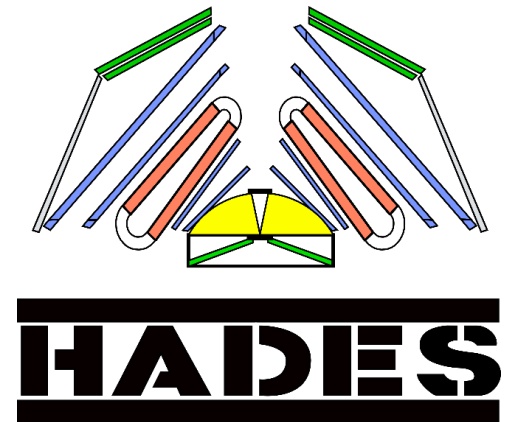
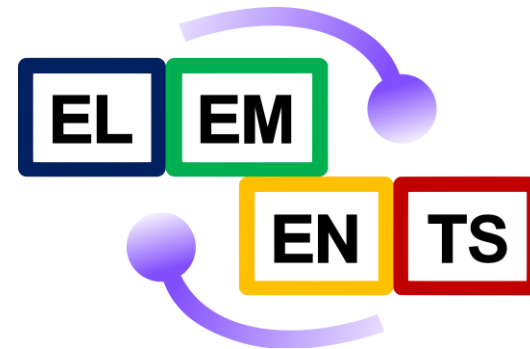


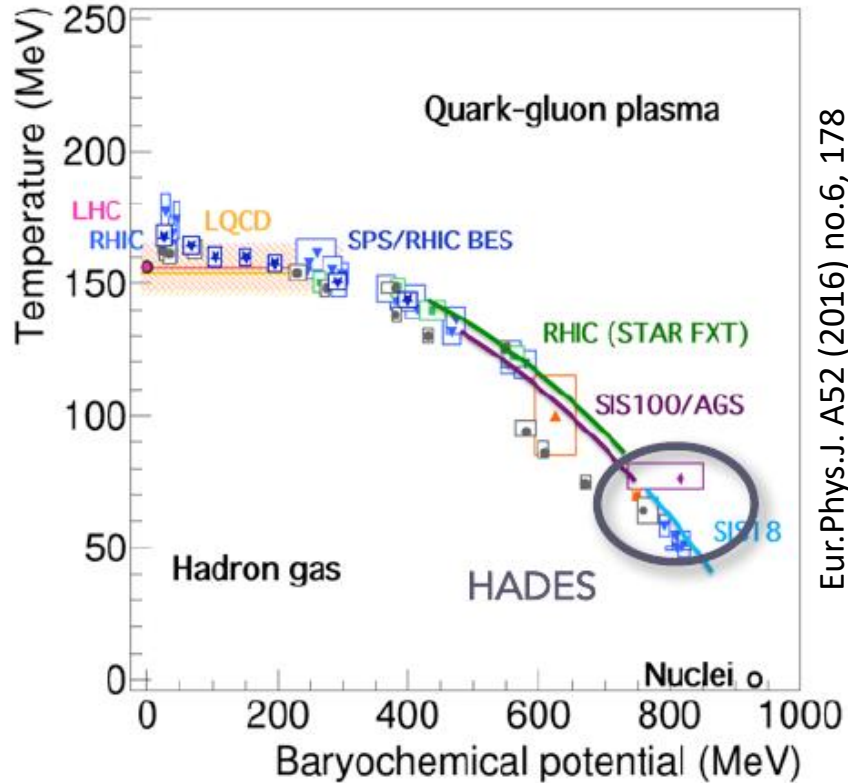
# HADES Flashtalk

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Exploring QCD matter at high density in Ag+Ag collisions at  $\sqrt{s_{NN}} = 2.55$  GeV measured with HADES

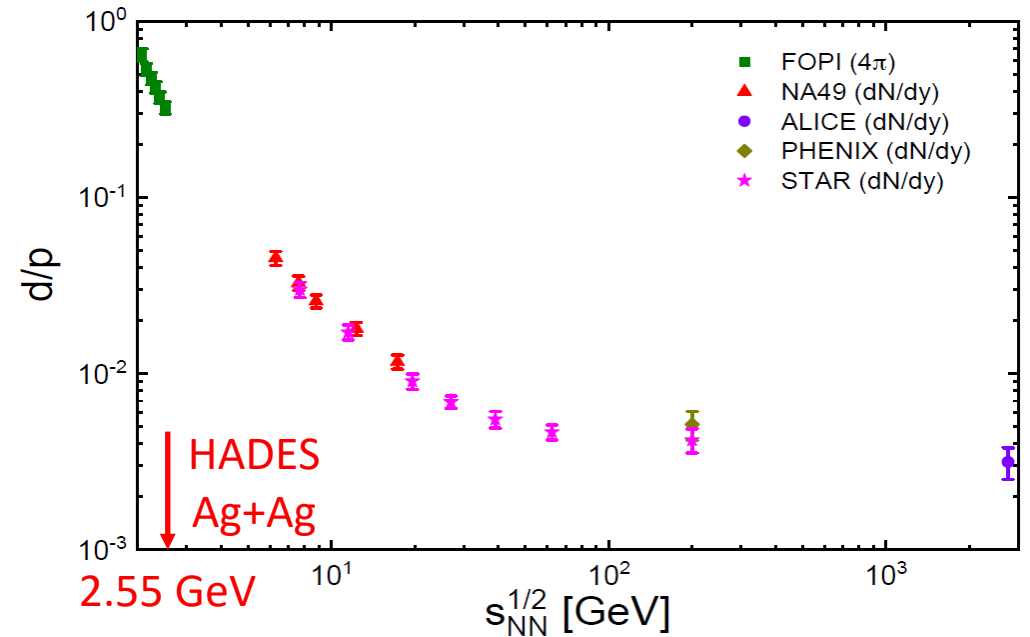


# Nuclear collisions at few GeV



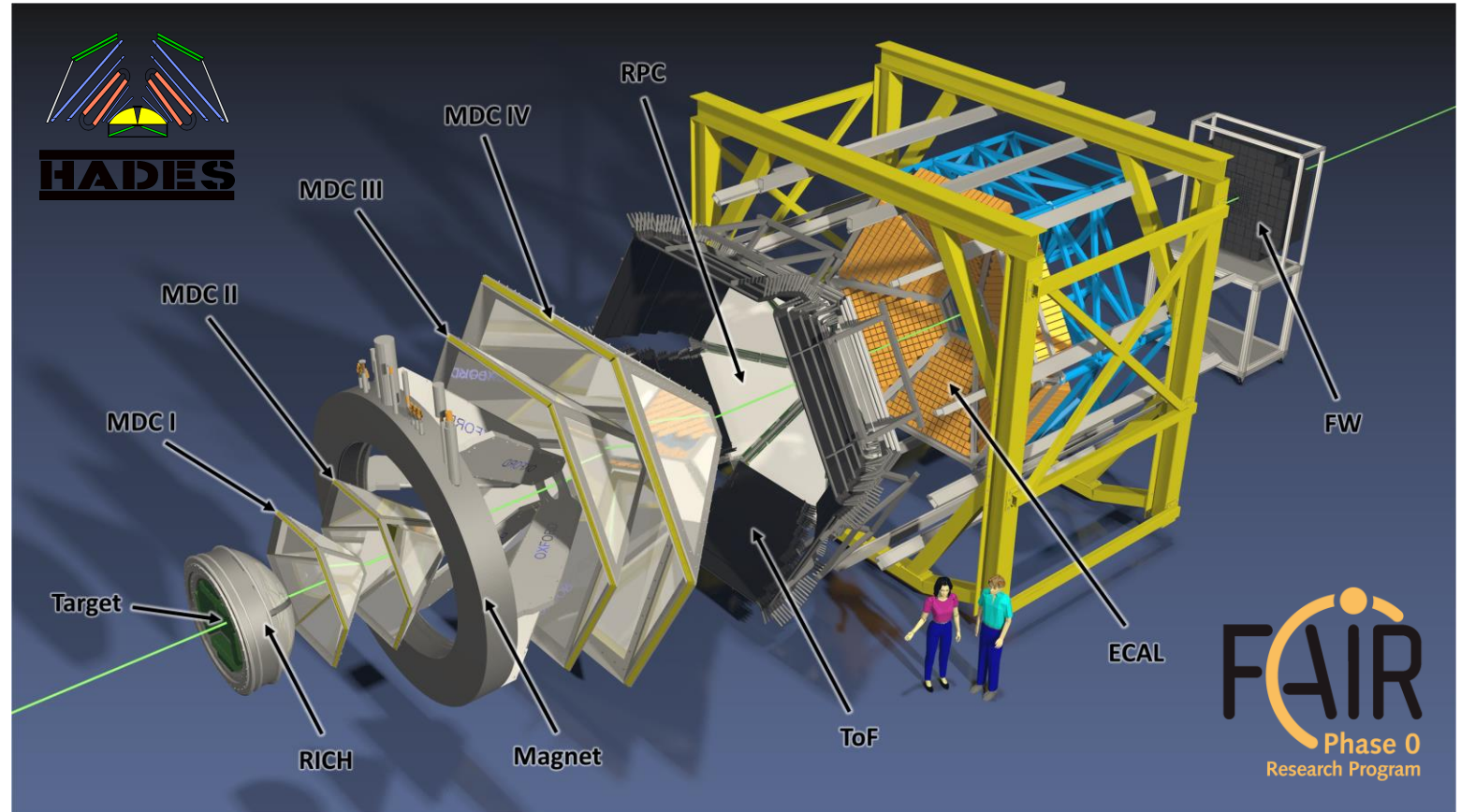
- Similar conditions as expected in merging neutron stars (Nature Physics **15**, 1040–1045 (2019), J. Phys.: Conf. Ser. **878** 012031, Phys. Rev. Lett. **122**, 061101)

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



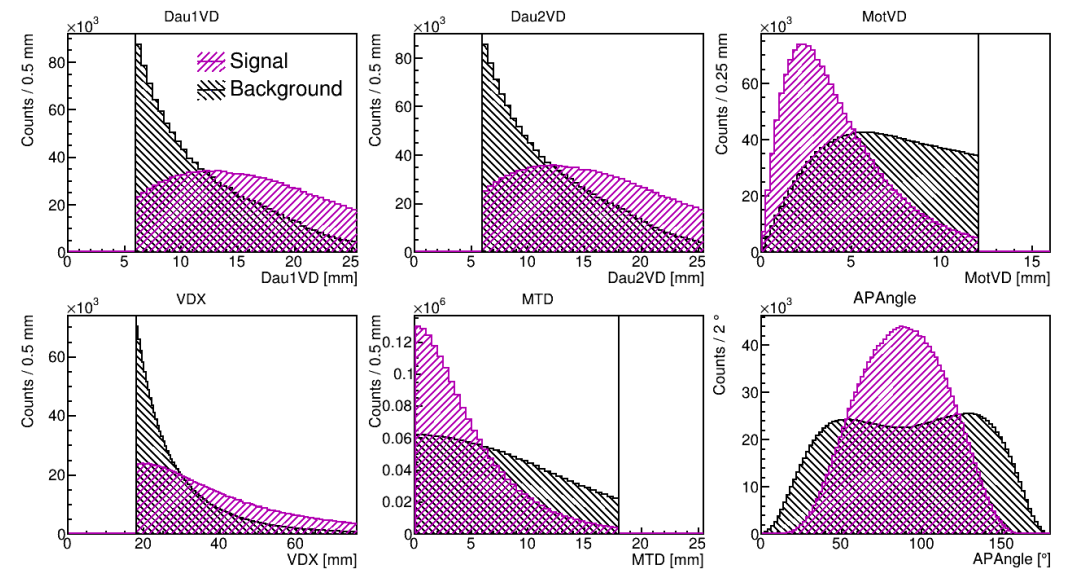
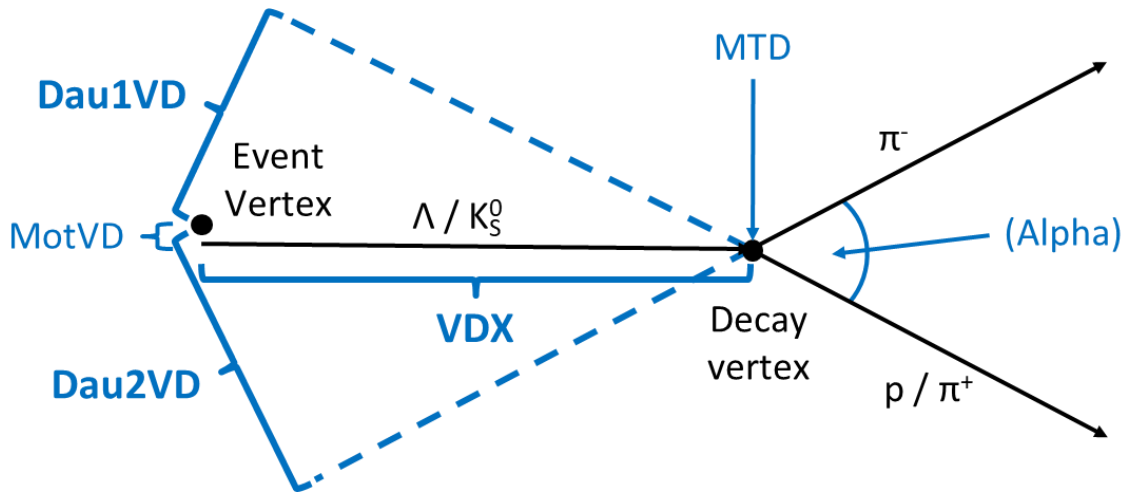
# The HADES Experiment

- 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  $18^\circ$  and  $85^\circ$  covered



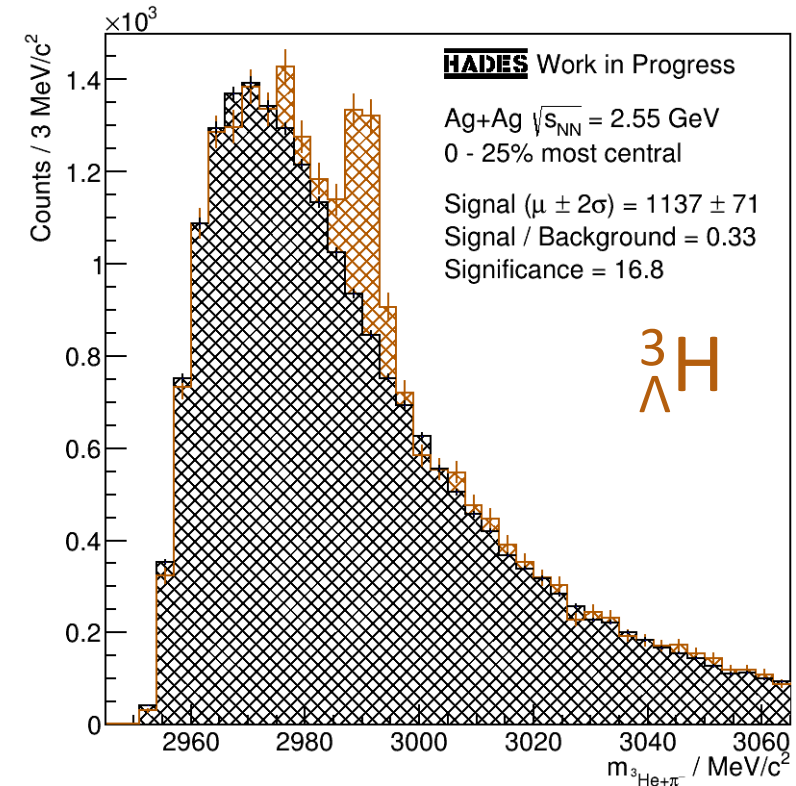
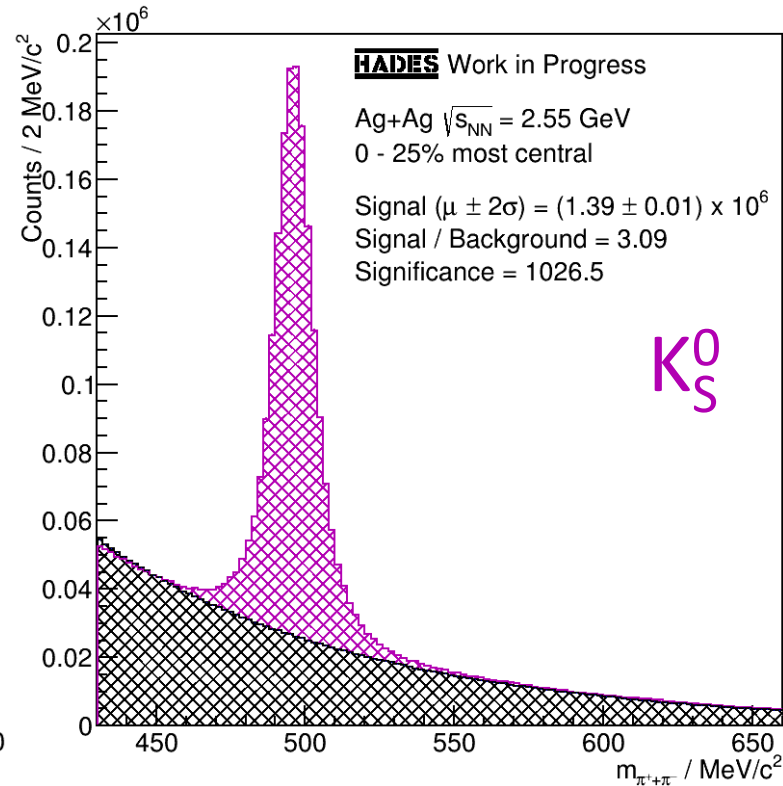
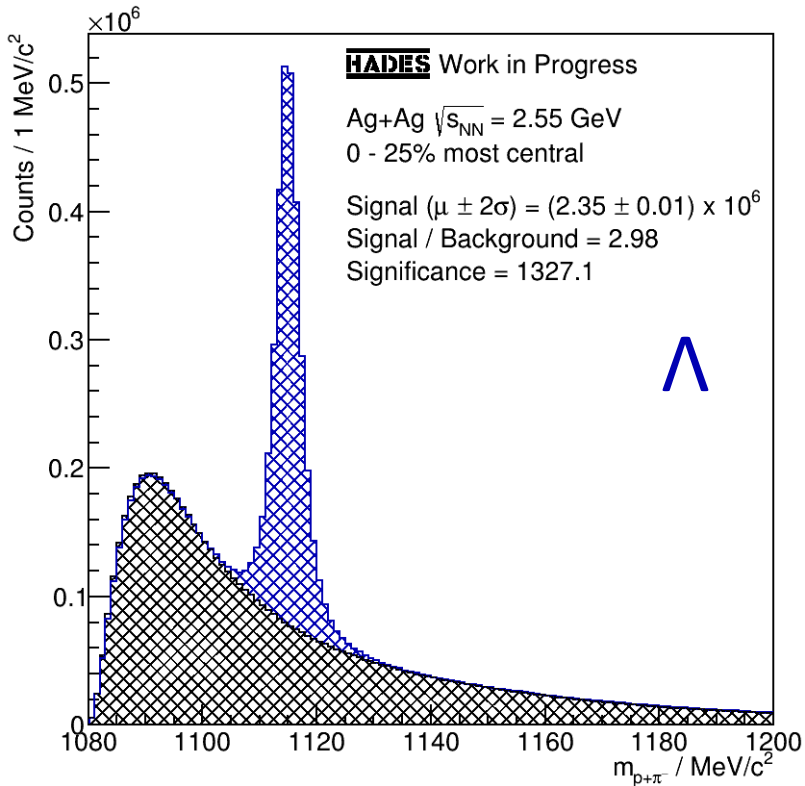
# Weak decay reconstruction

- 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]



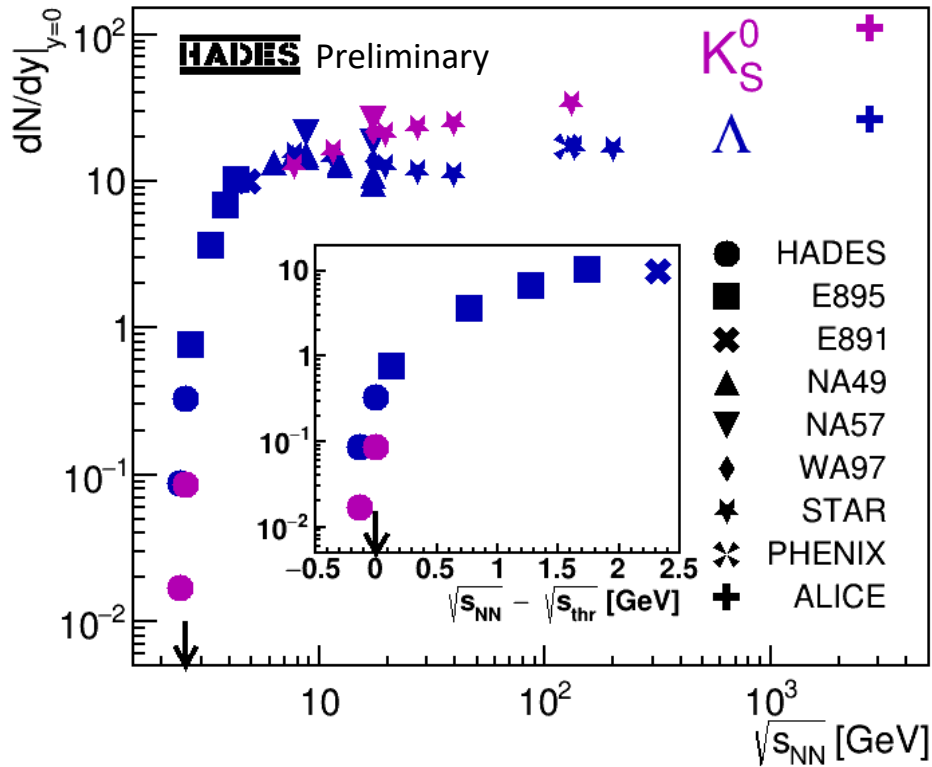
Toolkit for **M**ulti**V**ariate Data **A**nalysis with **R**OOT

# Weak decay reconstruction



➤ High detection resolutions → High statistic narrow signals!

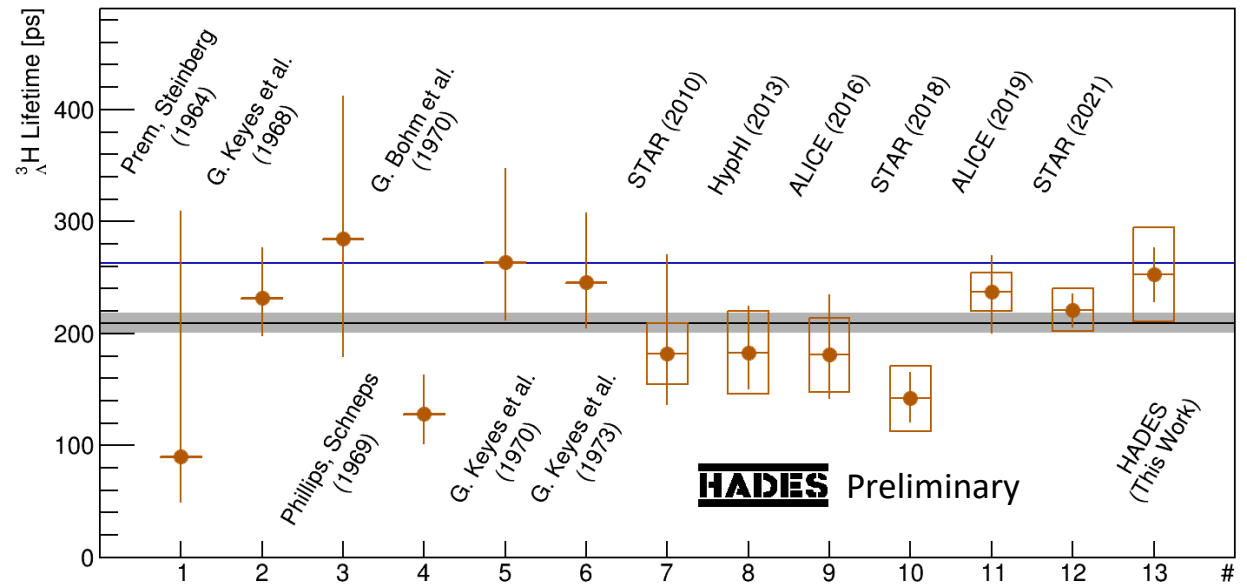
# Results



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

- Excitation functions of  $\Lambda$  hyperons and  $K_S^0$  mesons shows steep exponential rise

- ${}^3\Lambda$  lifetime of  $(253 \pm 24 \pm 42)$  ps measured
- Compatible with free  $\Lambda$  lifetime
- In line with recent measurements from STAR and ALICE



# The HADES Collaboration



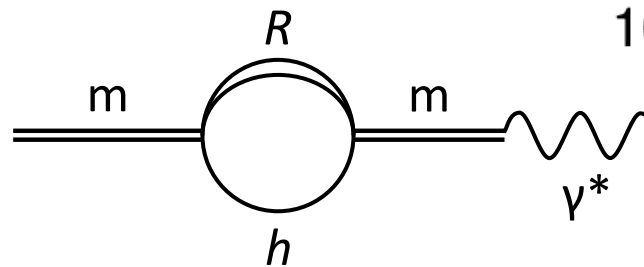
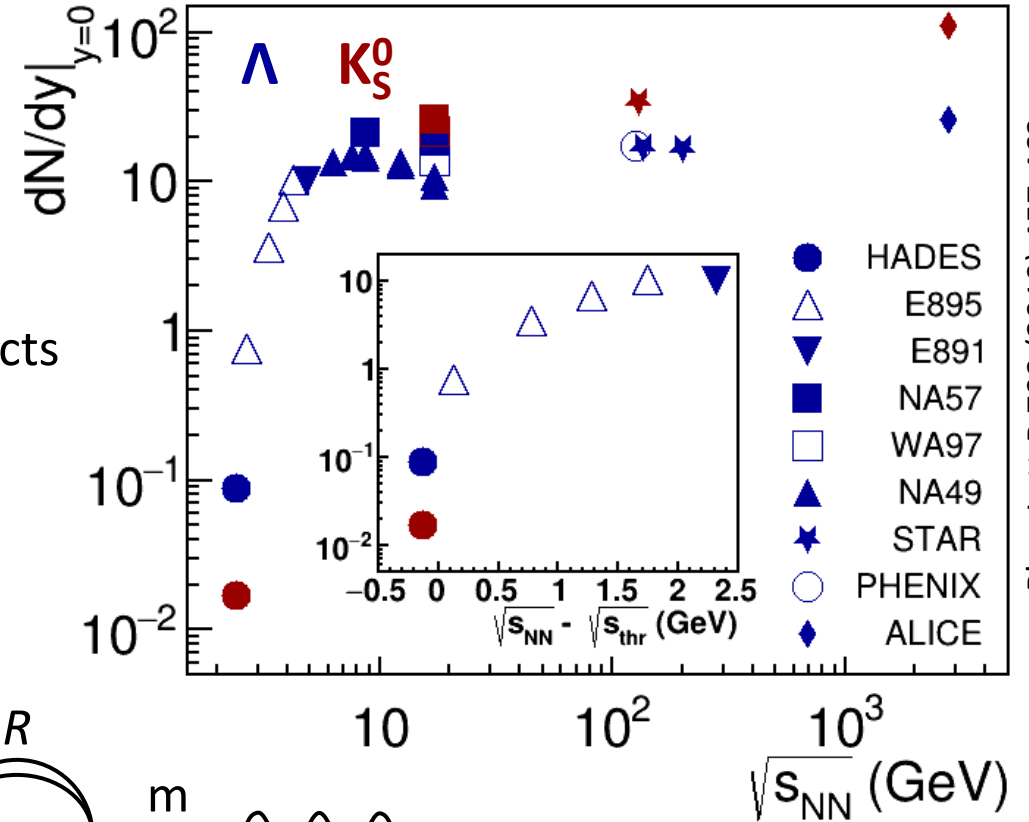
Thank you  
for your  
Attention!



# BACKUP

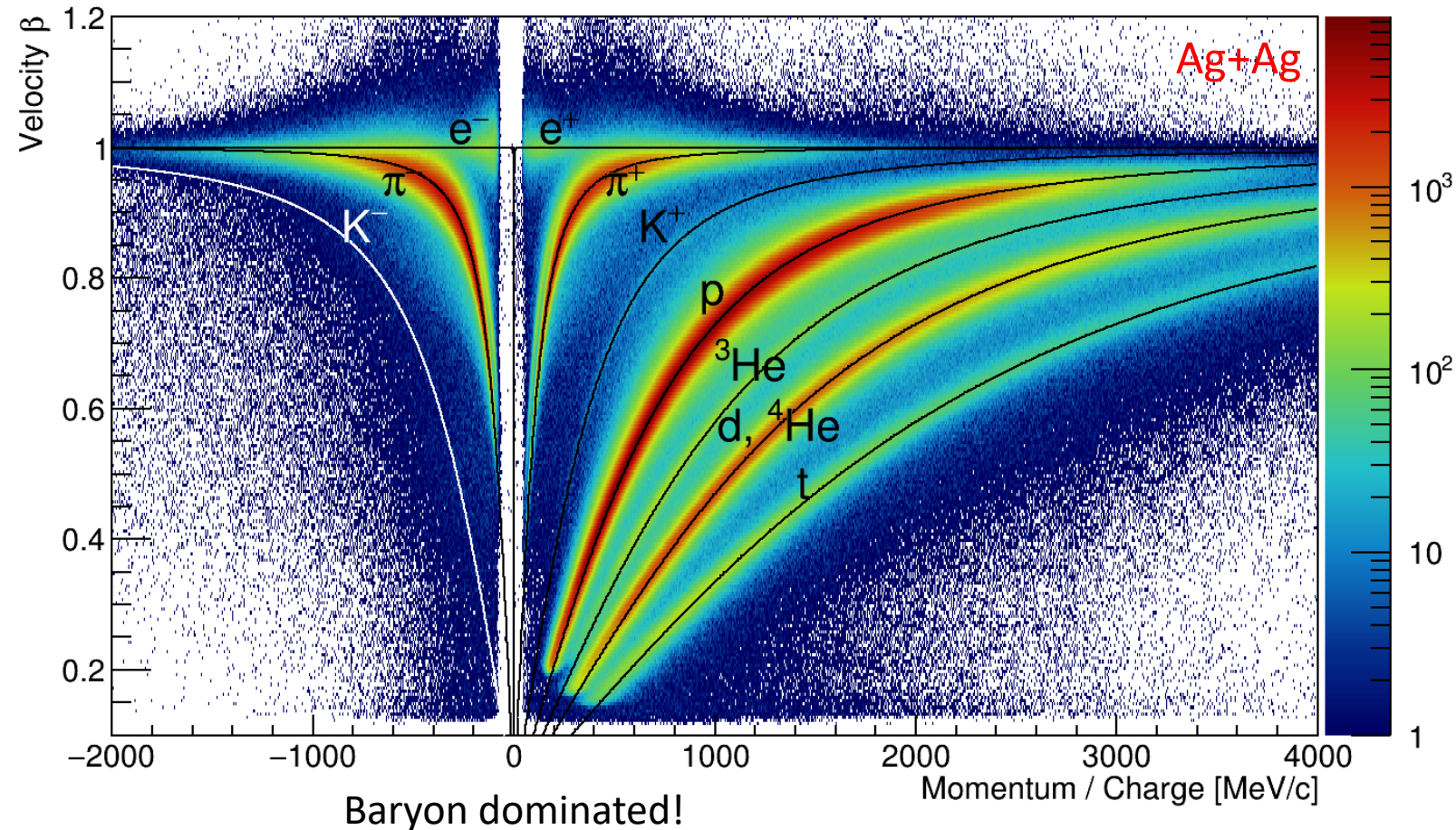
# Nuclear collisions at few GeV

- Strangeness production close to free NN threshold energy:  
 $N + N \rightarrow Y + K + N: \sqrt{s} = 2.55 \text{ GeV}$   
 $N + N \rightarrow K + \bar{K} + N + N: \sqrt{s} = 2.86 \text{ GeV}$
- Steep excitation function, sensitive to medium effects
- Strangeness exchange reactions:  $Y + \pi \rightarrow N + \bar{K}$
- Spectral functions of mesons modified by interactions with baryons and mesons
- Decay products – leptons – decouple from the fireball



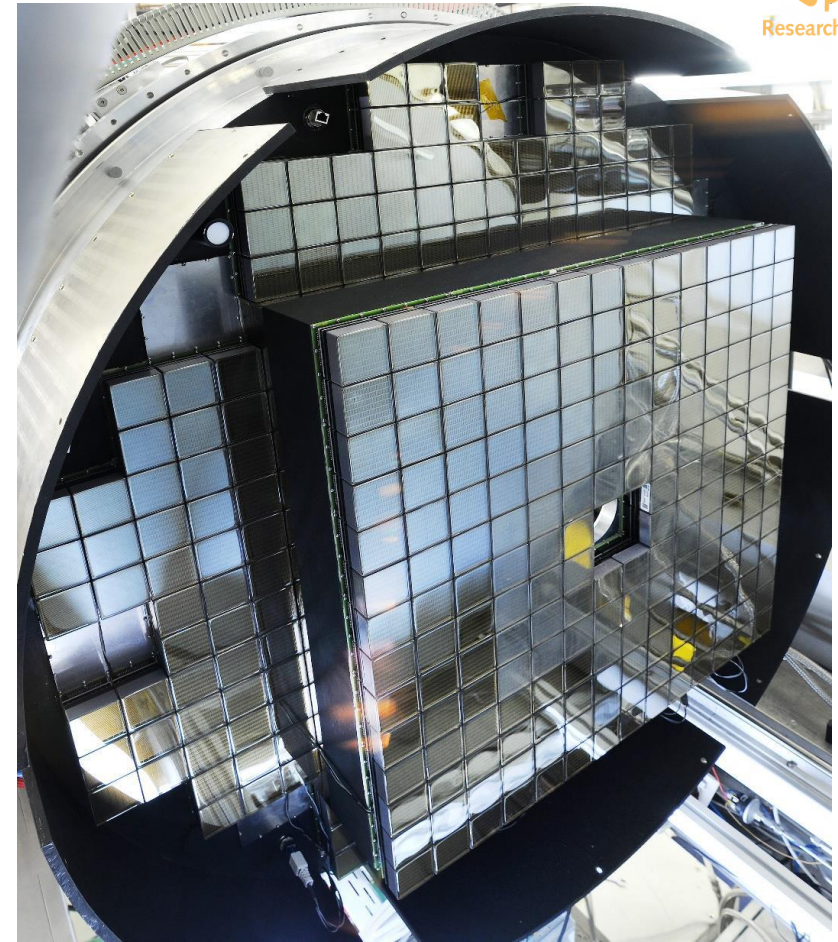
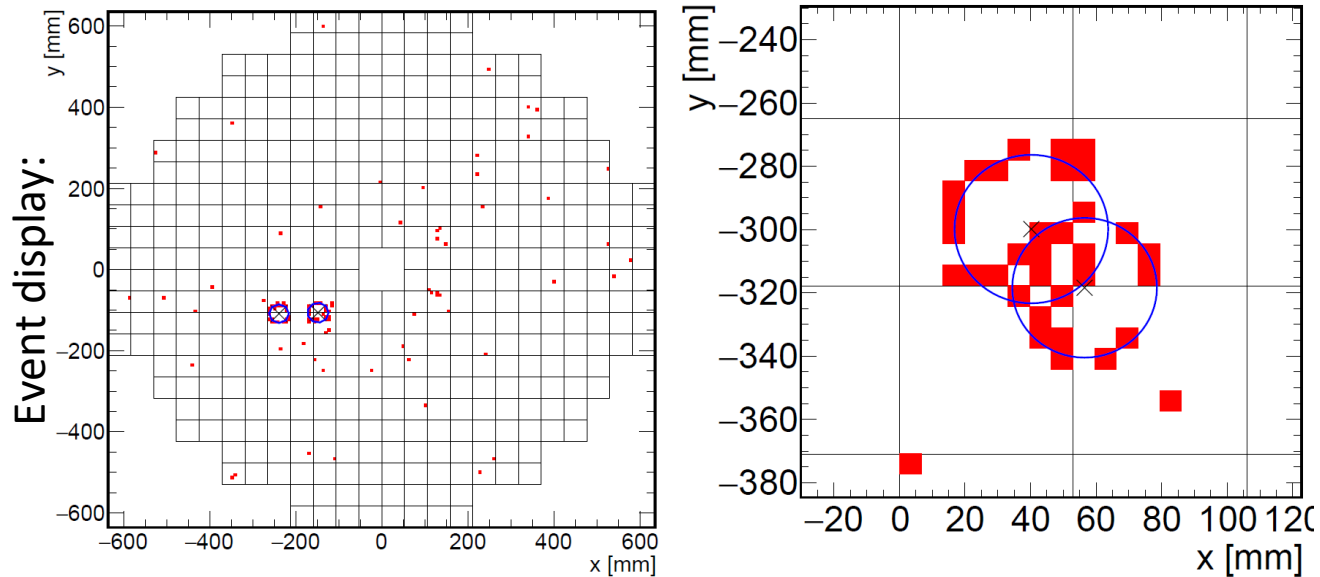
# The HADES Experiment

- 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



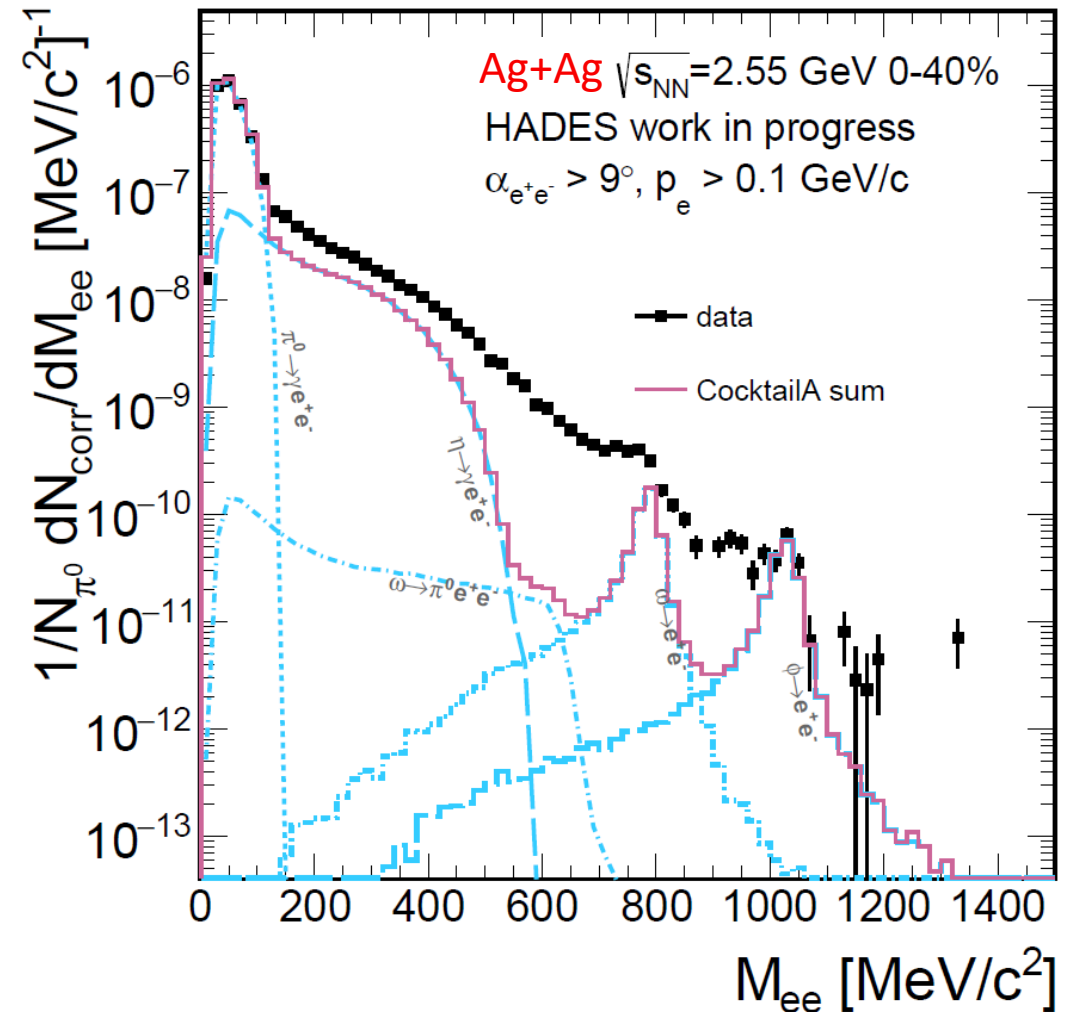
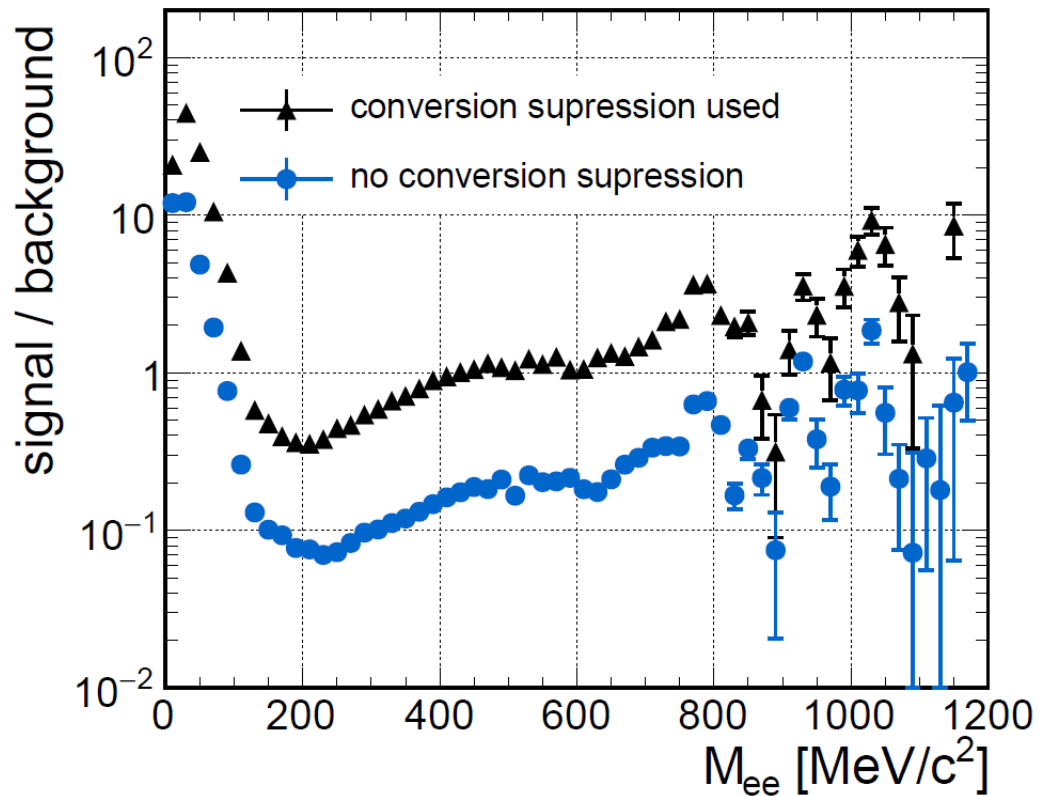
# Virtual Photons

- Upgraded RICH photodetection plane involving future CBM @ FAIR technology
- Significantly improved lepton identification and double-ring detection

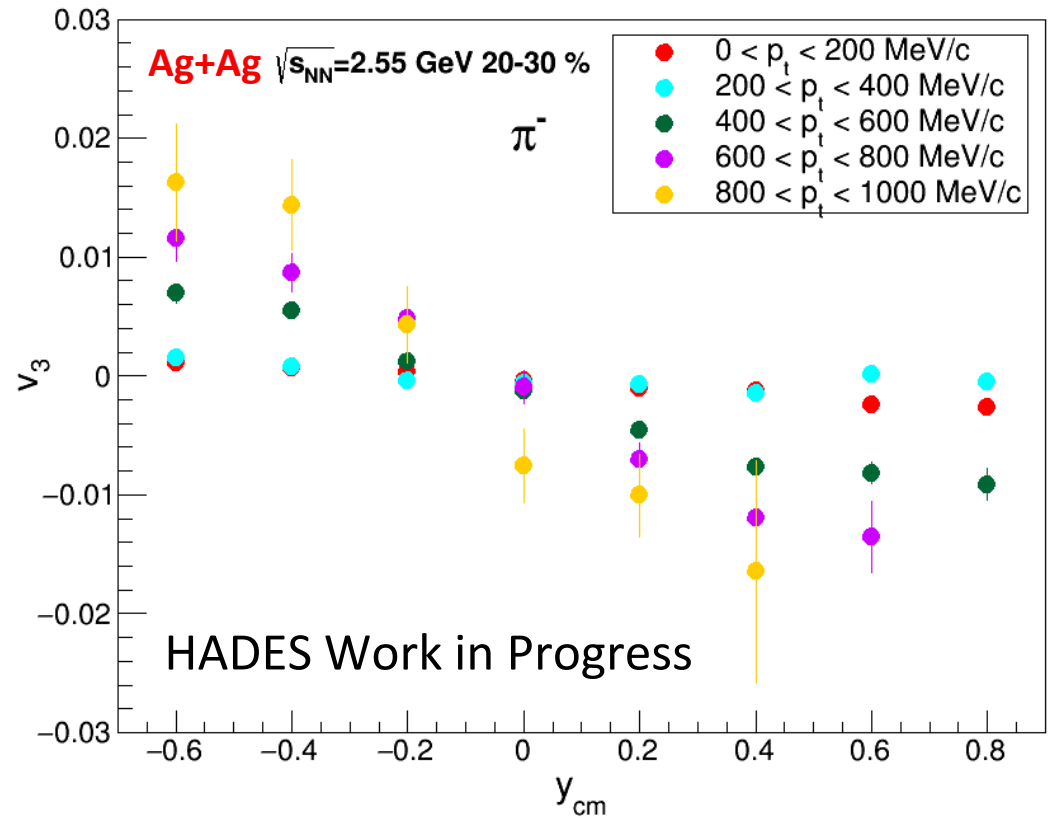
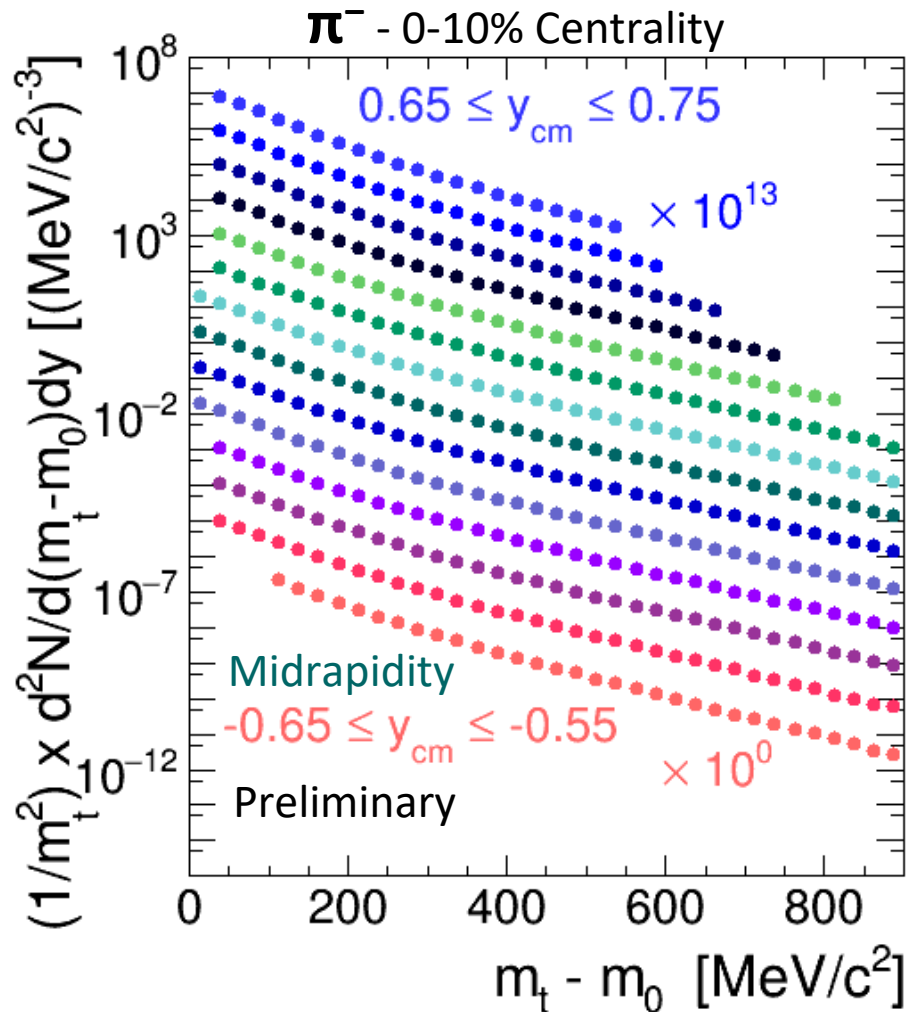


# Virtual Photons

- High statistics in all invariant mass regions
- Hint for extremely rare  $\phi \rightarrow e^+ + e^-$  signal

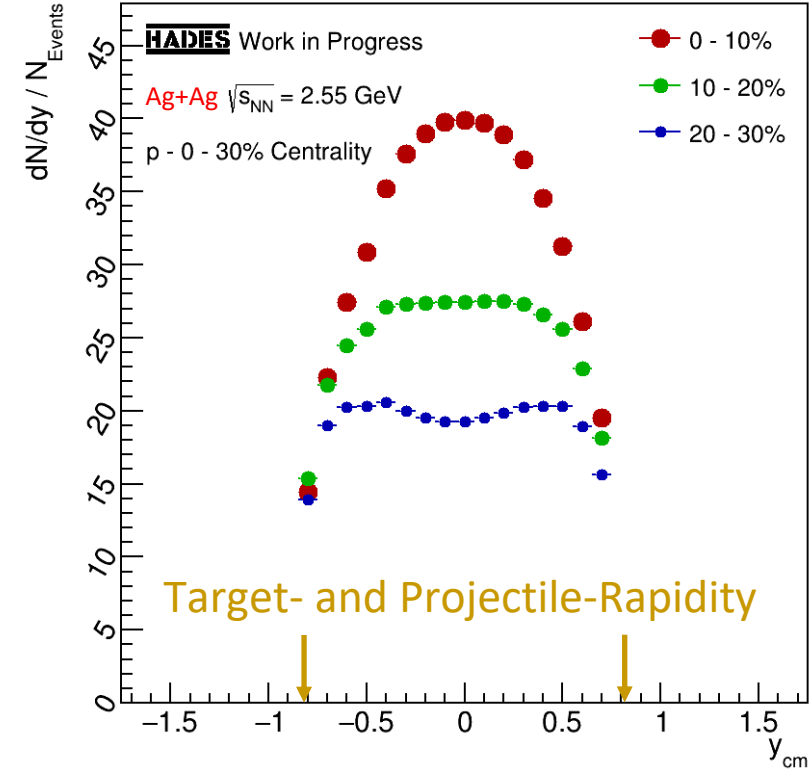
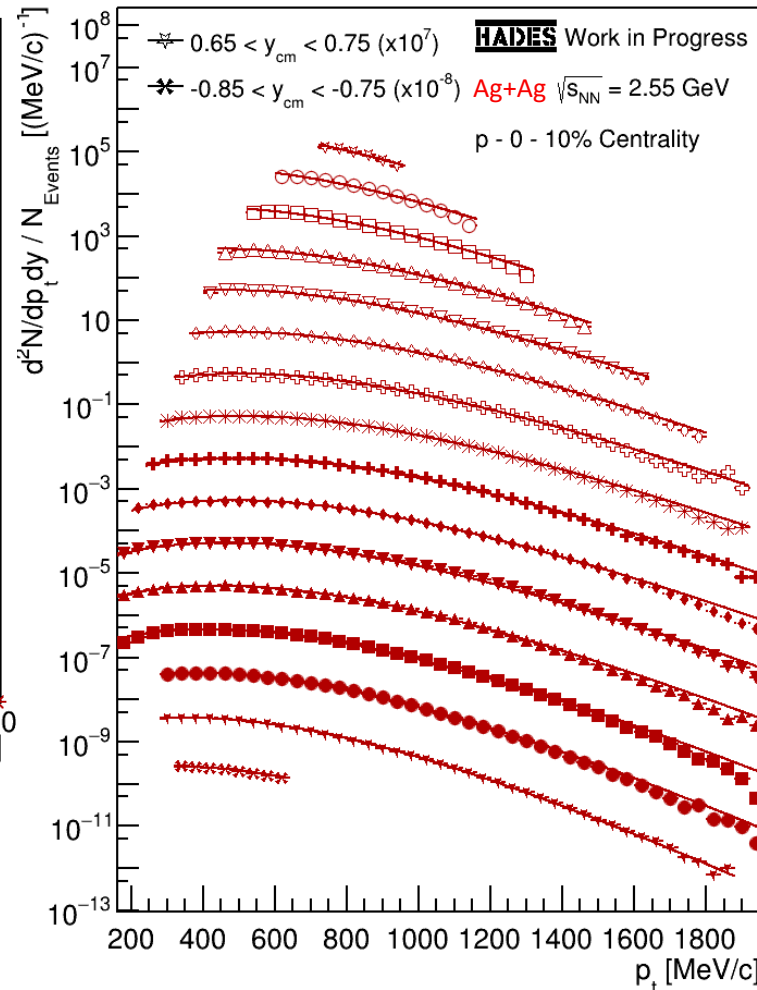
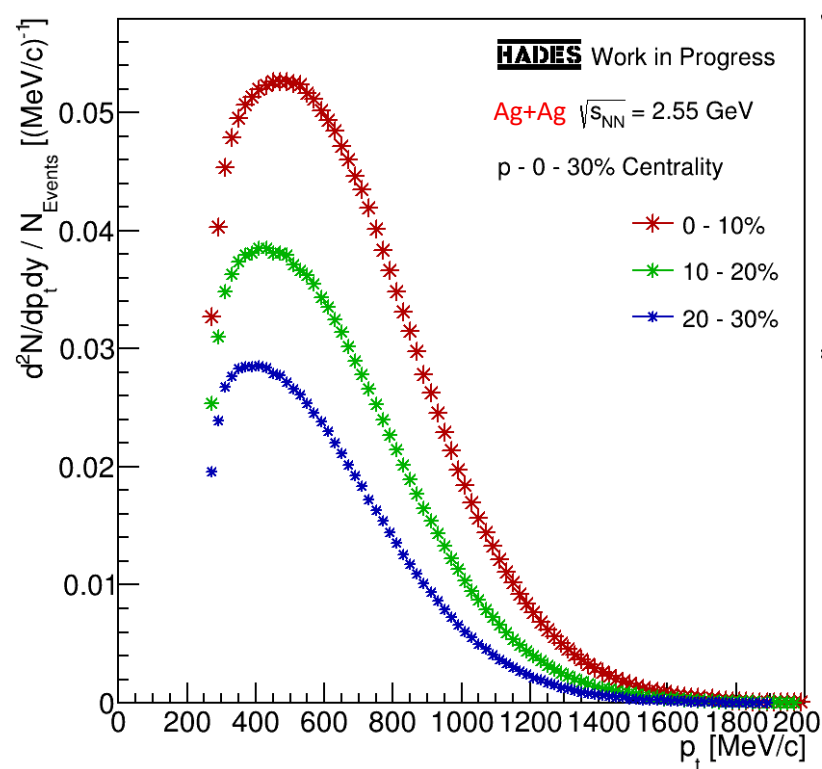


# Charged Pions



- High statistics allow for multi-differential analyses (Spectra, Angular distributions, Azimuthal anisotropy, Coulumb force, etc.)
- First observation of  $v_3$

# Proton: 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

# Flow (Au+Au)

- Proton, Deuteron and Triton flow coefficients  
Phys. Rev. Lett. **125**, 262301  
<https://doi.org/10.17182/hepdata.102468>

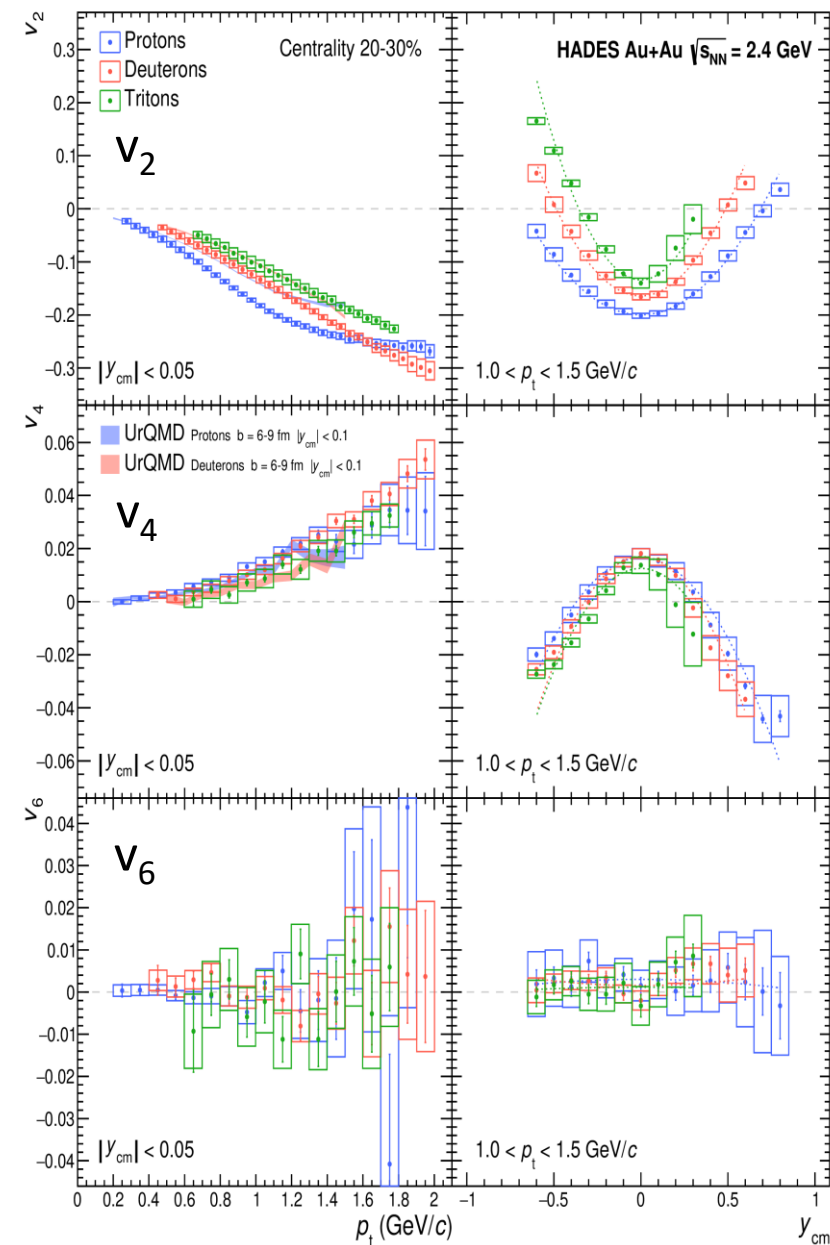
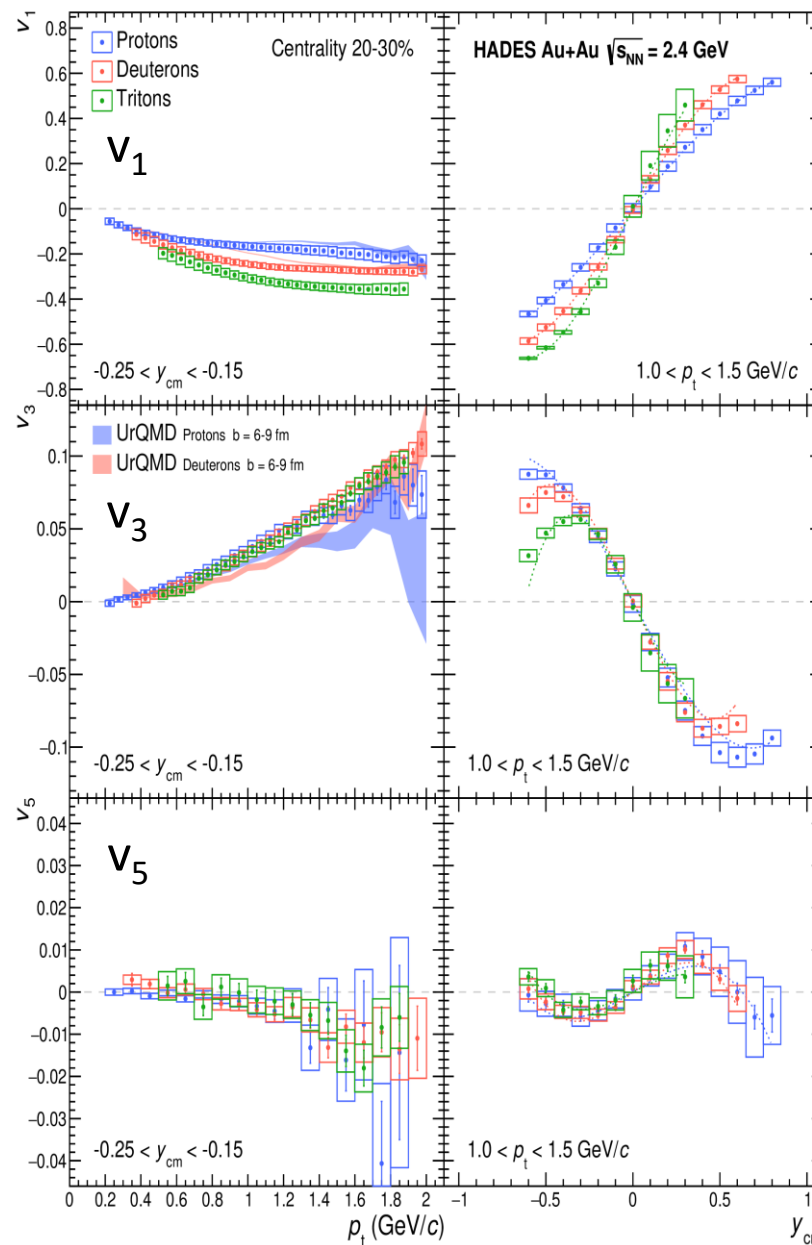
- First measurement up to  $v_6$  in this energy regime

- Parametrization of rapidity dependence:  

$$v_{1,3,5}(y_{cm}) = ay_{cm} + by_{cm}^3$$

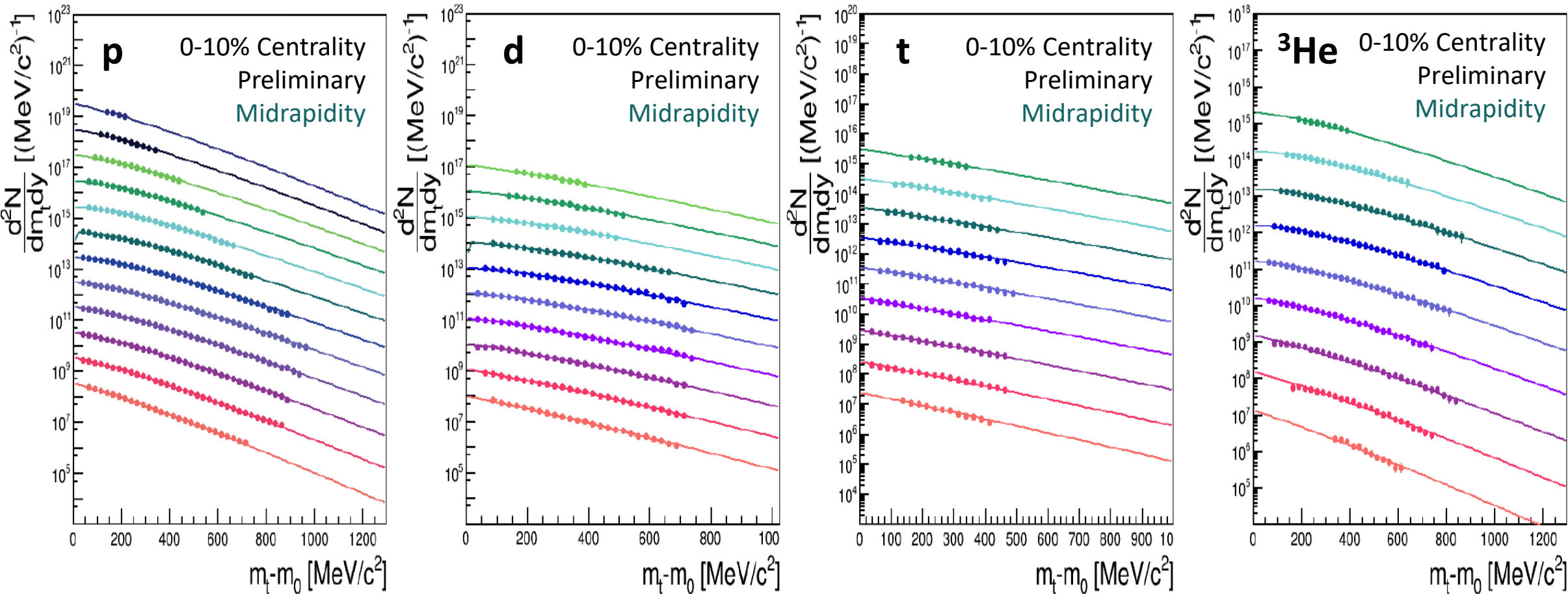
$$v_{2,4,6}(y_{cm}) = c + dy_{cm}^2$$

- Important input to model calculations, constrain of dense EoS



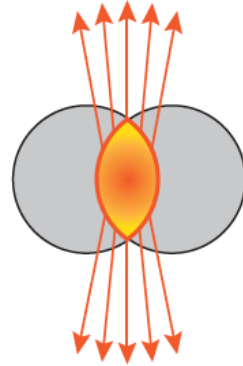


# Protons, Deuterons, Tritons and $^3\text{He}$ (Au+Au)

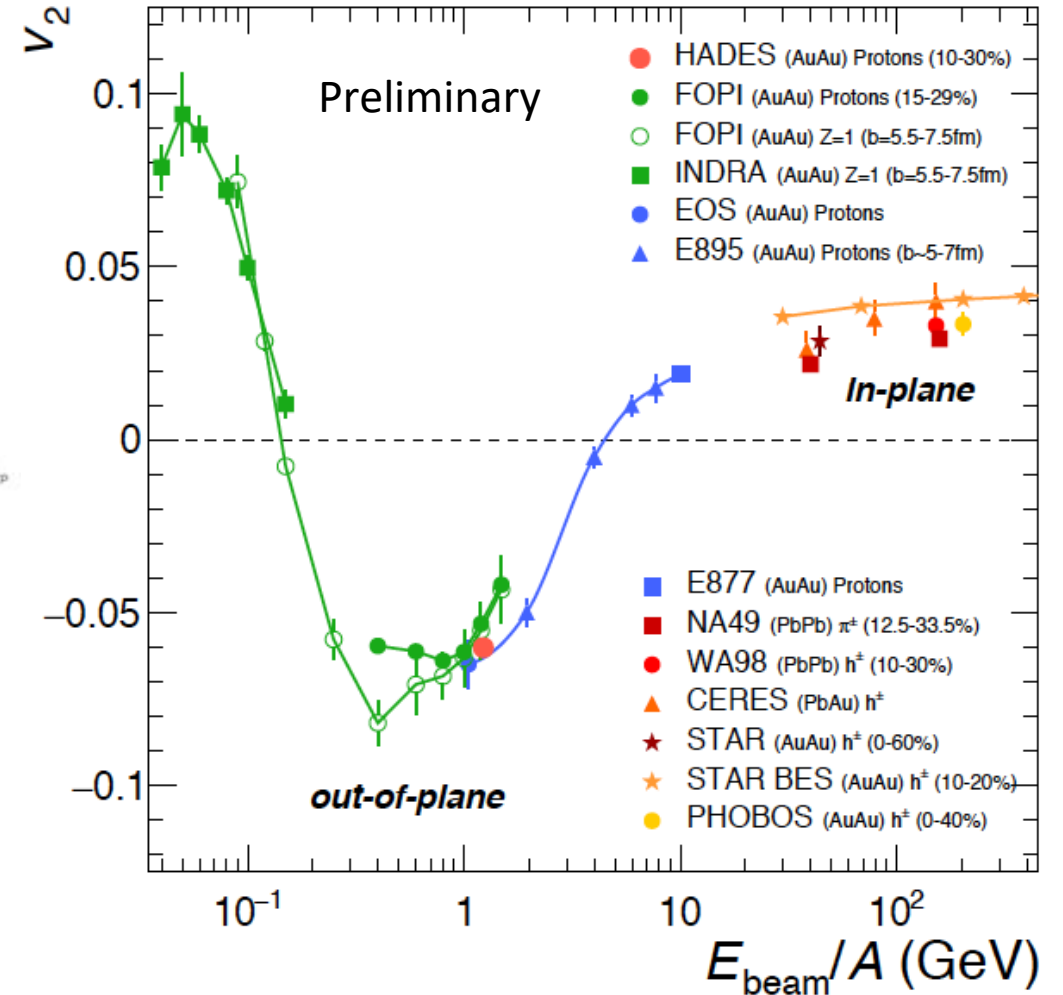
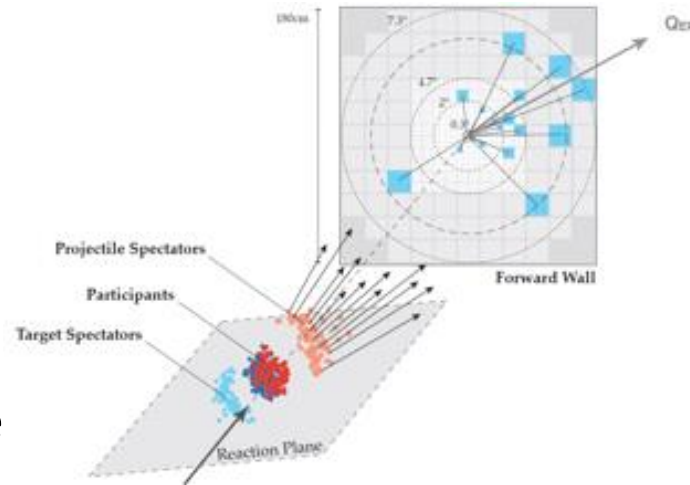


# Flow Anisotropies

- Out-of-Plane Emission  $v_2 < 0$
- Long spectator passing time  
 $\tau_{\text{Passing}} \approx \tau_{\text{Expansion}}$
- Squeeze-out

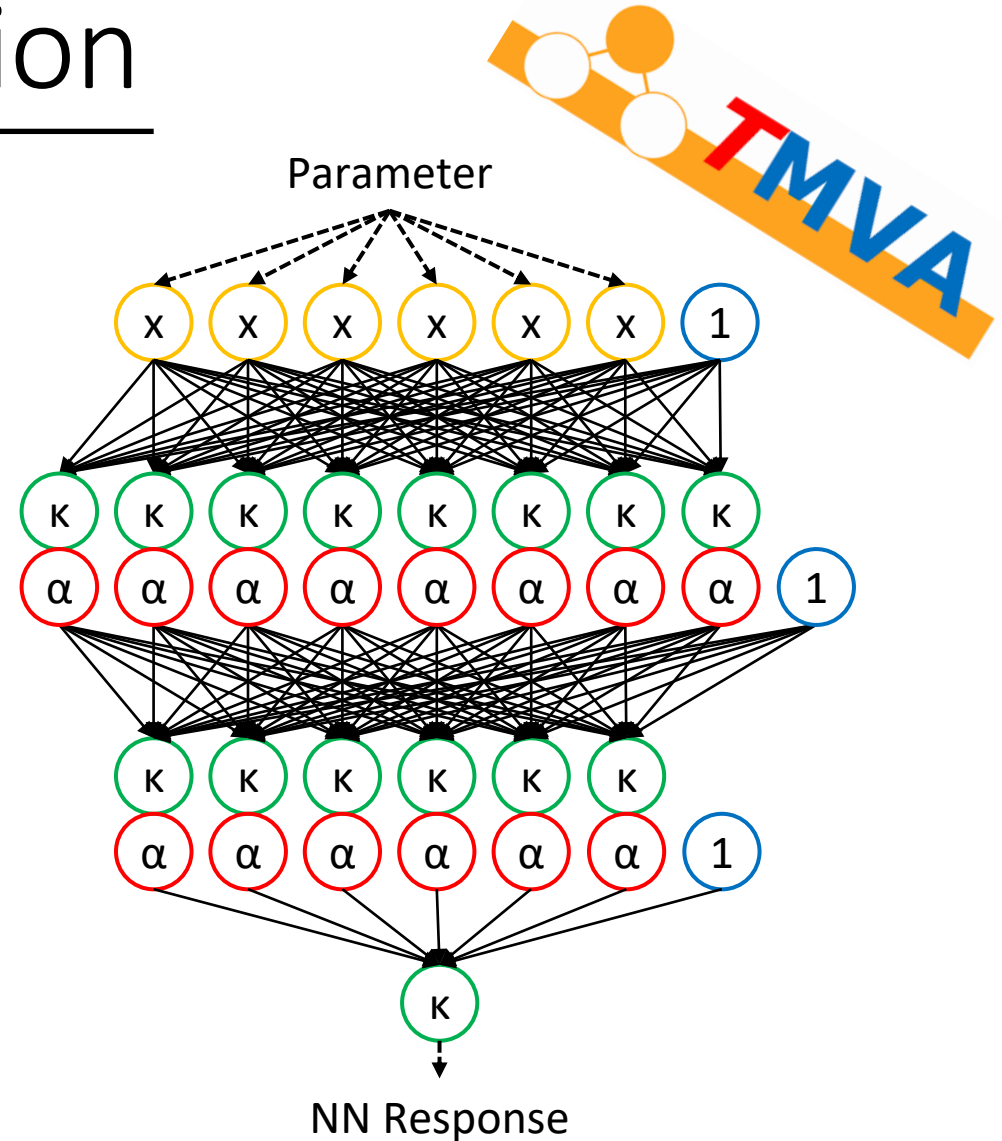
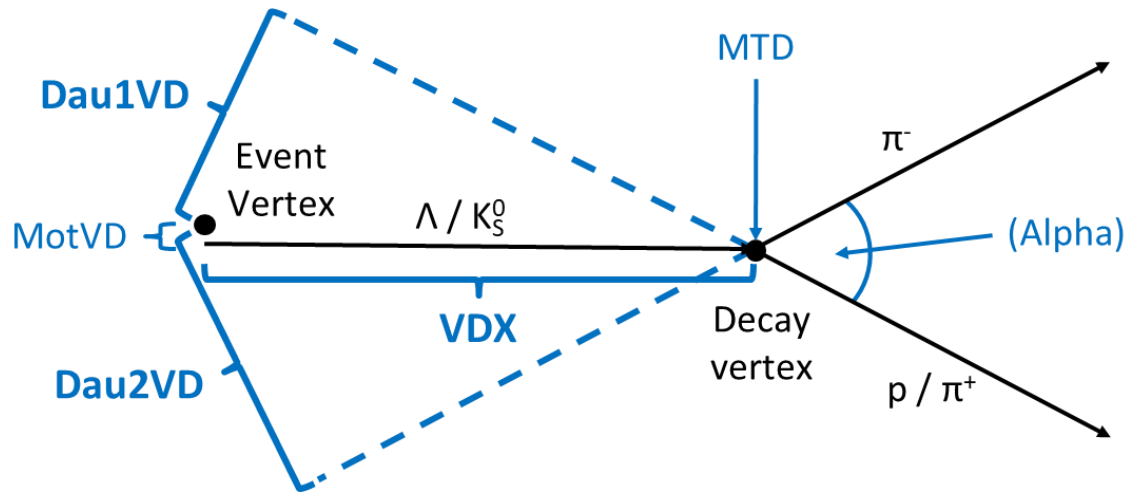


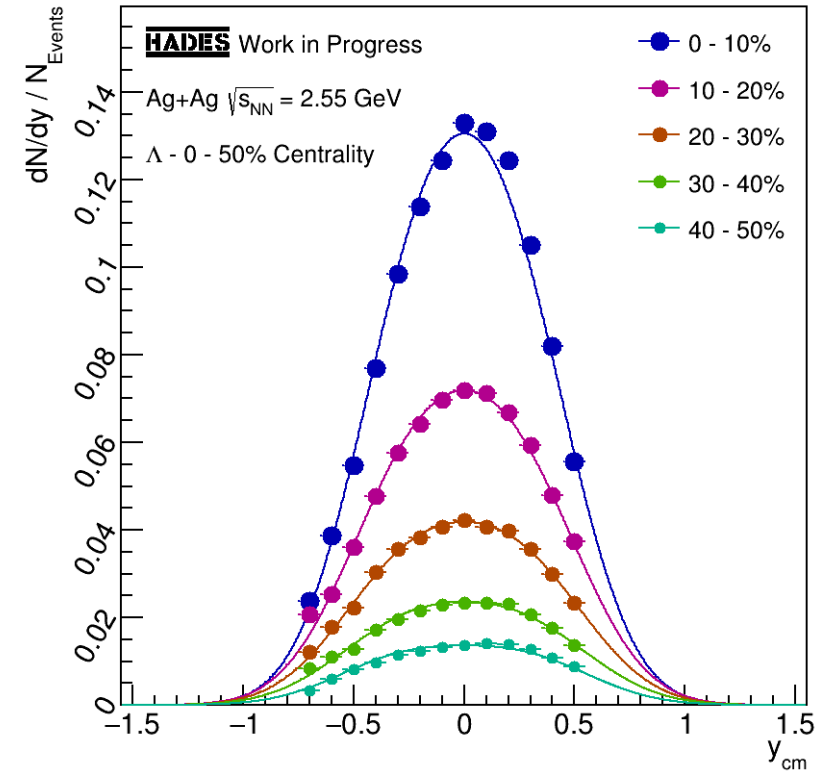
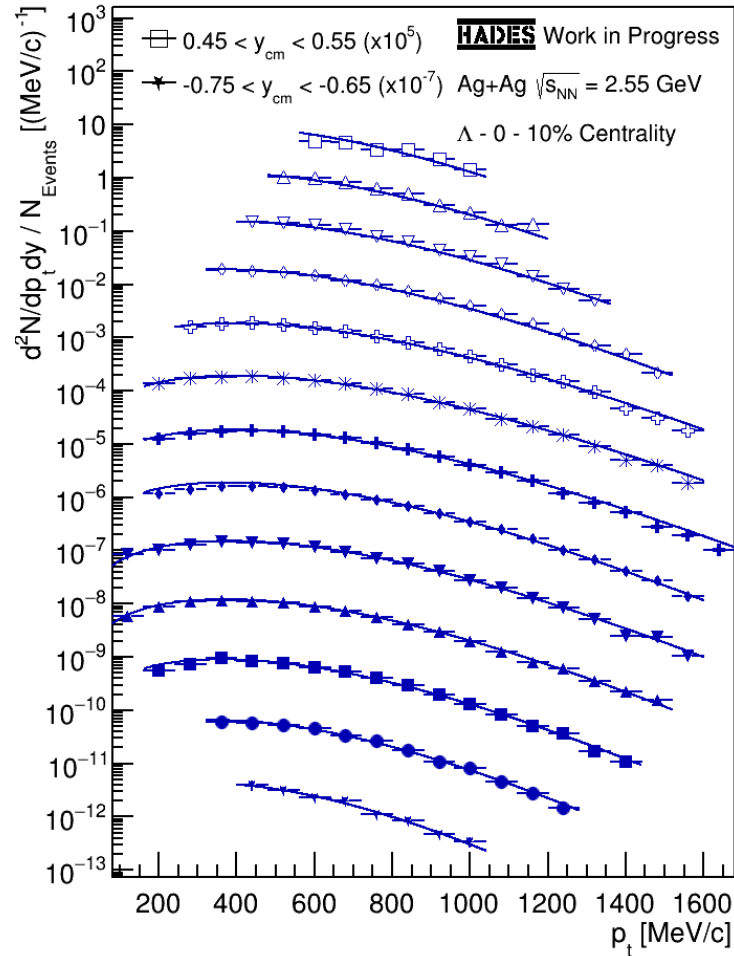
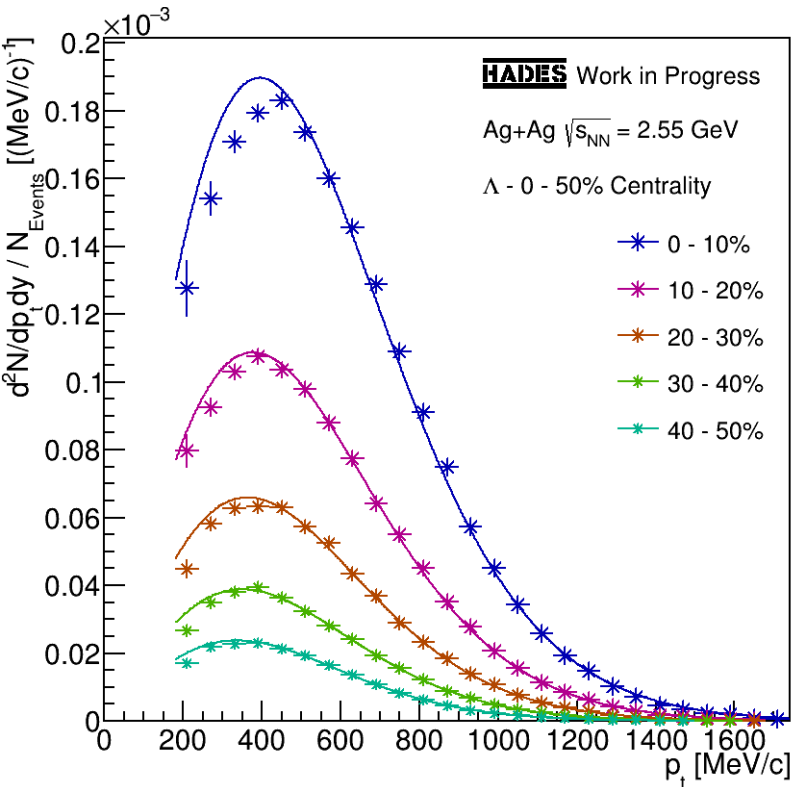
- HADES: Eventplane reconstruction based on hits of charged projectile spectators measured in the forward hodoscope

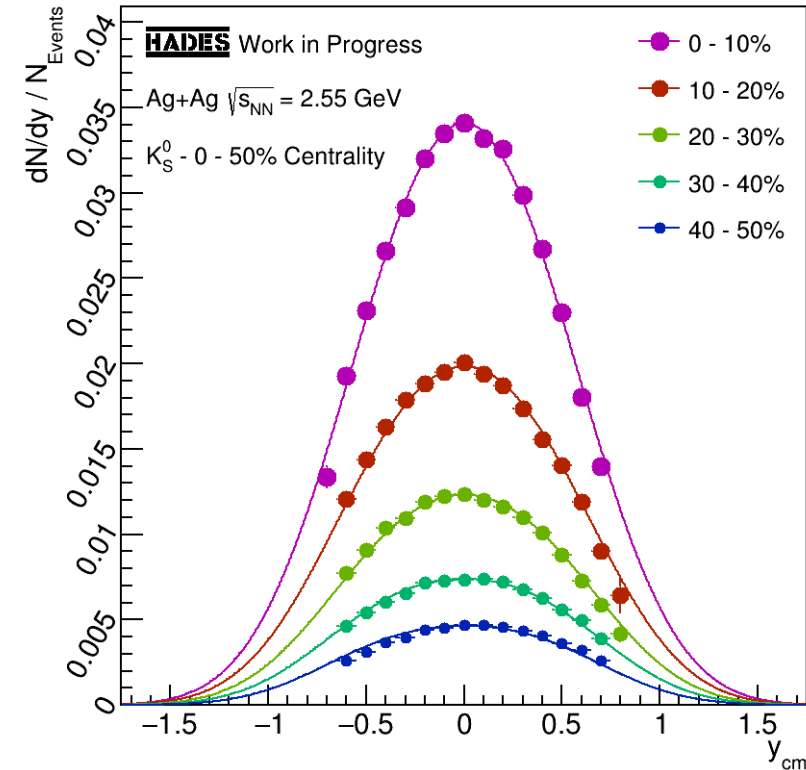
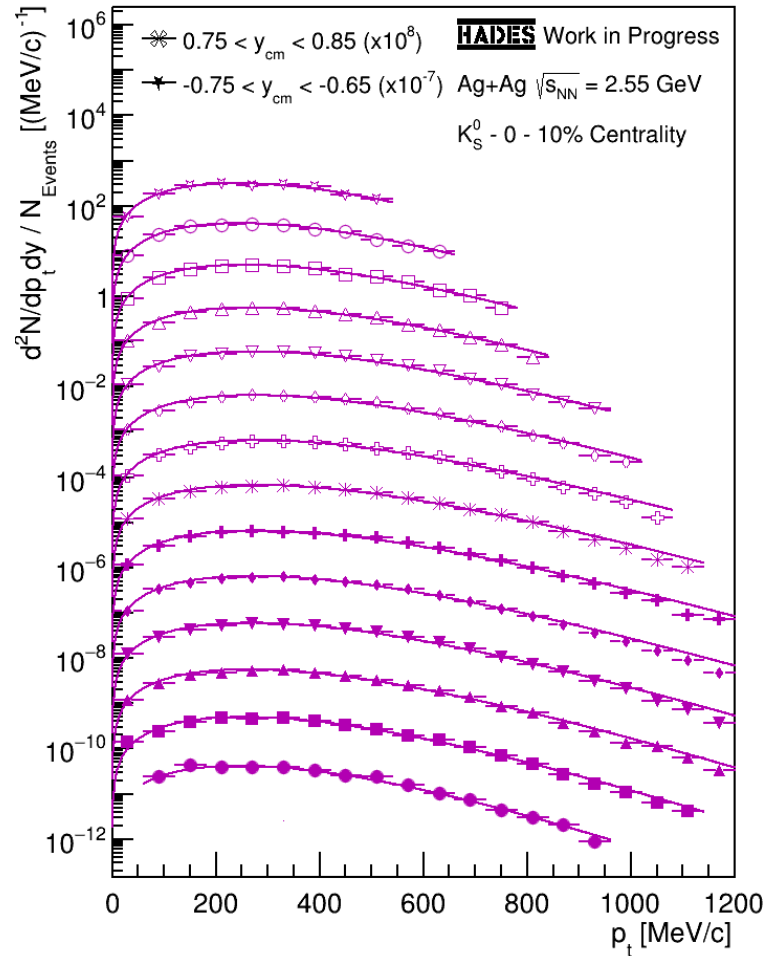
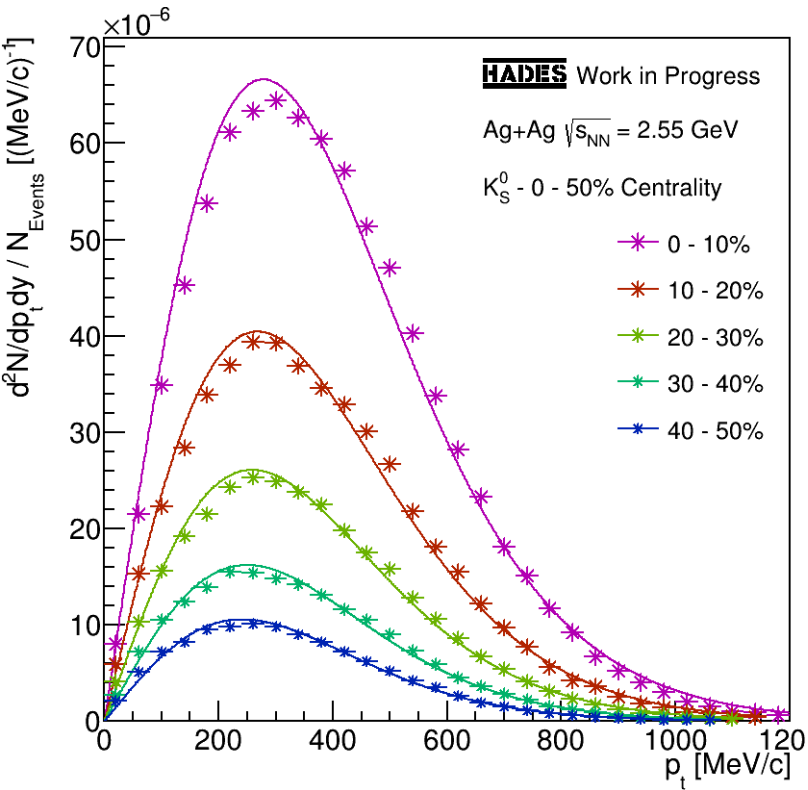
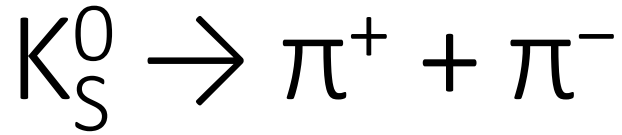


# Weak decay reconstruction

- 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]

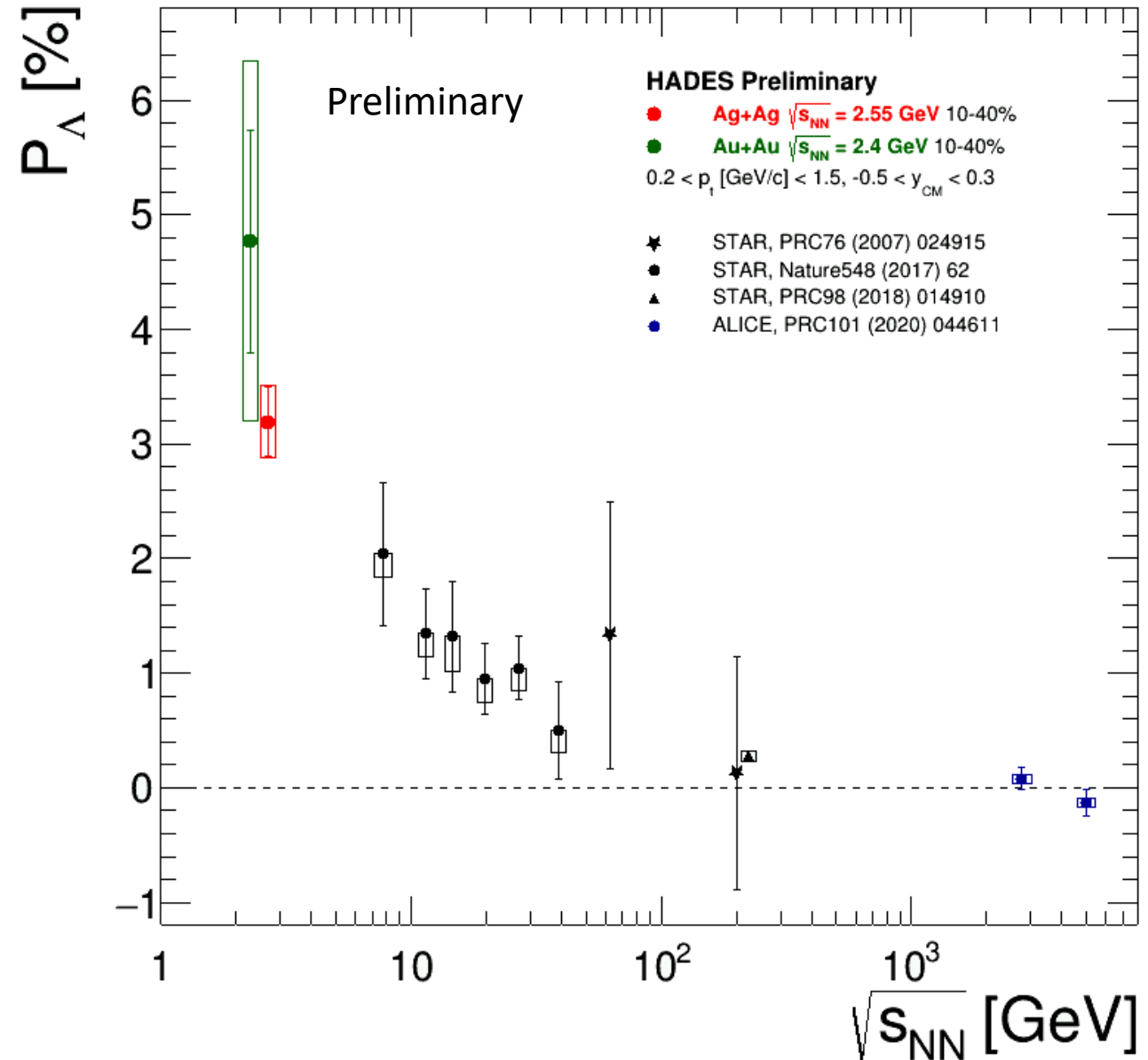






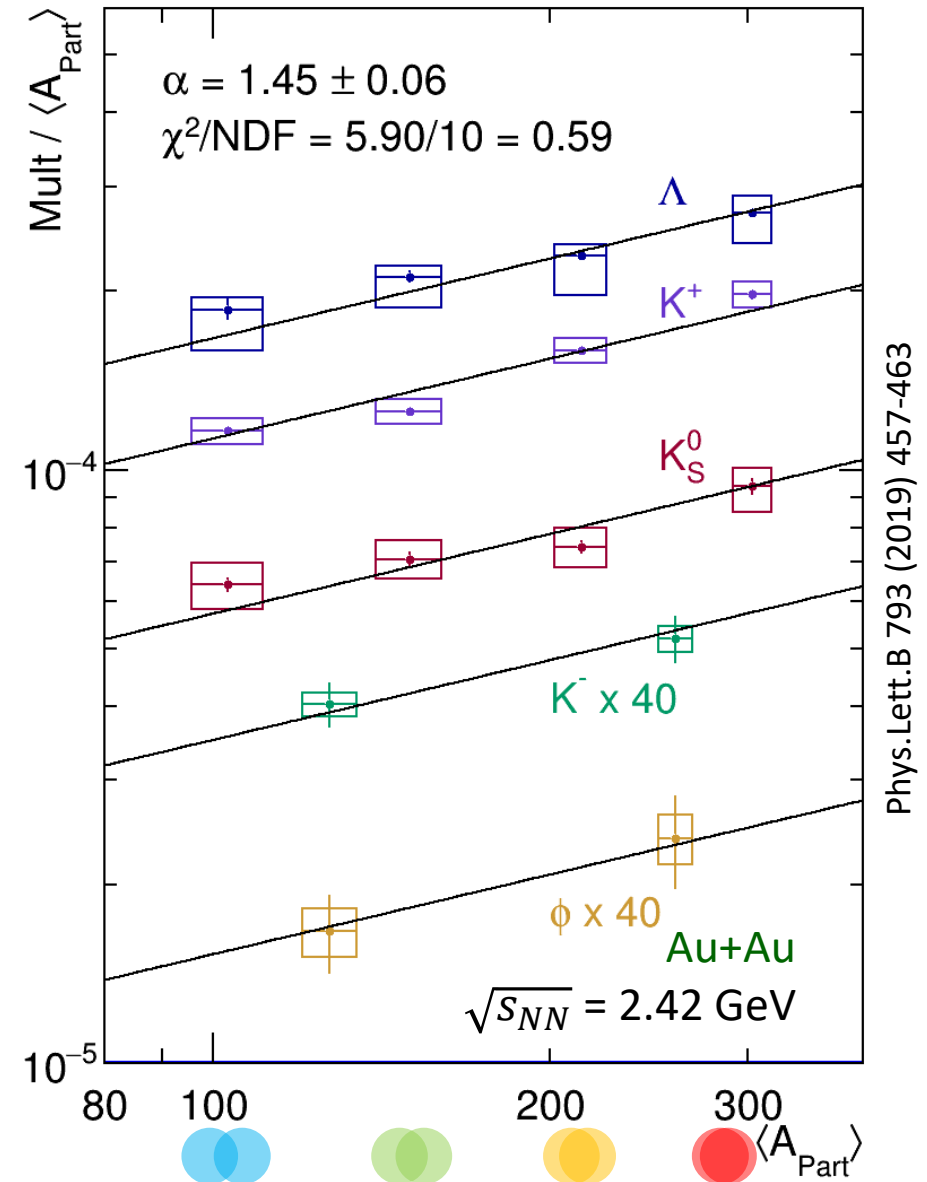
# $\Lambda$ Polarization

- Measurement of the global polarization using  $\Lambda$  decays
- Performed multi-differentially in  $p_t$ , rapidity and centrality
- Strongest polarization observed at low energies



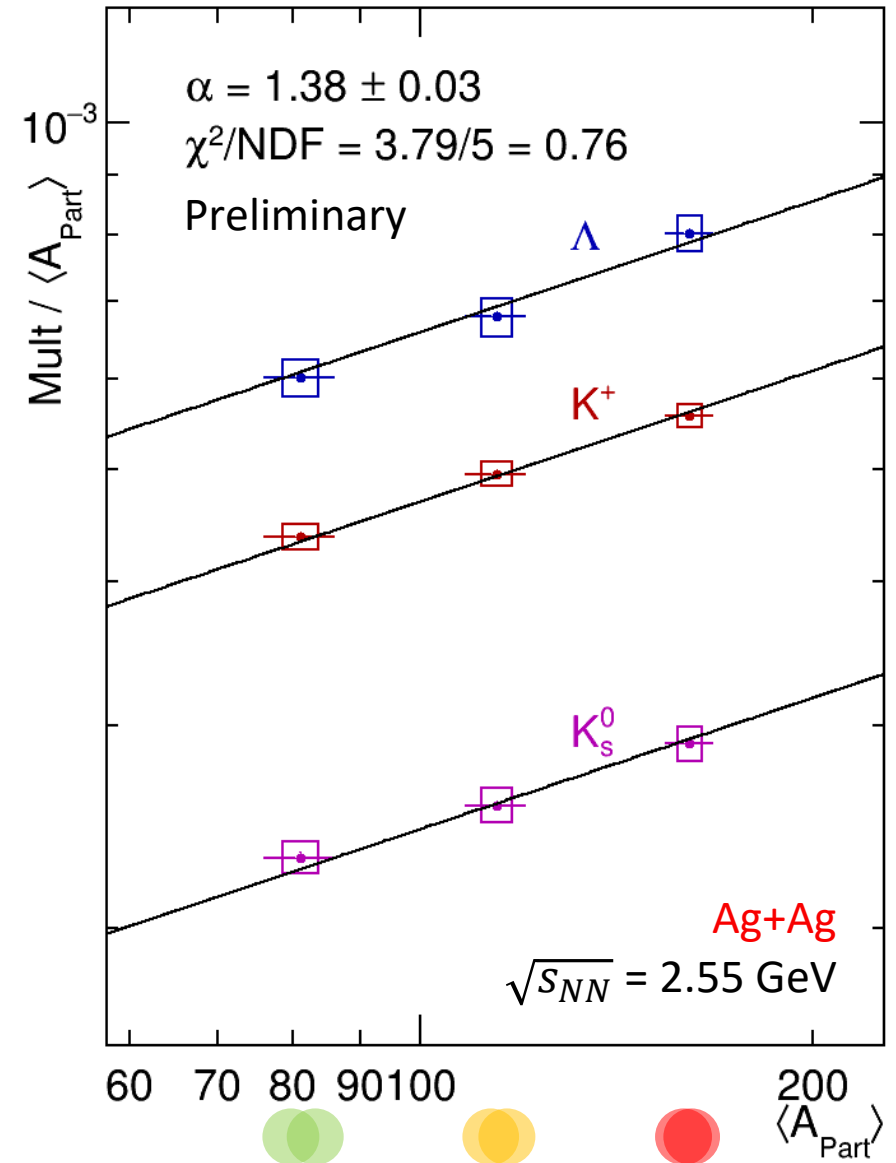
# Strange Yields vs. $\langle A_{\text{Part}} \rangle$

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



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

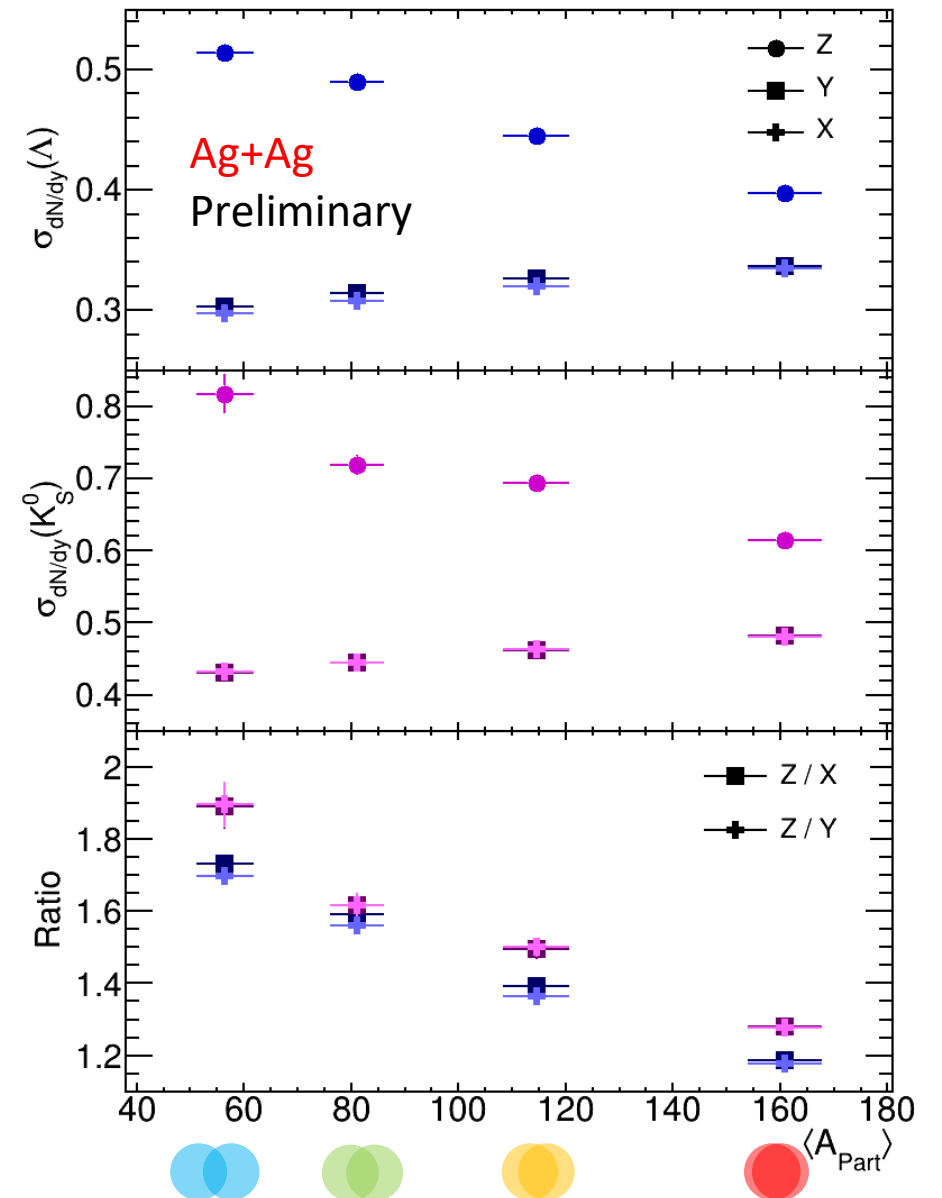
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- Hierarchy in production thresholds not reflected
- Scaling with absolute amount of  $s\bar{s}$
- Slightly lower slope  $\alpha_{\text{Ag+Ag}} = 1.38 \pm 0.03$
- Test for universal scaling:  $K^-$  and  $\phi$  in Ag+Ag?



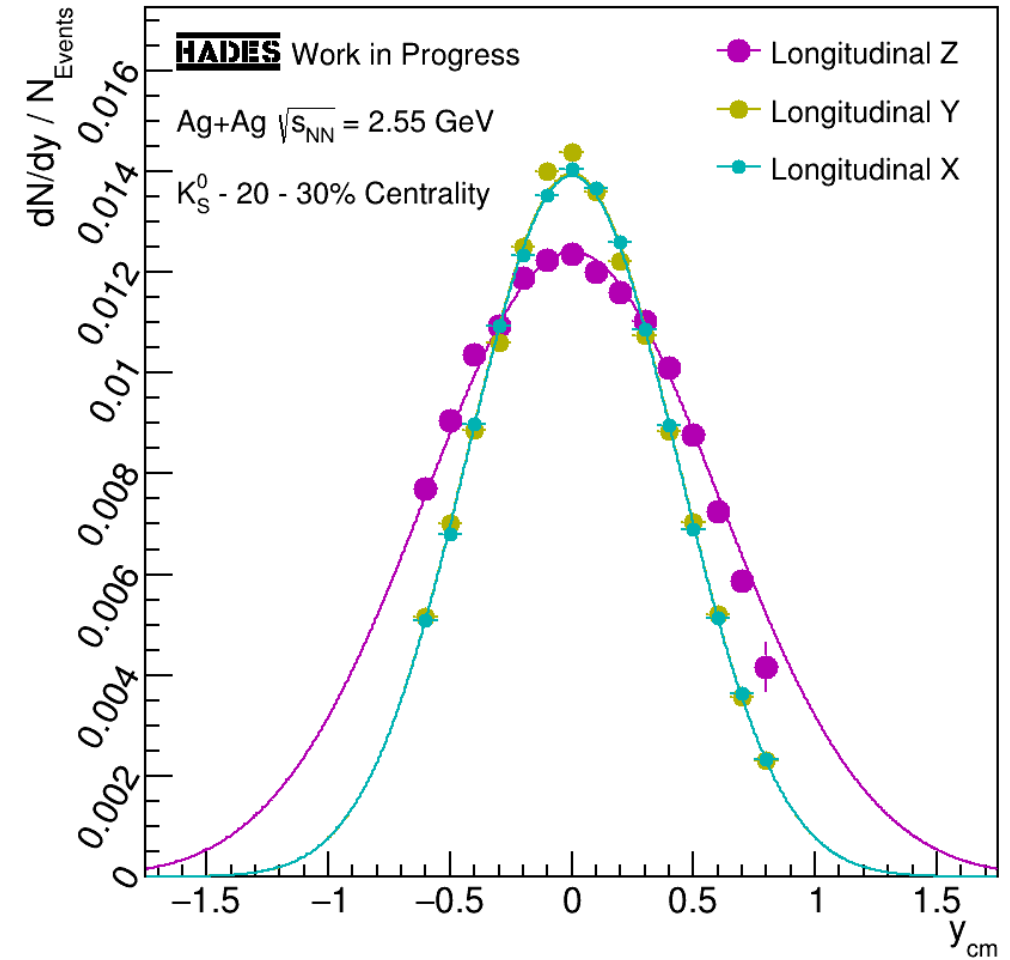
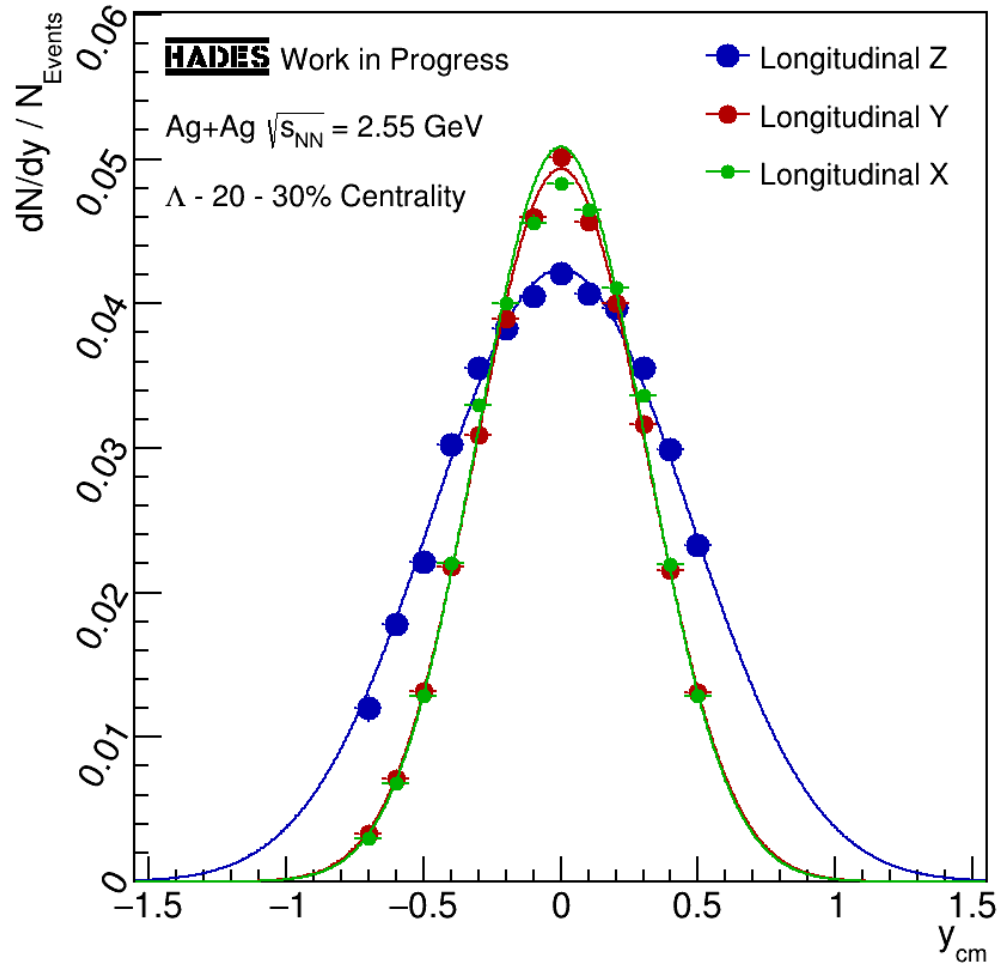


# Isotropic Emission of Strangeness?

- Approximated width of thermal  $dN/dy$  distribution:  $\sigma \approx \sqrt{T_{Eff}/m_0}$
- Comparison of longitudinal ( $y_z$ ) and transverse ( $y_x$  and  $y_y$ ) rapidity distributions
- Larger widths in longitudinal direction
- Isotropic shape approached in central collisions but not reached



# Isotropic Emission of Strangeness?



# Strange Light Nuclei

- Lightest known hypernucleus:  
 ${}^3_{\Lambda}\text{H}$ :  $m_0 = 2991 \text{ MeV}/c^2$
- Very low nuclear binding energy  $< 3 \text{ MeV}$
- Reconstructed via its two-body-decay channel  
 ${}^3_{\Lambda}\text{H} \rightarrow {}^3\text{He} + \pi^-$  (BR  $\approx 1/3$ )
- **First observation at midrapidity at this energy**
- Contribution to  ${}^3_{\Lambda}\text{H}$  lifetime measurements

