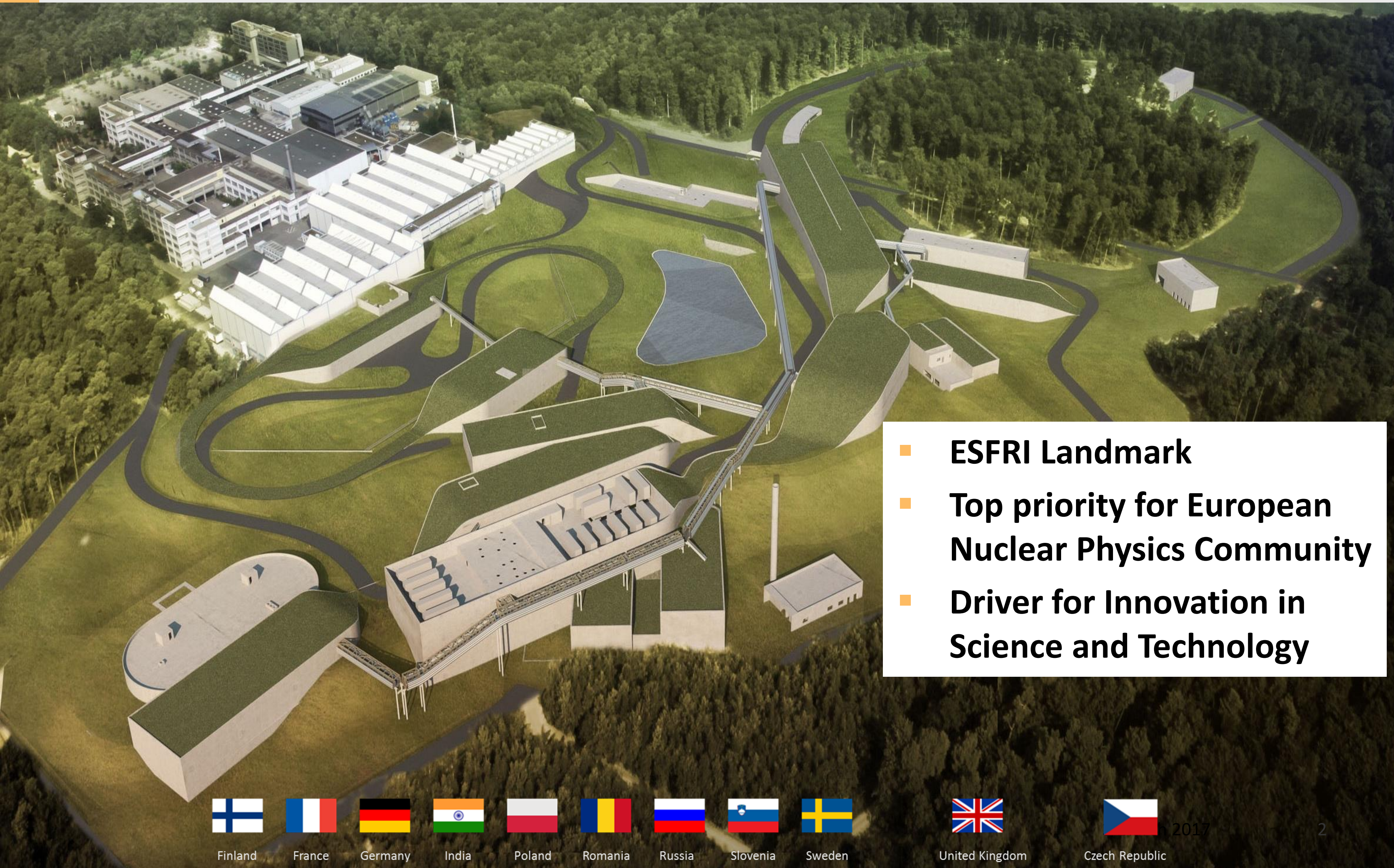
FAIR Status

and the PANDA Experiment

Anastasios Belias, GSI

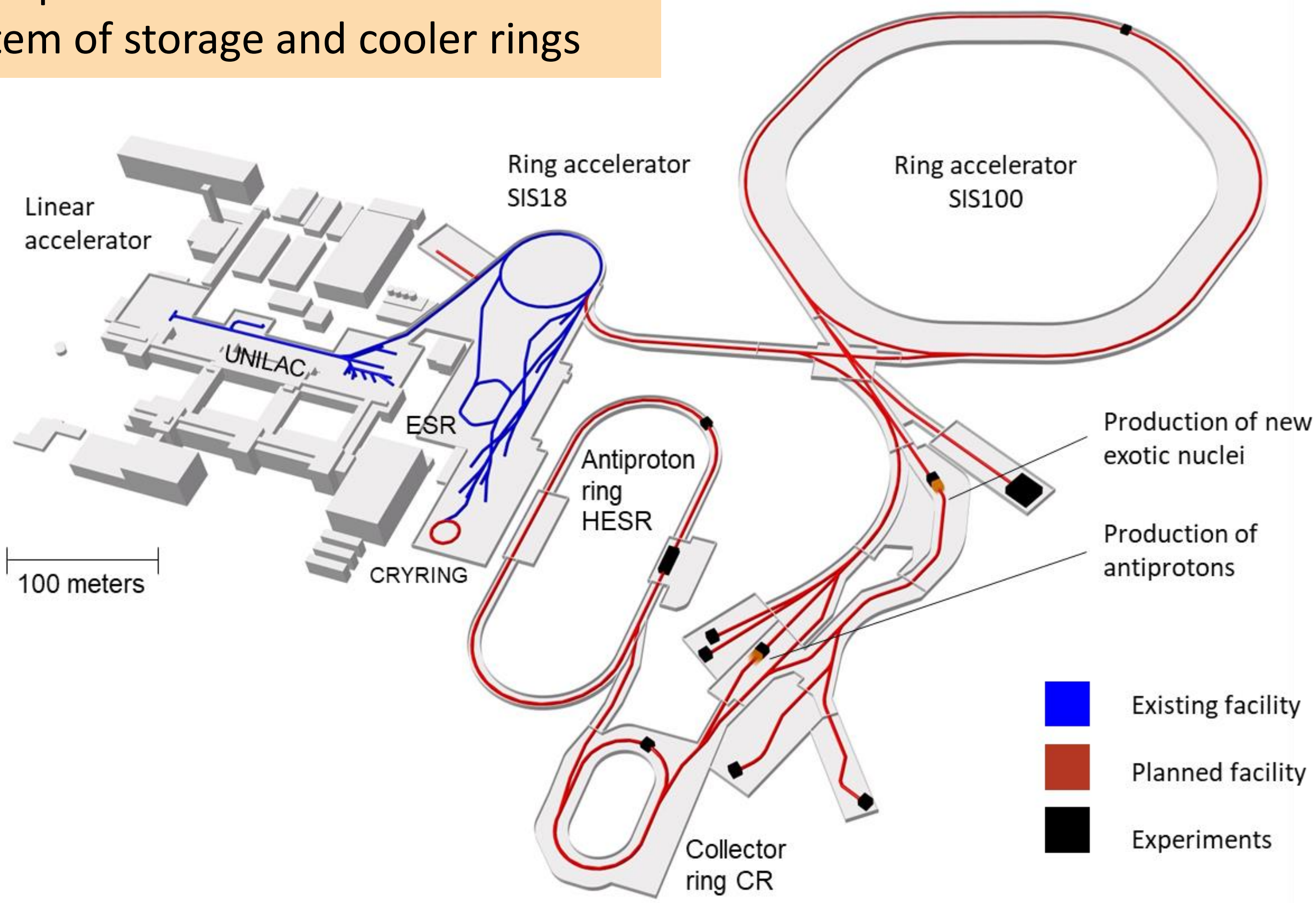
FAIR: Facility for Antiproton and Ion Research



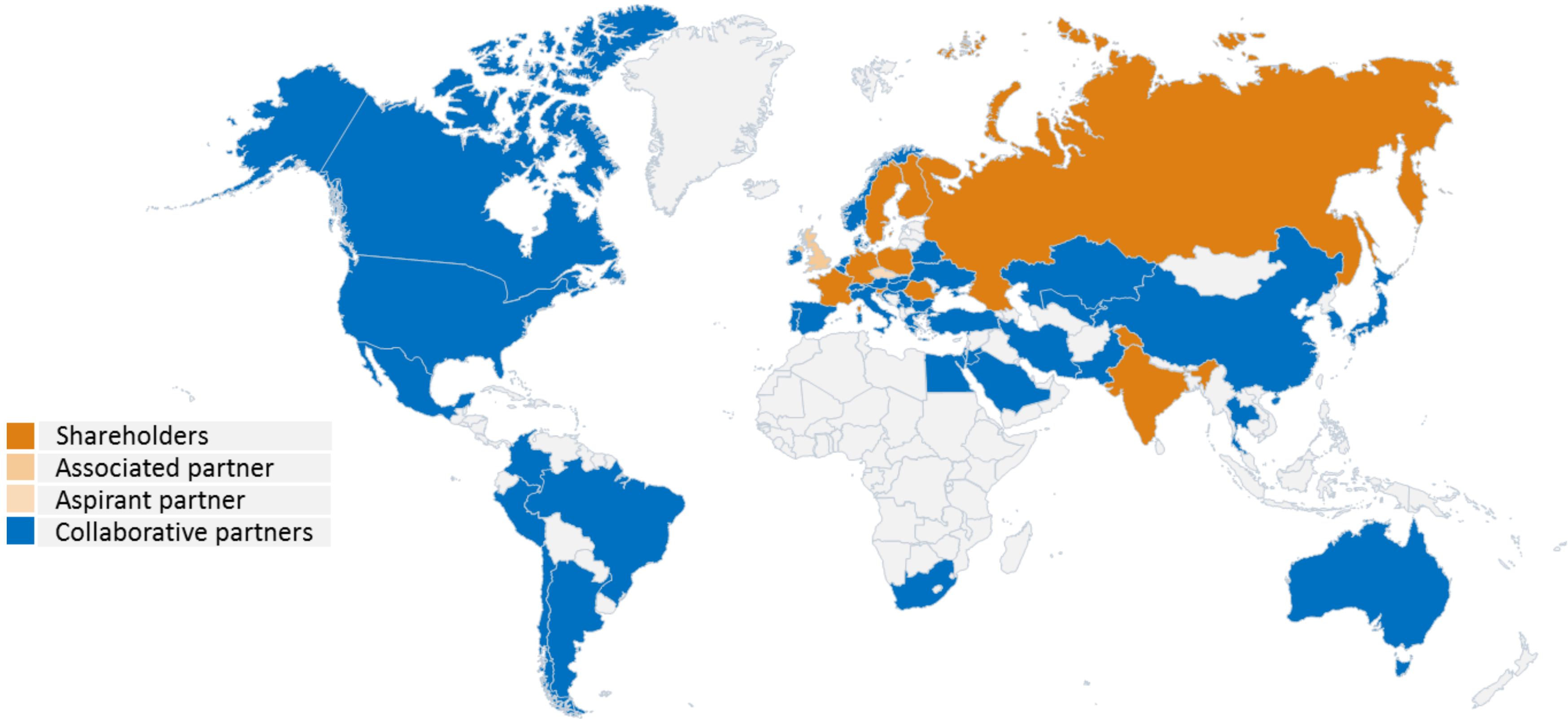
- **ESFRI Landmark**
- **Top priority for European Nuclear Physics Community**
- **Driver for Innovation in Science and Technology**

FAIR – The Facility

- **Intensity gain: x 100 – 1000**
- 10 x energy (comp. to GSI)
- **Antimatter:** antiproton beams
- **Precision:** System of storage and cooler rings



FAIR: International Cooperation



- **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

Status of FAIR: Accelerators: construction / procurement progress

~ 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

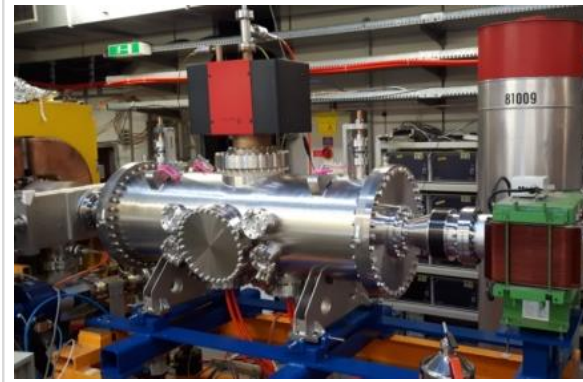
Delivery of 1st 6 series Power Converter from India, (ECIL, India)

Status of FAIR: Accelerators:
construction / procurement progress

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

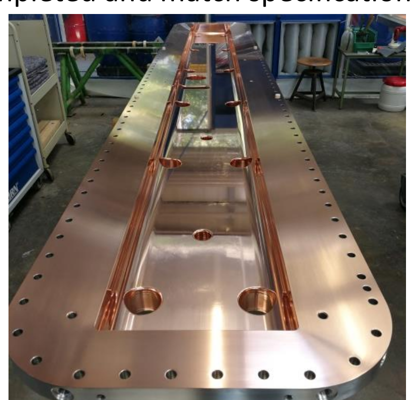
First-of-Series of the Super-FRS short SC Multiplet arrived in February 2019 at CERN test facility for execution of the Site Acceptance Test

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

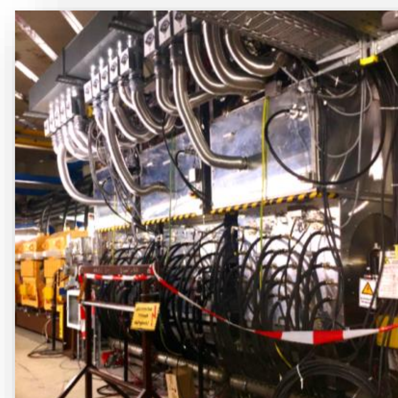


Successfully First-of-Series FAT for the Super-FRS short SC Multiplet took place in Italy at January 2019

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.

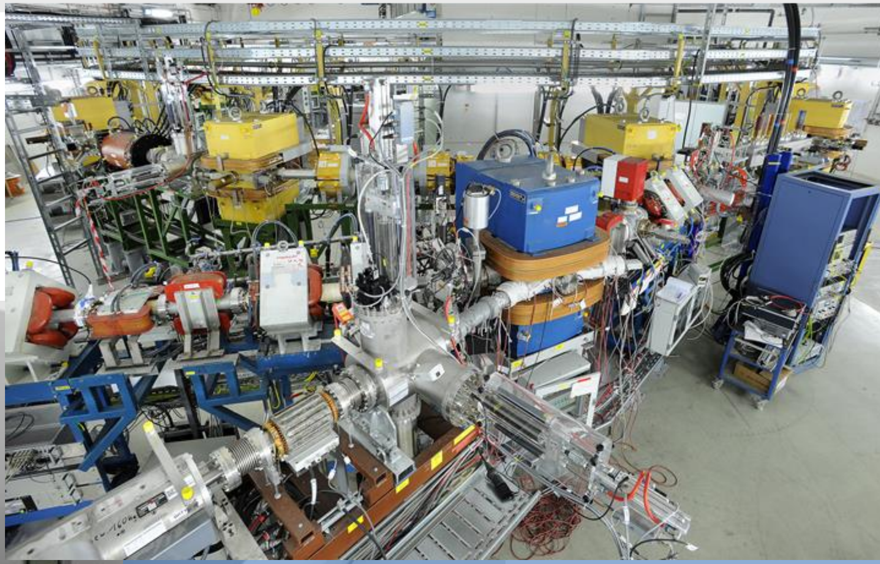
CERN: Test facility completed for the Super-FRS s.c. dipoles and multipletts

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

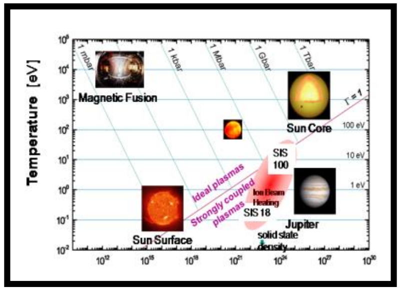
- FIRST FAIR accelerator
- ready for experiments and tests



View from local injector to the ring

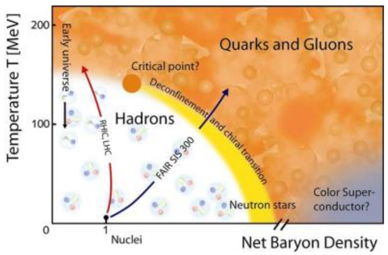
CRYRING –
heavy ion storage ring, relocated to FAIR from Manne Siegbahn Lab. of Stockholm Uni.

The FAIR science: four pillars



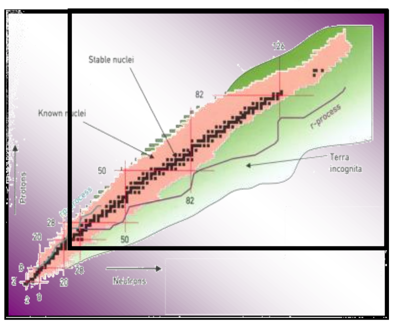
atomic physics, biophysics, plasma physics, material research, other applications

APPA



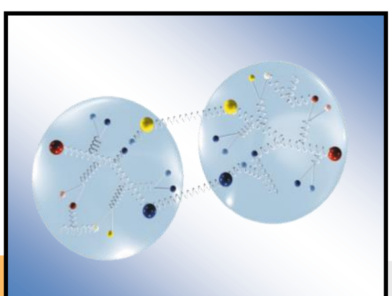
nuclear- and quark-matter

CBM



nuclear structure and nuclear astrophysics

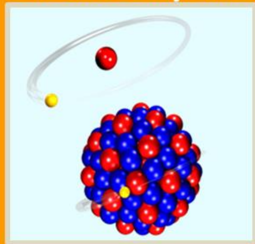
NuSTAR



hadron structure and dynamics

PANDA

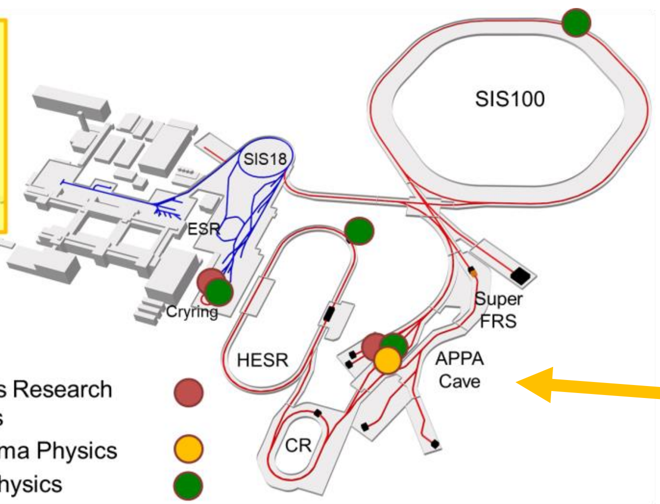
APPA –
Atomic Physics, Plasma Physics, and Applied Sciences

Atomic Physics	Plasma	Materials	Bio
			
SPARC	HED@FAIR	MAT/BIOMAT	BIO/BIOMAT

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

FACILITIES
SIS100
HESR
APPA-Cave

ESR
CRYRING
HITRAP

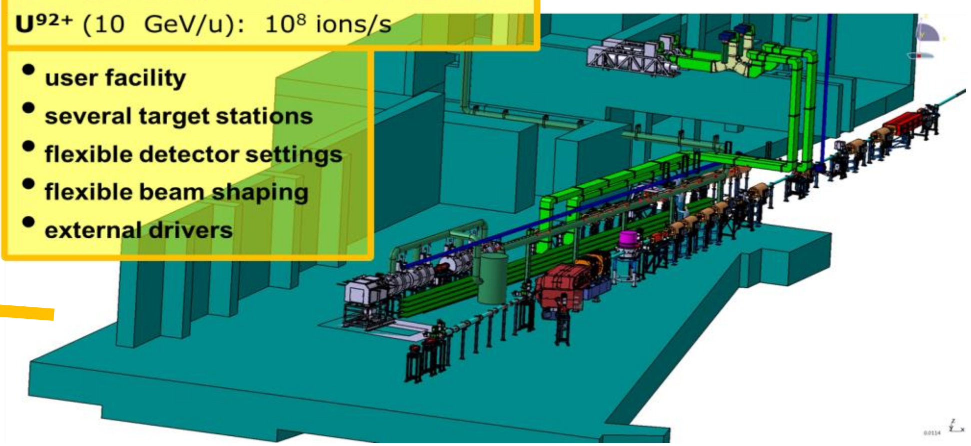


BIOMAT: Materials Research and Biophysics
HED@FAIR: Plasma Physics
SPARC: Atomic Physics

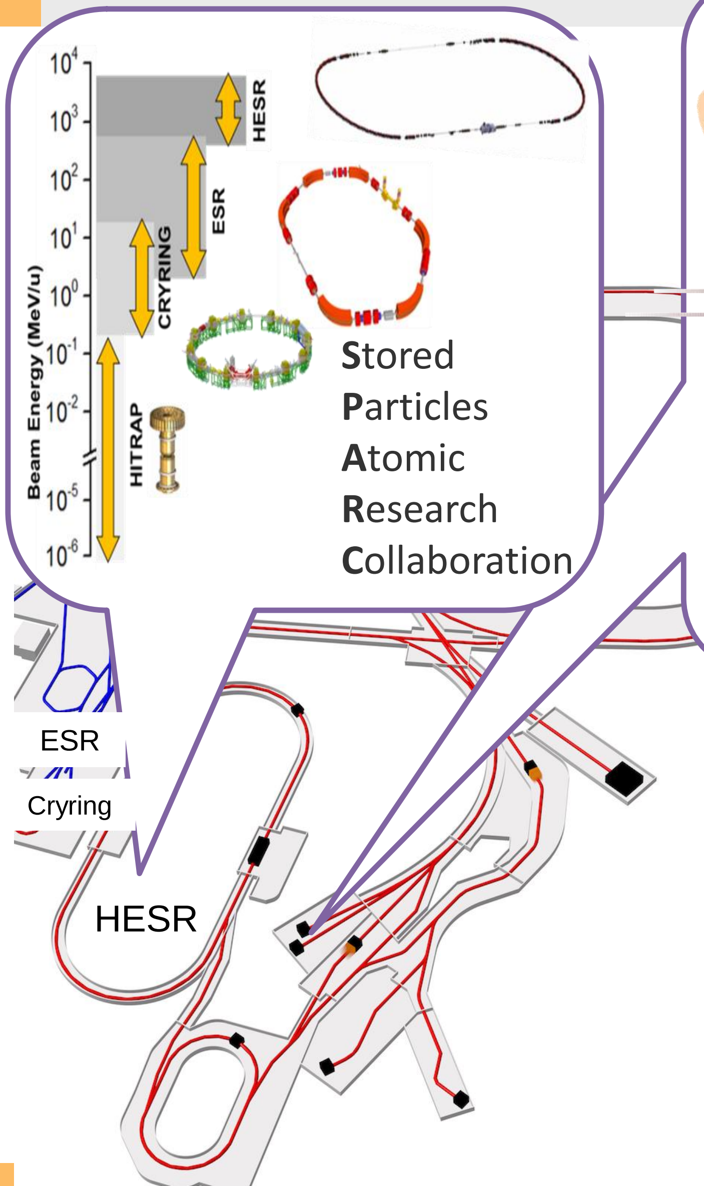
protons (10 GeV): 2 x 10^{13} p/bunch
U^{28+} (2 GeV/u): 5 × 10^{11} ions/bunch
U^{92+} (10 GeV/u): 10^{8} ions/s

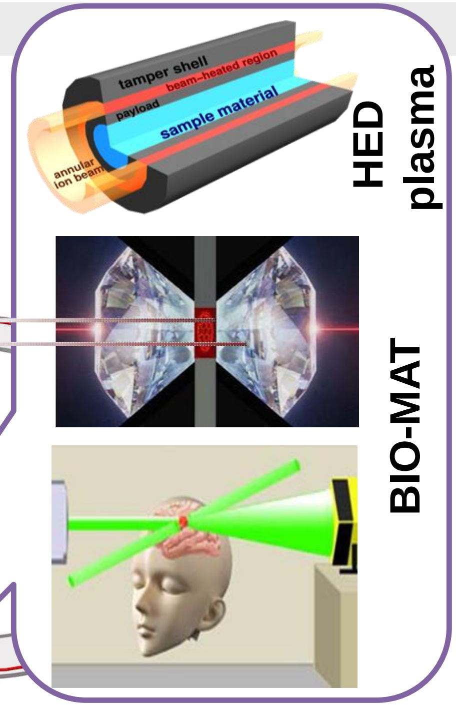
- user facility
- several target stations
- flexible detector settings
- flexible beam shaping
- external drivers

APPA Cave



APPA





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

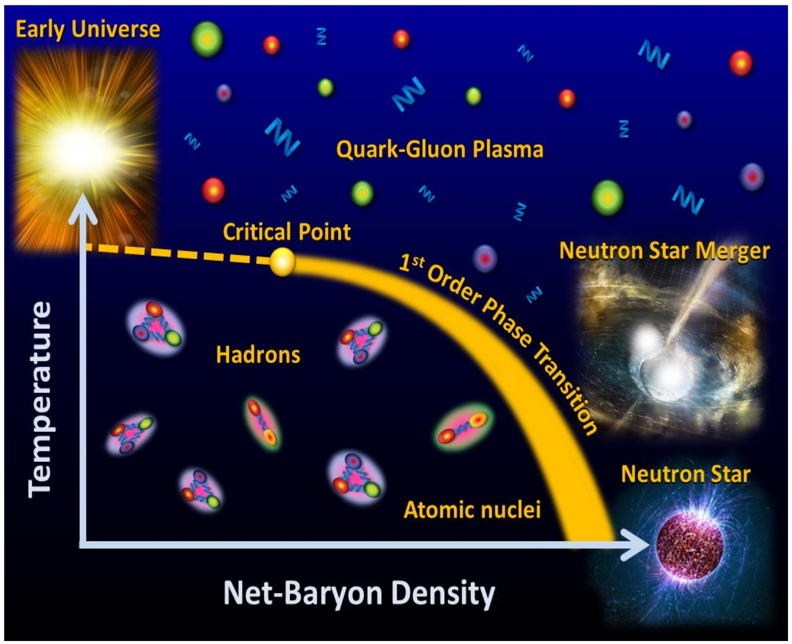
Atomic Physics
SPARC: ~400 members from 26 countries

Plasma Physics
HED: ~300 members from 16 countries

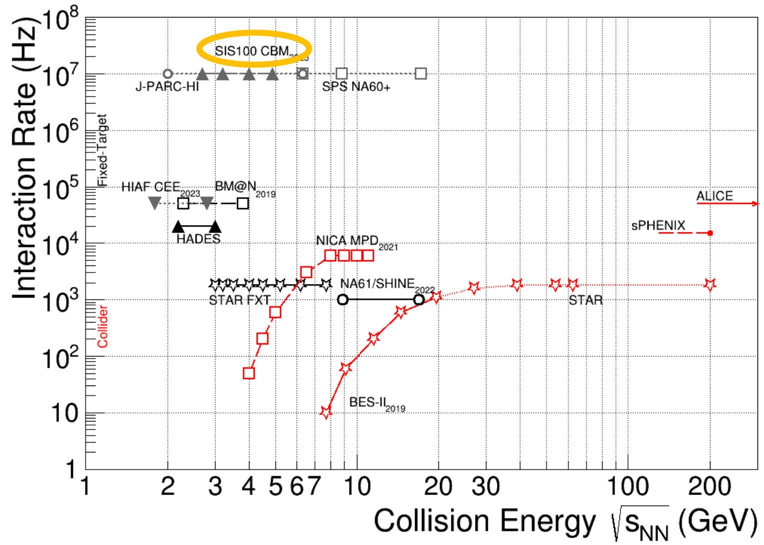
Materials Research and Biophysics
BIOMAT: ~100 members from 12 countries

CBM - Compressed Baryonic Matter

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 μ_B

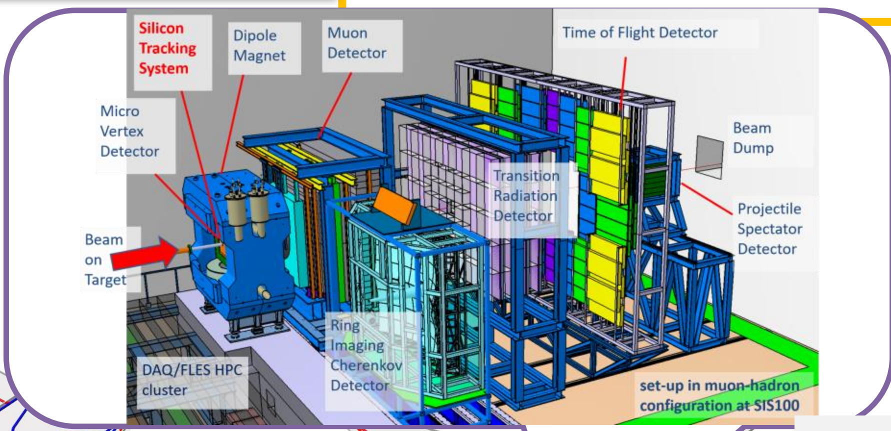


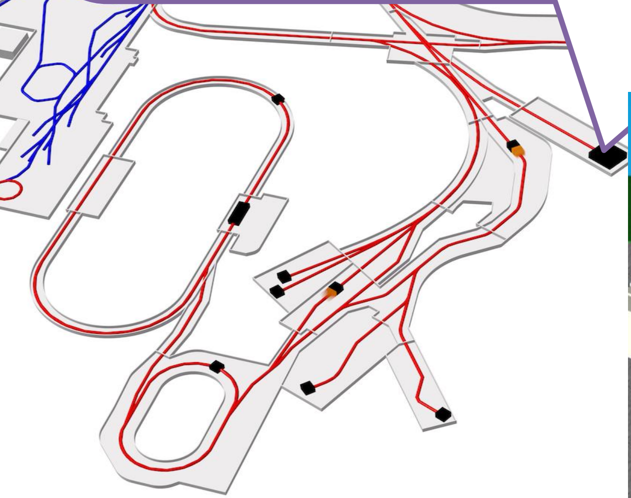
CBM collaboration: 55 institutions, 470 members in 11 countries

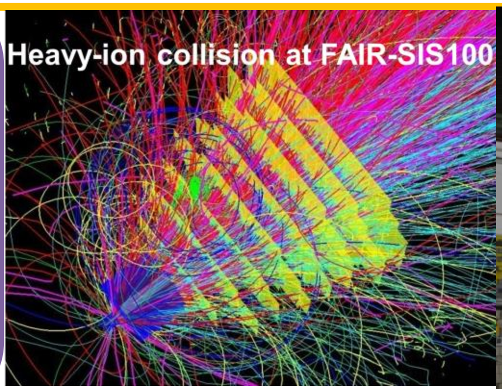
CBM Experiment – Construction Phase

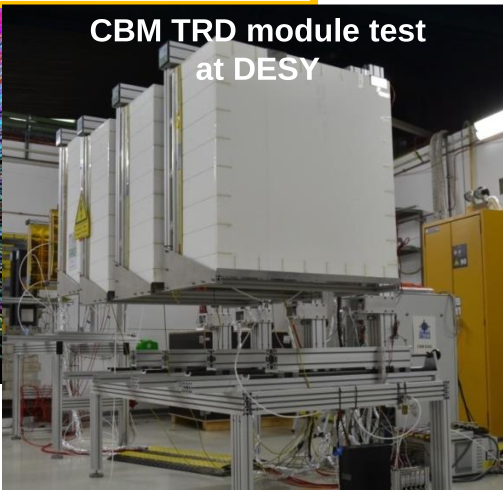
- typical collision system: Au^{79+} +Au at 4 to 11 AGeV
- Day 1: beam intensity: $5x10^7$ ions/sec; interaction rate 0.5 MHz
- MSV: beam intensity: 10^9 ions/sec; interaction rate 10 MHz

STS
→*Poster: P. Pfistner*

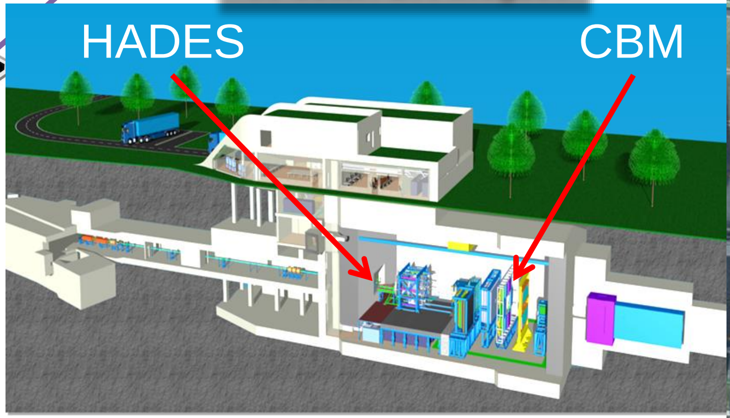






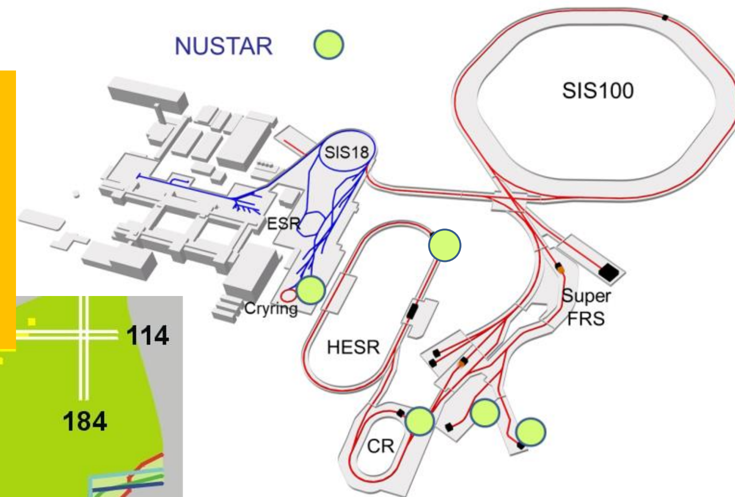


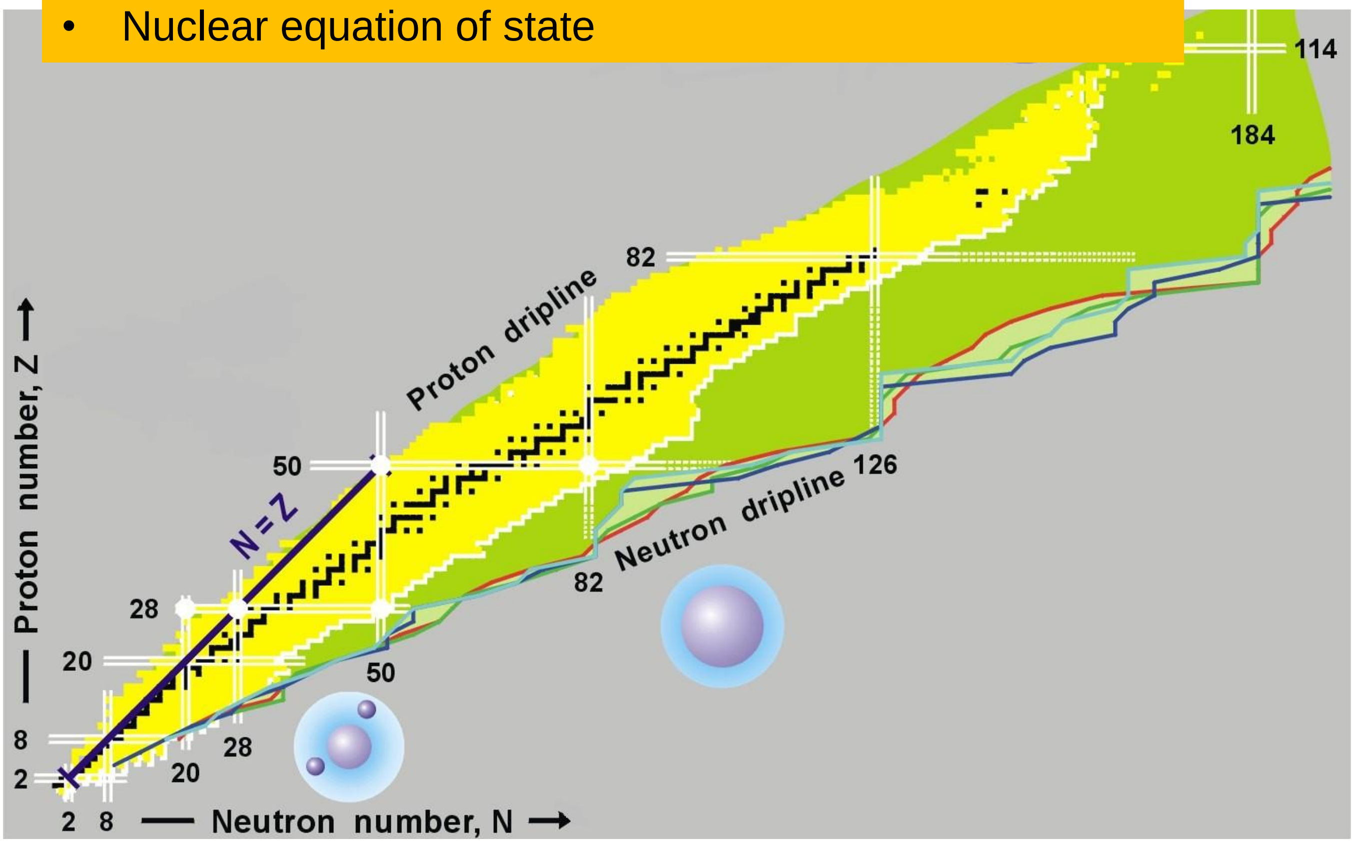
PSD
→*Poster:* **D. Finogeev**



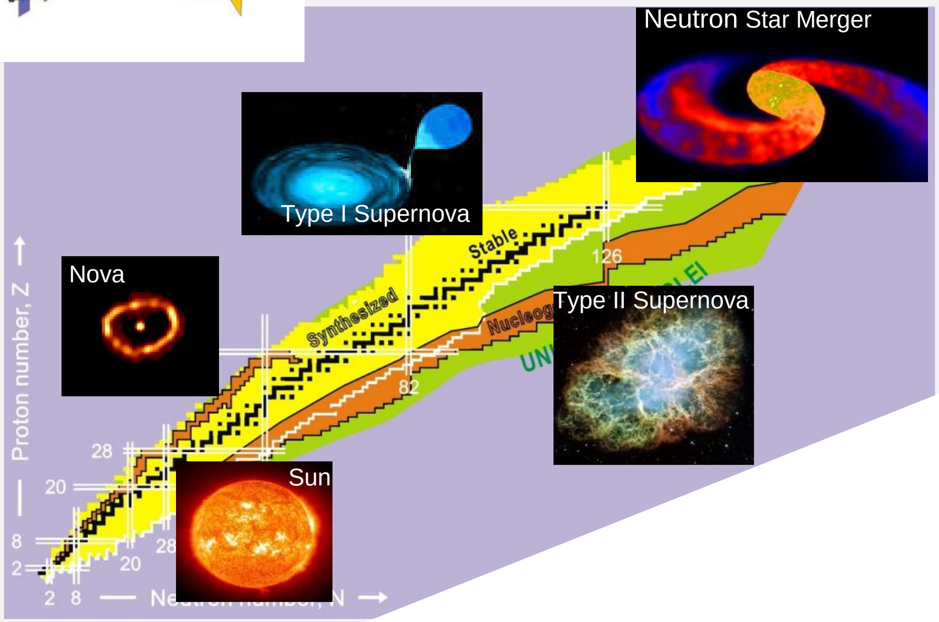
NUclear STructure Astrophysics and Reactions

- 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

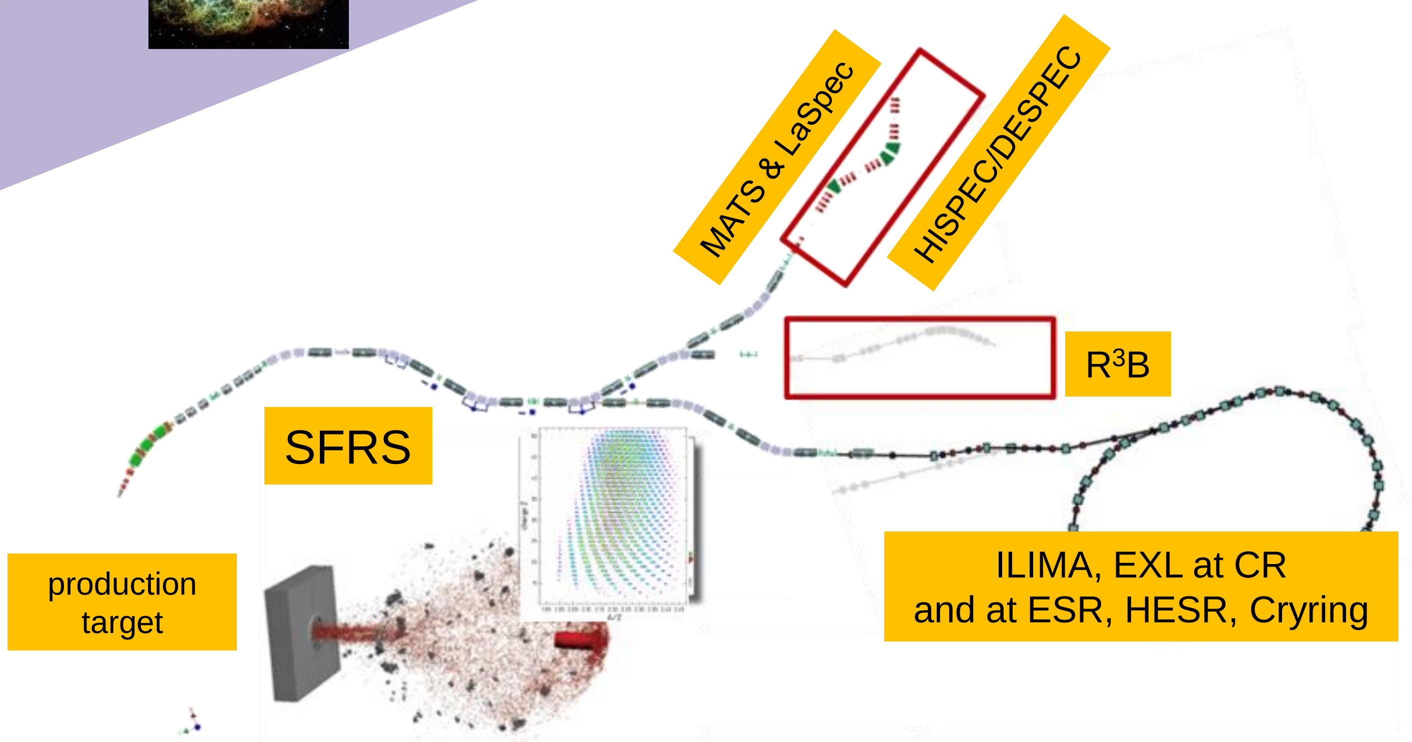


„Nucleosynthesis sites“ in the universe

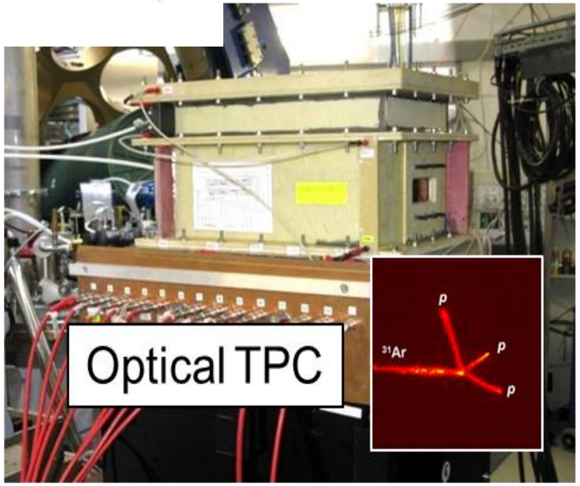
„Nucleosynthesis sites” at FAIR

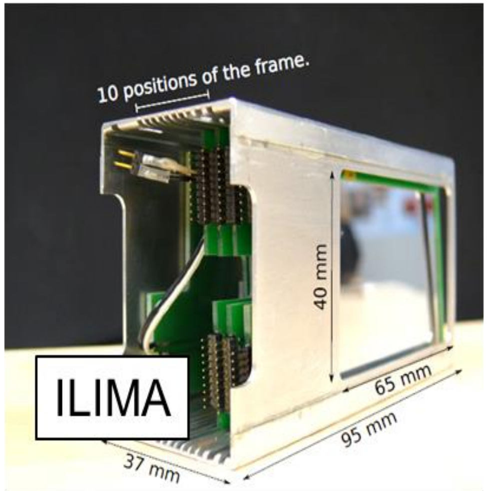
Primary intensities vs. GSI: x 100

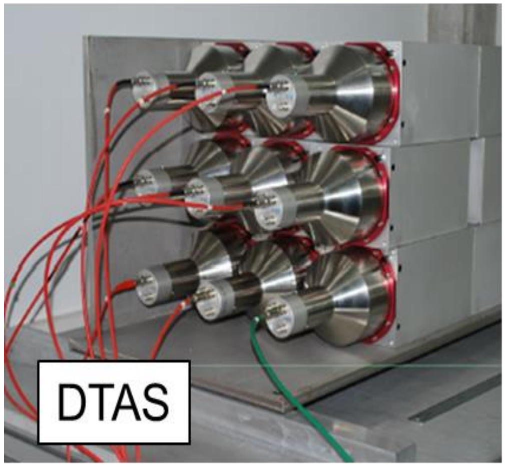
SIS 100

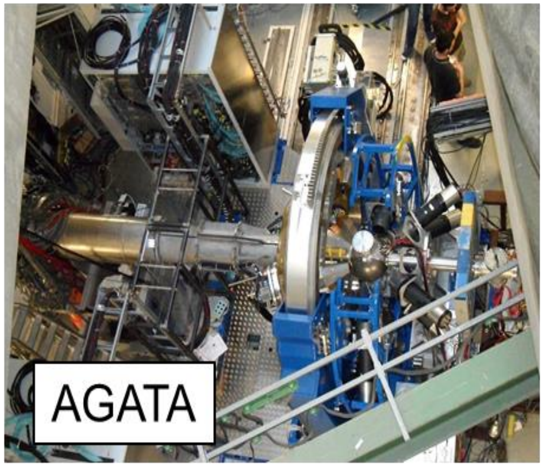


Status of NuSTAR experiments
- detector R&D and construction

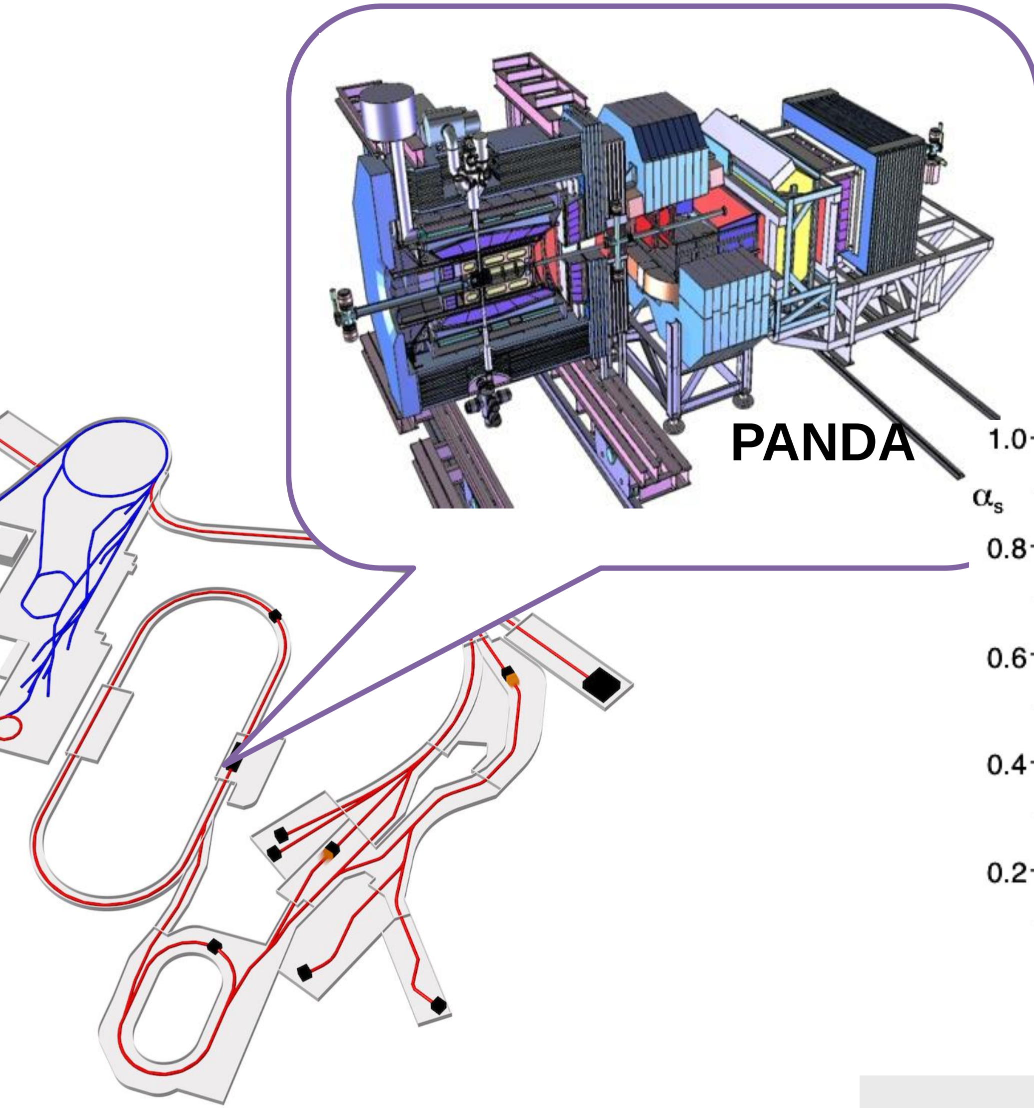




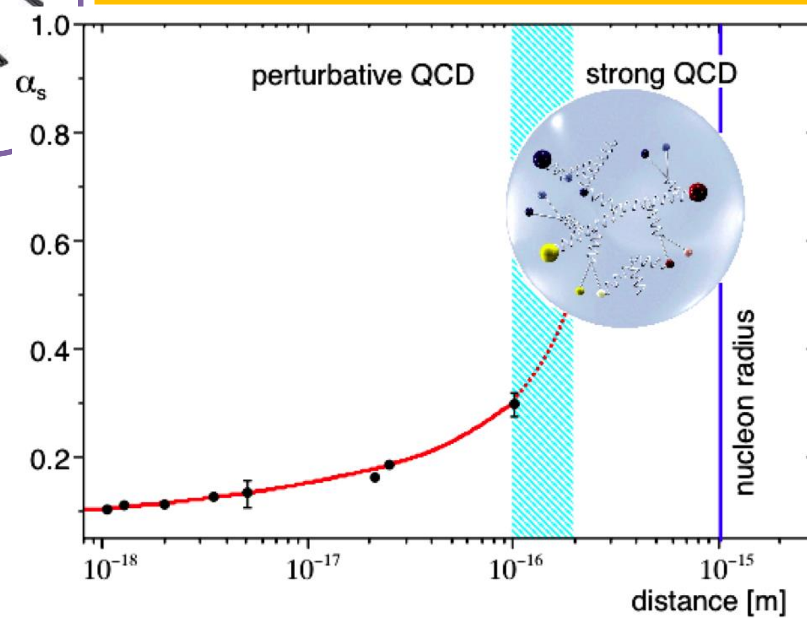




PANDA



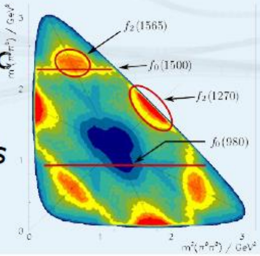
PANDA
anti**P**roton
ANnihilations at **DA**rmstadt



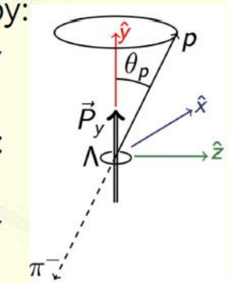
PANDA - Anti**P**roton **An**nihilation at **D**armstadt

Bound States of Strong Interaction

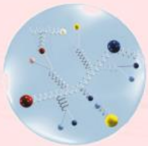
Spectroscopy
- New narrow XYZ: *Search for partner states*
- Production of exotic *QCD states: Glueballs & hybrids*



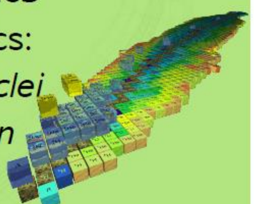
Strangeness
- Hyperon spectroscopy: *excited states largely unknown*
- Hyperon polarisation: *accessible by weak, parity violating decay*



Nucleon Structure
- Generalized parton distributions: *Orbital angular momentum*
- Drell Yan: *Transverse structure, valence anti-quarks*
- Time-like form factors: *Low and high E, e and μ pairs*



Nuclear Hadron Physics
- Hypernuclear physics:
  - *Double Λ hypernuclei*
  - *Hyperon interaction*
- Hadrons in nuclei: *Charm and strangeness in the medium*



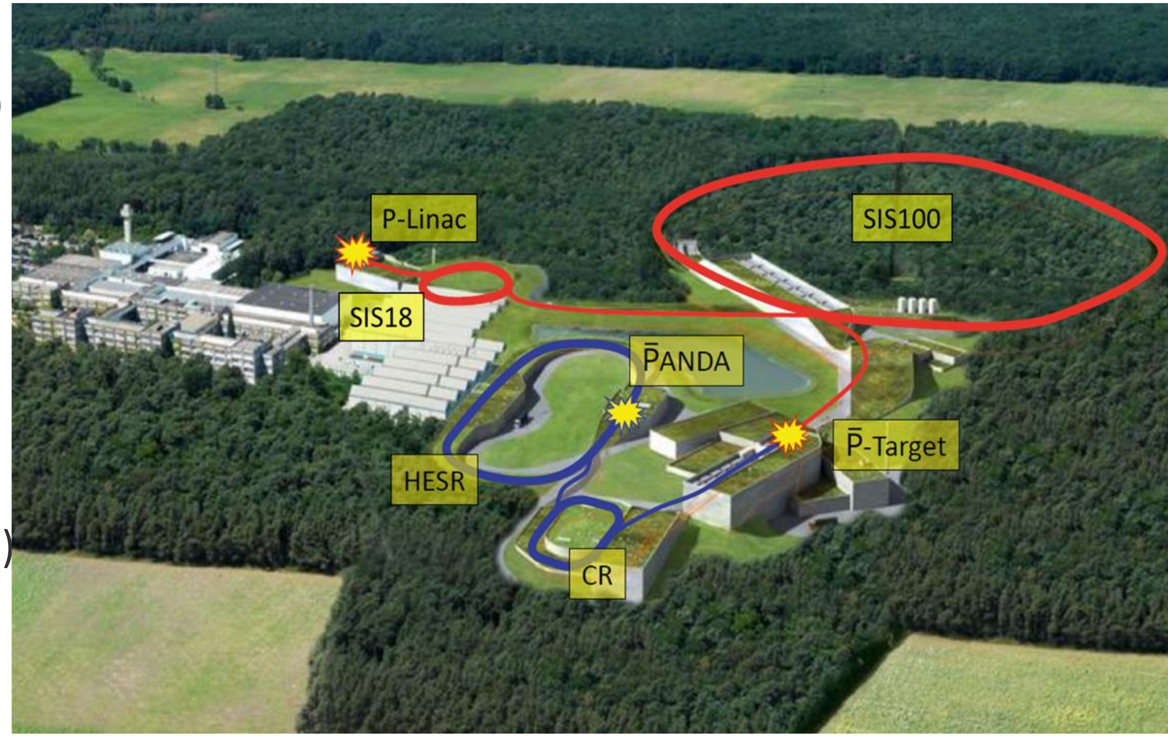
NuPECC Long Range Plan

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.

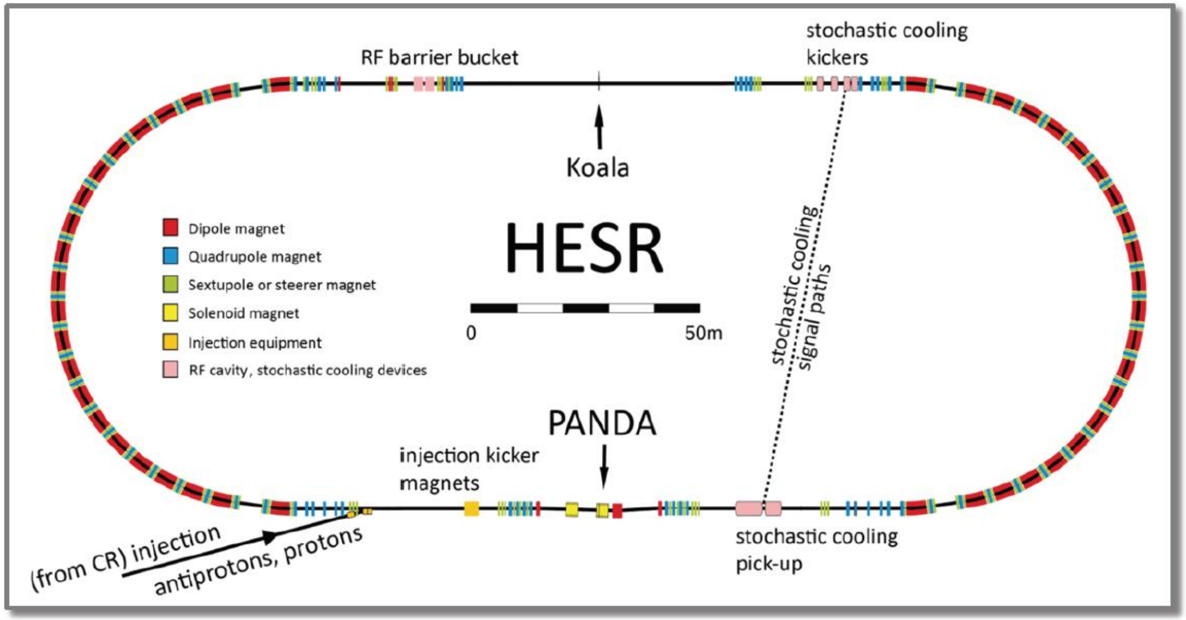
Antiprotons at FAIR

- **Antiproton production**
- Proton Linac *(70 MeV)*
- Accelerate p in SIS18/100 *(4/29 GeV)*
- Produce p̄ on Ni/Cu target *(3 GeV)*
- Collection in CR, fast cooling
- Accumulation in HESR
- PANDA luminosity ≤ $2x10^{31}cm^{-2}s^{-1}$
- p̄ 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 ≤ $2x10^{32}cm^{-2}s^{-1}$



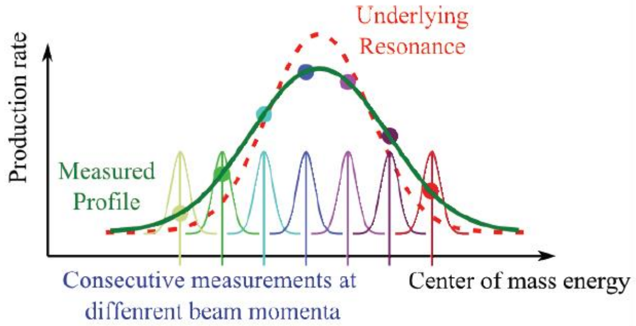
HESR - High Energy Storage Ring



Circumference	575 m
Momentum	1.5 – 15 GeV/c

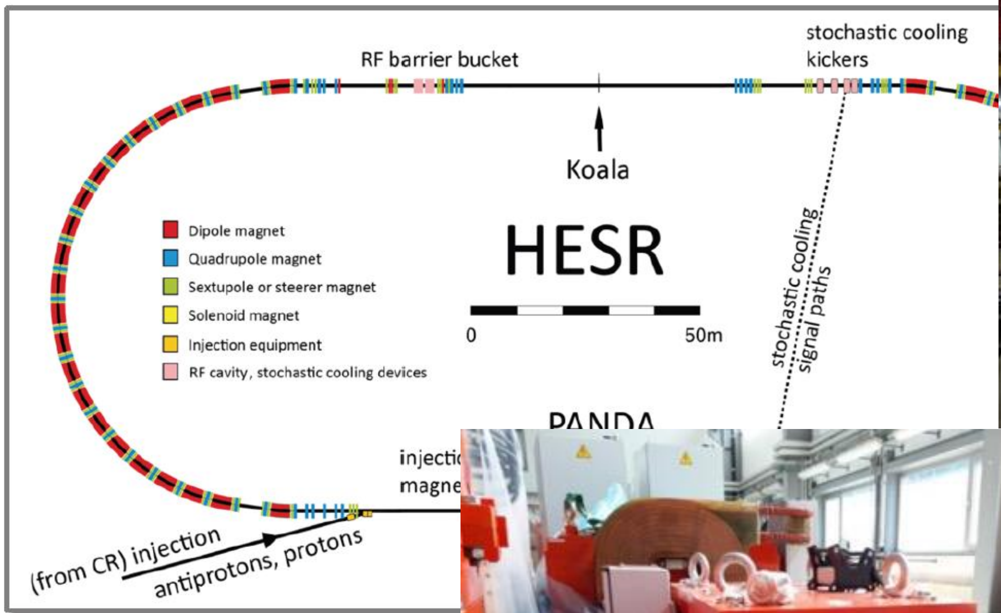
Stochastic cooling
over full momentum range
$\longrightarrow \Delta E \approx 50$ keV

Production experiments
with high-precision beam energy



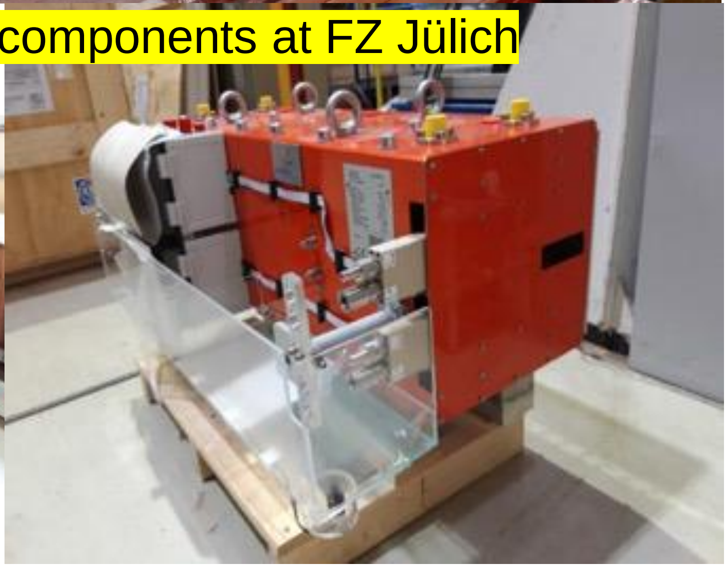
Mode	High luminosity (HL)	High resolution (HR)
$\Delta p/p$	$\sim 10^{-4}$	$\sim 4\times10^{-5}$
L ($cm^{-2}s^{-1}$)	2×10^{32}	2×10^{31}
Stored $\bar{p}$	10^{11}	10^{10}

HESR - High Energy Storage Ring



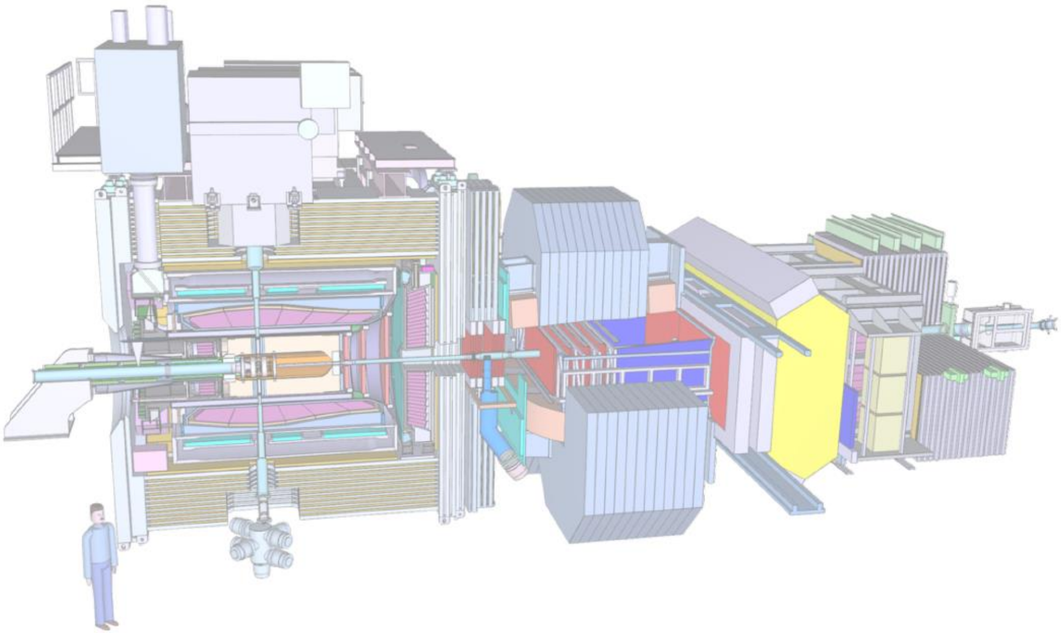
Mode	High
Δp/p	
L ($cm^{-2}s^{-1}$)	
Stored p̄	

HESR components at FZ Jülich

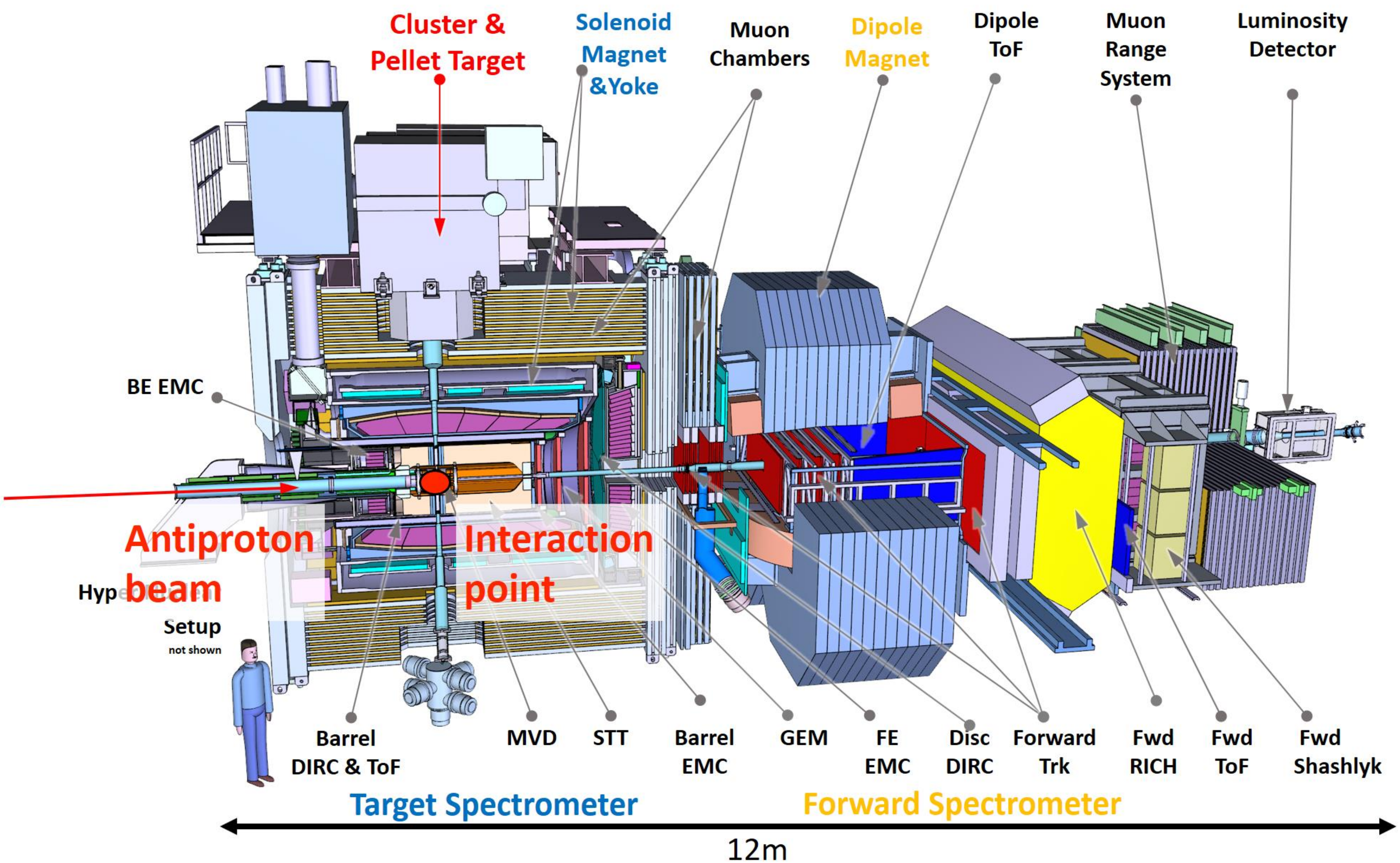


PANDA Detector Requirements

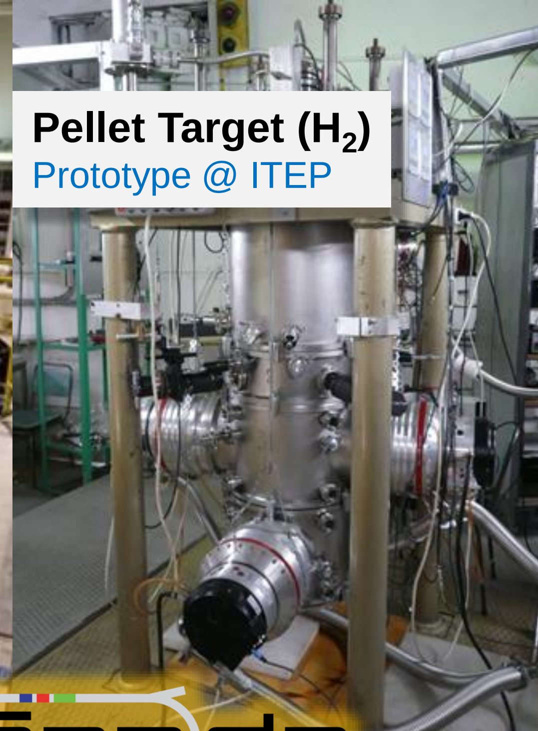
- 1.5 – 15 GeV/c antiprotons on fixed target
  → asymmetric layout
- 4π acceptance
- High rate capability: up to
  20MHz average interaction rate
- Efficient event selection for data reduction
- Continuous data acquisition
- Momentum resolution: ~1%
- Precision vertex information for D, K^0_s, Y
- γ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



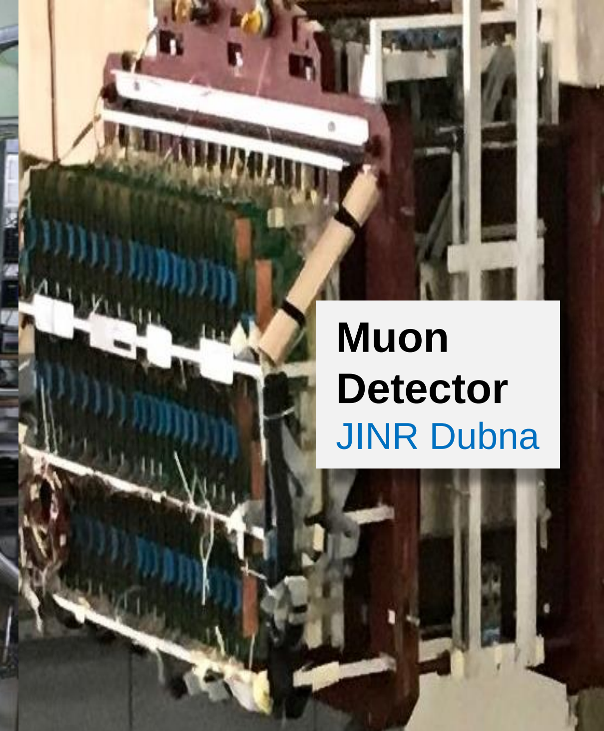
PANDA Detector



Cluster Jet Target (H_2)
World record $4 \times 10^{15} cm^{-2}$ target density achieved



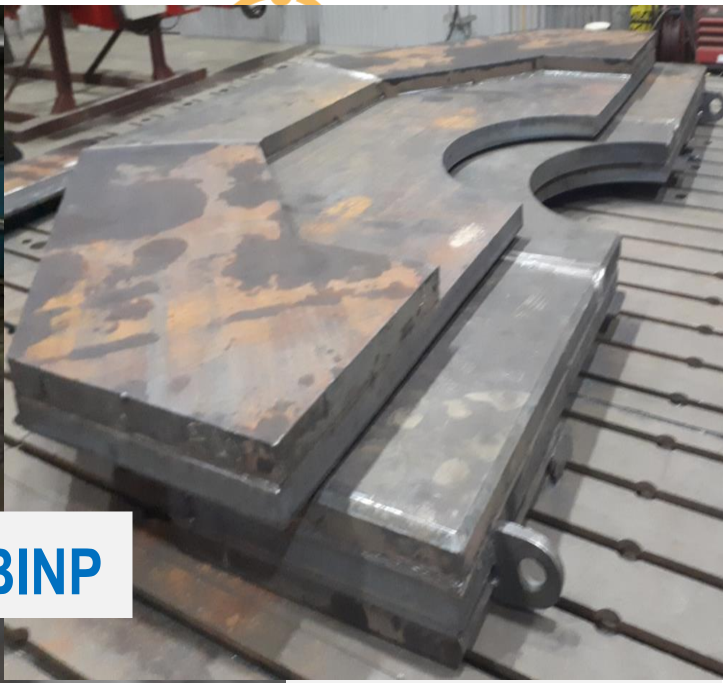
Pellet Target (H_2)
Prototype @ ITEP



Muon Detector
JINR Dubna

Target Beam Dump
Tests @ COSY

Magnet Yoke Octant
Production @ BINP
→ Talk: E. Pyata

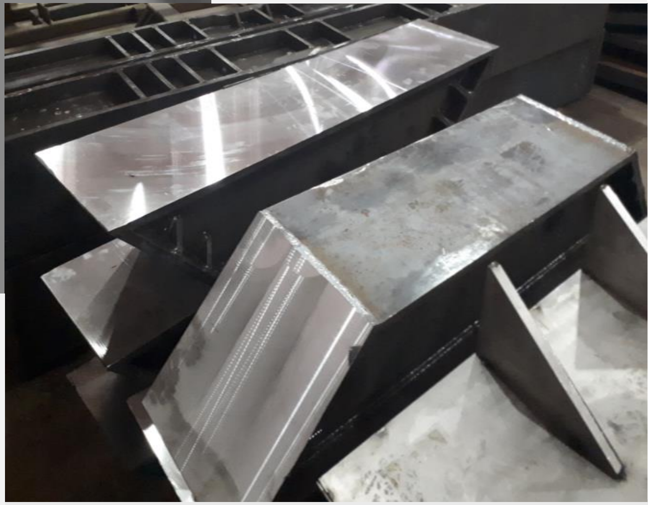


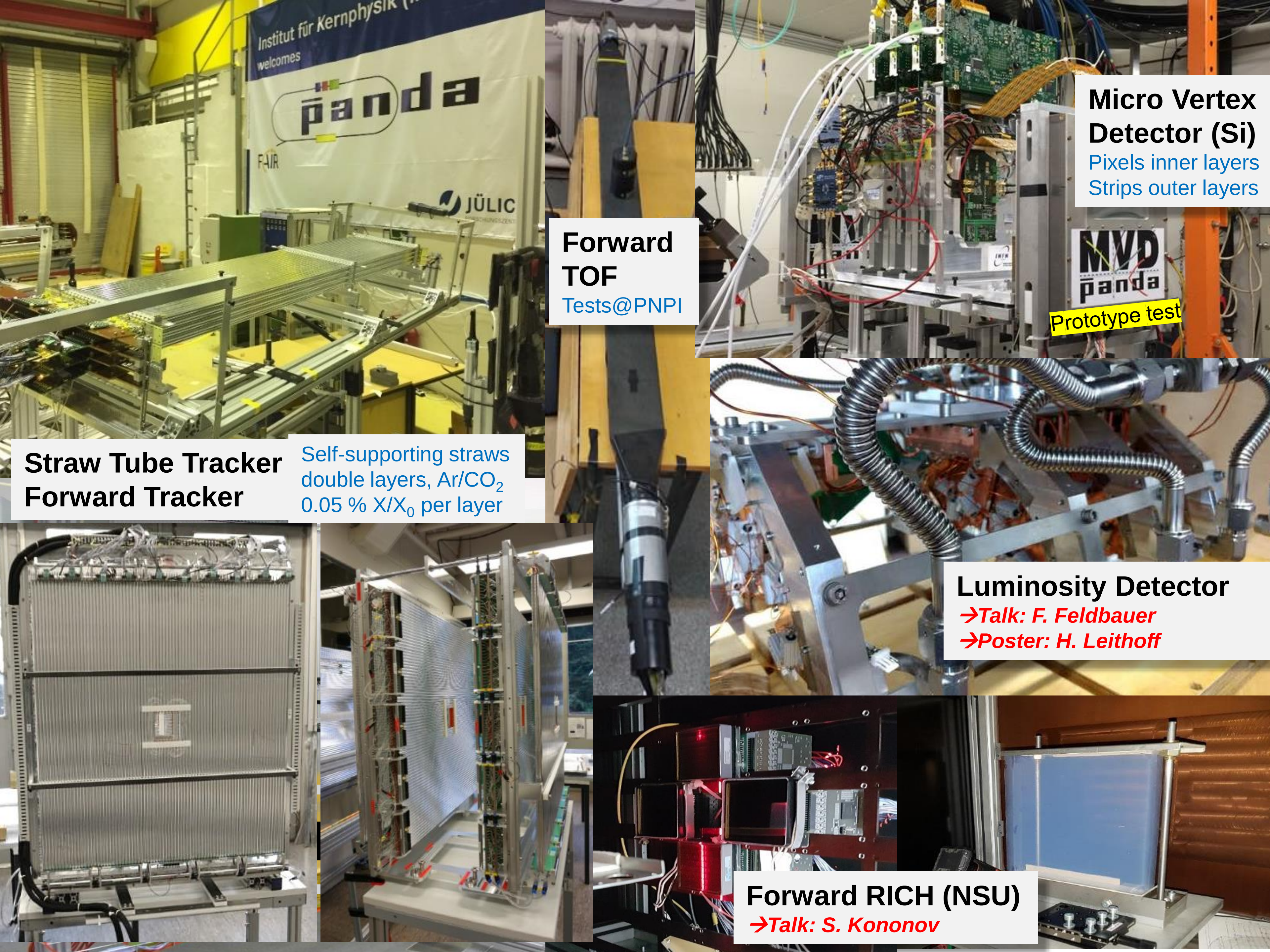
Solenoid Magnet production @ BINP

Laminated Doors
Yoke Supports

All 8 Yoke Octants ready.
Assembly in preparation.

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




Institut für Kernphysik
welcomes
panda
FAIR
JÜLICH
Forward
TOF
Tests@PNPI
Micro Vertex
Detector (Si)
Pixels inner layers
Strips outer layers
MVD
panda
Prototype test
Straw Tube Tracker
Forward Tracker
Self-supporting straws
double layers, Ar/CO2
0.05 % X/X0 per layer
Luminosity Detector
→Talk: F. Feldbauer
→Poster: H. Leithoff
Forward RICH (NSU)
→Talk: S. Kononov

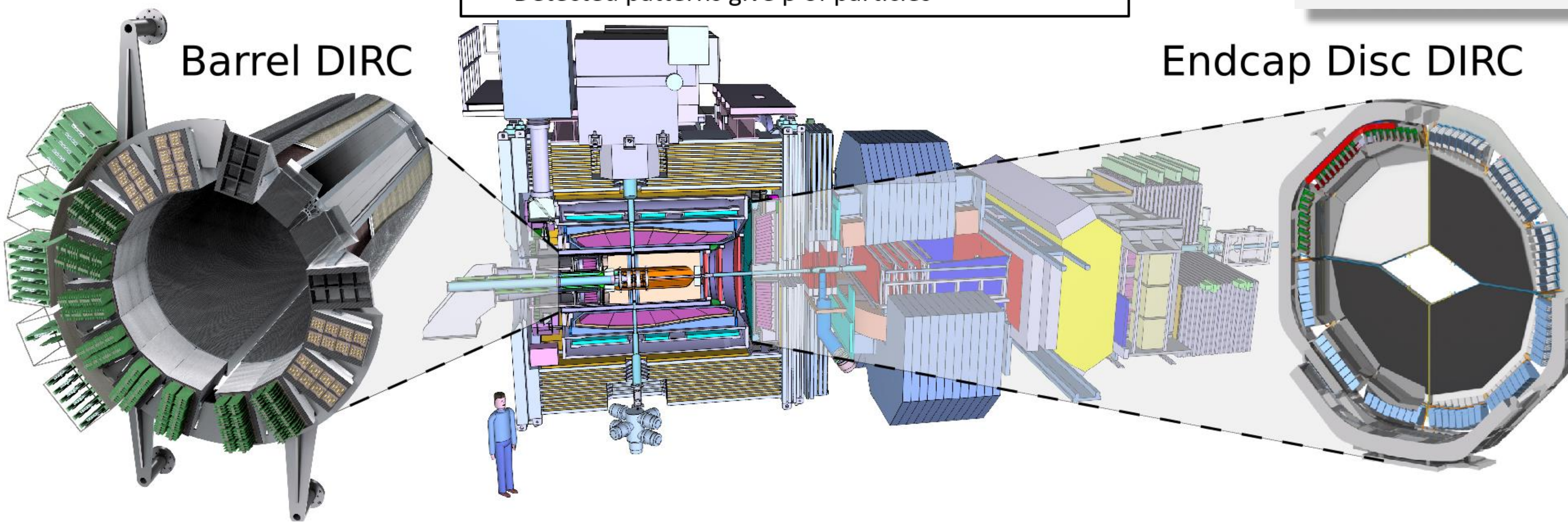
PANDA – DIRC Detectors

Detection of Internally Reflected Cherenkov light pioneered by BaBar

- Cherenkov detector with SiO_2 radiator
- Detected patterns give β of particles

DIRC

→Talk: C. Schwarz
→Poster: A. Ali



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

Key technologies:

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

Endcap Disc DIRC

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

PANDA - Target Electromagnetic Calorimeter

Crystal Calorimeter based on ~15,500 high quality second-generation PWO II ($PbWO_4$) crystals

- Small radiation length X_0 = 0.89 cm (20cm ≈ 22 X_0)
- Short decay time τ=6.5 ns
- Increased light yield, at -25°C
- Time resolution <2ns
- Coverage: 99.8% of 4π
- TDR approved

Challenges

- temperature stable to 0.1 ºC
- control radiation damage

Large Area APDs

Barrel Calorimeter

11000 crystals PWO II

LAAPD readout, 2x1cm²

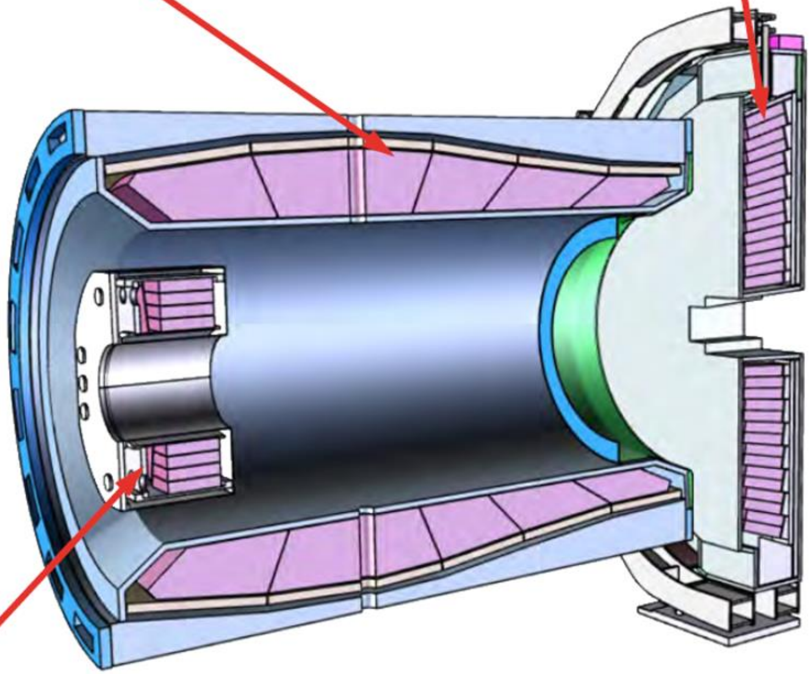
σ(E)/E~1.5%/√E + const.

Forward Endcap

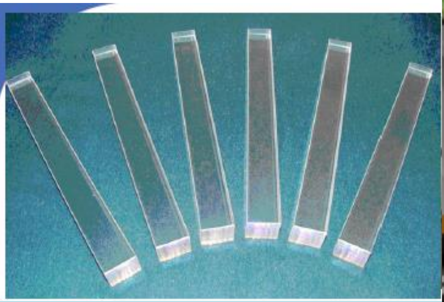
4000 crystals PWO II

High occupancy in center

LA APD and VPTT



Backward Endcap for hermeticity, 530 crystals PWO II



Crystal Production

~60% produced at BTCP (Russia)

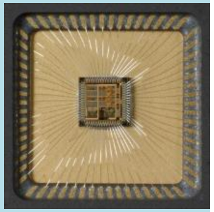
New producer Crytur (Czech Rep.)

APD / Preamp / VPTT

Screening 30000 APDs

ASIC preamp design ready

VPTT Modules ready

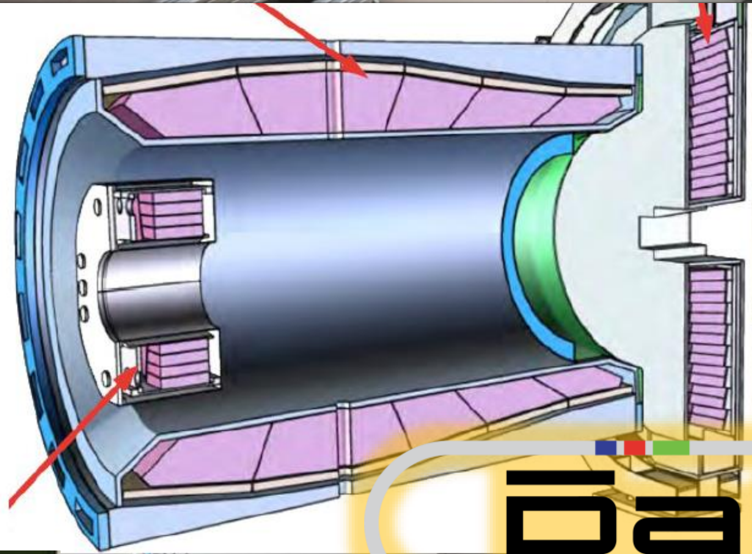


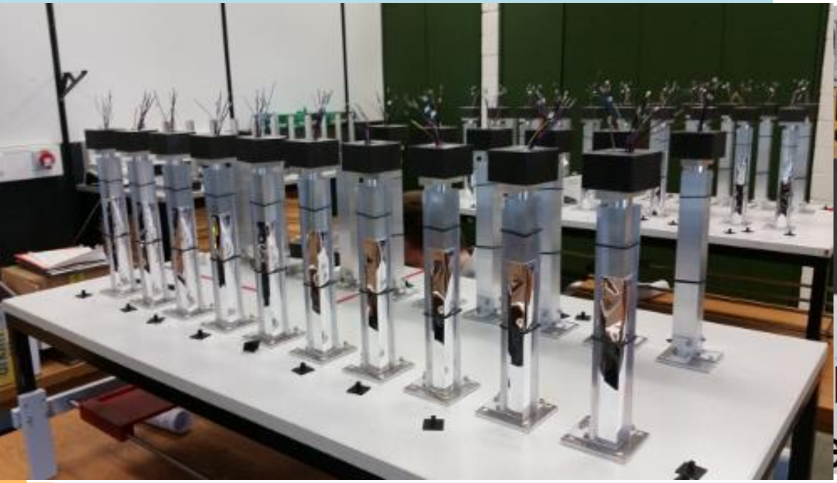
Assembly

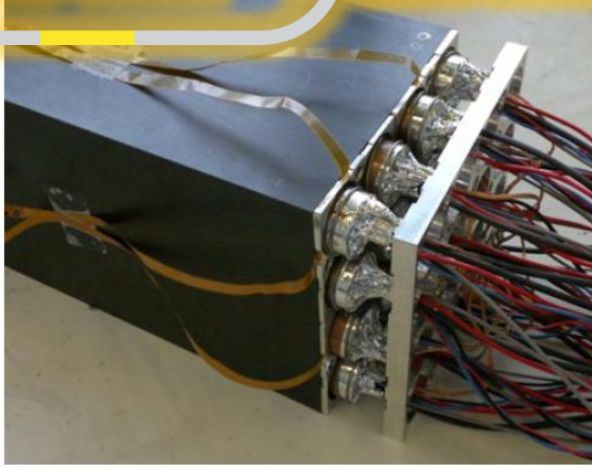
Forward-EMC: near completion

Backward-EMC: production started

Barrel-EMC: 1st slice completed



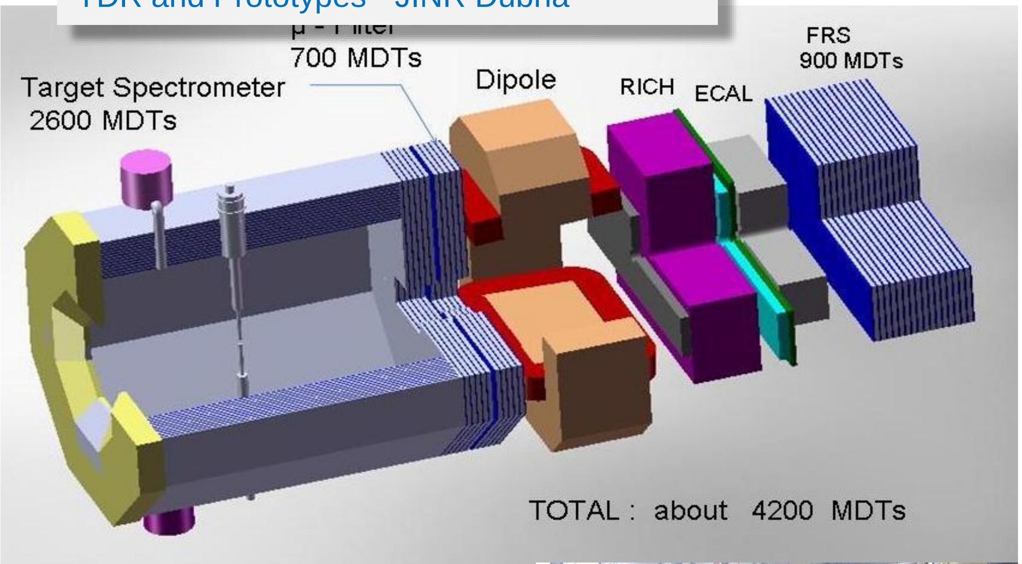




PANDA

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

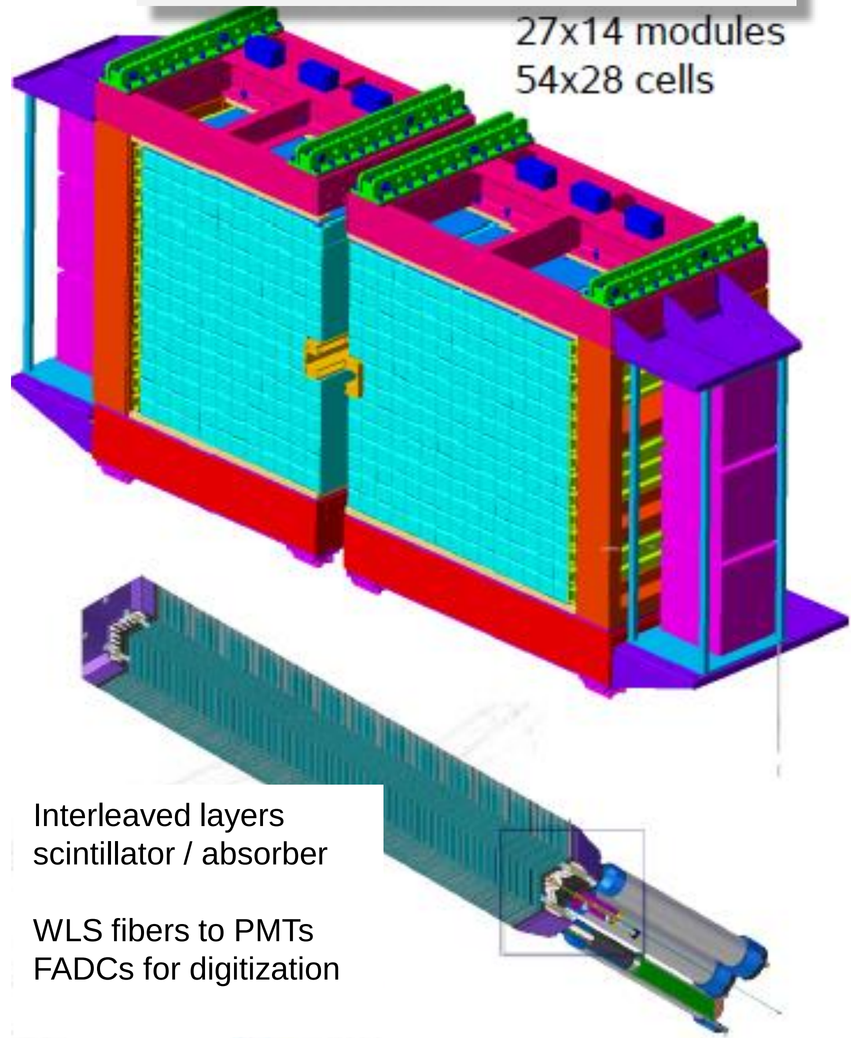
FEE FPGA development

Production designs @ JINR

Forward Shashlyk Calorimeter

TDR and Prototypes - IHEP Protvino

→Talk: M. Preston



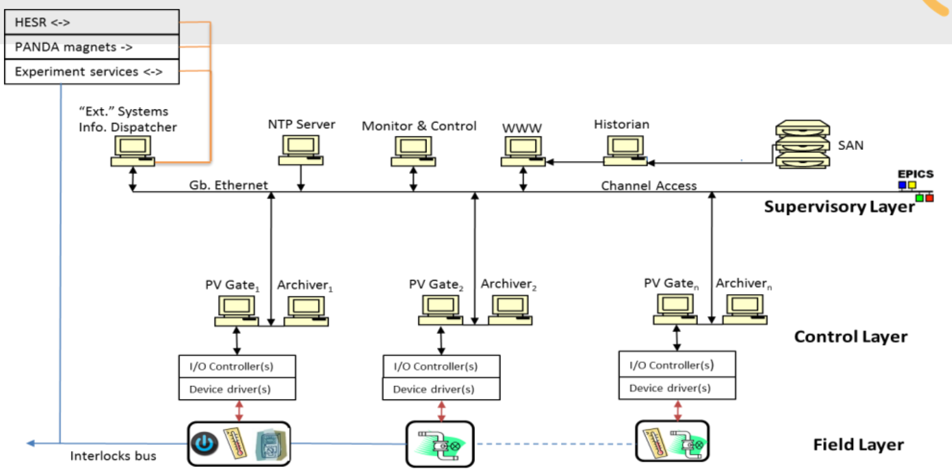
Interleaved layers scintillator / absorber

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

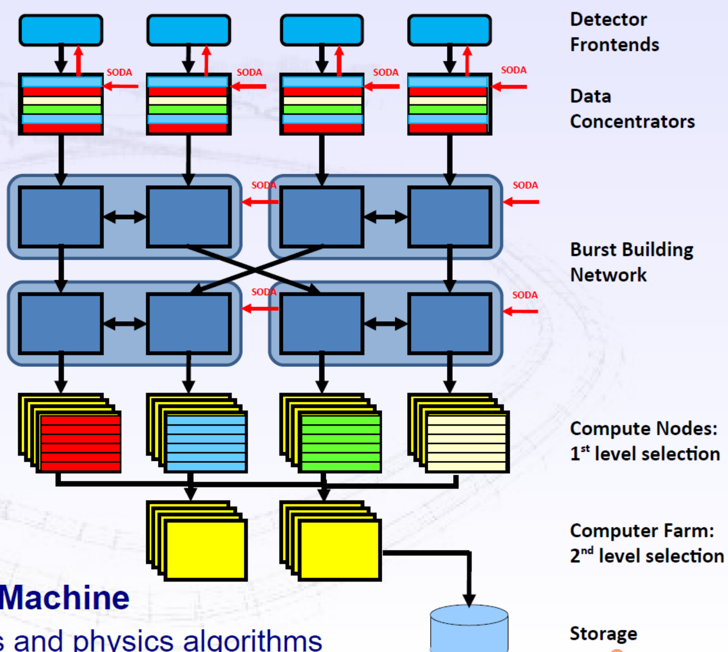
Field Layer
PANDA sub-systems specific
Interface: Detector Safety System

DAQ Timing

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

Online Event Filter



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

Detector Frontends
TDC developments @GSI
→*Talk: M. Traxler*

FPGA h/w

Machine Learning Schemes

PANDA Collaboration

Collaboration

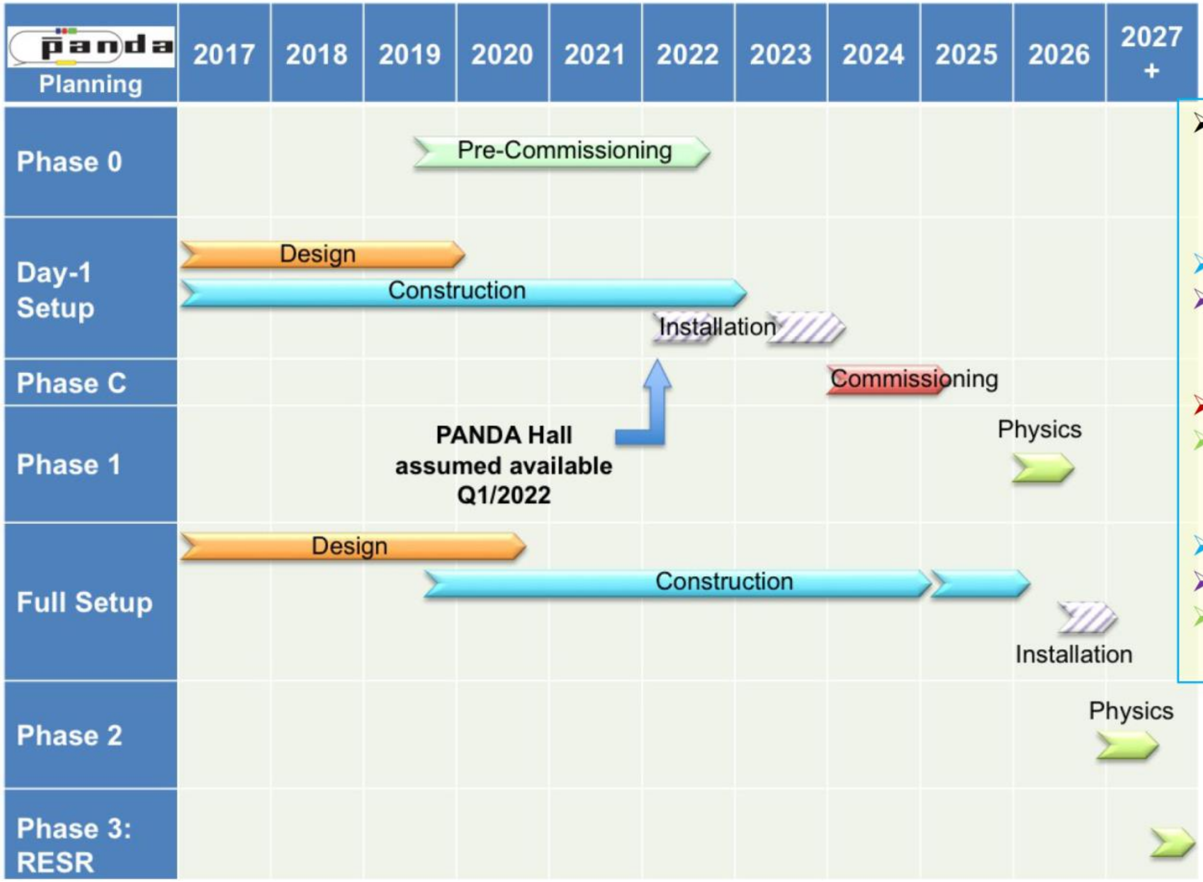
UP Marche Ancona
U Basel
IHEP Beijing
U Bochum
Abant Izzet Baysal
U Golkoy, Bolu
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
Cracow UT
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Erlangen
NWU Evanston
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
Giresun U
U Glasgow
KVI-CART Groningen
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
Doğuş 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
BINP 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

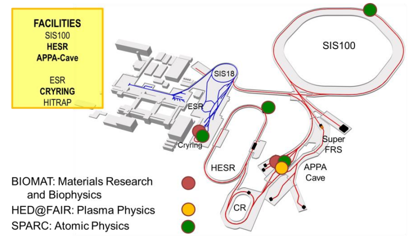


- Phase 0 Experiments of PANDA detectors and software at HADES, MAMI, COSY and GlueX
- Construction of Phase 1 systems
- Installation periods
  1. Solenoid, Dipole, Supports
  2. Detectors
- Commissioning with protons
- Physics with antiprotons
- Construction of Phase 2 systems
- Installation period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

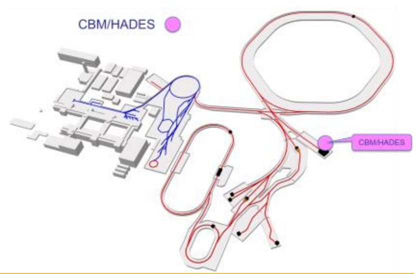
Schedule for FAIR Science

- 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+

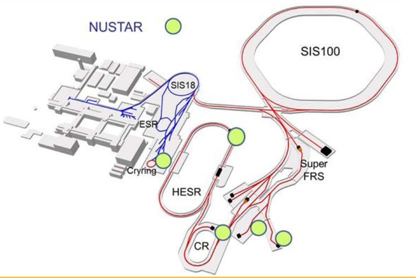
APPA



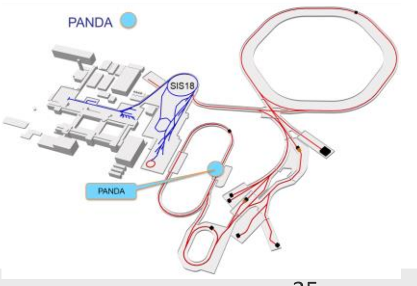
CBM



NUSTAR

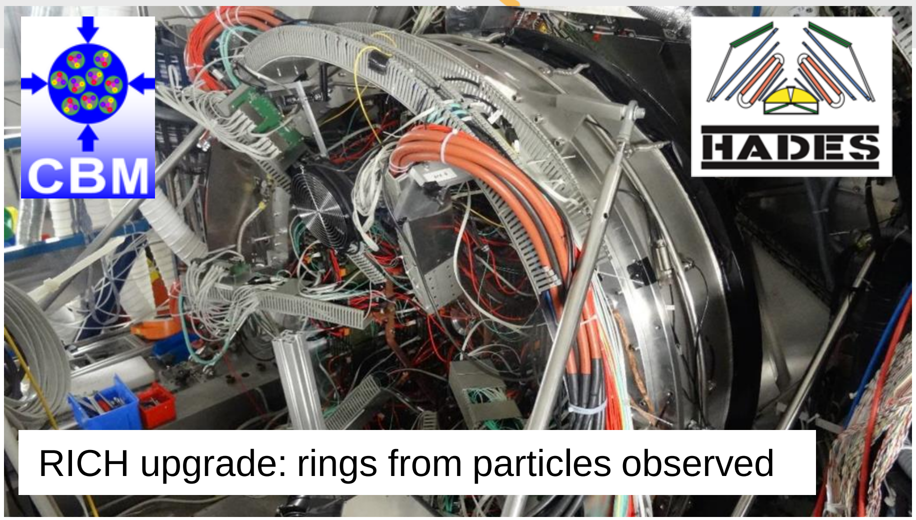


PANDA



Phase-0 at GSI: HADES (CBM, PANDA)


ECAL upgrade: 4 sectors tested with beam


RICH upgrade: rings from particles observed

- **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**

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.

FAIR 2025

Unique Opportunities

. . . & Challenges

Thank You!