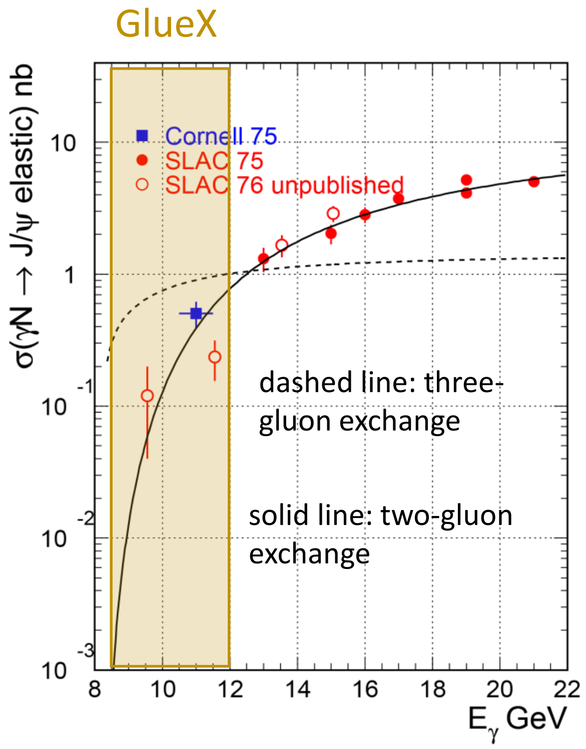
J/ψ update

Why it is important?

- JLab 12GeV accelerator has UNIQUE opportunity (high intensity, correct energy, polarized beam) to study J/ψ photo-production right above the threshold (E_γ=8.2 GeV) up to 12 GeV – poorly (If at all) covered by previous old measurements
- Look for threshold enhancement: sensitive to proton gluonic content (high x); other interesting effects expected near threshold
- Hall D is the only hall that can have E_γ>11 GeV – needed to allow continuity from the high energy data; so far only in 2016 we had data >11.5 GeV – when will be the next time we can have 12 GeV?
- GlueX coherent peak right above the threshold – improved statistics at the very important point



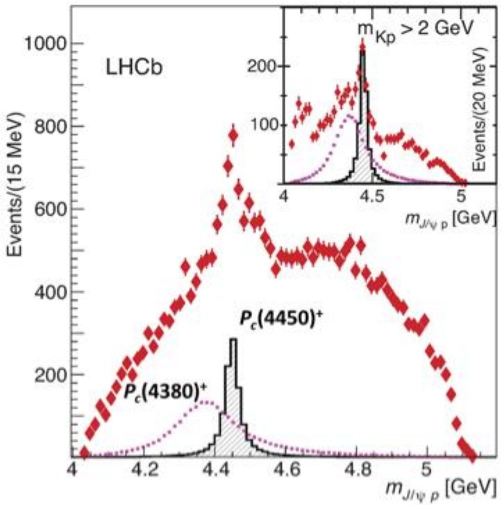
Pentaquark photoproduction

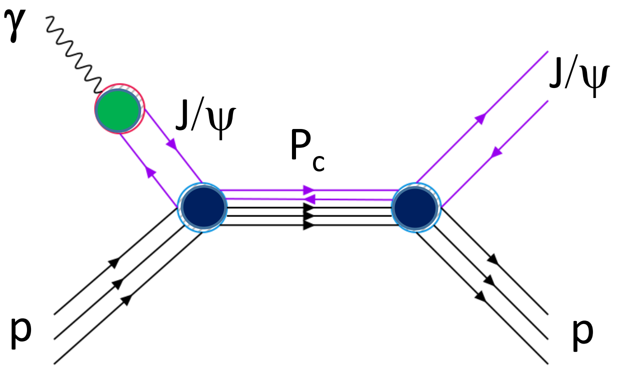
Why it is important?

- Also because of the LHCb pentaquarks - DIRECT relation – if they exist they should be seen in s-channel photoproduction:

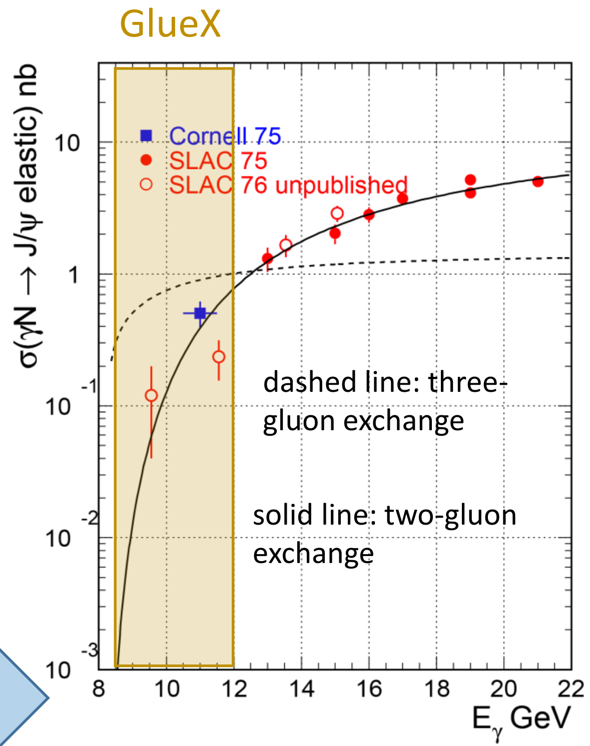
$\sigma \sim BW(\Gamma_{Pc}, M_{Pc}) * BR(P_c \to \gamma p) * BR(P_c \to J/\psi p)$

$BR(P_c \to \gamma p) \sim \Gamma(J/\psi \to \ell^+ \ell^-) * BR(P_c \to J/\psi p)$ (VMD)

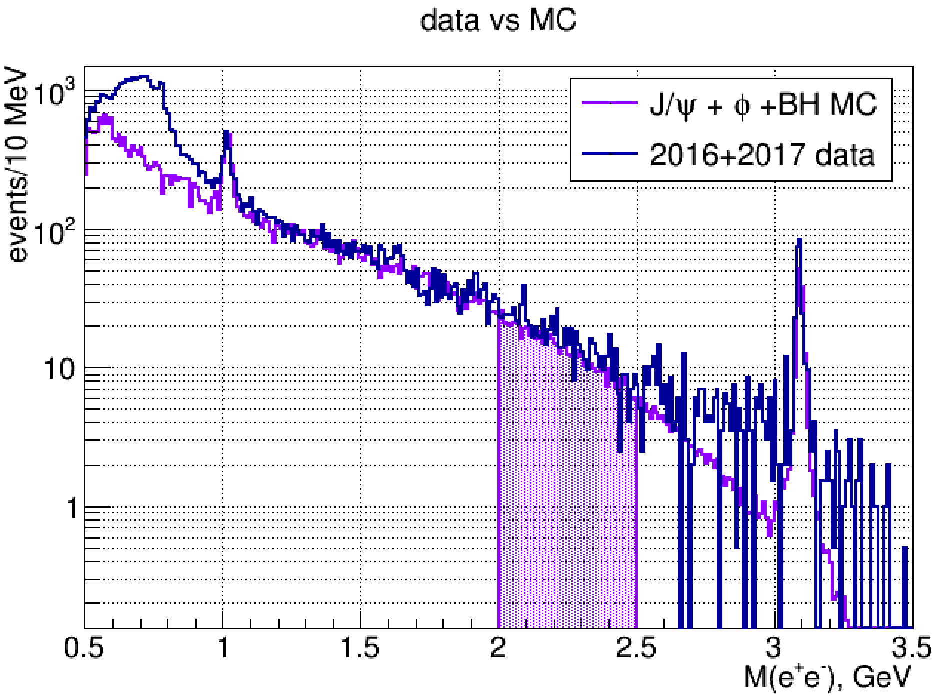




Direct relation



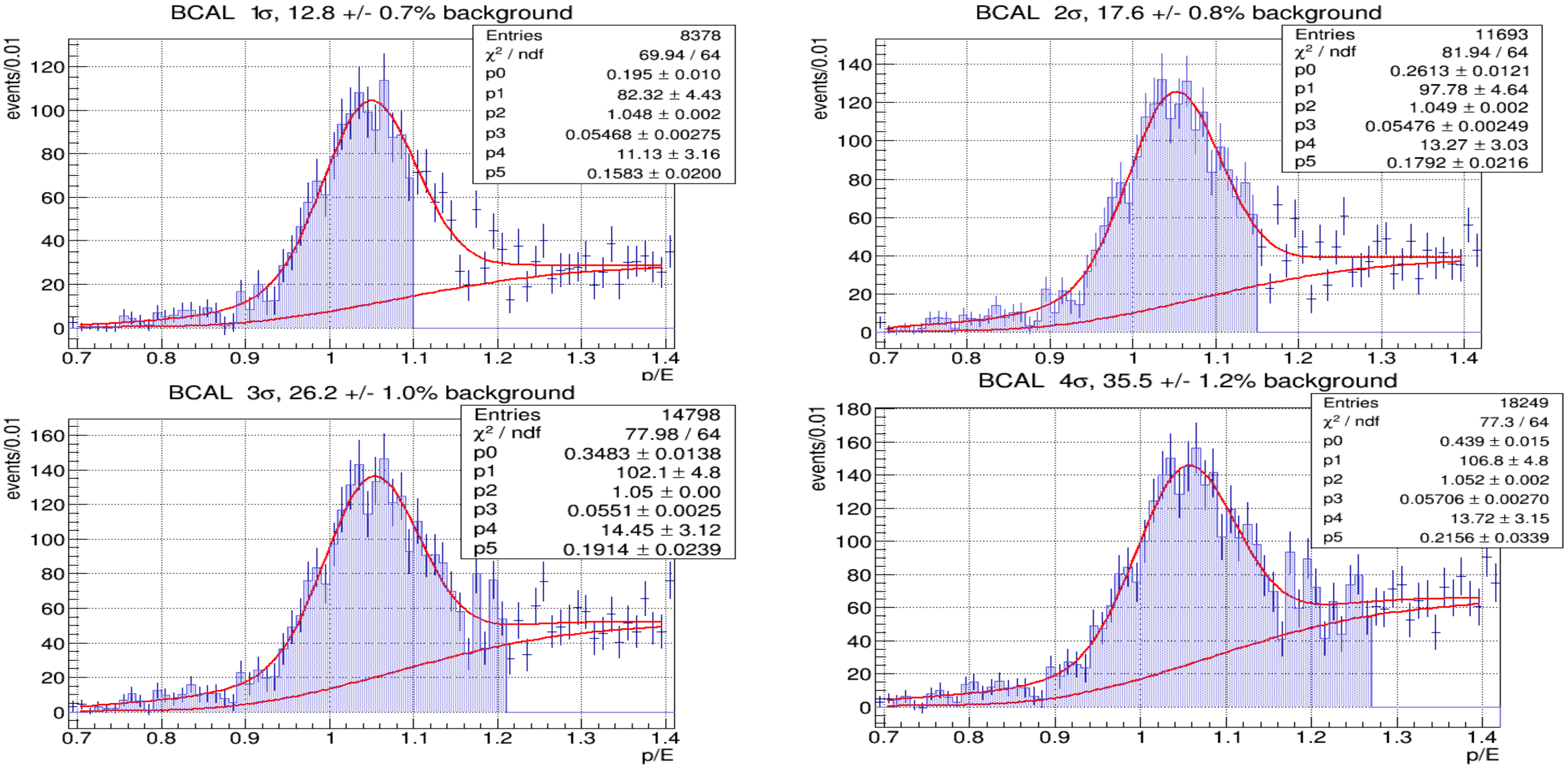
Strategy for normalizing J/ψ x-section



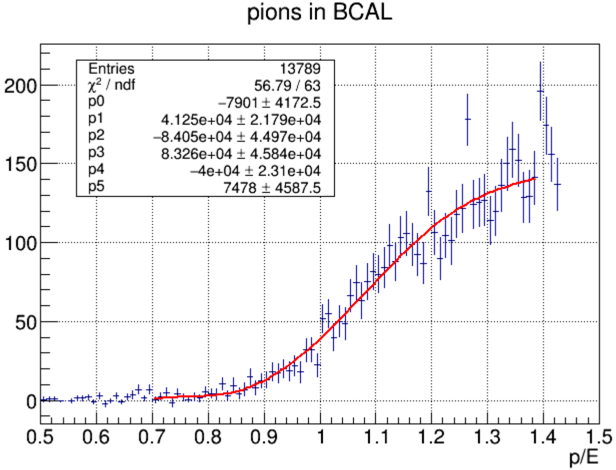
MC, ϕ, or Bethe-Heitler x-section?

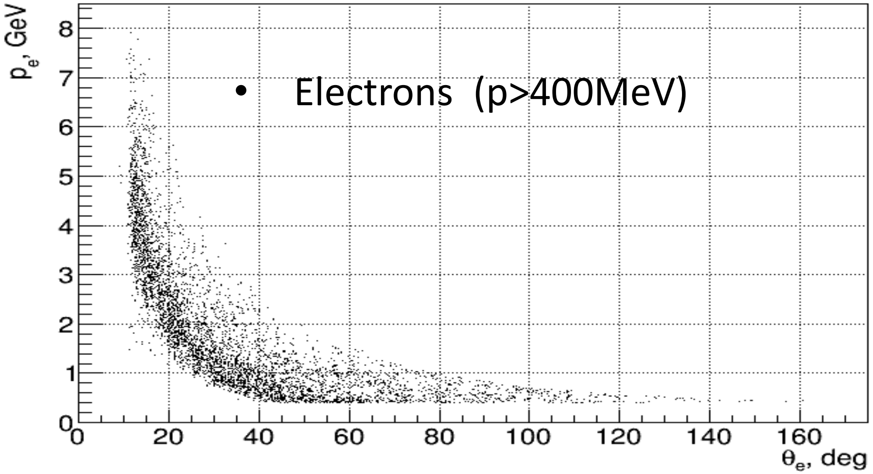
- MC – not yet …
- ϕ – too far in invariant mass, different kinematics/detectors involved, but 10MeV-width peak can be separated from background
- BH pros – e.m. process can be calculated exactly (apart from singularity regions, involves proton FFs (known), and higher order processes - TCS), more statistics, energy dependence similar to J/ψ - the only way to normalize 11.75 data point from 2016
- BH cons – continuum containing background; resonances (ρ') should be excluded – inv. mass region 2-2.5 GeV.

Pion background suppression

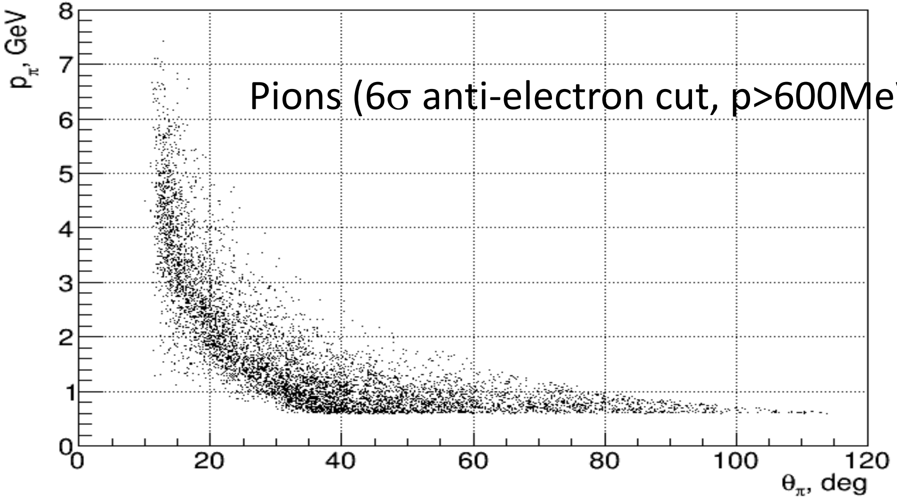


Pion background suppression – pion sample



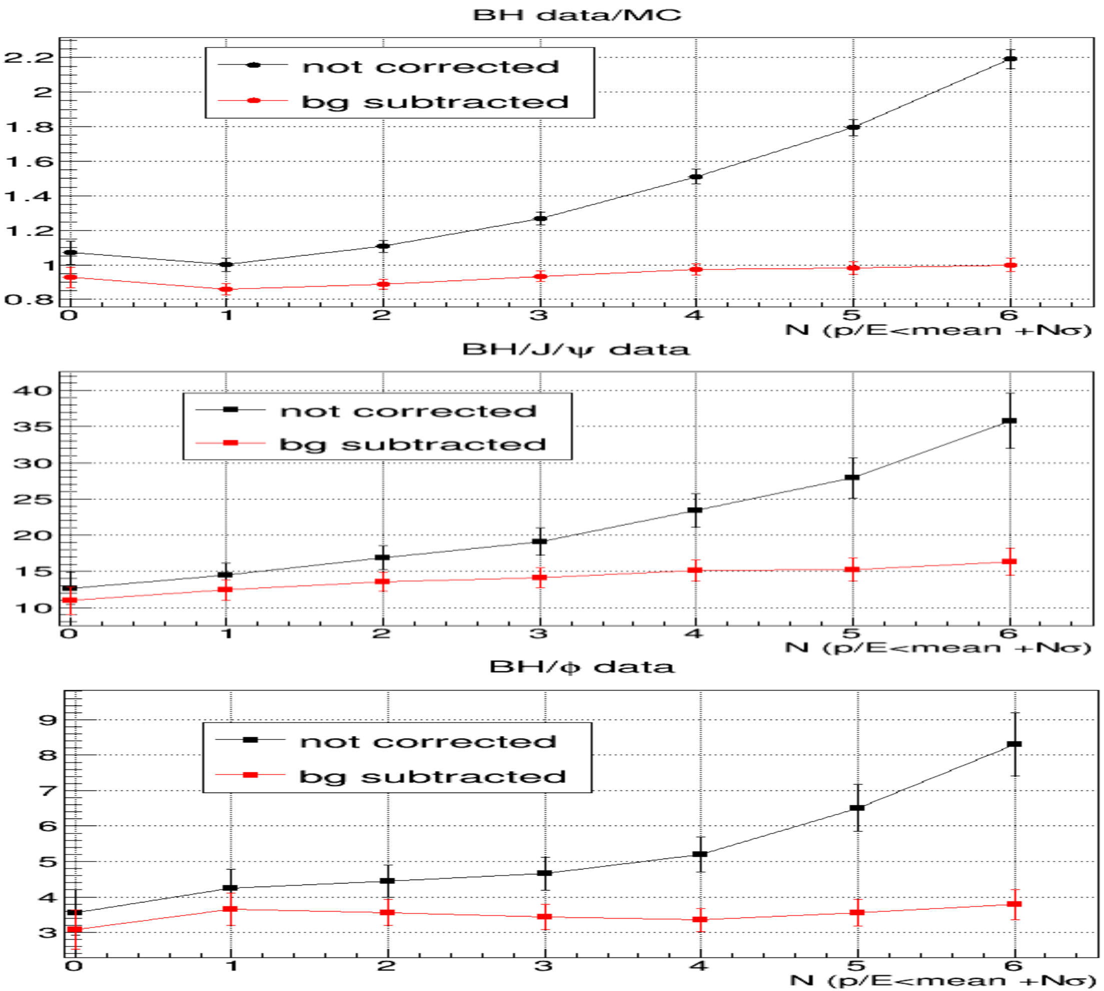


- Electrons (p>400MeV)

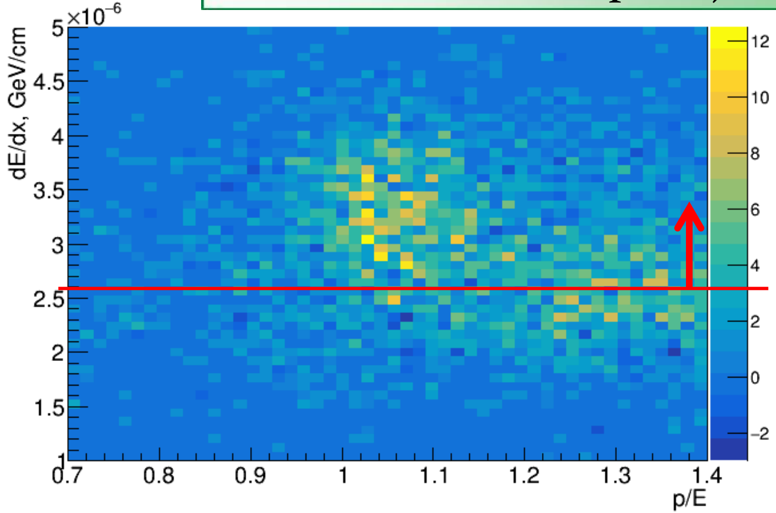


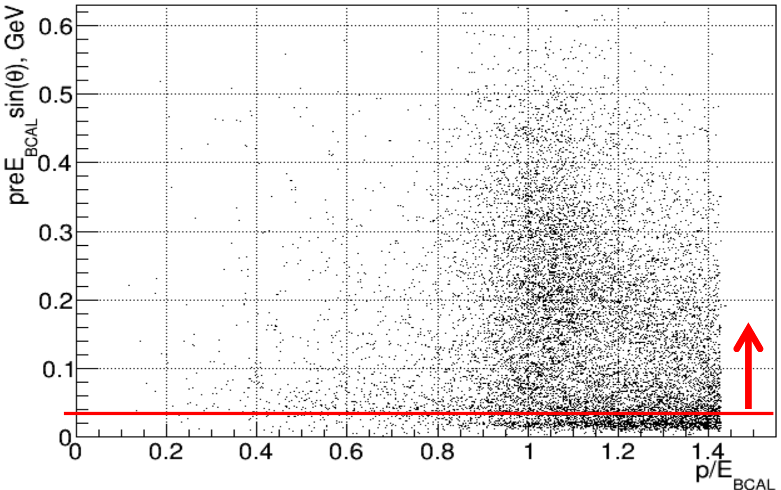
Pions (6σ anti-electron cut, p>600MeV)

Pion background suppression



BCAL pre-sjower, dE/dx, and other cuts





- CDC dE/dx>2.6 keV/cm
- BCAL presh.*sin(θ)> 30 MeV
- θ(e+,e-)>2 deg
- p(e+,e-)>0.4 GeV
- abs(M(p,π+/π-)-1.23)>0.1 GeV

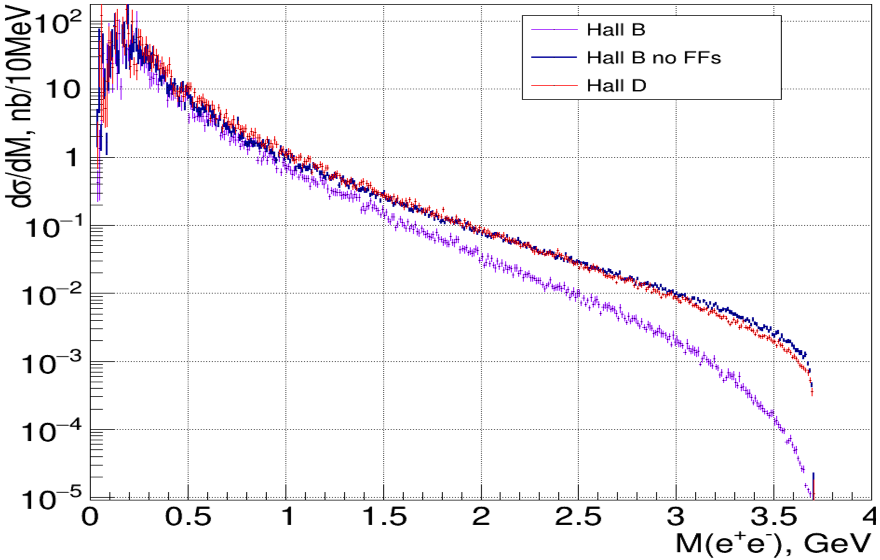
Bethe-Heitler Simulations

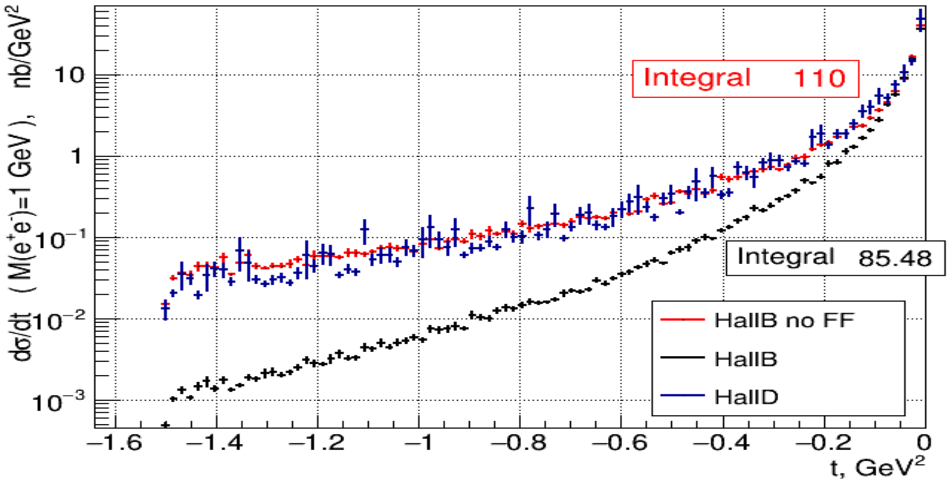
Generator /author	Based on	Proton FFs	Phase space	Singularities	Implemeted for HallD
Rafayel Paremuzyan	Berger et.al* formulas	yes	flat, dynamic	Acceptance cut	yes
Mike Dugger	Feynman diag. (numerical)	no	weighted	Propagator cut	yes
Richard Jones	Feynman diag. (numerical)	yes	weighted	Propagator cut	no
Marie Boer	M.Boer at.al** numerical	yes	flat	Acceptance cut	no

- *Berger, E., Diehl, M. & Pire, B. Eur. Phys. J. C (2002) 23: 675. https://doi.org/10.1007/s100520200917
- **M.Boer, M.Guidal, M.Vaderhaeghen, EPJA 51 (2015) no.8, 103.

Bethe-Heitler Simulations – proton FFs

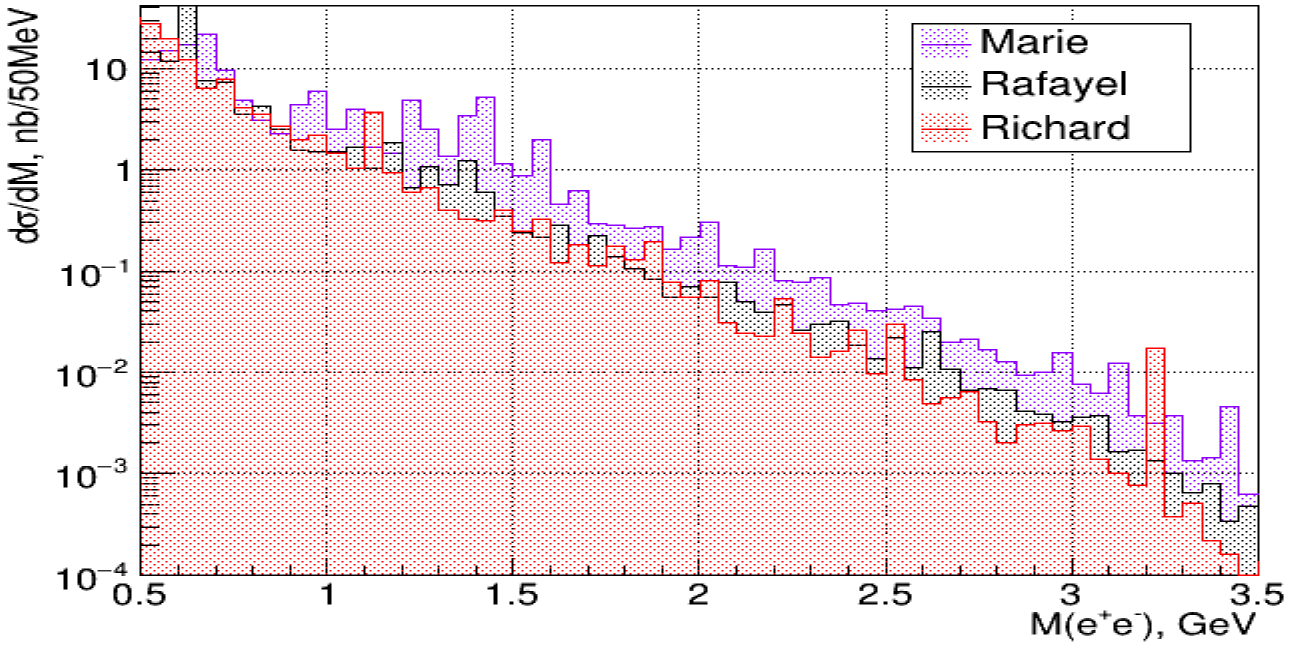
- Hall B (Rafayel) vs Hall D(Mike) E_γ = 11 GeV, θ_e>0.01
- Proton FFs explain differences
- Right plot: t dependence at M(e+e-)=1 GeV
- t_{min} increases with M(e+e-)





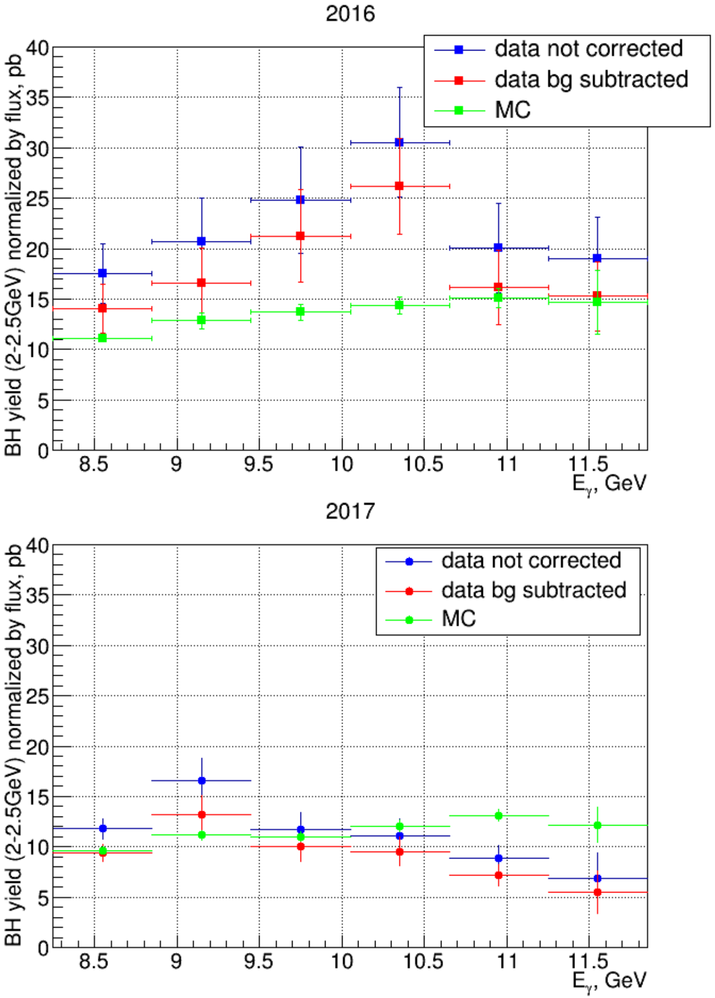
Bethe-Heitler Simulations - comparison

- Three BH generators: using dipole FFs

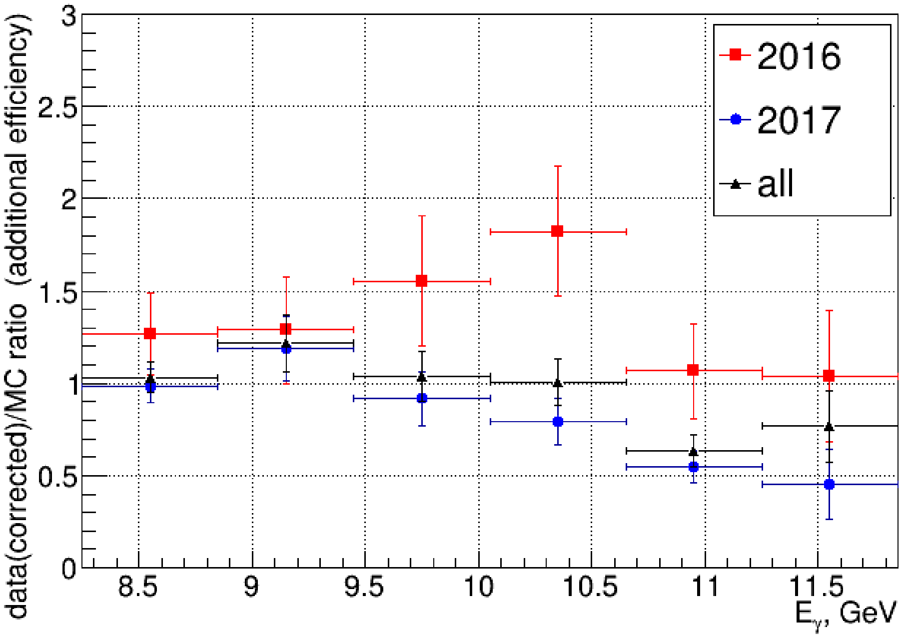


E_γ = 11 GeV   40<θ<140   0.04<|t|<3.5 GeV^2

Normalization – E dependence

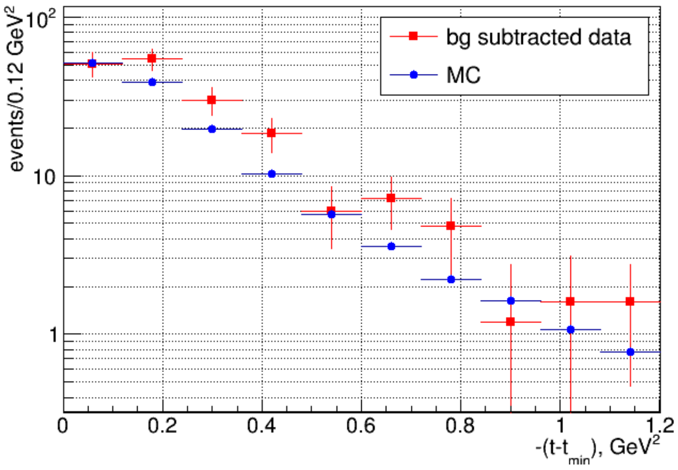


BH $2<M(e^+e^-)<2.5$ GeV

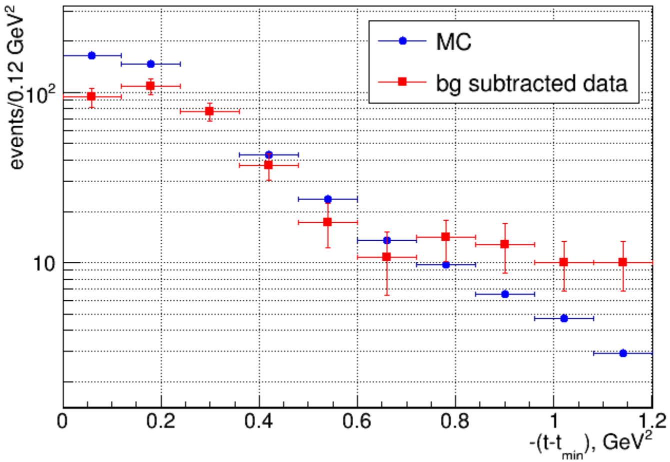


Normalization – t dependence

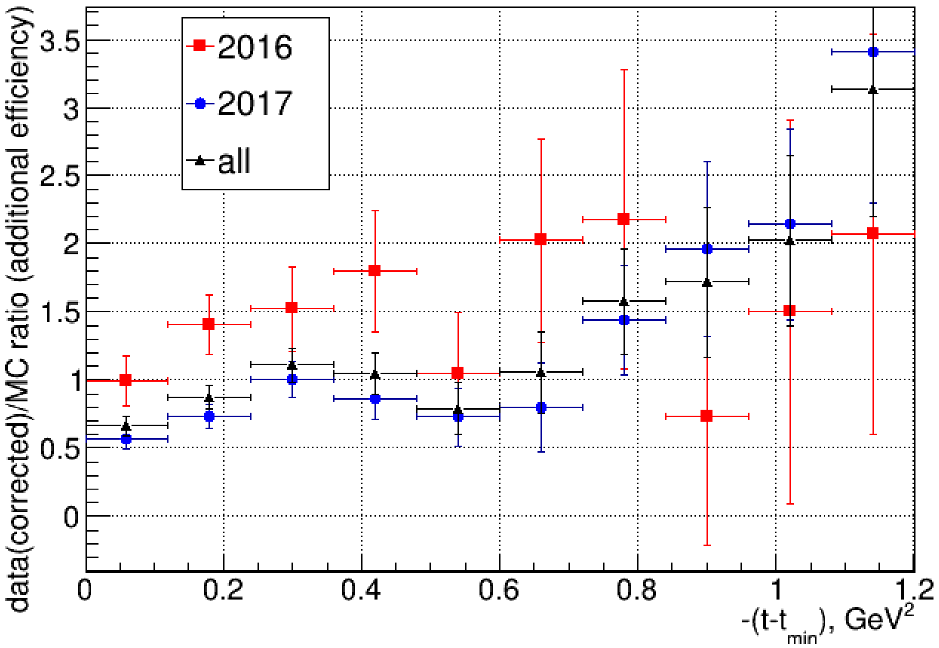
2016



2017

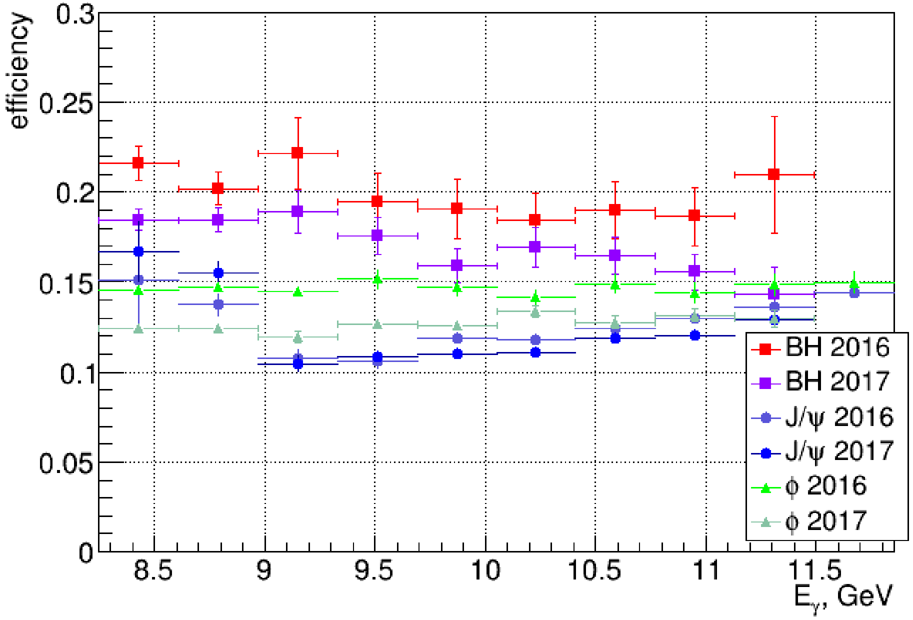


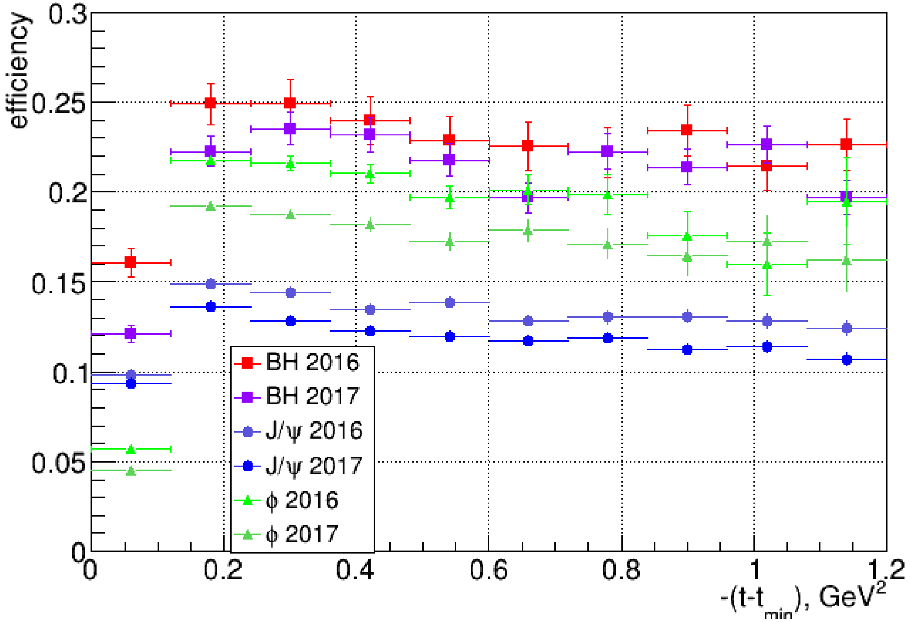
BH $1.5<M(e^+e^-)<2.5$ GeV



➡ Noise? at >0.7 GeV^2 in 2017 data

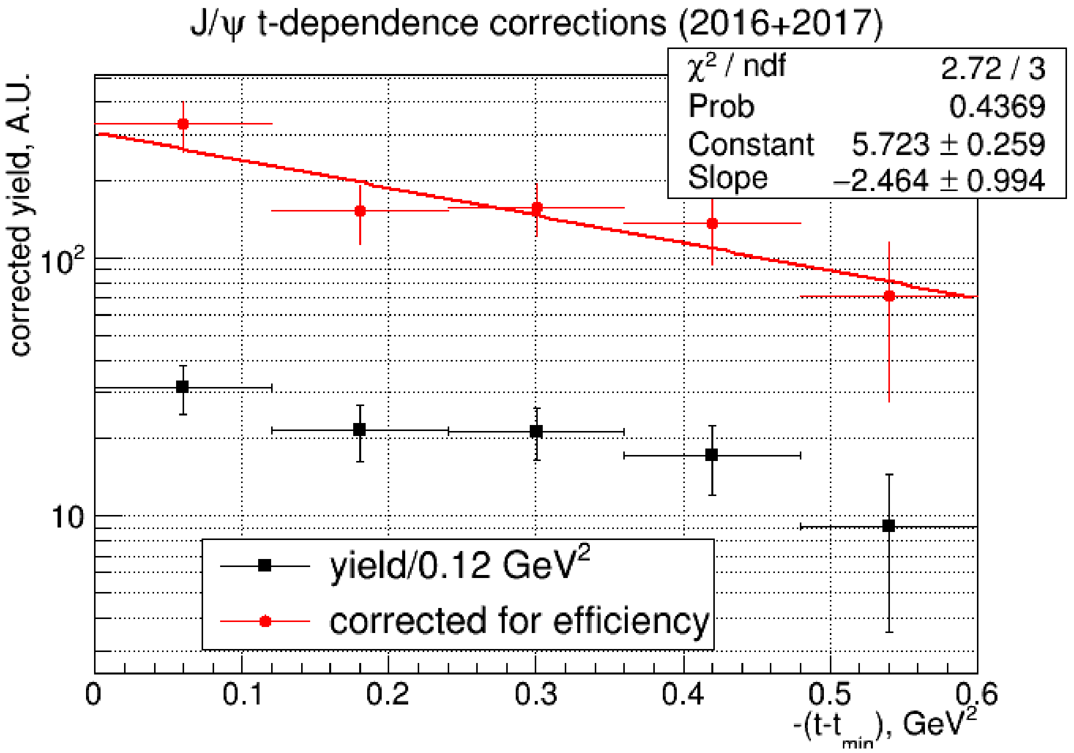
Efficiencies





- 2016 efficiency higher than 2017
- dE/dx cut mostly BH and J/ψ
- Why BH higher than J/ψ – very important to understand

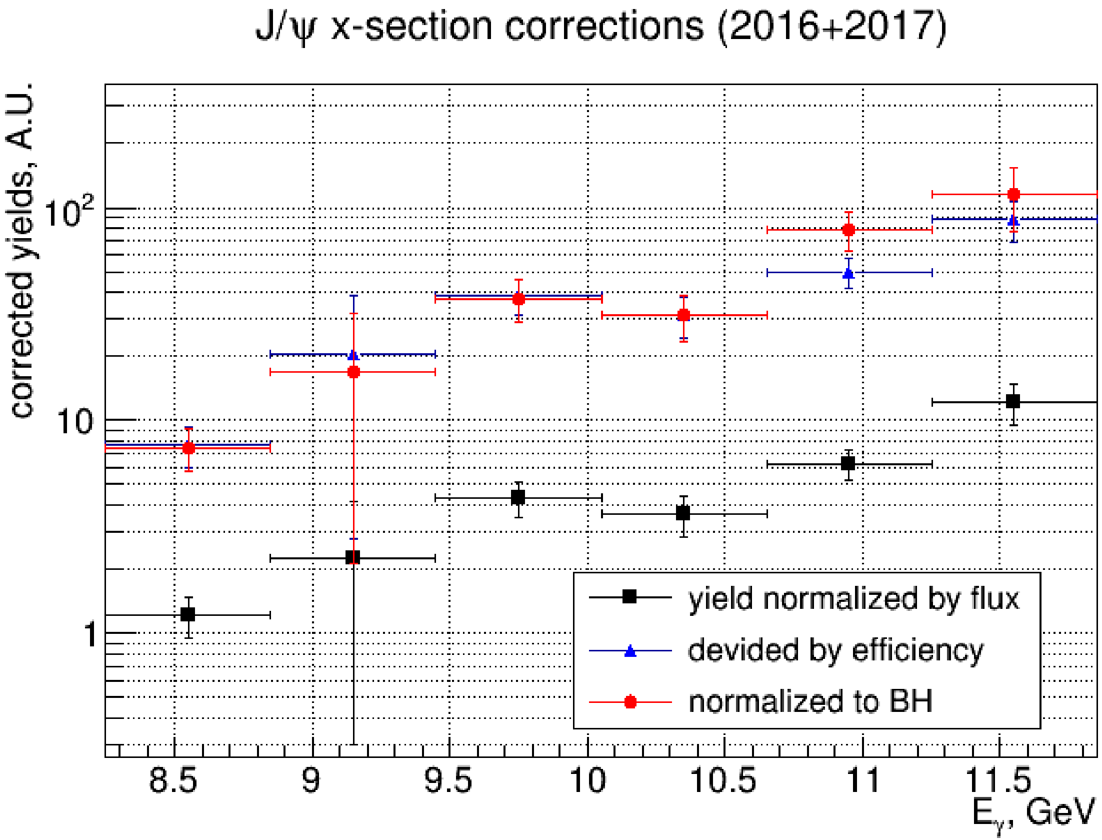
J/ψ analysis in bins of $t\text{-}t_{min}$



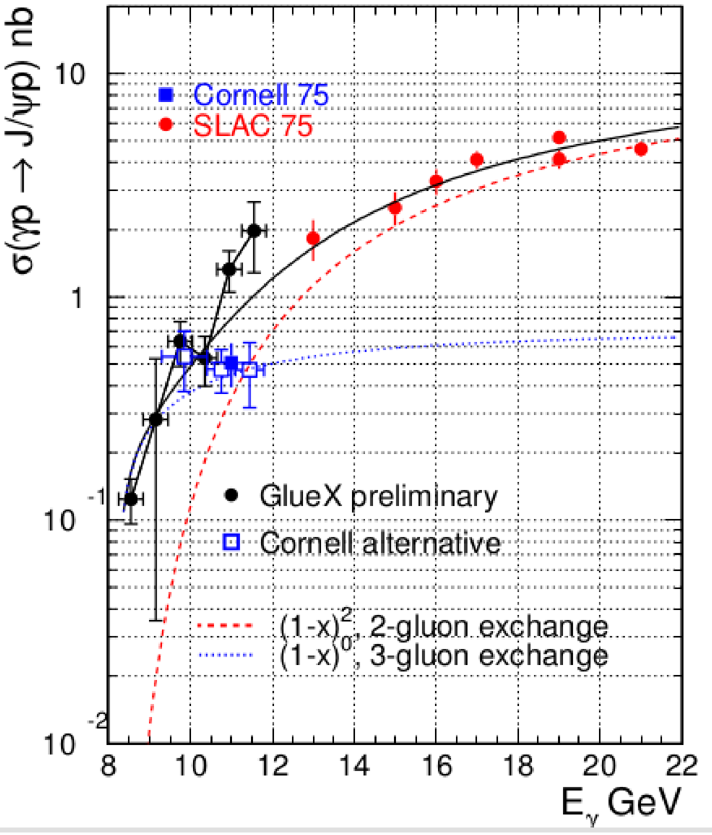
Cornell: 1.25 +/- 0.2 GeV^{-2} at E_γ = 11 GeV

SLAC: 2.9 at E_γ = 19 GeV

J/ψ analysis in bins of E



J/ψ cross-section vs E



From Sean

Model Fitting

- Want to test different production models and provide accurate determination of the confidence intervals of their parameters
- Implementing unbinned fitter
  - Performing toy MC tests to verify accuracy
- Plan: Finalize fitting code and extract expected limits before applying to data

$$\frac{d\sigma}{dt} \propto \frac{1}{E_\gamma^2} A^2 e^{2b(t-t_0)} \left(\frac{s-s_{\text{thr}}}{s_0}\right)^{2\alpha(t)}$$

with

$$\begin{aligned} \alpha(t) = \alpha_0 + \alpha' t \quad &: \quad \text{Pomeron} \\ A \quad &: \quad \text{Normalization} \\ b \quad &: \quad t - \text{Slope} \end{aligned}$$

Total cross section:

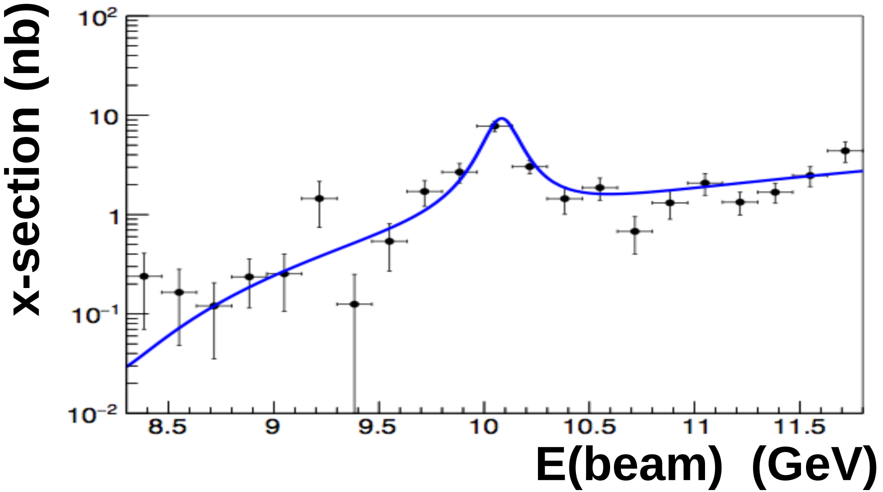
$$\sigma = \int_{t_{\text{max}}}^{t_{\text{min}}} \frac{d\sigma}{dt} dt$$

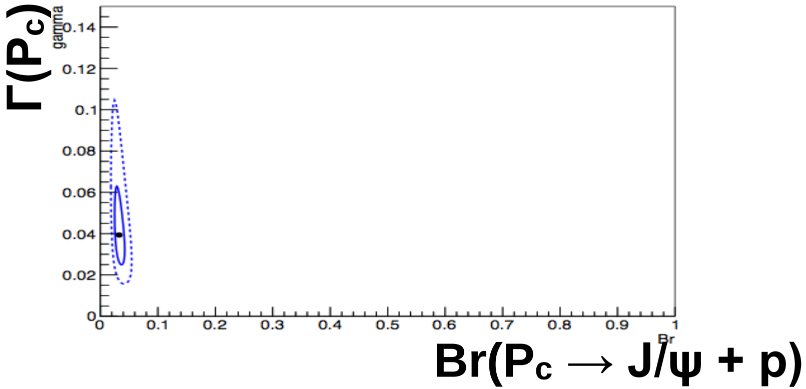
JPAC Model via A. Austregeslio

From Sean

Model Fitting

- Example: JPAC model
  - $N(J/\psi) = 300$
  - $M(P_c) = 4.45$ GeV
  - $\Gamma(P_c) = 0.039$ GeV
  - $spin(P_c) = 5/2$
  - $Br(P_c \to J/\psi + p) = 3\%$
  - Statistical uncertainties only





Analysis outlook

- Normalization to Bethe-Heitler is the only option now to get the cross-section using 2016 and 2017 data
- Waiting for reconstruction/analysis of 2016 data (both golden and non-golden runs) to be included in the final data set
- Apart from the problem of 2016/2017 efficiency, we have to understand:
  - Effect of the random hits on the efficiencies
  - BH/J/ψ relative efficiency
  - Reason for “noise” at high t in 2017 data
  - Cut out singularity regions (mostly outside acceptance) in BH calculations
- Possible changes/improvements:
  - Extend BH region down to 1.5 GeV – how argue about ρ' contribution
  - Remove dE/dx cut – gain ~30% statistics, but π contamination increases to 40+/-10%
  - Include higher t in the t-slope fit?
- Unbinned analysis in (E,t) plane – how to get normalization for each point, background subtraction, ….

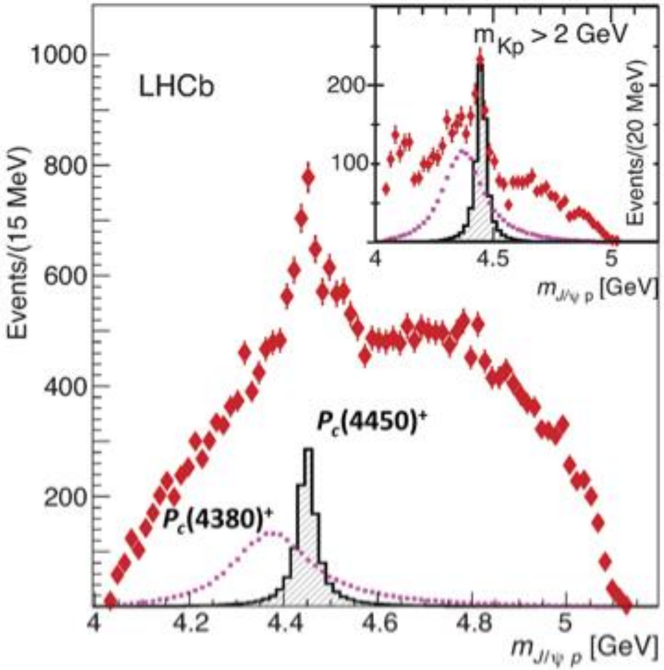
Back-ups

LHCb Pentaquarks

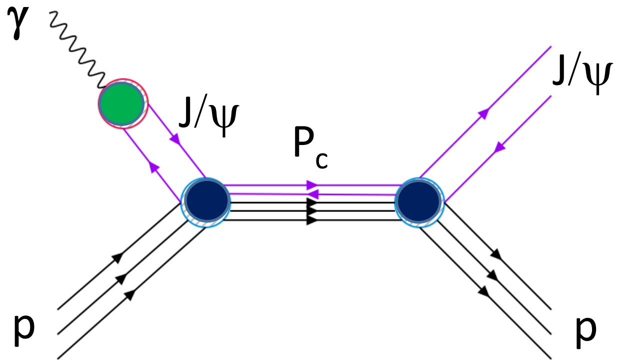
Λ_b -> K^-(J/ψ p)

Pc(4380): Γ=205 MeV $J^P=3/2^{+(-)}$
Pc(4450): Γ=39 MeV $J^P=5/2^{-(+)}$

Interpretations:
- (charmed baryon) – (anti-charmed meson) molecule ($\bar{D}^*\Sigma_c$)
- Resonance in terms of quark degrees of freedom
- Kinematic effects: threshold effect (χ_{c1} p) , ATS



Phtotoproduction of LHCb Pentaquarks



$\sigma \sim BW(\Gamma_{Pc},M_{Pc})*BR(P_c\text{->}\gamma p)*BR(P_c\text{->}J/\psi p)$

$BR(Pc\text{->}\gamma p) \sim \Gamma(J/\psi \text{->} \ell^+\ell^-)*BR(P_c\text{->}J/\psi p)$ (VMD)

$\sigma \sim BR^2(P_c\text{->}J/\psi p)$

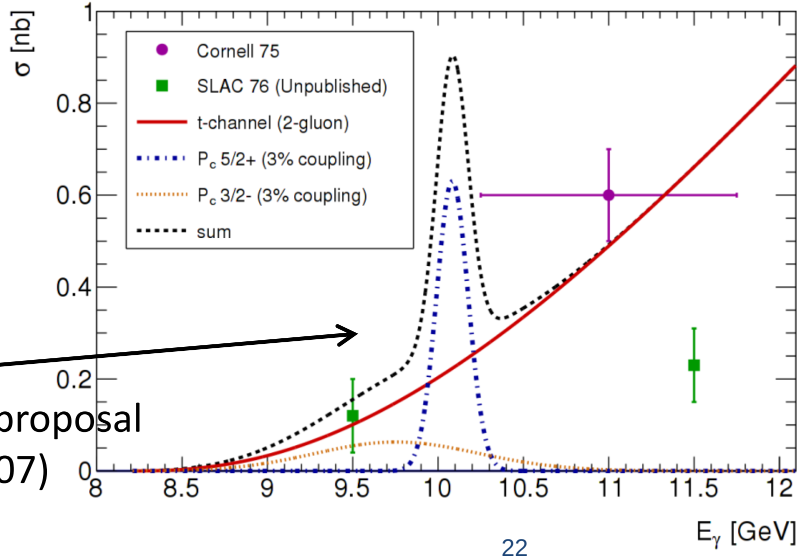
1)V.Kubarovsky and M.B.Voloshin, arXiv: 1508.00888.
2)M.Karliner and J.Rosner, arXiv: 1508.01496.
3)A.Blin, C.Fernandez-Ramirez, A.Jackura, V.Mathieu, V.Mokeev, A.Pilloni, and A.Szczepaniak,arXiv: 1606.08912

all three papers $\sigma^{max} \sim 10\ \mu b$ for $P_c(5/2+)$ 100% BR

1)Q.Wang, X.Liu, and Q.Zhao,arXiv: 1508.00339

$\sigma^{max} \sim 0.7\ \mu b$ for $P_c(5/2+)$ 100% BR

Hall C 5q-proposal
(E12-16-007)



Upper limit for BR($P_c \to p\, J/\psi$)

- If preliminary results hold (~ factor of 2) we can put upper limit of BR(P_c->$J/\psi p$) < 2% or less

- What about lower limit?

LHCb has measured:

BR(Λ_b -> $K^- J/\psi$ p) = 3.2 10^{-4}

BR(Λ_b -> $K^- P_c$)*BR(P_c->J/ψ p) = 1.3 10^{-5}

If BR(P_c->J/ψ p) too small then

BR(Λ_b -> K^- + J/ψ p) << BR(Λ_b -> K^- +!(J/ψ p))

(M.Karliner and J.Rosner, PRL 115 122001)