A Quartz Fibre Calorimeter Hodoscope for the Luminosity Measurement at HERA

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- The HERA Luminosity upgrade...
- ... its impact on the luminosity system,
- ... the new luminosity detector of H1,
- ... and associated topics.

The HERA 2000 Luminosity Upgrade

HERA: $e^{+/-}(27.6\,\mathrm{GeV})\rightarrow\leftarrow p(820\,\mathrm{GeV})$ $\boxed{\sqrt{s} = 300\,\mathrm{GeV}}$

1992–1997: integrated $\mathcal{L}$ doubled each year

1997: 35 pb^{-1}/year $\mathcal{L}_{\mathrm{peak}} = 1.2 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

(design value $\mathcal{L}_{\mathrm{peak}} = 1.5 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)

2000: **fivefold $\mathcal{L}$ increase**

2000–2005: 200 pb^{-1}/year $\mathcal{L}_{\mathrm{peak}} = 7.4 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

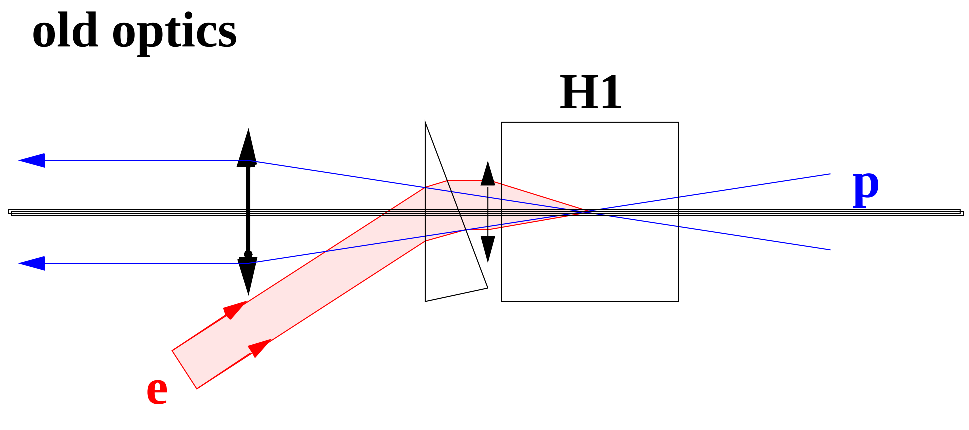
AND $e^{+/-}(30\,\mathrm{GeV})\rightarrow\leftarrow p(920\,\mathrm{GeV})$ $\boxed{\sqrt{s} = 330\,\mathrm{GeV}}$

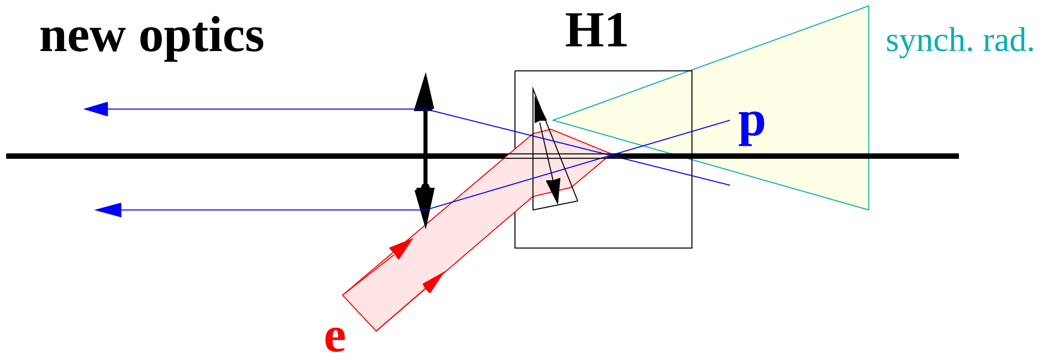
HOW? Decrease β function at the I.P.

⇒ move p focusing magnets from 26 m to 11 m from the I.P.

⇒ focus and bend $e^{+/-}$ with ...

superconducting combined function magnets inside detectors





Longitudinal Polarization of $e^{+/-}$

$$\boxed{\mathcal{P} = 70\%}$$

present: revert electron spin precession due to main solenoid of H1 and ZEUS detectors with a compensating solenoid in order to preserve transverse polarisation (spin rotators in HERMES detector only)

2000: no more place for compensator
$\Rightarrow$ longitudinal polarization in all detectors

- electroweak cross-sections are helicity dependent (high Q^2)
- polarization is bunch dependent

Consequence:

$\Rightarrow$ measure $\mathcal{P}$ precisely ($\approx 2\%$) bunch by bunch

$\Rightarrow$ measure $\mathcal{L}$ with comparable precision ($\approx 1\%$) bunch by bunch

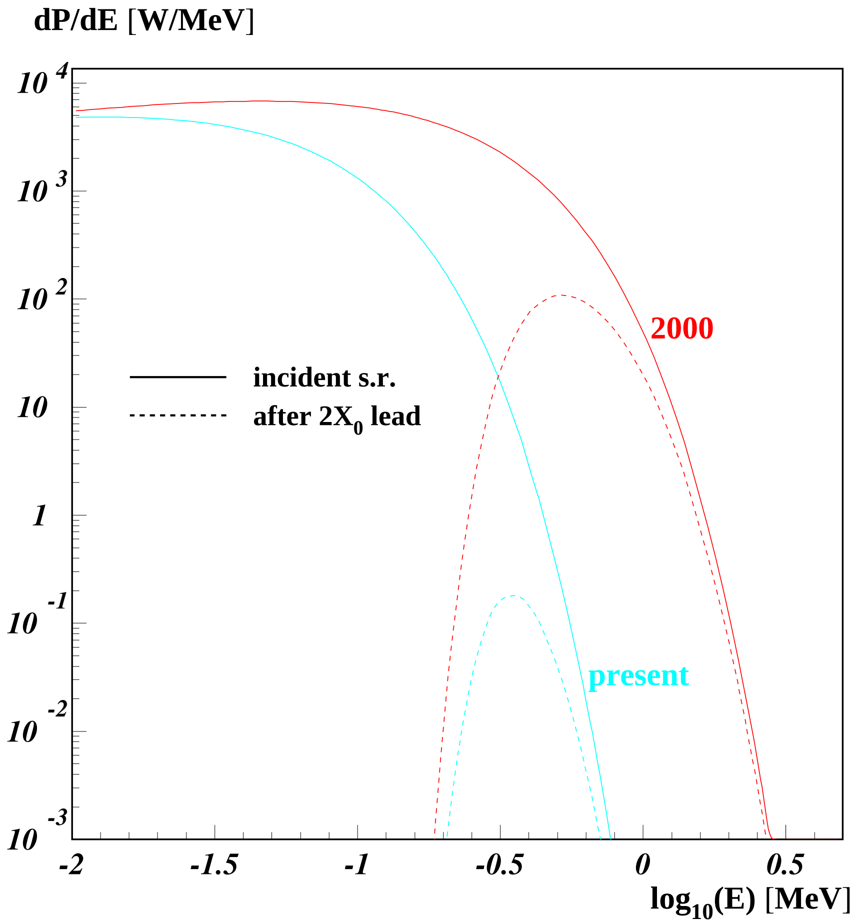
Synchrotron Radiation

Critical energy E_C increases! present: $E_C = 45\,\mathrm{keV}$

2000: $E_C = 160\,\mathrm{keV}$

⇒ total radiated power $\times\mathbf{5}$

⇒ harder spectrum (up to 1–2 $\mathbf{MeV}$)



Consequence:

synchrotron radiation must not hit the beam-pipe

but must be absorbed far away

⇒ complicated beam pipe

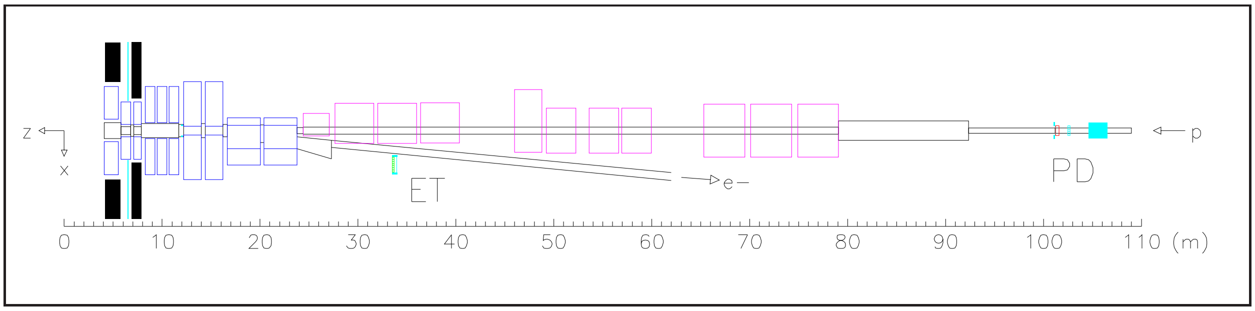
⇒ rearrangement of silicon trackers

⇒ high radiation doses on $\mathcal{L}$ system

The Luminosity measurement at HERA

▶ **Principle:** bremsstrahlung process $\mathbf{ep \rightarrow ep\gamma}$

$\Rightarrow \gamma$ counting & Bethe-Heitler (BH) cross section σ_{BH}



▶ **Lumi system tasks:**

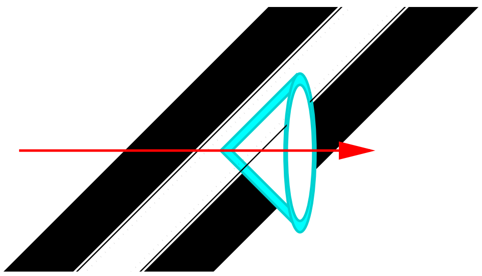
- online: measure instantaneous $\mathcal{L}$ (every 10 sec)
  measure γ position (e-beam tilt, acceptance)
- offline: measure integrated $\mathcal{L}$ (precision in 1997: 1.3%)
- physics: tag ISR events → photon detector (PD)
  tag photoproduction events → electron tagger (ET)

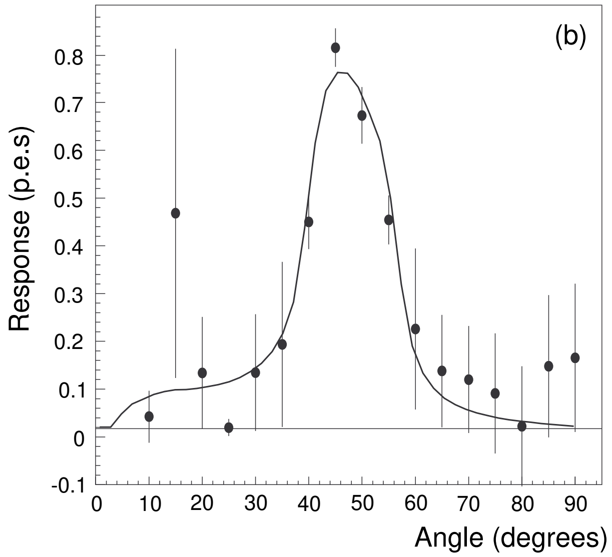
▶ **Impact of $\mathcal{L}$ upgrade on $\mathcal{L}$ measurement:**

- new lattice + space constraints ⇒ new electron tagger
- high radiation doses on photon detector
  bremsstrahlung dose: 25 Mrad/year
  (unshielded) synchr. rad. dose: $\mathcal{O}($ Terarad/year$)$
  ⇒ radiation hard photon detector + optimal s.r. shielding
- in–bunch γ pile-up: $\langle n_\gamma \rangle = 4.2$ for $E_\gamma > 10\,\mathrm{MeV}$
  (autoconvolution of BH spectrum)
  ⇒ fast histogramming DAQ + online fit
- longitudinal polarization ⇒ measure $\mathcal{L}$ bunch by bunch

Čerenkov fibre calorimetry

Principle:





- used in CMS very forward HCAL [N. Akchurin et al., NIM A 399 (1997)]
- advantages:
  - radiation hardness (using quartz fibres)
  - better containment: ($R_{\mathrm{eff.}} < R_{\mathrm{M}}$)
  - directionality: insensitivity to halo muons
- major drawback: low light yield
  $\rightarrow$ photostatistics contributes significantly
  $\rightarrow$ increase light yield by respecting angle condition
- typically achieved E-resolution in EM calorimetry:
  $\sigma(E)/E = 25\%/\sqrt{E} \oplus 3\%$ with $\mathrm{Pb} : \mathrm{fibre} = 4$
  [P. Gorodetzky et al., NIM A361 (1995)]
- fluorinated quartz (Q/Q) v/s polymer (Q/P) clad quartz fibres

	Q/Q	Q/P
radiation hardness	+	−
cost	−	+
UV transmission	+	−
numerical aperture	−	+

The H1 Photon Detector in 2000

- absorber material: lead (1mm) or tungsten(0.7mm)
- sampling frequency = 0.35
- high volume ratio $\frac{V_{\text{fibre}}}{V_{\text{absorber}}} \approx 0.55$
- longitudinal segmentation:

precal	$\approx 4X_0$	6+6 layers	Q/Q fibres
calo	$\approx 21X_0$	29+29 layers	Q/P fibres
total depth	$\approx 25X_0$	70 layers	

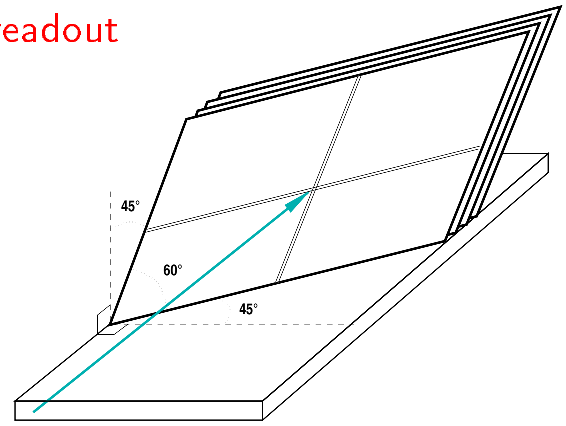
- $\approx$ 14000 fibres, ≈ 9000 m

precal	Q(600)/Q(F)(660)/PI(690)	>20 MGy*
calo	Q(600)/silicone(750)	7MGy*

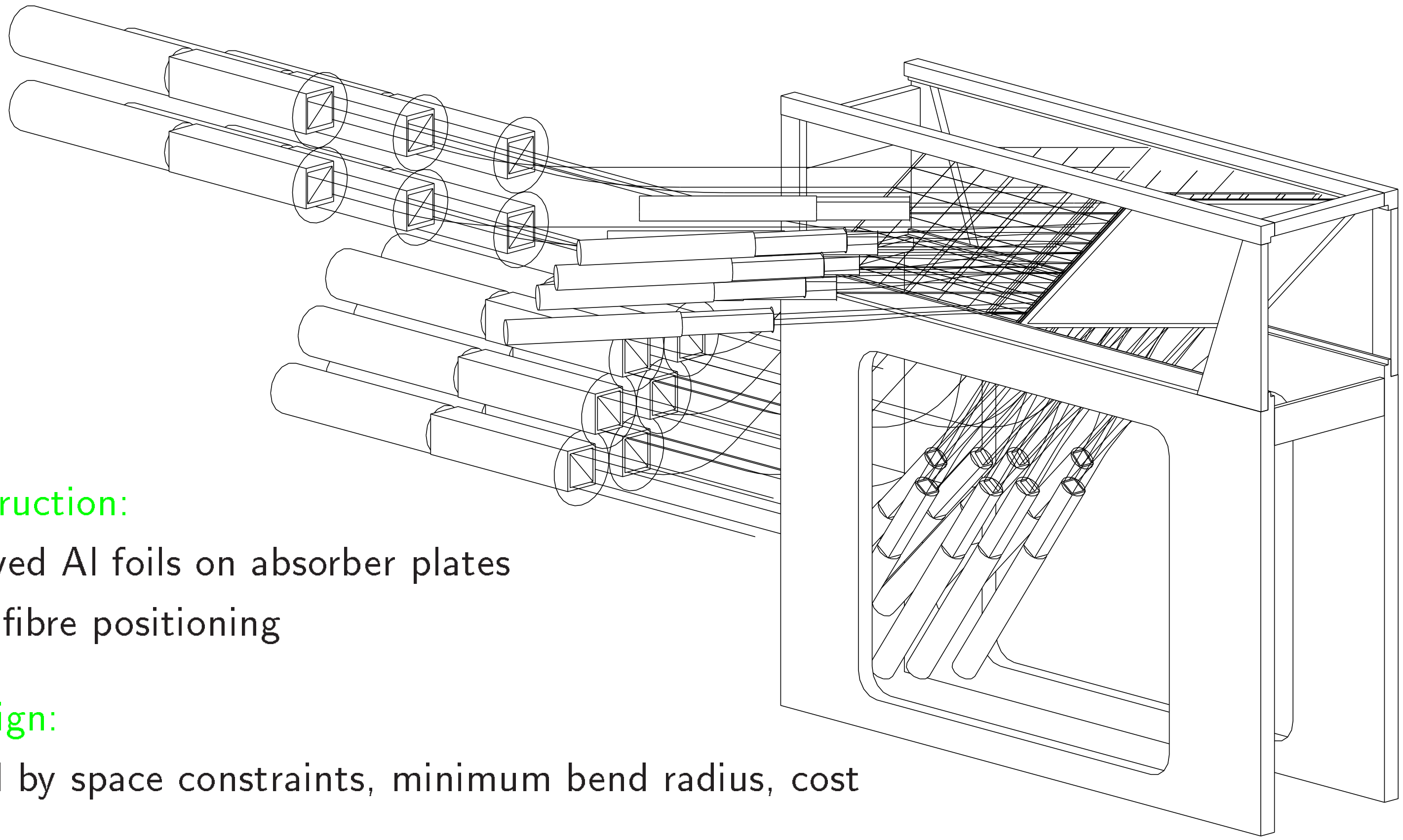
*20% Č light loss, high dose rate (0.17 MGy/min)
[P. Gorodetzky et al., NIM A361 (1995)]

- expected energy resolution: $\sigma(E)/E = 23\%/\sqrt{E}$
(photostatistics: 12% , sampling fluctuations: 19%)
[following M. Lundin et al., NIM A372 (1996)]

- hodoscope with horiz. and vert. strip readout
  - alternating strips in x and y (orthogonal in projection)
  - oblique geometry ($\alpha_{\text{inc}} \approx 55°$)
  - segmentation: 6 strips of 2 cm (four 1 cm strips in centre of precal)
  - dimensions: $\approx 12 \times 12\text{cm}^2$



Design of the H1 Photon Detector



- layer construction:

  mold grooved Al foils on absorber plates

  $\rightarrow$ precise fibre positioning

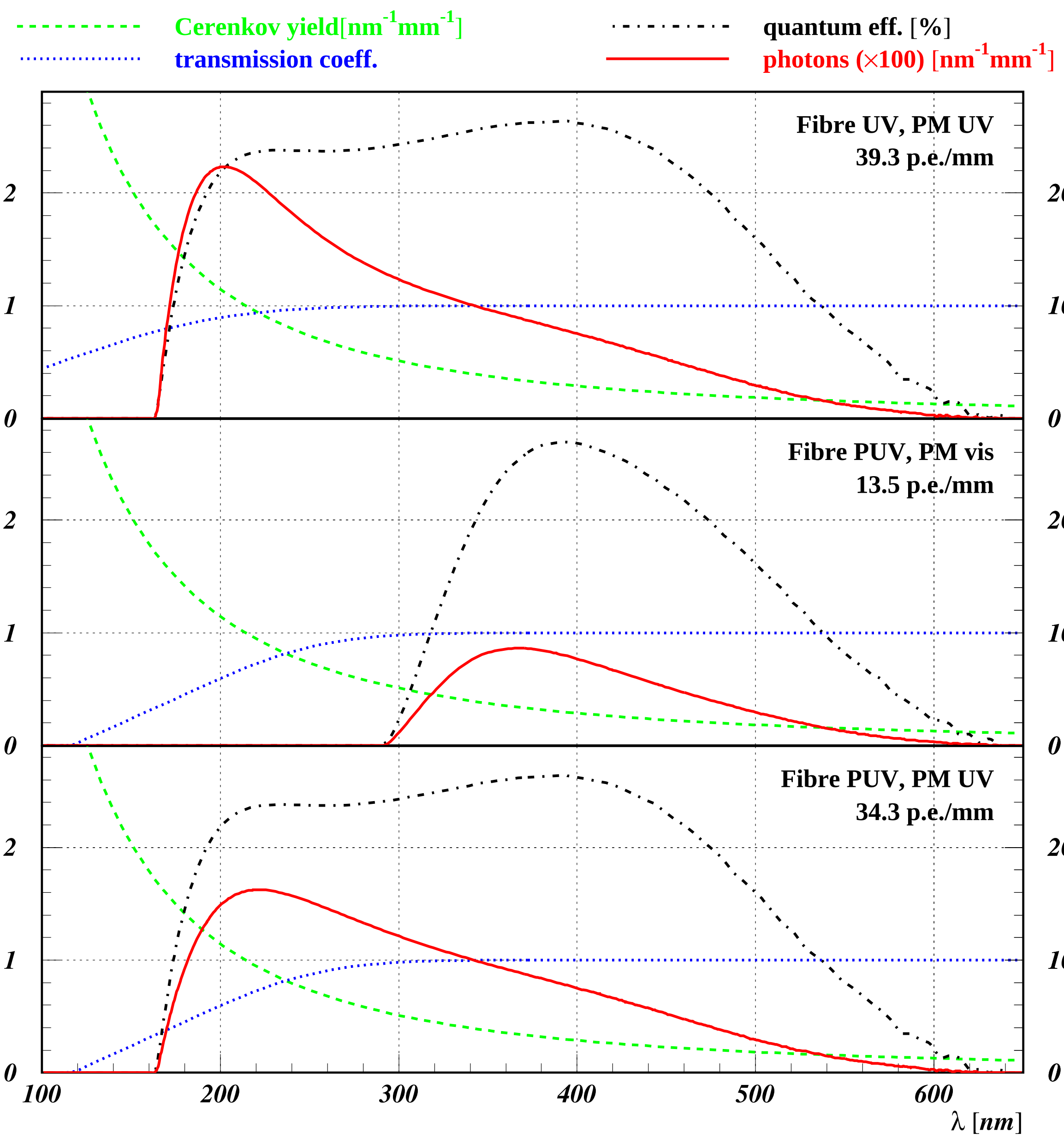
- bundle design:

  determined by space constraints, minimum bend radius, cost

- light mixers:

  hollow aluminized LM v/s solid quartz LM

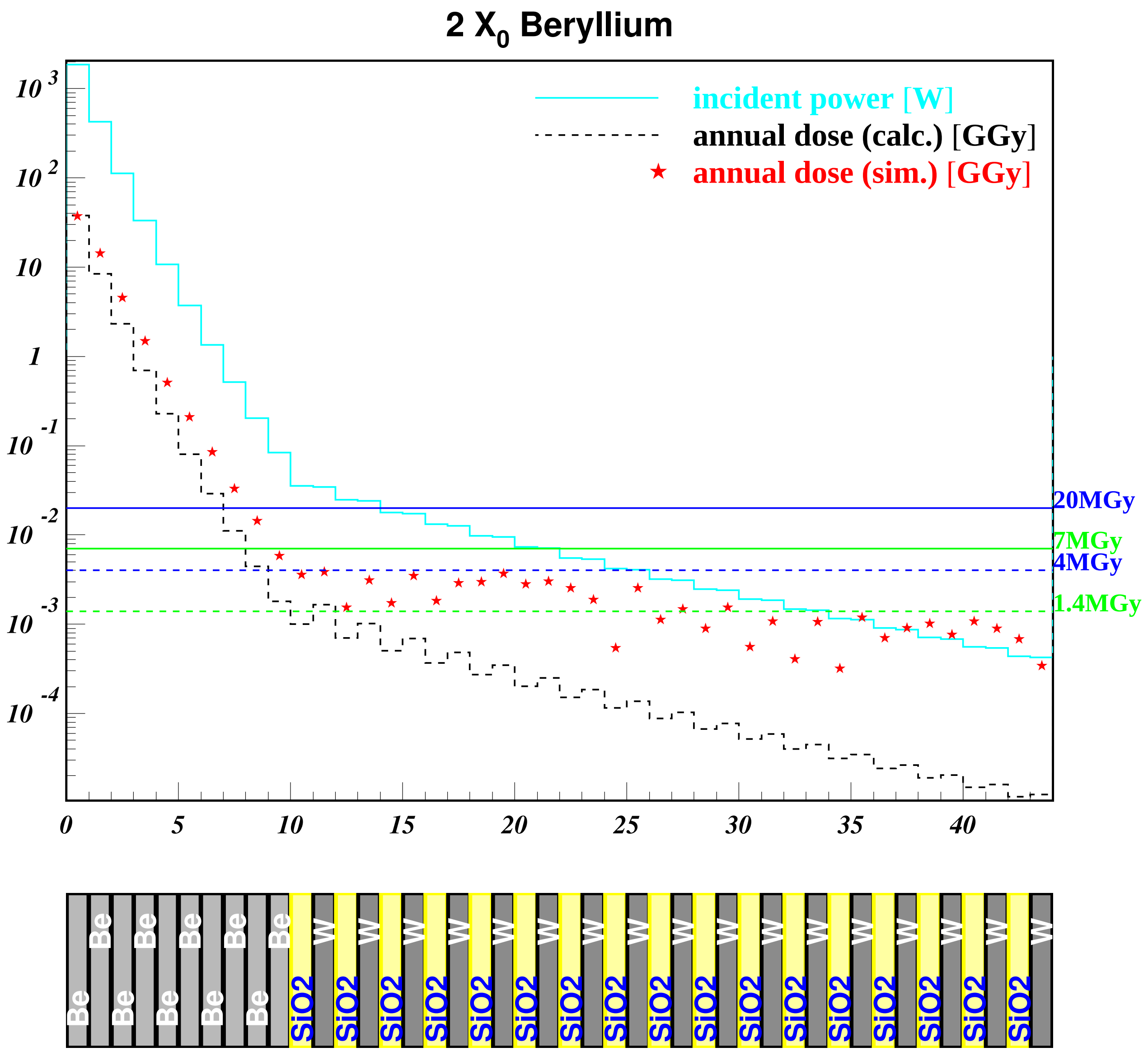
Read polymer-clad fibres with UV sensitive PMTs?



$\Rightarrow \approx 2.5\times$ higher photostatistics

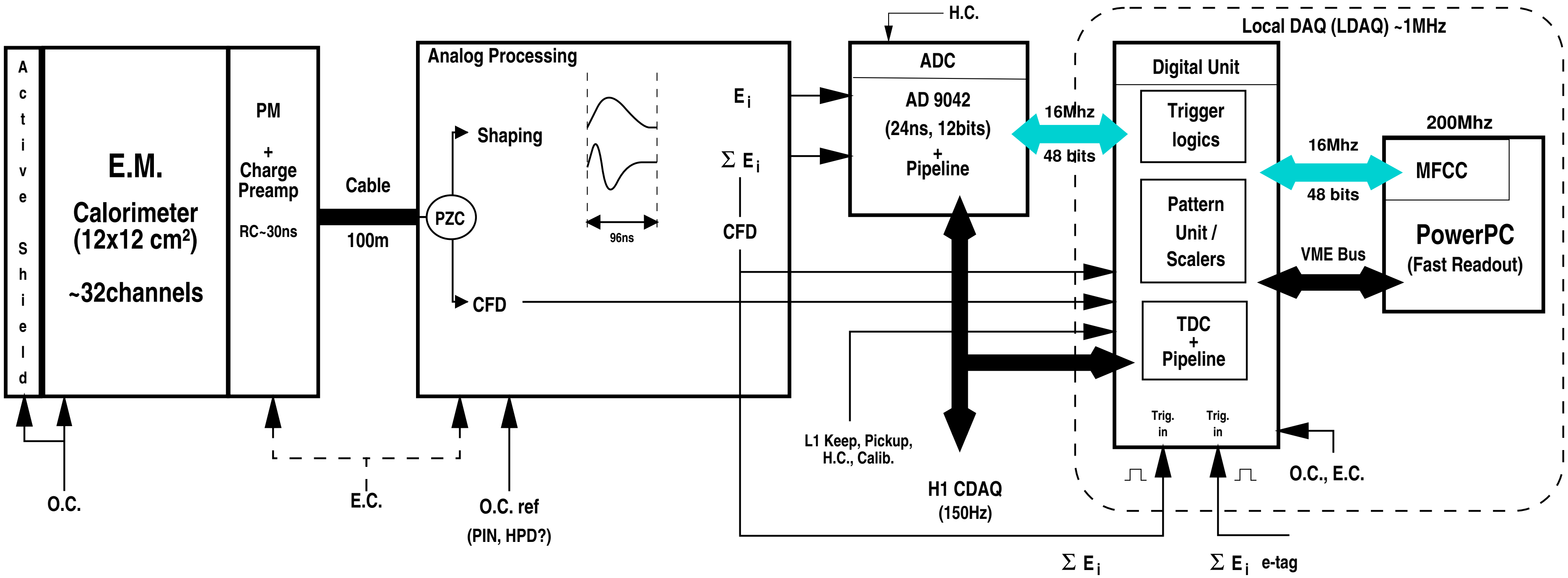
Synchrotron Radiation Filter

- reach tolerable dose on first fibre layer in min. thickness (x/X_0)
  $\Rightarrow$ use low Z materials
- minimize back- and side-scattering
- minimize shower size



Electronics, Trigger & DAQ:

- $\sim 4\gamma/\mathrm{bunch\ crossing}$ for $E_\gamma > 10\,\mathrm{MeV}$ at max. $\mathcal{L}$
  - $\Rightarrow$ NO bunch to bunch pile-up ($\rightsquigarrow$ pulse shaping)
- 12 bit ADC, 4 samples per bunch crossing (1 B.C.=96 ns)
- measure $\mathcal{L}$ per bunch at the same rate as $\mathcal{P}$($\sim$ 1/min.)
  - $\Rightarrow$ dedicated fast DAQ [$\mathcal{O}(\mathrm{MHz})$] (same for $\mathcal{P}$ DAQ ?)



O.C. = Optical Calibration
E.C. = Electronics Calibration