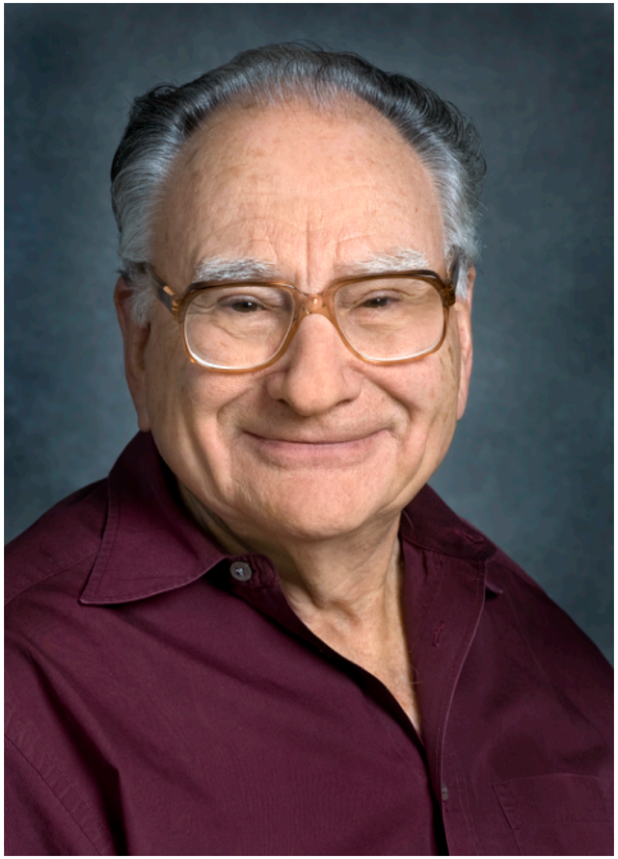
The Symposium on Collective Flow



Arthur Poskanzer
Research Highlights

Bevalac to CERN and RHIC

Reinhard Stock

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

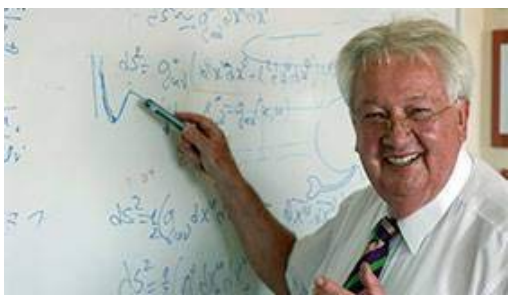
FIAS Frankfurt Institute for Advanced Studies

The GSI-LBL-Marburg-Collaboration

- founded by
  Rudolf Bock
  Arthur Poskanzer
  Reinhard Stock
  1974
- The first Group
  at Berkeley

- from Theory: Swiatecki, Randrup, Gyulassy, Danielewicz

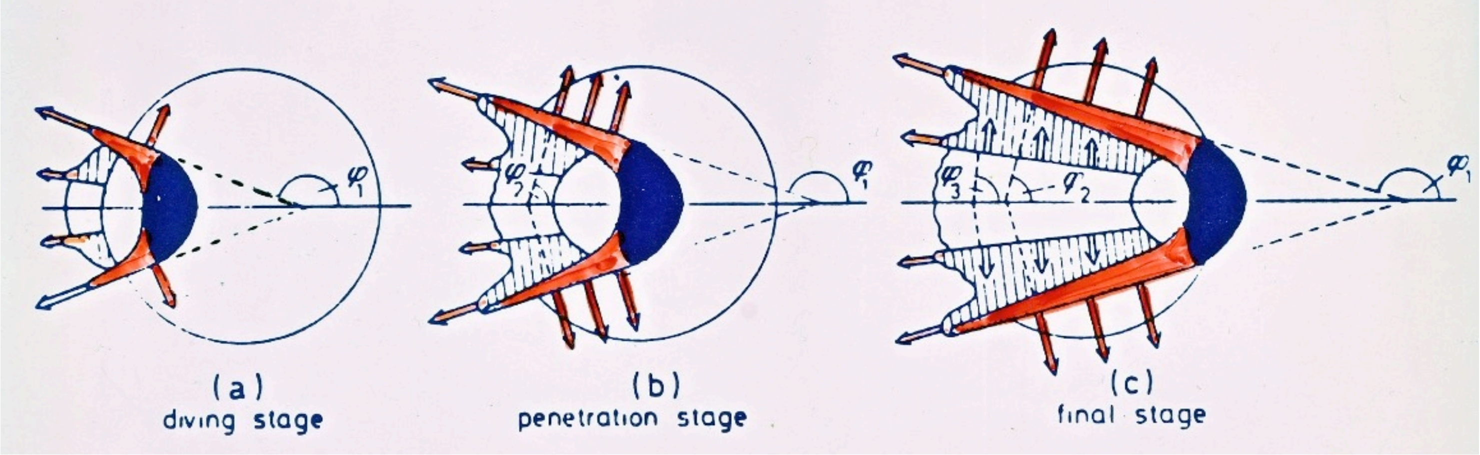
Pioneers from Overseas



- Rudolf Bock and Christoph Schmelzer agreed to send team to LBL
- Reinhard Stock and Rudolf Bock brokered deal with Art Postkanzer
- Hans Gutbrod from GSI joined Art Poskanzer at LBL
- Walter Greiner and Horst Stöcker developed idea of shock compression and side splash
- Shoji Nagamiya from Japan Spectrometer
- Andres Sandoval from Mexico Streamer Chamber

Shock Waves

- The first attempt: Emission of relativistic Shock Waves



Baumgardt, Schott, Sakamatom, Schopper, Stöcker, Greiner, Z.Ph. 253 (1975)

VOLUME 35, NUMBER 25 PHYSICAL REVIEW LETTERS 22 DECEMBER 1975

Search for Fragment Emission from Nuclear Shock Waves*

A. M. Poskanzer, R. G. Sextro, and A. M. Zebelman
Lawrence Berkeley Laboratory, University of Californ'a, Berkeley, California 94720

and

H. H. Gutbrod
Gesellschaft für Schwerionenforschung, Darmstadt, Germany

and

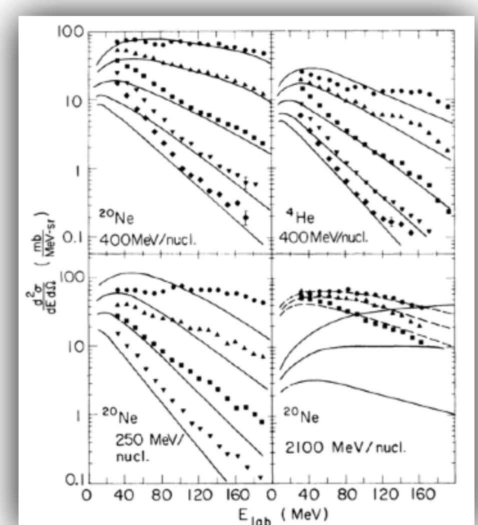
A. Sandoval and R. Stock
Fachbereich Physik, Universität Marburg, Marburg, Germany

(Received 6 October 1975)

Energy spectra and angular distributions have been measured of ^{3}He and ^{4}He fragments emitted from Ag and U targets, bombarded with 2.7-GeV protons, and 1.05-GeV/nucleon α particles and ^{16}O ions. All cross sections increase dramatically with projectile mass. No narrow peaks are found in the angular distributions or in the energy spectra.

not so!

Discovery of the Fireball



VOLUME 37, NUMBER 18 PHYSICAL REVIEW LETTERS 1 NOVEMBER 1976

Nuclear Fireball Model for Proton Inclusive Spectra from Relativistic Heavy-Ion Collisions*

G. D. Westfall, J. Gosset,† P. J. Johansen,‡ A. M. Poskanzer, and W. G. Meyer
Lawrence Berkeley Laboratory, Berkeley, California 94720

and

H. H. Gutbrod
Gesellschaft für Schwerionenforschung, Darmstadt, Germany, and Lawrence Berkeley Laboratory, Berkeley, California 94720

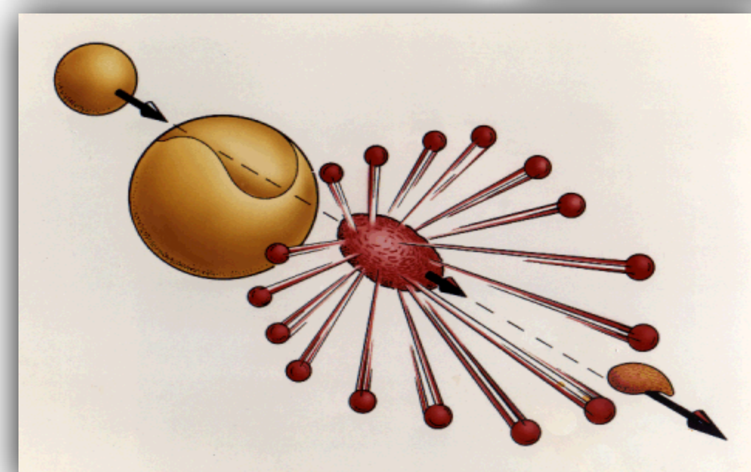
and

A. Sandoval
Fachbereich Physik, Universität Marburg, Marburg, Germany, and Lawrence Berkeley Laboratory, Berkeley, California 94720

and

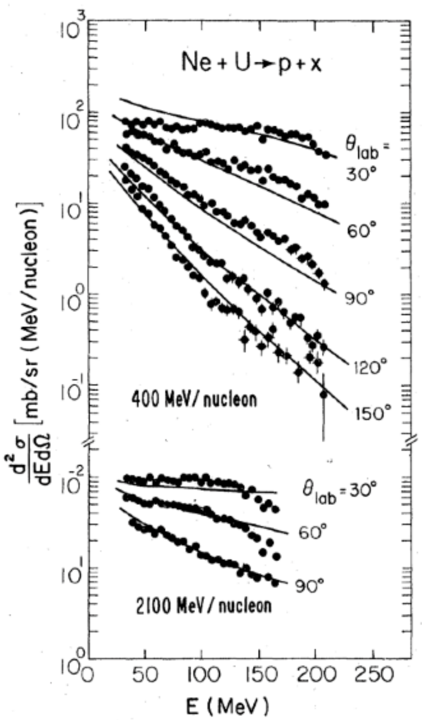
R. Stock
Fachbereich Physik, Universität Marburg, Marburg, Germany

(Received 30 August 1976)



Fireball Model

- **Three Ingredients:**
  - **Effective CM frame from Spectator/Participant picture**
  - **Global thermal equilibrium à la Hagedorn - AMP idea**
  - **Isotropic emission from fireball CM**



PHYSICAL REVIEW C VOLUME 18, NUMBER 2 AUGUST 1978

Calculations with the nuclear firestreak model*

J. Gosset,† J. I. Kapusta, and G. D. Westfall
Lawrence Berkeley Laboratory, Berkeley, California 94720
(Received 27 March 1978)

A model is presented which is capable of calculating simultaneously the spectra of pions, nucleons, and light nuclei from the collision of relativistic heavy ions. It is based on the nuclear thermodynamics of Mekjian and Kapusta. Maximum use is made of the conservation laws for baryon number, charge, energy, momentum, and angular momentum. Single particle inclusive cross sections were calculated and compared with experiment for a wide range of beam energies and observed fragments. Except for some conflicting normalizations and high-energy pions good agreement is found. The density at which hadrons effectively cease to interact, which is the only parameter in the model, is determined to be 0.12 hadrons/fm^3.

[NUCLEAR REACTIONS Relativistic heavy ions; firestreaks, hadronic thermal equilibrium; calculated differential cross sections of $\pi^{\pm}$, p, d, t, ^{3}He, ^{4}He; comparisons with experiment.]

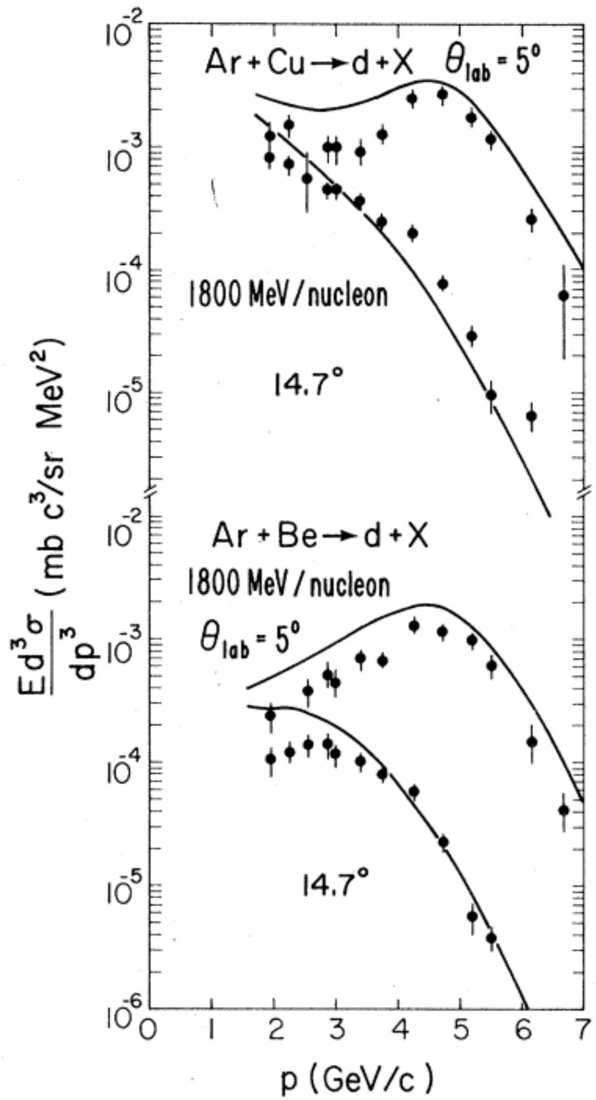
Cluster Production: Light Nuclei

- **Deuterons from Firestreak Model**
- **Alternative View: Coalescence**

$$< d > \;\propto\; < p, n >^2$$

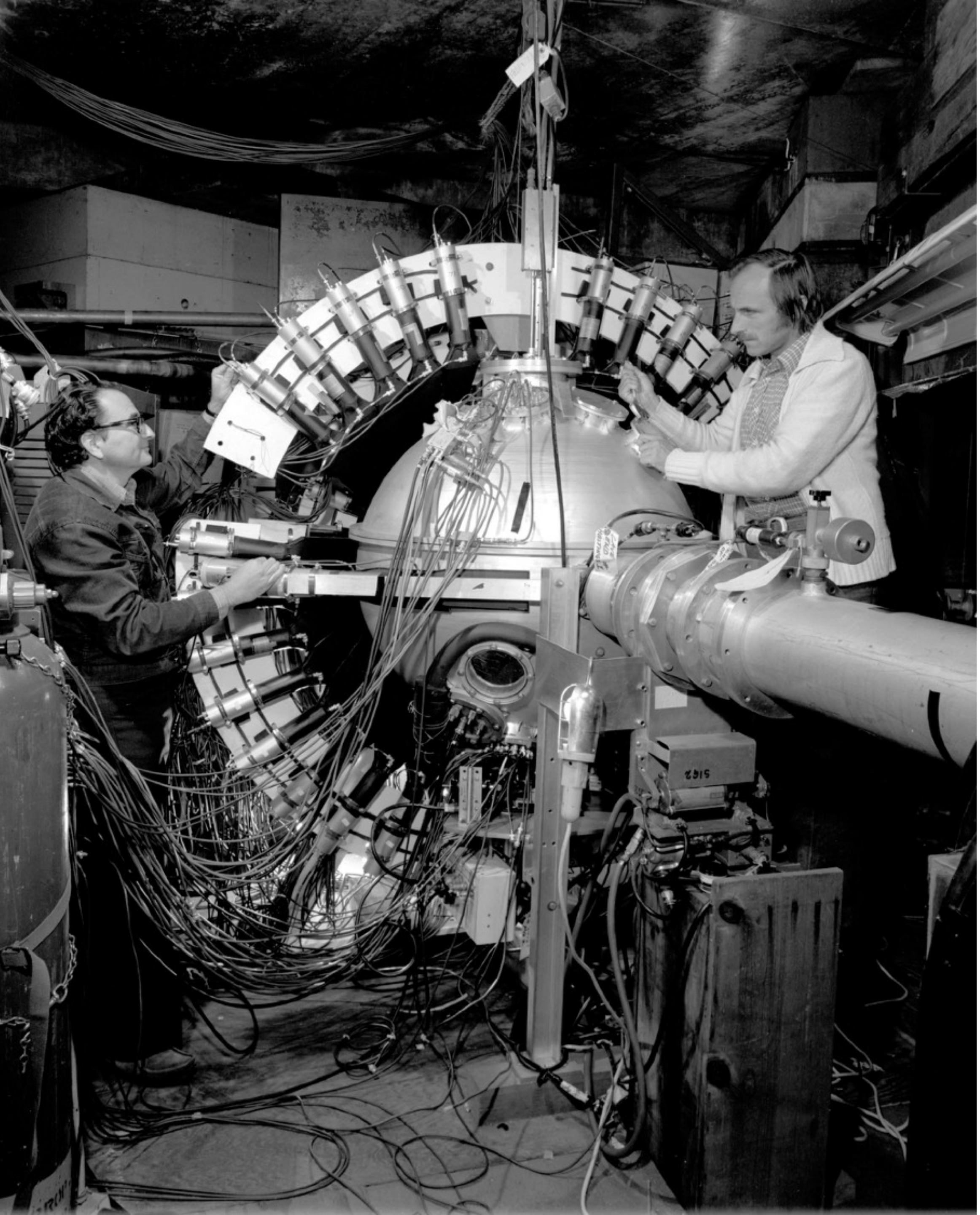
- **Ed Remler translated by Miklos Gyulassy**
- **Thermodynamics by Aram Mekjian**

Hot until today!
"Snowballs in Hell"



Physics for Four Decades

- **Statistical Fireball → Critical Temperature from Hadron Yields: Hadro Chemistry T ≈ 160 MeV**
- **Origin of Clusters (Quantum Mechanics?)**

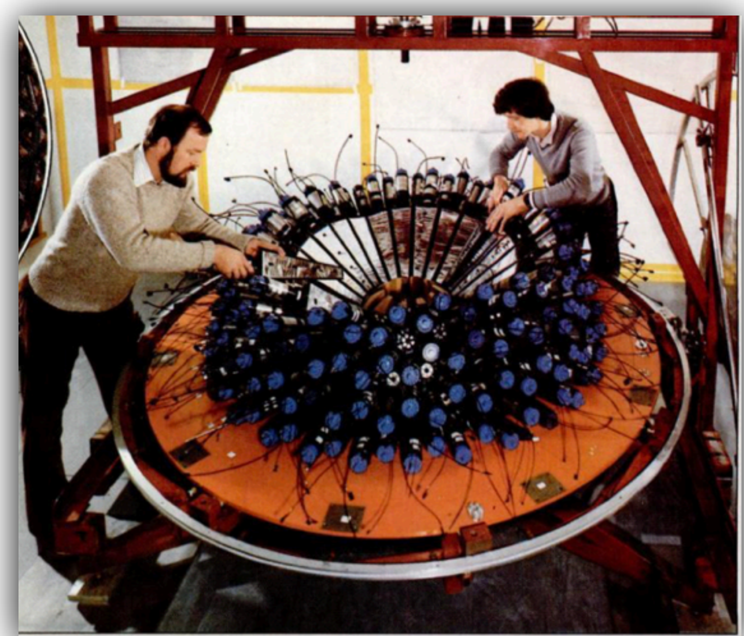


Art Poskanzer: "the Berkeley Hippy who finally became a dignified Frankfurt Professor…."

The Plastic Ball Era
1980 ff

- Hydrodynamic Flow studied with the Plastic Ball
- 4π-Detector instead of "Keyhole"-Physics
- Three "parents":
  - Stanford Crystal Ball
  - Wilkinson Phoswitch with 2 Scintillators, CaF_2 & Plastic
  - ΔE/E Analysis from low energy Nuclear Physics

1981: Assembly of 1st sphere at LBL

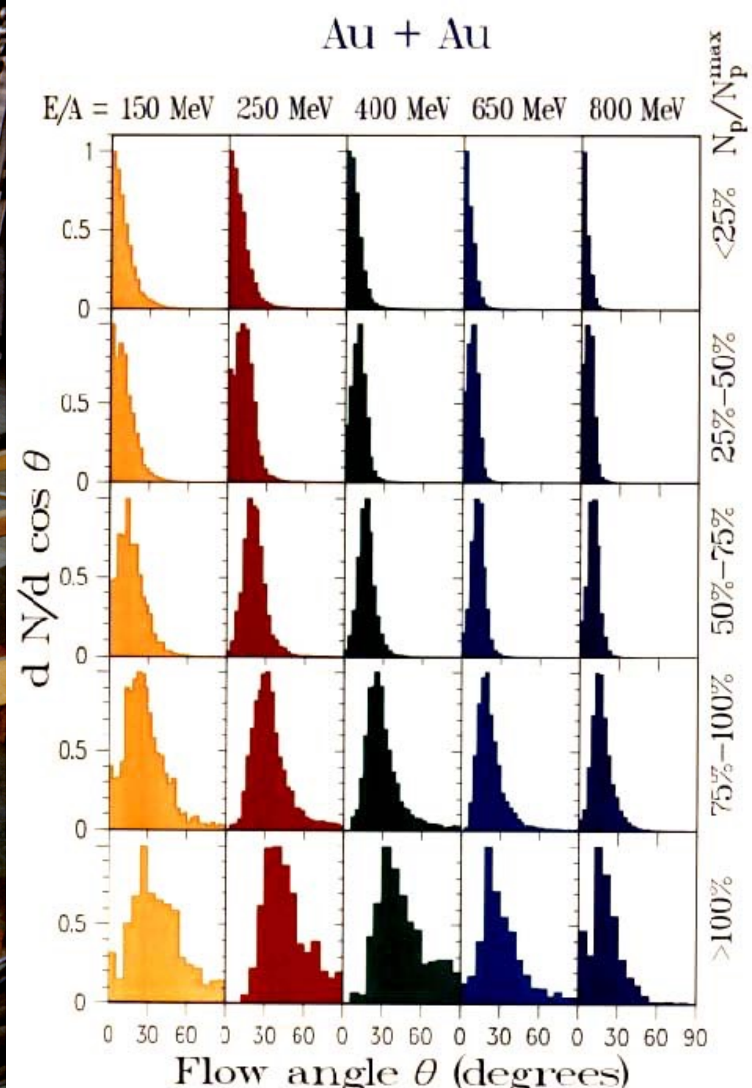


View from bottom

Plastic Ball Detector System

- **Principal Actors:**
  Hans-Georg Ritter
  Hans Gutbrod
  Arthur Poskanzer

Plastic Ball Detector System



- **The Big Bang**

VOLUME 52, NUMBER 18 PHYSICAL REVIEW LETTERS 30 APRIL 1984

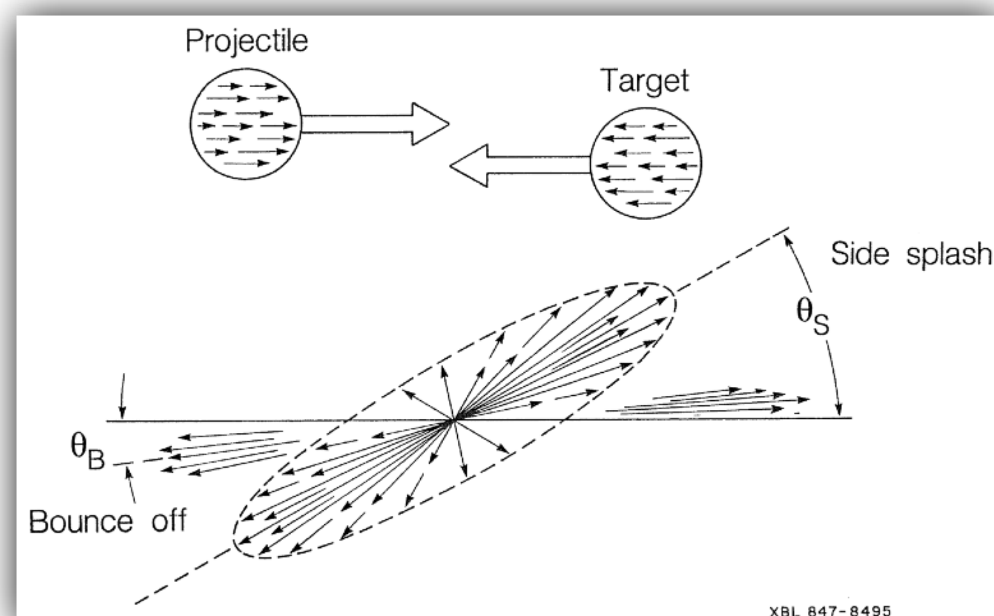
Collective Flow Observed in Relativistic Nuclear Collisions

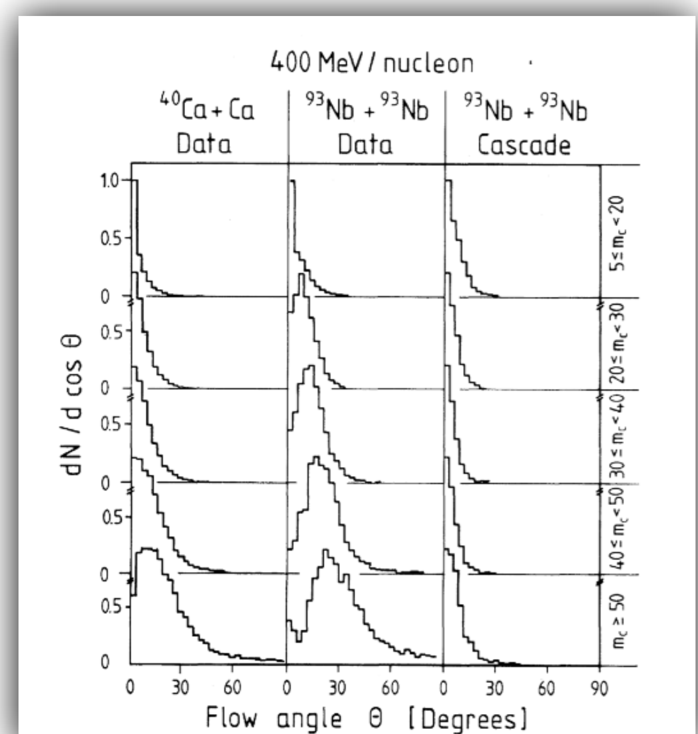
H. A. Gustafsson, H. H. Gutbrod, B. Kolb, H. Löhner,[(a)] B. Ludewigt, A. M. Poskanzer, T. Renner, H. Riedesel,[(b)] H. G. Ritter, A. Warwick,[(c)] F. Weik,[(d)] and H. Wieman
Gesellschaft fur Schwerionenforschung, Darmstadt, West Germany, and Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 21 February 1984)

The reactions Ca + Ca and Nb + Nb at 400 MeV/nucleon have been studied at the Bevalac using the "Plastic Ball" spectrometer. A global analysis of the events shows two nontrivial collective flow effects: the bounceoff of the projectile fragments, and the side-splash of the intermediate-rapidity fragments for the higher-multiplicity Nb + Nb events. Neither effect is seen in a knockon cascade calculation. A simulation with an event-generating statistical model has been done in order to extract the magnitudes of the effects.

$$F_{ij} = \frac{1}{2}\sum_{\nu} \vec{p}_i(\nu)\vec{p}_j(\nu)/m(\nu)$$

(Sphericity Analysis)





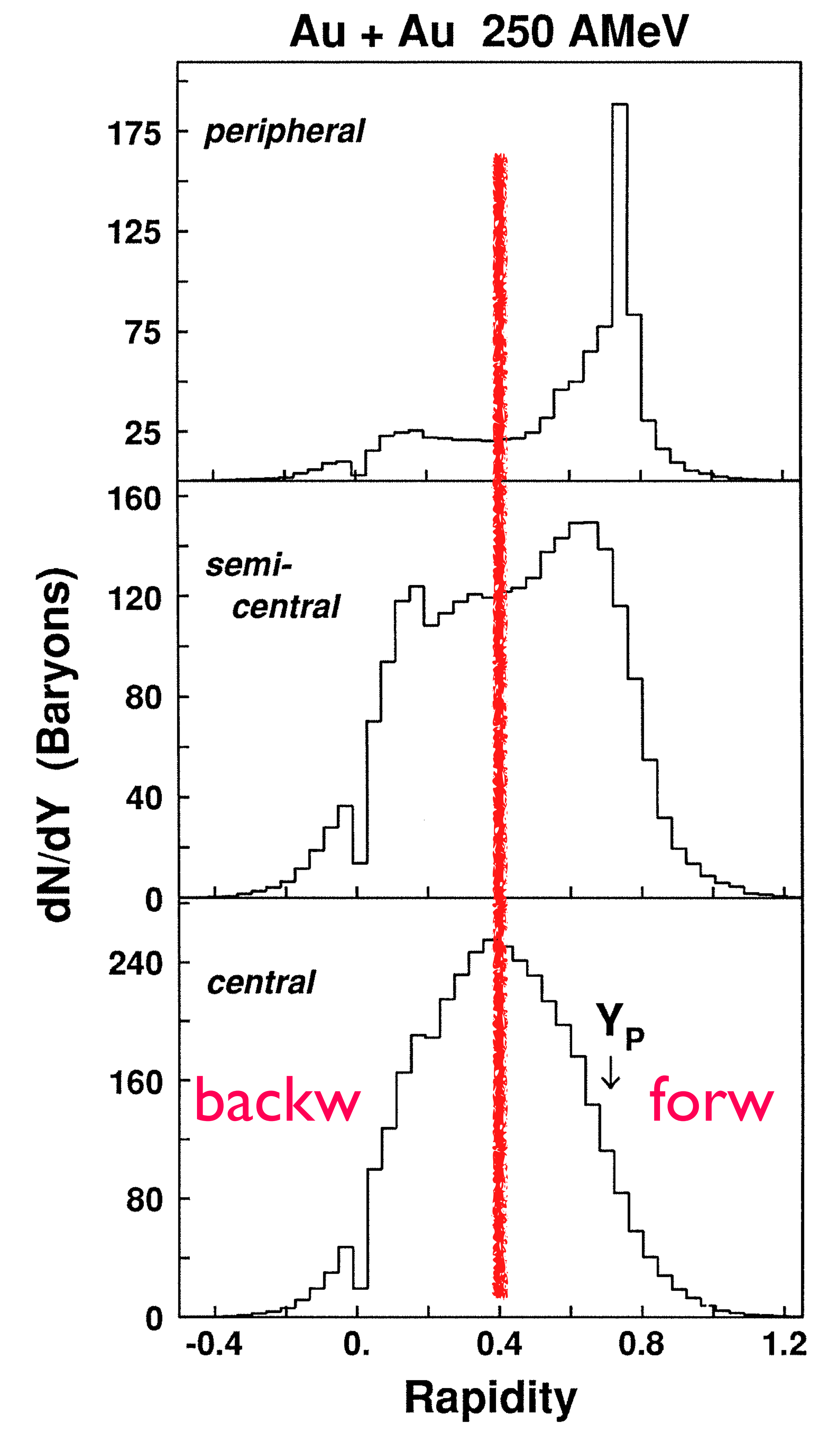
Transverse Momentum Analysis

1985

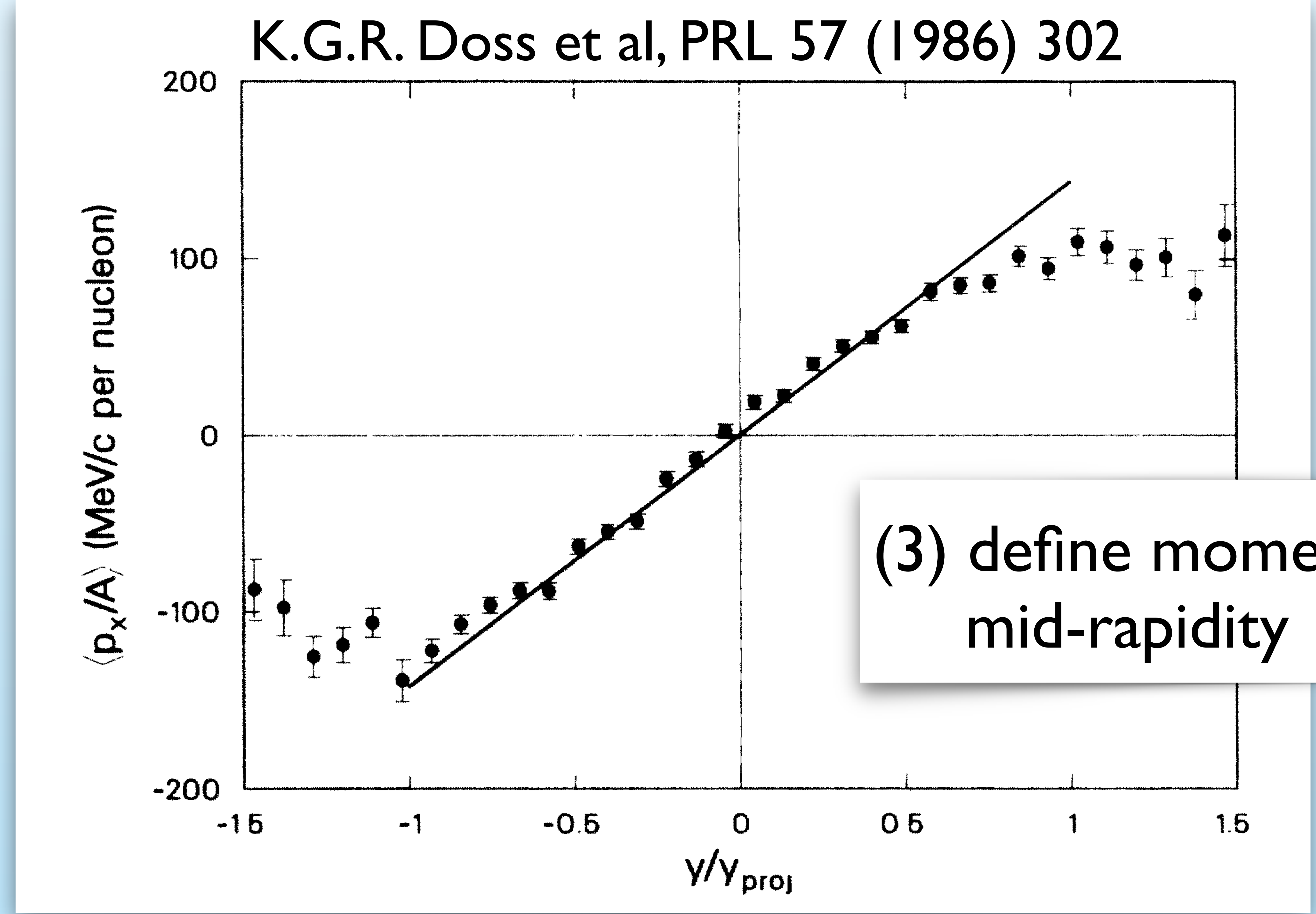
New method of analysis introduced by P. Danielewicz and G. Odyniec; Phys. Lett. 157B (1985) 146

(1) calculate reaction plane: $\vec{Q} = \sum_i \vec{p}_{\perp,i}^{\,\mathrm{forw}} - \vec{p}_{\perp,i}^{\,\mathrm{backw}}$

Plastic Ball Data



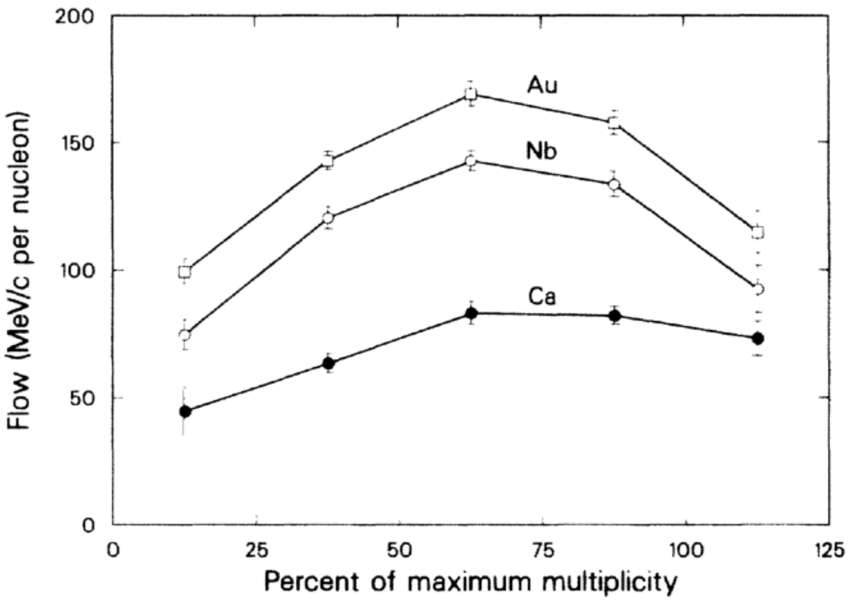
(2) project event into reaction plane → p_x



(3) define momentum flow by slope at mid-rapidity

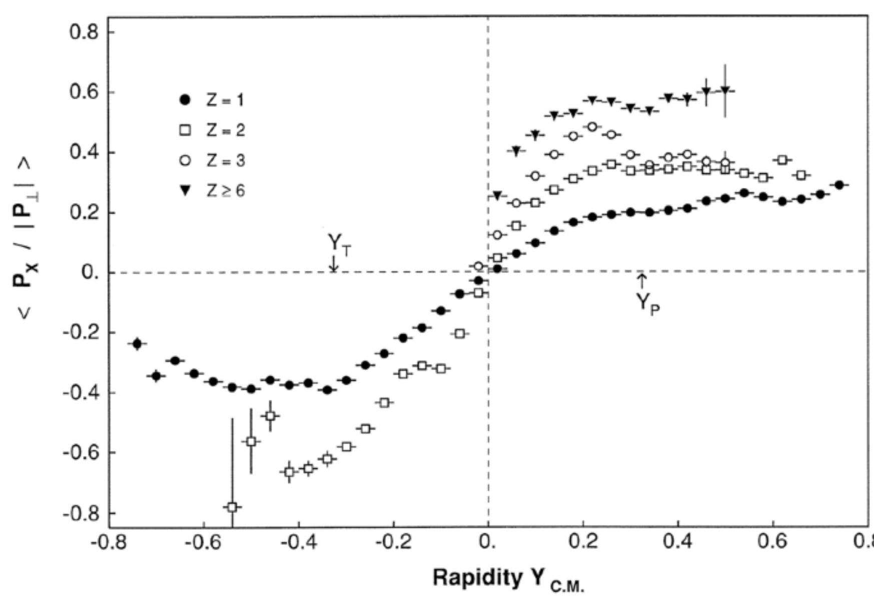
Plastic Ball Sidewards Flow v1

… as a fct of centrality

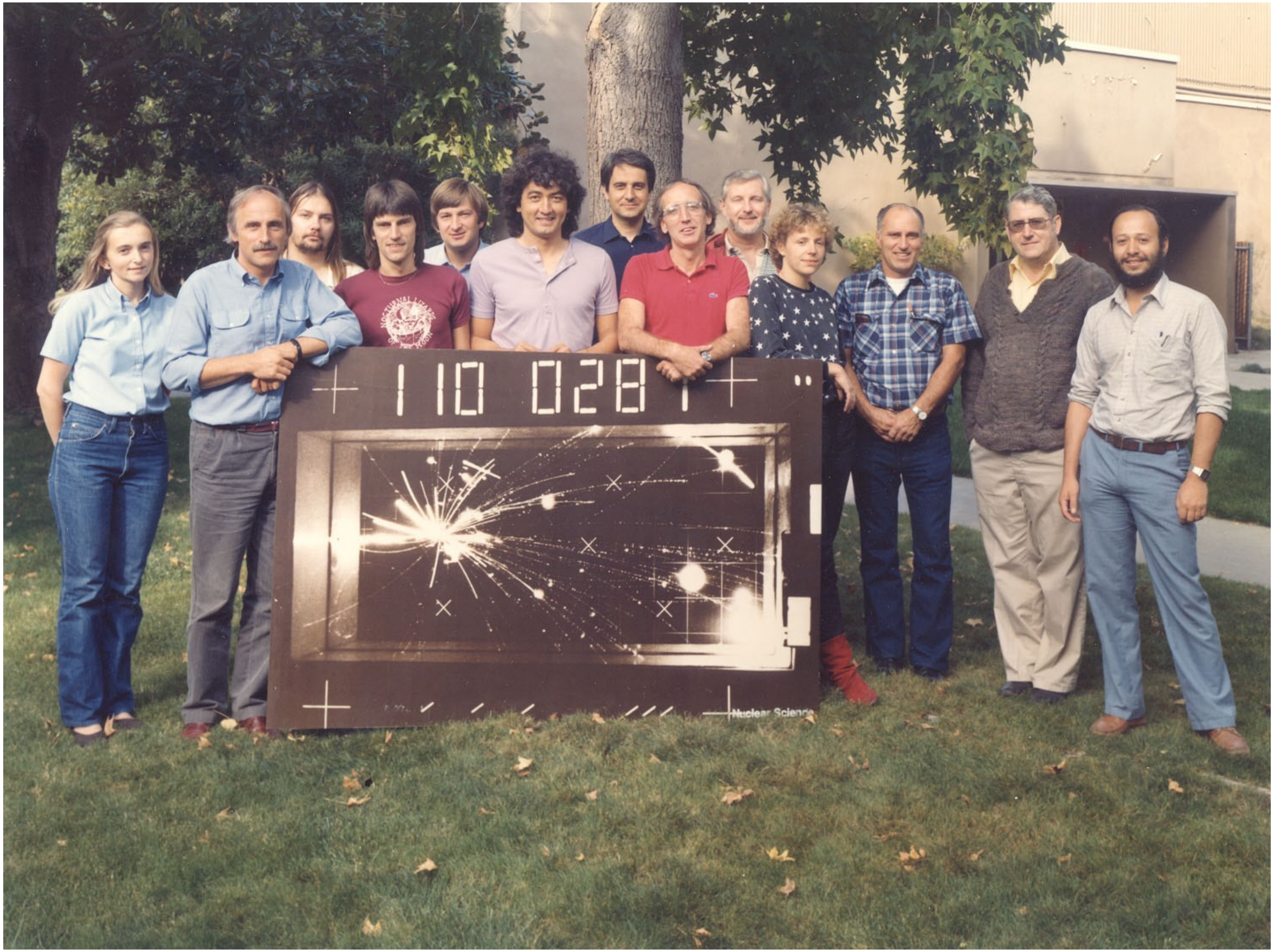


… as a fct of ejectile mass in Au+Au at 200 AMeV

K.G.R. Doss et al, PRL 59 (1987) 2720

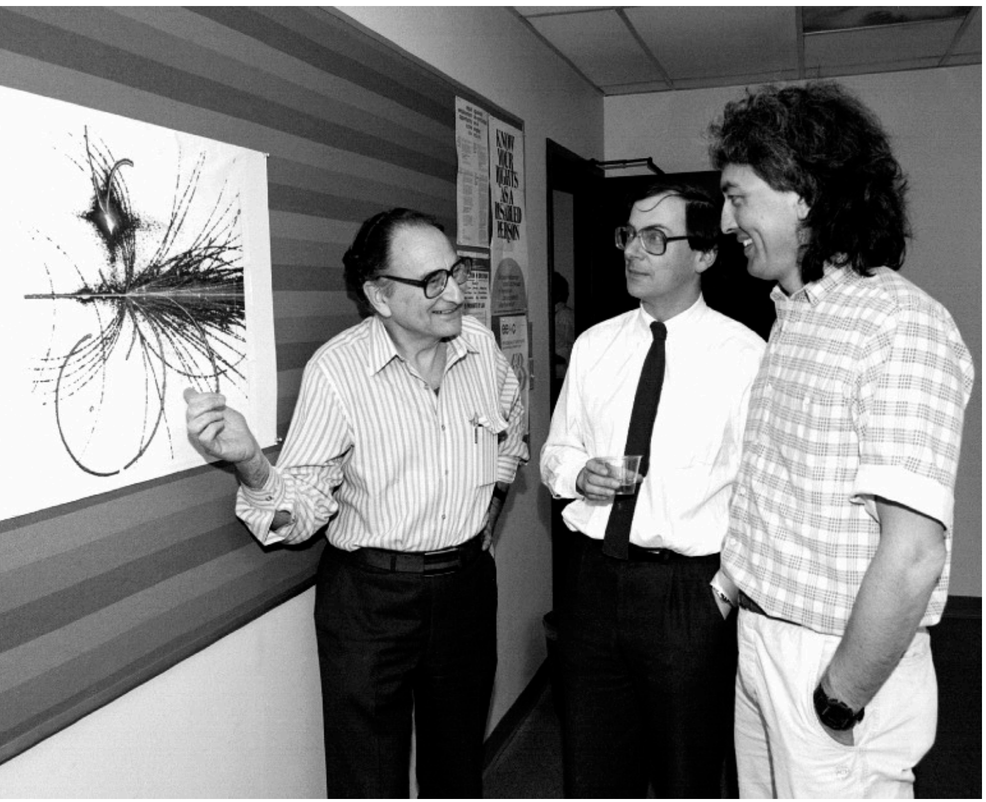


The Streamer Chamber Collaboration at LBL 1983



CERN Era

- **Art explains NA35**



STUDY OF RELATIVISTIC NUCLEUS-NUCLEUS REACTIONS INDUCED

BY ^{16}O BEAMS OF 9-13 GEV PER NUCLEON AT THE CERN PS

Proposal submitted to the CERN PSCC by the

GSI[1]-LBL[2]-Heidelberg[3]-Marburg[4]-Warsaw[5]-Collaboration

February 1982

N. Angert[1], H. Bialkowska[5], R. Bock[1], H.H. Gutbrod[1], H. Harris[1],
M.R. Maier[4], A.M. Poskanzer[2], F. Pühlhofer[4], H.G. Pugh[2],
R.E. Renfordt[3], H.G. Ritter[1], A. Sandoval[1], L.S. Schroeder[2],
E. Skrzypczak[5], R. Stock[1], H. Ströbele[1], R.Szwed[5], A. Warwick[1],
F. Weik[1], H. Wiemann[1], K.L. Wolf[2]

Elliptic Flow v2

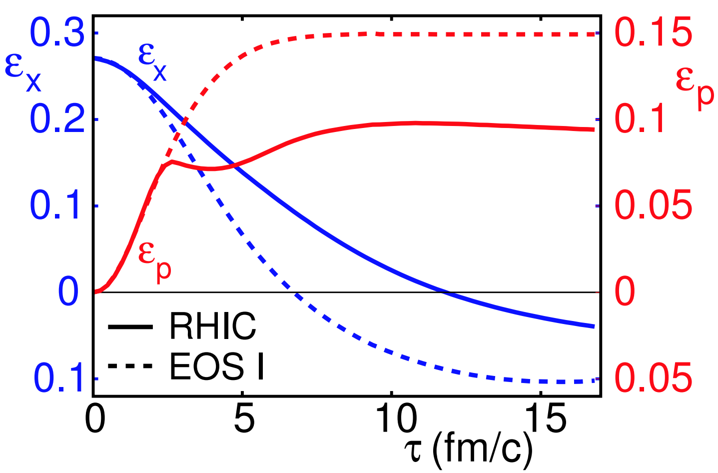
- Collective Emission from Fireball:
- Various Moments: radial, sidewards, elliptic and higher order
- Art popularised the term "elliptic flow", and he became leader of its analysis for the next decade

The famous formula:

Poskanzer and Voloshin (1998)

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\,\frac{d^2N}{p_t\;dp_t\;dy}\left(1+2\sum_{n=1}^{\infty} v_n(p_t,y)\cos(n\phi)\right)$$

- ascending moments of azimuthal hydrodynamic expansion flow



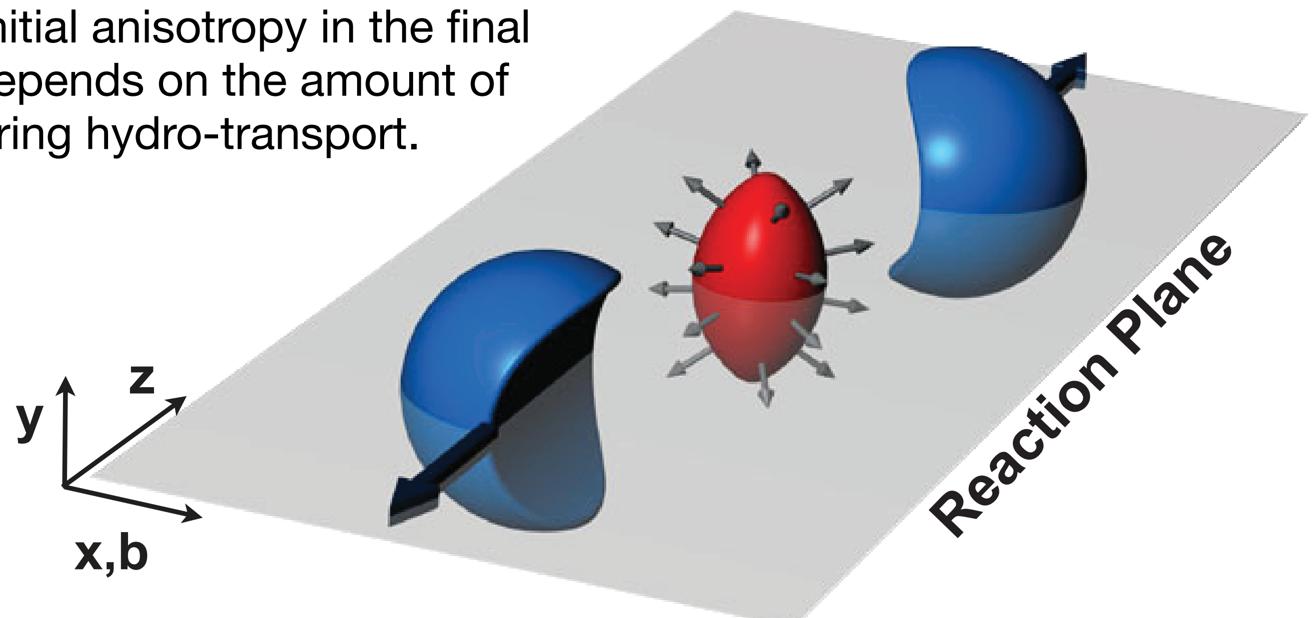
- U. Heinz: Transition of anisotropy from primordial spacial coordinate to momentum space
  enabled by the high time resolution in the dynamic at RHIC and LHC

Elliptic Flow Initialisation

- At RHIC and LHC this picture is semi-realistic because the resolution of the primordial time scale is $\Delta t < 0.1$ 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.

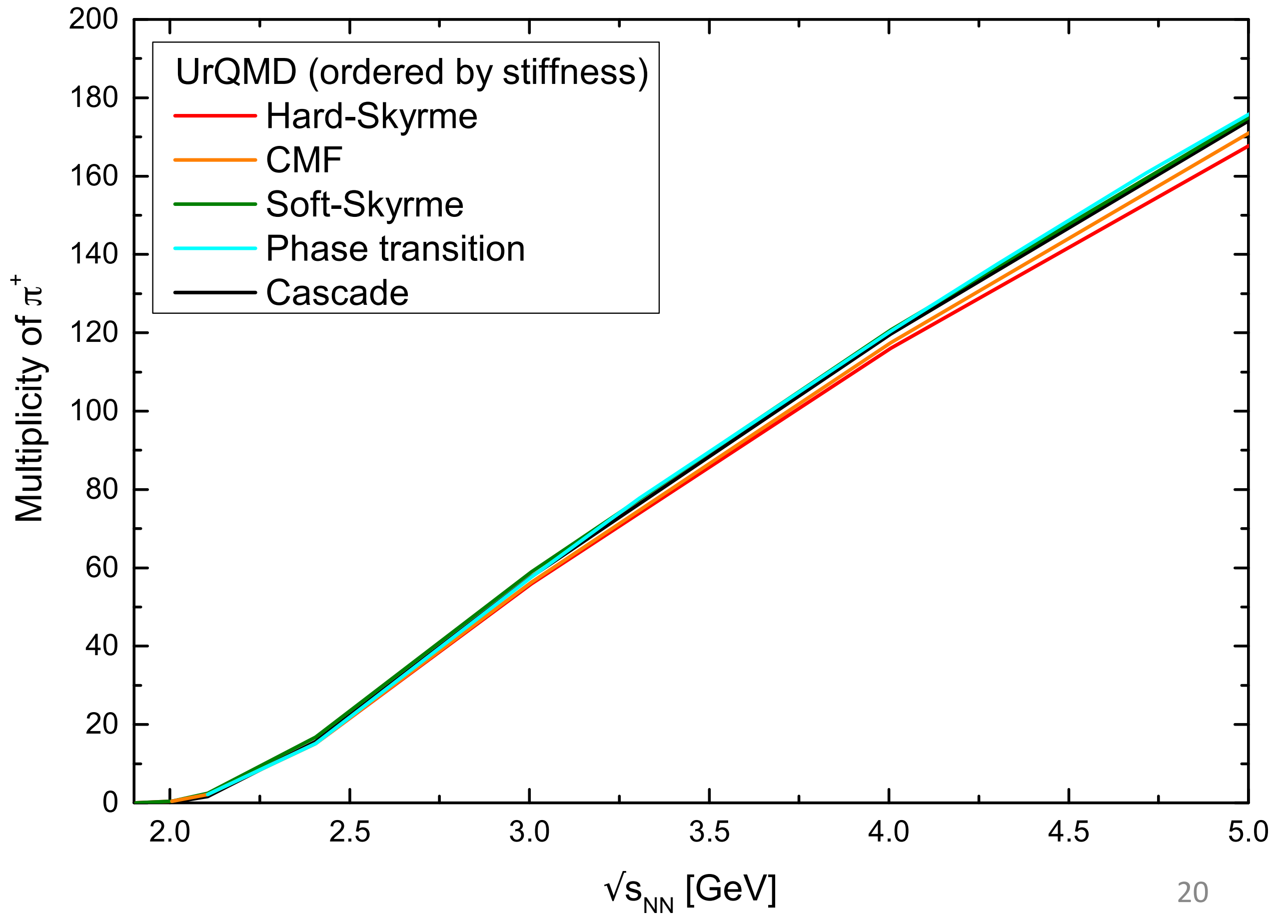
  Quantified by **η/s**

The "famous picture"



NOWADAYS, still intense work

Jan Steinheimer (Frankfurt) and coworkers



UrQMD with 5 different EOS

NO SENSITIVITY!