THE PROGRAM AT FAIR

Joachim Stroth
Goethe University Frankfurt / GSI
ALICE 3 workshop, remote
October 18 – 19, 2021
FAIR: Facility for Antiproton and Ion Research

A World-Wide Unique Accelerator Facility

- ESFRI Landmark
- Top priority for European Nuclear Physics Community
- Driver for Innovation in Science and Technology
FAIR – The Facility

“Gain factors” rel. to GSI
- 100 – 10,000 x intensity
- 10 x energy
- antiproton beams
Four Scientific Collaborations

- Atomic Physics and Fundamental Symmetries,
- Plasma Physics,
- Materials Research,
- Radiation Biology,
- Cancer Therapy with Ion Beams / Space Res.

**APPA**
- Dense and Hot Nuclear Matter

**CBM**
- Nuclear Structure far off stability,
- Physics of Explosive Nucleosynthesis (r process)

**NUSTAR**
- Hadron Structure & Dynamics with cooled antiproton beams
FAIR: International Cooperation

Realization and operation in international cooperation
Nine international shareholders
Participation of 3,000 scientists from all continents
Construction as of June 2022

North

South
APPA
QED as “strong interaction”

- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions, influence on nuclear decay properties
- Precision determination of fundamental constants

\[ Z \alpha \approx 1 \]
NUSTAR
NUSTAR - Origin of elements in the universe

„Nucleosynthesis sites“ in the universe

„Nucleosynthesis sites“ at FAIR

SIS100: Low-charge state primary beam at high intensities

production target

ILIMA, EXL at CR and at ESR, HESR, Cryring
Reactions with Relativistic Rare-isotope Beams

- Novel technique: Knock-out reactions in inverse kinematics
- Beam energies around 1 A GeV provide “clean” knock-out” processes
- Projectile residue can be traced and identified

Neutron removal to constrain the asymmetry energy of the EOS

Measure Short Range Correlations in neutron and proton rich nuclei
Patsyuk, Aumann, Duer, Hen and BM@N collaboration: arXiv:2102.02626 [nucl-ex]
PANDA
PANDA Day-1 / Phase-1 / Phase-2

Cluster & Pellet Target
Solenoid Magnet
Muon Det
Dipole Magnet
Dipole ToF
Muon Range System
Luminosity Detector

Not shown: Hypernuclear Setup

BE EMC
Barrel DIRC & ToF
MVD
STT
Barrel GEM Trk
Disc DIRC
FE EMC
Forward Tracker
FRICH
FToF
FSC
Bound states of Strong Interaction

Spectroscopy
- Narrow XYZ states: search partners
- Production of exotic QCD states: Glueballs & hybrids

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

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

Nuclear Hadron Physics
- Hypernuclear physics:
  - Double Λ hypernuclei
  - Hyperon interaction
- Hadrons in nuclei:
  - Charm and strangeness in medium
PANDA Micro Vertex Detector

Pixels
- Hybrid silicon pixels
- 10 million pixels
- 2 barrel-layers
- 6 disks

Strips
- Silicon micro-strip
- In total 296 sensors and 200,000 strip channels
- 2 barrel-layers
- 2 disks

Requirements
- Spatial resolution in: $r$-$\phi < 100 \mu m$
- $z \approx 100 \mu m$
- Time resolution $< 10$ ns
- Radiation length $\approx 1 \% / \text{layer}$
- Radiation hardness $\approx 1014 \text{ neq/cm2}$
- $\approx 10$ MRad
- Amplitude measurement for PID
CBM & HADES
The Compressed Baryonic Matter setup
Compressed Baryonic Matter

The CBM detector from Day-1 on HADES during FAIR Phase-0

P. Salabura, JS: Prog. Part. Nucl. Phys. 120, 103869 (2021)
High-$\mu_B$ experiments word-wide
CBM time line

Building

Shell construction - basic services

Technical Building Installation

construction site rules

normal operation rules

crane

cryo

Dipole foundation
Rails, platform
Magnet, Supports Infrastructure Services
Detectors + systems User space Pre-commissioning
Global commissioning

1. Heavy infra.
2. Supports services
3. Detectors
4. M11 - rdy for beam
Silicon Tracking System

Main CBM detector for charged particle measurement incl. momentum determination.

Performance requirements:
- track point measurement in high-rate collision:
  \(10^5 \text{ -- } 10^7/s\) (A+A), up to \(10^9/s\) (p+A)
- physics aperture, position in dipole magnet:
  \(2.5^\circ \leq \Theta \leq 25^\circ,\ 0.2 \text{ m} \leq z \leq 1.0 \text{ m}\)
- 8 tracking stations
  - double-sided silicon microstrip sensors
  - hit spatial resolution \(\approx 25 \mu\text{m}\)
- self-triggering front-end electronics
  - time-stamp resolution \(\approx 5 \text{ ns}\)
- material: \(\approx 0.3\% \text{ -- } 1.5\% \times_0\) per station
  - \(\Delta p/p < 2\%\) (\(p > 1 \text{ GeV/c, 1 Tm field}\))
System breakdown

1.4 m

2.3 m

1.0 m

8 tracking stations

18 mechanical half-units

876 modules

System in thermal enclosure

sensors at \( \sim 10 \, ^\circ\text{C} \) (gas cooling)

electronics liquid cooling through thermal interfaces (NOVEC, \(-40 \, ^\circ\text{C}\))

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front-end electronics board in cooling shelves

module:
- 2 \( \times \) FEBs \( \times 8 \) read-out ASICs/128 ch.
- 2 \( \times \) 8 ultra-thin read-out cable stacks
- double-sided silicon micro-strip sensor, 1024 strips per side

system:
- \( \sim 1.8 \) million read-out channels
- \( \sim 14 \, 000 \) read-out ASICs "STS-XYTER"
- \( \sim 40 \, \text{kW} \) power dissipation

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8/10 modules on CF support

C-frame

material budget/station [%X]

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106 ladders
MVD in a nutshell

Four stations of MIMOSIS (CPS) sensors with 100% fill factor positioned close to the target.

Enhanced track reconstruction efficiency for tracks with low-momentum and factor ten improved vertex resolution over STS alone. Two configuration: "vertex", "tracking".

Operation in vacuum and in a one-Tesla magnetic field. Liquid cooled down to -20°C.

70 W heat extracted laterally, (0.2 – 0.5) % $X_0$ / station. 288 sensors, 148 M pixel, 200 kfps, 5 μm precision.
The MIMOSIS sensor

Challenges:

- 100 kHz rate Au+Au
- Occupancy gradients
- Beam intensity fluctuations

Design aspects

- Discriminator on 27x30µm² pixel (~5 µs readout speed anticipated)
- Multiple data concentration steps (early averaging of Poisson fluctuations)
- Elastic output buffer (up to 3x nominal beam during 50µs)
- 8 x 320 Mbps links (switchable)
- Triple redundant electronics
- Numerous self-test features
MIMOSIS-1

Sensing part | Amplification | In-pixel Memory
---|---|---
AC coupling Bias2 | Shaping time few μs | Pixel output
MV Bias1 | | Dual Port 2 words of 1 bit
Charge inj. 160 aF | Comp | Analog test output (Comparator)
DC coupling Bias1 | | Analog test output (Amplifier)
Charge inj. 160 aF | | Green

Proposed by W. Snoeys et al.
H. Pernegger et al., 2017 JINST 12 P06008

Split 3

Split 4

Extra deep pwell implant

3 wafer designs \( \times (2 \times \text{DC} + 2 \times \text{AC}) = 12 \) variants

**FIX PATTERN NOISE:** 5 - 17 e ENC

- **h** \( \text{threshold} \)
  - Entries: 193013
  - Mean: 132.8
  - Std Dev: 10.69

**THERMAL NOISE:** 3 - 5 e ENC

- **h** \( \text{pixel noise} \)
  - Entries: 193013
  - Mean: 4.923
  - Std Dev: 0.5318

standard epi matrix B, DC pixels

- at 15°C
- \( V_{\text{SUB}} = 0 \text{V} \)
- \( V_{\text{VCASN}} \approx 385 \text{mV} \)

T = 15°C

standard epi matrix B, DC pixels

- at 15°C
- \( V_{\text{SUB}} = 0 \text{V} \)
- \( V_{\text{VCASN}} \approx 385 \text{mV} \)

T = 15°C
LGAD for timing applications

State-of-the-art

- **50 \( \mu \text{m} \) active sensor thickness, 5×4.3 mm\(^2\), pitch of 146 \( \mu \text{m} \), strip-to-strip distance of 20 \( \mu \text{m} \)**
- **Fill factor 50\%, single sensor thickness 570 \( \mu \text{m} \)**
  
  First FBK production of 50 \( \mu \text{m} \) UFSD

- **Leading-edge discriminators / FPGA based TDC**
  (trb.gsi.de)
- **At 10 kHz / channel \( \rightarrow \) MHz/cm\(^2\)**
- **Without active cooling, at 30\° Celsius**
- **LGAD timing precision 47 ps**
  

Application short term (<2024)

- **\( p, \pi \), heavy-ion beams FAIR Phase-0 (HADES, mCBM)**
- **R&D for tracking purposes**
  
  - Production of new sensors at FBK (available at GSI)
  - 5 different geometries:
    2×2 cm\(^2\)/ 1×1 cm\(^2\), pitch 370 to 50 \( \mu \text{m} \)
  - Sensor thickness: 200 \( \mu \text{m} \)

Near future

- **4D tracking system based on strip LGAD**
- **Development of a dedicated ASIC**
  
  - Pitch 100 \( \mu \text{m} / 50 \mu \text{m} \)
  - Timing below 20 ps
  - Rate capabilities 10 MHz/ch \( \rightarrow \) 1 GHz/cm\(^2\)

LGAD strip sensor

(1) Analog Amp/Disc
(2) TDC

LGAD Sensor production and R&D

- **thinning 200 \( \mu \text{m} \) \( \rightarrow \) 50 \( \mu \text{m} \)**
- **fill-factor improvements**
  (AC LGAD, trench isolated LGAD)
Selection of observables (already now by HADES)

Higher-order flow components (protons) and HBT w.r.t. event plane (pions)


Thermal dileptons $\text{Au+Au} \ (\sqrt{s} = 2.4 \ A \ GeV)$

- Microscopic transport$^{(2)}$:
  - Vacuum $\rho$ spectral function and $\Delta$ regeneration
  - Explicit broadening and density dependent mass shift

- Coarse-grained UrQMD$^{(3)}$:
  - Thermal emissivity with in-medium propagator$^{(4)}$
  - $\rho - a_1$ chiral mixing$^{(5)}$
    (not measured so far)

$^{(2)}$ E. Bratkovskaya

$^{(3)}$ CG FRA Endres, van Hees, Bleicher

$^{(4)}$ Rapp, van Hees; arXiv:1411.4612v

$^{(5)}$ Rapp, Hohler; arXiv:1311.2921v
Dilepton performance

$$e^+ e^-$$

$$\mu^+ \mu^-$$
QCD landmarks at high $\mu_B$

- First-order deconfinement phase transition
  Search for nonmonotonic excitation function of:
  - Excess yield (longer expansion due to softening of EOS)
  - Step in the temperature (latent heat)

- $\chi$ symmetry restoration
  - $\rho$ broadening observed, in agreement with expectations but no proof in itself – signatures of $\rho - a_1$ mixing

Open charm measurements

- Performance depends on so far unknown cross section
- Reduced multiplicity in Ni*Ni reaction allows higher interaction rate
- Reconstruction obtained with the KF-particle package (kinematic refit)

\[ D^0 \rightarrow K + \pi \]

\[ \bar{D}^0 \rightarrow \bar{K} + \pi \]
Thank you!!