Hard Photoproduction in A-A Collisions

Diffractive Physics with Heavy Ions at RHIC

Probing small x structure of nuclei and protons at LHC (with M.Strikman and R.Vogt)

Sebastian White, BNL

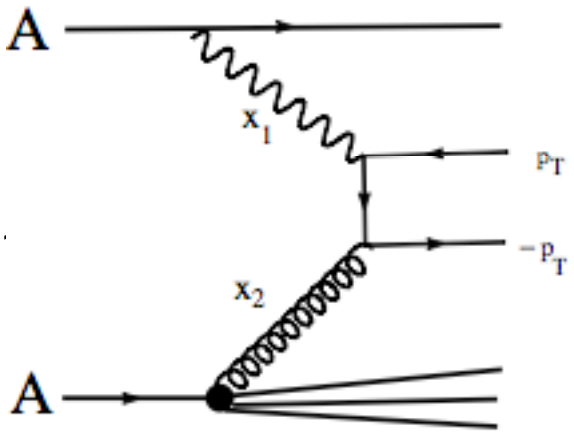
Photoproduction in AA Collisions at RHIC and LHC

RHIC: σ_{tot} in AuAu and Aud
low mass e^+e^- and ρ^0 (STAR)
high mass e^+e^- and J/psi (PHENIX)

LHC: hard photoproduction in ATLAS
ATLAS ZDC
forward measurements in pp
photoproduction rates in PbPb and Pb+p

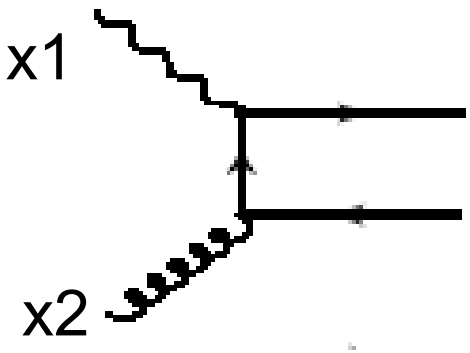
Can one continue HERA program with higher $s_{\gamma N}$ at LHC?

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) $cm^{-2}s^{-1}$



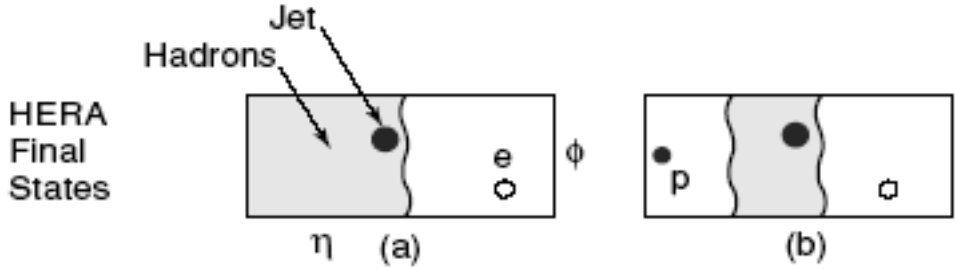

Christian Griepenkerl (1839-1916): Raub des Feuers. Photo © Maicar Förlag - GML

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



di-jet photoproduction-> parton distributions,x
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 vet

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



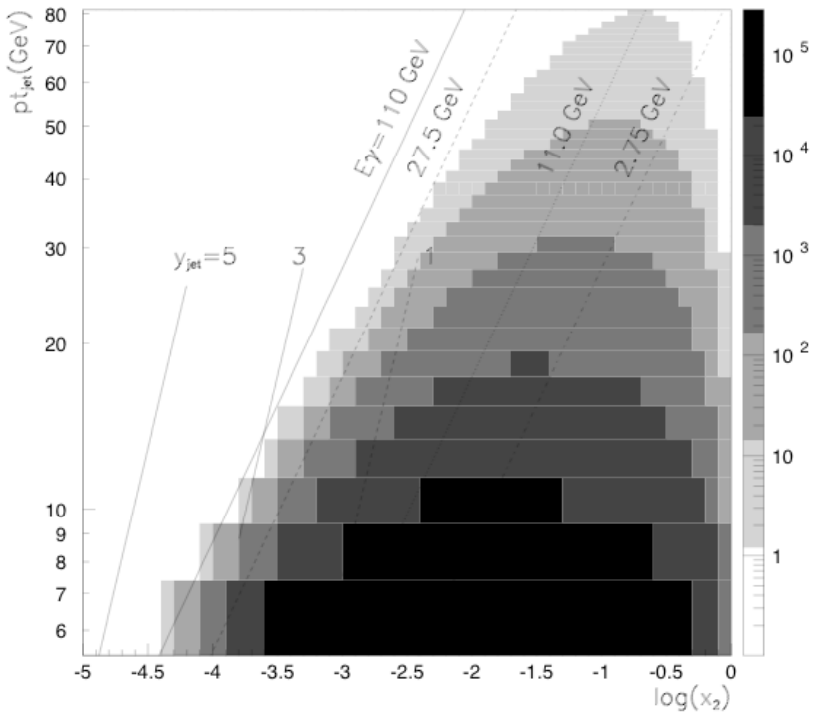
Analogous upc interactions and gap structure

diffractive Non-diffractive

Rates and Kinematics(more later)

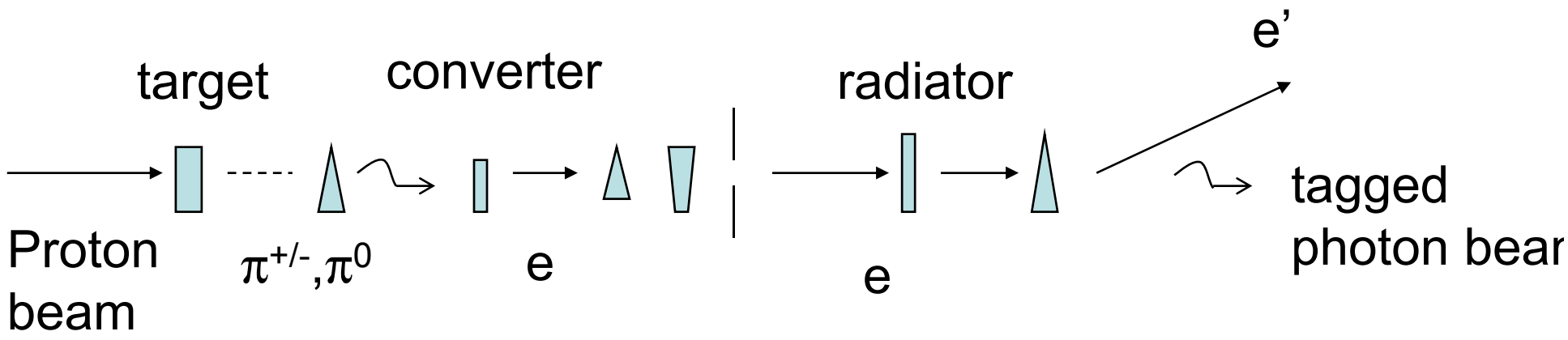
Event yields from a 1 month HI (Pb-Pb) run at nominal Luminosity (4 10^{26} $cm^{-2}s^{-1}$).
Counts per bin of δpt=2 GeV
δx2/x2=+/- 0.25

(with M. Strikman and R. Vogt



arXiv:hep-ph/0508296 v1 29 Aug 2005

Tagged Photon beam (fixed target)



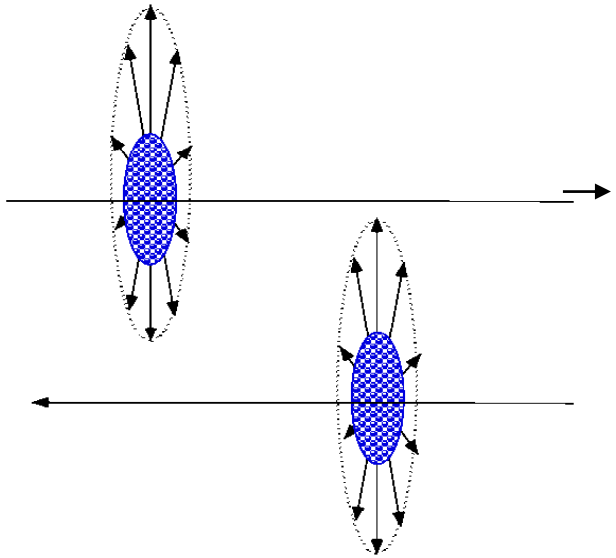
<u>At FNAL ('80's and '90's)</u>

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

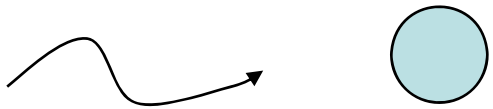
Diffractive γp->Xp E612 (CGSSW)

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

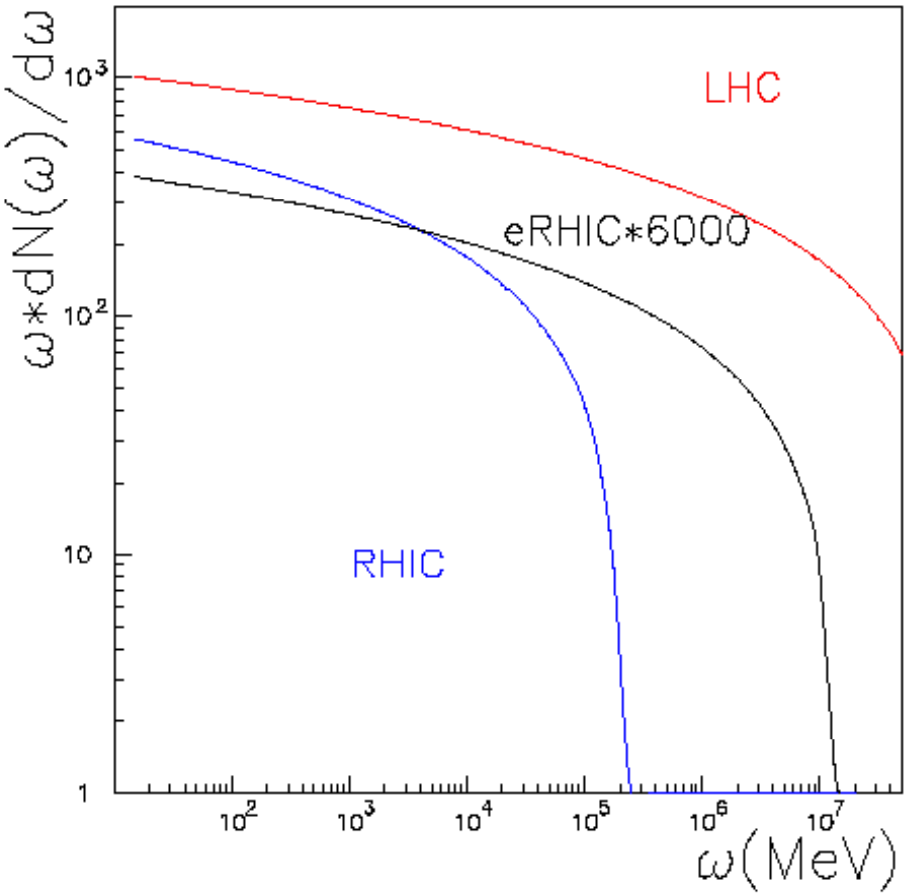
Heavy Ions

$$\omega\frac{1}{2}\frac{dN(\omega)}{d\omega}=\frac{2\alpha Z^2}{\pi}\ln\left(\frac{0.68\overline{\hbar c\gamma_{eff}}}{R_{nucleus}\bullet\omega}\right)$$

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-hadro collider

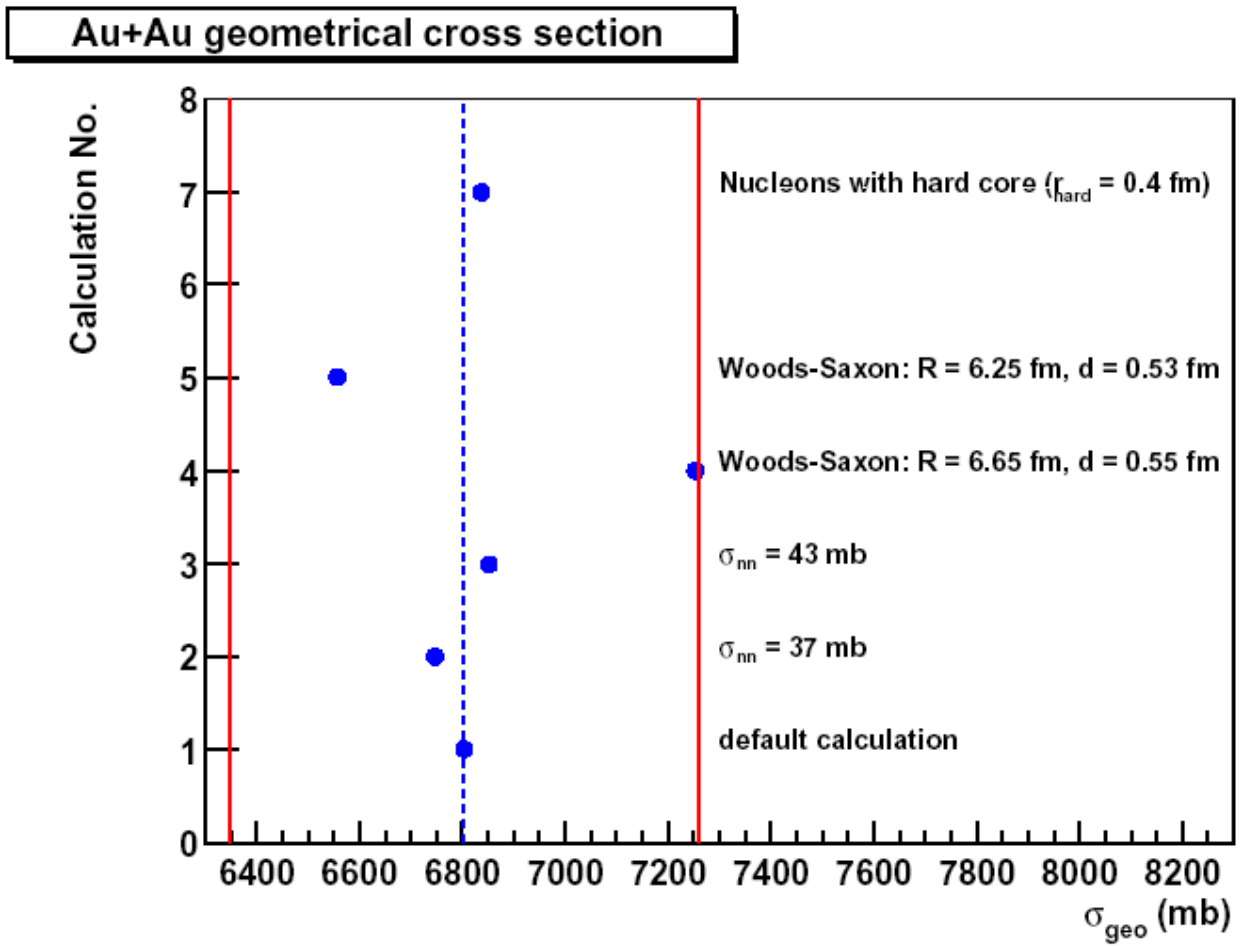
->100 TeV @ LHC

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					

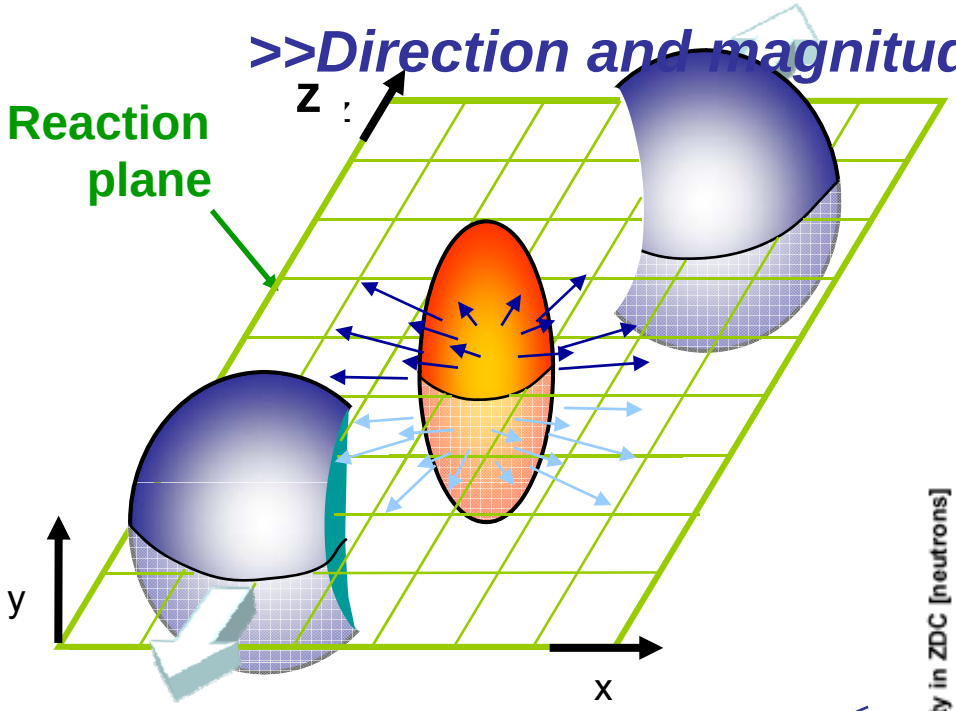
Total Cross Sections (II)



(from K.Reygers, PHENIX note)

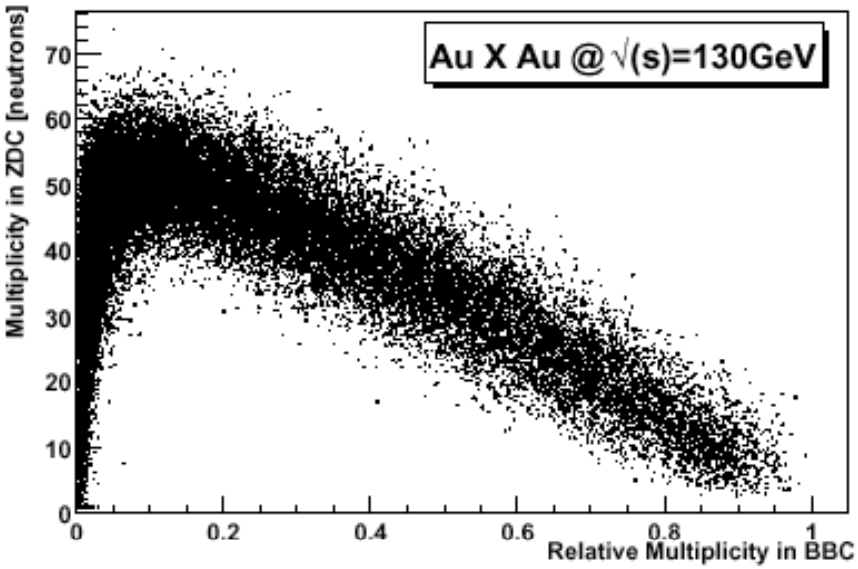
Heavy ions:Event characterization with forward detectors

>>Direction and magnitude of impact parameter, b



Magnitude from complementary parameters

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

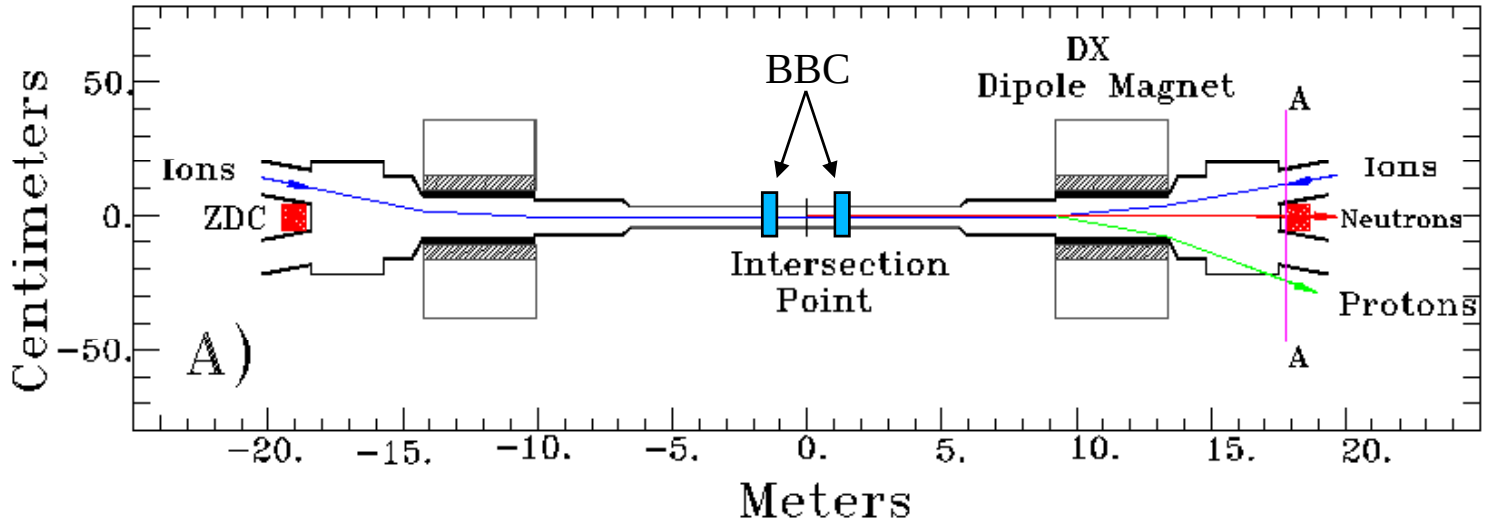


Spectator neutrons
- **measure centrality,**
- **Min_min_bias trigger**

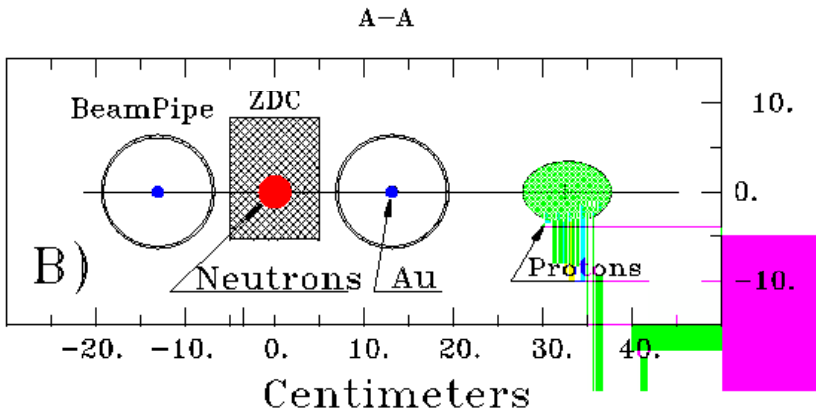
(Calorimeter@θ<2mr.)

Beam-Beam Counter Mult/1000

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



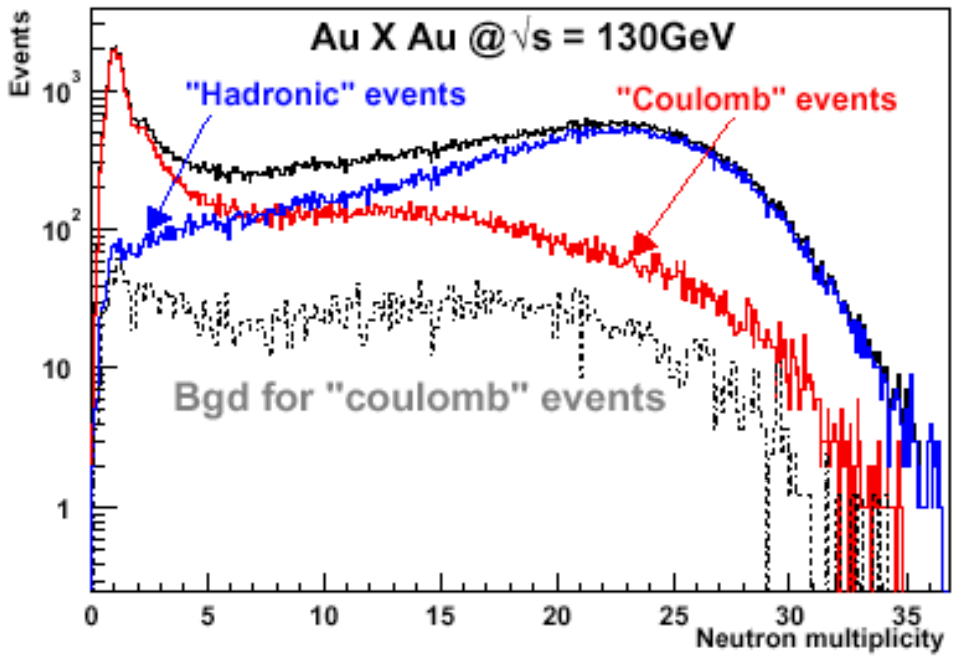
Run I

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.

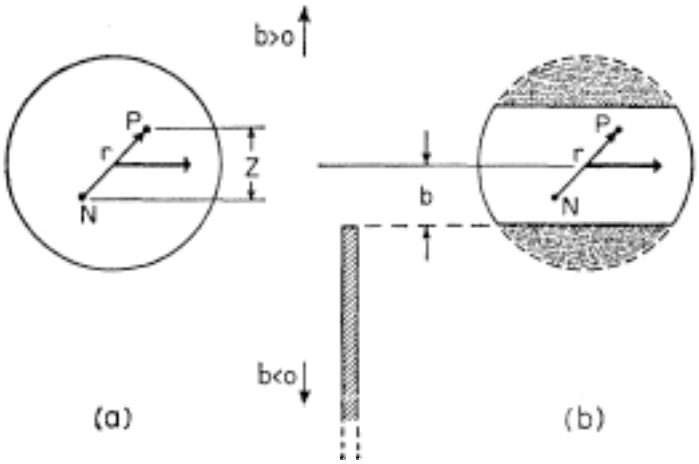


d-Au Inelastic cross section

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):



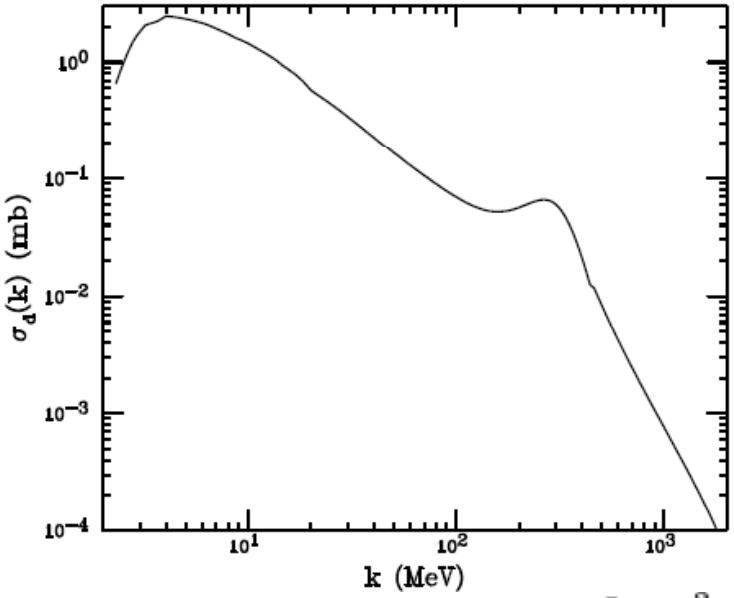
$$J(b)=\int_{|z|>2b}|\varphi_0(\mathbf{r})|^2 d\mathbf{r}, \qquad (1)$$

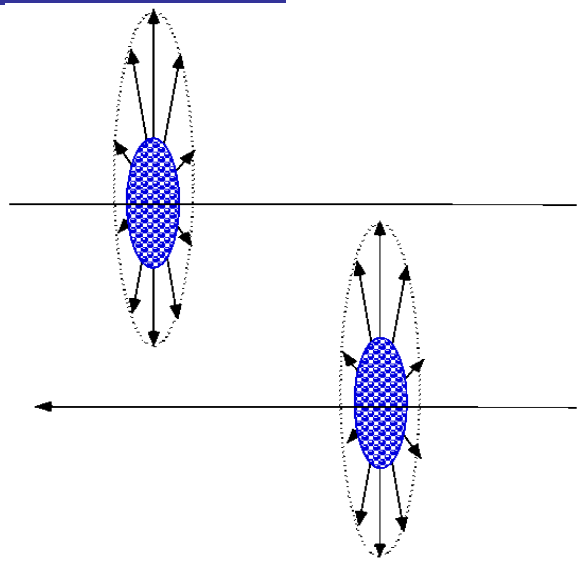
$$\sigma_{f.d.}=\int_0^\infty J(b)[1-J(b)]db. \qquad (5)$$

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

d->n+p dissociation process(2)

2) Coulomb Dissociation (Fermi '25):





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

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

PHENIX measurement of deuteron dissociation

PHENIX used 2 types of min bias triggers:

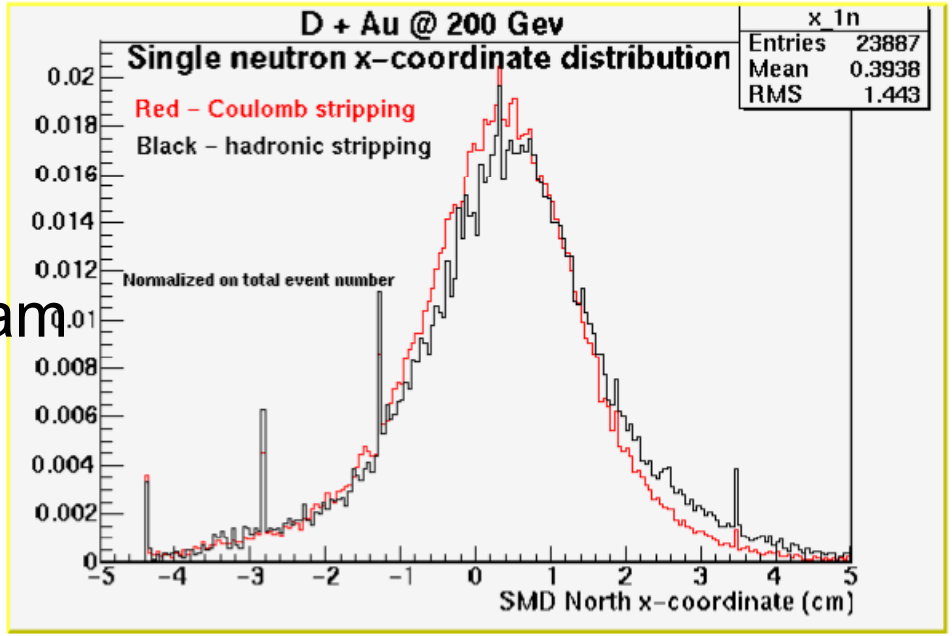
1)BBCN*S=coinc of 3<|η|<4

(excludes "rapidity gaps")

And

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

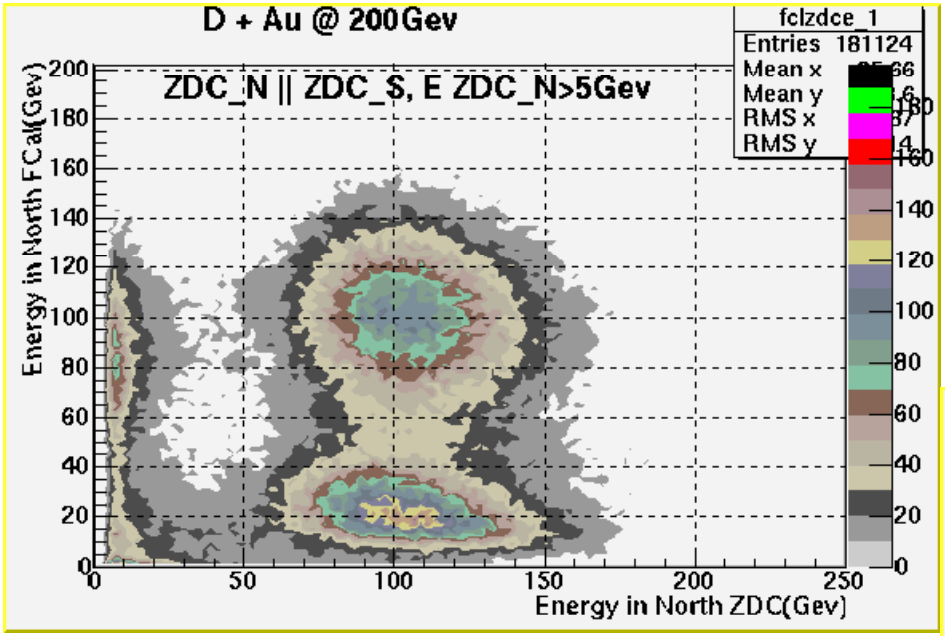
(includes "gap" events,
~12M events recorded)



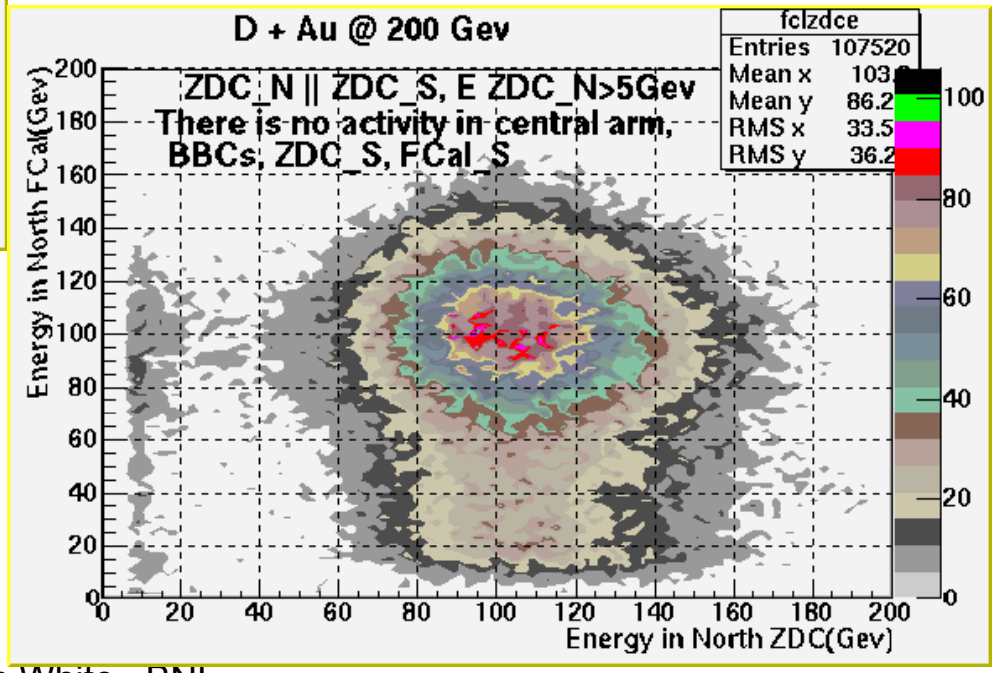
Our measurement is from 2) which
includes d+Au->n+p+Au

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)



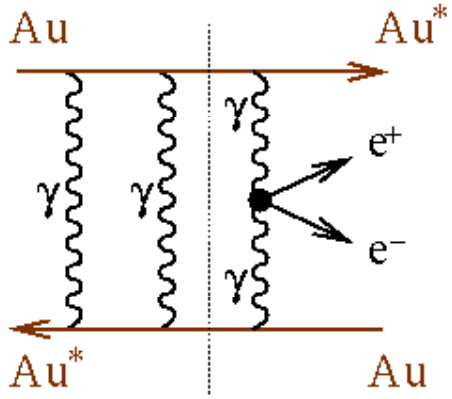
<----Inclusive data set



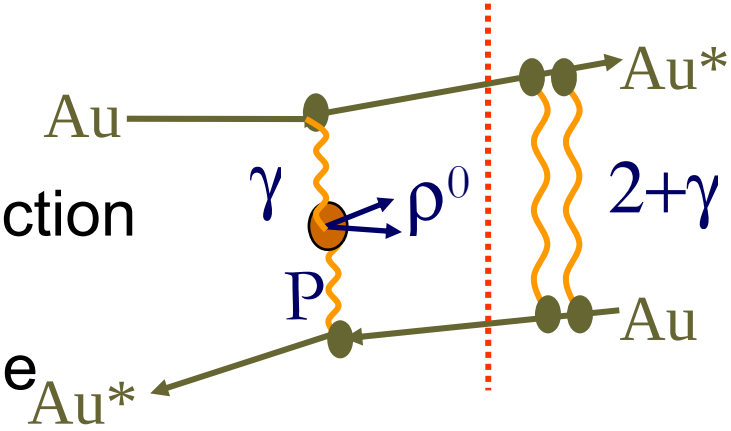
Cut on central activity--> &Au fragmentation

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

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



Coherent Vector meson photoproduction
-STAR measured $\rho \to \pi\pi$
-new data from PHENIX on J/psi->ee



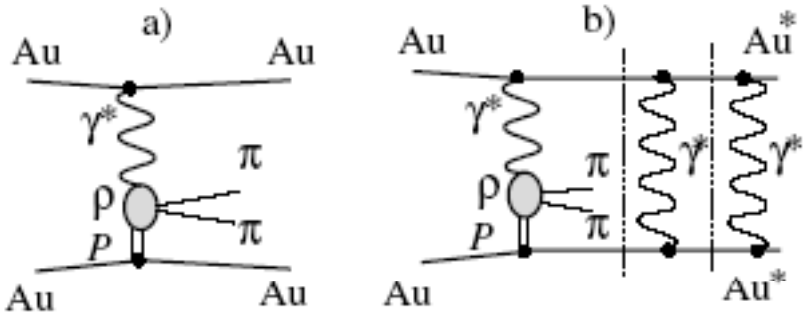
Tagged photon spectrum

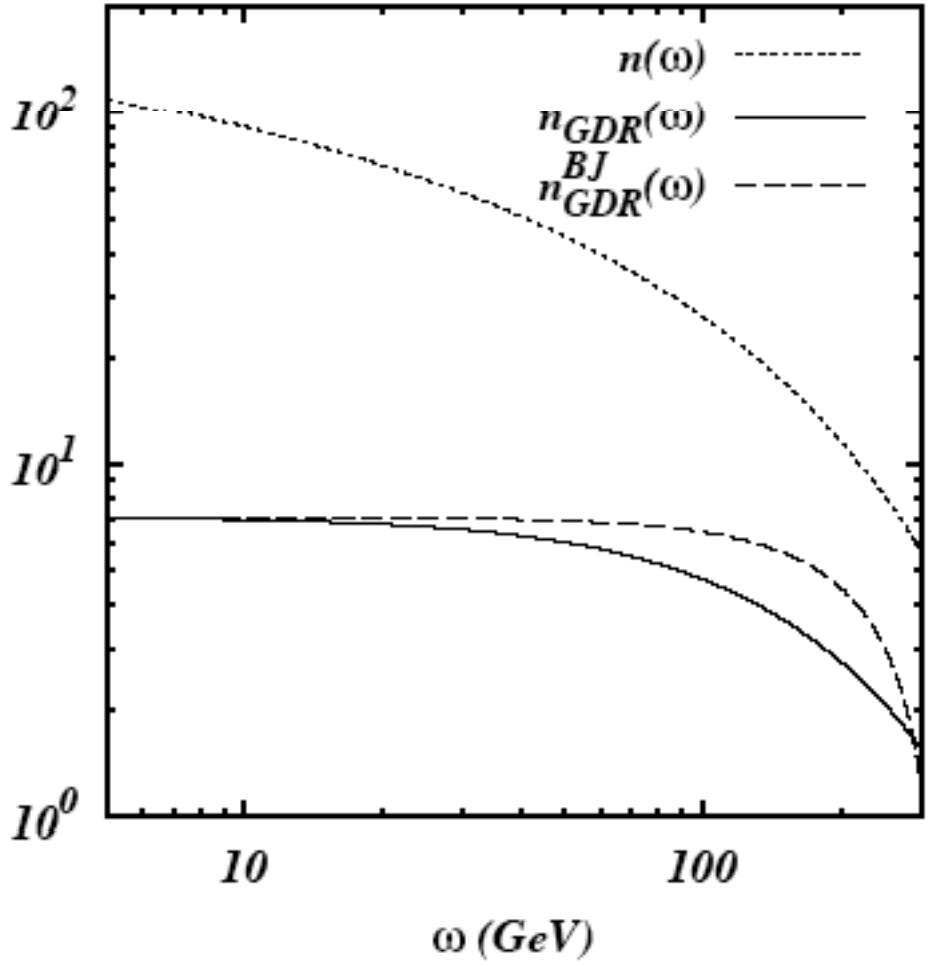
Strength of interaction

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

2nd γ exchange leads to hardened photon beam (implemented in "STARlight" not yet in "DPEMC")

(seeG.Baur et al. Nucl-th/03070310)





PHENIX J/psi and e+e- continuum

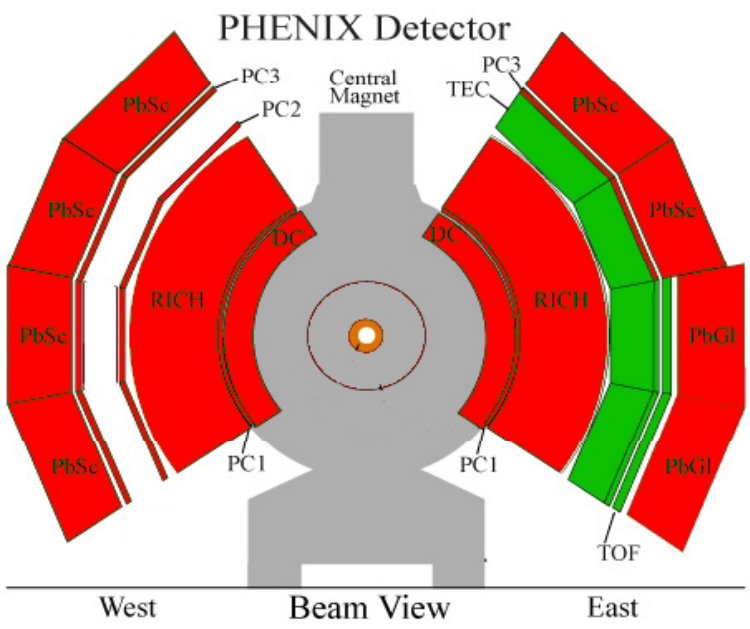
UPC trigger: (ZDCN || ZDCS) && (!BBCLL1noVtx) && (ERT2x2)

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/psiψ]

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]

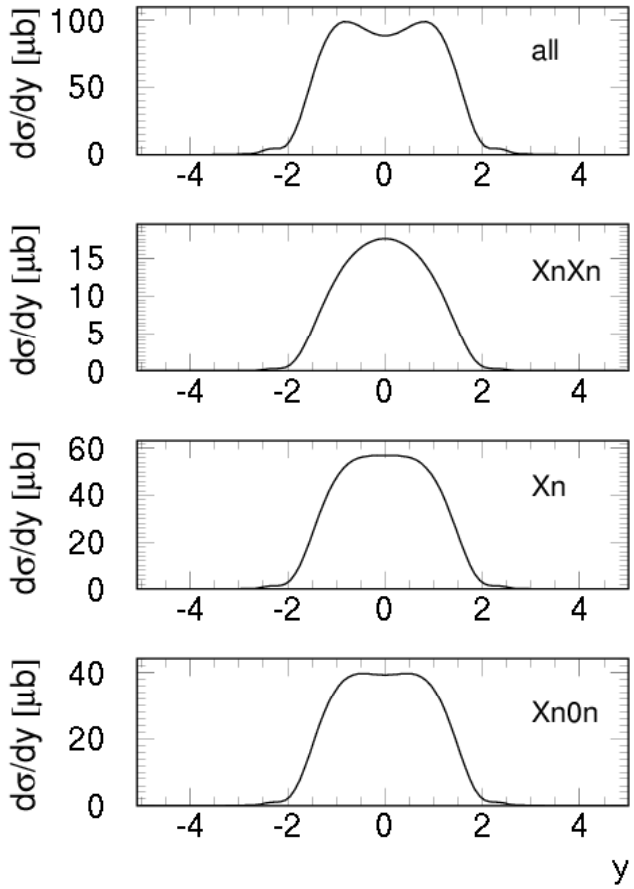
Background subtraction: [unlike-sign] - [like-sign]

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

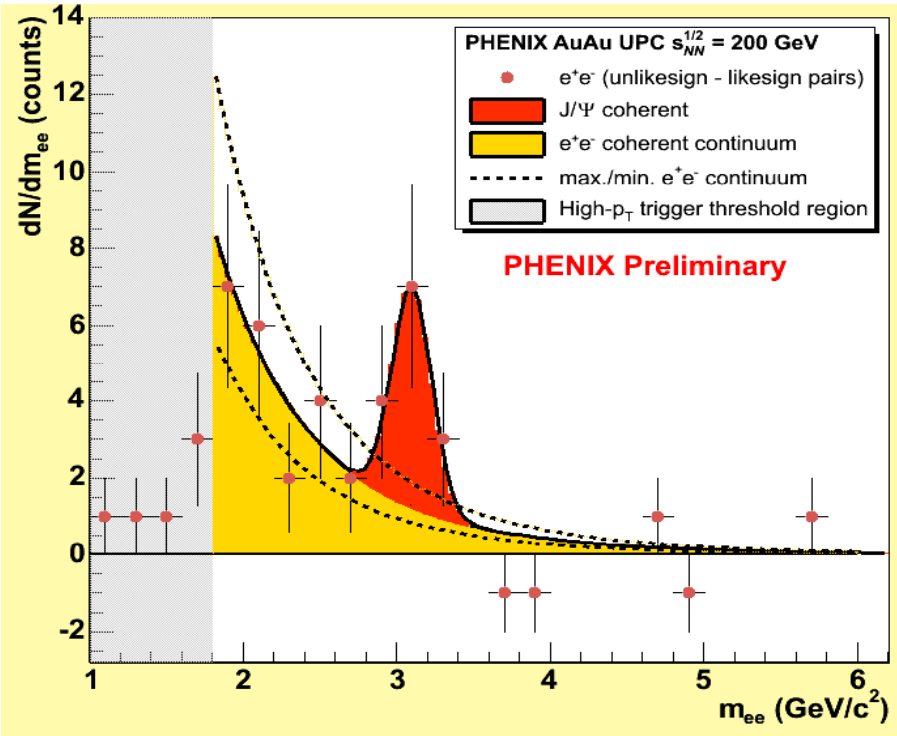
ZDC trigger bias

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

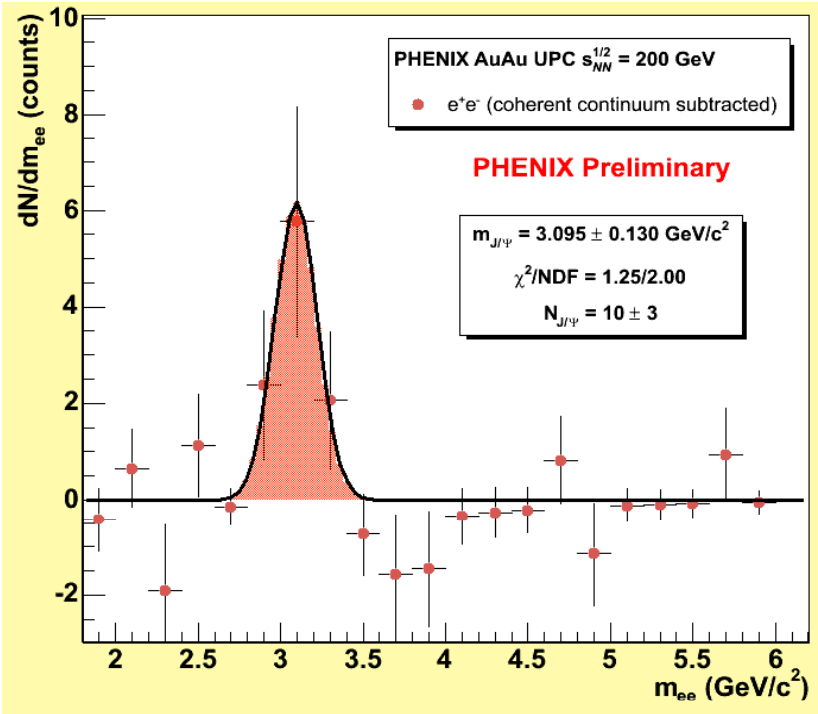
~20% with 2 arm n tag



J.Nystrand/STARlight

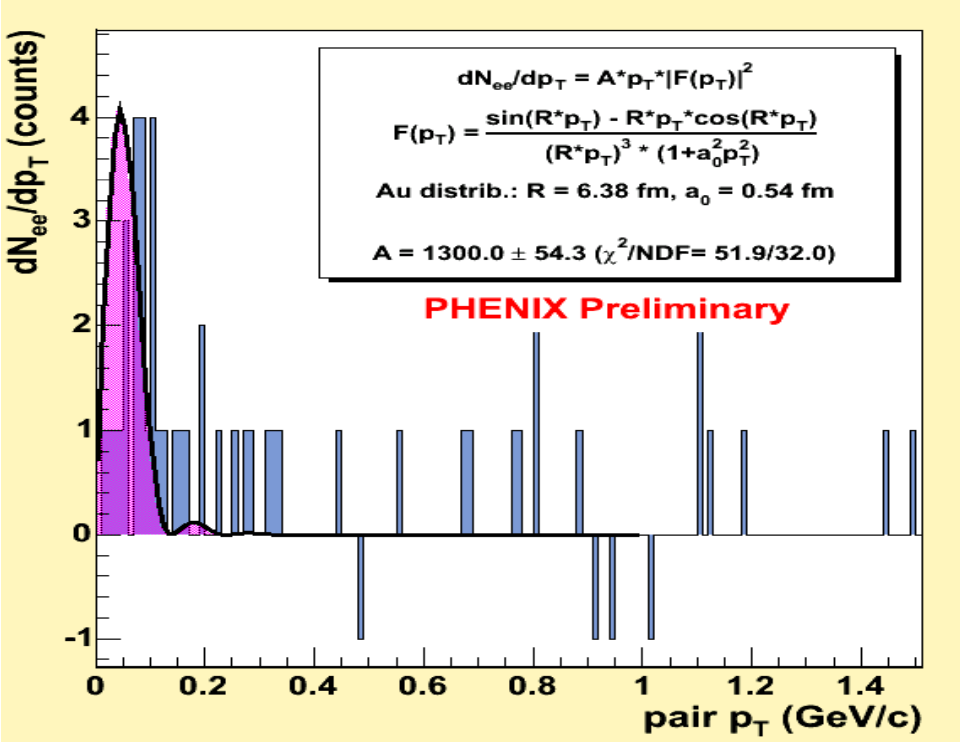


Dominant uncertainty in signal extraction from continuum fit



J/psi after continuum subtracted

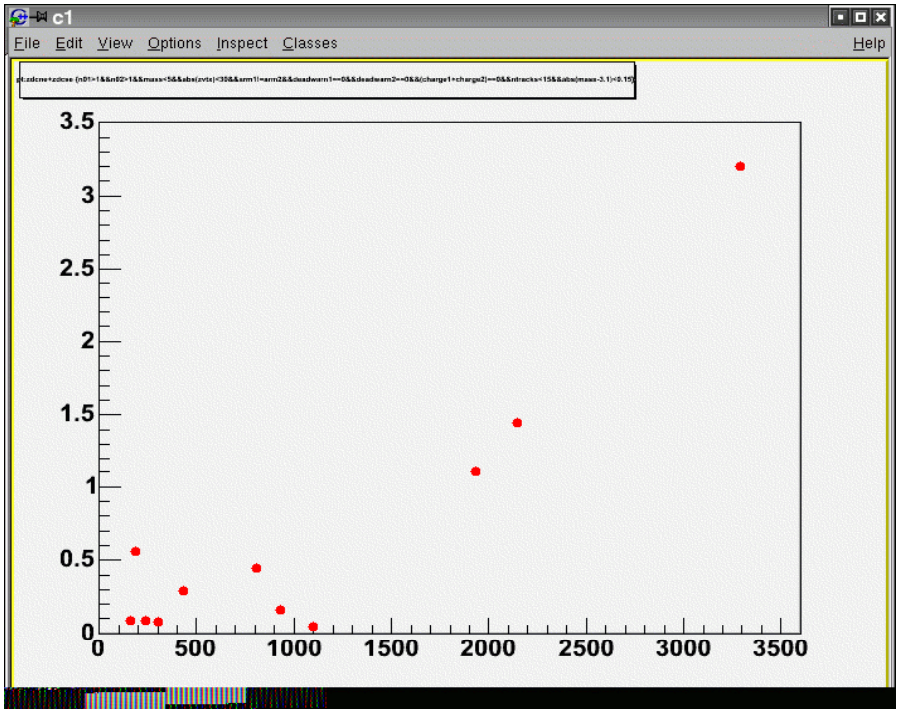
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.



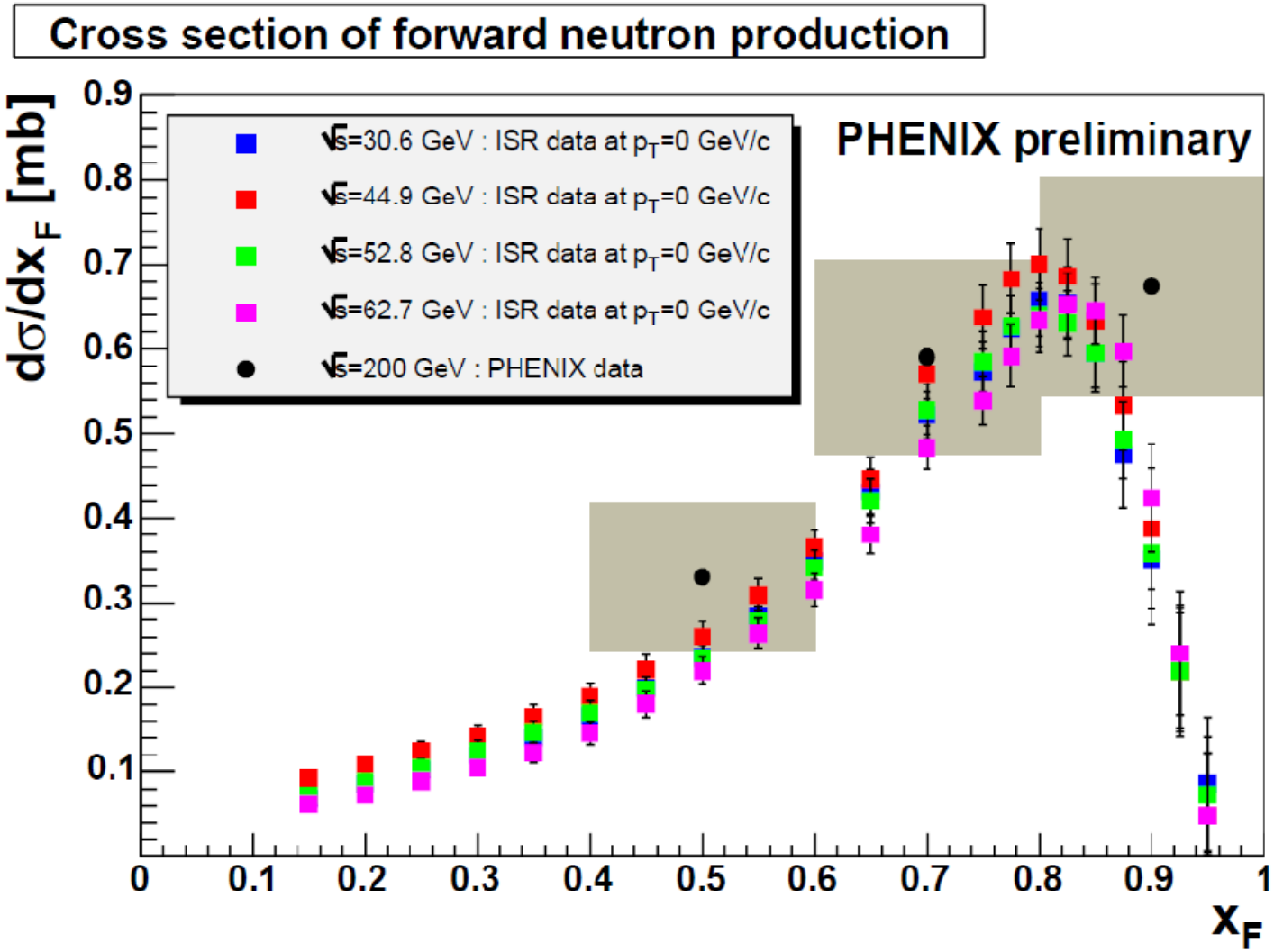
-Clear coherent peak consiste with Au form factor

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

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

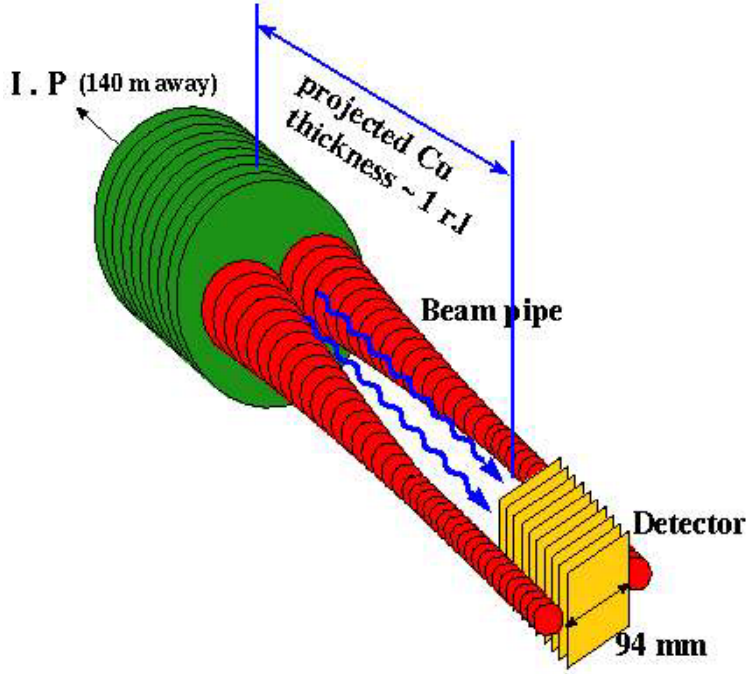


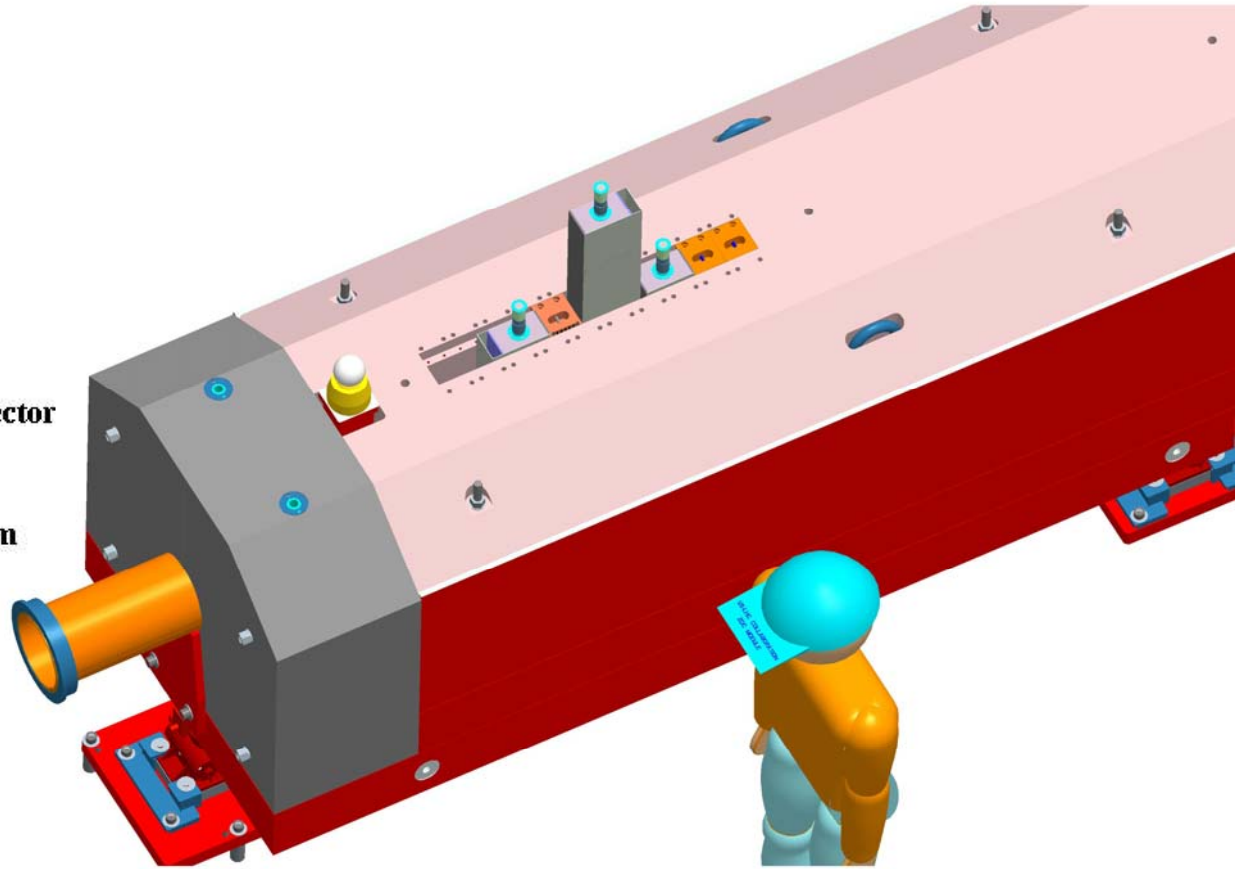
PHENIX neutron cross section in pp



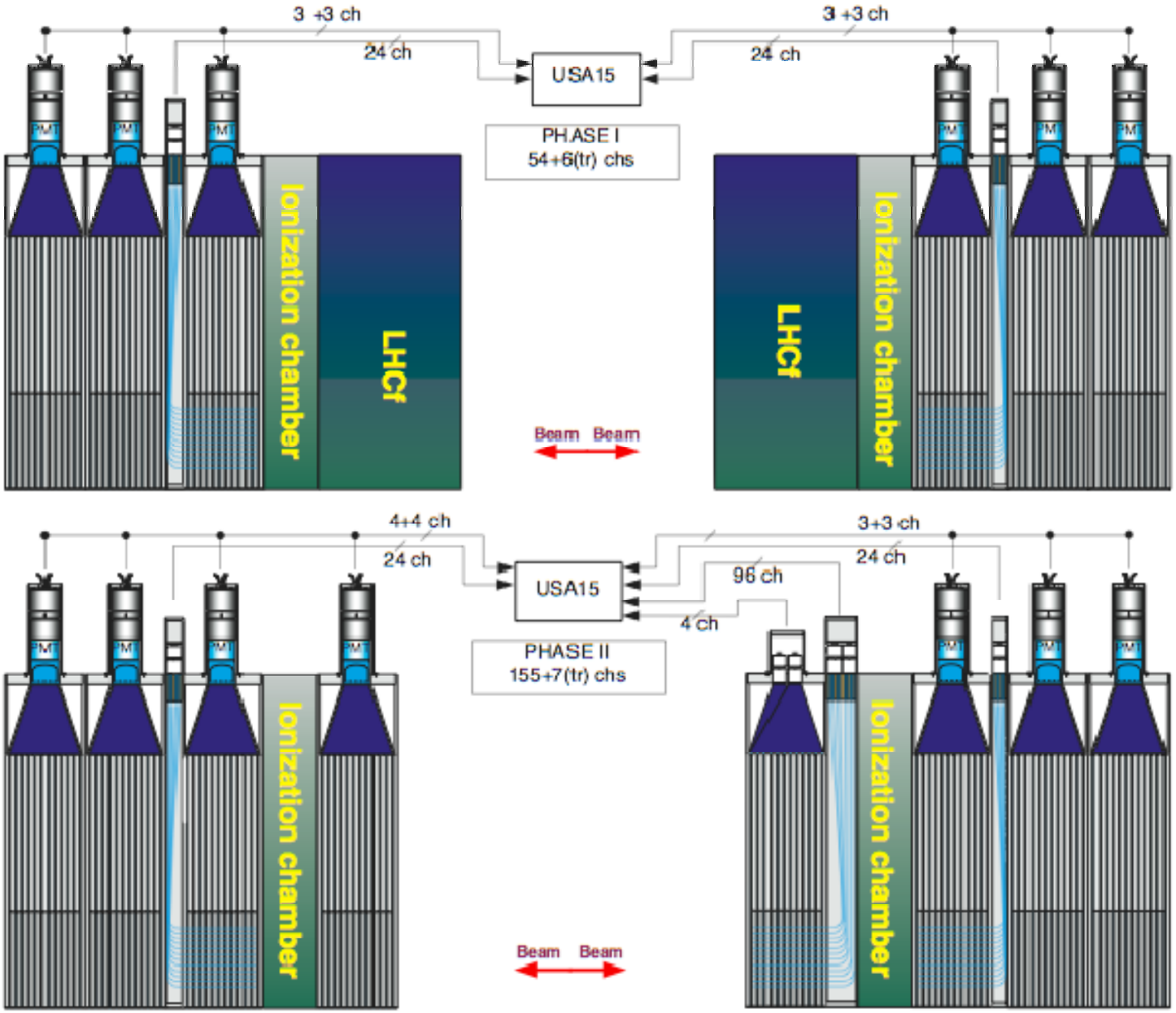
ZDC in ATLAS

The Zero Degree Calorimeters (ZDC) resides at the junction where the two beam pipes of the LHC become one – at 0° from the pp collisions. It is housed in the shielding unit that protects the S.C magnets from radiation, and measures neutral particle production at 0°. It can play many roles.



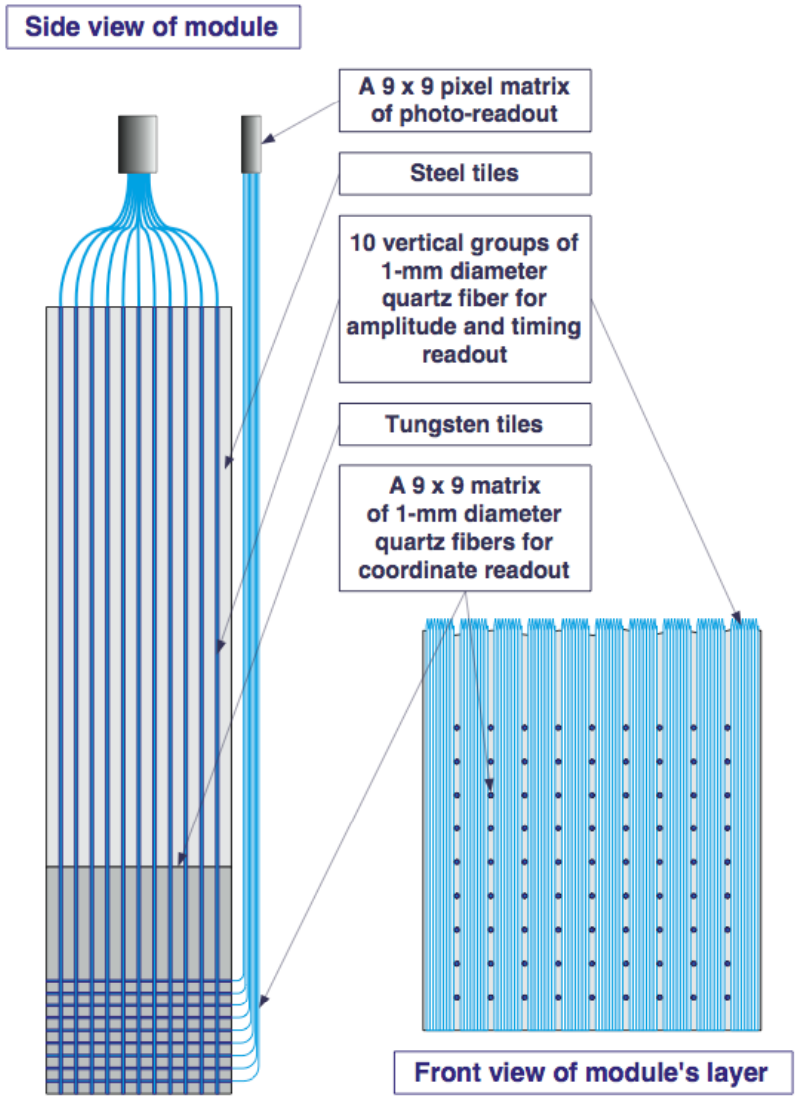


ZDC scenarios and cabling



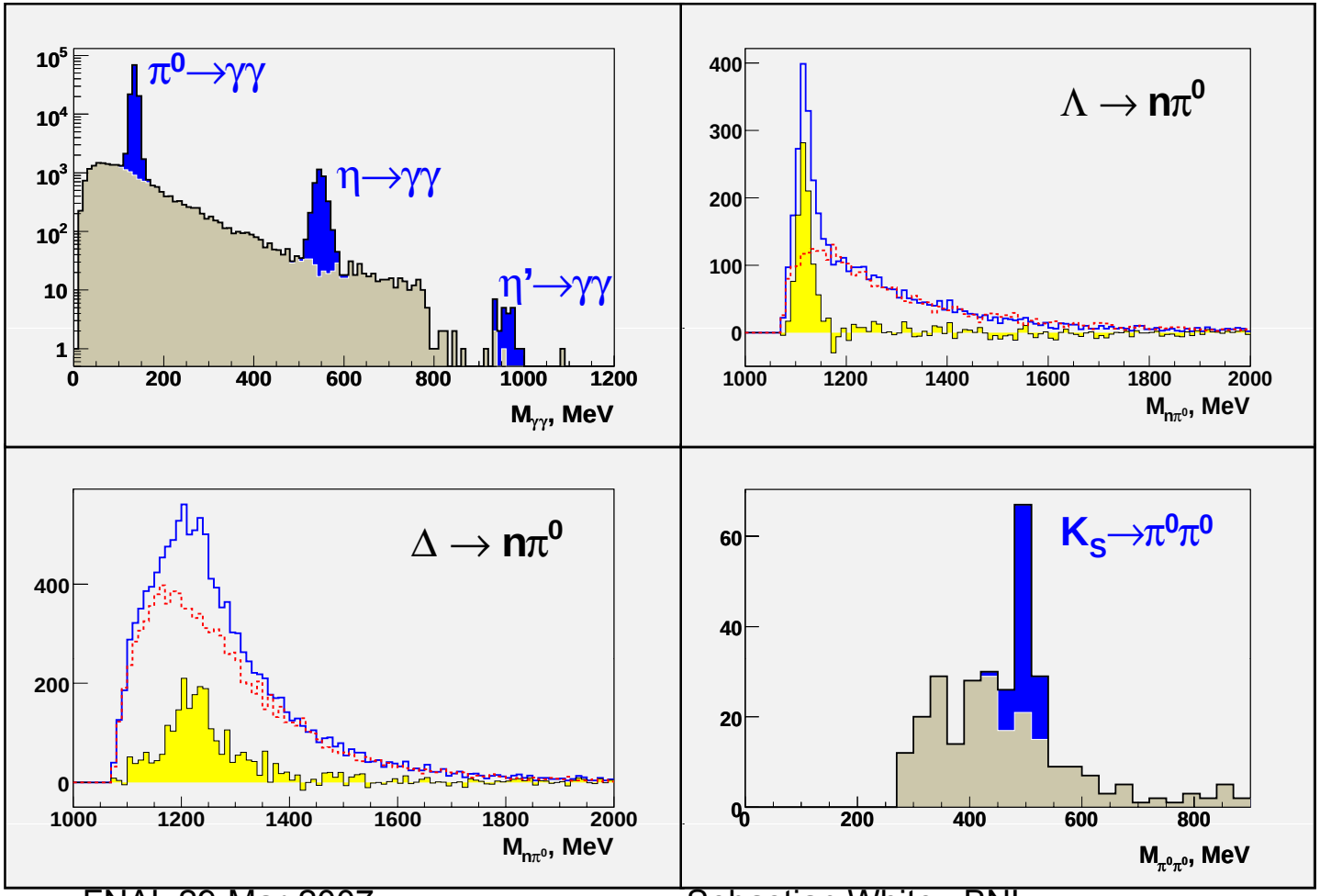
- Basic design is W/Quartz sandwich (energy&time)
- Coordinate measurement(σ~2mm)implemented with projective fibers

Self Calibrating:
from 1 neutron energy peak(HI)
and Λ, π^0 decays in pp



ZDC in pp(Phase II configuration)

In pp, the ZDC can measure forward production cross sections for several types of particles at very high energies. This will be useful for adjusting parameters for simulations and models, and for cosmic ray physics where the energy in one proton's rest frame is 10^{17} eV – a very interesting energy for extended air showers.

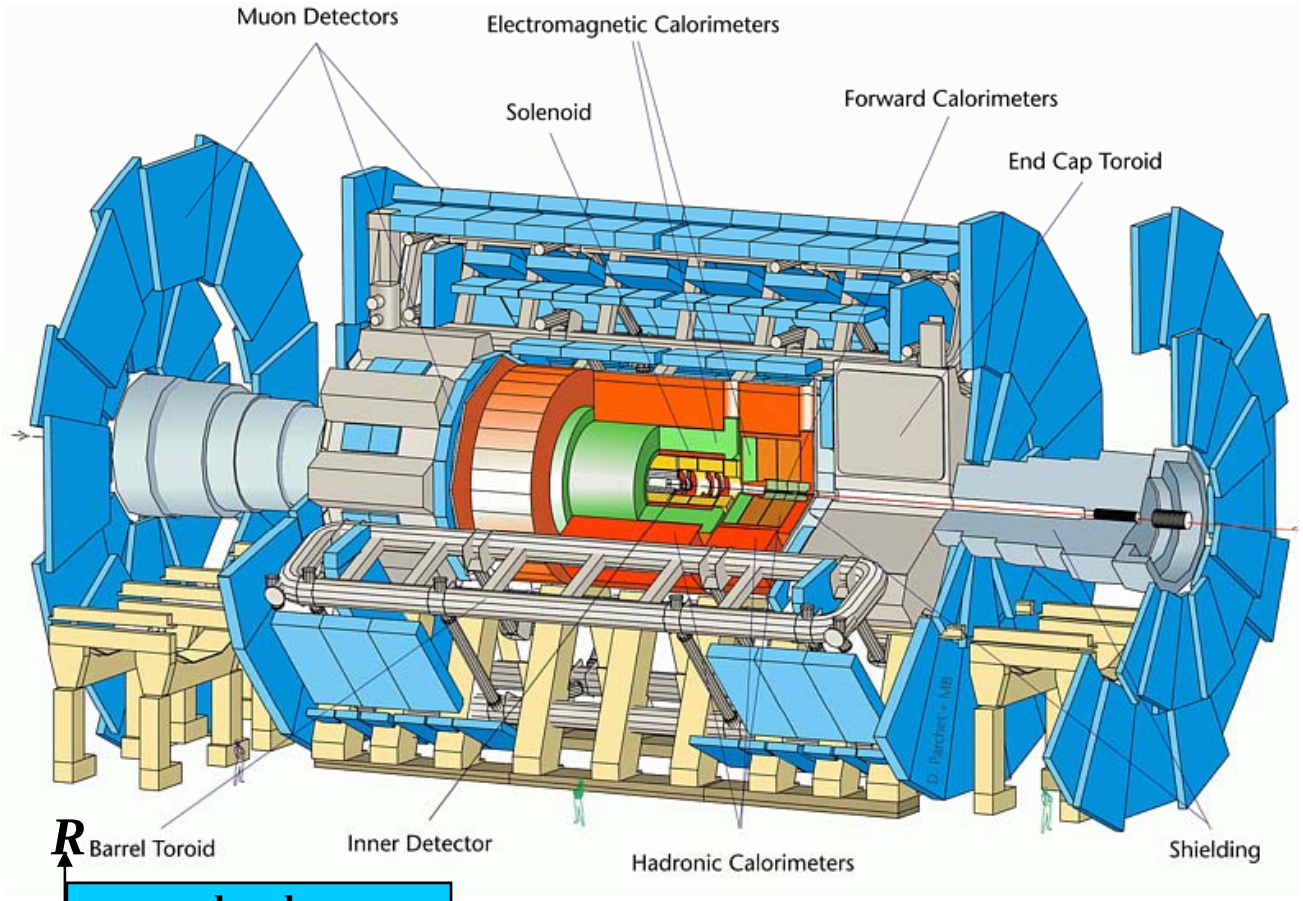


What happens when a high energy proton hits the upper atmosphere?

The ZDC can find a pi0 in the midst of several neutrons.

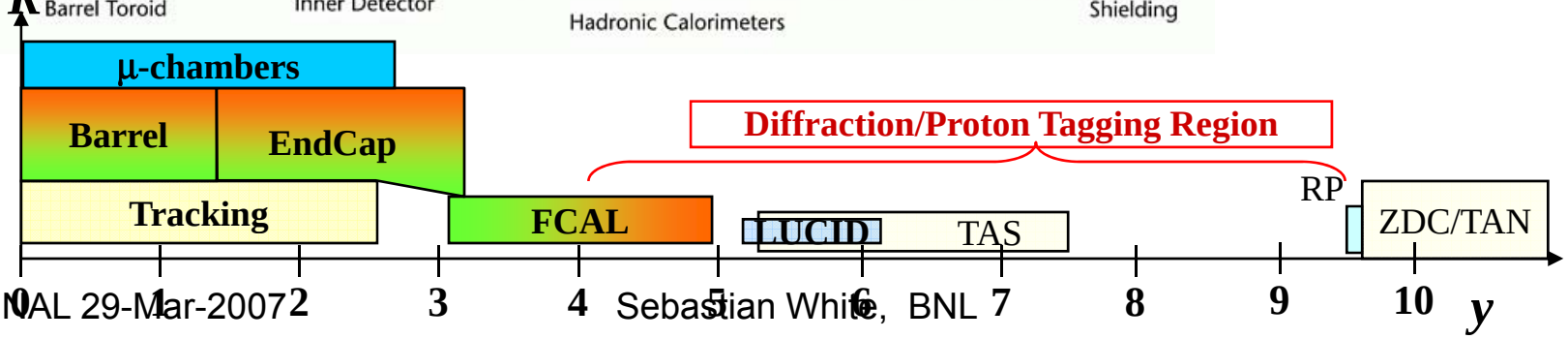
(1M Pythia events analyzed by a ZDC)

The ATLAS Detector



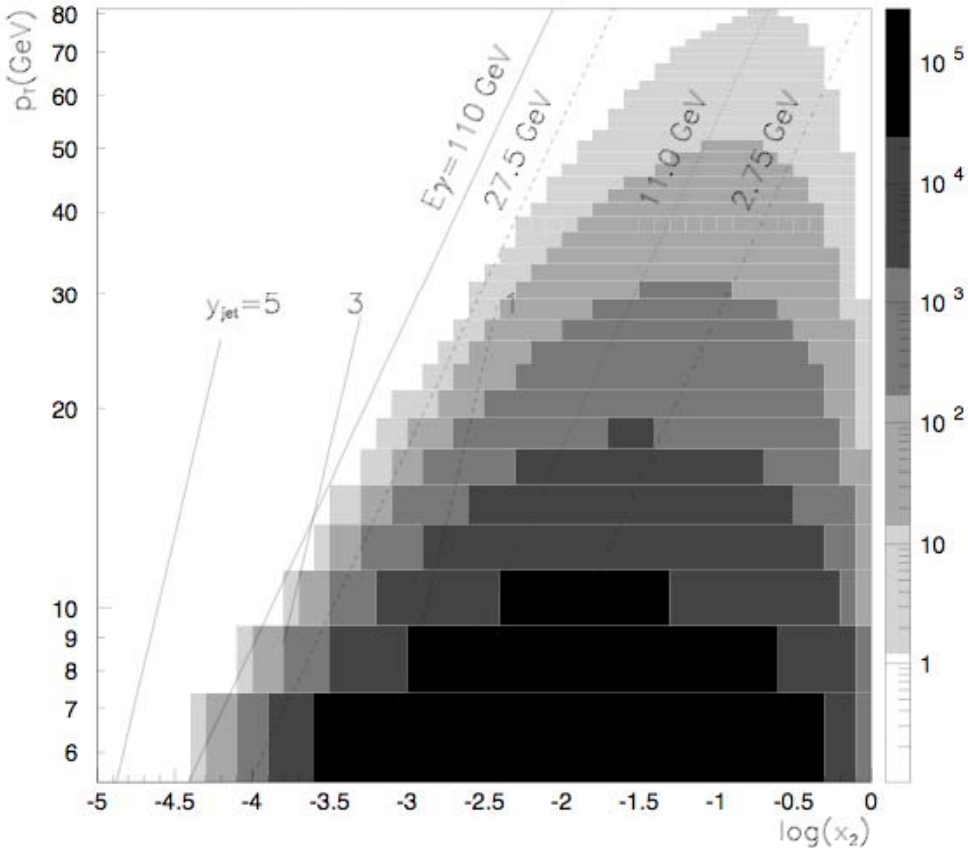
Detector:
fully hermetic to η=5
Highest segmentation
Superior jet en resolution
(50%/sqrt(E))
Excellent b-tagging

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



ATLAS dijet photoproduction

Min. pt issue for detailed simulation



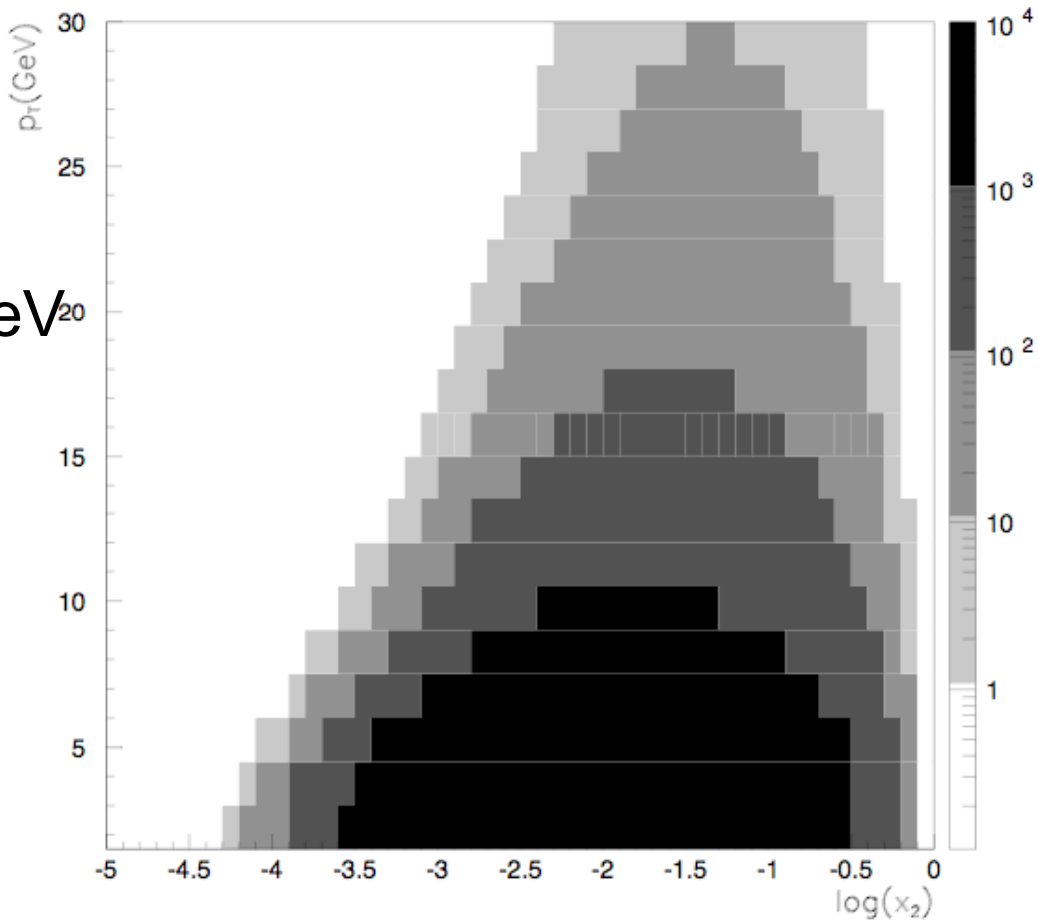
Also diffractive rates from

•Frankfurt, Guzey and Strikman Phys.lett. B 586, pp41-52(2004) "leading twist nuclear Diffractive partor 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
$\delta x2/x2$=+/- 0.25

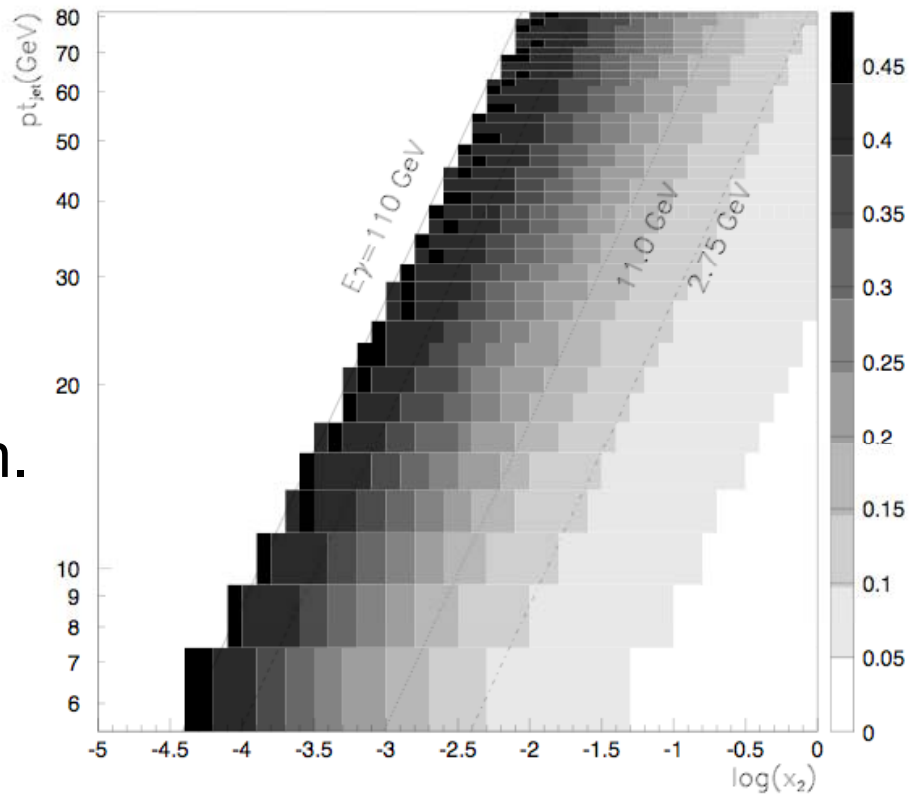
b-jet from soft lepton tag or detached vertex



ATLAS ZDC tag fraction

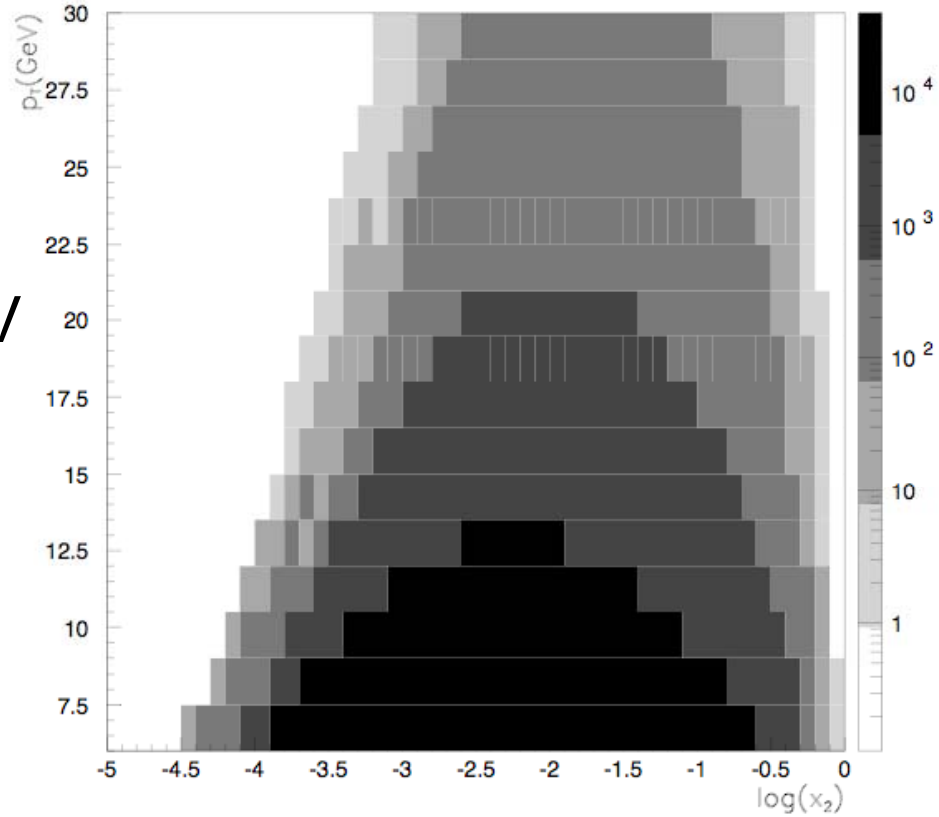
Fraction of diffractive events with additional γ exchanges leading to 2 arm ZDC tag

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



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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

Extra slides

Electromagnetic Interactions of Heavy Ions:

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

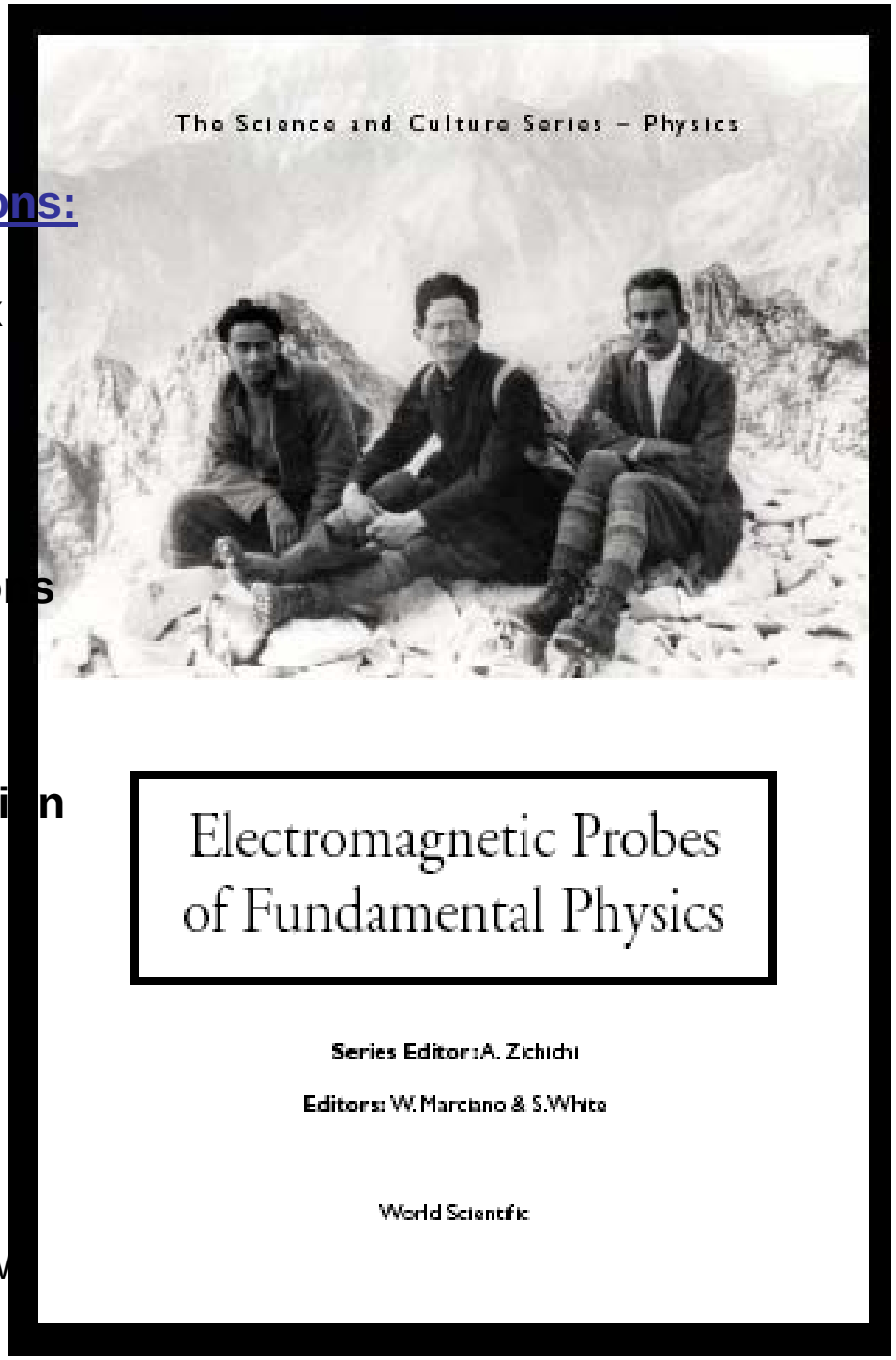
S.W. : hep-th/0205086

('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

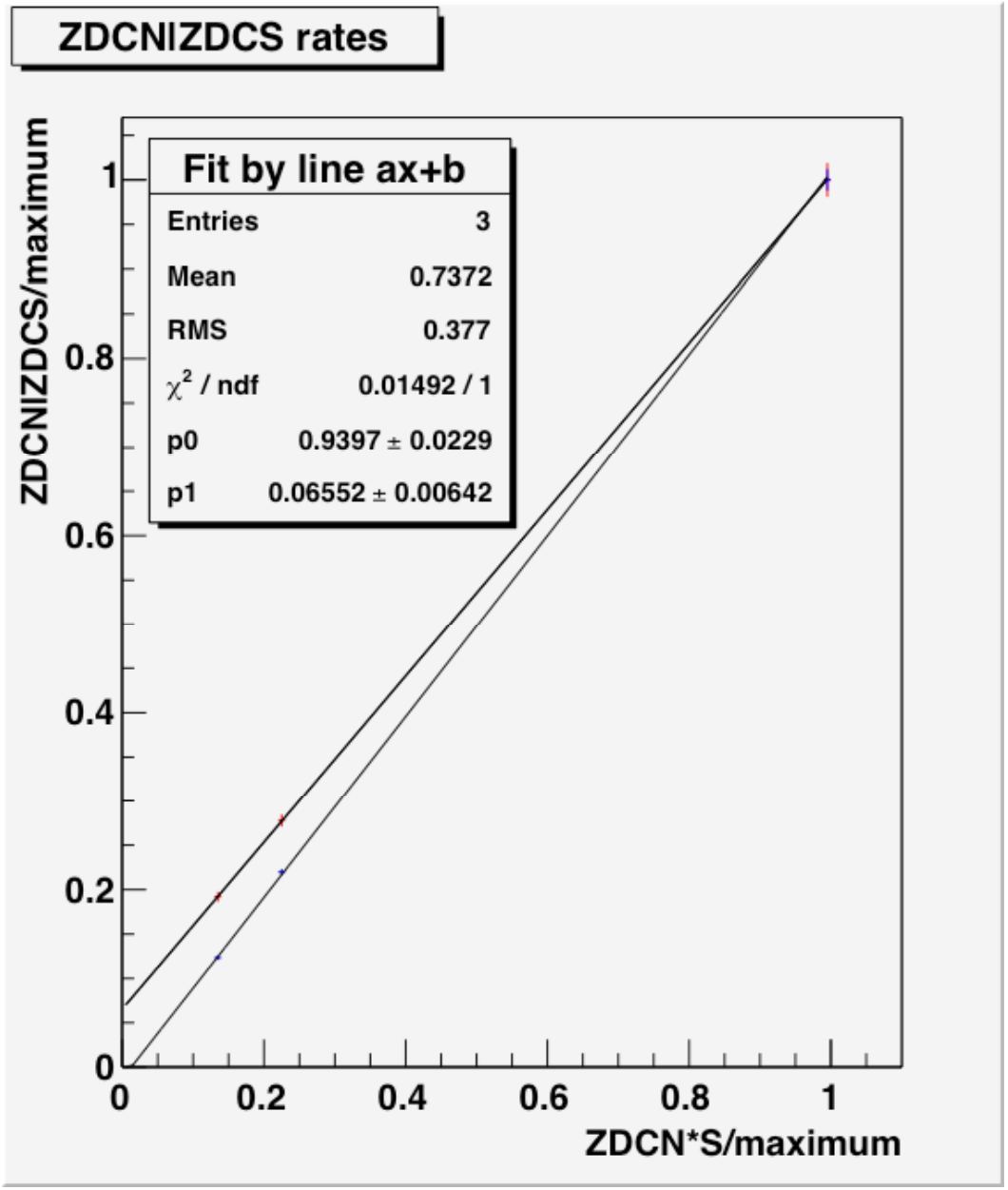
('03->)- "rapidity gap" physics w. Heavy Ions @ RHIC & LHC



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

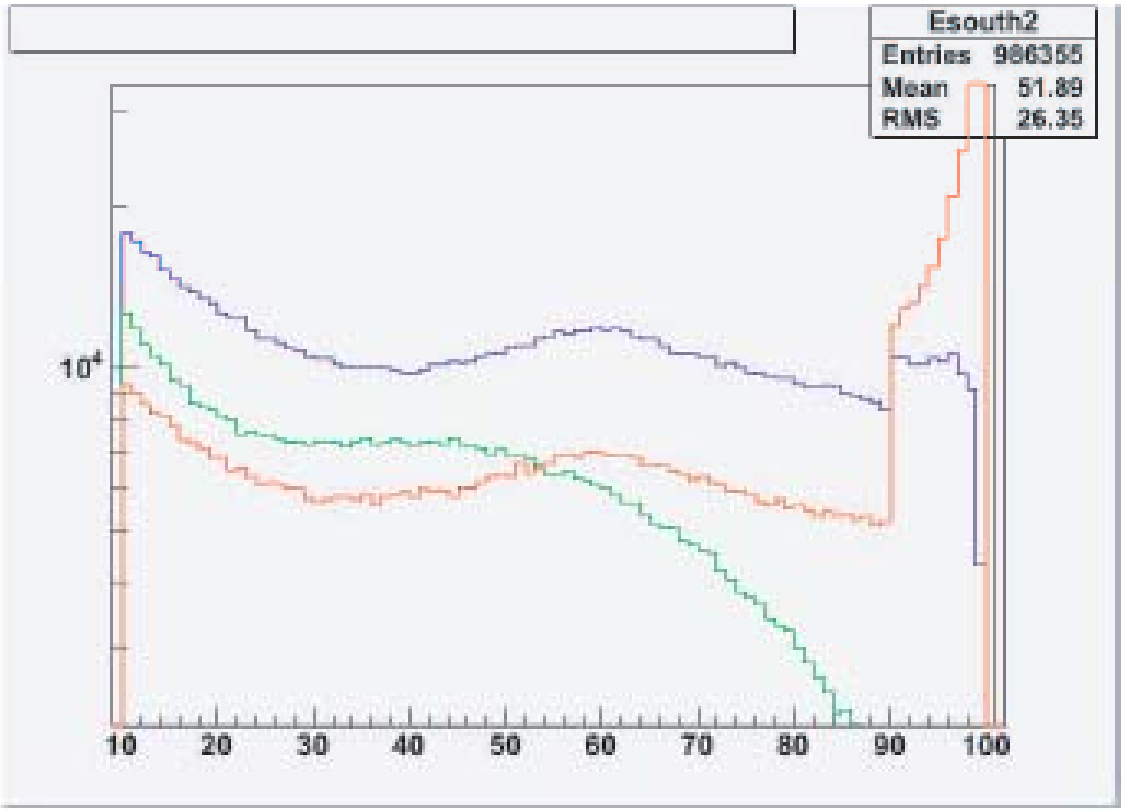


Projection on ZDC

(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.



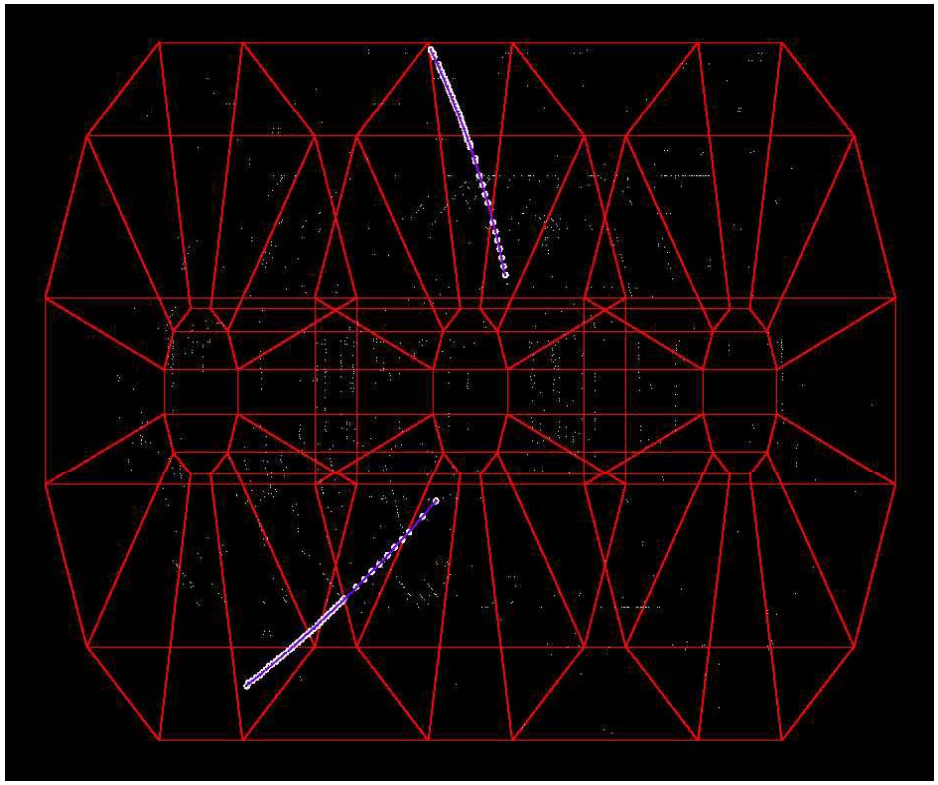
Simulation of RHIC ZDC en from:
Single diff (red)
Double Diffractive (blue)
Non-diffractive (green)

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

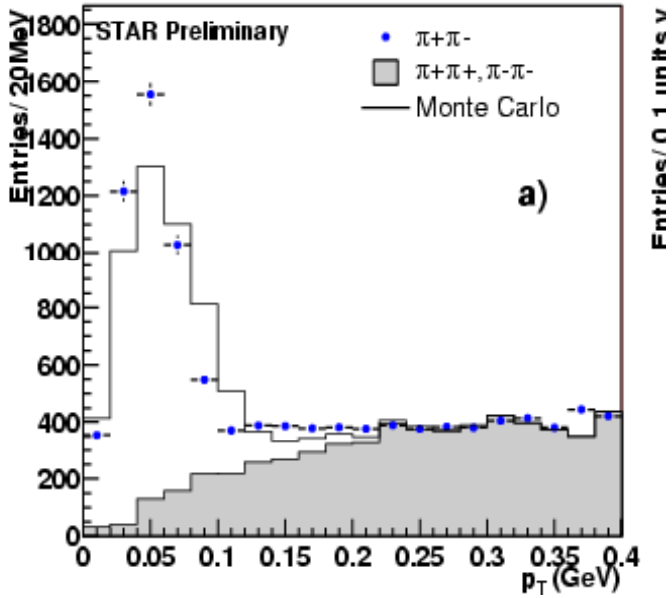
For Heavy Ions ZDC is absolute luminometer

STAR ρ^0 measurement (2002)

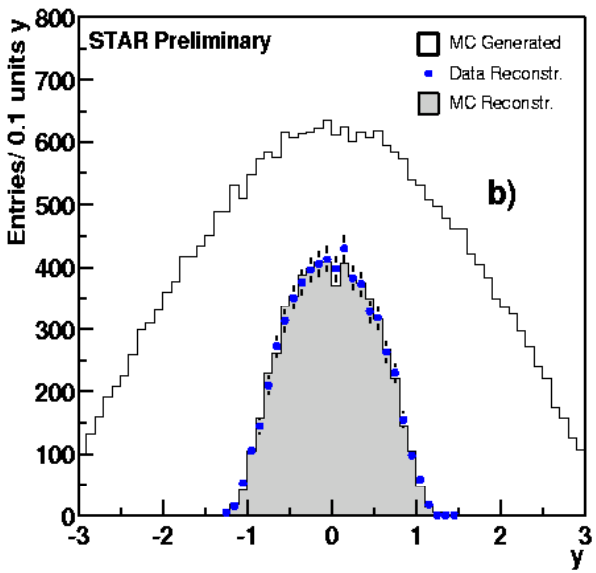
Triggered on ZDC coincidence
Reconstruct $\pi\pi$ in central TPC



ρ reconstructed p_t

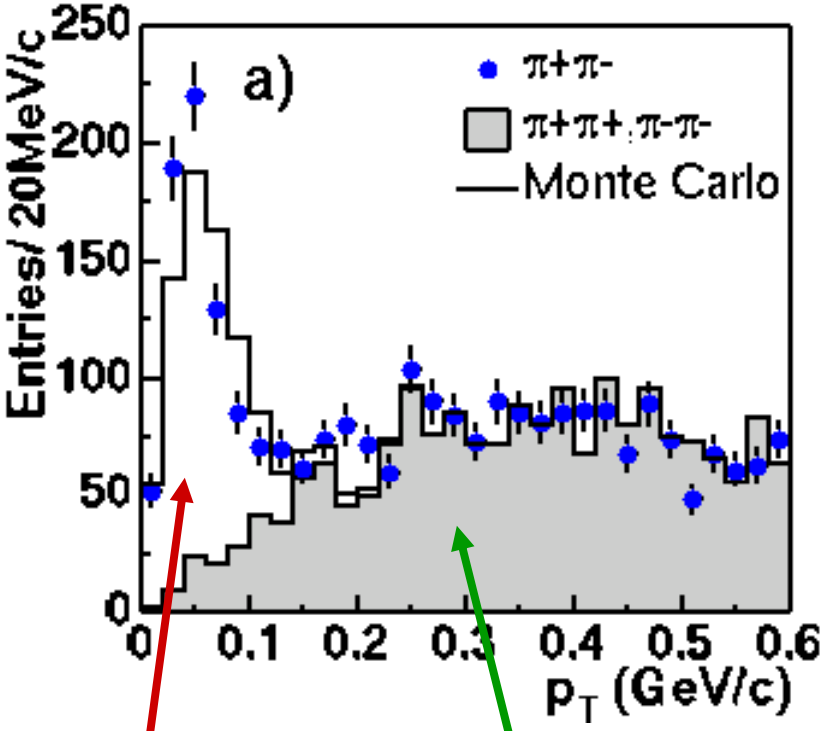


rapidity



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

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