Silicon tracking: requirements to reconstruct vector mesons

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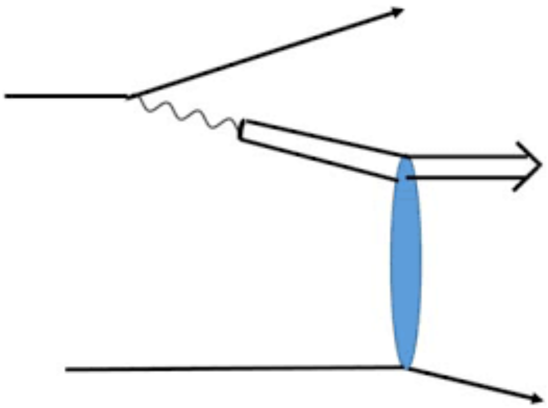
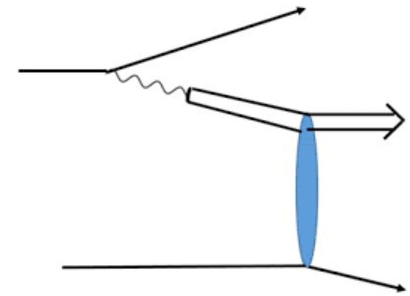
EIC Silicon pixel workshop, Sept. 2-4,. 2020

- Exclusive vector meson production
- Detector requirements & simulations
  - Pseudorapidity coverage
  - $\Phi \to K^+K^-$ and low momentum particles
  - Separating the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$
  - Other requirements
- Conclusions

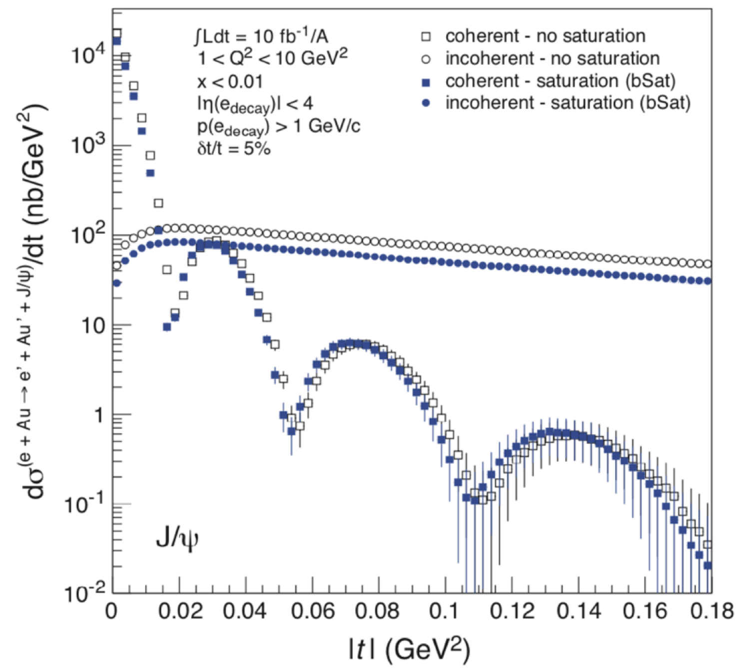


Work done in collaboration with Sam Heppelman

Vector meson photoproduction and electroproduction



- Coherent photoproduction (in exclusive group) and incoherent photoproduction (in diffraction and tagging) differ only in the presence of nuclear breakup.
- In Good-Walker paradigm:
  - Coherent photoproduction is sensitive to the average nuclear configuration
    - $d\sigma/dt$ maps out parton positions, ala GPDs
    - Spatial distribution of shadowing
  - Incoherent photoproduction is sensitive to fluctuations, in nuclear positions and also to the presence of gluonic hot spots
- Good separation is critical!
- Major treatment in 2012 “White Paper”

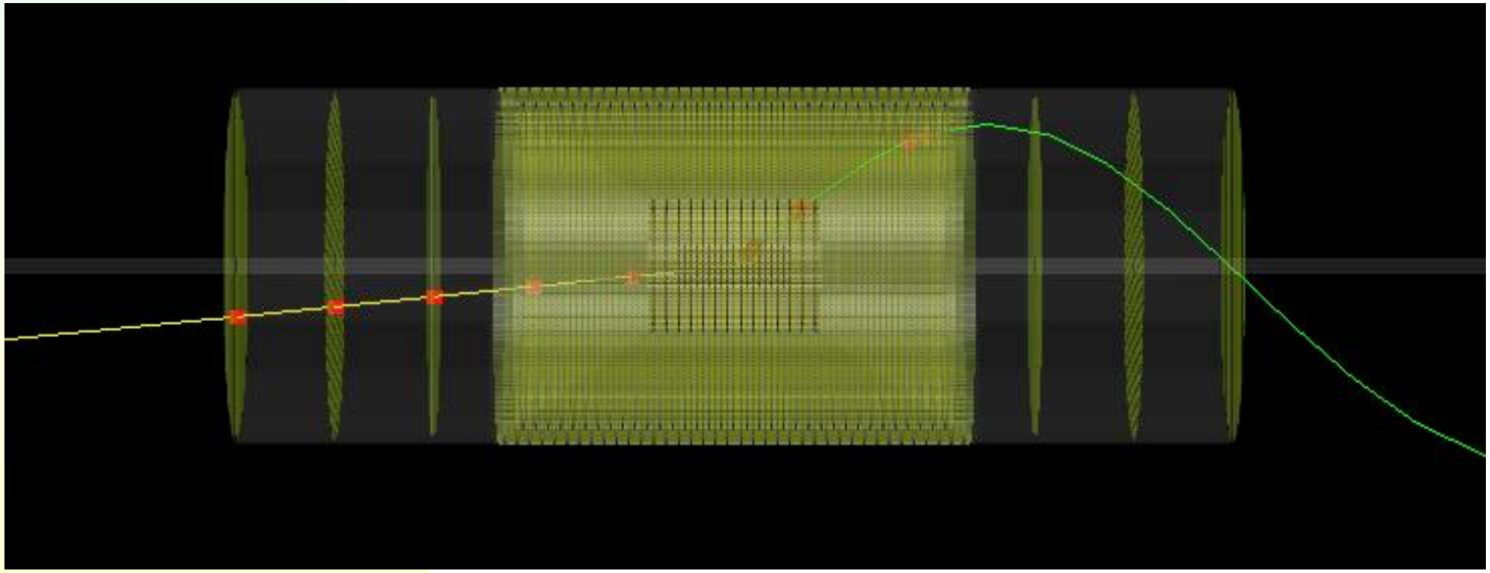


Focus on ‘simple’ final states

- J/ψ -> ee, $\mu\mu$
  - Easiest case
- Ψ' -> ee, $\mu\mu$
  - Well separated from J/ψ; separation is easy
- Υ(1S), Υ(2S) and Υ(3S) -> ee, $\mu\mu$
  - Mass splittings are smaller; imposes momentum resolution requirement
- Φ->K^+K^-
  - Challenging; for photoproduction ($Q^2 \sim 0$), kaons are so soft
  - White paper only considered $Q^2 > 1$ GeV^2, but smaller virtualities are also important for understanding transition into saturation
- $\rho \rightarrow \pi^+\pi^-$
  - This reaction requires the broadest rapidity range
- Plus (for larger Q^2) the scattered lepton
- N. b. Some of the requirements are very tough to meet

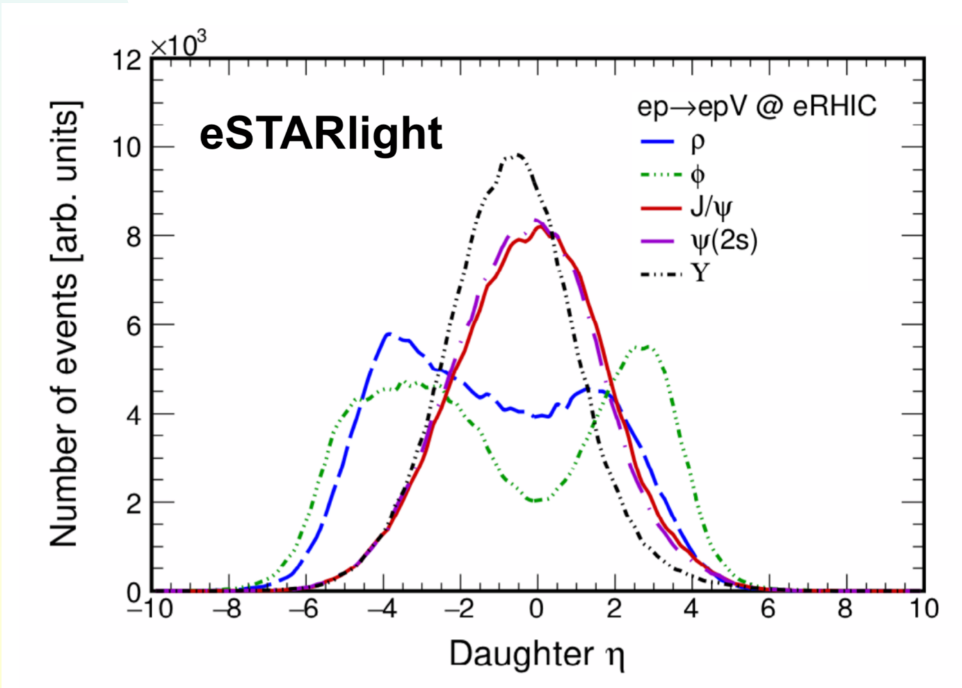
Technical details

- Simulations with eSTARlight, usually 275 GeV p or 100 GeV/n A on 18 GeV electrons
- Simulations are for an all-silicon detector
  - 6 layers of barrel tracking
  - 5 endcap disks on each end (2 inside the outer barrel)
- 1.5 T solenoidal field standard, 3 T field sometimes considered



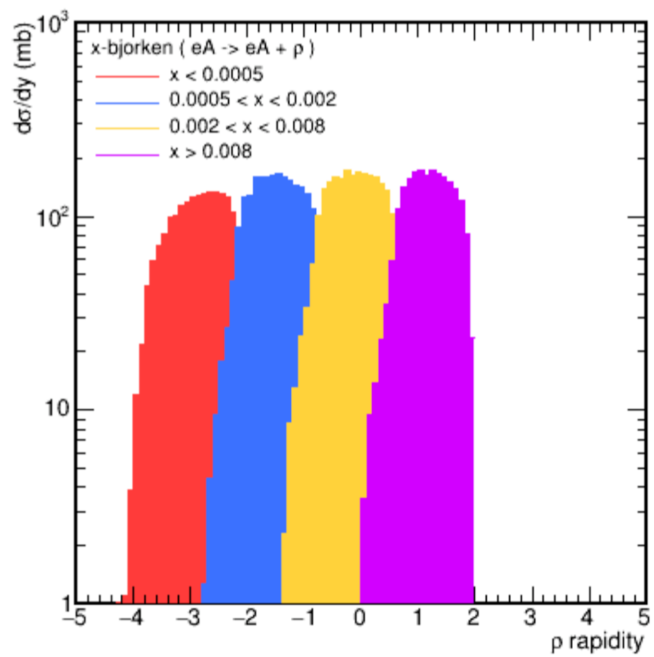
From VM rapidity to π/K/e/μ pseudorapidity

- The relationship between VM rapidity and daughter pseudorapidity depends on the angular distribution of the decay in the VM rest frame.
  - Clebsch-Gordon coefficients for J=1 decays to two J=1/2 particles are different from decays to two J=0 particles

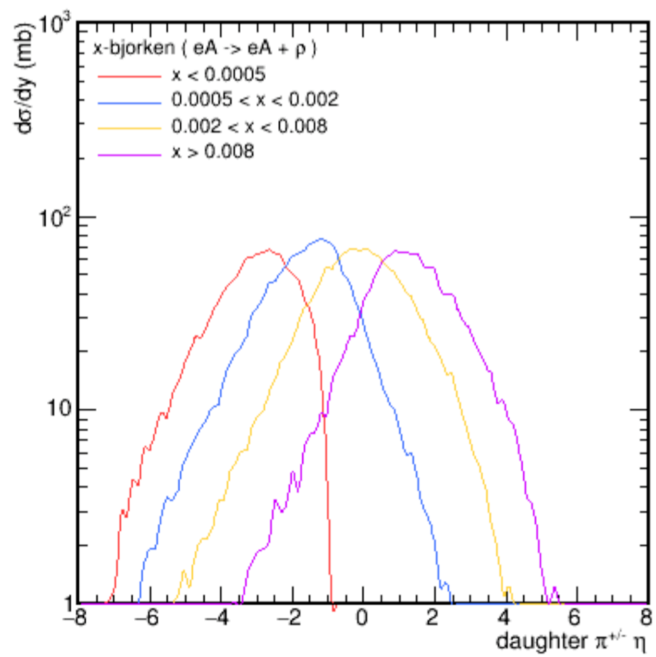


Vector meson rapidity & Bjorken-x

- Full coverage in x requires wide acceptance in pseudorapidity
  - $y = \ln(2\gamma x M_p/M_V)$ so lowest Bjorken-x -> smallest y
    - Kinematic cutoff in y is at $2\gamma x M_p k = M_V^2$
  - Positive rapidity -> large x for threshold behavior, pentaquarks….
- ρ^0 is the hardest case, since it is the lightest VM
- Need at least +1 unit of η for good detection efficiency & to study longitudinal to transverse cross-section ratio



ρ rapidity



π pseudorapidity

18 GeV e on 275 GeV p

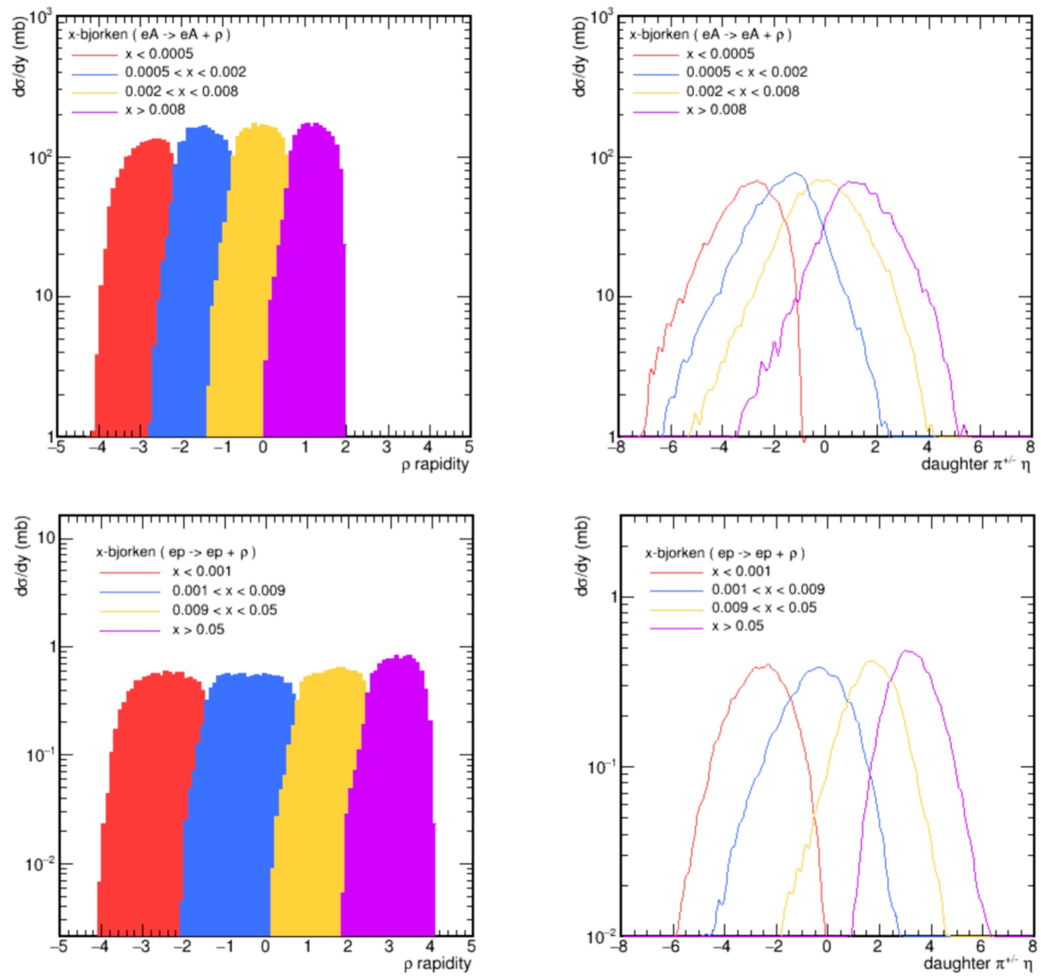
Rapidity ranges for eA

- eA has lower per-nucleon energy
  - Lower energy/nucleon –> shifted scale wrt Bjorken-x
  - Lower $\sqrt{s_{eN}}$ -> Narrower rapidity range

ρ photoproduction

eA

ep



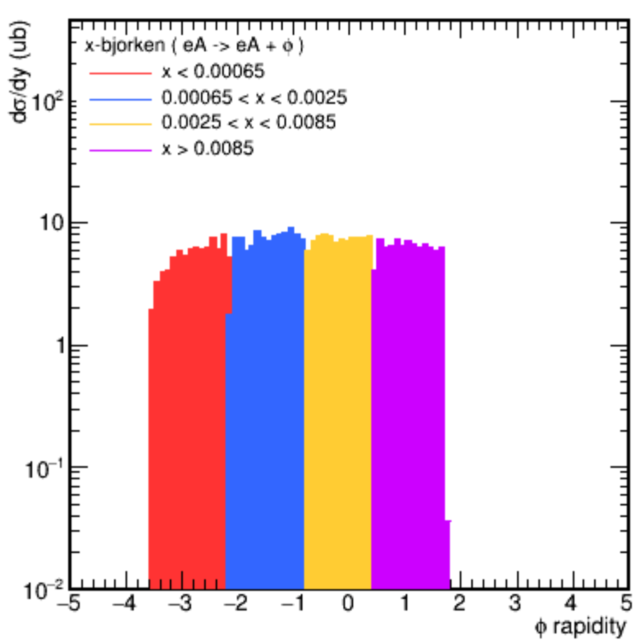
Is the full rapidity range really needed?

- Good pseudorapidity acceptance needed for polarization measurements (longitudinal vs. transverse polarization)

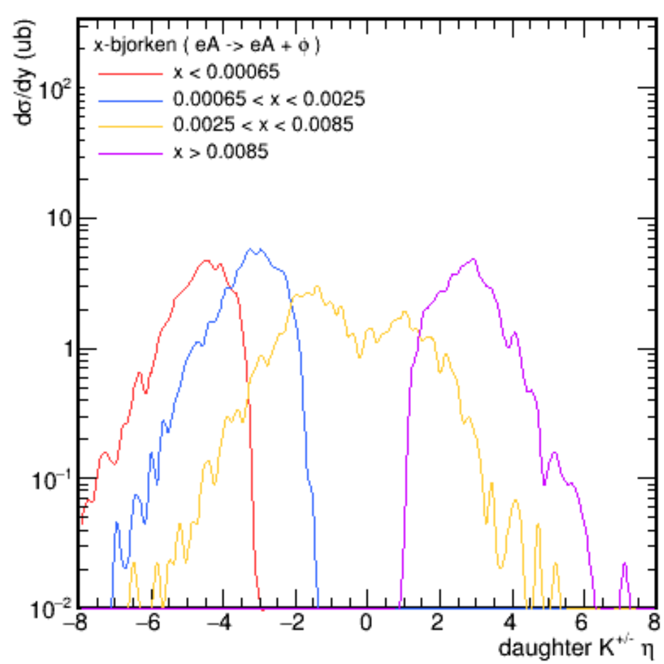
- Light meson (ρ,…J/ψ) threshold region covered by Jlab
  - Is overlap needed? How much?
- HERA already covered the highest energy photons for ep
  - EIC will have higher statistics
  - eA is a narrower rapidity range than ep -> less difficult

Φ->K^+K^- reconstruction

- Soft decay: P_{Kaon}=135 MeV/c (β~0.2) in ϕ rest frame
  - β~0.2 -> quite heavily ionizing
- ϕ acceptance problematic at low ϕ p_T
  - Especially at small |rapidity| where there is no/little Lorentz boost
  - There is a gap in photoproduction acceptance at |y|~0
  - Most detectors are not sensitive to such soft kaons



Φ rapidity

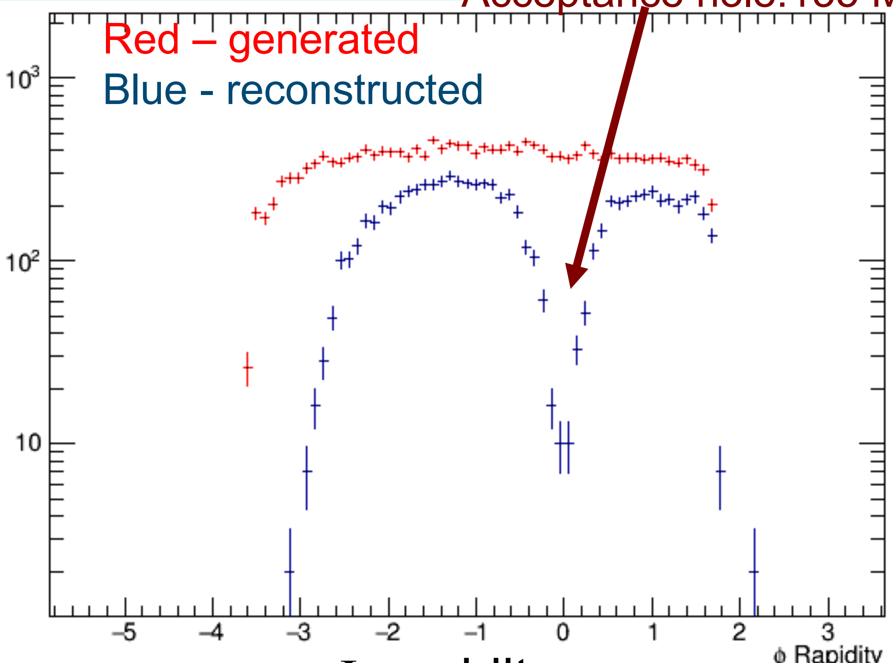


Kaon pseudorapidity

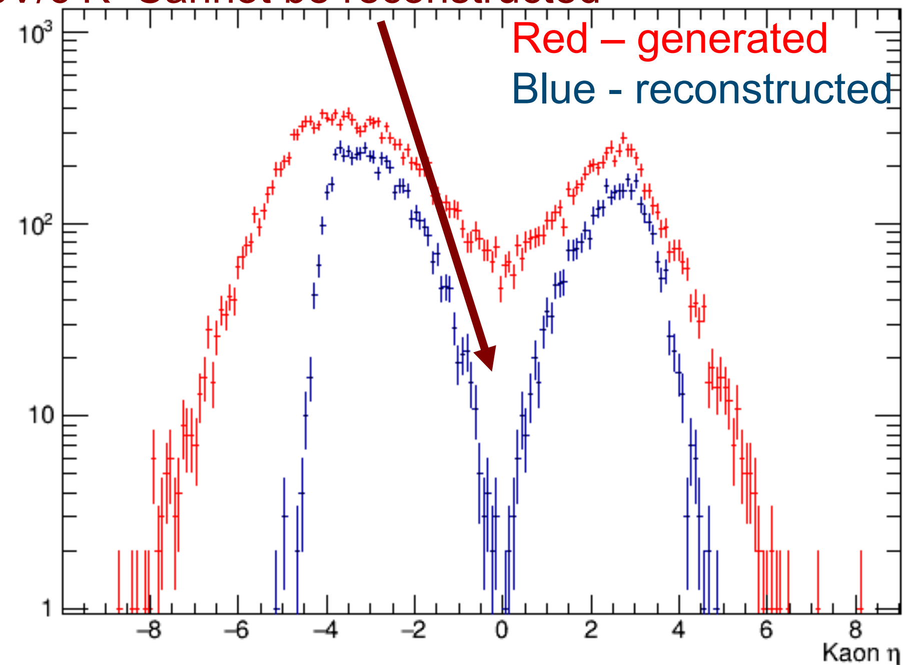
ϕ detection efficiency

- All Q^2, but dominated by low Q^2
- Acceptance hole at mid-rapidity (for low Q^2)
  - No acceptance for p_T=135 MeV kaons at η=0.
- $\phi \rightarrow K_S K_L$ seems tough, and ϕ-=> ee, $\mu\mu$ have very small ($3*10^{-4}$) branching ratios

Acceptance hole:135 MeV/c $K^{\pm}$ Cannot be reconstructed



Φ rapidity

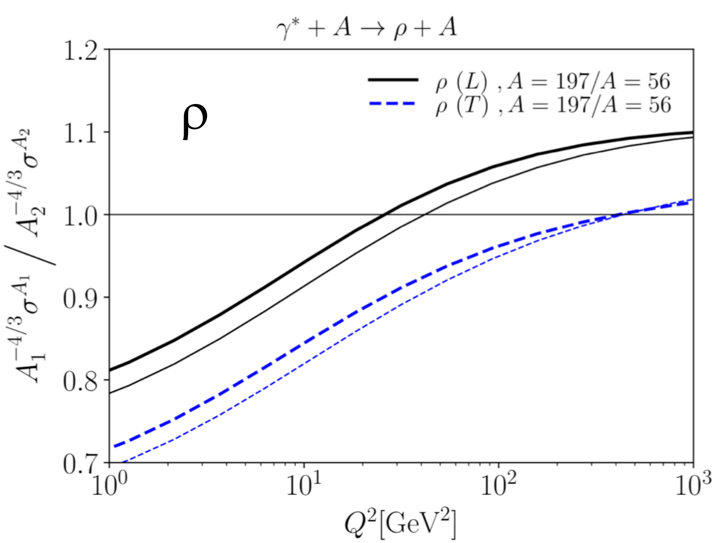


Kaon pseudorapidity

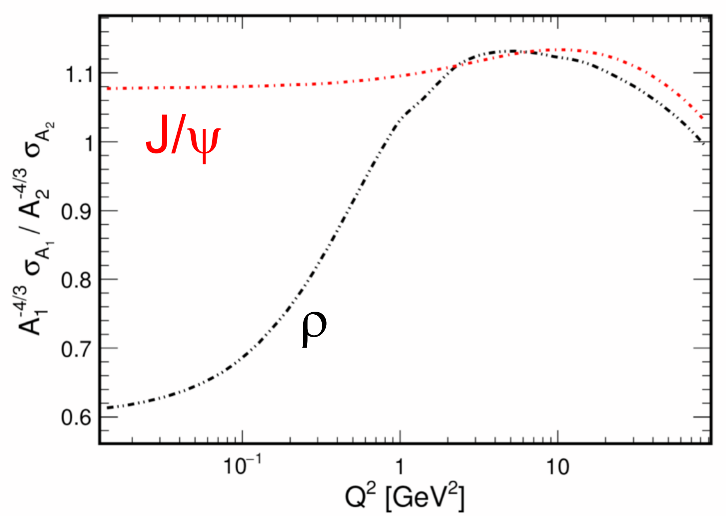
Sam Heppelman

Do we need full coverage for the ϕ?

- The ϕ was highlighted in the 2012 White Paper
  - But, the plots only considered $Q^2 > 1\ GeV^2$
- Is photoproduction ($Q^2 \sim 0$) needed?
  - Studying Q^2 dependence of shadowing is a key goal for EIC
- Is the ρ an acceptable substitute for the ϕ here?
- Is a hole at mid-rapidity/medium, $W_{\gamma p}$ acceptable?

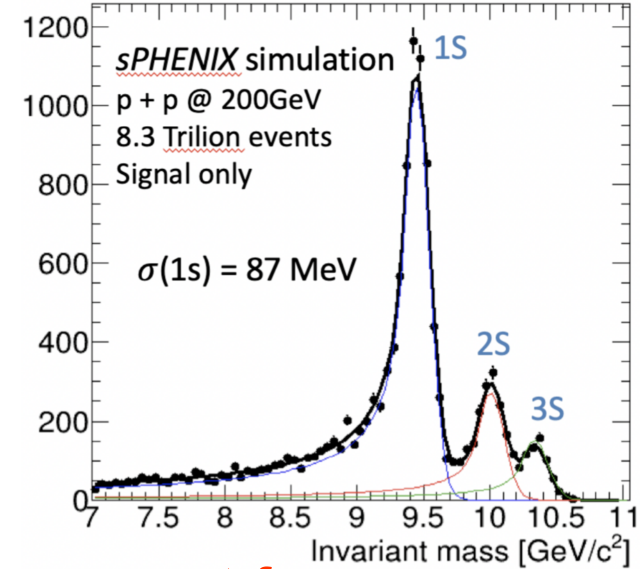


Mantysaari and Venugopolan
Phys.Lett.B 781 (2018) 664-671



eSTARlight

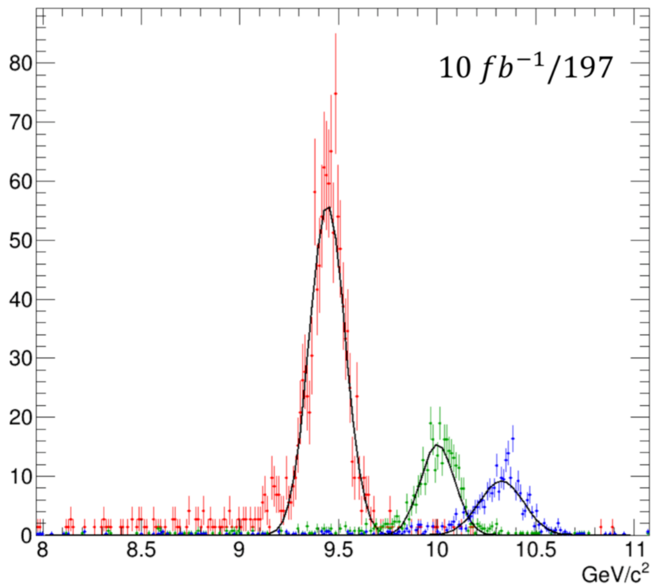
Separating the Υ states



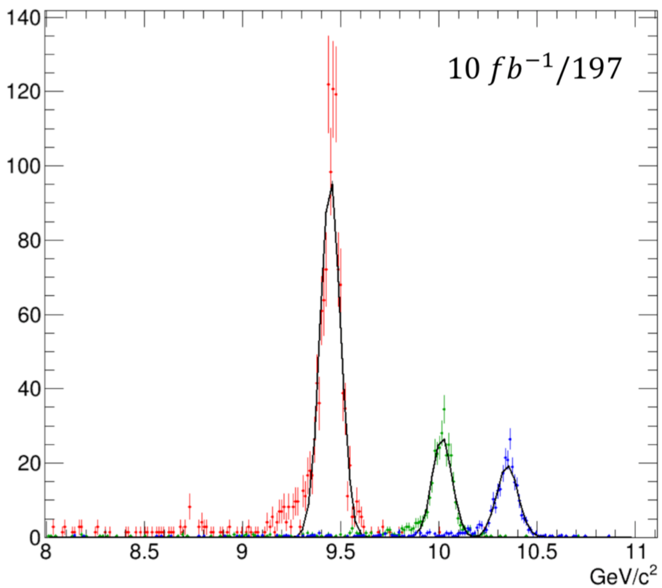
- The Υ(2S) and Υ(3S) are separated by only ΔM=331 MeV
  - ΔM/M~ 3%
  - J/ψ-ψ' splitting is much larger
- Separating the Υ states is a signature measurement for sPHENIX
  - They spec. mass resolution σ(M)=100 MeV/c, or about 1% M(Ψ)
    - This plot shows σ(M)=87 MeV
- For two back-to-back equal momentum tracks M=2|p|
  - σM/M~ σp/p
  - σp/p ~ 1% at 5 GeV [for mid-rapidity]
  - Slightly more sophisticated arguments indicate that the resolution requirement is slightly relaxed at larger rapidity or Q^2

Simulations…

- eSTARlight simulations in silicon detector
  - 3 Υ states are separable even at B=1.5 T
- Resolution is better than in sPHENIX simulations
  - Hard to beat silicon at large |p|
  - Caveat – we have not studied large |y| carefully



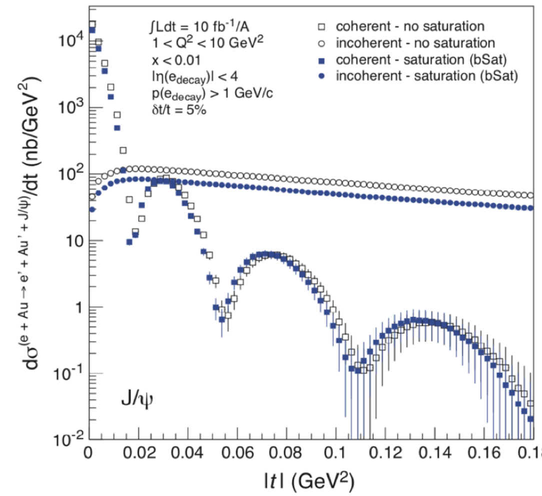
1.5 Tesla



3.0 Tesla

Some other requirements for VM

- Low mass, to minimize electron energy loss
- Resolution to resolve diffractive minima
  - Limited by other factors, including electron beam momentum spread
- Good π/γ acceptance for nuclear transitions
  - $\psi' \to \pi\pi J/\psi$
  - $\psi' \to \gamma\chi_c$, $\chi_c \to \gamma J/\psi$
- Good acceptance for scattered electron, down to the kinematic limit where the electron stays in the beam
- Good separation of coherent and incoherent photoproduction, via detection of nuclear breakup and photons from low energy nuclear dissocation



Conclusions

- Vector meson photoproduction or electroproduction leads to low-multiplicity final states (2 charged particles + scattered electron), but there are still some challenges for a central detector.
- ρ^0 reconstruction at small Bjorken-x requires sensitivity at large negative pseudorapidity.
  - Tracking is desirable up to pseudorapidity 5.
- Reconstruction near threshold requires sensitivity at larger positive pseudorapidity
  - Tracking is desirable up to pseudorapidity-5.
- Φ->K^+K^- is a challenge because the kaons are so soft
- Separating the three Υ states requires reasonably good momentum resolution, $\sigma p/p$=1% at 5 GeV. In ep, leptons from Υ are produced over the range |pseudorapidity|<4.

Backup

Toward detector requirements

- Detector requirements are emerging from parts of the diffraction and tagging group
- For vector meson reconstruction
  - Large pseudorapidity (at least $|\eta<4|$) acceptance, to cover the full Bjorken-x range
  - $\Delta p/p \sim 1\%$ at 5 GeV required to separate Υ states
  - Mid-rapidity $\phi \to K^+K^-$ photoproduction produces 135 MeV/c kaons
- For many purposes (vector mesons, short range correlations…)
  - Full kinematic coverage for downstream protons and neutrons
  - Detailed requirements & designs from meson structure function group
- To separate coherent and incoherent VM production
  - For heavy ions, downstream photon detection, down to ~ < 100 MeV
  - For light ions, detection of intact ions with small energy loss & P_T