Inelastic Diffraction in Au-Au, d-Au and pp collisions at RHIC

(with PHENIX UPC group)

Prospects for Diffractive Physics with Heavy Ions in ATLAS

With M. Strikman & R. Vogt

Topics in Diffraction

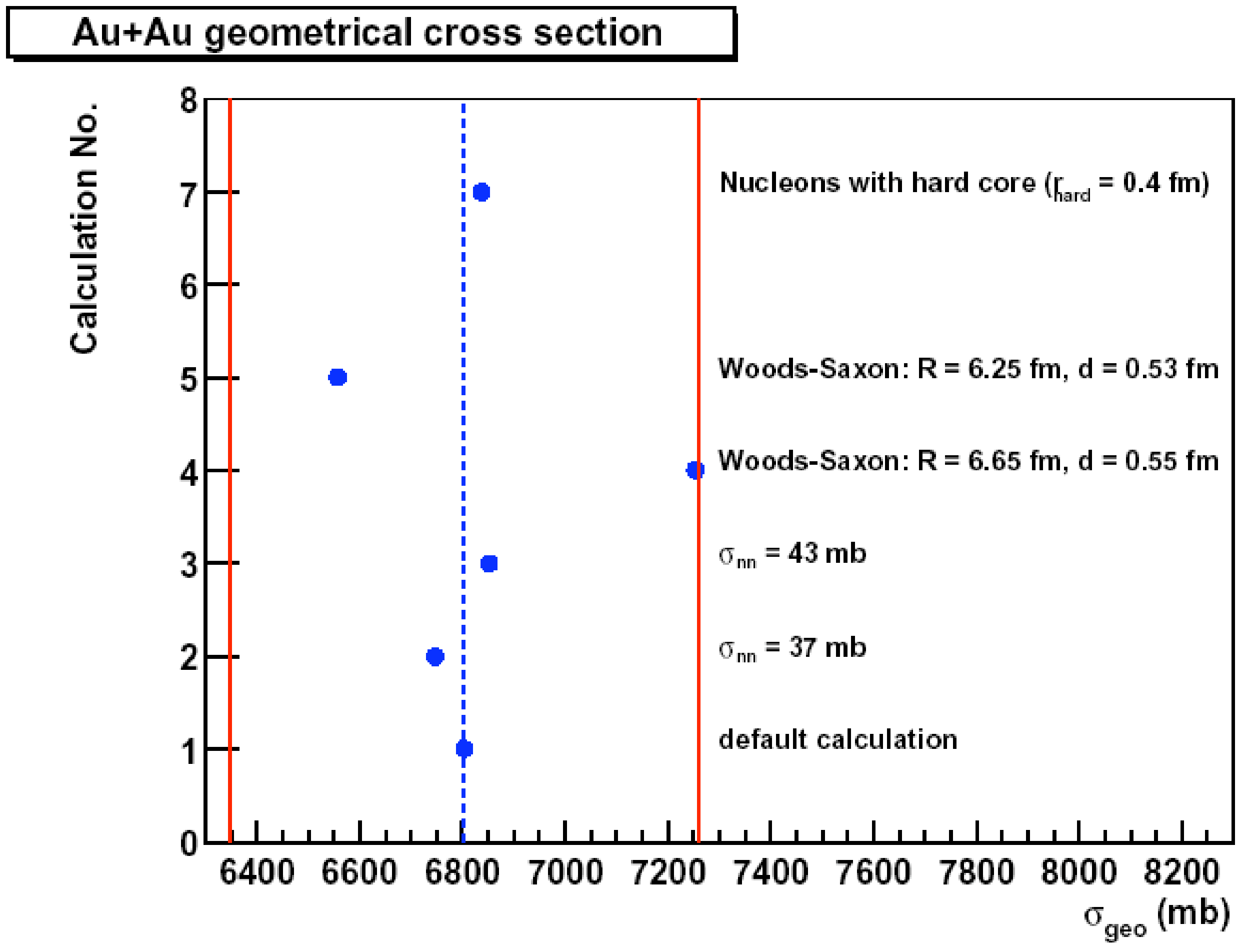
- Total Cross Sections
  - RHIC methodology uses calculable EM cross sections to calibrate (eg Coulomb Dissociation, γ+d->n+p)
- "Peripheral γ-A interactions"
  - Diffractive Vector meson production
  - $\gamma\gamma \to e^+e^-$
- Deep inelastic γ-A interactions
  - -dijet, jet+γ, Heavy Flavor production
- Other Forward Physics, eg pp->n+X

Total Cross Sections(I)

-B.Kopeliovich, Phys Rev C 68(2003) 044906

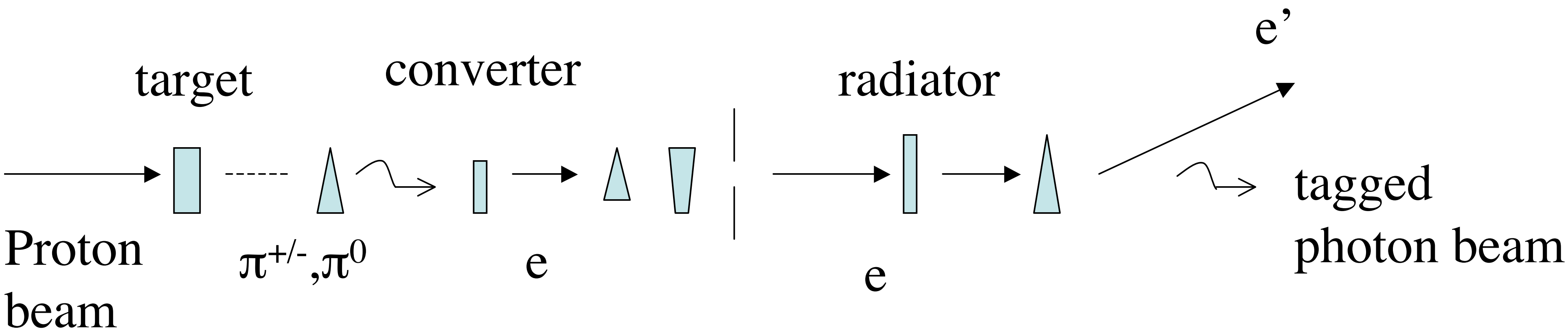
	Observable	Glauber model	Valence quark fluctuations	Plus gluonic excitations	Correction factor
	σ_{tot}^{dAu}[mb]	4110.1	3701.0	3466.2	
S	σ_{in}^{dAu}[mb]	2422.7	2226.6(2335.8)	2118.3(2228.3)	
T	Factor K in (5)-(6)	K_{GL} =1.04		$K_{Gr} = 0.87(0.92)$	K=0.91(0.96)
A	$N_{coll}^{in}(min.b.)$	6.9	7.5	7.9	
R	$\sigma_{in}^{dAu}(tagg)$[mb]	458.4	544.9(511.5)	551.8(520.1)	
	$N_{coll}^{in}(tagg)$	2.9	4.4	5.0	
P	$\sigma_{non-diff}^{dAu}$[mb]	2146.0	1998.3(2100.1)	1930.3(2033.7)	
H	Factor K	$K_{Gl} = 0.92$		$K_{Gr} = 0.9(0.95)$	K=0.83(0.87)
E	$N_{coll}^{non-diff}(min.b.)$	5.5	5.9	6.1	
N	$\sigma_{non-diff}^{dAu}(tagg)$[mb]	324.3	480.2(451.5)	498.4(470.6)	
I	$N_{coll}^{non-diff}(tagg)$	2.3	2.9	3.2	
X					

Total Cross Sections (II)



(from K.Reygers, PHENIX note)

Tagged Photon beam (fixed target)



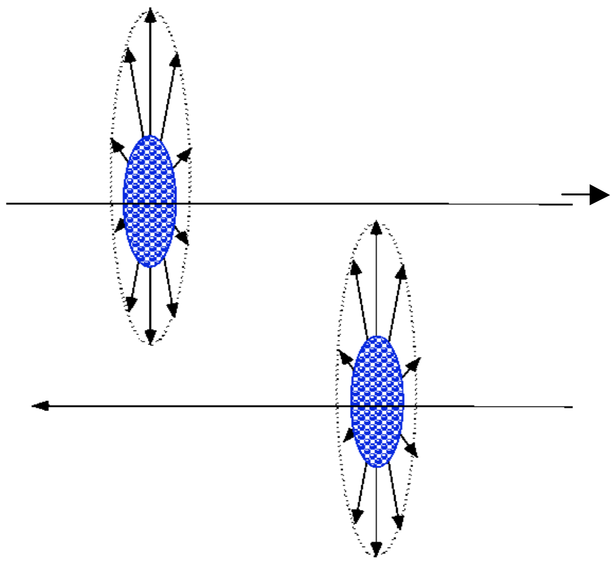
<u>At FNAL ('80's and '90's)</u>

$\sigma_{total}(\gamma p)$

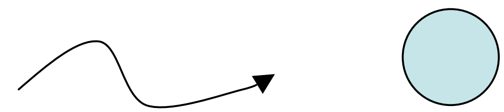
Diffractive γp->Xp E612 (CGSSW)

γp->Charm+X E691--->E791

RHIC and LHC as high Luminosity γ-Hadron colliders



$\gamma_{beam}^{Rhic}=100$



$S=2m_A\omega'$

=>Nucleus at rest,effective lorentz $\gamma_{eff}=2*\gamma_{beam}{}^2-1$

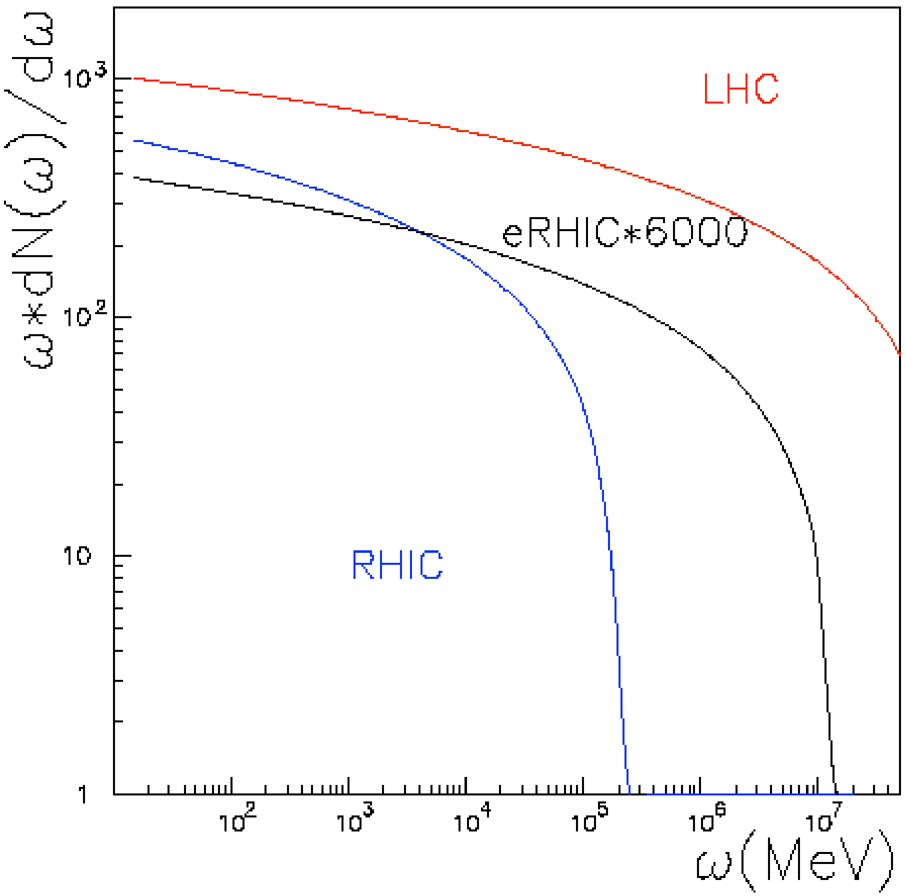
Heavy Ions

$$\omega\frac{1}{2}\frac{dN(\omega)}{d\omega}=\frac{2\alpha Z^2}{\pi}\ln\left(\frac{0.681\overline{hc\gamma_{eff}}}{R_{nucleus}\bullet\omega}\right)$$

e-Hadron collider

$$\omega\frac{dN(\omega)}{d\omega}=\frac{2\alpha}{\pi}\ln\left(\frac{\overline{m_e\bullet\gamma_{eff}}}{\omega}\right)$$

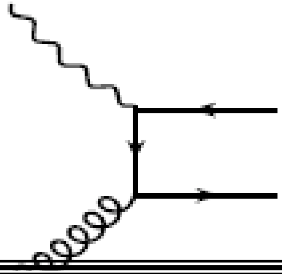
Equivalent Photon spectrum in target nucleus frame

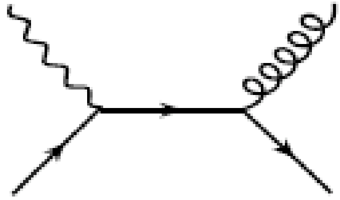


"Quasi-real" γ spectra compared to an e-hadron collider

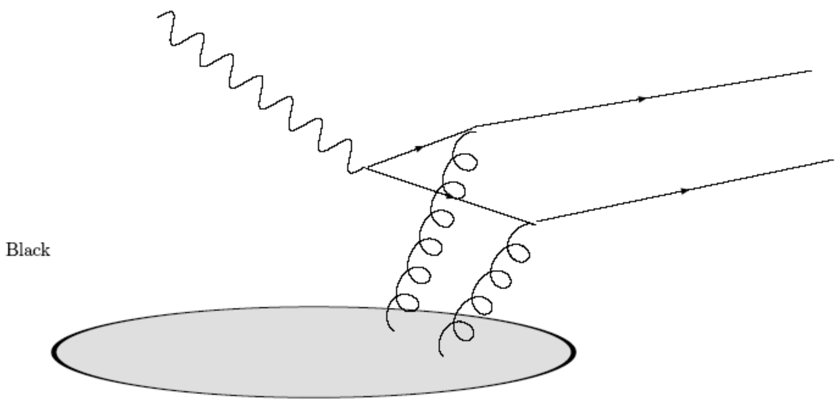
->100 TeV @ LHC

$$S^2_{NN}\frac{d^2\sigma^{\rm dir}_{\gamma A\to {\rm jet}+{\rm jet}+X}}{dT\,dU\,d^2b} = 2\int dz\int_{k_{\rm min}}^{\infty} dk\frac{d^3N_\gamma}{dk\,d^2b}\int_{x_{2_{\rm min}}}^{1}\frac{dx_2}{x_2}\Big[\sum_{i,j,l=q,\bar q,g} F_i^A(x_2,\mu^2,\vec b,z)s^2\frac{d^2\sigma_{\gamma i\to jl}}{dt\,du}\Big]$$





Probing nuclear parton distribution w.Quasi-real photons

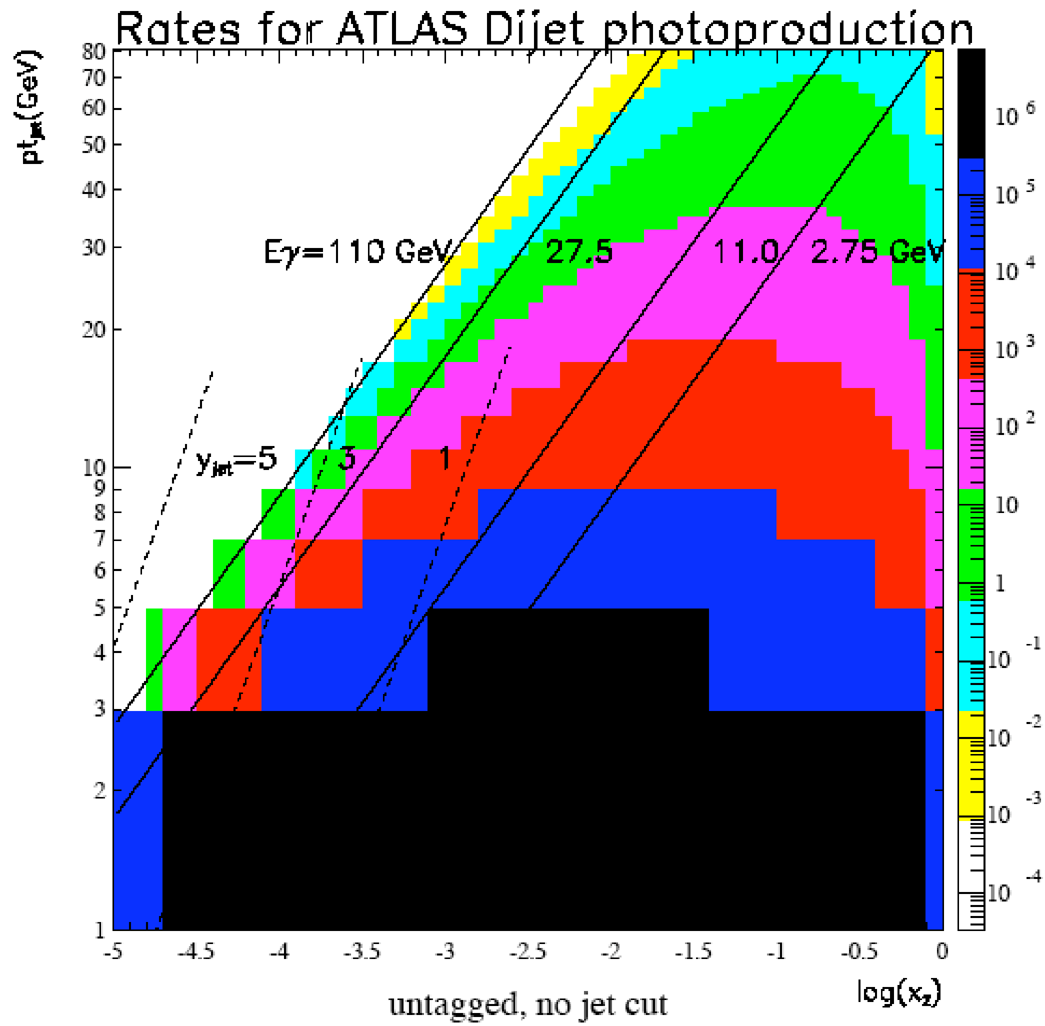


Diffractive J/Psi production
(like 2-gluon exchange)
t-distribution measures size of gluon source
eg-Kowalski and Teaney hep/ph/0304189

Rates and Kinematics(more later)

Event yields from a 1 month HI (Pb-Pb) run at nominal Luminosity.
Counts per bin of δpt=2 GeV
δx2/x2=+/- 0.25

(with M. Strikman and R. Vogt)



Physics Opportunities

<u>The black disk limit:</u> Diffractive scattering was observed in over 10% of all DIS events at HERA. ---- operation with nuclei should allow the observation of a far greater fraction of diffractive events, approaching the quantum mechanical limit of 50%. The detailed diffractive data will provide a stringent test on our understanding of the strong interactions.

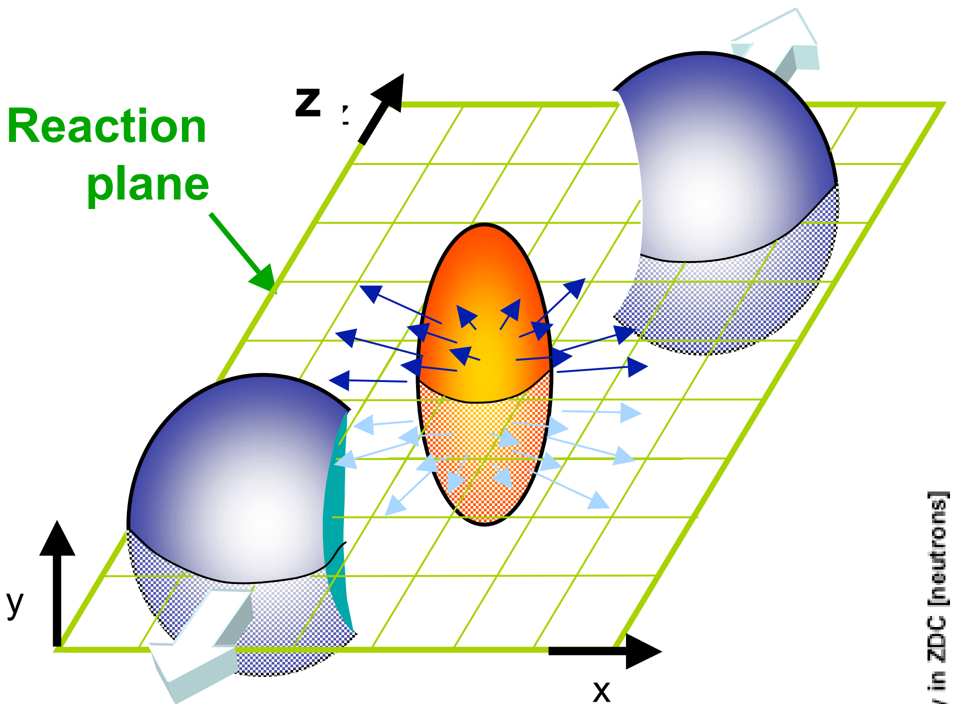
<u>Three Dimensional Mapping of Strong Matter:</u> The study of exclusive reactions, such as the production of vector mesons or real photons, will allow the mapping of strongly interacting matter in nucleons and nuclei. These data are sure to bring a great leap forward in our understanding of how nuclear matter is formed, and will be critical in the search for the Color Glass Condensate.

<u>Radiation Patterns in Strong Interactions:</u> The study of the fundamental radiation patterns in strong interactions, which lead to the small-x structure of nucleons, will be studied by studying jet and particle production over a large rapidity range.

<u>Hadronization in nucleons and nuclei</u>: The evolution of colored quarks and gluons struck by the virtual photon in deep inelastic scattering into observed colorless hadrons is one of the clearest manifestations of confinement.

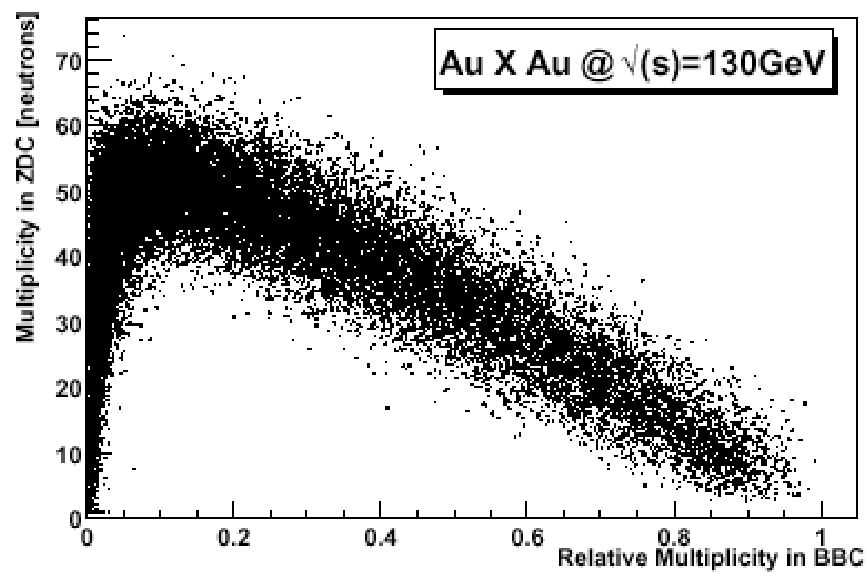
Heavy ions:Event characterization with forward detectors

>>Direction and magnitude of impact parameter, b



Magnitude from complementary parameters

$N_{participant}=2*A-N_{spectator}$



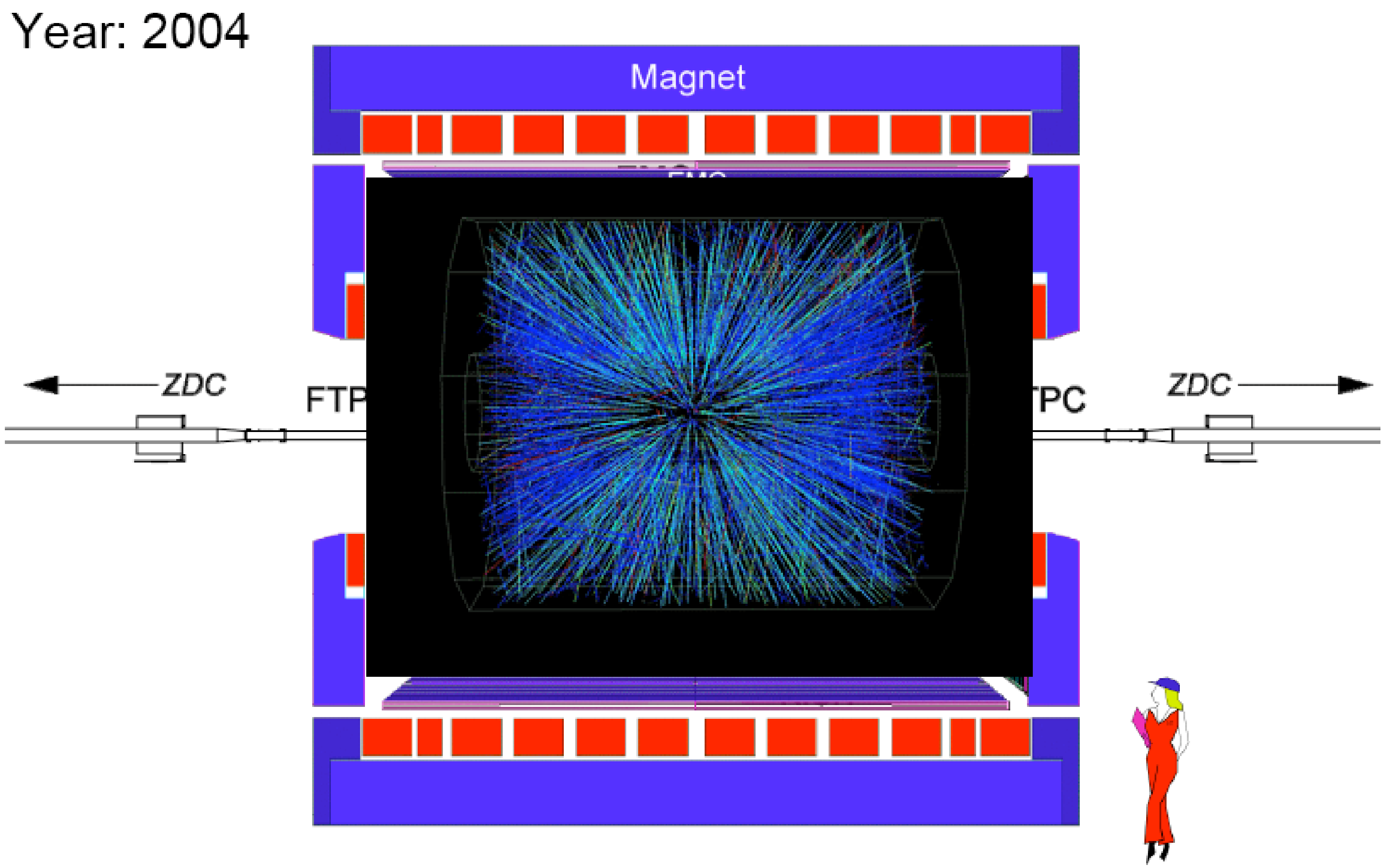
Beam-Beam Counter Mult/1000

Spectator neutrons

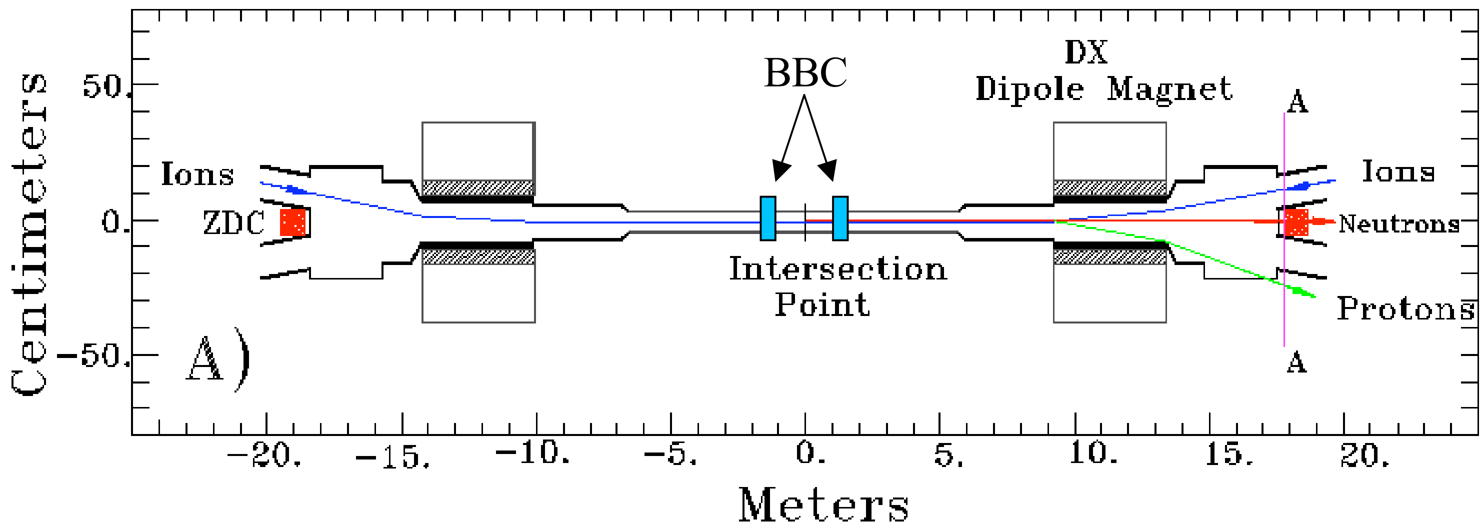
- **measure centrality,**
- **Min_min_bias trigger**

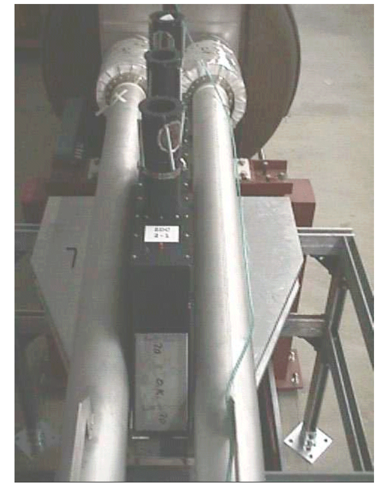
(Calorimeter@θ<2mr.)

A RHIC Central detector:STAR

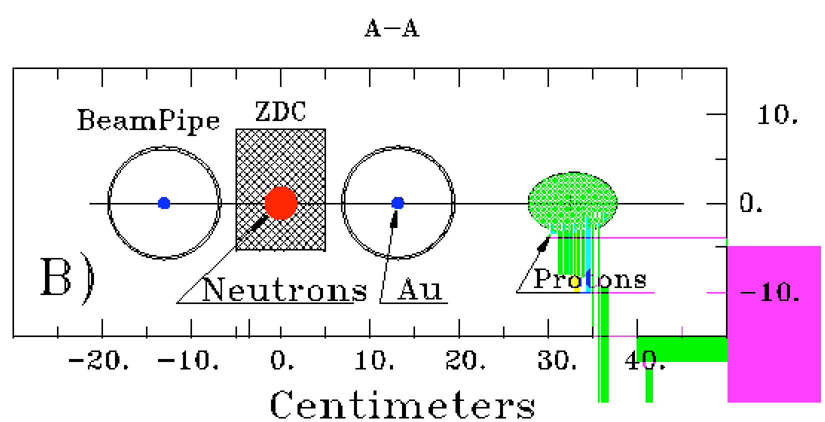


Forward Instrumentation

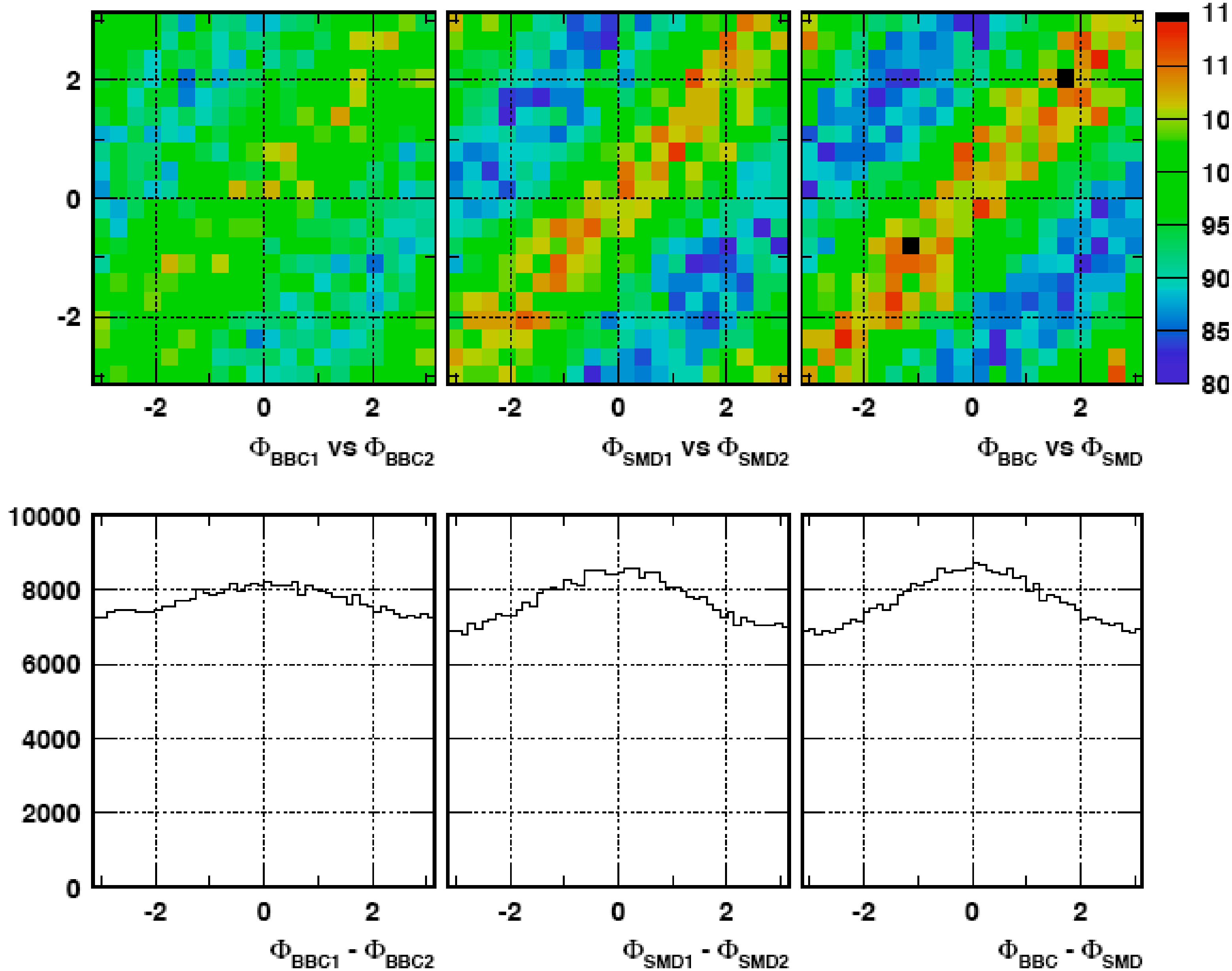




- •All AuAu Interactions->low p_t neutron “spectators”
- •Peripheral Coulomb Interactions->neutron tag from Au*->n+X
- •Deuteron Photodissociation_> n+p in forward calorimeters



Directed flow, v_1, is largest at ZDC location



RHIC results on Au-Au UPC

–the photon flux factor

–large cross sections processes

–“tagging” and the modified flux

–event characterization

•Geometry from fermi to micron scale

•STAR rho and PHENIX J/Psi

Electromagnetic Interactions of Heavy Ions:

('24)-E.Fermi develops Equivalent γ approx for int of e^- and α's with atoms

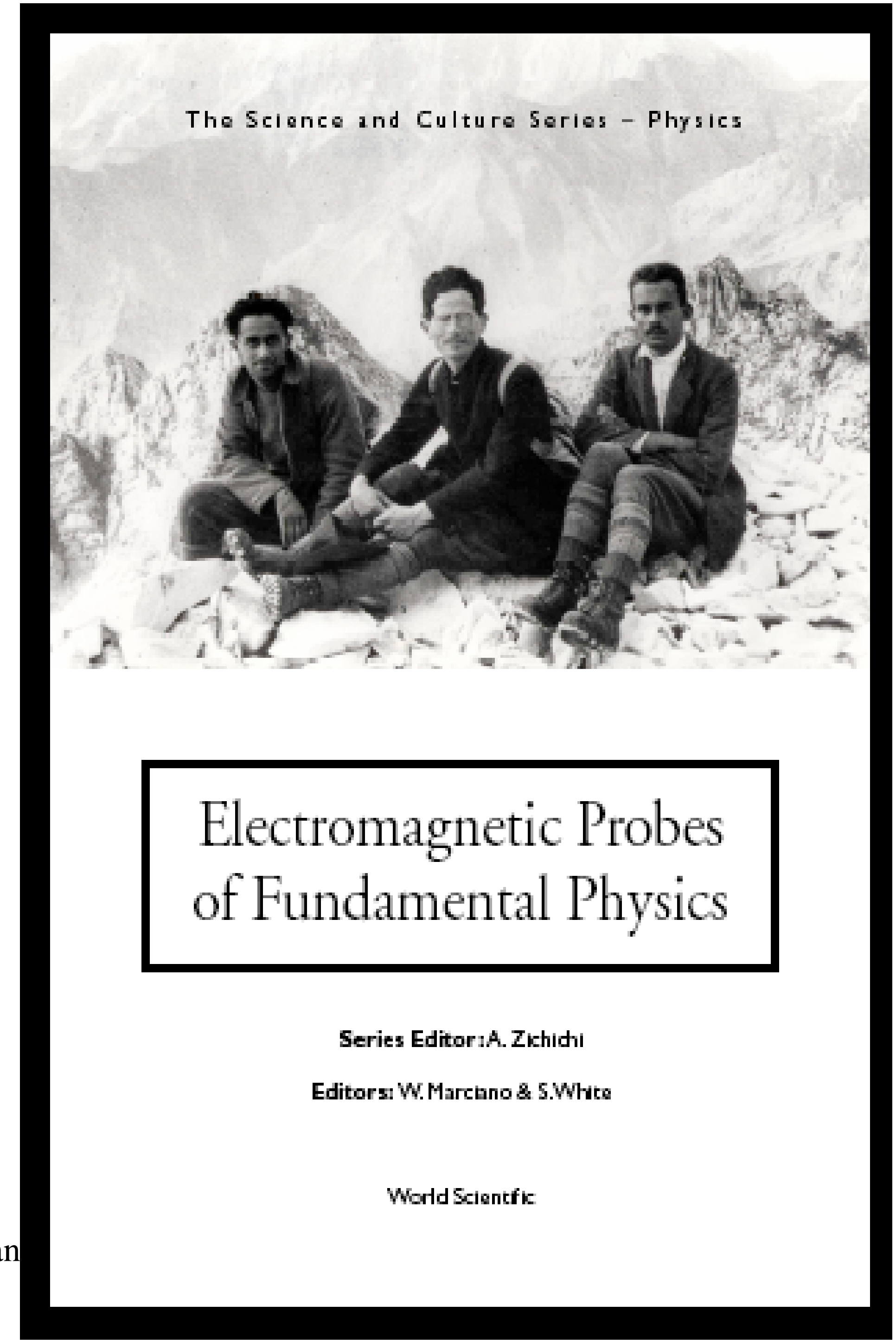
S.W. : hep-th/0205086

('33) -Weiszacker and Williams

(50's) demonstration of EPA with interactions of ~500 MeV e^- with Nuclei- (Wilson, Panofsky et al. @ Stanford)

(80-90's) -first measurement of EM interaction using ion beams @Bevalac SPS and AGS

('03->)- "rapidity gap" physics w. Heavy Ions @ RHIC & LHC



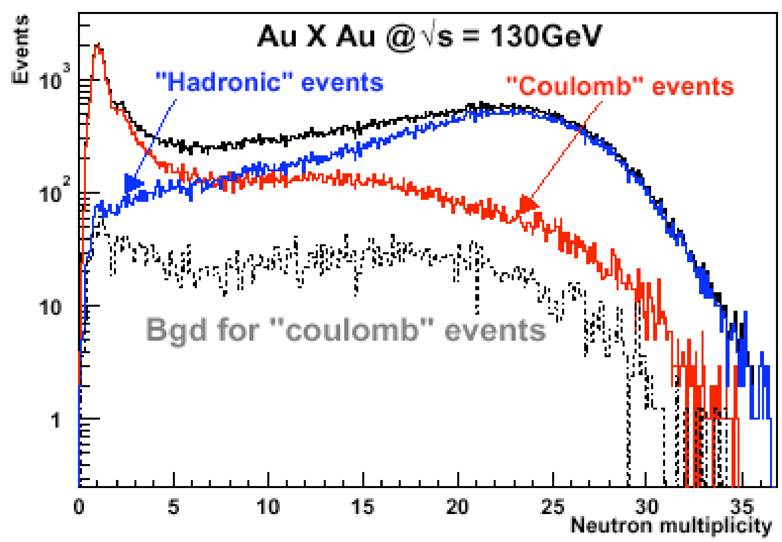
Run I

PRL

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 ± 0.014
electromagnetic			
$\frac{\sigma(1n,Xn)}{\sigma_{tot}}$	0.125	xx	$0.117 \pm 0.003 \pm 0.002$
$\frac{\sigma(1n,1n)}{\sigma_{1n,Xn}}$	0.329	xx	$0.345 \pm 0.01 \pm 0.006$
$\frac{\sigma(2n,Xn)}{\sigma_{1n,Xn}}$	xx	0.327	$0.345 \pm 0.011 \pm 0.01$

(1)Baltz & SNW
(2)Bondorff et al.
Meas.=Chiu et al.

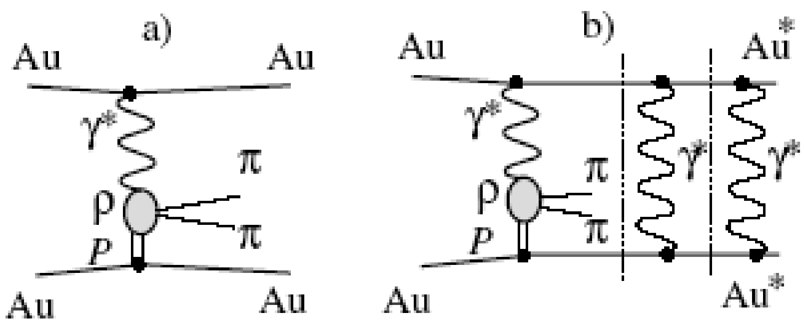


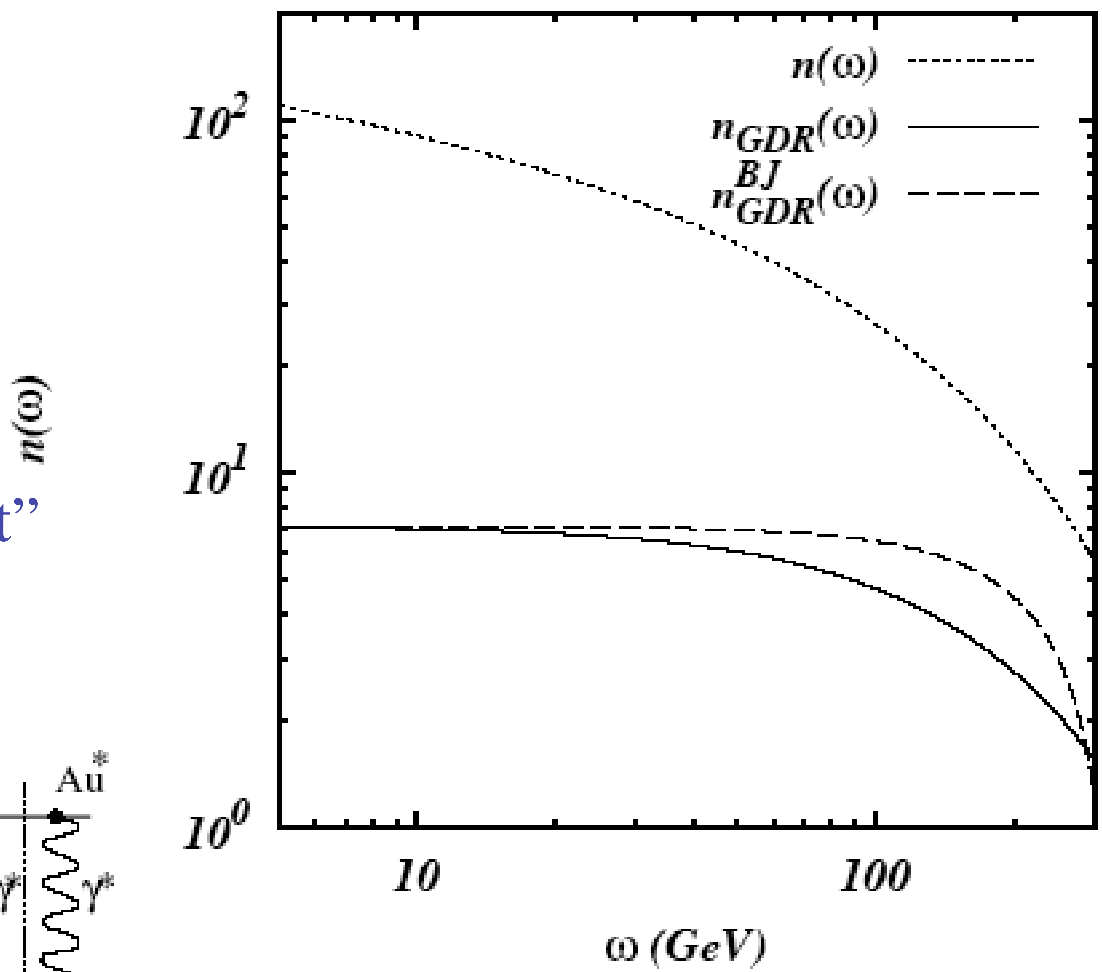
Tagged photon spectrum

Strength of interaction

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar v} \approx Z_1 Z_2 \alpha$$

2nd γ exchange leads
to hardened photon beam
(implemented in "STARlight"
not yet in "DPEMC")
(seeG.Baur et al. Nucl-th/03070310)

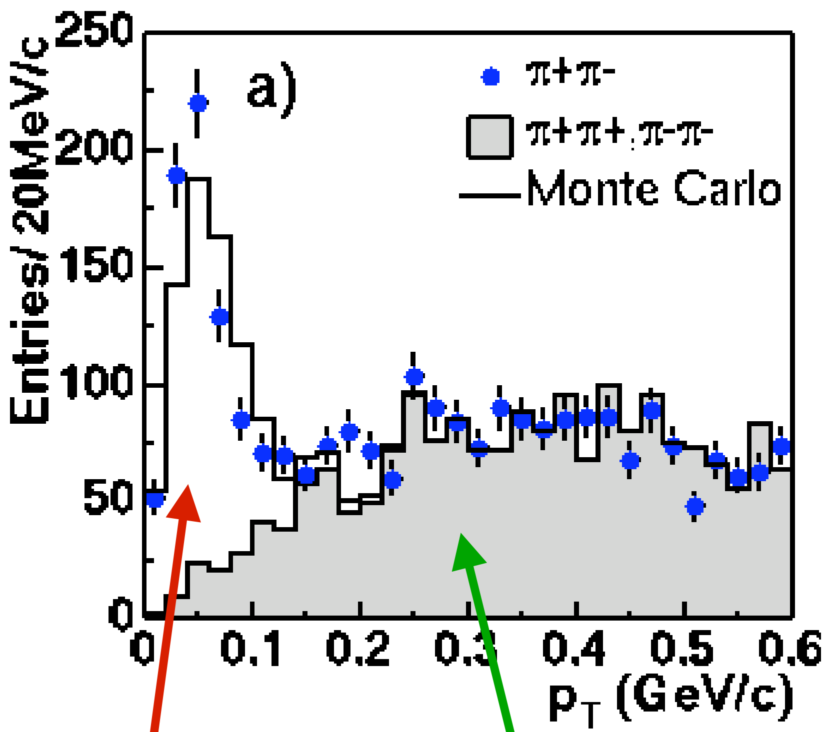




ρ photoproduction: STAR Collaboration at RHIC $\sqrt{s_{nn}}$ =130 GeV

(C. Adler et al., Phys. Rev. Lett. 89(2002)272302)

p_T spectrum shows clear coherent signal



Cross section	STAR (mb)	Ref. [5] (mb)
$\sigma^{\rho}_{xn,xn}$	$28.3 \pm 2.0 \pm 6.3$	27
$\sigma^{\rho}_{1n,1n}$	$2.8 \pm 0.5 \pm 0.7$	2.6
$\sigma^{\rho\,\text{(inc. overlap)}}_{xn,xn}$	$39.7 \pm 2.8 \pm 9.7$	...
$\sigma^{\rho}_{xn,0n}$	$95 \pm 60 \pm 25$	...
$\sigma^{\rho}_{0n,0n}$	$370 \pm 170 \pm 80$	...
$\sigma^{\rho}_{\text{total}}$	$460 \pm 220 \pm 110$	350

Large exp. uncertainty in luminosity and trigger efficiency.

background, like-sign pairs

Signal+background, unlike-sign pairs

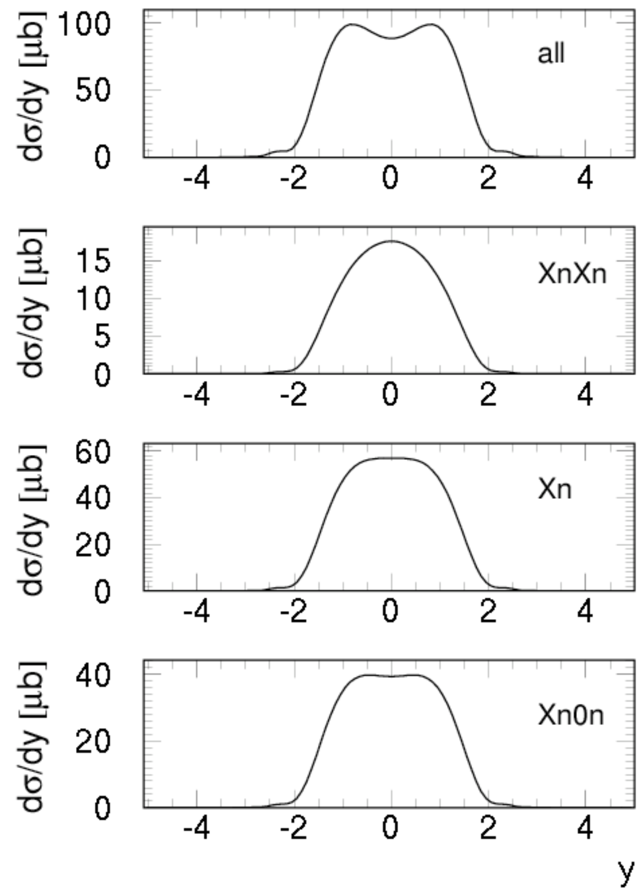
PHENIX Run-4 J/Psi trigger

Trigger:
n-tag & rapidity Gap
& 1 EM cluster>0.8 GeV

very loose trigger
with rate ~0.4% *$\sigma_{inelastic}$!

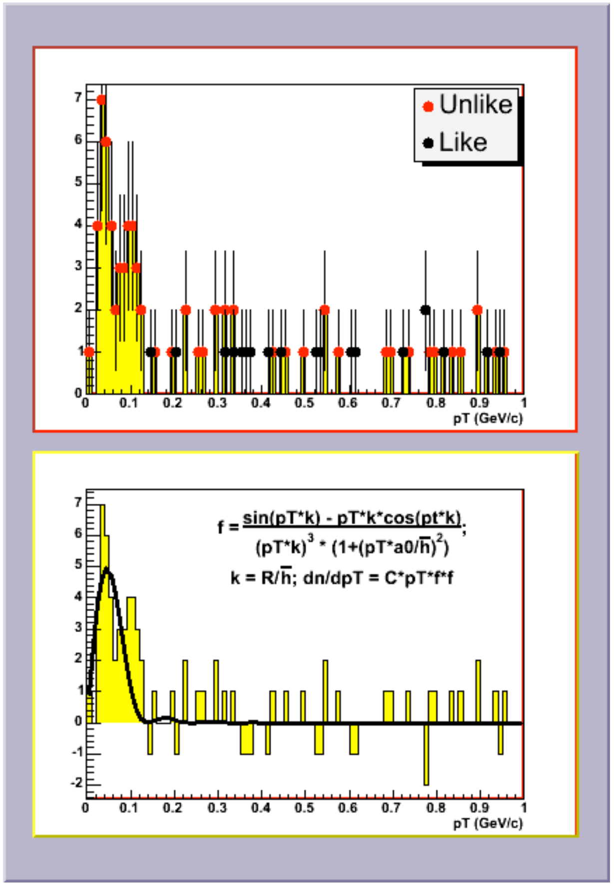
-->Collected
8.5 M UltraPeripheral triggers

Calculated yield~30 J/Psi->e+e-
And ~100 γ +γ->e+e-



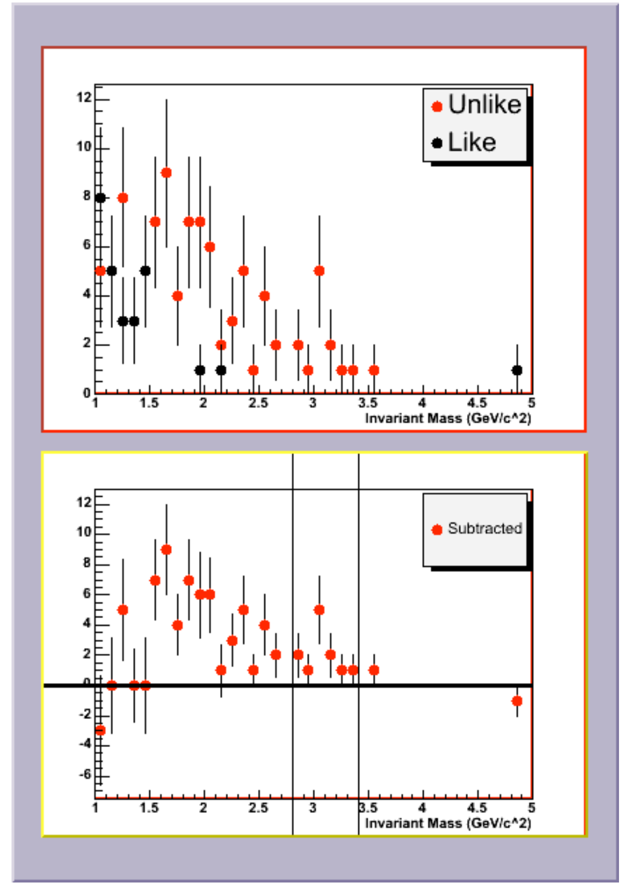
J.Nystrand/STARlight

p_t(e+e-)



~20% sample

M_{inv}(e+e-)



Note that coherent events are expected to have a peak at low pT: < 150 MeV w. shape given by form factor (see e.g. nucl-th/0112055); somewhat more complicated for γ+γ continuum => ~ Approx. agreement with expectations seen.

D-Au: test of Glauber Calculation

How to measure $\sigma^{in}{}_{dAu}$? How does it depend on bias?
PHENIX uses 2 types of min bias triggers:
1)BBCN*S=coinc of $3<|\eta|<4$
(excludes “rapidity gaps”)
And
2)ZDC N or S= >0 n, either beam
(includes “gap” events,
~12M events recorded)

Our normalization is from 2) which Includes d+Au->n+p+Au

Photodisintegration from Klein &Vogt

σ_{diss}=1.38+/-0.07 barns

Preliminary Result:

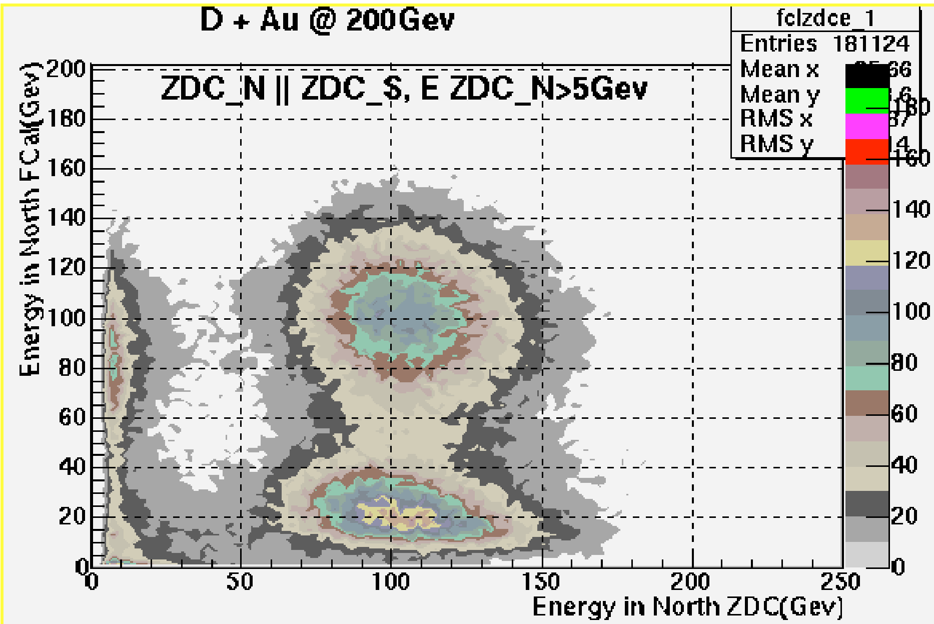
$\sigma^{in}{}_{(1)}=\sigma_{diss}(N_{in}/N_{diss})\varepsilon_{BBC}{}^{-1}$

=1.9-2.2 barn

$\sigma^{in}{}_{(2)}$ and systematics to follow

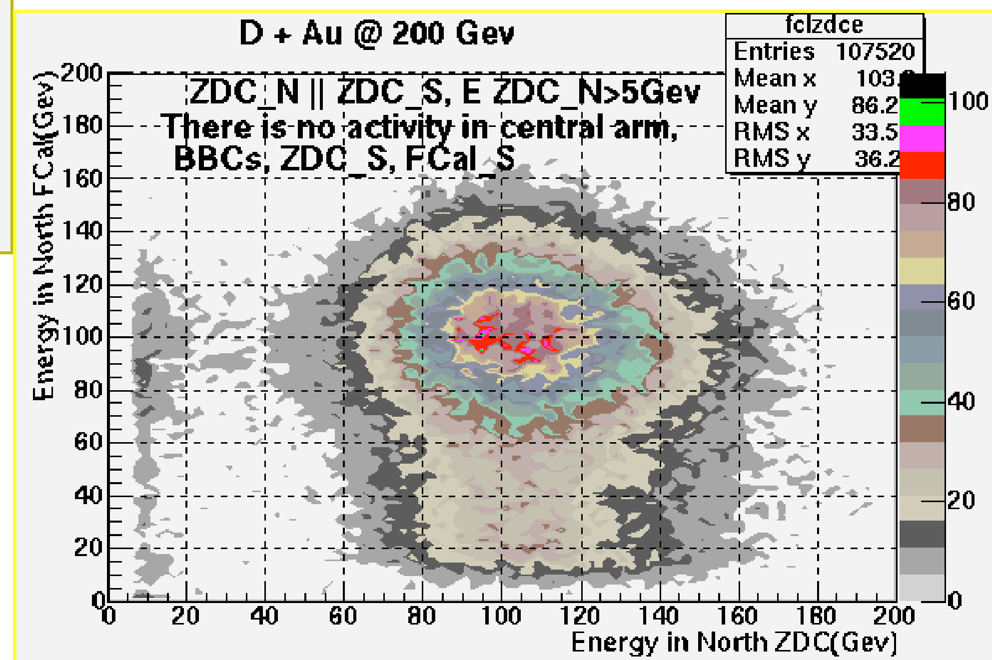
Cp. 0.83*2.33b of B.K.

ZDC N or S trigger , ie at least 1 n from either d or Au beam, (no rapidity gaps bias)



<----Inclusive data set

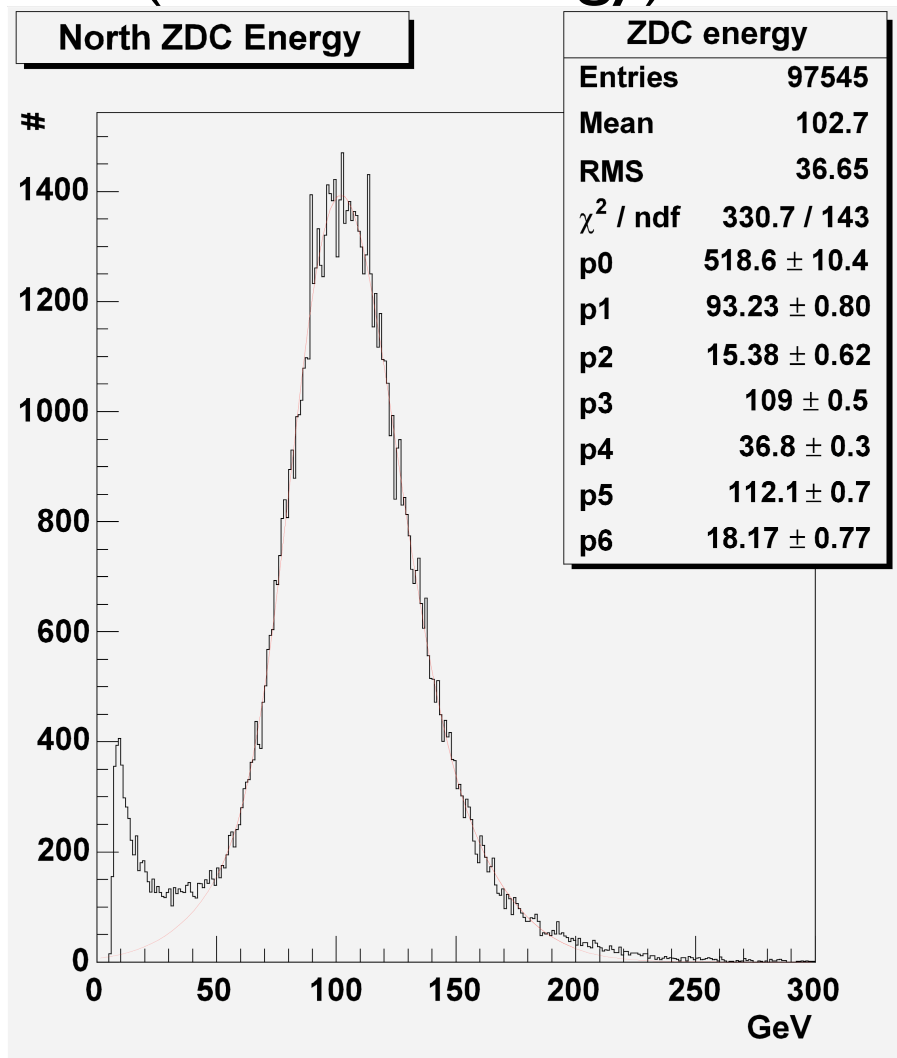
Cut on central activity-->
&Au fragmentation



Projection on ZDC (neutron energy)

Dominant uncertainty in Background from non-diffractive (ie inelastic dAu Collisions) from excess at E_{ZDC}<50 GeV which corrsponds to 6% of fitted area.

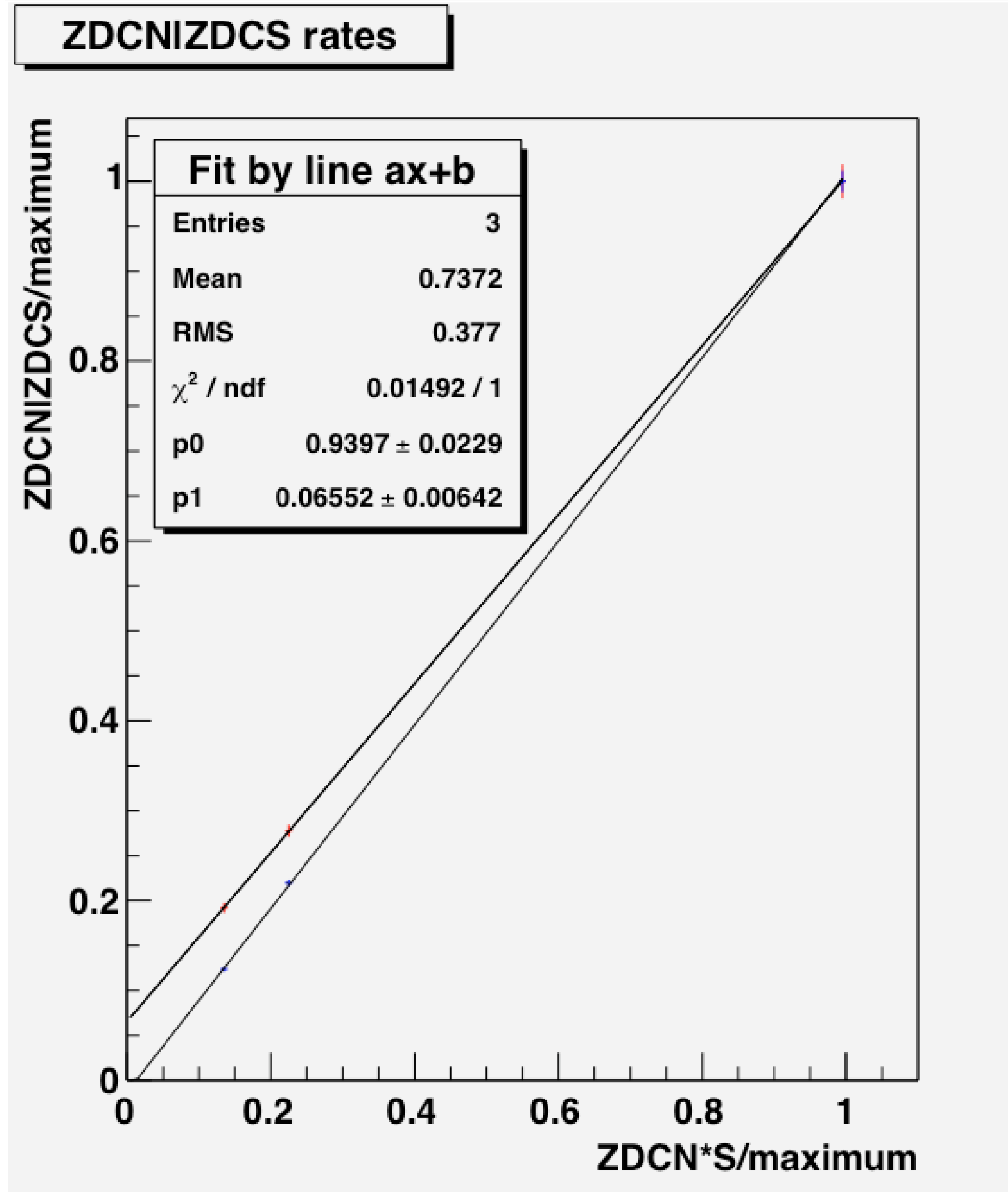
This is current limit on systematic error.



How to measure accelerator background to d+Au->n+p ?

Separate beams through beam steering and measure rates:

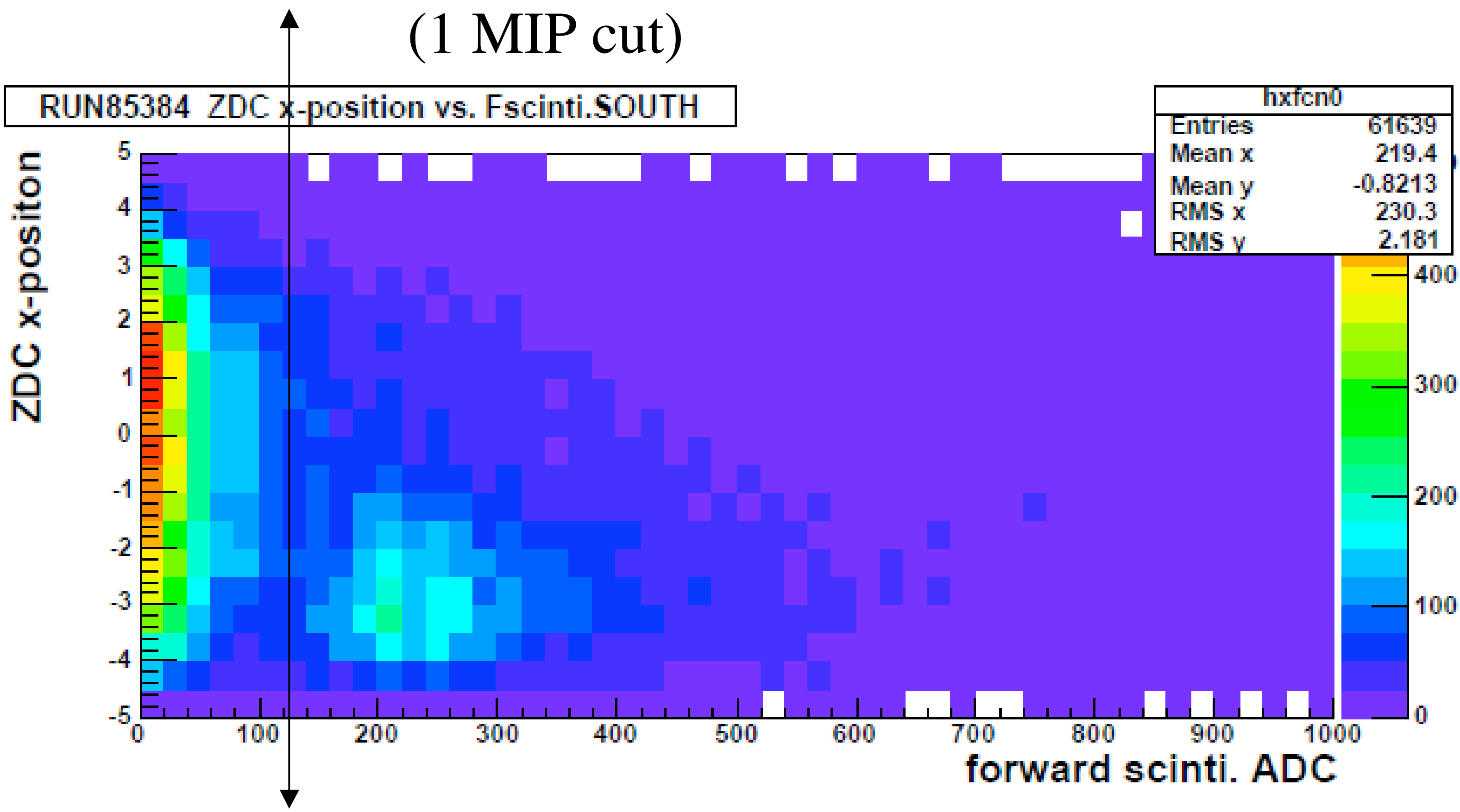
Red(upper)=raw trigger
Blue(lower)=cuts added



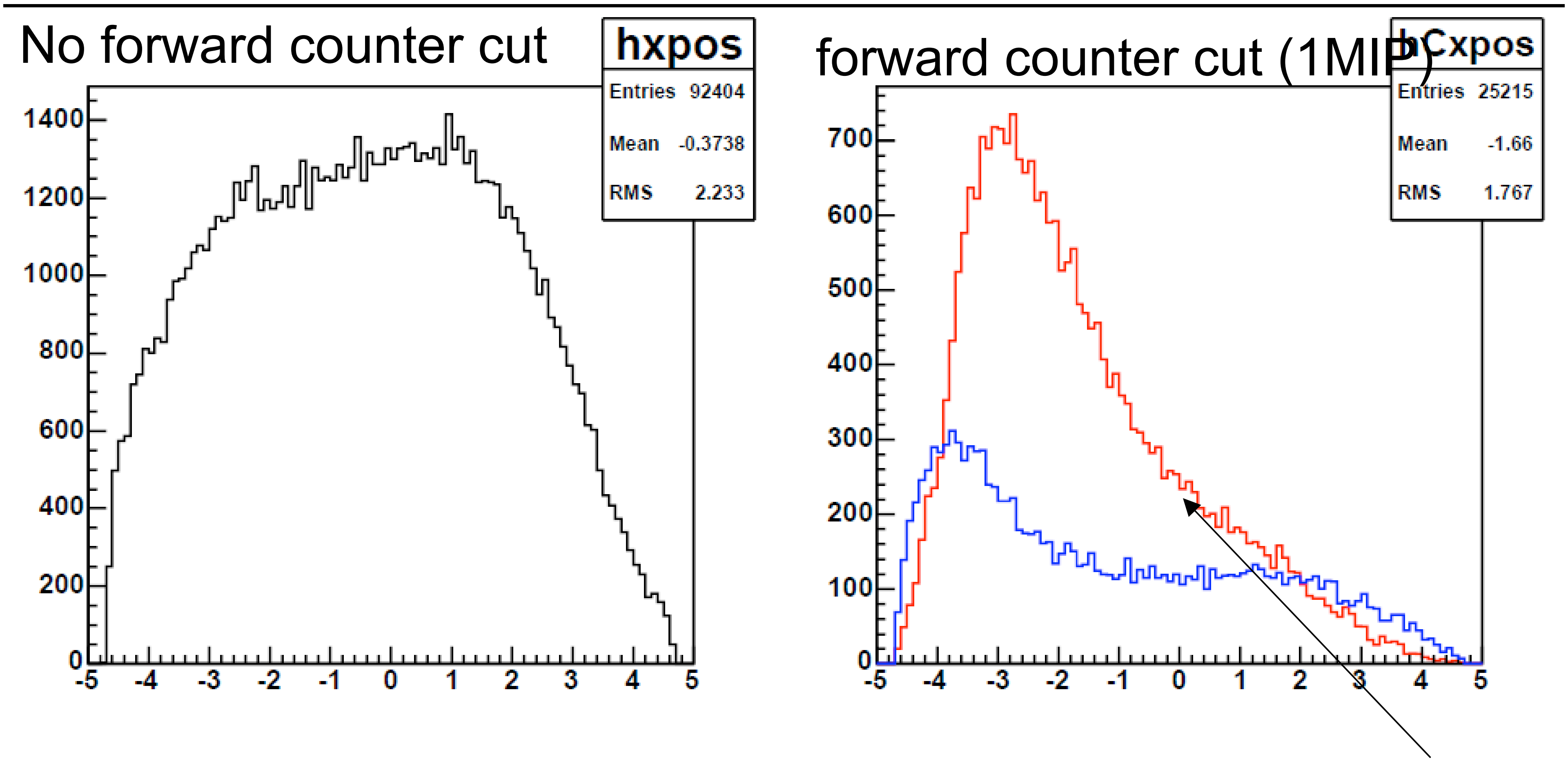
Forward energy in pp->(n,γ,p)+x

Part is pp-p+X (ie single diffraction dissociation)

(1 MIP cut)



X-position

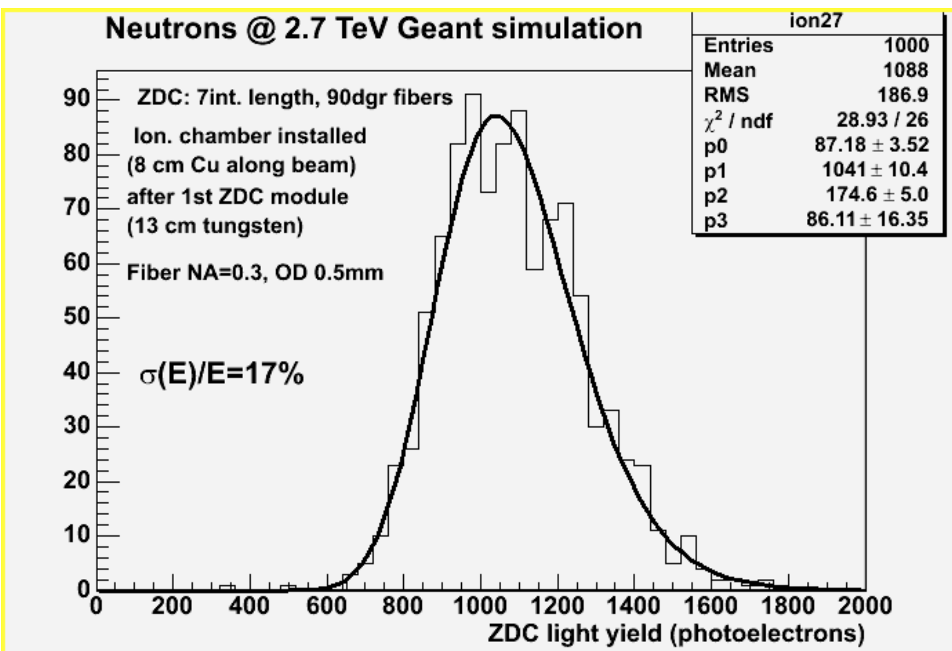


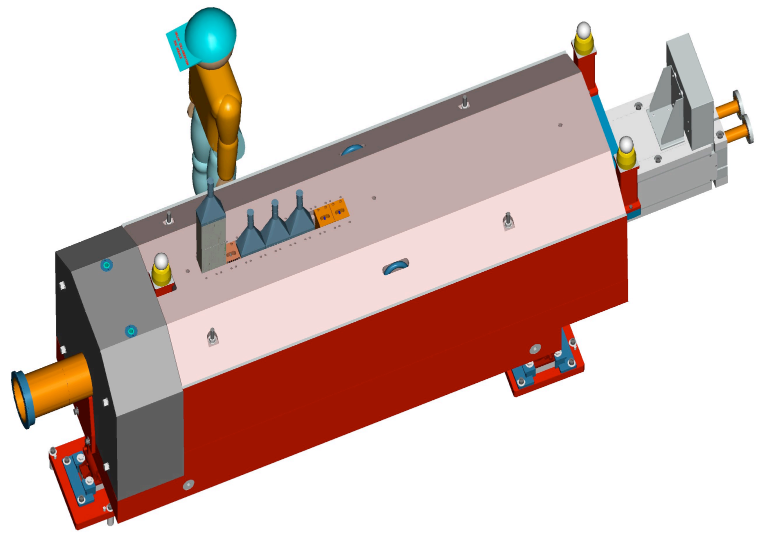
Cut less/more than 50 with ZDC energy

Red > 50 blue < 50

Towards the LHC

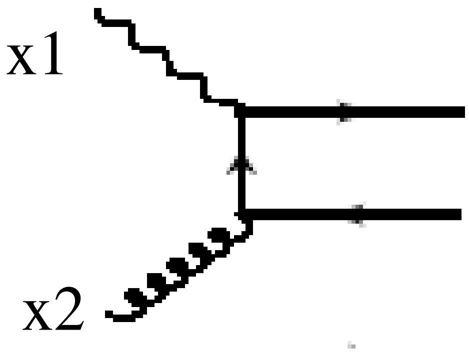
- ATLAS Coverage
- Forward Instrumentation
- ATLAS reach in jj and γj





Pro-E model of ZDC for ATLAS and full simulation of Energy response

Probing small x structure in the Nucleaus with γN->jets, heavy flavor.



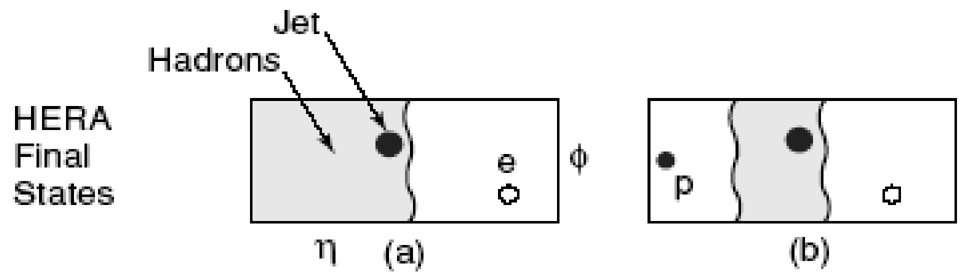
di-jet photoproduction-> parton distributions,x2 by γ with momentum fraction, x1

$4p_t^2/s=x1*x2$

<y>~ -1/2*ln(x1/x2)

Signature: rapidity gap in γ direction(FCAL veto)

ATLAS coverage to $|\eta|<5$ units. P_t ~2 Gev "rapidity gap" threshold



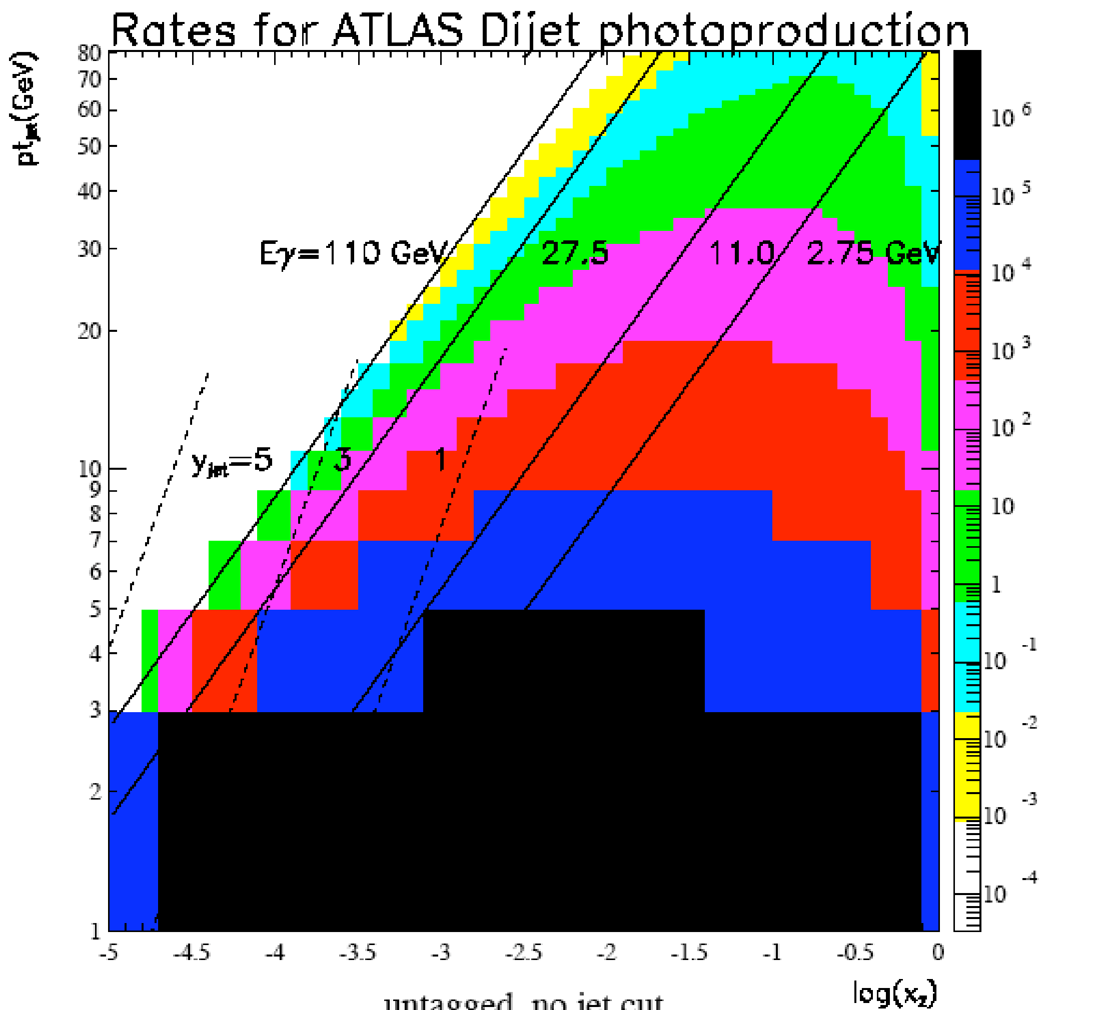
Analogous upc interactions and gap structure

diffractive Non-diffractive

Dijet photoproduction (results also for b-bbar and γ-jet)

Also diffractive rates from

•Frankfurt, Guzey and Strikman
Hep-ph/0308189
"leading twist nuclear Diffractive parton distribution functions (nDPDF's)"



untagged, no jet cut

Summary

- Large cross section diffractive processes used to normalize AuAu and dAu data in PHENIX
- High mass e+e- and J/Psi diffractive photo-production data collected in PHENIX
- Rapidity gap and n-tag powerful tool in Heavy Ions
- Photoproduction measurements with ATLAS will explore a wide range of topics in Diffraction