LUMI detectors: per-bunch rates

W. Schmidke, BNL
EPIC Far-Back
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Bremsstrahlung rates:

- Bremsstrahlung cross sections $d\sigma/dE_\gamma$
- EIC per bunch luminosities
- EIC bremsstrahlung per-bunch dN_γ/dE_γ

LUMI detectors:

- not fully defined yet, take some considered examples here to start discussion

- LUMI zero-degree photon calorimeters
- Electron taggers
- LUMI pair spectrometer

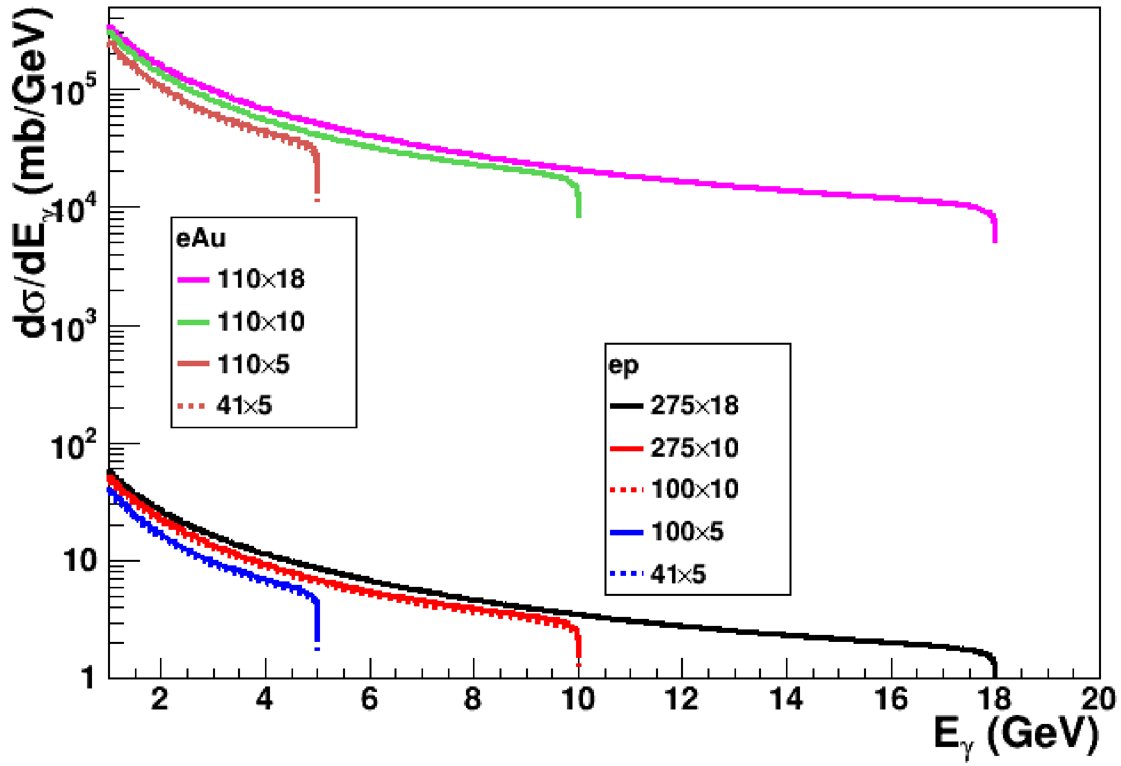
EIC parameters from CDR, e.g. Table 3.3 (ep high divergence)
Table 3.5 (eAu)

Bremsstrahlung cross sections

- Classical Bethe-Heitler bremsstrahlung $ep \to ep\gamma$:

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E'_e}{E_\gamma E_e}\left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE'_e}{m_pm_eE_\gamma} - \frac{1}{2}\right)$$

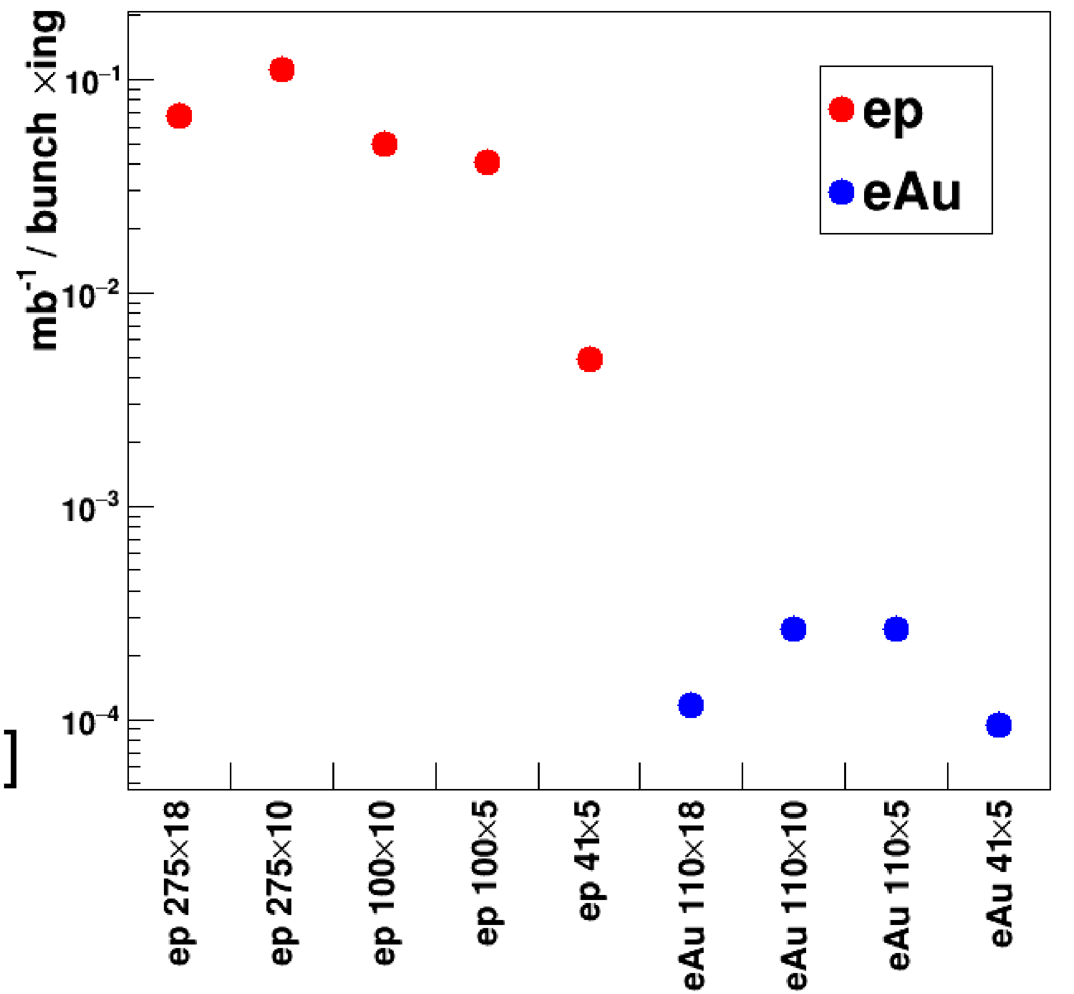
- For eAu: scale by $Z_{Au}^2 = 79^2 = 6241$
- For all EIC configurations:



- Clearly $\sigma_{eAu} >> \sigma_{ep}$

LUMI per bunch

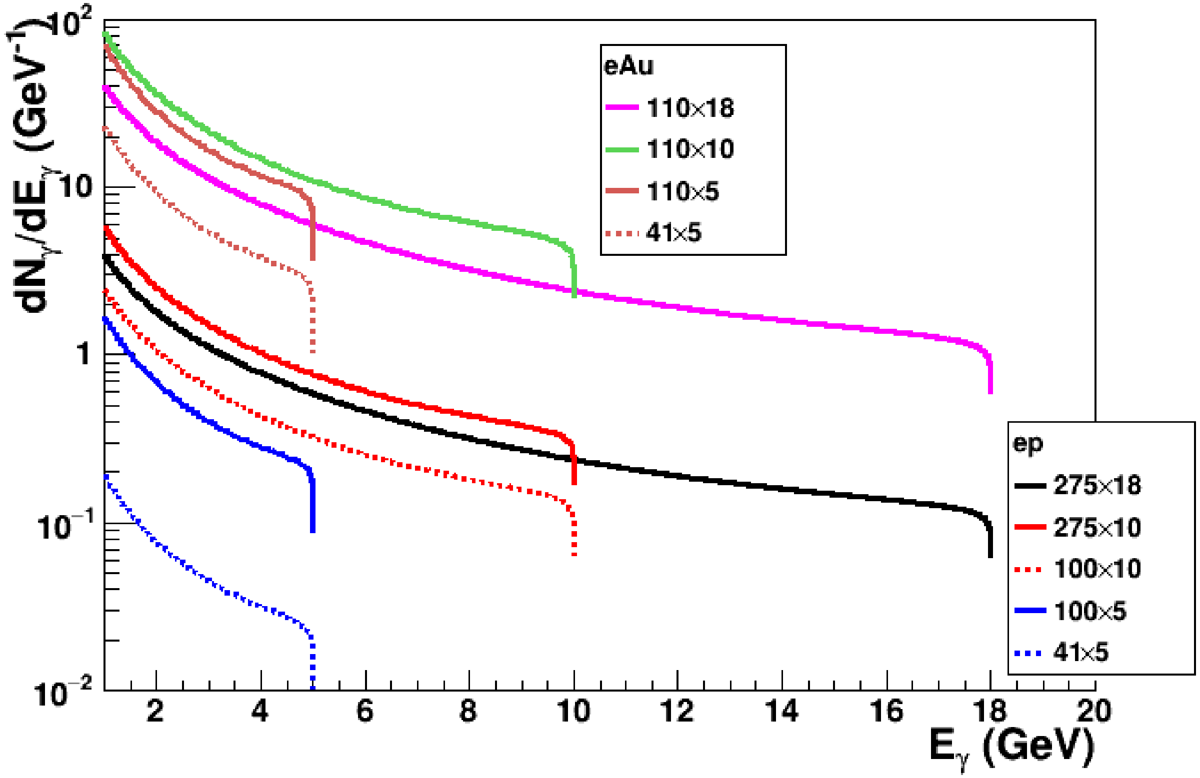
- CDR table values are instantaneous L_{inst} [$cm^{-2}s^{-1}$]
- Per bunch $L_{bunch} = T_{bunch} \cdot L_{inst}$
- $T_{bunch} = T_{RHICrev}/N_{bunch}$;
  $T_{RHICrev}$ = 12.8 μs (CDR eq. 3.59)
  N_{bunch} = 1160 (E_e = 5,10 GeV)
  T_{bunch} = 11 nS
  = 290 (E_e = 18 GeV)
  T_{bunch} = 44 nS
- CDR values are flux of nucleons [nucleons·$cm^{-2}s^{-1}$]
  need flux of nuclei [nuclei·$cm^{-2}s^{-1}$]
  $= L_{CDR}/A$ $A_p = 1$, $A_{Au} = 197$
- Handy conversion:
  1 mb = 10^{-27} cm^2



- Generally L_{bunch}(ep) >> L_{bunch}(eAu)

Bremsstrahlung per-bunch dN_γ/dE_γ

- Per bunch photon spectrum $dN_\gamma/dE_\gamma = L_{bunch} \cdot d\sigma/dE_\gamma$
- For all EIC configurations:



- Quick picture of photon rates
- As expected: eAu very challenging
- 10's-100's of γ's per bunch ×ing

Detectors: acc $\rightarrow \sigma \rightarrow$ rate

- Each LUMI detector samples some portion of brems. spectrum: defines acceptance $acc(E_\gamma)$
- This defines a brems. cross section for the detector:
  $\sigma_{det} = \int dE_\gamma \cdot acc(E_\gamma) \cdot d\sigma/dE_\gamma$
- Then detector hits per bunch $\times$ing is:
  $N_{det} = L_{bunch} \cdot \sigma_{det}$

(this is actually the cross section used to measure LUMI: $L=N/\sigma$)

<u>LUMI detectors:</u>

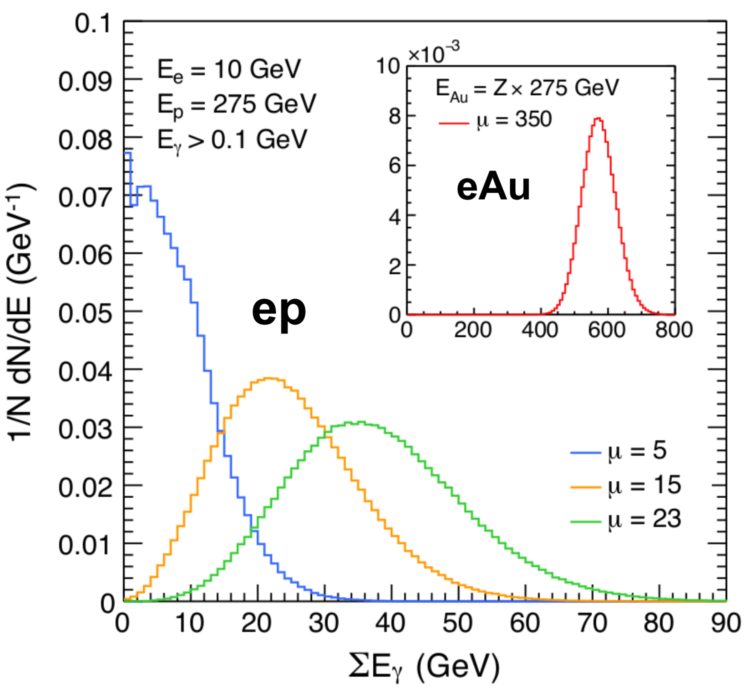
- need to pick some sizes, positions $\Rightarrow$ acceptances
- not fully defined yet, take some considered examples here to start discussion
- no segmentation, only whole detector rates

Photon calorimeters

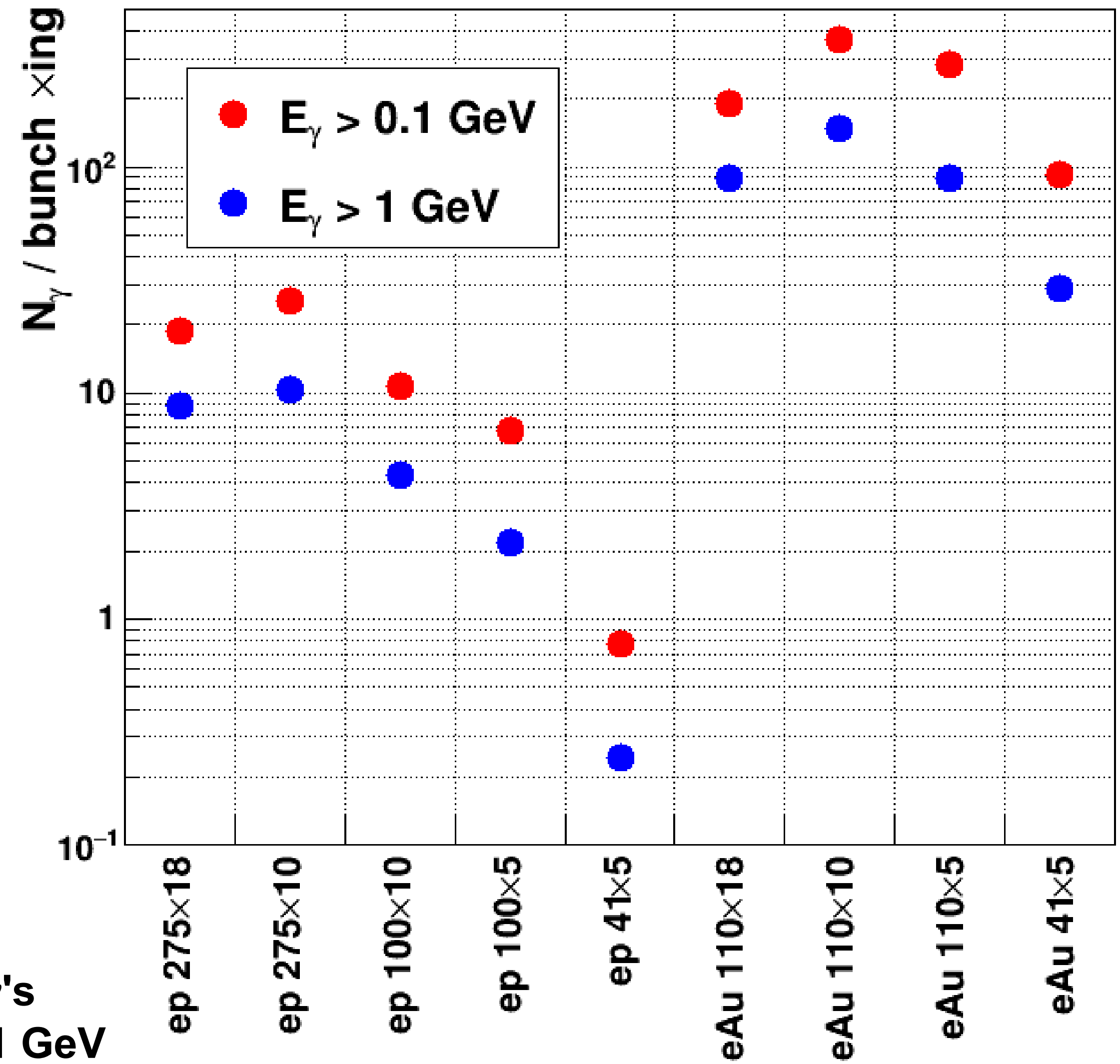
- Typically sensitive to all γ's with E_γ > 0.1-1 GeV: $\sigma_{CAL} = \int_{Emin}^{Ee\text{-}beam} dE_\gamma \cdot d\sigma/dE_\gamma$
- For all EIC configurations:

<u>Multi-γ calorimeter signal</u>

- $\sum$ over many brems. spectra $E_\gamma > E_{cutoff}$
- 100's γ's, ~ Gaussian
- $L_{bunch} \propto \sum E_{CAL}$; LUMI is calorimetric measurement



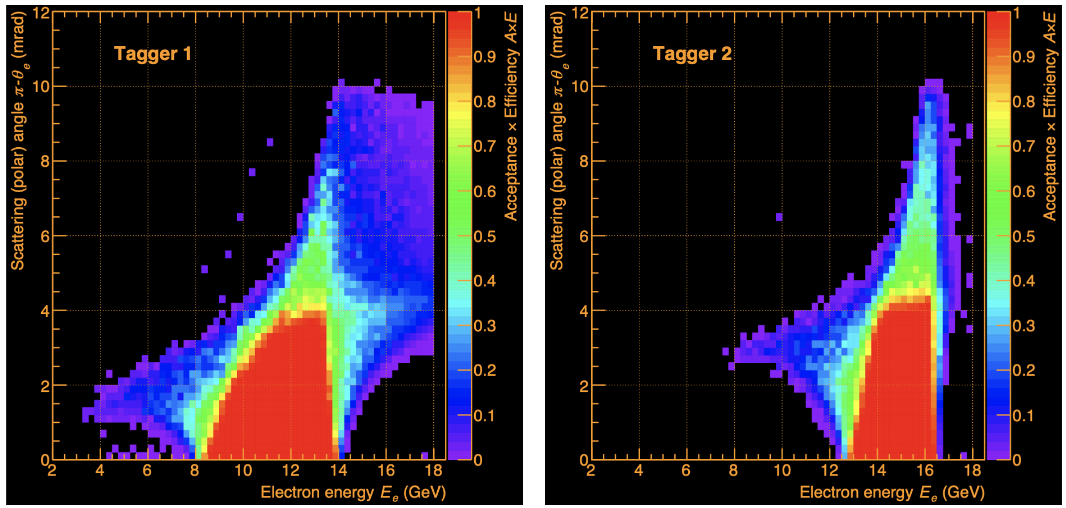
μ = # γ's
E_γ > 0.1 GeV



Electron taggers

- Take example layout from Jarda, FarBack mtg. 04.08.22*
- Electron acceptance $E_{e'}$ vs θ_{scat}:

18×275 GeV



- Shown for low-Q^2 quasi-real; brems. is region at θ_{scat}~0
- Read off brems. acceptance
  Tag1: $8.5< E_{e'} <13.5$ GeV; Tag2: $13< E_{e'} <16.5$ GeV
- Photon $E_\gamma = E_{e\text{-beam}} - E_{e'}$
  Tag1: $4.5 < E_\gamma < 9.5$ GeV; Tag2: $1.5 < E_\gamma < 5$ GeV
- Brems. acceptance ~100% this range E_γ

*https://indico.bnl.gov/event/15881/contributions/66625/attachments/42581/71366/JA-Tagger_discussion_20220804.pdf

Electron taggers

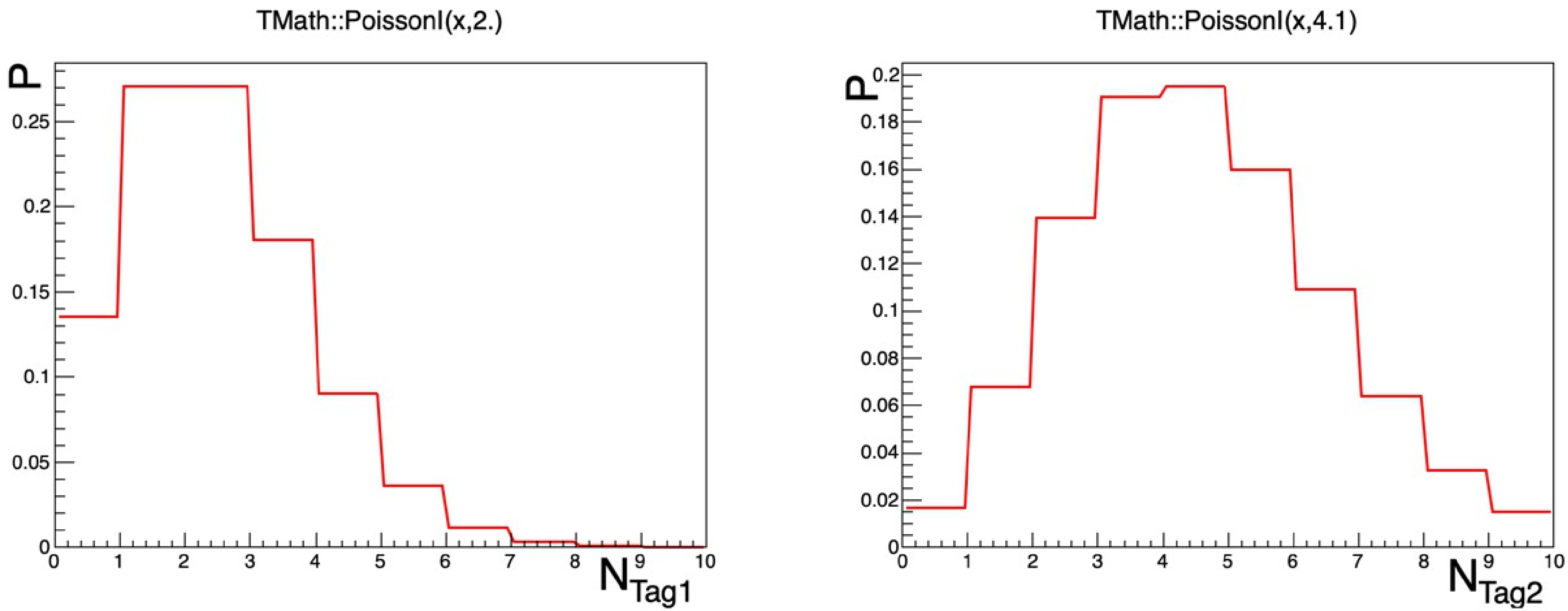
- Do the integrals $\sigma_{Tag} = \int_{E1}^{E2} dE_\gamma \cdot d\sigma/dE_\gamma$

$$\sigma_{Tag1} = 29.9 \text{ mb};\ \sigma_{Tag2} = 60.1 \text{ mb}$$

- L_{bunch}(18×275 GeV) = 0.068 mb^{-1}
- Mean hits per bunch ×ing = $L_{bunch} \cdot \sigma_{Tag}$:

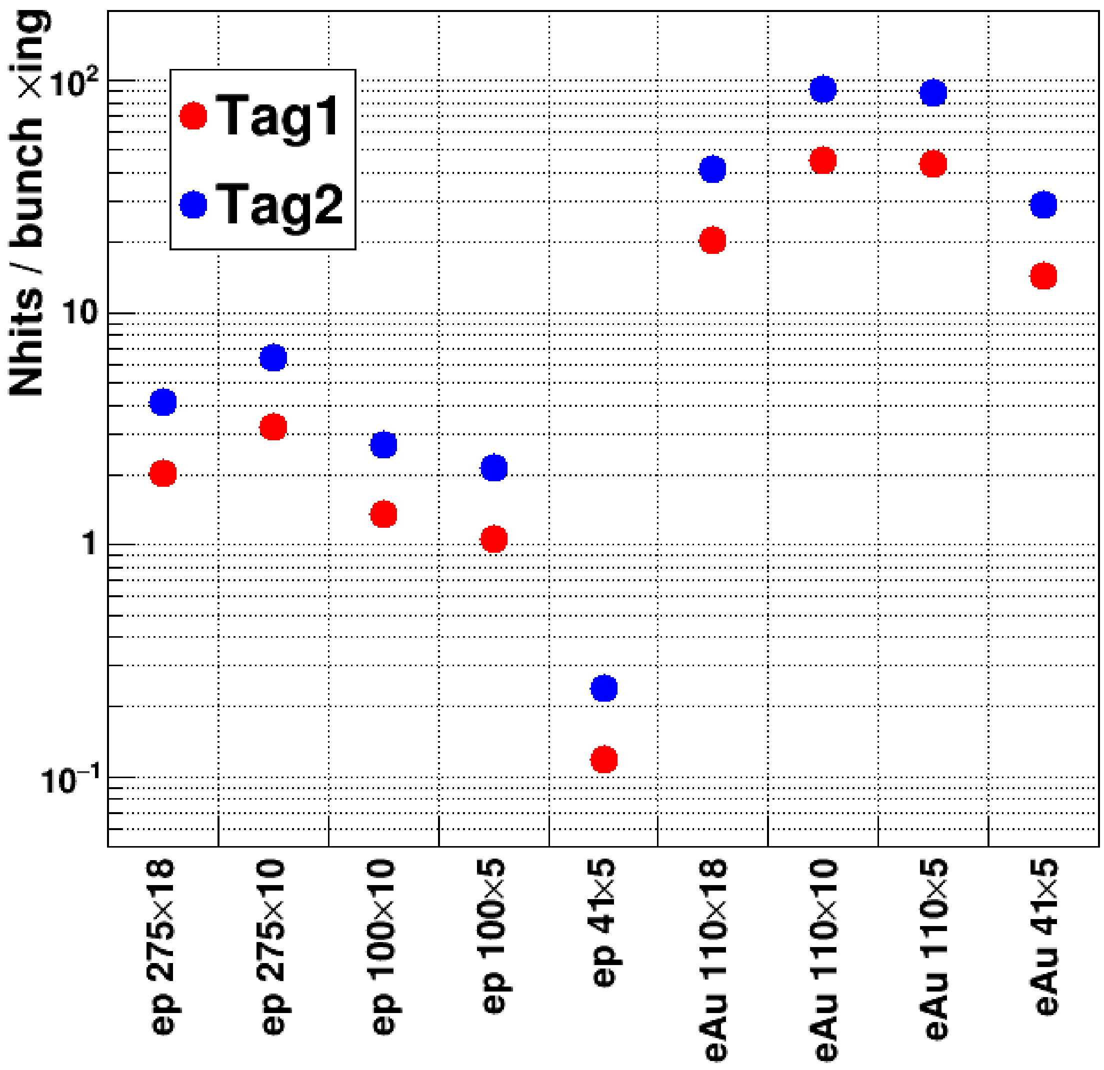
$$\langle N_{Tag1} \rangle = 2.0;\ \langle N_{Tag2} \rangle = 4.1$$

- Poisson distributions:



Electron taggers

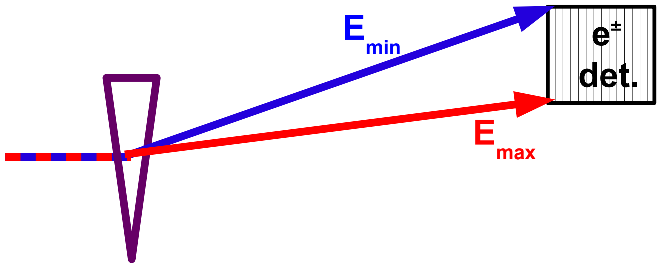
- Tagger energy ranges scale with $E_{e\text{-beam}}$
- For all EIC configurations:
  (J. Adam config.)



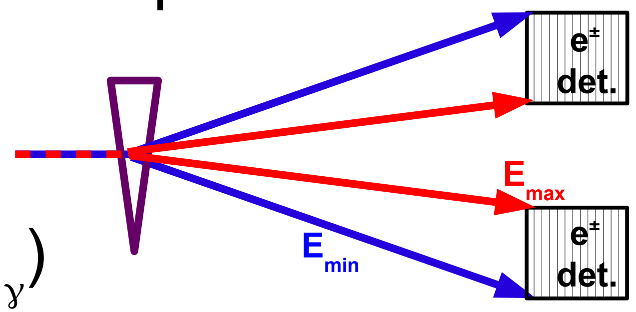
Hits per bunch ×ing:
- Tag2 ~2 × Tag1
- ep ~1-10
- eAu ~10-100

Pair spectrometer

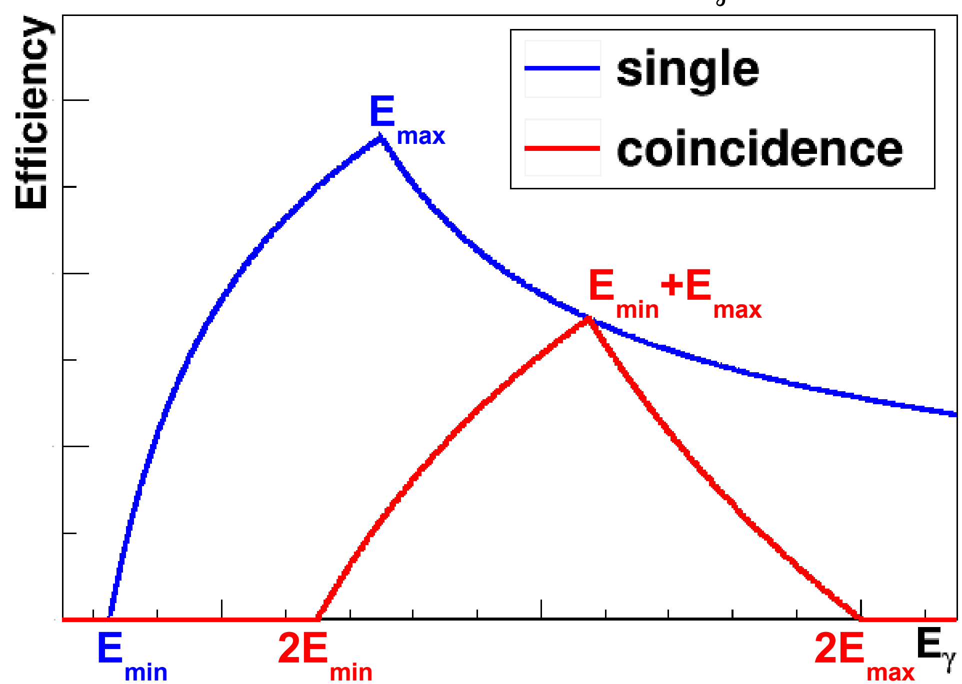
- Spectrometer geometry: ∫B·dL,
  detector transverse size, longitudinal location



- Determines min., max. energies (E_{min},E_{max}) of $e^{\pm}$ that can hit detector
- Determines range of $z=E_{e+}/E_{\gamma}$, fraction of $\gamma \rightarrow e^{+}e^{-}$ accepted
- Subset of single detector hits are coincidences:

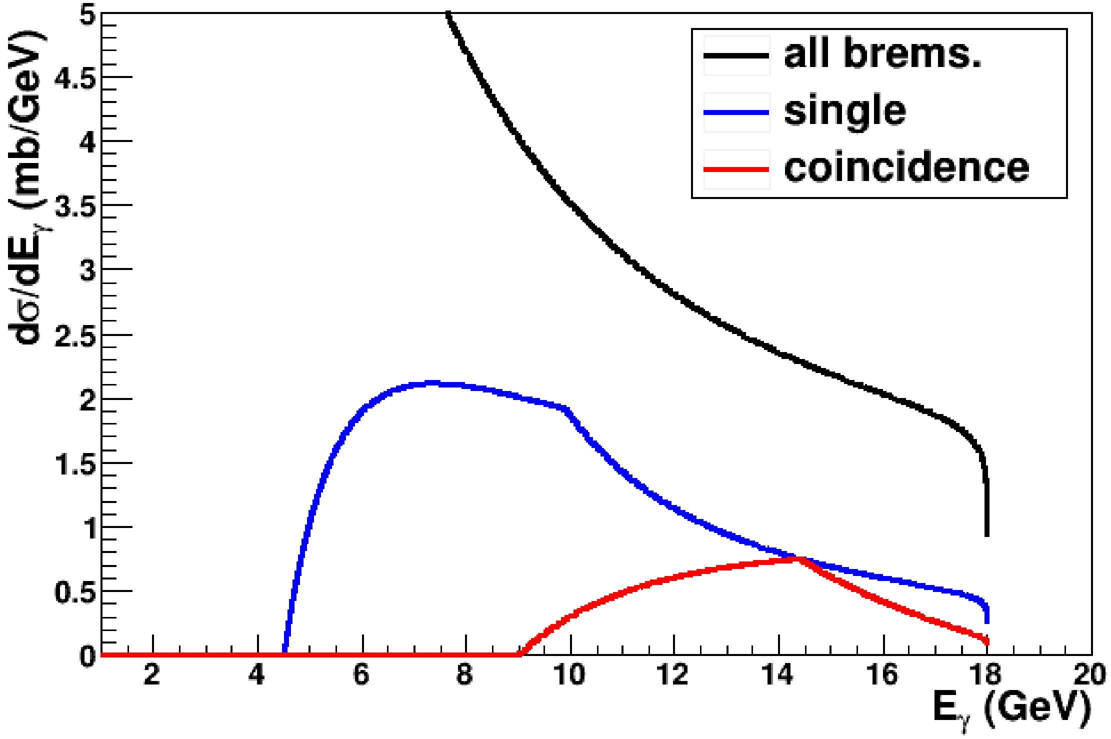


- From z ranges straightforward to calculate acc(E_{γ}) (details on extra slides)



Pair spectrometer

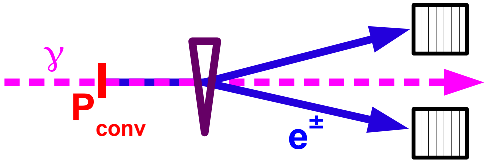
- Take example: ZEUS LUMI pair spectrometer
- Scale (E_{min},E_{max}) with $E_{e\text{-}beam}$, here for 18×275 GeV
- Accepted brems. single, coincidence cross sections vs E_γ:



Integrals:

- σ_{sngl} = 17.2 mb
- σ_{coin} = 4.2 mb

- Take photon conversion prob. ~ZEUS: P_{conv} = 0.1 (hope to get P_{conv}<0.1, more later)

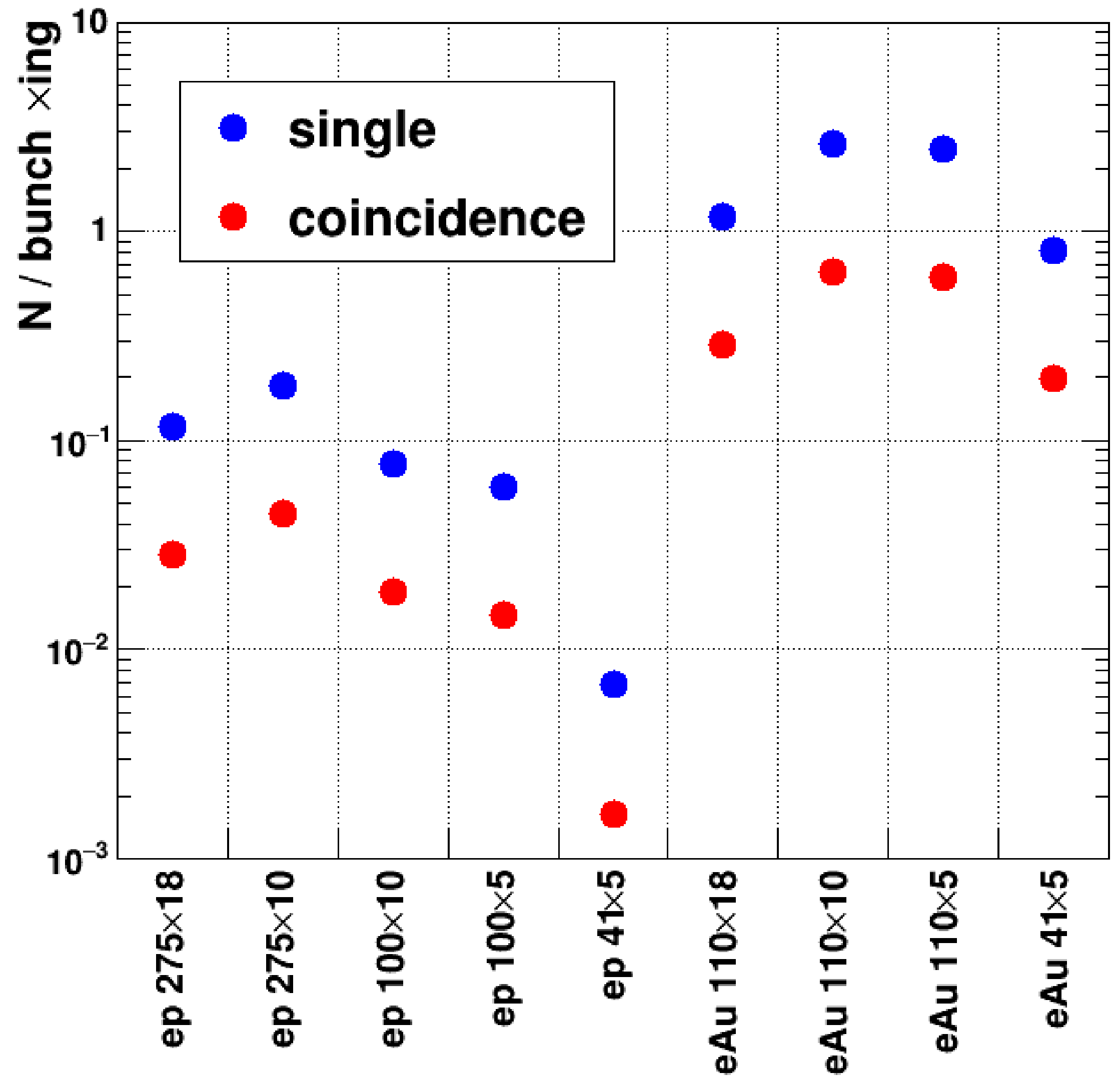


- With L_{bunch}(18×275 GeV) = 0.068 mb^{-1}, mean hits per bunch ×ing:

$$\langle N_{sngl} \rangle = 0.12;\ \langle N_{coin} \rangle = 0.029$$

Pair spectrometer

- Detector (E_{min},E_{max}) scale with $E_{e\text{-}beam}$
- For all EIC configurations:
  (ZEUS config.)

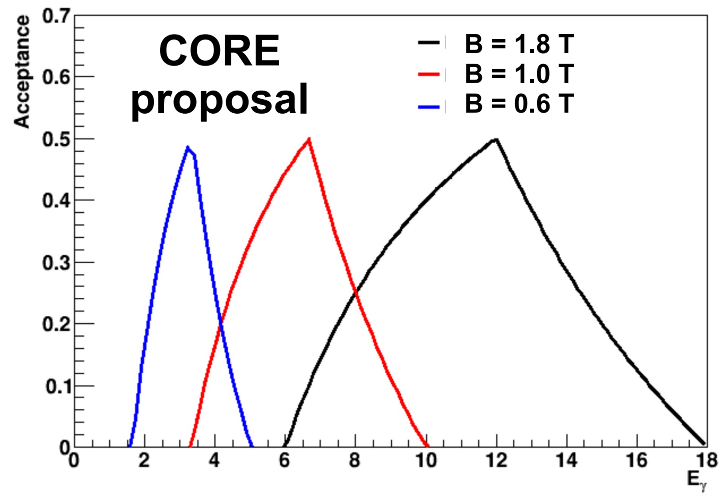


- For N <~ 1 can do spec. LUMI measurement as a counting experiment, minimal pileup corrections
- some eAu:
  > 2 singles / bunch ×ing

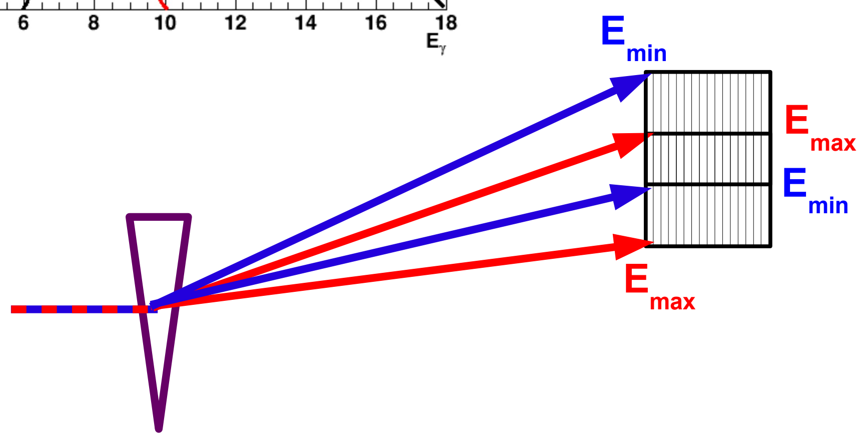
Pair spectrometer

Options to mitigate high rates

- Change dipole strength
  - ratio E_{max}/E_{min} fixed



- Change detector vertical range
  - not physically, just use more/less available channels for measurement
  - changes ratio E_{max}/E_{min}

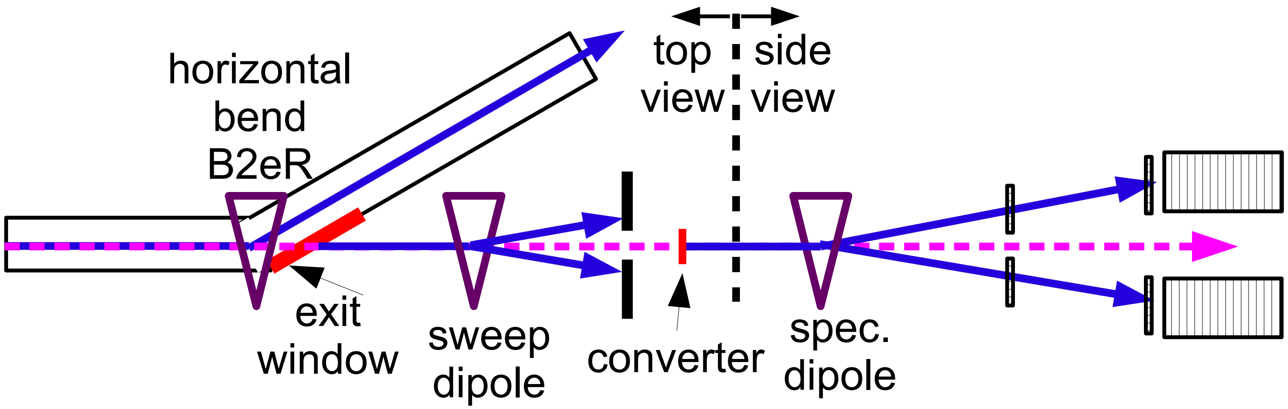


- Together move acceptance to low-σ region of brems. spectrum (near & beyond $E_{e\text{-}beam}$ endpoint)

Pair spectrometer

Options to mitigate high rates

- Minimize conversion probability P_{conv}:
  - best layout proposal so far:
    thick exit window → sweeping magnet → thin converter → pair spec.
    (K. Piotrzkowski, FarBack mtg, 11.08.22*)
  - minimize P_{conv}<0.1
  - minimize multiple scattering effects on $e^{\pm}$ measurement



Need adequate mitigation:

- Keep spec. hit rates < 1 per bunch ×ing
- LUMI measurement as hit counting: $L=N_{hits}/\sigma_{spec}$
- Minimize pileup correction to N_{hits}

*https://indico.bnl.gov/event/16634/contributions/66891/attachments/42688/71667/lumi-11-8-KP.pdf

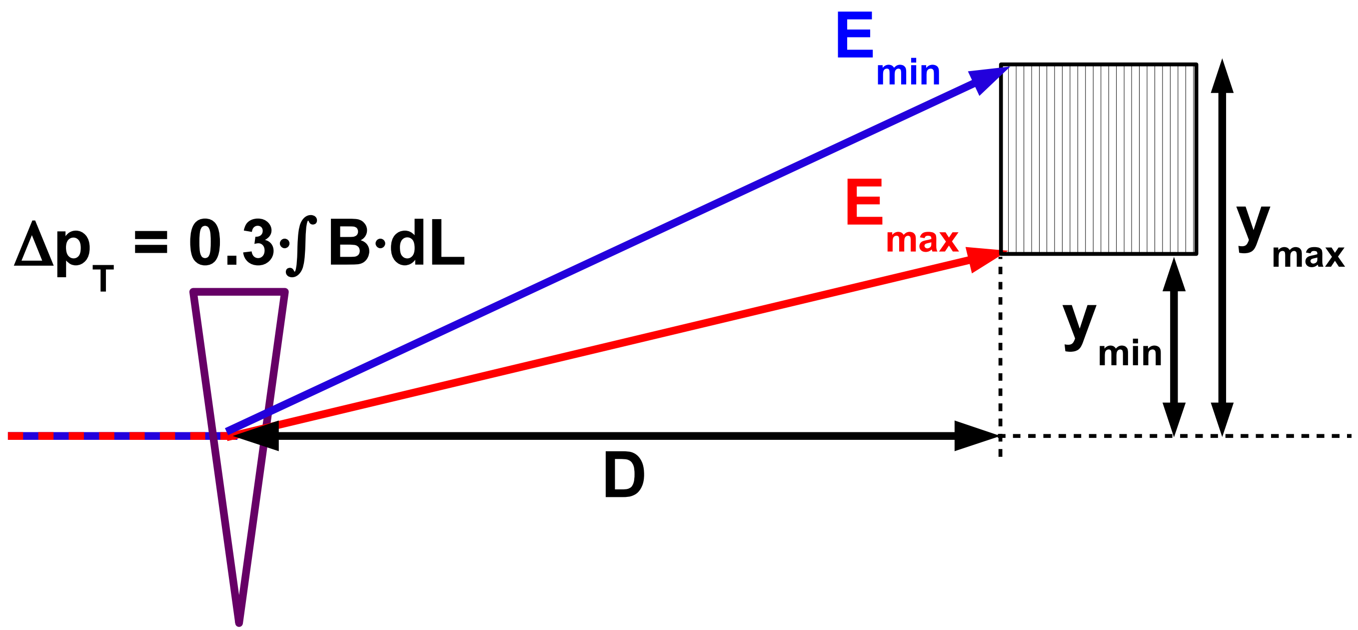
Summary

- Reliable bremsstrahlung per-bunch hit rates, all EIC configs.
  adequate to guide detector design
- eAu most problematic, especially 110×10 & 110×5 GeV
- Photon calorimeters: 1-10's (ep) & 10's-100's (eAu) per-bunch
  - LUMI necessarily a calorimetric E measurement
    calibration & stability critical
- Electron taggers: 1-10 (ep) & 10-100 (eAu) per-bunch
  - difficult to separate from low-Q^2 physics hits
- Pair spectrometer: 0.1 (ep) & few (eAu) per-bunch
  - acceptance defined by dipole, det. geometry:
    detector E resolution not critical
  - several handles to minimize rate to <<1,
    keep LUMI measurement counting experiment,
    minimize pileup corrections
  - pileup correction harder with cross-bunch interference:
    detector signal T_{det}<10 nS

Extras

Pair spectrometer parameters

- Fundamental parameters E_{min}, E_{max} in terms of dipole, geometry:

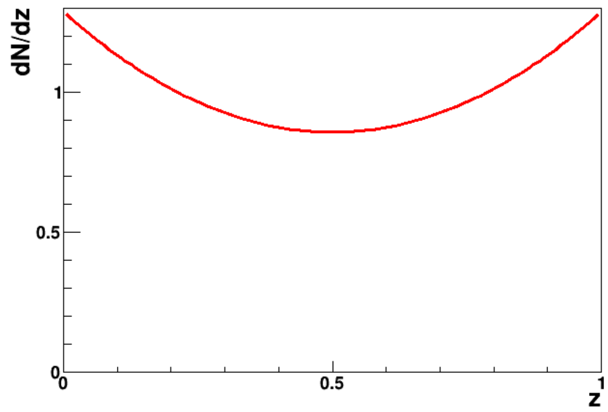


$$E_{min} = \Delta p_T \cdot D / y_{max} \qquad E_{max} = \Delta p_T \cdot D / y_{min}$$

Spec. acceptance vs E_γ

- Energy sharing for $\gamma \rightarrow e^+e^-$: $z=E_{e+}/E_\gamma$, $0<z<1$
- Distribution $dN/dz \propto 1 - (4/3)\cdot z\cdot(1-z)$

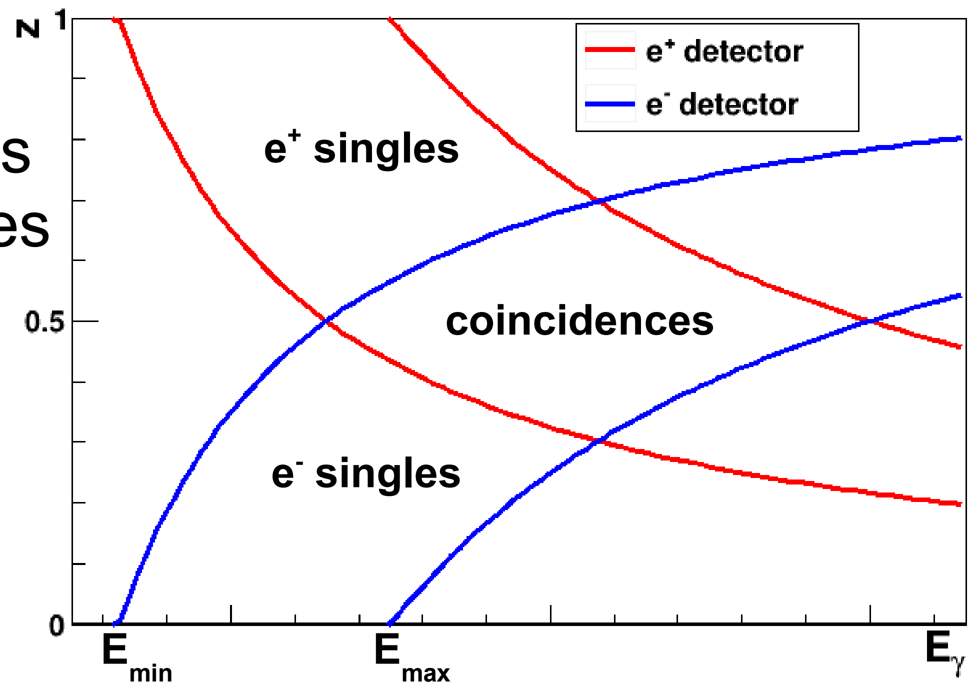
[PDG eq. 34.31]



- Energy range of spec. det. (E_{min},E_{max}) defines z ranges:

$z_{min,max} = E_{min,max}/E_\gamma$ for e^+ det. & $(1-z_{max},1-z_{min})$ for e^- det. $(0<z<1)$

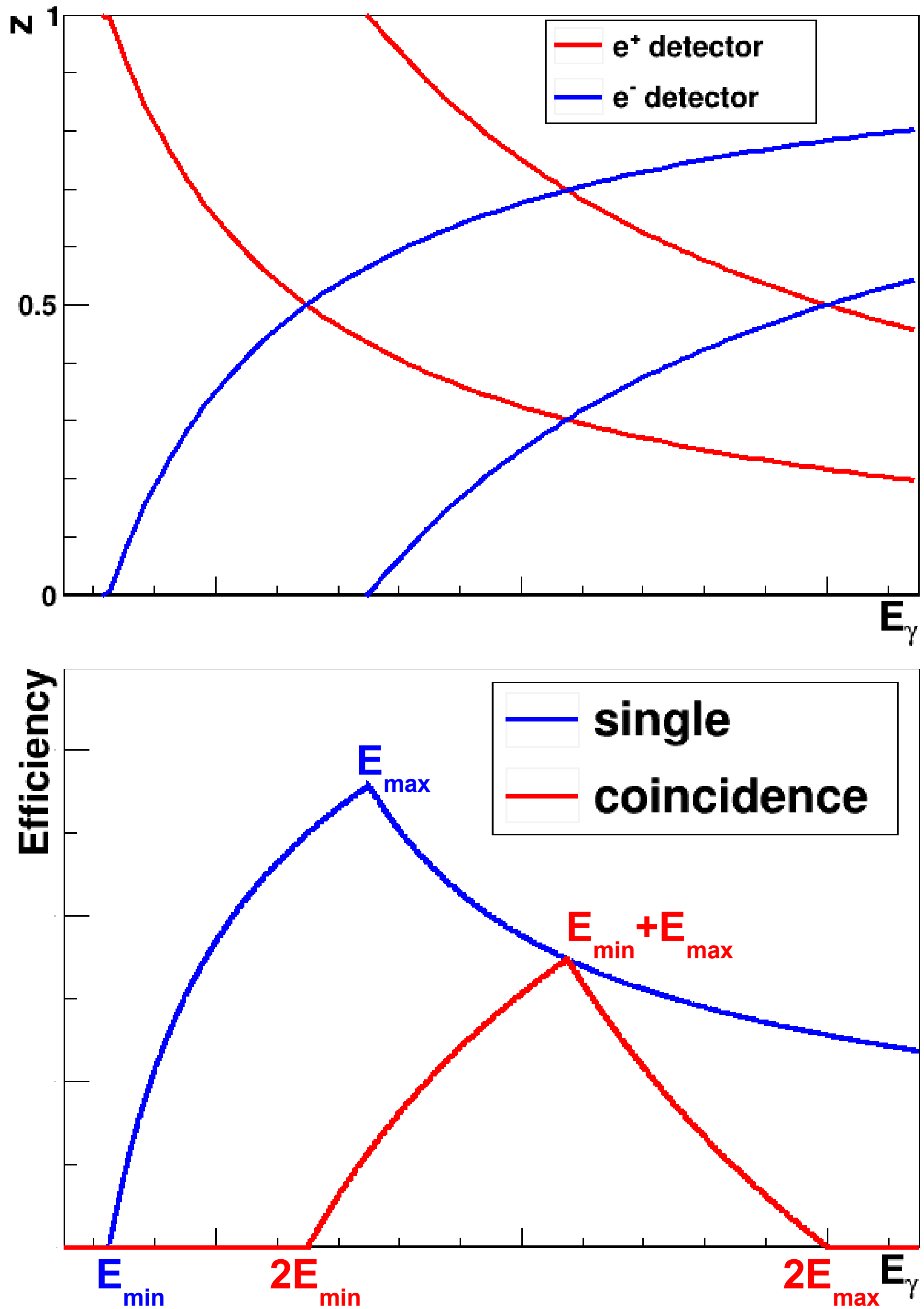
- Acceptance in E_γ-z plane:
  - e^+ singles between red curves
  - e^- singles between blue curves
  - coincidence in diamond shaped region



Spec. acceptance vs E_γ

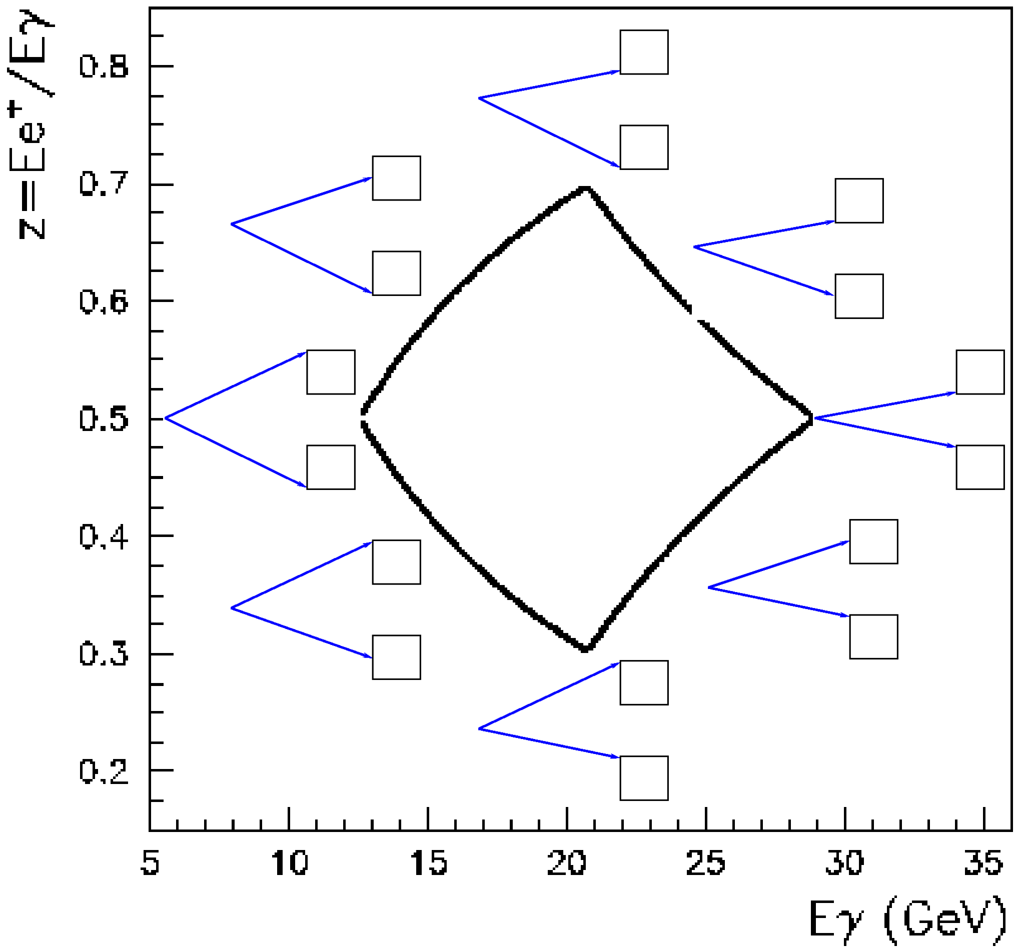
$acc(E_\gamma) = \int dz \cdot dN/dz$

- single:
  integrate between red/blue curves
- coincidence:
  integrate in diamond shaped region



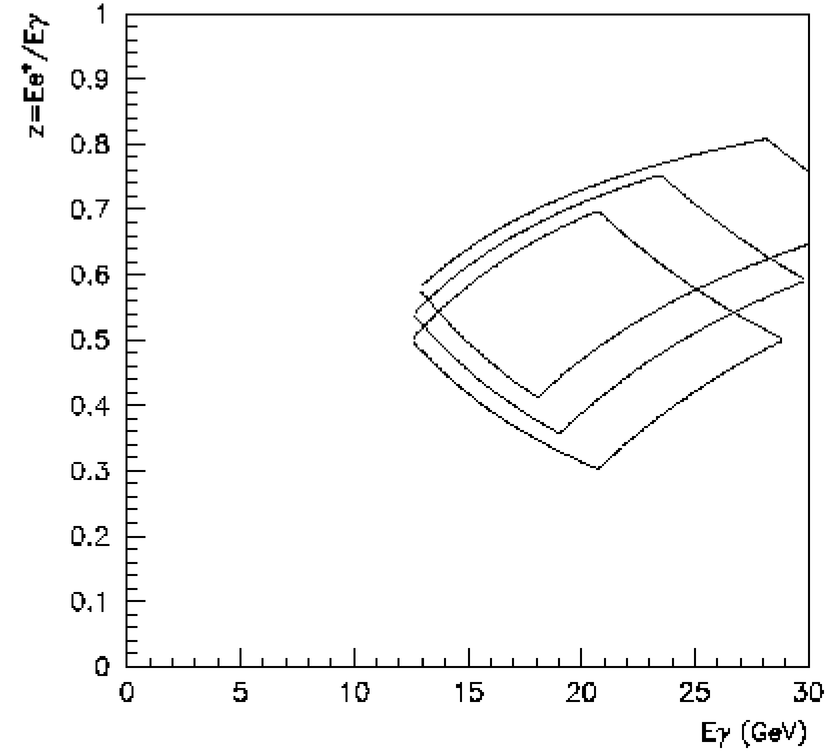
Coincidence region E_γ-z plane

- Insets show pair detector configurations at edges, corners of acceptance region



Spec. acceptance vs y_γ

- Coincidence region in γ-z plane varies with γ vertical position
- Shown here for 0,1,2 cm above spec. midpoint



- Prescription previous slides outlines acceptance for a given γ vertical position y: $acc(E_\gamma, y)$
- γ vertical position distribution due beam divergence: Gaus(y)
- Then overall acceptance $acc(E_\gamma) = \int dy \cdot Gaus(y) \cdot acc(E_\gamma, y)$
- Easily evaluated numerically as in previous examples, providing estimates including beam divergence