FAIR Status

and the PANDA Experiment

Anastasios Belias, GSI
ESFRI Landmark
Top priority for European Nuclear Physics Community
Driver for Innovation in Science and Technology
- **Intensity gain:** x 100 – 1000
- 10 x energy (comp. to GSI)
- **Antimatter:** antiproton beams
- **Precision:** System of storage and cooler rings
- 9 international FAIR Shareholders
- 1 Associated Partner (United Kingdom)
- 1 Aspirant Partner Czech Republic (Since 2018)
- Participation of **3,000 scientists from all continents**
Status of FAIR Project: Civil Construction
Progress since ground breaking event 4-July-2017

before July 2017

July 4th 2017

Oktober 2019
~ 60 sc dipole SIS100 modules manufactured at BNG and 55 shipped to GSI and tested

SIS100 quadrupole units shipped from JINR to BNG for integration into FOS module

All 51 HEBT vacuum chambers of batch 1 delivered (BINP, Russia)

The series production of RF – debunchers

All HESR Dipoles are produced, in Jülich and 65% are delivered to FAIR

Delivery of 1st 6 series Power Converter from India, (ECIL, India)
Two FoS vacuum chambers for the quadrupole doublet modules of the SIS100 arrived from China. They will be installed by the integrator in the quadrupole units.

First-of-Series of the Super-FRS short SC Multiplet arrived in February 2019 at CERN test facility for execution of the Site Acceptance Test.

First HESR Stochastic cooling pick-up and kicker in operation at COSY.

Successfully First-of-Series FAT for the Super-FRS short SC Multiple took place in Italy at January 2019.

Copper plating and first tests of the RFQ accelerator cavity for the pLinac have been completed and match specifications.

Three new MA acceleration cavities installed and commissioned with beam.
Distributed testing infrastructure for the FAIR superconducting magnets

GSI: Series test facility for the SIS100 s.c. dipole magnets, string test, current leads and local cryogenics components.

CERN: Test facility completed for the Super-FRS s.c. dipoles and multipletts

INFN: Test facility in Salerno for testing the series of SIS100 quadrupole modules

JINR, Series test facility in Dubna for testing of the series of SIS100 s.c. quadrupole units
New CRYRING@GSI/FAIR

- FIRST FAIR accelerator
- ready for experiments and tests

CRYRING – heavy ion storage ring, relocated to FAIR from Manne Siegbahn Lab. of Stockholm Uni.

View from local injector to the ring
The FAIR science: four pillars

atomic physics, biophysics, plasma physics, material research, other applications

nuclear- and quark-matter

nuclear structure and nuclear astrophysics

hadron structure and dynamics

APPA

CBM

NuSTAR

PANDA
APPA – Atomic Physics, Plasma Physics, and Applied Sciences

<table>
<thead>
<tr>
<th>Atomic Physics</th>
<th>Plasma</th>
<th>Materials</th>
<th>Bio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPARC</td>
<td>HED@FAIR</td>
<td>MAT/BIOMAT</td>
<td>BIO/BIOMAT</td>
</tr>
</tbody>
</table>

- **strong field research**
  - ... probing of fundamental laws of physics
- **warm dense matter**
  - ... states of matter common in astrophysical objects
- **radiation hardness**
  - ... mechanical and electrical degradation of materials
- **space travel**
  - ... cosmic radiation risk and shielding

**FACILITIES**
- SIS100
- HESR
- APPA-Cave
- ESR
- CRYRING
- HITRAP

**BIOMAT: Materials Research and Biophysics**
**HED@FAIR: Plasma Physics**
**SPARC: Atomic Physics**

**APPA Cave**

- **protons** (10 GeV): $2 \times 10^{13}$ p/bunch
- **U^{28+}** (2 GeV/u): $5 \times 10^{11}$ ions/bunch
- **U^{92+}** (10 GeV/u): $10^8$ ions/s

- user facility
- several target stations
- flexible detector settings
- flexible beam shaping
- external drivers
Atomic, Plasma Physics and Applications

- About 800 members
- Wide field of science
  - basic research into material, biological and medical applications and space research

Atomic Physics
SPARC: ~400 members from 26 countries

Plasma Physics
HED: ~300 members from 16 countries

Materials Research and Biophysics
BIOMAT: ~100 members from 12 countries
CBM Experiment at FAIR: Systematically explore QCD matter at large baryon densities with high accuracy and rare probes, at highest interaction rates in the field.

- QCD Equation of State
- Search for exotic phases and 1st order phase transition
- Critical endpoint
- Chiral symmetry restoration at high $\mu_B$

**CBM collaboration:** 55 institutions, 470 members in 11 countries
- **typical collision system**: Au^{79+} + Au at 4 to 11 AGeV
- **Day 1**: beam intensity: 5x10^7 ions/sec; interaction rate 0.5 MHz
- **MSV**: beam intensity: 10^9 ions/sec; interaction rate 10 MHz
NUclear
STructure Astrophysics and Reactions

• The limits of nuclear existence (lifetimes, decays, …)
• Ground state properties (masses, radii, …)
• Structure of excited states (shell structure, shapes, …)
• Unbound and other exotic system (halo, skin, …)
• Nuclear equation of state
NUSTAR
- Origin of Elements in the Universe

„Nucleosynthesis sites“ in the universe

„Nucleosynthesis sites“ at FAIR

Primary intensities vs. GSI: x 100

SIS 100 ⟷ production target

SFRS

ILIMA, EXL at CR and at ESR, HESR, Cryring

MATS & LaSpec
HISPEC/DESPEC
R³B
Status of NuSTAR experiments
- detector R&D and construction

Optical TPC

ILIMA

Ion Catcher for MATS/LASPEC

DTAS

AGATA

NeuLAND
PANDA

antiProton
ANnihilations at DArmstadt
The combination of PANDA’s discovery potential for new states, coupled with the ability to perform high-precision systematic measurements is not realised at any other facility or experiment in the world.
Antiprotons at FAIR

- **Antiproton production**
  - Proton Linac (70 MeV)
  - Accelerate p in SIS18/100 (4/29 GeV)
  - Produce $\bar{p}$ on Ni/Cu target (3 GeV)
  - Collection in CR, fast cooling
  - Accumulation in HESR
  - PANDA luminosity $\leq 2 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$
  - $\bar{p}$ momentum: 1.5 – 15 GeV/c
  - Fixed target: cluster jet/pellet

- Full FAIR version (Phase 3, after 2026)
  - Accumulation in RESR, slow cooling
  - Storage in HESR
  - PANDA luminosity $\leq 2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$
HESR - High Energy Storage Ring

- Circumference: 575 m
- Momentum: 1.5 – 15 GeV/c

Stochastic cooling over full momentum range → ΔE ≈ 50 keV

Production experiments with high-precision beam energy

<table>
<thead>
<tr>
<th>Mode</th>
<th>High luminosity (HL)</th>
<th>High resolution (HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δp/p</td>
<td>~10^{-4}</td>
<td>~4×10^{-5}</td>
</tr>
<tr>
<td>L (cm^{-2}s^{-1})</td>
<td>2×10^{32}</td>
<td>2×10^{31}</td>
</tr>
<tr>
<td>Stored ϒ</td>
<td>10^{11}</td>
<td>10^{10}</td>
</tr>
</tbody>
</table>
HESR - High Energy Storage Ring

<table>
<thead>
<tr>
<th>Mode</th>
<th>High Intensity</th>
<th>Low Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta p/p$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L \text{ (cm}^2\text{s}^{-1})$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stored $\bar{p}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PANDA Detector Requirements

- 1.5 – 15 GeV/c antiprotons on fixed target
  → asymmetric layout
- 4π acceptance
- High rate capability: up to 20MHz average interaction rate
- Efficient event selection for data reduction
- Continuous data acquisition
- Momentum resolution: ~1%
- Precision vertex information for D, $K^0_S$, Y
- γ detection for 1 MeV – 10 GeV
  → crystal calorimeter
- Good Particle ID (e, μ, π, K, p)
  → dE/dx, ToF, RICH/DIRC, muon chambers
Cluster Jet Target (H₂)
World record $4 \times 10^{15} cm^{-2}$
target density achieved

Pellet Target (H₂)
Prototype @ ITEP

Target Beam Dump
Tests @ COSY

Muon Detector
JINR Dubna

Magnet Yoke Octant
Production @ BINP
→ Talk: E. Pyata
All 8 Yoke Octants ready. Assembly in preparation.

SC cable prototype BINP. Segmented Coil – Final Design Review by BINP and CERN.

Solenoid Magnet production @ BINP

Laminated Doors Yoke Supports
Straw Tube Tracker
Self-supporting straws double layers, Ar/CO$_2$
0.05 % X/X$_0$ per layer

Forward Tracker
Tests@PNPI

Forward TOF

Luminosity Detector
Talk: F. Feldbauer
Poster: H. Leithoff

Micro Vertex Detector (Si)
Pixels inner layers
Strips outer layers

Prototype test

Forward RICH (NSU)
Talk: S. Kononov
PANDA – DIRC Detectors

**Detection of Internally Reflected Cherenkov light pioneered by BaBar**
- Cherenkov detector with SiO₂ radiator
- Detected patterns give β of particles

**Barrel DIRC**
- Design similar to BaBar DIRC
- Polar angle coverage: 22° < θ < 140°
- PID goal: 3σ π/K separation up to 3.5 GeV/c

**Endcap Disc DIRC**
- Novel type of DIRC
- Polar angle coverage: 5° < θ < 22°
- PID goal: 3σ π/K separation up to 4 GeV/c

**Key technologies:**
- fast single photon timing in high B-fields with small pixels and long lifetime
- high-quality fused silica radiators

DIRC

Talk: C. Schwarz
Poster: A. Ali
PANDA - Target Electromagnetic Calorimeter

Crystal Calorimeter based on ~15,500 high quality second-generation PWO II (PbWO₄) crystals
- Small radiation length $X_0 = 0.89 \text{ cm}$ (20 cm $\approx 22 X_0$)
- Short decay time $\tau = 6.5 \text{ ns}$
- Increased light yield, at -25°C
- Time resolution < 2 ns
- Coverage: 99.8% of 4π
- TDR approved

Challenges
- temperature stable to 0.1 °C
- control radiation damage

Barrel Calorimeter
- 11000 crystals PWO II
- LAAPD readout, 2x1 cm$^2$
- $\sigma(E)/E \sim 1.5%/\text{VE} + \text{const.}$

Forward Endcap
- 4000 crystals PWO II
- High occupancy in center
- LA APD and VPTT

Backward Endcap for hermeticity
- 530 crystals PWO II

Large Area APDs
- CMS
- PANDA 7x14 mm$^2$
Crystal Production
~60% produced at BTCP (Russia)
New producer Crytur (Czech Rep.)

APD / Preamp / VPTT
Screening 30000 APDs
ASIC preamp design ready
VPTT Modules ready

Assembly
Forward-EMC: near completion
Backward-EMC: production started
Barrel-EMC: 1\textsuperscript{st} slice completed
Muon Detector system
TDR and Prototypes - JINR Dubna

Muon system rationale
Low momenta, high BG of pions
→ Multi-layer range system

Drift tubes with wire & cathode strip readout

FEE FPGA development
Production designs @ JINR

Forward Shashlyk Calorimeter
TDR and Prototypes - IHEP Protvino
→ Talk: M. Preston

Interleaved layers
scintillator / absorber

WLS fibers to PMTs
FADCs for digitization
PANDA – Data Acquisition and Controls

Experimental Physics and Industrial Control System

Supervisory Layer
- Controls GUI interface
- Databases & configurations
- Interface: HESR, DAQ

Control Layer
- I/O controllers
- Device Drivers
- Archiving sub-system

Field Layer
- PANDA sub-systems specific
- Interface: Detector Safety System

Self triggered readout
- Components:
  - Time distribution: SODA
  - Intelligent frontends
  - Powerful compute nodes
  - High speed network

Data Flow:
- Data reduction
- Local feature extraction
- Data burst building
- Event selection
- Data logging after online reconstruction

Programmable Physics Machine
- Online selection schemes and physics algorithms are a key for successful measurements

Detected Frontends
- TDC developments @GSI
  - Talk: M. Traxler

FPGA h/w

Machine Learning Schemes

Experimental Physics and Industrial Control System

Online Event Filter

DAQ Timing

Timing

Event Filter
PANDA Collaboration

Collaboration

UP Marche Ancona  
U Basel  
IHEP Beijing  
U Bochum  
Abant Izzet Baysal  
U Golkoy, Bolu  
U Bonn  
U Brescia  
IFIN-HH Bucharest  
AGH UST Cracow  
IFJ PAN Cracow  
JU Cracow  
Cracow UT  
FAIR Darmstadt  
GSI Darmstadt  
JINR Dubna  
U Erlangen  
NWU Evanston  
U Frankfurt  
LNF-INFN Frascati  
U & INFN Genova  
U Gießen  
Giresun U  
U Glasgow  
KVI-CART Groningen  
Gauhati U, Guwahati  
USTC Hefei  
URZ Heidelberg  
Doğuș U, Istanbul  
Okan U, Istanbul  
FZ Jülich  
IMP Lanzhou  
INFN Legnaro  
Lund U  
HI Mainz  
U Mainz  
RINP Minsk  
ITEP Moscow  
MPEI Moscow  
U Münster  
BINF Novosibirsk  
Novosibirsk State U  
U Wisconsin, Oshkosh  
U & INFN Pavia  
PNPI St. Petersburg  
West Boh. U, Pilzen  
Charles U, Prague  
Czech TU, Prague  
IHEP Protvino  
Irfu Saclay  
KTH Stockholm  
Stockholm U  
SUT, Nakhon Ratchasima  
SVNIT Surat-Gujarat  
S Gujarat U, Surat-Gujarat  
FSU Tallahassee  
Nankai U, Tianjin  
U & INFN Torino  
Politecnico di Torino  
U Uppsala  
SMI Vienna  
NCBJ Warsaw  
U York

more than 420 physicists from  
from more than 65 institutions in 18 countries

Technical Design Reports

https://fair-center.de/index.php?id=329&L=0
PANDA Planning

<table>
<thead>
<tr>
<th>Phase 0</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day-1 Setup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PANDA Hall assumed available Q1/2022</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Setup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3: RESR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Phase 0 Experiments of PANDA detectors and software at HADES, MAMI, COSY and GlueX
- Construction of Phase 1 systems
- Installation periods
  1. Solenoid, Dipole, Supports
  2. Detectors
- Commissioning with protons
- Physics with antiprotons
- Construction of Phase 2 systems
- Installation period remaining detectors
- Physics with antiprotons
Schedule for FAIR Science

- Working towards the completion of FAIR by 2025/26
- Major thrust is on construction of FAIR accelerators and experiments.
- At the same time *staged approach to FAIR science and progressive commissioning of accelerators and detectors:*

**FAIR phase 0: start in 2018/2019**
- FAIR day 1 configurations/phase 1 experiments with FAIR accelerators progressively approaching design parameters → 2024/25 ...
- Full FAIR operation 2025/26+
Phase-0 at GSI: HADES (CBM, PANDA)

- **First HADES beam data obtained** in February 2019 during commissioning of the beam on target
- **HADES production beam time** 28 days in March 2019 Unique studies of baryon-rich matter through 14 billion recorded events of Ag+Ag
- **HADES forward detection** system to be complemented this year utilising technology developed for and in close cooperation with PANDA

ECAL upgrade: 4 sectors tested with beam

RICH upgrade: rings from particles observed

Straw Tracker Stations
FAIR is coming

**FAIR is a unique opportunity for world science.**
- A fascinating and broad science program, with world class experiments

**The Project is rapidly developing**
- Both civil construction and procurement of accelerator components proceed rapidly, aiming at the start of FAIR by 2025
- The experiments are getting ready
- First-class intermediate research program, FAIR Phase-0 has started.
Unique Opportunities & Challenges

Thank You!