Luminosity Measurement @ EIC

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Det1 Far-backward Mtg.
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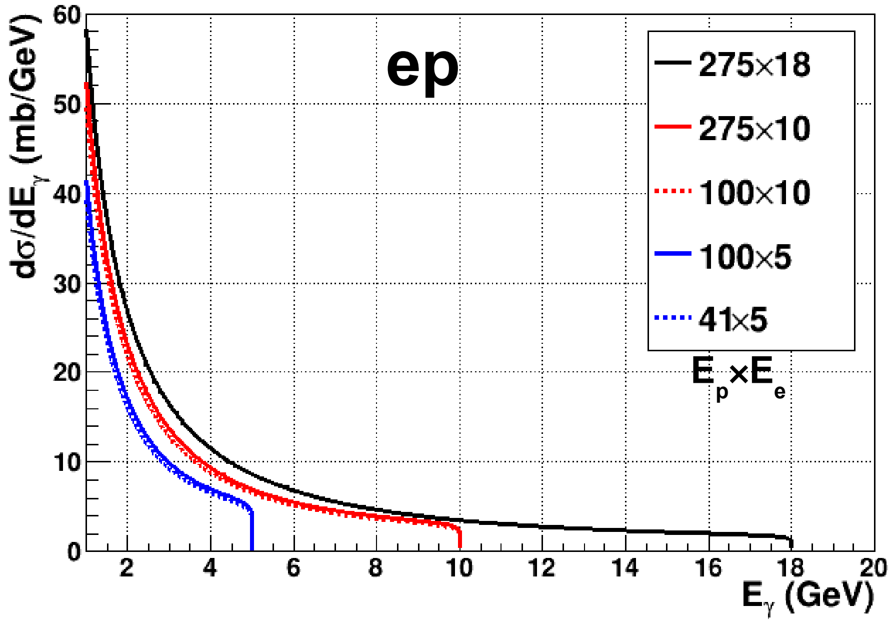
- LUMI process:
  Bremsstrahlung photons
- 2 methods photon measurement:
  - direct
  - pair spectrometer
- Measurement details
  & detector technologies
- Brems. e-tagging:
  LUMI calibrate & verify

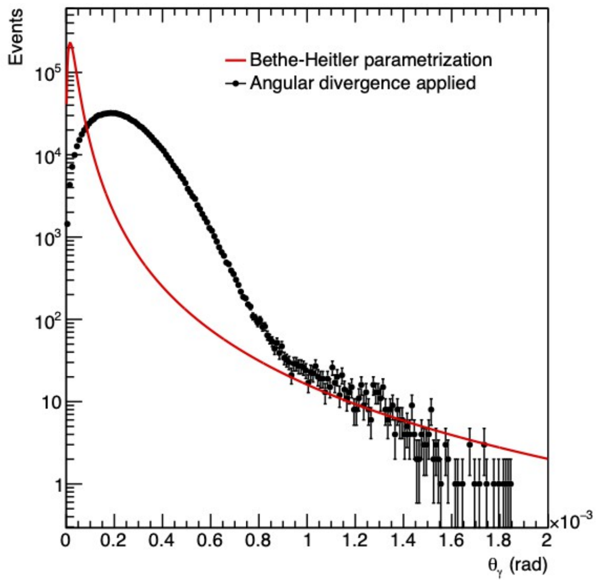
LUMI process: Bremsstrahlung

- Bremsstrahlung processes ep→epγ, eA→eAγ:
  - σ_{BREMS} precisely known from QED (~0.5%) Bethe-Heitler 1934
  - large σ_{BREMS} ⇒ high statistics



γ spectrum

- diverges $E_\gamma \to 0$
- endpoint @ $E_\gamma = E_{e\text{-beam}}$
- Nuclei $\sigma_{eA} = Z_A^2 \cdot \sigma_{ep}$

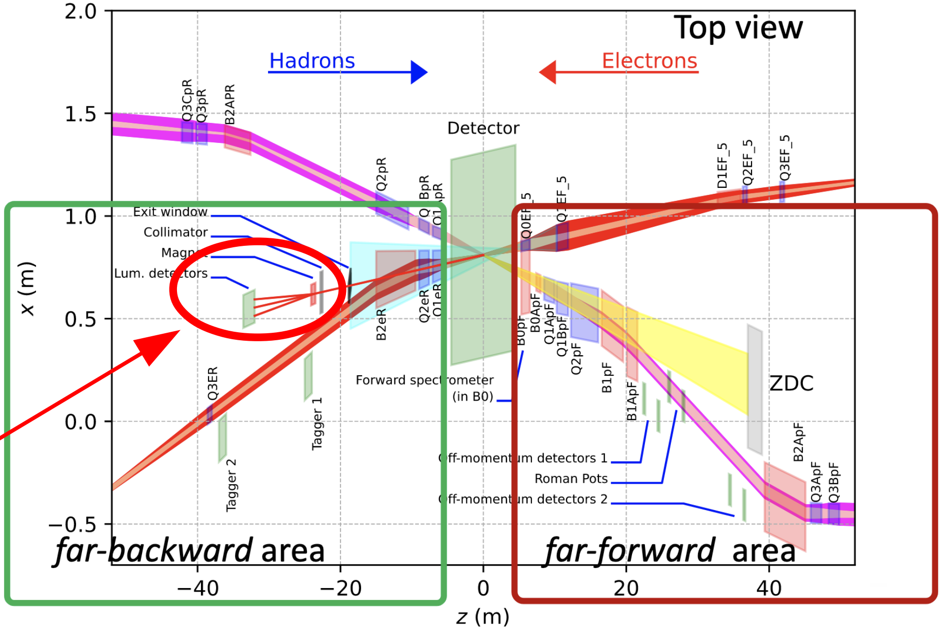


γ angular distribution

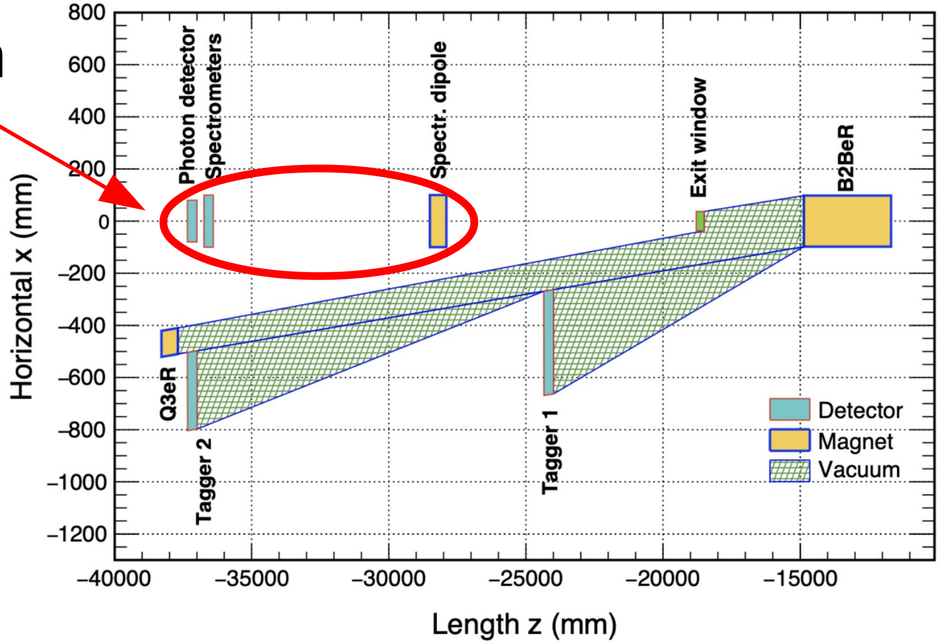
- strongly peaked @ beam 0°
- dominated by e-beam divergence
- diagnostic for beam steering, tuning

LUMI detector neighborhood

- Bremsstrahlung γ's travel along e-beam 0° direction:



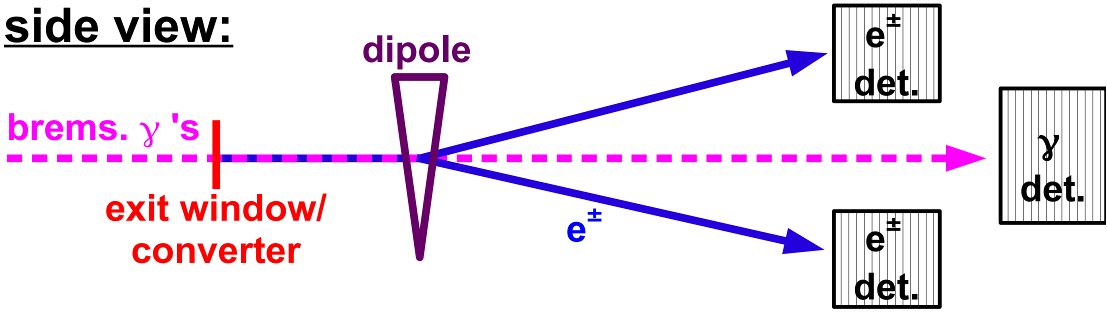
- LUMI detectors nestled between incoming hadron & outgoing electron beams



LUMI detectors

Two independent approaches:

- direct γ measurement @ 0°
- pair spectrometer (e.g. ZEUS @ HERA): convert $\gamma \to e^+e^-$, measure $e^\pm$



direct γ advantages:

1) simple concept
2) straightforward γ acceptance

pair spec. disadvantages:

1) more complex implementation
2) γ acceptance requires accurate simulation

direct γ disadvantages:

A) detector in primary sync. rad. fan
B) 'fuzzy' cutoff @ $E_\gamma \to 0$ divergence
C) pileup, many γ's per bunch ×ing

pair spec. advantages:

A) detectors outside primary sync. rad. fan
B) natural low-E_γ cutoff
C) pair hit rate adjustable: converter, geometry, dipole |B|

Successfully implemented by ZEUS @ HERA

Two approaches complement each other

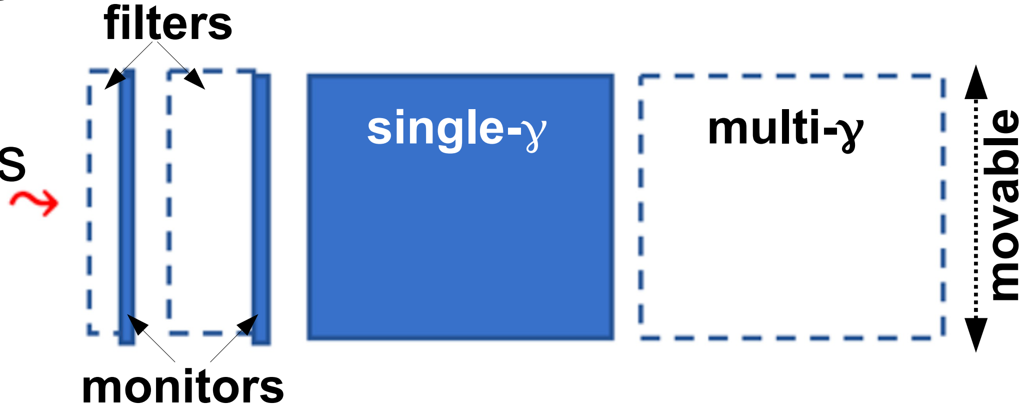
Direct γ detector considerations

Environment

- In primary sync. rad. fan
- @ full L_{inst}, many γ's per bunch ×ing

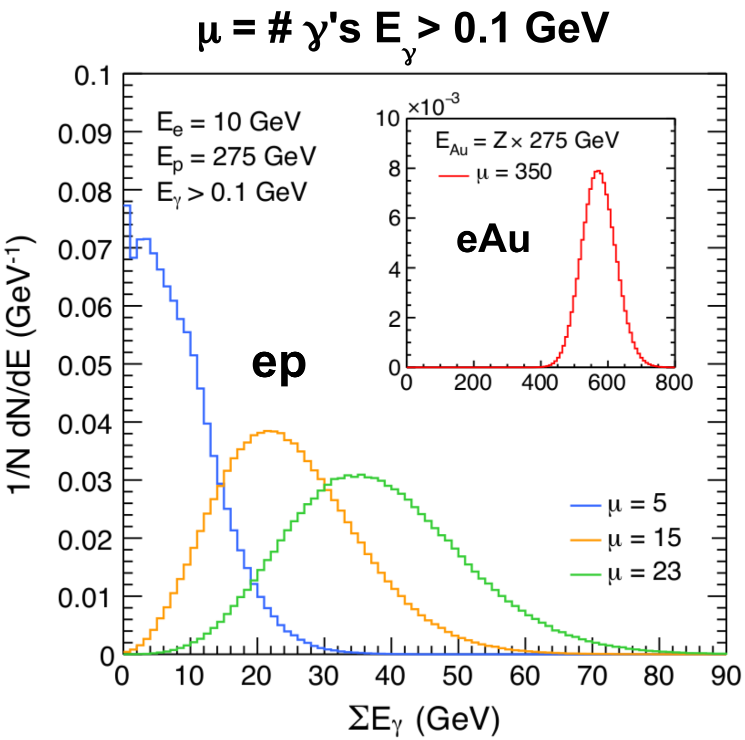
Detector components

- Sync. rad. filters (C), profile monitors
  monitors critical for beam diagnostics
- Single-γ calorimeter for low L_{inst}
  - optimized for single EM showers
  - position hodoscope inside
- Multi-γ calorimeter for full L_{inst}
- All components movable in/out beamline

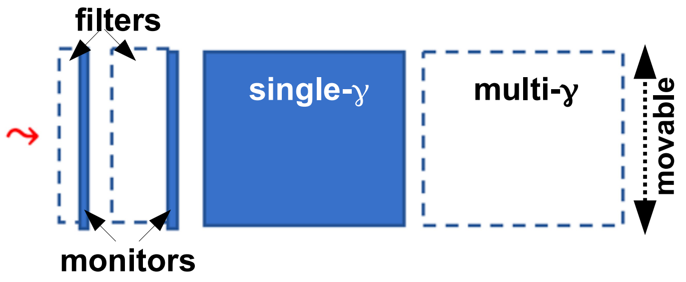


Multi-γ calorimeter signal

- $\sum$ over many brems. spectra $E_\gamma > E_{cutoff}$
- For 100's γ's, ~ Gaussian distribution
- $L_{bunch} \propto \sum \pm_{CAL}$



Direct γ detector technology



Sync. rad.

- Filters: 1-2 X_0 carbon (graphite)
- Monitors: Cerenkov quartz fibers→SiPMs

Single-γ calorimeter options

- W-spaghetti, rad. hard scint. fibers → fast PMTs [ATHENA]

Multi-γ calorimeter options

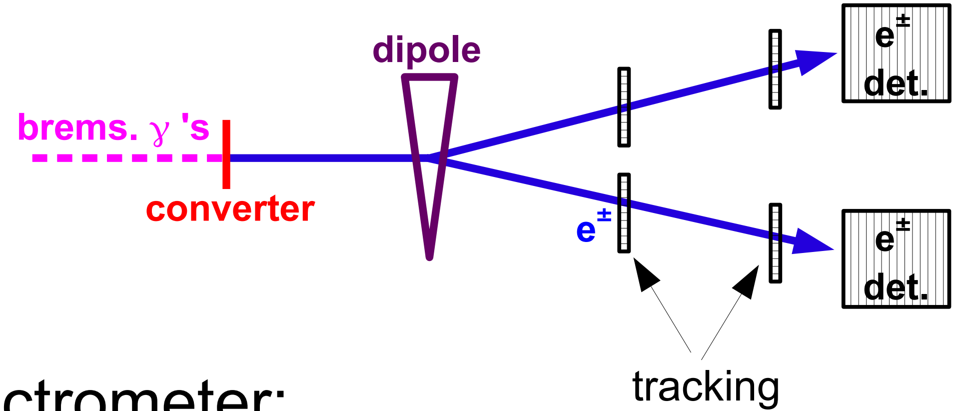
- 8×8 $PbWO_4$ crystals, each 2×2 cm^2, 20 cm long [ECCE]
- W-spaghetti Cerenkov quartz fibers→SiPMs [ATHENA]

- Recall: $L_{bunch} \propto \sum \pm_{CAL}$
- For γ calorimeters calibration & stability imperative:

LUMI uncertainty ∝ energy calibration uncertainty

Pair spectrometer $e^{\pm}$ measurement

- Baseline: detection as @ ZEUS calorimetric $e^{\pm}$ energy, position
- Add multiple planes $e^{\pm}$ tracking:



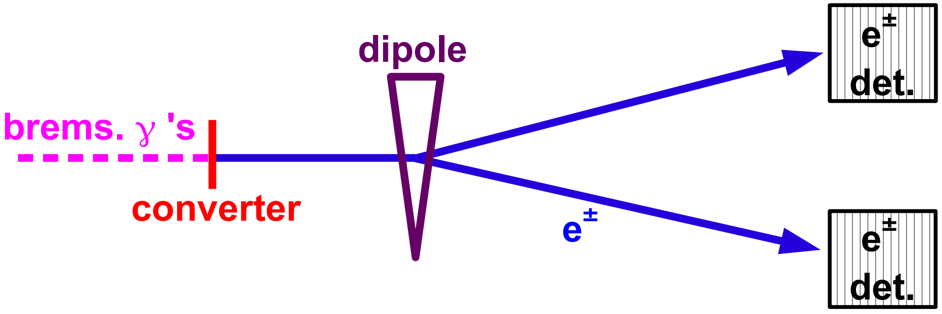
- Now a true spectrometer:
  from track vertical angle, dipole $\int B \cdot dl \Rightarrow e^{\pm}$ energy
- Tracking based photon reconstruction:
  for acceptance correction, MC verification etc.
- Reconstructed $e^{\pm}$ energy ⇒ calibrate calorimeters

- Still do LUMI measurement w/ ~100% efficient calorimeters
  avoid tracking inefficiencies
- Tracking adds: improved photon reconstruction
  calorimeter calibration
  pileup monitoring (e.g. multiple tracks)

Pair spectrometer considerations

Measure LUMI: **count** up+down coincidences, need <~1 per bunch ×ing

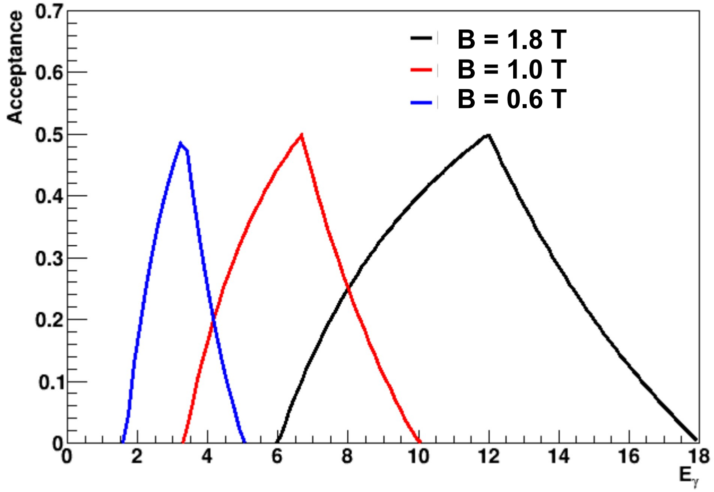
3 handles, control coincidence rate:

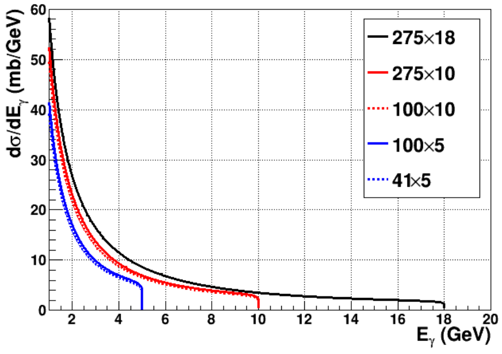


- geometry:
  detector transverse size &
  location along beamline

- dipole field strength |B|

  - geometry & |B|
    determine acceptance versus E_γ :
  - geometry fixed once installed
  - |B| is variable
  - adjust |B|, acceptance to
    optimize coincidence rate

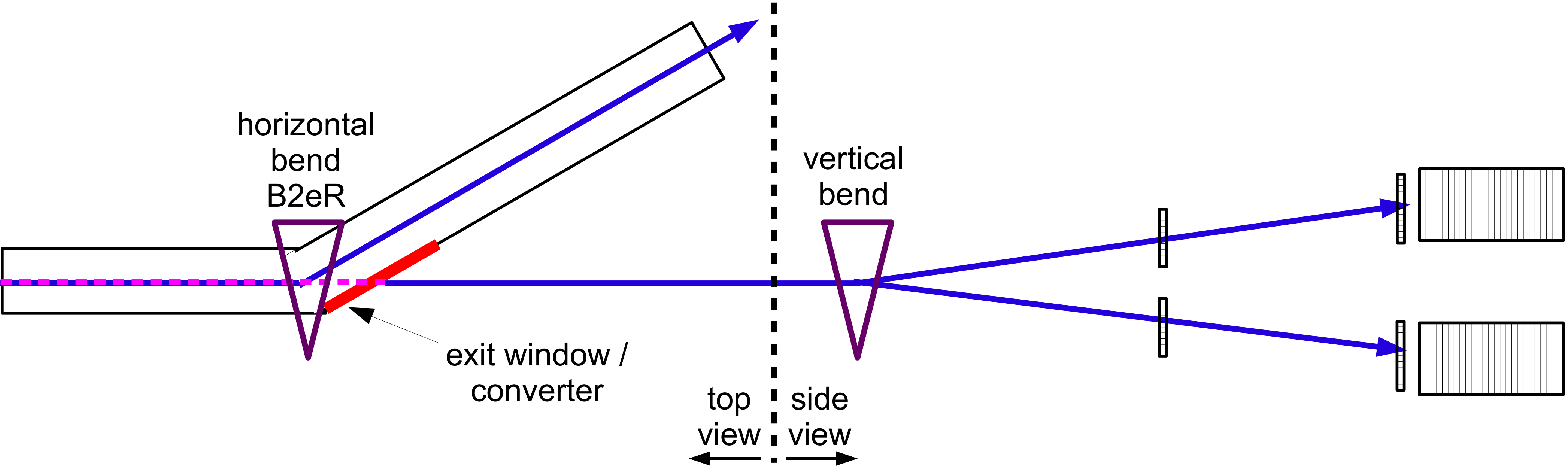




- conversion probability
  - property of exit window
  - integral part of beamline vacuum system ↘

Vacuum system: baseline

- Meet minimal requirements from ESR

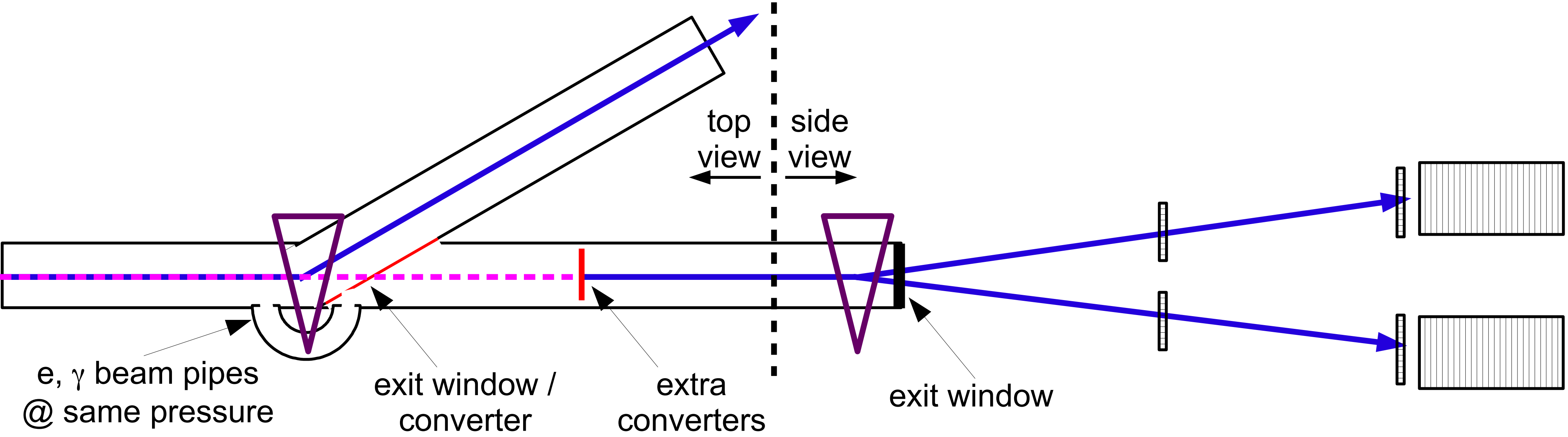


Exit window / converter

- Must be thick enough to support vacuum ✗
- Geometry, composition defined by e beam pipe constraints ✗
- Little/no control over converter properties ✗
- Long window→detector distance:
  large error on $e^{\pm}$/photon angles from multiple scattering in window ✗

Vacuum system: better

- Extend photon beam pipe vacuum through dipole



Exit window / converter

- Doesn't support vacuum, thin as possible consistent with: mechanical rigidity, synch. rad., e-beam impedance considerations ✓

Extra converters

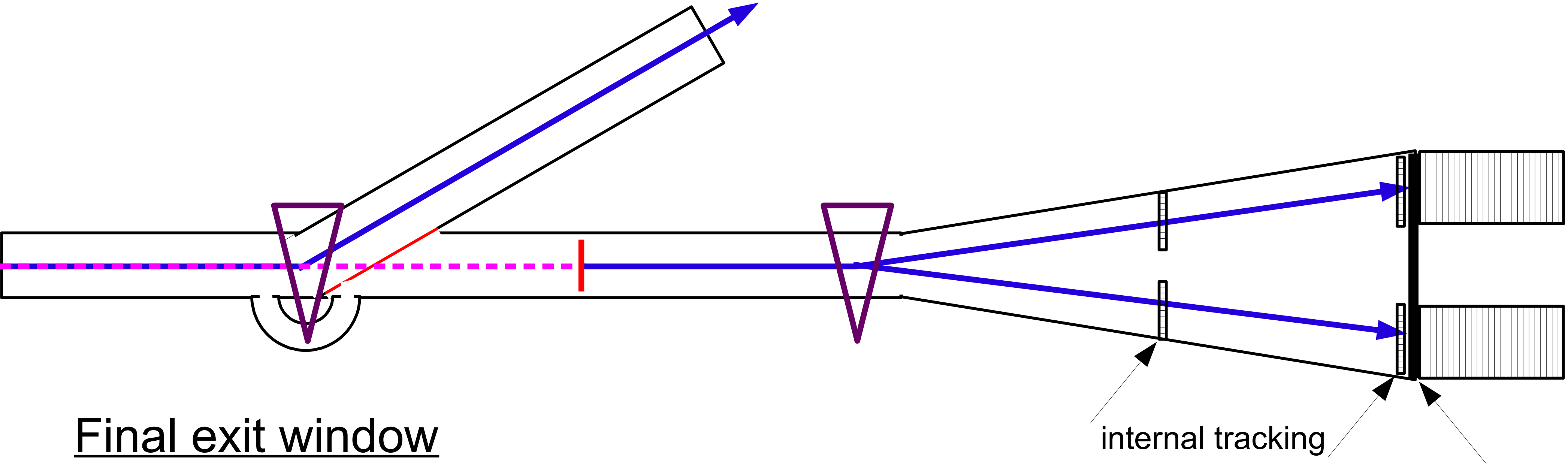
- Optimize thickness, geometry, composition ✓
- Several movable; configure for low/high lumi e.g. ep/eA ✓

Final exit window

- Thick, supports vacuum
- Multiple scattering: errors on $e^{\pm}$, γ angles ✗

Vacuum system: best

- Extend photon beam pipe vacuum to detectors



Final exit window

- After tracking, negligible mult. scat. error ✓

Optimized vacuum system

- Minimize pair conversion fraction
- Minimize errors on $e^{\pm}$ track measurements

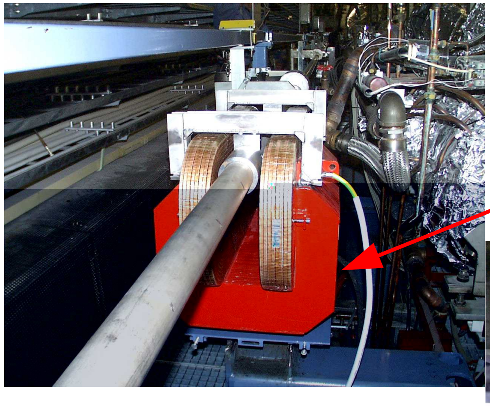
Pair spectrometer requirements

Vacuum system/converter

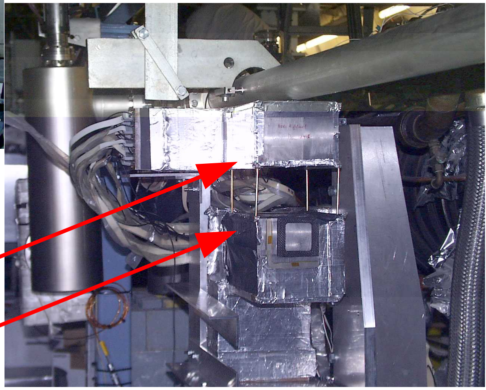
- Details previous slides
  hope to minimize coincidence rate <~1 per bunch ×ing

Dipole

- E.g. from ZEUS @ HERA, dipole BYZ:
  0.5 T × 0.6 m, Δp_T = 90 MeV
  can deflect 18 GeV $e^{\pm}$ to detectors



BYZ dipole in HERA tunnel



spec. cals. in HERA tunnel

Detector technologies

EM calorimeters for coincidence counting, calibration & resolution not critical. Options:

- W-scint. strip sandwich → PMTs [ZEUS]
- W-spaghetti, rad. hard scint. fibers → fast PMTs [ATHENA]

Tracking options:

need to resolve γ-beam profile: RMS >~ 4 mm @ detectors

- 1- 2 mm square scint. fibers → SiPMs [ATHENA]
- 8×16 cm^2 AC-LGADs [ECCE]
  (benefit from AC-LGAD development for Roman Pots)

LUMI detector technologies

- A few standard detectors: EM calorimeters, tracking planes
- High rates require radiation hard components
- Small size (10's cm), low channel count (few 100):
  - use best suited well developed technologies
  - no significant space/real estate constraints
  - limited drain on resources
- Benefit from relevant collaboration developed technologies

Readout / DAQ

- Significant info every bunch ×ing (up to 100 MHz), must read out
- Require info sorted by EIC bunch # (spin patterns)
- Use appropriate collaboration developed DAQ implementation
- Huge data volume:
  - online processing → LUMI results
  - save relevant info for offline reprocessing (e.g. histograms)

Last Word

- Focused here on γ's from Bremsstrahlung $ep \rightarrow ep\gamma$, $eA \rightarrow eA\gamma$
- e^- from Bremsstrahlung will hit e-taggers
- At low L_{inst} (<<1 e^- per bunch ×ing):

  e^- in tagger, energy $E_e \Rightarrow$ brems. γ, $E_\gamma = E_{e\text{-beam}} - E_e$

<u>Look in LUMI system:</u>

- Coincidence in pair spec.?
  - measure spectrometer acceptance, e.g. conversion probability
  - verify simulation for acceptance correction
- Shower in γ-calorimeter?
  - calibrate γ-calorimeters

e-taggers critical for precision LUMI measurement