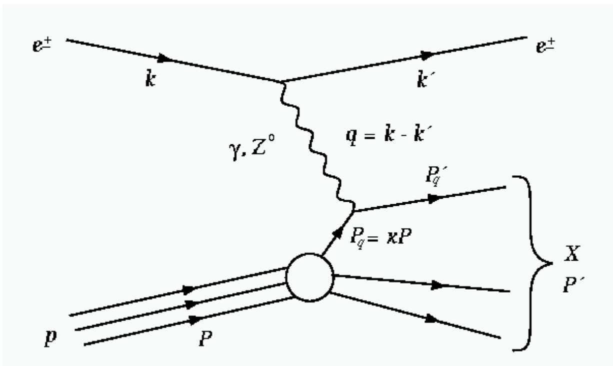
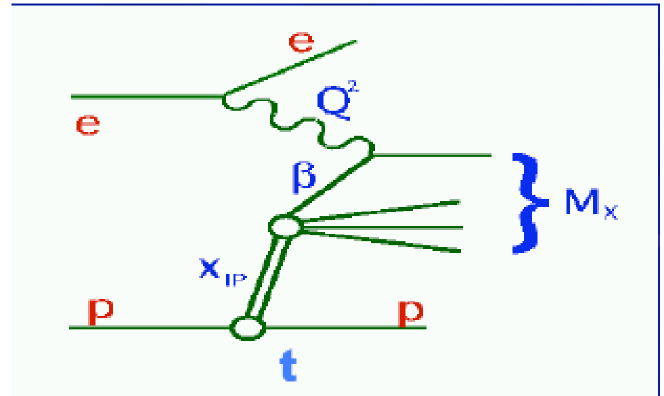
Inelastic Diffraction at LHC & RHIC



"HERA @LHC"



Rates and Kinematics for Diffractive Photoproduction in ATLAS

With M.Strikman and R. Vogt

Diffractive Physics in PHENIX

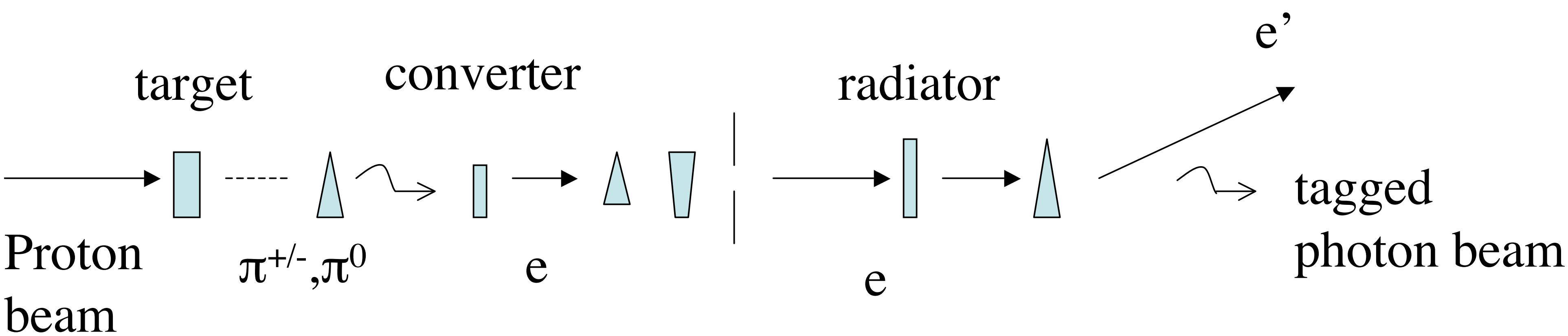
(UPC group= M.Chiu, D.d'Enterria, A.Denisov, J. Nystrand, D.Sylvermyr,&SNW)

Sebastian White
Brookhaven National Lab, USA

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

Tagged Photon beam (fixed target)



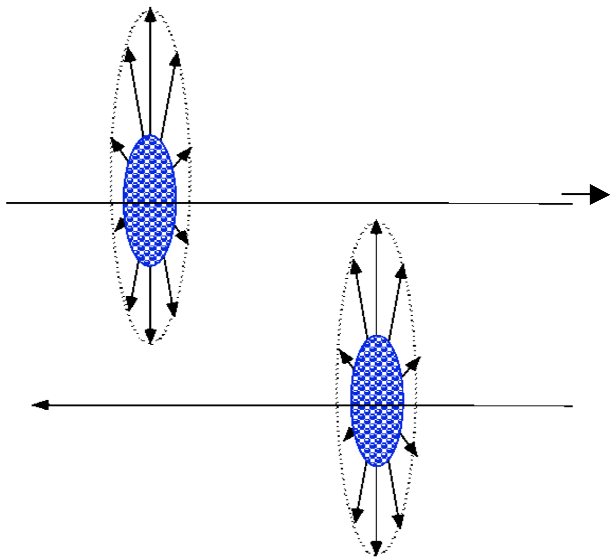
<u>At FNAL ('80's and '90's)</u>

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

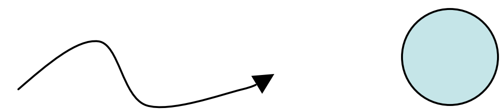
Diffractive γp->Xp E612 (CGSSW)

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 $\gamma_{eff}=2^*\gamma_{beam}^{2}-1$

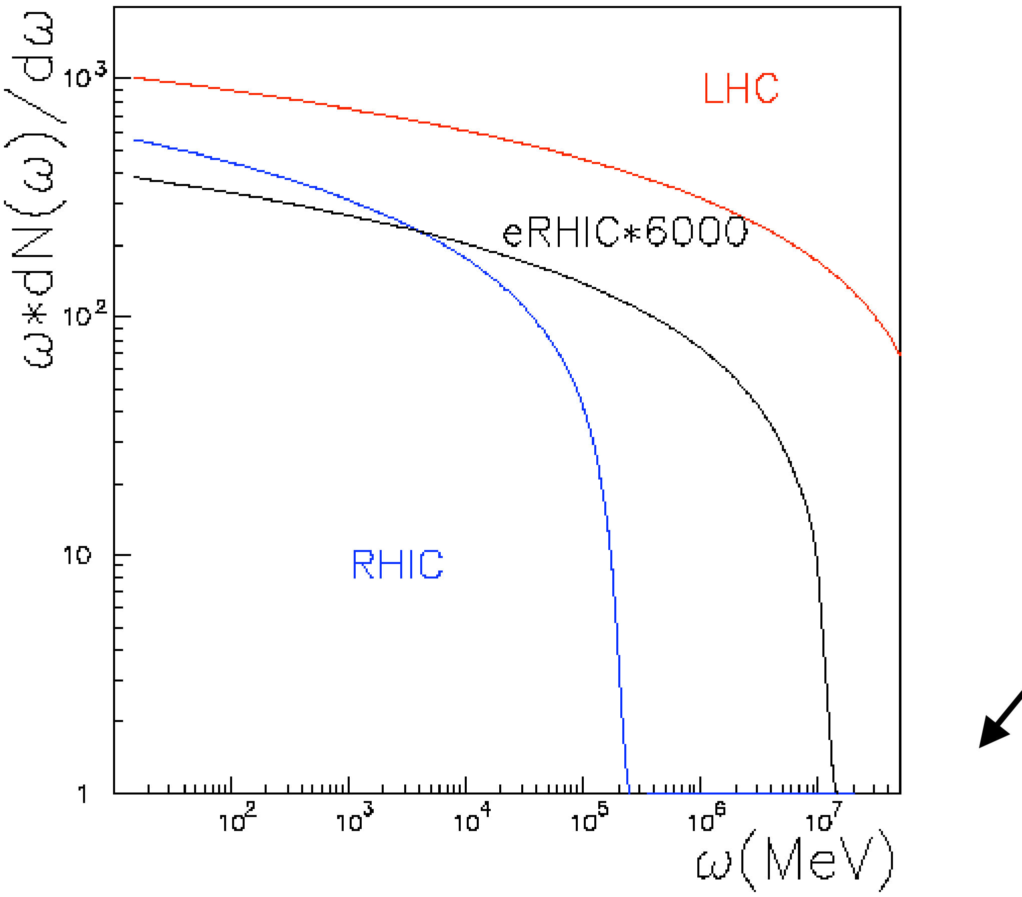
Heavy Ions

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

e-Hadron collider

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

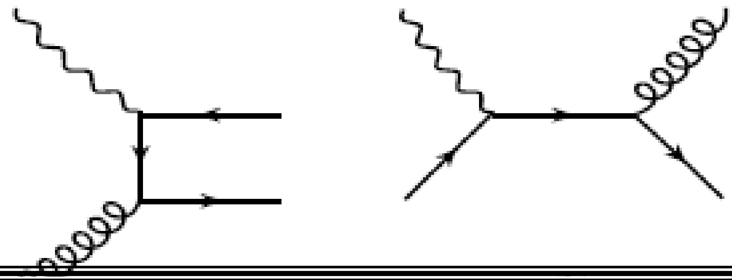
Equivalent Photon spectrum in target nucleus frame



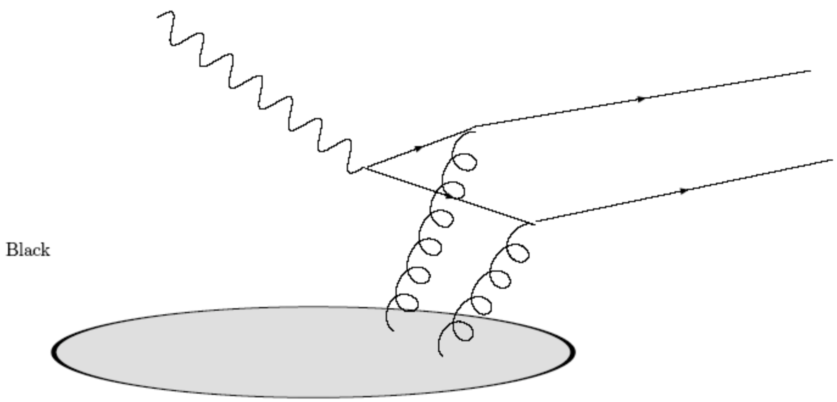
"Quasi-real" γ spectra compared to an e-hadron collider

->100 TeV @ LHC

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



Probing nuclear parton distribution w.Quasi-real photons

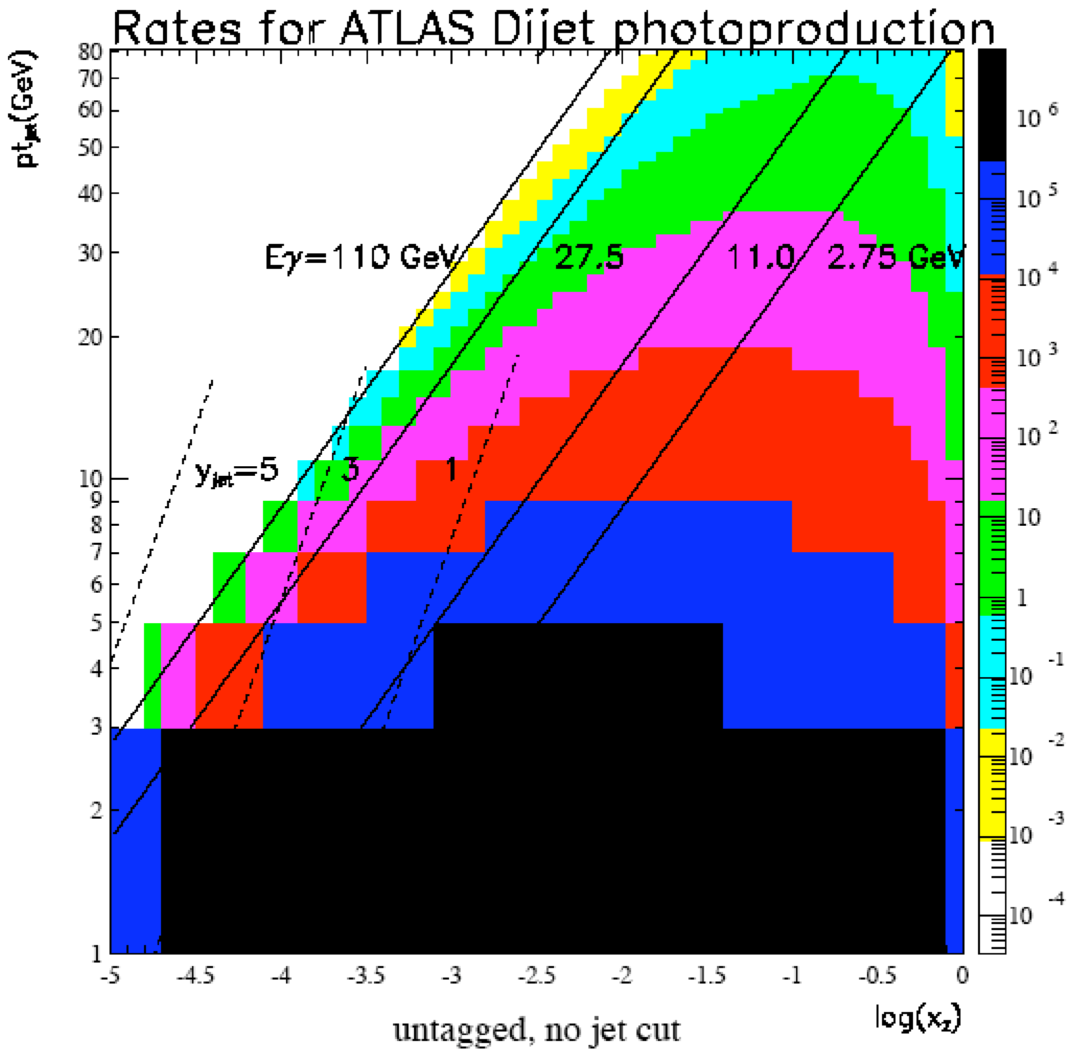


Diffractive J/Psi production
(like 2-gluon exchange)
t-distribution measures size of gluon source
eg-Kowalski and Teaney hep/ph/0304189

Rates and Kinematics(more later)

Event yields:
1 month HI (Pb-Pb) run
nominal Luminosity

Counts per bin:
δpt=1 GeV
$\delta x2/x2=+/- 0.25$



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.

“Forward Physics”

pp->n+X

p_t distributions of forward n in d-Au->n+X,

etc.

Forward Physics at RHIC

- **RHIC, like the LHC, is a dual function collider (HI and pp)**
- **At RHIC the large general purpose detectors designed with goals of Heavy Ion physics in mind (centrality,reaction plane, etc.).**
- **Also applied to physics with Deuteron and P beams.**

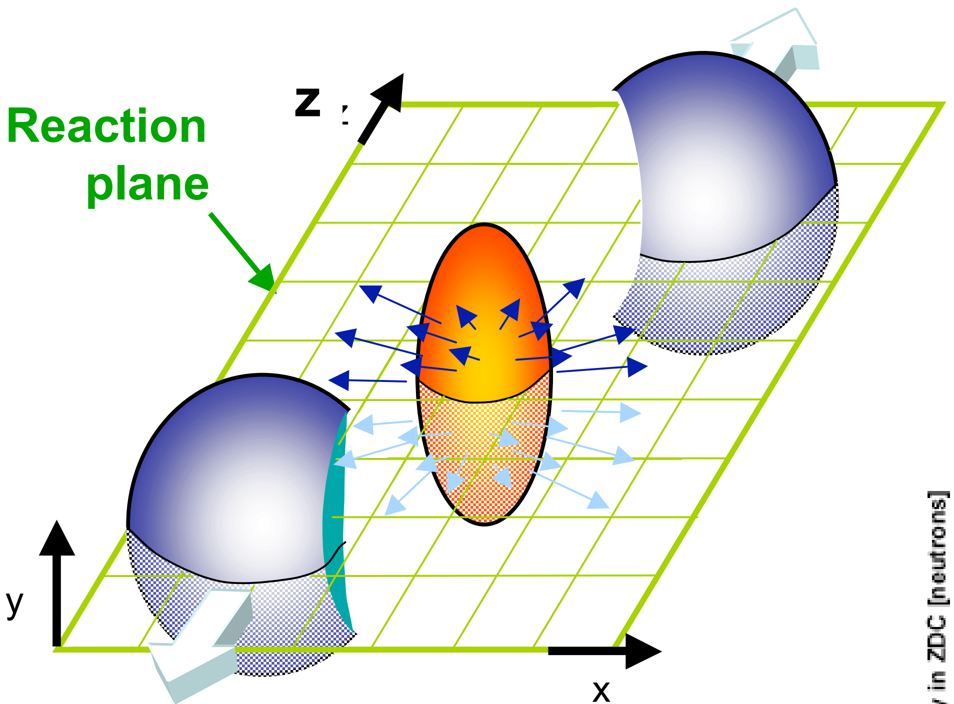
New data on inelastic diffraction with Au, d and proton beams.

- **Large mass diffractive e^+e^- pair production**
- **D photodissociation and Glauber model studies**
- **pp-> n +X**

many lessons for the LHC program

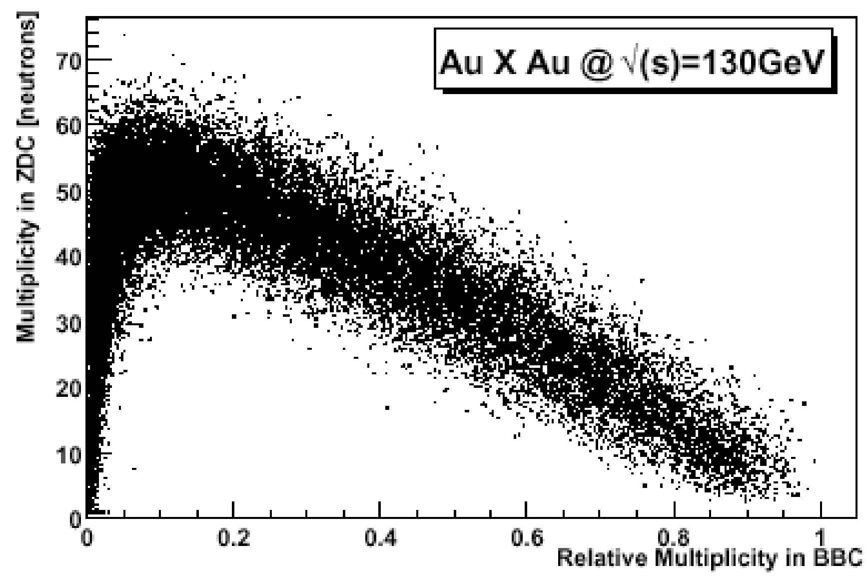
Forward Instrumentation driven by Heavy ion Goals

>>Direction and magnitude of impact parameter, b



Magnitude from complementary parameters

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

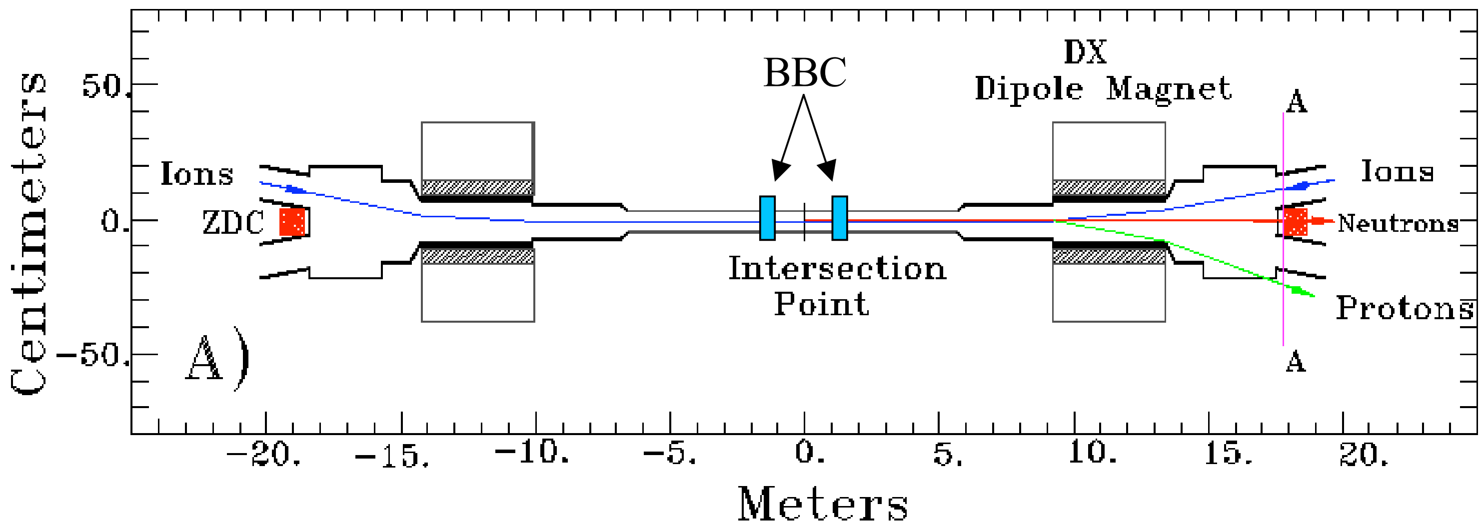


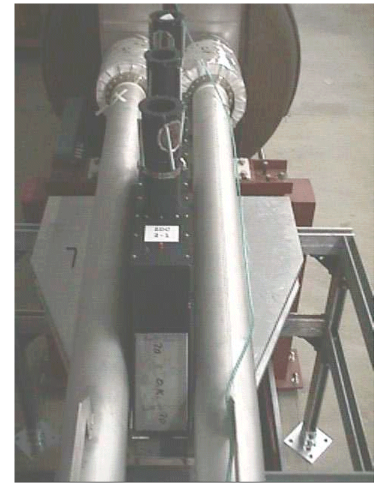
Spectator neutrons
•measure centrality,
•Min_min_bias trigger

(Calorimeter@θ<2mr.)

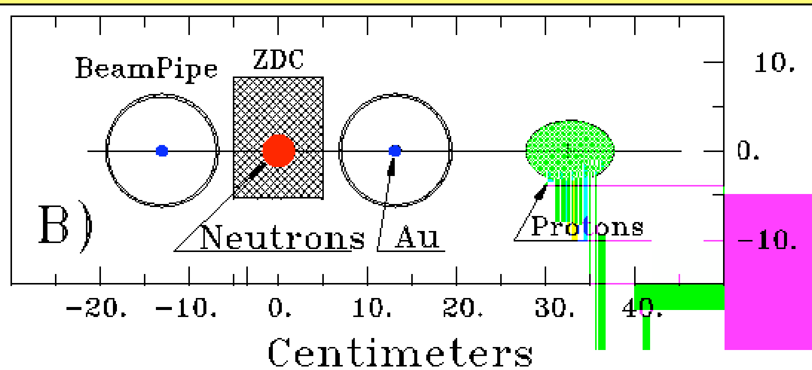
Beam-Beam Counter Mult/1000

Location, Location, Location

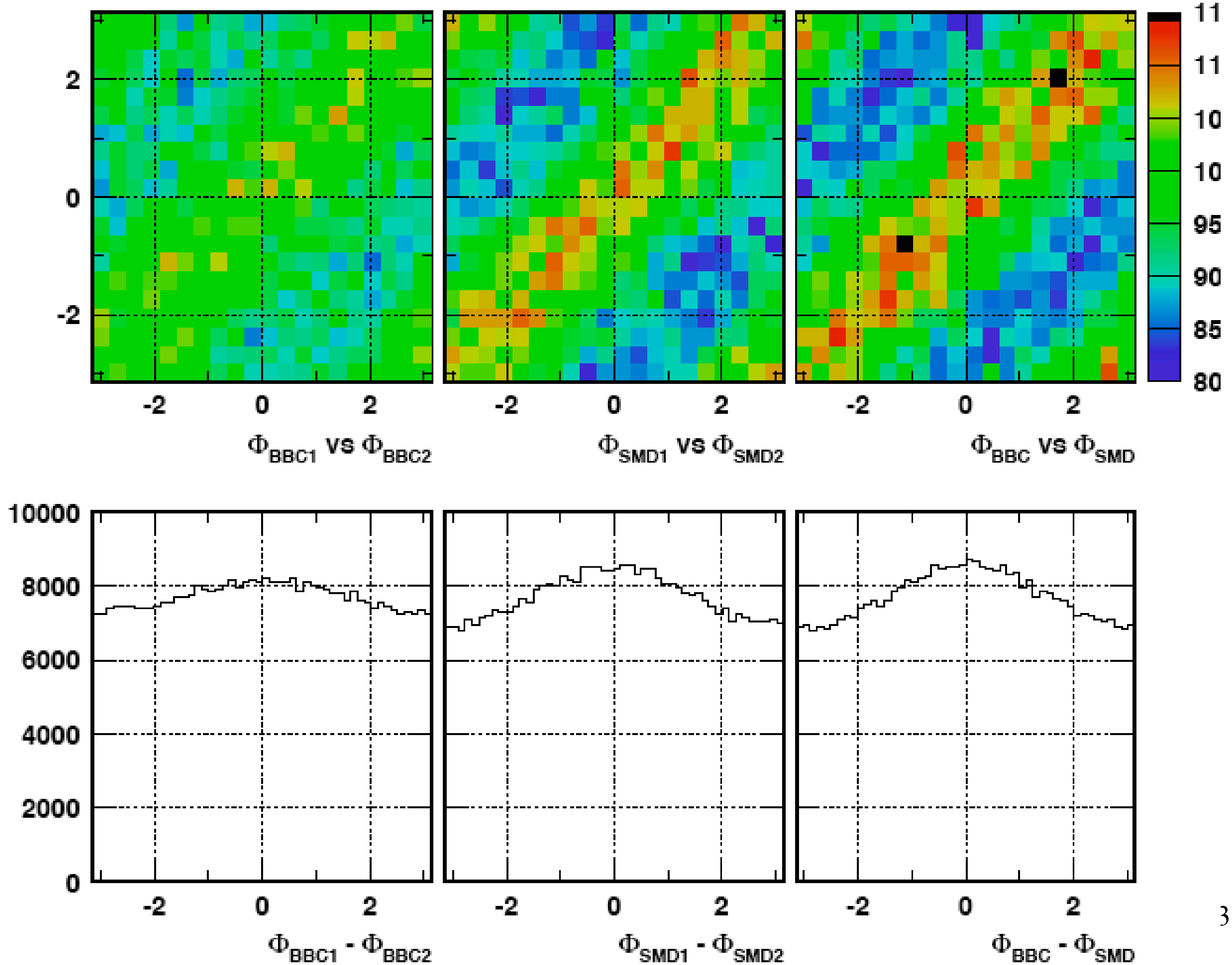




- All of the action is at forward rapidities
- In collider geometry access to all spectators limited to outside beamtube
- We sample participants through 128 chann hodoscope at $3<\eta<4$
  - Spatial Distribution of n and Charged Particles shown below
- Large Separation = Easy Timing = Very Clean Trigger against Beam Gas and Beam Scrape



Directed flow, v_1, is largest at ZDC location



RHIC results on Au-Au UPC

–the photon flux factor

–large cross section 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

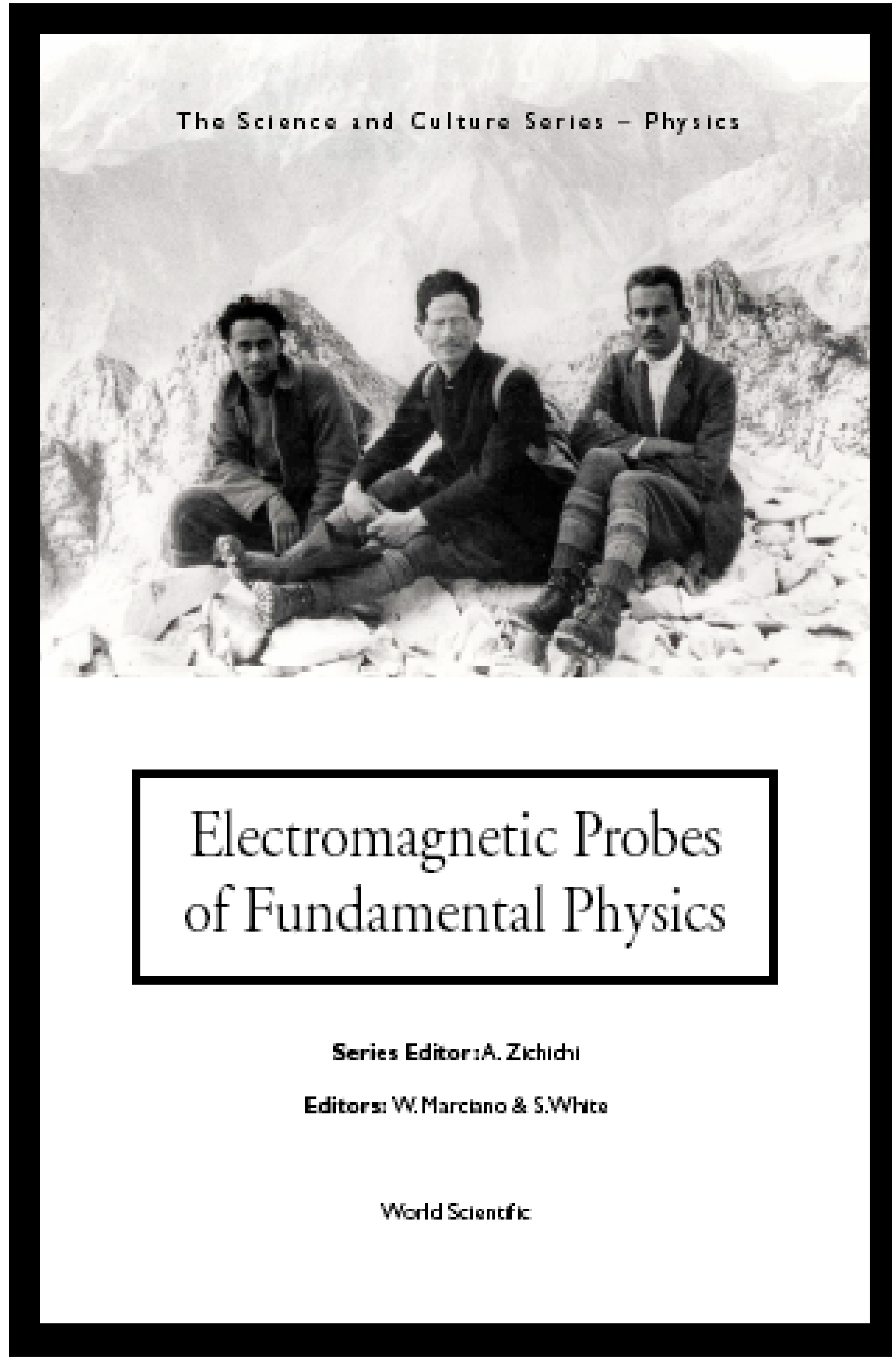


TABLE I. Cross sections calculated and derived from the data. The errors quoted on measurements include the uncertainty of the BBC cross section [8]

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	$0.345 \pm 0.011 \pm 0.01$

Cross sections from Run I in PRL

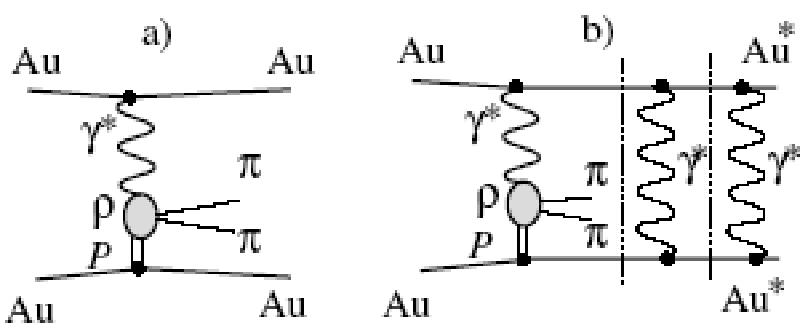
(1)Baltz & SNW
(2)Bondorff et al.
Meas.=Chiu et al.

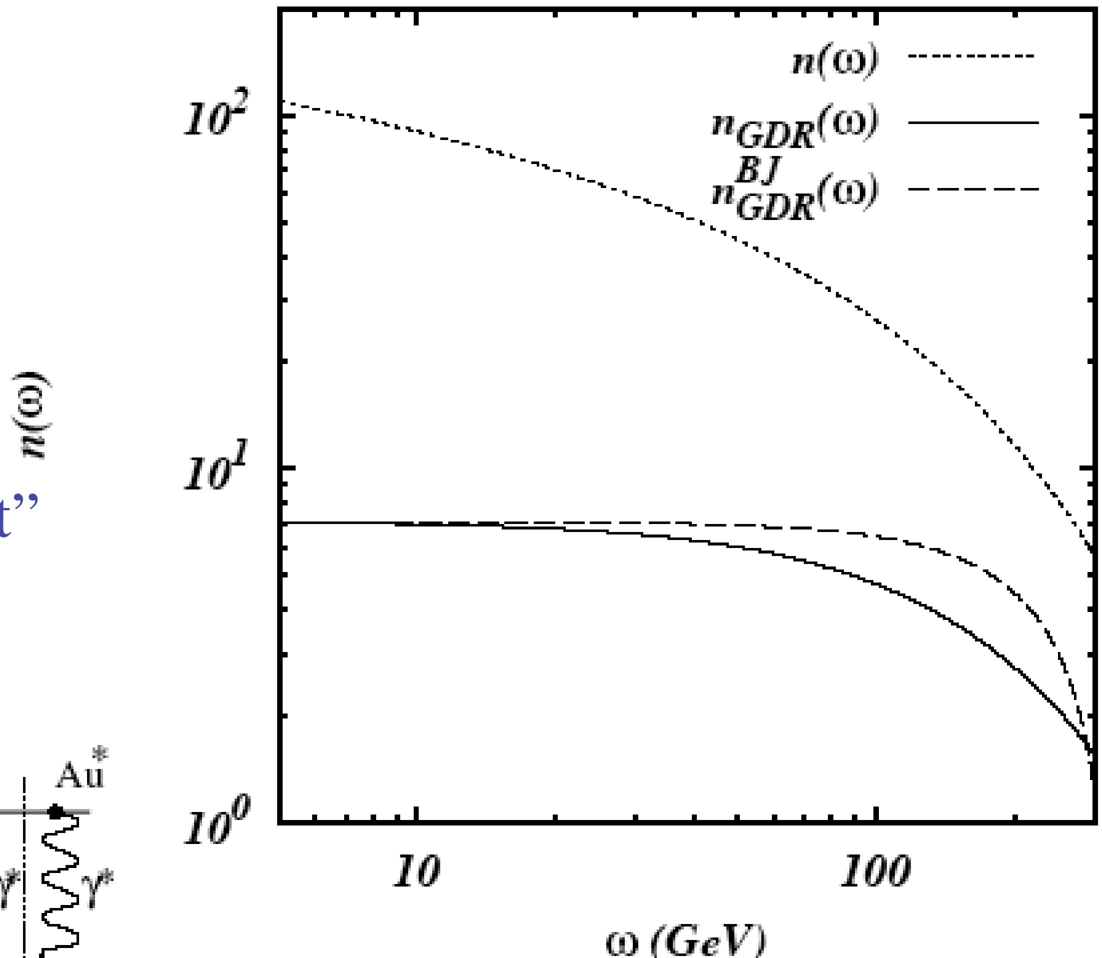
Tagged photon spectrum

Strength of interaction

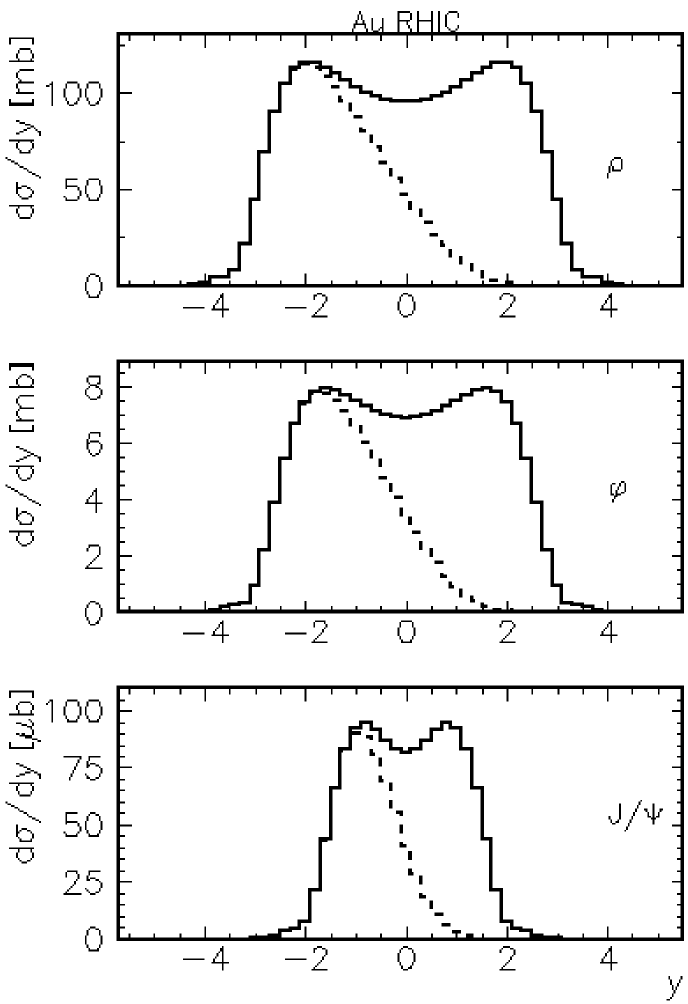
$$\eta = \frac{Z_1 Z_2 e^2}{\hbar v} \approx Z_1 Z_2 \alpha$$

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

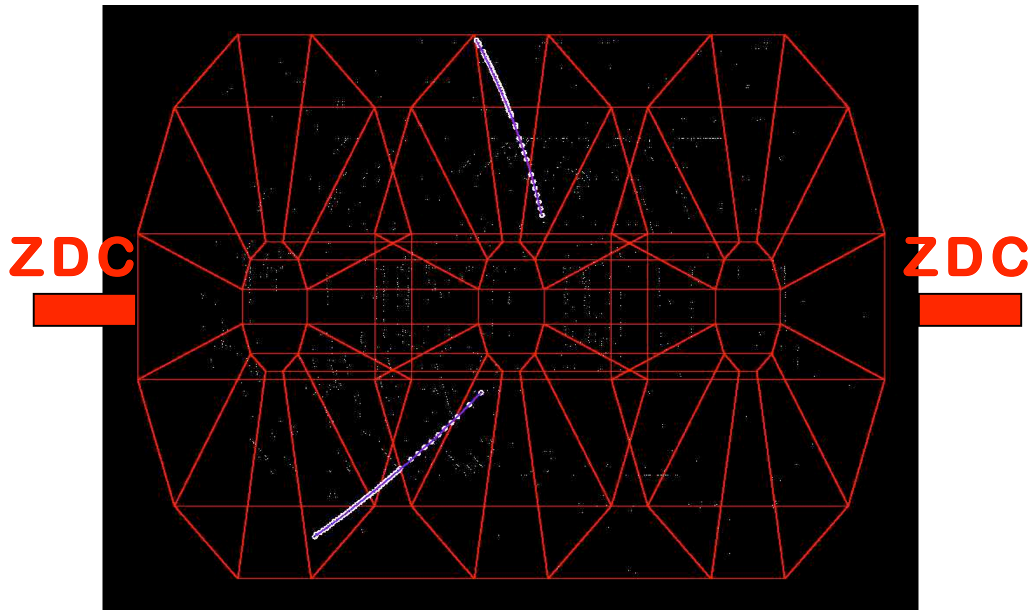




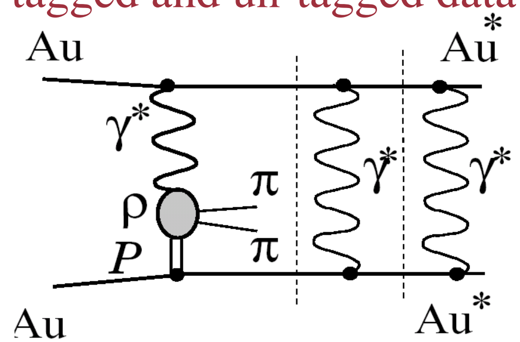
Calculated Distribuions[STARLight]
Au+Au 200 GeV at RHIC:



ρ event in STAR TPC



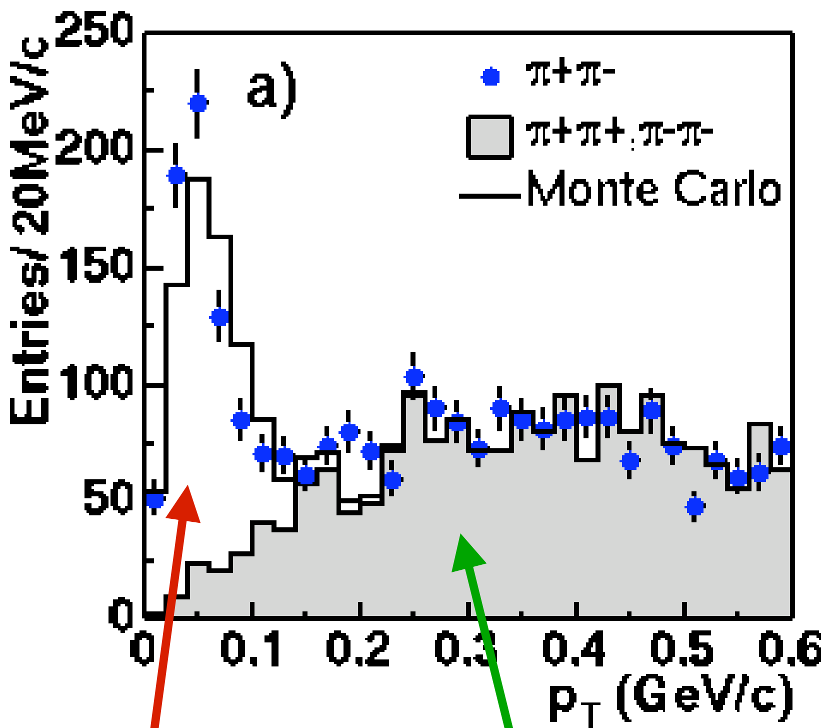
Both tagged and un-tagged data collected



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 Sample

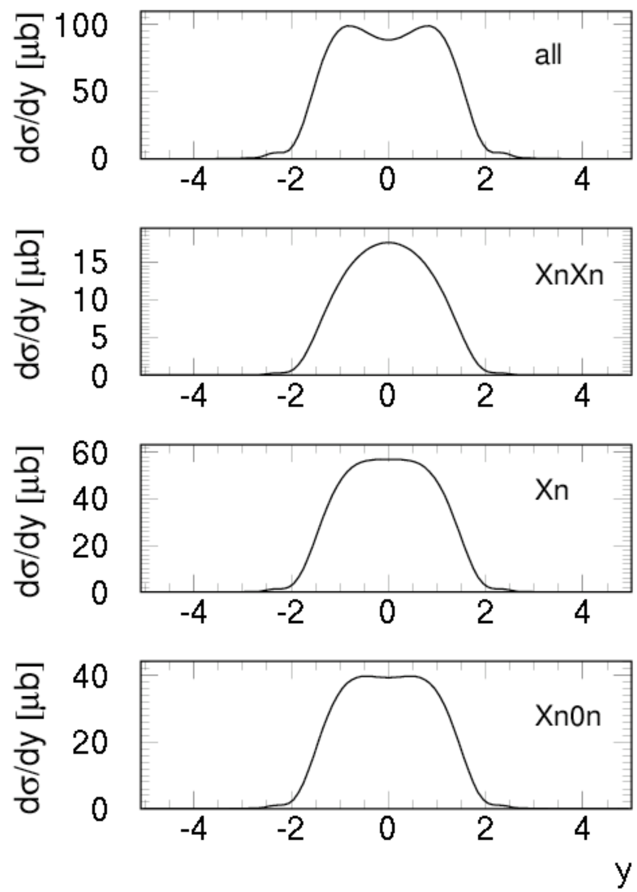
L1 Trigger: Statistics

UltraPeripheral = (ZDCN || ZDCS) && (!BBCLL1noVtx) && (ERT2x2) 1.8M evts.

>>UPC trigger cross section ~0.4% of inelastic cross section

Collected Ldt~ 137 μb^{-1} .

Calculated distributions for J/ψ Photoproduction s_{NN}=200 GeV AuAu



Total "tagged" cross section=159μb

Expected yield=Lσε*Br~30 events

Also continuum γγ->e^+e^- @~3*$N_{J/\psi}$

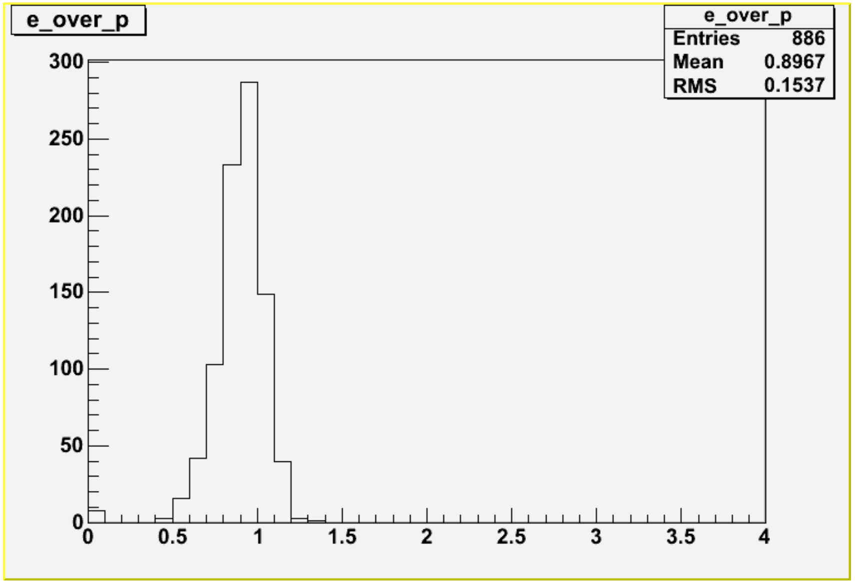
Electron Id.
(RICH+E/p)

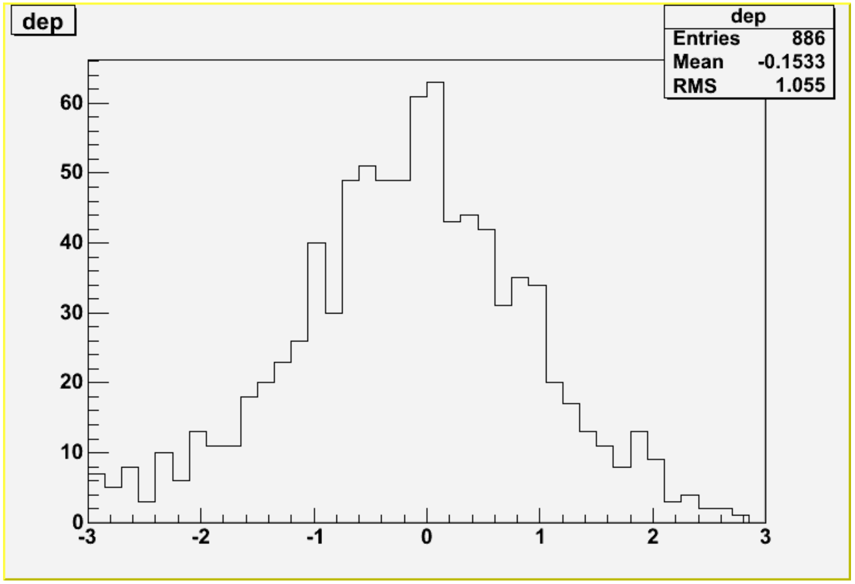
Disclaimer: Most Ultraperipheral events, don't have a reconstructed event vertex from BBC or ZDC. Expect significant reconstruction inefficiency at this early stage of analysis.

For such events, we try to reconstruct a vertex position from central tracks, using tracking and calorimetry.

RICH-track matching required.

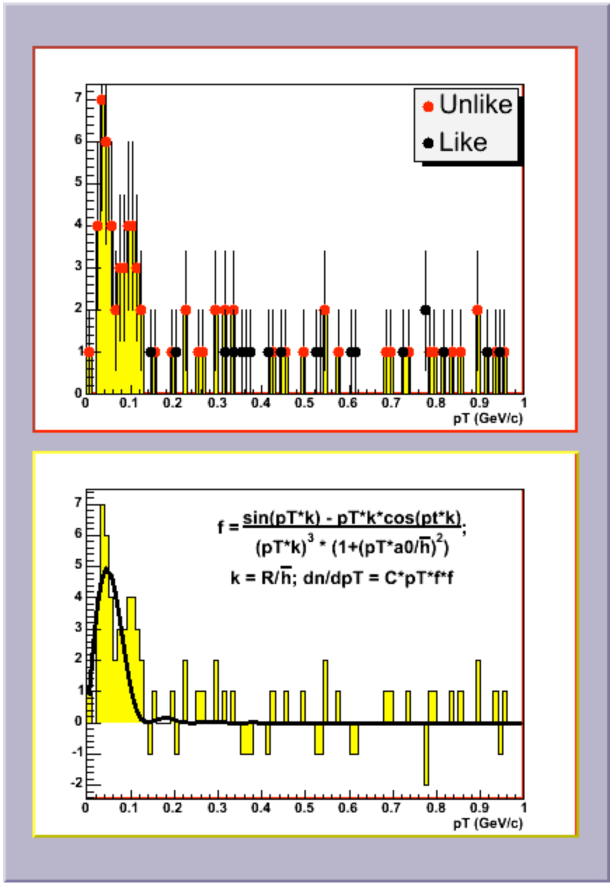
Calorimeter Cut variable
dep = (E-p)/sigma,
 where sigma is mom-dependent.

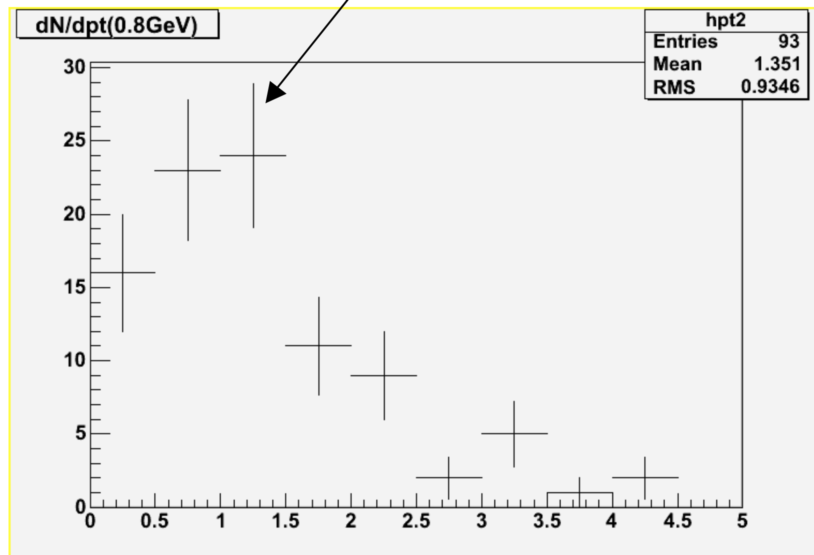




"Results" I - p_T

Peaks much later than coherent events..

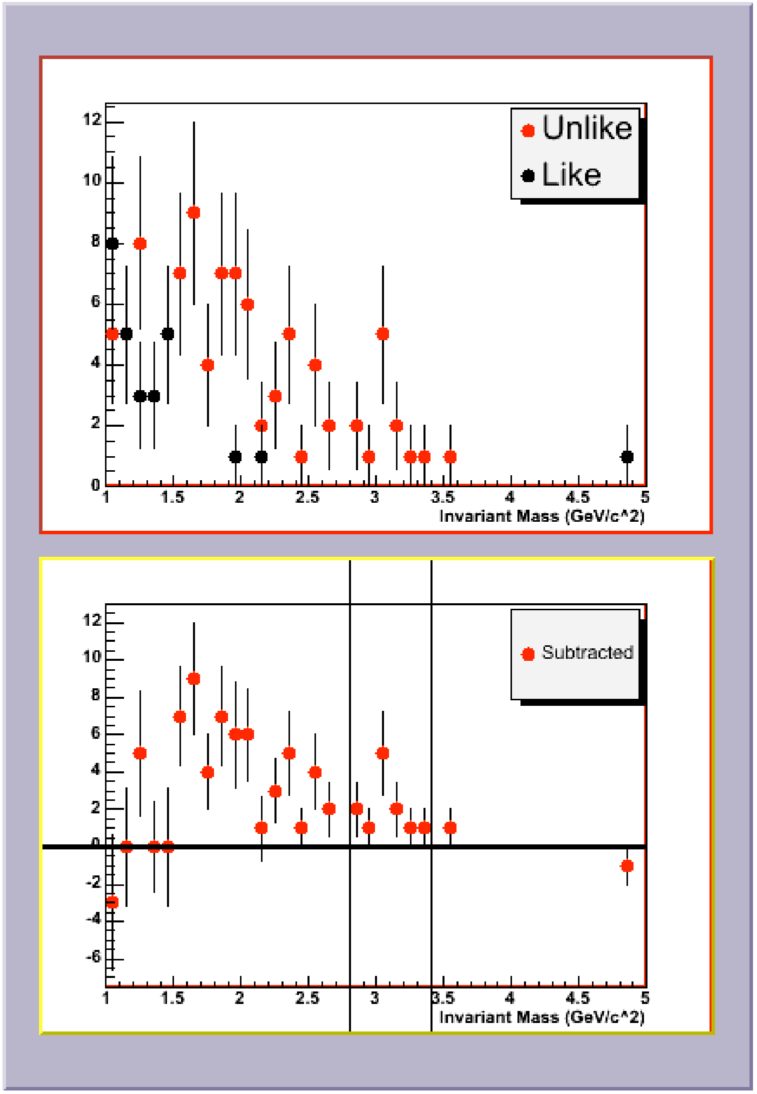




Left: Strict electron cuts applied(Calorimeter and RICH).
RightJ/Psi pt distribution in pp data.

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.

"Results" II - M_{inv}



Strict electron cuts applied..

Note that with Eth=0.8 GeV, coherent di-electron acceptance starts at ~1.6 GeV.

Hint of J/Ψ-signal (~5 counts) seen

+ coherent $\gamma+\gamma \rightarrow e^+e^-$ continuum

Critical test of Glauber Calculation

How to measure σ^{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= >=1 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:

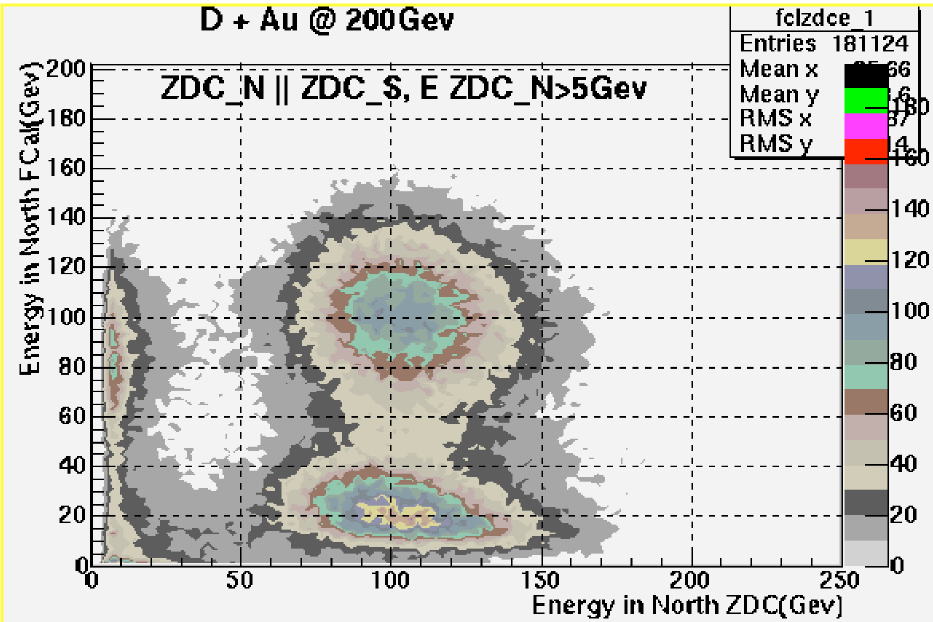
$\sigma^{in}_{(1)}$=(1.38b)*(0.88)/(0.508)

=2.39+/-0.12+/-0.24 barn

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

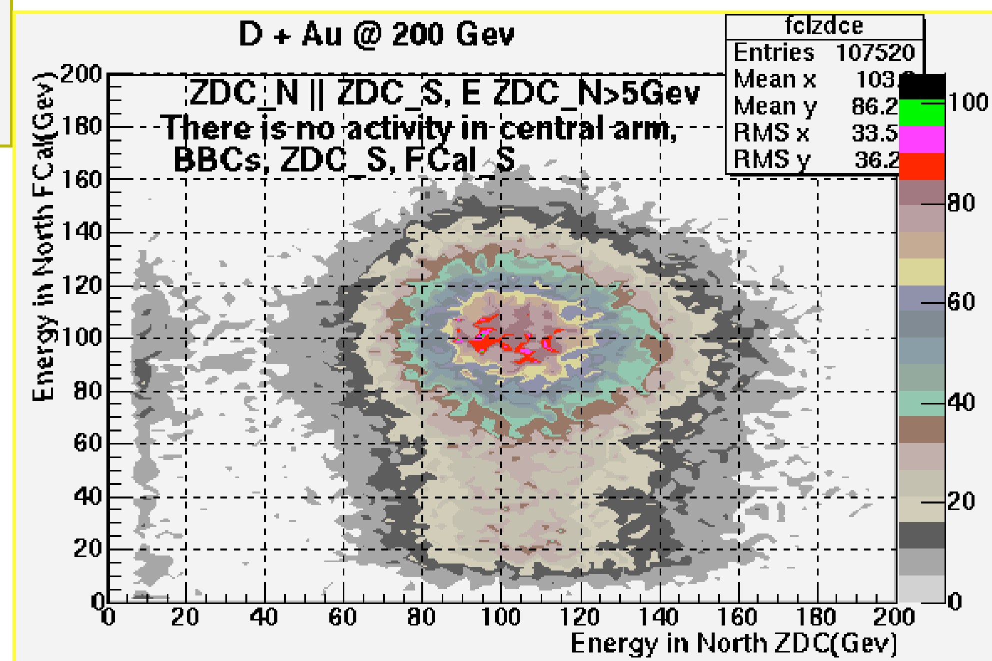
Cp. 0.83*2.33b of B.K.

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



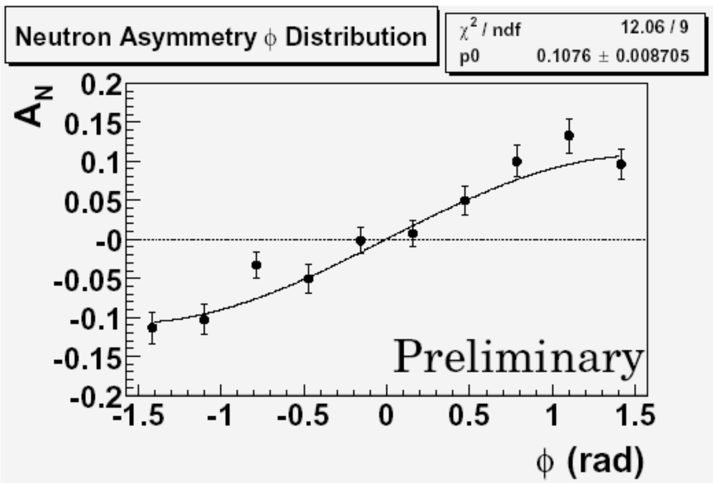
<----Inclusive data set

Cut on central activity-->
&Au fragmentation



PHENIX pp ->n+X

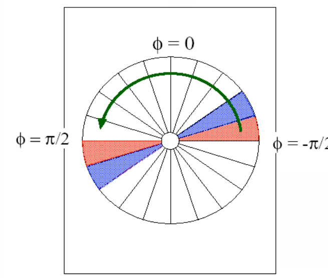
Currently under study because of its critical role in collider operation ie local polarimetry in PHENIX:



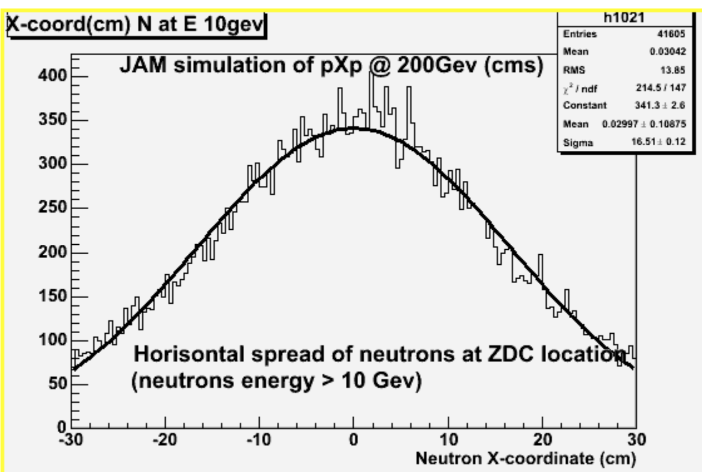
$$A_N = \frac{1}{P_B} \frac{\sqrt{N_{\uparrow L} N_{\downarrow R}} - \sqrt{N_{\uparrow R} N_{\downarrow L}}}{\sqrt{N_{\uparrow L} N_{\downarrow R}} + \sqrt{N_{\uparrow R} N_{\downarrow L}}}$$

calculated using square root formula

- "Left-Right" asymmetry
- measured for different slices in phi:

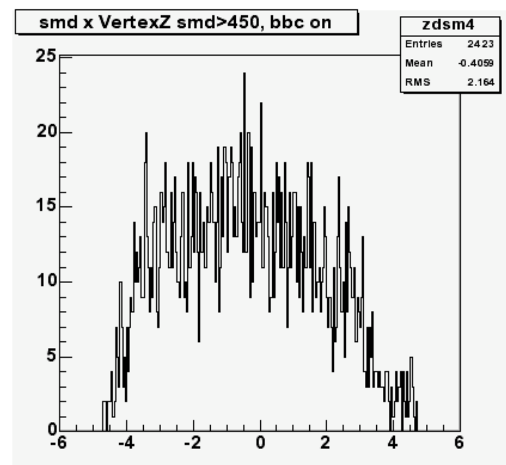


And LHC beam location through TAN Ion chambers:



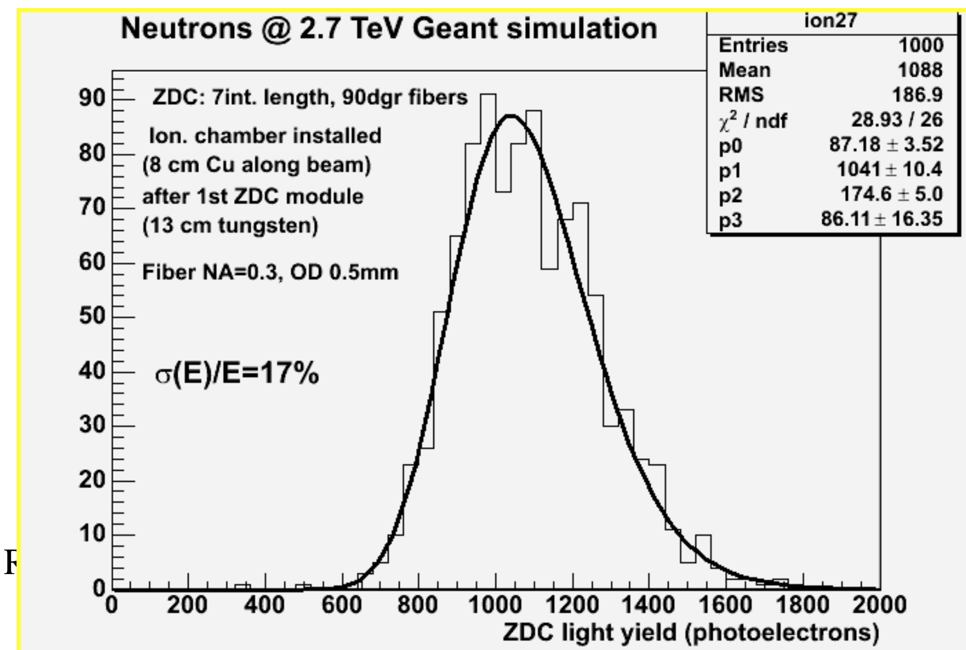
Test available event generators w. RHIC data

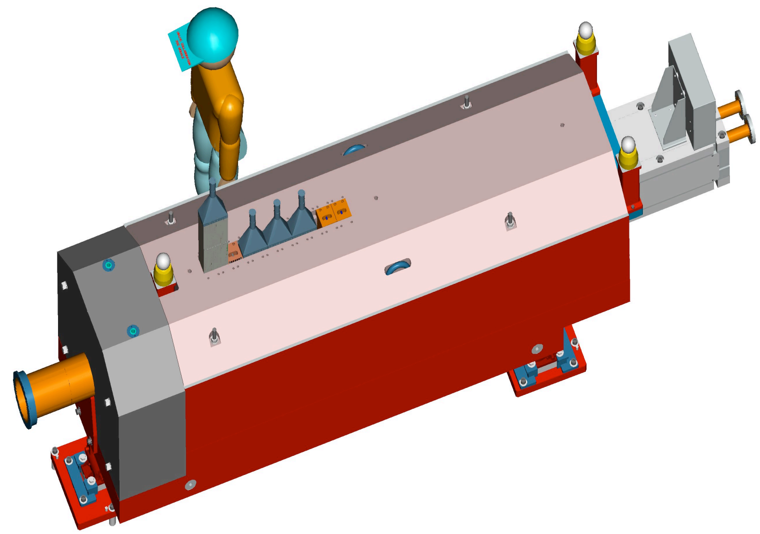
astian White



Towards the LHC

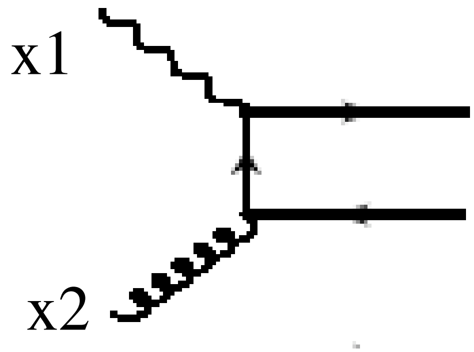
- •ATLAS Coverage
- •Forward Instrumentation
- •ATLAS reach in jj and γj





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.



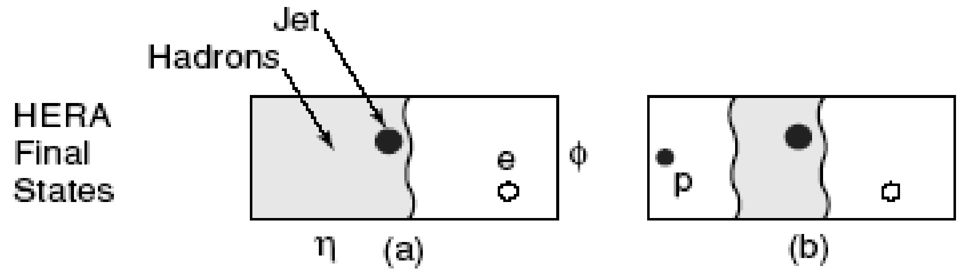
di-jet photoproduction-> parton distributions,x2 by γ with momentum fraction, x1

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

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

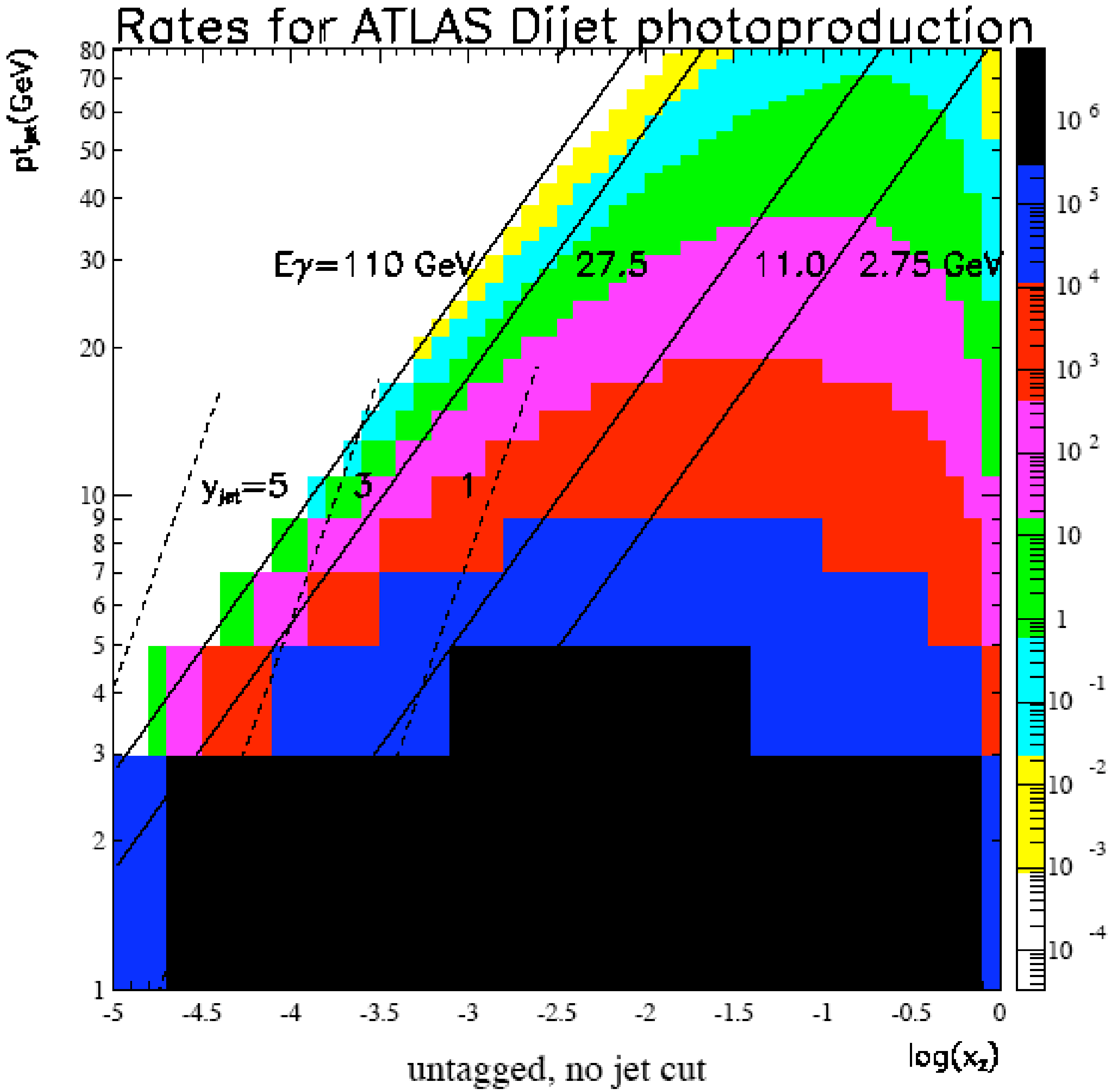
Signature: rapidity gap in γ direction(FCAL veto)

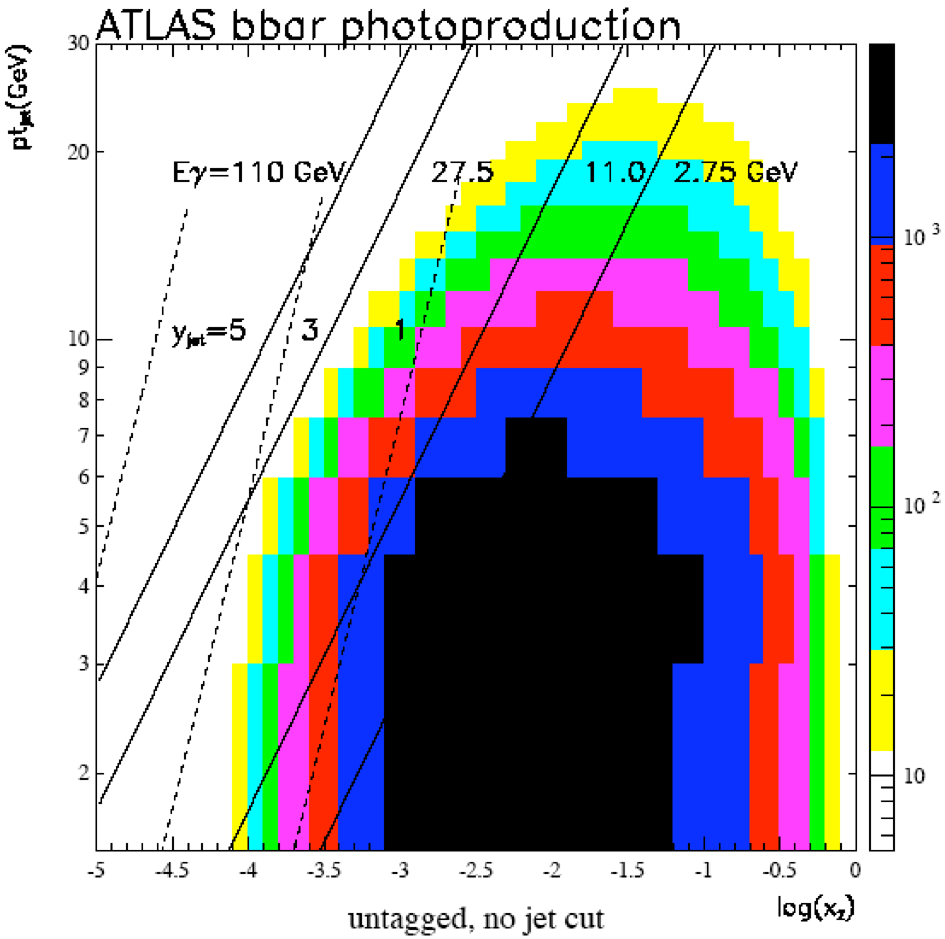
ATLAS coverage to |η|<5 units. P_t ~2 Gev "rapidity gap" threshold



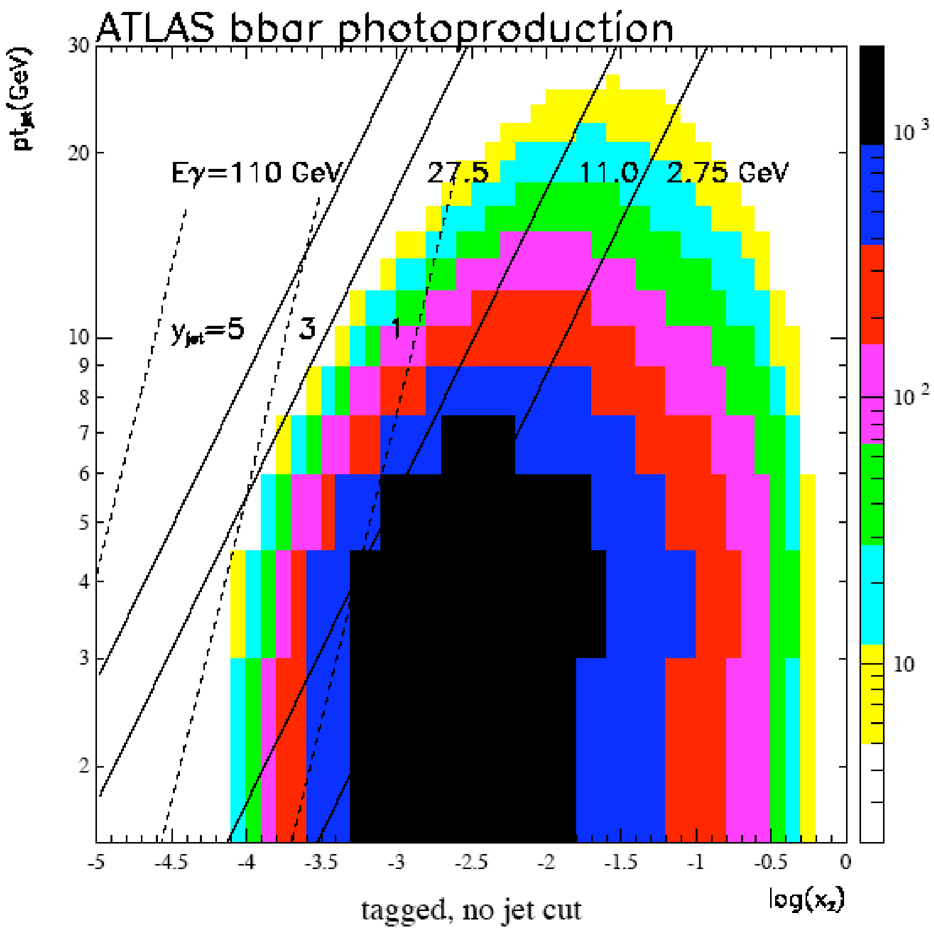
Analogous upc interactions and gap structure

diffractive Non-diffractive


Rates for ATLAS Dijet photoproduction
pt_jet(GeV)
Eγ=110 GeV
27.5
11.0
2.75 GeV
y_jet=5
3
1
log(x_z)
untagged, no jet cut



untagged, no jet cut

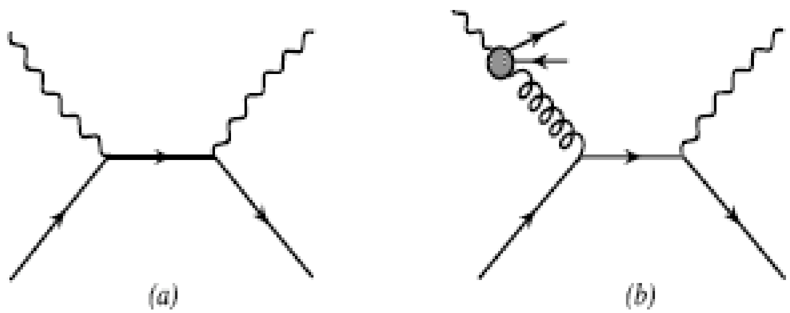


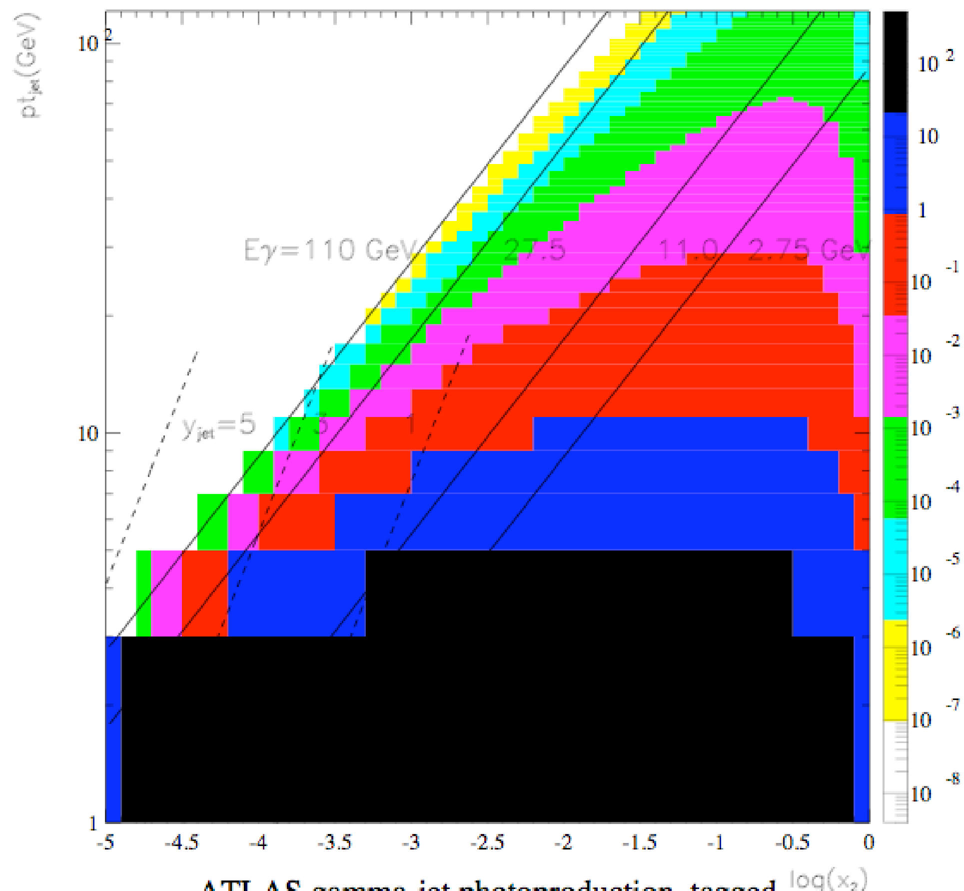
tagged, no jet cut

Tagged = 1 or more neutron from either beam

Also results on γ-jet and c-cbar,etc.

γ-jet





ATLAS gamma-jet photoproduction, tagged

Diffractive dijet and bbar

- L.Frankfurt, V. Guzey and M. Strikman

Hep-ph/0308189 calculate leading twist nuclear Diffractive parton distribution functions (nDPDF's) and find large (~40%) probability of diffraction for x=10^-4 with ~A=200 nuclear targets.

We will complete the full calculation in ~1 week

Summary(or perspective)

- Like RHIC, the LHC will be a combined function machine (pp and HI)
- The interplay of these 2 programs will very likely be interesting also at LHC(it should only get better).
- I have described an approach which is targeted to the realities of working in a large experiment and at a complex facility like LHC.
- it worked!