Upsilon projections from full simulation

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ATHENA Exclusive & Tagging weekly meeting

Introduction

- Upsilon cross section from eStarlight
  - Heavy flavor meson production in eStarlight
  - Upsilon production kinematic plots
- Results from new simulation samples
  - Updated projection plots for Upsilon rates and mass resolution (very tiny difference)

Event generator and photon flux

- Event generator: eStarlight detail intro: PRC 99, 015203 (2019) source code: https://github.com/eic/estarlight

$$\sigma(eA \to eAV) = \int \frac{dW}{W} \int dk \int dQ^2 \frac{d^2N_\gamma}{dk\,dQ^2} \sigma_{\gamma^* A \to VA}(W, Q^2)$$

photon flux

W: photon-p center of mass energy
k: photon energy
Q^2: photon virtuality

- Photo flux: In target rest framework

$$\frac{d^2N_\gamma}{dkdQ^2} = \frac{\alpha}{\pi}\frac{dk}{k}\frac{dQ^2}{Q^2}\left[1 - \frac{k}{Ee} + \frac{k^2}{2E_e^2} - \left(1 - \frac{k}{Ee}\right)\left|\frac{Q^2_{\min}}{Q^2}\right|\right]$$

E_e is the electron energy $Q^2_{\min} = \frac{m_e^2 k^2}{E_e(E_e - k)}$

- Heavy meson cross-section:

$$\sigma_{\gamma^* A \to VA}(W, Q^2) = f(M_V)\sigma(W, Q^2 = 0)\left(\frac{M_V^2}{M_V^2 + Q^2}\right)^n$$

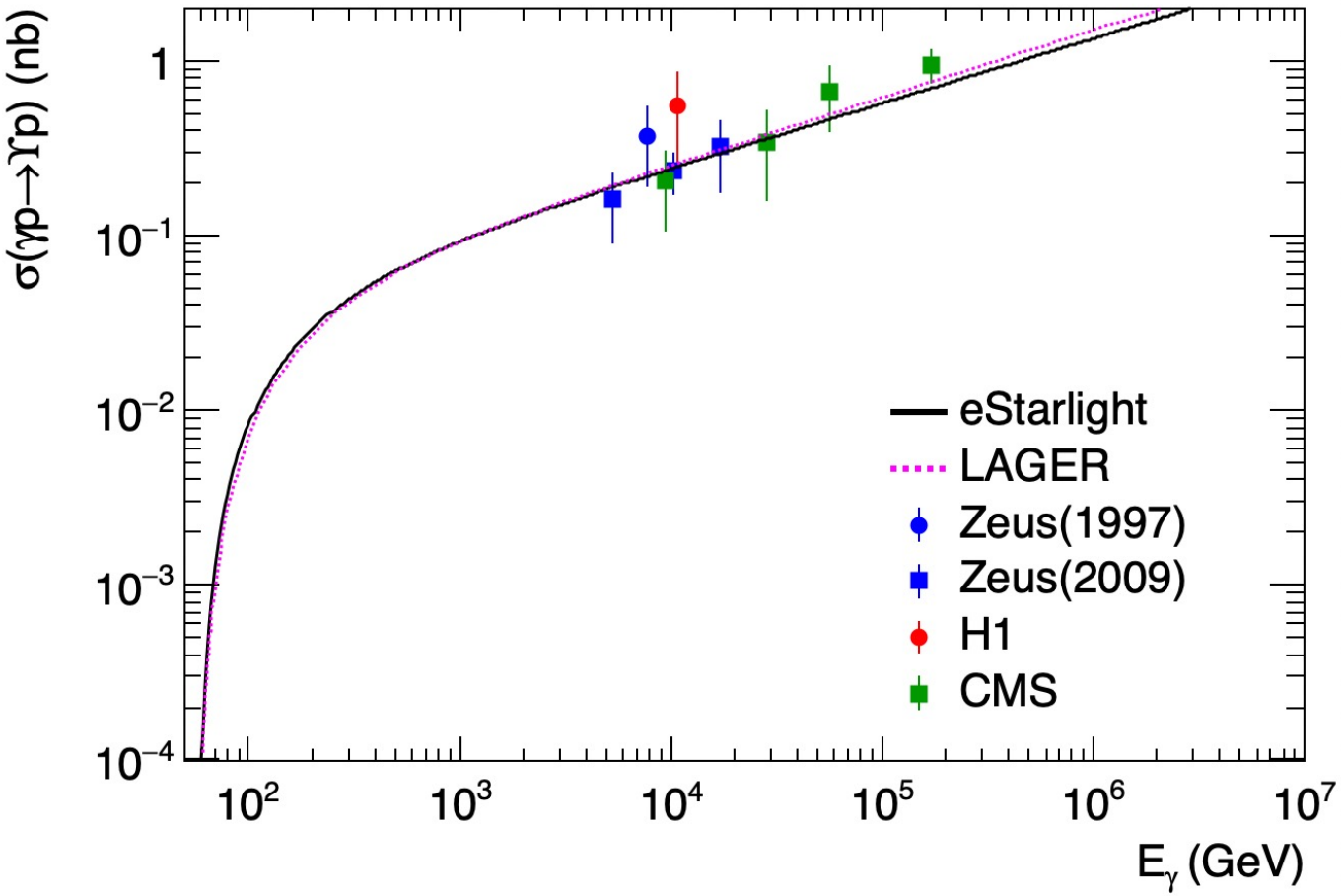
$$n = c_1 + c_2(Q^2 + M_V^2)$$

$$\sigma(W, Q^2 = 0) = \sigma_P W^\epsilon$$

For Upsilon(1S):
$\sigma_P = 6.4$ pb, $\epsilon = 0.74$ arXiv:1607.03838

Upsilon(1S) cross section

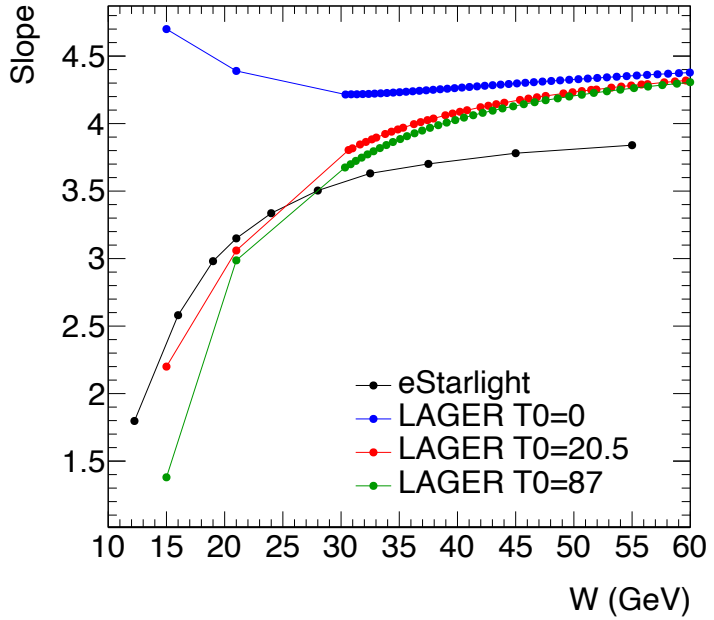
Zeus: Phys. Lett. B 437:432-444,1998
Phys. Lett. B 680:4-12, 2009
H1: Phys. Lett. B 483:23-35, 2000
CMS: Eur. Phys. J. C 79:277, 2019

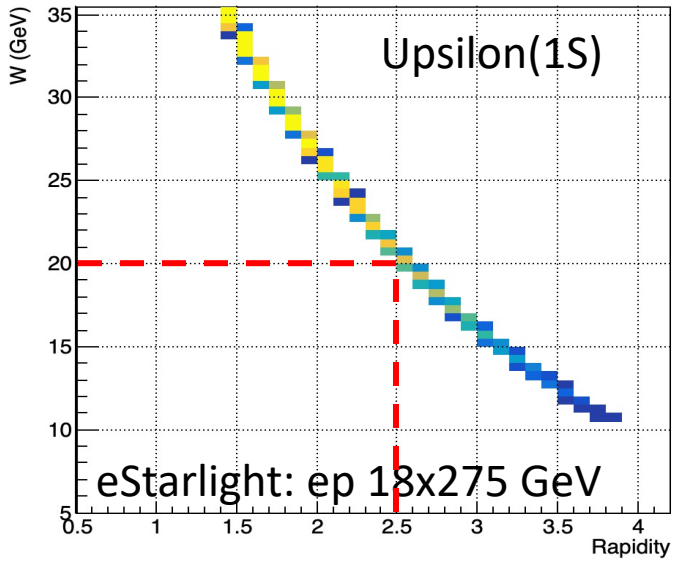


LAGER: PRD 102, 014016 (2020)

eStarlight/Lager prediction on the slope

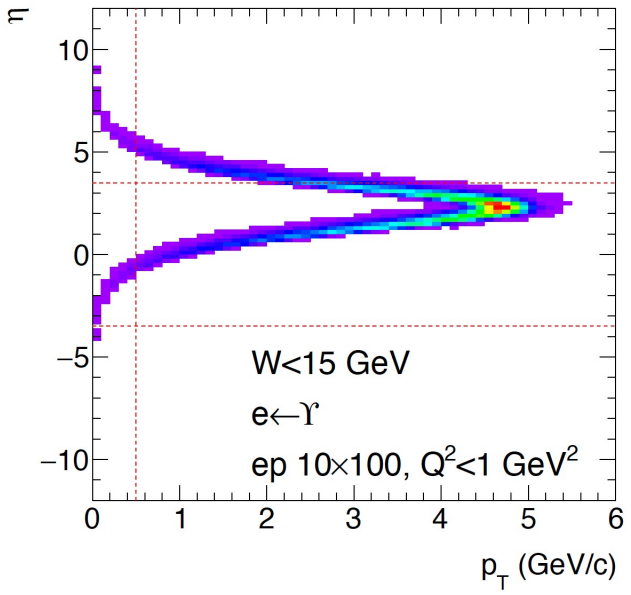
LAGER: PRD 102, 014016 (2020)

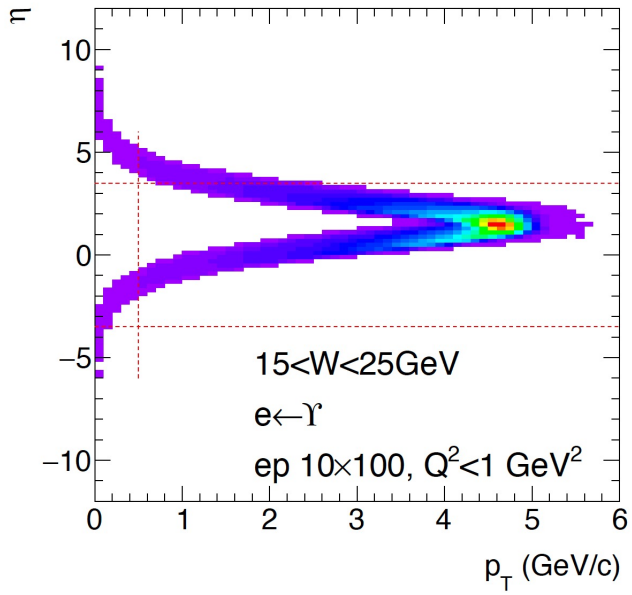


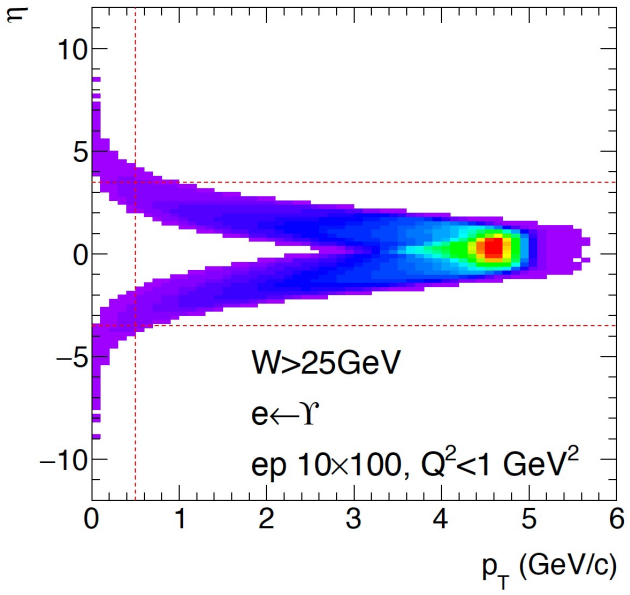


Kinematics of e ← ϒ

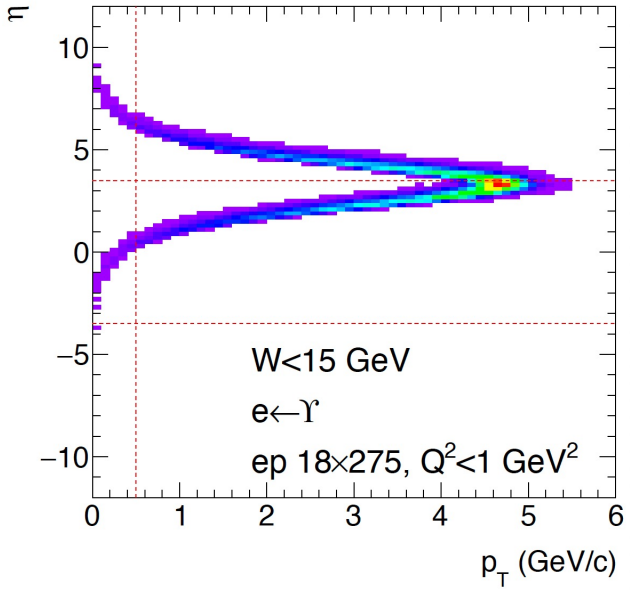
ep 10x100 GeV

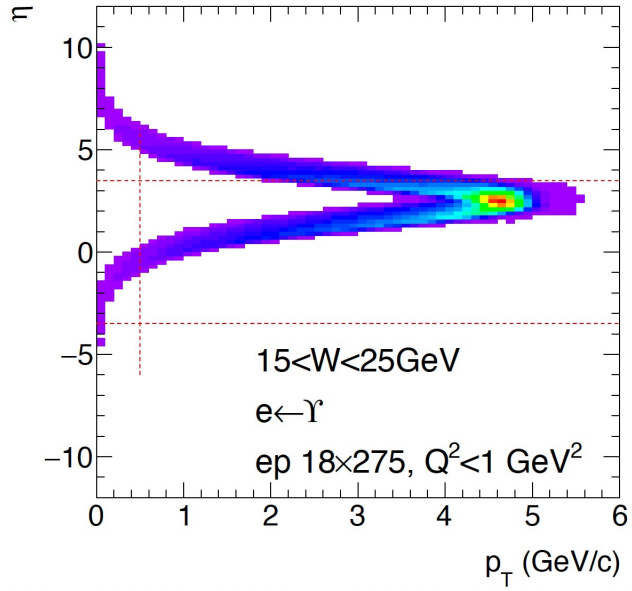


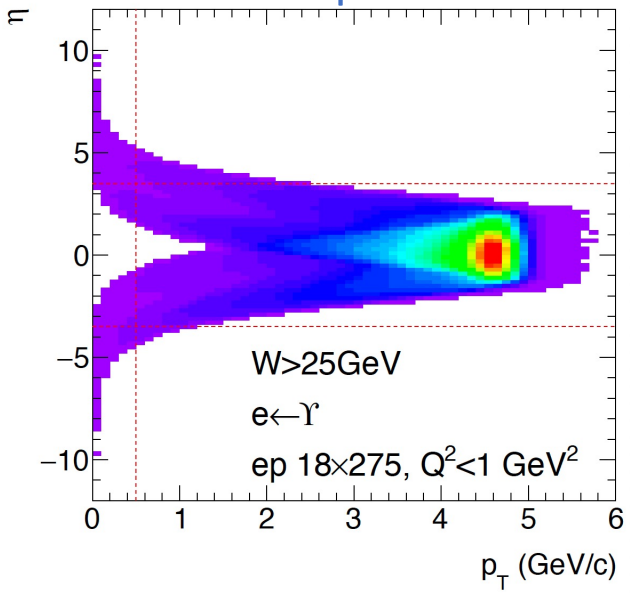




ep 18x275 GeV







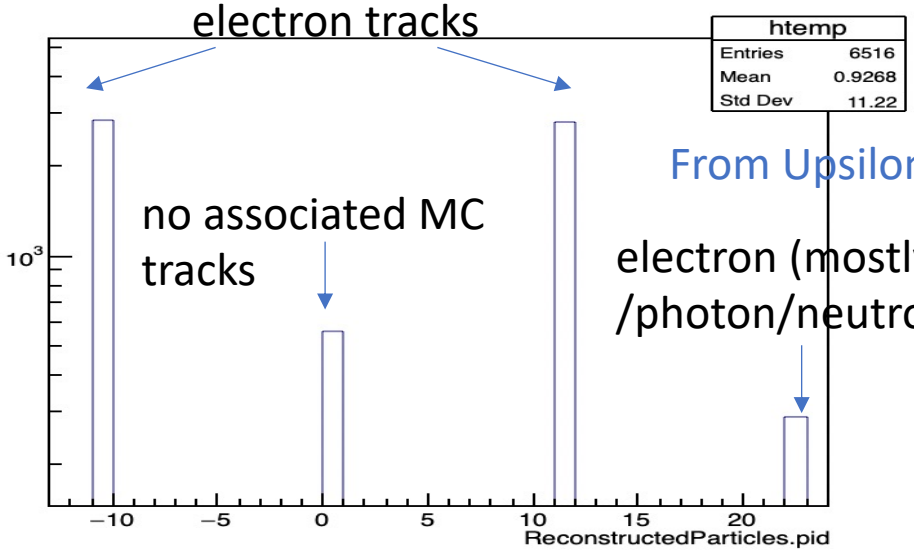
New simulation sample

- Old simulation samples generated around Oct 24
- New material map used in DD4HEP
  - expected better momentum resolution from full simulation
- New samples ready:
  - MC files generated by eStarlight
  - Full $W_{\gamma p}$ energy, ep->epΥ, $\Upsilon \rightarrow e^+e^-$ at ep 18x275 GeV range for Upsilon 3 states
  - Selected $W_{\gamma p}$<25 GeV, ep->epΥ(1S) events at ep 18x275 GeV and at ep 10x100 GeV
  - https://dtn01.sdcc.bnl.gov:9001/buckets/eictest/browse/QVRIRU5BL1JFQ08vY2FueW9ubGFuZHMtdjEuMi9FWENMVVNJVkUvVVBTSUxPTl9BQkNPTlYv

Electron tracking

ReconstructedParticles PID

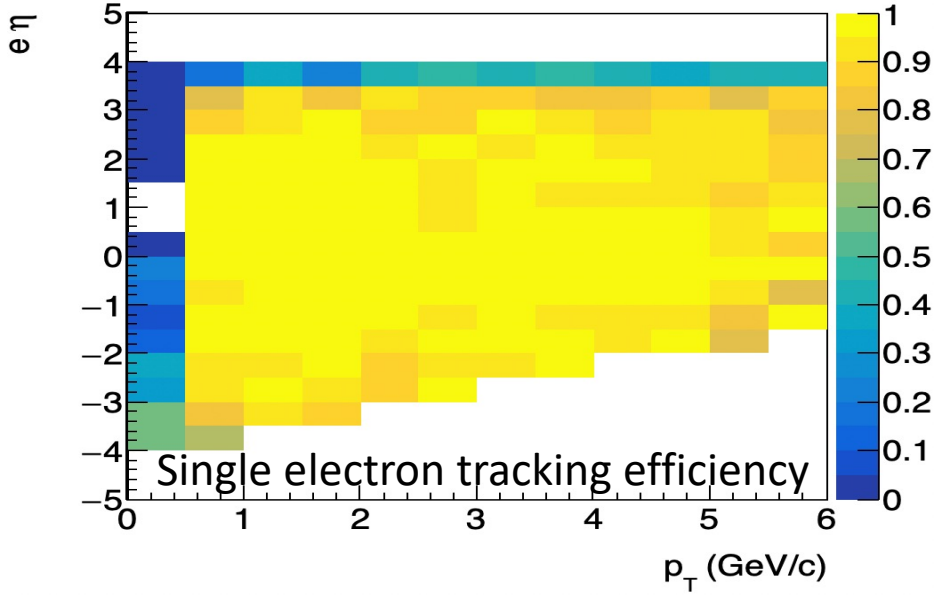
electron tracks



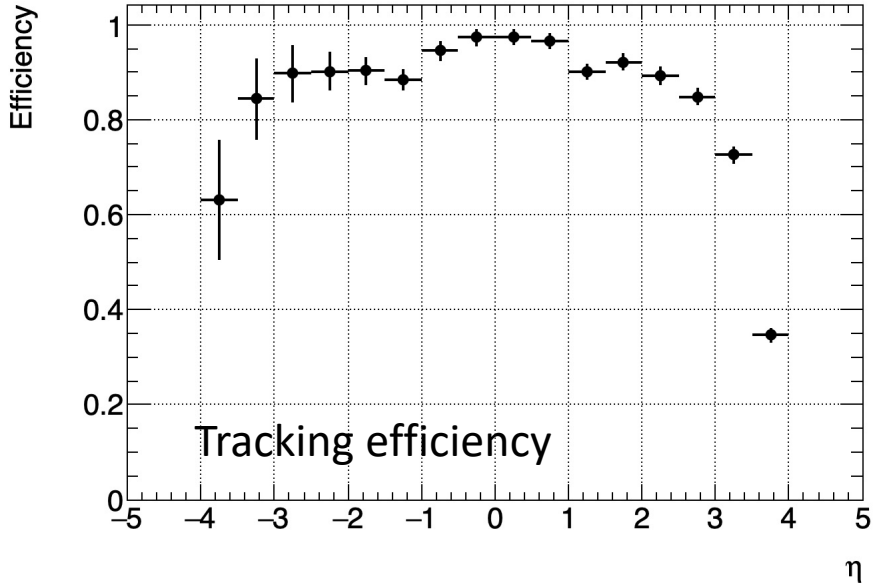
From Upsilon(1S)

no associated MC tracks

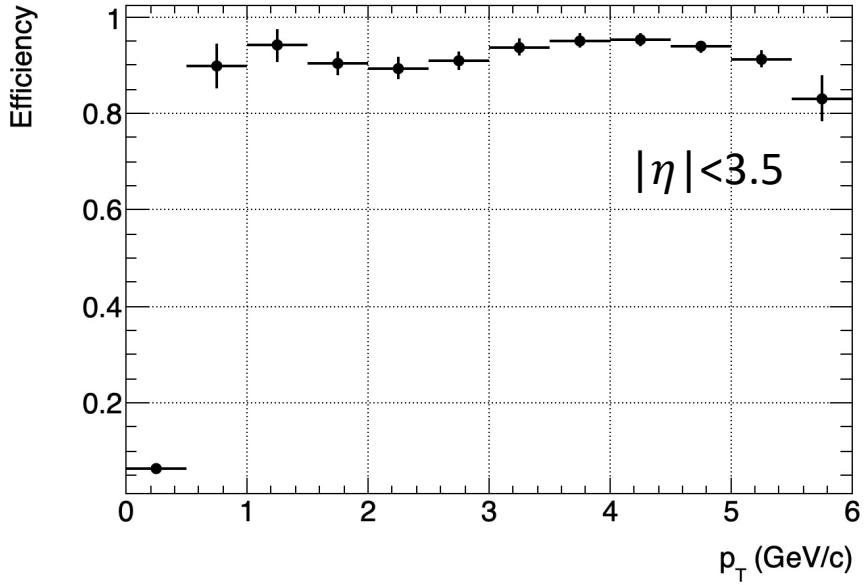
electron (mostly) /photon/neutron



Combine all electron tracks from simulations



$\frac{\text{gene. particle}}{\text{reco. particle}}$

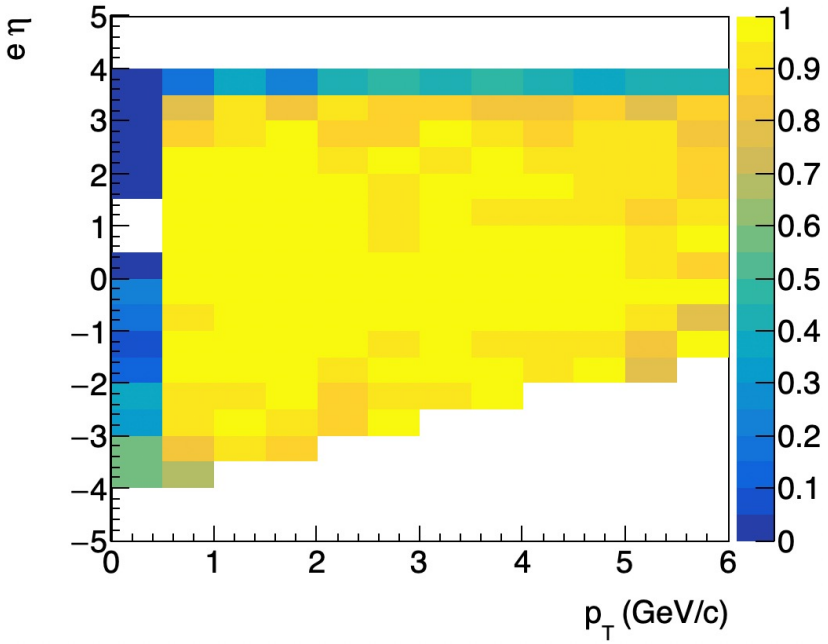


Fast simulation to obtain Reco. efficiency

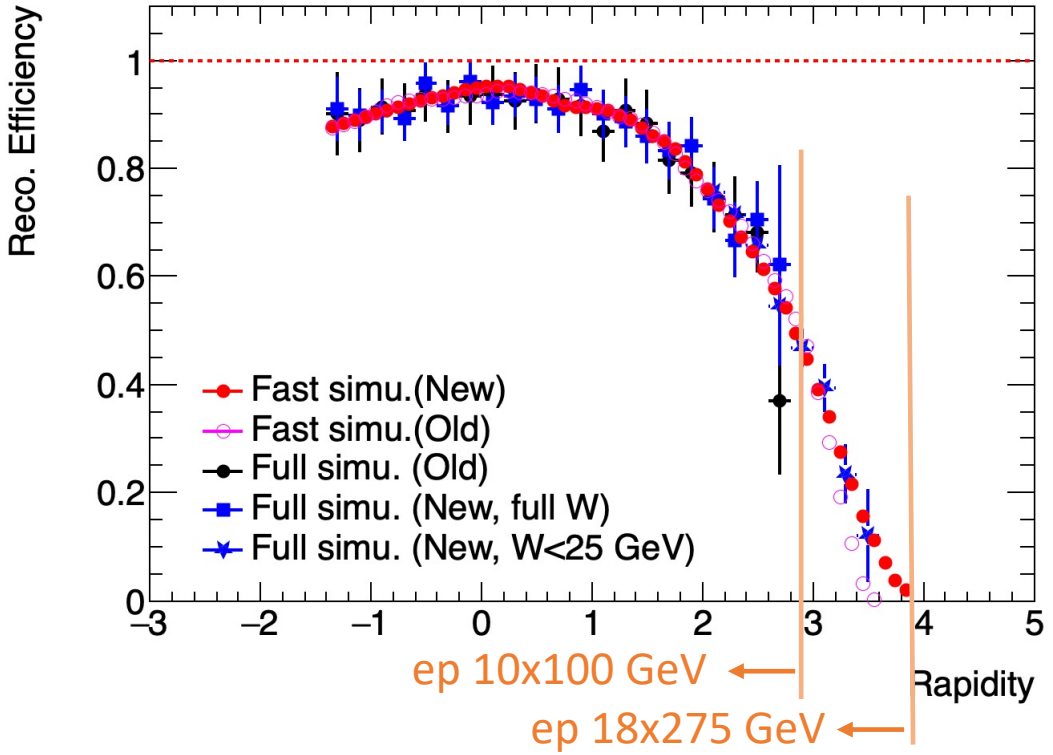
- Extract electron Tracking efficiency from simulation files
- Fast simulation
  - MC events generated from eStarlight
  - Take single electron tracking efficiency as weighting factor
    - Eff(Upsilon) = Eff(e^+)*Eff(e^-)

$$\text{Eff.} = \frac{\text{No. Generated particle}}{\text{No. reconstructed particle}}$$

Combine all Upsilon simulations



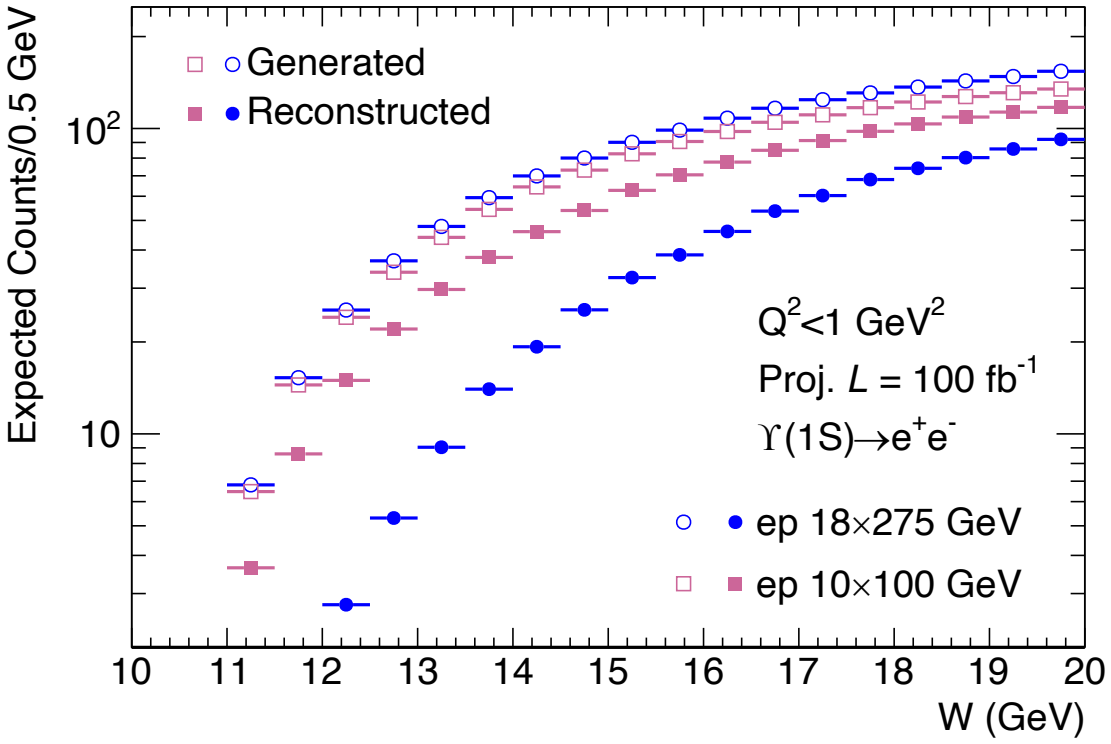
Single electron tracking efficiency



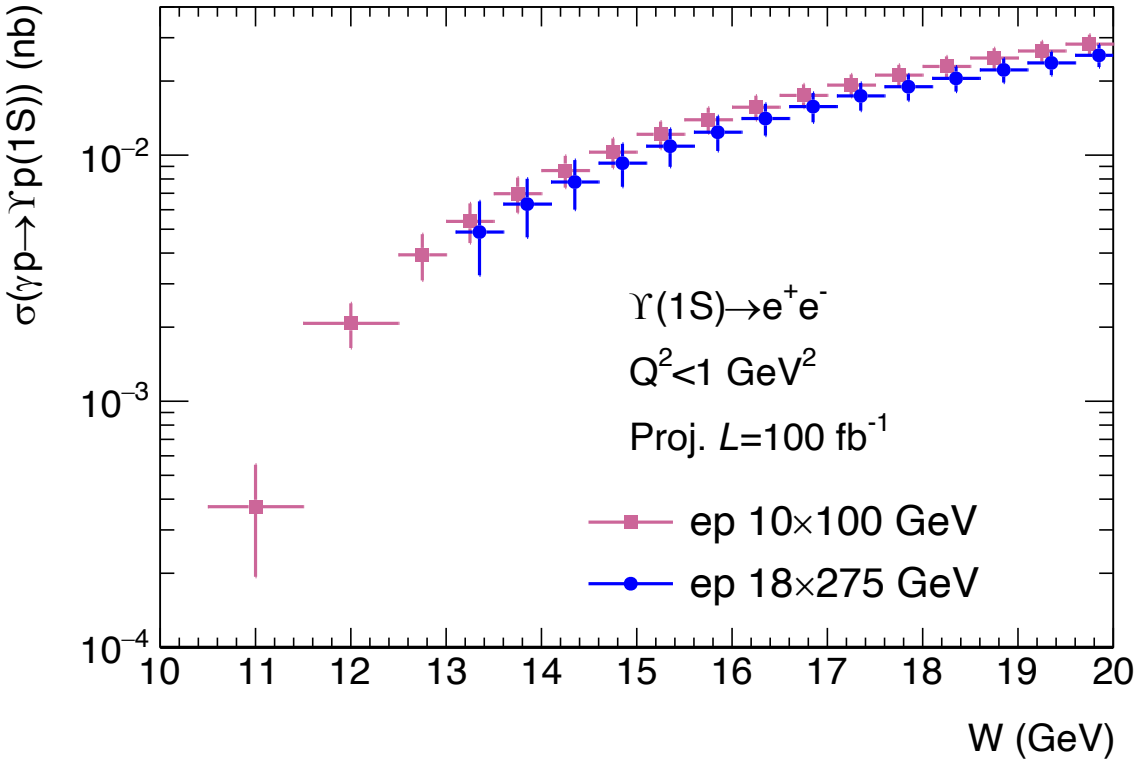
Upsilon(1S) reconstruction efficiency

Projected Upsilon rates in EIC

- Generated (MC) Upsilon rates from eStarlight prediction
- Upsilon reconstruction efficiency gotten from fast simulation



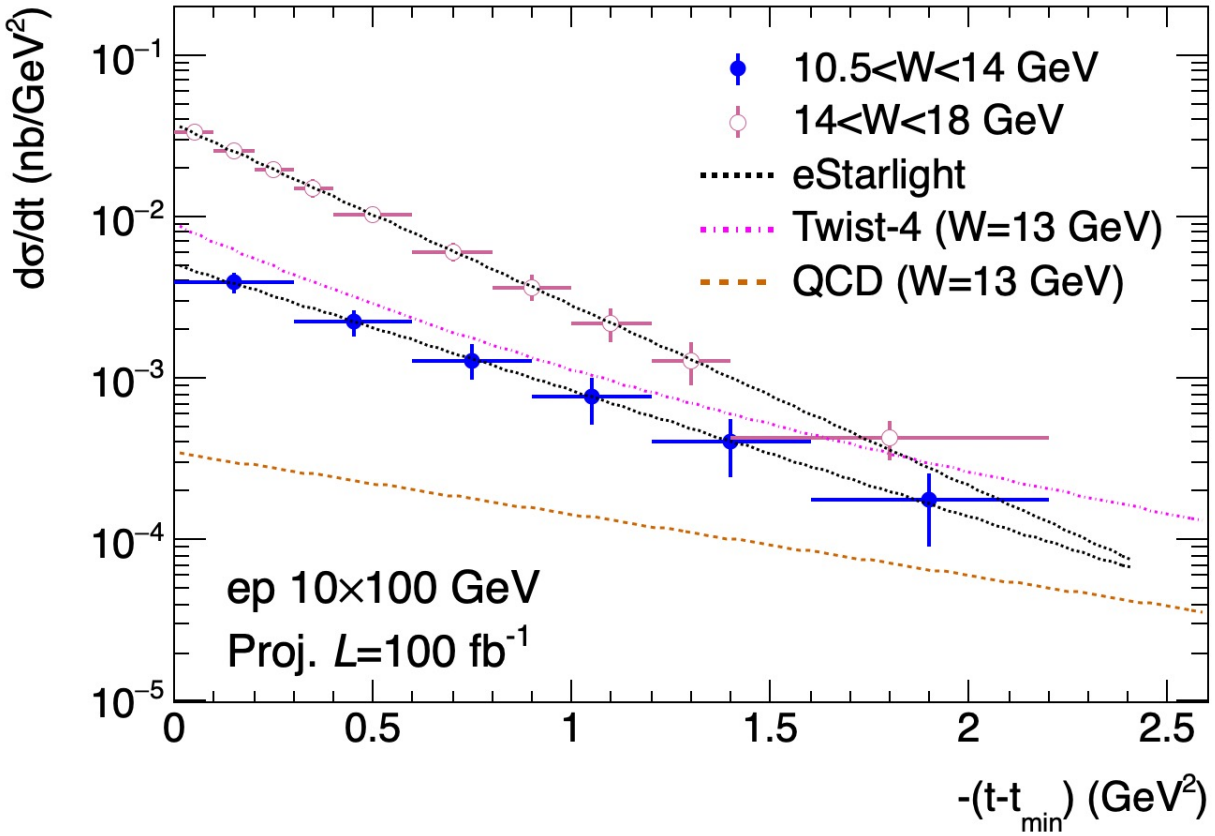
Projected upsilon rates in two collision energies



Projected uncertainties for upsilon total cross section

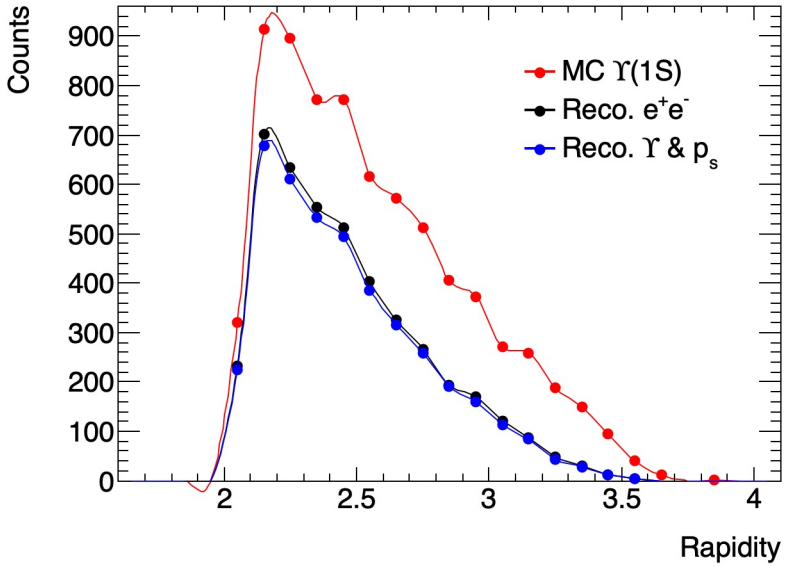
Projected ds/dt in two W bins

- Upsilon reconstruction efficiency from fast simulation
- t resolution and acceptance not considered
  - uncertainty dominated by Upsilon reconstruction
  - scattered proton in FF detector ~ 95% reconstructed
- Take eStarlight prediction as mean value



p_s: Scattered proton

From full simulation (W<25 GeV)



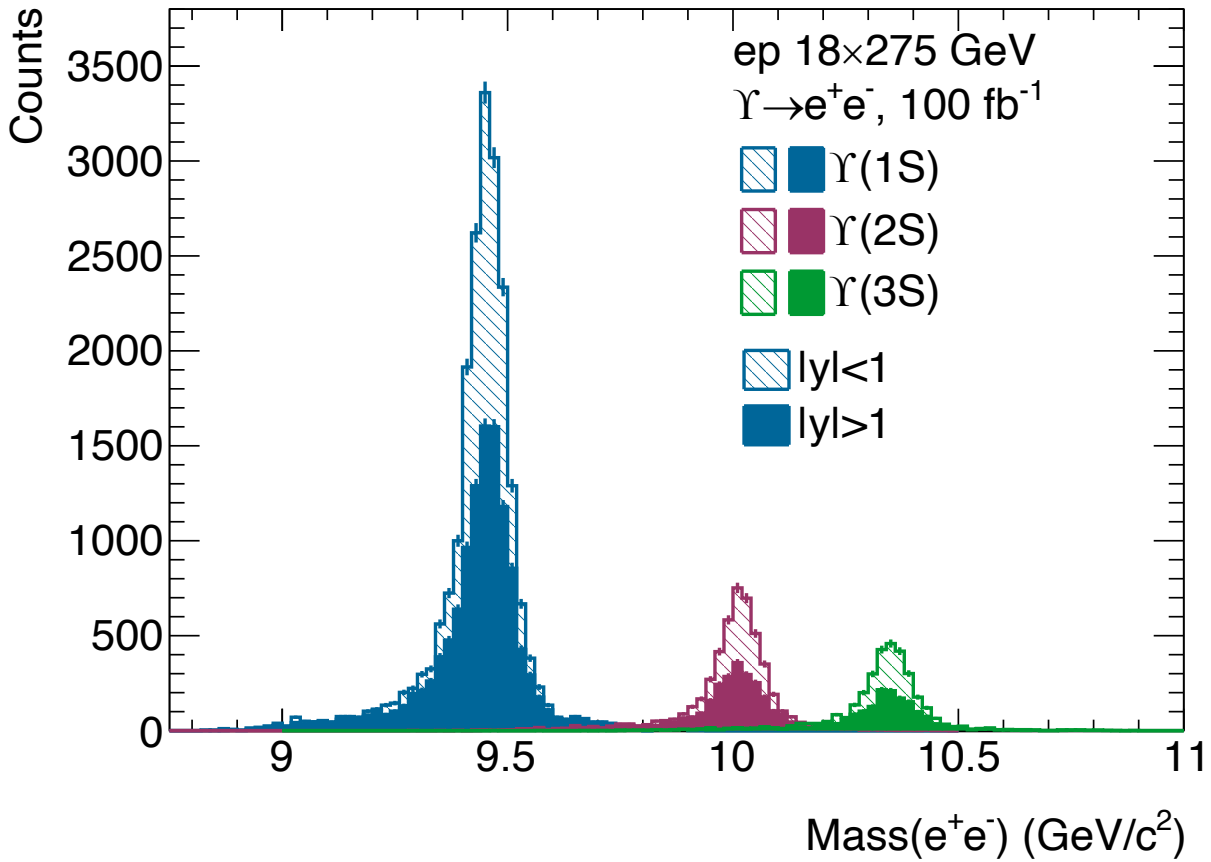
Twist-4: PLB 822,136655 (2021)

QCD: PRD 103, 096010 (2021)

Updated Upsilon mass plot for proposal

B.R($\Upsilon \rightarrow e^+e^-$)=0.0238 used in the projection

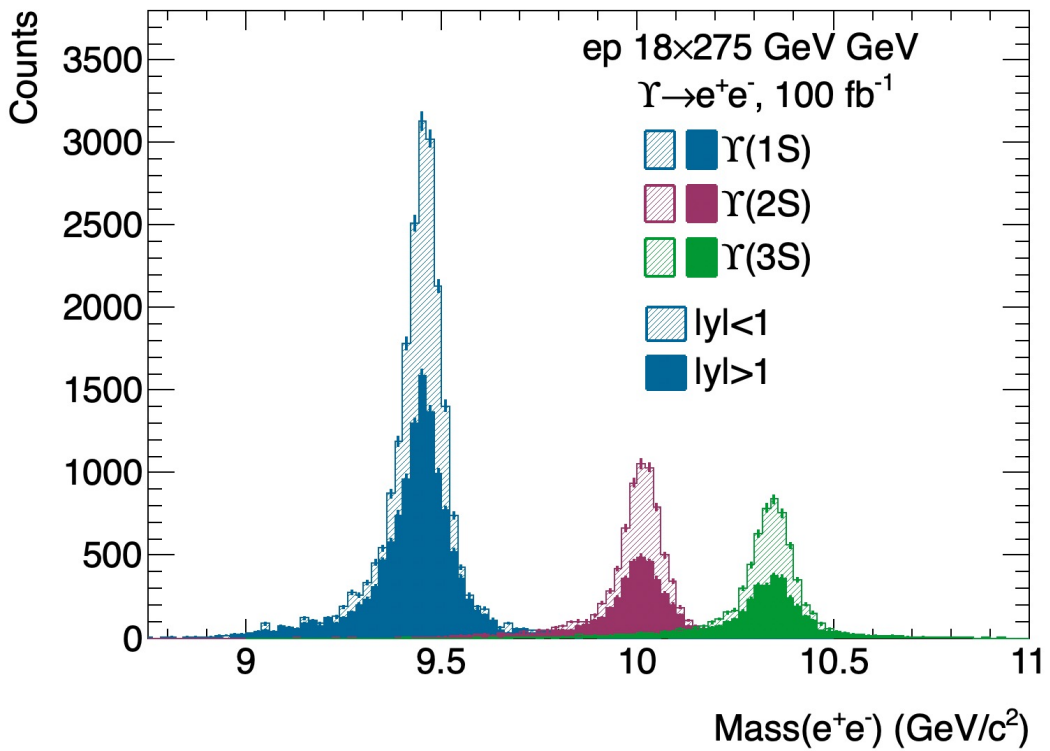
Athena



New plot

- No by eye difference compared to old simulation

Old simulation

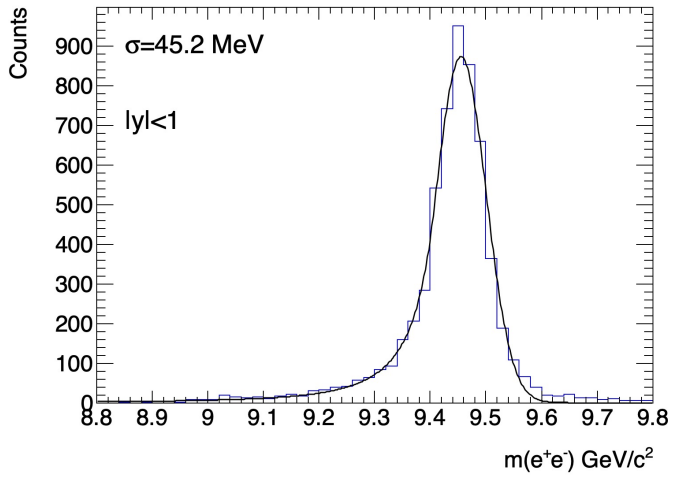


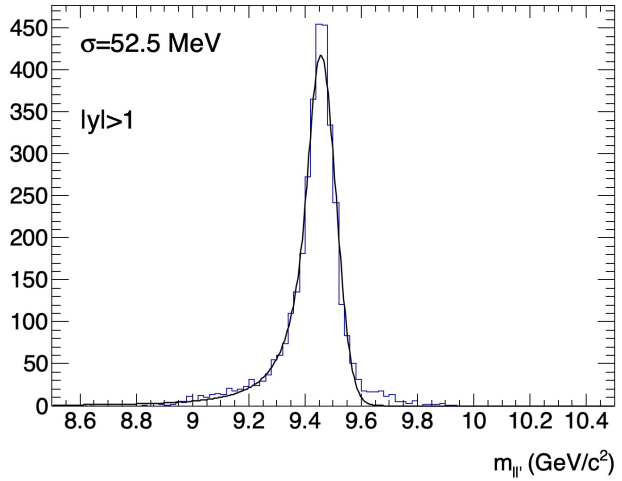
Updated Upsilon mass width for Athena

- Improved upsilon mass resolution compared with old simulation

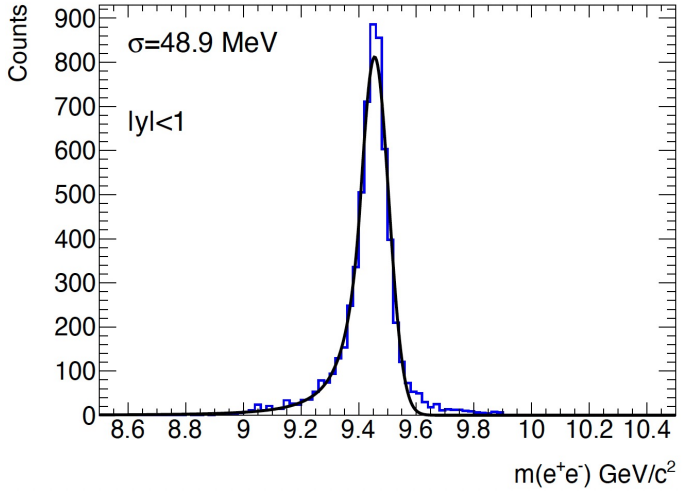
  Fit with crystal ball function for new simulation:

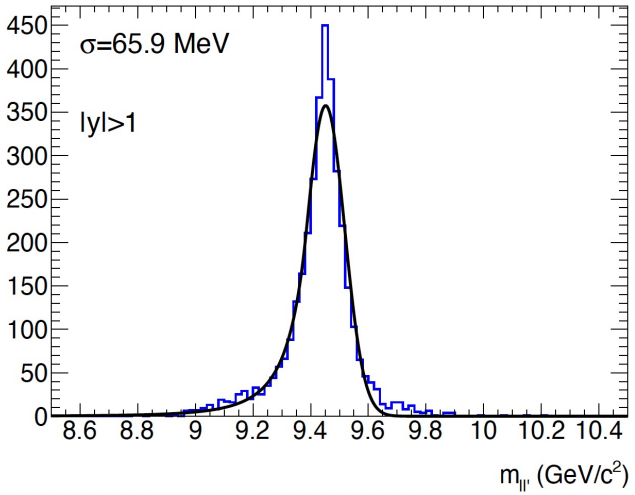
New





Old





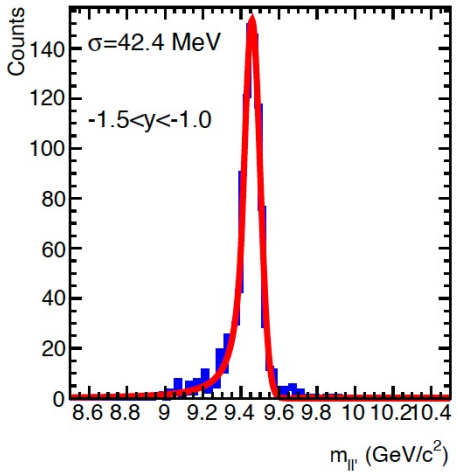
Upsilon(1S) Mass resolution with Athena
(Oct 27 sample with old material map)

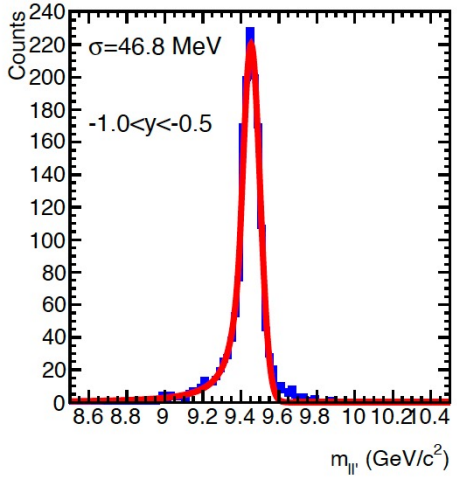
$|y|<1$, 45 MeV/c^2 (old: 49 MeV/c^2)
$|y|>1$, 53 MeV/c^2 (old: 66 MeV/c^2)

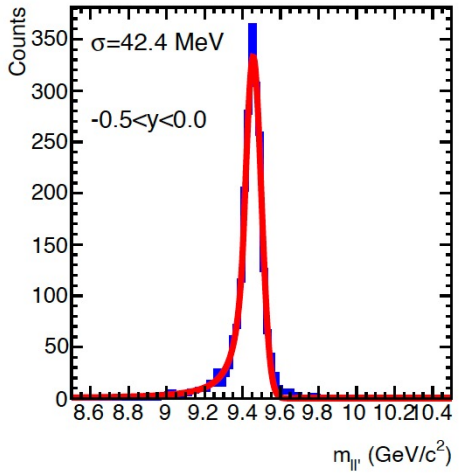
Mass resolution with all silicon detector in YR

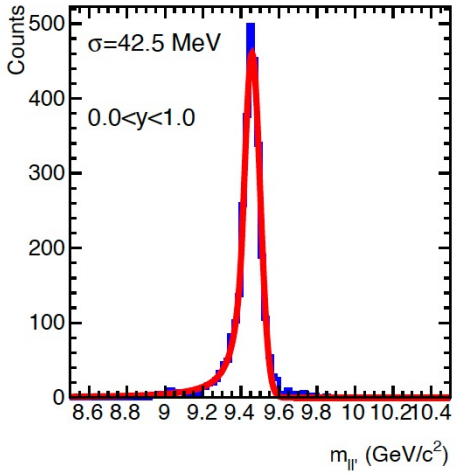
Rapidity	1.5 T field	3.0 T field
$\|y\| < 1$	66 MeV/c^2	40 MeV/c^2
$\|y\| > 1$	79 MeV/c^2	51 MeV/c^2

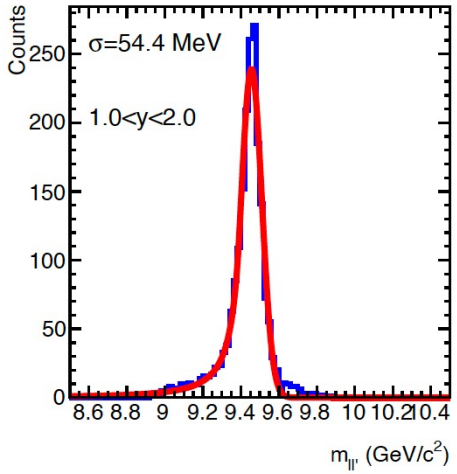
Reconstructed $\Upsilon(1S) \rightarrow e^+e^-$ vs rapidity

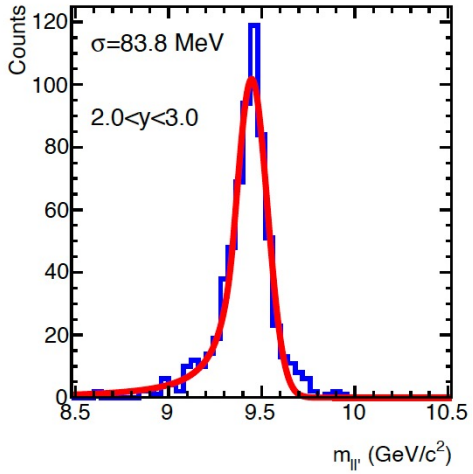










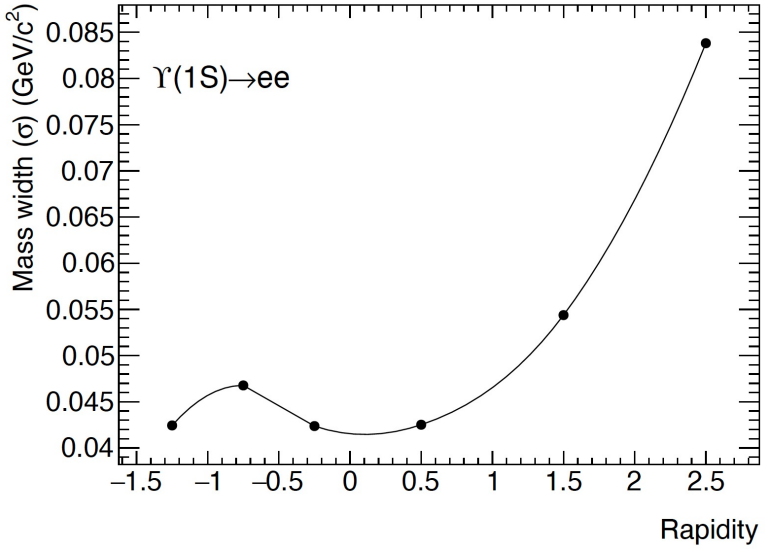


Fitting function:

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

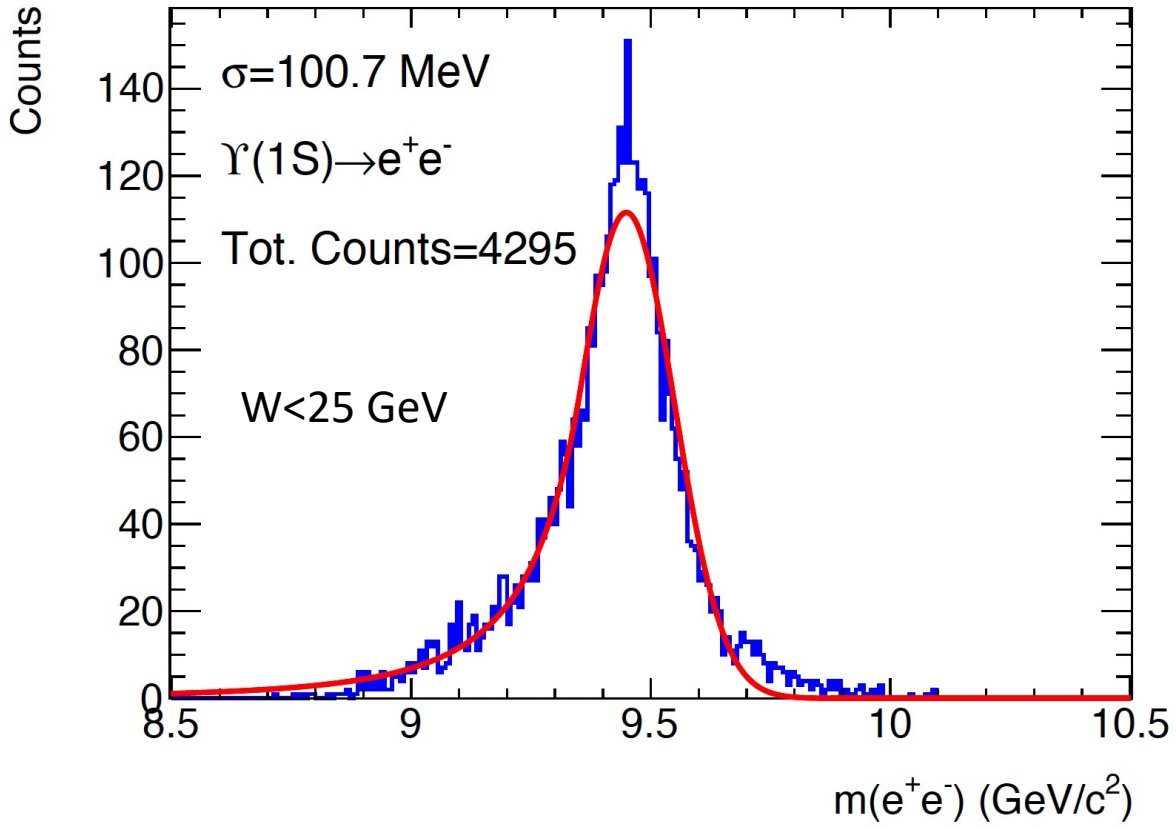
α= 1.14; n= 2.5

Upsilon mass width



Mass resolution at near threshold

- ep 18x275 GeV
- 2<y<4, near threshold production

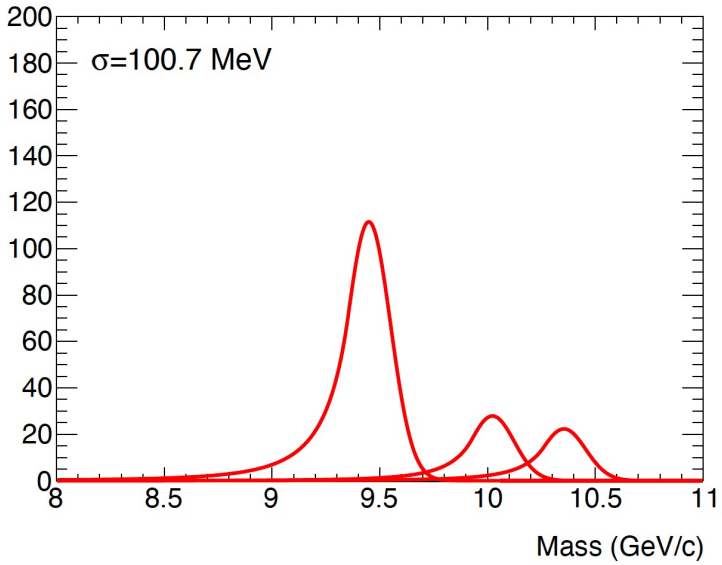


Fitting: Crystal function

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

α= 0.94; n= 3.5

Expected signal shape for upsilon 3-states with such precision



Summary

- Updated Upsilon projection plots from new simulation samples
  - Reconstruction efficiency of upsilon estimated by hybrid method: single electron eff. from full simu. -> fast simu.
  - Only very tiny difference compared to submitted plot to proposal
  - Improved mass resolution with new material map
    - 45 MeV @ |Y|<1, 53 GeV @|Y|>1, comparable to Yellow report