Correlated pion-proton pair emission off hot and dense QCD matter

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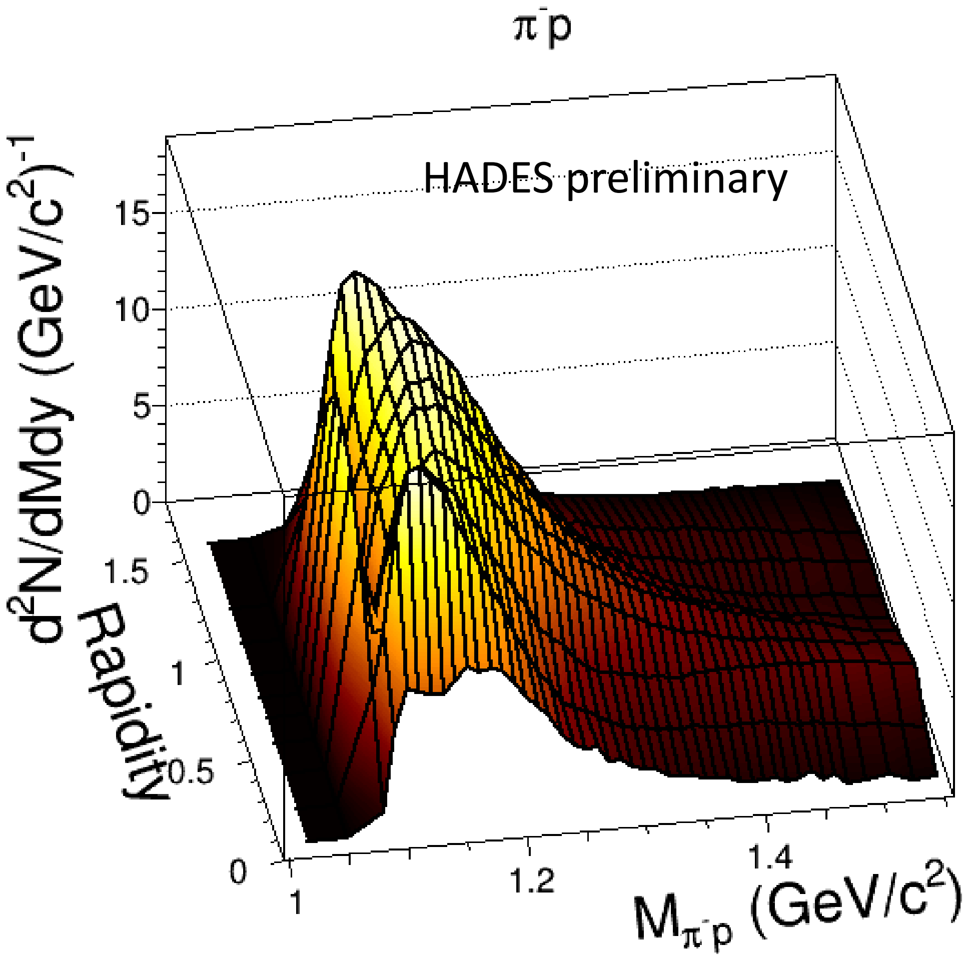
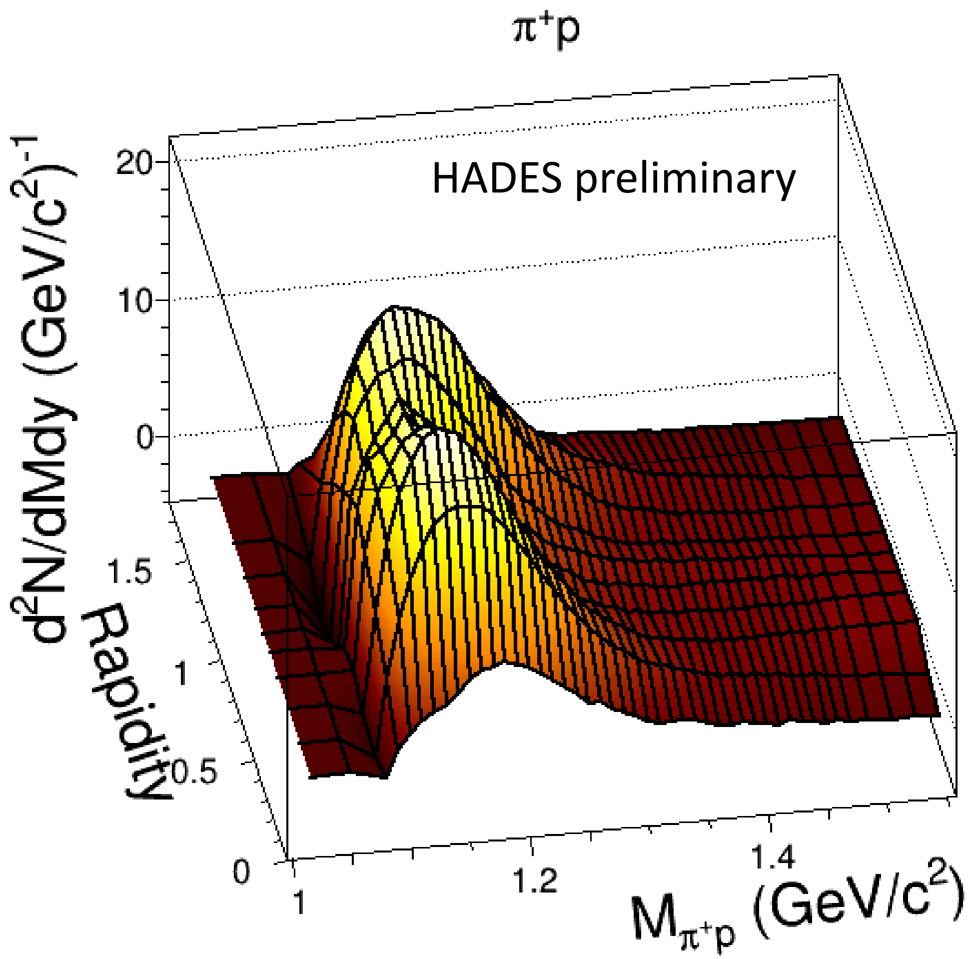
Correlated pion – proton pairs





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

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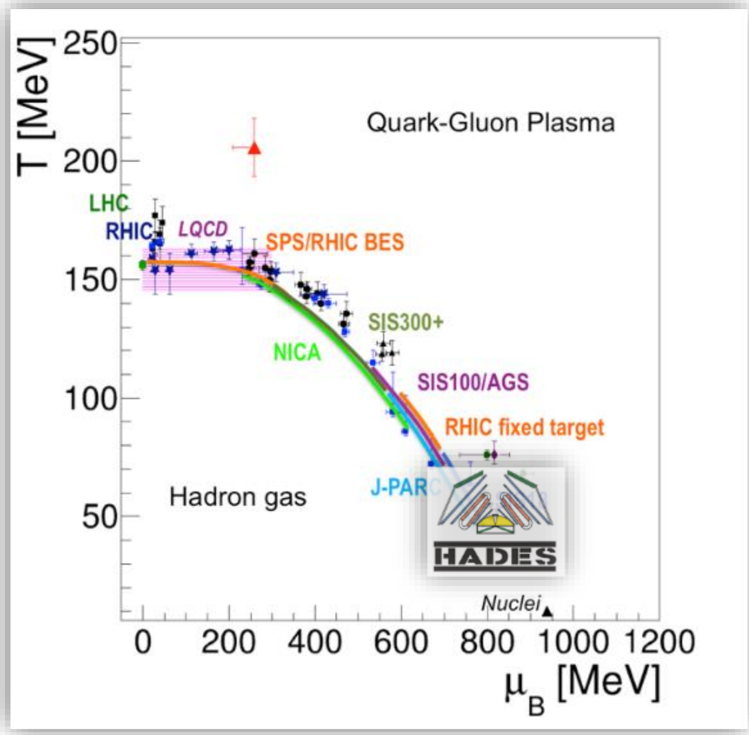
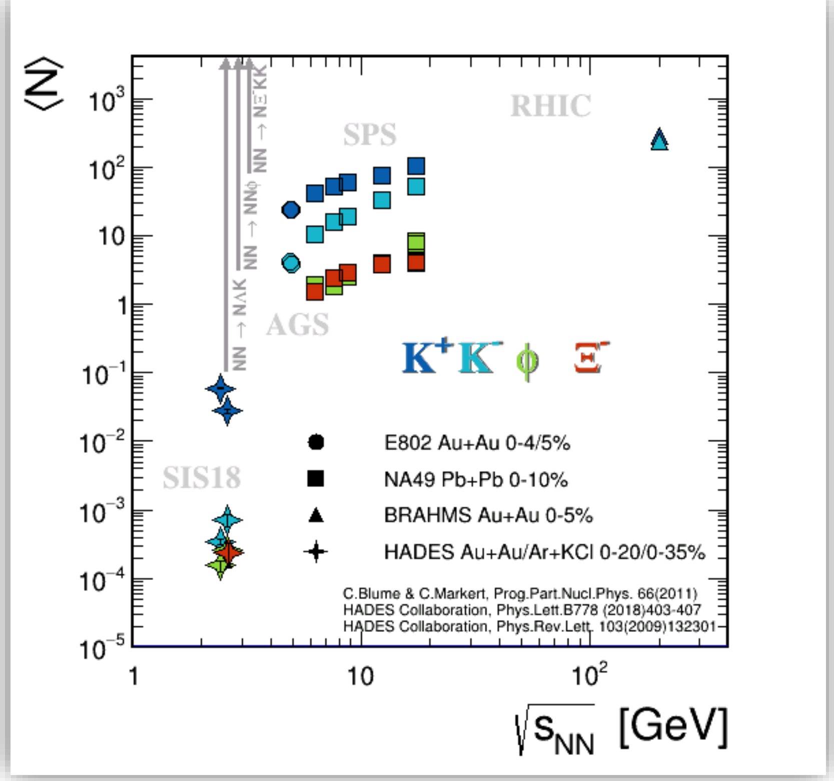
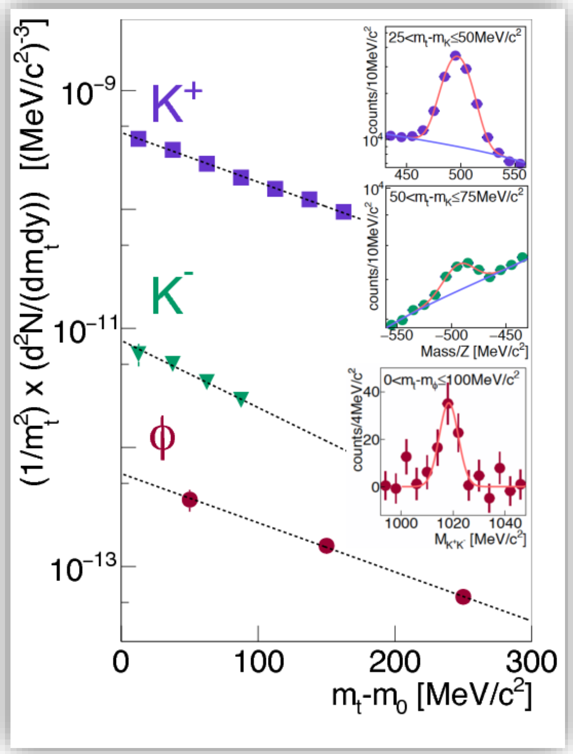
Elementary and heavy-ion beams $\sqrt{s}$ = 2.3-2.7 GeV at SIS18

- HADES explores baryon-rich matter
- Rare and penetrating probes
- Strangeness production below $\sqrt{s_{NN}}$ threshold

Rare probes:
$\phi \rightarrow 2\mathrm{x}10^{-4}$/Event in K^+K^-
~1 decay in 5000 events!







Phys.Lett. B778 (2018) 403-407

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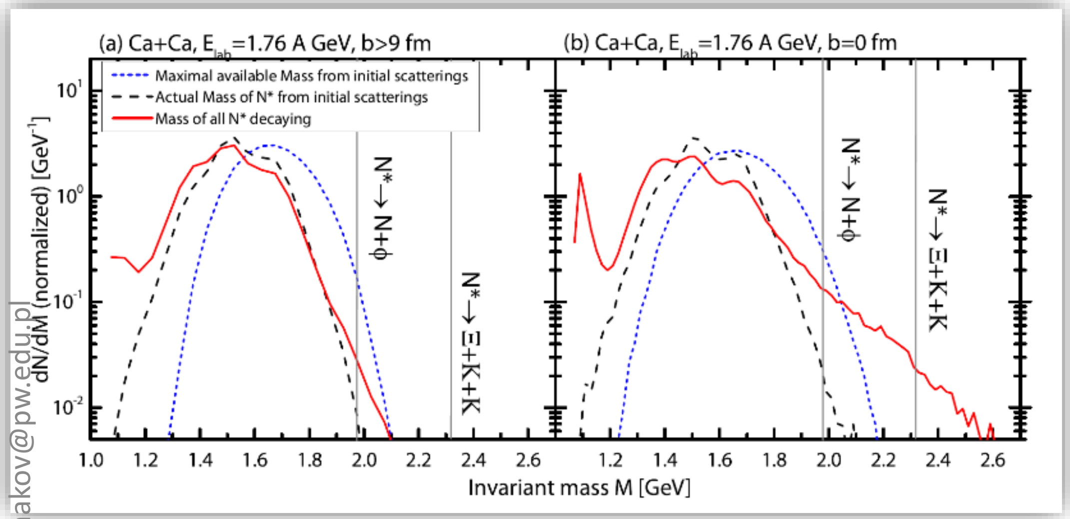
Models for strangeness production below NN threshold

- "Abundant" (multi)-strange particles demand an energy reservoir to be produced sub-threshold

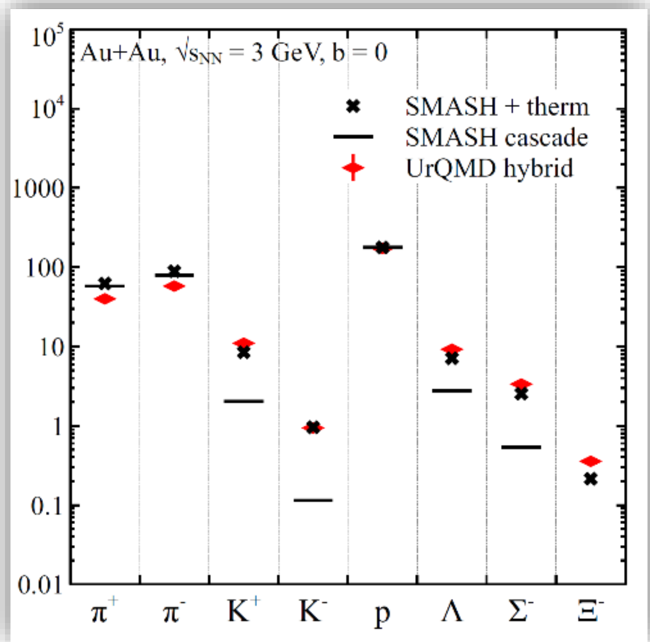
Different approaches:

➢ Decays



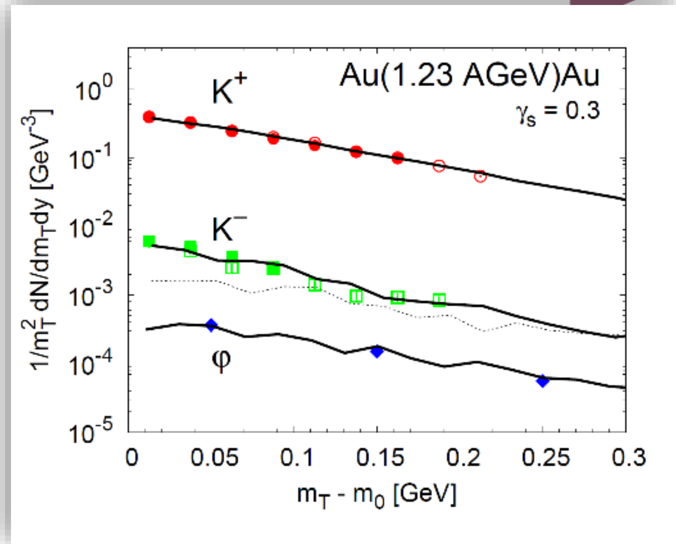
J. Steinheimer and M. Bleicher 2017
J. Phys. Conf. Ser. 779 012017

➢ Local forced thermalization



D. Oliinychenko and H. Petersen.
J.Phys. G44 (2017) no.3, 034001

➢ Hagedorn states



K. Gallmeister, M. Beitel, C. Greiner
arXiv:1712.04018 [hep-ph]

Baryon resonances play a key role!

Direct measurement needed

Casual list of models each one with its own recipe for resonances

Transport

JAM

GiBUU

UrQMD

PHSD

IQMD

SMASH

- **Thermal models**
- **S-matrix formulation & phase shifts**
- **Blast-wave models (including resonances)**
- **In medium spectral functions**
- **Hybrid models**
- **…**
- **…**
- **…**

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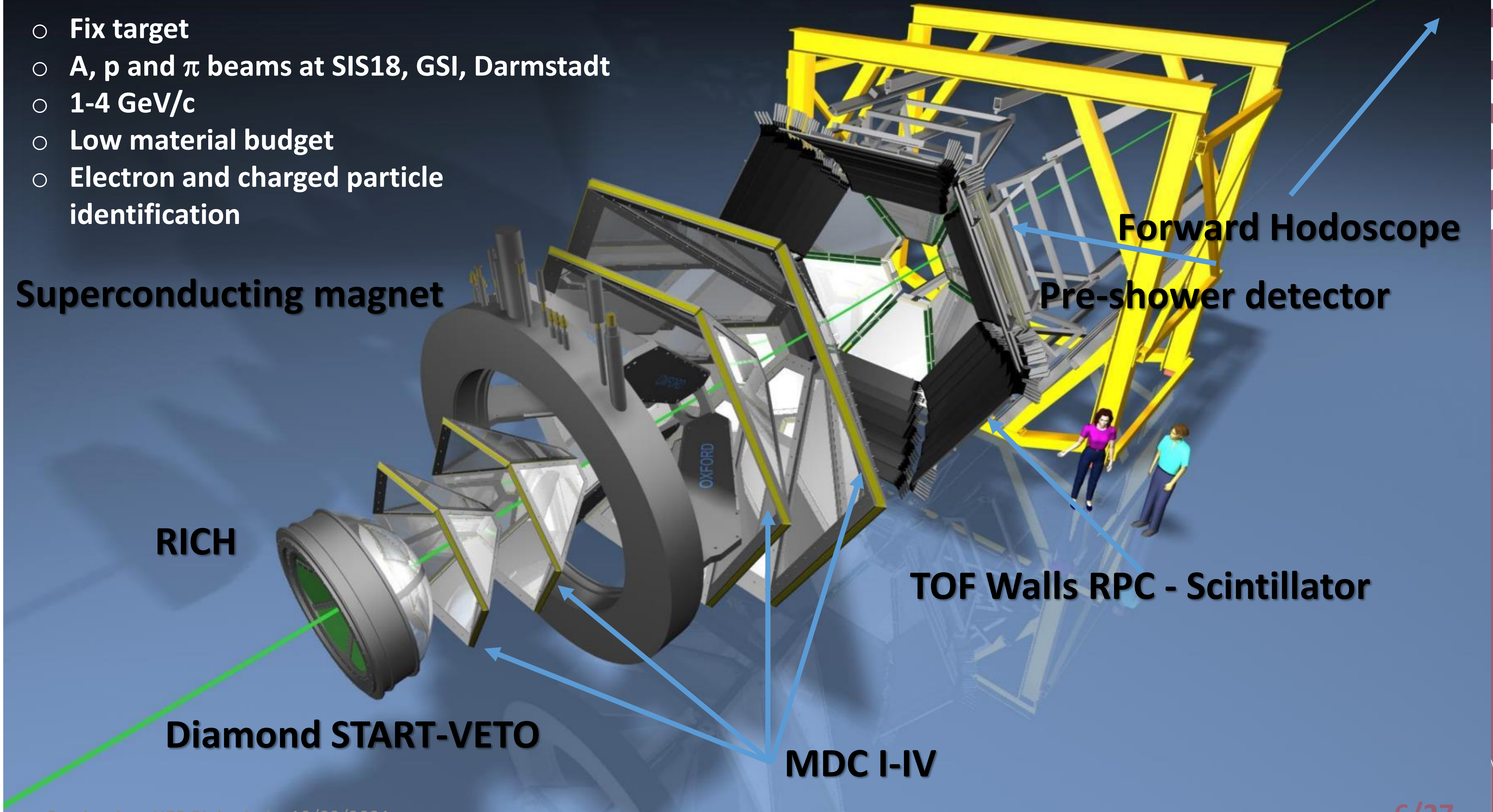
High Acceptance Di-Electron Spectrometer

- Fix target
- A, p and π beams at SIS18, GSI, Darmstadt
- 1-4 GeV/c
- Low material budget
- Electron and charged particle identification



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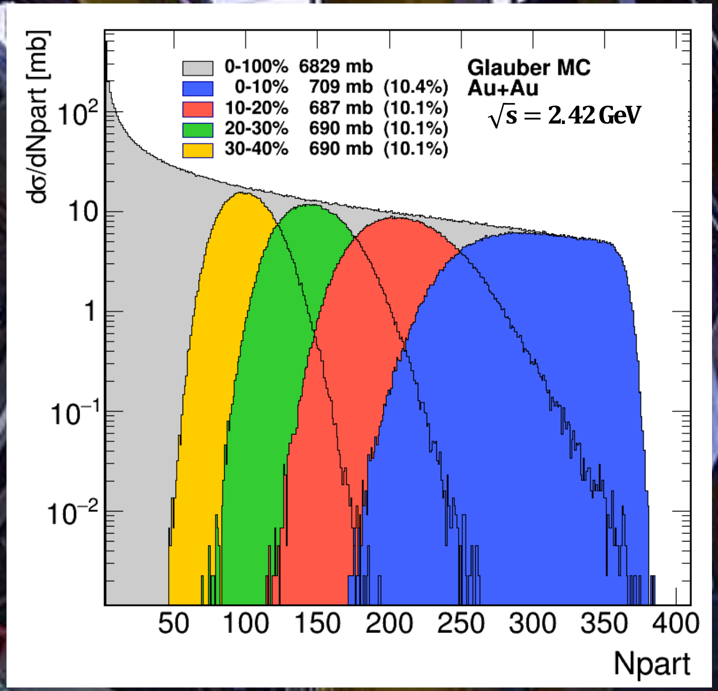
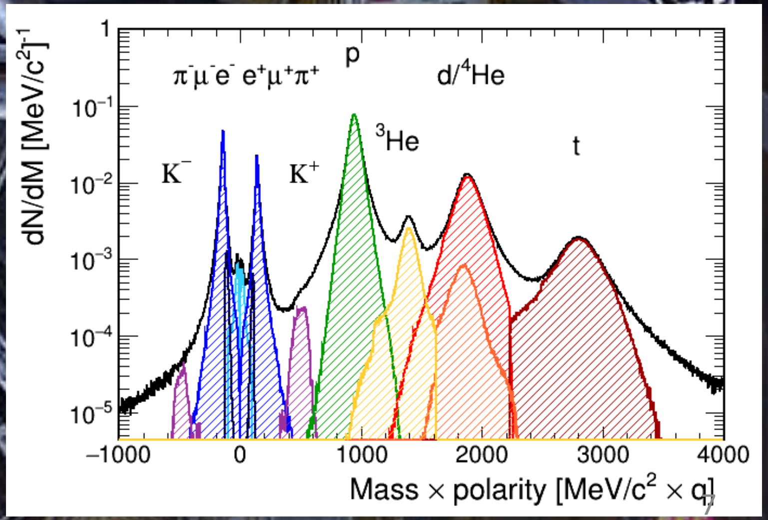
HADES Au+Au $\sqrt{s}$=2.42 GeV

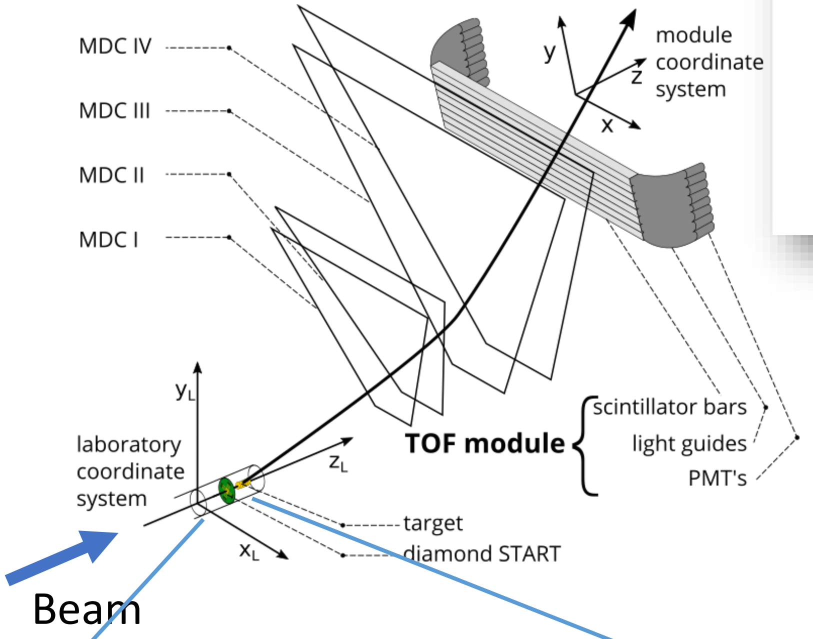
- **Full azimuthal coverage**, 18-85° polar angle
- **Fast detector**: 1.5 x 10^6 Au ions/s (8 kHz)
  - 7×10^9 events recorded
- Off-line centrality selection:
  - Hit/track multiplicity
  - Forward Wall
- **High purity** hadron detectors:
  - MDC: momentum ($\Delta P/P<2\%$) and dE/dx
  - TOF (Diamond T_0, RPC and Scintillator Walls)

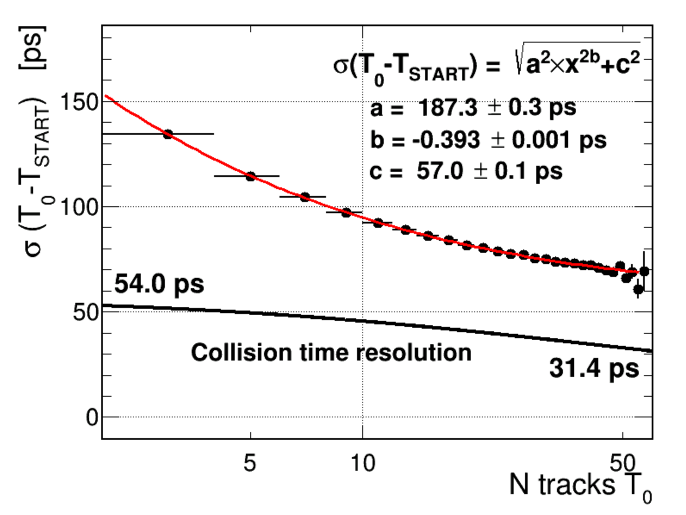


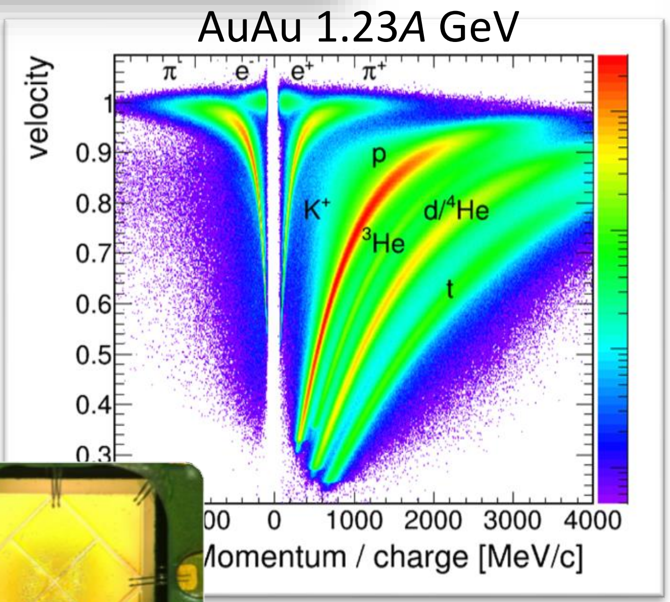
[HADES Collaboration]
arXiv:1712.07993 [nucl-ex]

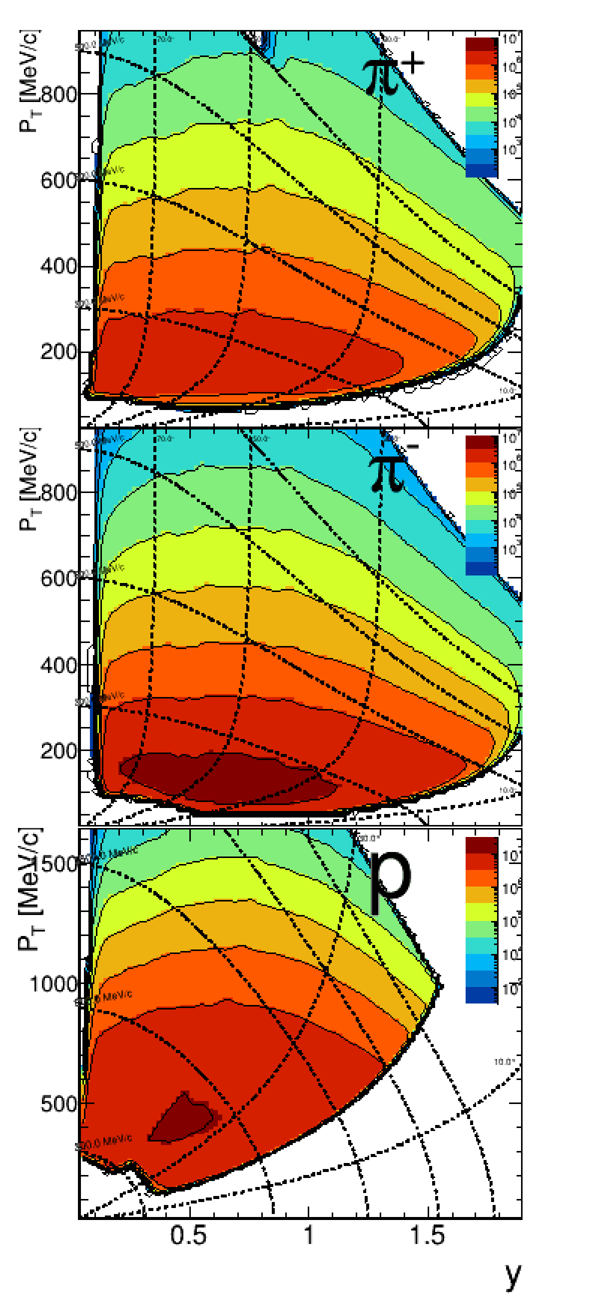


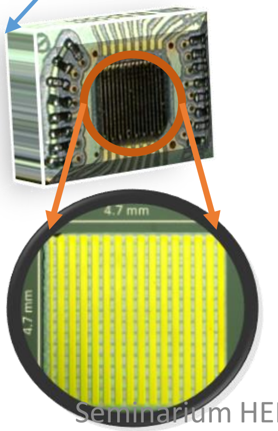
Particle identification

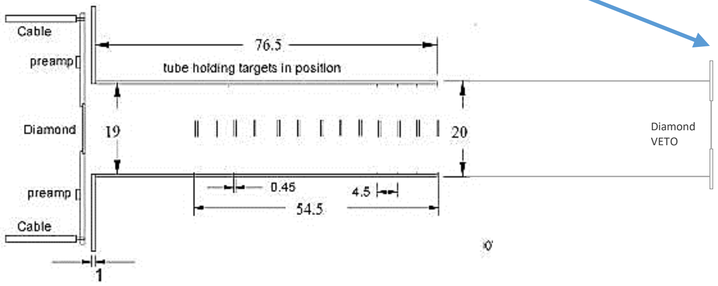












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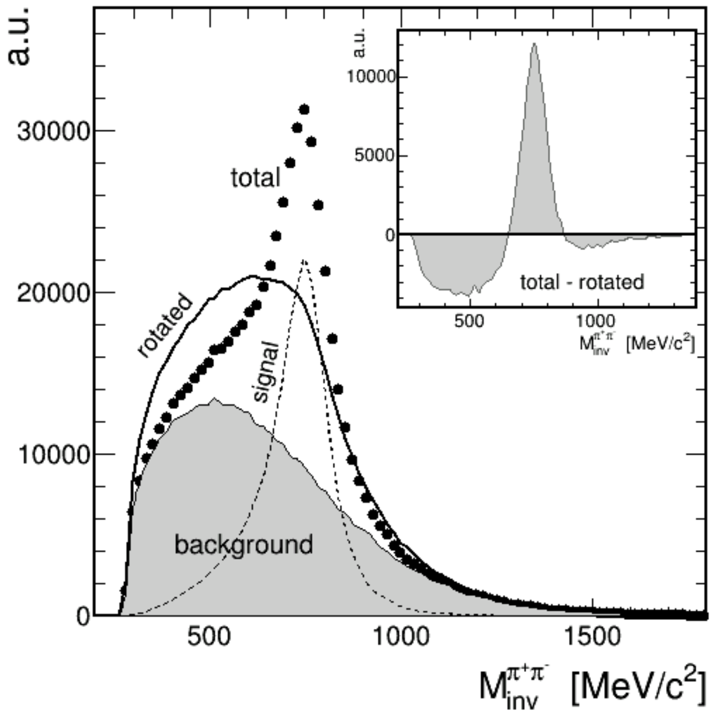
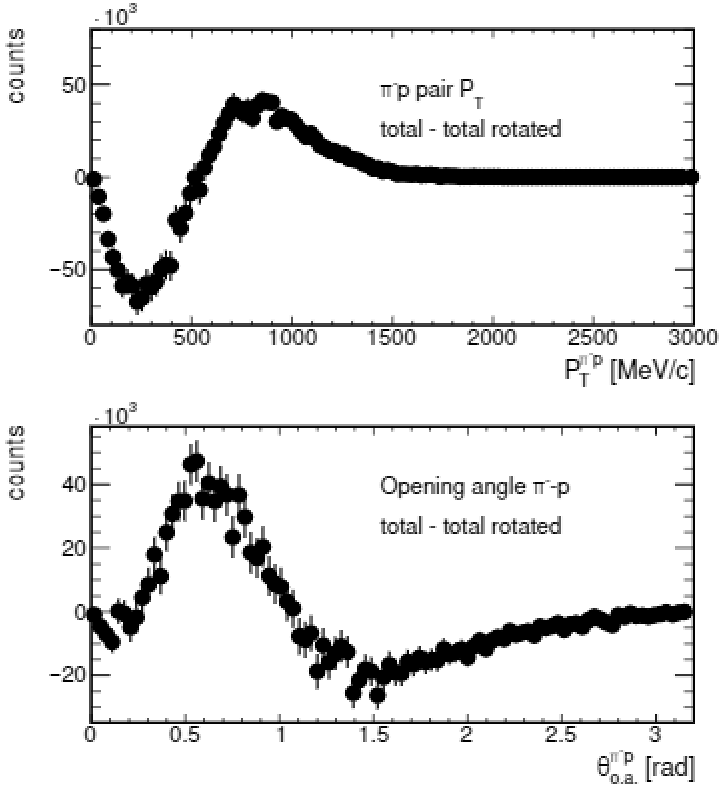
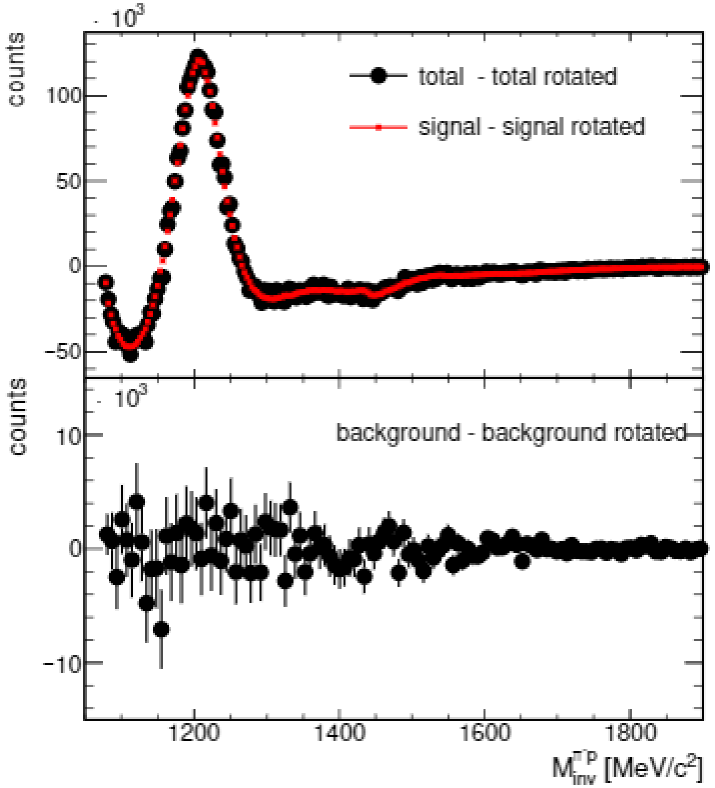
The iterative method for BG identification

GK, T. Galatyuk, Eur.Phys.J.A 55 (2019) 11, 204 arXiv [1808.05466](https://arxiv.org/abs/1808.05466) [physics.data-an]







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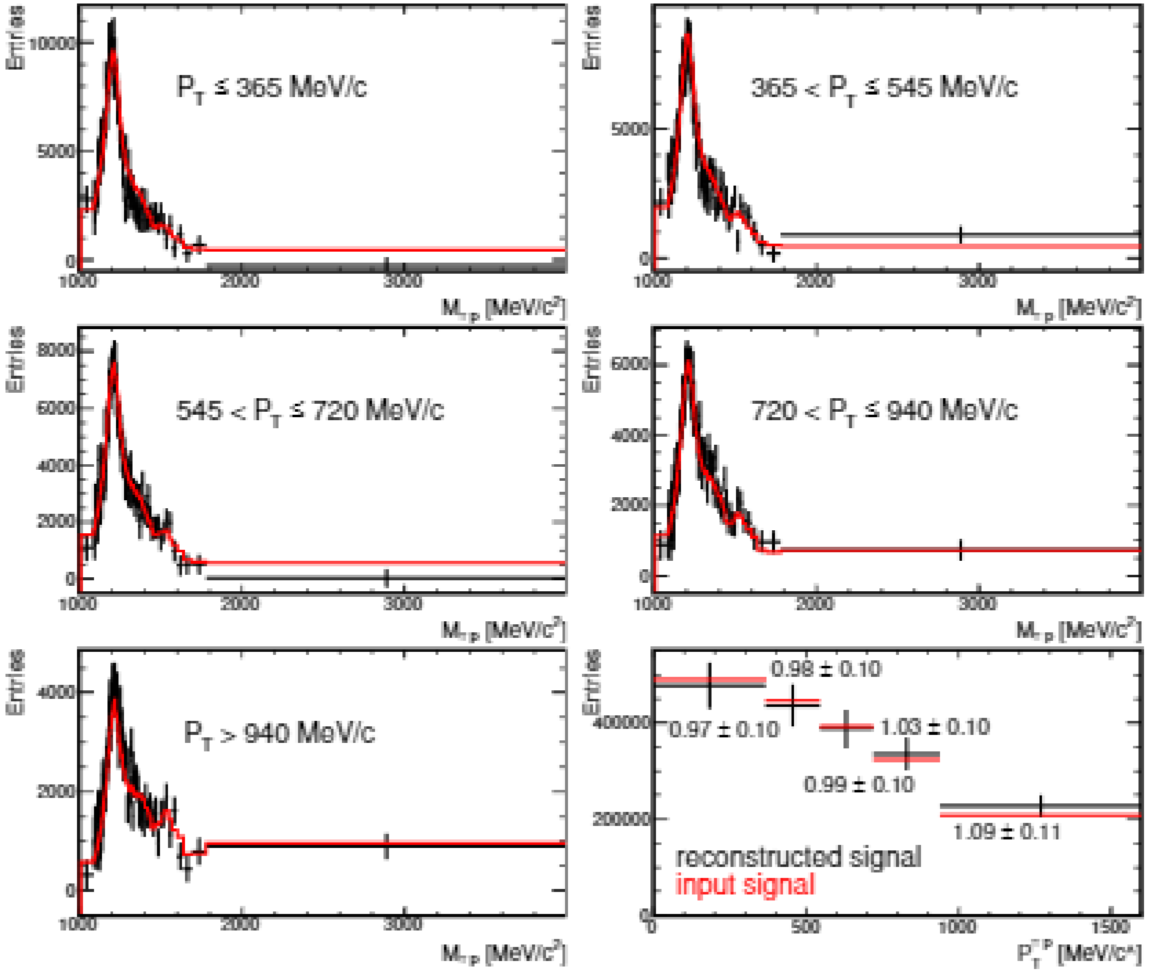
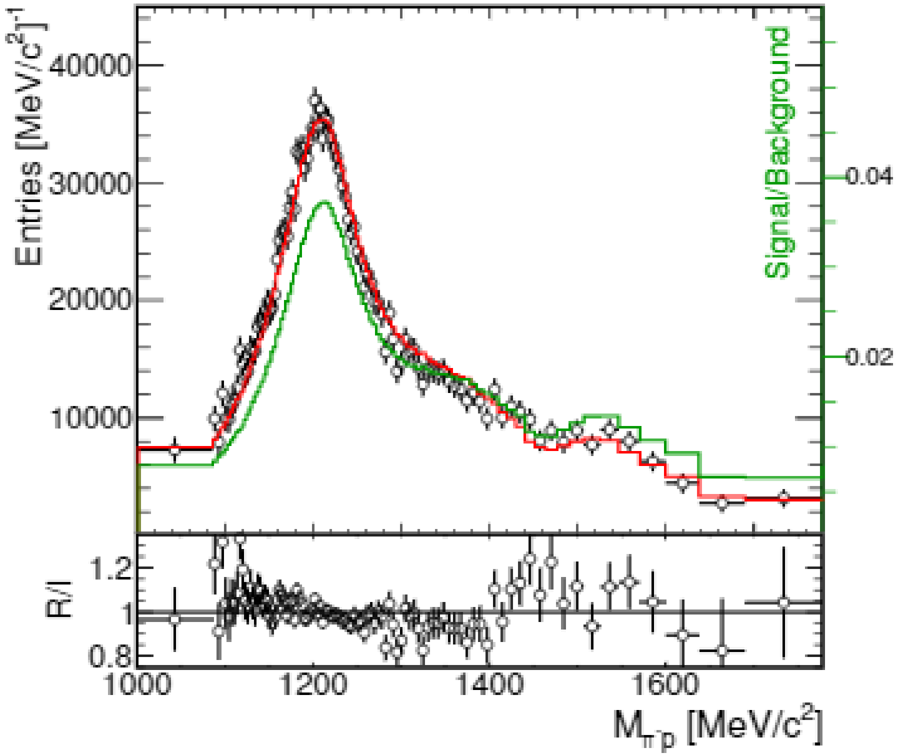
Test of the iterative procedure on simulated data (*PLUTO)





* I. Frohlich et al. arXiv:0708.2382 [nucl-ex]

	N/Nprot	Channels	Γ/Γ_i
$\Delta(1232)^0$	5 %	π^-p	1
$N(1440)^0$	2 %	π^-p, pρ^-,$\Delta^+\pi^-$	0.62/0.02/0.36
$N(1535)^0$	1.5 %	π^-p, pρ^-,$\Delta^+\pi^-$	0.70/0.06/0.23
$\Delta(1620)^0$	1 %	π^-p, pρ^-,$\Delta^+\pi^-$	0.18/0.12/0.70
$\Delta(1920)^0$	0.5 %	π^-p, pρ^-,$\Delta^+\pi^-$	0.7/0.2/0.1
p	20		
π^-	10 %		

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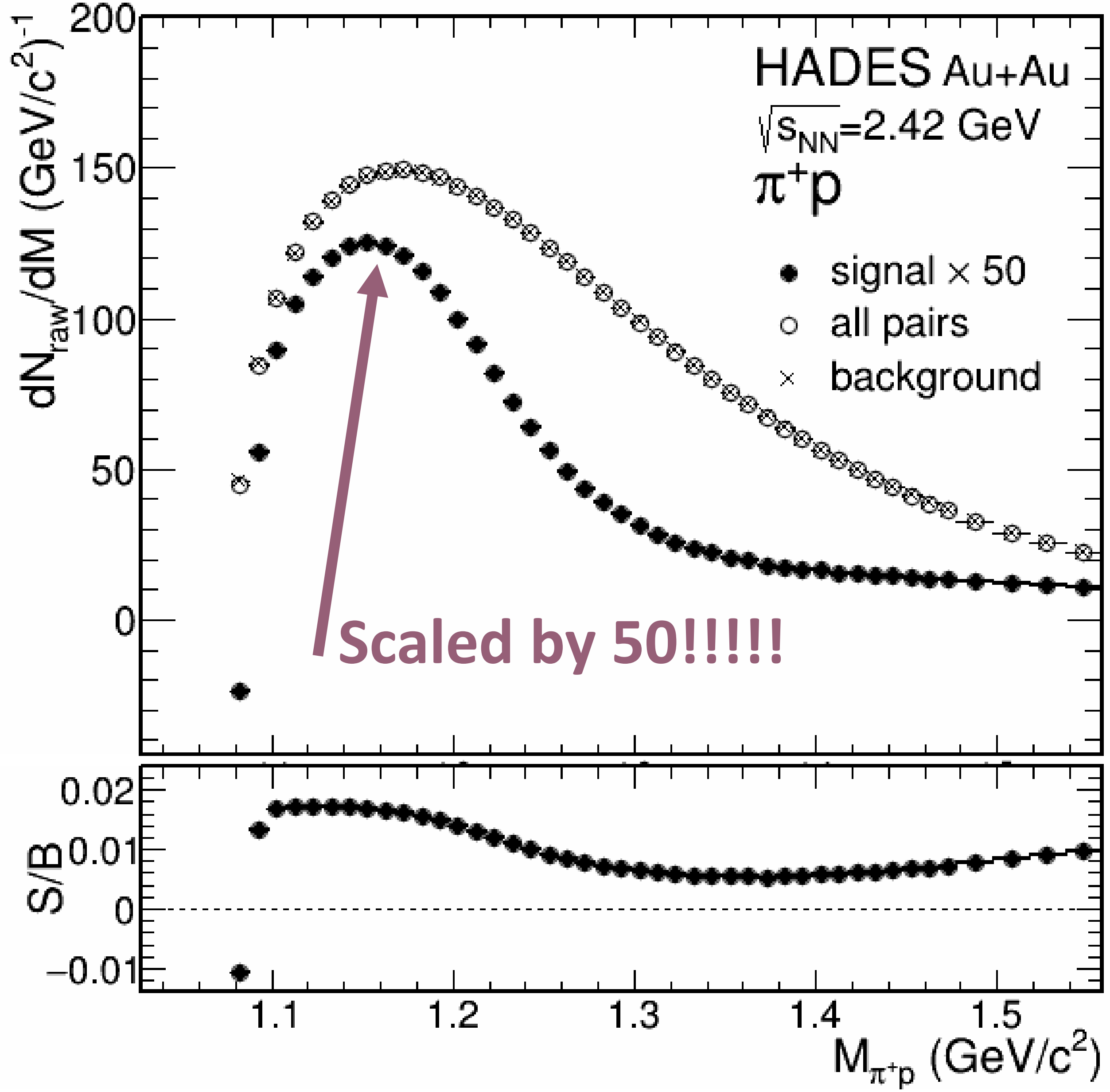
Extraction of the signal



The signal is obtained as a function of $M_{inv} - p_T - y$

←Raw signal integrated and projected to the invariant mass plane

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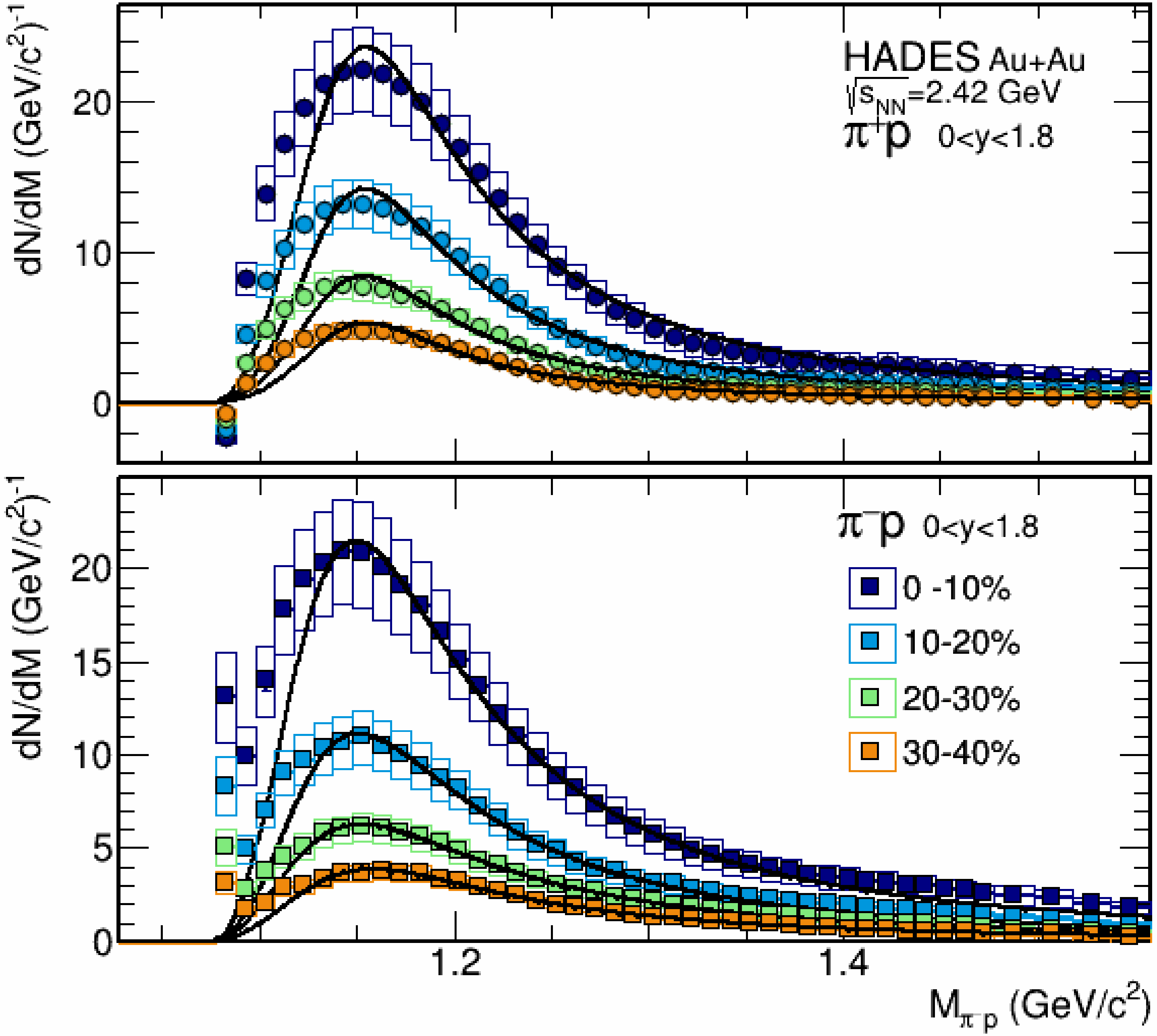
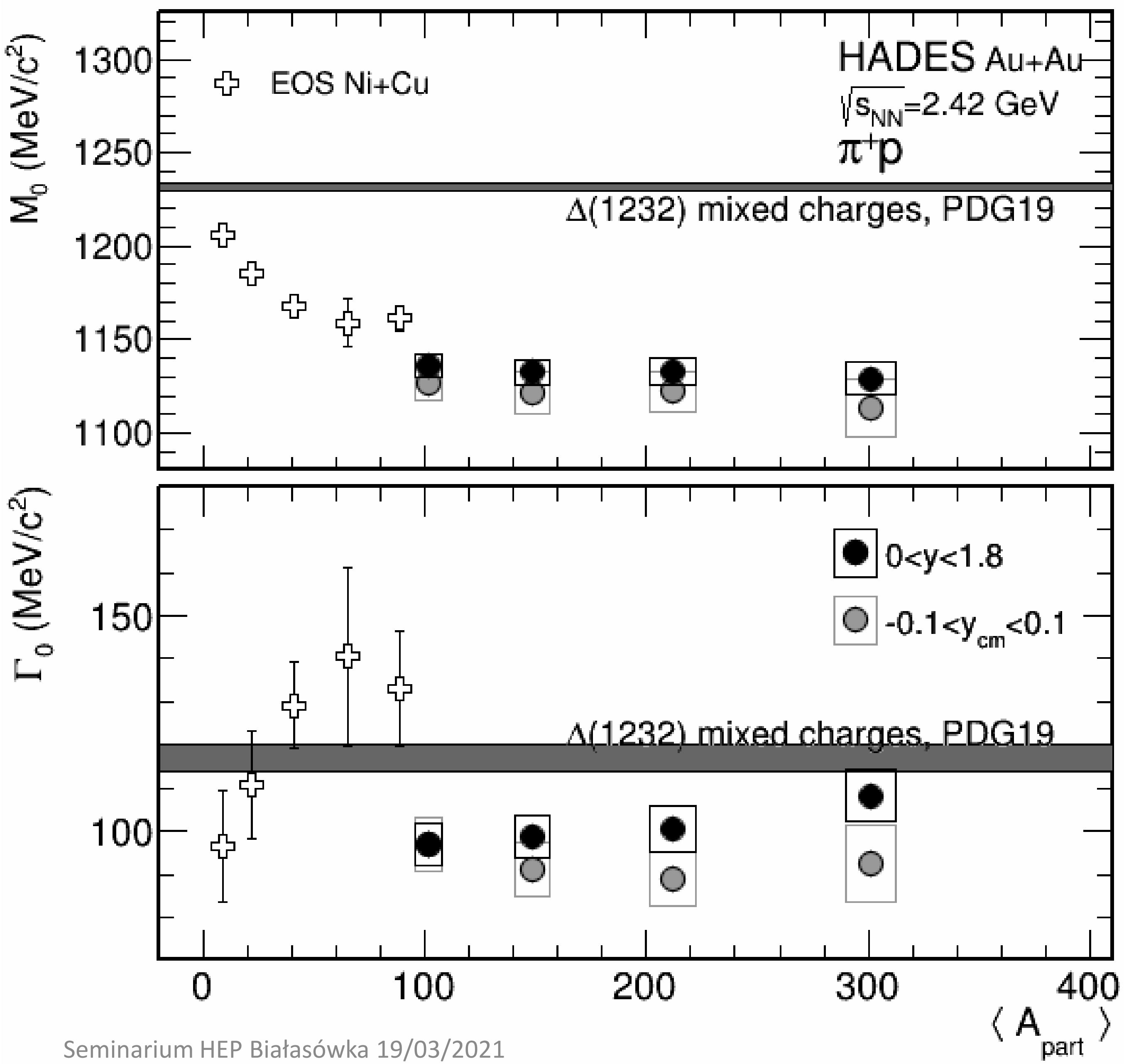
Invariant mass distributions

- ✓ Corrected for acceptance and efficiency
- ✓ No Λ peak due to broad mass binning and subthreshold production



BW M_0 and Γ and comparison to other experiments



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

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

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

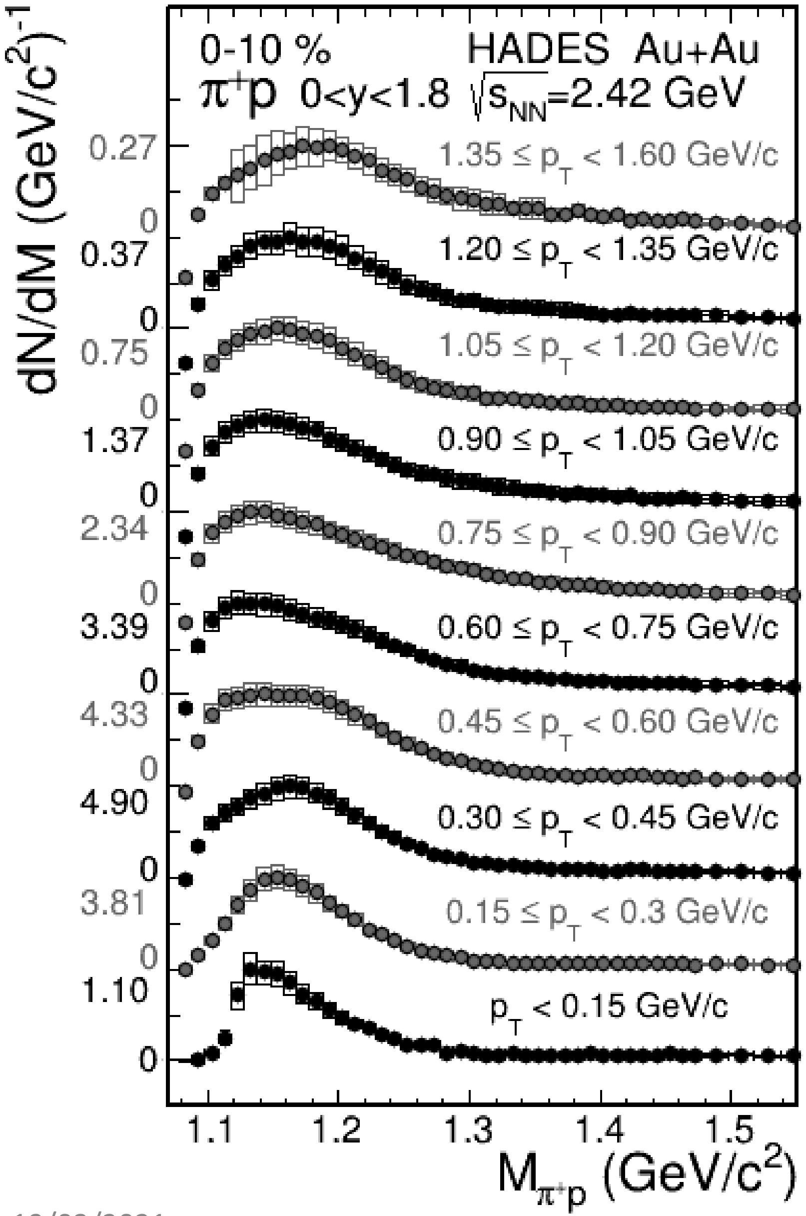
DIOGENE (p+C, p+Nb, p+Pb)
Reduction of M_0 10-60 MeV/c^2

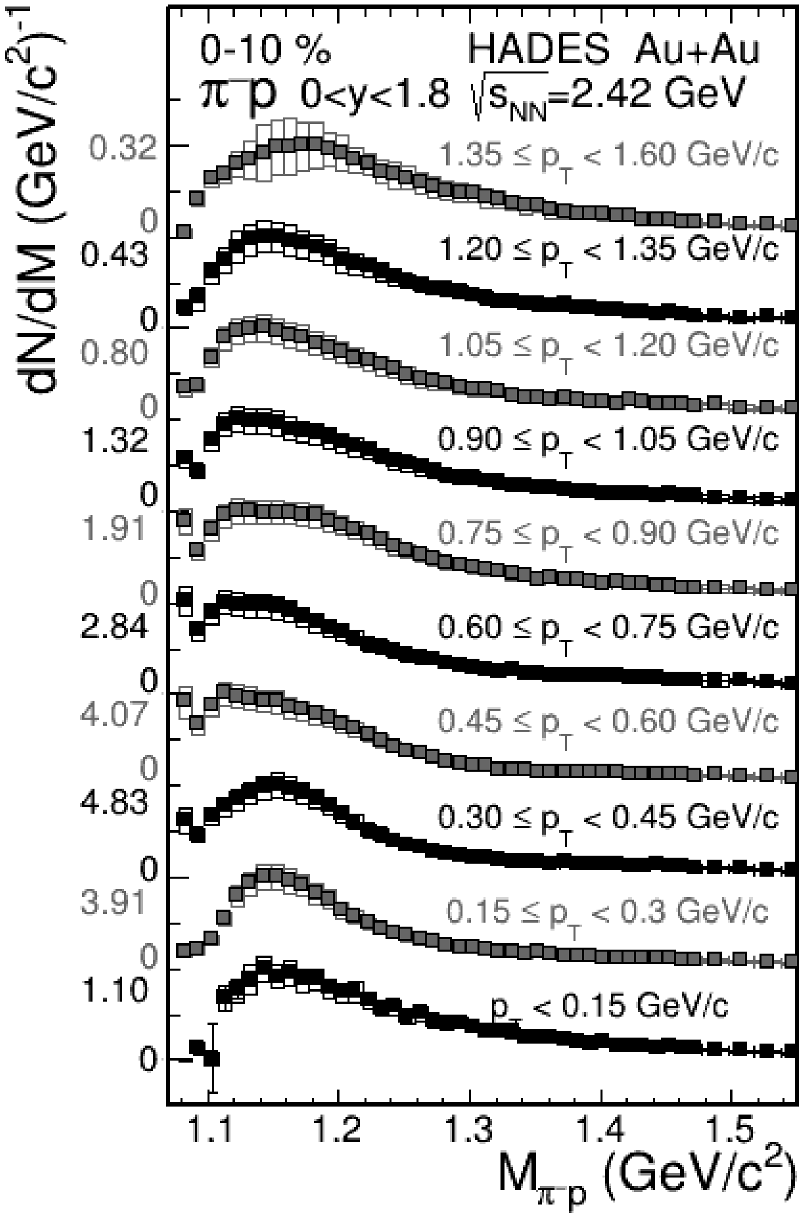
[DIEOGENE] Z. Phys. A ***340****, 325-331 (1991), M. Trzaska ,et al.*

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

0-10 %

10 p_T intervals
150 MeV/c bin width





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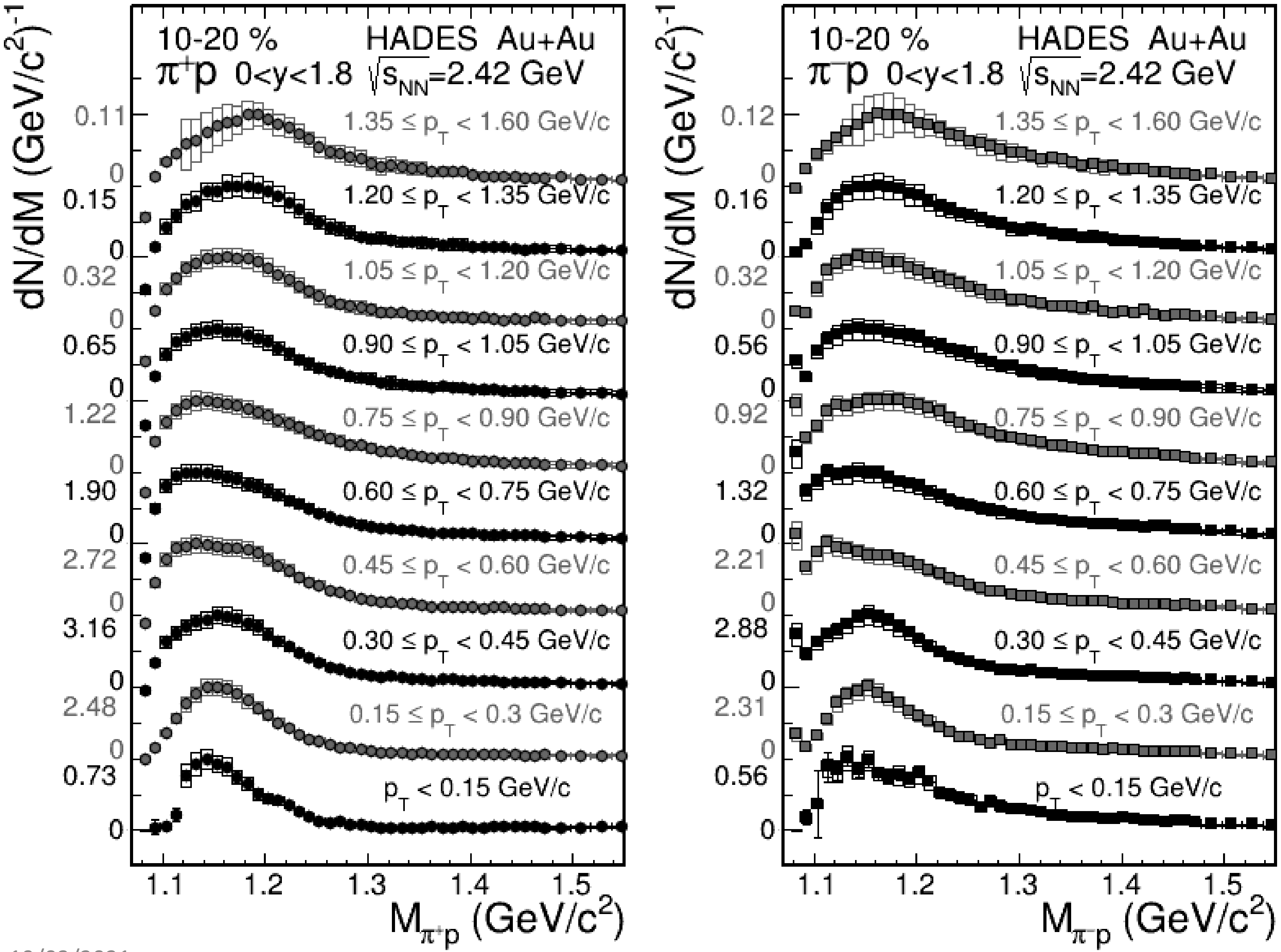
10-20 %



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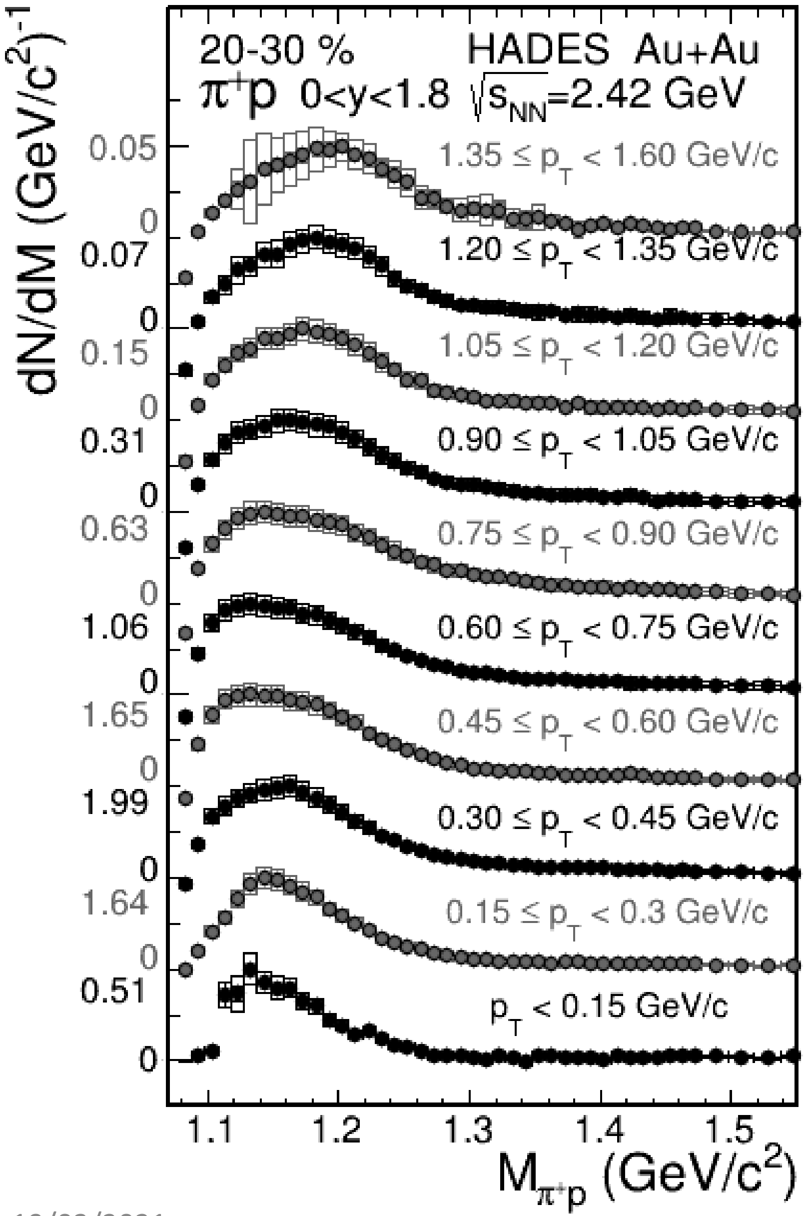
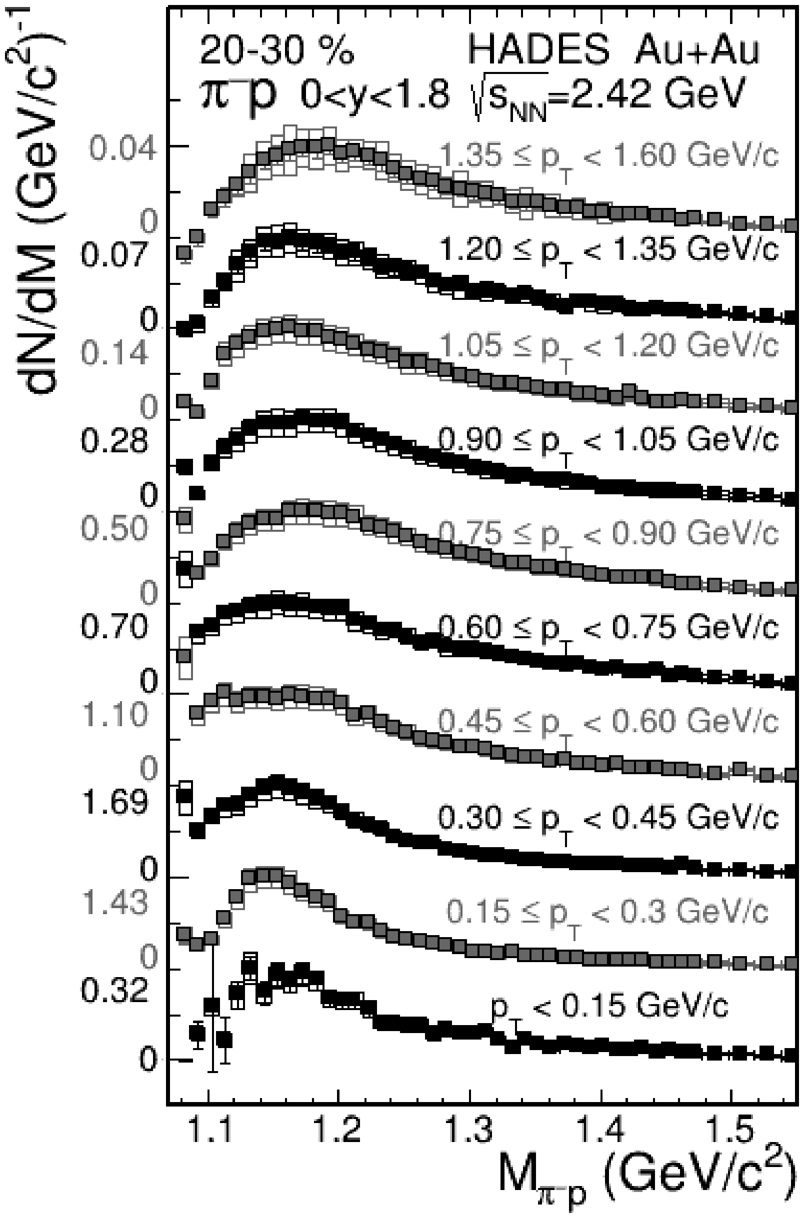
20-30 %





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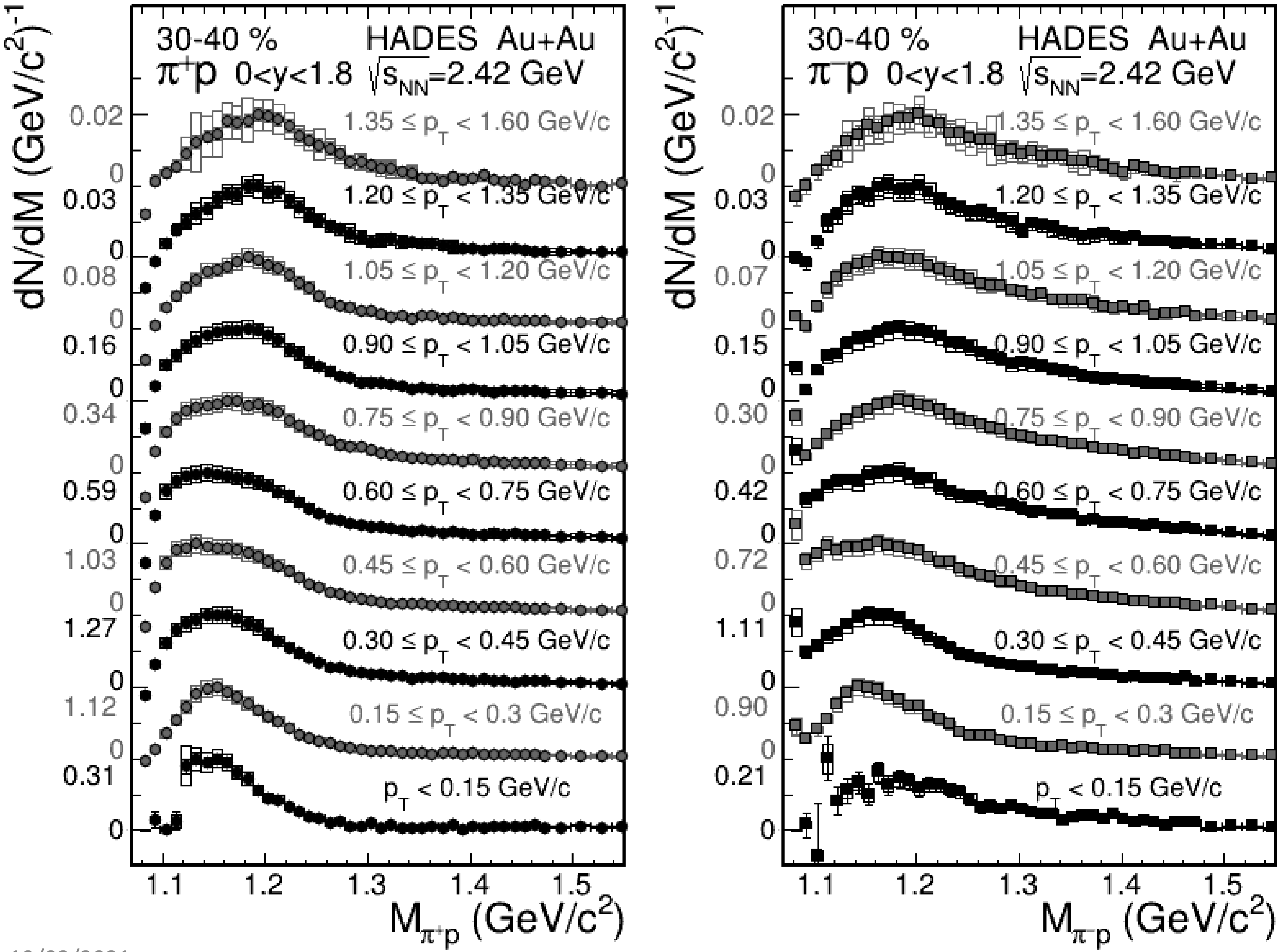
30-40 %



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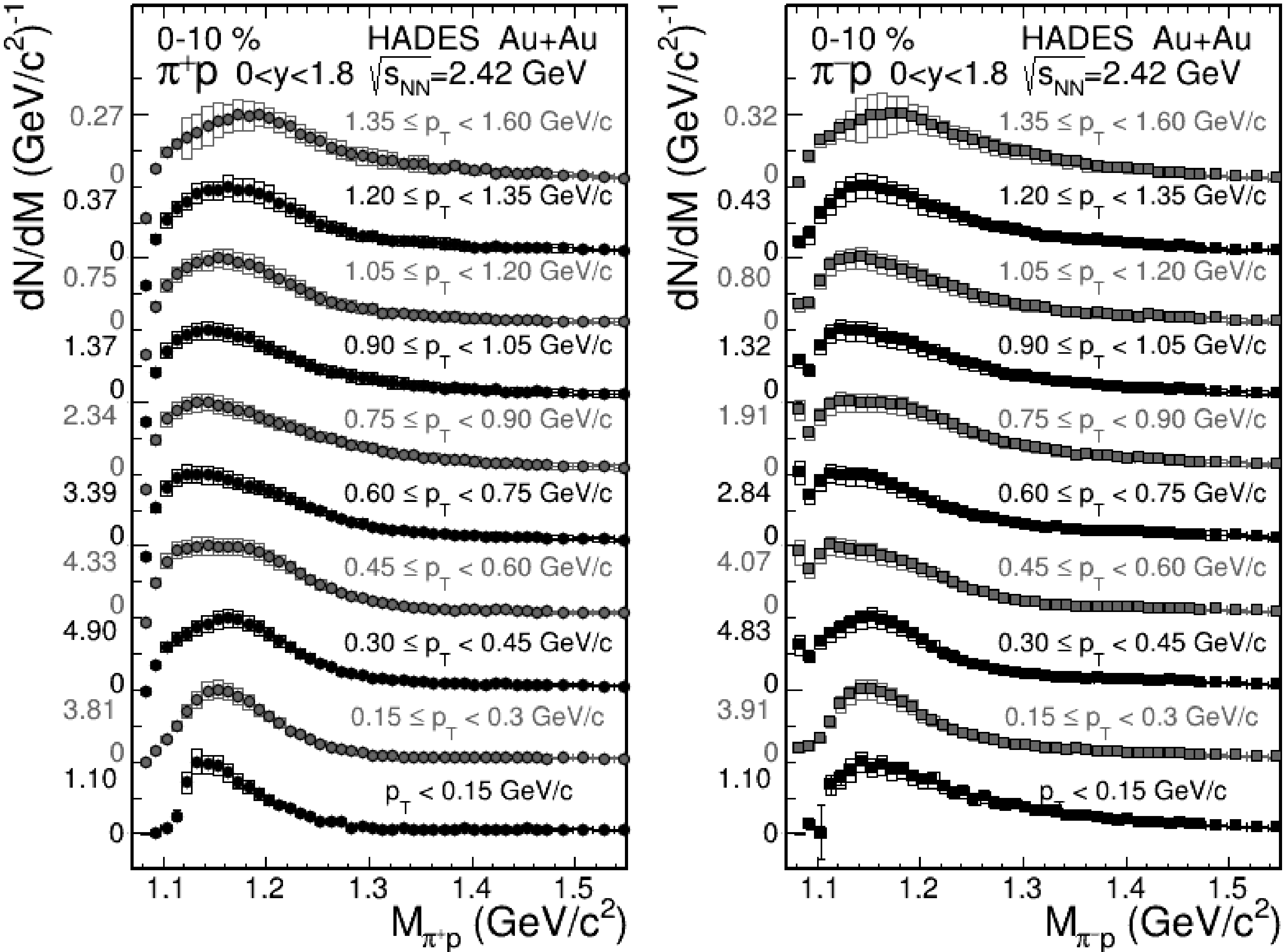
0-10 %



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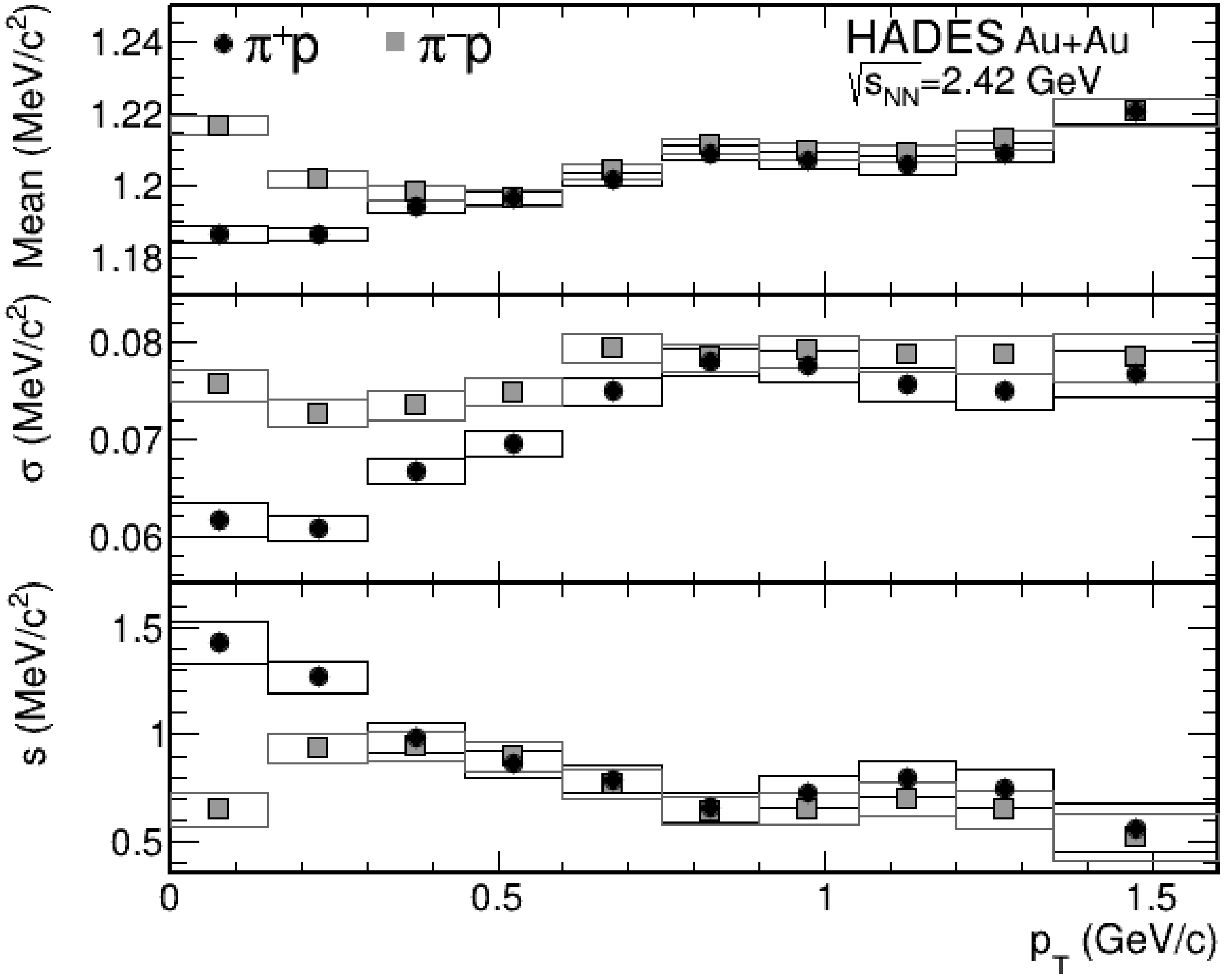
Moments

Vacuum expectation from pp collisions at same energy:
<M> = 1.24 GeV/c^2
$\sigma = 0.057$ GeV/c^2
$s = 0.5$



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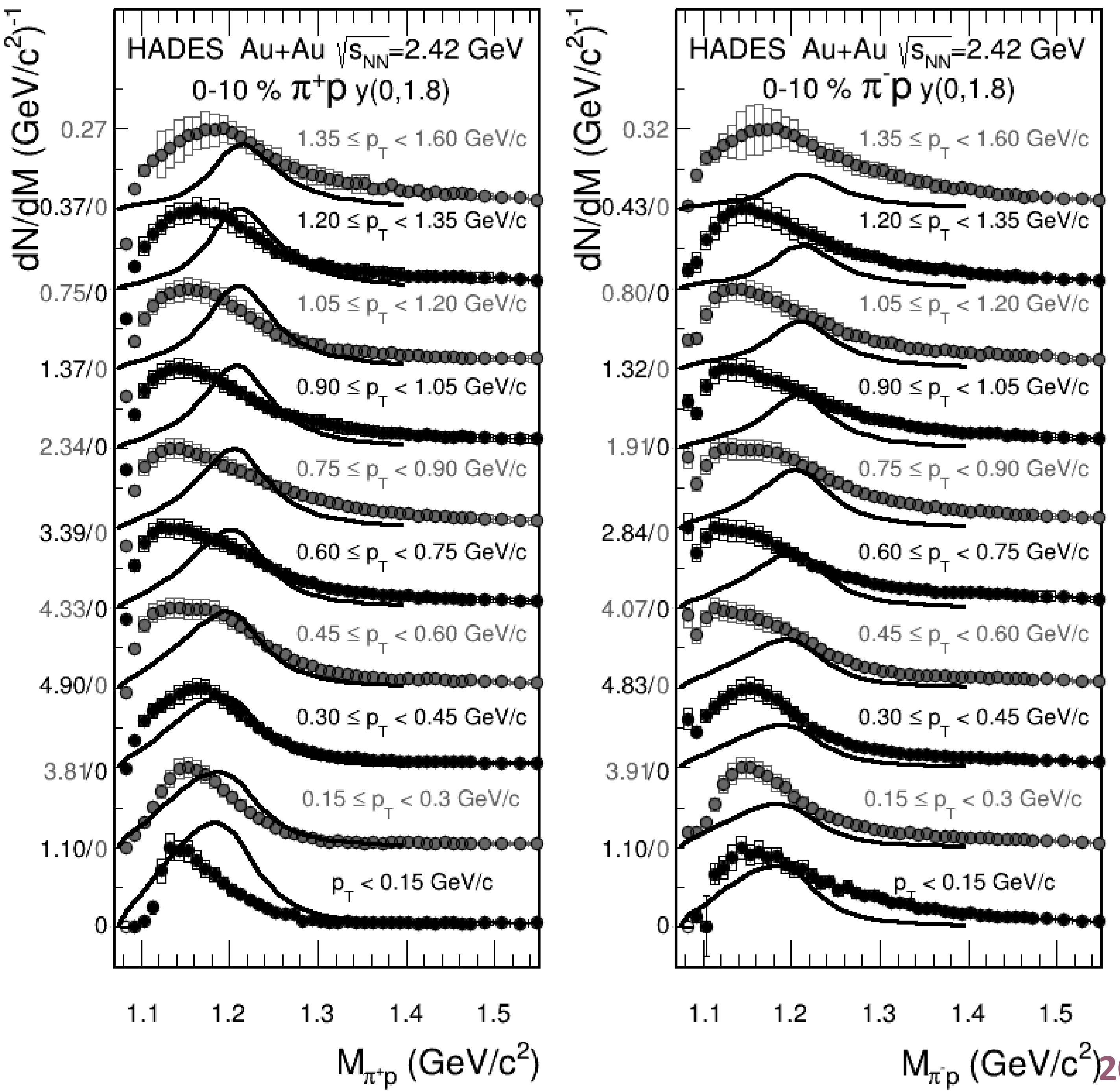
UrQMD?

Not the latest code version!!!



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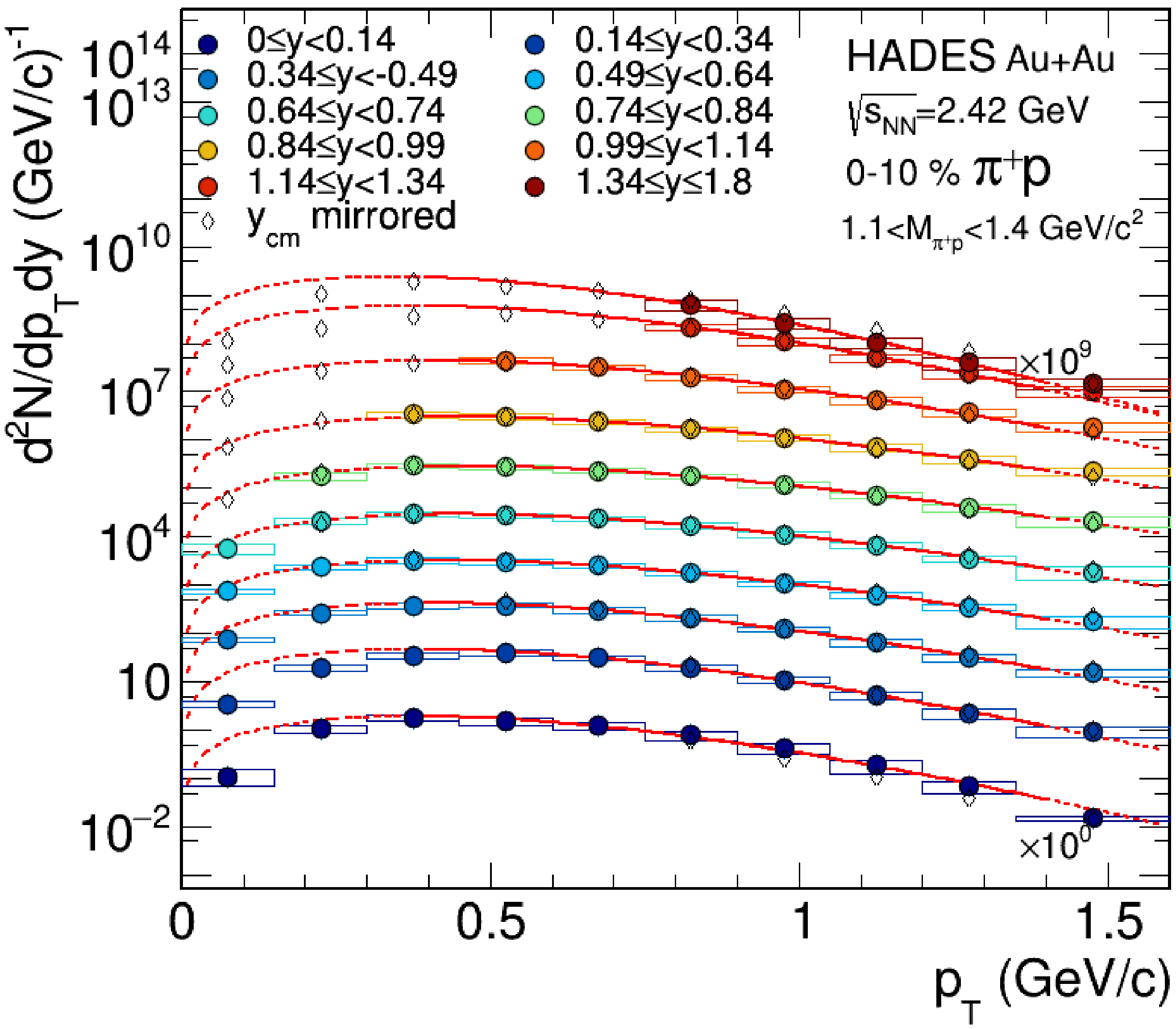
Pt-differential 0-10 %

Good agreement with reflected rapidities (diamonds)

$$\frac{1}{p_T}\frac{dN}{dp_T} \propto m_T K_1\left(\frac{m_T}{T_{eff}}\right)$$



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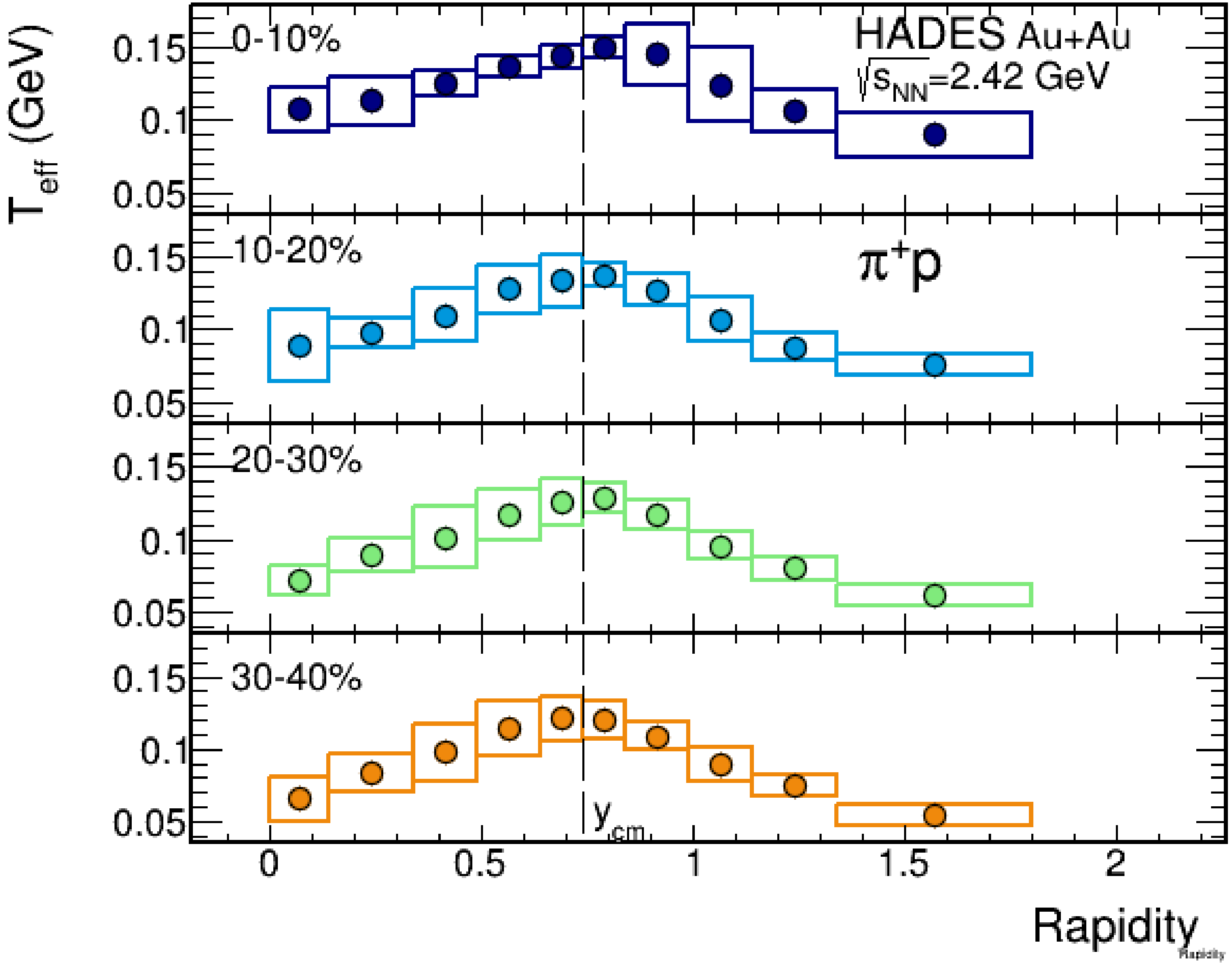
Effective T

Assuming a common expansion velocity of β=0.3
T_{fo} = 50 MeV

→ **Dilepton inv. Mass slope 71.8 +- 2.1 MeV**
Nature Physics, 15, 2019 1040-1045



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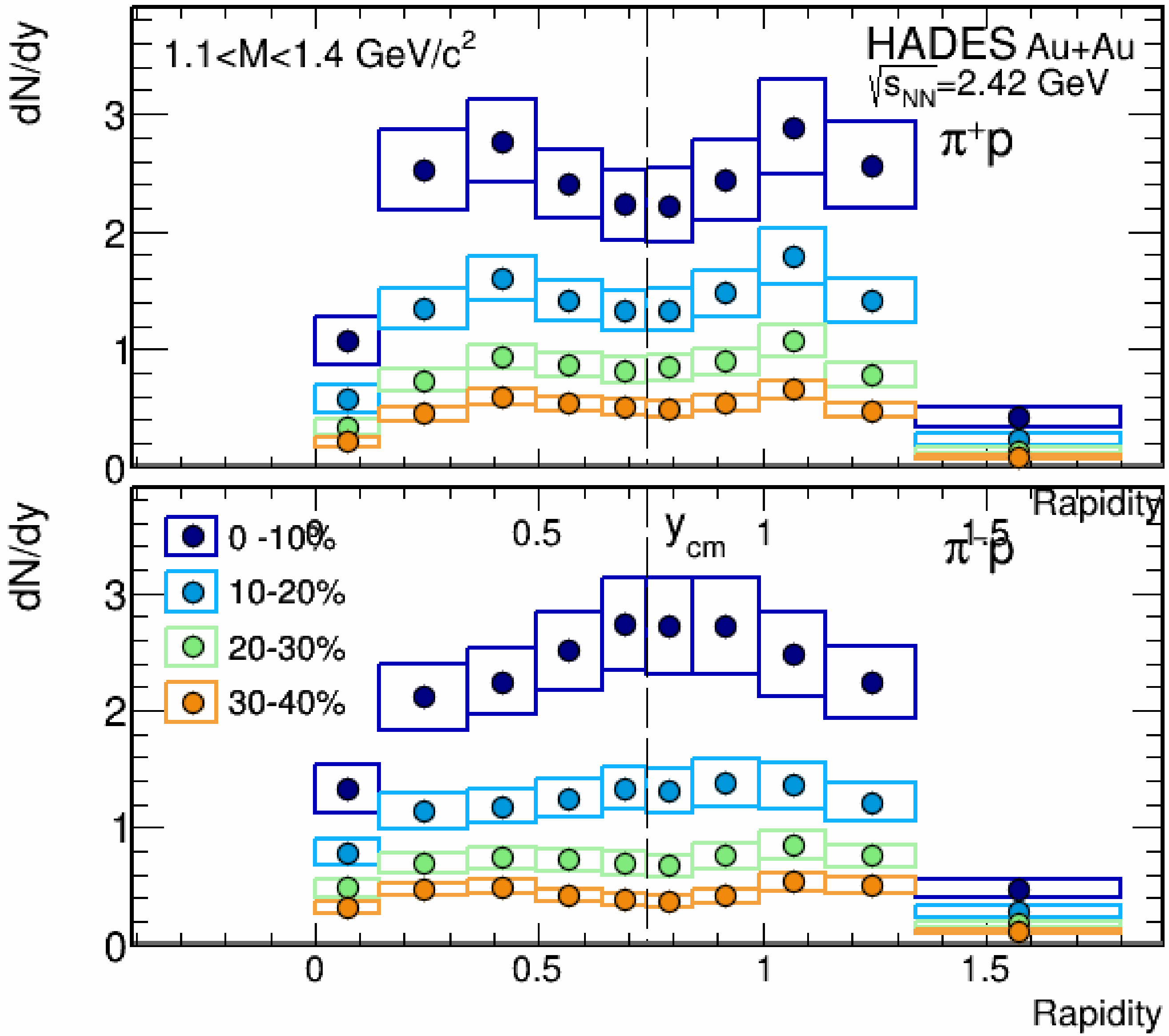
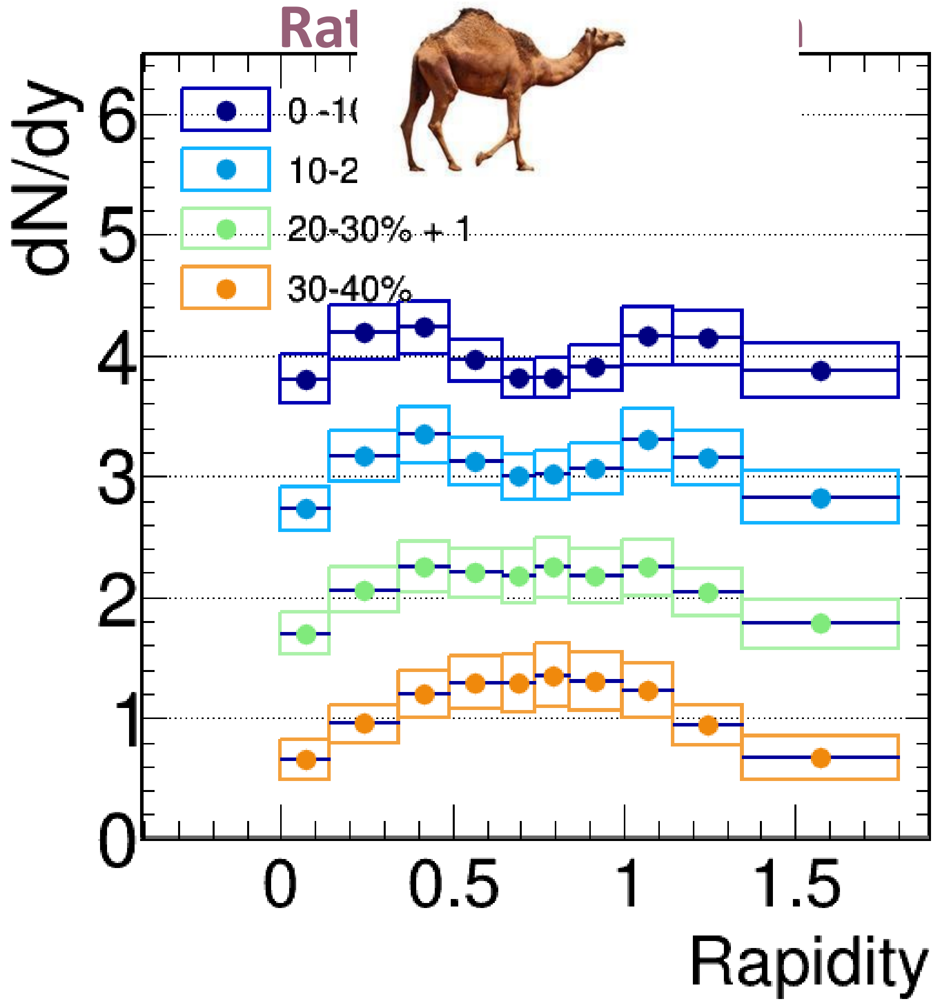
Structures in the rapidity spectra?

Cam



Rat



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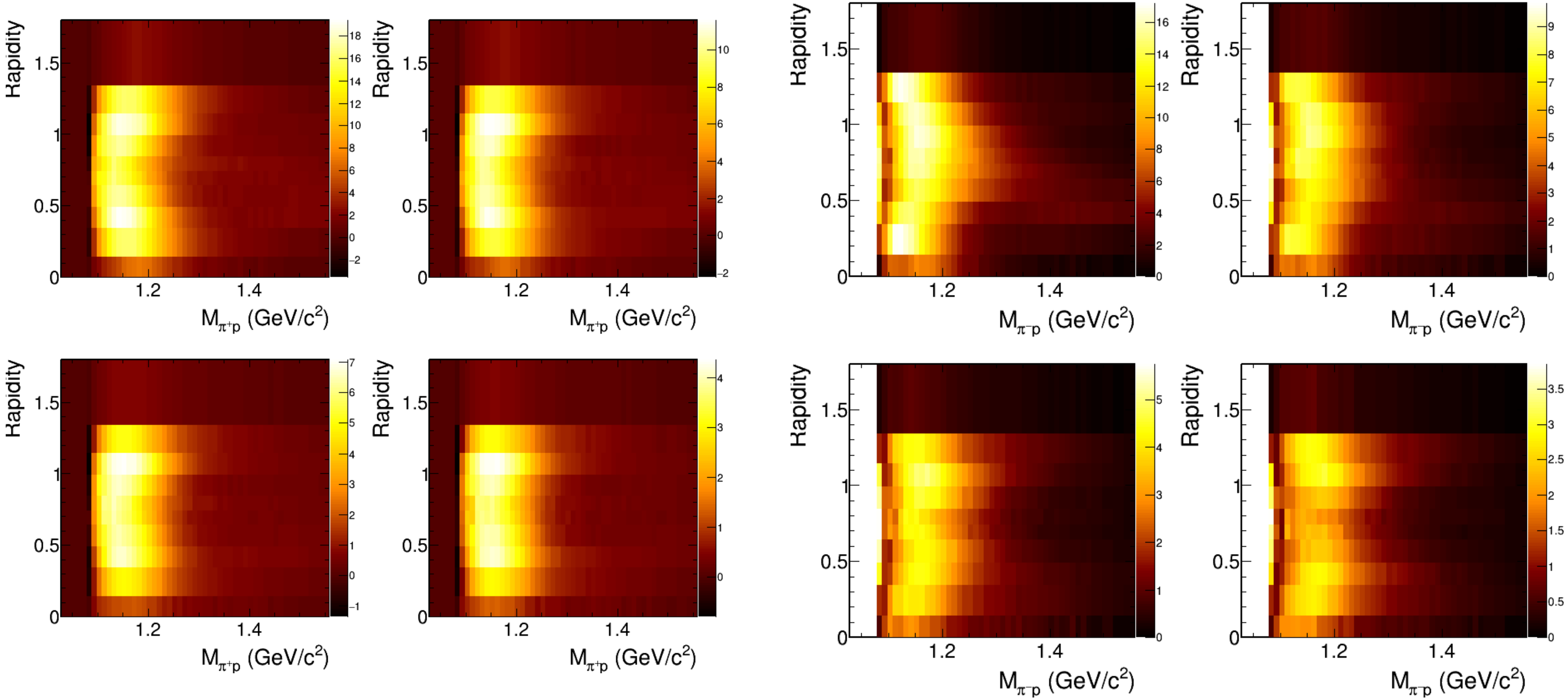
Rapidity – Inv. Mass

Coulomb interaction with the source?



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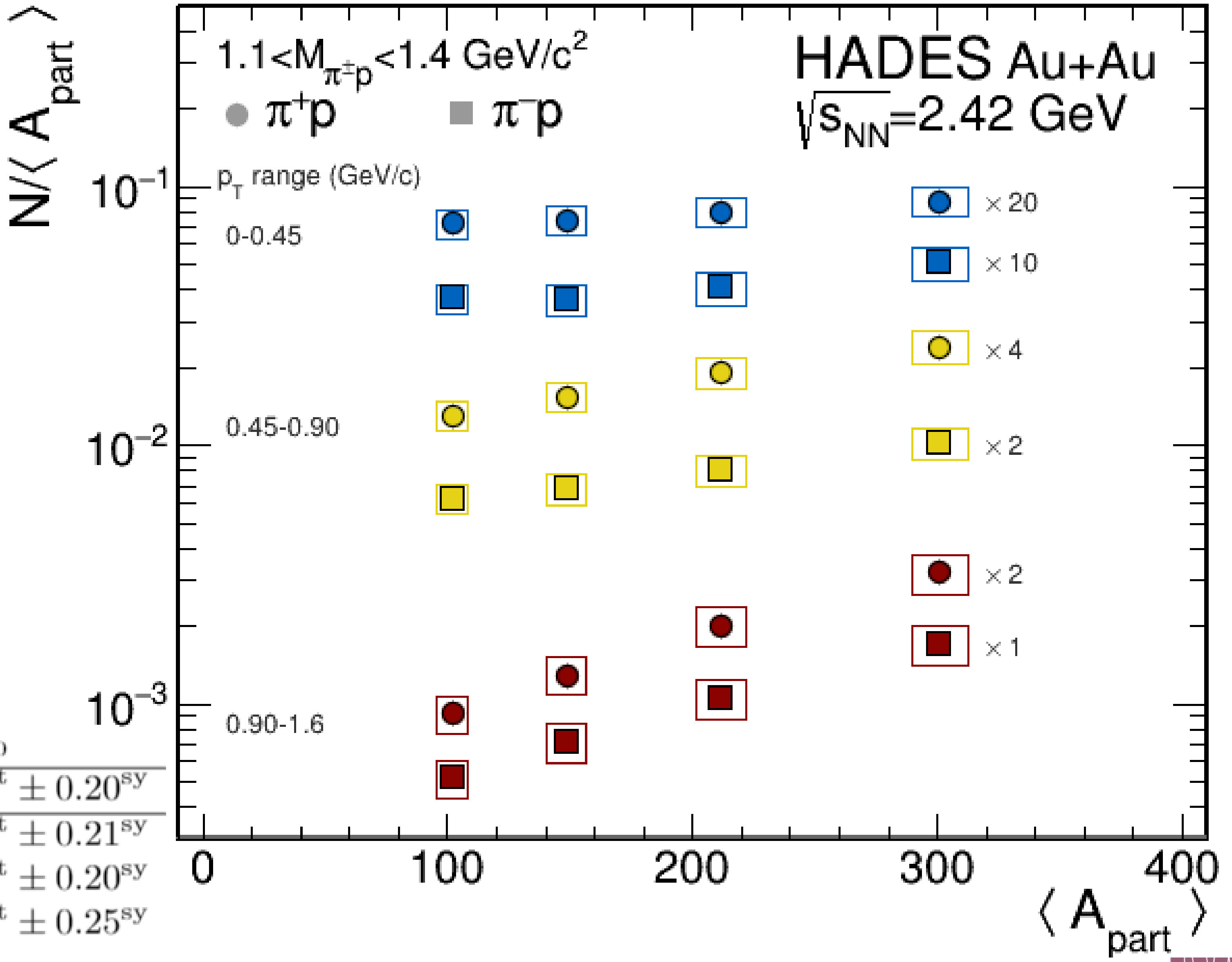
Integrated yields

Both channels show equal yields!



p_T (GeV/c)	$\alpha_{\Delta^{++}}$	α_{Δ^0}
0 – 1.6	$1.49 \pm 0.08^{st} \pm 0.21^{sy}$	$1.48 \pm 0.09^{st} \pm 0.20^{sy}$
0 – 0.45	$1.20 \pm 0.09^{st} \pm 0.19^{sy}$	$1.33 \pm 0.09^{st} \pm 0.21^{sy}$
0.45 – 0.9	$1.58 \pm 0.11^{st} \pm 0.20^{sy}$	$1.47 \pm 0.10^{st} \pm 0.20^{sy}$
0.9 – 1.6	$2.18 \pm 0.14^{st} \pm 0.26^{sy}$	$2.13 \pm 0.14^{st} \pm 0.25^{sy}$

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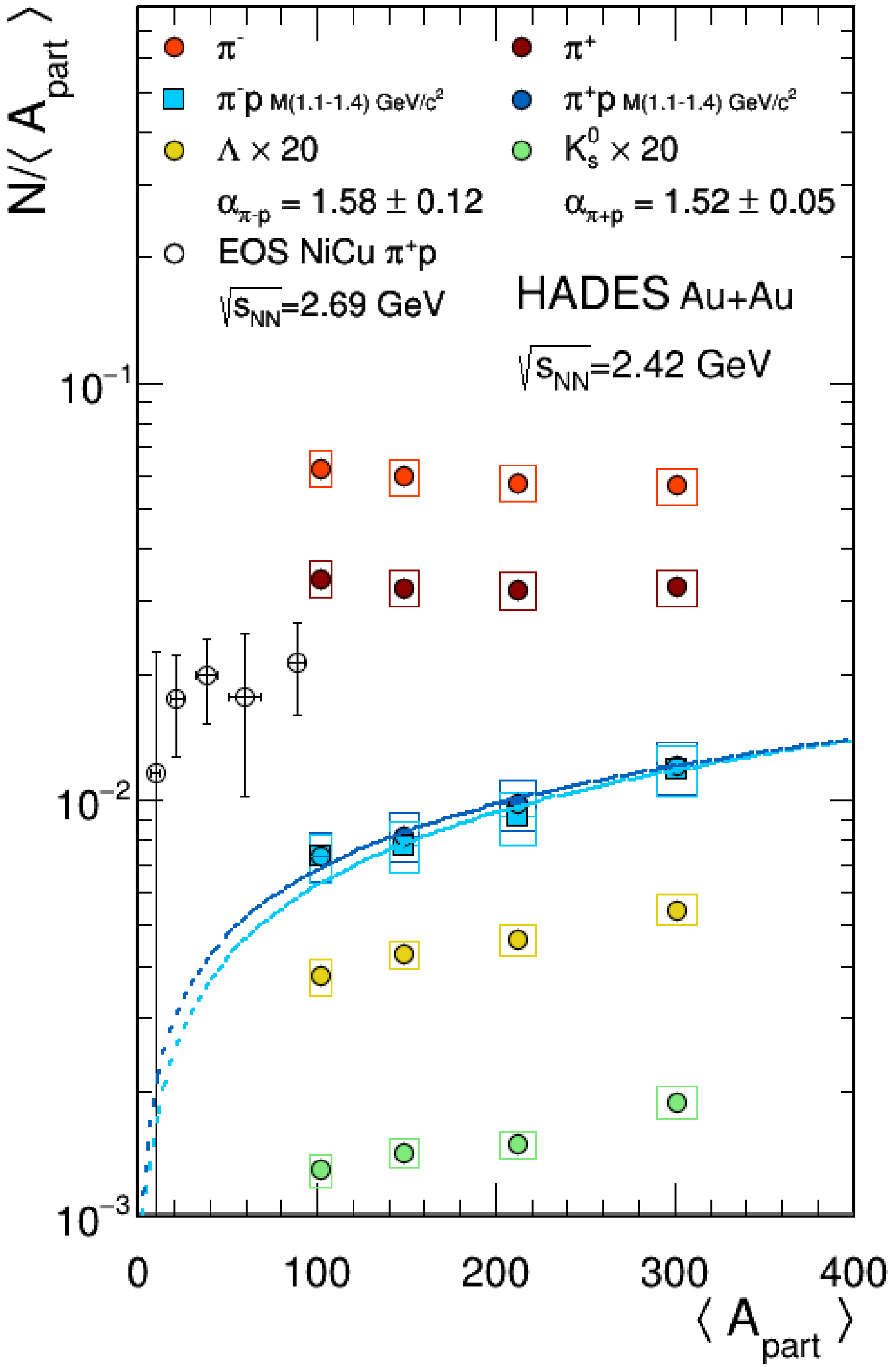
- Comparison to pions and strange particles



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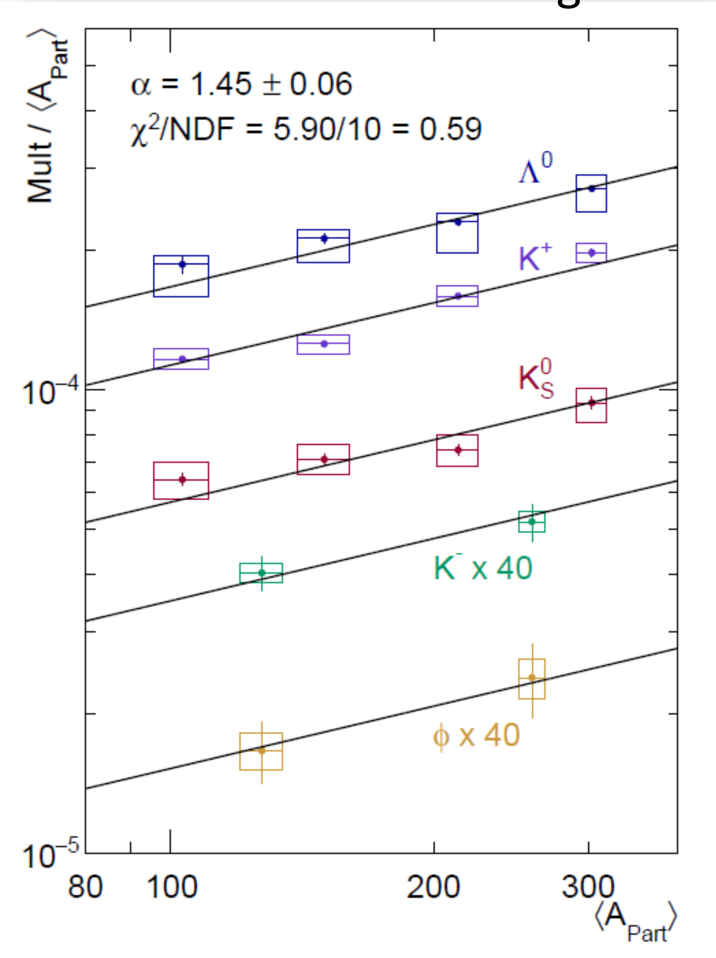
Production scaling Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV

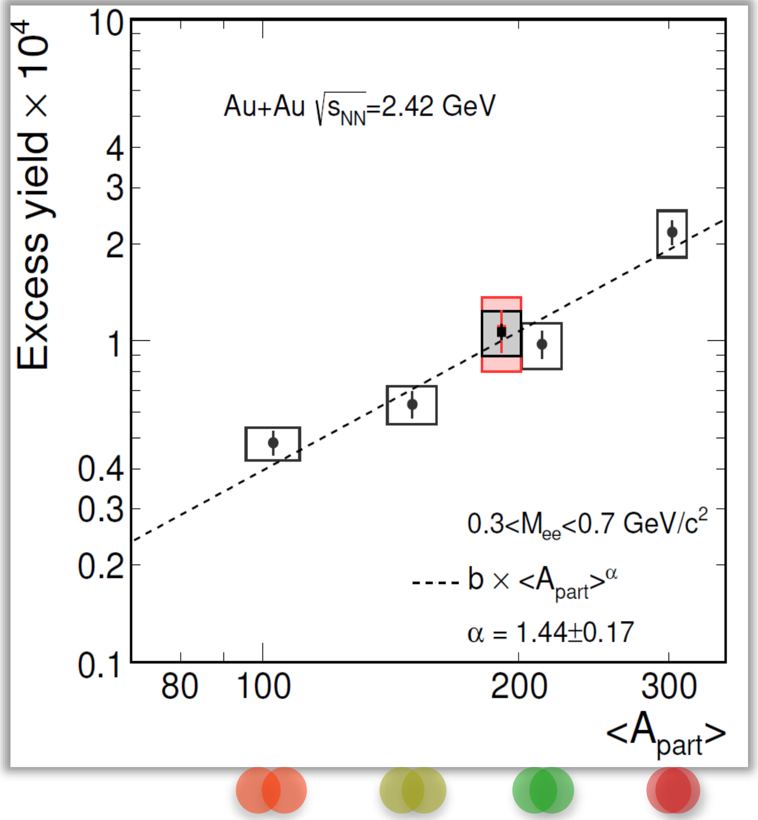
Scaling $N \propto \langle A_{part} \rangle^{\alpha}$ with parameter similar to that of strange hadrons and excess yield of virtual photons!

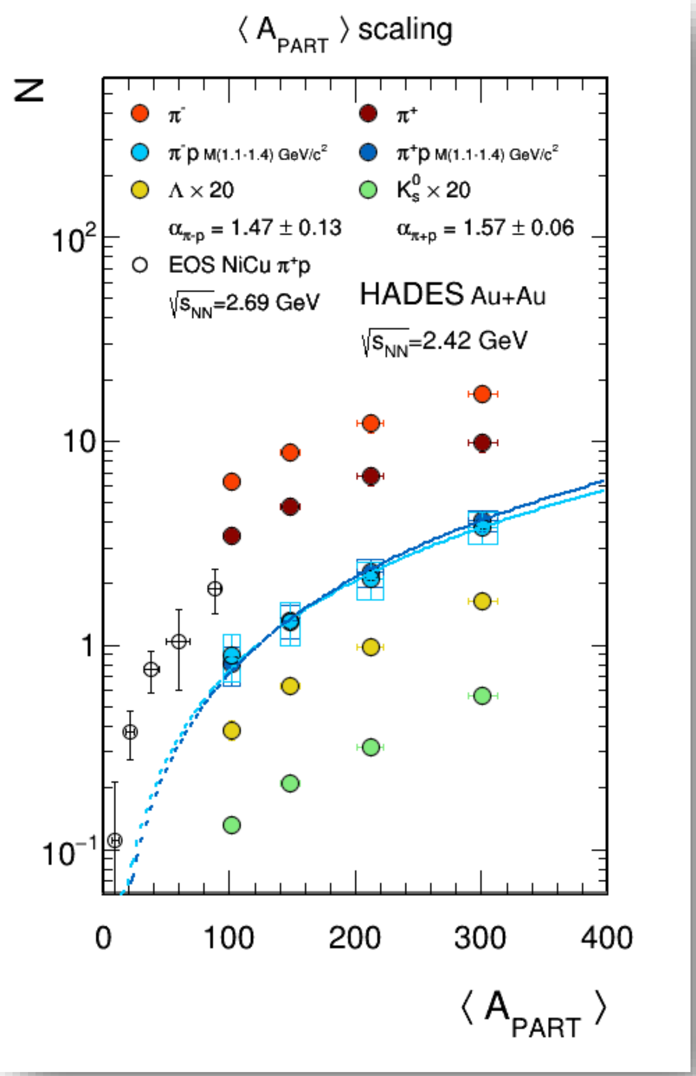
HADES Collab., Phys.Lett. B793 (2019)
[arXiv:1812.07304](https://arxiv.org/abs/1812.07304)

Strangeness



Dileptons





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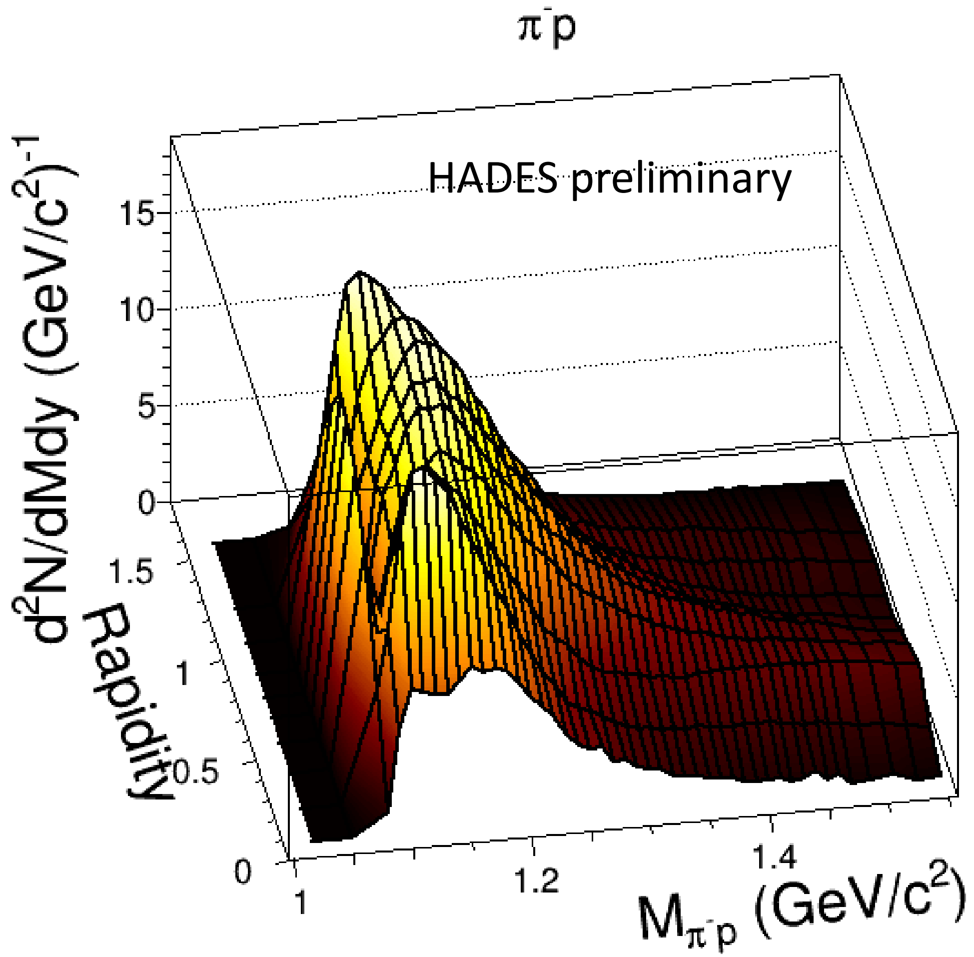
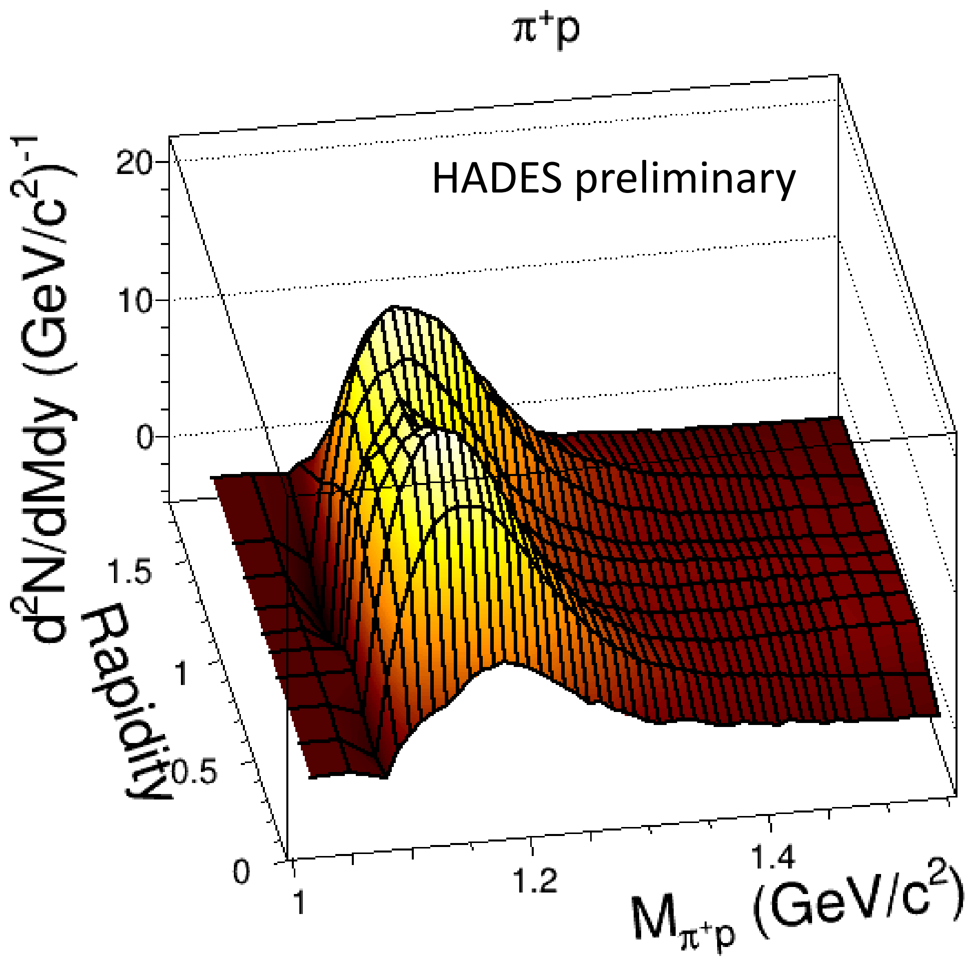
Summary





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

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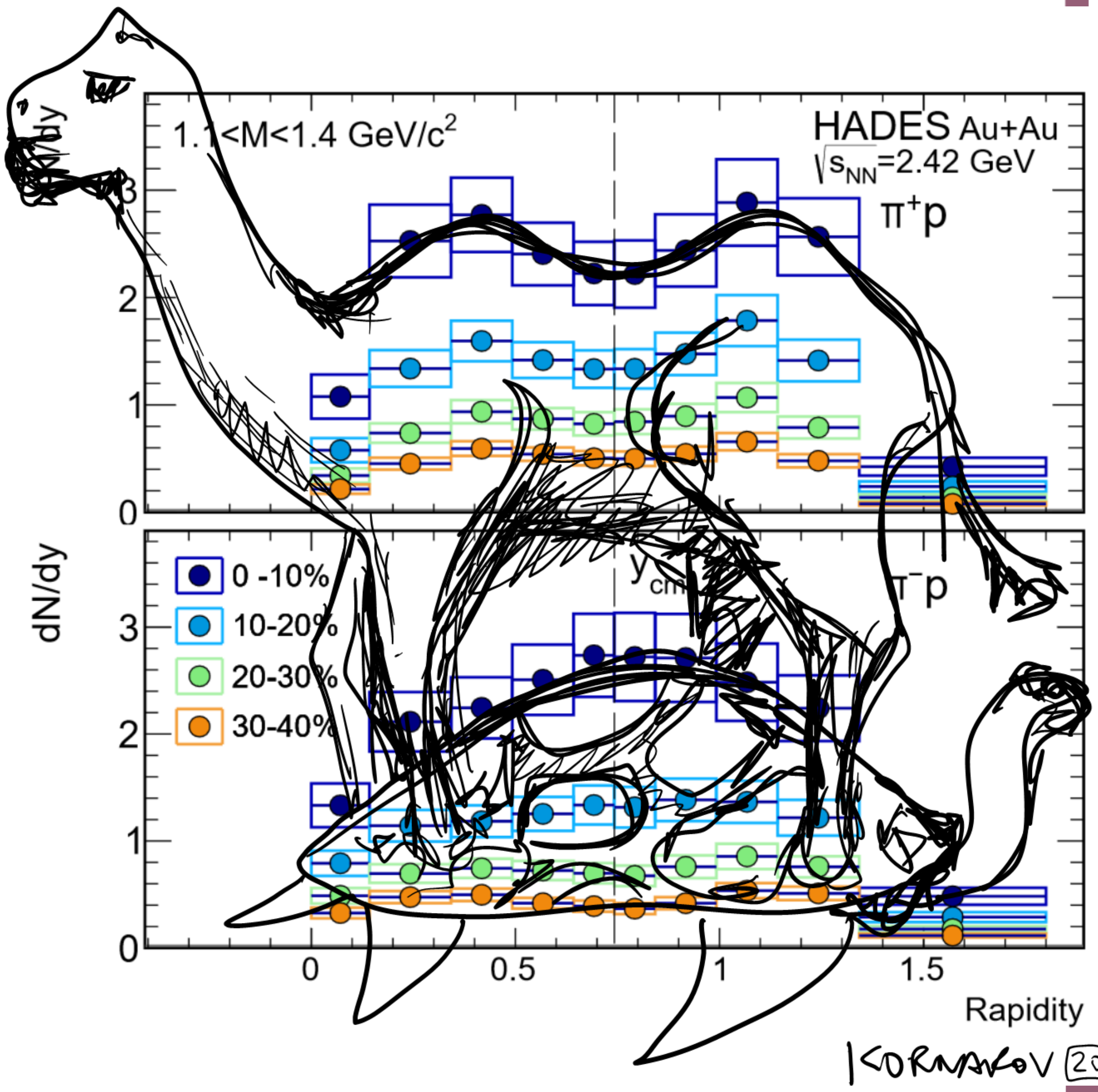
Summary & conclusions

- Delta reconstructed from central Au+Au collisions at $\sqrt{s_{NN}}$= 2.42 GeV
- 85 MeV/c^2 drop of the BW mass of the Delta
- Equal populations at freeze-out of π^-p and π^+p correlated pairs
- Tfo = 50 MeV (dilepton 72 MeV)
- Interesting rapidity-pt-M dependence



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Thank you for your attention!

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