Future J/ψ Production on Nuclear Targets with SoLID

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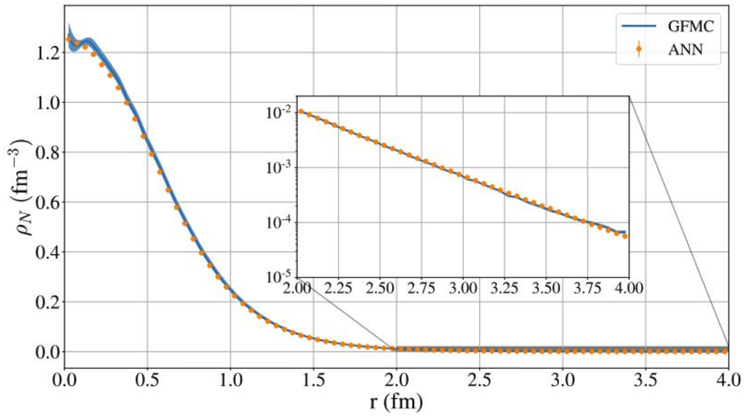
SoLID Opportunities and Challenges of Nuclear Physics at the Luminosity Frontier,
Argonne National Laboratory, 6/17/2024–6/22/2024

Contents

- Physics Motivation of coherent J/ψ electroproduction on Nuclear Target
- Measurement of the coherent J/ψ electroproduction off ^{4}He with SoLID
- Recoil detector and target options
- Summary

Nuclear charge distribution and form factor

Spatial charge distribution $\varrho(r)$



C. Adams et al., Phys. Rev. Lett. 127, 022502 (2021)

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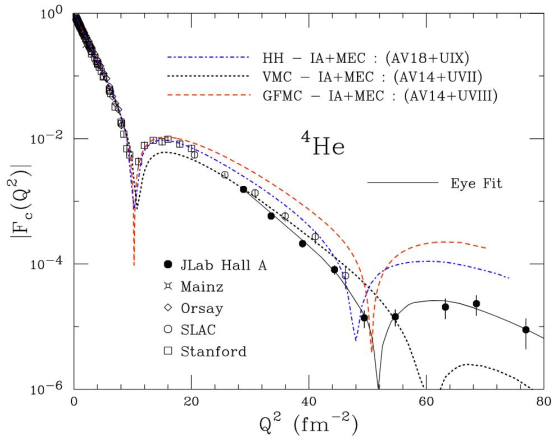
Charge Form Factor $F_c(t)$



A. Camsonne et al., Phys. Rev. Lett. 112, 132503 (2014)

- Theoretical prediction
- Matching with the experimental results

- Measurement of elastic scattering
- Hall A measurement around the second diffraction minimum!

Location of diffraction minimum characterizes the size of the charge distribution.

Nuclear Gravitational Form Factors

Spatial gluon distribution $\varrho(r)$

Gravitational Form Factors
$A(t)$, $D(t)$, …

- Theoretical prediction
- Matching with the experimental results
- c.f.) D. Hackett's talk on Monday for nucleon

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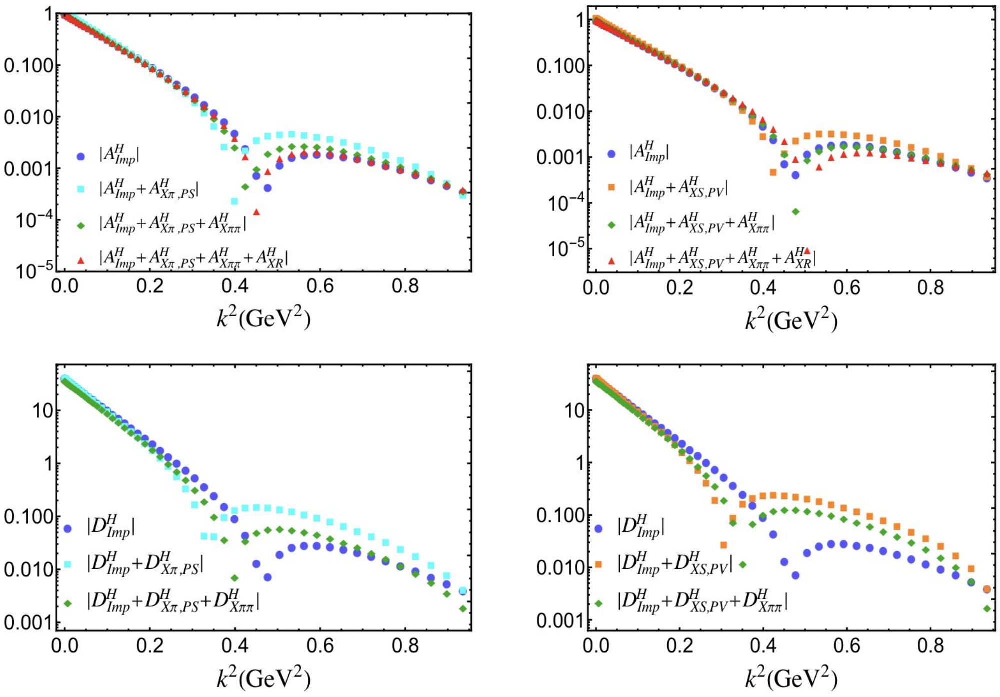
- Measurement of coherent J/ψ production
- c.f.) S. Joosten's talk on Monday for nucleon

Location of diffraction minimum will characterize the size of the gluon distribution.
Direct probe of gluonic structure inside the nuclei.

c.f.) I. Zahed's talk on Monday morning

Recent Studies on Nuclear GFFs



F. He and I. Zahed, arXiv:2406.07412 (2024)

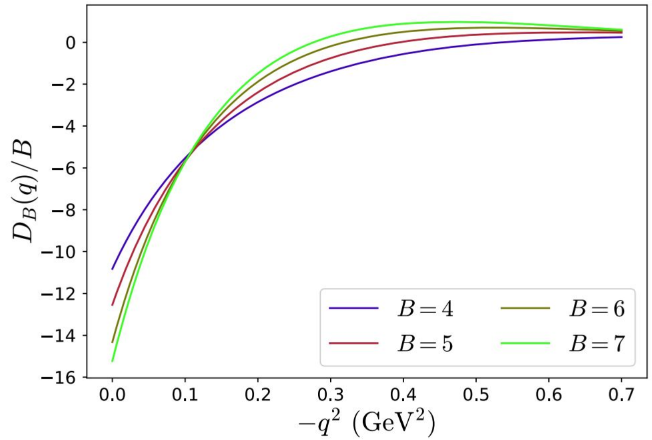


FIG. 3. The D gravitational form factor of the skyrmions with $B = 4$, 5, 6, and 7, normalized by B, for the $\lambda = 0$ case.

A. G. Martín-Caro, M. Huidobro, and Y. Hatta, PRD 108, 034014 (2023)

Recent Studies on Coherent J/ψ Production Cross Section

VM production cross section from the GFF

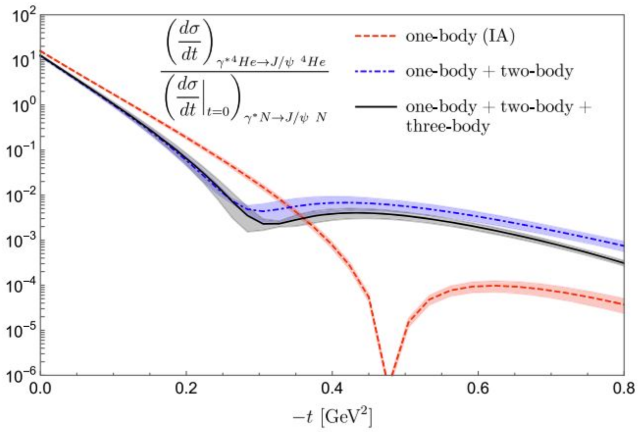
$$\frac{d\sigma}{dt} = \frac{\alpha_{\rm EM} e_c^2}{4(s - M_{He}^2)^2} \frac{(16\pi\alpha_S)^2}{3M_{J/\psi}^3} |\psi_{\rm NR}(0)|^2 |G(t,\xi)|^2$$

$$= 70.2 \frac{1}{(s - M_{^4He}^2)^2} |G(t,\xi)|^2 [\text{nb}/\text{GeV}^2]$$

$$= 70.2 \frac{1}{(s - M_{^4He}^2)^2} \frac{4}{\xi^4} |A_{^4He}(t) + \xi^2 D_{^4He}(t)|^2 [\text{nb}/\text{GeV}^2]$$

Y. Guo, X. Ji, Y. Liu, PRD 103,9, 096010 (2021)
Y. Guo, X. Ji, Y. Liu, and J. Yang, PRD 108, 3, 034003 (2023)
F. He and I. Zahed, Private Communication
See I. Zahed's talk on Monday

Nuclear effect @ EIC kinematics



V. Guzey, M.Rinaldi, S.Scopetta, M. Strikman, and M. Viviani,
PRL 129, 242503 (2022)

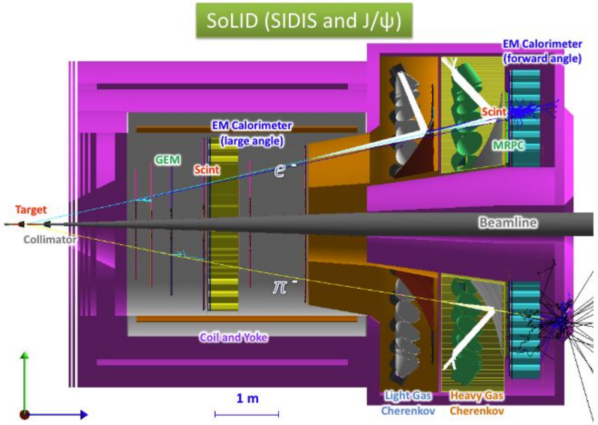
Future J/ψ Production on Nuclear Targets with SoLID

SoLID is a large acceptance spectrometer that effectively measures J/ψ production off nuclear targets

- Scattered electron
- e^+e^- from J/ψ decays
- Recoil detection is important for coherent processes

SoLID can measure the reaction at high luminosity

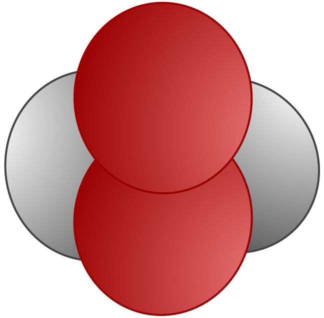
- Large statistics allows fully exclusive measurements
- An ideal place to measure J/ψ production on nuclear targets!



From SoLID White Paper (2022)

Measurement of the coherent J/ψ electroproduction off ^4He with SoLID

^{4}He, from Nucleon to Spin Zero Nuclei



- Spin-0 → simpler structure for the electromagnetic and gravitational

$$\langle p', s'|T^a_{\mu\nu}|p, s\rangle = \bar{u}(p')\left[\frac{1}{2}\gamma_{\{\mu}P_{\nu\}}A_a(t) + \frac{iP_{\{\mu}\sigma_{\nu\}\rho}q^\rho}{4M_N}B_a(t) + \frac{q_\mu q_\nu - g_{\mu\nu}q^2}{M_N}C_a(t) + M_N\bar{C}_a(t)g_{\mu\nu}\right]u(p)$$

$$= \bar{u}(p')\left[\frac{P_\mu P_\nu}{M_N}A(t) + \frac{iP_{\{\mu}\sigma_{\nu\}\rho}q^\rho}{2M_N}J(t) + \frac{q_\mu q_\nu - g_{\mu\nu}q^2}{4M_N}D(t) + M_N\bar{C}^a(t)\right]u(p)$$

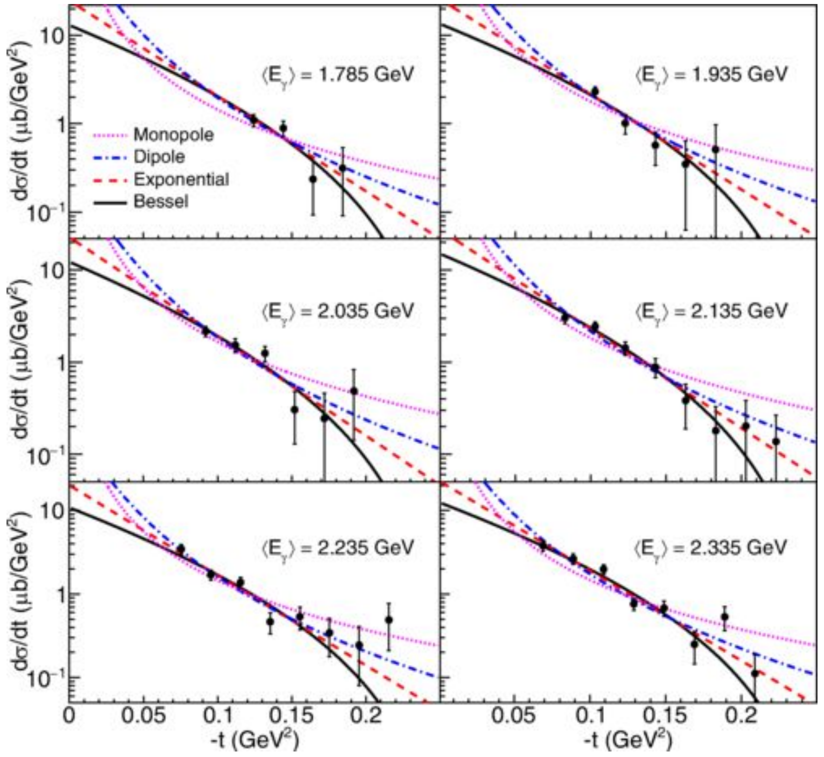
$$\longrightarrow \quad \langle p'|T^a_{\mu\nu}(x)|p\rangle = \left[2P_\mu P_\nu A^a(t) + \frac{1}{2}(q_\mu q_\nu - g_{\mu\nu}q^2)D^a(t) + 2M_N^2\bar{C}^a(t)\right]$$

$$\sum_a \bar{C}_a(t) = 0, \;\; a = g, u, d, \ldots$$

- Light nuclei
  - has a comparable mass to the J/ψ (^{4}He: 3.73 GeV, J/ψ: 3.1 GeV)
  - large enough first diffraction minimum

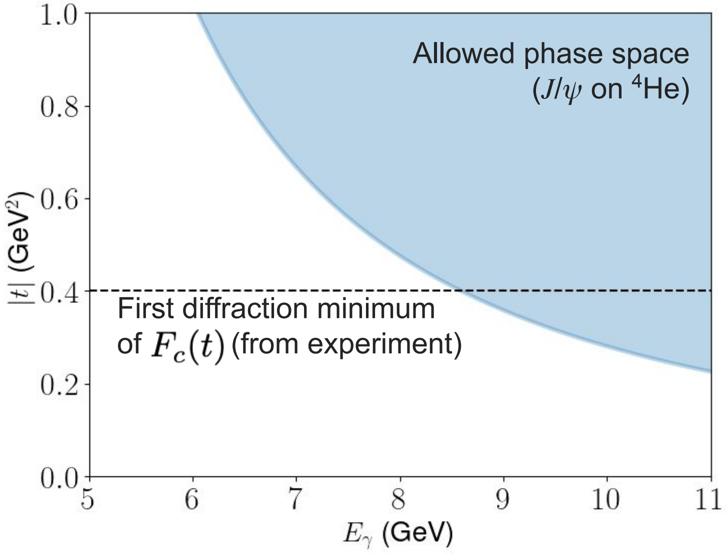
Recent ϕ Production Results

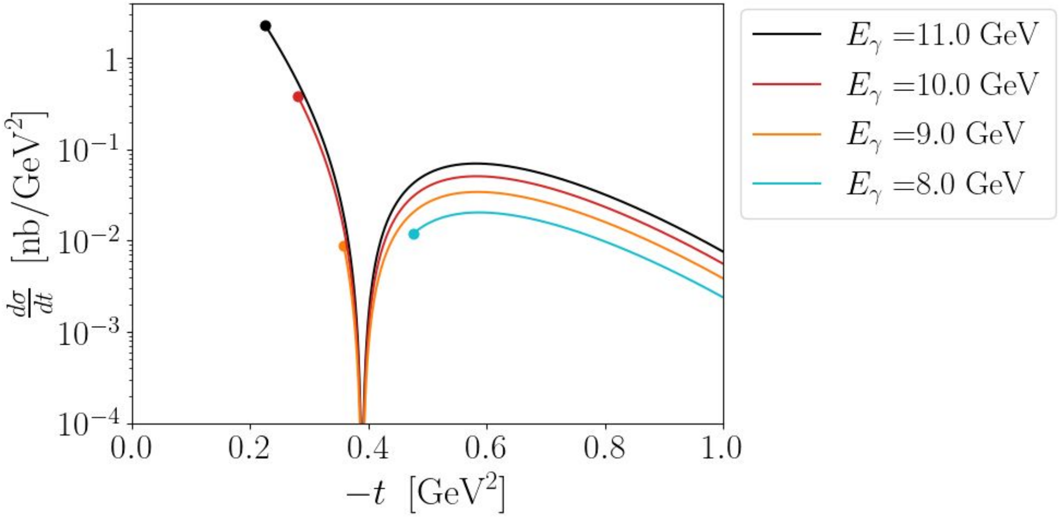
- ϕ production can also probe gluons
- Gluon distribution extraction from LEPS at SPring8 (2018) →
- No direct measurement around the diffraction minimum of $F_c(t)$
- Probing this region with J/ψ channel is essential for studying the gluon distributions inside ^{4}He nucleus.



R. Wang et al, Phys. Rev. C 109 (2024), L012201

Coherent J/ψ Production on ^{4}He—Phase Space

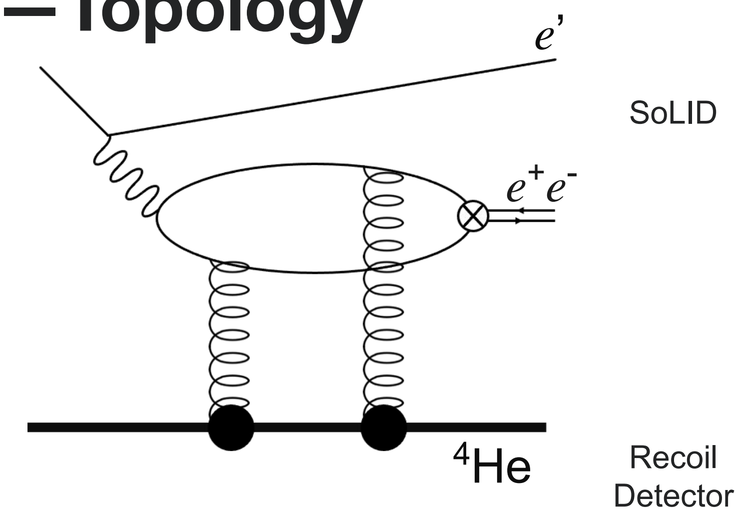




Measurement with photon energy E_γ is important.
= detection of low energy scattered electron is required.

Coherent J/ψ Production on ^{4}He—Topology

Particle	Detector	Condition
e'	SoLID	p > 0.5 GeV/c 8°<θ<24°
e^+e^-	SoLID	p > 0.5 GeV/c 8°<θ<24°
^{4}He	Recoil detector	Low energy, forward angle

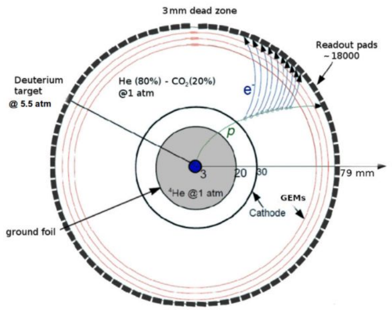


- Tagging the recoil is required.
  - PID to veto incoherent background
  - Energy (momentum) measurement to determine t
  - Detection of low energy, forward angle recoil is the most important.
- Either of following is necessary.
  - e^+e^- detection. Better event selection, BR ($J/\psi \rightarrow e^+e^-$) = 5.971%
  - e' detection. Better resolution in E_γ
- SoLID is a unique place allows the full exclusive measurement at high luminosity.

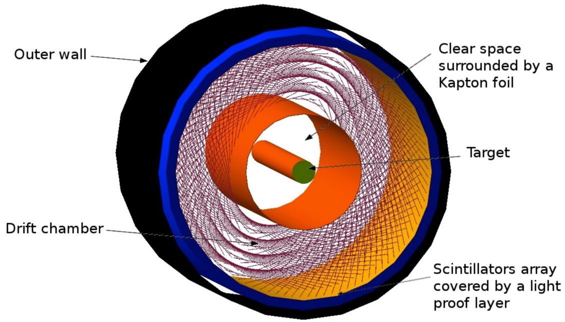
Recoil Detector and Target Options

Existing Target and Recoil Detector Options

- Gaseous ^{4}He target
  - O(10^{21} cm^{-2}) per nucleus (ex) CLAS12: 5 atm, 40 cm)
- Compatible conventional recoil detectors
  - RTPC: Used for the BoNUS12 Experiment
  - ALERT: Run Group L starts soon in Hall B
    - Being installed for the upcoming runs in Hall B
    - Good energy resolution, PID for ^{4}He detection
    - Fast detector, trigger to veto background
    - *LOI12-24-011 submitted to PAC 52*
  - CLAS12's solenoidal field is 5 T.

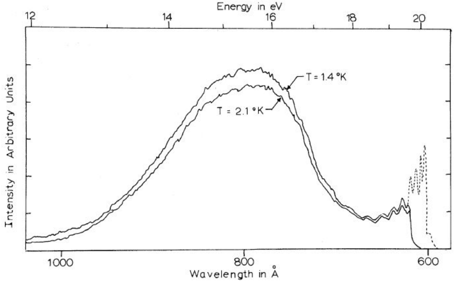


I. Albayrak et al., RTPC NIM paper (2024)



From ALERT Run Group Proposal
(W. Armstrong et al, arXiv:1708.00891)

LHe Active Target with SNSPD

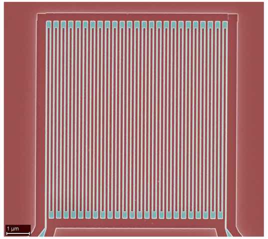


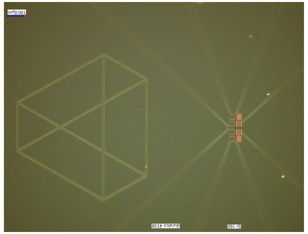
M. Stockton et al., PRA 5 (1972), 372

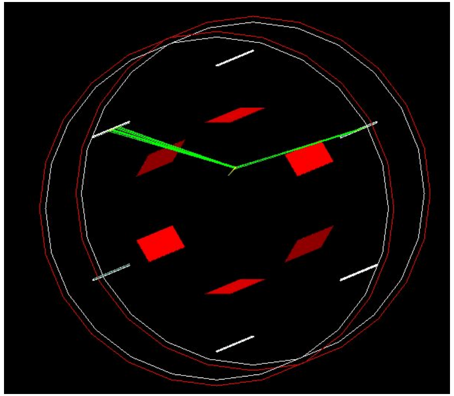
- Liquid ^{4}He emits 60–100 nm, prompt scintillation lights.
  delay time ~ 5 ns

- Superconducting Nanowire Single Photon Detector (SNSPD) is a cryogenic photon sensor
  w/ fast-timing, high efficiency, low timing jitter
  high granularity, little dark counts
- liquid ^{4}He transparent to its own prompt scintillation
- no optical surfaces between scintillator and sensor
- can immerse the sensor in LHe
- can detect scintillation light from O(10–100) MeV recoil
- thin screens to block scintillation from the beam (ex) Kapton)

→ Liquid ^{4}He Active Target







Tomas Polakovic

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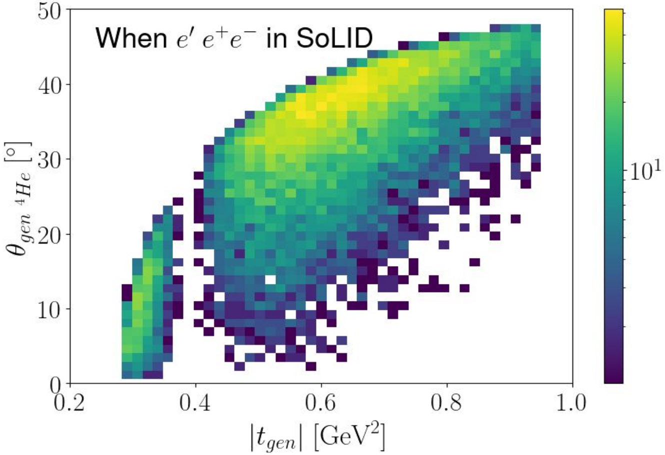
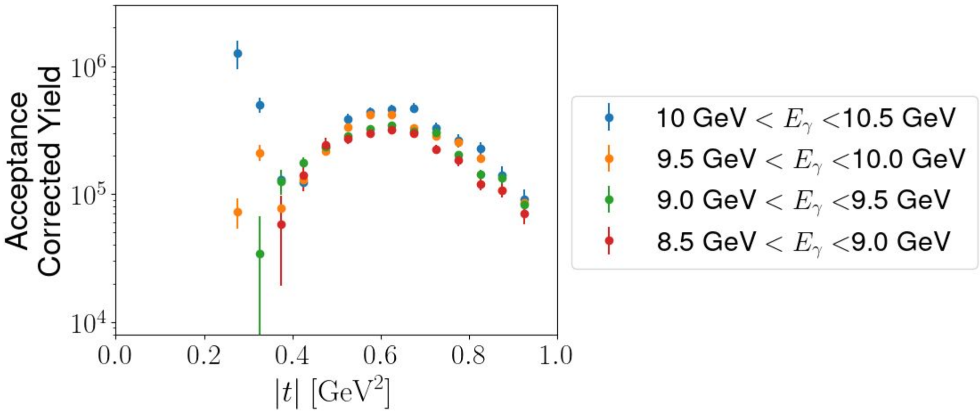
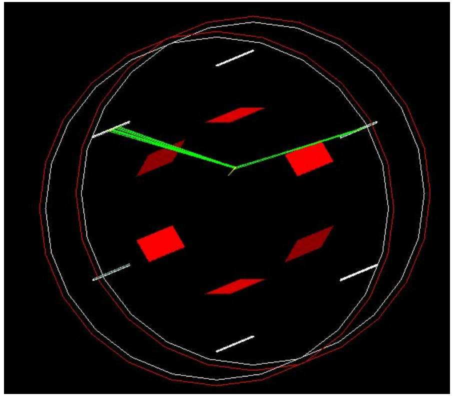
Prediction with SoLID and LHe Active Target





- Left: allowed phase space of ^{4}He at generator level when $e'e^+e^-$ are within SoLID acceptance.
- Right: acceptance corrected yield for different t, E_γ bins
- Assumed flat 50% efficiency and 5% momentum resolution on recoils (θ >15°)
- Needs further study on the active target acceptance.
- Challenge is tagging the low energy recoil at forward angle.



Other Related Physics Programs in 12 GeV Program

- LOI12-24-011 (CLAS12 + ALERT)
  - Coherent J/ψ production on ^{4}He, working on the full proposal

- E12-12-006 (SoLID)
  - J/ψ production on p

- LOI12-20-003 (SoLID)
  - Incoherent J/ψ production on D (PAC 48)

- E12-10-006A, E12-11-007, LOI12-16-007 (SoLID)
  - Physics cases with the ^{3}He target with SoLID

- C12-23-009 (GlueX)
  - Incoherent J/ψ on ^{4}He

Summary

Summary

- Energy momentum tensor and Gravitational Form Factor provides an elegant framework to study gluon distributions inside the hadron. Measurement of J/ψ production around the diffraction minima plays a central role in characterizing the gluon distribution relative to charge in the nucleus.

- Case study of ^{4}He measurement, with an emphasis on diffraction minimum search was discussed, with a few realistic target and recoil detector configurations.

- VM production on nuclear target is an important science case, and SoLID is the ideal place to study this reaction.
  Not limited to, but starting with J/ψ on ^{4}He, the measurement of VM on a nuclear target is a nice scientific case to study the gluon distributions inside the nuclei.