Charged pion production in few-GeV heavy ion collisions

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HADES

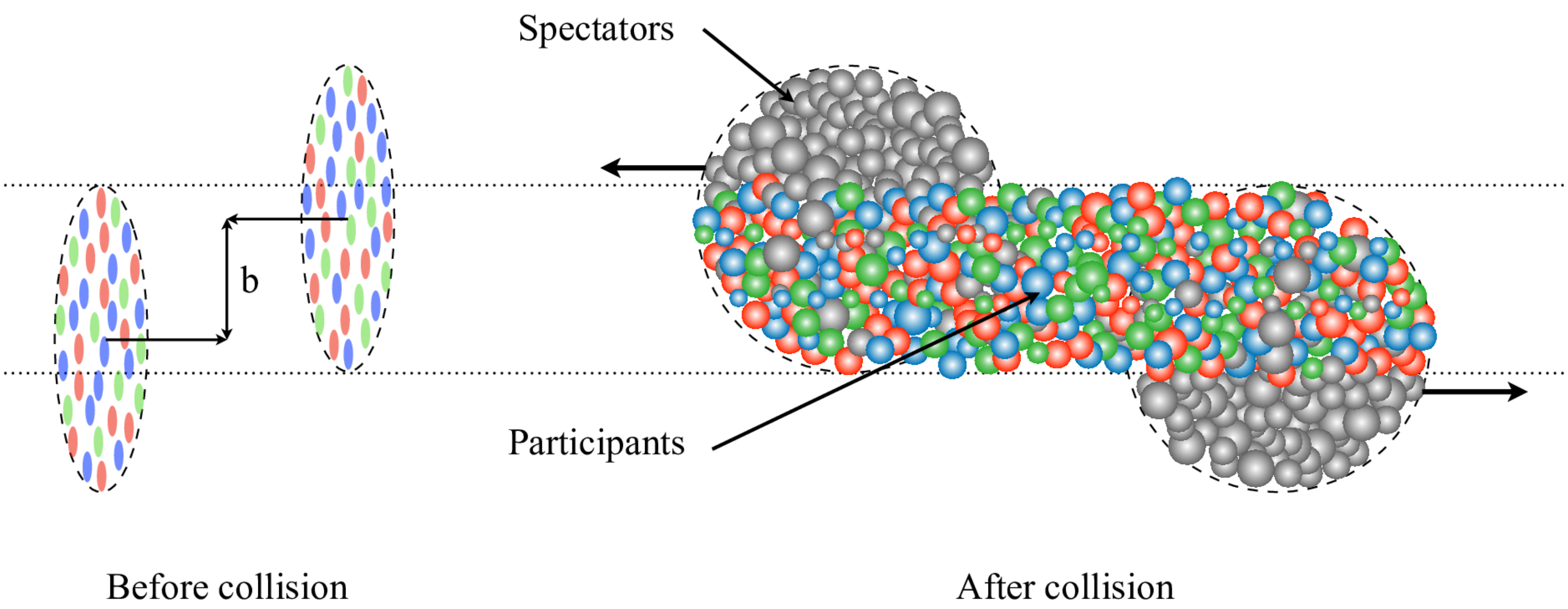
Plan of presentation

- ➠ HADES experiment & motivation
- ➠ Pion identification
- ➠ Phase-space distribution
- ➠ Systematic errors
- ➠ Pion multiplicity
- ➠ Comparison with other data
- ➠ Summary & outlook

HADES experiment

- **H**igh **A**cceptance **D**i-**E**lectron **S**pectrometer is a detector array measuring particles produced in relativistic collisions
- Located at GSI (Darmstadt, Germany)
- Installed at the SIS18 synchrotron: proton, pion or heavy-ion beam in the few-GeV energy regime
- HADES achieves high precision and acceptance both in lepton and hadron measurements

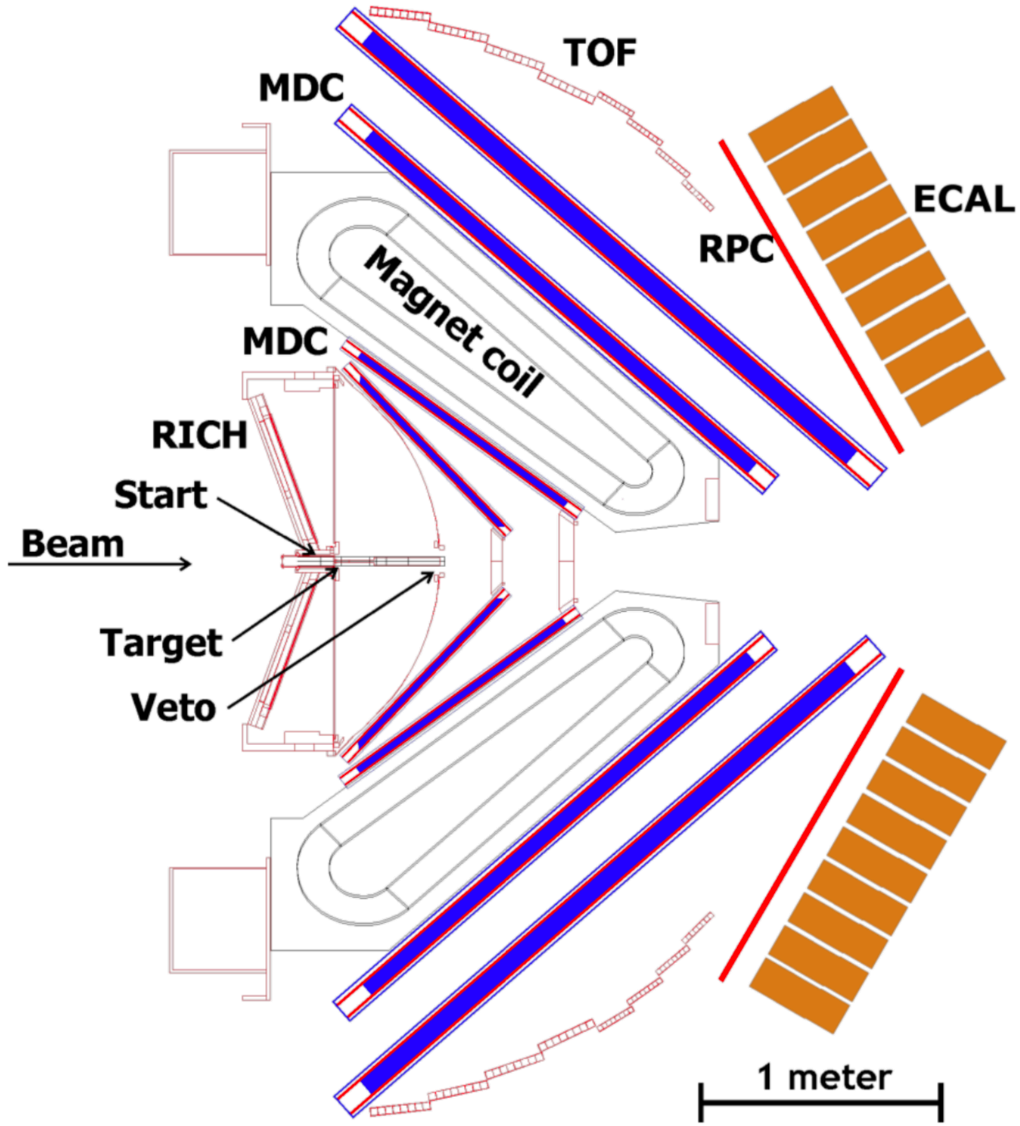
Schematic of a relativistic nuclear collision



Aaij, Roel *et al* - arXiv:2111.01607CERN-LHCb-DP-2021-002

HADES experiment - schematic

- **START & VETO** responsible for trigger and time measurement.
- **MDC + magnet** allow tracking and momentum reconstruction
- **TOF/RPC** allow for centrality determination and time measurement



HADES experiment - motivation

➠ Studying nuclear matter in states of extreme pressure, matter density and temperature;

➠ Probing the nuclear *equation of state*;

➠ Producing new particles (hadrons and leptons).

Charged pions:

- ➠ lightest mesons with $m_0 \approx 139.4$ MeV (abundant production!)
- ➠ comprise *u* and *d* (anti)quark
- ➠ measurements of the Coulomb potential → model-dependent determination of size of collision zone
- ➠ decay products of many interesting particles, eg. Δ resonances

Data used for analysis

➠ Ag + Ag collisions registered in March 2019:

- 30 days at T_{beam} = 1.58A GeV
- 3 days at T_{beam} = 1.23A GeV

➠ The lower energy ($\sqrt{s_{NN}}$ = 2.4 GeV) is the focus of this work

For charged pions from higher energy see Marvin Nabroth's talk at 4:20 PM

➠ 800 million events divided into four 10%-wide centrality classes

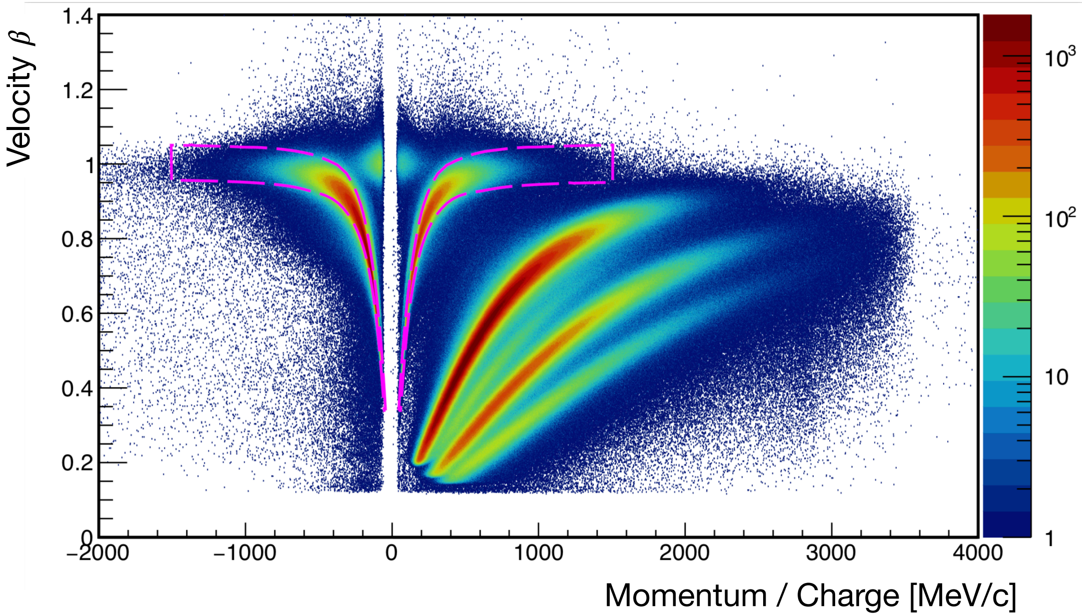
➠ In each event, tracks are only accepted in regions of:
- momentum between 50 and 1500 MeV
- acceptable "track quality"

Charged pion identification

Pion identification

For relativistic particles the dependence between velocity (β) and momentum (p) is defined only by one parameter: **mass**.

$$|\beta| = \frac{|p|}{\sqrt{p^2 + m^2c^2}}$$



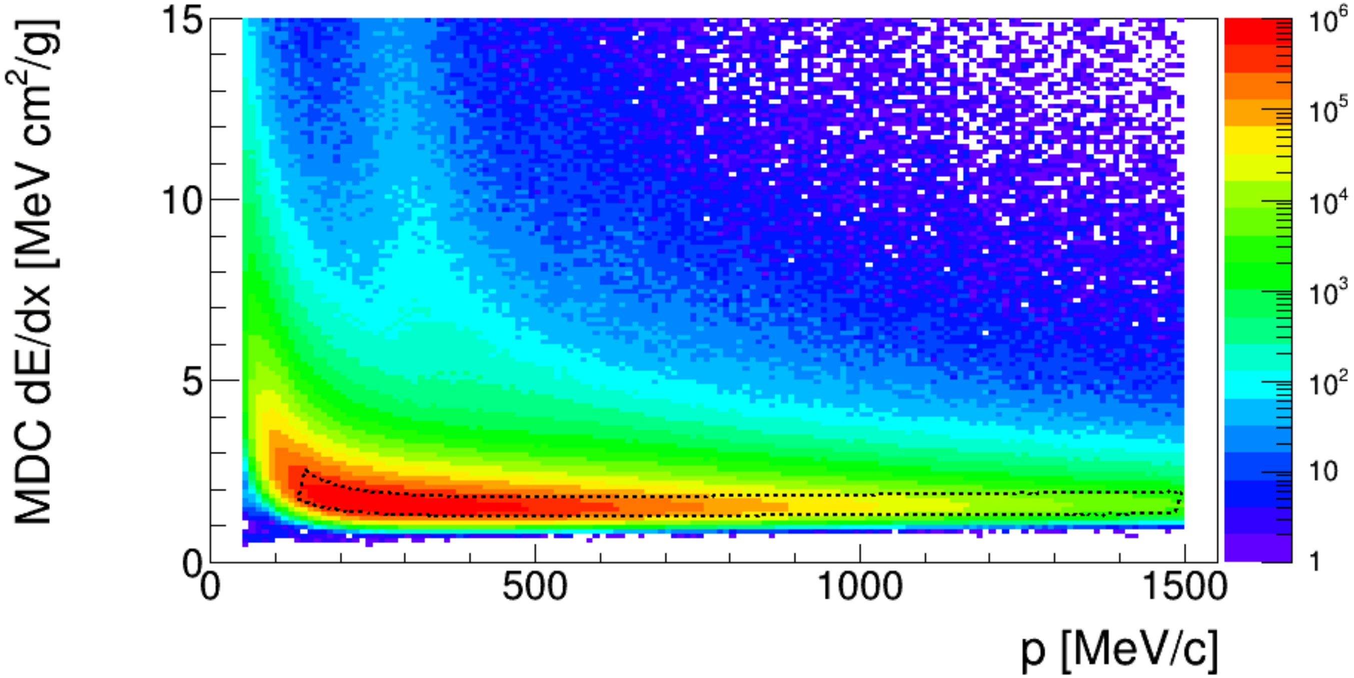
Gaussian smear due to uncertainties has to be taken into account.

A 2σ cut was used.

Pion identification

For positive π mesons there is significant a contamination from protons.

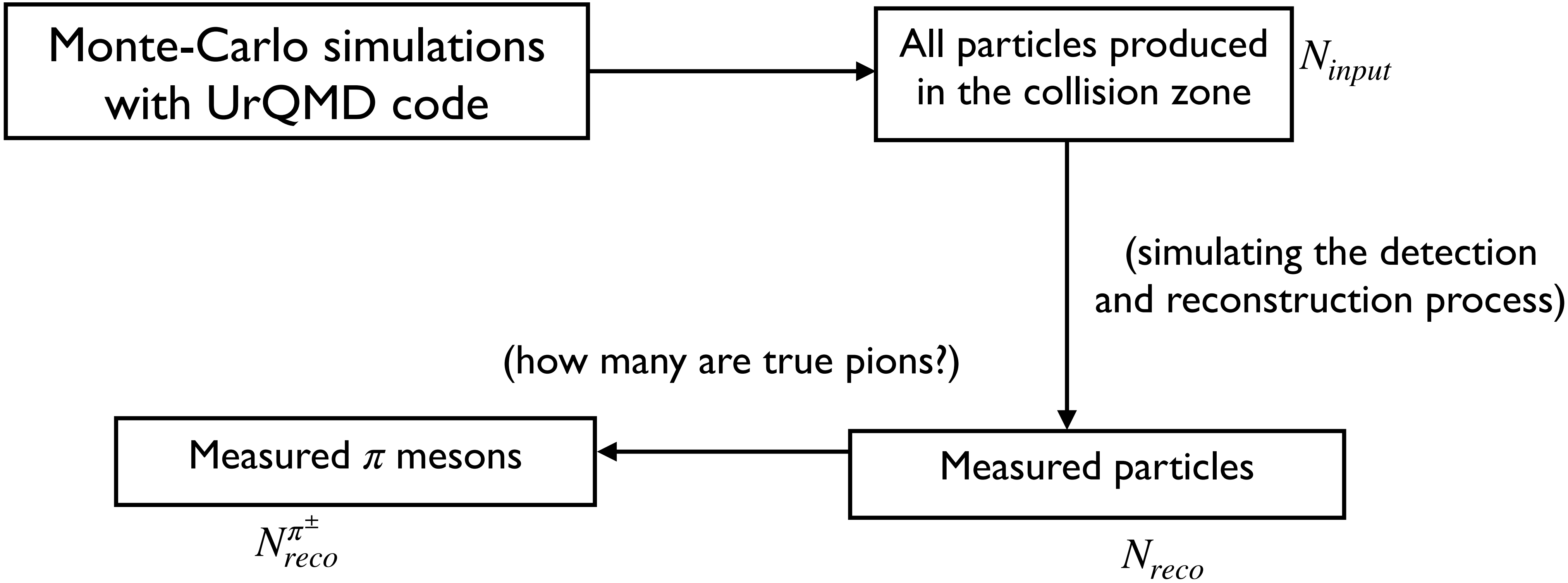
Solution: use additional condition - energy loss in MDC stations as a function of momentum (1σ cut was used).



Contamination with protons is clearly seen on log scale - **even after β : p cut.**

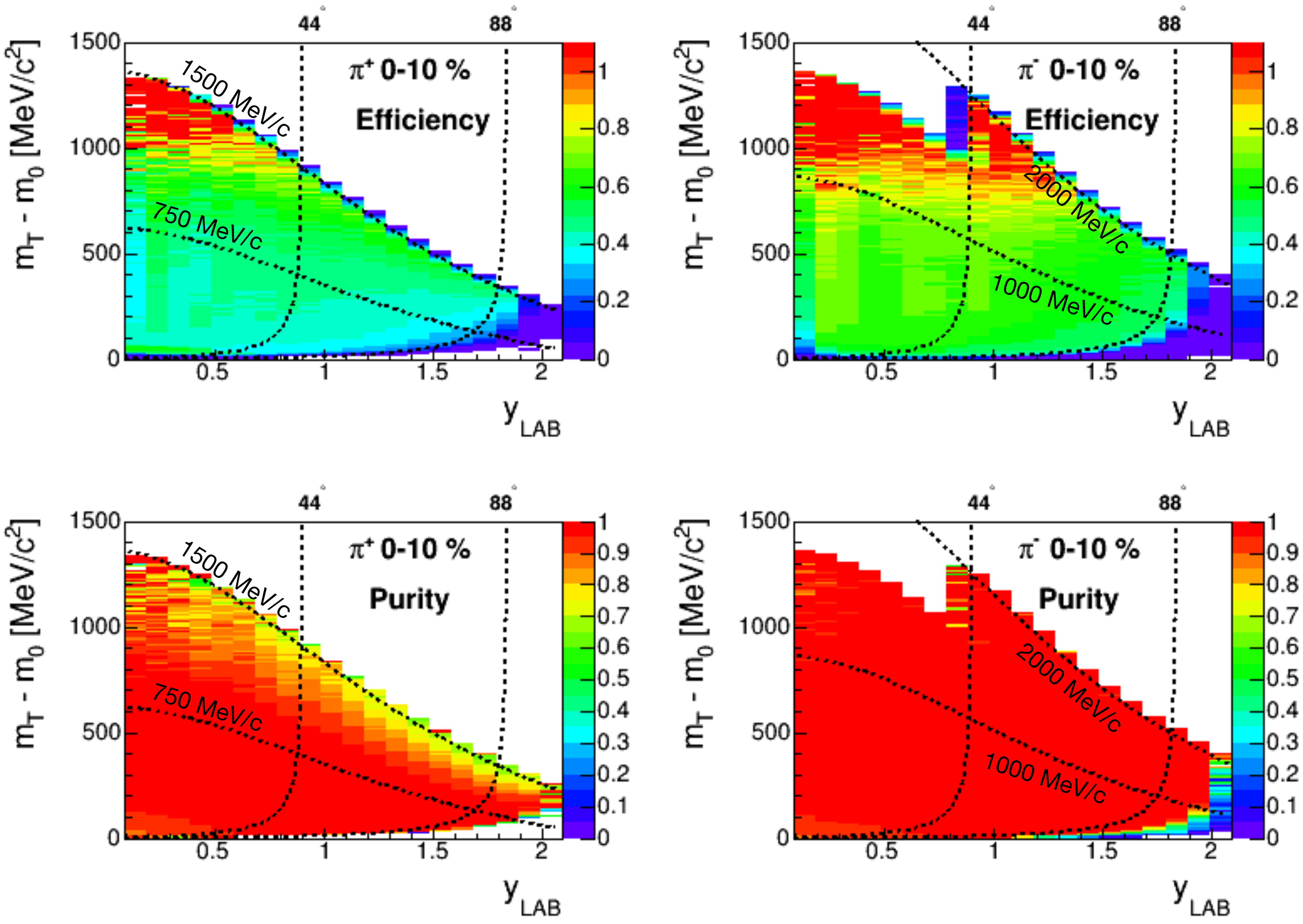
Increase in pion purity at higher momenta by a factor of few %.

Verifying the efficiency (ϵ) and purity ($\mathscr{P}$)



$$\epsilon = \frac{N_{reco}}{N_{input}} \qquad \mathscr{P} = \frac{N_{reco}^{\pi^{\pm}}}{N_{reco}}$$

Efficiency $*$ acceptance and purity



Cells of the phase space were accepted only if:

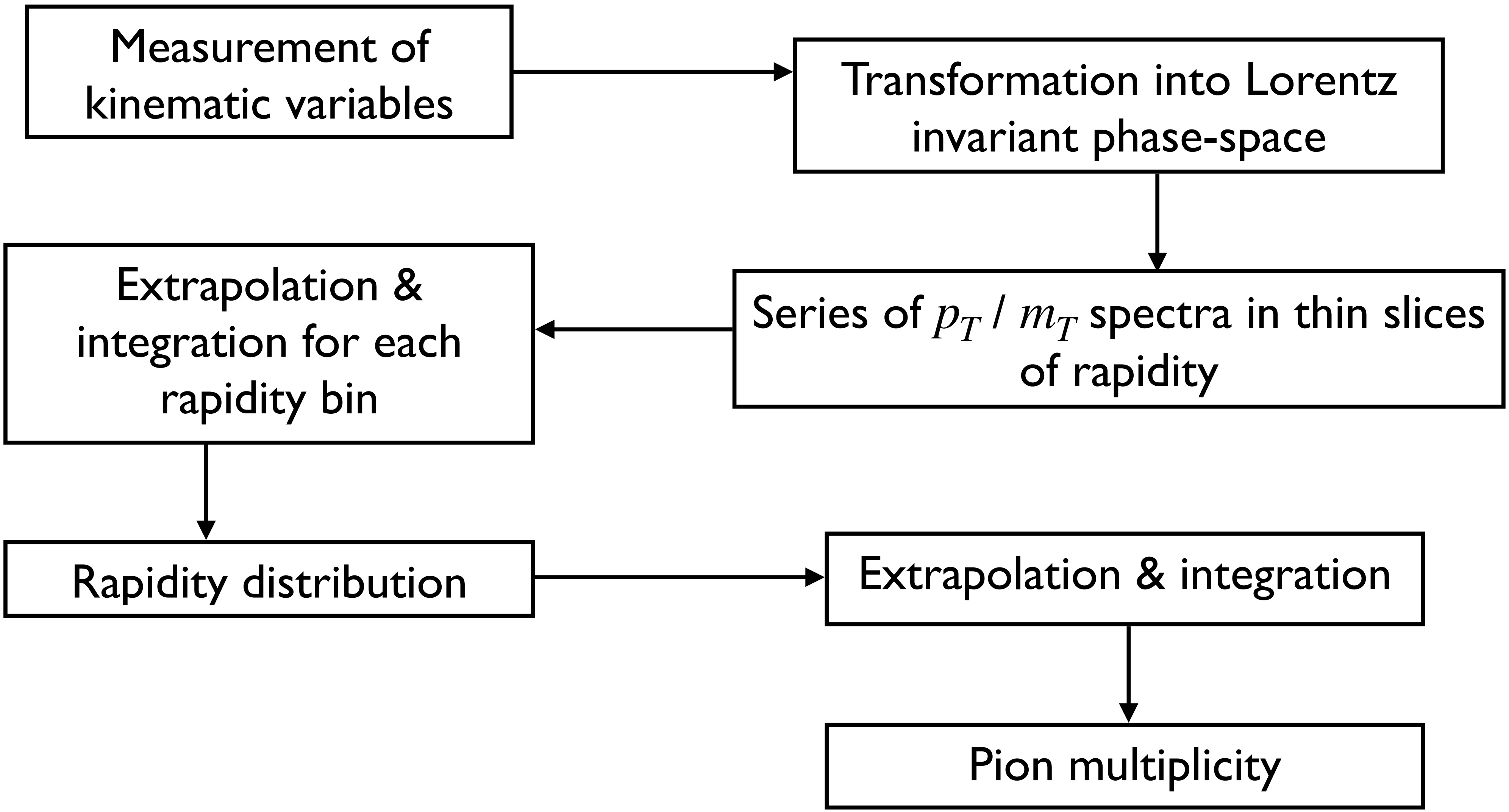
→ $25\,\% < \epsilon < 100\,\%$

→ $\mathscr{P} > 80\,\%$

θ_{LAB} curves correspond to borders of detectors in META array.

p_{LAB} curves guide the eye and mark the acceptance borders

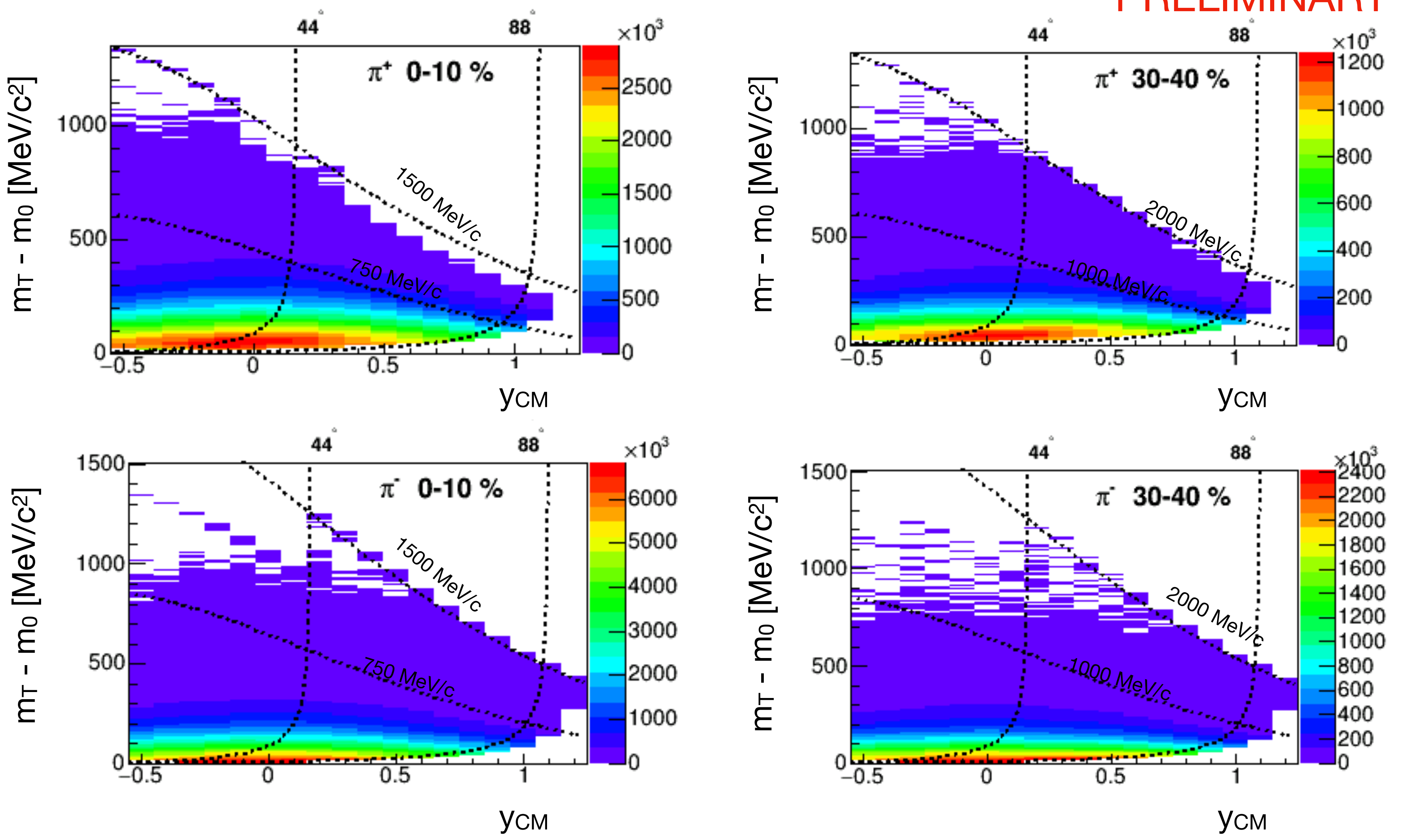
Strategy of pion analysis



Phase-space distribution

Phase-space ($m_T - m_0$ vs. y_{CM}) distributions

PRELIMINARY



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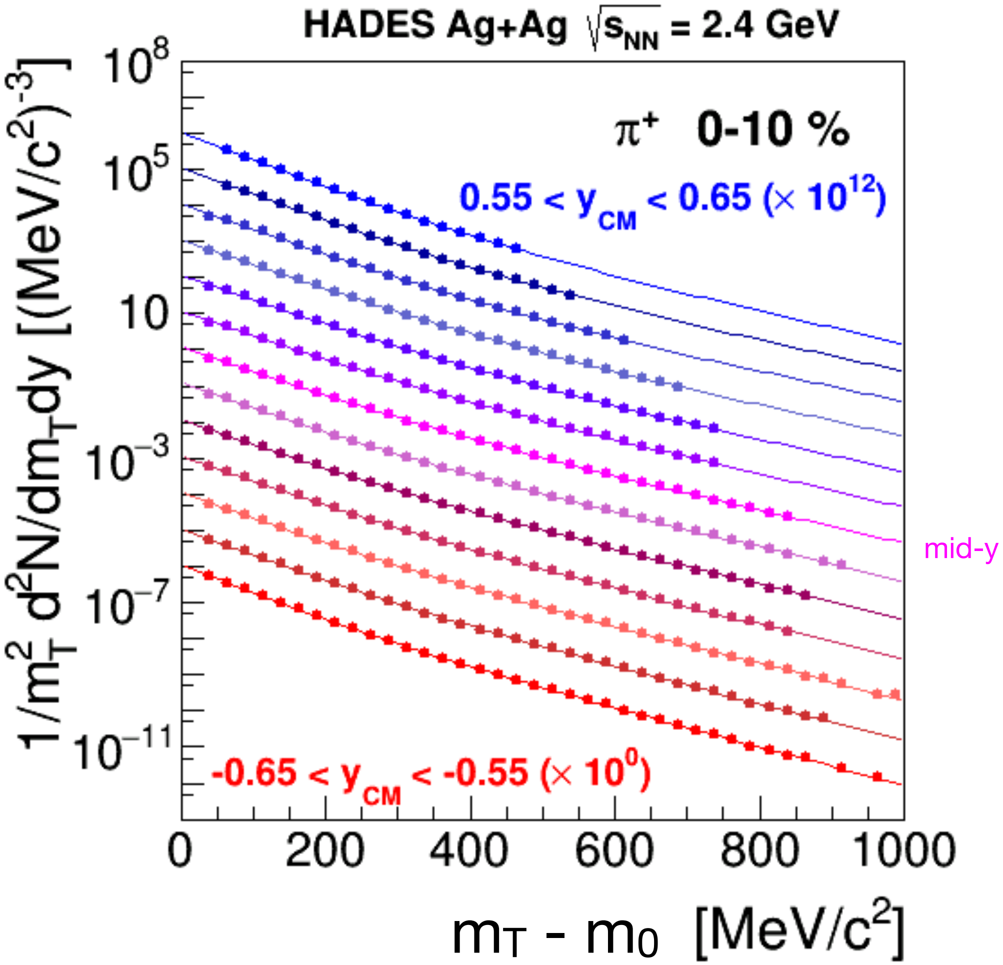
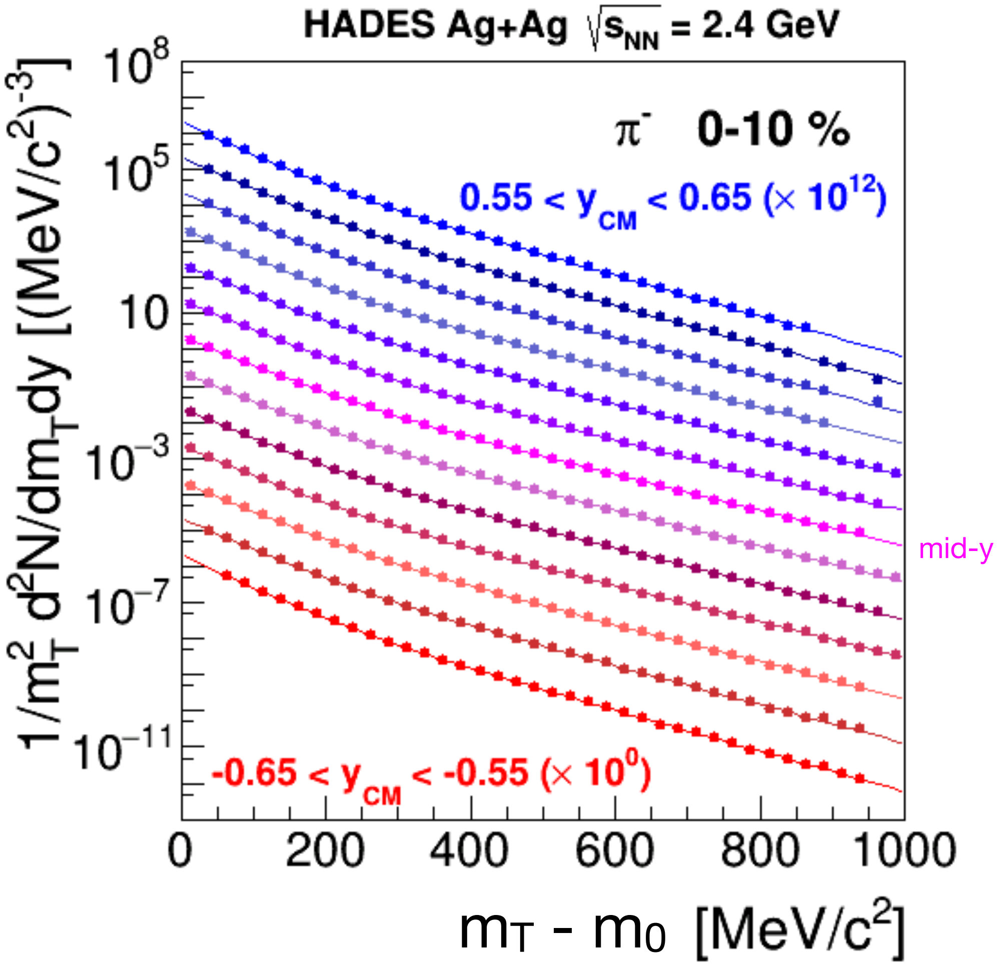
m_T spectra in rapidity slices

PRELIMINARY

Fit function: $$\frac{1}{m_T^2}\frac{dN}{dm_T}\bigg|_{y=y_i} = c_1 \exp\frac{-m_T}{T_1} + c_2 \exp\frac{-m_T}{T_2}$$

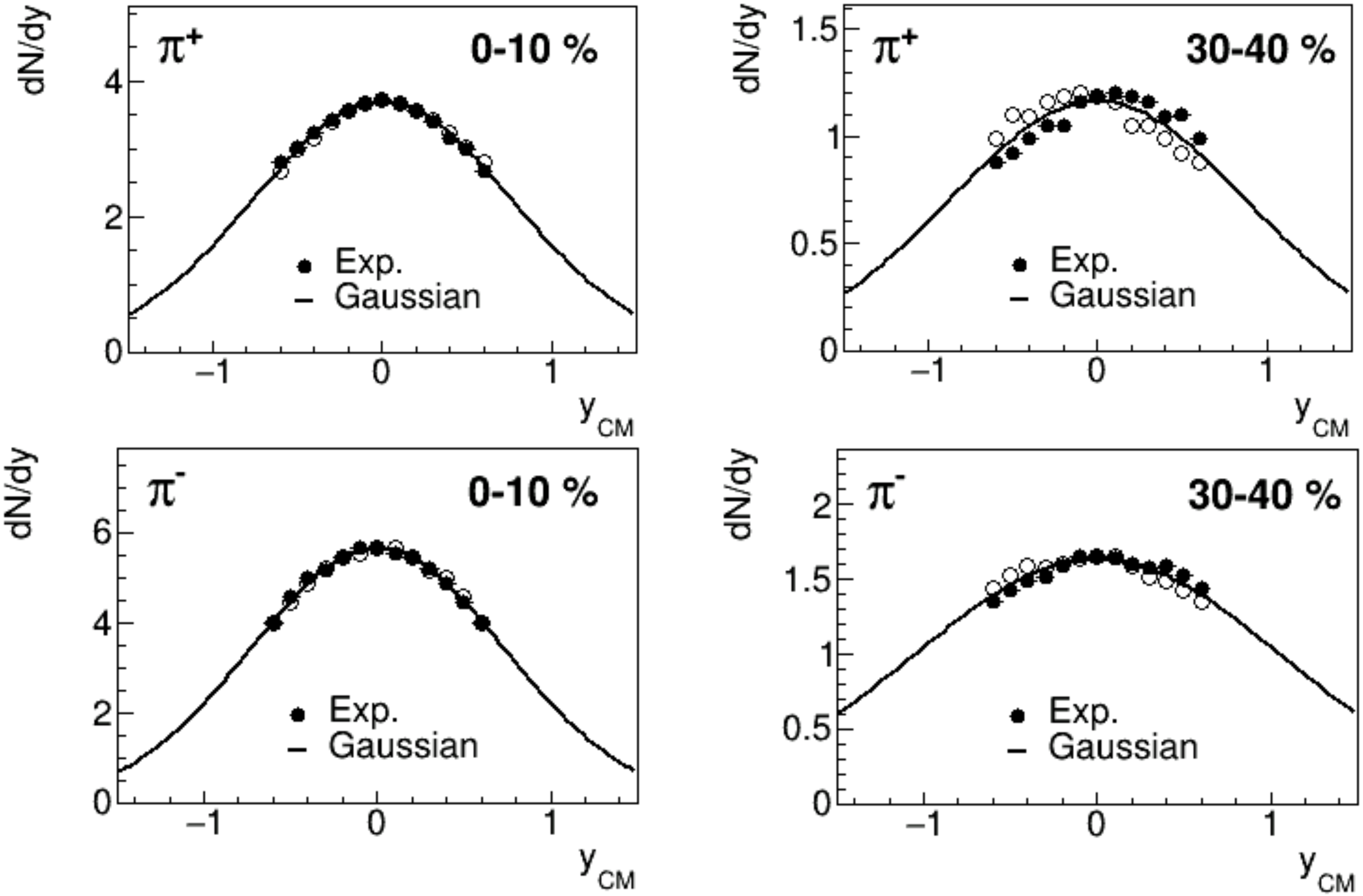




Rapidity distributions

PRELIMINARY

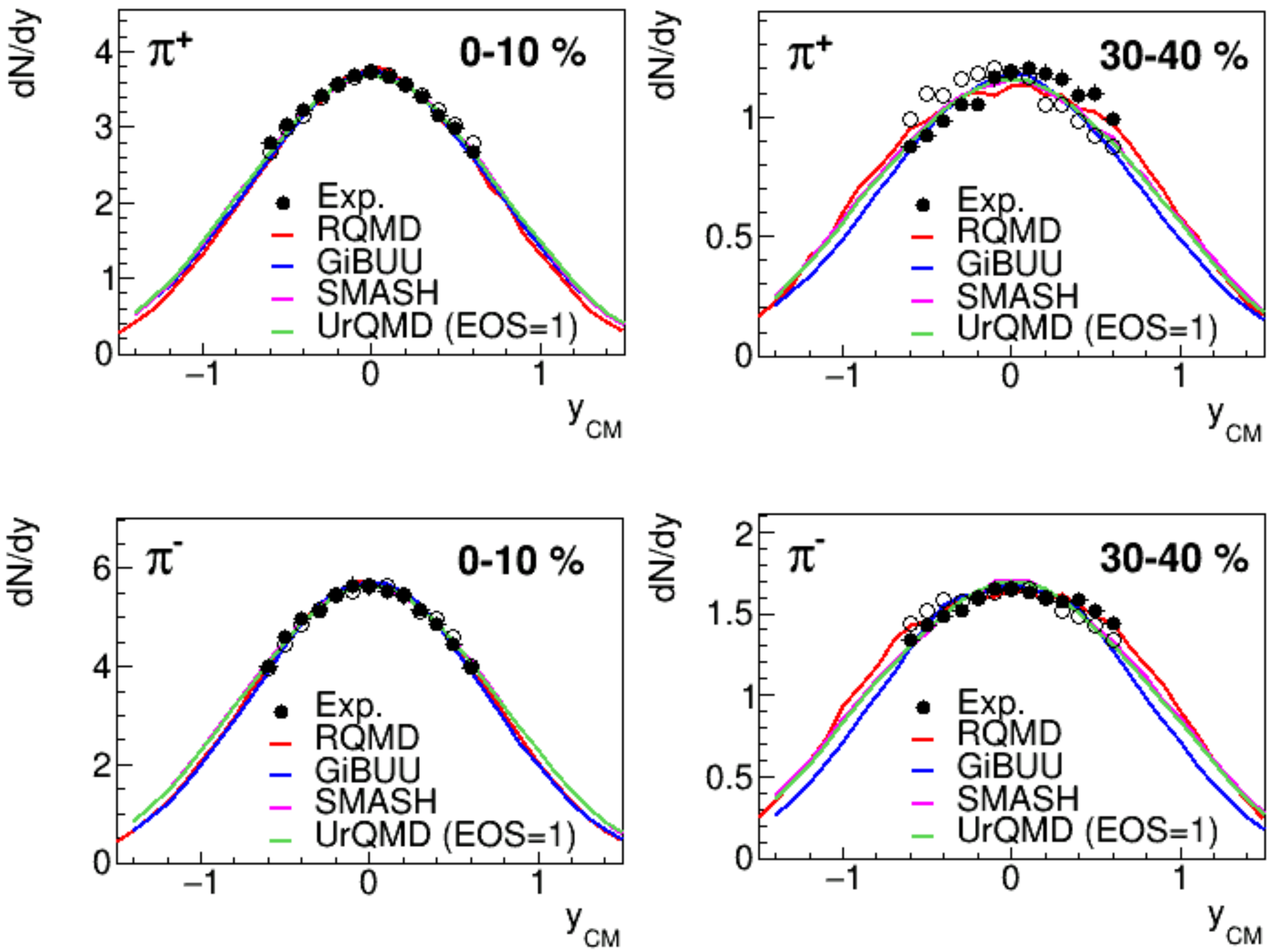
w/o systematic errors



Rapidity distributions - extrapolation

w/o systematic errors

PRELIMINARY



Transport models are normalised to data in measured rapidity area.

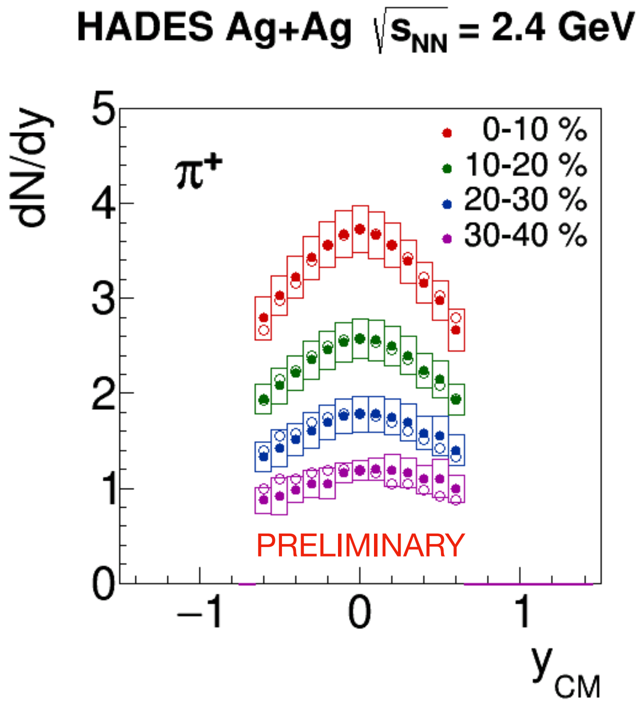
That way we extract from them only the distribution profile.

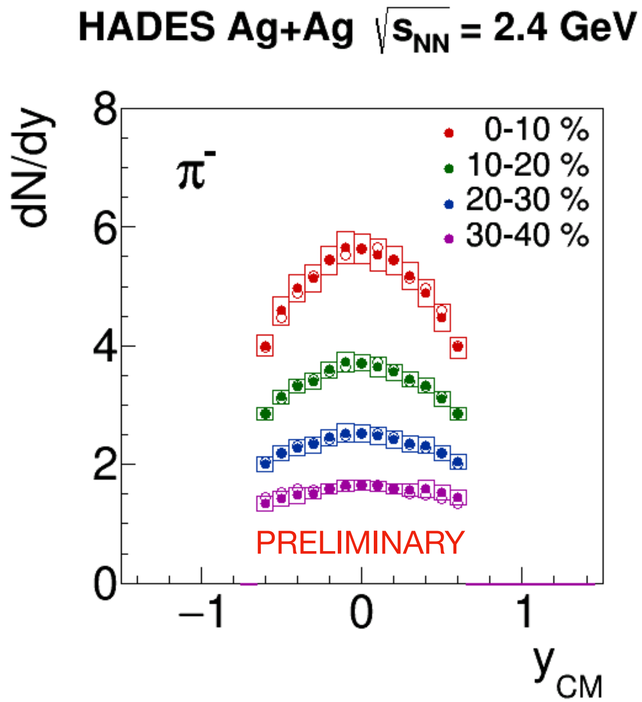
The variety of available models contributes to systematic errors.

Systematic errors considered

- ➠ Sector-wise inconsistencies or distortions
- ➠ p_T / m_T extrapolation distortions
- ➠ Using different widths of cuts for pion identification
- ➠ Applying the additional energy loss cut
- ➠ Different models for rapidity extrapolation
- ➠ Different efficiency cut-offs
- ➠ Asymmetry in rapidity distribution

Final results

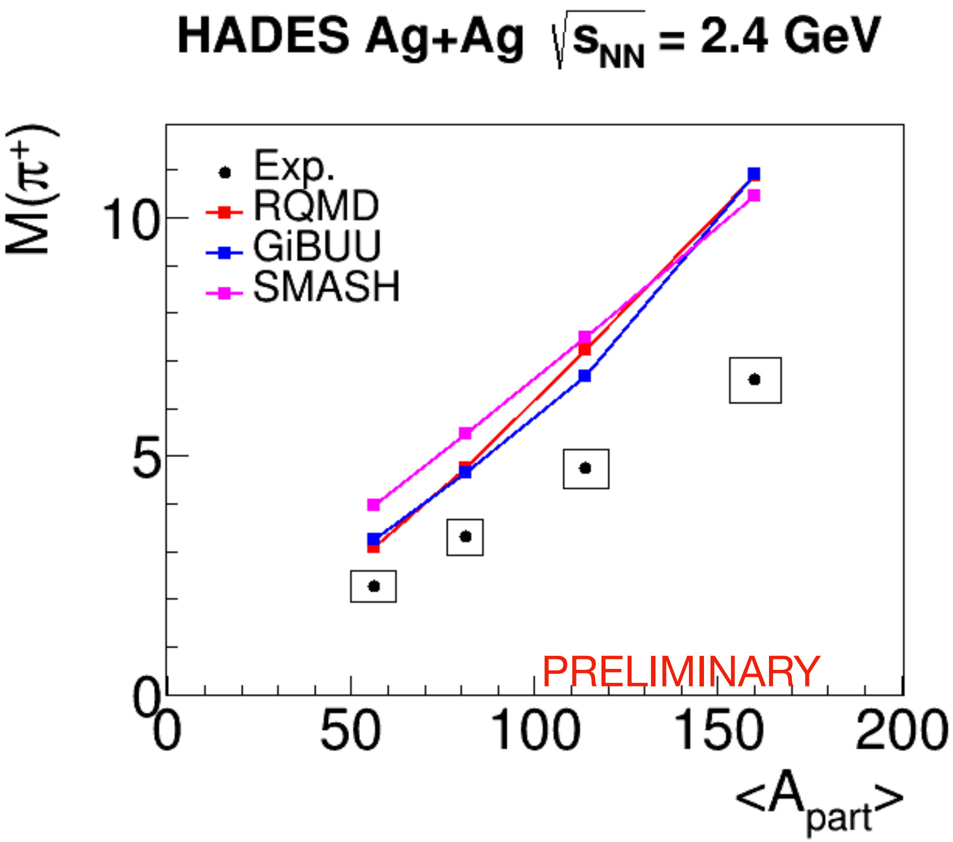


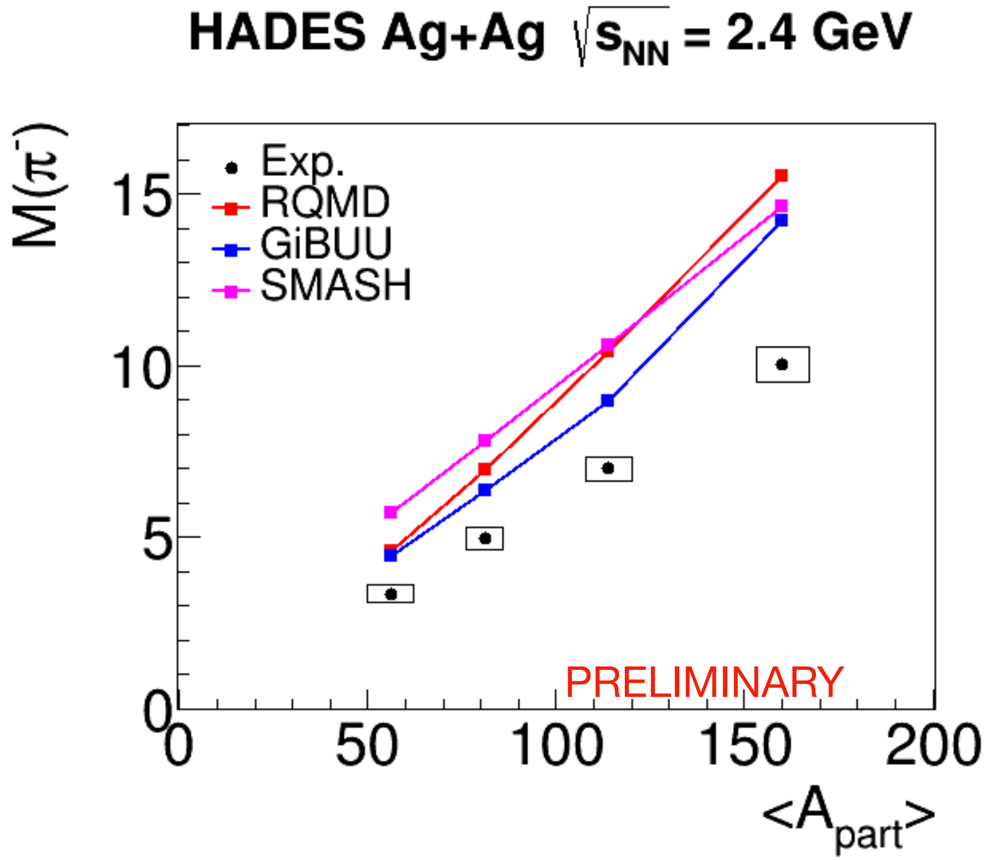


Particle	Centrality class	$< A_{part} >$	Multiplicity			Systematic error
			No extrapolation	Extrapolated with Gauss	Extrapolated w/ transport models	
π^+	0 - 10 %	160	4,0	7,4	6,6	7,1 %
	10 - 20 %	114	2,8	5,3	4,7	8,5 %
	20 - 30 %	81	2,0	3,8	3,3	11 %
	30 - 40 %	56	1,3	2,6	2,3	14 %
π^-	0 - 10 %	160	6,1	10,7	10,0	5,2%
	10 - 20 %	114	4,1	8,1	7,0	5,0 %
	20 - 30 %	81	2,8	6,1	4,9	6,8 %
	30 - 40 %	56	1,9	4,5	3,3	7,8 %

Comparison to transport models and other experimental results

Why normalize the transport models?

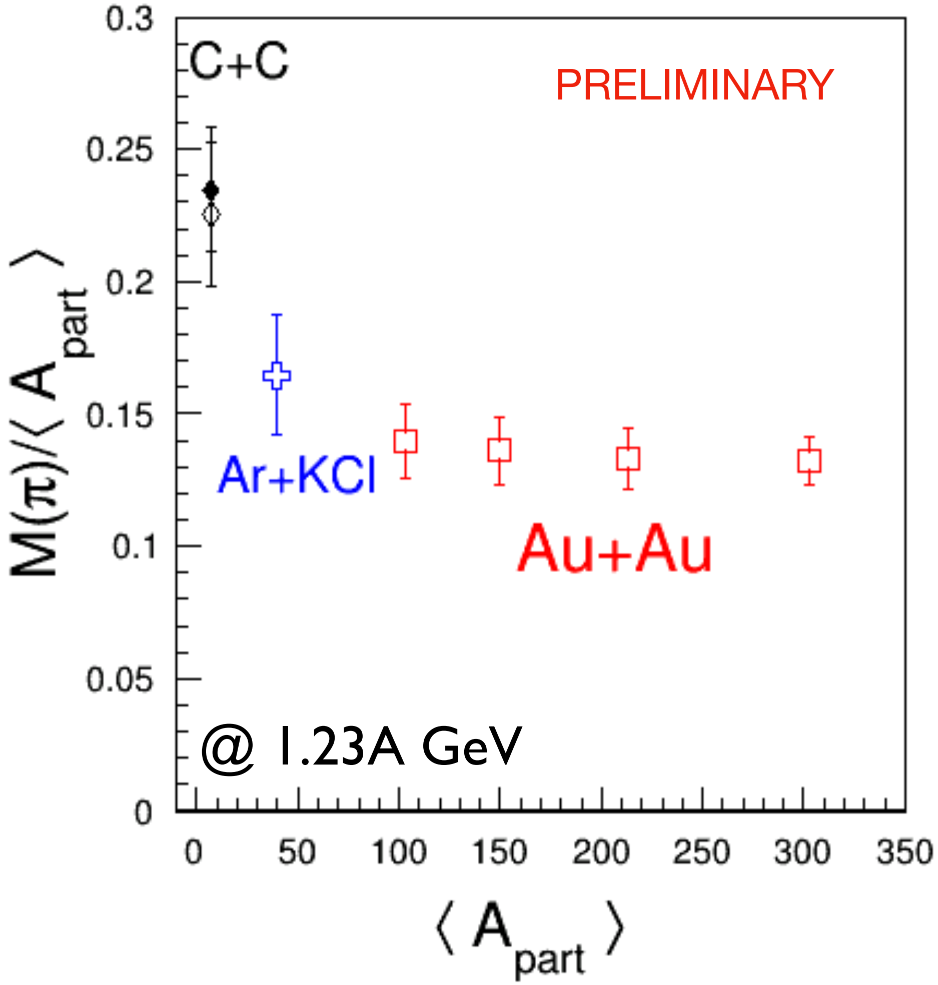


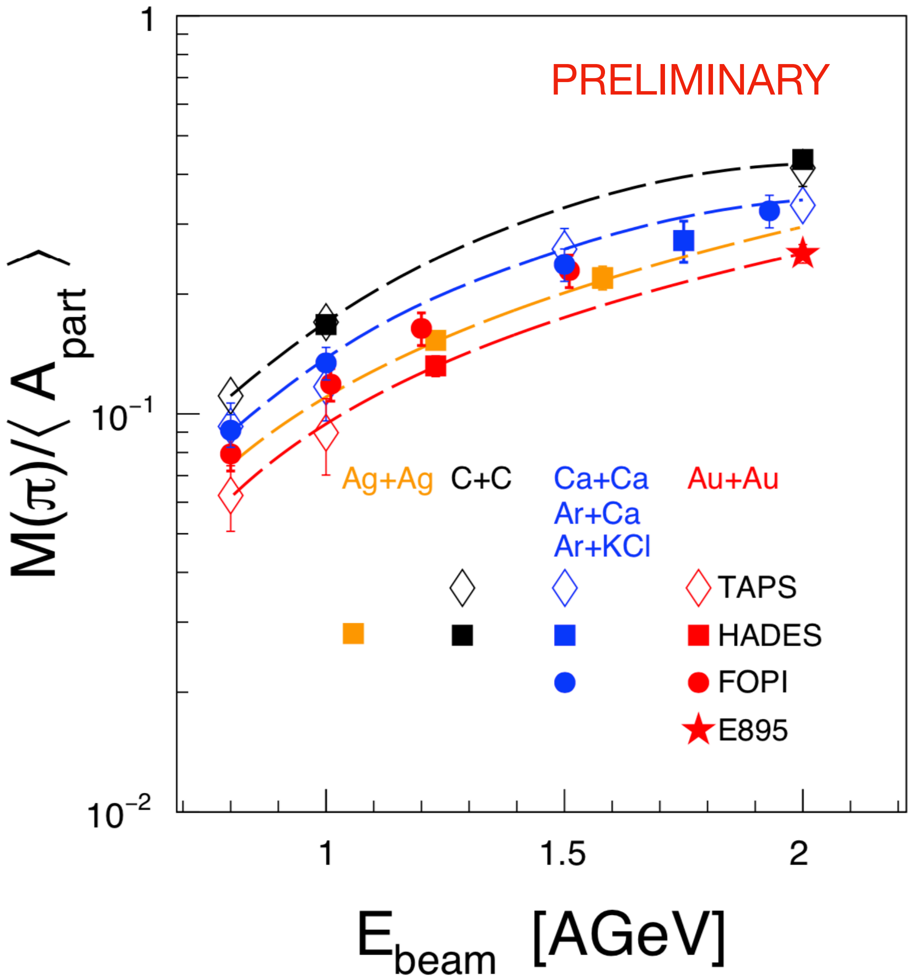


Models generally overestimate pion yields by a factor ~1.5

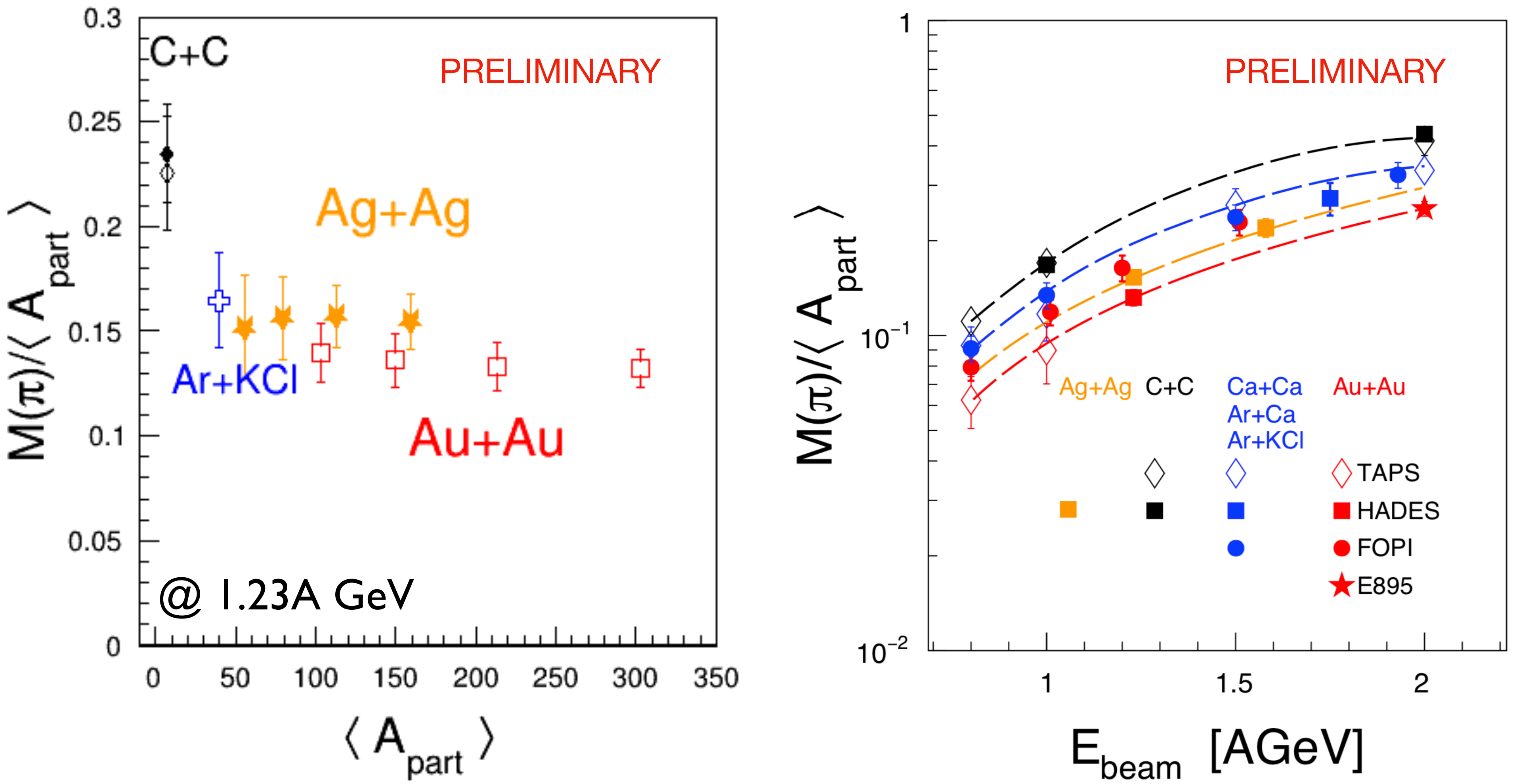
See also: J. Adamczewski-Musch *et al.* (HADES Collaboration) Eur. Phys. J. A **56,** 259 (2020).

Pion production systematics





Pion production systematics



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Summary & outlook

- ➠ Few-GeV heavy ion collision allow for abundant production of charged π mesons.
- ➠ Reconstruction of pion production was performed for Ag+Ag collisions at beam kinetic energy of 1.23A GeV
- ➠ The resulting multiplicities are consistent with other experimental work
- ➠ The systematic errors need to be reduced...
- ➠ ... then we can bring the data to final stage!

Thank you for your attention!

contact me at: j.orlinski@gsi.de

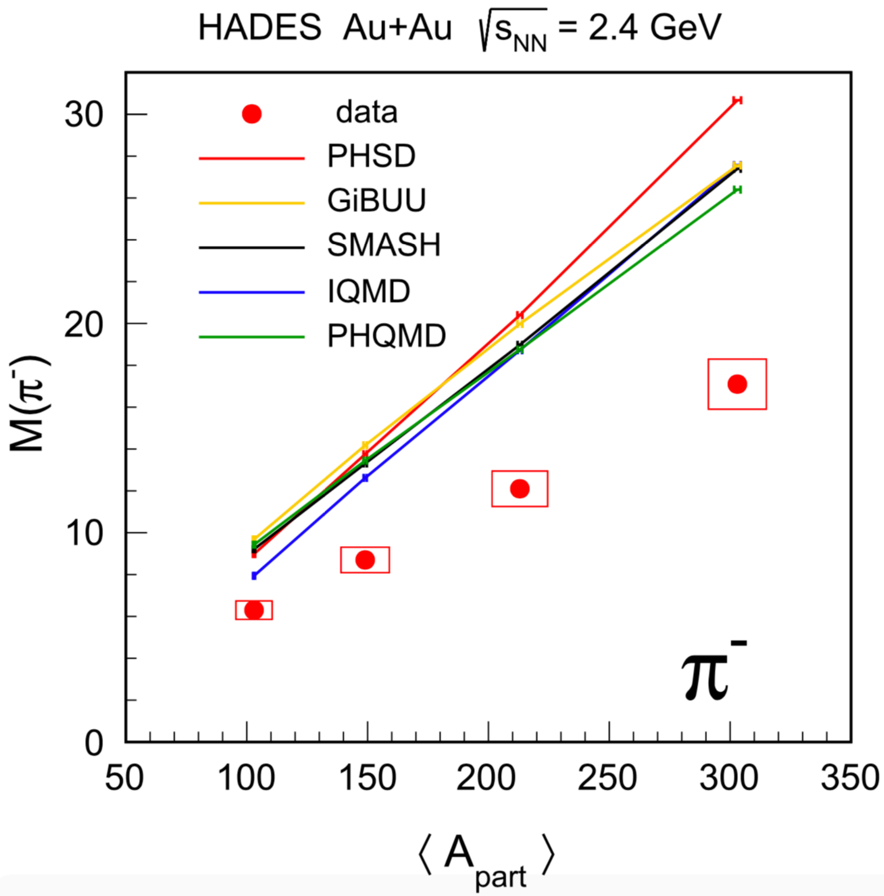
Upcoming talks from members of the HADES Collaboration:
Marvin Kohls (12:00), Konrad Sumara (16:00), Marvin Nabroth (16:20), Niklas Schild (16:40), Tetiana Povar (17:30), Alexandr Prozorov (17:50), Fatima Hojeij (18:10), Gabriela Perez Andrade (16:20 tomorrow), Jana Rieger (17:50 friday)

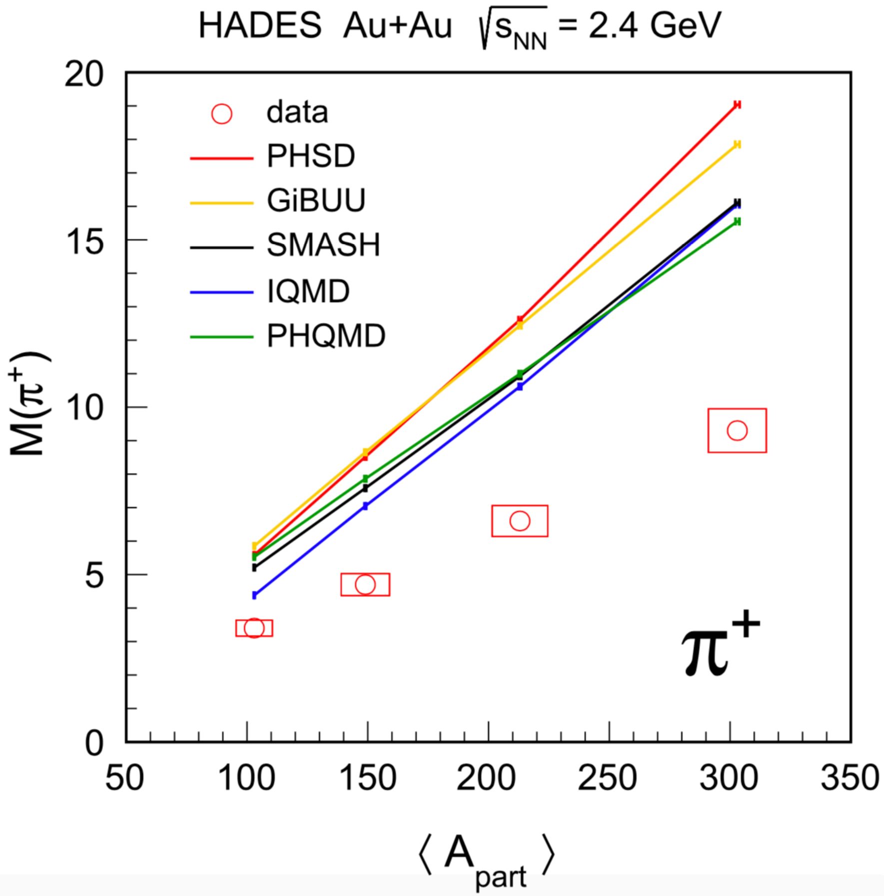
HADES Collaboration Meeting in Dresden, March 2020

Backup slides

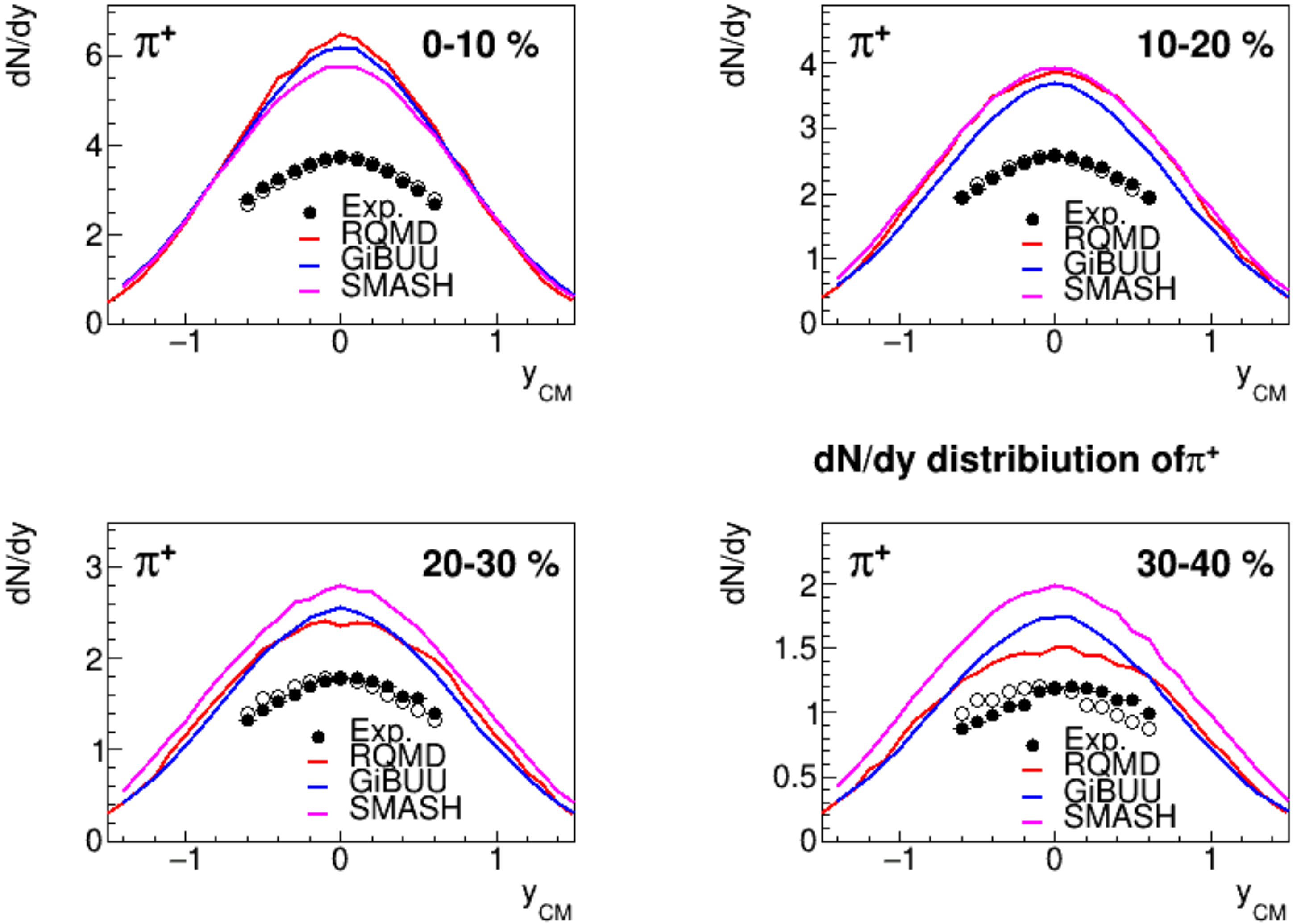
Yields vs. transport models from HADES Au+Au analysis

Fig from: J. Adamczewski-Musch *et al.* (HADES Collaboration) Eur. Phys. J. A **56,** 259 (2020).





dN/dy distributions vs. transport models (π^+)



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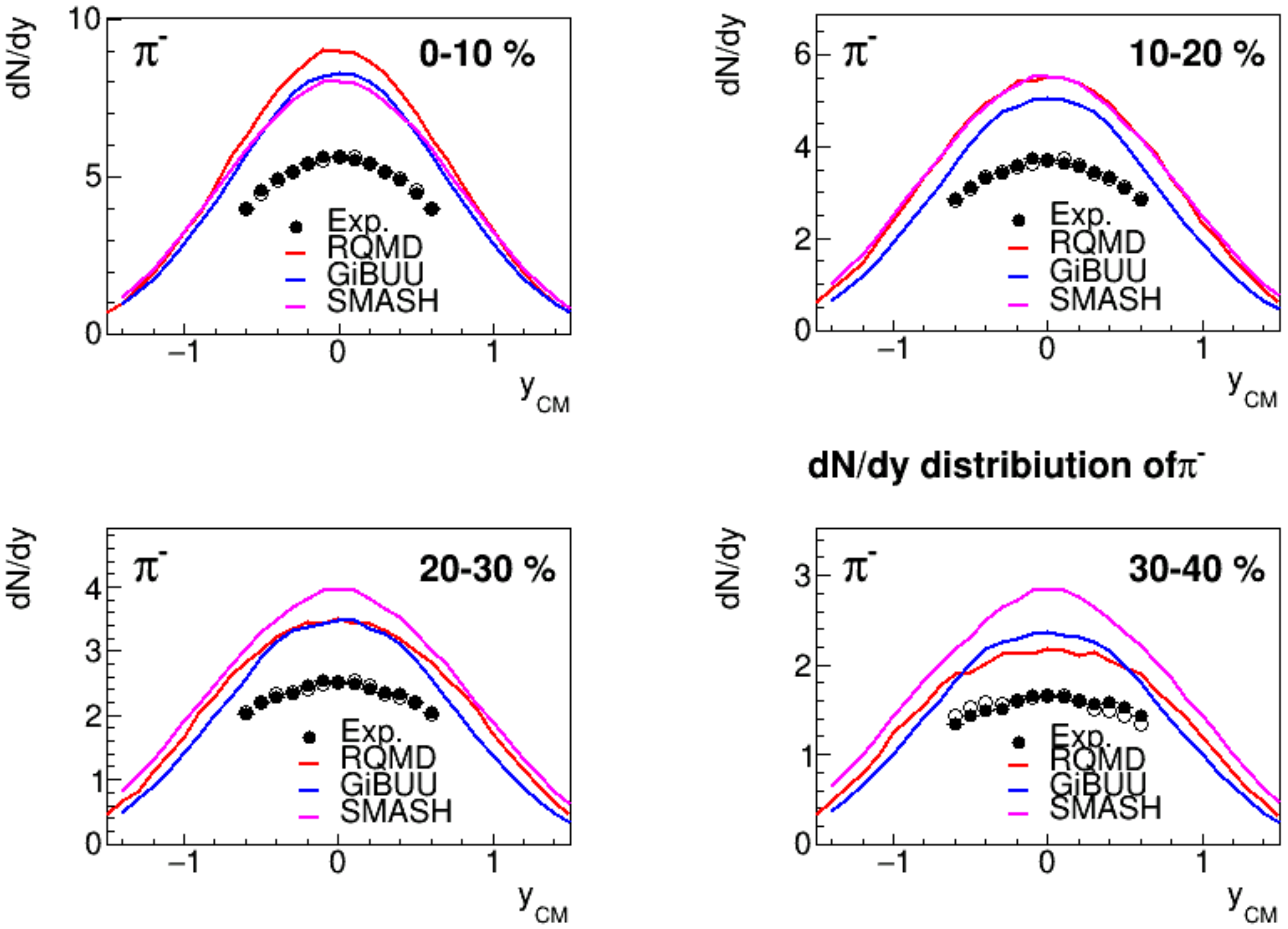
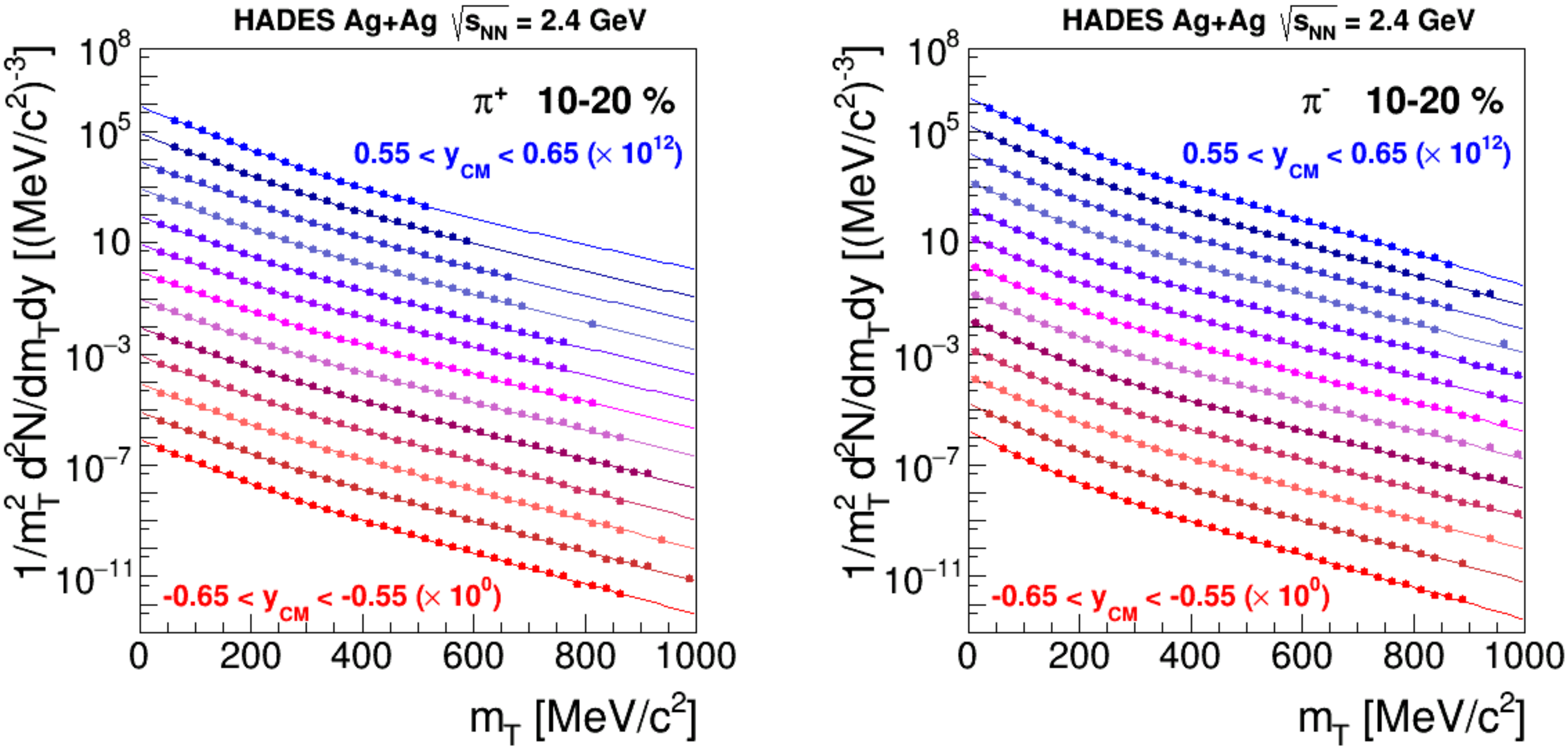


dN/dmt distributions for remaining centrality classes



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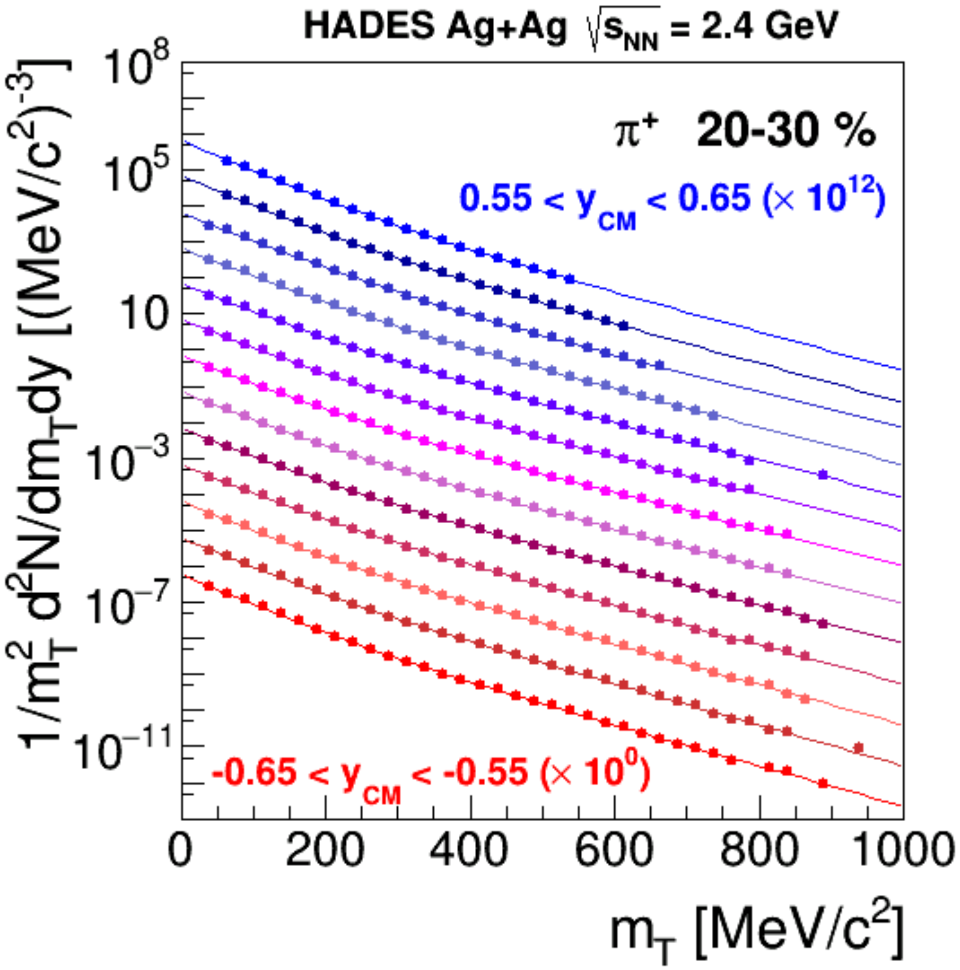

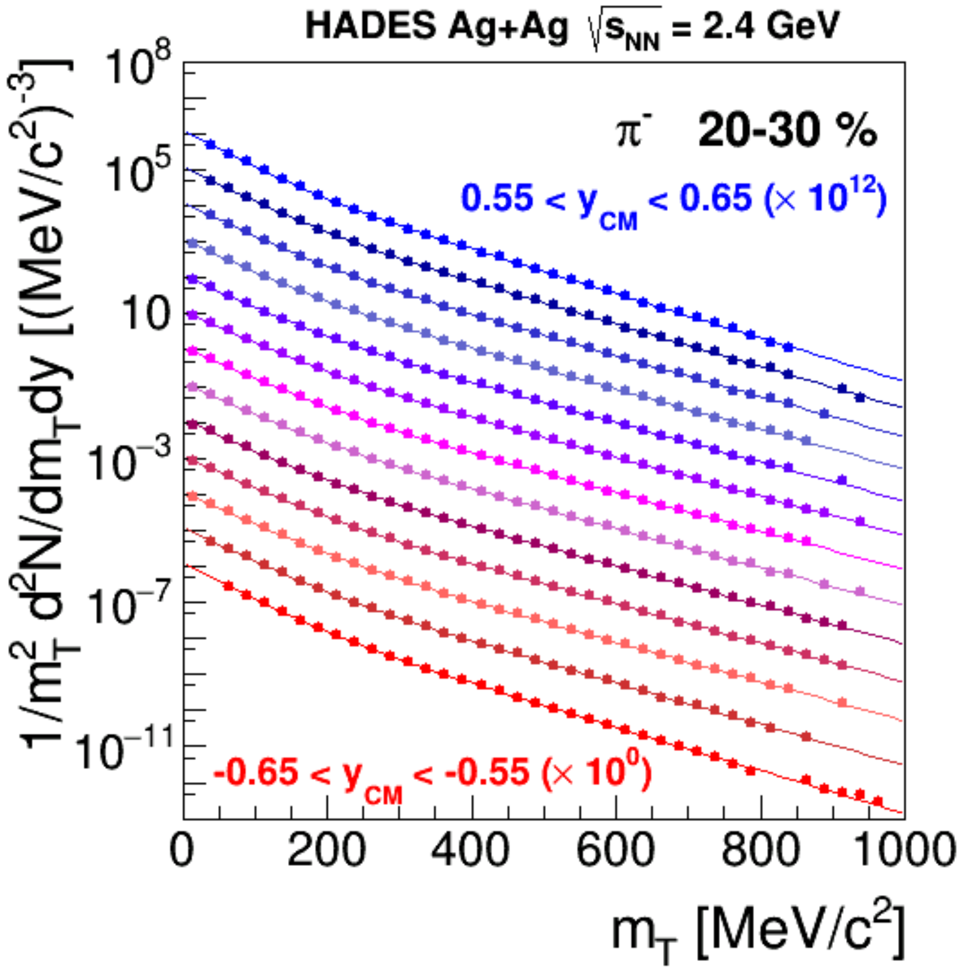

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