Timelike Compton Scattering with CLAS12

Positron identification
R ratio and Forward Backward asymmetry
-
CLAS Collaboration meeting - 29th April 2020

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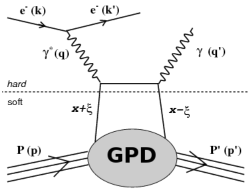
Outline

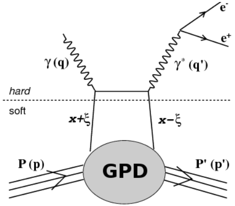
- Physics motivations
- TCS event selection
- Positron identification
- Ratio R and Forward/Backward asymmetry extraction
- CD proton efficiency correction (in progress)

From DeeplyVirtualComptonScattering to TimelikeComptonScattering

DVCS ($\gamma^* p \to \gamma p$)



TCS ($\gamma p \to \gamma^* p$)



Compton Form Factors (CFF)

$$\mathcal{H} = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx H^q(x,\xi,t) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \right\}$$

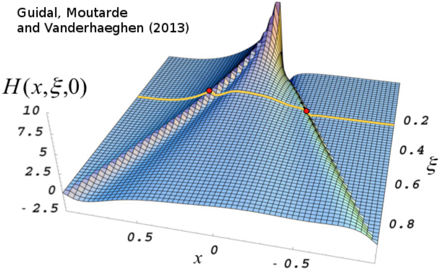
Imaginary part

- Measured in DVCS asymmetries
- TCS γ polarization asymmetry

Real part

- Accessible in DVCS cross section
- Charge asymmetry (E. Voutier talk)
- TCS cross section angular modulation (R and F/B asymmetry)

Guidal, Moutarde and Vanderhaeghen (2013)



Physics motivations

1 **Nucleon D-term**

- The CFFs dispersion relation at leading-order and leading twist :

$$Re\mathcal{H}(\xi,t) = \mathcal{P}\int_{-1}^{1} dx \left(\frac{1}{\xi - x} - \frac{1}{\xi + x}\right) Im\mathcal{H}(\xi,t) + D(t)$$

- D-term expansion

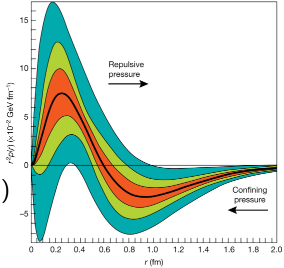
$$D(t) = \frac{1}{2}\int_{-1}^{1} dz \frac{D(z,t)}{1-z}$$

$$D(z,t) = (1-z^2)[d_1(t)C_1^{3/2}(z) + ...]$$

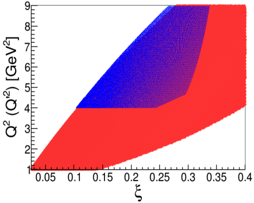
- $d_1(t)$ is directly related to the pressure distribution in the nucleon.

2 **Test of universality of GPDs**

- Photon polarization asymmetry sensitive to $Im\mathcal{H}$



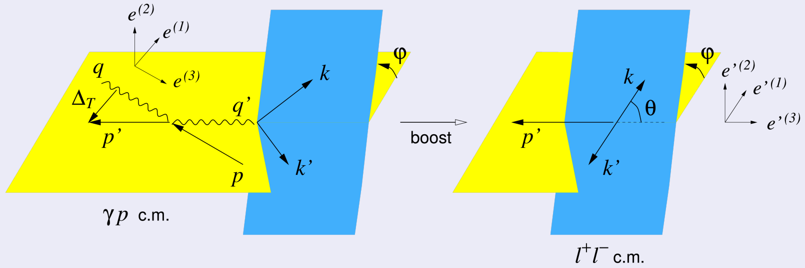
Nature (2018) Burkert, Elouadrhiri, Girod



DVCS phase space
TCS phase space

Boër, Guidal, Vanderhaeghen (2015)

$\gamma p \to e^+ e^- p$ kinematics



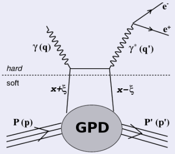
$$Q'^2 = (k + k')^2 \qquad t = (p' - p)^2$$

$$L = \frac{(Q'^2 - t)^2 - b^2}{4} \qquad L_0 = \frac{Q'^4 sin^2\theta}{4} \qquad b = 2(k - k')(p - p')$$

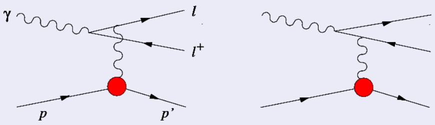
$$\tau = \frac{Q'^2}{2p \cdot q} \qquad s = (p + q)^2 \qquad t_0 = -\frac{4\xi^2 M^2}{(1 - \xi^2)}$$

TCS and Bethe-Heitler

$\gamma p \to e^+ e^- p$

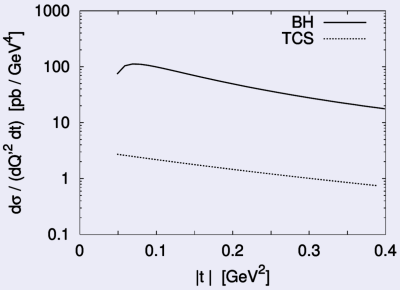


Timelike Compton Scattering



Bethe-Heitler

TCS cross section



$$\frac{d^4\sigma}{dQ'^2 dt d\Omega} = \sigma_{TCS} + \sigma_{BH} + \sigma_{INT}$$

TCS cross section not accessible directly

Use interference term to access GPDs

Berger, Diehl and Pire (2002)

Event selection

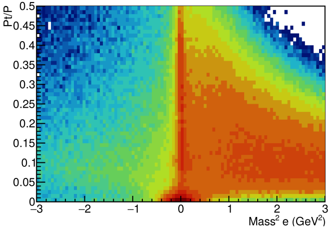
$$ep \rightarrow e'\gamma p \rightarrow (e')e^+e^-p'$$

Final state

- Use the CLAS12 reconstruction software PID
- Additional positron pid (next 3 slides)
- Events with exactly one e^+,one e^- and one proton are selected

Scattered electron

- Cut on scattered electron missing mass
- Cut on missing transverse momentum
- These cuts constrain the virtuality of the photon $Q^2 \propto 1 - cos(\Theta_{scattered})$



Exclusivity cuts

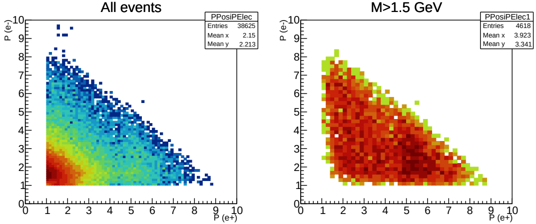
$$\frac{Pt}{P} < 0.05$$

$$Mass^2 < 0.4\ GeV^2$$

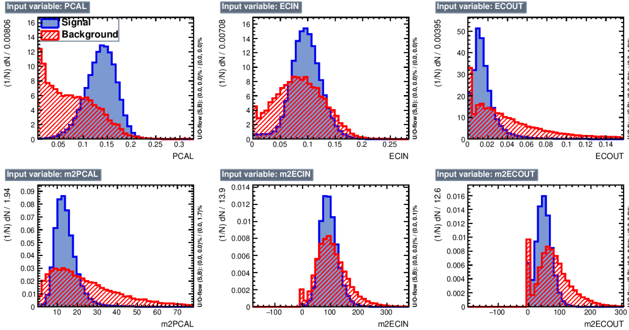
$$P_{lepton} > 1\ GeV$$

Lepton identification

Clear π^+ contamination above HTCC threshold



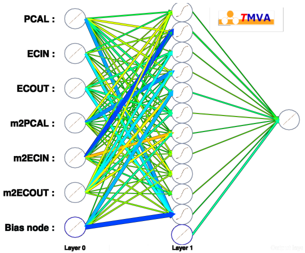
Training of Multivariate Analysis methods on simulation

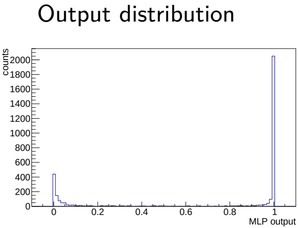


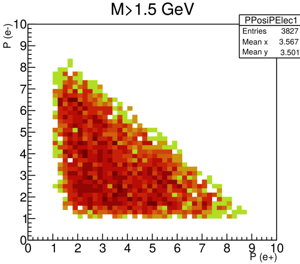
- Use e^+ and π^+ simulation samples
- Train MVAs on reconstructed e^+
- Use SFs and second shower moment (averaged over U,V,W)
- Apply on data

Positrons identification

Applying neural network pid

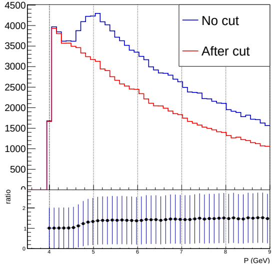


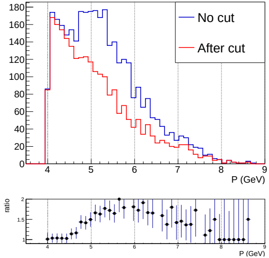


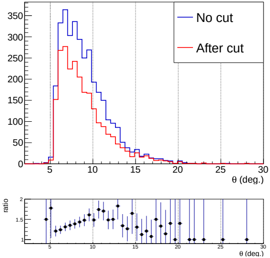


Simulation

Data





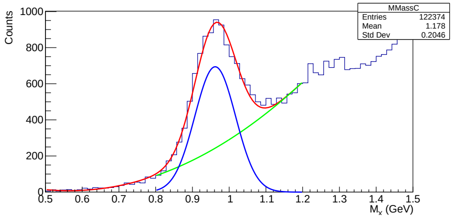


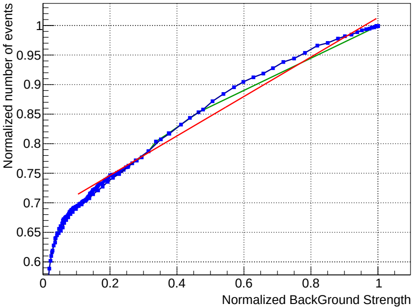
Estimation of the absolute contamination of π^+ in the TCS sample

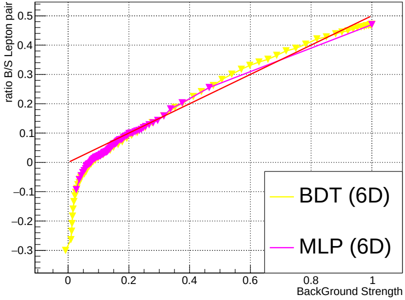
- Use pure uncorrelated background sample :

$$ep \rightarrow ee^+_{m_\pi}(n)$$

- Compare effect of cut on the NN output on both samples



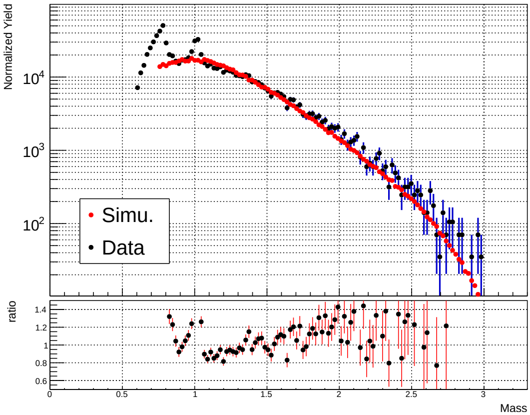




→ This method reduces B/S from 0.5 to 0.05

Lepton pair mass spectrum

Complete RG-A inbending data set used in the following



Data/BH simulation comparison in the high mass region 4 $GeV < E_\gamma < 10$ GeV

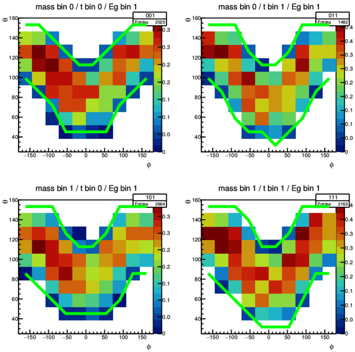
0.15 $GeV < -t < 0.8$ GeV

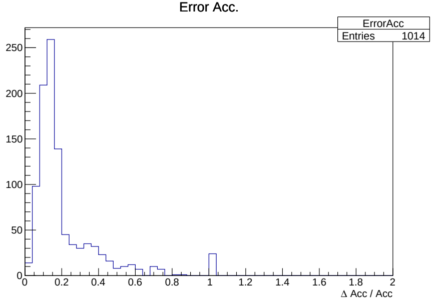
No large vector meson background

Acceptance and fiducial cuts

$$Acc_{\Omega=(E_\gamma, Q'^2, -t, \phi, \theta)} = \frac{N_{REC\ \Omega}}{N_{GEN\ \Omega}}$$

4 bins in $-t$ and Q'^2, 3 bins in E_γ, 10x10 bins in the ϕ/θ plane. Bins with $\frac{\Delta Acc}{Acc} > 0.5$ and $Acc < 0.05$ are discarded (ΔAcc is statistical error).





3M events simulation set

$4\ GeV < E_\gamma < 10\ GeV \quad 1.5\ GeV < m_{e^+e^-} < 3\ GeV \quad 0.15\ GeV^2 < -t < 0.8\ GeV^2$

Fiducial cuts on PCAL included

$\gamma p \to e^+e^-p$ cross section and R ratio

Interference cross section

$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\left[\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)} \mathrm{Re}\,\tilde{M}^{--} + \ldots\right]$$

$$\to \tilde{M}^{--} = \frac{2\sqrt{t_0-t}}{M}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right]$$

BH cross section

$$\frac{d^4\sigma_{BH}}{dQ'^2 dt d\Omega} \approx -\frac{\alpha_{em}^3}{2\pi s^2}\frac{1}{-t}\frac{1+\cos^2(\theta)}{\sin^2(\theta)}\left[\left(F_1^2 - \frac{t}{4M^2}F_2^2\right)\frac{2}{\tau^2}\frac{\Delta_T^2}{-t} + (F_1+F_2)^2\right]$$

BH cross section diverges at $\theta \approx 0^\circ$ and 180°

Weighted cross section ratio

$$R(\sqrt{s}, Q'^2, t) = \frac{\int_0^{2\pi} d\phi\, \cos(\phi)\, \frac{dS}{dQ'^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2 dt d\phi}} \qquad \frac{dS}{dQ'^2 dt d\phi} = \int_{\pi/4}^{3\pi/4} d\theta \frac{L}{L_0}\frac{d\sigma}{dQ'^2 dt d\phi d\theta}$$

R' ratio measurement

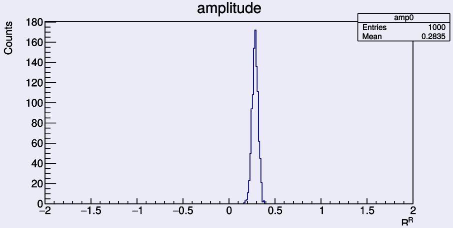
Weighted cross section ratio

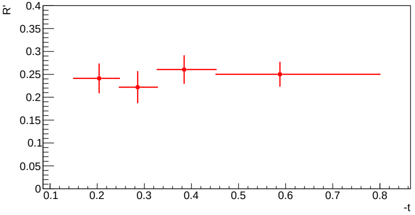
$$R = \frac{\sum_{\phi} Y_{\phi} \cdot cos(\phi)}{\sum_{\phi} Y_{\phi}},$$

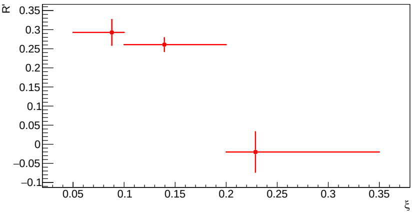
$$Y_{\phi} = \sum_{\theta \in [\frac{\pi}{4}, \frac{3\pi}{4}]} \frac{L}{L_0} \frac{1}{Acc},$$

$$\delta Y_{\phi} = \sum_{\theta \in [\frac{\pi}{4}, \frac{3\pi}{4}]} \left(\frac{L}{L_0} \frac{1}{Acc} \right)^2.$$

Statistical error calculation with MC method (R calculated 1000 times with Y_{ϕ} within error bars)

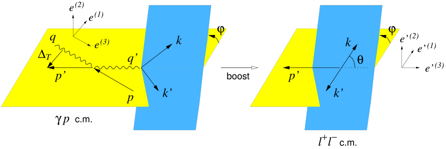






Large dependence on the integration domain. Need a careful check of this dependence using Monte Carlo. Or total BH cs extraction could help in interpreting this observable

Forward Backward asymmetry



Unpol. cross section

$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} \propto -\frac{L_0}{L}\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)} Re\ \tilde{M}^{--}$$

Forward-Backward Asymmetry

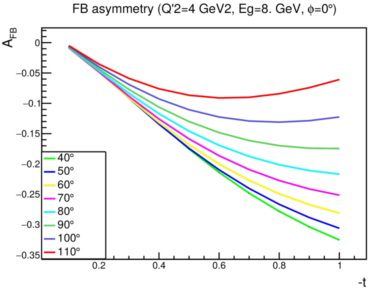
Concept explored for J/Ψ production [Gryniuk and Vanderhaeghen(2016)].
No prediction for TCS published yet.

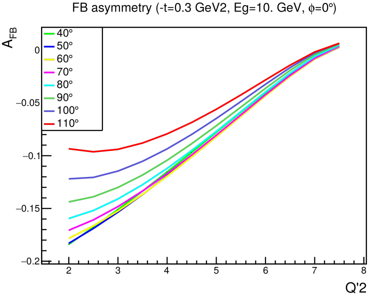
$$A_{FB}(\theta_0,\phi_0) = \frac{d\sigma(\theta_0,\phi_0) - d\sigma(180^\circ-\theta_0, 180^\circ+\phi_0)}{d\sigma(\theta_0,\phi_0) + d\sigma(180^\circ-\theta_0, 180^\circ+\phi_0)} \propto Re\tilde{M}^{--}$$

→ Access to real part of the CFFs with no integration over angles (removes large dependencies on angular acceptance)

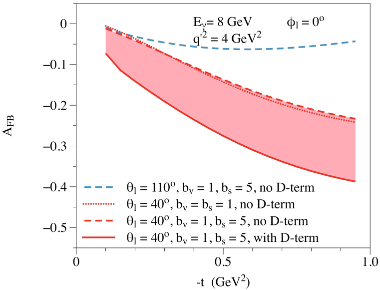
A_{FB} projections

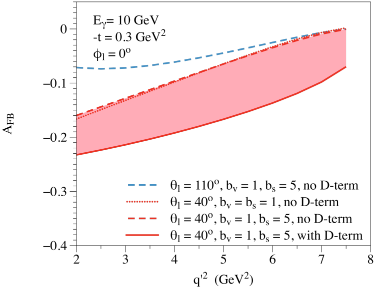
Projections from VGG ($b_{val} = b_{sea} = 1$, no D-term)





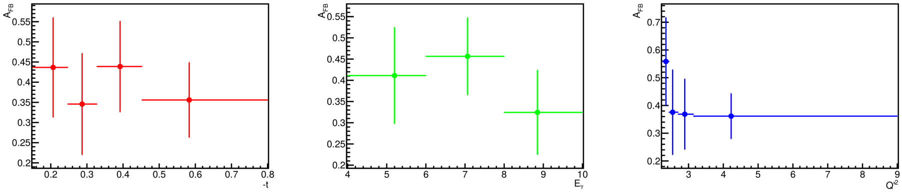
Projections from VGG (Cross check by M.Vanderhaegen)

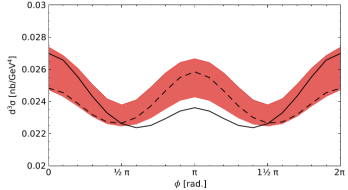




A_{FB} measurement

- Forward direction: Integration over $\phi \in [-50^\circ, 50^\circ]$ and $\theta \in [50^\circ, 70^\circ]$
- Backward direction: Integration over $\phi < -130^\circ$ *or* $\phi > 130^\circ$ and $\theta \in [110^\circ, 130^\circ]$
- Each event is weighted by $\frac{1}{Acc}$ / Error bars given by propagating $\delta\sigma \propto \sqrt{\sum(1/Acc)^2}$





NLO/LO (solid/dashed line) TCS+BH cs (GK model)
doi.org/10.1140/epjc/s10052-020-7700-9

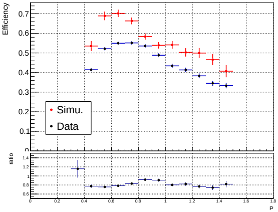
- A_{FB} is positive
- Three possible explanations:

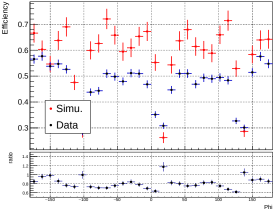
1. Error in angle definition or other bug in the analysis (cross check in progress but seems consistent)
2. Error in CFF definitions in the projections (sign problems)
3. NLO corrections. VGG projections are done at twist-2. NLO corrections could change the sign of $Re\tilde{M}^{--}$

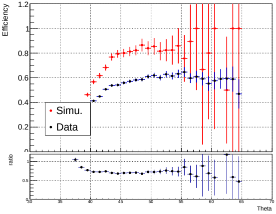
CD proton efficiency correction (in progress) (1)

Use $e(p')\pi^+\pi^-$ reaction, where the missing proton goes in the CD. All the analysis is done using kinematic variables of the missing proton.

Data set: $e\pi^+\pi^-(X)$, cut on the ρ mass in the $m_{\pi^+\pi^-}$ spectrum
Simulation set: Events generated with genev, $ep\rho$







$$Eff_{DATA} = \frac{N_{REC}}{N_{Missing}} \qquad Eff_{SIMU} = \frac{N_{REC}}{N_{Missing}} \qquad Eff_{Corr} = \frac{Eff_{DATA}}{Eff_{SIMU}}$$

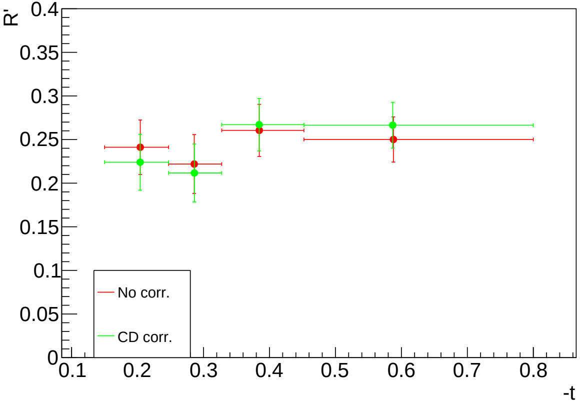
4 bins in momentum, 2 bins in θ, 30 in ϕ

CD proton efficiency correction (in progress) (2)

Change in the acceptance calculation

Events with a proton in the CD are weighted by the efficiency correction, the weight for event in the FD is 1

$$Acc = \frac{\sum Eff_{Corr}}{N_{Gen}}$$



$\approx$ 10% correction

Summary

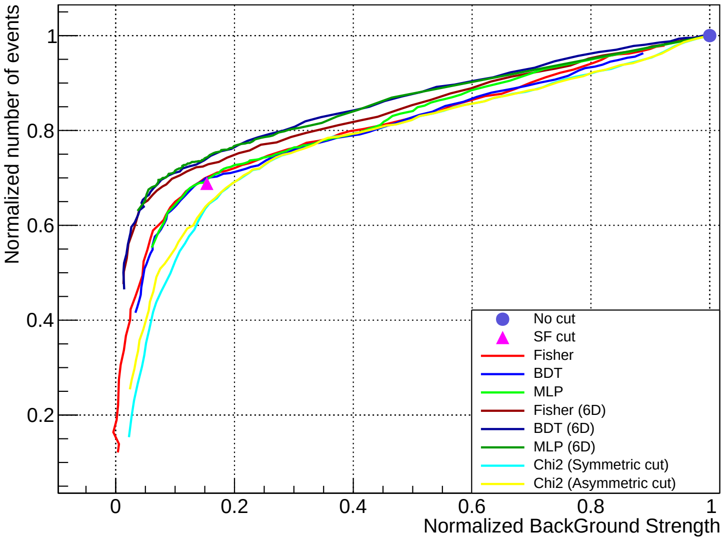
- Use of MVA techniques for positron id necessary and implemented in analysis.
- First values of R' ratio and A_{FB} extracted
- Full fiducial cuts still to be implemented (using trains ?)
- CD proton detection efficiency in progress
- Full detailed systematics still needed
- Interpretation of the A_{FB} still needed
- Analysis note under way (the goal is to start review by the end of the summer)

Bibliography

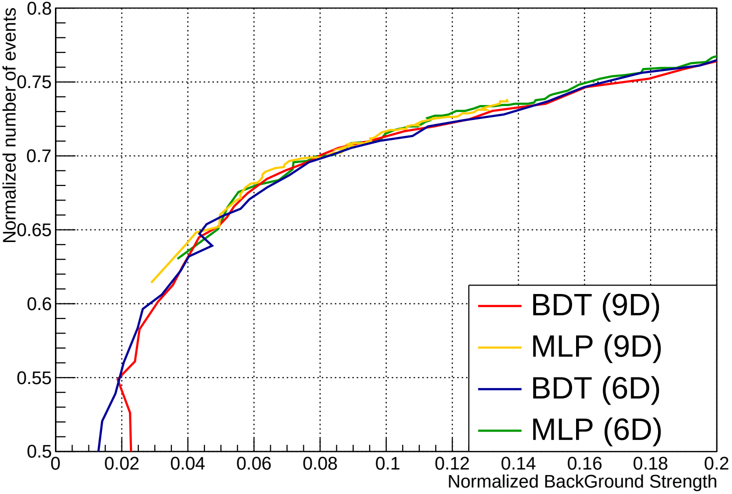
Oleksii Gryniuk and Marc Vanderhaeghen.
Accessing the real part of the forward $j/\psi - p$ scattering amplitude from j/ψ photoproduction on protons around threshold.
Phys. Rev. D, 94:074001, Oct 2016.
doi: 10.1103/PhysRevD.94.074001.
URL https://link.aps.org/doi/10.1103/PhysRevD.94.074001.

Back-up slides

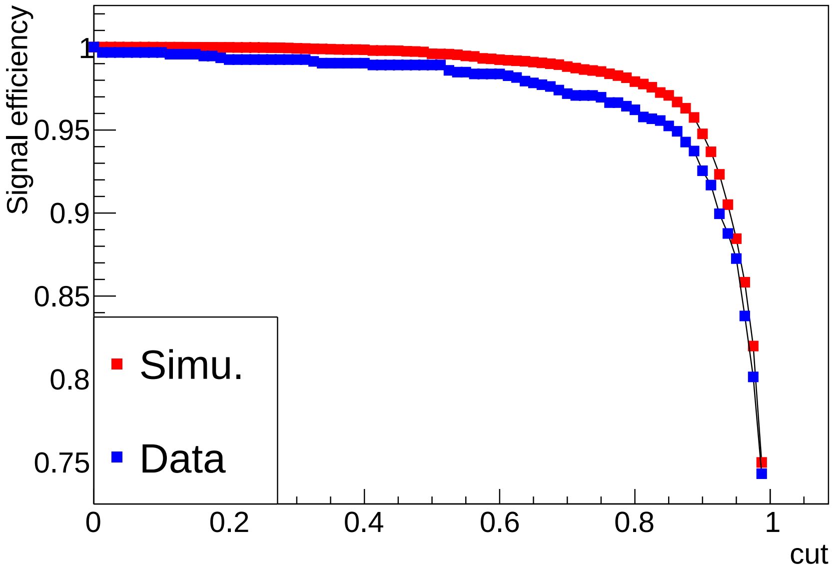
MVA comparison (1)



MVA comparison (2)



NN on electron



Absolute contamination from ROC curve

$$y(x) = \frac{S(x) + x \cdot \beta}{S(1) + \beta} \tag{1}$$

extrapolated it to $x = 0$:

$$y(0) = \frac{S(0)}{S(1) + \beta} \tag{2}$$

The *Normalized number of TCS events* is:

$$y(x_0) = \frac{S(x_0) + x_0 \cdot \beta}{S(1) + \beta} \tag{3}$$

For a given x_0, $\frac{y(x_0)}{y(0)} - 1$ gives a good estimate of the ratio $\frac{B(x_0)}{S(x_0)}$:

$$\frac{y(x_0)}{y(0)} - 1 = \frac{S(x_0) + x_0 \cdot \beta}{S(0)} - 1 \tag{4}$$

and

$$\frac{y(x_0)}{y(0)} - 1 = \frac{S(x_0)}{S(0)} \left(1 + \frac{x_0 \cdot \beta}{S(x_0)}\right) - 1 \tag{5}$$

$$\frac{y(x_0)}{y(0)} - 1 \simeq \frac{B(x_0)}{S(x_0)} \tag{6}$$

Mass spectrum