Extension of Glauber-like model for Proton-Proton collisions using anisotropic and inhomogeneous density profile

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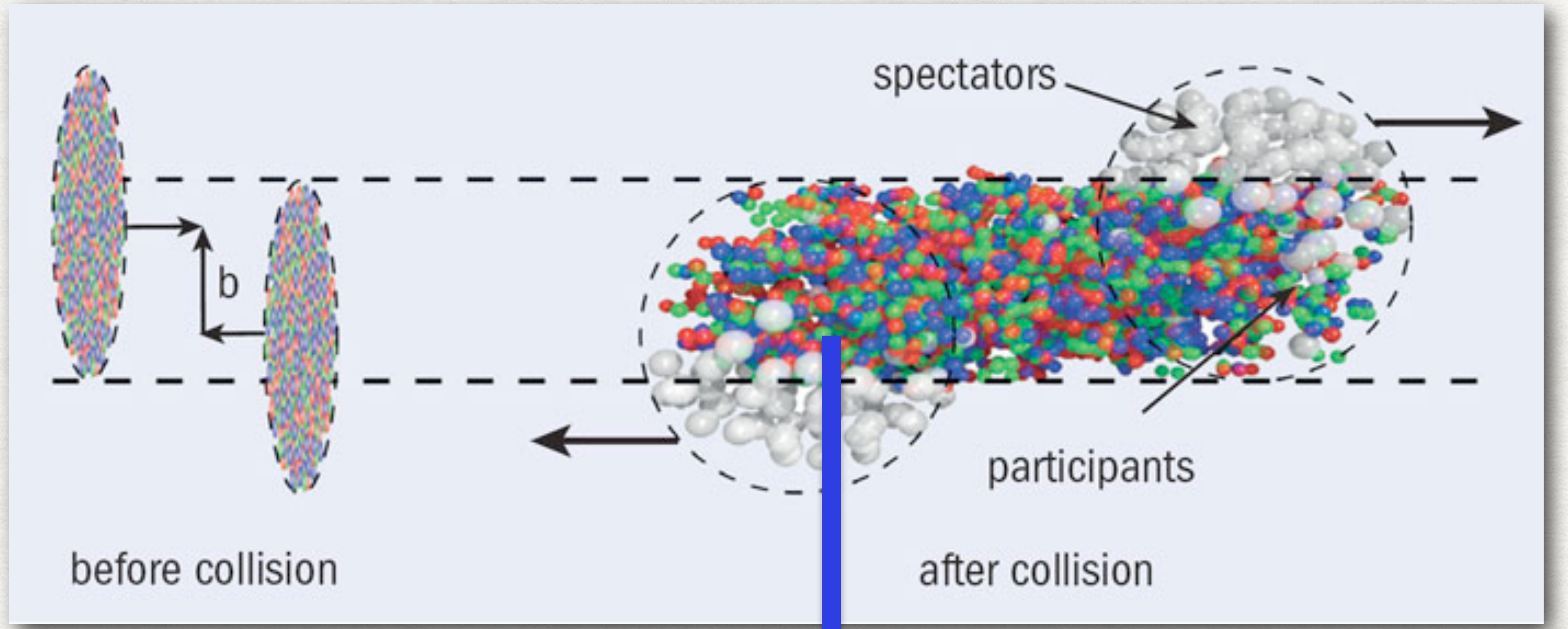
1. Introduction

- Results of relativistic proton proton (pp) collisions are traditionally used as base line for interpreting results of heavy ion collisions at relativistic energies to understand the Physics of Quark-Gluon Plasma (QGP)
- For instance, enhancement of strange hadrons and suppression in the number of J/Ψ in heavy ion collisions with respect to pp are taken as signatures of QGP in such collisions
- For such interpretations, it is assumed that, in pp collisions, no partonic medium is formed
- However recent results of pp collisions like enhancement of Multi-strange Particles and Multi-particle Ridge-like Correlations shows such assumptions may not be correct
- Understanding of pp collisions is crucial for characterization of the QCD medium formed in a heavy ion collision

2. Motivation

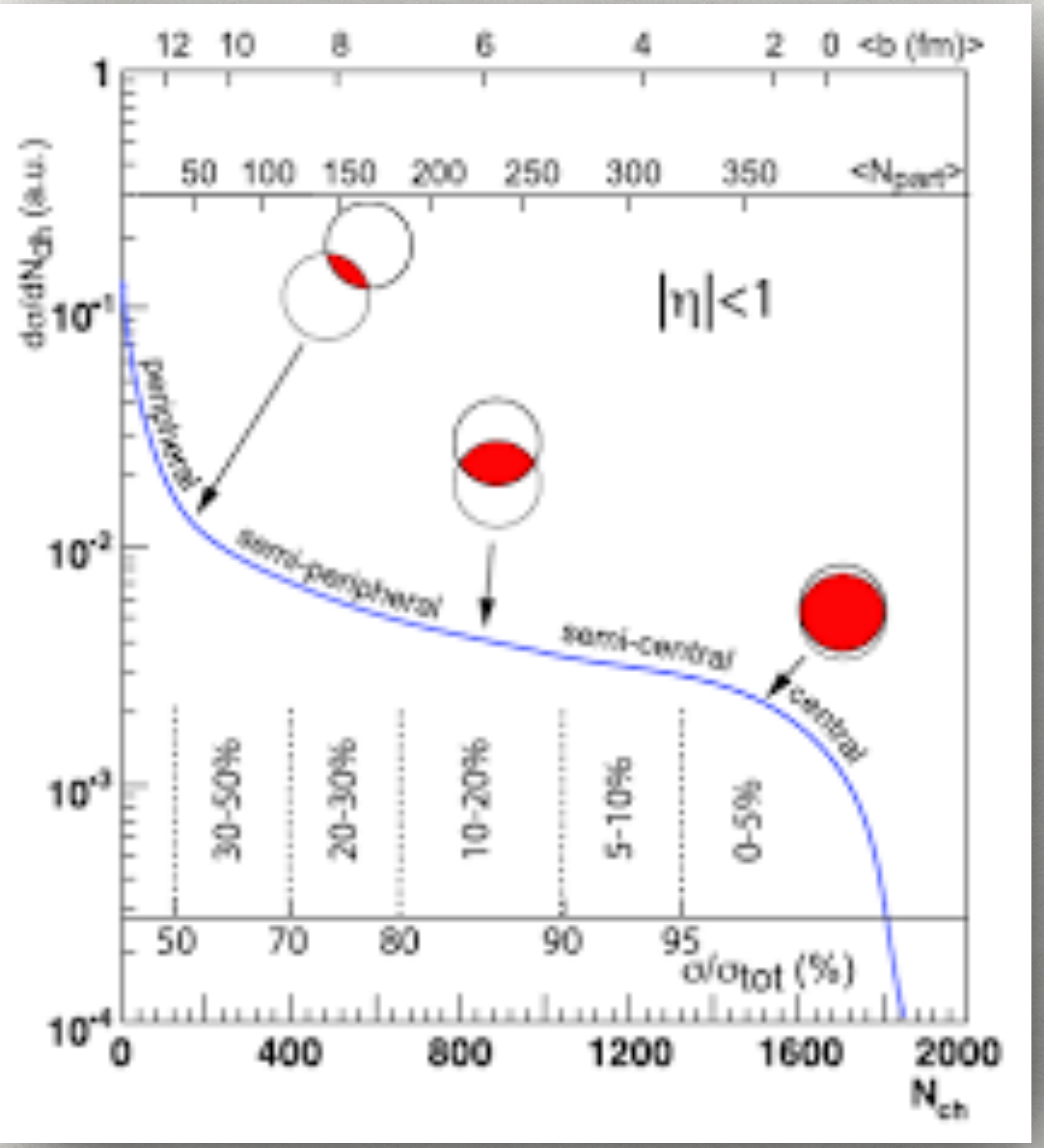
- The interpretation of results in the heavy-ion collisions, relies on models like Glauber model based on initial matter distribution resulting from the overlap of the two colliding nuclei at a given impact parameter (b)
- Thus, it is imperative to understand the initial condition of the medium formed in pp collisions in approximately similar way

3. Formalism: Glauber model for heavy-ion collision-main idea



Two-component model

$$\frac{dN_{ch}}{d\eta} \approx [(1-f)\frac{N_{part}}{2} + fN_{coll}]$$



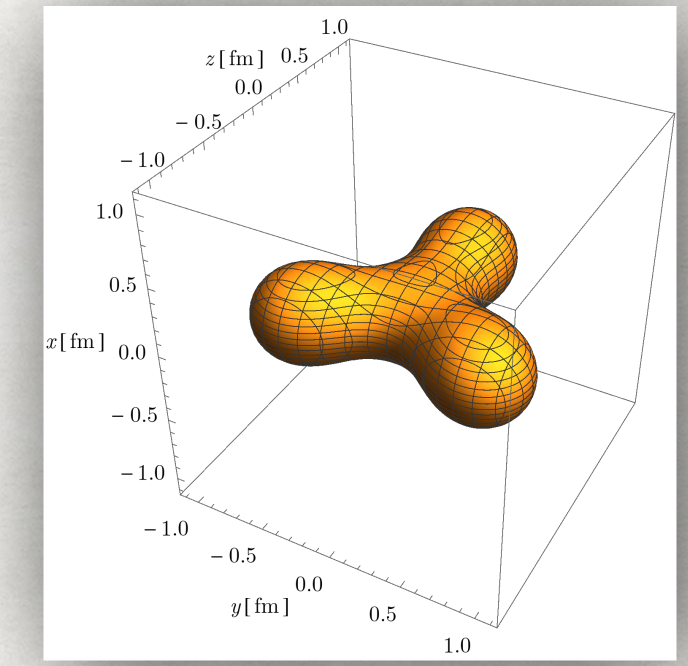
4. Glauber Formalism from pp system

- Azimuthally asymmetric and inhomogeneous density distribution of a proton

$$\rho_{G-f}(\mathbf{r};\mathbf{r}_1,\mathbf{r}_2,\mathbf{r}_3) = N_g\frac{1-\kappa}{3}\sum_{k=1}^{3}\rho_q(\mathbf{r}-\mathbf{r}_k;r_q) + N_g\frac{\kappa}{3}\sum_{k=1}^{3}\rho_g[\mathcal{R}^{-1}[\theta_k,\phi_k](\mathbf{r}-\frac{\mathbf{r}_k}{2};r_q,\frac{r_k}{2}]$$

where, $\rho_q(\mathbf{r};r_q) = \frac{1}{(2\pi)^{3/2}r_q^3}e^{-\frac{r^2}{2r_q^2}}$, $\rho_g(\mathbf{r};r_s,r_l) = \frac{1}{(2\pi)^{3/2}r_s^2 r_l}e^{-\frac{x^2+y^2}{2r_s^2}-\frac{z^2}{2r_l^2}}$

$\mathcal{R}[\theta,\phi]$ transform vector (0,0,1) to $(cos\phi sin\theta, sin\phi cos\theta, cos\theta)$



- Thickness function: $T(x,y) = \int \rho(x,y,z)dz$

- Overlap function:

$$T_{pp}(b) = \int\int T_A(x-\frac{b}{2},y)T_B(x+\frac{b}{2},y)dxdy$$

- Different orientation of three quarks within proton are considered

$$\mathbf{r}_1 = (\tfrac{d}{2}\cos(\tfrac{\pi}{3}+\psi), \tfrac{d}{2}\sin(\tfrac{\pi}{3}+\psi)\cos\alpha, -\tfrac{d}{2}\sin(\tfrac{\pi}{3}+\psi)\sin\alpha),$$
$$\mathbf{r}_2 = (\tfrac{d}{2}\cos(\tfrac{5\pi}{3}+\psi), \tfrac{d}{2}\sin(\tfrac{5\pi}{3}+\psi)\cos\alpha, -\tfrac{d}{2}(\sin\tfrac{\pi}{3}+\psi)\sin\alpha),$$
and $\mathbf{r}_3 = (\tfrac{d}{2}\cos(\psi), \tfrac{d}{2}\sin\psi\cos\alpha, -\tfrac{d}{2}\sin\psi\sin\alpha),$

Generalised Configuration considering the tilt Ψ along the x -axis and rotation by the angle α

5. Testing model

- The model here provides number of participant (N_{part}) and Number of binary collisions (N_{coll}) for an event with a given impact parameter (b)

$$N_{coll}(b) = \sigma_{gg} T_{pp}(b) \ , \ N_{part}(b) \propto N_{coll}^{3/4}(b) \ \text{ and } \ \sigma_{gg} = 4.3 \pm 0.6 \ mb \ \ [1]$$

- In heavy ion collisions, the concept of number of "ancestors" (independently emitting sources of particles) is parametrised in terms of N_{part} and N_{coll} as follows

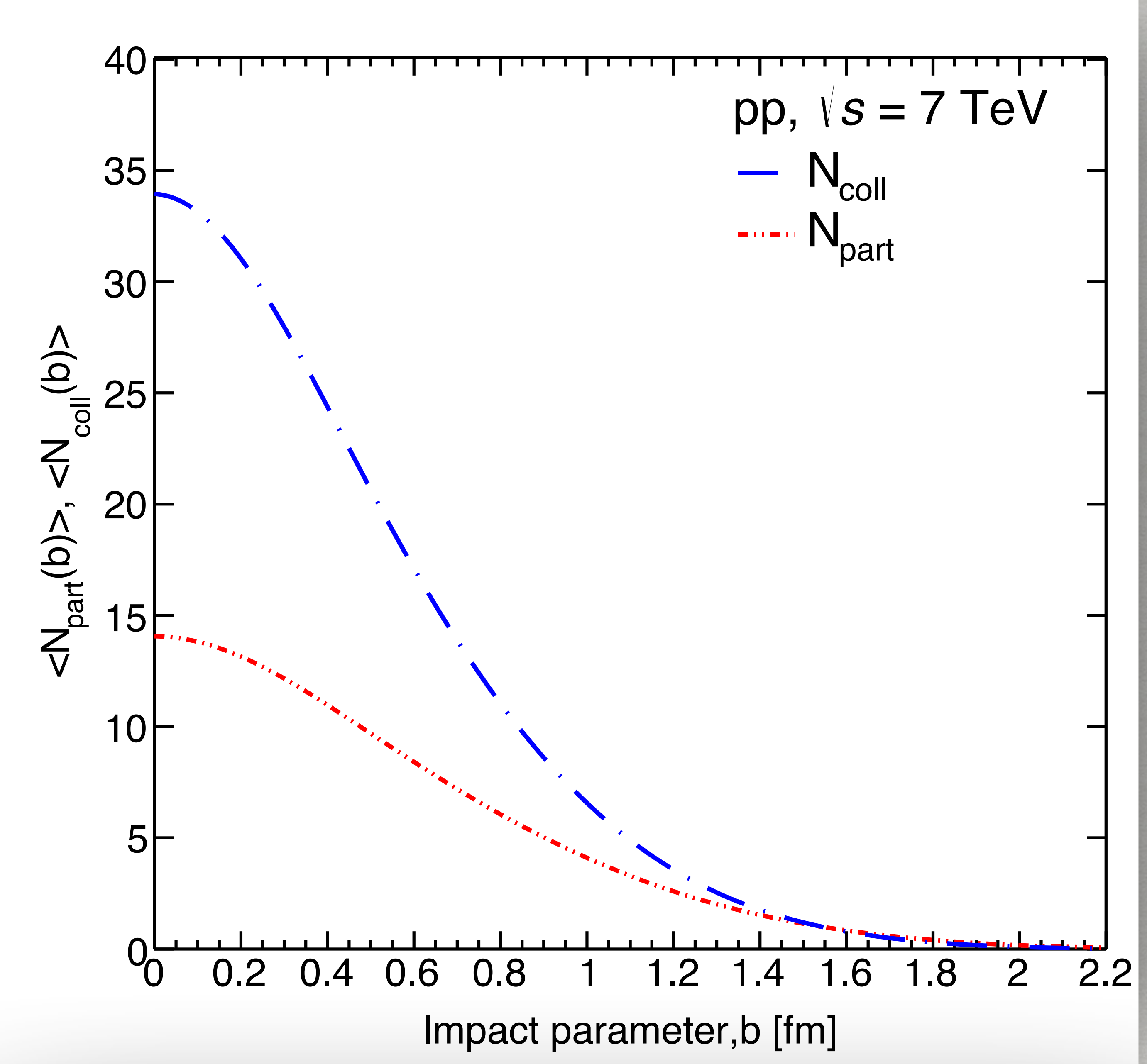
$$N_{ancestors} = f N_{part} + (1-f) N_{coll}$$

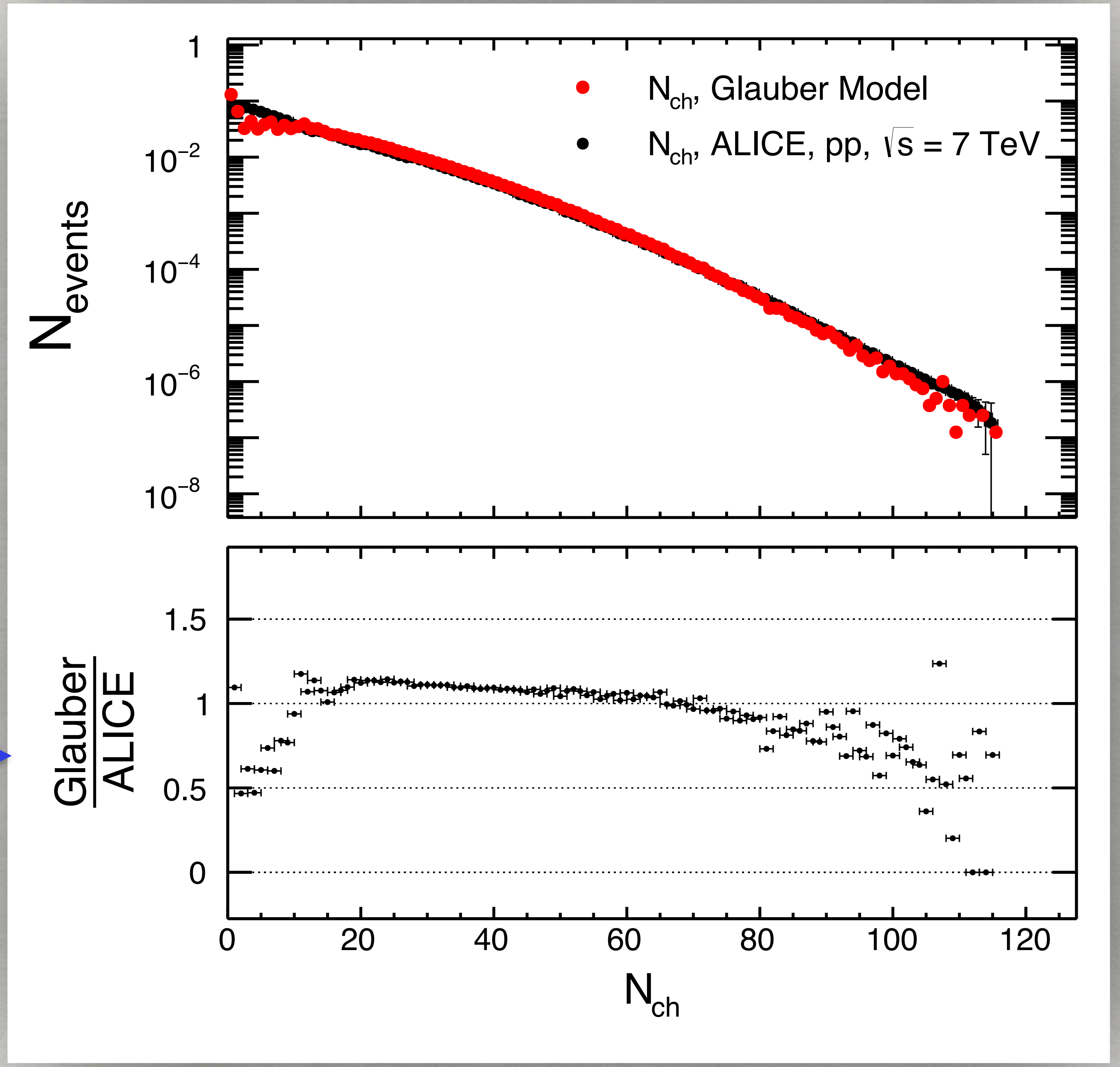
- As the negative binomial distribution (NBD) is able to well reproduce the charged-particle distribution in pp system, we use the two-parameter NBD to calculate the probability of producing n particles per ancestor:

$$P(n;\bar{n},k) = \frac{\Gamma(n+k)}{\Gamma(k)\Gamma(n+1)} \left[\frac{\bar{n}}{k+\bar{n}}\right]^n \left[\frac{k}{k+\bar{n}}\right]^k$$

where $\bar{n}$ is the average multiplicity and k characterizes the width of the distribution.

- By using different combinations of f [2], $\bar{n}$ and k [3], the process of obtaining the multiplicity distribution for a large sample of events repeated, until our model simulates the experimental multiplicity distribution.





1. H. J. Drescher et.al., Phys. Rev. C 76, 024905 (2007)
2. C. Loizides, Phys. Rev. C 94, 024914 (2016)
3. D.d'Enterria et.al., Eur. Phys. J. C 66, 173 (2010)

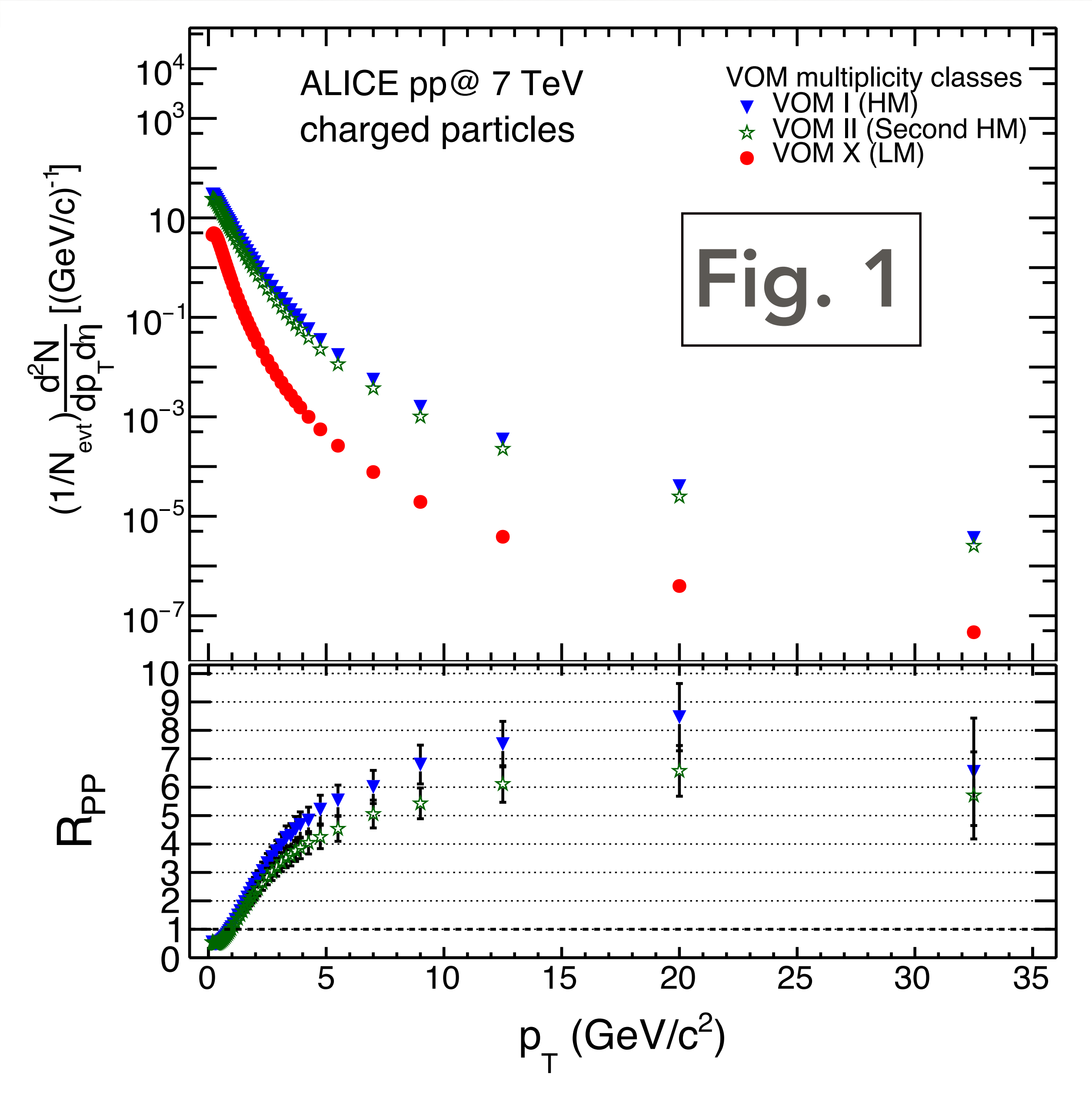
5. Result and discussions

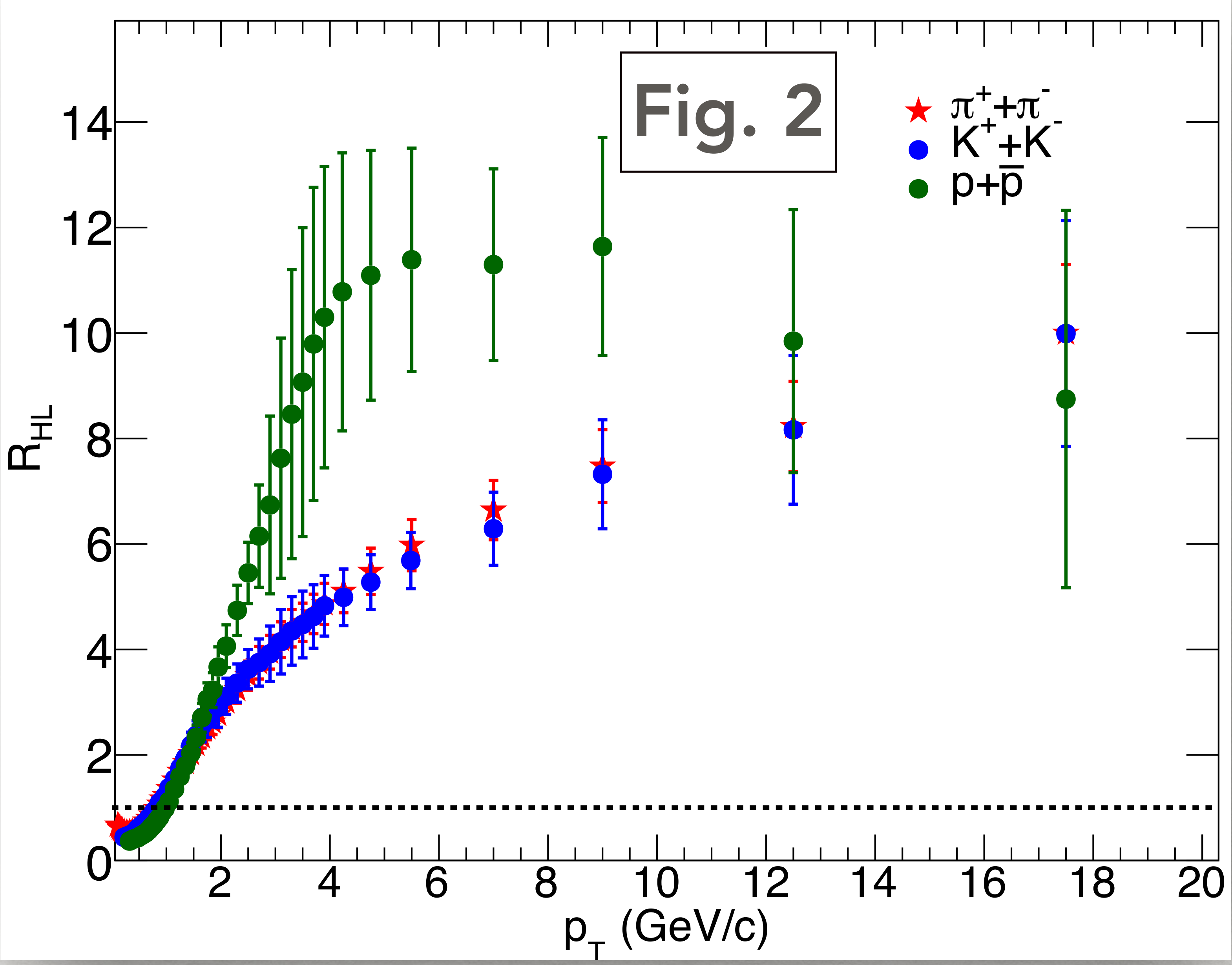
Below table shows geometric properties ($\langle b\rangle, \langle N_{ch}\rangle, \langle N_{part}\rangle, \langle N_{Coll}\rangle$) of pp collisions for different multiplicity (mult) classes using Glauber Monte Carlo calculation along with a Negative binomial distribution fit to charged particle multiplicity distribution at $\sqrt{s}$ = 7 TeV for the ALICE experiment at the LHC

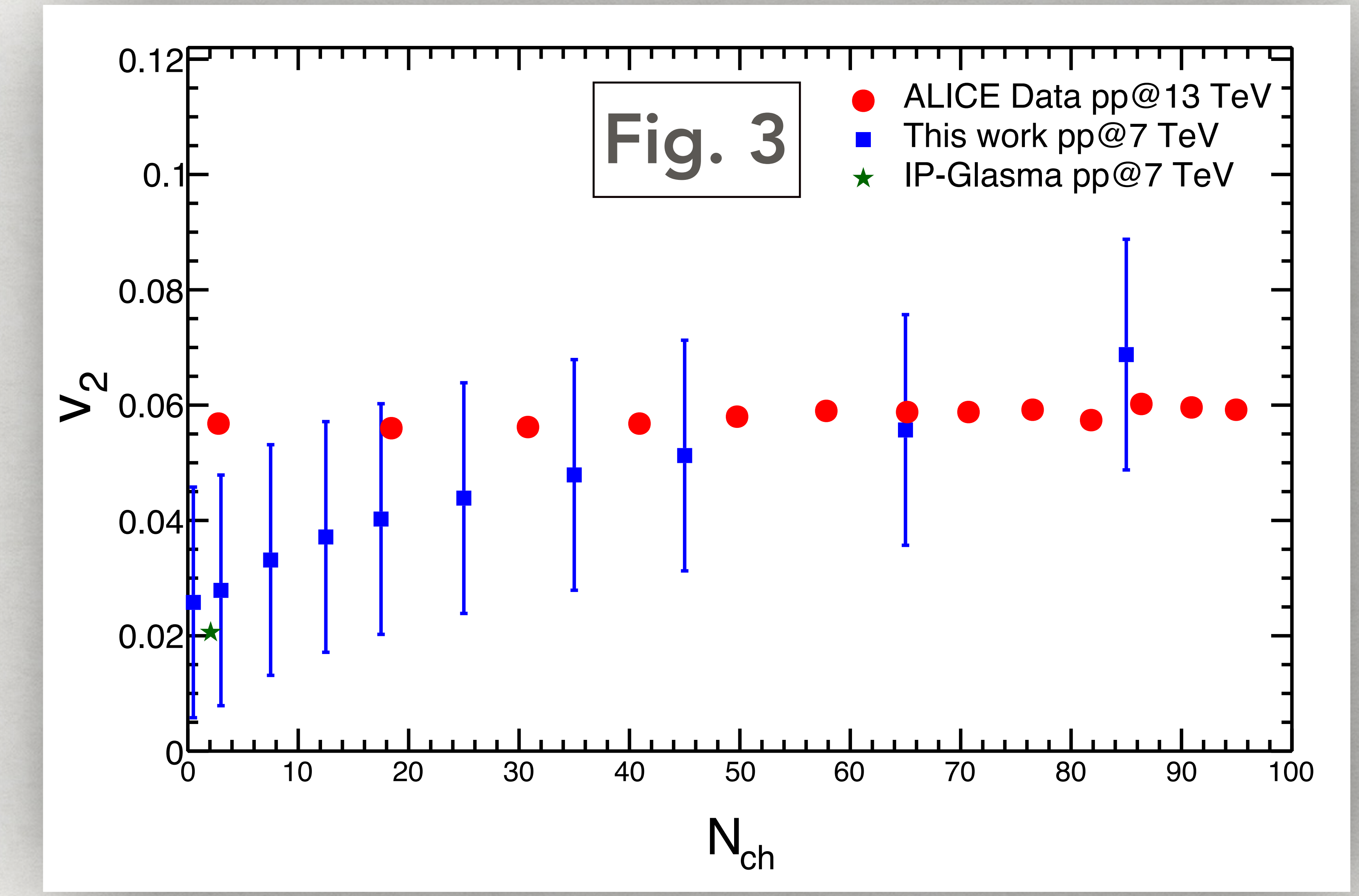
Multiplicity [%]	b range [fm]	$\langle dN_{\rm ch}/d\eta\rangle^{\rm Glauber}$	$\langle dN_{\rm ch}/d\eta\rangle^{\rm expt}$	$\langle N_{\rm part}\rangle$	$\langle N_{\rm coll}\rangle$
0–1	0–0.25534	19.69	$28.82^{+0.86}_{-0.84}$	13.142	31.156
1–5	0.25535–0.46909	16.24	$20.34^{+0.58}_{-0.57}$	11.164	24.815
5–10	0.46909–0.58484	13.37	$15.80^{+0.34}_{-0.32}$	9.244	19.478
10–15	0.58484–0.66430	11.61	$13.07^{+0.24}_{-0.22}$	8.037	16.153
15–20	0.66431–0.72766	10.28	$11.25^{+0.19}_{-0.18}$	7.131	13.818
20–30	0.72767–0.83026	8.94	$9.21^{+0.15}_{-0.14}$	6.116	11.326
30–40	0.83027–0.91819	7.48	$7.13^{+0.12}_{-0.11}$	5.268	9.215
40–50	0.91820–1.00117	6.49	$5.65^{+0.11}_{-0.09}$	4.418	7.340
50–70	1.00118–1.17163	5.12	$3.81^{+0.07}_{-0.06}$	3.395	5.208
70–100	1.17164–2.54998	3.66	$1.66^{+0.05}_{-0.04}$	1.968	2.591

- We observe the calculated $\langle dN_{ch}/d\eta\rangle$ is consistent with the experimental value expect at high and low must regions
- This is because of artifact of the model where $\sigma_{gg} = 4.3 \pm 0.6\ mb$ contains 14% uncertainties which is reflected in the calculation of $\langle dN_{ch}/d\eta\rangle$
- Example: Value of $\langle dN_{ch}/d\eta\rangle$ for minimum bias (0-100%) collisions : Our model = 7.47 and Experimental data = $6.01 \pm 0.01^{+0.20}_{-0.12}$ [5]

5. B.Abelev et al., ALICE Collaboration, Phys. Lett. B 712, 165 (2012)







- To understand the possibility of a formation of a medium, Nuclear modification factor like observables for charged particle and identified hadrons are plotted in Fig. 1 and Fig 2 respectively using following relation

$$R_{pp}(p_T) = \frac{d^2N/dp_T d\eta|^{HM}}{d^2N/dp_T d\eta|^{LM}} \times \frac{\langle N_{coll}^{LM} \rangle}{\langle N_{coll}^{HM} \rangle}$$

- Elliptic flow (v_2) is plotted as a function of charged pseudo rapidity density in Fig. 3 and compared with experimental data and IP- Glasma model. Elliptic flow is obtained here by considering linear scaling as

$$v_2 = \Omega\epsilon \quad \text{where}, \Omega = 0.3 \pm 0.02 \quad [4]$$

4. H. J. Drescher et.al., Phys. Rev. C 76, 024905 (2007)