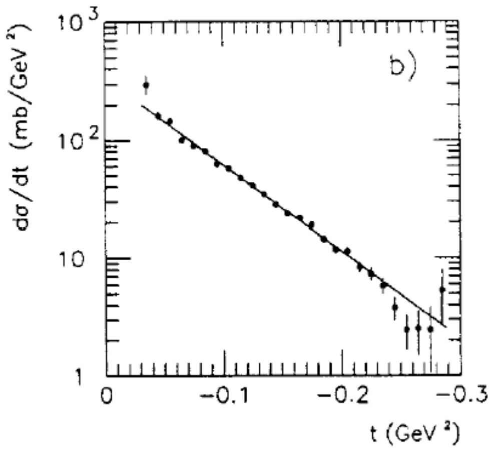
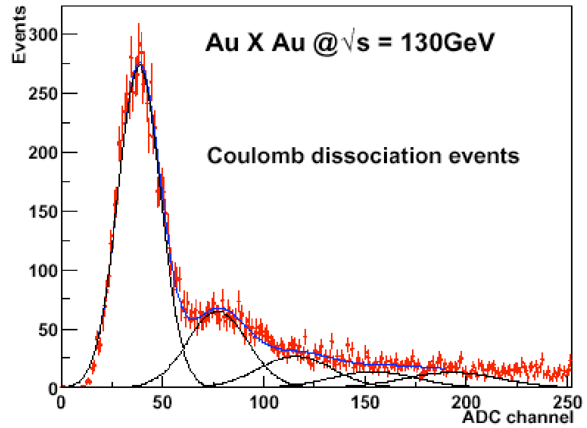


Luminosity Measurement at pp&Heavy ion colliders



I. Determination in pp using elastic scattering

II. Determination for Heavy Ions

III. The role of accelerator tools

LEMIC Workshop on Luminosity 9/12/02

Sebastian White, BNL

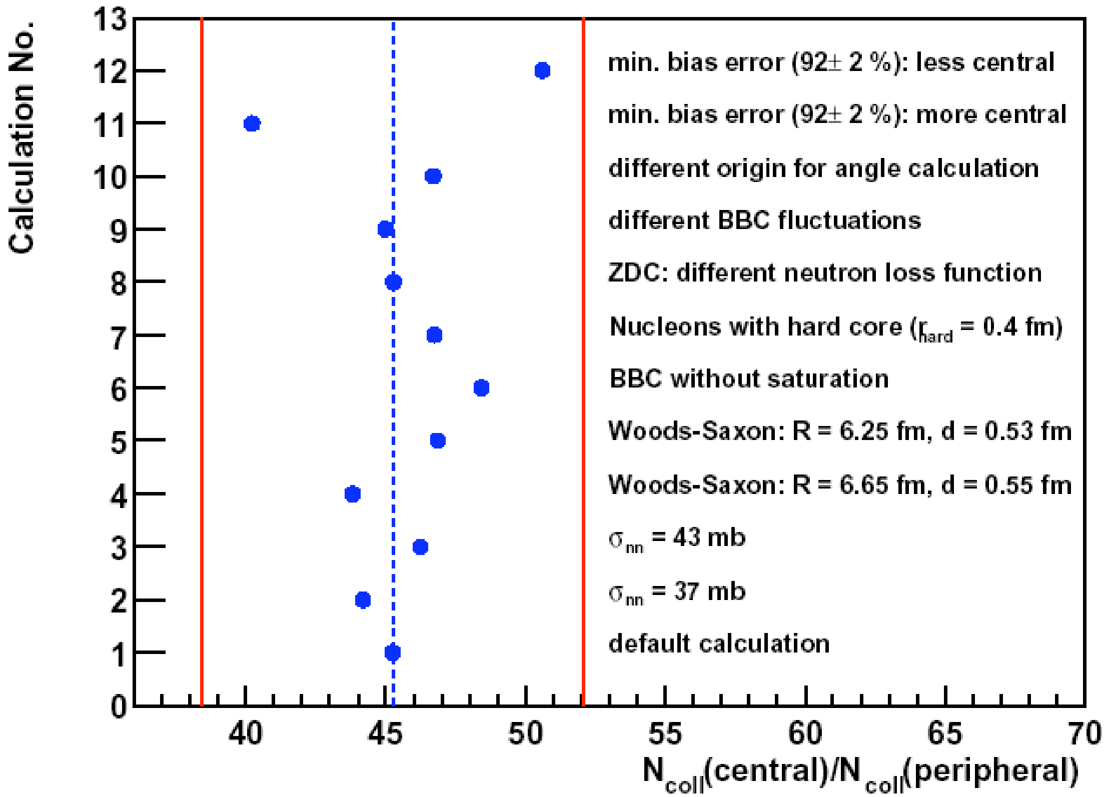
pp versus AA methodology

p-p(bar)	Heavy Ion
Elastic scattering Special optics/det	Minimum Bias (standard dets)
Available ~4-5 yrs after startup	Available ~day-1
$\square_L$~3%	$\square_L$ ~5% 2% possible

AA cross-normalization with pp

1) From pp comparison data
   - Error from AA &pp Luminosity uncertainties and ncollision

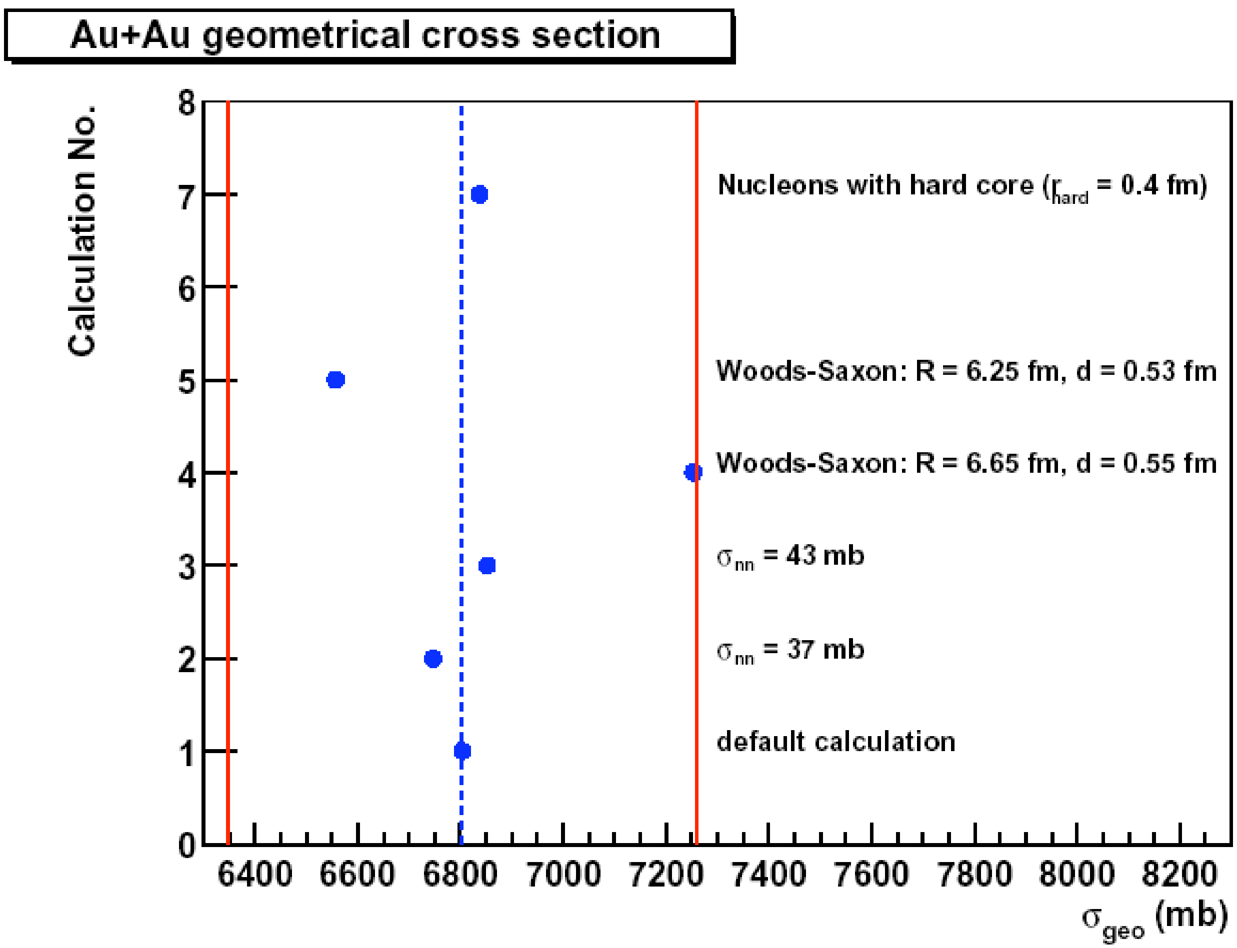
2) From central/peripheral
   - Error from determination of centrality classes



<- *Klaus Reygers, PHENIX internal note 7/01*

Total Inelastic Cross sections

Ion Geometric cross sections decouple from σ_{nn}



<- *ditto*

pp Methodology to calculate Luminosity

Since ISR, collider expts. have used:

1. Accelerator based calculation (more later)
   - uses I_{beam}, □, □*
1. "Dead reckoning" from published data
   ie D0- uses E710&CDF average
2. "Luminosity independent method"
   -uses $□_{tot}$, $□_{el}$, □
3. "Pure Coulomb" region elastic scattering
   -uses $□_{em}$ and G(t)

Luminosity at Hadron Colliders

•In 70's, near end of ISR career, Cern-Roma and Pisa-SB joined forces and invented the "Luminosity independent method". Subsequent studies of comparison w. van der Meer method and limits on precision(~1-2%)

•Van der Meer in machines with zero x-ing angle more complicated.

•At SPPS, UA4 used "Lum Indep Method", revised in UA4'

•At TevI, 4 measurements disagree. Lum discrepancy not resolved.

In 1994 D0 increased it's "luminosity constant" by 12.4% to reflect world average and assigned an error of 12% to Luminosity

•RHIC Luminosity uncertainties in AuAu and pp data 5%, 30%

QM 2002

pp Methodology for Luminosity

1. In "pure coulomb" region t ~10^{-4} $(GeV/c)^2$ and scattering angle (ie □=1-2 mrad at LHC)is ~$□□_{beam}$
   - a 2nd generation elastic scatt experiment
2. "Luminosity Independent Method" uses nuclear slope (ie t ~$10^{-2}(GeV/c)^2$) and optical theorem:

$$(1+\varrho^2)\cdot\sigma_{tot}^2 = \mathcal{L}^{-1}16\pi(hc)^2\frac{dR_{elast}}{dt}\Big|_{t=0}$$

From which:

$$(1+\varrho^2)\cdot\sigma_{tot} = \frac{16\pi(hc)^2}{R_{elastic}+R_{inelastic}}\cdot\frac{dR_{elast}}{dt}\Big|_{t=0}$$

pp Luminosity independent method

A large acceptance Luminosity monitor counter is embedded in the measurement which is calibrated in the process.

$$\sigma_{DA} = \frac{\sigma_{DA}}{\sigma_{tot}} \cdot \sigma_{tot} = \frac{R_{DA}}{(R_{elast} + R_{DA} + R_{SA} + R_{extrap})^2} \cdot \frac{16\pi(hc)^2}{(1+\varrho^2)} \cdot \frac{dR_{el}}{dt}\Big|_{t=0}$$

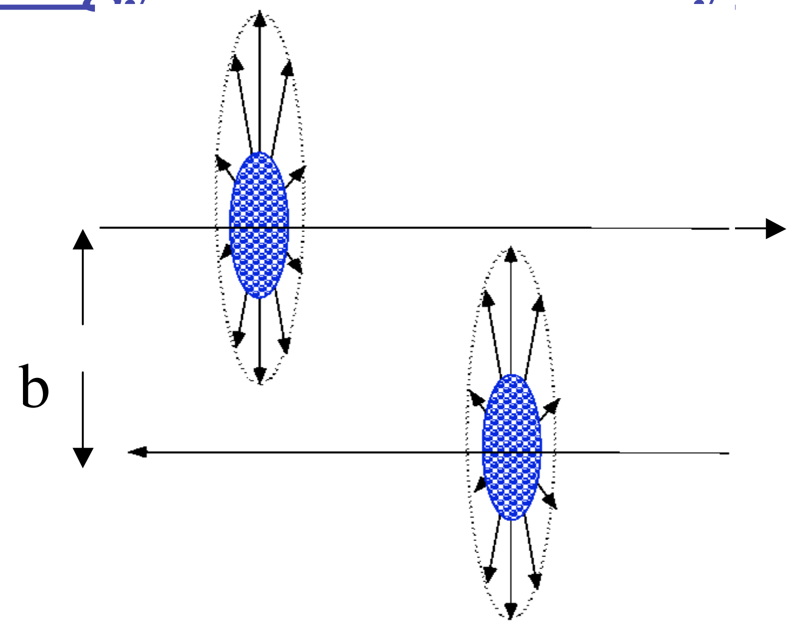
UA4:

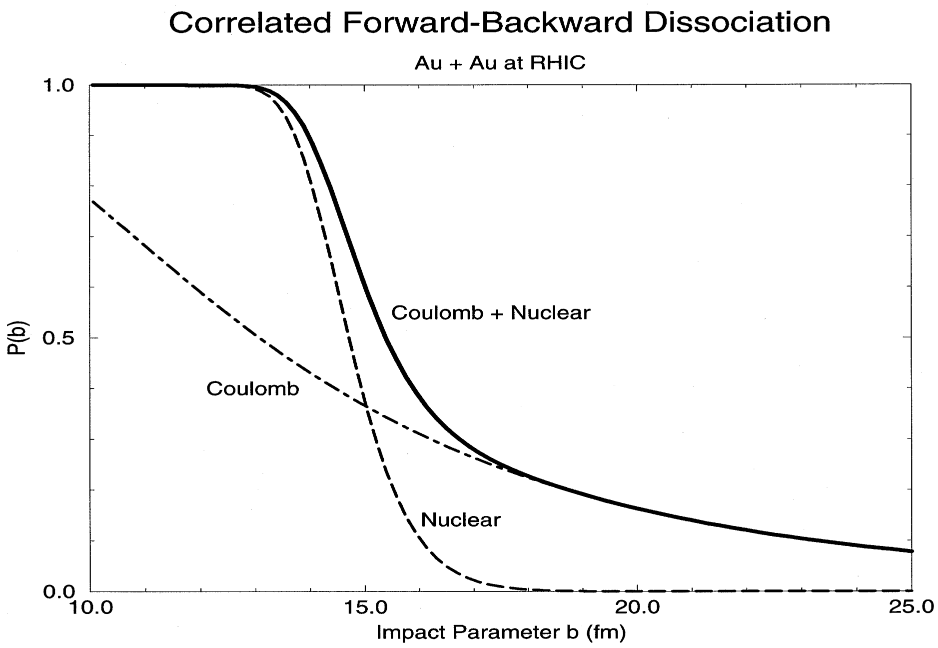
Trigger Contribution	η-range	Fraction of N_{inel} %
Double-arm(= f_{DA})	3.0 - 5.6	82.7 $\pm$ 0.8
Single Arm	2.5 - 5.6	16.3 $\pm$0.6
Central Detector	$\leq$1.7	0.08 $\pm$0.04
Small-angle extrapolation	$\geq$ 5.6	0.9$\pm$0.2
Large angle correction	1.7 - 2.5	0.04 $\pm$ .02

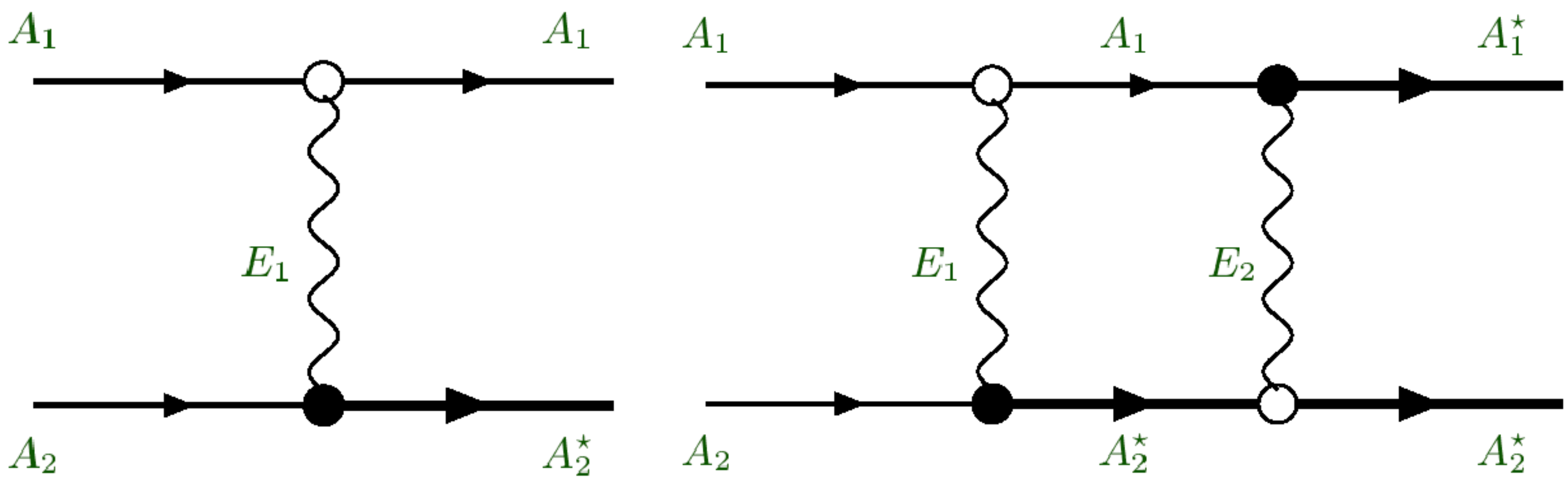
Heavy Ion methodology for Luminosity

AuAu->Au+Au* 92 barns
→ X+neutrons

AuAu->Au*+Au* 3.6 barns
→ X+neutrons
→ Y+neutrons







Weizsäcker-Williams (WW) method

[1] A.Baltz, M.J.Rhoades-Brown, J.Weneser, Phys. Rev. E 54 (1996) 4233.

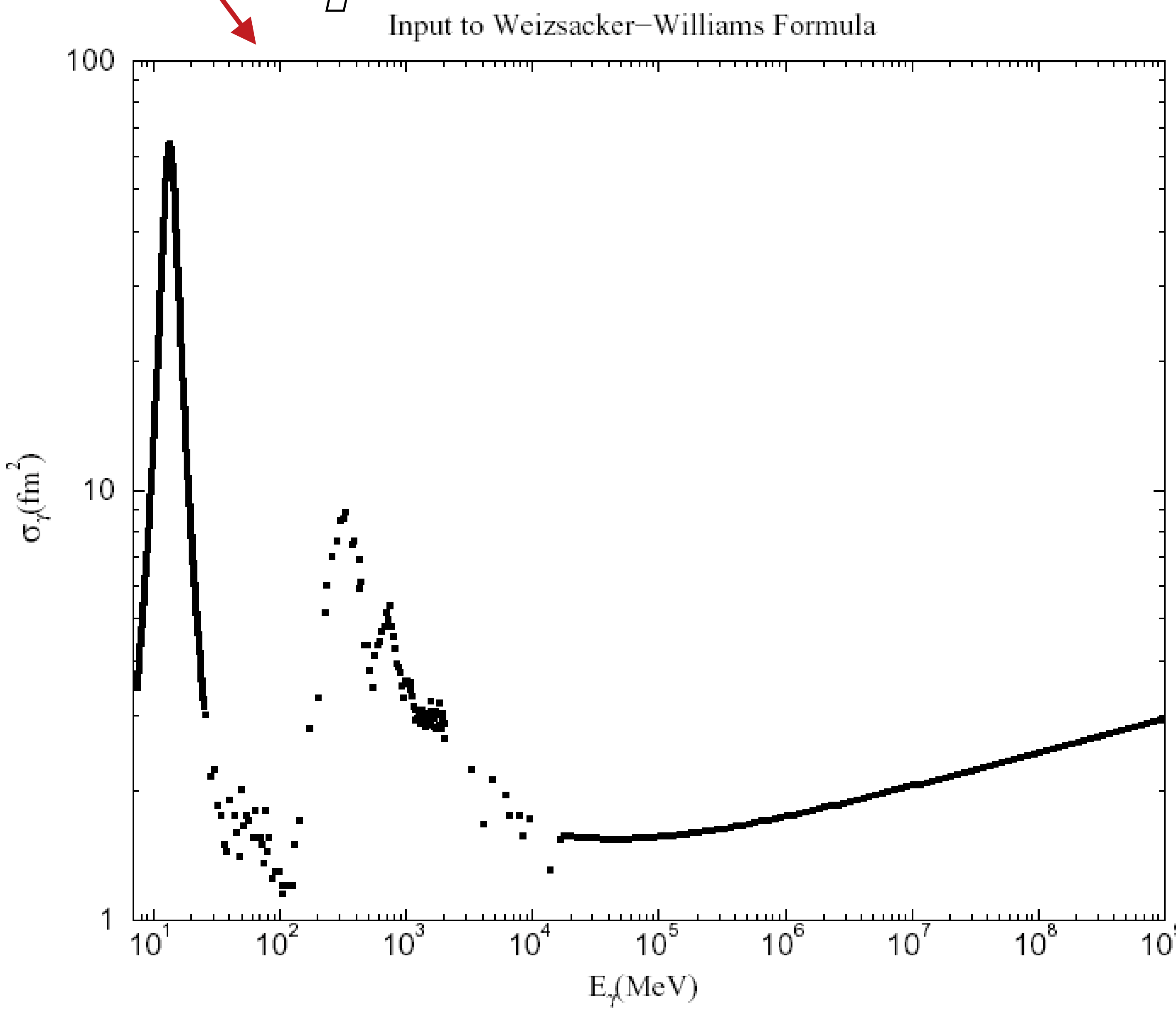
[2] A.J. Baltz, S.N.White, RHIC/DET Note 20, BNL-67127 (1996)

[3] S.N.White, Nucl. Instrum. Meth. A409, 618 (1998).

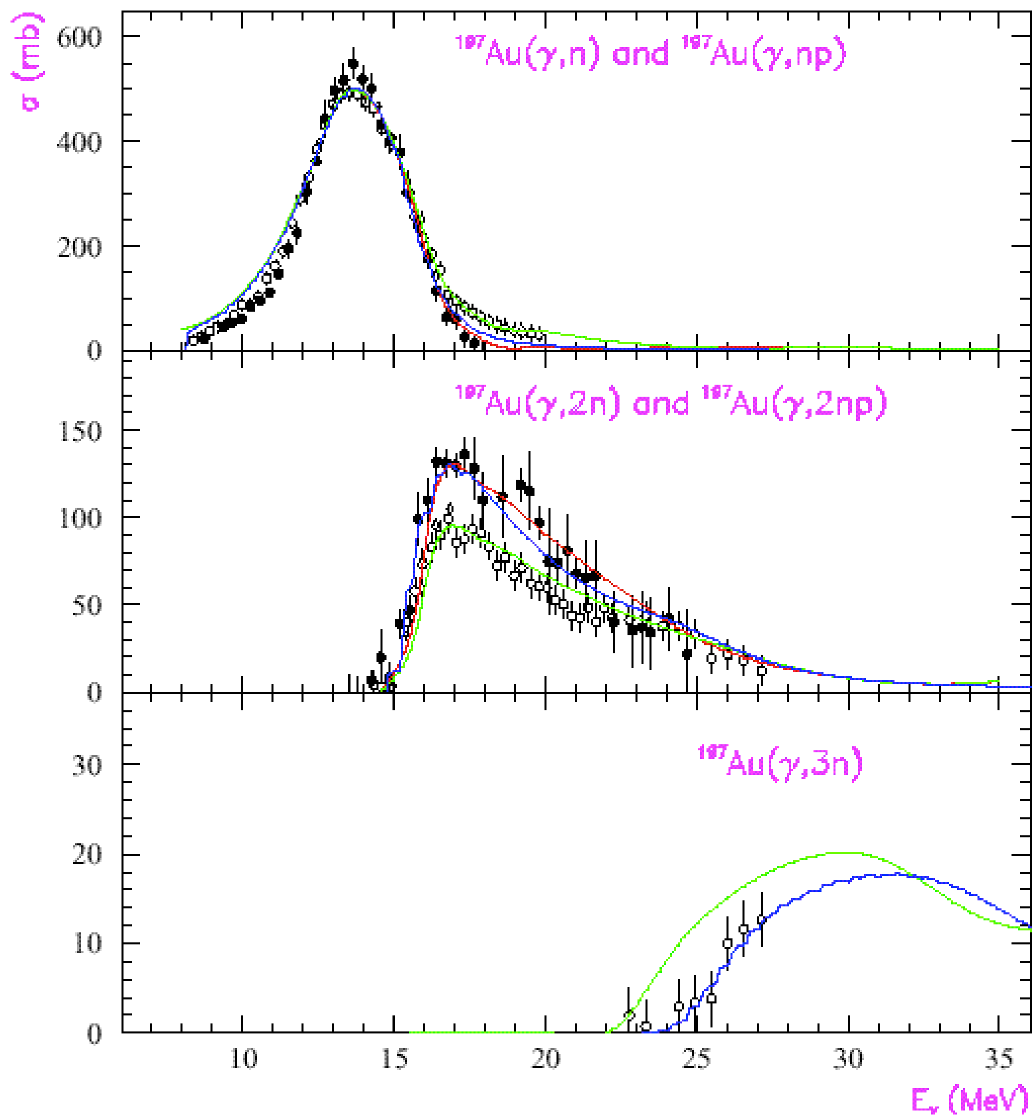
[4] A.J.Baltz, C.Chasman and S.N.White, Nucl. Instrum. Meth. A417, 1 (1998) nucl-ex/9801002.

[5] I.A. Pshenichnov , J.P. Bondorf , I.N. Mishustin , A. Ventura , and S. Masetti, nucl-th/0101035

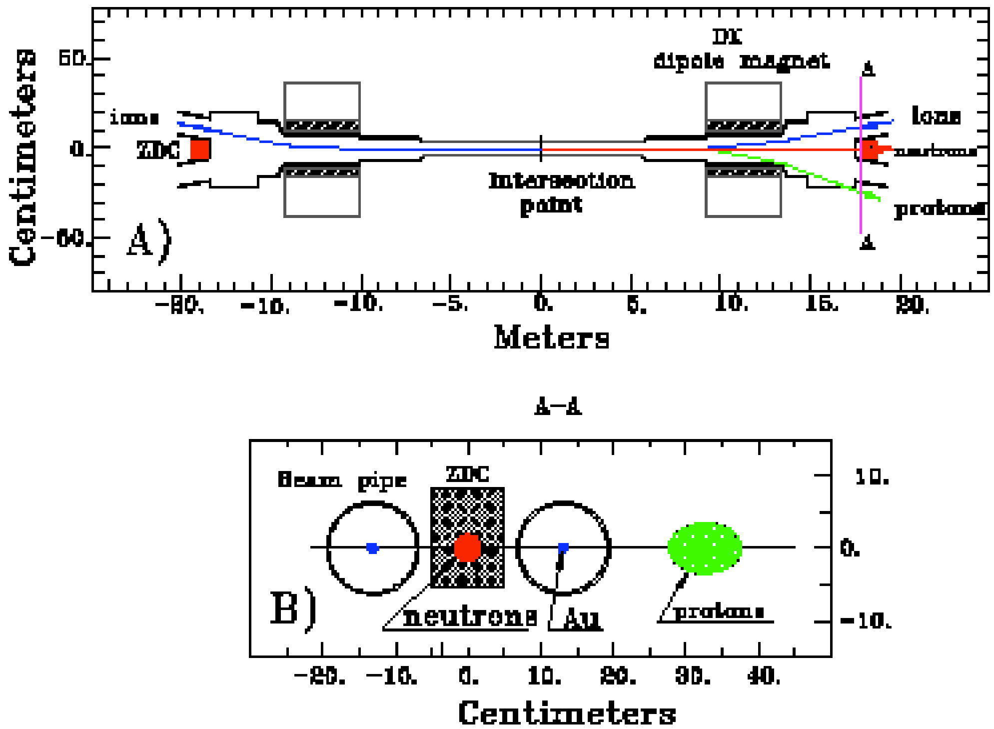
$$\sigma_{MCD} = \frac{2\alpha^2 Z^4}{\pi^3 \gamma^4} \int_{b_0} b\,db \left[\int \omega\, d\omega\, \sigma_{ph}(\omega) K_1^2\left(\frac{b\omega}{\gamma}\right)\right]^2$$



Low Energy Photonuclear Cross sections and n-multiplicities,momenta (Saclay & Livermore data)

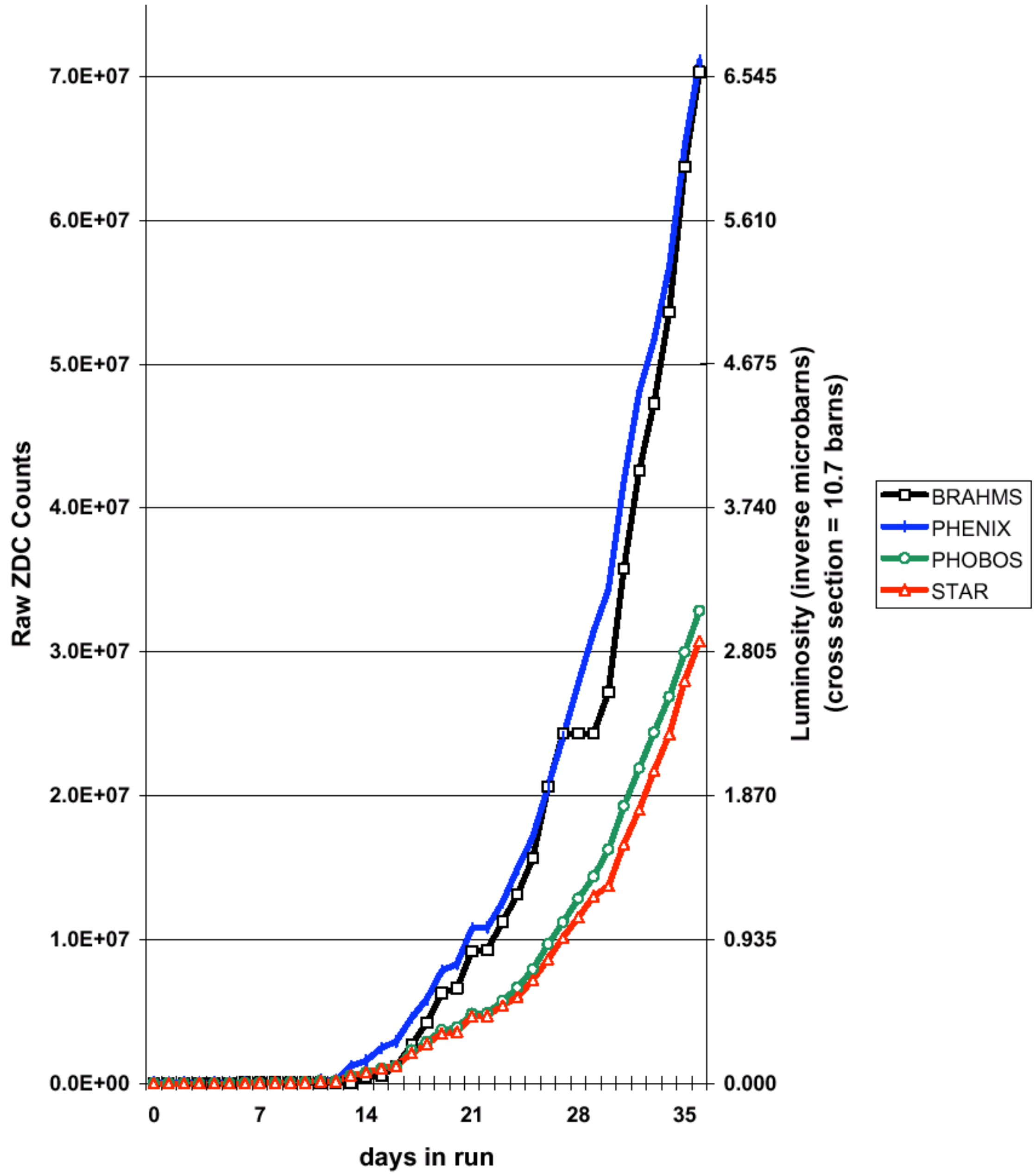


Interaction Region Geometry



Zero Degree Calorimeter Acceptance

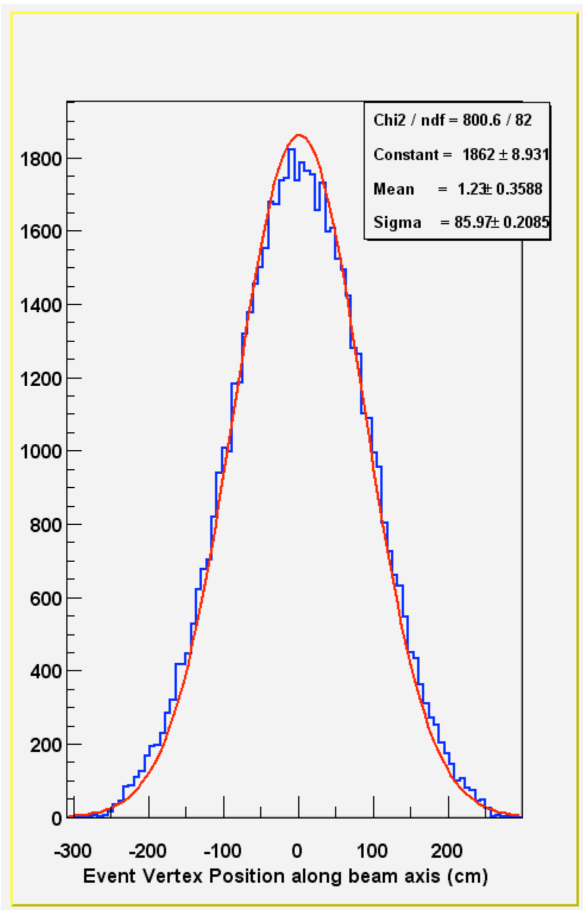
Luminosity and Beam Quality

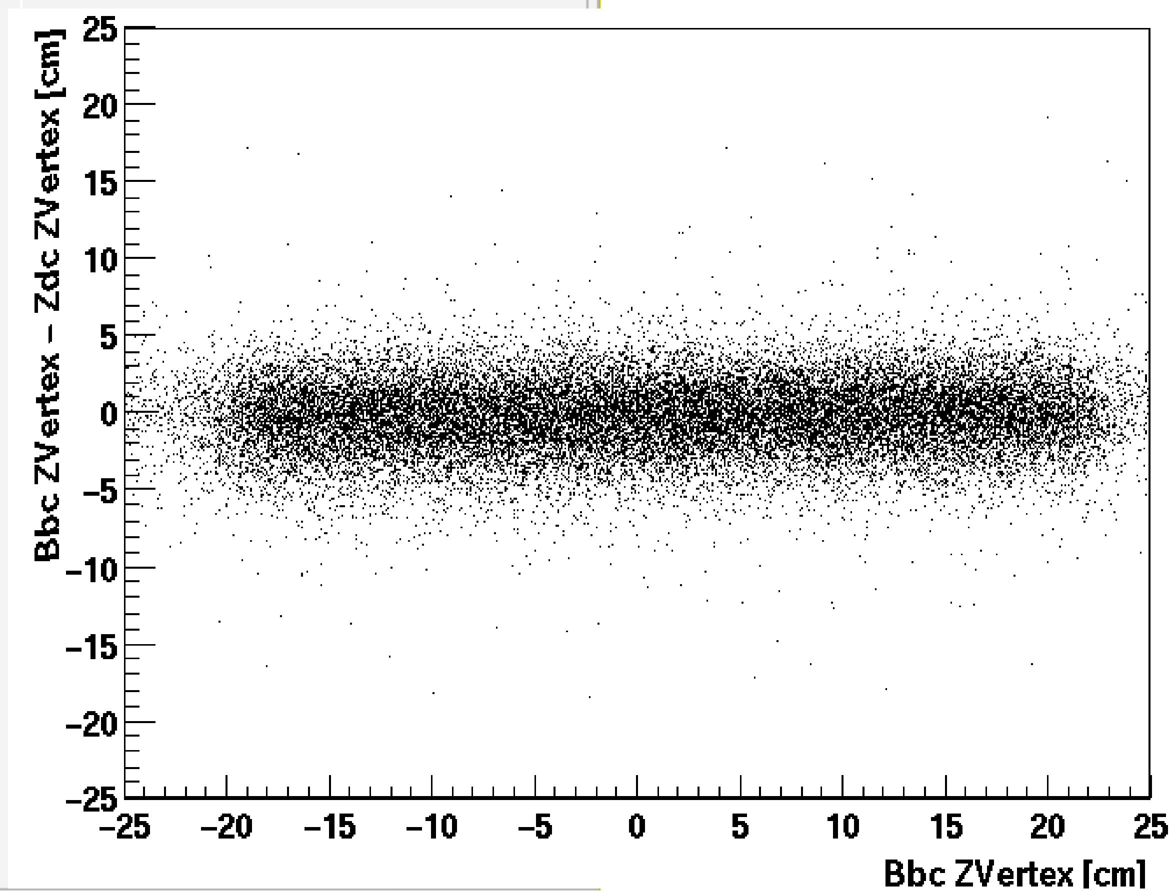


ZDC measurement of Luminosity profile:z_{int}

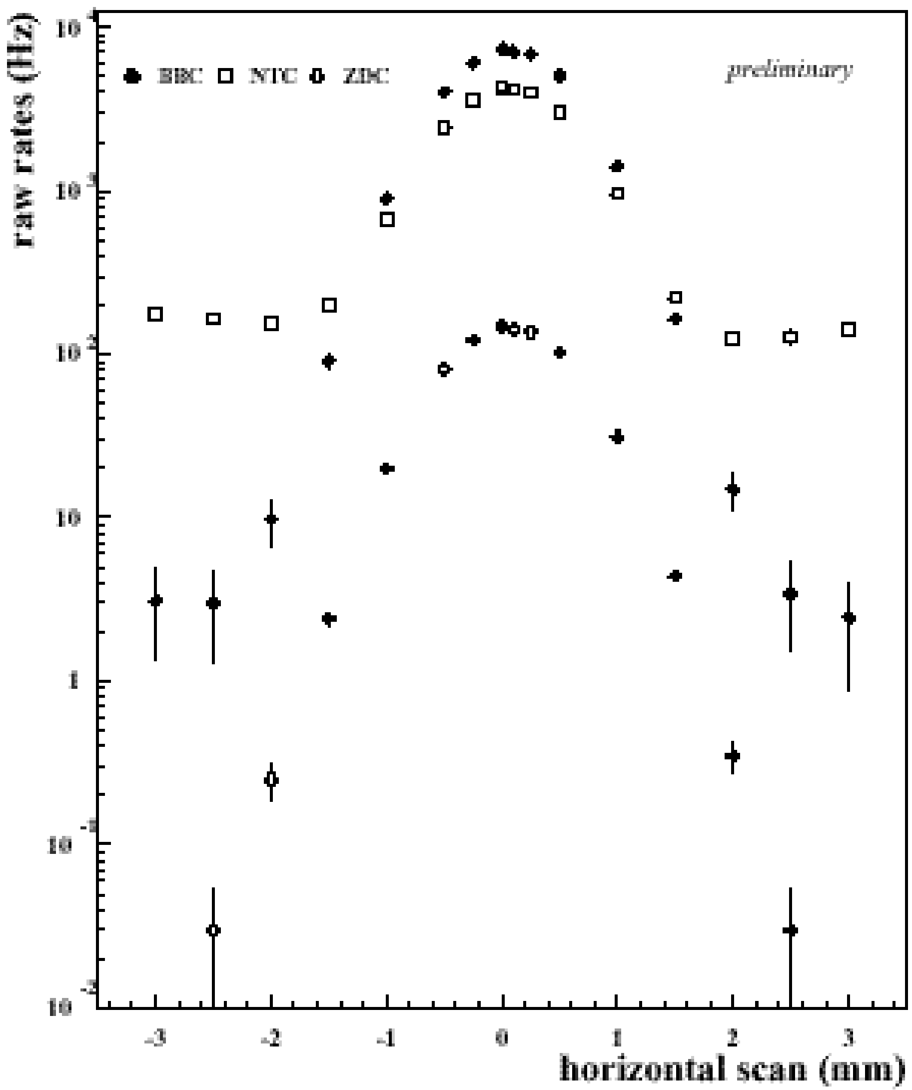
Interaction point(z)

ZDC resolution ~2 cm (σ_t~120 ps)





Van der Meer scans
Using different interaction triggers



RHIC UPC Physics results from Run I.

published

VOLUME , NUMBER PHYSICAL REVIEW LETTERS

Measurement of Mutual Coulomb Dissociation in $\sqrt{s_{NN}} = 130$ GeV Au + Au Collisions

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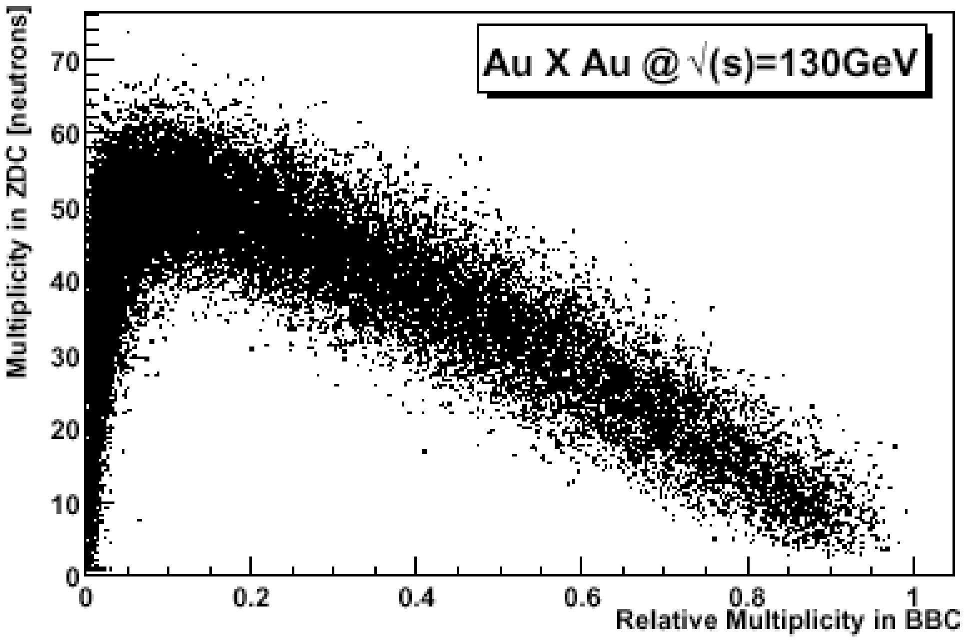
(Received 28 September 2001; revised manuscript received 19 November 2001; published)

submitted

Coherent ρ^0 Production in Ultra-Peripheral Heavy Ion Collisions

C. Adler[11], Z. Ahammed[23], C. Allgower[12], J. Amonett[14], B.D. Anderson[14], M. Anderson[5], G.S. Averichev[9],
J. Balewski[12], O. Barannikova[9,23], L.S. Barnby[14], J. Baudot[13], S. Bekele[20], V.V. Belaga[9], R. Bellwied[31], J. Berger[11],
H. Bichsel[30], L.C. Bland[2], C.O. Blyth[3], B.E. Bonner[24], A. Boucham[26], A. Brandin[18], A. Bravar[2], R.V. Cadman[1],
H. Caines[20], M. Calderón de la Barca Sánchez[2], A. Cardenas[23], J. Carroll[15], J. Castillo[26], M. Castro[31],
D. Cebra[5], P. Chaloupka[20], S. Chattopadhyay[31], Y. Chen[6], S.P. Chernenko[9], M. Cherney[8], A. Chikanian[33],
B. Choi[28], W. Christie[2], J.P. Coffin[13], T.M. Cormier[31], J.G. Cramer[30], H.J. Crawford[4], W.S. Deng[2],
A.A. Derevschikov[22], L. Didenko[2], T. Dietel[11], J.E. Draper[5], V.B. Dunin[9], J.C. Dunlop[33], V. Eckardt[16],



Efficiencies(hadronic):

ϵ_{bbc}= (92 ± 2)% (HIJING)*

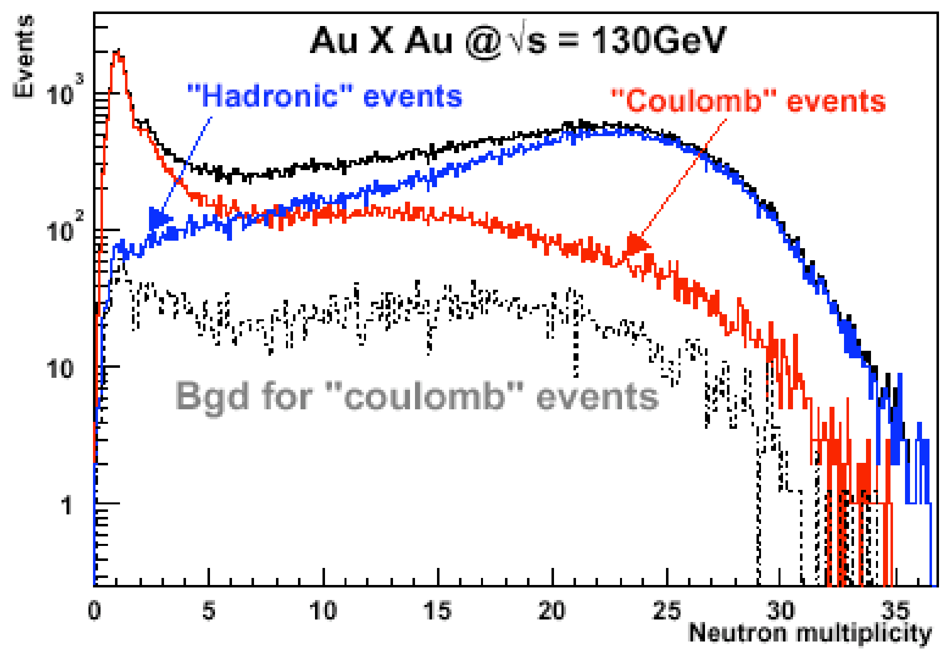
ϵ_{bbc} = (93 ± 2)% (JAM)

ϵ_{zdc} = (98 ± 2)% (conservative),

ϵ_{zdc} = (99.5 - 1.5)% (realistic)

*(in PHENIX Multiplicity PRL)

BBC ineff-> Coulomb bkg

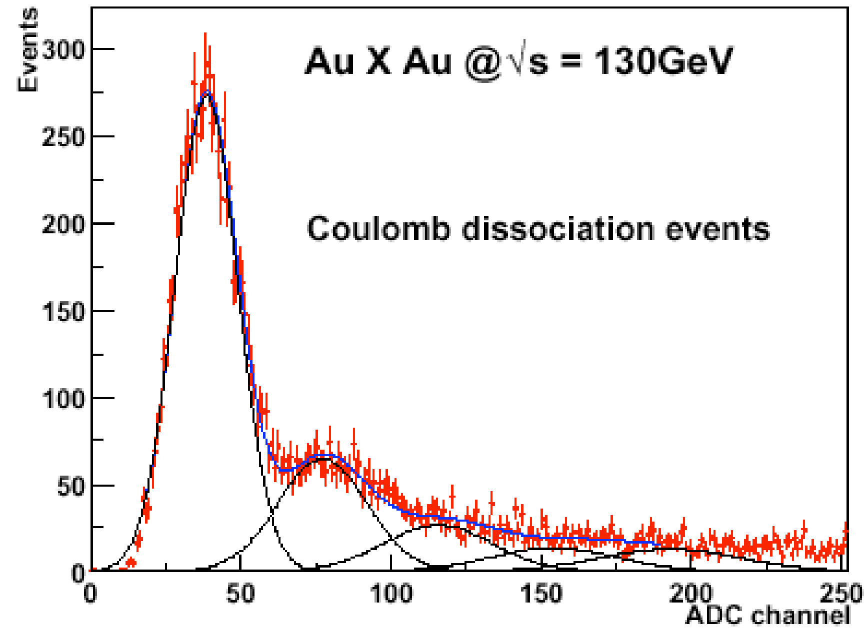


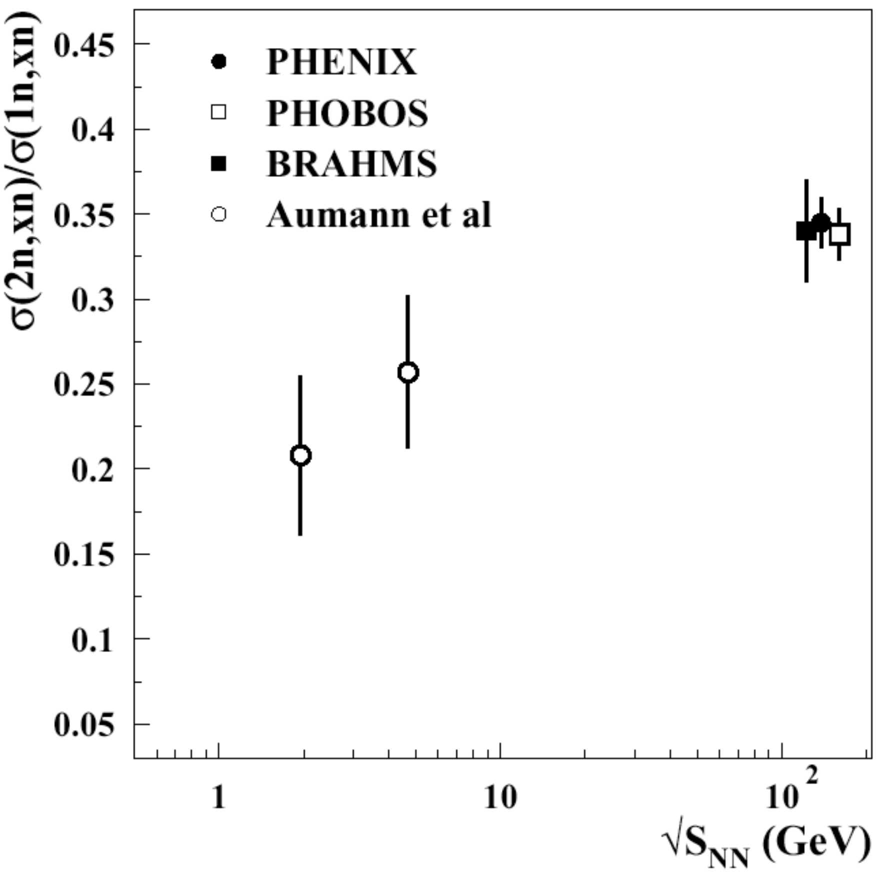
Other corrections

- Coulomb-> BBC hits
- Coulomb->ZDC miss
- Diffraction Dissociation

(all negligible)

Left ZDC neutron multiplicity
cut on 1n in Right ZDC





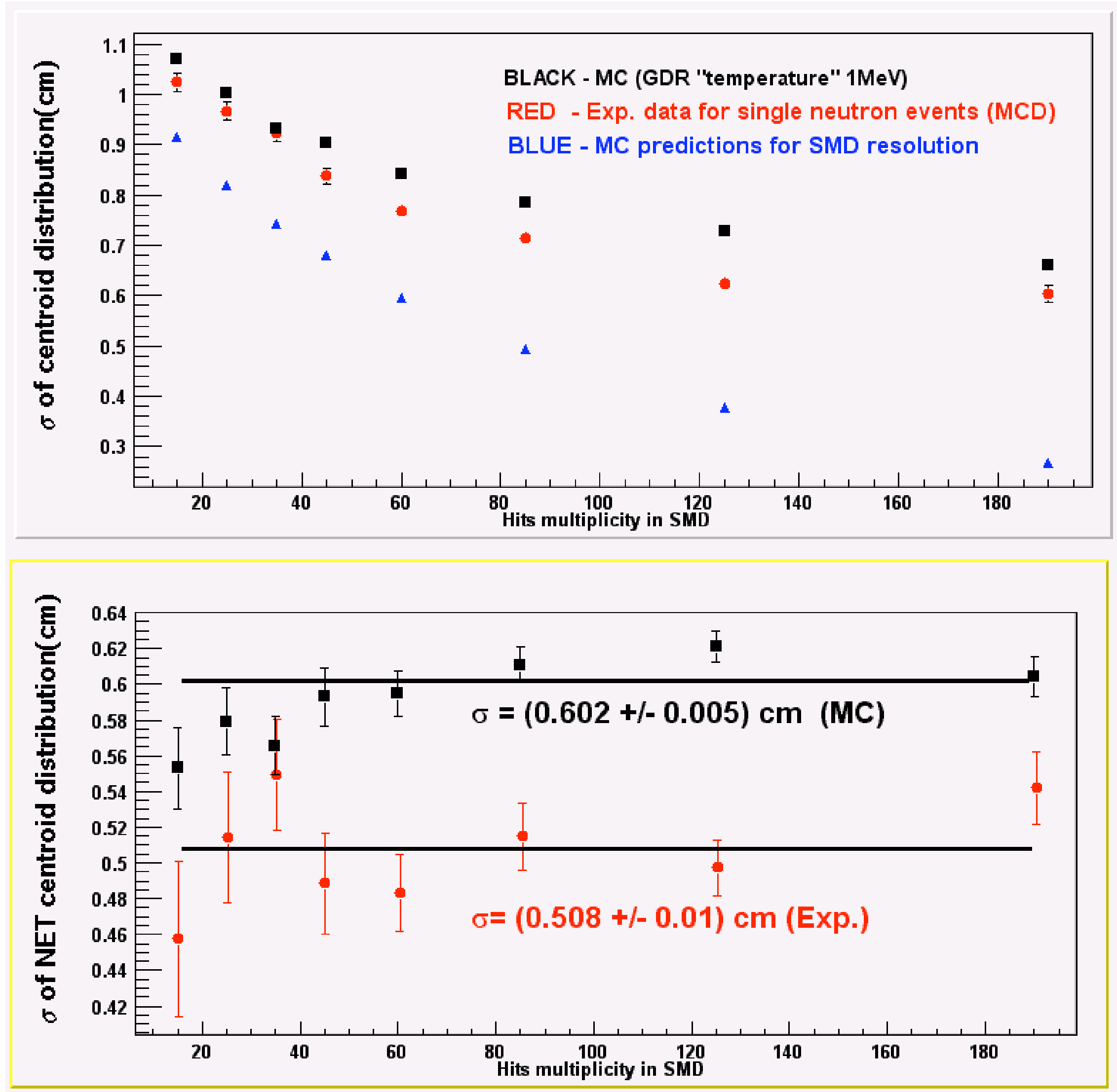
2n/1n cross sections, compared
To low energy radiochemical data

SMD centroid width for single neutron MCD at 100GeV

Top panel presents the dependence of shower centroid width (sigma of Gaussian fit) on light yield in the SMD for events with single neutron (MCD events, red points). Black points are ones for MC GDR events. Blue points are MC prediction for SMD resolution.

Bottom panel presents "net" widths for neutron x-distribution in MCD events after subtraction of SMD resolution.

The measured width of the centroid distribution is about 20% less than the one for MC events which heve been generated for GDR with a decay temperature of 1.0 Mev.



PHENIX
“Private”
data

Centroid distribution for multineutron events

“Broad” part of the

distribution is due to spectator neutrons with a Fermi-motion spread.

his spread corresponds to

□ = 2.21 cm

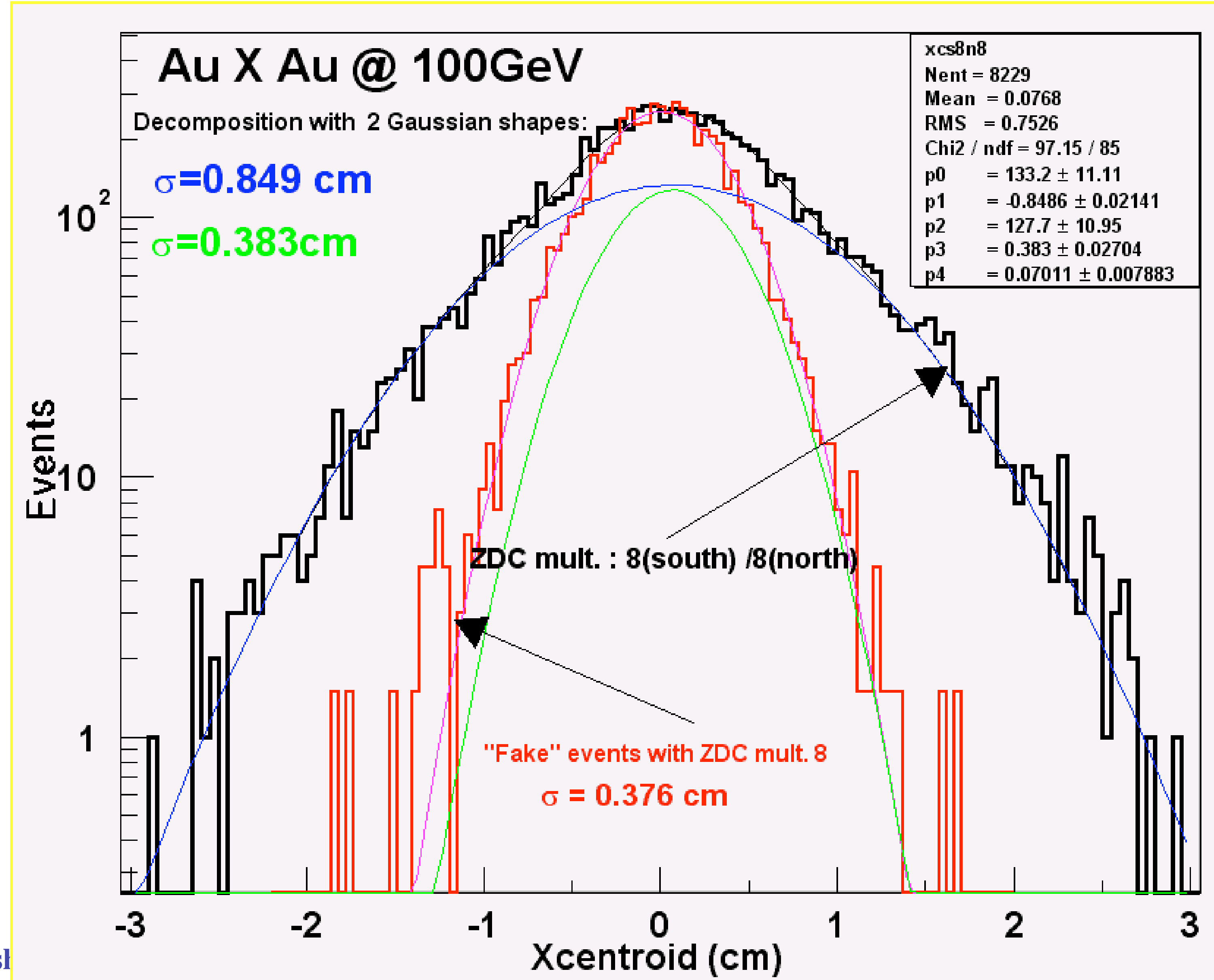


TABLE I. Cross sections calculated and derived from the data. The errors quoted on measurements include the uncertainty of the BBC cross section [8]

Cross Section	Calculated Value(1)	Calculated Value(2)	Measured
σ_{tot} *	10.83 ± 0.5Barns	$11.19 \pm$	N.A.
σ_{geom}	$7.09 \pm xx$	$7.29 \pm$ xx	N.A.
$\frac{\sigma_{geom}}{\sigma_{tot}}$	0.67	0.65	0.661 $\pm$0.014
electromagnetic			
$\frac{\sigma(1n,Xn)}{\sigma_{tot}}$	0.125	xx	0.117 ± 0.003 $\pm$0.002
$\frac{\sigma(1n,1n)}{\sigma_{1n,Xn}}$	0.329	xx	$0.345 \pm 0.01 \pm 0.006$
$\frac{\sigma(2n,Xn)}{\sigma_{1n,Xn}}$	xx	0.327	$0.345 \pm 0.011 \pm 0.01$

*Definitions

$\sigma_{tot}=\sigma_{(Mutual\ Coulomb\ Dissociation)}+\sigma_{(geom)}==\sigma_{(hadronic)}$

Calculated cross sections for PbPb@LHC

A.J.Baltz, C.Chasman and SNW NIM A417(1998)p.1

(errors can be inferred from above RHIC discussion)

$\sigma_{1n,1n}$	0.537 barns
$\sigma_{1n,xn}$	1.897
$\sigma_{xn,xn}$	14.75
σ_{xn}	227.3

Accelerator Based Determination of Luminosity

To 1st order based on 3 accelerator measurements- ie.

$$\mathcal{L} = B \frac{N_p N_{\bar{p}}}{4\pi \, \sigma_x \sigma_y} f$$

N_p = total current in a "bunch"
$\sigma_{x,y}$= transverse dimensions of the bunches

Above methodologies developed to check the instrumentation which measures these parameters.
This calibration is essentially independent of the beam species.
-ie calibrate at one energy-> all others (CDF example)
-@LHC calibrate with whatever species is more precise (pp or AA)

Accelerator based.. (to next order)

$$\mathcal{L}_{i,j} = N_p N_{\overline{p}} \int \frac{1}{\sqrt{2\pi}\sigma_z} \frac{e^{-\frac{z^2}{2\sigma_z^2}}}{4\pi\sigma_x(z)\sigma_y(z)} dz$$

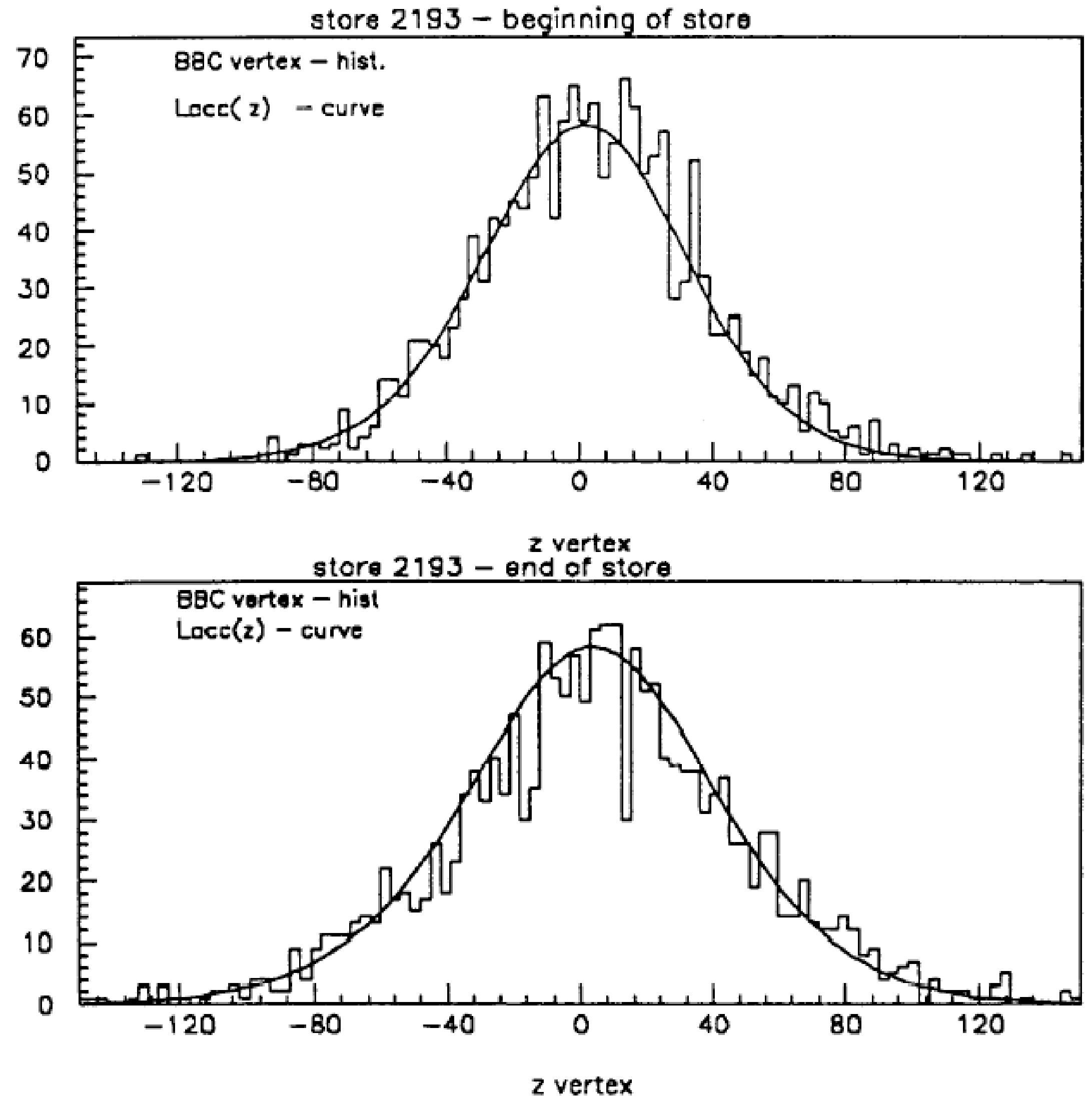
$$\sigma_x^2(z) = \frac{1}{6\pi\gamma}(\beta_x(z)\epsilon_x) + (\eta(z)\frac{dp}{p})^2$$

$$\sigma_y^2(z) = \frac{1}{6\pi\gamma}\beta_y(z)\epsilon_y$$

ie things are more complicated if momentum dispersion.ne.0 or □* << bunch length

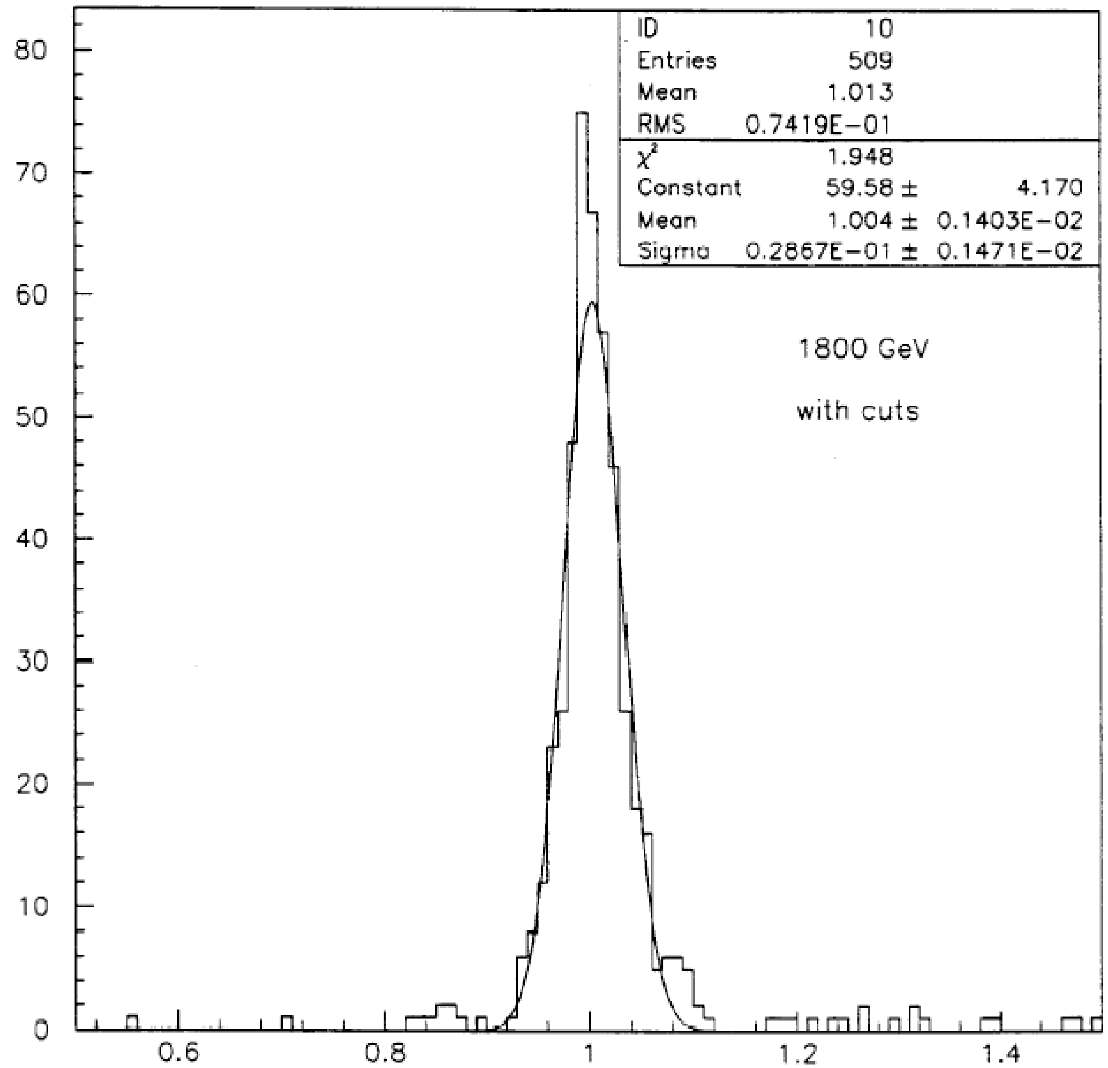
CDF experience:

C.Grosso-Pilcher and SNW ,FN-550(1990)



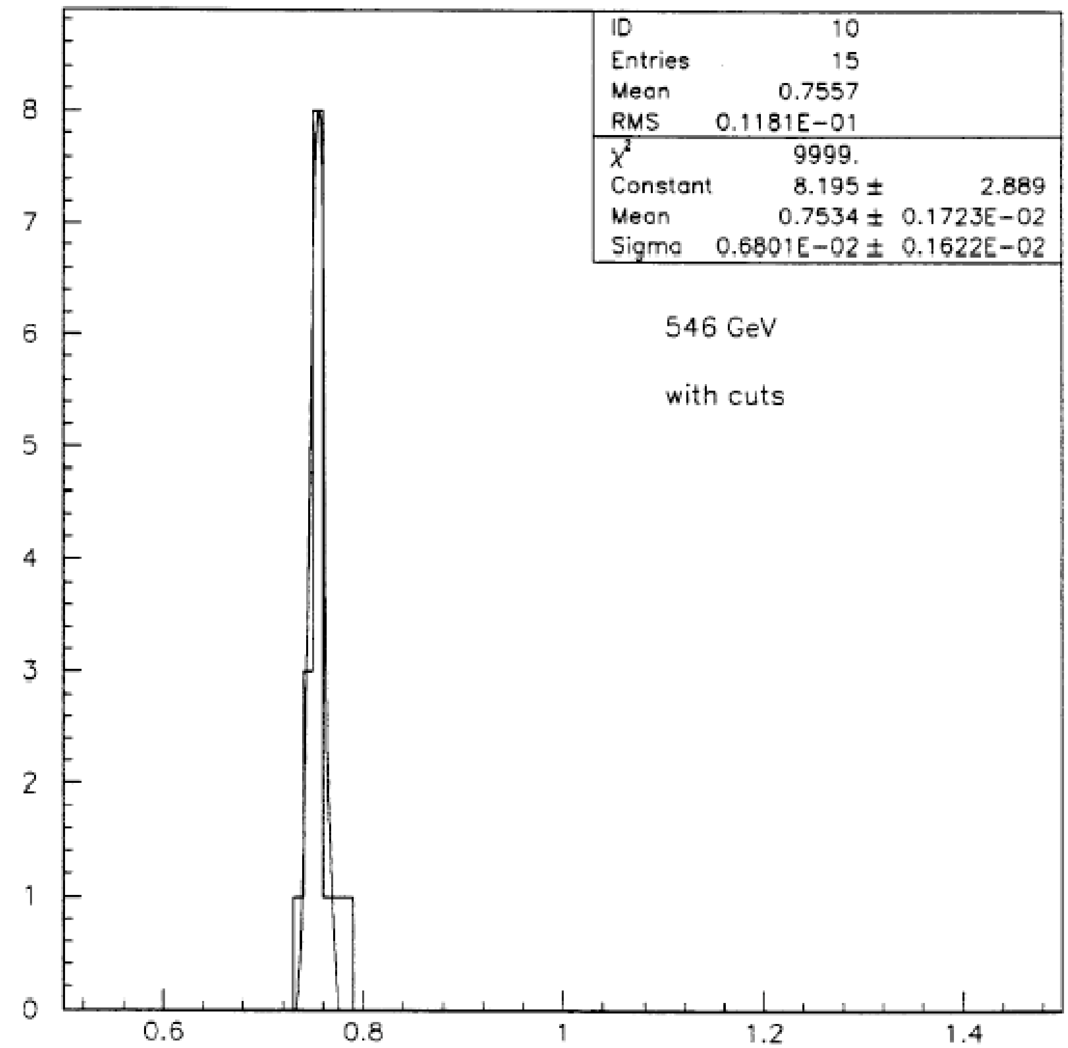
CDF experience: (continued)

Ratio of monitor rate
to accelerator calculated
Luminosity
(1 event=1 scan)
1800 GeV data

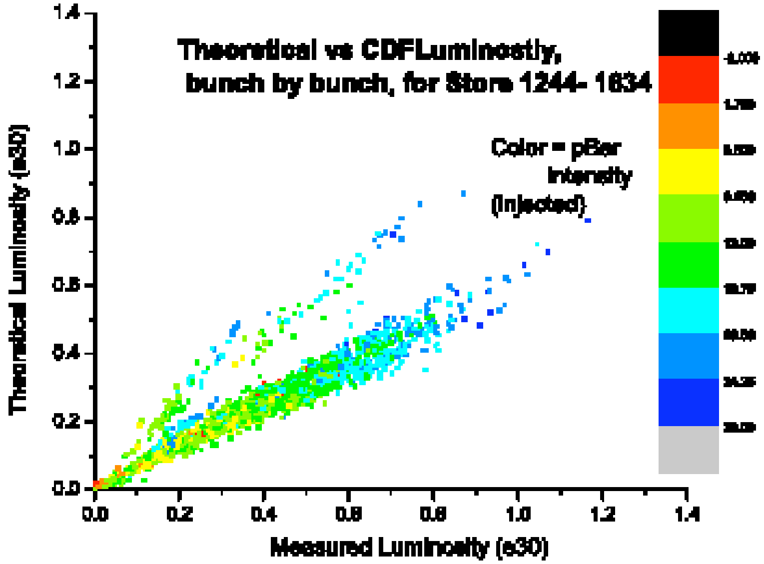


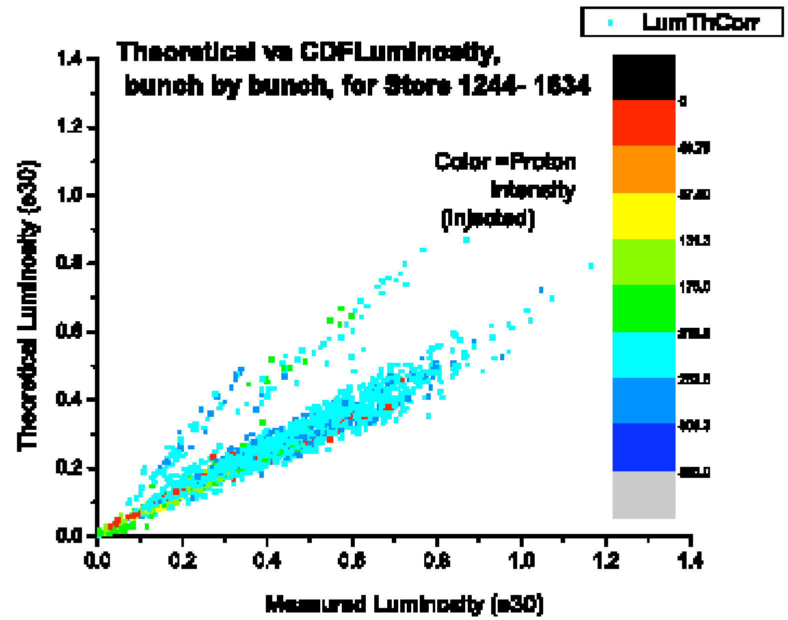
CDF experience: (continued)

Ratio of monitor rate
to accelerator calculated
Luminosity
(1 event=1 scan)
546 GeV data

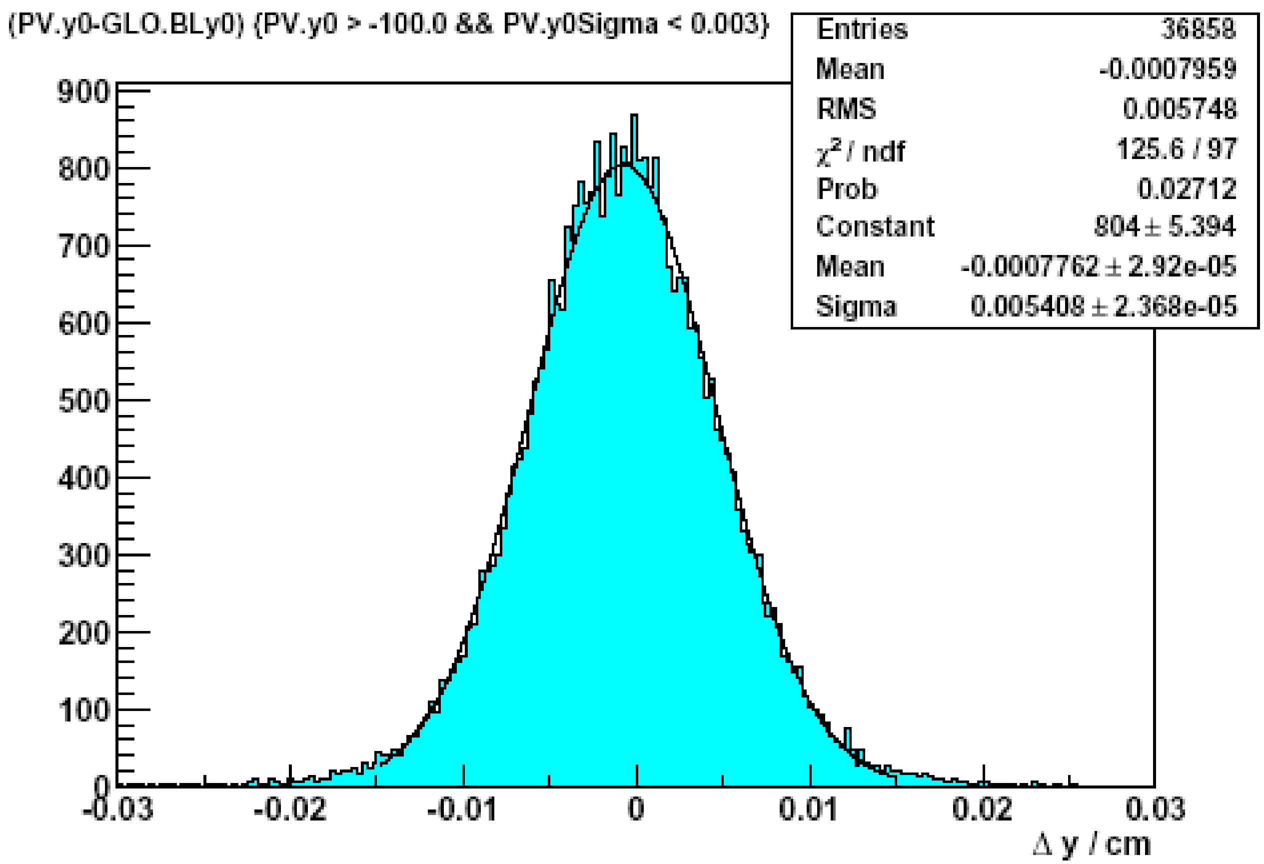


Similar studies in 2002 (courtesy P.Lebrun)





CDF measurement of beam position and sigma (2002- SVX)



Conclusions

1. 5% Luminosity measurement was achieved "at startup" in HI

2. This will be improved to ~2% before LHC era

3. A coordinated luminosity measurement scheme was successfully implemented in 4 experiments (and usec reliably also in RHIC acc. Control room)

4. It was very useful in pp running also.

A Proposal

- A coordinated approach to LHC Heavy Ion luminosity measurements->performance criteria (LARP, DOE-NP, LHC Instrum)
- Actual detector technologies could differ(RHIC example)
- This has interesting implications for pp

MC simulation of the ZDC response to 2.7 TeV neutrons from GDR decay.
ZDC module: 10mm Tungsten+0.5(dia) fibers @ 45Dgr, 13layers/module, (2λ)

Fiber's NA = 0.3. **Fit: ~exp(-(x-μ)**2/(2σ**2))** **μ=p1, σ = p2 + p3*(x-μ)/μ**