The PANDA@HADES physics program for SIS 18

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for the HADES collaboration and UU Hyperon group
Presentation plan:

➢ HADES experiment (History, physics program, old setup, results)
➢ Phase0 – FAIR / PANDA@HADES
➢ Upgrades
➢ Planed measurements
The HADES collaboration

- Started in 1995
- First measurement on SIS 18: 2003

➢ Cracow (Univ.), Poland
➢ Darmstadt (GSI), Germany
➢ Dresden (FZD), Germany
➢ Dubna (JINR), Russia
➢ Frankfurt (Univ.), Germany
➢ Giessen (Univ.), Germany
➢ Jülich (FZJ), Germany
➢ München (TUM), Germany
➢ Moscow (ITEP, MEPhI, RAS), Russia
➢ Nicosia (Univ.), Cyprus
➢ Orsay (IPN), France
➢ Rez (CAS, NPI), Czech Rep.
➢ Sant. de Compostela (Univ.), Spain
➢ Wuppertal (BUG), Germany
➢ Coimbra (Univ.), LIP, Portugal
HADES @ FAIR

HADES - first detector of FAIR Phase0 (2018-2020)

Diagram showing the layout of HADES and other FAIR projects, including SIS18 and SIS100, UNILAC, CRYRING, CBM, HESR, and PANDA.
The HADES spectrometer

- **Detector geometry**
  Full azimuthal range covered, 6 sectors
  Polar angle: $16^\circ < \theta < 84^\circ$

- **Tracking**
  Superconducting coils, toroidal field
  24 Mini Drift Chambers

- **Particle identification** (e, p, K, p)
  RICH, MDC, TOF, TOFINO, Shower (RPC)

- **Resolutions**
  $\Delta M/\omega \sim 2.1\%$ at $\omega$ peak
  $\Delta p/p \sim 2-3\%$ for proton and $\pi$

- **Forward Wall:**
  Plastic scintillators covering $\theta$ angles up to $7^\circ$
  Detector dedicated to tag proton spectator

- **Cells in FW:**
  140 small 4x4cm $\rightarrow (0^\circ < \theta < 2^\circ)$
  64 middle 8x8cm $\rightarrow (2^\circ < \theta < 3.3^\circ)$
  84 large 16x16cm $\rightarrow (3.3^\circ < \theta < 7.2^\circ)$
The physics program of HADES

- Studies of dense and hot matter:
  - C + C for 1 and 2 GeV/n, Ar + KCL @ 1.75 GeV/n, Au + Au @ 1.25 GeV/n

- Cold matter at normal nuclear densities: p + Nb @ 3.5 GeV/c and π⁻ + W/C 1.7 GeV/c

- Dilepton emission in elementary collisions pp, dp and π⁻p
  - As a reference to HI measurements
  - Dalitz decays of baryon resonances

- Simultaneous measurements of hadronic channels (inclusive and exclusive meson production 1π, 2π, η, ρ, ω,...)

- Strangeness measurement program: K⁻, K⁰, φ, Σ(1385), Λ(1405), Λp correlations
Au + Au @ 1.25 GeV/n

- In medium effects, the Au + Au spectrum not described by a superposition of elementary reactions (1/2 np + pp)
- $\rho$ meson spectrum width modification
Elementary reactions pp and np @ 1.25 GeV/c

$\Delta$ and $\pi^0$ production cross section deduced from PWA of one pion production channels


$\Delta$ Dalitz $\Delta \rightarrow p^+e^-e^-$
- « photon-point » $G_M=3$, $G_E=G_\pi=0$
- Ramalho/Pena model
- $\pi^0$ Dalitz decay branching ratio $BR(\Delta \rightarrow Ne^+e^-) = 4.19 \pm 0.42$ (model) $\pm 0.46$ (sys.) $\pm 0.34$ (stat.) $10^{-5}$

First measurement of $\Delta(1232)$ Dalitz decay branching ratio $BR(\Delta \rightarrow Ne^+e^-) = 4.19 \pm 0.42$ (model) $\pm 0.46$ (sys.) $\pm 0.34$ (stat.) $10^{-5}$.

**Figure:**
- Graph showing distribution of $M_{inv}(e^+e^-)$ vs $M_{inv}(e^+e^-)$ [GeV/c^2].
- Graph showing $d\sigma/d\cos \theta_{e^-}$ vs $\cos \theta_{e^-}$.
Elementary reactions pp and np @ 1.25 GeV/c

Significantly larger production at large $M_{ee}$ than in pp

**S&M:** Shyam & Mosel Phys. Rev. C 82:062201, 2010

HADES Puzzle: Ξ(1321) production

✓ strong enhancement in respect to existing models (UrQMD, GiBUU) for Ar + KCL @ 1.76 GeV sub-threshold production
✓ No data close to threshold in NN interactions

PRL 114, 212301 (2015)
PANDA@HADES detector upgrades
The Forward detector

- Enable the possibility of track reconstruction originating from charged particles at $\Theta < 7$ deg
- No magnetic field
- Time of flight from RPC

STS1 (FZ Jülich):
- 640 straws in 4 layers
- Length 766 mm, $\Phi = 10.05$mm
- Compatible with PANDA FT 3,4
- Active area: 766mm by 800mm

STS2 (UJ Kraków/IPN Orsay):
- 1024 straws in 4 layers
- Length: 1250 mm, $\Phi = 10.05$mm
- Compatible with FT 5,6
- Active area: 1131mm by 1280mm
- Gas system (IFJ-PAN Kraków)
- Fastening system (INP Orsay)
Almost 90% of protons form the decay are emitted with $\theta < 7$ deg!

$p(@4.5\text{ GeV}) + p \to \Xi^- K^+ K^+ p$

$$\Xi^- \to \Lambda \pi^-$$

$$\Lambda \to p \pi^-$$

K. Nowakowski
JU group Krakow
Benchmark channels - preliminary

$\Xi^-$ production

$p+p@4.5\text{ GeV} \rightarrow pK^+K^+\Xi^-$

$\Lambda(1520)$ Dalitz decays

$p + p@4.5\text{ GeV} \rightarrow pK\Lambda(1520)$

$\Gamma_{\Lambda(1520)} = 15.6\text{ MeV}, \Gamma_\gamma = 167 \pm 43\text{ keV}$

$\text{BR}_{\Lambda(1520) \rightarrow \Lambda e^+e^-} = 7.8 \times 10^{-5}$

CLAS, PRC74, 065202 (2006)

$\approx 406 \times 10^3 \Xi^-$

$\varepsilon_{\Xi^-} \approx 0.79\%$

reconstruction efficiency:

$\varepsilon_{\Lambda(1520)} \approx 0.5\%$ ($\angle e^+e^- > 4^\circ$)

within 4 weeks of beam: $\approx 613 \Lambda(1520)$

$\rightarrow$ PE target: $x7$
The physics program of UU hyperon group

The physics program of UU hyperon group

• The Dalitz decays of neutral hyperons, e.g. $\Sigma^0$ and $\Lambda$ (1520), with PANDA@HADES. → Forward Detector

  \[(\Delta \rightarrow N e^+e^- \text{ similar to } \Sigma^0(1385) \rightarrow \Lambda^0 e^+e^-)\]

• Low-$q^2$ quantities of hyperons, such as magnetic dipole moments and helicity amplitudes, by radiative decays $Y_1 \rightarrow Y_2 \gamma$ with PANDA@HADES. → ECAL

• Search for $Y^* \rightarrow Y\gamma$ decays of excited hyperons, e.g. $\Sigma^*(1385) \rightarrow \Sigma\pi\gamma$ and $\Sigma^*(1385) \rightarrow \Lambda\pi\gamma$ with PANDA@HADES. → ECAL + Forward Detector
Backup
pp → ppπ⁺π⁻ E=3.5 GeV

Extraction of one and two baryon production cross sections
Calorimeter module
(Info for reminder)

Glass properties:
- chemical composition:
  SiO2 - 39%, PbO - 55%, K2O - 2%, Na2O - 3%
- density: 4.06 g/cm³
- radiation length ($X_0$): 2.51 cm
- refractive index: 1.708 (at 400 nm)
- Molière radius: 3.6 cm

Cherenkov detector module of the ECAL
1 – Lead glass CEREN25; 2 – PMT; 3 – Alumin. cover; 4 – brass can; 5 – Optical LED-system

ECAL-Modules have PMTs Hamamatsu R6091, PC-diam. 3 inch
and PMTs THORN EMI 9903 KB, PC-diam. 1.5 inch
Particle identification with HADES

Momentum + RICH + TOF + Pre Shower

$P_0 = \frac{p}{\beta \gamma}$

Au+Au @ 1.23 AGeV

log. z axis!
Strangeness, hyperon production @HADES

Inclusive analysis $pp \to \Lambda + X$


The extracted cross section:
$\sqrt{s} = 3.18$ GeV of $\sigma(pp \to \Lambda + X) = 207.3 \pm 1.3$
+6.0 $-7.3$ (stat.) $\pm 8.4$ (syst.) $+0.4 -0.5$ (model) $\mu$b
RPC (Resistive Plate Chambers) TOF detector

- Timing resolution < 100 ps,
- Efficiency > 98 %,
- Single module: 1380 × 960mm
- Two vertical and horizontal modules for TOF
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Basic design of the HADES Electromagnetic calorimeter ECAL
(6 Sectors with 163 X 6 = 978 Modules)
Hyperon production @HADES p + Nb @ 3.5 GeV


Average polarisation

$<P> = -0.119 \pm 0.005 \text{ (stat)} \pm 0.016 \text{ (syst)}$
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**Designed for di-electron spectroscopy, also suited for the charged hadron detection**