Workshop: Exotic Meson Spectroscopy and Structure with EIC

Hard Exclusive Physics with Muons at EIC

& why considering a dedicated muon detector and/or trigger?

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& credit to Tyler Schroeder (VT, W&M) for simulations and figures

CFNS center workshop, Aug. 15-19th, 2022, Stony Brook, USA

Physics Goals

Not exactly in line with the rest of the workshop (exotics), but related (exclusive)
* Hard Exclusive Vector Meson Production
Why? Generalized Parton Distributions & nucleon imaging

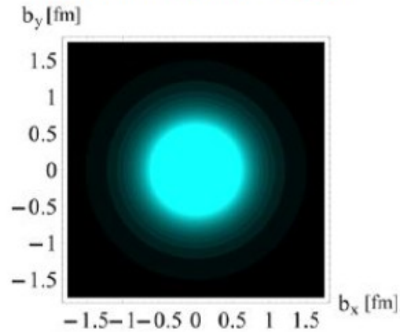
3D mapping of the nucleon ⇒ tomography

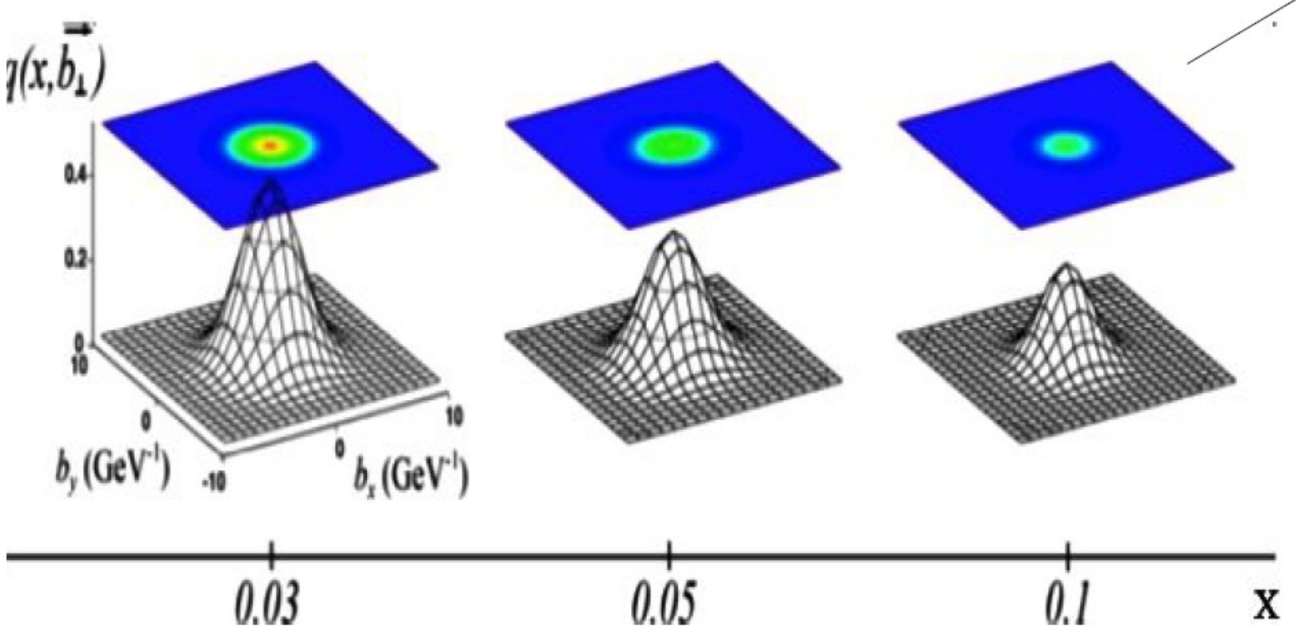
Transverse parton distributions for different region in x
→ probabilistic interpretation ≡ gluons, valence quark regions

"momentum dissected Form Factors"

integral over x

transverse charges from Elastic Scat.





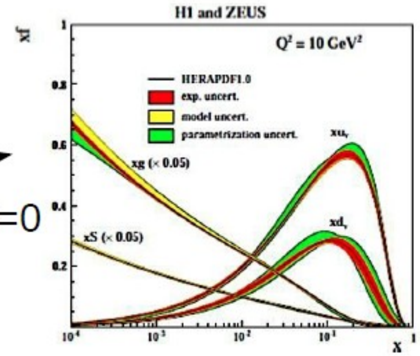
gluons dominate

gluons, sea quarks "meson cloud"

valence quarks region

parton densities from Deep Inelastic Scat.

t=0



Physics Goals

Why Vector Mesons?

Practical argument: cross sections for pseudo-scalars & others are small at high energy

Physics argument:

- complement Compton-like reactions and access to H & E GPDs in a global multi-reactions GPD fitting approach

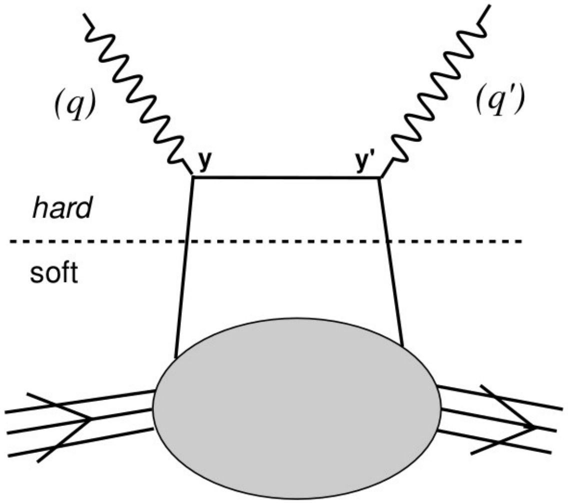
- independent information brought in fitting approach

- factorization and better knowledge of meson DA (from “spectroscopy” community)

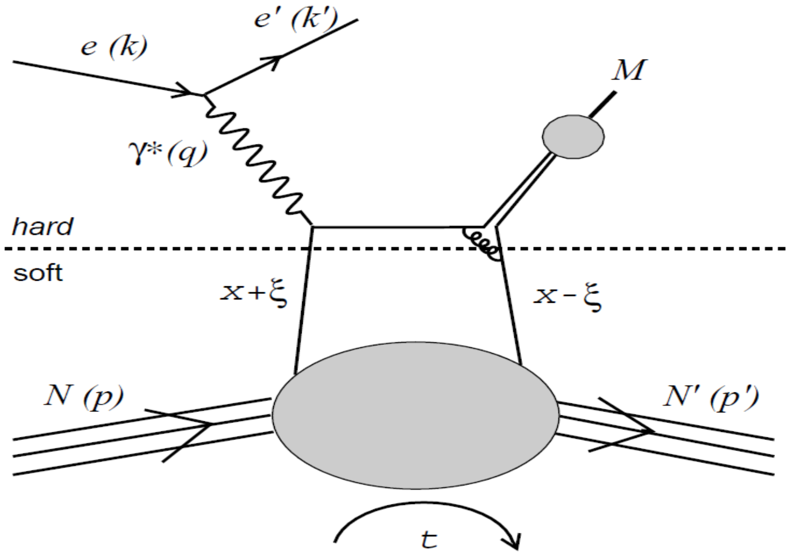
Note: not talking here about Compton like. DVCS will be measured at EIC, TCS maybe, DDVCS likely not, potentially others but very low cross sections at high energy

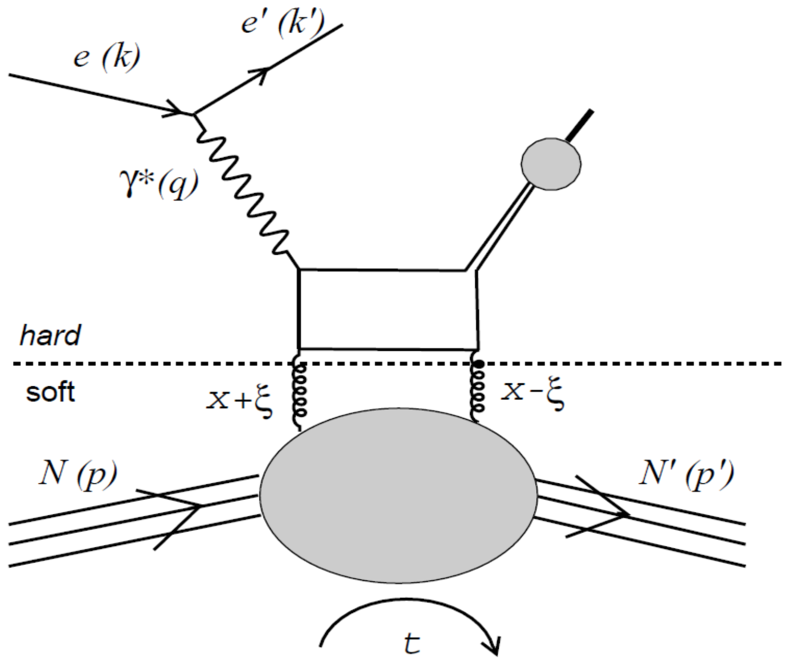
Handbag diagram approach for VM

Compton-like



VM





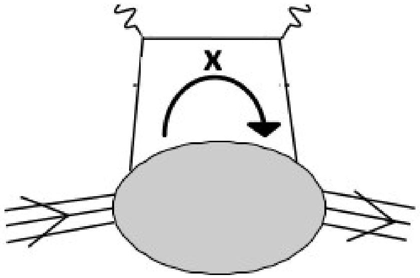
(leading order for Compton,
Light VM or quarkonia)

Same spin-parity than photon
Same approach, “same” diagrams

Multi-reactions fitting approach

Based on extension of VGG model and fitting for DVCS (Guidal & al.)
Other models can/are implemented but not in use so far in this work (fit part, not projections)

ξ, t = measurable
x = loop
x±ξ = propagator



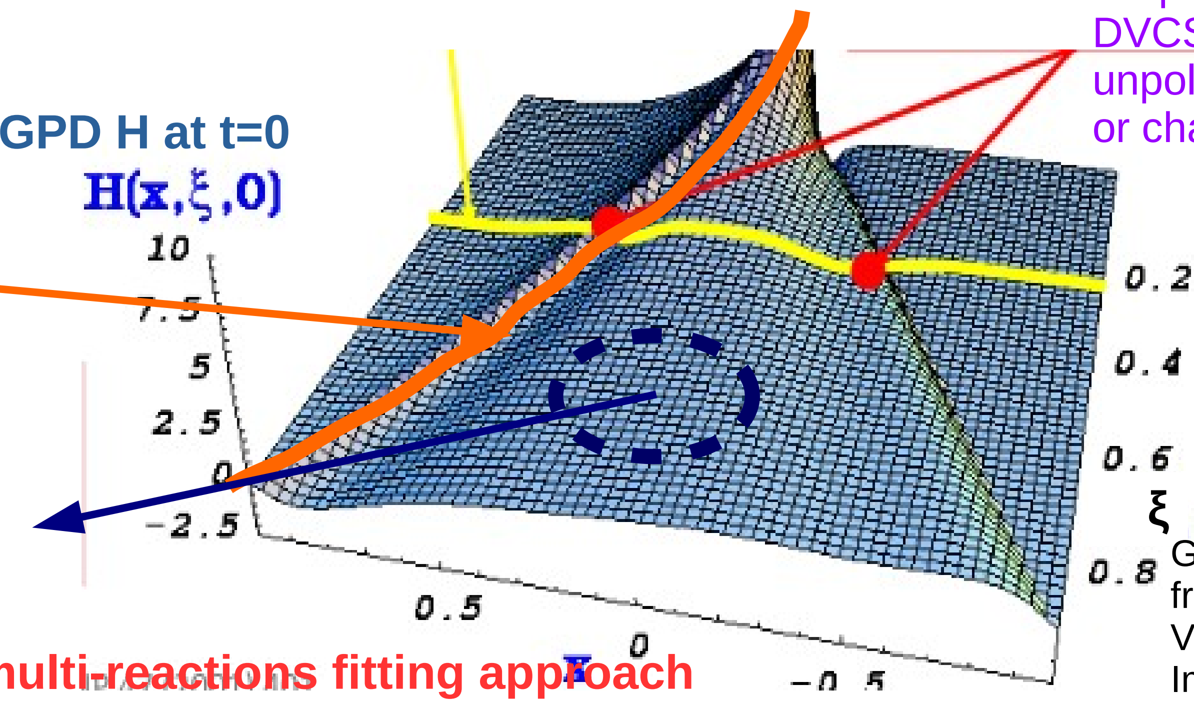
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$$

Re $(\mathcal{H})$ Im $(\mathcal{H})$

Compton Form Factor
Indirect access to GPDs
Here : propagator for DVCS or TCS. With DDVCS or HEMP, “lever arm”with Q’² or M

Re part → ∫dx GPD
DVCS and TCS,
unpol or double pol. σ
or charge asymmetries

Im part → GPD at x= ± ξ
DVCS and TCS unpol σ,
single spin pol. σ



Off diagonal:
DDVCS, HEMP

GPD in VGG model,
from Guichon,
Vanderhaeghen, Guidal
Image: M. Guidal

⇒ **multi-observables / multi-reactions fitting approach**

DVCS+TCS fits: Hall C note #999 (2018), interpretation methods: Boer, Guidal, J.Phys. G42 (2015) 3, 034023

Why multi-reaction approach with VM?

Main goal:

Extrapolate to zero-skewness case using mass evolution at fixed Q^2
- Use mass as lever arm in propagator CFF

Other goals; independent data sets

- GPDs universality
- factorization limits, higher twist…

EIC is ideal place to study NLO effects and diminish higher twist effects observed (?) at JLab or other lower energy experiments

H1/ZEUS data available for some VM, but low statistics, may hide some effects

- Higher cross-sections than Compton-like reactions increase statistical precision
Not the same kinematics, however, rely on understanding of the meson wave-function

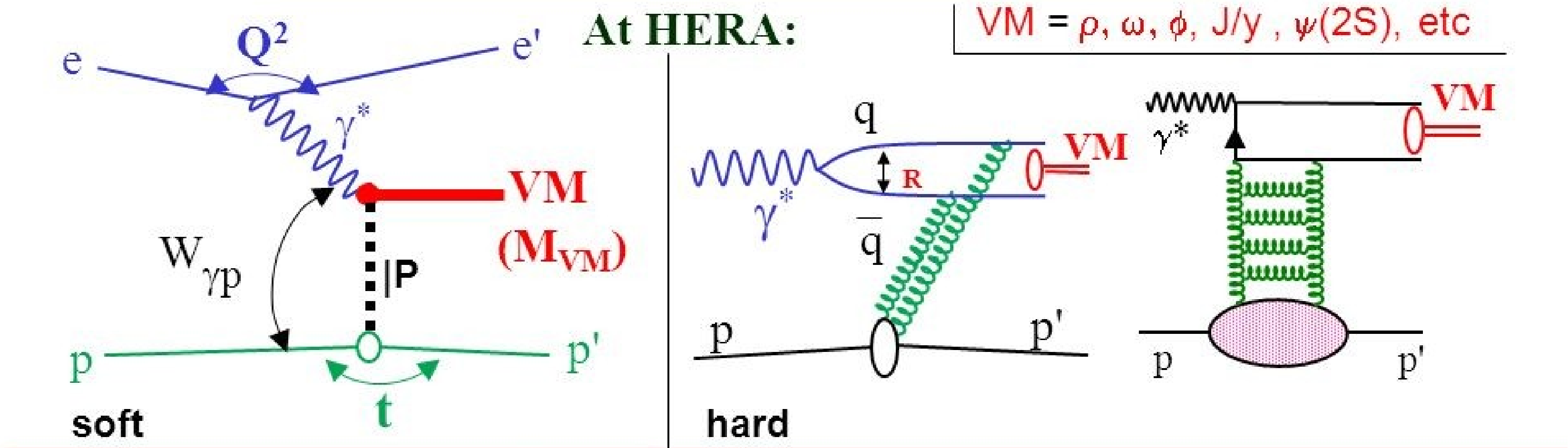
Not in this work, but other approaches include studies of resonances, pentaquark...

Parametrization of cross sections in this work for VM

Slide: M. Barbi

Certainly not the ideal one, here using Regge-like approach
- VGG model, Broadsky et al. Parametrizations for quarkonia, Frankfurt et al.
"homemade" model for some of our projections

Exclusive Vector Meson Production



Soft (Regge + VDM)		Hard (pQCD)
$d\sigma/dt \propto W^{4(\alpha_P(t)-1)} e^{-b(W)\|t\|}$ $\alpha_P(t) = \alpha_P(0) + \alpha'_P\, t$ At low |t| ⇒ $\sigma(W) \propto W^{0.22}$	Cross section $\sigma(W) \propto W^{\delta}$	$\sigma \propto \left[xg(x, Q^2_{eff})\right]^2$ $x \approx 1/W^2$ Gluon from fit to F_2 scaling violation ⇒ $\sigma(W) \propto W^{0.8}$
———	Scale	Q^2 , |t| , M_{VM}^2
$b(W) = b_0 + 4\alpha' \ln W$ $b \propto R^2$	Transv. size of the interaction region	Small size. No W dependence.

M. Barbi

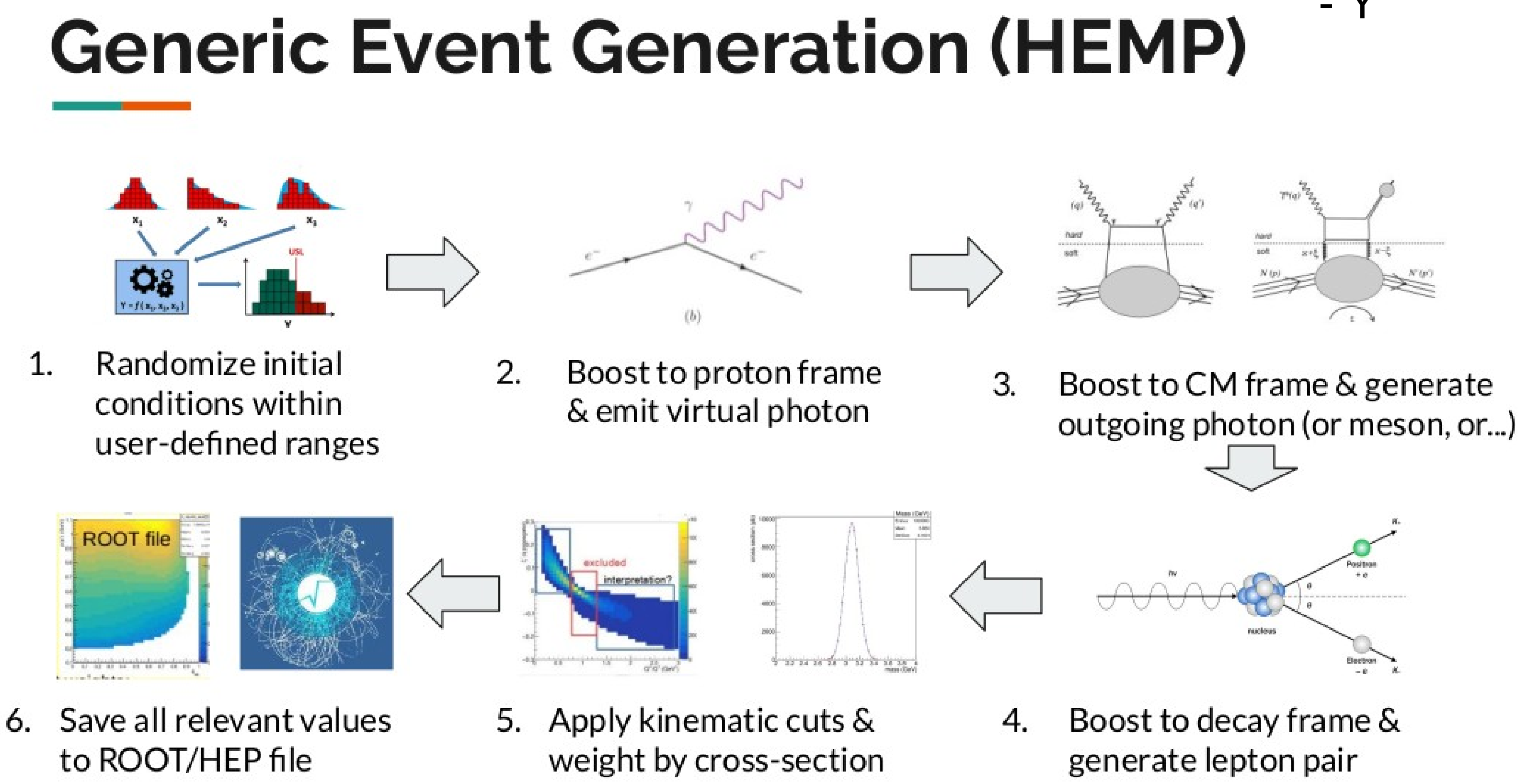
Our tools and models

DEEPSim event generator developed for EIC projections, based on DEEPGen generator, developed for JLab

DEEPGen:
Hard exclusive processes:
- DVCS
- TCS
- DDVCS
- some VM and PS mesons

Other processes:
- VCS
- Elastic scattering
- DIS
- Low energy pion
- Low energy kaon

DEEPSim (in progress):
Hard exclusive processes:
- DVCS
- TCS
- DDVCS
- HEMP
- ρ
- J/Ψ
- ϒ



* some public versions for DEEPGen, not yet for DEEPSim

Some technical features

DEEPGen and DEEPSim are weighted generators

- Avoid peaks & spikes in regions that are less physically interesting

Multi-weighting system

- 2 gluon only, BH only, meson+BH interference only,..
- Allow tuning at analysis level
- Saves significant CPU time

DEEPSim only: Crossing angle corrections (optional)

DEEPGen (DEEPSim in progress):

- Radiative corrections and polarization vectors
- Polarized cross sections

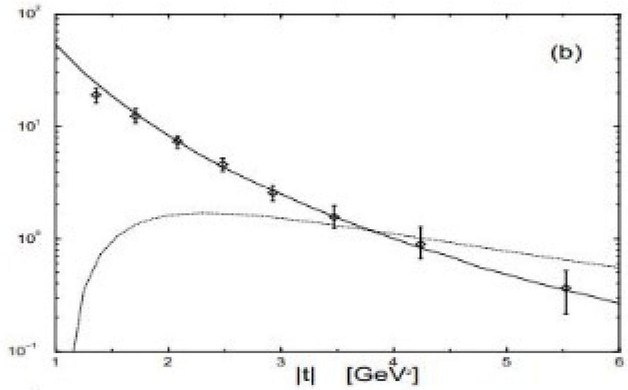
In particular **tools at generator leve**l to perform kinematic and physics studies: cut out Bethe-Heitler peaks...

* some public versions for DEEPGen, not yet for DEEPSim

Projections for quarkonia at EIC

(slides from Tyler Schroeder, W&M graduate, VT summer student in 2021)

Quarkonia Production

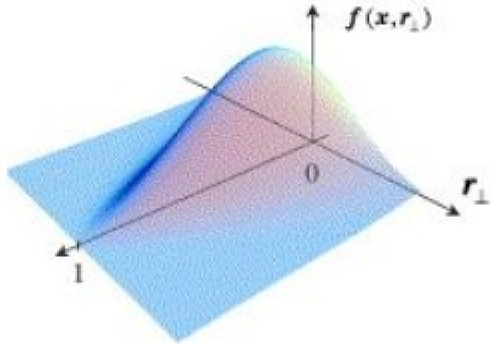


- **Flexible framework** for meson production
- Hard exclusive **J/Ψ** production
  - User provides ratio between **two-gluon** and **three-gluon** cross-sections
  - Two-gluon dominates at EIC et al, three-gluon near threshold
    - Three-gluon gives more flexible momentum transfer
- Hard exclusive **ϒ** production
  - Currently using similar model to J/Ψ
  - Plan to compare w/ numerical BKFL xsec: $\mathcal{F}_{BFKL}(s',t) = \frac{t^2}{(2\pi)^3}\int d\nu \frac{\nu^2}{(\nu^2+1/4)^2} e^{\chi(\nu)z} I_\nu^{q^*}(Q_\perp) I_\nu^{\gamma V}(Q_\perp),$
  - Handles 1S, 2S, 3S resonances
- Currently extending to **other vector mesons**

Note: 3 gluon mode turned off after discussion with theorists (forbidden transition), no impact on results

GPD parameterizations

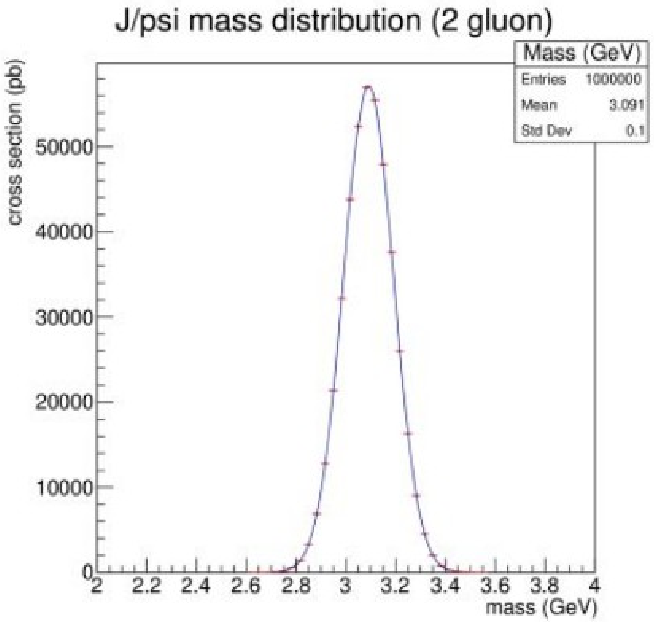
- **Easy to swap GPDs in and out** by design
  - Using generic model for EIC projections (GPD = PDF * *t*-dependent dipole)
  - Includes both quark & gluon GPDs
- Current reference: CTEQ 2018 data for PDFs
  - *t* dependence experimentally set to $e^{1.13t}$ (Brodsky et. al, 2000)
  - May require tuning for high energies at EIC (fits from HERA, etc.)

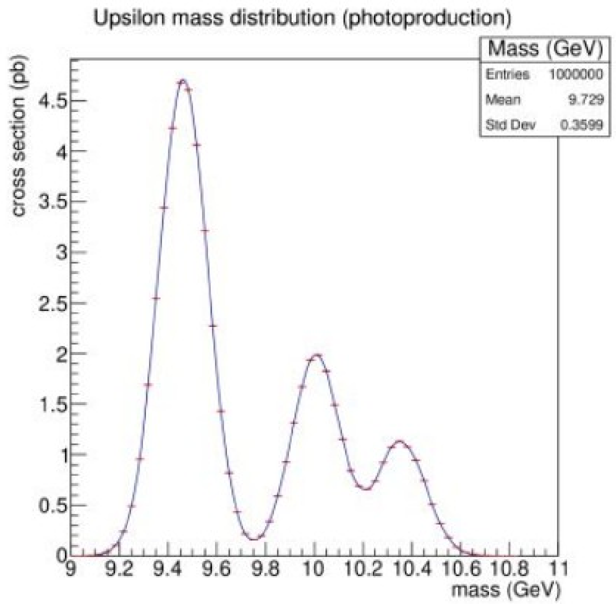


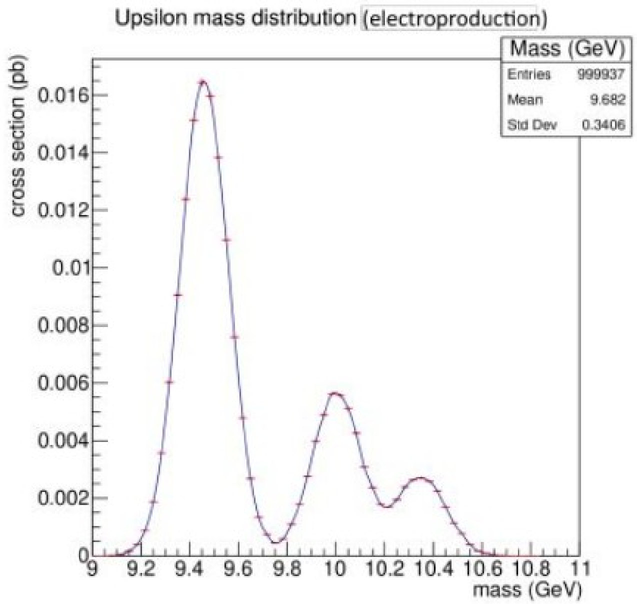
Production modes

- J/Ψ: Both **photoproduction** (JLab) & **electroproduction** (EIC et. al) handled by **same cross-sections (**varying 2-3 gluon ratio)
- Beam:
  - Quasi-photoproduction & electroproduction for EIC: scale by **flux factor** (HERA collab. Z)
  - JLab: not factorized for electroproduction, using quasi-real photon flux + Bremsstrahlung (dep. on target) for quasi-photoproduction
  - Real photoproduction possible at JLab
- Spin:
  - Polarization handled at JLab (weighting still a work in progress)
  - Would like to expand to EIC energies
- Measuring both J/Ψ and ϒ through lepton decay modes (e^+e^-, $\mu^+\mu^-$)

Some cross sections for quarkonia (not realistic normalization, acceptance)
Out of Tyler's work in 2021







(1S, 2S, 3S normalization extrapolated from LHC)

Assuming 10% resolution with muons, we can distinguish Y resonances

Mass resolution for Y peaks will not be sufficient going to electrons

This is one argument for muons, but can we really study exclusive quarkonia into electrons for GPDs?
(low -t, exclusivity, low statistics/high background/BH interference, semi-inclusive background and associated production...)

Projection for 5x41 GeV beams, done by Tyler Schroeder

Our response is no, we can’t go to di-electrons, or only under very specific conditions

- Low virtuality photon, “quasi real” production: OK, electron is going backward, we should be able to neglect anti-symmetrization effects since large rapidity gap and “live” in very different phase space. Resolution may be the limitation

Otherwise:

If final leptons are electrons, we have 2 identical leptons!

- Need antisymmetrization of wavefunction (hard to extract GPDs)
- experimentally define the kinematics ???

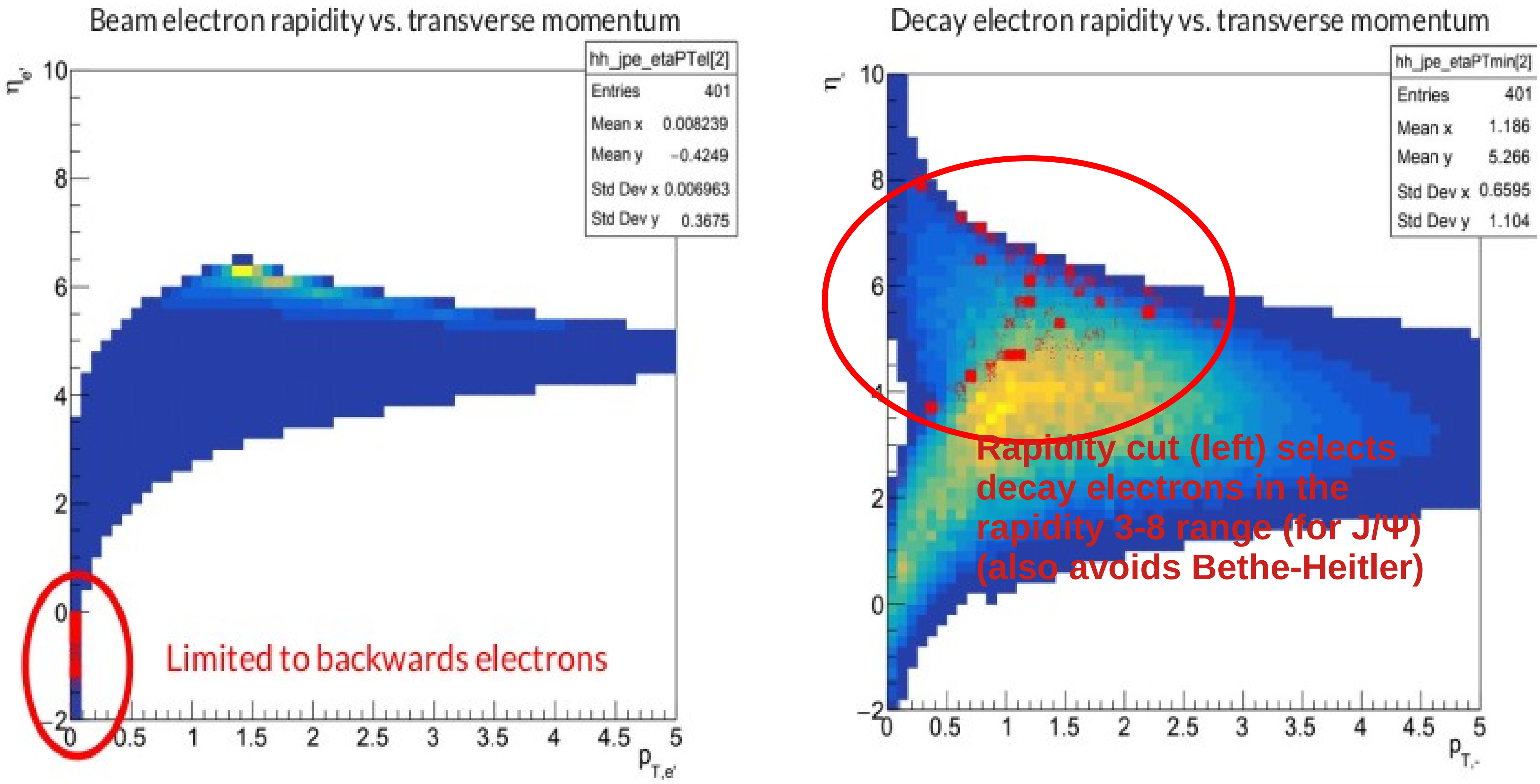
High risk to “create” a particle, can’t reduce background.

At EIC, beam electrons can be backwards

- For very specific kinematics, we assume small interference
- Ideally, assumption can be checked with e+e- vs. mu+mu-

Solutions: large rapidity gap (EIC), photoproduction (JLab+EIC w/ hard scale provided by meson mass), and/or muon detectors

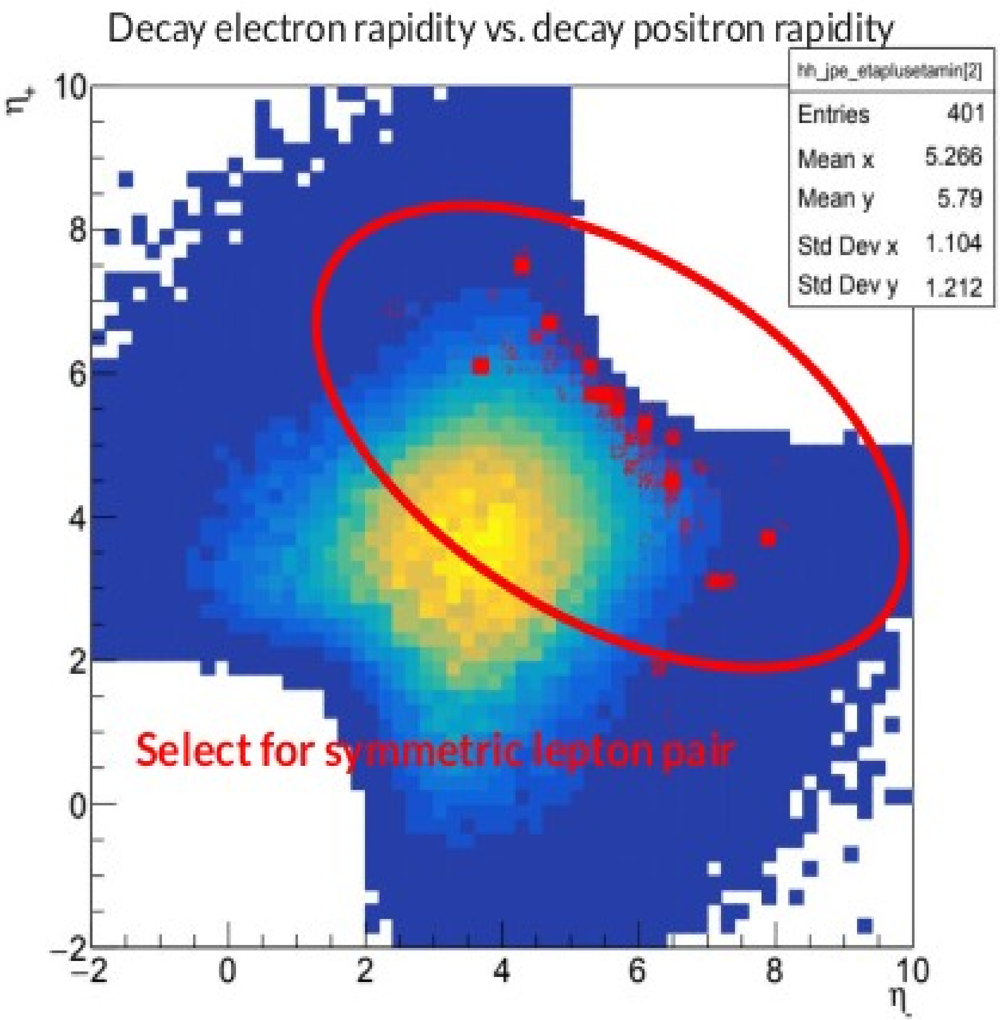
J/Psi rapidity vs pT for decay vs pair electron (no acceptance cut)

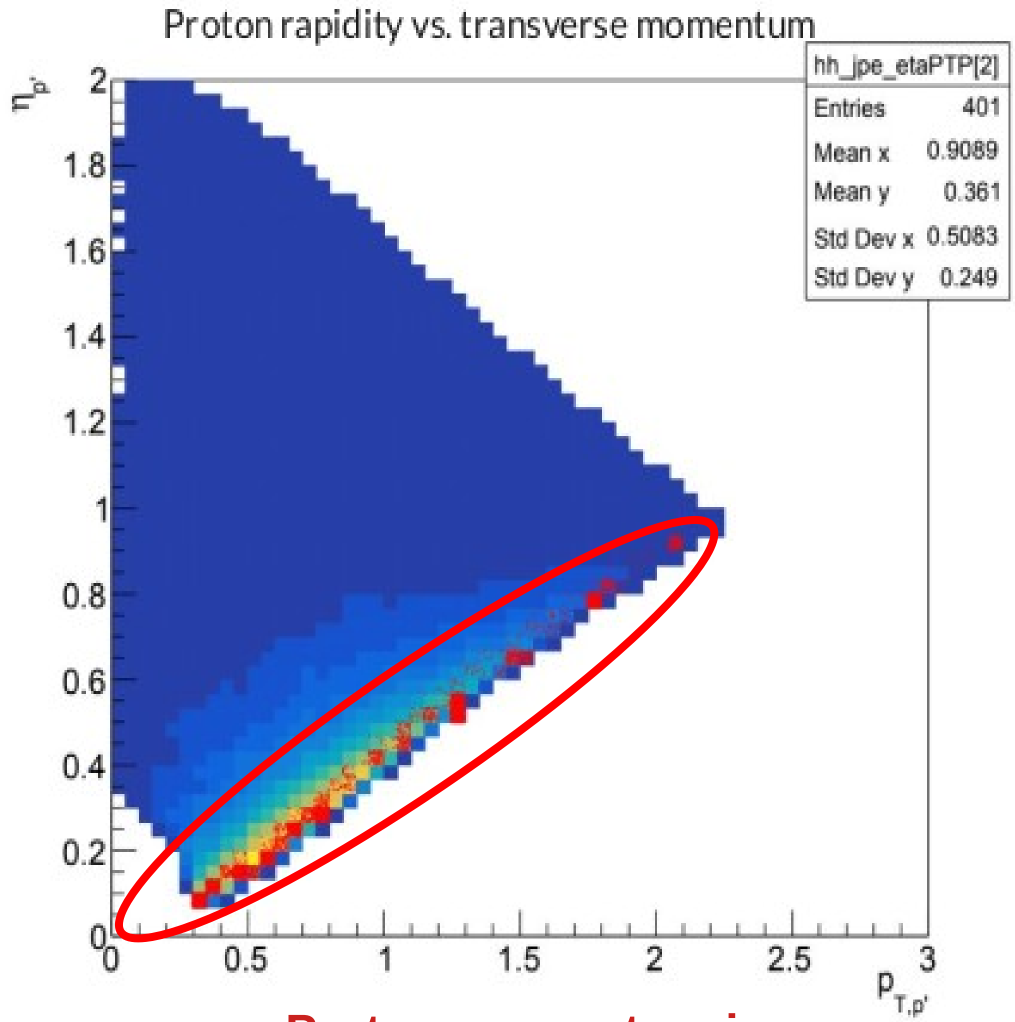


Being "safe" limits us to electrons close to the rapidity acceptance limits for EIC
- limit eta 3.5 can't be extended (tracking, beamline…) should be same or lower with a det 2.

Access all the range with muons

J/Psi proton rapidity vs pT for “symmetric pairs” (no acceptance cut)





- cut applied to stay out of BH peaks region,
Selects accessible region in t
Want to stay at lower t.

Proton momentum is unconstrained, but only lowest rapidity is measured
-> selects the range in t for GPDs

Why (not) adding muon detectors?

- Some people claim that all can be done with electrons only: our conclusions show otherwise

- Some people claim that PID is good enough for muons without dedicated detectors,
And that we can identify muons with accurate resolution after HCAL: we don’t know!

Our plans:

- Full simulations with electrons and muons with updated ePIC detector, accounting resolutions
What can be achieve without muon detectors/trigger?

- Adding simple detector (hodoscope) near beamline: how does it improve PID?

Constraints for our physics: need statistics (OK for J/psi), need lower -t, need all decay particle, need precision (10%)?

- work very preliminary for now, starting full simulations and GEANT4 studies to see the
Experimental pros and cons of adding muon detectors/trigger

Detector 1 vs detector 2:
- Due to lower crossing angle, IP6 is better for this physics (achieve resolutions)
- design is more open as of now for a potential detector 2

=== We want to see what can and can’t be done to improve physics outcome in channels producing muons.

SUMMARY

Open to discussion!!!

Physics wise, our conclusion is that we NEED muon channels

- for exclusive physics (GPDs…)
- likely for semi-inclusive physics (TMDs…) but we haven't explore it yet

Hardware wise:

- is it possible to add muon detectors?
- what kind of detector or trigger?
- cost?
- significant improvement in PID?
- what can be achieved without dedicated muon detectors?
- 2 interaction regions?

Our near-future plans to
Address all or some of these
questions
+ finding collaborators

Other questions:
- How not having muon or fine resolution affects GPD extraction?
- Other physics, with/without muons?
- Quarkonia + charmed/beauty meson?
- TMDs and other nucleon's imaging approach in the low -t region?
- certainly many more questions!