Light Nuclei Production in Au+Au Collisions

Melanie Szala for the HADES Collaboration

Strangeness in Quark Matter 2019

11 June 2019, Bari (Italy)

Outline

Introduction

HADES

Particle Analysis

Statistical Description

Coalescence Parameters B_A

Summary and Outlook

Foto: J. Hosan/GSI

Motivation

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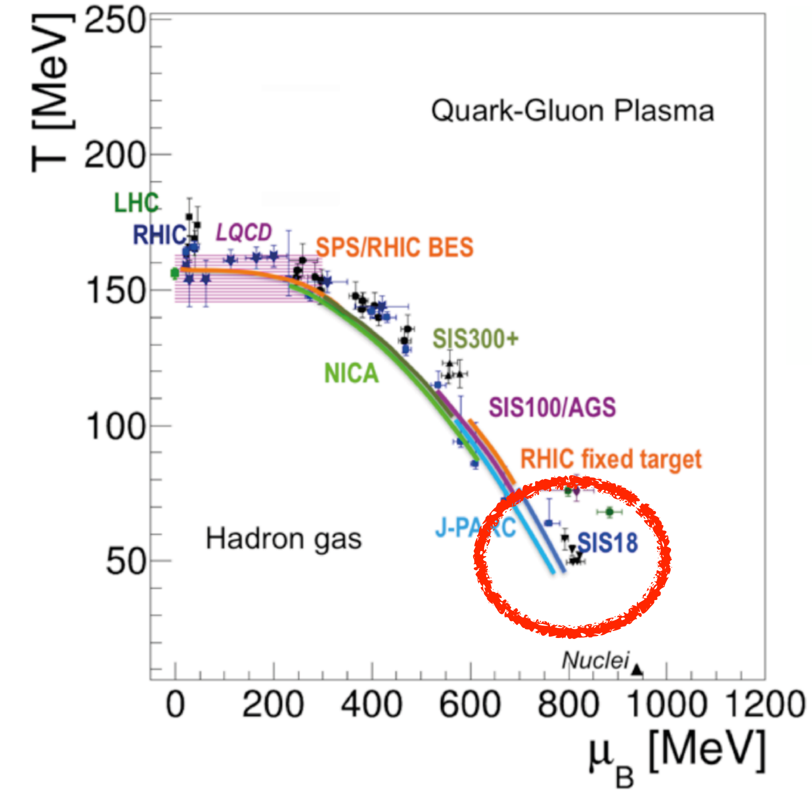
- HADES located at SIS18, GSI
(energy regime up to $\sqrt{s_{NN}} \approx$ 2-3 GeV)



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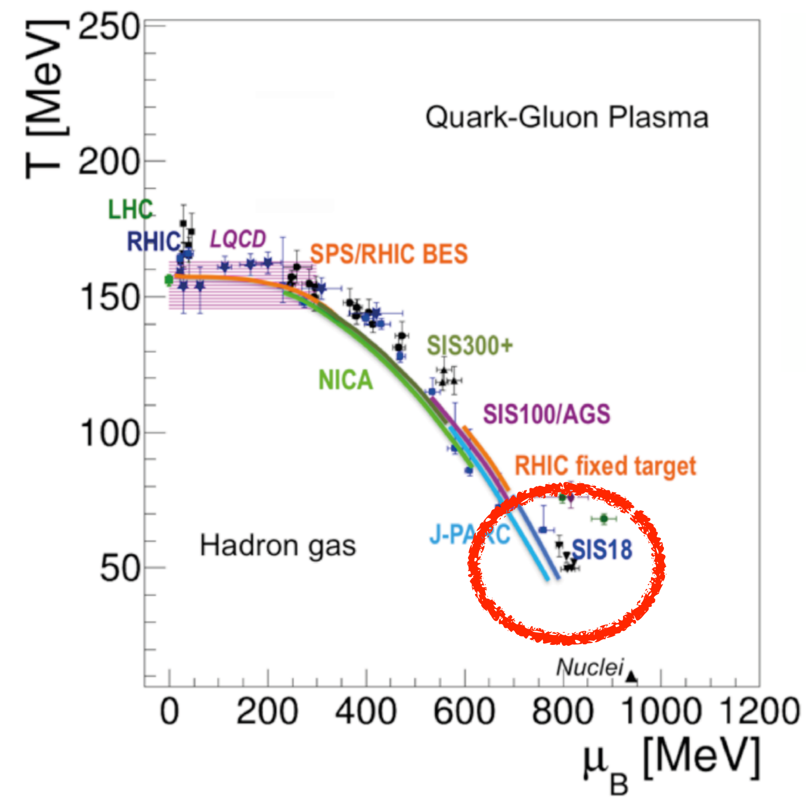
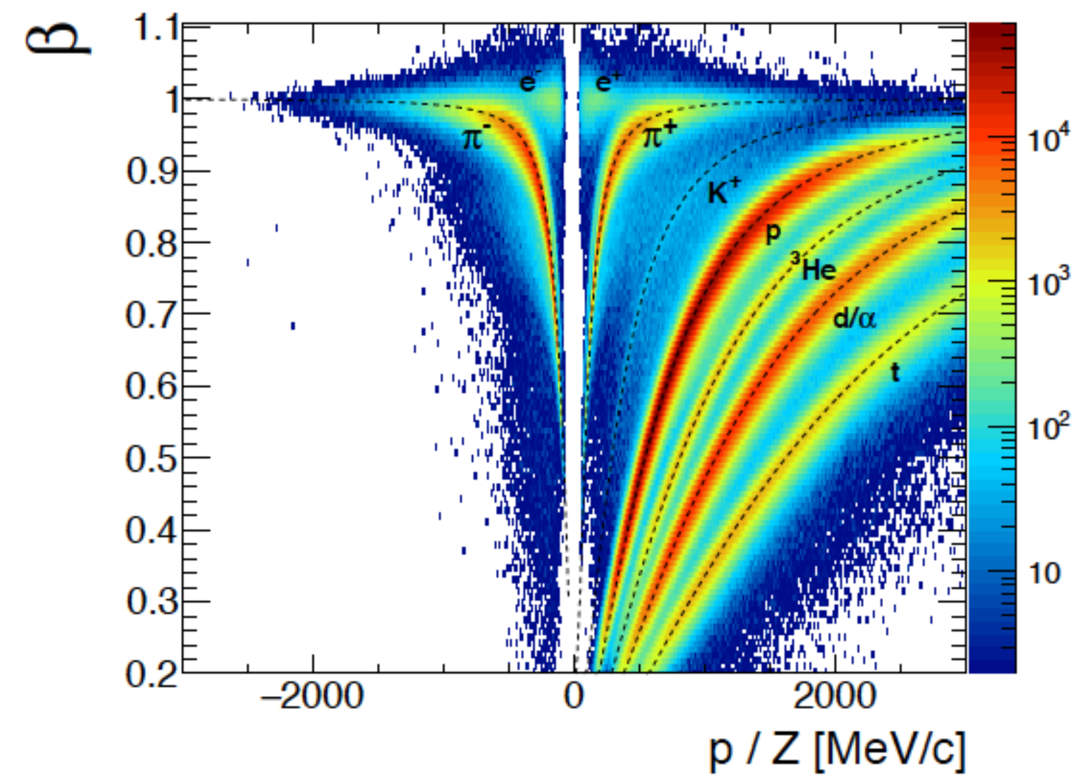
- Clear hierarchy in particle multiplicities (M):
  - $M_p \approx 100$
  - $M_\pi \approx 10$
  - $M_{K+} \approx 10^{-2}$, $M_{K-} \approx 10^{-4}$
  - $M_{\text{bound p}} \approx 50$





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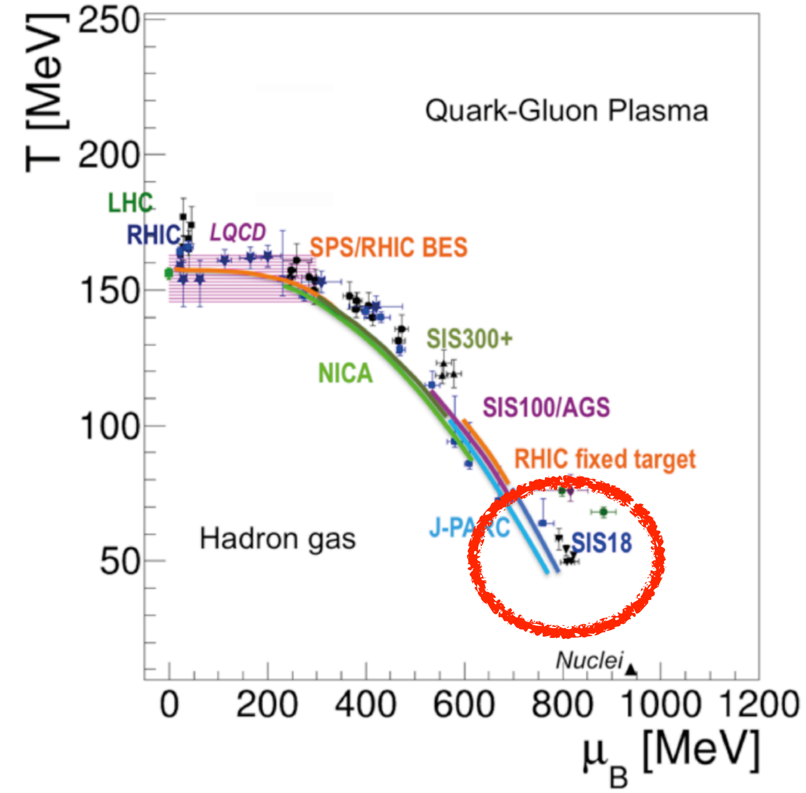
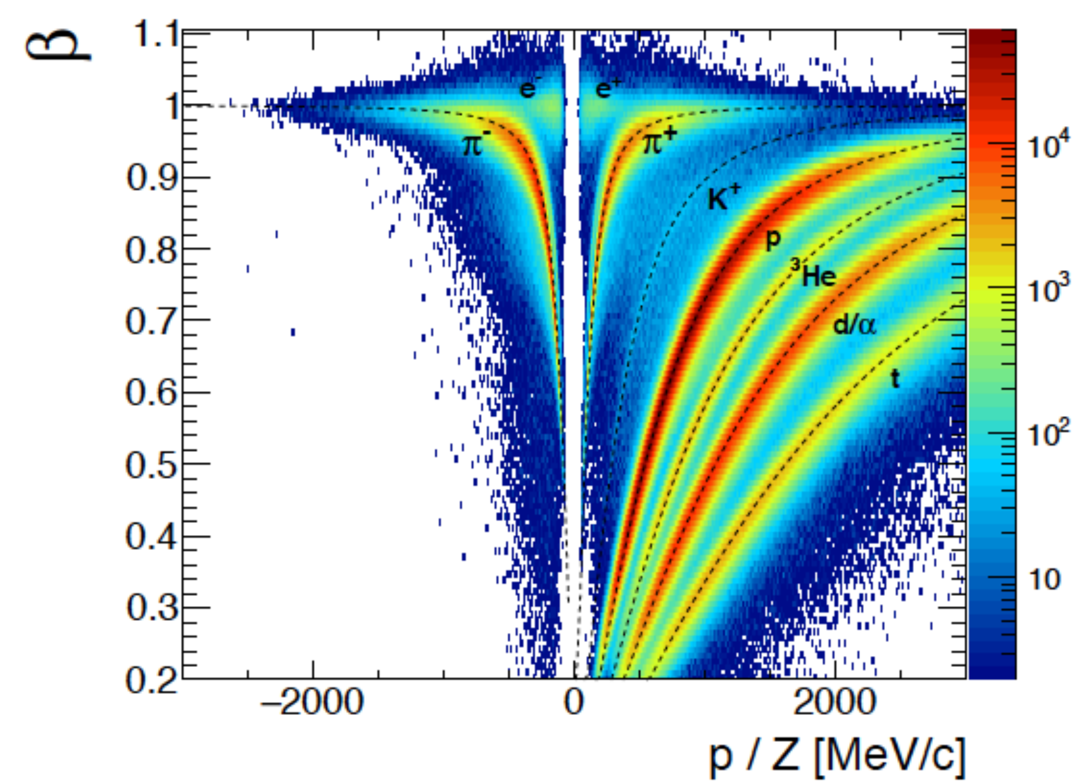
- Light nuclei not a rare probe, contribute to the bulk
- Detailed investigations needed to understand created medium





Formation of Light Nuclei

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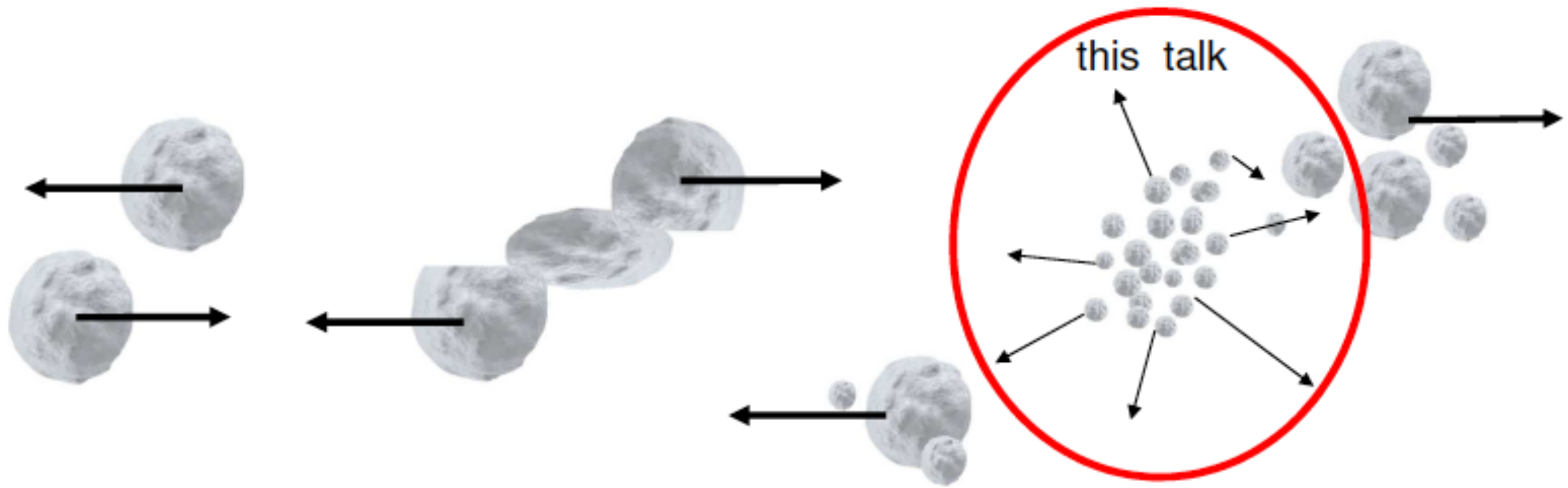

Two distinguished regions

- mid-rap. participants
- spectator break-up regions
- no clear separation between projectile/target spectators and participants at HADES energies

Y. Leifels, EMMI Workshop
11.02.-13.02.2019, GSI

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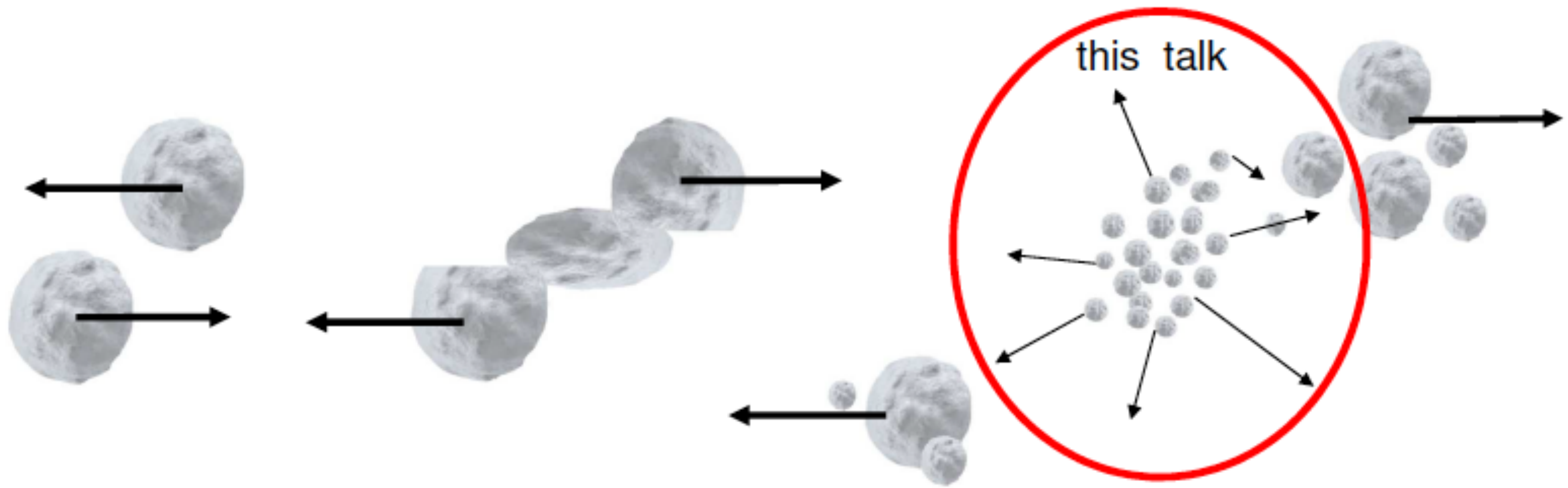

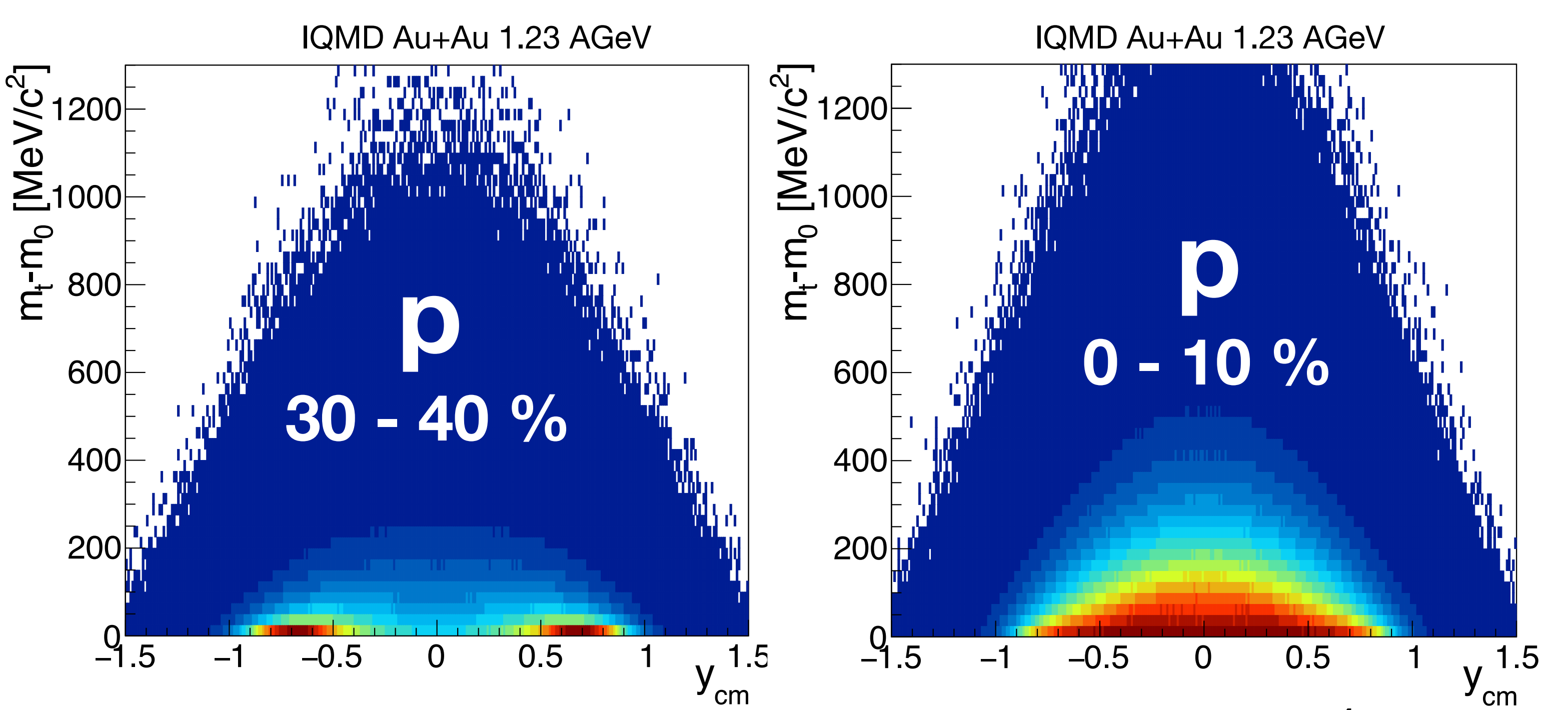

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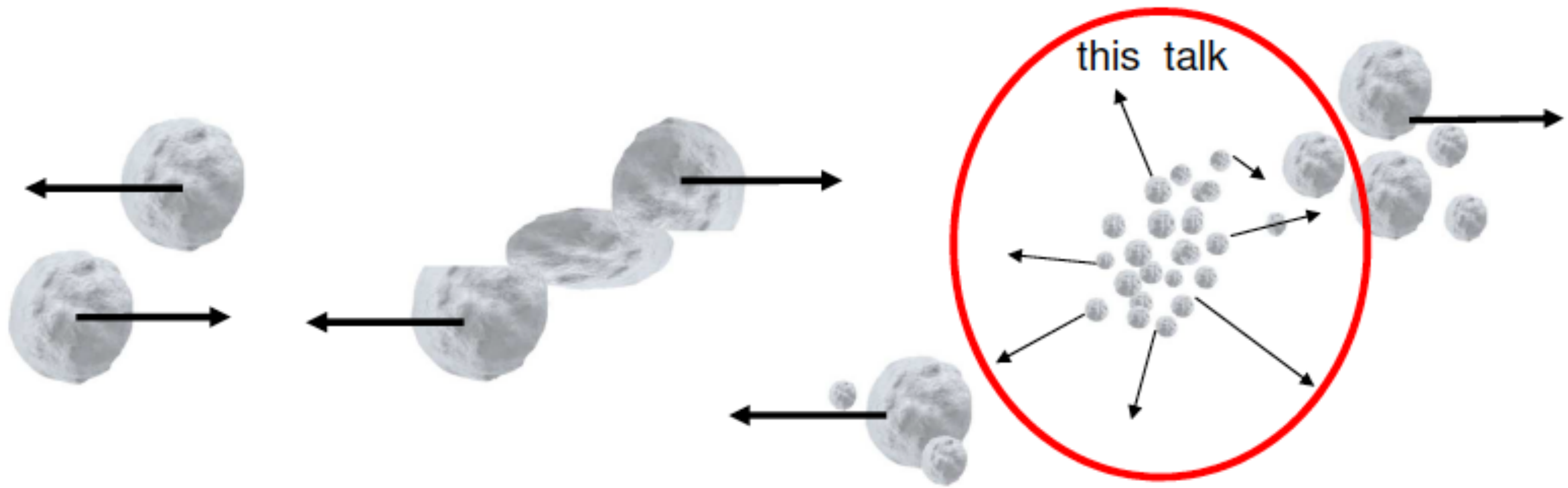
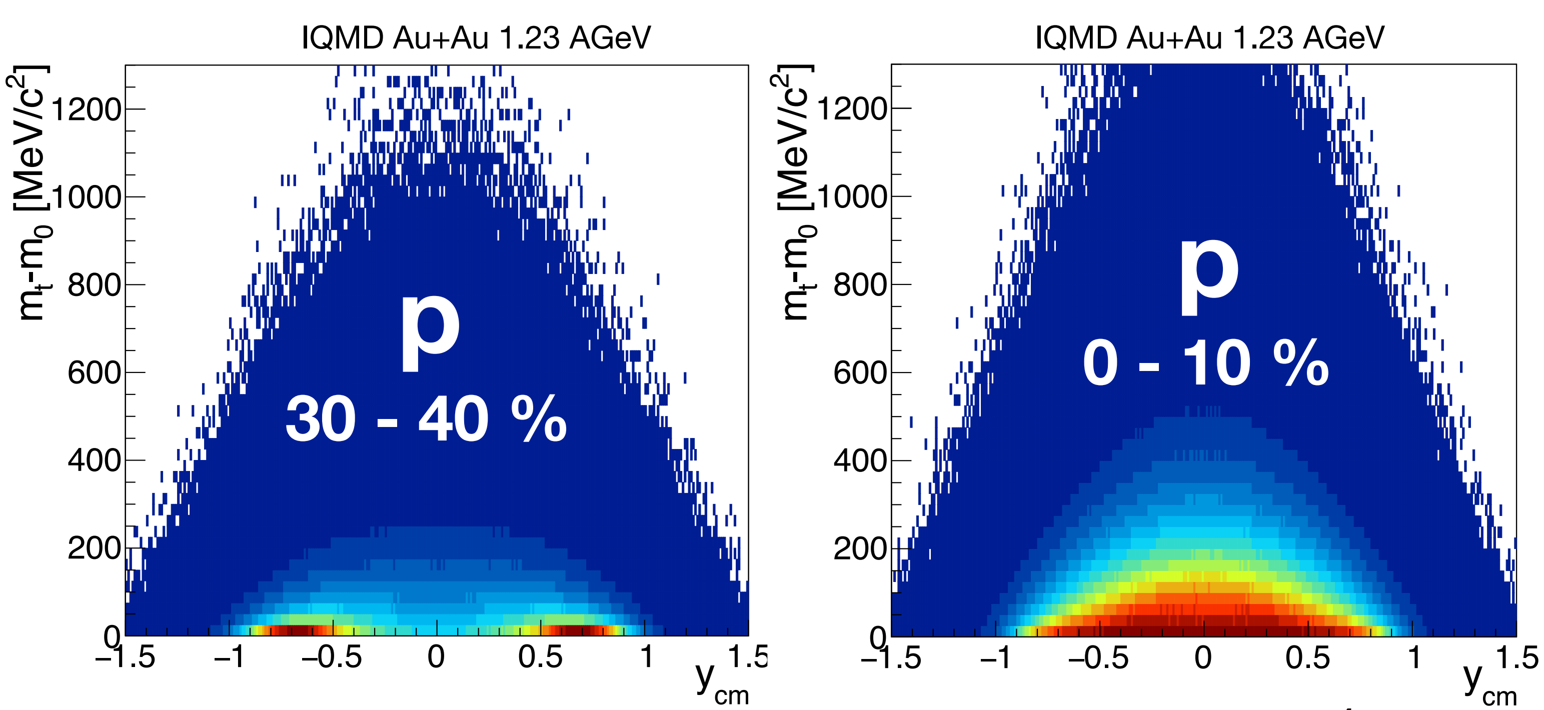




Two distinguished regions

- mid-rap. participants
- spectator break-up regions
- no clear separation between projectile/target spectators and participants at HADES energies
- ▸ mid-rap. source observed best in **central collisions**

HADES spectrometer

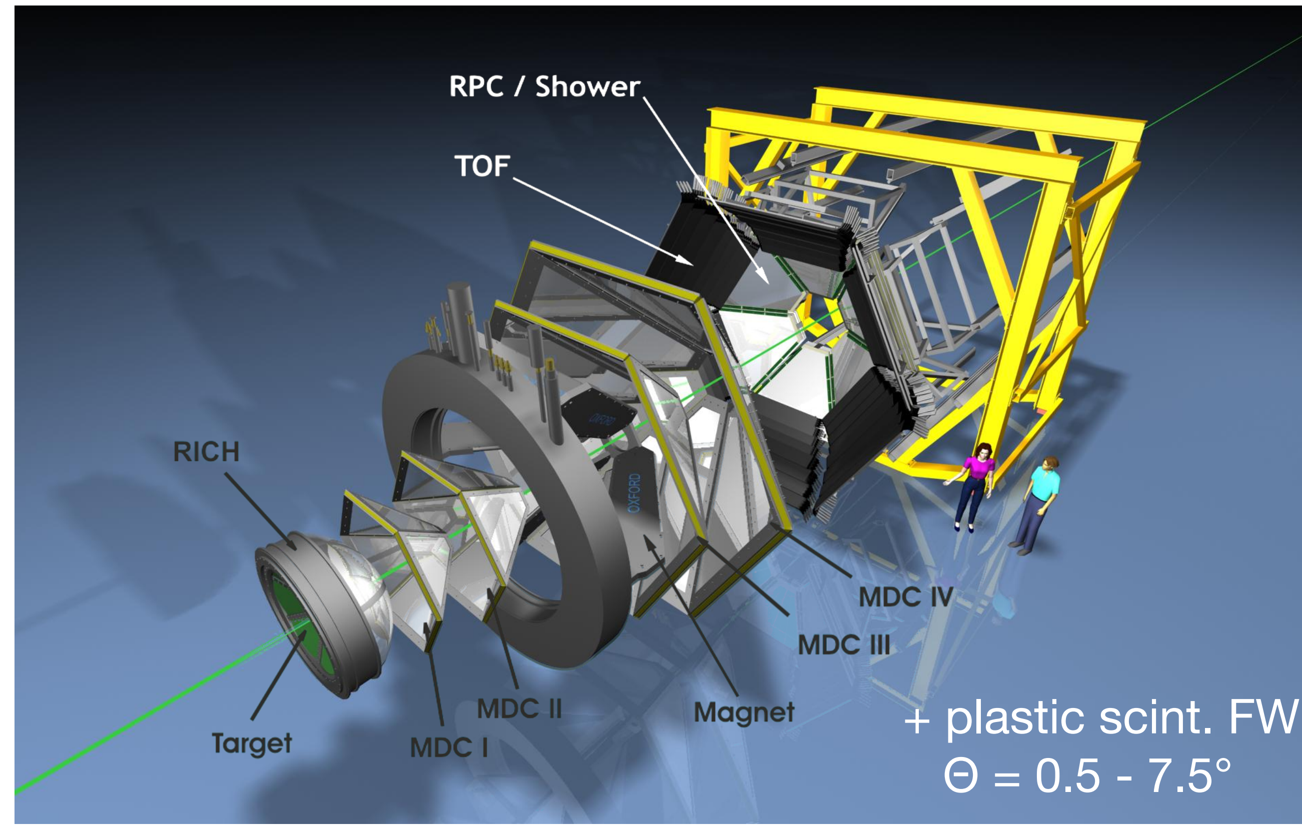
Located at SIS18, GSI, fixed target experiment

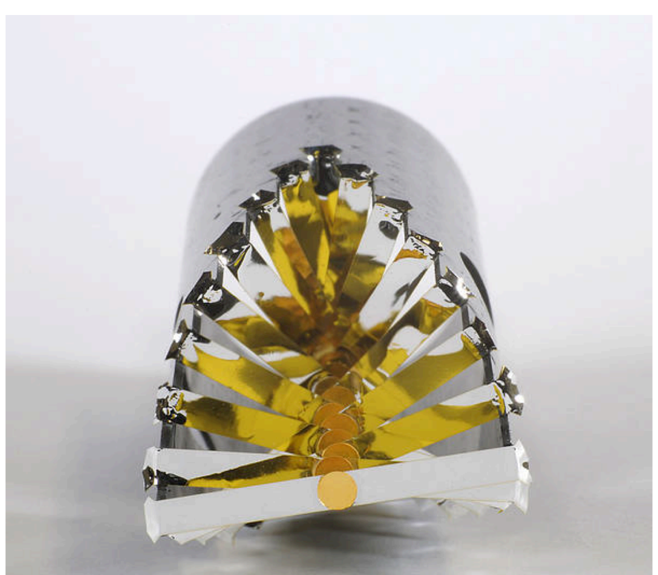
Large acceptance

- Symmetric azimuthal coverage
- 18°-85° in polar angle

Fast detector

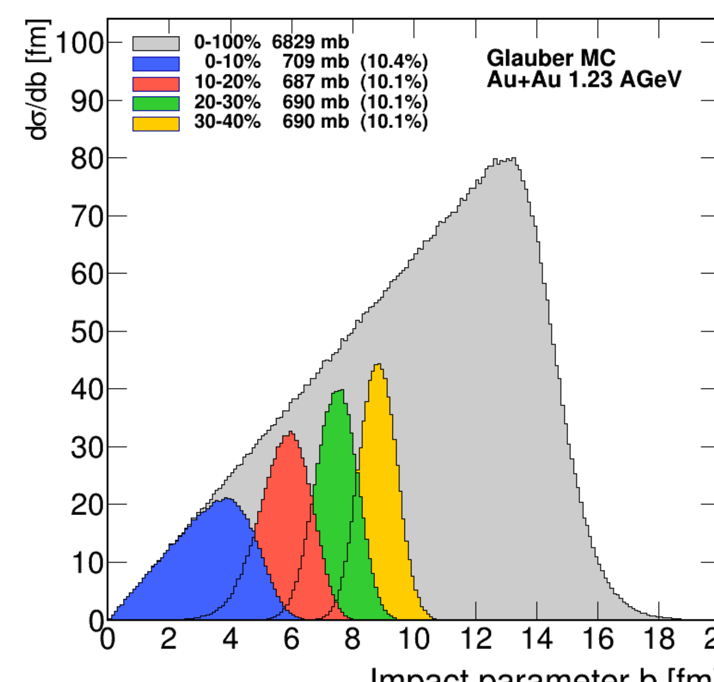
- Trigger rate 8 kHz (16 kHz in Ag+Ag)
- Large statistics





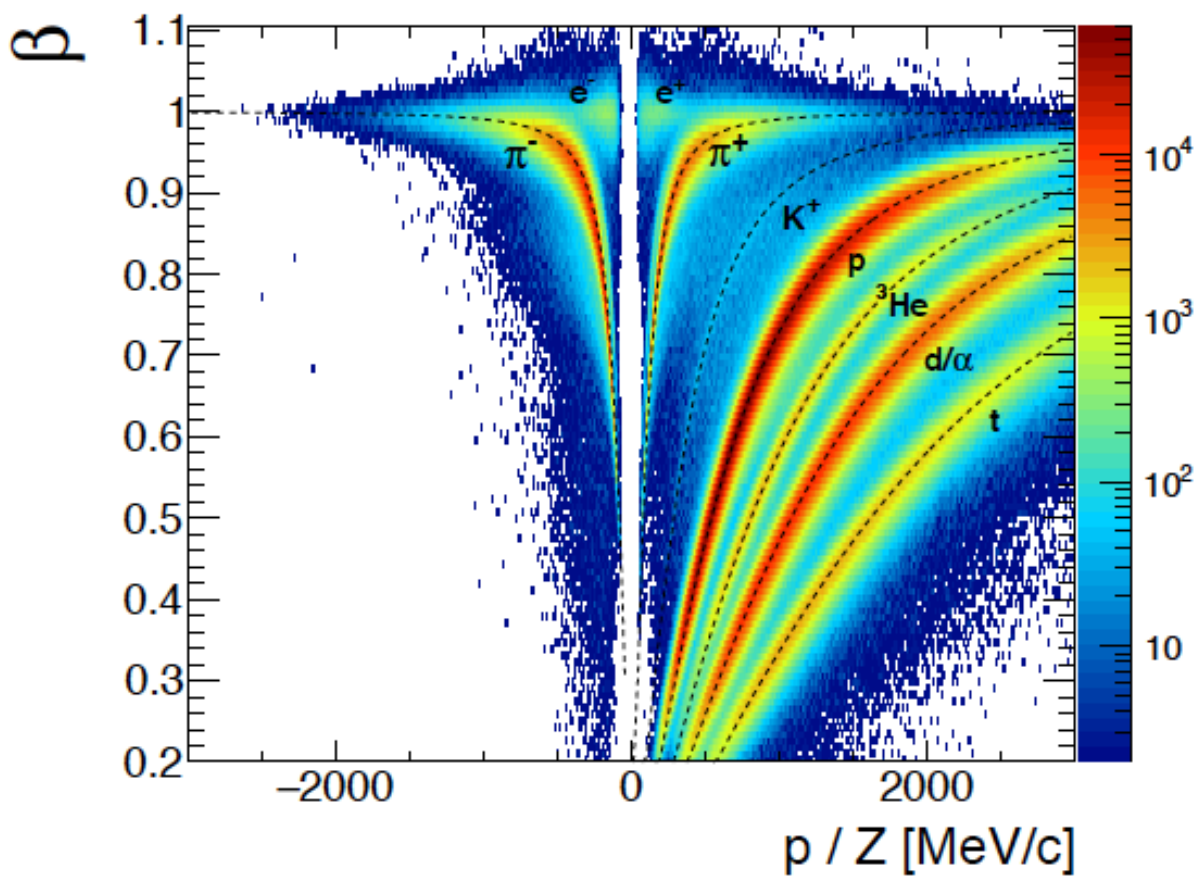
Au + Au @1.23 AGeV, $\sqrt{s_{NN}}$=2.4 GeV

- 15 fold segmented Au target
- 2.2 x 10^9 events analysed
- Trigger on 40% most central collisions

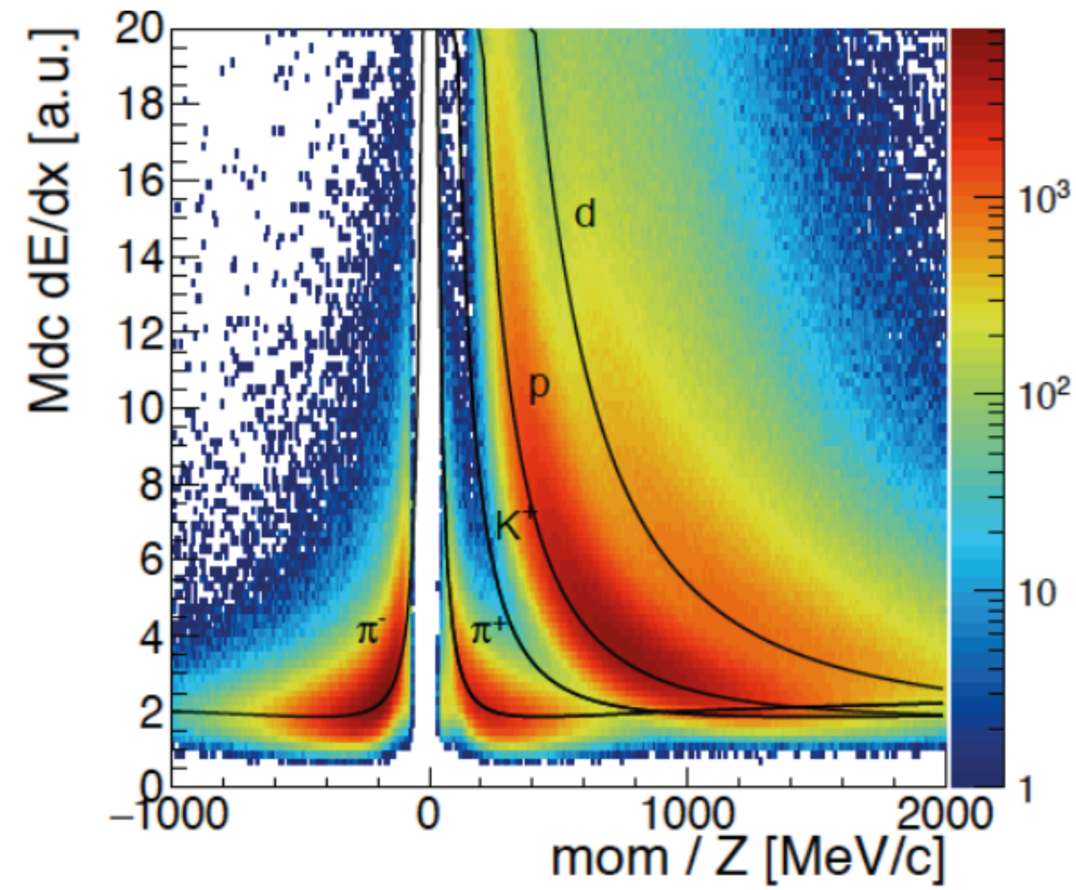


HADES Collaboration, Eur. Phys. J. A (2018) 54: 85

Particle Identification



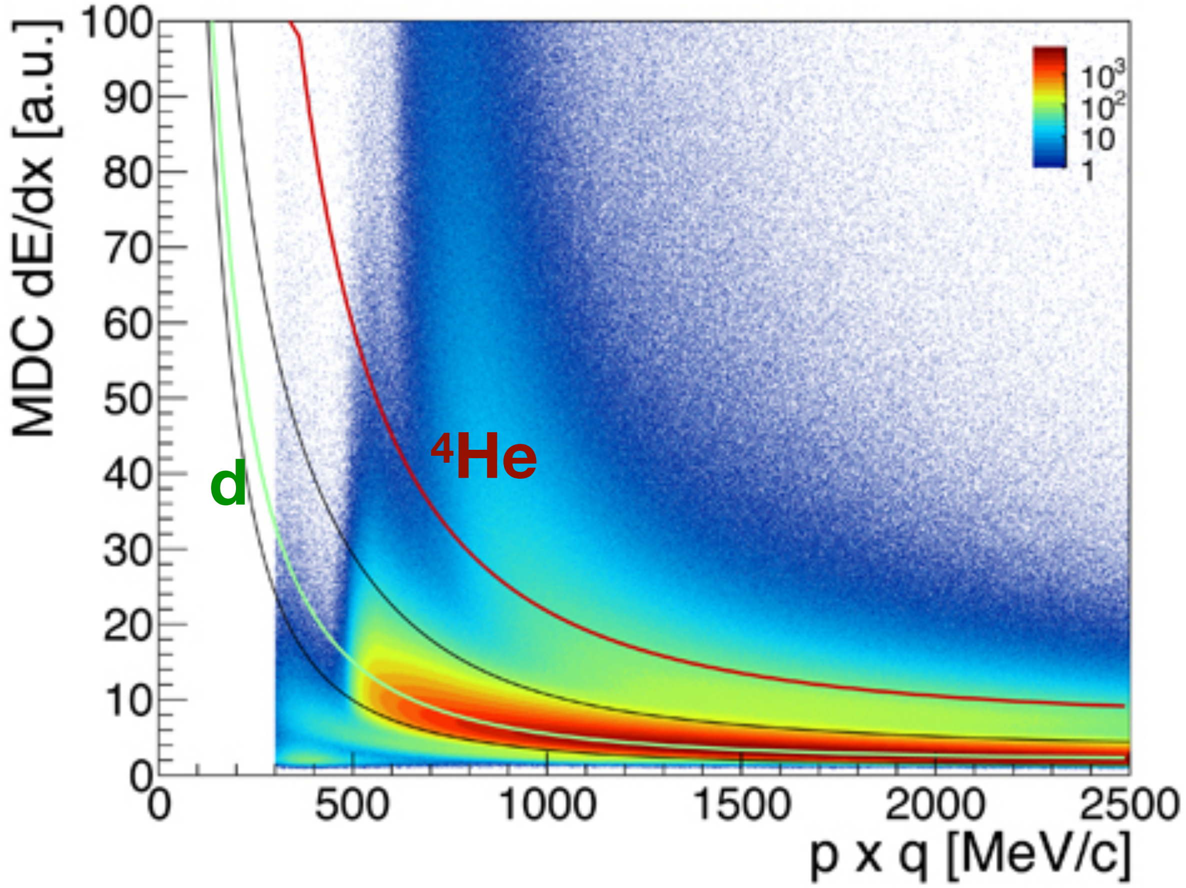
Time-of-Flight



Energy loss

- drift chambers
- TOF detector

PID of p, d, t

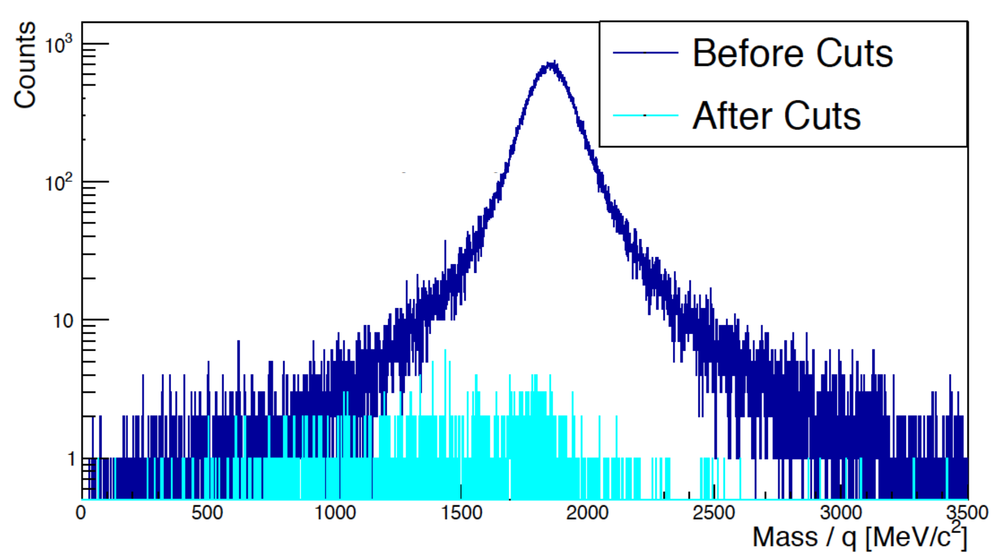


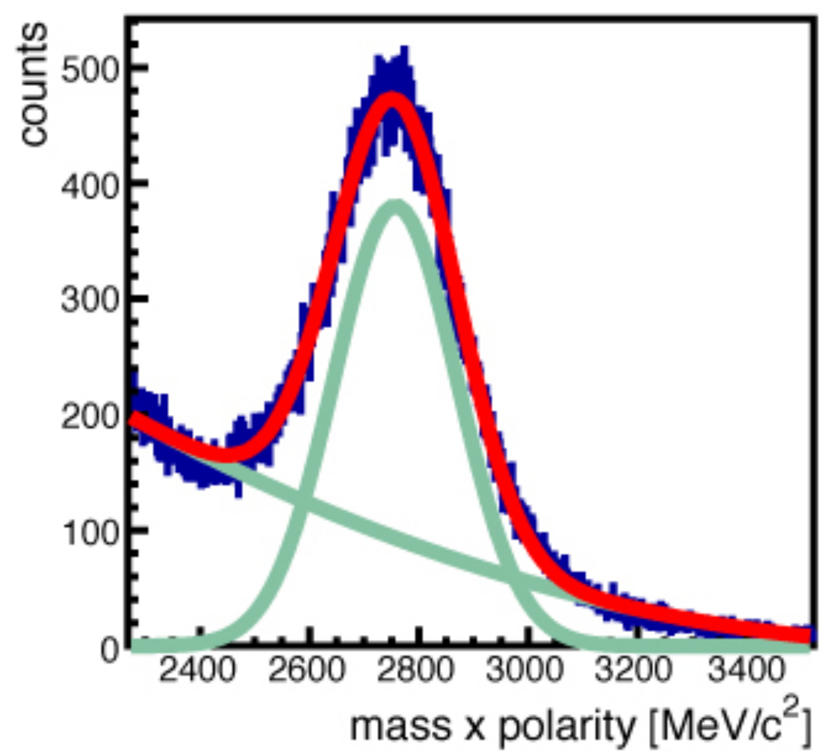
MDC dE/dx cut

Suppresses ^{4}He contamination for deuterons

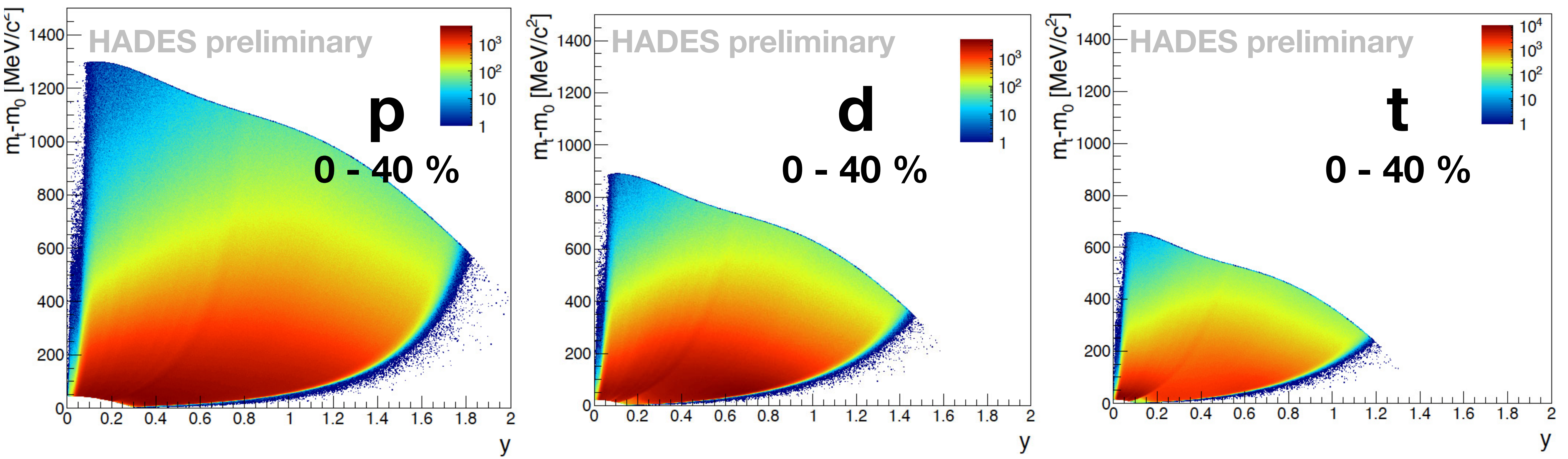
Background

Background is reduced by subtraction from the signal in each m_T-m_0 bin



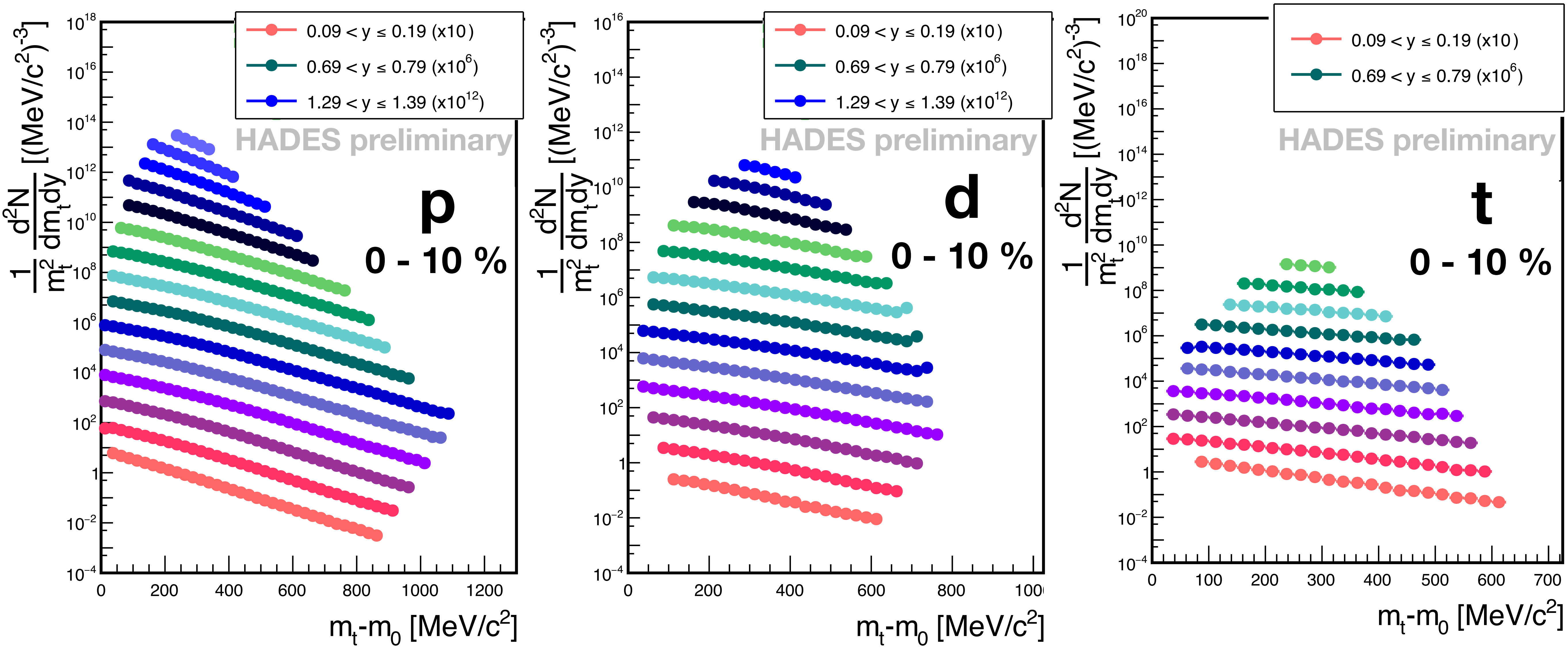


Phase space coverage



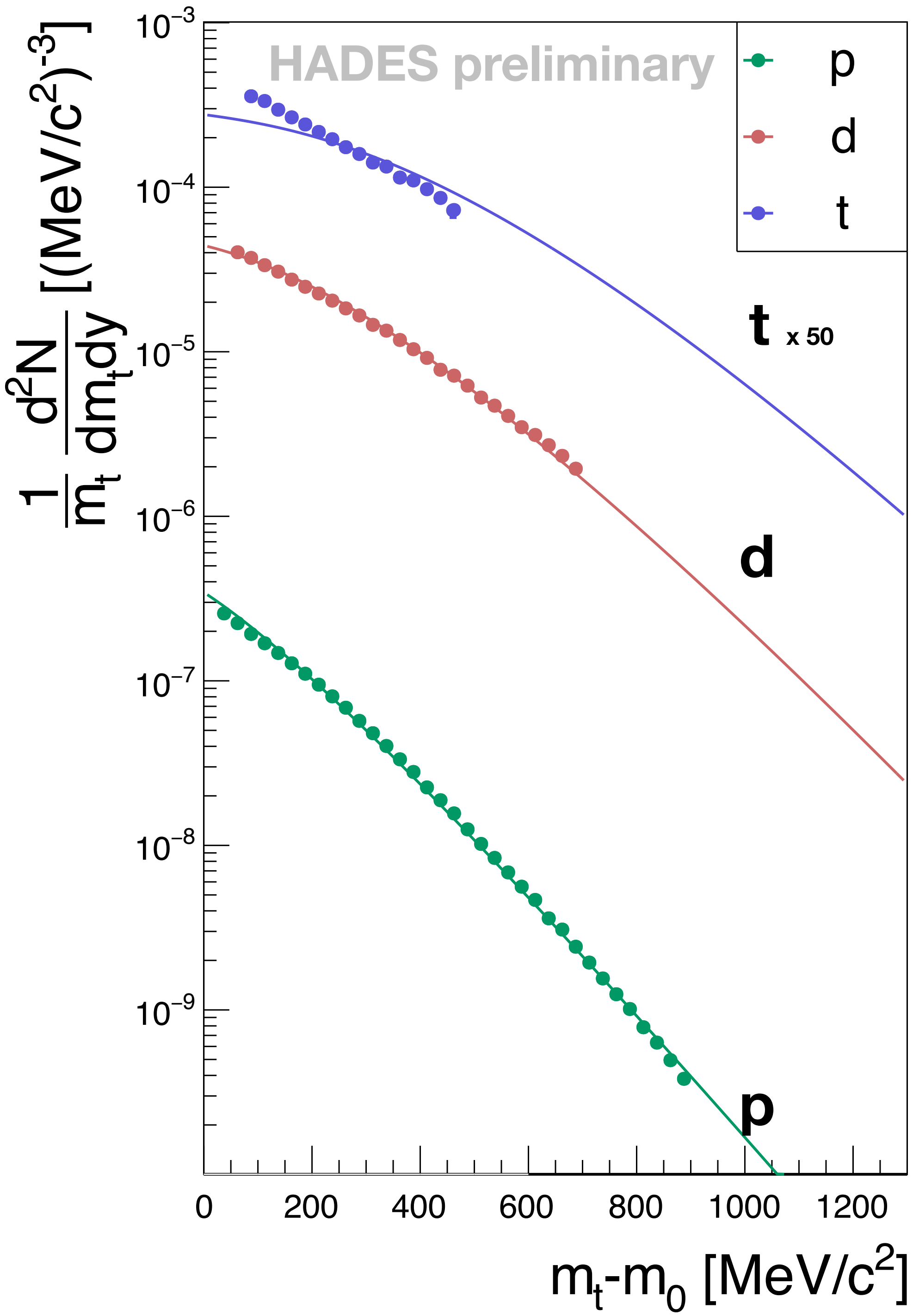
Track candidates

Particle spectra



High statistic multi-differential data

Blast Wave Fit



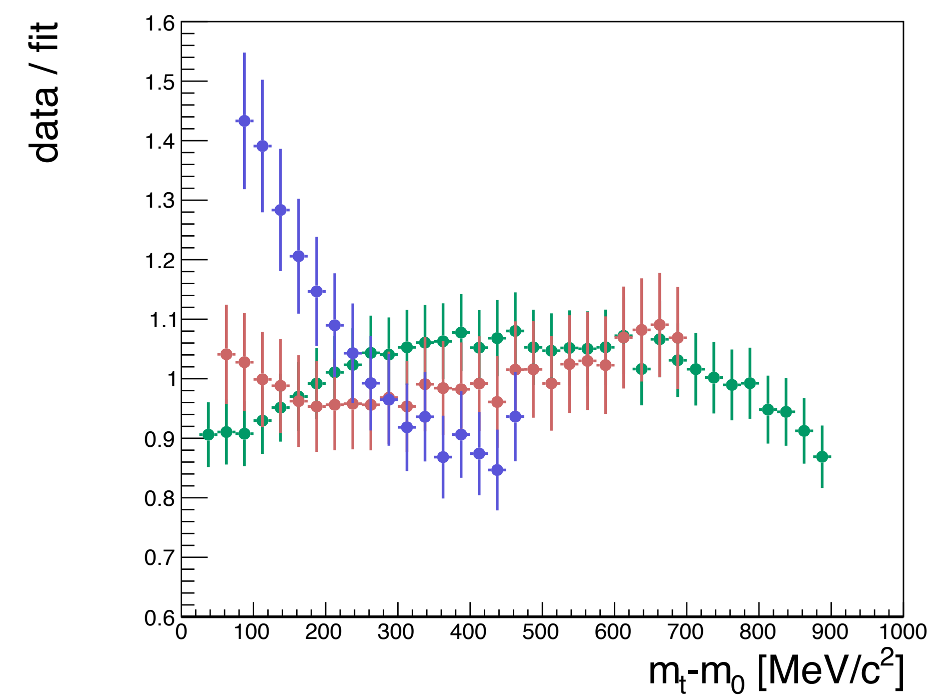
Blast Wave Model: Phys.Rev.C48:2462-2475,1993

$$\frac{dn}{m_T\,dm_T} \propto \int_0^R r\,dr\,m_T I_0\Big(\frac{p_T\sinh\rho}{T}\Big)K_1\Big(\frac{m_T\cosh\rho}{T}\Big)$$

T_{kin} = 66 ± 8 MeV

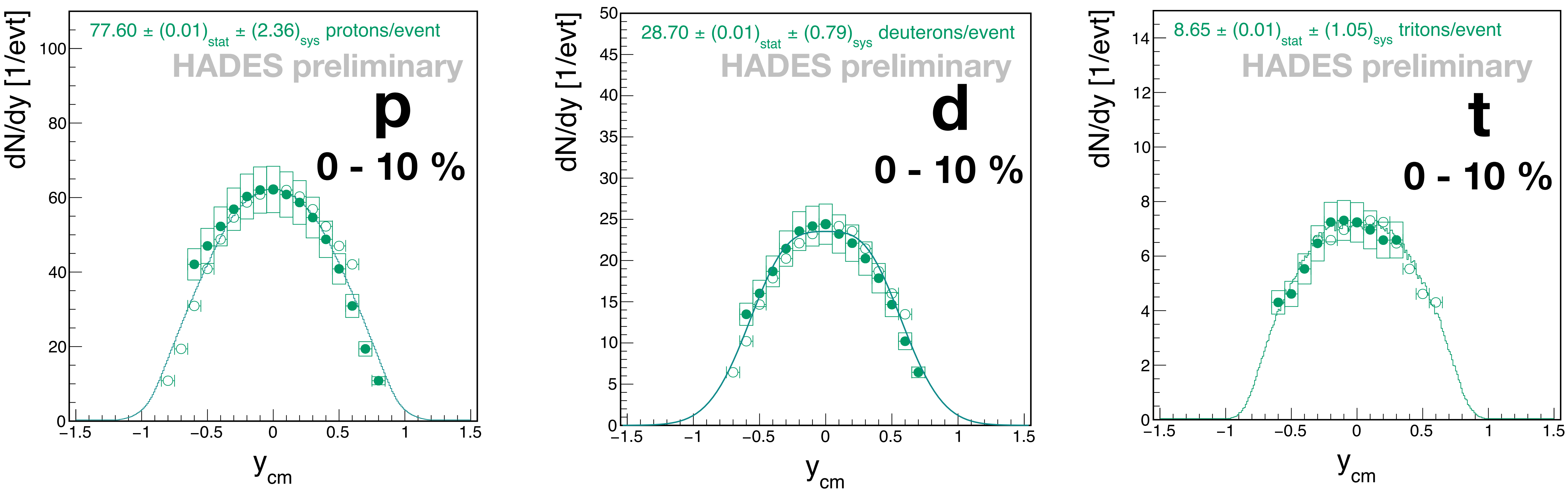
< β_r> = 0.34 ± 0.02

Linear velocity profile



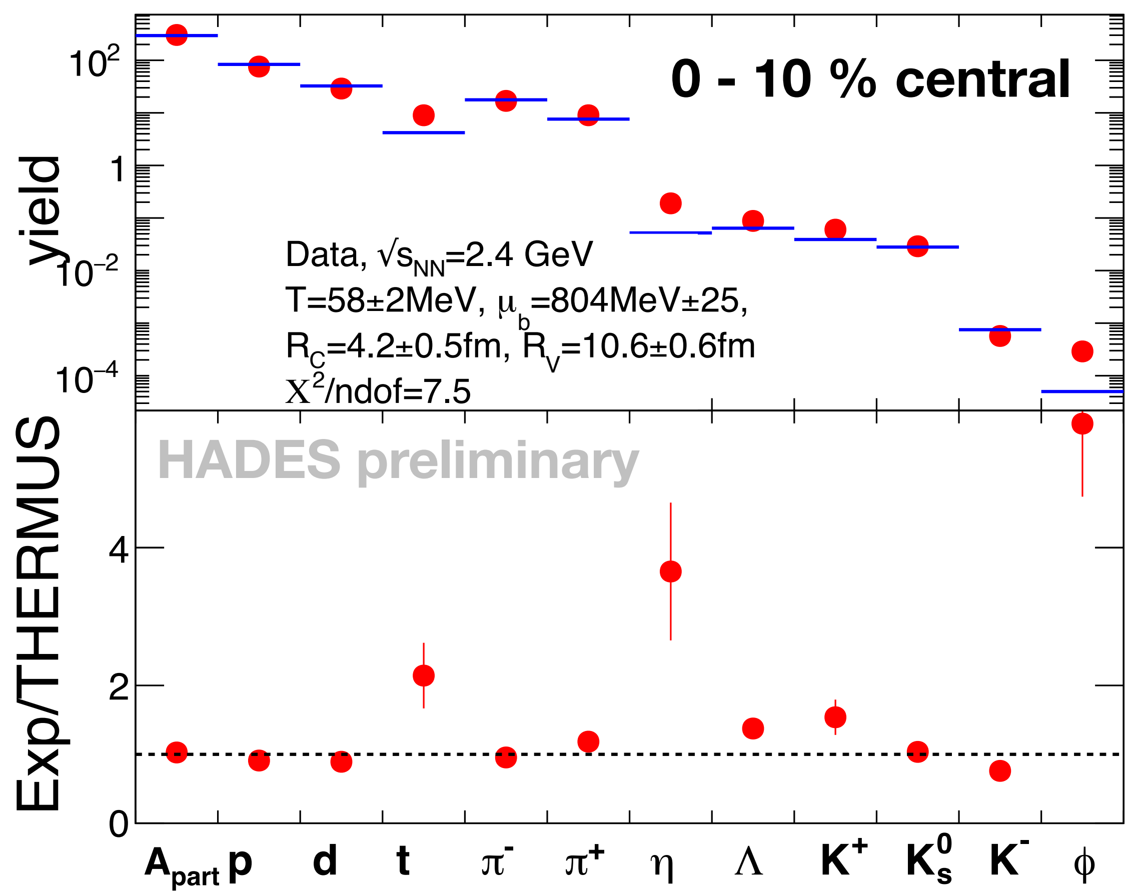
- **p, d described with simple BW model**
- **shape of t more complicated**

Particle yields



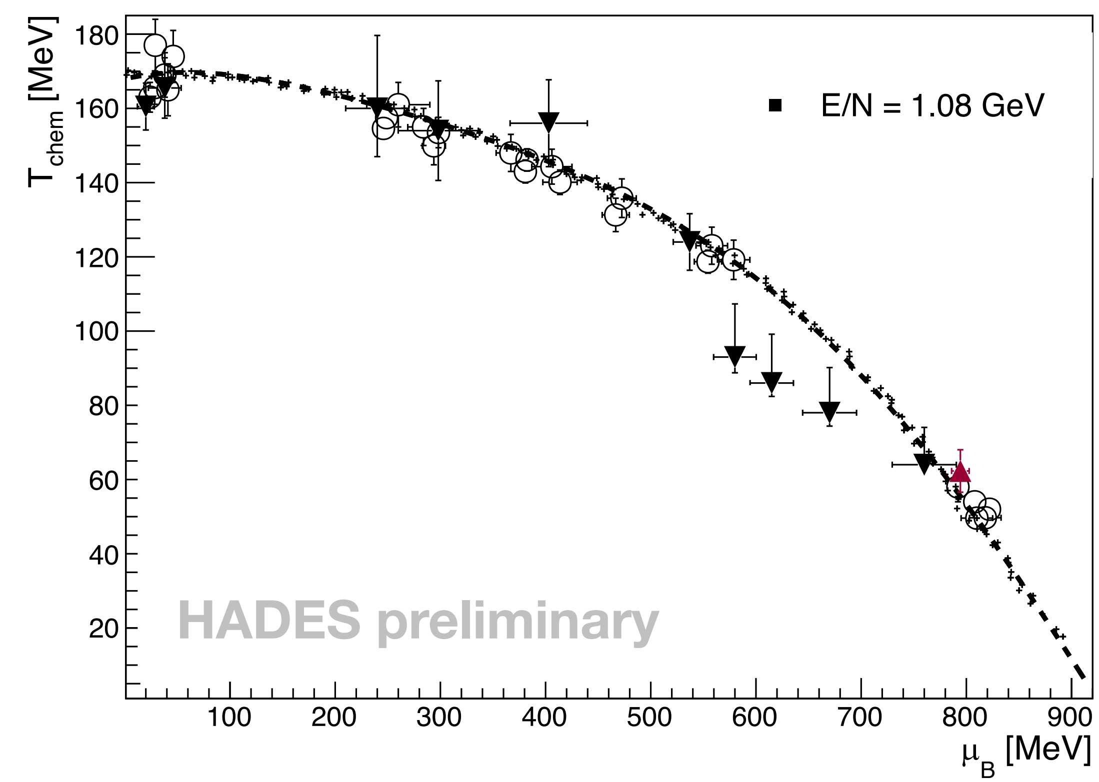
Large y coverage

Statistical model



J. Cleymans, H. Oeschler, K. Redlich, Phys.Rev. C59 (1999)

Thermus 3.0



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- Fit to HADES data consistent with previous works
- Fit to full hadron spectra results in large χ^2

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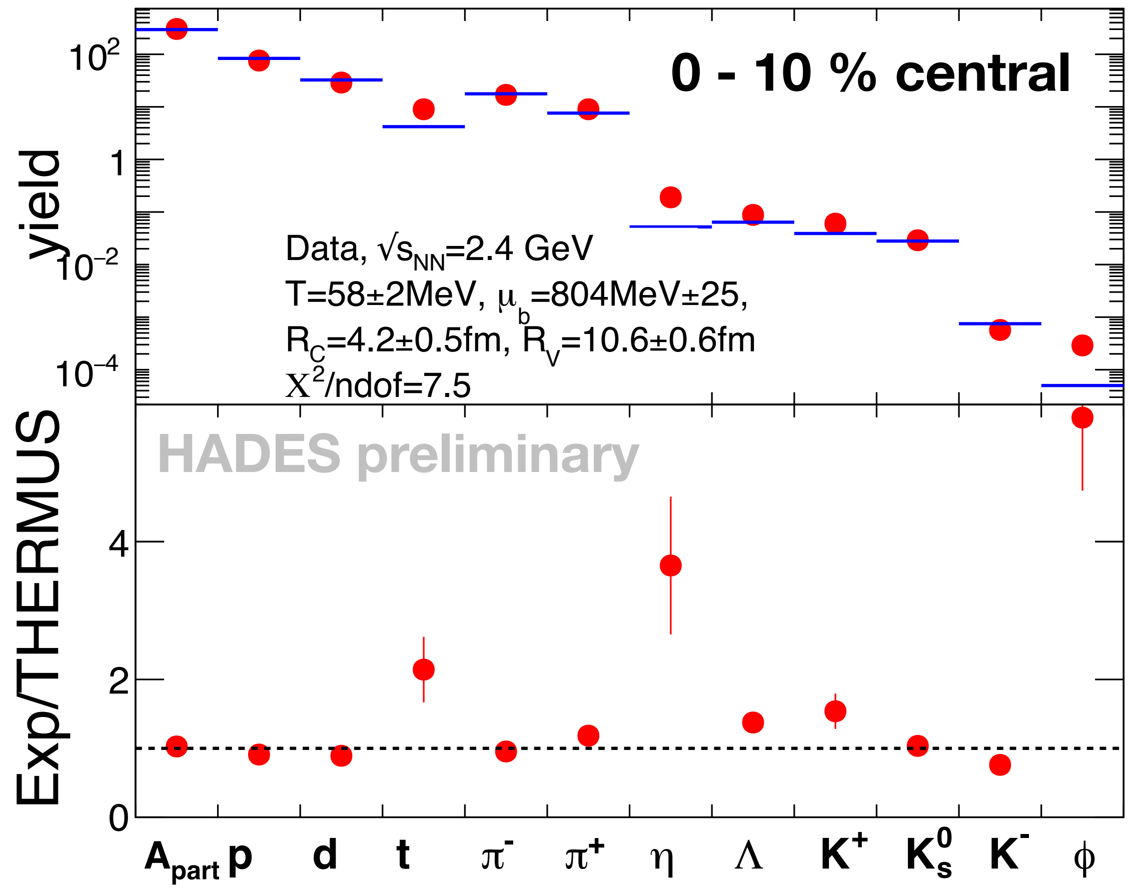

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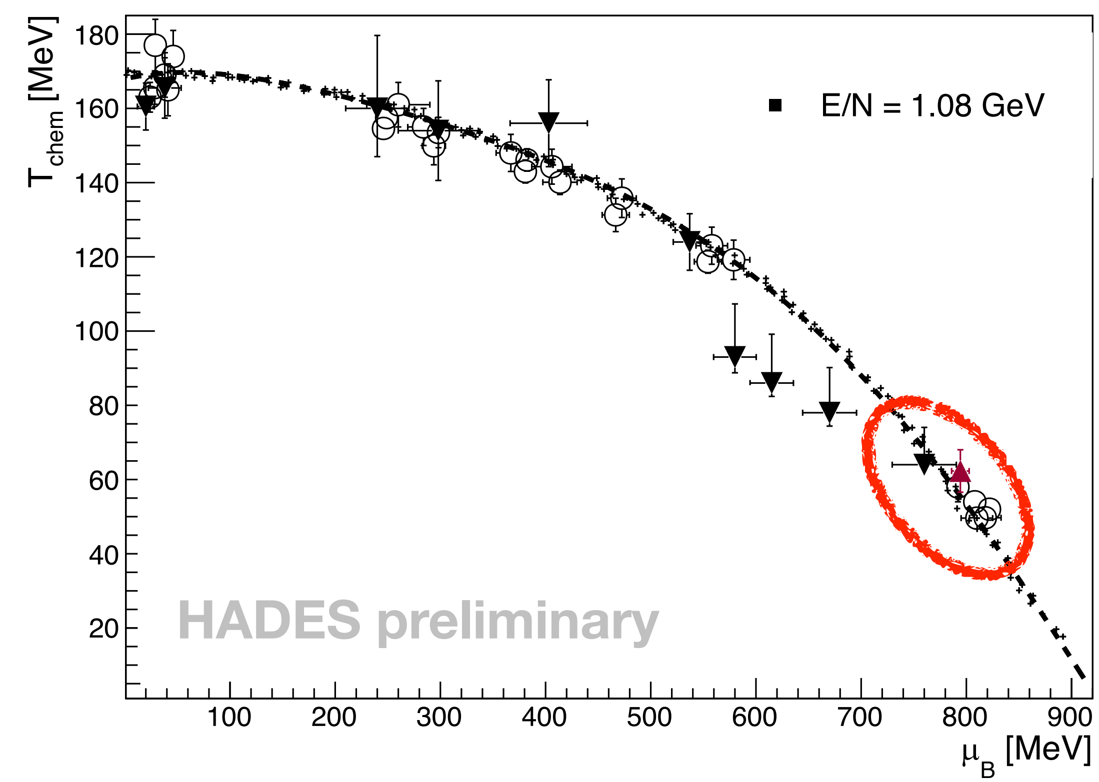

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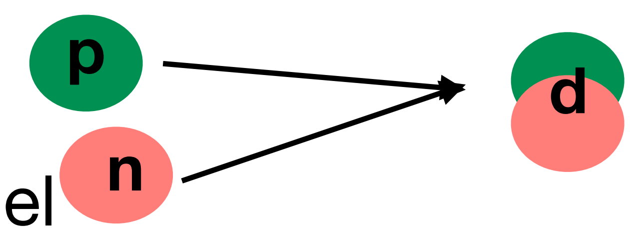
Nucleon Coalescence

- Lightly bound state, e.g. deuteron E_B =2.2 MeV
  - production in the freeze-out phase?



- Coalescence Model
  - description for the formation of deuterons by recombination of a proton and neutron
  - close enough in phase space
  - Coalescence parameter B_A: probability that number of A nucleon coalesce

- Comparing the invariant yield of the light nuclei to the invariant yield of the coalescing nucleons (assumption p = n)

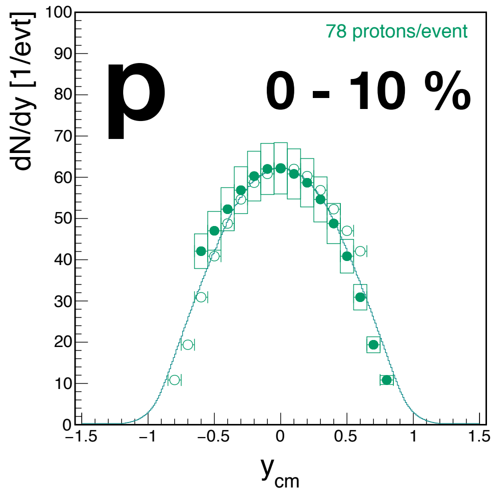
$$E_A \frac{\mathrm{d}^3 N_A}{\mathrm{d}p_A^3} = B_A \left(E_P \frac{\mathrm{d}^3 N_p}{\mathrm{d}p_p^3} \right)^A_{p_p = p_A/A}$$

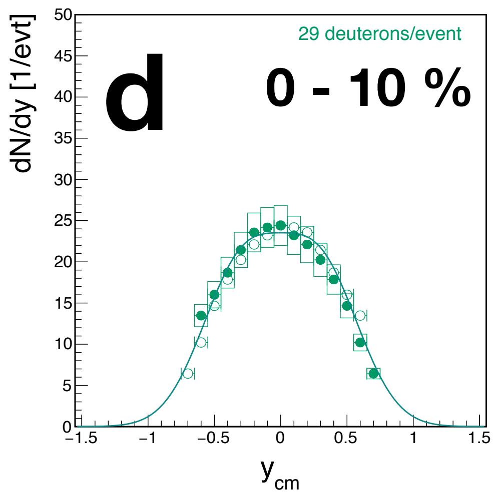
- or as a function of the rapidity y and the transverse momentum p_t

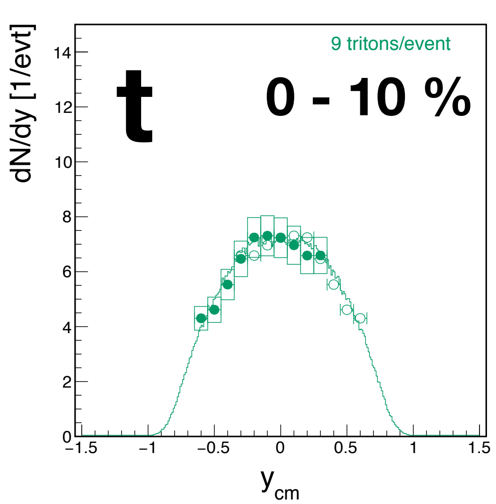
$$\frac{1}{2\pi(p_t/A)} \frac{\mathrm{d}^2 N_A}{\mathrm{d}y_{cm}\mathrm{d}(p_t/A)} = B_A \left[\frac{1}{2\pi p_t} \frac{\mathrm{d}^2 N_p}{\mathrm{d}y_{cm}\mathrm{d}p_t} \right]^A$$

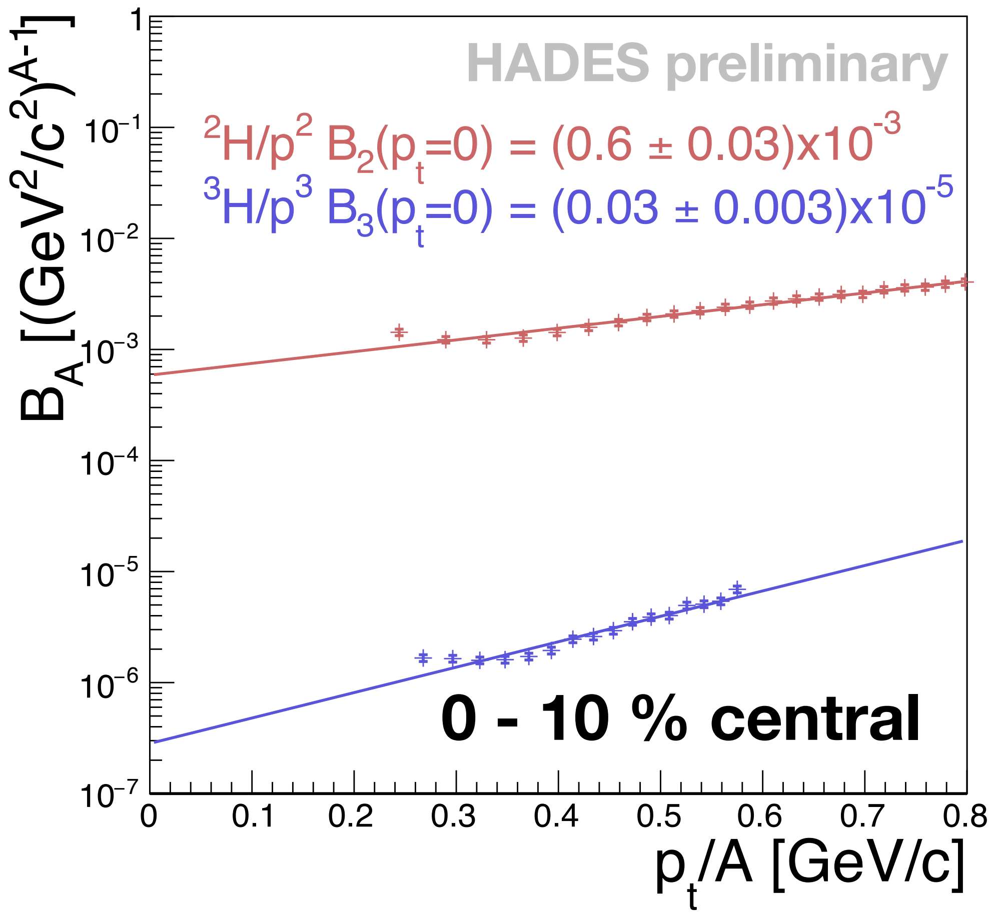
with $p_t = \sqrt{m_t^2 - m_0^2},$

Nucleon Coalescence









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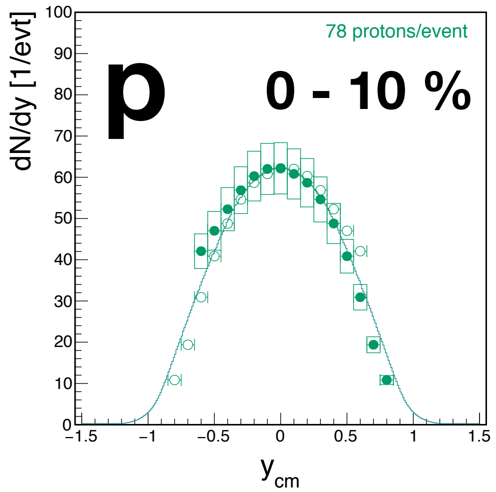

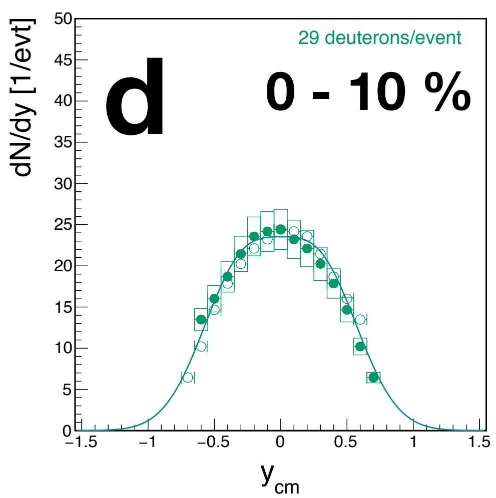

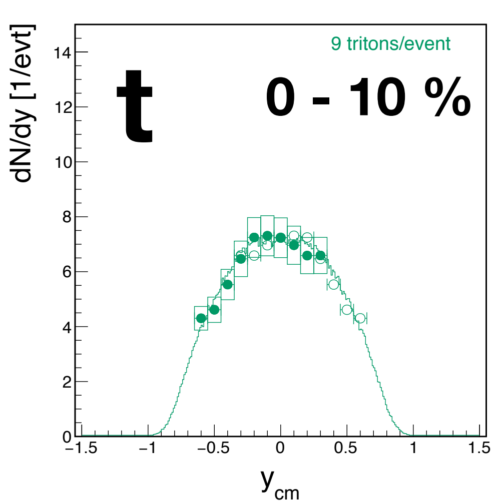

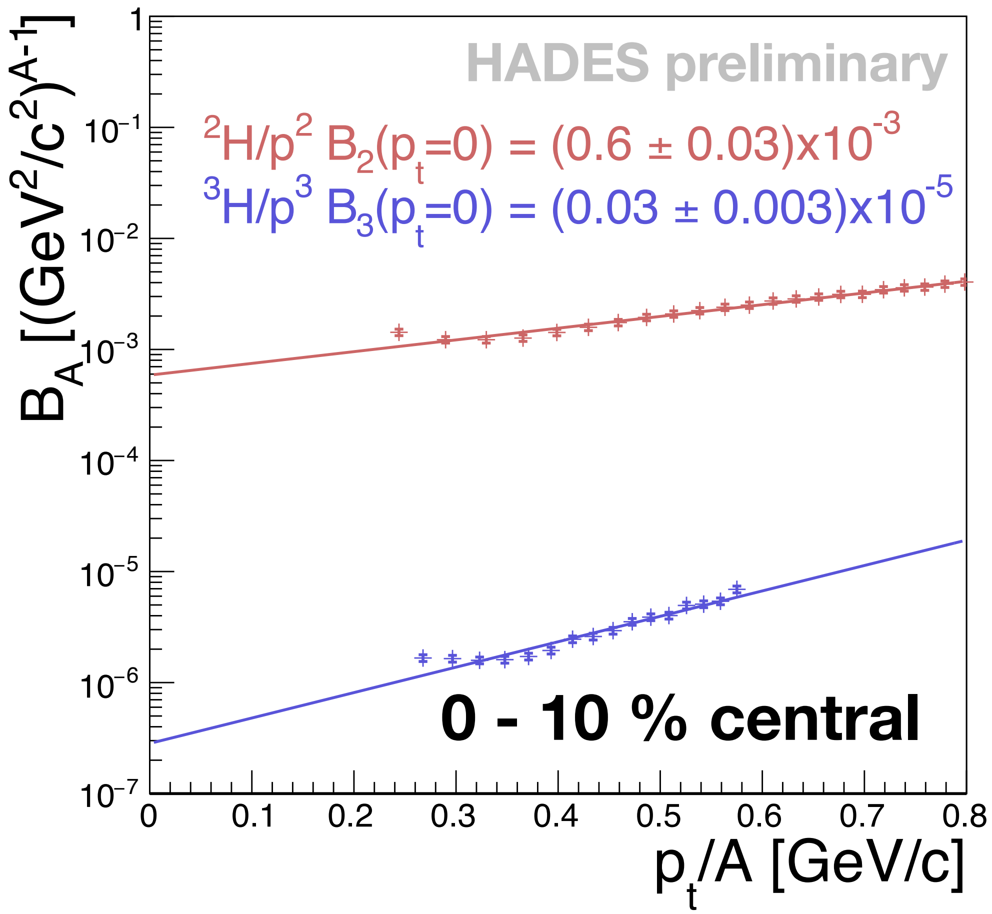

$$B_{2,integral} = \frac{29}{78^2} = 4.7x10^{-3}$$

$$B_{3,integral} = \frac{9}{78^3} = 1.9x10^{-5}$$

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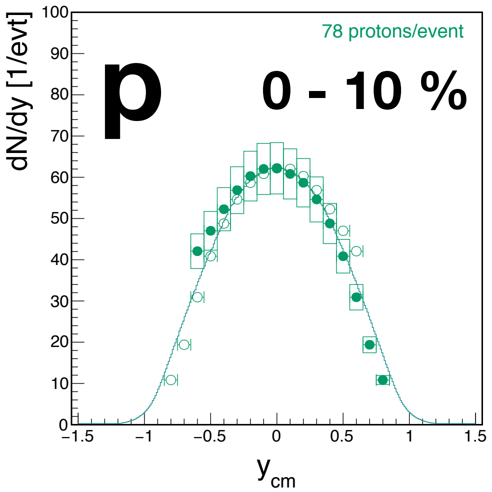

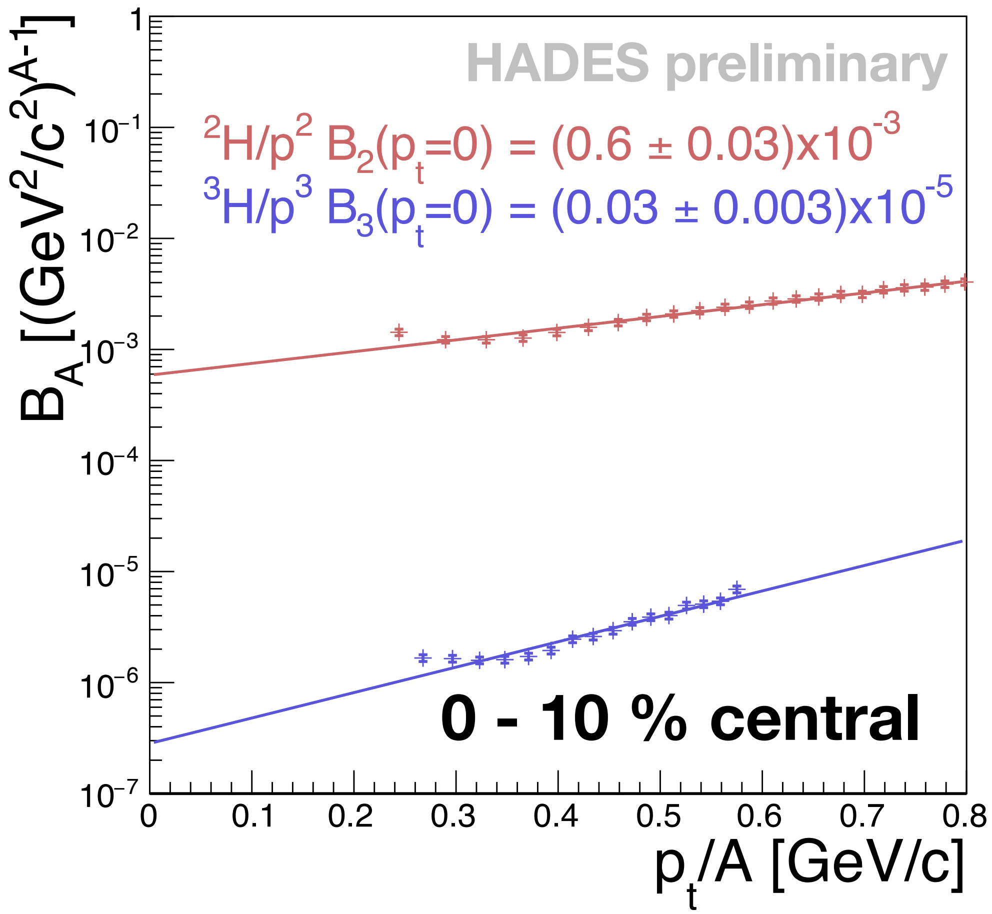

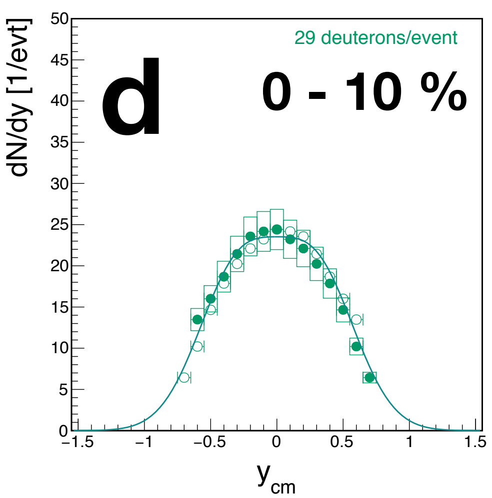

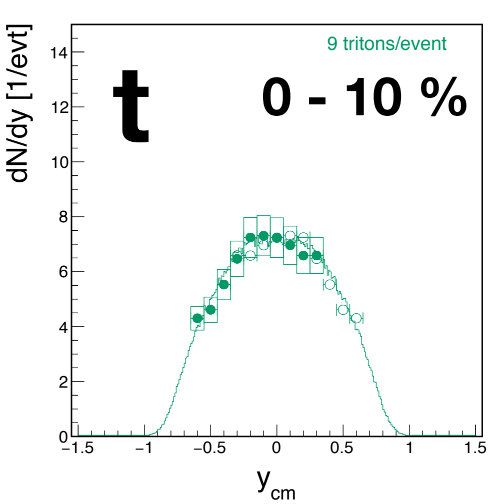

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$$B_{2,y_{cm}} = \frac{24}{61^2} = 6.5x10^{-3}$$

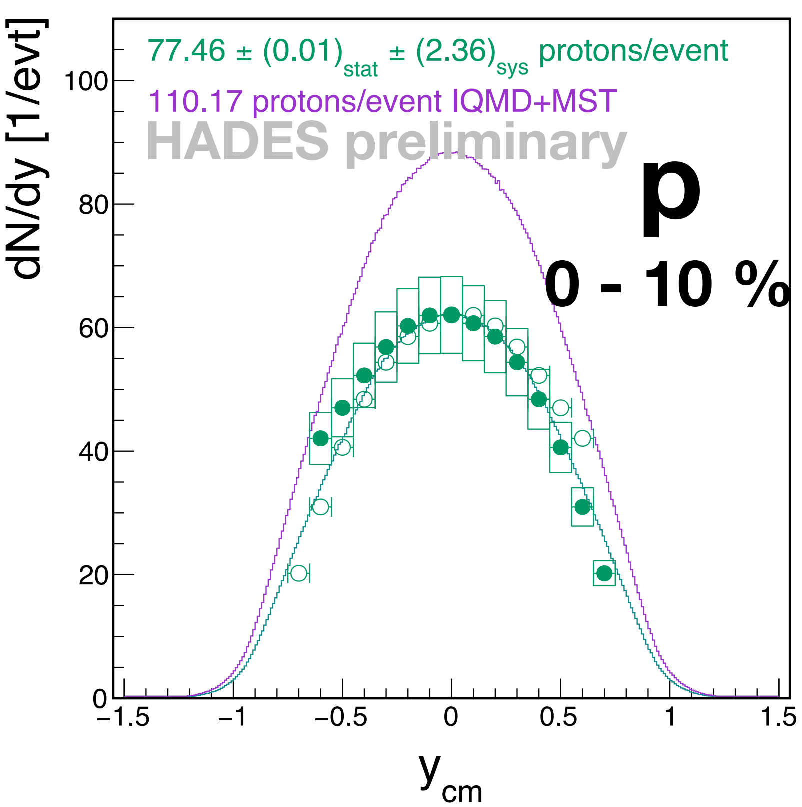
$$B_{3,y_{cm}} = \frac{7}{61^3} = 3.1x10^{-5}$$

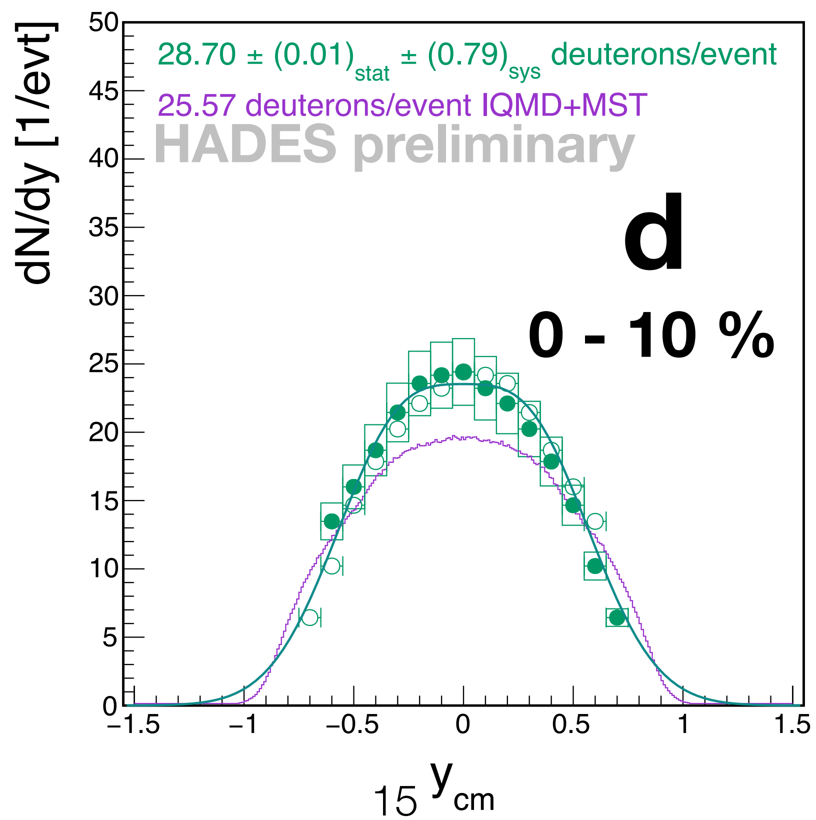
Comparison to model

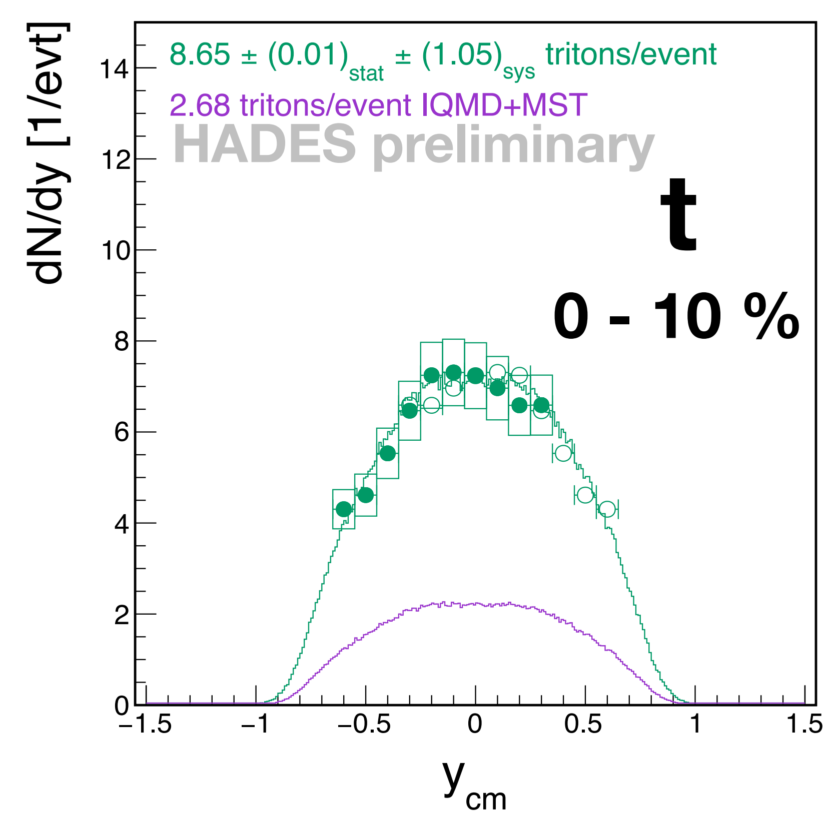
IQMD + MST model

- Light nuclei are clustered with the help of some coalescence afterburner
  - IQMD plus minimal spanning tree (MST):
  - r = 4 fm in position space and t = 200 fm/c
- fractions of light nuclei not reproduced by IQMD

➡ **Light nuclei yields are underestimated by coalescence afterburners around mid-rapidity**



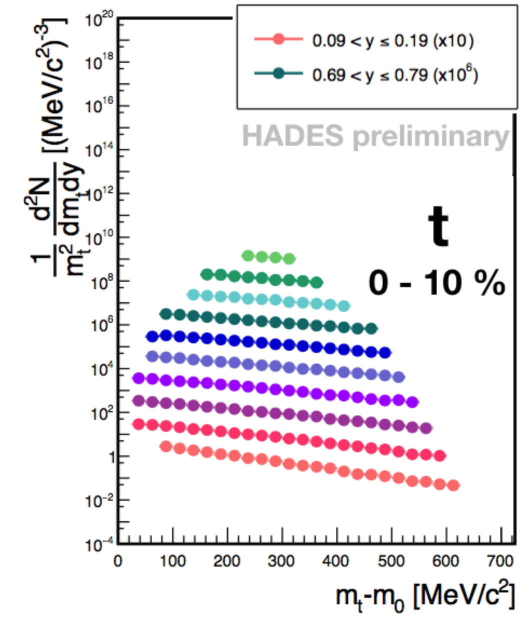


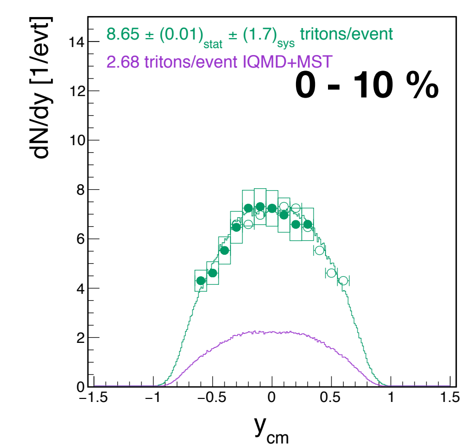


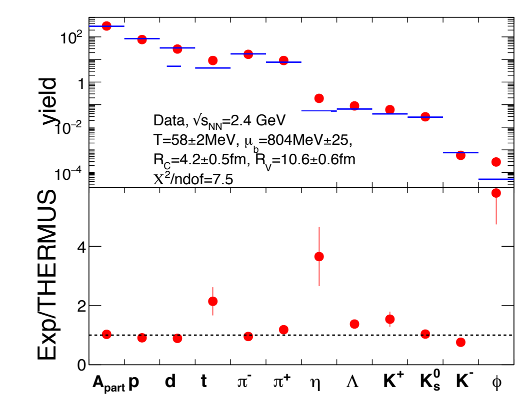
Thanks to Y. Leifels

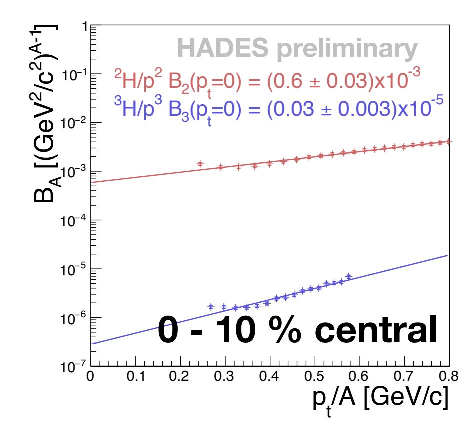
Summary

- High statistic data sample
- Differential analysis of p, d, t performed
- High degree of cluster formation even in most central collisions
- Light nuclei production cannot be described consistently in simple statistical models
- Simple coalescence model does not reproduce light nuclei yields in the participant region
- B_A parameters as function of $p_T(y)$ provided









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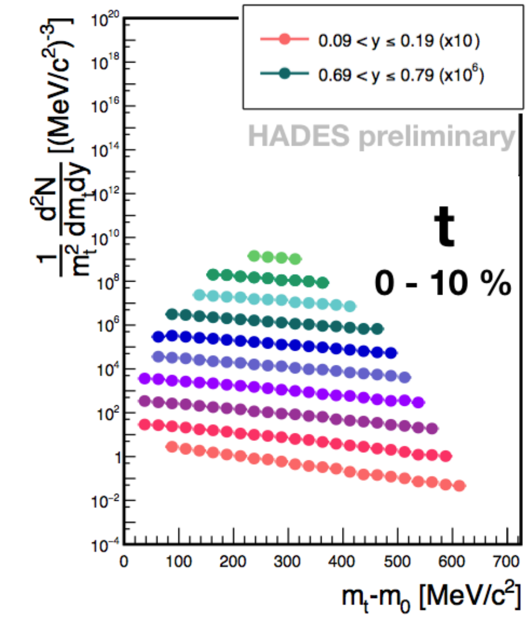
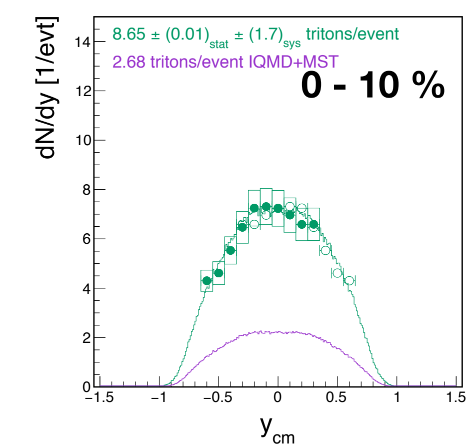
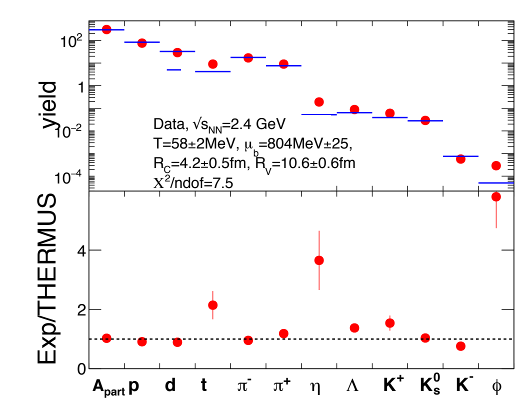
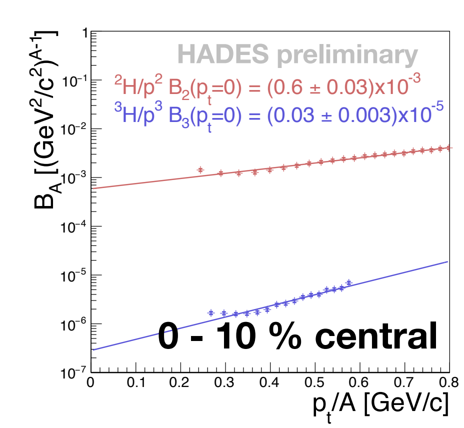
B. Kardan
Tue 18:45
Poster session









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  - major difficulty in formation of clusters
  - is often oversimplified or not omitted

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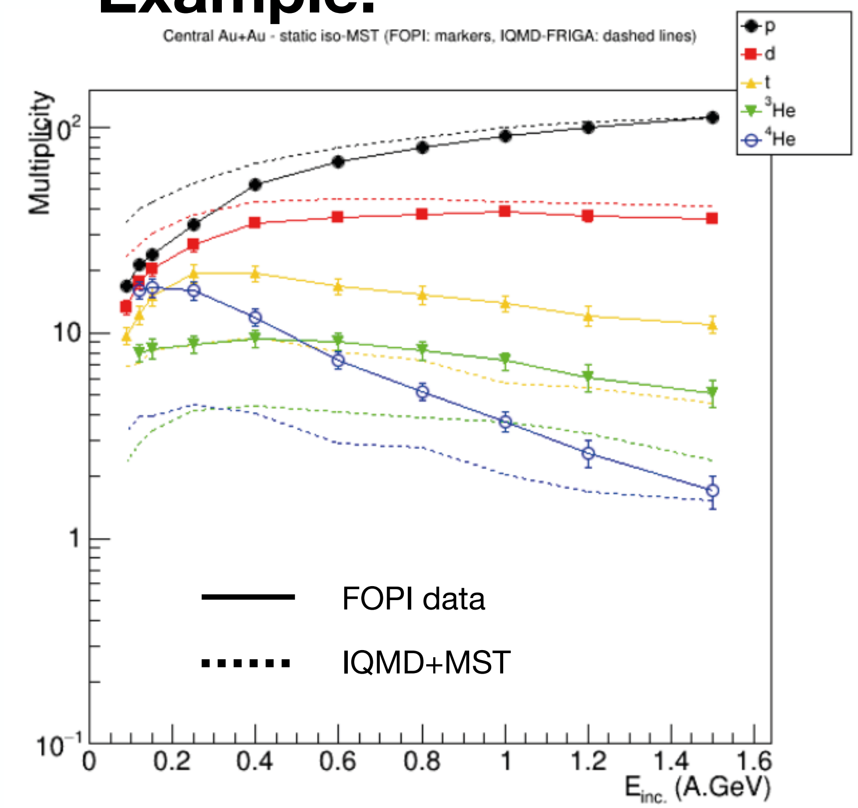

Arnaud Le Fèvre, EMMI Workshop, 11.02.-13.02.2019, GSI
FOPI Collaboration, Nuclear Physics A 848 (2010) 366–427

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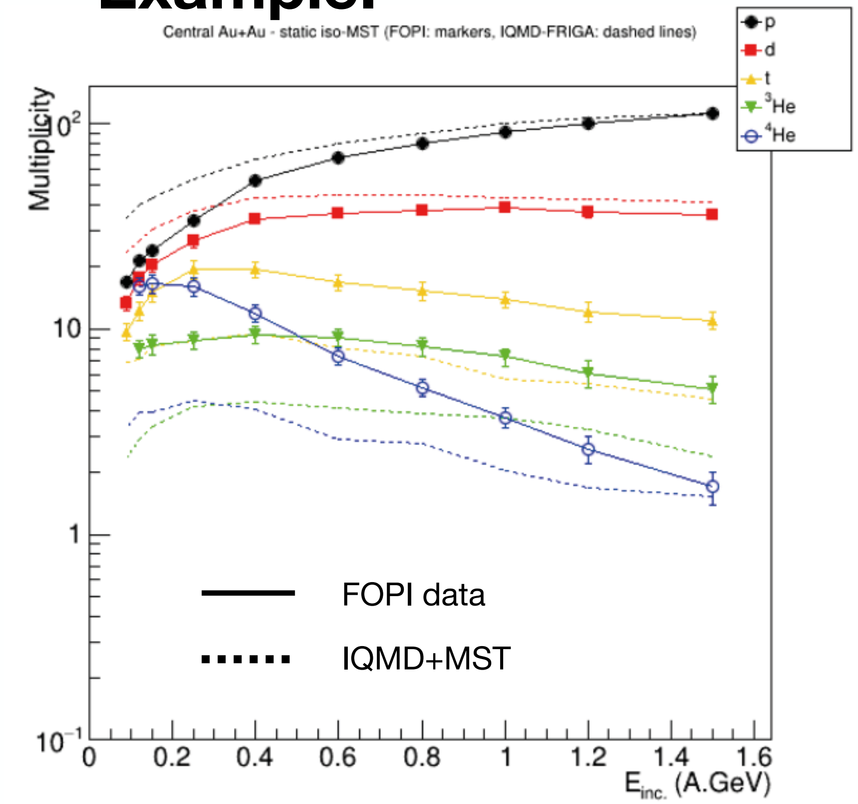

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- Nucleon Coalescence model
  - simple coalescence model could not explain behaviour
- Light nuclei are formed in multitude of processes but not generally by simple coalescence
- More advanced models for light nuclei production are needed, e.g FRIGA, PHQMD

P. Danielewicz and Q. Pan, Phys. Rev. C 46, 2002 (1992).
C. Kuhrts, M. Beyer, P. Danielewicz, and G. Ropke, Phys.Rev. C 63, 034605 (2001).
Akira Ono, EPJ Web of Conferences 122, 11001 (2016).
Le Févre, Y. Leifels, J. Aichelin, Ch. Hartnack, V. Kireyev, E. Bratkovskaya. J.Phys.Conf.Ser. 668 (2016) no.1, 0120

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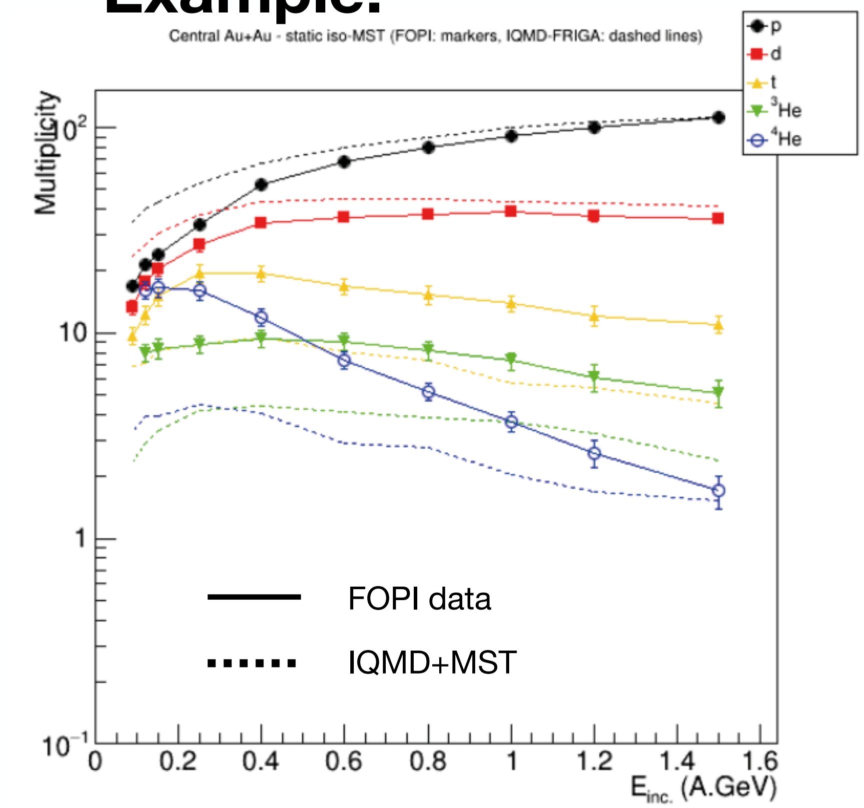
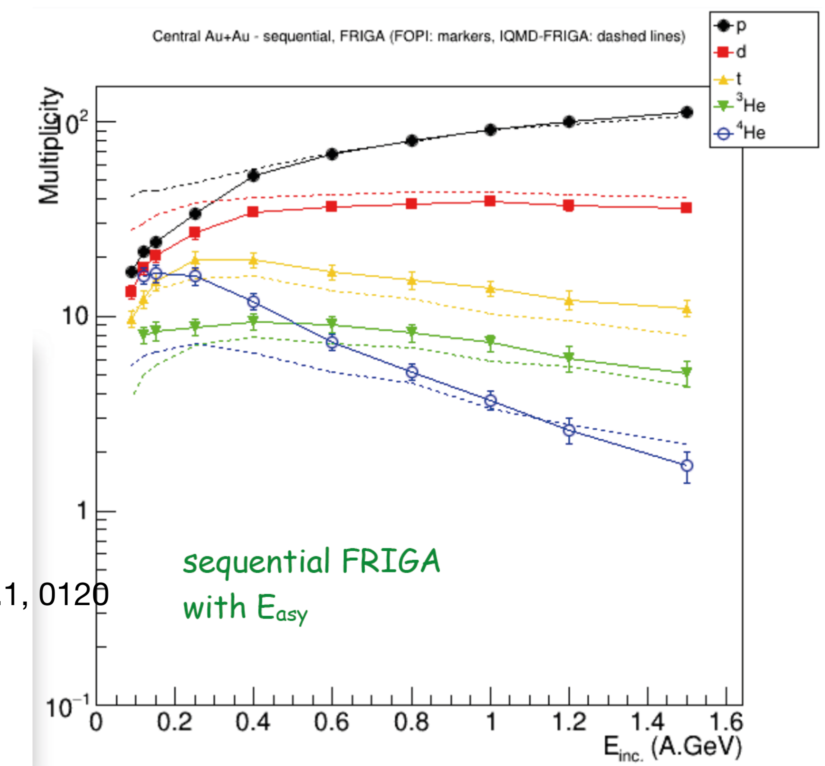
Example:





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FOPI Collaboration, Nuclear Physics A 848 (2010) 366–427

Outlook

- Transport models
  - major difficulty in formation of clusters
  - is often oversimplified or not omitted

- Nucleon Coalescence model
  - simple coalescence model could not explain behaviour

- Light nuclei are formed in multitude of processes but not generally by simple coalescence

- More advanced models for light nuclei production are needed, e.g FRIGA, PHQMD

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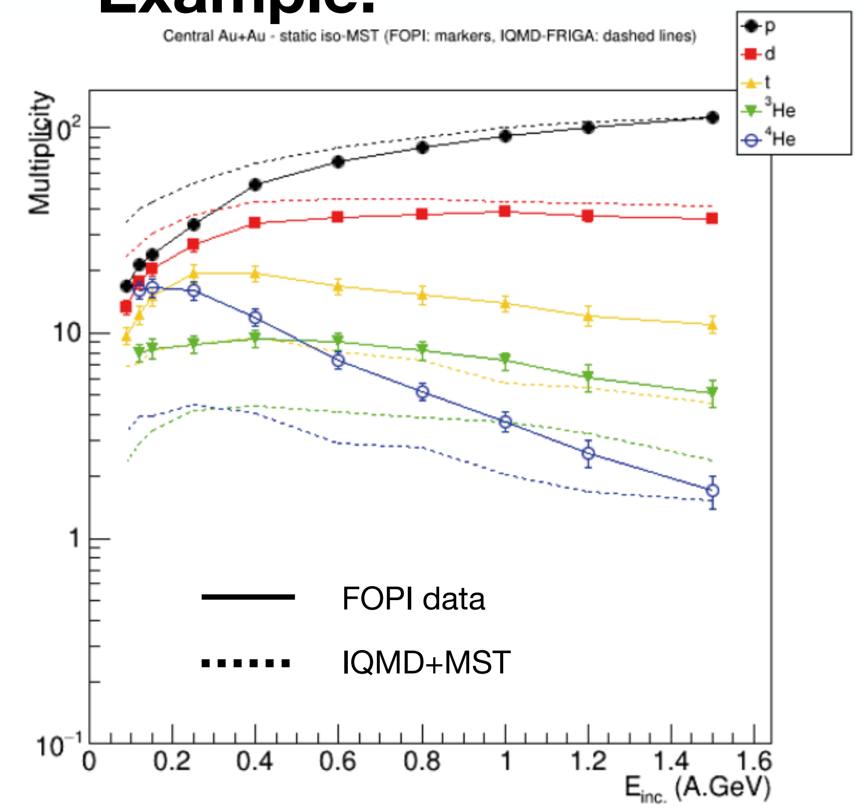
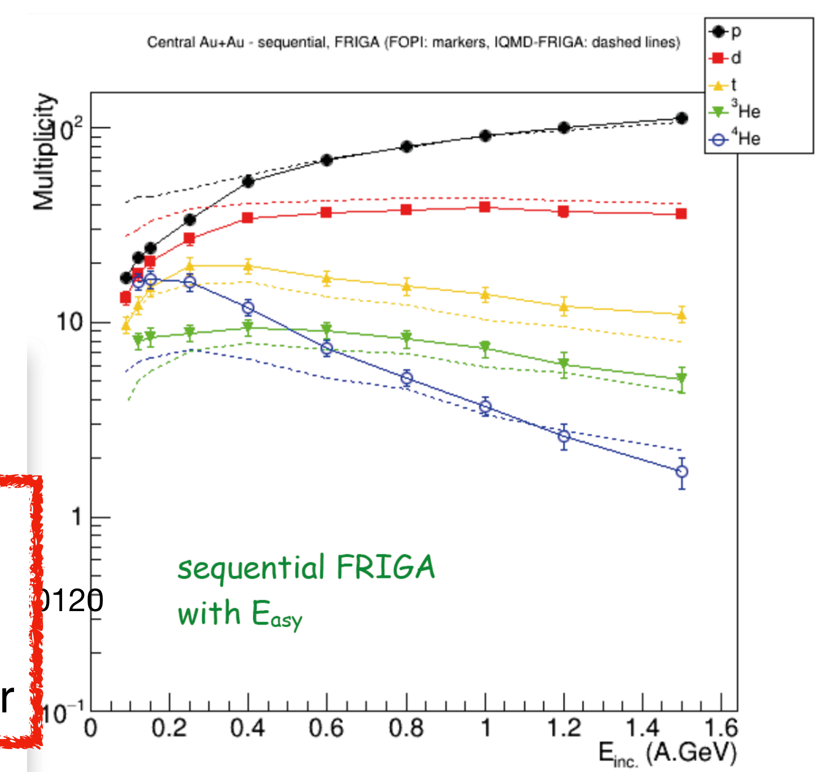
E. Bratkovskaya
Thu 14:40
Strangeness and Light Flavour

Example:





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Thank you for your attention