The PANDA Detector at FAIR

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on behalf of the PANDA collaboration

New Trends in High Energy Physics

Odessa, Ukraine

2019/05/14

Antiproton Production at FAIR

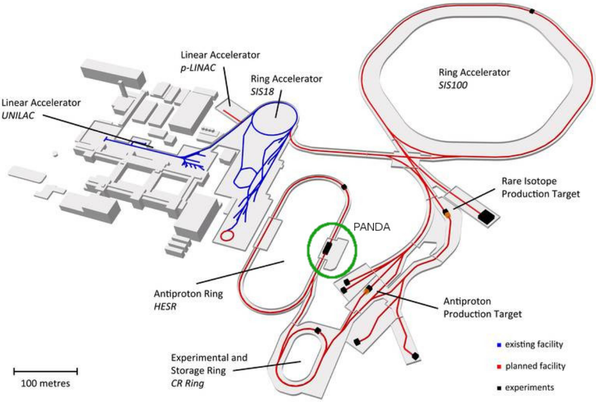
FAIR (Facility for Antiproton and Ion Research):
Extension to existing GSI (Gesellschaft für Schwerionenforschung in Darmstadt)

Proton LINAC:
70 MeV

Production of antiprotons with Ni target

Collection in CR
Storage in HESR

PANDA positioned in HESR



FAIR Construction

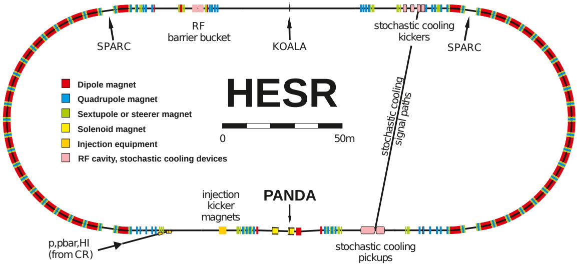
Construction site view taken from drone video (March 2019)

High Energy Storage Ring

Injection momentum: 3.8 GeV/c

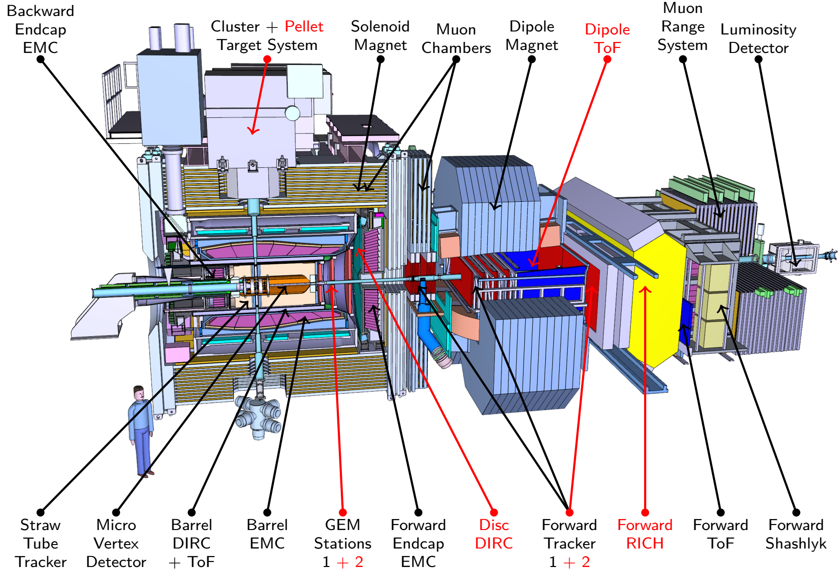
Circumference: 575 m

Stochastic cooling over full momentum range

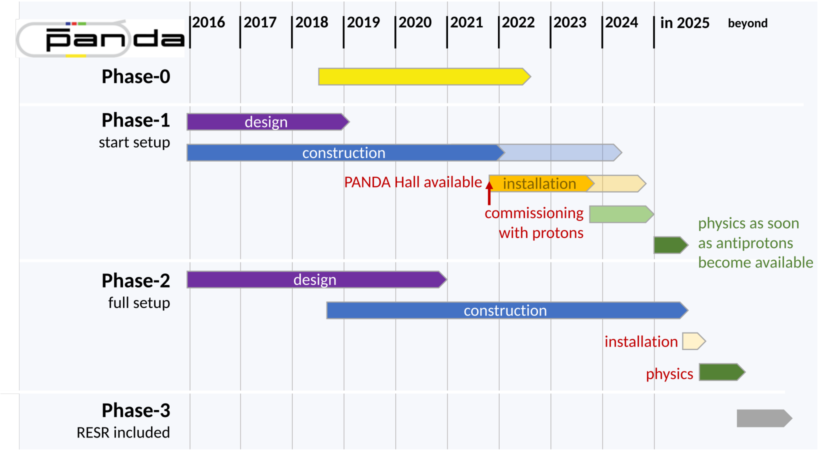


Mode	High Resolution	High Luminosity
Momentum p	1.5 – 15 GeV/c	1.5 – 15 GeV/c
Energy E	2.3 – 5.5 GeV	2.3 – 5.5 GeV
Antiprotons N	10^{10}	10^{11}
Luminosity $\mathcal{L}$	$2 \cdot 10^{31}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$	$2 \cdot 10^{32}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$
Resolution $\Delta p/p$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$

The PANDA Detector



PANDA Time Schedule



Phase 0: Subdetectors are under construction and will be used in other HEP experiments until hall is available.
Phase 1: The first physics experiments can be done with the initial setup.
Phase 2: The full setup of PANDA will be available.
Phase 3: Physics beyond Phase 2 (RESR required).

PANDA Physics Program

Nucleon Structure

- Generalized parton distributions
- Drell Yan process
- Time-like form factors

Hadron Spectroscopy

- Production of exotic QCD states
- Understanding new XYZ states
- Investigation of charm hadrons
- Production of states with all quantum numbers

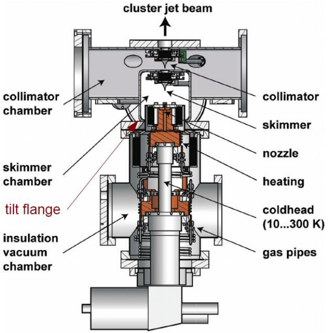
Nuclear Physics

- Hypernuclear physics
- Hadrons in nuclei

Dedicated physics talk from Myroslav Kavatsyuk on Thursday

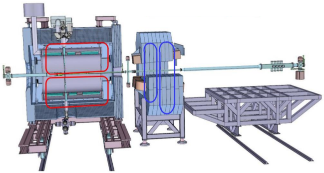
Proton Target

- Cluster Jet Target
  - Expansion of pre-cooled and compressed hydrogen gas into beam pipe
  - Cluster jets move with supersonic speed during condensation
  - Cluster size: $10^3 - 10^5$ atoms/cluster
- Pellet Target
  - Small droplets of frozen hydrogen created in triple point chamber
  - Pellet diameter: $10 - 30\,\mu$m
  - Vertical injection into target tube
  - Falling speed: 60 m/s
  - Flow rate: 100,000 pellets/s
- Further targets possible

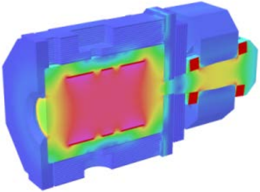


Magnets

Magnetic field lines:



Field map:

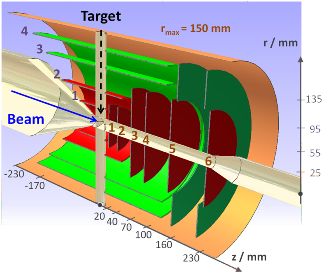


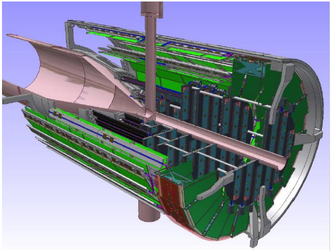
Combination of solenoid and dipole field

- Solenoid magnet (target region)
  - Super conducting coil
  - Field: 2 T
  - Diameter: 1.9/2.3 m (inner/outer)
  - Length: 4.9 m
  - Weight: 300 t
  - Iron yoke instrumented with muon chambers
  - Field inhomogeneity $\leq 2\%$
- Dipole magnet (forward region)
  - Field: 1 T
  - Size: 1 m $\times$ 3 m opening
  - Length: 2.5 m
  - Weight: 220 t
  - Ramping operation synchronous with storage ring (ramp speed 1.25%/s)

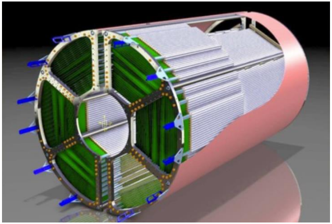
Tracking: Micro Vertex Detector

- Micro Vertex Detector (MVD) inner most detector
- Closest to primary interaction vertices
- 4 barrels around interaction point
- 6 disks in forward direction
- Inner layers: hybrid pixels ($100\,\mu$m $\times$ $100\,\mu$m)
- Outer layers: double sided pixels
- Time resolution: 6 ns
- Pixel resolution: $28\,\mu$m
- Strip resolution: $14\,\mu$m
- Vertex resolution: $50\,\mu$m (important for D mesons)





Tracking: Straw Tube Tracker

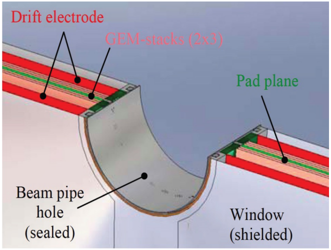


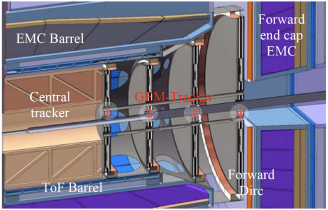
- Cylindrical shape around MVD
- 4,200 Al-mylar drift tubes filled with Ar/CO_2 in 21 – 27 layer
- Readout with ASIC + TDC or FADC
- 8 layers skewed by 3°
- Avalanche gain: approx. 100
- Inner radius: 15 cm
- Outer radius: 42 cm
- Tube diameter: 10 mm
- Tube length: 150 cm
- ϱ/ϕ plane resolution: 150 μm
- z resolution: 1 mm
- Most tubes produced

Tracking: GEM Tracker

- Up to 3 stations with 4 projections each
- Large area GEM foils from CERN ($50\,\mu$m Kapton, $2 - 5\,\mu$m copper coating)
- ADC readout for cluster centroids $\Rightarrow$ approx. 35,000 channels
- Position resolution: $\leq 100\,\mu$m

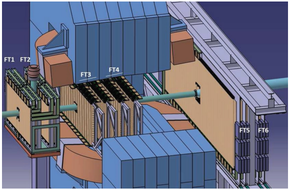
Station	1	2	3
Weight [kg]	20	30	40
Target distance [cm]	117	153	189
Diameter [cm]	90	112	148



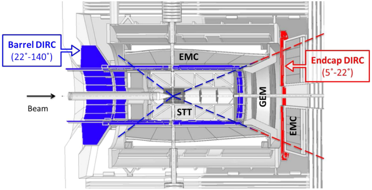


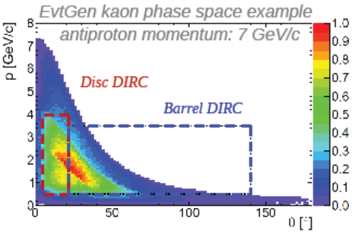
Tracking: Forward Tracker

- Straw tubes similar to central tracker
- Tube diameter: 10 mm
- Momentum acceptance: $\geq 0.03 \cdot p_{\text{beam}}$
- Dipole field scaled according to p_{beam}
- 3 pairs of planar tracking stations (in front of, behind, and inside magnet yoke)
- Coverage: $\pm 10^\circ$ horizontally $\pm 5^\circ$ vertically
- Position resolution: 0.1 mm/layer
- Momentum resolution: $\leq 1\%$



Particle Identification

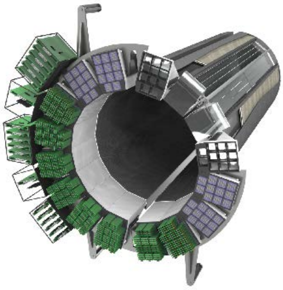




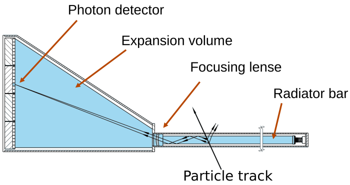
- Excellent Particle Identification (PID) required
- No hadronic calorimeter used in PANDA
- Separation of particle species with 3 detector types:
  - Cherenkov detectors:
    2 DIRCs (TS)
    1 RICH (FS)
  - Time of Flight (ToF)
  - Muon detection system
- Almost full kaon phase space covered by DIRC detectors

Particle Identification: Barrel DIRC

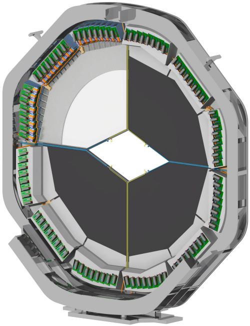
- DIRC (Detection of Internally Reflected Cherenkov light)
- Barrel shape around target
- Radius: 476 mm
- 16 fused silica bars
- 128 Multichannel plate photo multipliers (MCP-PMTs) $\Rightarrow$ approx. 10,000 channels
- 100 ps time resolution
- Momentum range: 0.5 – 3.5 GeV/c
- Polar angle range: 22° – 140°
- π/K separation: ≥ 3 s.d.

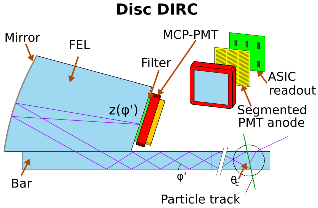


Barrel DIRC



Particle Identification: Disc DIRC

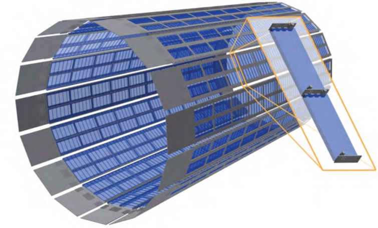


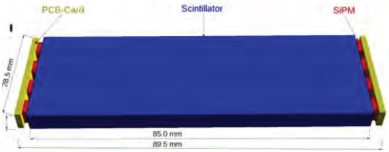


- Placed at forward endcap
- 2 m away from interaction point
- 4 independent fused silica quadrant
- Radius: approx. 1200 mm
- 96 MCP-PMTs ⇒ approx. 30,000 channels
- 100 ps time resolution
- Momentum range: 0.5 – 4.0 GeV/c
- Polar angle range: 5° – 22°
- π/K separation: ≥ 3 s.d.

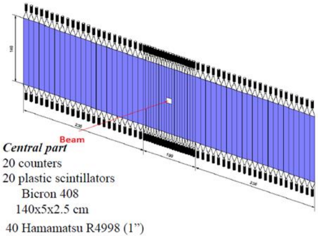
Particle Identification: Barrel ToF

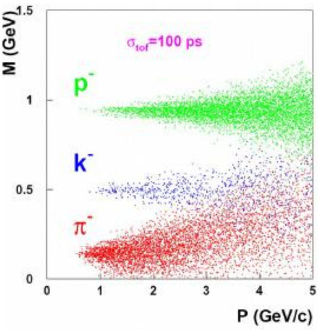
- PID of low momentum particles $p \leq 1\,\mathrm{GeV/c}$
- Excellent time resolution of approx. 100 ps
- 5,760 scintillator tiles with sizes about $30\,\mathrm{mm} \times 30\,\mathrm{mm} \times 5\,\mathrm{mm}$
- Light weight construction
- Scintillator material: plastic (EJ-228 or EJ-232)
- Readout: Hamamatsu SiPM
- Front-end electronics: PETsys TOFPET ASICs





Particle Identification: Forward ToF

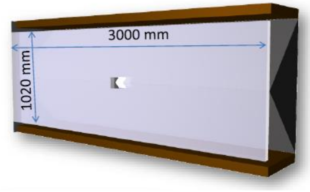


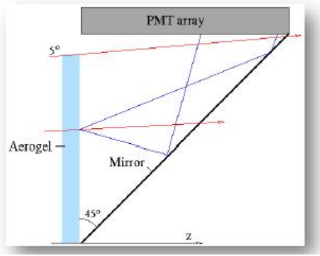


- Time of flight in forward spectrometer essential
- No start counter ⇒ relative timing to Barrel ToF
- Scintillator wall of slabs
- Distance to target: 7.5 m
- Slab geometry: 140 cm × 10 cm (sides), 140 cm × 10 cm (center)
- Material: Bicron 409 scintillator
- Photon read out with PMTs on both ends
- Side part: 2 × 32 counters ⇒ 92 PMTs for photon read out

Particle Identification: Forward RICH

- 2 layers of aerogel
- Refractive index: $n_1 = 1.050$ and $n_2 = 1.047$
- Only flat mirrors
- π/K separation up to $p = 10\,\mathrm{GeV/c}$
- mu/K separation up to $p = 10\,\mathrm{GeV/c}$
- Read out with Hamamatsu MaPMTs
    - 8×8 anode pixels with $6\,\mathrm{mm}$ size
    - Relatively cheap $\approx 1800\,\mathrm{EUR/unit}$
    - Robust and long life time



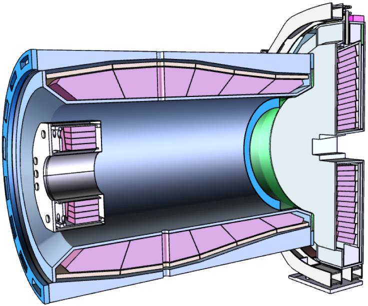


Energy Measurement

- Only electromagnetic calorimeter (no hadronic)
- Complete reconstruction of multi-photon and lepton-pair channels required
- Good energy and spatial resolution for photons up to 15 GeV/c
- High yield and background rejection
- Target spectrometer: Homogeneous barrel part and two endcaps
- Forward spectrometer: Sampling calorimeter
- Energy threshold: 10 MeV
- Spatial coverage: 98% of 4π
- Single crystal rate: up to $10^6\,\mathrm{s}^{-1}$

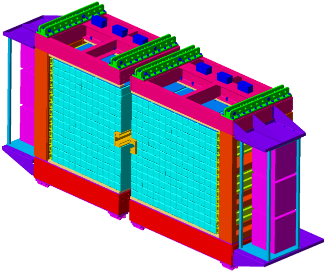
Energy Measurement: Target Spectrometer

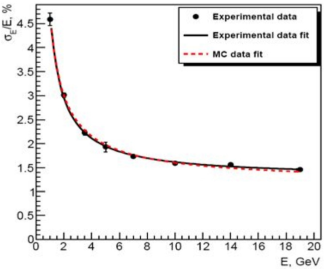
- 2^{nd} generation $PbWO_4$ crystals (improved photon yield and radiation hardness)
- In total 15744 crystals
- Operation temperature: $(-25 \pm 0.1)^{\circ}$C (4x photon yield)
- Radiation length: 0.9 cm
- Molière radius: 2.1 cm
- Typical crystal dimensions: $20\,\text{cm} \times 2.5\,\text{cm} \times 2.5\,\text{cm}$
- Time resolution: $\leq 1\,\text{ns}$ ($\geq 100\,\text{MeV}$)
- Energy resolution: $1\% \oplus 2\%/\sqrt{E[\text{GeV}]}$
- Spatial resolution $\leq 1.5\,\text{mm}$
- 75% of crystals in phase 1



- Shashlyk type sampling calorimeter
- Interleaved scintillator and lead absorber
- Photon read out with PMTs and FADCs for digitization
- Active area: $297 \times 154\,\mathrm{cm}^2$
- Energy resolution:

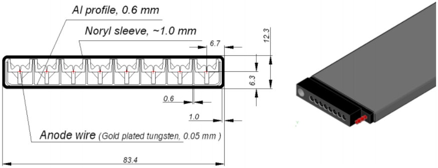
$$\frac{\sigma_E}{E} \leq 1.3\% \oplus \frac{2.8\%}{\sqrt{E[\mathrm{GeV}]}} \oplus \frac{3.5\%}{E[\mathrm{GeV}]}$$

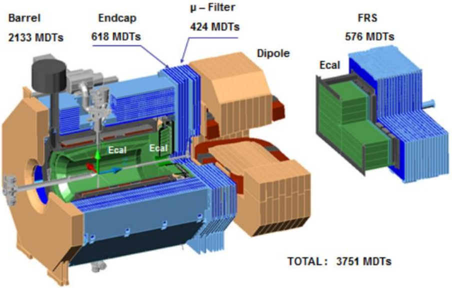




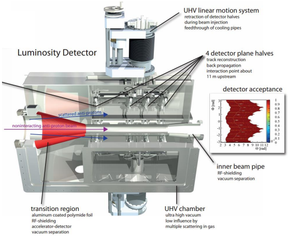
Muon Detector System

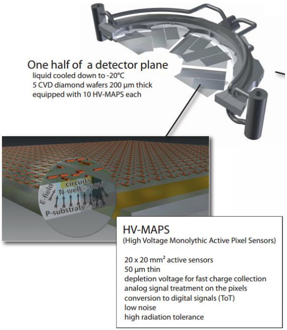
- Drift tubes with wire and cathode strip readout
- High π background due to low muon momenta
  $\Rightarrow$ Multi-layer range system required
- Barrel part: 12+2 layers in iron yoke
- Endcap part: 5+2 layers
- Muon filters: 4 layers
- Forward part: 16+2 layers





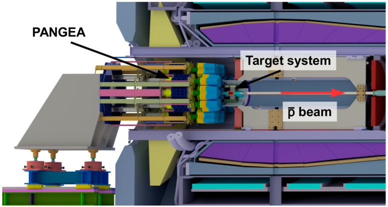
Luminosity Detector

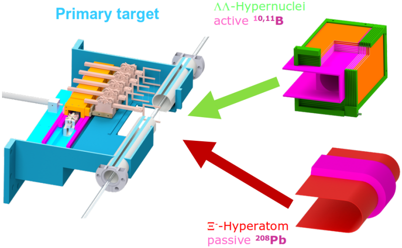




- Roman pot system
- Measuring elastic cross section of $\bar{p}p$ interactions
- 11 m away from target
- Silicon pixel detector
  - 5 CVD diamond wafers (200 μm thickness) with 10 HV MAPS each
  - Pixel size: 80 μm $\times$ 80 μm
- Collaboration with Heidelberg (HV MAPS developed for Mu3e experiment)
- Active pixel sensor in HV CMOS
- Digital processing on chip
- High efficiency: approx: 99.5%

Hypernuclear Setup

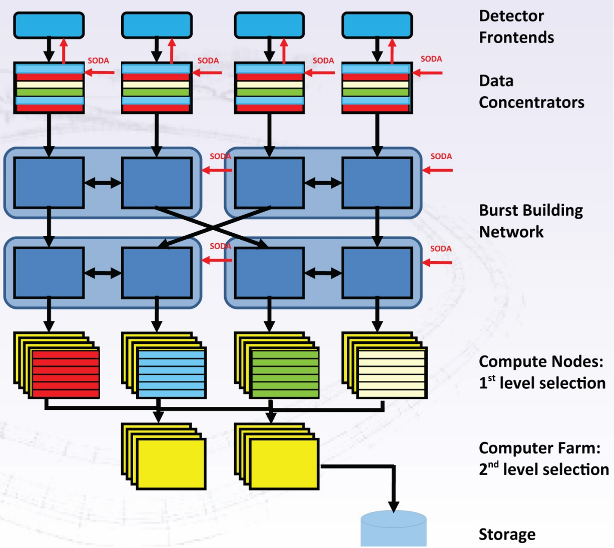




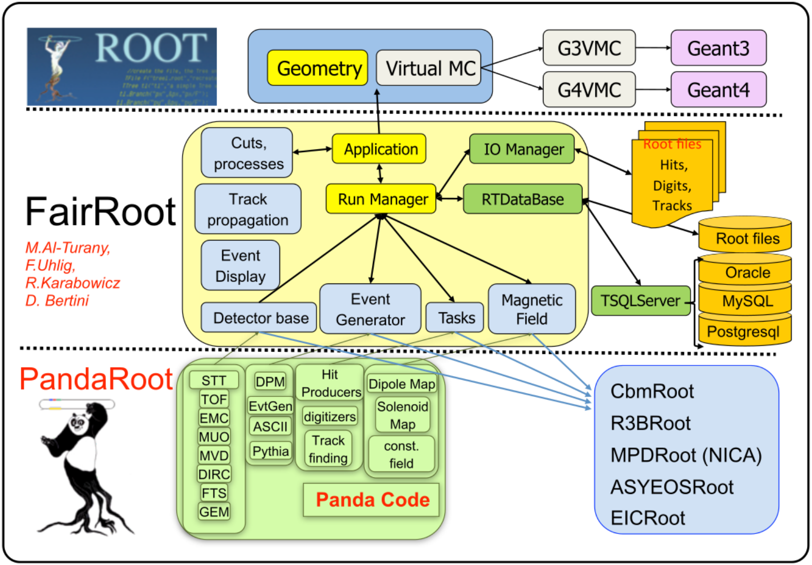
- Alternative setup
- Production of hypernuclei from captured Ξ
- Primary retracted wire/foil target
  - Diamond wire
  - Piezo motored wire holder
- Secondary active target for capturing Ξ and track products with Si strips
  - Silicon microstrips
  - Absorbers
- HP Ge detector for γ spectroscopy

Data Acquisition

Triggerless DAQ and high interaction rate



Simulation Framework



PANDA Collaboration

Collaboration

UniVPM Ancona
U Basel
IHEP Beijing
U Bochum
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
U Cracow
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara

FIAS Frankfurt
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
U Glasgow
BITS Pilani KKBGC, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
FH Iserlohn
FZ Jülich
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz

U Mainz
INP Minsk
ITEP Moscow
MPEI Moscow
BARC Mumbai
U Münster
Nankai U
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SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Uppsala
U Valencia
SMI Vienna
U Visva-Bharati
SINS Warsaw

more than 460 physicists from
from 75 institutions in 19 countries

Summary & Outlook

- Development and construction ongoing
- HESR and PANDA well in time
- Detector design for PANDA finalized (2 phases)
- Huge progress in development of subdetectors
- Studies of physics experiments for Day-1 and phase 1 & 2 still ongoing
- Addressing large amount of physics questions with full setup after 2025

Thank you very much for your attention!

Backup Slides