Coherent Diffraction off Au Nuclei with vector mesons in the STAR UPC program

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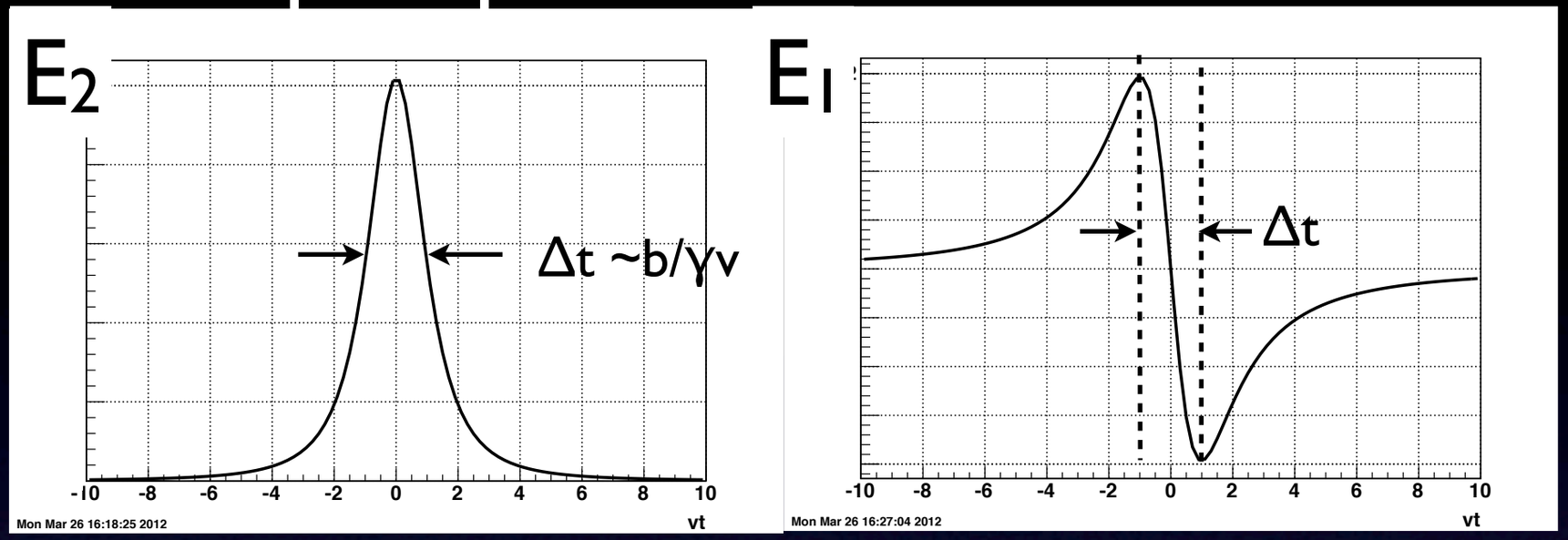
Winter Workshop Nuclear Dynamics 7-14 April 2012

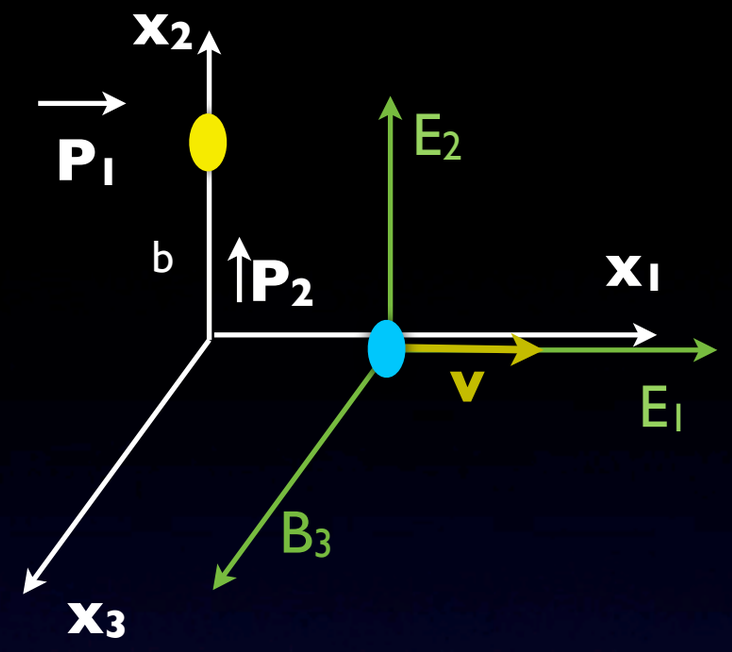
Outline

- The physics of Ultra Peripheral Collisions.
- STAR UPC triggers.
- The ρ meson reconstruction.
- Generation of the $d^2\sigma/dydt$ distribution.
- Comparison to calculations.
- Summary and Future plans.

The physics of UPC events

At impact parameter $b>2R_A$



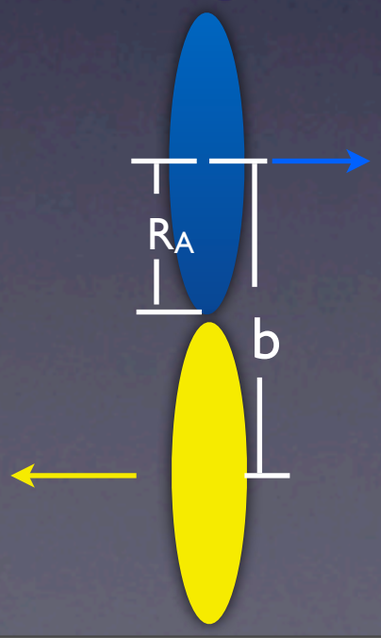


flux of photons: $dI_1/d\omega \propto |E_2(w)|^2$ $dI_2/d\omega \propto 1/\gamma^2 \sim 0$ J.D. Jackson EM

Δt is the effective duration of the equivalent pulse

of photons, with maximum energy $\hbar\omega_{max}=\hbar/\Delta t=\gamma\hbar c/b$

At high γ impulse has no transverse component.



Accelerator	Ions	Max. Energy per nucleon pair (CM)	Luminosity	Max. γp	Max. $\gamma\gamma$ energy
CERN SPS	Pb+Pb	17 GeV	—	3.1 GeV	0.8 GeV
RHIC	Au+Au	200 GeV	4×10^{26} cm^{-2} s^{-1}	24 GeV	6.0 GeV
RHIC	p+p	500 GeV	6×10^{30} cm^{-2} s^{-1}	79 GeV	50 GeV
LHC	Pb+Pb	5.6 TeV	10^{27} cm^{-2} s^{-1}	705 GeV	178 GeV
LHC	p+p	14 TeV	10^{34} cm^{-2} s^{-1}	3130 GeV	1400 GeV
Tevatron	p+$\bar{p}$	20 TeV	5×10^{31} cm^{-2} s^{-1}	320 GeV	200 GeV

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Bertulani, Klein, Nystrand
Annu. Rev. Nucl. Part. Sci. 2005. 55:271–310

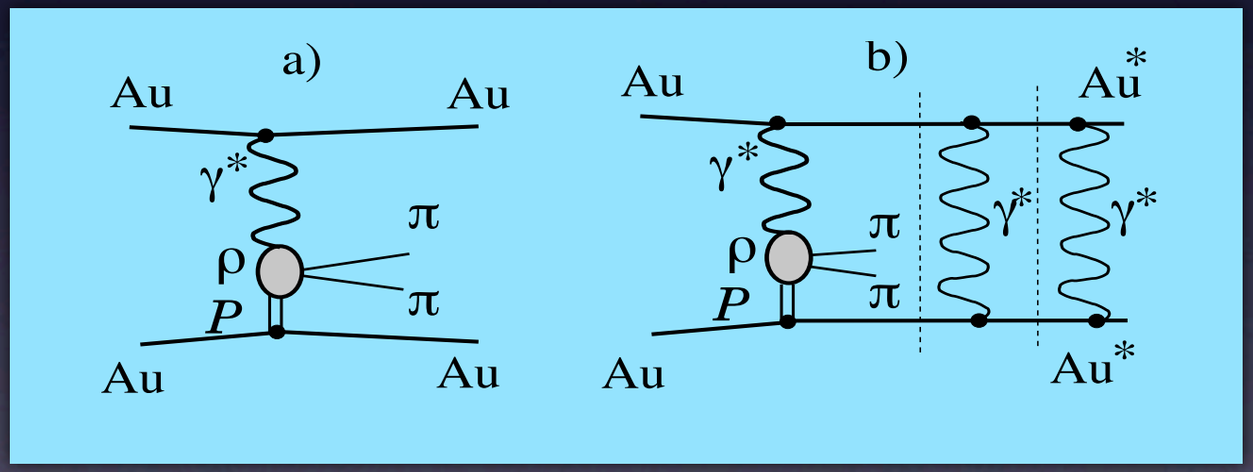
STAR UPC triggers

The interaction between ions is described as:

a) W-W photon, emitted by one ion, fluctuates into a $q\bar{q}$ dipole (mostly vector meson) which then interacts elastically with the other ion through Pomeron exchange.

(At lower energies the exchanged entity is a system of pions.)

b) The flux of W-W photons is so high that one can also find events where the ions exchange more photons and emit neutrons from decay of Giant Dipole Resonances.



The a type events are collected with the UPC_Topo trigger: Back to back tracks in TPC + veto for Up-Down tracks (cosmic rays) found by TOF. Low multiplicity in TOF, veto BBC

Type b events collected with UPC_Main trigger: 1 ≤#neutrons in ZDCs ≤6, Low multiplicity TOF, veto BBC

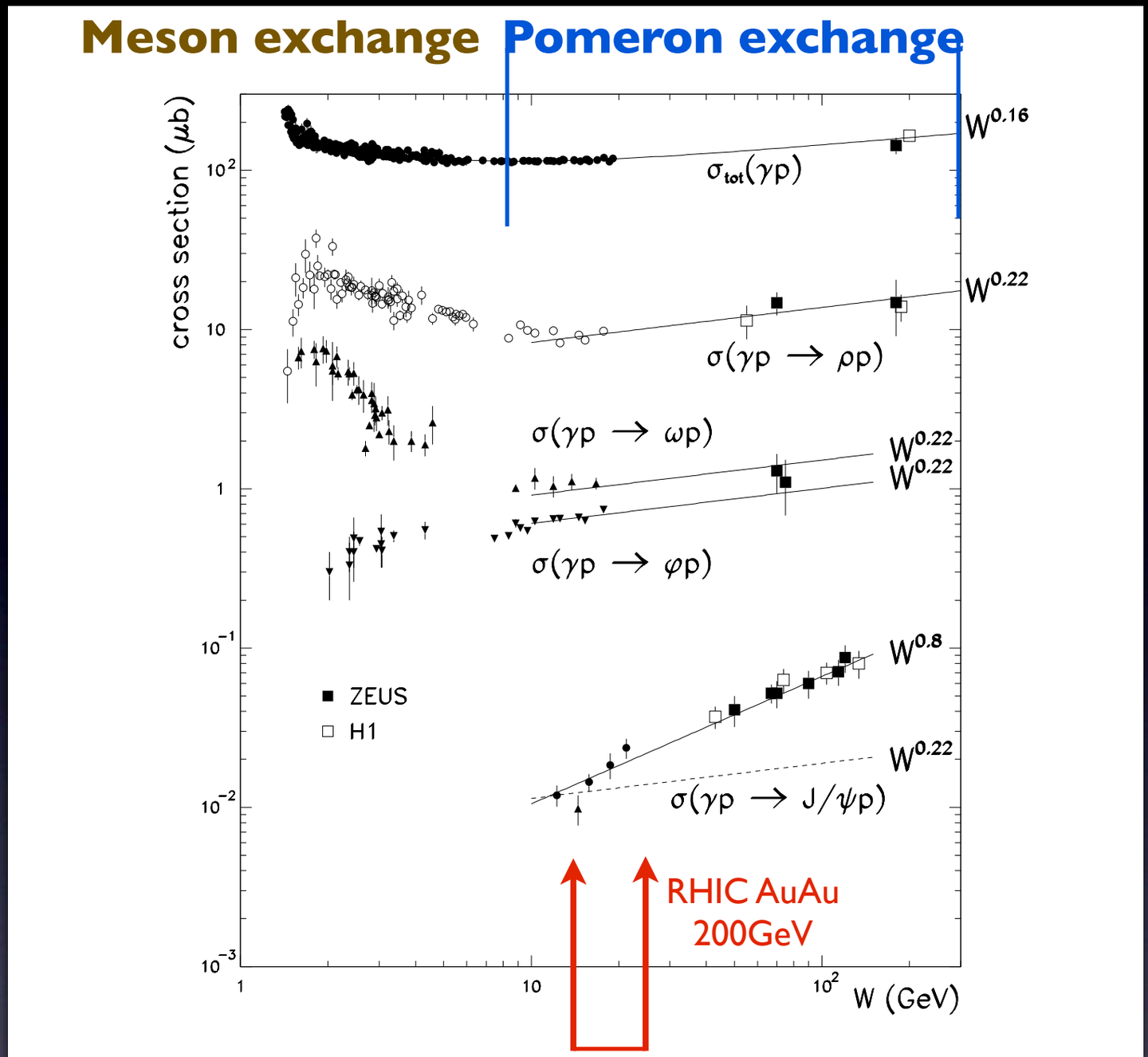
The average value of the Pomeron x is ~0.002 (according to event generator Sartre

INT-PUB-11-034, **arXiv:1108.1713 [nucl-th]**)

Minimum γ energy to produce a ρ at rest: 0.5GeV

W_{min}~14GeV

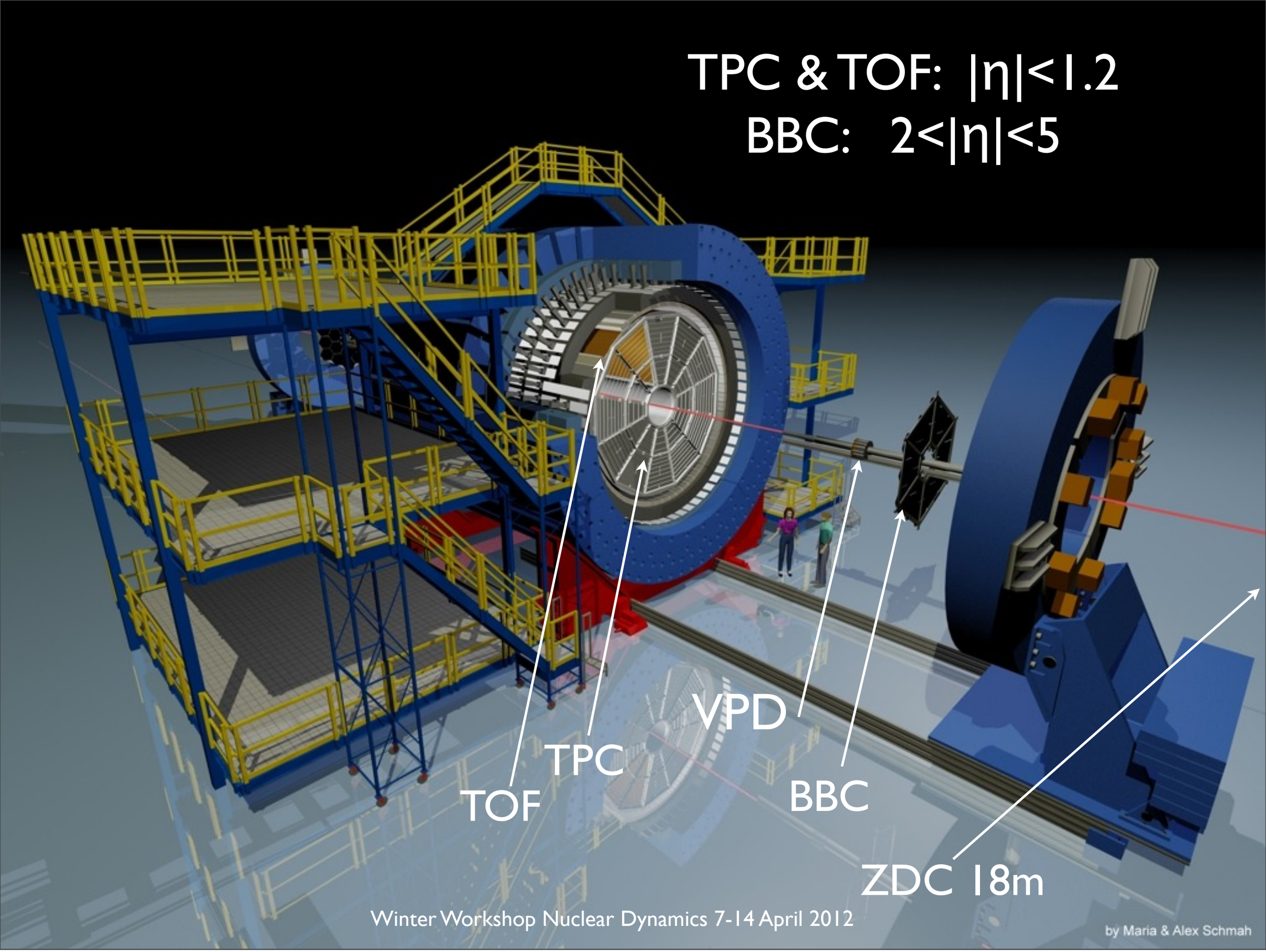
We argue that at RHIC energies we are well into a Pomeron dominated region. Even though they may be "soft Pomerons".



J.A. Crittenden Springer Tracts in Modern Physics Volume 140 (Springer, Berlin, Heidelberg, 1997)

TPC & TOF: $|\eta|<1.2$

BBC: $2<|\eta|<5$



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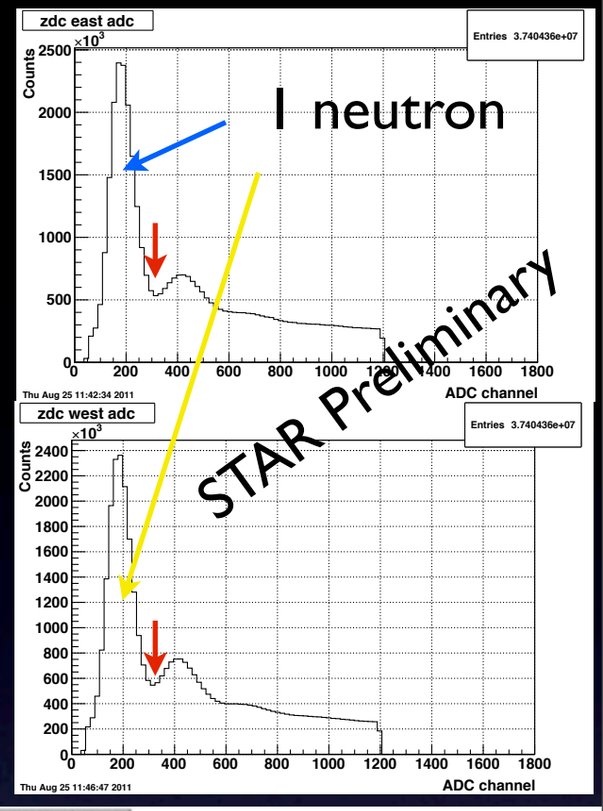
by Maria & Alex Schmah

Data selection

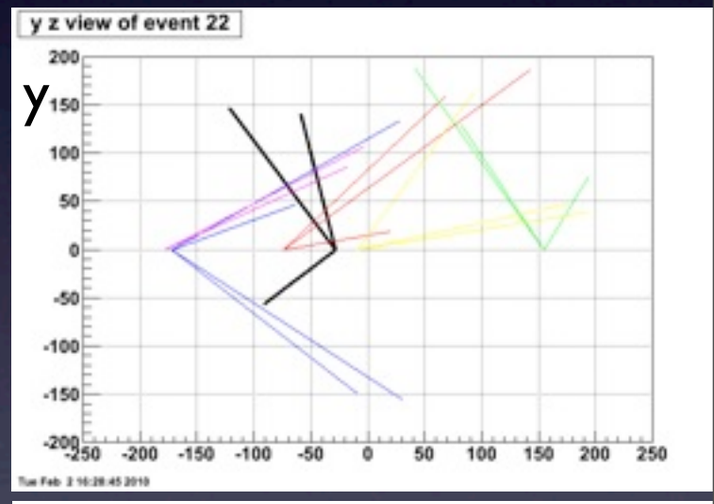
The majority of our ρ events were collected with the UPC_Main trigger.

For this analysis we demand:

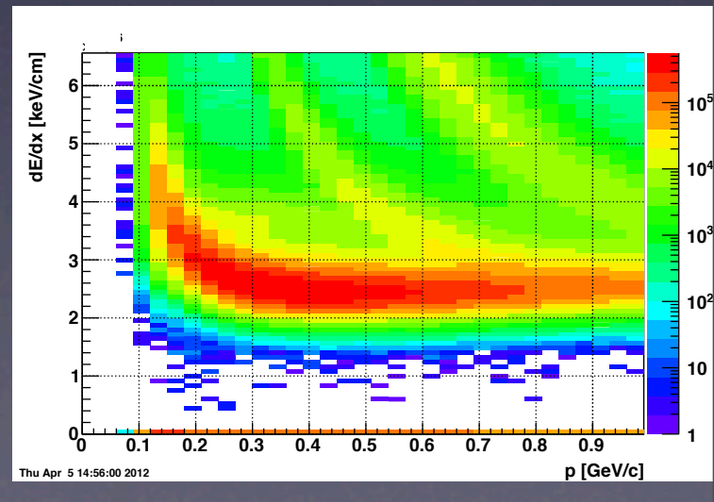
a) Only one neutron in each ZDC:



b) Connect vertex to TOF trigger to eliminate pile-up events:

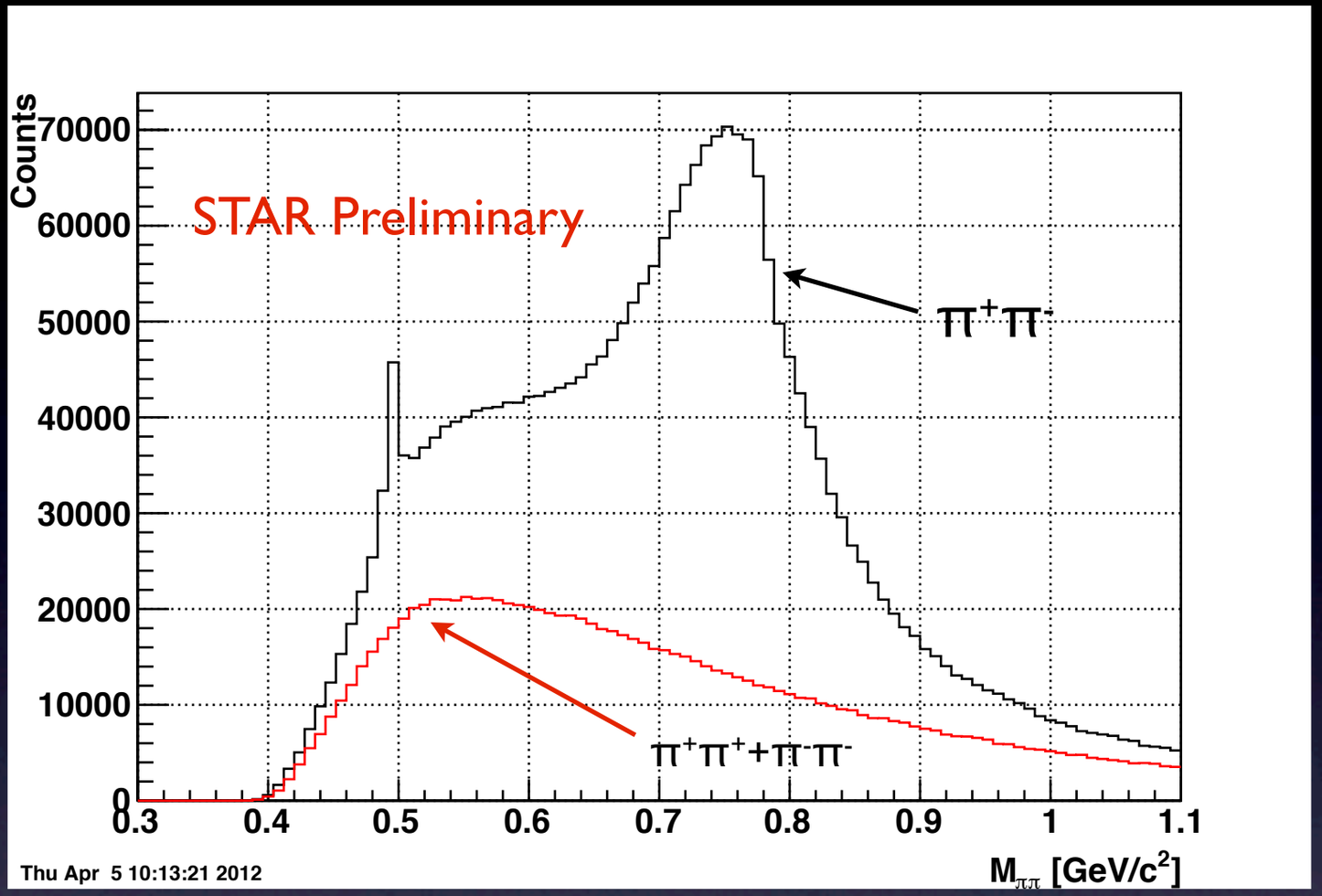


c) Select pions with TPC dE/dx:



d) Only two tracks out of selected vertex. Exclusive production.

The ρ meson reconstruction



a)Pion pairs from selected vertex

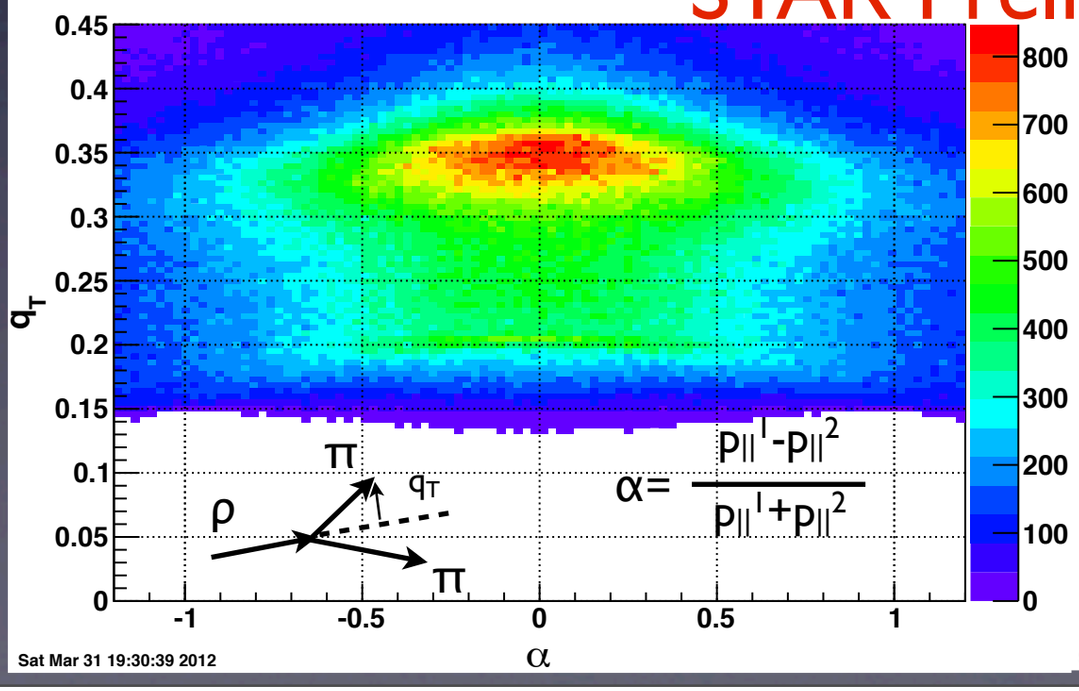
b) At least one track matches a TOF hit.

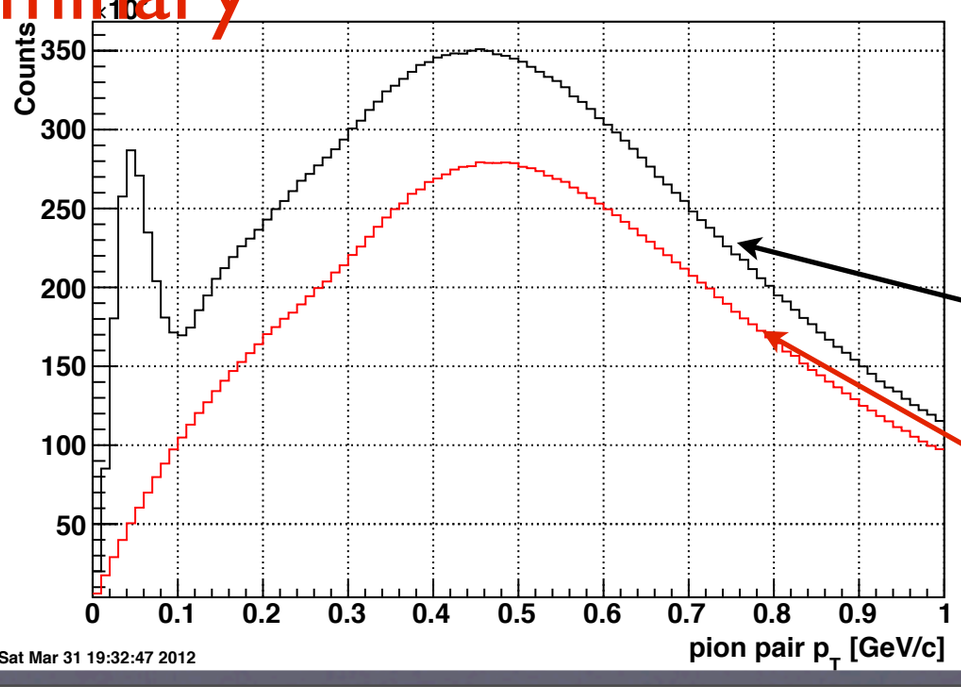
c) At least 14 hits in TPC (45)

2.82 million ρ candidates

Background shape and magnitude obtained from equal charge pion pair distribution.

STAR Preliminary

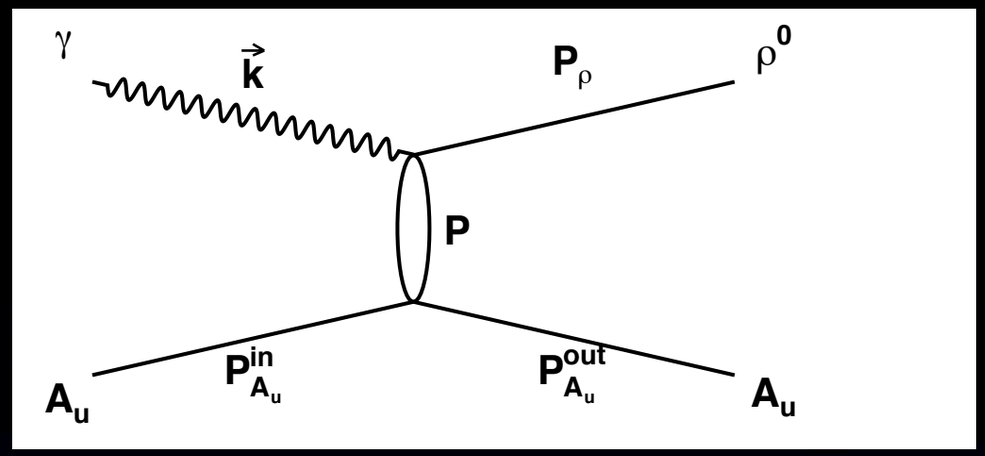


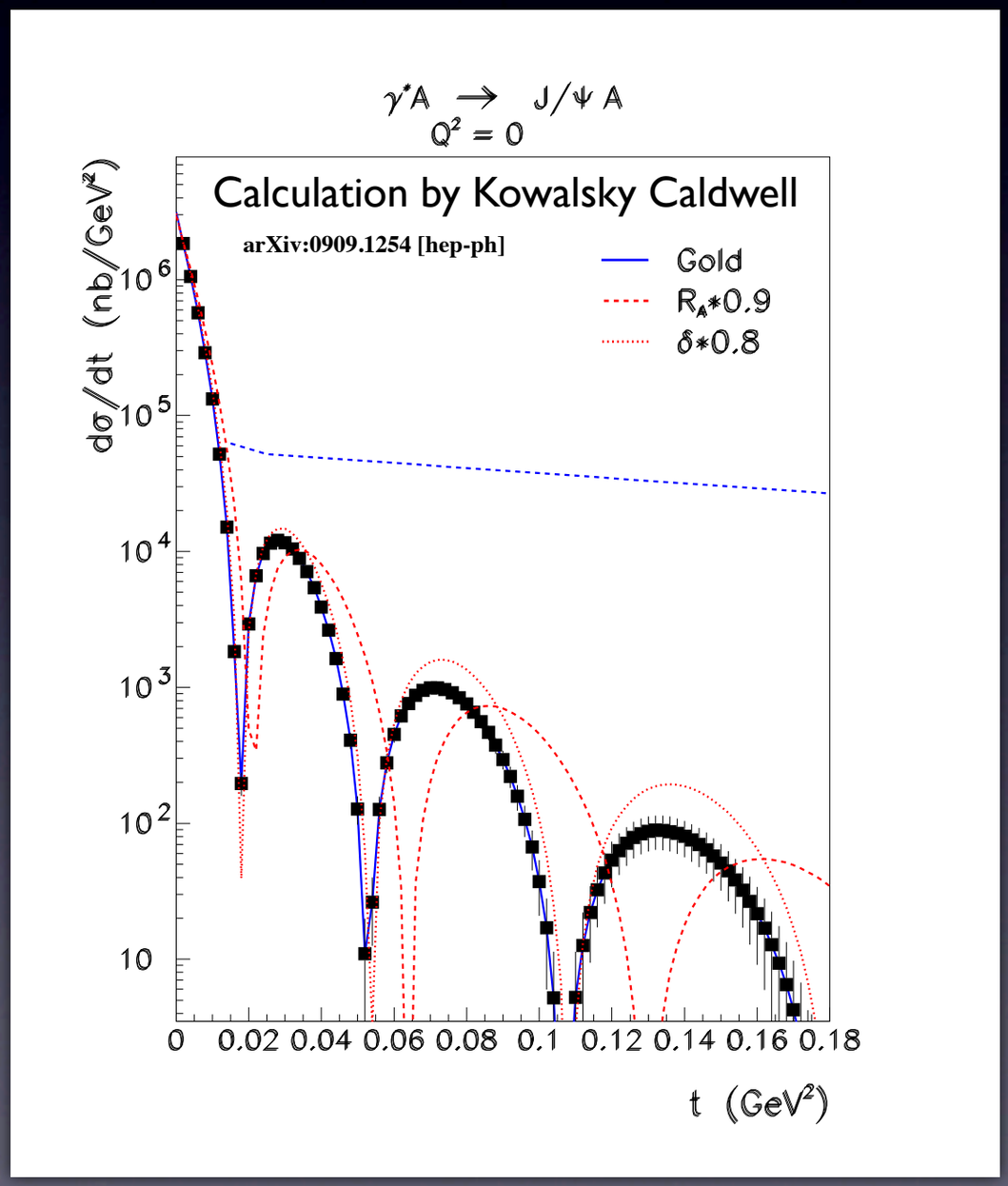


To first order, the photon has no transverse component and the ρ transverse momentum balances that of the recoiling Au nuclei. We are thus measuring the p_T imparted to the Au nuclei.

As preparations are made to design a physics program for an EIC we place our result in the context of future studies of nucleons and nuclei.

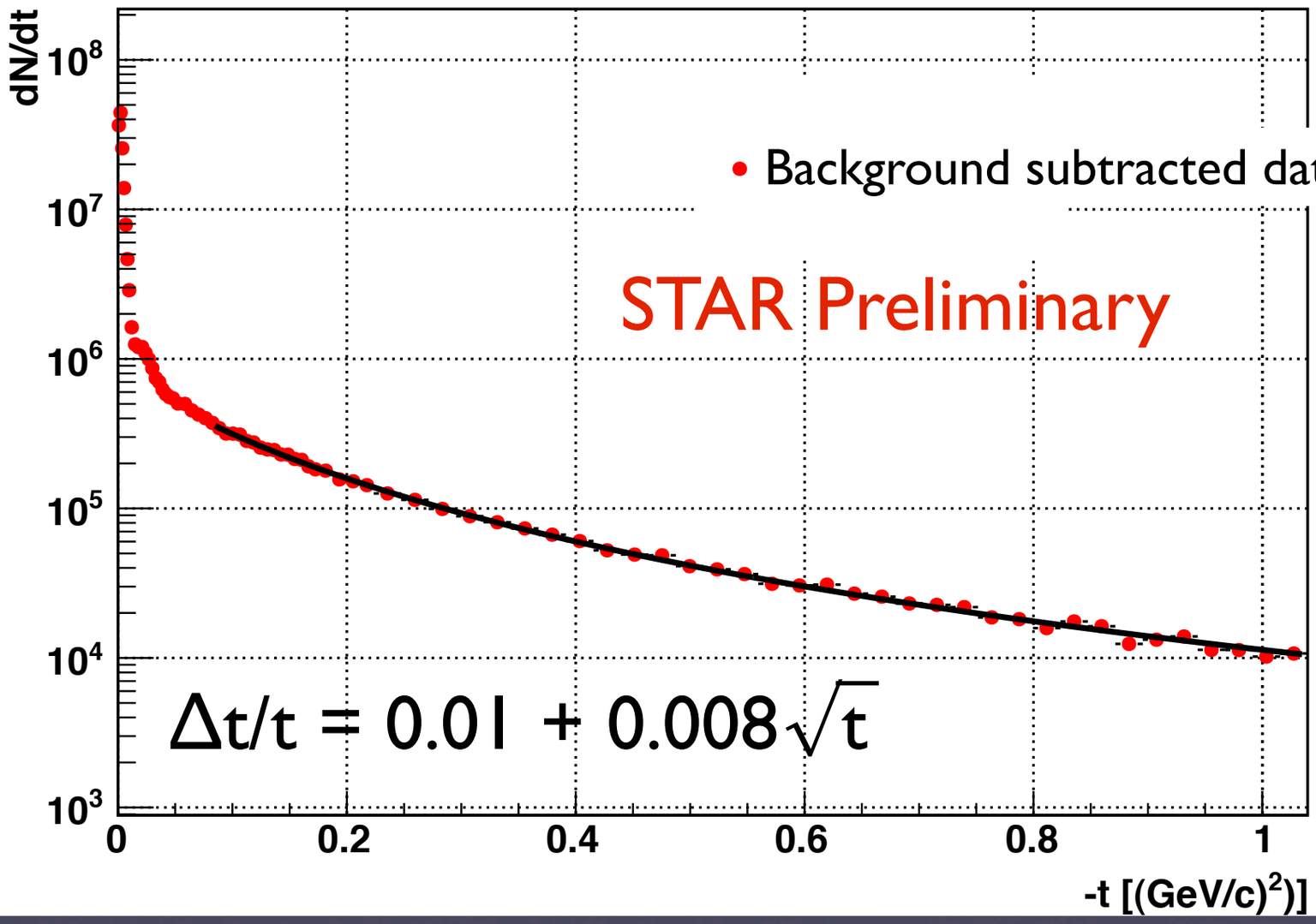
In particular, GPDs with the addition of t (which is reciprocal to b) besides Q^2, x.





Generation of the $d^2\sigma/dydt$ distribution

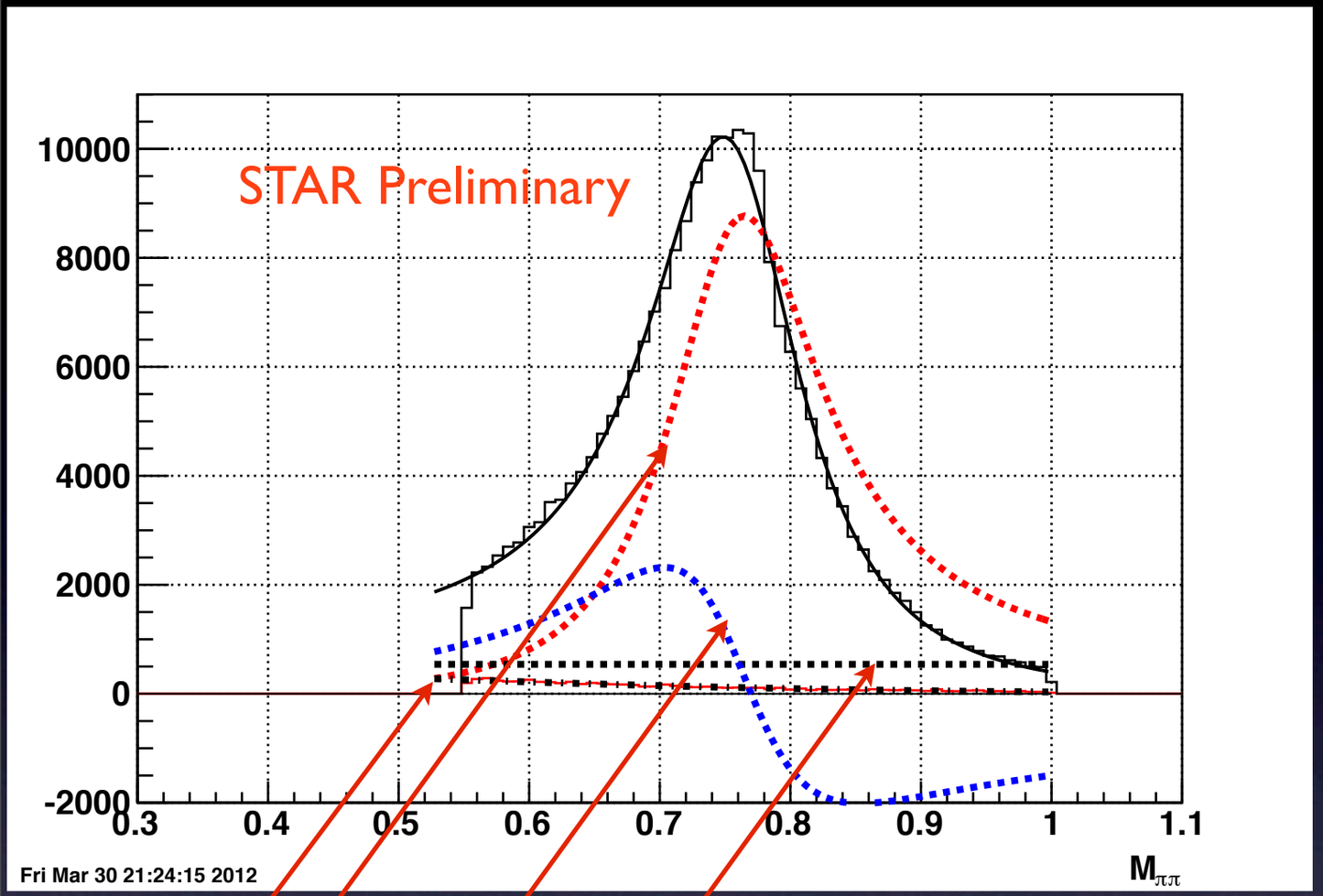
Background subtracted distribution



The dN/dt ($t=-p_T^2$) is built with opposite sign pion pairs. Similar distribution is formed with equal sign pion pairs (++ --) and is taken as a good approximation of the shape and magnitude of the background.

Above figure shows the result of the background subtraction dN^{+-}/dt - dN^{++--}/dt. The incoherent component is then fit to a power law function (black curve). $A/(1+t/p_0)^n$ $p_0=0.23\pm0.1$ $n=2.8\pm0.4$

Pion pair interference



From first t bin

The ρ meson production happens along with pion pair production; there is thus an interference term that has to be included in the final ρ detection:

$$\frac{dN}{dM_{\pi^+\pi^-}} = \left| A\frac{\sqrt{M_{\pi^+\pi^-}M_{\rho^0}\Gamma_{\rho^0}}}{M^2_{\pi^+\pi^-} - M^2_{\rho^0} + iM_{\rho^0}\Gamma_{\rho^0}} + B \right|^2 + f_p$$

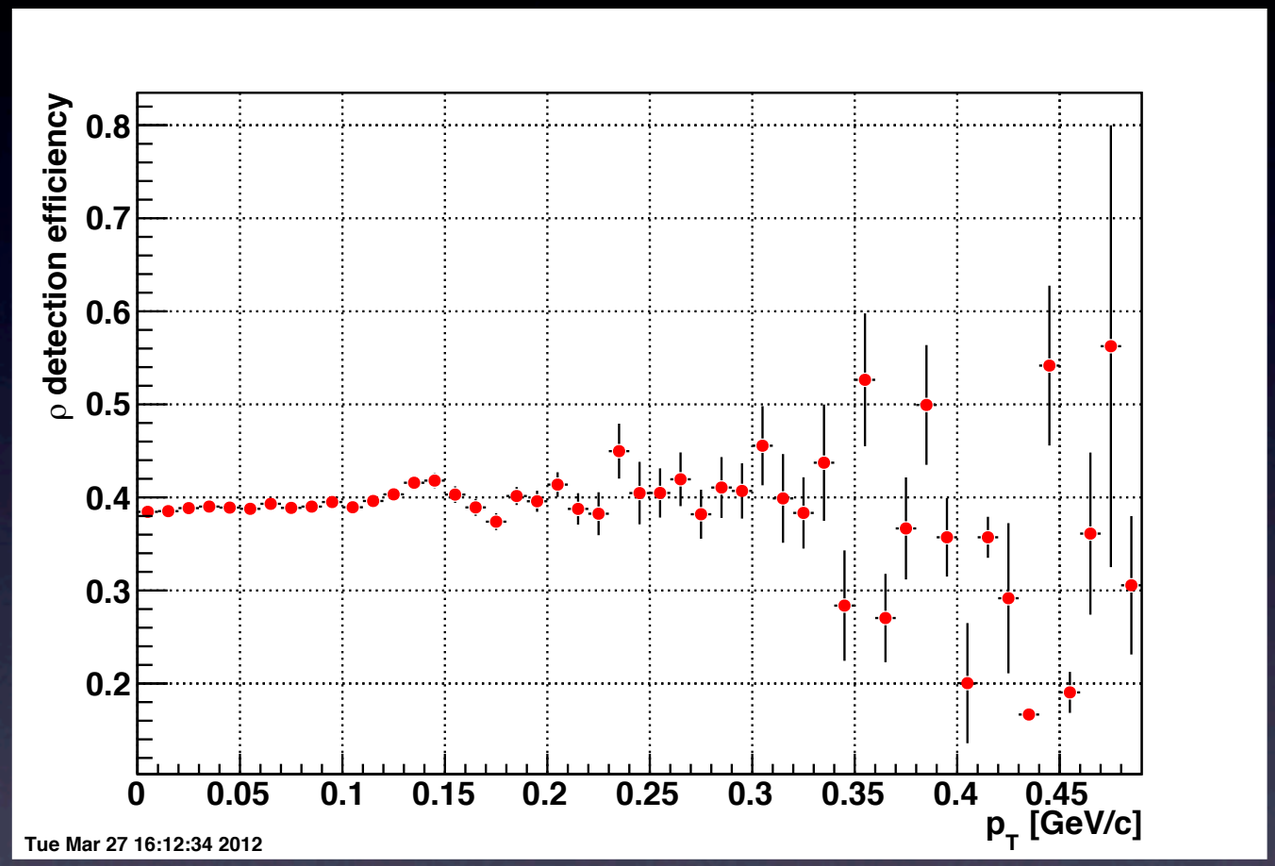
$$\Gamma_{\rho^0} = \Gamma_0 \cdot (M_{\rho^0}/M_{\pi^+\pi^-}) \times \left[(M^2_{\pi^+\pi^-} - 4m^2_\pi)/(M^2_{\rho^0} - 4m^2_\pi)\right]^{3/2}$$

Small (~20%) constant in t correction applied to dN/dt to remove the pion continuum entries from the invariant mass distributions.

Normalization

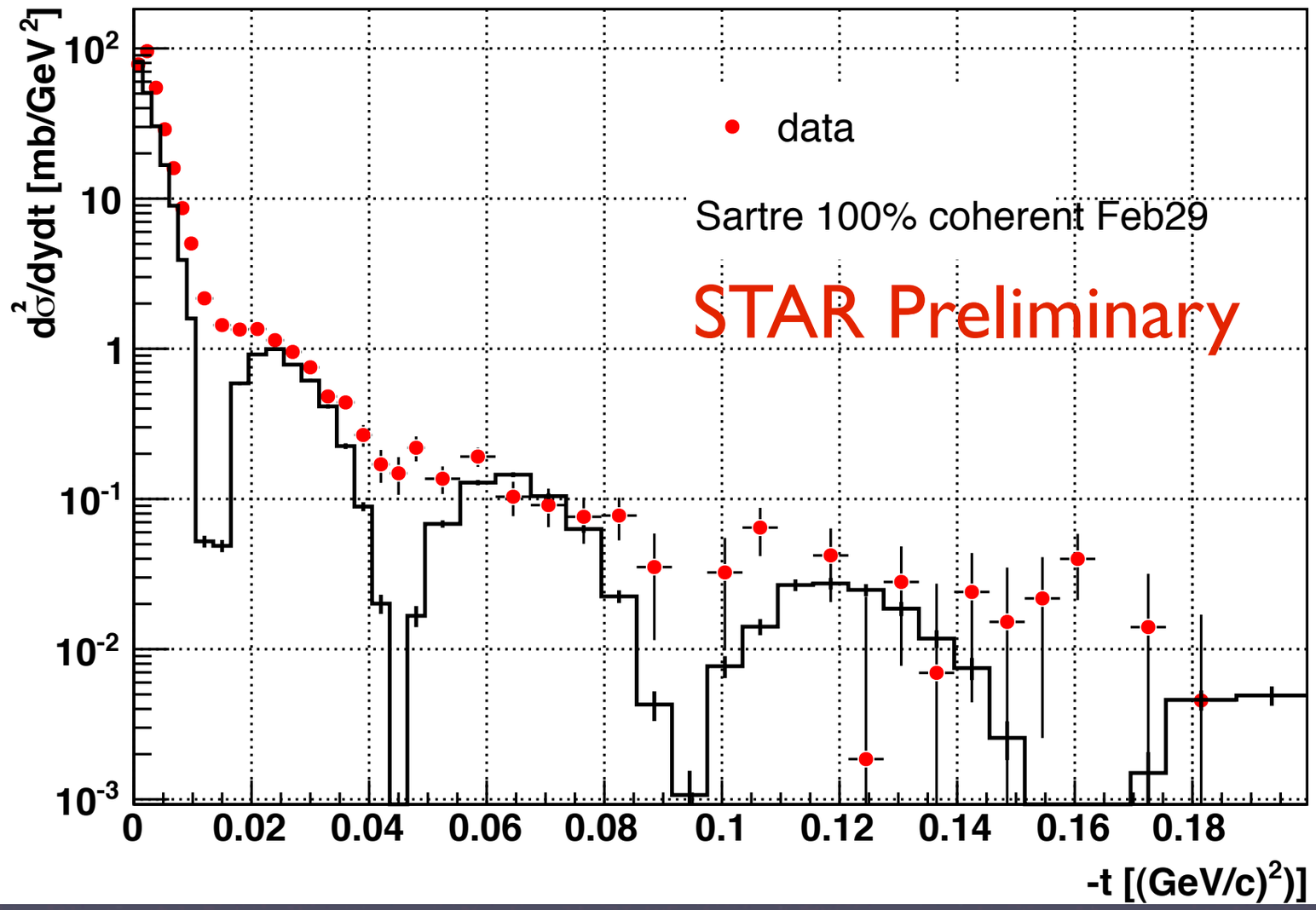
Luminosity from min_bias : 0.679 nb^{-1} Scaler counts from the "minbias_monitor" trigger uses VPD and assumes 6 b cross section.

ρ meson detection efficiency obtained from embedding of Starlight pion pair from ρ into zero-bias events: averaged over -1<η<1



Division by bin width, Δy and trigger scale down

Diffractive pattern produced by elastic ρ scattering off Au nuclei



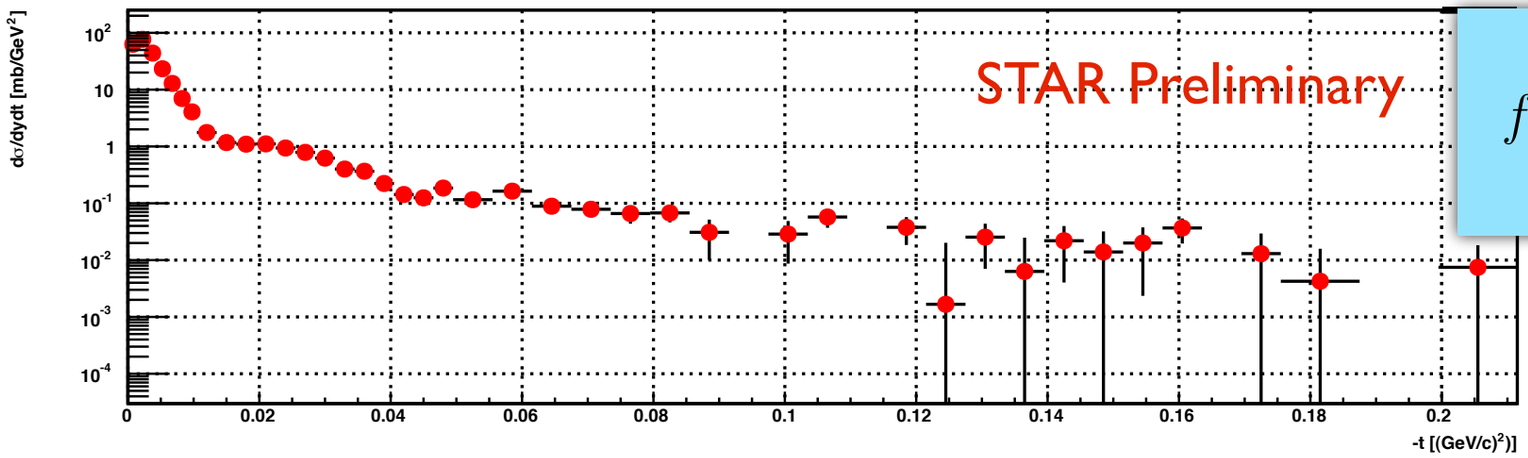
The diffraction pattern is evident up to its third peak, the slope of the first peak as well as the location of the peaks is consistent with the coherent interaction with an object with dimensions comparable to the Au nuclei.

Sartre is an event generator based on an impact parameter dependent dipole model T. Ulrich and T. Toll

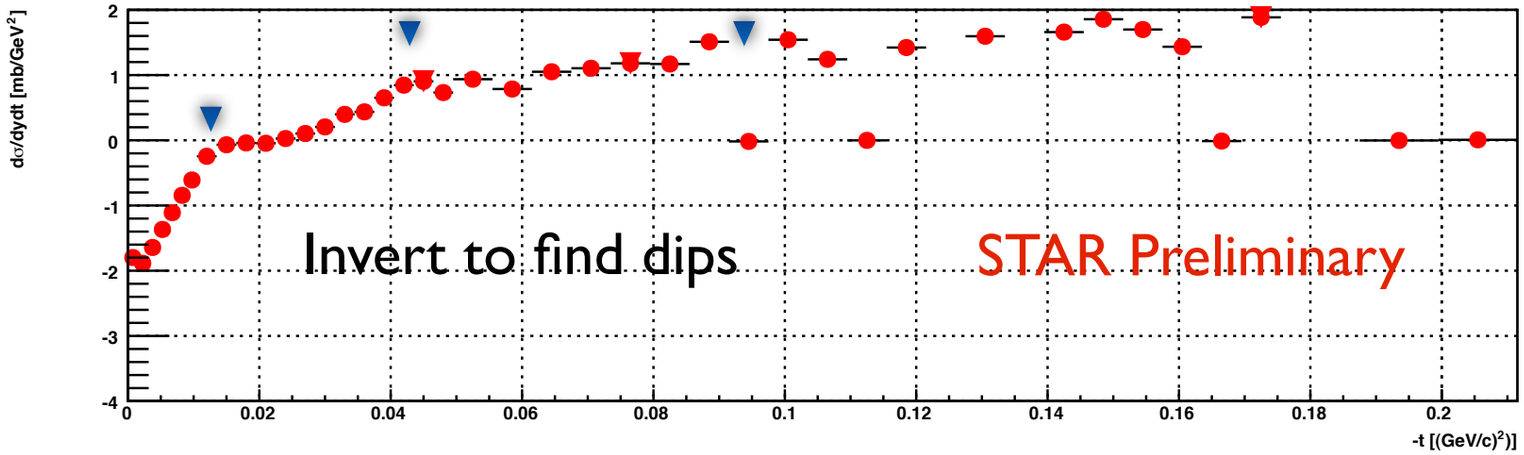
INT-PUB-11-034, **arXiv:1108.1713 [nucl-th]**

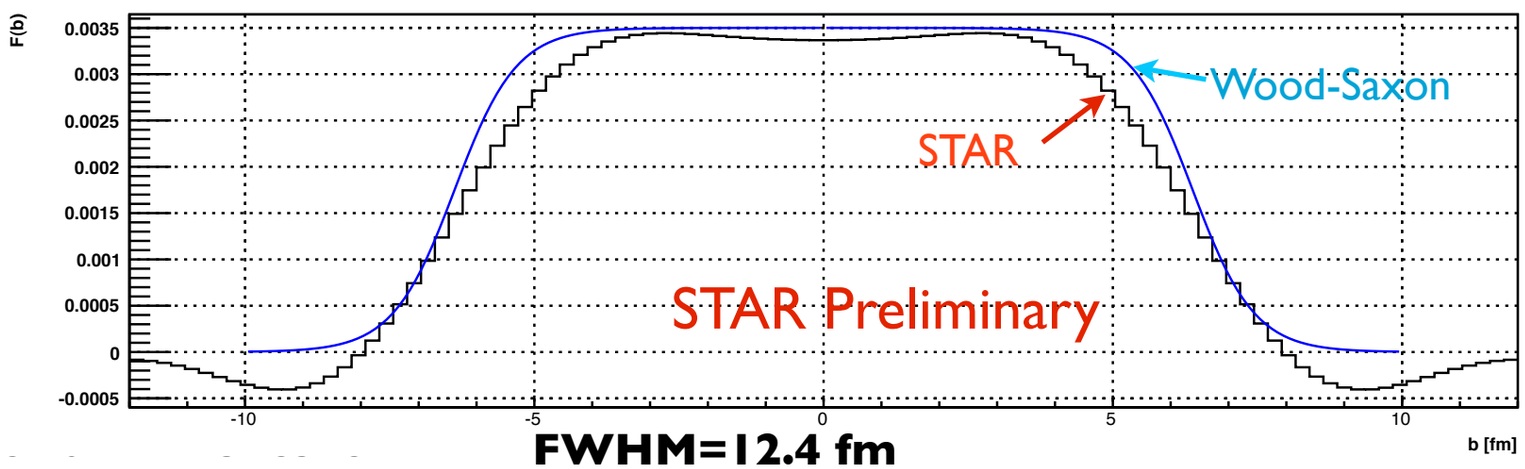
Nuclei described with Wood-Saxon R=6.38 fm a=0.53 fm

Fourier transformation of $d^2\sigma/dtdy$ relates to the partonic form factor of Au



$$f(b) = \int_0^{2\sqrt{t_{max}}} \sqrt{F(x^2)} J_0(xb/\hbar c) \frac{x}{2\pi} dx$$





Blue smooth curve is Wood-Saxon with parameters listed in table below.

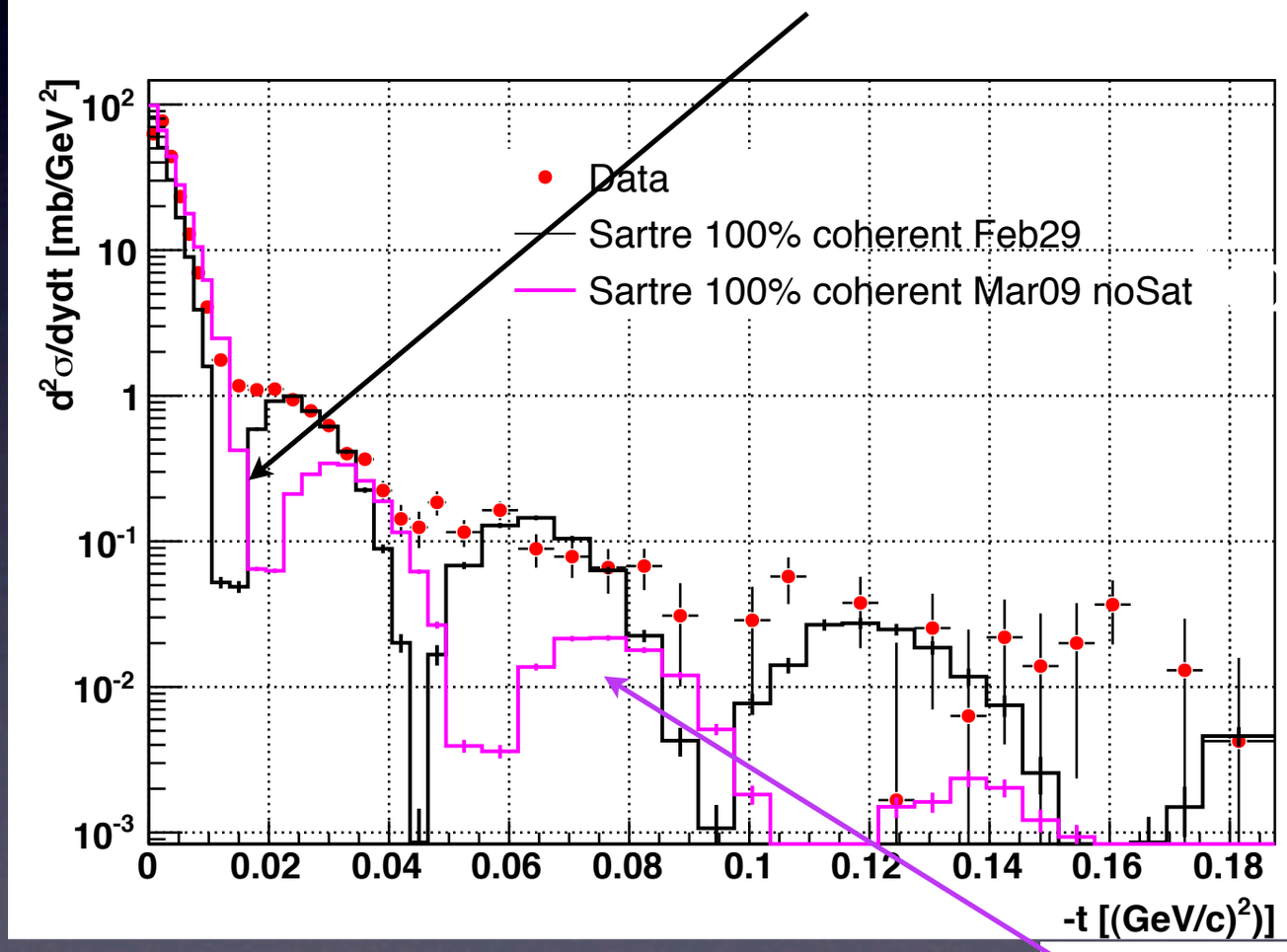
Nucleus	A	R	a	w
C	12	2.47	0	0
O	16	2.608	0.513	-0.051
Al	27	3.07	0.519	0
S	32	3.458	0.61	0
Ca	40	3.76	0.586	-0.161
Ni	58	4.309	0.516	-0.1308
Cu	63	4.2	0.596	0
W	186	6.51	0.535	0
Au	**197**	**6.38**	**0.535**	**0**
Pb	208	6.68	0.546	0
U	238	6.68	0.6	0

H. DeVries, C.W. De Jager, C. DeVries, 1987
ATOMIC DATA AND NUCLEAR DATA TABLES 36,495536 (1987)

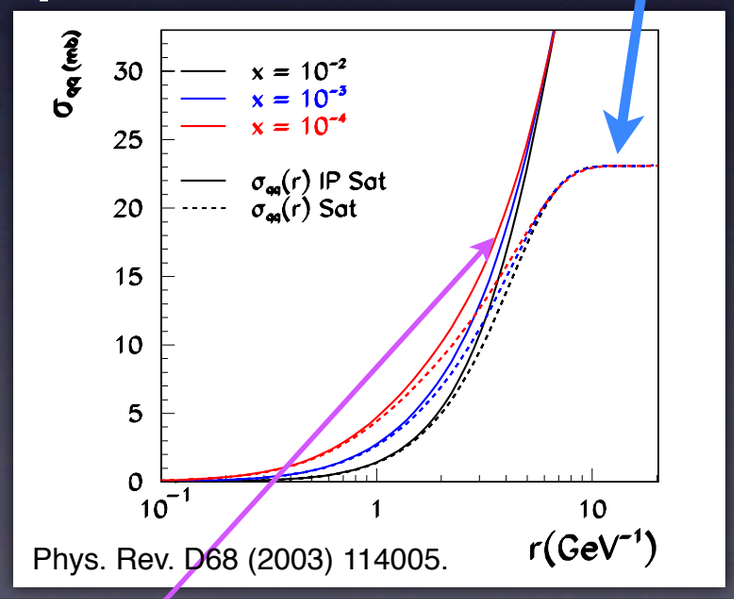
Comparison to calculations.

$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \boldsymbol{\Delta}) = i \int \mathrm{d}^2\mathbf{r} \int \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} \left(\Psi_V^* \Psi\right)(r, z) e^{-i\mathbf{b}\cdot\boldsymbol{\Delta}} \frac{\mathrm{d}\sigma_{q\bar{q}}^{(p)}}{\mathrm{d}^2\mathbf{b}}(x, r, \mathbf{b})$$

$$\frac{\mathrm{d}\sigma_{q\bar{q}}^{A}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) \sum_{i=1}^{A} T_p(\mathbf{b} - \mathbf{b}_i)\right)\right]$$



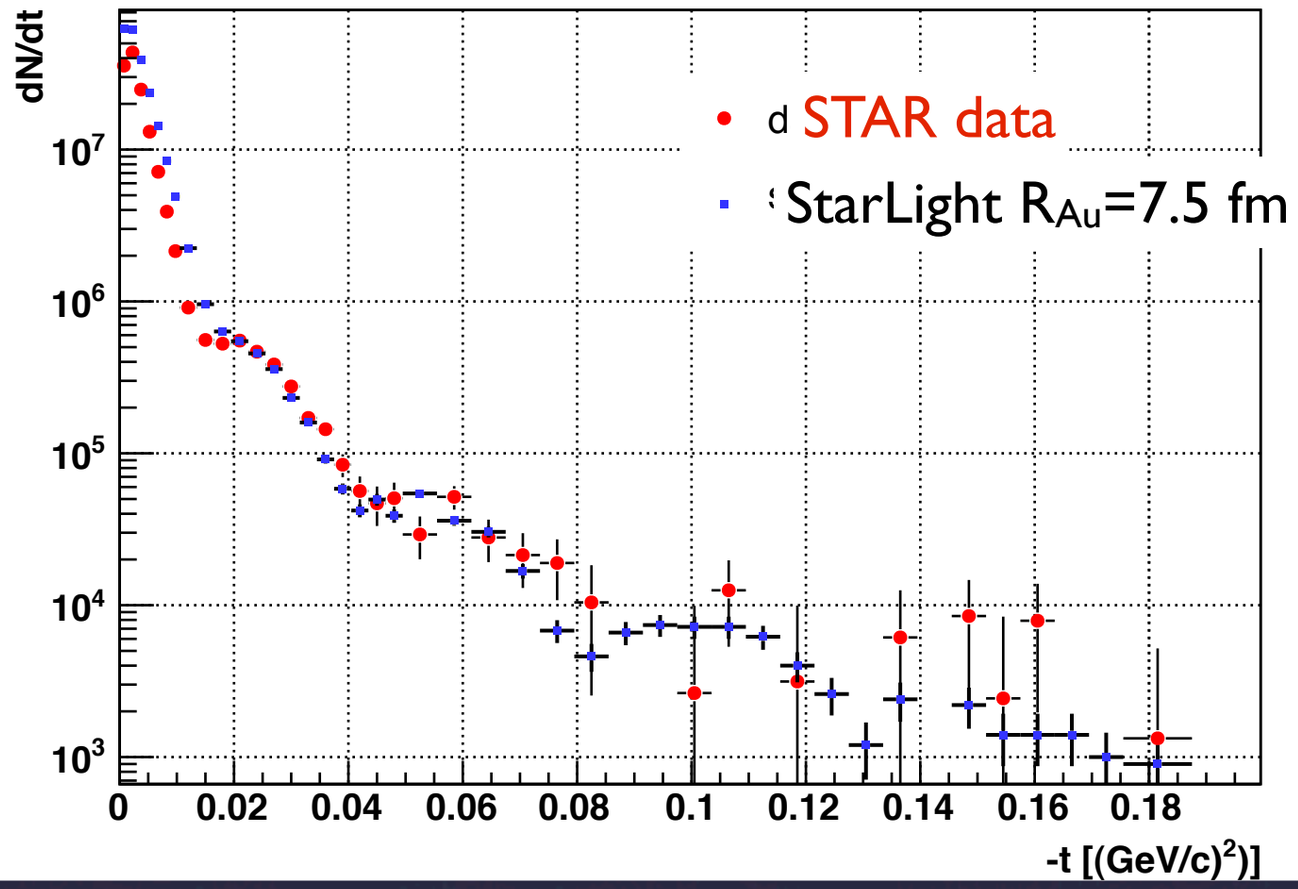
The details of this diffraction pattern will constrain the models dipole cross section.



Phys. Rev. D68 (2003) 114005.

$$\frac{\mathrm{d}\sigma_{q\bar{q}}^{(A)}}{\mathrm{d}^2 b} = \frac{\pi^2}{N_C} r^2 \alpha_s(\mu^2) x g(x, \mu^2) \sum_{i=1}^{A} T(|\mathbf{b} - \mathbf{b}_i|)$$

Comparison to StarLight



StarLight: Object-oriented simulator of $\gamma\gamma$ or γp interaction in UPC events.

From our presentation at the last DNP:
StarLight required R_{Au}=7.5 fm to match the data. The authors are working on an improved version to bring the radius back to ~6 fm

StarLight doesn't have deep valleys between diffraction peaks because it allows for a transverse component in the photon momentum.

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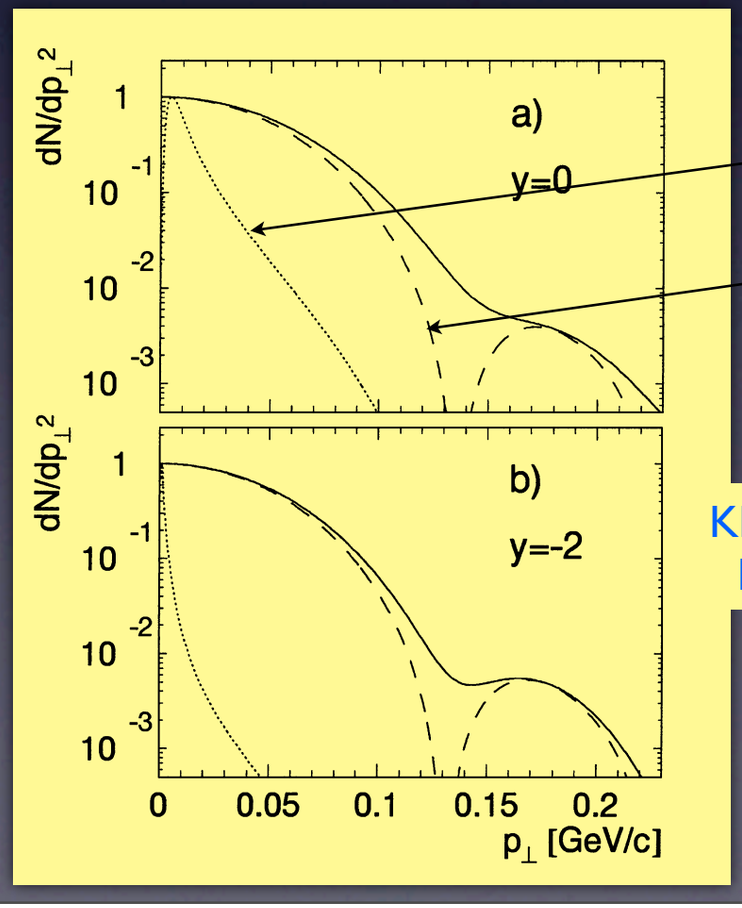
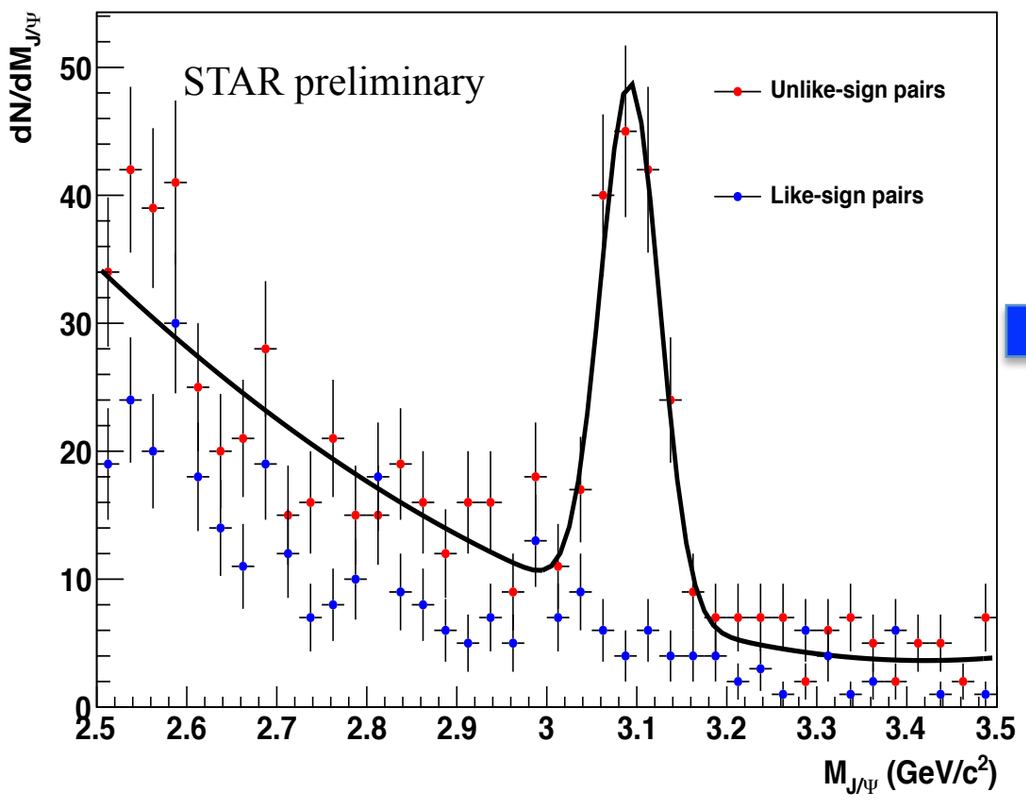
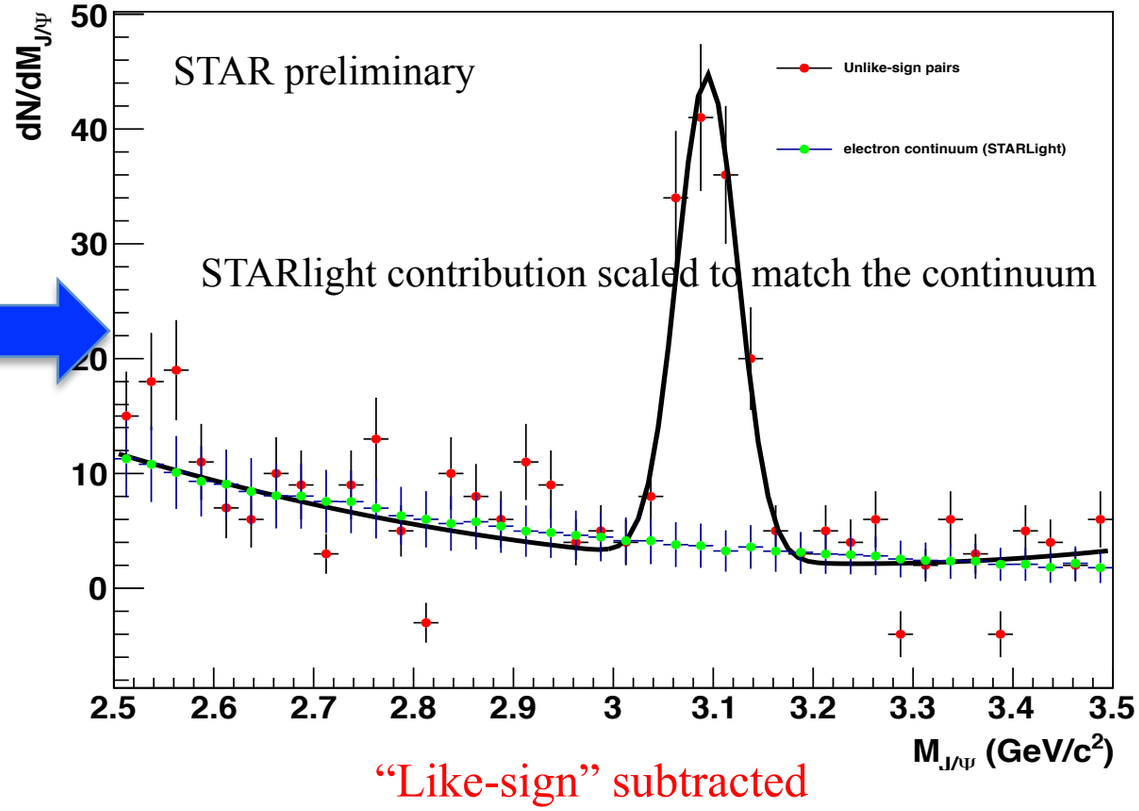


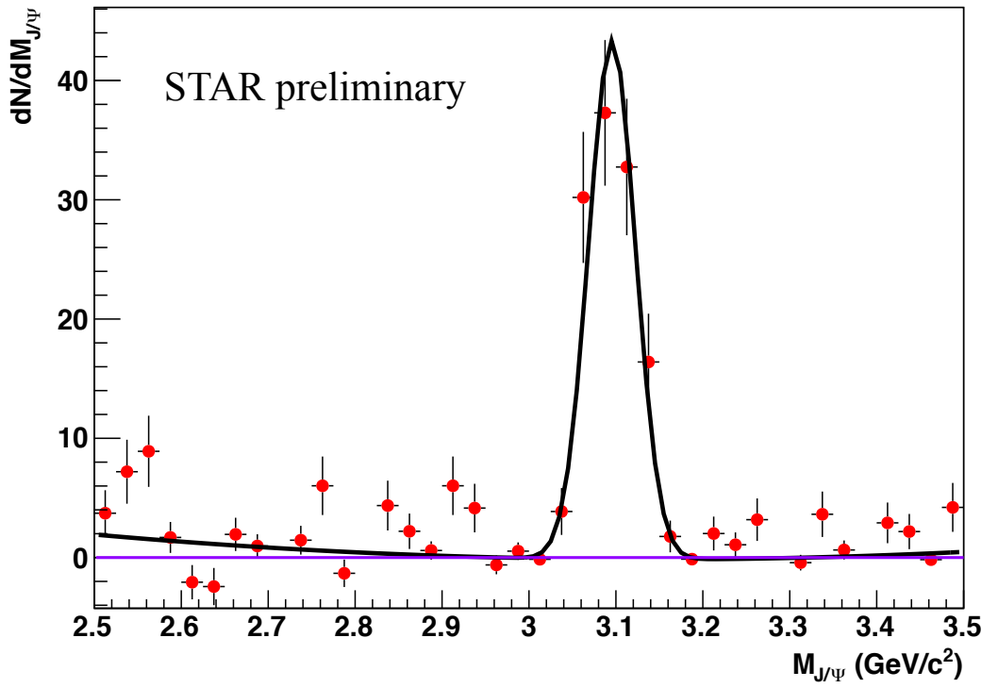
Klein Nystrand PRL84 2330

J/Ψ Inv.mass Distribution





"Like-sign" subtracted



Gaussian for J/Y signal and polynomial for remaining background

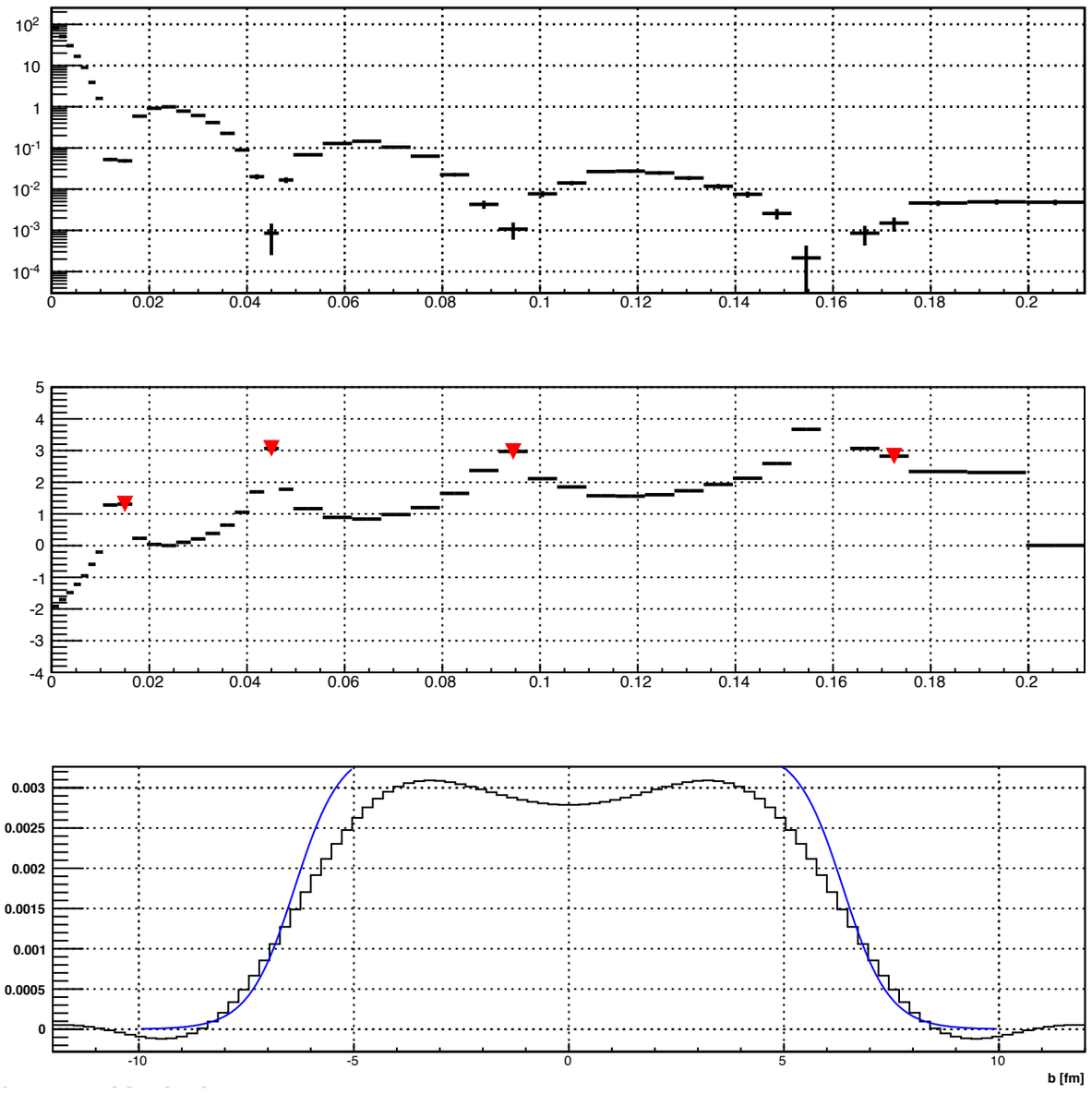
~113 events in the peak

Summary

- The STAR UPC program has collected a big sample of events with exclusive ρ production.
- We have been able to separate the events where the ρ meson scatters coherently from the entire Au nuclei.
- This result foretells an easier task in future eA studies where similar measurements were expected to be swamped by the incoherent component of the scattering.
- We will soon complement this dataset with a similar size set collected in run 11.

Backups

bSat



noSat