HYPERON PHYSICS AT HADES AS PART OF THE FAIR PHASE-0 PROGRAM

19TH INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY AND STRUCTURE IN MEMORIAM SIMON EIDELMAN
26/07/21 – 31/07/21, MEXICO CITY (ONLINE)

30/07/2021 I Gabriela Pérez Andrade[1], Rafal Lalik[2], James Ritman[3,1], Piotr Salabura[2], Peter Wintz[1] FOR THE HADES COLLABORATION

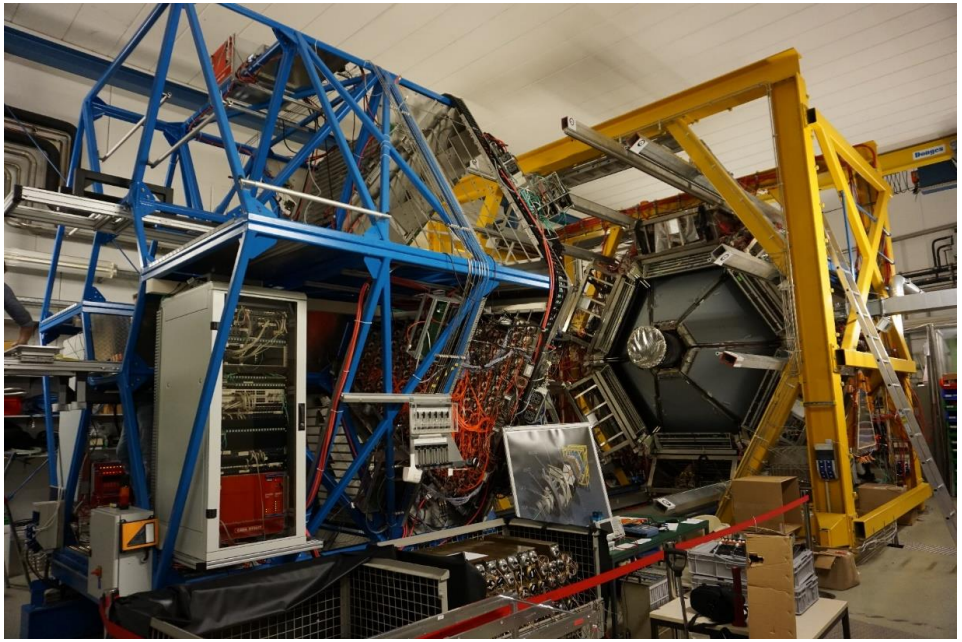
[1]INSTITUTE FOR NUCLEAR PHYSICS OF THE RESEARCH CENTER JÜLICH

[2]SMOLUCHOWSKI INSTITUTE OF PHYSICS, JAGIELLONIAN UNIVERSITY IN KRAKÓW

[3]GSI HELMHOLTZ CENTRE FOR HEAVY ION RESEARCH

Overview

- FAIR Phase-0 @HADES:
  - ➢Hyperon Physics Program
  - ➢Hardware Upgrade
  - ➢Simulation Feasibility Studies
- HADES Commissioning Beamtime
- Summary



Hyperon Electromagnetic Decays

- Hyperon structure probed by measurement of electromagnetic Transition Form Factors (eTFF) :
  - Space-like region ($q^2 < 0$) accessible in electron scattering experiments
  - Time-like region ($q^2 > 0$) accessible via e^+e^- annihilation (BaBar, CLEO-C, BESIII) and Dalitz decays (**HADES**)
  - CLEO provided first measurements of hyperon (Λ, $\Sigma^{\pm,0}$, $\Xi^{-,0}$, and Ω) magnetic form factors at $q^2 > 14$ GeV^2 [1]
- Comparison between strange and non-strange baryons helpful to pin-point the role of the pion cloud at small q^2

- **Radiative** hyperon decays **$Y^* \rightarrow \Lambda\,\gamma$**
  - Can help to differentiate between theoretical models [2]
  - Very sparse experimental results (*e.g.* $\Lambda(1520) \rightarrow \Lambda\,\gamma$, $\Sigma(1385)^0 \rightarrow \Lambda\,\gamma$ [3], $\Sigma(1385)^+ \rightarrow \Sigma^+\gamma$ [4])

- **Dalitz** hyperon decays **$Y^* \rightarrow \Lambda\,e^+e^-$**
  - Probe hyperon structure at low q^2 where mesonic degrees of freedom are expected
  - Experimentally unexplored

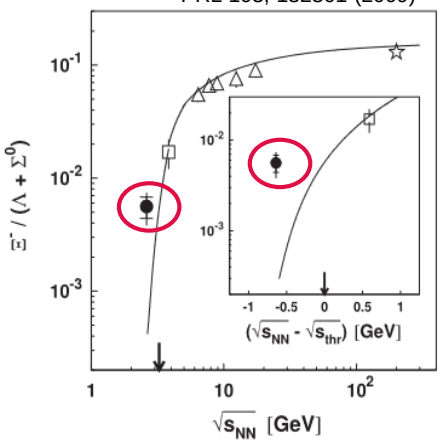
Measurements of hyperon EM decays will improve the understanding of hyperon structure in the lower q^2 region.

[1] E. Kaxiras, E. J. Moniz, and M. Soyeur, Phys. Rev. D 32, 695 (1985)
[2] S. Dobbs *et al.*, Phys. Lett. B 739, 90 (2014)
[3] S. Taylor *et al.* (CLAS), Phys. Rev. C 71, 054609 (2005)
[4] D. Keller *et al.* (CLAS), Phys. Rev. D 85, 052004 (2012)

Production of Double Strangeness (Ξ^- , $\Lambda\Lambda$)

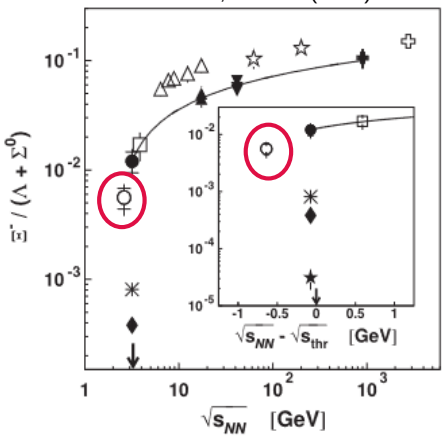
- **Ξ^- production:**
  - Very little is known about multi-strange hyperons produced at low q^2
  - Puzzling enhancement of Ξ^- production in previous HADES measurements

PRL 103, 132301 (2009)



*Filled black circle shows yield in **Ar + KCl** at 1.75 GeV by HADES Collaboration*

PRL 114, 212301 (2015)



*Empty circle shows yield in **p + Nb** at 3.5 GeV by HADES Collaboration*

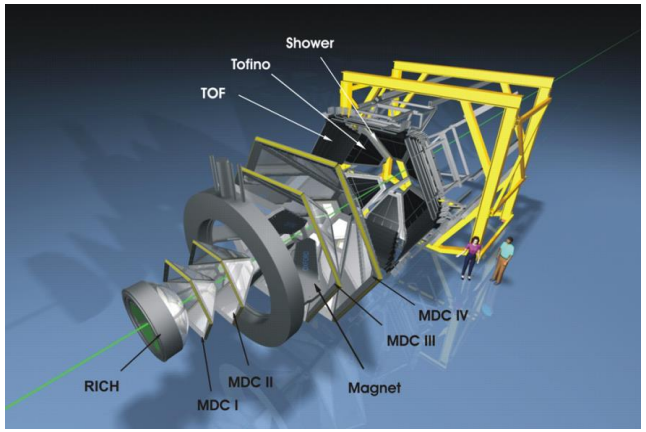
HADES will provide pp references to quantify the expected strangeness enhancement in heavy ion collisions

- **Λ-Λ measurement:**
  - Y - Y interaction is poorly known
  - Λ - Λ interaction plays important role in neutron star core studies[3]
  - Complementary to upcoming PANDA studies of $\Lambda\Lambda$ ($\Lambda\,\overline{\Lambda}$) in pp($p\bar{p}$)

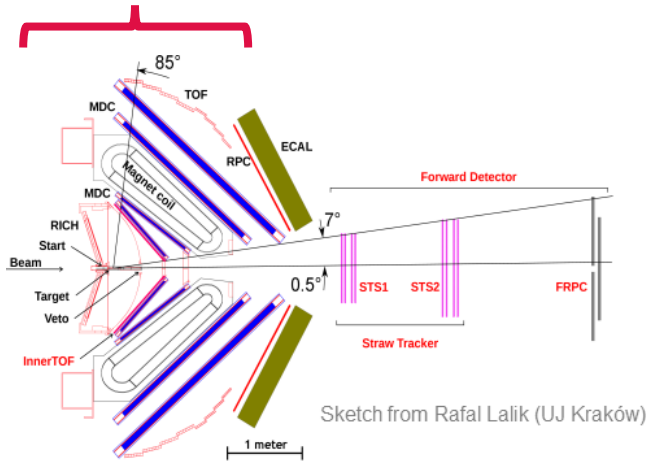
[3]N. K. Glendenning, APJ 293, 470 (1985)

High Acceptance DiElectron Spectrometer

Designed to measure charged **hadrons**, **leptons** and **photons** produced at few GeV in proton, secondary pion and heavy ion induced reactions on a fixed target (proton or nuclear).



- Toroidal magnetic field for momentum reconstruction
- Charged particle tracking with Mini-Drift Chambers (MDC I-IV)
- Particle identification: e^+/e^- (RICH), K^+/K^-, p (TOF)
- $\Delta M/M \sim 2.5\%$ in the ρ/ω/φ region
- Acceptance over polar angles within $18° < \theta < 85°$



Sketch from Rafal Lalik (UJ Kraków)

Spectrometer upgrade for FAIR Phase-0:

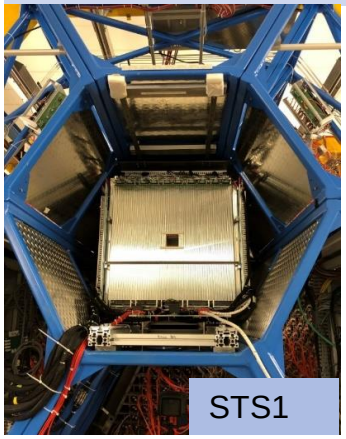
- Upgraded RICH and START detectors
- New ECAL and Inner TOF detector
- **New Forward Detector:**
  - **Straw tracker stations STS1, STS2 (low material budget)**
  - **Forward Resistive Plate Chamber (FRPC)**
  - **Angular acceptance extended to polar angles ~ $0.5° < \theta < 7°$**
- Upgrade of DAQ system: up to 200 kHz trigger rate

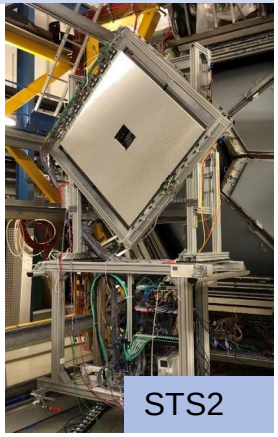
HADES Forward Detector for FAIR Phase-0

- No magnetic field ⟶ No direct momentum measurement
- Path length and time of flight to calculate velocity and PID
- Track reconstruction combines information from STS and FRPC
- Daughter baryon from the hyperon decay is strongly forward peaked in the lab frame due to fixed target kinematics:

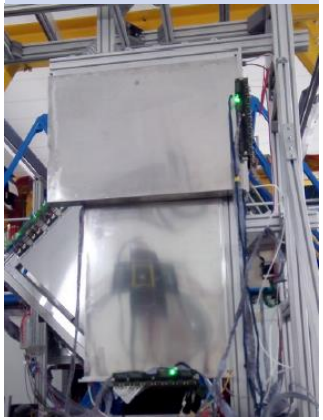
The FD is crucial for hyperon reconstruction

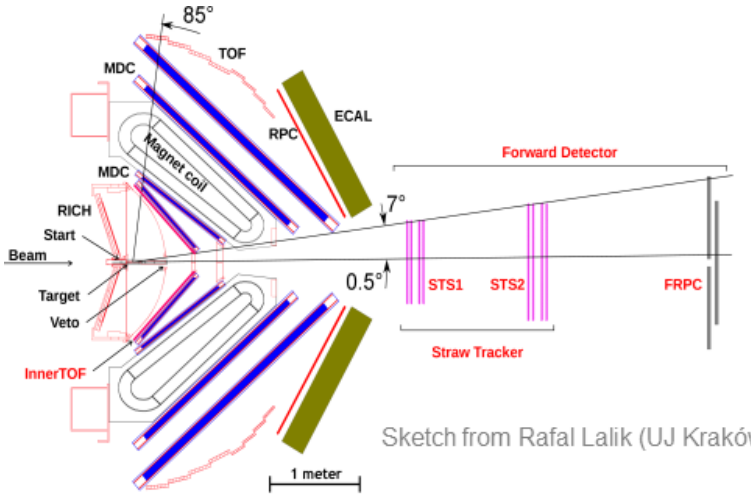
Straw Tracking Stations
(coll. with PANDA@FAIR) σ(x)~150 μm





FRPC TOF
σ(TOF) ~ 100 ps





Sketch from Rafal Lalik (UJ Kraków)

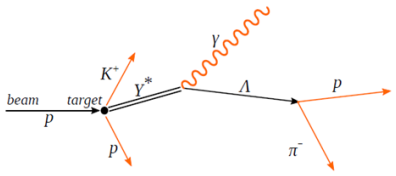
Simulation Feasibility Studies, FAIR Phase-0@HADES

- All simulations performed for a p beam of 4.5 GeV incident on a 4.7 cm long LH_2 target
- The **new components from the forward detector (FD) were included**
- Dominant background channels are included in the simulations
- Production cross-section estimates:
  - Little or no information is currently available for cross-sections at 4.5 GeV
  - Extrapolated from other energies or predicted based on previous measurements
- All (except radiative decays) assume semi-inclusive reconstruction tagged by a Λ reconstruction:
  - In general, pions from Λ decays stay within HADES acceptance and **protons are detected in the FD**

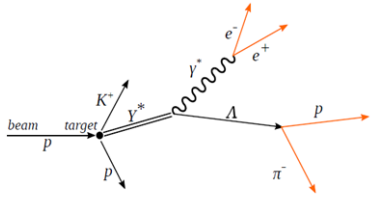
Experiment beamtime is approved and is scheduled for February 2022.

Hyperon Electromagnetic Decays

- Investigated reaction: pp → pK⁺ Y*
- Investigated hyperons: Σ(1385)°, Λ(1405), Λ(1520)
- Decay branching ratios (BR) for Y → Λ γ obtained from CLAS and estimated for Y→ Λ γ*
- Λ(1405) signal too small to be measured



Topology of hyperon radiative Decay

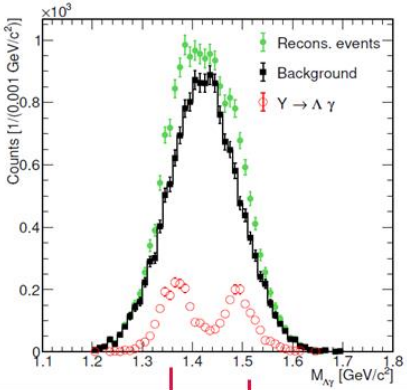


Topology of hyperon Dalitz decay

Radiative decays Y* → Λ γ

- Exclusive reconstruction to suppress background from Y → Λ π⁰

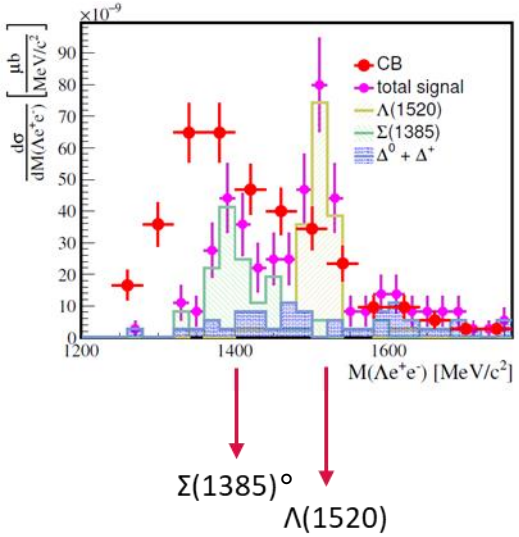
Λγ Invariant mass distribution of reconstructed events in the signal region

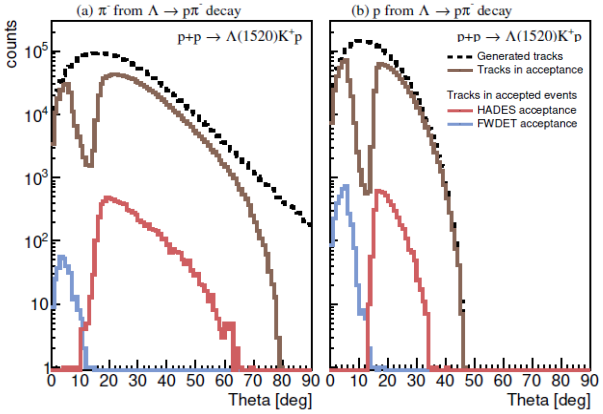


Dalitz decay of hyperons Y* → Λ e⁺e⁻ (inclusive)

- Prominent background from π⁰ dalitz decays: dilepton mass is required to be $M_{e+e-} > 140\ MeV/c^2$

Λe⁺e⁻ Invariant mass distribution of reconstructed events in the signal region





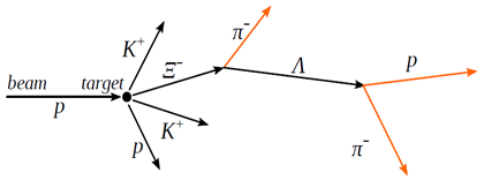
41% of the protons from Λ(1520) decays are within the FD acceptance

All Images from Adamczewski-Musch, J., *et al*. "Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR." *The European Physical Journal A* 57.4 (2021): 1-21.

Production of Double Strangeness

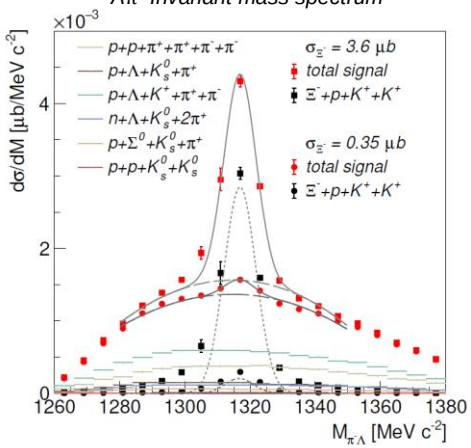
Ξ^- production

- Studied channel: pp → $pK^+K^+\Xi^-$
- Estimations of Ξ^- production cross section: upper limit from p-N interactions and lower estimate using (high energy) pp data.



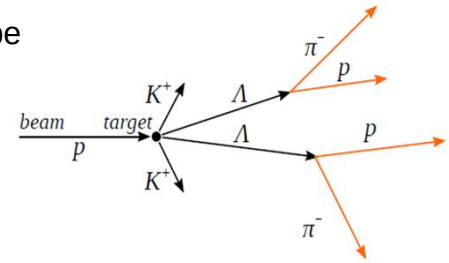
Topology of Ξ^- decay

$\Lambda\pi^-$ Invariant mass spectrum



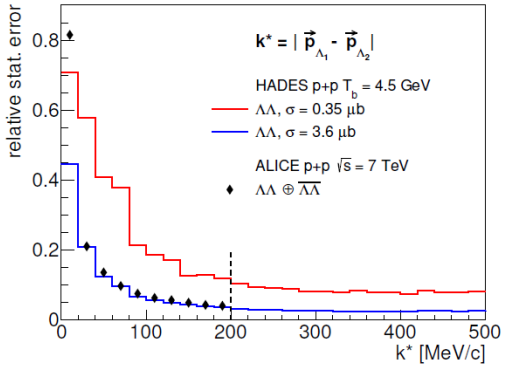
$\Lambda\Lambda$ production

- Studied reaction pp → $K^+K^+\Lambda\Lambda$
- Estimated $\Lambda\Lambda$ production cross section taken to be equal to the pp → $pK^+K^+\Xi^-$



Topology of $\Lambda\Lambda$ production

Relative error of the yield for $\Lambda\Lambda$ pairs as a function of the relative momentum.



88% of $pK^+K^+\Xi^-$ events have both pions reconstructed within HADES and the proton within the FD
89% of the $K^+K^+\Lambda\Lambda$ events include at least one particle within the FD

All Images from Adamczewski-Musch, J., *et al*. "Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR." *The European Physical Journal A* 57.4 (2021): 1-21.

Simulation Feasibility Studies Results

Channel	σ (μb)	BR	acc · ϵ[%]	Counts/day (LH_2)
$\Sigma(1385)^0 \rightarrow \Lambda\gamma$	56	9.07×10^{-3}	0.030	99
$\Lambda(1520) \rightarrow \Lambda\gamma$	69	7.03×10^{-3}	0.026	82
$\Sigma(1385)^0 \rightarrow \Lambda e^+e^-$	56	8.94×10^{-5}	0.48	15
$\Lambda(1520) \rightarrow \Lambda e^+e^-$	69	6.93×10^{-5}	0.58	18
$\Xi^- \rightarrow p\pi^-\pi^-$	3.6	0.64	1.68	2.43×10^4
$\Xi^- \rightarrow p\pi^-\pi^-$	0.35	0.64	1.68	2.43×10^3
$pp \rightarrow \Lambda\Lambda K^+K^+$	3.6	0.64^2	0.34	3.15×10^3
$pp \rightarrow \Lambda\Lambda K^+K^+$	0.35	0.64^2	0.34	3.15×10^2

The count rates were calculated taking into account:

- Acceptance times reconstruction efficiency
- A beam duty cycle of 50%
- $\mathcal{L} = 1.5 \times 10^{31}\ cm^{-2}\ s^{-1}$

All proposed channels with hyperon Dalitz decays except Λ(1405) can be measured at HADES/FD

HADES Commissioning Beamtime February 2021

- Preparation for pp@4.5 GeV production run in February/2022
- Test of quality of beam and focus on target
- Test of new detectors : STS, fRPC, iTOF

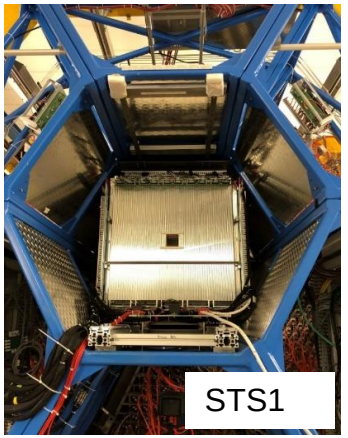
- SIS18 proton beam extraction with 2 GeV and 4.2 GeV kinetic energy
- Particle rates up to 10^8 p/s
- Target: LH_2

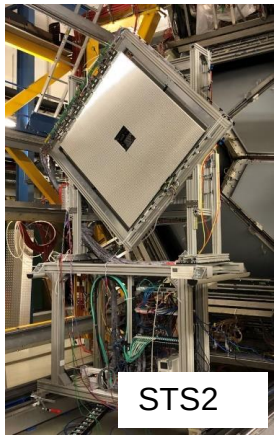
- Currently, analysis of the test data:
  - Calibration for new detectors
  - Set up of tracking software for new detectors
  - Combine event tracking with HADES and forward detectors
  - Vertex reconstruction
  - Specific background reaction: pp elastic scattering

Straw Tracking Stations (STS)

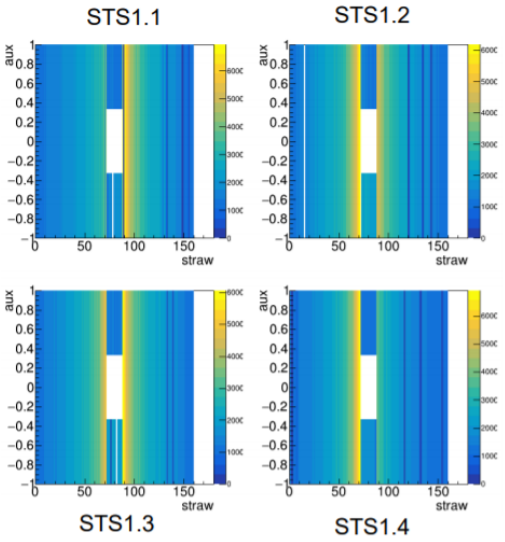
- Two stations (STS1/2) consisting of four double layers of self supporting gas-filled straws

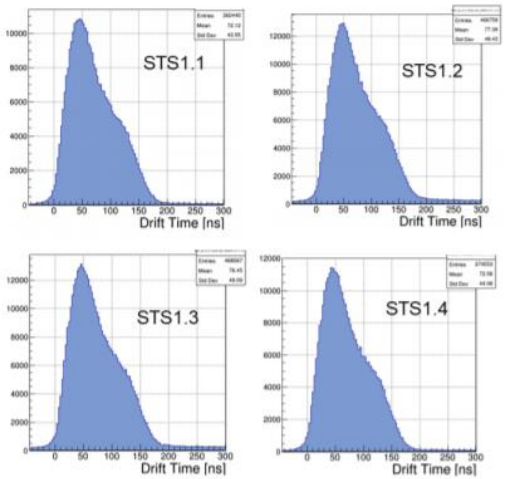
Station	STS1	STS2
No. Straws	704	1024
Straw length	76 cm	125 cm
Orientation	0º, 90º, 90º, 0º	0º, 90º, 45º, -45º
Beam opening	8 × 8 cm^2	16 × 16 cm^2
Distance to target (commissioning)	~ 3.50 m	~ 5.50 m

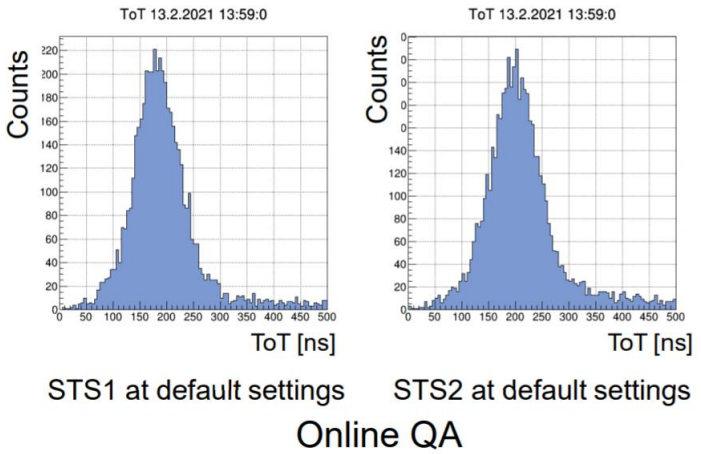




- STS stations and readout performance tested under experiment conditions
- STS operation was stable and no self-sustaining currents were observed even at the highest beam intensities (10^5 p/s per straw)

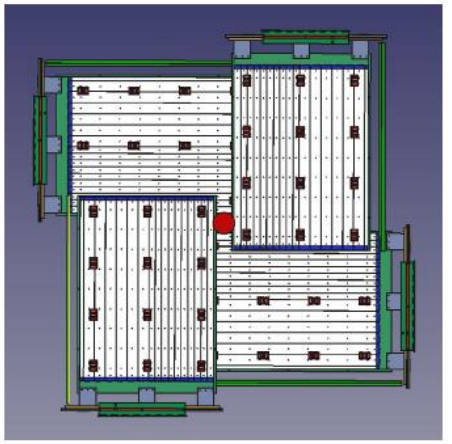


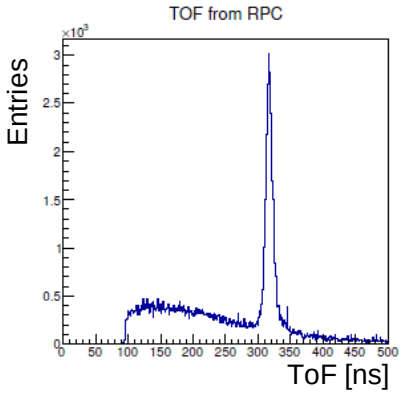


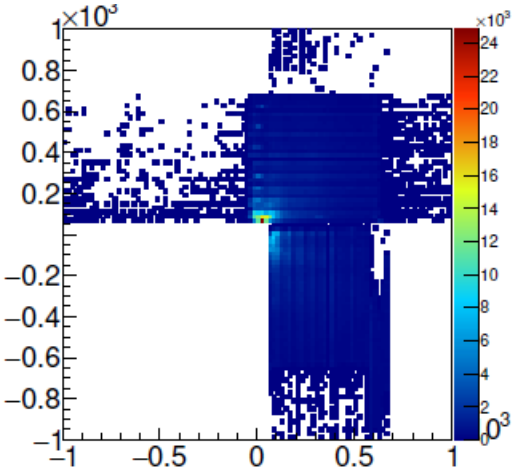


Forward RPC

- Four sectors with 32 individually shielded hybrid (metal glass) strip-like RPCs
- Currently 2 sectors installed (2 x 32 strips)
- FRPC, located at ~ 6.60 m to target (commissioning)
- Half FRPC tested in realistic beam conditions (preliminary):
  - ➢Efficiency 85 - 90 %
  - ➢Time resolution 100 - 120 ps
- Full system will be ready in autumn 2021



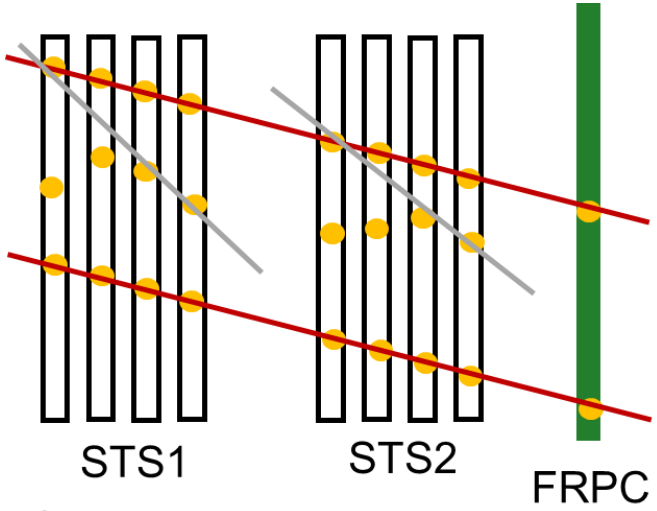


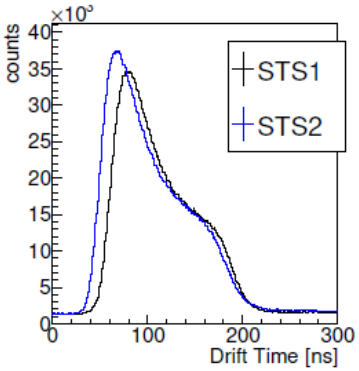


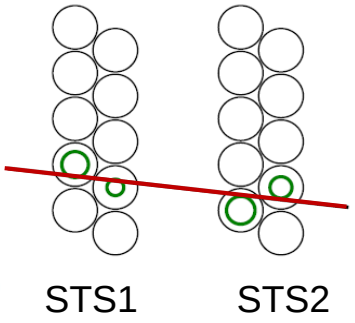
Front **Side** **Rear**

Forward Detector Tracking

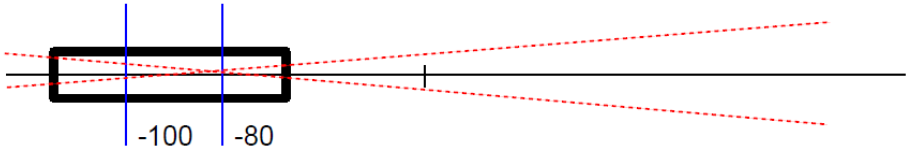
- Tracking software for the new detectors has been implemented:
  - ➢ Identify and associate hits within STS and FRPC to form a track
  - ➢ Refit tracks using drift radius information from straws (isochrones)
  - ➢ Vertex reconstruction with tracks extrapolation

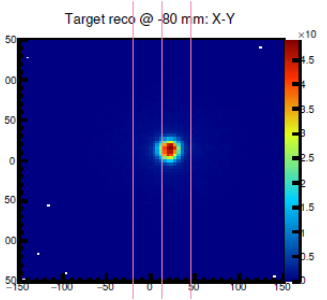


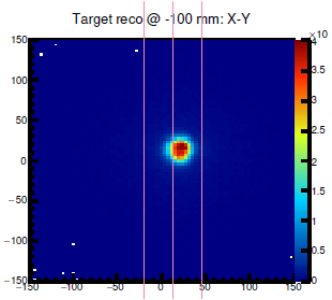




Tracking (preliminary) results

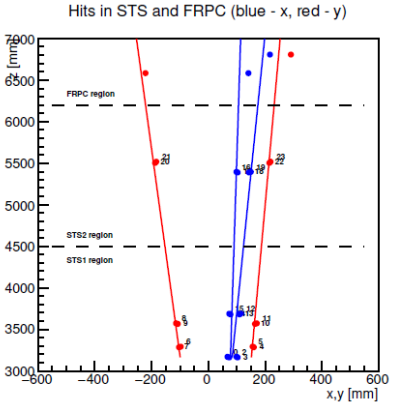


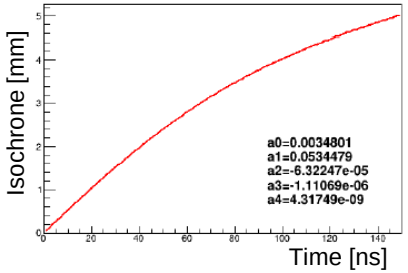




Label = be21045042940

Nevents = 2960055
[+] PT1 = 2181859 (73.71 %)
[ ] PT4 = 8827 (0.30 %)
[ ] PT5 = 4243 (0.14 %)
[ ] PT8 = 773665 (26.14 %)
N tracks = 303860 (10.27 %)
N(-80) = 257208 (84.65 %)
N(-100) = 256823 (84.52 %)





Conclusions and Summary

- The planned measurements of hyperon EM decays and double strangeness production will make important contributions to the understanding of hyperon structure.
- Dalitz decays (low q^2) will be studied for the first time in pp collisions
- Detailed feasibility studies show that the proposed benchmark channels, except Λ(1405), will be successfully measured at HADES upgraded by the new forward detector system
- The FD componenets are crucial for hyperon reconstruction

- New forward detector components were successfully tested under experiment conditions
- New components operated without failure during commissioning beamtime
- The new components are included in the HADES DAQ
- A rich data base is available to prepare the data-taking and analysis software for the upcoming experiment
- **A four week experiment beamtime with the upgraded HADES is scheduled for February 2022.**

THANK YOU!

Questions?