Intro to Glauber Model

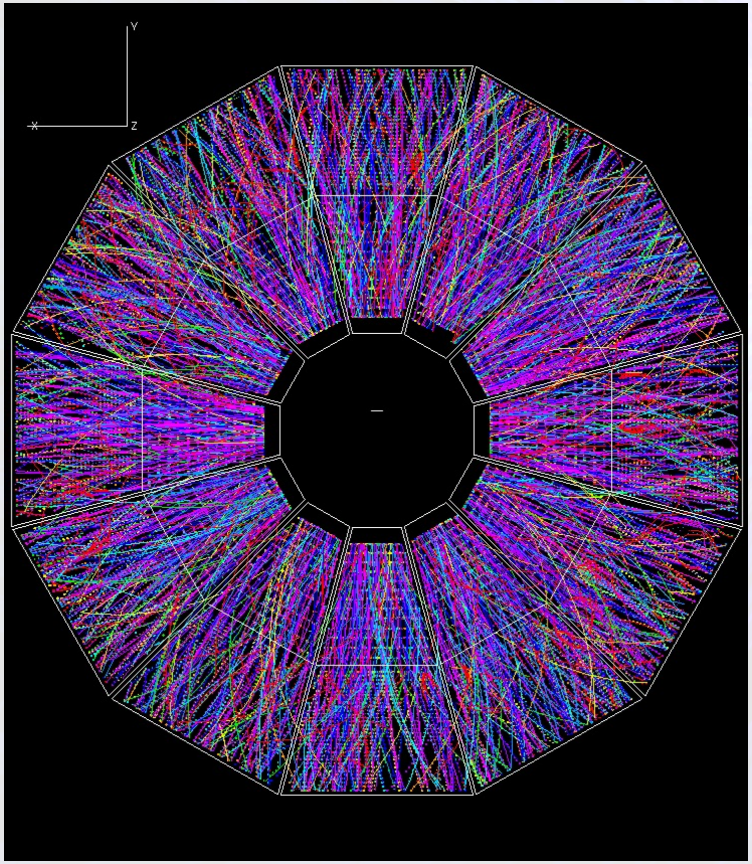
Modeling the experimental observables to determine centrality.

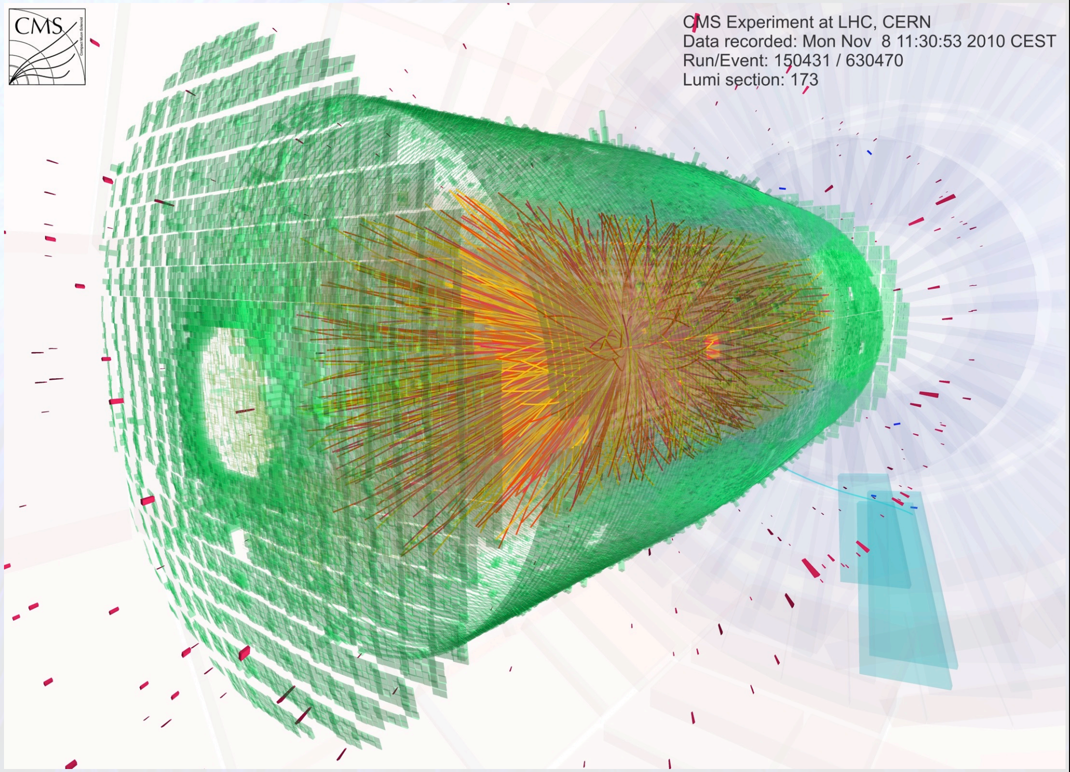
UCDAVIS
DEPARTMENT OF PHYSICS

Manuel Calderón de la Barca Sánchez

Calculate particle multiplicity

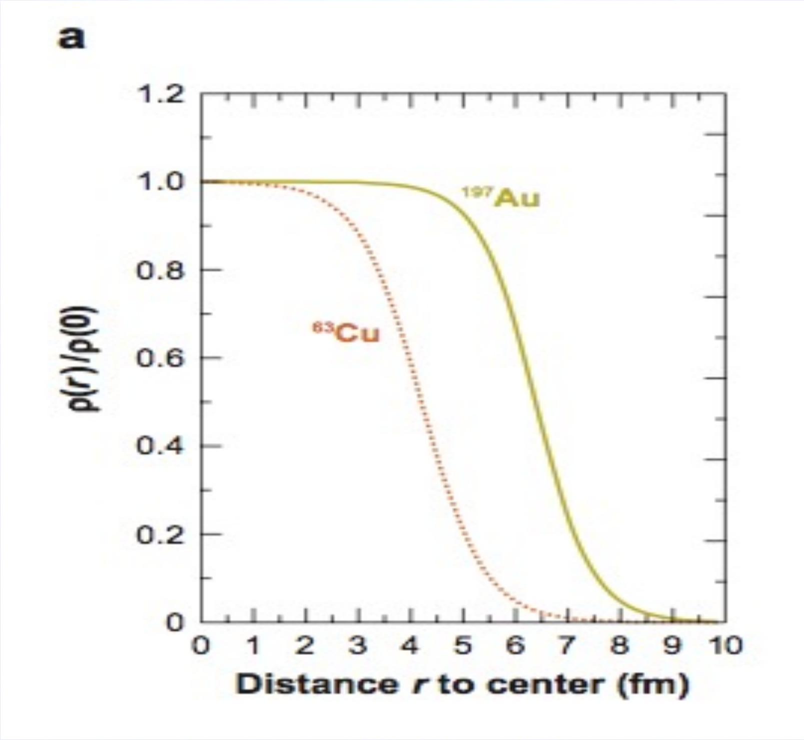
- Event displays





Nuclear Charge Densities

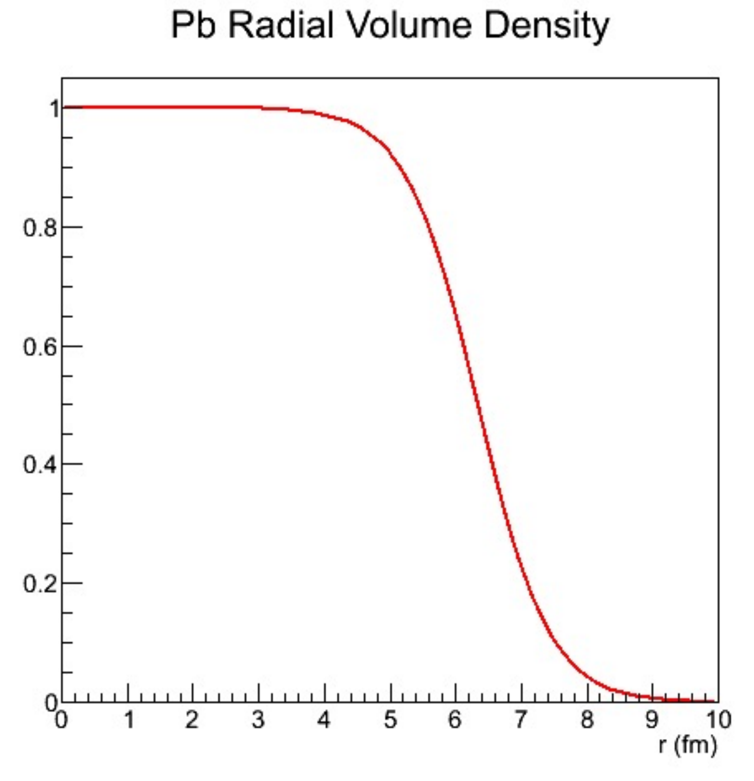
- Charge densities: similar to a hard sphere.
  - Edge is “fuzzy”: Woods-Saxon distribution

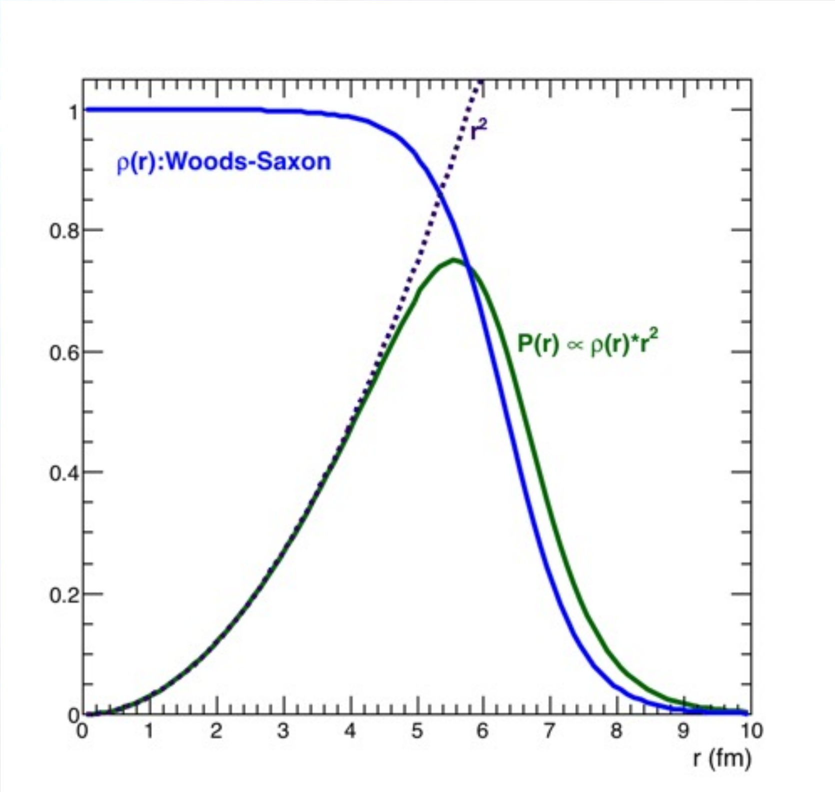


For the Pb nucleus (used at LHC)

- Woods-Saxon density:
  - $R = 1.07\ \text{fm} * A^{1/3}$
  - $a = 0.54\ \text{fm}$
  - A = 208 nucleons
- Probability : $\propto r^2 \rho(r)$

$$\rho(r) = \frac{\rho_0}{1 + e^{\frac{r-R}{a}}}$$





Glauber model parameters

- PbPb at 5.02 TeV

Nuclear radius	6.62 ± 0.06 fm
Skin depth	0.546 ± 0.010 fm
d_{min}	0.4 ± 0.4 fm
σ_{NN}^{inel}	70 ± 5 mb

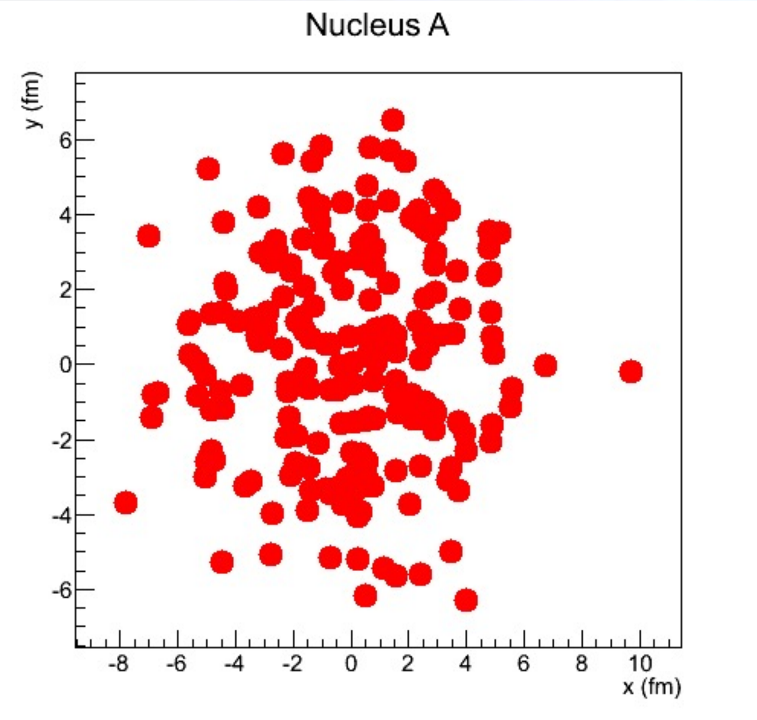
- http://dx.doi.org/10.1016/j.softx.2015.05.001

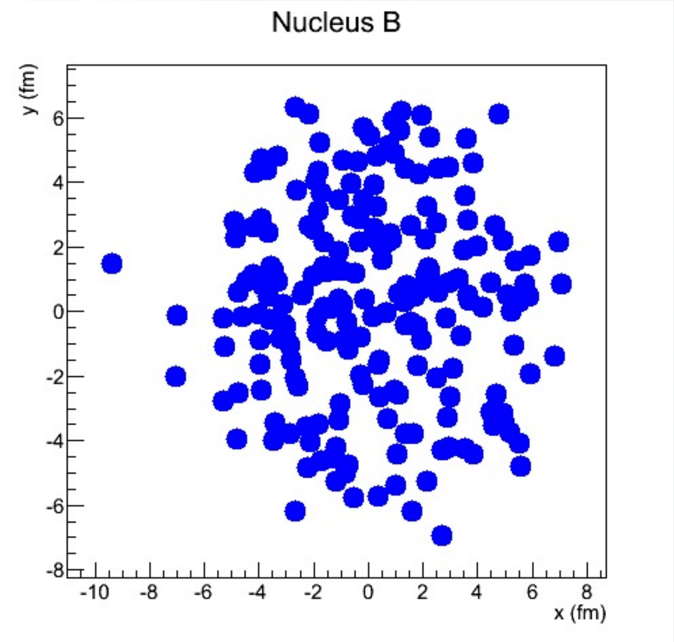
Nuclei: A bunch of nucleons

- Each nucleon is distributed with:

$$P(r,\theta,\phi) = \rho(r)dV = \rho(r)r^2 dr d(\cos\theta) d\phi$$

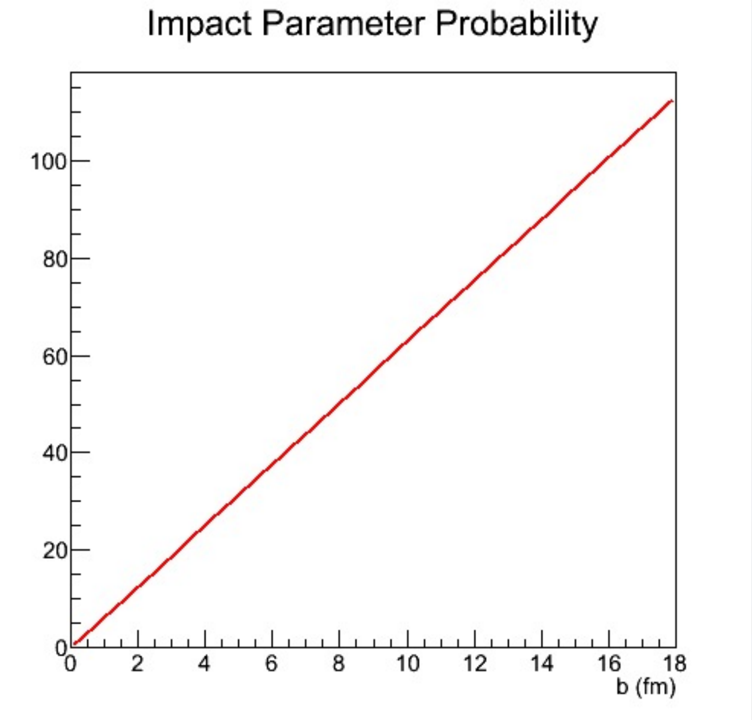
  - Angular probabilities:
    - Flat in ϕ, flat in $\cos(\theta)$.





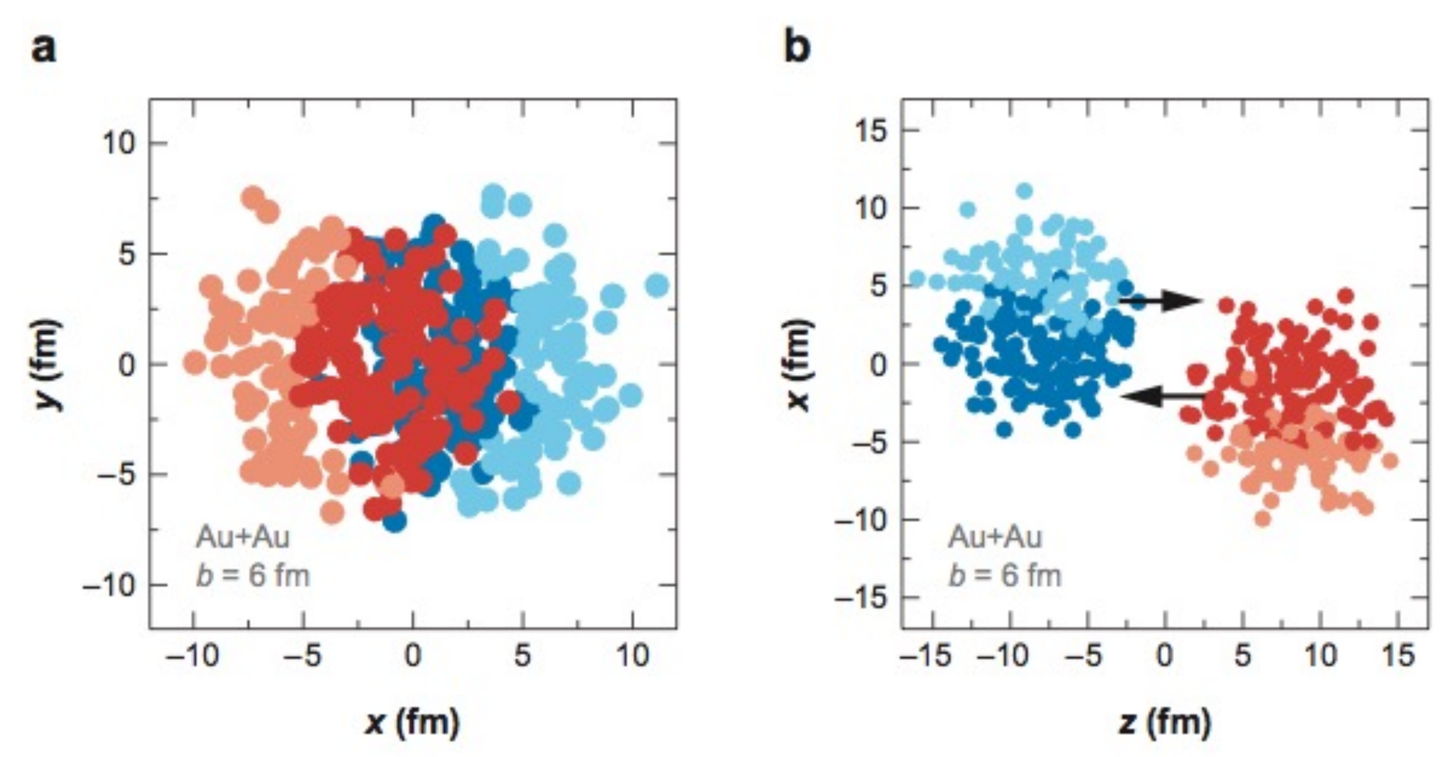
Impact parameter distribution

- Like hitting a target:
- Rings have more area
- Area of ring of radius *b*, thickness *db*: $2\pi b db$
- **Area proportional to probability**



Collision:

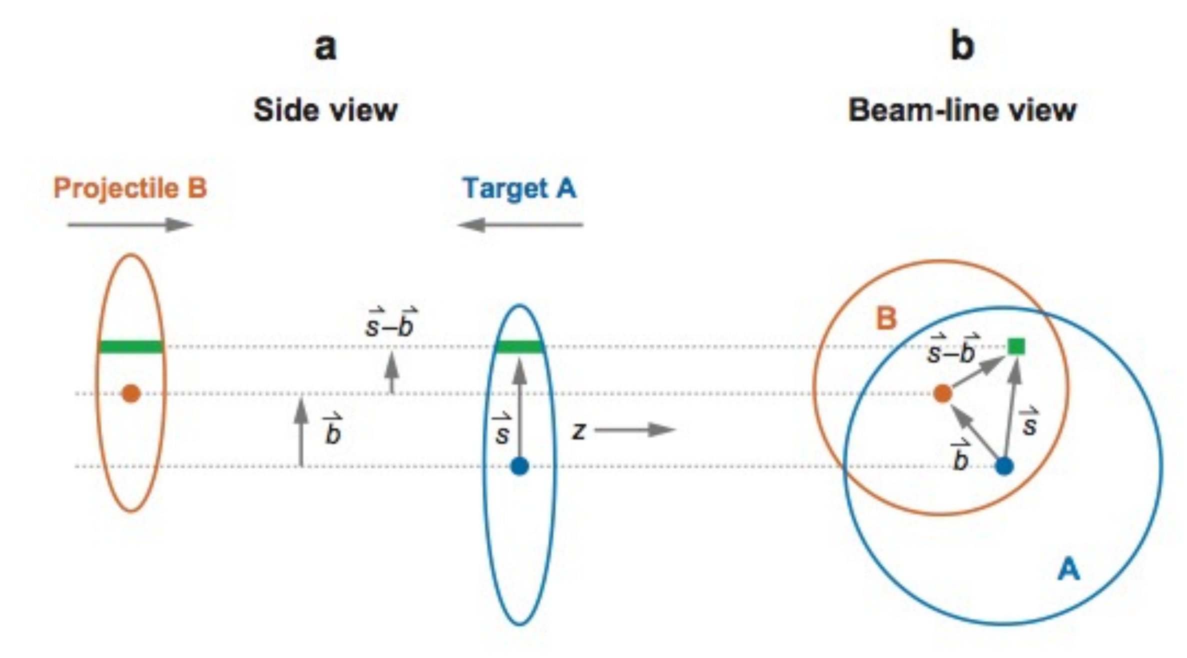
- 2 Nuclei colliding
- Red: nucleons from nucleus A
- Blue: nucleons from nucleus B



M.L.Miller, et al. Annu. Rev. Nucl. Part. Sci. 2007.57:205-243

Monte Carlo Model of nuclear collisions

- Nuclear Collisions, Glauber model



Monte Carlo Model of Nuclear Collisions

1. Nuclear Density Function
    - Make plots of the nuclear density for the Pb nucleus
2. Distribution of nucleons in the nucleus
    - Using the nuclear density function, write a function that will randomly distribute A nucleons in the nucleus (A=208 for Pb).
    - Make a plots of the x-y, and x-z coordinates of the nucleons in sample nucleus.
        - You will need to distribute them in 3D. You can use spherical polar coordinates, then convert to cartesian.

Project: Monte Carlo Model of Nuclear Collisions

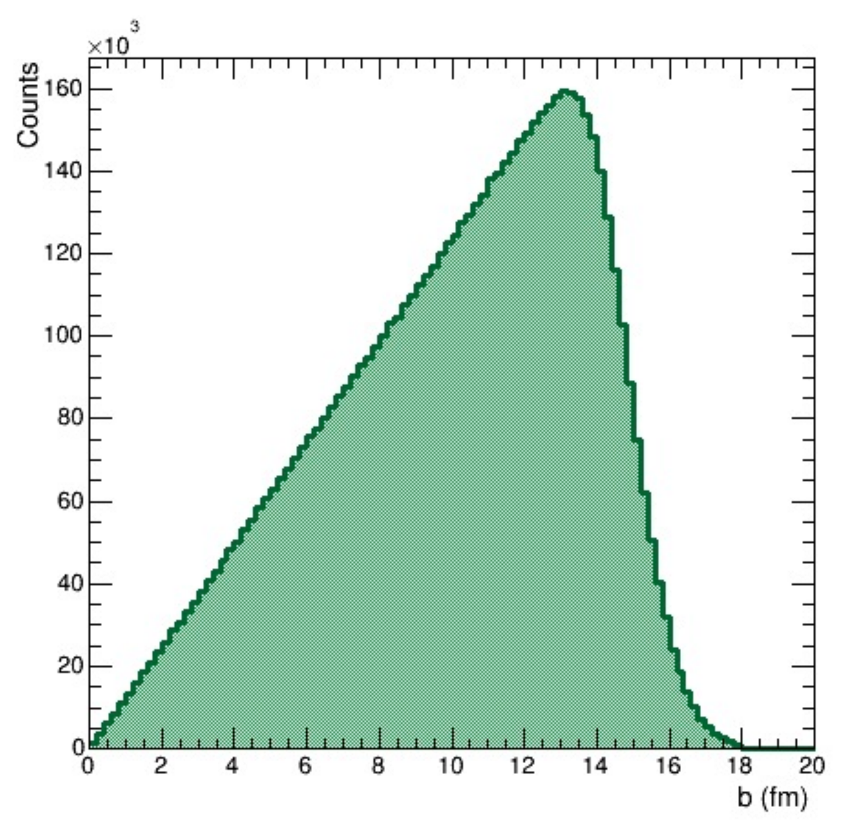
3. Impact Parameter, b
   - Make a plot of the impact parameter probability distribution
   - For b = 6 fm, make an example collision between two nuclei. Plot the x-y coordinates of the nucleons in each nucleus.
4. Number of collisions, Number of participants
   - For each pair of nucleons (one from nucleus A, one from nucleus B), check if there is a collision.
     - Nucleon-Nucleon Collision:
       - Find the distance d in the x-y plane between each nucleon-nucleon pair (the z axis is the beam axis, see slide 6)
       - Collision: when $d^2 < \sigma/\pi$. **Use σ = 65 mb (where 1 b = 10^{-28} m^2).**
     - **Any nucleon that collides is called a "participant". Color each participant a darker color.**
     - **Count the number of nucleon-nucleon collisions.**

Project: Monte Carlo Model of Nuclear Collisions

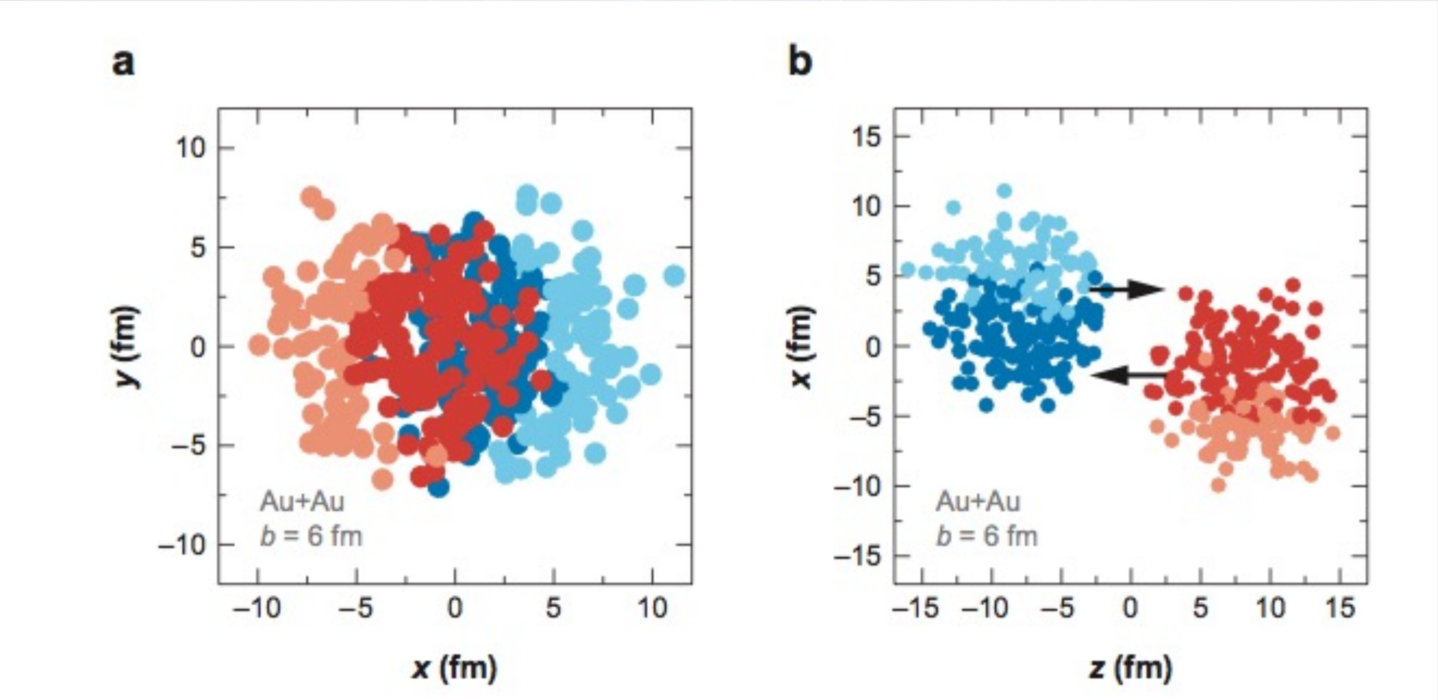
5. **Many collisions!**
    - Simulate 10^6 nucleus-nucleus collision events.
    - Draw a random impact parameter from the distribution (P(*b*) proportional to *b*).
    - Calculate Npart, Ncoll for each collision.
    - For those events where there was an interaction (Ncoll>=1), fill histograms of
        - the impact parameter, *b*.
        - the number of participants
        - the number of collisions
    - In part II of the project, we will model particle production, and compare it against data.

Interaction Probability vs. Impact Parameter, b

- After 10M events
- Beyond *b*~2*R* Nuclei miss each other
  - Note fuzzy edge
- Largest probability:
  - Collision at b~12-14 fm
- Head on collisions:
  - b~0: Small probability



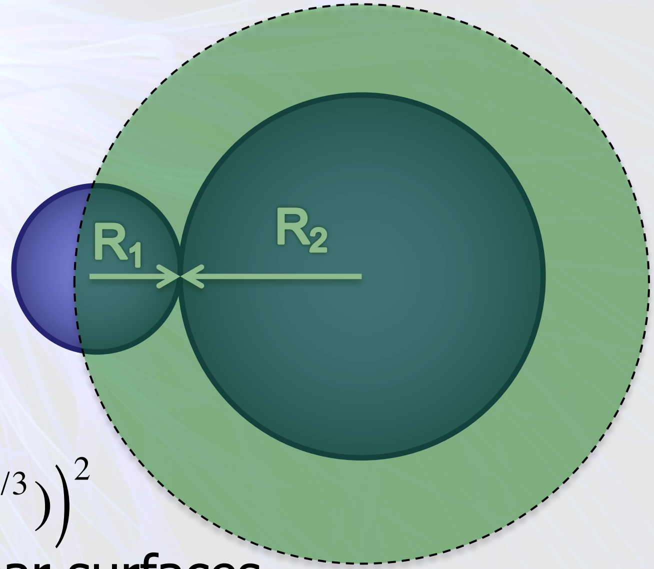
Binary Collisions, Number of participants



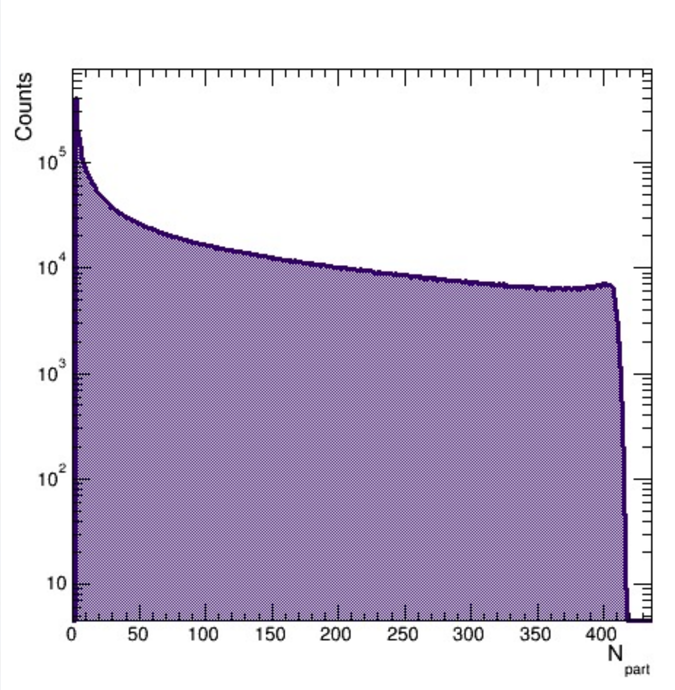
- If two nucleons get closer than $d^2 < \sigma/\pi$ **they collide.**
- **Each colliding nucleon is a "participant" (Dark colors)**
- **Count number of binary collisions.**
- **Count number of participants**

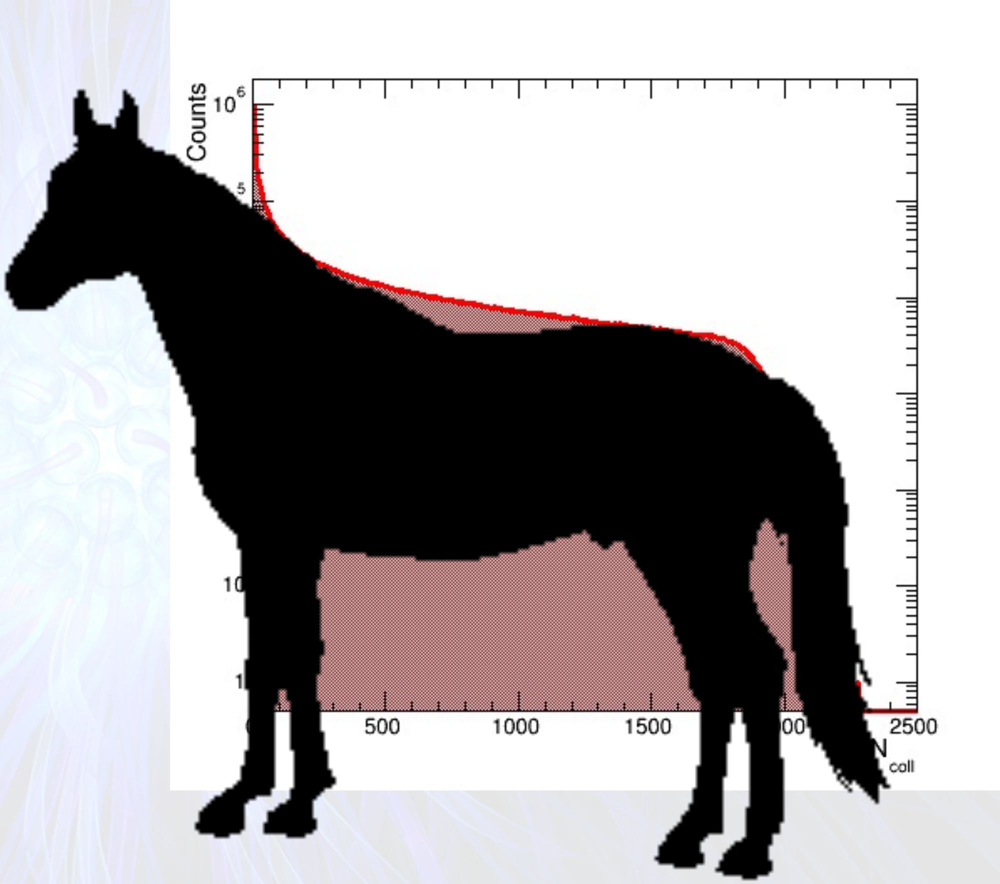
Cross Section in Nuclear Collisions

- Nuclear forces are short range
  - Range for Yukawa Potential $R \sim 1/M_x$
    - Exchanged particles are pions: $R \sim 1/(140\ \text{MeV}) \sim 1.4\ \text{fm}$
  - Nuclei interact when their edges are ~ $1\,\text{fm}$ apart
  - 0th Order: Hard sphere
  - $\sigma_{\text{geom}} = \pi\left(R_1 + R_2\right)^2 = \pi r_0^2\left(A_1^{1/3} + A_2^{1/3}\right)^2$
    - $r_0 = 1.2\ \text{fm}$
  - Bradt & Peters formula
    - $\sigma_{\text{geom}} = \pi r_0^2\left(A_1^{1/3} + A_2^{1/3} - b\right)^2$
    - b decreases with increasing A_{min}
  - J.P. Vary's formula:
    - $\sigma_{\text{geom}} = \pi r_0^2\left(A_1^{1/3} + A_2^{1/3} - b_0(A_1^{-1/3} + A_2^{-1/3})\right)^2$
    - Last term: curvature effects on nuclear surfaces



Find N_{part}, N_{coll}, b distributions

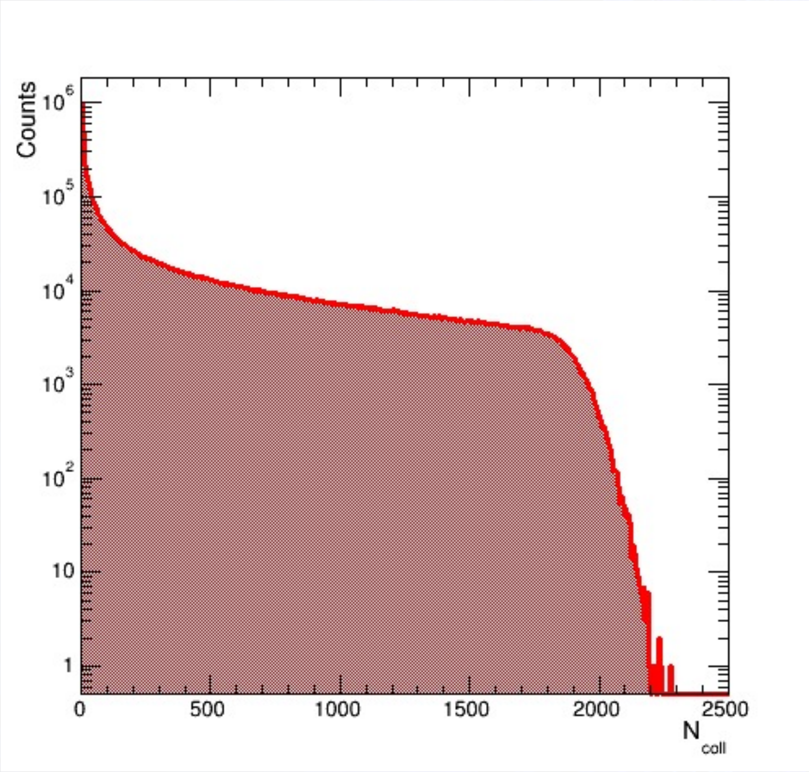


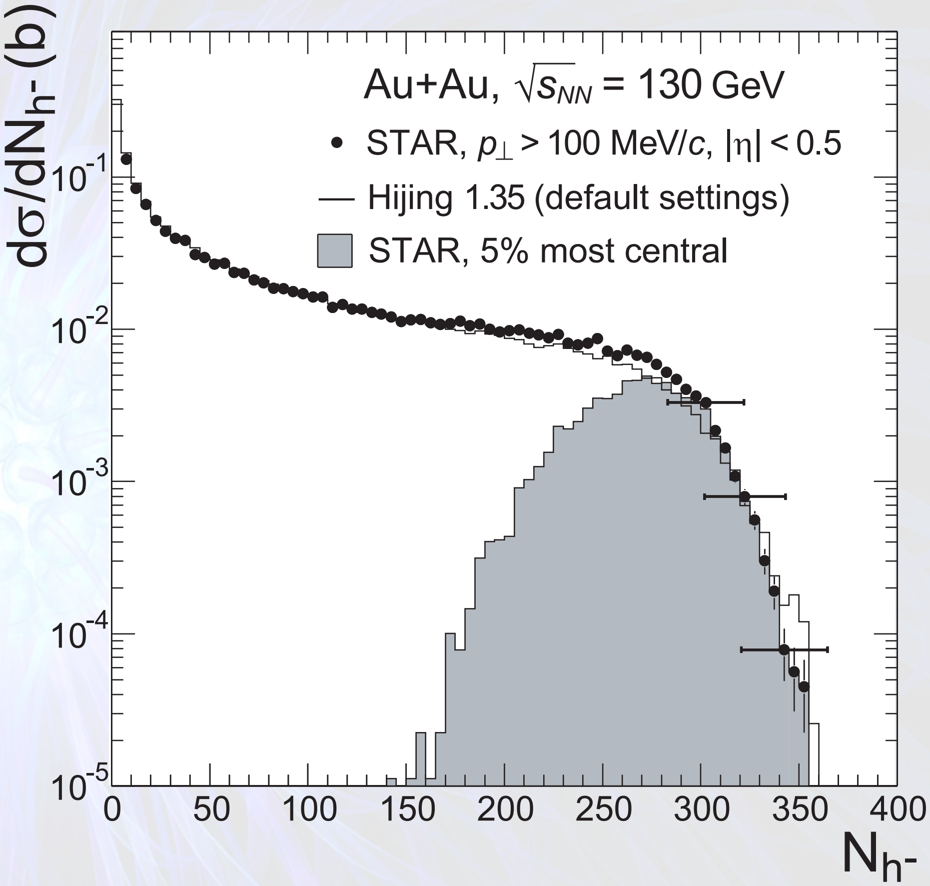


- Nuclear Collisions

From Glauber to Measurements

- Multiplicty Distributions in STAR



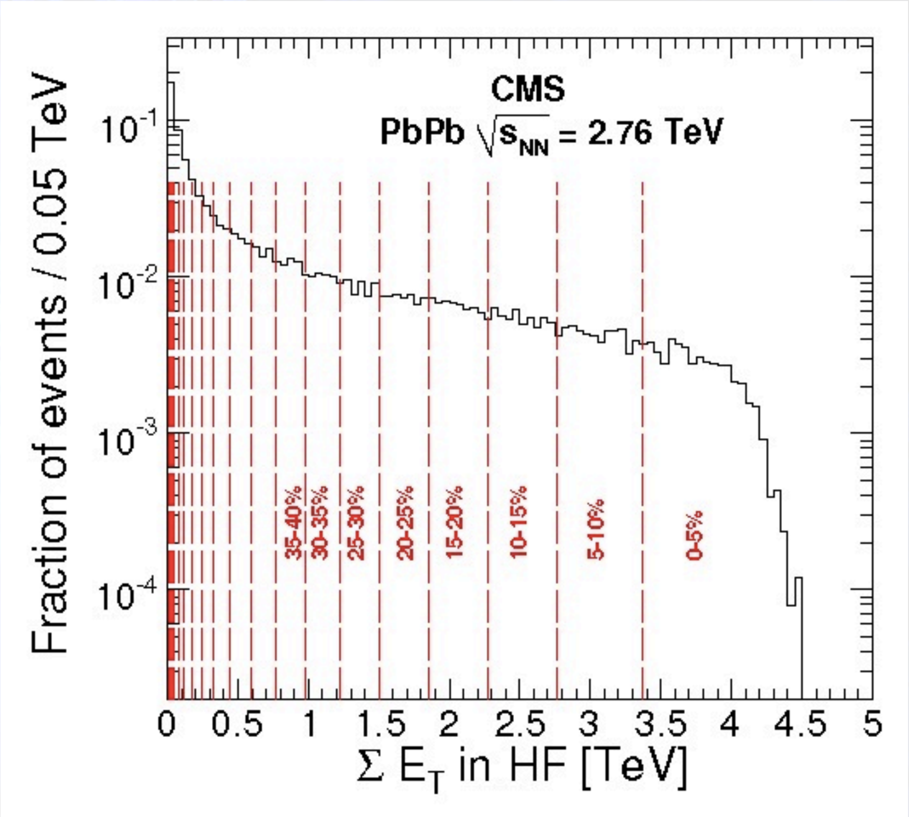


MCBS, Ph.D Thesis

Phys.Rev.Lett. 87 (2001) 112303

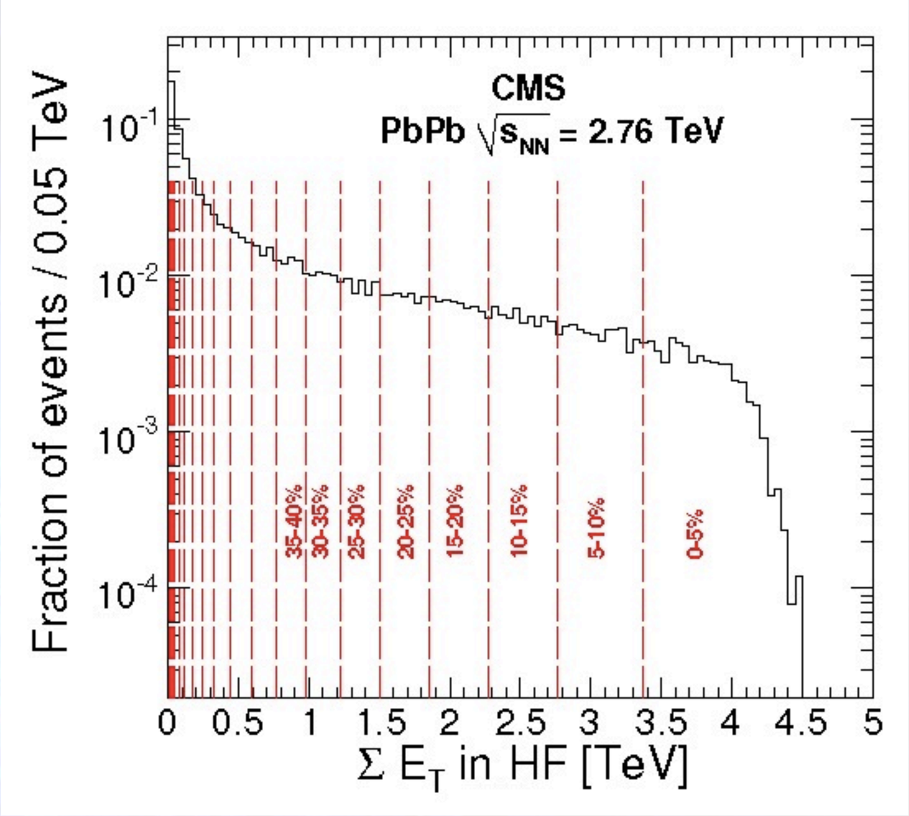
Comparing to Experimental data: CMS example

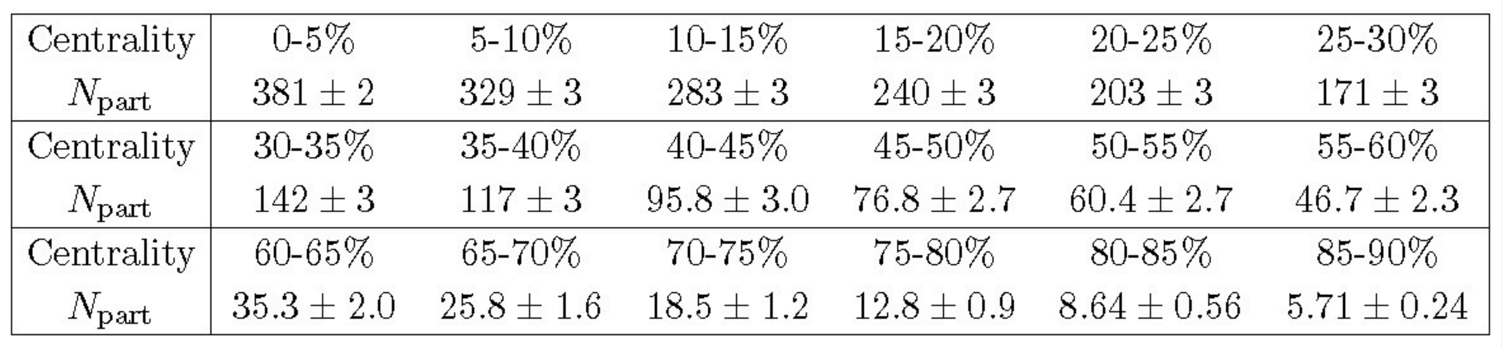
- Each nucleon-nucleon collision produces particles.
  - Particle production: negative binomial distribution.
- Particles can be measured: tracks, energy in a detector.
- CMS: Energy deposited by Hadrons in “Forward” region



Centrality Table in CMS

- From CMS MC Glauber model.
- CMS: HIN-10-001,
- JHEP 08 (2011) 141





Centrality	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%
N_{part}	381 ± 2	329 ± 3	283 ± 3	240 ± 3	203 ± 3	171 ± 3
Centrality	30-35%	35-40%	40-45%	45-50%	50-55%	55-60%
N_{part}	142 ± 3	117 ± 3	95.8 ± 3.0	76.8 ± 2.7	60.4 ± 2.7	46.7 ± 2.3
Centrality	60-65%	65-70%	70-75%	75-80%	80-85%	85-90%
N_{part}	35.3 ± 2.0	25.8 ± 1.6	18.5 ± 1.2	12.8 ± 0.9	8.64 ± 0.56	5.71 ± 0.24