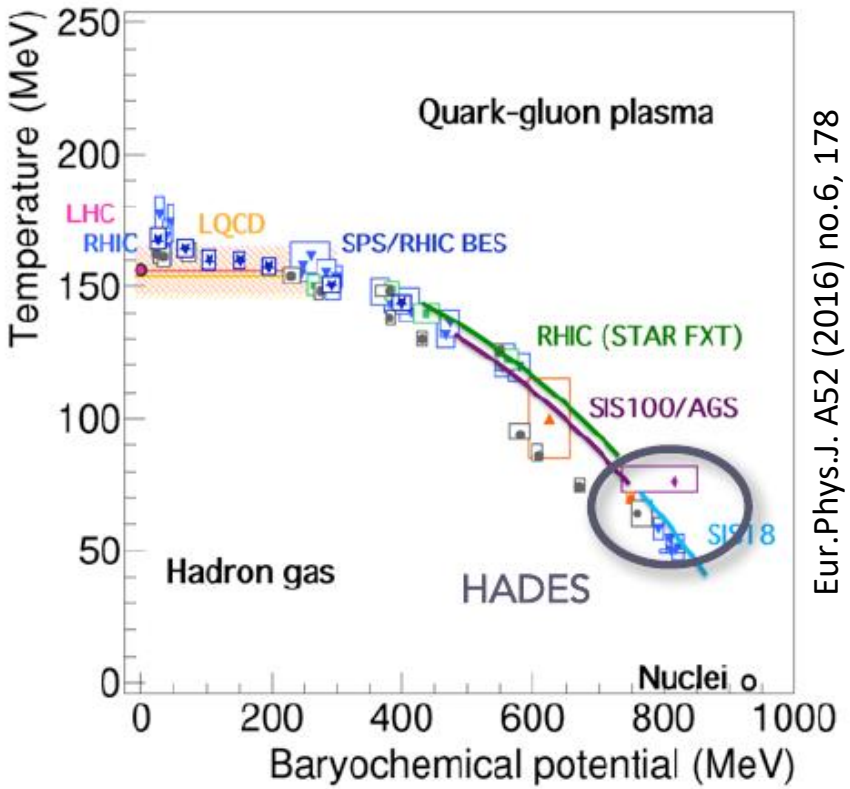
Hypernuclei at HADES

Recent results from the measurement of Hypernuclei in Ag+Ag collisions at $\sqrt{s_{NN}}$ = 2.55 GeV with the HADES experiment

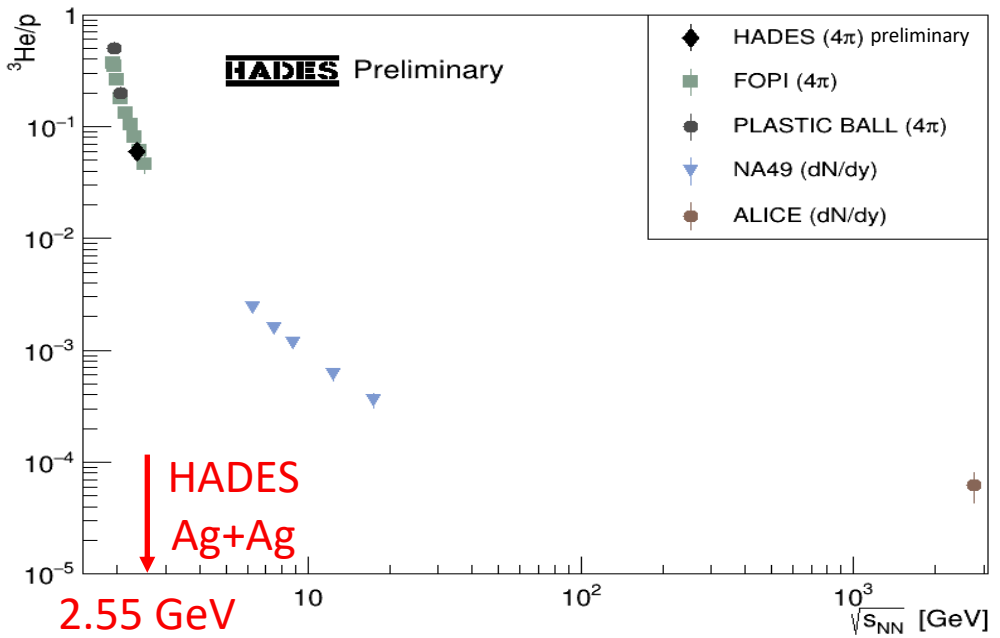
Nuclear collisions at few GeV



Eur.Phys.J. A52 (2016) no.6, 178

- Similar conditions as expected in merging neutron stars (Nature Physics **15**, 1040–1045 (2019), J. Phys.: Conf. Ser. **878** 012031, Phys. Rev. Lett. **122**, 061101)

- Nucleons stopped in collision zone
  - Baryon dominated fireball N(B) ≈ 10 N(π)
- Large proportion of baryons clustered in light nuclei (About 50% of protons)

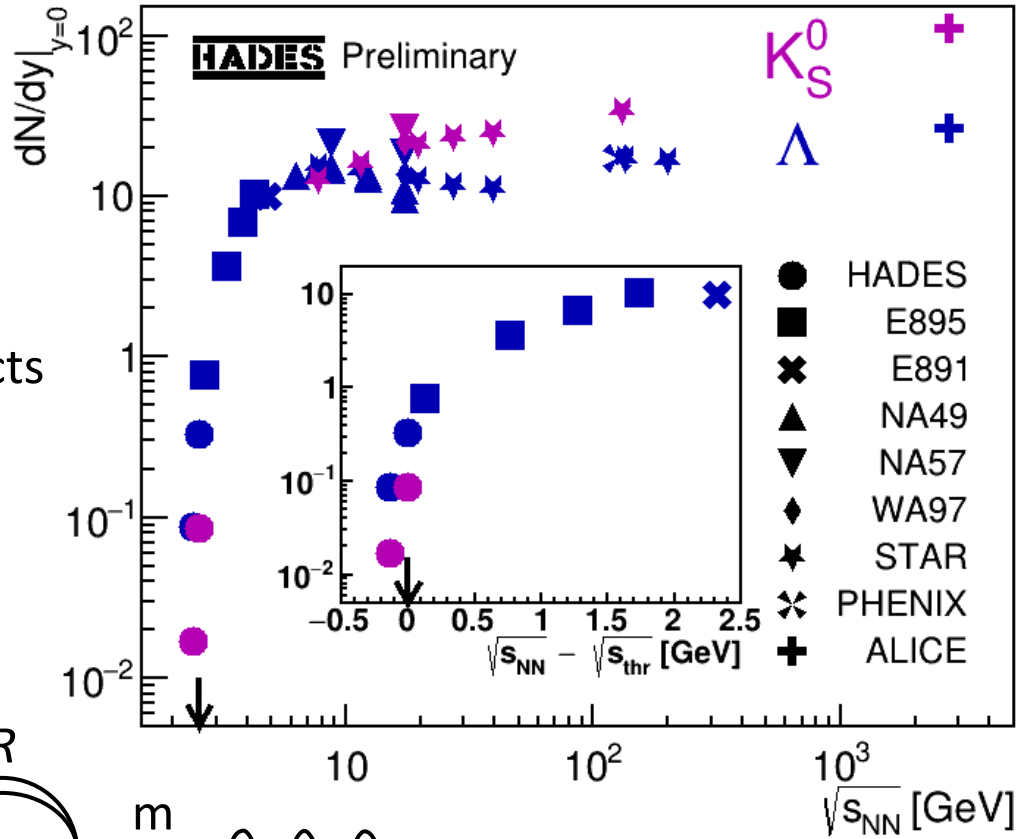


Data Collection: Phys.Lett.B 809 (2020) 135746

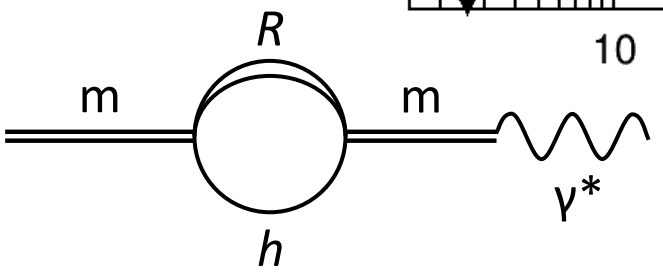
Nuclear collisions at few GeV

- Strangeness production close to free NN threshold energy:
  N + N → Y + K + N: $\sqrt{s}$ = 2.55 GeV
  N + N → K + $\overline{K}$ + N + N: $\sqrt{s}$ = 2.86 GeV
  - Steep excitation function, sensitive to medium effects
  - Strangeness exchange reactions: Y + π → N + $\overline{K}$

- Spectral functions of mesons modified by interactions with baryons and mesons
  - Decay products – leptons – decouple from the fireball

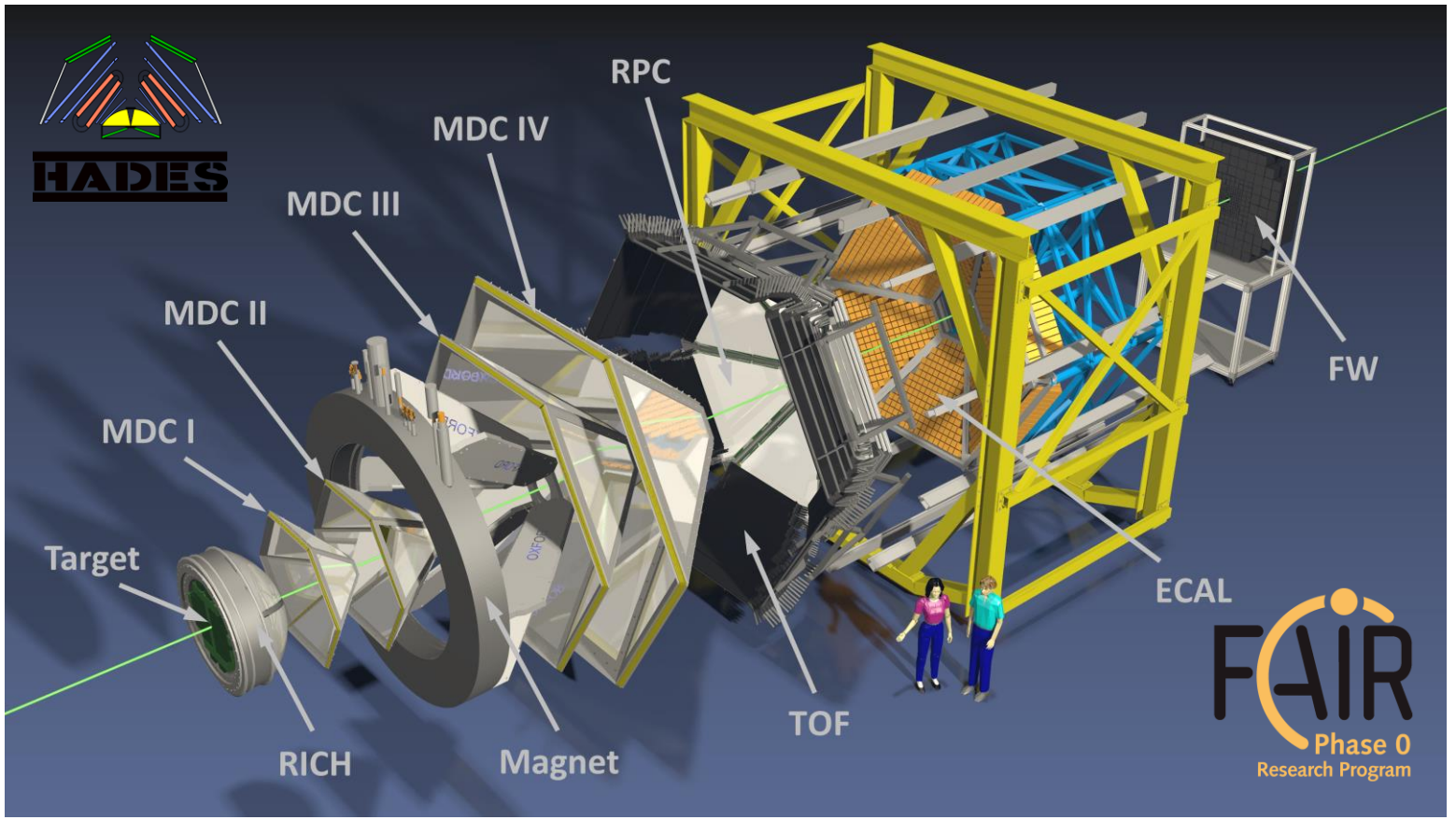


Data: Phys.Lett.B 793 (2019) 457-463



The HADES Experiment

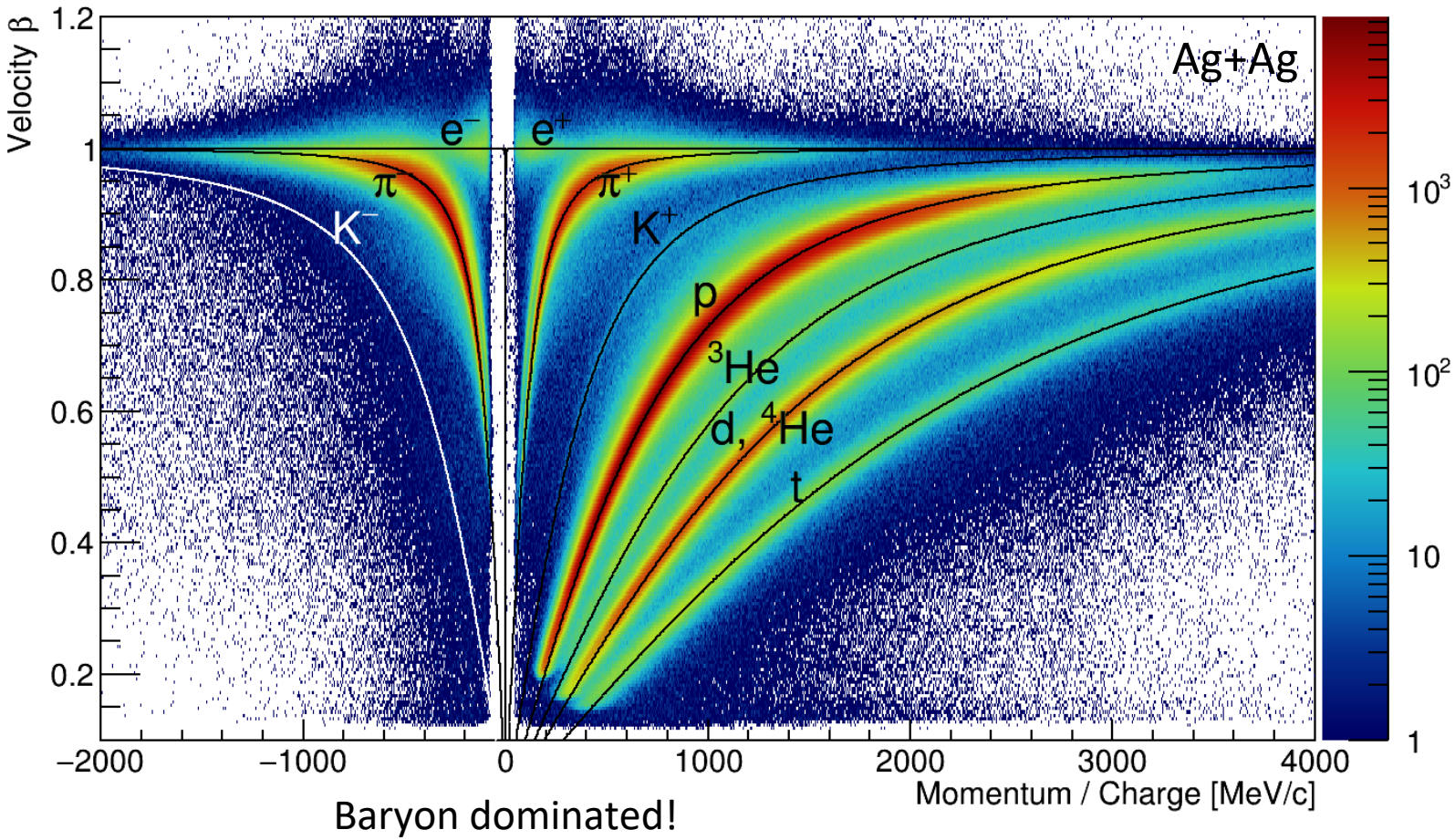
- Fixed target experiment at SIS18 (GSI, Germany)
- Magnet spectrometer
- Low mass Mini-Drift-Chambers (MDCs)
- Time of flight walls RPC and ToF
- RICH and ECAL for e^+e^- and photon identification
- Forward hodoscope for spectators detection



- Almost full azimuthal angle and polar angles between 18° and 85° covered

The HADES Experiment

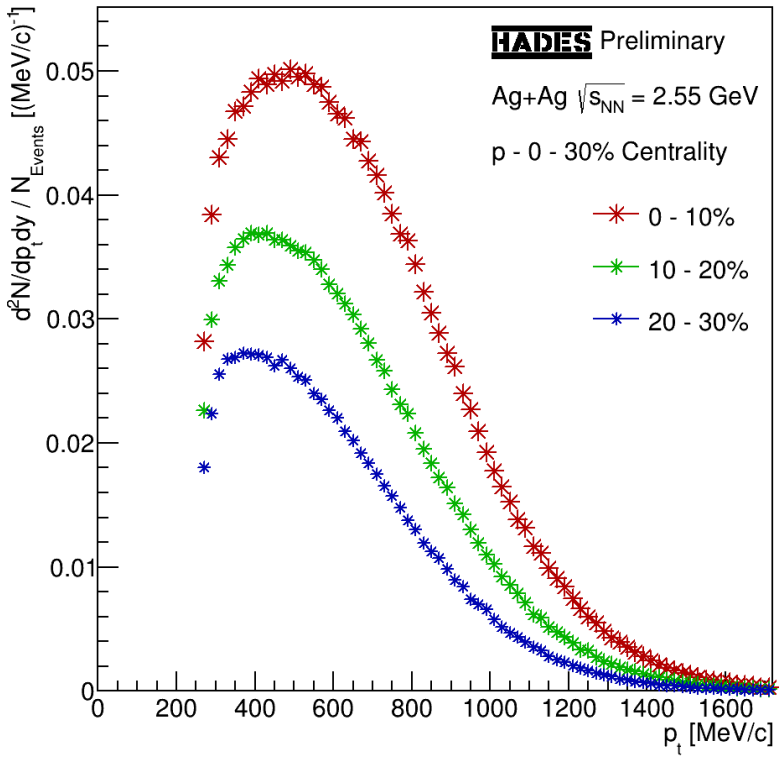
- PID primarily via. momentum and velocity
  - Separation of multiple charged particles via. specific energy loss
- Heavy-ion beamtimes:
  - 2012: Au(1.23A GeV)+Au
    $\sqrt{s_{NN}}$ = 2.42 GeV
    7 billion events
  - 2019: Ag(1.58A GeV)+Ag
    $\sqrt{s_{NN}}$ = 2.55 GeV
    14 billion events

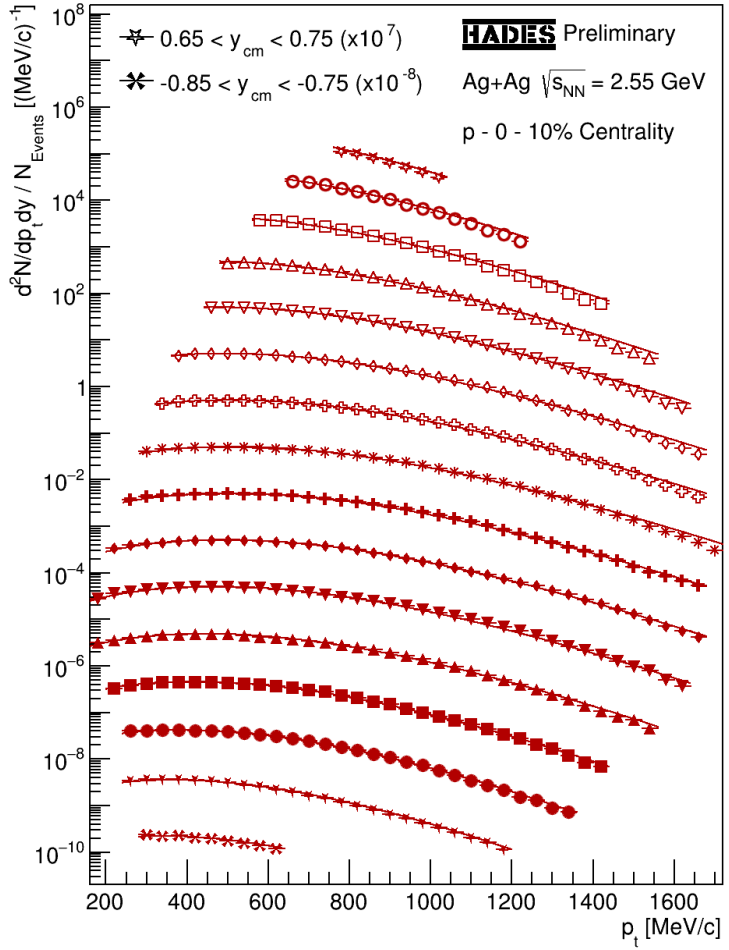


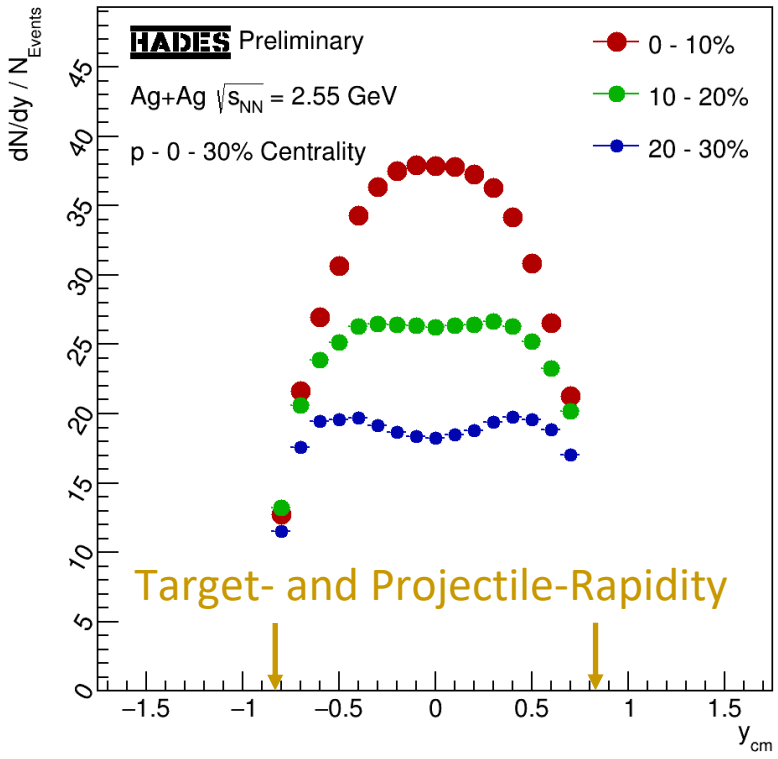
Charged Particles

Analysis of Protons, Light Nuclei and Pions

Protons: Yield and Kinematic Distributions







- Large phase space coverage with small statistical and systematic errors

- 0-10%: Nucleons almost stopped
- 10-30%: Nucleons not stopped and contaminated with spectators

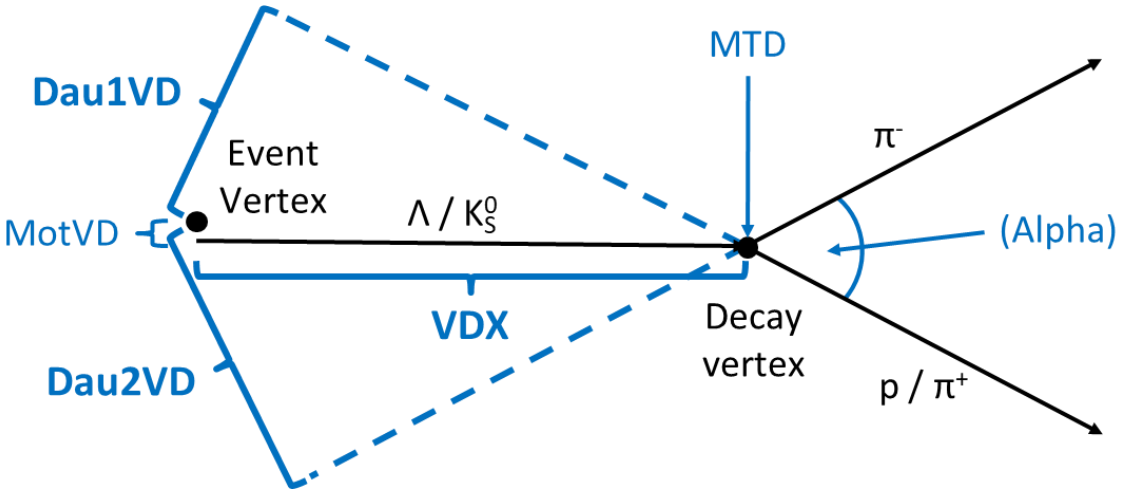
Weak Decays

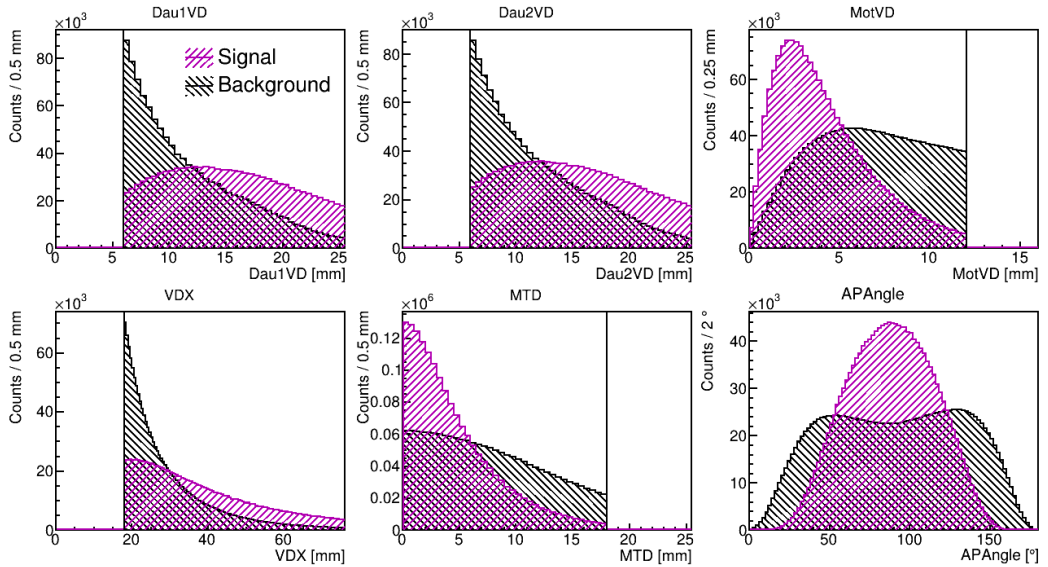
Reconstruction and Analysis of weakly decaying Hadrons

Weak decay reconstruction

- Combinatorial background about factor 10,000 above signals
- Long lifetimes → Off-vertex-topology
- Evaluated by an artificial neural network

  TMVA: arXiv:physics/0703039v5 [physics.data-an]





Toolkit for **M**ulti**V**ariate Data **A**nalysis with ROOT

Weak decay reconstruction

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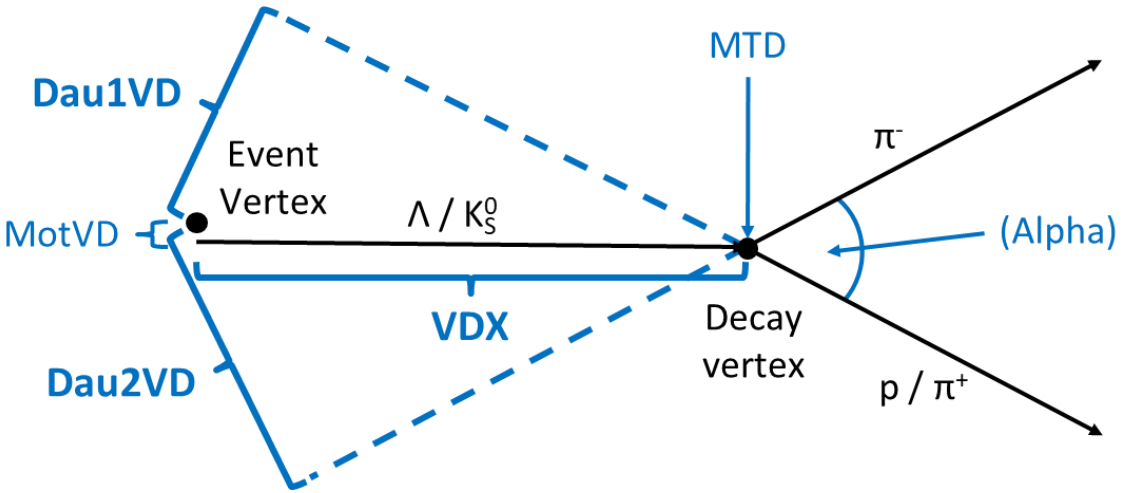
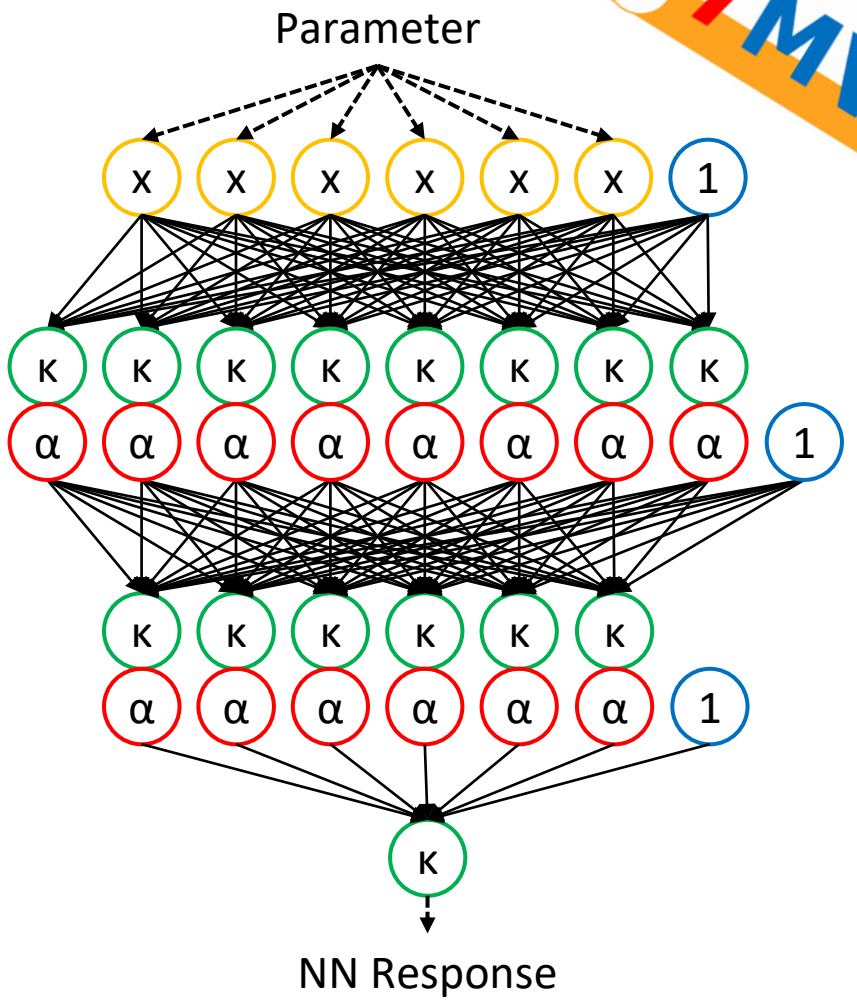
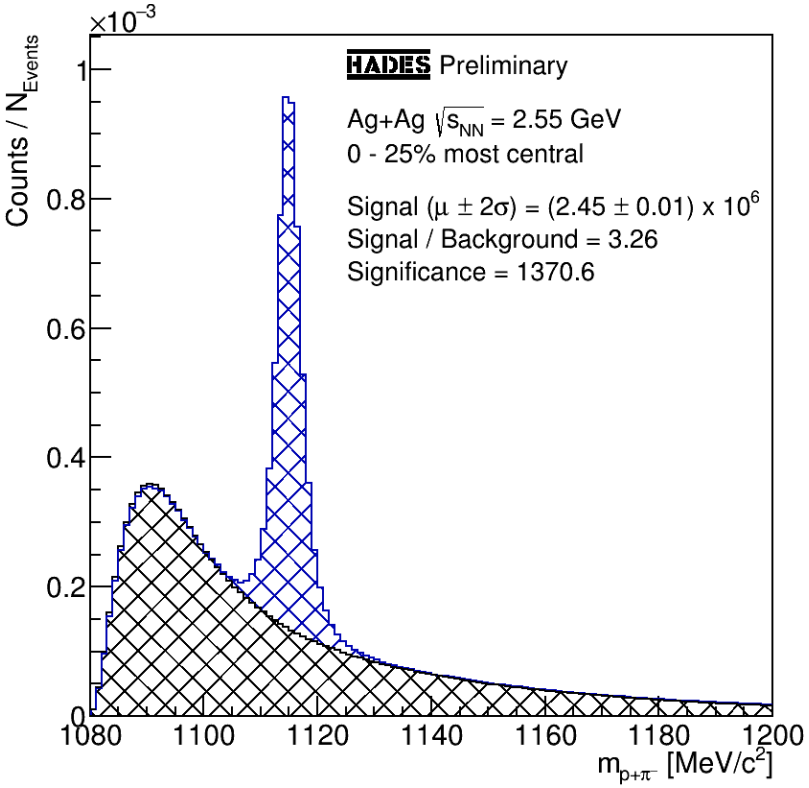
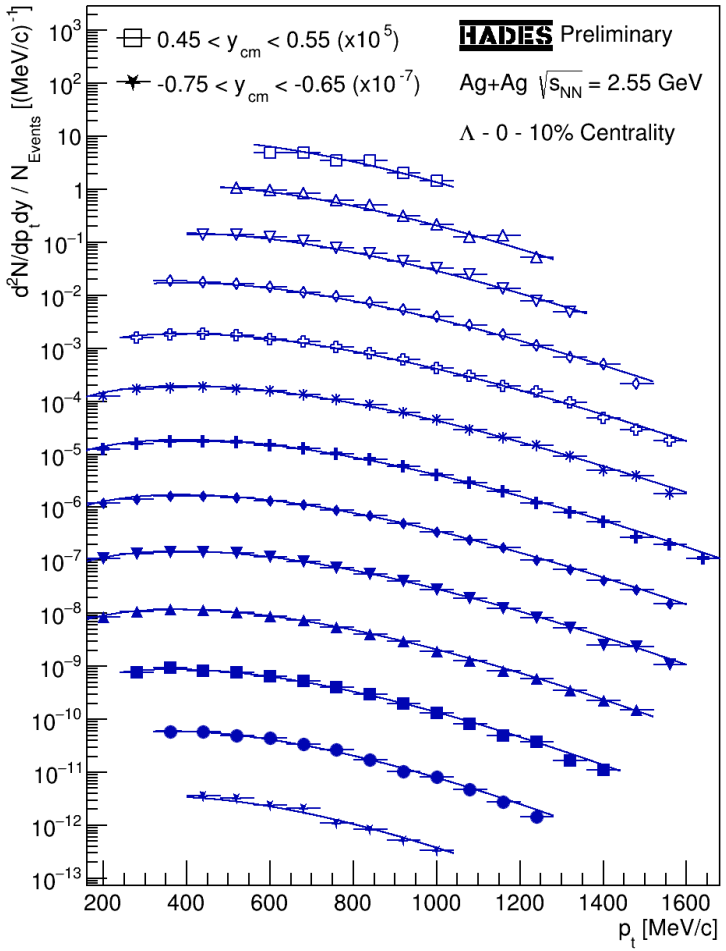
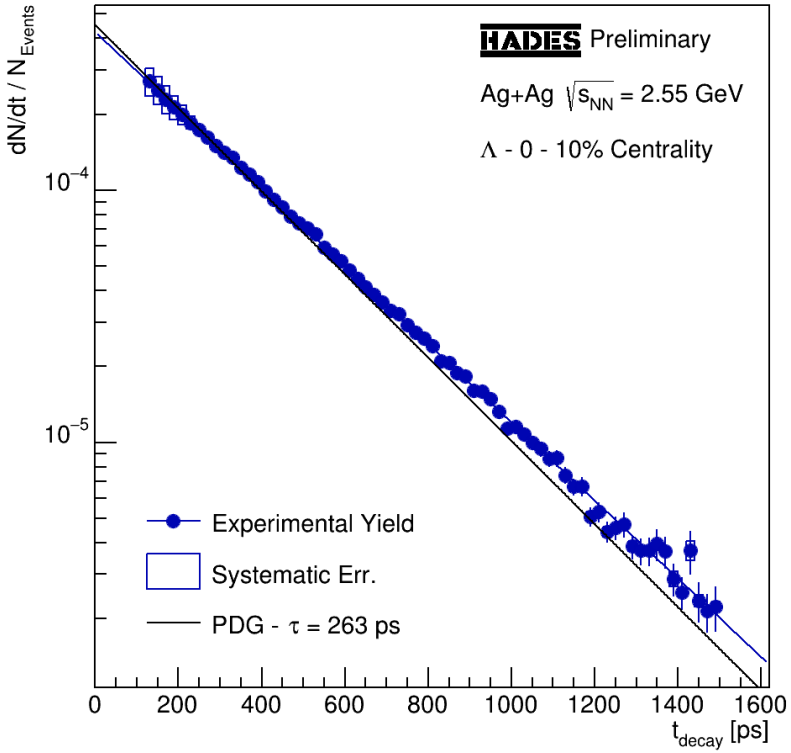




Reconstruction and Analysis of Λ Hyperons





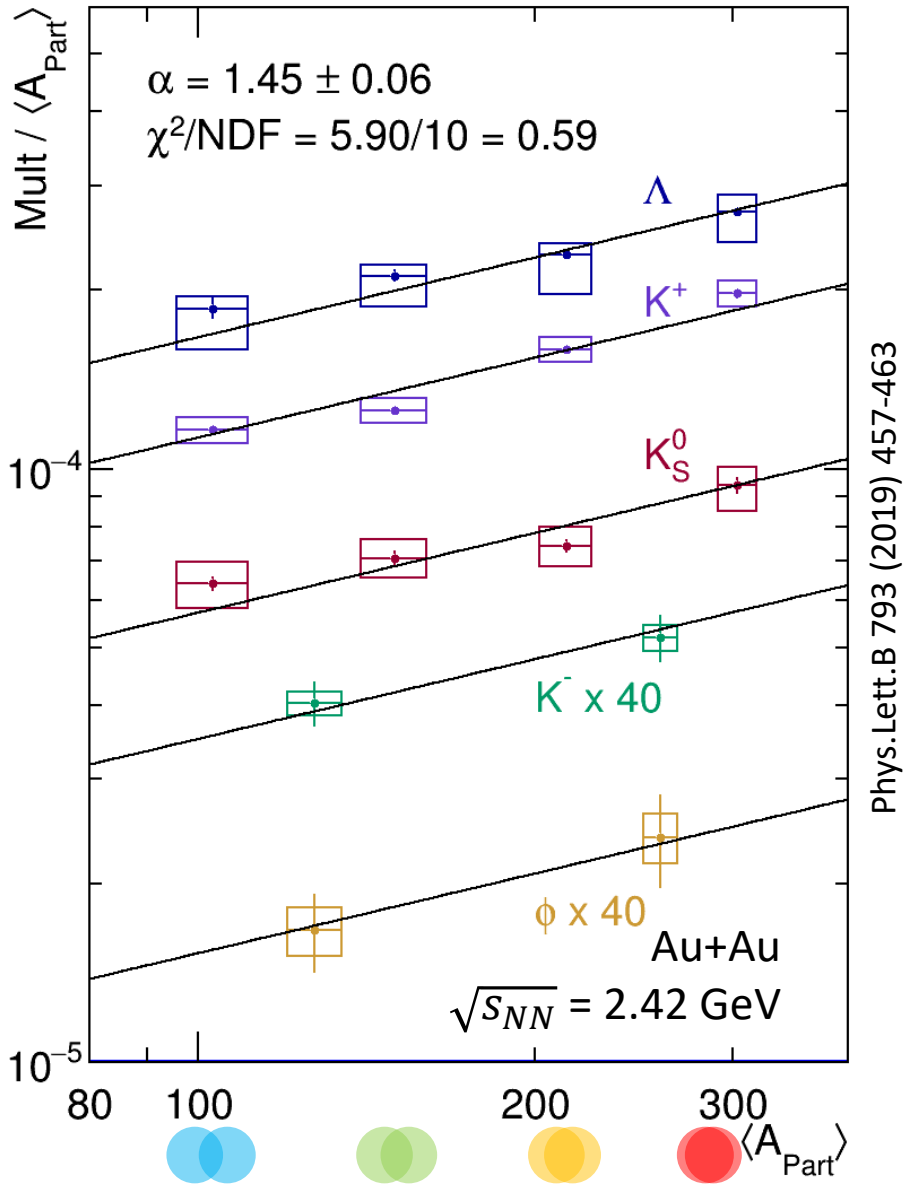


- Very significant signal
- Detailed analyses of hyperon production possible

- Lifetime measurement as test-case
- Result of (278 ± 3 ± 13) ps compatible with PDG value

Strange Yields vs. $\langle A_{Part} \rangle$

- Production below (at) free NN-threshold:
  N + N → Y + K + N: $\sqrt{s}$ = 2.55 GeV
  N + N → K + $\overline{K}$ + N + N: $\sqrt{s}$ = 2.86 GeV
  - Energy provided by the system
- Strange hadron yields scale similar with $\langle A_{Part} \rangle$:
  Mult ~ $\langle A_{Part} \rangle^{\alpha}$ with α_{Au+Au} = 1.45 ± 0.06
  - Hierarchy in production thresholds not reflected
- Scaling with absolute amount of $s\bar{s}$



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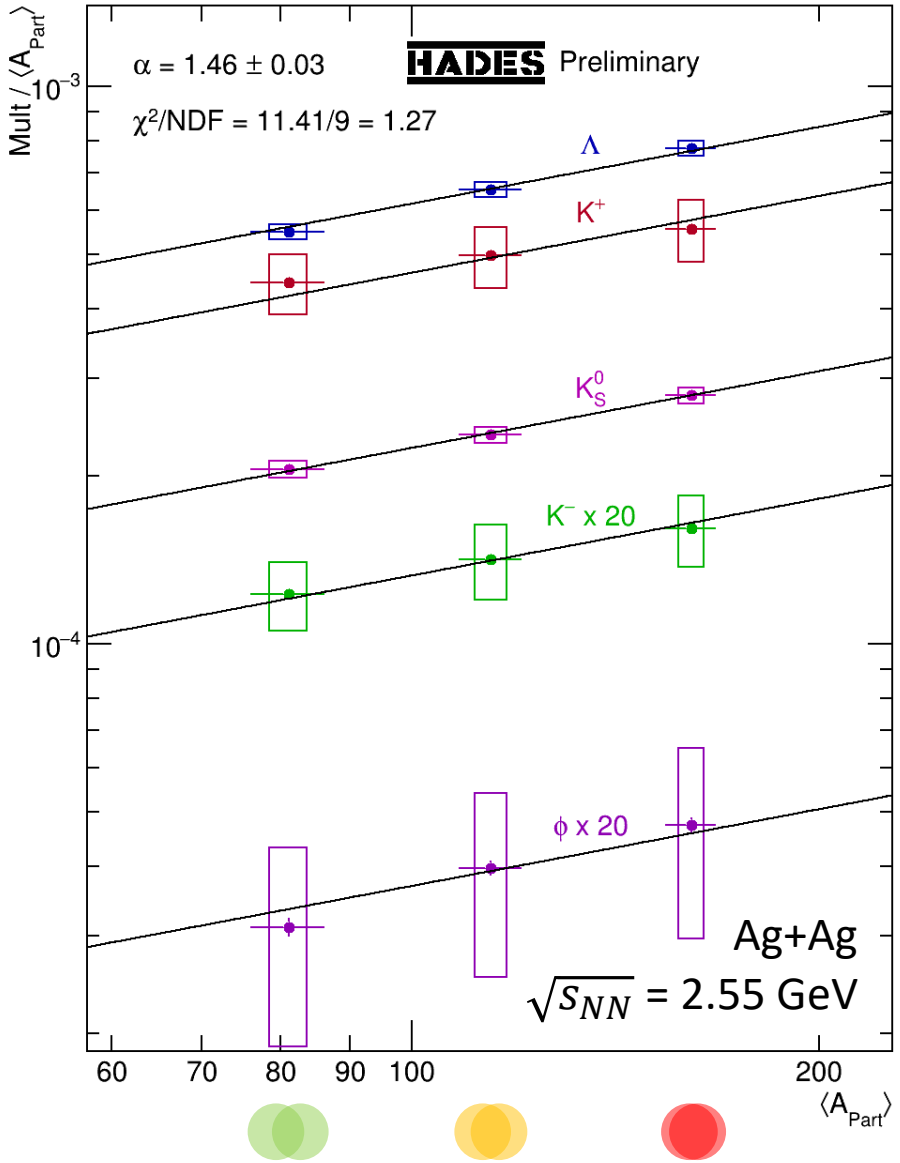
  - Hierarchy in production thresholds not reflected
- Scaling with absolute amount of $s\bar{s}$
- Ag+Ag slope equal within errors α_{Ag+Ag} = 1.46 ± 0.03
- Further reduction of systematic uncertainties ongoing



Hypernuclei

Reconstruction and Analysis of Hypernuclei

Hypernuclear Properties

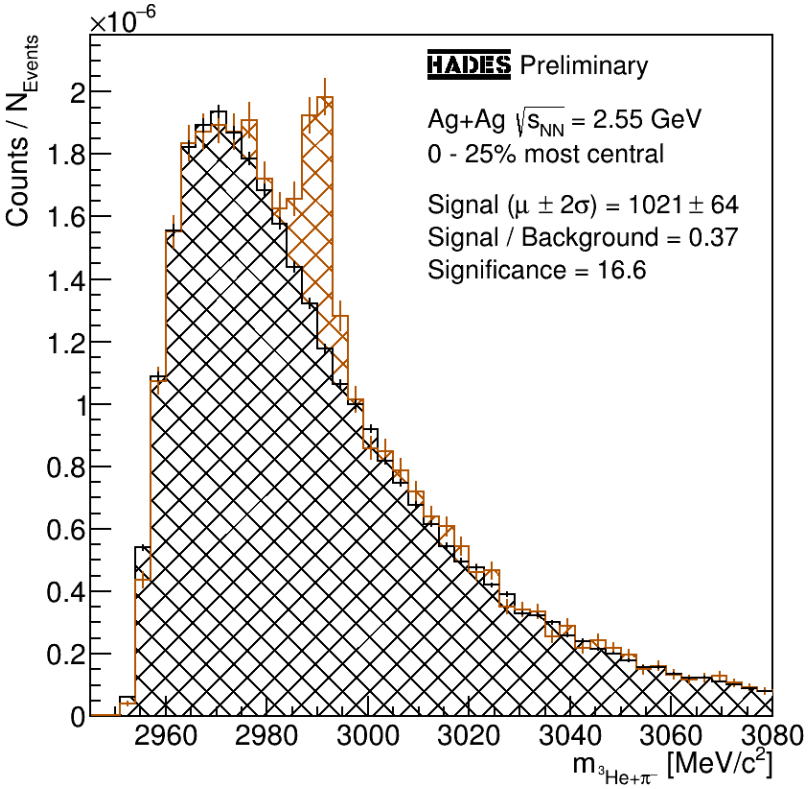
The Hypertriton – ${}^{3}_{\Lambda}\mathrm{H}$

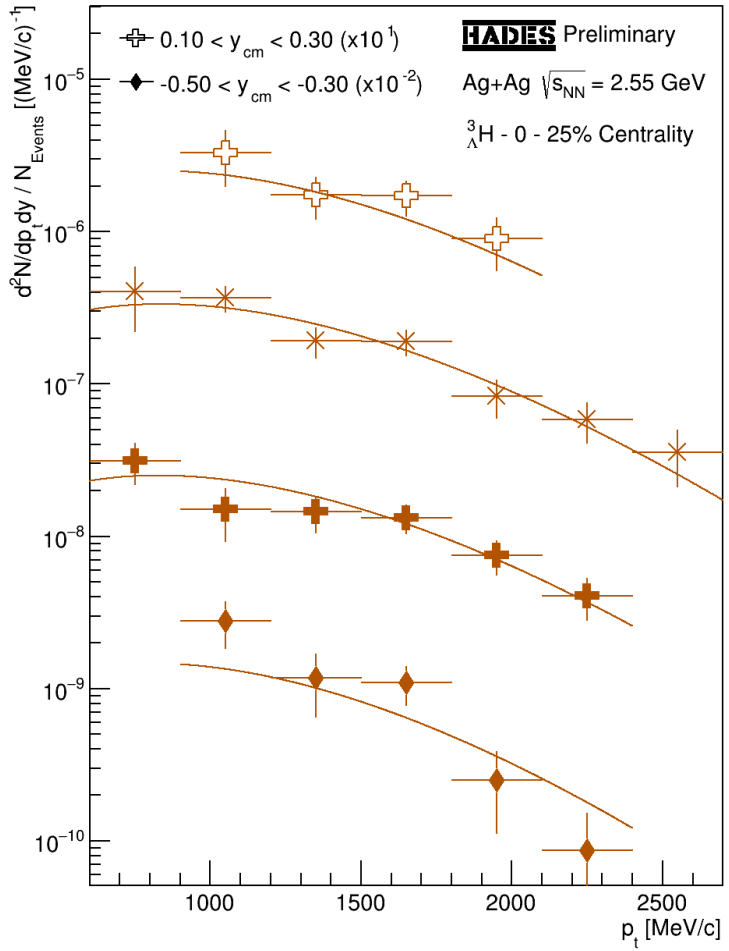
- Mass of ≈ 2991 MeV/c^2
  - Binding energy B(${}^{3}_{\Lambda}\mathrm{H}$) ≈ 0.79 MeV/A
- Primarily four mesonic decay channels:
  - **${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^-$ (BR ≈ 27%)**
  - ${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \pi^0$ (BR ≈ 13%)
  - ${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{p} + \pi^-$ (BR ≈ 40%)
  - ${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{n} + \pi^0$ (BR ≈ 20%)
- Lightest known hypernucleus
- Current World-Average Lifetime: (211 ± 9) ps

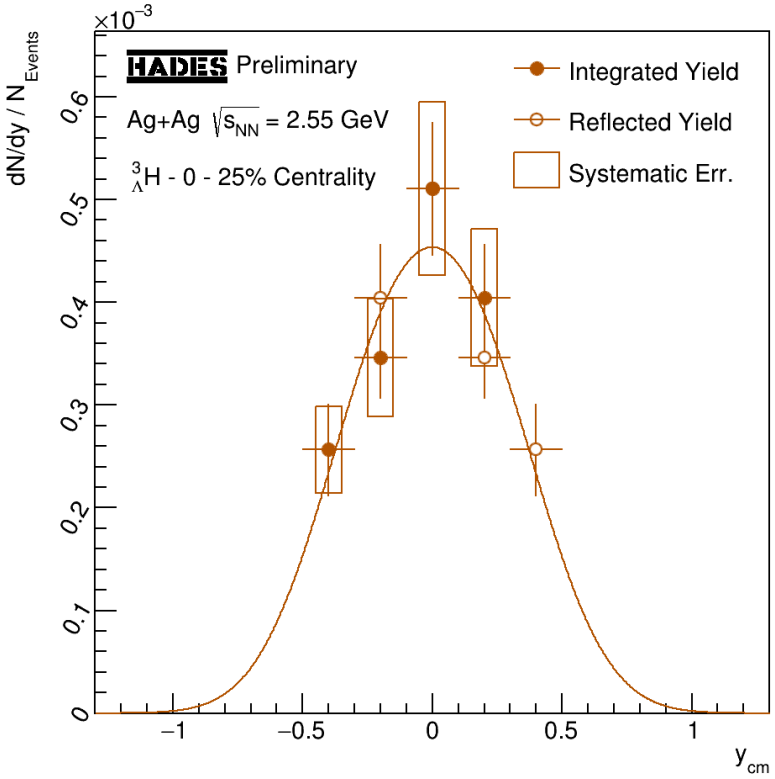
The Hyperhydrogen4 – ${}^{4}_{\Lambda}\mathrm{H}$

- Mass of ≈ 3923 MeV/c^2
  - Binding energy B(${}^{4}_{\Lambda}\mathrm{H}$) ≈ 2.63 MeV/A
    → ≈ 3.3 B(${}^{3}_{\Lambda}\mathrm{H}$)
- Primarily three mesonic decay channels:
  - **${}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^-$ (BR ≈ 50%)**
  - ${}^{4}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \mathrm{p} + \pi^-$ (BR ≈ 33%)
  - ${}^{4}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \mathrm{n} + \pi^0$ (BR ≈ 17%)
- Compared to the ${}^{3}_{\Lambda}\mathrm{H}$ higher binding energy and BR of the two-body decay channel
- Current World-Average Lifetime: (218 ± 5) ps

${}^{3}_{\Lambda}\mathrm{H}$ Two-Body Decay: ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$



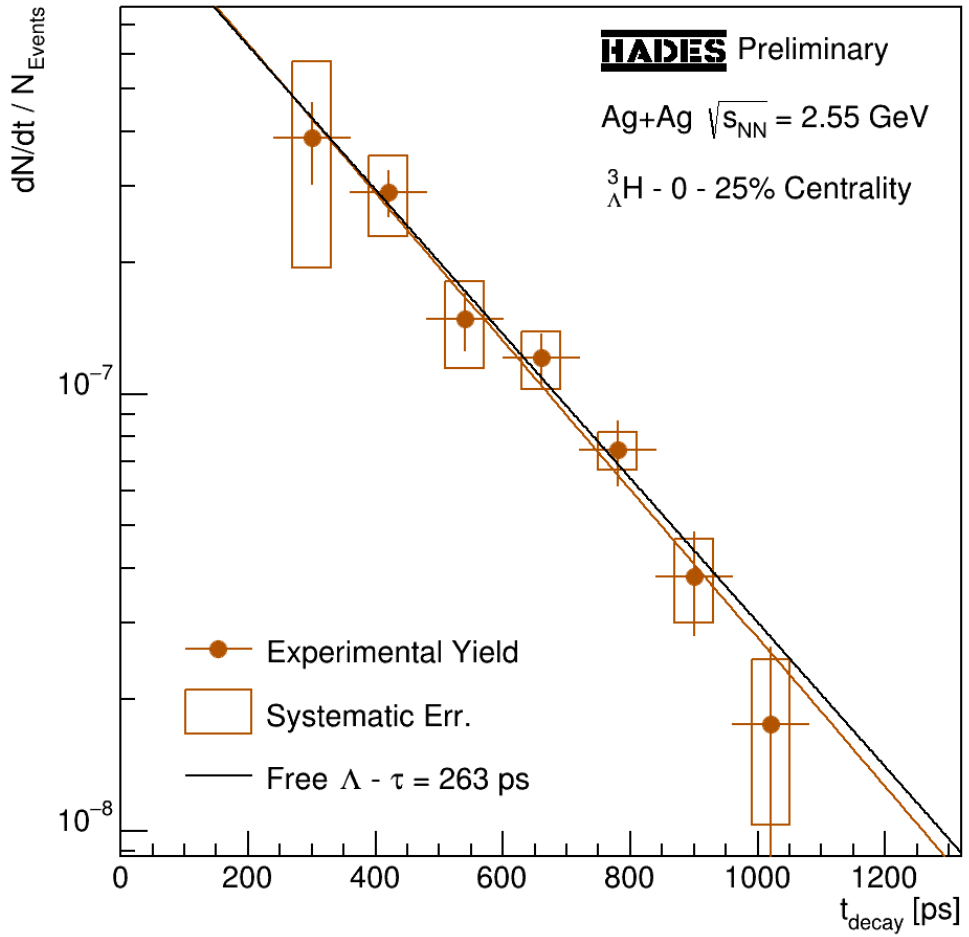




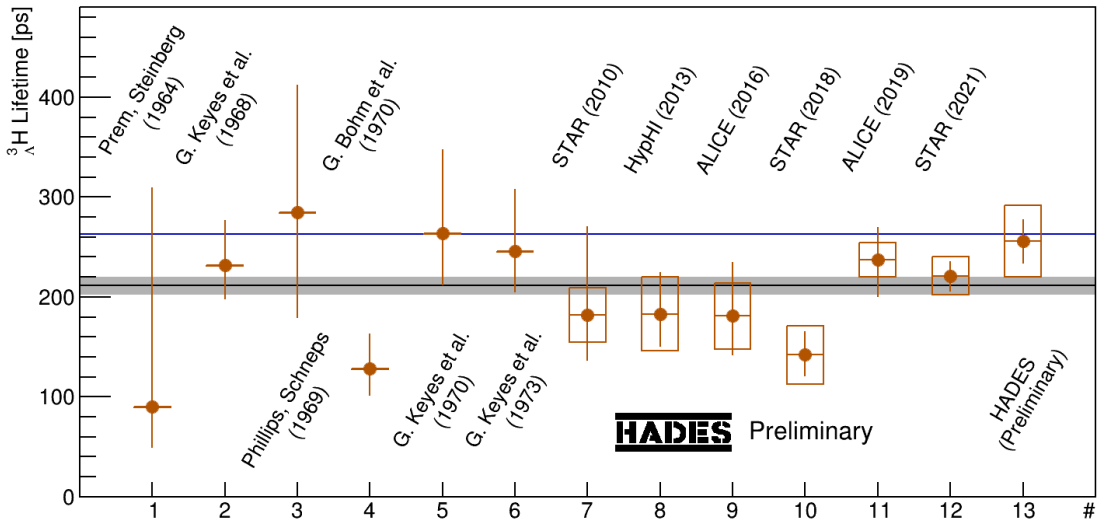
- Significant signal
- Multi-differential analysis of ${}^{3}_{\Lambda}\mathrm{H}$ production possible

- **First measurement at mid-rapidity at this energy**
- Systematic studies ongoing

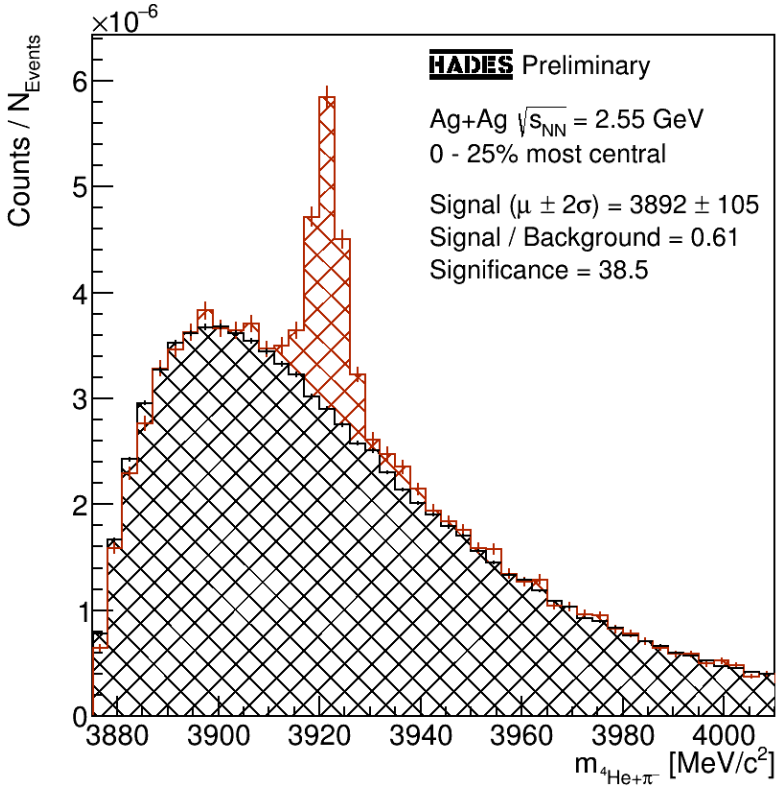
${}^{3}_{\Lambda}$H Two-Body Decay: ${}^{3}_{\Lambda}$H → ^{3}He + π^-



- ${}^{3}_{\Lambda}$H Lifetime measurement to contribute to resolving the ${}^{3}_{\Lambda}$H lifetime puzzle
- Lifetime of (256 ± 22 ± 36) ps compatible with free Λ lifetime measured
- Further uncertainty analyses required



${}^{4}_{\Lambda}\mathrm{H}$ Two-Body Decay: ${}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$



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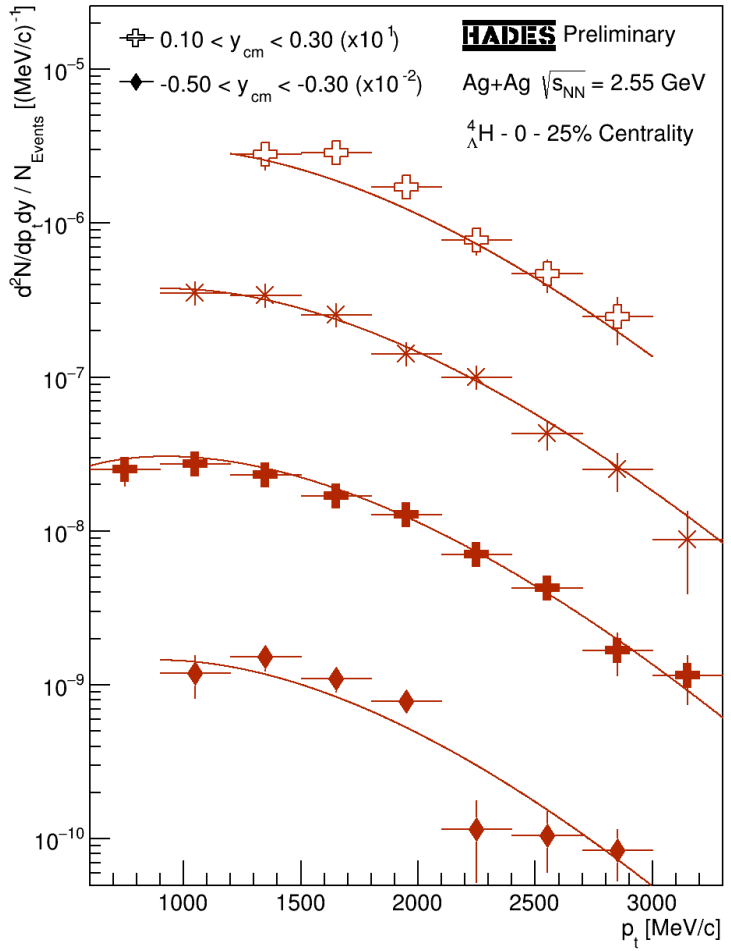
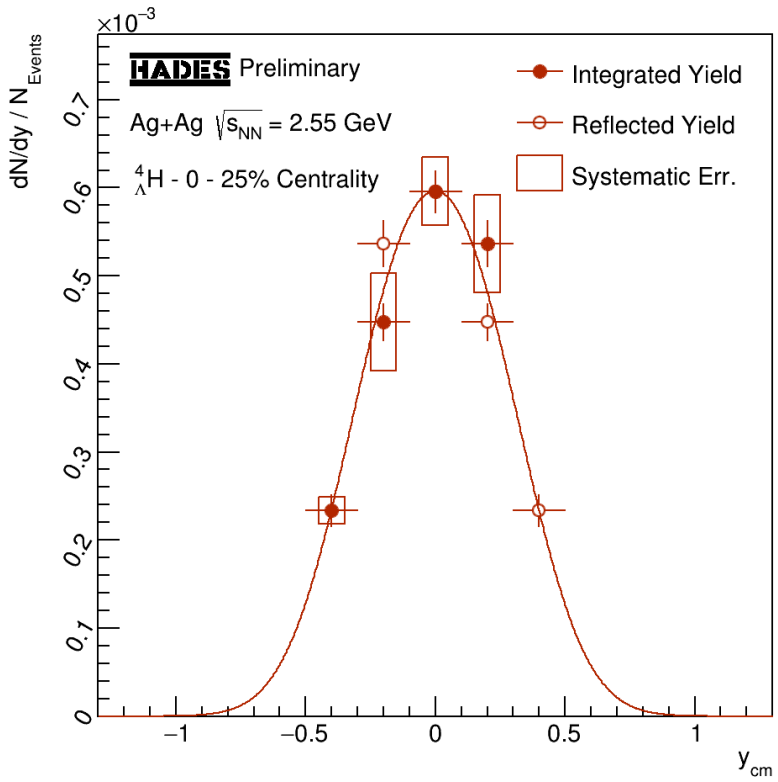
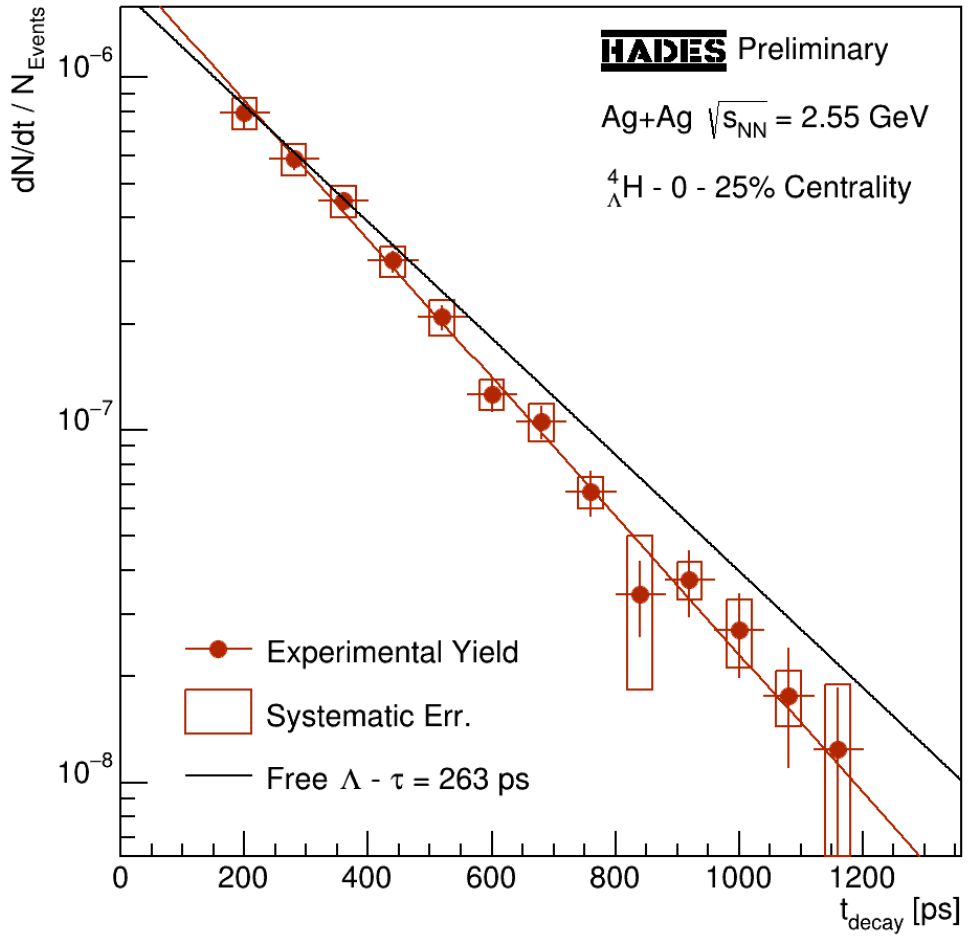


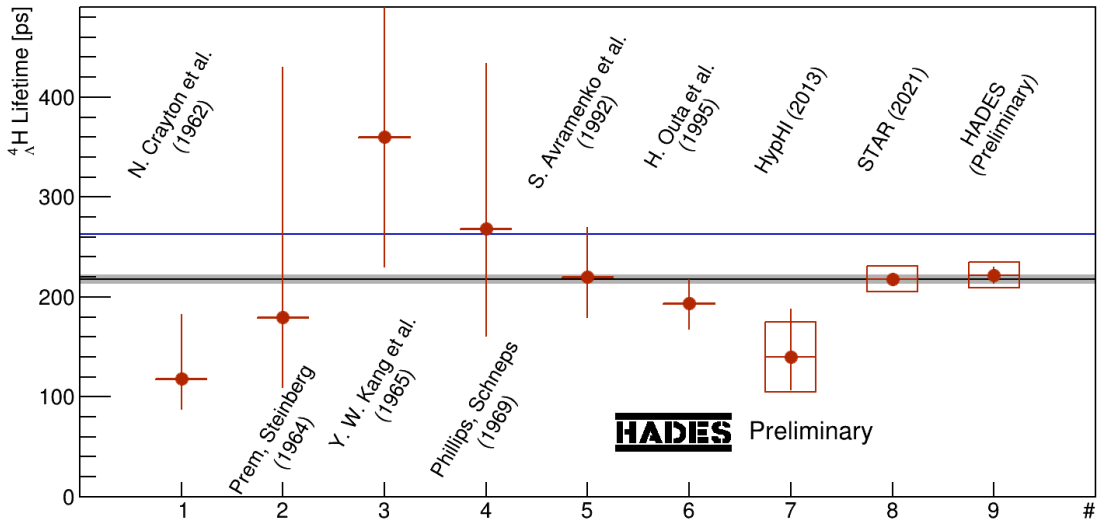


- **First measurement at mid-rapidity at this energy**
- Systematic studies ongoing

${}^{4}_{\Lambda}$H Two-Body Decay: ${}^{4}_{\Lambda}$H → ^{4}He + π^-

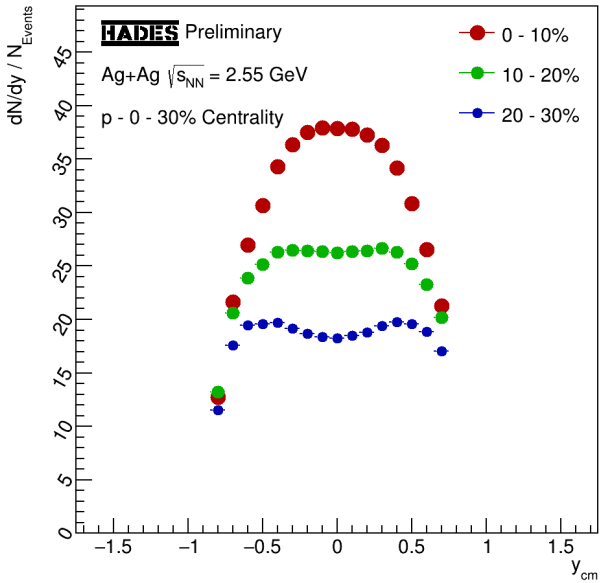


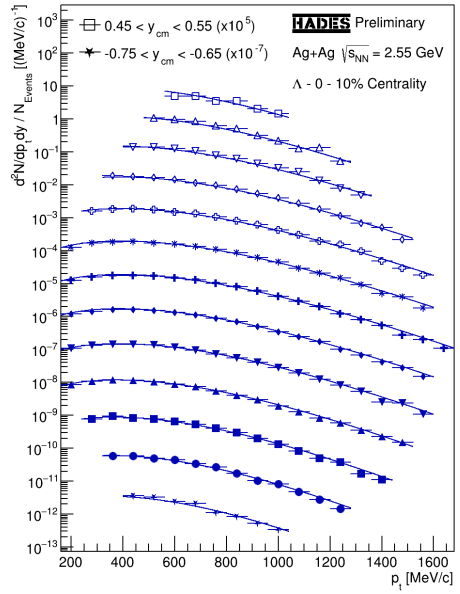
- ${}^{4}_{\Lambda}$H Lfetime measurement to contribute to world data on Hypernuclei lifetimes
- Lifetime of (222 ± 8 ± 13) ps compatible with earlier measurements measured
- Further uncertainty analyses required

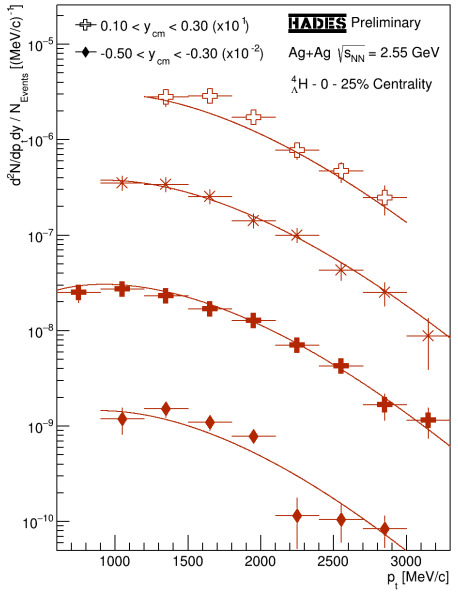


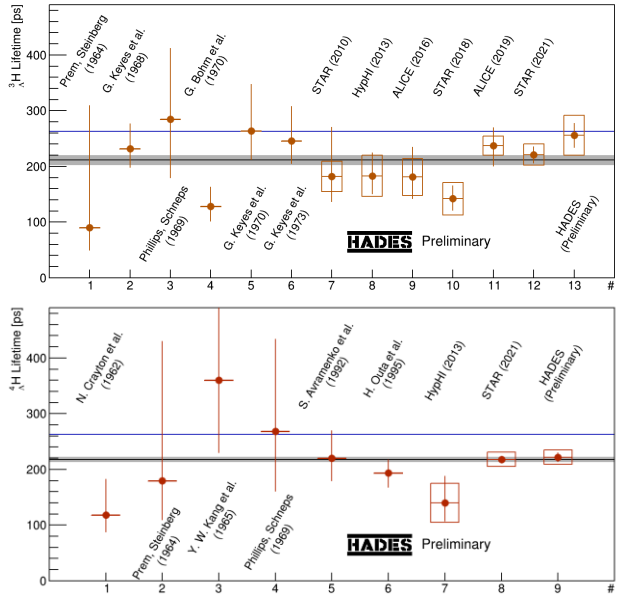
Summary

- HADES detector upgraded with FAIR technology (ECAL, RICH, STS1,2 and fRPC)
- 14 billion Ag(1.58A GeV)+Ag events collected in 2019 run
- Very detailed analyses of bulk particles (Protons, Light Nuclei and Pions)
- High quality analysis of weak decays with an artificial neural network
  - First multi-differential analysis of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H production around mid-rapidity at SIS18 energies
  - Contribution to $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H lifetime measurements









The HADES Collaboration


Thank you
for your
Attention!
1500
1000
500
0
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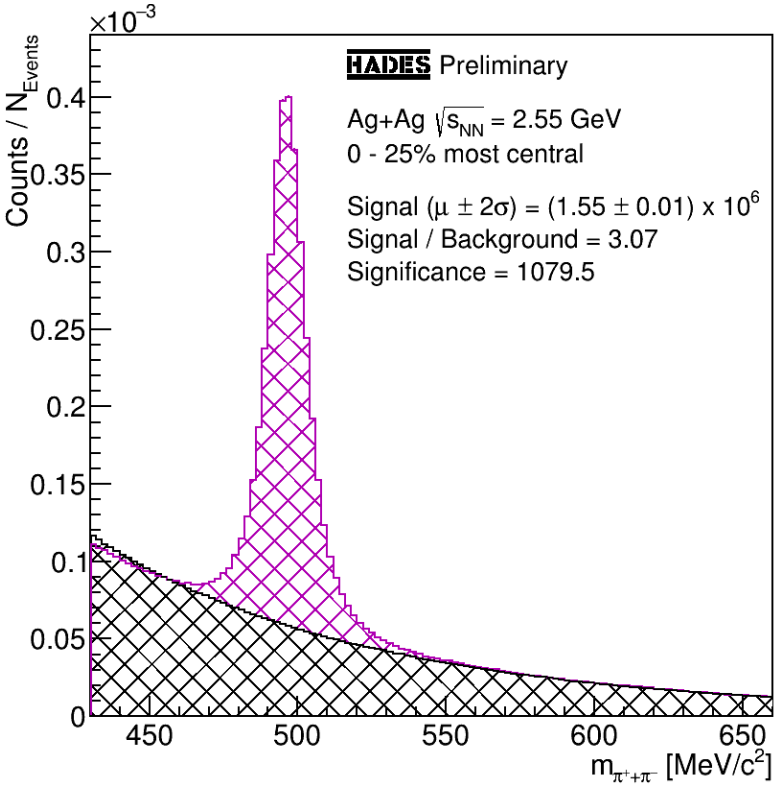
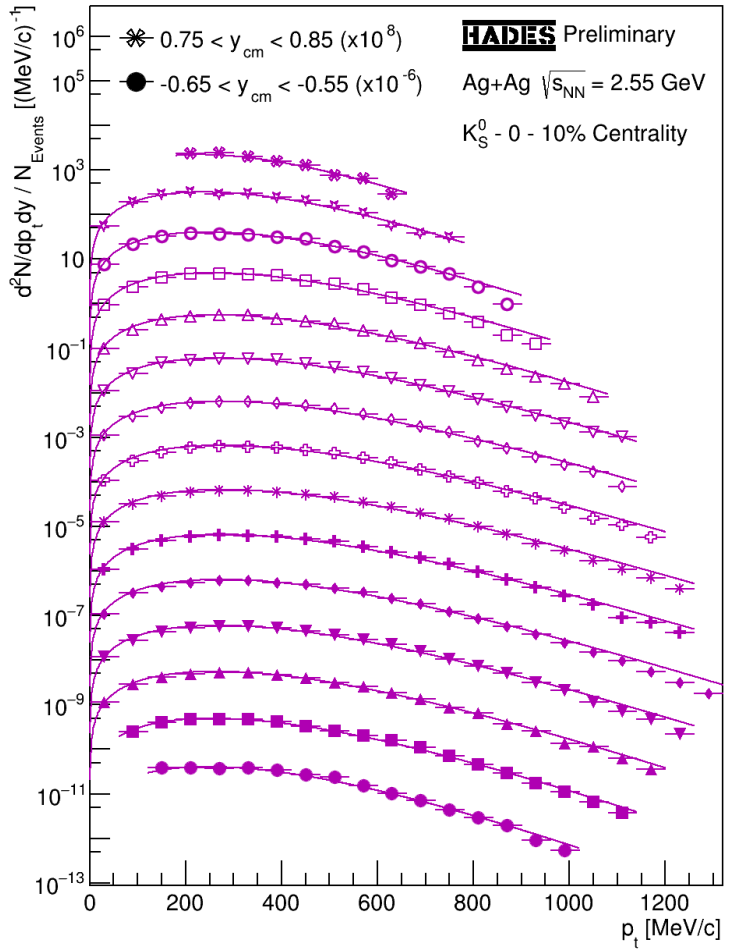
2000

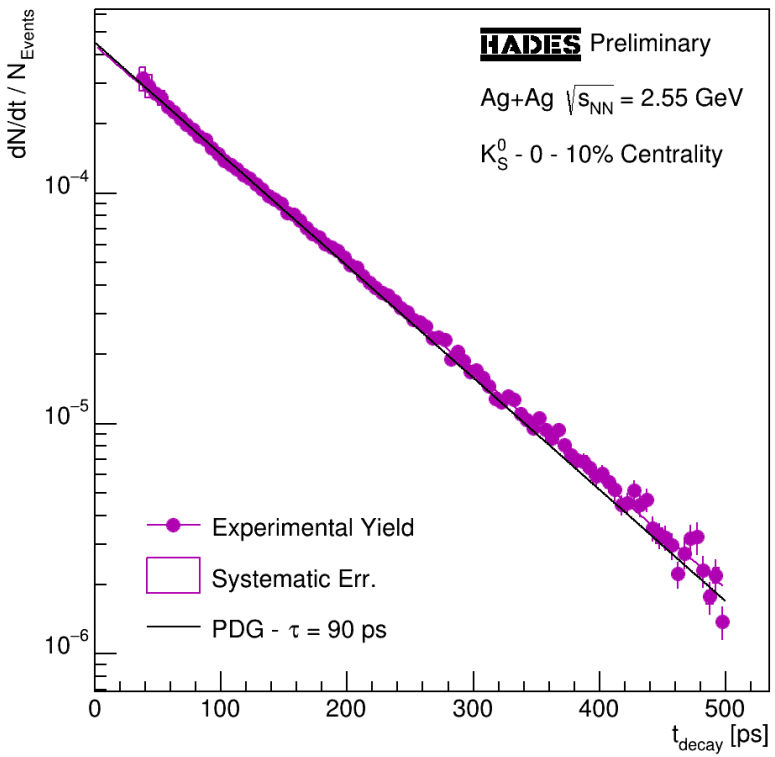
BACKUP

Reconstruction and Analysis of K^0_S Mesons



- Very significant signal
- Detailed analyses of strange meson production possible





- Lifetime measurement as test-case
- Result of (92 ± 1 ± 6) ps compatible with PDG value