Near threshold J/ψ production in Hall-B

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The outline

- Current experiments: RG-A, RG-B
  - Analysis status

E12-12-001
E12-12-001A
E12-11-003B

- Remaining beam time
  - Luminosity upgrade x2

- Luminosity upgrade 10^{37} $cm^{-2}s^{-1}$
  - Possibilities of J/ψ measurement near the threshold with such a high Luminosity

- Energy upgrade
  - Estimate number of J/ψs
  - In addition to J/ψ, XYZ states will be accessible

Run Group A (RG-A)

Target:
5cm Unpolarized LH2

Run periods

- Spring 2018
  - Beam energy 10.6 GeV
  - DC HVs were not optimized: poor mom. resol.
  - Data was not used in the analysis
- Fall 2018
  - Beam energy 10.6 GeV
  - Run with in-bending and *outbending* torus polarities
- Spring 2019
  - Beam energy 10.2 GeV.
  - Inbending only

Run Group B (RG-B)

Target:
5cm Unpolarized LD2

Run periods

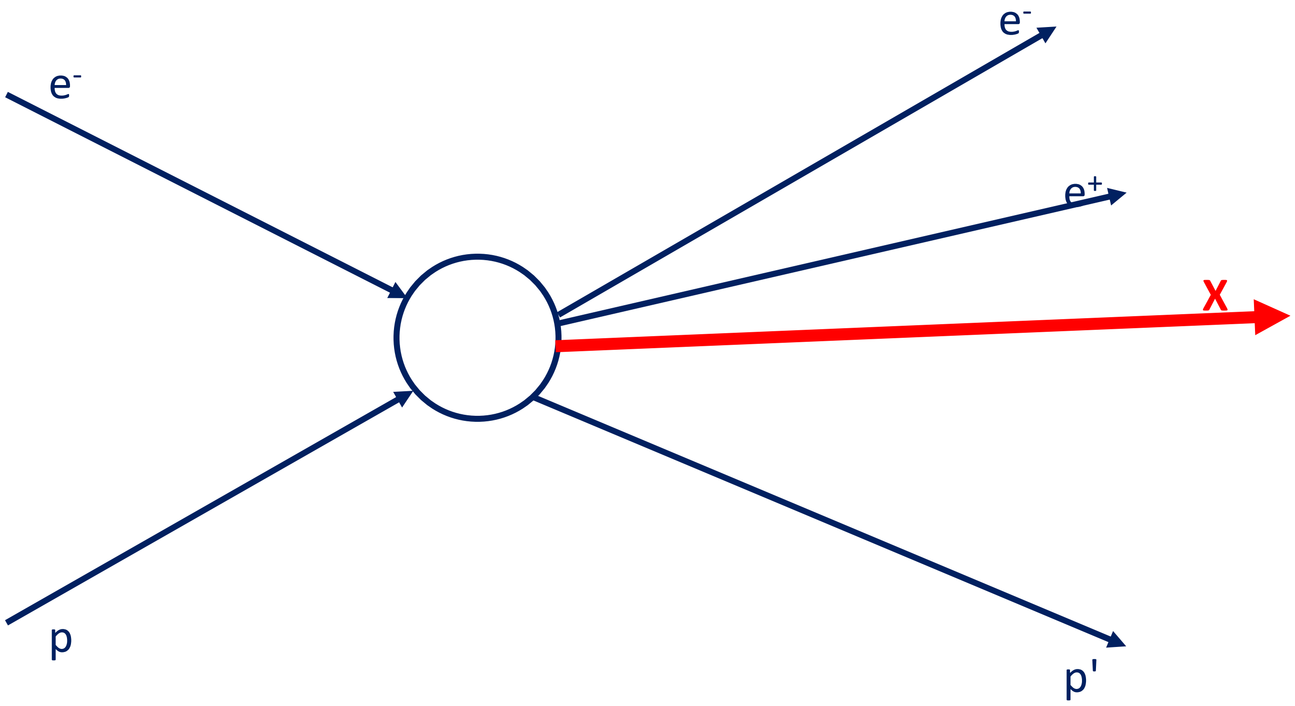
- Spring2019
  - Beam energy 10.6 GeV and 10.2 GeV
  - Torus polarity inbendng
- Fall 2019
  - Beam energy 10.4 GeV
  - Torus polarity *outbending*
- Winter 2020
  - Beam energy 10.4 GeV
  - Torus polarity inbending

The reaction of interest

The primary channel to measure J/ψ is e^-e^+p

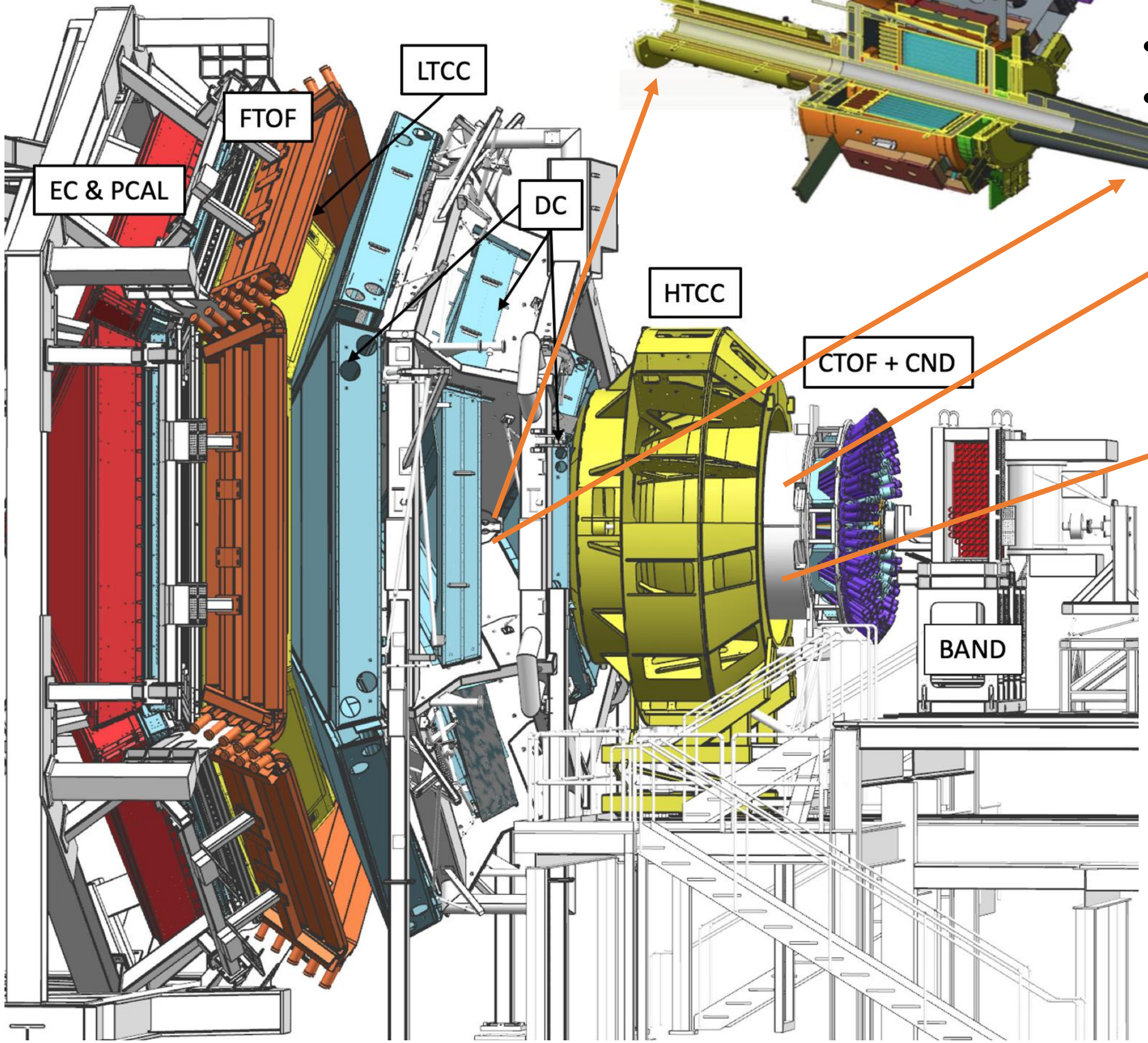
When the beam electron scatters ~0 angle, the exchanged photon is very soft Q^2~0. The production is also known as quasi-real photoproduction.

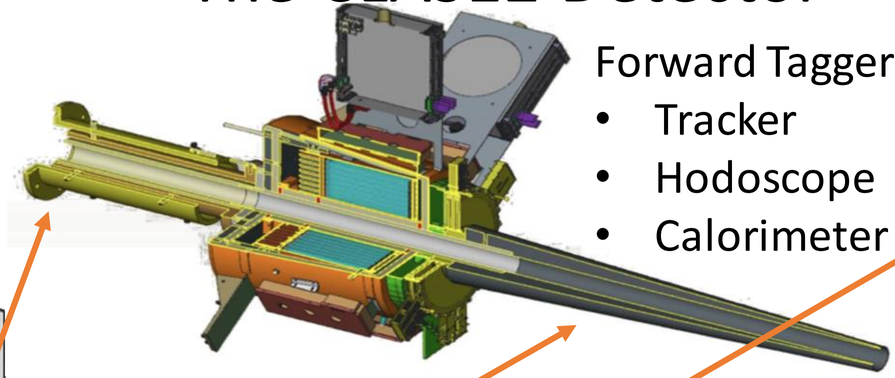
The scattered electron (and consequently the photon energy) is deduced from the missing 4 momentum analysis.



Events with $1e^-$ $1e^+$ and 1 proton are selected for the analysis

The CLAS12 Detector

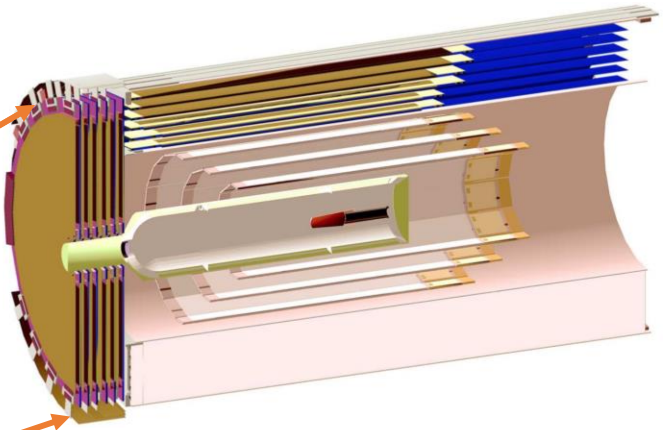




Forward Tagger

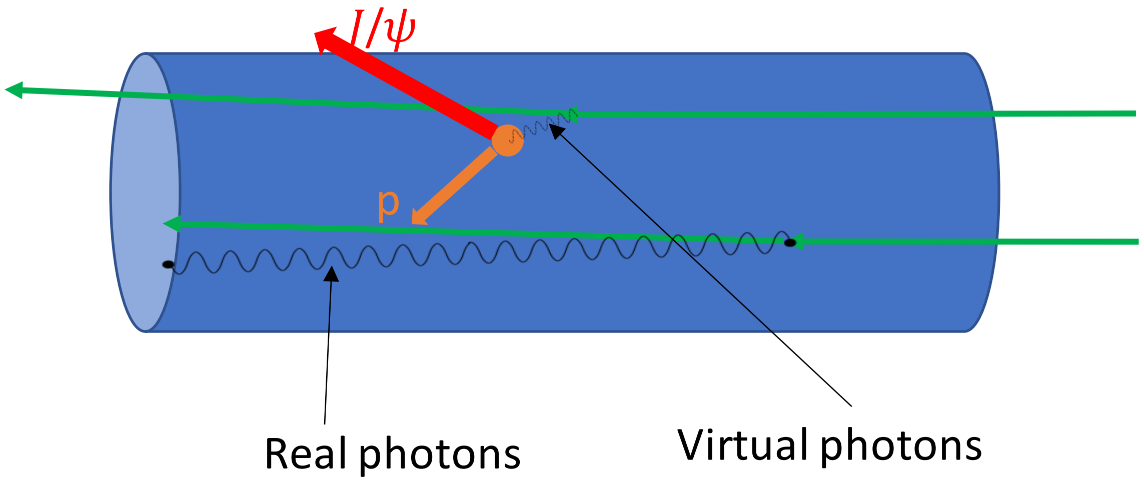
- Tracker
- Hodoscope
- Calorimeter

Central Vertex Tracker



Real and virtual photon sources:

Real photons are produced inside the target



Photoproduction with electron beam

Electroproduction cross-section can be expressed as:

$$\frac{d\sigma}{dt} = \Gamma_\gamma \cdot \frac{d\sigma_\gamma}{dt} + \Gamma_{\gamma*} \cdot (\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt})$$

Real photon flux   Virtual photon flux

At small Q^2, $\boldsymbol{\sigma}_L$ approaches to 0.

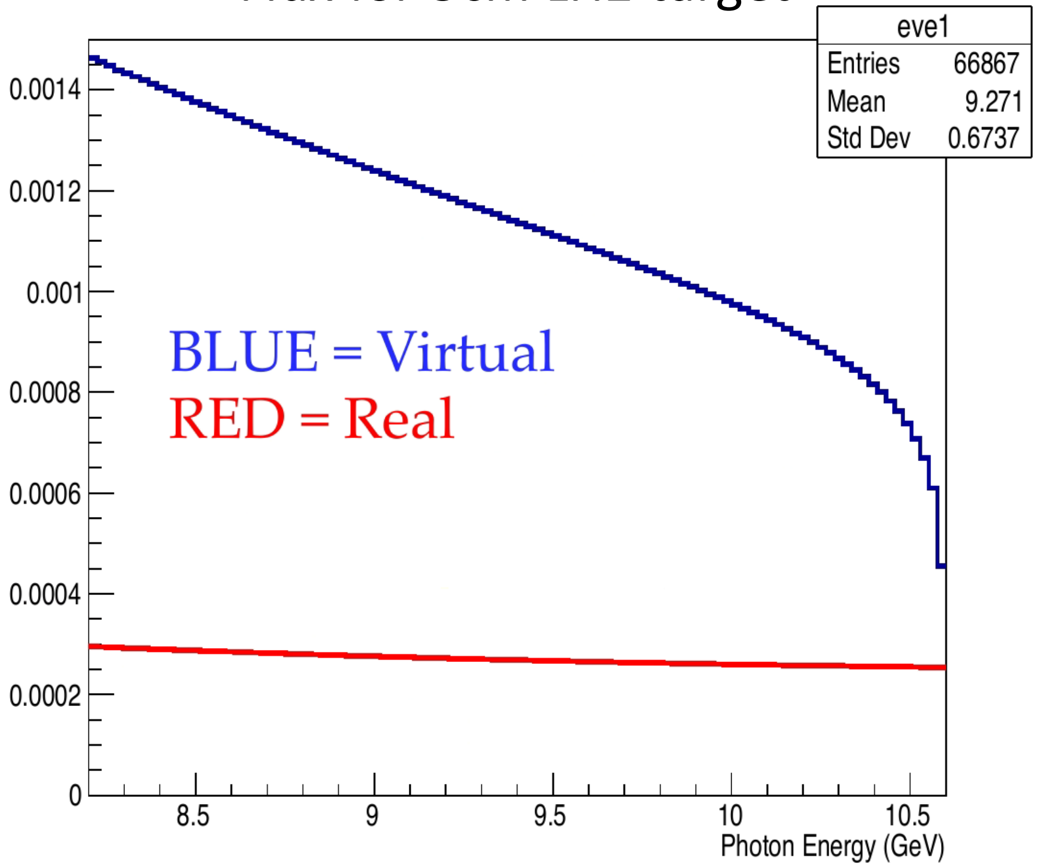
$$\frac{d\sigma}{dt} = (\Gamma_\gamma + \Gamma_{\gamma*}) \cdot \frac{d\sigma_\gamma}{dt}$$

$$n(E_\gamma) = \frac{l}{2 \cdot X_0} \frac{1}{E_\gamma} \cdot \left(\frac{4}{3} - \frac{4}{3} \frac{E_\gamma}{E_b} + \frac{E_\gamma^2}{E_b^2} \right) dE$$

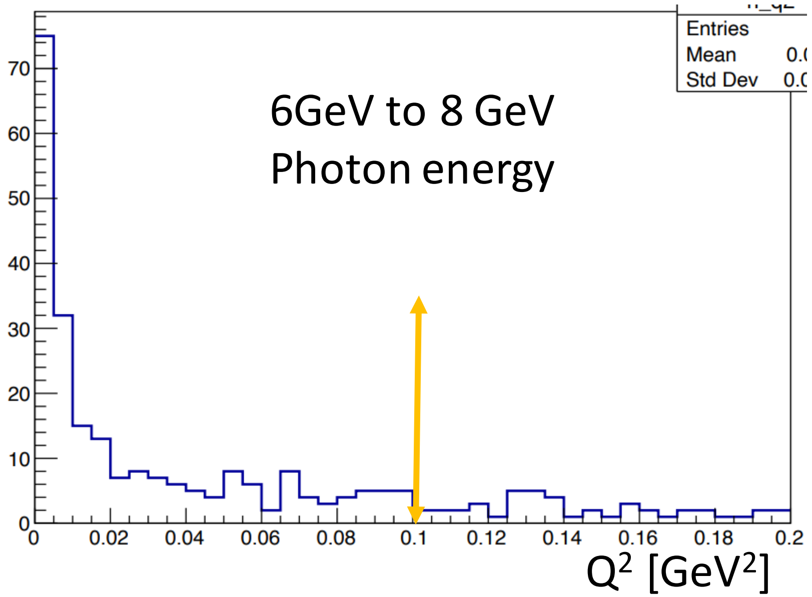
$$\Gamma(E_\gamma) = \frac{1}{E_b} \frac{\alpha}{\pi \cdot x} \cdot \left((1 - x + \frac{x^2}{2}) \cdot log(\frac{Q^2_{max}}{Q^2_{min}}) - (1 - x) \right) dE$$

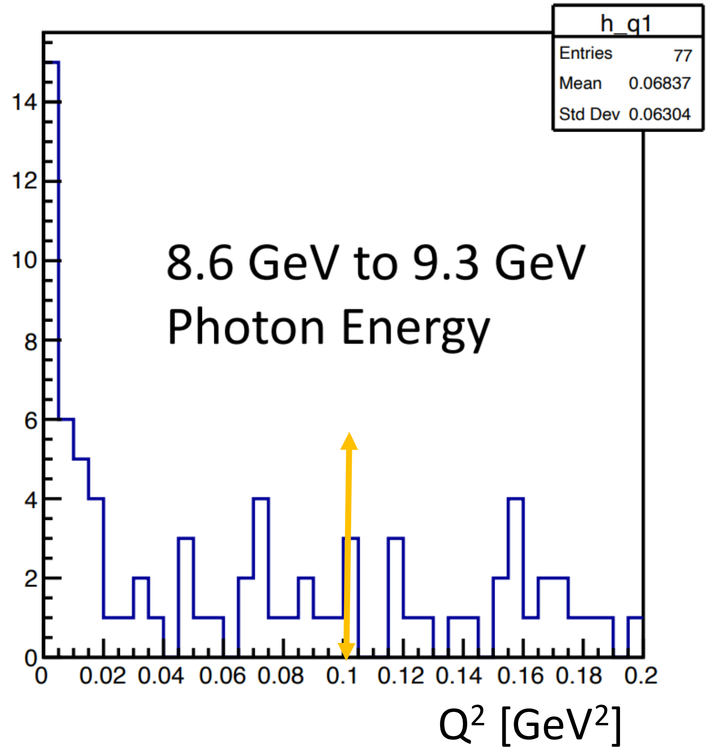
Where $x = \frac{E_\gamma}{E_b}$

Flux for 5cm LH2 target



Exclusivity cuts

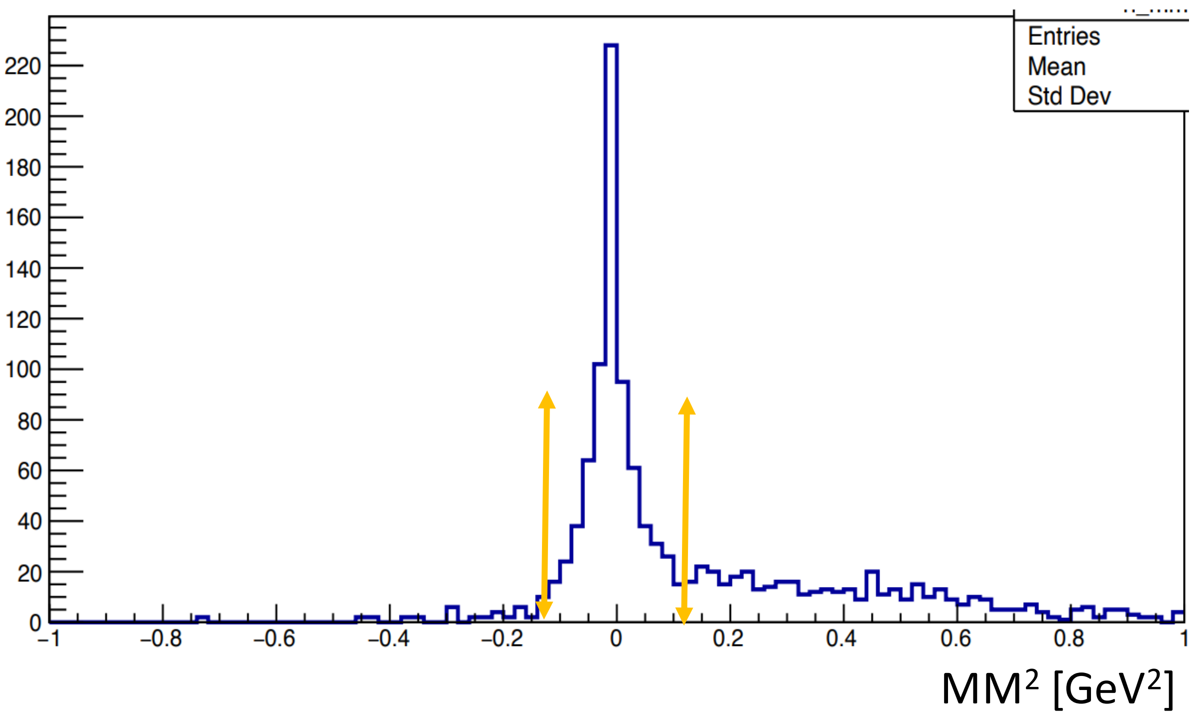




$$Q^2 = (e - e^{'})^2 = 2E_b P_{e^{'}}(1 - cos^2\theta)$$

$$MM^2 = (e + p - e^- - e^+ - p)^2$$

The reaction ep->e^-e^+p(e')

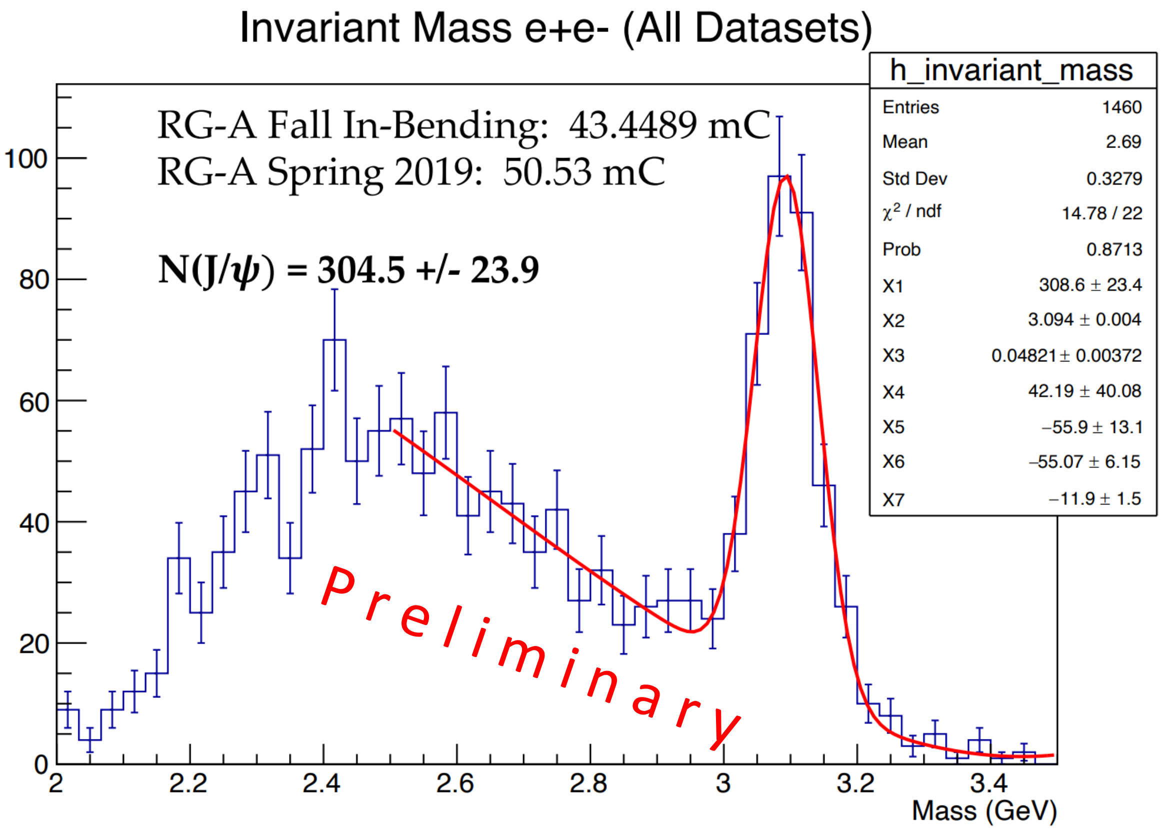


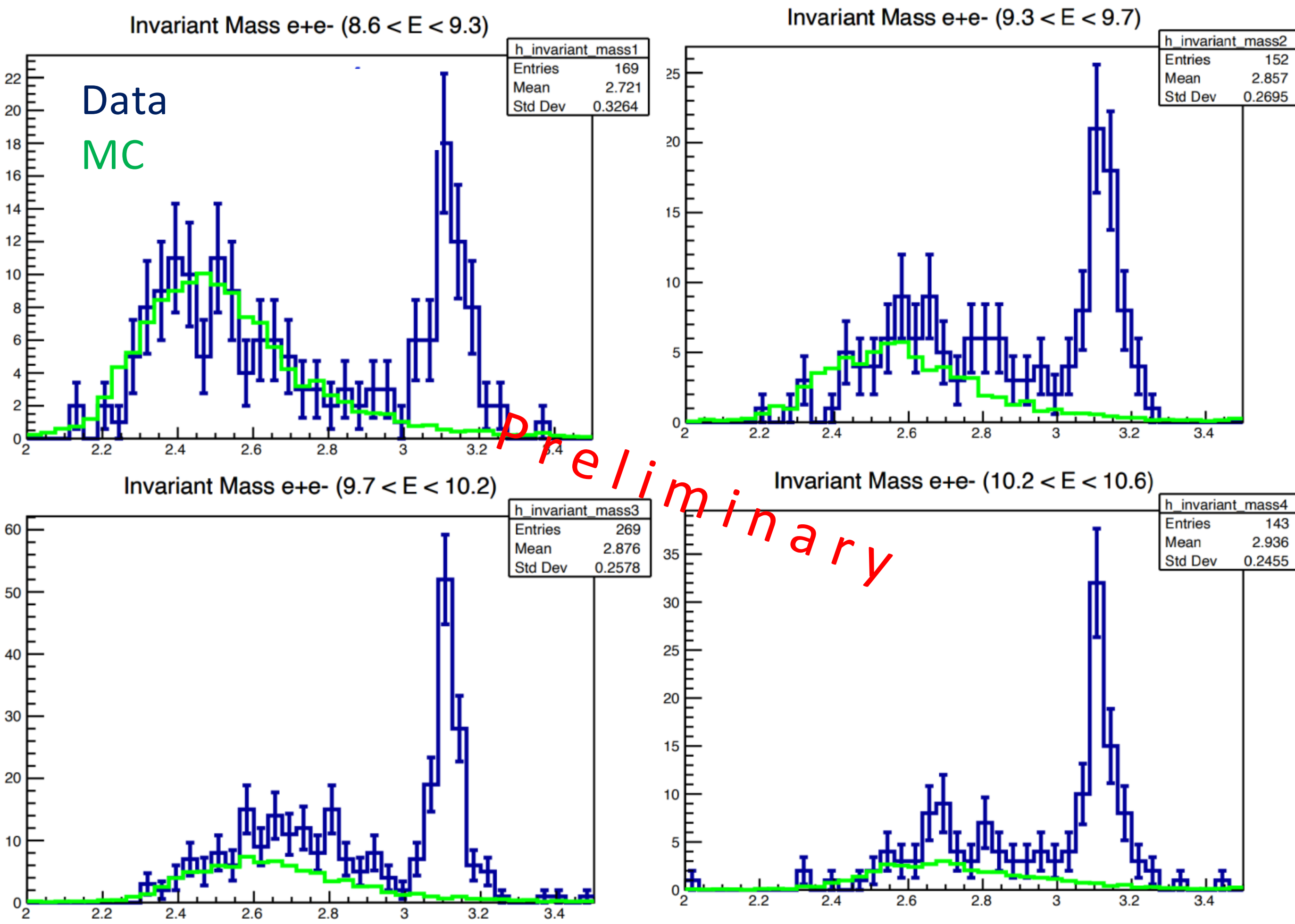
Quasi-real photoproduction events are identified as events with Q^2~0 AND MM^2 ~ 0

J/ψ RG-A data

- P(lepton) > 2 GeV
- $Q^2 < 0.2$ GeV^2
- $MM|^2 < 0.1$ GeV^2.

Analysis of J. Newton





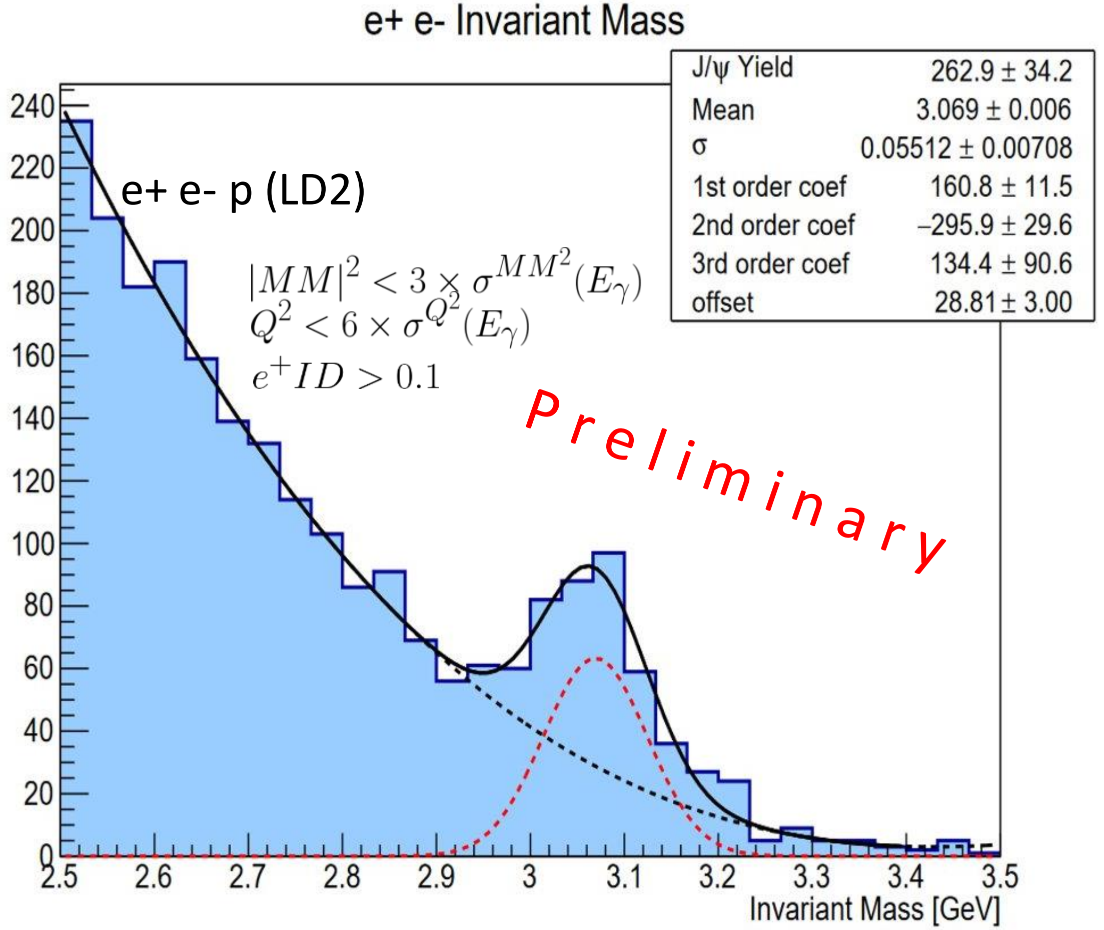
At high energy bins MC underestimates the Data.

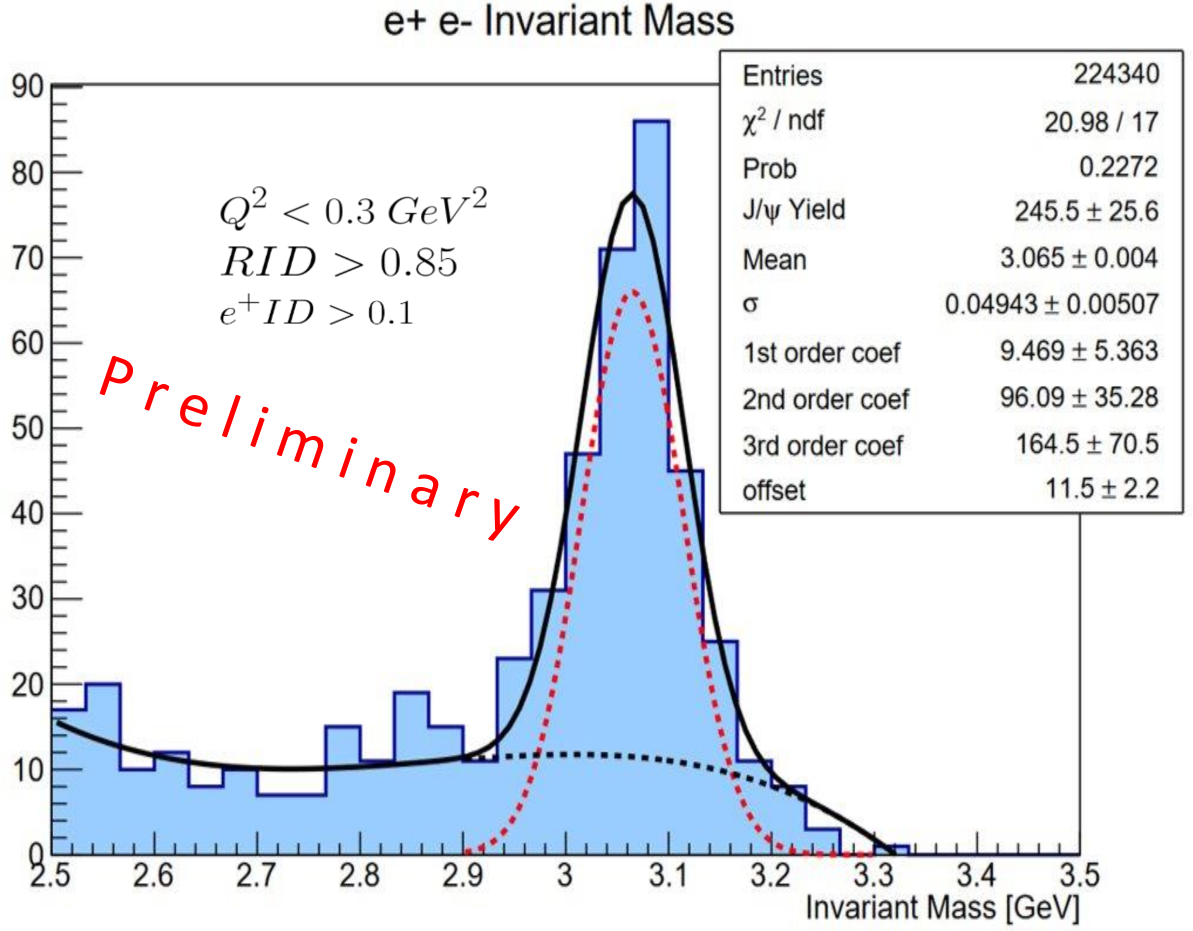
Under investigation.

J/ψ RG-B data

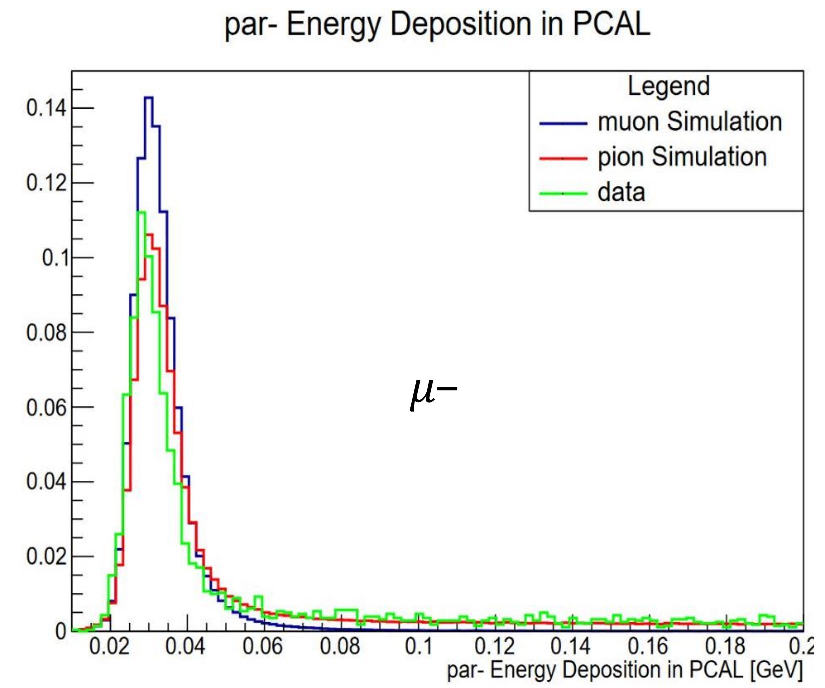
The target is LD2

Analysis of R. Tyson





Machine learning based event selection RID > 0.85

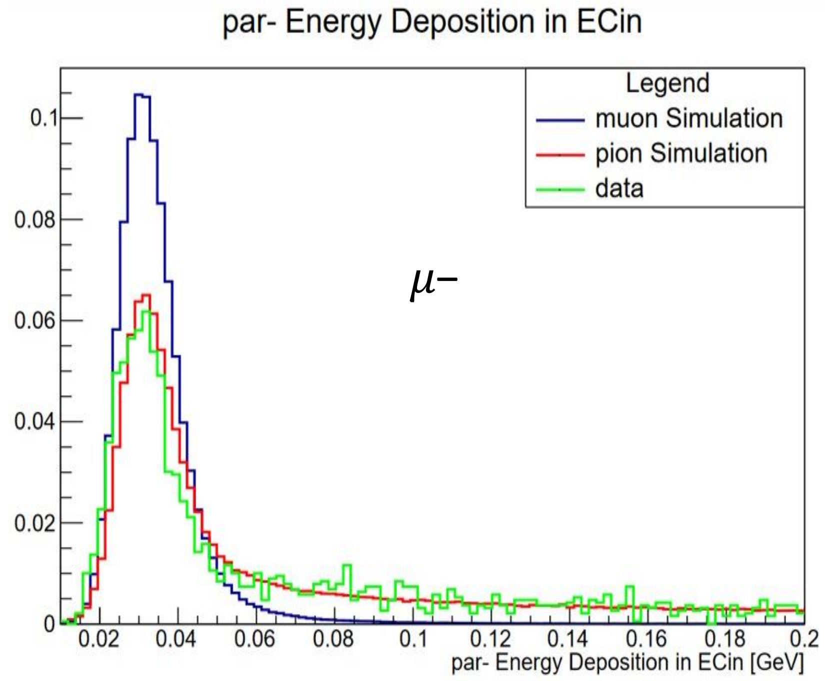


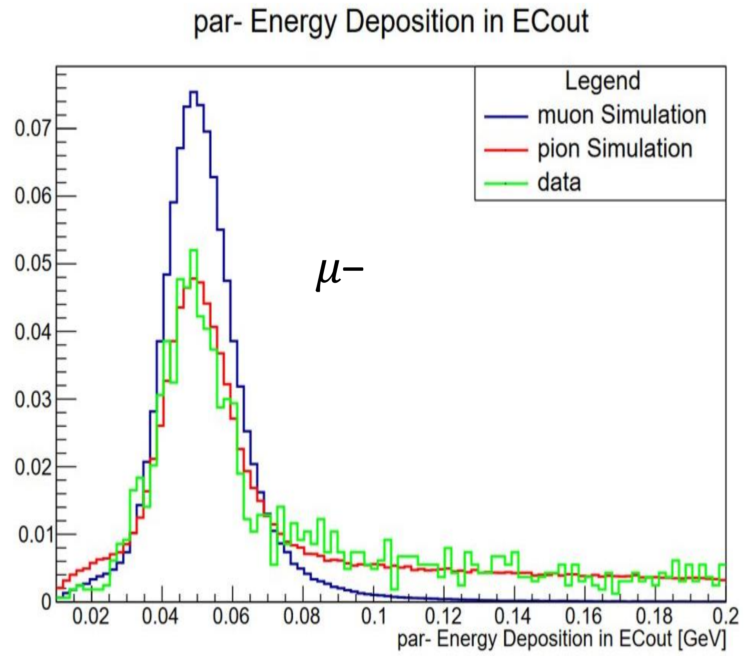
Muon selection

Analysis of R. Tyson

While in the PCal most of pions show MIP signature, at the ECOuter, already a significant number of pions will not pass the MIP selection cuts.

Similar distribution for positive muons





Muon energy deposition cuts

$$E_{PCal} < 60\ \mathrm{MeV}$$

$$E_{EC_{in}} < 80\ \mathrm{MeV}$$

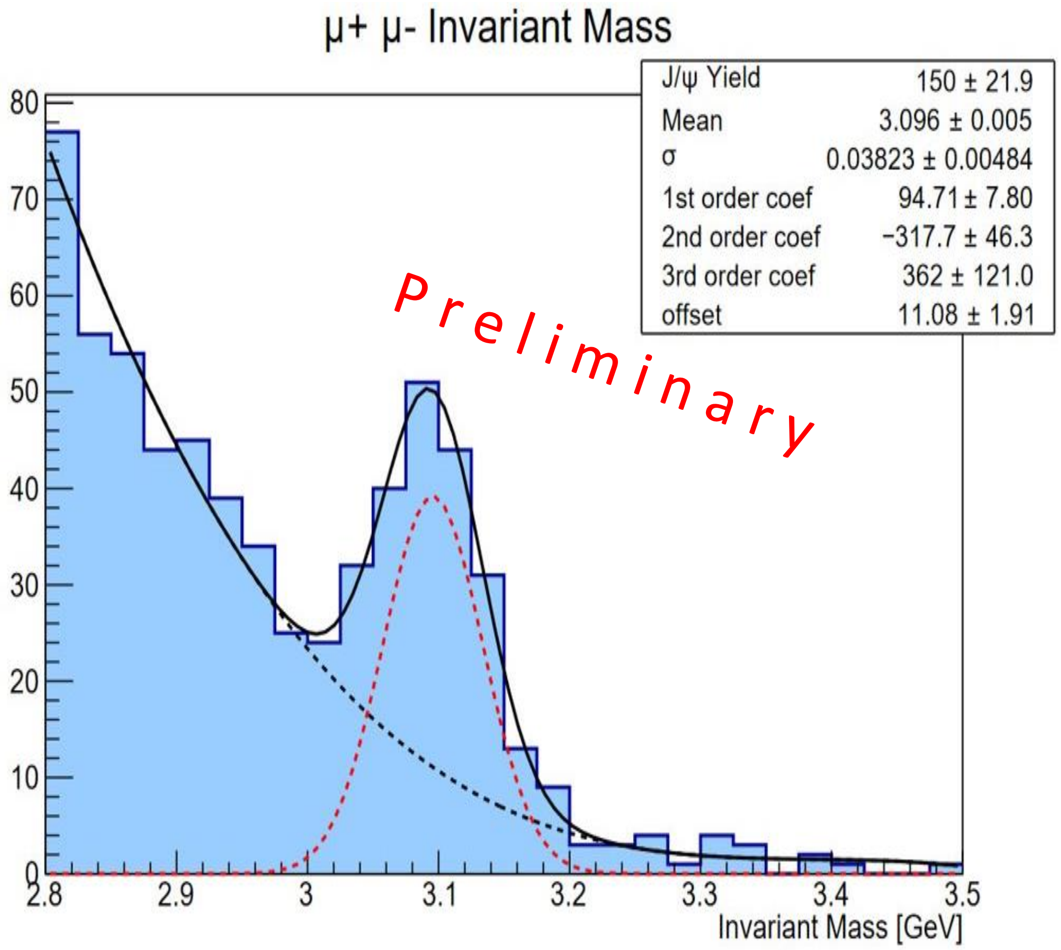
$$E_{EC_{out}} < 110\ \mathrm{MeV}$$

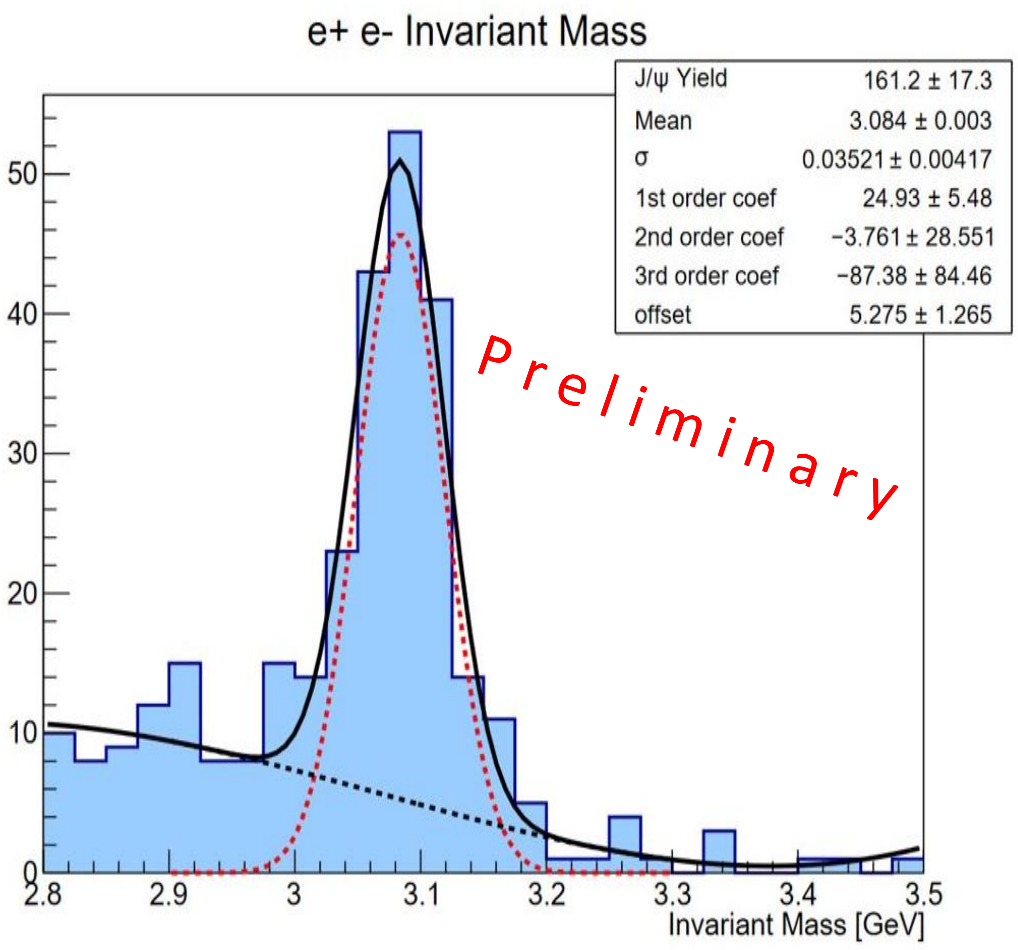
Comparing yields in e-e+ and μ-μ+ channels

Analysis of R. Tyson

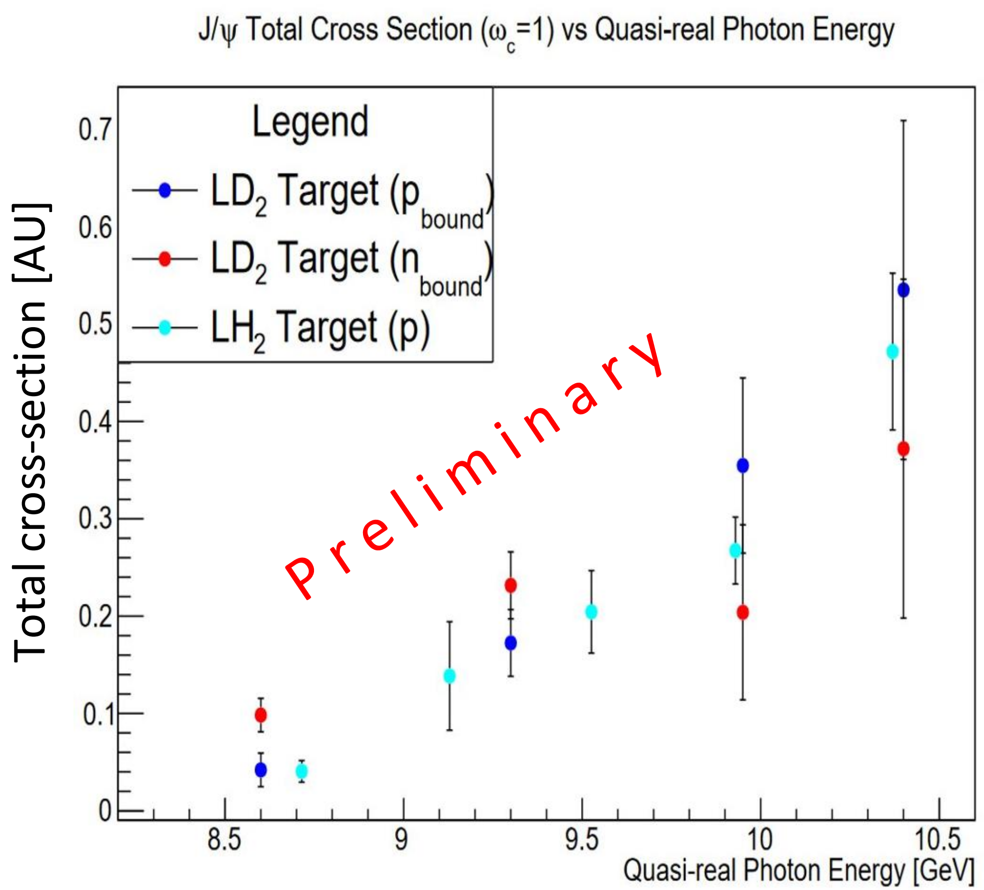
Preliminary analysis on the limited amount of data, shows almost the same amount of J/ψ in (e^-e^+) and ($\mu^-\mu^+$) channels

RG-A fall 2018 data set





Status and plans



Analysis chain is well developed. We need to understand why MC doesn't describe MC very well.

Alternative approach: instead of normalizing to BH cross-section, just take individual detector efficiencies into account.

CLAS12 is working on x2 Luminosity upgrade

Assuming the rest of RG-A and RG-B data will be taken at x2 Lumi. We expect about 5 times more data to collected.

AI implementation in the track reconstruction shows about 30% increase of statistics in e^-e^+p final state.

In total about >x6 increase of statistics is expected from already approved CLAS12 experiments.

A need for $L \geq 10^{37}\ cm^{-2}\ sec^{-1}$

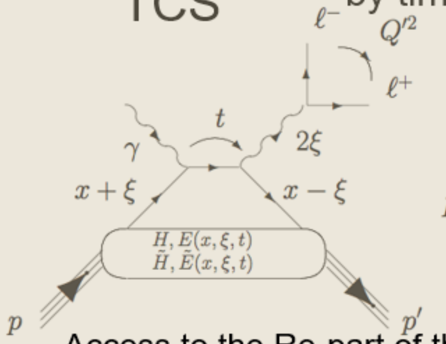
Slide borrowed from S. Stepanyan

CLAS12 Flagship program – accessing GPDs through measurements of beam/target asymmetries and the cross sections of Compton processes (TCS and DVCS)

First experimental measurement with CLAS12
PRL 127, 262501 (2021)

TCS

Hard scale is defined by time-like photons



$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^-(\xi,x) H(x,\xi,t)$$

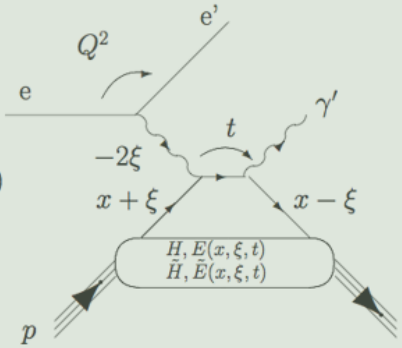
$$Im\ \mathcal{H}(\xi,t) = i\pi H(\xi,\xi,t)$$

Access to the Re-part of the Compton amplitude

Started in 2001, PRL 87, 182002.
Now is the flagship physics program

DVCS

Hard scale is defined by space-like photon

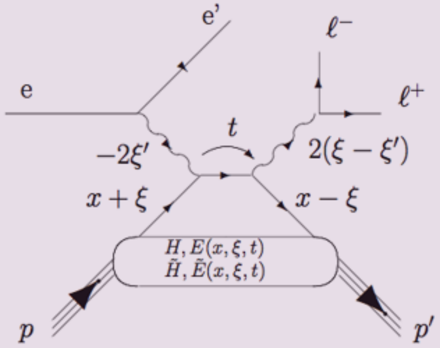


Jefferson Lab at the luminosity frontier is the only place in the world DDVCS can be measured!

μCLAS12 is one of two proposed facilities capable of carrying out such measurements.

DDVCS

Both space-like and time-like photons can set the hard scale



$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

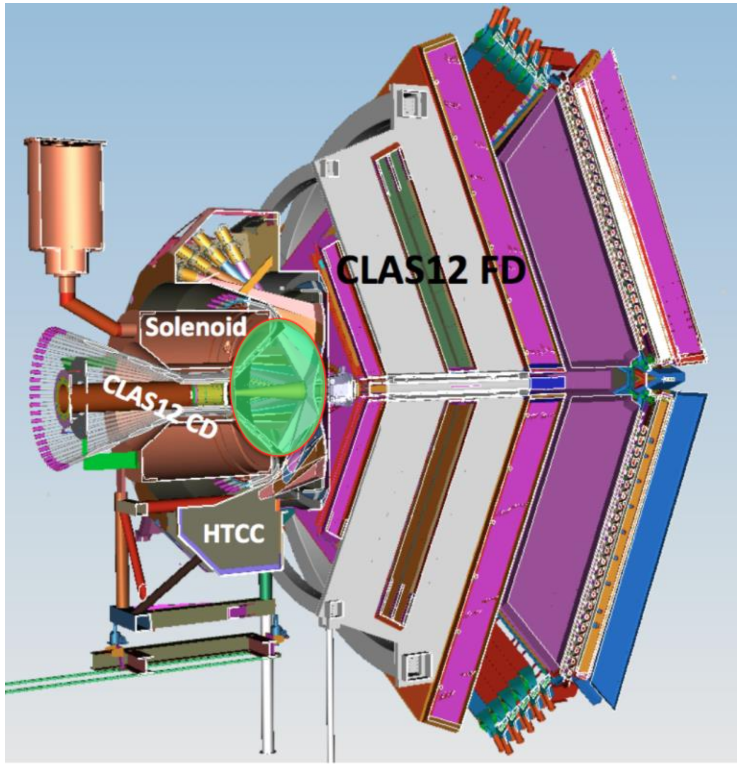
σ-DDVCS is three orders of magnitude smaller than σ-DVCS

Luminosity upgrade by x100

- Long-term project: increase the CLAS12 luminosity by 100 times.

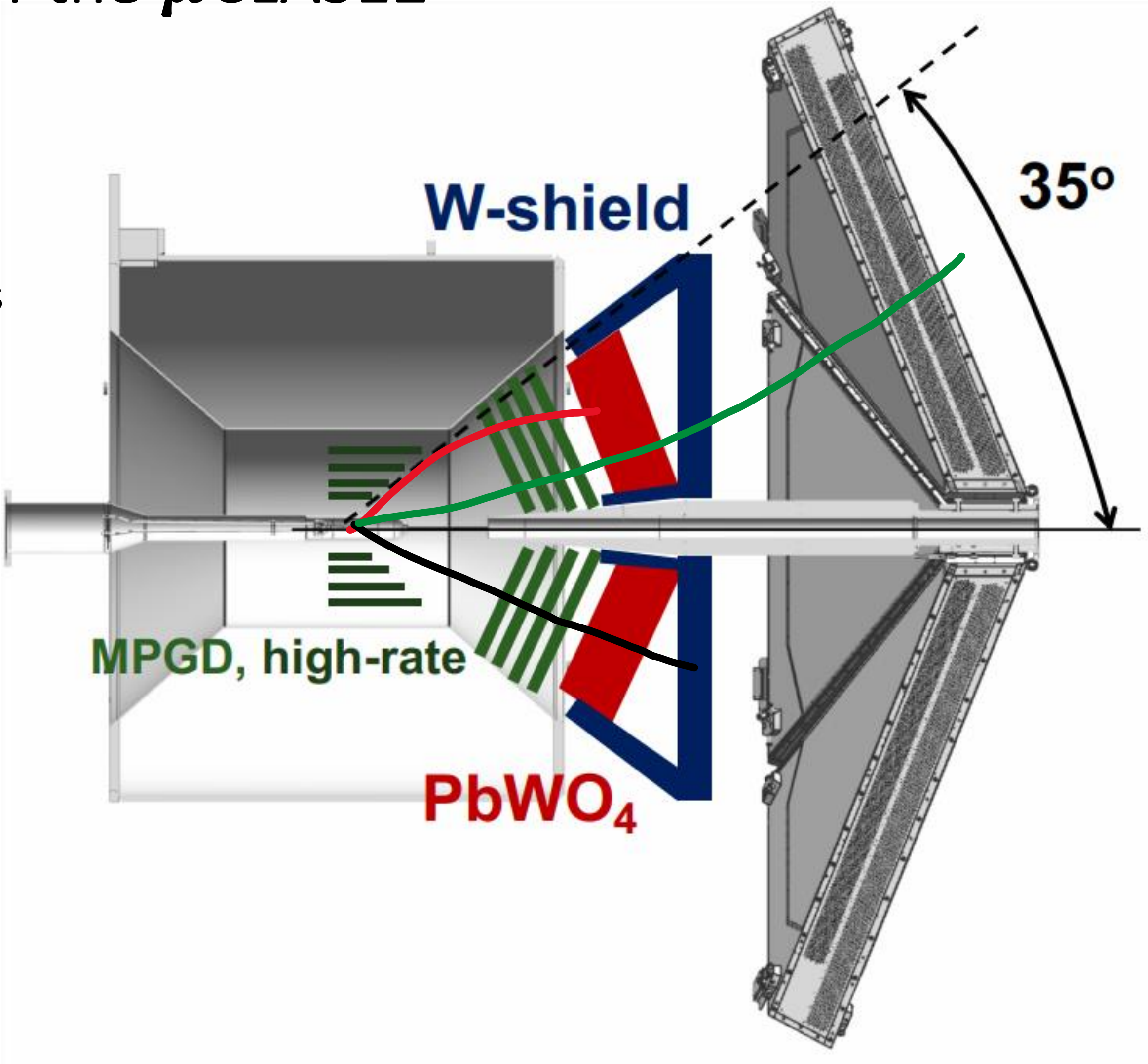
- Main motivation: Measure DDVCS, has **a very low x-sec**. Not reasonable to measure with standard CLAS12 detector configuration.
- The process ep->e'μ−μ+p allows to measure DDVCS, TCS, J/ψ photo and electroproduction.
- Requires Modification of the CLAS12 detector

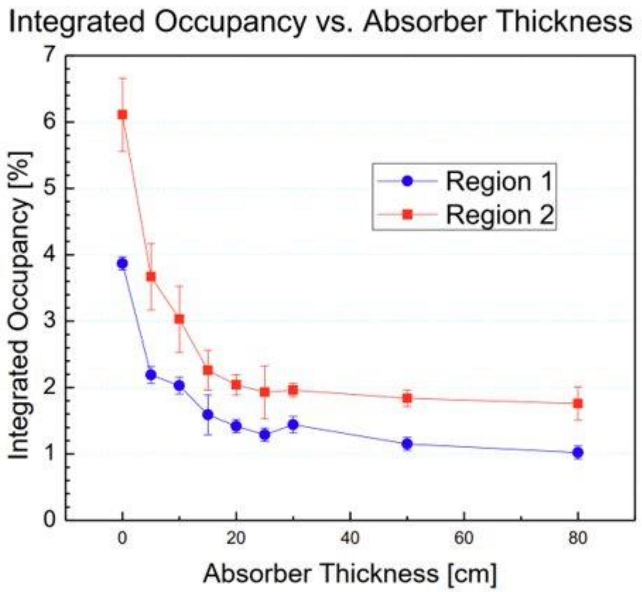
- Remove HTCC
- Install a Moeller cone (tungsten material) extending up to 7.5 deg polar angle
  - In order to reduce huge rate of Moeller electrons
- Add a new $PbWO_4$ calorimeter that covers 7° to 30° polar angular range with 2π azimuthal coverage
  - In order to recover electron detection
- Next to the $PbWO_4$ calorimeter add thick tungsten shield/absorber covering the full FD region
  - In order to absorb all electromagnetic and hadronic background originating from the target.
- Install a new GEM based detector in front of the calorimeter
  - In order to be able to reconstruct vertex parameters (angles and positions)



Conceptual design of the μCLAS12

- The Electromagnetic calorimeter Plus the tungsten shield will absorb all the electromagnetic and hadronic particles from the, allowing only muons to pass through.
- The length of the tungsten shield is chosen by GEMC simulations requiring a low (2%-3%) occupancy in Drift Chambers
- Trigger rate:
    - Requiring 5 hits FDC AND MIP signature in calorimeter have 75/95 KHz for positive/negative single tracks:
    - Using a 50 ns coincidence time this translates into about 360 Hz





This concept was first described in the LOI12-16-004.

J/ψ and ψ' rates

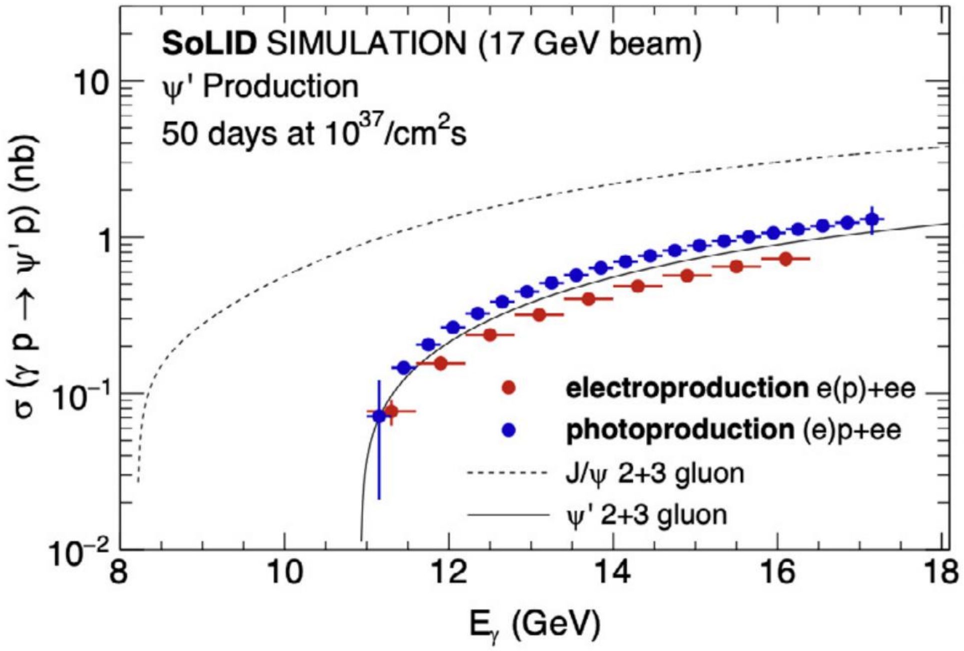
With 10^{37} cm^{-2}s^{-1} at μCLAS12

Avg x-sec: 0.65 nb

The flux from threshold up to 22 GeV is 103.74 nb^{-1}.

BR(ψ'->$\mu-\mu+$)= 0.8%

With 10^{37} cm^{-2}s^{-1}, and 4% acceptance the expected rate of detected ψ' is about 77/hour.



J/ψ production rate is estimated using the currently detected 300 J/ψs from RG-A analysis.

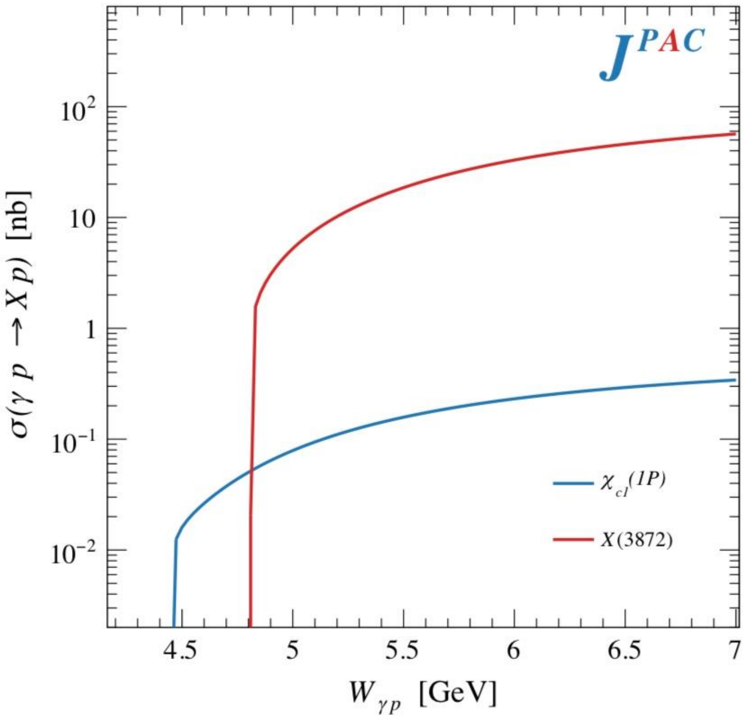
Accounting for tracking improvements (AI), increase of the flux, and scaling for 100 days @10^{37}cm^{-2}s^{-1} we expect about 234K/1.17M detected J/ψs in 100 days of running (2.34K/day)/(11.7K/day) for 10.6 GeV/22 GeV electron beams

XYZ spectroscopy: $\chi_{c1}(3872)$

Slide from S. Stepanyan

In addition of measuring J/ψ cross-section in a wide kinematic range new interesting physics opportunities arise too.

- Several states in charmonium region have been discovered that do not fit into a simple $q\bar{q}$ model.
- JLAB energy upgrade (20+ GeV) will open a phase space for photoproduction of some of these states.
- Lowest mass state and the best-known exotic is $\chi_{c1}(3872)$, also known as X(3872), first discovered by Belle in 2003. The quantum numbers have been determined by LHCb, $J^{PC} = 1^{++}$(Phys. Rev. Lett. 110, 222001 (2013), arXiv:1302.6269)
- Photoproduction cross section for $\chi_{c1}(3872)$ has been estimated by [JPAC] M. Albaladejo et al., arXiv:2008.01001, doi:10.1103/PhysRevD.102.114010
- Energy and the t dependence should be studied, which provide important insight to the production mechanism



$\chi_{c1}(3872)$ decay modes:

- $\chi_{c1} \to \omega J/\psi$ B.R. ≈ 4.3%
  - $\omega \to \gamma\pi^0$ BR=8.28%
  - $J/\psi \to \mu^+\mu^-$ BR=6%
    - $\chi c1 \to \gamma\gamma\gamma\mu^+\mu^-$ > 2*10^-4^

- $\chi_{c1} \to \gamma\, \psi(2S)$ > 4%
  - $\psi(2S) \to \mu^+\mu^-$ BR=0.8%
    - $\chi_{c1} \to \gamma\mu^+\mu^- \geq 2.3*10^{-4}$

μCLAS12 at 10^{37} cm^{-2} sec^{-1}

Photon luminosity in the energy range: 13 GeV to 22 GeV is 100 nb^{-1}, even with modest efficiency of 2% one expects about **50 detected χ_{c1}(3872) per hour** in each decay mode

Summary

- J/ψ analysis from CLAS12 data is in advanced stage
- Data on hands that will be re-analyzed: pass2 and possible increase of statistics.
- Tagged J/ψ analysis is ongoing

- There will be several upgrades of CLAS12
  - x2 Luminosity upgrade
  - x100 Luminosity upgrade
    - Requires modification of standard CLAS12 configuration: μCLAS12
    - Offers reach physics (DDVCS/TCS, high stat J/ψ photo and electro production)
  - The same modified μCLAS12 will work equally well with 20 GeV+ beam energies
    - In addition of measuring DDVCS/TCS and J/ψ, interesting new physics opportunities will arise (χ_{c1}(3872), ψ')