Search for Fractionally Charged Particle in ATLAS

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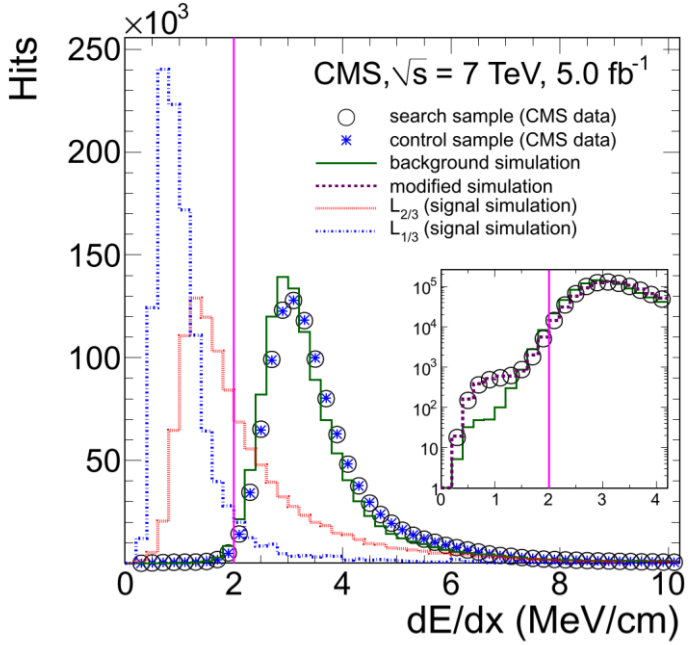
On behalf of USTC FCP team

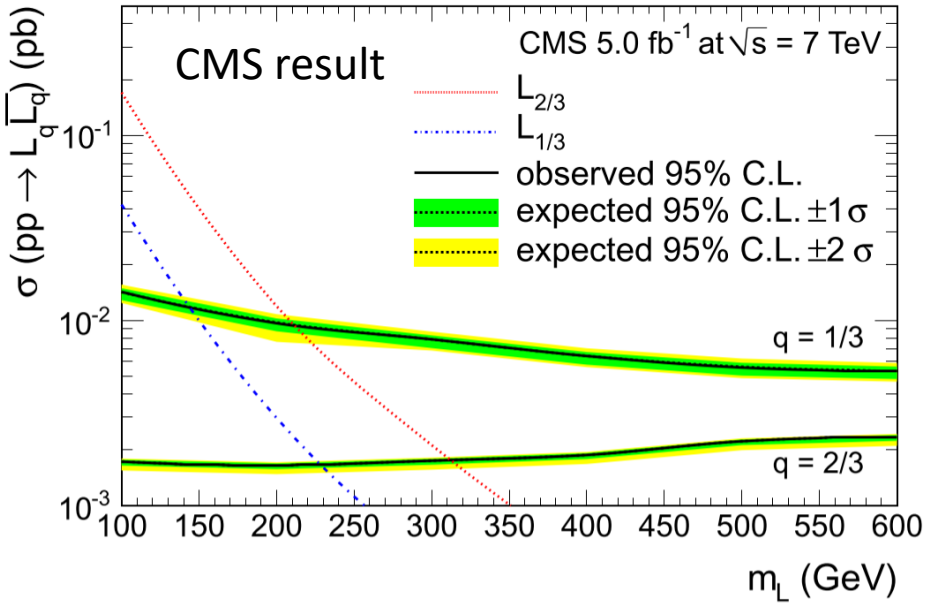
Outline

- Introduction
- The ATLAS detector
- FCP simulation
- FCP reconstruction
- Summary

Introduction

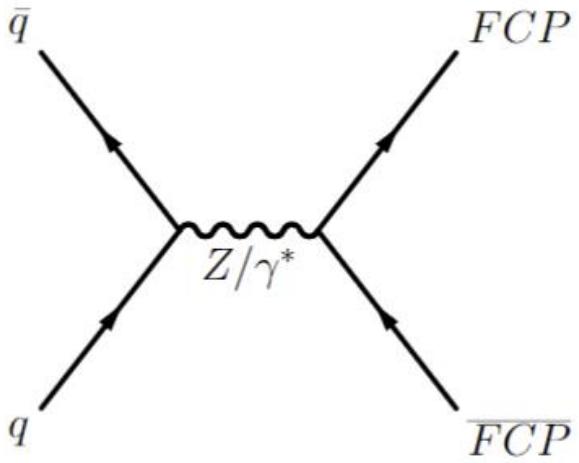
- Fractionally Charged Particles
  - Hypothetic particles from beyond SM theories
  - Originates from the mystery of ‘integer charge’
- LHC CMS work
  - Well known background on collider searches
  - Utilized $5\ \mathrm{fb}^{-1}$ pp collision data, at $7\ \mathrm{TeV}$
  - Relied on pixel dE/dx only





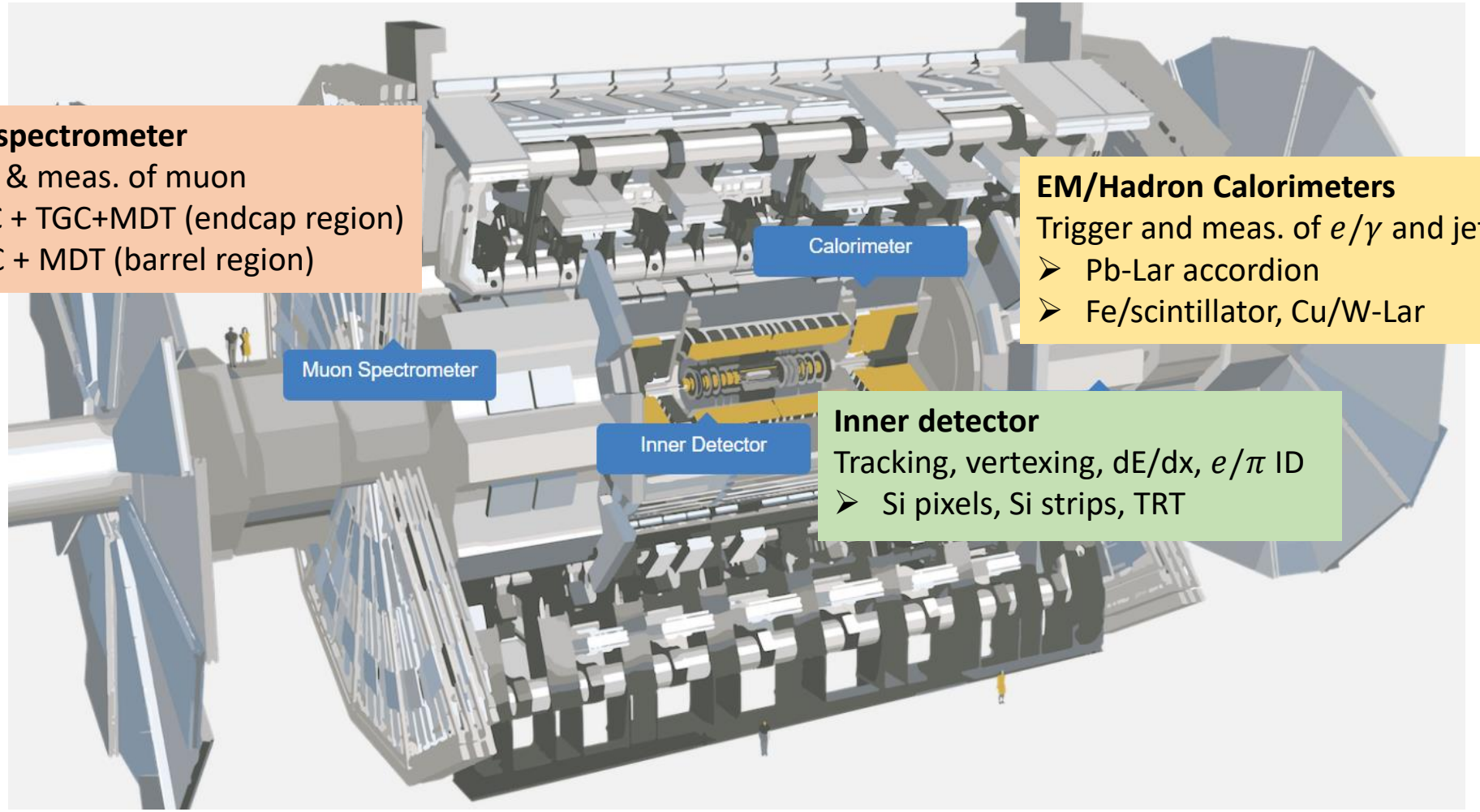
Introduction: search strategy

- Use $139\ fb^{-1}$ ATLAS Run II data, at 13 TeV
- Mass assumption:
  - From $30\ GeV$ to $1000\ GeV$
  - $m > 100\ GeV$ is region of interest
- Charge assumption:
  - $\pm\frac{1}{3}e, \pm\frac{1}{2}e, \pm\frac{2}{3}e$
- Participate EM/weak interactions:
  - The lightest FCPs are long-lived
  - Muon-like from the view of detectors
- Reconstruct FCPs as muons
- Distinguish FCPs from SM muons



The ATLAS detector

Muon spectrometer
Trigger & meas. of muon
- CSC + TGC+MDT (endcap region)
- RPC + MDT (barrel region)

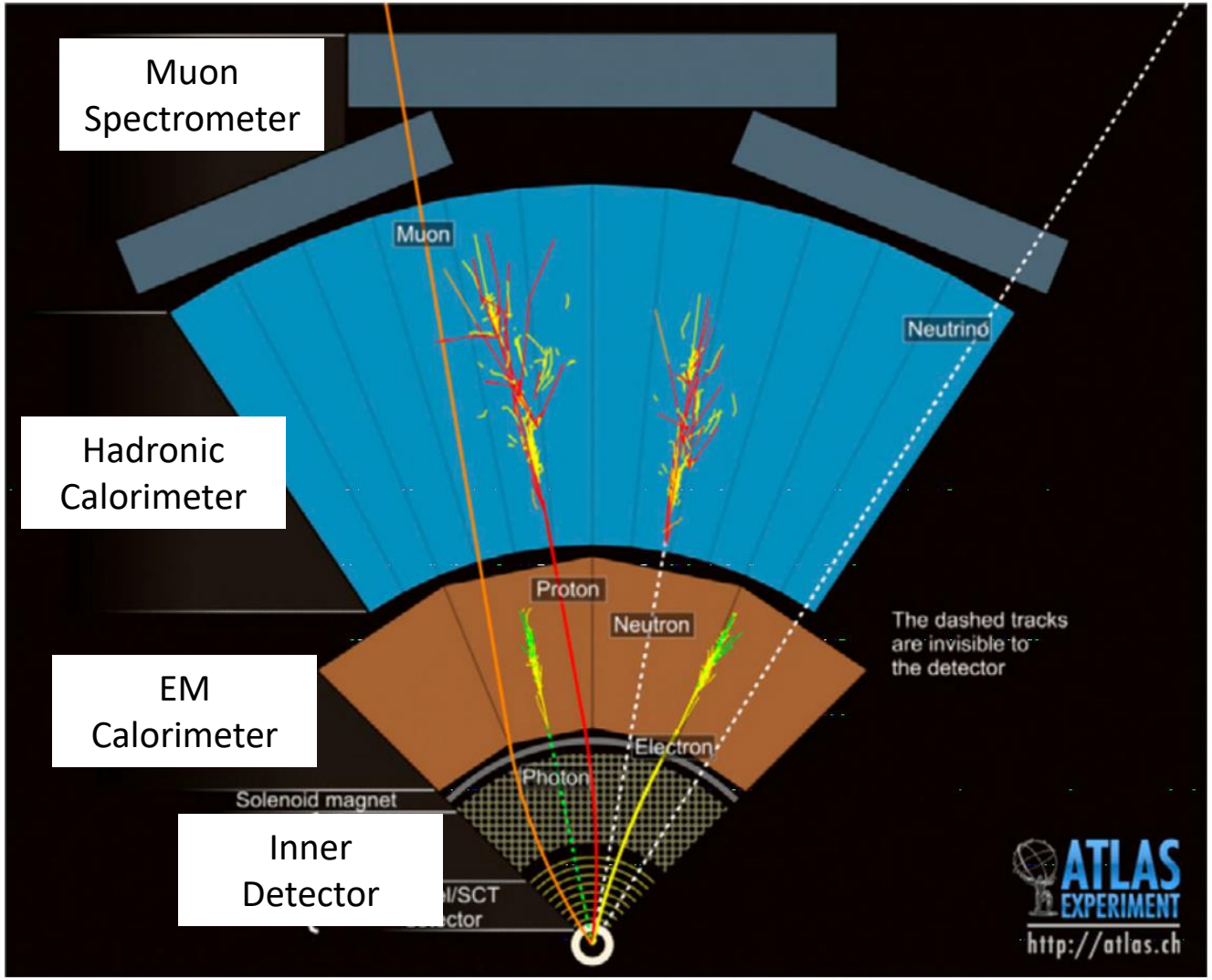


EM/Hadron Calorimeters
Trigger and meas. of e/γ and jet/Emiss
- Pb-Lar accordion
- Fe/scintillator, Cu/W-Lar

Inner detector
Tracking, vertexing, dE/dx, e/π ID
- Si pixels, Si strips, TRT

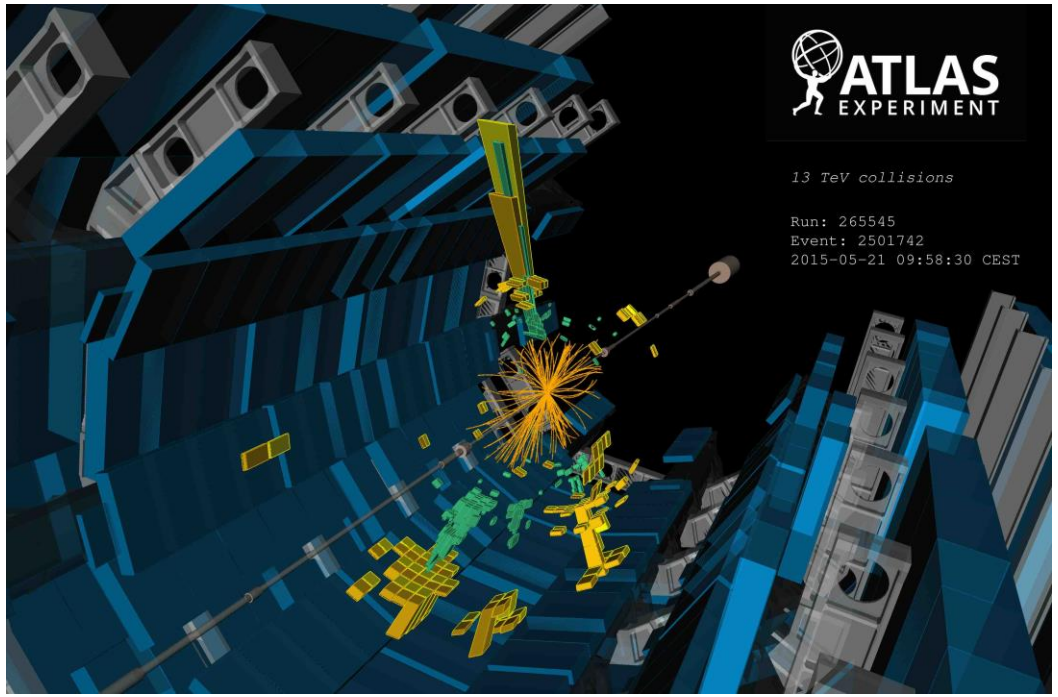
The ATLAS detector

- Muon/FCP
  - Penetrate the whole ATLAS
  - Leave hits along tracks
- Photon/electron
  - Stops at EM calo.
  - Leave hits in EM calo. , pixel detectors
- Proton/neutron
  - Stops at Hadronic calo.
- Neutrino



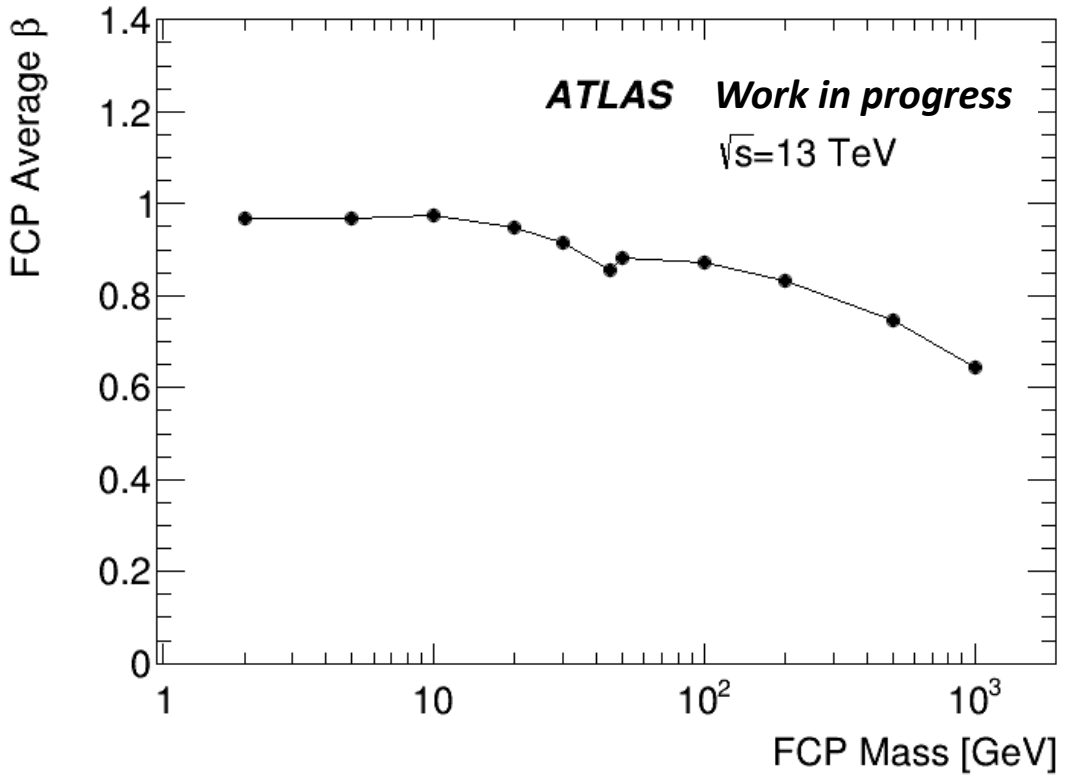
FCP simulation chain

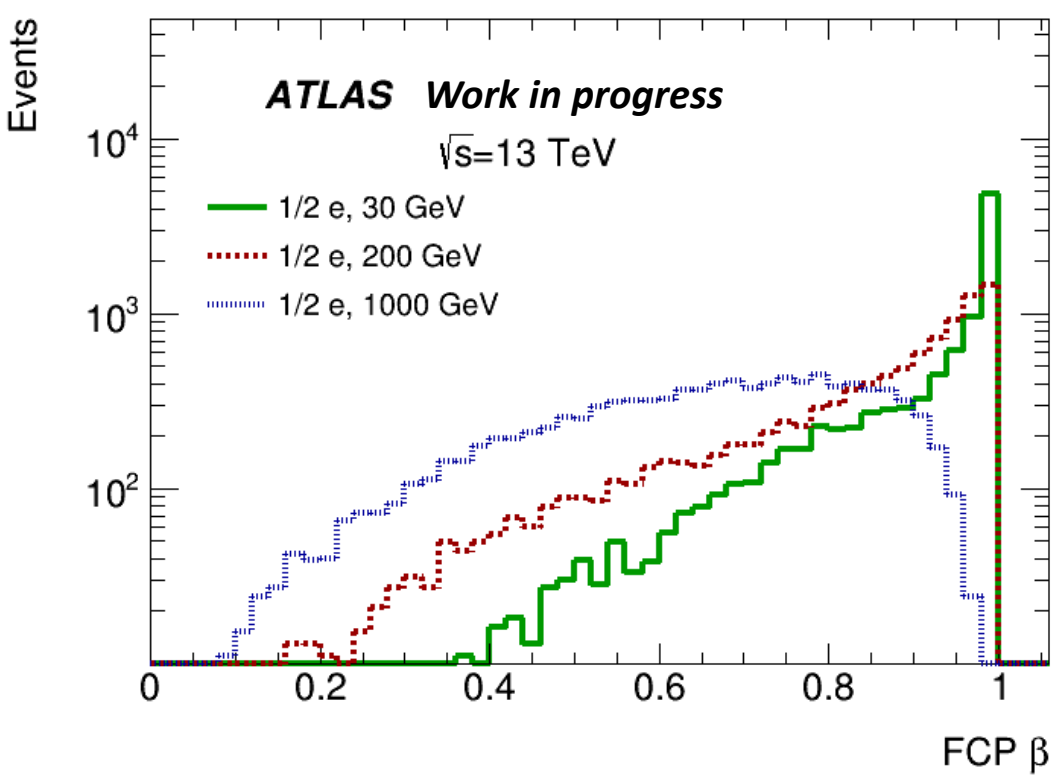
- Parton level:
  - MadaGraph5 v2.6.5
  - PDF: NNPD23LO
- Parton shower:
  - Pythia 8
- ATLAS detector simulation
  - Simulate the deposited energy
  - Convert into digital information
- ATLAS particle reconstruction
  - The same algorithm for both MC and data
  - Reconstruct hits into tracks and particle candidates



FCP simulation: kinematic attributes

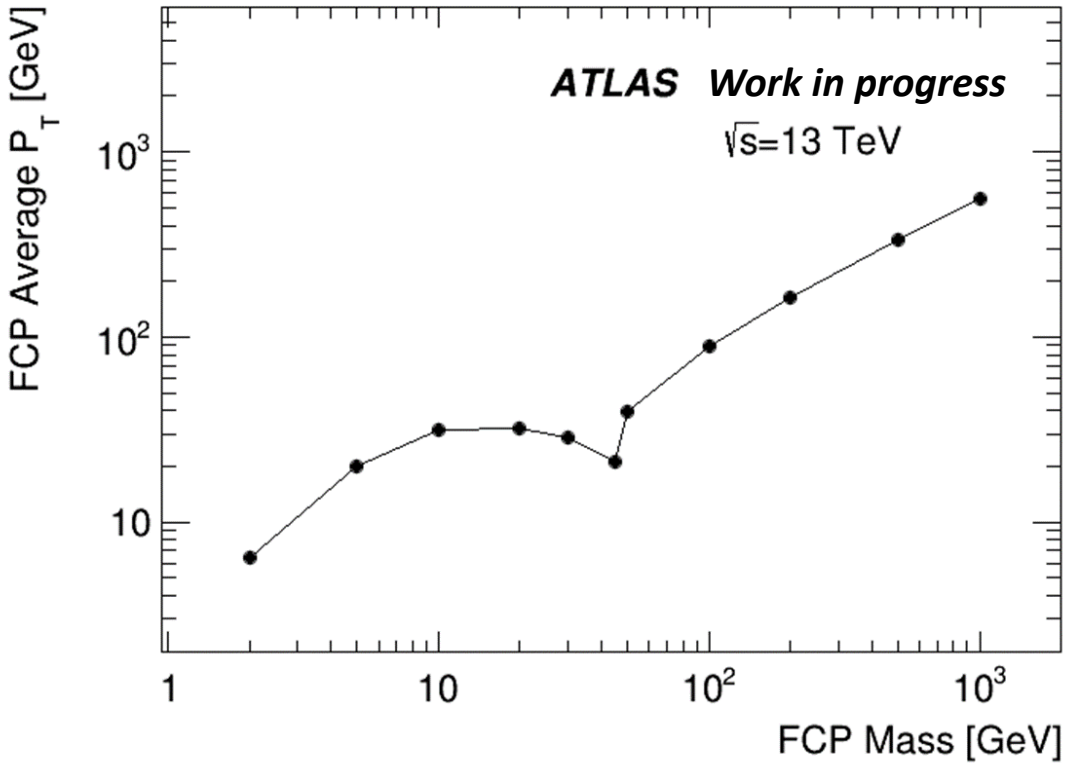
- Beta β at generation level
  - Light FCPs ($m < 30\ GeV$) have a β close to 1, like muons
  - Heavy FCPs in region of interest ($m > 100\ GeV$) have a β lower than 1
  - The dip is due to Z resonance

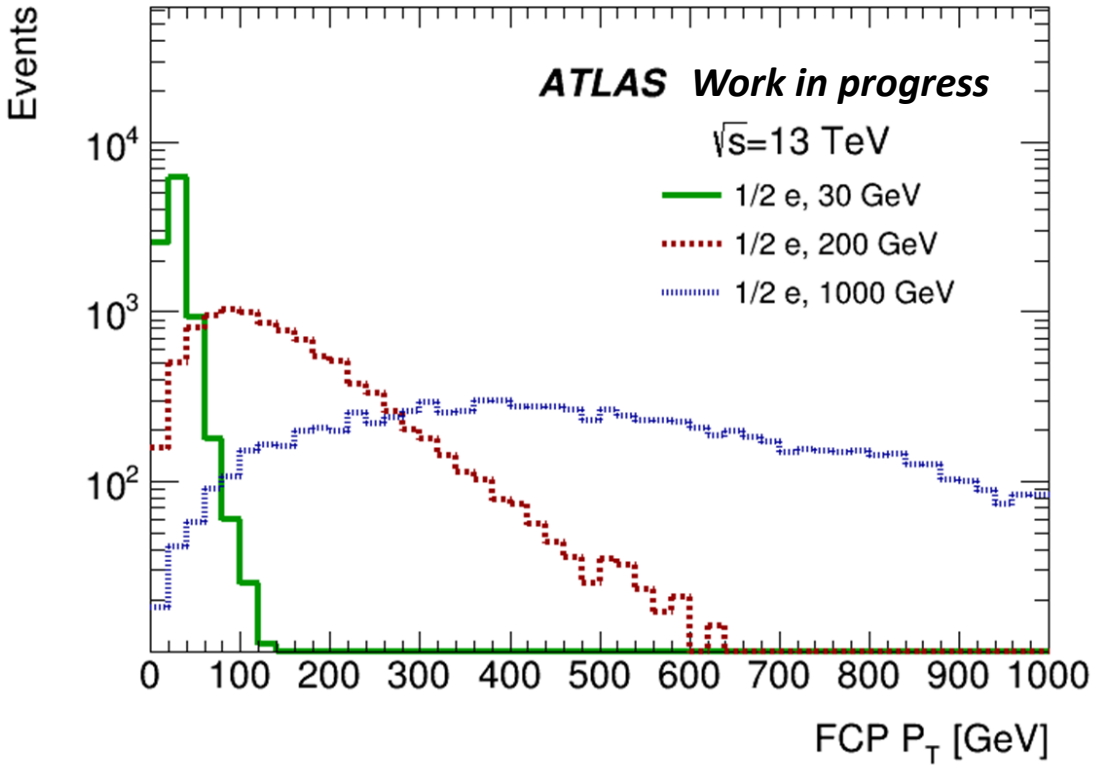




FCP simulation: kinematic attributes

- Transverse momentum p_T at generation level
  - p_T increases as FCP mass getting larger
  - p_T is high enough for FCP to penetrate the magnetic field
  - The dip is due to Z resonance





FCP reconstruction

- Reconstruct FCPs as muons in ATLAS
  - FCPs are fractionally charged, and massive (comparing to muons)
  - FCPs interact weakly with detectors, reach the Muon Spectrometer
- Two muon reconstruction algorithms
  - Standard muon reco. algorithm :
    - Widely used for muon reconstruction
    - Assume muon propagating at light speed
  - ✓MuGirl algorithm:
    - Fits the hit time to reconstruct particle velocity
    - Higher reconstruction efficiency for high-mass FCPs

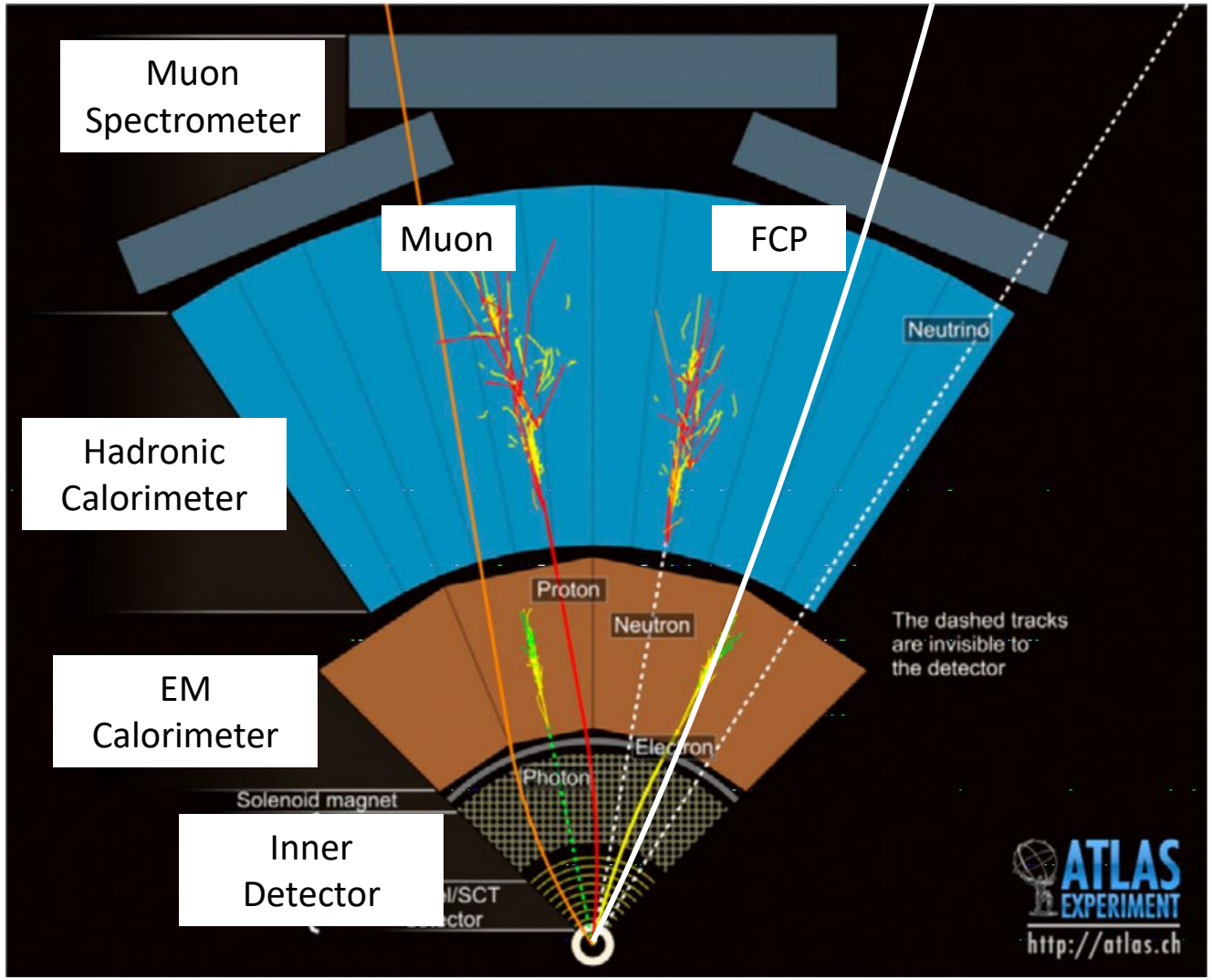
	$1/3\ e$	$1/2\ e$	$2/3\ e$
$1000\ GeV$	$(9.7 \pm 0.2)\%$	$(43.8 \pm 0.3)\%$	$(86.6 \pm 0.2)\%$
$200\ GeV$	$(3.2 \pm 0.1)\%$	$(18.3 \pm 0.2)\%$	$(71.3 \pm 0.3)\%$
$30\ GeV$	$(0.4 \pm 0.0)\%$	$(7.7 \pm 0.2)\%$	$(58.8 \pm 0.3)\%$

Reconstruction efficiency for FCPs

- 1/2 e and 2/3 e FCPs are focused

FCP reconstruction: Muon vs. FCP

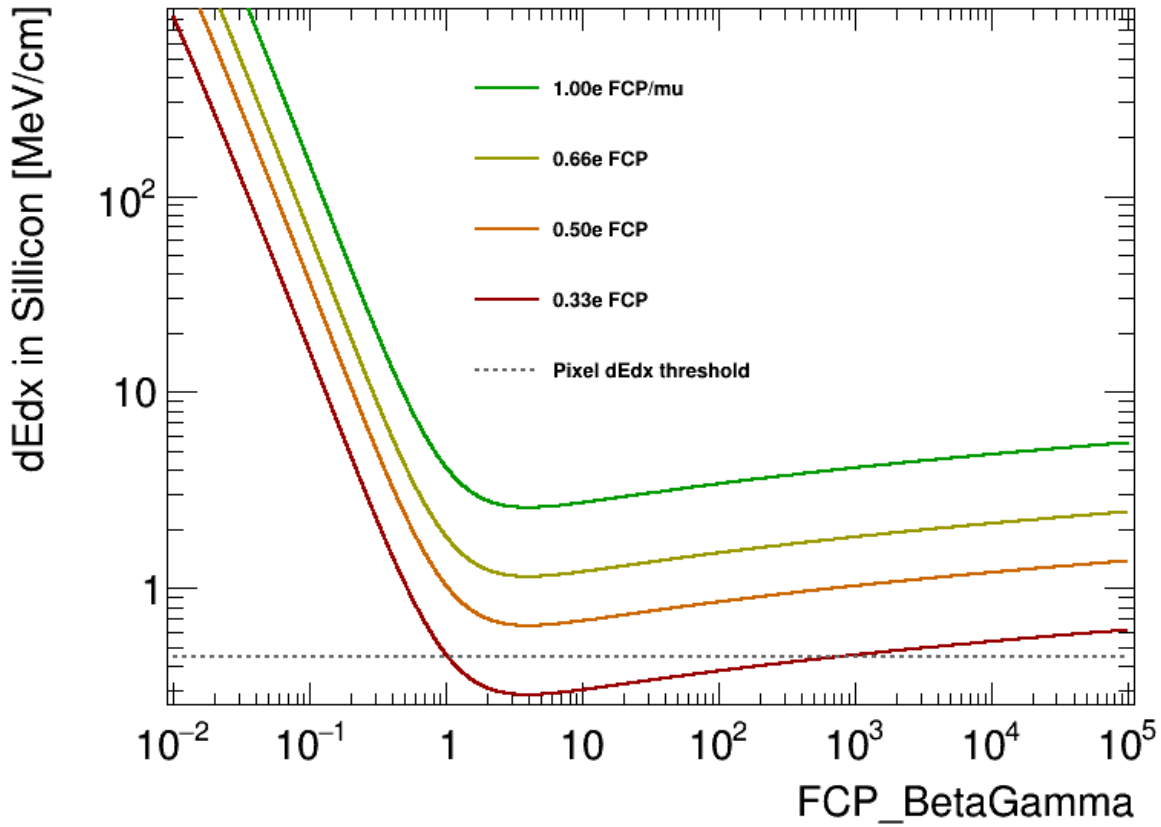
- How to distinguish FCPs from muons?
  - Characteristics kinematics?
    - Maybe model-dependent
  - Energy deposition?



dE/dx described by Bethe-Bloch formula

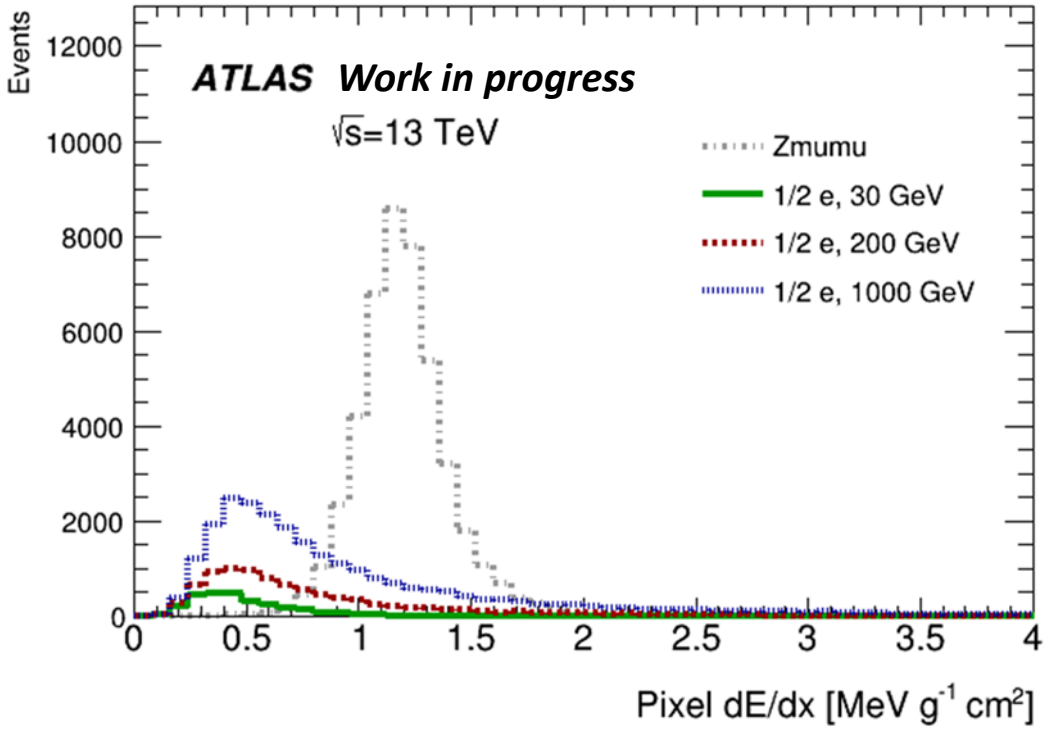
$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

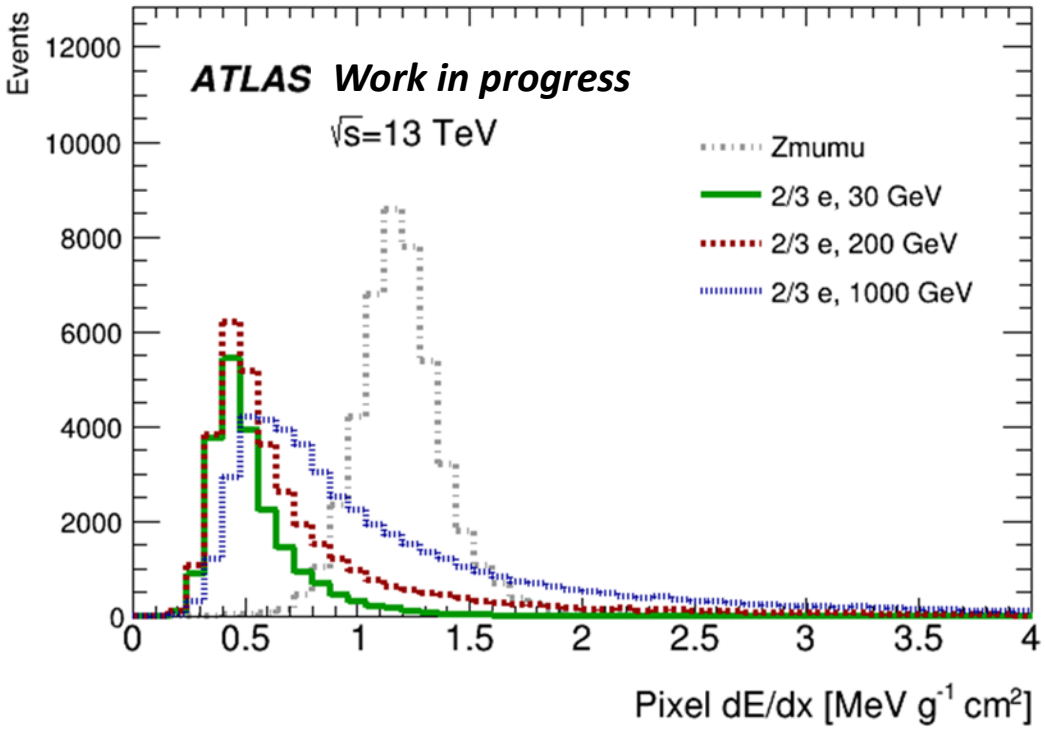
- dE/dx
  - Proportional to charge
  - Tuned by $\beta\gamma$
  - Insensitive to income particle mass ($> 0.1\ GeV$)
- ATLAS Pixel detectors
  - For positioning, vertexing
  - Also offers dE/dx measurements



FCP reconstruction: dE/dx information

- Pixel dE/dx
  - FCPs have lower deposited energy than muons decay from Z
  - FCPs with larger mass leave higher energy deposition
    - Tuned by $\beta\gamma$ following Beth-Bloch formula
    - Leading to the long tail

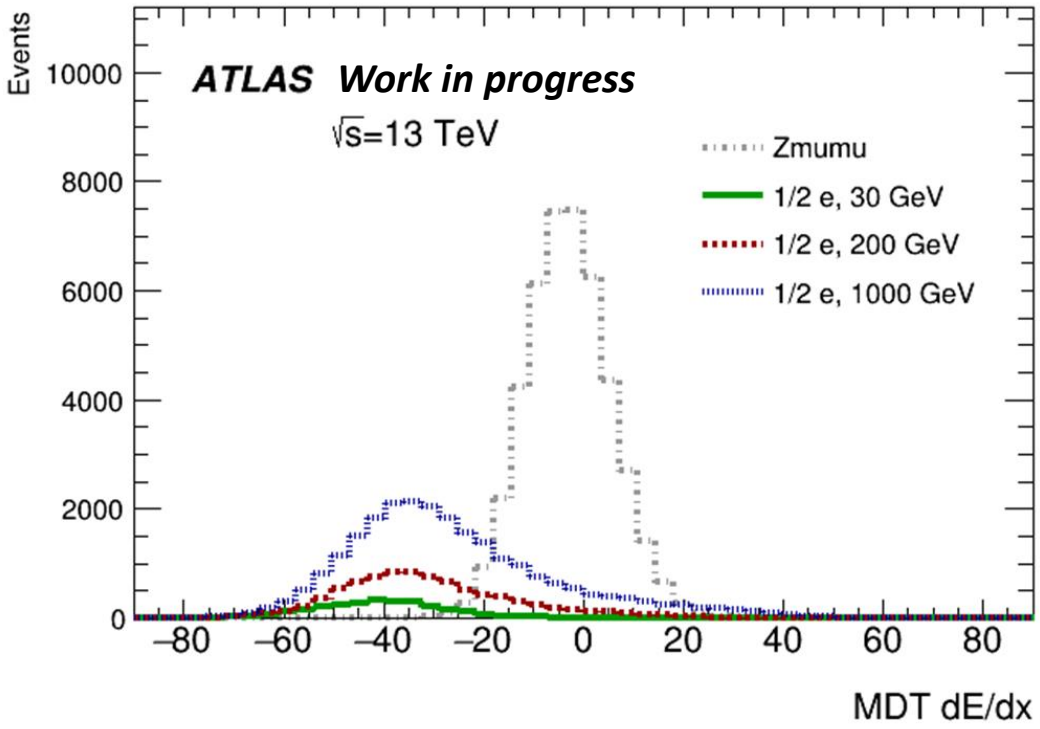


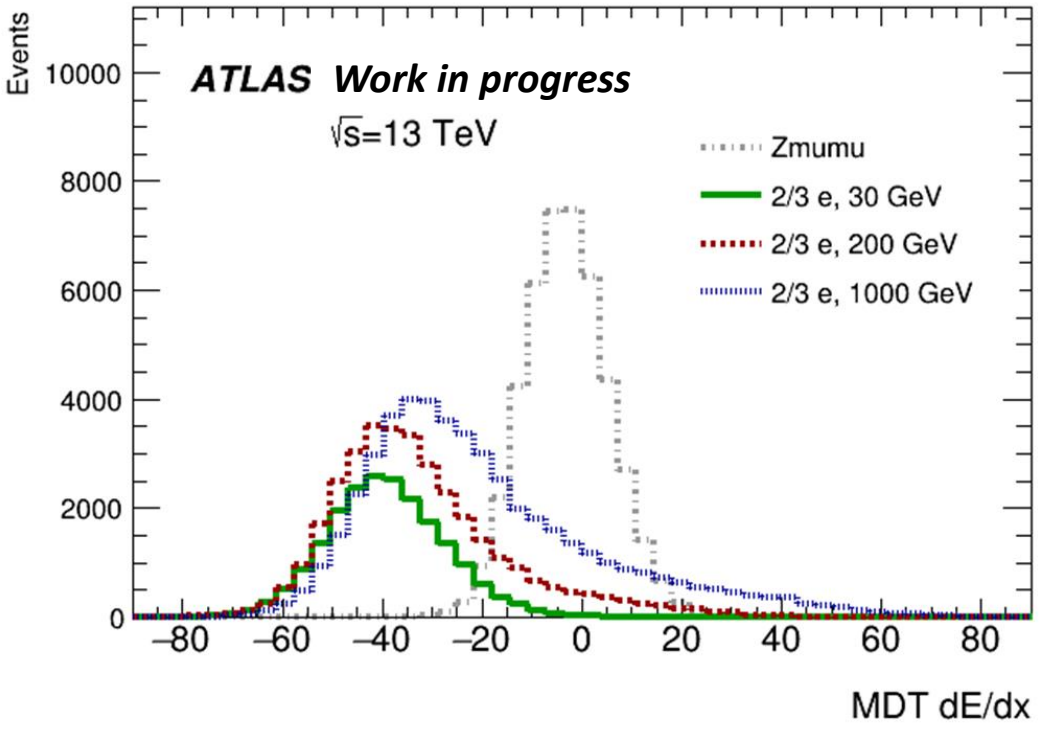


Total events reflect the reconstruction efficiency

FCP reconstruction: dE/dx information

- MDT dE/dx
  - The time-over-threshold of MDT hit is used to estimate energy deposition
  - MDT dE/dx describe the bias in energy deposition comparing standard muons
  - Similar distribution as pixel detectors





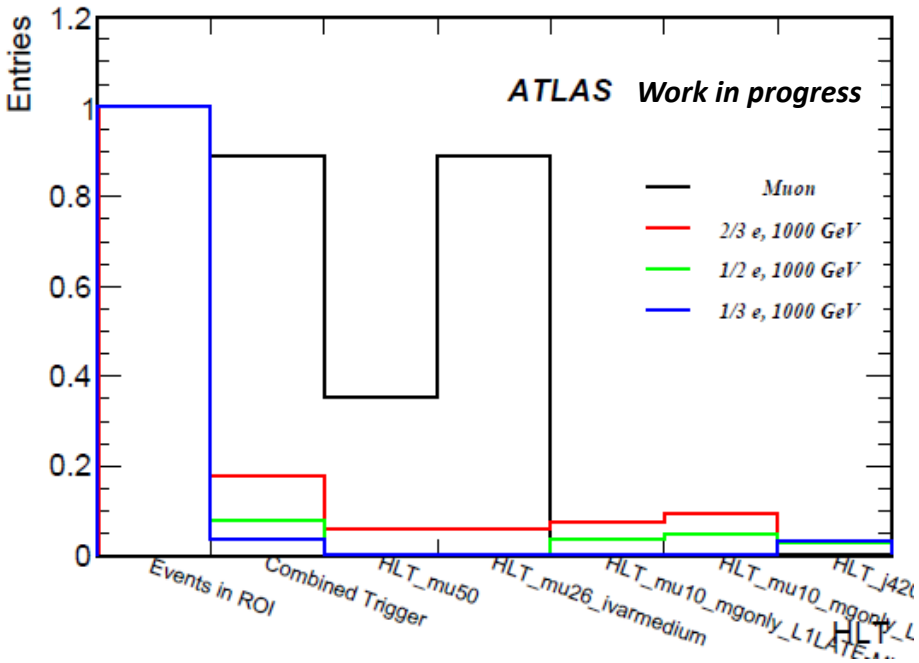
Total events reflect the reconstruction efficiency

FCP reconstruction: Trigger

- Trigger aims at filtering physical events
  - Fired by muons, jet, e …
  - A combination of different HLTs are used to increase trigger efficiency
- Overall trigger efficiency remains low
  - Due to less deposited energy
  - Due to high discriminator threshold
    - TGC threshold is too high for FCP (endcap regions)

	$1/3\ e$	$1/2\ e$	$2/3\ e$
$1000\ GeV$	$(3.66 \pm 0.1)\%$	$(7.9 \pm 0.2)\%$	$(17.7 \pm 0.3)\%$
$200\ GeV$	$(0.88 \pm 0.1)\%$	$(2.6 \pm 0.3)\%$	$(17.9 \pm 0.3)\%$
$100\ GeV$	$(0.22 \pm 0.0)\%$	$(0.9 \pm 0.1)\%$	$(18.1 \pm 0.4)\%$
$30\ GeV$	$(0.02 \pm 0.0)\%$	$(0.5 \pm 0.1)\%$	$(22.2 \pm 0.5)\%$

HLT efficiency for FCPs in barrel region



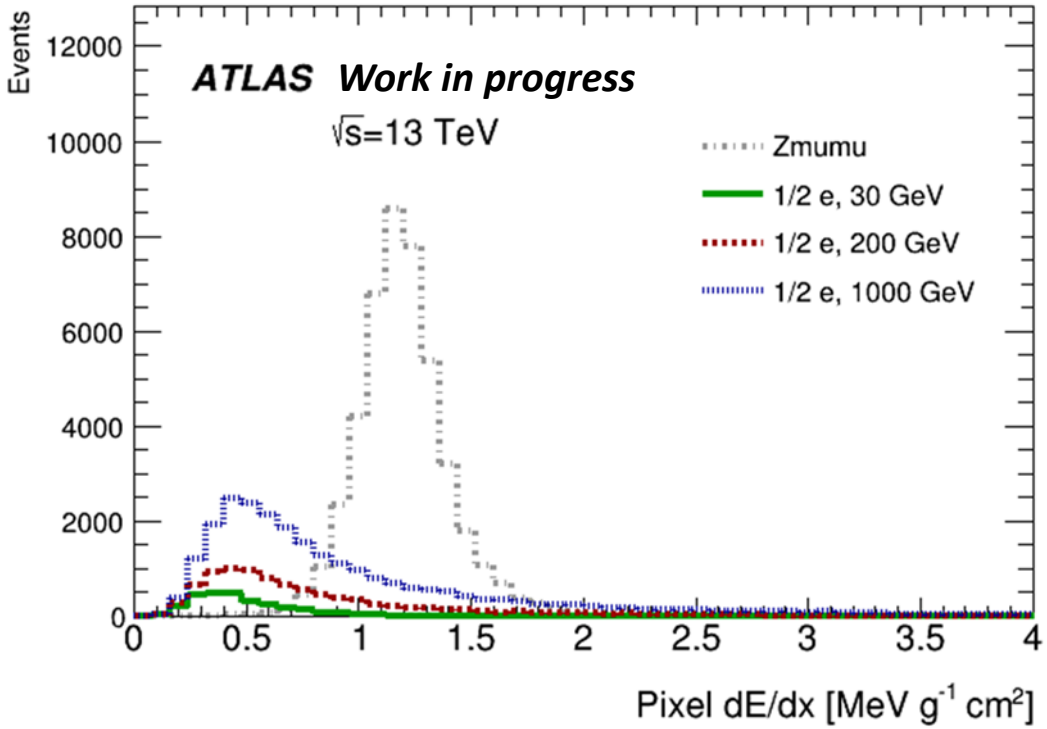
HLT efficiency for FCPs

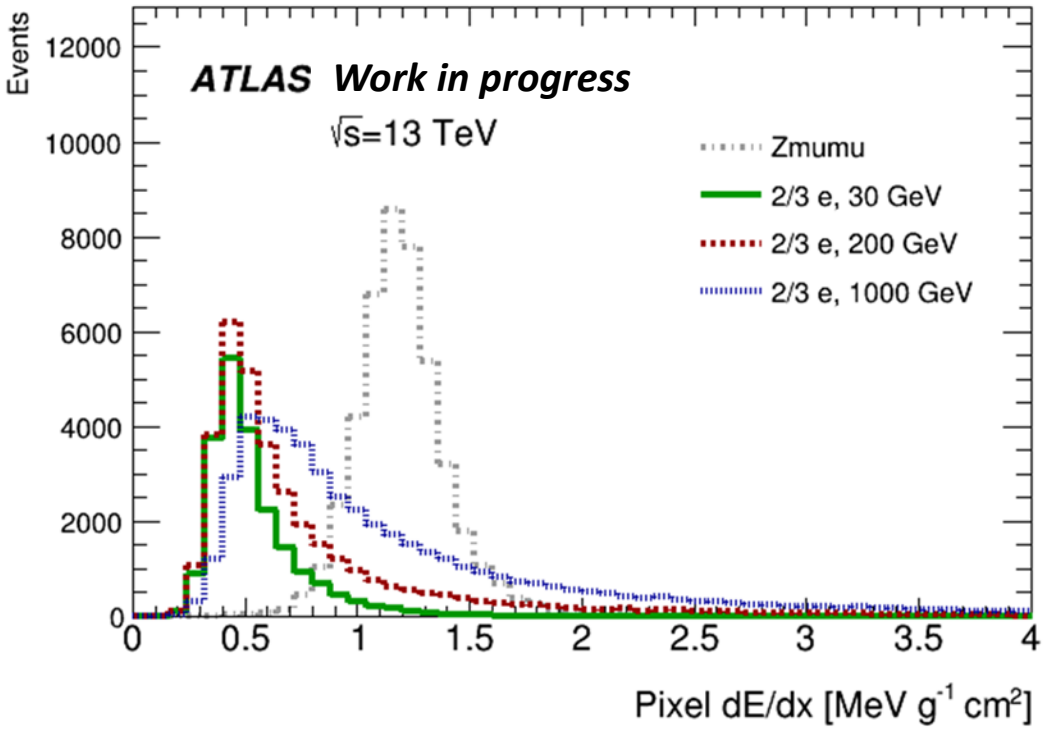
Summary: existing progresses

- Simulation chain has been developed
  - Now compatible with FCPs
  - dE/dx well simulated
  - To be calibrated before further analysis
- Different reconstruction algorithms are utilized
- Trigger efficiency is studied

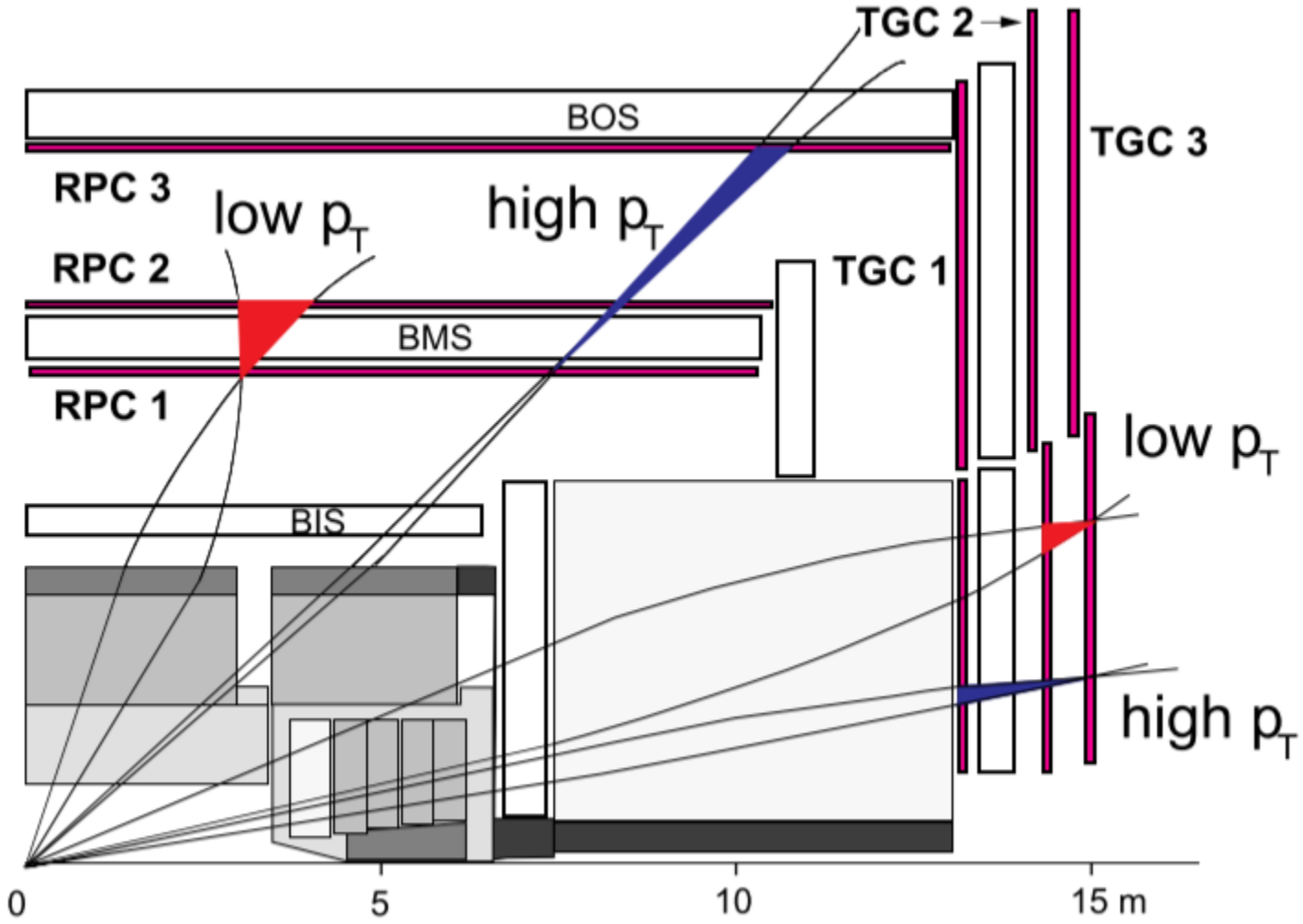
Backup FCP reconstruction: dE/dx information

- Pixel dE/dx
  - FCPs with larger mass leave higher energy deposition
    - Tuned by $\beta\gamma$ following Beth-Bloch formula
    - Leading to the long tail
  - FCPs with 2/3 e feature higher energy deposition





Backup


TGC 2
BOS
TGC 3
RPC 3
low p_T
high p_T
RPC 2
TGC 1
BMS
RPC 1
low p_T
BIS
high p_T
0
5
10
15 m

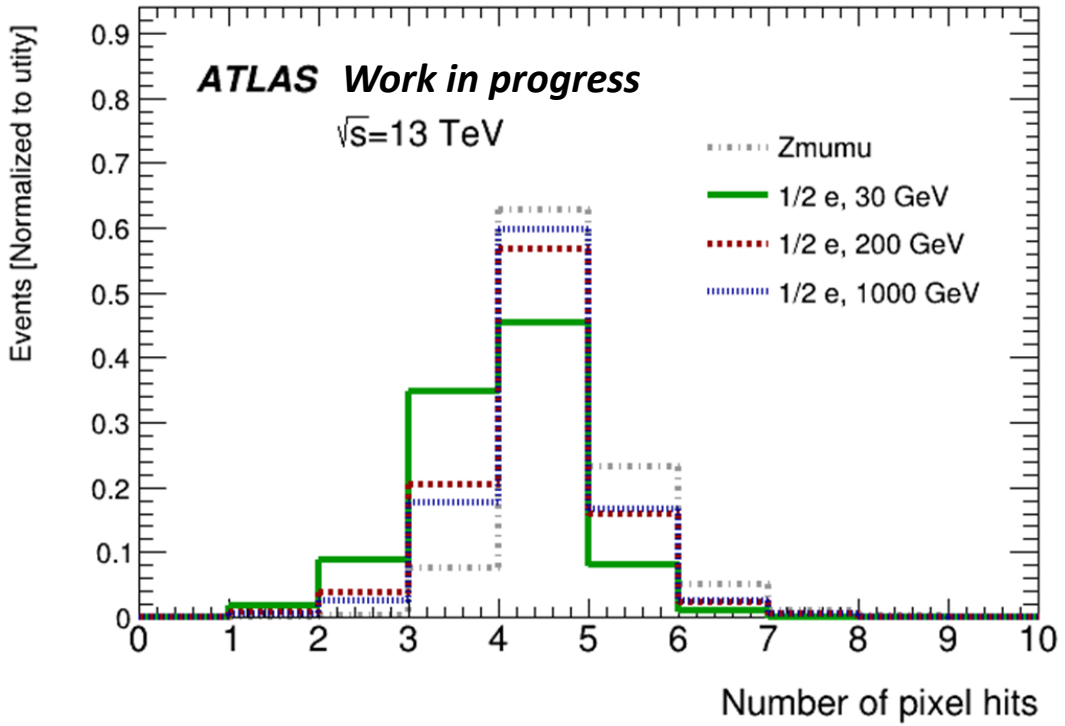
Backup: trigger def.

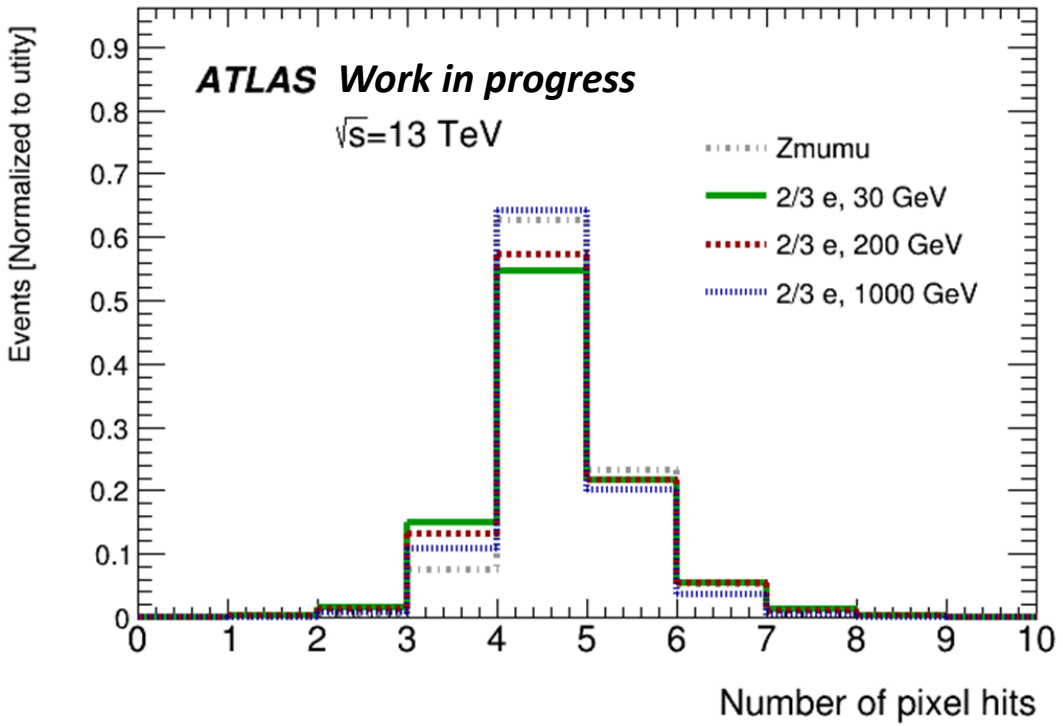
	Requirements
HLT_mu50	at least one muon with p_T > 50 GeV
HLT_mu26_ivarmedium	at least one muon with p_T > 26 GeV and identification "medium"
HLT_mu10_mgonly_L1LATE-MU10_J50	at least one muon with p_T > 10 GeV in the next bunch crossing of L1_J50
HLT_mu10_mgonly_L1LATE-MU10_XE40	at least one muon with p_T > 10 GeV in the next bunch crossing of L1_XE40
HLT_j420	at least one jet with p_T > 420 GeV

Table 5: Detailed requirements of different HLTs.

FCP reconstruction: number of hits

- Pixel number of hits





Total events reflect the reconstruction efficiency