Update on Separation of Three Υ states in ePIC

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Exclusive/Diffraction/Tagging meeting

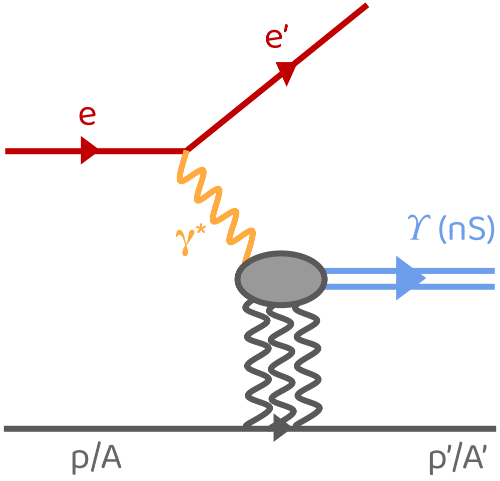
30 Sep 2024

Introduction

- Exclusive Vector Mesons:
  - $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S) \rightarrow e^+e^-$
  - Heavy vector mesons can probe gluon GPDs
    $\rightarrow$ provide information about gluon saturation

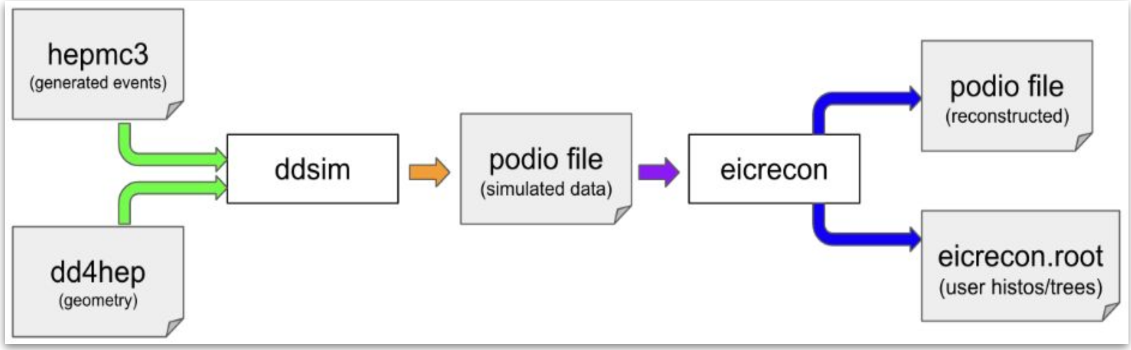
- Preliminary Study: Tracker resolution using Invariant mass spectrum of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ in the electron (muon) channel by ePIC
  $\rightarrow$ ePIC TDR
  $\rightarrow$ Benchmark

- Current status:
  Obtained the invariant mass resolution of three Υ states in electron (muon) channel, depending on the upsilon rapidity regions, using both truth seeding and realistic seeding



Sample Production Steps

- Simulation Procedure:
  1. eSTARlight: generate Upsilons 1S, 2S, and 3S each with the HepMC3 output
     (Generated the sample using the ratio for the yields 1 : 0.45 : 0.33 from the STARlight paper)
  2. Combined three HepMC3 files into one
  3. afterburner under eic-shell: add beam effects
  4. npsim under eic-shell: detector (Geant4) simulation
  5. eicrecon under eic-shell: reconstruct events and tracks



↑ Sample production work flow from EICrecon introduction

Sample / Software Information

- Input Information of the Sample:
  - ep 18 x 275 GeV
  - Υ (NS) to e^+e^- ($\mu^+\mu^-$)
  - $0.001 < Q^2 < 10$ GeV^2
  - No limit on W

- Software Information:
  - Generated under eic-shell
  - epic version: v24.07.0
  - eStarlight version: v1.2.0
  - AfterBurner version: v0.1.1
  - EICrecon version: v1.15.0

ePIC Detector Geometry

- The central detector instruments the -4 < η < 4 region with full coverage of the range $|\eta|$ < 3.5
- This resolution study focuses on Υ states reconstructed by the Si tracker

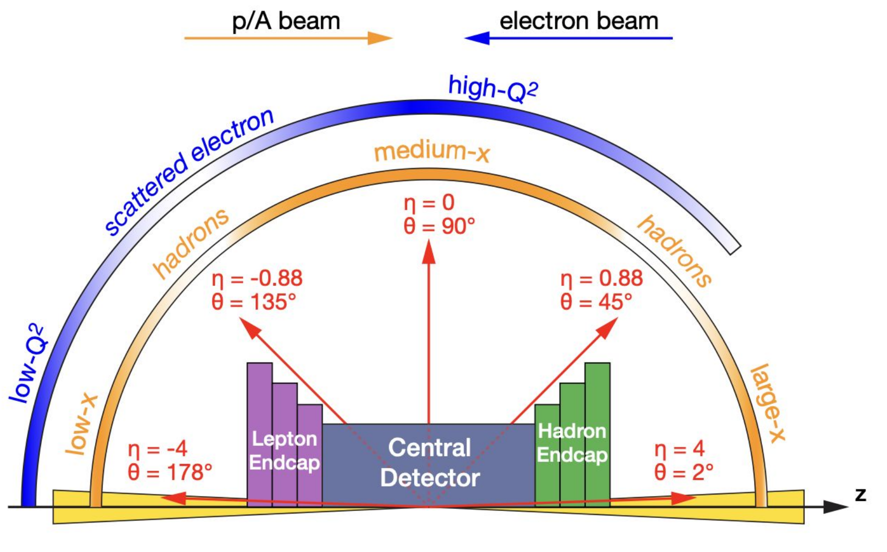
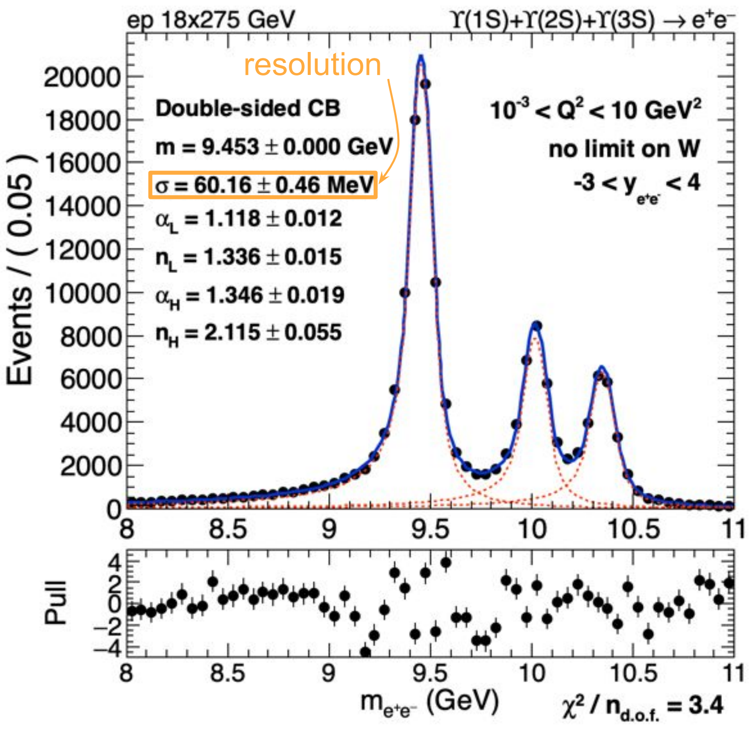


Figure 9.1: A schematic showing how hadrons and the scattered lepton for different $x - Q^2$ are distributed over the detector rapidity coverage.

↑ From EIC Yellow Report

Fit Model: DSCB



- Fit to Double Sided Crystal Ball (DSCB) functions
  - Double Sided Crystal Ball (DSCB) function

$$\mathrm{DSCB}(m;\mu,\sigma,\alpha_L,n_L,\alpha_H,n_H) = \begin{cases} e^{-0.5t^2} & \text{if } -\alpha_L < t < \alpha_H \\ e^{-0.5\alpha_L^2}\left[\frac{\alpha_L}{n_L}\left(\frac{n_L}{\alpha_L} - \alpha_L - t\right)\right]^{-n_L} & \text{if } t < -\alpha_L \\ e^{-0.5\alpha_H^2}\left[\frac{\alpha_H}{n_H}\left(\frac{n_H}{\alpha_H} - \alpha_H + t\right)\right]^{-n_H} & \text{if } t > \alpha_H \end{cases}$$

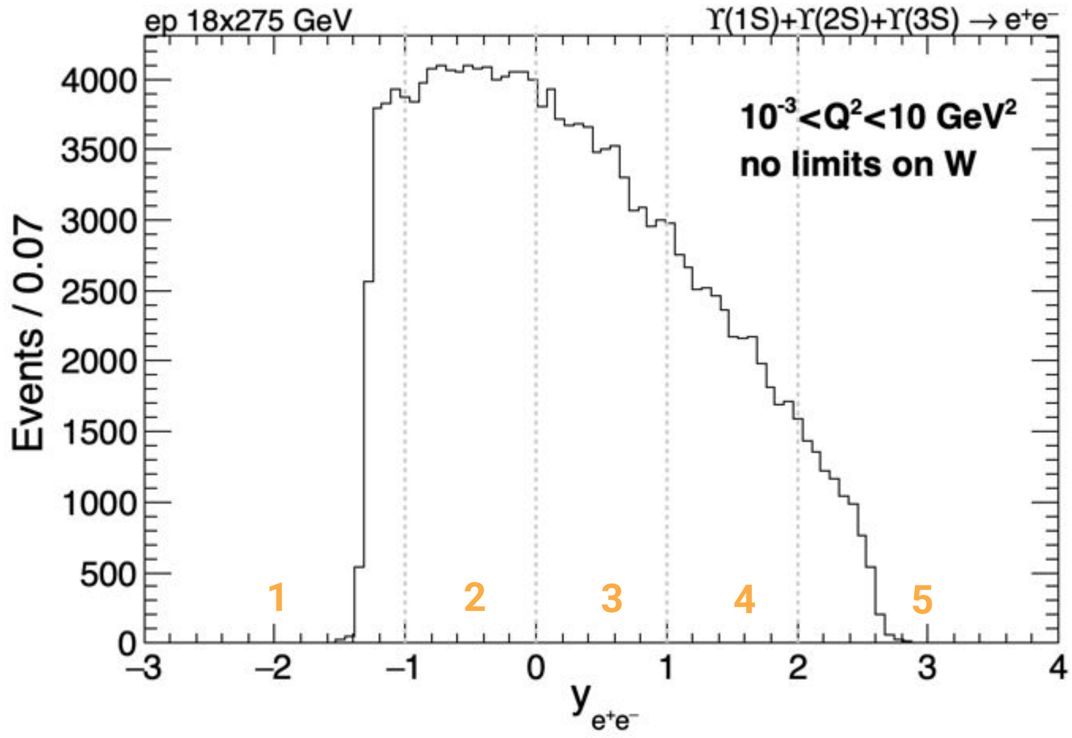
where $t = (m - \mu)/\sigma$

- Constraints:
  - Used the same tail parameters (n, α) for three Υ states
  - Scaled m and σ of Υ (2S) and Υ (3S) peaks with PDG mass values:

$$m(\sigma)_{\Upsilon nS} = m(\sigma)_{\Upsilon 1S} * \frac{\mathrm{PDGmass}_{nS}}{\mathrm{PDGmass}_{1S}}$$

Rapidity of Upsilon (e^+e^-)

Realistic Seeding (ChargedReconstructedSeededParticle)

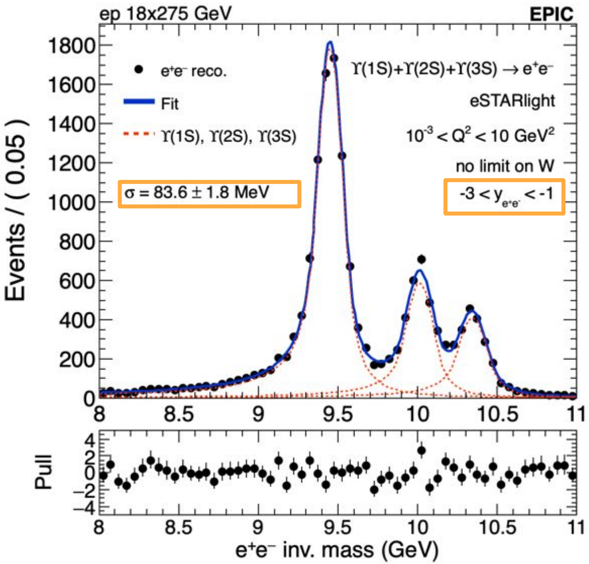


- Separate the regions depending on the reconstructed upsilon rapidity:
  - 1: $-3 < y < -1$
  - 2: $-1 < y < 0$
  - 3: $0 < y < 1$
  - 4: $1 < y < 2$
  - 5: $2 < y < 4$

Upsilon Invariant Mass Fit (e^+e^-)

Realistic Seeding (ChargedReconstructedSeededParticle)

1



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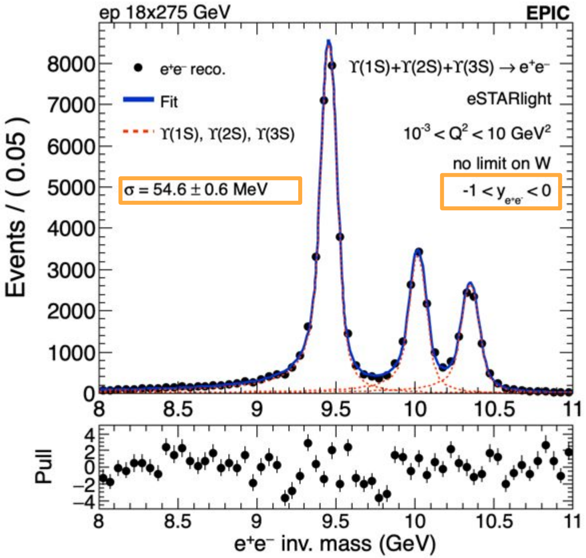

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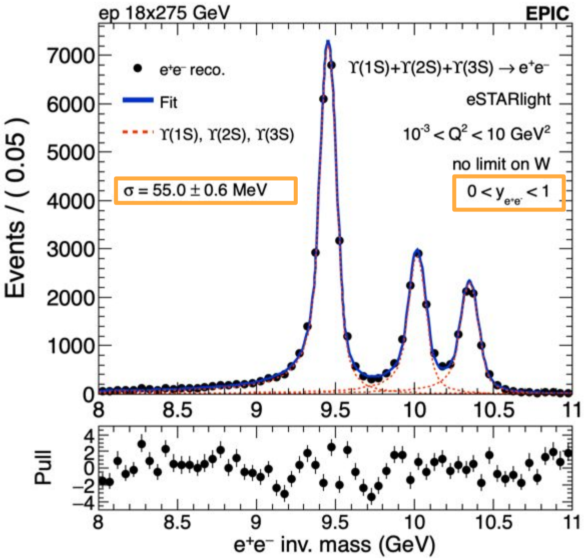
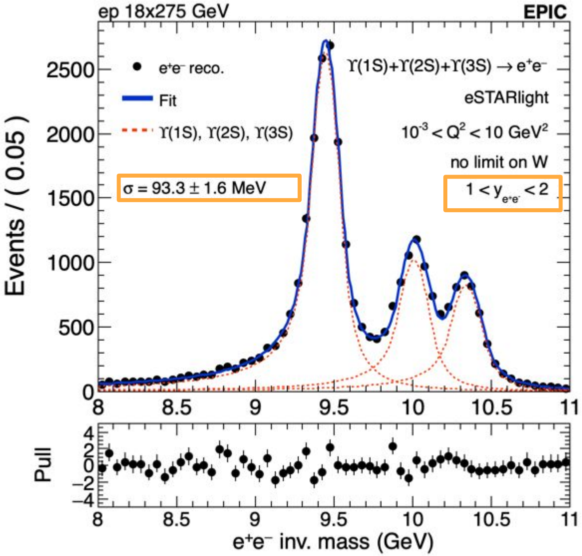


Upsilon Invariant Mass Fit (e^+e^-)

Realistic Seeding (ChargedReconstructedSeededParticle)

4



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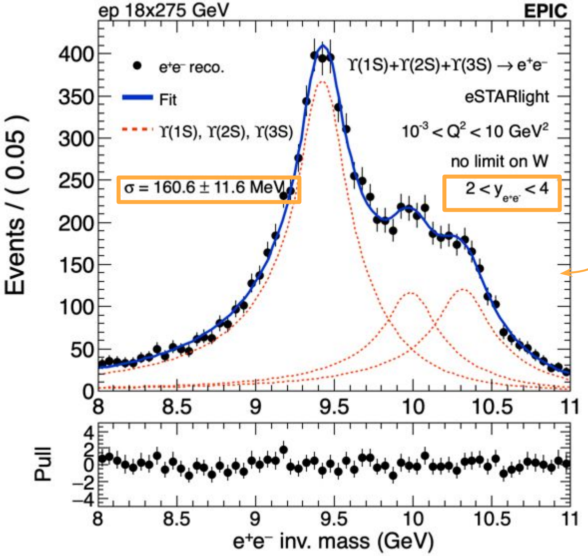
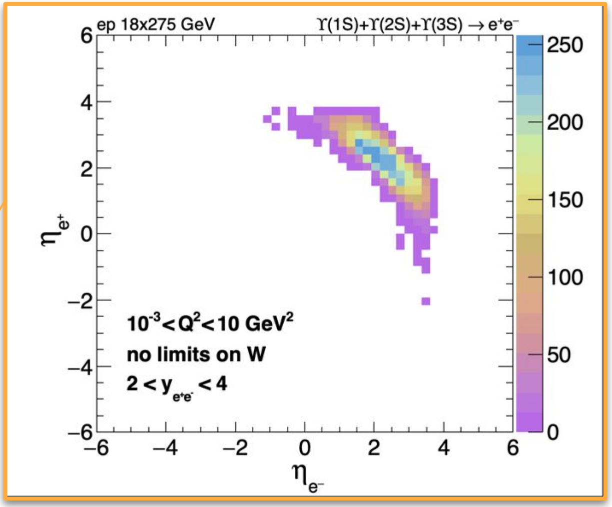
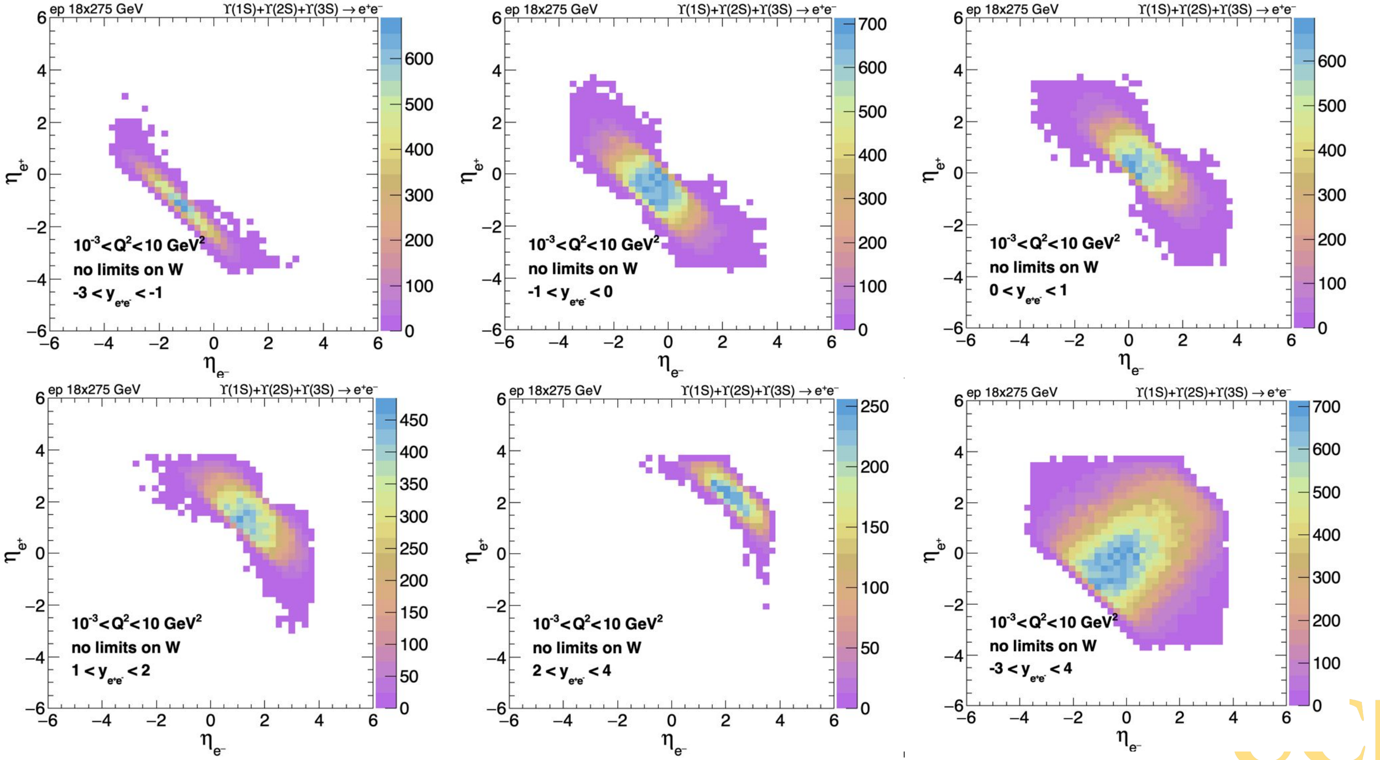




Pseudorapidity of Daughters (e^+e^-)

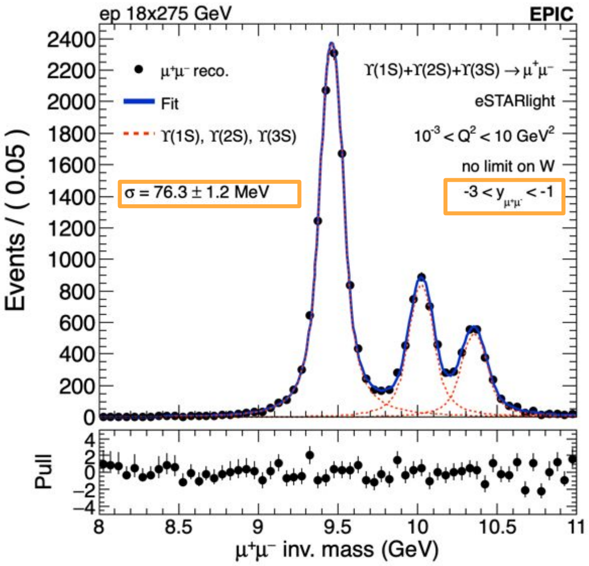
Realistic Seeding (ChargedReconstructedSeededParticle)



Upsilon Invariant Mass Fit ($\mu^+\mu^-$)

Realistic Seeding (ChargedReconstructedSeededParticle)

1



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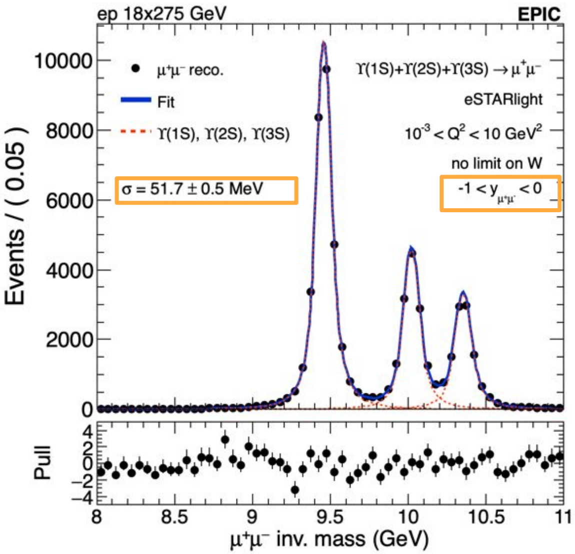

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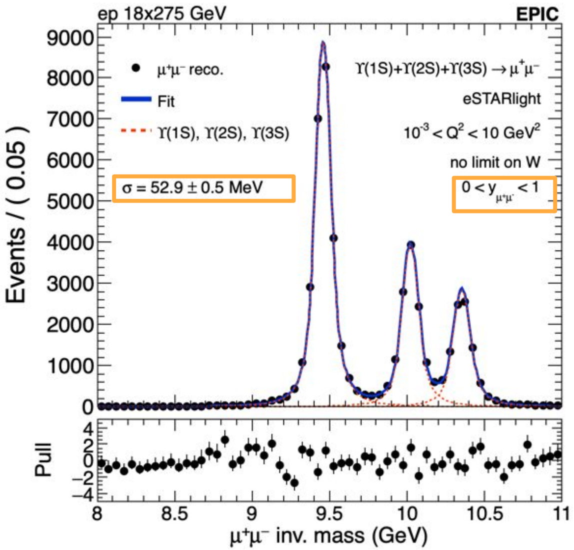

Upsilon Invariant Mass Fit ($\mu^+\mu^-$)

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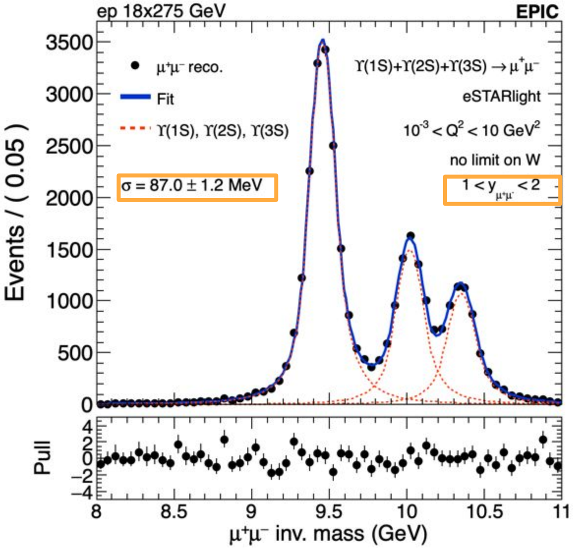

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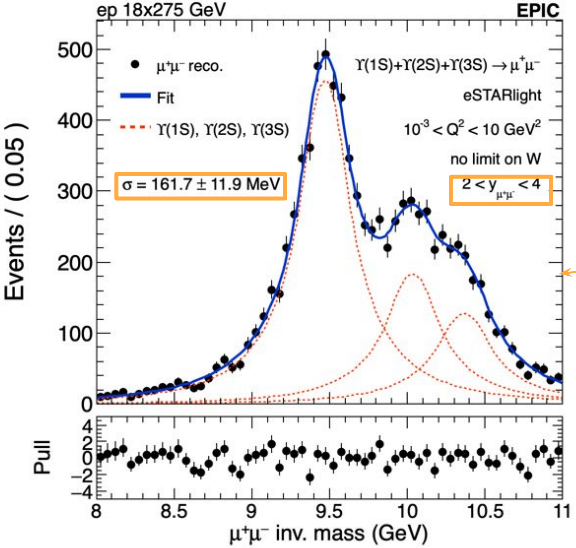

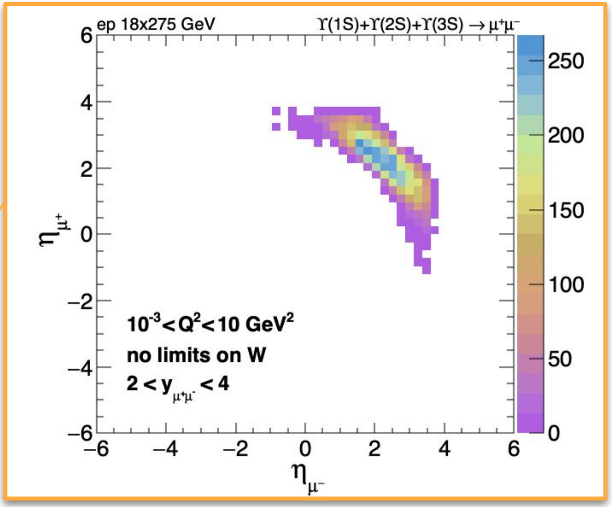

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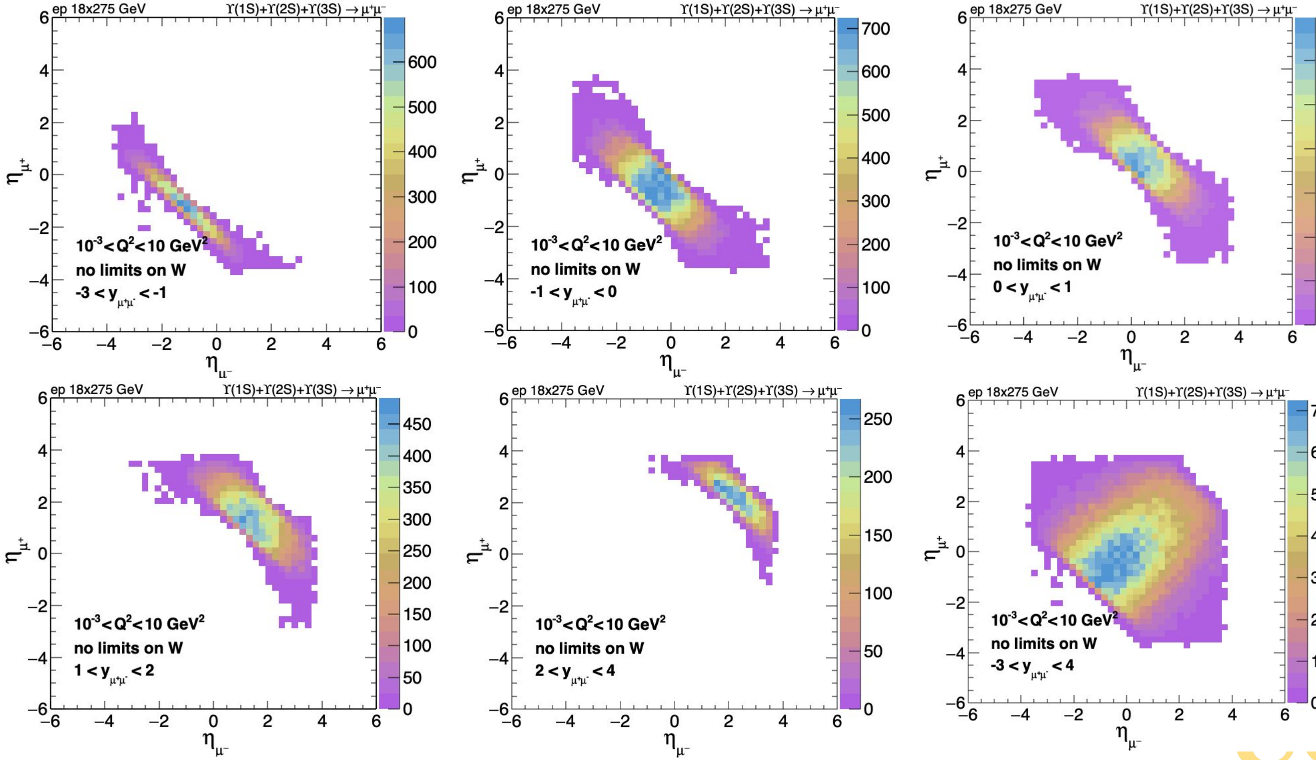

Summary & Outlook

- Tracker resolution study to separate $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ states using simulation
  - eSTARlight (generate seeds) → AfterBurner (beam effects) → npsim (digitalization) → EICrecon (reconstruction)

- The resolution of the three Υ states was obtained using DSCB fits in the region of $0.001 < Q^2 < 10$ GeV^2 with the realistic seeding

(electron channel)
  - $-3 < y < -1$: $\sigma = 83.6 \pm 1.8$ MeV
  - $-1 < y < 0$: $\sigma = 54.6 \pm 0.6$ MeV
  - $0 < y < 1$: $\sigma = 55.0 \pm 0.6$ MeV
  - $1 < y < 2$: $\sigma = 93.3 \pm 1.6$ MeV
  - $2 < y < 4$: $\sigma = 160.6 \pm 11.6$ MeV

(muon channel)
  - $-3 < y < -1$: $\sigma = 76.3 \pm 1.2$ MeV
  - $-1 < y < 0$: $\sigma = 51.7 \pm 0.5$ MeV
  - $0 < y < 1$: $\sigma = 52.9 \pm 0.5$ MeV
  - $1 < y < 2$: $\sigma = 87.0 \pm 1.2$ MeV
  - $2 < y < 4$: $\sigma = 161.7 \pm 11.9$ MeV

- Future work:
  - Resolution studies including ECal
  - Include the study to the Benchmark simulation with the monthly sample production

Backup Slides

About eSTARlight

- eSTARlight generator:
  A Monte Carlo that simulates coherent vector meson photo- and electro-production in electron-ion collisions.

- eSTARlight github: https://github.com/eic/estarlight?tab=readme-ov-file

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About AfterBurner

- AfterBurner adds to MC:
  - Crossing angle
  - Beam effects (divergence, crabbing kick, etc.)
  - Vertex spread (position, time)

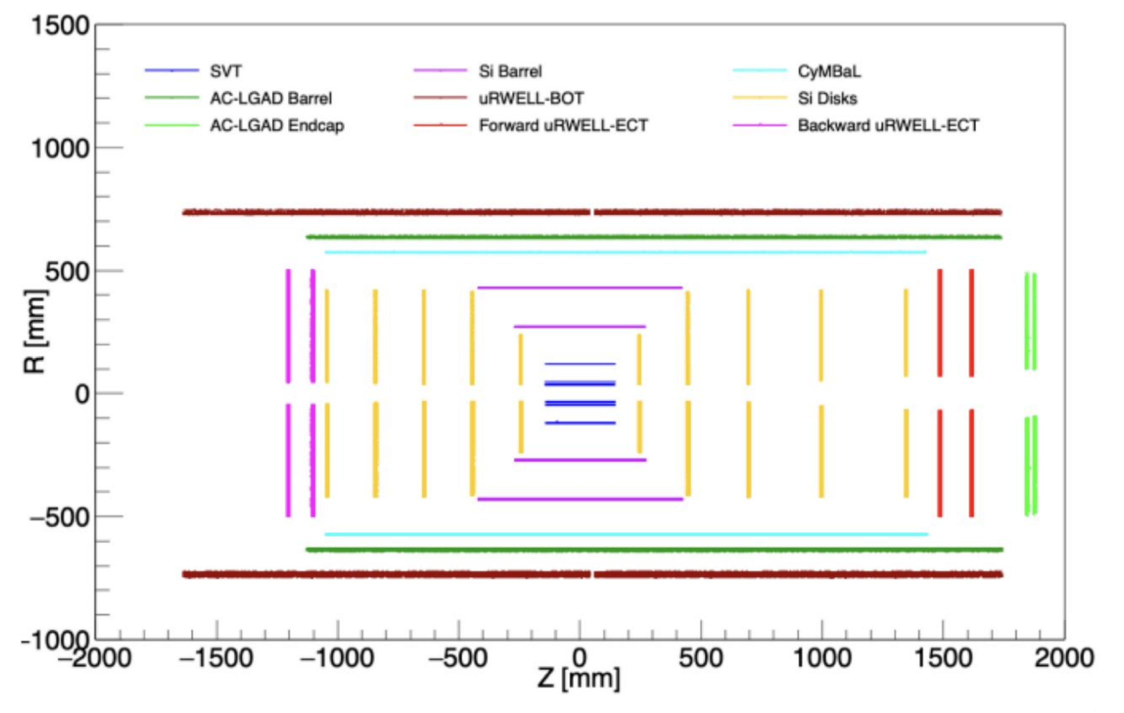
- Details about how AfterBurner works: https://github.com/eic/documents/blob/master/reports/general/Note-Simulations-BeamEffects.pdf

- AfterBurner Github: https://github.com/eic/afterburner?tab=readme-ov-file

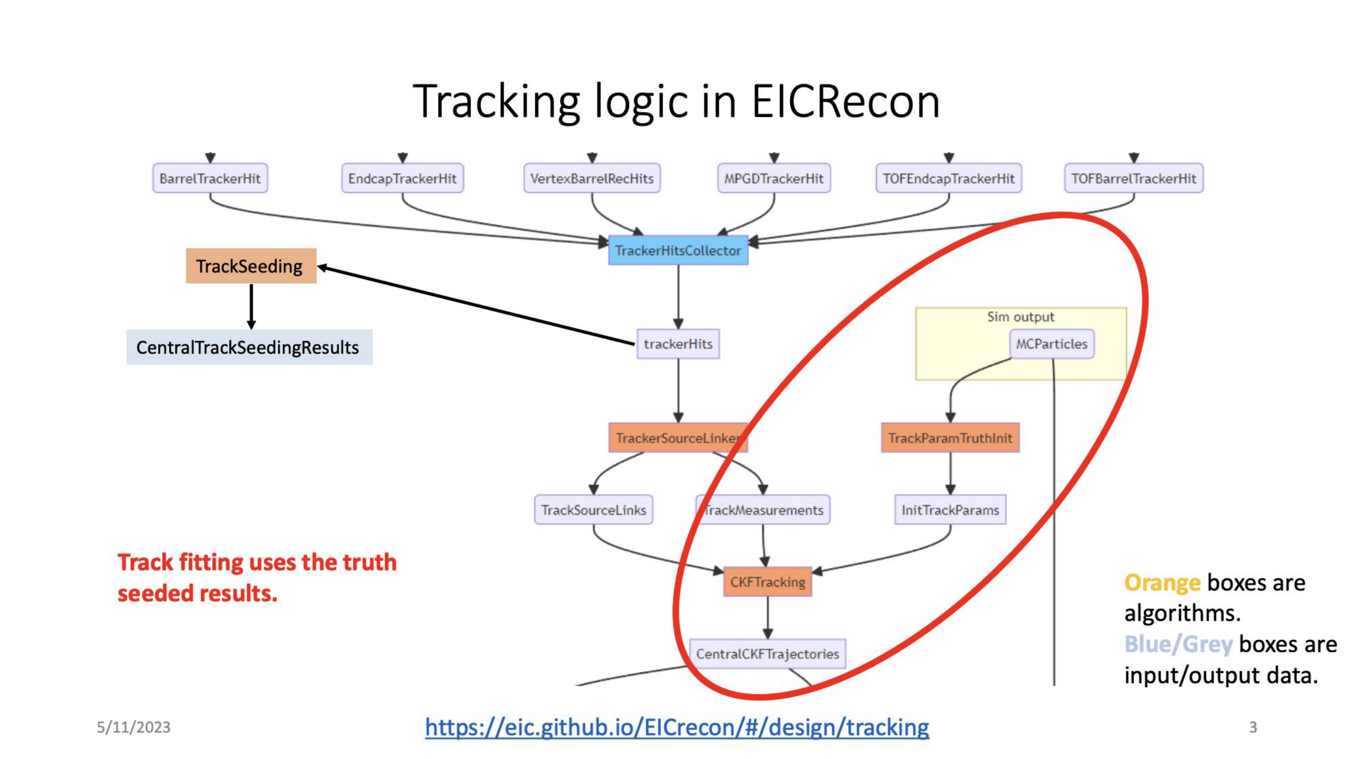
```
ab::AfterburnerConfig ab::EicConfigurator::preset_ip6_hidiv_275x18() {
    ab::AfterburnerConfig cfg;

    // Crossing angle
    cfg.crossing_angle_hor = 25e-3;          // Crossing angle in horizontal plane [rad]
    cfg.crossing_angle_ver = 100e-6;         // Crossing angle in vertical plane [rad]

    cfg.hadron_beam.beta_crab_hor = 1300000.0;
    cfg.lepton_beam.beta_crab_hor = 150000.0;

    // Beam divergence
    cfg.hadron_beam.divergence_hor = 150e-6;
    cfg.hadron_beam.divergence_ver = 150e-6;
    cfg.lepton_beam.divergence_hor = 202e-6;
    cfg.lepton_beam.divergence_ver = 187e-6;

    // Beam beta star [mm]
    cfg.hadron_beam.beta_star_hor = 800;
    cfg.hadron_beam.beta_star_ver = 71;
    cfg.lepton_beam.beta_star_hor = 590;
    cfg.lepton_beam.beta_star_ver = 57;

    // RMS emittance
    cfg.hadron_beam.rms_emittance_hor = 18e-6;
    cfg.hadron_beam.rms_emittance_ver = 1.6e-6;
    cfg.lepton_beam.rms_emittance_hor = 24e-6;
    cfg.lepton_beam.rms_emittance_ver = 2e-6;

    // RMS bunch length
    cfg.hadron_beam.rms_bunch_length = 6 * cm;
    cfg.lepton_beam.rms_bunch_length = 0.9 * cm;
    return cfg;
}
```

↑ beam parameters from [AfterBurner GitLab]

ePIC Tracker Geometry



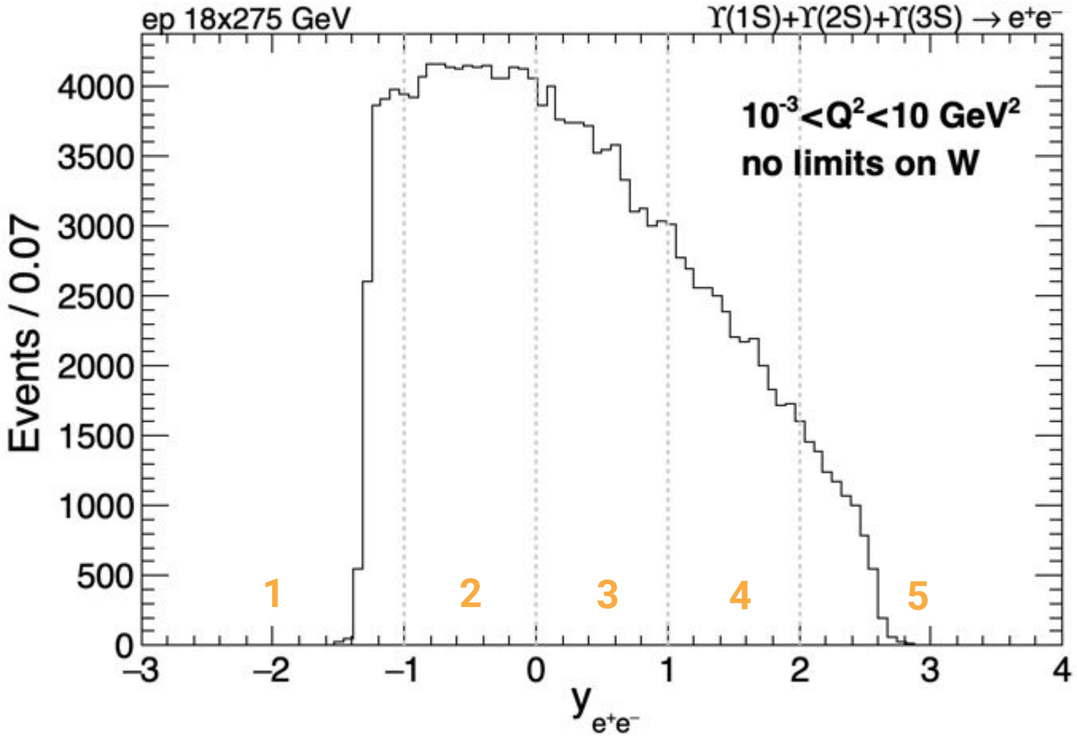
MC Truth Seeded Tracking



↑ Tracking logic from [Barak's presentation]

Rapidity of Upsilon (e^+e^-)

Truth Seeding (ChargedReconstructedParticle)



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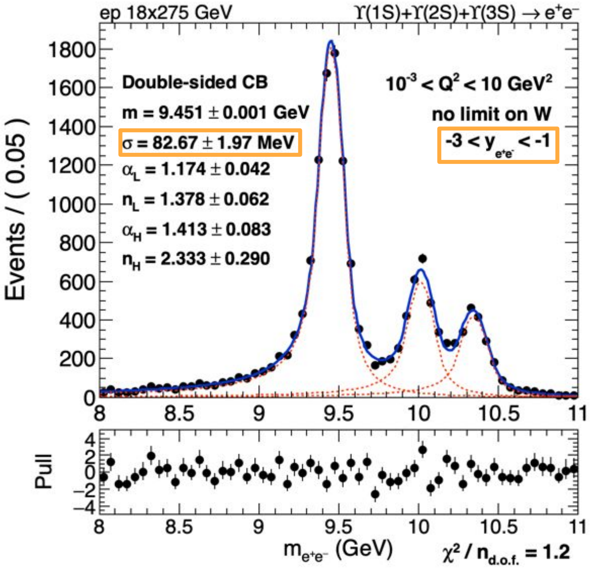
1



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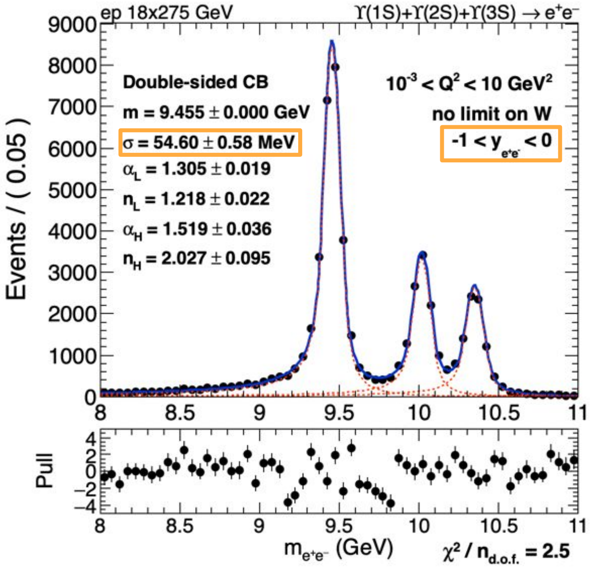

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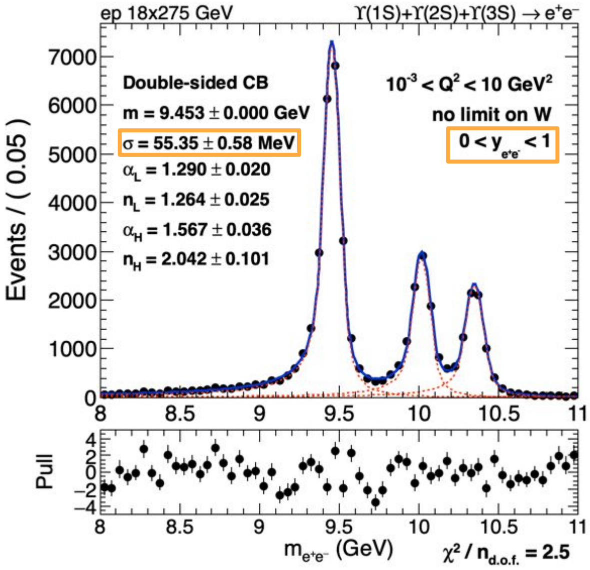

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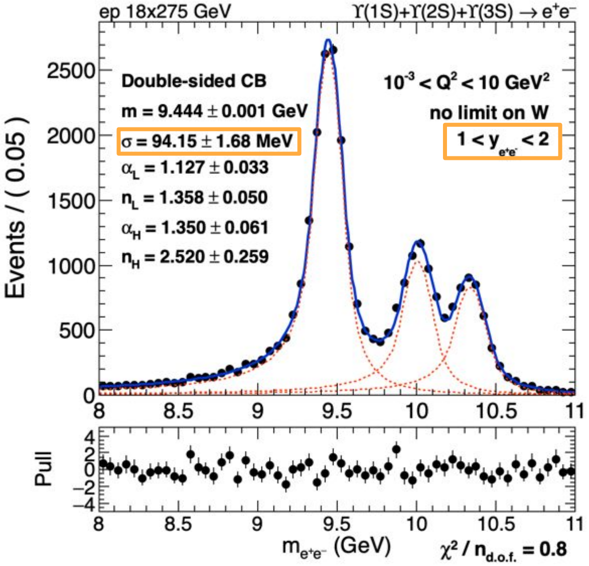
Upsilon Invariant Mass Fit (e^+e^-)

Truth Seeding (ChargedReconstructedParticle)

4



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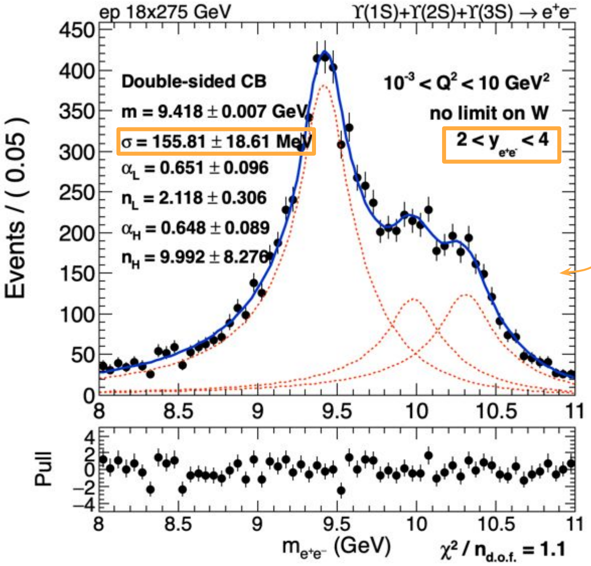

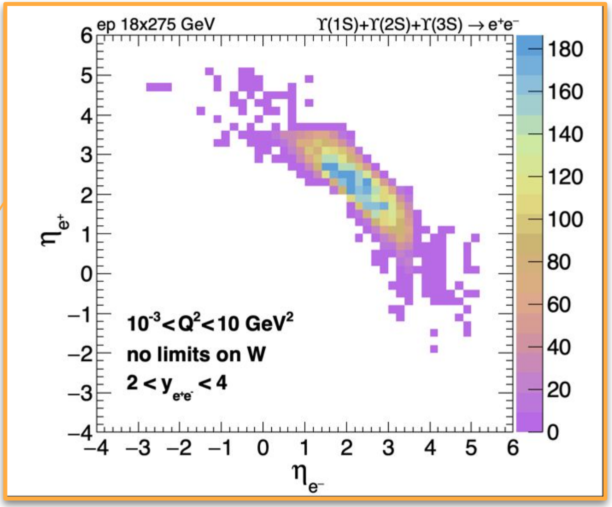

Pseudorapidity of Daughters (e^+e^-)

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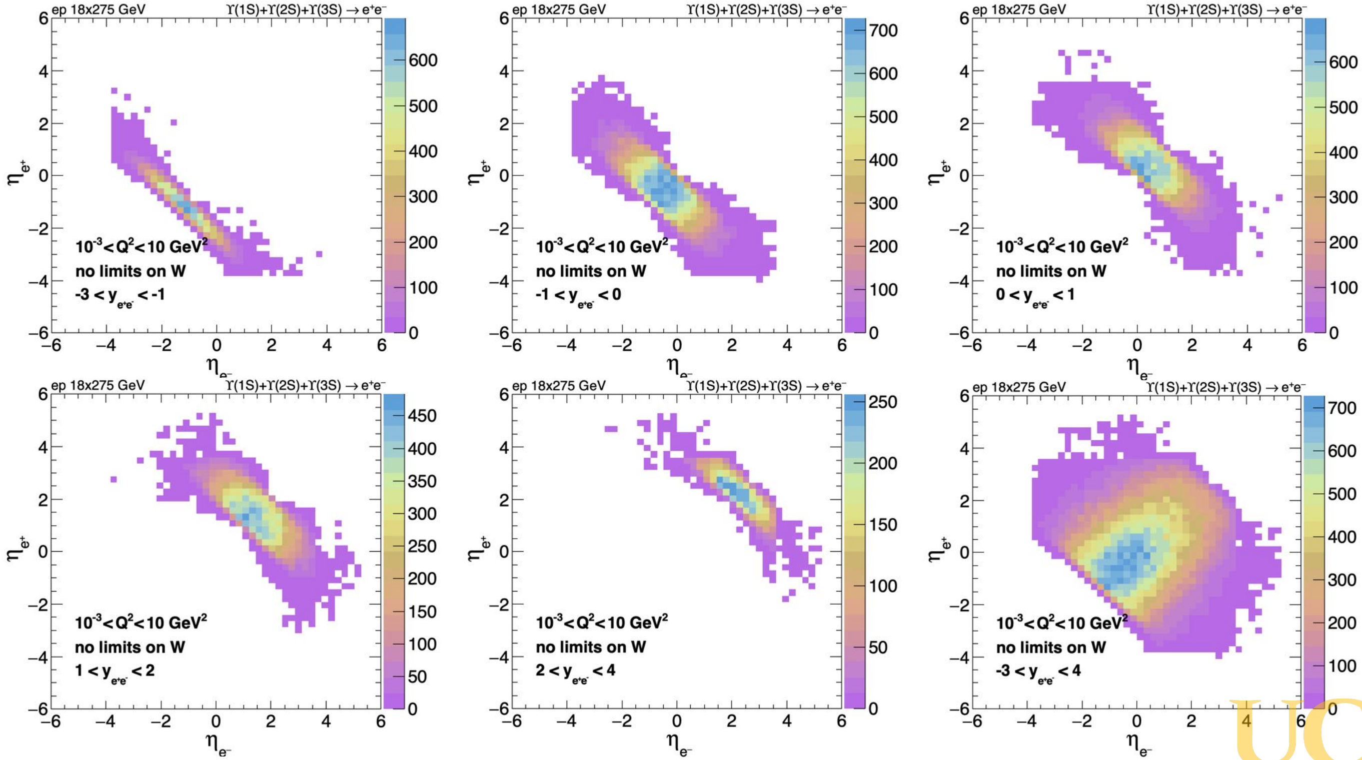
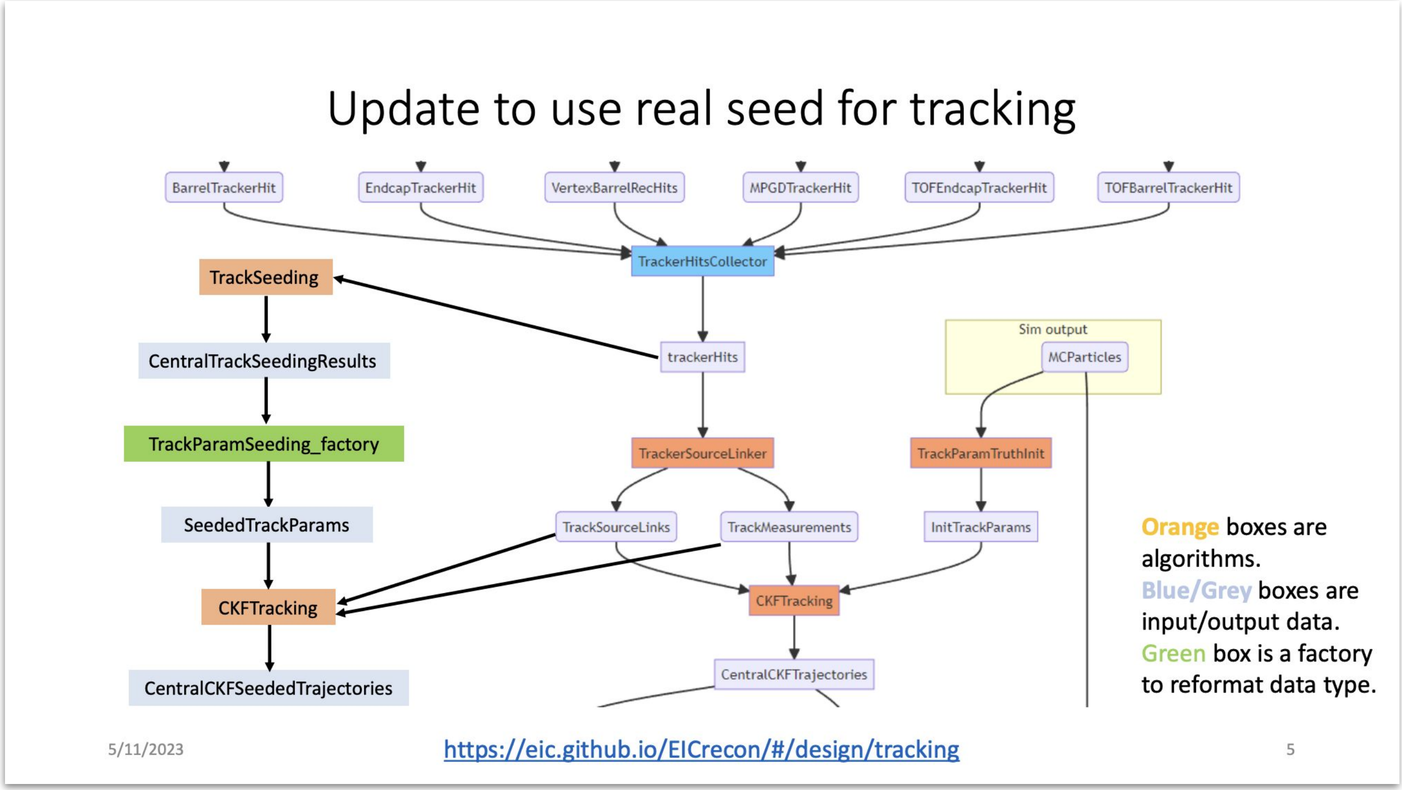


Realistic Seeded Tracking



↑ Tracking logic from [Barak's presentation]

Some Branches in EICrecon Output Tree

- ‘GeneratedParticles’ Branch

daughter electron and positron

```
GeneratedParticles.PDG = 11, 11, -11, 2212
GeneratedParticles.type = 1, 1, 1, 1
```

final states particles

```
GeneratedParticles.momentum.x = -0.589718, 3.660043, -2.709021, -7.201378
GeneratedParticles.momentum.y = 0.417540, 3.544635, -3.140867, -0.805943
GeneratedParticles.momentum.z = -15.517923, 2.304192, 4.414106, 265.785461
```

- ‘MCParticles’ Branch

0 1 2 3 4 5 6

```
MCParticles.PDG = 11, 22, 11, 2212, 11, -11, 2212, 11, 11, 22, 11, 11, 11, 22, 11, 11, 11
MCParticles.generatorStatus = 4, 13, 1, 4, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

```
MCParticles.momentum.x = 0.002996, 0.592714, -0.589718, -6.843054, 3.660043, -2.709021, -7.201378, -0.[illegible]59051, -0.001421, -0.000891, 0.000329, -0.003687, -0.912660, -0.000677, -0.001986, -0.000012, -0.810232, -0.0028
MCParticles.momentum.y = -0.000721, -0.418260, 0.417540, 0.016086, 3.544635, -3.140867, -0.805943, 0.3[illegible]0745, -0.002588, -0.000987, -0.001598, -0.004057, -1.003064, -0.000743, -0.002181, 0.000054, -0.888553, -0.00310
MCParticles.momentum.z = -17.998564, -2.480602, -15.517923, 274.98[illegible]765, 2.304192, 4.414106, 265.785461, -12.420634, 0.000885, 0.001417, 0.001718, 0.005854, 1.446919, 0.001072, 0.003145, 0.001486, 1.278861, 0.004477,
```

- ‘ReconstructedChargedParticles’ Branch

```
ReconstructedChargedParticleAssociations.simID = 4, 5
```

```
ReconstructedChargedParticles.momentum.x = -1.320642, 3.596476, -2.880852
ReconstructedChargedParticles.momentum.y = 0.979386, 3.483802, -3.335703
ReconstructedChargedParticles.momentum.z = -35.363762, 2.265088, 4.688744
```

```
ReconstructedChargedParticles.PDG = 0, -11, 11
```

not always true

```
ReconstructedChargedParticles.mass = 0.000000, 0.000000, 0.000000
```

store 0 for mass

```
ReconstructedChargedParticles.type = -1, 0, 0
```

Upsilon Resolution in STAR

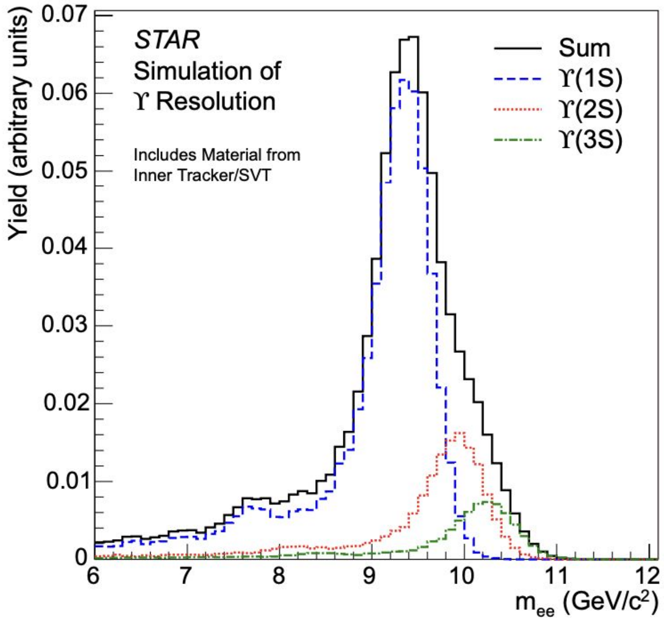


Figure 44. The ϒ family dielectron mass spectrum from a STAR simulation. *Reference?*

↑ From R. Vogt et al., RHIC-II Heavy Flavor White Paper, 2008

Detector Simulation Issue with Ion Energy

- Another problem with the sample in eA collisions:
  - After adding beam effects using AfterBurner, the speed of the detector simulation is so slow.. (10 events ~ 1 hour and 10 mins)

    → splited the file into 1000 containing 100 events each

    → timeout in the reconstruction step

- It's a known issue:

  https://indico.bnl.gov/event/23379/contributions/91676/attachments/54499/93261/FFDetector_performance_BGU.pdf#page=7

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