

MVD

- Basic layout of the MVD and the two additional disks in forward direction (top).
  - The red (inner parts) are equipped with silicon hybrid pixel sensors.
  - Double-sided silicon micro-strip detectors in the outer layers are in green.
  - The additional forward disks (7 and 8) are based on the design of the outer strip disks.
- Bottom: Illustration of the solid angle coverage.
  - The MVD covers polar angles, θ, from 3^o up to 150^o.

    A minimum of four detector layers contribute in a range of $9^o < \theta < 145^o$

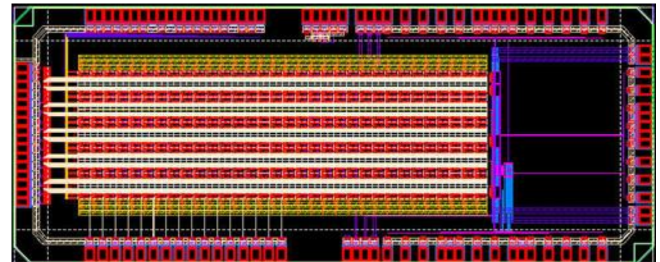




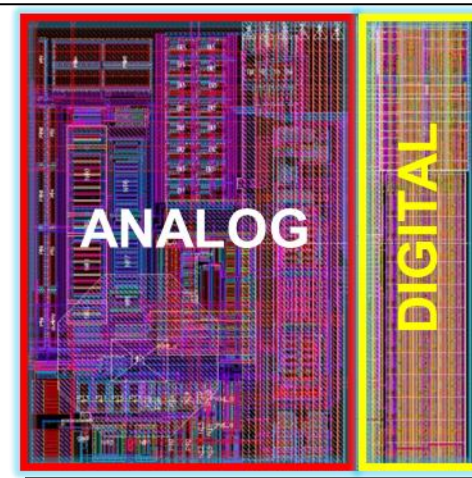
Pixel detector development: Front-end electronics

ToPix specifications:
Custom made pixel readout chip developed using 130 nm CMOS technology

Pixel readout size	100μm x 100μm
Chip active area	11.4 mm x 11.6 mm
dE/dx measurement	ToT, 12 bits dynamic range
Noise	<0.032 fC (200 e^-)
Clock frequency	155.52 MHz
Time resolution	6.4 ns (1.85 ns rms)
Power consumption	<<500 mW/cm2
Max. event rate @$2\cdot10^7$pbar-p ann/s:	~ $12\cdot10^6$ hits/($cm^2\cdot s$)

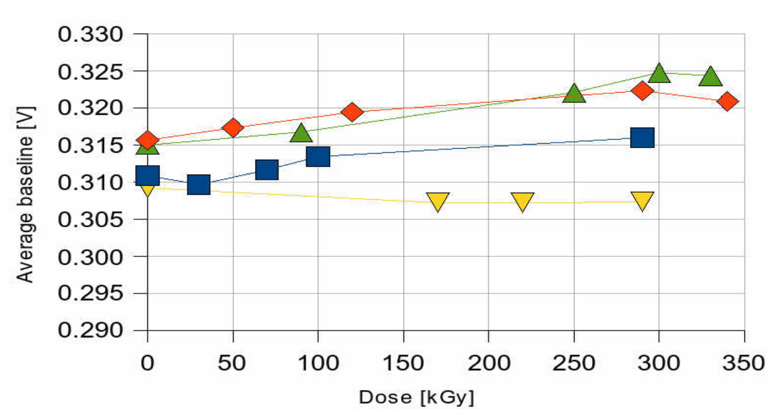


Prototype with 320 readout cells

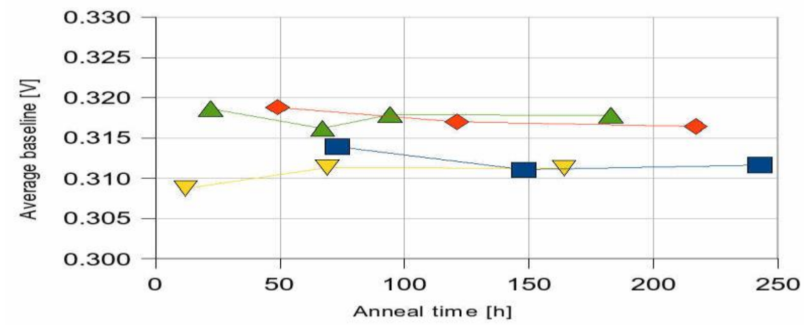


Pixel readout cell,
100 μm x 100 μm size

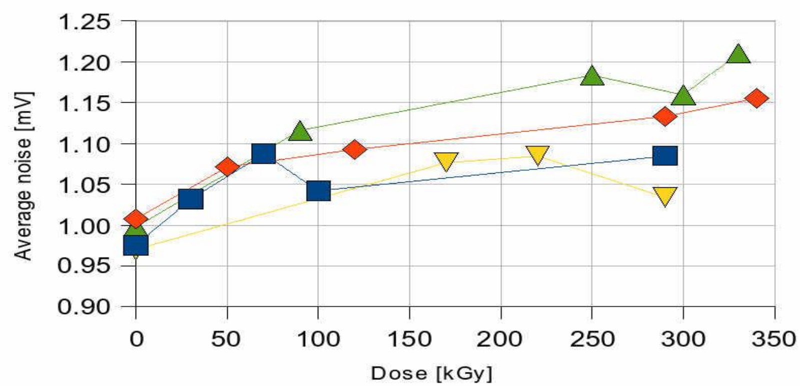
Irradiation test ToPix2



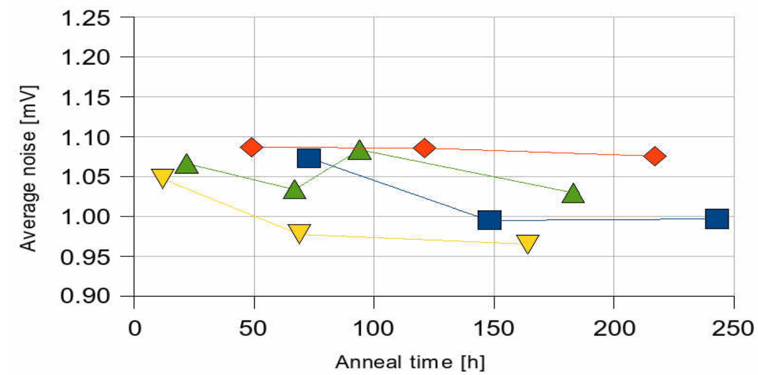
Average baseline during irradiation



Average baseline during annealing



Average noise during irradiation

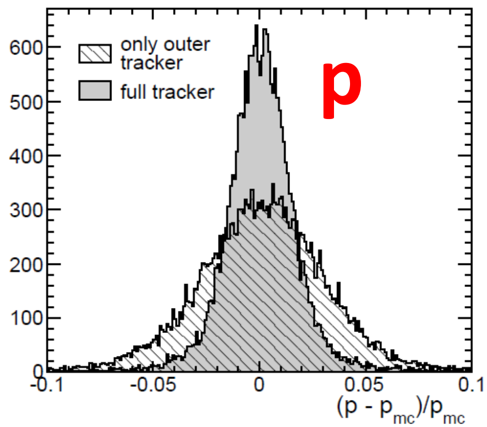


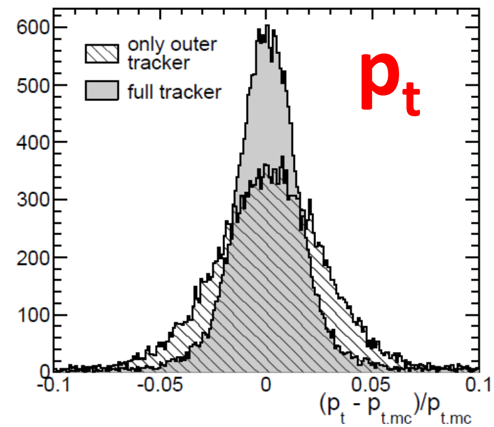
Average noise during annealing

Momentum resolution (simulation)

Momentum resolution

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





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

$\sigma(p)$ with MVD = 1.4 %

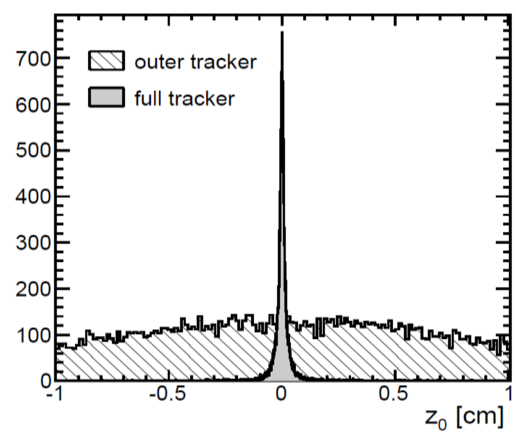
$\sigma(p_t)$ without MVD = 2.9 %

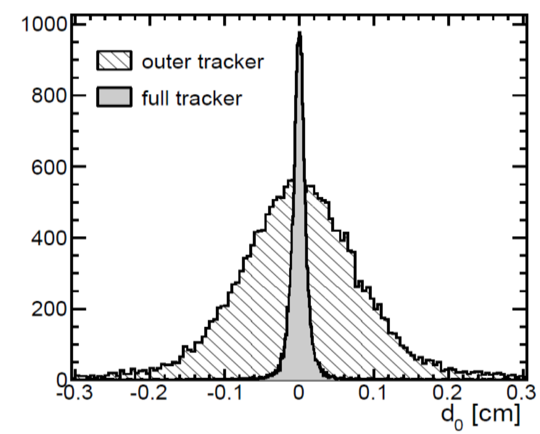
$\sigma(p_t)$ with MVD = 1.4 %

→ Improvement by 50%

Single track resolution

→ No resolution along z without MVD





PANDA R&D and construction strategy

- 2011 and 2012 – tests at CERN (RE22)
- End 2011 to have TDR for each sub-detector
  - 2 TDR's are approved
  - 3 TDR are submitted
- 2012 start detector construction
- 2015 - assembling and tests at Juelich parts of detectors
- 2017 - PANDA Detector assembly at Darmstadt
- Total Price 66.3 M Euro (in January 2005 costs)

Backup slides

High Energy Storage Ring

Parameter

- Injection of $\overline{p}$ at 3.7 GeV
- Slow synchrotron (1.5-15.0 GeV/c)
- Luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron) $\Rightarrow \Delta p/p \leq 4 \cdot 10^{-5}$

- **Resonance scan:**
  - Energy resolution down to ~50 keV
  - Tune E_{CM} to probe resonance
  - Get precise mass and width

Mode	High Resolution	High Luminosity
Momentum range	1.5 - 8.9 GeV/c	1.5 – 15 GeV/c
Stored antiprotons	10^{10}	10^{11}
Luminosity	$2 \cdot 10^{31}$ $cm^{-2}s^{-1}$	$2 \cdot 10^{32}$ $cm^{-2}s^{-1}$
Mom. Resol. (rms)	$\Delta p/p \leq 4 \cdot 10^{-5}$	$\Delta p/p = 1 \cdot 10^{-4}$
Beam cooling	Electron (≤ 8.9 GeV/c)	Stochastic (≥ 3.8 GeV/c)

PANDA Detector requirements

- Nearly 4π solid angle for PWA
- High rate capability: $2 \cdot 10^7$ s^{-1} interactions
- Momentum resolution better 1%
- Vertex info for D, K_0 Σ, Λ (cτ = 317 μm for $D^{\pm}$)
- Good PID (γ, e, μ, π, K, p)
- Photon detection 1 MeV – 15 GeV

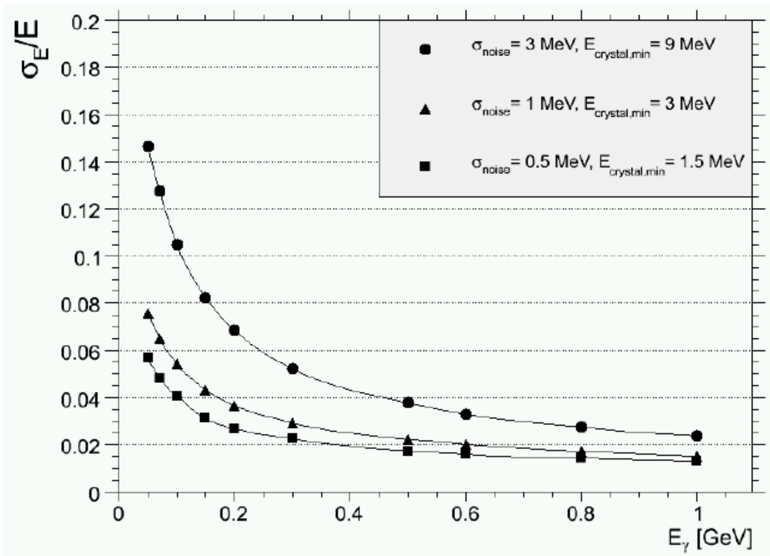
Other sub-detectors

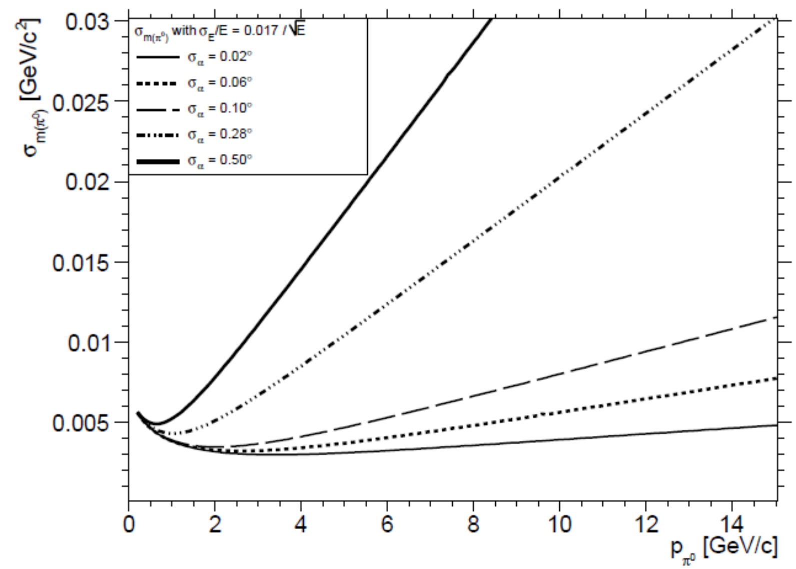
- **Target** – cluster or pellet
- **Central tracker** (Resolution: $\sigma_{r\varphi}$~150μm , σ_z~1mm, δp/p~1% Material budget ~1% X_0)
  - **Straw Tube Tracker (**27 μm thin mylar tubes, 1 cm Ø, 8 skewed layers, 27 total, or 4500 channels)
  - **Or GEM Time Projection Chamber (**Approx. 100k channels, TPC gas $NeCO_2$
- **Muon system layout**: (Drift tubes with wire and cathode strip readout, Iron absorbers)
  - *Barrel*: 12+2 layers in yoke
  - *Endcap*: 5+2 layers
  - *Muon Filter*: 4 layers
  - *Forward Range System*: 16+2 layers

PANDA EMC requirements

	Required performance value		
Common properties			
energy resolution σ_E/E	$\leq 1\,\% \oplus \frac{\leq 2\,\%}{\sqrt{E/\mathrm{GeV}}}$		
energy threshold (photons) E_{thres}	10 MeV (20 MeV tolerable)		
energy threshold (single crystal) E_{xtl}	3 MeV		
rms noise (energy equiv.) $\sigma_{E,noise}$	1 MeV		
angular coverage $\%\,4\pi$	99 %		
mean-time-between-failures t_{mtbf} (for individual channel)	2000 y		
Subdetector specific properties	backward ($\geq 140°$)	barrel ($\geq 22°$)	forward ($\geq 5°$)
energy range from E_{thres} to	0.7 GeV	7.3 GeV	14.6 GeV
angular equivalent of crystal size θ	4°		1°
spatial resolution σ_θ	0.5°	0.3°	0.1°
maximum signal load f_γ $(E_\gamma > E_{xtl})$	60 kHz		500 kHz
($p\bar{p}$-events) maximum signal load f_γ $(E_\gamma > E_{xtl})$	100 kHz		500 kHz
(all events) shaping time t_s	400 ns		100 ns
radiation hardness (maximum annual dose $p\bar{p}$-events)	0.15 Gy	7 Gy	125 Gy
radiation hardness (maximum annual dose from all events)	10 Gy		125 Gy

EMC required resolutions



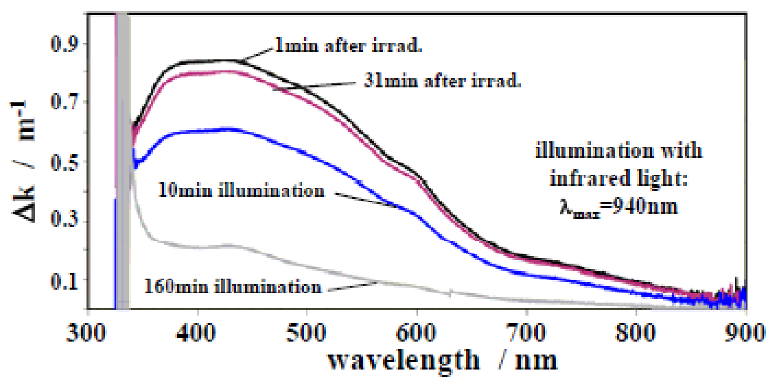


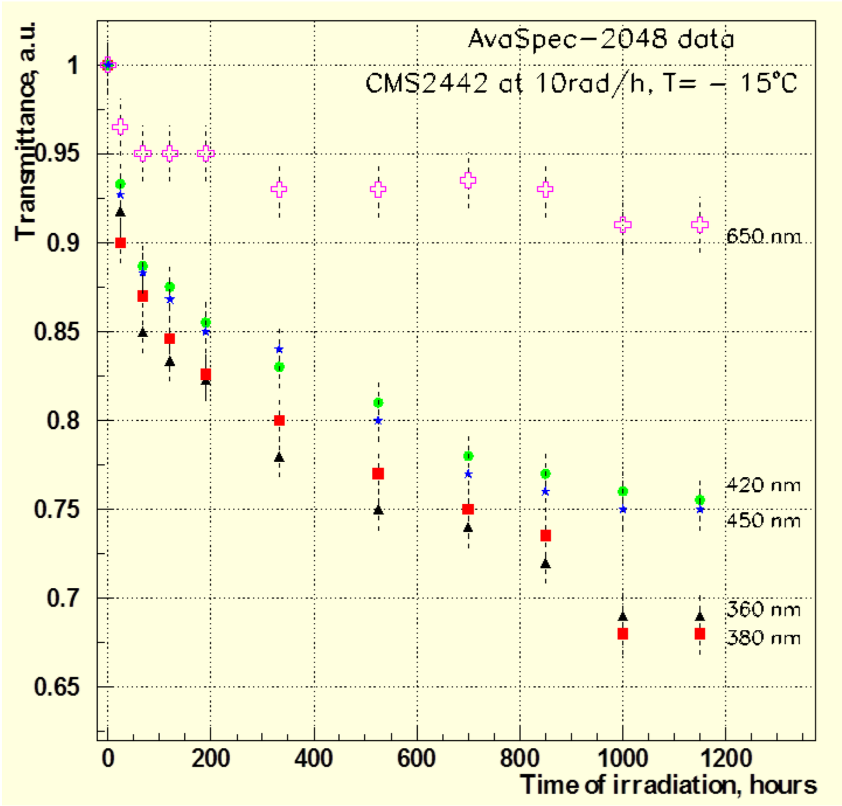
Comparison of the energy resolutions for three different single crystal reconstruction thresholds.

- noise 0.5 MeV,E(single)=1.5 MeV
- noise 1 MeV, E(single) = 3 MeV
- noise 3 MeV, E(single) = 9 MeV

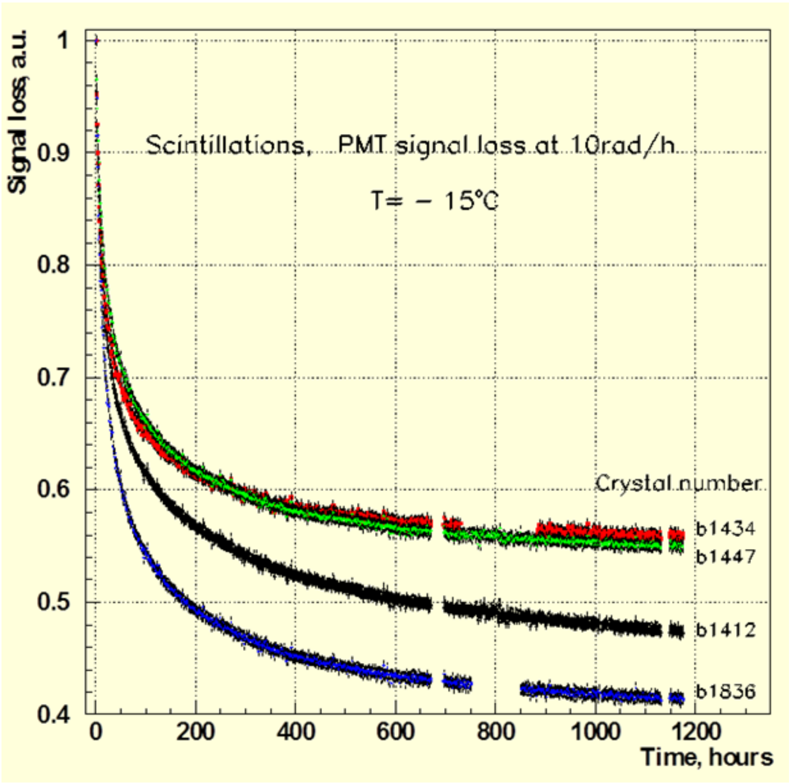
π^0 mass resolution for various spatial resolution values vs. beam momentum.

Transparency loss under irradiation

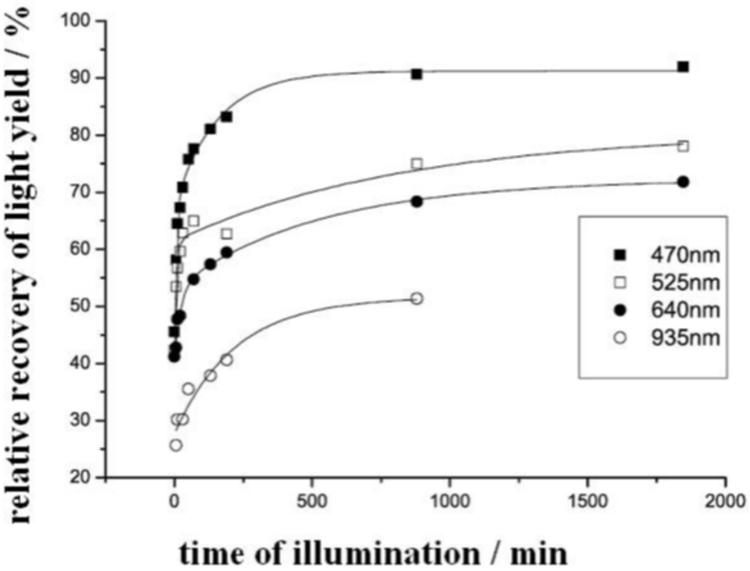




Change of the full spectral distribution of the induced absorption coefficient of a PWO-II crystal after irradiation with an integral dose of 30Gy measured at room temperature. The spectra are measured 1 and 31 minutes after irradiation as well as after additional illumination for 10 and 160 minutes, respectively, with infrared light at 940nm.



Signal loss a.u.
Scintillations, PMT signal loss at 10rad/h
T= − 15°C
Crystal number
b1434
b1447
b1412
b1836
Time, hours

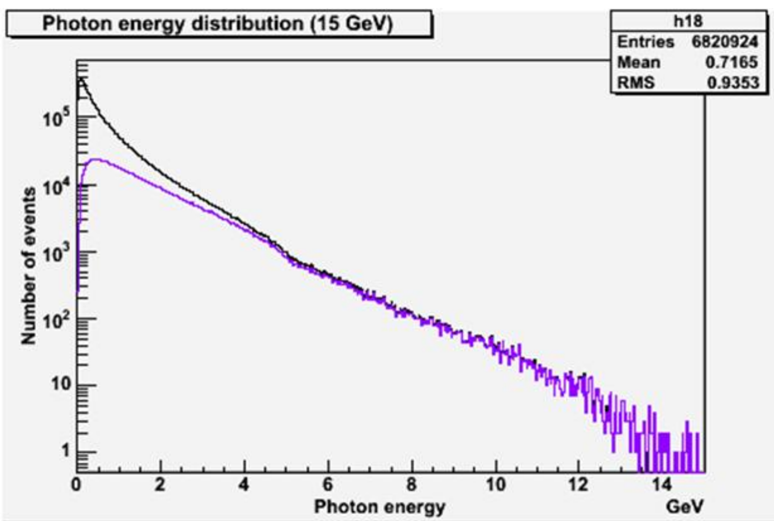


relative recovery of light yield / %
time of illumination / min
470nm
525nm
640nm
935nm

Forward spectrometer calorimeter (FSC) requirements

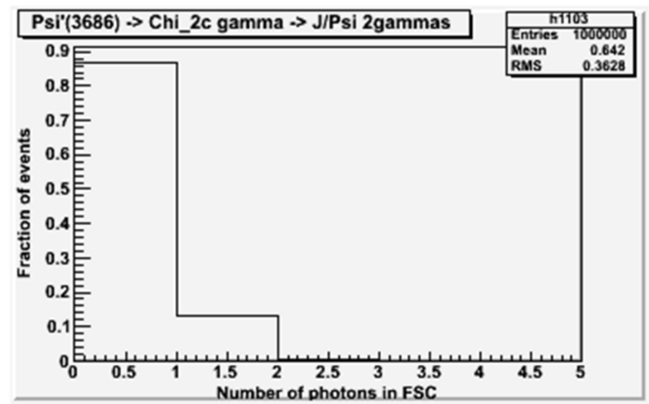
Important to have closed geometry for PWA.

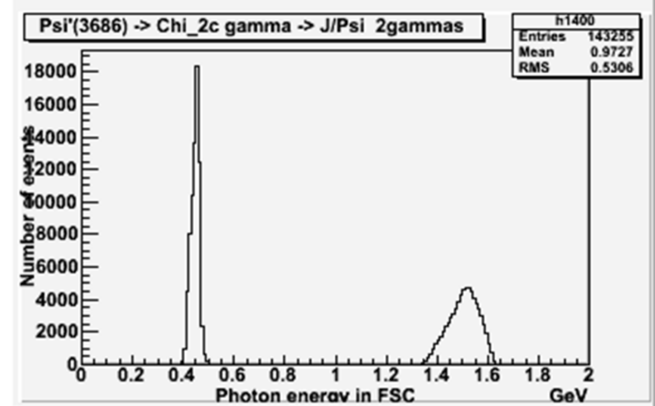
Photons energy from 0 to 15 GeV



Charmonium study,

6.27 GeV/c beam



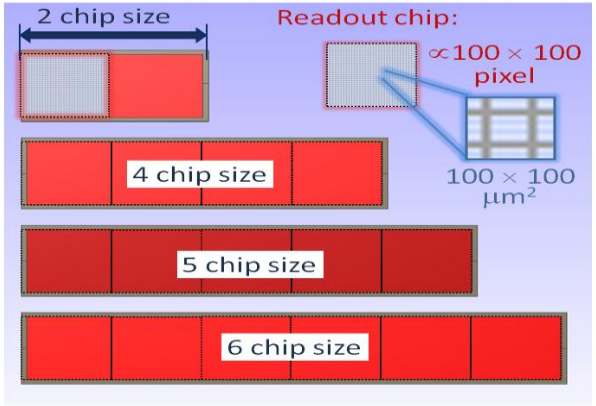


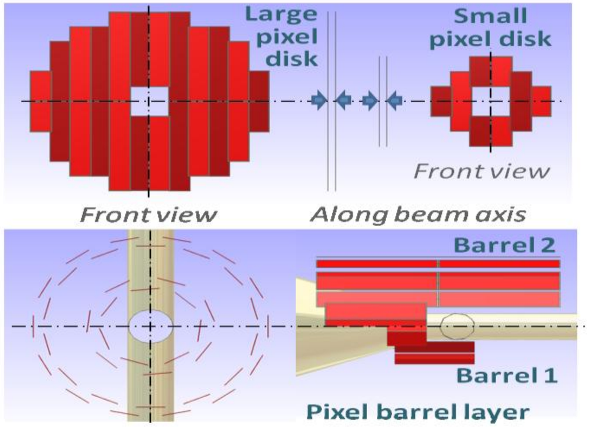
EMC electronics

- Barrel EMC: First realistic mechanical design for the SADC s is ready
- Commercial SADC (Struck SIS3302): (8 channels,16 bit (input range – 5V single-ended or1V differential), up to 100 Msps, Customized firmware with PANDA feature-extraction algorithm
- OR 14 bit ±1V differential or ±2V differential), 125 Msps, Virtex-5 FPGA (XC5FX70T)

- The EMC SADC is expected to be available by theend of this year (hardware)

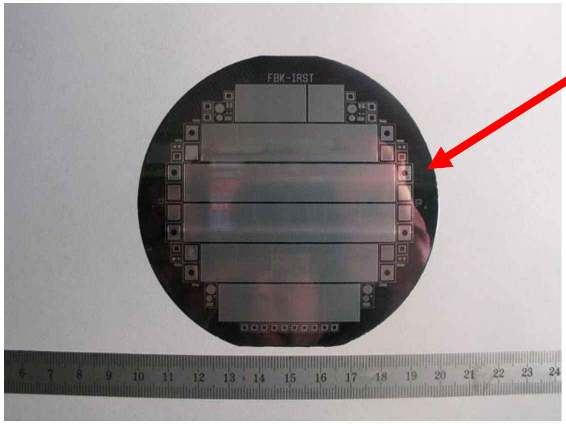
PANDA MVD pixel sensor





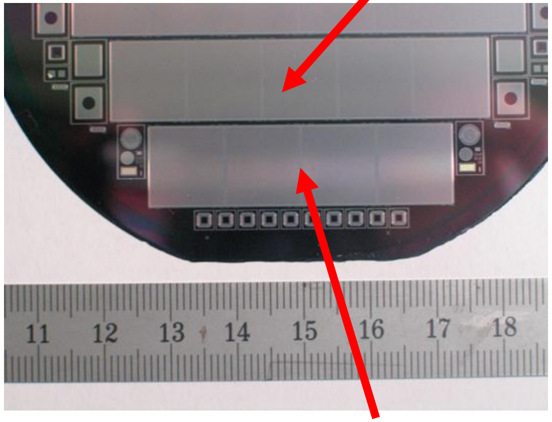
- Schematics of the basic pixel sensor geometry.
- Top: Main pixel sensor types. The design is based on a quadratic pixel cell size of 100x100 µm and and effective readout area of approximately 1 cm per individual readout chip.
- Bottom: Pixel sensor arrangement in different detector layers.

Pixel detector development: sensor

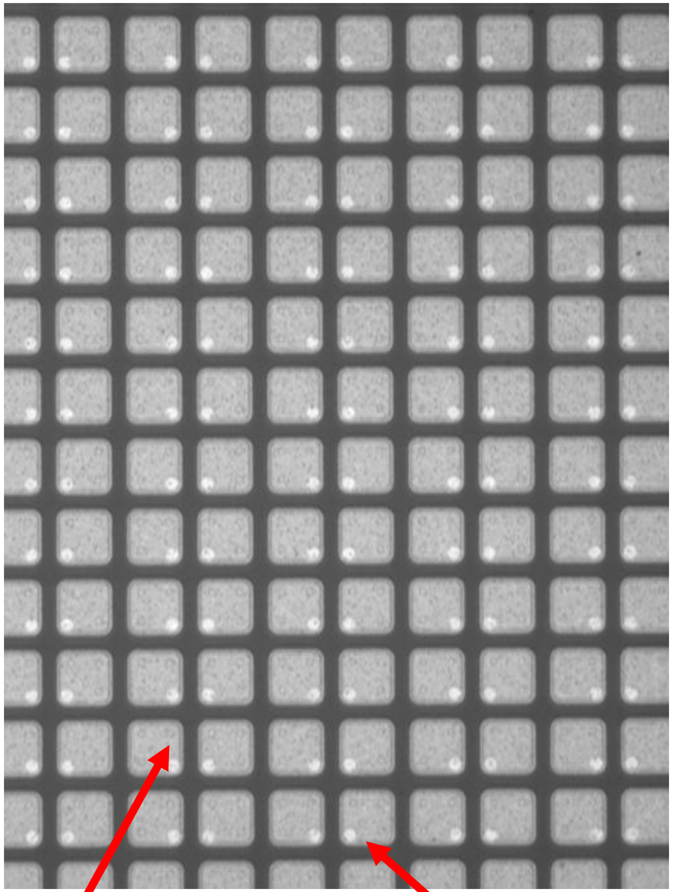


Epitaxial wafer with sensor: first design

5 readout chip sensor



4 readout chip sensor

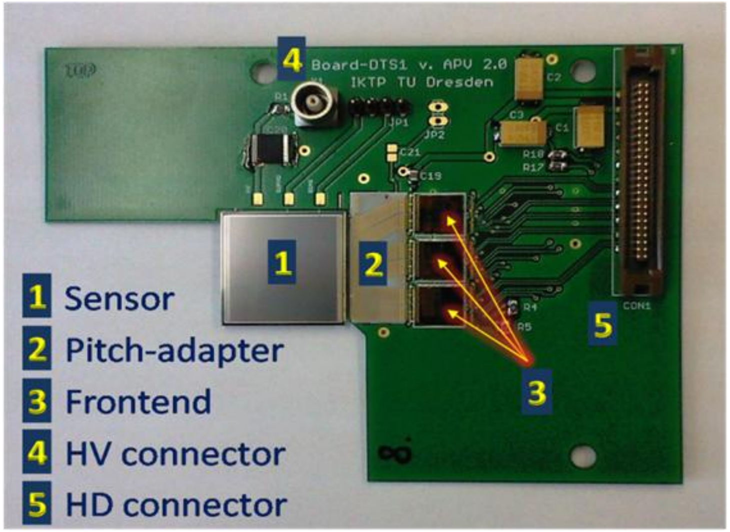


pixel

Pad for bump bonding

Strip detector development

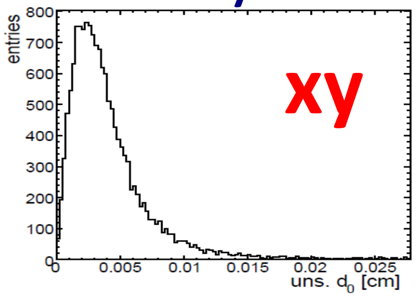
- Different sensor types are used:
  - rectangular shape with a stereo angle of 90° and readout pitch of 130 µm (barrel part)
  - trapezoidal shape with a stereo angle of 15° and readout pitch of 70 µm (disk part) 200 µm thickness

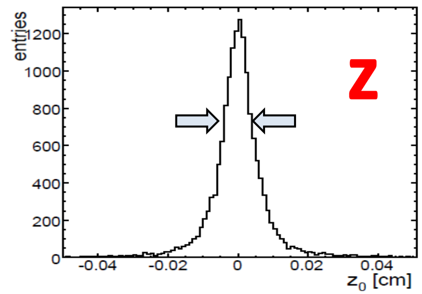


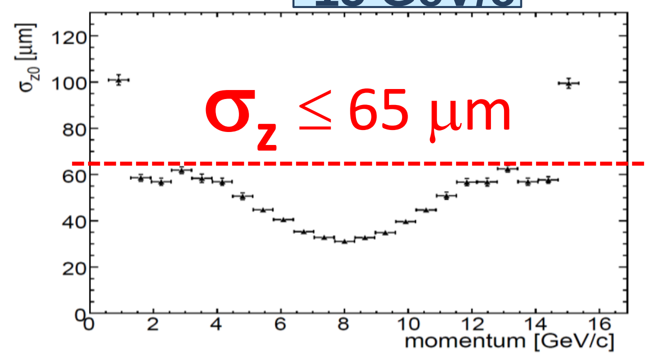
Sensor:
2 cm side length
300 µm thickness
90° stereo angle
50 µm pitch
Readout: APV25 – S1

MVD resolution (simulation)

- 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

→ Primary and secondary vertex resolution:

$\sigma_{x,y} \leq 35$ μm

$\sigma_z \leq 100$ μm