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Deep-Inelastic Scattering and
Related Subjects
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Measuring very forward (backward) at the LHeC

Armen Buniatyan
DESY

Detectors located outside of the main detector
(~ 10 ÷ 100m from the Interaction Point)

Goals:

- Instantaneous luminosity
- Tag photo-production (Q^2~0)
  - Luminosity Detectors, Electron Tagger
- Electron beam polarisation
  - Polarimeters
- Very forward nucleons
  - Zero Degree Calorimeter, Forward Proton Spectrometer

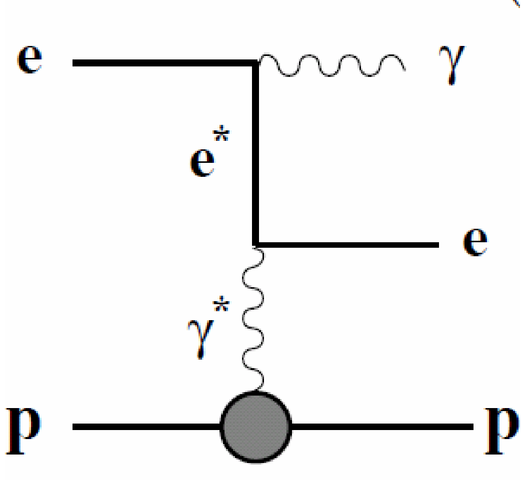
Luminosity measurement

Goals:

- Integrated luminosity with precision $\delta L \sim 1\%$
- Fast beam monitoring for optimisation of *ep*-collisions and control of mid-term variations of instantaneous luminosity

Need to prepare several 'alternative' methods for luminosity determination !

Luminosity measurement: physics processes



Bremsstrahlung ep→ eγp

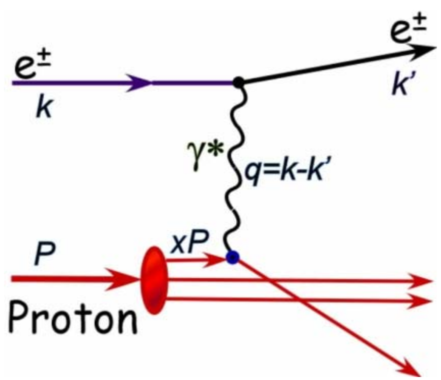
Bethe-Heitler (collinear emission):

- very high rate of 'zero angle' photons and electrons, but
- sensitive to the details of beam optics at IP
- requires precise knowledge of geometrical acceptance
- suffers from synchrotron radiation
- aperture limitation
- pile-up

QED Compton (wide angle bremsstrahlung):

- lower rate, but
- stable and well known acceptance of central detector

➔ **Methods are complementary, different systematics**



NC DIS in (x,Q^2) range where F_2 is known to $O(1\%)$ for relative normalisation and mid-term yield control

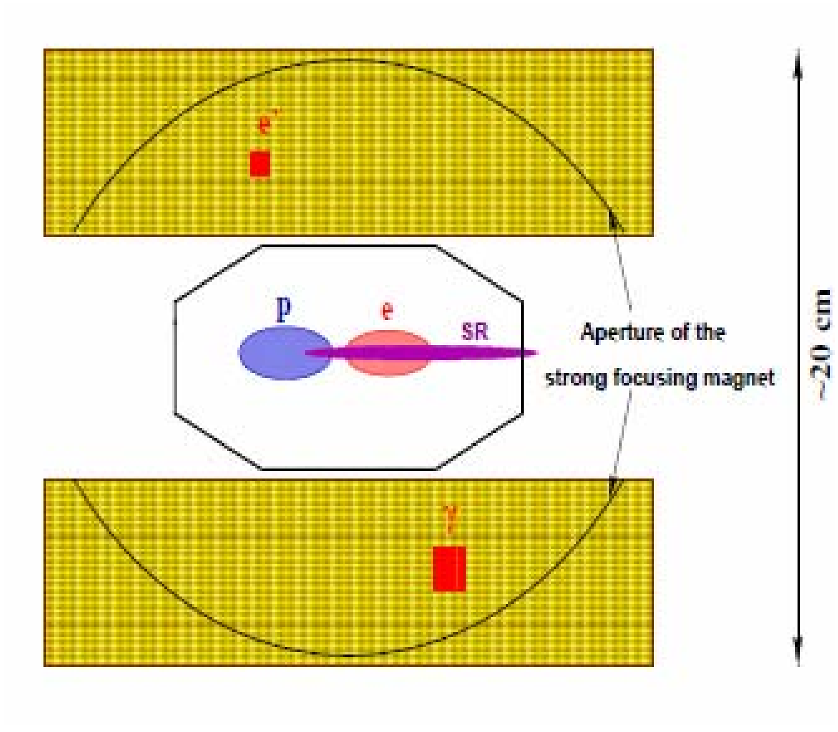
Luminosity measurement: QED Compton

electron and photon measured in the main detector (backward calorimeter)

σ_{vis} ~3.5nb (low Q^2 setup), 0.03nb (high Q^2 setup)➔stat.precision ~0.5%/month

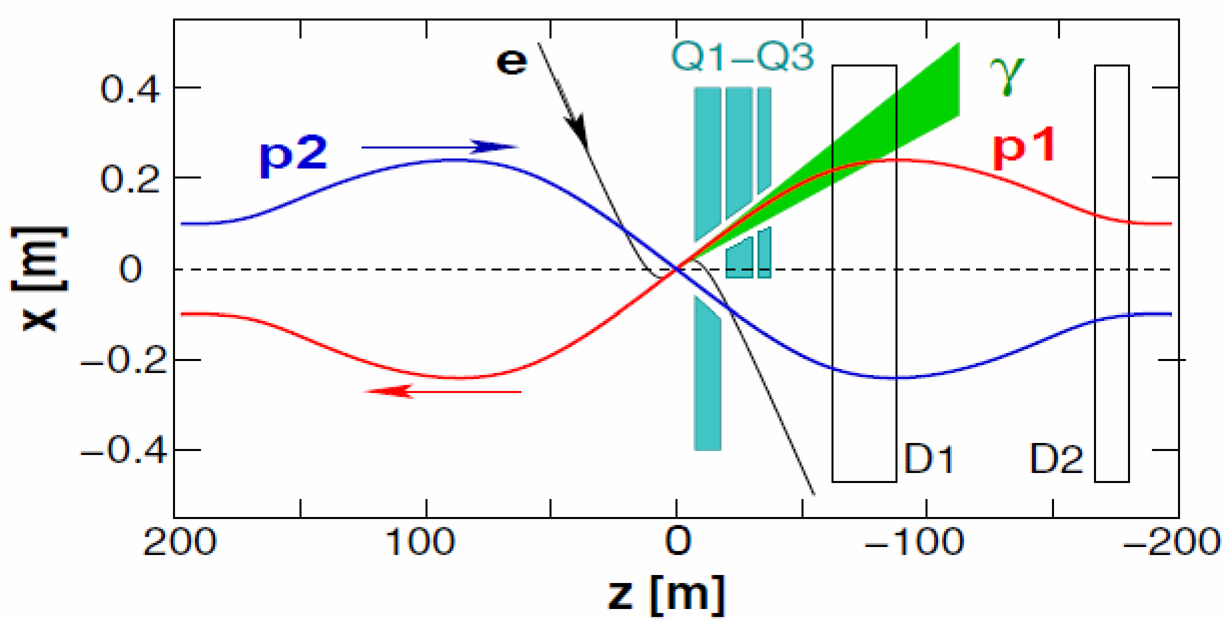
Install additional 'QEDC tagger' at z≈-6m →increase visible cross section for QEDC to ~4.3nb

→ e.g. two moveable sections approaching the beam-pipe from top and bottom $\theta \approx 0.5 \div 1^{o}$ (in addition, a small Si-detector to reconstruct event vertex and for e/γ separation)



Luminosity measurement: Bethe-Heitler (ep→eγp)

For **LR** option the photons travel along the proton beam direction and can be detected at z≈-120m, after the proton bending dipole.
→ Place the photon detector in the median plane next to interacting proton beam

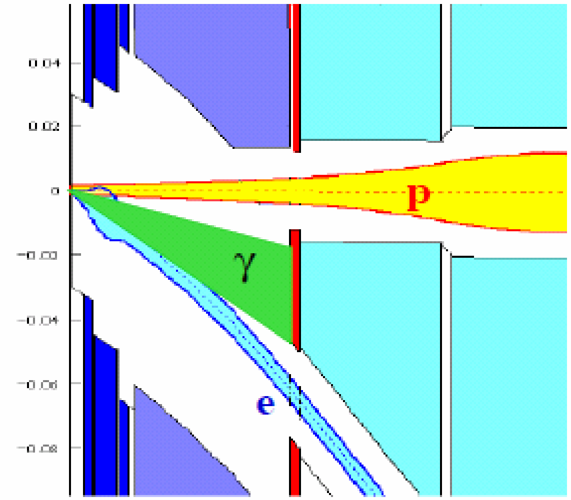


Main limitation – geometrical acceptance, defined by the aperture of Q1-Q3.
May be need to split dipole D1 to provide escape path for photons.
Geometrical acceptance of 95% is possible, total luminosity error δL=1%.

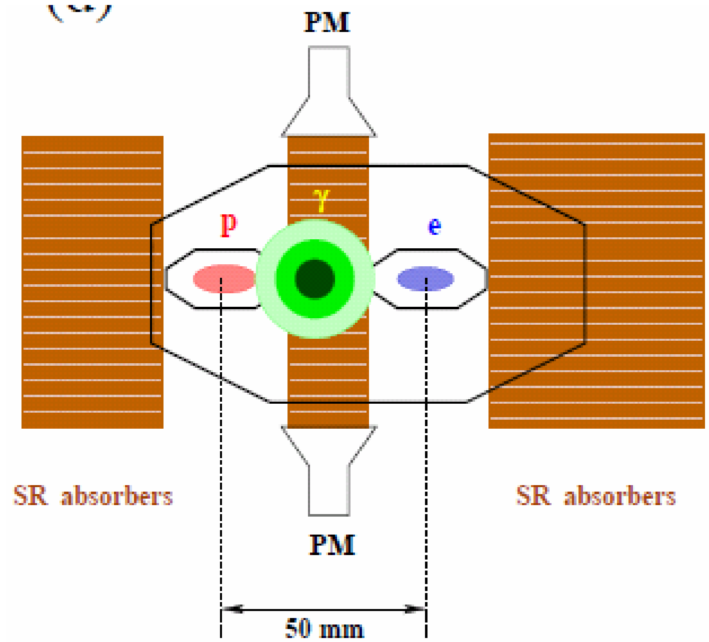
Bethe-Heitler (ep→eγp)

For **RR** option (1mrad crossing angle) the dominant part of BH photons will end up at z≈-22m

→ **very high synchrotron radiation !**



Idea is to use the cooling water of SR absorber as active media for Čerenkov calorimeter; r/o two PMs:
- radiation hard
- insensitive to SR

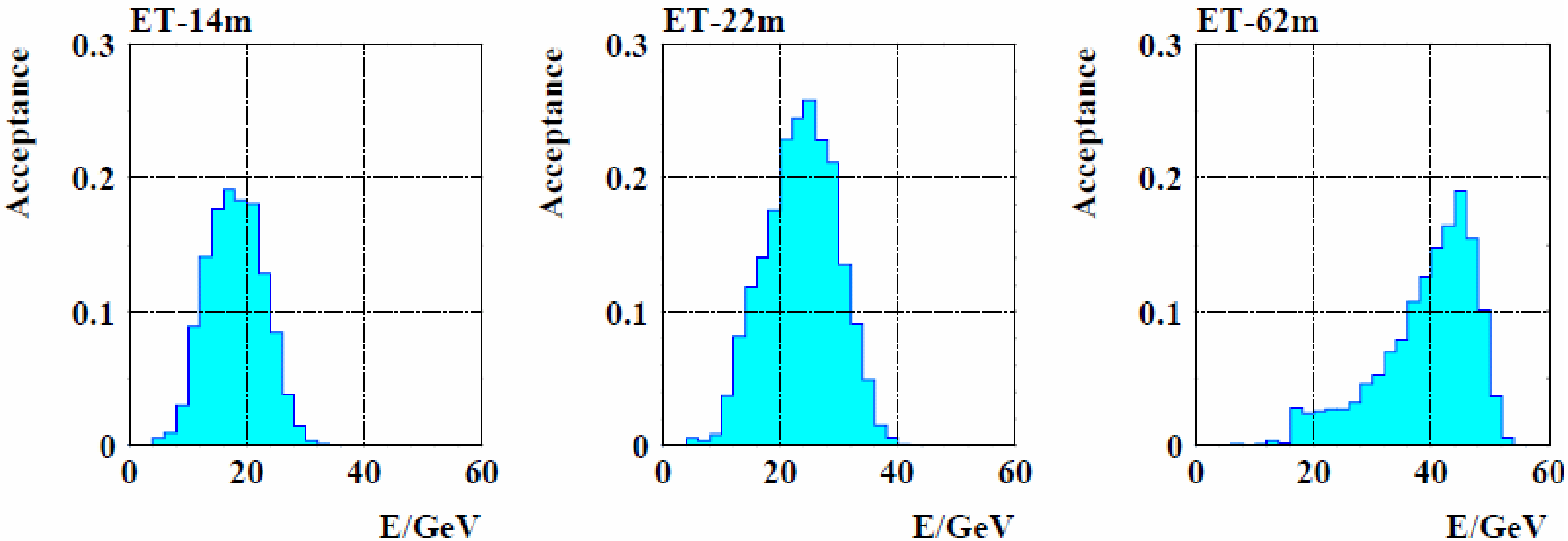


Geometrical acceptance of ~90% allows fast and reliable luminosity determination with 3÷5% systematic uncertainty

Electron tagger

detect scattered electron from Bethe-Heitler (also good for photoproduction physics and for control of γp background to DIS)

Clean sample – background from e-gas can be estimated using pilot bunches.
Three possible positions simulated→ acceptances reasonable (up to 20÷25%)



Acceptance depends on the distance of the detector from the e-beam axis and on the details of the e-beam optics (beam tilt, trajectory offset)

Need a precise monitoring of beam optics and accurate position measurement of the e-tagger to control geometrical acceptance to a sufficient precision (e.g. 20μm instability in the horizontal trajectory offset at IP leads to 5% systematic uncertainty in the visible cross section)

Measurement of Polarisation

Based on 'Compton scattering' (as at HERA and SLC):

- γ–beam from laser scatters off the electron beam;
- scattered γ (and electron) measured in the calorimeters
- longitudinal polarisation of electron beam - from a fit to the scattered γ and e energy spectra

Polarisation from the scattered photons:

- the single and few scattered photons regime

- extract the polarisation from a fit to the scattered γ energy spectrum;
- *in situ* calibration to the kinematical edge of the energy spectra;
- background (e.g. synchrotron radiation) is difficult to model precisely

- the multi-photon regime

- extract the polarisation from an asymmetry between the average scattered energies corresponding to a circularly left and right laser beam polarisations;
- background – negligible
- no energy calibration *in situ*, rely on extrapolation from low energy

With a very stable pulsed laser beam, with adjustable energy and operating in different regimes, one can calibrate the calorimeter and optimise the dynamical regime to improve the uncertainty on the polarisation

Polarisation from the scattered electrons

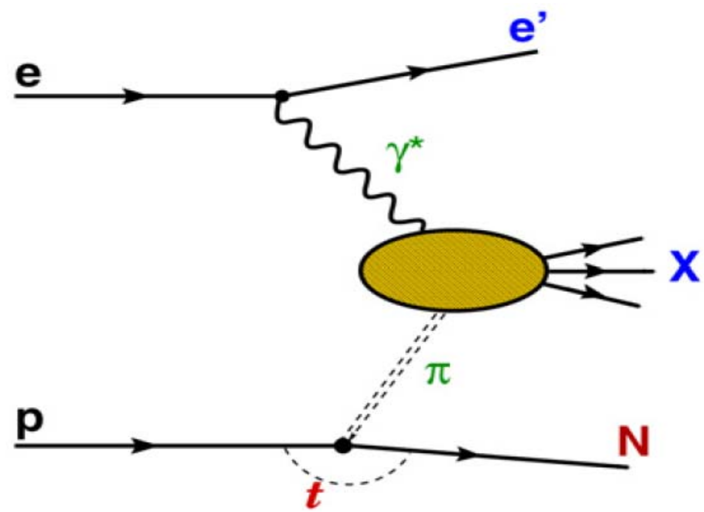
Design a Compton interaction region in order to implement a dedicated electron spectrometer followed by a segmented electron detector to measure the scattered electron angular distribution, related to the electron energy spectrum.

- γ and e-measurements are complementary and improve the precision

Both (electron and photon) measurements are foreseen for the future ILC with the goal to reach the per mille level precision on the longitudinal polarisation measurement. Same has to be considered for LHeC.

Zero Degree Calorimeter (ZDC): physics potential

Measure neutrons and photons scattered at ~0°.



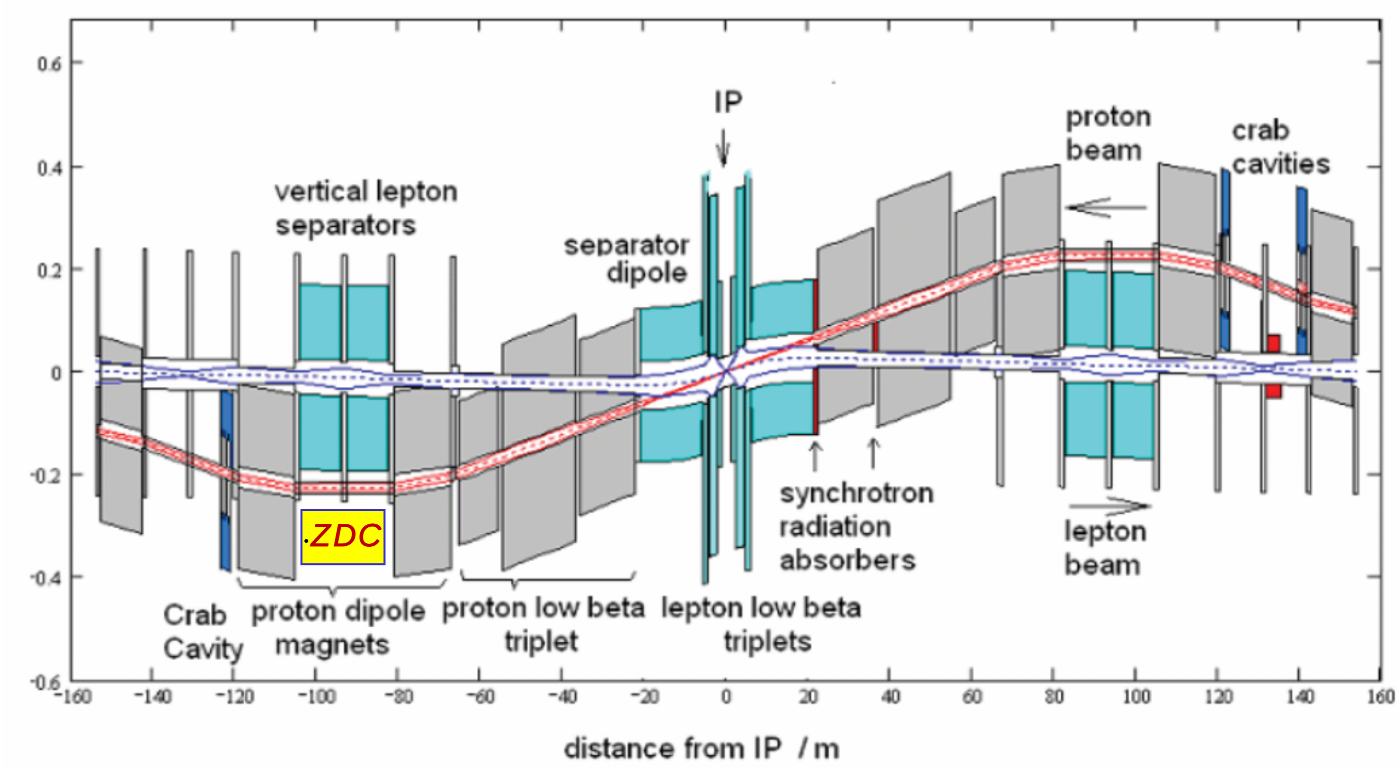
- tag pion exchange process, pion structure, absorptive /gap survival effects
- colour single exchange, diffractive scattering
- Crucial in ed-scattering to tag spectator neutron, distinguish spectator and scattered neutrons
- Crucial in diffractive eA, to distinguish coherent from incoherent diffraction
- Measurements for cosmic ray data analysis
  proton fragmentation, forward energy and particle flows…
- New forward physics phenomena
- …

At HERA, both experiments had FNC calorimeters.
At the LHC, Alice, ATLAS, CMS and LHCf experiments have ZDC.

Zero Degree Calorimeter

- The position of ZDC in the tunnel and the overall dimensions depend mainly on the space available for installation (~90mm space between two beampipes at z~ 90÷100m)

→need detailed info/simulation of beam-line



ZDC design - general considerations

· Geometric constraints- depends on the available space and angular aperture

• Requirement to the neutron calorimeter: detect neutrons and photons with θ<0.3mrad (or more) and E~O(100) GeV to 7 TeV with a reasonable resolution of few percent
• identify γ (π^0), n; measure energy and position of n and γ with reasonable resolution; reconstruct >1 particles, evtl. reconstruct $\pi^0 \rightarrow 2\gamma$; control beam position and beam spot during data taking
• radiation resistant

One can consider also the ZDC for the measurement of spectator protons from eD or eA scattering (positioned external to proton beam as done for ALICE)

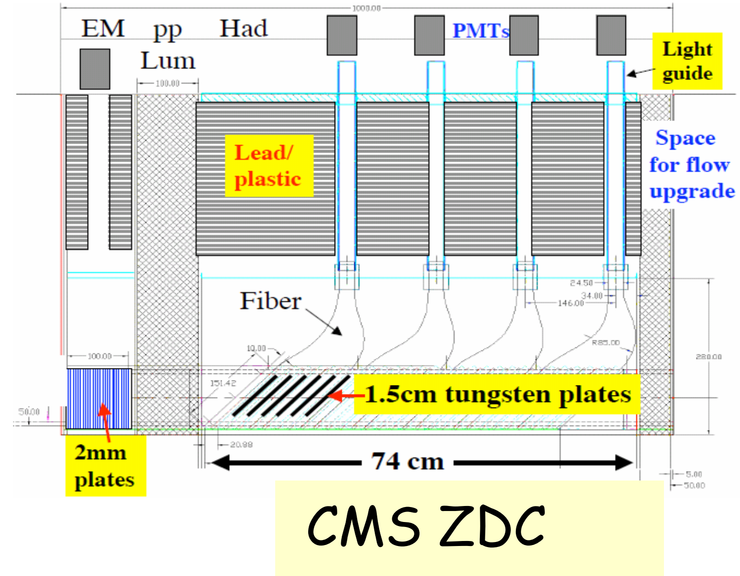
ZDC design – possible solutions

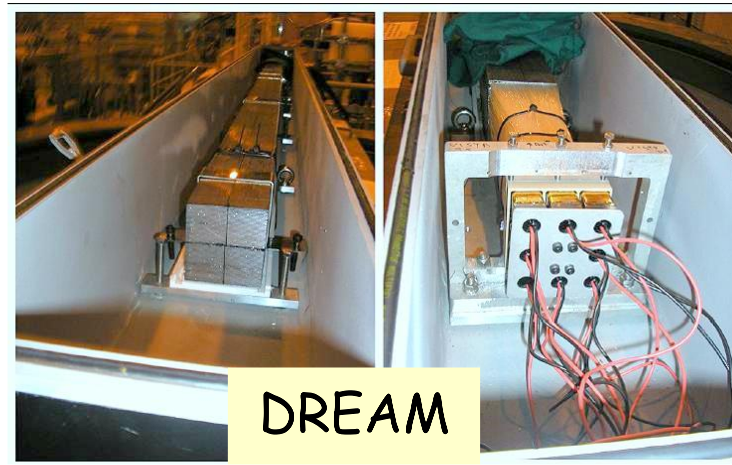
- Longitudinally segmented calorimeter: e/m (~1.5λ_I, fine granularity to reconstruct impact point) and hadronic (~7-8λ_I) sections, transverse size ~3λ_I, long.segmnetation to control radiation damage

Experience from the LHC, RHIC – sampling hadron calorimeter: absorber-W plates, active media – quartz fibers or THGEM
Tungsten/Čerenkov detectors are fast, rad. hard, narrow visible showers

- Make use of recent developments in calorimetry: Dual Readout (DREAM); Tungsten absorber with both quartz and scintillators fibres, SiPM readout; γ/n separation using timing structure

(G.Gaudio and R.Wigmans, DREAM Collaboration (RD52), Progress report June 2011)





<u>Proton calorimeter</u> – similar technique as for neutron detector, at about same distance from IP; can be smaller- few cm small size of spectator proton spot, but sufficient to obtain shower containment

ZDC calibration and monitoring

-Stability of the photomultiplier gain and radiation damage in fibres can be monitored using laser or LED light pulse.
-In the dual-readout approach, make readout from both sides of fibres – control of radiation damage

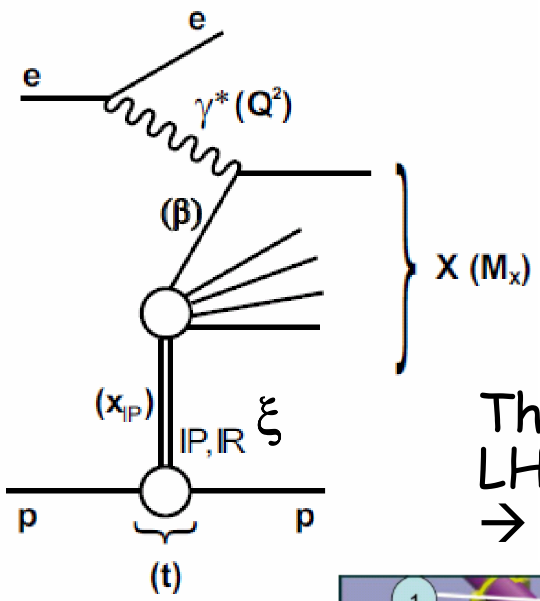
- Stability of absolute calibration using neutron spectra from beam-gas interaction.

- Invariant masses $\pi^0 \rightarrow 2\gamma$, $\Lambda,\Delta \rightarrow n\pi^0$ (Need to reconstruct several particles in ZDC within same event)

need to care about

-Background rate (beam-gas), pileup
-How large (and how well known) is the proton beam spread and 0^0 direction at IP ?
-Beam emittance, divergence → main limitation for t (p_T) resolution

Forward Proton Detection

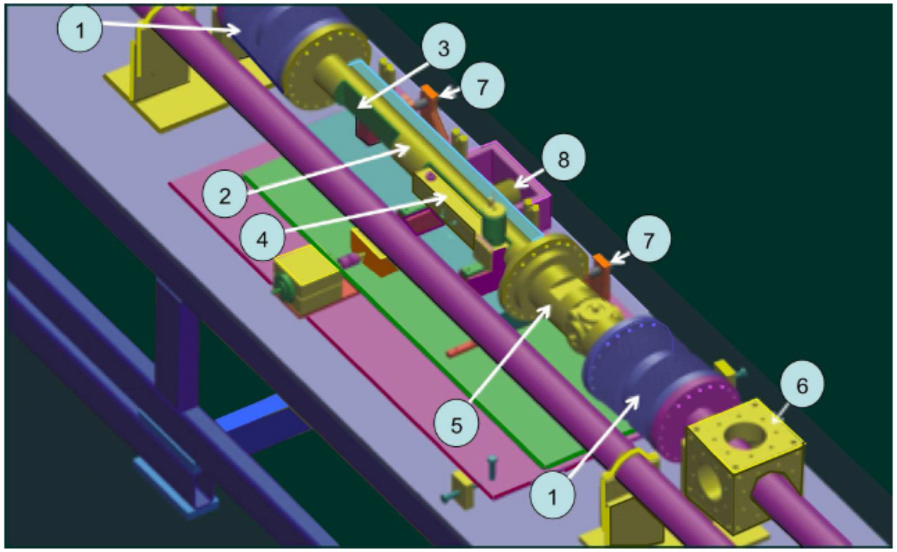


ep→ eXp' diffractive scattering

(proton survives a collision and scatters at a low angle along the beam-line)

$\xi \approx 1 - E_{p'}/E_p \sim 1\%$

The feasibility to install forward proton detectors along the LHC beamline investigated at the ATLAS and CMS
→ the results of R&D studies are relevant for LHeC



(from ATLAS AFP Project)

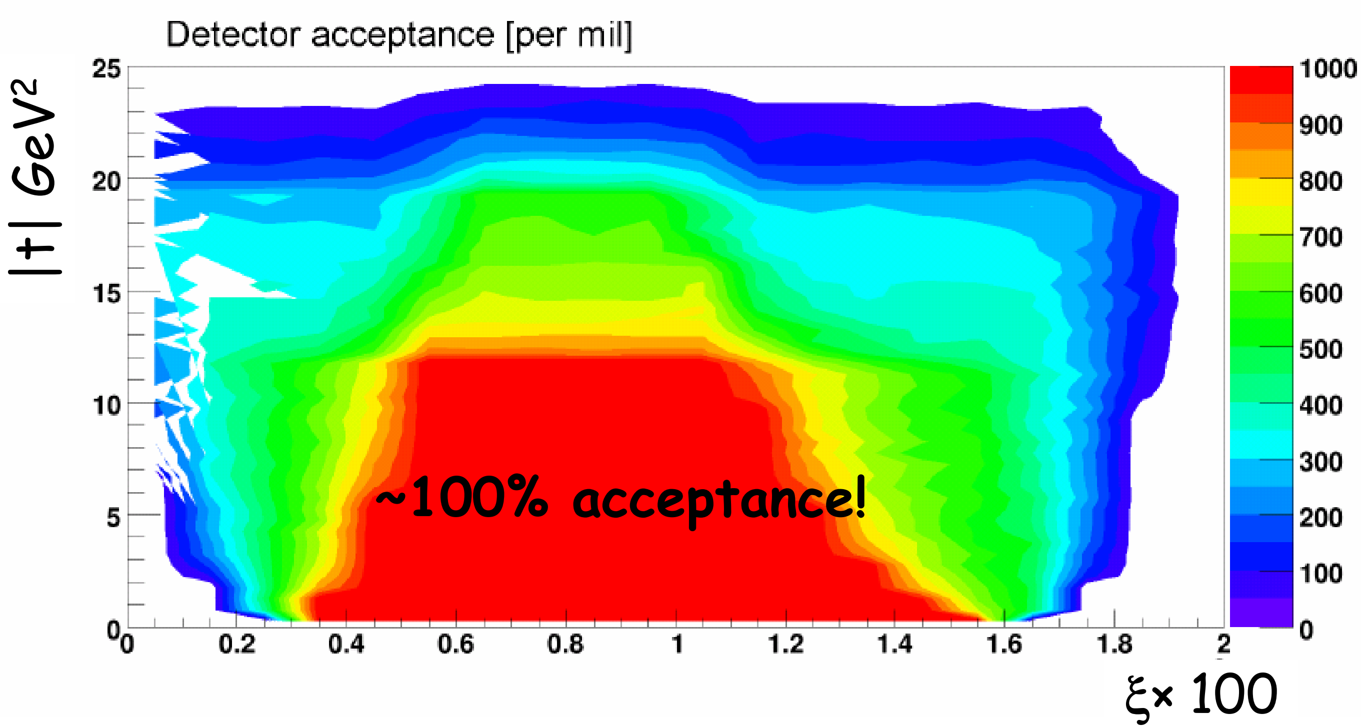
Figure 3.2: Top view of one detector section: bellows (1), moving pipe (2), Si-detector pocket (3), timing detector (4), moving BPM (5), fixed BPM (6), LVDT position measurement system (7), emergency spring system (8).

Acceptance for forward protons at LHeC

- Scattered protons are separated in space from the nominal beam: ($x_{offset}=D_x \times \xi$; D_x - energy dispersion function)

- Acceptance window is determined by the closest approach of proton detectors to the beam, and by the size of beam-pipe walls

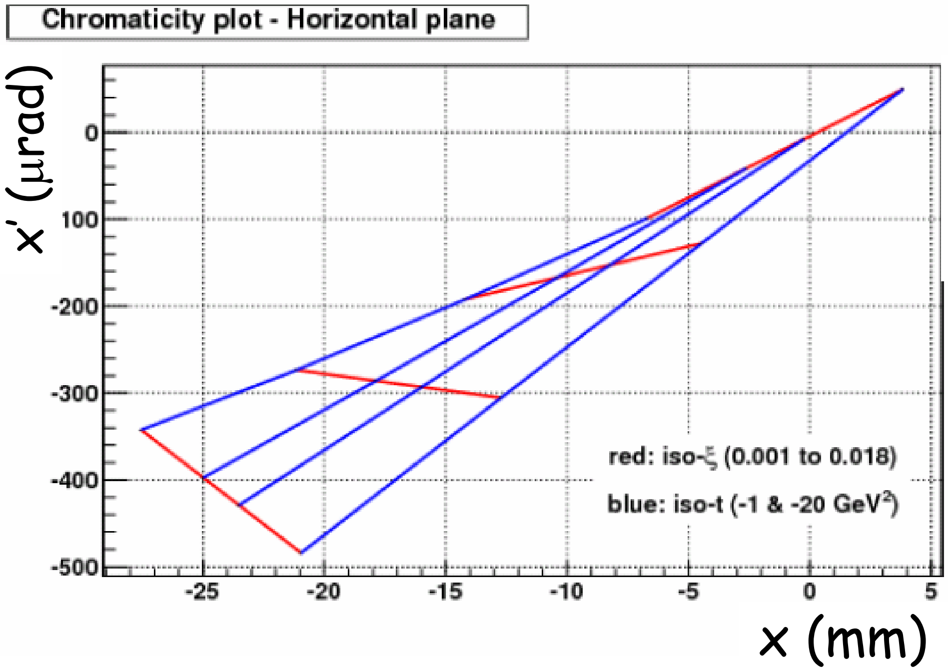
Assume closest approach $12\sigma_{beam}$ (σ_{beam}=250μm at 420m), $R_{beampipe}$≈2cm, D_x≈ 1.5m

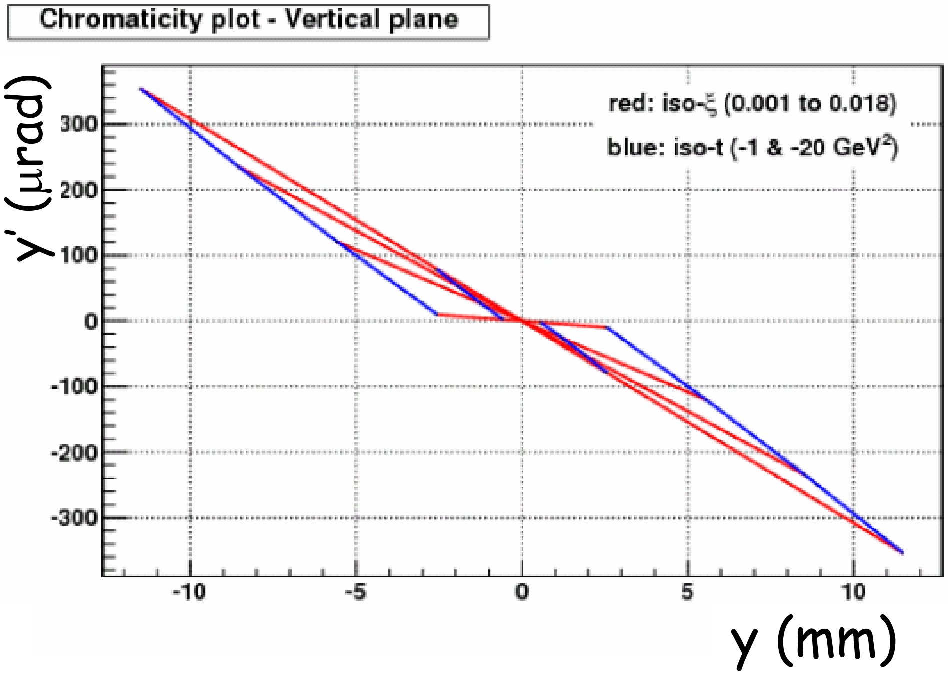


Good acceptance for 0.002<ξ<0.013

Forward protons: Reconstruction of event kinematics

The event kinematics ξ and $t \approx (1-\xi)E_{beam}\theta^2$ can be determined from the measurement of proton position and angle w.r.t. nominal beam





Relation between position and angle w.r.t. nominal beam and the t and ξ

Resolution limited due to beam divergence and width: typically 0.5‰ for ξ and 0.2μrad for θ.

Forward protons: alignment

Alignment of FPS - crucial: detector position with respect to the beam direction is not constant

➔ need to align (and monitor) detector position for each luminosity fill

- kinematic peak method - cross section maximal for forward scattering;
- use exclusive system, with well defined kinematics (e.g. $ep \rightarrow e' + \rho + p'$, ρ-meson reconstructed in the central tracker)

→ Need detailed studies

Conclusions

Forward and backward 'tunnel' detectors – important parts of the future ep (ed,eA) experiment

Ideas for the luminosity detectors, electron tagger, polarimeters, ZDC and FPS detectors described in the LHeC CDR

Next steps: clarify the geometrical constraints; investigate the possible design options in details

Design of detectors – challenging task !
- Use the experiences from HERA, LHC, RHIC,...
- Explore novel particle detector methods.

backup

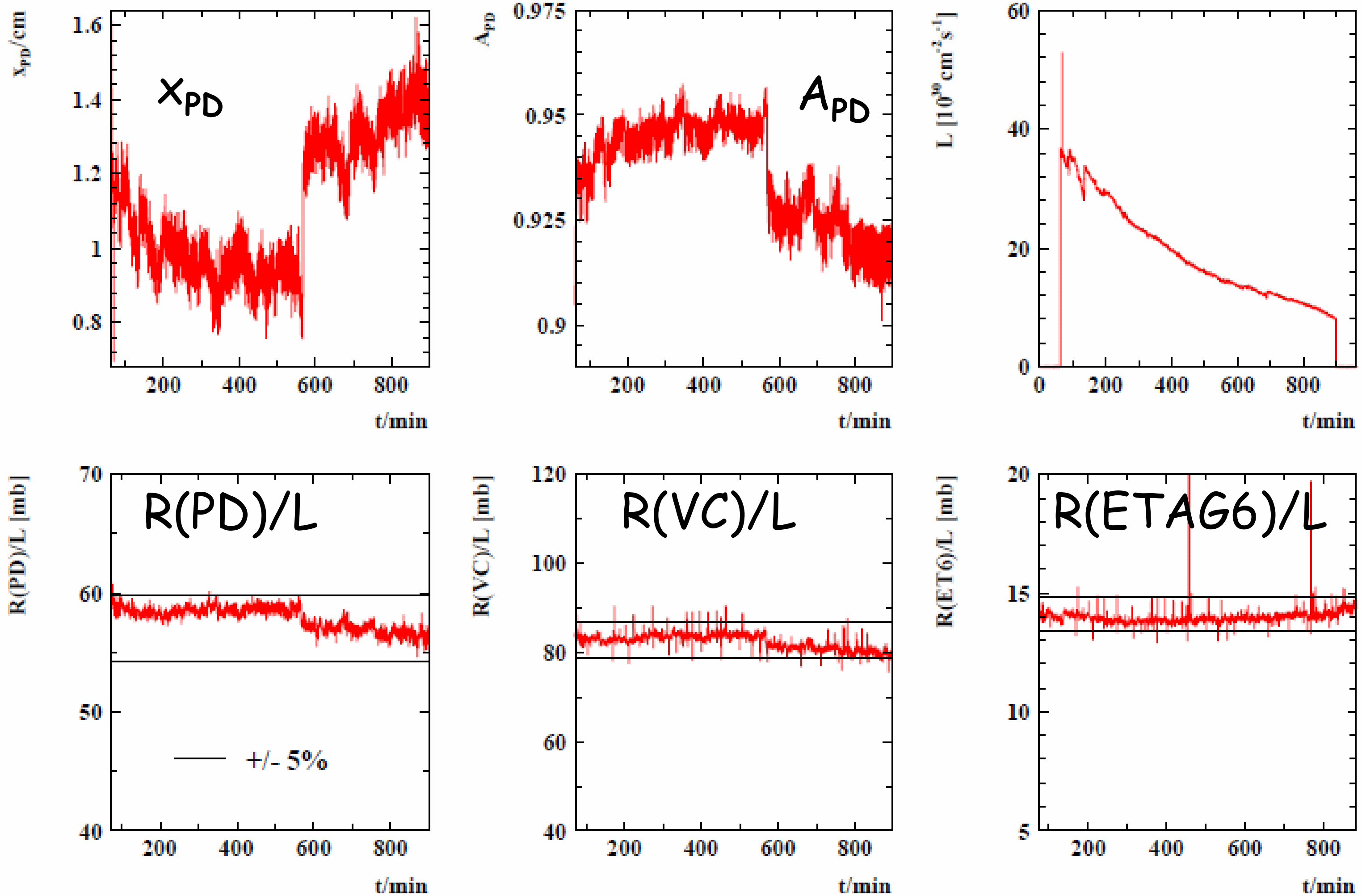
Luminosity measurement: dominant systematics for various methods

Requirements to physics process (visible cross sections)

fast monitoring	(δL=1%/sec	→ 10kHz)	σ_{vis}>100μb
mid-term control	(δL=0.5%/hour	→ 10Hz)	σ_{vis}>100nb
physics normalisation	(δL=0.5%/week	→ 0.1Hz)	σ_{vis}>1nb

Method	Stat. error	Syst.error	Systematic error components		Application
BH (γ)	0.05%/sec	1 – 5%	$\sigma(E \gtrsim 10\text{GeV})$	0.5%	Monitoring, tuning,
			acceptance, A	$10\%(1-A)$	short term variations
			E-scale, pileup	0.5 – 4%	
BH (e)	0.2%/sec	3 – 6%	$\sigma(E \gtrsim 10\text{GeV})$	0.5%	Monitoring, tuning,
			acceptance	2.5 – 5%	short term variations
			background	1%	
			E-scale	1%	
QEDC	0.5%/week	1.5%	σ (el/inel)	1%	Absolute $\mathcal{L}$,
			acceptance	1%	global normalisation
			vertex eff.	0.5%	
			E-scale	0.3%	
NC DIS	0.5%/h	2.5%	σ ($y < 0.6$)	2%	Relative $\mathcal{L}$,
			acceptance	1%	mid-term variations
			vertex eff.	1%	
			E-scale	0.3%	

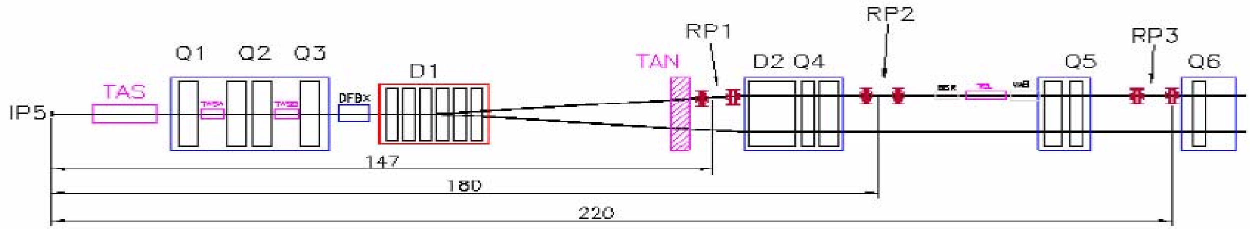
Table 14.1: Dominant systematics for various methods of luminosity measurement.

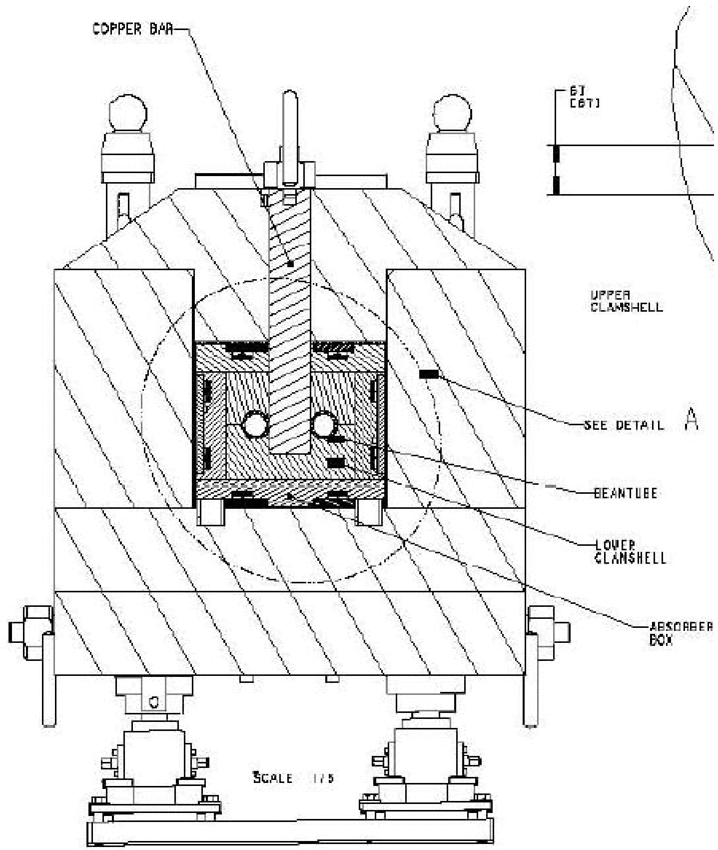


PD - total absorption electromagnetic calorimeter for the BH photons
VC - water Cerenkov counter
ET6- electron tagger

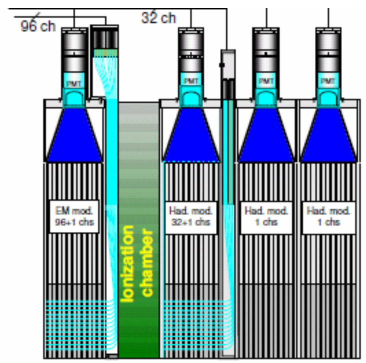
online luminosity estimate by every of those detectors is well within 5%

ZDC at the LHC detectors

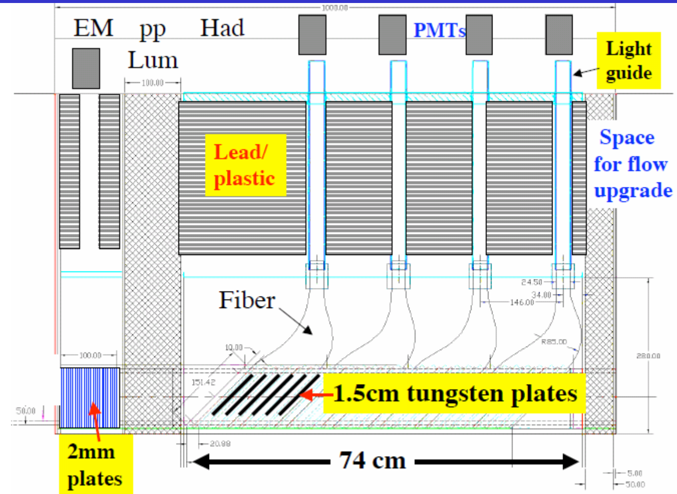




ZDC within TAN absorber



ATLAS



CMS

ALICE