J/ψ in UPC @ STAR

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For the STAR Collaboration

DIS2016
DESY, Hamburg

- Ultra Peripheral Collisions (UPC)
- New results: UPC J/ψ in AuAu
  - STAR detector, data selection
  - J/ψ signal
  - cross sections vs. rapidity: model comparison
  - cross sections vs. p_T: coherent/incoherent components
- Future studies: UPC J/ψ in polarized p↑p↑, p↑Au
  - Generalized Parton Distributions (GPDs)
  - Access to GPD E_g ~ gluon orbital L_g
  - STAR Romans pots: final state proton measurement
  - Estimates for future RHIC runs: √s=500 GeV p↑p↑ (2017)
    √s=200 GeV p↑Au (202?)

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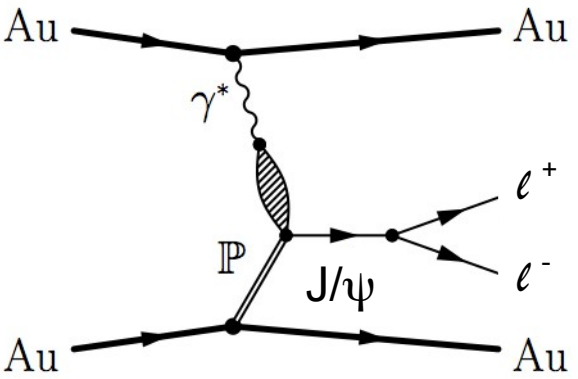
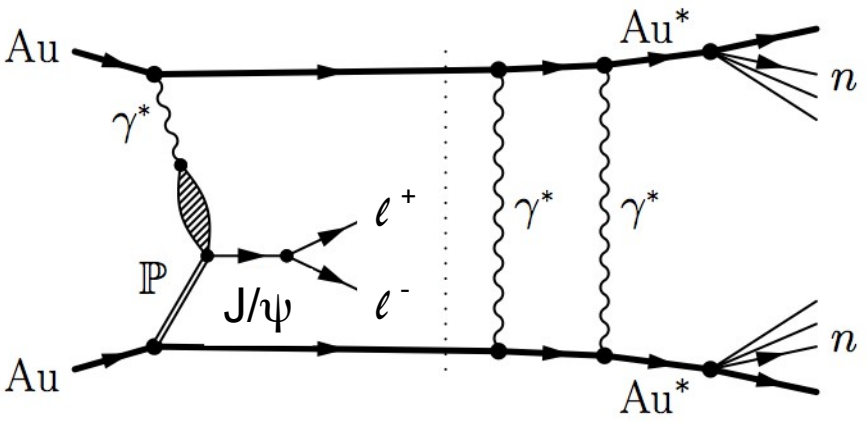
Ultra Peripheral Collisions

- High-Z nucleus, high flux Weizsaeker-Williams photons
- Photoproduction on other nucleus,
  typically VM production:
  - J/ψ production sensitive to Au gluon content



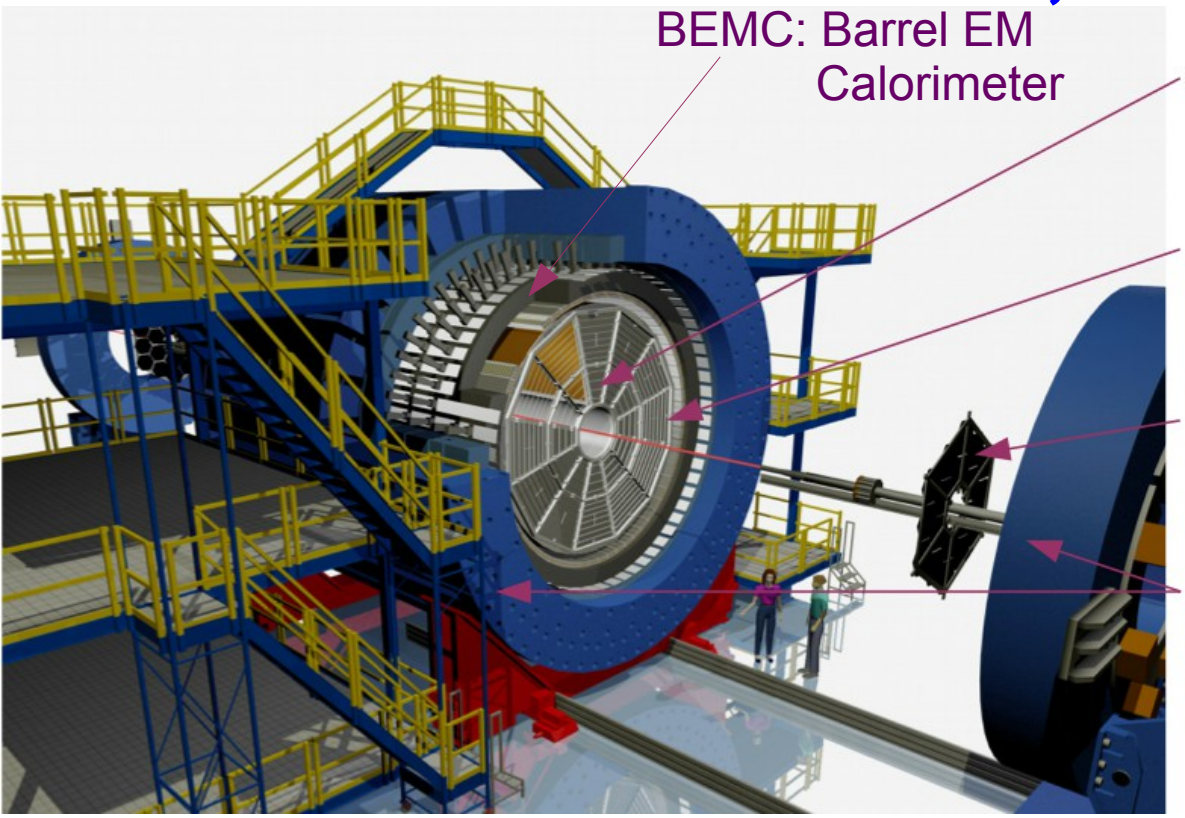
- Photoproduction can occur:
  - coherently off whole nucleus (large size, low p_T)
  - incoherently, off individual nucleons (small size, high p_T)

- Also: Coulomb excitation of nuclei,
  forward neutron production
  - ~10% total cross section
  - forward neutrons helpful for triggering



- Models: cross section estimates, acceptance corrections
  - Starlight: WW flux, Glauber photonuclear cross section,
    inclusive Coulomb excitation
  - RELDIS: estimates of #neutron spectra

STAR detector, data selection



Data set: RHIC 2010,2011

$L = 1.9\ nb^{-1}$

Trigger:

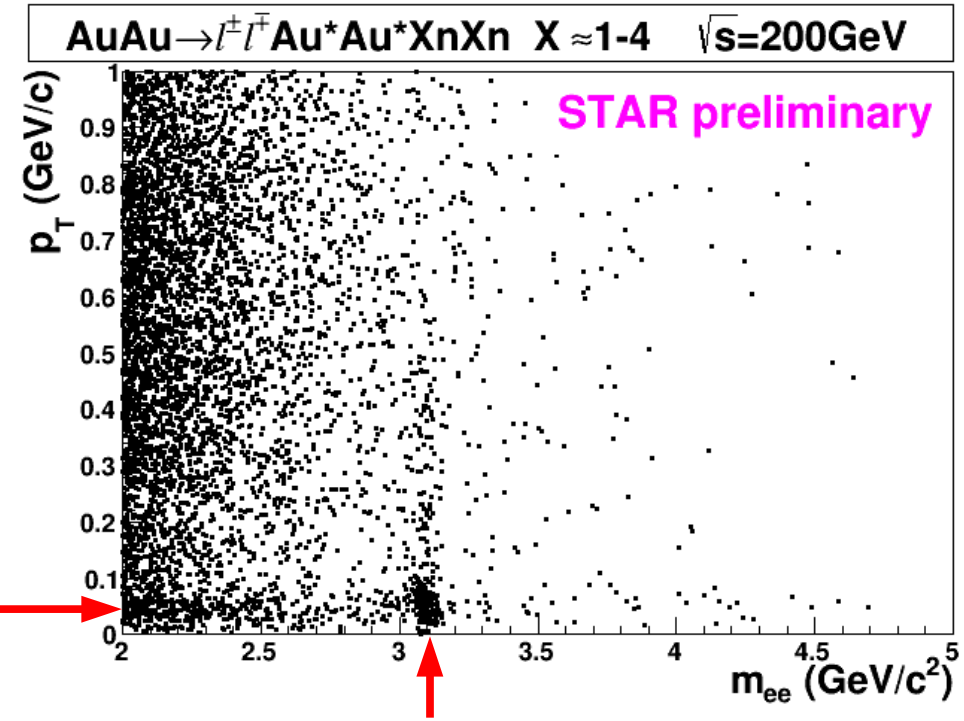
- 2-6 hits in TOF (low mult. event)
- each ZDC #neutrons ≥ 1 (define real event) & < 5 (not hadronic)
- veto BBC (reject hadronic central collisions)

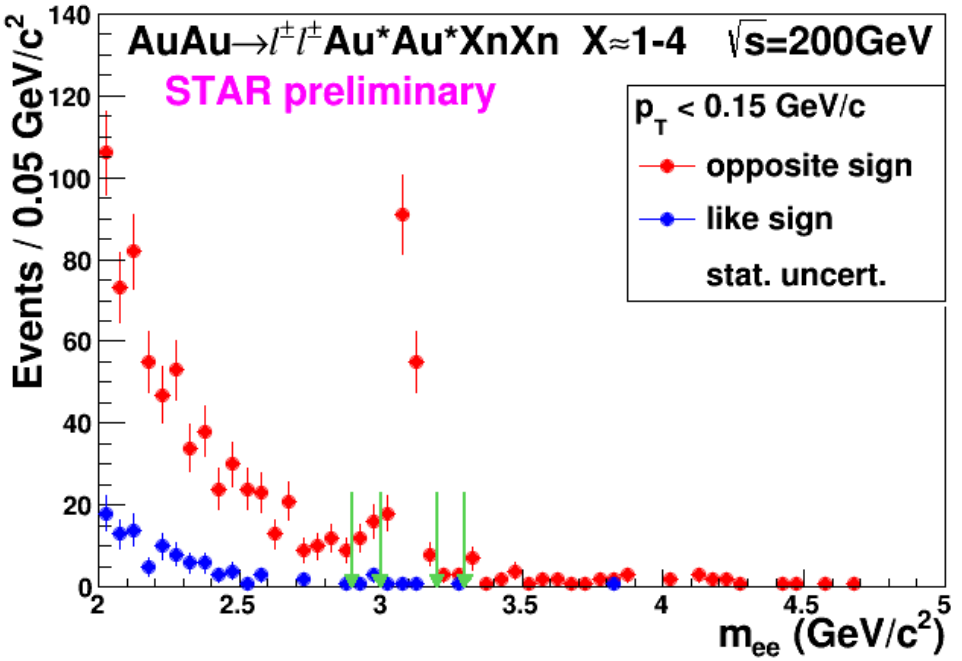
Offline selection:

- 2 tracks ≥15 hits in TPC (of 45 possible, well reconstructed)
- Tracks match hits in TOF (trigger requirement, in-time tracks)
- Vertex in STAR center, 2 or 3 tracks (low mult. event)
- Reject pair rapidity $|y|<0.02$ (cosmics)

Pair mass, p_T distributions

- Selections give sample of $J/\psi \rightarrow e^+e^-, \mu^+\mu^-$:

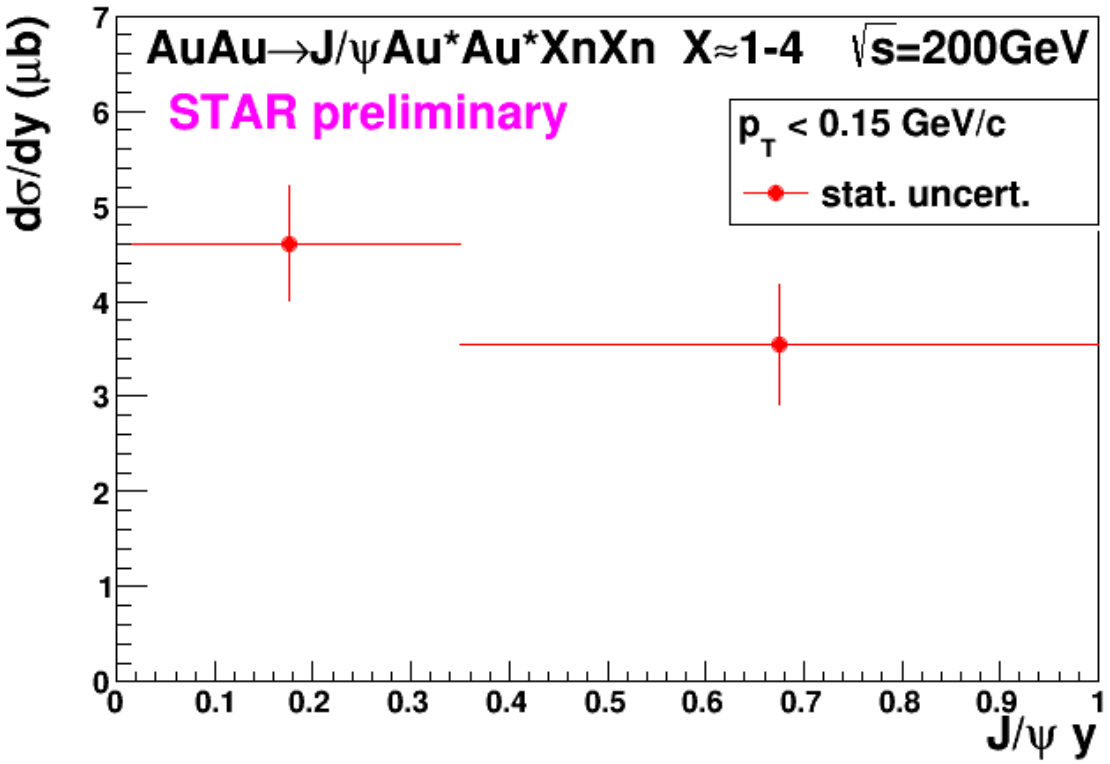




- m_{ee} proxy for pair mass,
  $m_{\mu\mu}$-m_{ee} < 10 MeV/c^2
- Band near p_T~0:
  coherent J/ψ, continuum $\pi^+\pi^-$,
  QED $e^+e^-, \mu^+\mu^-$
- Band near $m_{ee} \sim m_{J/\psi}$:
  coherent & incoherent J/ψ

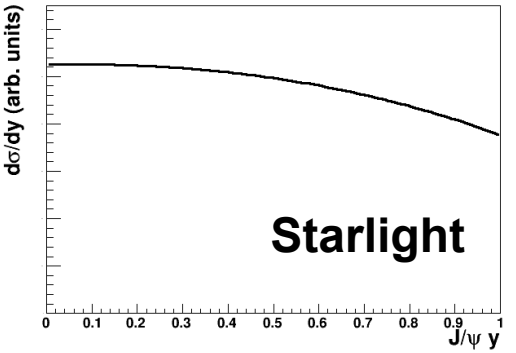
- ↓ indicate J/ψ mass peak, side bands
- Subtractions for J/ψ signal:
  - (opposite sign pairs) - (like sign)
  - (peak) – (side bands)

Cross section vs. rapidity

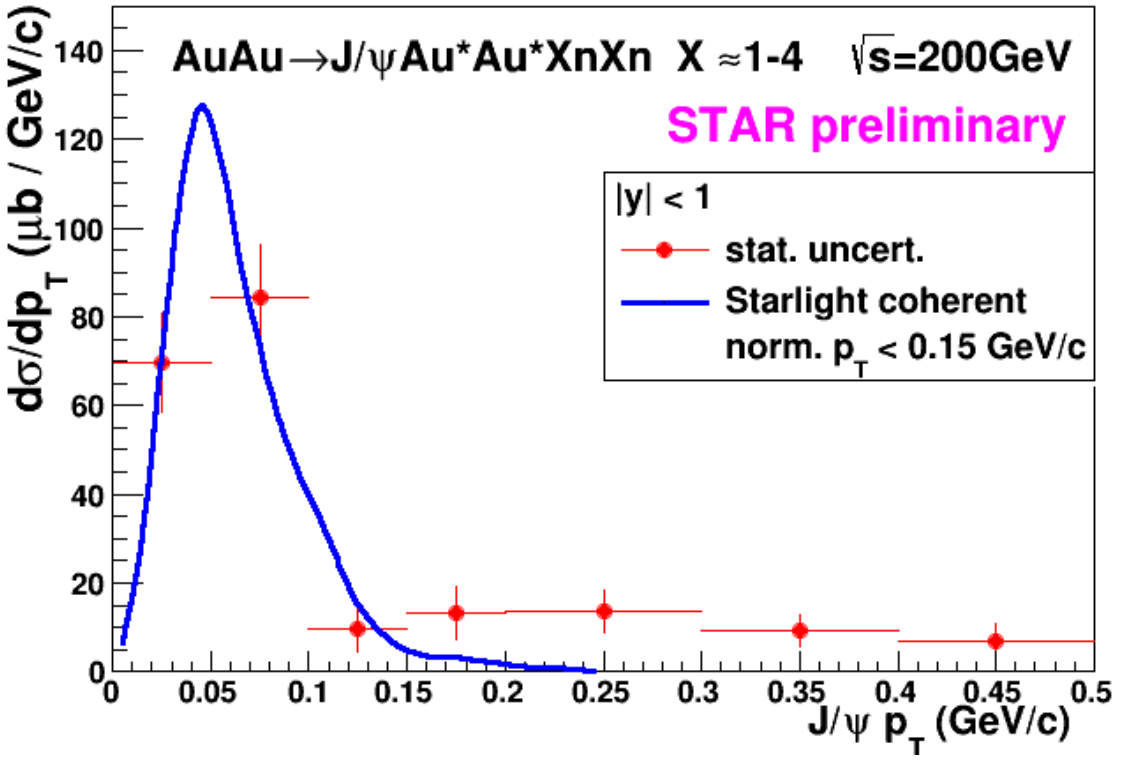


Measured for coherent region p_T<0.15 GeV/c

- Physics distribution dσ/dy symmetric under y↔-y (symmetric beams)
  Boost stat. significance: events y<0 binned |y|>0, total counts halved
- Cross section falls slowly for 0<y<1, as Starlight:
- Cross section factor ~2½ lower than
  Starlight + RELDIS XnXn→4n4n correction
  - uncertainties in Starlight Coulomb excitation
  - uncertainties in RELDIS #neutron spectra



Cross section vs. p_T



Measured for |y|<1 (STAR acceptance)

- Cross section for p_T > 0.5 GeV/c consistent with zero
- Starlight coherent normalized to data @ p_T < 0.15 GeV/c

  ⇒ dominant coherent component
- Significant incoherent component p_T > 0.15 GeV/c

  ~30% of total signal

Summary & outlook: UPC J/ψ in AuAu

Results so far:

- Clear UPC J/ψ signal
- Cross section ~2½ lower than Starlight/RELDIS expectation
- Rapidity distribution ~flat as expected
- Dominant coherent (low p_T) component, plus ~30% incoherent

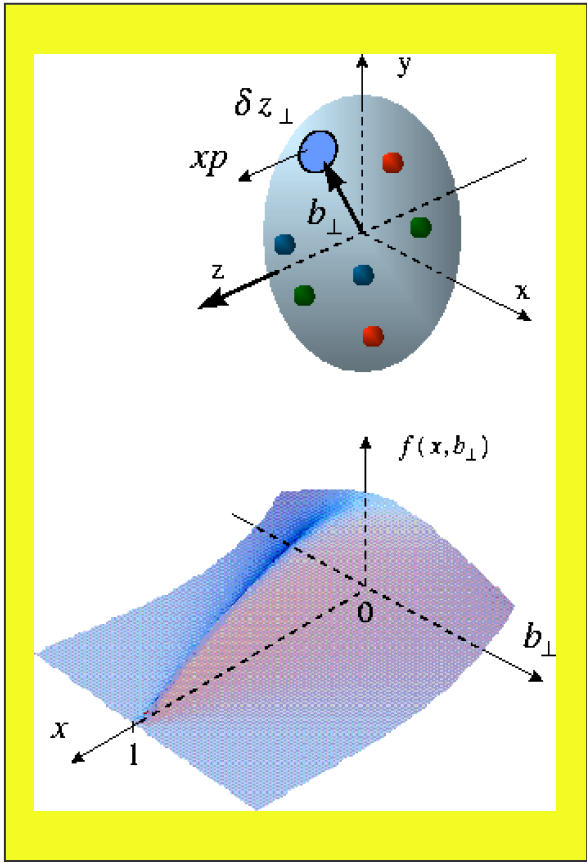
Looking ahead (beyond ~200 events here):

- RHIC Run14 data processed soon:
  - ~75% identical data sample
  - new EM calor. trigger for $J/\psi \rightarrow e^+e^-$, ~3½ larger sample
- Current RHIC Run16:
  - EM trigger quiet, drop neutron requirement, factor ~10 in σ
  - factor ~10 increase total luminosity, but lost ½ $J/\psi \rightarrow \mu^+\mu^-$

  ⇒ factor ~30-50 larger data sample coming
- Enable:
  - better cross section comparison, models w/o Coulomb dissociation
  - finer study of p_T distribution: coherent/incoherent, diffractive peaks?

Generalized Parton Distributions

- GPDs: Correlated quark momentum and helicity distributions in transverse space
- Access to:
  - 3D imaging of proton
  - *q* & *g* orbital angular momentum L_q & L_g
- GPDs characterized, for each *q*,*g:*



	unpolarized	polarized
conserve nucleon helicity →	$H^q(x,\xi,t)$	$\tilde{H}^q(x,\xi,t)$
flip nucleon helicity →	$E^q(x,\xi,t)$	$\tilde{E}^q(x,\xi,t)$

- Spin Sum Rule: $\frac{1}{2} = J_q^z + J_g^z = \frac{1}{2}\Delta\Sigma + \sum_q \mathcal{L}_q^z + J_g^z$

$$J_{q,g}^z = \frac{1}{2}\left(\int_{-1}^{1} x\,dx\left(H^{q,g} + E^{q,q}\right)\right)_{t\to 0}$$

- The GPDs $E^{q,g}$ responsible for orbital angular momentum

Generalized Parton Distributions

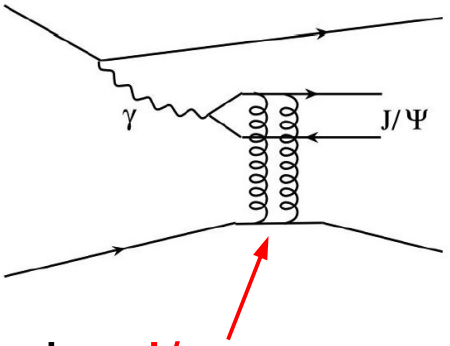
Quantum #s final state → select different GPDs

- DVCS ep → epγ: H^q E^q $\tilde{H}^q$ $\tilde{E}^q$

  $\propto \sum_q e_q^2 q$, $g \propto \partial q/\partial Q^2$
- Pseudo-scalar mesons: $\tilde{H}^q, \tilde{E}^q$

  π: $2\Delta u+\Delta d$ η: $2\Delta u-\Delta d$
- Vector mesons: H^q E^q

  ρ^0: 2u+d, 9g/4 ω: 2u-d, 3g/4 ϕ: s, g ρ^+: u-d J/ψ: g

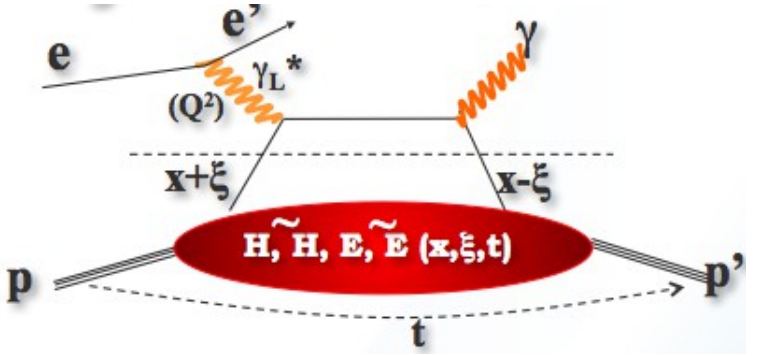


- Measure GPDs through exclusive reactions

- Golden Channel: DVCS ep → epγ

  access to all GPDs

  all kinematics measured

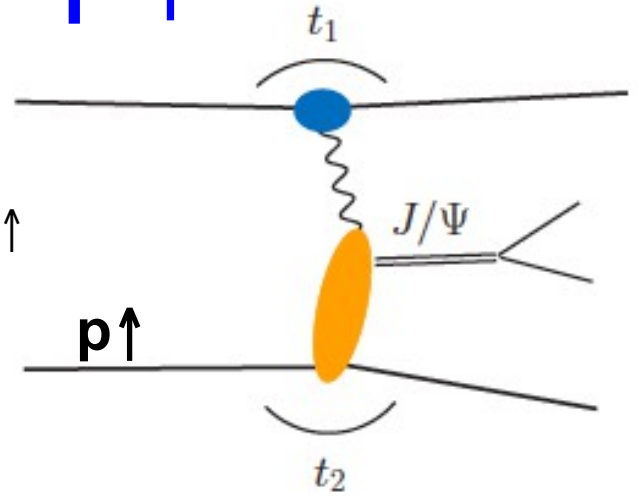


- We don't have an Electron Ion Collider yet
- But we can explore at RHIC:
  - VM production in Ultra Peripheral Collisions (UPC)
  - with polarized protons

UPC with polarized p↑

- WW photon from one beam particle
- Target particle polarized proton p↑:
  - $d\sigma/d\varphi \propto (1 + A_{UT}\cdot\cos\varphi)$, φ = J/ψ azimuthal angle w.r.t. p↑
  - measure J/ψ transverse asymmetry A_{UT}

  (Unpolarized beam γ, Transverse polarized target p↑)



- A_{UT} calculable with GPDs:

$$A_{UT}(t,t) \sim \frac{\sqrt{t_0 - t}}{m_p} \frac{\mathrm{Im}(E^* H)}{|H|} \qquad t = \frac{M^2_{J/\Psi}}{s}$$

$A_{UT} \propto E_g \Rightarrow$ sensitive to gluon orbital angular momentum L_g

Scales:

- This is photoproduction, with $Q^2 \sim 0$
- But for VM the resolution scale is

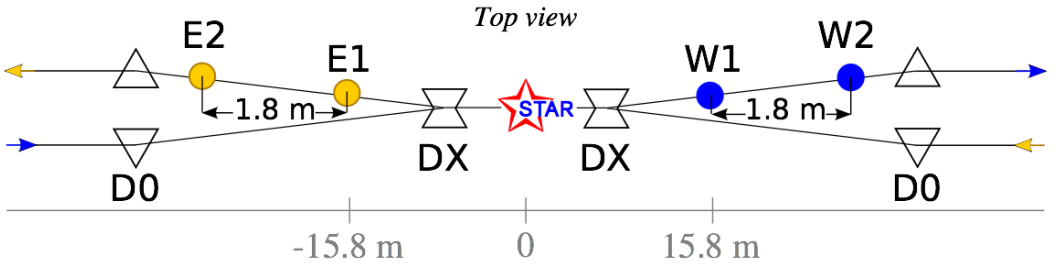
  $Q^2 + M_V^2 \sim 10\ \mathrm{GeV}^2$
- Similarly, longitudinal momentum scale

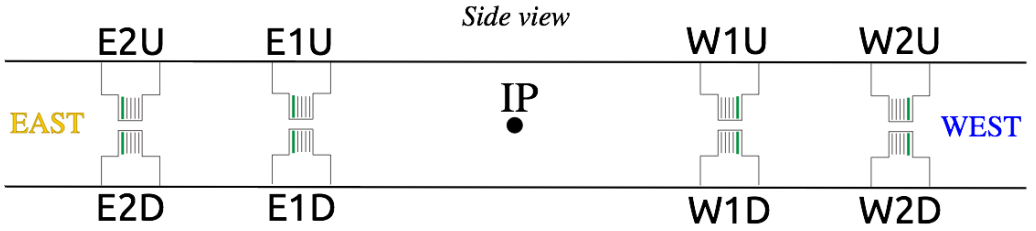
  $\xi = x_V/(2-x_V)$, $x_V = x_B\cdot(1 + M_V^2/Q^2)$, x_B = usual Bjorken x

STAR capabilities for p↑: Roman Pots

- Already discussed calorimeter trigger for $J/\psi \rightarrow e^+e^-$
- Also for p↑, STAR has Roman Pot system: tag/measure scattered p:

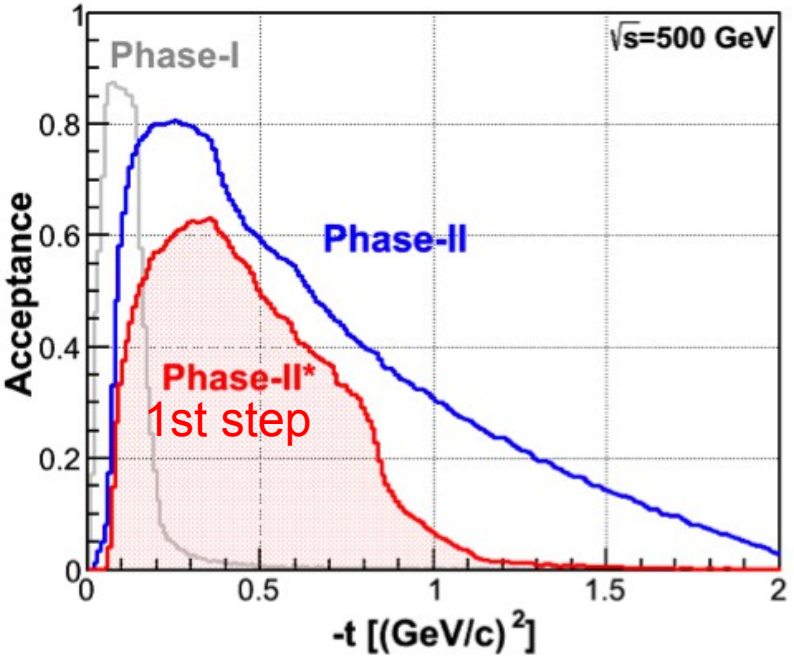
- Silicon strip detectors, x&y strips, 15-17m from IP
- Approach above/below beam to ~20mm
  ~50% azimuth acceptance





Setup has evolved

- 2009 Phase-I: detectors farther from IP, lower |t|
- 2015 Phase-II*: detectors closer, larger |t| range, increased acceptance
- 202? Phase-II: increased acceptance

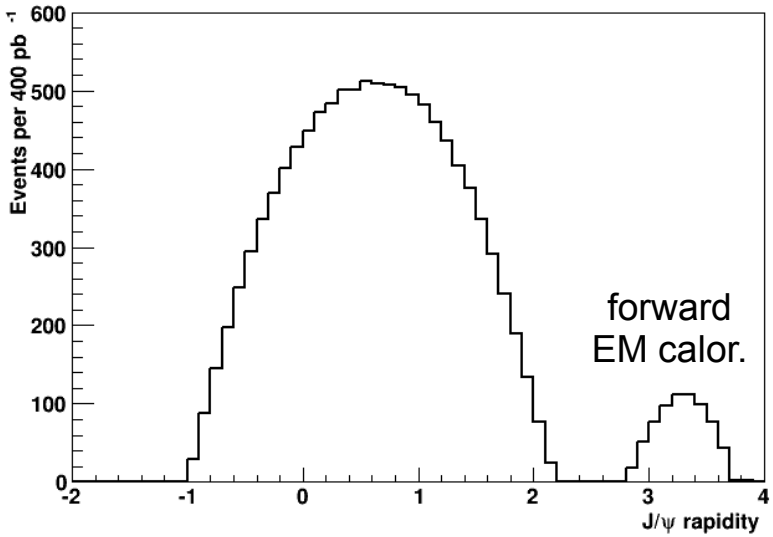


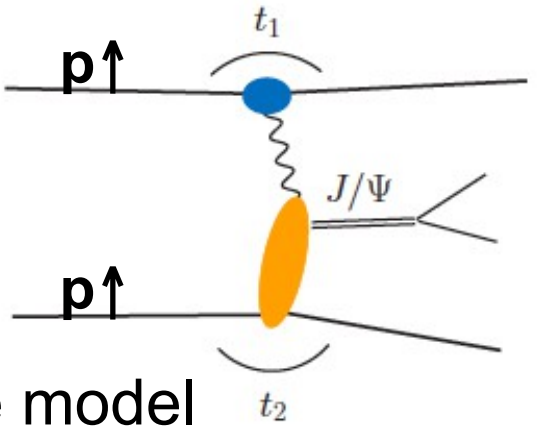
for acceptance @ s=√200 GeV scale $(100/250)^2$

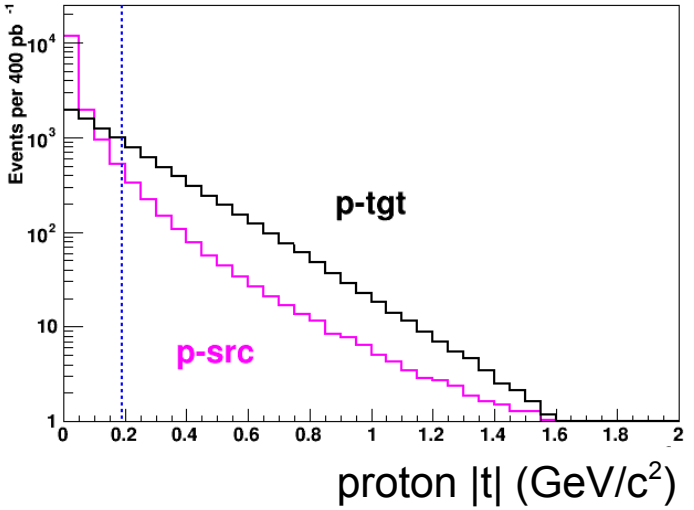
J/ψ in p↑p↑ UPC

RHIC plans:
Spin arXiv:1501.01220
Cold QCD arXiv:1602.03992

- Planned: √s=500 GeV p↑p↑ Run17 L~400 pb^{-1}
- Trigger on:
  - 2 EM showers STAR calorimeters ($J/\psi \rightarrow e^+e^-$)
  - Hit in either Roman Pot
  - no BBC activity (ensure diffractive)
- Events rates estimated w/ Sartre:
  - VM production & DVCS based on bSat color dipole model
  - designed for ep, eA; extended w/ WW flux to pp, pA
- RP measures 0.19<|t|<1.9 (GeV/c)^2; detect either/both protons from:
  - source of photon (lower |t|)
  - target of photon (higher |t|)
- $J/\psi \rightarrow e^+e^-$ in STAR EMC:



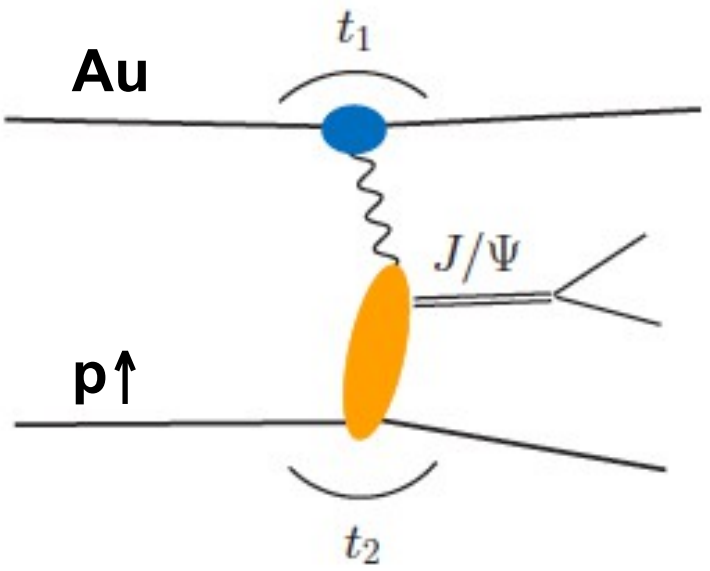


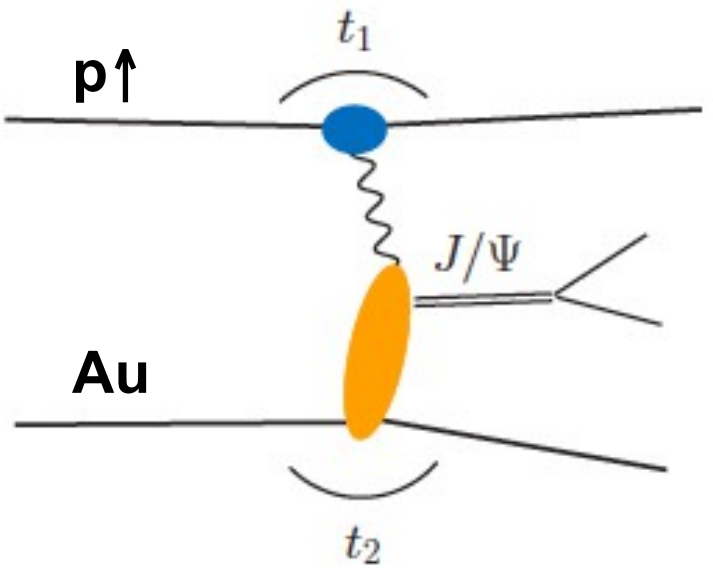


- Expect ~11k J/ψ's
- Good sample 1st look at $A_{UT} \propto E_g$

J/ψ in p↑Au UPC

- Considered: √s=200 GeV p↑Au Run 202? L~1.75 pb^{-1} (already had p↑Au 'test run' 2015, L~0.14 pb^{-1})
- Here 2 processes:



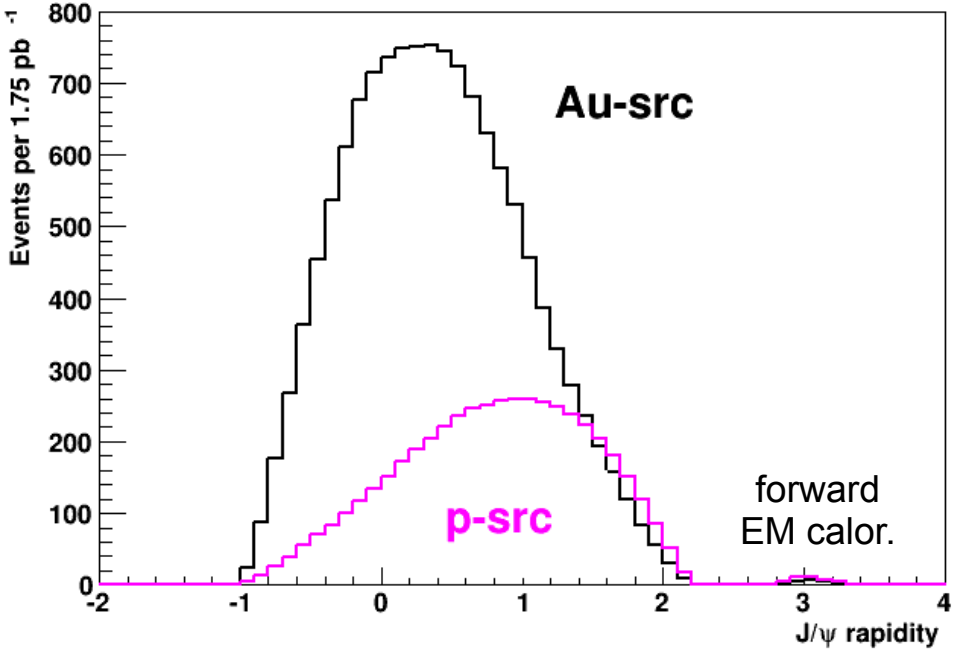


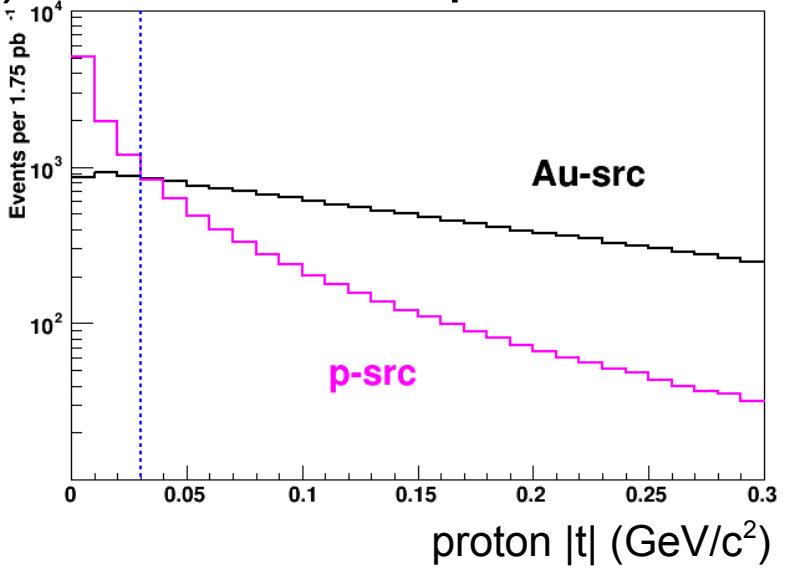
- Au photon source, p↑ target
- Boost in photon flux ∝ Z_{Au}^2
- Polarized target: measure $A_{UT} \propto E_g$

- p↑ photon source, Au target
- Boost in γA cross section ∝ A_{Au}^2 (coherent)
- Unpolarized target: no asymmetry

J/ψ in p↑Au UPC

- Trigger on:
  - 2 EM showers STAR calorimeters ($J/\psi \rightarrow e^+e^-$)
  - Hit in Roman Pot facing p↑ beam
  - no BBC activity (ensure diffractive)
- Events rates estimated w/ Sartre
- RP measures $0.03<|t|<0.3$ $(GeV/c)^2$; detect either proton from:
  - source of photon, Au target mostly below RP |t| range
  - target of photon, Au source mostly in RP |t| range
- $J/\psi \rightarrow e^+e^-$ in STAR EMC:





- Expect ~13k J/ψ's p↑-target
  background ~5k Au-target
  ('test run' 2015 ~ 1k sig. /400 bkg.)
- Adjust signal/ background:
  vary RP |t| , J/ψ rapidity
- Good sample for $A_{UT} \propto E_g$

Outlook: J/ψ in p↑p↑, p↑Au UPC

- Next year 2017: large sample √s=500 GeV p↑p↑
- Considered for 202?: large sample √s=200 GeV p↑Au
  (and small (1/10) test sample from 2015 analyze soon)

With UPC J/ψ on polarized p↑:

- Through asymmetry A_{UT} access to GPD E_g ∝ gluon orbital L_g
- Non-zero A_{UT}

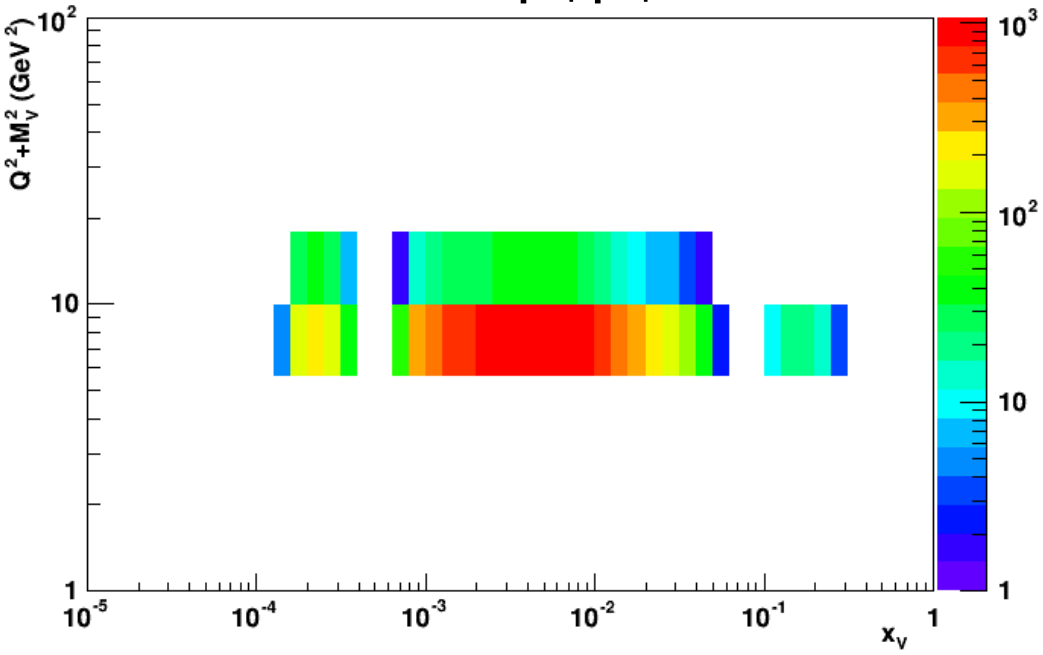
  ⇒ non-zero E_g

  ⇒ non-zero gluon orbital angular momentum
- First look at this before EIC

Extras

Kinematic ranges

- UPC J/ψ on polarized p↑
- #event estimates using Sartre
  - √s=500 GeV p↑p↑



  - √s=200 GeV p↑Au