Roy Glauber: in Memoriam

The Glauber-Model
in High Energy Nucleus-Nucleus Collisions

Reinhard Stock, Goethe University Frankfurt
Roy Glauber

- born Sept. 1, 1925 New York
- 1941 undergrad. Harvard
- 1943 Manhattan Project
- 1949 PhD. with J. Schwinger Harvard
- 1976 Professor at Harvard
  - Quantum Electrodyn. of interacting light and matter
  - Quantum optics
  - High energy Hadron-Nucleus Collisions
- 2005 Nobel Prize
- He died on Dec. 26, 2018
Fraunhofer Diffraction Scattering in pA and AA Collisions

- An “optical” view of hadron scattering
- Nucleons at high E are essentially undeflected because $p_{\text{long}} \gg p_t$
- like light “rays”
- Along their linear trajectories they add up the phase shifts from successive scattering encounters
- They cast a shadow, like X-Ray pictures: Eikons

V. Franco and R. Glauber, PRL 22 (1996) 370
Participant and Collision-Number

The hypothesis of independent linear trajectories of the constituent nucleons of target and projectile nuclei makes it possible to simply count the number of participating nucleons and the number of N-N collisions in dependence on the basic input N-N cross section.

The collision geometry: target mass $A$ and projectile mass $B$ and impact parameter $b$

$$\{A, B, b, \sigma_{NN}\} \leftrightarrow N_{\text{part}}, N_{\text{coll}}$$

$$\Rightarrow \sigma_{AB,\text{tot}}$$


M. Miller, K. Reygers, S. Sanders, P. Steinberg
Bevalac Physics: Carved-out Fireballs

- Geometric Picture: W. Swiatecki
  \( \text{E}_{\text{lab}}, N_{\text{partA}}, N_{\text{partB}} \rightarrow E_{\text{cm}} \) and \( N_{\text{fireball}} \)
  Abrasion-Ablation model
  [Diagram]

- Thermal equilibrium a la Hagedorn

\[ \Rightarrow \text{Hadron Spectra} \]

\[ \beta_{\text{inc}} \]

\[ \beta \]

20Ne+U up to 2.1 AGeV


FIG. 1. A neon nucleus is incident on the uranium nucleus with a velocity \( \beta_{\text{inc}} \) in the laboratory frame and impact parameter \( b \). The swept-out nucleons from the projectile and target are called the fireball, and their center of mass has the velocity \( \beta \) in the laboratory frame.
Note: In collisions of A<B the dynamics and composition of the fireball depend critically on impact parameter $b$

Fig. 2. "Rows on rows". An illustration of the one-dimensional cascade model. Projectile and target are decomposed into rows of nucleons (in beam direction). Only corresponding rows on the same straight line scatter by each other. For instance, projectile nucleon 1 scatters by target nucleons 1 to 7, then projectile nucleon 2 scatters by target nucleons 1 to 7, etc. Interactions among projectile and among target nucleons are excluded.
Difficulty with very Asymmetric Collisions-Systems

⚠️ Watch out in p+A, d+A etc.!

the effective CM-System of soft production falls significantly below $y_{\text{mid}}$ of hard production!

$\Delta y_{\text{mid}} \approx 2$ depending of impact parameter

This explains the preference for equal mass systems:

- U+U at Bevalac, Pb+Pb at SPS,
- Au+Au at AGS

P. Steinberg, arXiv:nucl-ex/0703002
The $<b>$ windows from $<N_{ch}>$ windows

- Experiment determines average $N_{ch}$ in windows of centrality
- Modeling of connection between $N_{ch}$ and $N_{part}$
- All the rest follows from the Glauber Model

The Nuclear Modification Factor

Hypothesis:

• High $p_t$ “hard” hadrons result from primordial leading partons produced in hard collisions

• Upon penetration of the co-traveling QCD medium they suffer suppression

• Hadron suppression at high $p_t$

• This determines the QCD transport Coefficient $\hat{q} = \langle q^2_T \rangle / \lambda$

Define $R_{AA} = \frac{d\sigma_{AA \rightarrow h} / d^3 p}{N_{coll}(AA, b)d\sigma_{pp \rightarrow h} / d^3 p}$

$R_{AA} = 1$ if A+A is a simple scaling of p+p
Hadron suppression

PHENIX Au+Au (central collisions):
- Direct $\gamma$
- $\pi^0$ Preliminary
- $\eta$
- GLV parton energy loss ($dN^g/dy = 1100$)
Elliptic Flow Initialisation

• At RHIC and LHC this picture is semi-realistic because the resolution of the primordial time scale is $\Delta t < 0.1 \text{ fm/c}$

• Very high shutter speed!

• Good primordial time resolution unlike at SPS and RHIC BES

• Observation of the initial anisotropy in the final momentum space depends on the amount of viscous damping during hydro-transport. Quantified by $\eta/s$
Single Event Analysis

- 3 transverse density profiles at 0.01, 0.2 and 5.2 fm/c
- Falling energy density scales!
- Smoothening by $\eta/s = 0.12$
- Events show structure beyond present $v_n$ analysis
"Glauber Tomography"-Results

\( \hat{q} \) and \( \eta/s \) anti-correlated:

\[ \frac{\eta}{s} = \text{const.} \frac{T^3}{\hat{q}} \]

emerging at RHIC and LHC