Exploring the hot and dense QCD matter with HADES

- Heavy ions, cold matter and elementary reactions.
- A, p, pion beams
- Probing the dense and hot matter with: electromagnetic probes, sub-threshold strangeness production, emission anisotropies, particle correlations (femtoscopy, resonances)…
- Au+Au $\sqrt{s_{NN}}$ =2.42 GeV and Ag+Ag $\sqrt{s_{NN}}$ = 2.55 GeV

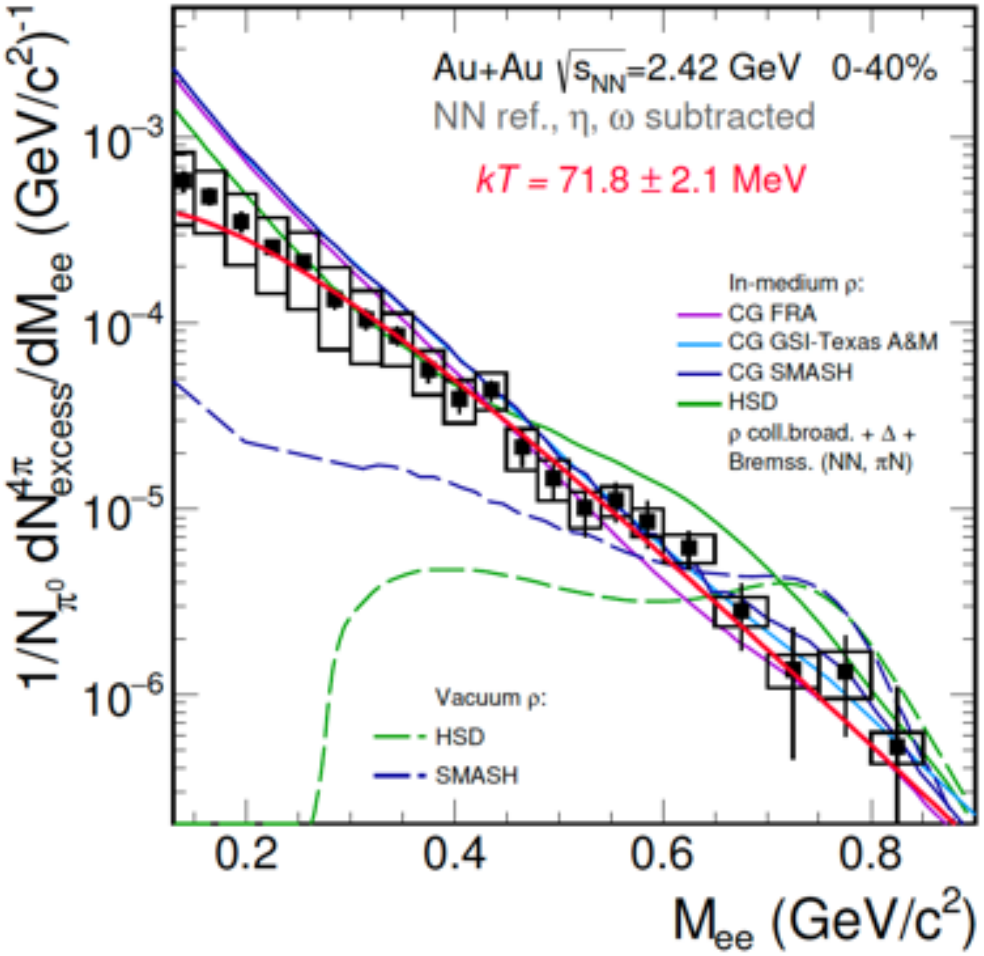
Georgy Kornakov

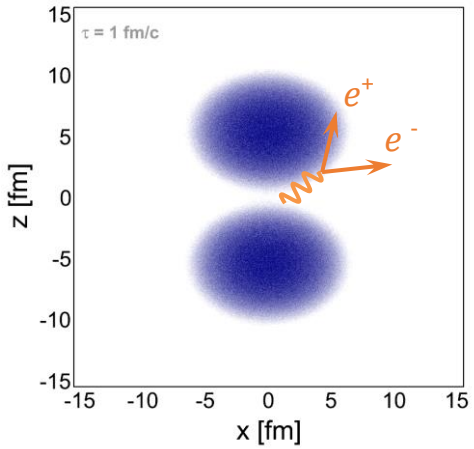
Warsaw University of Technology

INPC, 29 July- 2 August 2019 Glasgow

Thermal dielectrons at $\sqrt{s_{NN}} = 2.42$ GeV

e^+e^- invariant mass distribution fully corrected for acceptance





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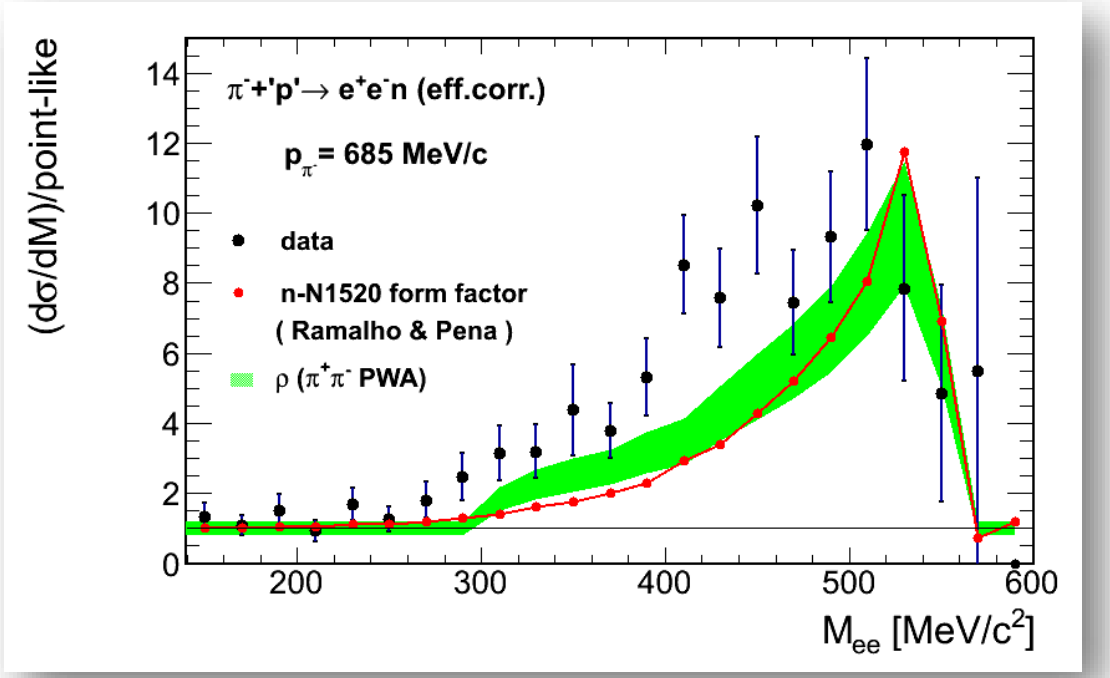
- Strong broadening of the in-medium ρ spectral function
- Enable measurement of fireball temperature
$$\langle T_{fireball} \rangle = 72 \pm 2\ MeV$$
- Thermal rates folded over coarse-grained UrQMD medium evolution works at low energies
- Supports baryon-driven medium effects at SPS and RHIC (LHC).

HADES Collab., accepted for publication in Nature Physics

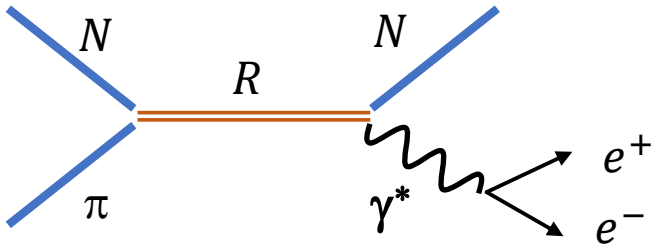
Verify the ρ-baryon coupling mechanism

π^- beam $\sqrt{s} = 1.49$ GeV

e^+e^- invariant mass distribution ratio to point-like contributions



HADES Collab., in preparation

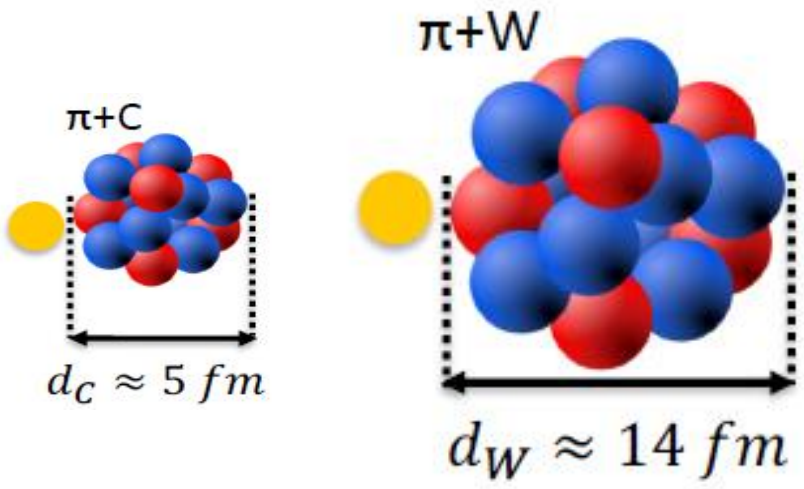


- Dominance of the N* (1520) resonance
- Invariant mass and angular distributions (4 differential analysis) are consistent with
  - ρ decays
  - VDM form factors (pion cloud)

G. Ramalho, T. Pena Phys. Rev. D95 (2017), 014003
E. Speranza et al., Phys.Lett. B764 (2017) 282

Φ-AntiKaon Interplay in Cold Matter

HADES Collab., PRL 123, 022002 (2019) arXiv:1812.03728



→ Mean free path $\boldsymbol{\lambda_\pi = 1.5\ fm}$
$(p_\pi = 1.7\ GeV/c\,, \rho_B \approx \rho_0)$

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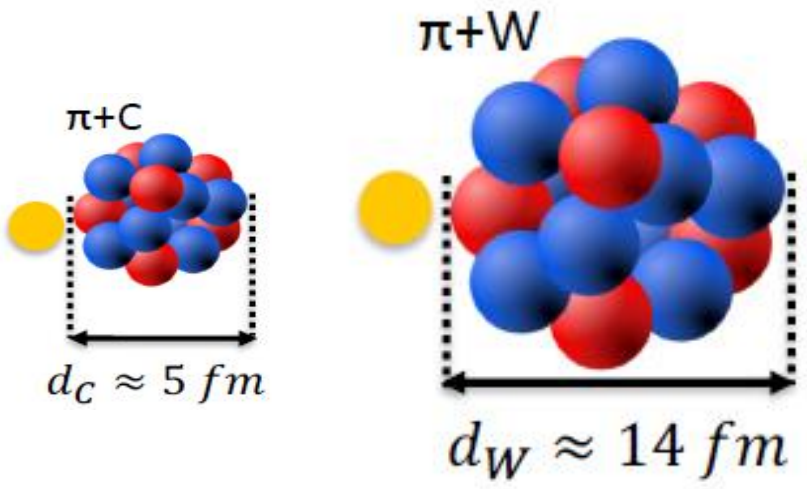

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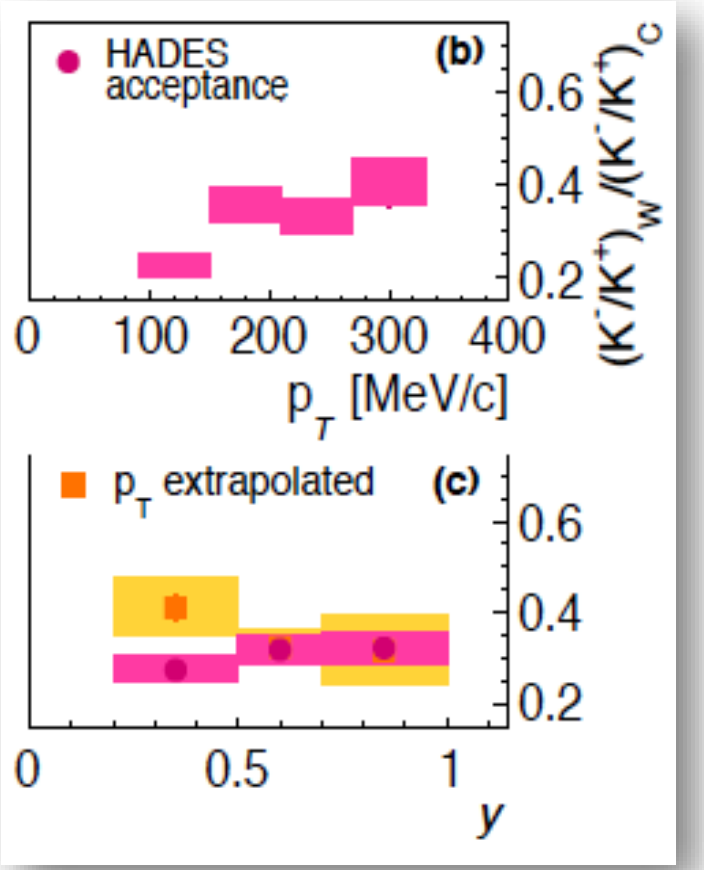

- Suppression of K^- relative to K^+
- Similar suppression for φ like for K^-

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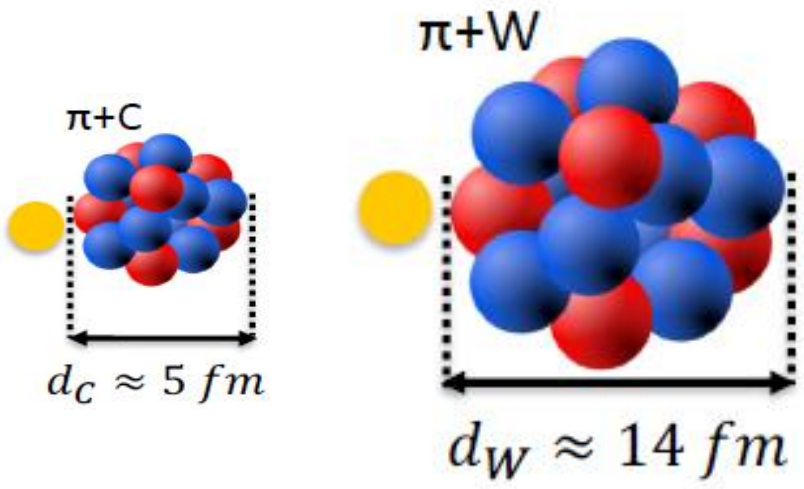

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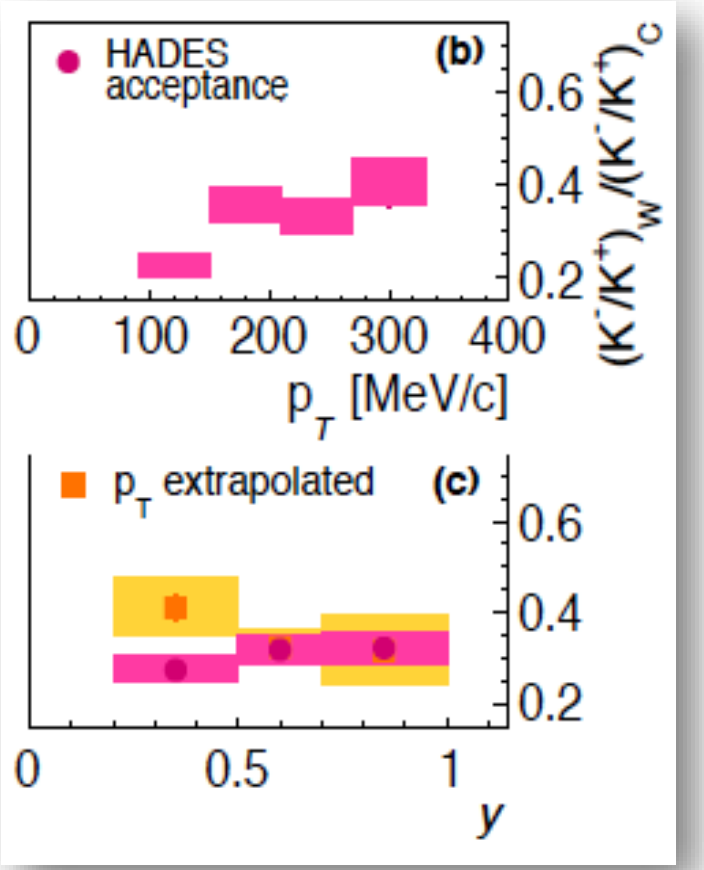

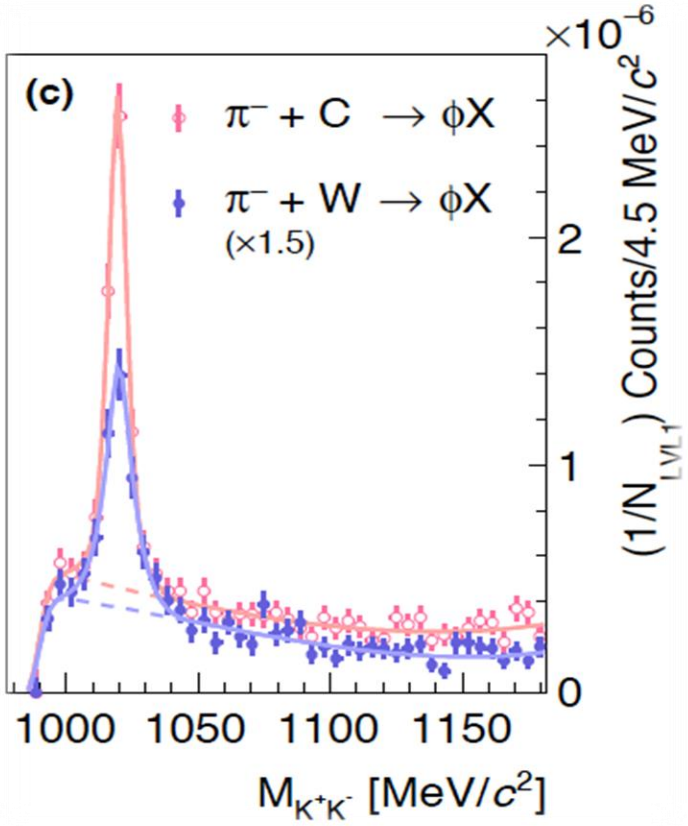

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- Suppression of K^- relative to K^+
- Similar suppression for φ like for K^-

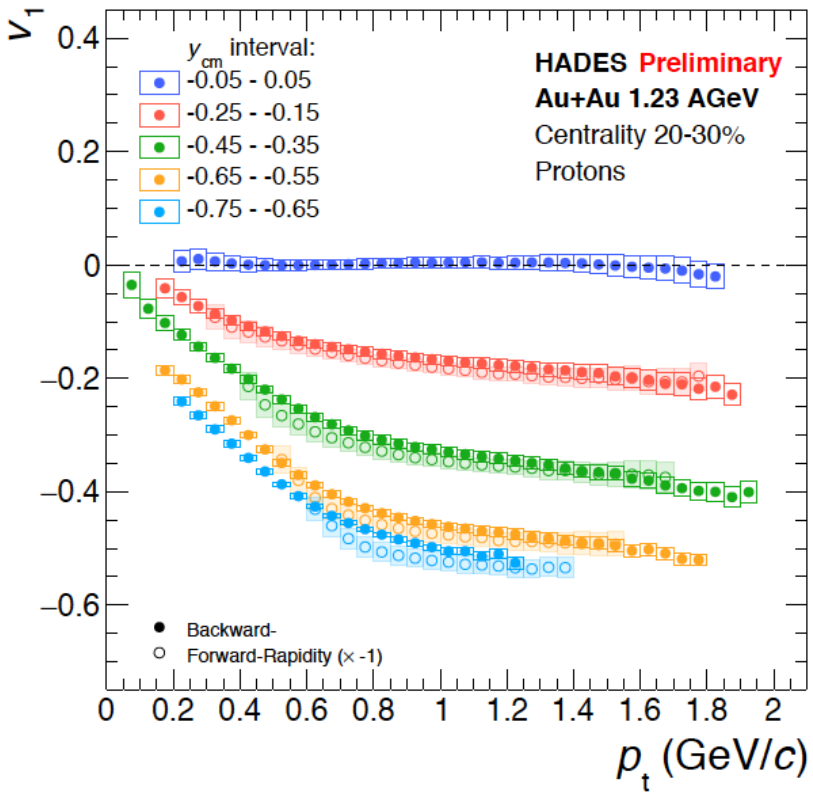
In HADES acceptance:

$$(\phi/K^-)_C = 0.55 \pm 0.04(stat)^{+0.06}_{-0.07}(sys)$$

$$(\phi/K^-)_W = 0.63 \pm 0.06(stat) \pm 0.11(sys)$$

p, d, t v_1, v_2, v_3, v_4

Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

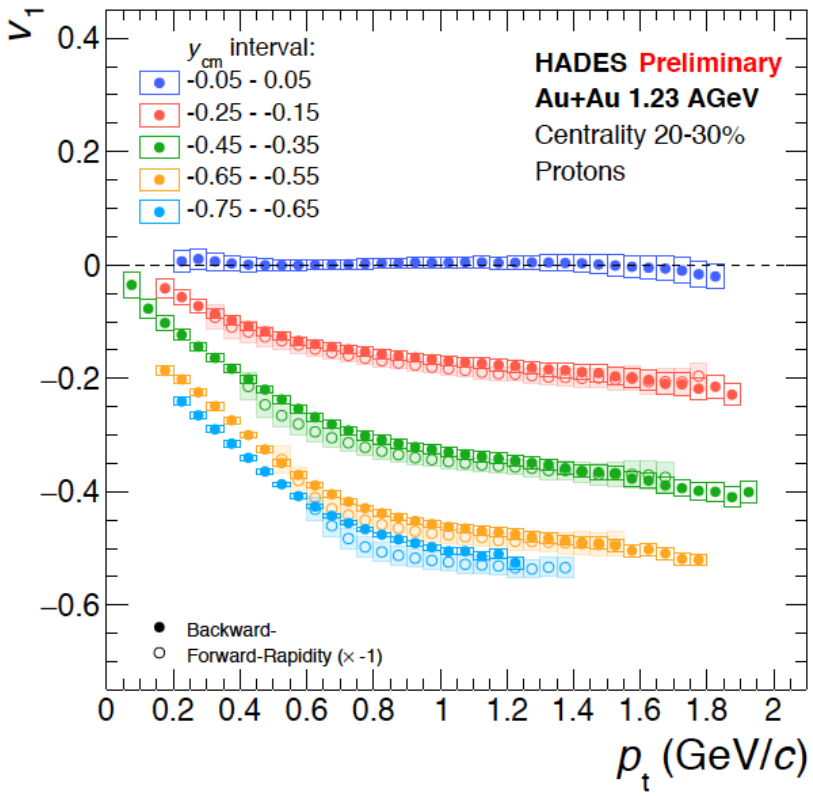


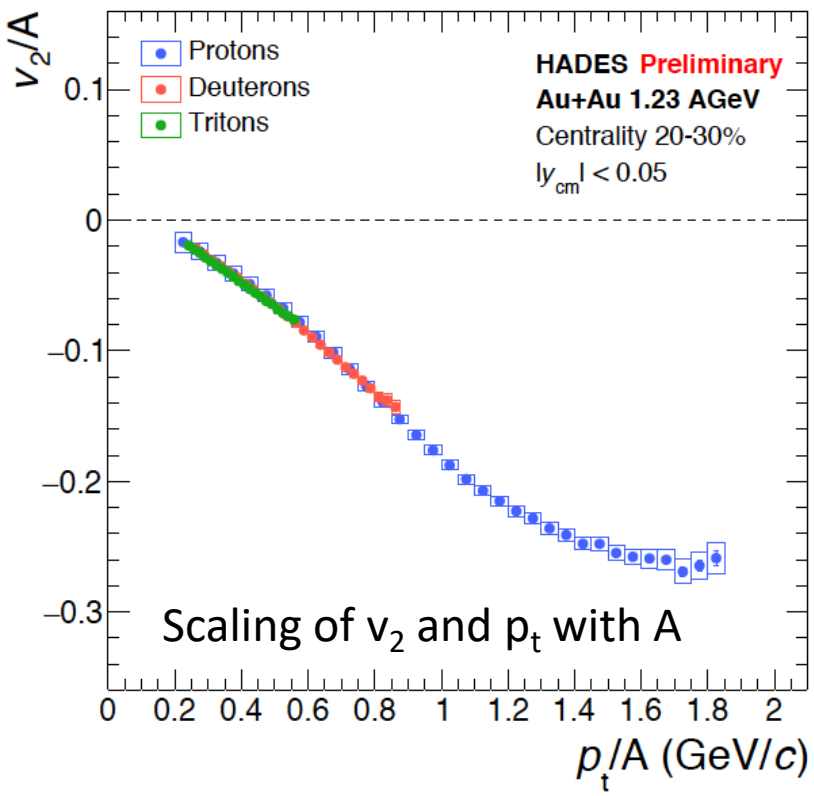
High statistic multi-differential data

N. Borghini and J.-Y. Ollitrault, PLB 642 2006

p, d, t v_1, v_2, v_3, v_4

Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV





High statistic multi-differential data

Comparison p,d,t at mid-rapidity

N. Borghini and J.-Y. Ollitrault, PLB 642 2006

p, d, t v_1, v_2, v_3, v_4

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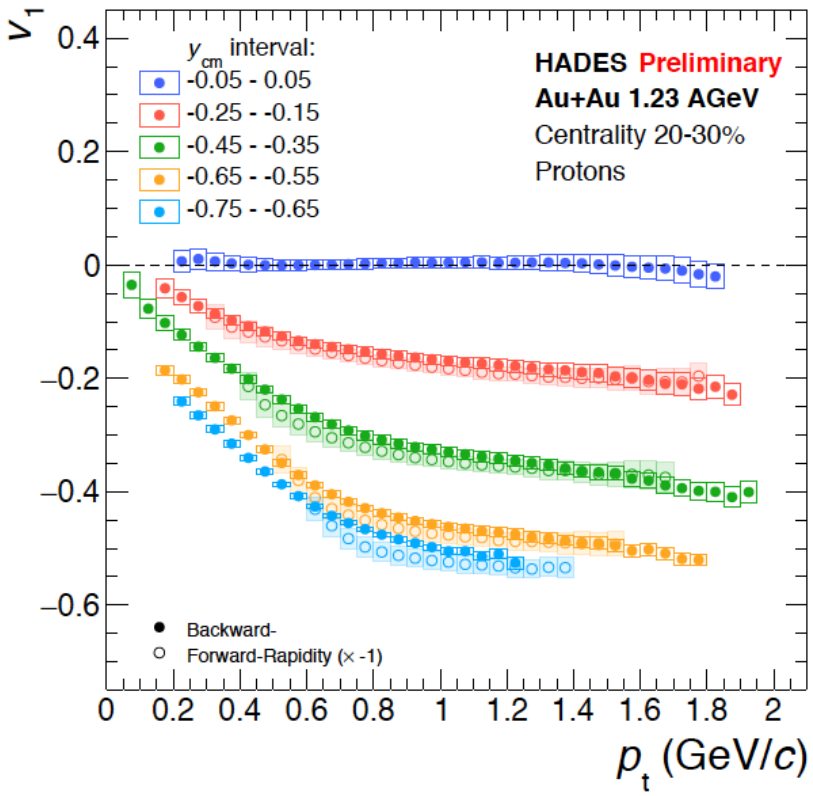

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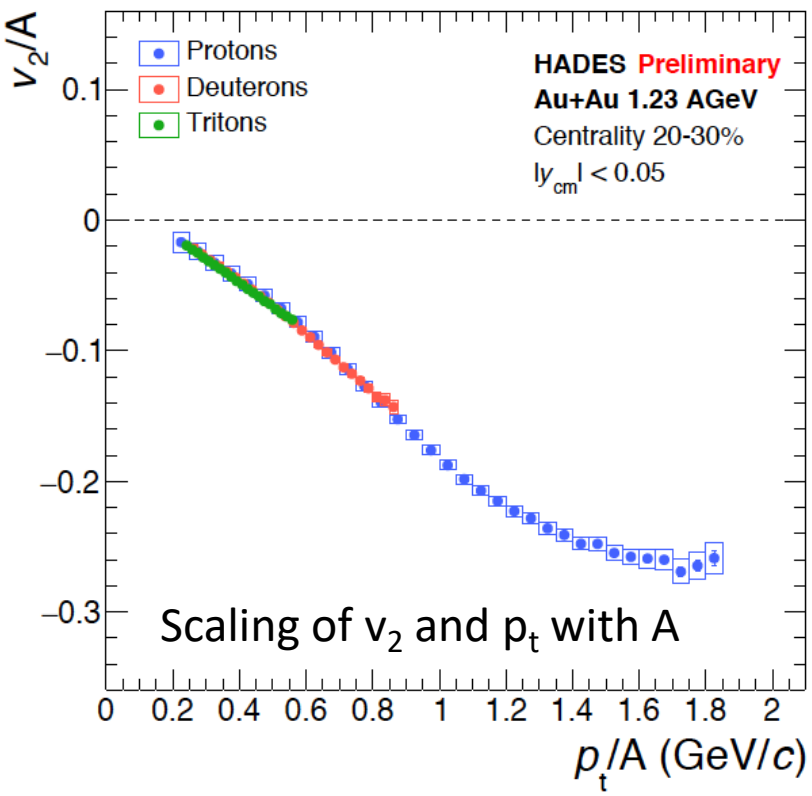

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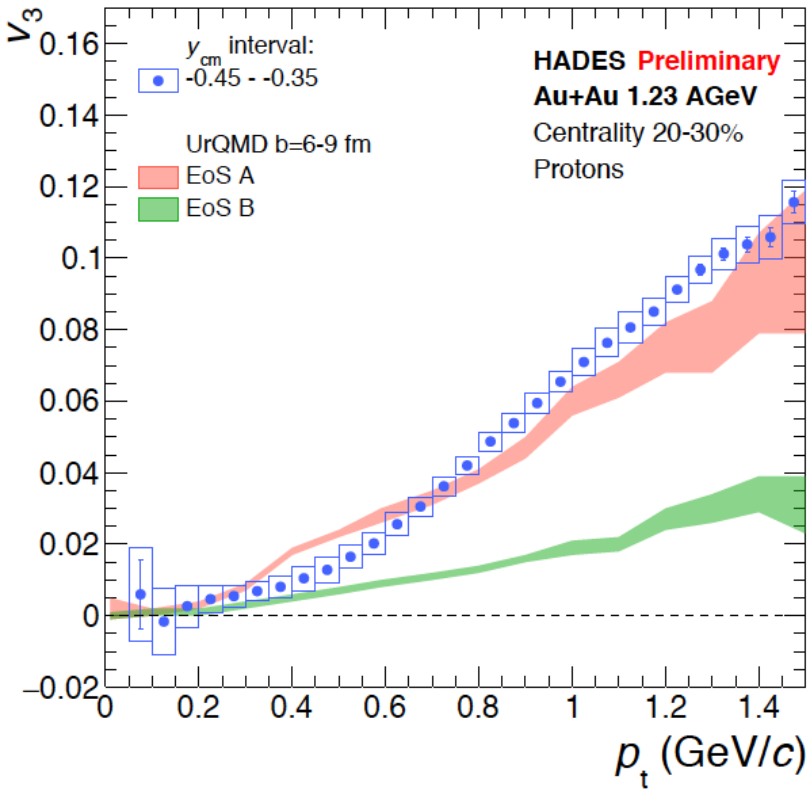

Sensistivity to the equation of state

UrQMD prediction: P. Hillmann et al.
J.Phys. G45 (2018) no.8, 085101

$$V_{Sk} = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma}$$

Parameters	hard EoS	soft EoS
α [MeV]	-124	-356
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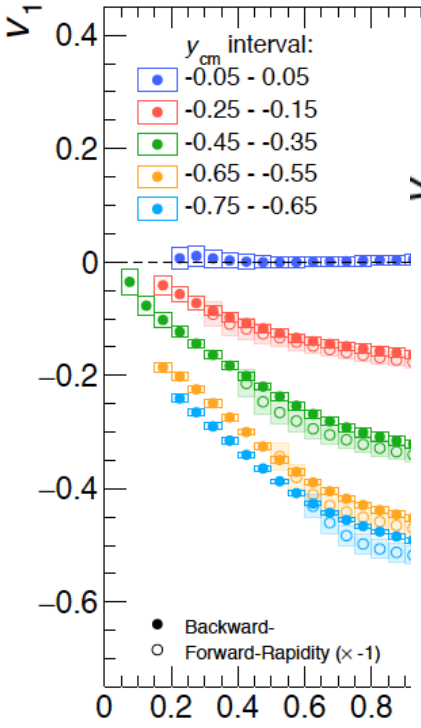

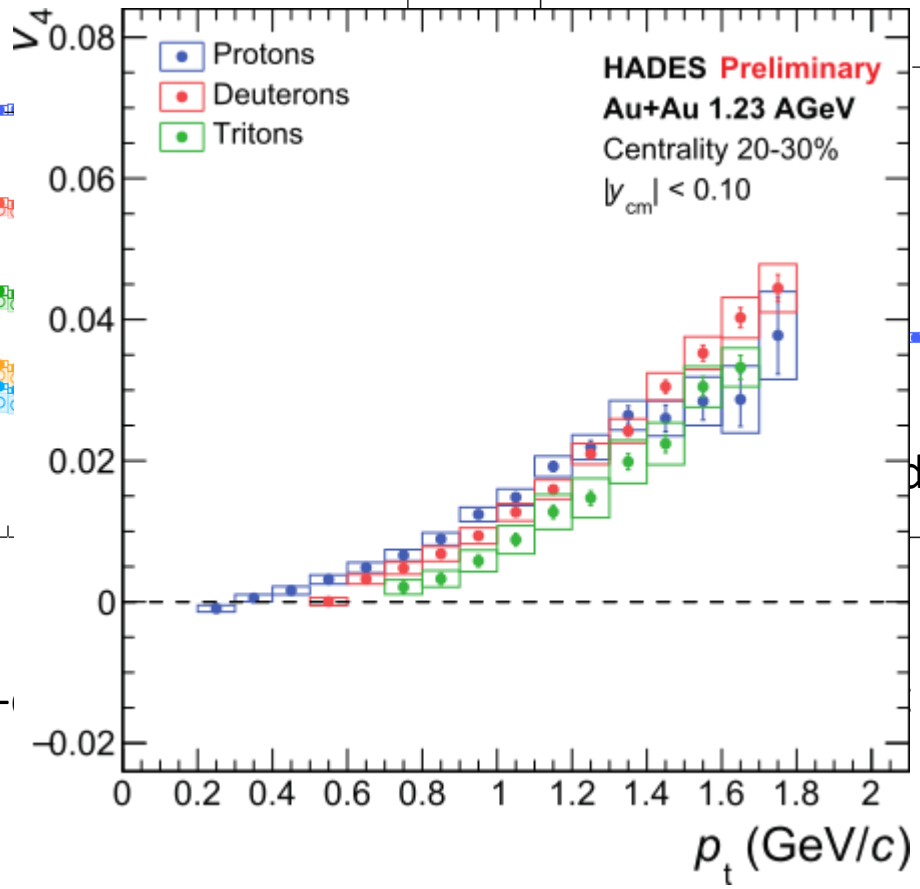

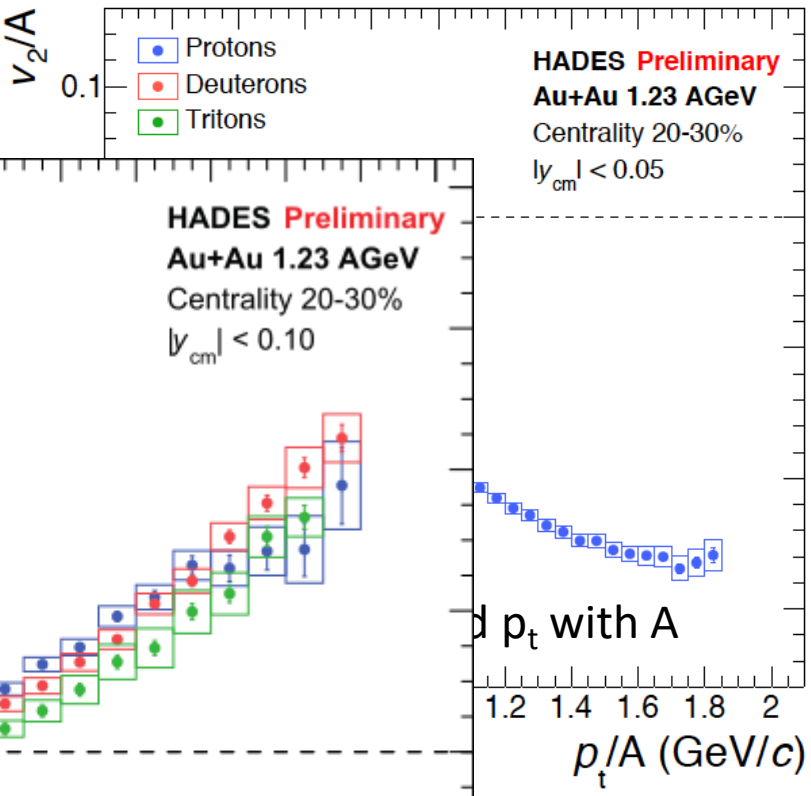

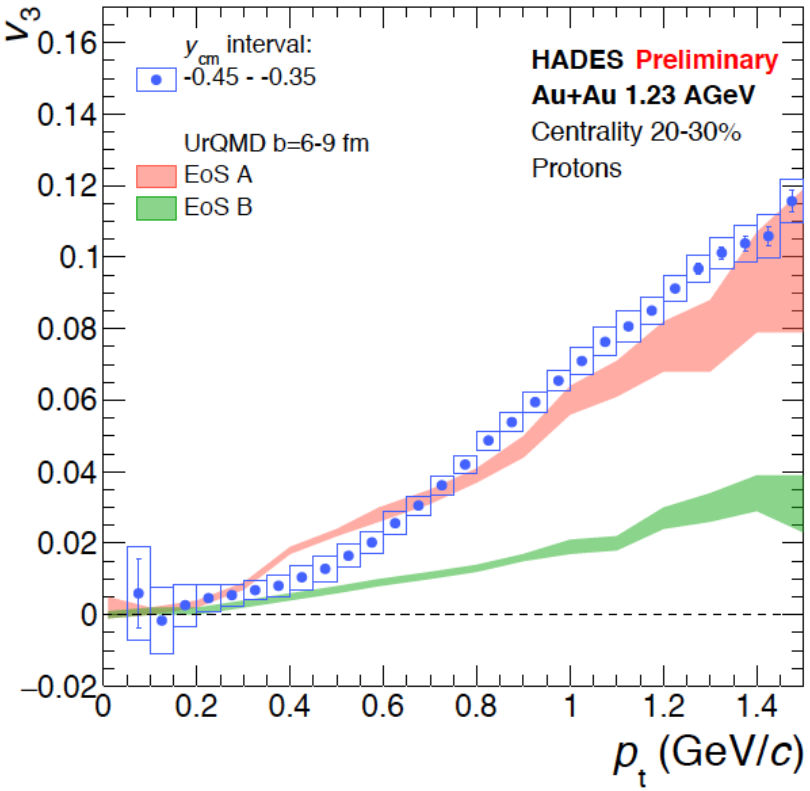

High statistic multi-

d p_t with A

mid-rapidity

Sensitivity to the equation of state

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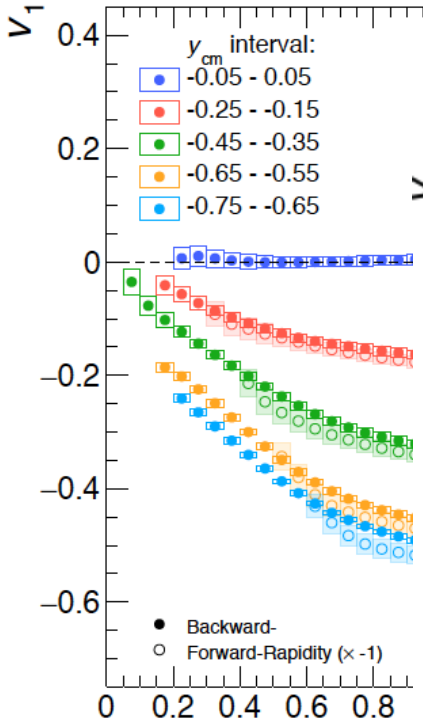
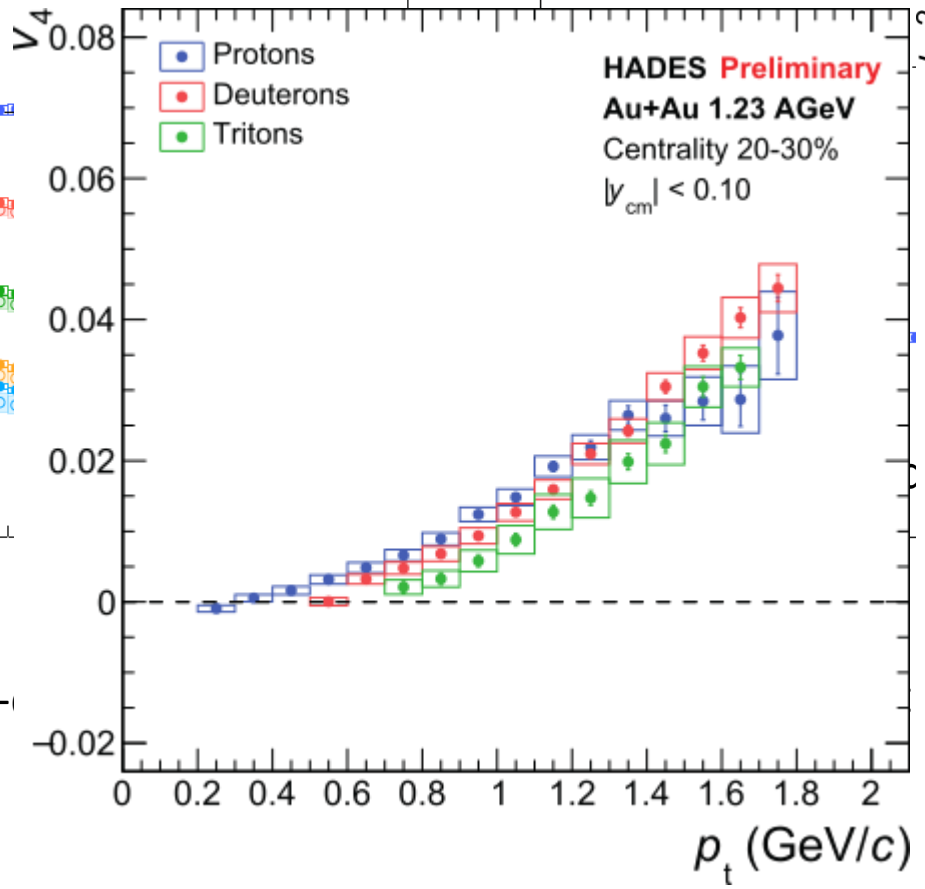
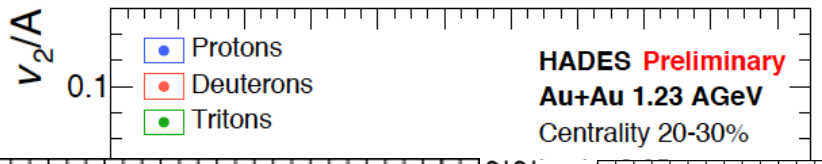
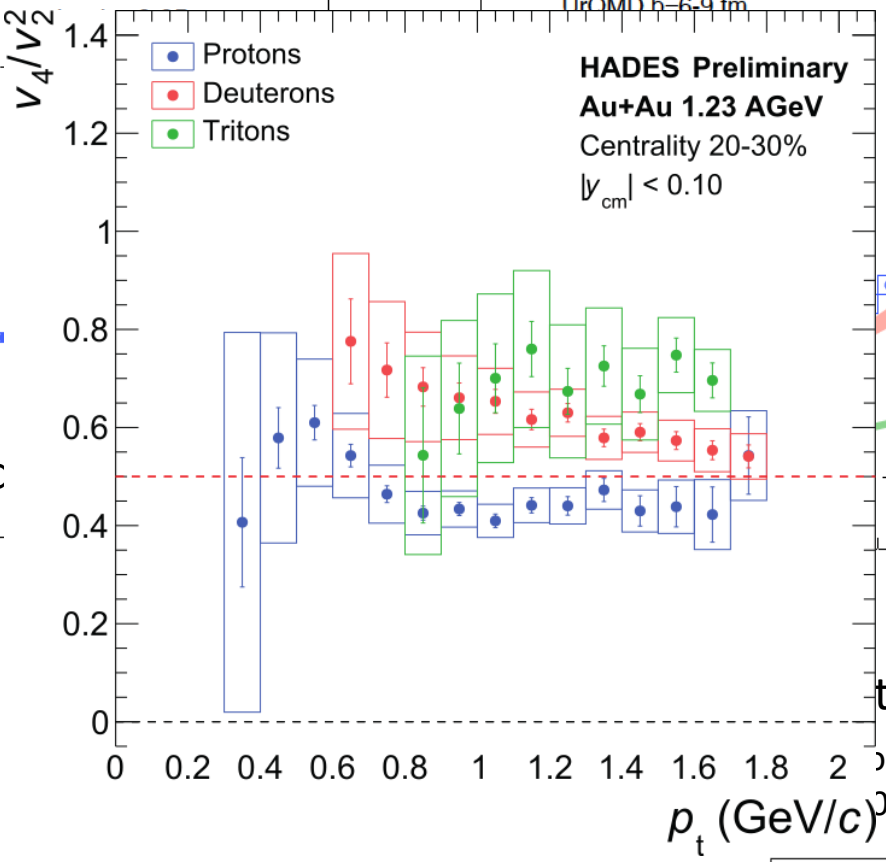
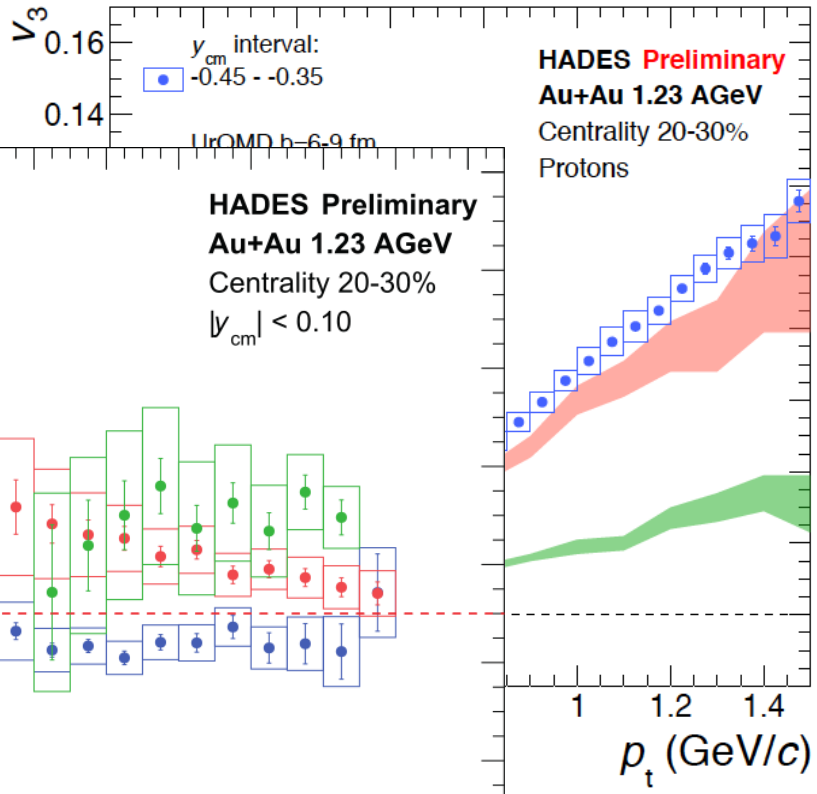
Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV











High statistic multi- ... tion of state

...on: P. Hillmann et al. ...018) no.8, 085101

Ideal-fluid scaling: the limit of the v_2 contribution to v_4 at large p_t is given by $v_4 = 0.5\ v_2^2$

N. Borghini and J.-Y. Ollitrault, PLB 642 2006

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Parameters	hard EoS	soft EoS
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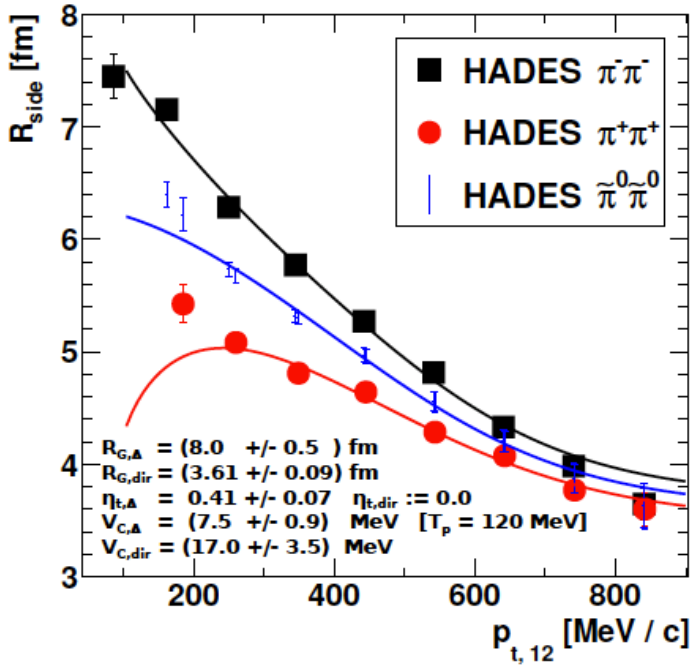
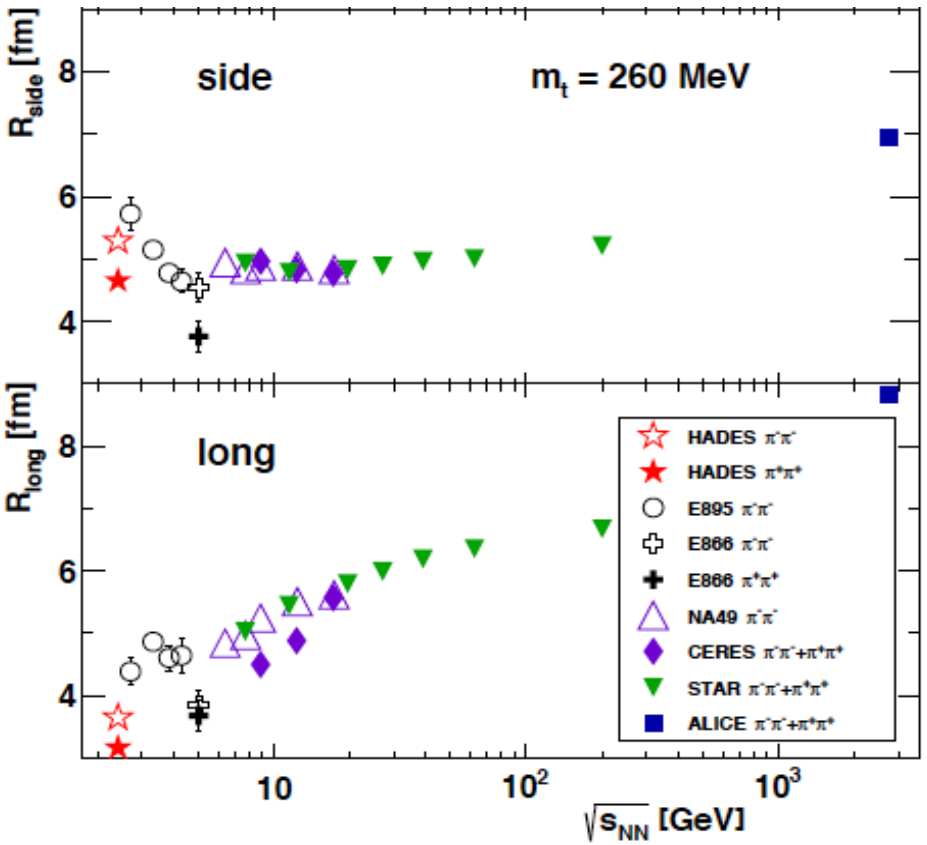
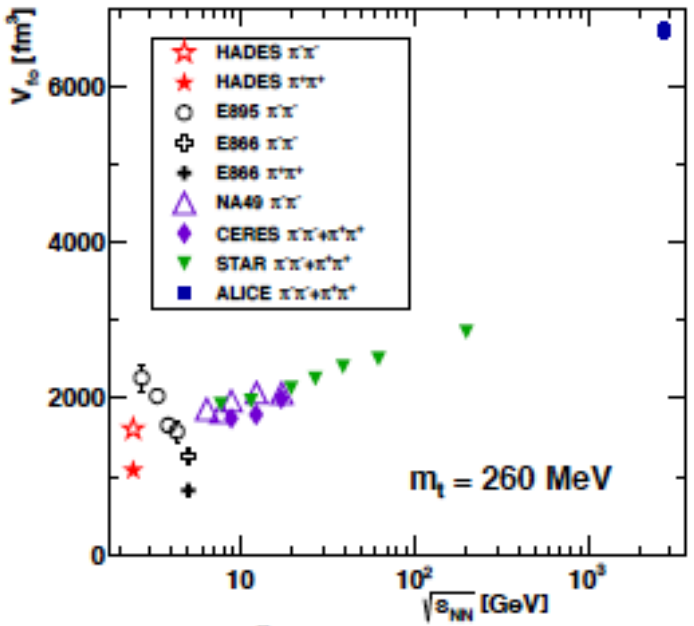
HBT freeze-out radii

Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

HADES Collab., PLB **795** (2019) arXiv:1811.06213







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Indications for charge-sign differences reported previously:

E866 R. A. Soltz, M. Baker, J. H. Lee, Nucl. Phys. A 661, 439c (1999)
E877 D. Miskowiec et al., Nucl. Phys. A590, 473c (1995)
NA44 I.G. Bearden et al., Nucl. Phys. A638, 103c (1998)

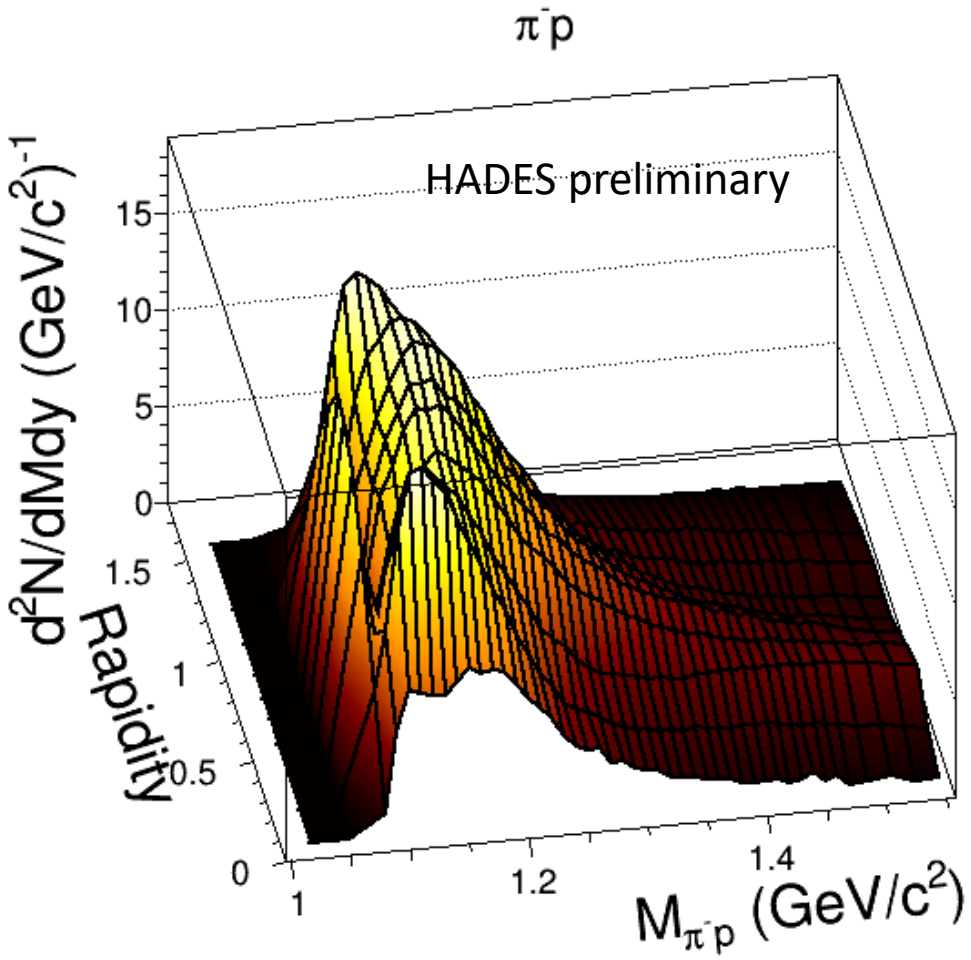
First time observation of significant charge-sign splitting!

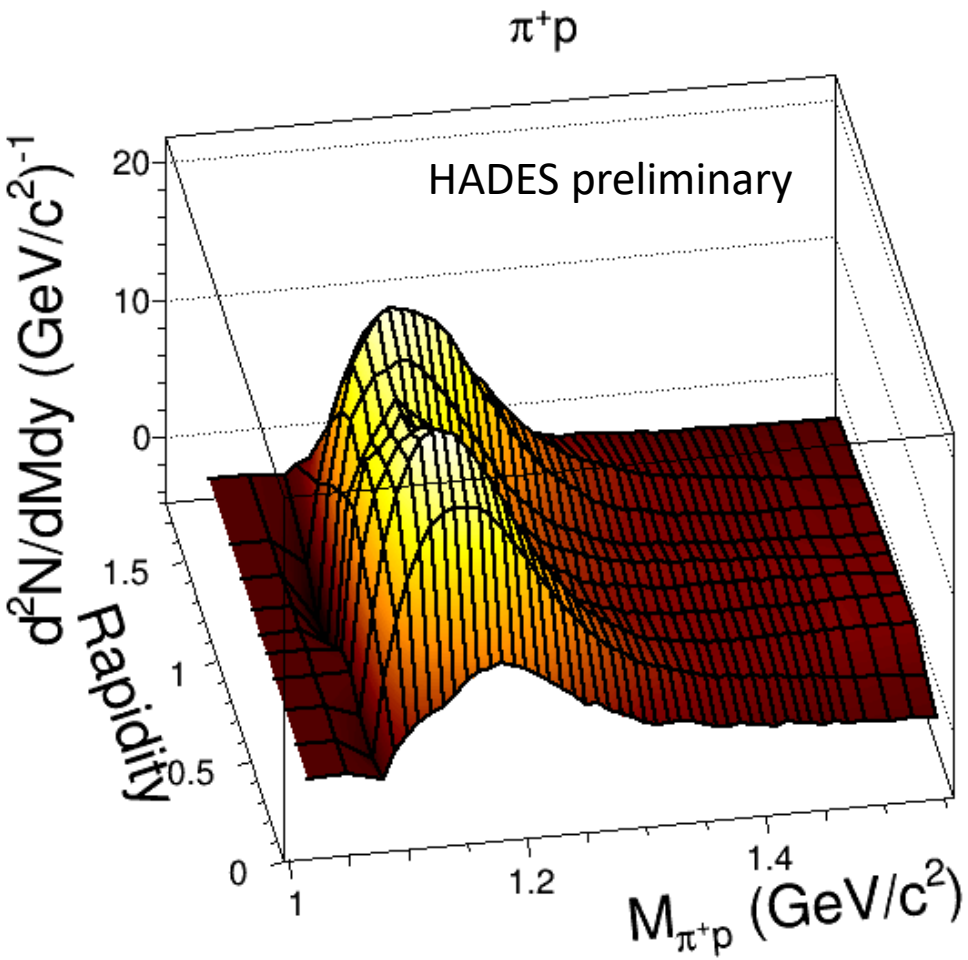
HADES follows trend from higher energies STAR and NA49 data than trend from E895

→ room for structures?

Correlated pion – proton pairs

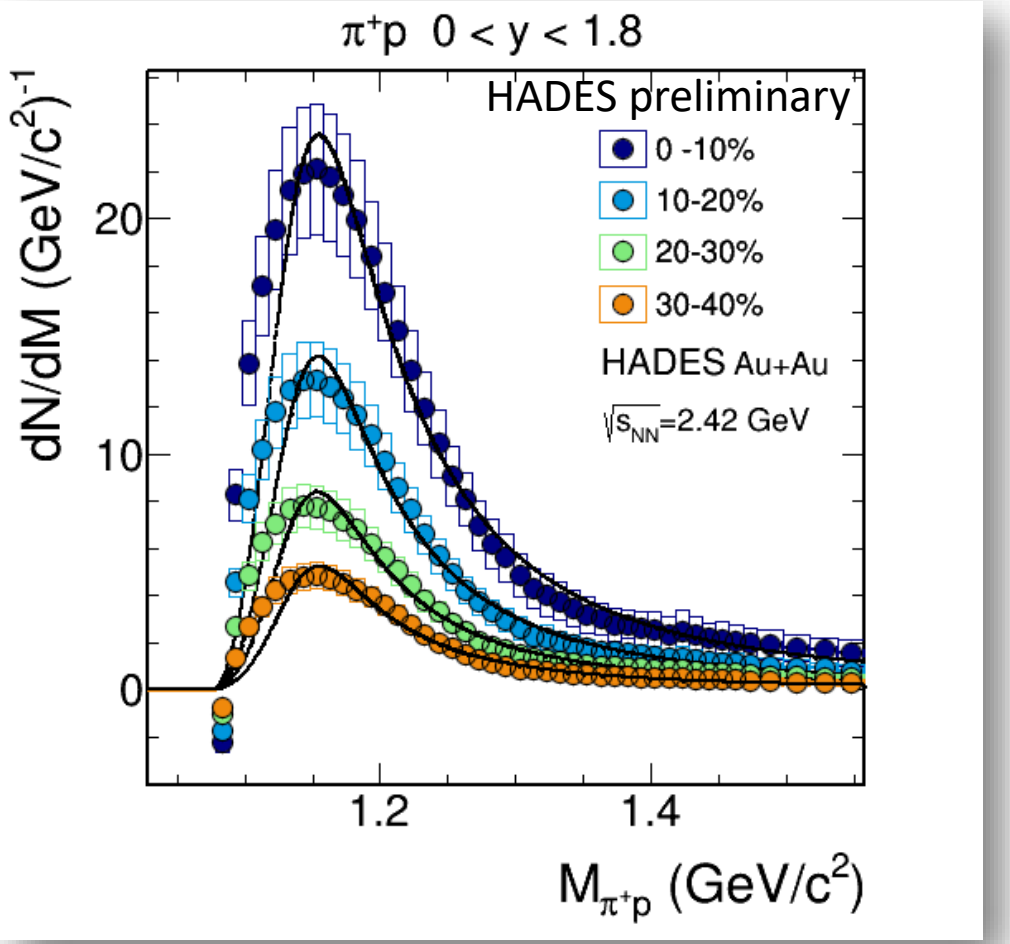
Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

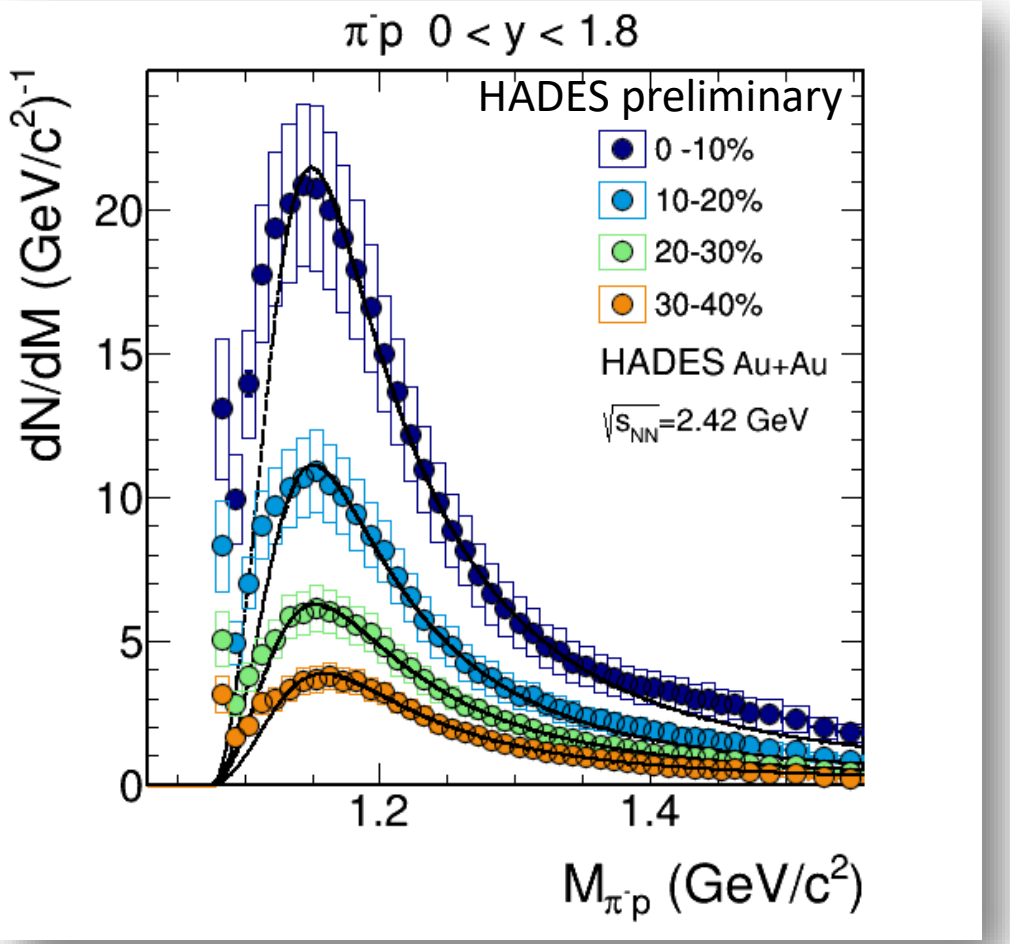




$\pi^{\pm}$p correlated yield

Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV





*J. Cugnon M.C. Lemaire, Nucl.Phys. A **489**, 781 (1988)*

$$\sigma(M) = a\frac{q^3}{q^3 + 180^3}\frac{1}{4\left(\frac{M - M_0}{\Gamma_0}\right)^2 + 1}$$

$$q = \sqrt{\frac{\left(M^2 - \left(M_p + M_\Pi\right)^2\right)\left(M^2 - \left(M_p - M_\Pi\right)^2\right)}{4M^2}}$$

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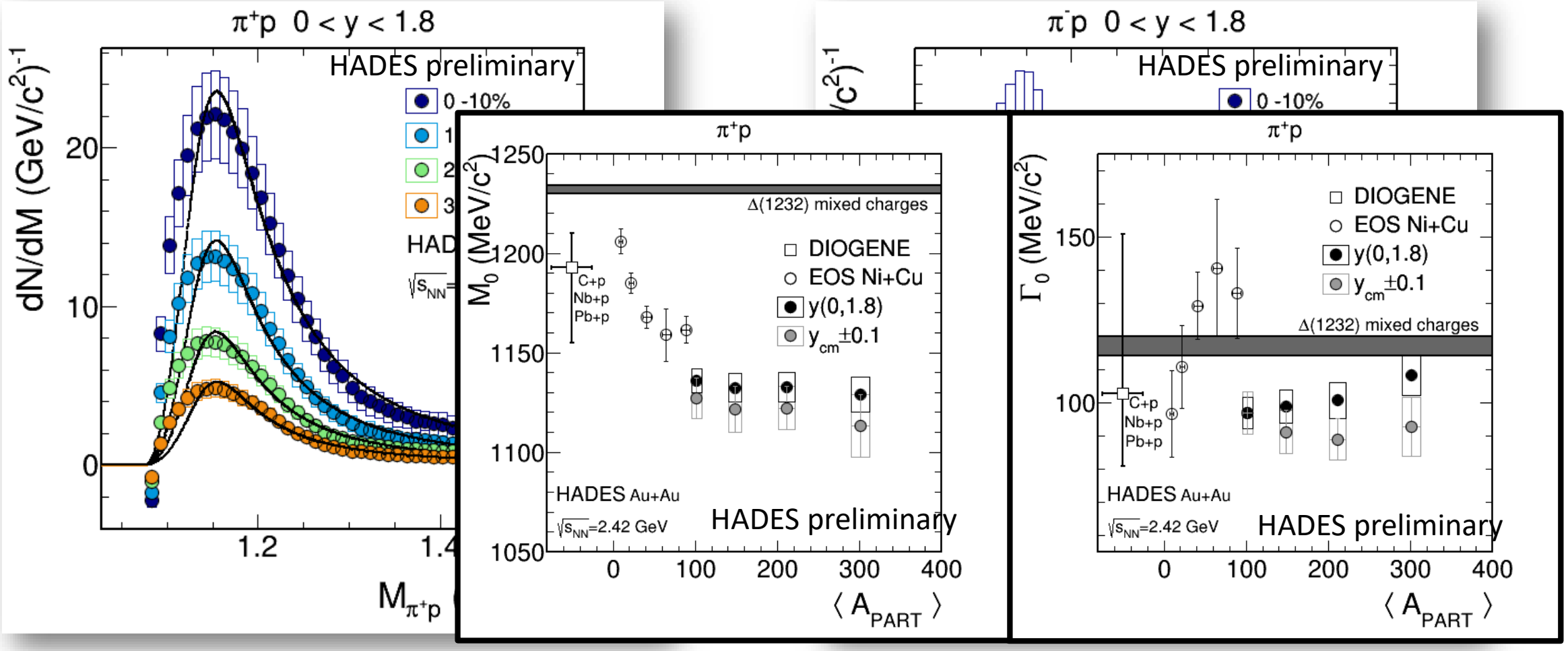

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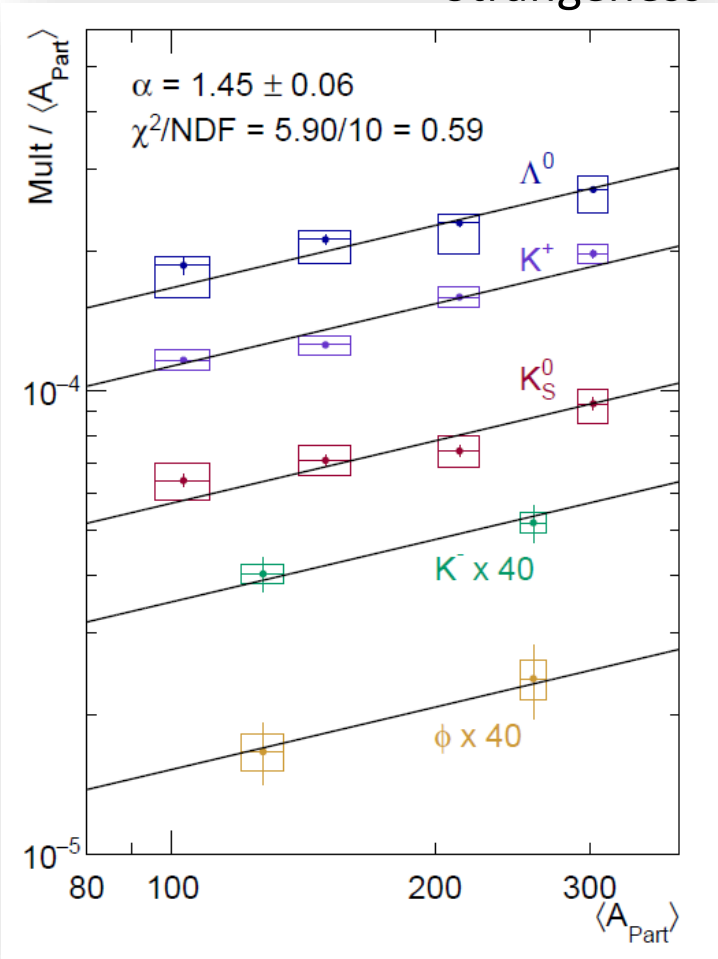
*[EOS] Phys. Rev. Lett. **79**, 4345-4348 (1997), E. L. Hjort, et al.*
*[DIEOGENE] Z. Phys. A **340**, 325-331 (1991), M. Trzaska ,et al.*
*J. Cugnon M.C. Lemaire, Nucl.Phys. A **489**, 781 (1988)*

Production scalings Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

HADES Collab., Phys.Lett. B793 (2019)
arXiv:1812.07304

Strangeness



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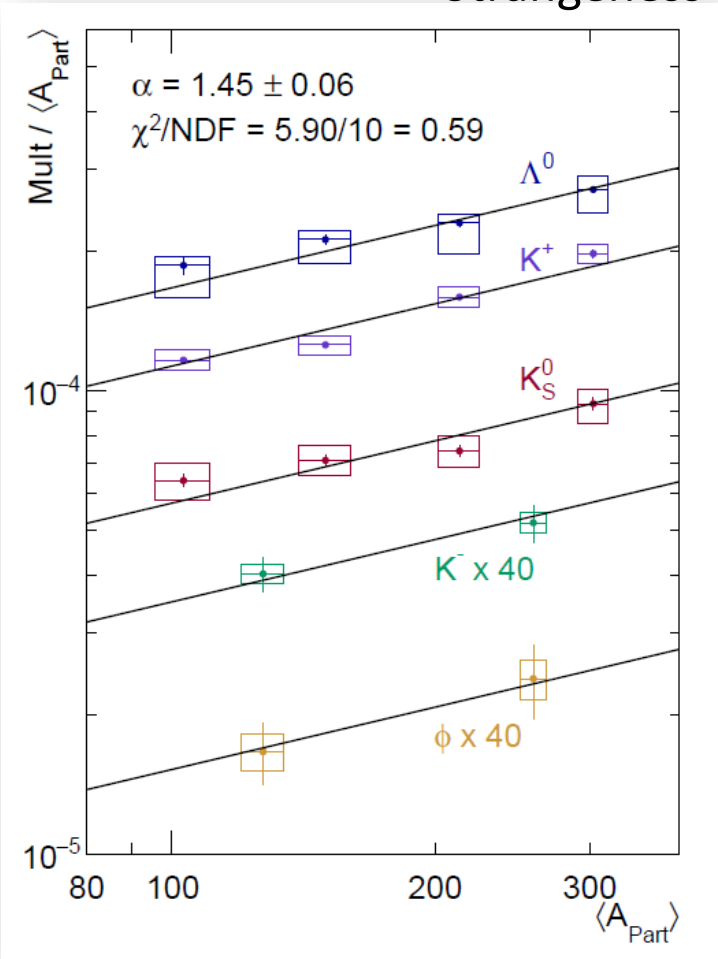
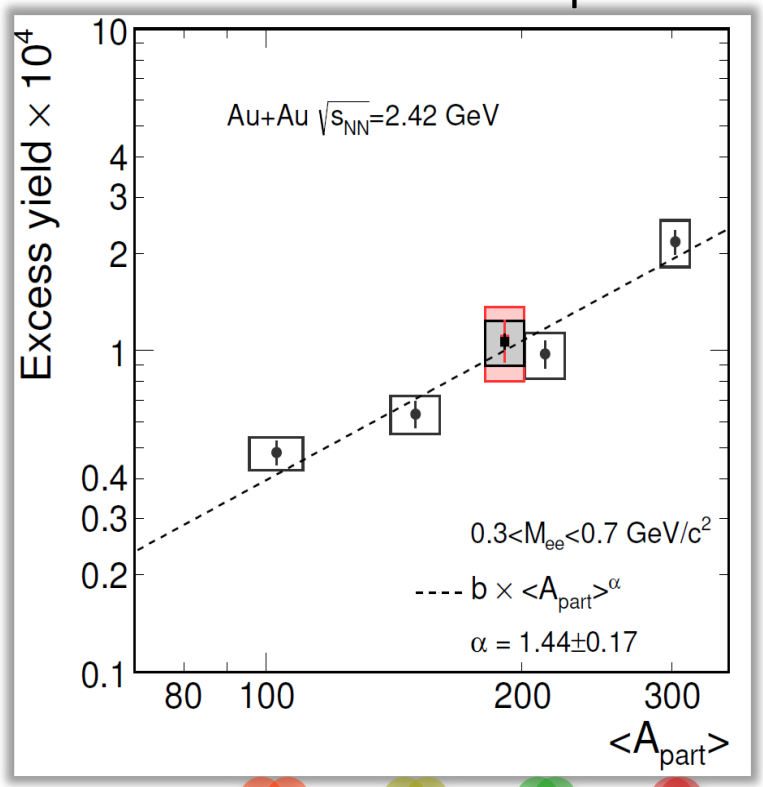


Dileptons

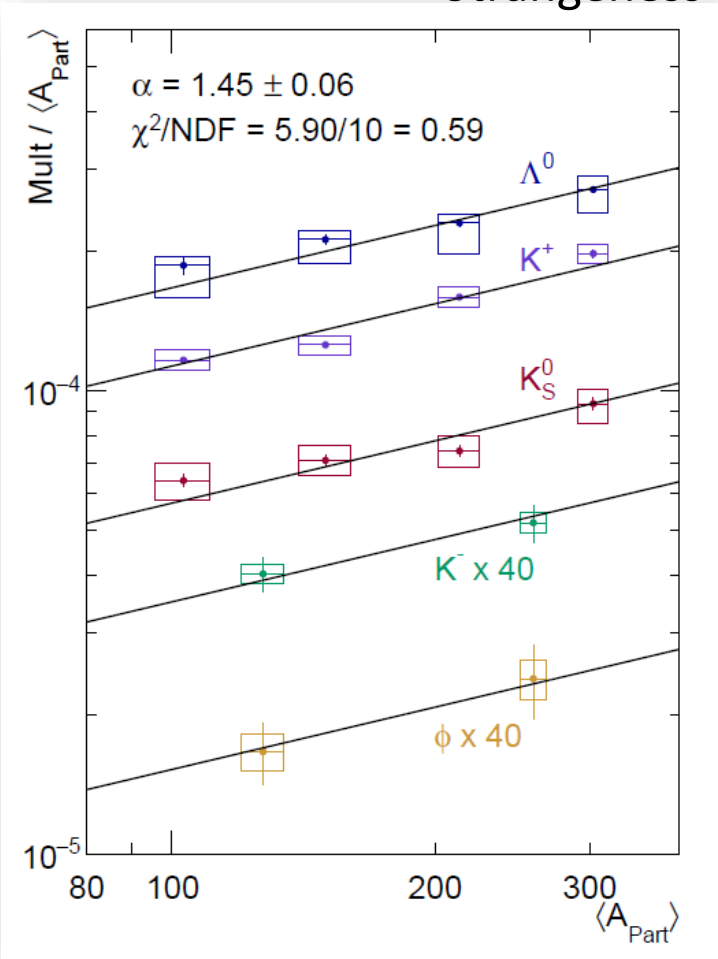


Production scalings Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

Scaling N $\propto$ $\langle A_{part}\rangle^{\alpha}$ with parameter similar to that of strange hadrons and excess yield of virtual photons!

HADES Collab., Phys.Lett. B793 (2019)
arXiv:1812.07304

Strangeness



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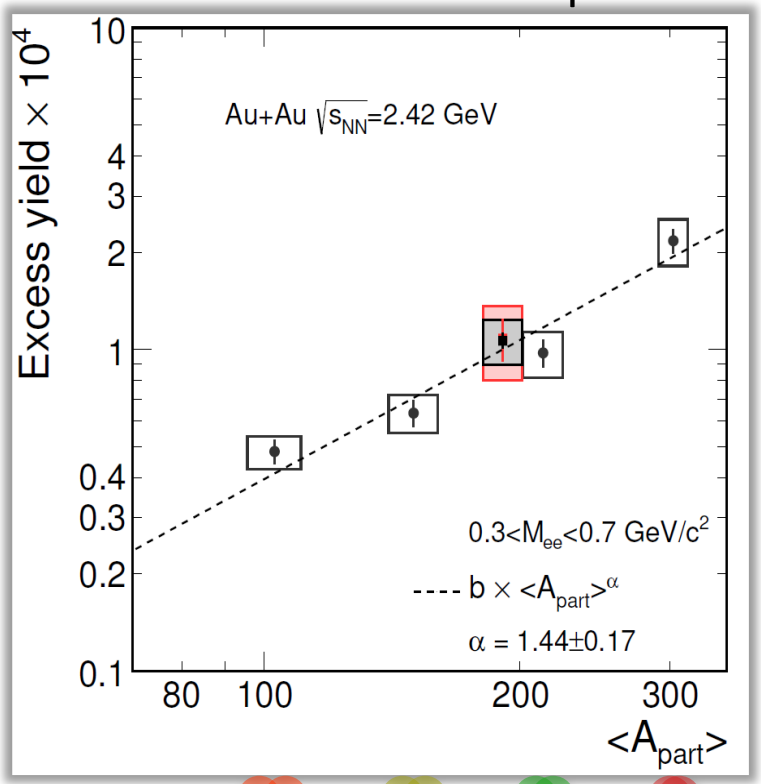

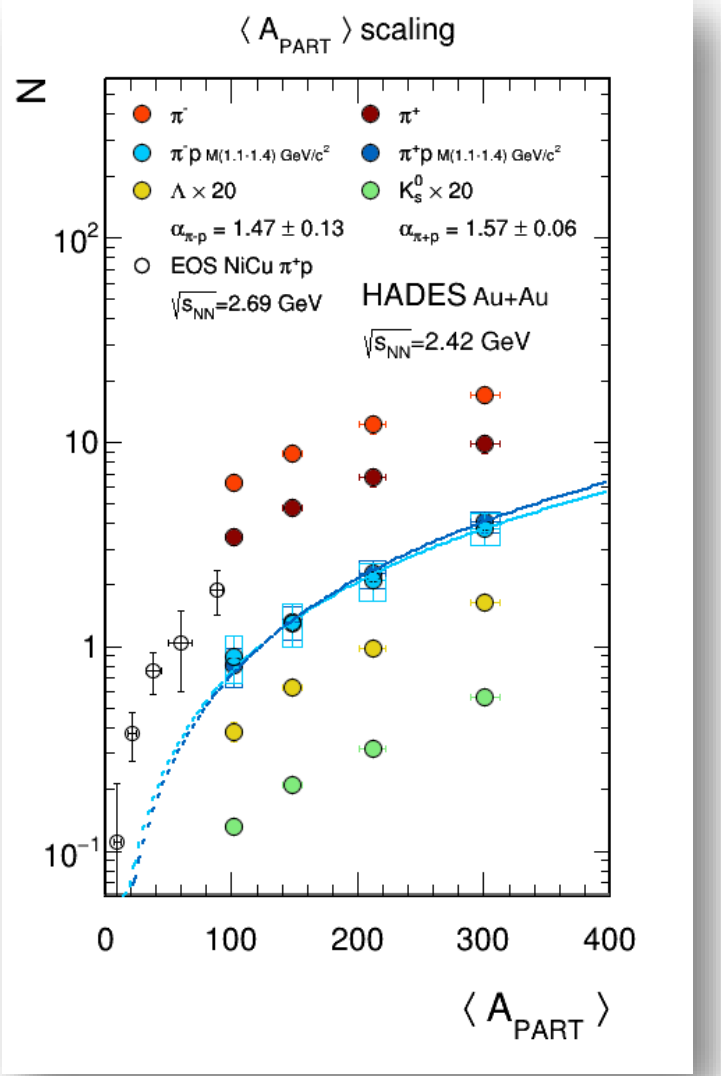

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Ag+Ag $\sqrt{s_{NN}} = 2.55$ GeV

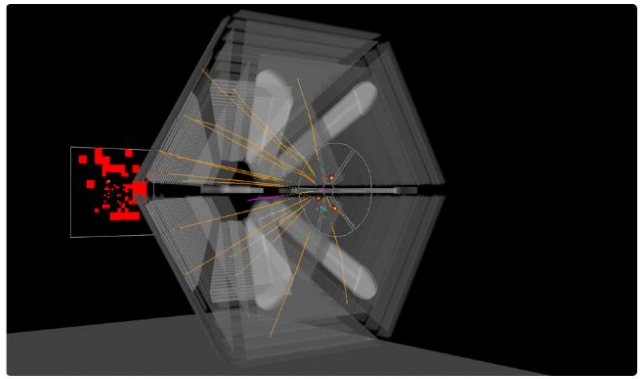
HADES: FAIR Phase 0 Experiment

HADES monitoring

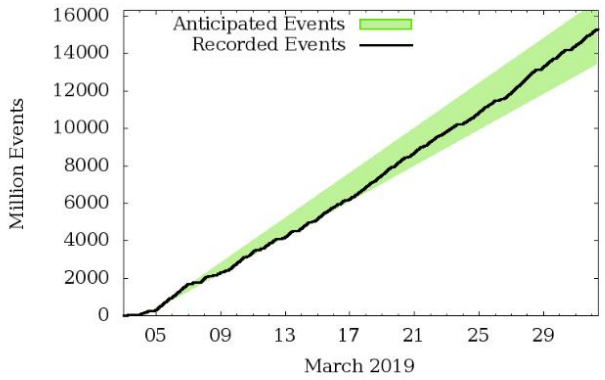
Ag+Ag 1.58A GeV

Date:	01 April 2019
Event rate:	16-18 kHz
Collected events:	15268.68 × 10^6
Collected data:	359.23 TB
Last update:	6:00

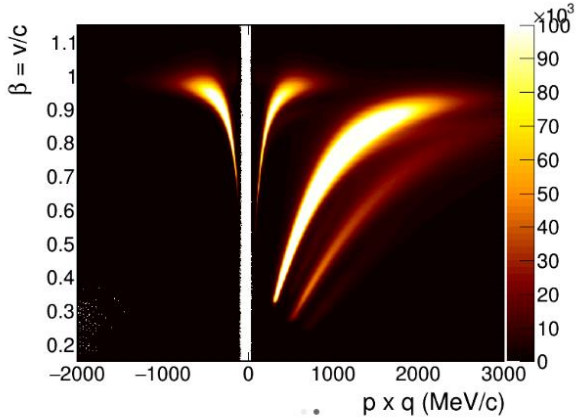
Event Display



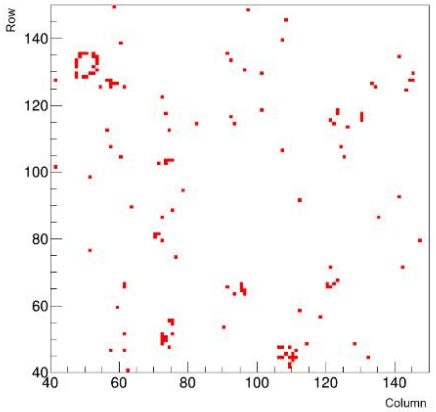
Run statistics



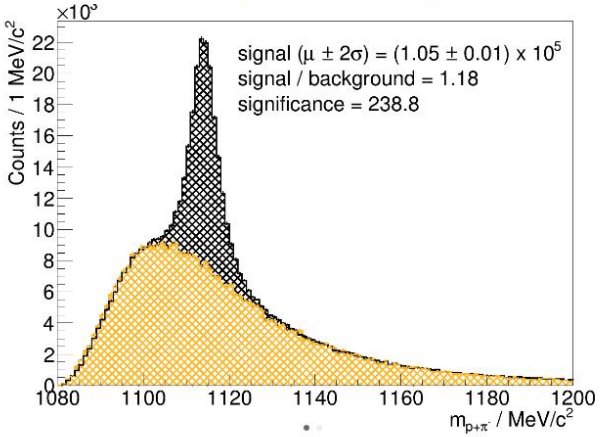
PID: Velocity vs Momentum - RPC



e^+/e^- Cherenkov Rings



Online Hyperons: $\Lambda \rightarrow p + \pi^-$



Ag+Ag $\sqrt{s_{NN}} = 2.55$ GeV

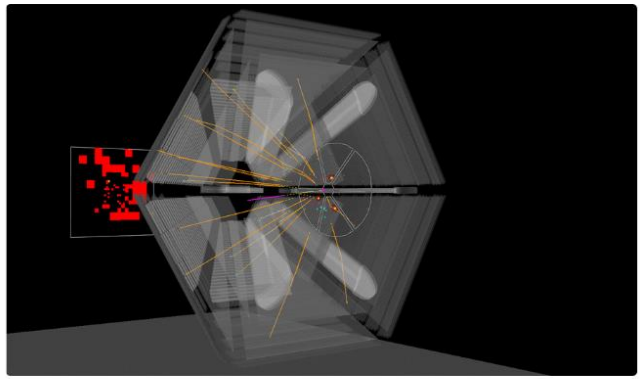
HADES: FAIR Phase 0 Experiment

HADES monitoring

Ag+Ag 1.58A GeV

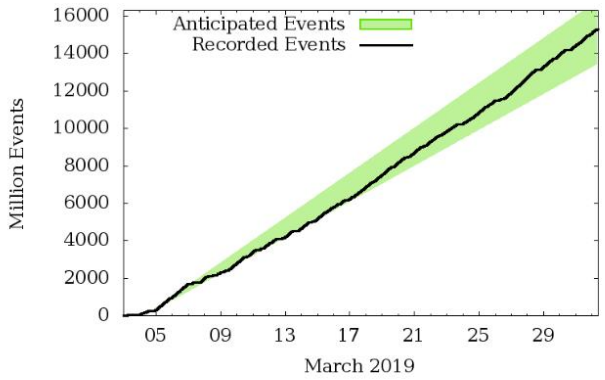
Date:	01 April 2019
Event rate:	16-18 kHz
Collected events:	15268.68 × 10^6
Collected data:	359.23 TB
Last update:	6:00

Event Display

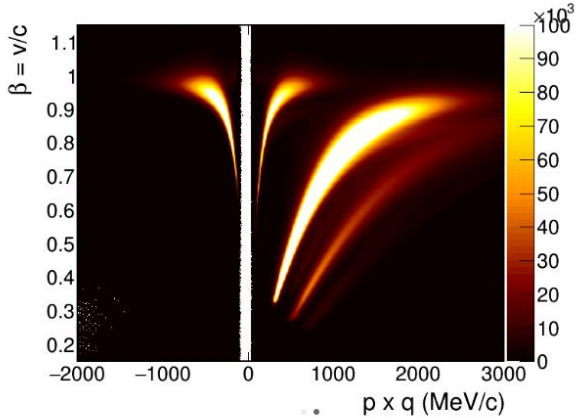


Run statistics

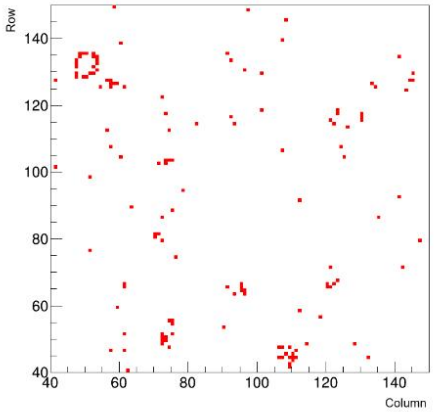
~ 15 billion events



PID: Velocity vs Momentum - RPC



e^+/e^- Cherenkov Rings



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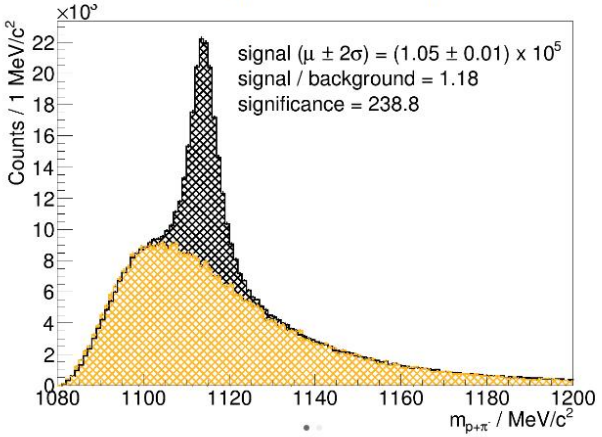
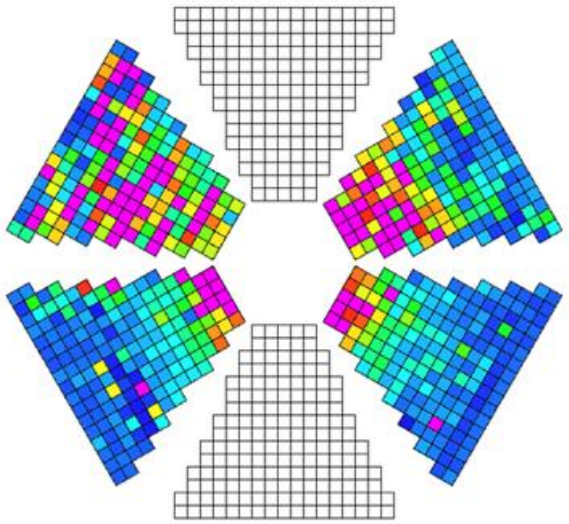


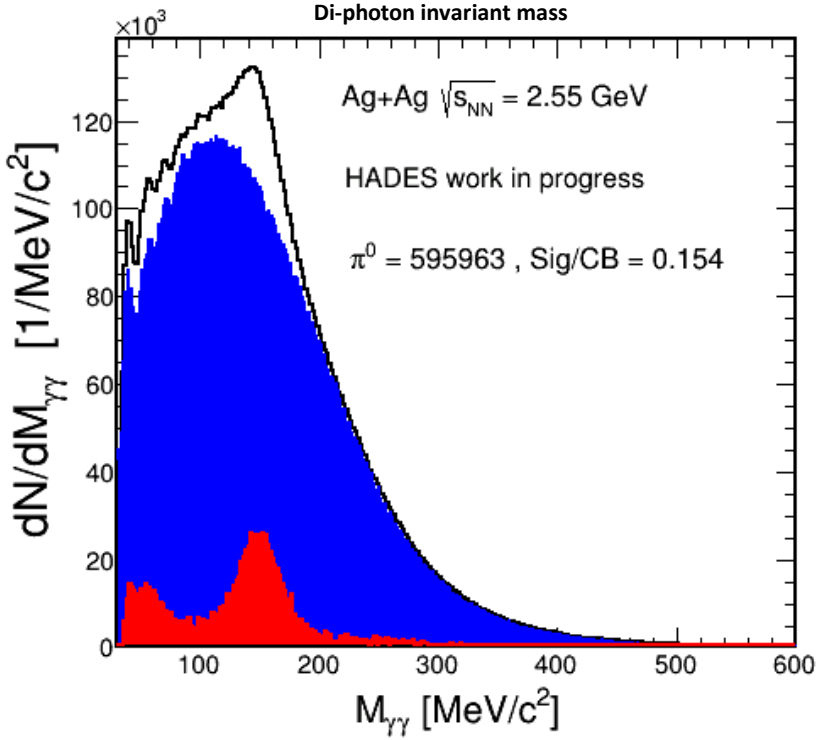
The new HADES ECAL

- Based on lead glass recycled from OPAL
- Refurbished and complemented with HADES TRB3 PADIWA read-out system based on commodity hardware

Four sectors installed, used in the Ag+Ag 1.58A GeV 2019



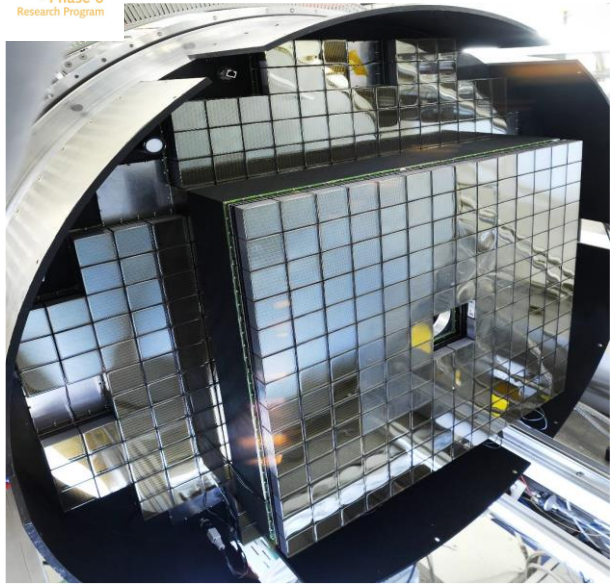
Di-photon invariant mass

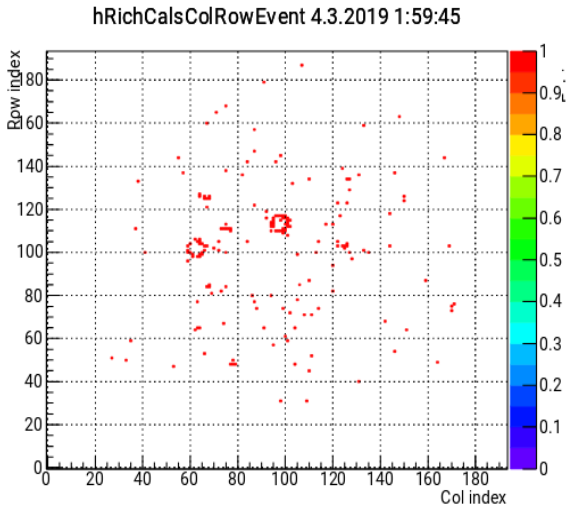


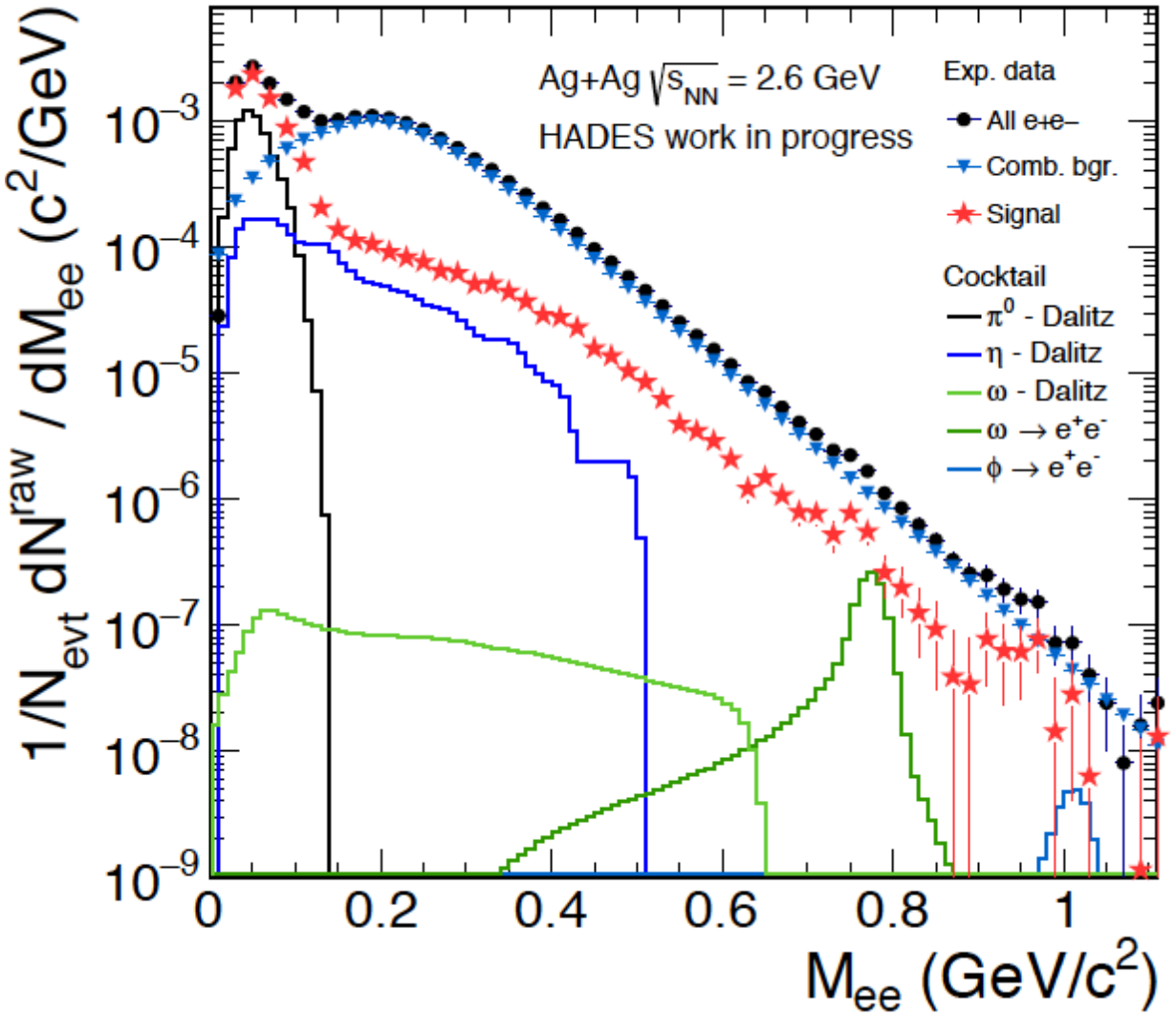
Electromagnetic Calorimeter in the HADES cave

Georgy Kornakov, WUT

Ag+Ag $\sqrt{s_{NN}}$= 2.6 GeV: Virtual Photons







- ½ of the CBM RICH photon detector
- Stable operation during 4 weeks of beamtime

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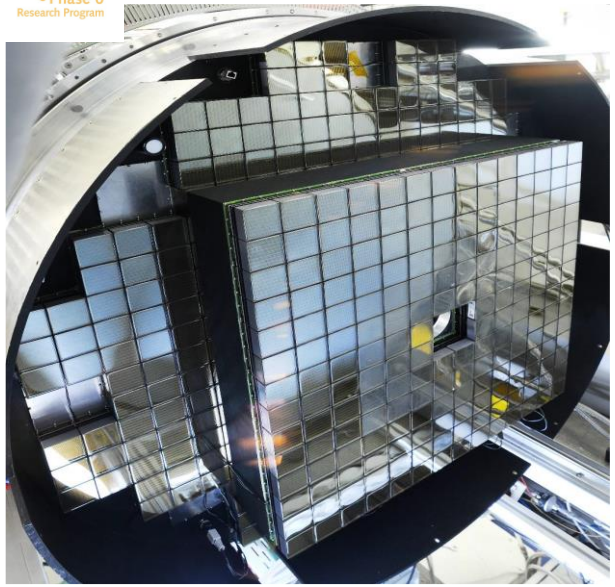

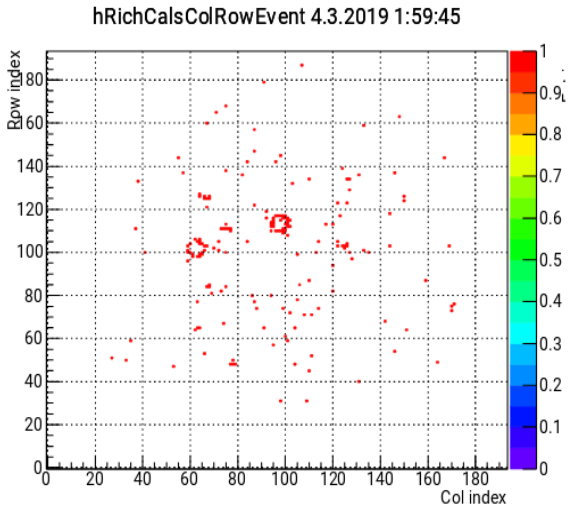

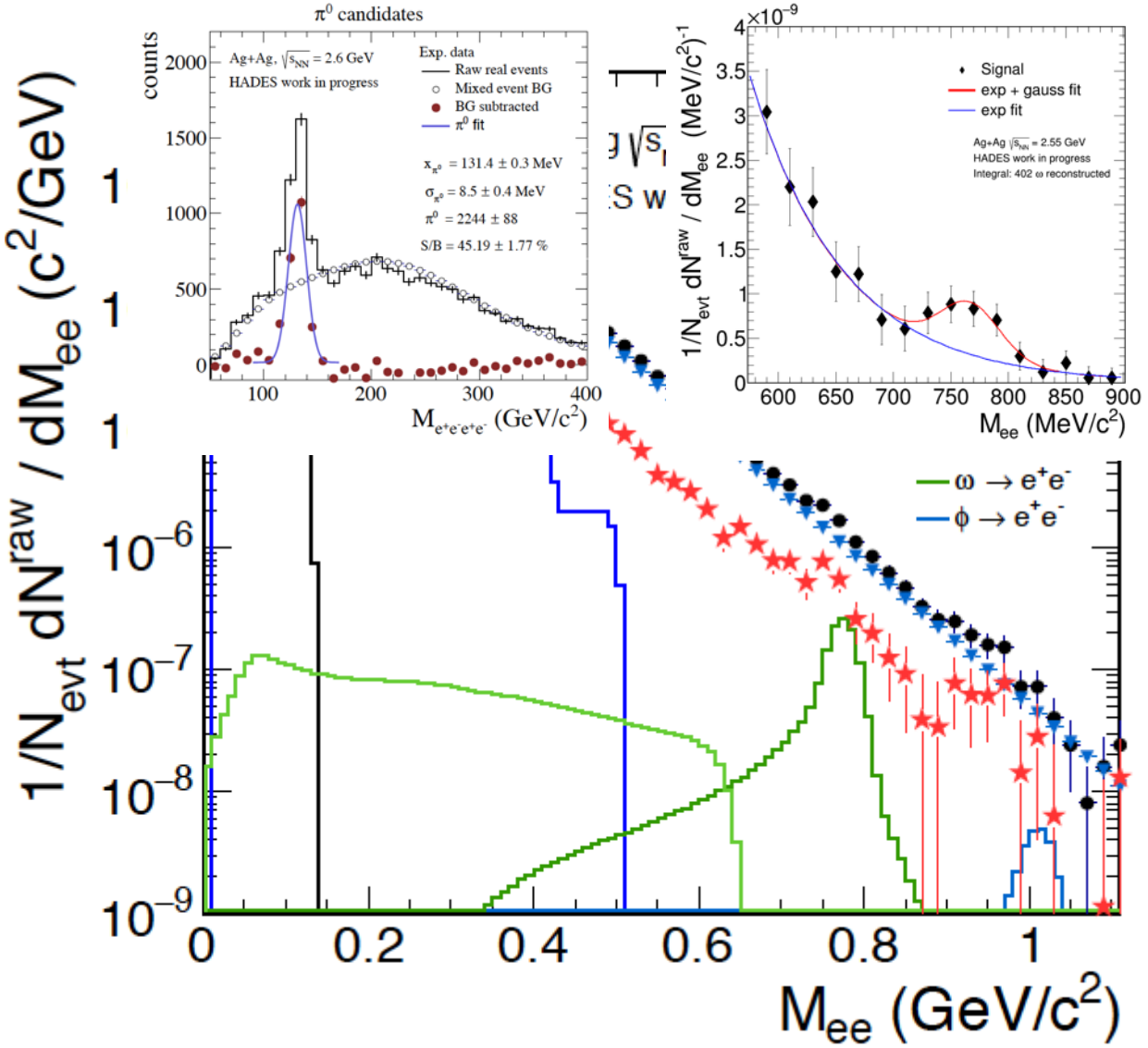

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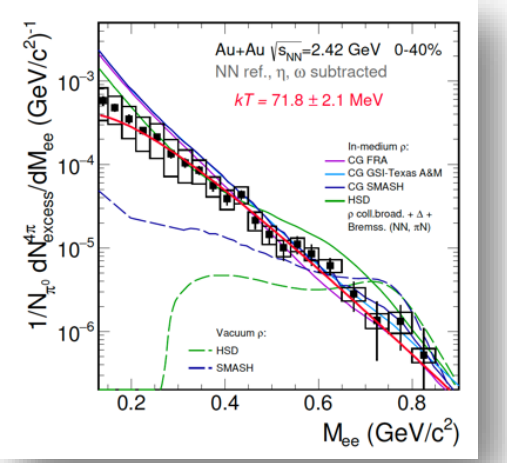
Summary



- Exponential falling di-electron spectrum, $<T_{ee}>$=72 MeV, ρ melted.
- Universal production scaling as a function of Apart regardless strangeness content despite different production thresholds.
- Systematic measurement of v1,v2,v3,v4, femtoscopy and baryonic resonances.
- FAIR-Phase0: Ag+Ag data fresh on tape! Work in progress

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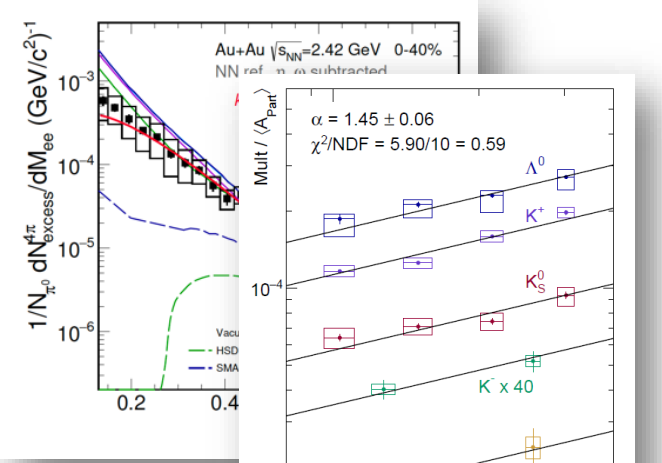

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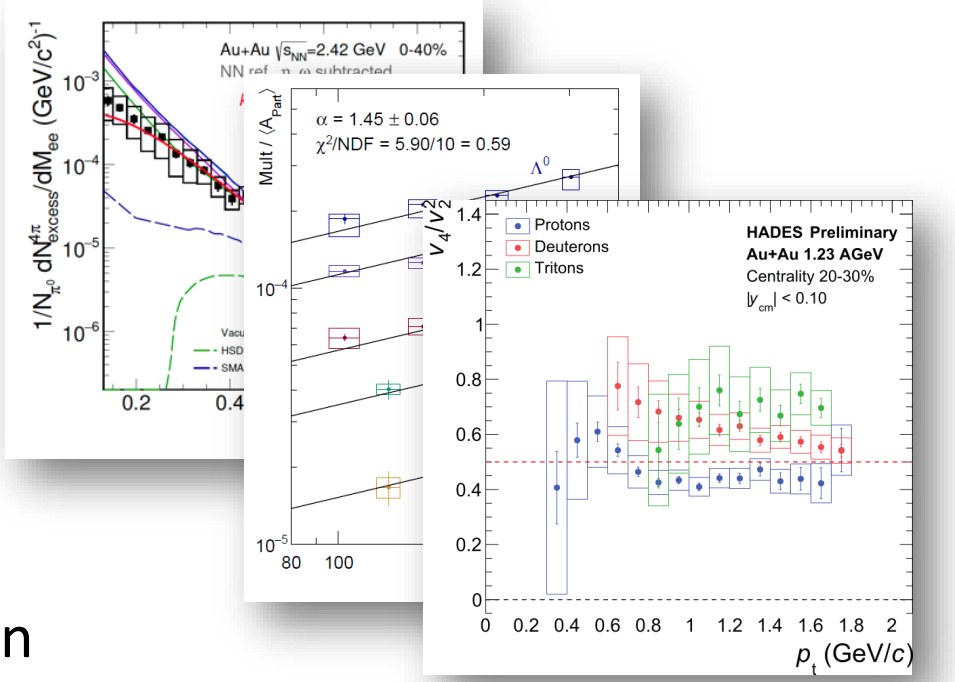

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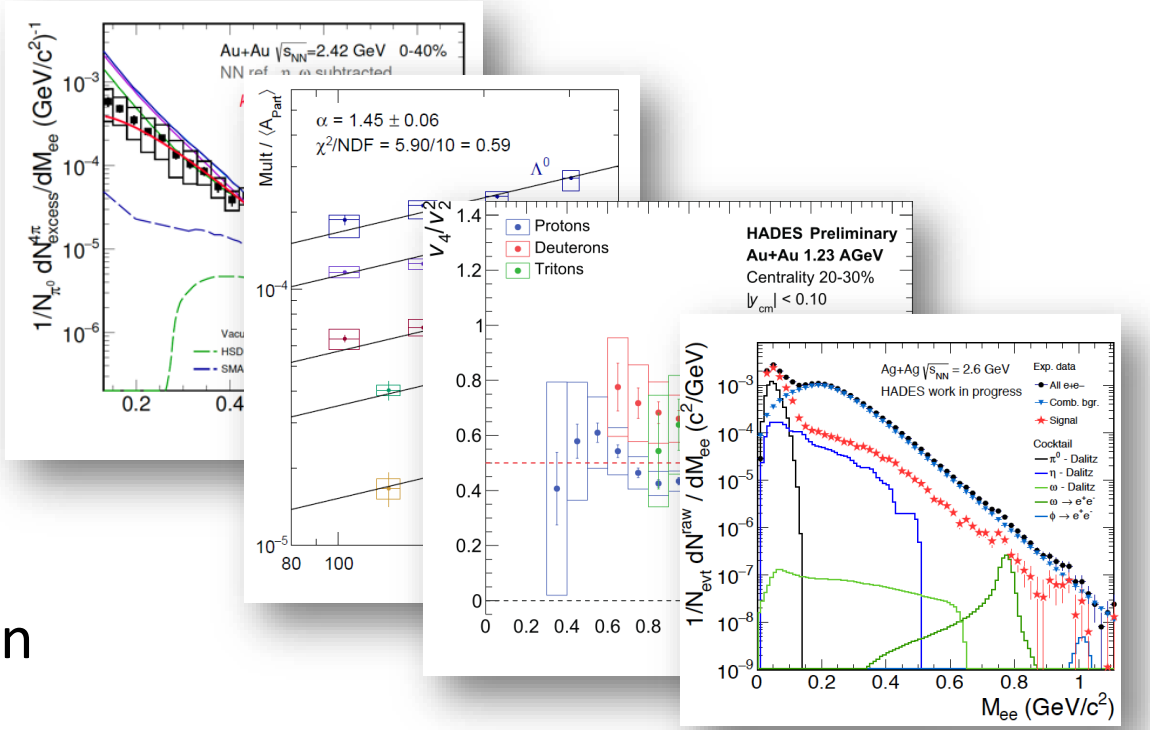

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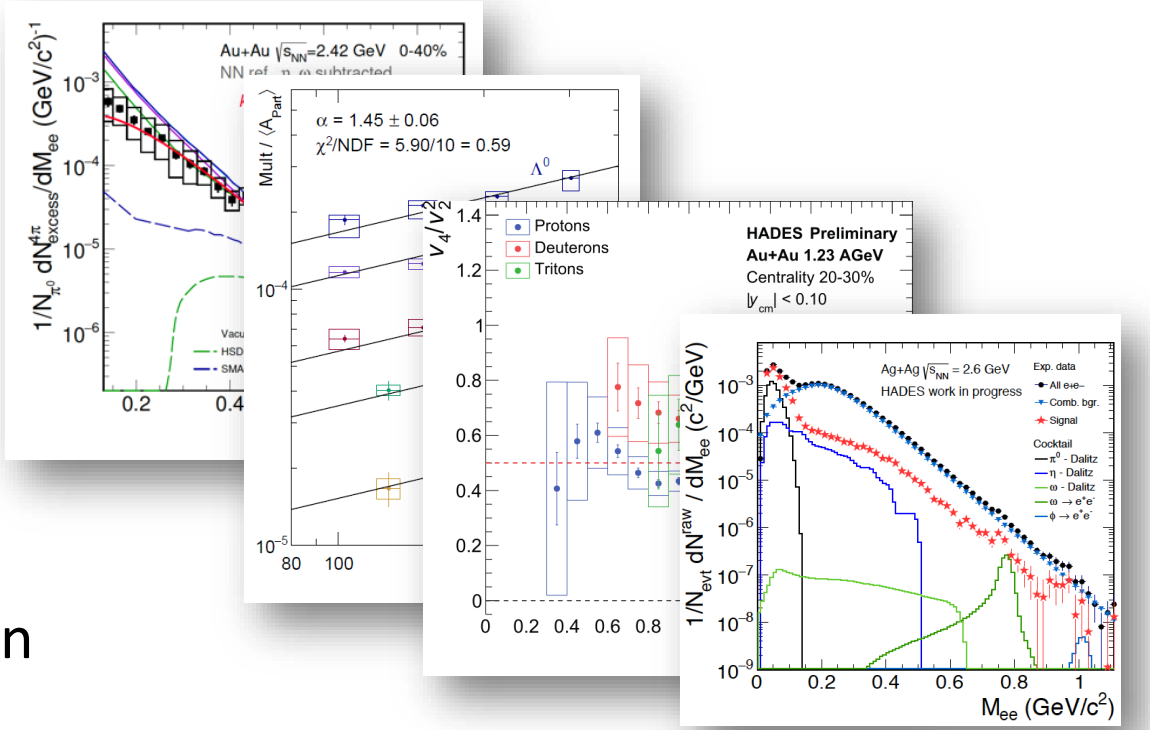

Backup