Particle Fluctuations in STAR

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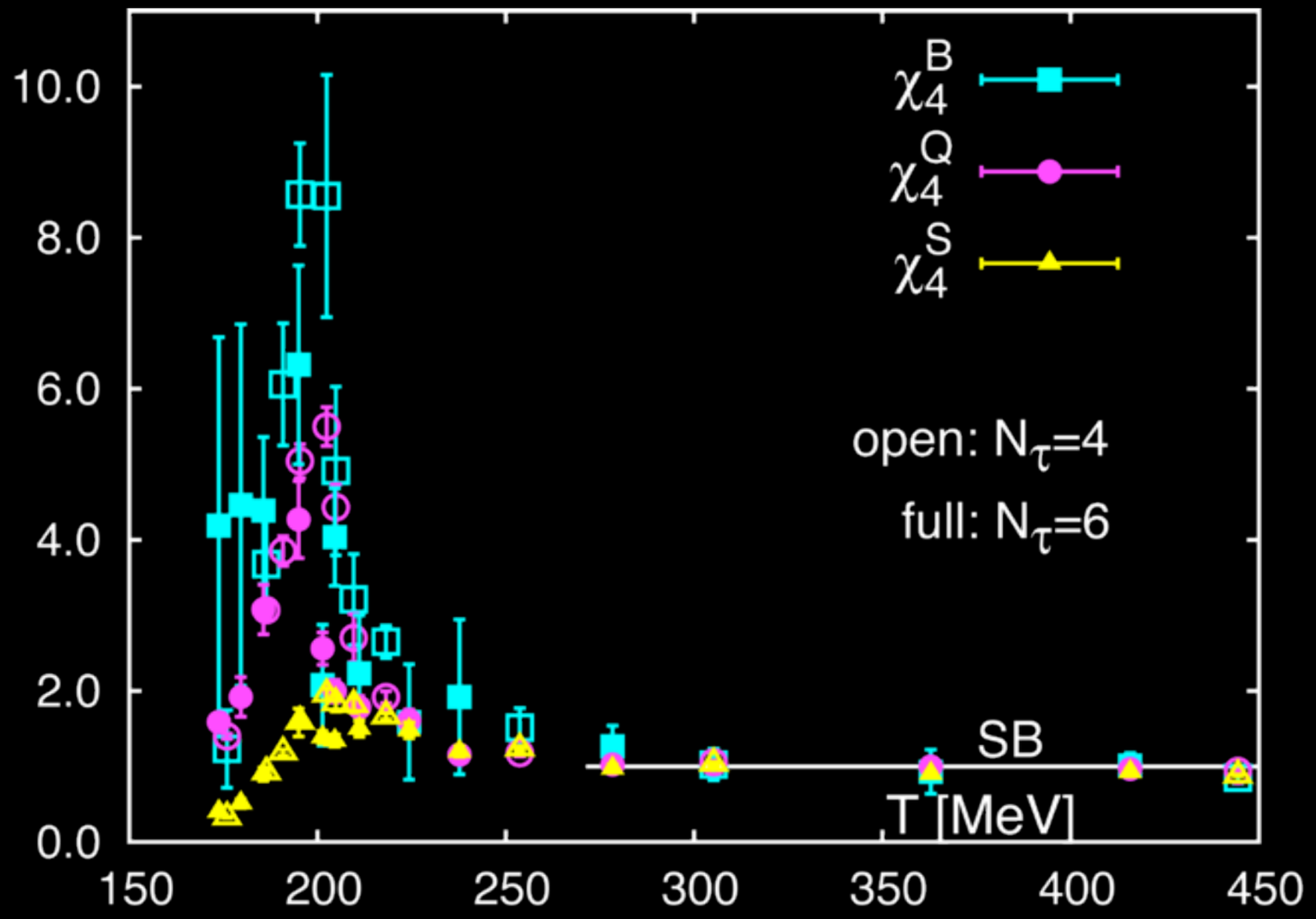
Search for QCD Transitions

- If we pass through a QCD phase transition, we expect a change in the number of degrees of freedom and a corresponding change in particle number fluctuations
  - Hadronic matter to quark gluon matter
- If we pass near a QCD critical point, we expect an increase in susceptibilities and a corresponding increase in particle number fluctuations
- Look for changes in fluctuations as a function of incident energy

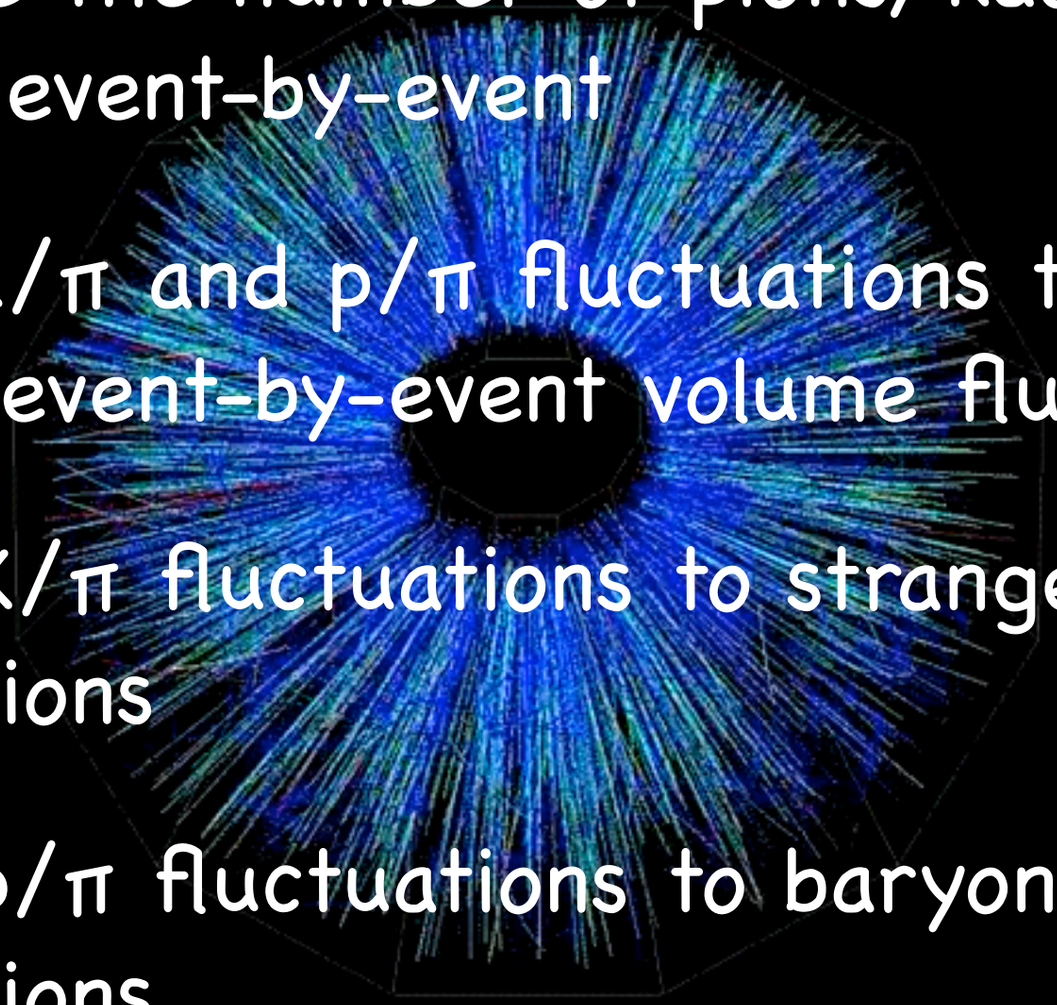
Lattice QCD Calculations



- Cheng et al., arXiv:0811.1006v2 [hep-th], quadratic and quartic fluctuations of baryon number, electric charge and strangeness, all quantities normalized to hadron gas

Fluctuations

- Measure the number of pions, kaons, and protons event-by-event
- Study K/π and p/π fluctuations to help remove event-by-event volume fluctuations
- Relate K/π fluctuations to strangeness fluctuations
- Relate p/π fluctuations to baryon number fluctuations



Fluctuation Observables

$$\sigma_{\mathrm{dyn}} = \mathrm{sgn}\left(\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mixed}}\right)\sqrt{\left|\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mixed}}\right|}$$

σ is the relative width of the

K / π or p / π distributions

Measure deviation from Poisson behavior

$$\nu_{\mathrm{dyn},i\pi} = \frac{\left\langle N_i\left(N_i - 1\right)\right\rangle}{\left\langle N_i\right\rangle^2} + \frac{\left\langle N_\pi\left(N_\pi - 1\right)\right\rangle}{\left\langle N_\pi\right\rangle^2} - 2\frac{\left\langle N_i N_\pi\right\rangle}{\left\langle N_i\right\rangle\left\langle N_\pi\right\rangle},\ i = K, p$$

It turns out that

$\sigma^2_{\mathrm{dyn}} \approx \nu_{\mathrm{dyn}}$ for K/π and p/π

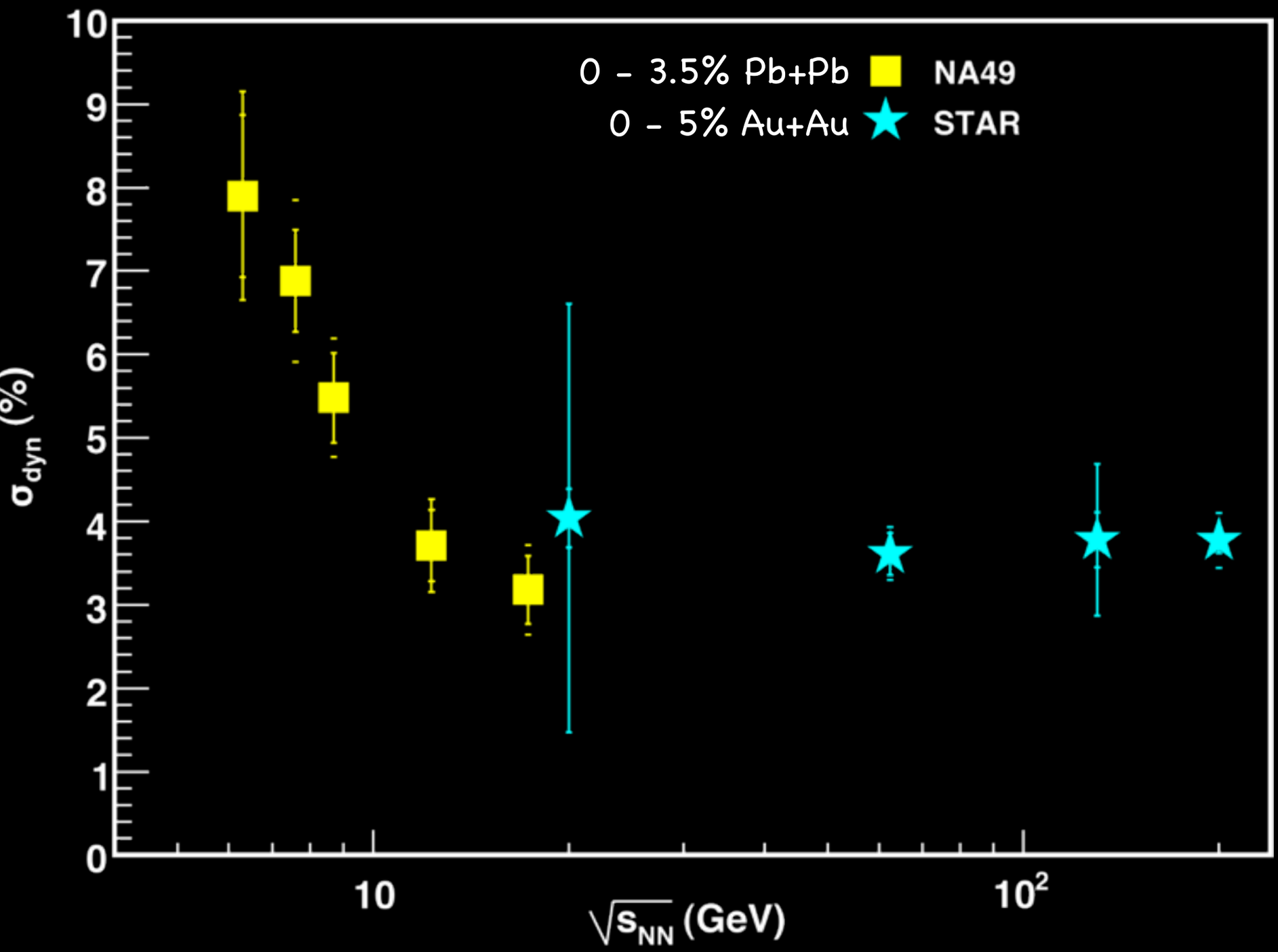
Fluctuations Data

- STAR Collaboration
  - Au+Au at 20, 62.4, 130, and 200 GeV
  - Phys. Rev. Lett. 103, 092301 (2009) for K/π and preliminary results for p/π
- NA49 Collaboration
  - Pb+Pb central collisions (0 - 3.5%) at 6.3, 7.6, 8.8, 12.3, and 17.3 GeV for K/π and p/π
  - Phys. Rev. C79, 044910 (2009)

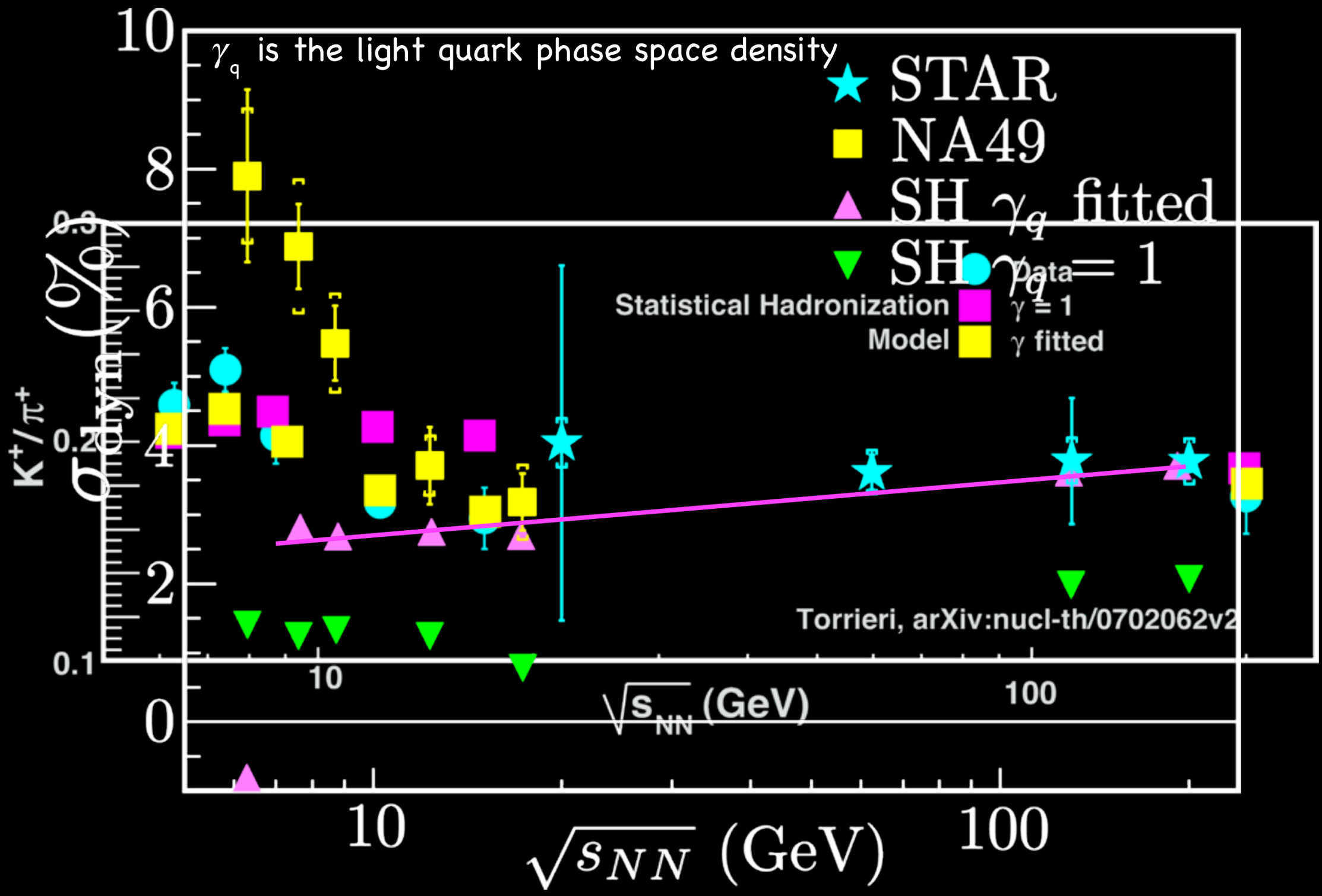
Models

- **SH**, Statistical Hadronization Model
  - Torrieri, arXiv:0710.0380v1 [nucl-th] (2007)
  - Torrieri et al., arXiv:1001:0087v1 [nucl-th] (2009)
- **HIJING**
  - Phys. Rev. D44, 3501 (1991).
- **UrQMD**, Ultrarelativistic Quantum Molecular Dynamics,
  - http://th.physik.uni-frankfurt.de/~urqmd/
- **HSD**, Hadron String Dynamics,
  - Phys. Rev. C79, 024907 (2009)

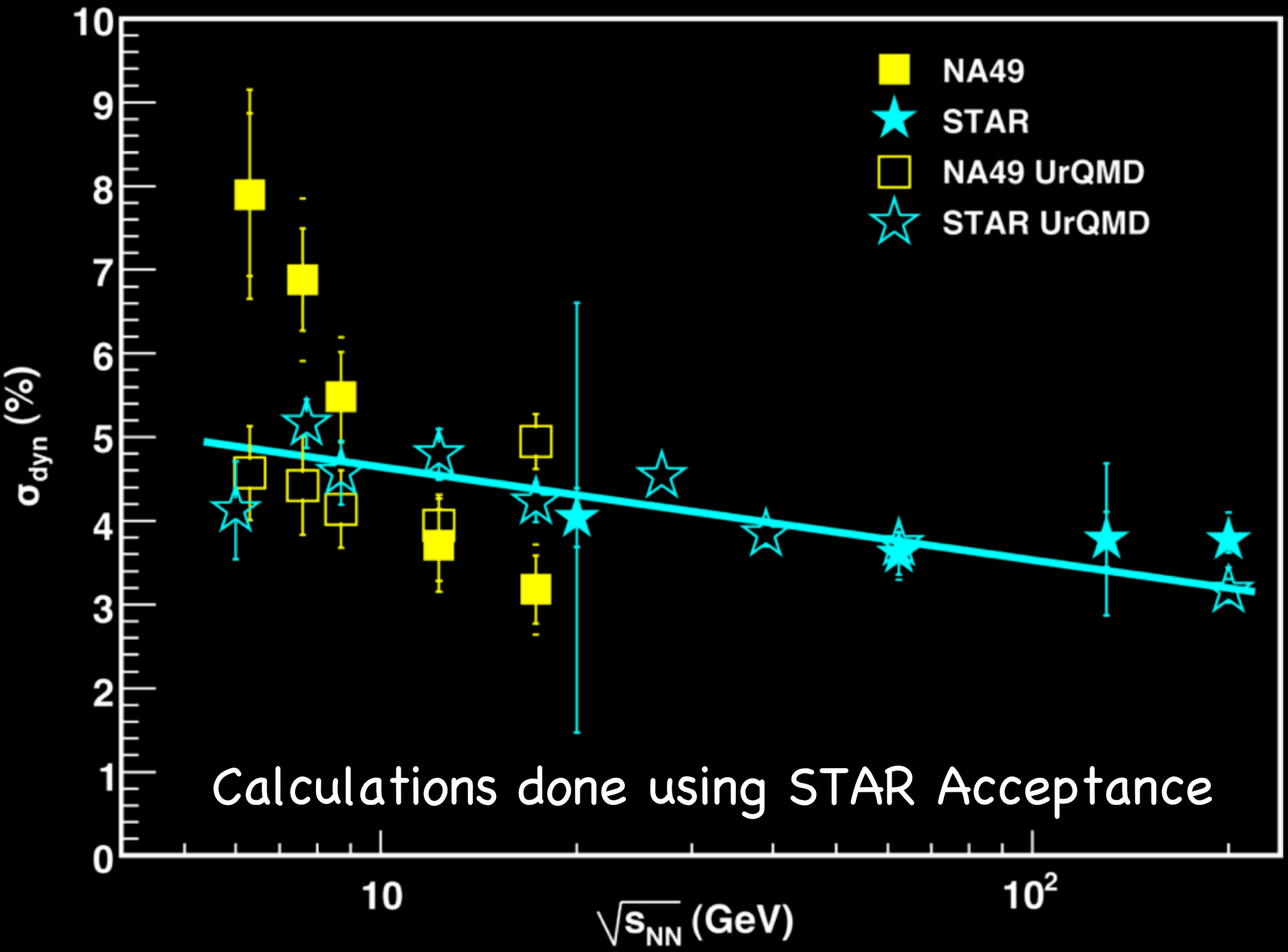
K/π Fluctuations in Central Collisions



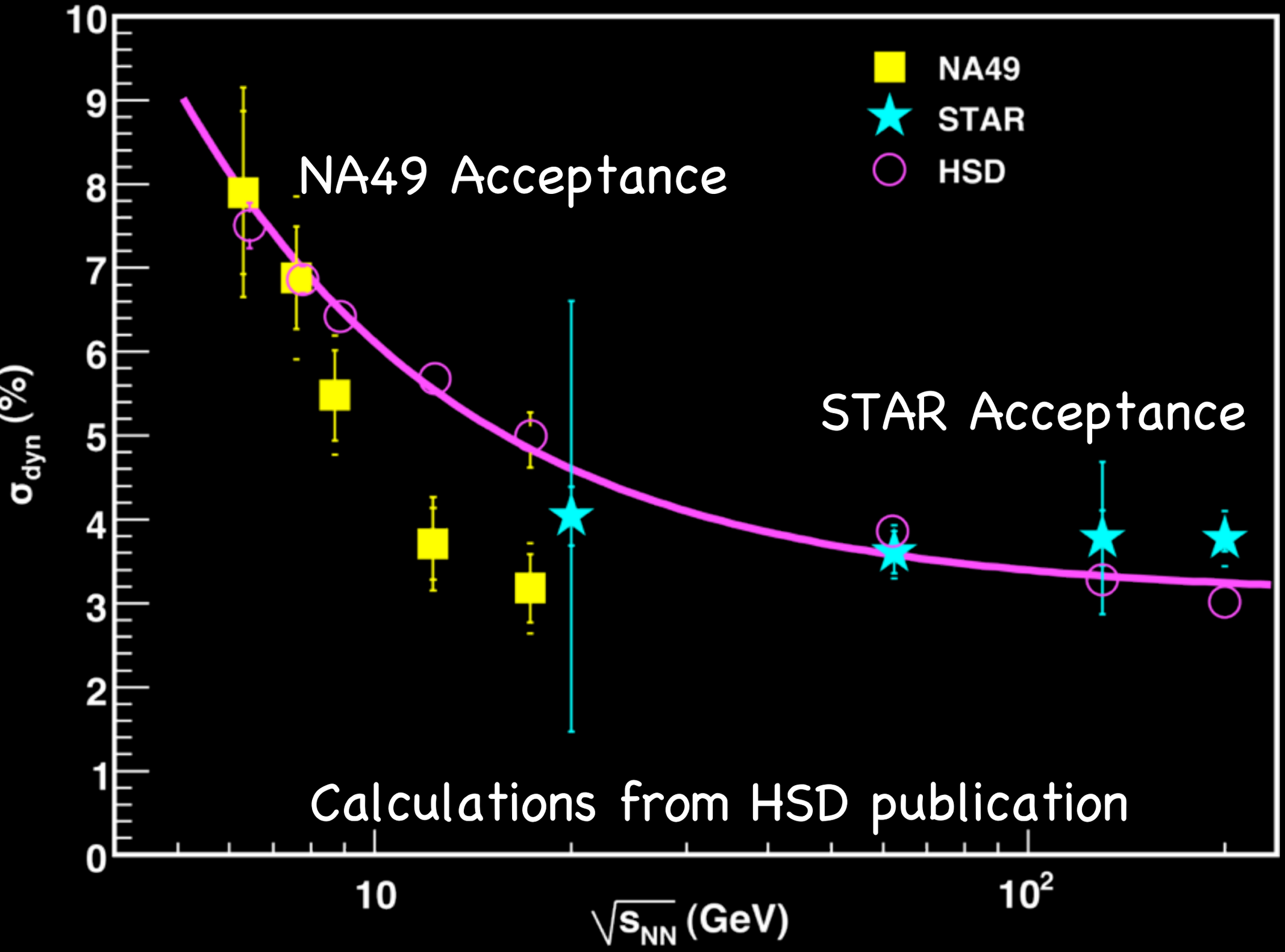
Statistical Hadronization Model



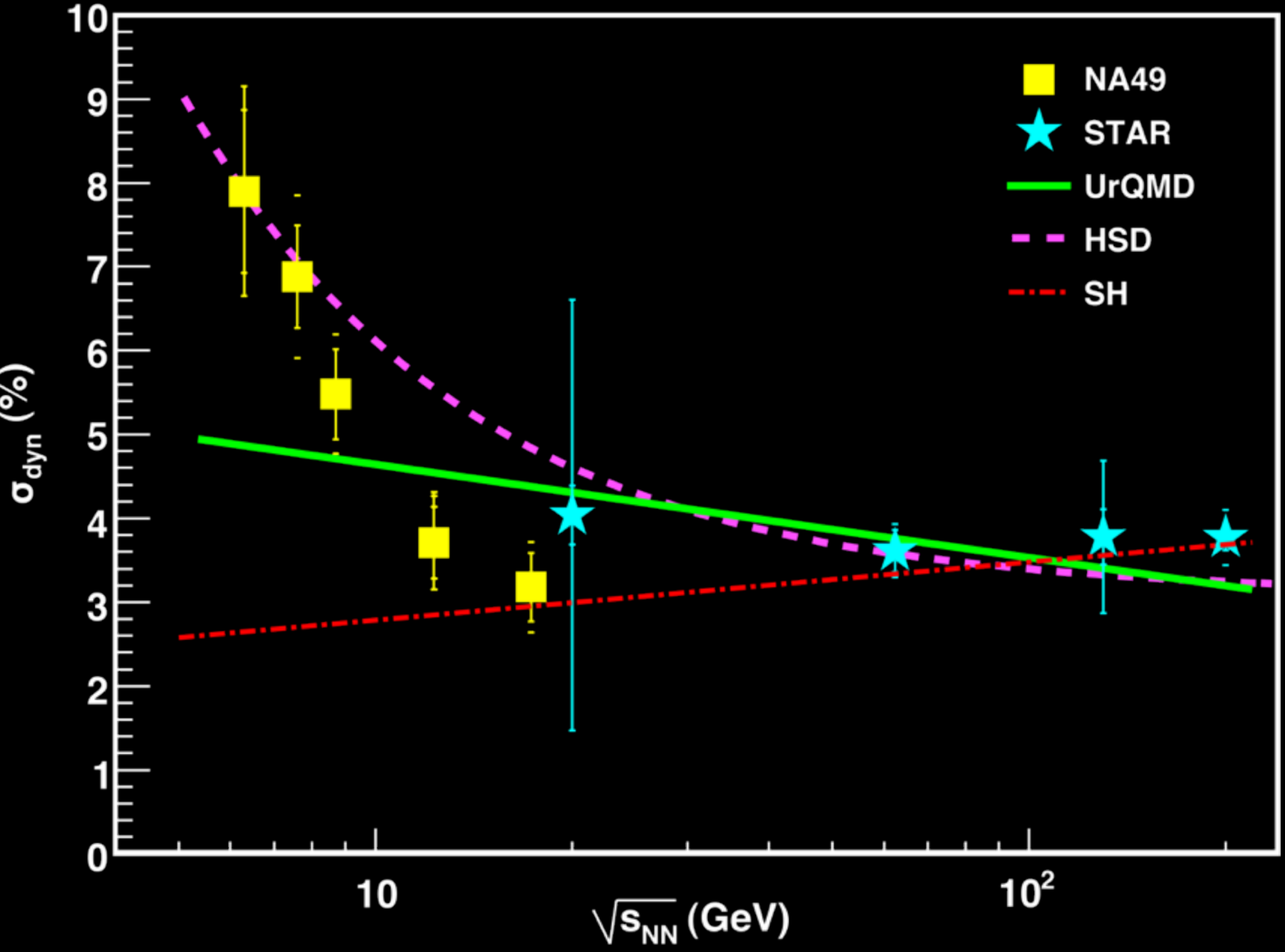
UrQMD


NA49
STAR
NA49 UrQMD
STAR UrQMD
σ_{dyn} (%)
10
9
8
7
6
5
4
3
2
1
0
10
10^2
$\sqrt{s_{NN}}$ (GeV)
Calculations done using STAR Acceptance

HSD

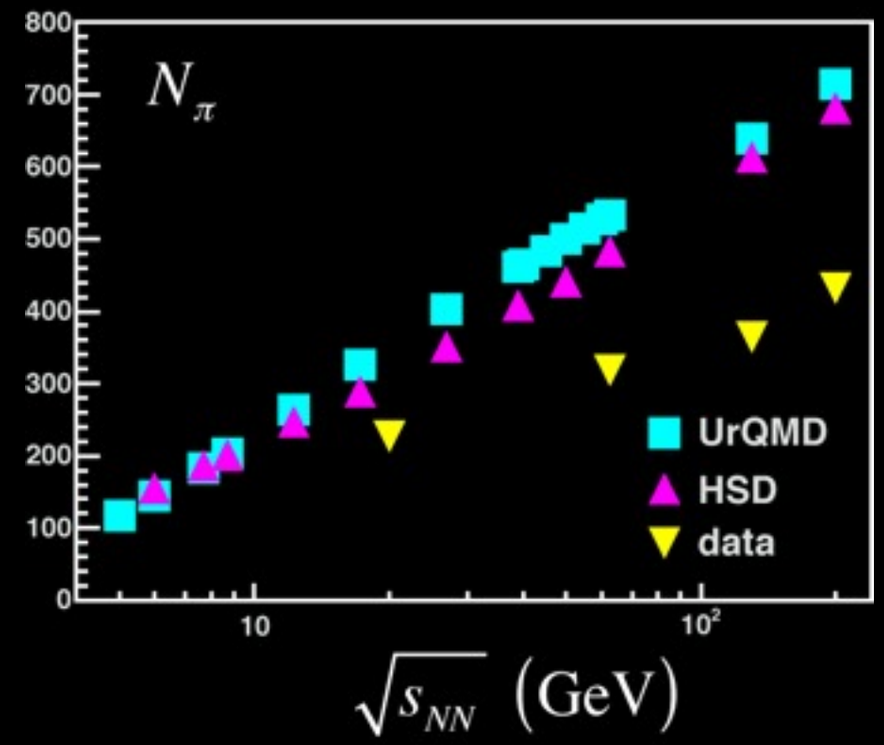

NA49
STAR
HSD
NA49 Acceptance
STAR Acceptance
Calculations from HSD publication
σ_{dyn} (%)
$\sqrt{s_{NN}}$ (GeV)
0
1
2
3
4
5
6
7
8
9
10
10
10^2

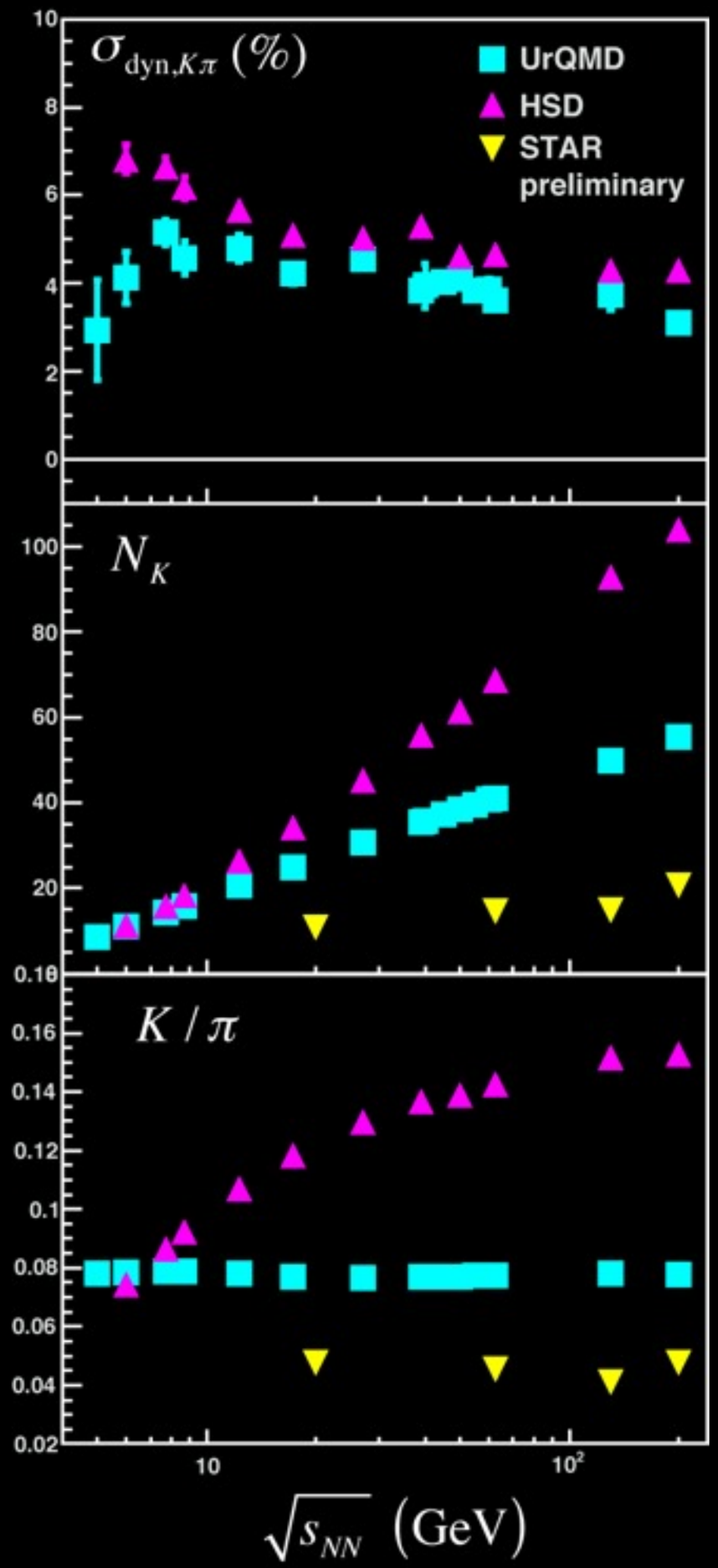
Compare UrQMD, HSD and SH



Compare STAR K/π Data with UrQMD and HSD

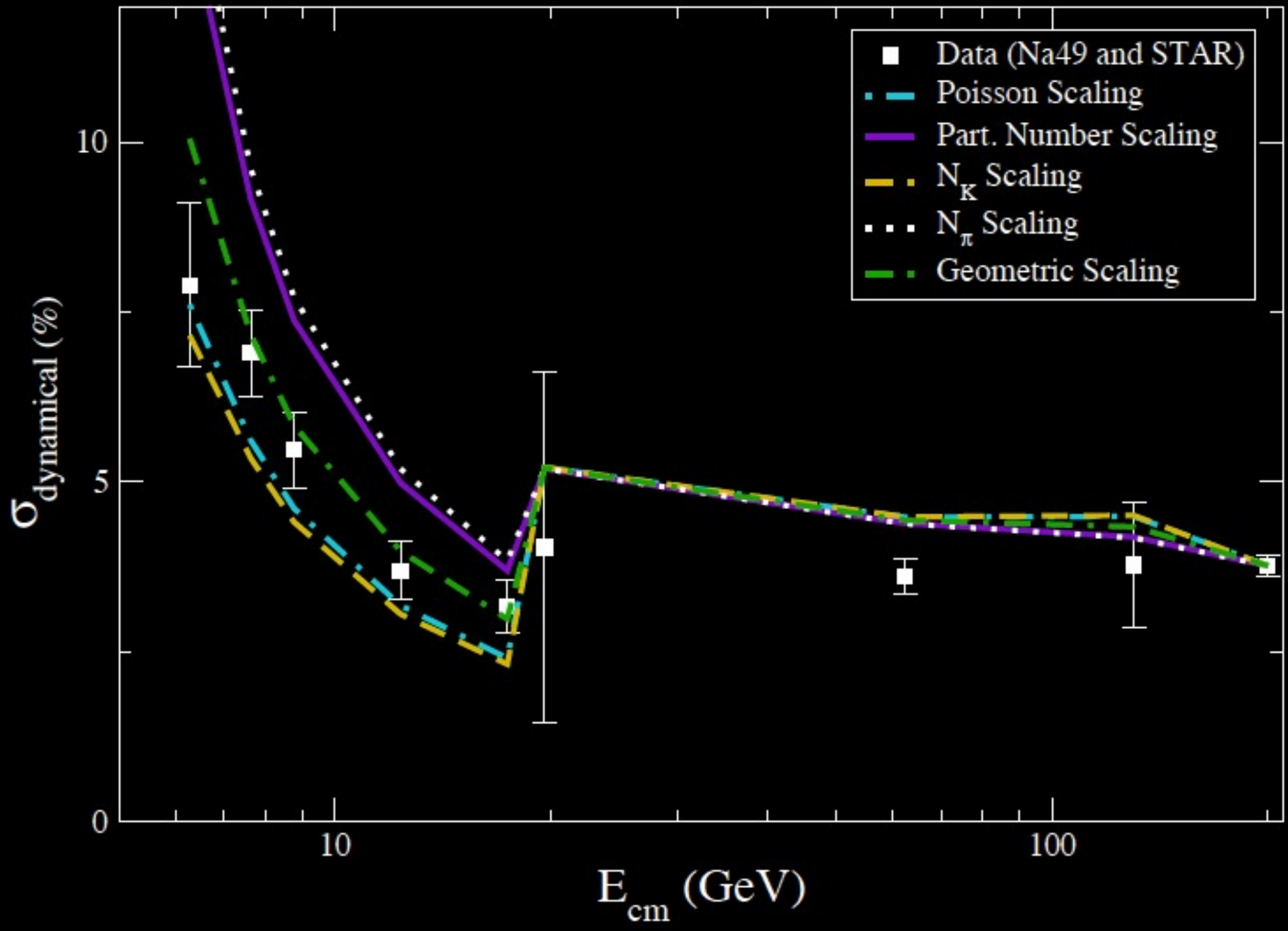
- STAR acceptance used for all energies





Another Explanation for K/π

Koch and Schuster, arXiv 0911.1160v1 (2009)



Scaling for K/π Fluctuations

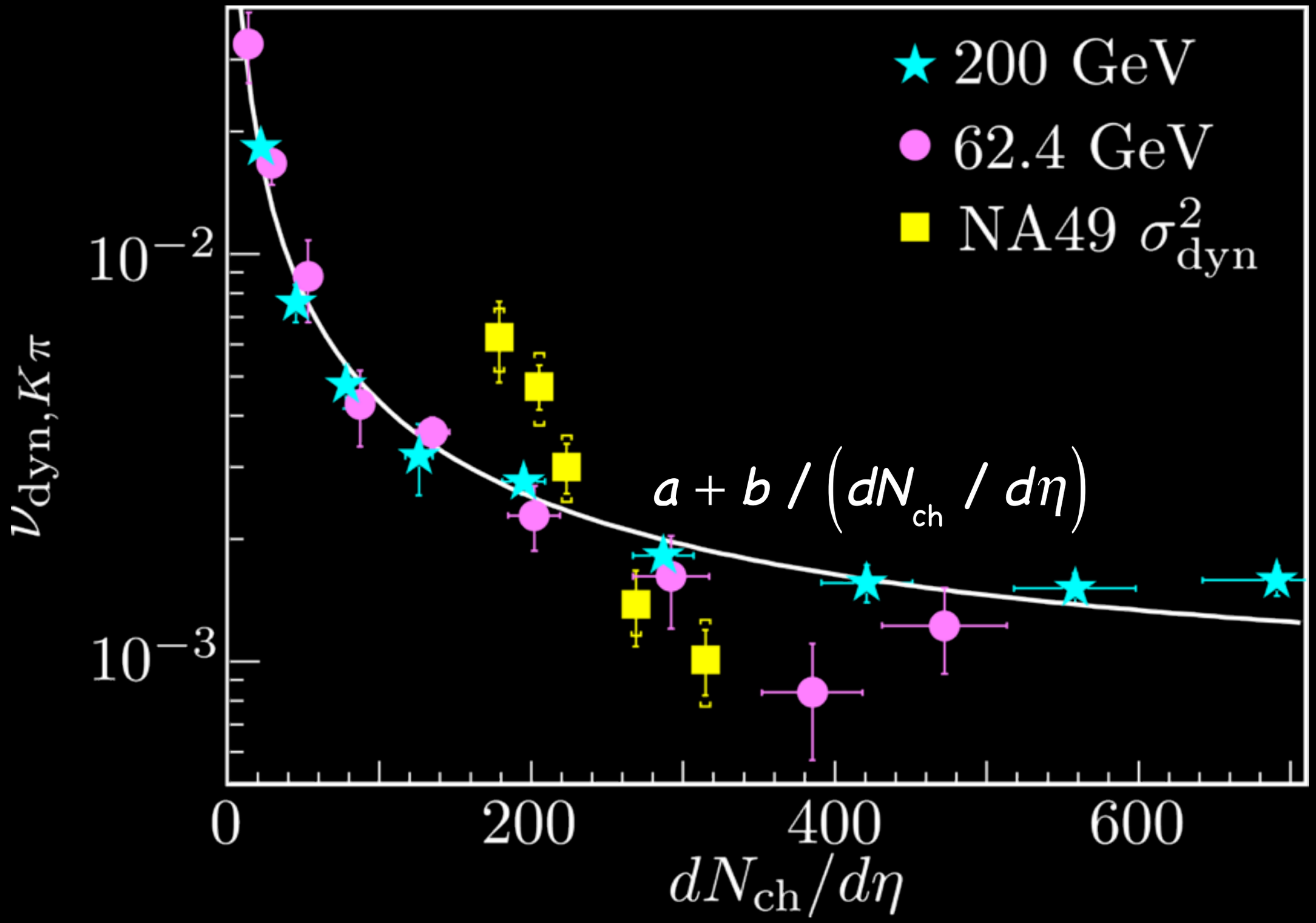
Poisson: $\sigma_{dyn}\left(\sqrt{s}\right) = \sigma_{dyn}\left(200\ GeV\right)\dfrac{\left[\sqrt{\dfrac{1}{\langle K\rangle}+\dfrac{1}{\langle \pi\rangle}}\right]_{\sqrt{s}}}{\left[\sqrt{\dfrac{1}{\langle K\rangle}+\dfrac{1}{\langle \pi\rangle}}\right]_{200\ GeV}}$

Particle Number: $\sigma_{dyn}\left(\sqrt{s}\right) = \sigma_{dyn}\left(200\ GeV\right)\dfrac{\left[\sqrt{\langle K\rangle+\langle \pi\rangle}\right]_{200\ GeV}}{\left[\sqrt{\langle K\rangle+\langle \pi\rangle}\right]_{\sqrt{s}}}$

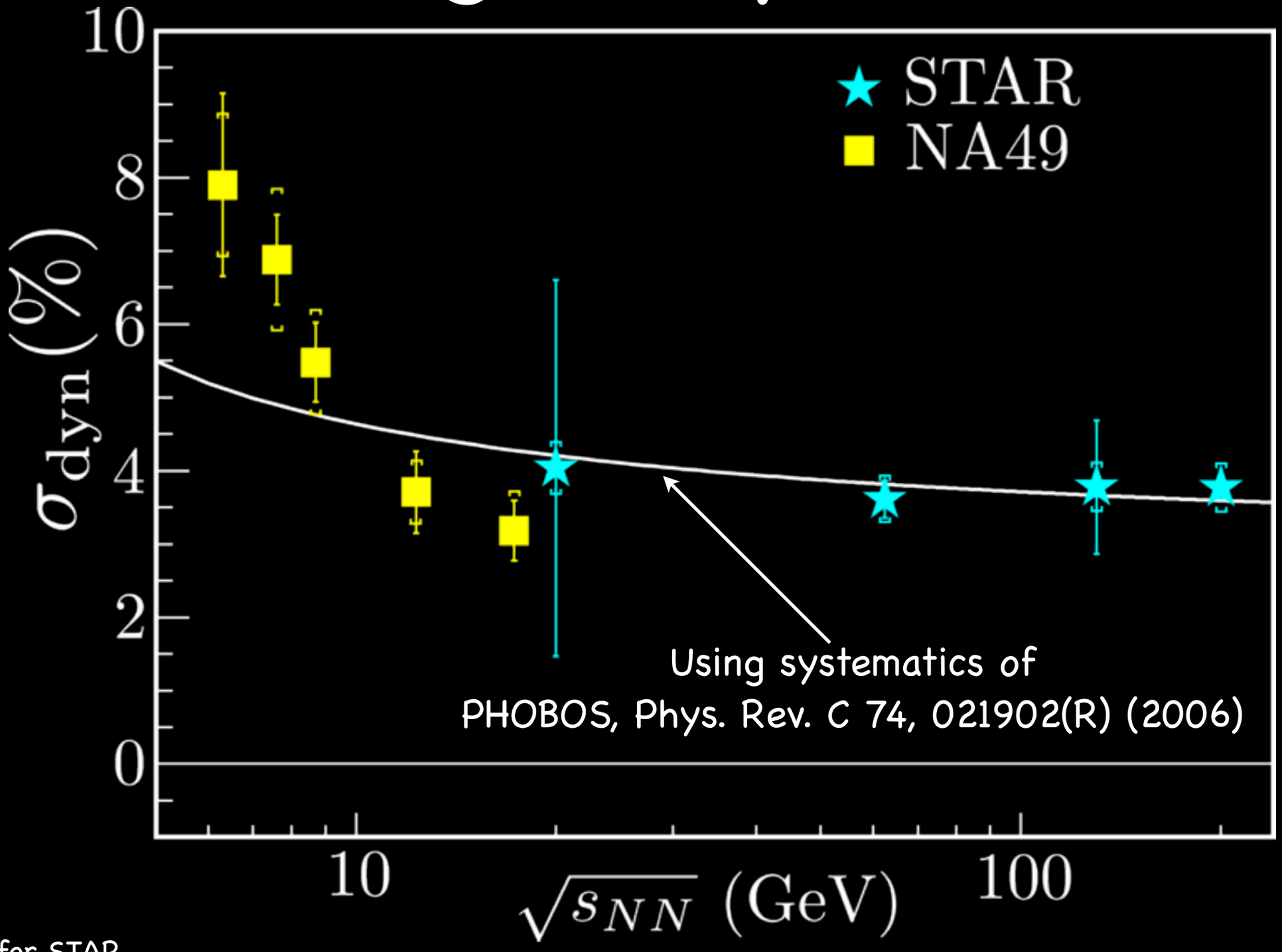
N_K : $\sigma_{dyn}\left(\sqrt{s}\right) = \sigma_{dyn}\left(200\ GeV\right)\dfrac{\left[\sqrt{\langle K\rangle}\right]_{200\ GeV}}{\left[\sqrt{\langle K\rangle}\right]_{\sqrt{s}}}$ N_π in a similar way

Geometric: $\sigma_{dyn}\left(\sqrt{s}\right) = \sigma_{dyn}\left(200\ GeV\right)\dfrac{\left[\left(\langle K\rangle\langle \pi\rangle\right)^{1/4}\right]_{200\ GeV}}{\left[\left(\langle K\rangle\langle \pi\rangle\right)^{1/4}\right]_{\sqrt{s}}}$

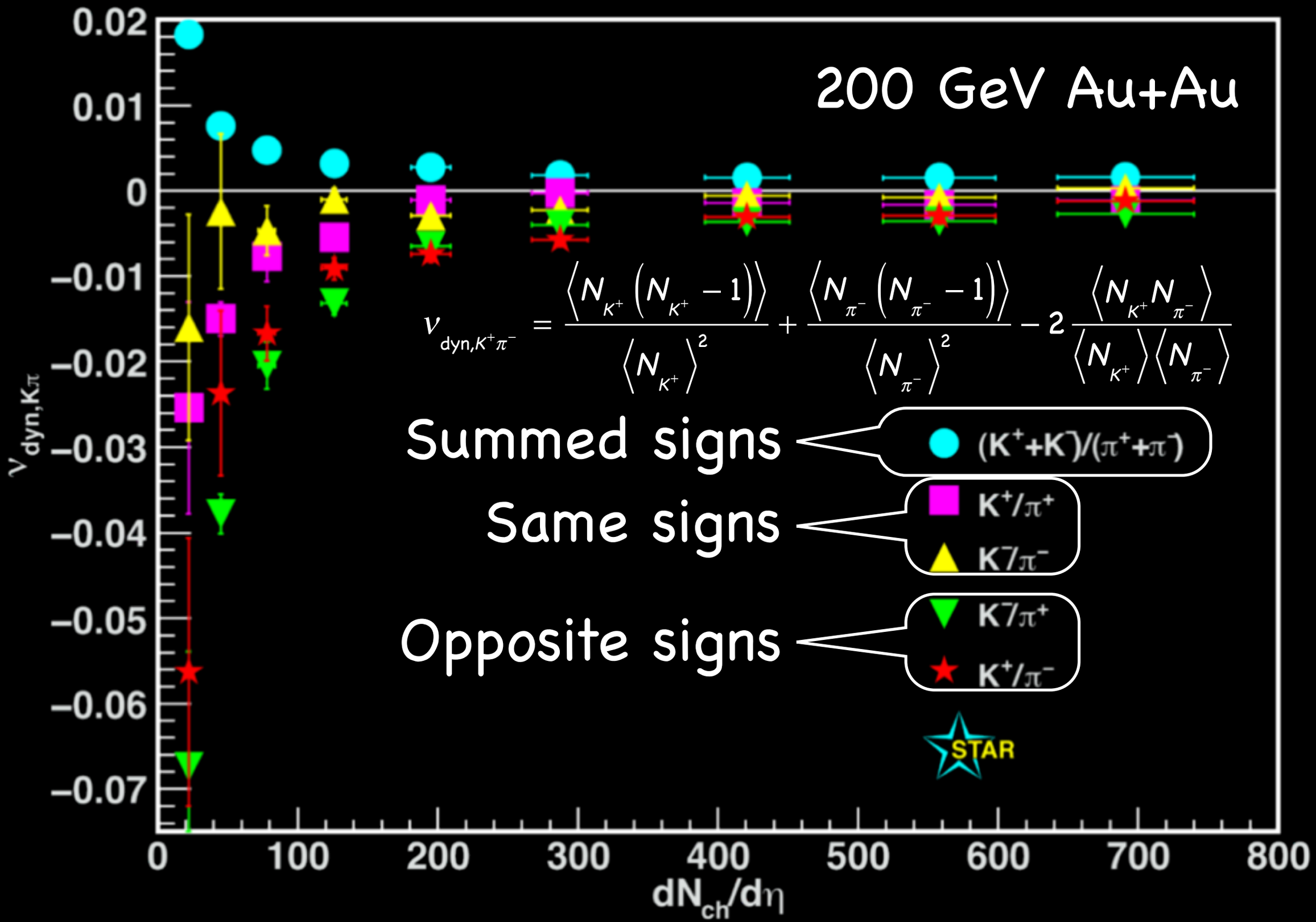
Centrality Dependence



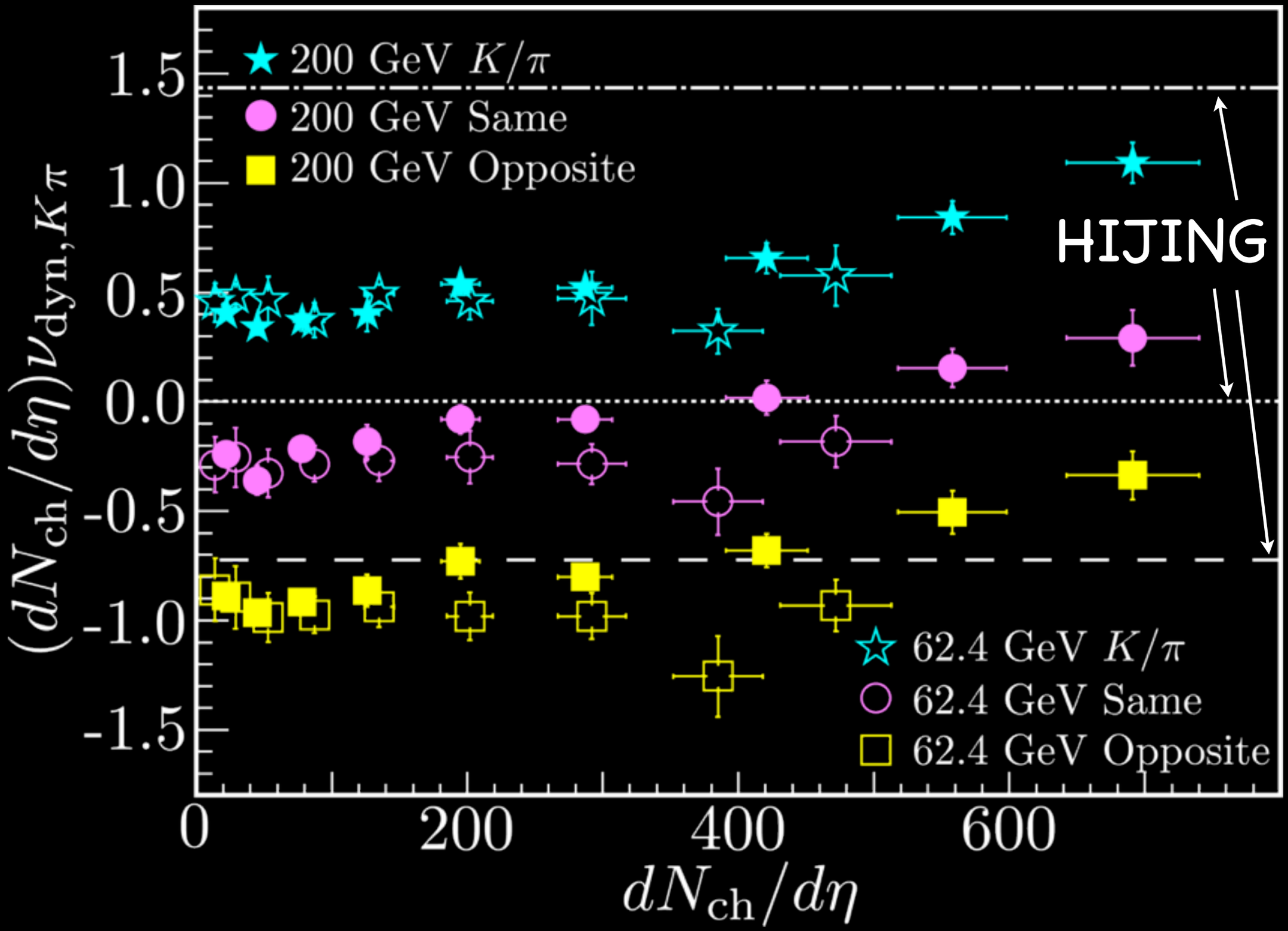
Relate Centrality Dependence to Energy Dependence



Separate Signs



Scale with $dN_{ch}/d\eta$



Relation of K/π Fluctuations to Resonance Re-interaction

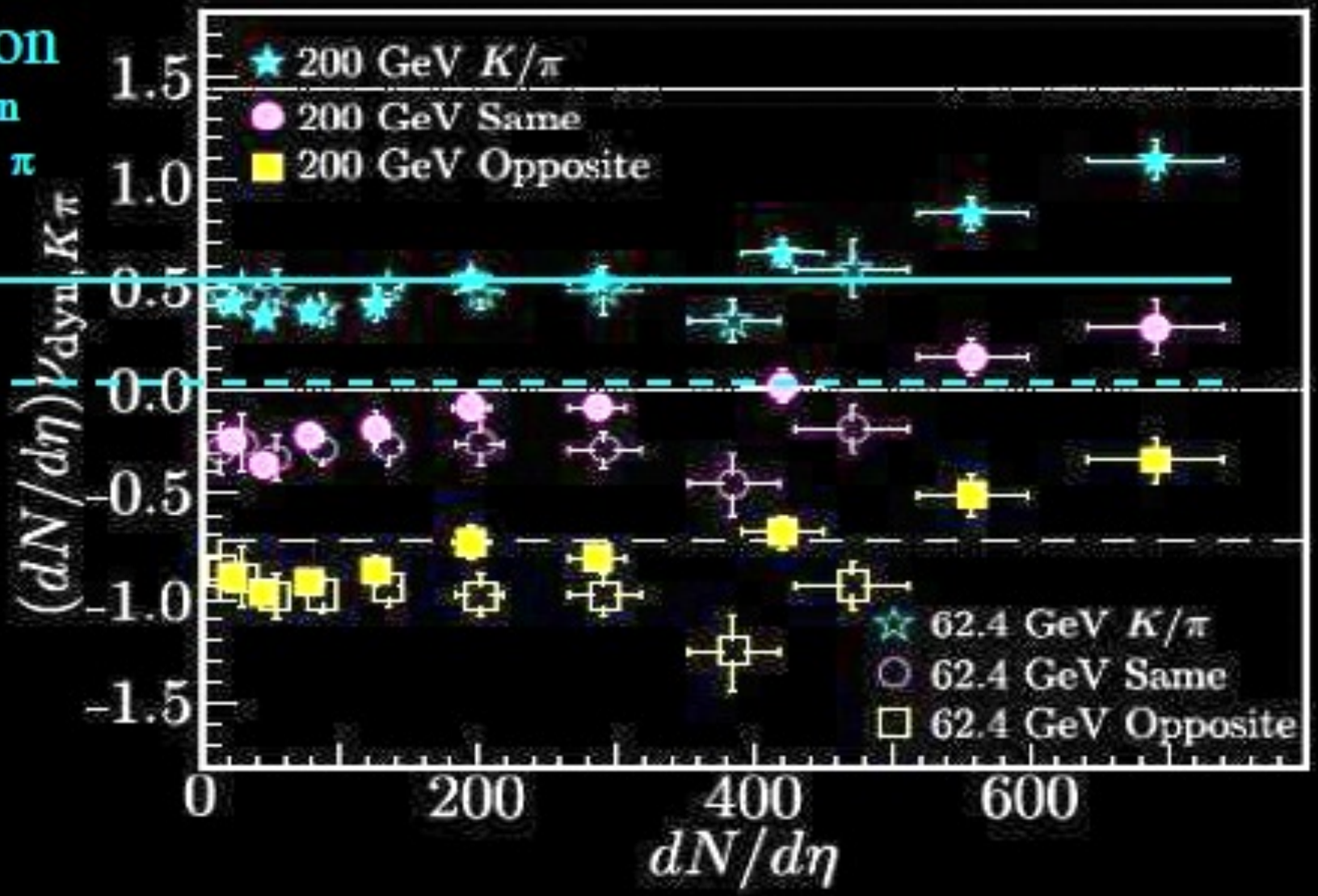
- Predict K/π fluctuations and resonance production using the statistical hadronization model
  - Torrieri et al., SQM, arXiv:1001:0087v1 [nucl-th] (2009)
- Relate $\nu_{dyn,K-\pi-}$ and $\nu_{dyn,K+\pi-}$ to $K^{*0}(892)/K^-$ ratio
  - $(3/4)\langle N_{\pi-}\rangle(\nu_{dyn,K-\pi-} - \nu_{dyn,K+\pi-}) \approx K^{*0}/K^-$

SH Predictions

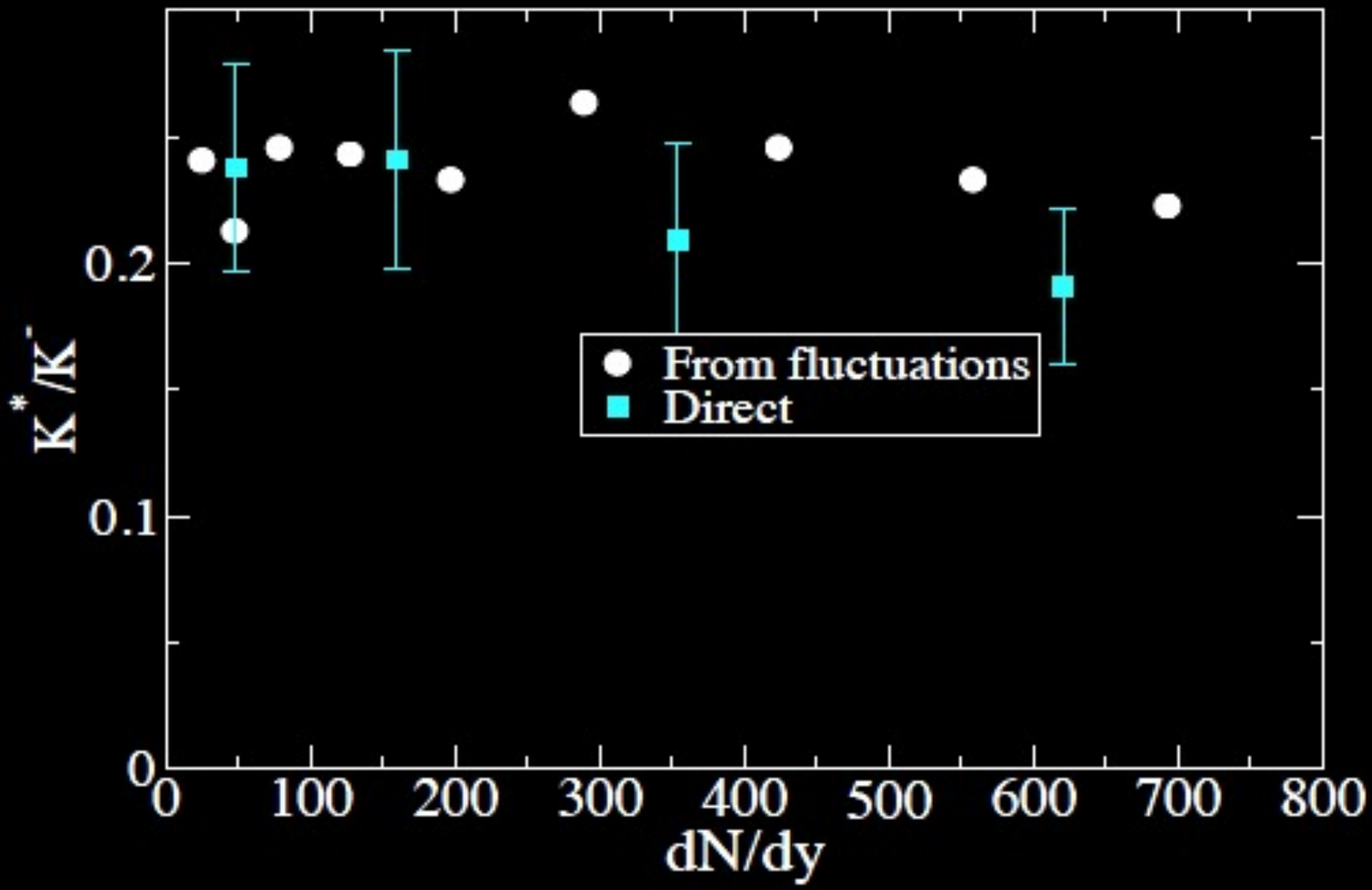
SHM expectation for $(dN/dy)\ \sigma^{dyn}_{K/\pi}$

T=170 $\gamma_{q,s}=1$

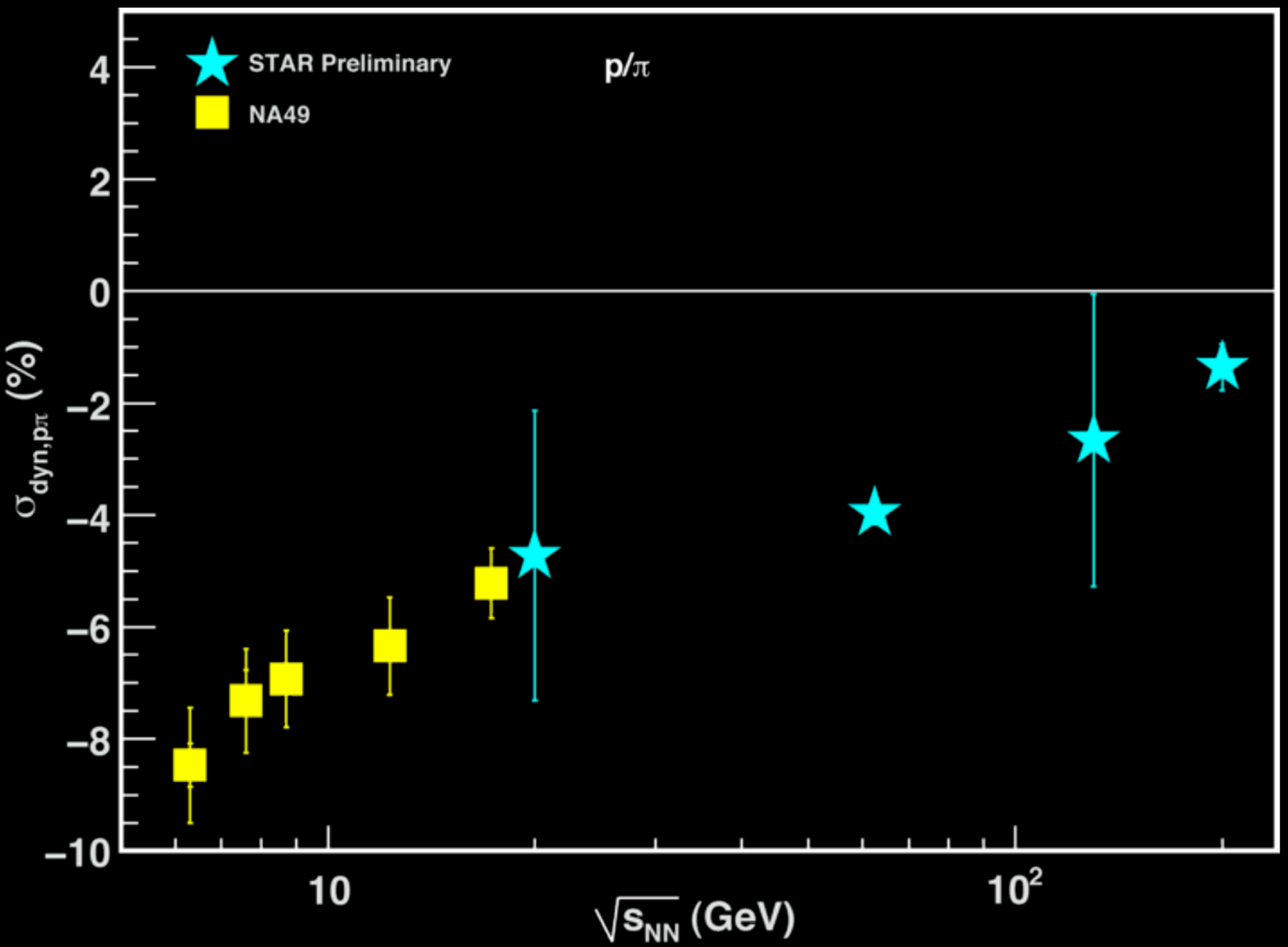
T=140 $\gamma_{q,s}>1$



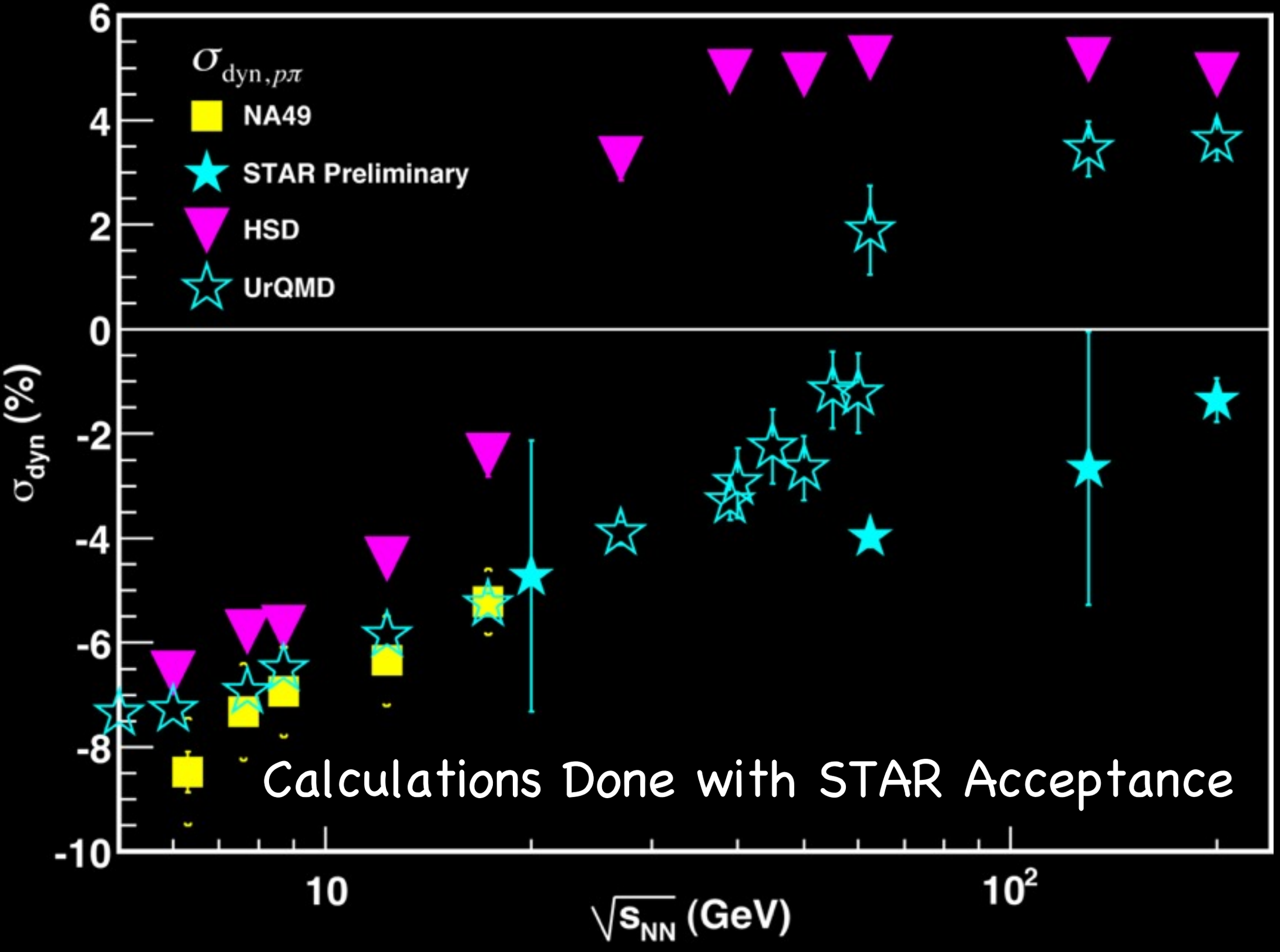
SH Predictions



p/π Fluctuations in Central Collisions

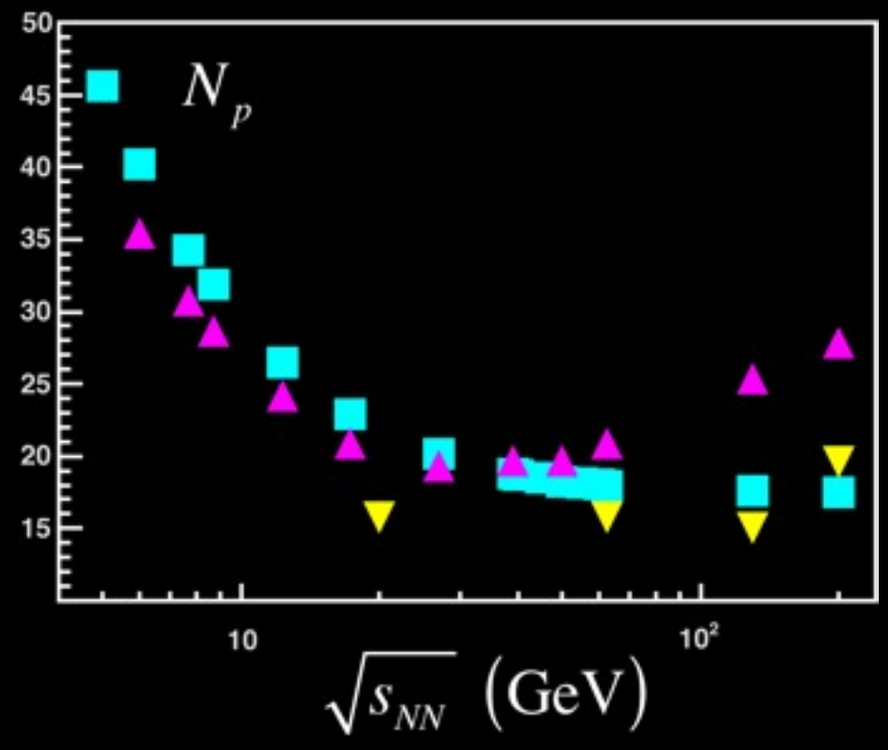


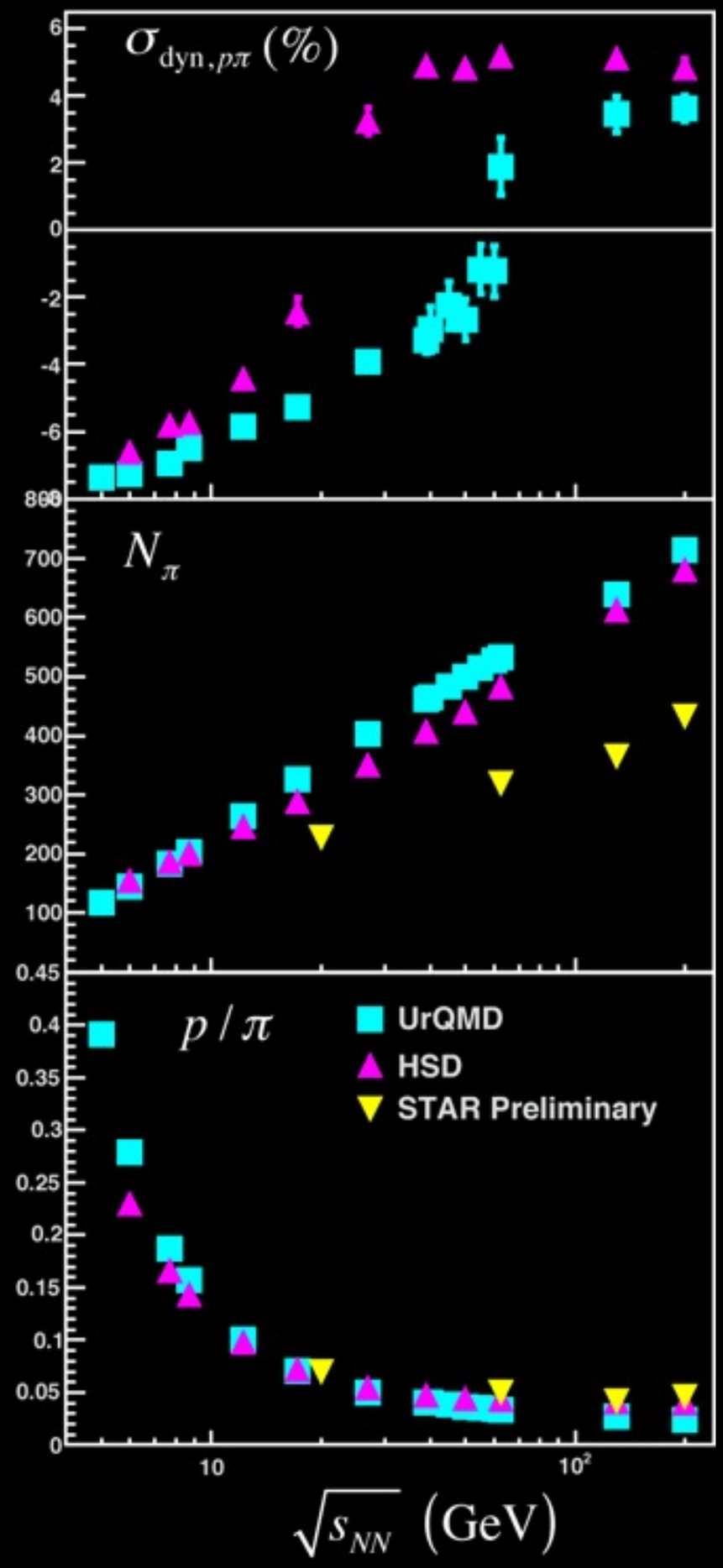
UrQMD and HSD



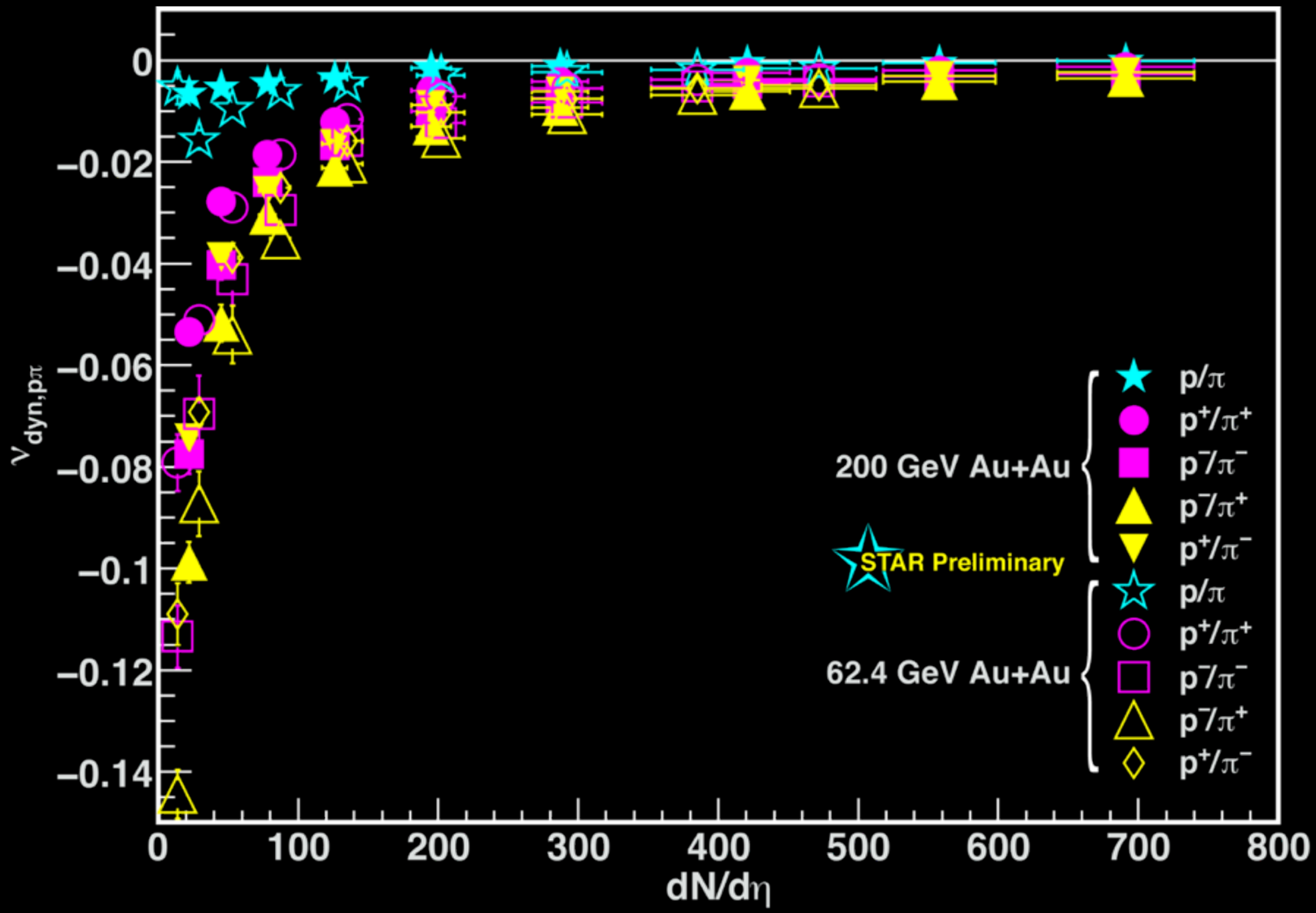
Compare STAR Data with UrQMD and HSD

- STAR acceptance used for all energies

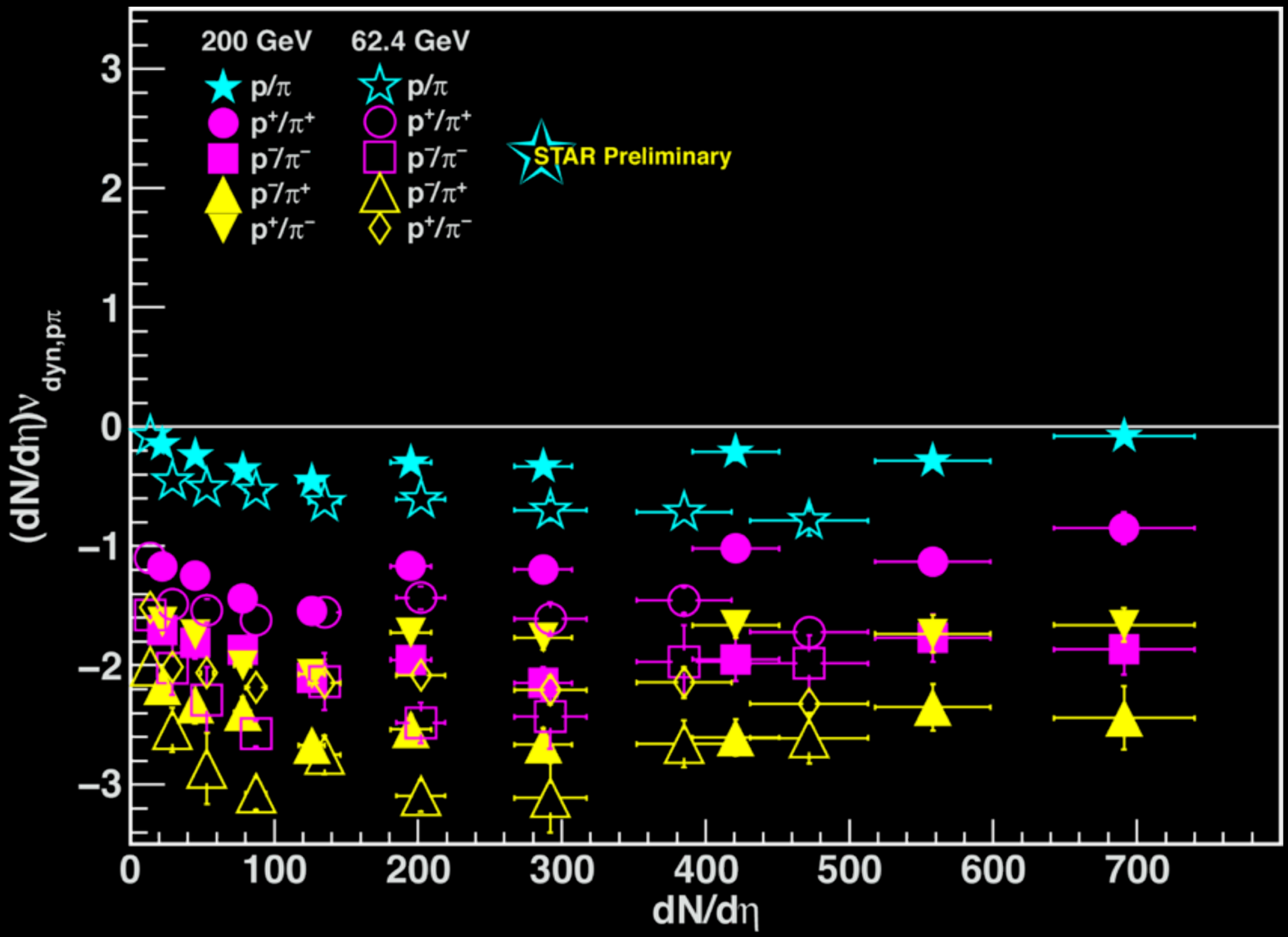




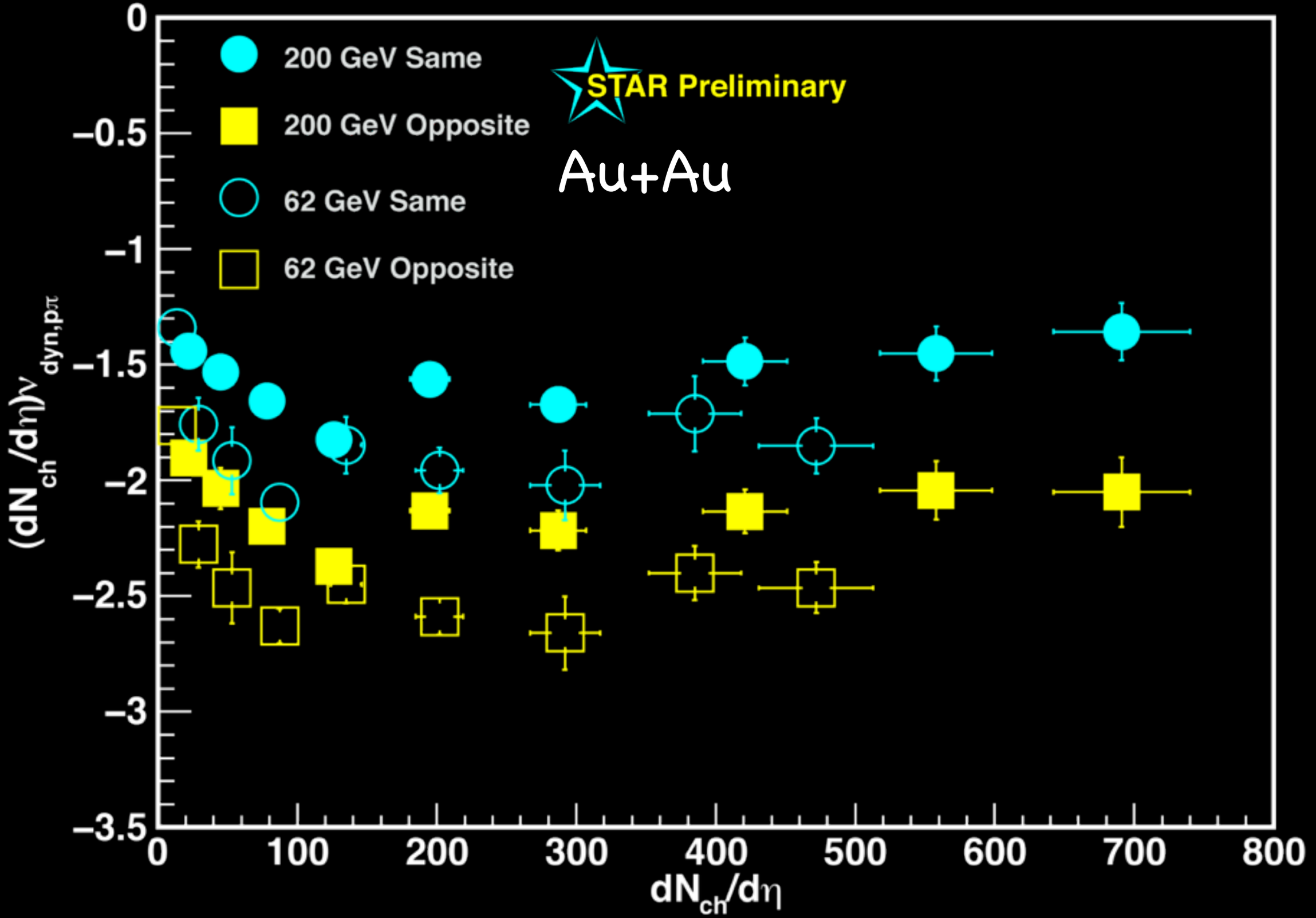
Separate Signs



Scale with $dN_{ch}/d\eta$



Same and Opposite Signs



Conclusions - K/π

- Current data for the incident energy dependence of K/π fluctuations in central collisions are insufficient to state whether there are any deviations from monotonic behavior and models disagree on what the monotonic behavior should be
- Centrality-selected K/π fluctuations seem to scale with $dN_{ch}/d\eta$ for 62.4 and 200 GeV Au+Au collisions
- Same-sign K/π fluctuations are close to zero
- Opposite-sign K/π fluctuations are negative
- Sign-selected K/π fluctuations can be related to resonance production, K^*/K^-

Conclusions - p/π

- Current data for p/π fluctuations in central collisions show a relatively smooth dependence on incident energy
- UrQMD and HSD calculations for p/π fluctuations reproduce the trend observed in central collisions at low energies but over-predict the observed fluctuations at higher energies
- Centrality selected p/π fluctuations for 62.4 and 200 GeV Au+Au collisions don't seem to scale as well with $dN_{ch}/d\eta$ as the K/π fluctuations
- Sign selected p/π fluctuations are always negative

Extra Slides

Comparison Between UrQMD and HSD