

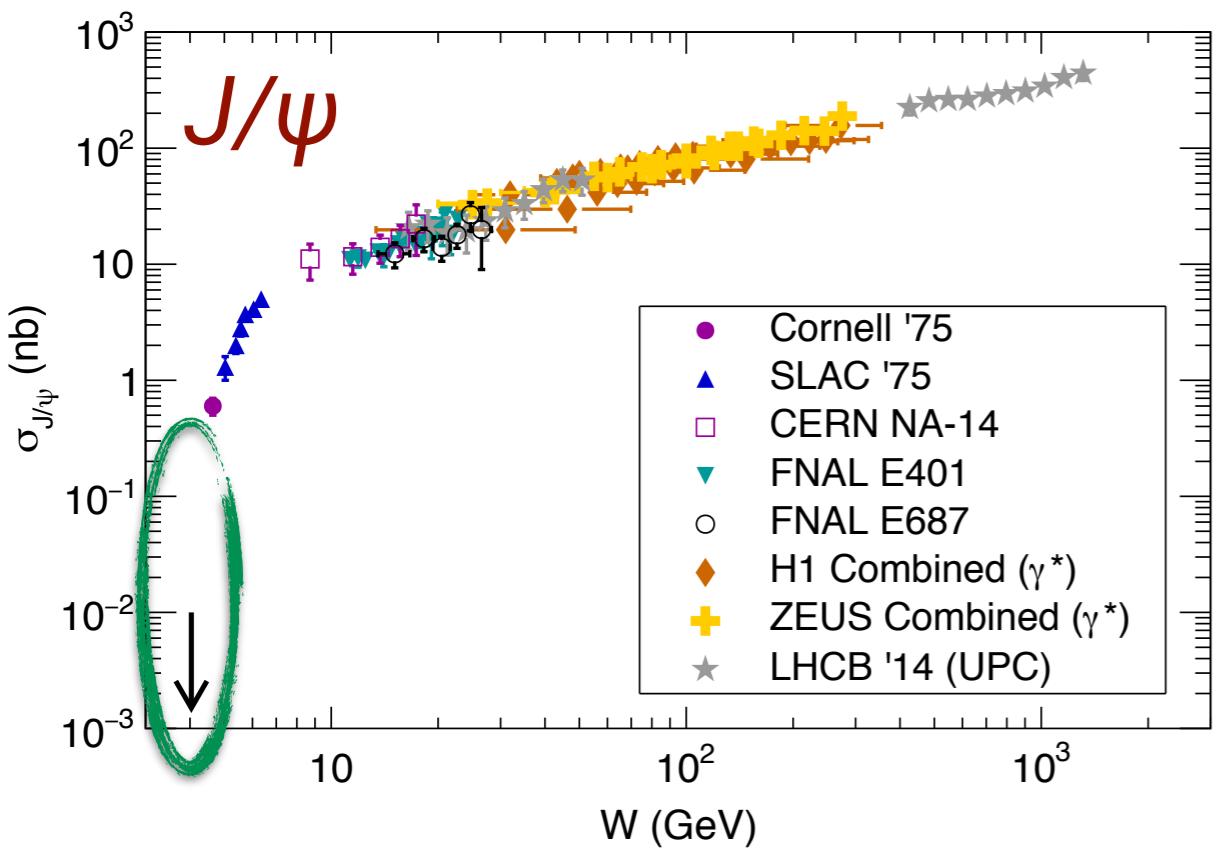
# (Towards a) LOI: Interference between Bethe-Heitler and $J/\psi$ in photo-production

**Sylvester Joosten**

[sylvester.joosten@temple.edu](mailto:sylvester.joosten@temple.edu)

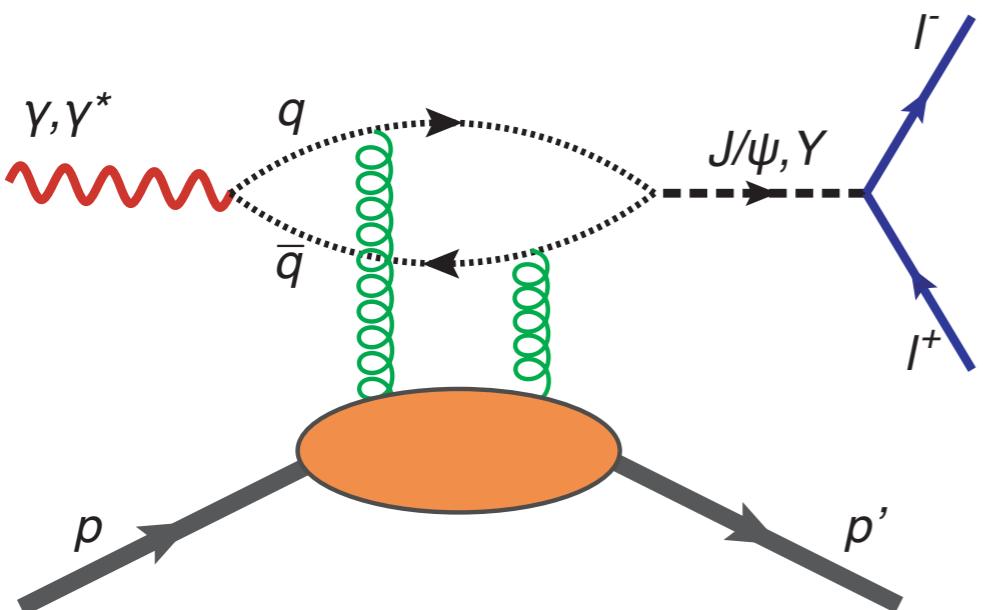
SoLID Collaboration Meeting  
June 2018, Jefferson Lab

# Why the threshold region?

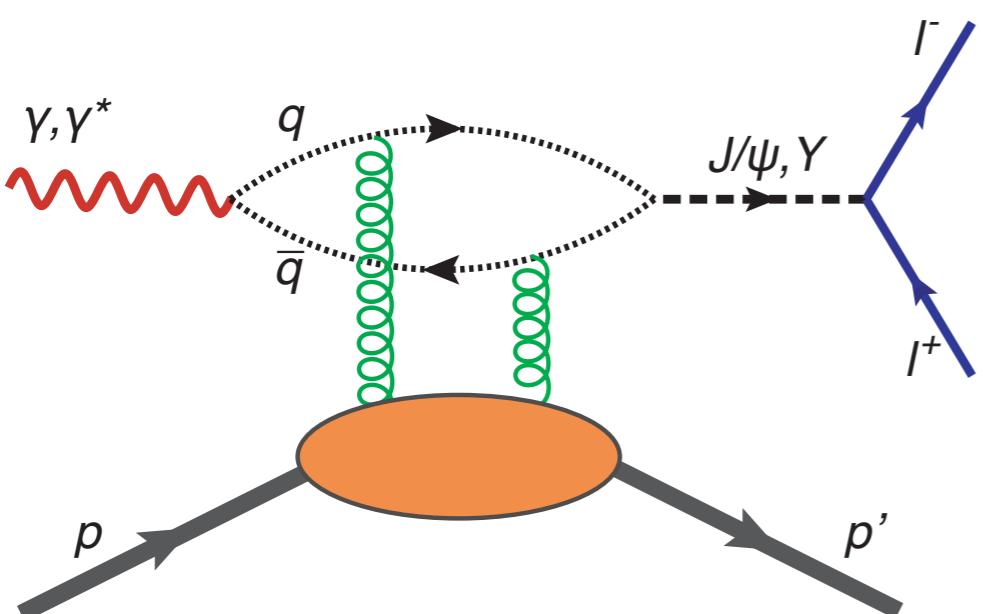
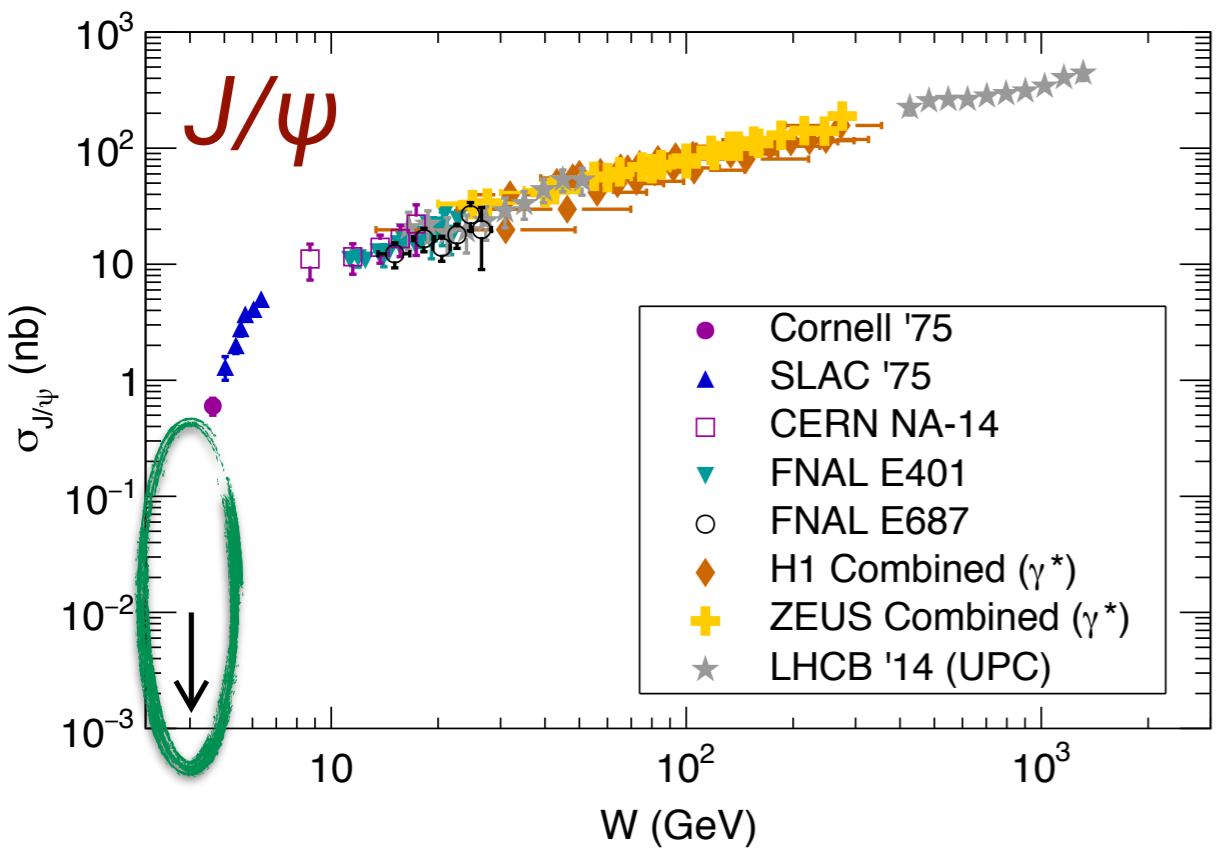


## ***J/ψ* photo-production:**

- ★ Well constrained above  $W > 15$  GeV
- Dominated by ***t*-channel 2-gluon exchange**
- ★ **Almost no data near threshold**



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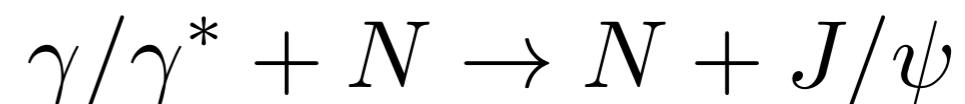
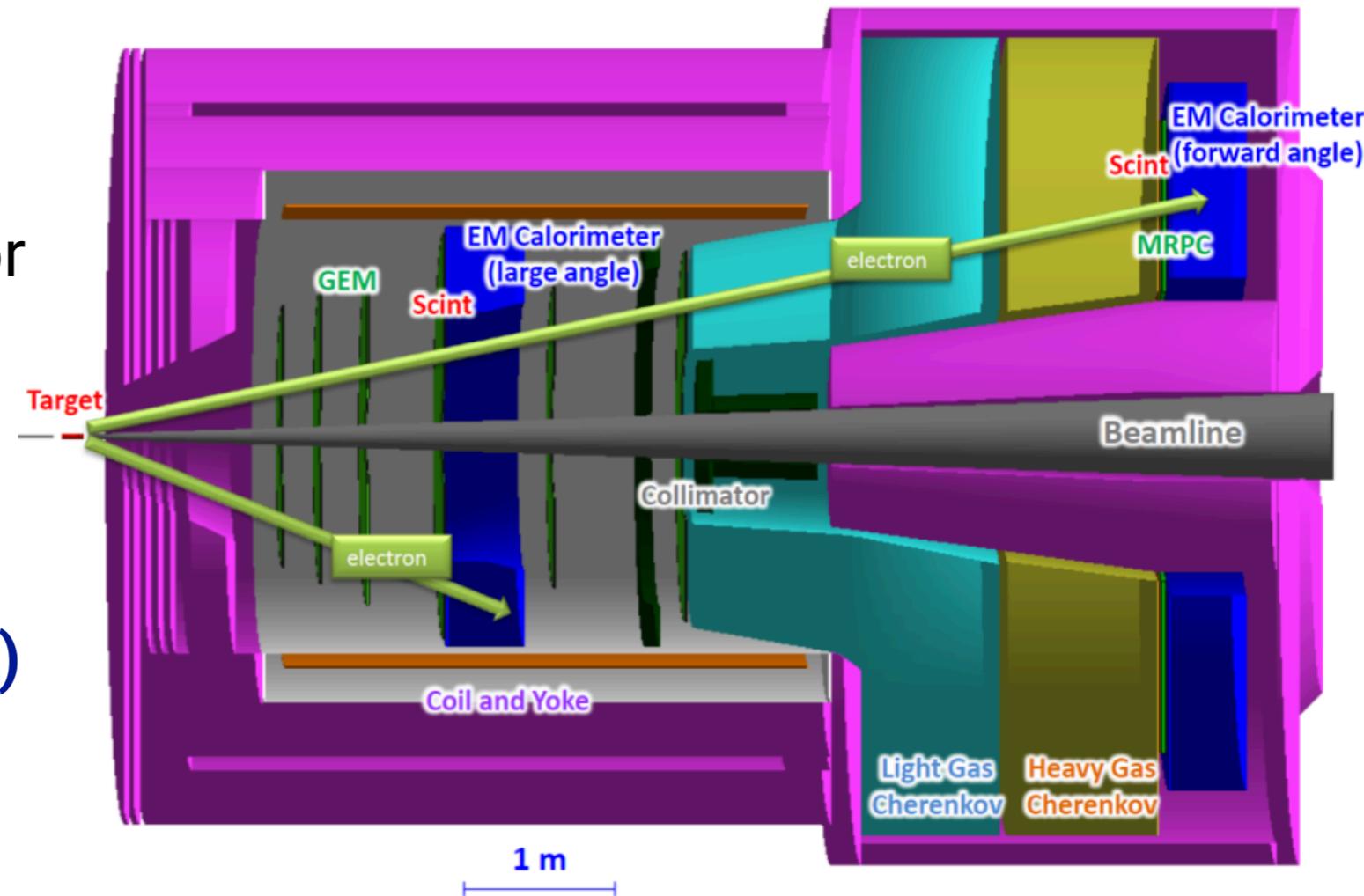
## **Near threshold:**

- ★ **Origin of proton mass**, trace anomaly of the QCD energy-momentum tensor.
- ★ **Gluonic Van der Waals force**, possible quarkonium-nucleon/nucleus **bound states**
- ★ **Mechanism** for quarkonium production

# $J/\psi$ experiment E12-12-006 at SoLID

ATHENNA Collaboration

- 3 $\mu$ A electron beam at 11 GeV for **50 days**
- 11 GeV beam 15cm **liquid hydrogen target**
- **Ultra-high luminosity (43.2 ab<sup>-1</sup>)**
- General purpose **large-acceptance** spectrometer
- Symmetric acceptance for electrons and positrons



- Electro-production
- Real photo-production through bremsstrahlung in the target cell

# $J/\psi$ experiment E12-12-006 at SoLID

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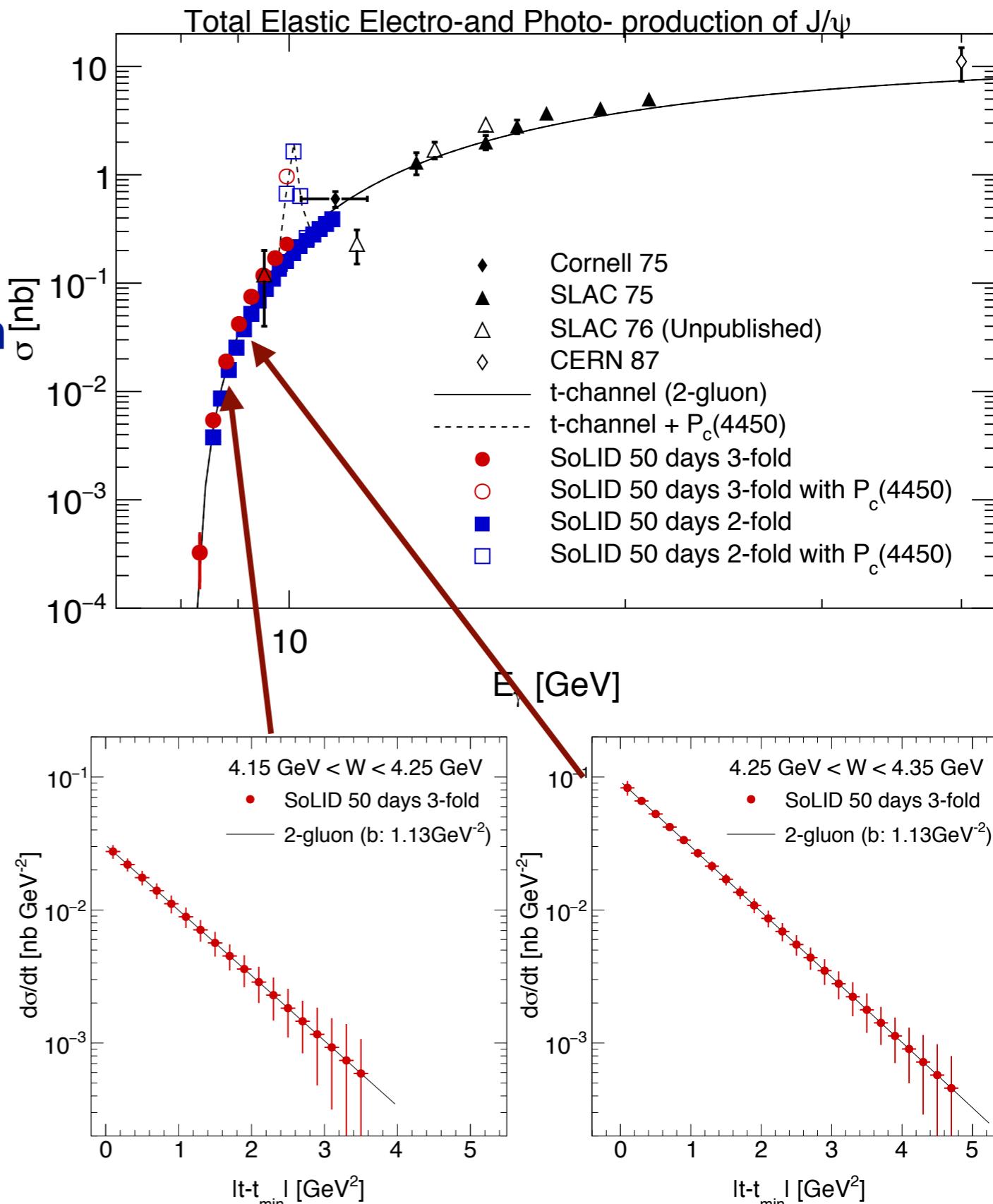
## Photo-production

- 2-fold coincidence + recoil proton
- $t$ -channel  $J/\psi$  rate: **1627 per day**
- Advantage over electro-production**
  - Energy reach in charmed pentaquark region
  - High rate

## Electro-production

- 3-fold coincidence (3 leptons)
- $t$ -channel  $J/\psi$  rate: **86 per day**
- Advantage over photo-production:**
  - Less background
  - Closer to threshold

Sensitivity below  $10^{-3}$  nb !



# Quarkonium-nucleon scattering amplitude

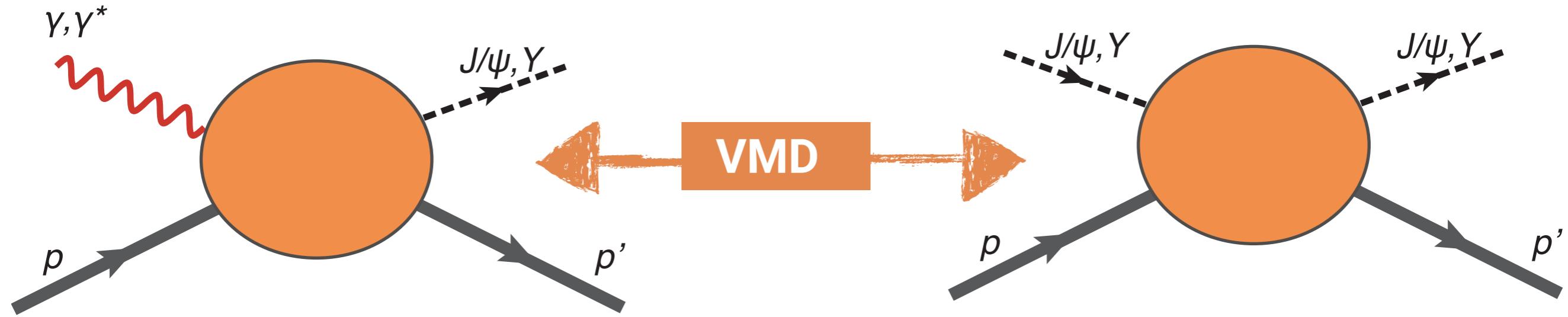


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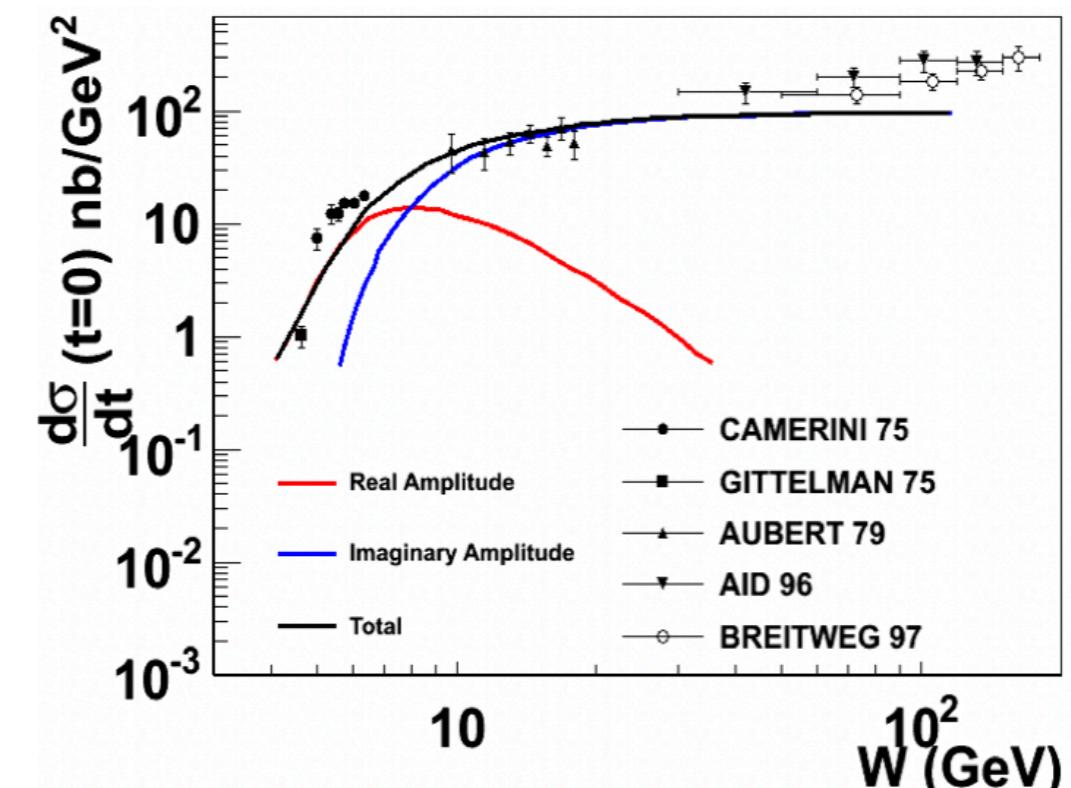


- ★ VMD relates photo-production cross section to quarkonium-nucleon scattering amplitude  $T_{\psi p}$

# Quarkonium-nucleon scattering amplitude

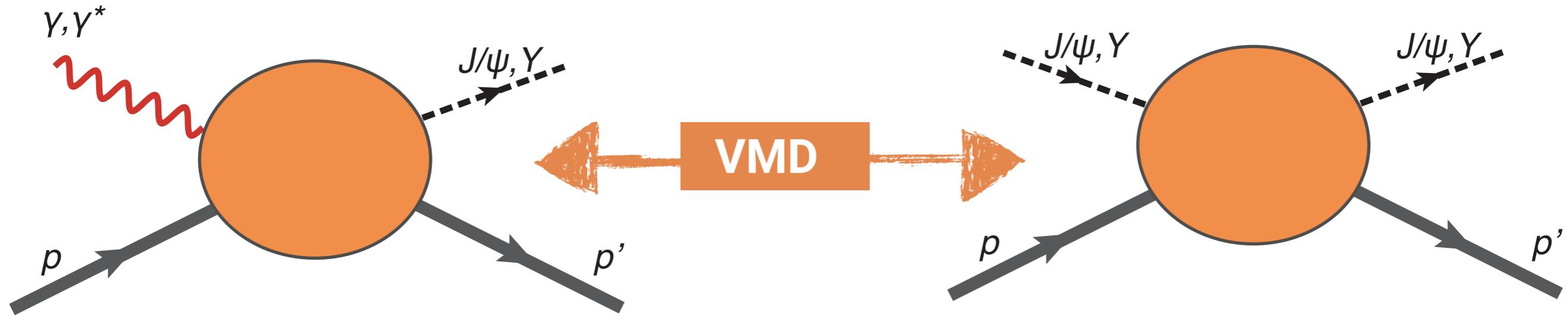


- ★ VMD relates photo-production cross section to quarkonium-nucleon scattering amplitude  $T_{\psi p}$ 
  - Approach works well at **high energies**, constrains  $\text{Im}(T_{\psi p})$
  - Need  $\text{Re}(T_{\psi p})$  to describe threshold region (calculated through dispersion relations)

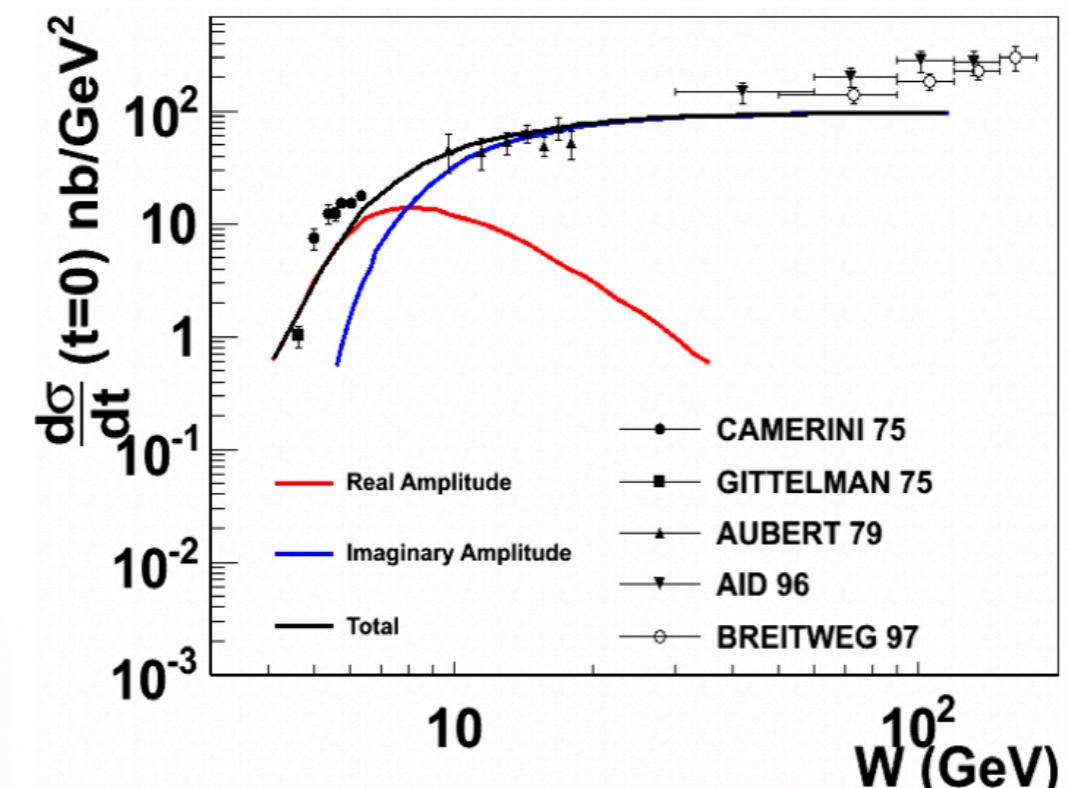


D. Kharzeev, Proc.Int.Sch.Phys.Fermi 130 (1996) 105-131  
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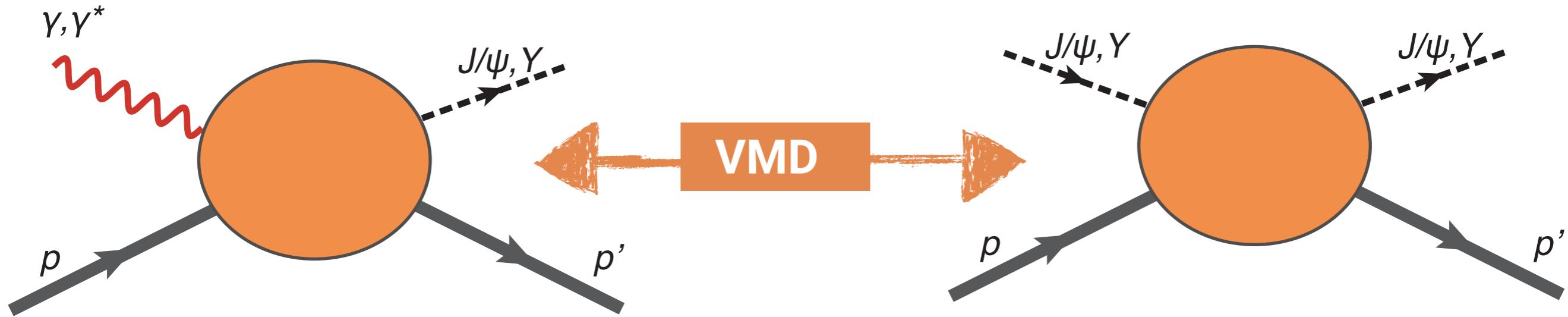


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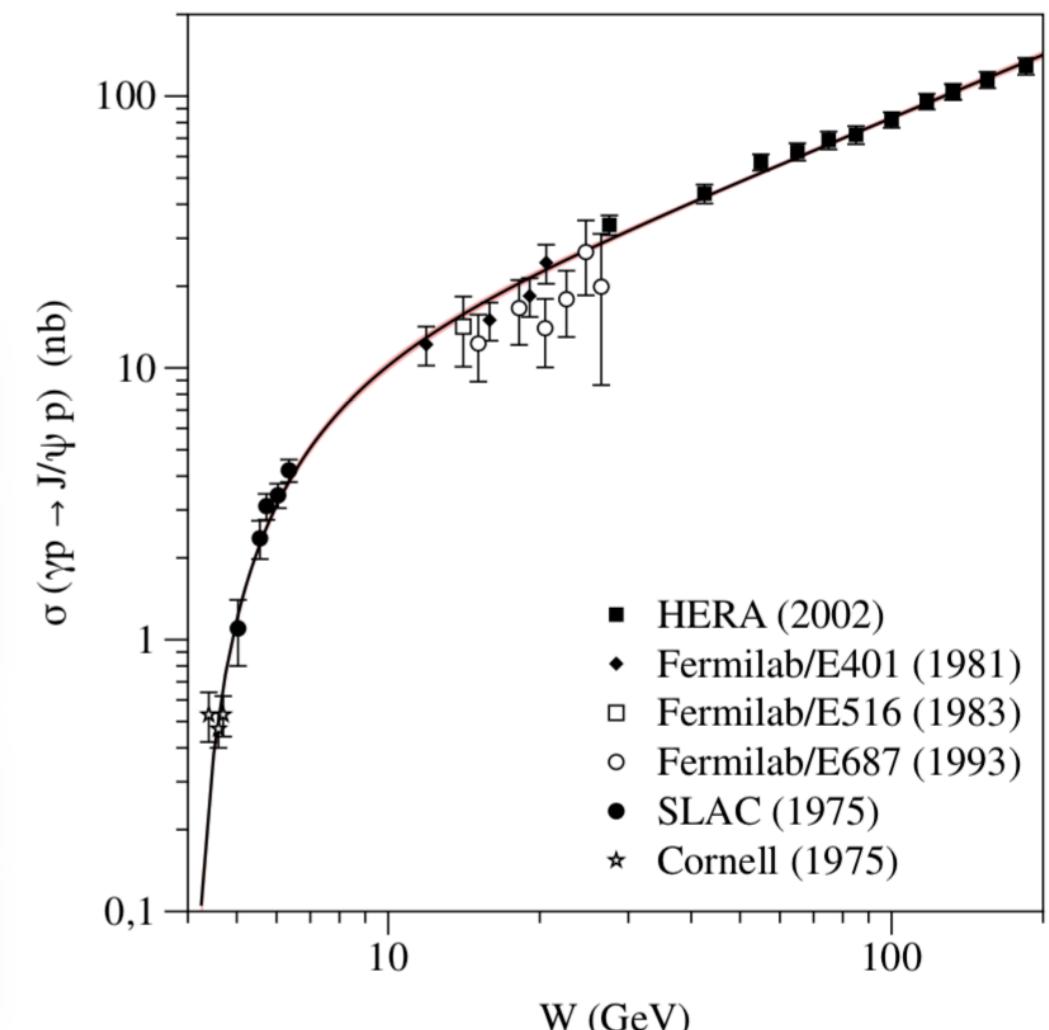


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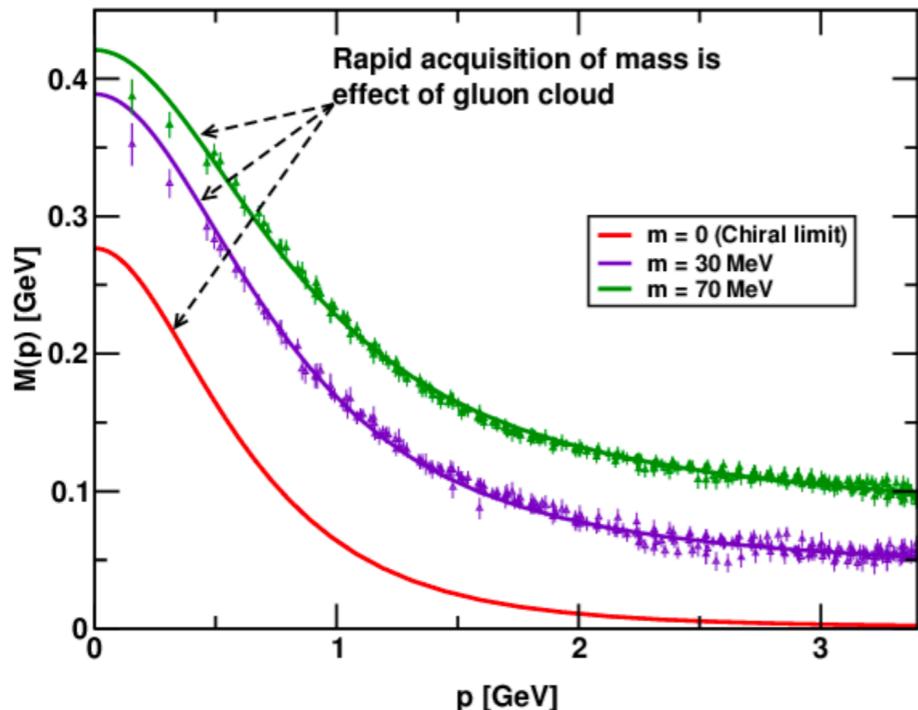
- ★ Works well in recent global fit:
  - ★  $\text{Im}(T_{\psi p})$  from  $J/\psi$  and open charm
  - ★  $\text{Re}(T_{\psi p})$  through dispersion relations

O. Gryniuk and M. Vanderhaeghen, Phys. Rev. D 94, 074001 (2016)

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# From $\text{Re}(T_{\psi p})$ to **mass** and **binding**



M. S. Bhagwat *et al.*, Phys. Rev. C 68, 015203 (2003)  
I. C. Cloet *et al.*, Prog. Part. Nucl. Phys. 77, 1-69 (2014)

## Dynamic origin of the proton mass

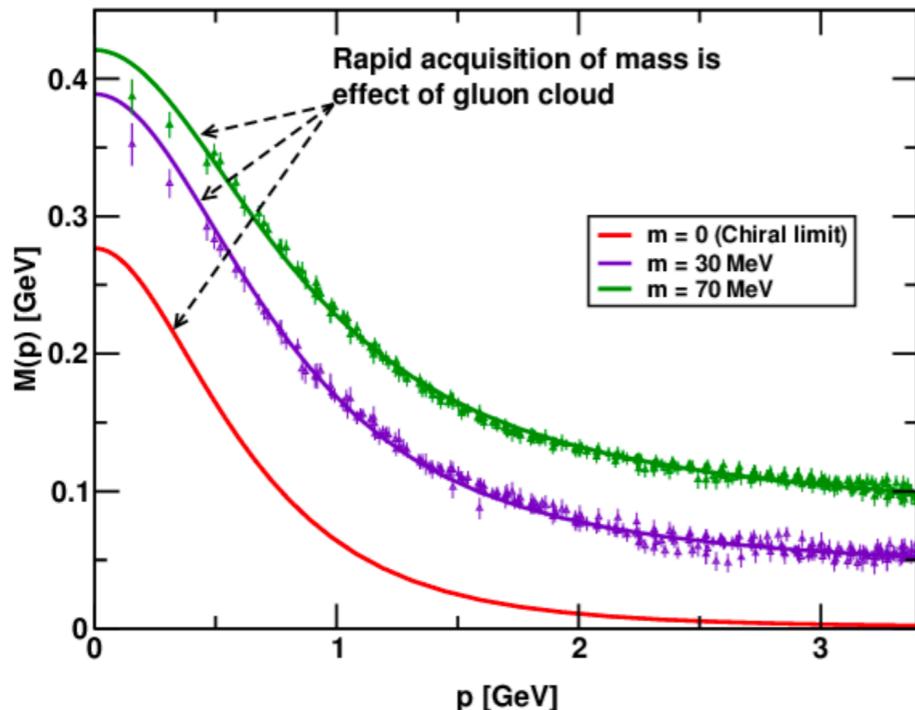
- ★ Trace anomaly of QCD key piece to proton mass all decompositions

X. Ji, PRL 74, 1071 (1995) & PRD 52, 271 (1995)  
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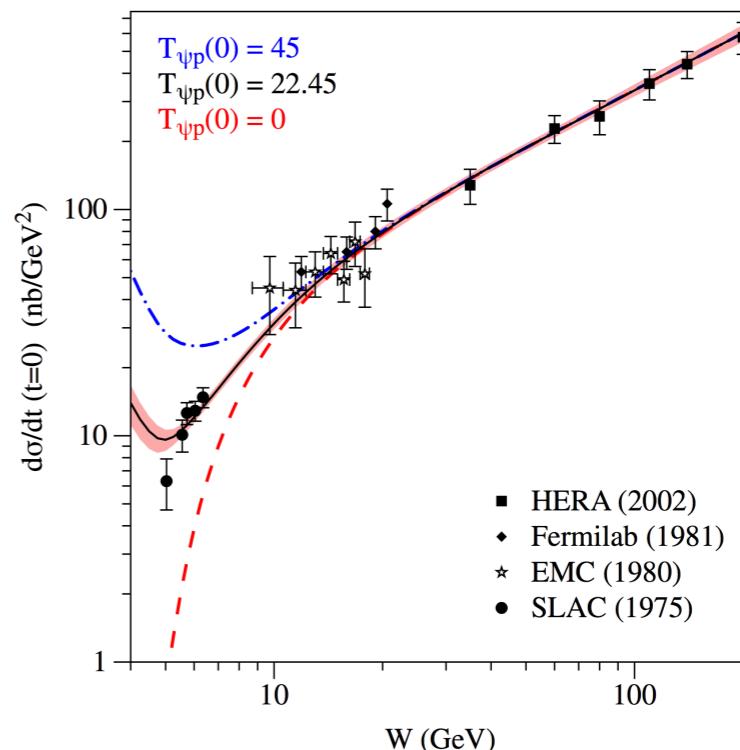
- ★ Proportional to **quarkonium-proton scattering amplitude  $T_{\psi p}$  at threshold**

M. Luke *et al.*, PLB 288 (1992) 355-359

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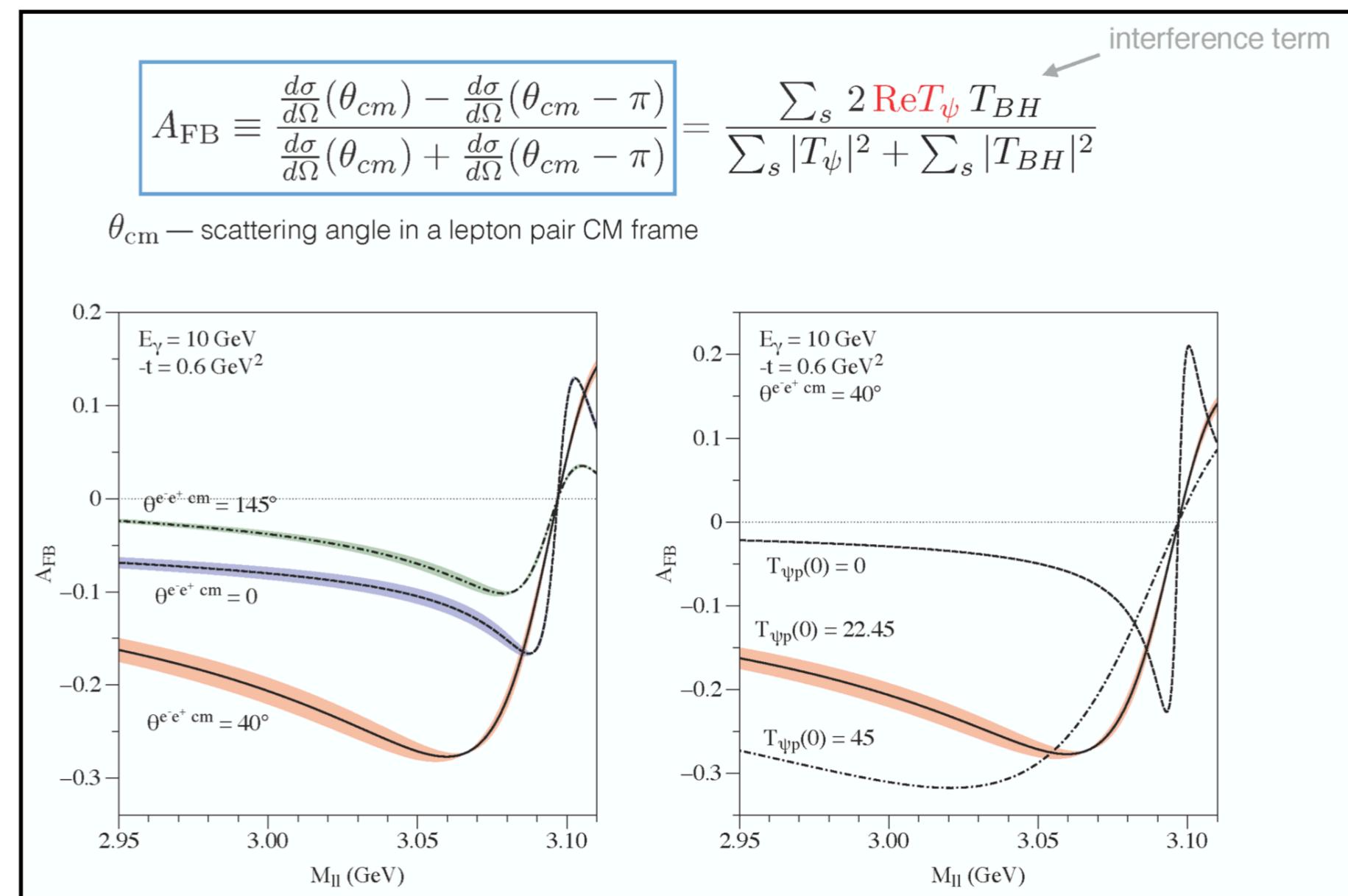
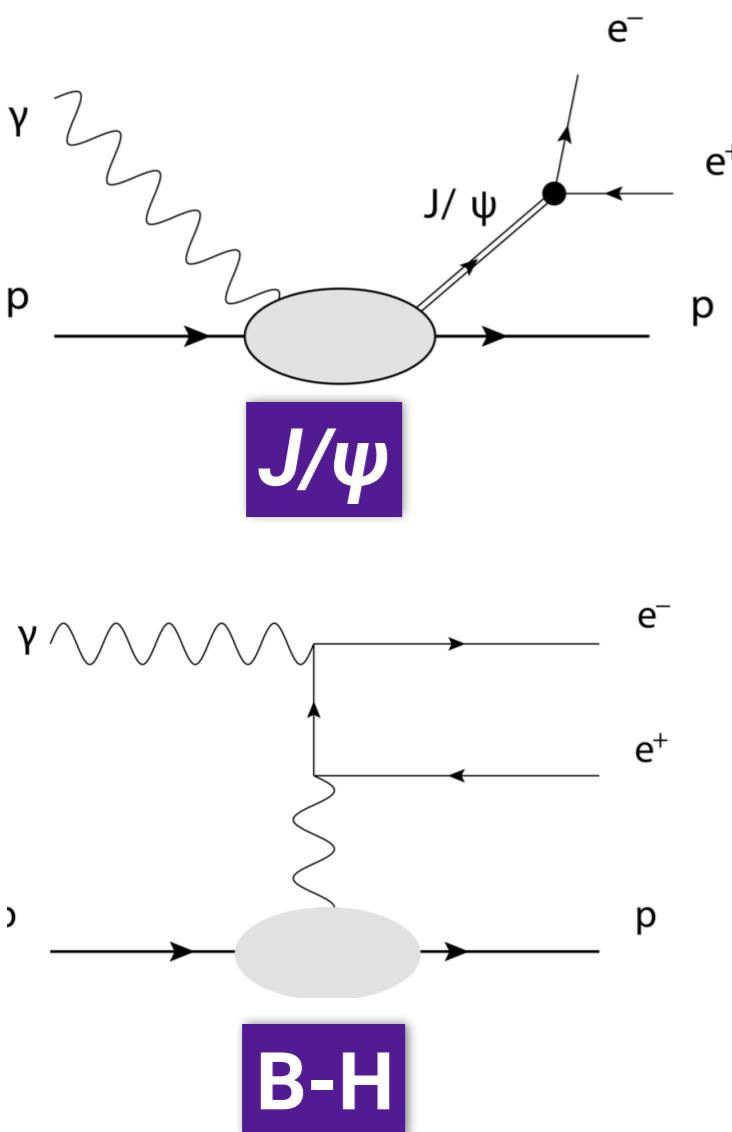
## $J/\psi$ -nucleon binding energy

- ★ Binding accessed through **s-wave scattering length  $a_{\psi p}$**
- ★ Scattering length **related to scattering amplitude  $T_{\psi p}$  at threshold**

O. Gryniuk and M. Vanderhaeghen, Phys. Rev. D 94, 074001 (2016)

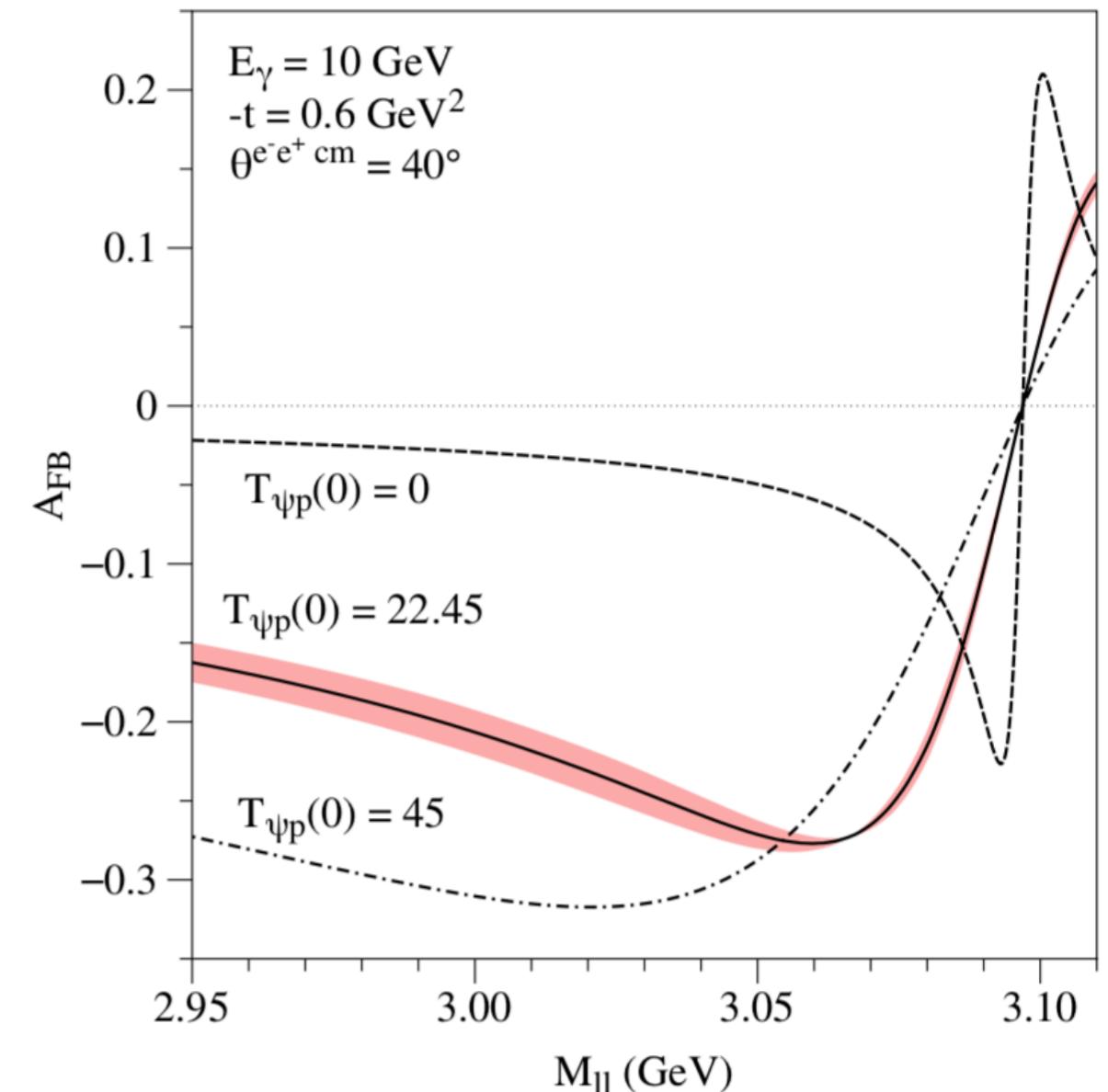
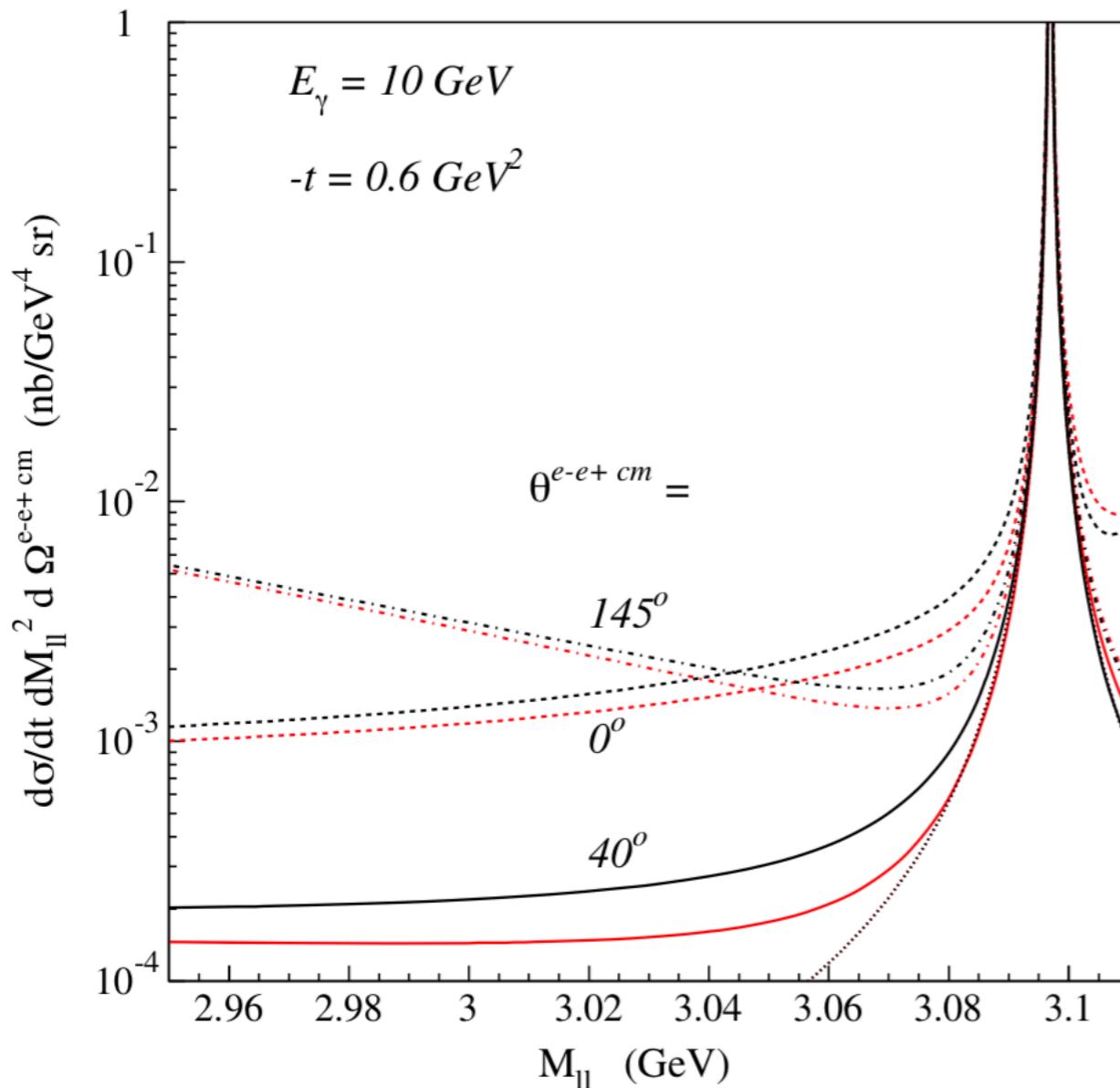
# B-H asymmetry: access scattering length $\text{Re}(T_{\psi p})$

- ★ **Interference** between elastic  **$J/\psi$  production** near threshold and **Bethe-Heitler**
- ★ **Forward-backward asymmetry** near the  $J/\psi$  invariant mass peak
- ★ Sensitive to real part of the scattering amplitude, hence  $a_{\psi p}$  and  $B_{\psi p}$



# Main difficulty: very low cross section

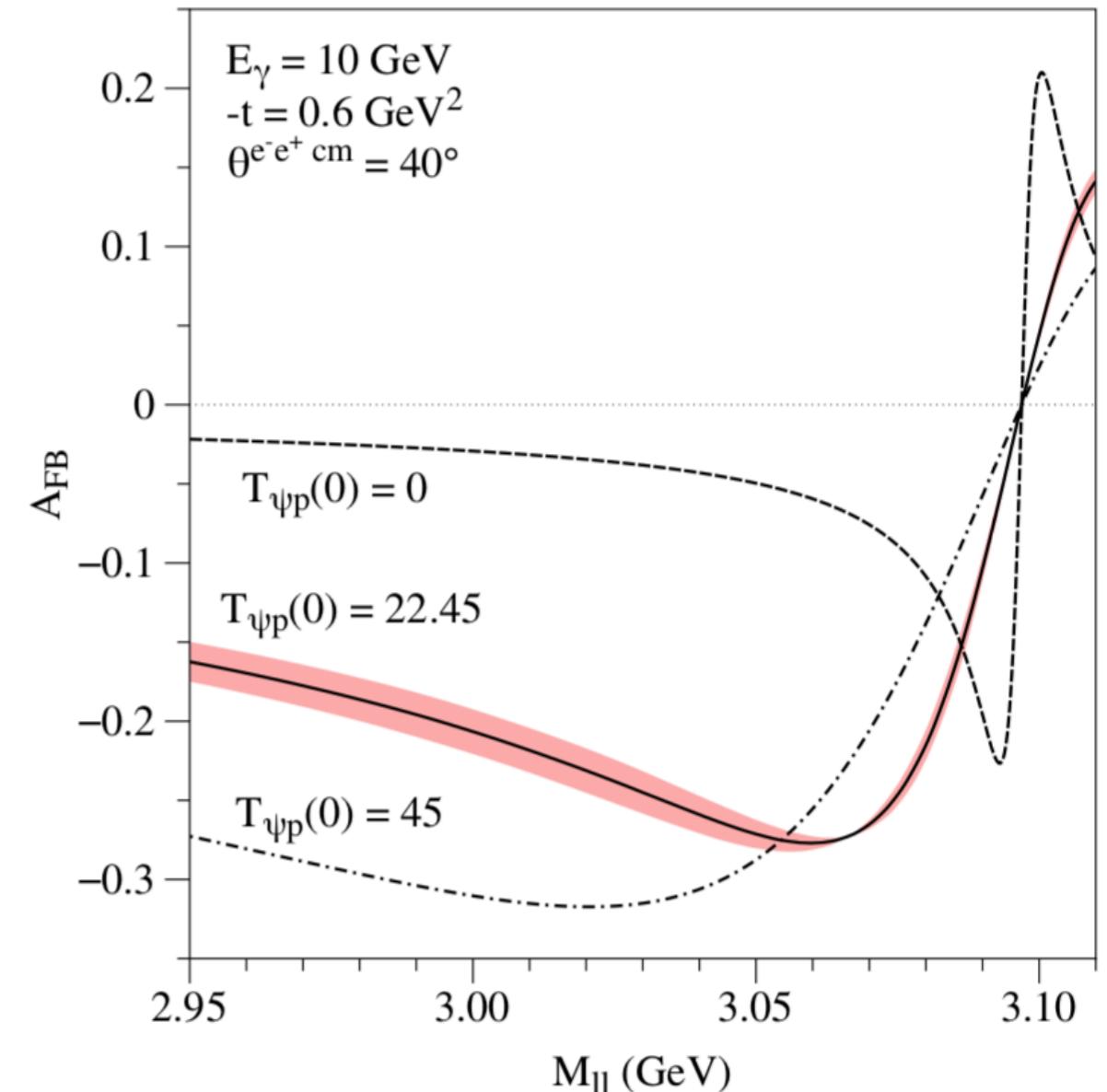
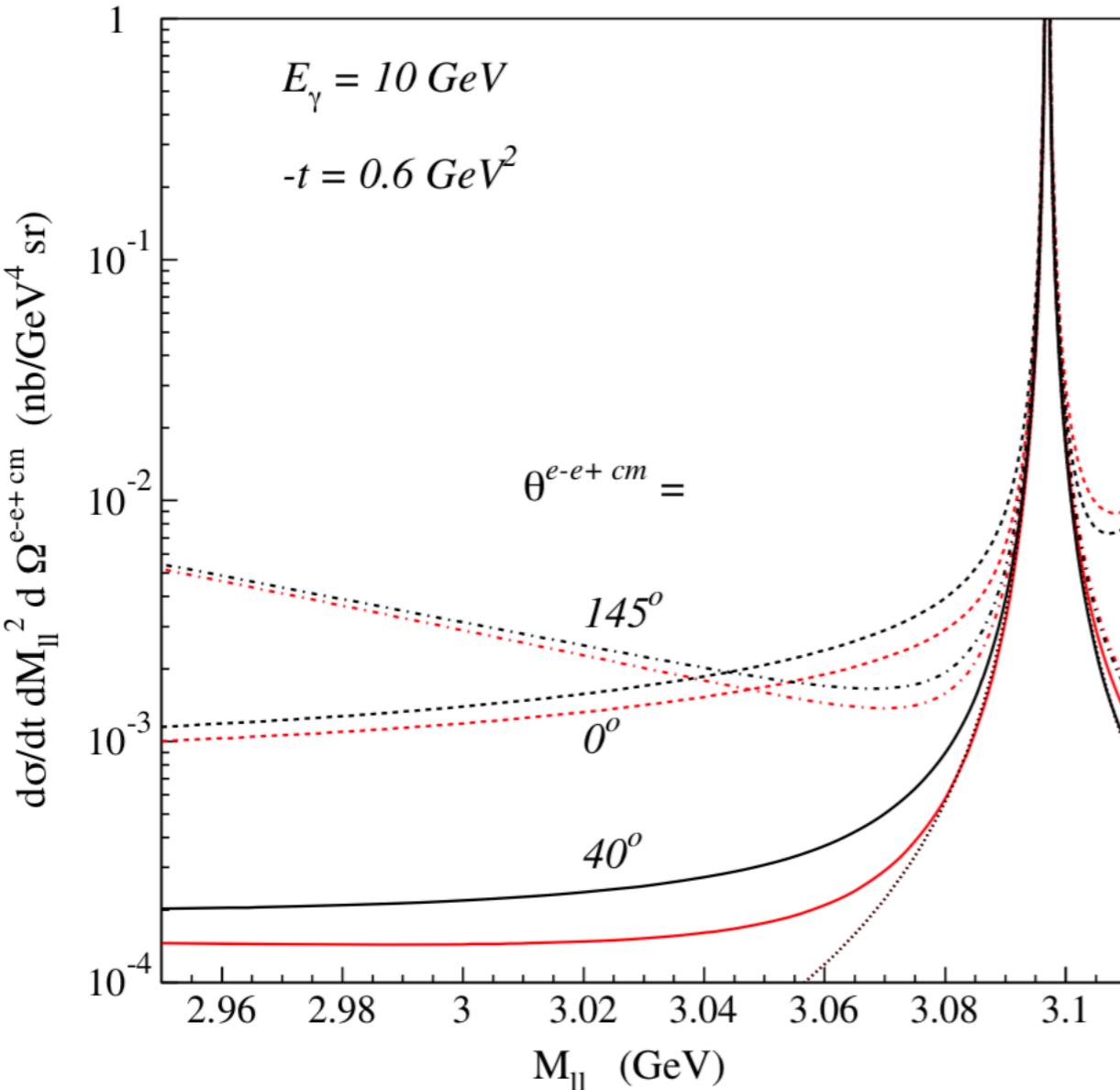
O. Gryniuk and M. Vanderhaeghen, Phys. Rev. D 94, 074001 (2016)



$$A_{FB} \equiv \frac{d\sigma(\theta^{e-e+ \text{cm}}) - d\sigma(\theta^{e-e+ \text{cm}} - 180^\circ)}{d\sigma(\theta^{e-e+ \text{cm}}) + d\sigma(\theta^{e-e+ \text{cm}} - 180^\circ)}$$

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SoLID the only place where  
we have a chance!

# Acceptance

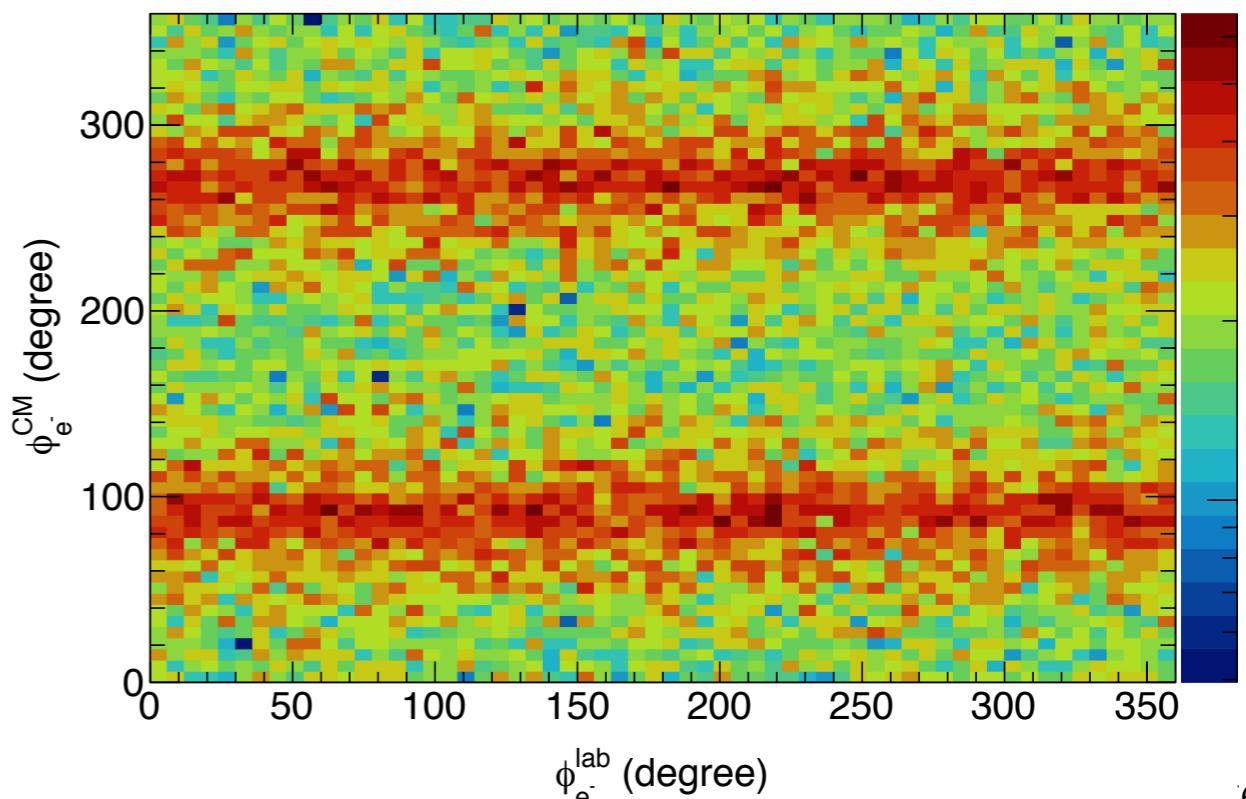
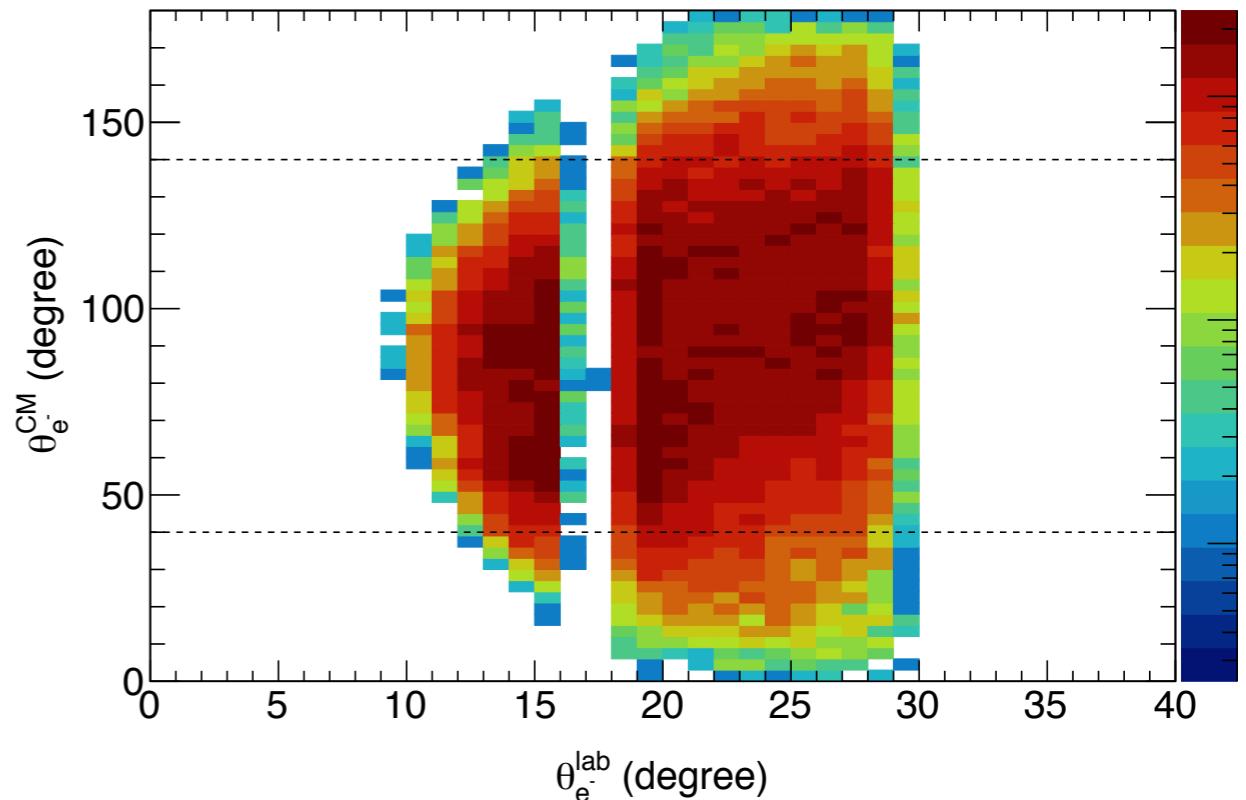
Electron angle in  
 $J/\psi$  helicity frame

Invariant mass of  
lepton pair

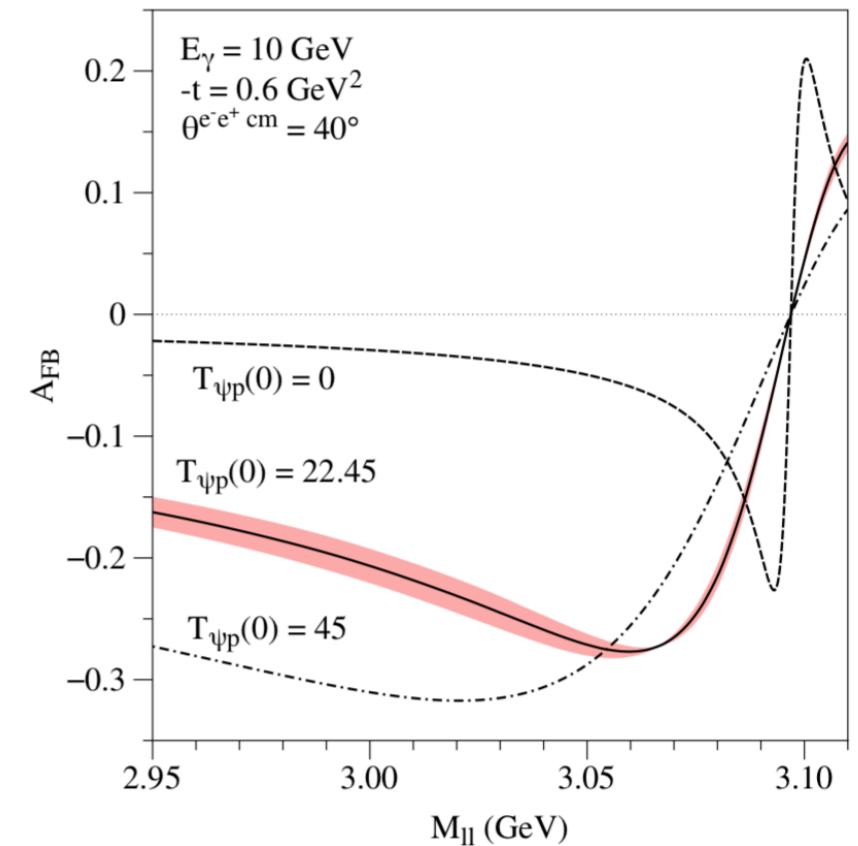
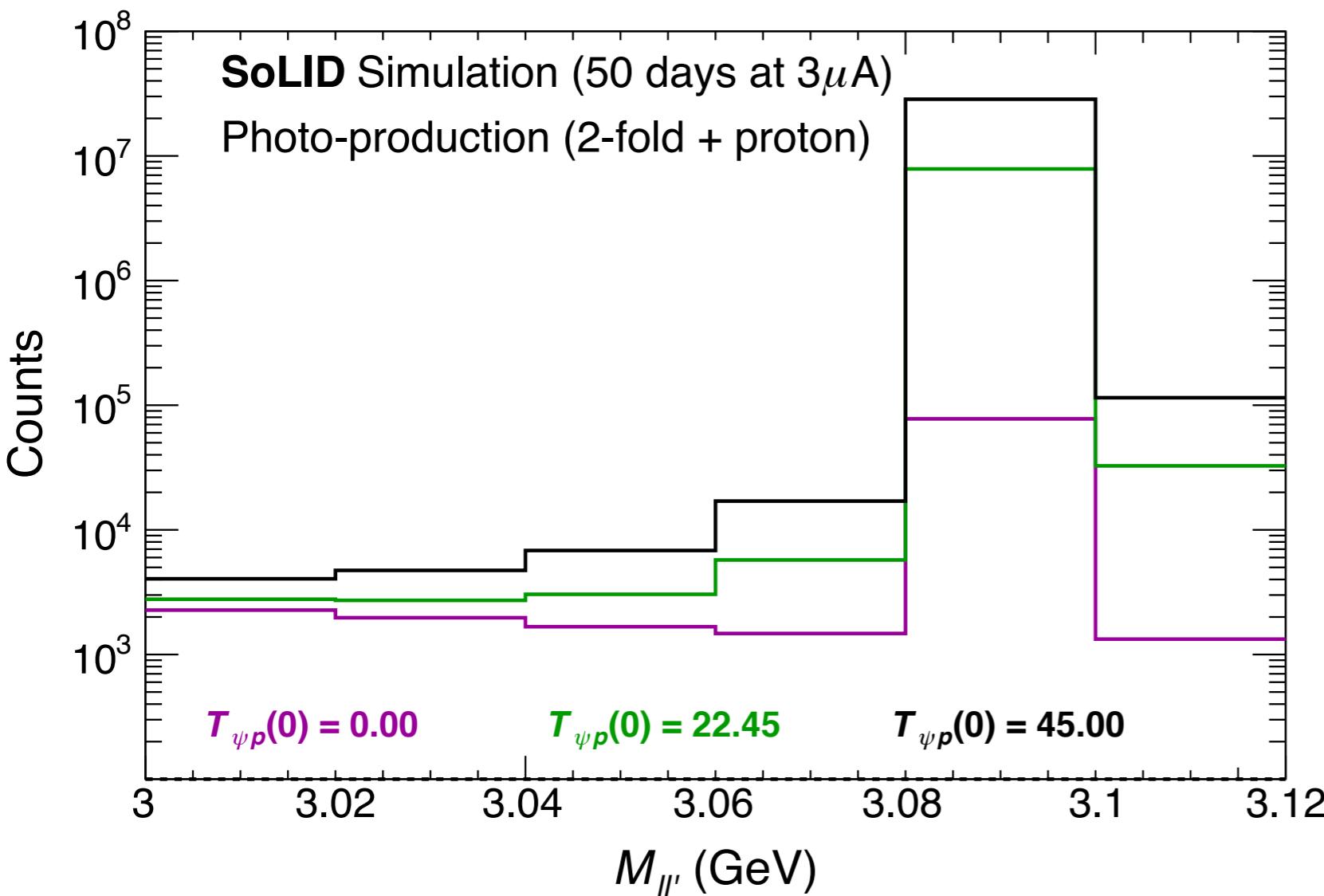
$\theta_{\text{CM}}$     $\phi_{\text{CM}}$

$M_{ll'}$

- ★ **Polar angle:** good acceptance for  $40^\circ < \theta_{\text{CM}} < 140^\circ$
- ★ **Question:** Can we integrate, and work with a “left-right” asymmetry to avoid complications?
- ★ **Azimuthal angle:** full coverage

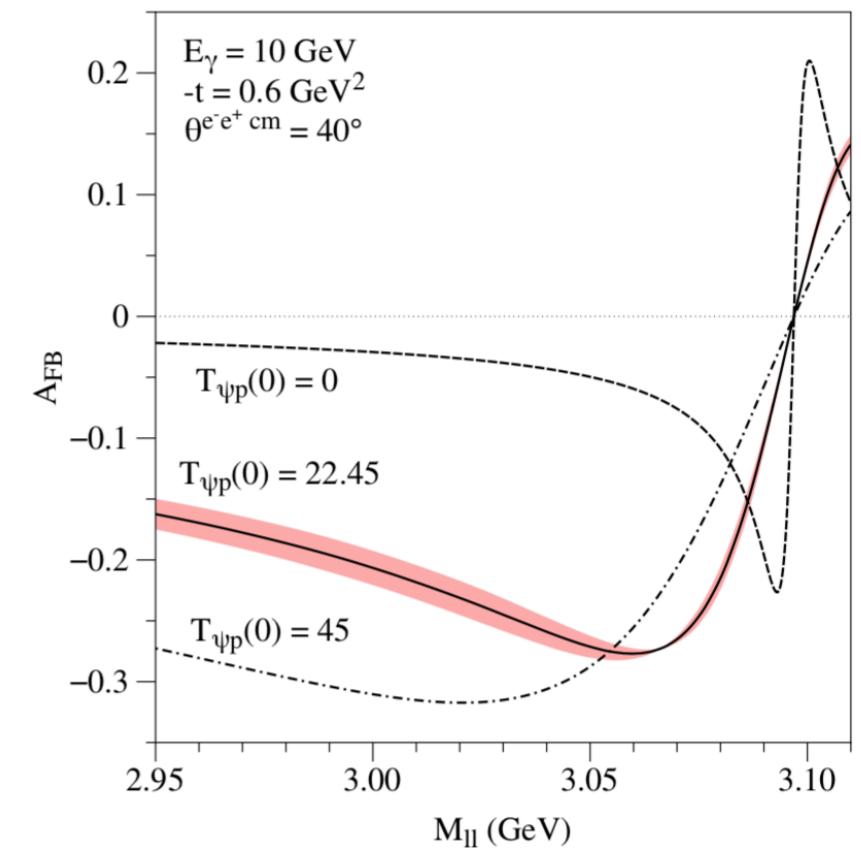
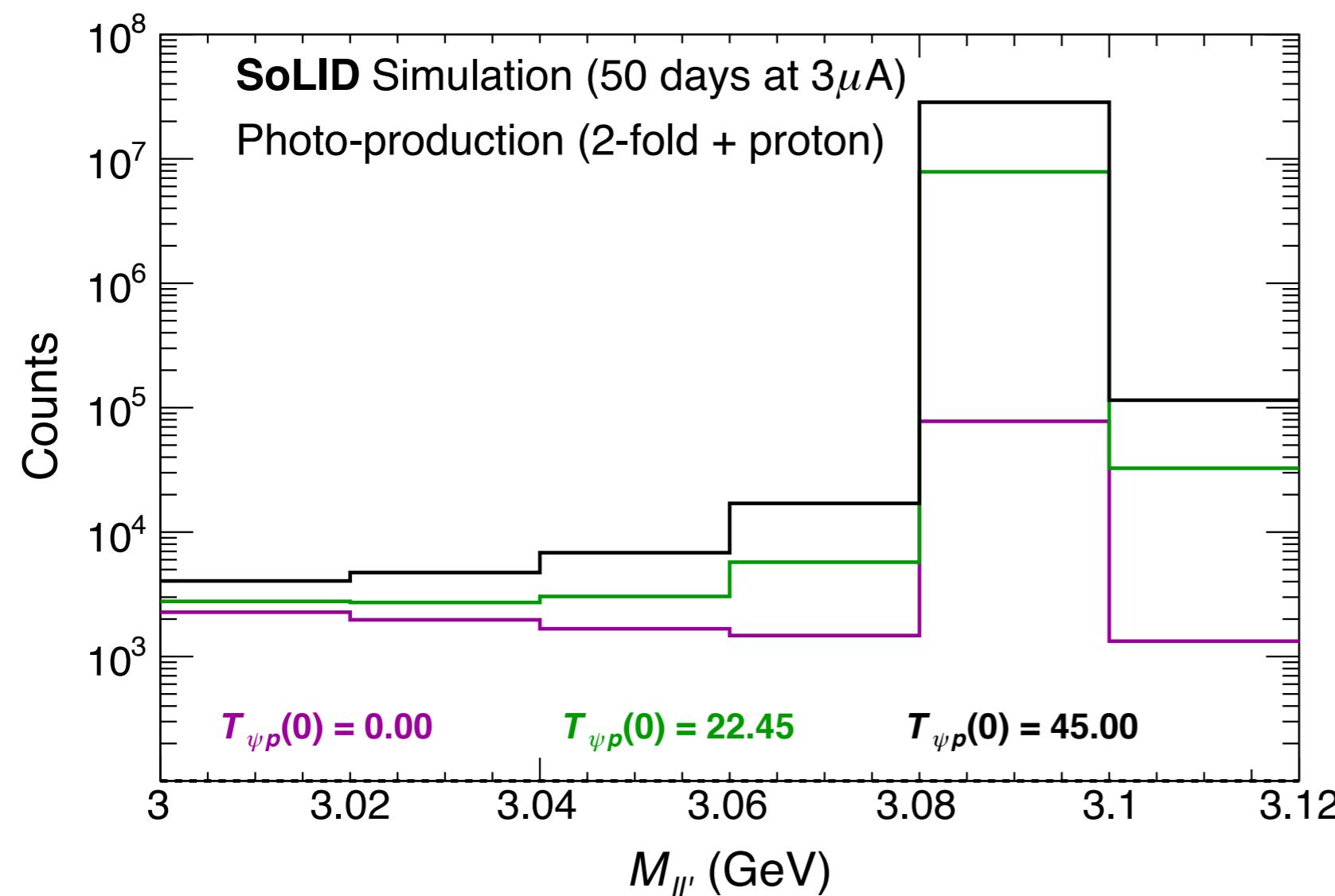


# Projected counts



- Large variation in  $J/\psi$  count depending on assumed binding
  - (purple/no binding in-line with 2-gluon estimate)
- Note: Asymmetry has a node at the  $J/\psi$  peak

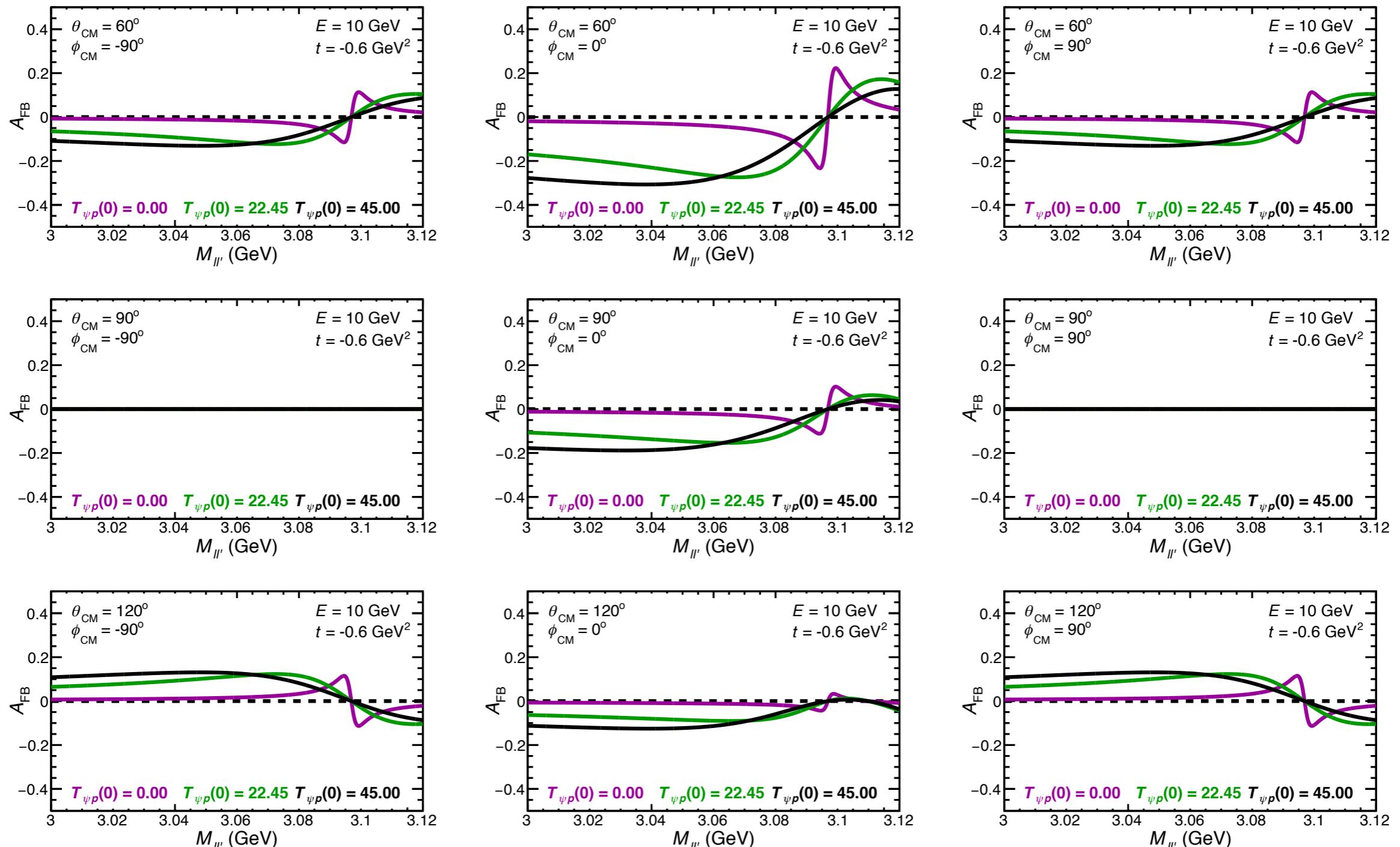
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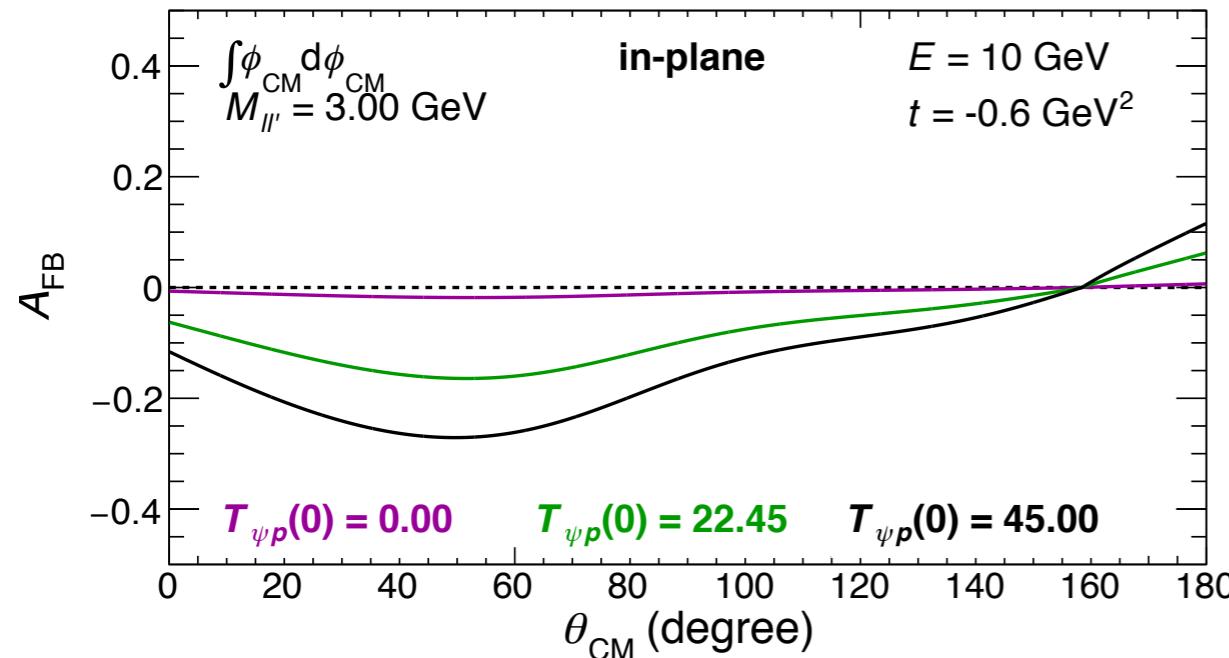
Big unknown: **background!!!**  
(B-H rates in some bins ~40/day)

# Can we use a left-right asymmetry?

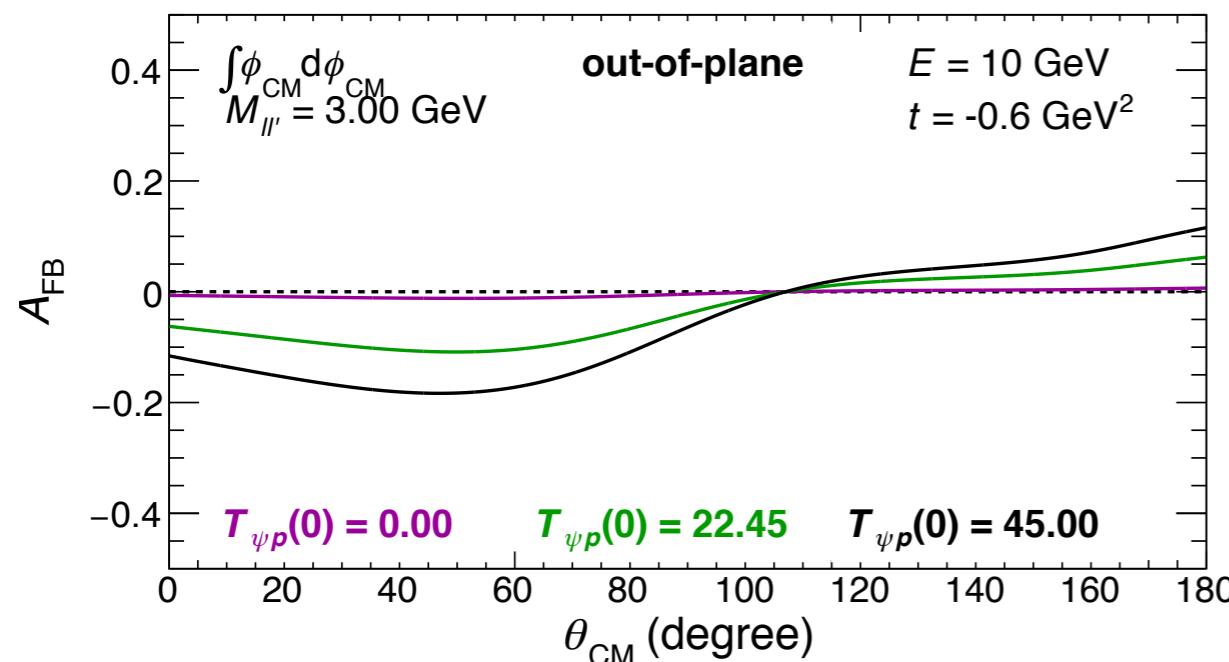


- **In-plane:** no node in asymmetry for all values of theta
- **Out-of-plane:** asymmetry will partially cancel

# Can we use a left-right asymmetry?



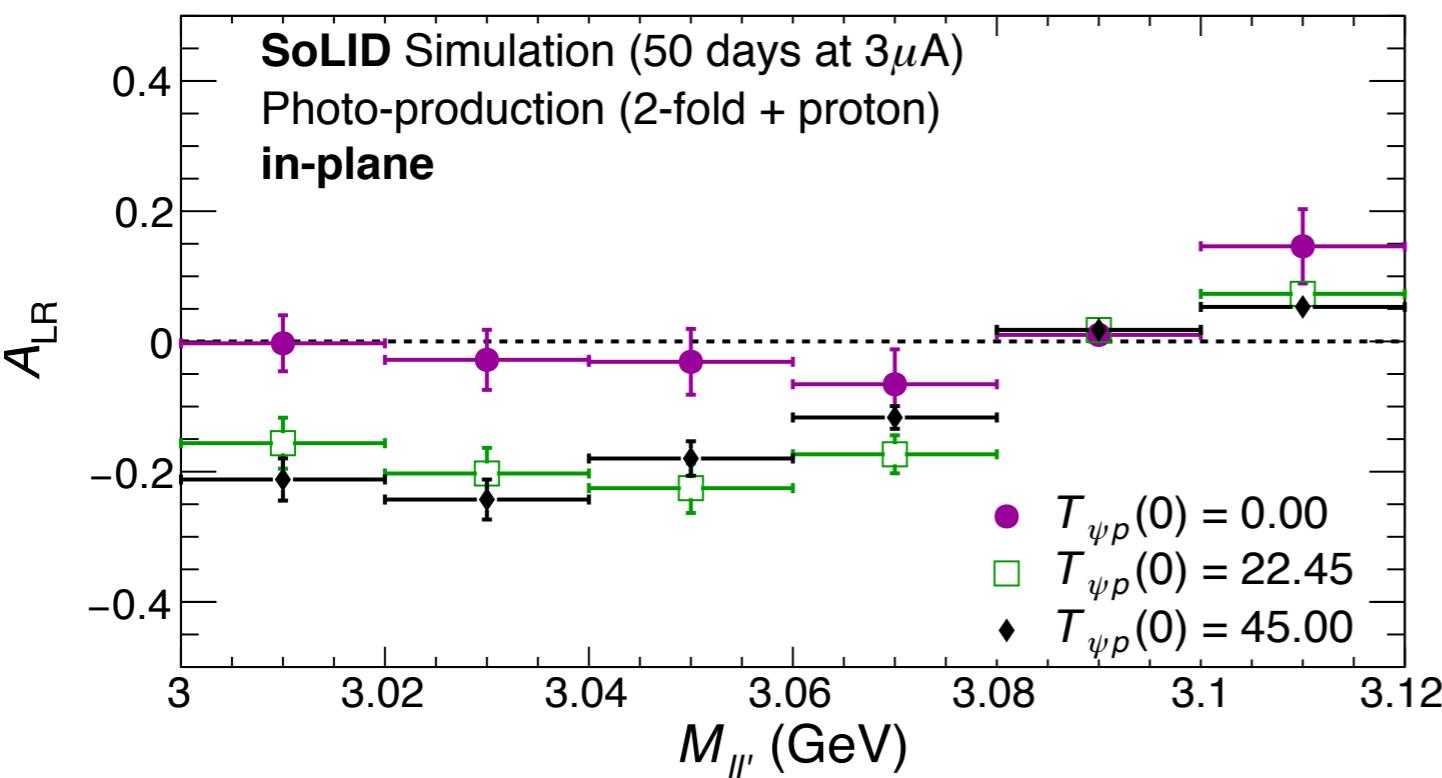
$-45^\circ < \phi_{CM} < 45^\circ$   
**In-plane**



$-90^\circ < \phi_{CM} < -45^\circ$   
 $45^\circ < \phi_{CM} < 90^\circ$   
**Out-of-plane**

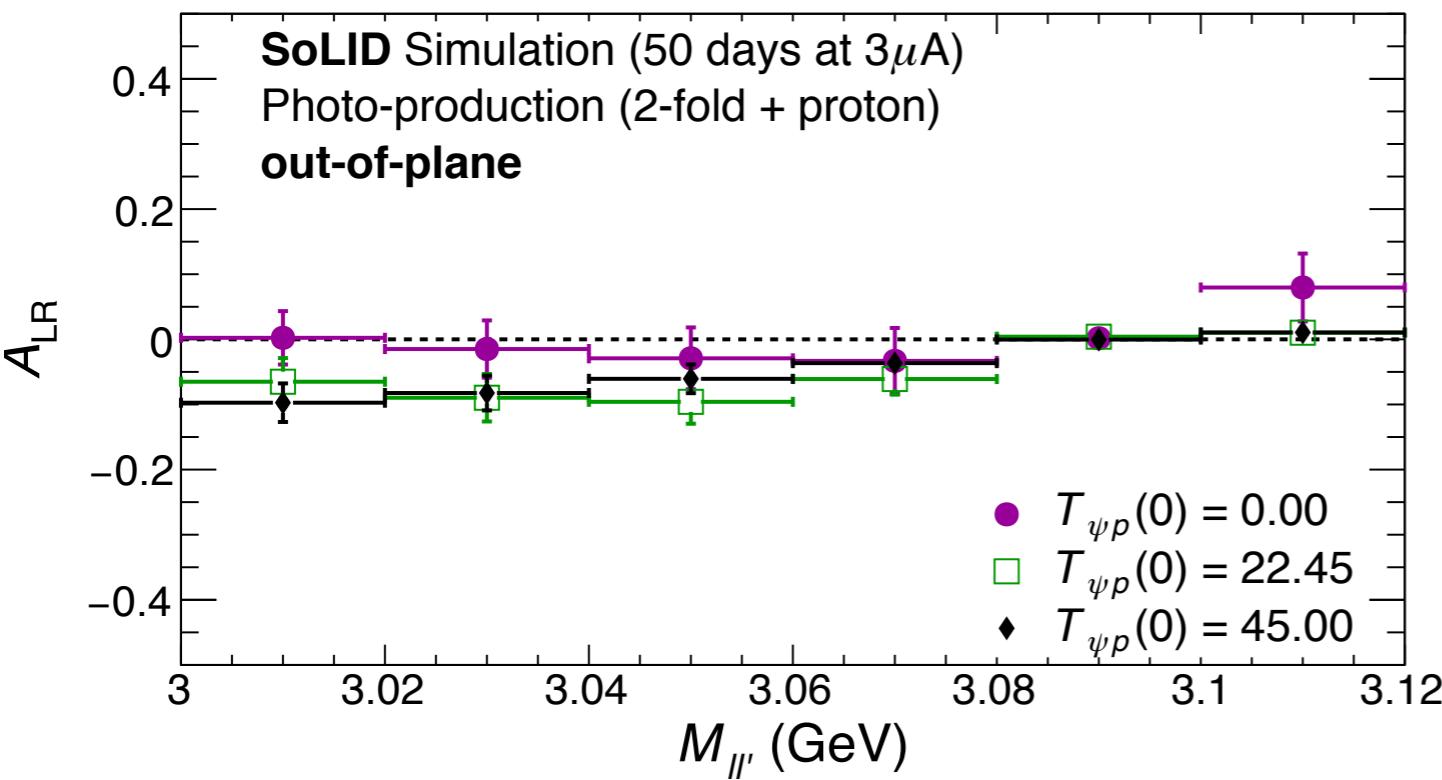
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# Projected Results



$-45^\circ < \phi_{CM} < 45^\circ$   
**In-plane**

$-90^\circ < \phi_{CM} < -45^\circ$   
 $45^\circ < \phi_{CM} < 90^\circ$   
**Out-of-plane**



- **In-plane:** sensitive to binding
- **Out-of-plane:** reduced sensitivity due to cancelations

# Conclusion

- **Threshold production** of quarkonium can shed light on the **trace anomaly**, quarkonium-nucleon **binding** and **proton mass**
- Can access threshold physics away from threshold through the interference between  $J/\psi$  and Bethe-Heitler.
- High luminosity measurement can in principle be done **in parallel with the SoLID  $J/\psi$  experiment**
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Question: what is procedure for parasitic LOI?

# BACKUP SLIDES

# Projected Results: all together

