

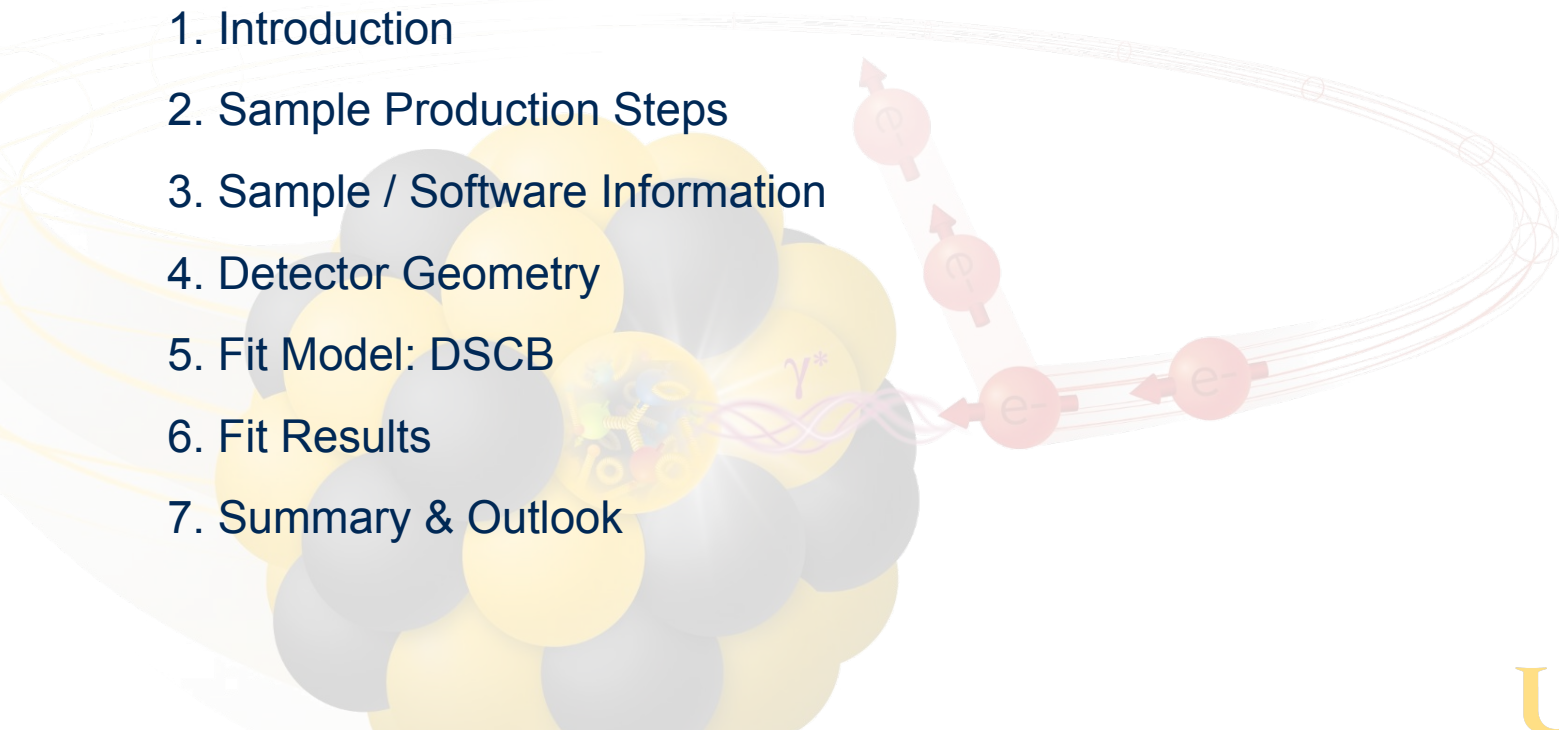
Separation of Three γ states in ePIC

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California EIC Consortium Meeting, Davis
August 15, 2024



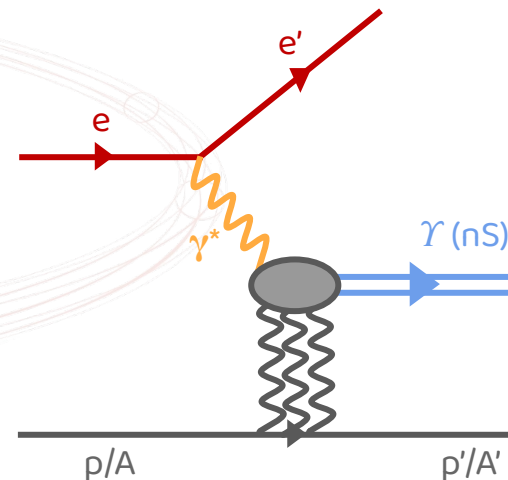
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Introduction

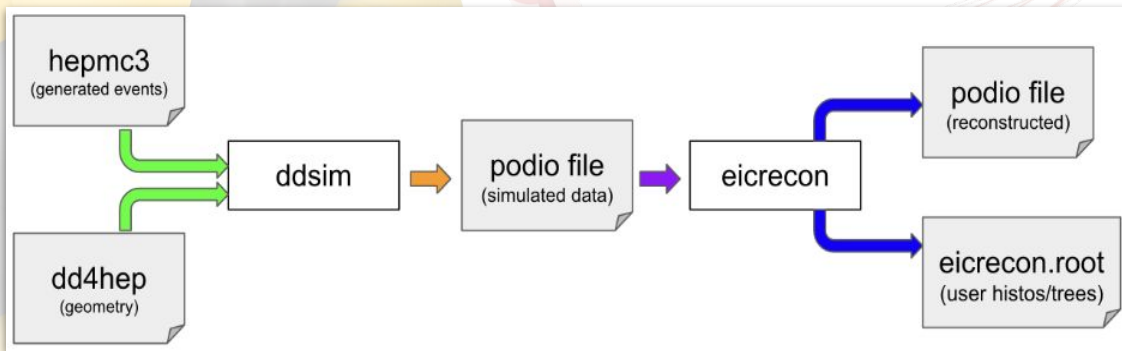
- Exclusive Vector Mesons:
 - $\gamma(1S)$, $\gamma(2S)$ and $\gamma(3S) \rightarrow e^+e^-$
 - Heavy vector mesons can probe gluon GPDs
→ provide information about gluon saturation
- Preliminary Study: Tracker resolution using Invariant mass spectrum of $\gamma(1S)$, $\gamma(2S)$, and $\gamma(3S)$ in the electron channel by ePIC
 - ePIC TDR
 - Benchmark
- Current status:
Obtained the invariant mass resolution of three γ states in electron channel, depending on the upsilon rapidity regions, using both truth seeding and realistic seeding



Sample Production Steps

- Simulation Procedure:

1. [eSTARlight](#): generate Upsilon's 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:

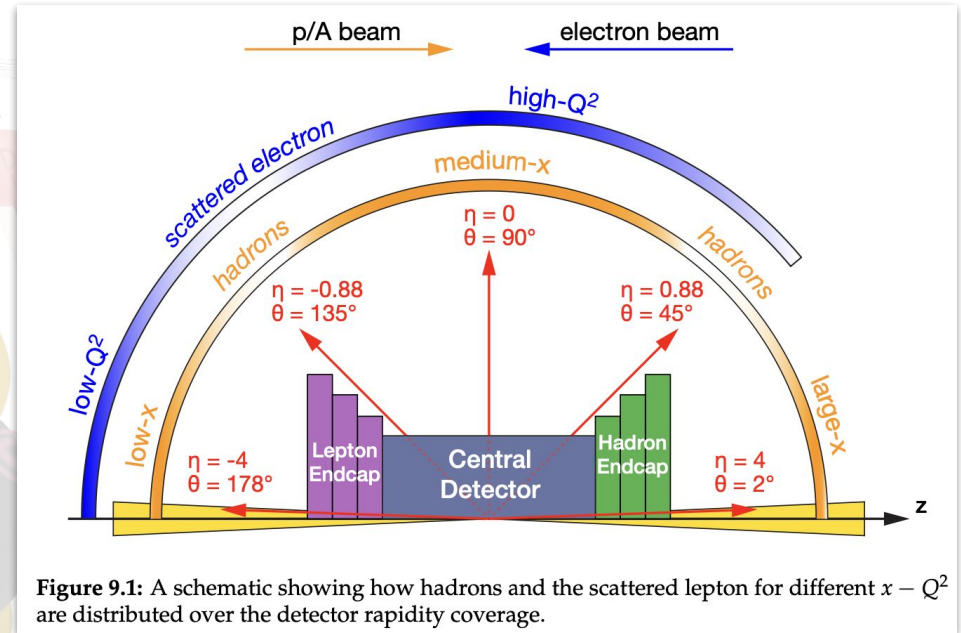
- ep 18 x 275 GeV
- γ (NS) to e^+e^-
- $0.001 < Q^2 < 10 \text{ GeV}^2$
- No limit on W

- Software Information:

- Generated on Jul 29th 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

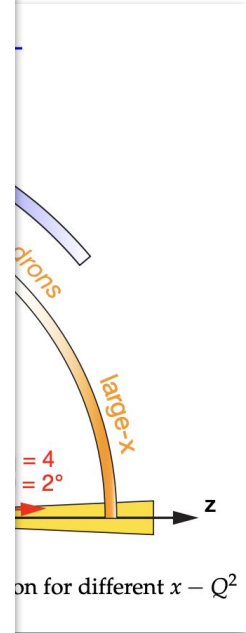
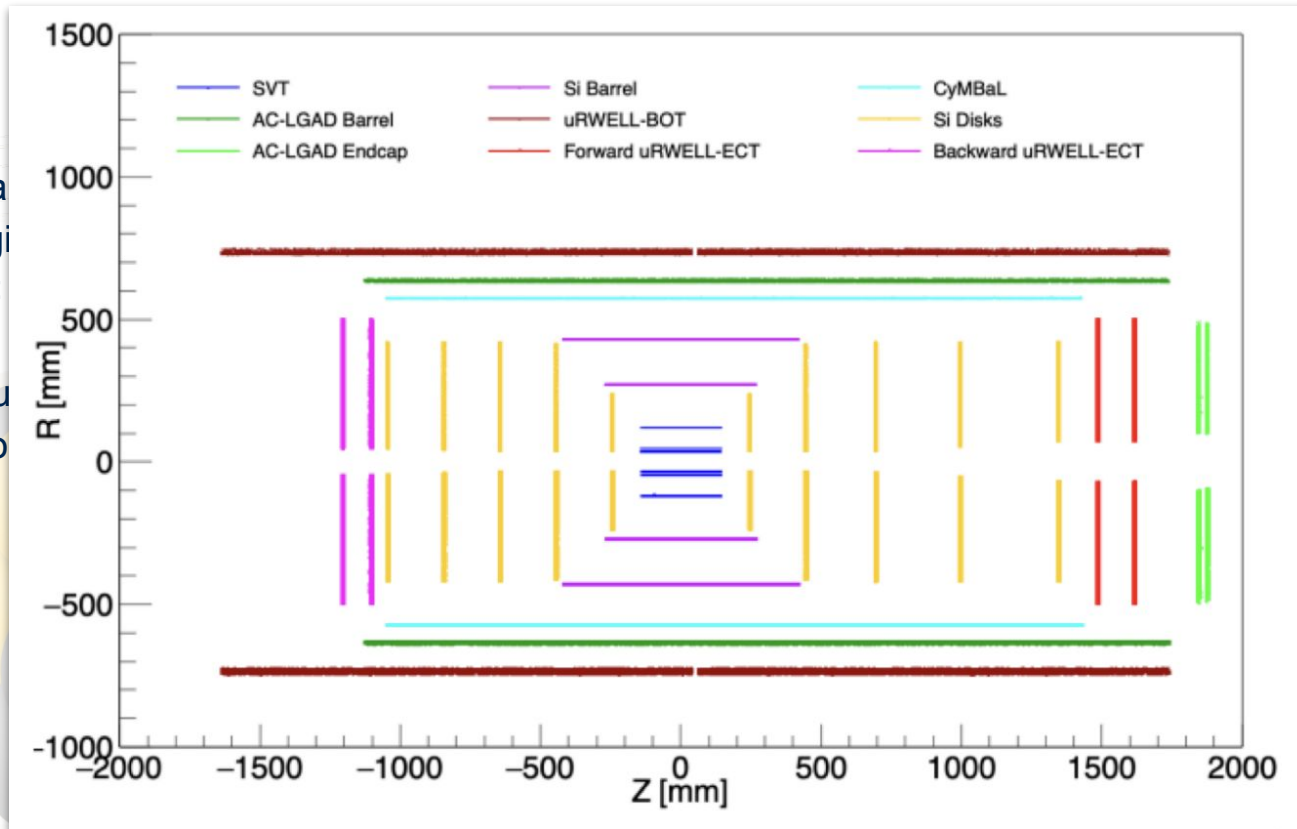
- The central detector instruments the $-4 < \eta < 4$ region with full coverage of the range $|\eta| < 3.5$
- This resolution study focuses on γ states reconstructed by the Si tracker



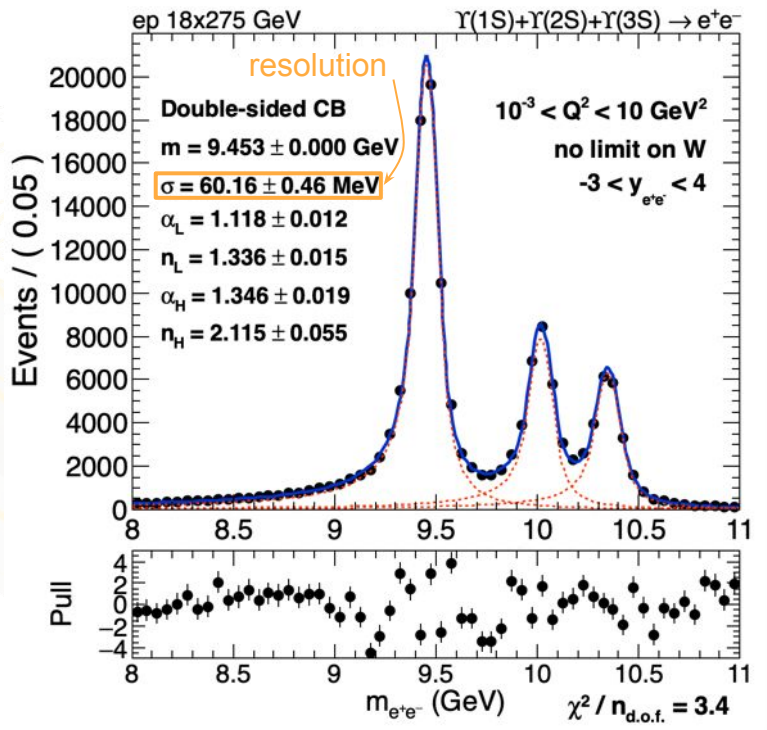
↑ From [EIC Yellow Report](#)

ePIC Detector Geometry

- The central region $|\eta| < 4$ region
- This resolution states reco



Fit Model: DSCB



- Fit to Double Sided Crystal Ball (DSCB) functions

- Double Sided Crystal Ball (DSCB) function

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

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

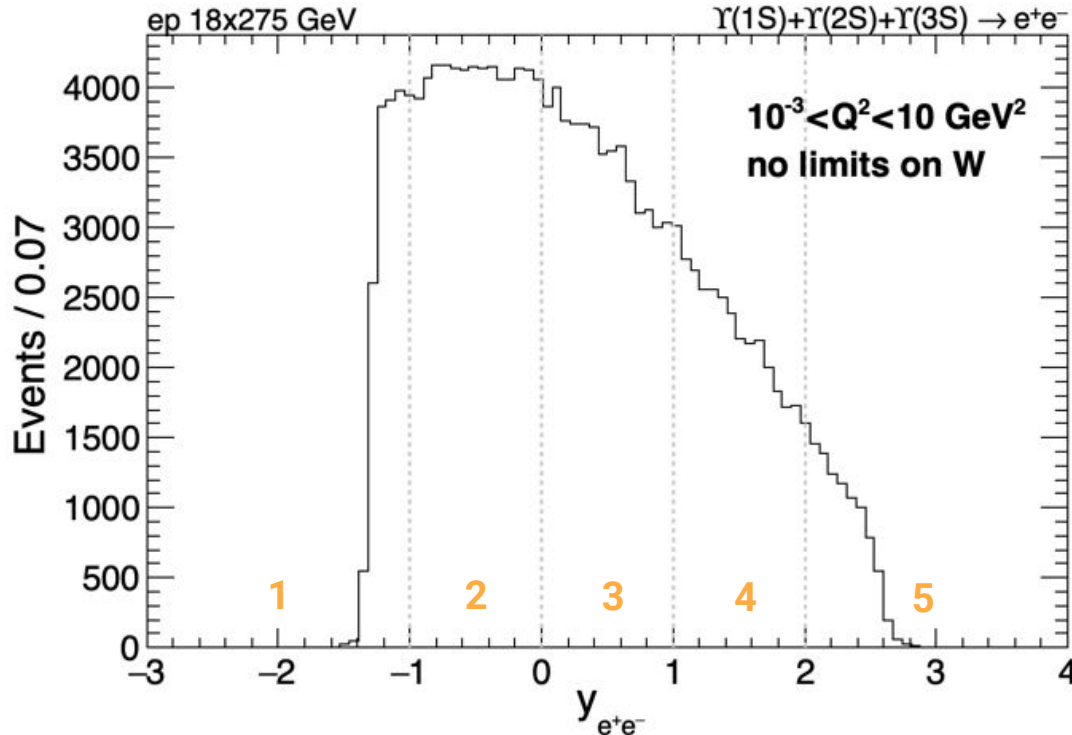
- Constraints:

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

$$m(\sigma)_{\gamma\text{NS}} = m(\sigma)_{\gamma\text{1S}} * \frac{\text{PDGmass}_{\text{NS}}}{\text{PDGmass}_{\text{1S}}}$$

Rapidity of Upsilon

Truth Seeding (ChargedReconstructedParticle)

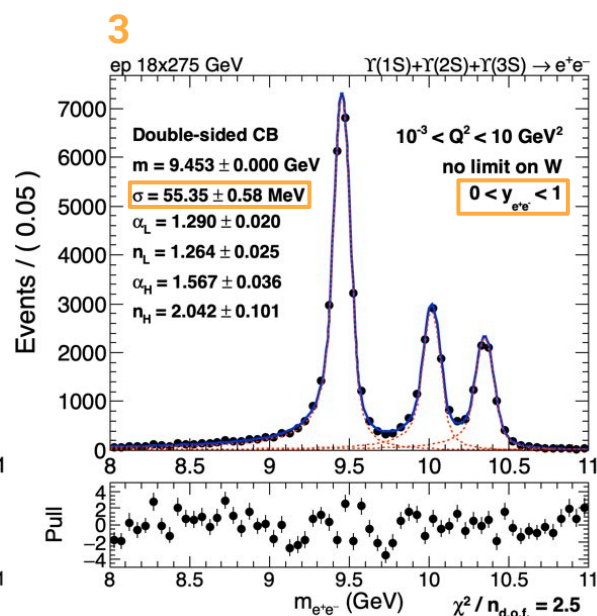
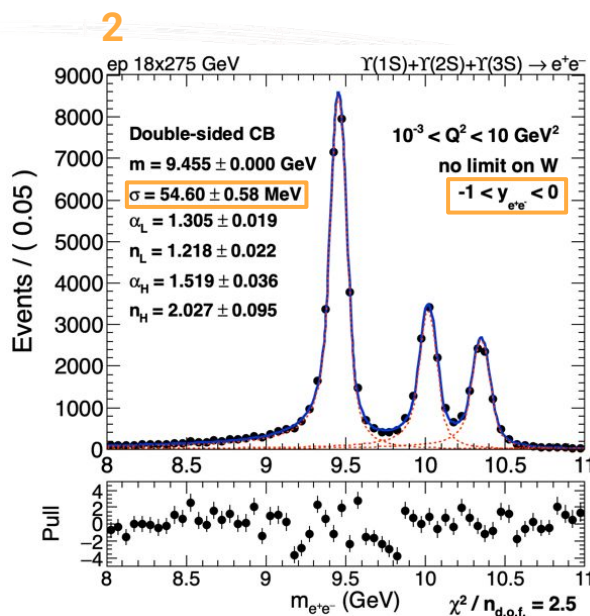
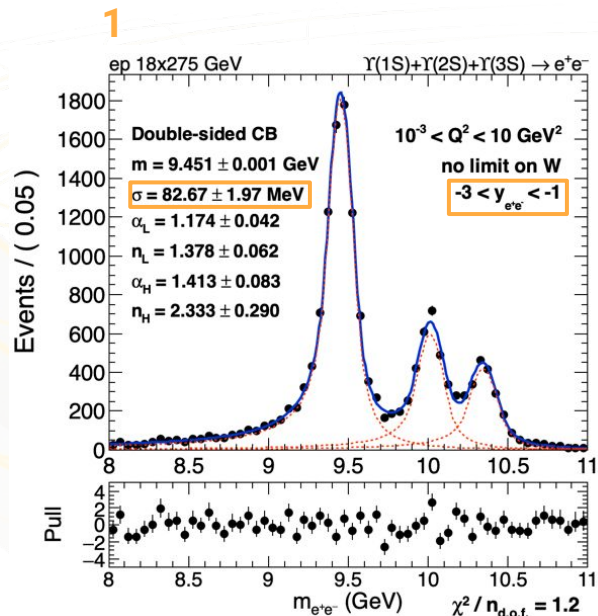


- Separate the regions depending on the reconstructed upsilron rapidity:

- 1: $-3 < y < -1$
- 2: $-1 < y < 0$
- 3: $0 < y < 1$
- 4: $1 < y < 2$
- 5: $2 < y < 4$

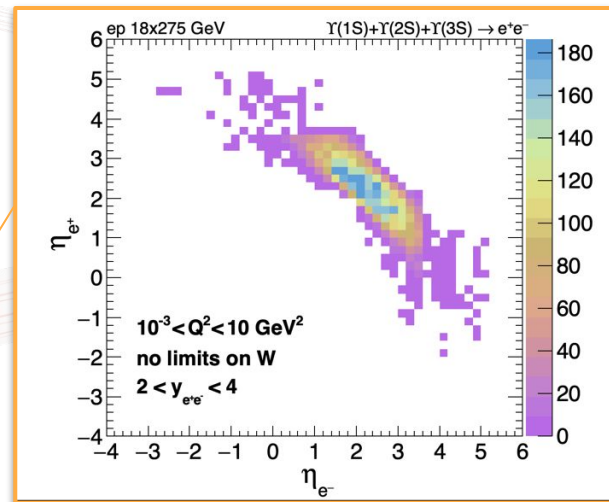
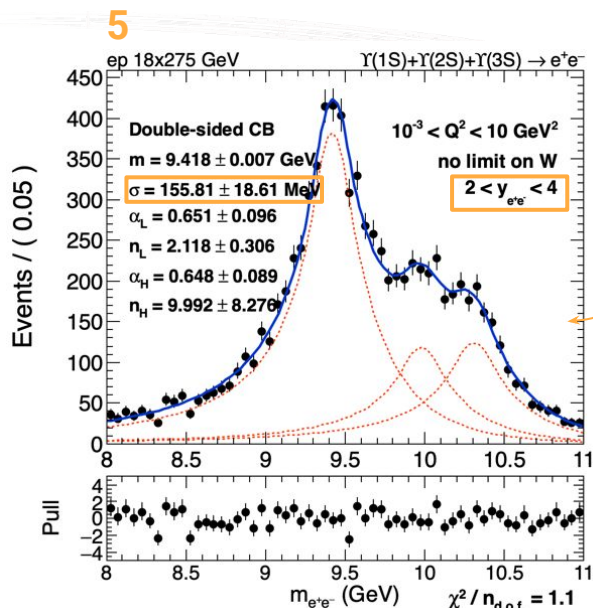
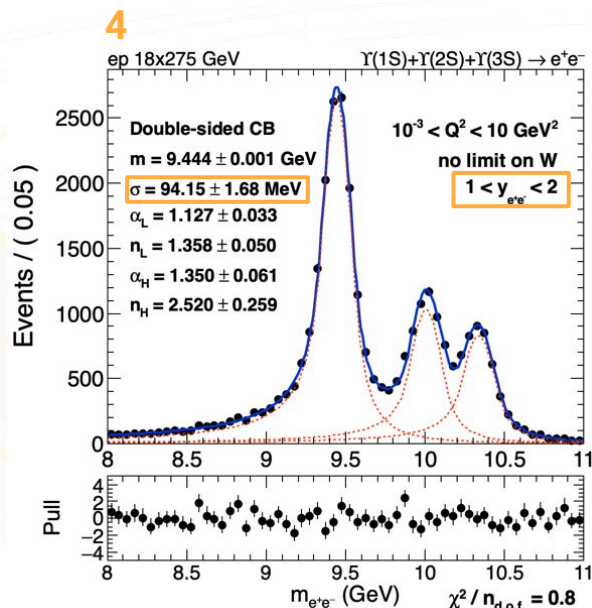
Upsilon Invariant Mass Fit

Truth Seeding (ChargedReconstructedParticle)



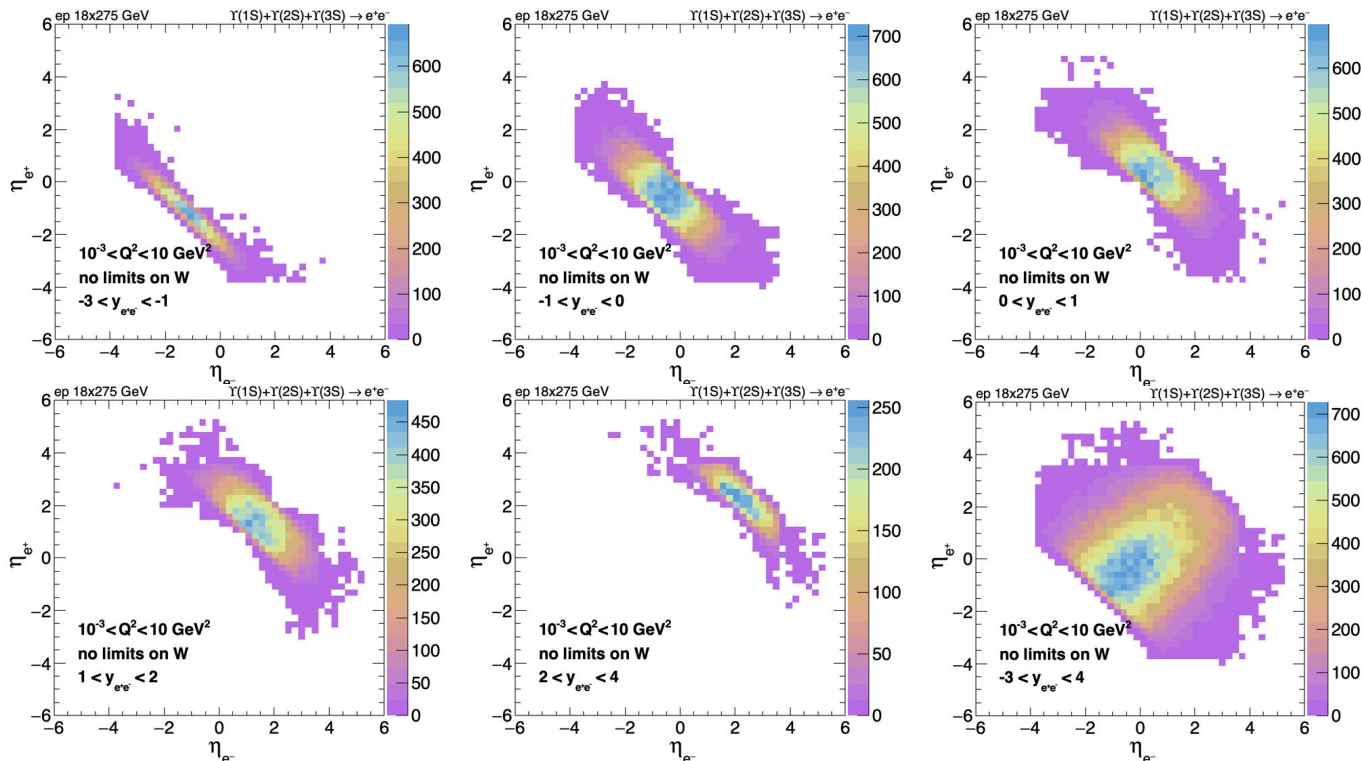
Upsilon Invariant Mass Fit

Truth Seeding (ChargedReconstructedParticle)



Pseudorapidity of Daughters

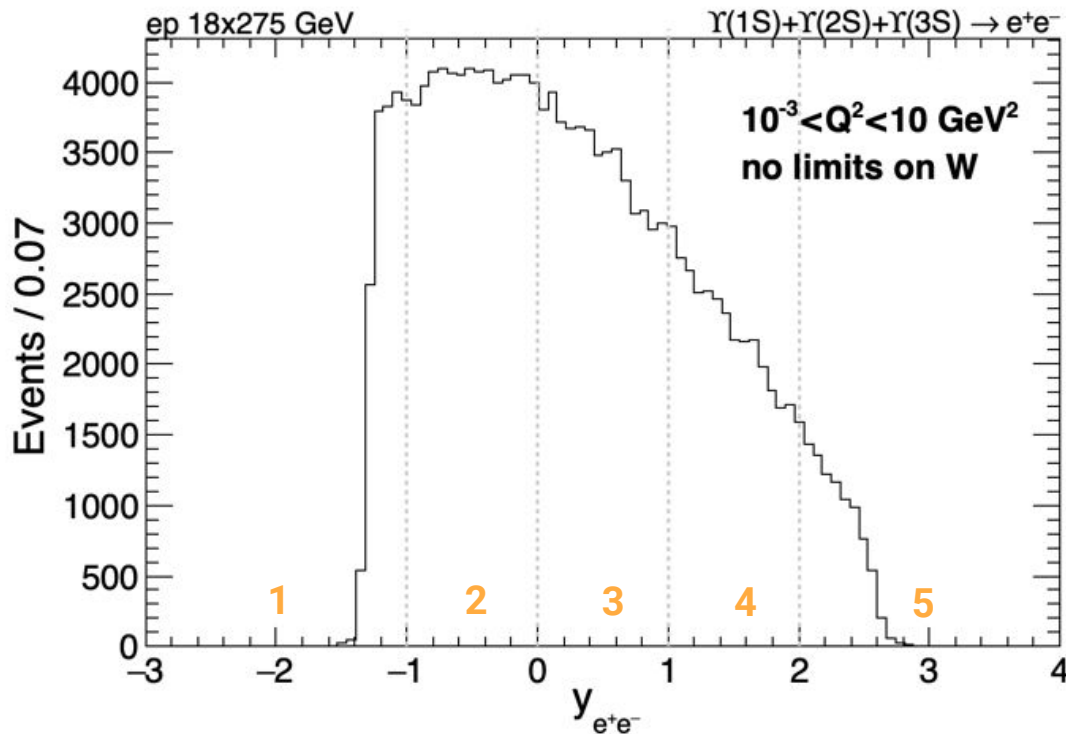
Truth Seeding (ChargedReconstructedParticle)



DAVIS

Rapidity of Upsilon

Realistic Seeding (ChargedReconstructedSeededParticle)

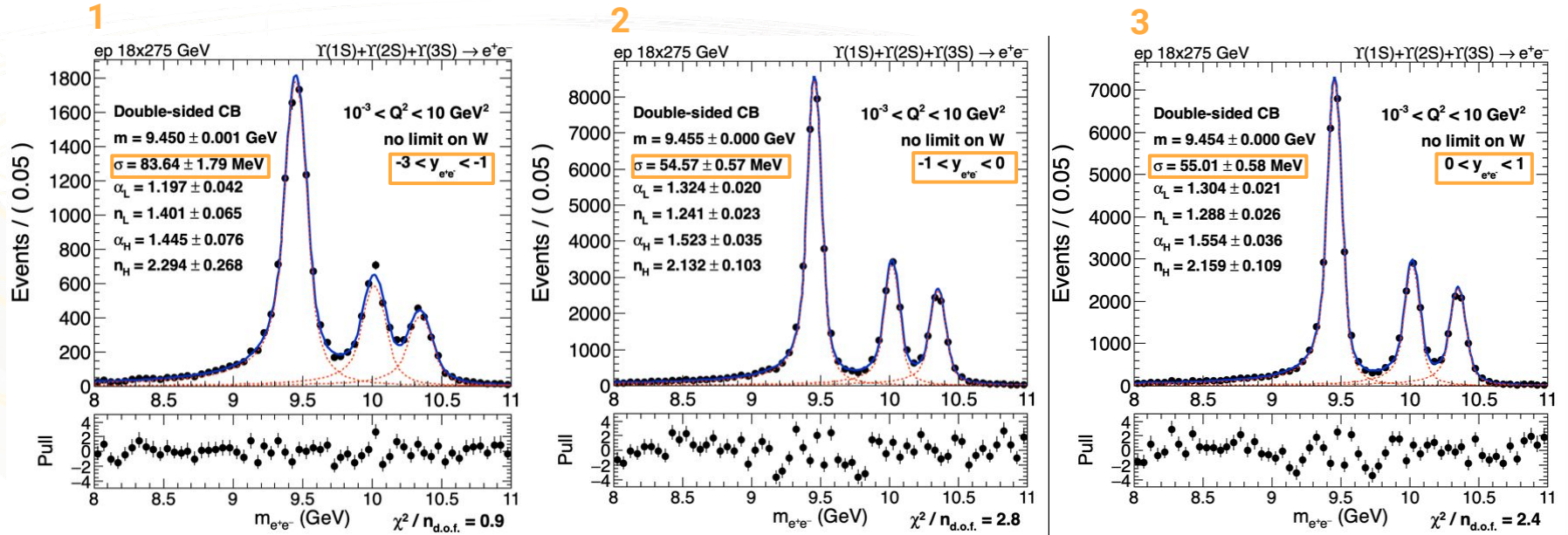


- Separate the regions depending on the reconstructed upsilon rapidity:

- 1: $-3 < y < -1$
- 2: $-1 < y < 0$
- 3: $0 < y < 1$
- 4: $1 < y < 2$
- 5: $2 < y < 4$

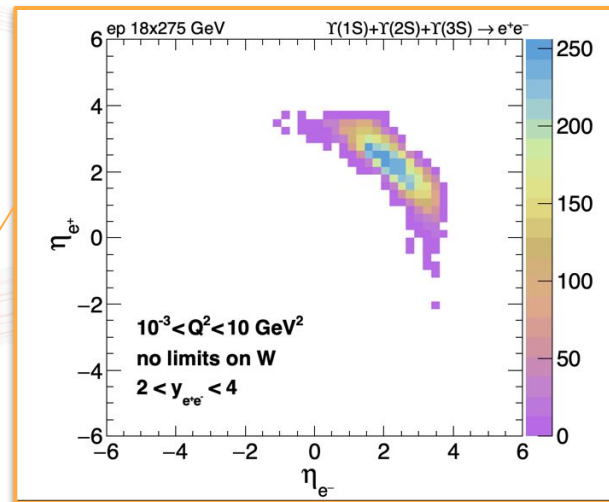
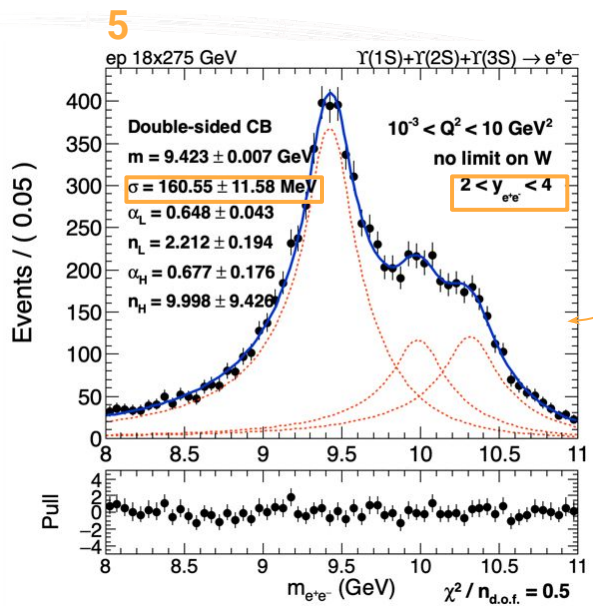
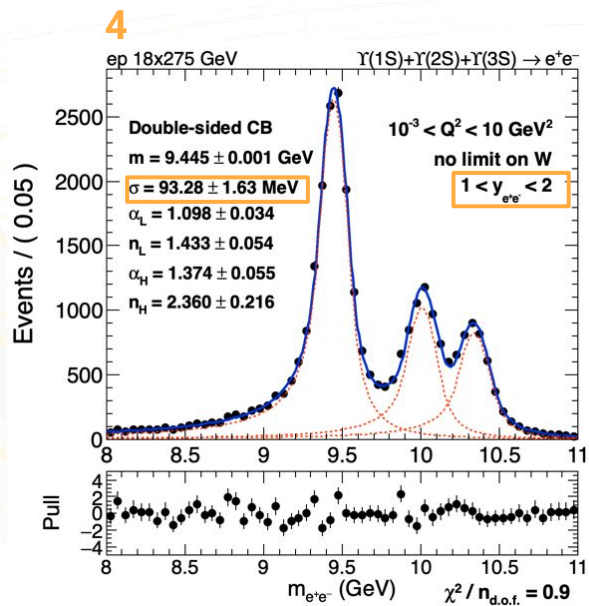
Upsilon Invariant Mass Fit

Realistic Seeding (ChargedReconstructedSeededParticle)



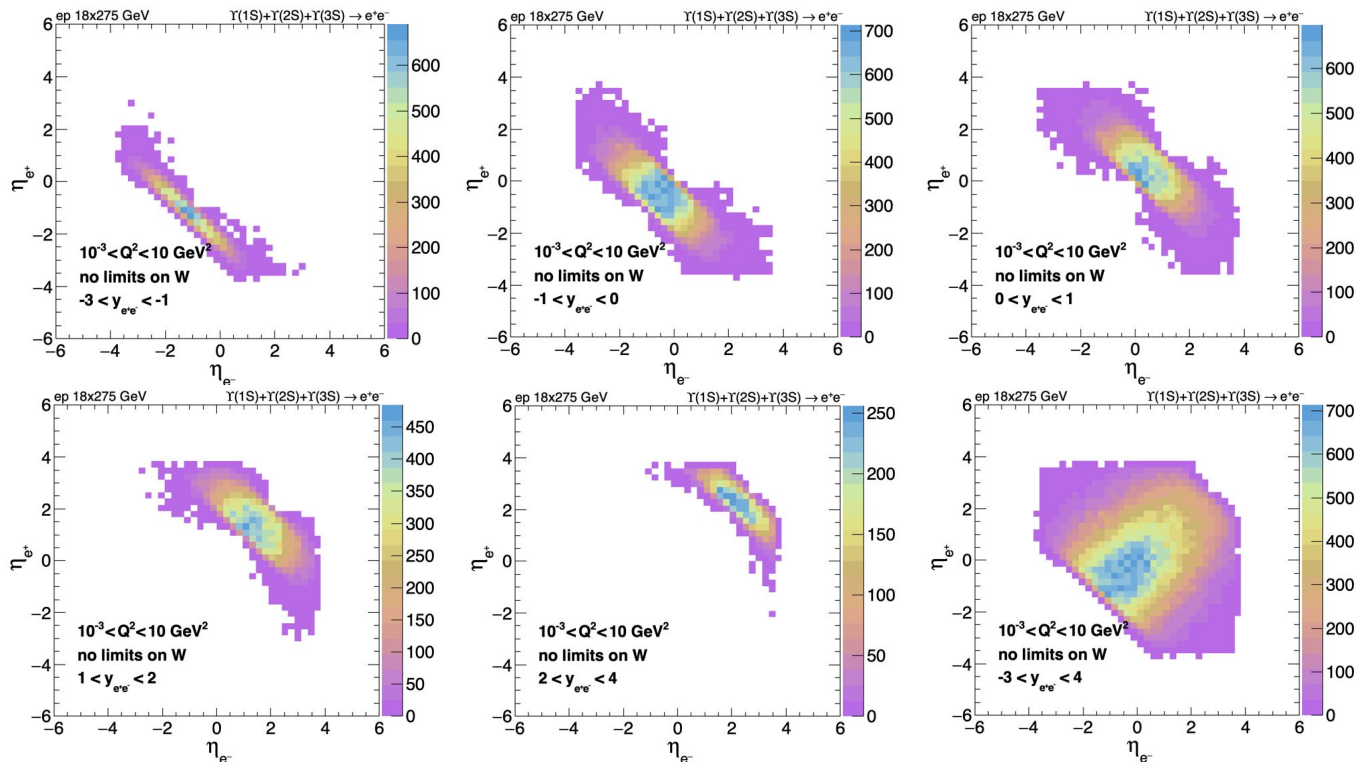
Upsilon Invariant Mass Fit

Realistic Seeding (ChargedReconstructedSeededParticle)



Pseudorapidity of Daughters

Realistic Seeding (ChargedReconstructedSeededParticle)



DAVIS

Summary & Outlook

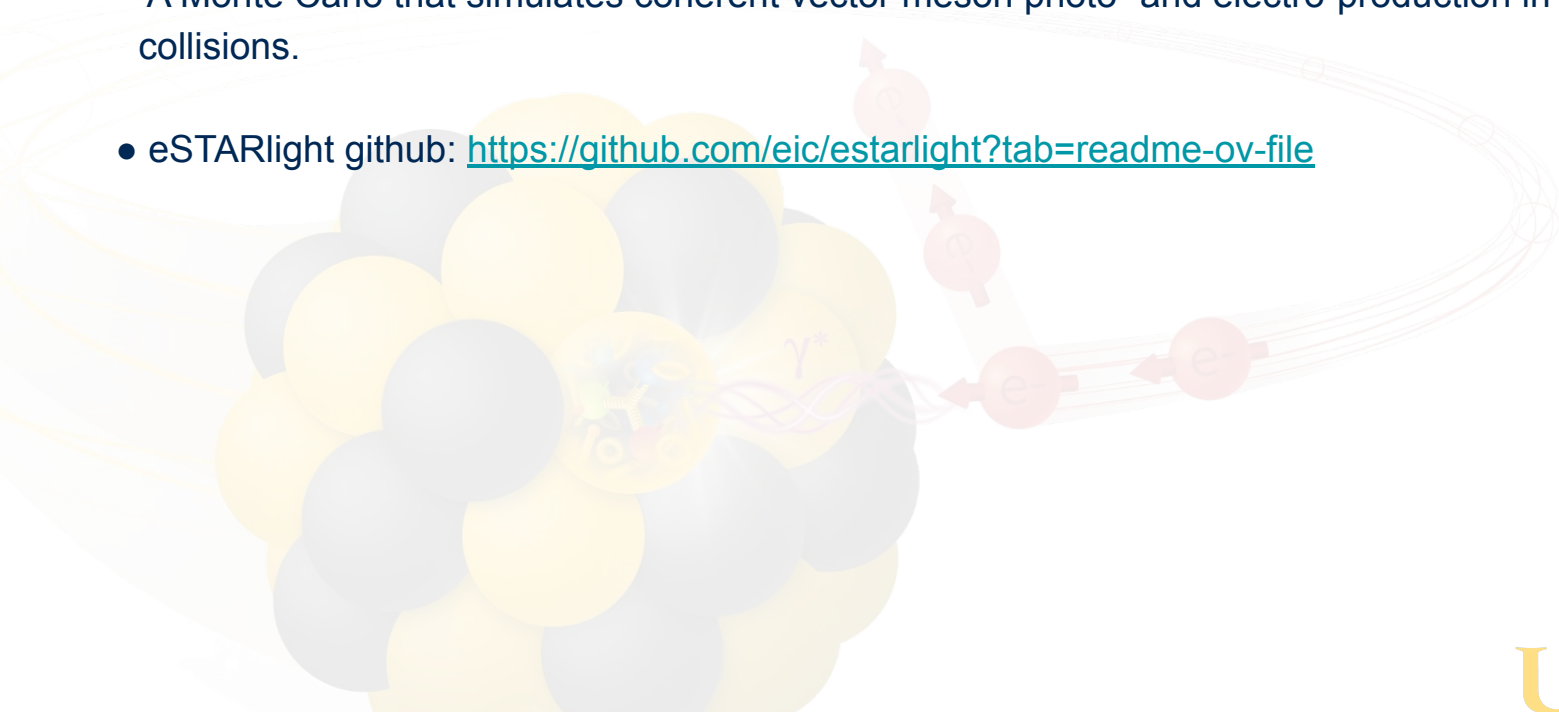
- Tracker resolution study to separate $\gamma(1S)$, $\gamma(2S)$, $\gamma(3S)$ states using simulation
 - eSTARlight (generate seeds) $\rightarrow$ AfterBurner (beam effects) $\rightarrow$ npsim (digitalization) $\rightarrow$ ElCrecon (reconstruction)
- The resolution of the three γ states was obtained using DSCB fits in the region of $0.001 < Q^2 < 10$ GeV² with both the truth seeding and the realistic seeding
 - (truth seeding)
 - $-3 < y < -1$: $\sigma = 82.7 \pm 2.0$ MeV
 - $-1 < y < 0$: $\sigma = 54.6 \pm 0.6$ MeV
 - $0 < y < 1$: $\sigma = 55.4 \pm 0.6$ MeV
 - $1 < y < 2$: $\sigma = 94.2 \pm 1.7$ MeV
 - $2 < y < 4$: $\sigma = 155.8 \pm 18.6$ MeV
 - (realistic seeding)
 - $-3 < y < -1$: $\sigma = 83.6 \pm 1.8$ 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
- Future work:
 - Include the study to the Benchmark simulation with the monthly sample production

The background features a faint, stylized illustration of a particle accelerator. A large, horizontal oval ring represents the main acceleration path. Inside this ring, several smaller circular components and arrows indicate the flow of particles. On the left side, a cluster of yellow and grey spheres represents a nucleus. A pink arrow labeled e^- points towards the nucleus, and a pink arrow labeled γ^* points away from it, suggesting a scattering process.

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>



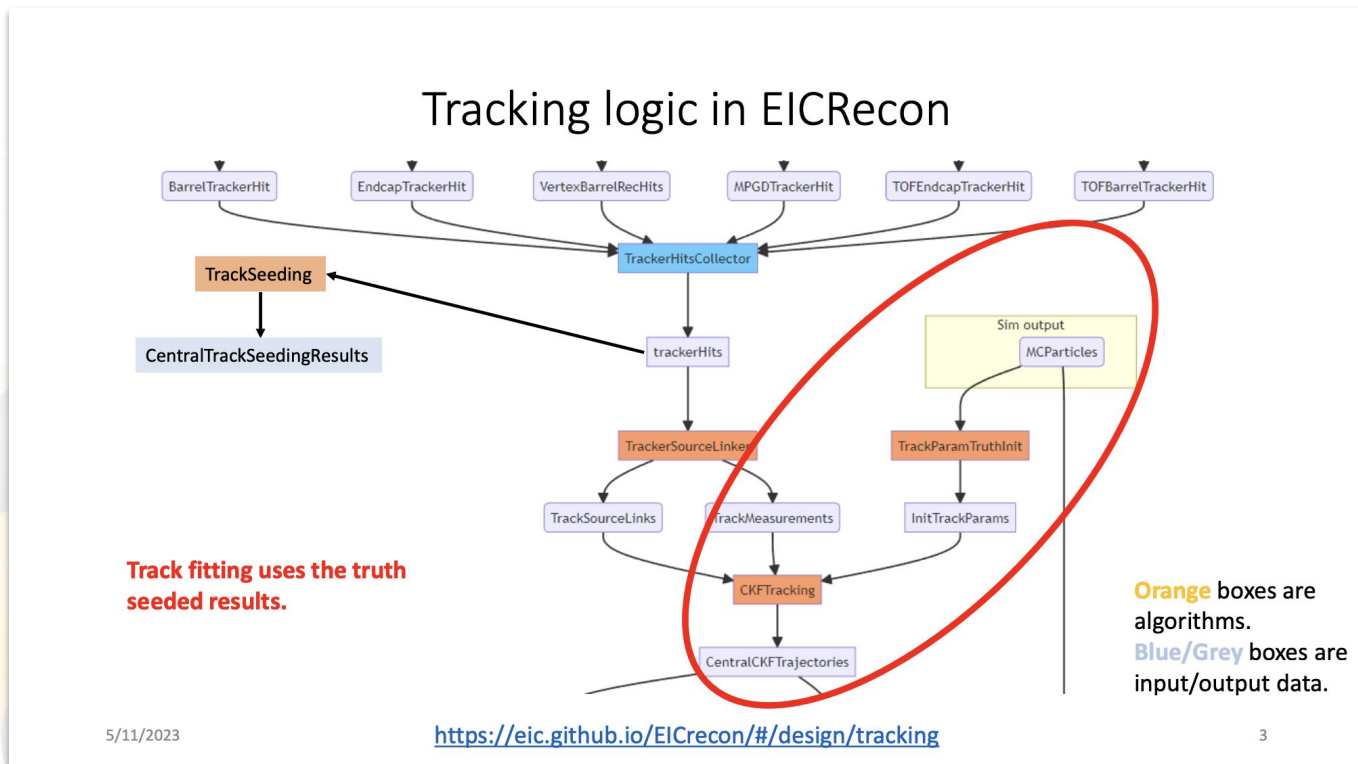
About AfterBurner

- 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/ports/general/Note-Simulations-BeamEffects.pdf>
- AfterBurner Github:
<https://github.com/eic/afterburner?tab=readme-ov-file>

```
471 ab::AfterburnerConfig ab::EicConfigurator::preset_ip6_hidiv_275x18() {
472     ab::AfterburnerConfig cfg;
473
474     // Crossing angle
475     cfg.crossing_angle_hor = 25e-3;           // Crossing angle in horizontal plane [rad]
476     cfg.crossing_angle_ver = 100e-6;         // Crossing angle in vertical plane [rad]
477
478     cfg.hadron_beam.beta_crab_hor = 1300000.0;
479     cfg.lepton_beam.beta_crab_hor = 150000.0;
480
481     // Beam divergence
482     cfg.hadron_beam.divergence_hor = 150e-6;
483     cfg.hadron_beam.divergence_ver = 150e-6;
484     cfg.lepton_beam.divergence_hor = 202e-6;
485     cfg.lepton_beam.divergence_ver = 187e-6;
486
487     // Beam beta star [mm]
488     cfg.hadron_beam.beta_star_hor = 800;
489     cfg.hadron_beam.beta_star_ver = 71;
490     cfg.lepton_beam.beta_star_hor = 590;
491     cfg.lepton_beam.beta_star_ver = 57;
492
493     // RMS emittance
494     cfg.hadron_beam.rms_emittance_hor = 18e-6;
495     cfg.hadron_beam.rms_emittance_ver = 1.6e-6;
496     cfg.lepton_beam.rms_emittance_hor = 24e-6;
497     cfg.lepton_beam.rms_emittance_ver = 2e-6;
498
499     // RMS bunch length
500     cfg.hadron_beam.rms_bunch_length = 6 * cm;
501     cfg.lepton_beam.rms_bunch_length = 0.9 * cm;
502     return cfg;
503 }
```

↑ beam parameters from [AfterBurner GitLab](#)

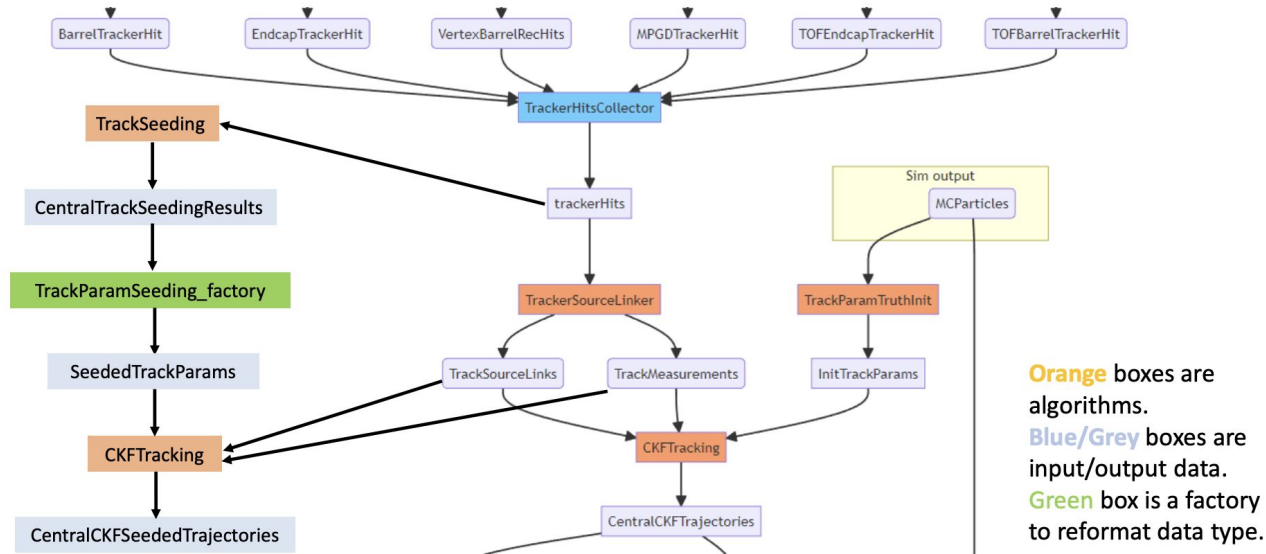
MC Truth Seeded Tracking



↑ Tracking logic from [Barak's presentation](#)

Realistic Seeded Tracking

Update to use real seed for tracking



5/11/2023

<https://eic.github.io/ElCrecon/#/design/tracking>

5

↑ Tracking logic from [Barak's presentation](#)

UC DAVIS

Some Branches in ElCrecon 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, -0.59051, -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, 0.30745, -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, 274.983765, 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

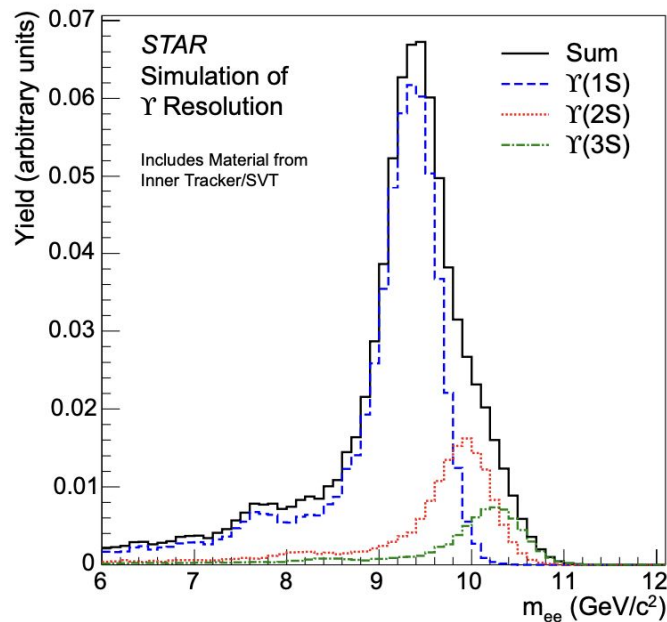


Figure 44. The Υ family dielectron mass spectrum from a STAR simulation.
Reference?

↑ 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)
 - splitted 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