Center for Frontiers in Nuclear Science

Stony Brook University

IISER PUNE

CFNS Review Presentation

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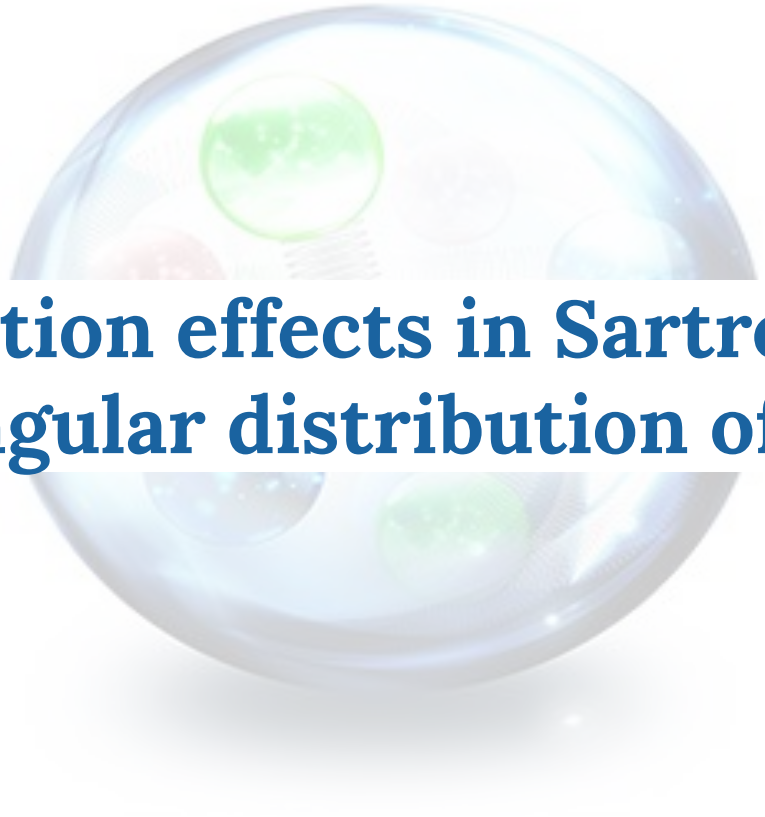
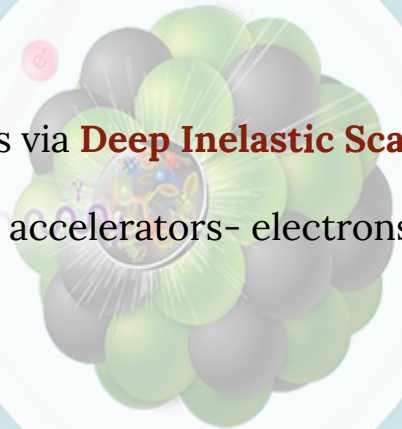


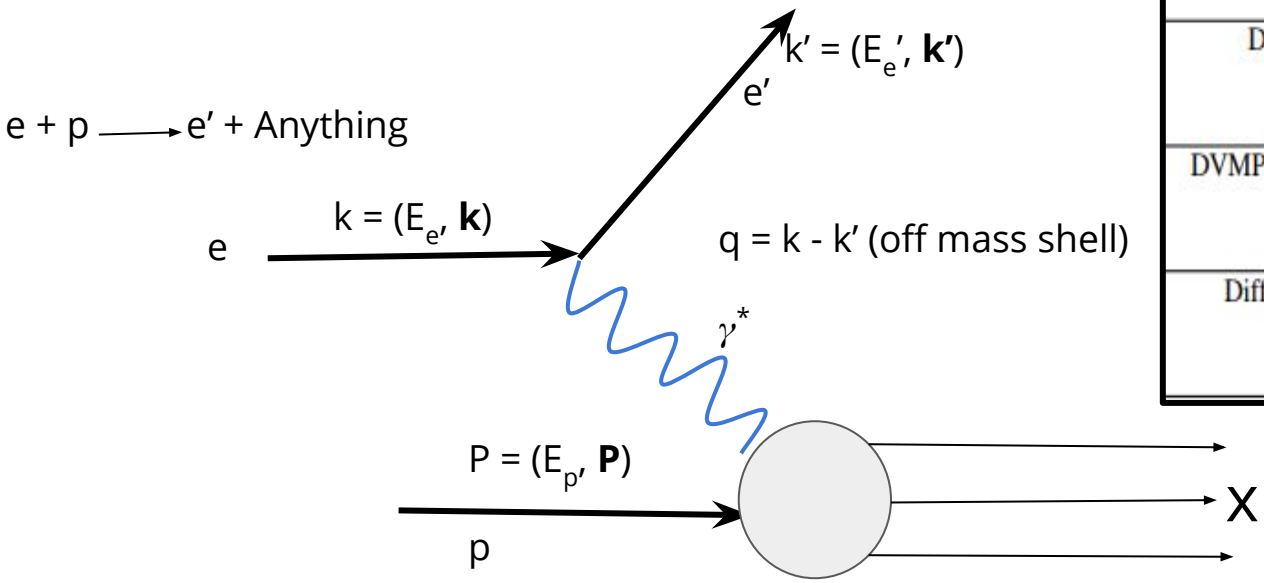
Polarization effects in Sartre and decay angular distribution of e+e-

Electron ion collider

- Upcoming machine to unveil the secrets of the strong force in nature
- CT Scanner of the atomic nucleus
- Probe the structure of the nucleus via **Deep Inelastic Scattering**
- Would consist of two intersecting accelerators- electrons and protons/heavy nuclei, which are steered into head-on collisions



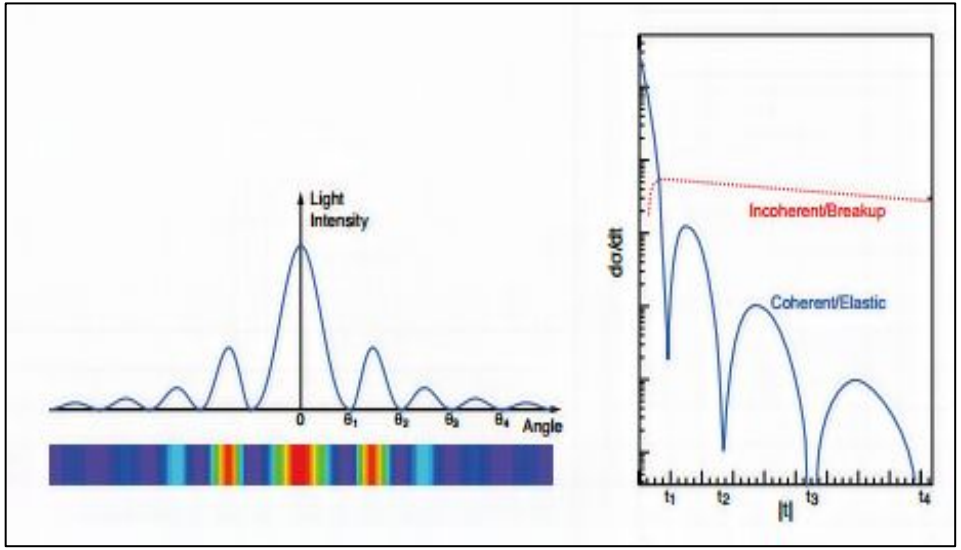
Deep Inelastic Scattering



Measurement	Beam	Measured Final State
Inclusive DIS	e+p	scattered e^-
Semi-Inclusive DIS	e+p	scattered e^- identified hadron
DVCS	e+p	scattered e^- photon scattered p
DVMP with J/Ψ	e+p	scattered e^- $e^- + e^+$ from J/Ψ decay scattered p
Diffraction	e+A	scattered e^- rapidity gap n from nuclear dissociation

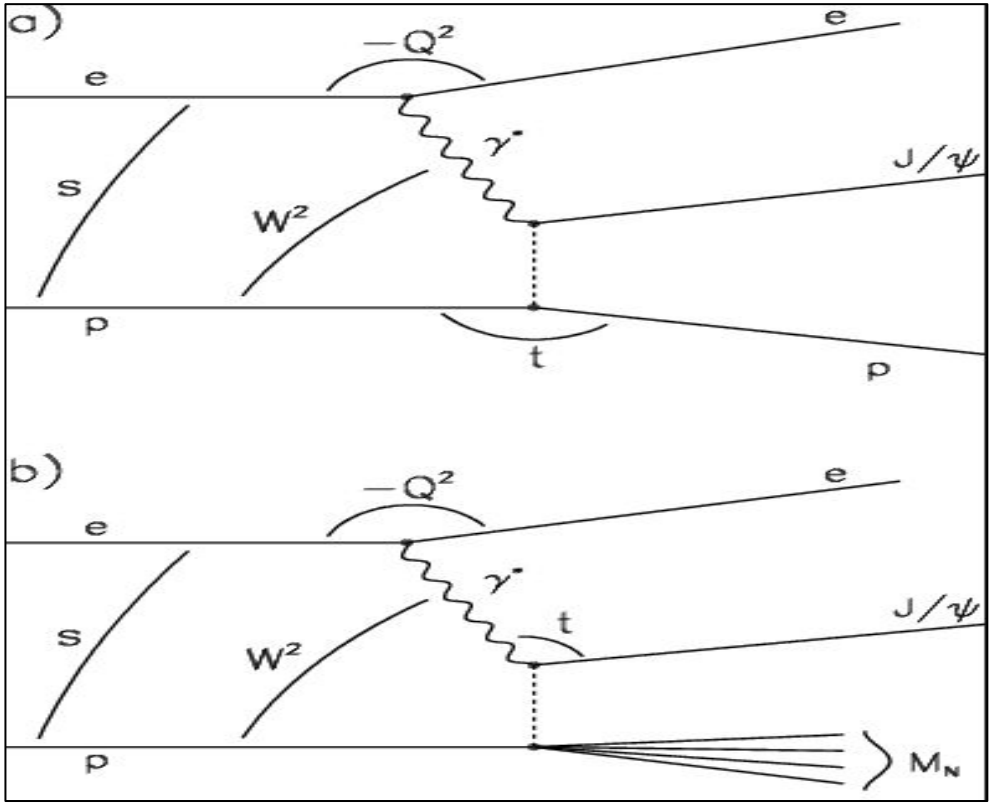
Diffractive Deep Inelastic Scattering (DDIS)

- Sensitive to geometric structure of hadrons
- Gluon spatial distribution inside nuclei
- Sensitive to saturation phenomena
- Coherent and Incoherent
- Presence of rapidity gap
- Almost 15% of events at HERA



Diffractive Vector Meson Production

- Only one new final state : V = J/ψ , ρ, ϕ, γ



a) coherent diffractive VM production

b) incoherent diffractive VM production

Sartre [arXiv:1307.8059]

- The dipole model Monte Carlo generator - Tobias Toll , Thomas Ullrich
- Event generator for exclusive diffractive vector meson production and DVCS in ep and eA collisions based on the dipole model.
- It describes the process: e p → e' p' V and e A → e' A' V where V = J/ψ, φ, ρ, γ.

The Path Forward..

1. Sartre does not take into account the polarization effects of the virtual photon, if any.
2. Based on the event kinematic reconstruction studies done at a generator level using Sartre, the **scattered electron method** gives the best resolution among all. Hence, measuring energy and scattering angle of the primary electron accurately is important!!
3. How to separate it from the J/ψ decay product electron ??

Thus, further studies focusing on the decay angular distribution of J/ψ.

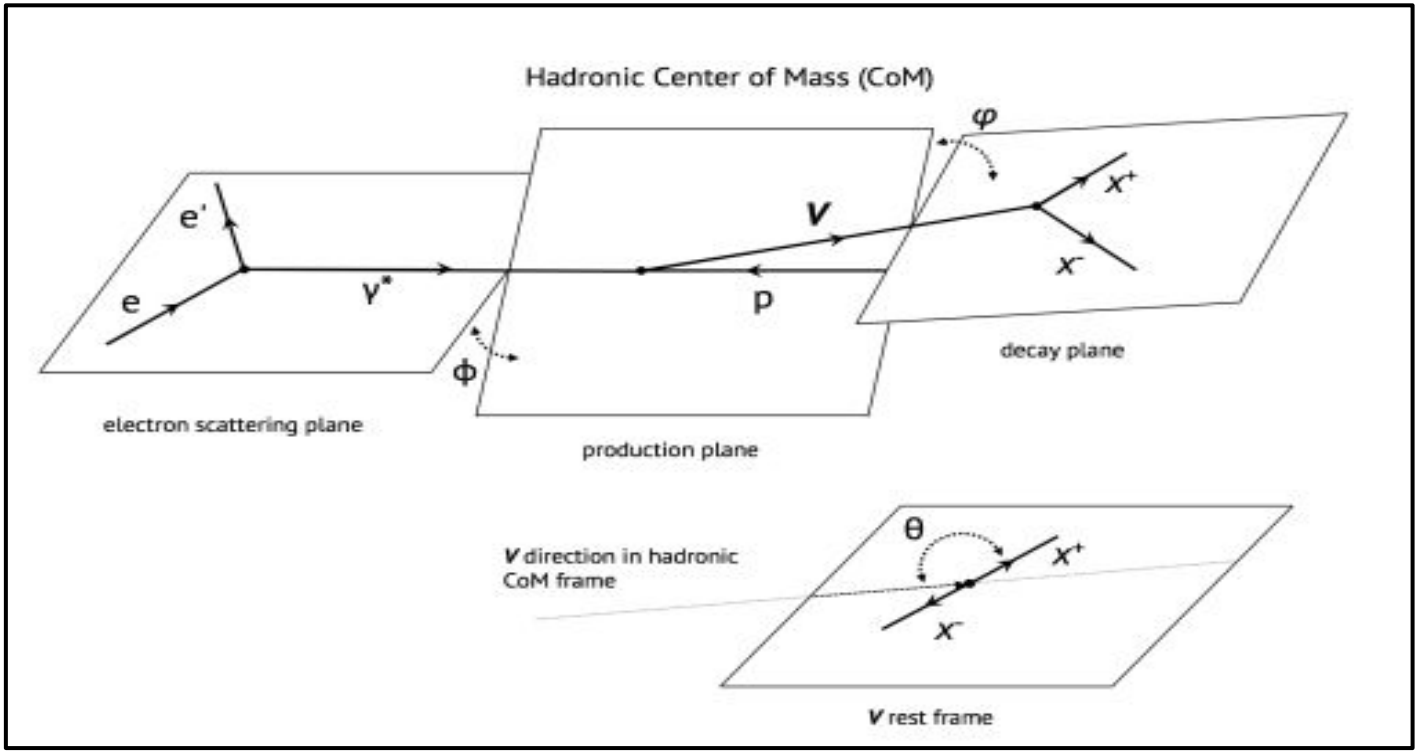
Decay Angular Distribution of the VM

Decay Angular Distribution of VM

Reference：***Exclusive vector meson production at an electron-ion collider*** ,Michael Lomnitz and Spencer Klein

- The polarization of the virtual photon accounts for decay angular distribution of the VM
- In the limit $Q^2 \rightarrow 0$, the photons are polarized transverse to the beam direction; they can be decomposed into a mixture of 50% right-handed and 50% left-handed photons.
- The VM retains the photon spin state, and the angular distributions come from the relevant spherical harmonics and Clebsch-Gordan coefficients.
- As the photon Q^2 rises, the photons can also be longitudinally polarized, along the direction of motion, and the angular distributions become more complicated.

VM production $ep \rightarrow eVp$ and subsequent decay $V \rightarrow X^+ X^-$



The ratio of the longitudinal to transverse cross-section can be written as,

$$R_V(W^2, Q^2) = \frac{\sigma_{L,\gamma^* p \to Vp}}{\sigma_{T,\gamma^* p \to Vp}}$$
$$= \frac{(Q^2 + m_{V,T}^2)^2}{m_{V,T}^4} \xi_V^2 \left[\frac{\pi}{2} \frac{m_{V,L}^2}{Q^2} - \frac{m_{V,L}^3}{\sqrt{Q^2}(Q^2 + m_{V,L}^2)} - \frac{m_{V,L}^2}{Q^2} \arctan\left(\frac{m_{V,L}}{\sqrt{Q^2}}\right) \right]^2 \quad (16)$$

According to the SCHC approximation, this can be expressed in terms of the spin matrix element in the following way,

$$R = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

The decay angular distribution, after the approximations, is found to be dependent on the θ, and uniform in φ. Hence, the modulation in θ can be expressed the following ways

For ρ and ϕ mesons which decay to spin-0 mesons,

$$\Omega(\cos\theta) \propto 1 - r_{00}^{04} + (3r_{00}^{04} - 1)\cos^2(\theta)$$

For J/Psi meson which decay to spin-½ leptons,

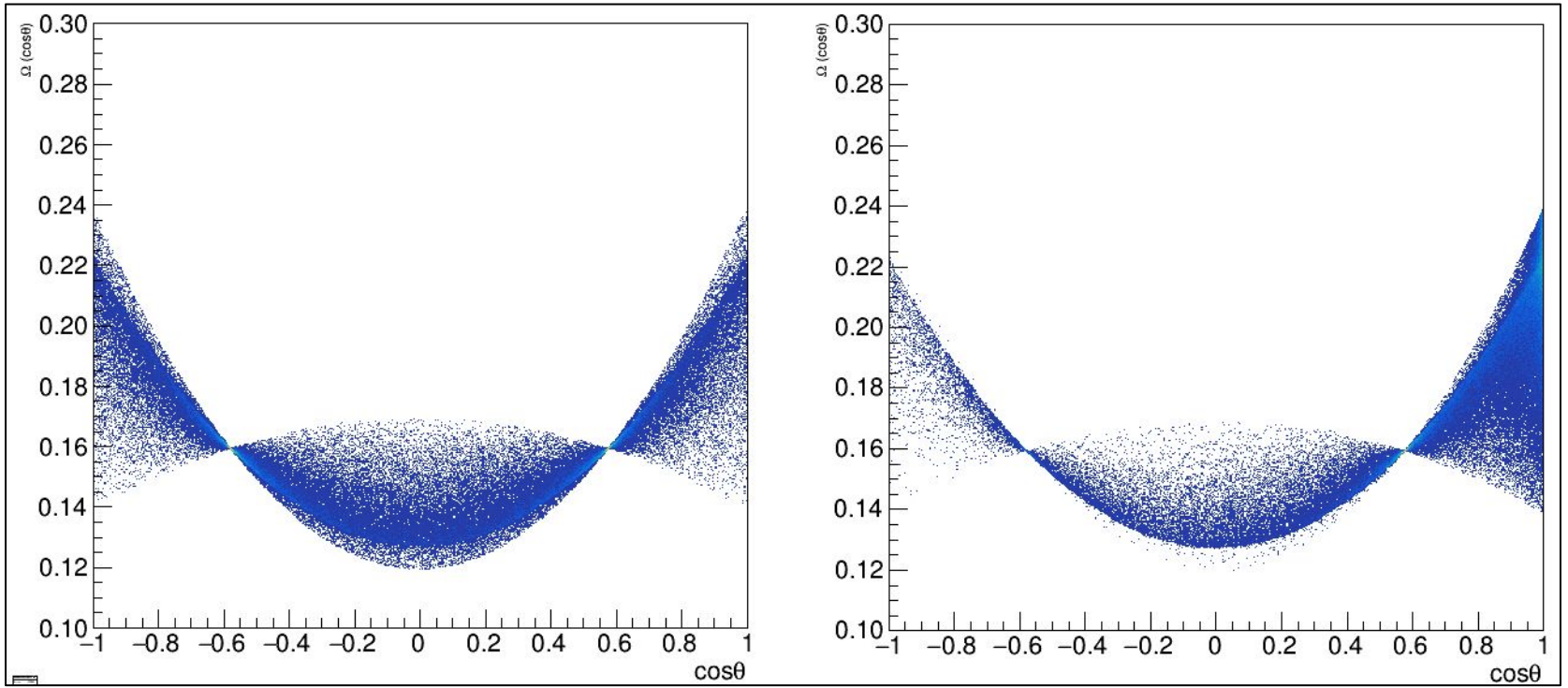
$$\Omega(\cos\theta) \propto 1 + r_{00}^{04} + (1 - 3r_{00}^{04})\cos^2(\theta)$$

Analysis and Interpretations

Method of Approach

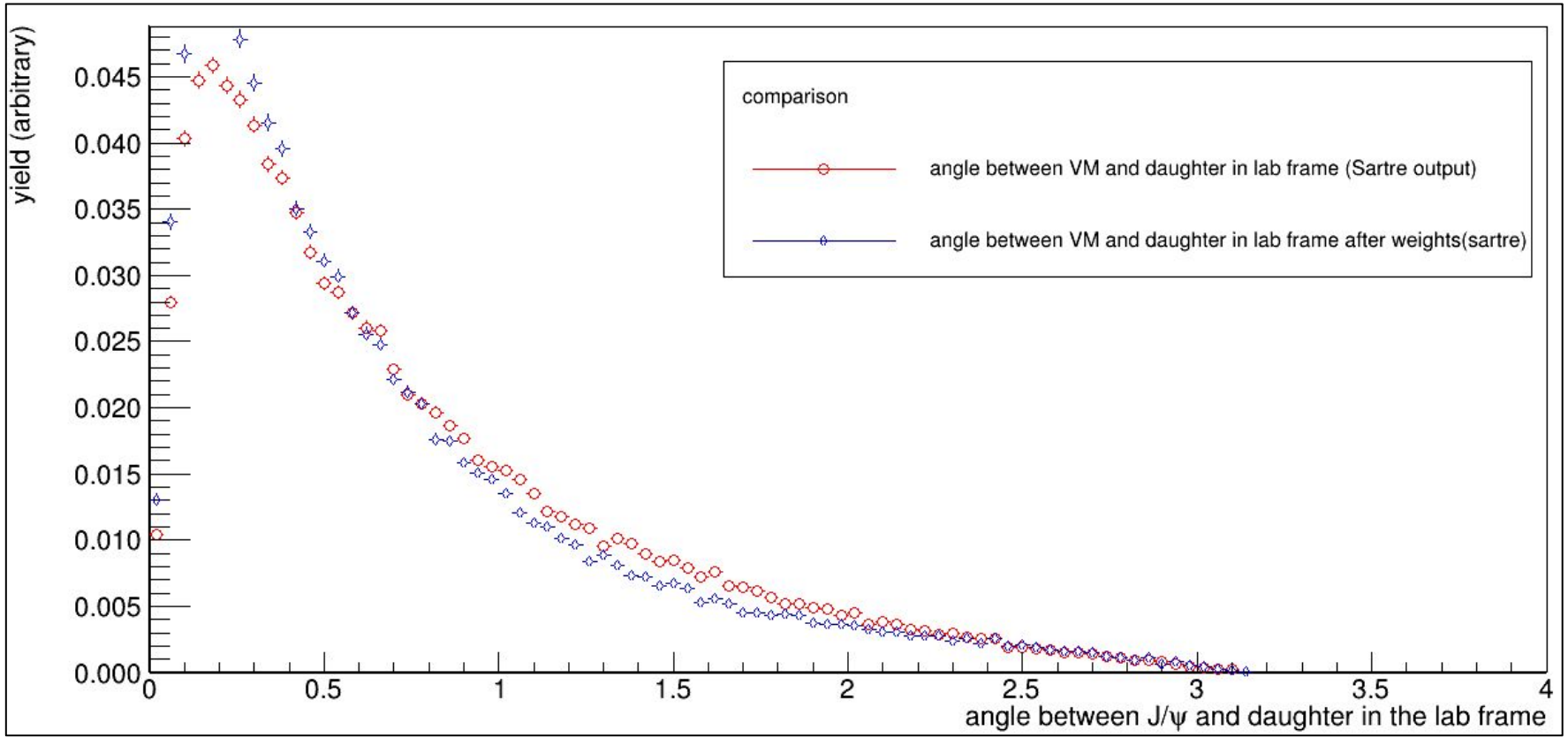
1. Boosted the VM from lab frame to hadronic COM frame
2. Generated VM decay in the VM rest frame
3. In the VM rest frame, the angle between one of the VM daughters and the VM momentum direction in the hadronic COM frame is calculated, and this angle is used to provide the event weight.
4. VM daughters are first boosted to the hadronic COM frame and then to the lab frame to get their 4-vector in the lab frame, and calculated the angle between VM and daughter after applying weight
5. Compared the distribution with the default Sartre output (after normalization)

Angular distribution (Ω) as a function of cosθ (Angle between J/ψ and daughter)



Rest Frame **Lab Frame**

The normalized decay angular distribution



Summary

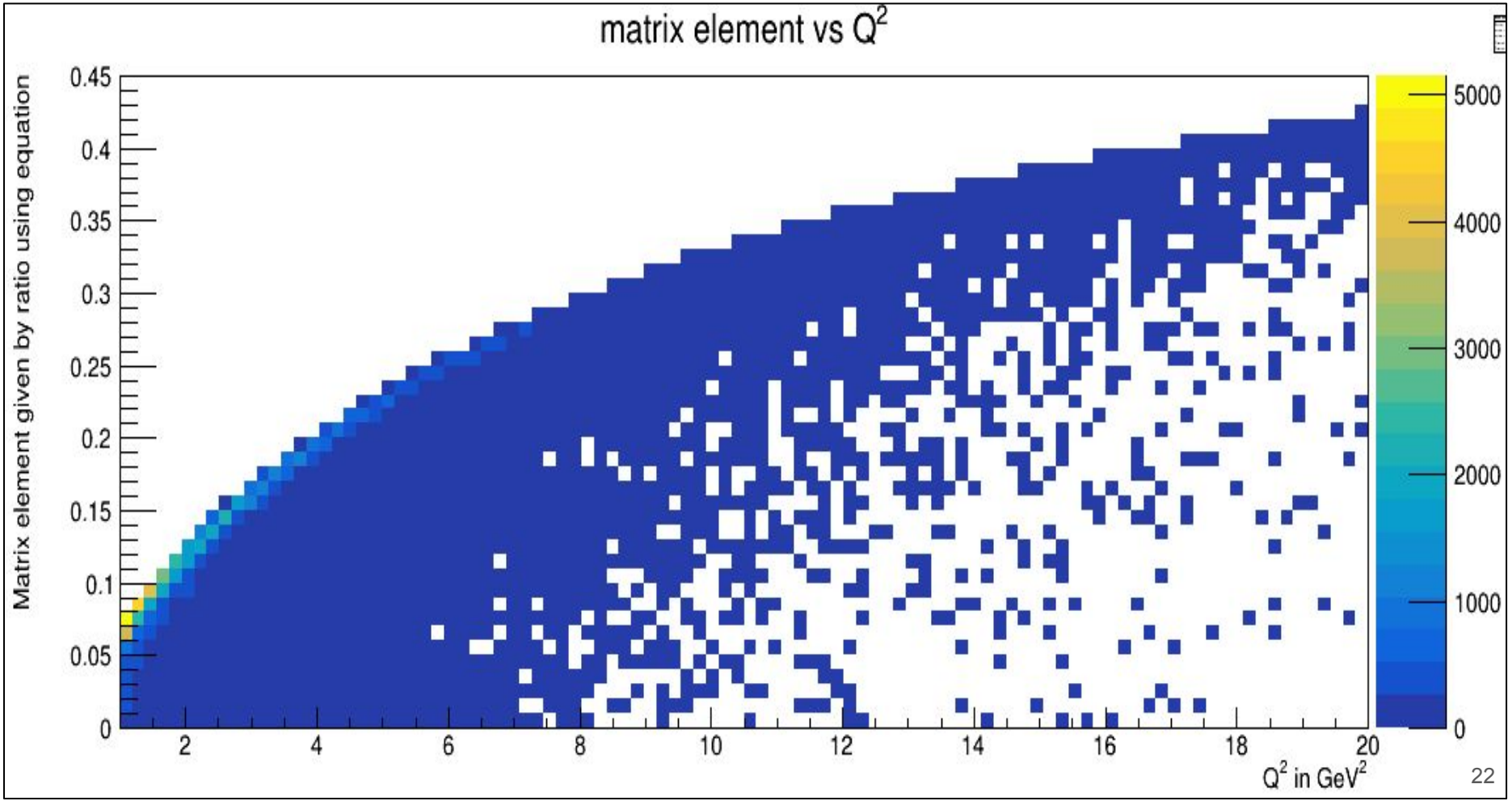
1. It turns out that the **polarization of the virtual photon affects the decay angular distribution of the VM** and it is relevant for future studies.
2. The ratio of the longitudinal to transverse cross-section has **no significant dependence on t or W** but **depends on Q^2** (thus the ratio is consistent using the equation and Sartre)
3. In the lab frame, daughter moves closer to the VM as we expect.
4. The primary electron and the J/ψ daughter are well separated in detector φ but overlap in certain η regimes.

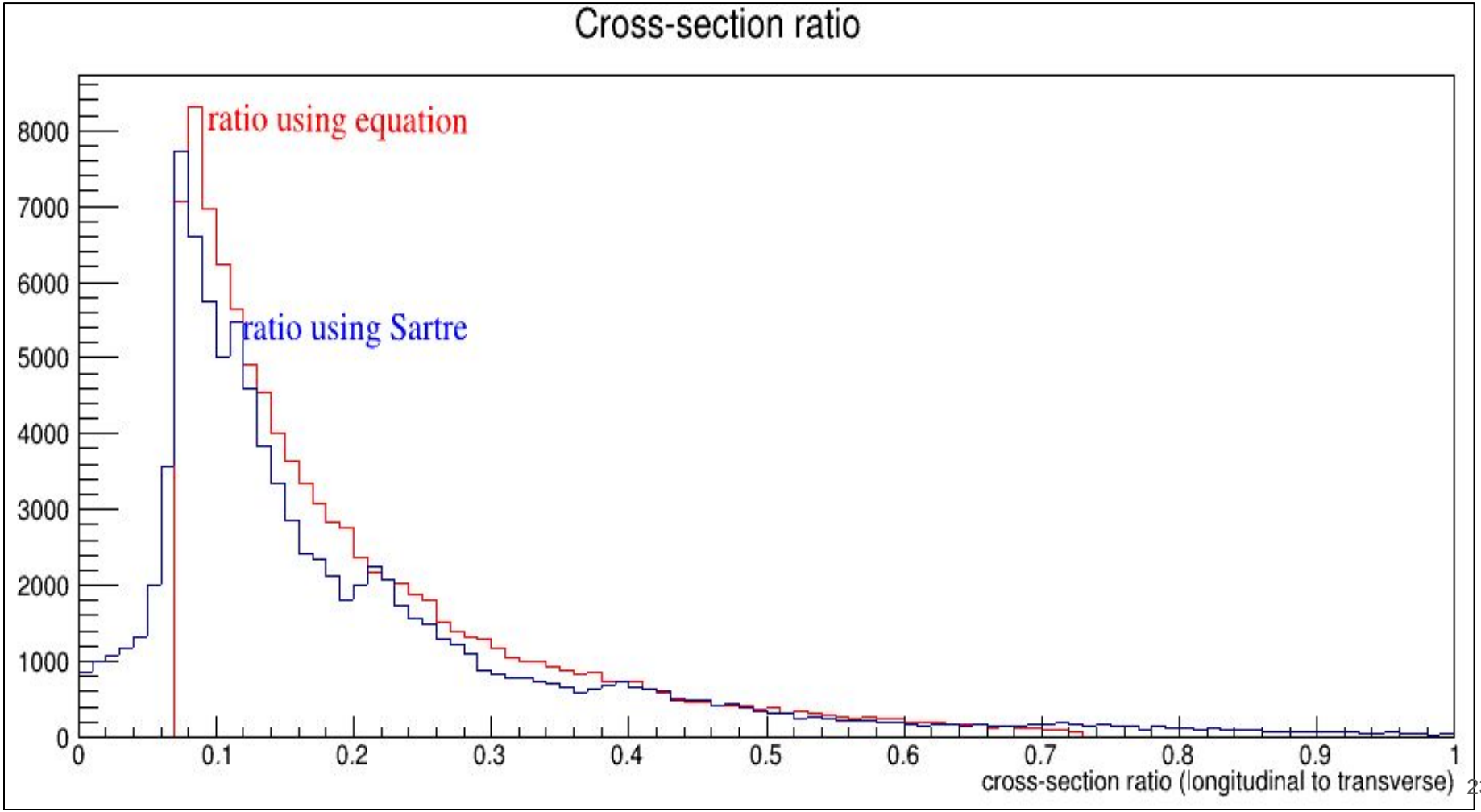
References

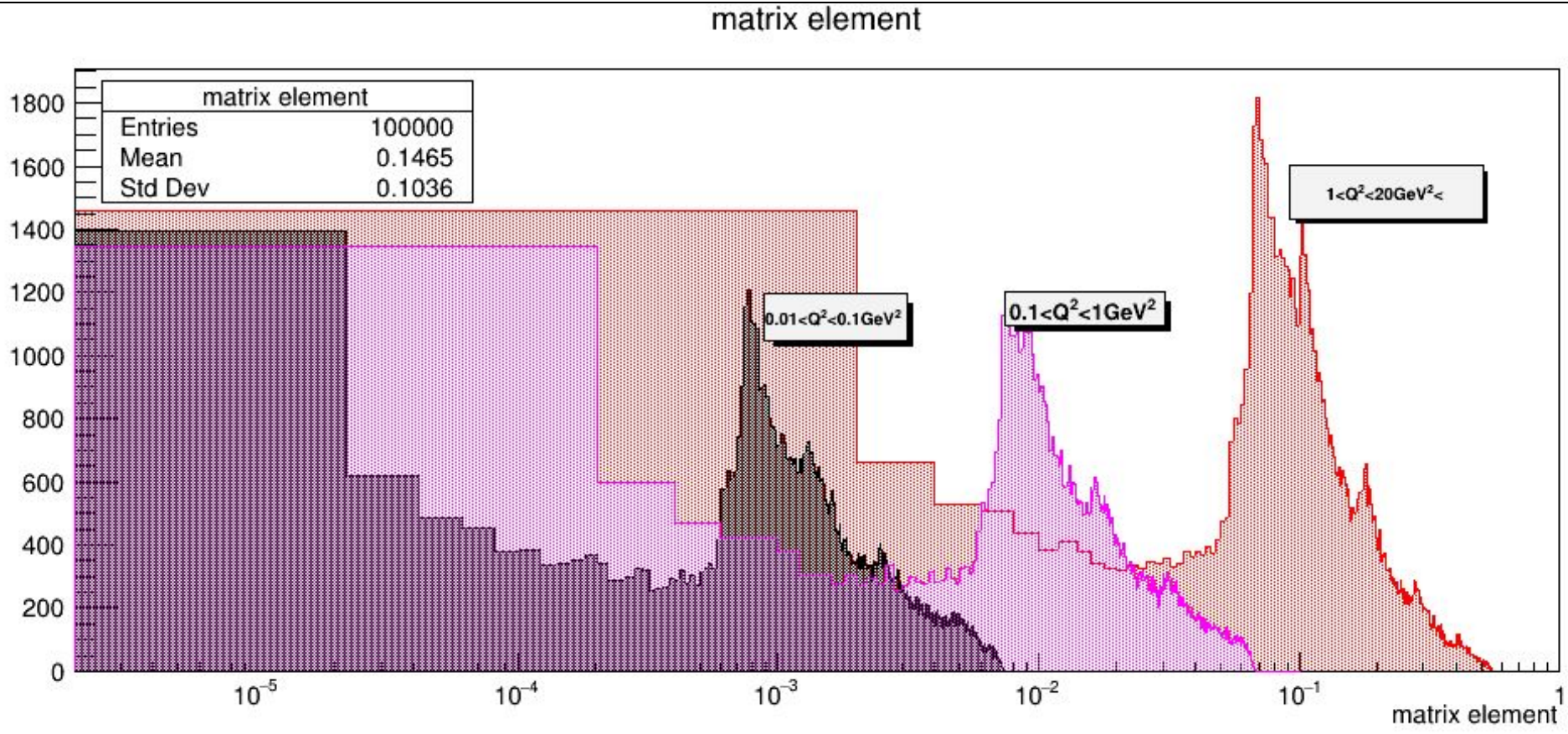
1. Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all [https://arxiv.org/abs/1212.1701]
2. The dipole model Monte Carlo generator Sartre 1 [https://arxiv.org/abs/1307.8059]
3. Exclusive vector meson production at an electron-ion collider [https://arxiv.org/abs/1803.06420]
4. Elastic electroproduction of ρ mesons at HERA [https://arxiv.org/abs/hep-ex/9902019]

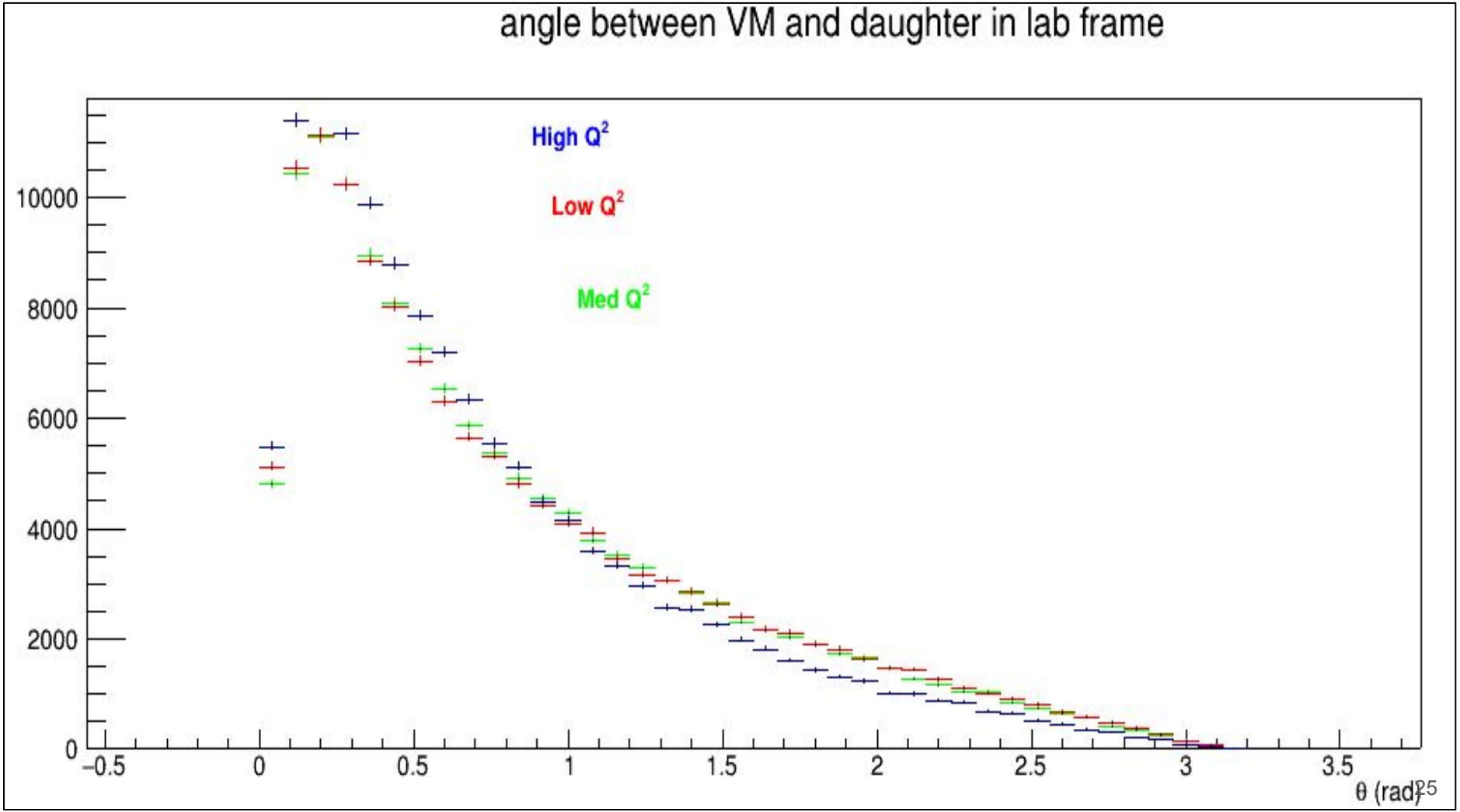
Thank You!

Back up

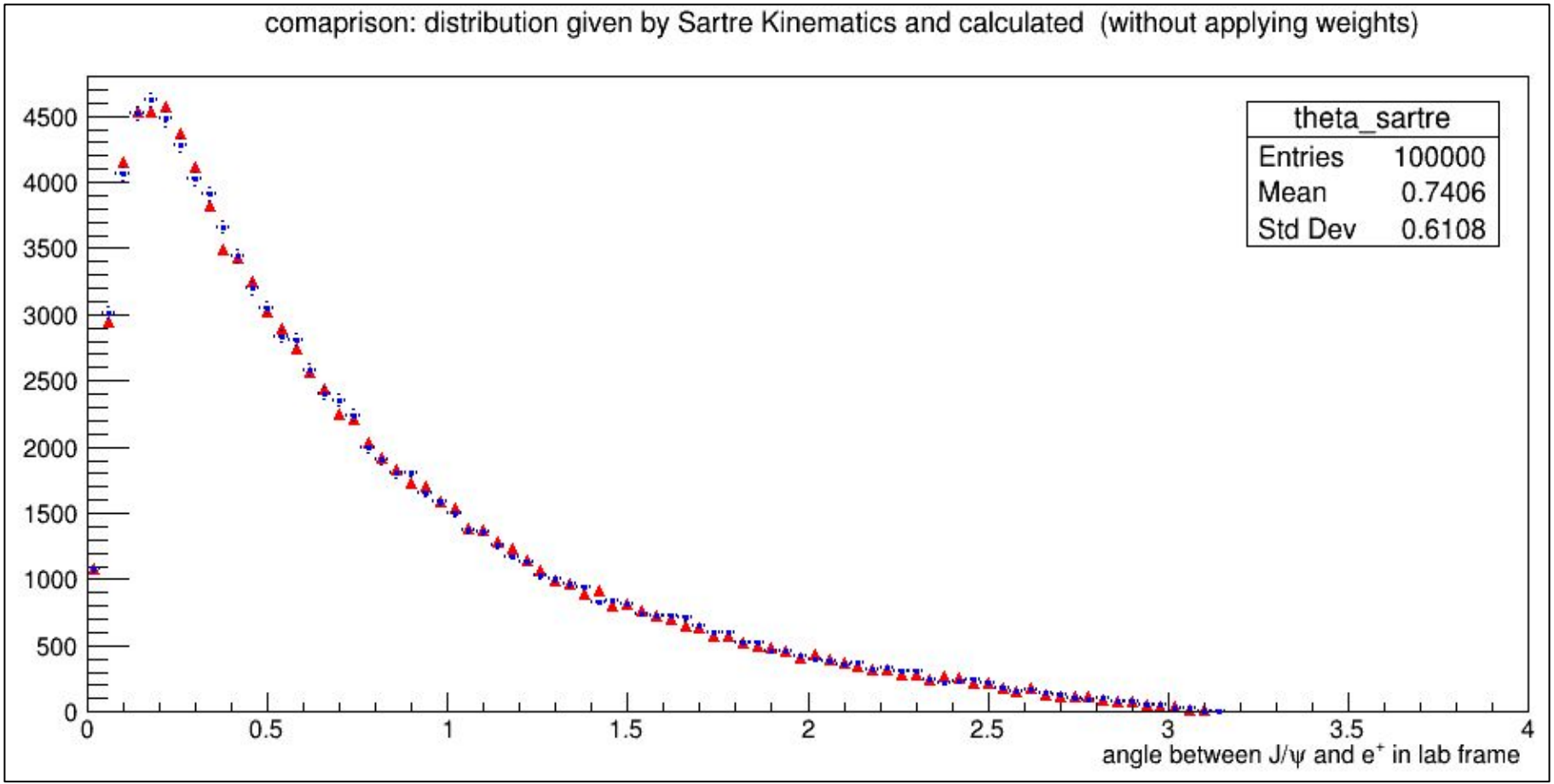

matrix element vs Q^2
Matrix element given by ratio using equation
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
14
16
18
20
Q^2 in GeV^2
5000
4000
3000
2000
1000
0


Cross-section ratio
ratio using equation
ratio using Sartre
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
cross-section ratio (longitudinal to transverse)


matrix element
matrix element
Entries 100000
Mean 0.1465
Std Dev 0.1036
0.01<Q²<0.1GeV²
0.1<Q²<1GeV²
1<Q²<20GeV²<
1800
1600
1400
1200
1000
800
600
400
200
0
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
matrix element


angle between VM and daughter in lab frame
High Q²
Low Q²
Med Q²
10000
8000
6000
4000
2000
0
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
θ (rad)

Mesons	$m^2_{V,L}$	$m^2_{V,T}$	ζ_V
ρ	$0.71\ m^2_{\rho}$	$0.68\ m^2_{\rho}$	1.06
ϕ	$0.57\ m^2_{\phi}$	$0.41\ m^2_{\phi}$	0.9
J/ψ	$0.6\ m^2_{J/\psi}$	$0.6\ m^2_{J/\psi}$	1


comaprison: distribution given by Sartre Kinematics and calculated (without applying weights)
theta_sartre
Entries 100000
Mean 0.7406
Std Dev 0.6108
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
angle between J/ψ and e+ in lab frame