Determination of participants in HIC

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- Centrality definitions
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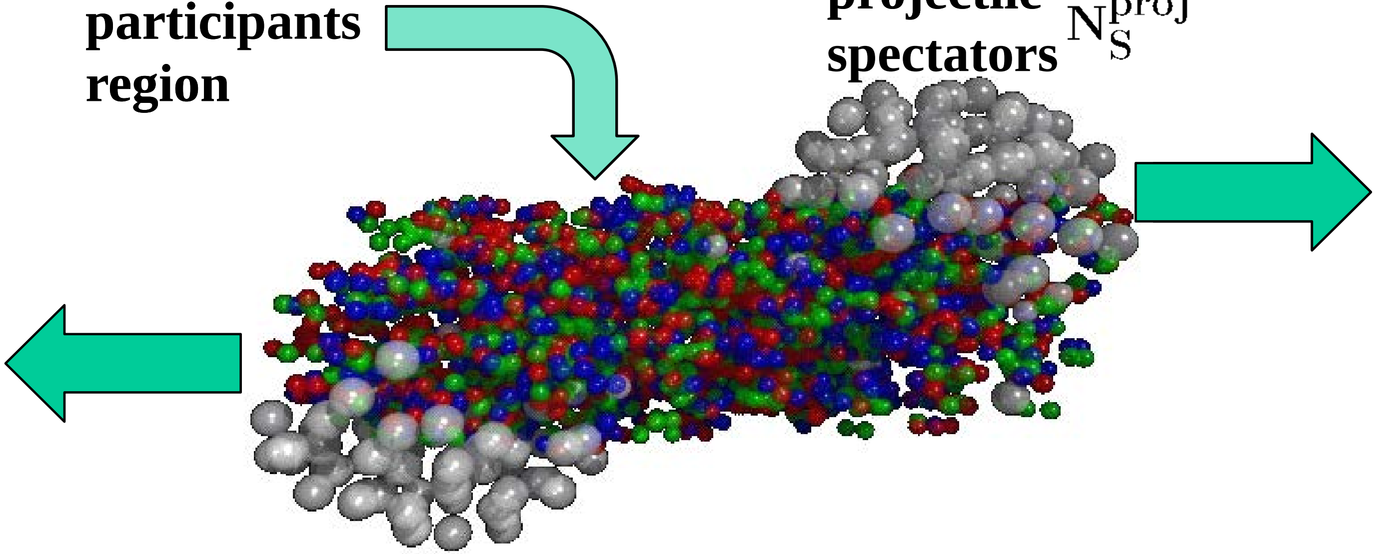
Heavy Ion Collision



participants region

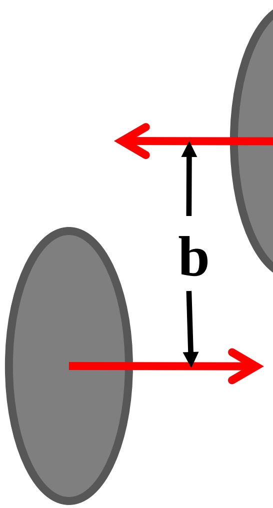
projectile spectators $\mathrm{N}_{\mathrm{S}}^{\mathrm{proj}}$

target spectators $\mathrm{N}_{\mathrm{S}}^{\mathrm{targ}}$

Heavy ion collisions

Geometrical considerations

Cross Section



$$\sigma = 2\pi\int b\,\mathrm{d}b(1-|s(b)|^2) = 2\pi\int b\,db\,Tr(b)$$

$|s(b)|^2$– transparency function
Tr(b) =1- $|S(b)|^2$ – transmission function (opacity)

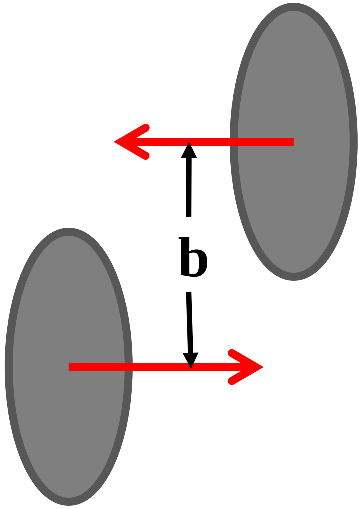
Sharp spheres A and B with radii R_A and R_B then

$$\begin{aligned} Tr(b) &= 1 \text{ for } b \leq R_A + R_B \\ &= 0 \text{ for } b > R_A + R_B \end{aligned}$$

Total cross section

$$\sigma_R = 2\pi \int_0^{R_1+R_2} b db = \pi(R_1 + R_2)^2.$$

Centrality definitions



- Impact parameter interval

$$b_{\min} \leq b \leq b_{\max} \quad (\mathrm{fm})$$

- The Fraction of the Cross Section

$$\left(\frac{b_{\min}}{2R_A}\right)^2 \bigg/ \left(\frac{b_{\max}}{2R_A}\right)^2 \quad (\%)$$

- Multiplicity of charged particles and/or net protons

$$\mathbf{N_{ch}}$$

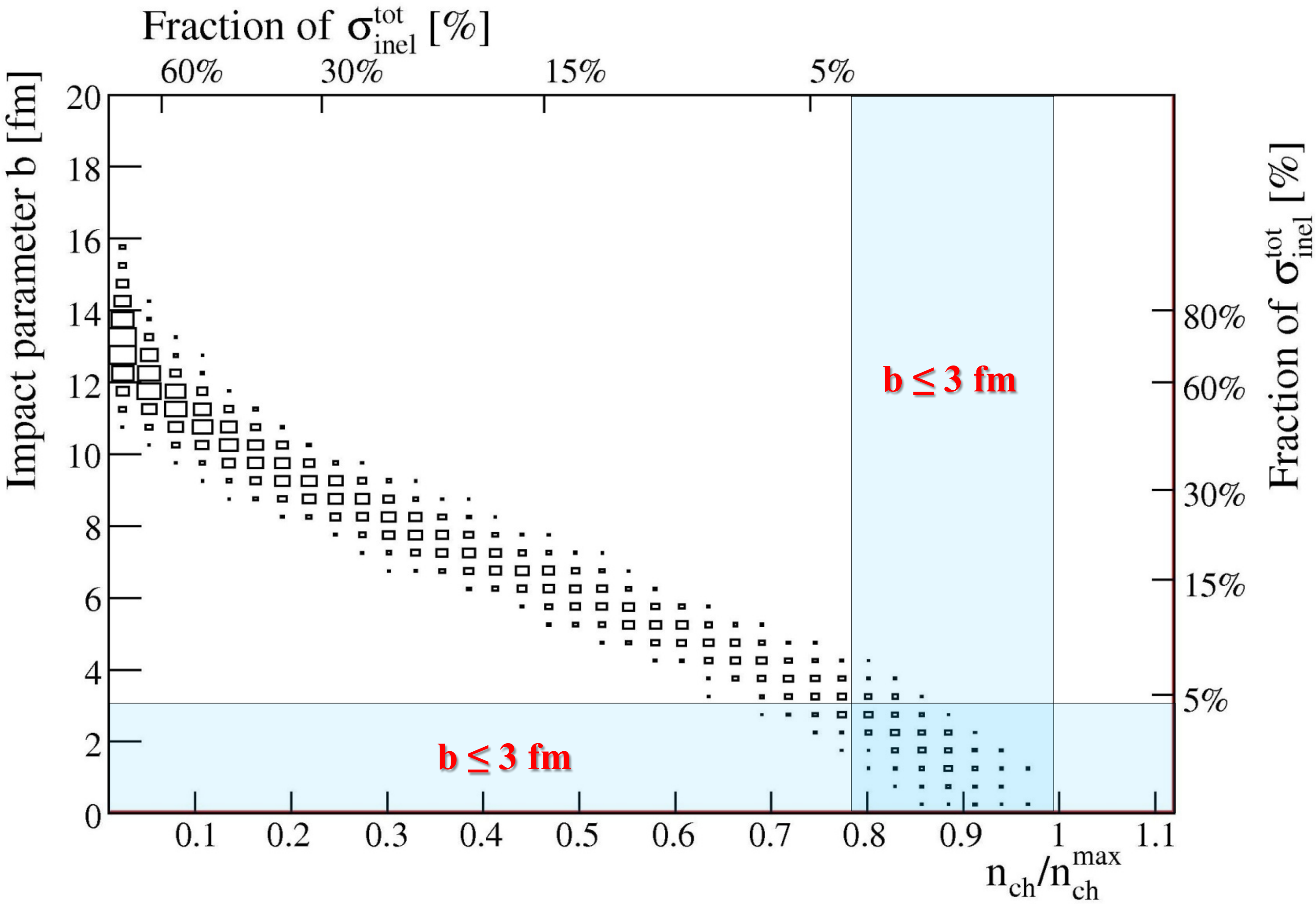
- Number of Participants or Wounded Nucleons

$$\mathbf{N_{part}} \text{ or } \mathbf{N_{wound}}$$

- Number of Spectators

$$\mathbf{N_{spec}}$$

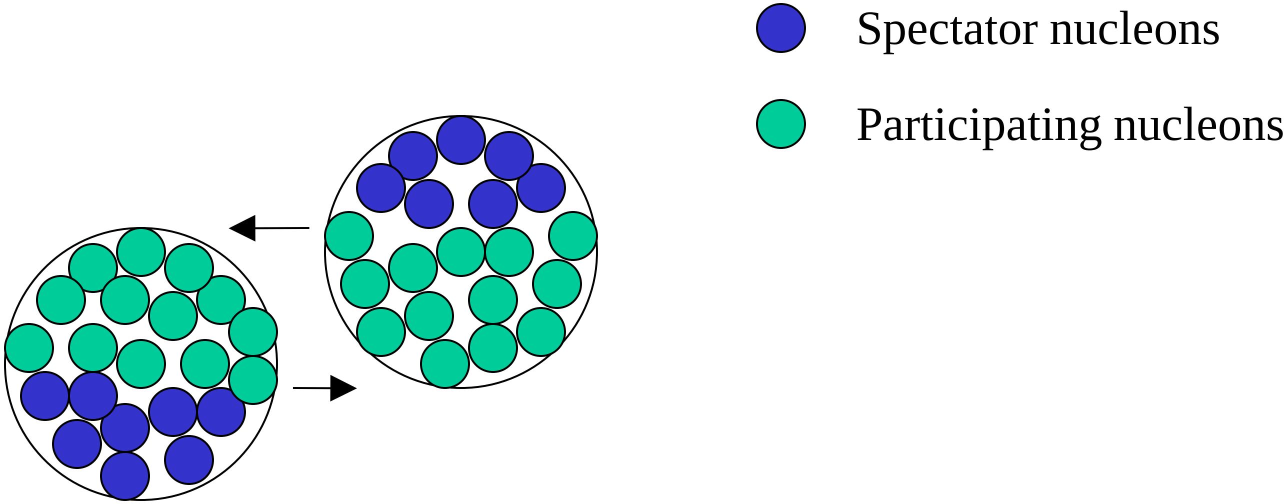
Centrality – impact parameter – charged multiplicity



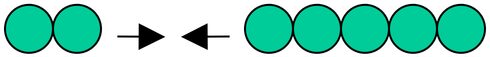
Calculation the number of collisions and participants

Assumption:

Inelastic collisions of two nuclei (A-B) can be described by incoherent superposition of the collision of “an equivalent number of nucleon-nucleon collisions”.



To calculate $\mathbf{N}_{\mathbf{part}}$ or $\mathbf{N}_{\mathbf{coll}}$, take



$\mathbf{N}_{\mathbf{part}} = 7$

$\mathbf{N}_{\mathbf{coll}} \cdot = 10$

I.1. Glauber theory for n+A

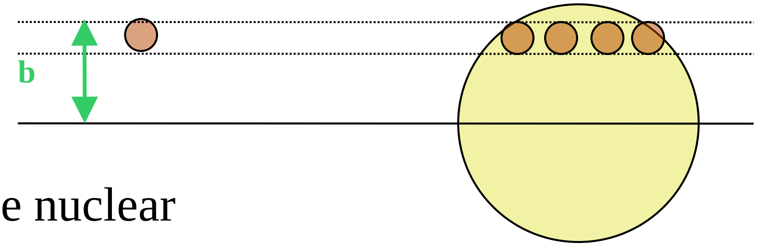
We want to calculate:

N_{part} = number of participants = number of ‘wounded nucleons’, which undergo at least one collision

N_{part} = number of n+n collisions, taking place in an n+A or A+B collision

We know the single nucleon probability distribution within a nucleus A, the so-called nuclear density *$\rho(b,z)$*

$$\int dz\, db\, \rho(b,z) = 1$$



We are only interested in the transverse density, the nuclear profile function

$$T_A(b) = \int_{-\infty}^{\infty} dz\ \rho(b,z)$$

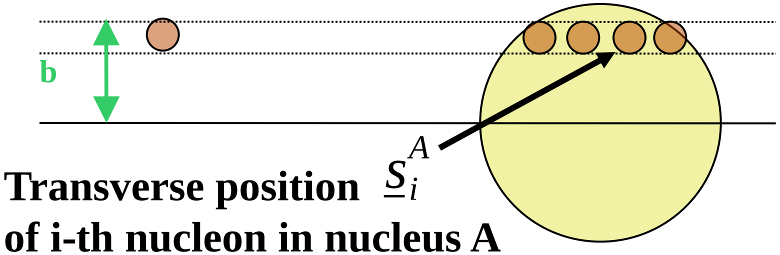
I.3. Glauber theory for n+A

To calculate number of collisions: probability of interacting with i-th nucleon in A is

$$p(\underline{b},\underline{s}_i^A) = \int d\underline{s}_i^A \, T_A\left(\underline{s}_i^A\right) \sigma\left(\underline{b} - \underline{s}_i^A\right) = T_A(\underline{b}) \, \sigma_{nn}^{inel}$$

Probability that projectile nucleon undergoes n collisions:

$$P(\underline{b},n) = \binom{A}{n} (1-p)^{A-n} \, p^n$$



Transverse position $\underline{s}_i^A$ of i-th nucleon in nucleus A

Average number of nucleon-nucleon collisions in n+A:

$$\overline{N}_{coll}^{nA}(\underline{b}) = \sum_{n=0}^{A} n \, P(\underline{b},n) = \sum_{n=0}^{A} n \binom{A}{n} (1-p)^{A-n} \, p^n = A \, p$$

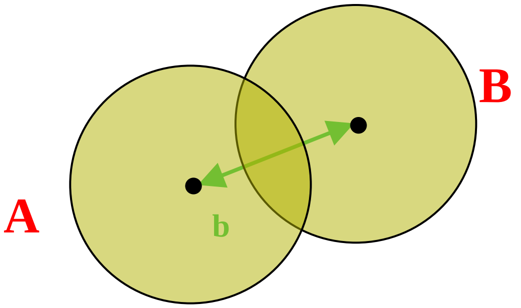
$$= A \, T_A(\underline{b}) \, \sigma_{nn}^{inel}$$

Average number of participants in n+A:

$$\overline{N}_{part}^{nA}(\underline{b}) = 1 + \overline{N}_{coll}^{nA}(\underline{b})$$

I.4. Glauber theory for A+B collisions

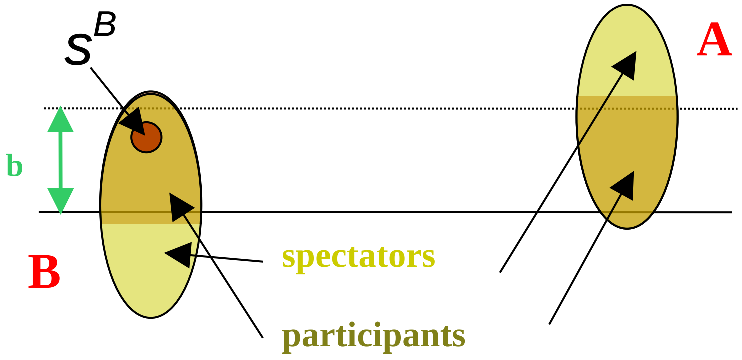
We define the nuclear overlap function



$$T_{AB}(\vec{b}) = \int_{-\infty}^{\infty} d\vec{s}\; T_A(\vec{s})\, T_B(\vec{b}-\vec{s})$$

The average number of collisions of nucleon at s^B with nucleons in A is

$$\overline{N}^{nA}_{coll}(\underline{b}-\underline{s}^B) = A\, T_A(\underline{b}-\underline{s}^B)\, \sigma^{inel}_{nn}$$



The number of nucleon-nucleon collisions in an A-B collision at impact parameter b is

$$\overline{N}^{AB}_{coll}(\underline{b}) = B \int d\underline{s}^B T_B(\underline{s}^B)\, \overline{N}^{nA}_{coll}(\underline{b}-\underline{s}^B)$$

$$= AB \int d\underline{s}\, T_B(\underline{s})\, T_B(\underline{b}-\underline{s})\, \sigma^{inel}_{nn}$$

$$= A\, B\, T_{AB}(\underline{b})\, \sigma^{inel}_{nn}$$

U.A.Wiedemann

I.6. Glauber theory for A+B collisions

Number of collisions: $N(b)_{coll} = ABT_{AB}(b)\sigma_{NN}$

Number of participants: $N(b)_{part} = \overbrace{A[1 - [1 - T_{AB}(b)\sigma_{NN}]^{B}]}^{N^{B}_{part}} + \overbrace{B[1 - [1 - T_{AB}(b)\sigma_{NN}]^{A}]}^{N^{A}_{part}}$

The nuclear density is commonly taken to follow a Wood-Saxon parametrization

$$\rho(\vec{r}) = \rho_0 \Big/ \left(1 + \exp\left[-(r - R)/c\right]\right); \qquad R \equiv 1.07\,A^{1/3}\,fm, c = 0.545\,fm.$$

The inelastic Cross section is energy dependent, typically

$$\sigma_{nn}^{inel} \approx 40\,mb \qquad at \qquad \sqrt{s_{nn}} = 100\,GeV.$$

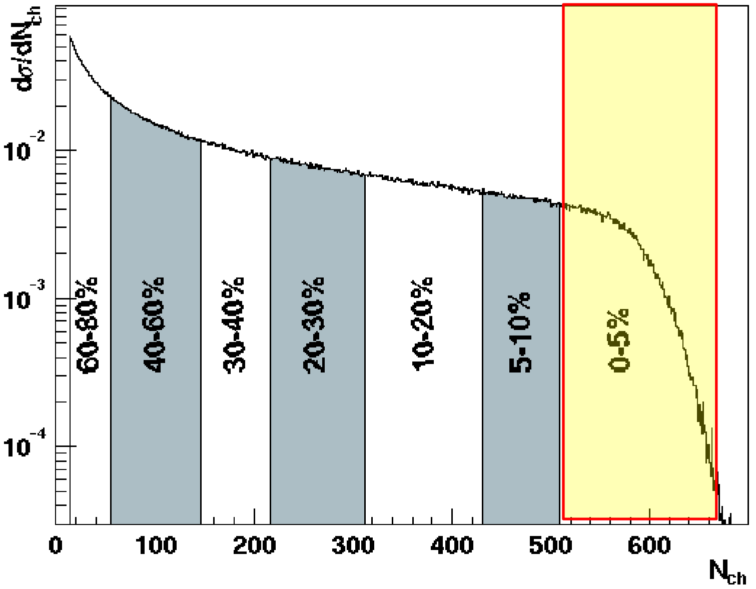
But σ_{nn}^{inel} is sometimes used as fit parameter.

U.A.Wiedemann

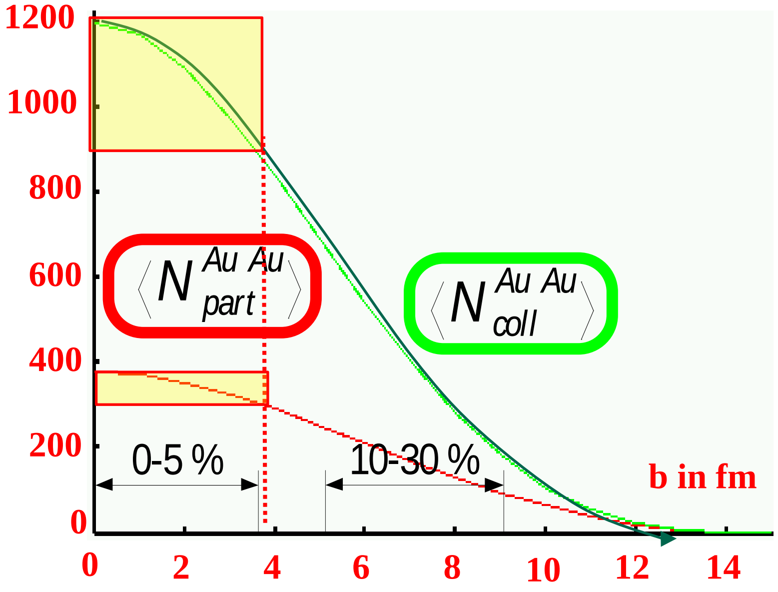
Multiplicity as a Centrality Measure → $N(b)_{coll}$ and $N(b)_{part}$

The connection between event **multiplicity** and *$N(b)_{coll}$* and *$N(b)_{part}$* via **centrality**

Multiplicity distribution



$N(b)_{coll}$, *$N(b)_{part}$* vs impact parameter



U.A.Wiedemann

Multiplicity in **A+B** collisions vs multiplicity in **pp** collisions

Determination of **participants** from **multiplicity** N^B_{part} N^a_{part}

(without centrality)

The total charged particle multiplicity in **pp** collision for a center of mass energy √s is given by

$$< n_{ch} >_{pp} = 0.88 + 0.44 \ln(s) + 0.118(\ln(s))^2$$

The center of mass energy for pair of participants from nucleus **A** and nucleus **B** can be written as

$$s_{\alpha\beta} = [2E_{cm} /(\alpha+\beta)]^2 \ ,$$

where $\alpha = N^A_{part}\ , \beta = N^B_{part}\ ,$

$$E^2_{cm} = ((\alpha E_A + \beta E_B)^2 – (\alpha \mathbf{P}_A + \beta \mathbf{P}_B)^2)$$

And the total multiplicity in A+B collision in the case of nucleons participating from nucleus A and participating from nucleus B can be written as

$$<N_{ch}>_{AB} = (0.88 + 0.44 \ln(s_{\alpha\beta}) + 0.118(\ln(s_{\alpha\beta}))^2)((\alpha+\beta)/2)$$

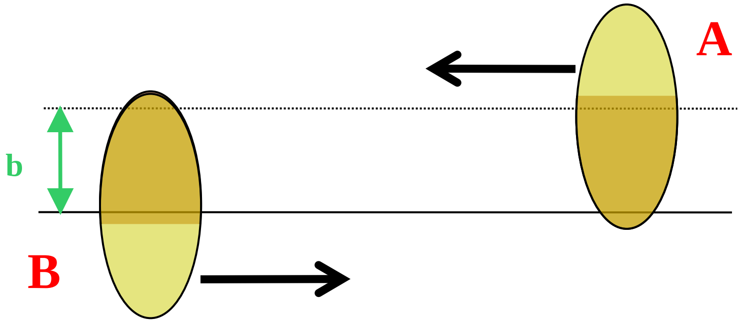
$$\boxed{(\alpha+\beta) \approx 2<N_{ch}>_{AB} / < n_{ch} >_{pp}}$$

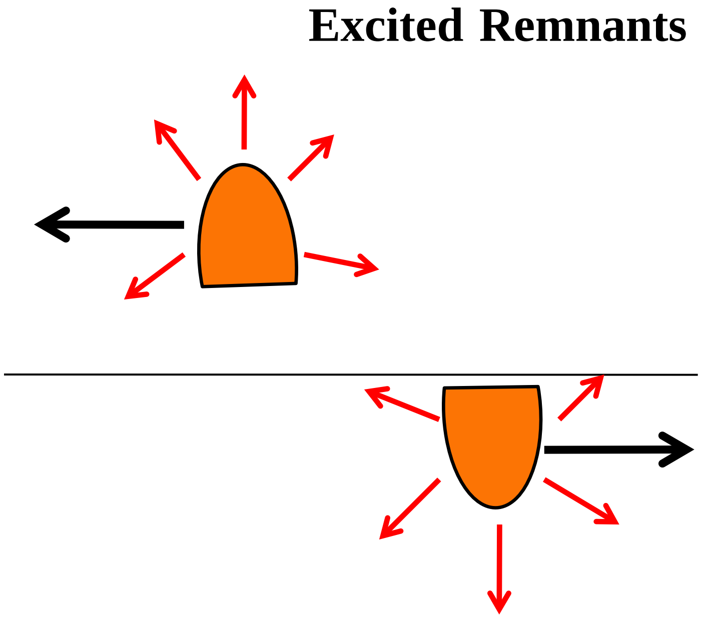
Determination of participants number by spectators

- **Number of Spectators**
    - protons
    - neutrons
    - nuclear fragments (stable and radioactive)

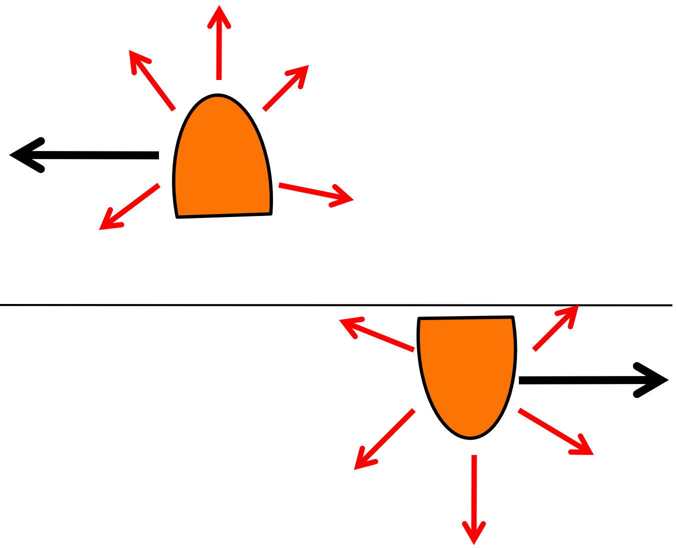
Nuclear Spallation

- Nuclear evaporation and multifragmentation (at medium and small b)





Spallation of Excited Remnants

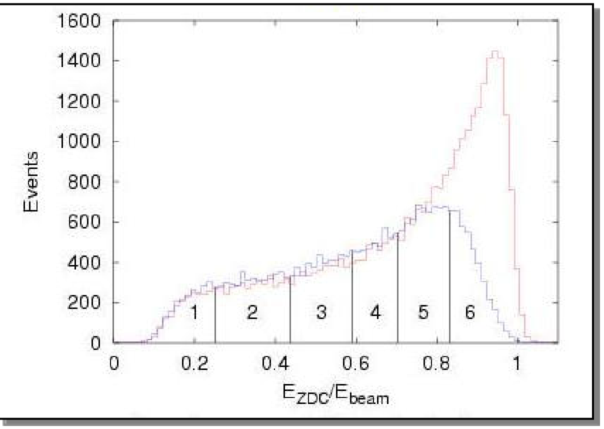


- **Evaporation**
  - ✓neutrons
  - ✓protons
  - ✓light nuclei (d, t, He3, He4)

- **Multifragmentation**
  - ✓protons
  - ✓neutrons
  - ✓nuclear fragments (stable and radioactive)

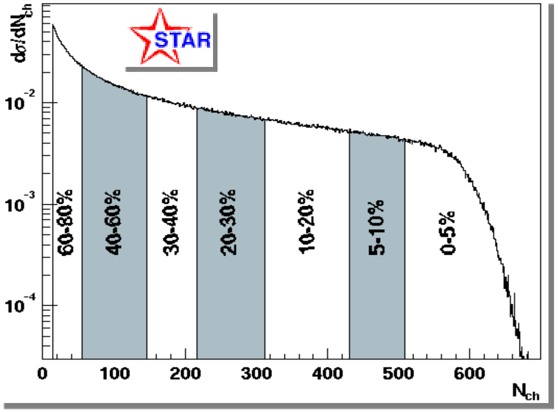
Measurement of participants in experiments

NA49



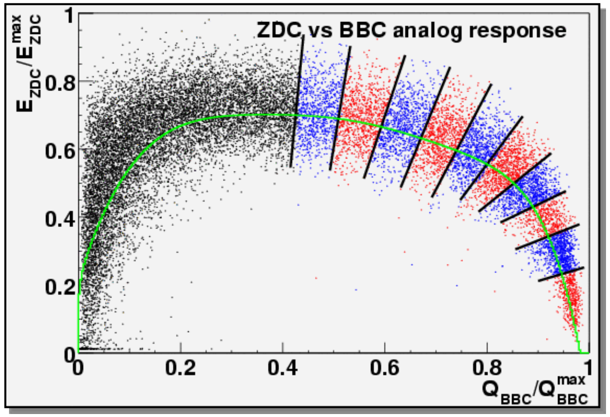
$$E_{ZDC} = (A - N_{part}/2) / \sqrt{s}/2$$

STAR



$$N_{part}/2 \approx \langle N_{ch} \rangle_{AB} / \langle n_{ch} \rangle_{pp}$$

PHENIX



$$Q_{BBC} = (N_{part}/2) / \sqrt{s}/2$$

$$E_{ZDC} = (A - N_{part}/2) / \sqrt{s}/2$$

NA49	ZDC Only - spectators
STAR	TPC only - participants
PHENIX	BBC & ZDC – participants + spectators

A.G.Litvinenko

MULTIPLICITY FLUCTUATIONS

Multiplicity fluctuations are studied by looking at the simple variable

$$\omega = \frac{\sigma^2}{< N >}$$

Centrality and pseudo-rapidity acceptance dependence

Participant model:

$$N = \sum_{i=1}^{N_{part}} n_i$$

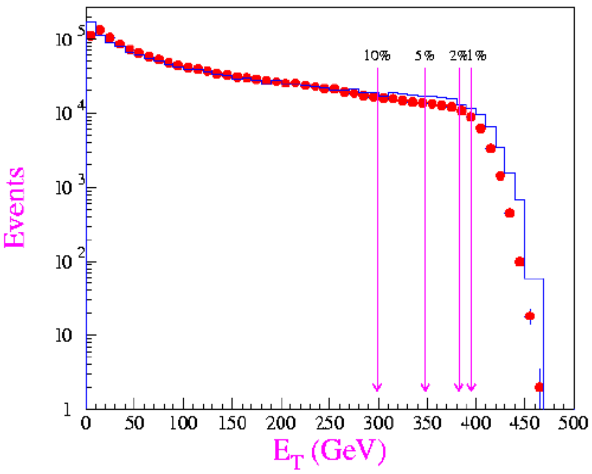
$$\omega_N = \omega_n + < n > \omega_{N_{part}}$$

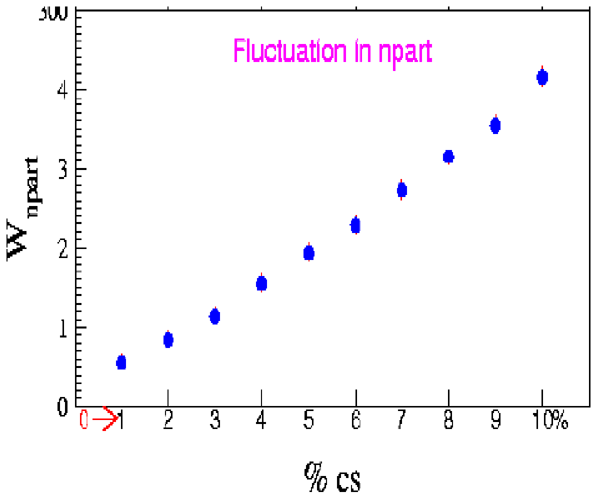
N : Particle Multiplicity

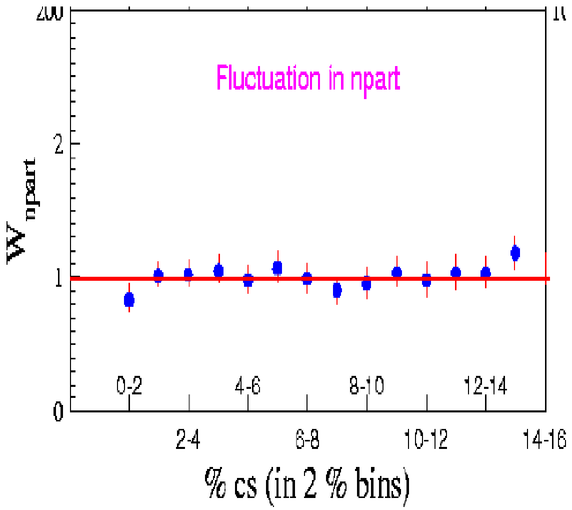
N_{part} : No. of participants

n_i : No of particles produced by ith participant, accepted within the acceptance of detector

CENTRALITY SELECTION







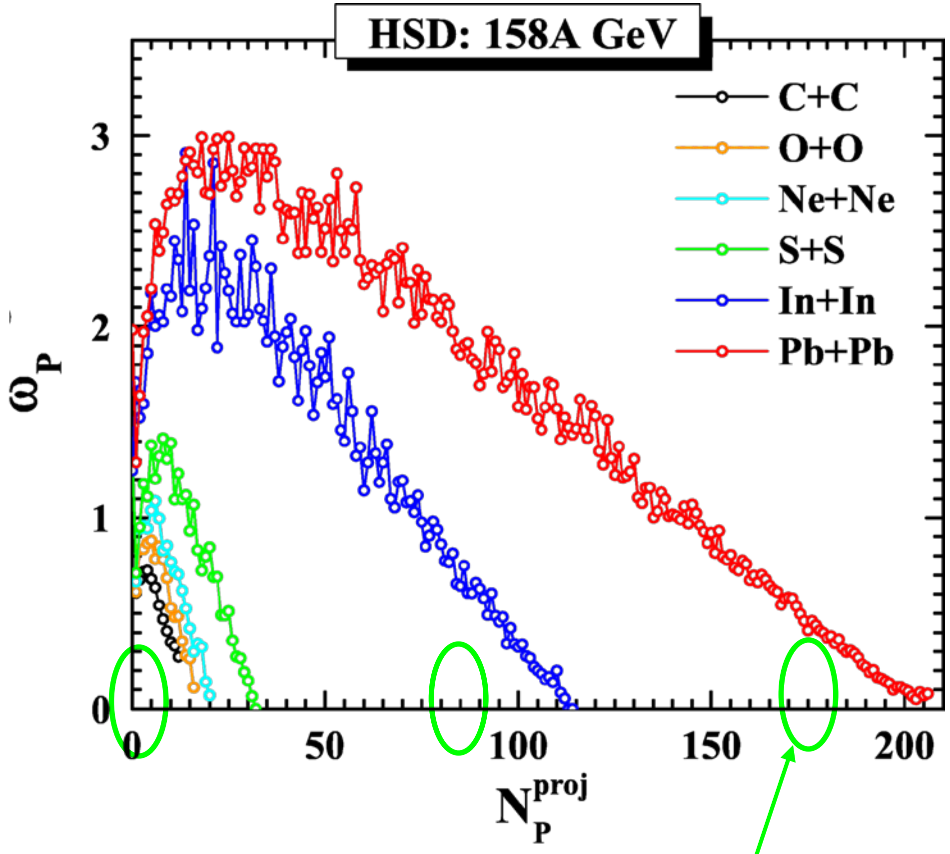
Fluctuations in number of participants increases with increasing % cs but for 2% cs bins ~ 1

Fluctuations should be calculated for narrow bins in centrality (2% cs bins) such that fluctuations in number of participants are Poisson-like

Fluctuations in the number of participants in HSD

Phys. Lett. B640 (2006) 155

Phys. Rev. C73 (2006) 034902; C78 (2008) 024906



To get rid of the fluctuations in the participant number one needs to consider only the most central collisions!

Thanks!