Impact of HCAL removal on physics measurements

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Introduction

- During LS3, the plan is to **replace HCAL with a muon shielding**
- It's necessary to understand the **impact of HCAL removal** from a **physics** perspective
- Some **preliminary studies** have been done:
  - Jets reconstruction
  - Electron reconstruction
  - Electron/hadron separation and PID performance
- **More studies need to be done**, to fully assess the situation, in view of a very rich physics program for U2
- **Disclaimer:** might be a bit unbalanced toward the high-p_{T} physics range

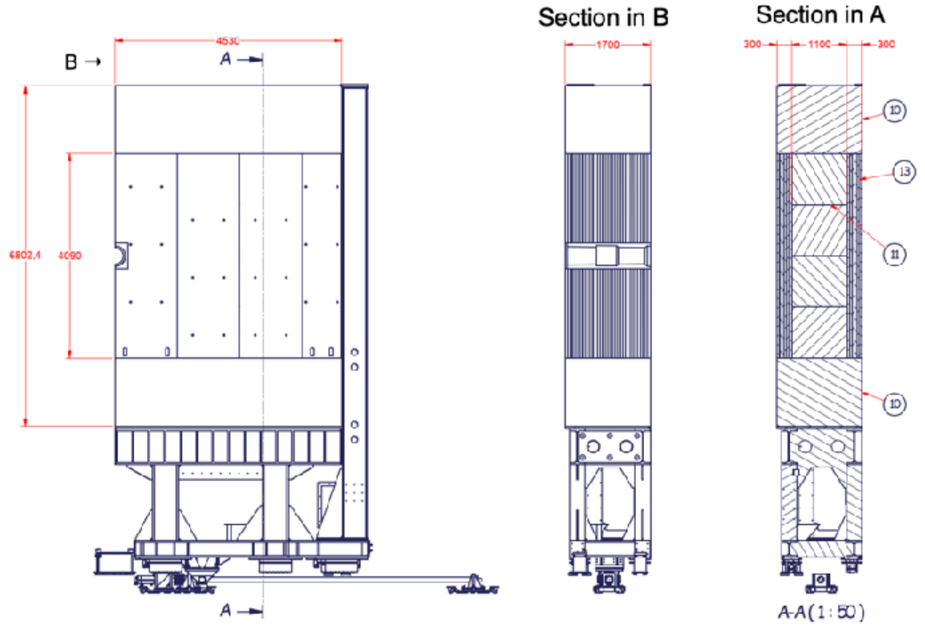
Slides from M. Palutan

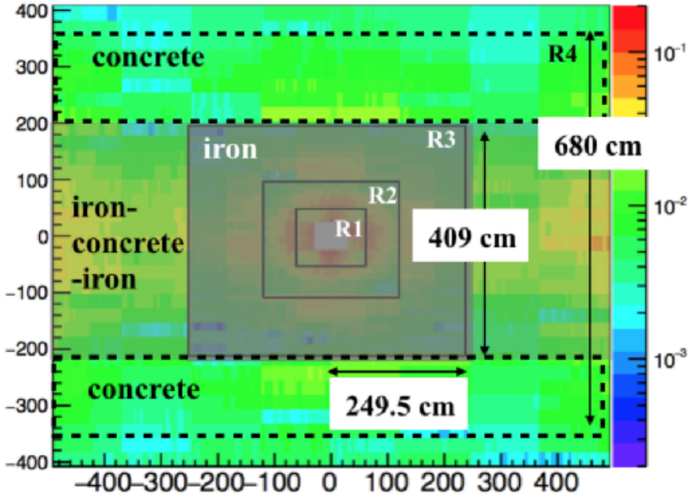
HCAL removal and muon shielding

- Proposed iron core + concrete-iron sandwich shielding
- Structure optimized to reduce particles multiplicity in muon stations

	Run 3	Iron wall	Iron core + concrete	Iron core + concrete expanded	Iron core + concrete-iron sandwich
M2 R1	54.5	34.8 x0.64	32.6 x0.60	32.5 x0.60	31.3 x0.58
M2 R2	42.1	17.0 x0.40	14.7 x0.35	13.2 x0.31	13.2 x0.31
M2 R3	19.0	8.0 x0.42	9.0 x0.47	7.0 x0.37	6.8 x0.36
M2 R4in	6.1	3.7 x0.61	15.2 x2.49	12.0 x1.97	7.5 x1.2
M2 R4out	6.6	6.0 x0.91	11.2 x1.70	5.9 x0.89	5.1 x0.8

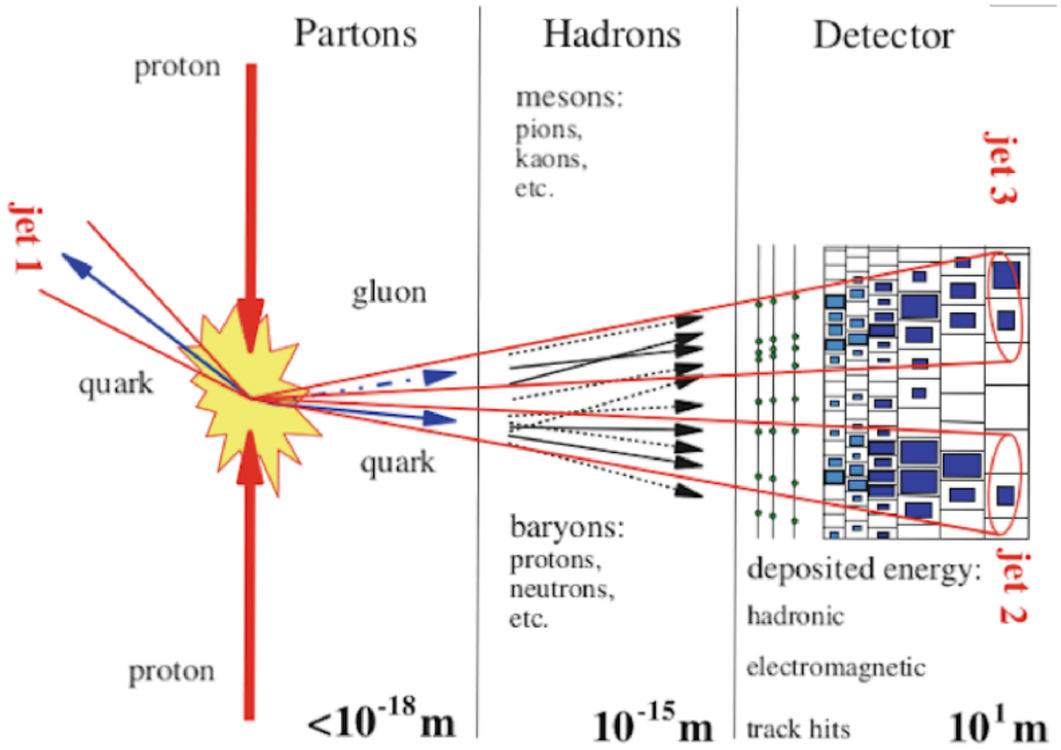
- The muon efficiency is fully recovered by the use of concrete
- A better usage of muon information seems to recover the loss of PID performance





Jets reconstruction

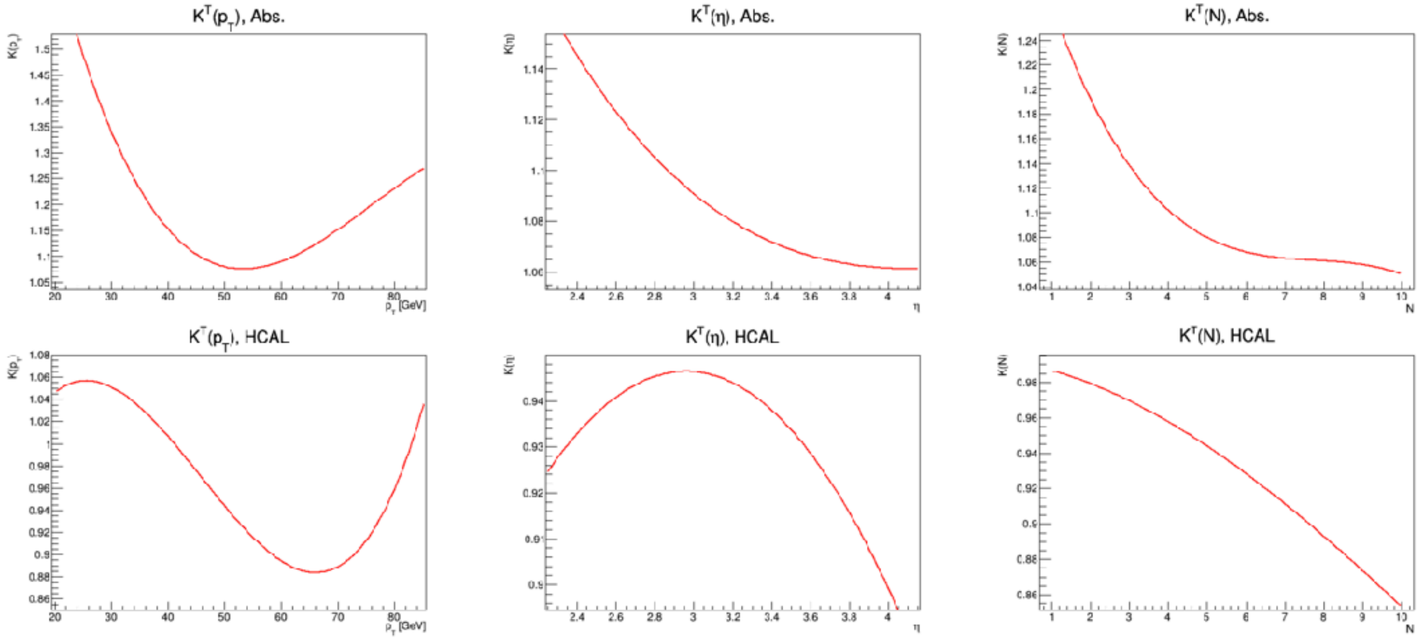
- **Jets** are **streams of particles** resulting from **fragmentation** and **hadronization** of quarks
- A relevant fraction of jets constituents (**~10%**) is reconstructed by HCAL
- At LHCb jets are reconstructed using the **Particle Flow** algorithm
- So far, HCAL removal studies have been performed in **Run 4 condition** (PU~7.6)
- Simulations have been performed with HCAL or with the iron+concrete absorber



Jets reconstruction

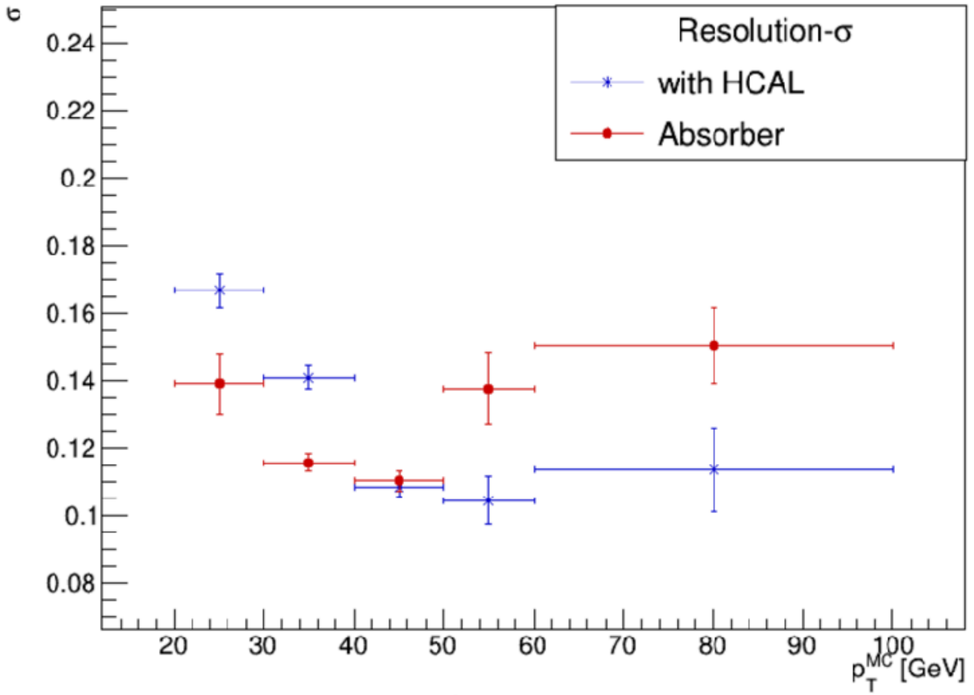
- Physics process: $Z \to b\bar{b}$ (standard candle for heavy flavour jets)
- Interesting figures of merit:

Jet Energy Scale



Higher energy JES with **iron+concrete absorber**, need to **correct more**

Jet Energy Resolution

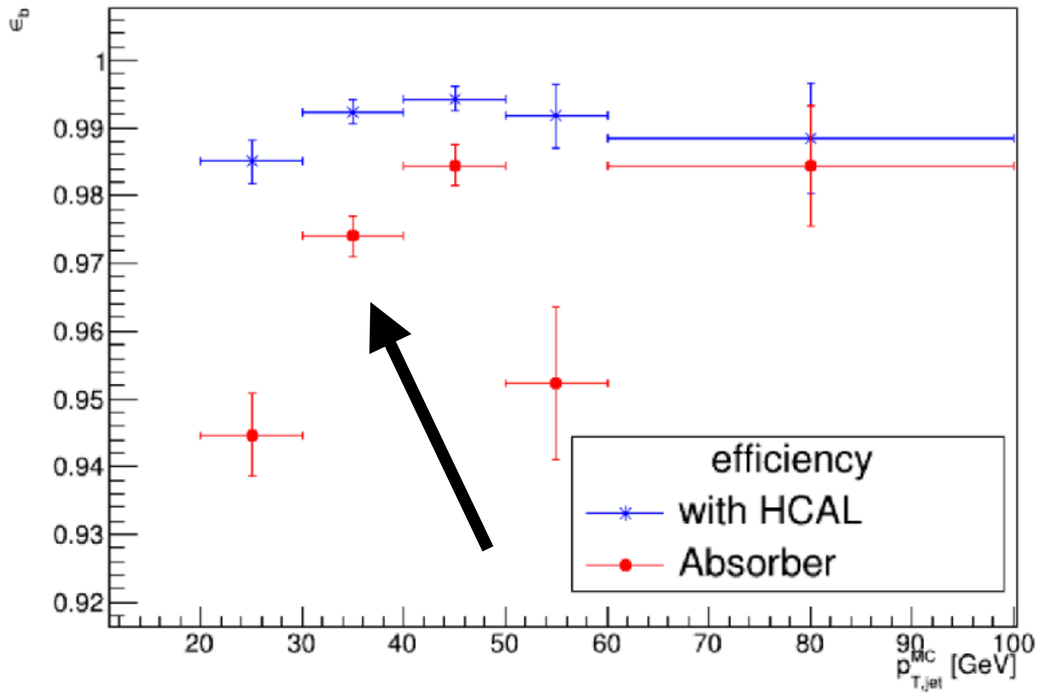


Worse resolution for **higher** p_{T} range, still better resolution for lower p_{T}

Jets reconstruction

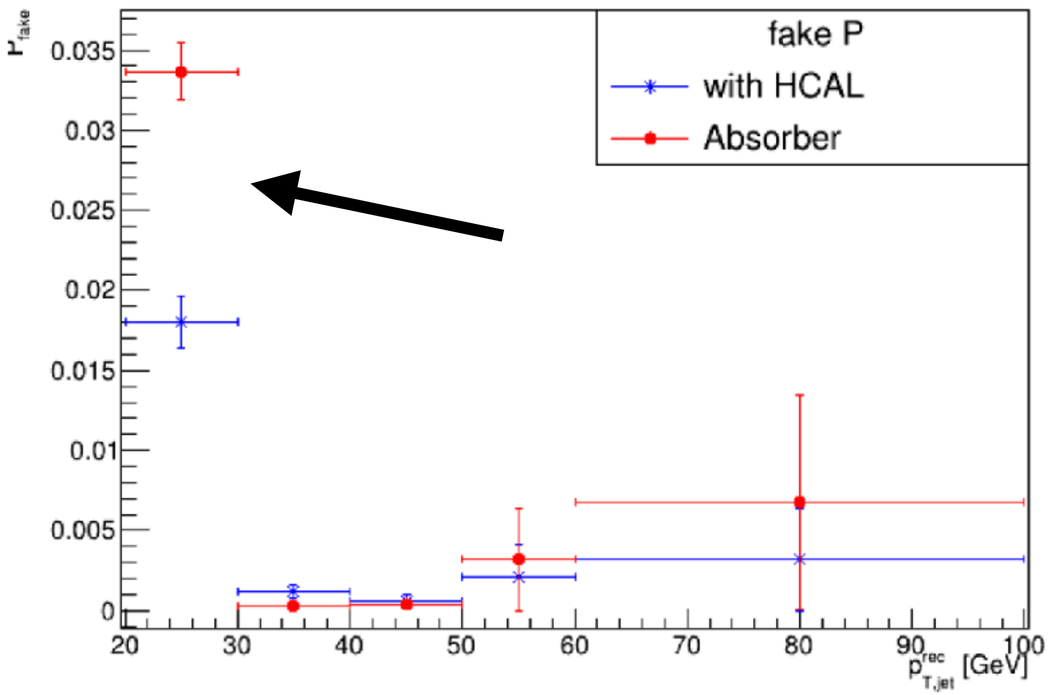
- Physics process: $Z \rightarrow b\bar{b}$ (standard candle for heavy flavour jets)
- Interesting figures of merit:

Efficiency



Definitely **worse efficiency** with **iron+concrete** shielding, particularly in the **low p_T range**

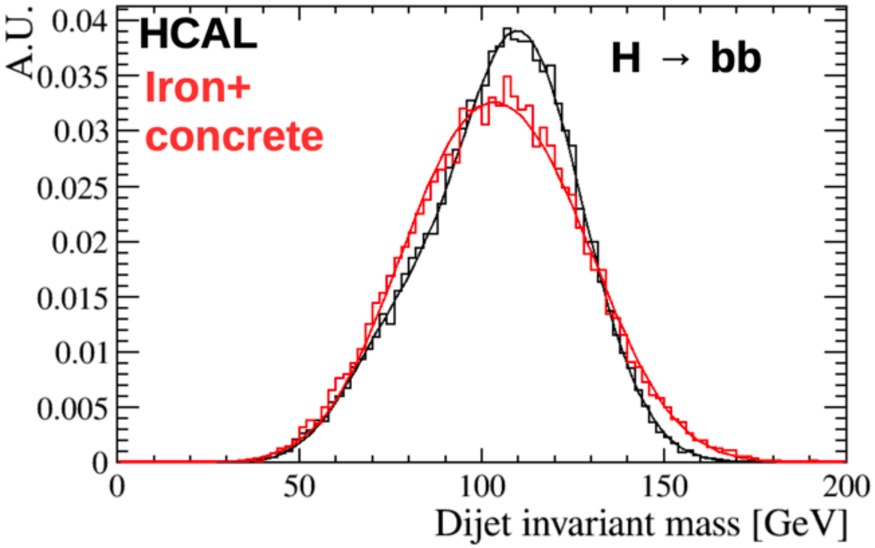
Fake probability

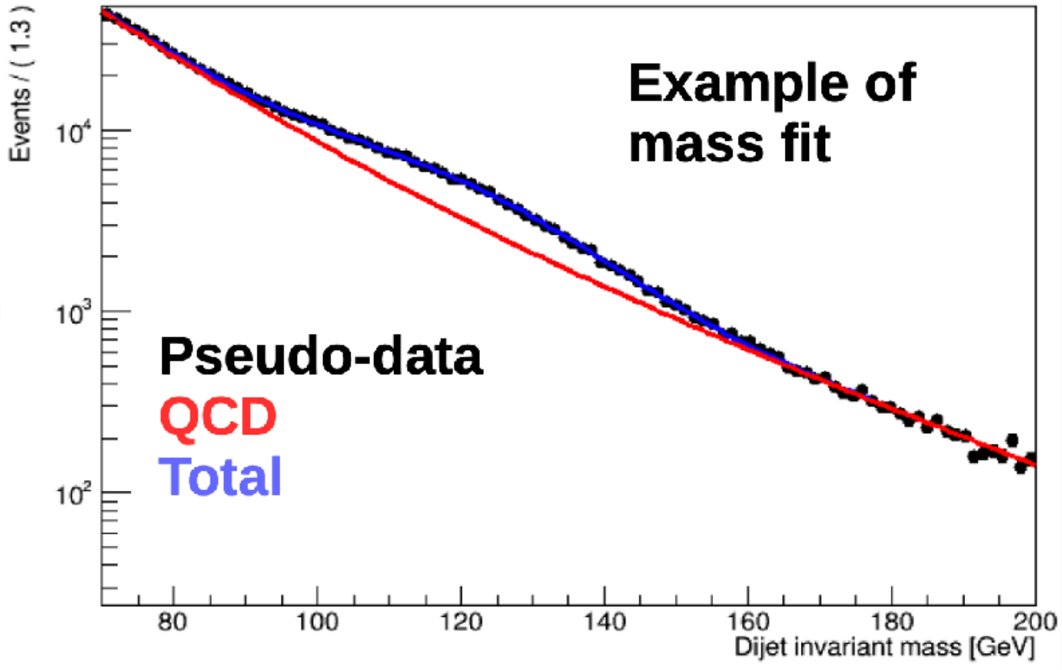


Higher fake probability with **iron+concrete** shielding in the low p_T range

Jets reconstruction

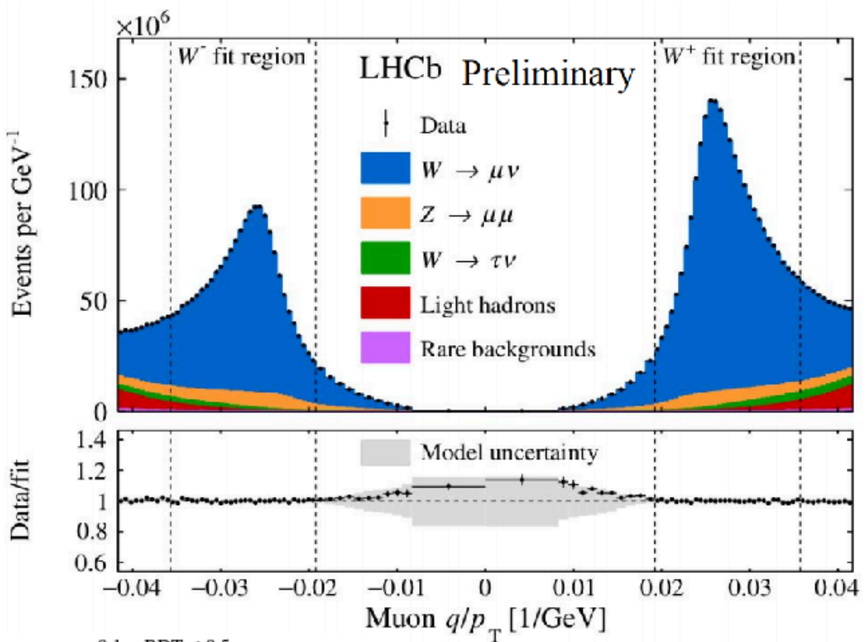
- The results shown before affect the analyses results
- As an example, impact on $h \rightarrow b\bar{b}$ measurement
  - Inclusive Higgs measurement are obtained by a fit to the di-jet invariant mass
- **Toy study:** Higgs and QCD background are simulated, Higgs+QCD pseudo-data are generated
- The ratio of the significance obtained in the **iron+concrete case** to the significance obtained in the **HCAL case** is calculated
- The ratio is ~85%, which means that there is a concrete loss in significance removing HCAL

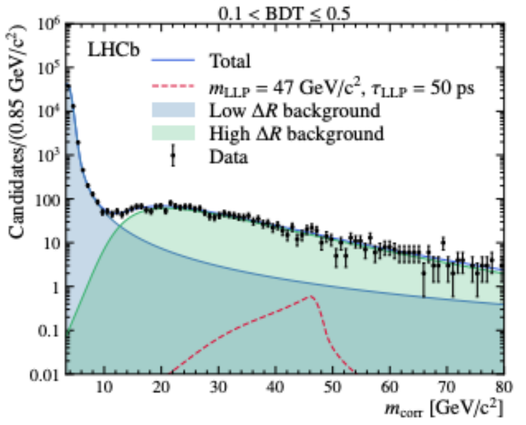


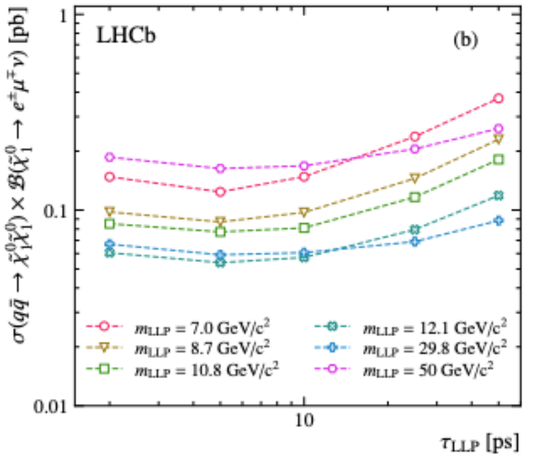


Electron reconstruction

- High-p_{T} electrons play a **fundamental** role in **EW** physics
- **Several measurements** might benefit from better electron reconstruction
  - $t\bar{t}$ asymmetry
  - W boson mass measurement
  - Direct search for New Physics
  - ...
- HCAL is quite helpful in **identifying high-p_{T} electrons**



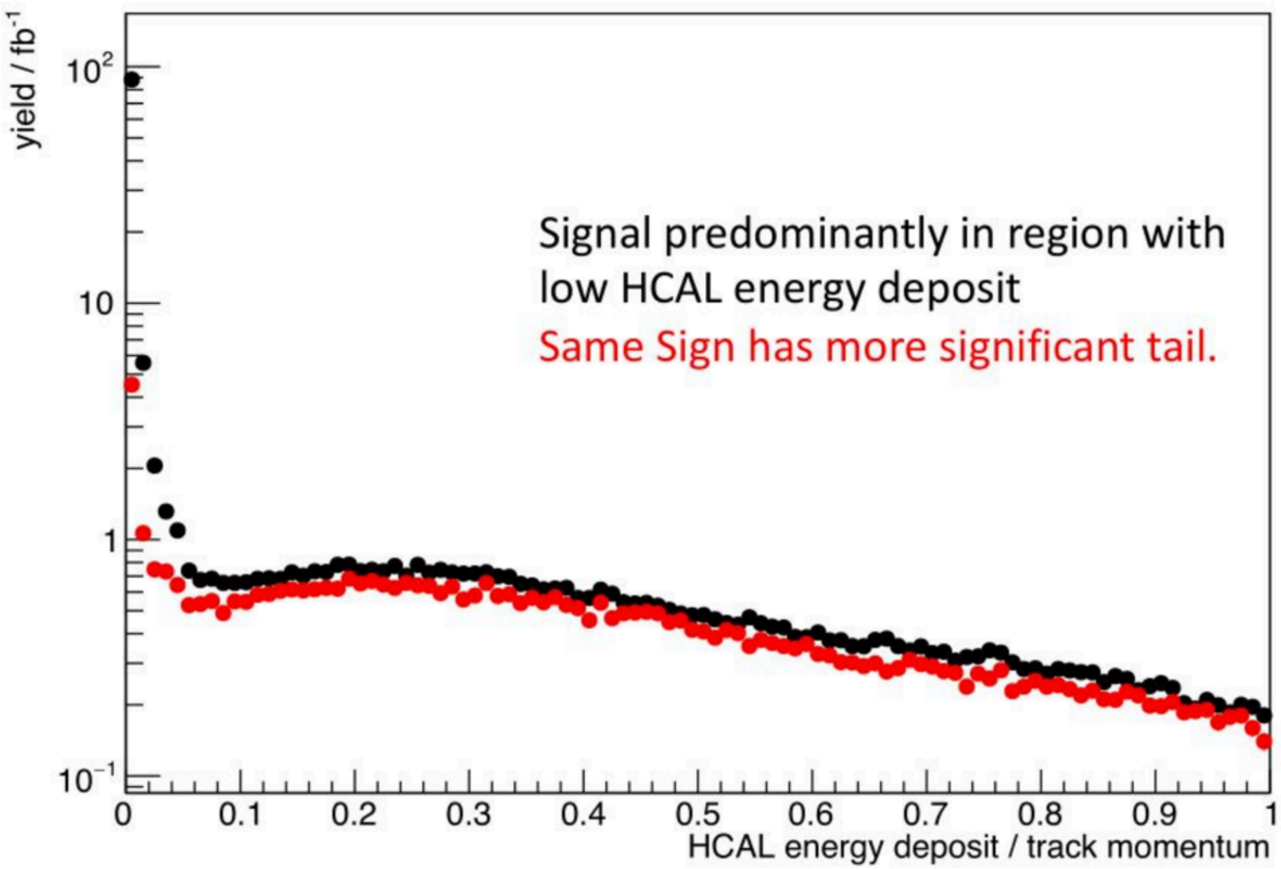




Work done by W. Barter

Electron reconstruction

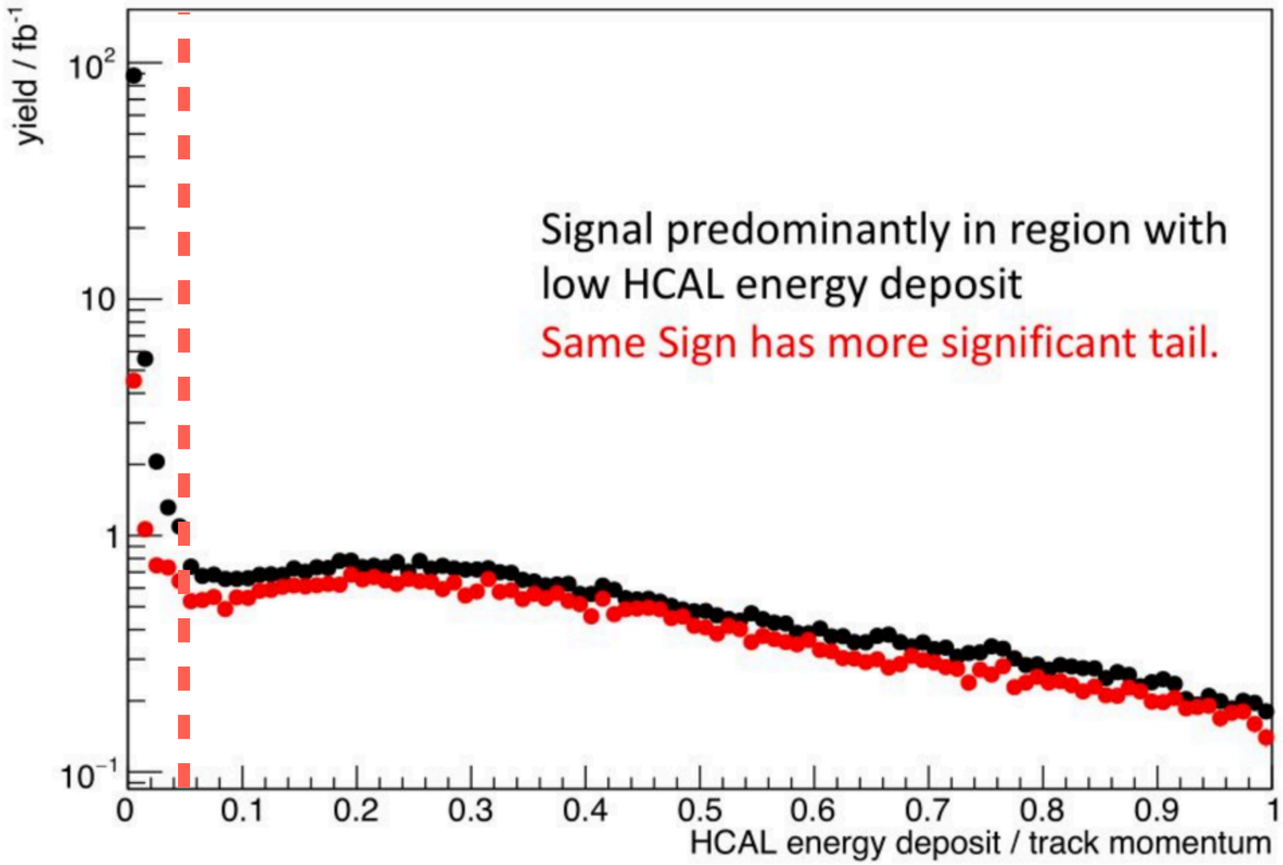
- A preliminary study has been performed using **2016 data**
- Standard $Z \rightarrow ee$ selection applied
  - Note of caution: ECAL saturation at $E_{\mathrm{T}} \sim 10$ GeV (but not relevant for this discussion)
- Compare **Same Sign** (SS) and **Opposite Sign** (OS) HCAL energy deposits
- **SS come from very energetic hadrons misidentified as electrons**



Work done by W. Barter

Electron reconstruction

- Typical **cut at 0.05** to remove SS contribution
- HCAL removal → **not able to use this cut anymore**

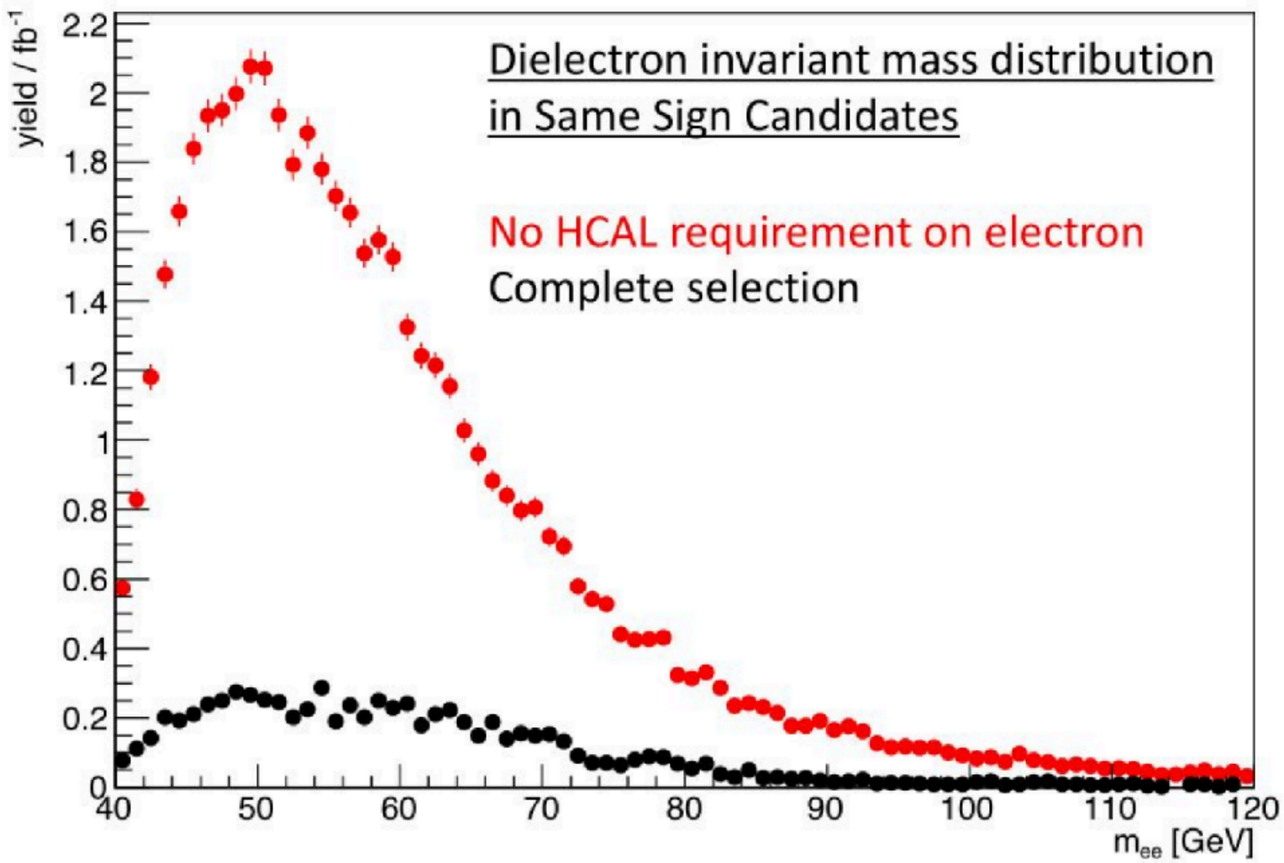


Work done by W. Barter

Electron reconstruction

- Typical cut at 0.05 to remove SS contribution
- HCAL removal → not able to use this cut anymore
- **"No HCAL" requirement applied on one electron**
- A look at the invariant mass of SS candidates shows an **increase of background**
- Rough estimate for S/B:

S/B = 11.8 **S/B = 1.8**



Definitely worse results for precision measurements!

Electron/hadron separation and PID performance

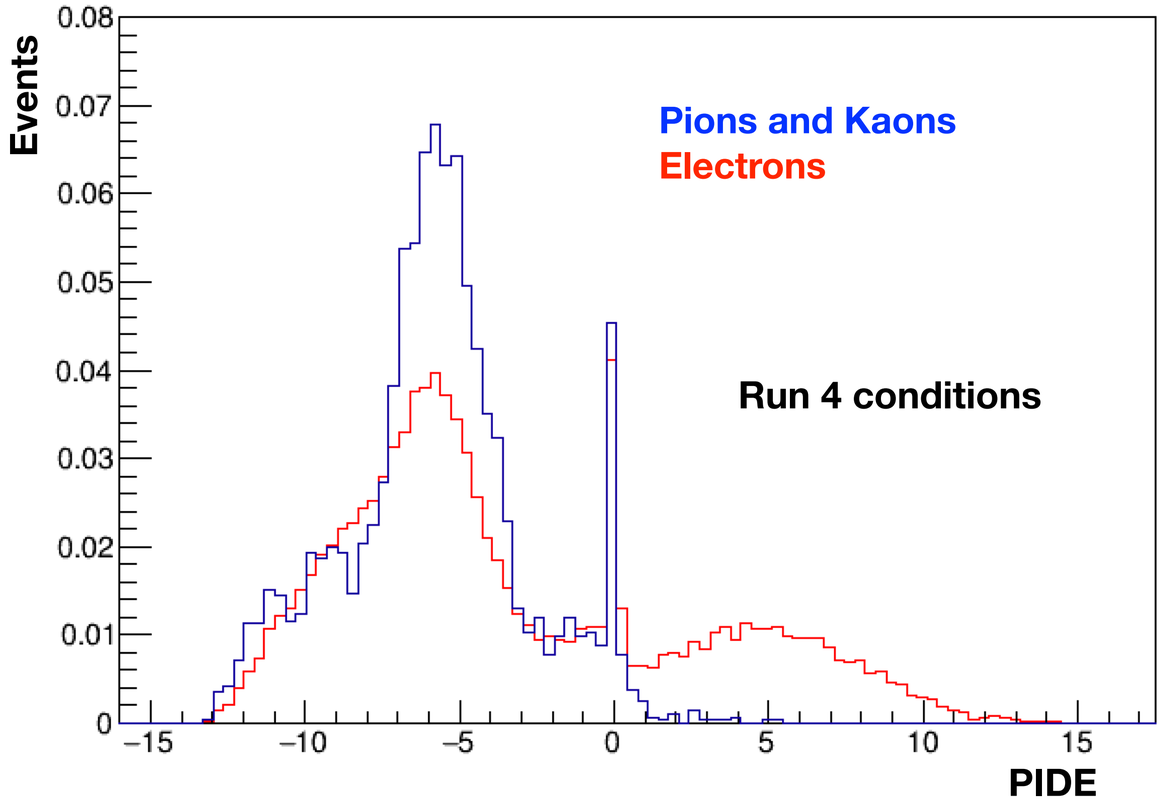
- As already explained by Maarten, **HCAL plays a role in electron/hadron separation**
- A “more LHCb-ish” channel is studied, search for $D^0 \to ee$
  - Interesting because it might hints to **LFV**
- If electron/hadron discrimination is not good, $D^0 \to K\pi$ is a **peaking background**

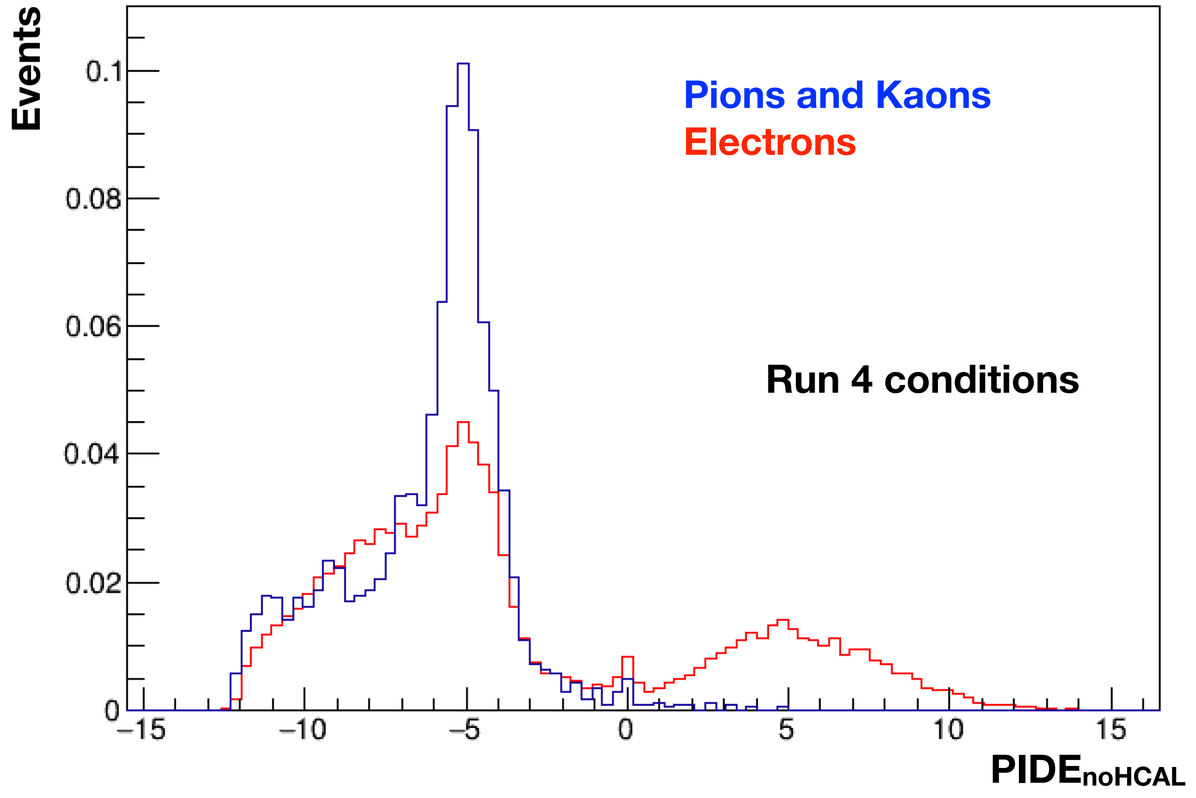
- $D^0 \to K\pi$ events are simulated in Run 4 conditions
- Events are reconstructed as ee, **without any requirement on PID**
- Cut on electron PID to get a fixed electron reconstruction efficiency
- See how many $D^0 \to K\pi$ are reconstructed as $D^0 \to ee$

Electron/hadron separation and PID performance

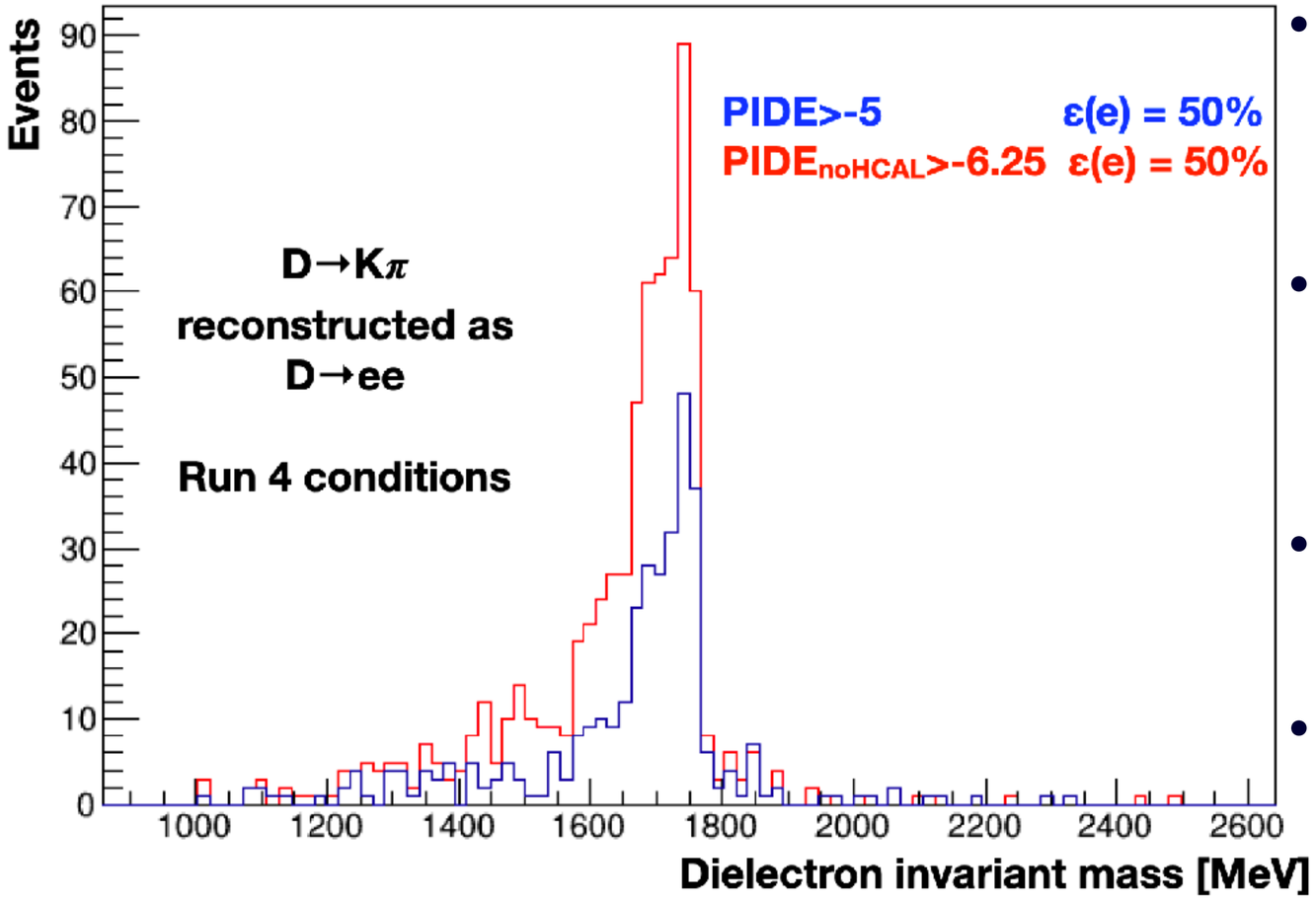
- PID are built in such a way that

$$\mathrm{PID}_{\mathrm{noHCAL}}(e) = \mathrm{PID}(e) - \mathrm{PID}_{\mathrm{HCAL}}(e)$$





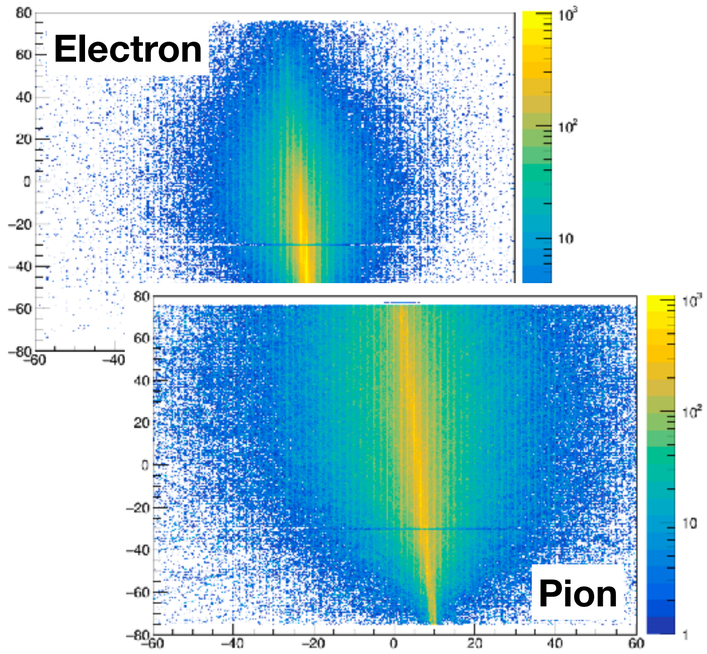
Electron/hadron separation and PID performance

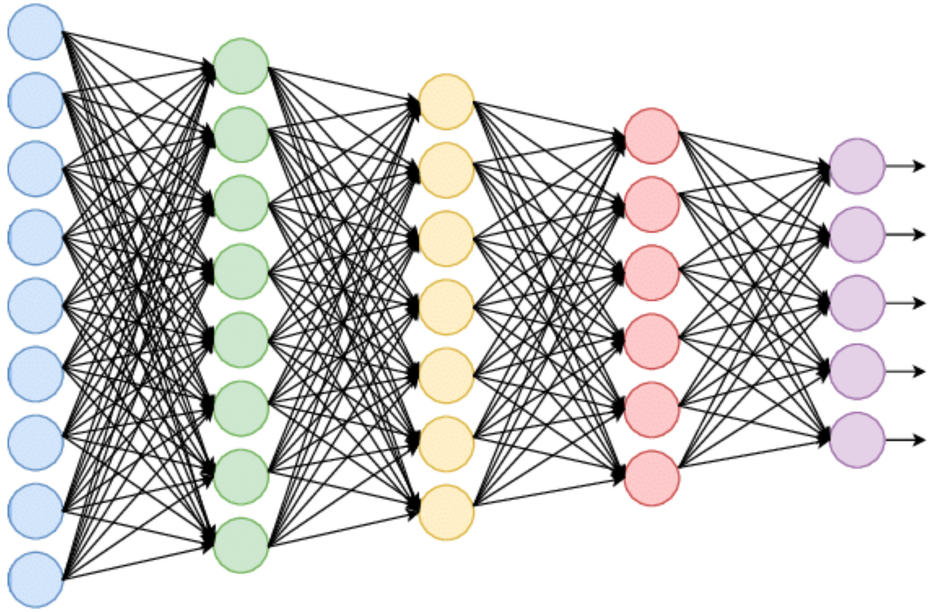


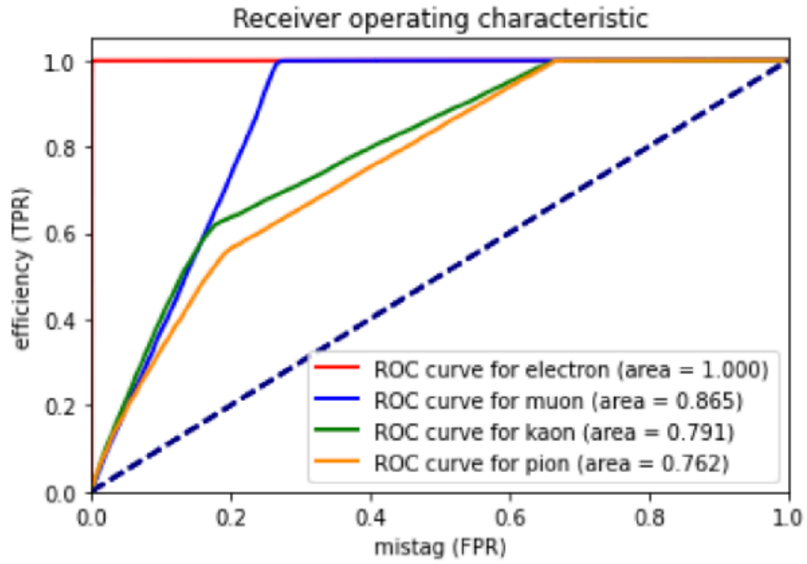
- If keeping an electron reconstruction efficiency $\varepsilon(e) = 50\,\%$, **without HCAL almost twice events are retained**
- The background is of course peaking at the D^0 mass, therefore **quite problematic for the search**
- There might be other relevant physics channels suffering for the same problem!
- A similar study can be done using $\mu\mu$ **final state** to assess the **impact of HCAL removal** on **muons PID**

Electron/hadron separation and PID performance

- We can partially recover PID performance exploiting SPACAL segmentation
- Quick study using a single SPACAL module to perform separation between electron, pions, muons and kaons
- Cells energies used as inputs of a CNN



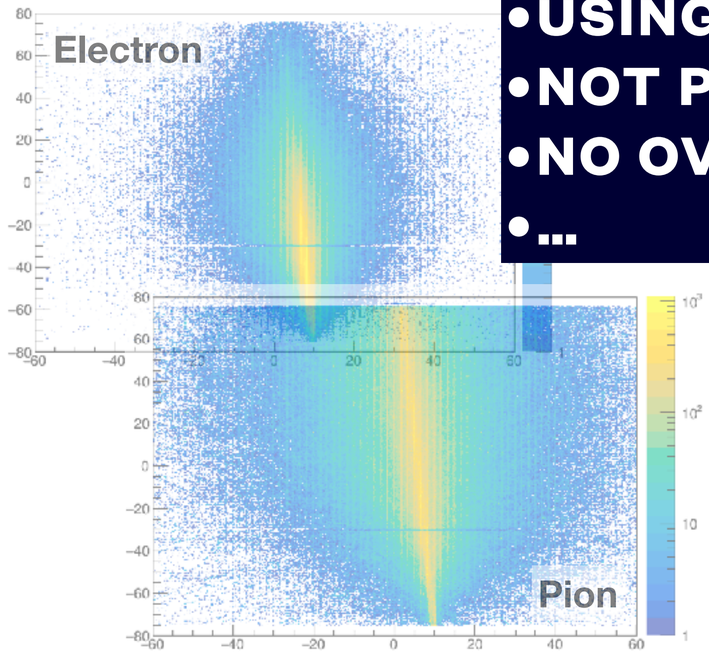


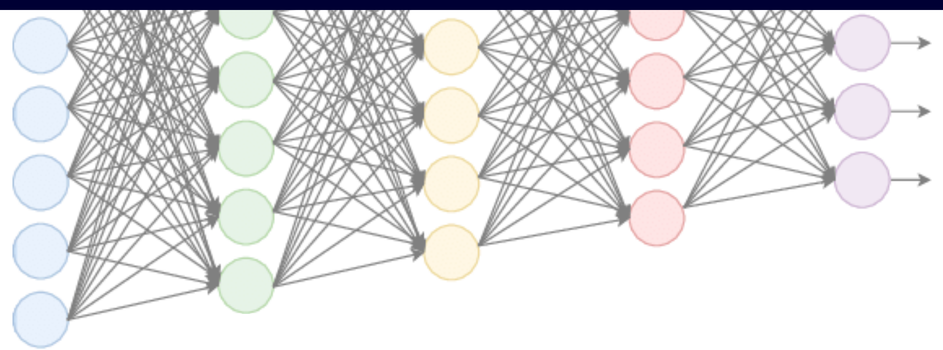


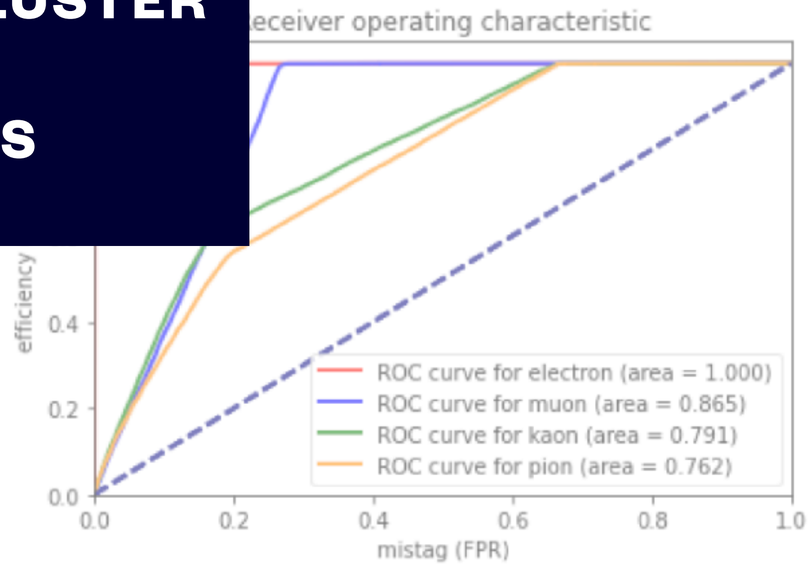
Electron/hadron separation and PID performance

- We can partially recover PID performance exploiting SPACAL segmentation
- Quick study using a single SPACAL module to perform separation between electron, pions, muons and kaons
- Cells energies us

STILL A VERY OPTIMISTIC STUDY:
- **ONE PARTICLE PER MODULE**
- **USING THE FULL MODULE, NOT 3X3 CLUSTER**
- **NOT PILE-UP EFFECTS**
- **NO OVERLAPPING BETWEEN CLUSTERS**
- **…**







Conclusions

- **HCAL might still be important**
  - For sure in the **high-p_{T} range**…
    - Jets energy will get worse, need to **correct more → lower resolution**
    - High-p_{T} electrons reconstruction might still be an issue
  - …but also in the “most LHCb-ish” range of physics
    - A quick look at $D^0 \to ee$ evidently shows the **importance of HCAL**
- There might be some **ways to recover HCAL removal**:
  - New algorithms, ECAL longitudinal segmentation, instrumenting muon shielding,…
  - But we should discuss them now and find a common way to proceed

Thank you for your attention!

Backup

HCAL removal and muon shielding (in simulations)

- The shielding geometry has been implemented in the standard LHCb simulation framework
- Same geometry as Run 3, but replacing HCAL with shielding
- Few tweaks at Boole (reconstruction) level, to make everything working
- So in principle, we can perform simulations with or without HCAL