The importance of wounded-parton model in high-energy nuclear collisions

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with Piotr Bożek and Wojciech Broniowski

Institute of Nuclear Physics, PAN, Krakow

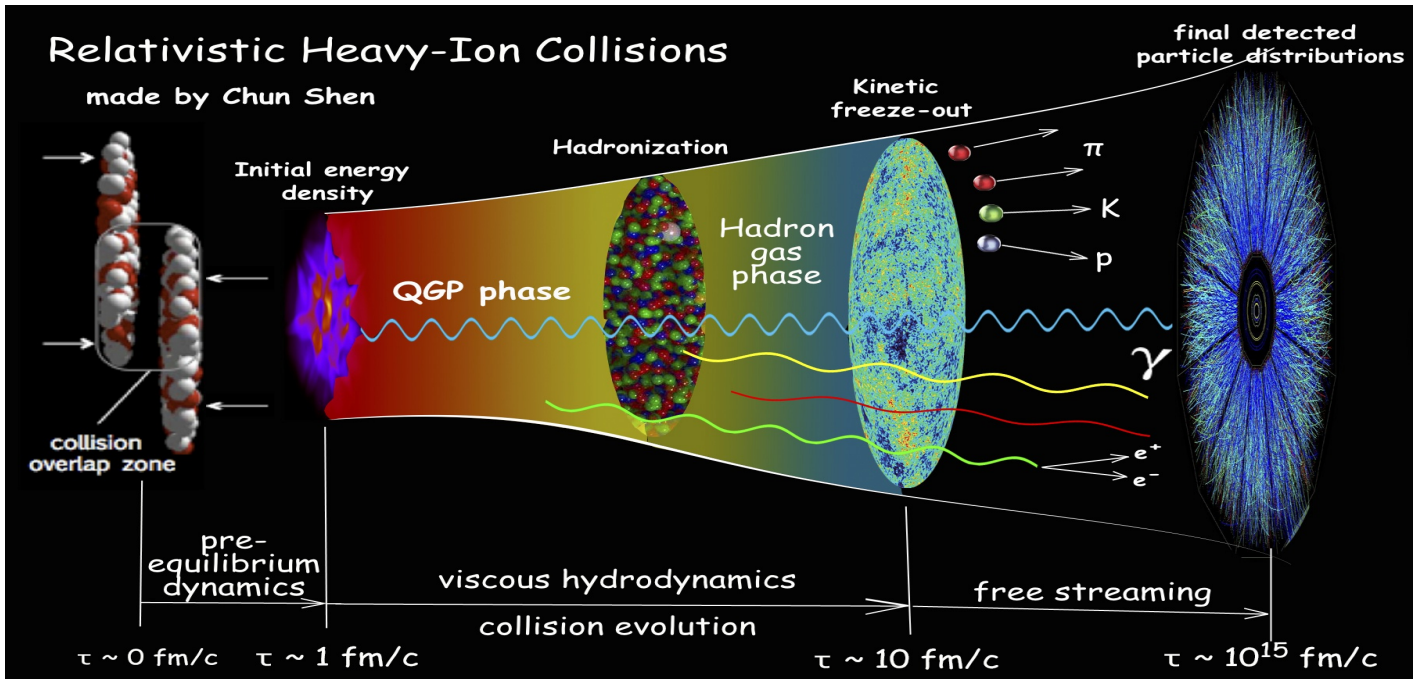
Bialasowka HEP seminar, 20.11.2026





NATIONAL SCIENCE CENTRE POLAND

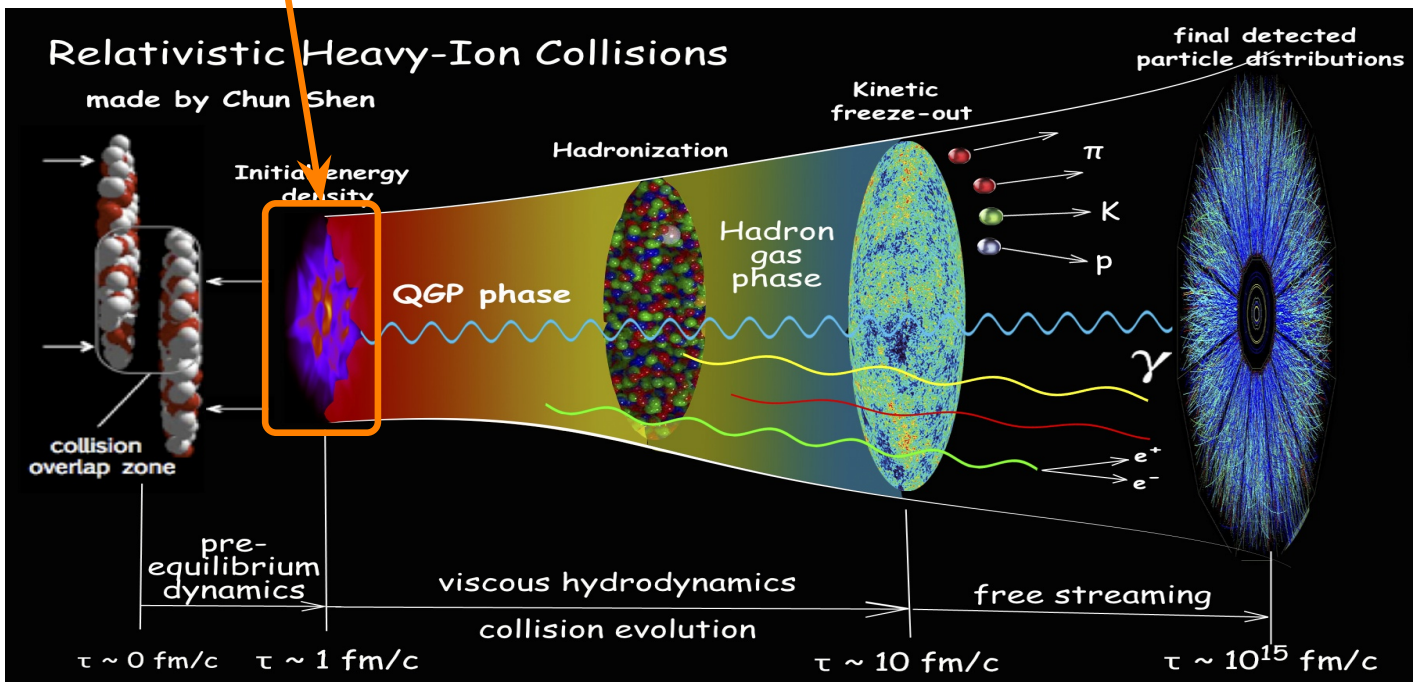
High energy nuclear collision: "The Little Bang"



Shen, Heinz, arXiv:1507.01558

High energy nuclear collision: "The Little Bang"

Initial state
entropy density $s(\mathbf{x}_\perp)$ from participants
$S = \int d^2x_\perp\, s$, eccentricities ε_n

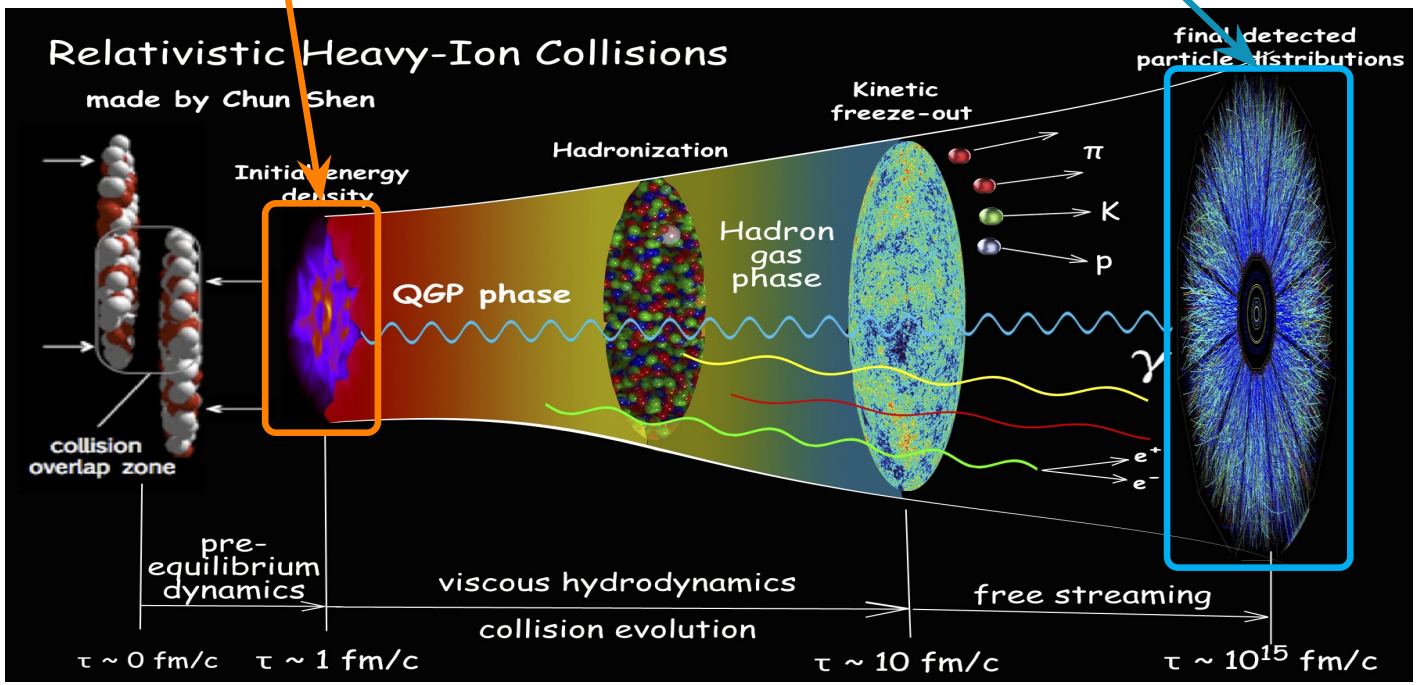


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Final state
$dN_{\rm ch}/d\eta$, v_n, $\langle p_T \rangle$

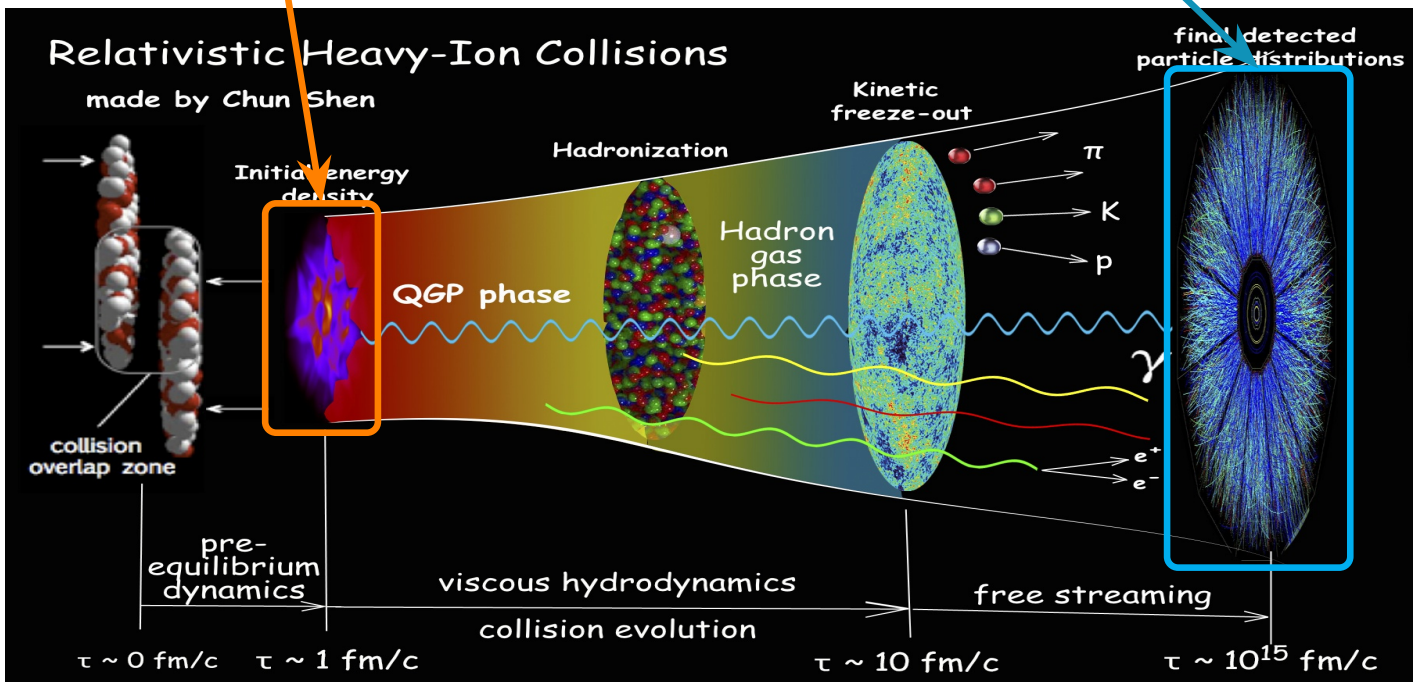


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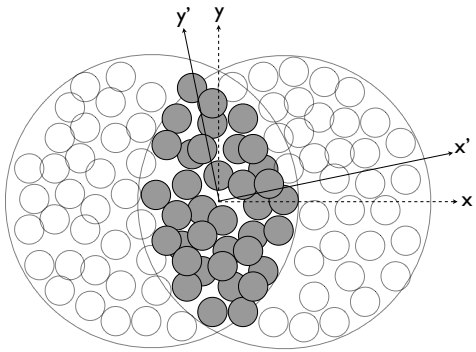
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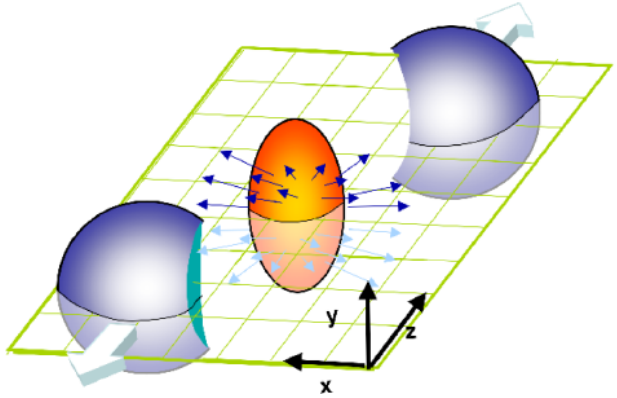


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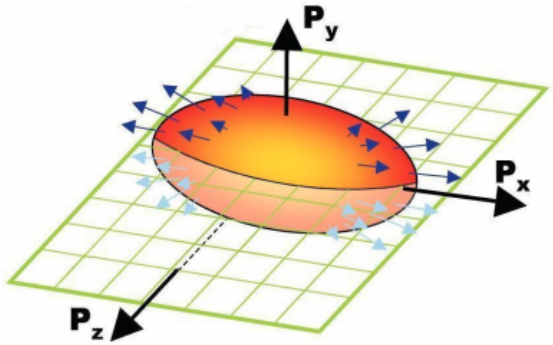
near-ideal hydro: entropy conserved $\Rightarrow \dfrac{dN_{\rm ch}}{d\eta} \propto \dfrac{dS}{d\eta}$ linear response: $v_n \simeq \kappa_n\, \varepsilon_n$



PHOBOS arXiv:0711.3724



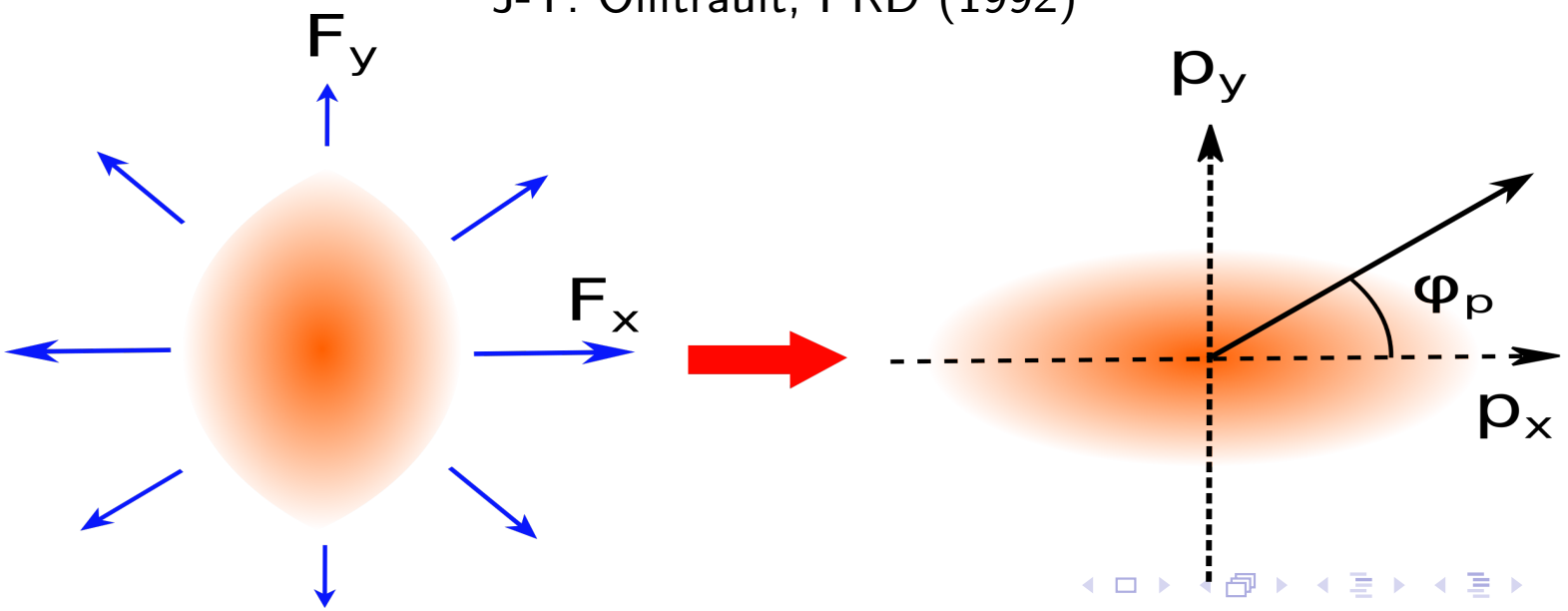
U. Heinz, arXiv:0810.5529



BNL: RHIC

Asymmetry in source distribution ⇒ **Collective expansion of fireball** ⇒ **Momentum anisotropy**

J-Y. Ollitrault, PRD (1992)

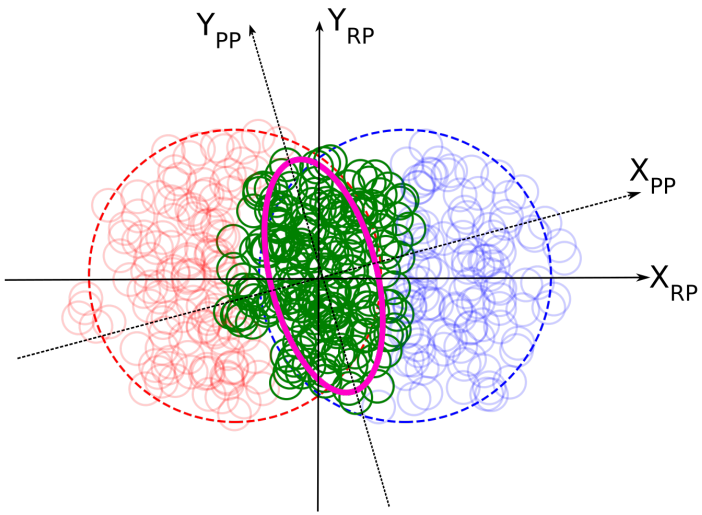


Modeling the anisotropy : Harmonic flow

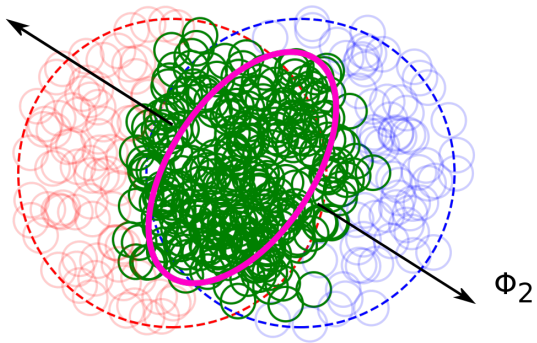
Momentum anisotropy as fourier expansion of flow harmonics

$$\frac{dN}{dp_T d\phi} \propto 1 + 2v_2 \cos\left[2(\phi - \Psi_2)\right] + 3v_3 \cos\left[3(\phi - \Psi_3)\right] + \ldots$$

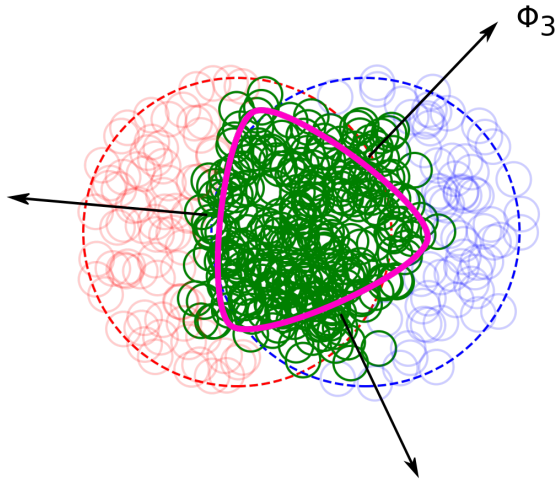
elliptic flow triangular flow



participant eccentricity



ellipticity: $v_2 \propto \epsilon_2$

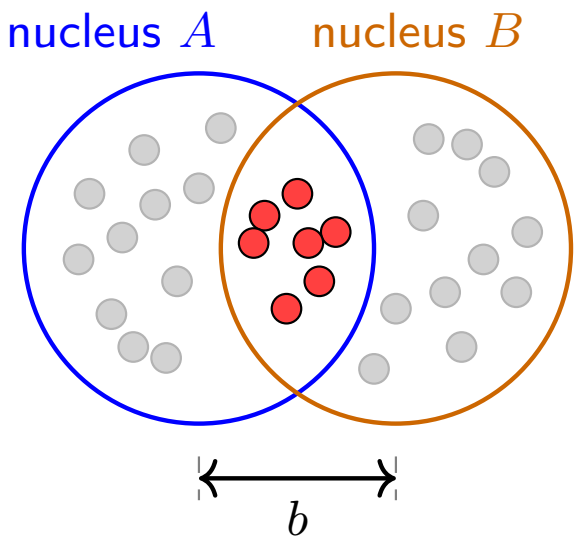


triangularity:

$v_3 \propto \epsilon_3$

Particle production in HI collision : from wounded nucleons to wounded partons

- Wounded Nucleon Model (WNM):
  Initial entropy $(S) \propto \#$ wounded nucleons N_w
  "Wounded" $\rightarrow$ undergone at least one collisions
  Doesn't work at high-energy; cannot describe light-ion collision !

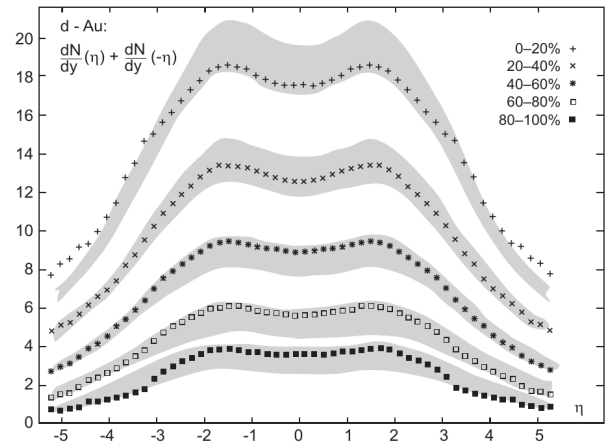


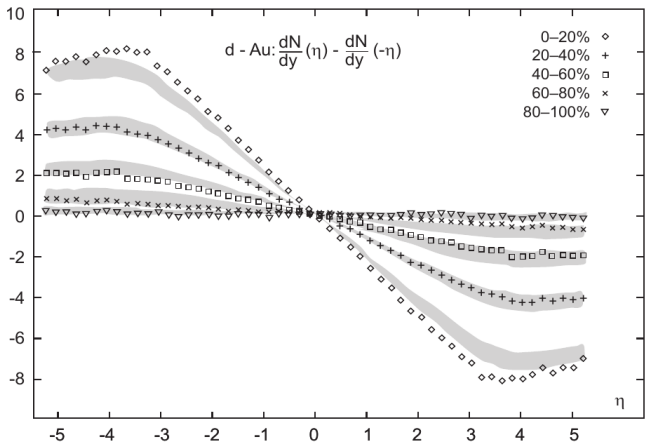
$$N_{ch} \propto N_w$$

Białas, Błeszyński, Czyż (1976)

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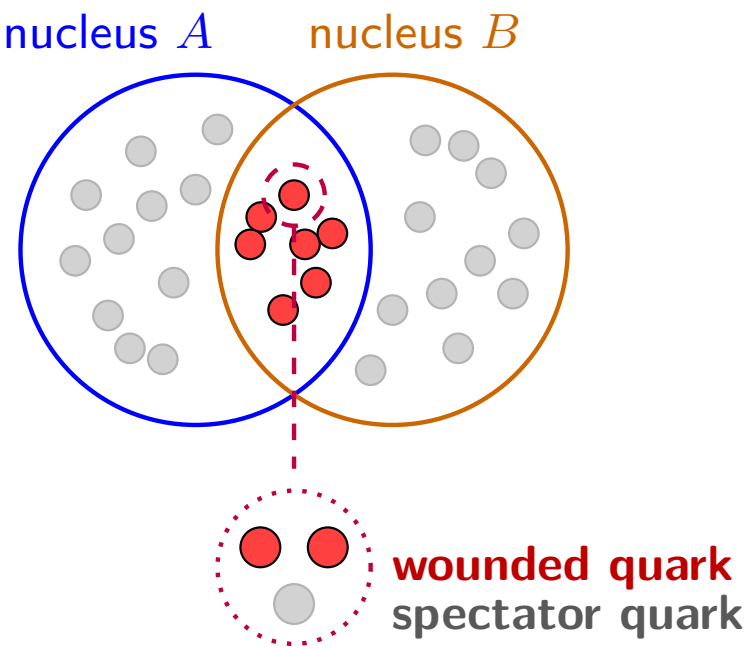




Białas, Czyż (2004)

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- Need for wounded quarks ; quark-diquark picture $\longrightarrow$ **WQM explains the data at high energy**



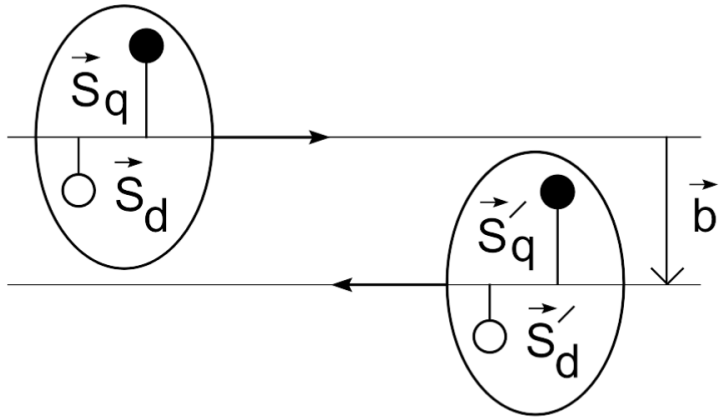
one wounded nucleon
but 2 wounded quarks

$$N_{ch} \propto N_{wq}$$

Białas, Czyż, Furmański (1977)

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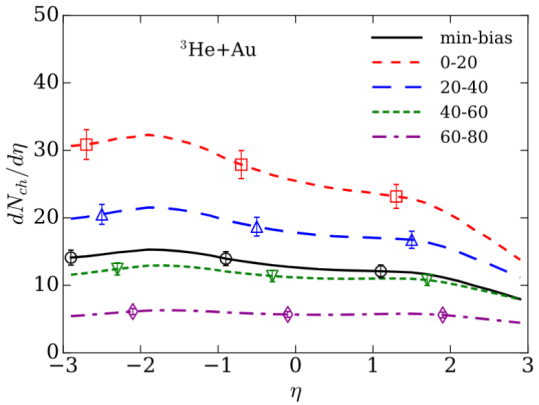
Quark-diquark model for cross-section

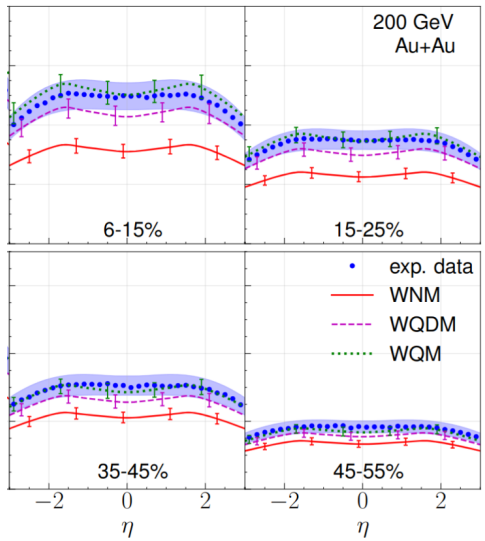
Białas, Bzdak (2006)

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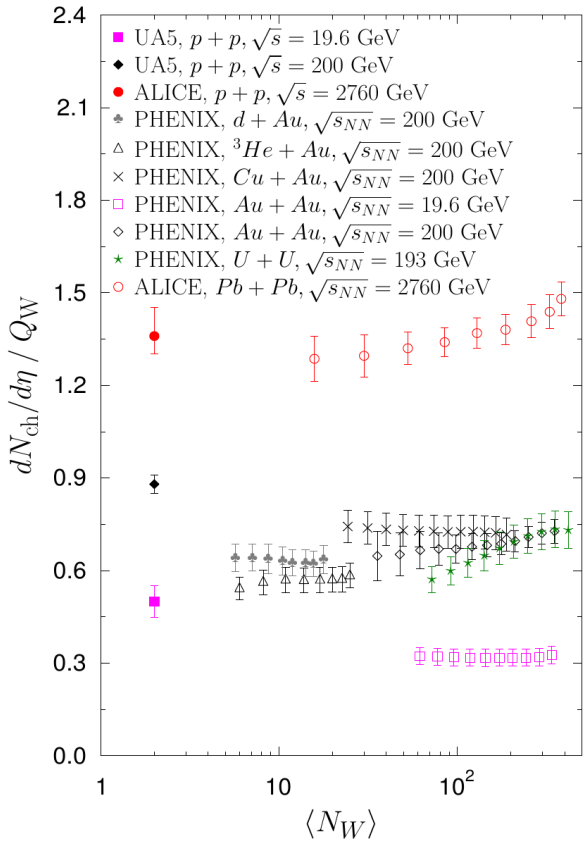




Barej, Bzdak, Gutowski (2019)

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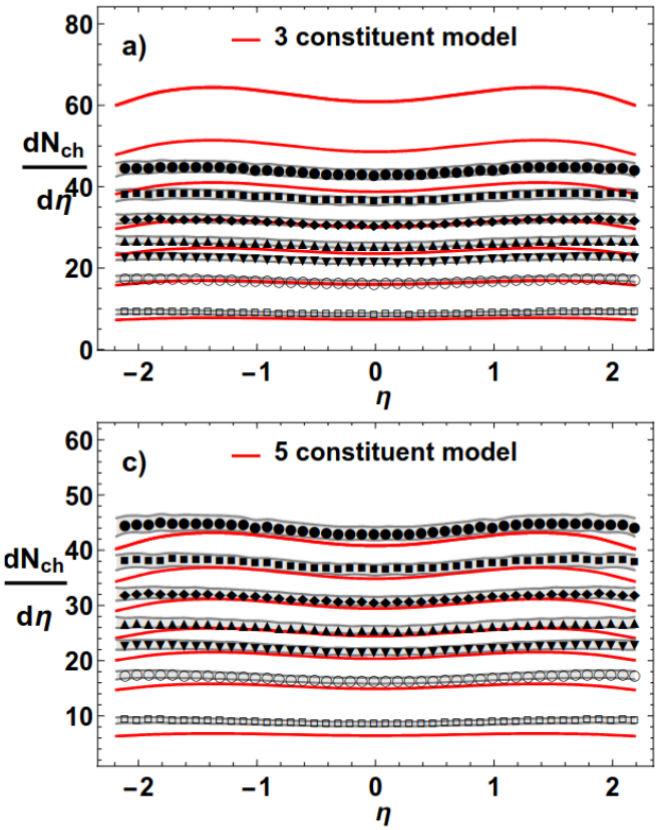


Bożek, Broniowski, Rybczyński (2016)

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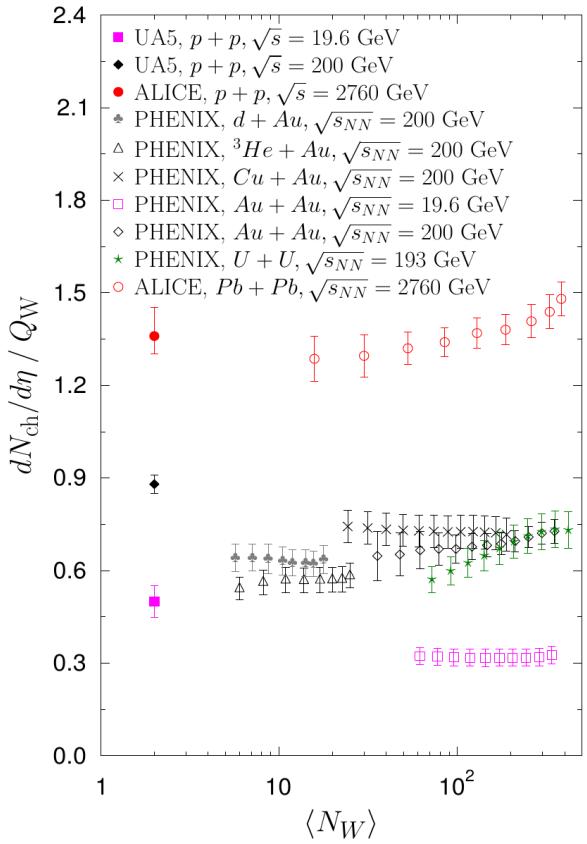
symmetric part, p+Pb @ 5.02 TeV



Rohrmoser, Broniowski (2020)

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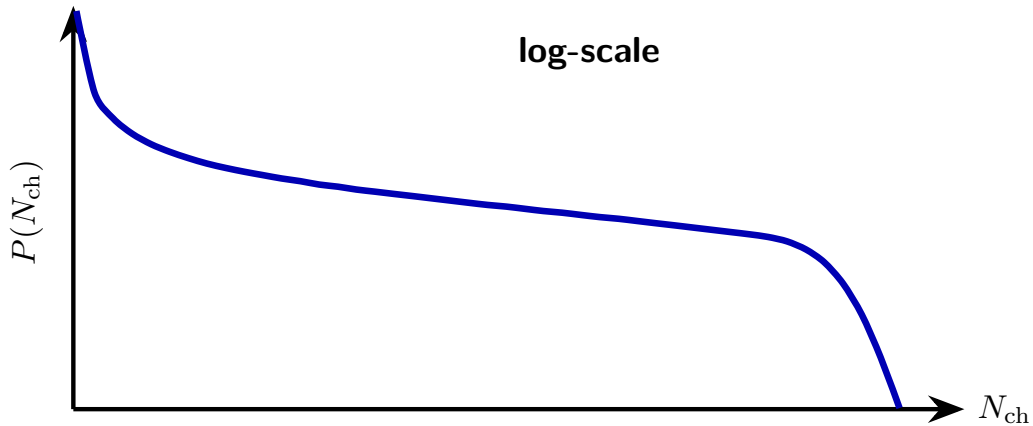
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- **Question: Does this partonic universality survive down to smaller LHC systems: O+O and Ne+Ne?**

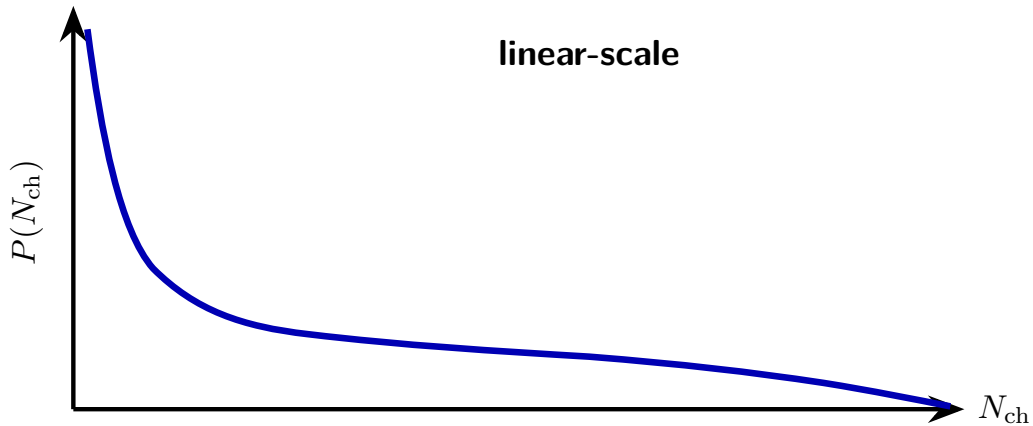


Bożek, Broniowski, Rybczyński (2016)

Multiplicity distribution and centrality mapping

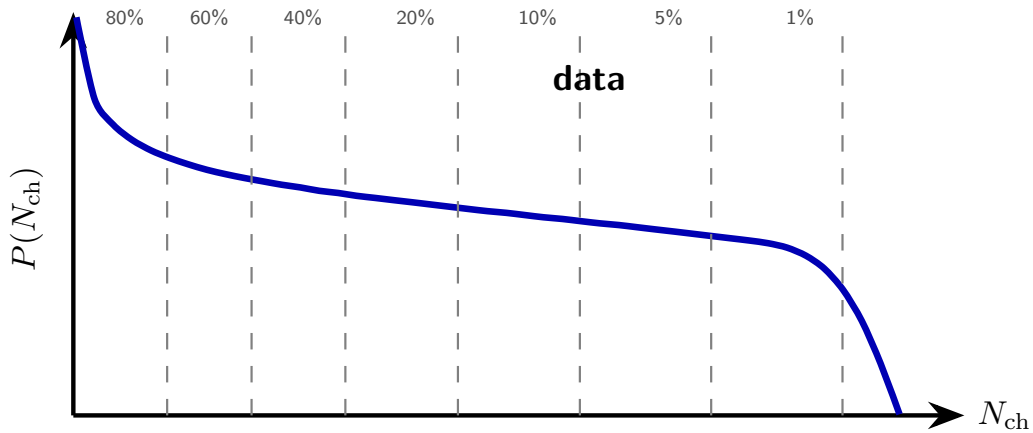
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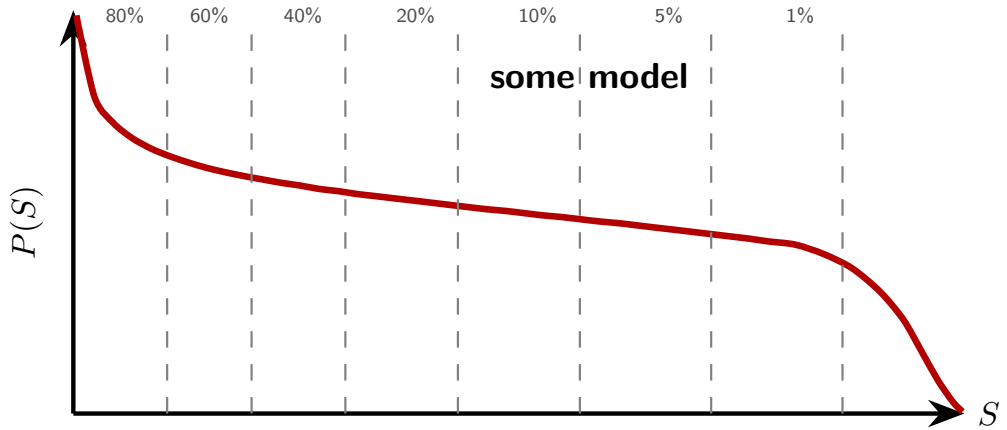




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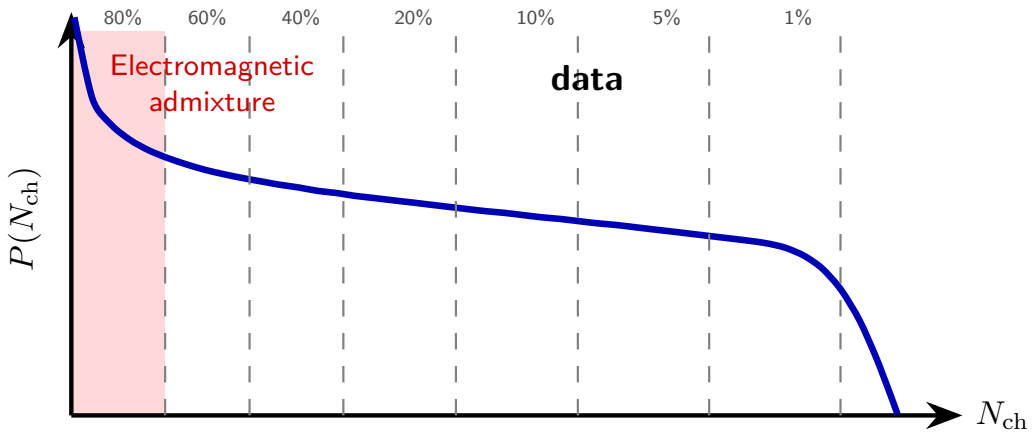
- Multiplicity distribution: **crucial for model to data comparison**
- Normalized $P(N_{\rm ch}) \rightarrow$ used for binning into centrality classes (quantiles): 0–1%, 1–5 %... 70–80%. **Centrality mapping is tricky.**

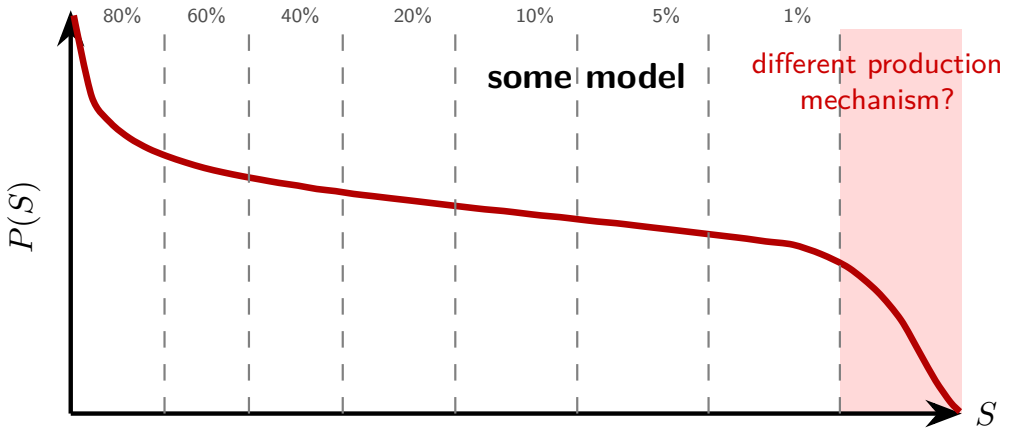




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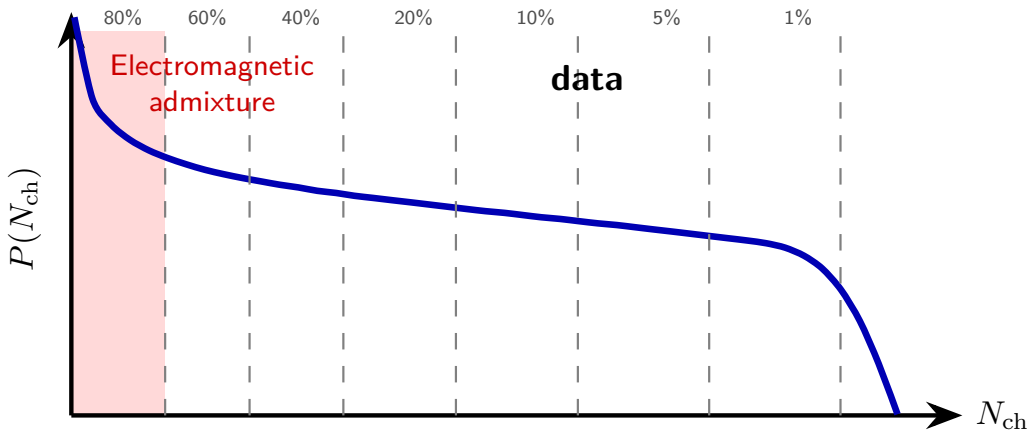
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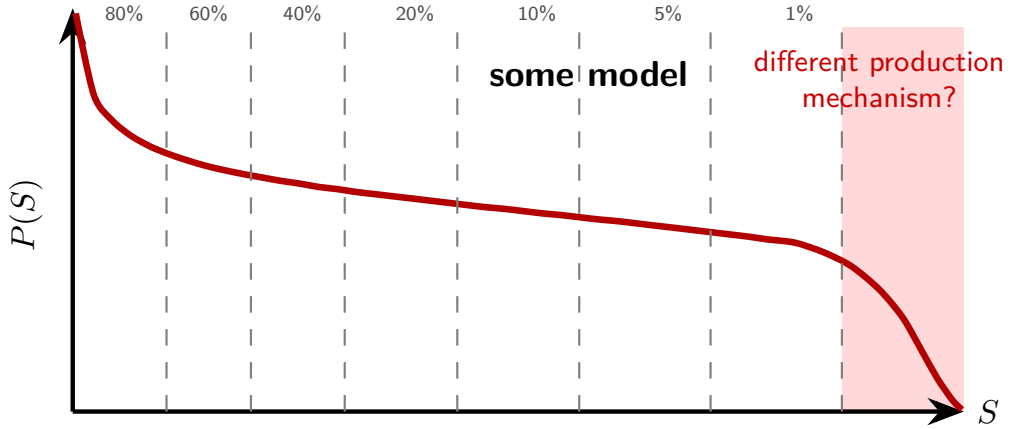




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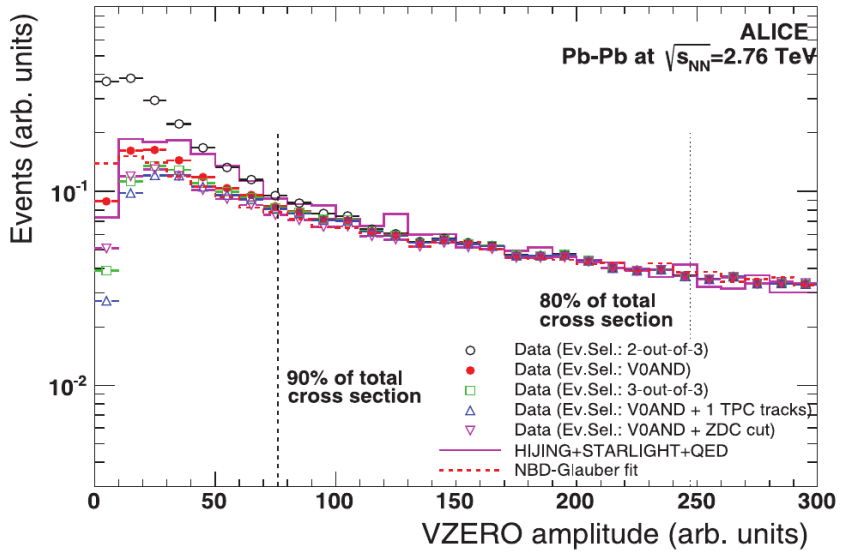
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- Central tail in model: Model needs fluctuations but in ultra-central domain particle-production mechanism may differ (e.g saturation) **Ambiguity in both tails propagate into centrality binning $\longrightarrow \langle N_{ch} \rangle$ in centrality class**

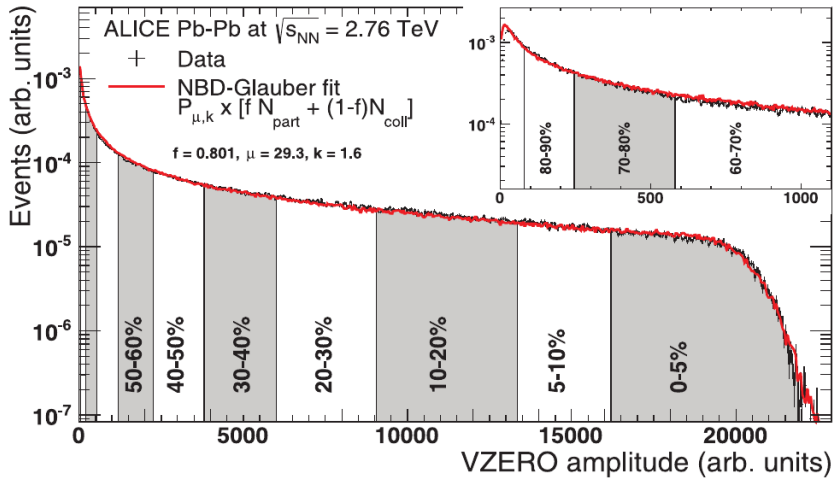




Centrality estimation in data (ALICE) PRC 88 044909 (2013)

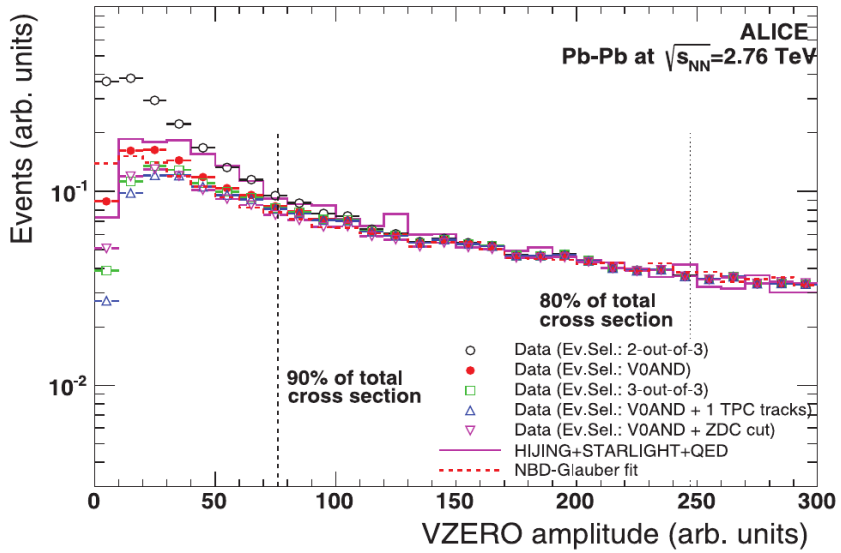
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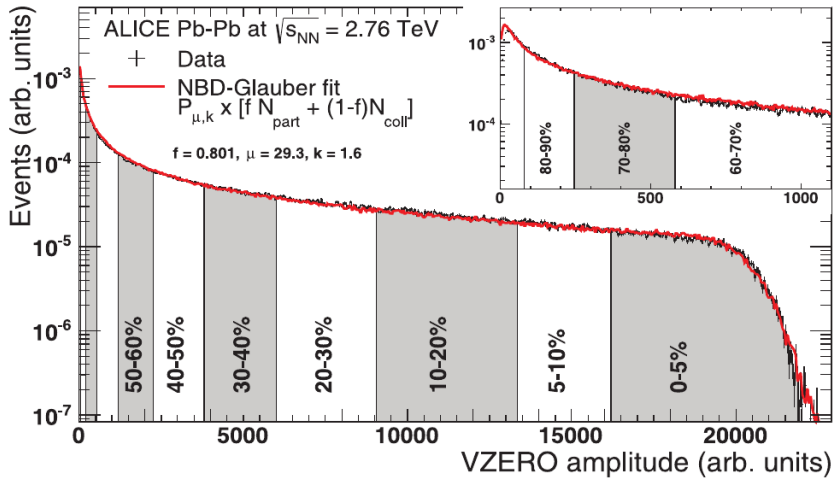




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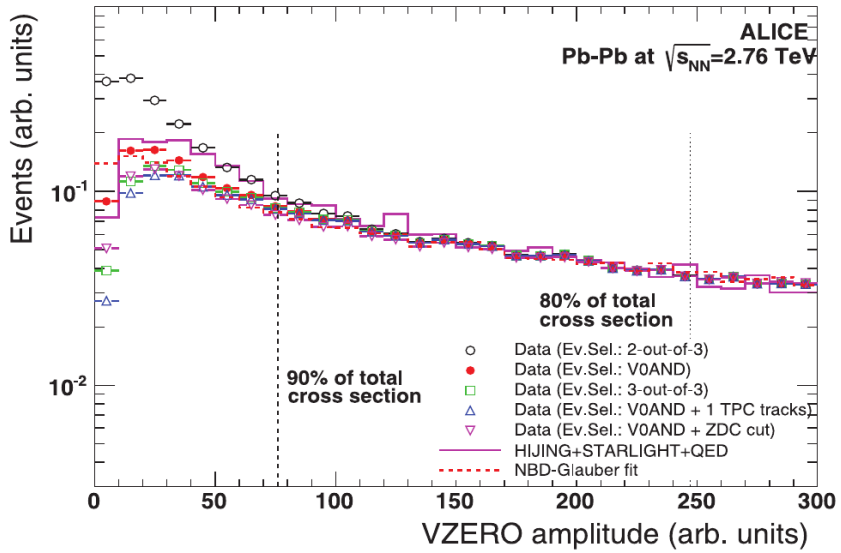


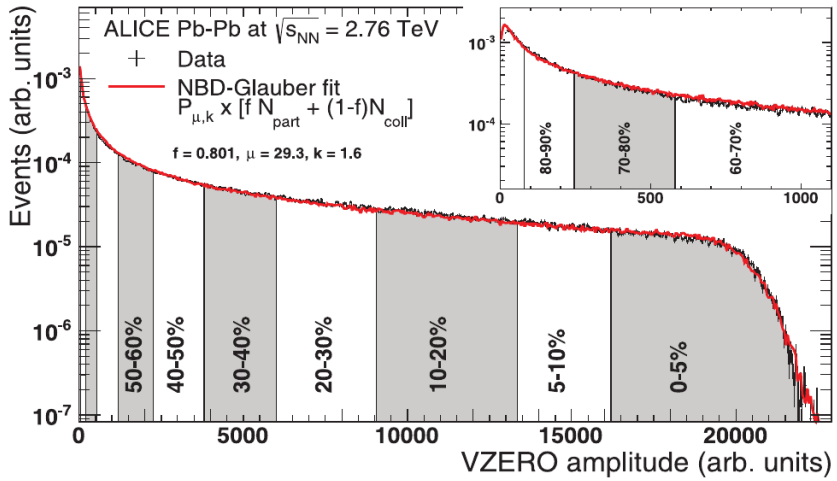


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- Top 10 % centrality is defined by,

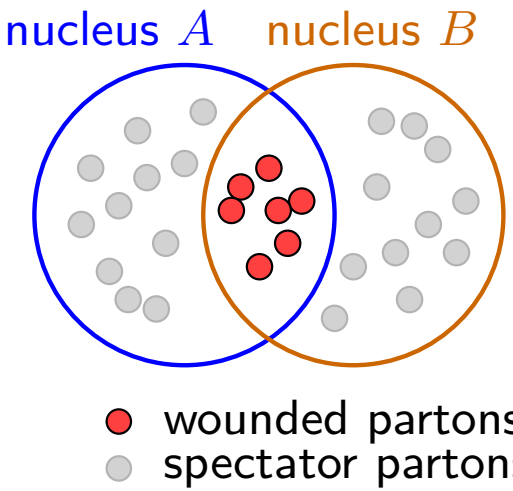
$$\frac{\int_{V0_{10}}^{\infty}(dN_{\rm evt}/dV)\,dV}{\int_{V0_{\rm AP}}^{\infty}(dN_{\rm evt}/dV)\,dV}=\frac{1}{9}.$$





Model for S : Wounded Parton Model (WPM) + Negative Binomial fluctuations (NBD)

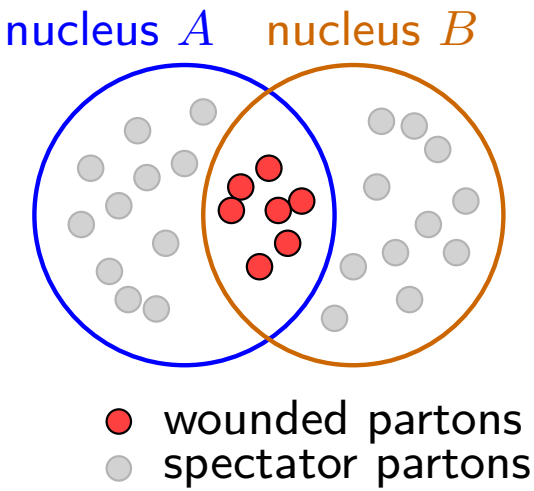
- Nucleon resolved into N_p constituent partons



Model for S : Wounded Parton Model (WPM) + Negative Binomial fluctuations (NBD)

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- Parton-parton inelastic profile (Gaussian):

$$p_{\rm in}^{qq}(\sqrt{s}, b) \propto \exp\left[-\frac{\pi b^2}{\sigma_{\rm in}^{qq}(\sqrt{s}; N_p)}\right]$$

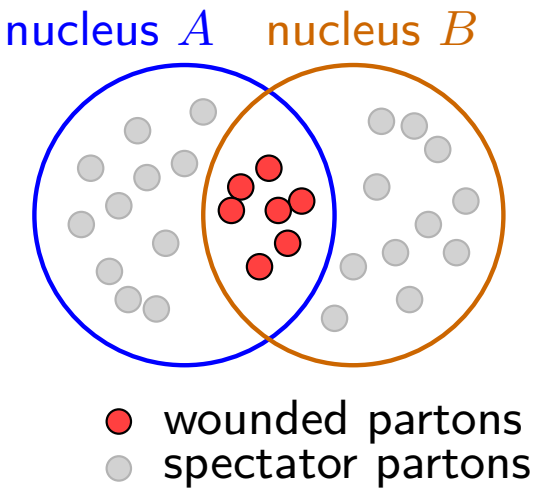


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- $\sigma_{\rm in}^{qq}$ **tuned** according to the COMPETE parametrization for $\sigma_{\rm in}^{pp}$ Patrignani *et al.* (2016)

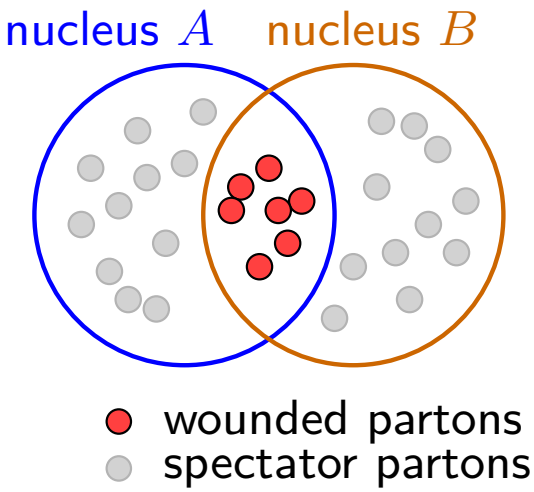


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- Nuclear density implemented in **GLISSANDO 3** Bożek *et al.* (2019)

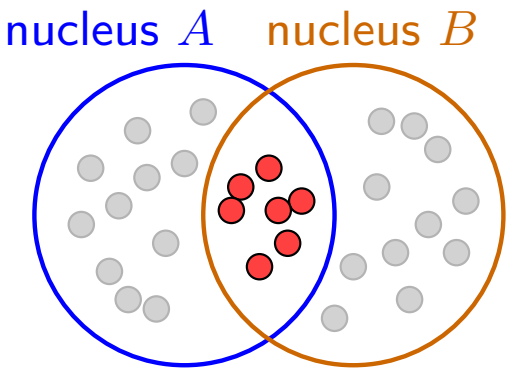


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$$p_{\rm in}^{qq}(\sqrt{s}, b) \propto \exp\left[-\frac{\pi b^2}{\sigma_{\rm in}^{qq}(\sqrt{s}; N_p)}\right]$$

- $\sigma_{\rm in}^{qq}$ **tuned** according to the COMPETE parametrization for $\sigma_{\rm in}^{pp}$ Patrignani *et al.* (2016)
- Nuclear density implemented in **GLISSANDO 3** Bożek *et al.* (2019)



- Each wounded parton deposits entropy via a negative binomial distribution (NBD), mean $\bar{n} = 1$:

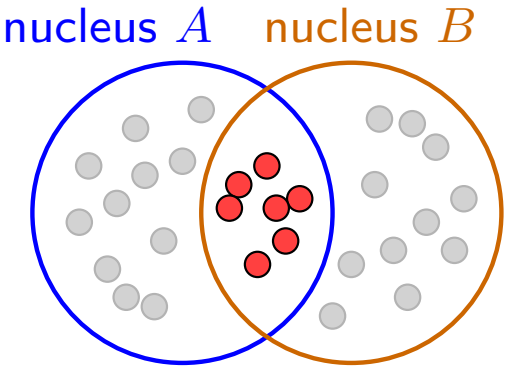
$$P_{\rm NB}(n \,|\, \bar{n}, \kappa) = \frac{\Gamma(n+\kappa)}{\Gamma(n+1)\,\Gamma(\kappa)} \frac{\kappa^{\kappa}\,\bar{n}^{\,n}}{(\bar{n}+\kappa)^{n+\kappa}}\,, \qquad \text{var} = \frac{\bar{n}^2}{\kappa} + \bar{n}$$

Model for S : Wounded Parton Model (WPM) + Negative Binomial fluctuations (NBD)

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$$S = \sum_{i \in \text{wounded partons}} n_i \,,$$

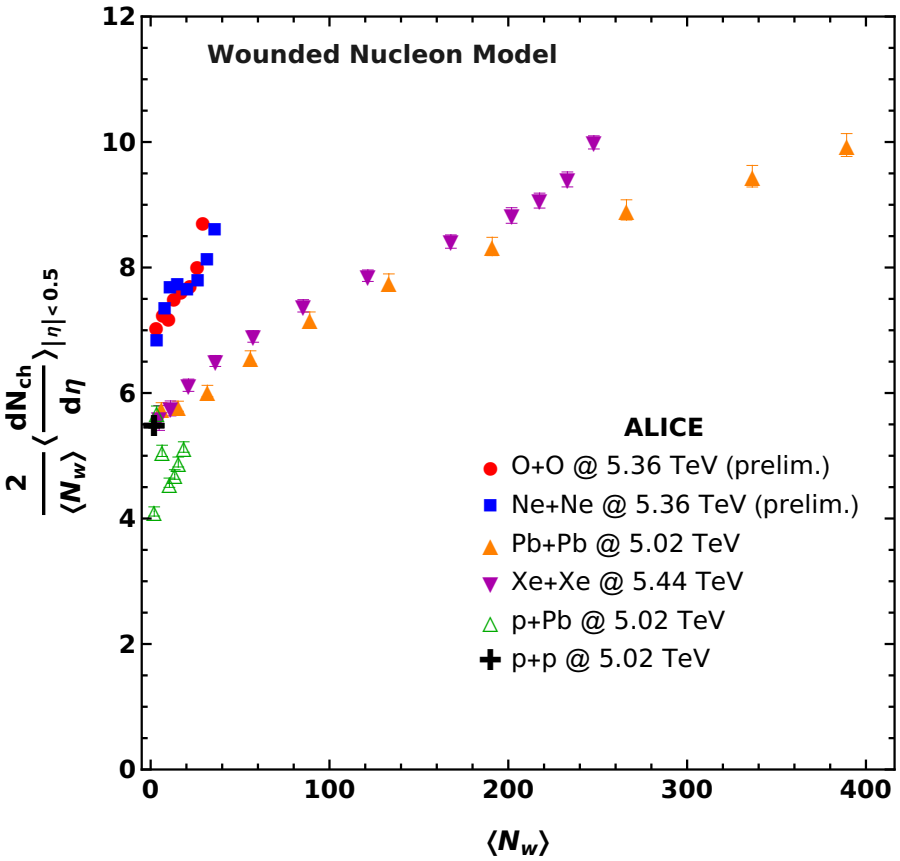
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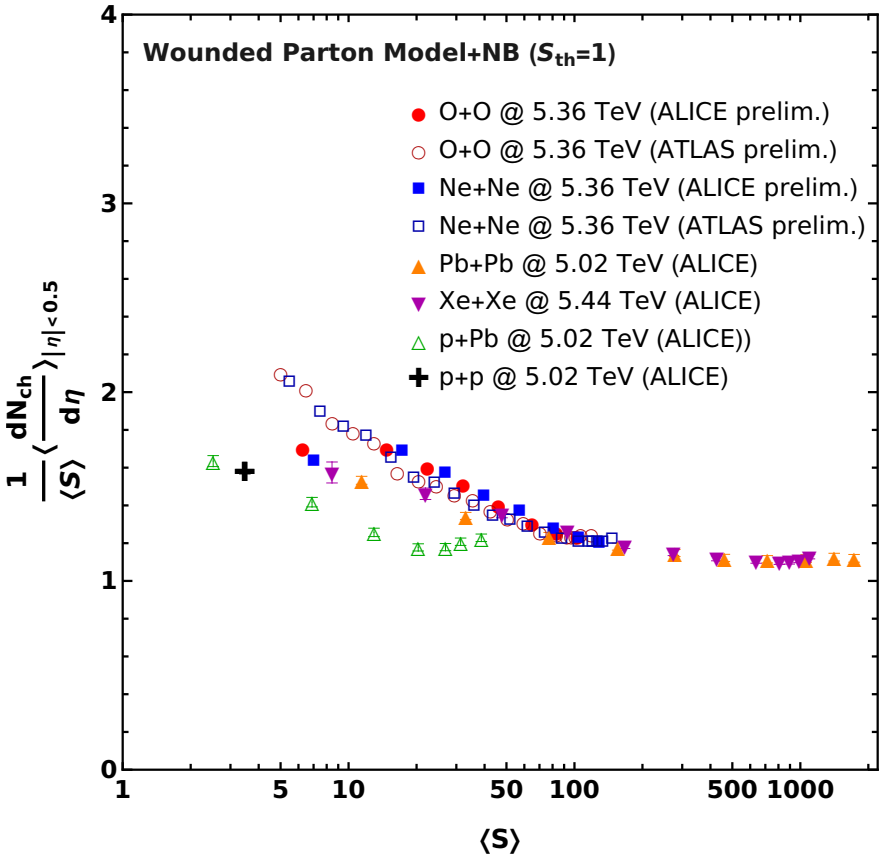
Model comparison using a same anchor-point analogy

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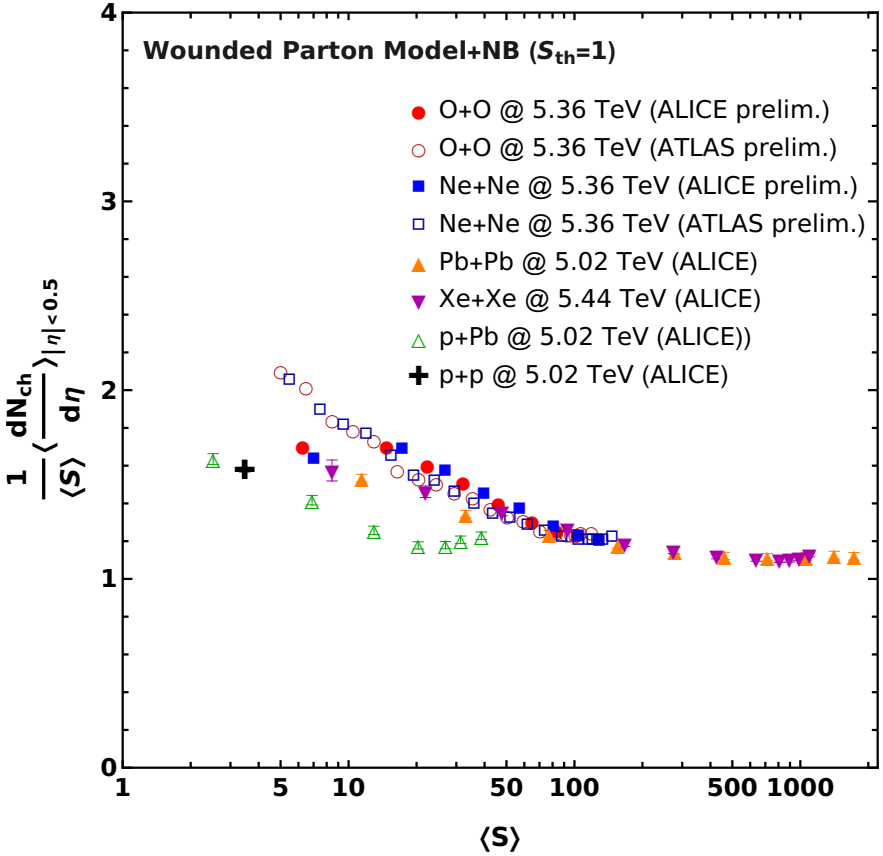
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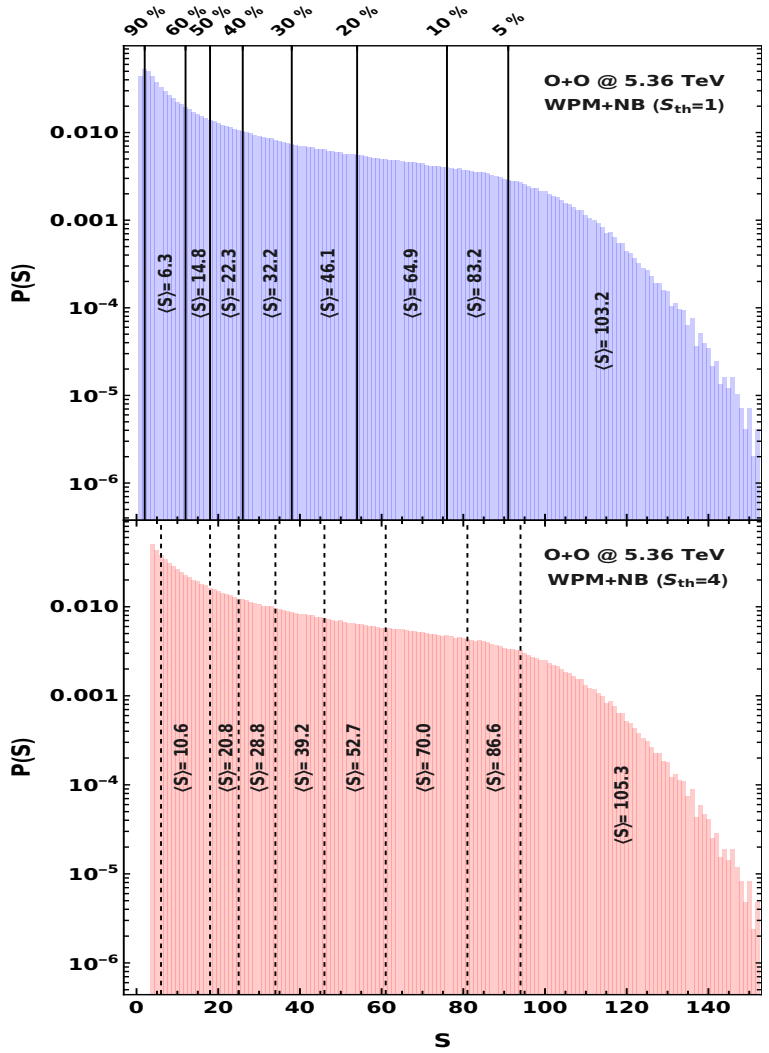
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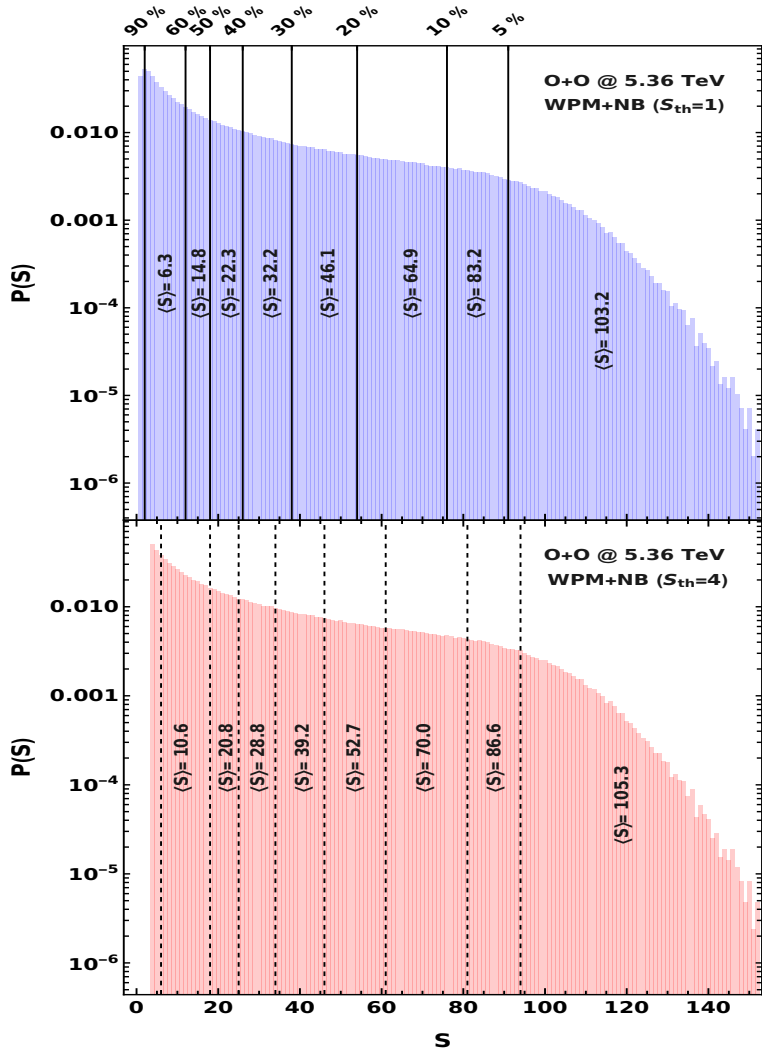
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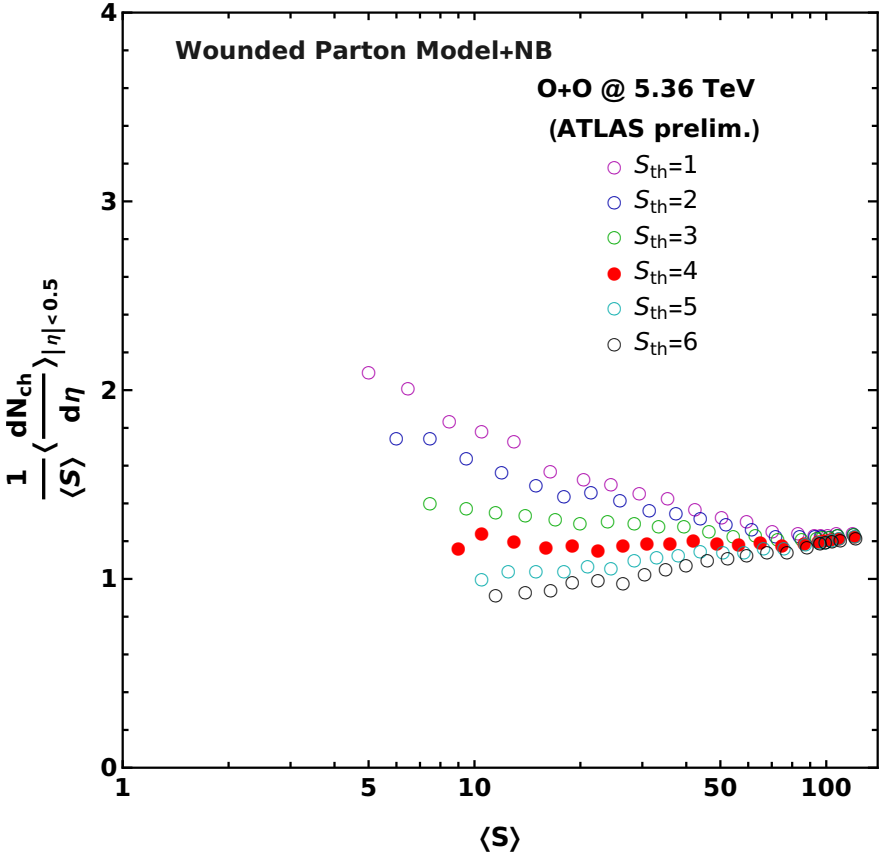
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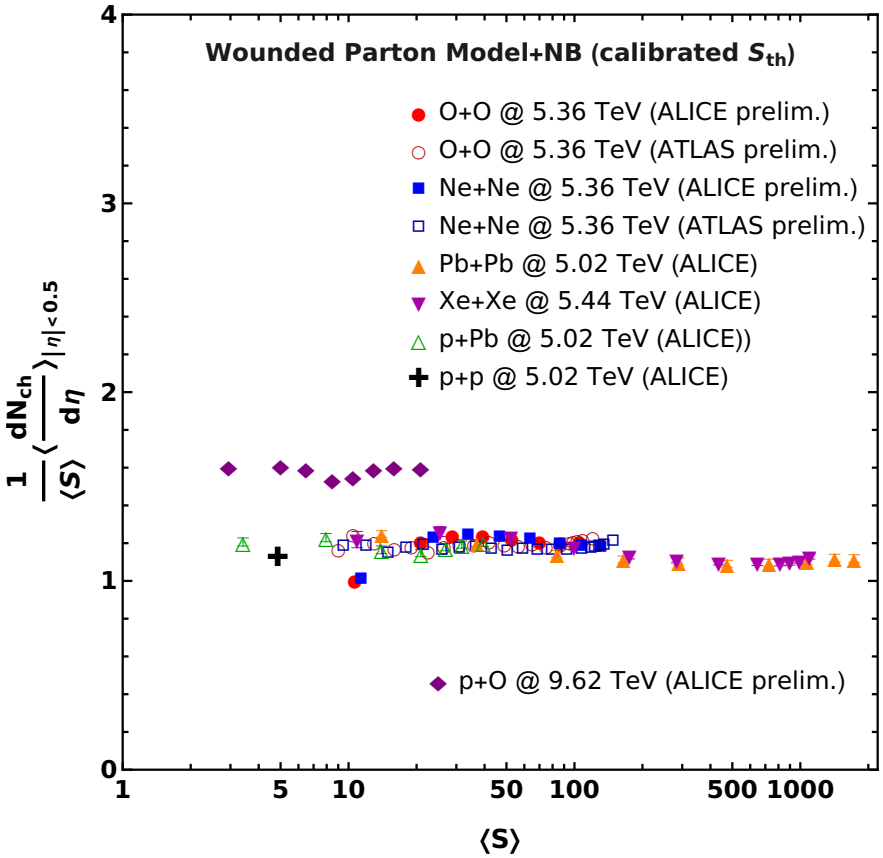
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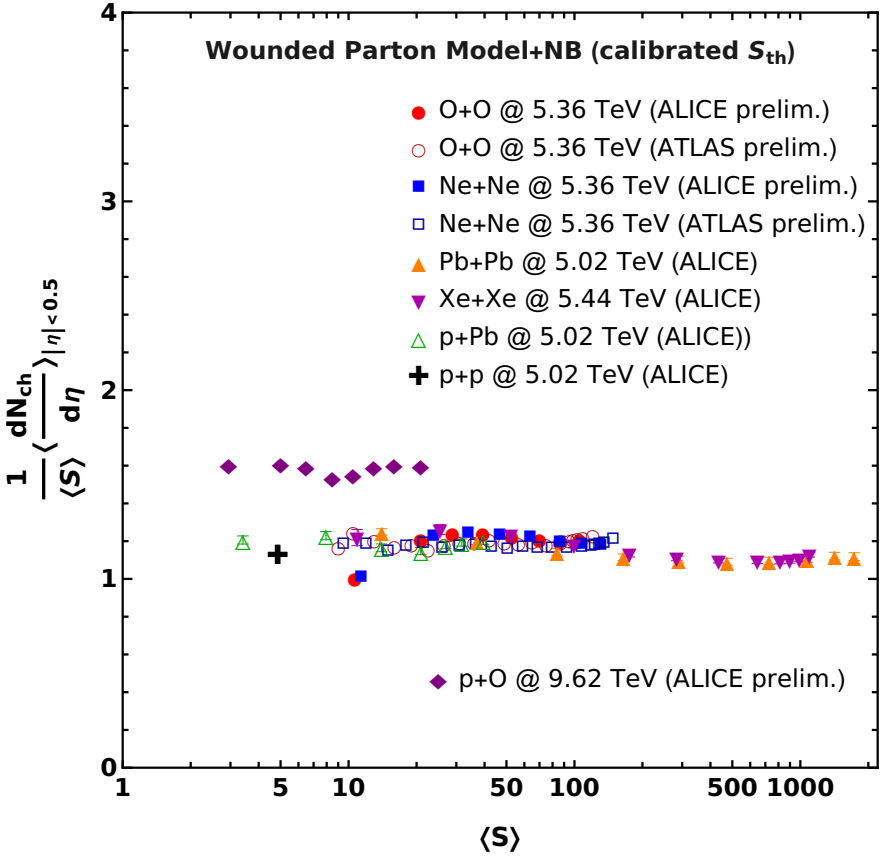
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- **A perfect scaling can be achieved by calibrating** S_{th} **!!**
- **But there is no physical reason to calibrate** S_{th} **in model !?**

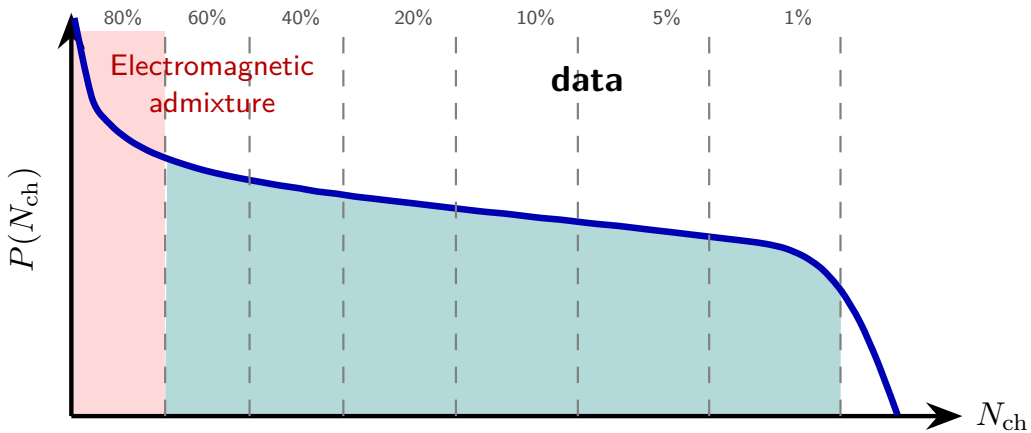


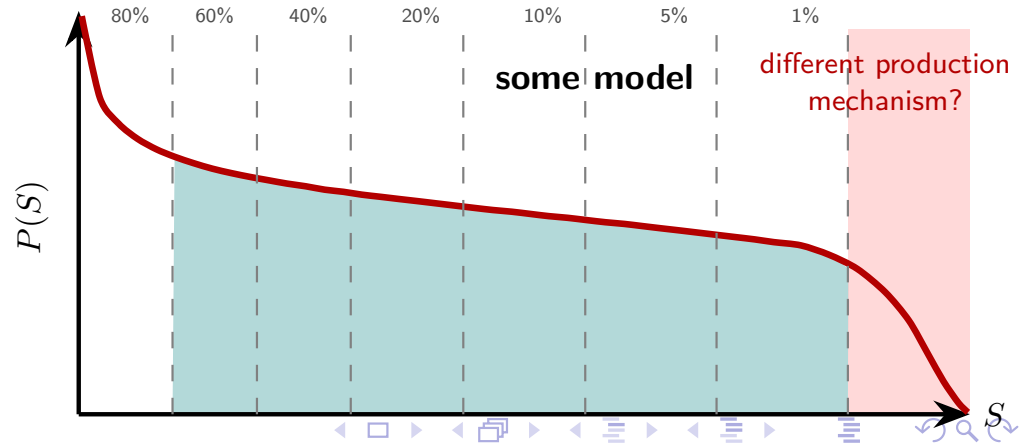
The pivot RS, Bozek, Broniowski, arXiv:2607.16485

Stop matching centrality classes !

Compare directly to the raw, uncorrected $P(N_{\rm ch})$.

- Choose a fiducial window (say, $c = 1 - 80\%$) that avoids both problematic tails.





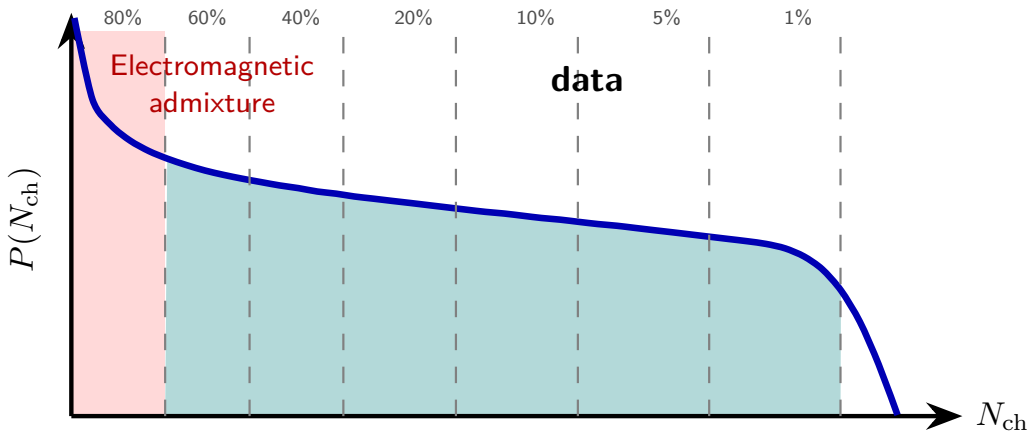
The pivot RS, Bozek, Broniowski, arXiv:2607.16485

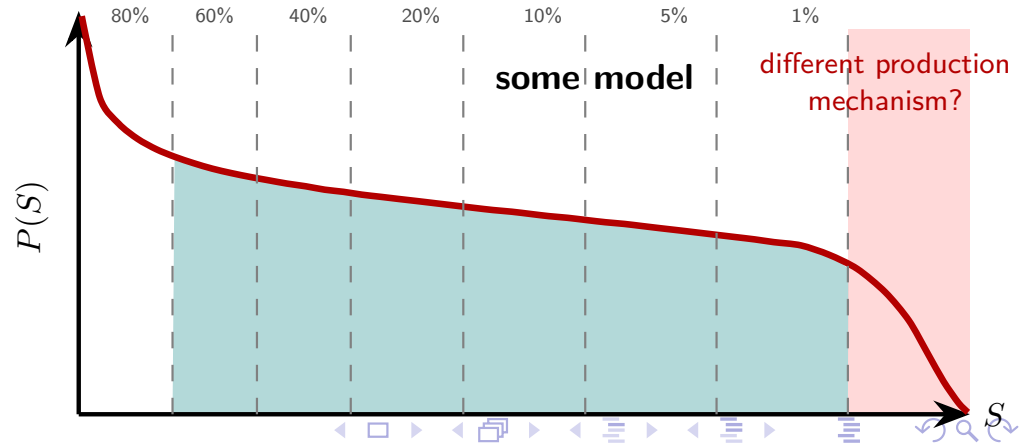
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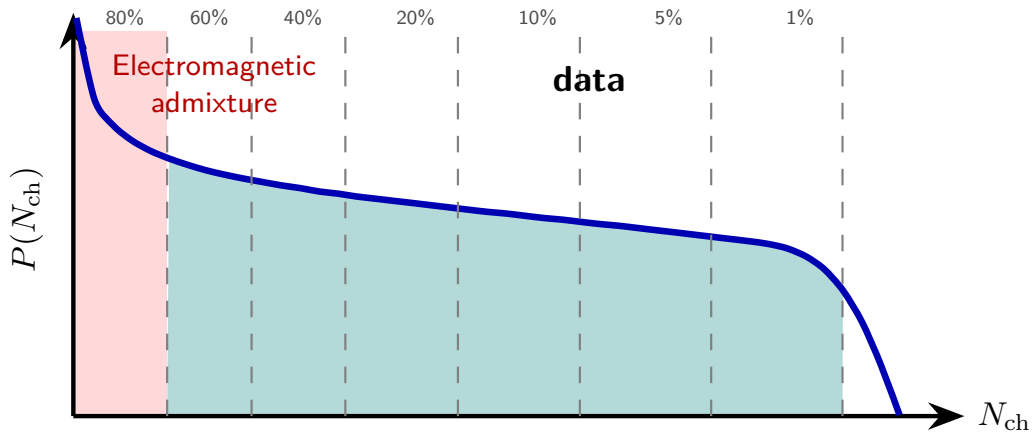
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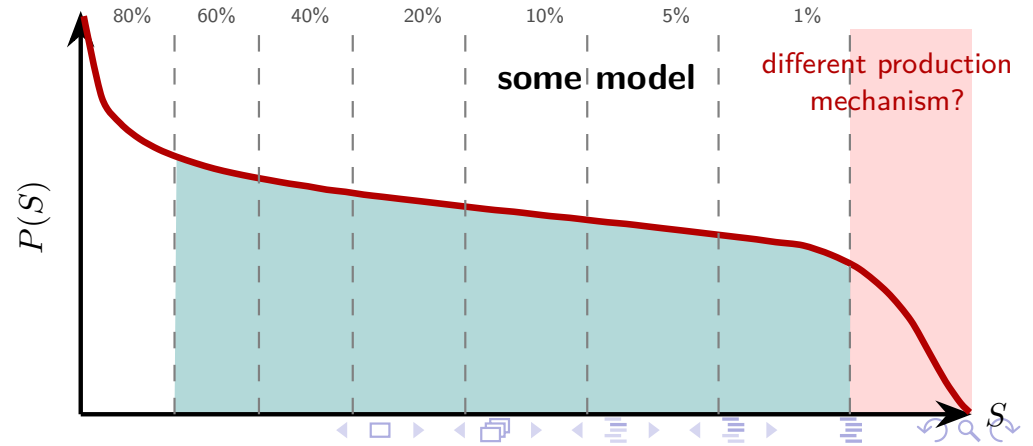
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- Then one can perform χ^2-like fit using :

$$P_{AA}^{\rm data}(N_{\rm ch}) \propto P_{AA}^{\rm mod}\left(\frac{N_{\rm ch}}{\beta}\right)$$





Fitting method: raw histograms, one global fit for all
Four systems: Pb+Pb , Xe+Xe, Ne+Ne, O+O $\sim$ 5 TeV

RS, Bozek, Broniowski, arXiv:2607.16485

- Fit the raw ATLAS $P(N_{\rm ch})$ histograms directly, over N_i between $c = 1\%$ and 80%:

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- Global χ^2-like fit across four systems (6 shared parameters):

$$\chi^2(\beta, \{\gamma_{AA}\}, \kappa) = \sum_{AA}\sum_{i} \frac{\left[P_{AA}^{\rm data}(N_i) - \frac{\gamma_{AA}}{\beta} P_{AA}^{\rm mod}(N_i/\beta)\right]^2}{\sigma_{i,\rm data}^2 + \sigma_{i,\rm mod}^2}$$

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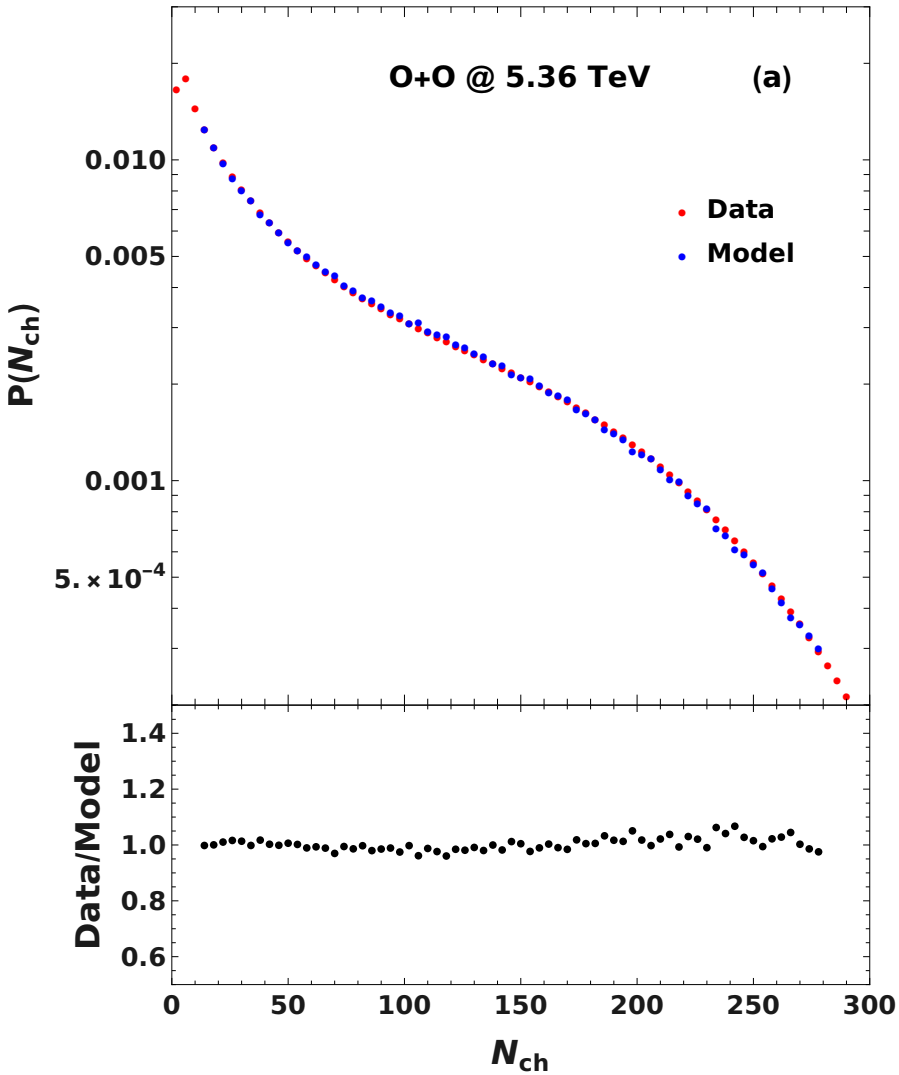
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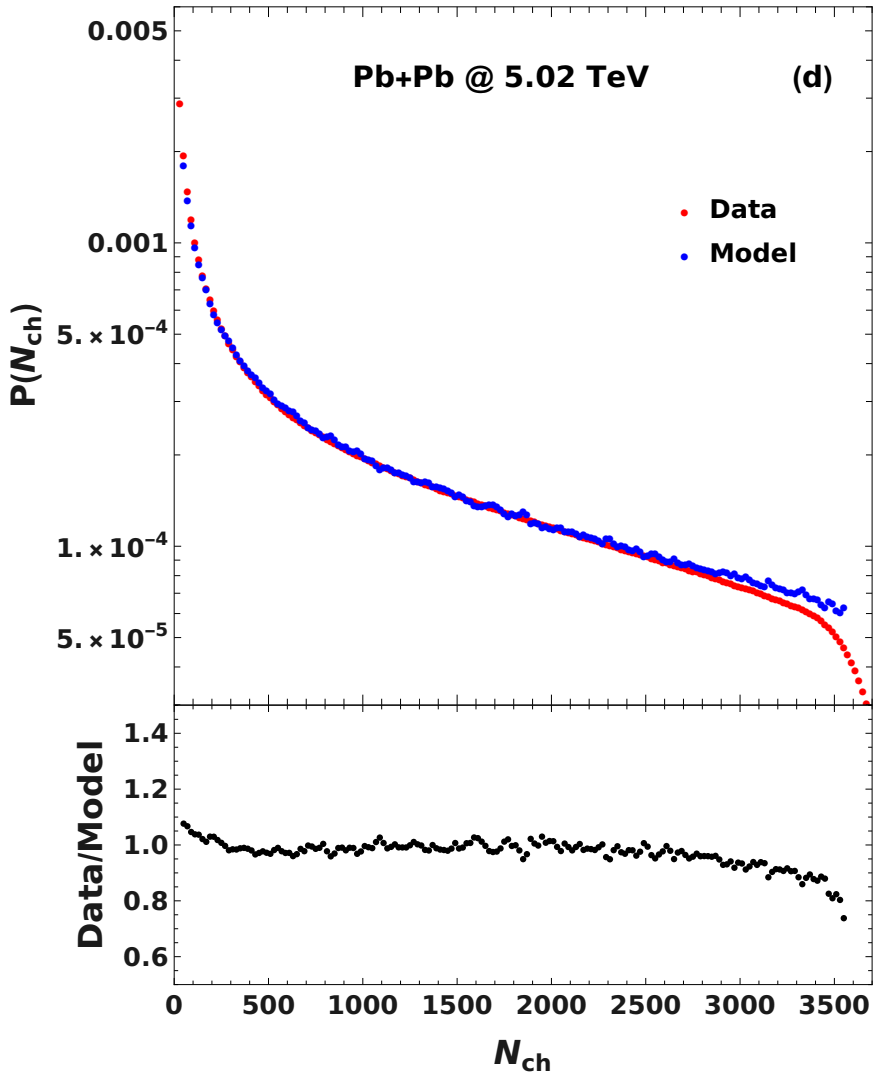
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- **Universality: the same N_p, κ, β, fixed once, for every system and every centrality**

Result : Fitted multiplicity distributions

RS, Bozek, Broniowski, arXiv:2607.16485

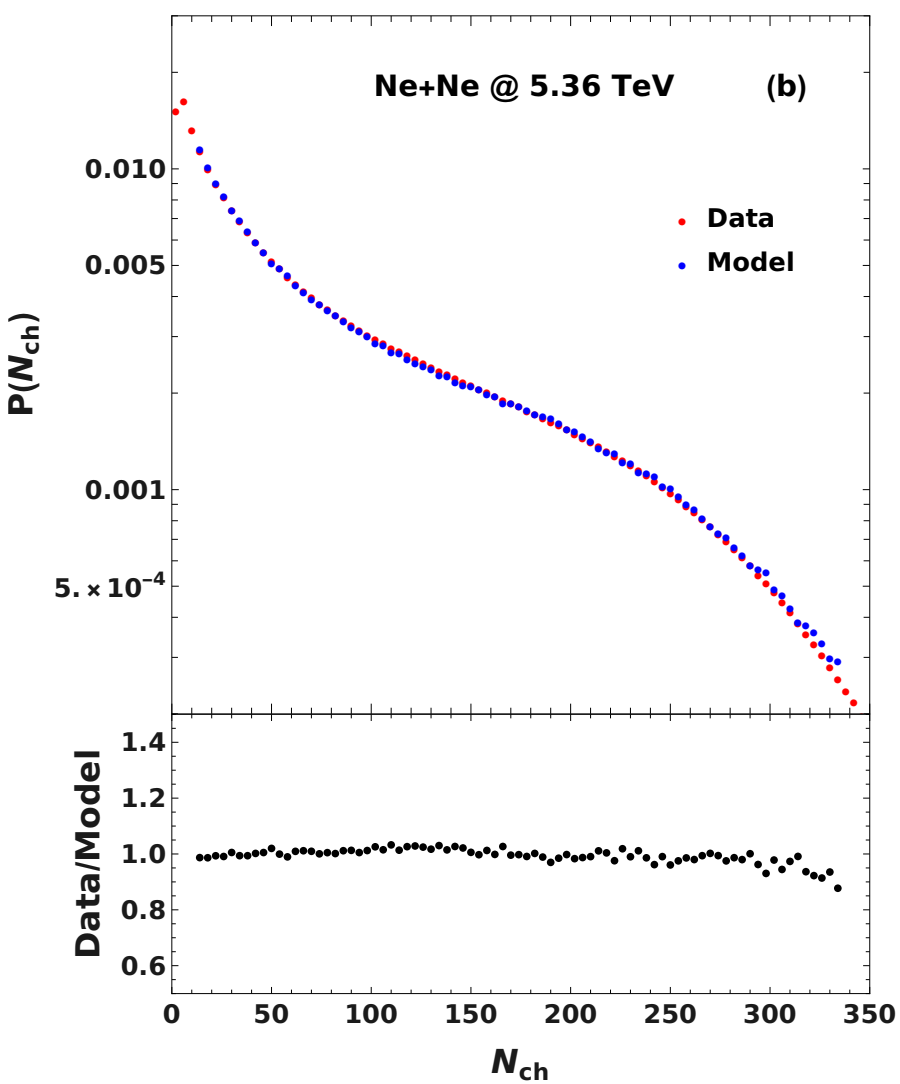


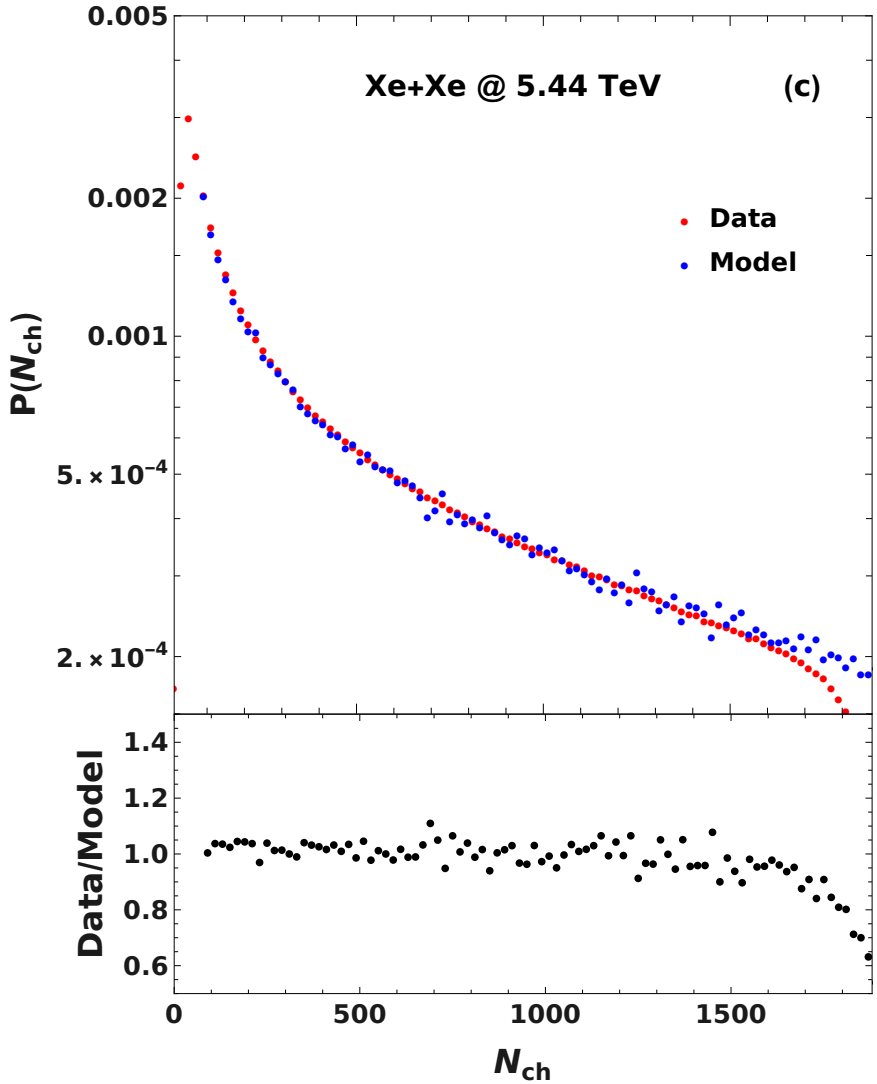


Data: ATLAS (2026), arXiv: 2509.05171

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RS, Bozek, Broniowski, arXiv:2607.16485

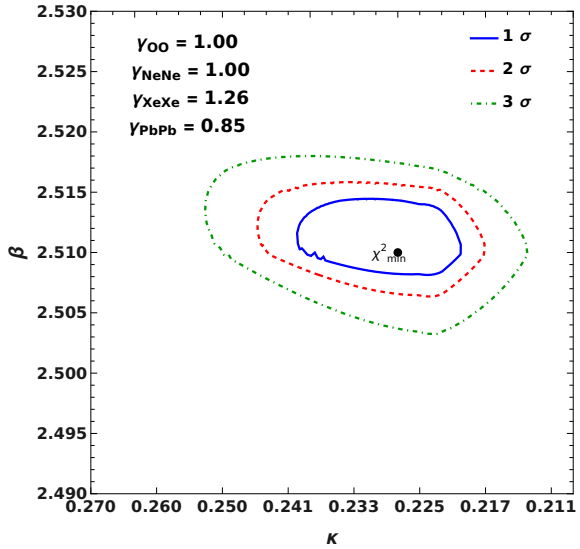


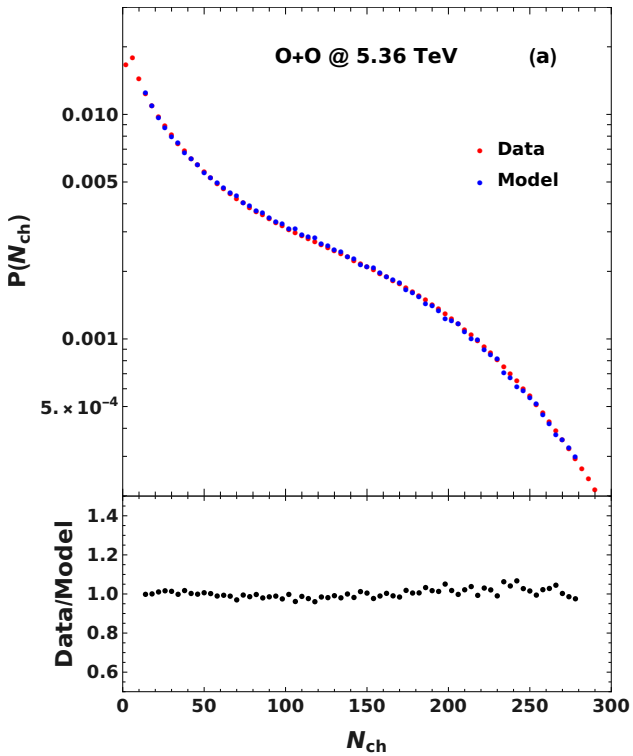


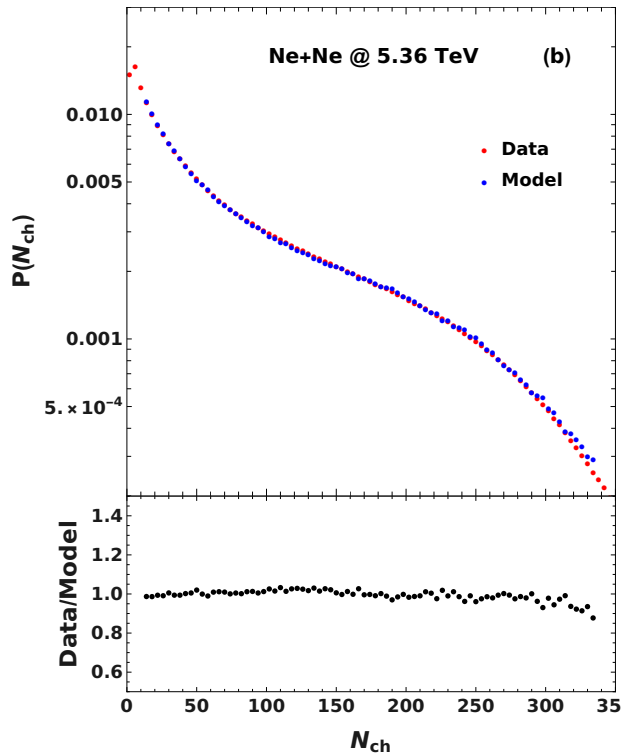
Data: ATLAS (2023), arXiv: 2205.00039

Fit results

- Best fit: $N_p = 4$, $\beta = 2.51$, $\kappa = 0.23$, $\chi^2/\mathrm{DOF} = 0.86$

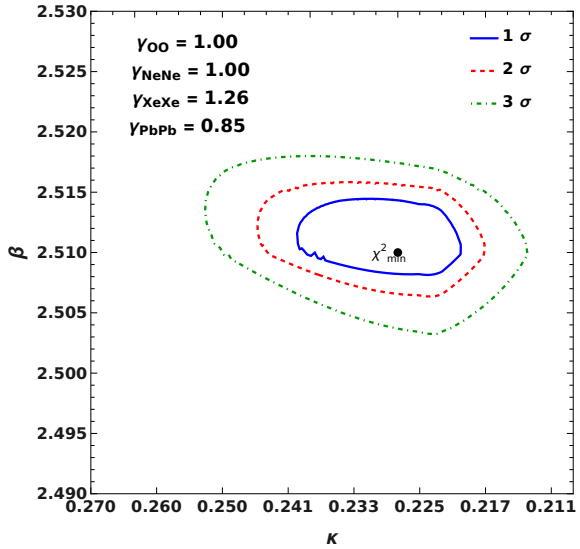


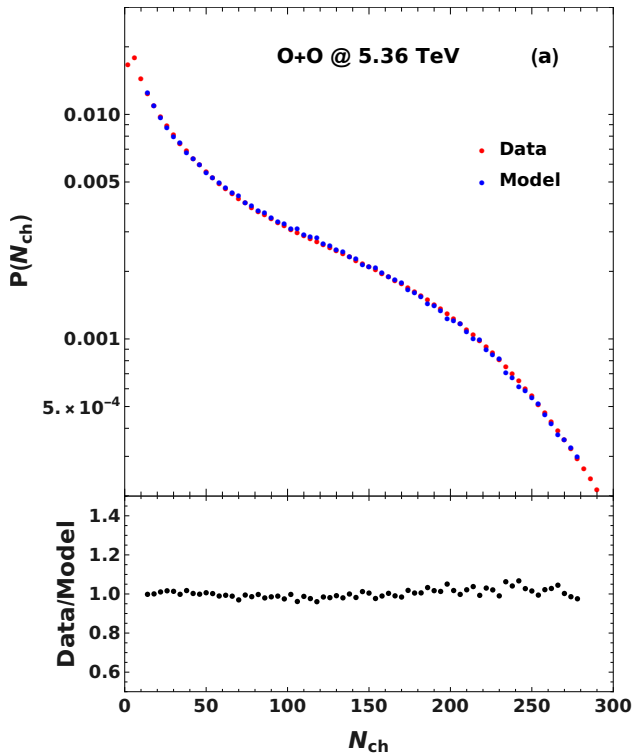


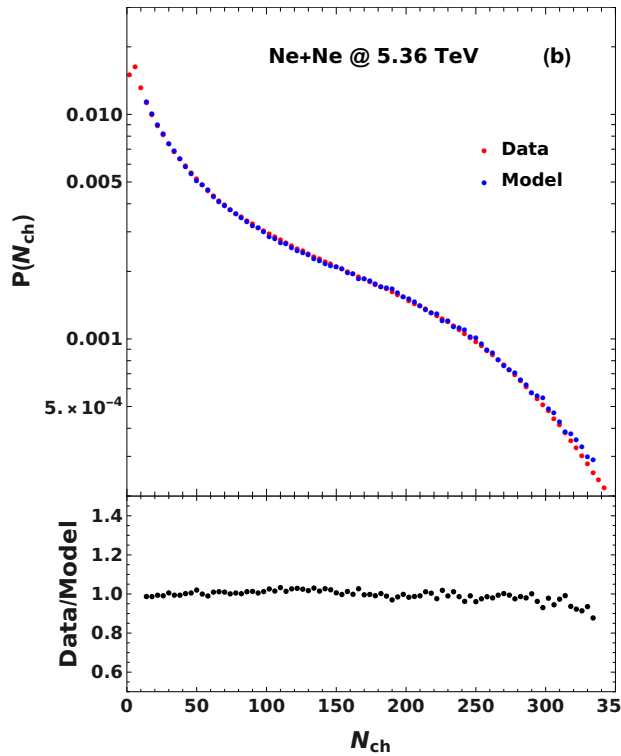


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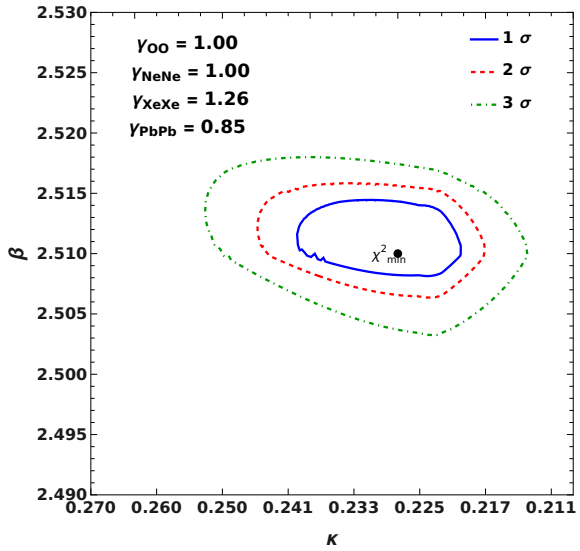


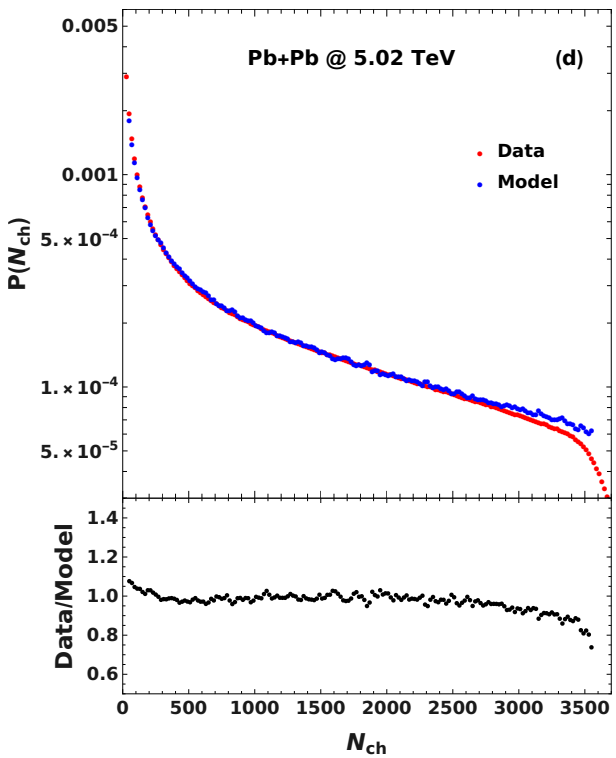


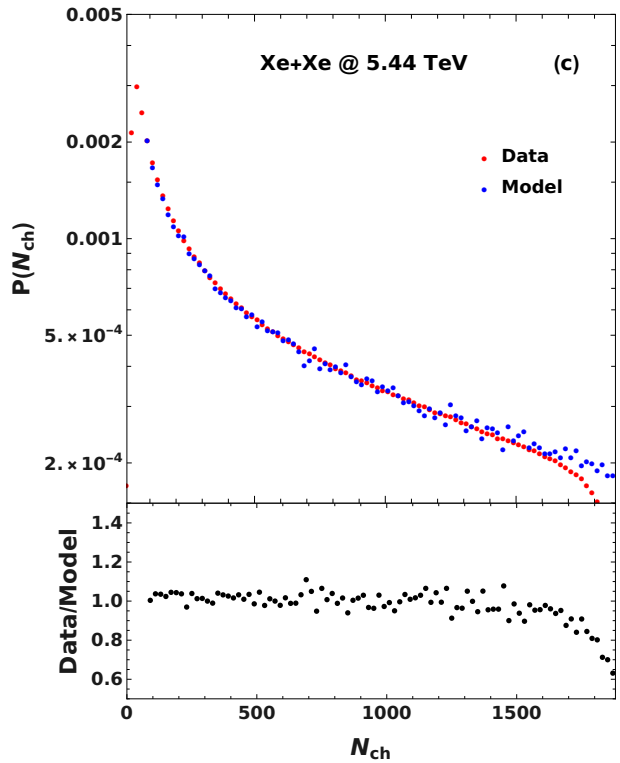


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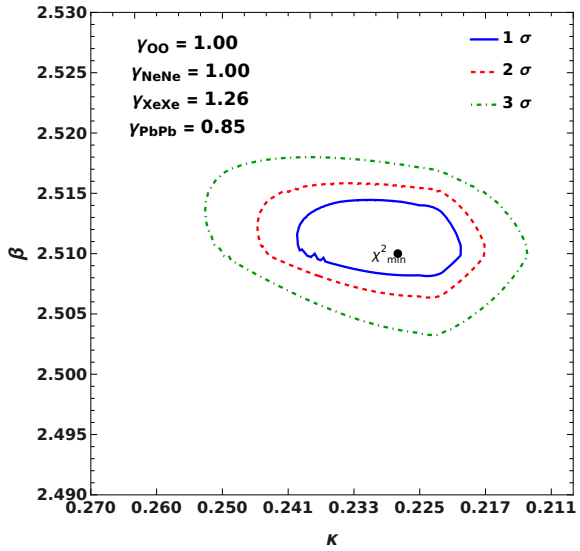


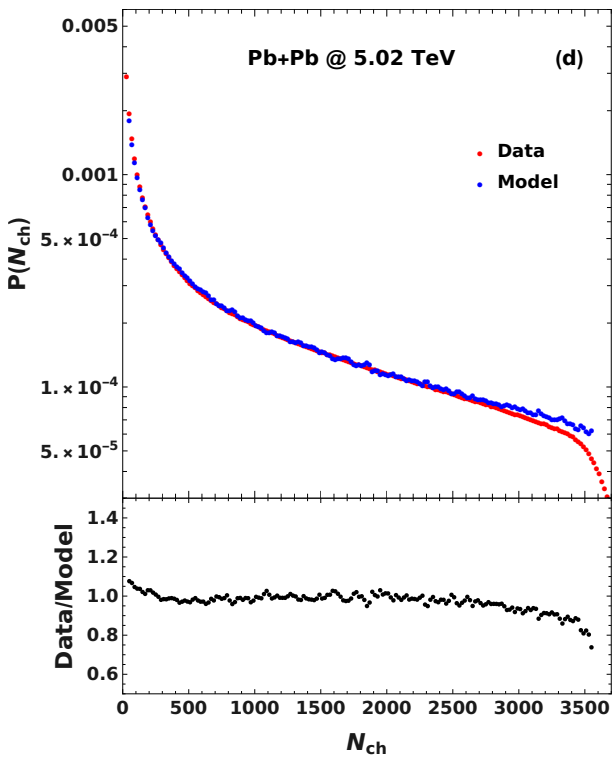


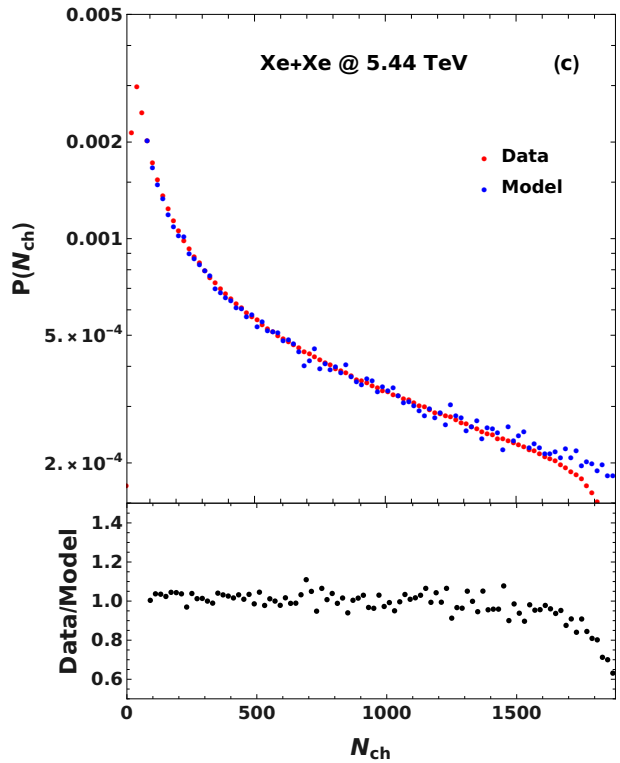


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- **WPM+NBD: good model for multiplicity distribution** across system-size.

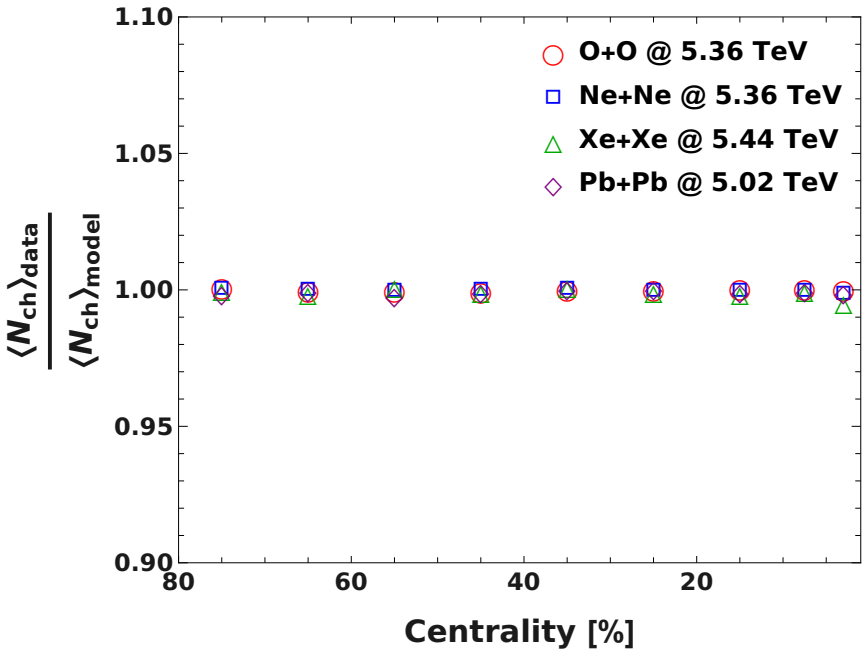






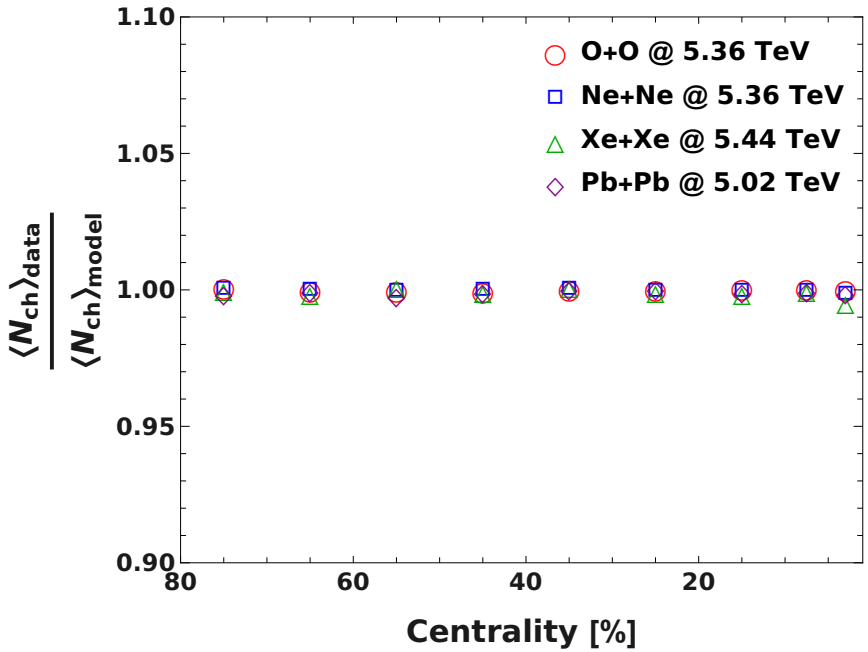
Result: cross-check with $\langle N_{\rm ch} \rangle$

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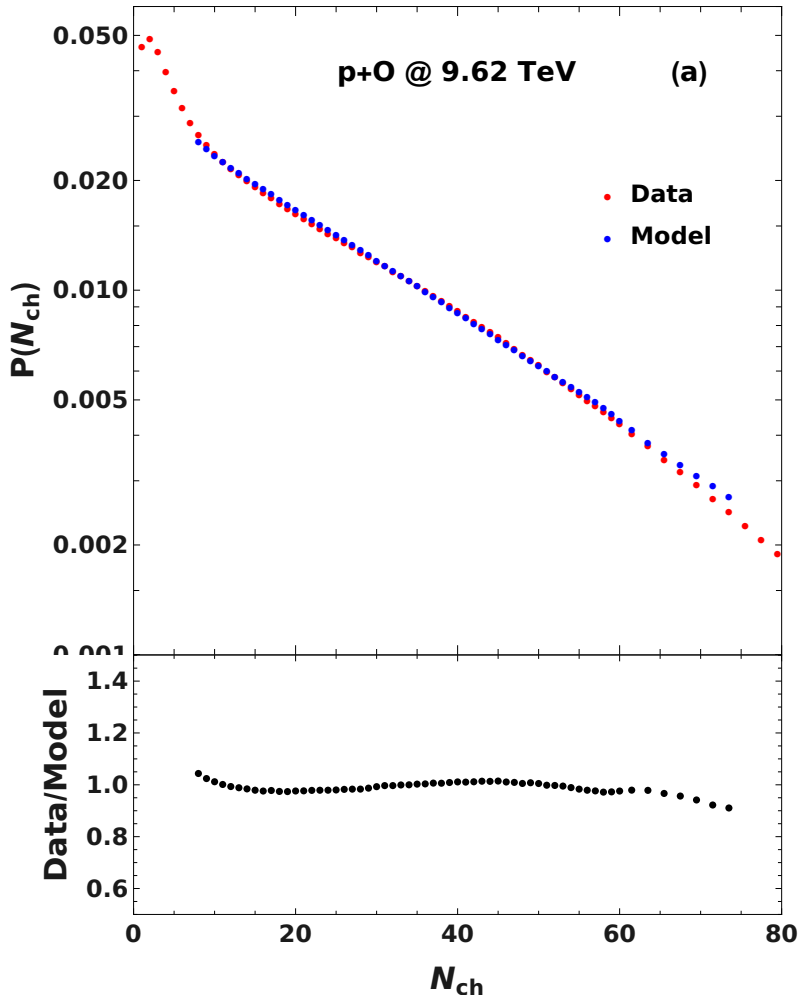
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- **Universality observed: data favours Wounded-Parton picture**



Check with $p + O$ @ 9.62 TeV

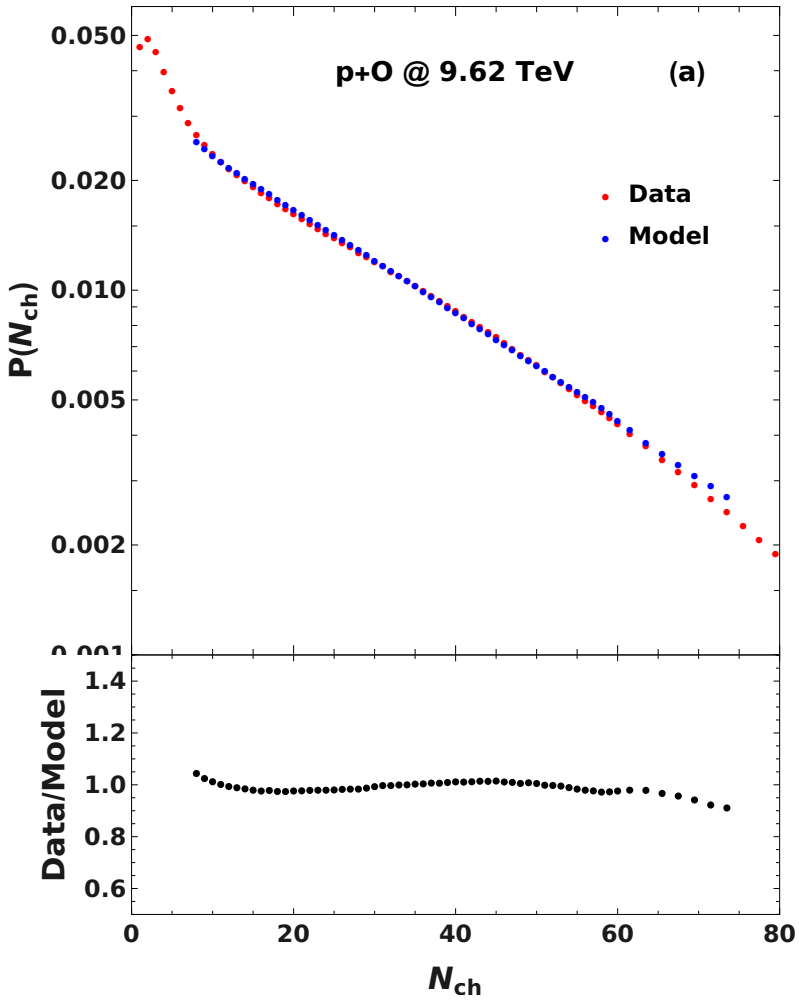
- Fit results with $N_p = 4$:
  $\beta = 3.74, \kappa = 0.181, \gamma_{pO} = 0.95$
  smaller correction for pO.



Data: ATLAS (2026), arXiv: 2604.05512

Check with $p + O$ @ 9.62 TeV

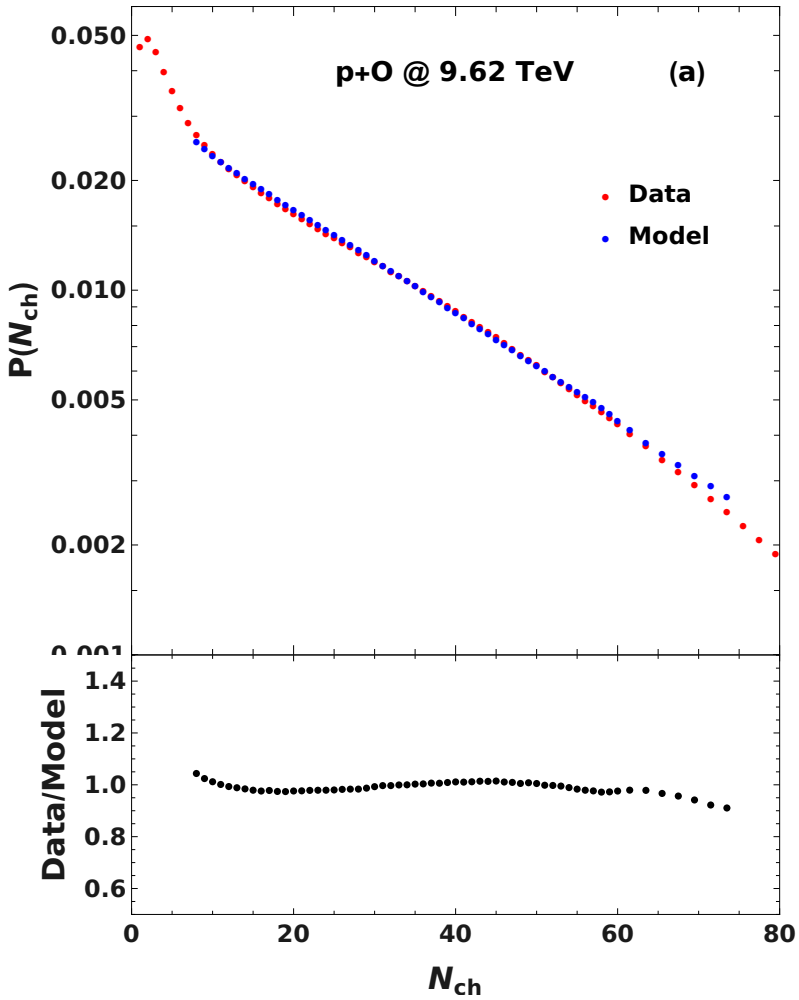
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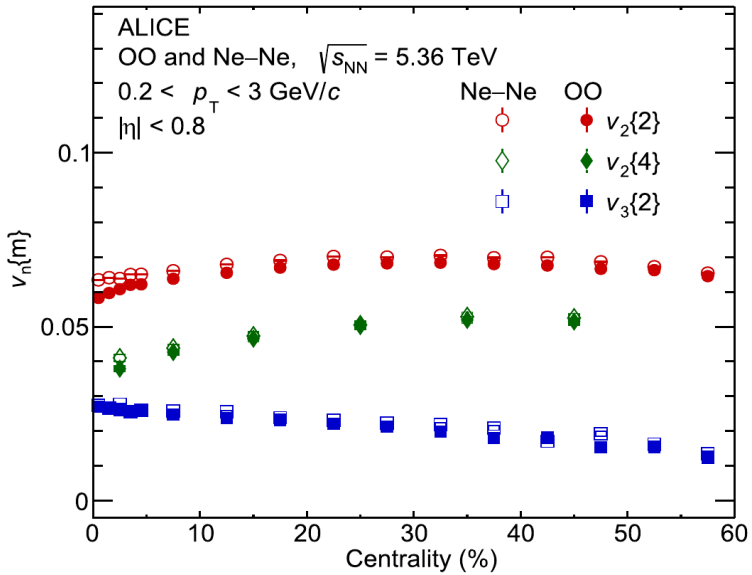


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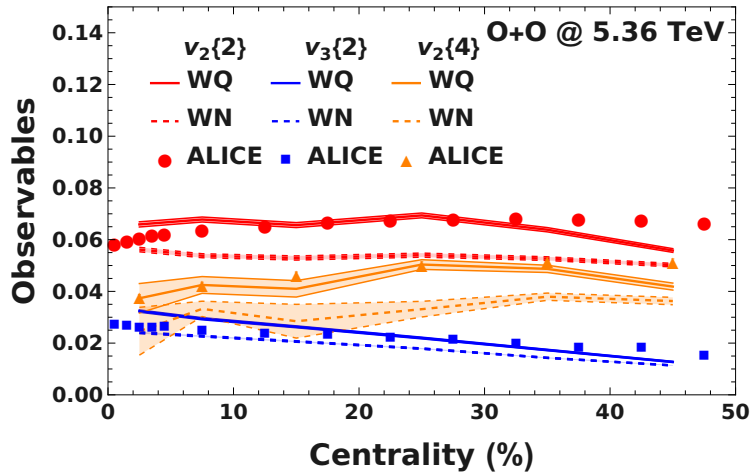


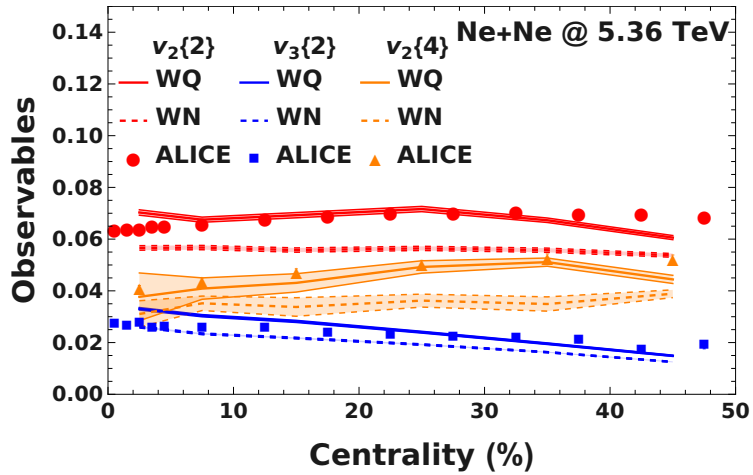
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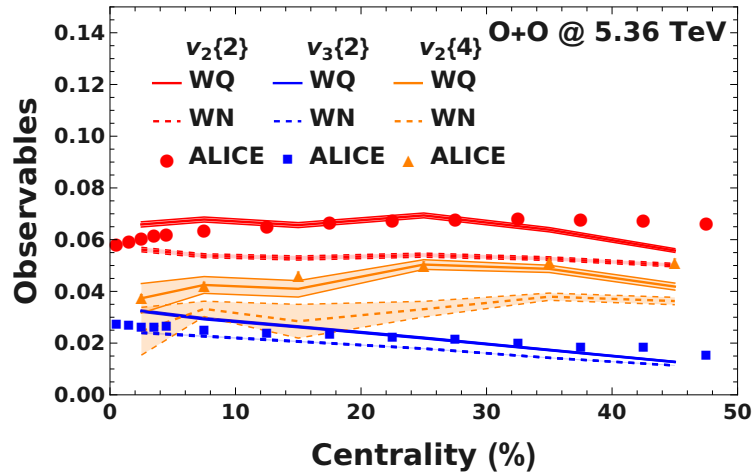


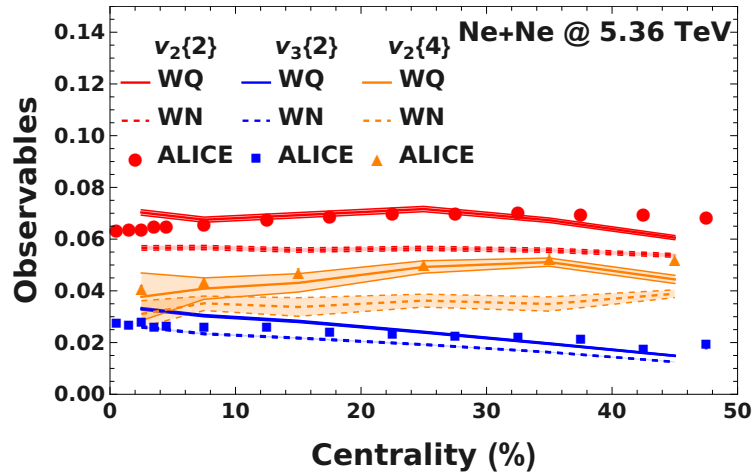
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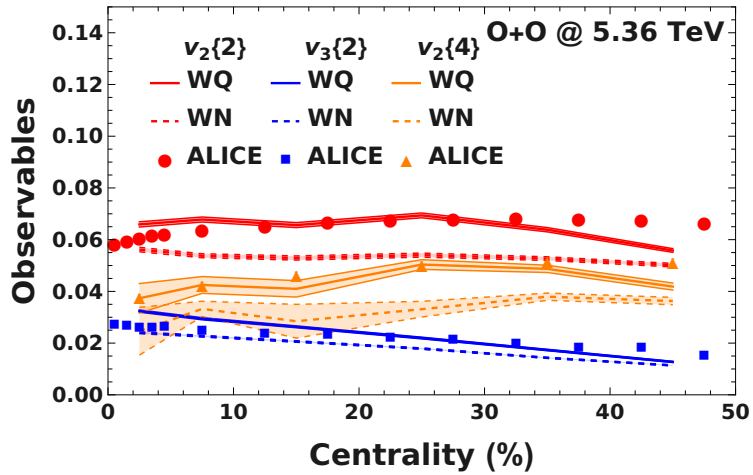


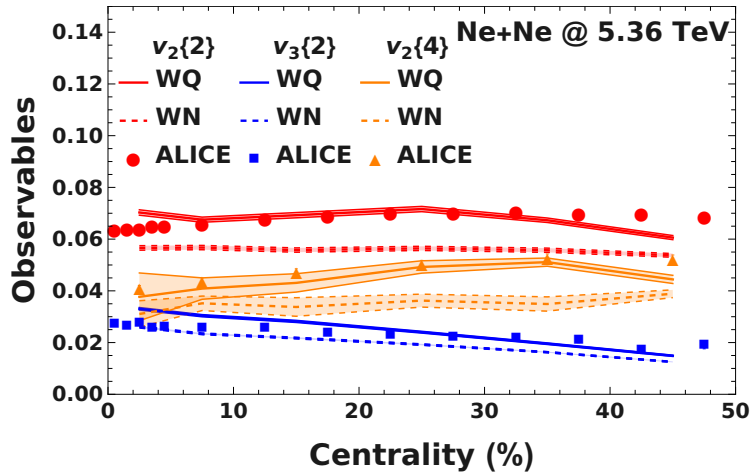
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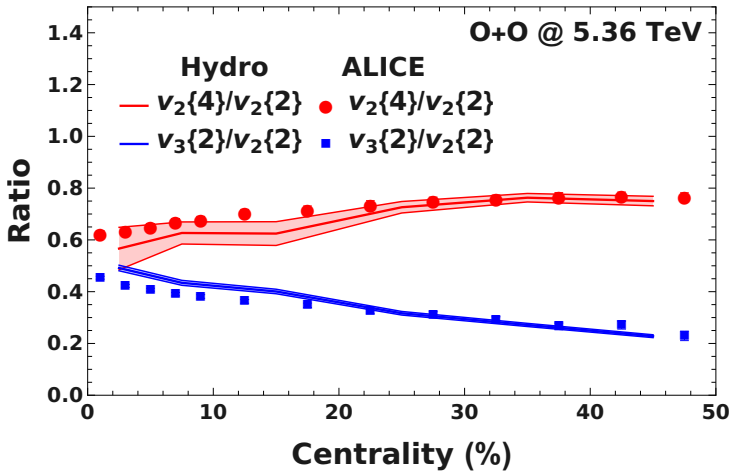


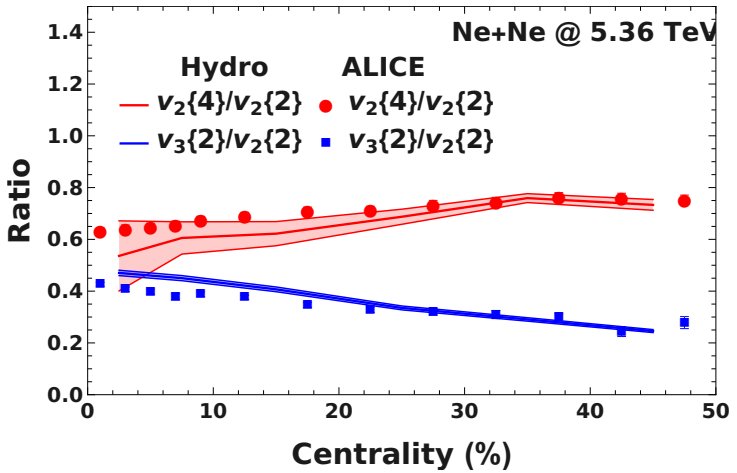
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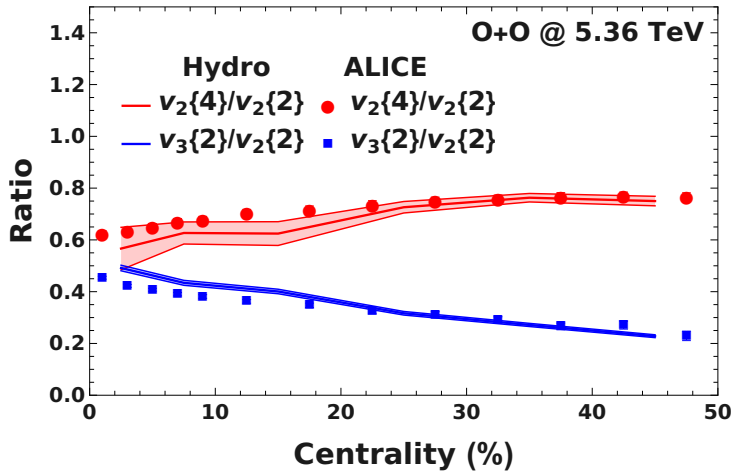


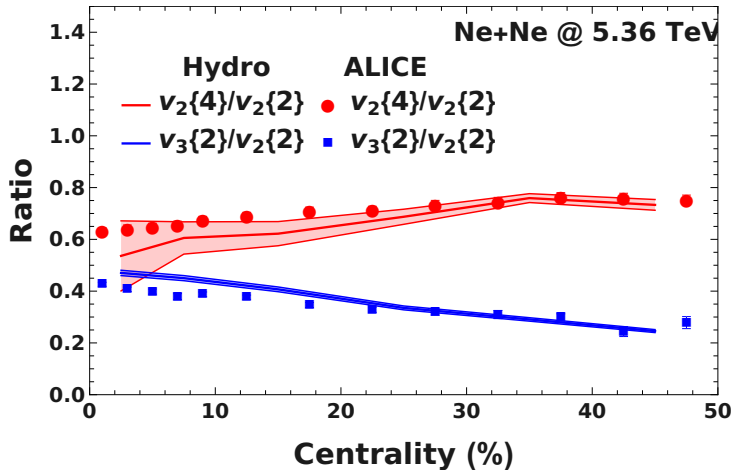
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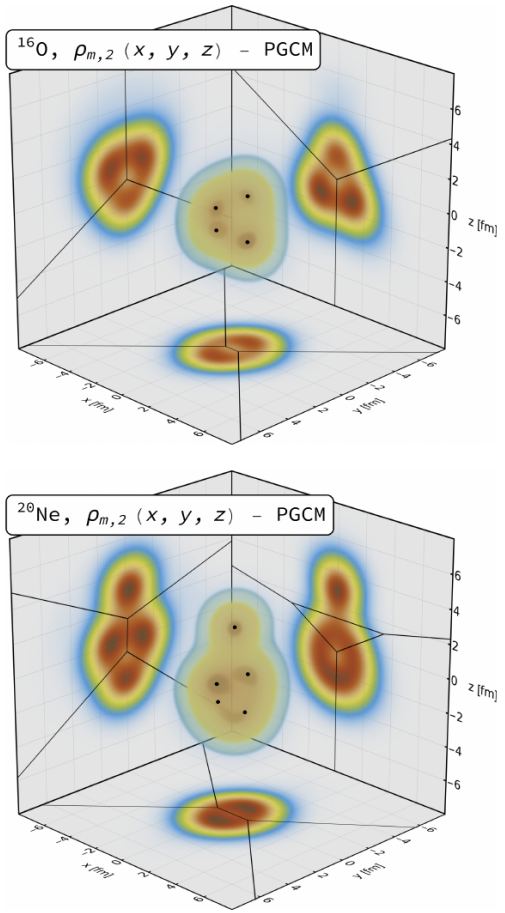
PRELIMINARY

Different initial conditions

- Different nuclear distributions:
  –ab-initio: PGCM, from low-energy calculation
  –Woods-Saxon spherical, deformed

$$\rho(r,\theta) \propto 1/\{1+\exp[\frac{r-R(\theta)}{a}]\}$$

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Giacalone et al. (2024)

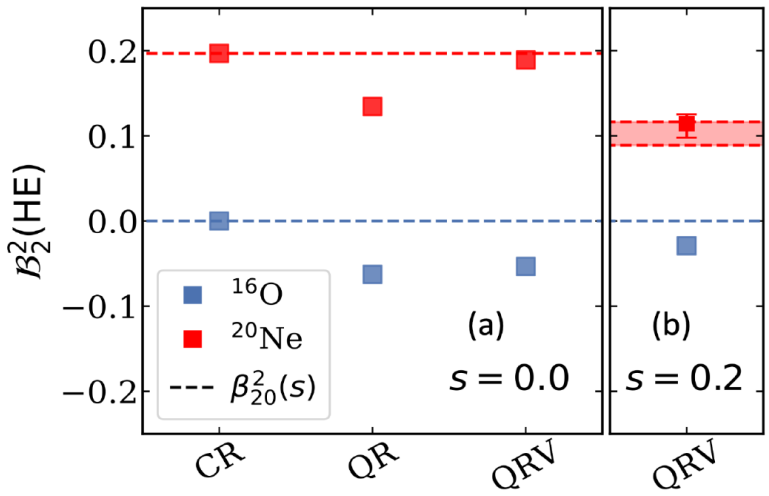
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Ding et al. (2026)

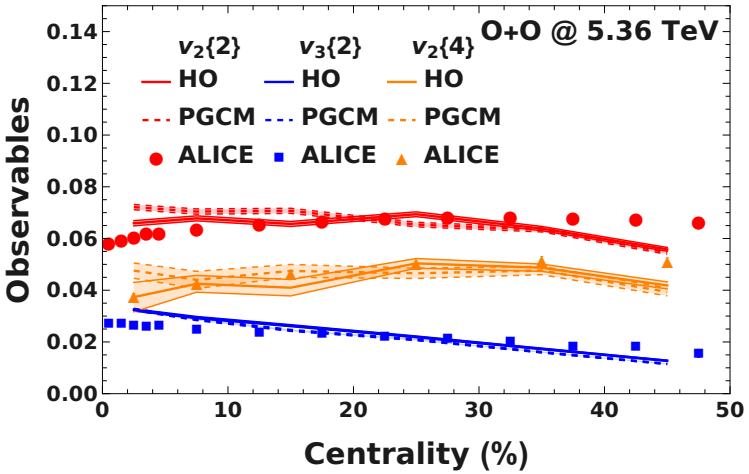
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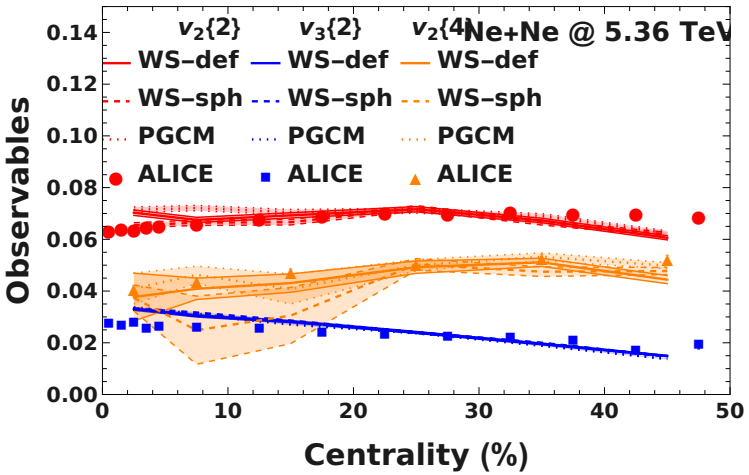
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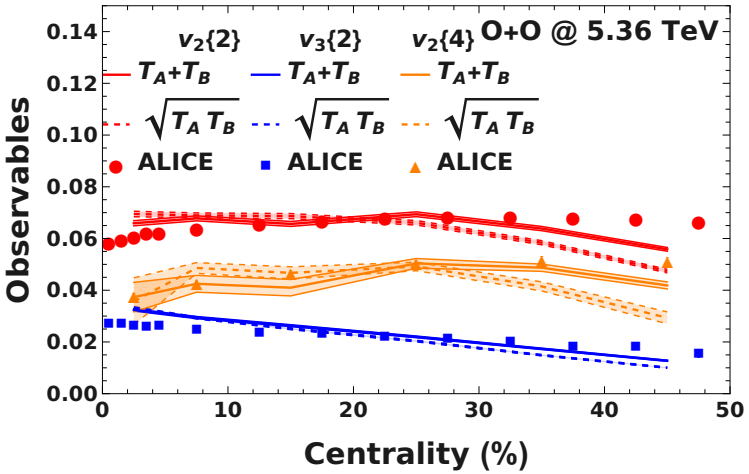
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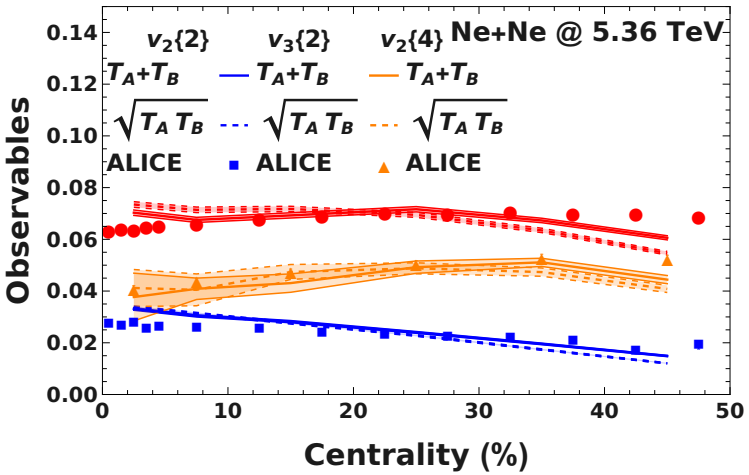
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PRELIMINARY

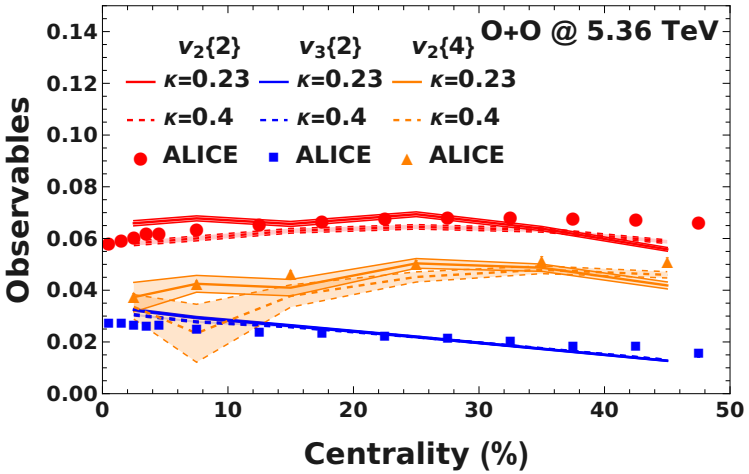
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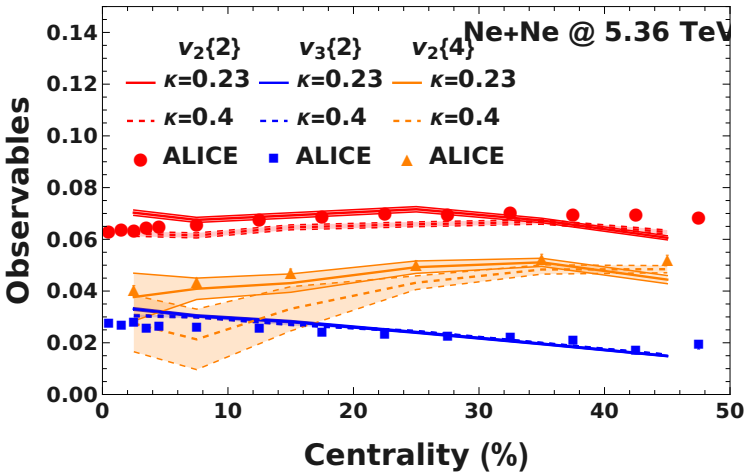
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PRELIMINARY

Model predictions

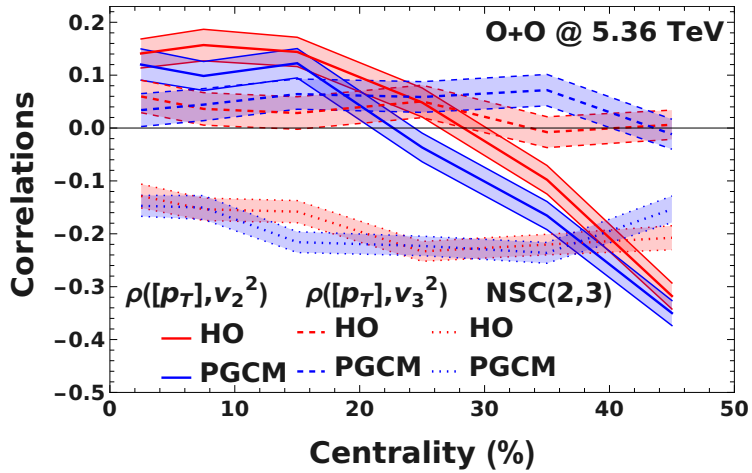
- We provide model predictions for correlation observables:
  1. **Bozek's correlator**:

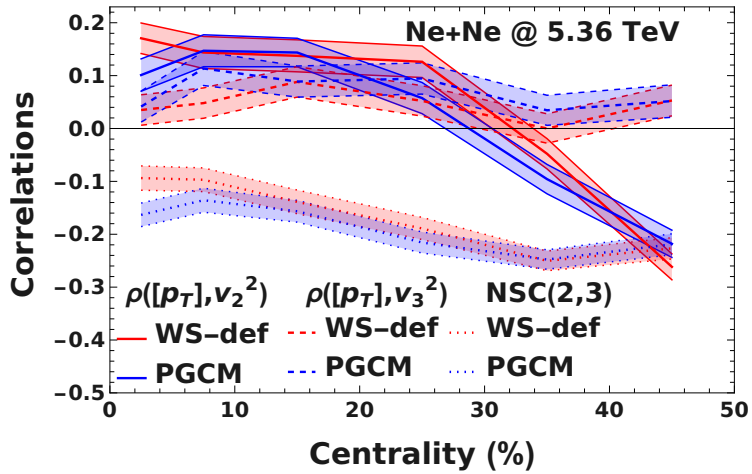
$$\rho([p_T], v_n^2) = \frac{Cov([p_T], v_n^2)}{\sigma_{p_T}\sigma_{v_n^2}}$$

  2. **Normalized symmetric cumulant** :

$$NSC(2,3) = \frac{Cov(v_2^2, v_3^2)}{\langle v_2^2\rangle\langle v_3^2\rangle}$$

- Our prediction could be verified in upcoming experimental data





PRELIMINARY

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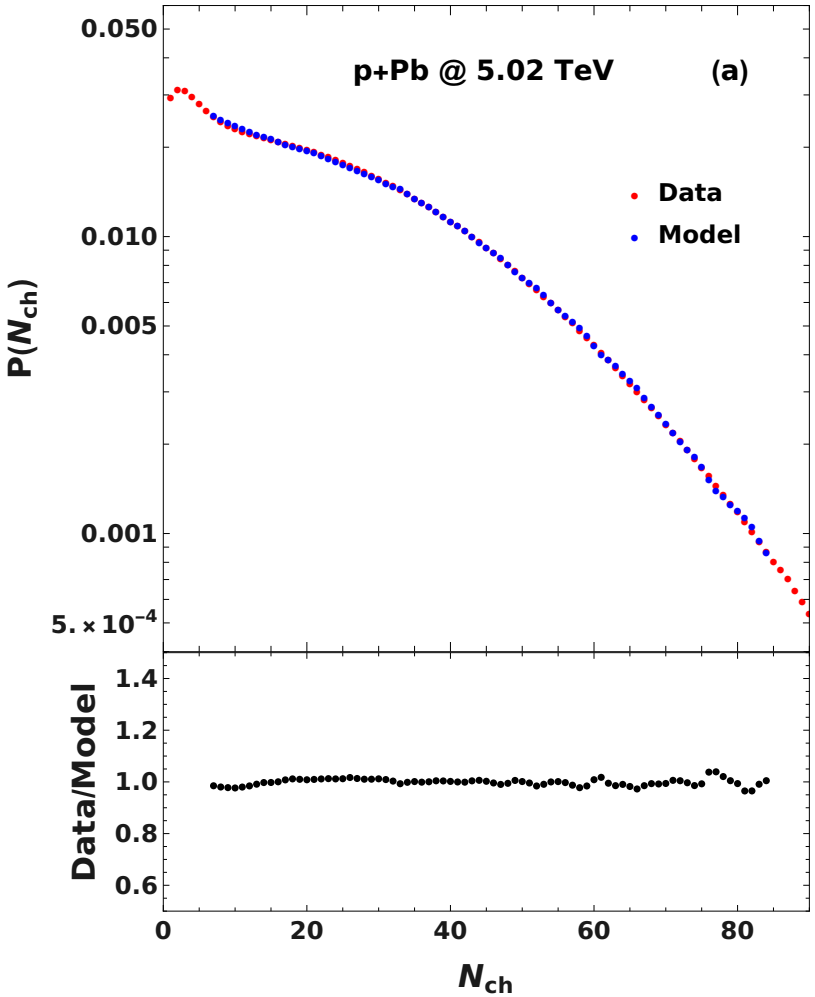
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Thank you !

Backup

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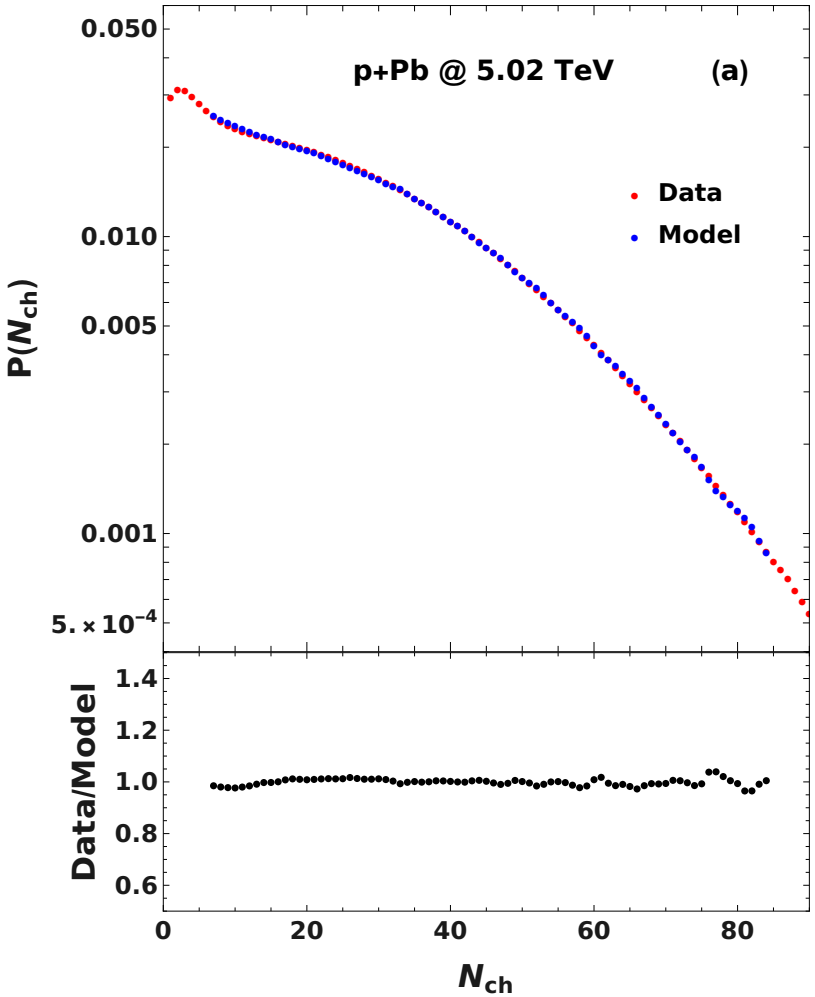
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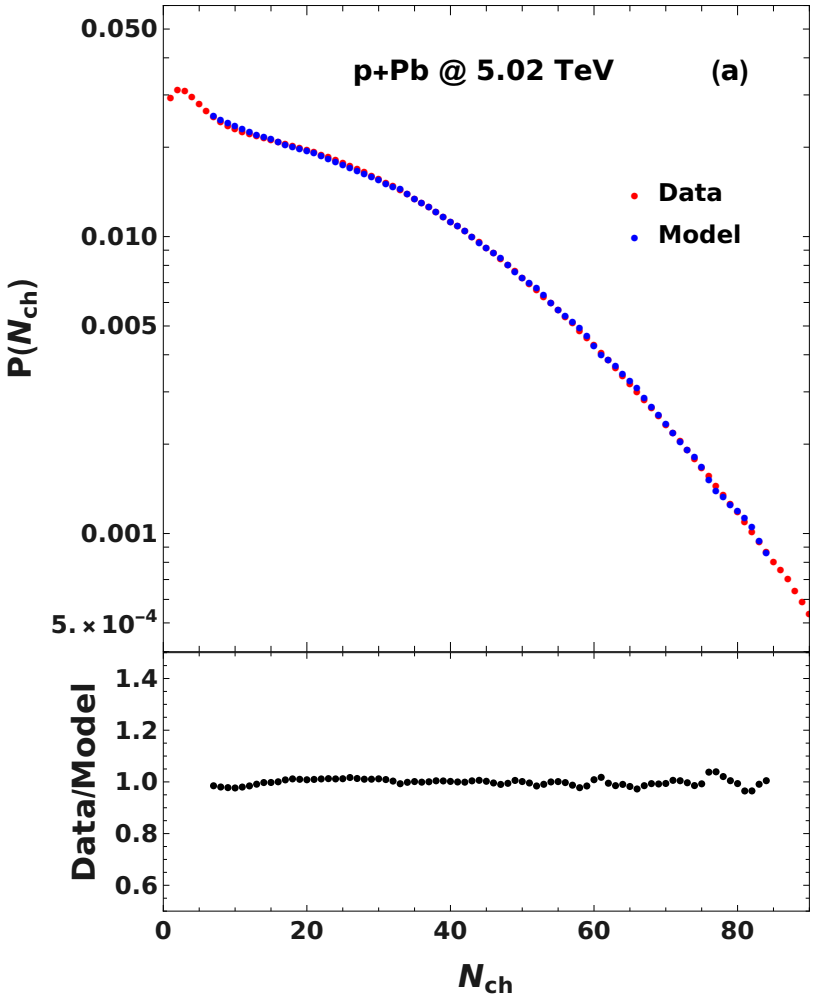
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- WPM works: a joint fit we need data with same kinematic acceptance.



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Choice of N_p: fit quality

- $N_p = 3$ gives worse fit $\longrightarrow$ significantly larger χ^2/DOF
- $N_p = 5$: statistically indistinguishable from $N_p = 4$
  $N_p = 4$: $\chi^2/\mathrm{DOF} = 0.86$ (best)
  $N_p = 5$: only slightly larger χ^2/DOF, consistent with 1, essentially equivalent description

Details

- Both distributions are normalized:

$$\sum_{N_{\rm ch}} P_{AA}^{\rm data}(N_{\rm ch}) = 1, \quad \sum_{S} P_{AA}^{\rm mod}(S) = 1$$

- Parton radial density:

$$\rho(r) \propto r^2 \exp\left[-\frac{3}{2}\left(1-\frac{1}{N_p}\right)\left(\frac{r}{r_0(\sqrt{s};N_p)}\right)^2\right]$$

- r_0, $\sigma_{\rm in}^{qq}$ tuned to the COMPETE pp parametrization Patrignani *et al.* (2016)