Toward detector requirements: What tracking momentum resolution is required to separate the 3 Upsilon states?

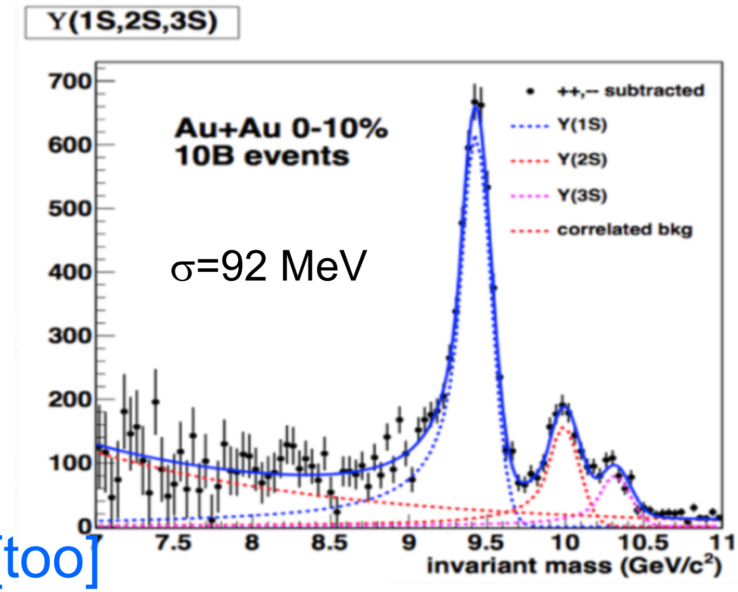
Spencer Klein *LBNL*

EIC WG meeting, April 23, 2020

- Why this matters: The three Υ states are three different particles, with different wave functions. By studying all three states, we probe nuclear targets with three different dipole wave functions
- What resolution is required?

What is needed

- Studied in Υ-> ee and μμ
- Upsilon masses:
  - Υ(1S): 9460 MeV
  - Υ(2S): 10023 MeV; Δm_{21}=331 MeV
  - Υ(3S): 10355 MeV; Δm_{32}=331 MeV [too]



S. Tardafar for sPHENIX, PoSMPGD, 2017067

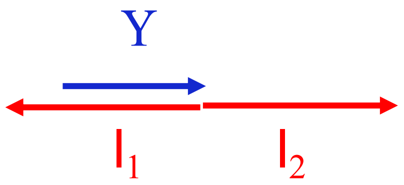
- Υ Separation is the signature tracking requirement for sPHENIX.
  - sPHENIX conclusion: σM_{ll} ~ 100 MeV is required
    - 1.5 σ from peak to mid-point cut line
    - 20-40% better resolution is desirable
- 3 components to resolution |p|, zenith & azimuthal angles
  - Today (like almost everyone else) will focus on |p|, since it involves sagitta, which is small for large |p|
- N. b. Rough estimates for pedagogical purposes
  - Simulations are needed

Momentum Resolution for σM_{ll}=100 MeV

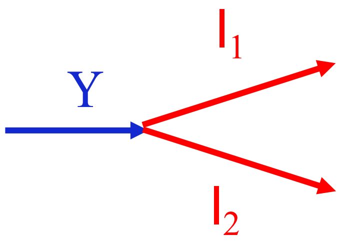
- $M_{ll}^2 = E^2 - p^2 = [\sqrt{m_l^2+p_1^2}) + \sqrt{(m_l^2+p_2^2)}]^2 - (p_1+p_2)^2$
- Assume $m_l<|p_1|, |p_2|$
- First consider photoproduction, with $Q^2 \sim 0$, so net dilepton p_T is small, near mid-rapidity
  - Leptons are back-to-back azimuthally
    - θ = angle between leptons, ~ 180^0
  - $|p_1| \sim |p_2| \sim 5$ GeV/c
- $M_{ll}^2 = \sim 2|p_1||p_2|(1-\cos(\theta))$
- For $\theta=180^0$ and $|p_1| \sim |p_2|=p$
  - $M_{ll}^2 = 4p^2$
  - $M\sigma_M=4p\sigma_p$ and $M \sim 2p$,
- We require $\sigma_p= \sigma_M/2 \sim 50$ MeV/c, or $\sigma_p/p \sim 1\%$
- Uncertainty on emission angles is neglected
  - ATLAS dilepton experience is that this is small

Momentum Resolution for $Q^2>0$

- $Q^2 \sim p_{T,U}^2$
- Q^2 reach is somewhat limited due to statistics.
  - Consider $Q^2=(3.75\text{ GeV})^2$
- Individual lepton p_T depend on orientation
  - Aligned – one p rises, the other drops



    - $M_{ll}^2 = 4|p_1||p_2|$
    - Constraint becomes $\sigma p_1=M\sigma_M/4p_2$, plus switched version
      - P_{slower}=3.1 GeV/c, p_{faster}=6.8 GeV/c
      - σp_{faster}= 80 MeV/c, $\sigma p/p$ = 1.1%
      - σp_{slower} = 36 MeV/c, $\sigma p/p$= 1.1%
    - Needs checking, but conditions seem relaxed(?)
  - Perpendicular; both p rise, opening angle drops

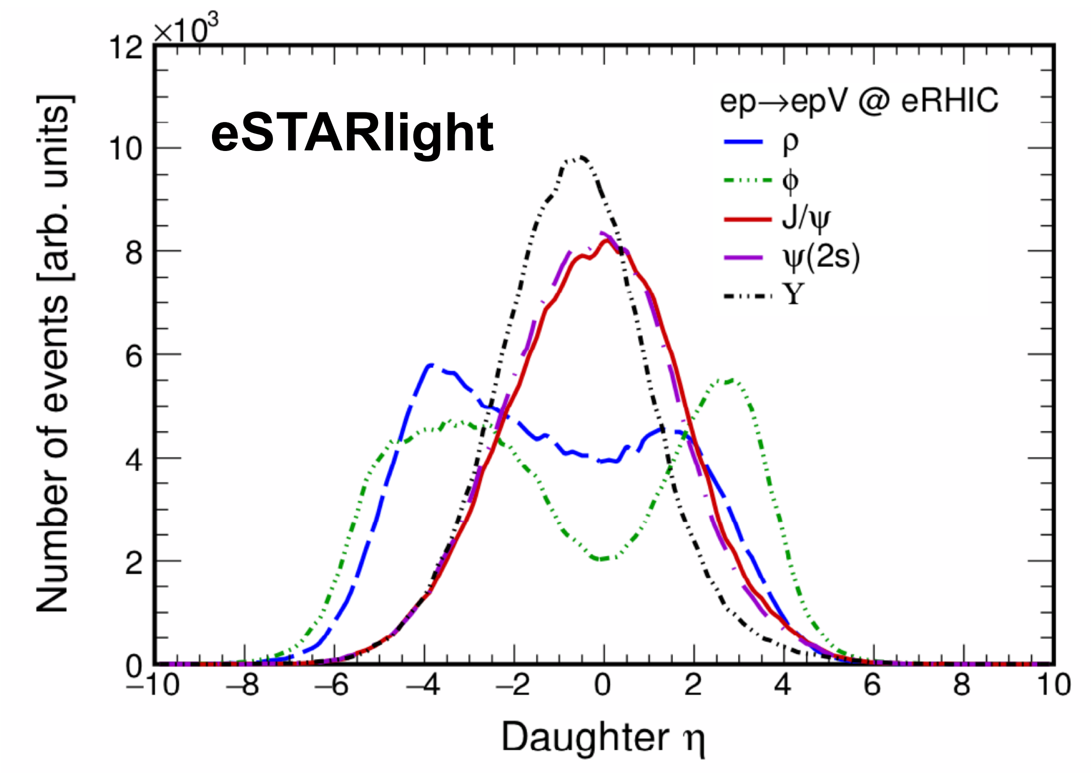


    - $M_{ll}^2 = \sim 2p^2(1-\cos(\theta))$ so $\sigma p=M\sigma M/2p(1-\cos(\theta))$
      - Rough estimate $\cos(\theta)=0$, p~6 GeV
      - σ_p ~ 80 MeV, so $\sigma p/p$=1.3%
- $Q^2>0$ slightly relaxes momentum resolution requirements

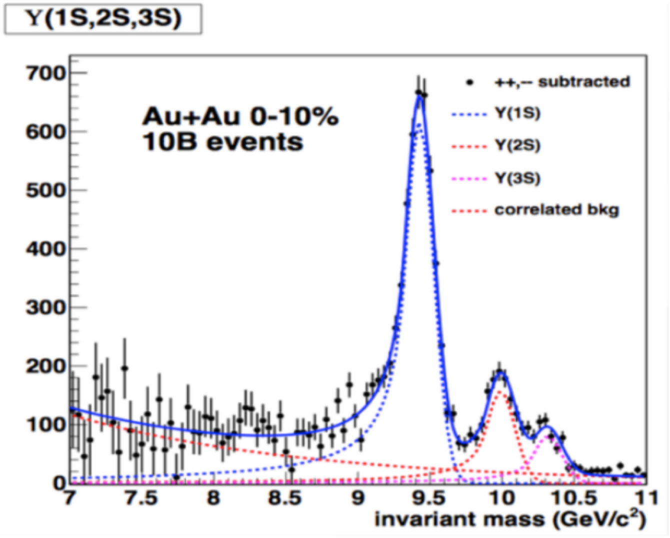
η range

Should cover most of the lepton daughters from Υ decays

- Cost/benefit question in rapidity coverage
  - 4< η < 4 seems like a reasonable choice



Technical Summary



- sPHENIX criteria for separating 3 Υ states:
  - σM_{ll} = 100 MeV/c
    - 20-40% better than this would yield physics gains
- Requires $\sigma|p|/p \sim 1\%$ at 5 GeV/c for $Q^2 \sim 0$
- Other considerations:
  - $\sigma(\theta)$ angle wrt the beampipe (for rapidity determination)
  - $\sigma(\phi)$ azimuthal angle is likely important for determining Υ p_T
- Do we need limits on material, which can affect the low-mass bremsstrahlung tail?
- How sophisticated/nuanced do the requirements need to be?

“Detector Requirement” language

- How formal should they be
- Tentative proposal:
  - Tracking momentum resolution $\delta p/p<1\%$ for p=5 GeVc in the momentum range for $4< \eta < 4$
    - A case could be made for a slightly tighter choice
- Alternate less detector focused approach:
  - Upsilon mass resolution for ee and $\mu\mu$ channel $\sigma_M <= 100$ MeV/c
- Even less detector specific
  - Able to separate the three Upsilon peaks
- Optional – some limit on material budget to minimize bremsstrahlung tails