Special thanks to Rogelio Garcia, Alessandro Polini, Peter Kostka and Paul Newman

Forward Detectors

Electrons for the LHC: Workshop on the LHeC, FCC-eh and PERLE

25 October 2019

Yuji Yamazaki (Kobe University)

Forward detectors at the LHeC

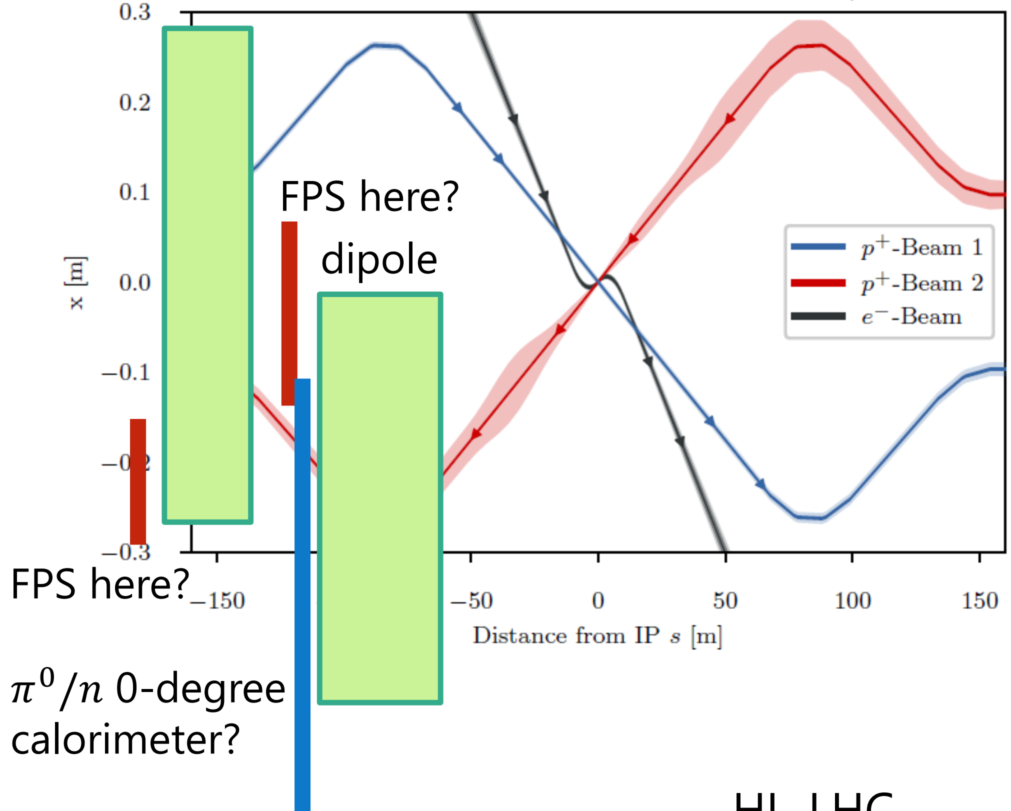
IP design with ERL recently available

- Proton spectrometer
  - Difference in bending scheme and space from pp IP's
- π^0 + neutron zero-degree calorimeter (ZDC)
  - Space? Aperture?

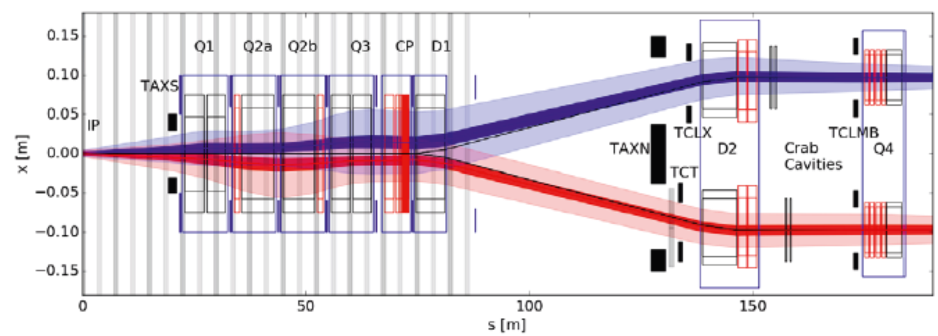
To be or not to be?

First qualitative estimation today
No real simulation
No guarantee

From LHeC CDR manuscript (R. Garcia)



HL-LHC



Physics with proton tagging for *ep*

- Exclusive measurements
  - Diffraction, VM production (Anna, Paul …)
  - QED processes $ep \to e\gamma p$ etc.
  - Higgs thru WW fusion, reconstruction via elastically scattered proton (??)

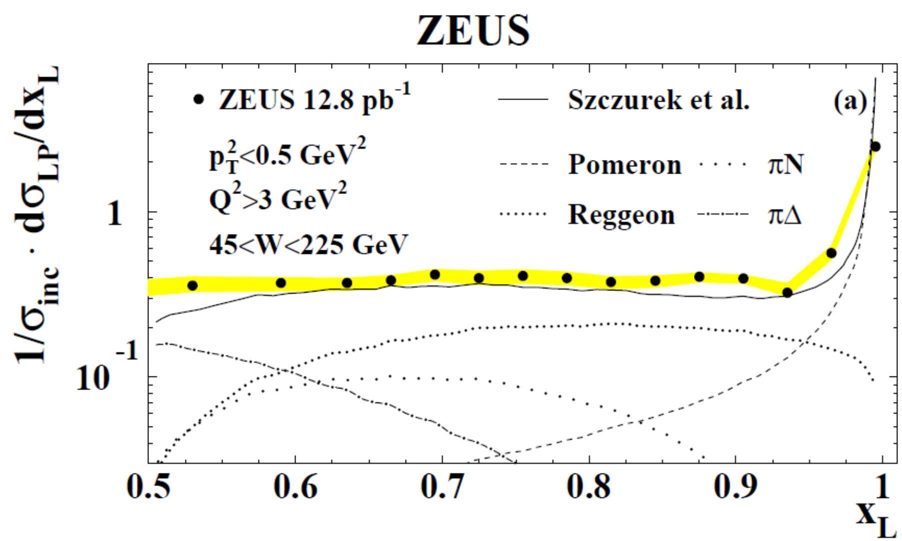
Soft vertex: $\xi = 1 - x_F \ll 1, p_T \simeq \Lambda_{QCD} \approx O(200\text{MeV})$

$\Rightarrow \mathbf{10^{-3} < \xi < 0.05}$ (or larger), $\boldsymbol{p_T <}$ **a few GeV**

- Inclusive measurements

Spectrum of slower leading protons ($x_F < 1$)

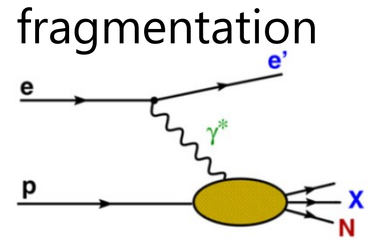
⇒ lower x_F, larger p_T also interesting

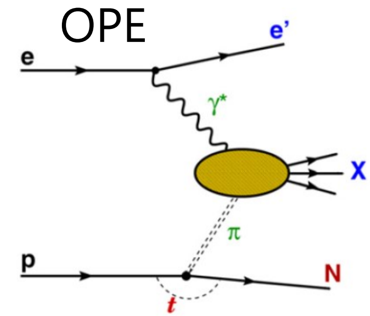


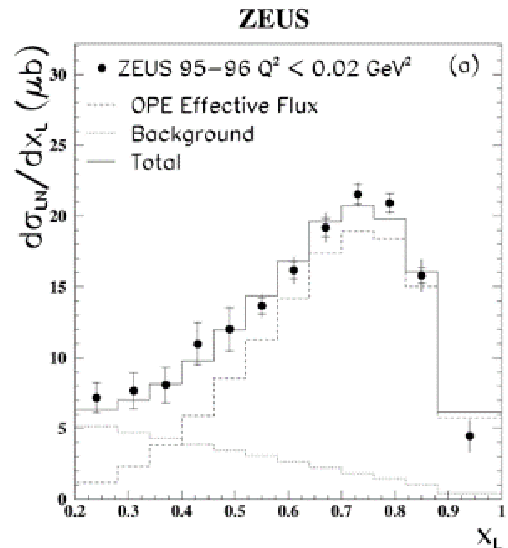
Neutron tagging for *ep*

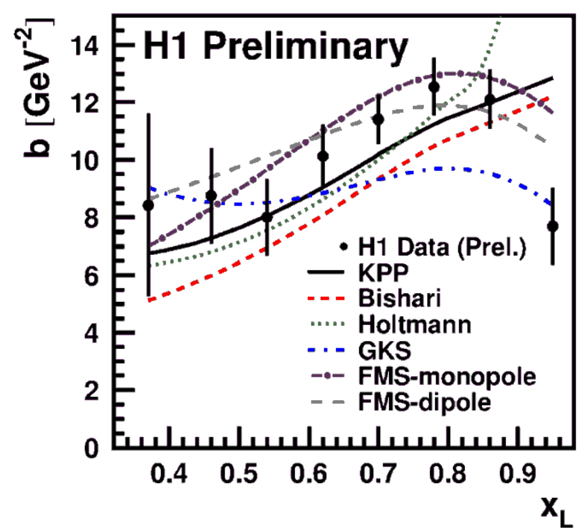
- Inclusive measurement @ HERA:
  - supporting one-pion exchange
  - b-slope (~ 8 GeV^{-2}) compared to various models of pion fluxes

- **$0.1 < x_F \leq 1$ and >1 GeV in p_T needed**
  - Effectively wider aperture at the LHeC (7 vs 1 TeV) than HERA $p_T^{max} = p\theta_{max}(1 - x_F)$







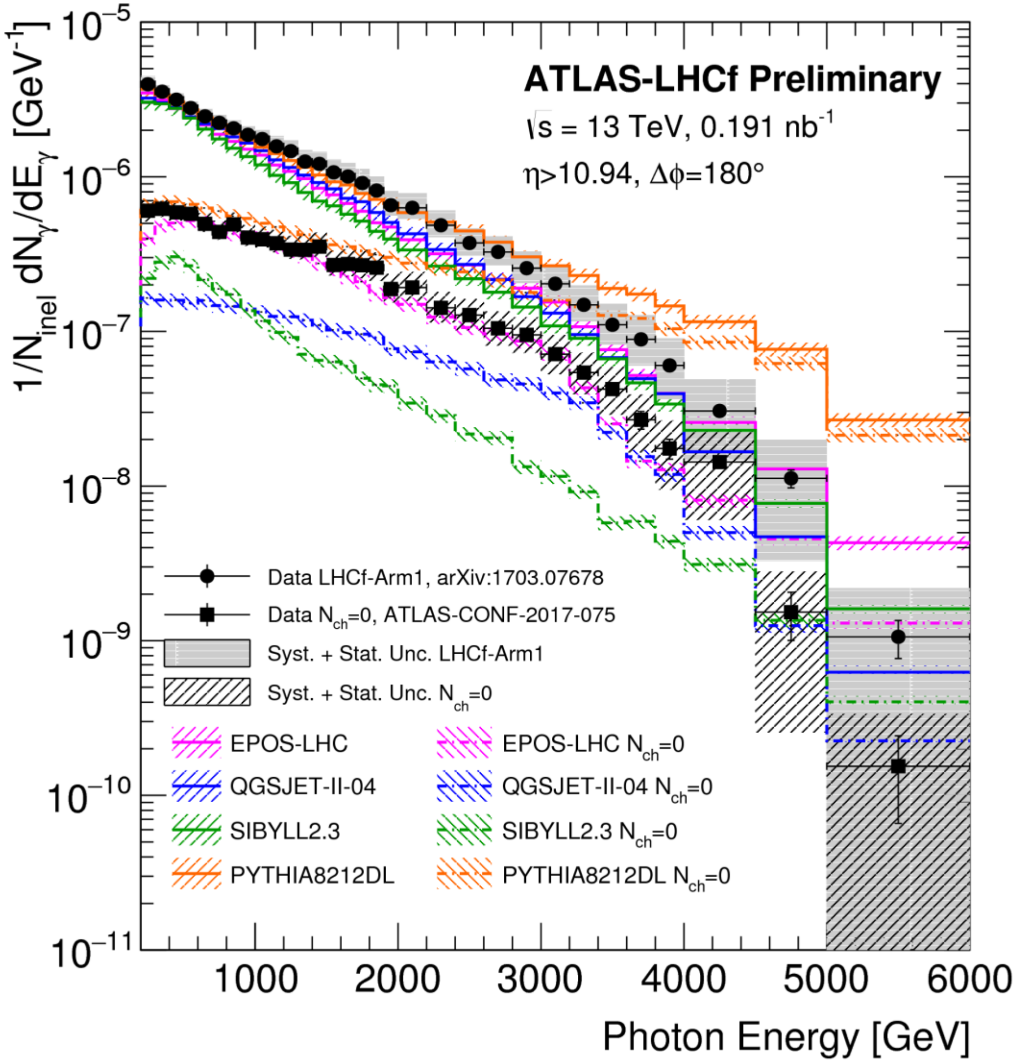


π^0 production by LHCf and ATLAS

- Impact to cosmic ray simulation
- π^0 tagging thanks to excellent position resolution of the LHCf calorimeter (200 μm for 100 GeV e^-)
- Diffractive events tagged by LRG in ATLAS

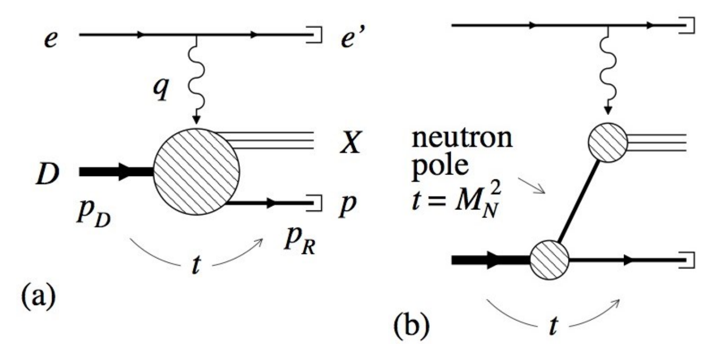
Need EM section with excellent position resolution

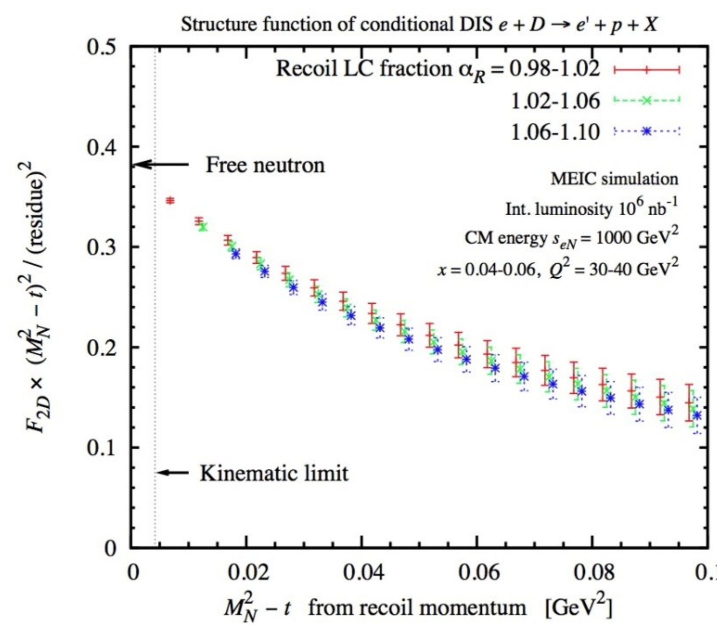
ATLAS-CONF-2017-075

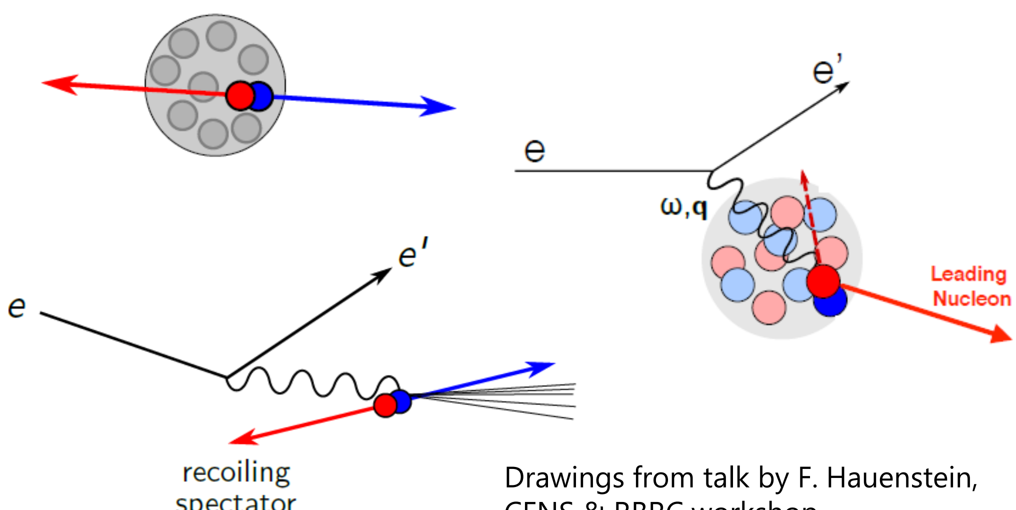


Proton/neutron tagged eD/eA DIS

- Proton-tagged $\boldsymbol{eD}$ and $\boldsymbol{eA}$ scattering
  - $e(p+n) \rightarrow en + p$ **DIS for neutron!**
  - Way to understand **nuclear (EMC) effect** or short-range correlation **(SRC)** by comparing small and large system
- Neutron-tagged $(ep + n)$:
  - Cross-check with ep runs







Drawings from talk by F. Hauenstein, CFNS & RBRC workshop https://indico.bnl.gov/event/6568/

J.Phys.Conf.Ser. 543 (2014) 012007

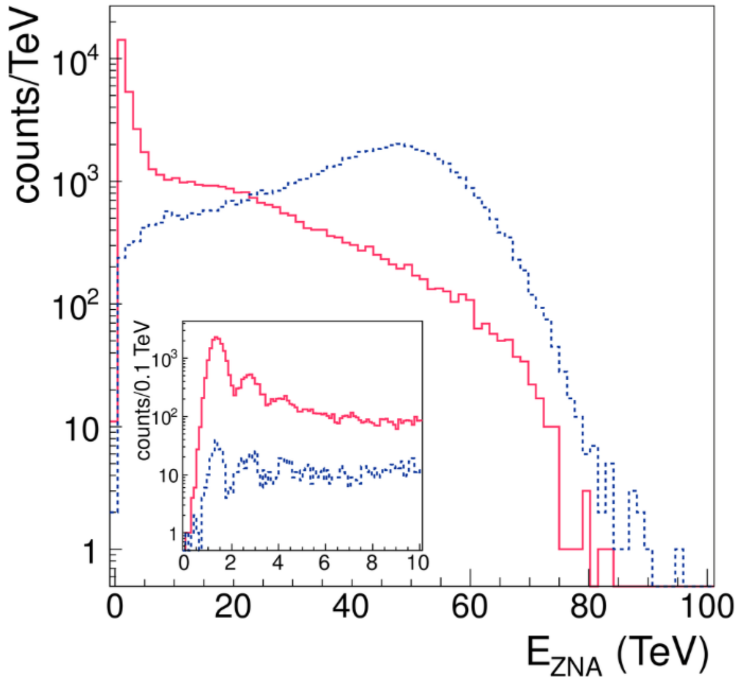
For bigger nucleus

- Diffraction and Ultra-Peripheral Collisions (UPC) :
  A may break up (Brian's talk)
  - multiplicity and energy of neutron vs t ?
  - Dissociated particles tagged by FPS? (Paul's talk 2018)

- Geometry (e.g. centrality) determination

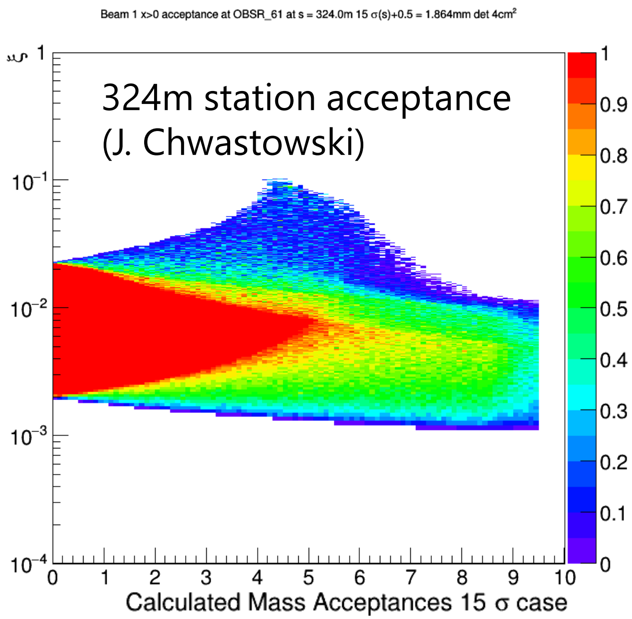
need to measure beyond 100 TeV

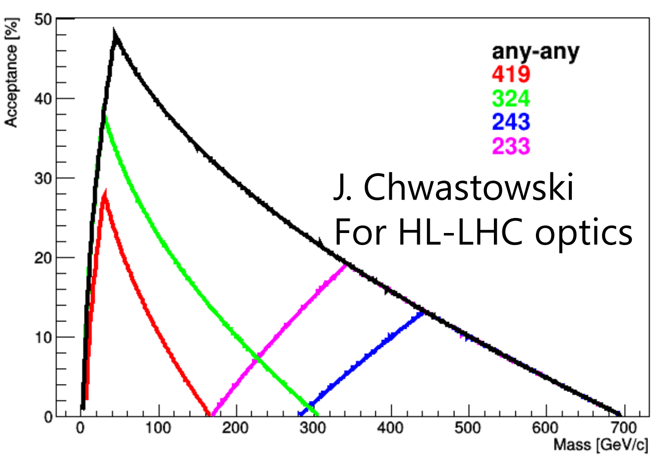
ALICE ZDC (A-side)
with and without
activities in plug area
2.76 TeV run

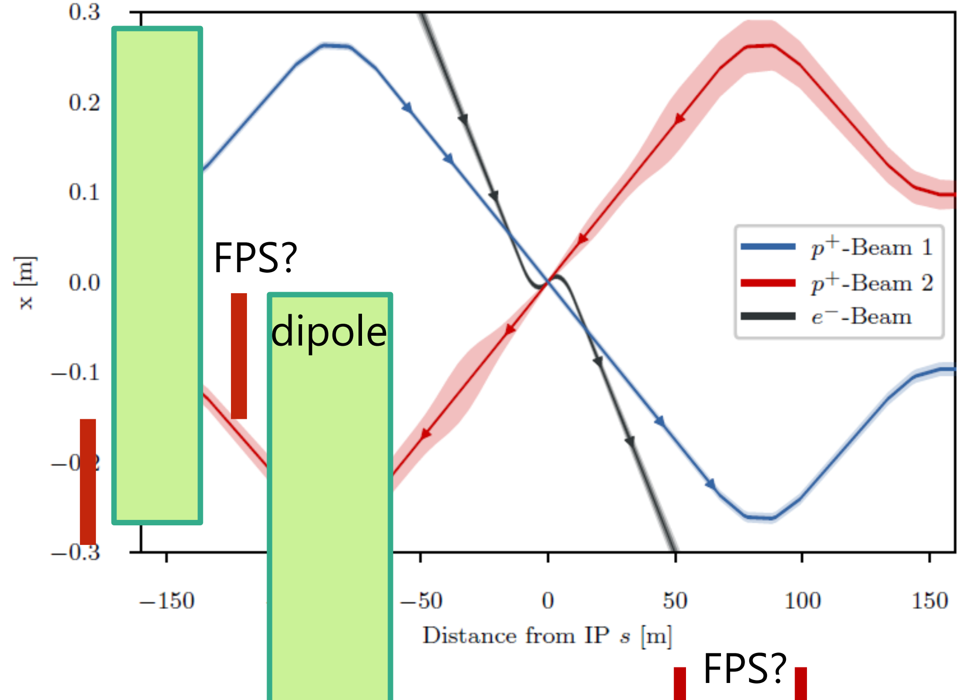


Proton: acceptance and resolution

- Good acceptance for HL-LHC

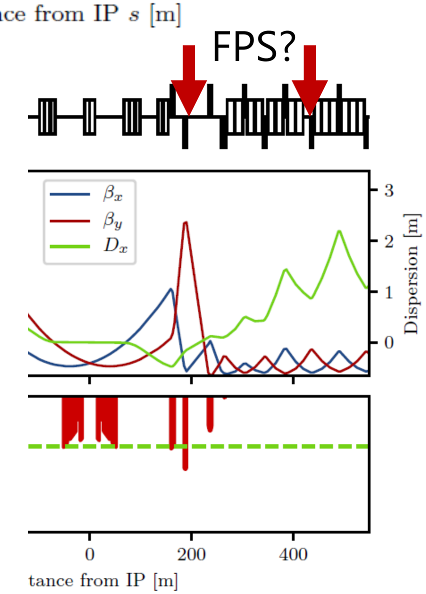






Better acceptance
for stations at 220/420 m?
(gap between magnets
also for LHeC)

Time to calculate
with new LHeC optics!!!



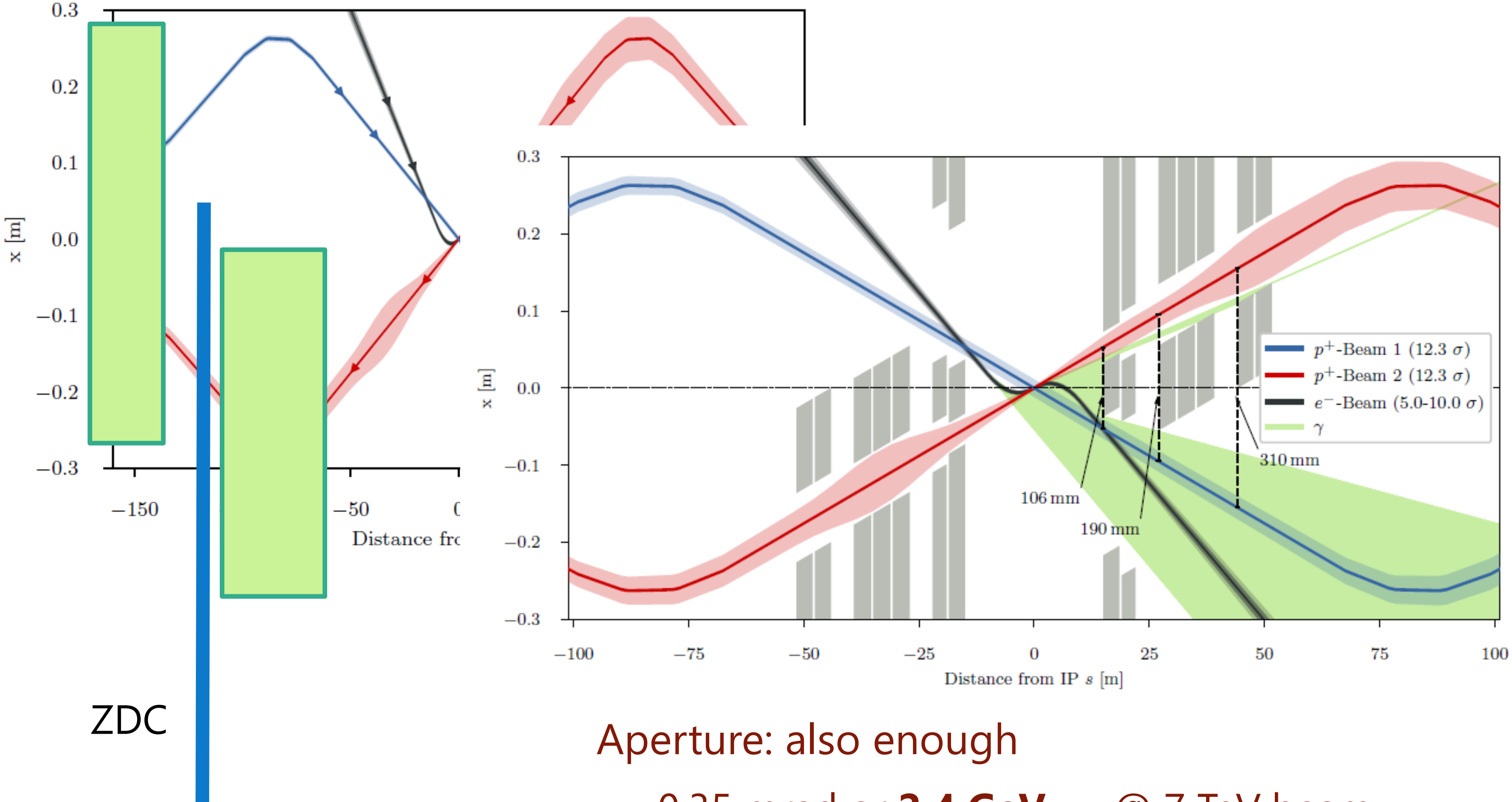
Zero-degree calorimeter (ZDC) requirement

- Energy resolution:
  - high energy ⇒ stochastic term not very important
  - dominated by
    - **Non-compensation (e/h)**
    - **Leak:** need **big calorimeter**

- Position resolution:
  - 70 MeV : 7 TeV = 10^{-5} = 0.01mrad ⇒ **1 mm** @ z = 100m **for neutrons**
  - Need **very fine segmentation** EM section
    to track particles from primary interaction

- Dynamic range

ZDC requirement (2) aperture and space



Big calorimeter like

$60 \times 60 \times 200$ cm possible for good energy resolution!

Aperture: also enough

- 0.35 mrad or **2.4 GeV p_T** @ 7 TeV beam assuming LHC magnet the aperture is ± 35 mm
- Horizontal aperture would be larger

Running scenario

- Nominal run for $L = 10^{34}\ \mathrm{cm^{-2}s^{-1}}$:
  $\beta^* = 5\ \mathrm{cm}, \sigma(p_T) = 8 \times 10^{-5}\ \mathrm{rad} \times 7\ \mathrm{TeV} = 0.56\ \mathrm{GeV}$
  - Too large beam dispersion for soft physics
  - In principle **one could retract the calorimeter for high lumi runs?**
  - Or, replace with ZDC with minimum function (with fused silica etc.)

- **need $\boldsymbol{\beta^*} \gtrsim$ 1m run:** $\sigma(p_T) \ll$ 100 MeV
  - $L = 10^{32}\ \mathrm{cm^{-2}s^{-1}}$: should be ~enough for soft / low-x physics?

Radiation dose

7 TeV dose / event ~ 3×10^{-7} Joule / event

ep cross section: 68 μb → $680\ \text{kHz} @ 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ → 1.8 Joule/s

- LHCf simulation (about $1\lambda_I$):
  1/3 of dose in 1kg material (30Gy/nb for pp)
- For ep this corresponds to 0.6 Gy/sec ⇒ **6 MGy / year @ 10^{34}**

σ_{ep}: $10^{-3}\sigma_{pp}$

From beam-gas: much smaller: O(100kHz)

Radiation ~ O(10MGy) for 1-year operation: way below LHC pp

Technology on market

Radiation ~ O(10MGy)

- For EM section:
  silicon-based fine-segmentation calorimeter
  for position resolution + SW compensation
  - **CMS forward calorimeter** (Si + Scintillators)
    Operation at $-30\ \mathrm{C}^{\circ} \Rightarrow$ **OK for** $\boldsymbol{n_{eq} \sim 10^{16}}$
    Si sensor: $\sim 0.5 - 1\ \mathrm{cm}^2$
  - **ALICE FoCal** (EM section: MAPS + pads)
    Very fine shower image, also for neutron tracking

3mm (30um sensor size)

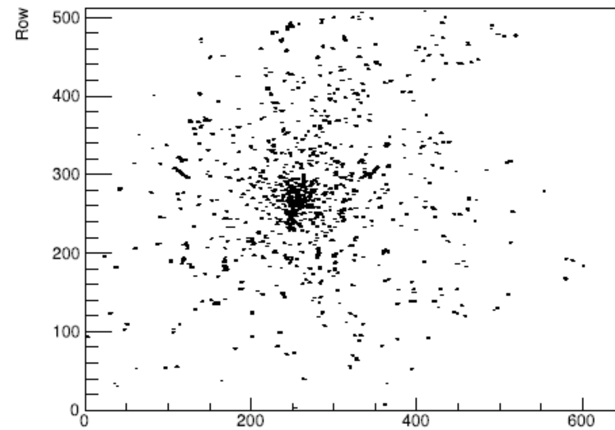


Fig. 8. Event display in a single ALPIDE chip of a 150 GeV electron

N. van der Kolk, NIMA (2019), https://doi.org/10.1016/j.nima.2019.04.013

- For Hadcal: cheaper options with compensation?
  - Good e/h: plastic scintillators + lead
    CMS uses for $n_{eq} < 3 \times 10^{13} \sim O(1\mathrm{MGy})$
  - Or full silicon calorimeter

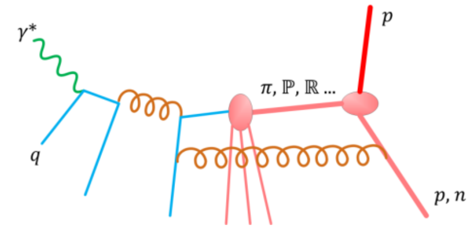
Summary

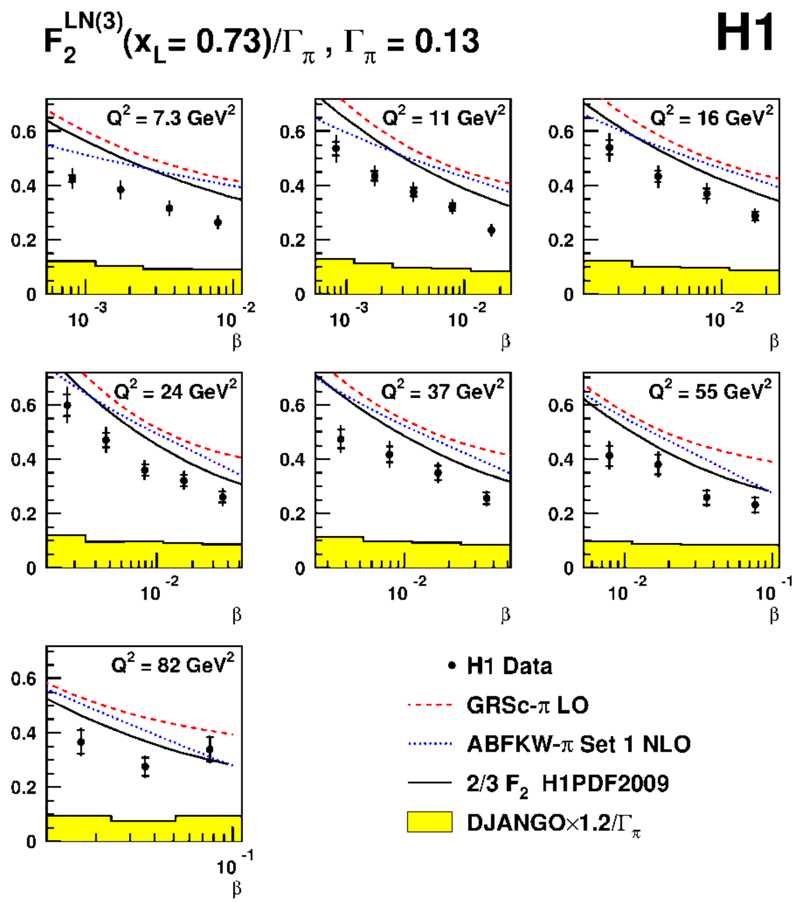
- New ERL IP design seems to allow us to place
  - **A big ZDC with enough aperture**
  - … and spaces to place forward proton spectrometers

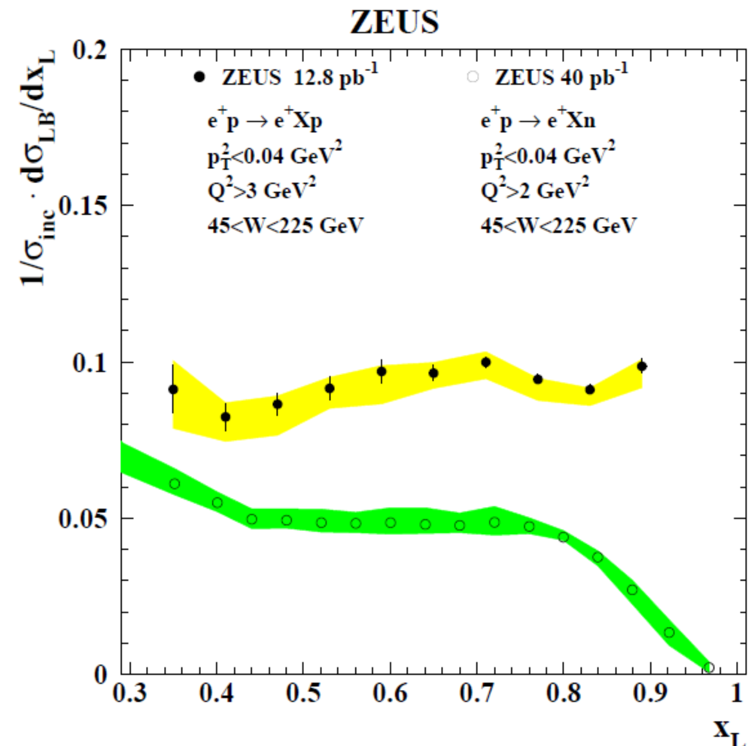
- Requirement for ZDC
  - Need **1mm position resolution for neutron**
  - **Radiation is low enough:** silicon for EM

BACKUP

Neutron puzzle (1) suppression?







- Neutron yield is 20-30% fewer than naïve prediction of $p : n = 1 : 2$ expected from isovector exchange
- Absorbtion? Rescattering?

- Protons are more than neutron
  - Again no consistent with isovector exch.

Where did neutron disappear?

Neutron puzzle (2): pp vs ep

- Limited fragmentation ⇒ the same spectra
- LHCf data similar but models suggest harder spectrum at $x_F \sim 1$
  - due to projectile fragmentation? $pp \rightarrow N^* + Y,\ N^* \rightarrow n + \text{(hadrons)}$
  - Corresponding to proton dissociation for ep DIS: $\gamma^* p \rightarrow XN^*$
    LRG-tagged neutron?