Hard Photoproduction in A-A Collisions

Diffractive Physics with Heavy Ions at RHIC

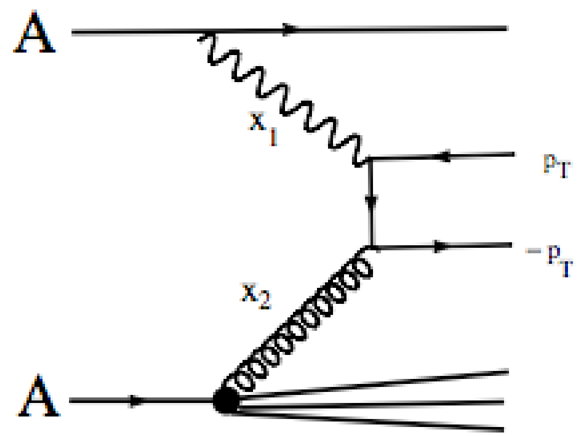
PHENIX

Probing small x structure of nuclei and protons at LHC

(with M.Strikman and R.Vogt)

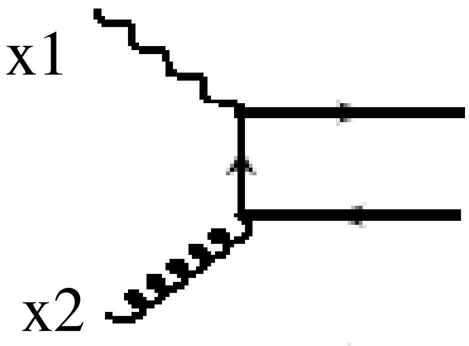
Skopelos, Sept 30, 2005 Sebastian White, BNL

Can one continue HERA program with higher $s_{\gamma N}$ at LHC?



Electron beam ->Z=82 at 5.5 TeV/n
Pb target (AA) or proton (pA)
L=4 10^{26} (AA) and 7 10^{29} (pA) $cm^{-2}s^{-1}$

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



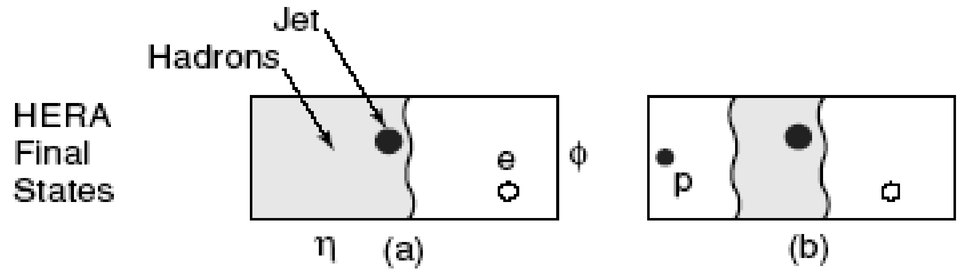
di-jet photoproduction-> parton distributions,x2 by γ with momentum fraction, x1

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

$\langle y\rangle \sim -1/2*\ln(x1/x2)$

Signature: rapidity gap in γ direction(FCAL veto)

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



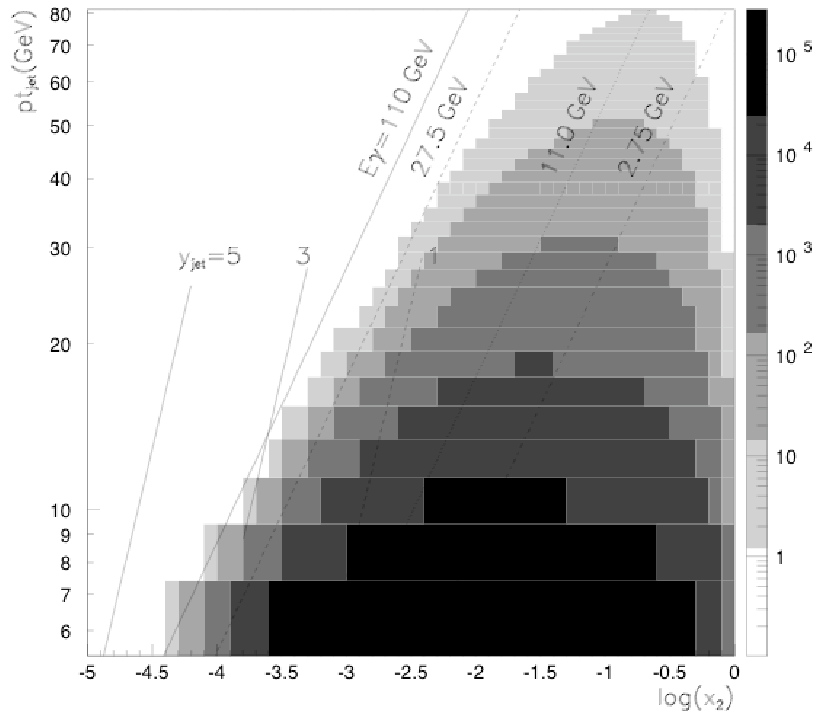
Analogous upc interactions and gap structure

diffractive   Non-diffractive

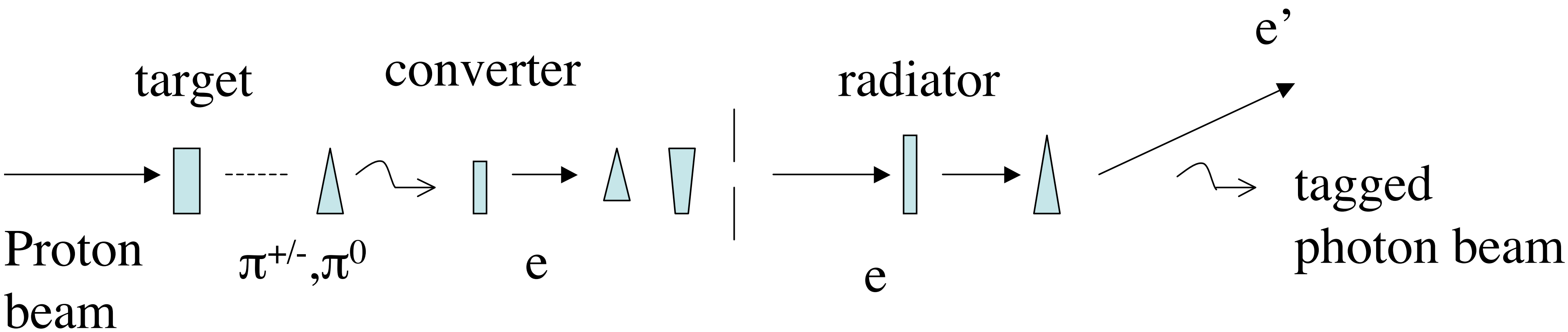
Rates and Kinematics(more later)

Event yields from a 1 month HI (Pb-Pb) run at nominal Luminosity (4 10^{26} $cm^{-2}s^{-1}$). Counts per bin of δpt=2 GeV $\delta x2/x2$=+/- 0.25

(with M. Strikman and R. Vogt)



Tagged Photon beam (fixed target)



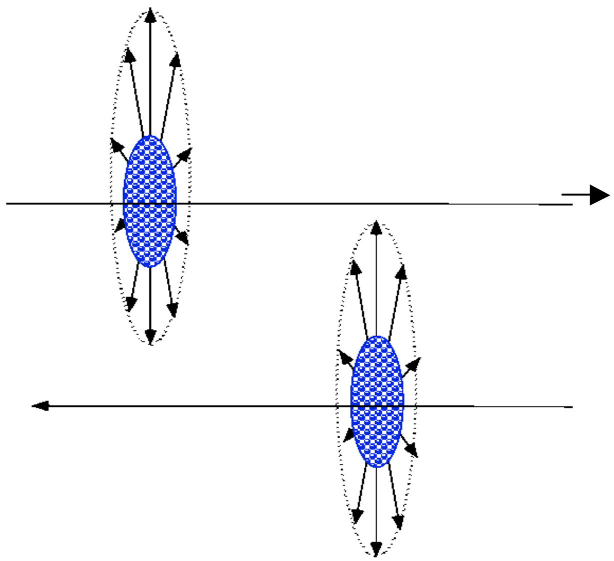
<u>At FNAL ('80's and '90's)</u>

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

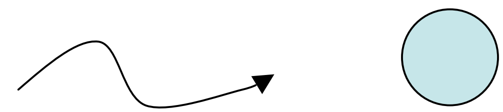
Diffractive γp->Xp E612 (CGSSW)

γp->Charm+X E691--->E791

RHIC and LHC as high Luminosity γ-Hadron colliders



γ_{beam}^{Rhic}=100



S=2m_Aω'

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

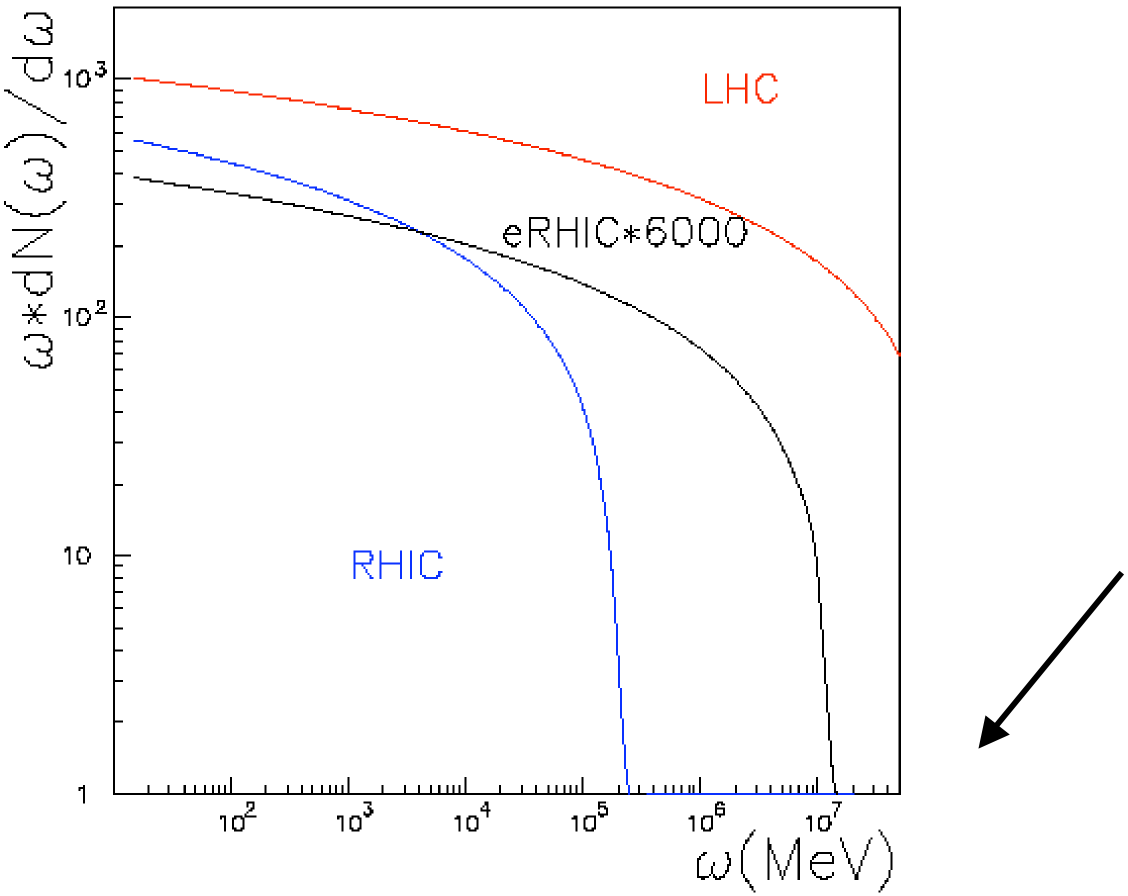
Heavy Ions

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

e-Hadron collider

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

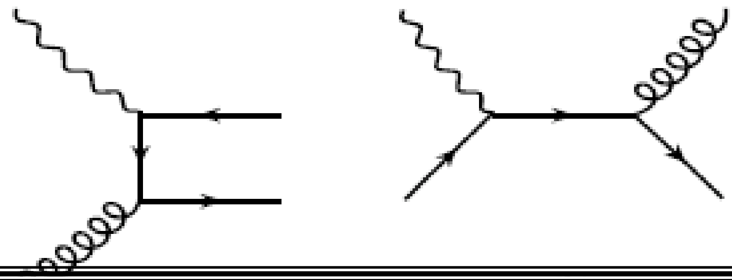
Equivalent Photon spectrum in target nucleus frame



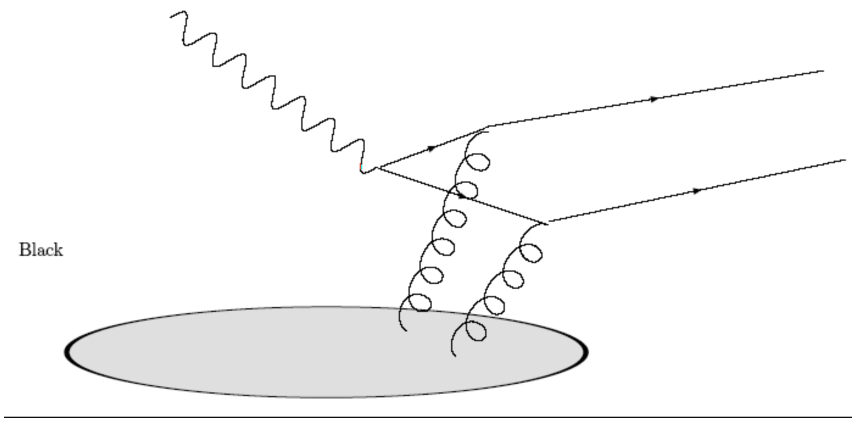
"Quasi-real" γ spectra compared to an e-hadron collider

->100 TeV @ LHC

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



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

Physics Opportunities

The black disk limit: 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.

Three Dimensional Mapping of Strong Matter: 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.

Radiation Patterns in Strong Interactions: 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.

Hadronization in nucleons and nuclei: 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.

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

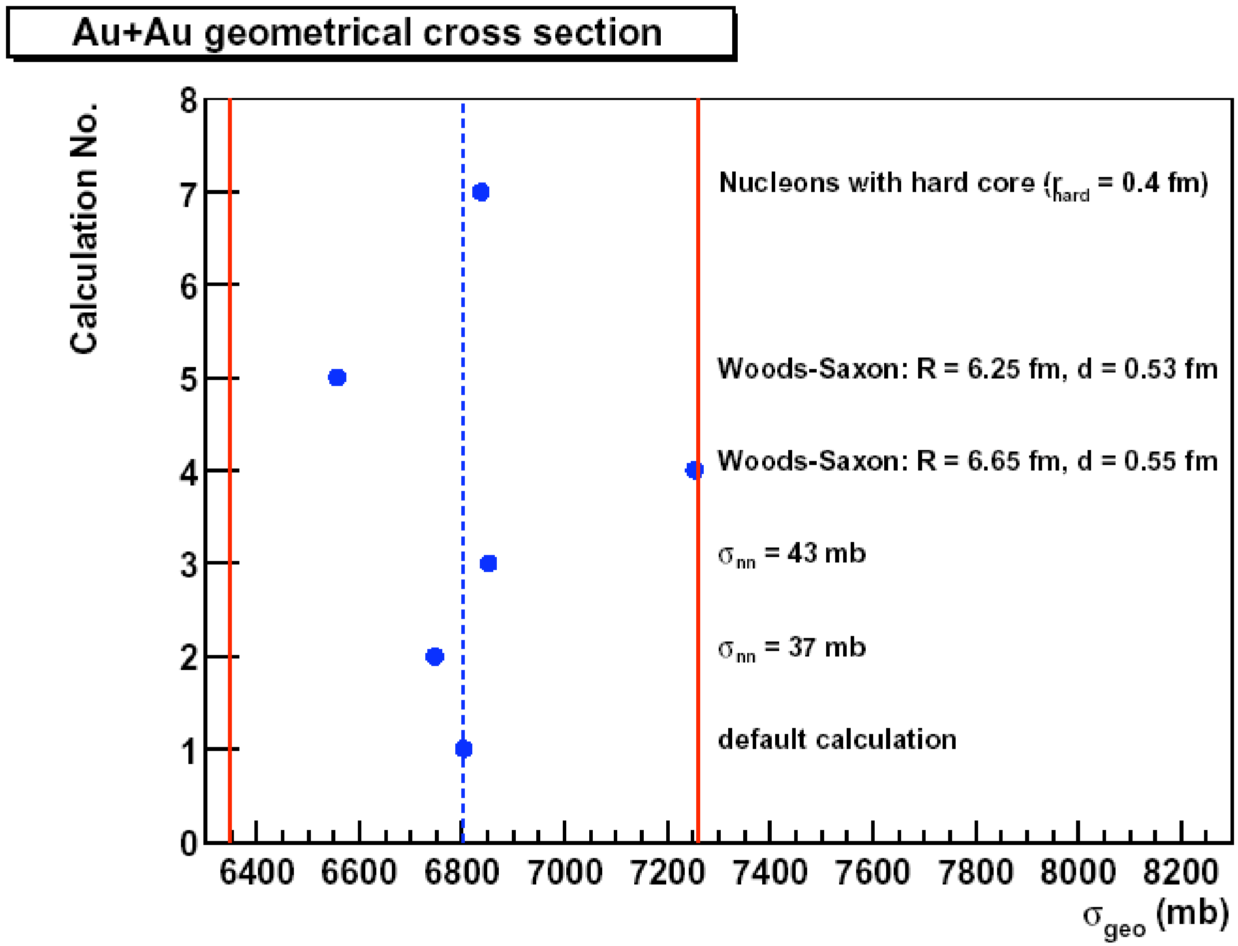
Total Cross Sections(I)

-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					

Skopel

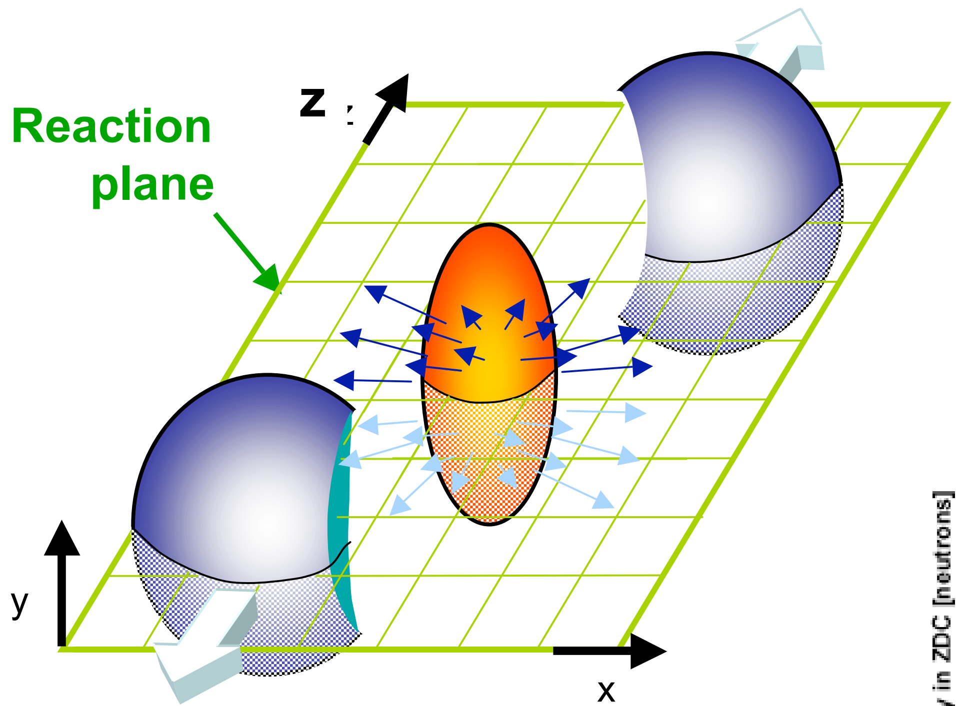
Total Cross Sections (II)



(from K.Reygers, PHENIX note)

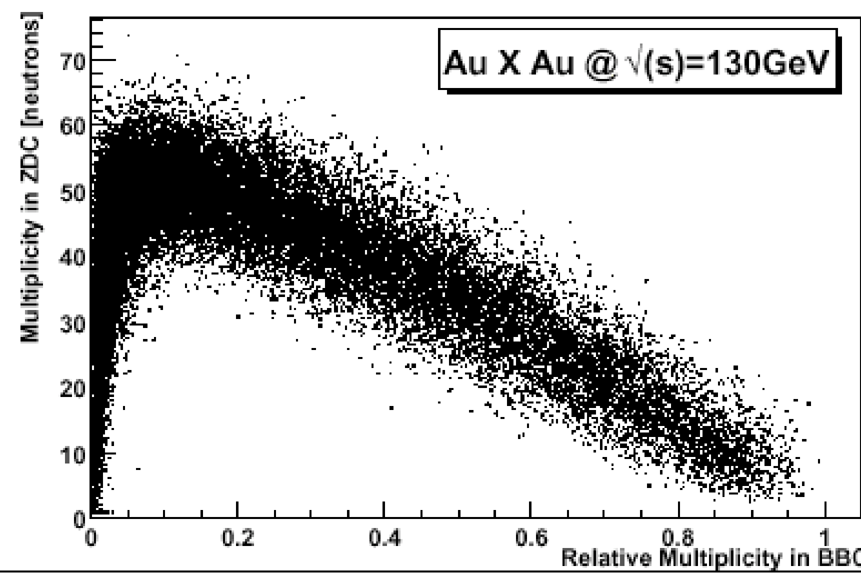
Heavy ions:Event characterization with forward detectors

>>Direction and magnitude of impact parameter, b



Magnitude from complementary parameters

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



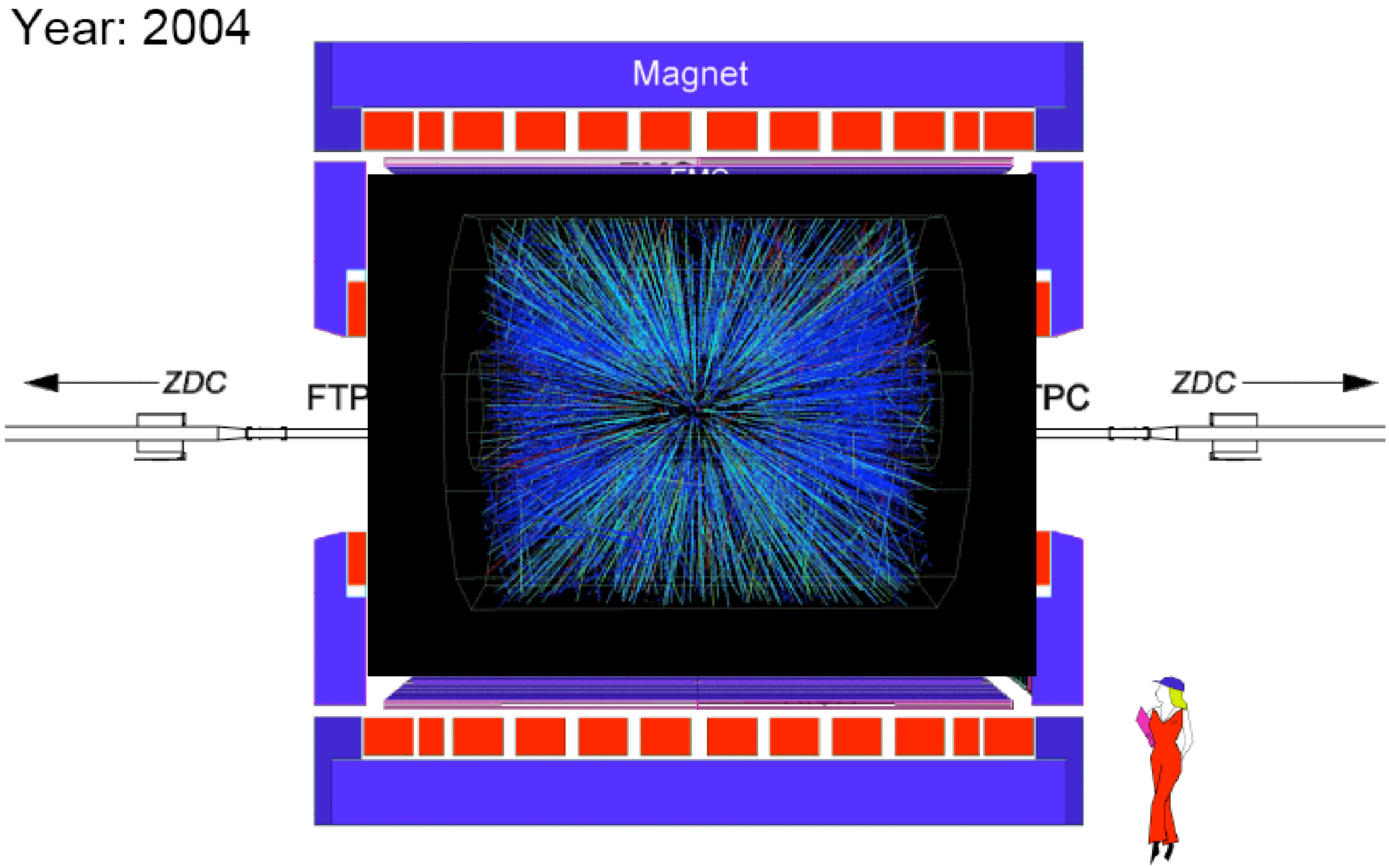
Beam-Beam Counter Mult/1000

Spectator neutrons

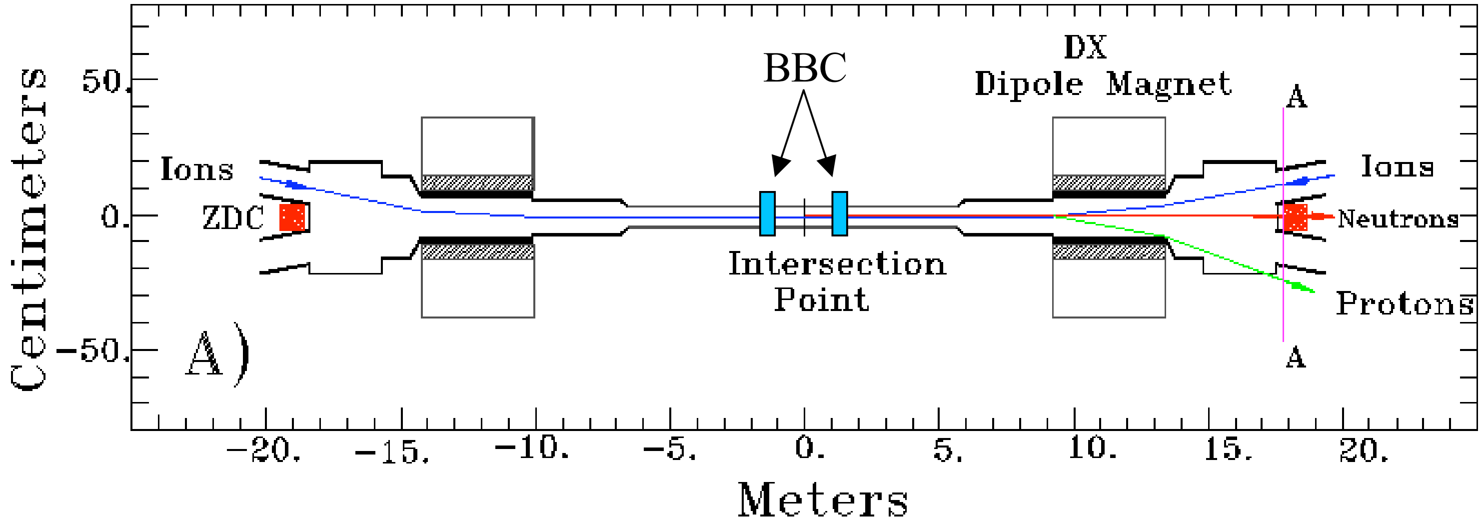
- **measure centrality,**
- **Min_min_bias trigger**

(Calorimeter@θ<2mr.)

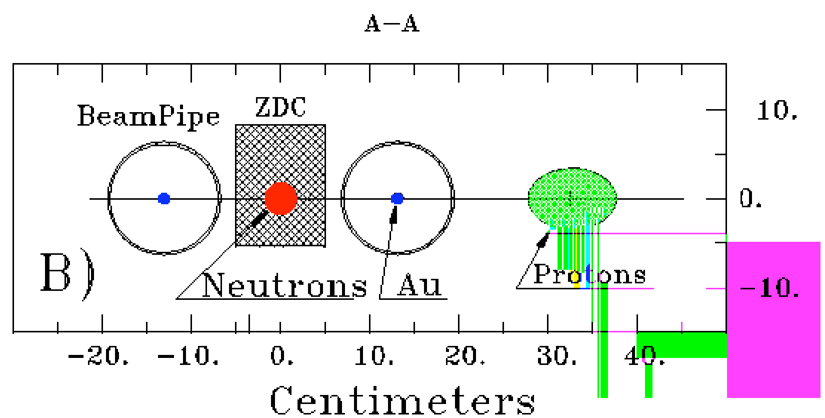
A RHIC Central detector:STAR



Forward Instrumentation

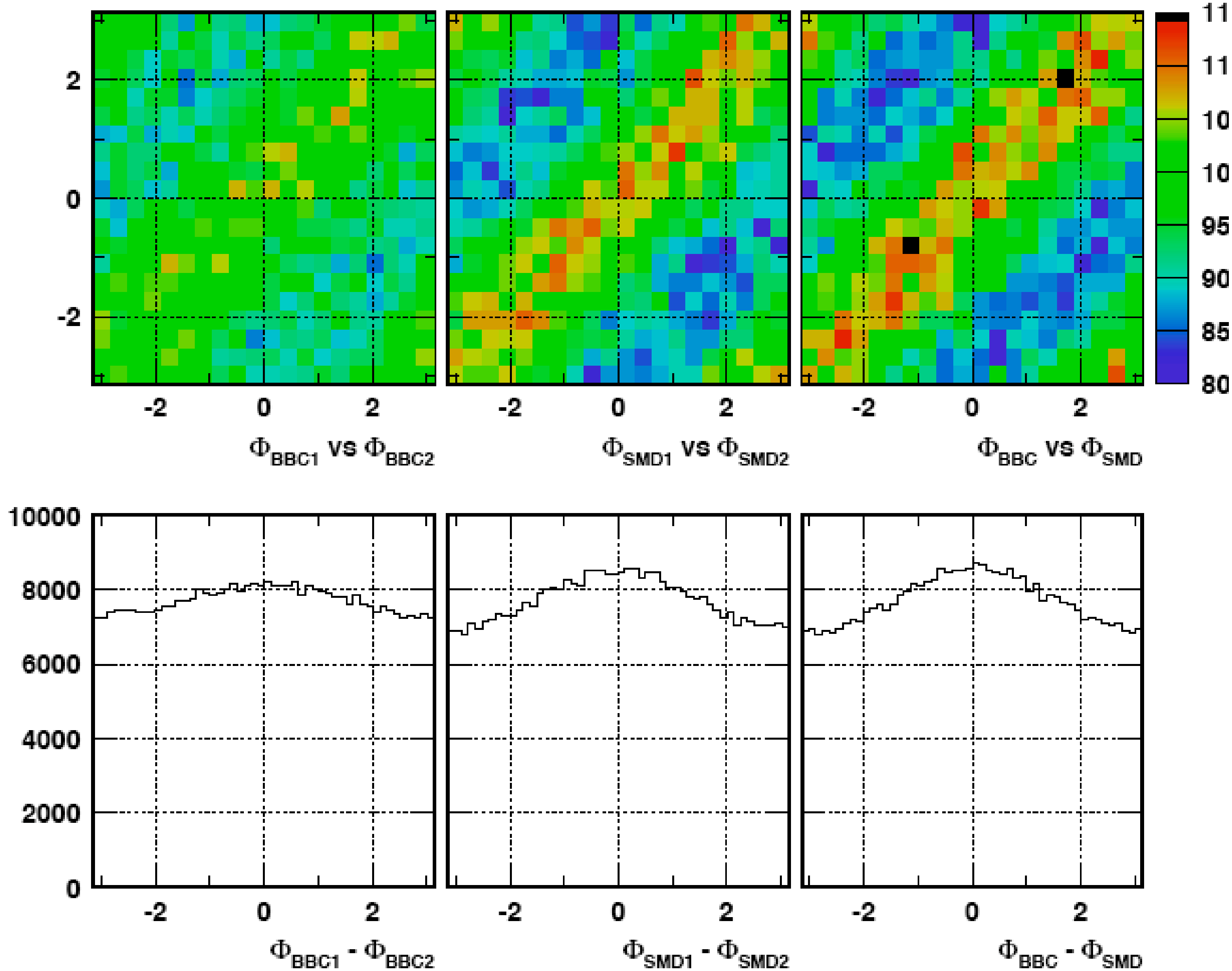


- •All AuAu Interactions->low p_t neutron "spectators"
- •Peripheral Coulomb Interactions->neutron tag from Au*->n+X
- •Deuteron Photodissociation_> n+p in forward calorimeters



Skopelos, Sept 30, 2005

Directed flow, v_1, is largest at ZDC location



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PHENIX Diffractive Data

AuAu σ_{tot}: Coulomb + Geometrical

dAu σ_{tot} " :Original system for Diffraction Dissociation
"Free Dissociation"+ Geometrical

$\gamma\gamma$-> e^+e^- : High Mass continuum (m_{ee} above ~2 GeV)

γAu-> J/psi+Au coherent photoproduction

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

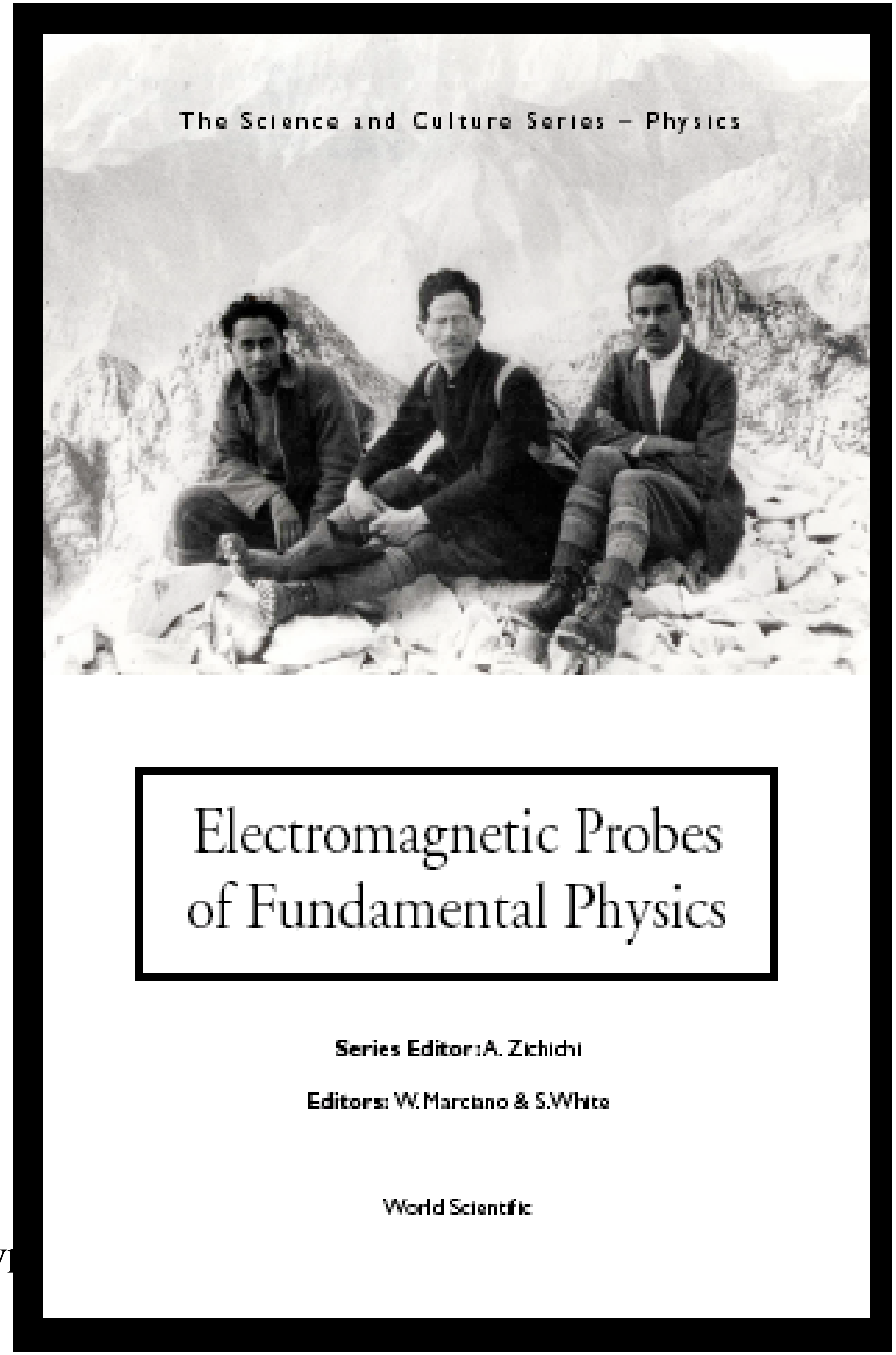


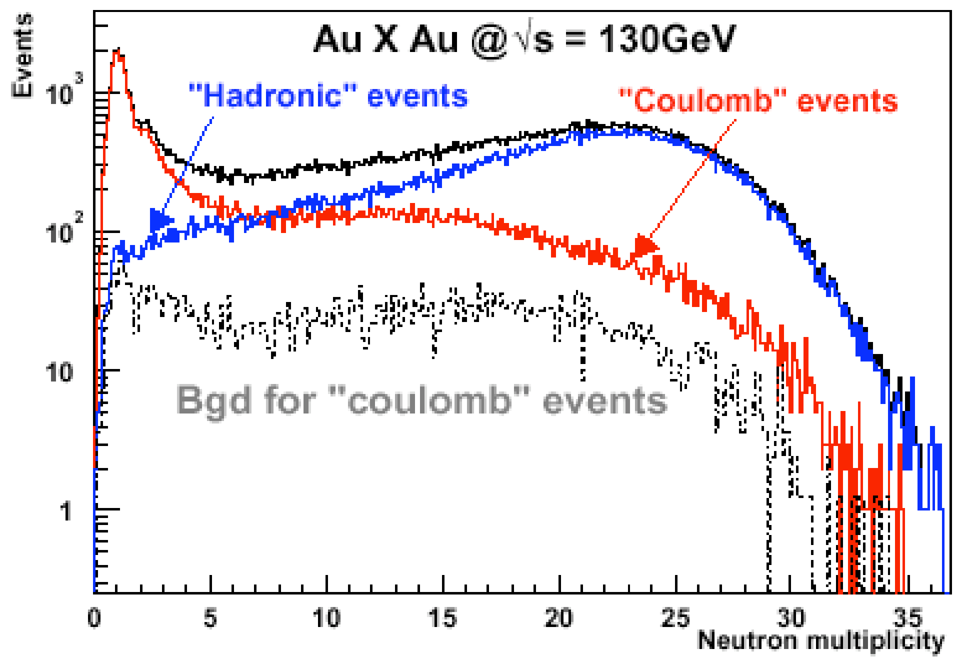
TABLE I. Cross sections calculated and derived from the data. The errors quoted on measurements include the uncertainty of the BBC cross section [8]

Run I

PRL

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.

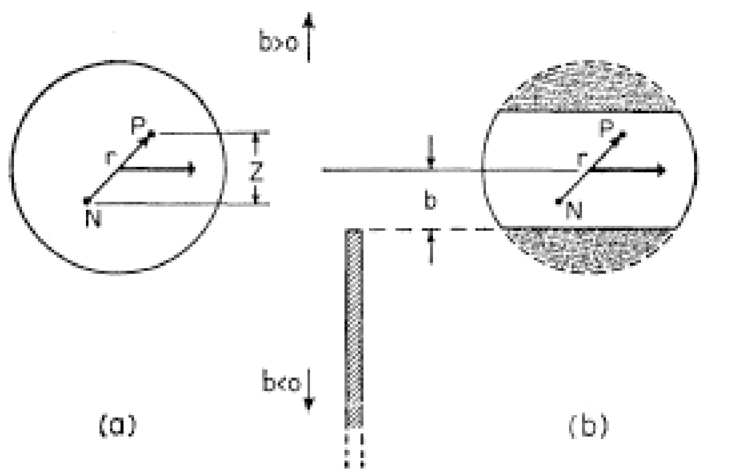


d-Au Inelastic cross section

Author	Calculated value(barn)
Kopeliovich	1.93 (uses non-diffractive,Gribov)
Kharzeev Levin,Nardi	2.26 ±0.1
STAR "standard"	2.36 (also find 7.1 b for AuAu Whereas vernier-> 6.1 barn)
PHENIX "standard"	2.18+-0.17
D. d'Enterria	2.32 +-.17 (n skin issue)
This work	**2.26(±1.6% ± 5.0% ± 4.5%)**

d->n+p dissociation process

1) Classical diffraction dissociation (Glauber '55):



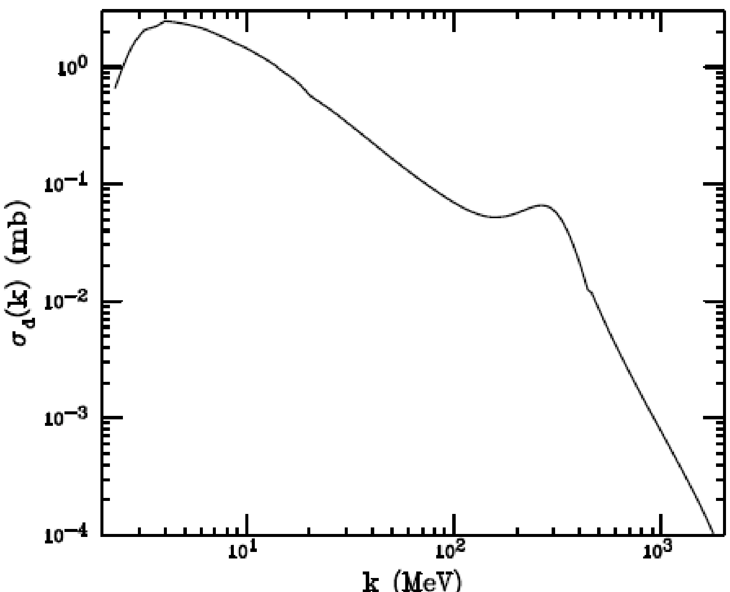
$$J(b)=\int_{|z|>2b}|\varphi_0(\mathbf{r})|^2 d\mathbf{r}, \qquad (1)$$

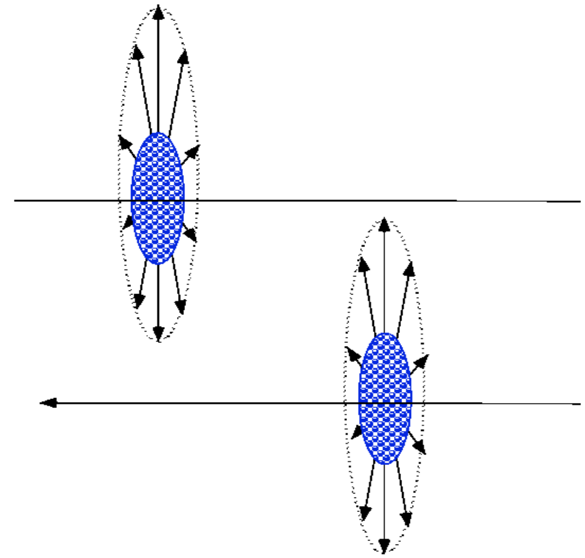
$$\sigma_{\mathrm{f.d.}}=\int_0^\infty J(b)[1-J(b)]db. \qquad (5)$$

$\Rightarrow \sigma_{f.d.}=0.14$ barn

d->n+p dissociation process(2)

2) Coulomb Dissociation (Fermi ‘25):





$$I(\nu) = \frac{8\pi c \varepsilon^2 \nu^2}{v^4} \left\{ K_0^2 \left(\frac{2\pi\nu b}{v} \right) + K_1^2 \left(\frac{2\pi\nu b}{v} \right) \right\} \quad (4)$$

=> $\sigma_{c.d.}$=1.24 barn (+/-5%, Klein &Vogt ‘03)

PHENIX measurement of deuteron dissociation

PHENIX used 2 types of min bias triggers:

1)BBCN*S=coinc of 3<|η|<4

(excludes "rapidity gaps")

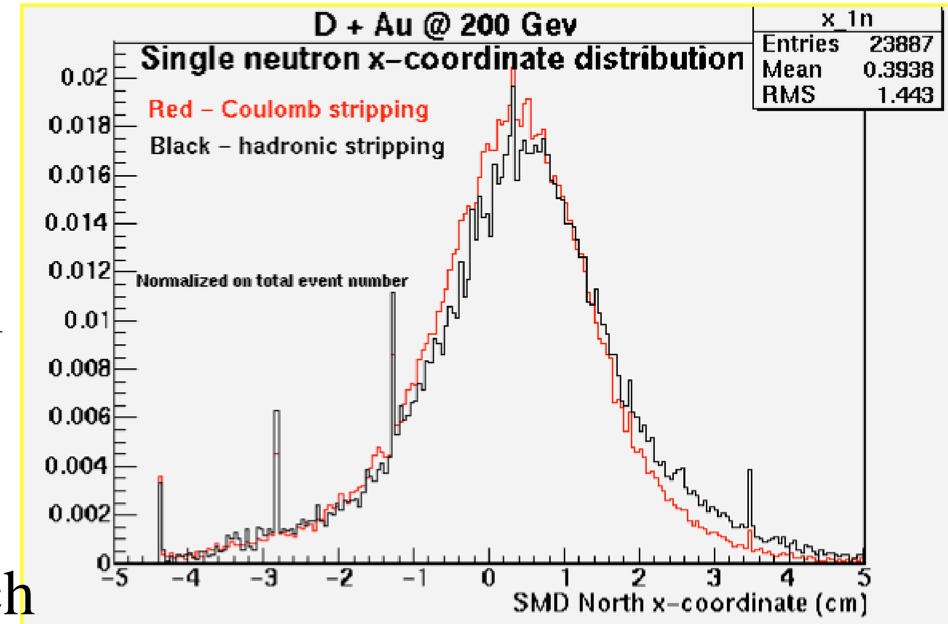
And

2)ZDC N or S= >0 n, either beam

(includes "gap" events,

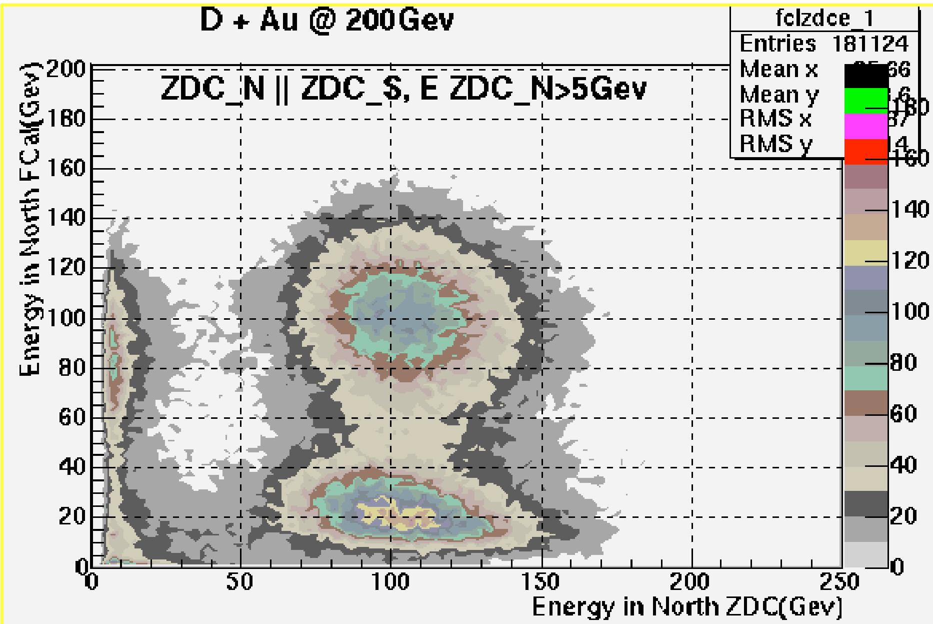
~12M events recorded)

Our measurement is from 2) which includes d+Au->n+p+Au



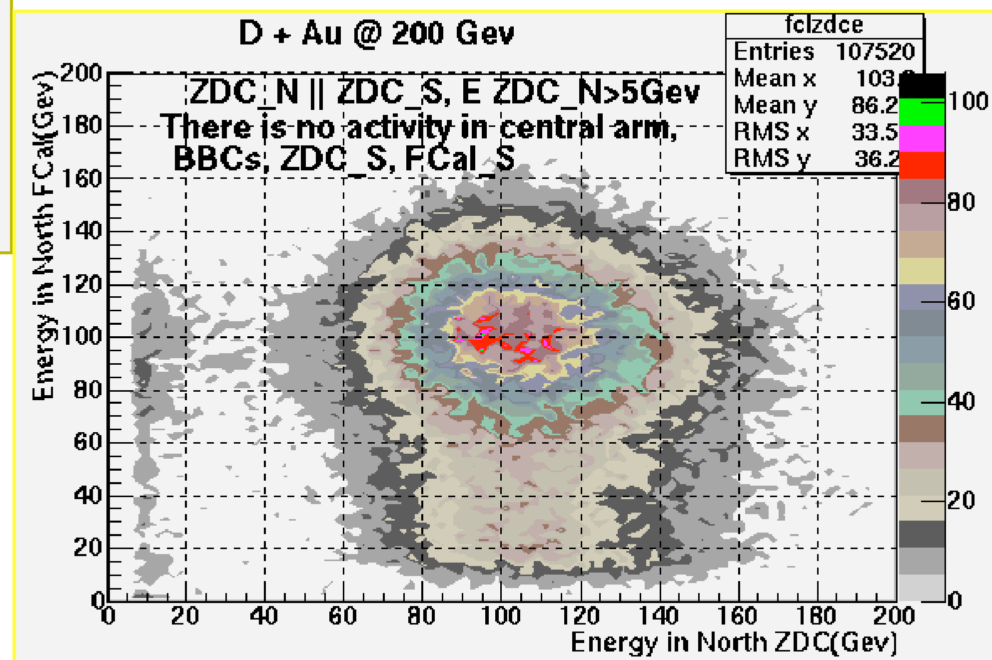
Impact position of neutrons
For both free dissociation
And stripping

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

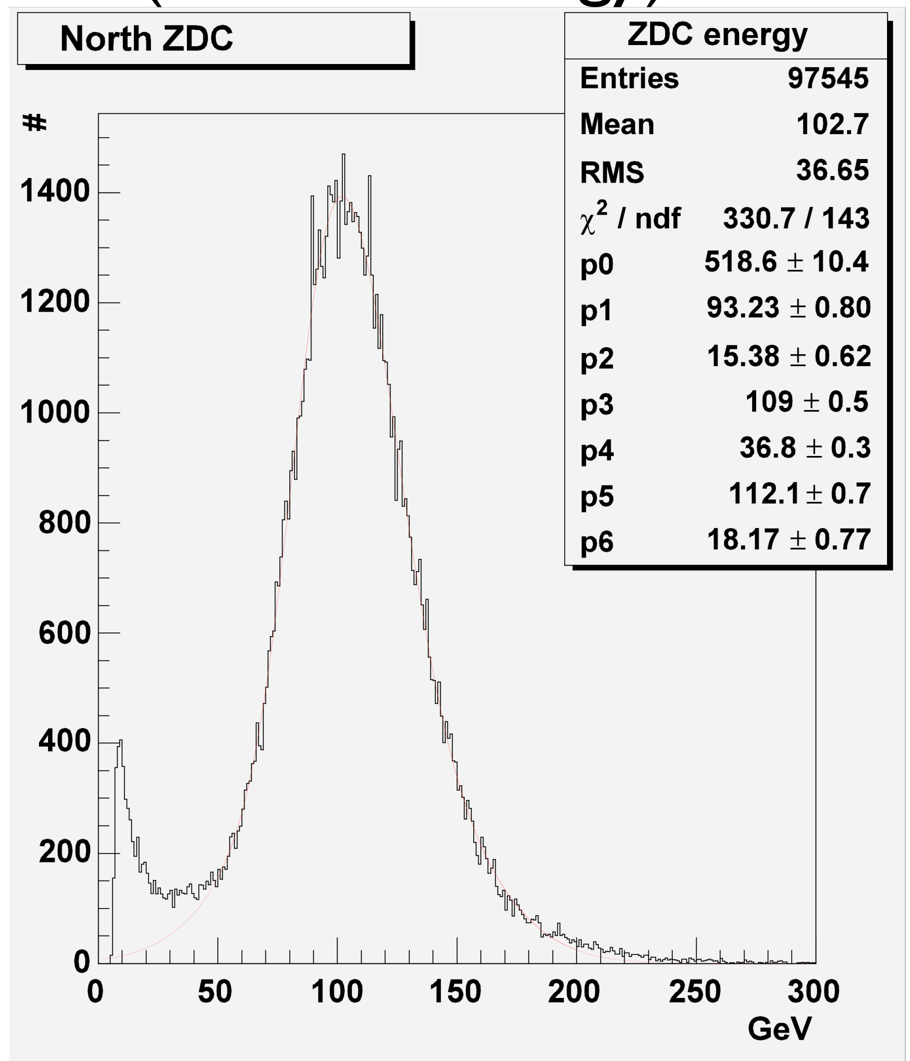


Projection on ZDC

(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.

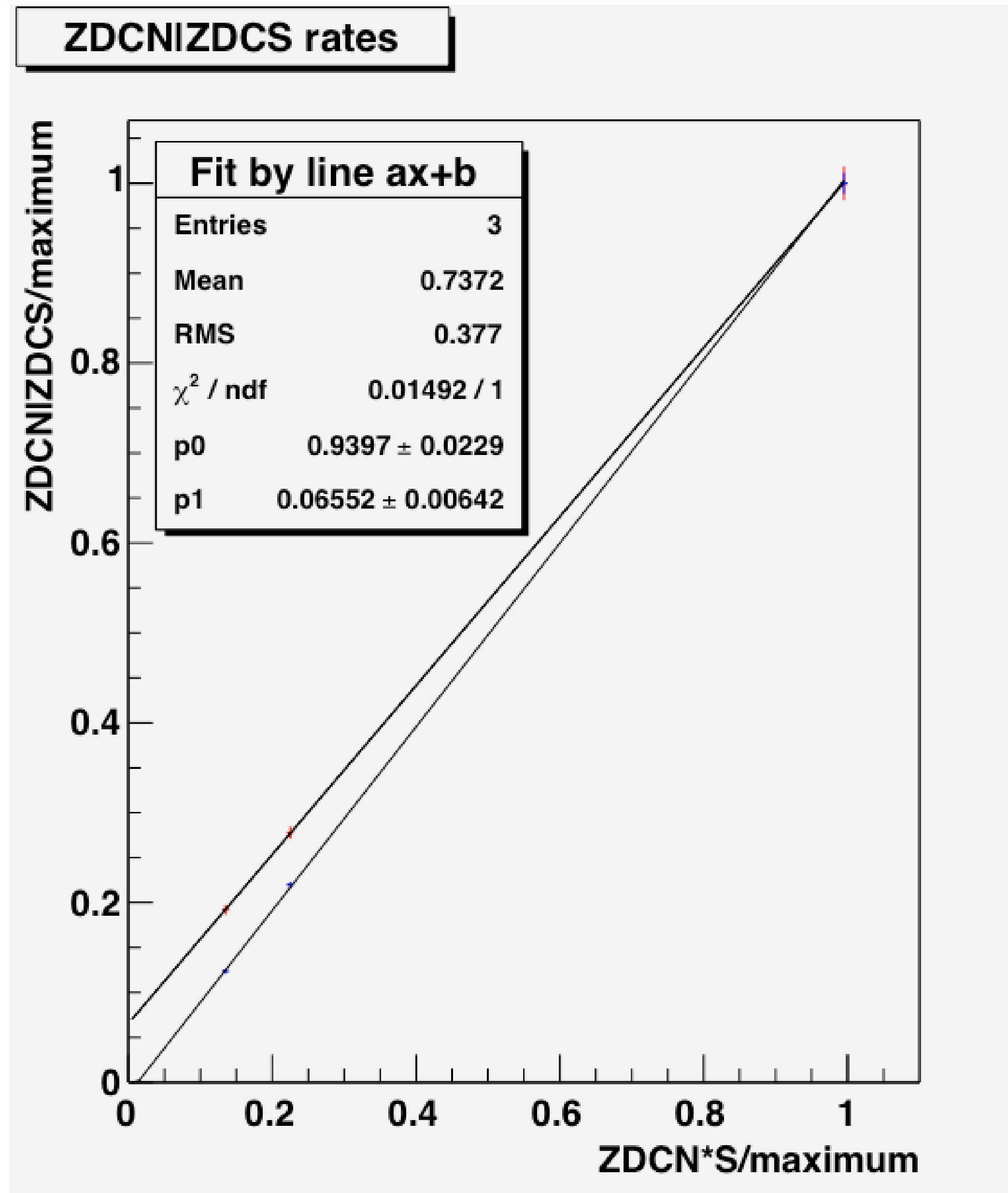
This is current limit on systematic error.



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

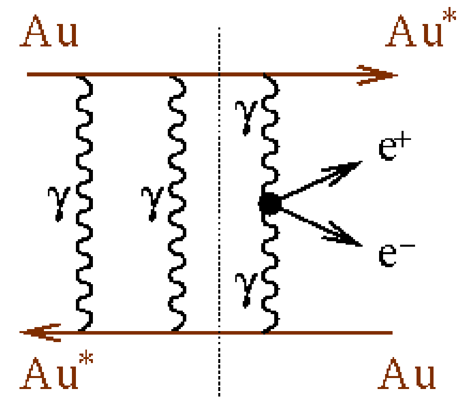
Separate beams through beam steering and measure rates:

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

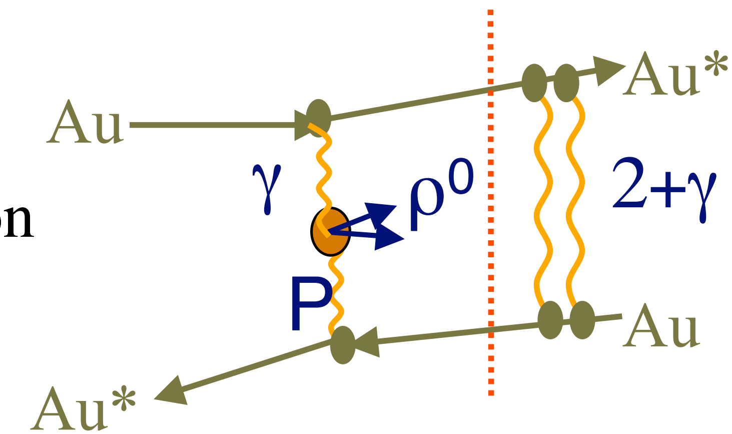


RHIC $\gamma\gamma$ physics and vector meson photoproduction

Continuum electron pair production
-total rate enorrmous (33 kbarn)
-spectrum peaked at small m_{ee}
-PHENIX measured m>2 GeV region



Coherent Vector meson photoproduction
-STAR measured ρ->ππ
-new data from PHENIX on J/psi->ee

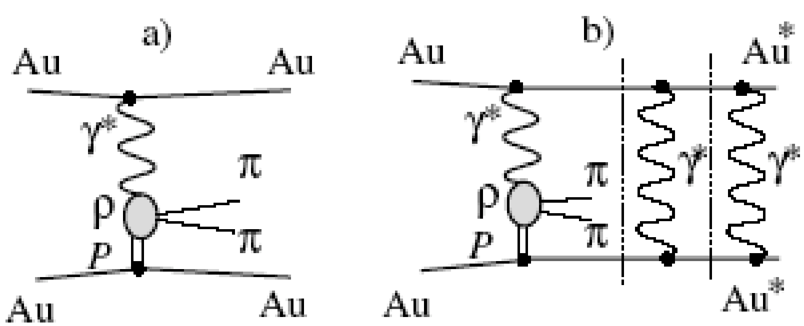


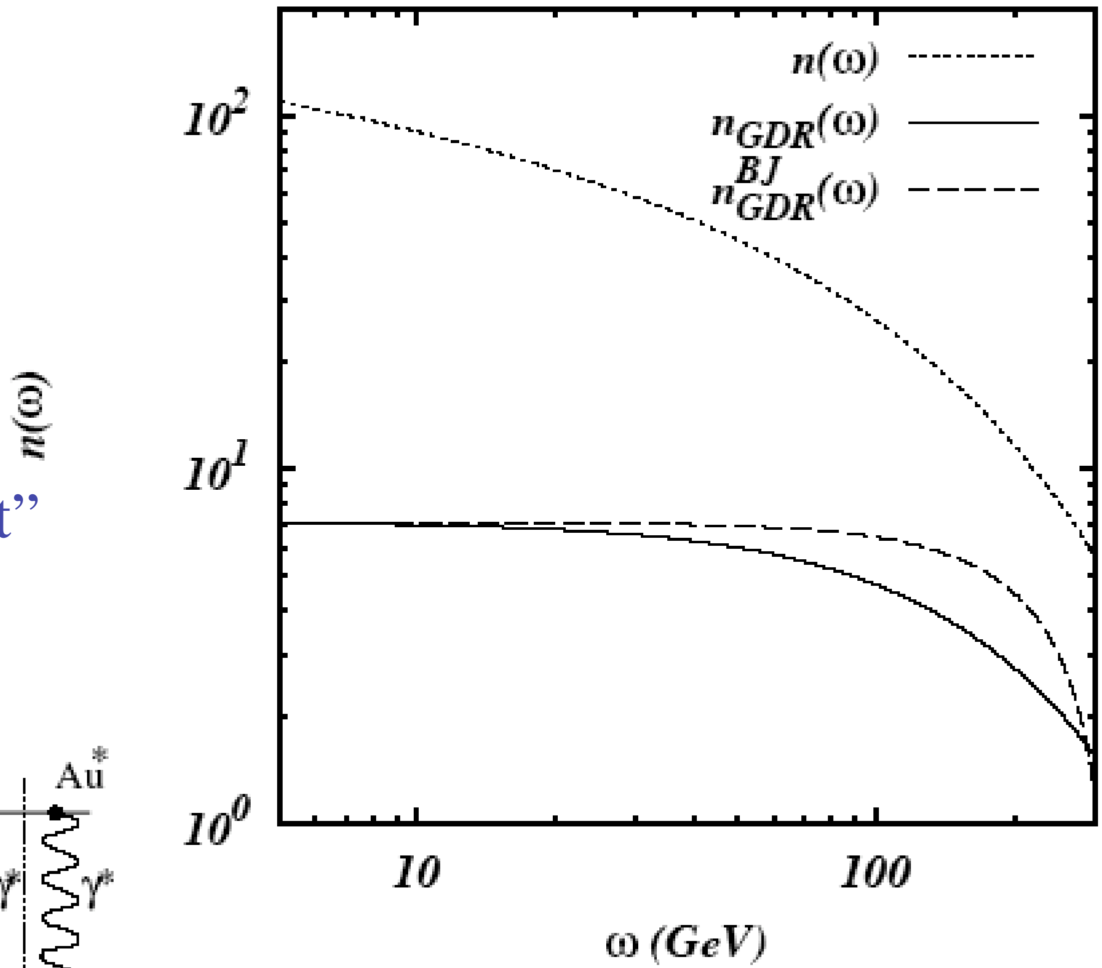
Tagged photon spectrum

Strength of interaction

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

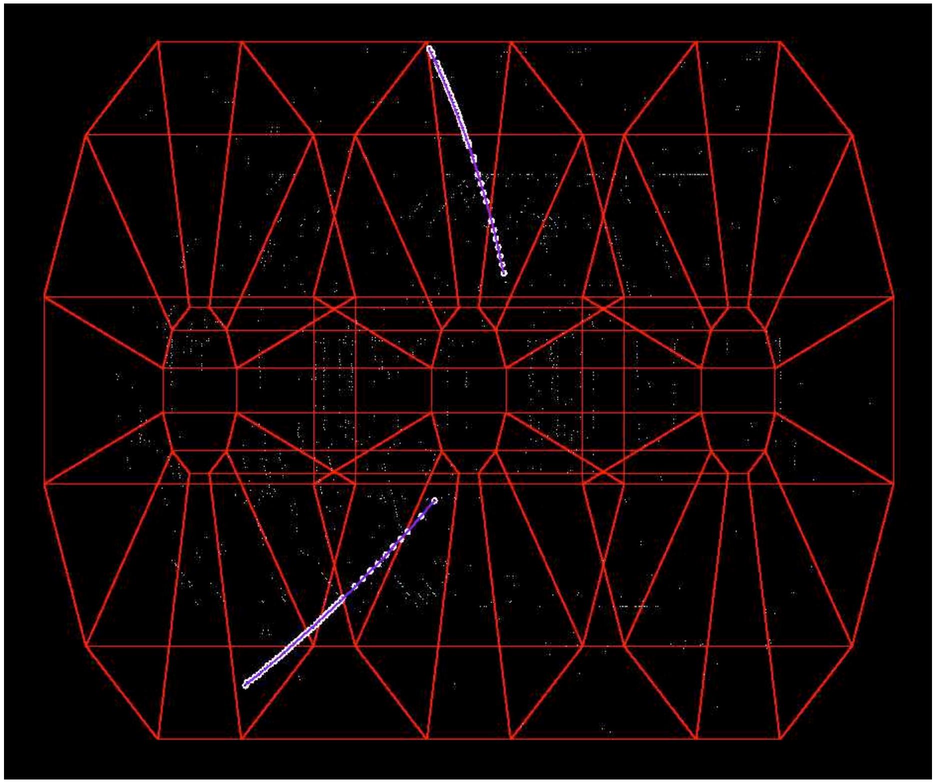
2nd γ exchange leads
to hardened photon beam
(implemented in "STARlight"
not yet in "DPEMC")
(seeG.Baur et al. Nucl-th/03070310)



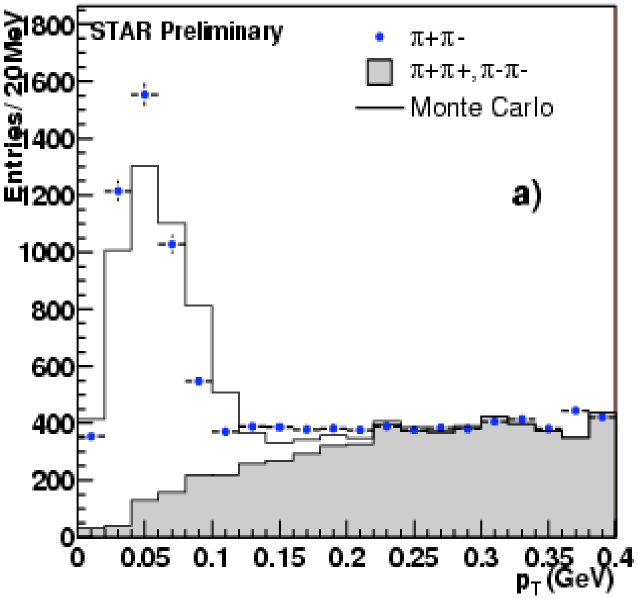


STAR ρ^0 measurement (2002)

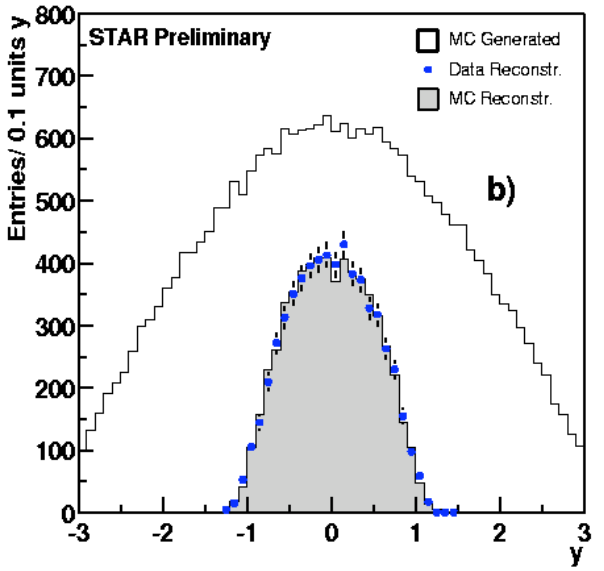
Triggered on ZDC coincidence
Reconstruct $\pi\pi$ in central TPC



ρ reconstructed p_t



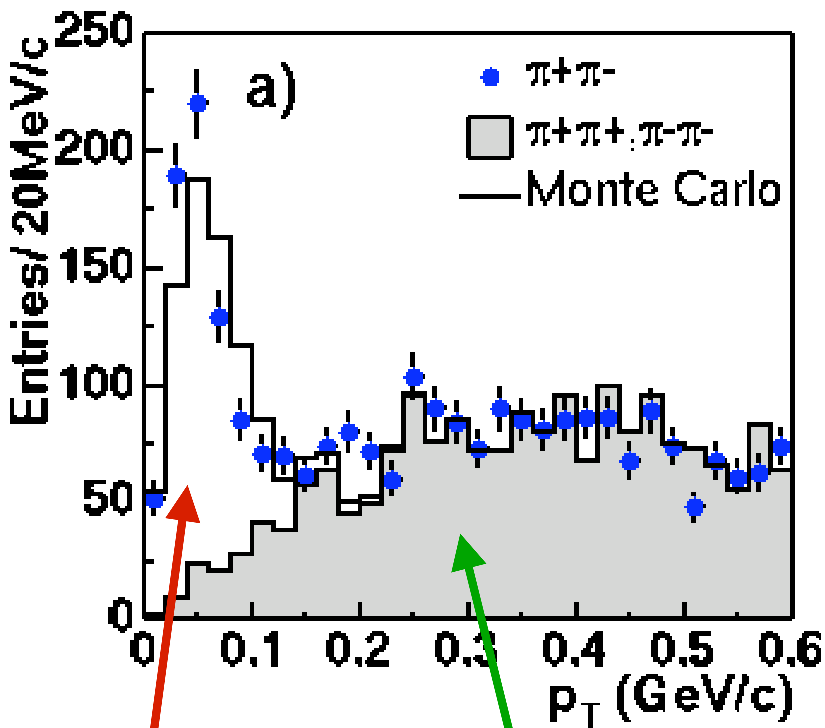
rapidity



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 trigger

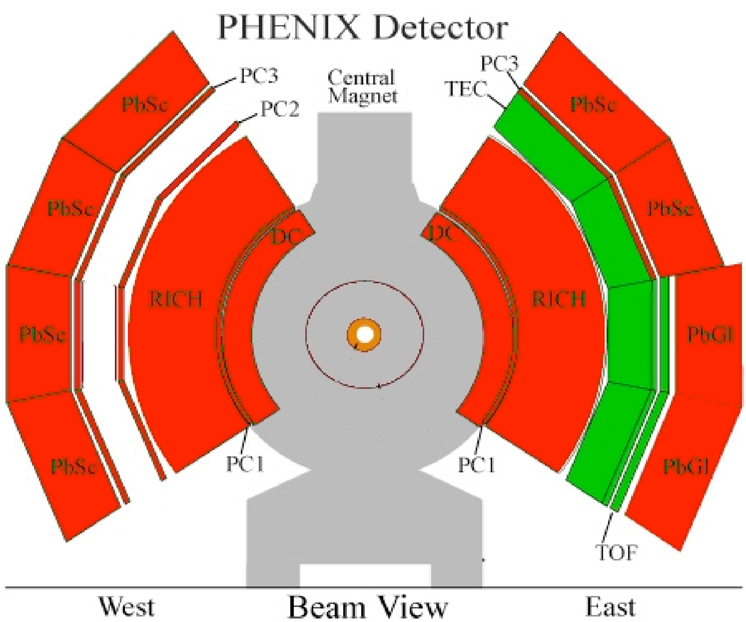
UPC: (ZDCN || ZDCS) && (!BBCLL1noVtx) && (ERT2x2)

Sensitive to γ +A $\rightarrow$ A*+J/psi ($\rightarrow$ e^+e^-):

- Veto on BBC (|y| ~3-4) [exclude periph. nuclear & beam-gas]
- Neutron(s) in at least one ZDC [from Au* Coulomb de-excitation]
- Large energy (>0.8 GeV) cluster in EMCal [e^+e^- decay from J/_]

Total data set: 1352 PRDFFs * 0.8 GB/file ~ 1.04 TB, 8.4M events

Total equivalent sampled luminosity: $L_{int} \approx 120\ \mu b^{-1}$



Global cuts: |zvtx| < 30 cm, track multiplicity <15

Single-track cuts:

- $N_0 \geq 2$ [# of RICH phototubes fired by e^+e^-].
- $E_1 > 0.8$ GeV || $E_2 > 0.8$ GeV [ERT threshold].
- No dead-warn tower around assoc. EMCal cluster [CNT-EMC matching. e+e- candidates].

Pair cuts: $arm_1 \neq arm_2$ [back-to-back di-electrons]

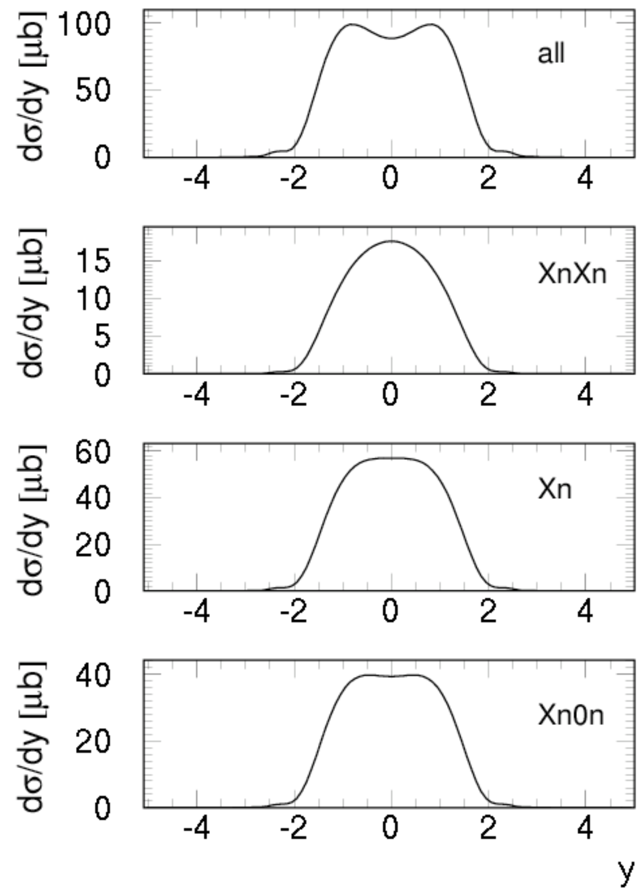
Background subtraction: [unlike-sign] - [like-sign]

Full GEANT MC for J/psi & high-mass $e^+ e^-$ continuum based on physics input from Starlight model

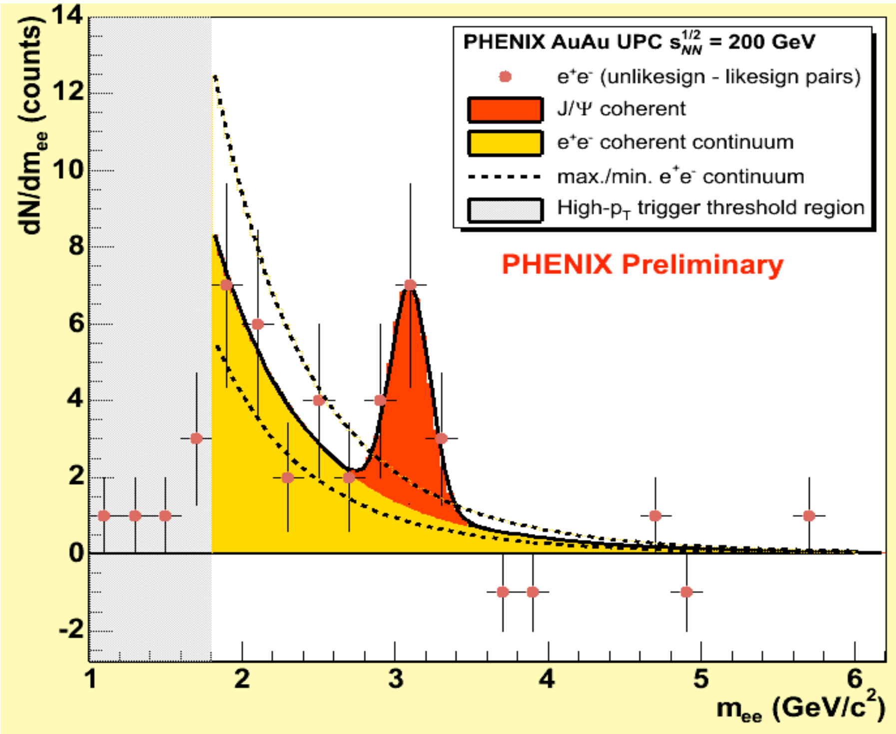
ZDC trigger bias

~60% of all J/psi with 1 neutron tag

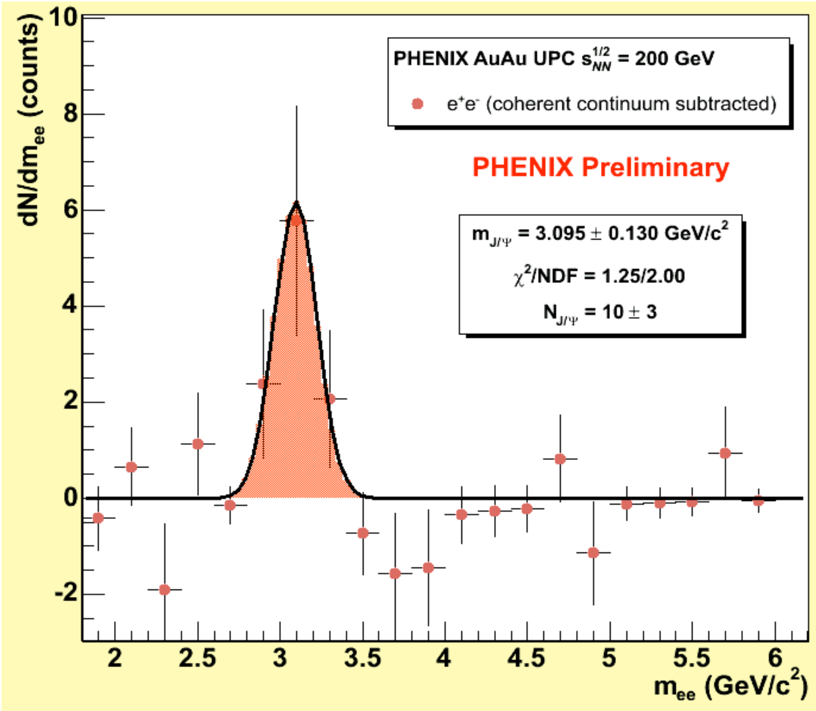
~20% with 2 arm n tag



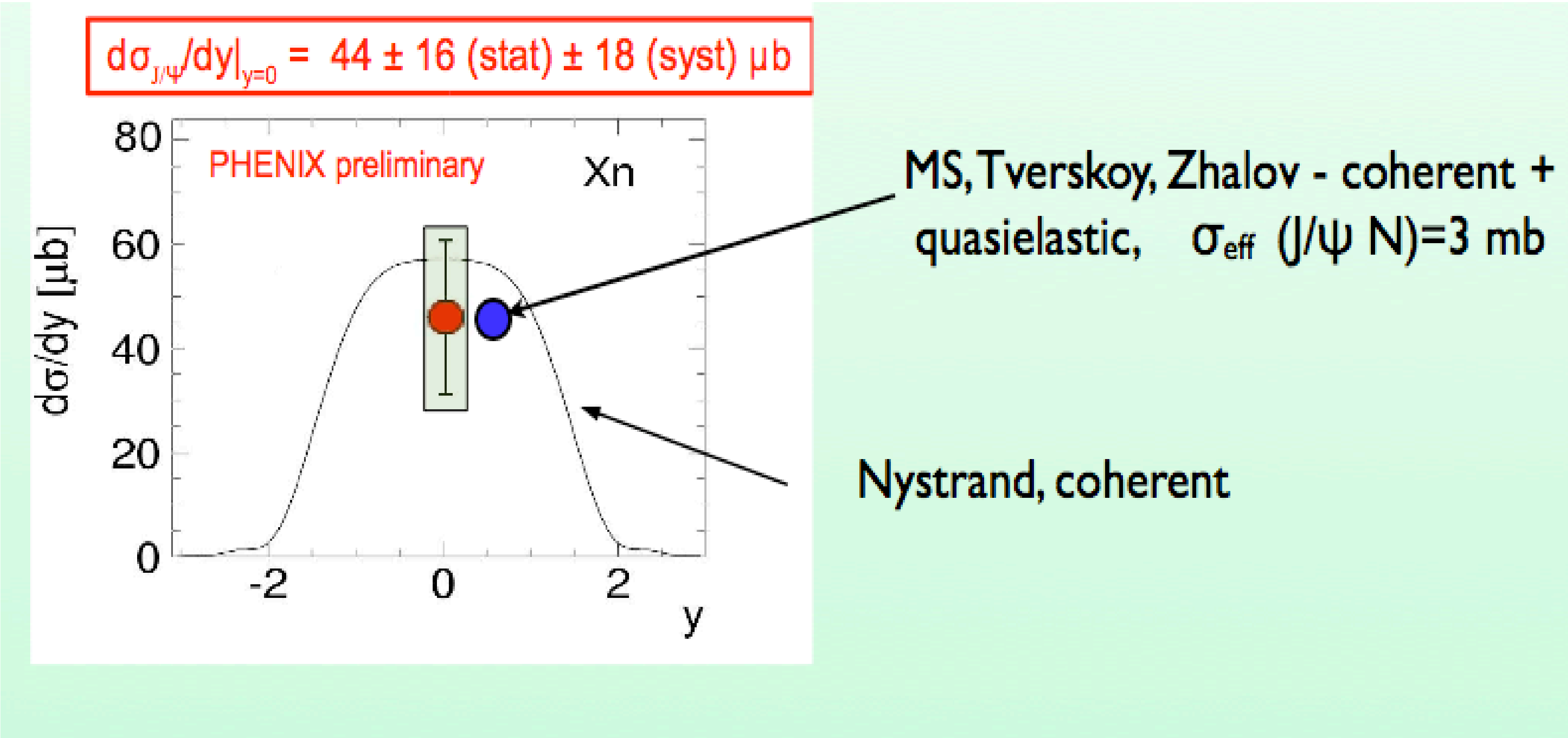
J.Nystrand/STARlight

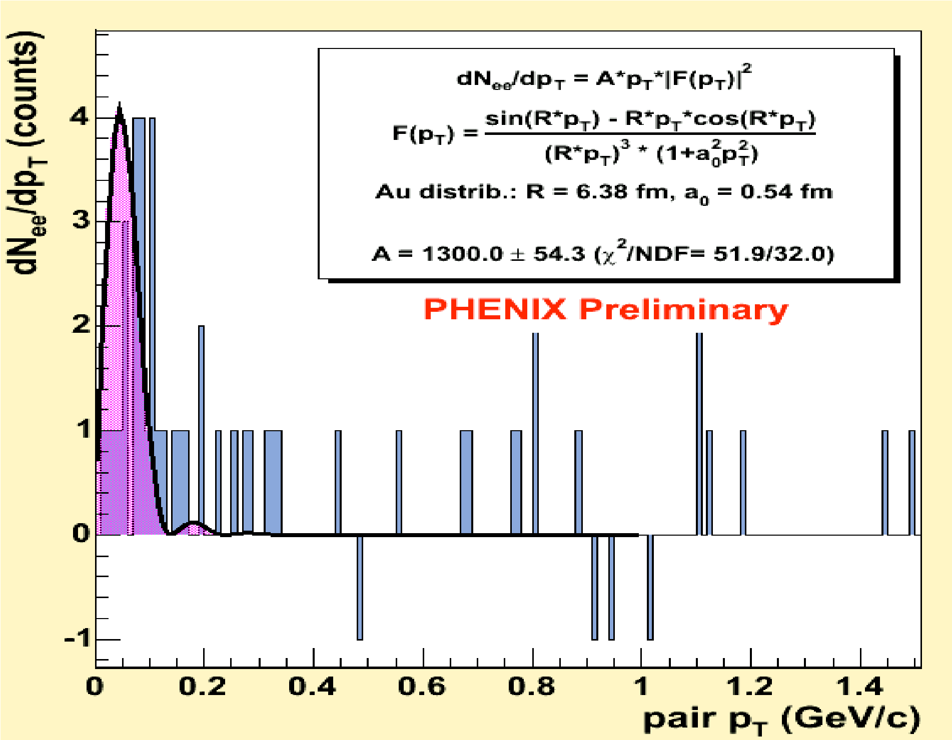


Dominant uncertainty in signal extraction from continuum fit



J/psi after continuum subtracted

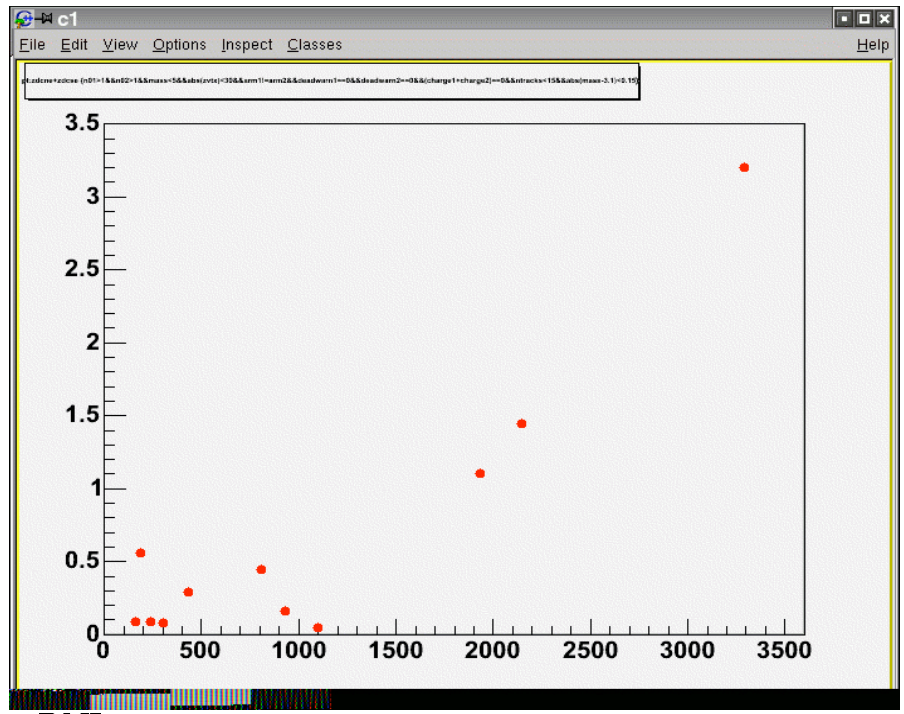

dσJ/ψ/dy|y=0 = 44 ± 16 (stat) ± 18 (syst) μb
PHENIX preliminary
Xn
dσ/dy [μb]
y
MS, Tverskoy, Zhalov - coherent + quasielastic, σeff (J/ψ N)=3 mb
Nystrand, coherent



-Clear coherent peak consistent with Au form factor

-cp.inclusive J/psi (<pt>~ 1 GeV/c)

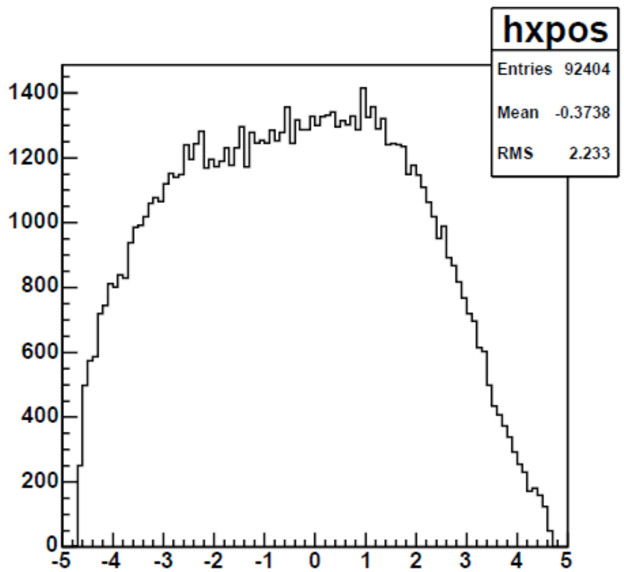
Incoherent extracted from J/psi pt vs E_{ZDC}

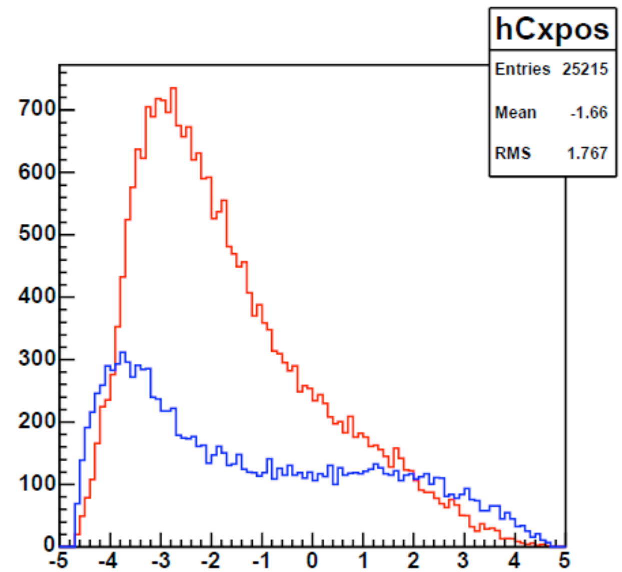


PHENIX Diffractive physics in pp

Spin dependent asymmetries in pp->n+X are basis for polarimetry in RHIC program.

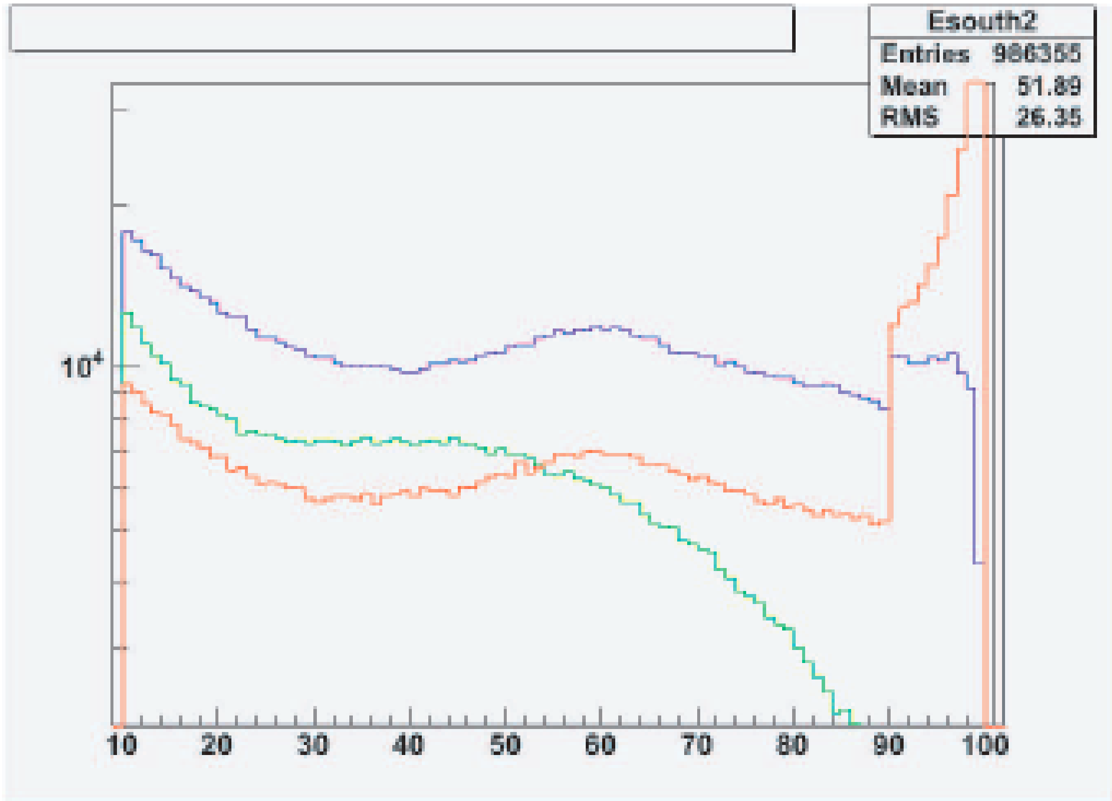
ZDC also measures protons with $t>t_{min}=0.2$ (GeV/c)^2 single diffraction without Roman pots





Distance from beam all identified protons

Skopelos, Sept 30, 2005 Sebastian White, BNL



Simulation of RHIC ZDC en from:
Single diff (red)
Double Diffractive (blue)
Non-diffractive (green)

At LHC, 9% of σ_{inel}->ZDC coincidence in pp

For Heavy Ions ZDC is absolute luminometer

On the Potential Use of Zero Degree Calorimeters for LHC Luminosity Monitoring

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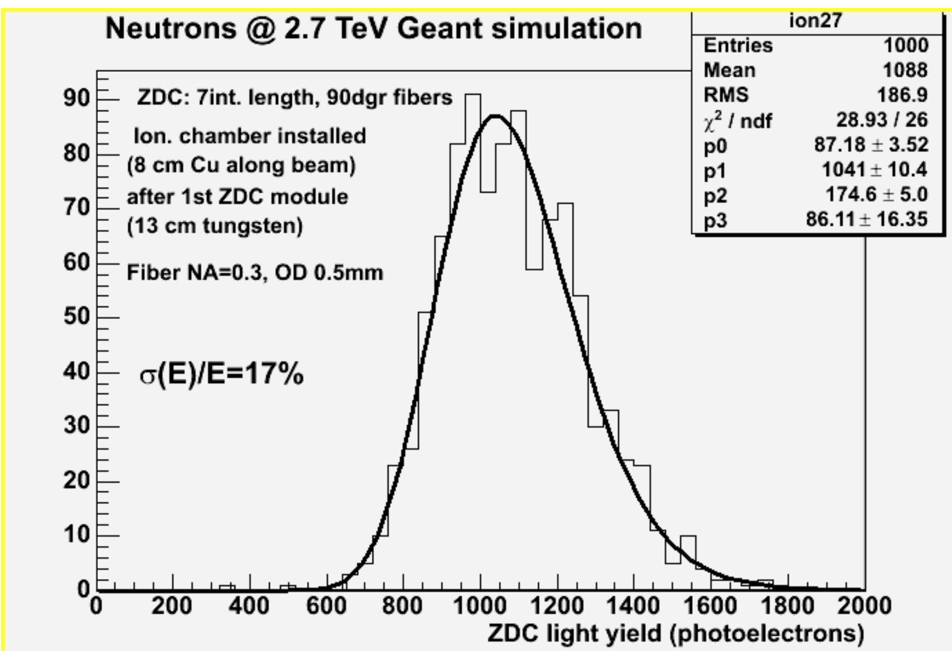
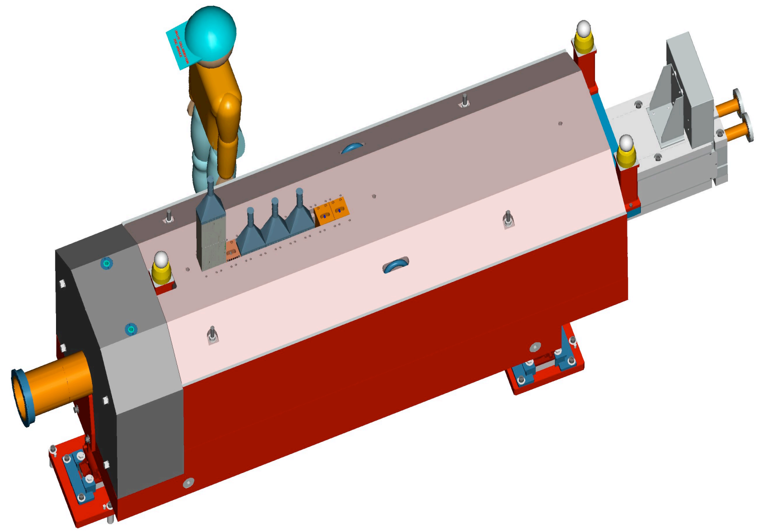
Abstract

We discuss the ZDC role in commissioning proton running at LHC.

Towards the LHC

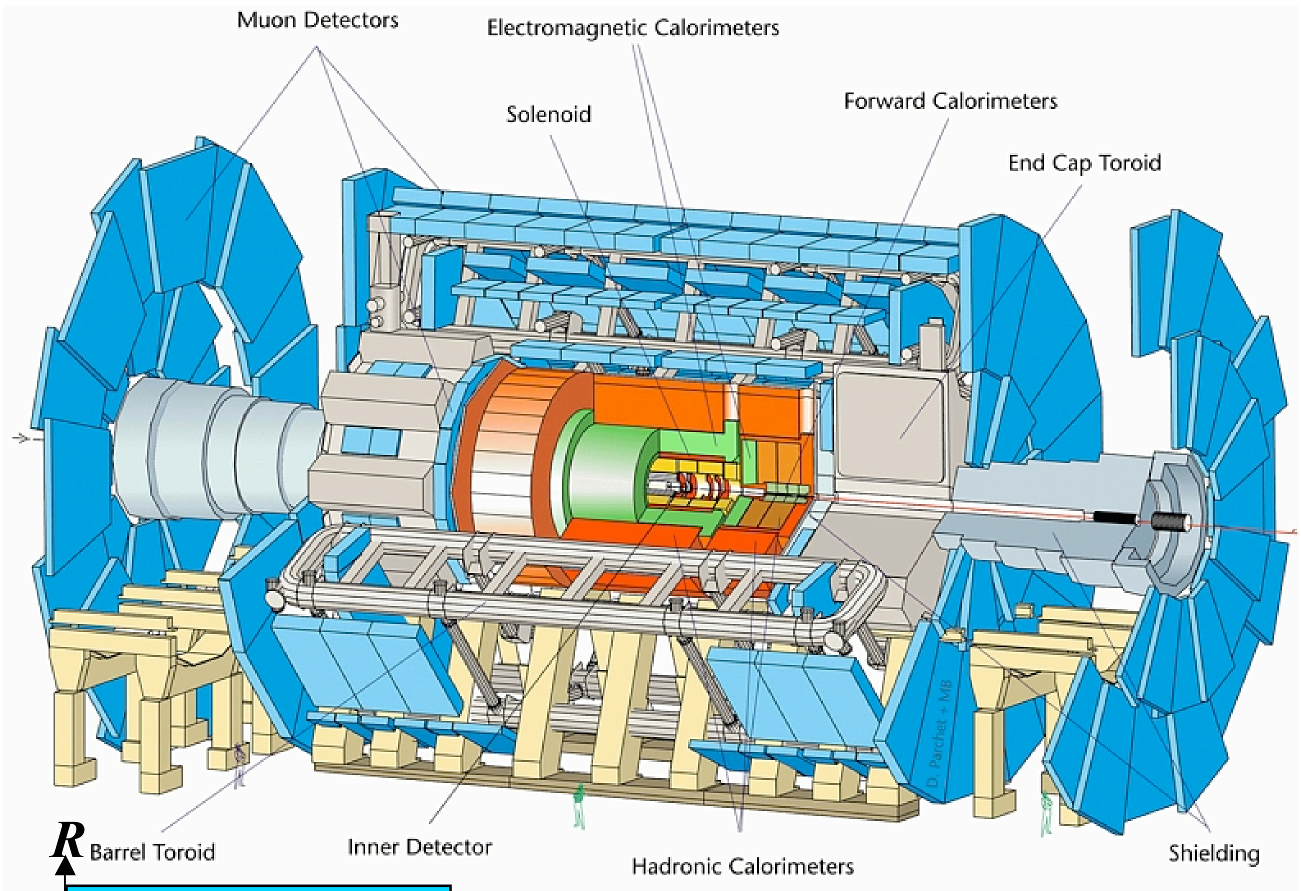
- ATLAS Coverage
- Forward Instrumentation
- ATLAS reach in jj and bbar





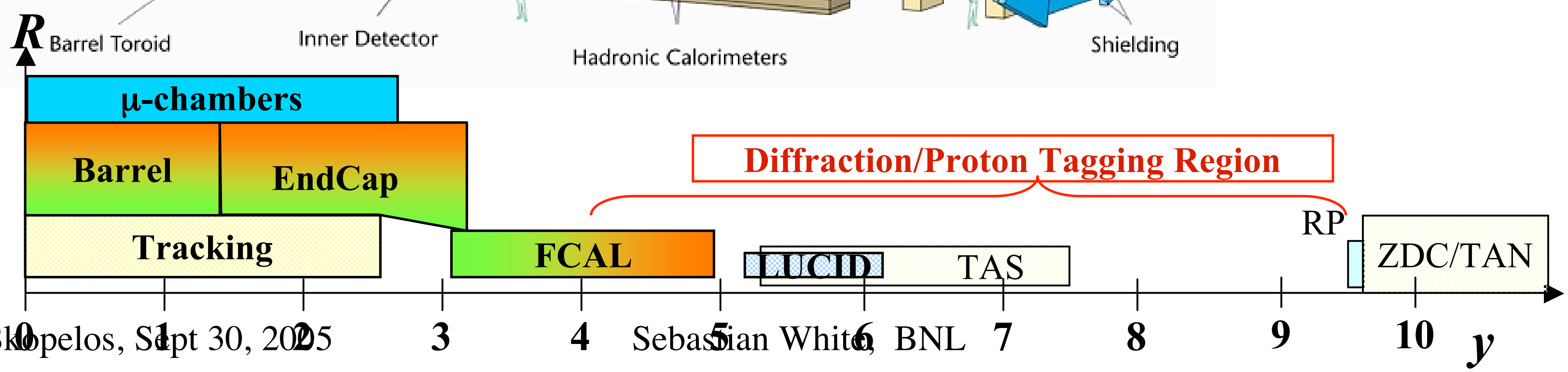
Pro-E model of ZDC for ATLAS and full simulation of Energy response

The ATLAS Detector



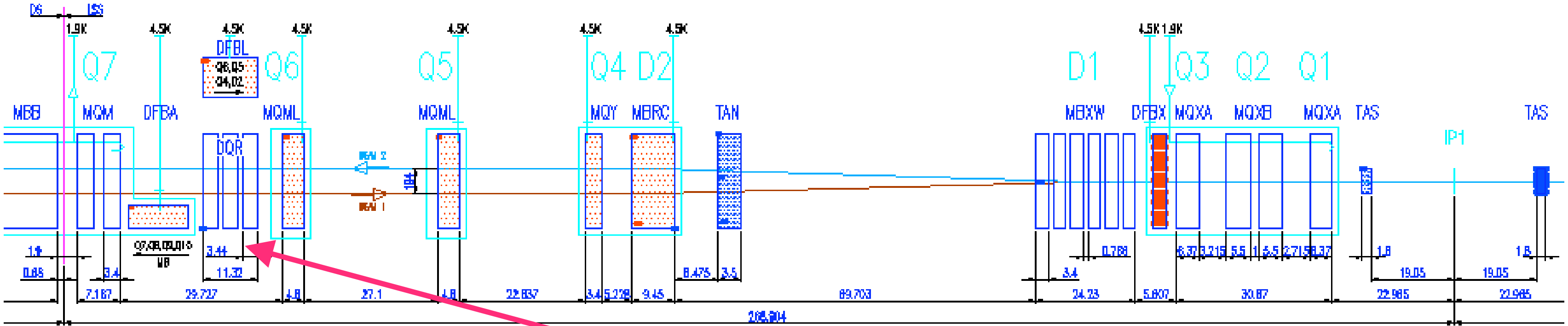
Detector:
fully hermetic to η=5
Highest segmentation
Superior jet en resolution
(50%/sqrt(E))
Excellent b-tagging

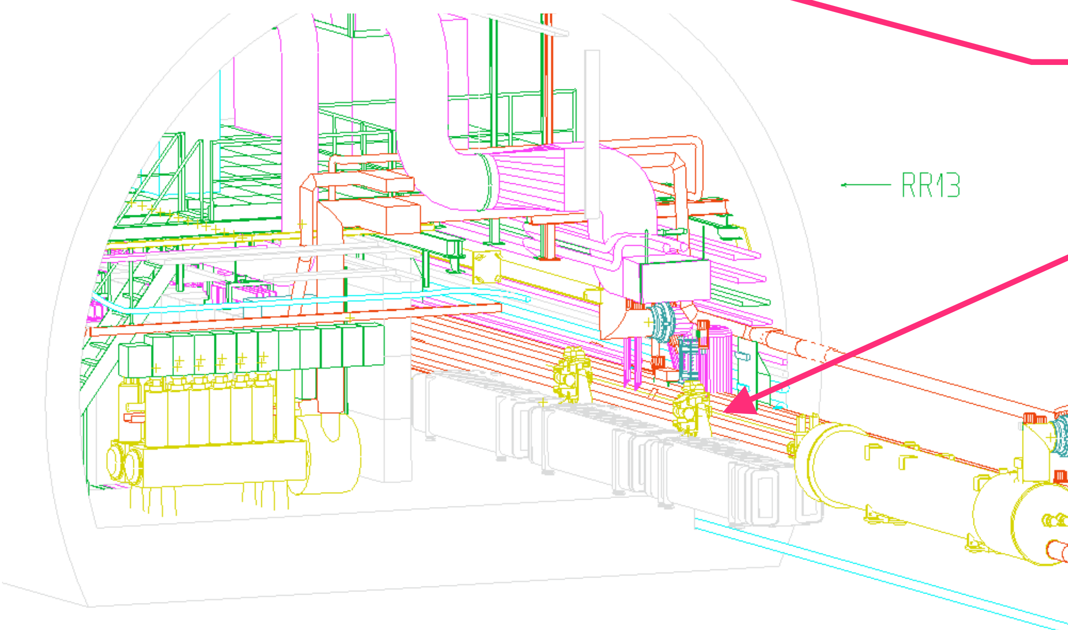
Collaboration:
Heavy Ion LOI in May ‘04
Encouraged to proceed to
physics TDR
Use existing detector + ZDC
Collaborative work on ZDC
with LHC commissioning



Roman Pot Locations

ATLAS





One **Roman Pot Station** per side on left and right from IP1

Each **RP station** consists of two **Roman Pot Units** separated by 3.4 m, centered at 240.0 m from IP1

ATLAS physics with UltraPeripheral Collisions

ATLAS is the highest resolution and granularity LHC calorimeter

UPC physics takes full advantage of strengths

-no pileup and negligible underlying event activity

FCAL allows rapidity gap at level of Et~2 GeV

ZDC neutron tag always present in inclusive

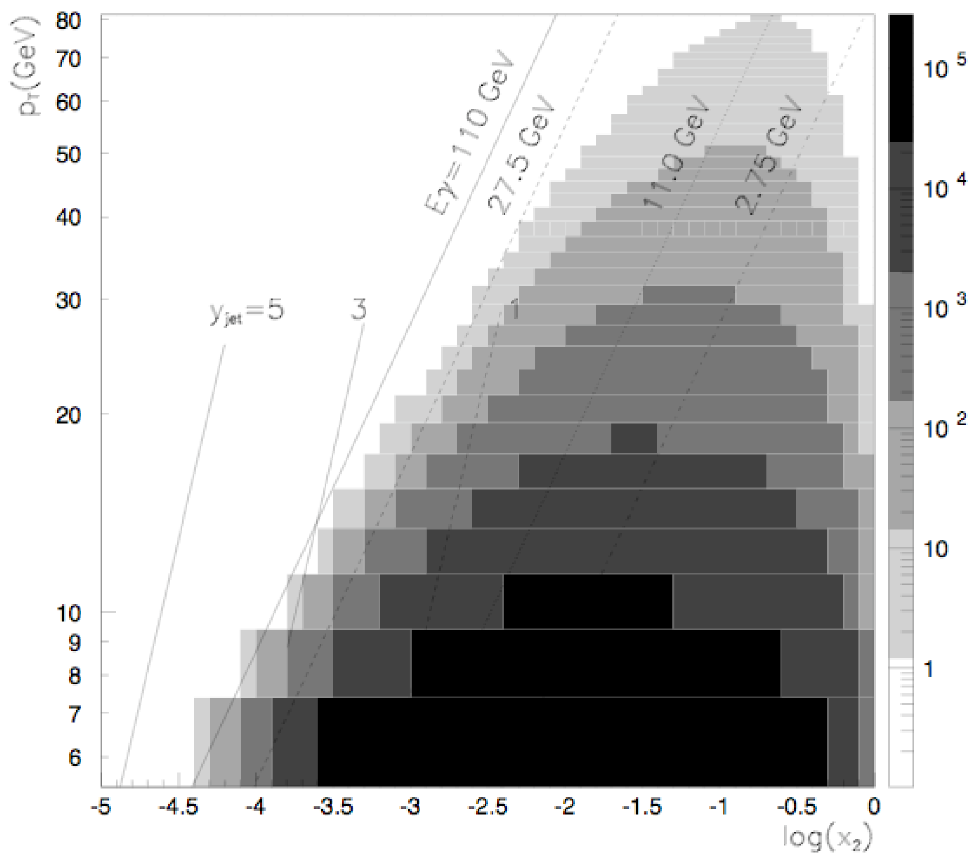
ie γ+Pb->jj+X

ZDC tag at ~20% level in diffractive

ie γ+Pb->jj+ Pb

ATLAS dijet photoproduction

Min. pt issue for detailed simulation



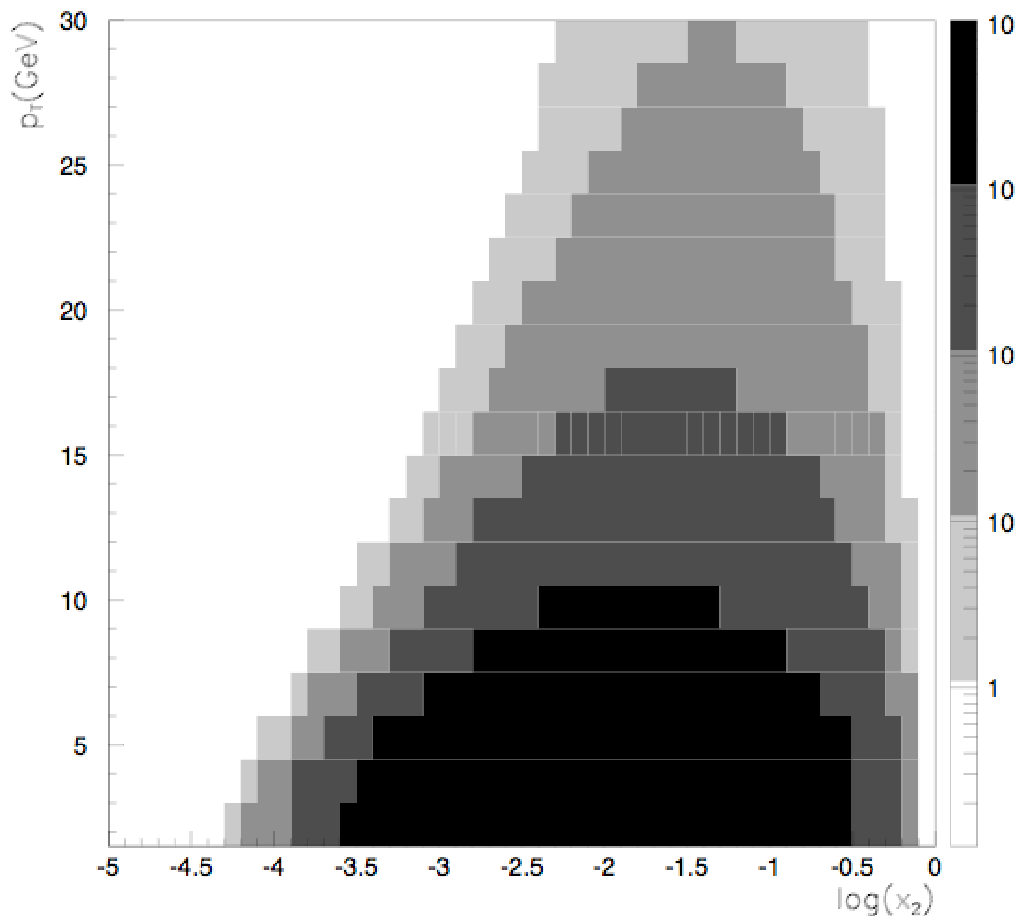
Also diffractive rates from

- Frankfurt, Guzey and Strikman Phys.lett. B 586, pp41-52(2004) "leading twist nuclear Diffractive parton distribution functions (nDPDF's)"

ATLAS b-quark jet production

Event yields from a 1 month HI (Pb-Pb) run at nominal Luminosity (4 10^{26} $cm^{-2}s^{-1}$). Counts per bin of δpt=1.5 GeV δx2/x2=+/- 0.25

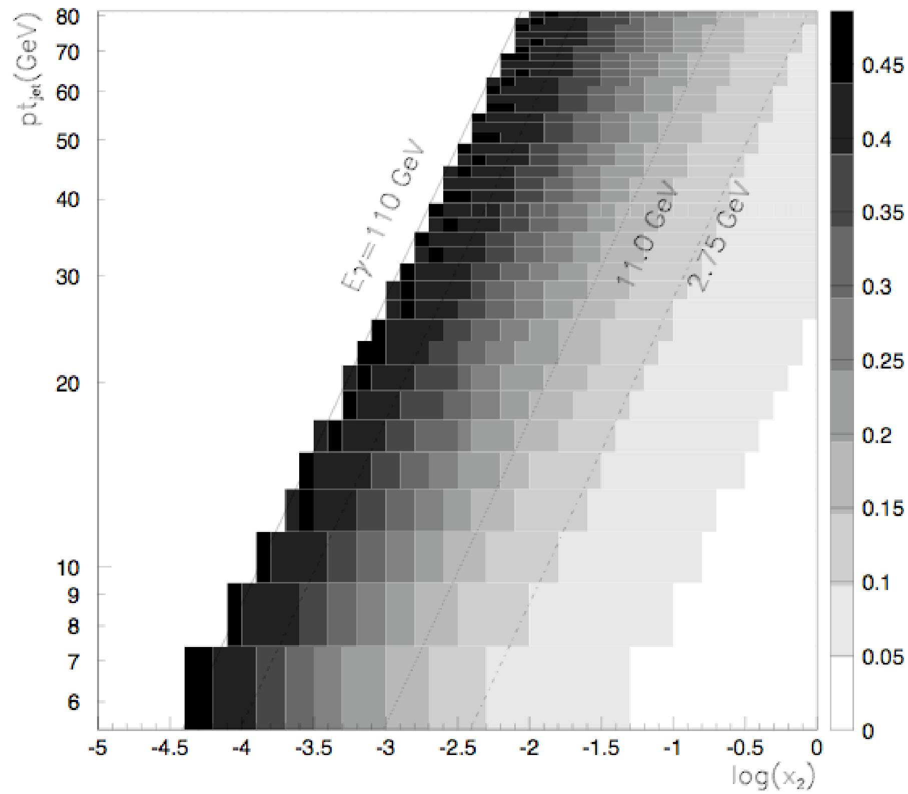
b-jet from soft lepton tag or detached vertex



ATLAS ZDC tag fraction

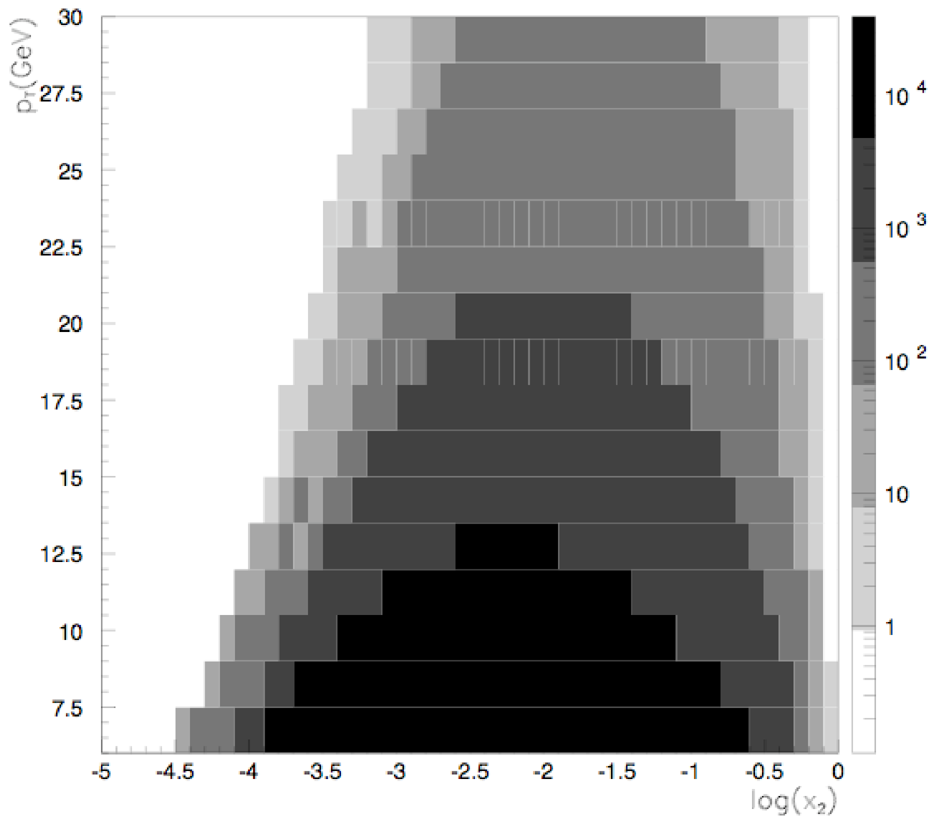
Fraction of diffractive events with additional γ exchanges leading to 2 arm ZDC tag

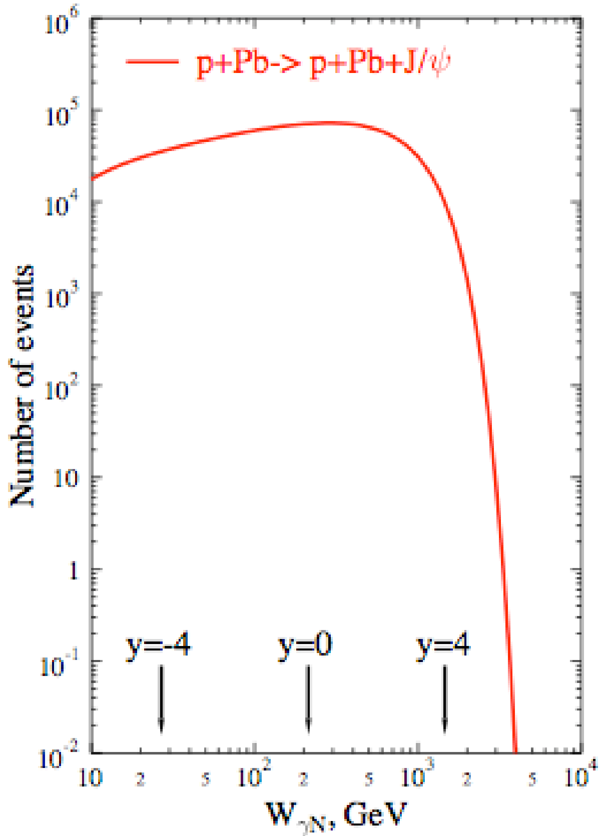
Note that directly correlated With E γ which is strongly Correlated with impact param.

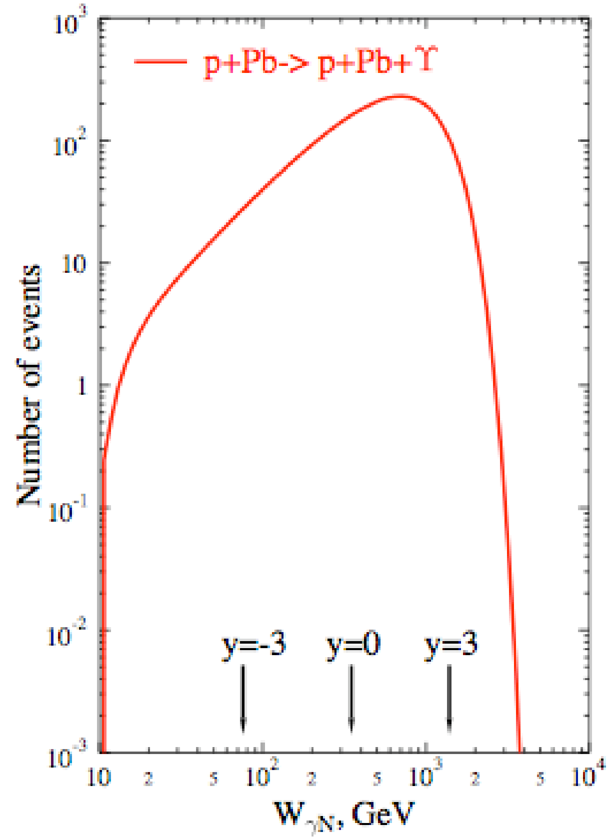


ATLAS jj photoproduction (p+Pb)

Event yields from a 1 month p+Pb run at nominal Luminosity (7 10^{29} $cm^{-2}s^{-1}$). Counts per bin of δpt=1.5 GeV $\delta x2/x2$=+/- 0.25







Zhalov & MS 05

Number of γ+p →V+N events per unit rapidity for a standard proton-lead run - branching of decay to muons is included. Comparable number of coherent γ+A →V+A is not shown.

Sufficient to check pQCD prediction of $\sigma \sim W^{1.6}$ for Upsilon production determination of the t-slope provided protons could be detected (420 m proposal)

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