pA studies 1972-2013

reminiscences

The pA play
as seen through the eyes of one of the actors

Act 1 before the early 1970's	The "A" of "pA" is more of a nuisance than a help!
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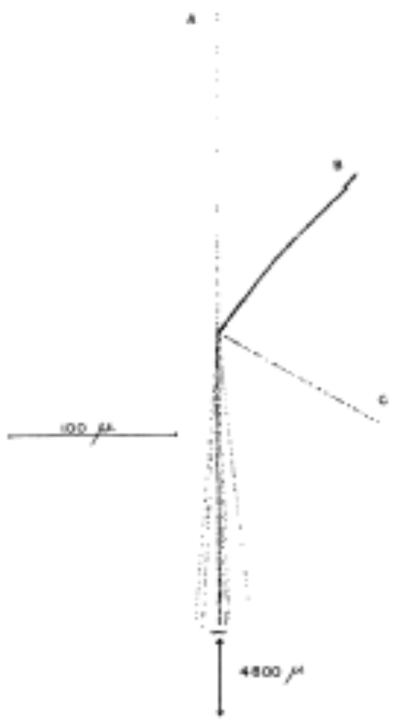
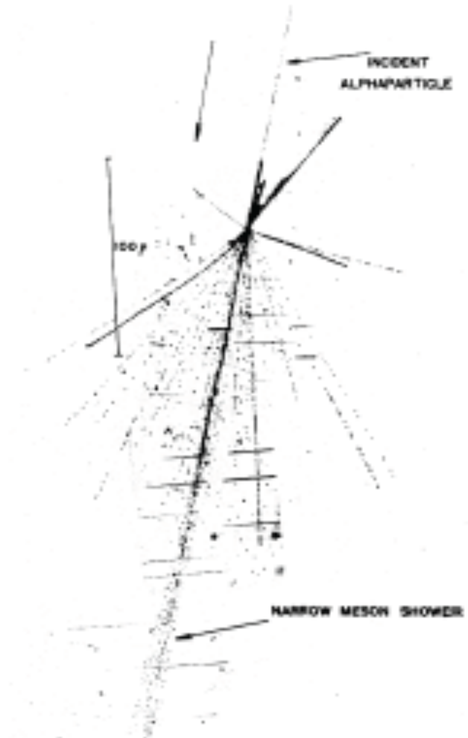
Act 5 To-day	Who is helping whom? pp & pA the understanding of AA or AA the understanding of pp & pA?

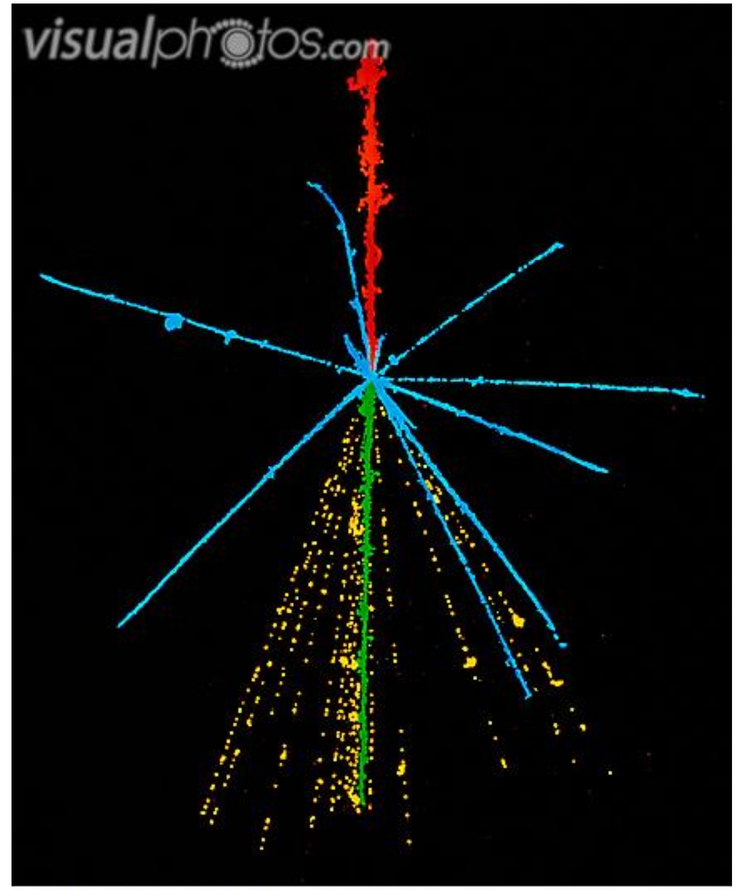
Cosmic ray interactions in nuclear emulsions ≈ 1950



p-p collision



α-emulsion collision

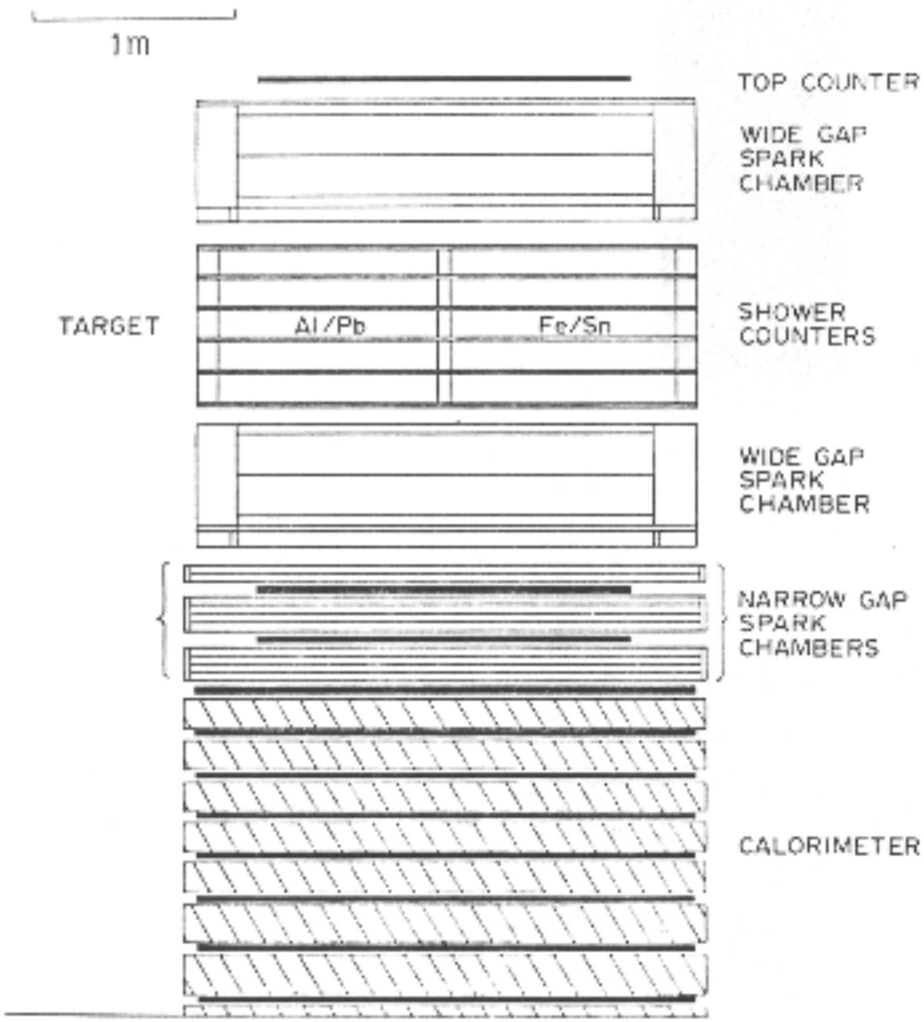


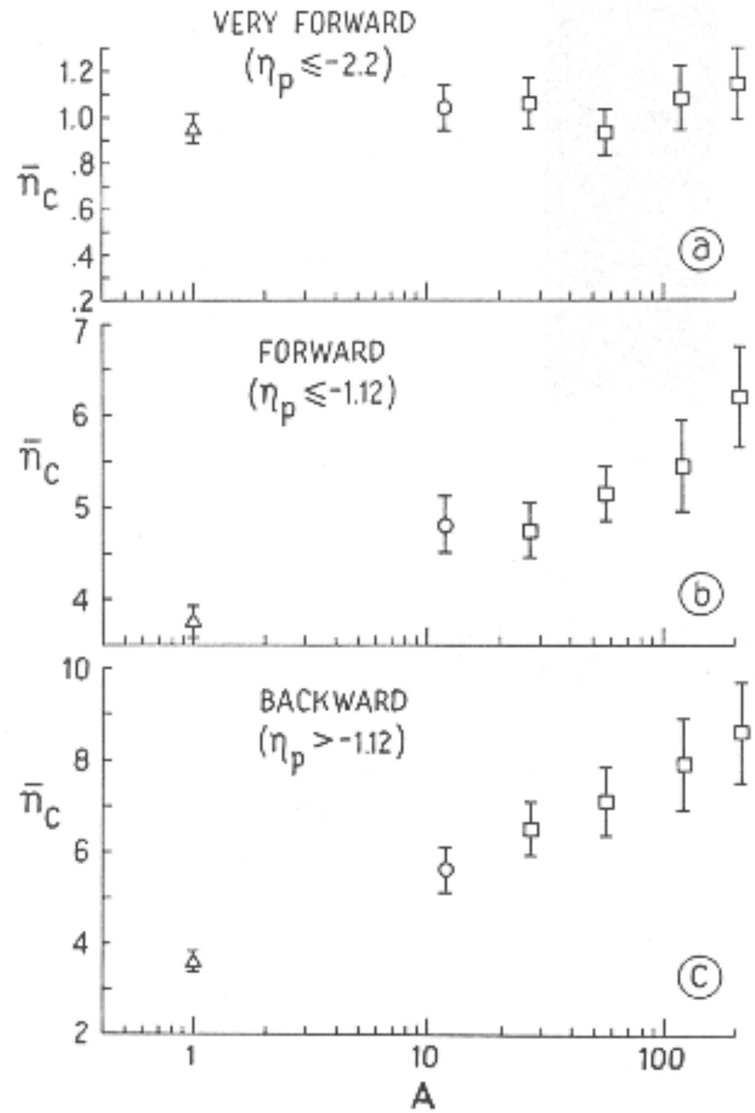
Composition of nuclear emulsion by weight: 83% (Ag+Br+I), 16% (C+N+O), 1% H

Echo Lake Calorimeter-Spark Chamber

(L.Jones et al. Preprint UM HE 74-23)

$$\sqrt{s_{NN}} = 13 - 31 GeV$$





The pA play
as seen through the eyes of one of the actors

Act 1
before the early 1970's

The "A" of "pA" is more of a nuisance than a help!

Act 2
The 1970's

Is there too much or too little cascading?

Act 3
late 1970's, early 1980's

Is there too much or too little quenching in the forward direction?

Act 4
Late 1980's, 1990's & 2000's

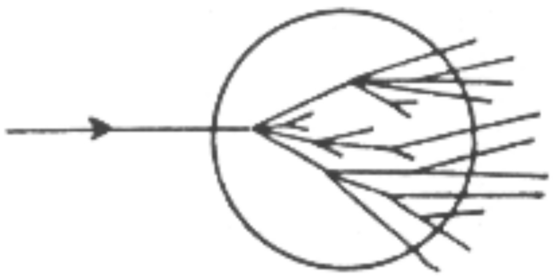
Who cares about the details of "pA" ? After all, it's only a reference!

Act 5
To-day

Who is helping whom?
pp & pA the understanding of AA or
AA the understanding of pp & pA?

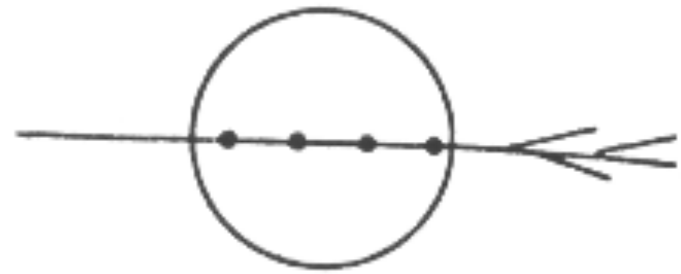
Questions from the early 1970's

- Mechanism of particle production in pp collisions?
- Space-Time evolution of the production process?



$\langle n \rangle_A \sim \langle n \rangle_p A^{1/3}$

or



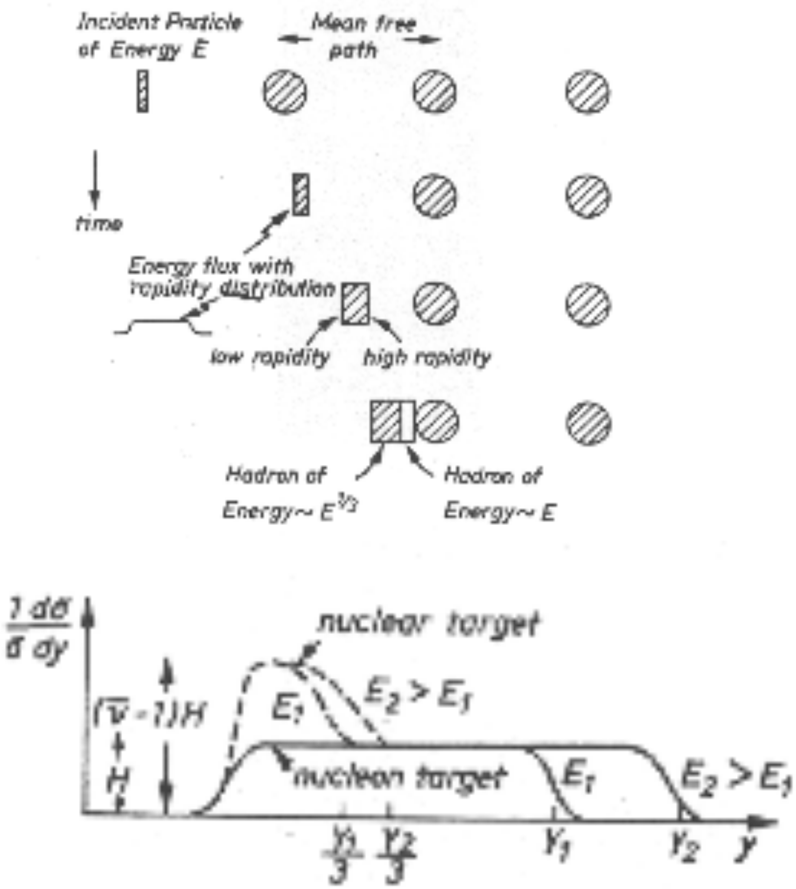
$\langle n \rangle_A \sim \langle n \rangle_p$ or

$\langle n(A,s) \rangle \sim \langle n(p,\bar{\nu}s) \rangle$

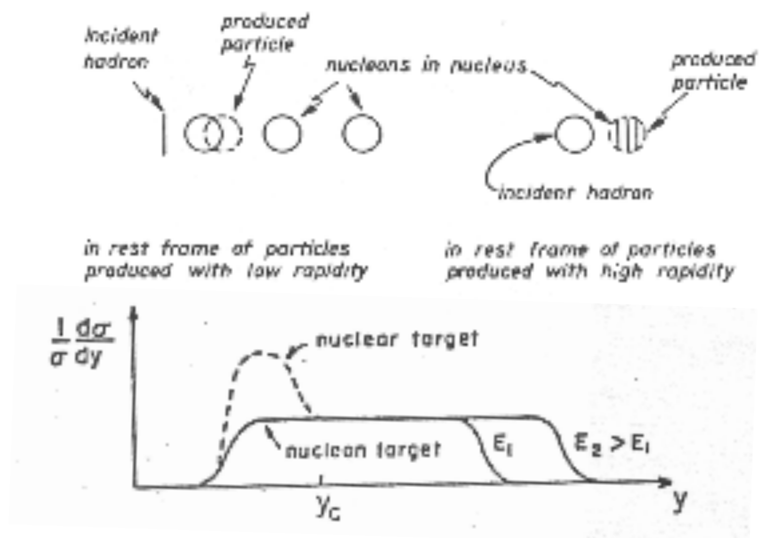
From Fermilab E178 proposal

Fashions in theory in 1970's

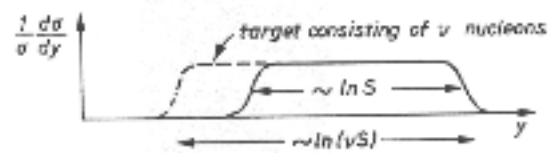
Godfried's energy cascade model



Parton and single chain multiperipheral type models



pA = pp at higher energy

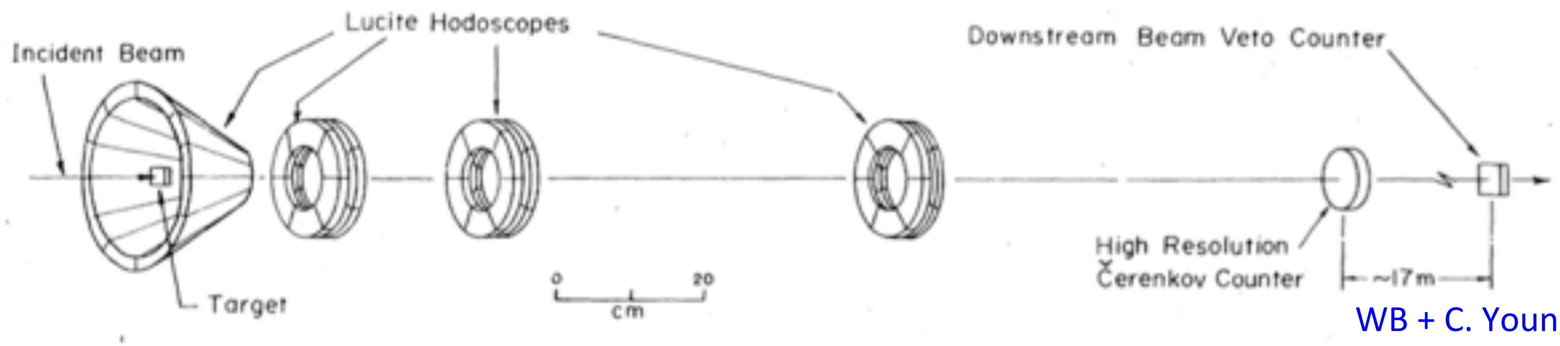


$$R_A \sim \frac{\ln(\nu S)}{\ln S} \sim 1 + \frac{\ln \nu}{\ln S} \to 1 \text{ as } E \to \infty.$$

None of these lead to the observed rapidity distributions, long range correlations, N_{part} -scaling or extended longitudinal scaling

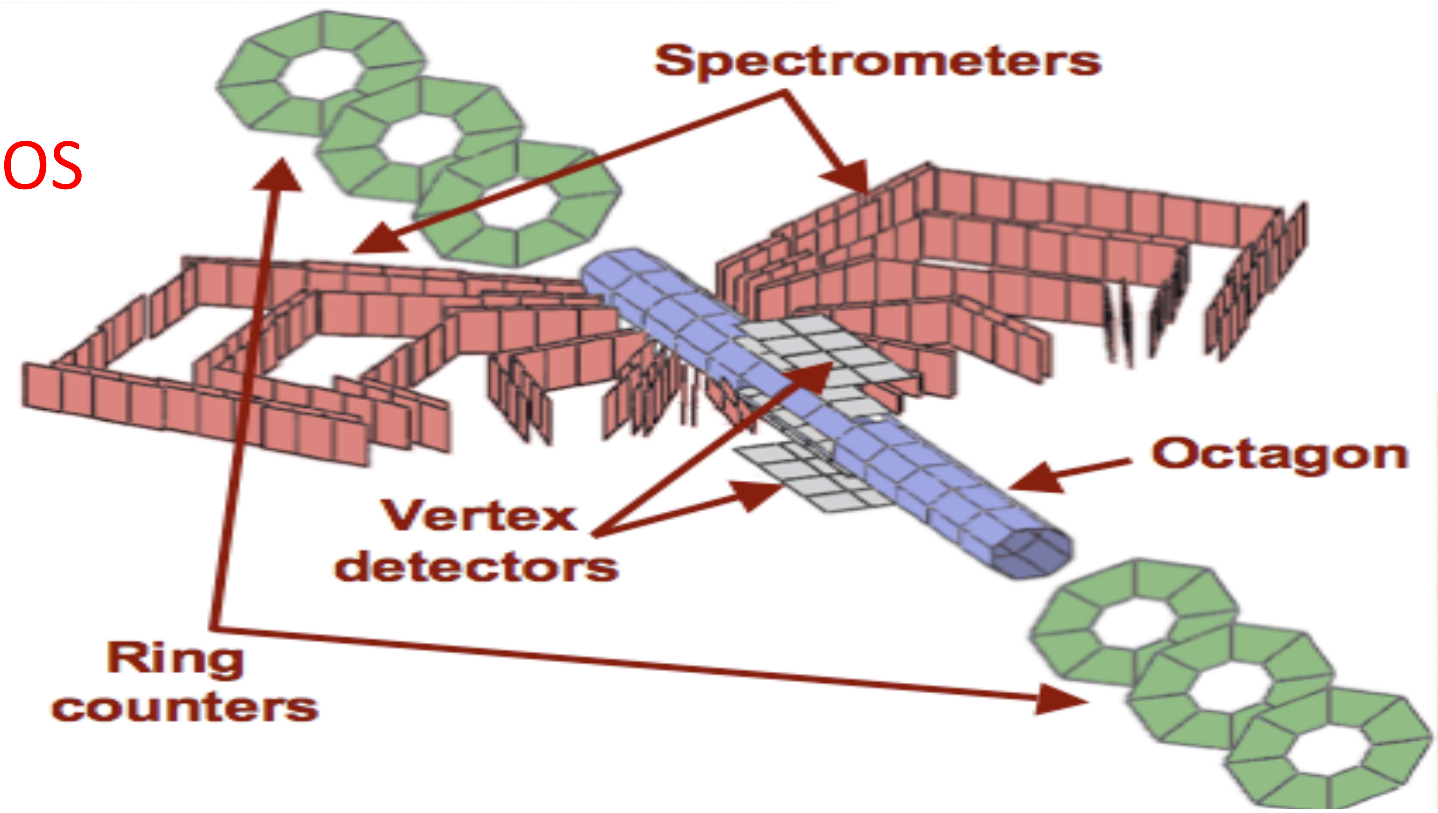
From WB review,
Acta Phys. Pol. B8(1977)

1972 Fermilab E178 (PHOBOS - 1)



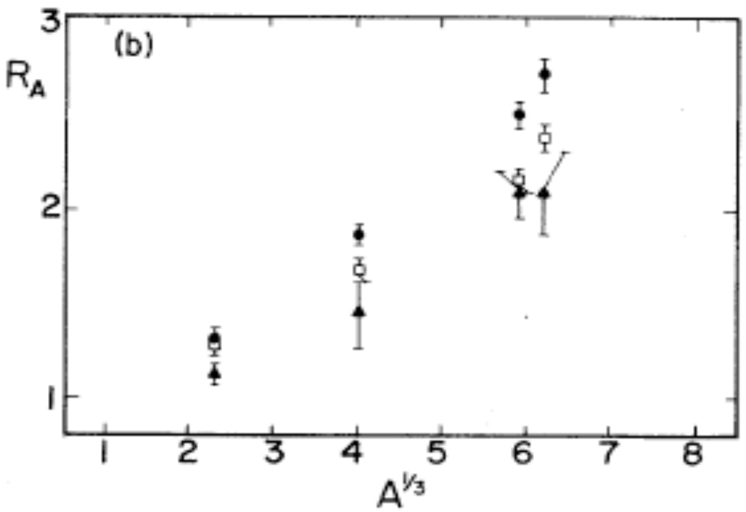
WB + C. Young

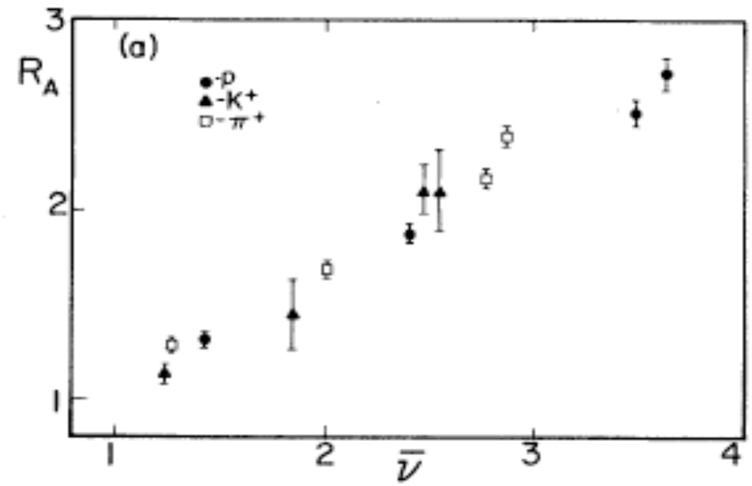
1991 PHOBOS

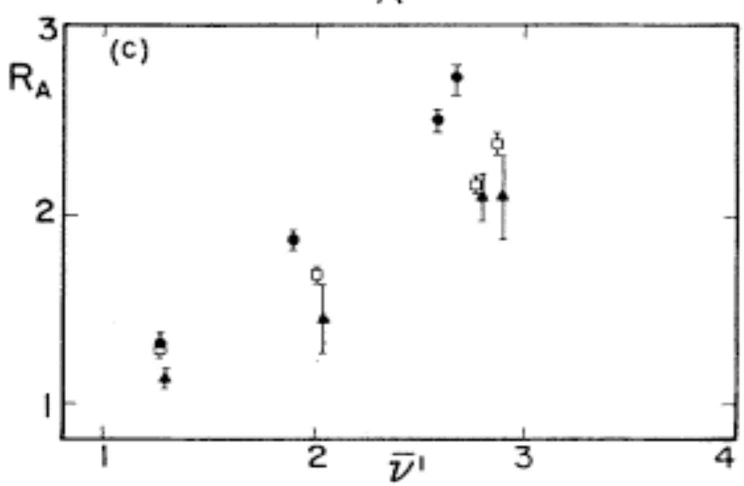


Surprise: participant scaling

$R_A = N_{pA} / N_{pp} = \frac{1}{2} + \frac{1}{2}\,\overline{\nu} = \frac{1}{2} + \frac{1}{2} N_{coll} = \frac{1}{2}$ wounded nucleons $= \frac{1}{2} N_{part}$







Different cross-section after the first collision

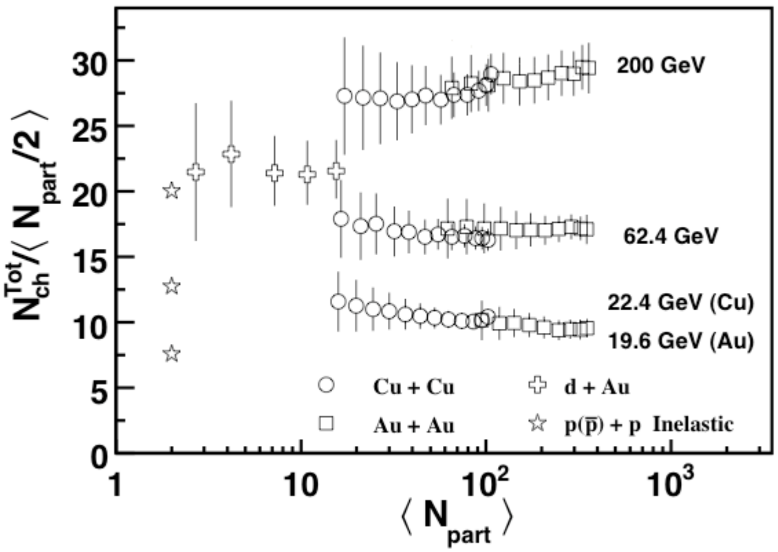
$\overline{\nu} = N_{coll} = N_{part} - 1 = A\sigma_{pp} / \sigma_{pA}$

π, *k*, *p* Data $\sqrt{S_{NN}}$ 10 to 20 GeV

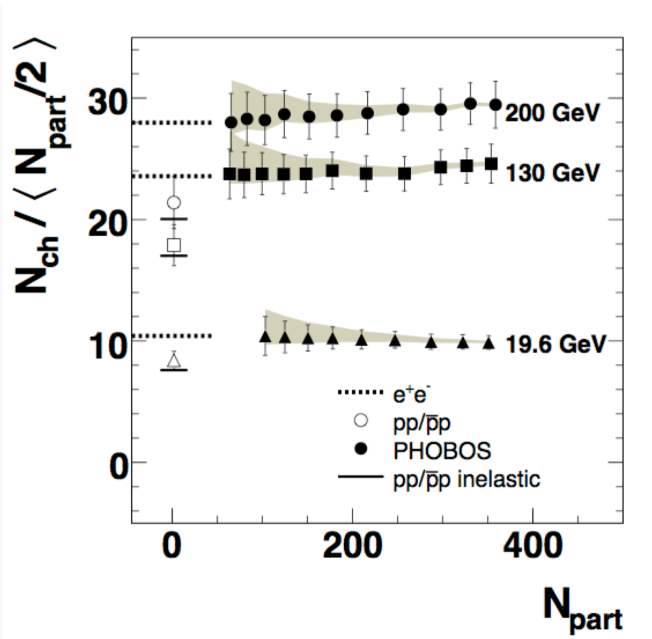
W.Busza et al. (E178) PRL34 (1975) 836

J. E. Elias et al., (E178) PRL 41 (1978) 285

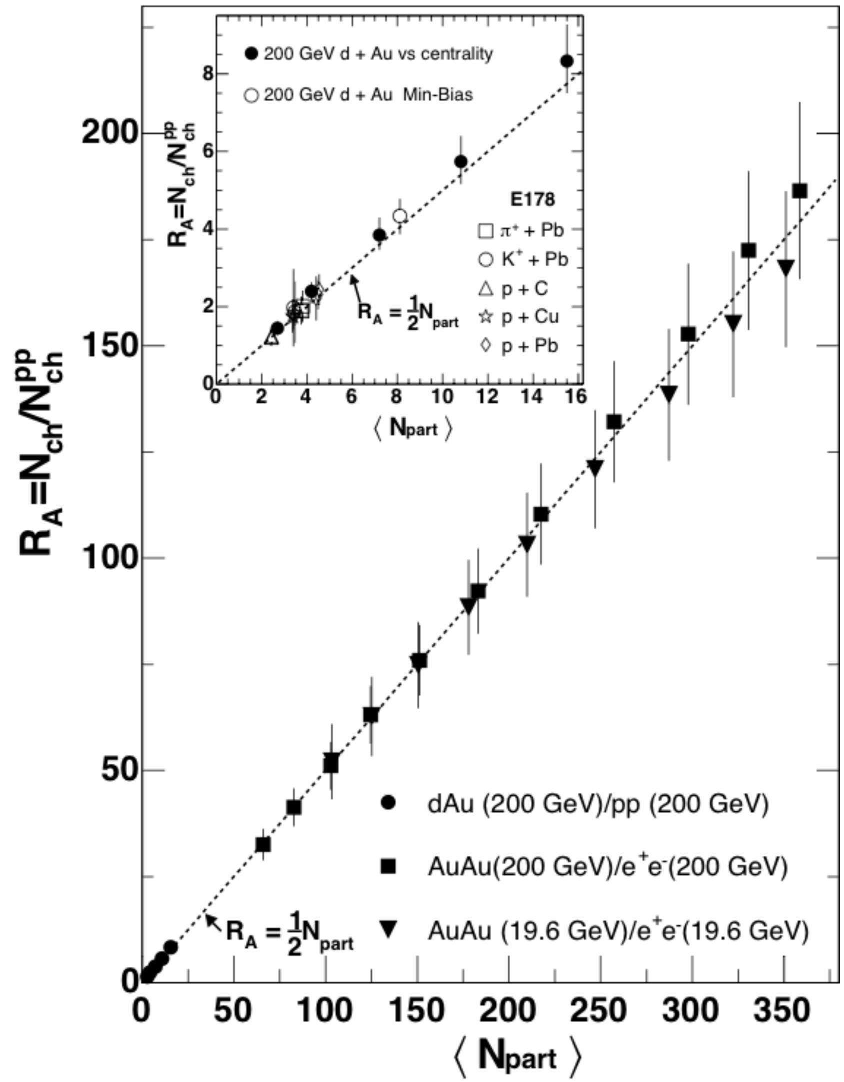
AA collisions consistent with N_{part} - Scaling



PHOBOS, arXiv:0709.4008 [nucl-ex]



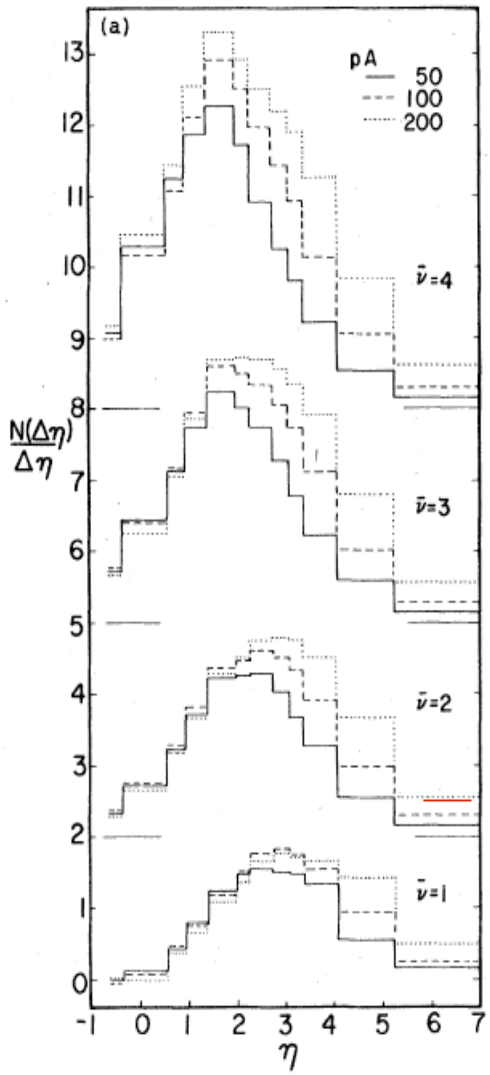
PHOBOS, Phys. Rev. C74 021902 (R) 2006



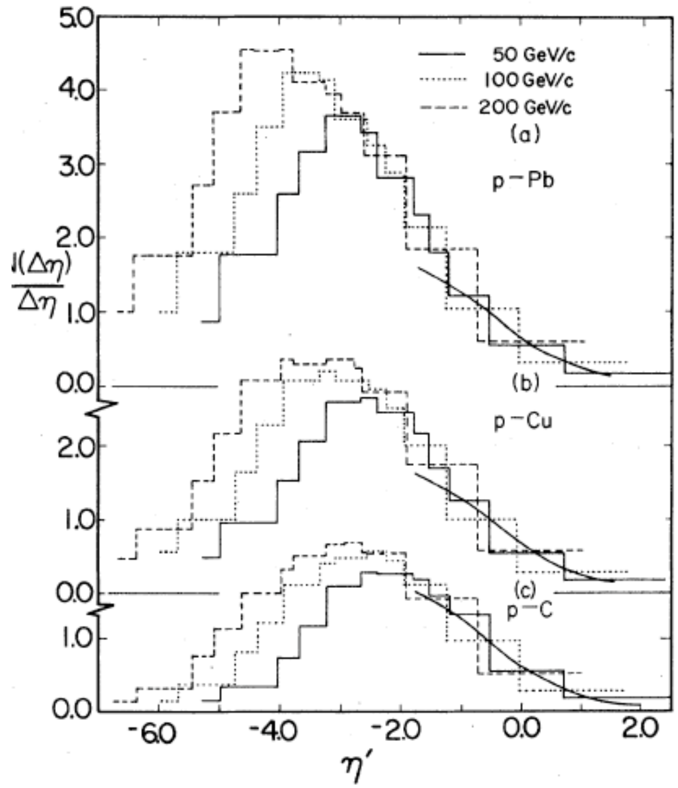
WB, Acta Phys. Pol. B35 (2004)2873

W.Busza et al. (E178) PRL34 (1975) 836

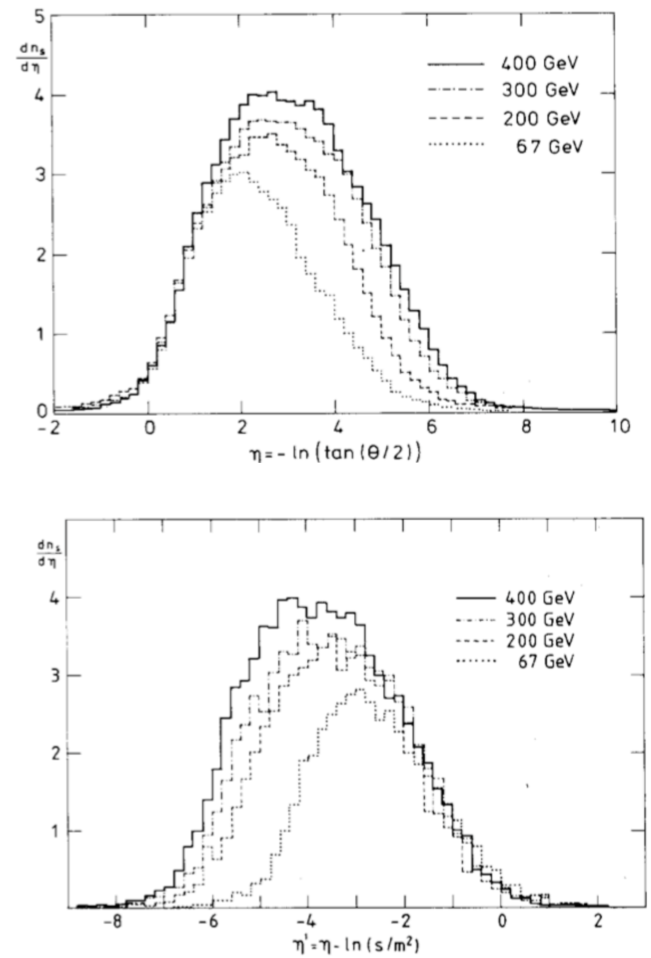
Extended Longitudinal Scaling in E178 Data for $\sqrt{s_{NN}}$ 10 - 20 GeV



Nucleus rest frame



Projectile rest frame

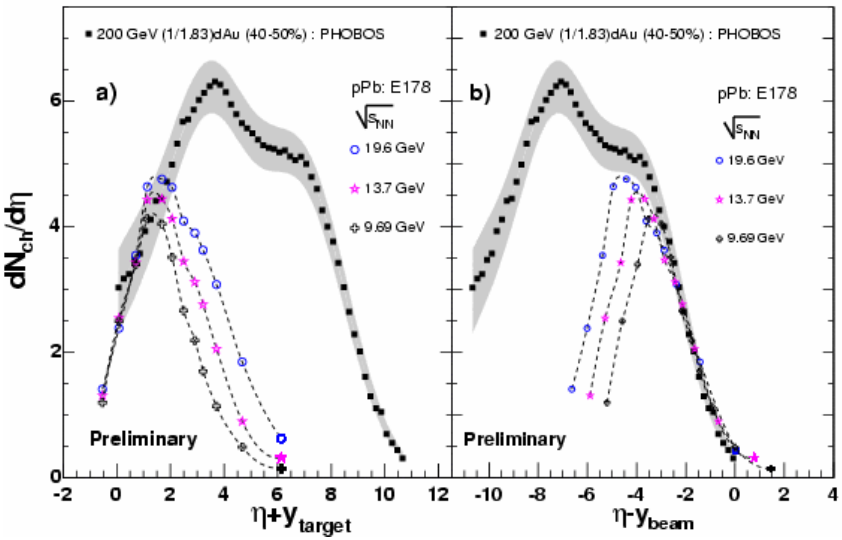


pEmulsion data (Otterlund et al., compilation NP B142 (1978) 445

J. Elias et al., (E178) PR D22 (1980)13

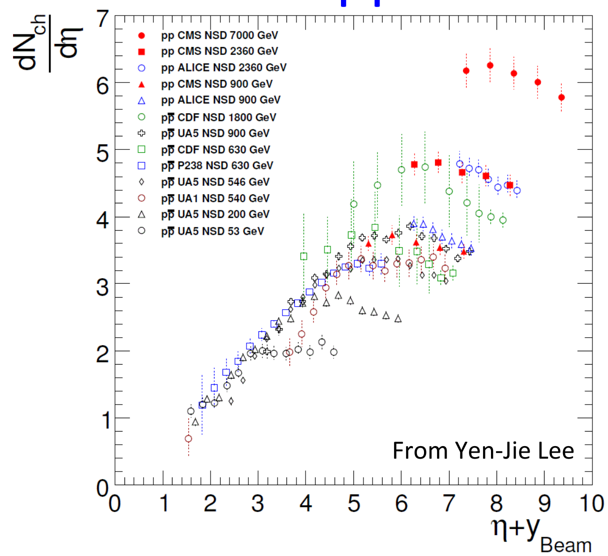
Universality of extended longitudinal scaling

p,d-A

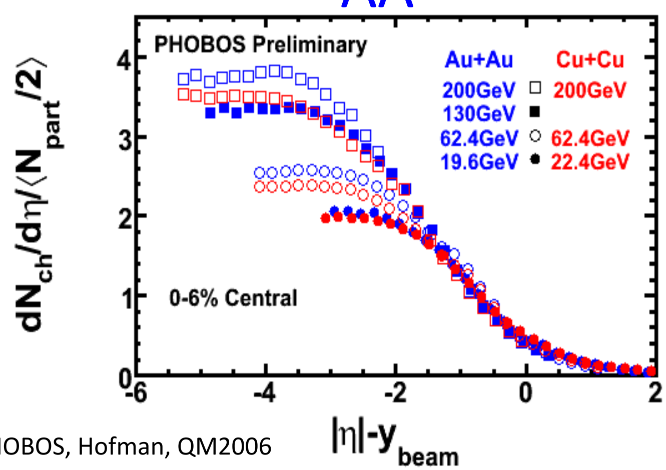


PHOBOS, Nucl. Phys. A 757 (2005) 28.
E178: PRD 22 (1980) 13

pp

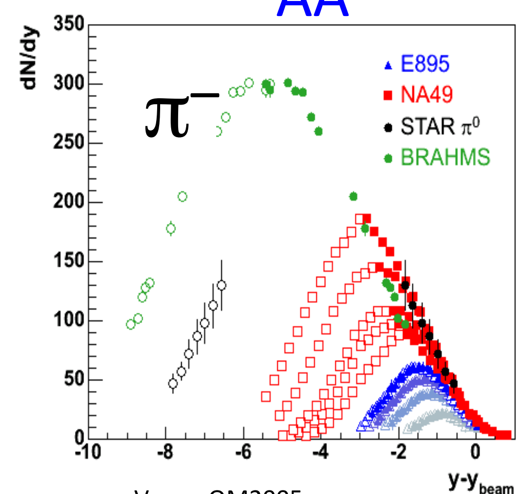


AA



PHOBOS, Hofman, QM2006

AA



Veres, QM2005

First Reference to RHIC

PUGH: I wonder if you would like to say a few words about an additional dimension which seems to be on the verge of experimental feasibility. That is the study of collisions between nuclei at relativistic speeds. I am referring to the present feasibility or near-feasibility of accelerating particles up to carbon or so in the intersecting storage rings at CERN and of conceivably designing new facilities like Isabelle to include such possibilities.

BUZSA: If the interpretation that a few nucleons in a row behave like a single particle is so--and I don't personally believe that--then I think it would have tremendous consequences. If you had two U nuclei colliding with each other they would provide a source of energy much higher than accelerators normally give, but I find it difficult to understand how a few nucleons in a row can behave as a single object.

FESHBACH: Just wanted to ask a foolish question. It occurred to me while you were speaking: Why isn't the explanation of multiplicity trivial? The produced forward particles are peripheral and only interact with the edge of the nucleus and, therefore, just see a few particles while those which come off at larger angles go through the middle of the nucleus, see many nucleons, and, therefore, have increased multiplicity.

A. GOLDHABER: Forward particles are not produced only peripherally, since as $A^{2/3}$ even for them. I also have three comments: 1) Otter-

Questions and Answers at "HE Physics and Nuclear Structure - 1975", page 237 @ Santa Fe & Los Alamos

The “Cronin effect”: that’s another play!

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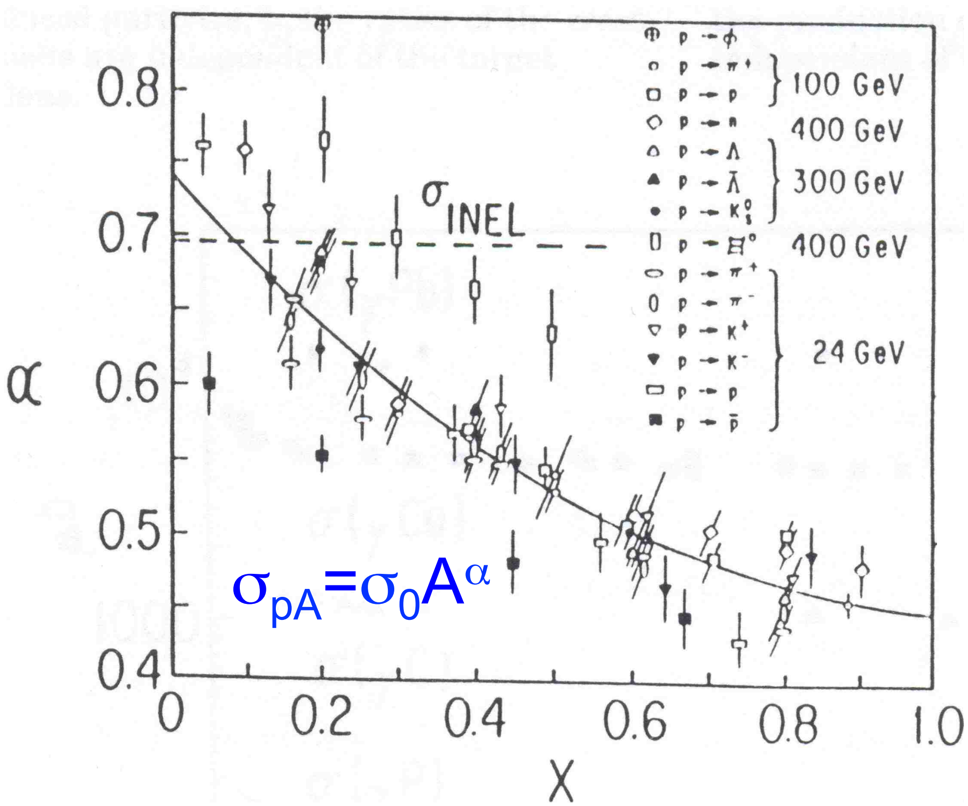
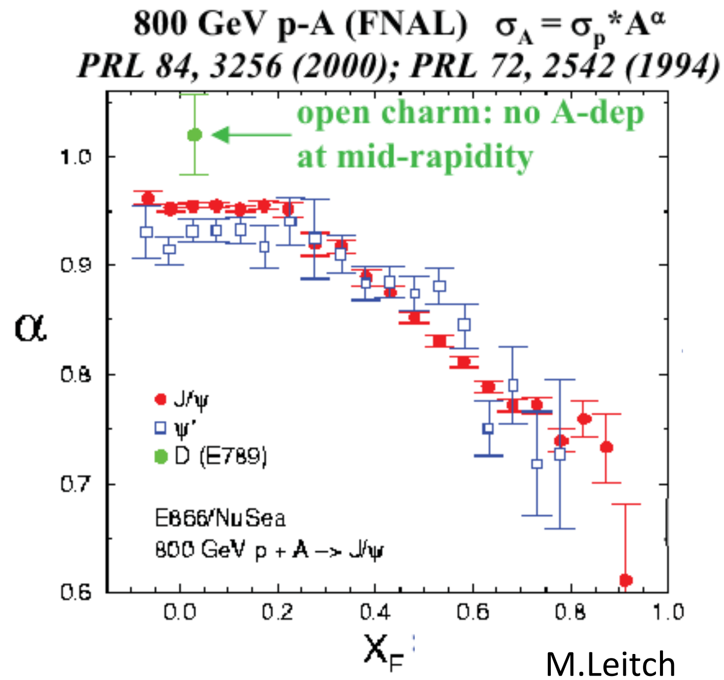
Forward production of particles in pA collsions (πA results are similar)

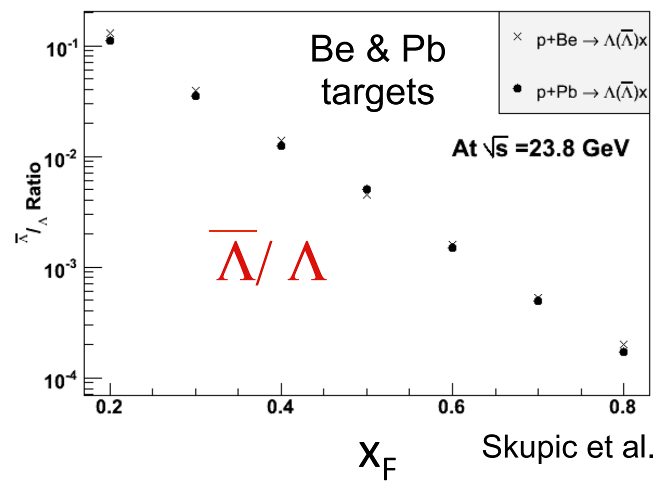
Various final states: ϕ, π^+, π^-,p ,p,n,Λ,K^0,Ξ,K^+,K^-
Various beam energies: 24, 100, 300, 400 GeV



D.Barton et al. (E451) PRD27 (1983) 2580
WB, Nucl. Phys. A544:49 (1992)



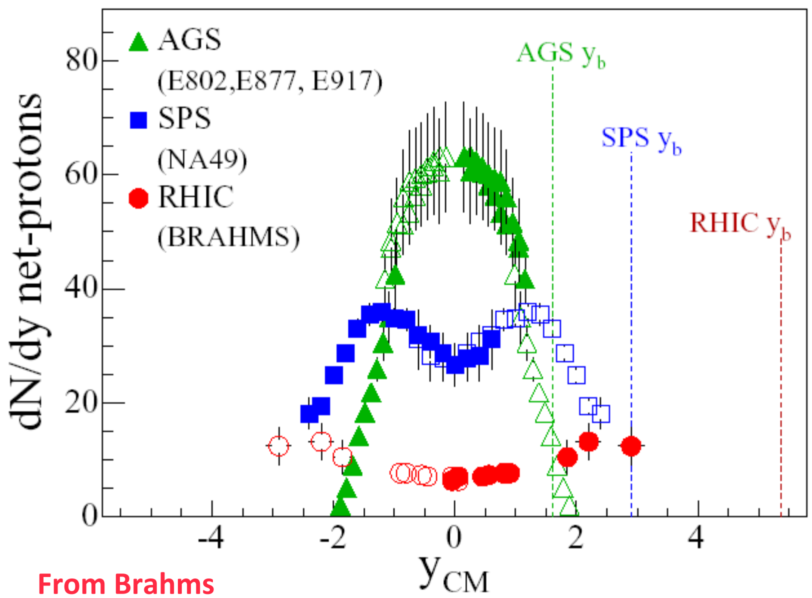
M.Leitch



Skupic et al.

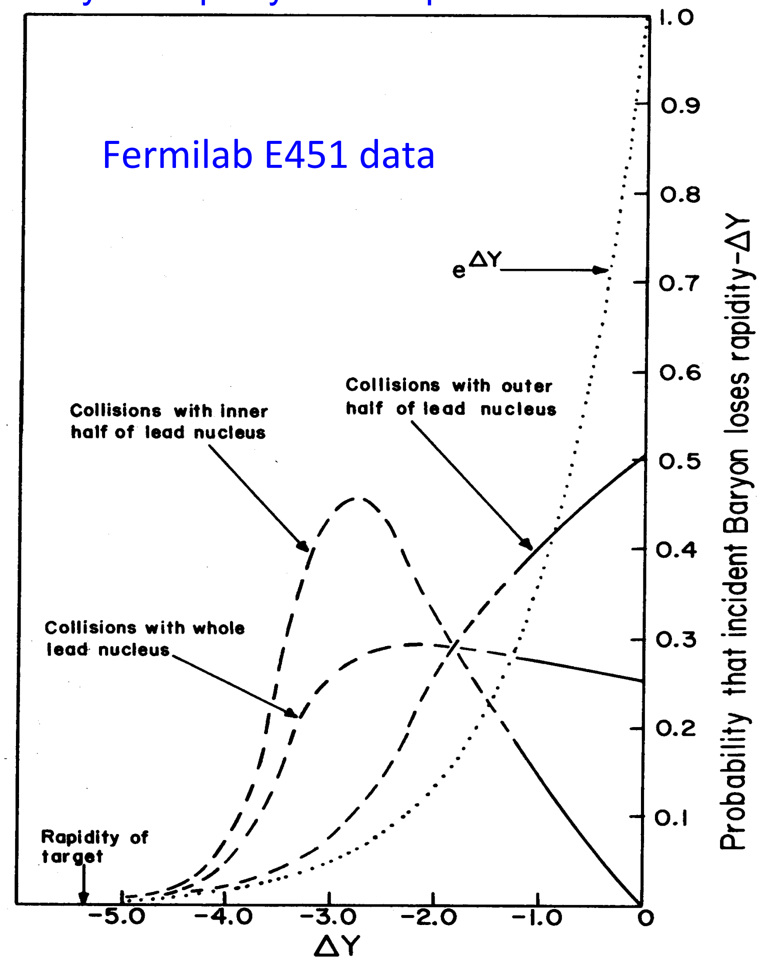
By-product of forward quenching studies:

estimate that, on average at RHIC, baryon will lose 85% of its energy as it goes through the center of the Au nucleus



From Brahms

Baryon Rapidity Loss in pA Collisions



From WB and A.S. Goldhaber

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PRL 91 (7), 070401–079702, 15 AUGUST 2003 (256 total pages)

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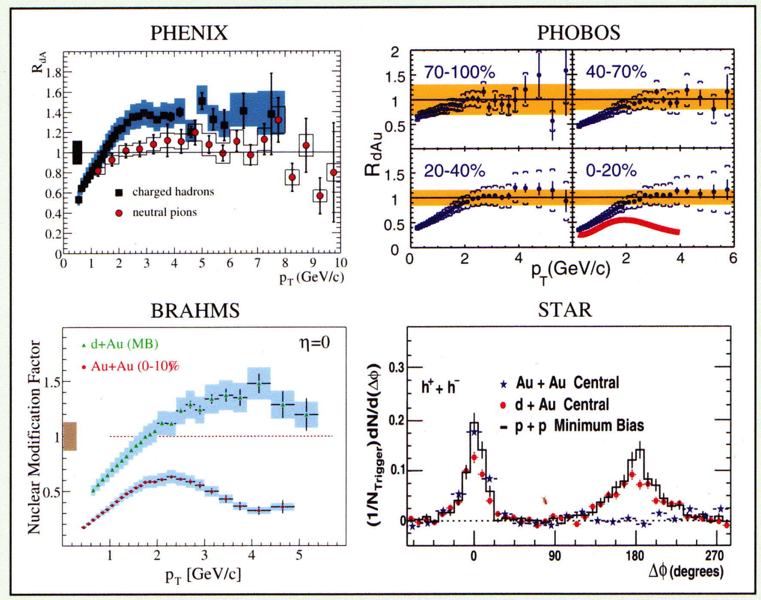
PHYSICAL REVIEW LETTERS

Articles published week ending
15 AUGUST 2003

Volume 91, Number 7



APS Published by The American Physical Society

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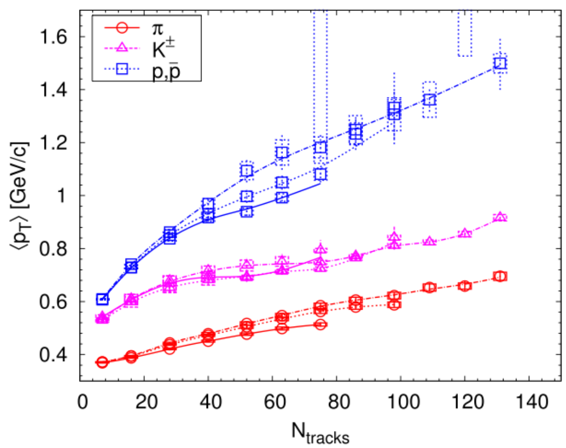
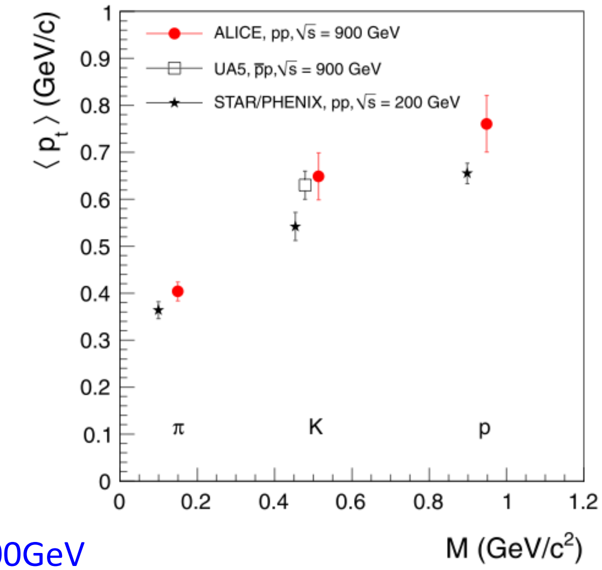
Remarkable similarity of mass dependence of average P_t in AA and pp

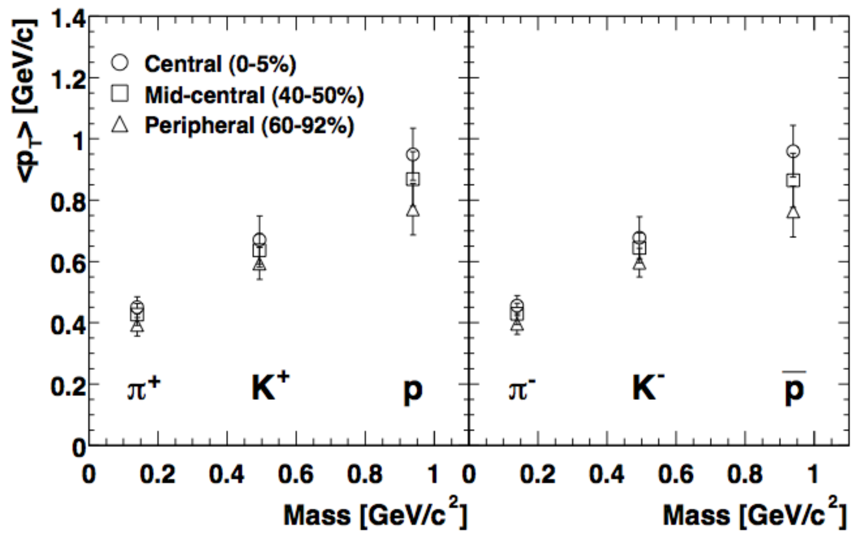
CMS, pp, 0.9, 2.76 and 7 TeV



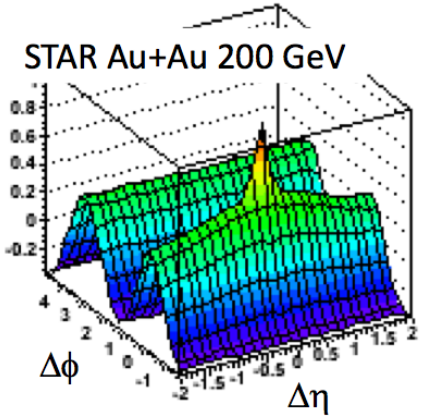
ALICE, UA5, STAR/PHENIX

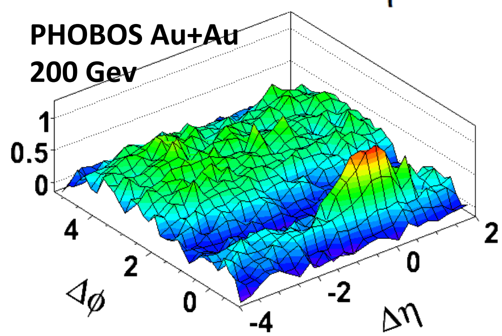


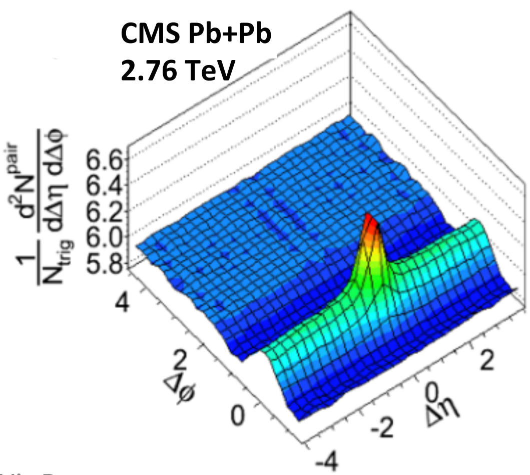
PHENIX, AuAu, 200GeV

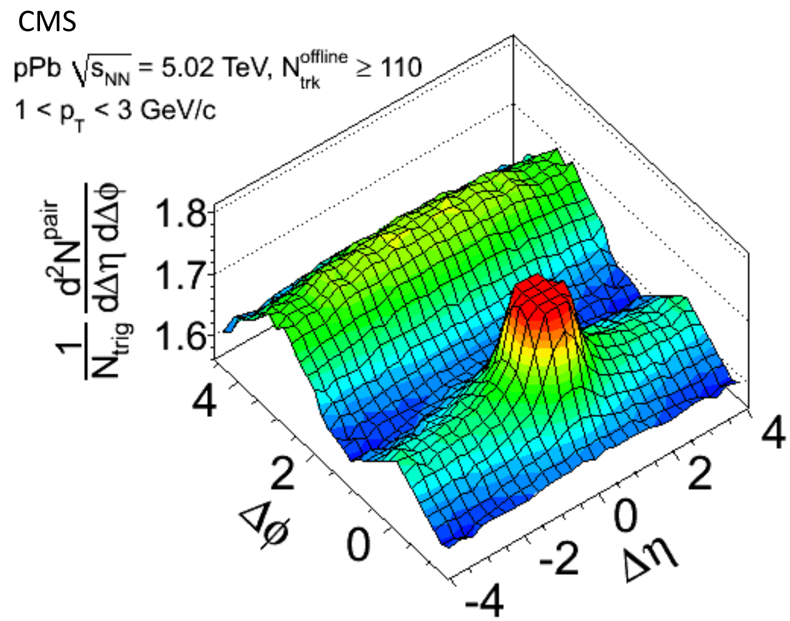


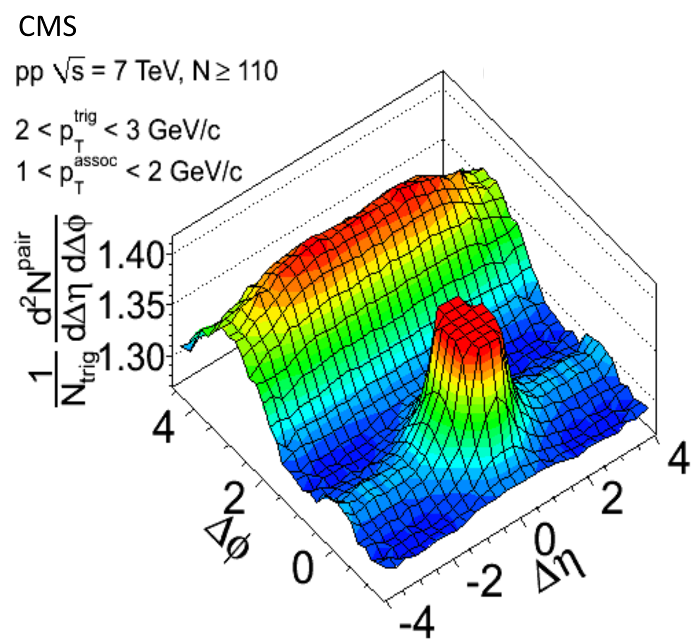
The ridge phenomenon











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Concluding remarks

pA data has, and continues to surprise us

- lack of cascading in the 1950' and 1960's
- long range correlations and simplicity of participant scaling in the 1970's
- "Cronin effect" in the the 1970's
- strong quenching of forward particles in the 1970's and 1980's
- "flow-like" behavior in the 2010's

pA is like a litmus test. Until we understand pA from our understanding of pp and AA, we cannot claim to have a deep understanding of pp and AA.

I take this opportunity to thank Andrzej Białas, Bj, Kurt Godfried, Freddie Goldhaber, Larry Jones, Miklos Gyulassy and Al Mueller, for helping make pA so much fun for me !