EIC requirement for Calorimeters and dose estimation

RIKEN+Tsukuba+Nagoya+Kobe discussion

30 October 2019

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Boundary condition for ZDC in EIC

dipole

Big aperture

4mrad = 12cm

Beam ~ 100 GeV

Size: ± 80 cm $\times$ 2m

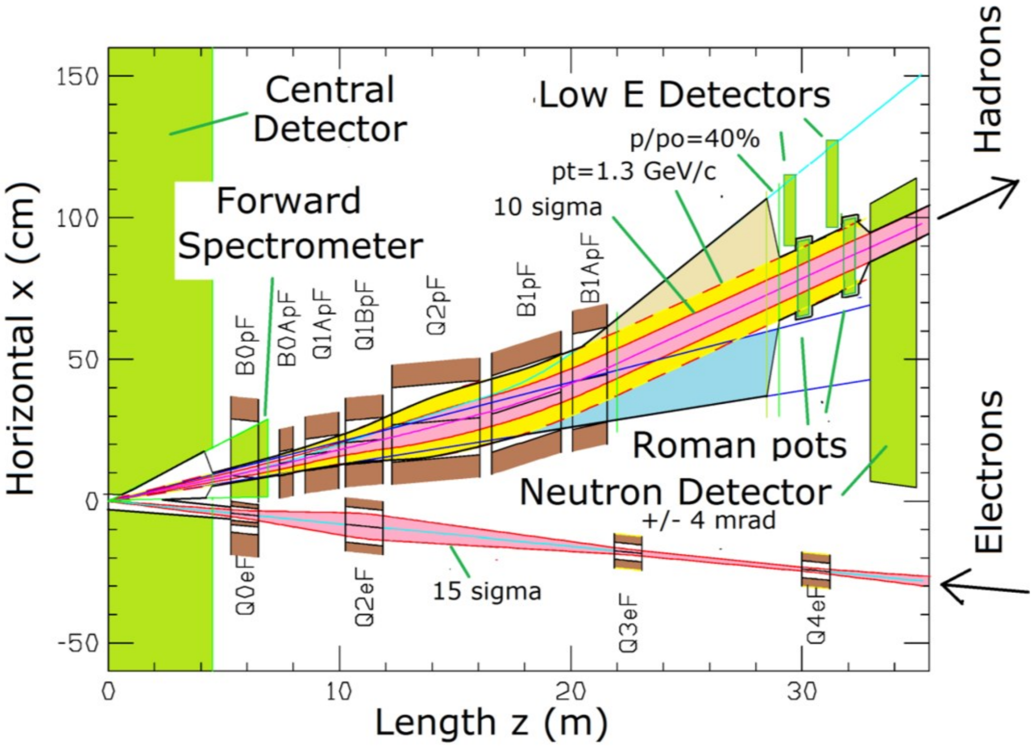
Big enough

Dose for ep

– for 300 fb^{-1} ?

Dose for eA

– How much int. lumi?



Energy or position resolution?

1mm / 33m = 0.03mrad = 3 MeV @ 100 GeV: 0.03%

Hadrons: $50\%/\sqrt{E}$ @ 10 GeV = 17%, @100 GeV = 5%

Photons: $4\%/\sqrt{E}$ @ 10 GeV = 1.3%, @100 MeV = 12%

Energy resolution is much more important

Position resolution: 1cm is enough

For HadCal:

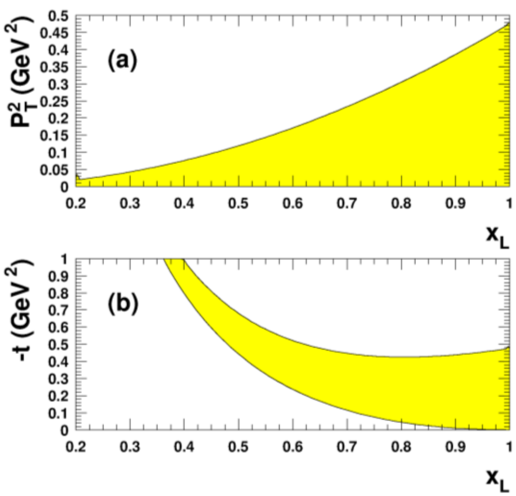
1. compensation by hardware or software
2. Small leakage of shower: need big calorimeter

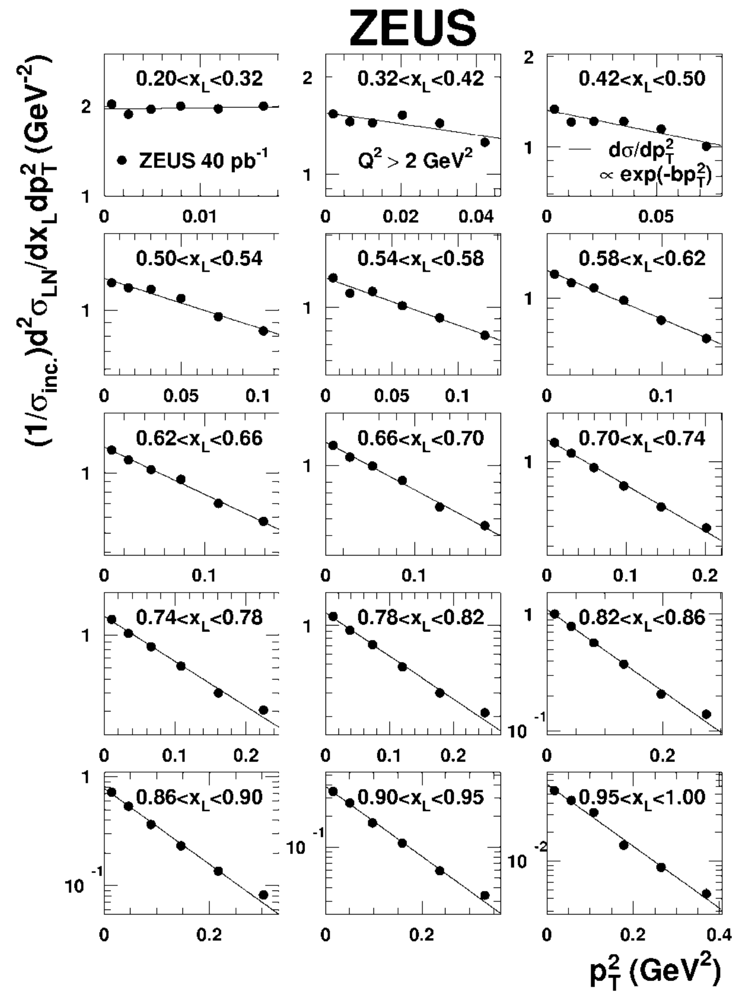
For EMCal: need non-sampling calorimetry

We should aim for $4\%/\sqrt{E}$

Aperture enough?

- eRHIC: 4mrad × 100 GeV = 400 MeV
  - $|t| < 0.2\ \mathrm{GeV}^2$: not much ....
  - OK for break-up neutrons
- JLEIC: 10mrad, 1 GeV
  - $|t| < 1\ \mathrm{GeV}^2$: much better....
- HERA: 0.5mrad = 0.5 GeV
- LHeC: 0.35 mrad = 2.5 GeV





Event rate for dose

- Numbers from Elke's presentation
- Event rate 600 kHz @ $1 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ luminosity
  - "DIS" cross section: 60 μb
    - Sounds a bit small: LHeC 68 μb
  - The events should be dominated by photoproduction: may be order(s) of magnitude wrong?
- beam-gas rate 10MHz assuming 10^{-9} mbar = 10^{-7} Pa (Elke)
  - Pessimistic assumption?
    LHeC estimation is based on 10^{-8} Pa
    (HERA was 10^{-6} Pa near IP)
  - Latifa's number in CFNS2019 workshop: 70kHz for 10^{-9} mbar with HERA IP and HERA counter: total rate may be hihger
- Anyhow let's assume Elke's number
  - 10^{14} events/year assuming 10 MHz

https://indico.bnl.gov/event/4737/contributions/24360/attachments/20396/27266/Latifa-SB.pdf

Radiation dose

100 GeV dose / event ~ 1.6×10^{-8} Joule / event

ep event rate 600 kHz @ 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1} \rightarrow$ 0.01 Joule/s

σ_{ep}: $10^{-3}\sigma_{pp}$, energy 1/70

- LHCf simulation (about $1\lambda_I$):
  1/3 of dose in 1kg material (30Gy/nb for pp)
- For EIC ep this corresponds to 0.003 Gy/sec ⇒ **30kGy / year @ 10^{34}**

From beam-gas: 14 times larger

⇒ **500kGy / year ??** Hope it would be rather 50kGy / yr

Radiation ~ O(100k – 1MGy) or $n_{\mathrm{eq}} \sim 3 \times 10^{12-13}$

for 1-year operation of ep (~ C. Hyde's number)

i.e. 10^{14-15} for lifetime

- eA luminosity/current 1/100 of ep? Then dose similar
- If the current is only 1/10 the dose would be a few times higher

Plastic scintillators?

- Silicon and LYSO should be OK for the dose
- How about plastic scintillators?
  - Very good resolution for hadrons

- Some plastic like PEN stands for >0.1 MGy radiation
  - http://inspirehep.net/record/1454399
  - Light yield decreases to 46.7% after 0.14 MGy to 50%, but recovers to 79.5% after 9 days
    - maybe too sensitive to accelerator operation condition: difficult to calibrate?
  - OK for cells of calorimeters outside the core of hadronic shower?
    - Need simulation
  - Silicon may have comparable resolution
    - much more expensive, though

BACKUP

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 (??)

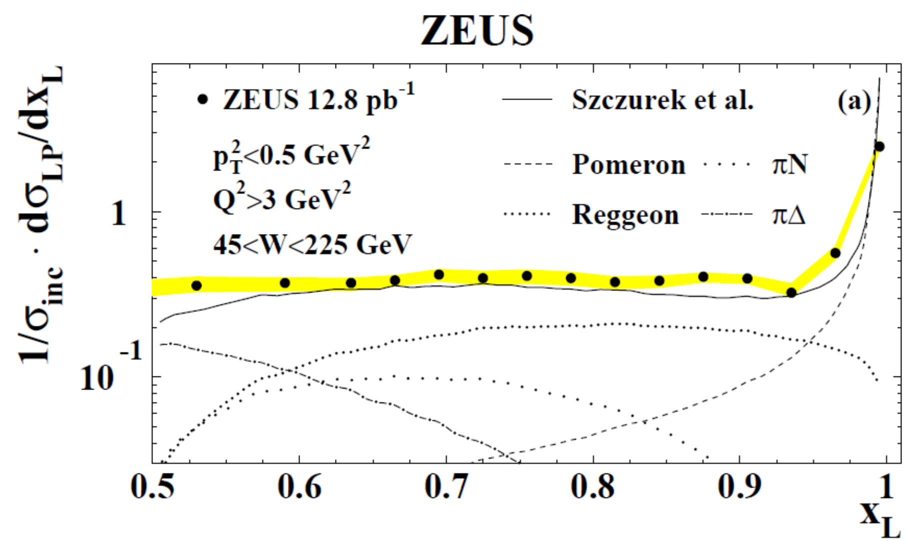
Soft vertex: $\xi = 1 - x_F \ll 1, p_T \simeq \Lambda_{QCD} \approx O(200\text{MeV})$

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

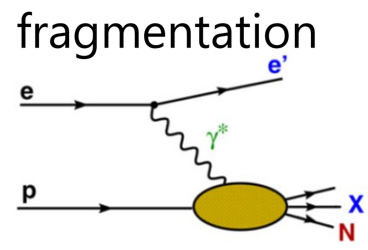
- Inclusive measurements

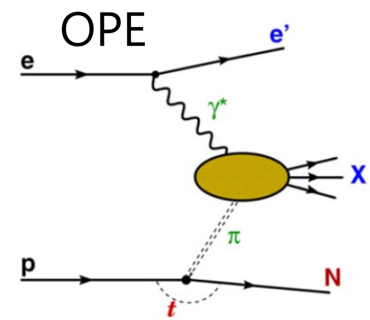
Spectrum of slower
leading protons ($x_F < 1$)

$\Rightarrow$ lower x_F, larger p_T
also interesting

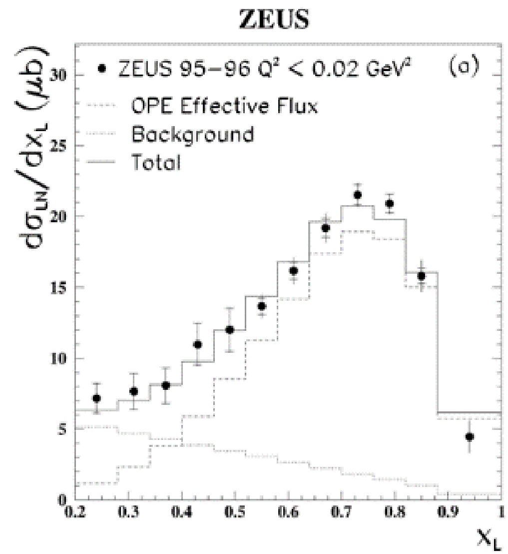


Neutron tagging for *ep*

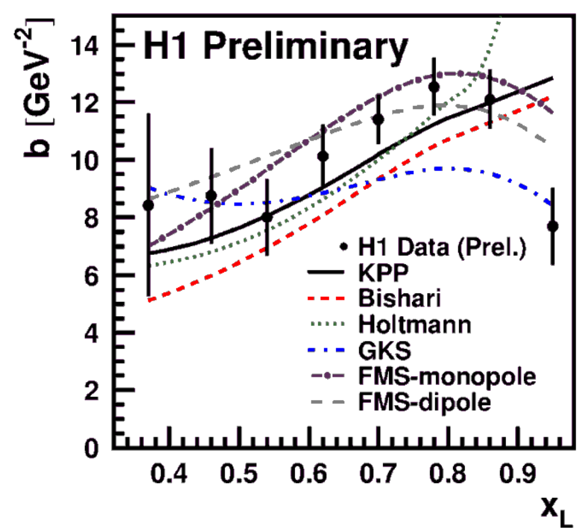




- Inclusive measurement @ HERA:
  - supporting one-pion exchange
  - b-slope (~ 8 GeV^{-2}) compared to various models of pion fluxes



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

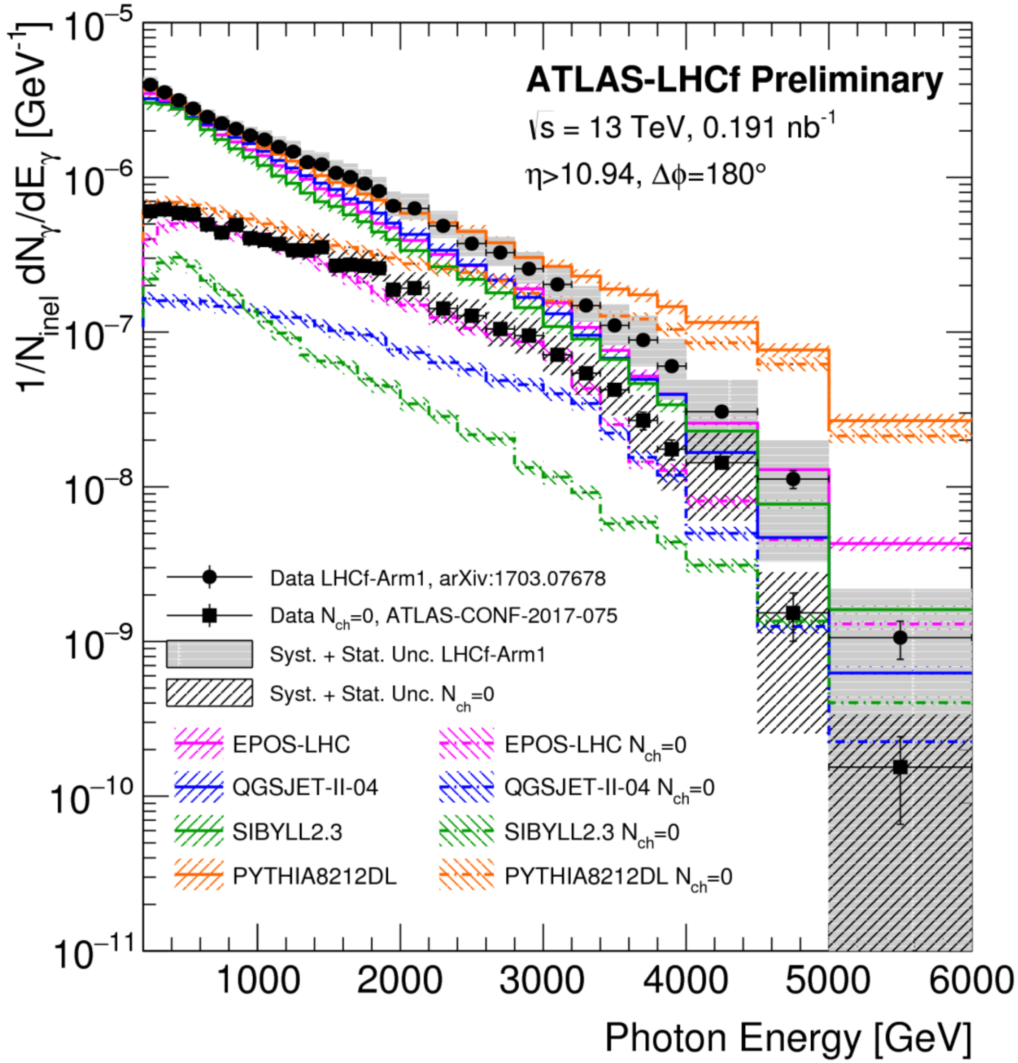


π^0 production by LHCf and ATLAS

- 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

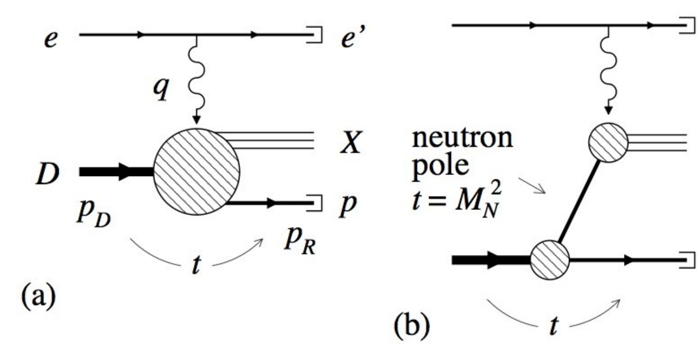
Need EM section with excellent position resolution

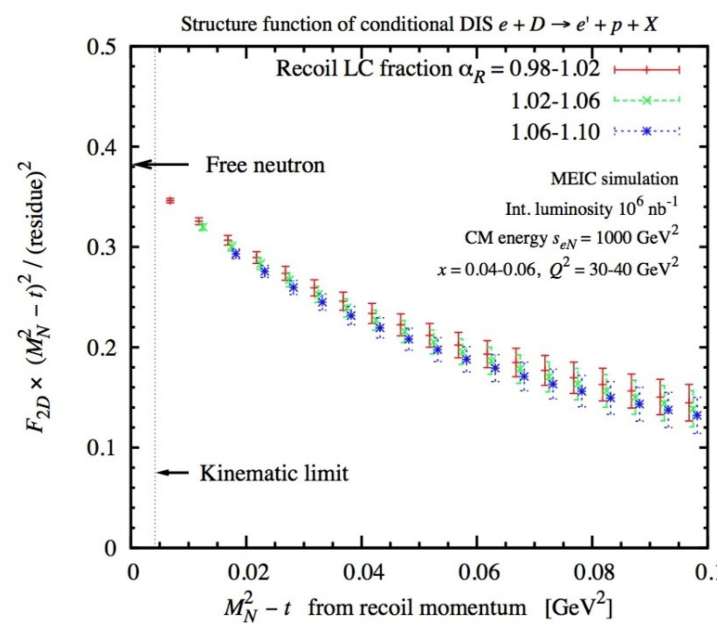
ATLAS-CONF-2017-075

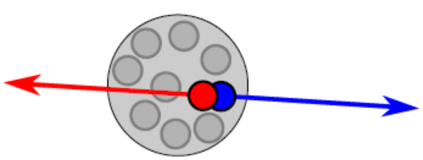


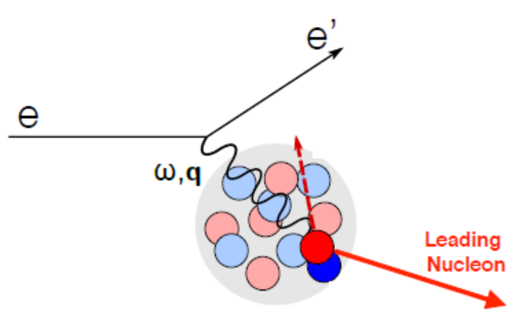
Proton/neutron tagged eD/eA DIS

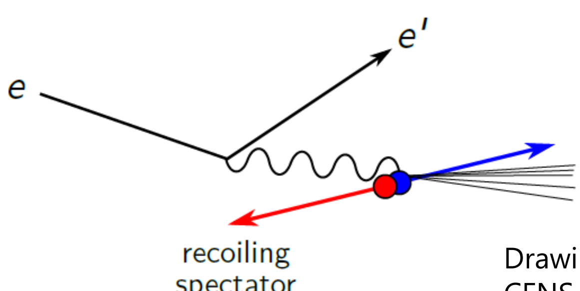
- Proton-tagged $\boldsymbol{eD}$ and $\boldsymbol{eA}$ scattering
  - $e(p+n) \rightarrow en + p$ **DIS for neutron!**
  - Way to understand
    nuclear (EMC) effect
    or short-range correlation **(SRC)**
    by comparing small and large system
- Neutron-tagged $(ep+n)$:
  - Cross-check with ep runs











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

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

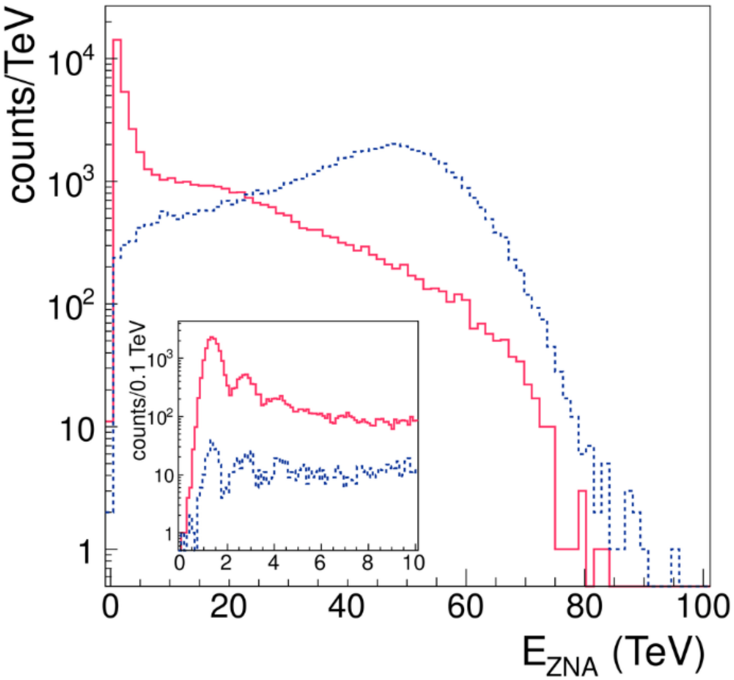
For bigger nucleus

- 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 1 TeV (rather 10 TeV?)

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



BACKUP

Beam-gas interactions

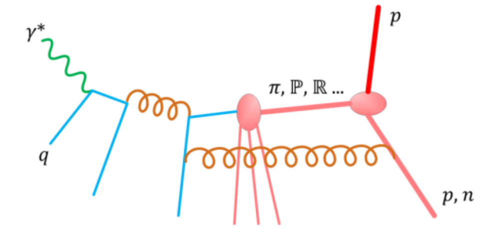
- First and foremost, need an excellent vacuum
- Some estimations
- Assumptions of the vacuum and layout from other facilities (HERA, LHC)

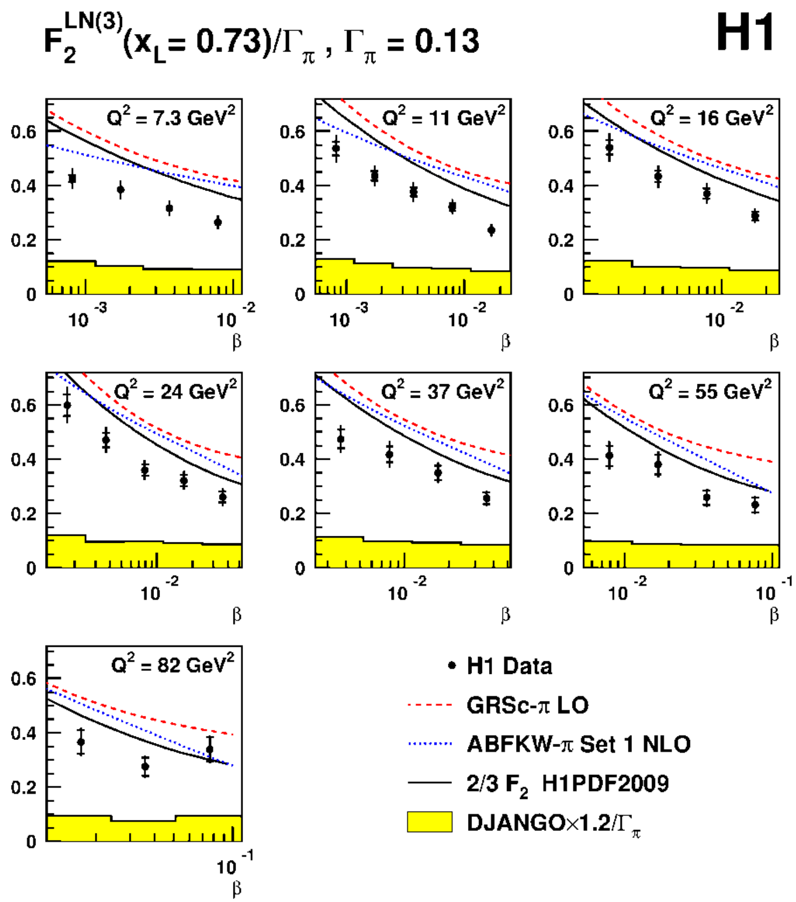
Vacuum pressure	10^{-9} mbar
Beampipe temperature	Room temperature
Average atomic weight of gas	Hydrogen (H^2)
Molecular density (for 10 m pipe)	2.65 x 10^{10} molecules/cm^2
Luminosity (Ring-Ring)	10.05 x 10^{33} $cm^{-2}s^{-1}$
Bunch intensity (R-R) (e/p)	15.1 / 6.0 x 10^{10}
Beam Current (R-R) (e/p)	2.5 / 1 A
Bunch spacing (Ring-Ring)	8.7 ns → 1320 bunches
ElectronxProton beam energy	10 GeV x 275 GeV

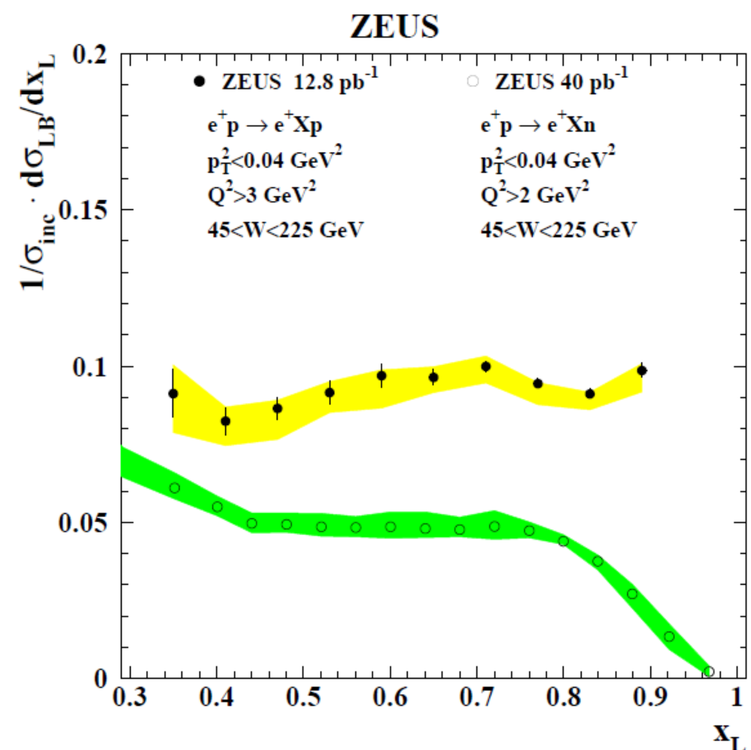
Ring-Ring :
DIS-event rate: 600 kHz
Beam-gas event rate: 9818 kHz in 10m

- Need to analyze the effect of the following assumptions:
- What is the realistic beam pipe temperature and how does it change around the IR?
- What is the gas density profile
- and detector acceptance for BG-events?
- How does the different SR load influence the vacuum

Neutron puzzle (1) suppression?







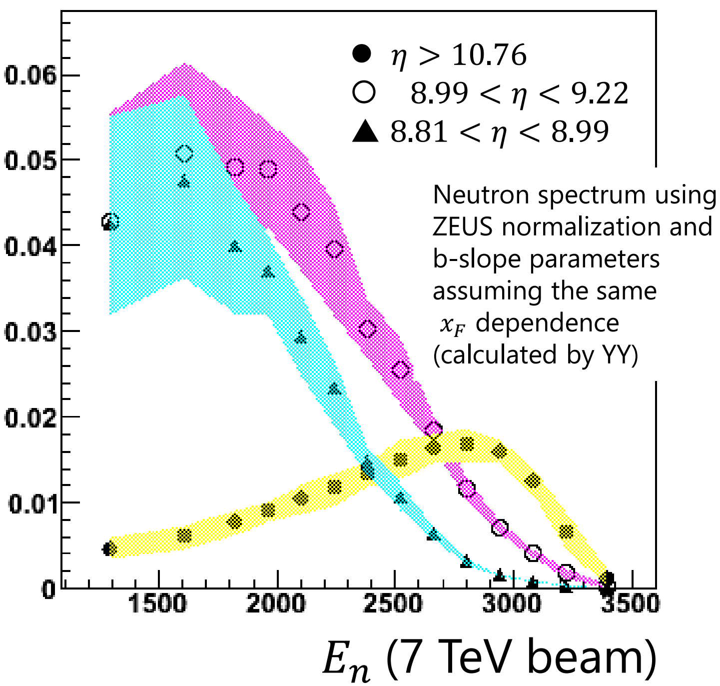
- Neutron yield is 20-30% fewer than naïve prediction of $p : n = 1 : 2$ expected from isovector exchange
- Absorbtion? Rescattering?

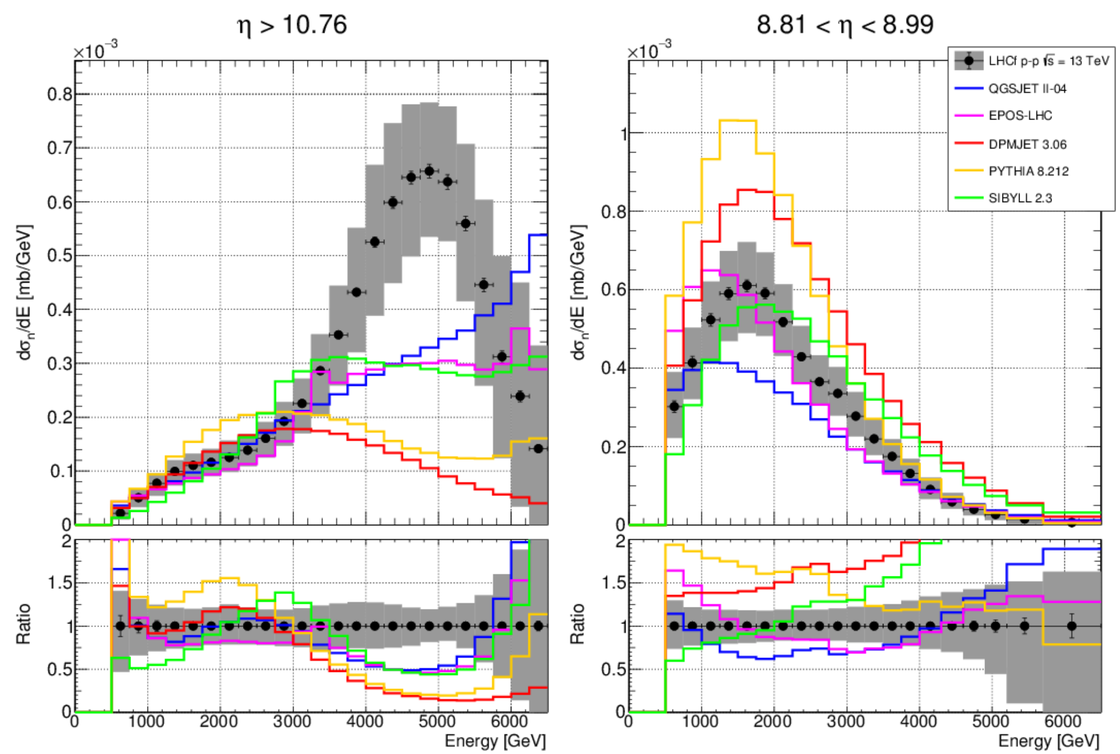
- Protons are more than neutron
  - Again no consistent with isovector exch.

Where did neutron disappear?

Neutron puzzle (2): pp vs ep

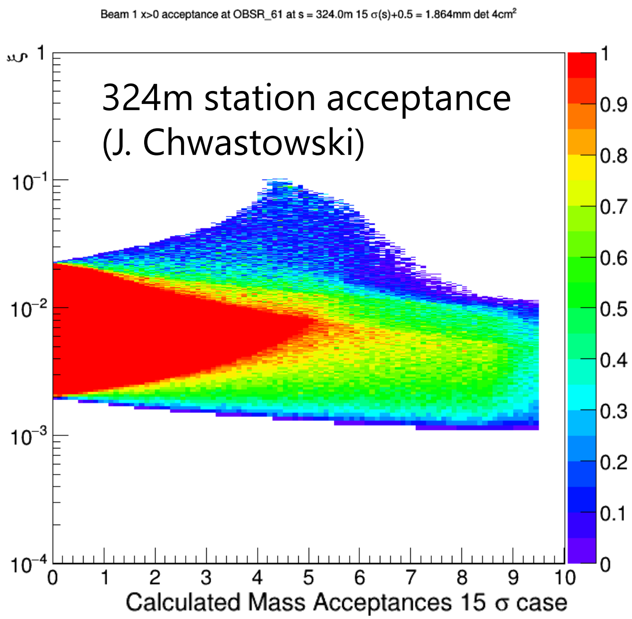
- Limited fragmentation ⇒ the same spectra
- LHCf data similar but models suggest harder spectrum at $x_F \sim 1$
  - due to projectile fragmentation? $pp \to N^* + Y,\ N^* \to n + (\text{hadrons})$
  - Corresponding to proton dissociation for ep DIS: $\gamma^* p \to XN^*$
    LRG-tagged neutron?

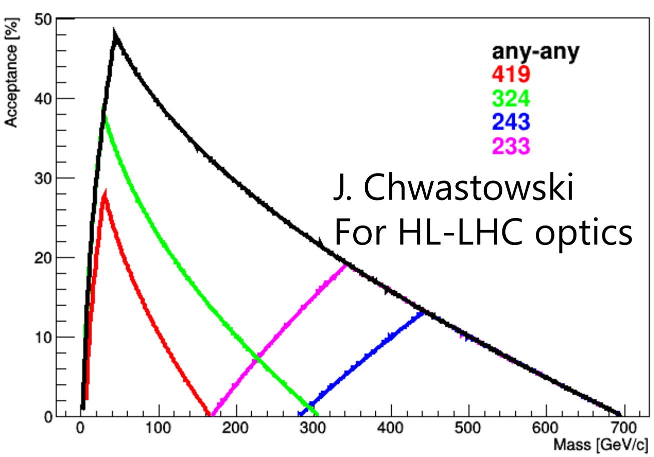


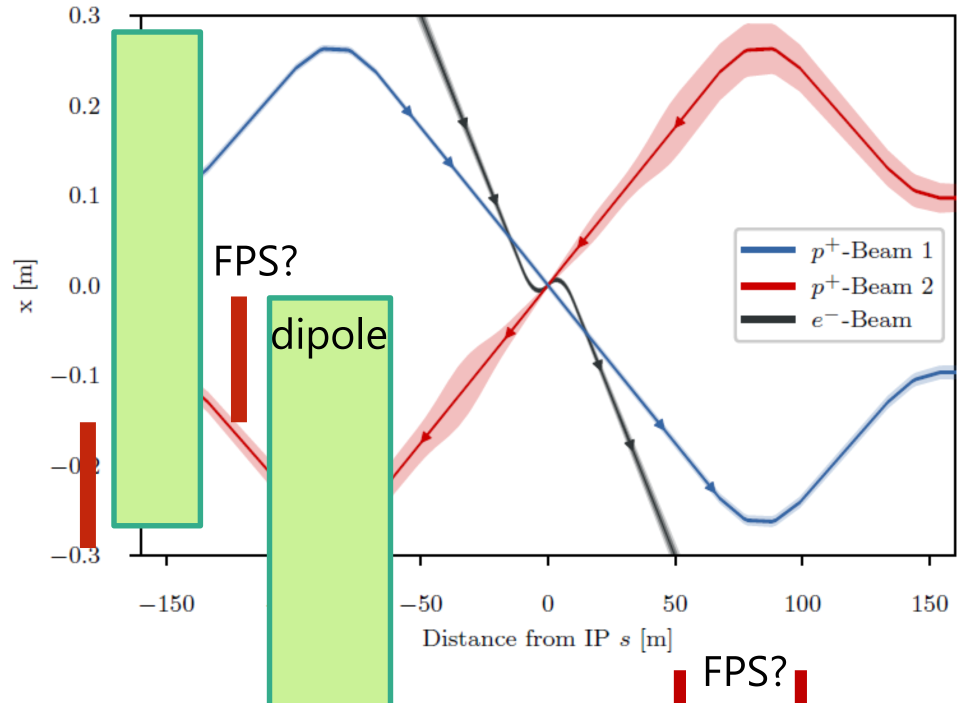


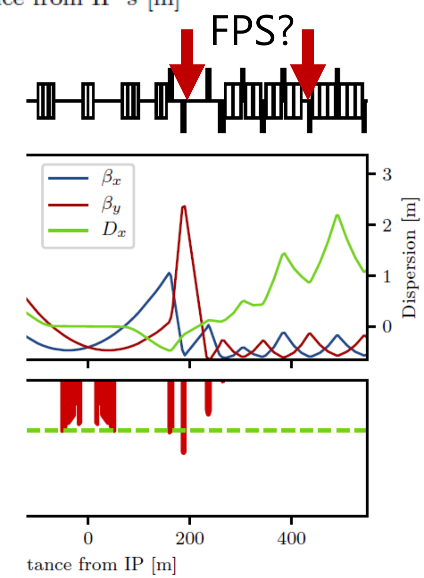
Proton: acceptance and resolution

- 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!!!

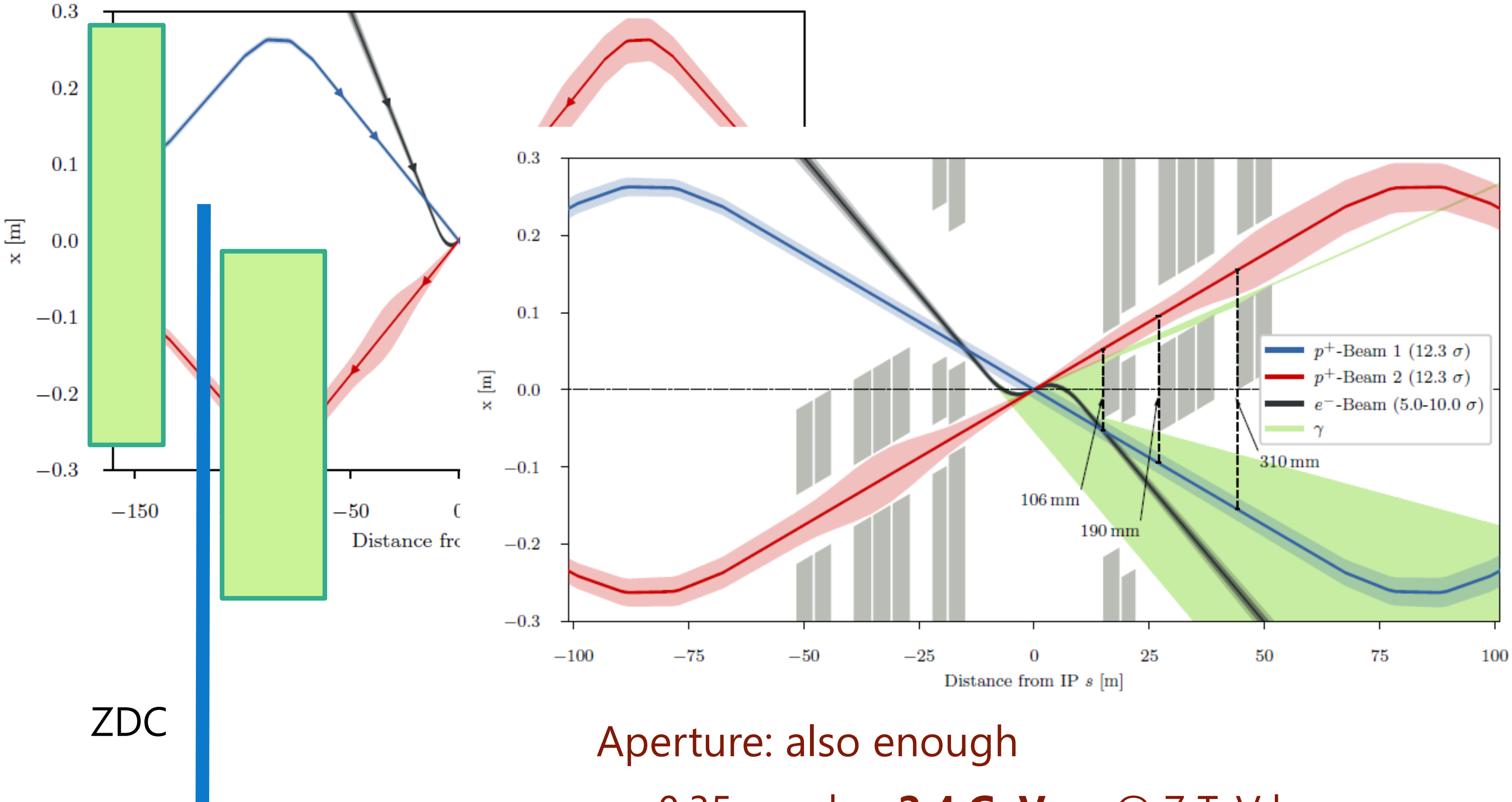
Zero-degree calorimeter (ZDC) requirement

- 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 kHz @ $10^{34}\ \mathrm{cm^{-2}s^{-1}}$ → 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 @ $\mathbf{10^{34}}$**

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

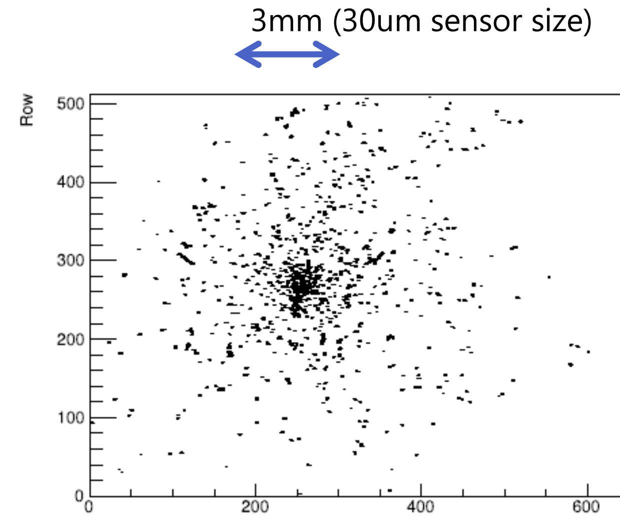


Fig. 8. Event display in a single ALPIDE chip of a 150 GeV electron

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

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 $n_{eq} \sim 10^{16}$**
    Si sensor: $\sim 0.5 - 1\ \mathrm{cm}^2$
  - **ALICE FoCal** (EM section: MAPS + pads)
    Very fine shower image, also for neutron tracking

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