

J/ψ Generator

Sylvester Joosten

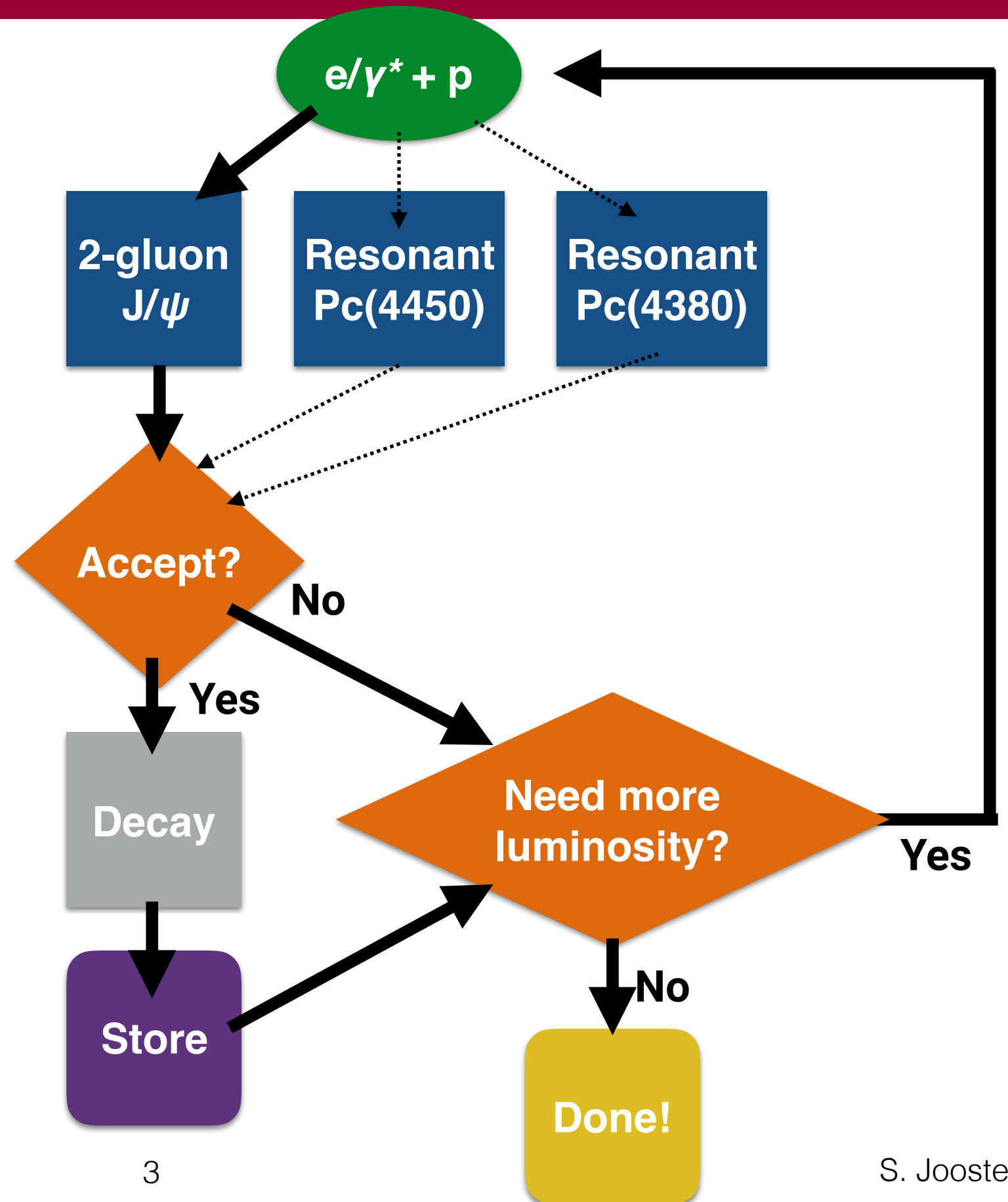
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...much more than a J/ψ Generator

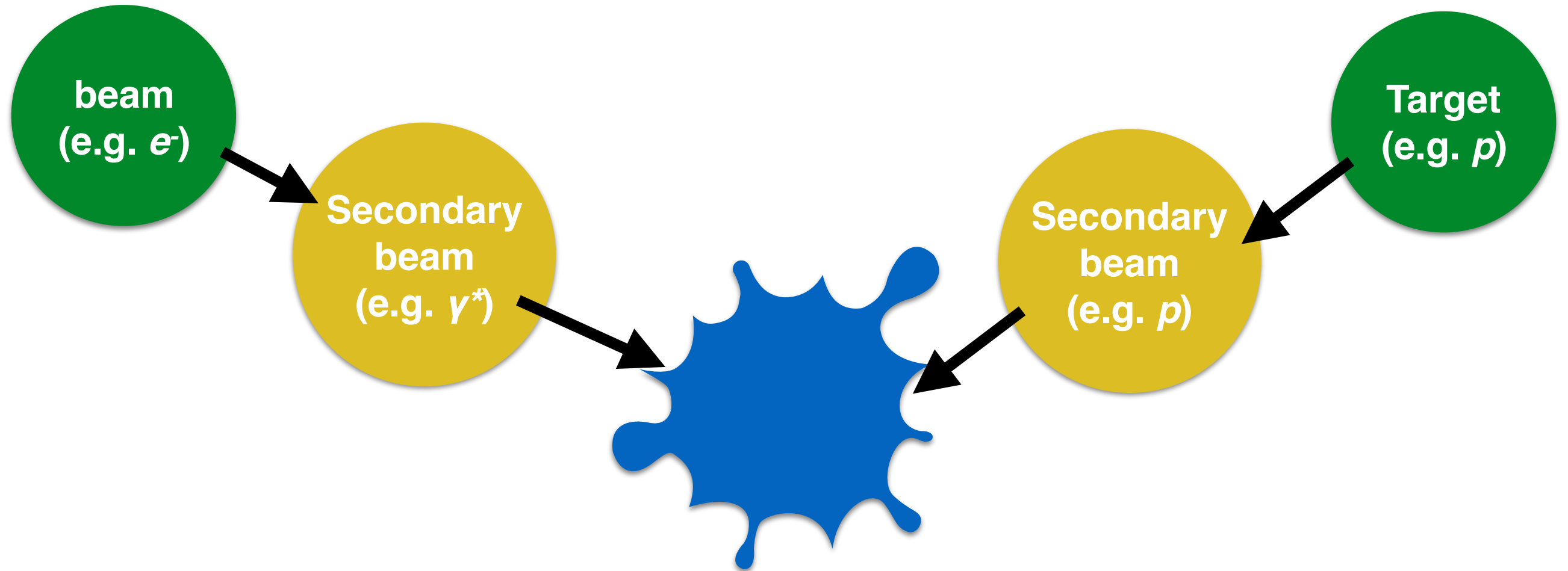
- Based on my generator for Hall C charmed-pentaquark search
- Modular event generator library
 - J/ψ generator uses this library
 - Written in modern C++ (C++14)
 - Can handle multiple processes in parallel
 - Easily extensible
- Accept-reject MC, no weighting necessary!
 - Able to events for a given integrated luminosity
- Modular event output
 - Currently supports gemc LUND and ROOT format
 - Plan to add HepMC3 and ProMC

Event generation loop

Generate initial hard scattering
Randomly pick a process depending on relative generation space size
Generate the process
Accept or reject
Handle particle decays
Update estimated total cross section and integrated luminosity
Repeat if we requested more luminosity (or events)



Initial state generation



Everything written in terms of four-vectors and invariants

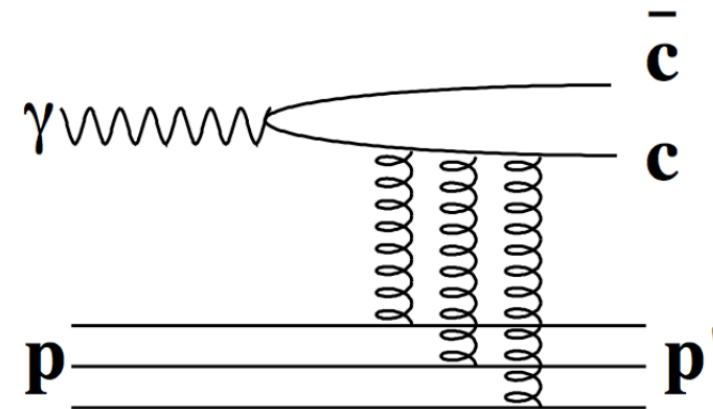
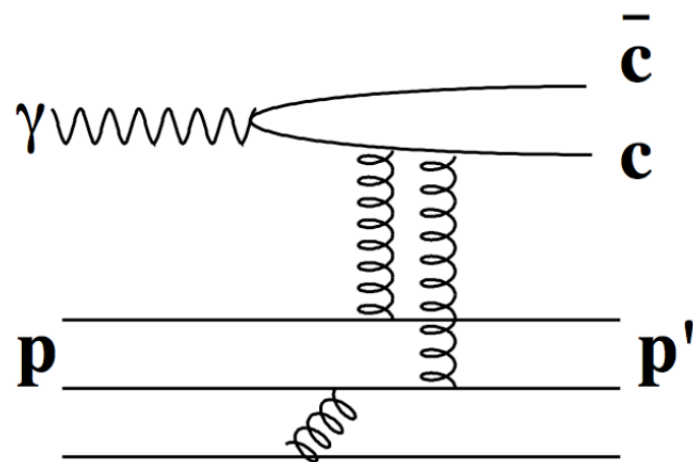
Simulate beam-within-beam:

- Virtual photon in electron beam (Tsai, *et al.*, Phys.Rev. 149 (4).)
- Bremsstrahlung photon in electron beam (Budnev *et. al.*, 1975, Physics Reports 15 (4))
- Nucleon in nucleus
- ...

Heavy quarkonia in photo-production

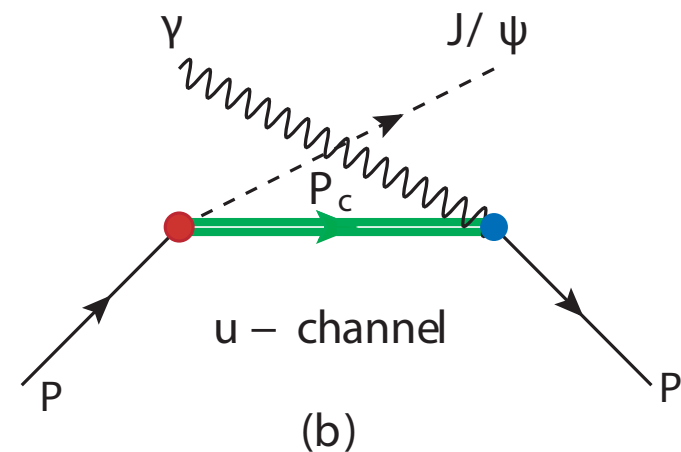
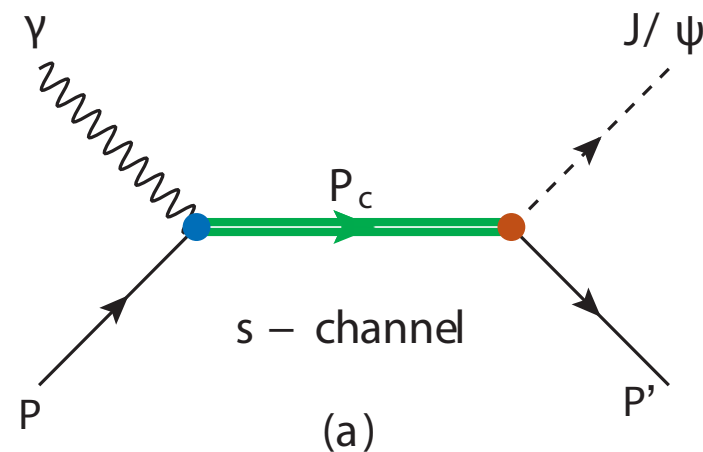
- t -channel production of heavy quarkonium (2- and 3-gluon exchange)

- (formalism from **Brodsky et al., PLB498, 23-28 (2001)**)

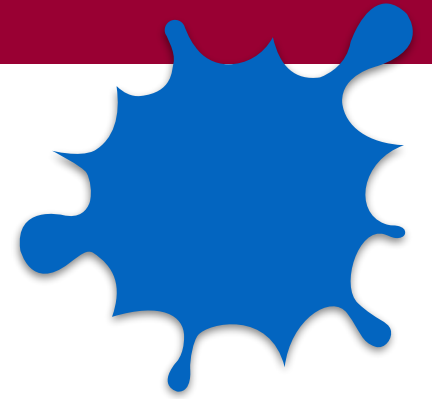


- Resonant production of $P_c(4380)$ and $P_c(4450)$

- (formalism from **Wang Q., et al., PRD 92-3 (2015) 034022-7**)



Heavy quarkonia in lepto-production



- Starting from photo-production formalism:

$$\frac{d\sigma}{dQ^2 dy dt} = \Gamma_T (1 + \epsilon R) D \frac{d\sigma_\gamma}{dt}$$

- R based on fit to world data

$$R = \left(\frac{AM_V^2 + Q^2}{AM_V^2} \right)^{n_1} - 1$$

- Martynov, et. al., "Photoproduction of Vector Mesons in the Soft Dipole Pomeron Model." PRD 67 (7), 2003. doi:10.1103/PhysRevD.67.074023
- R. Fiore et al., "Exclusive Jpsi electroproduction in a dual model." PRD80:116001, 2009"

- Dipole-like form factor similar to ρ^0 production

$$D = \left(\frac{M_V^2}{M_V^2 + Q^2} \right)^{n_2}$$

- A. Airapetian et al, "Exclusive Leptoproduction of rho0 Mesons on Hydrogen at Intermediate W Values", EPJ C 17 (2000) 389-398
- Adams et al., "Diffractive production of rho0 mesons in muon-proton interactions 470 GeV", ZPC74 (1997) 237-261.
- M Tytgat, "Diffractive production of rho0 and omega vector mesons at HERMES" DESY-Thesis 2001-018 (2001)
- P. Liebing, "Can the Gluon Polarization be Extracted From HERMES Data", DESY-Thesis (2004)

Angular dependence of the decay lepton pair

- SCHC Distribution in **old SoLID J/ψ generator** describes decay of vector meson to scalar particles
 - This is **wrong** for decay to fermions (e^+e^-)

✗ $\mathcal{W}(\cos \theta_h) = \frac{3}{4}(1 - r_{00}^{04} + (3r_{00}^{04} - 1) \cos^2 \theta_h)$

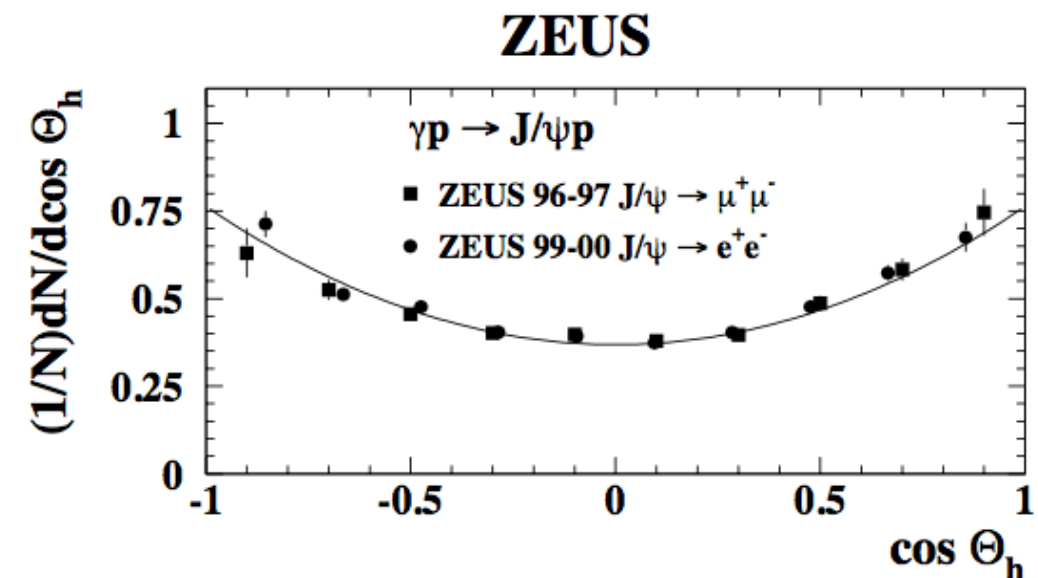
- Correct** distribution for decay to fermions

✓ $\mathcal{W}(\cos \theta_h) = \frac{3}{8}(1 + r_{00}^{04} + (1 - 3r_{00}^{04}) \cos^2 \theta_h)$

- Favors more asymmetric decay at low Q^2
- Reduces to $\sim \cos^2 \theta_h$ for photo-production
($r_{00}^{04} \rightarrow 0$ as $Q^2 \rightarrow 0$)

FORMULA FOR TWO FERMION DECAY

- J. Breitweg et al. (ZEUS), Exclusive electro-production of ρ^0 and J/ψ mesons at HERA, EPJ-C 6-4 (1999)
- Chekanov et al. (ZEUS), Exclusive photo production of J/ψ mesons at HERA (2002)
- K. Schilling et. Al, Nucl.Phys. B 61, 381 (1973)



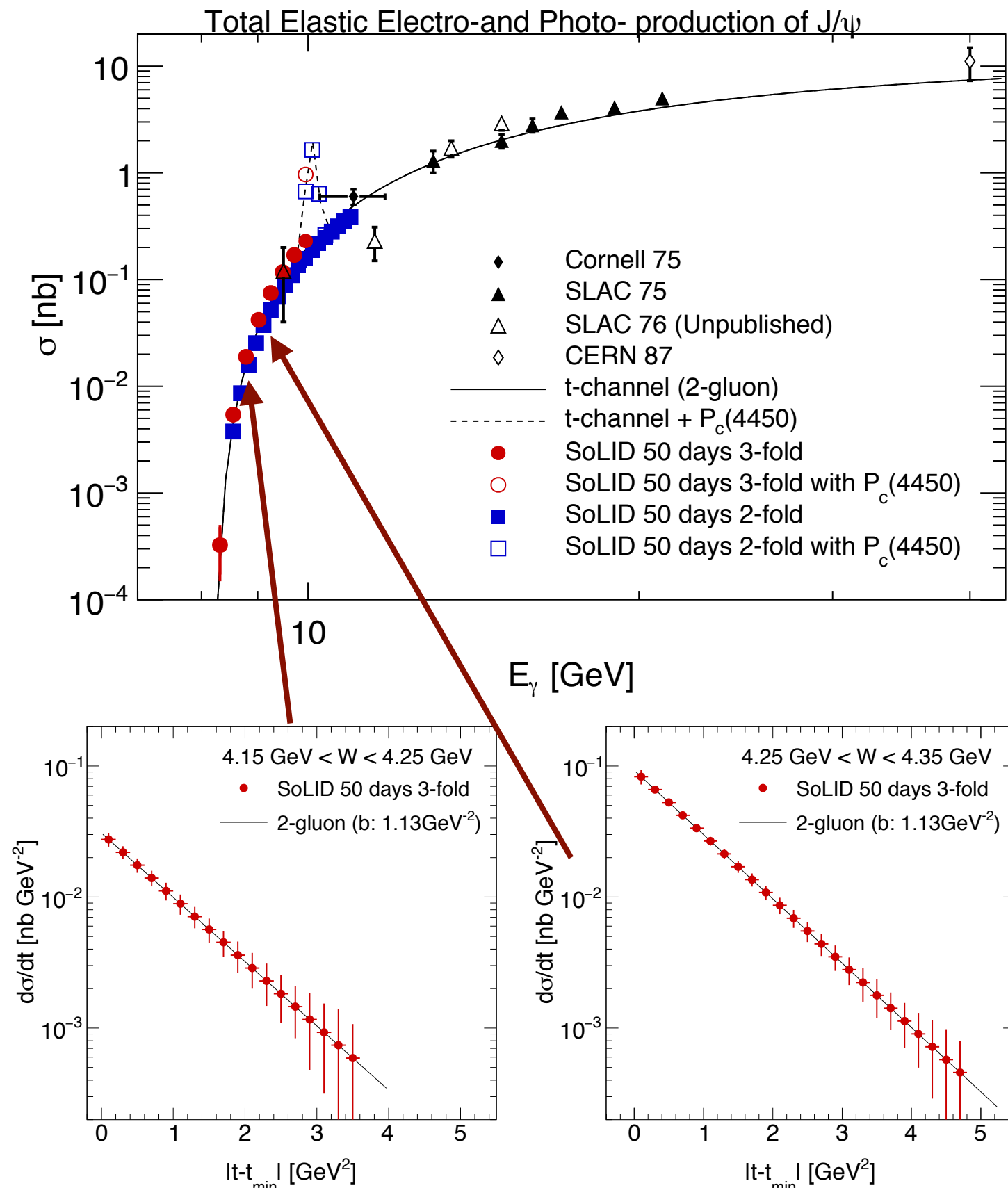
J/ψ rates still better than original proposal!

Photo-production

- 2-fold coincidence + recoil proton
- t -channel J/ψ rate: **1627 per day**
- $P_c(4450)$ rate: **927 per day**
 - ☆ (5% coupling)

Electro-production

- 3-fold coincidence (3 leptons)
- t -channel J/ψ rate: **86 per day**
- $P_c(4450)$ rate: **36 per day**
 - ☆ (5% coupling)

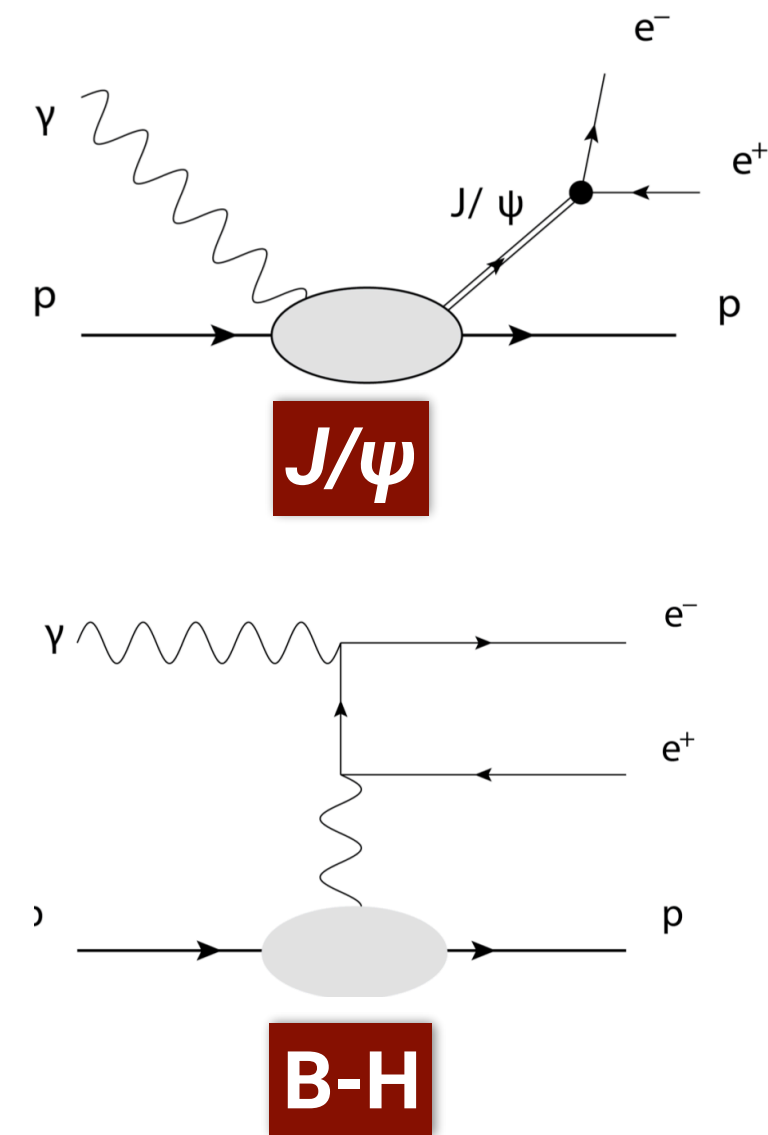
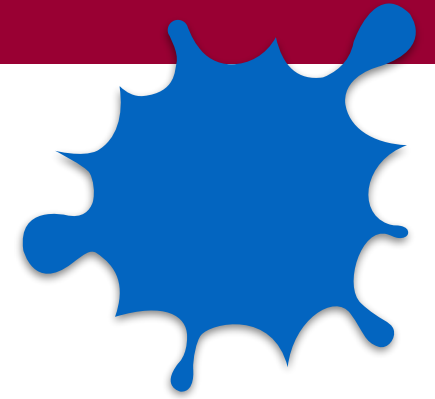


In progress: J/ψ – Bethe-Heitler interference

Interference between elastic J/ψ production near threshold and Bethe-Heitler

Forward-backward asymmetry near the J/ψ invariant mass peak

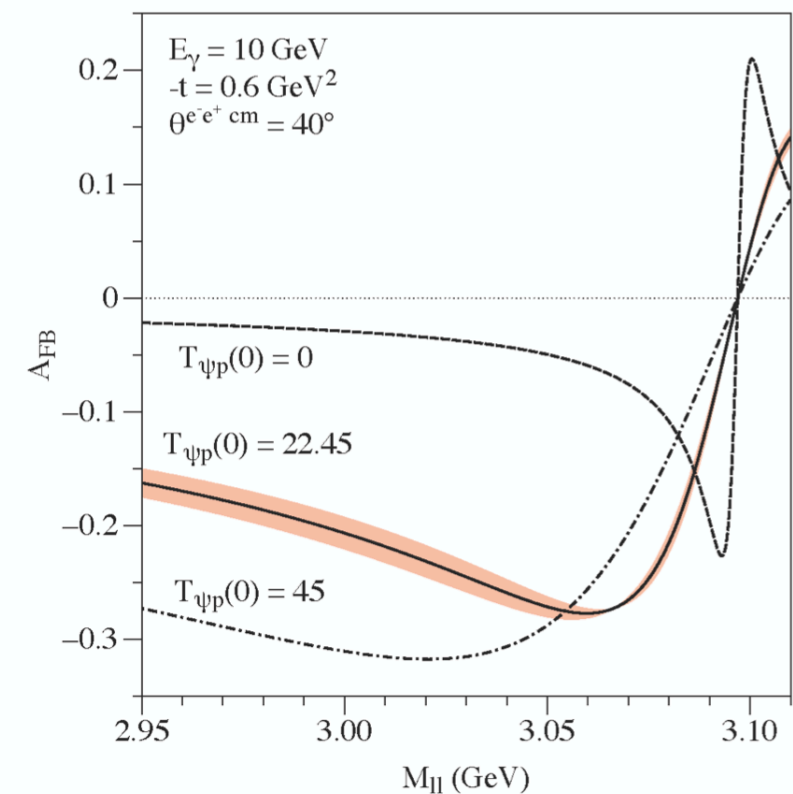
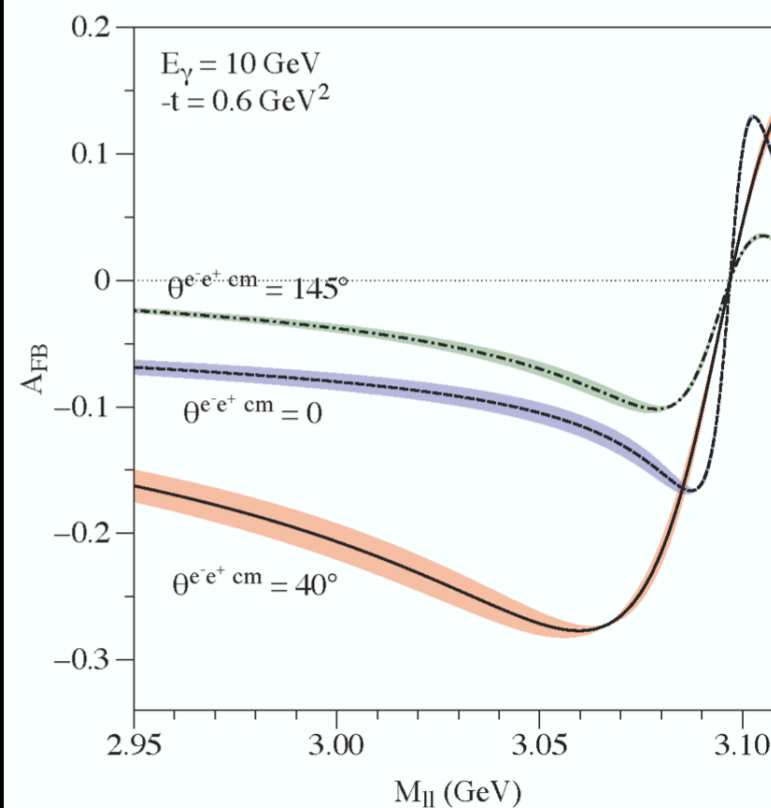
Sensitive to real part of the scattering amplitude, and therefore $a_{\psi p}$ and $B_{\psi p}$



$$A_{FB} \equiv \frac{\frac{d\sigma}{d\Omega}(\theta_{cm}) - \frac{d\sigma}{d\Omega}(\theta_{cm} - \pi)}{\frac{d\sigma}{d\Omega}(\theta_{cm}) + \frac{d\sigma}{d\Omega}(\theta_{cm} - \pi)} = \frac{\sum_s 2 \text{Re} T_\psi T_{BH}}{\sum_s |T_\psi|^2 + \sum_s |T_{BH}|^2}$$

interference term

θ_{cm} — scattering angle in a lepton pair CM frame



In progress: Radiative J/ψ decay

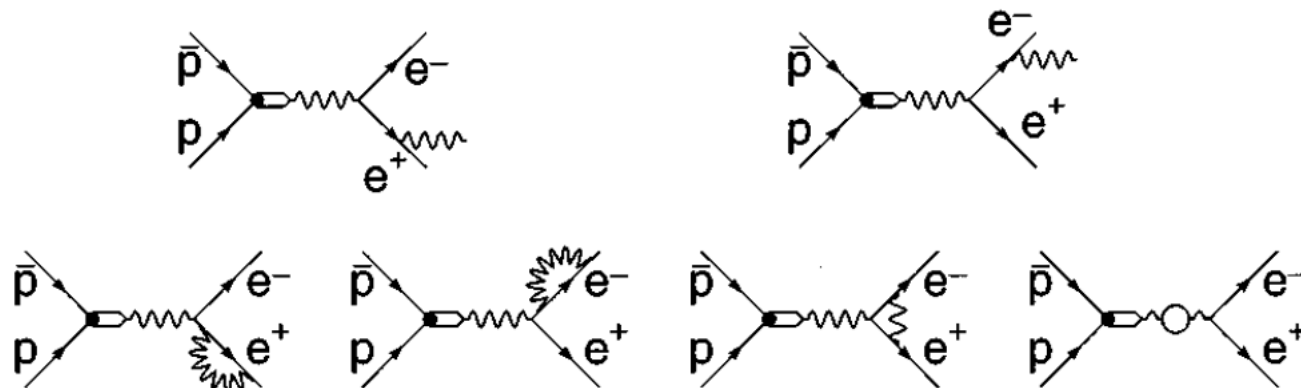
$J/\psi(1S)$ DECAY MODES

PDG (2016)	Mode	Fraction (Γ_i/Γ)	Stat. Conf.
Γ_1	hadrons	$(87.7 \pm 0.5) \%$	
Γ_2	virtual $\gamma \rightarrow$ hadrons	$(13.50 \pm 0.30) \%$	
Γ_3	$g g g$	$(64.1 \pm 1.0) \%$	
Γ_4	$\gamma g g$	$(8.8 \pm 1.1) \%$	
Γ_5	$e^+ e^-$	$(5.971 \pm 0.032) \%$	
Γ_6	$e^+ e^- \gamma$	$(8.8 \pm 1.4) \times 10^{-3} (E > 100 \text{ MeV})$	
Γ_7	$\mu^+ \mu^-$	$(5.961 \pm 0.033) \%$	

**+15% of e+e-
branching ratio!**

Contributing diagrams

Armstrong, et al., 1996. PRD 54 (11): 7067–70



- How does this impact J/ψ reconstruction near threshold?
- What is a reasonable photon energy cut-off at JLab?
- From proton-antiproton experiment: impact from electron leg?

THANK YOU!