3rd CERN-ECFA-NuPECC Workshop
on the Design of the LHeC
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Tagging very forward neutral particles at the LHeC

(Zero Degree Calorimeter)

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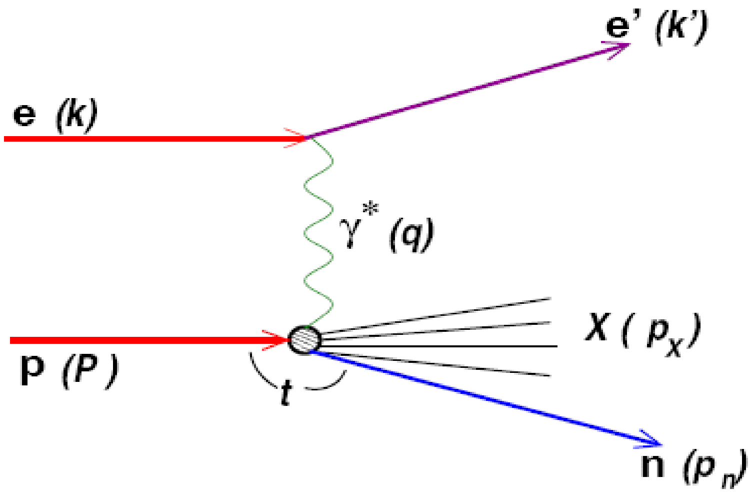
Introduction

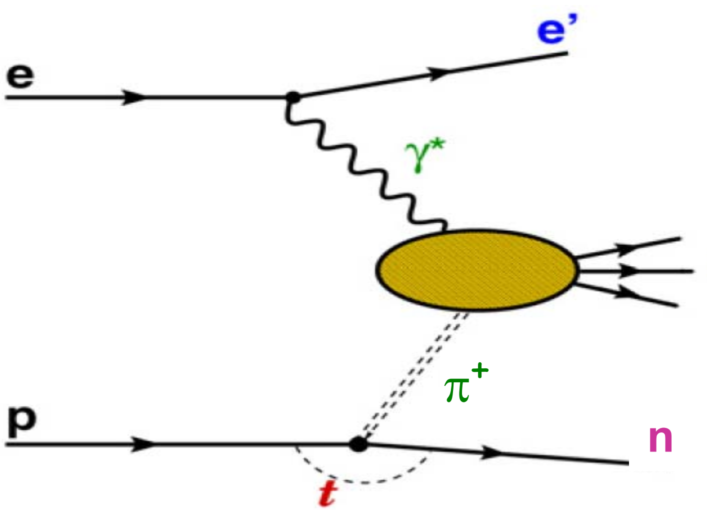
Investigate the feasibility for the detector for the very forward neutral particles.

In ep collisions these forward particles are produced at a very small angles from the proton fragmentation or from the exchange mechanism (π+, Reggeon, …):

fragmentation of proton remnant

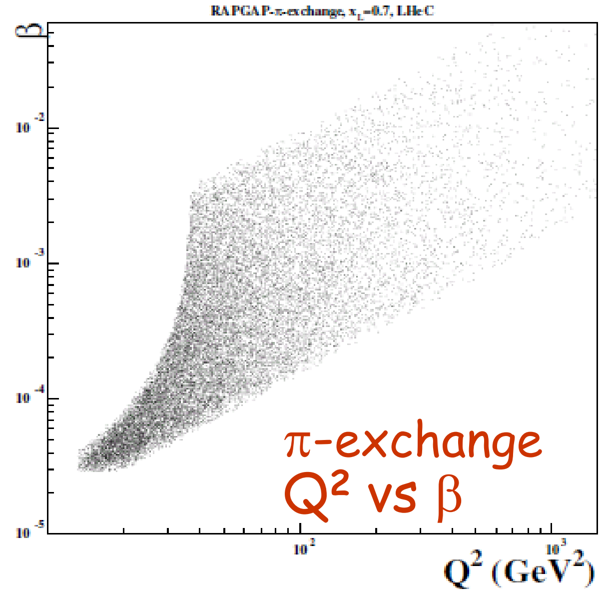


particle exchange (proton emits a virtual particle-e.g. π+ - which undergoes DIS with virtual photon)



At HERA, both experiments had the Forward Neutron Calorimeters (FNC): ~5% of DIS events contain neutron or photon in FNC

Physics potential of ZDC calorimeter



- pion structure, absorptive /gap survival effects (for F_2^{π} – an order of magnitude lower β than at HERA)
- colour single exchange, diffractive scattering
- QED processes ($p \to p+\gamma$) (luminosity)
- 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
- …

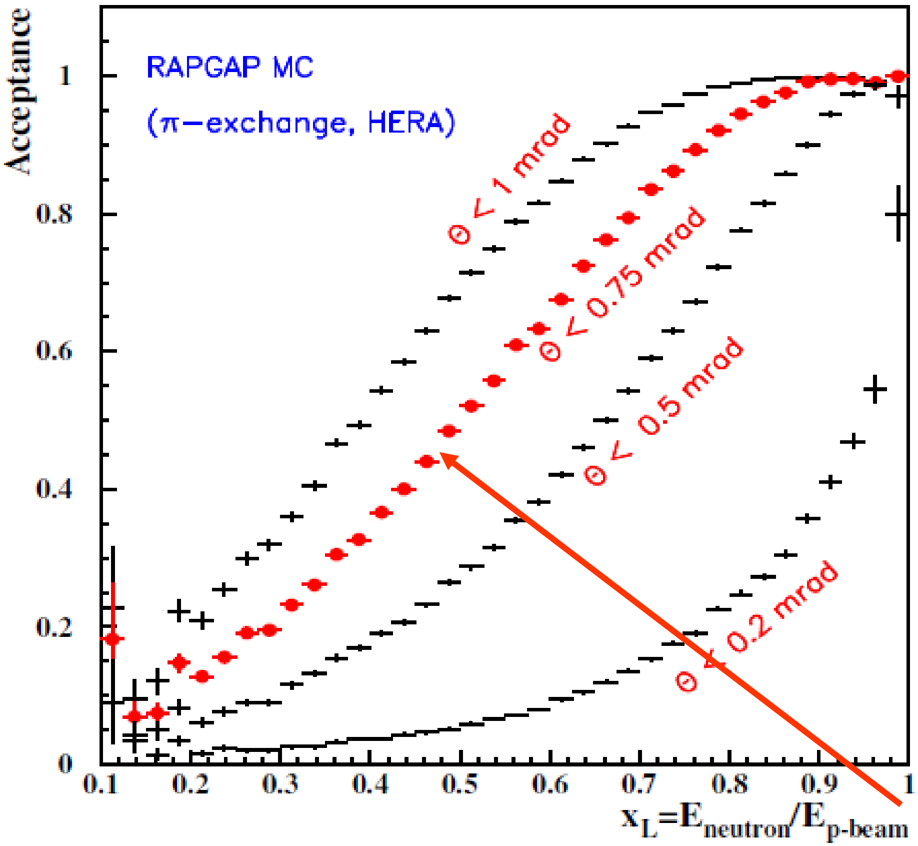
At HERA, both experiments had FNC calorimeters.
At the LHC, Alice, ATLAS, CMS and LHCf experiments have ZDC.

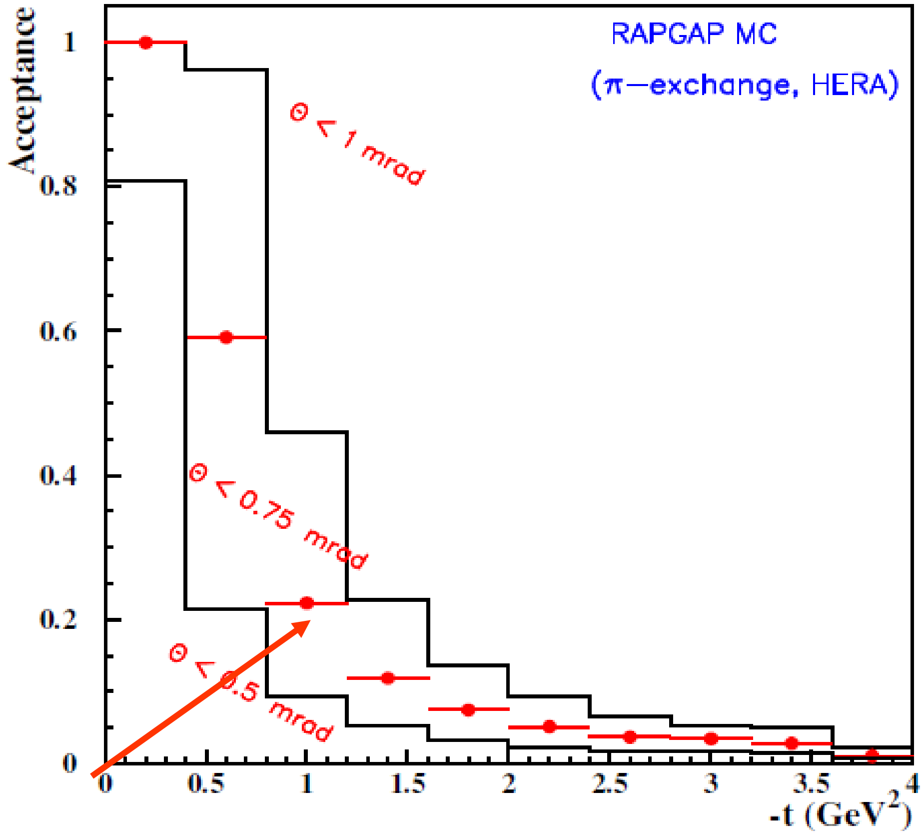
HERA case: Acceptance for forward neutrons vs $x_L=E_n/E_p$ and t

Acceptance is defined by the geometry of beamline elements

Acceptance vs $x_L=E_n/E_p$ and t for different theta cuts

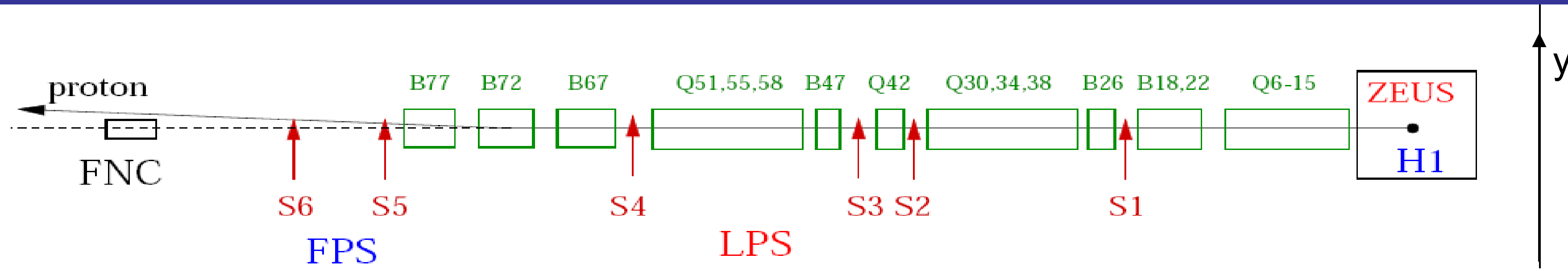
[for the detector at z~100m:
θ < 1.0 mrad ➔ ±10cm
θ < 0.5 mrad ➔ ±5cm
θ < 0.1 mrad ➔ ±1cm]



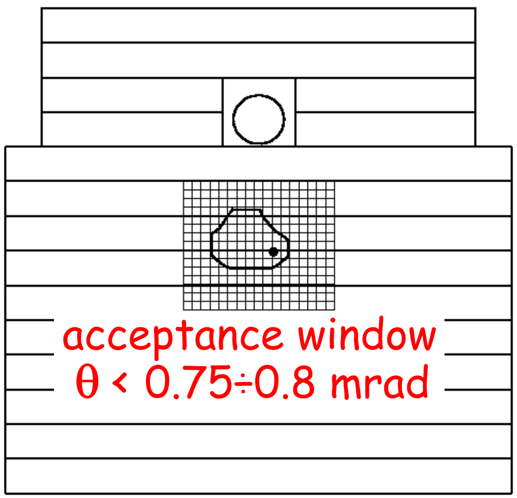


what we had in reality

H1 and ZEUS detectors for forward neutrons

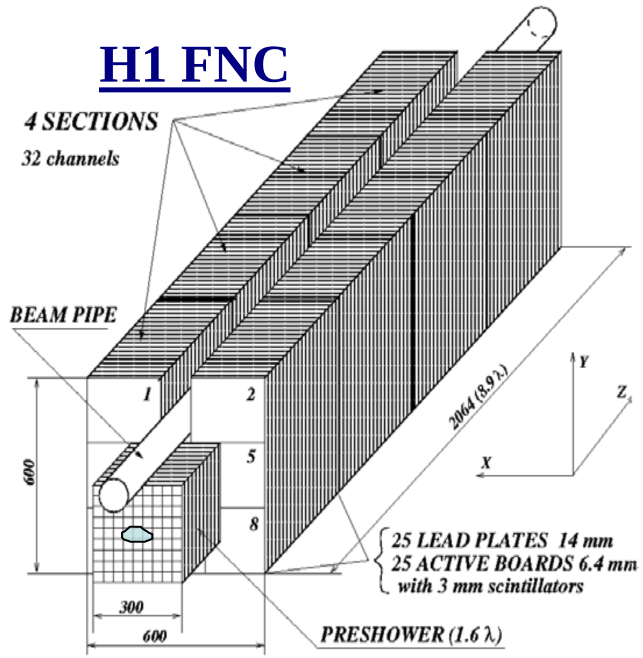


ZEUS FNC+FNT

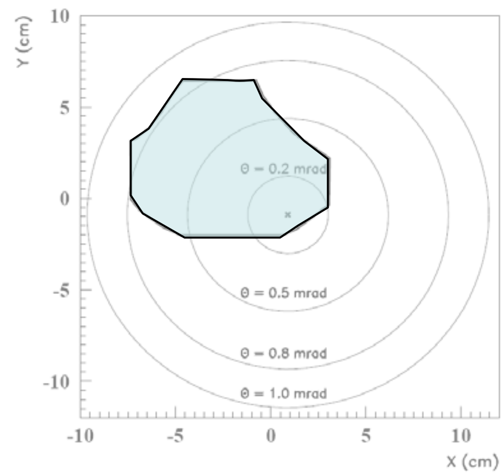


14 towers,
17x15 grid of the FNT hodoscopes,
$\sigma_E/E \approx 0.7/\sqrt{E}$

H1 FNC



$\sigma_E/E \approx 0.63/\sqrt{E} \oplus 2\%$
position resolution 2-3mm

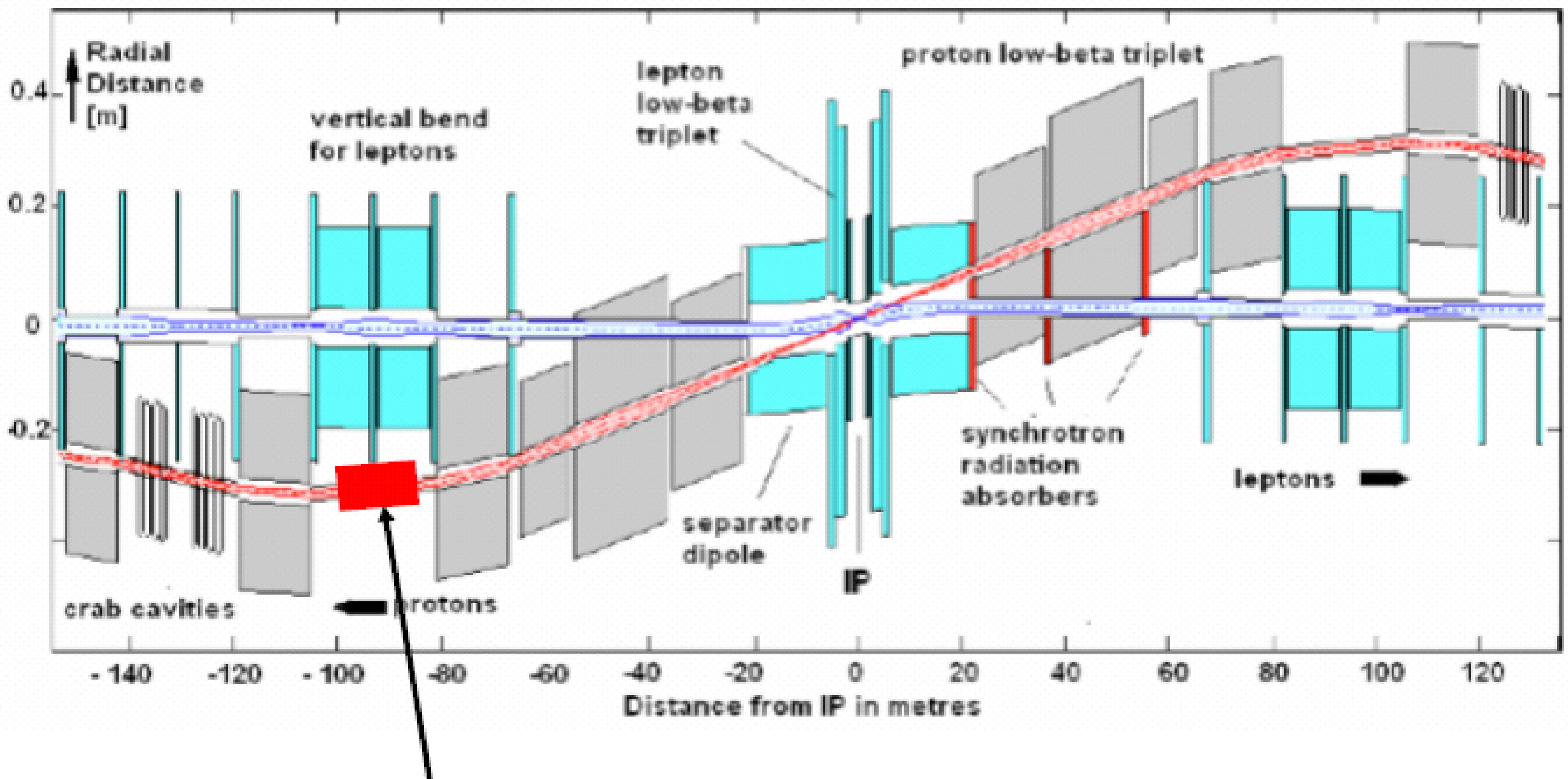


XY acceptance for LNs at HERA (position of impact point)

Acceptance limited by beam apertures to $\theta < 0.75$-0.8 mrad, asymmetric in ϕ
p_T resolution is dominated by p_T spread of proton beam (50-100 MeV)

Schematic Layout of LHeC IR

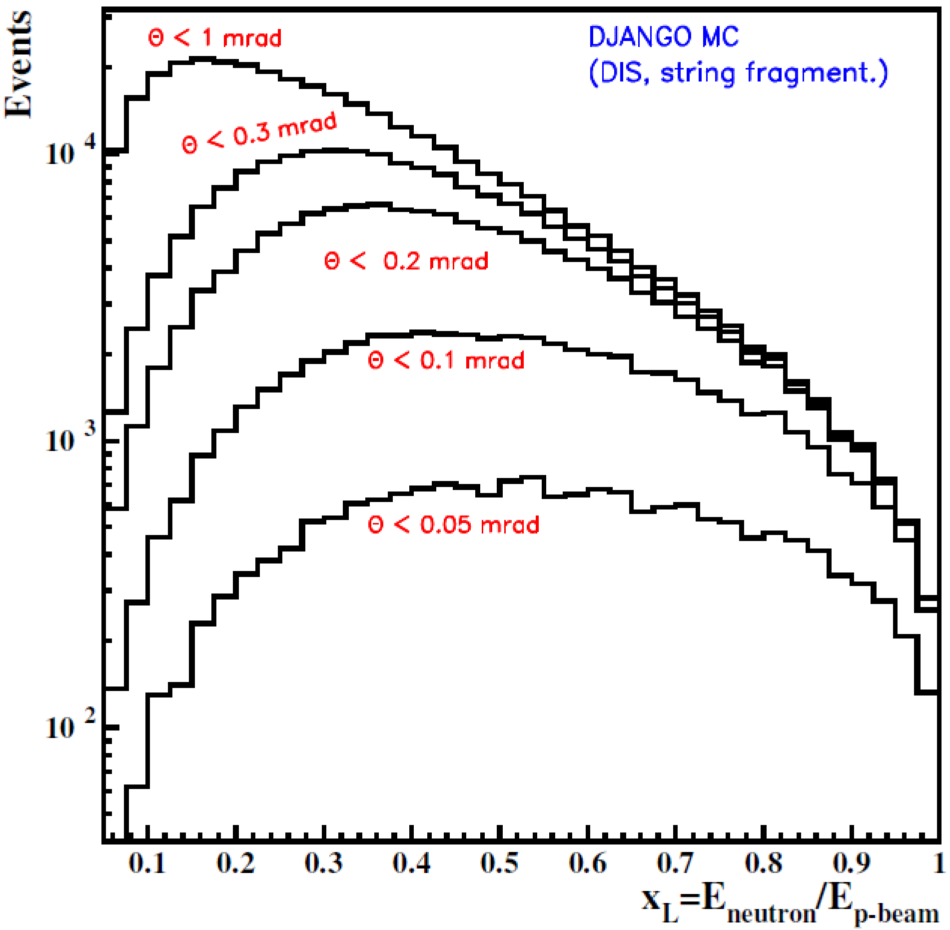
Ring-ring option
High lumi, 10^0 detector acceptance
2 mrad crossing angle
Present layout has 1.5 mrad crossing angle

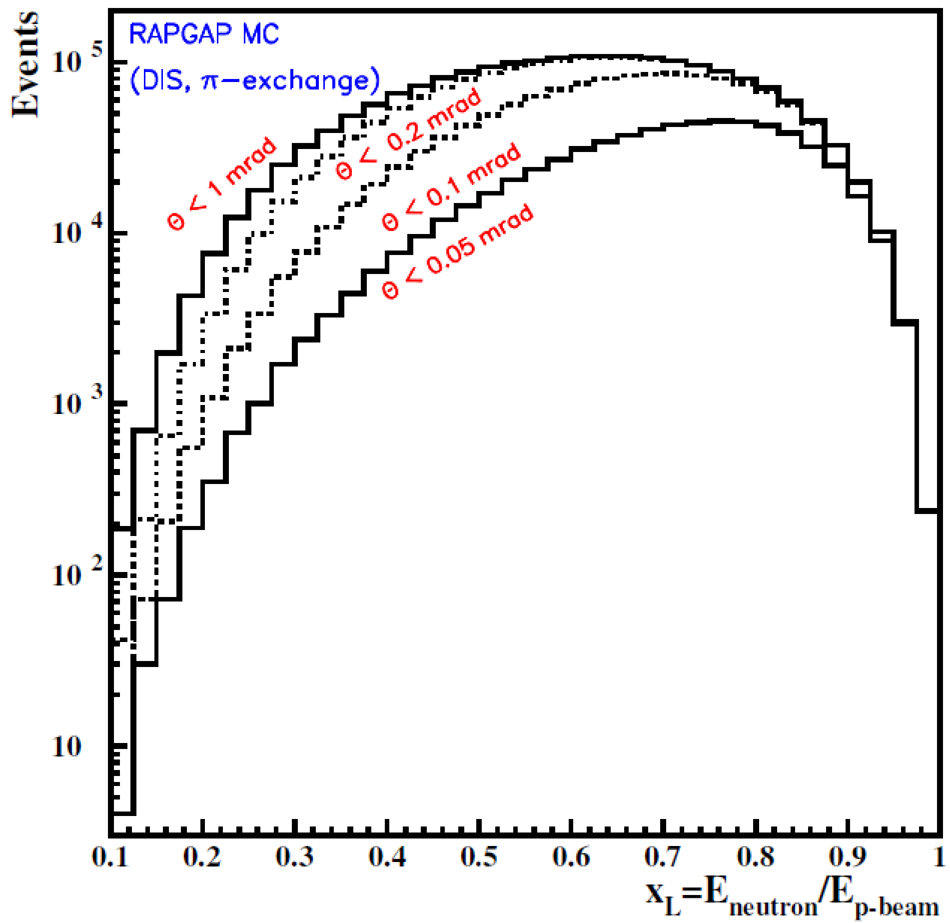


Possible location of FNC

Acceptance for forward neutrons vs energy for LHeC (7000 GeV x 70 GeV)

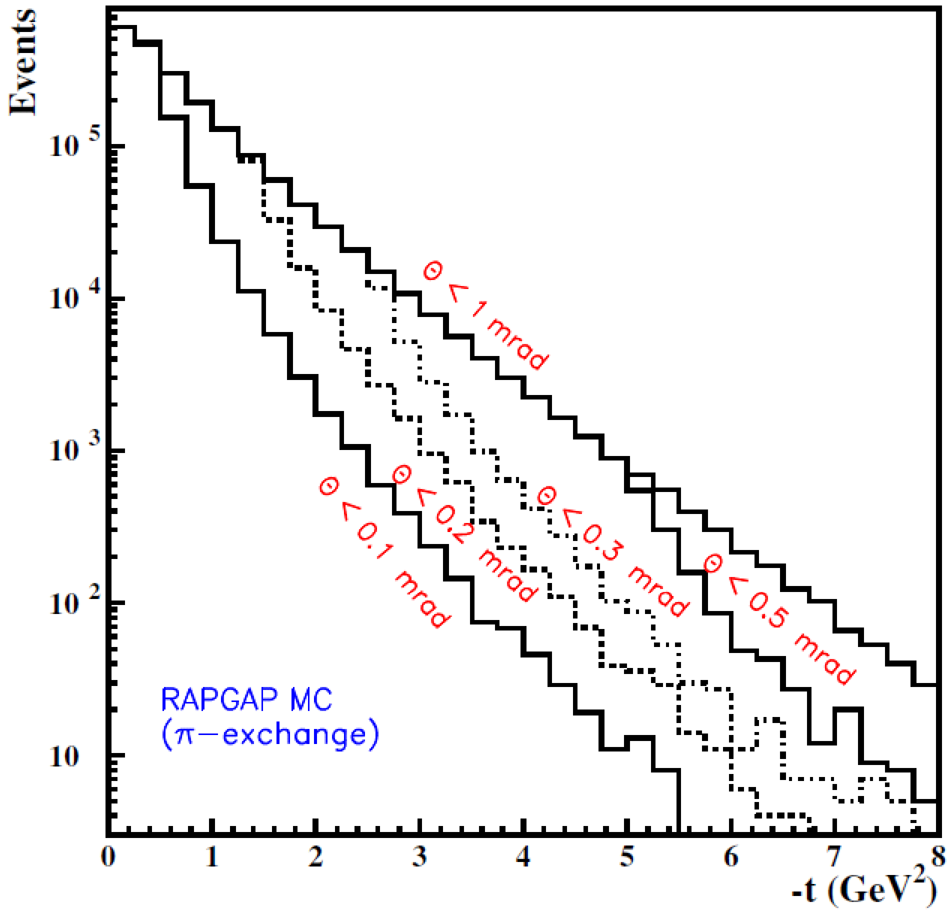
Look at neutron energy distributions depending on accessible angular range
assume neutron calorimeter at ~100m:
1mrad is ±10cm ;
0.1mrad is ±1cm ;

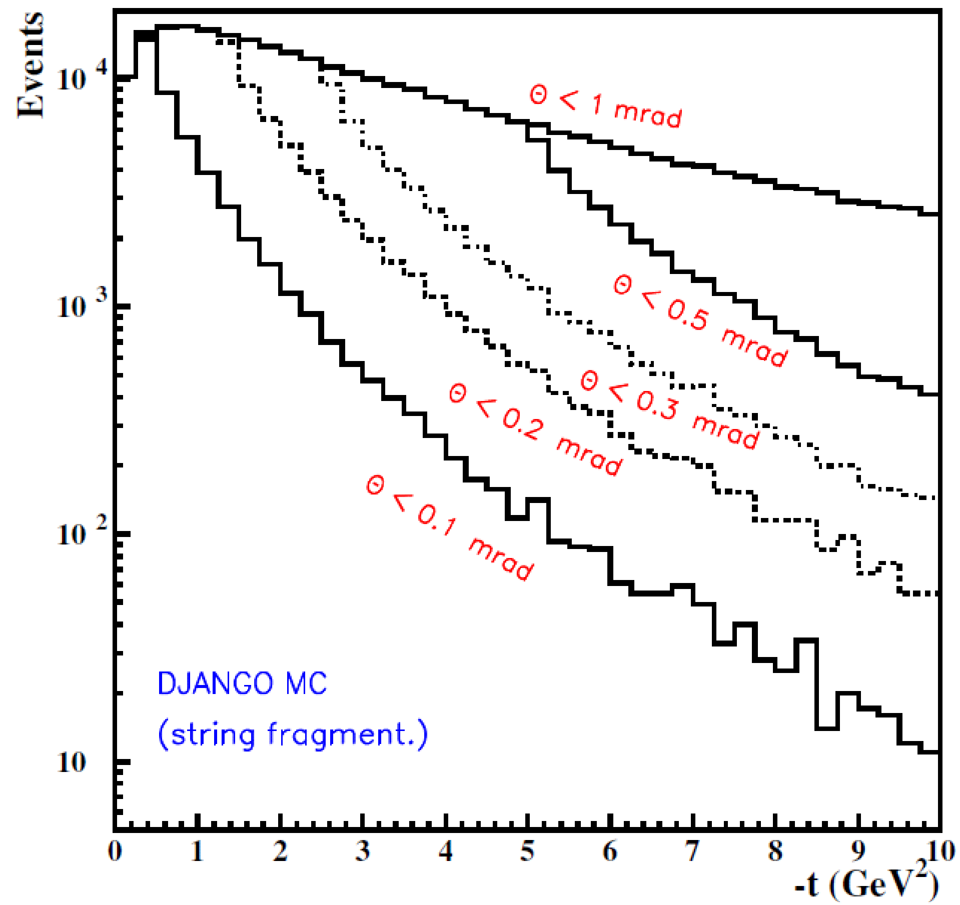




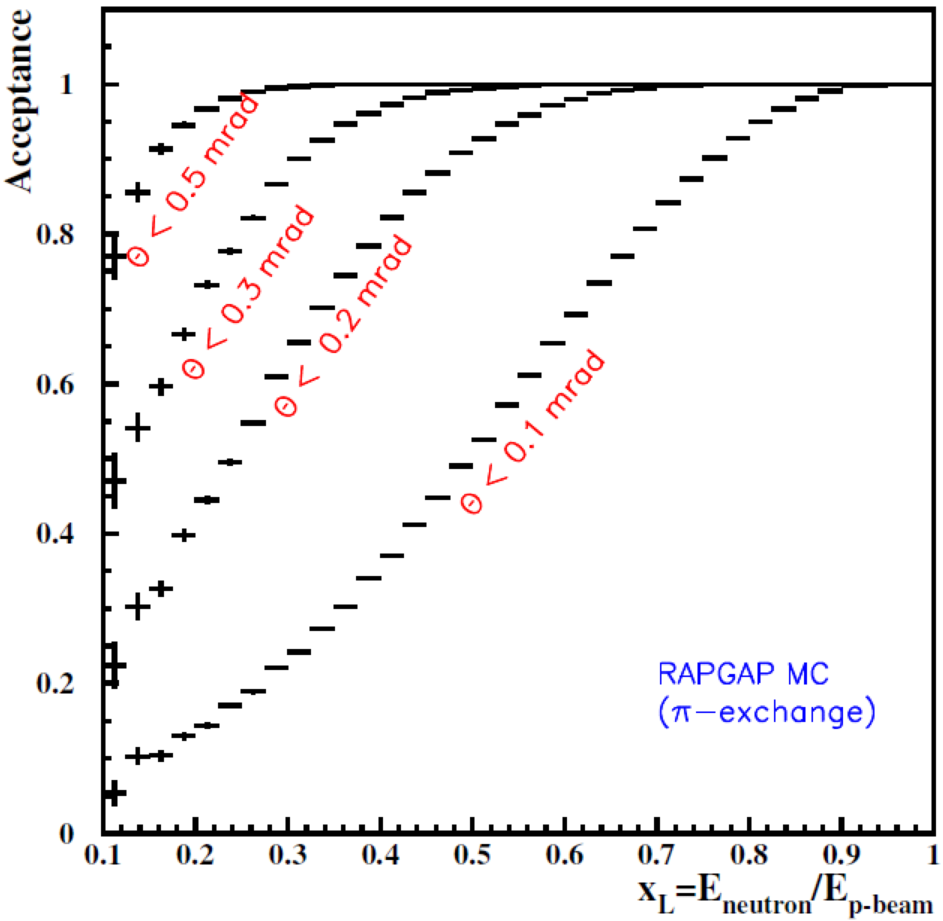
Acceptance for forward neutrons vs t for LHeC

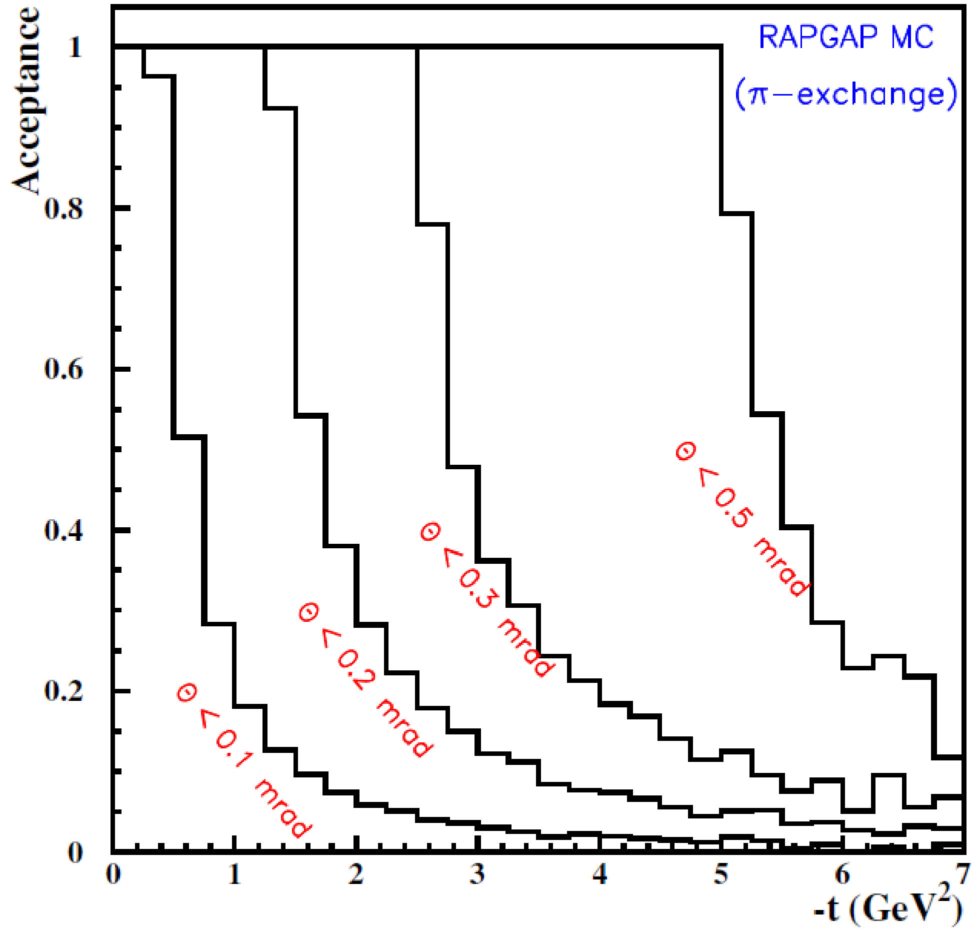
Look at *t* distributions depending on accessible angular range





Angular acceptance for forward neutrons vs energy for LHeC





0.75 mrad aperture cut at HERA corresponds to 0.1 mrad at LHeC !
With ~ ±3cm we can get quite reasonable acceptance, >90% for x_L>0.3, |t|<3 GeV^2

*Applying enerrgy resolution of 10% and x/y spread of 3mm doesn’t change the conclusions

To think about

- Detector design: general considerations

· Geometric constraints- depends on the available space and angular aperture
→need detailed info/simulation of beam-line

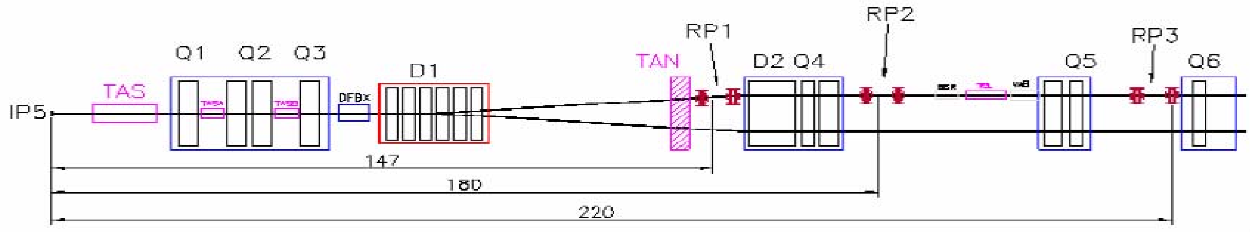
• Requirement to the calorimeter: 0°; identify γ (π^0),n; measure energy and position of n and γ with reasonable resolution; reconstruct >1 particles, evtl. reconstruct $\pi^0 \rightarrow 2\gamma$; control beam position and beam spot during data taking

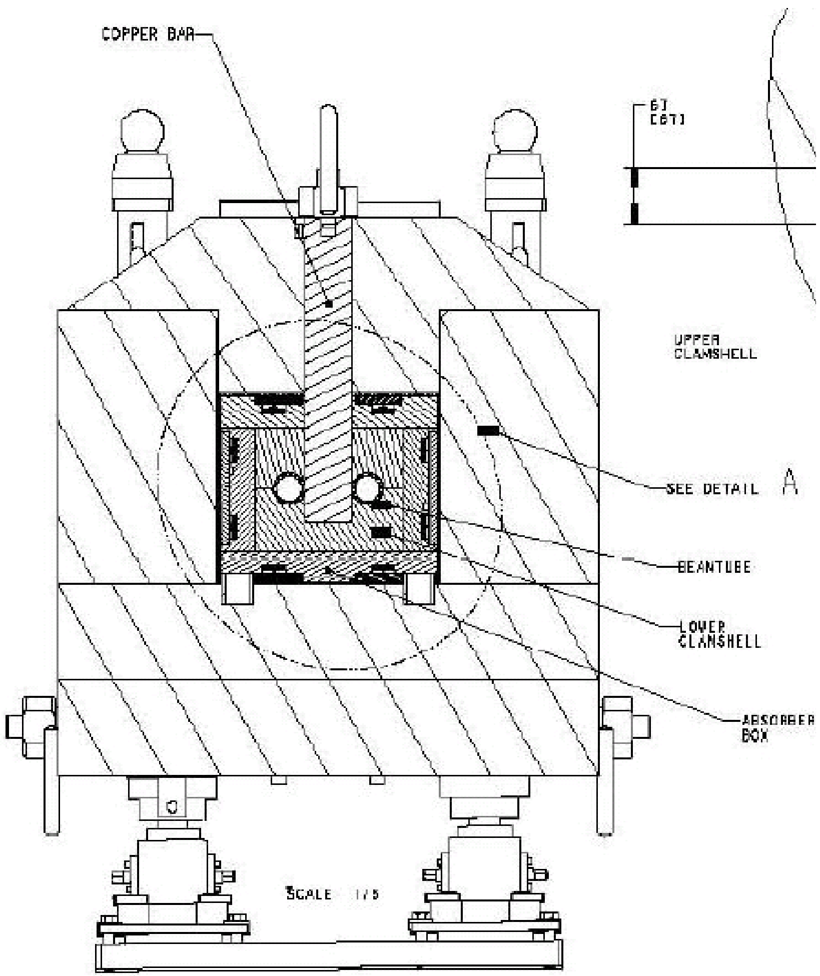
• Very radiation resistant

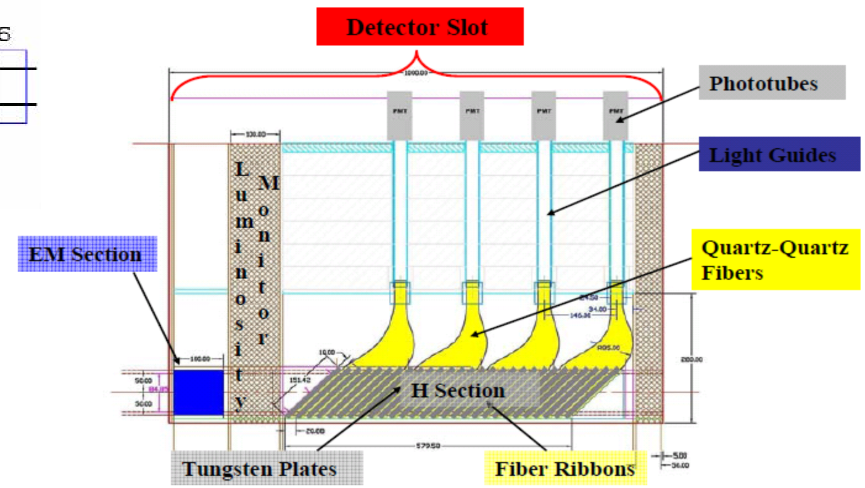
- e/m (1.5-2λ) and hadronic (~7-8λ) sections
- transverse size ~3λ (to contain 85-90% of shower)
  e/m section with fine segmentation to reconstruct the impact point
  long.segmnetation to control radiation damage

Experience from LHC, RHIC – sampling hadron calorimeter: absorber-W plates, active media – quartz fibers or THGEM
Tungsten/Cherenkov detectors are fast (signal formation), rad.hard and have good energy resolution; narrow visible showers (reasonable resolution in limited space)

ZDC at the LHC detectors

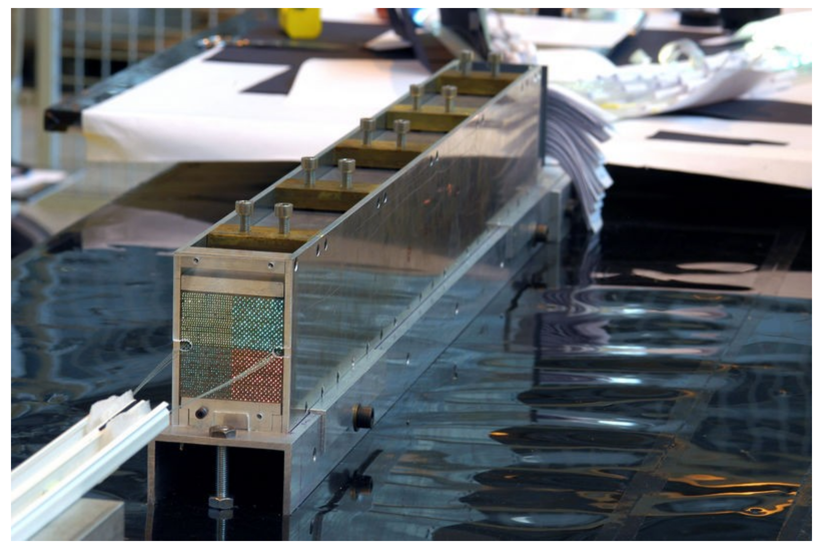






CMS

Alice



To think about

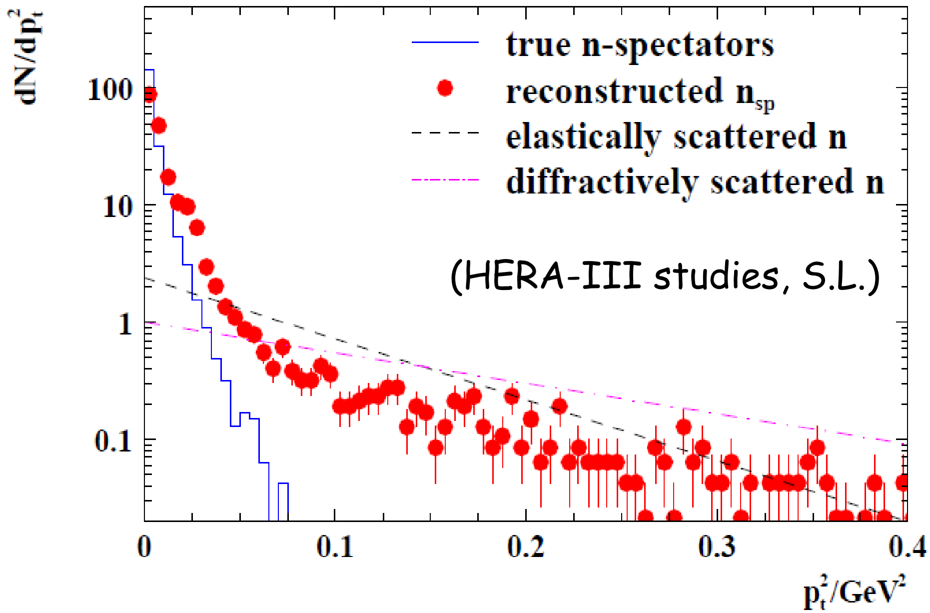
- ## Calibration

Need on-line gain monitoring, relative and absolute calibration

Neutron spectra from beam-gas interaction ? Invariant masses $\pi^0 \rightarrow 2\gamma$, $\Lambda,\Delta \rightarrow n\pi^0$ (?)

- ## Moreover, to worry about

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



Conclusions

Zero Degree Calorimeter – important part of the future ep(ed,eA) detector.

For LHeC energies, we may have quite reasonable energy acceptance for forward neutrons with the calorimeter at ~100m and transverse acceptance of up to 3cm

Requirement to the calorimeter: measure energy and position of neutrons and photons with a reasonable resolution, identify γ (π^0),n; reconstruct >1 particles ; radiation hard

Detector design – challenging task !
Based on the experience from FNC/ZDC calorimeters at the LHC, HERA and RHIC, explore novel methods

Next steps: clarify the geometrical constraints;
Investigate the possible design options.