Reminiscences of Wit Busza and 41 Years of p+A physics

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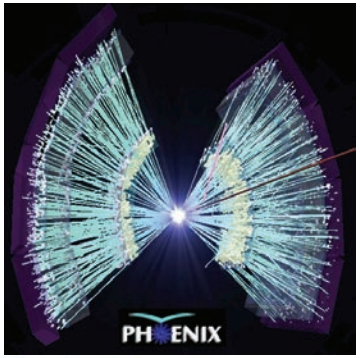

p+A Workshop
MIT, Cambridge, MA
May 17, 2013

One of the more memorable of the proposals from my service on Bob Wilson's Program Advisory Committee at FNAL from 1972-75

NAL Proposal NO. 178
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Cambridge, Mass. 02139
617- 864-6900 X7586
June, 1972

A study of the average multiplicity and multiplicity distributions in hadron-nucleus collisions at high energies

W. Busza, J. I. Friedman, H. W. Kendall and L. Rosenson
Massachusetts Institute of Technology, Cambridge, Massachusetts

ABSTRACT

In a simple counter experiment requiring about 40 hours of data taking time we propose to study the detailed shape of the multiplicity distribution for larger values of n and the average charged particle multiplicity in hadron-nucleus collisions at 100 and 200 Gev.

The results of the experiment should be a valuable input for comparison with theoretical models, in particular they should provide a sensitive test of whether multiparticle production in hadron-nucleon collisions proceeds through a one or two step process.

Wit proposed ONE photomultiplier!

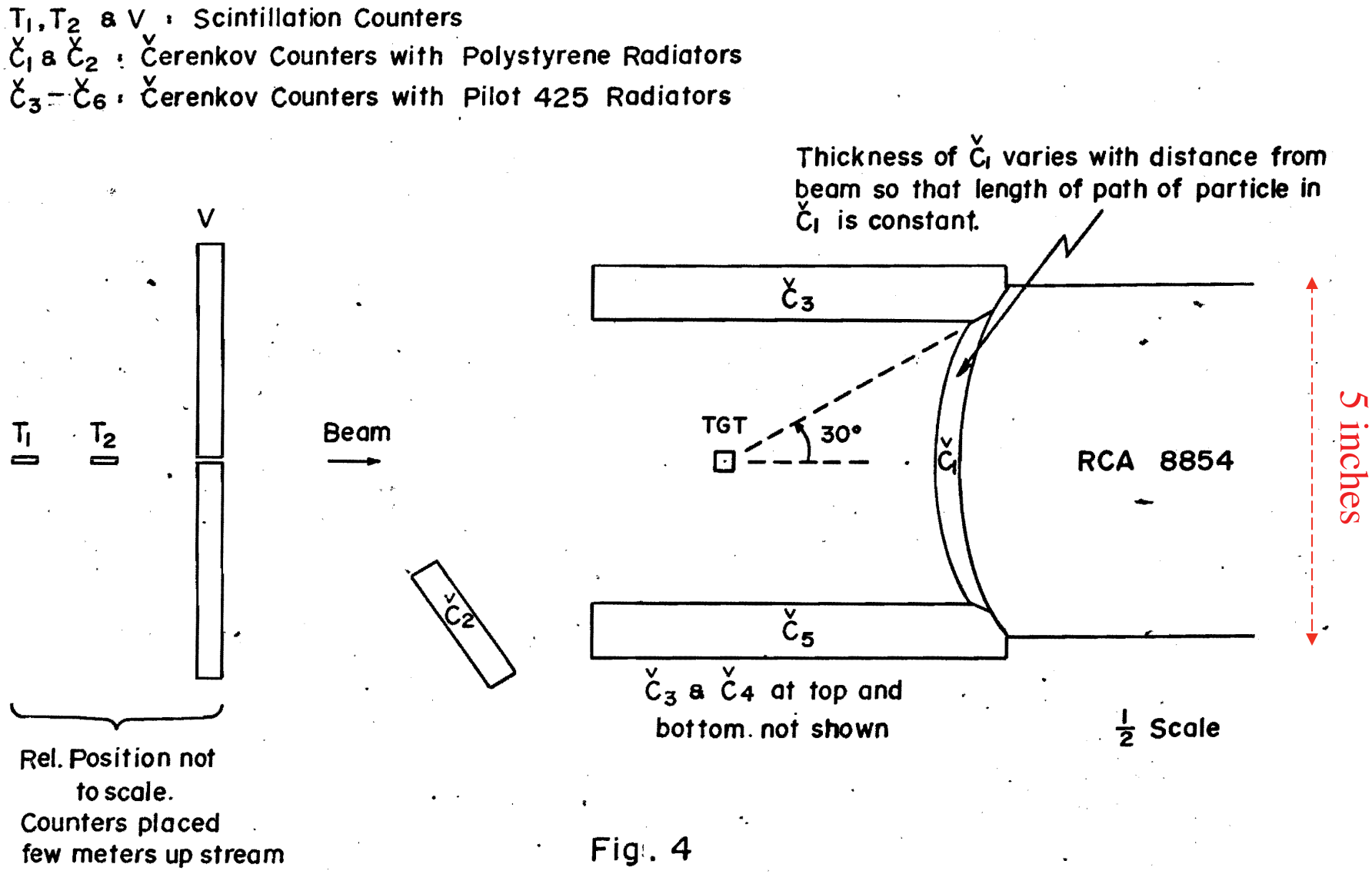


Fig. 4

State of the Art 1972 for charged multiplicity distribution from P-178

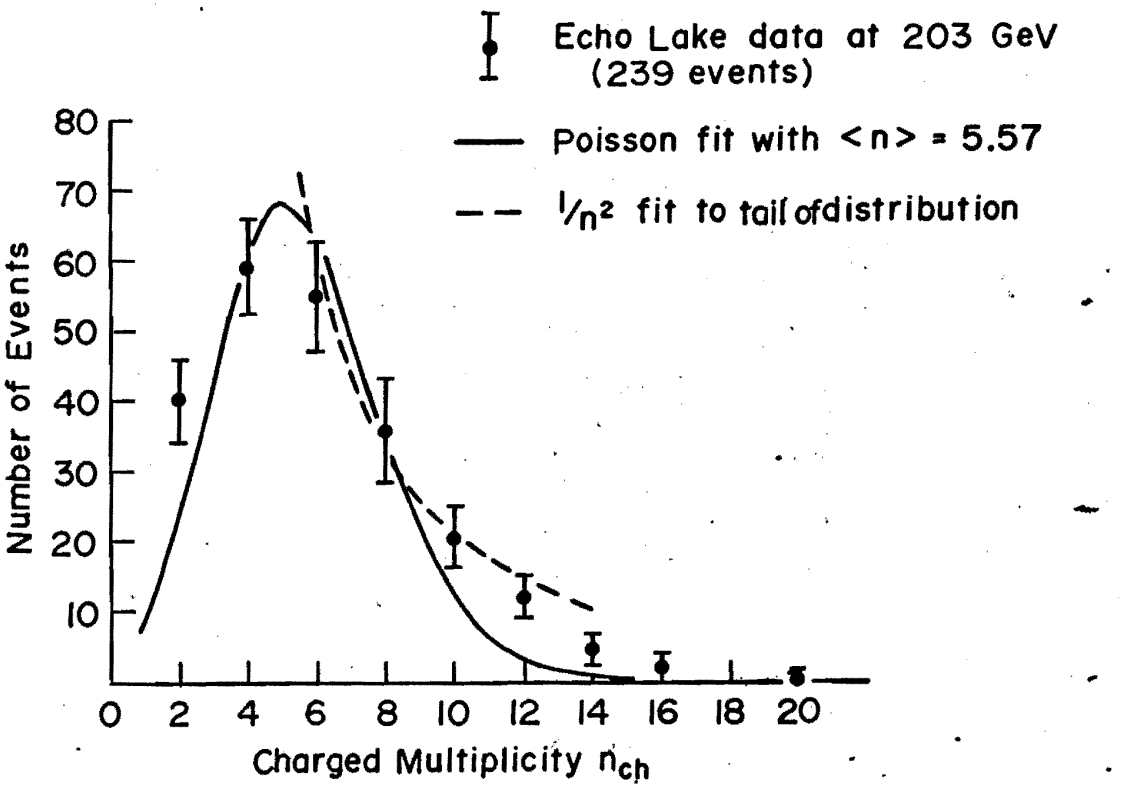
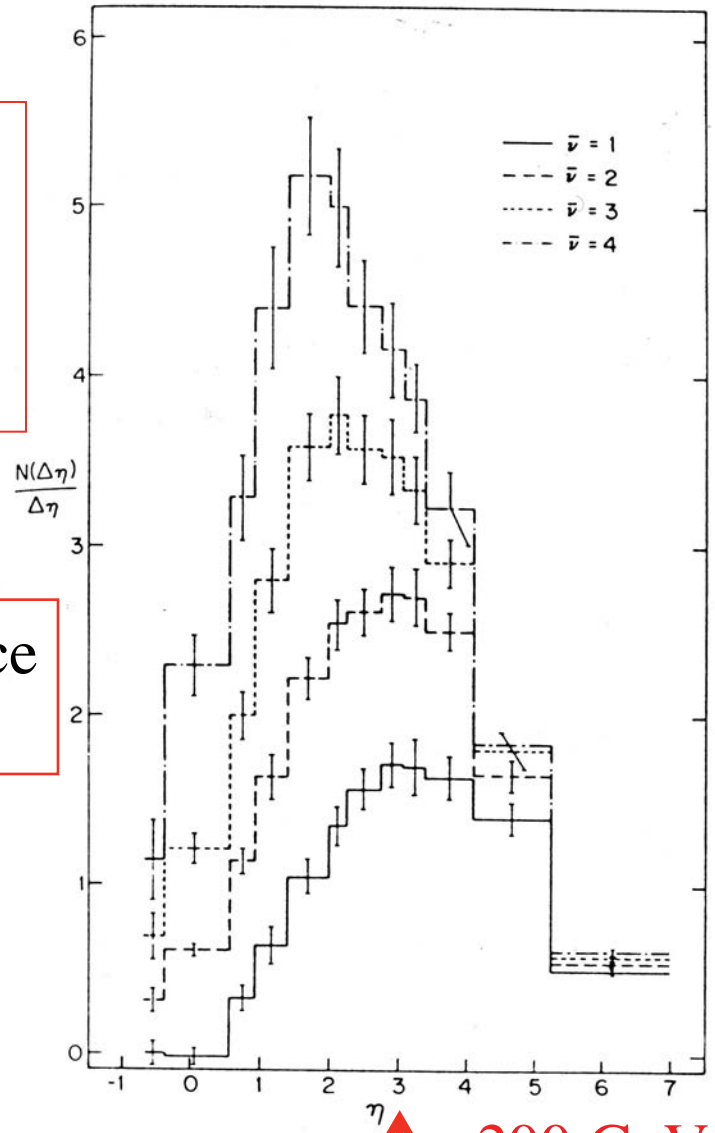


Fig.3

Result of E178 was revolutionary-I

p+A where A is represented by average number of collisions $\bar{\nu}$

Strong dependence on rapidity



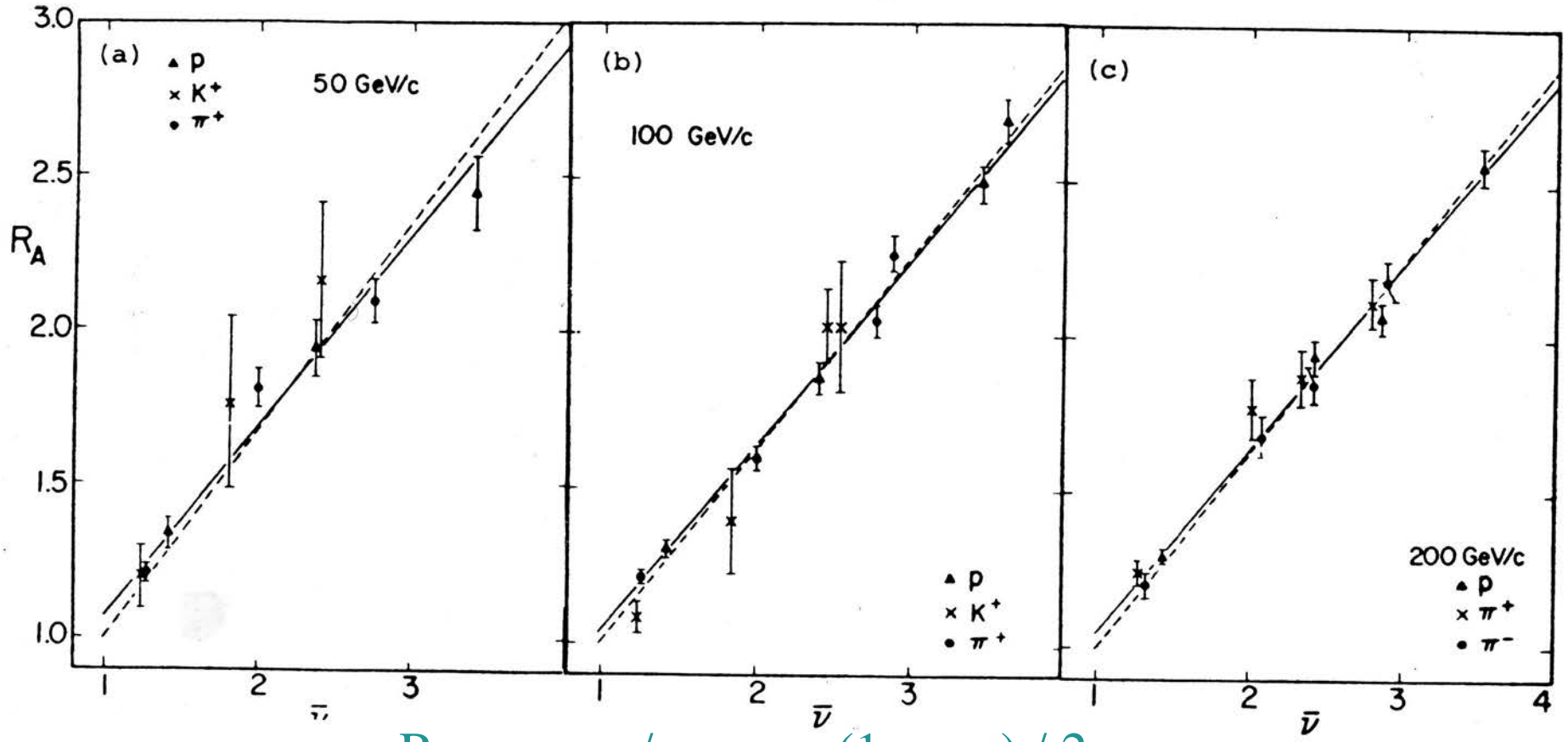
PRL **39**, 1499 (1977)

- NO CHANGE (η>5) Forward fragmentation proton passes through!!
- Tremendous Activity Target region (η<0.5)

★ Mid rapidity: dn/dη increases with A with small shift backwards with increasing A

Result of E178 was revolutionary-II

PRD **22**, 13 (1980) : N_{part} rather than N_{coll} governs particle production.
Confirms the wounded nucleon model: Bialas, et al, NPB**111**, 461 (1976)



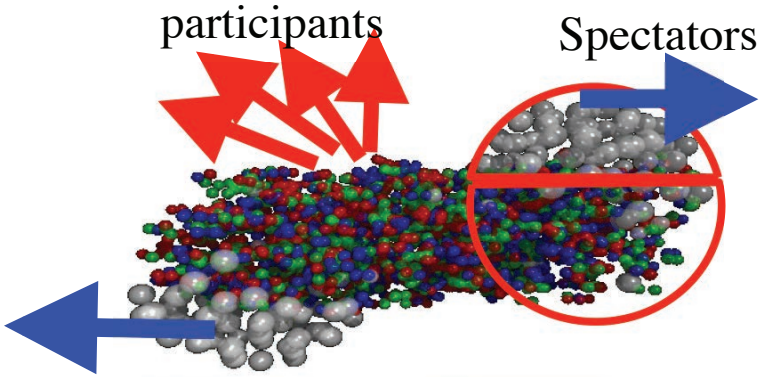
$$R_A = \langle n \rangle_{pA} / \langle n \rangle_{pp} = (1+\langle \nu \rangle) / 2$$

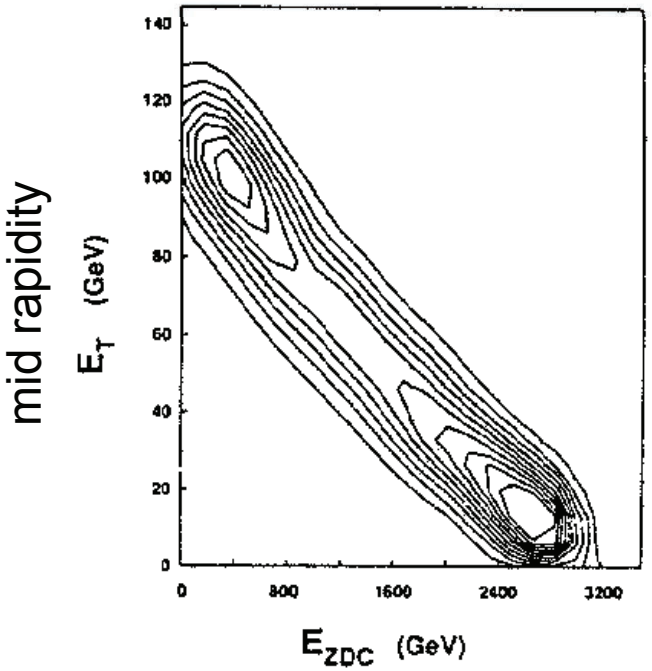
$\langle N_{part} \rangle_{pA}$ $\langle N_{part} \rangle_{pp}$

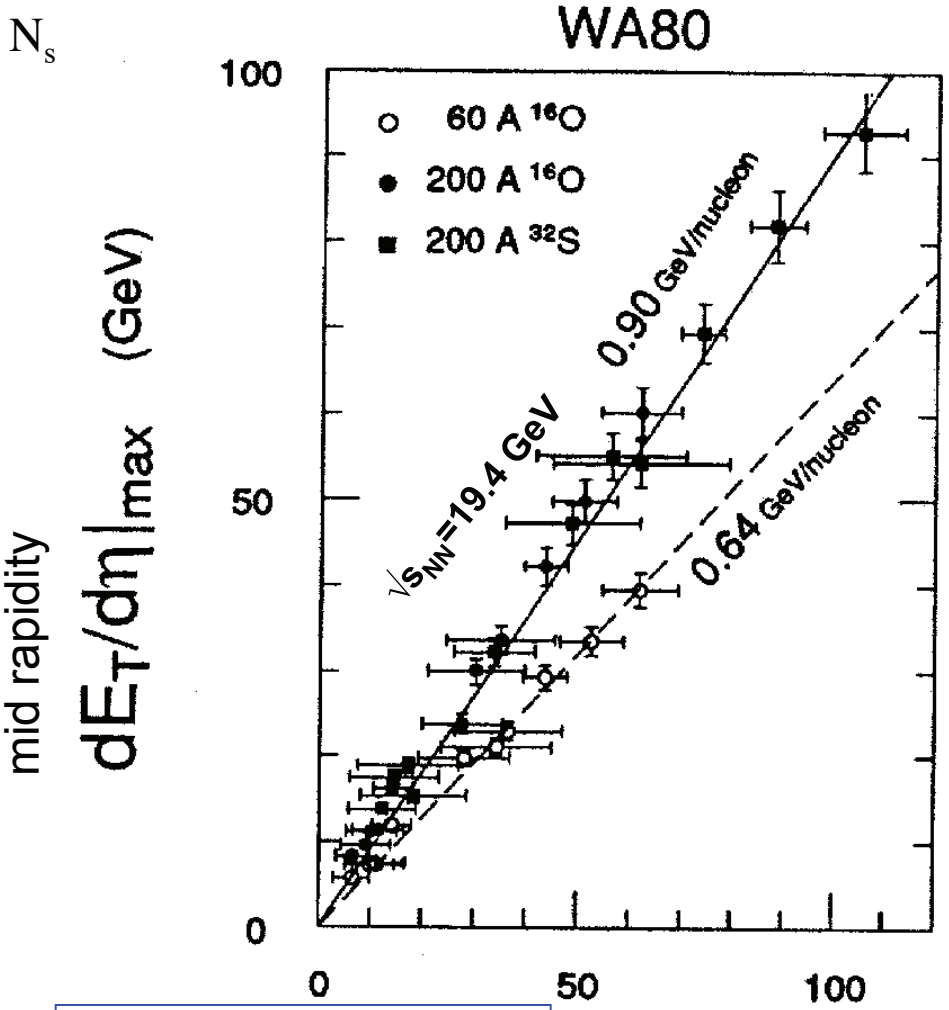
Extreme-Independent or Wounded Nucleon Models c. 1980

- Number of Spectators (i.e. non-participants) N_s can be measured directly in Zero Degree Calorimeters (more complicated in Colliders)
- Enables unambiguous measurement of (projectile) participants = $A_p - N_s$
- For symmetric A+A collision $N_{part}=2\ N_{projpart} = 2\ (A_p - N_s)$
- Uncertainty principle and time dilation prevent cascading of produced particles in relativistic collisions $\gamma\ h/m_\pi c > 10$fm even at AGS energies: particle production takes place outside the Nucleus in a p+A reaction.
- Thus, Extreme-Independent models separate the nuclear geometry from the dynamics of particle production. The Nuclear Geometry is represented as the relative probability per B+A interaction w_n for a given number of total participants (WNM), projectile participants (WPNM), wounded projectile quarks=color-strings (AQM), constituent quarks or other fundamental element of particle production.
- The dynamics of the elementary underlying process is taken from the data: e.g. the measured E_T distribution for a p-p collision represents, 2 participants, 1 n-n collision, 1 wounded projectile nucleon, a predictable convolution of quark-nucleon collisions.

WA80: proof of Wounded Nucleon Model at midrapidity for 60, 200 A GeV using ZDC



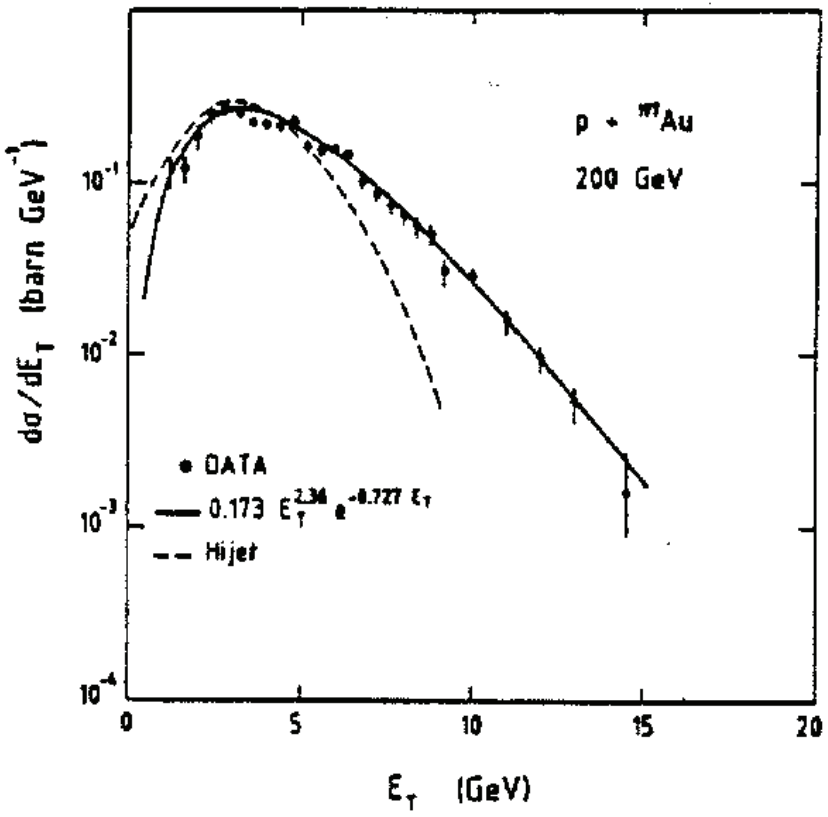


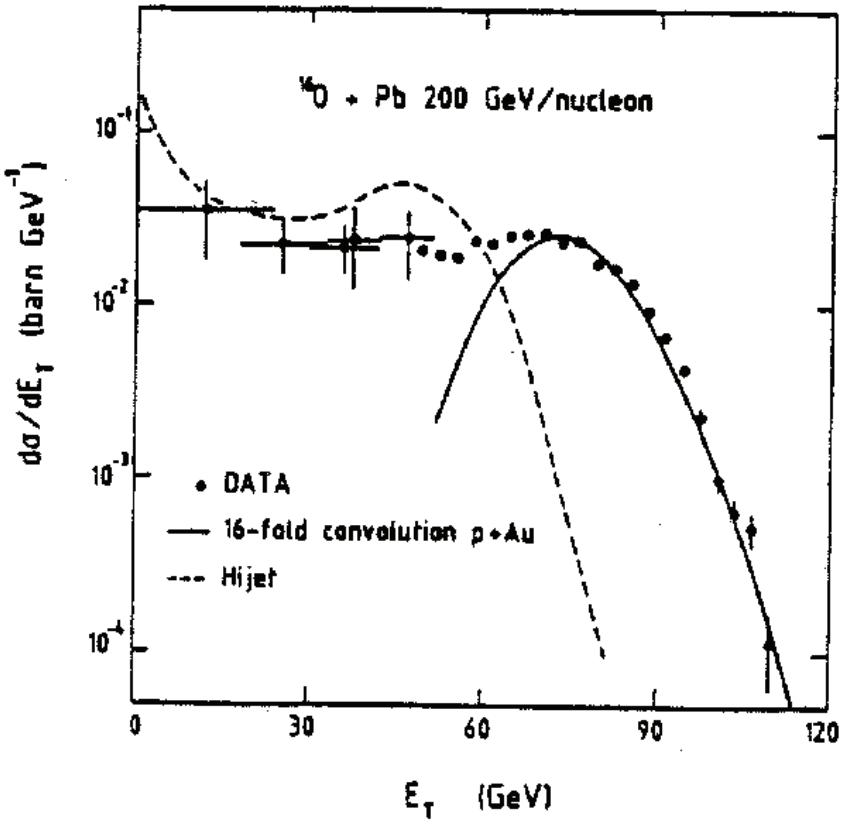


PRC **44**, 2736 (1991)

$\overline{W}$ = <Npart>

First RHI data NA35 (NA5 Calorimeter) CERN $^{16}O+Pb$ $\sqrt{s_{NN}}=19.4$ GeV midrapidity



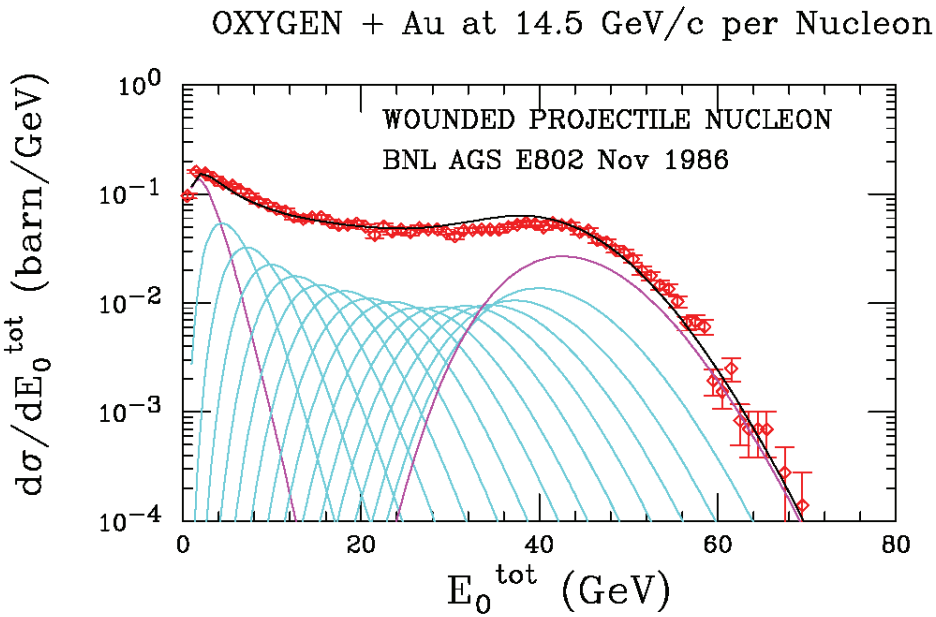


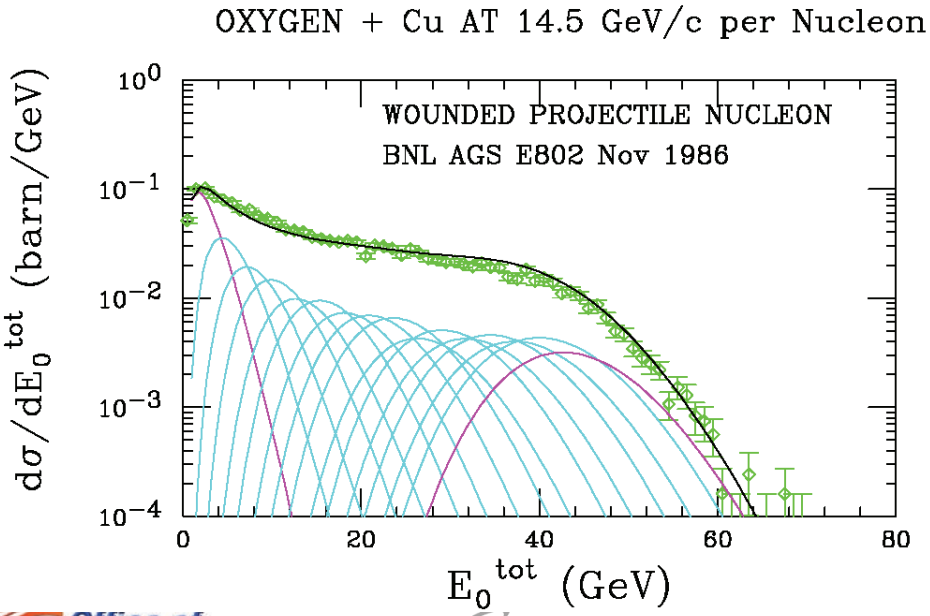
p+Au is a Γ dist p=3.36

PLB **184,** 271 (1987)

Upper Edge of O+Pb is 16 convolutions of p+Au. WPNM!!

WPN=Wounded Projectile Nucleon=projectile participant

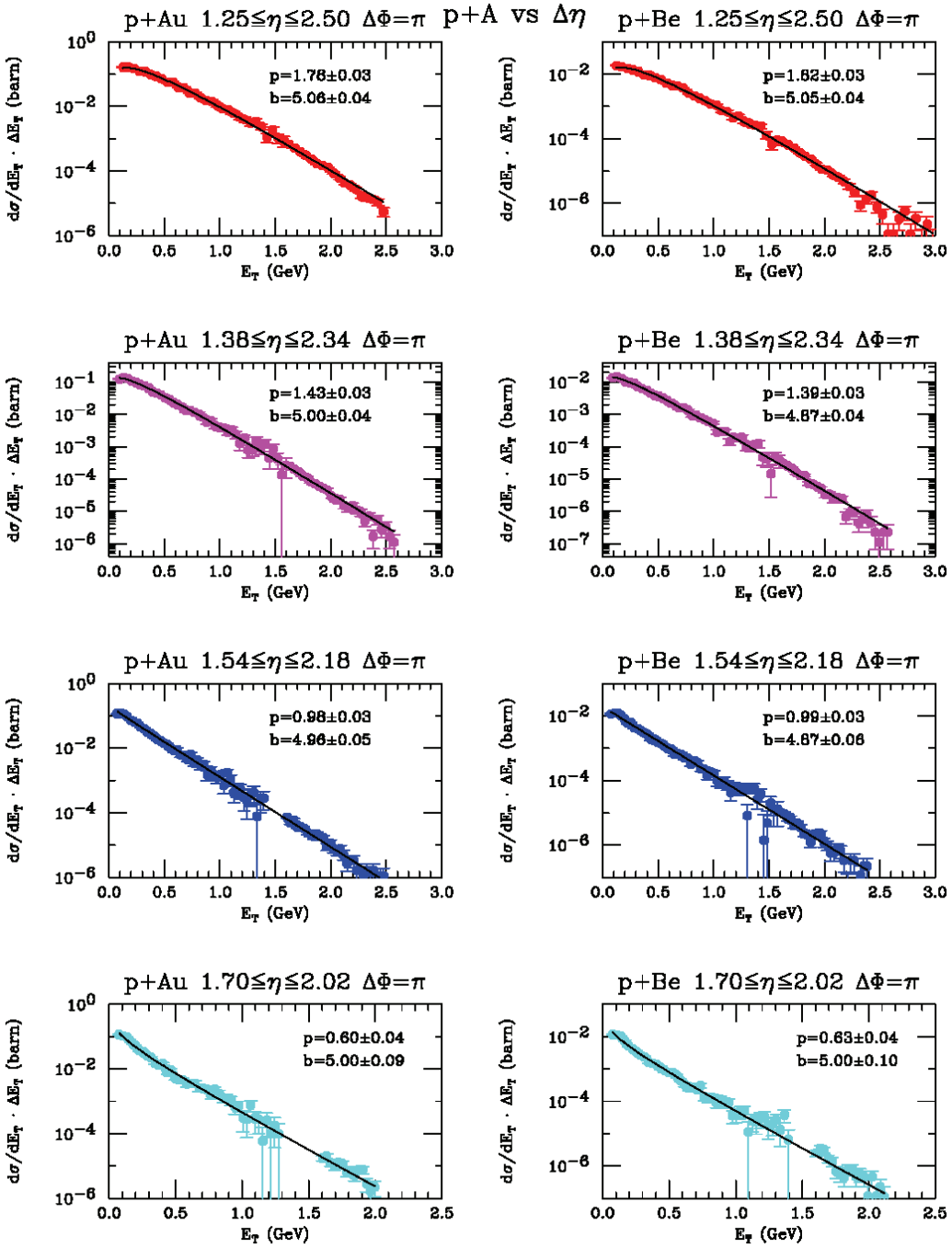




E802-O+Au, O+Cu midrapidity at AGS $\sqrt{s_{NN}}$=5.4GeV WPNM works in detail

PLB **197**, 285 (1987)
ZPC **38**, 35 (1988)

- Maximum energy in O+Cu ~ same as O+Au--Upper edge of O+Au identical to O+Cu dσ/dE * 6
- Indicates large stopping at AGS ^{16}O projectiles stopped in Cu so that energy emission (mid-rapidity) ceases
- Full O+Cu and O+Au spectra described in detail by WPNM based on measured p+Au **BUT**



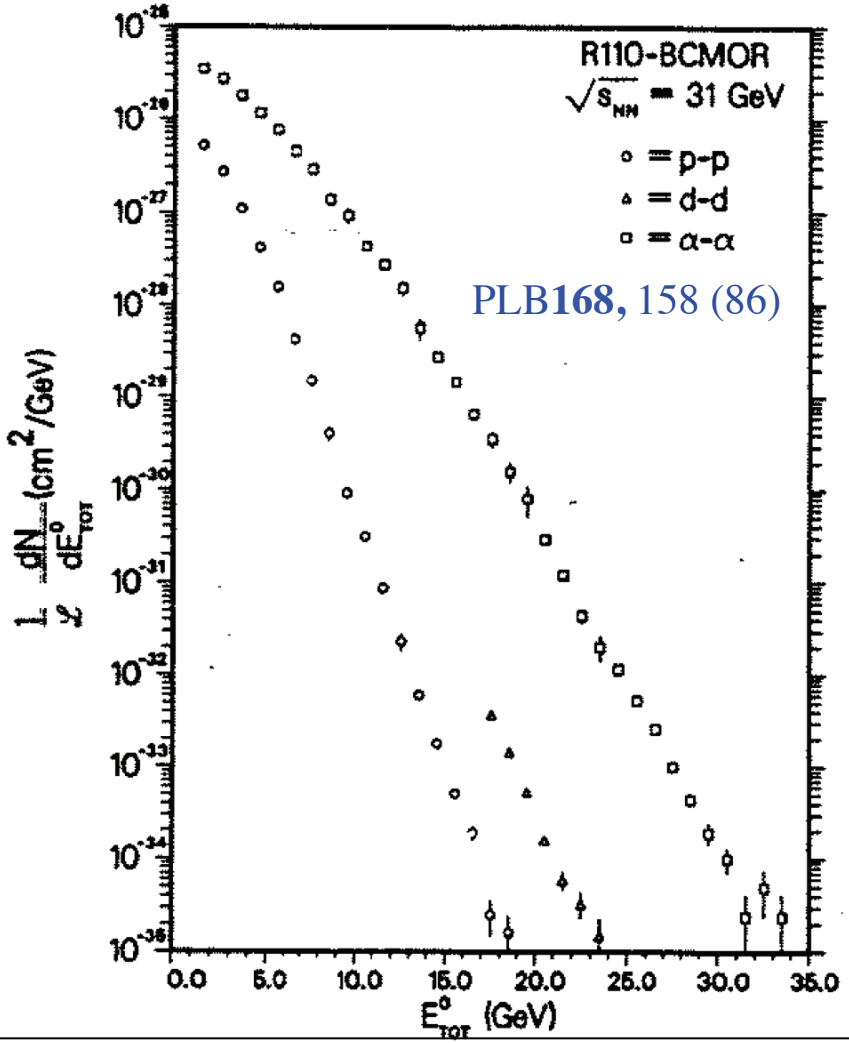
E802-AGS

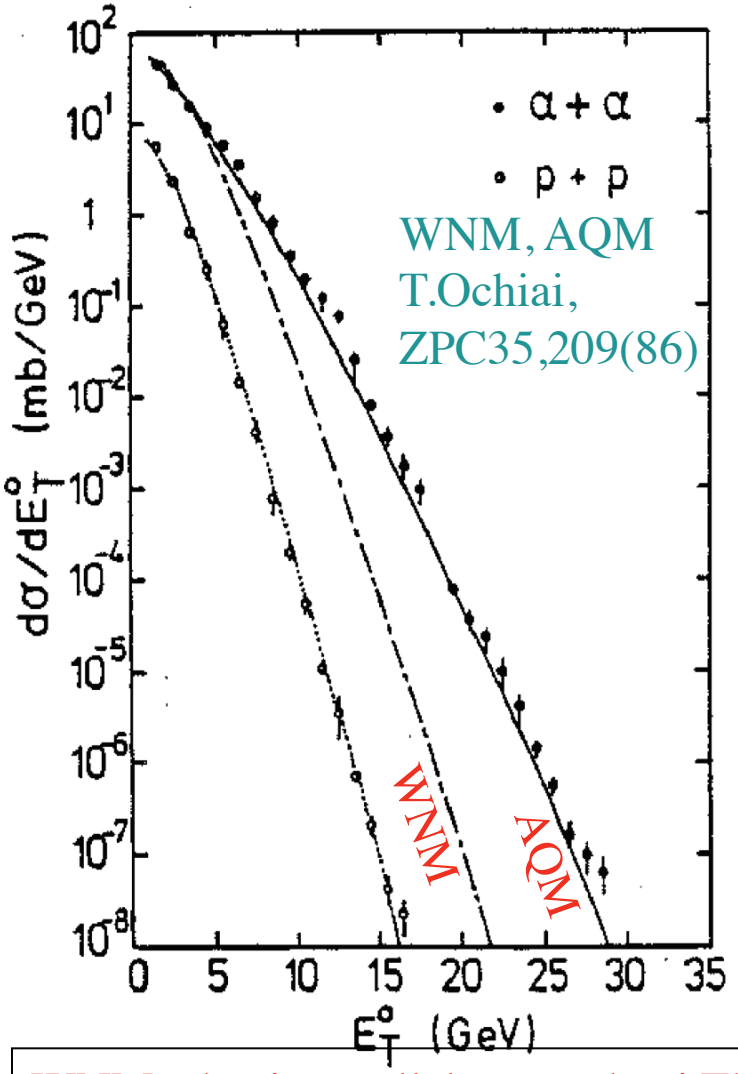
Midrapidity stopping! pBe & pAu have same shape at midrapidity over a wide range of δη

PRC **63**, 064602 (2001)

- confirms previous measurement PRC **45**, 2933 (1992) that pion distribution from second collision shifts by > 0.8 units in y, out of aperture. Explains WPNM.

ISR-BCMOR-αα $\sqrt{s_{NN}}$=31GeV: WNM FAILS! AQM works





Both p-p and alpha-alpha data are beautiful Γ-distributions with analytical convolution.

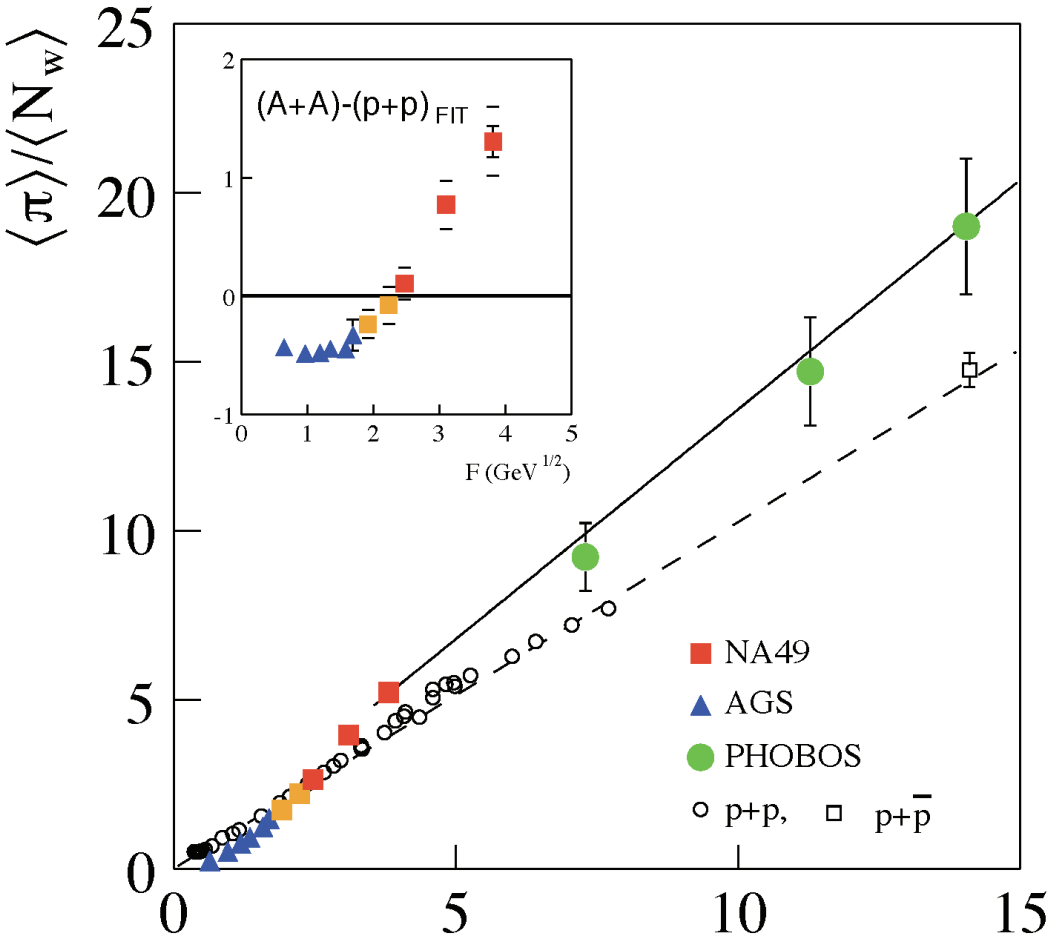
WNM edge is parallel to p-p data! This is due to dominance of 4th pp convolution

Summary of Wounded Nucleon Models at mid-rapidity c. 1991

- The classical Wounded Nucleon (N_{part}) Model (WNM) of Bialas, Bleszynski and Czyz (NPB **111**, 461 (1976)) works only at CERN fixed target energies, $\sqrt{s_{NN}}$~20 GeV.
- WNM overpredicts at AGS energies $\sqrt{s_{NN}}$~ 5 GeV (WPNM works at mid-rapidity)--this is due to stopping, second collision gives only few particles which are far from mid-rapidity. E802
- WNM underpredicts for $\sqrt{s_{NN}} \geq 31$ GeV---Additive Quark Model Works. BCMOR + Ochiai
- This is the explanation of the 'famous' kink, well known as p +A effect since QM87+QM84

i.e. The kink is a p+A effect well known since 1987-seen at FNAL,ISR,AGS

Marek Gazdzicki
QM2004, QM 2001...
Pions per participant



$$F\,(\mathrm{GeV}^{1/2}) \approx s^{1/4}$$

RHIC—PHOBOS--first dn/dη Measurement
First published measurement from RHIC

VOLUME 85, NUMBER 15 PHYSICAL REVIEW LETTERS 9 OCTOBER 2000

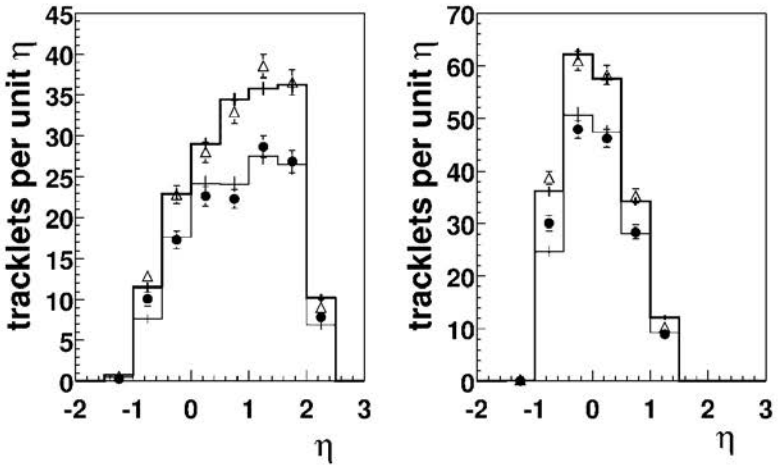


FIG. 3. Tracklet pseudorapidity density in the detector acceptance per event for data at $\sqrt{s_{NN}} = 56$ (circles) and 130 GeV (triangles) for SPEC (left) and VTX (right), in comparison to scaled HIJING simulations (solid lines).

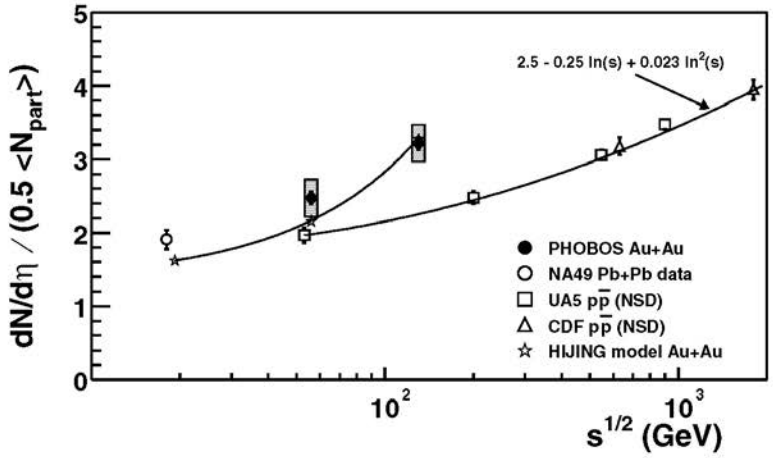


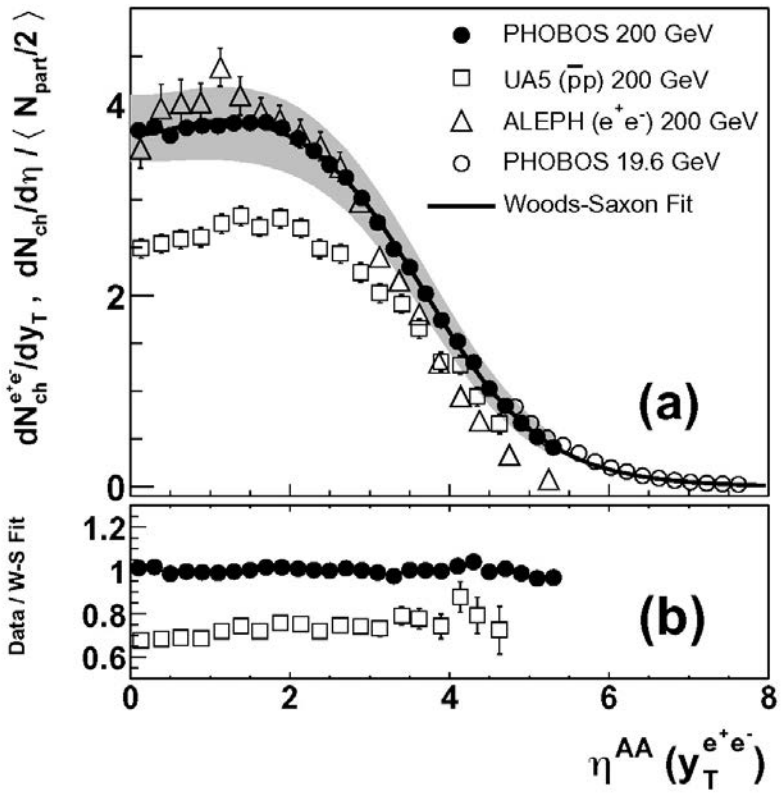
FIG. 4. Measured pseudorapidity density normalized per participant pair for central Au + Au collisions. Systematic errors are shown as shaded area. Data are compared with $p\overline{p}$ data and Pb + Pb data from the CERN SPS. Also shown are results of a HIJING simulation (with a line to guide the eye) and a parametrization of the $p\overline{p}$ data [7].

Large η coverage √s=56, 130 GeV

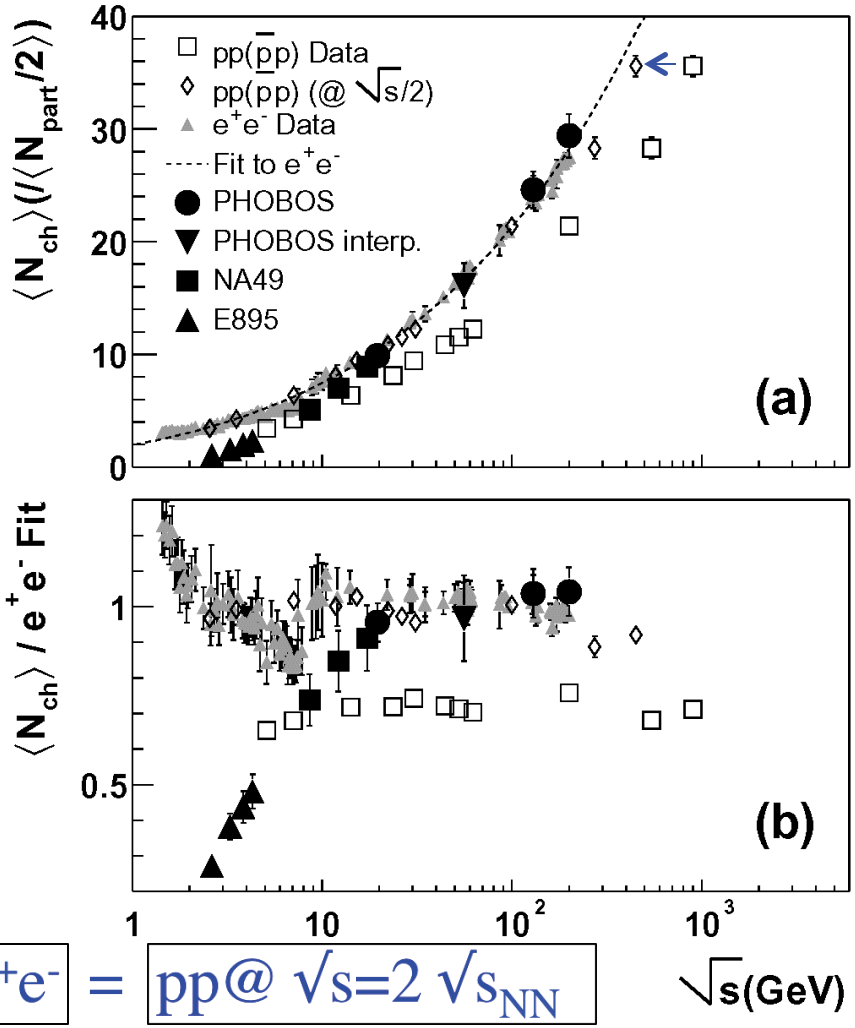
Establish standard of quoting mid-rapidity dn/dη/(0.5Npart); Confirms deviation from WNM

MJT-Erice 2003-For Nino PHOBOS dn/dη, N_{ch}

cf. M.Basile, A. Zichichi et al, PL **B92**, 367 (1980); **B95**, 311 (1980)



From 1993,published PRC74(2006)021902

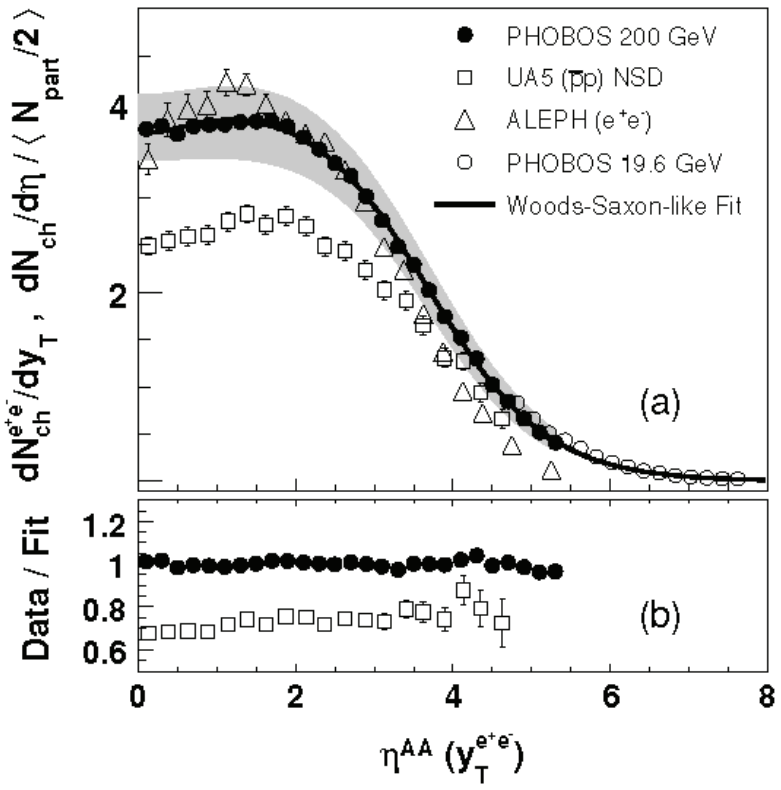


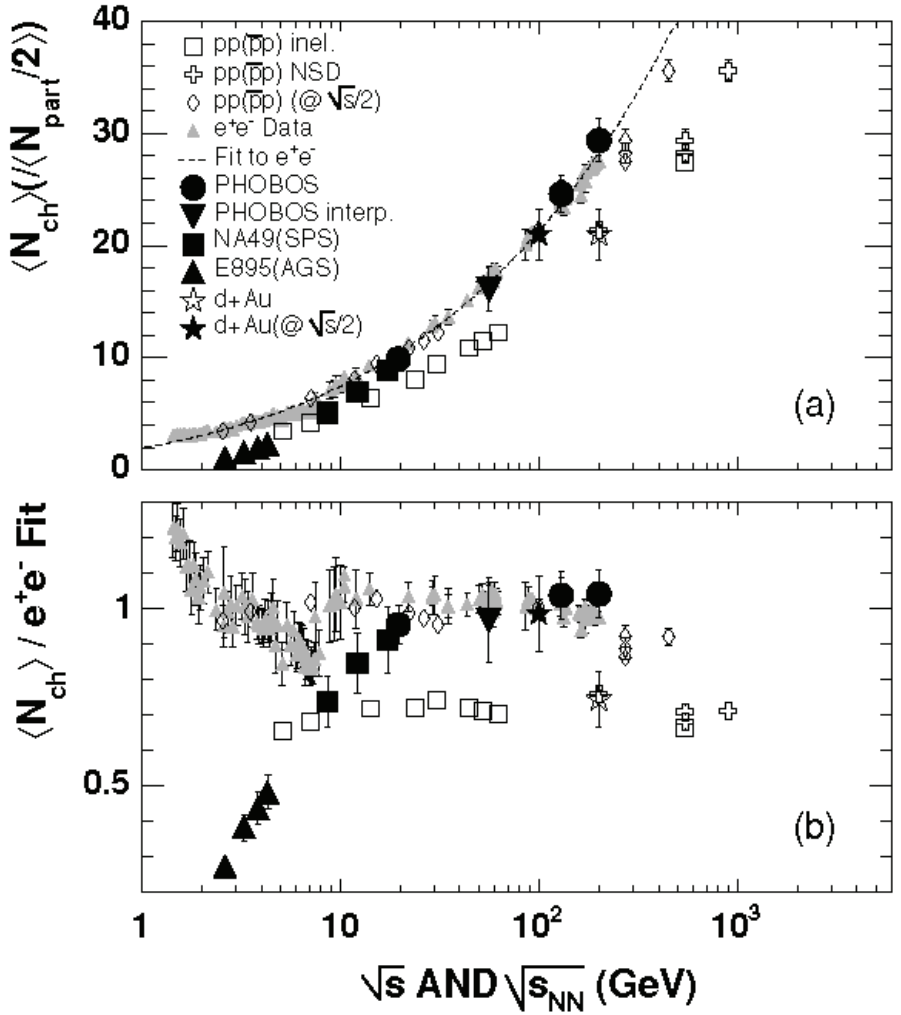
$N_{ch}/\langle N_{part}/2\rangle$ Au+Au @ $\sqrt{s_{NN}}$ ~ e^+e^- = pp@ $\sqrt{s}=2\sqrt{s_{NN}}$

Leading particle effect-in pp--Zichichi—vanishes in AuAu

MJT-Erice 2003-For Nino PHOBOS dn/dη, N_{ch}

cf. M.Basile, A. Zichichi et al, PL **B92**, 367 (1980); **B95**, 311 (1980)

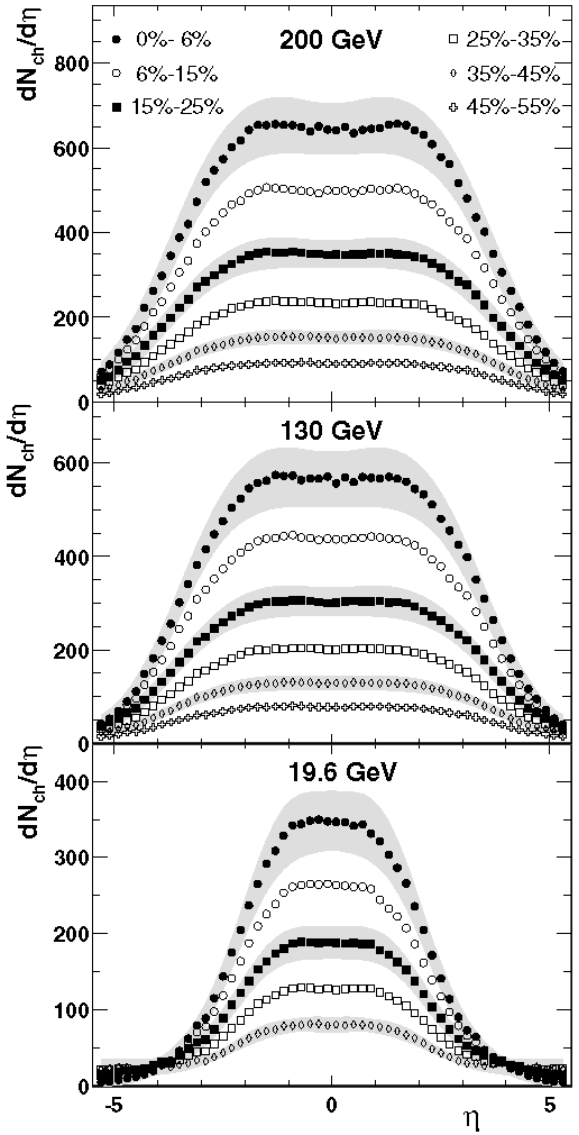


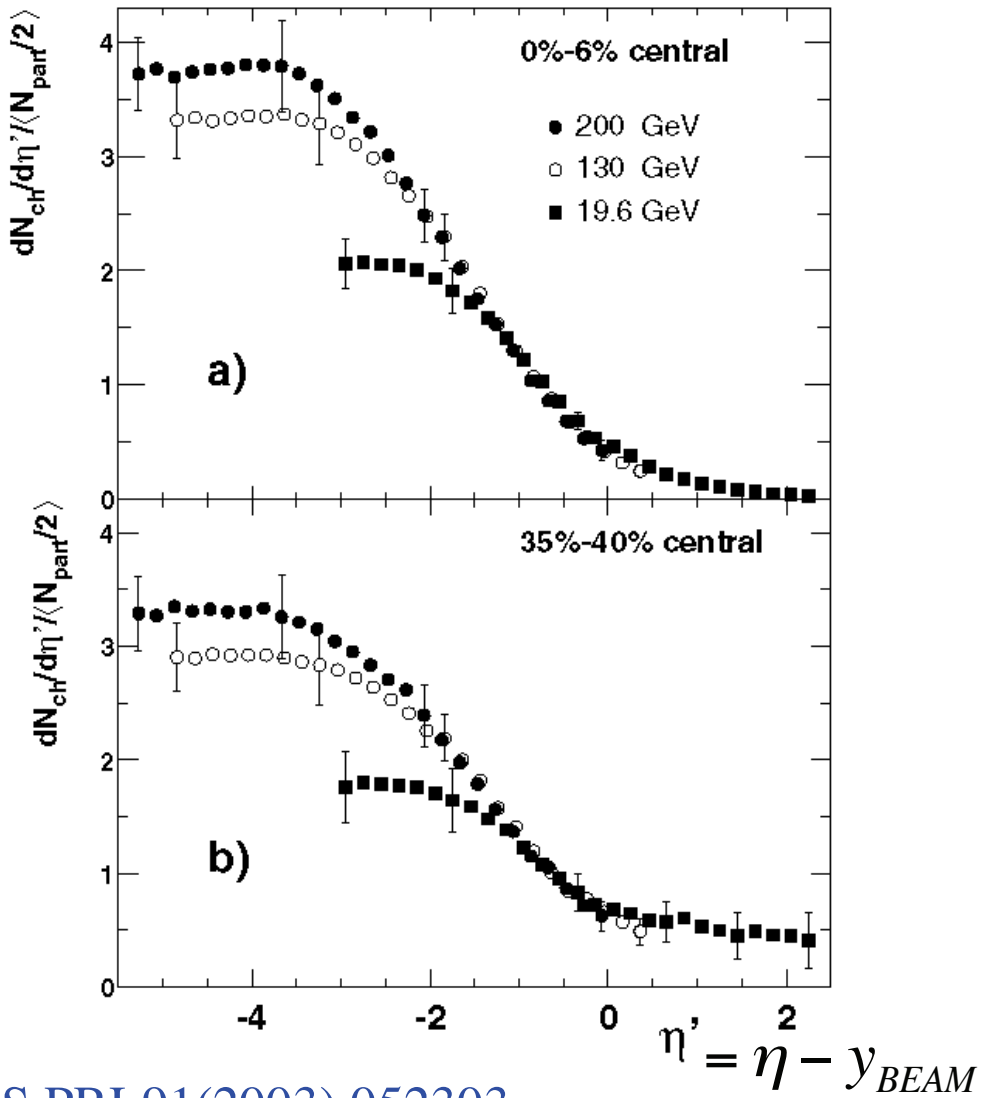


$N_{ch}/\langle N_{part}/2\rangle$ Au+Au @ $\sqrt{s_{NN}}$ ~ e^+e^- = pp@ √s/2

Leading particle effect-in pp--Zichichi—vanishes in AuAu

Phobos: Large Δη--Limiting Fragmentation

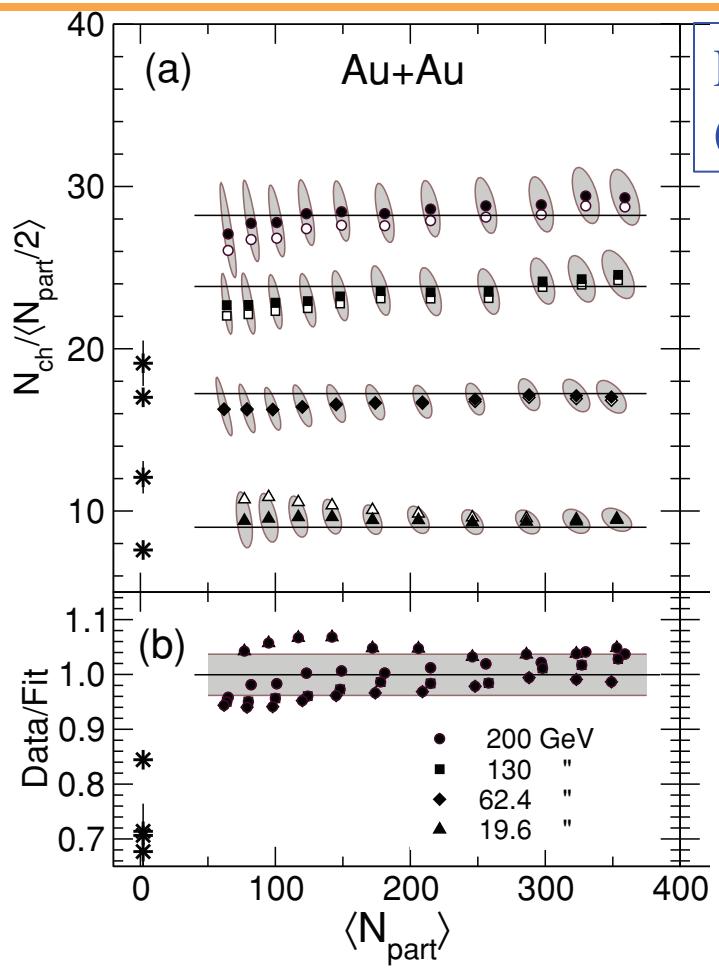


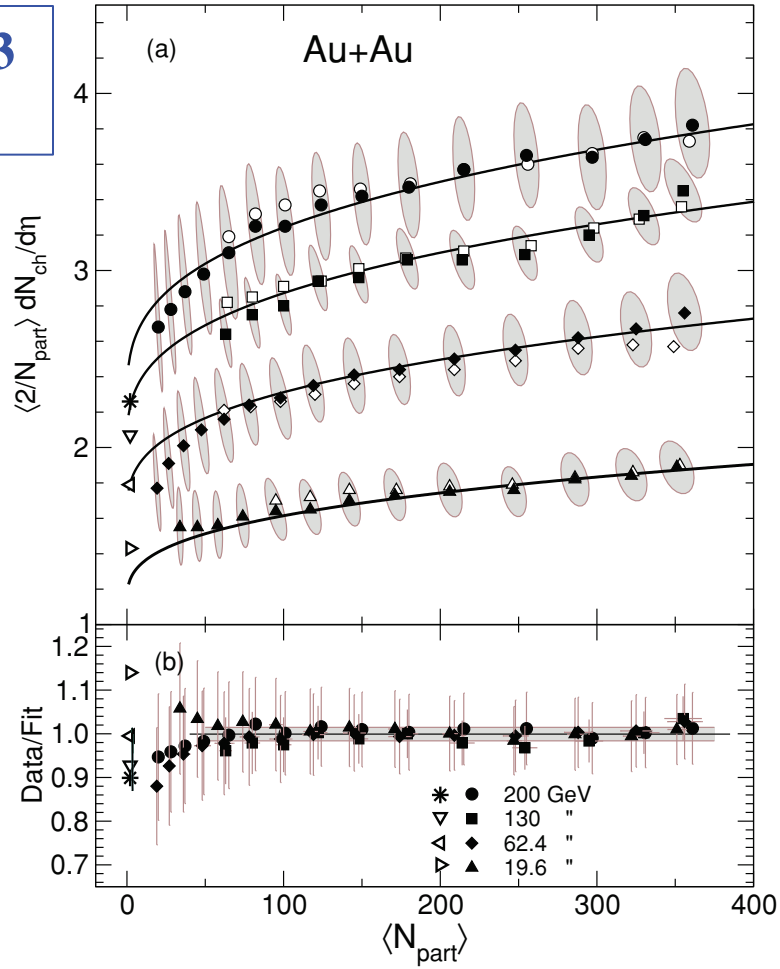


PHOBOS PRL91(2003) 052303

PHOBOS-Final Multiplicity Paper 2011

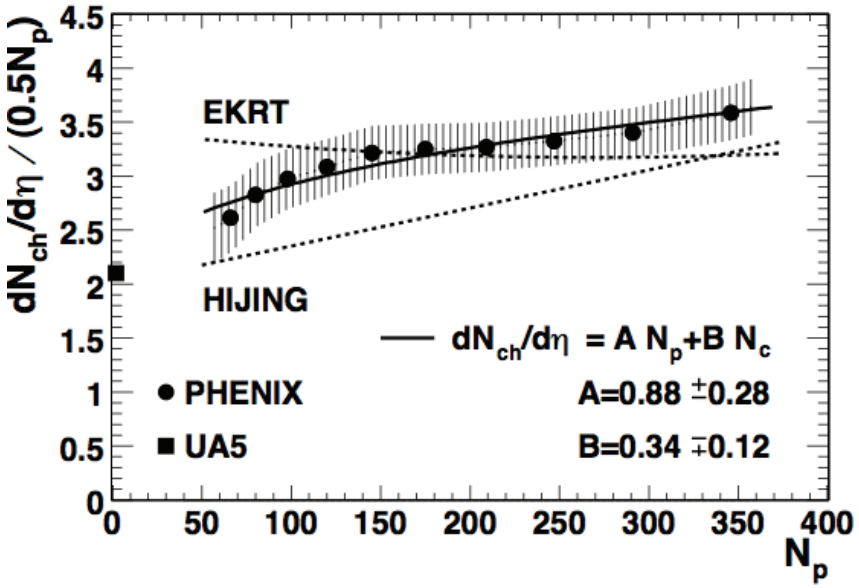
PHOBOS PRC **83** (2011) 024913



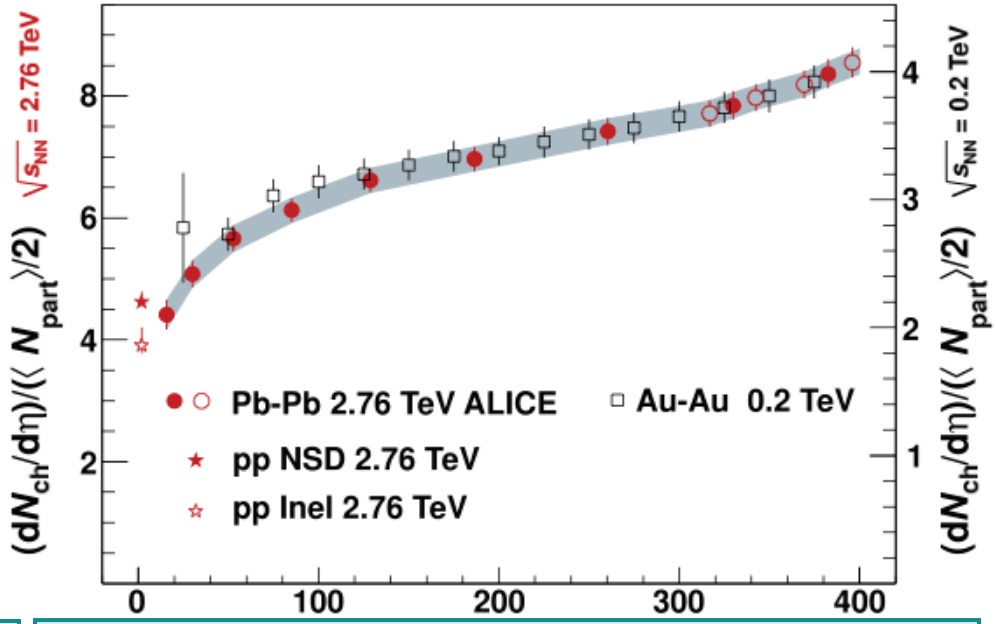


Using full rapidity range, total $N_{ch}/(0.5N_{part})$ does follow WNM (in AA only) but mid-rapidity $dN_{ch}/d\eta/(0.5N_{part})$ shows different but apparently universal dependence first seen by PHENIX and recently at LHC.

From RHIC to LHC to RHIC evolution of mid-rapidity $dN_{ch}/d\eta$ with centrality, N_{part}



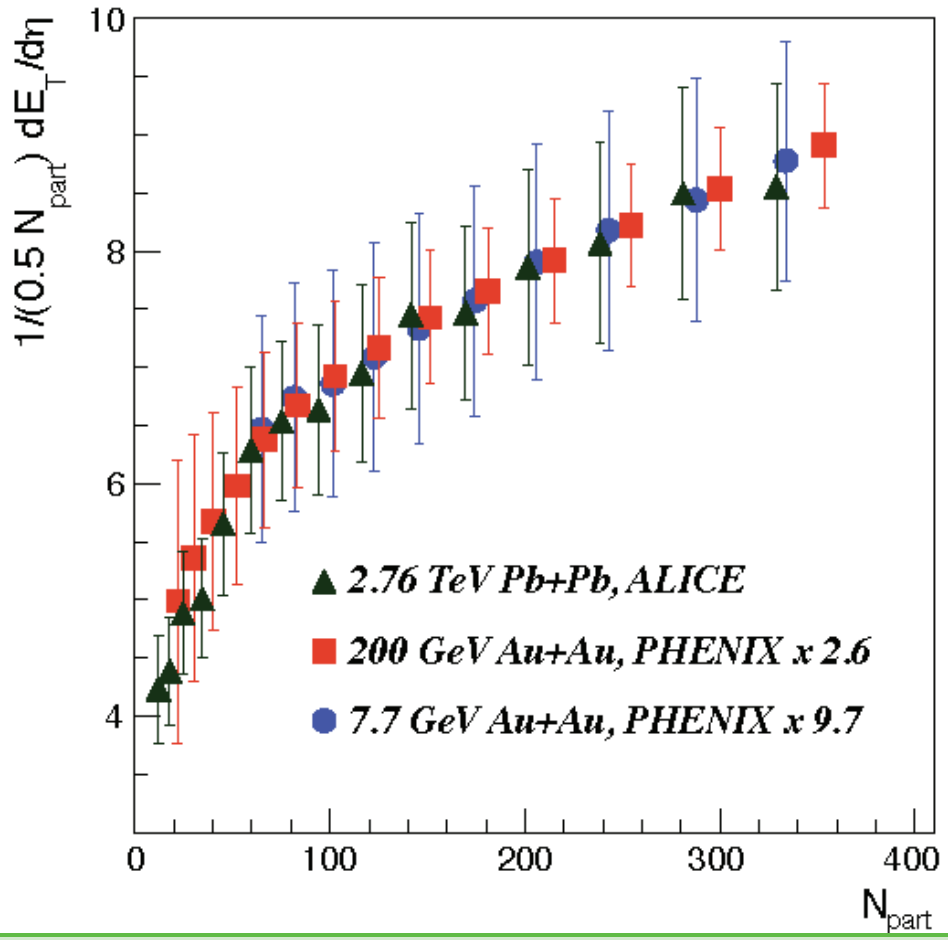
PHENIX $\sqrt{s_{NN}}$=130 GeV, PRL86 (2001)3500



ALICE $\sqrt{s_{NN}}$=2.76 TeV PRL 106(2011)032301

Identical shape of distributions indicates a nuclear-geometrical effect

New RHIC data for Au+Au at $\sqrt{s_{NN}}$ =0.0077 TeV show the same evolution with centrality



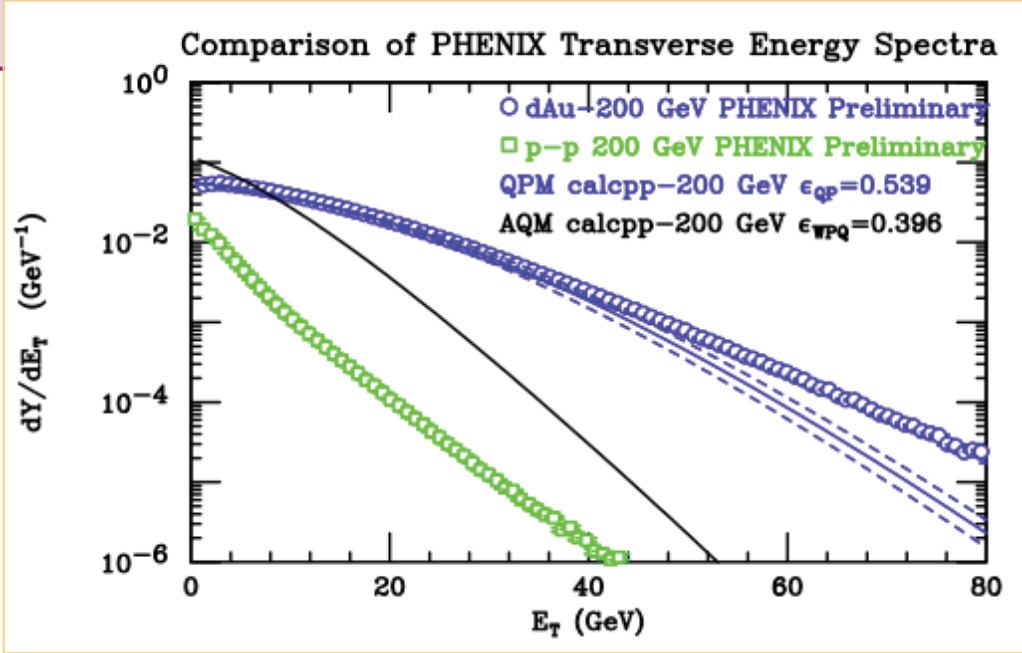
The geometry is the number of constituent quark participants/nucleon participant

Eremin&Voloshin, PRC 67, 064905(2003) ; De&Bhattacharyya PRC 71; Nouicer EPJC 49, 281 (2007)

But symmetric A+A collisions can't distinguish AQM (color strings) from constituent quarks

The Additive Quark Model (AQM), Bialas and Bialas PRD20(1979)2854 and Bialas, Czyz and Lesniak PRD25(1982)2328, is really a color string model. In the AQM model only one color string can be attached to a wounded quark. For symmetric systems, it is identical to the Quark Participant model. However for asymmetric systems such as d+Au it is a ``wounded projectile quark'' model since in this model, only 6 color strings can be attached to the d while the Au can have many more quark participants. PHENIX preliminary data shows that in fact it is the QPM not the color string model that works

MJT-QuarkMatter-2012 Poster



Some Personal Observations

- I've spent a lot of my research time on measurements and "Extreme Independent Models" based on and inspired by Wit's work.
- I've also enjoyed collaborating on E802... with Lee Grodzins, Steve Steadman, George Stephans and may great MIT graduate students.
- I'm also impressed with the excellent group that Wit has built up here at MIT and the outstanding contributions that they have made to RHI physics both at RHIC on PHOBOS and now at LHC on CMS
- However, my personal favorite RHIC result from the MIT group does not relate to N_{part} or N_{coll} but rather to:

A new ballgame-2010-v_3

- For the first 10 years of RHIC running and dating back to the Bevalac, all the experts* thought that the odd harmonics vanished at mid-rapidity due to the symmetry of the source for $\phi \rightarrow \pi + \phi$

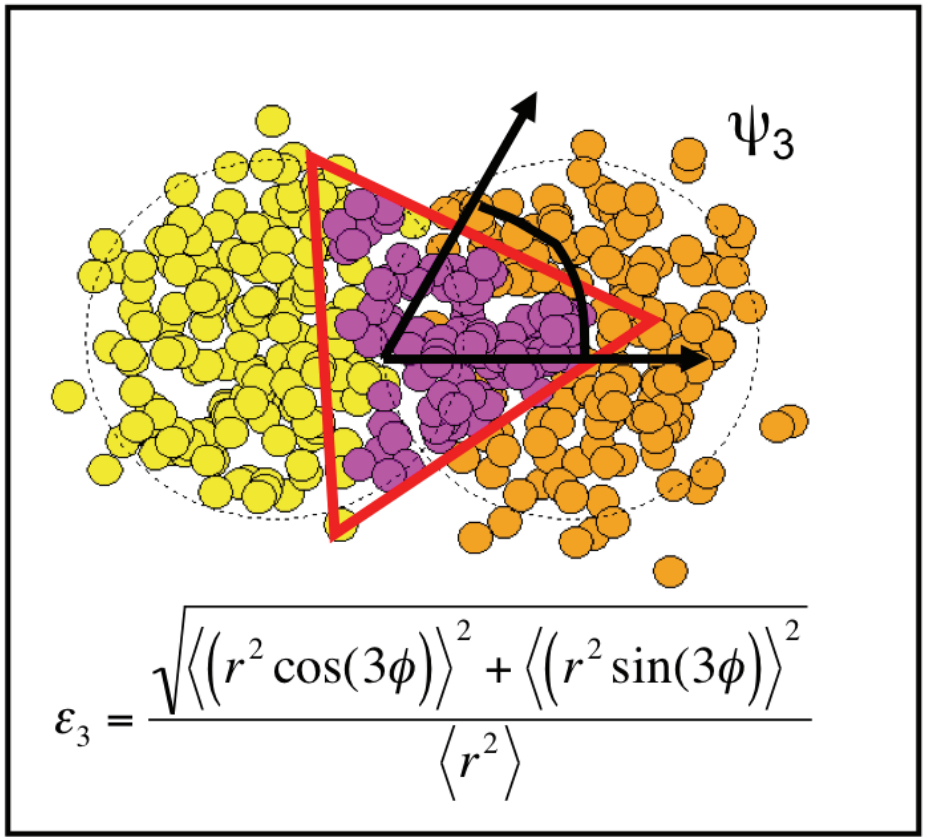
- Furthermore the 'head & shoulder' or "Mach Cones" prevented me from understanding the two-particle correlations from di-jets.

- But, in 2010, an MIT graduate student and his Professor in experimental physics, seeking (at least since 2006) how to measure the fluctuations of v_2 in PHOBOS at RHIC realized that due to fluctuations in the collision geometry on an event by event basis, the eccentricity of participants on any given event, did not respect the average symmetry, resulting in:

* In analogy to anisotropies in the Cosmic Microwave Background Radiation, an Indian group, A. P. Mishra, *et al*., PRC77, 065902 (2008) suggested that $\sqrt{v_n^2} = v_n^{r.m.s.}$ including odd harmonics might show the same effect in A+A collisions. Then a Brazilian theory collaboration, J.Takahashi, *et al*., PRL 103, 242301 (2009) who had an event-by-event hydrodynamics code showed that indeed odd harmonics v_3 exist in events with only soft-physics, no hard-scattering. The first measurement was made in 2010:

Triangular Flow-v_3

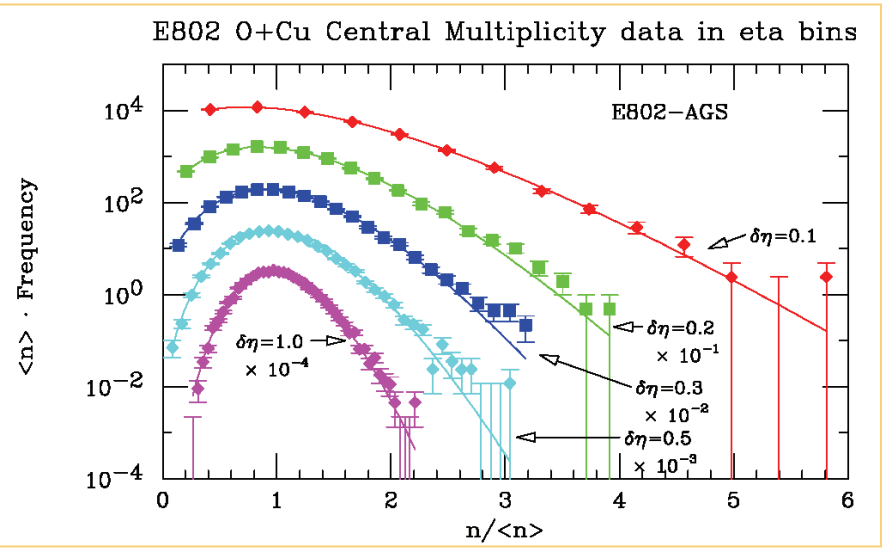
Participant Triangularity

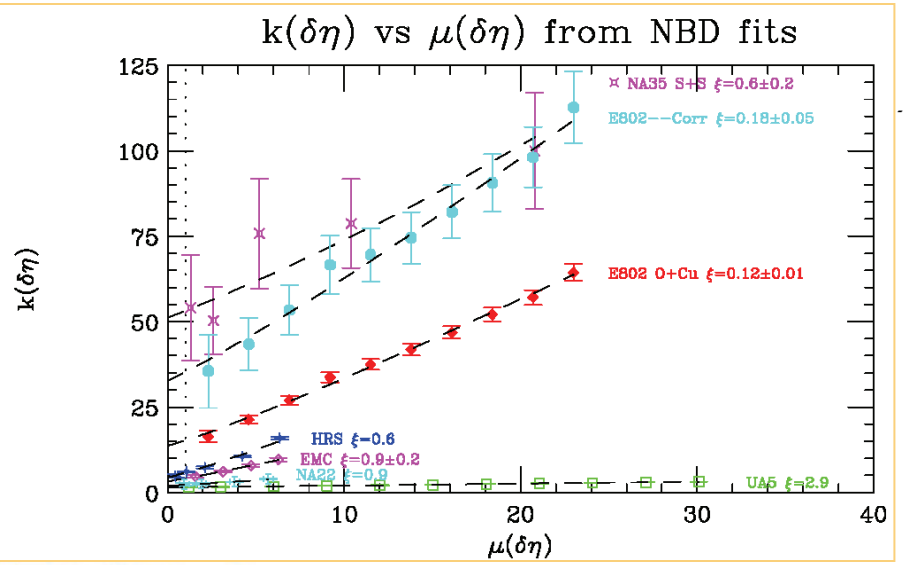


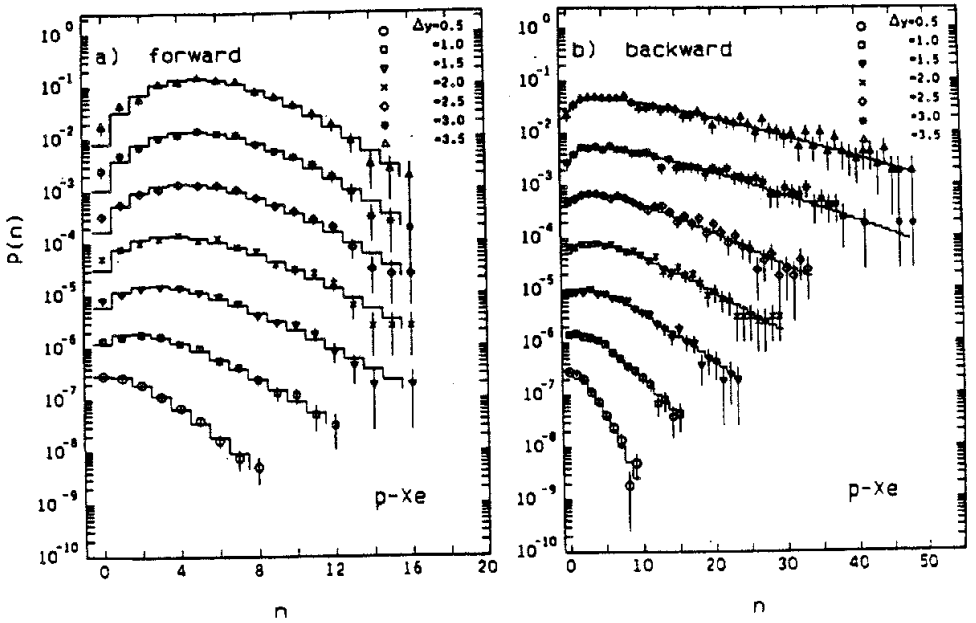
B. Alver and G. Roland, Phys. Rev. C 81, 054905 (May 2010)

EXTRAS

We now know that Multiplicity distributions in p-p and A+A are Negative Binomial







MPI (Munich) +Crakow ZPC33(1986)187

← E802 PRC 52 (1995) 2663