Future colliders

Sussex current involvement in future collider projects

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University of Sussex

Sussex EPP meeting - 13 October 2021

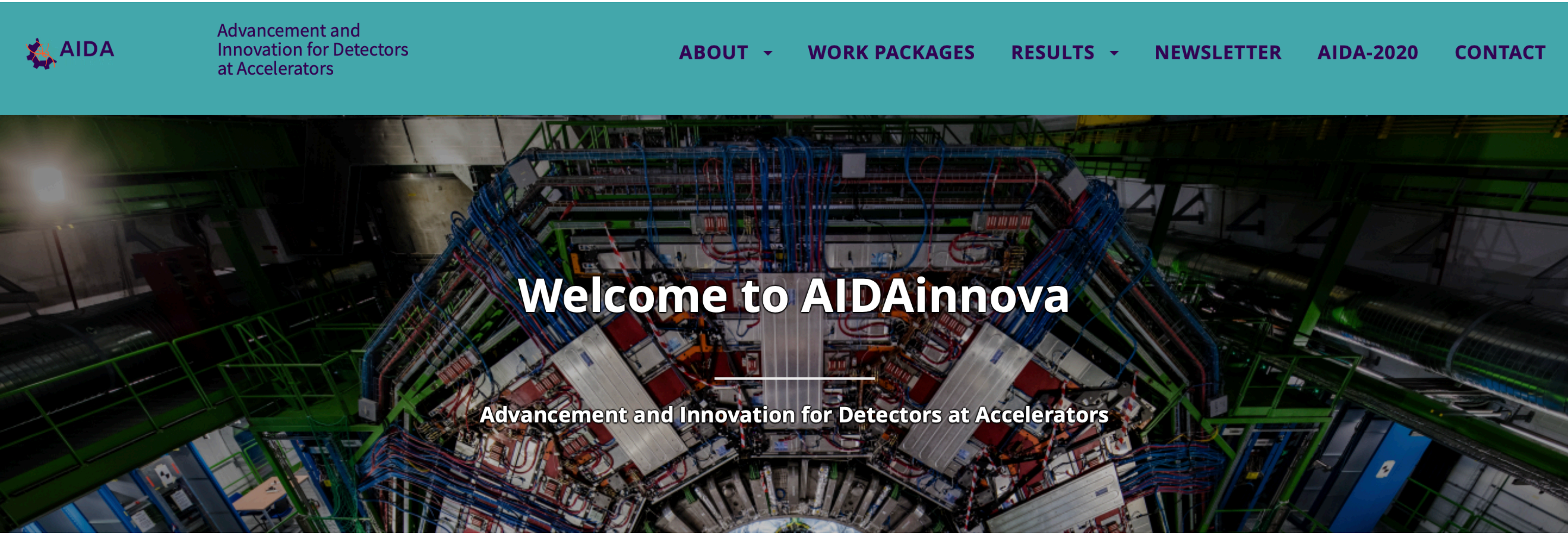
Outline

- **AIDAinnova:** Advancement and Innovation for Detectors and Accelerators:
  - Detector for FCCee/CePC: IDEA (and its dual readout calorimeter)
  - Software for generic online data monitoring
- **Muon collider**
- FASER and **FASER2**
- Impossible to give any detail in 20 mins - **see the "Detailed contributions"** folder on indico.

AIDA innova

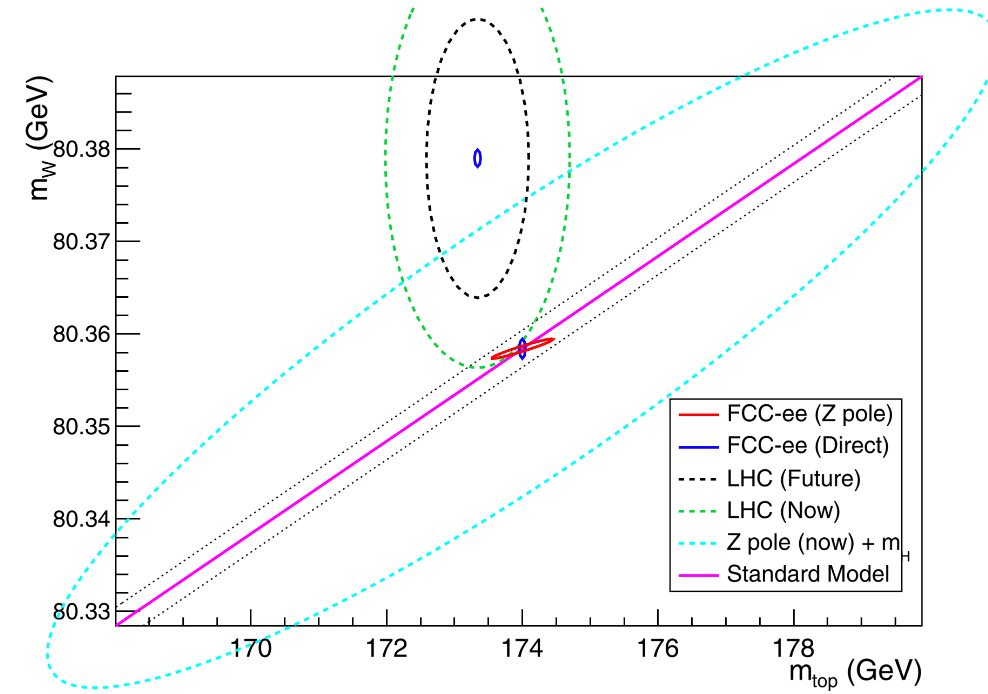
AIDAinnova and Sussex

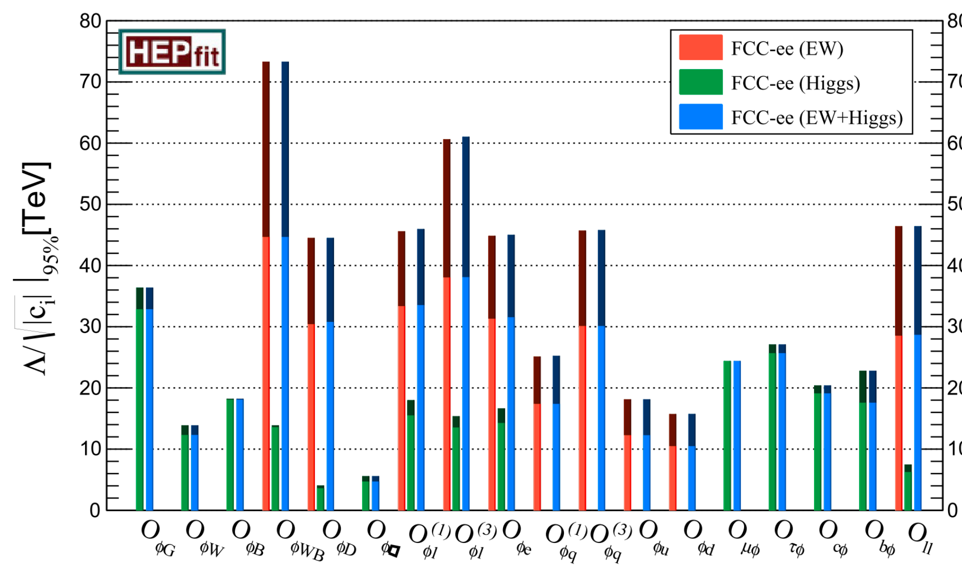
- Visit https://aidainnova.web.cern.ch
- **12 WP** spanning from hardware to simulation and reconstruction software
- Sussex is in **WP 3** (Test Beam and DAQ infrastructure), **WP 8** (Calorimeters and Particle Identification detectors) and **WP 12** (Software for future detectors)



What physics?

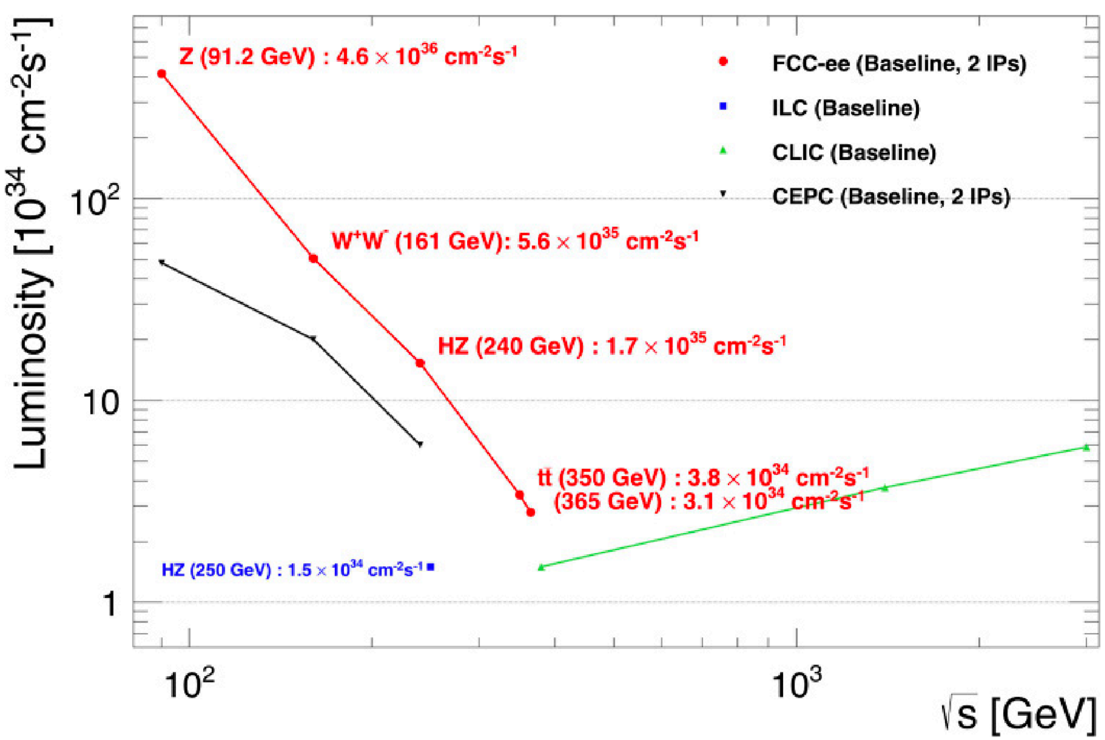
- $\sin^2\theta_W^{\text{eff}}$ mainly from $A_{\text{FB}}^{\mu\mu}$
- m_W and width at $o(1\ \text{MeV})$
- m_{top} and width at $o(10-50\ \text{MeV})$
- Auxiliary measurements ($\alpha_{\text{QED}}(m_Z^2)$, Z boson mass and width, $\alpha_S^2(m_Z^2)$)
- Model-independent Γ_H, Higgs couplings and Higgs to invisible
- BSM models (ALPs, dark photon, light dark matter, ….)





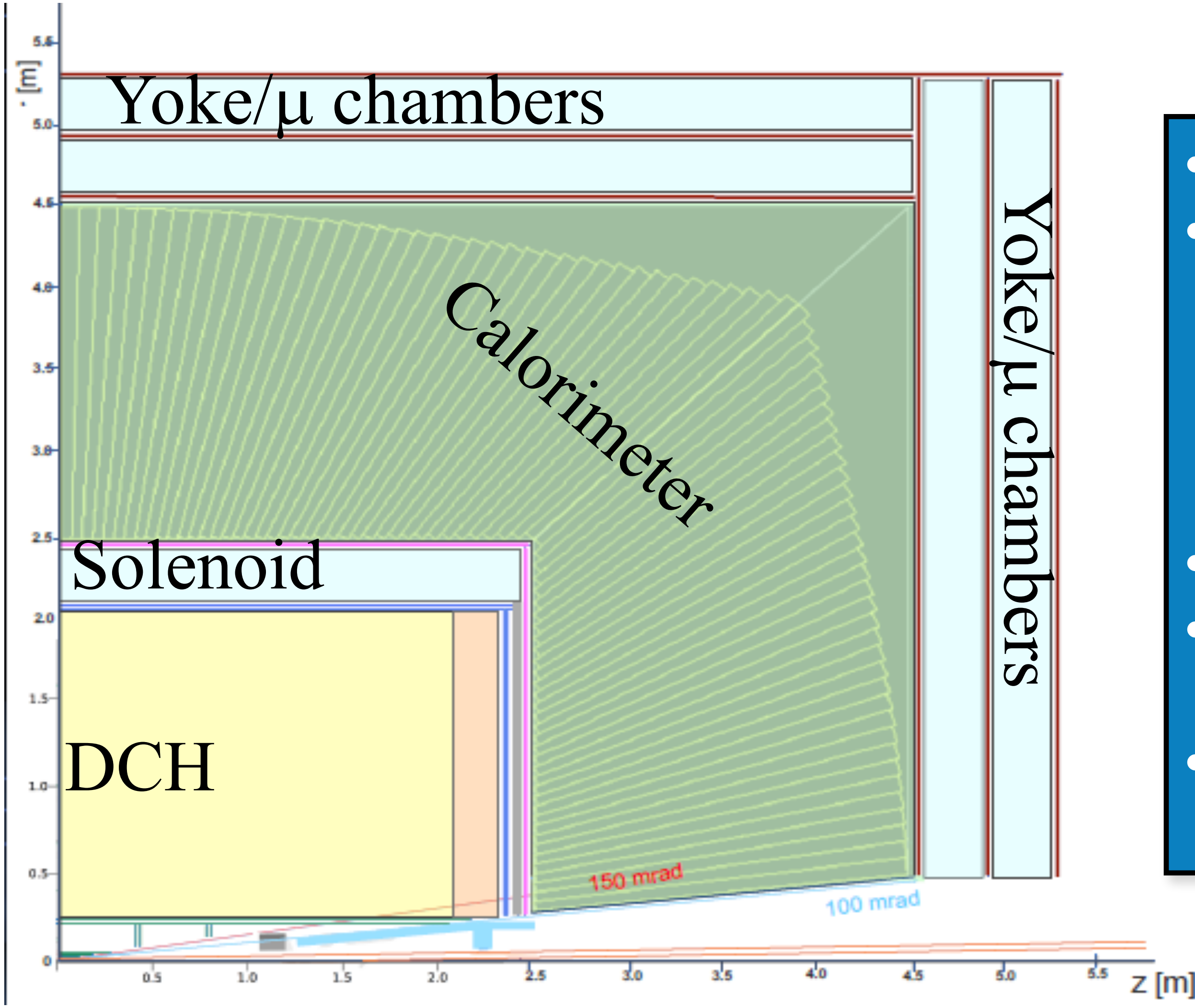
Machine plan (FCCee)

- **5×10^{12} Z, 10^8 WW pairs, 10^6 Higgs** bosons and **10^6 top pairs** expected.
- Different **running conditions** depending on beam energy



- **Synchrotron radiation losses** kept at 50 MW/beam.
- High-current/low RF at the Z pole, small-current/high RF voltage for $t\bar{t}$
- Bunch spacing ranging from **20 ns (Z) to 7 μs (top)**
- Crab-waist collision scheme guarantees high luminosity.

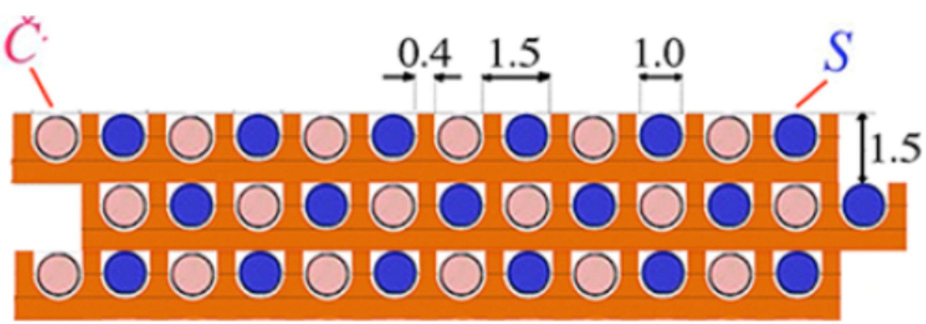
IDEA - overview

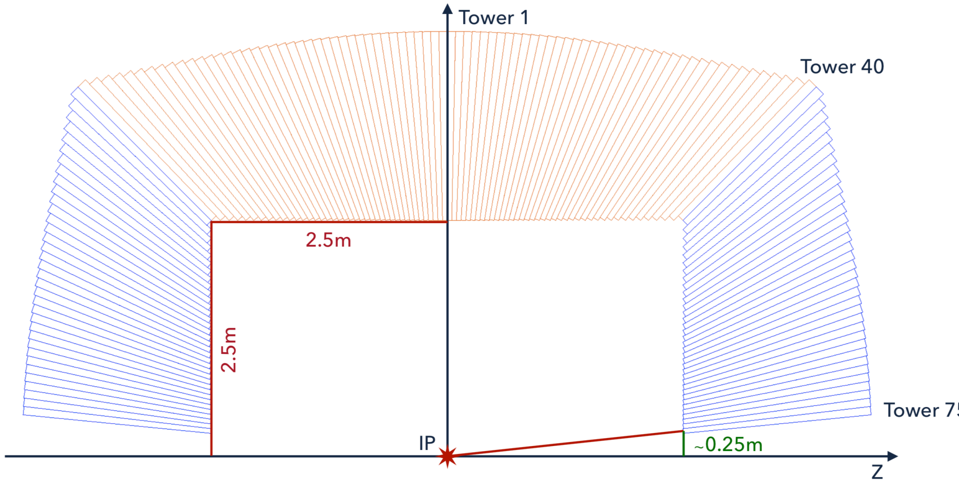


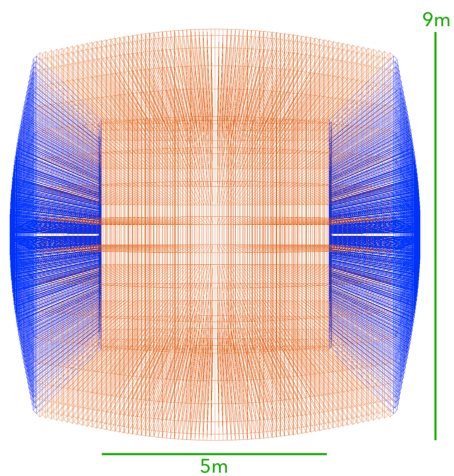
- Silicon vertex detector
- **Low material** in the tracking volume to **minimise multiple scattering.**
  - Tracking with **ultra-light drift chamber.**
- 2 T **thin solenoid** within calo.
- **Dual-readout calorimeter** + pre-shower.
- MPGD (μRwell) based Muon detector.

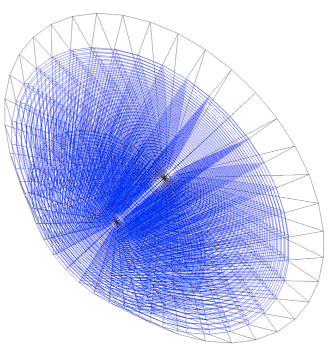
Calorimetry+preshower

- Preshower under optimisation, using μ-RWELL
- Single EM+HAD sampling calorimeter, with **1.5 mm fiber pitch** and Cherenkov/Scintillation dual-readout.
    - For details about dual-readout, see here
- No mechanical **longitudinal segmentation**, ~ 7 λ_I length.
- Good **EM intrinsic** energy resolution excellent **hadronic** resolution



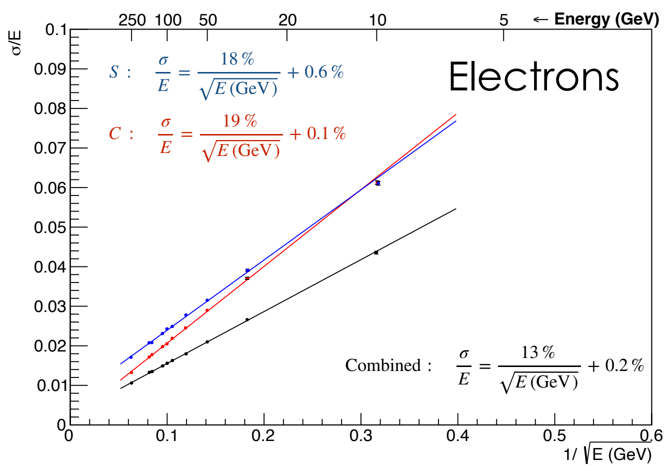


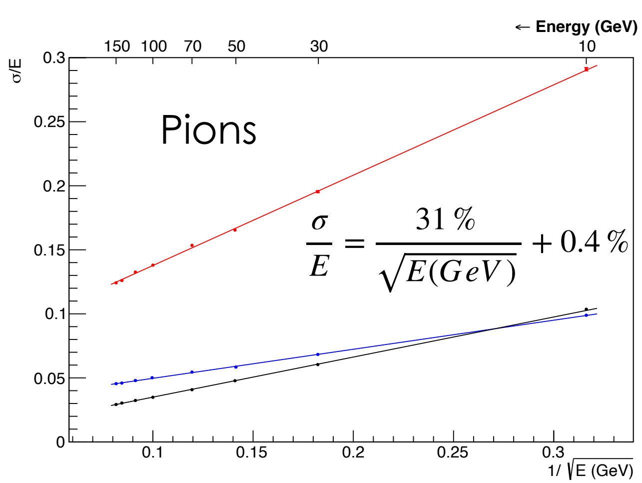


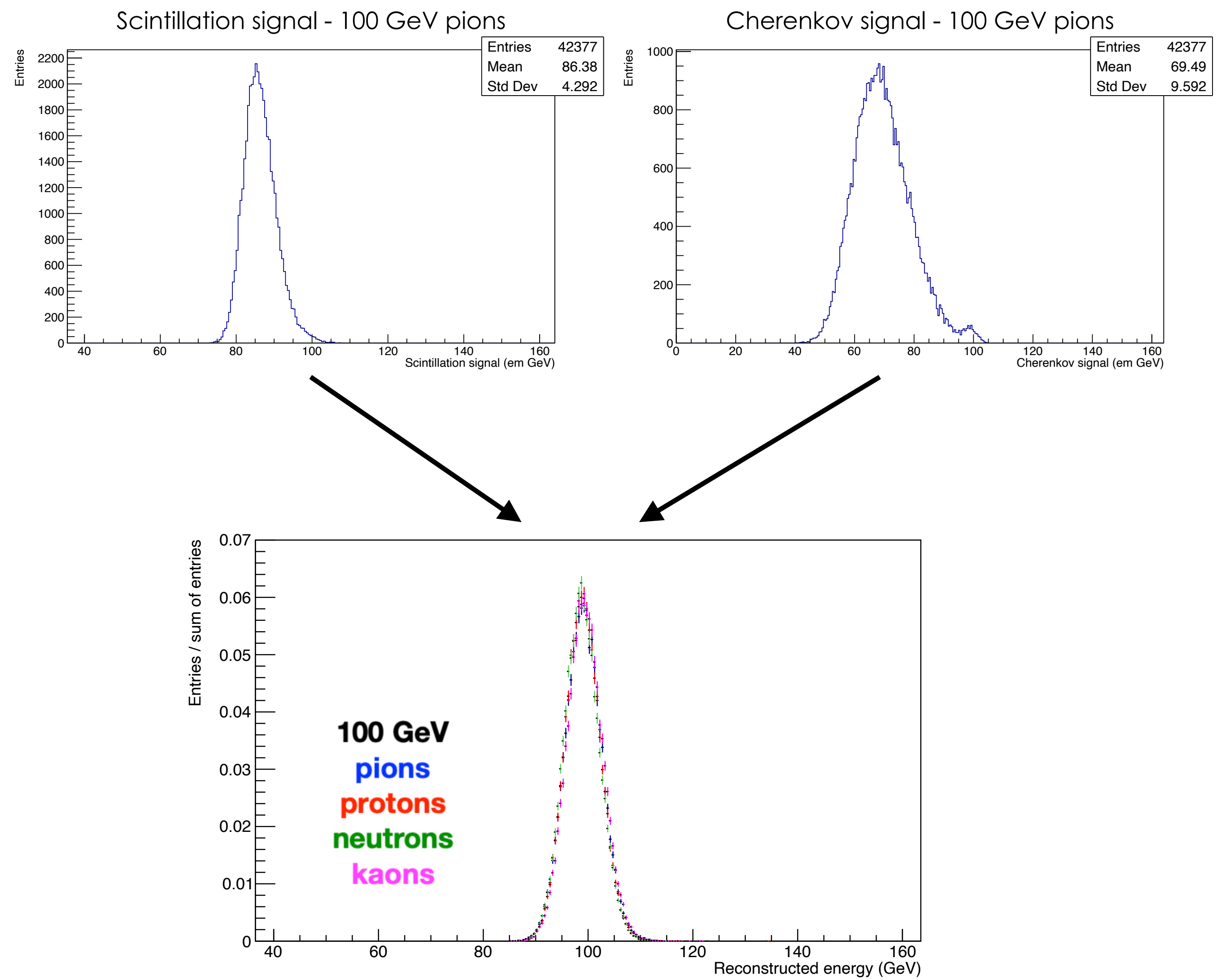


Calorimeter - single particle response

- Single particle response evaluated with calo-only IDEA-geometry G4 simulation

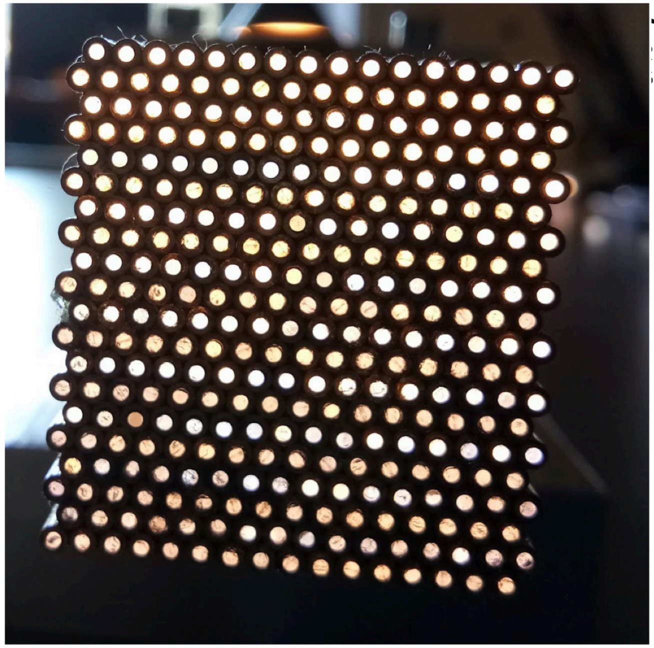






Test beam 2021

Challenges 2021/2022:
- -EM performance validation con dati TB (1 GeV - 100 GeV)
- -Shower shape separation pi/e
- -Signal timing profile exploitation



DQM software in a nutshell

Main goals of DQM systems in HEP

- Evaluate data quality and alert users of possible anomalies
  - Is the detector working fine?
  - Are the data what we expect?
  - Are they comparable to some baseline set of data?
- (quasi-)Online and offline monitoring
  - Distributed systems (TCP/IP)
  - Q-test automation
  - Event display
  - Interface to desktop/WEB systems

Data is the central concept in such systems. But ....

- Existing frameworks are highly dependent on the event data model
- Leads to duplication of software
- In test beam setups tend to use an ad-hoc software solution

Want to develop a generic DQM software for any HEP experiment/test beam setup

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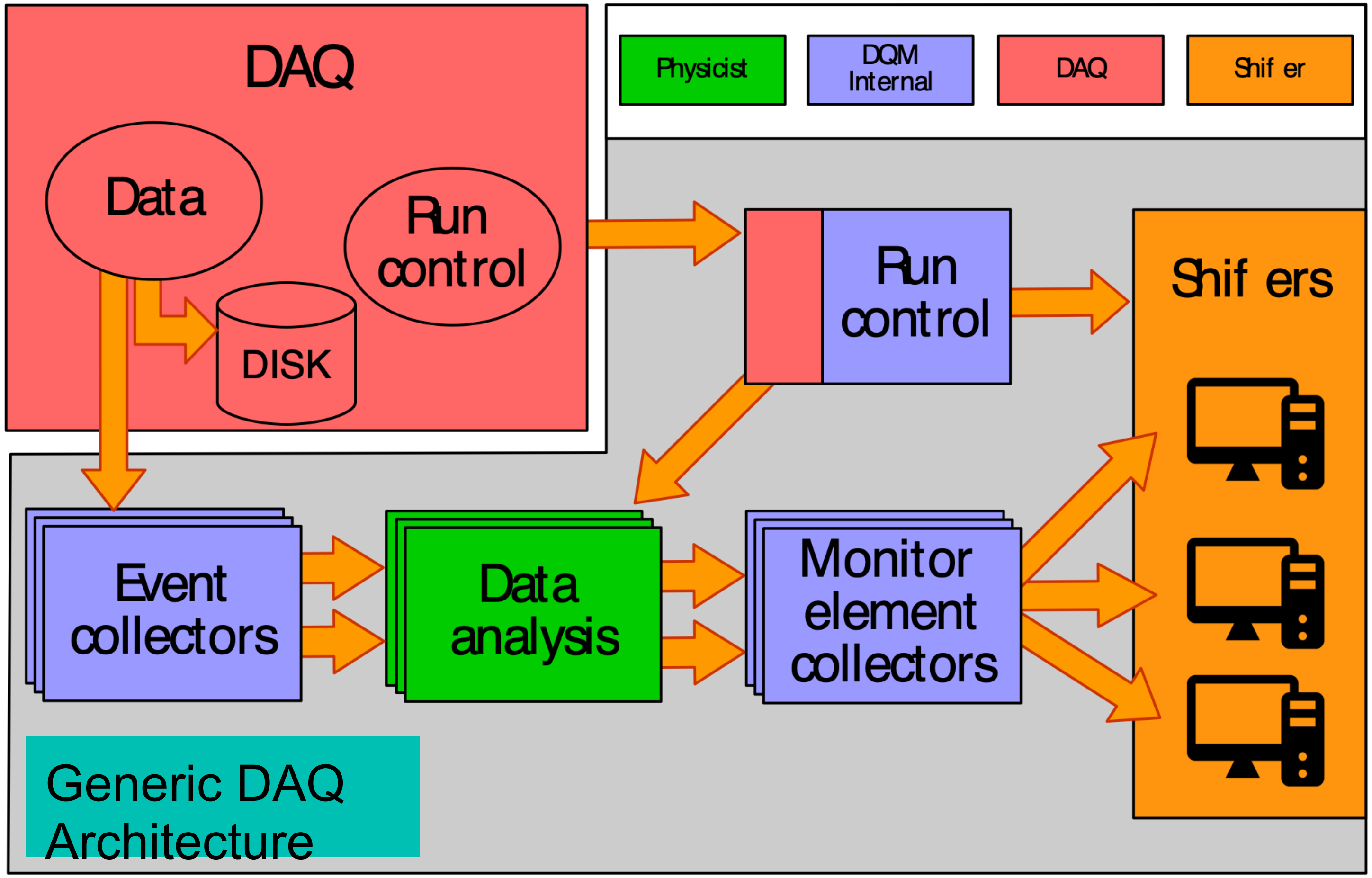
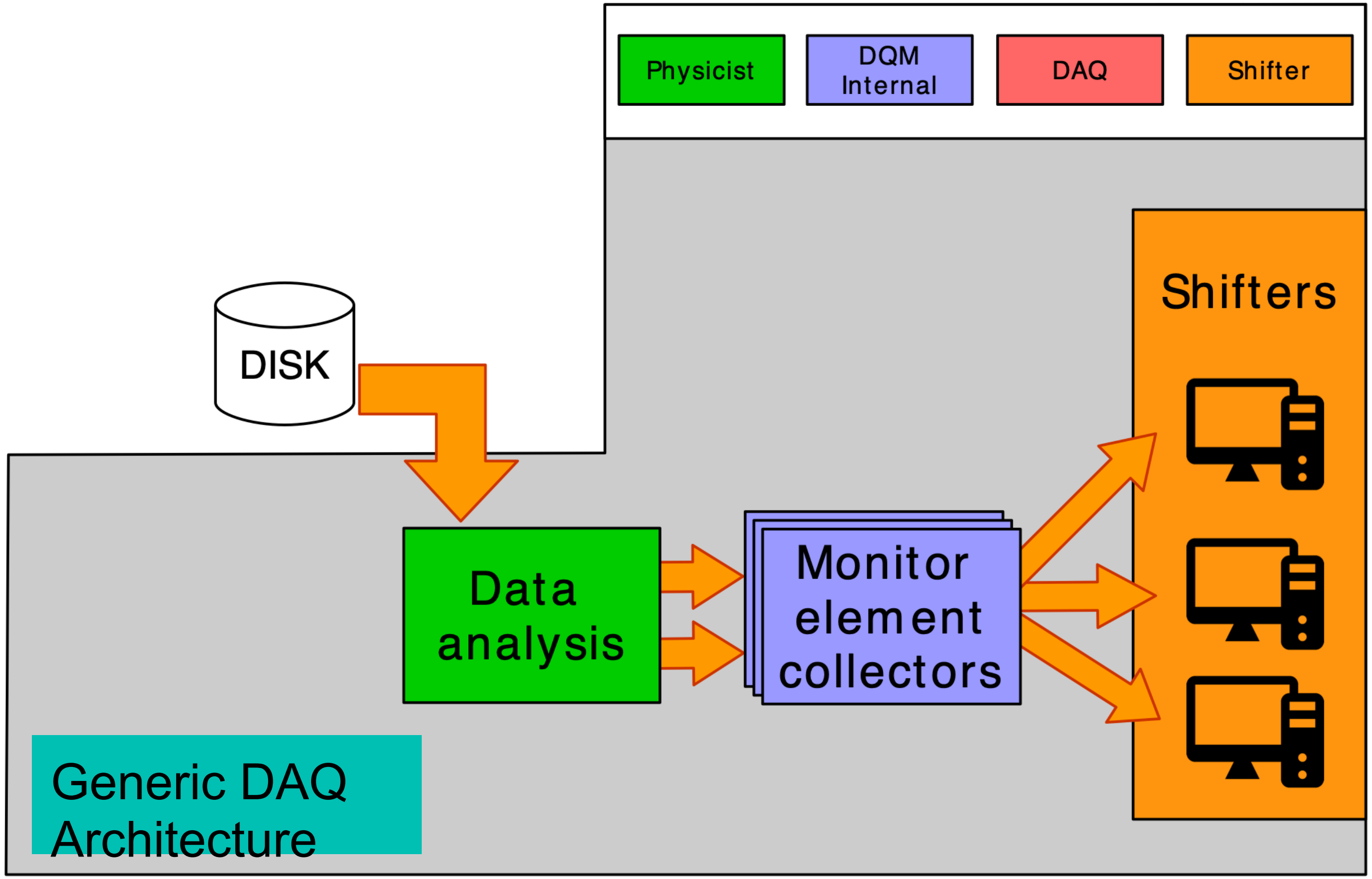
The DAQ Data Monitoring Architecture



The DAQ quasi-Online Architecture

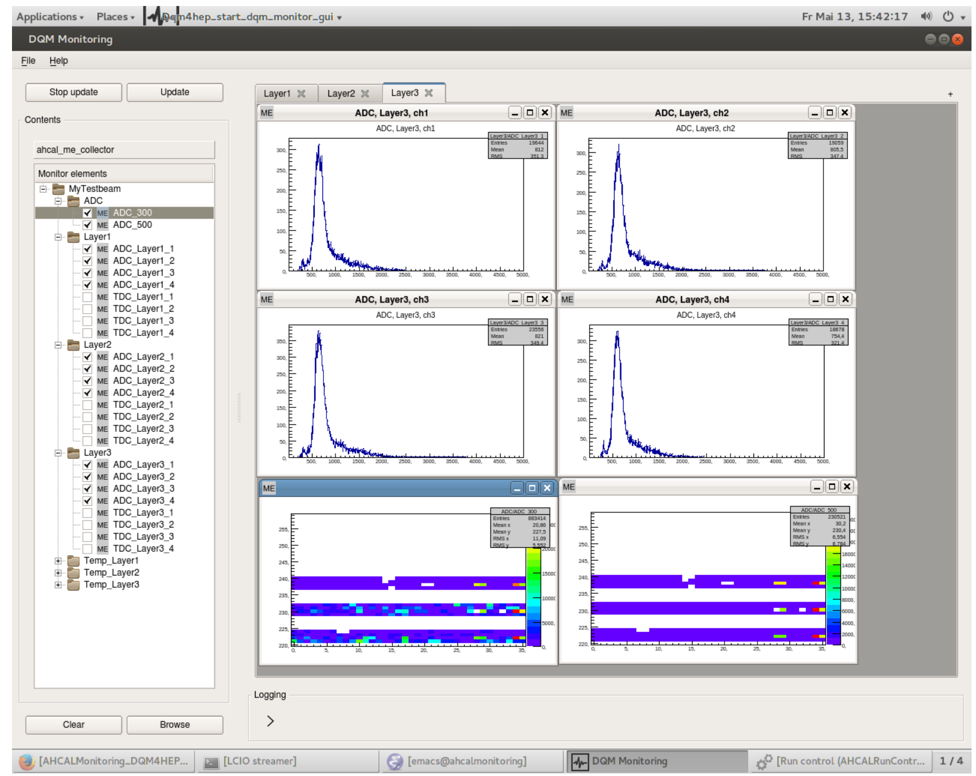


AIDA2020: DQM4hep

CALICE AHCAL Data Monitoring

First prototype: DQM4hep

- CALICE SDHCAL online system
  - Hit maps, GRPC HV/current, beam analysis, electronics performance
- CALICE AHCAL (quasi-)online system
  - Hit correlations, hit maps, SiPM currents, electronics performance
  - Standard tool for monitoring and DQM
  - Completely integrated into test beam and shifters workflow



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Sussex contributions (AIDAinnova)

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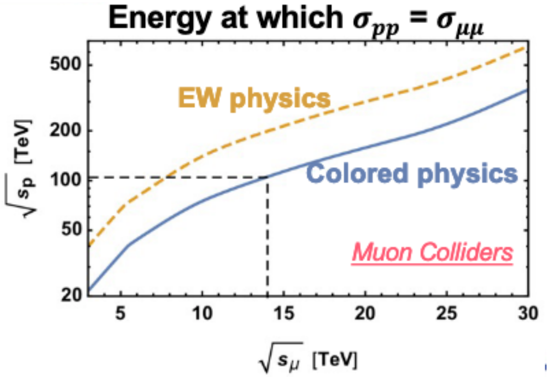
- **Hardware:**
  - Cherenkov and Scintillation fibres + characterisation
- **Software:**
  - Simulation and Event Data Model
  - Reconstruction (simulation and test beam)
  - Analysis (simulation and test beam)
- **Monitoring** TB2017, TB2018 - R&D on 2021 data

Muon collider

Muon Collider

- For the last 50+ years we have been colliding protons and electrons!
- A very timely shift in perspective in how we do particle physics:
  - A competitive probe for forefront physics with respect to next generation ee-ep-pp colliders
  - Especially relevant with nature's hints of Lepton Flavour Universality violations involving muons

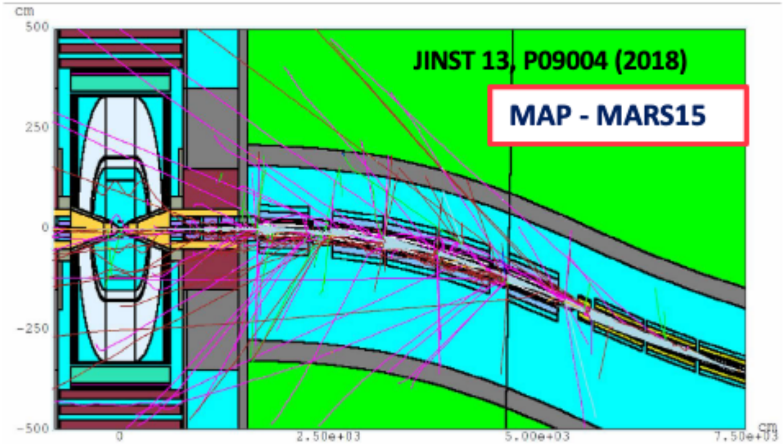


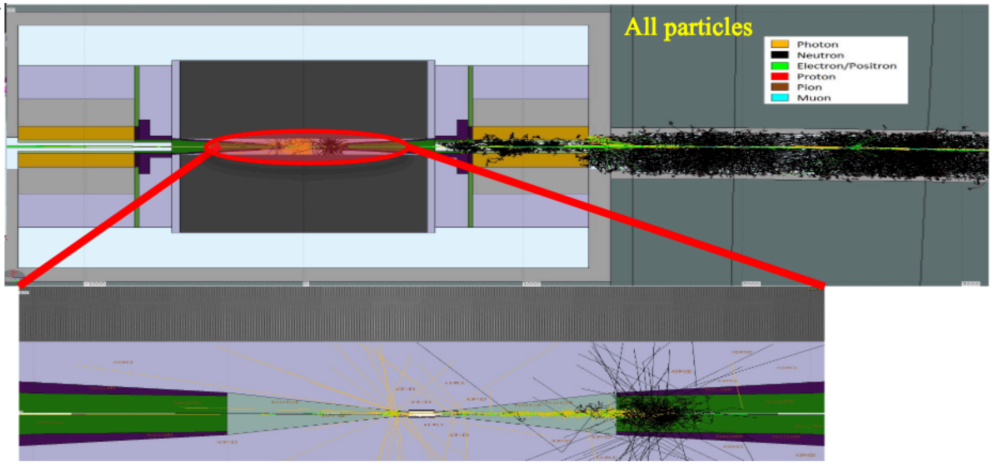
Theory community is excited:

307.04743	2005.10289	2008.12204	2012.11555	2102.11292	2104.05720
901.06150	2006.16277	2009.11287	2101.10334	2103.01617	etc …
003.13628	2007.14300	2012.02769	2102.08386	2103.14043	

Building a Detector for the Muon Collider environment is Challenging

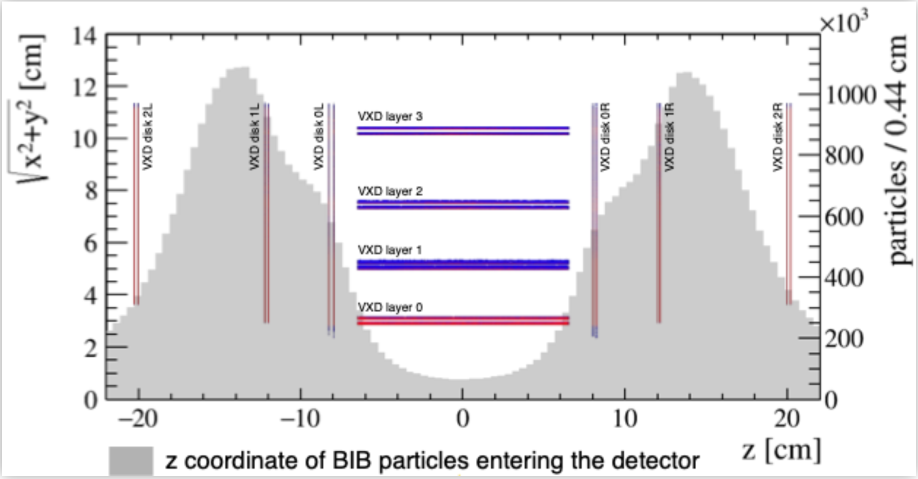
- For other next generation colliders the challenge is pile-up and collision rate
- At a muon collider the main issue is Beam Induced Background (BIB):
  - 4E5 decays/m/crossing @ 3TeV (tertiary muons and showers from final triplets)
- DAQ and track reconstruction/ background rejection are especially challenging

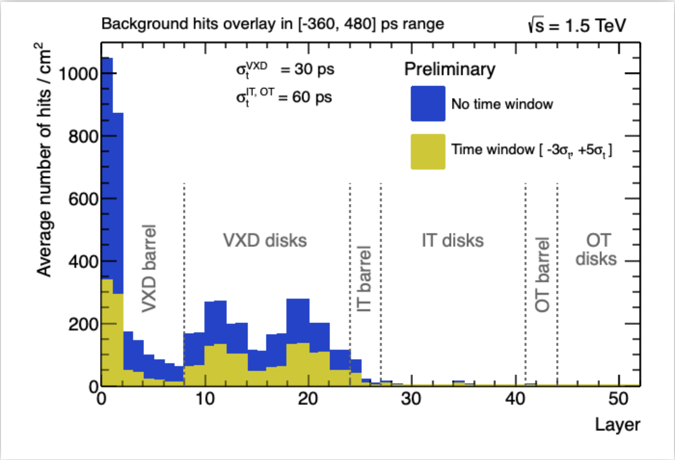


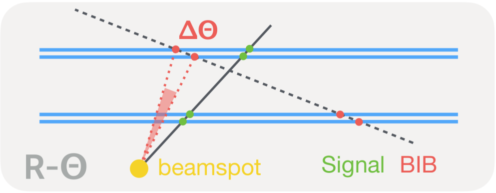


Tracker: designing around BIB

- Early rejection of non-collision hits crucial for acceptable readout rates
- Avoid “hottest” BIB areas
  - Geometrically
  - In readout time
- Additional selections considered:
  - Cluster shape
  - Detector doublets pointing towards IP







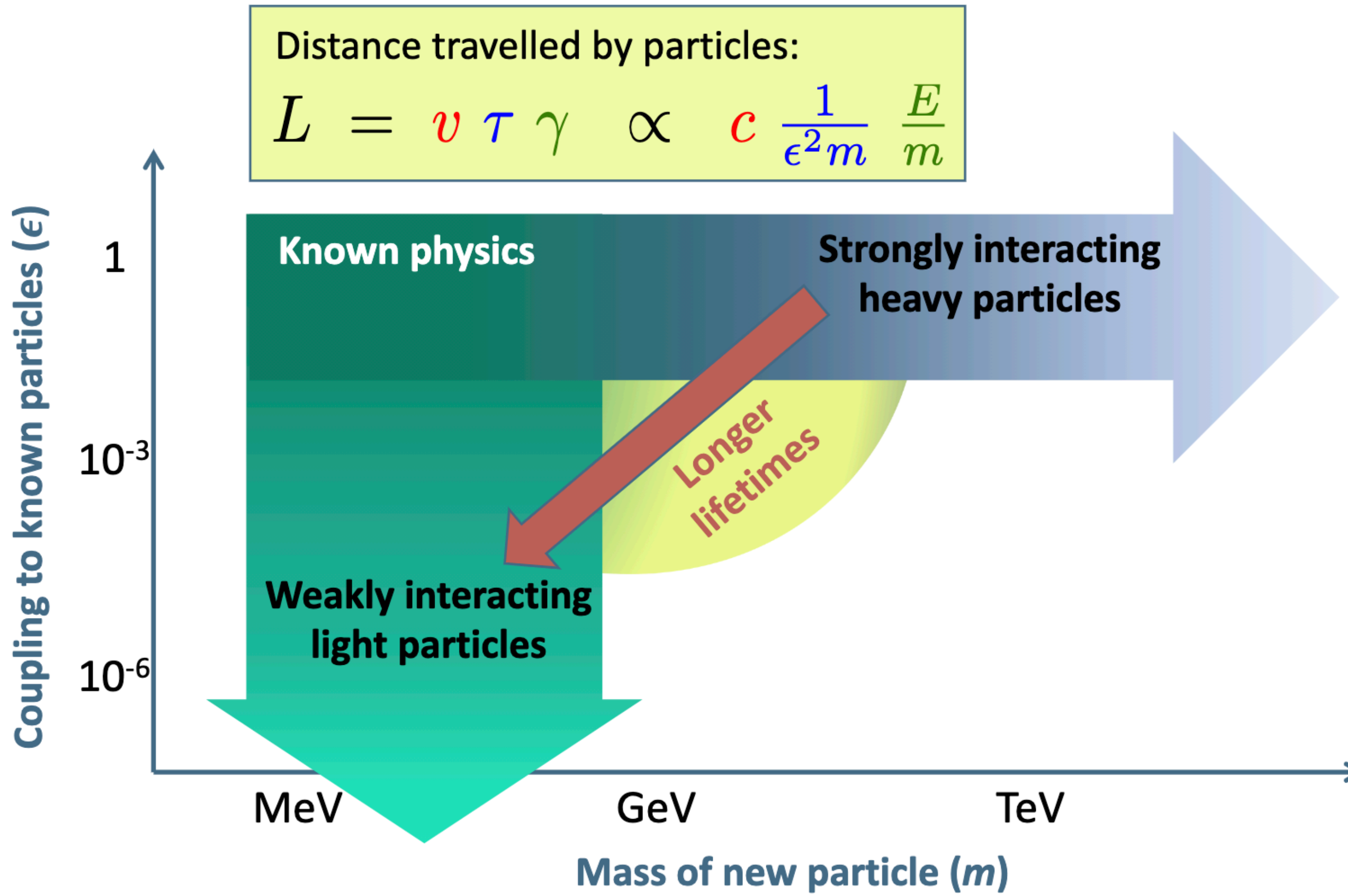
→ DAQ and real-time tracking

→ Application of real-time accelerator-based ML techniques

FASER/FASER2

Light Weak DM Motivation

- One of the defining characteristics of weakly interacting light particles is their **long lifetime**.
- Distinct signatures
- But could still be produced in large numbers in hadron decays at ATLAS!



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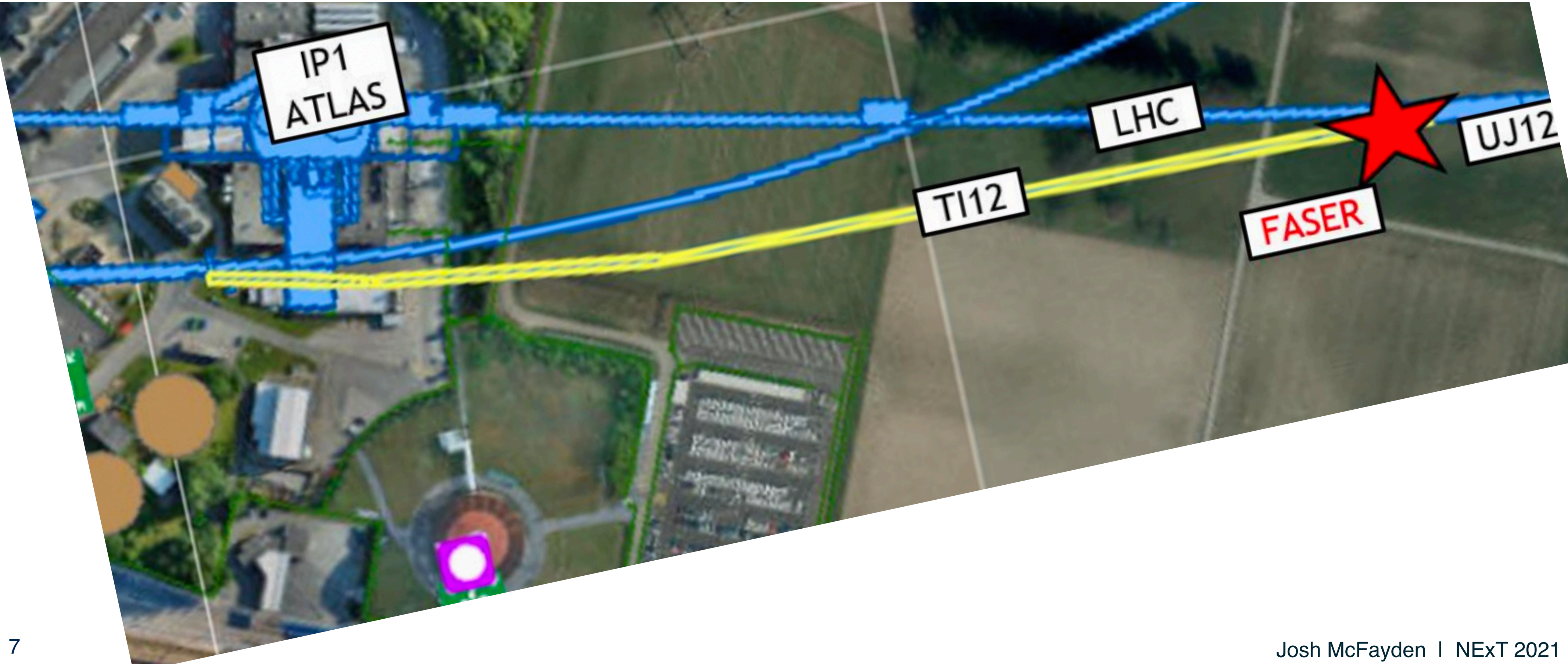
FASER Location

- In relation to ATLAS at Point 1



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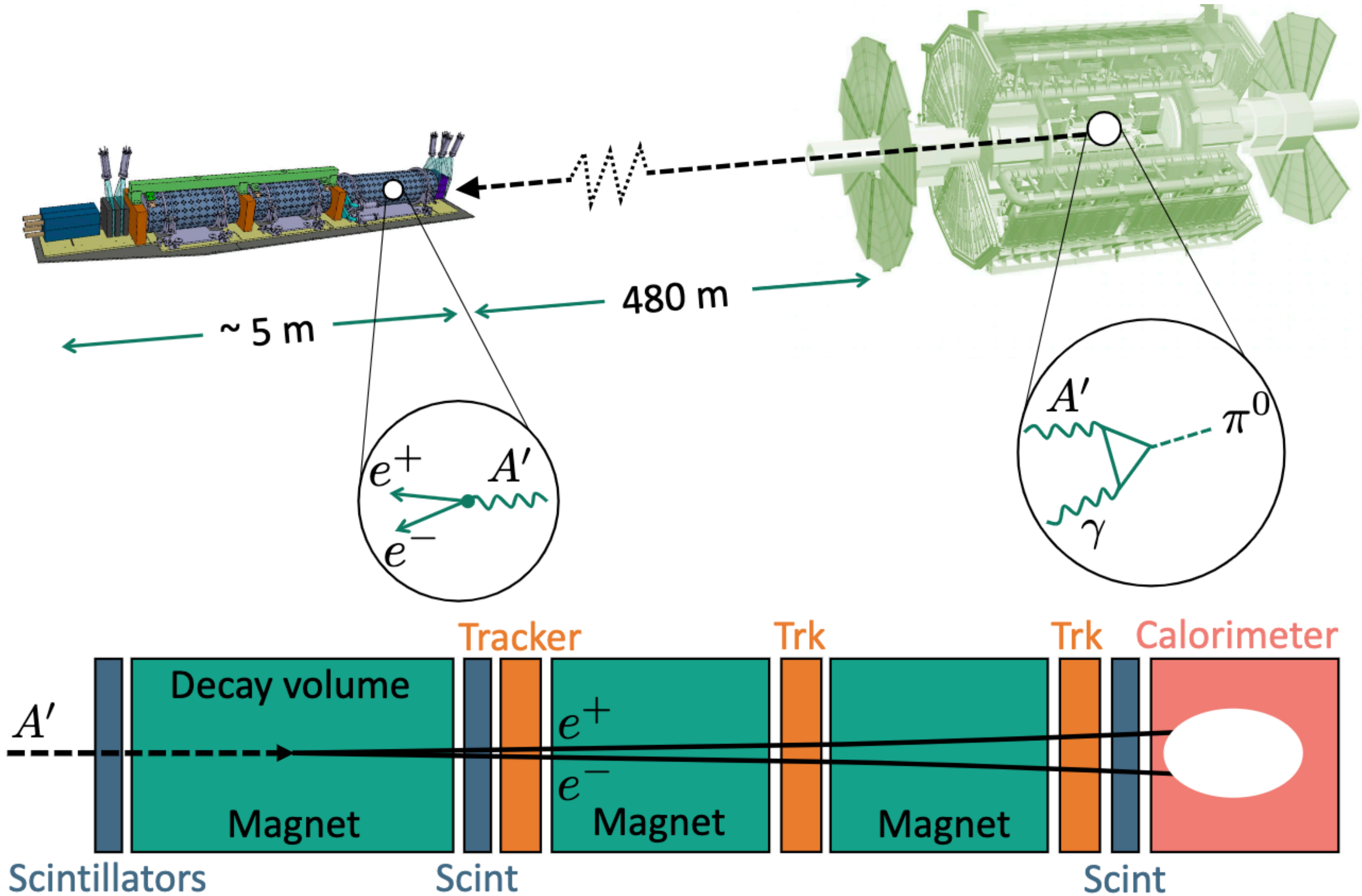
Target scenarios | Dark photon



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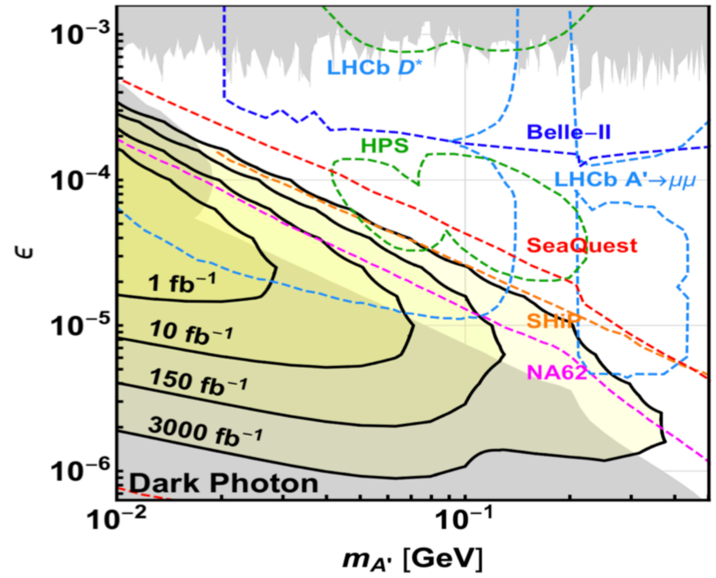
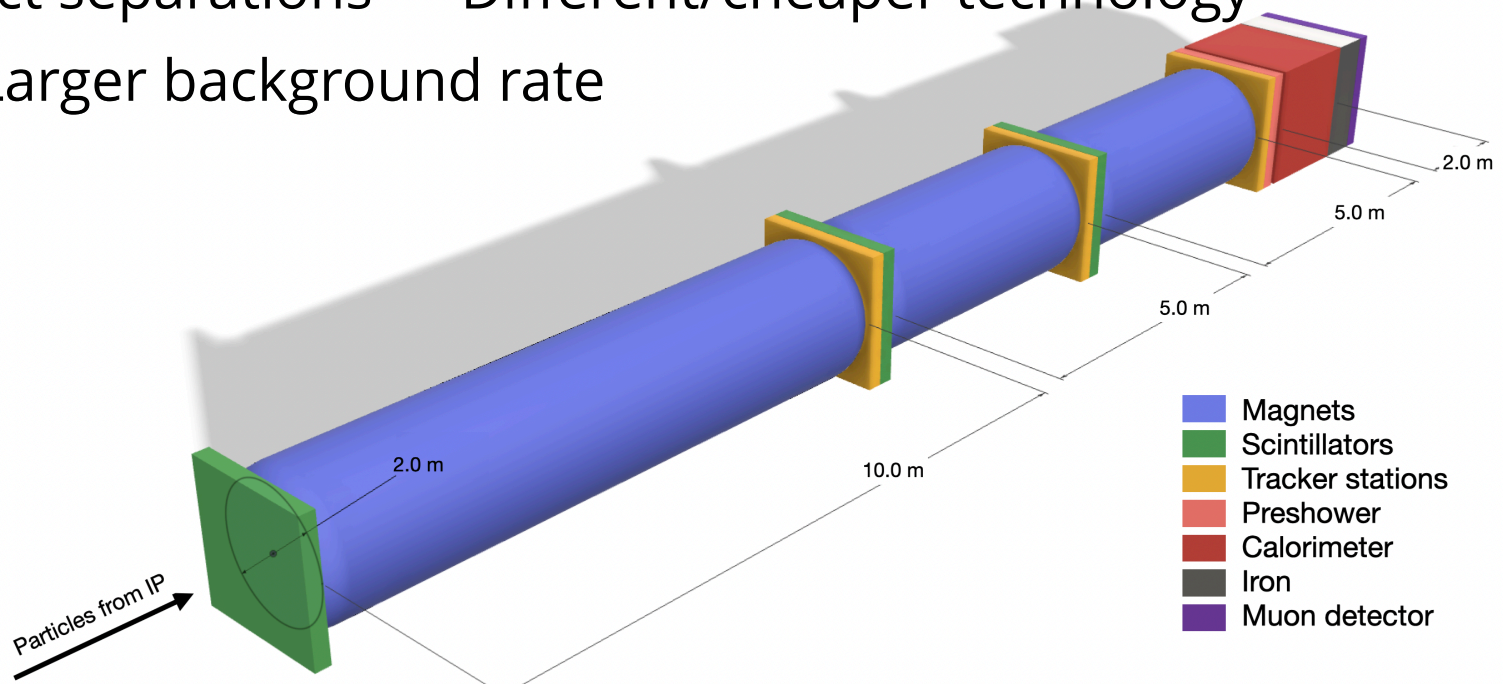


FASER2 Design

- **Design considerations for FASER2**
  - Larger radius → Being on-axis less important
  - More decay channels → Need for particle ID **→ Dual Readout Calo?**
  - Larger decay product separations → Different/cheaper technology
  - Larger detector → Larger background rate

- Still much to be studied in terms of possible detector configurations and technologies.



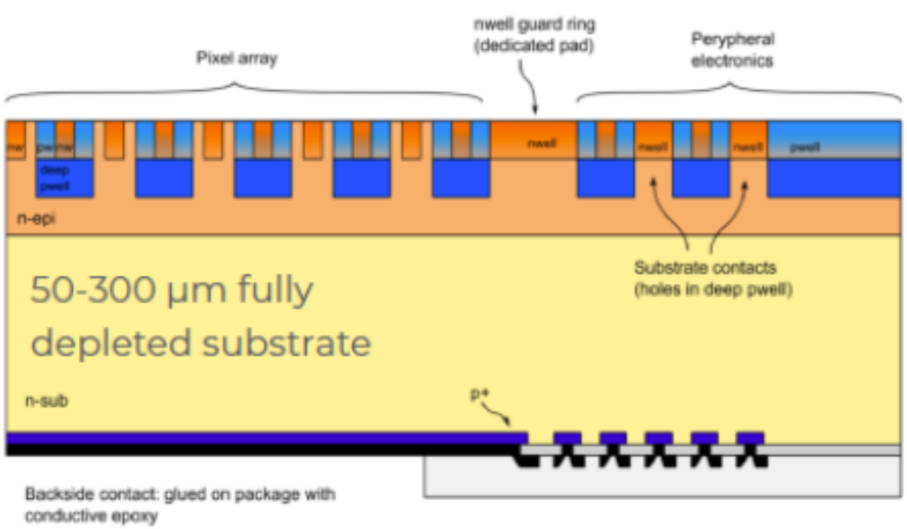
Summary

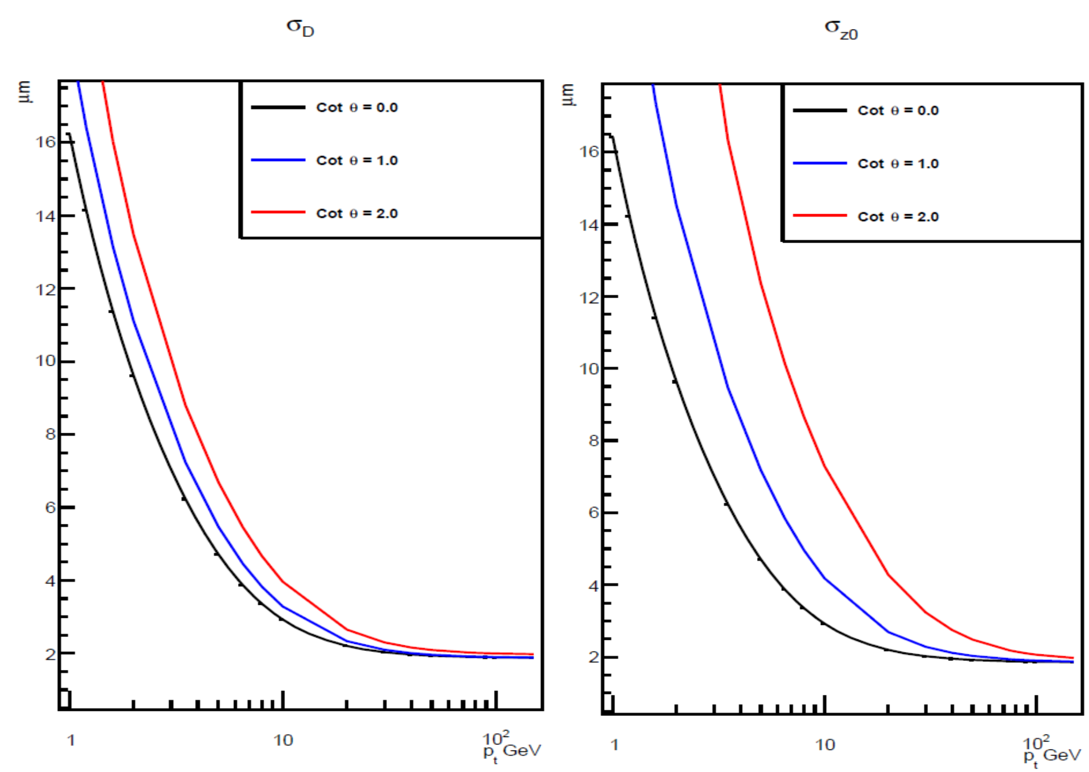
- So far, Sussex has been **punching above its weight** for future collider experiments
- AIDAinnova **instrumental** in consolidating this effort
  - ….and A. Löschcke has hit the ground running on TB analysis and DQM.
- AIDAinnova + potential synergies with other interests (FASER2) are **opening interesting scenarios**
- Activities for **muon collider** ongoing with focus on real-time tracking
- UK scenario for future funding is under definition - we need to be ready for that.

BACKUP

Vertex detector

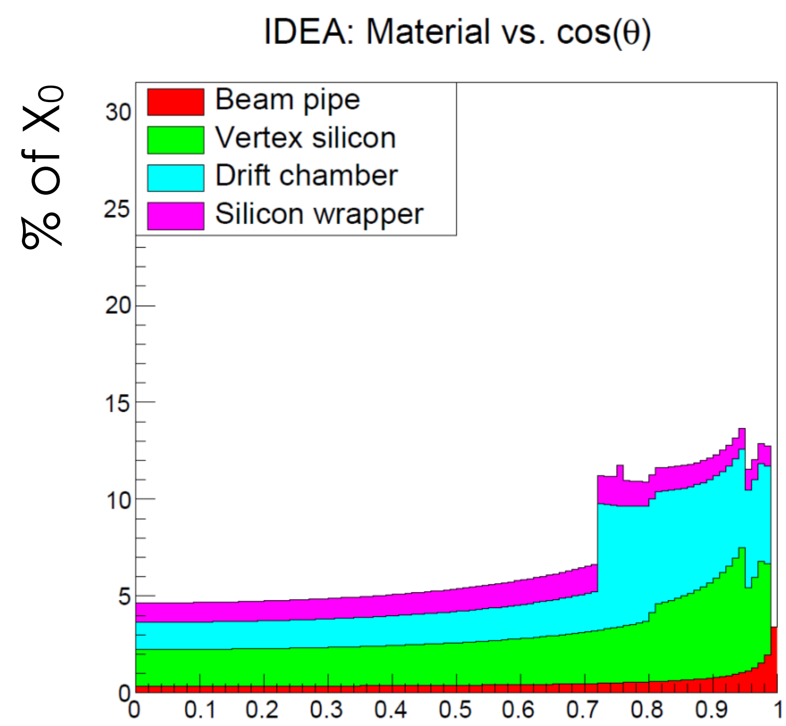
- Low power (< 20 mW/cm2) / high-resolution pixel detector
  - R&D performed within the ARCADIA framework
  - Monolithic sensors (MAPS) to provide **20 µm pixel for ~ 3 µm single point resolution**
    - Current ALICE ITS pixel size 30 µm for 5 µm single point resolution
  - Target hit efficiency - 99.9%

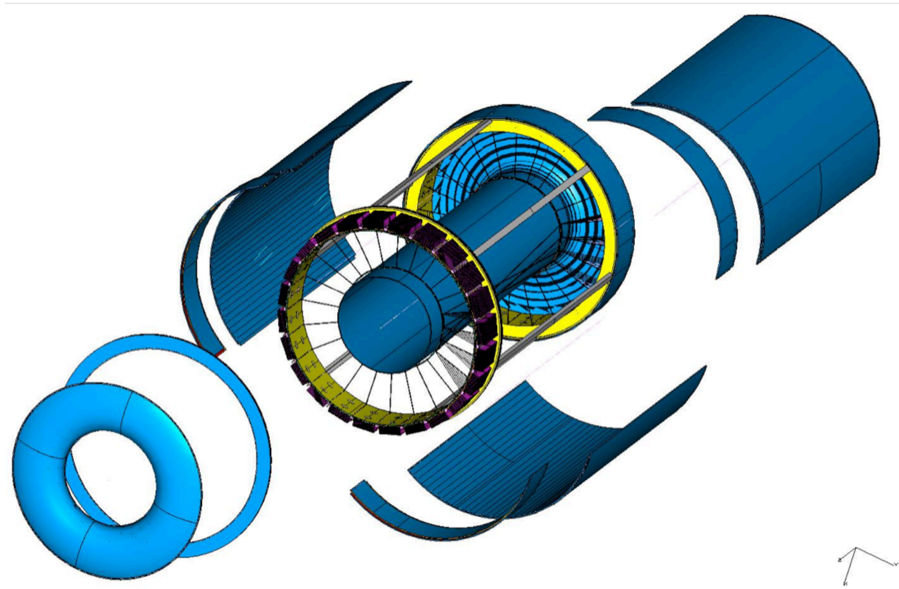


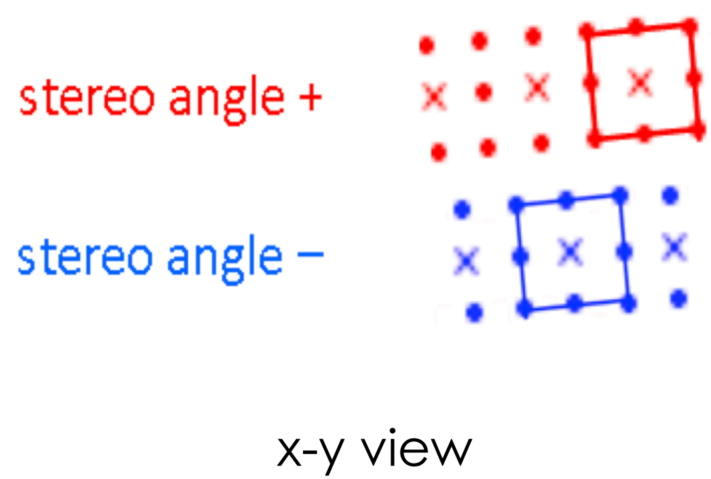


Tracking

- Tracking with drift chamber (similar in concept to MEG II chamber)
  - Minimising multiple scattering, adding only **2% X_0 to material in tracking volume**
  - R_{in} = 35 cm, R_{out} = 200 cm, L = 400 cm, drift time o(300 ns)
  - 90% He - 10% iC_4H_{10} - max drift time 360 ns, Stereo angle 30°
  - **Cluster counting (12.5 cm^{-1} clusters)** improves spacial resolution and dE/dx measurement
  - Single point precision (with cluster counting) **better than ~ 100 μm**.



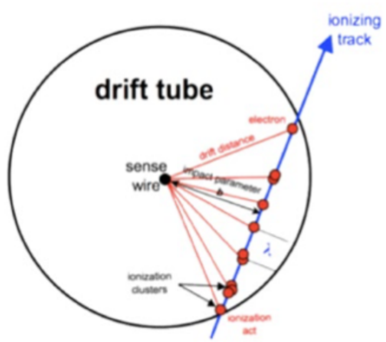


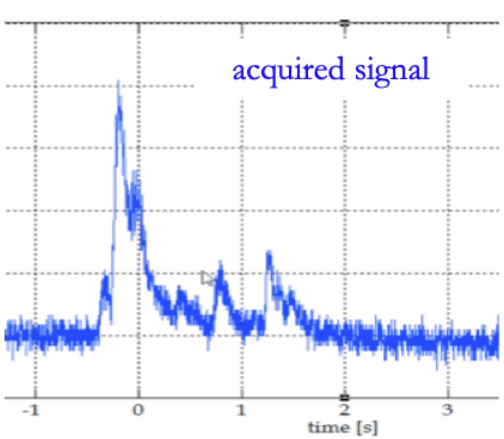


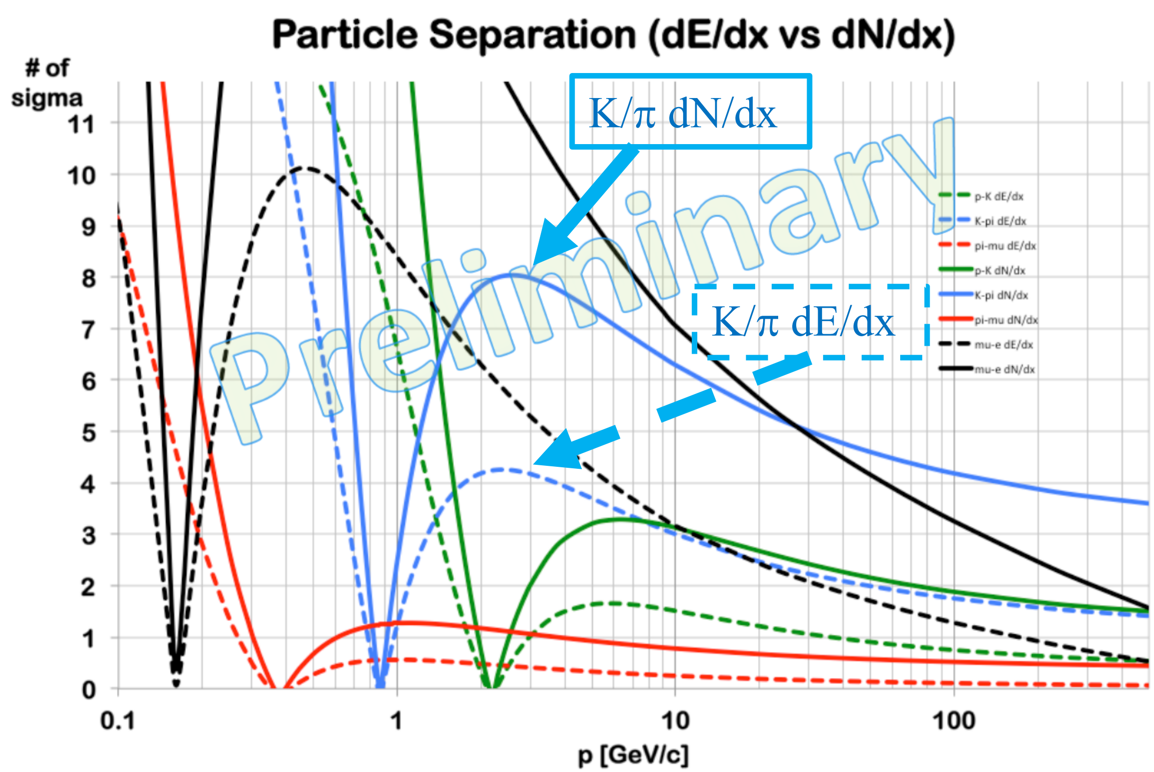
See here and talk from M. Primavera at this workshop for more details

Cluster counting

- Number of ionisation clusters along track **proportional to the energy loss**.
- With ~ 1 ns time resolution **waveform sensitive to individual clusters**.
  - Requires ~ GHz sampling and on-detector feature extraction.
- Excellent K/π separation for most momenta. TOF could help recover missing ranges.







The dual-readout principle in a nutshell

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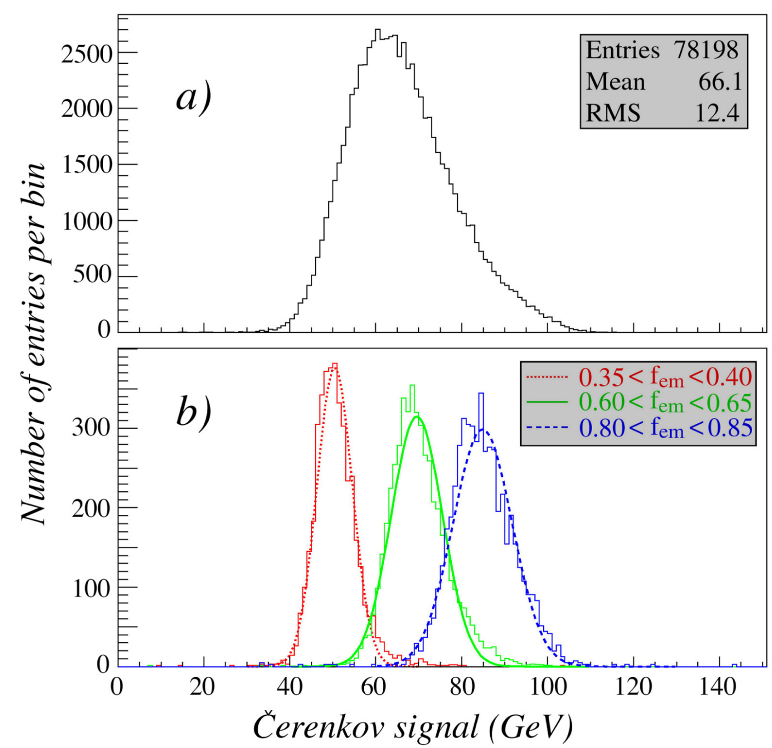
- Sampling the **hadronic shower** with two readouts of **different e/h factor** allows to correct event by event for non-compensation.
- Cherenkov (C) channel mostly sensitive to the em shower component, Scintillation (S) sensitive to all.

$$\begin{cases} E_S = E\left(f_{\text{em}} + \left(\frac{h}{e}\right)_S (1 - f_{\text{em}})\right) \\ E_C = E\left(f_{\text{em}} + \left(\frac{h}{e}\right)_C (1 - f_{\text{em}})\right) \end{cases}$$

Two equations in two unkowns (f_{em} and E)

$$E = \frac{(E_S - \chi E_C)}{1 - \chi} \qquad \chi = \frac{1 - \left(\frac{h}{e}\right)_S}{1 - \left(\frac{h}{e}\right)_C}$$



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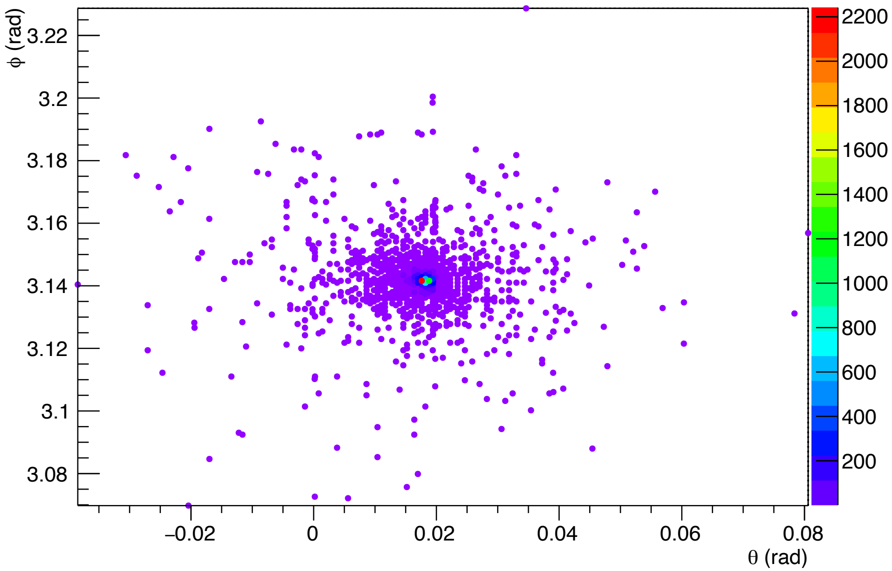
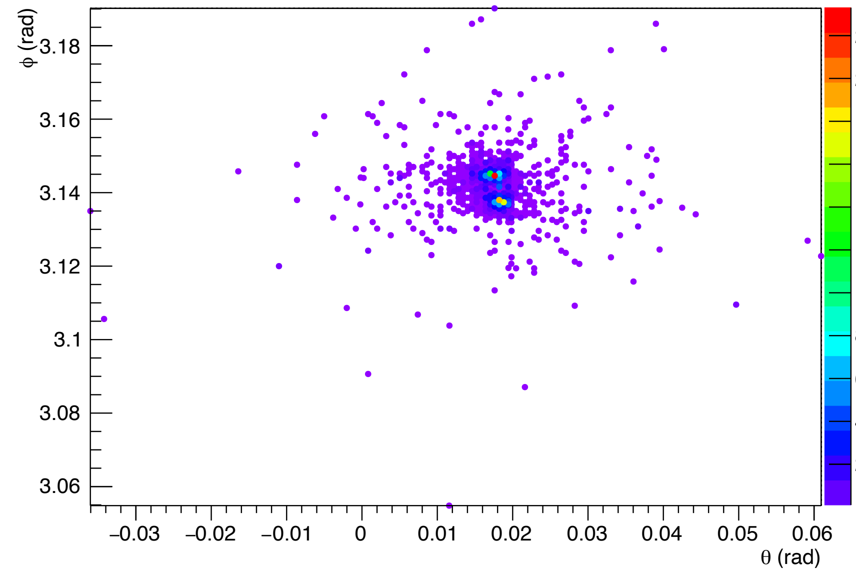
Calorimeter - Full granularity

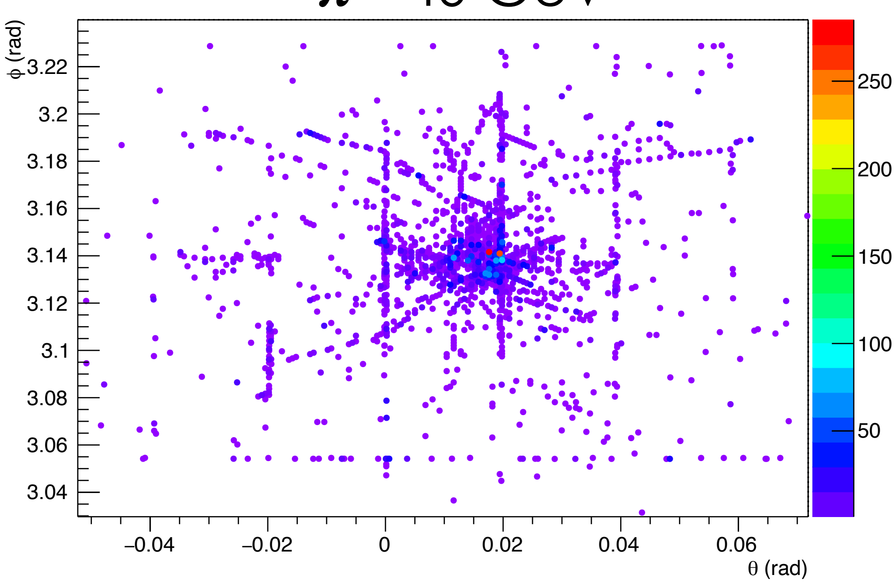
e⁻ 40 GeV



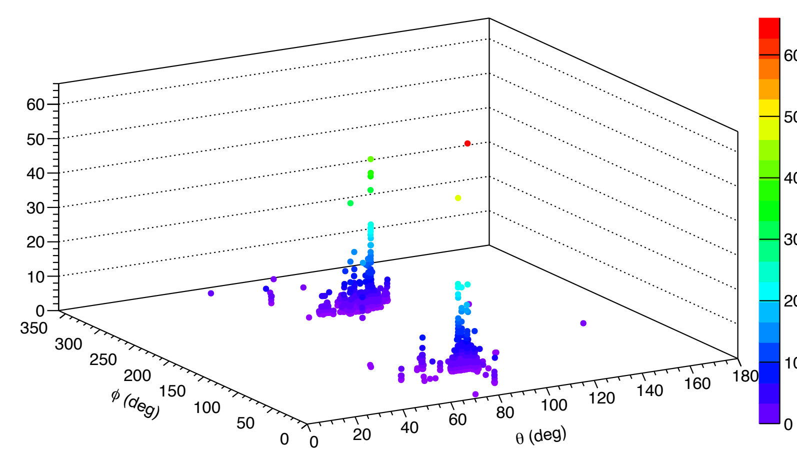
π^0 40 GeV



π^- 40 GeV



Di-jet



The Framework

Plugin system

- User’s logic is encapsulated in Plugins
- Plugin libraries are loaded at runtime
  - ‘plug’ user’s login in the framework during run
- Plugins are not ‘intrusive’
  - No ‘class inheritance’ structure

Abstract event data model (EDM)

- No pre-defined EDM → abstracted and user defined
- Event streamer also implemented as Plugin

Analysis framework fully based on abstract EDM and plugin system

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The Framework

Online

- Interface to DAQ system
  - DAQ data transfer
  - DAQ run control commands/state/config
- Online data processing
  - DAQ data monitoring
  - Slow control monitoring
  - DAQ data re-processing from file

Offline

- General purpose data monitoring
  - Data quality assertion and reporting (Q-test, Q-report)
  - Comparison with reference data (Chi2, Kolmogorov, etc)

+ Visualization Tools

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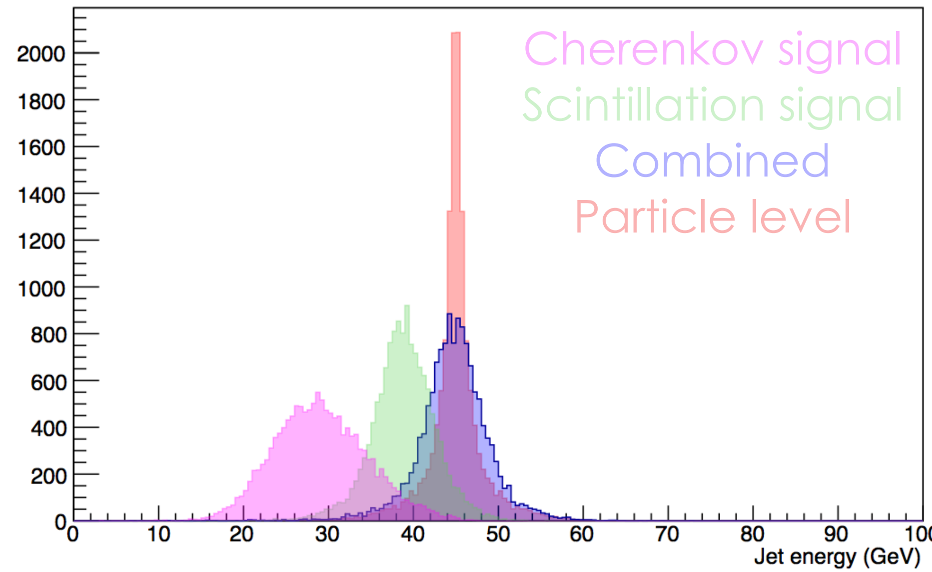
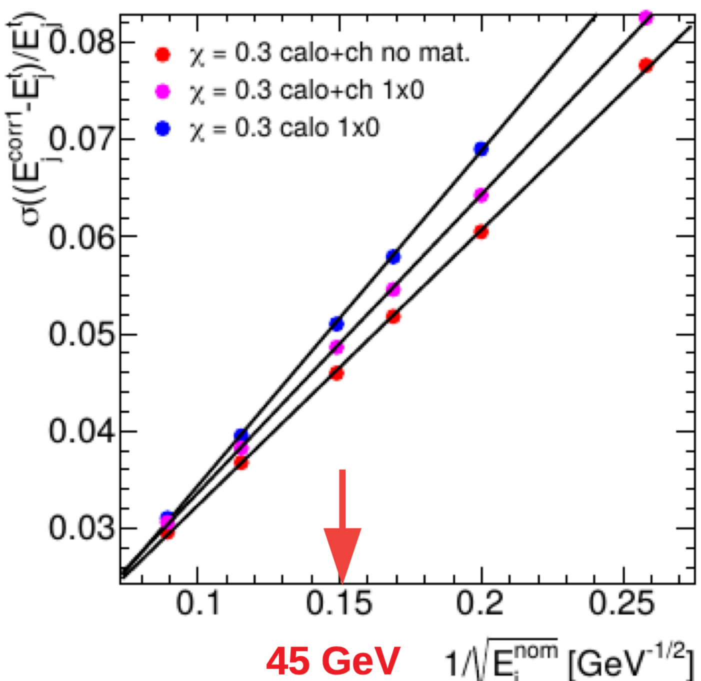
Calorimeter - jets

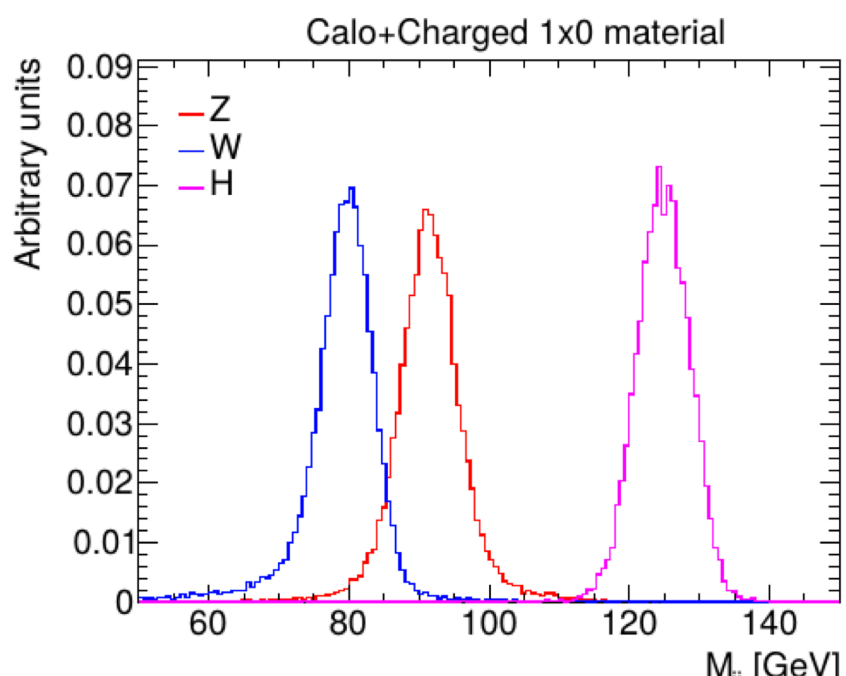
- IDEA: **pure calorimetric** measurement compared with a **“track aided”** calibration.

- Full collision events used:

$$e^+e^- \to ZH \to jj\tilde{\chi}_0^1\tilde{\chi}_0^1$$
$$e^+e^- \to WW \to jj\mu\nu$$
$$e^+e^- \to ZH \to \nu\nu bb$$







See talk from L. Pezzotti for more details