Energy Dependence of Cumulants of Net-Proton and Net-Baryon Multiplicity distributions in Au+Au collisions from JAM model

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Outline

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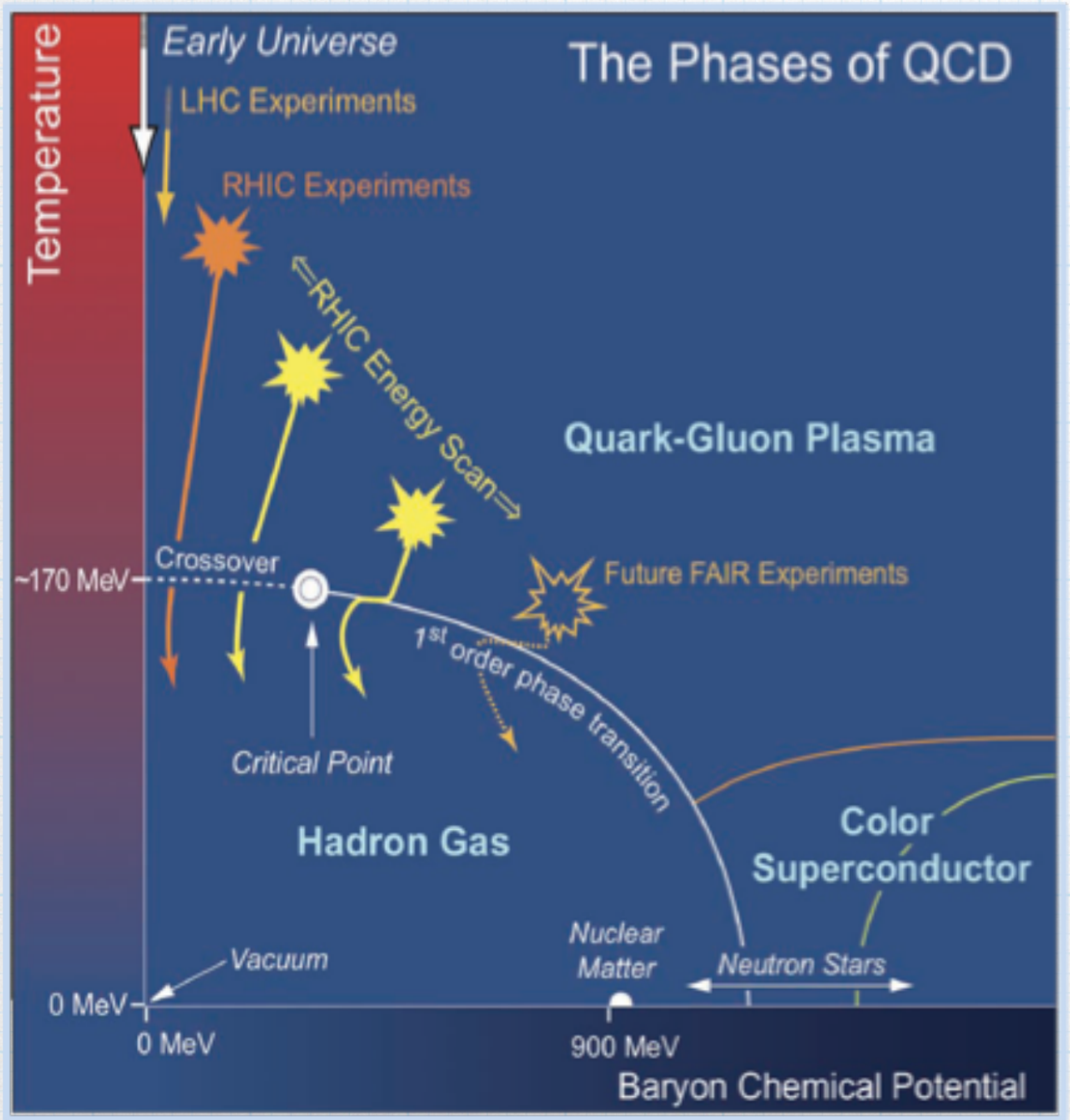
* Results from JAM model
* Summary

Motivation



Crossover at μ_B=0

First order phase transition at non-zero μ_B ?

A critical point at the end of 1st order transition line?

Motivation

Higher order cumulants of Conserved Quantities are good observables to locate the critical point.

Phys.Rev.C 86,069902(2012)

net baryon (net-proton, neutral hadrons are hard to detect)
net-strangeness (net-kaon)
net-charge

- Sensitive to the correlation length(ξ)

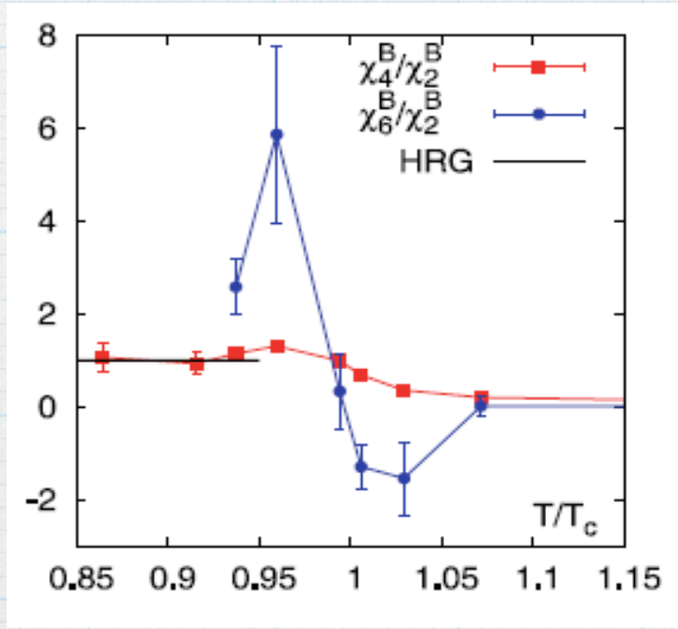
$$\langle(\delta N)^2\rangle \sim \xi^2, \langle(\delta N)^3\rangle \sim \xi^{4.5},$$
$$\langle(\delta N)^4\rangle - 3\langle(\delta N)^2\rangle^2 \sim \xi^7$$

M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
M. A. Stephanov, Phys. Rev. Lett. 107, 052301 (2011).
M.Asakawa, S. Ejiri and M. Kitazawa, Phys. Rev. Lett. 103, 262301 (2009).

- Directly connected to susceptibility of the system

$$\chi_q^{(n)} = \frac{1}{VT^3} * C_{n,q} = \frac{\partial^n \left(\frac{p}{T^4}\right)}{\partial(\mu_q)}, q = B, Q, S$$

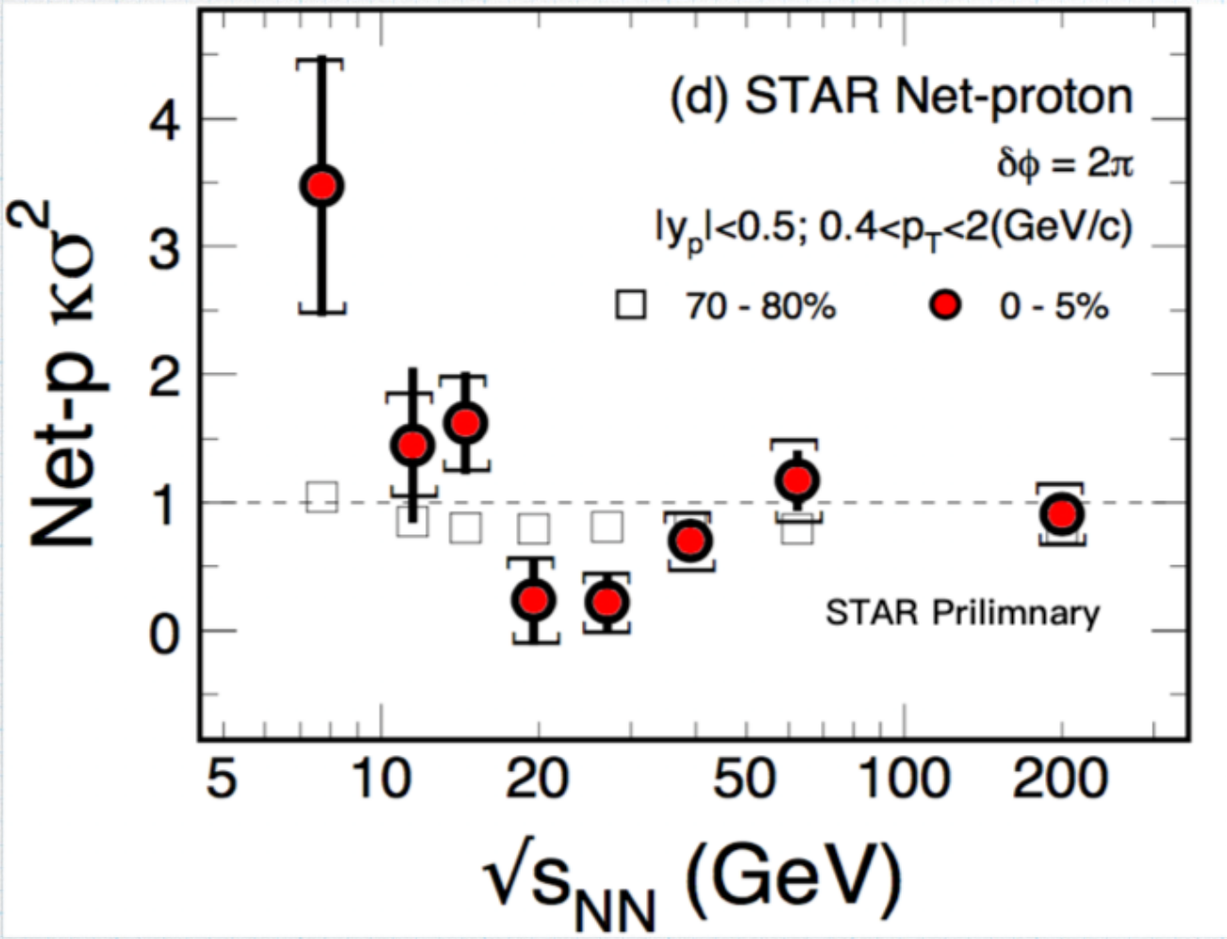
S. Ejiri et al,Phys.Lett. B 633 (2006) 275.
Cheng et al, PRD (2009) 074505. B. Friman et al., EPJC 71 (2011)
S. Gupta, et al., Science, 332, 1525(2011).
A. Bazavov et al., PRL109, 192302(12)



Higher Moments

- definition
  - $C_1 = \langle N \rangle$
  - $C_2 = \langle(\delta N)^2\rangle$
  - $C_3 = \langle(\delta N)^3\rangle$
  - $C_4 = \langle(\delta N)^3\rangle - 3\langle(\delta N)^2\rangle^2$
  - $S\sigma = \frac{C_3}{C_2}, \kappa\sigma^2 = \frac{C_4}{C_2}$
- reflect the shape of certain distribution
- Measure non-gaussianity
- Extensive quantities

Experiment results



STAR, PRL105,022302;; PRL112,032302 (2014).
X. Luo (for STAR Coll.), PoS CPOD2014 (2015) 019
Phys. Rev. Lett. 113 092301 (2014). Phys. Lett. B 785,)551)(2018).

Non-monotonic energy dependence of Net-proton's $\kappa\sigma^2$observed.

if non-critical backgrounds contribute to the non-monotonic energy dependence of $\kappa\sigma^2$?

- **Weak decay**
  - effects from secondary protons.
- **elastic scattering**
  - effects from final state interaction
    Phys.Rev.C 94.044905

Data production using JAM model

JAM http://www.aiu.ac.jp/~ynara/jam/

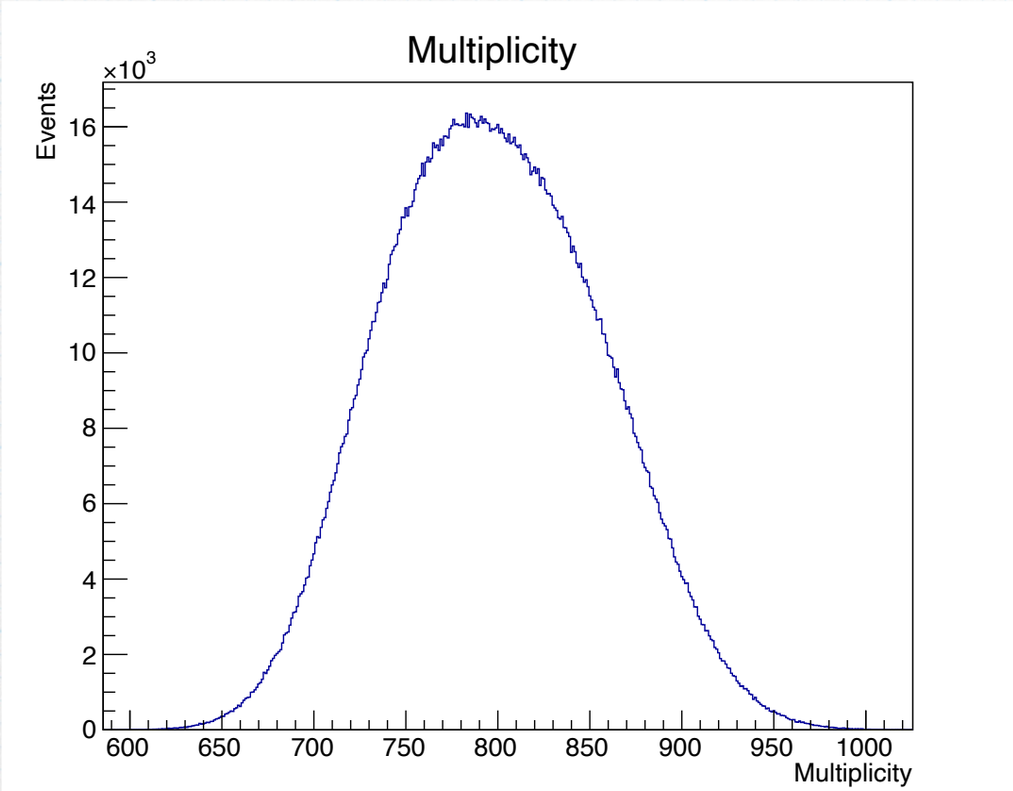
- a microscopic transport model
- simulate nuclear collisions from initial stage to final state

Production Detail

Au+Au, Impact parameter : **0-3 fm**								
$\sqrt{s_{NN}}/GeV$	7.7	11.5	14.5	19.6	27	39	62.4	200
Events	2.6	2.6	2.6	2.6	2.6	2.6	2.6	1
	Default Configuration							
	Turning off weak decay							
	Turning Elastic Scattering							

Calculation detail

- net-proton and net-baryon cumulants and their ratios
- with cuts: |y|<0.5, 0.4<pT<2.0
- centrality bin width corrected



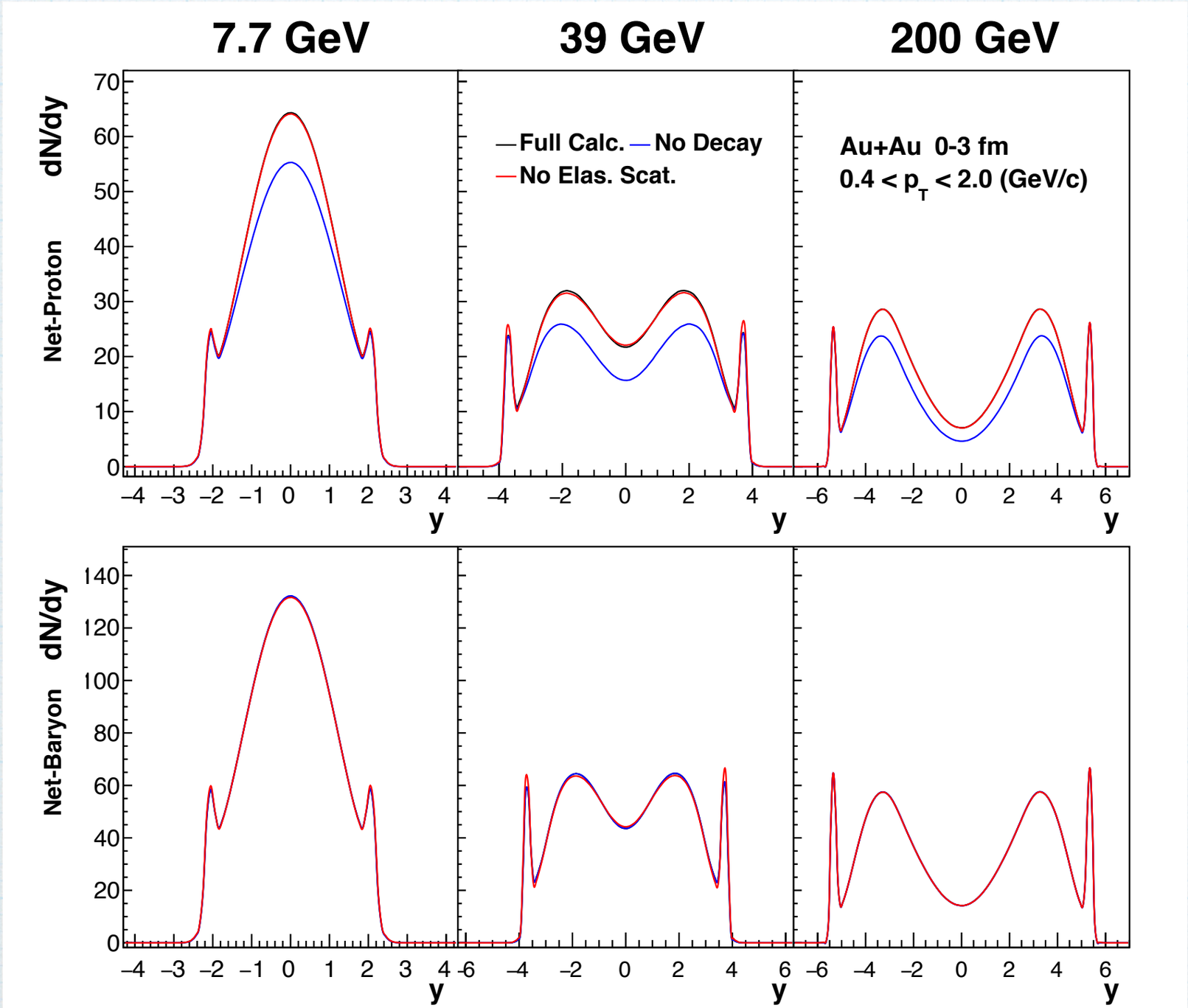
$$\sigma = \frac{\sum_r n_r \sigma_r}{\sum_r n_r} = \sum_r \omega_r \sigma_r$$

$$S = \frac{\sum_r n_r S_r}{\sum_r n_r} = S_r \omega_r S_r$$

$$\kappa = \frac{\sum_r n_r \kappa_r}{\sum_r n_r} = \sum_r \omega_r \kappa_r$$

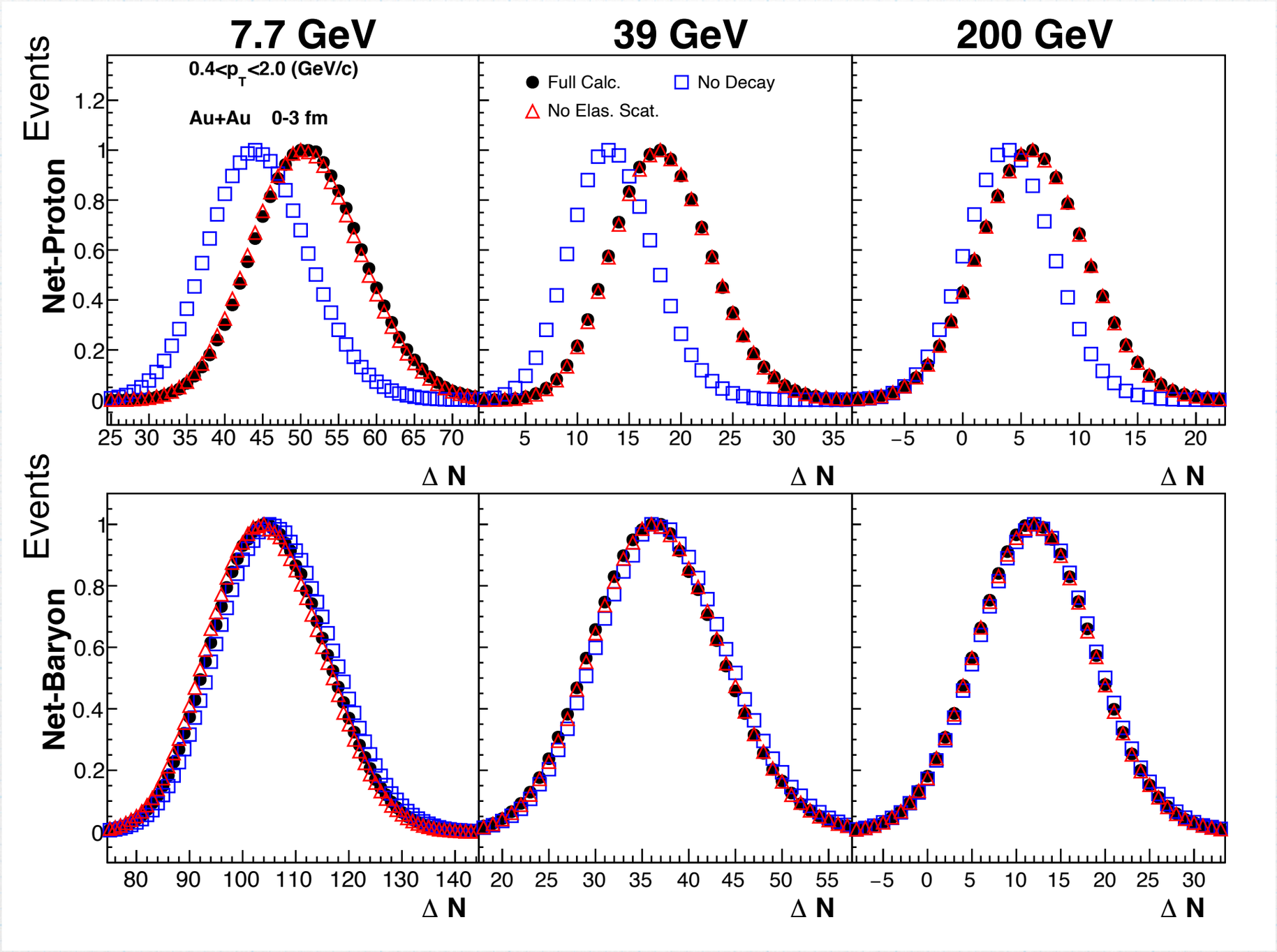
- statistical error using Delta theorem(Phys. Rev. C91, 034907)

Results : dN/dy distribution

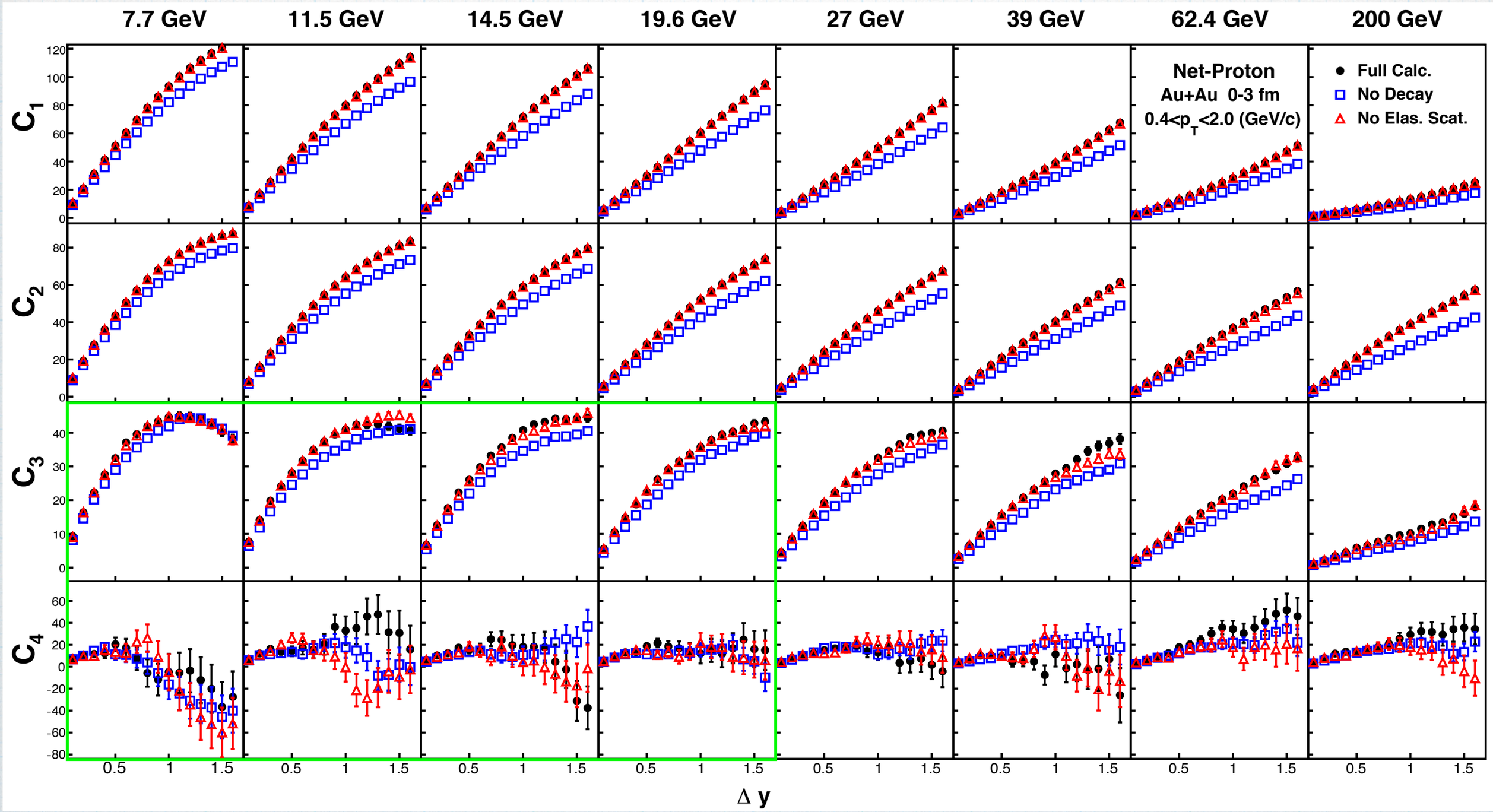


- Turning off weak decay will decrease proton number.
- Baryon stopping have larger effect at lower energies

Event by event distribution of net-proton and net-baryon



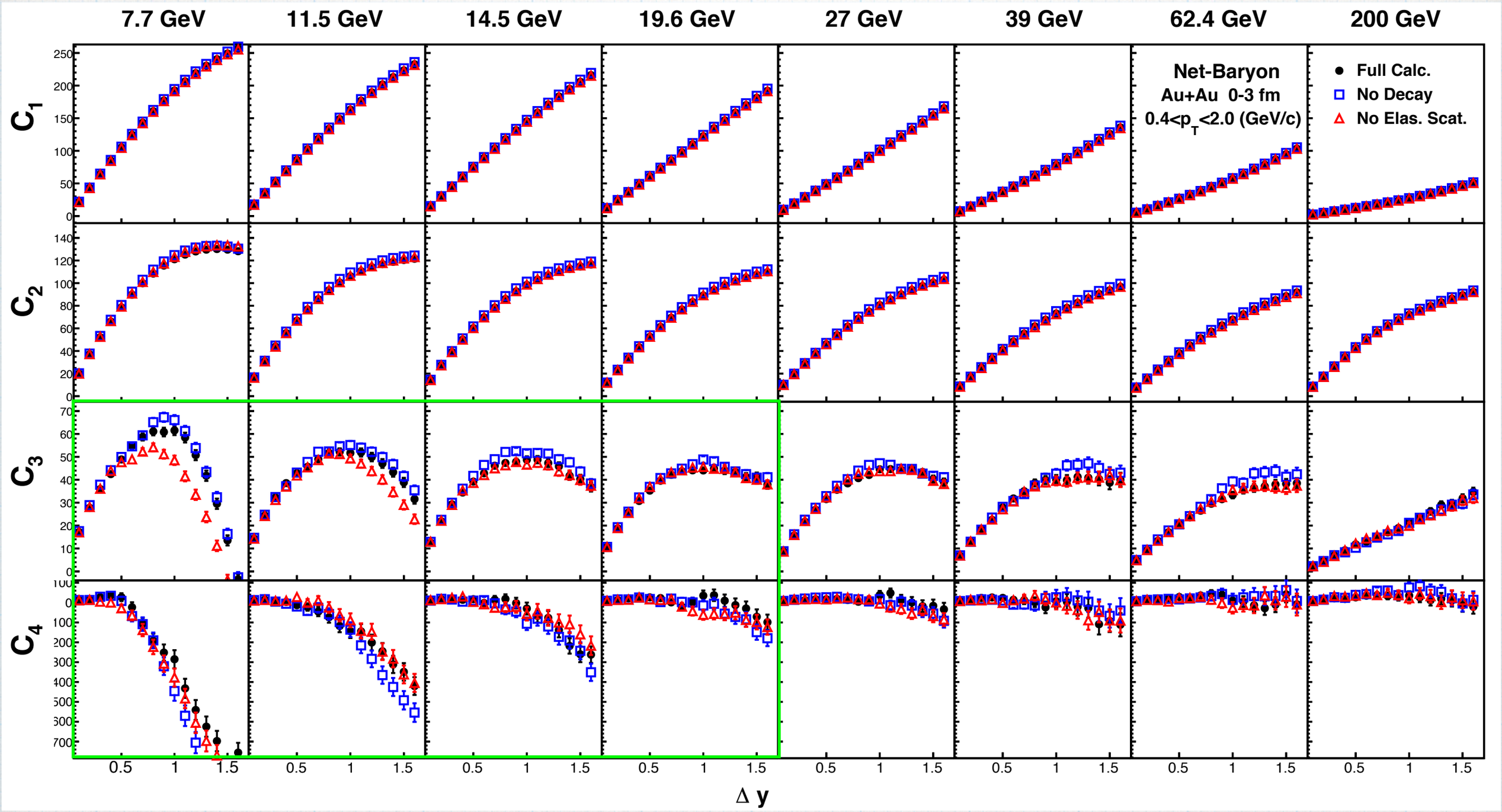
- turning off weak decay have little influence on net-baryon other than net-proton



$$-\Delta y/2 < y' < \Delta y/2$$

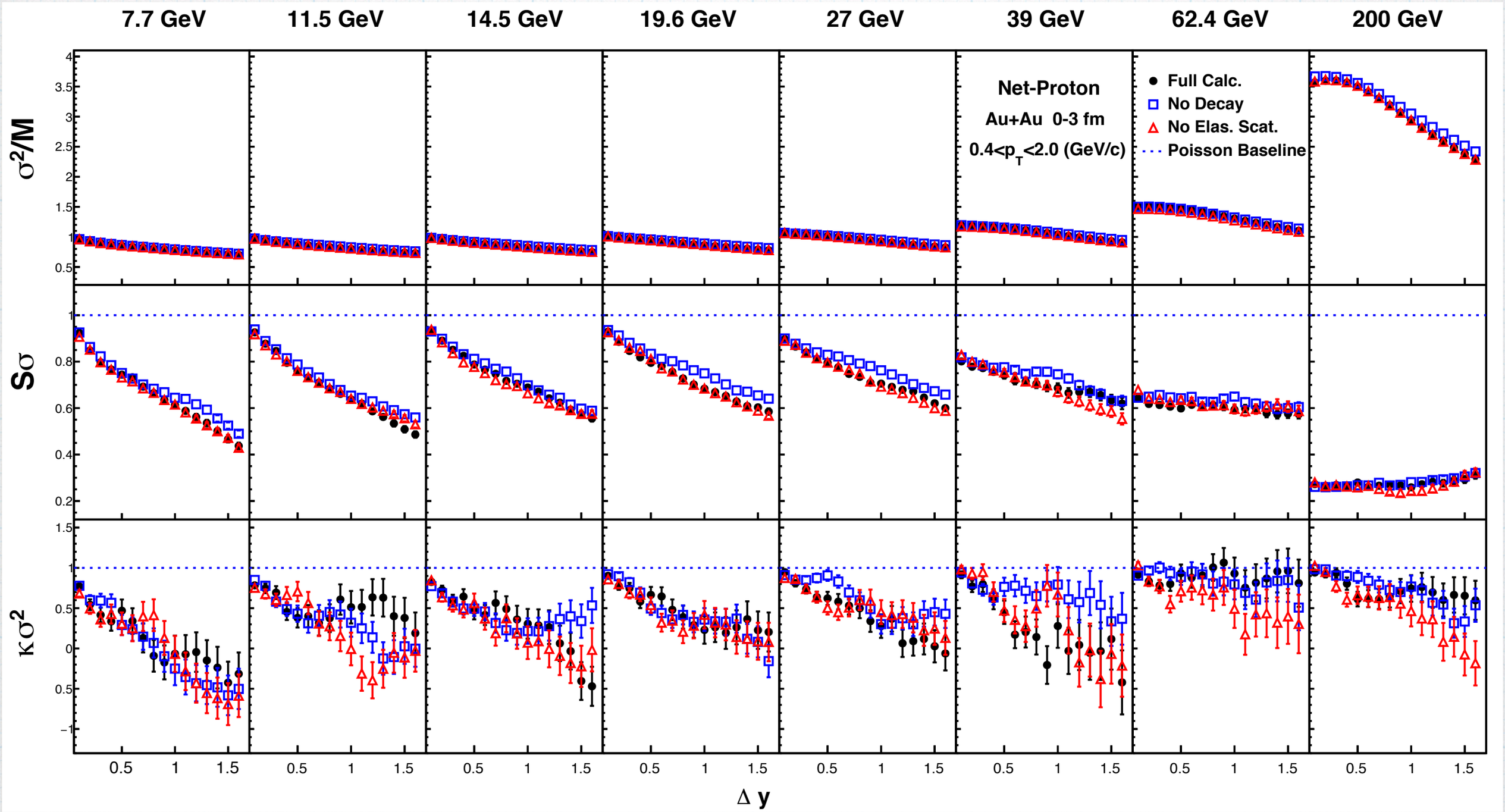
- 3rd and 4th order cumulants drop at larger rapidity window due to baryon number conservation.
- results from full calc. (default mode) and turning off elas. scat. overlap together

Rapidity dependence of Net-Baryon Cumulant



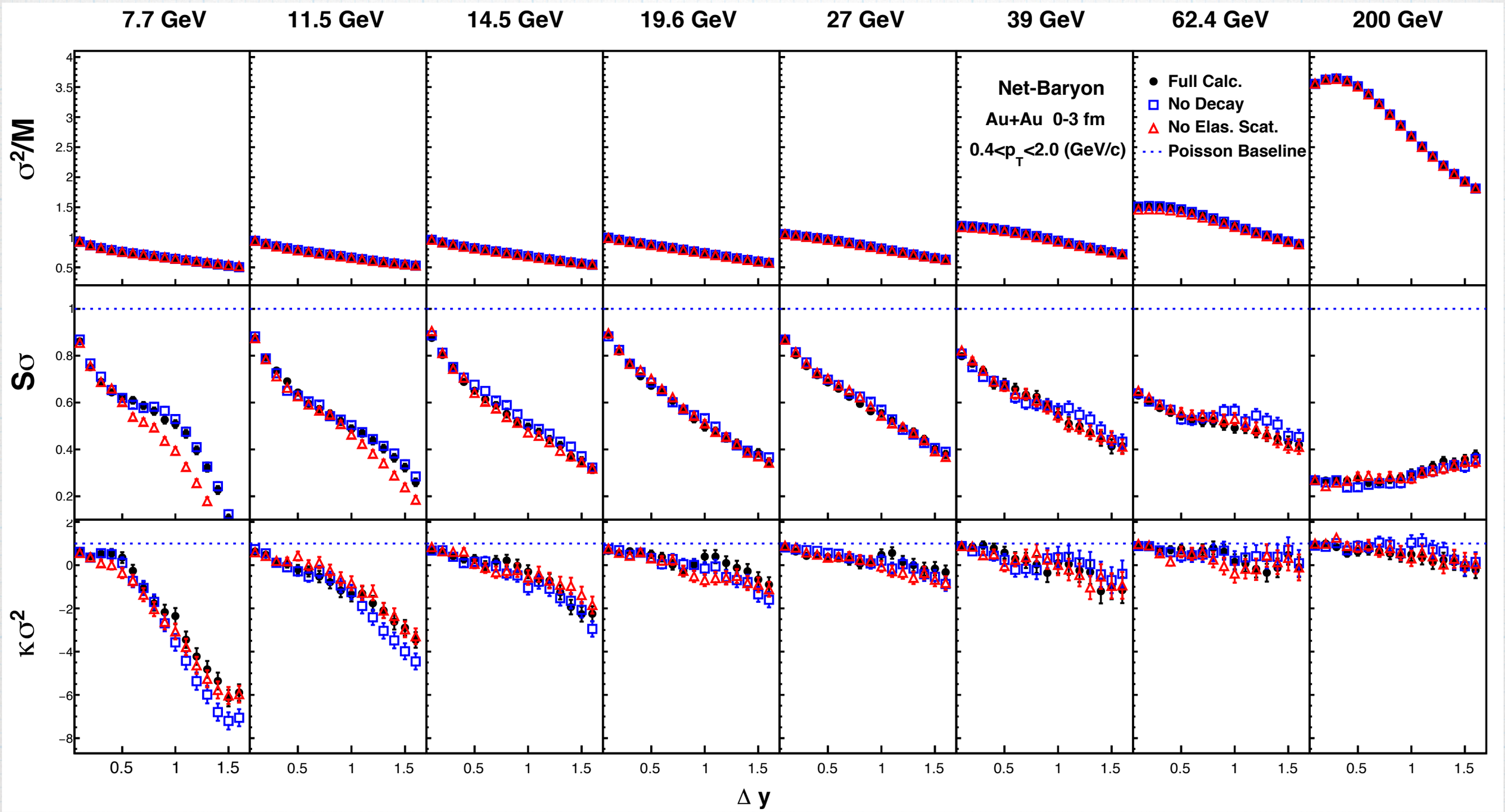
- Stronger effects from baryon number conservation on 3rd and 4th order cumulants.
- results from three conditions overlap together.

Rapidity dependence of Net-Proton Cumulant ratio



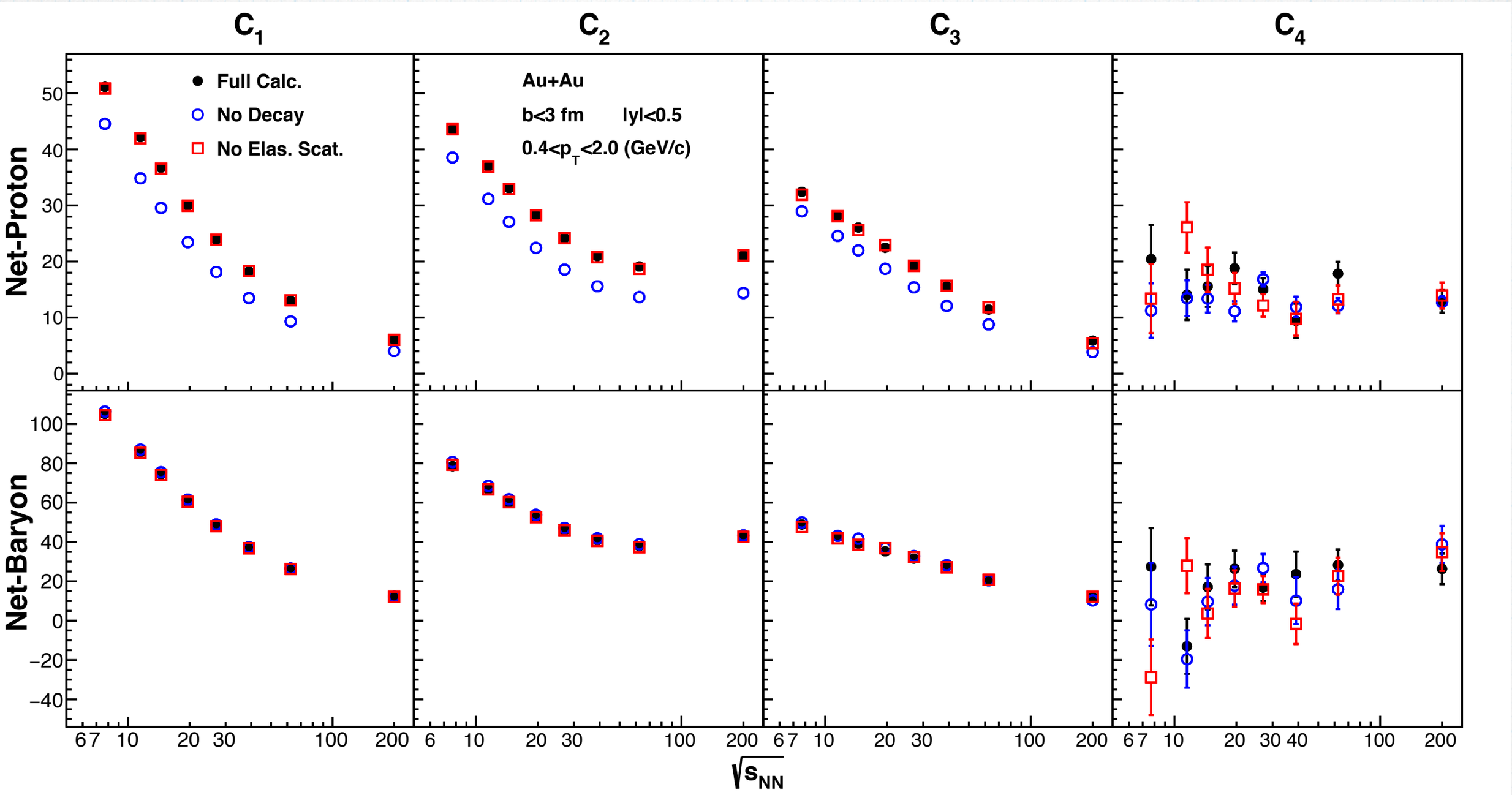
- No significant difference found between “Full Calc” and “No decay”.
- $\kappa\sigma^2$ are below unity at all energies.

Rapidity dependence of Net-Baryon Cumulant ratio



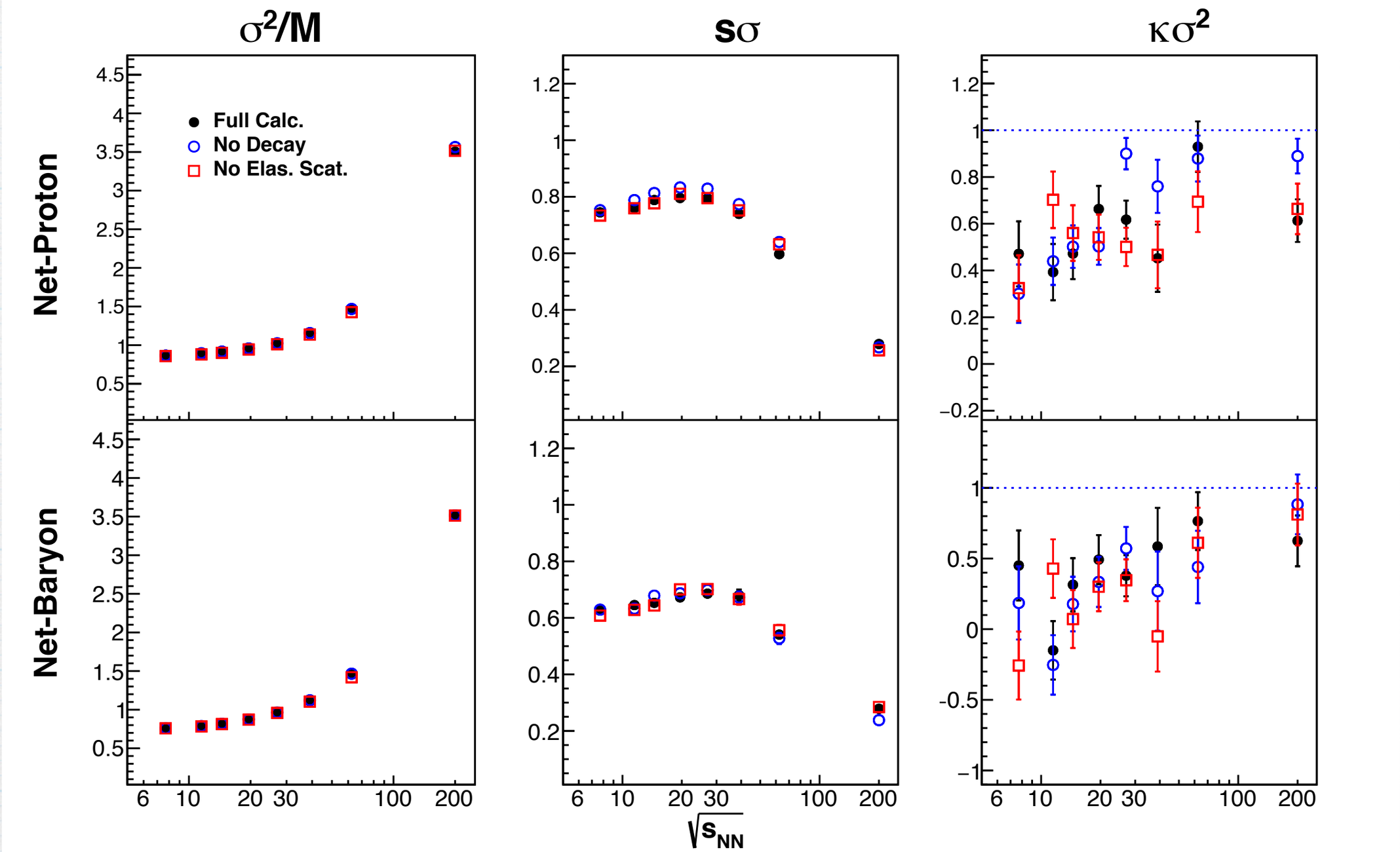
- Three conditions overlap together at σ^2/M and show small difference at $S\sigma$ and $\kappa\sigma^2$.

Energy dependence of Cumulant



- Turning off weak decay have larger effects on net-proton cumulants.

Energy dependence of Cumulant Ratio



- No large difference found at cumulant ratios of three scenarios.
- $\kappa\sigma^2$ are below unity at all energies and are linearly suppressed at lower energies.

Summary

- Weak decay has influence on net-proton cumulants but small influence on cumulant ratios.
- Elastic scattering have no significant influence on net-p and net-b cumulants and their ratios.
- $\kappa\sigma^2$ of net-p and net-b are below unity at all energies and cannot describe experiment.

Thank you!