Measurements of $dN_{ch}/d\eta$ in small systems (p+A, d+Au, ^{3}He+Au)

Darren McGlinchey
Los Alamos National Laboratory
For the PHENIX Collaboration

Motivation

√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

PHENIX

16 years of operation

9 collision species

9 collision energies

Motivation

√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

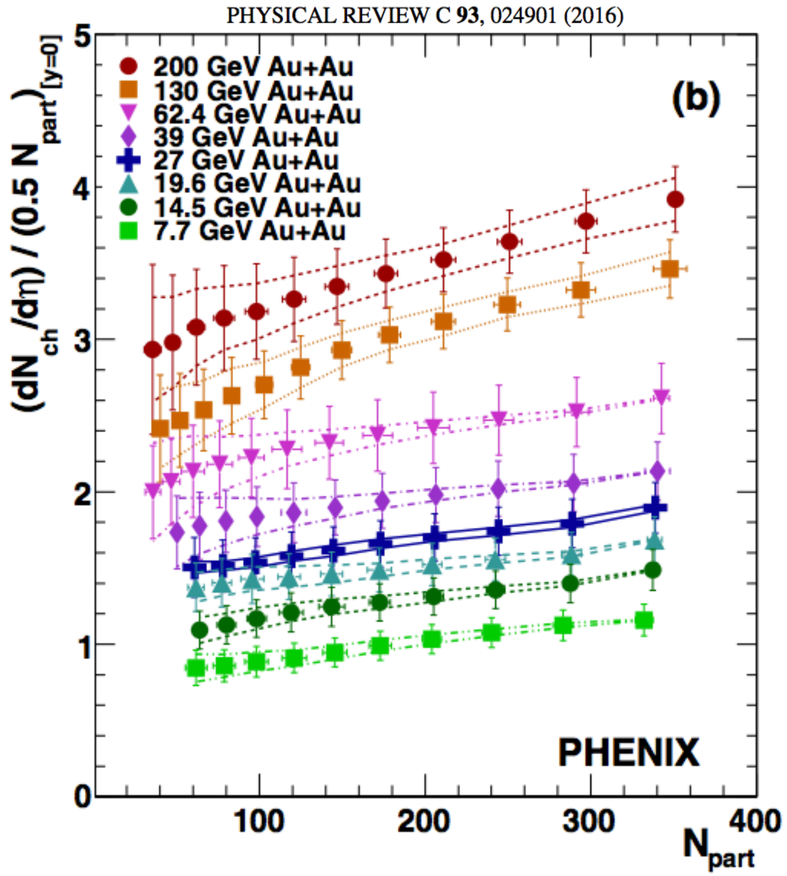
PHENIX

16 years of operation

9 collision species

9 collision energies

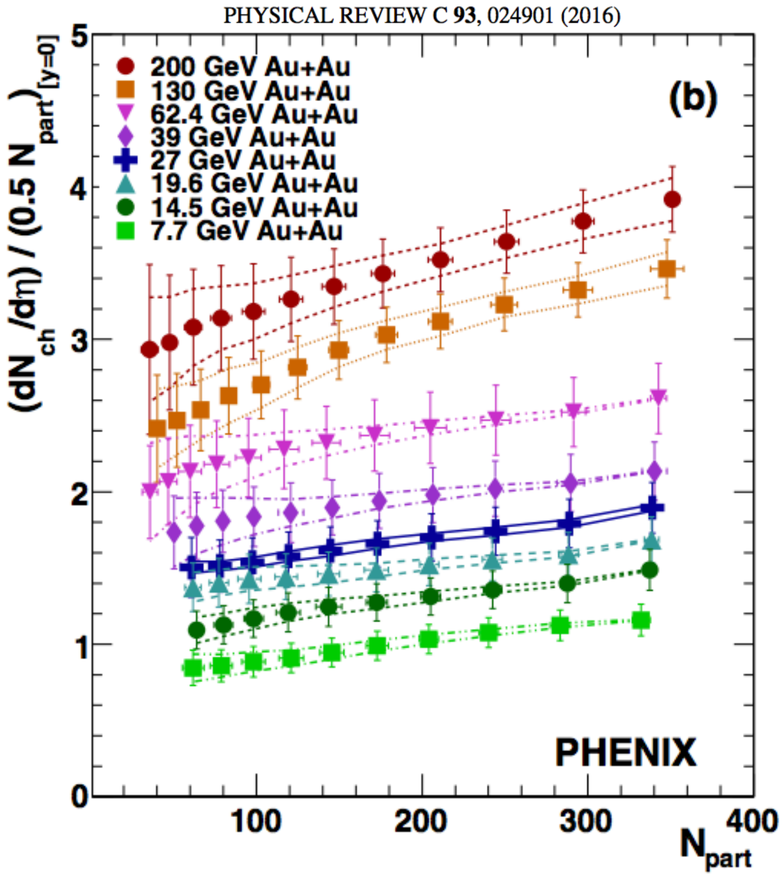
Many PHENIX measurements of $dN_{ch}/d\eta$ at mid rapidity!



Motivation

√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓							✓	
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

Many PHENIX measurements of $dN_{ch}/d\eta$ at mid rapidity!



PHENIX

16 years of operation

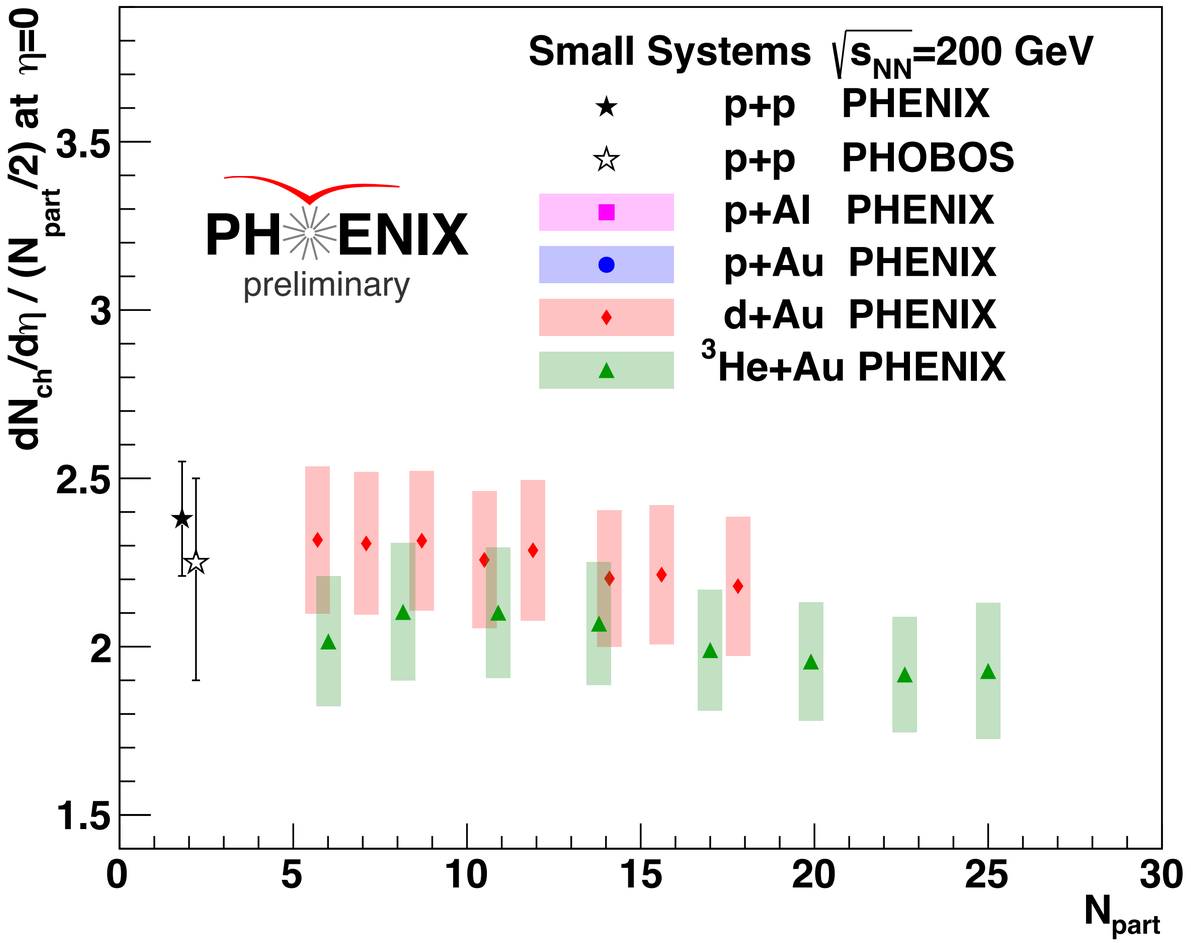
9 collision species

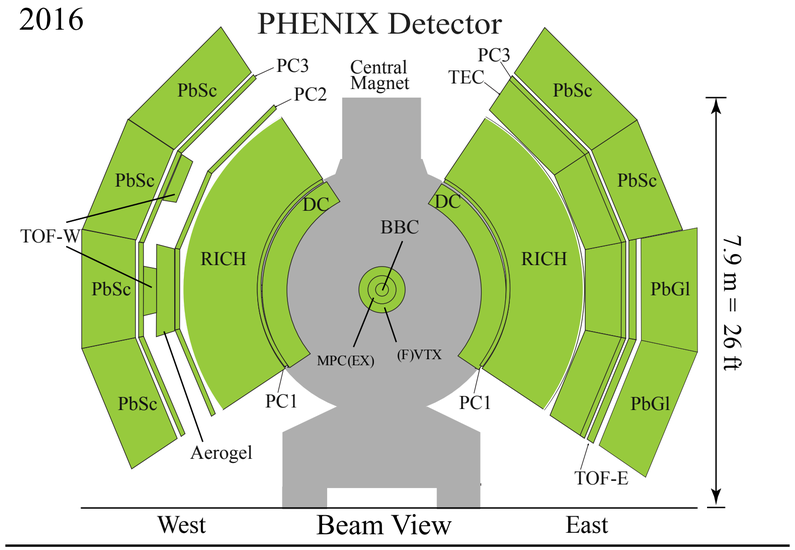
9 collision energies

What about small collision systems?

- Asymmetric systems present unique tests of particle production
- Can be used to check scaling behaviors between small/large collision systems

Midrapidity scaling

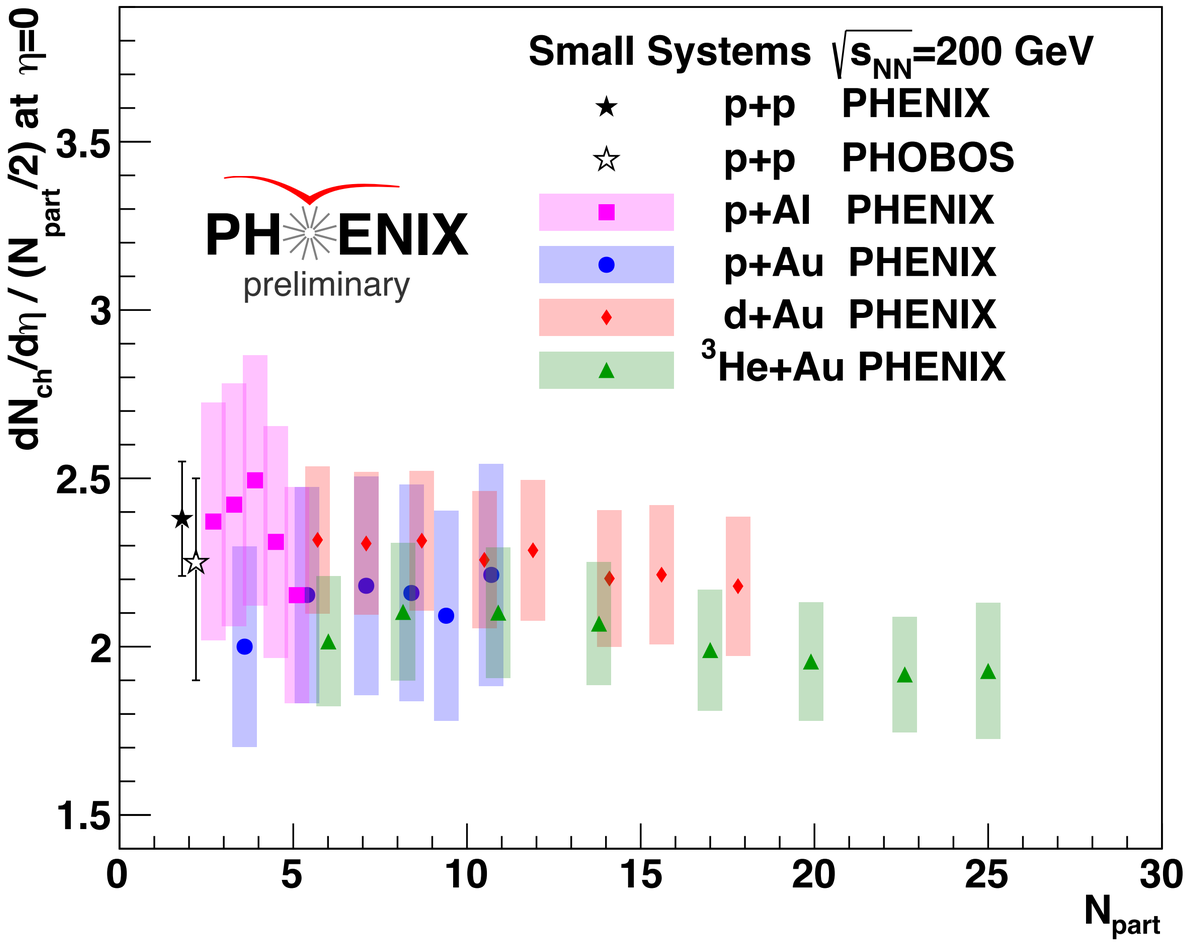


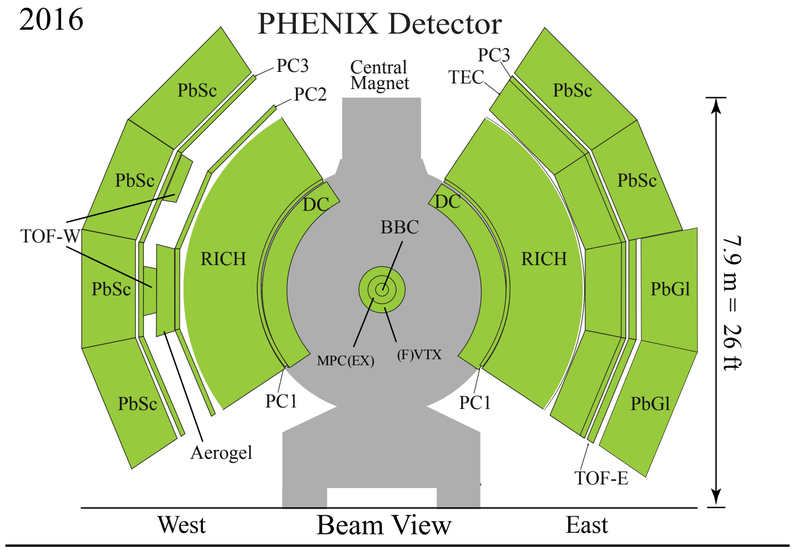


Using particle tracking in the central region

Previous results from d+Au and ^{3}He+Au indicate scaling with N_{part}

Midrapidity scaling





Using particle tracking in the central region

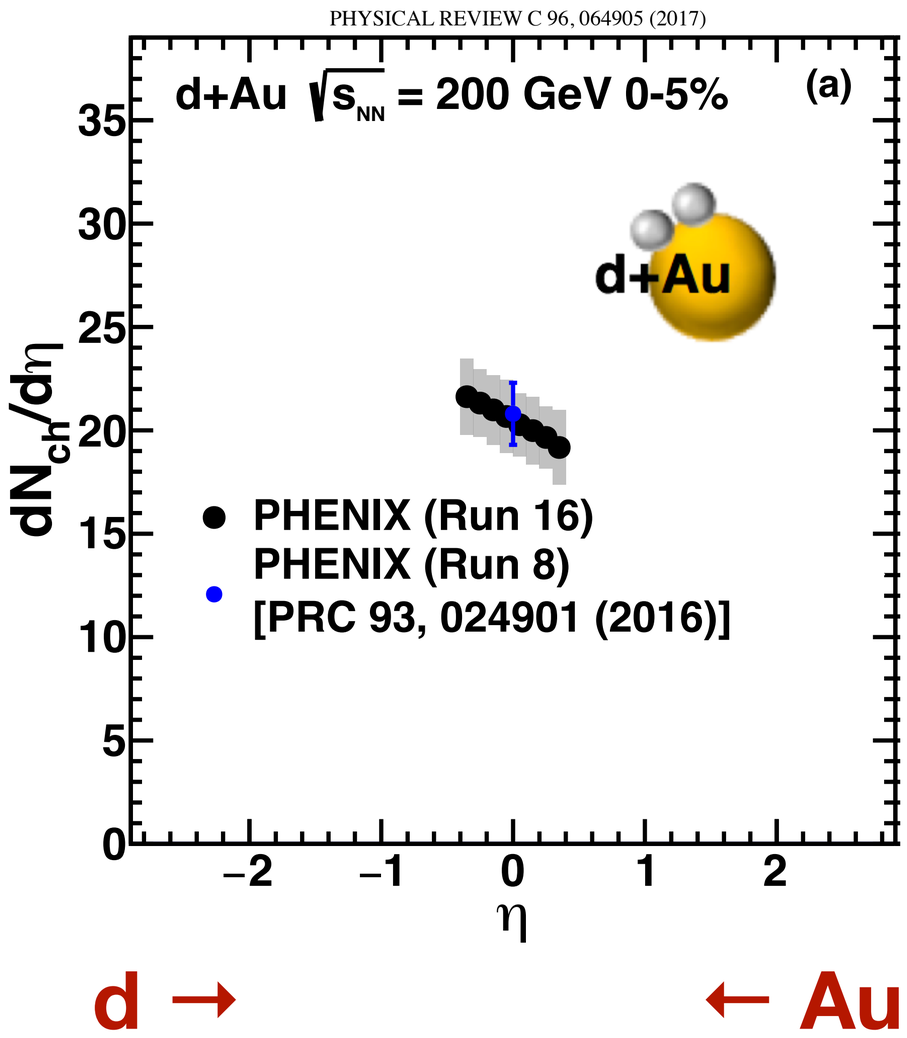
Previous results from d+Au and ^{3}He+Au indicate scaling with N_{part}

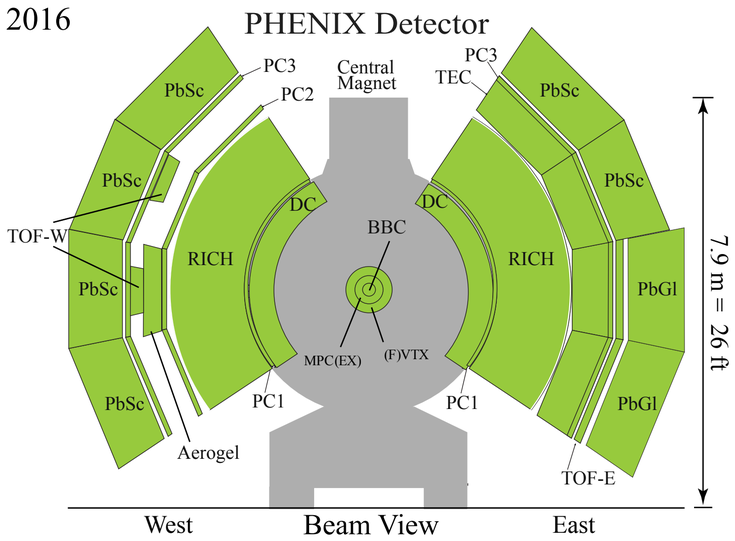
New results from p+Al and p+Au agree with the trend

Extending in Pseudorapidity

Using PHENIX Central Arms:

Run 16 in excellent agreement with Run 8



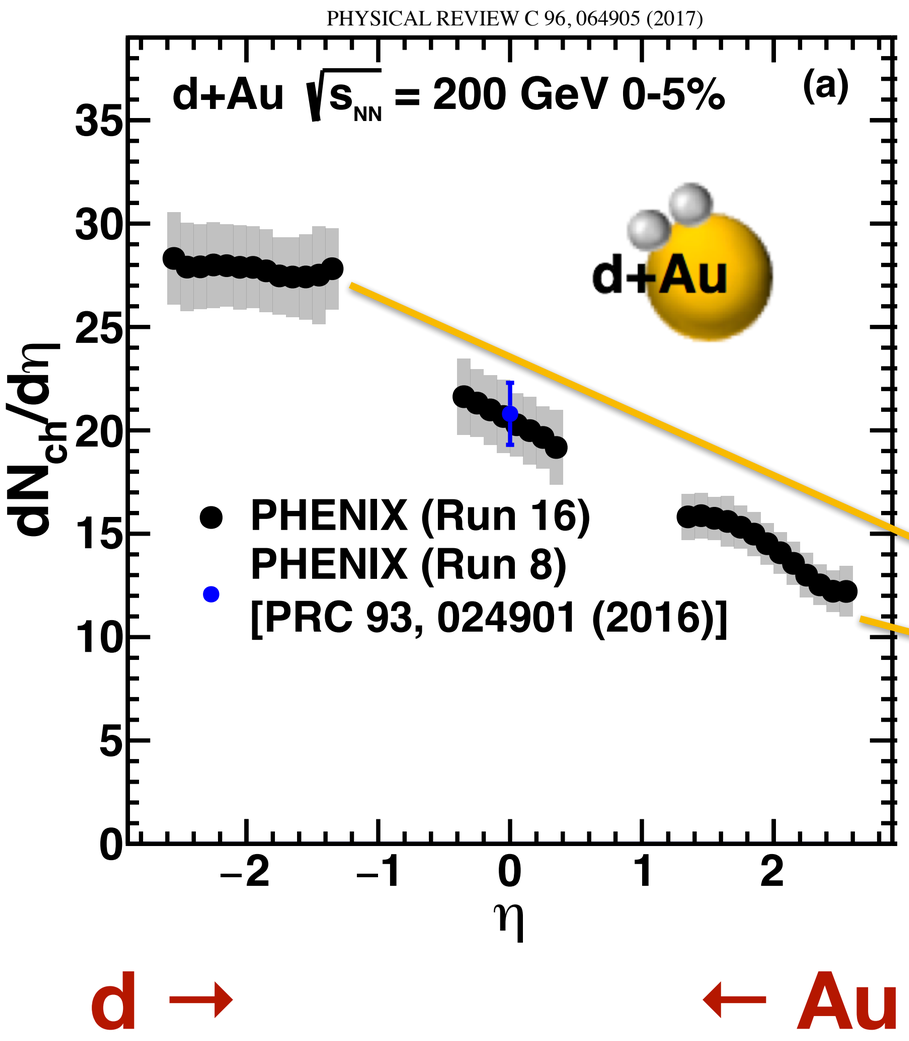


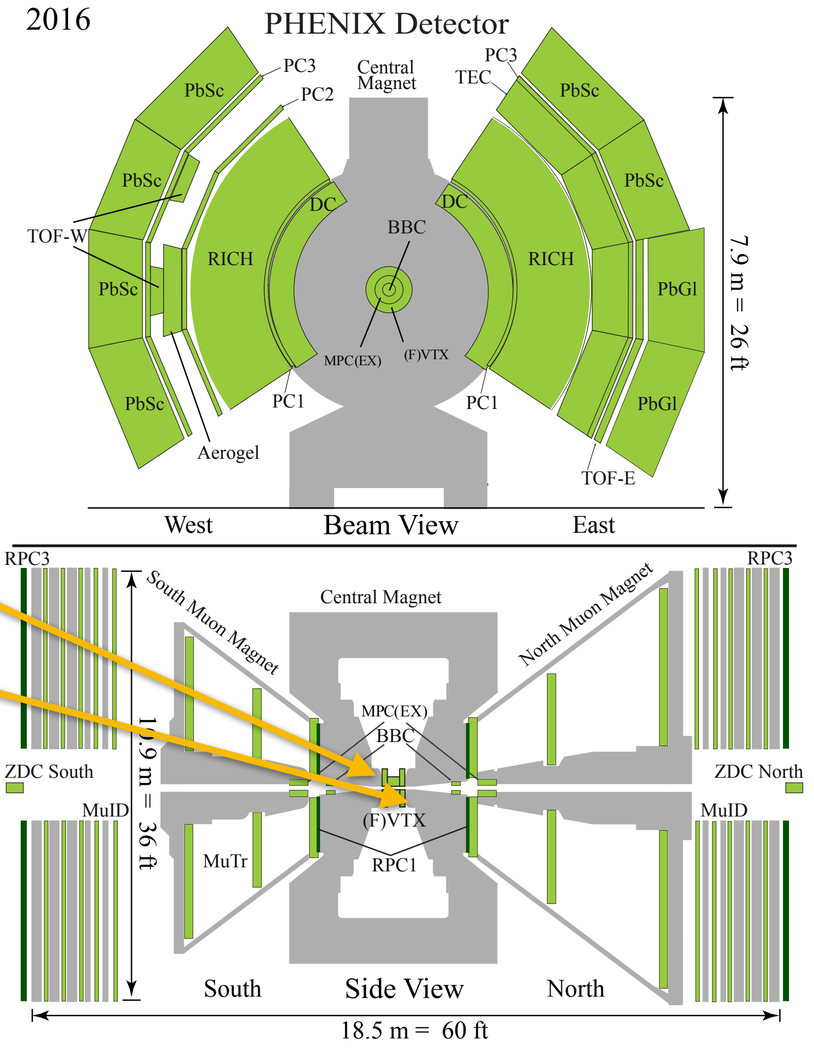
Extending in Pseudorapidity

Using PHENIX Central Arms:

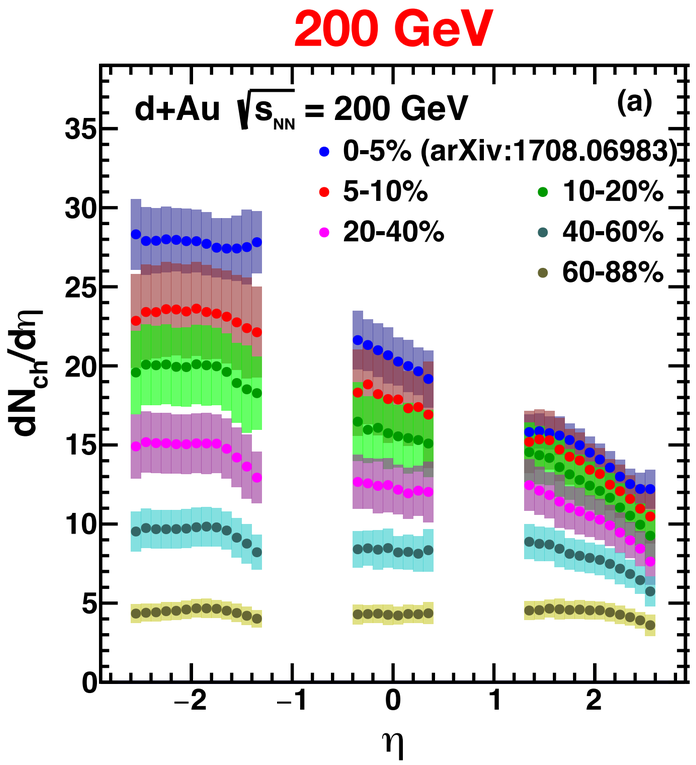
Run 16 in excellent agreement with Run 8

Extend measurement in η using FVTX





d+Au Centrality Dependence

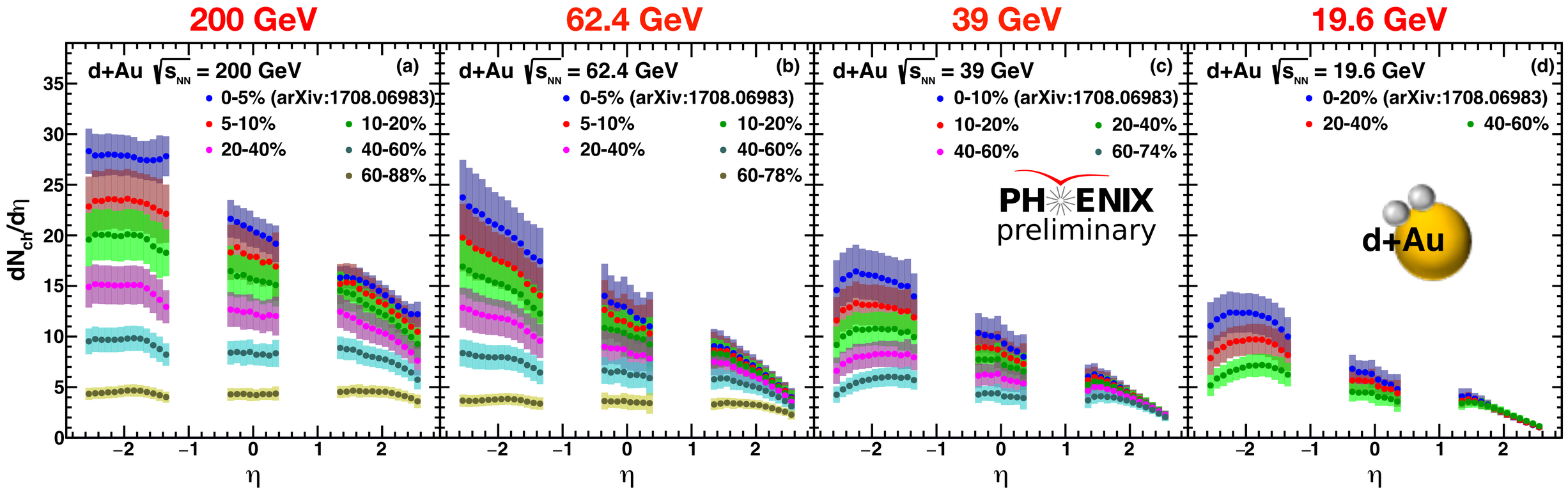


Include full centrality dependence

0-5%: highly asymmetric

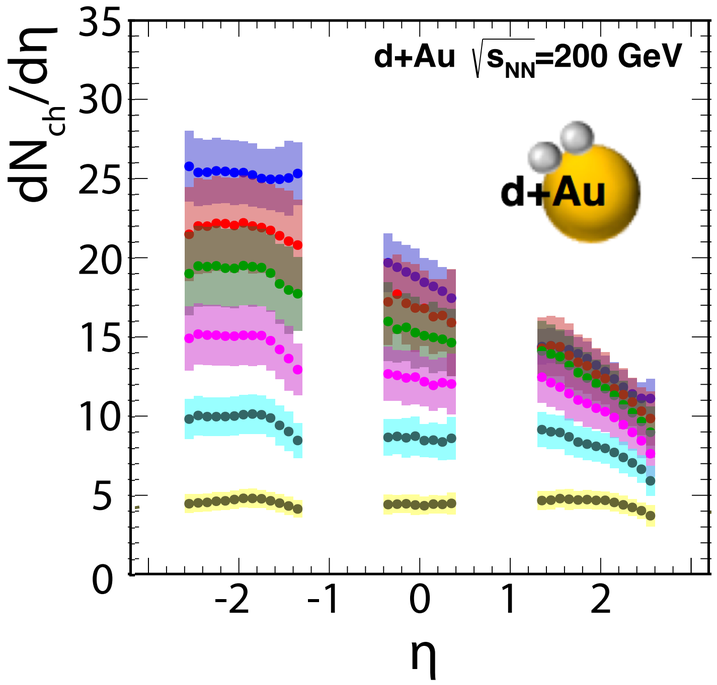
60-88%: symmetric and p+p like

d+Au Energy Dependence

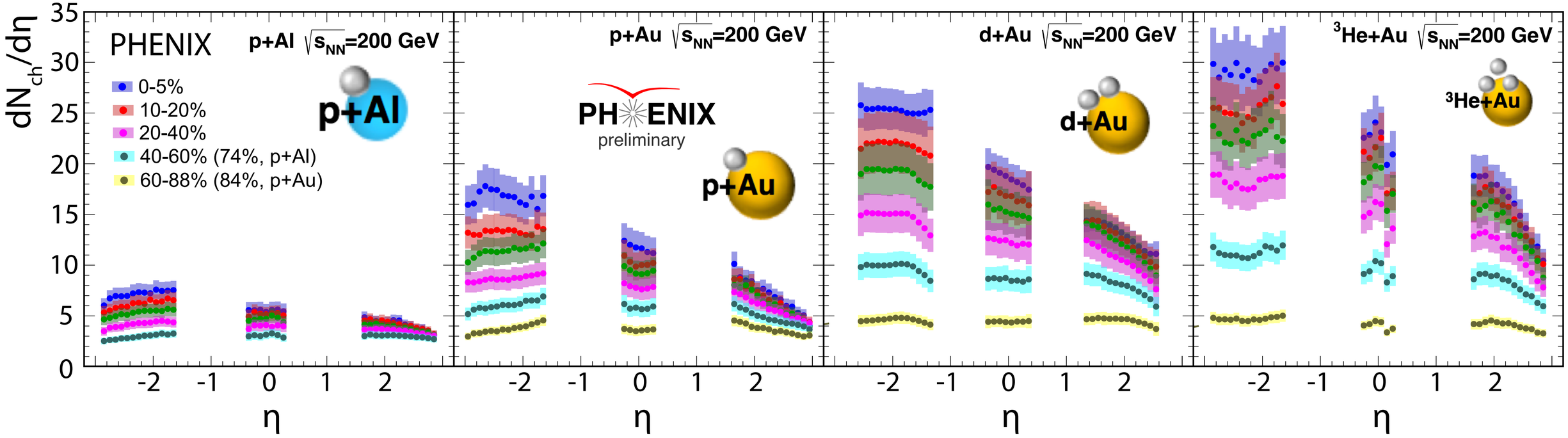


Factor of ~3 decrease in $dN_{ch}/d\eta$ from 200 to 20 GeV

Geometry Scan



Geometry Scan



$dN_{ch}/d\eta$ increases with system size

Wounded Quark Model

Wounded Quark Model:
(Simalar to wounded nucleon model)

$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

2 main pieces:

1) **$w_{L(R)}$: Mean number of wounded quarks in Target & Projectile**
2) **$F(\eta)$: Wounded quark emission function**

Wounded Quark Model

Wounded Quark Model:
(Simalar to wounded nucleon model)

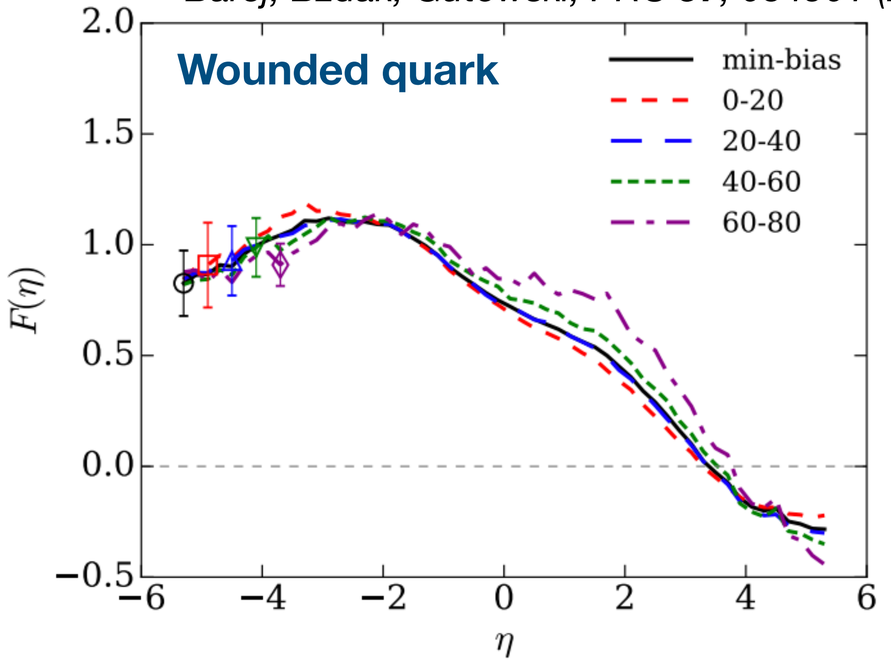
$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

2 main pieces:

1) **$w_{L(R)}$: Mean number of wounded quarks in Target & Projectile**
2) **F(η) : Wounded quark emission function**

Wounded quark emission functions
Extracted from fits to PHOBOS d+Au data

*Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018)*



Wounded Quark Model

Wounded Quark Model:
(Simalar to wounded nucleon model)

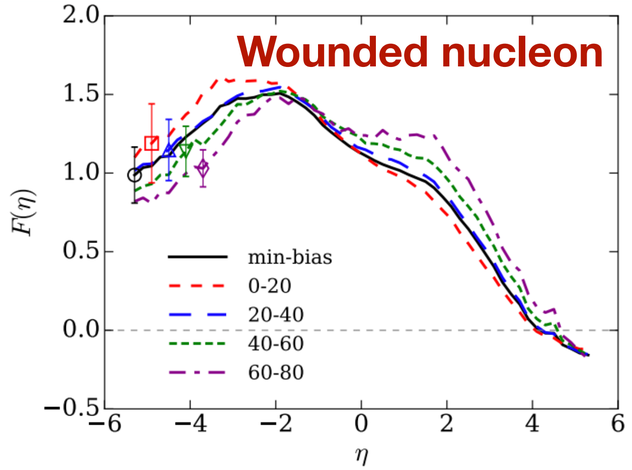
$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

2 main pieces:

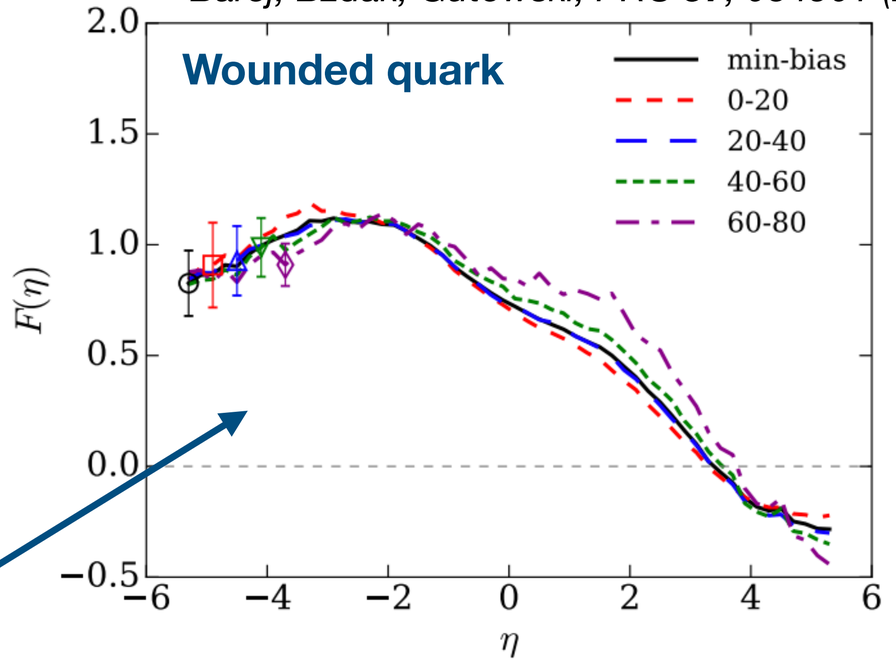
1) **$w_{L(R)}$: Mean number of wounded quarks in Target & Projectile**
2) **F(η) : Wounded quark emission function**

Wounded quark emission functions Extracted from fits to PHOBOS d+Au data

Wounded quark emission function universal, unlike wounded nucleon (top)



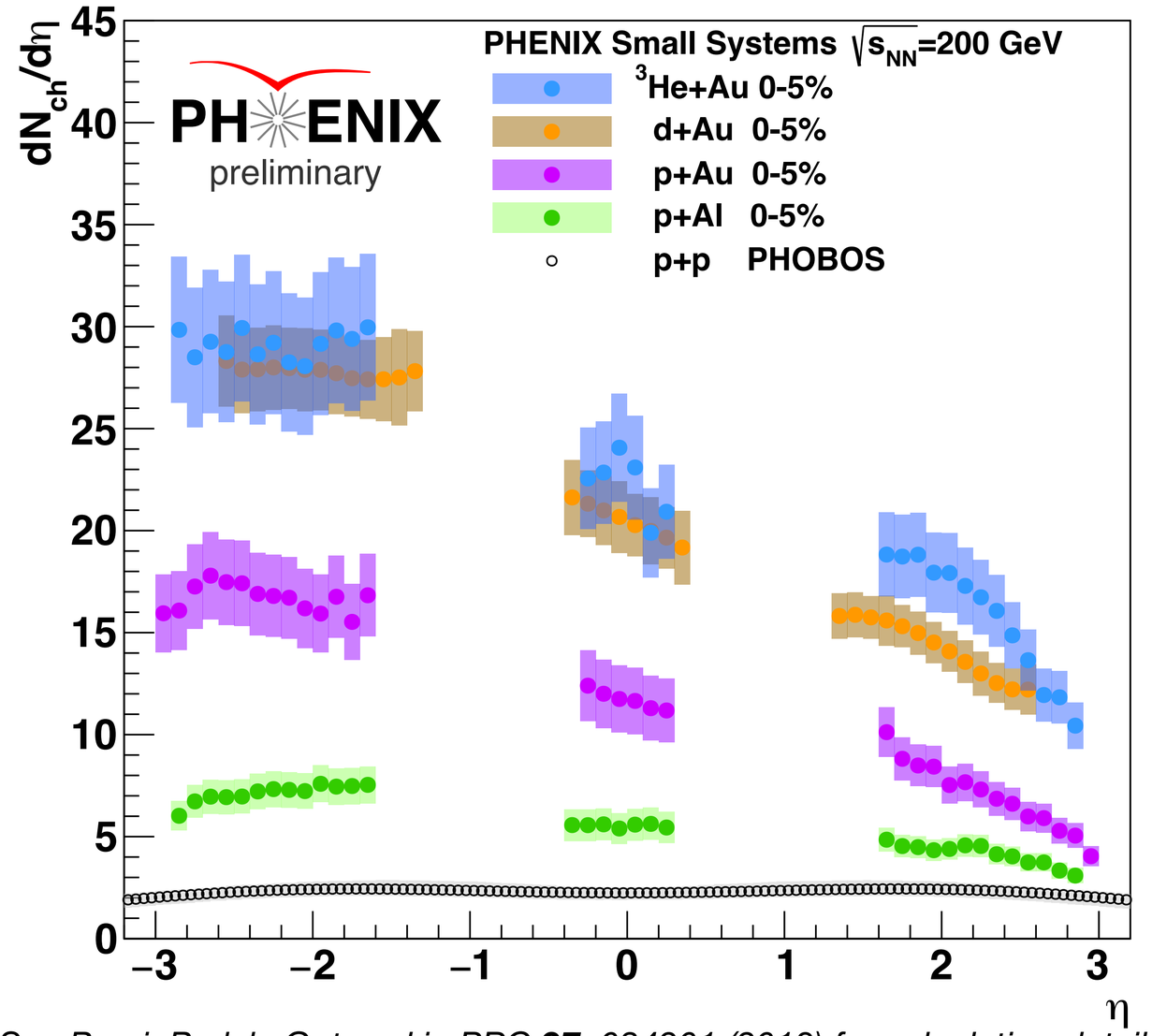
*Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018)*



Wounded Quark Model

$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

Same wounded quark emission functions used for all systems & centrality



*See Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018) for calculation details*

Wounded Quark Model

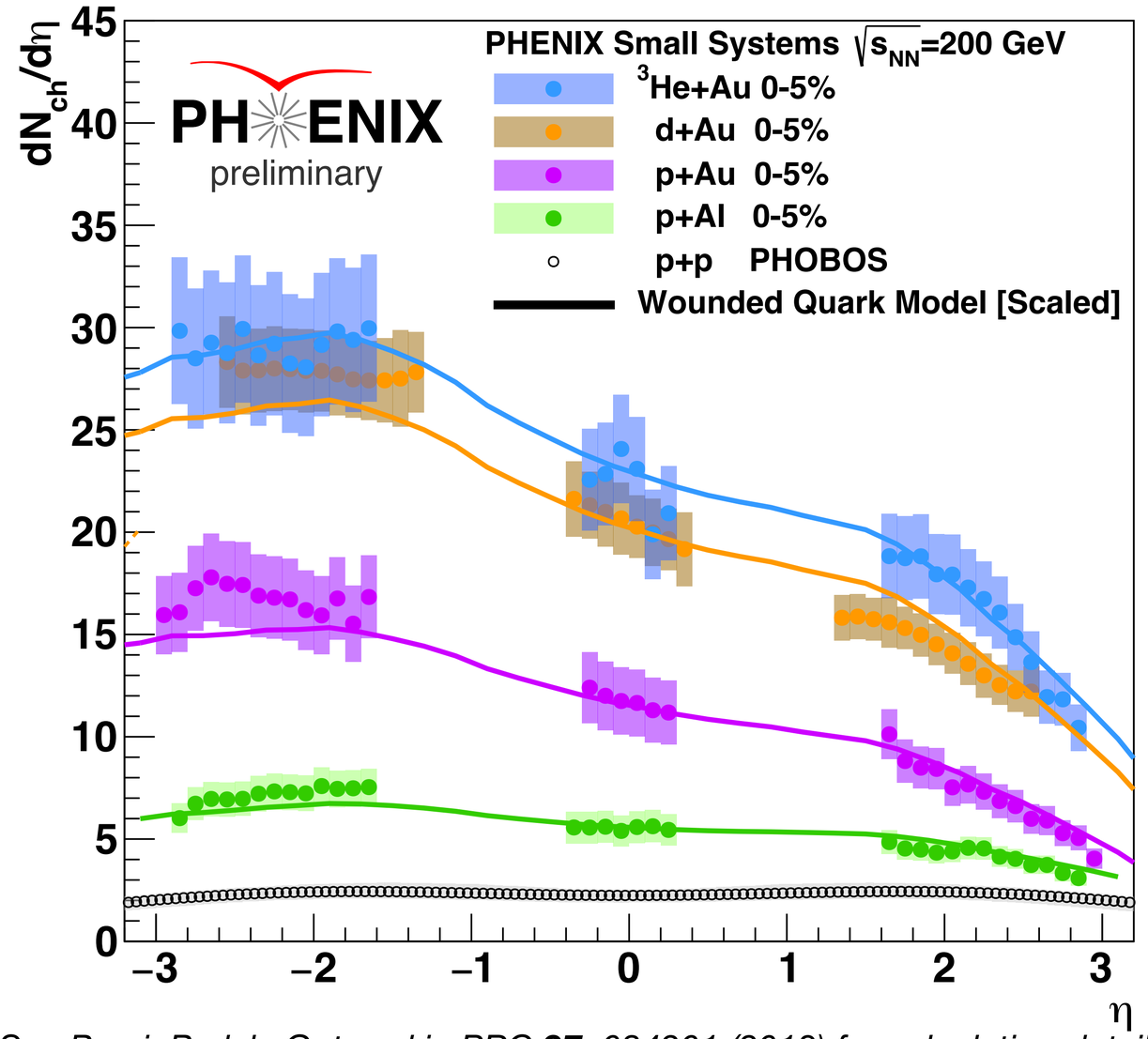
$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

Same wounded quark emission functions used for all systems & centrality

Curves show results for 0-5% central p/d/^{3}He+Al/Au collisions

***results are scaled to the data — shape is what's important**

Good agreement for all 4 systems!



*See Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018) for calculation details*

Wounded Quark Model

$$\frac{dN_{ch}}{d\eta} = w_L F(\eta) + w_R F(-\eta)$$

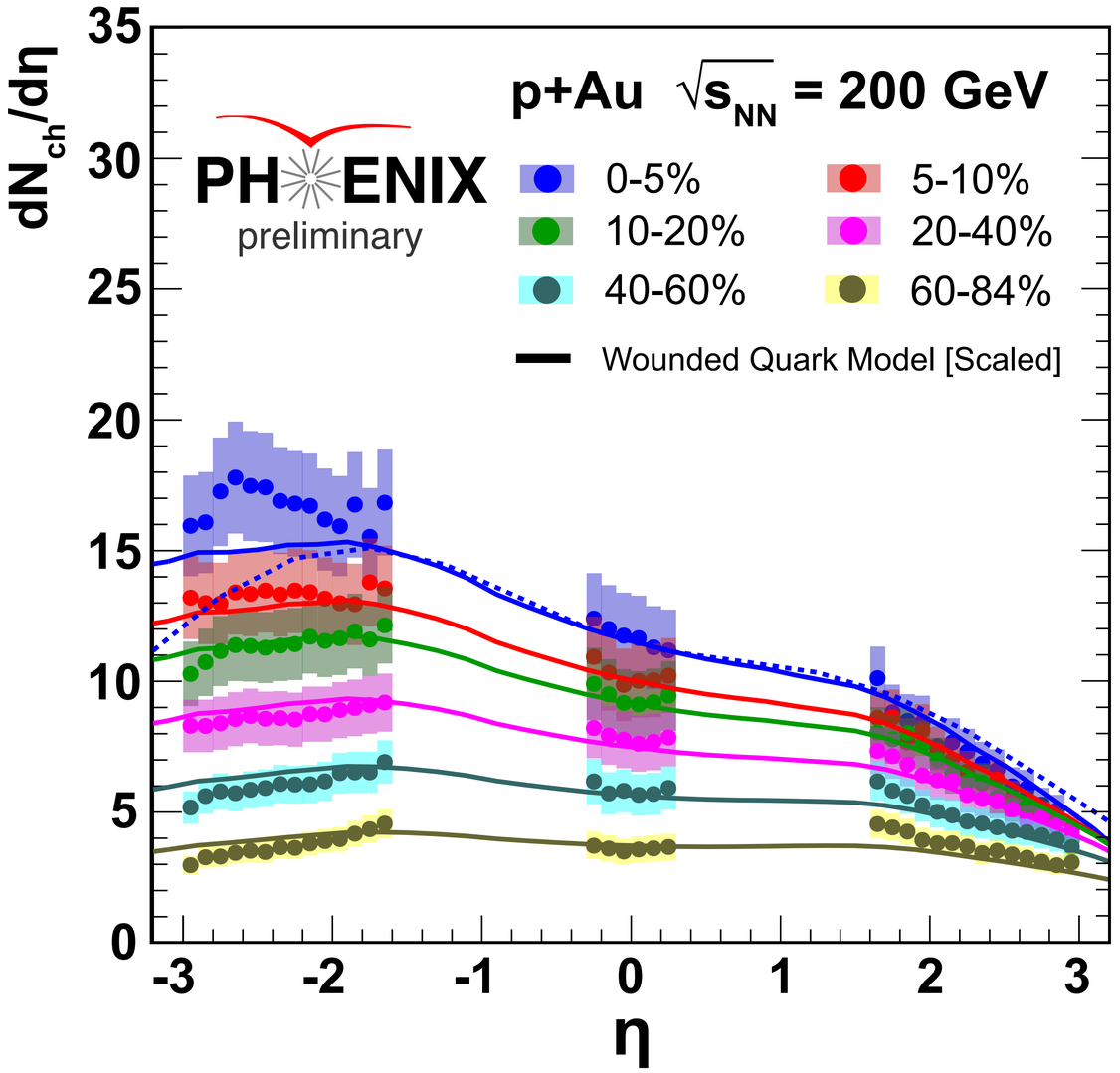
Same wounded quark emission functions used for all systems & centrality

Curves show results for 0-5% central p/d/^{3}He+Al/Au collisions

***results are scaled to the data — shape is what's important**

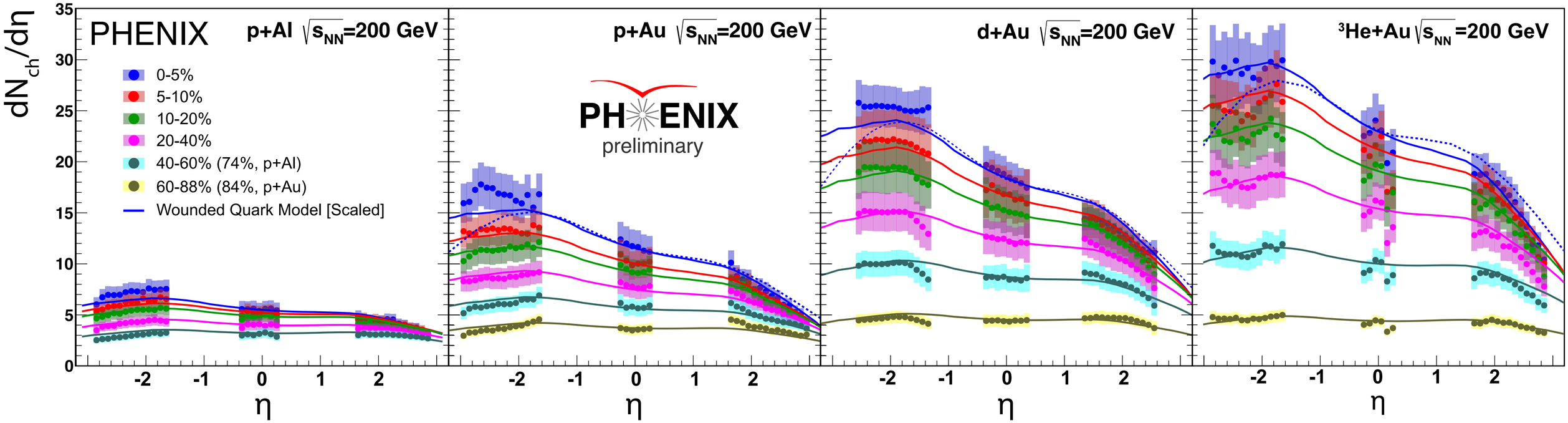
Good agreement for all 4 systems!

Good agreement for all centrality!



*See Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018) for calculation details*

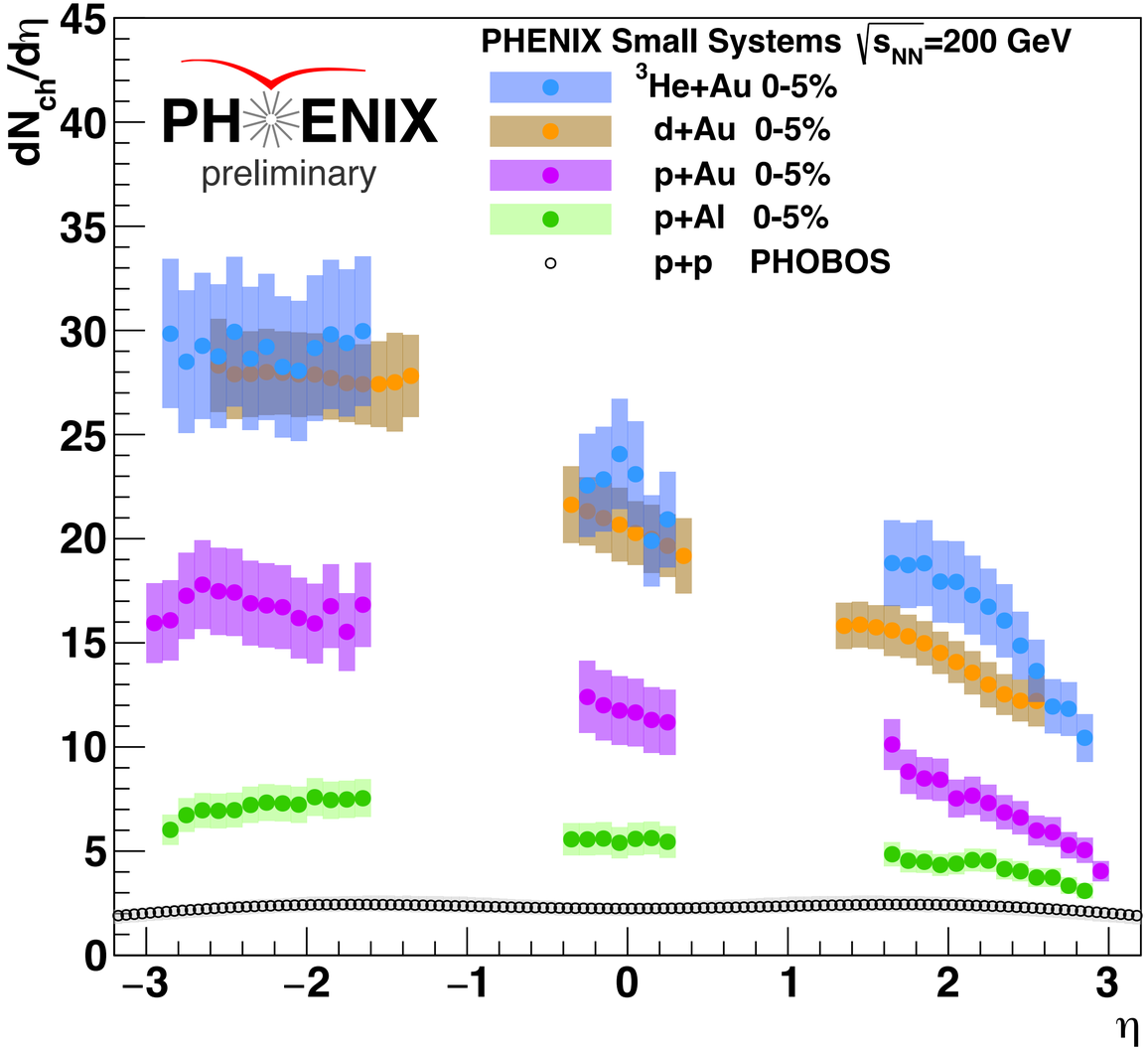
Wounded Quark Model



Common wounded quark emission function
Describes all systems & centralities
reasonably well

*See Barej, Bzdak, Gutowski, PRC **97**, 034901 (2018) for calculation details*

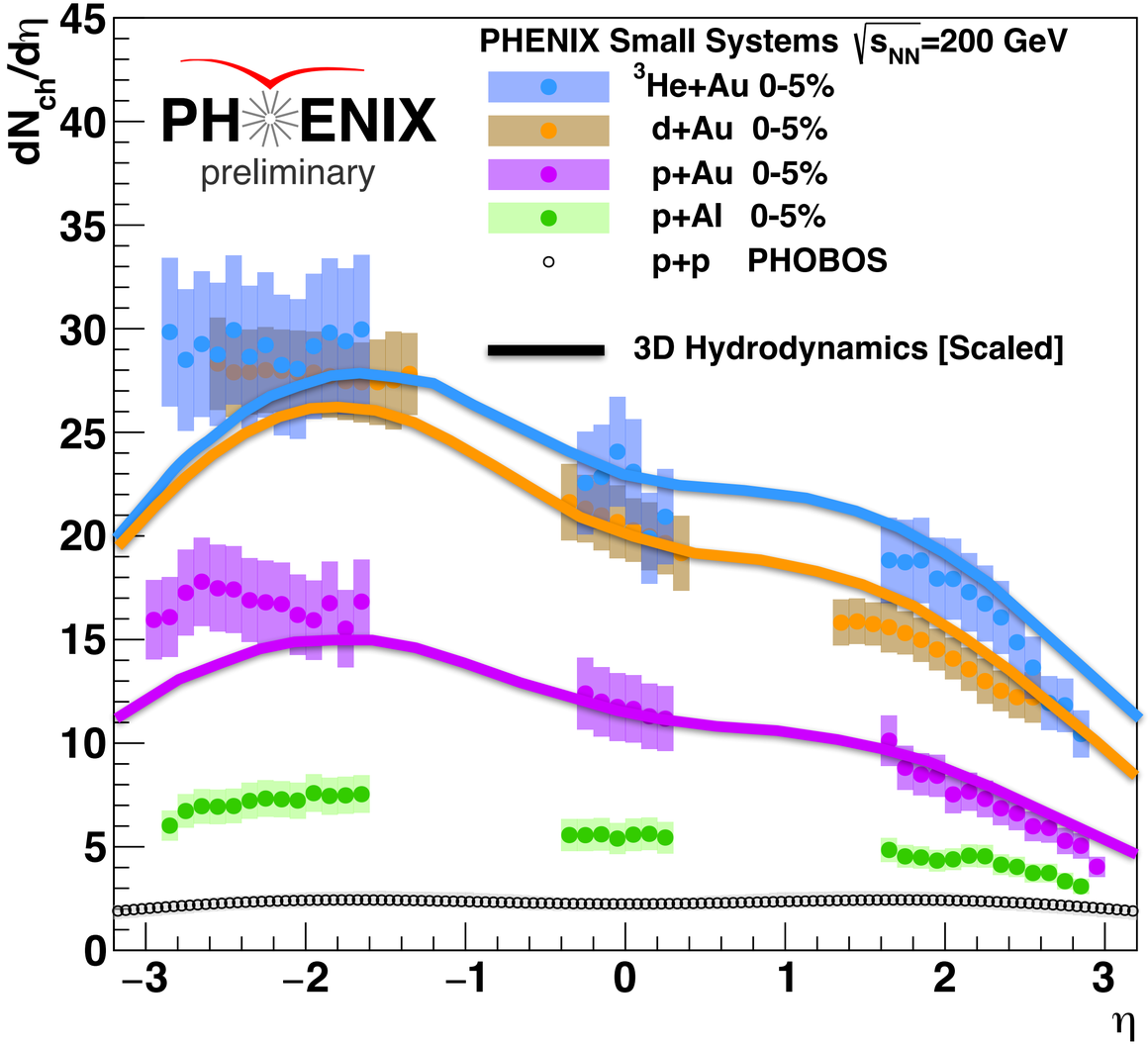
3D Hydrodynamics



Particle production in 3D hydrodynamics

See Bozek, Broniowski, Phys. Lett. B 739 (2014) for calculation details

3D Hydrodynamics



Particle production in 3D hydrodynamics

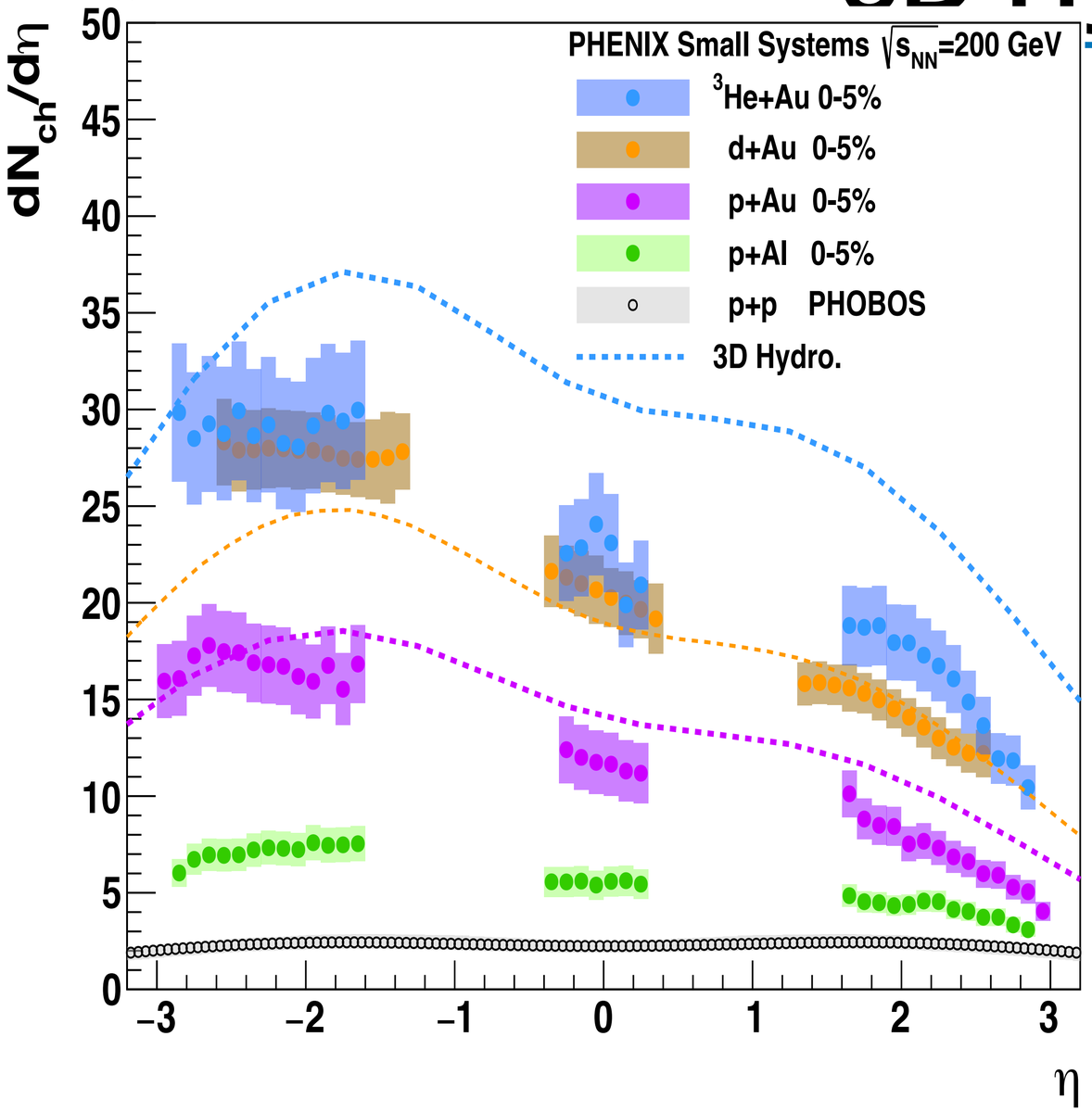
***results are scaled to the data — Same for wounded quark model**

Results fall faster at backward rapidity compared to data

Good agreement at mid and forward rapidity

See Bozek, Broniowski, Phys. Lett. B 739 (2014) for calculation details

3D Hydrodynamics



See Bozek, Broniowski, Phys. Lett. B 739 (2014) for calculation details

Particle production in 3D hydrodynamics

Results fall faster at backward rapidity compared to data

Good agreement at mid and forward rapidity

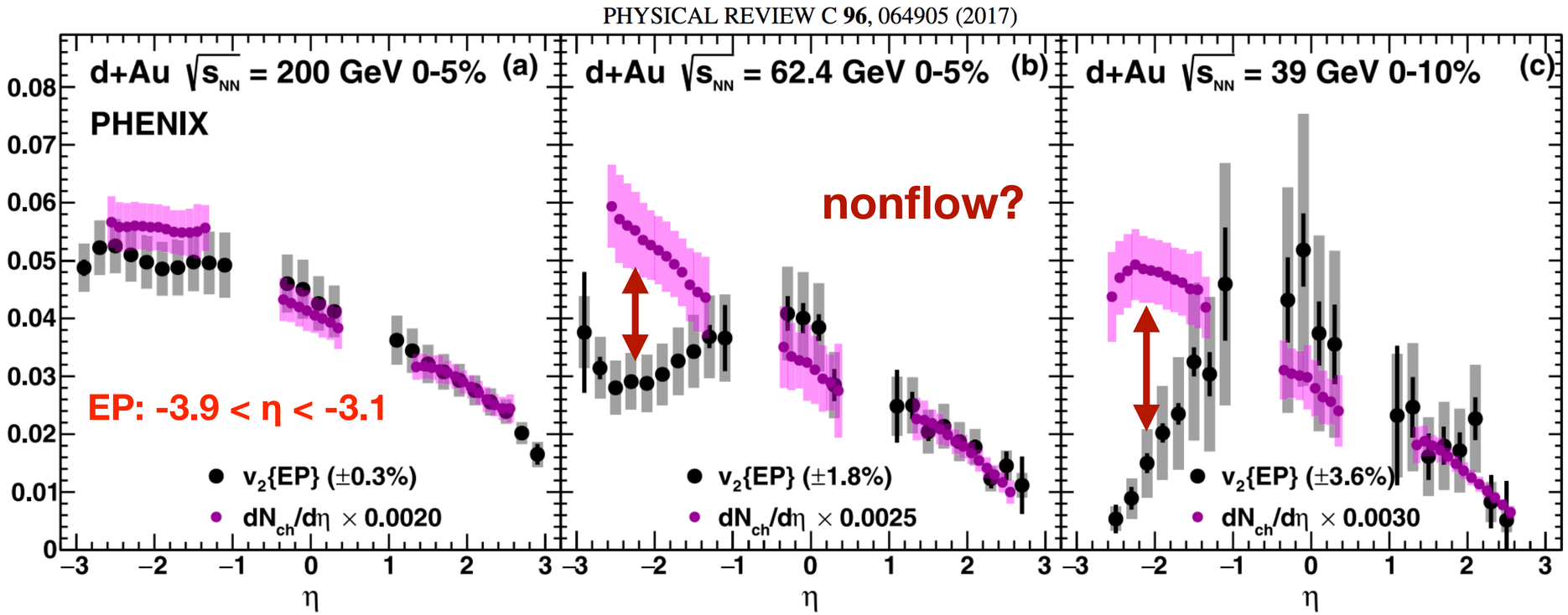
Scale factors:

^{3}He+Au - 0.75

d+Au - 1.05

p+Au - 0.81

v_2 scaling

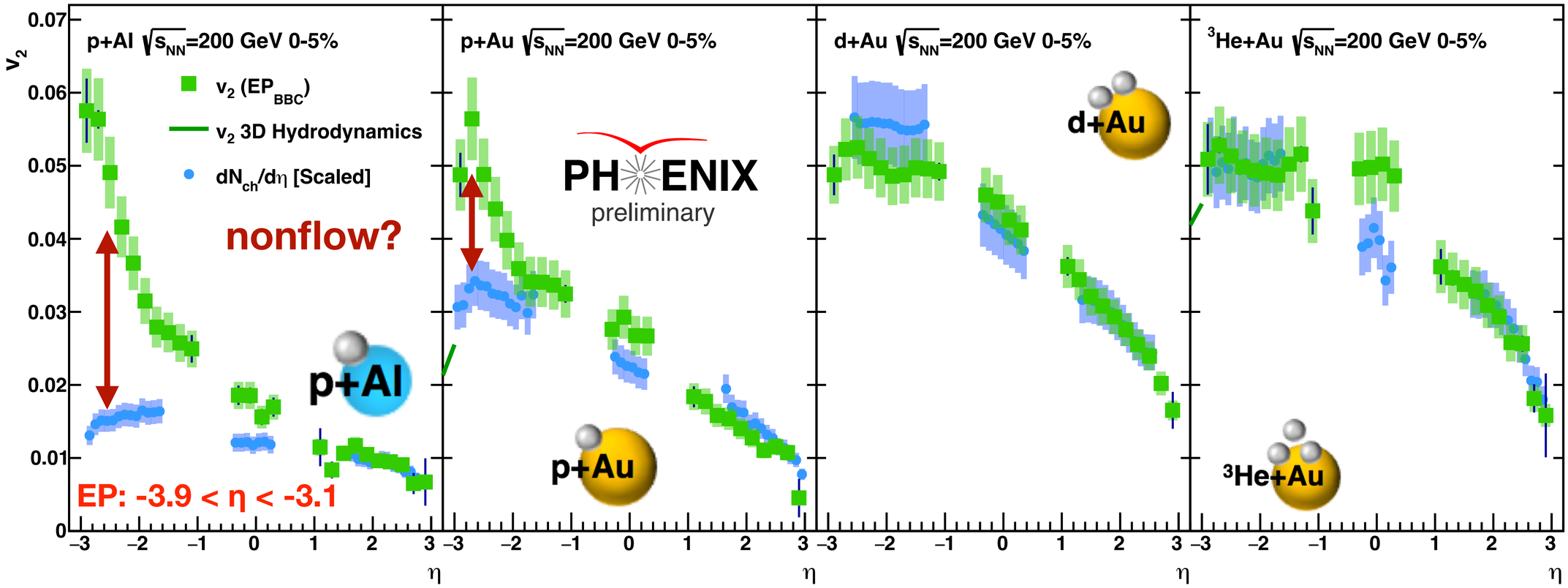


In d+Au, observed that v_2 appeared to scale with $dN_{ch}/d\eta$

Drop in backward rapidity at low energy attributed to nonflow

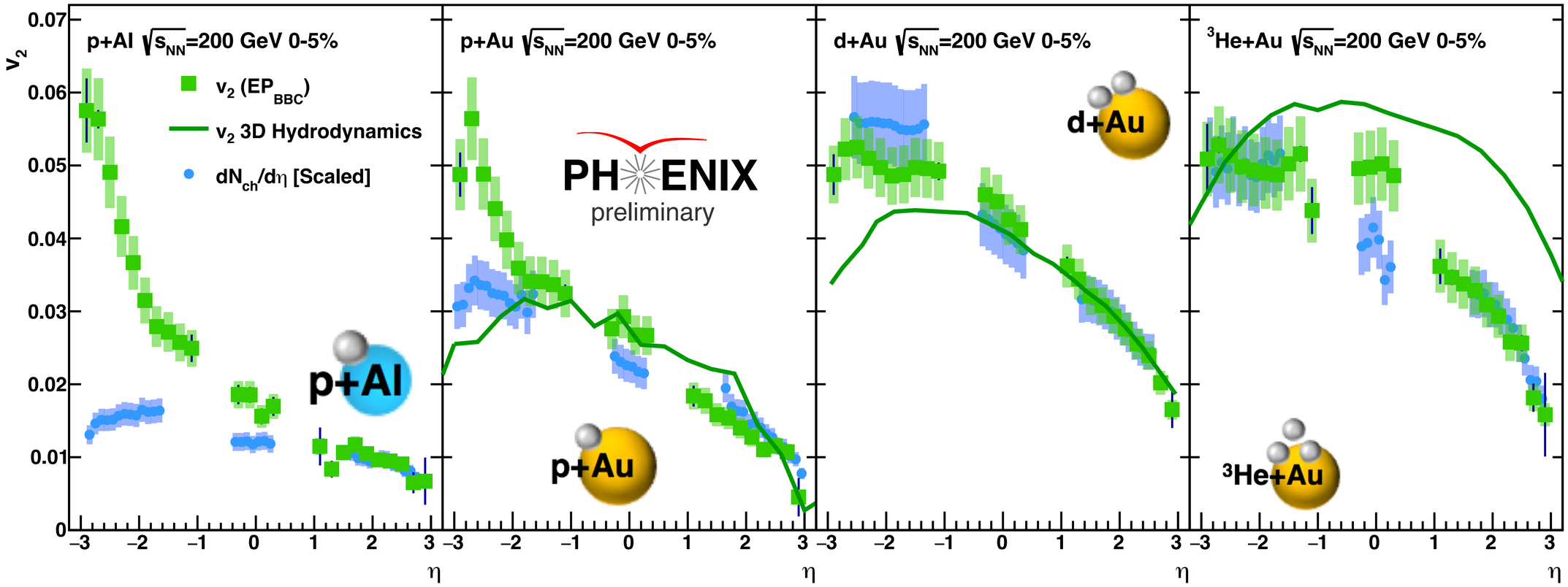
What about other small systems?

v_2 scaling



Scaling isn't as clear, and isn't expected in hydro
Coincidence?

3D Hydrodynamics



3D hydro in good agreement with p+Au and d+Au at mid and forward rapidities

Overpredicts v_2 in ^{3}He+Au — *Note that the $dN_{ch}/d\eta$ is also high by ~25%*

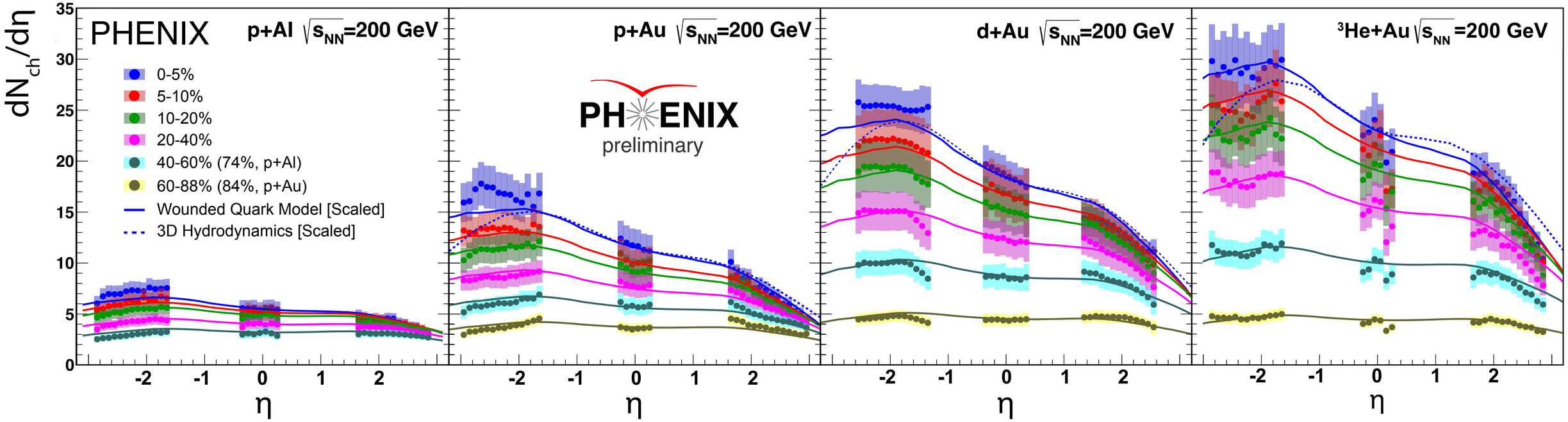
See Bozek, Broniowski, Phys. Lett. B 739 (2014) for calculation details

Summary

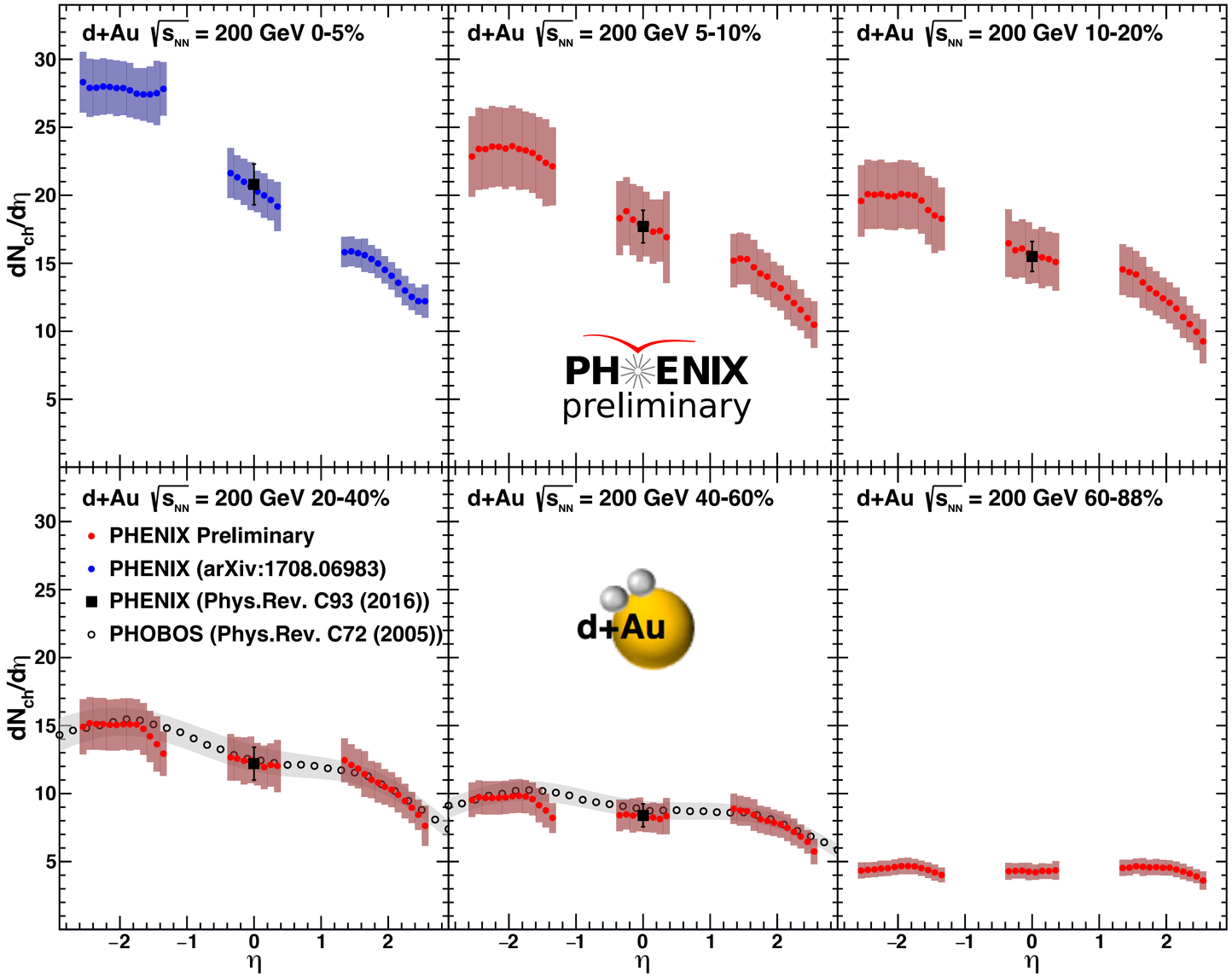
- New measurements of $dN_{ch}/d\eta$ over a broad range in pseudorapidity, centrality, collision system, and collision energy
- Wounded quark model using single wounded quark emission function in good agreement with $dN_{ch}/d\eta$ for all small systems
- 3D Hydrodynamics shows $dN_{ch}/d\eta$ falling off at backward rapidity quicker than data indicates
- 3D Hydrodynamics in good agreement with $v_2(\eta)$ at mid and forward rapidities. Backward rapidity complicated by nonflow.
- No clear scaling of $v_2(\eta)$ with $dN_{ch}/d\eta$

Thank you!

Full system & centrality dependence



Comparison to PHOBOS results



New PHENIX results in good agreement with previous mid rapidity results and PHOBOS measurements in the same centrality bins