Scaling of Spectator Fragments in Au+Au and Cu+Cu collisions

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(work done at Univ. Illinois at Chicago)

PHOBOS Collaboration

Outline

- Motivation
- PHOBOS Detector
- Multiplicity at large η
- Measurement of Fragments
- Results

Collaboration

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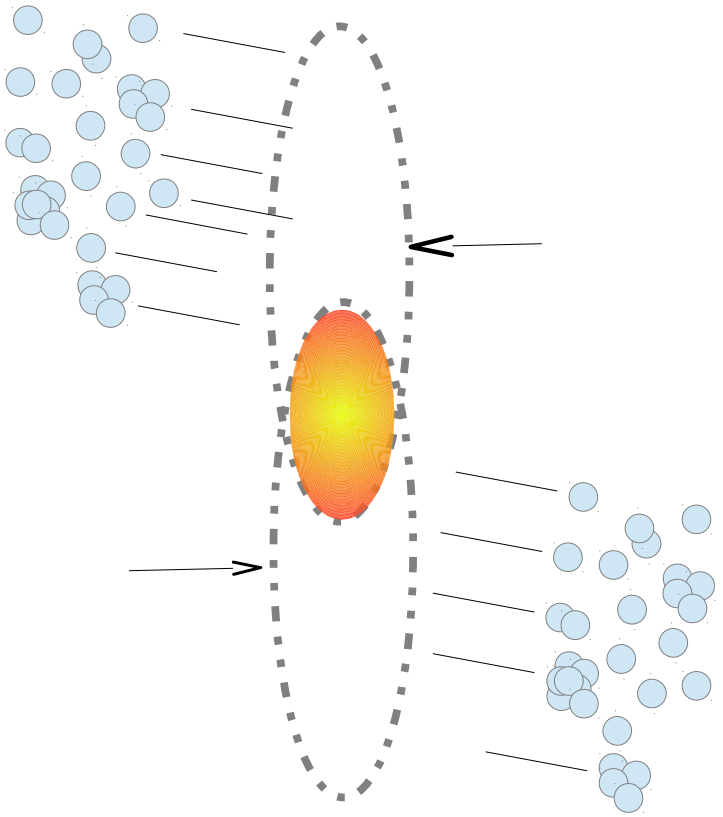
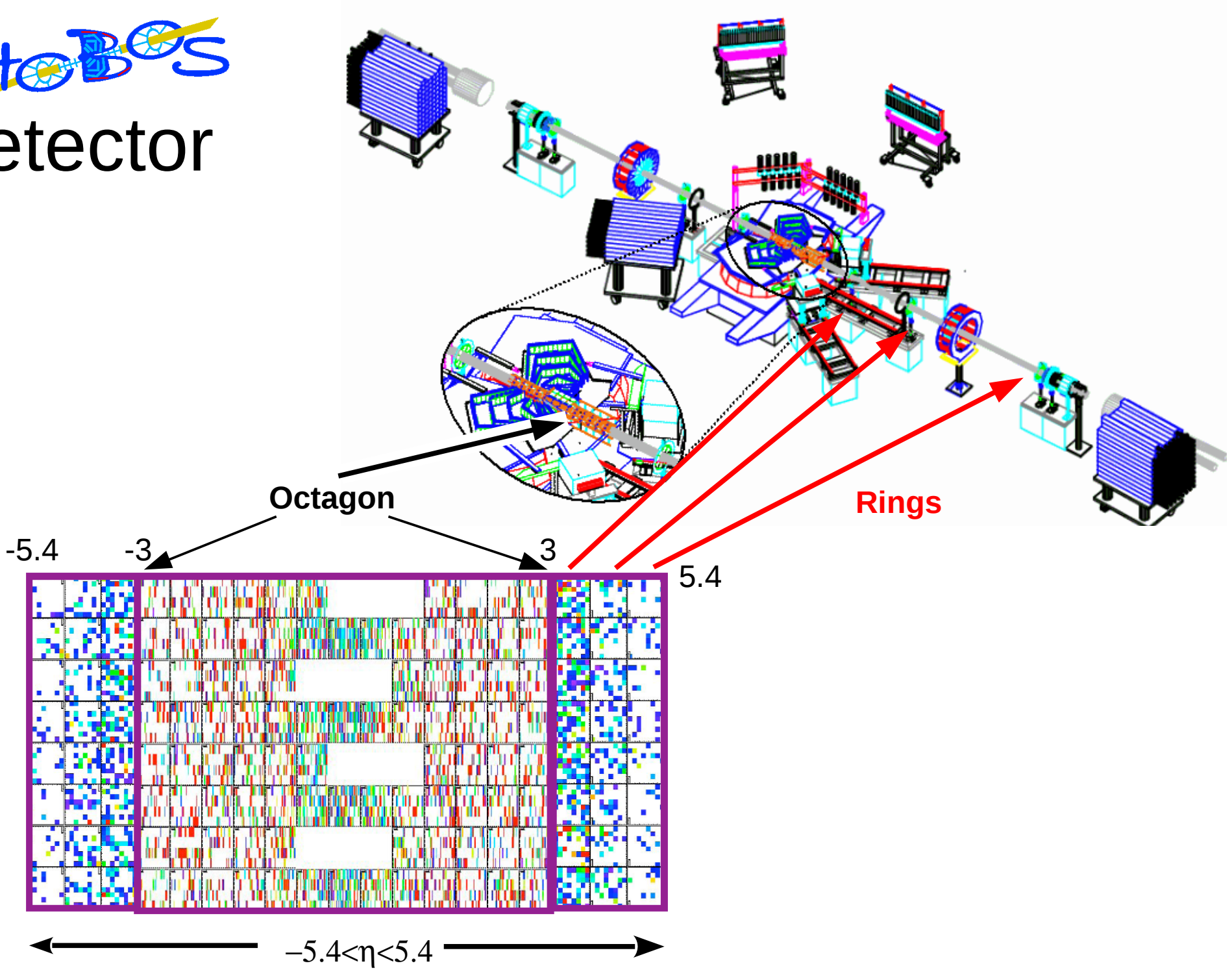
Nuclear Fragmentation

- What happens to a nucleus when a piece is sheared off?
  - Freed protons, neutrons?
  - Larger fragments, deuterons, helium, heavier?
- Complex conditions:
  - Initial binding energy
  - Deformed nucleus
  - Hot expanding “center” of produced particles



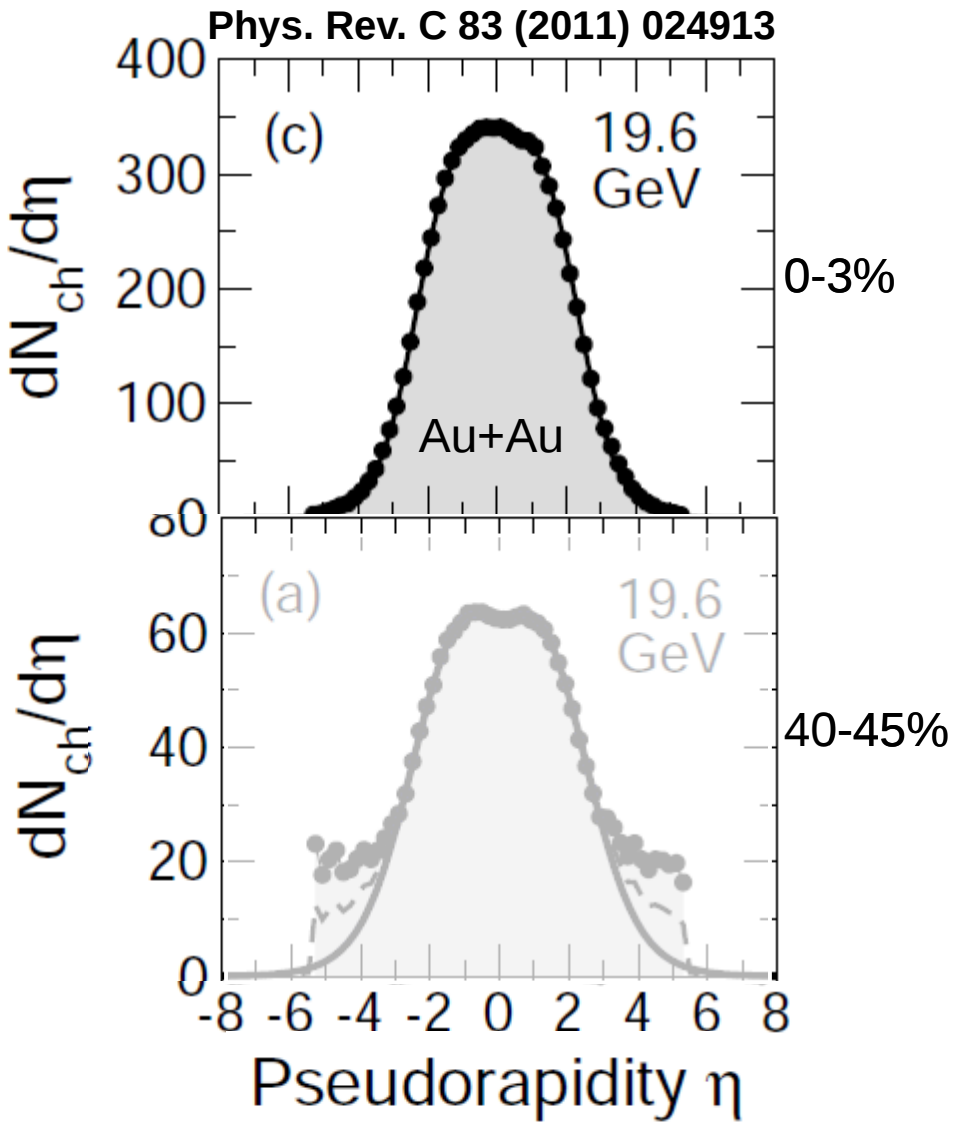
We discuss a data driven method to examine these questions as a function of centrality and collision system size

Detector



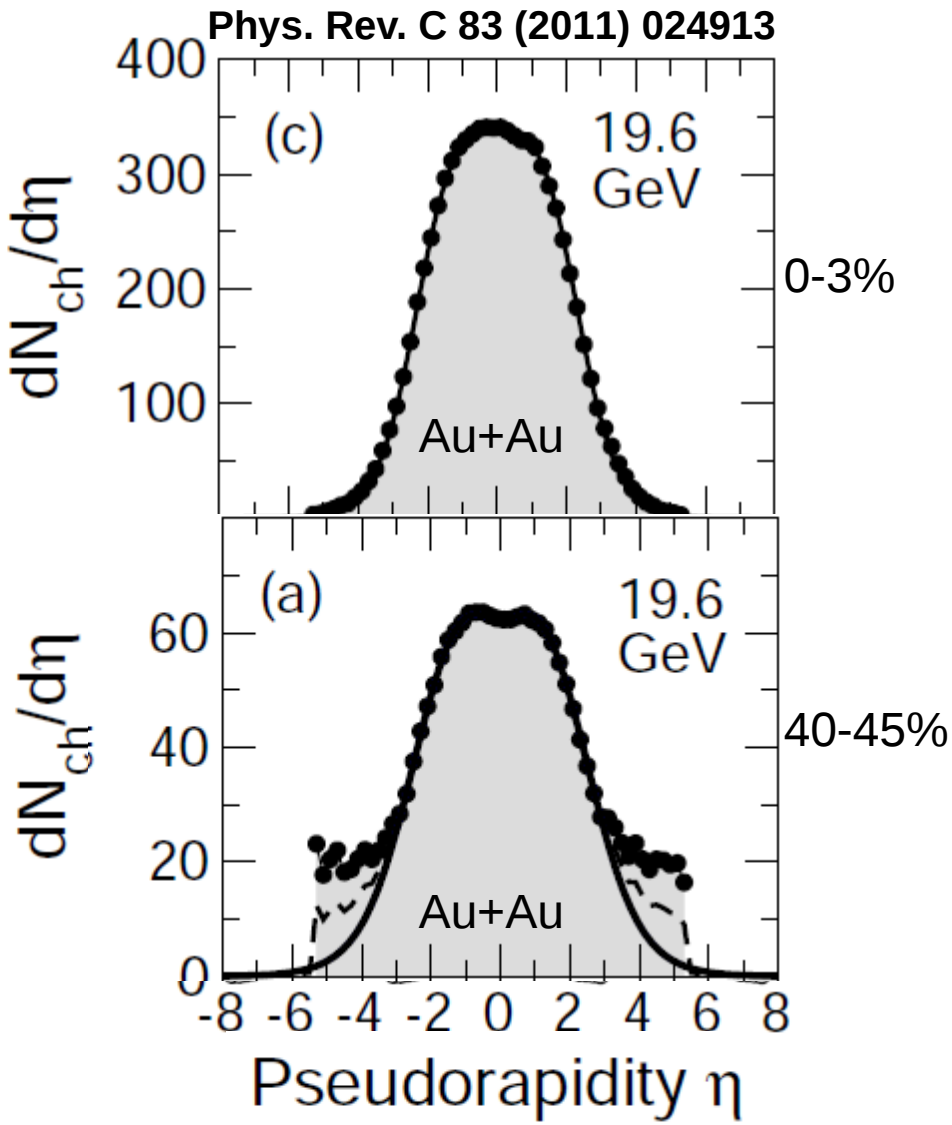
Multiplicity @ 19.6 GeV: Central

- Large η coverage
- Central data well represented by a double-Gaussian form
- Same fit, intriguingly, does not fit full η dependence in peripheral data
  - Deviation above beam rapidity



Multiplicity @ 19.6 GeV: Peripheral

- Large η coverage
- Central data well represented by a double-Gaussian form
- Same fit, intriguingly, does not fit full η dependence in peripheral data
  - Deviation above beam rapidity



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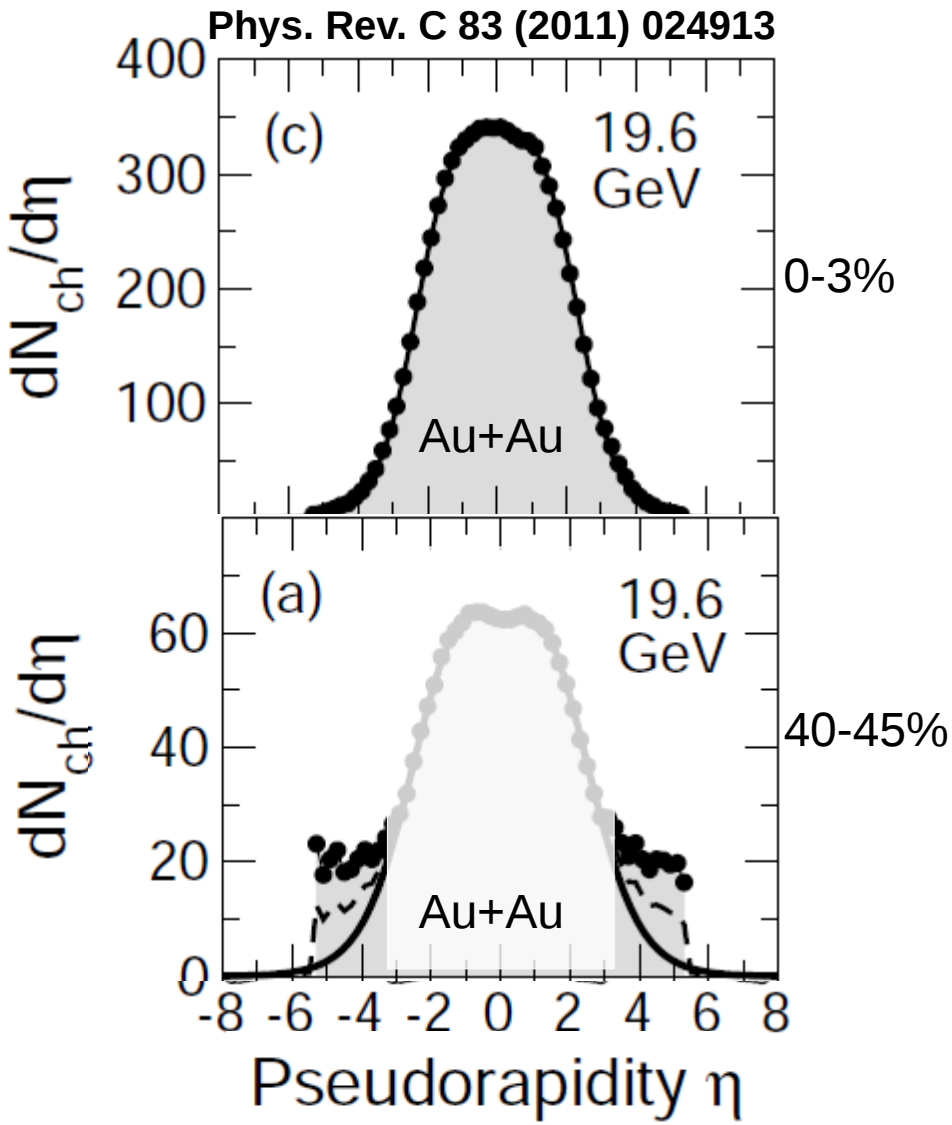
y_{beam} = 3.04 (19.6 GeV)

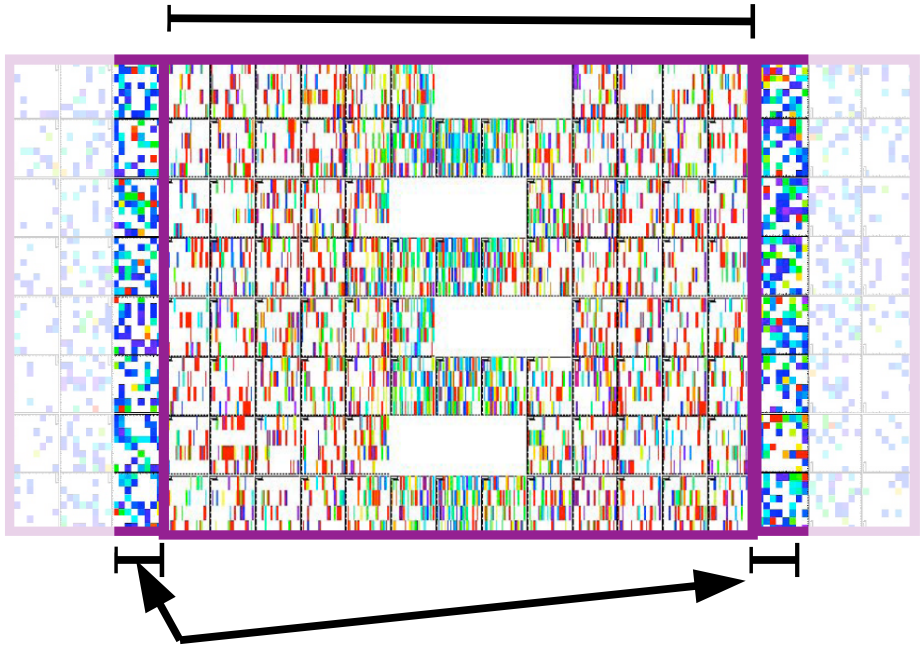
η < 5.4



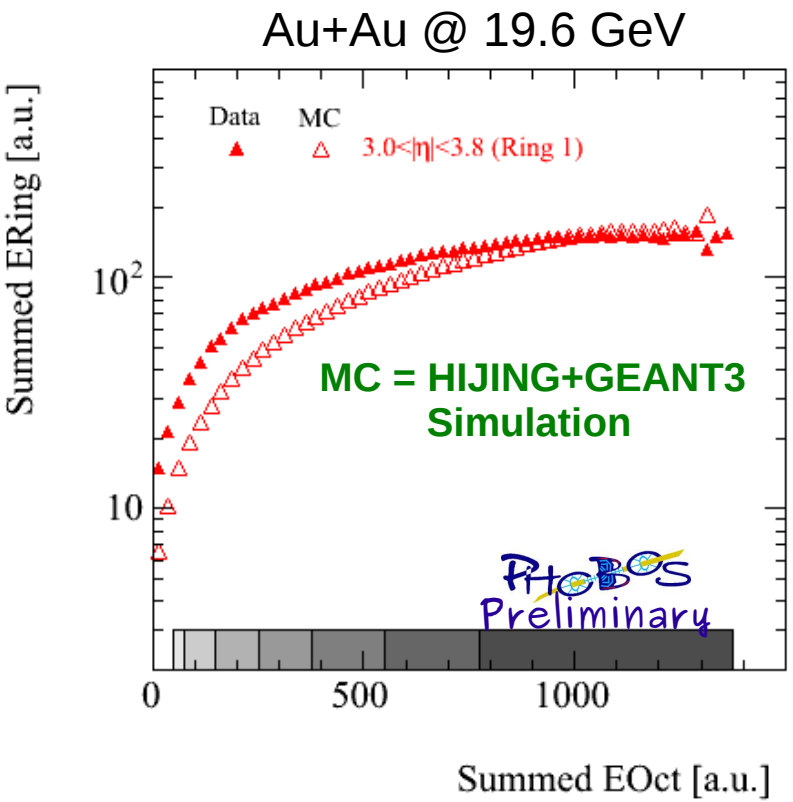
Integrated Forward dN/dη

First hints of spectators

- EOct: Energy measured in the central region



- ERing 1: 3.0<|η|<3.8
- Energy measured in the closest rings

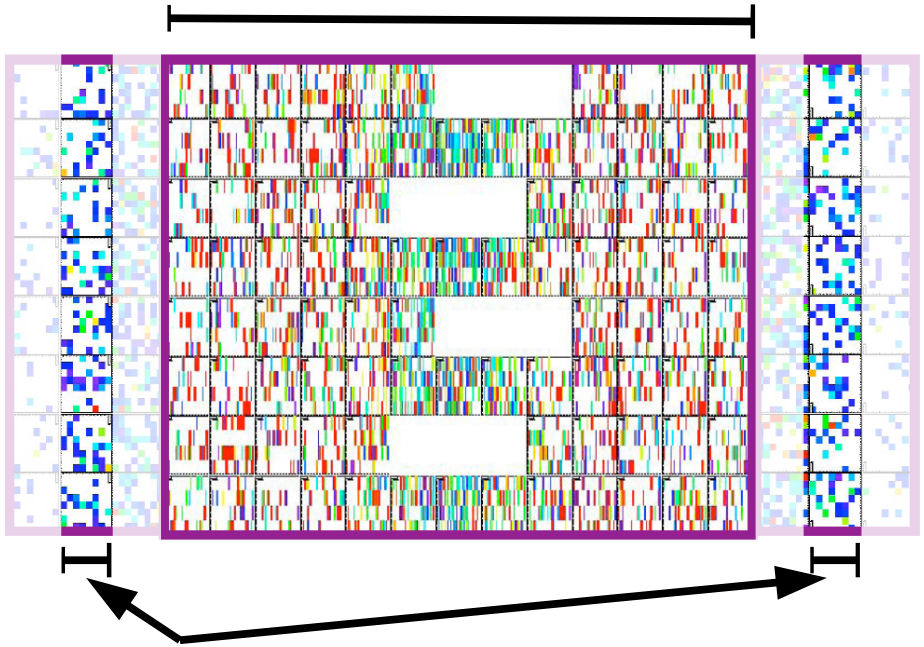


ERing 1 vs EOct: Monotonic
Data ~ MC
ERing data yield includes spectators and produced hadrons
ERing MC includes only produced particles

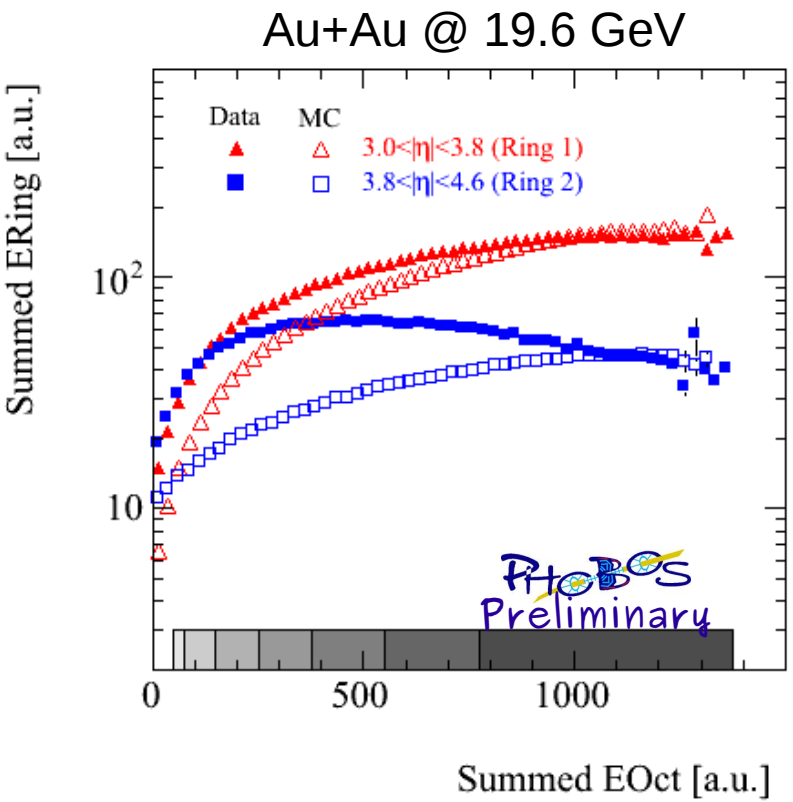
Integrated Forward dN/dη

First hints of spectators

- EOct: Energy measured in the central region



- ERing 2: 3.8<|η|<4.6

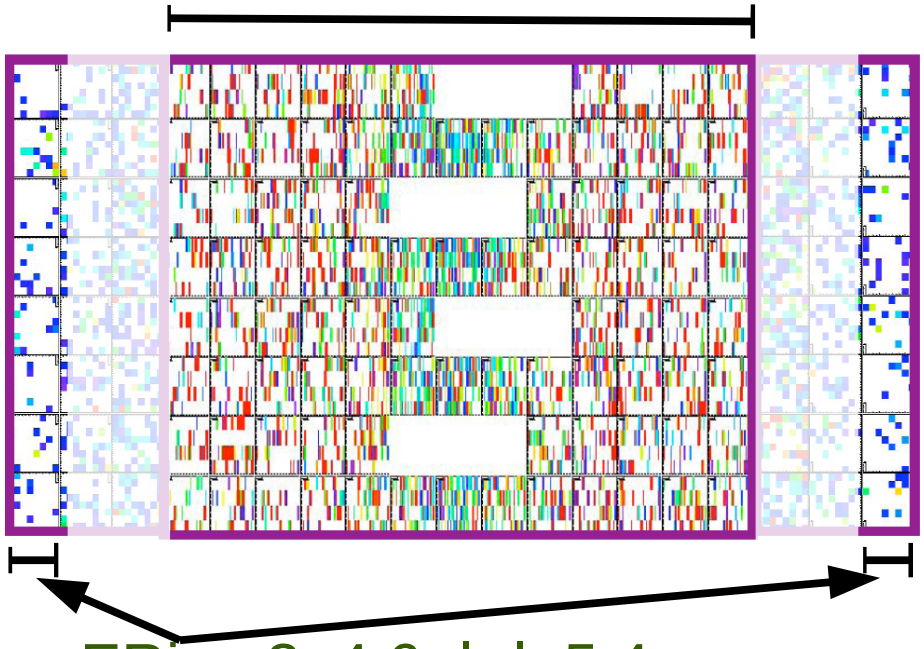


ERing 2 vs EOct: Non-monotonic
Data ≠ MC

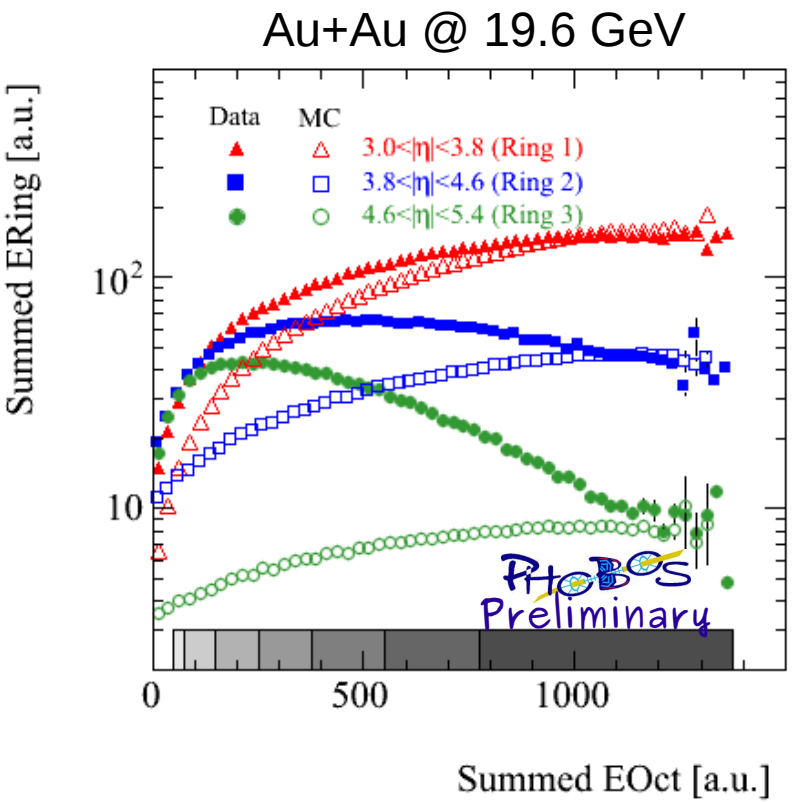
Integrated Forward dN/dη

First hints of spectators

- EOct: Energy measured in the central region



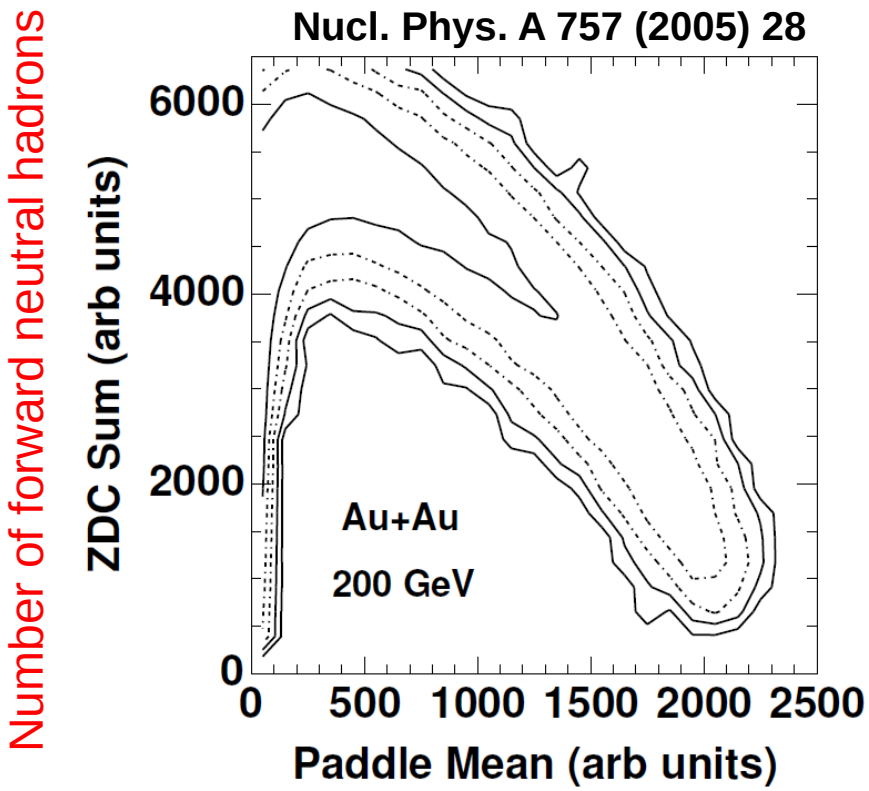
- ERing 3: 4.6<|η|<5.4
- Energy measured at the highest η



ERing 3 vs EOct: Non-monotonic
Data ≠ MC
Data distribution resembles
ZDC vs PdlMean in 200 GeV Au+Au

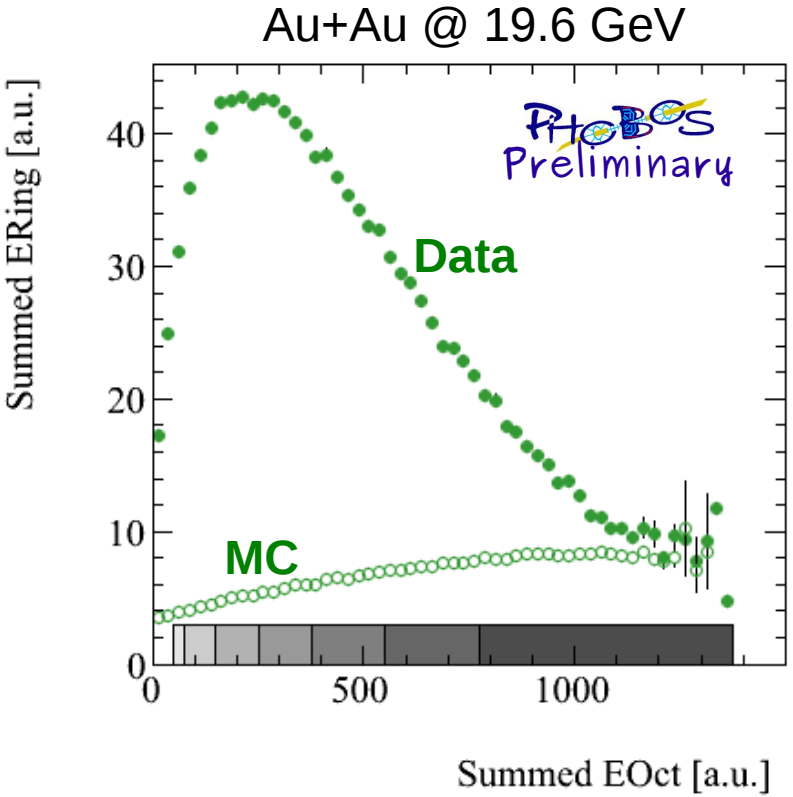
Integrated Forward dN/dη

First hints of spectators



Number of Produced Particles (3<|η|<4.5)

ZDC vs PdlMean in 200 GeV Au+Au



ERing 3 vs EOct: Linear scale

ERing data yield includes spectators and produced hadrons

ERing MC includes only produced particles

Analysis Roadmap

Four Steps:

(1) Identify spectator fragment nuclei

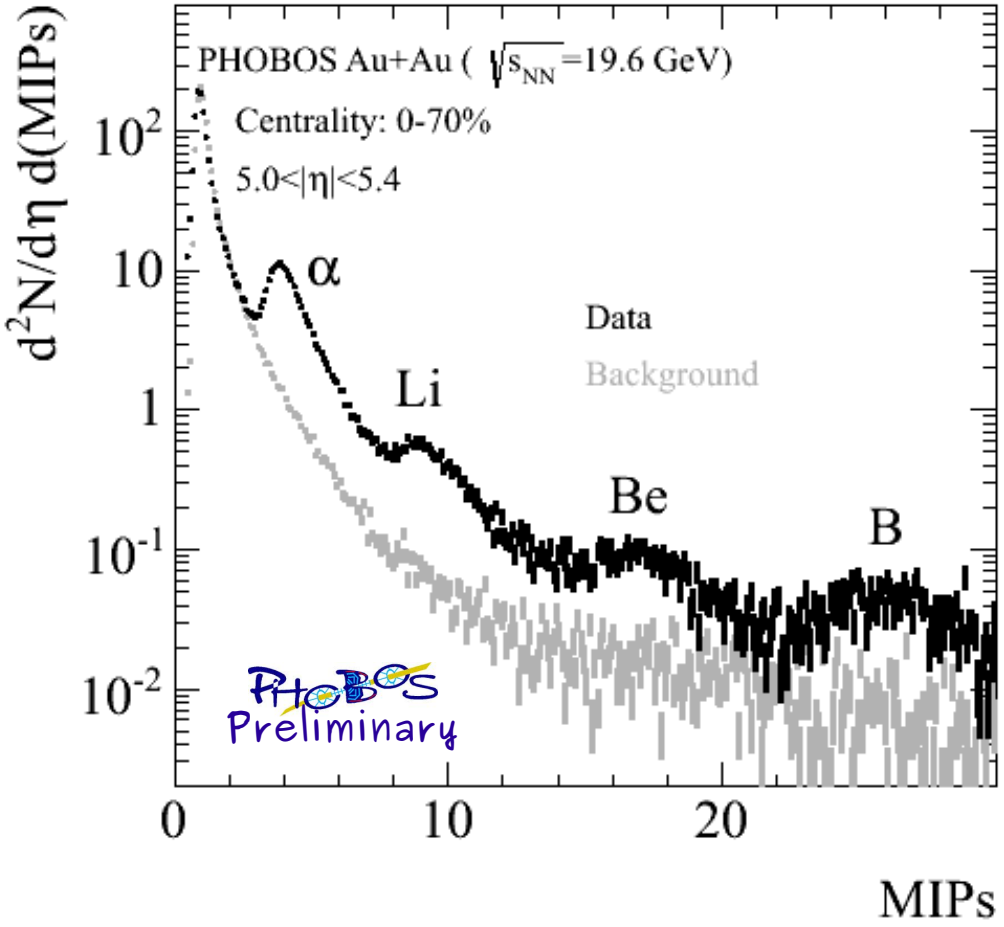
(2) Background subtraction

(3) Measure yields

(4) Acceptance correction

(1) Fragment Identification

- More detailed examination: Signal measured in the Rings
  - Z^2 dependence
  - Protons, deuterons, tritons at MIP~1
  - Helium (Z=2) MIP~4



Note: Fragment identification cannot distinguish isotopes, only charge content

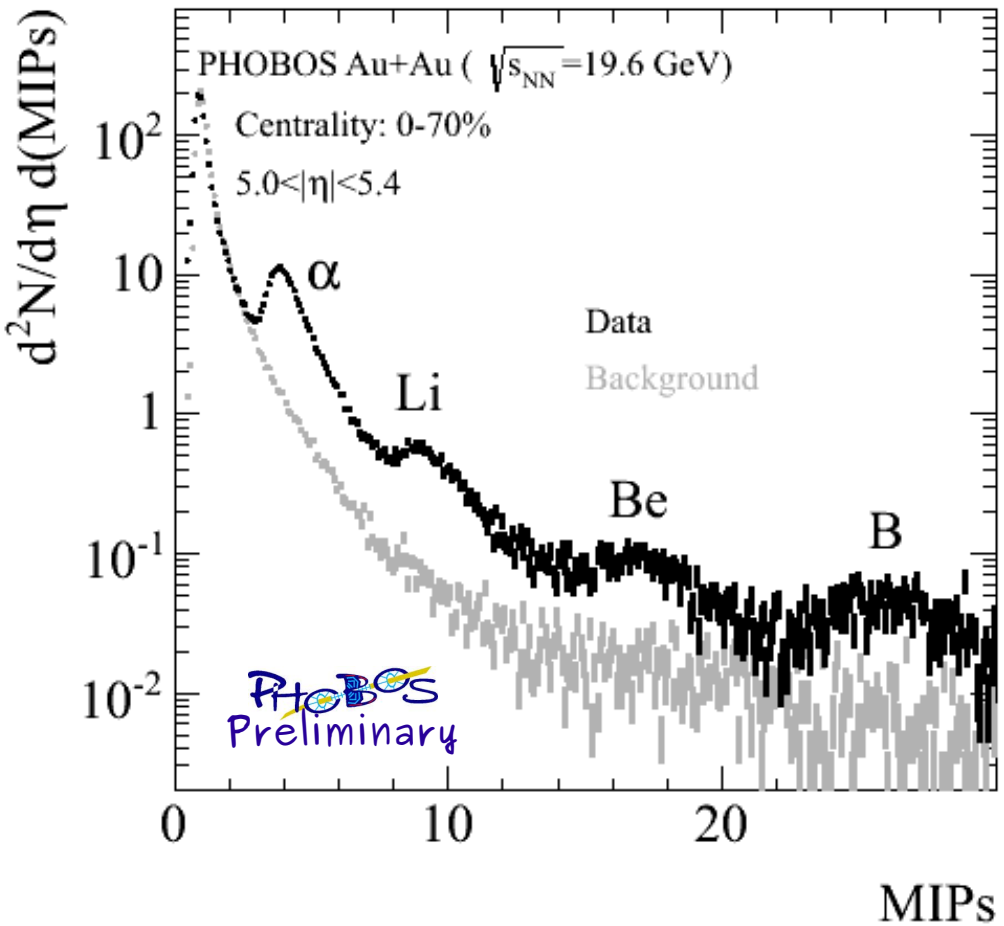
- **α → Z=2 fragments, Li → Z=3, etc**

(2) Background Subtraction

- Remove the background due to singly charged particles
  - Protons and other produced hadrons
  - Single particles per pad (1 MIP), and two single hits per pad (2 MIP)

- Used MC without spectators in the acceptance of the detector
  - Normalized MC amplitude at first MIP to data
  - Picked best fit from ensemble of MC samples with differing 2MIP/1MIP ratios

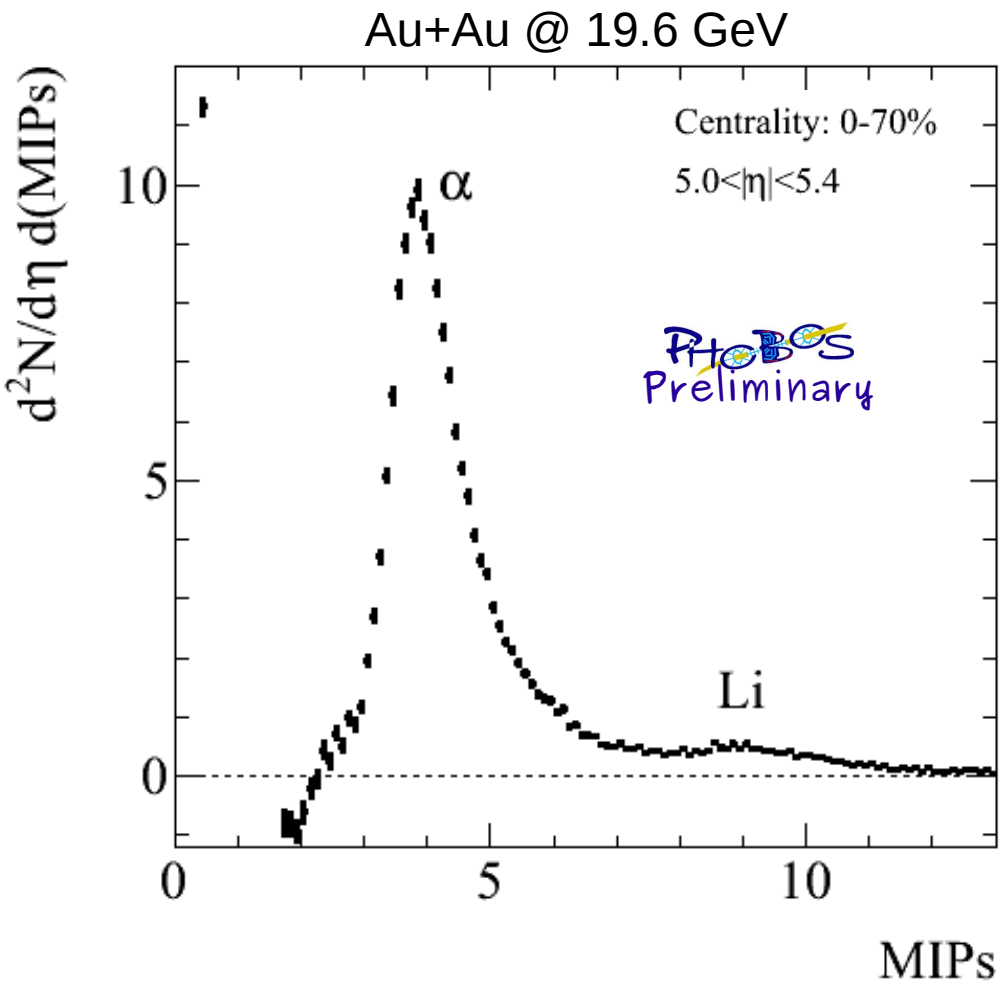
MC Background from a HIJING+GEANT3 Simulation



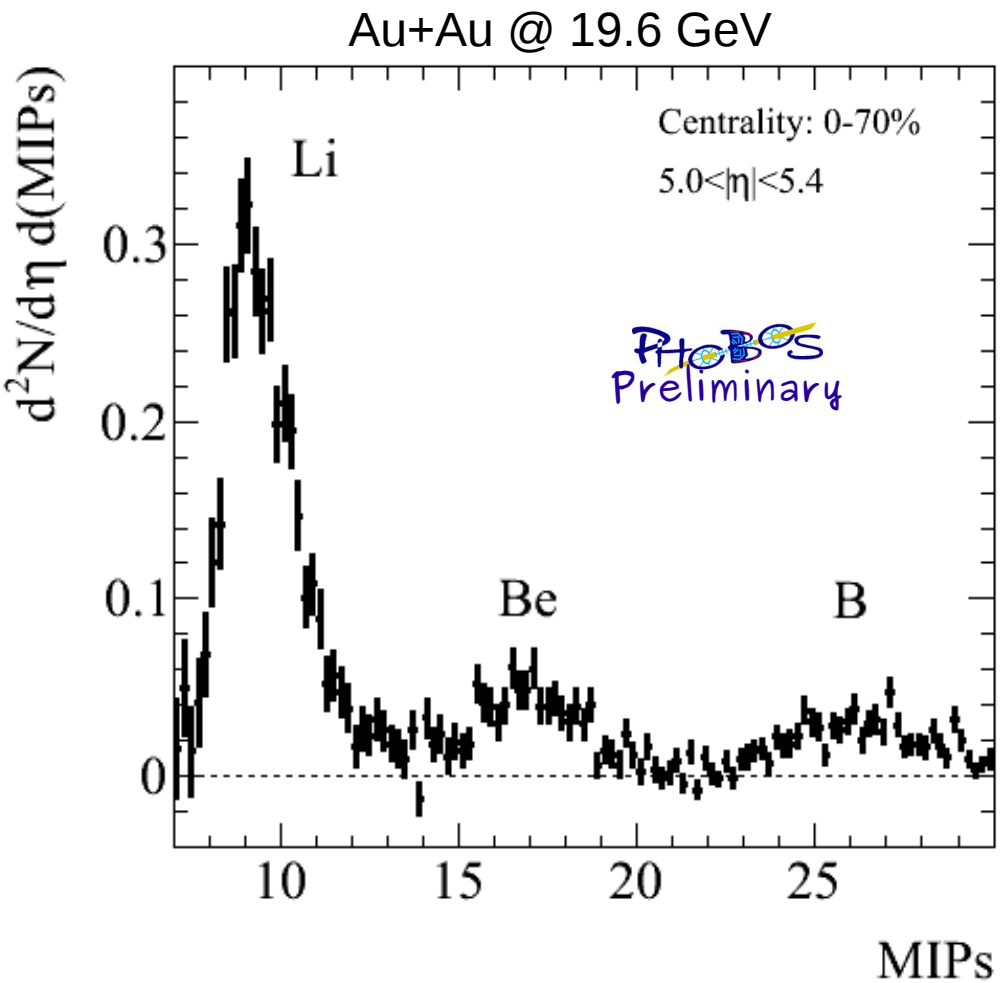
(3) Fragment Yields (I)

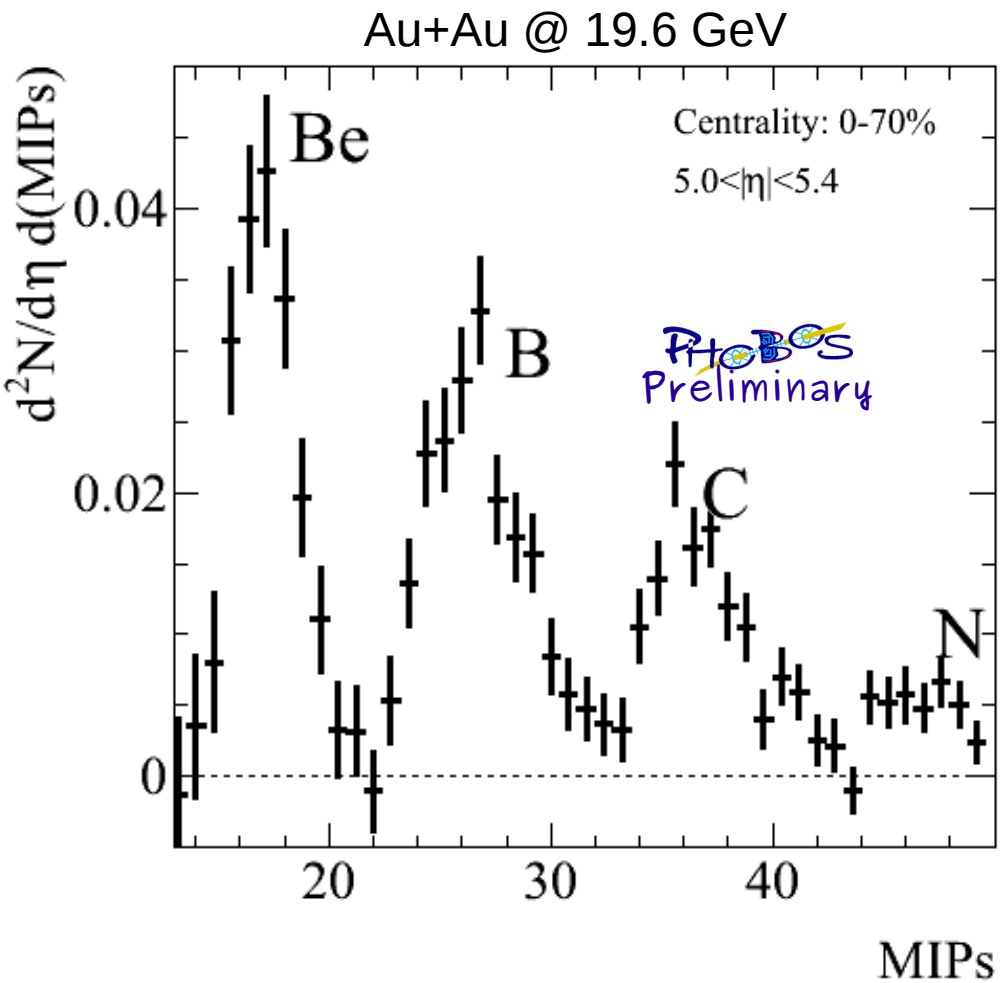
- Z=1 fragments/particles are explicitly subtracted
  - Only the Z>1 peaks remain
  - Dominated by α (Helium)

- Landau+Gaussian fit to α peak
  - Extrapolated under Lithium peak and subtracted



(3) Fragment Yields (II)





Li fit with Landau+Gaussian

Beryllium and Boron simultaneously fit with a two-Gaussian form

Note: Carbon and Nitrogen statistics too low for centrality and η dependence

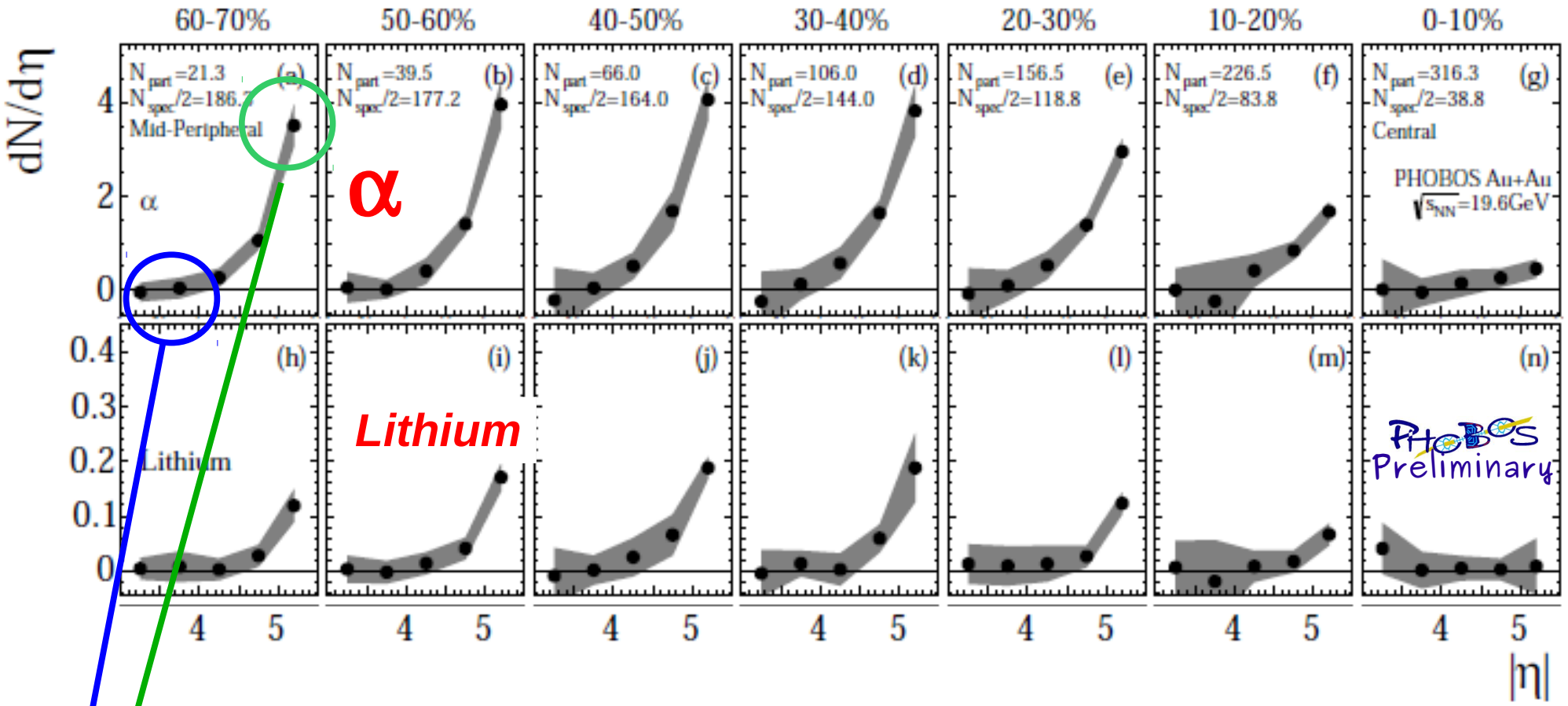
(4) Corrections

- Background due to lower Z fragments and produced particles explicitly subtracted
- Geometrical acceptance calculated from primary MC particles impinging on the detector
  - Accounts for dead areas in the detector
    - 50 to 75% efficient depending on pseudorapidity
- Systematic studies:

  (quoted for α at highest η)
  - Background selection
    - 3-12%
  - +/- η
    - 3-11%
  - Energy scale on MIP
    - 1-8%

Results

Fragment Yields: Au+Au @ 19.6 GeV

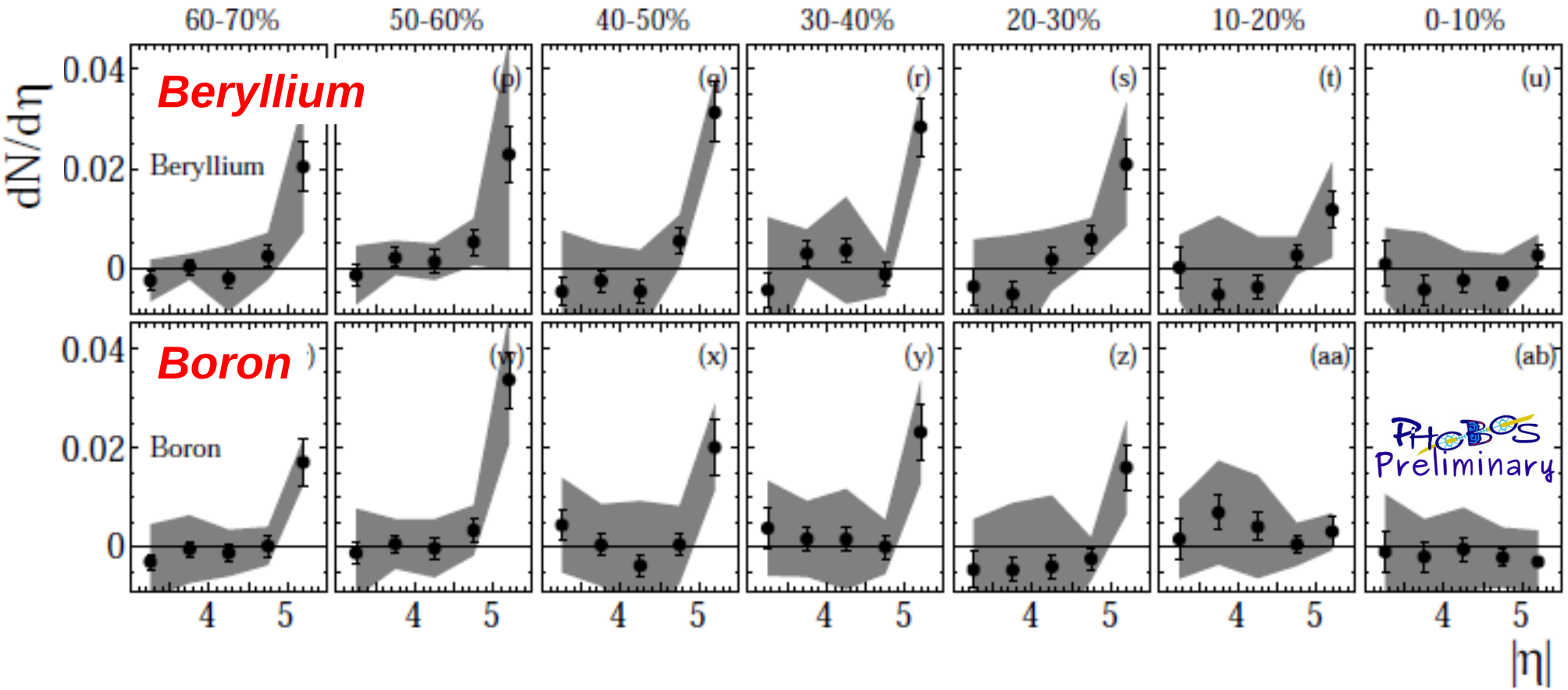


More fragments (Peripheral) → Fewer fragments (Central)

Fewer fragments at smaller η

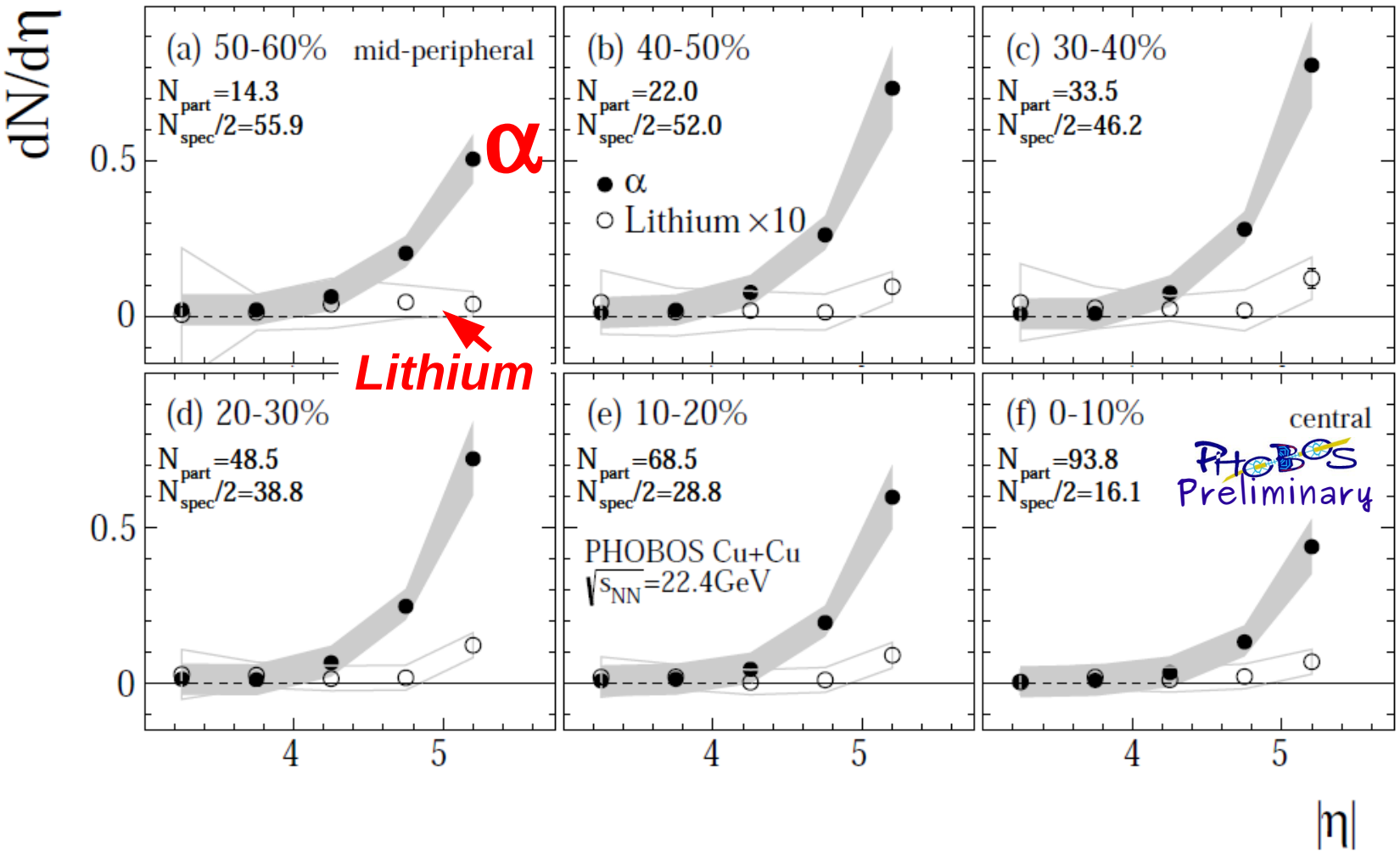
More fragments at largest η measured

Fragment Yields: Au+Au @ 19.6 GeV



Beryllium and Boron observed only at highest η in PHOBOS

Fragment Yields: Cu+Cu @ 22.4 GeV

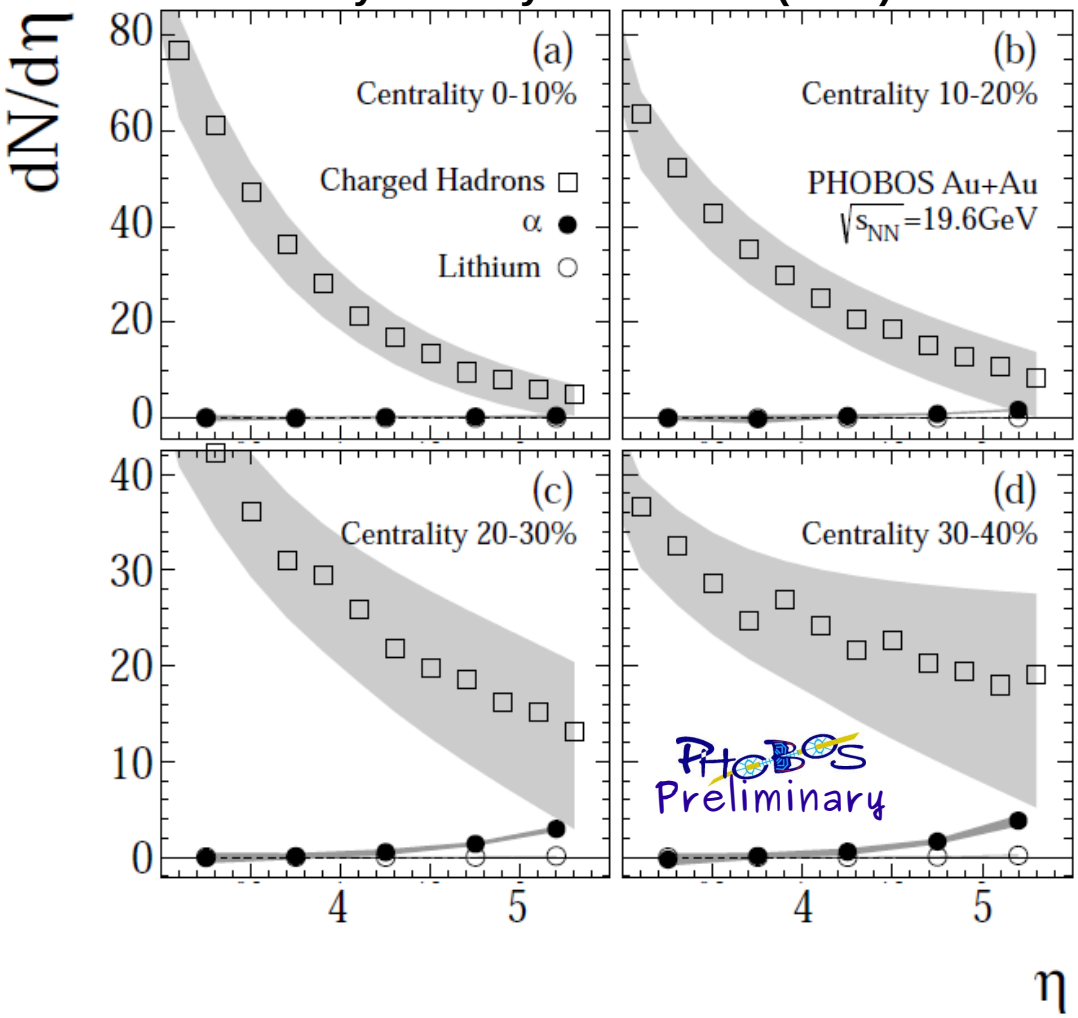


Significantly fewer fragments observed in Cu+Cu collisions

Comparison to Charged Particles

- Charged particles (light band):
  - Includes produced hadrons, along with singly- (p,d,t) and multiply-charged spectators
  - Multiply-charged particles were only counted once
- Z>1 spectator fragment yields account for only a fraction of the charged particle yield
- Singly-charged particles (produced and spectators) dominate

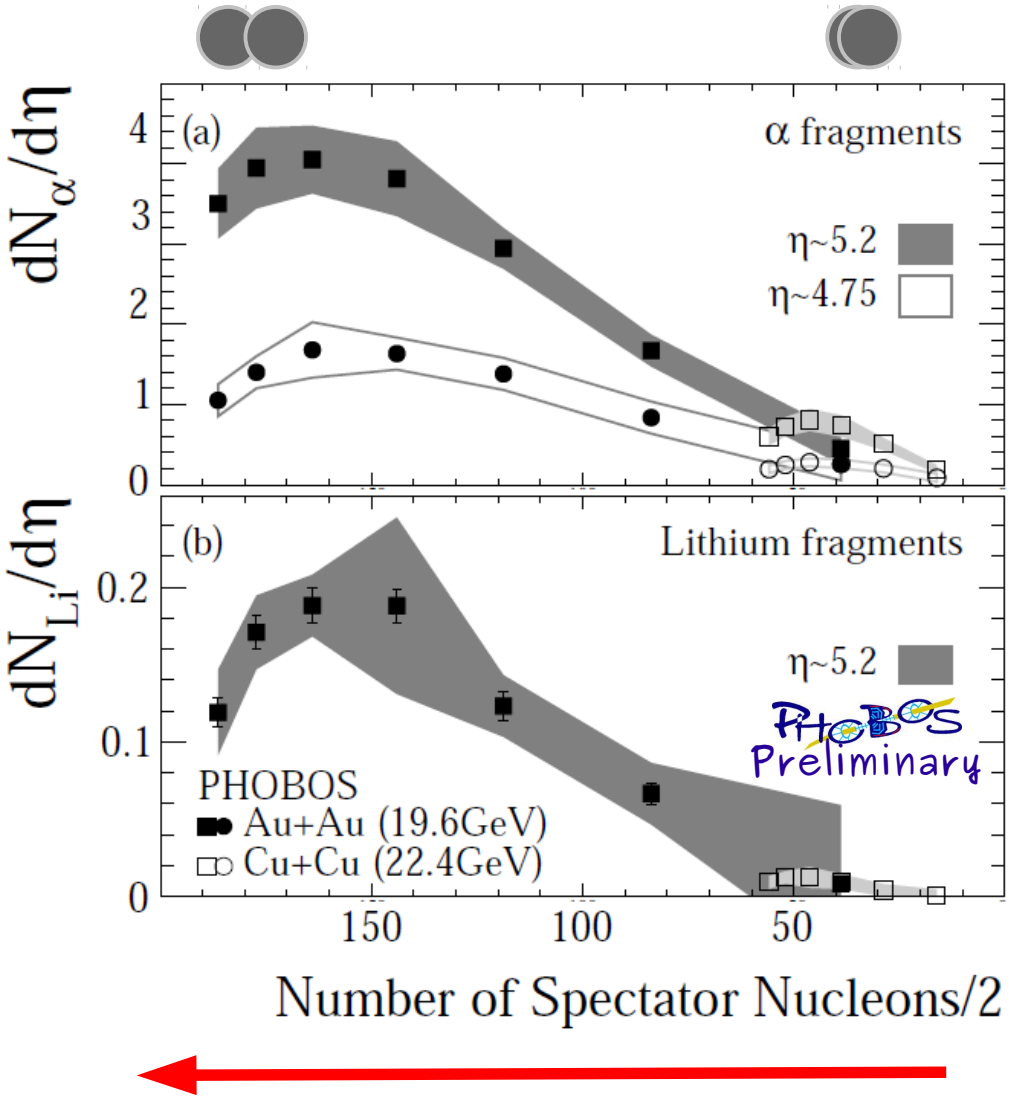
Inclusive yield: Phys. Rev. C 83 (2011) 024913



Au+Au Yield Compared to Cu+Cu

- Yield in the measured region is similar for Au+Au and Cu+Cu, at the same number of spectators

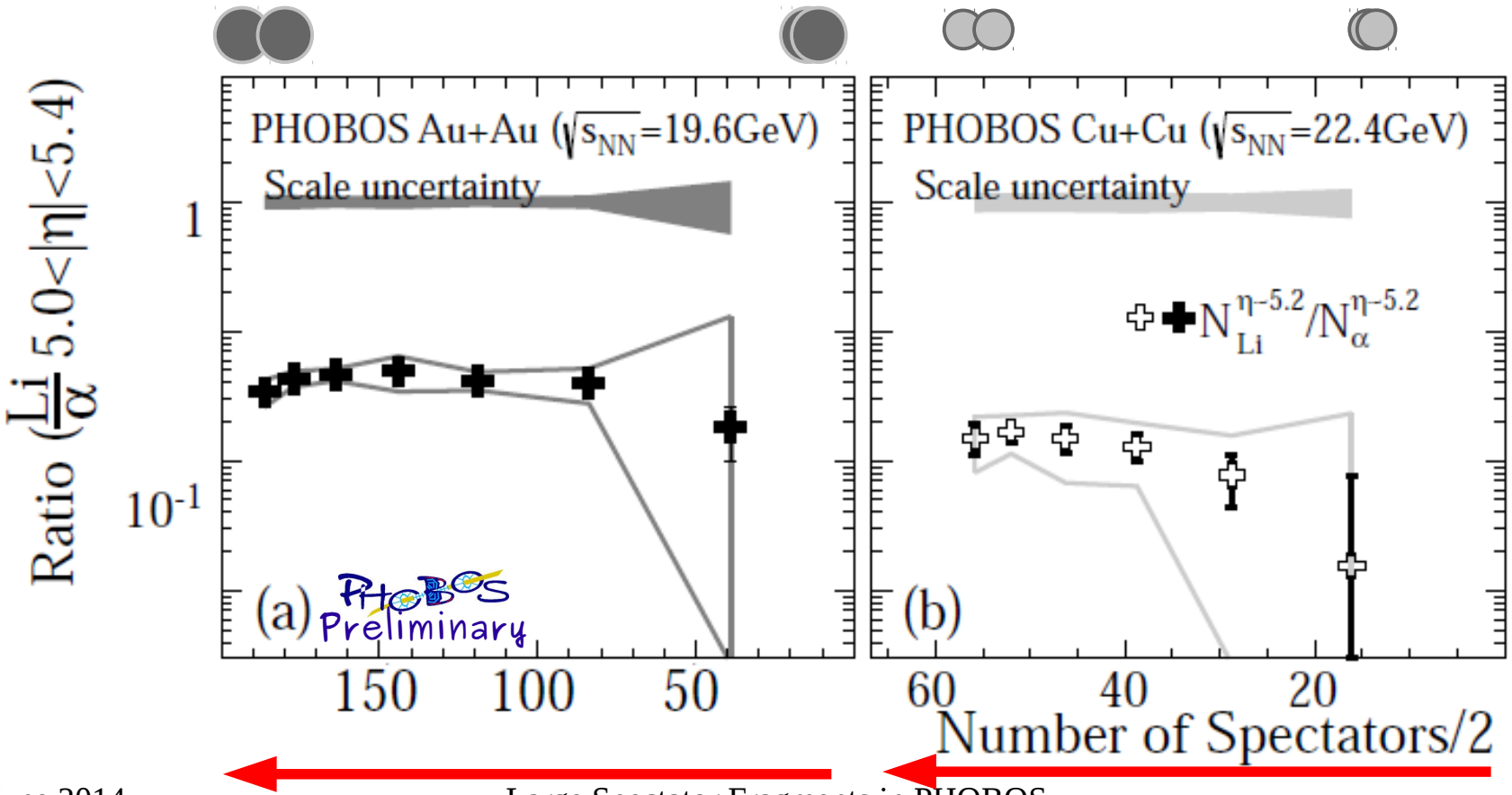
$$N_{spec}/2=(A-N_{part}/2)$$



Note inverted axis!

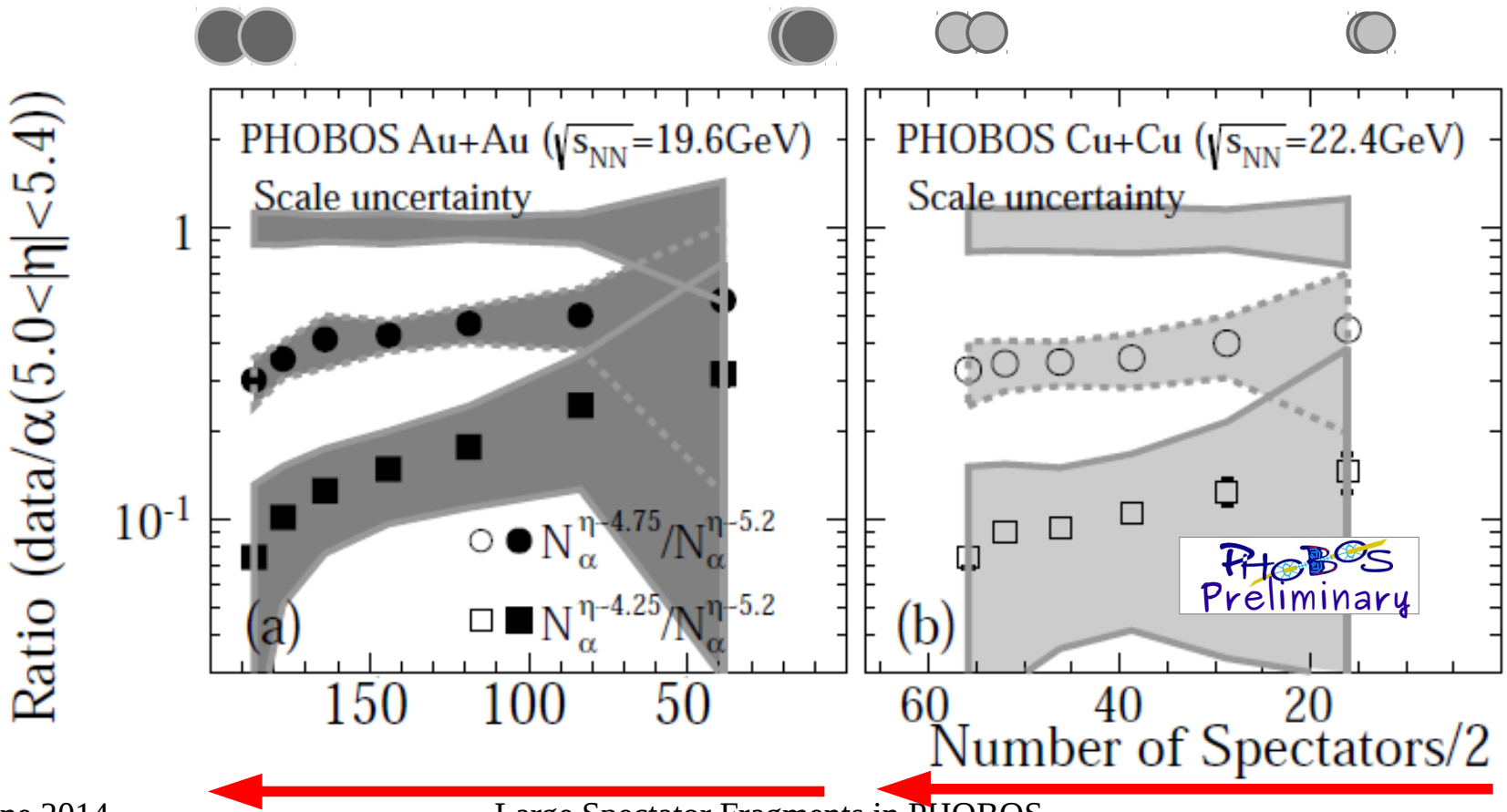
Relative Li/α Abundance

- Yield ratio: Li/α
  - Approximately flat dependence with centrality
  - Smaller ratio in Cu+Cu, indicates a more favorable emission of the lighter fragment in the smaller system



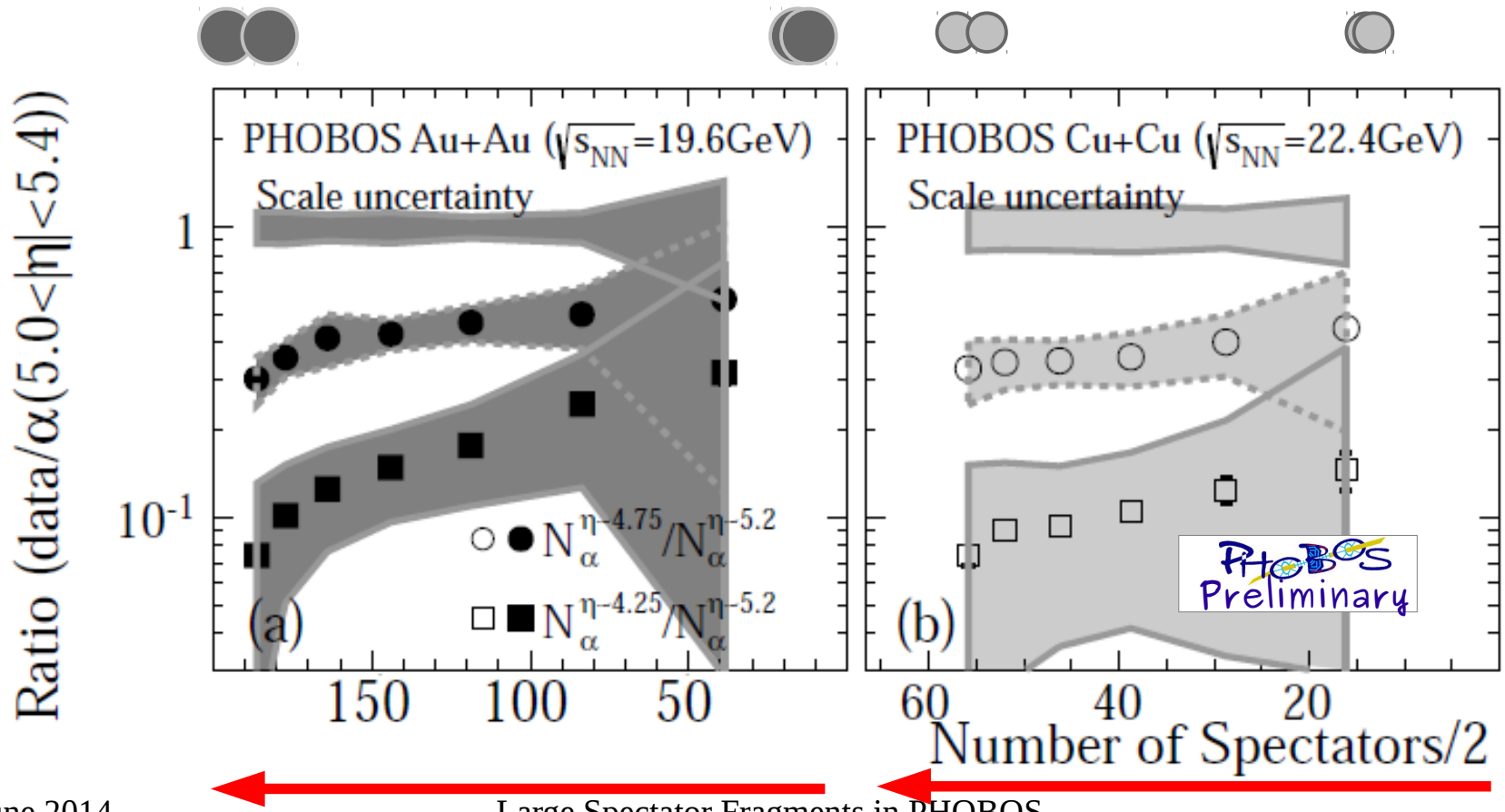
η and Centrality Dependence

- α yield ratio:
  - (4.5<|η|<5.0)/(5.0<|η|<5.4) – circles
  - (4.0<|η|<4.5)/(5.0<|η|<5.4) – squares



η and Centrality Dependence

- Centrality dependent
  - Lower η yields suppressed relative to higher η for more peripheral collisions
  - Indicates fragments move out of the acceptance (i.e. to higher η) for more peripheral collisions

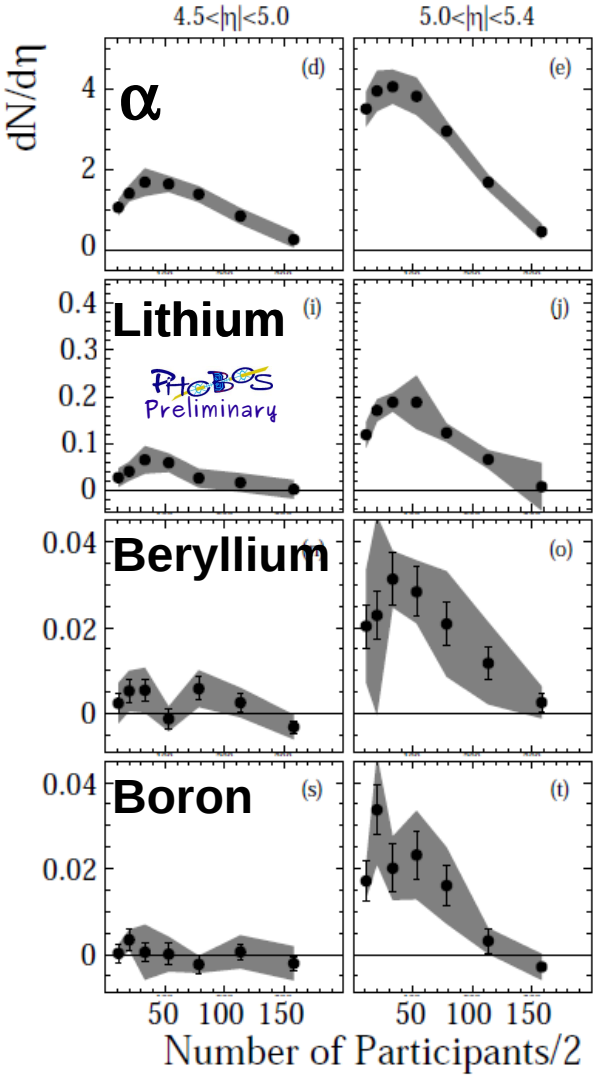


Summary

- First measurement of Z>1 spectator fragments at RHIC
  - α, Lithium, Beryllium, Boron
  - As a function of centrality and pseudorapidity

- Yield of α fragments approximately scales with the number of spectators

- dN(α)/dη distribution moves closer to lower η (lower y or higher p_T) for more central collisions



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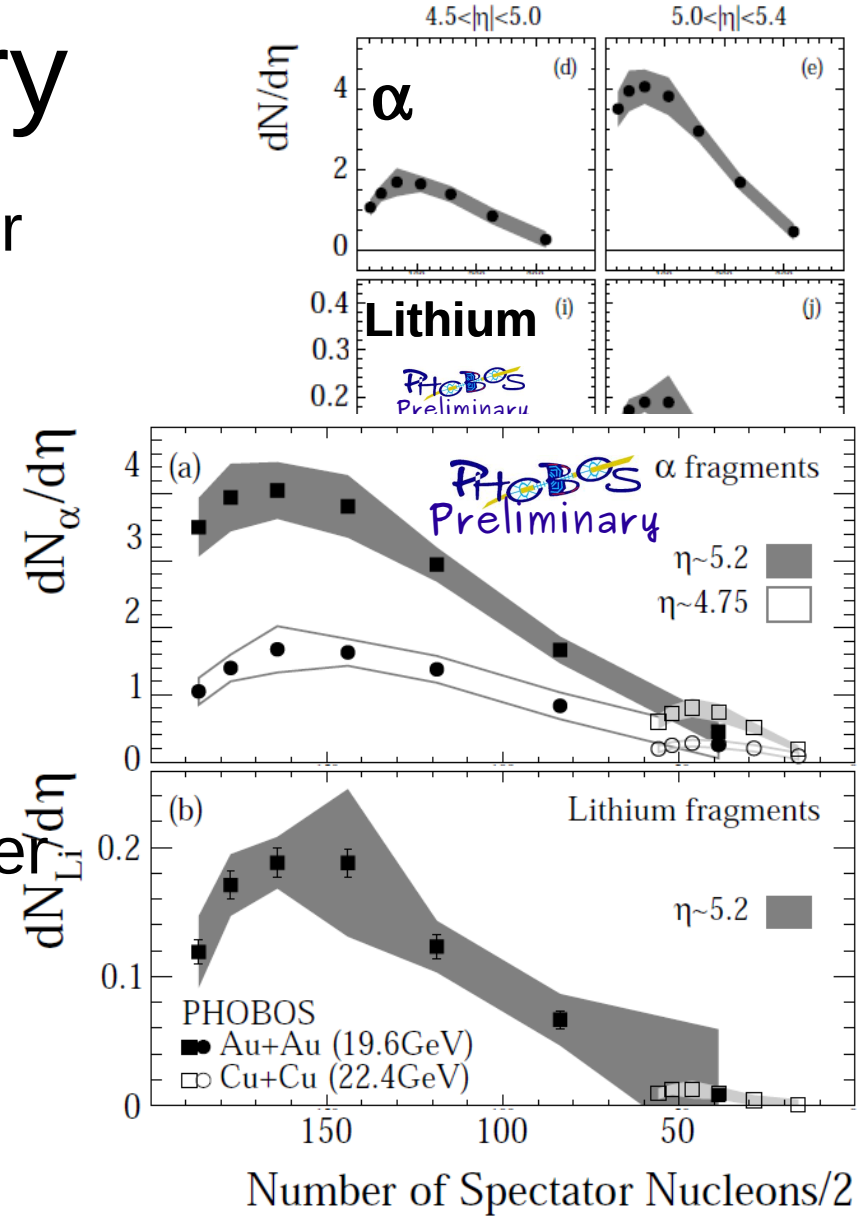

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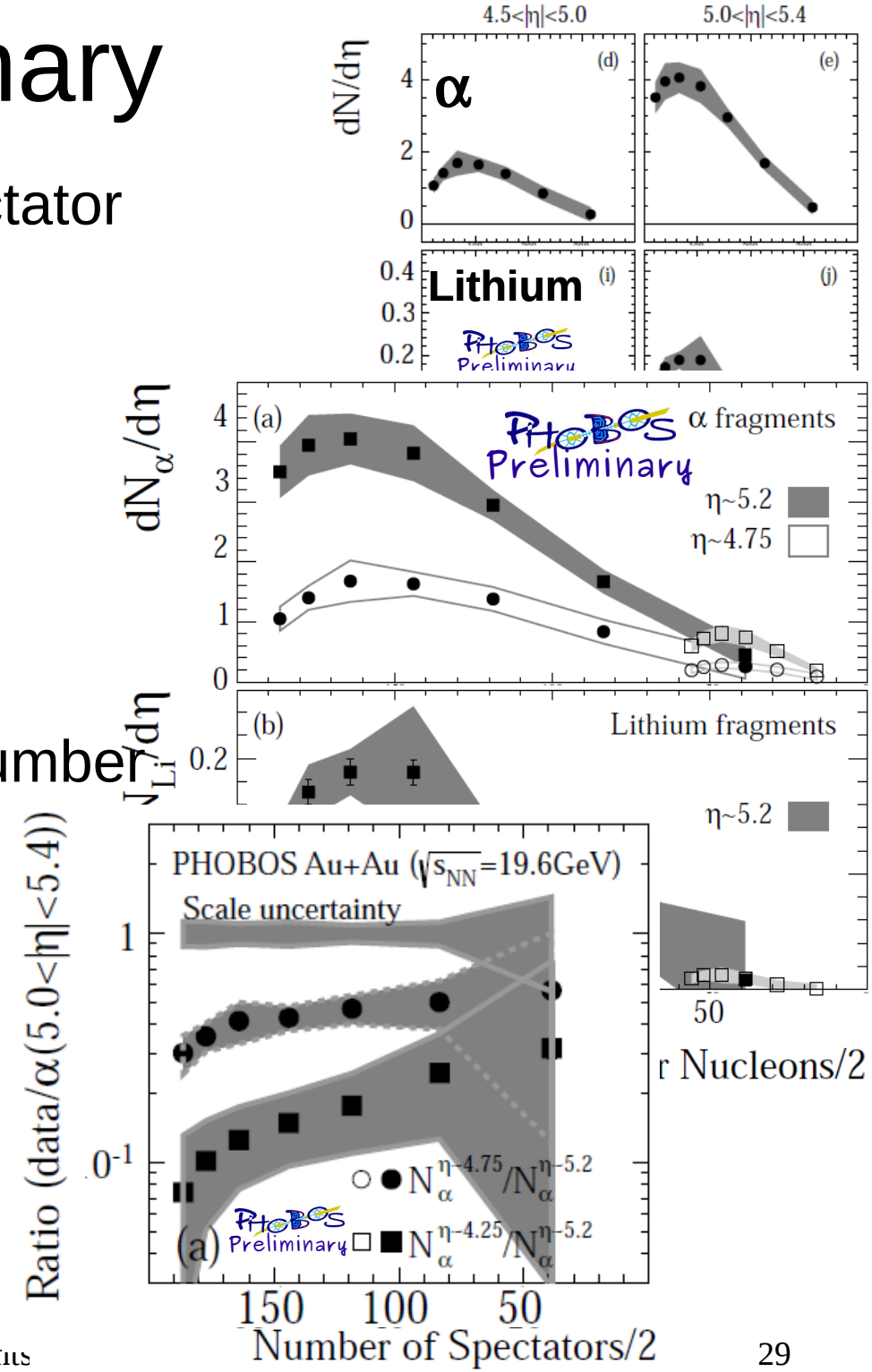
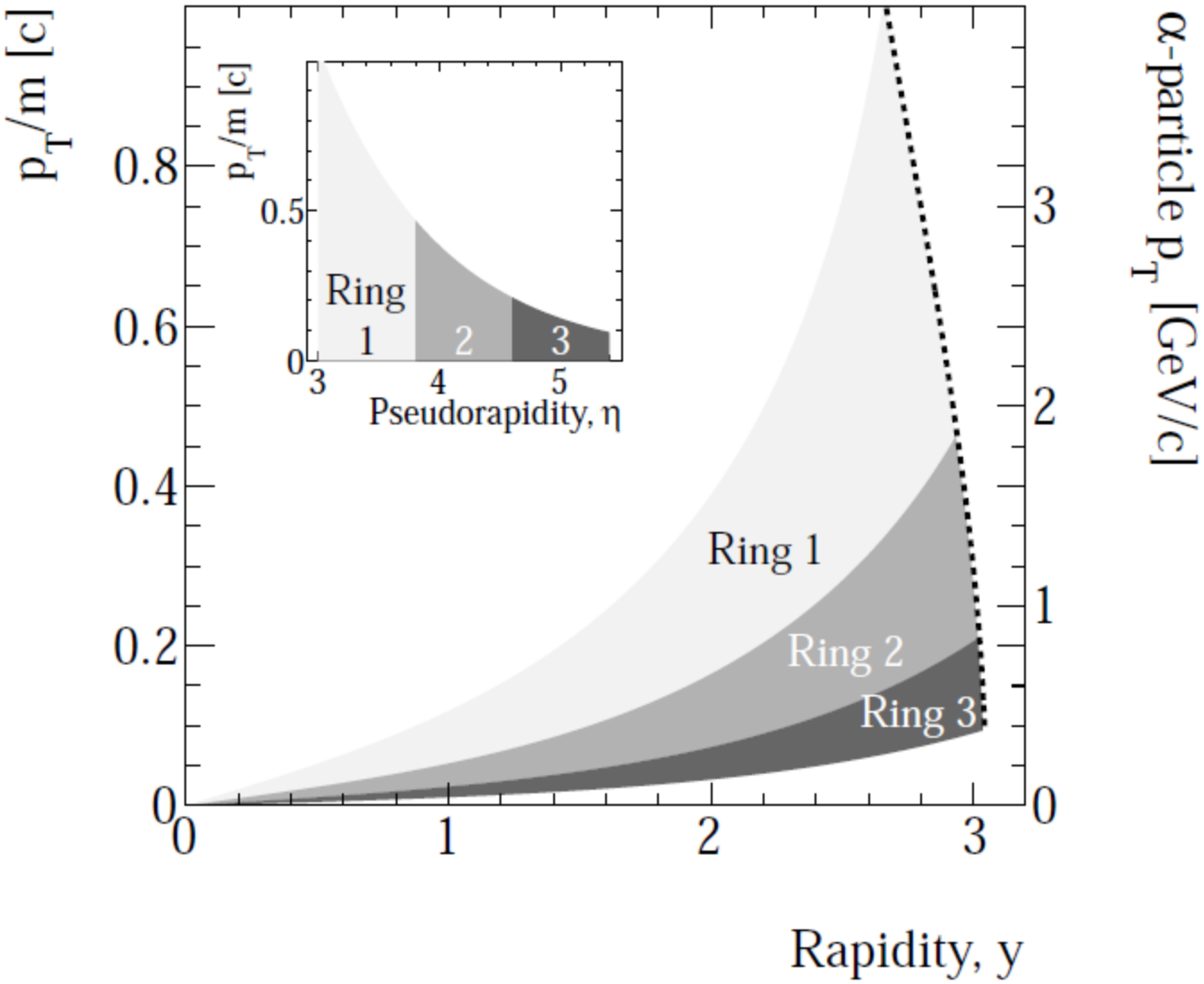
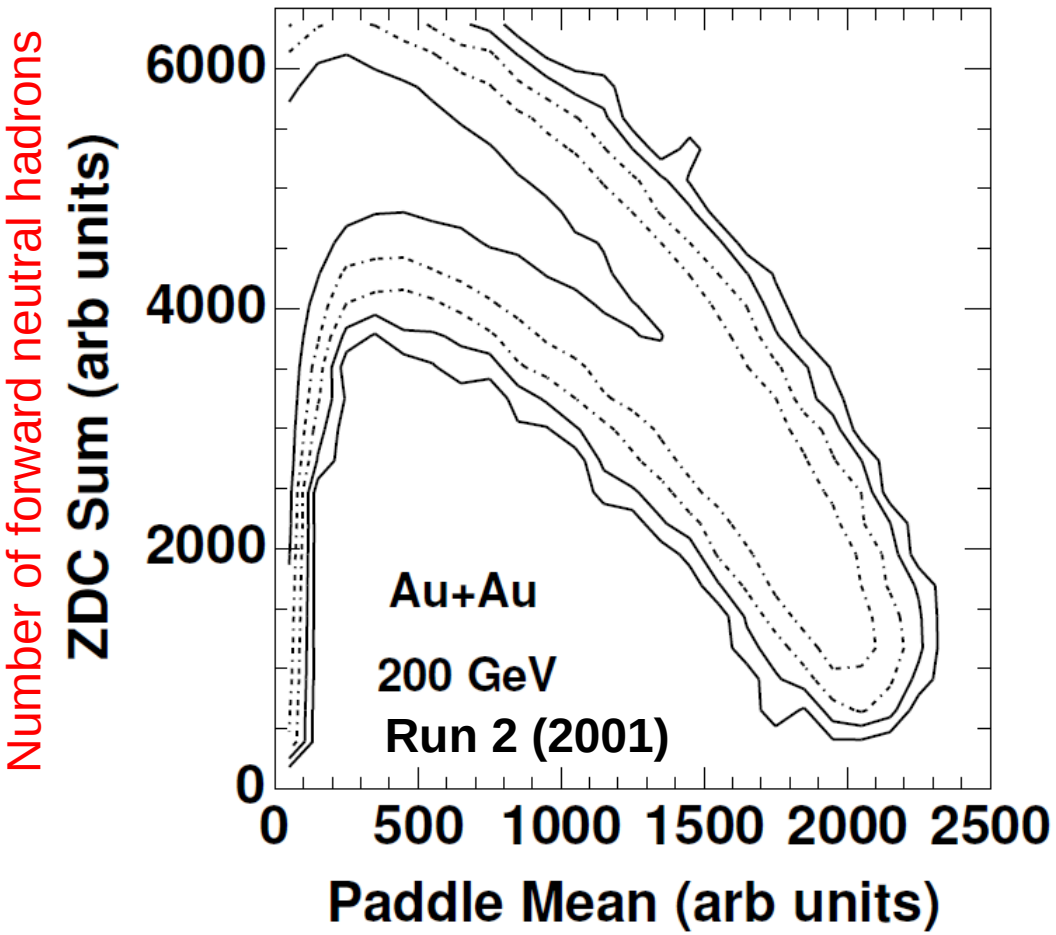


PHOBOS Kinematic Coverage



Freed Spectator Neutrons at RHIC

- One of the first measured quantities at RHIC:
  - Correlation between produced particles and very forward neutral hadrons (η>~8)
- Anti-correlation indicative of fewer spectator neutrons for more central data

Nucl. Phys. A 757 (2005) 28