UNIVERSITY OF SUSSEX

Dual Readout Calorimeter

Recent developments

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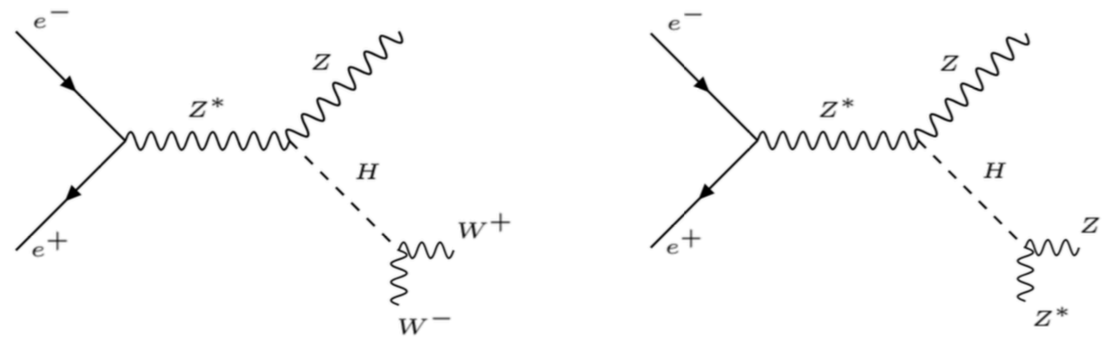
On behalf of RD_FA collaboration **[check]**

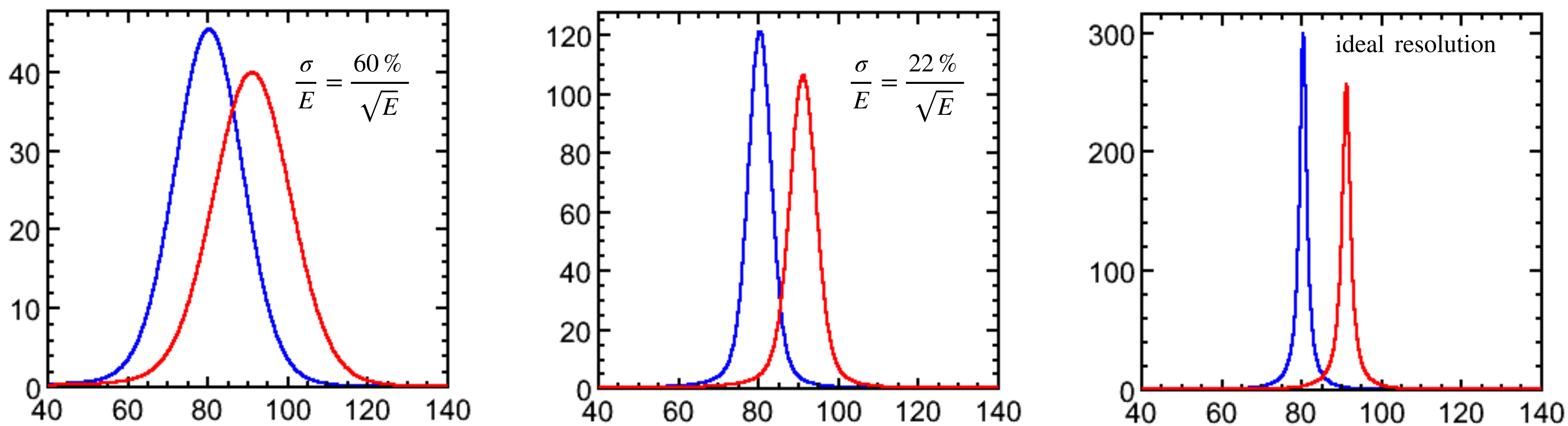
Outline

- Dual readout - the basic idea.
- Recent developments - options tested on beam:
  - Combined data taking with old prototypes
  - SiPM readout (with TB results)
  - Longitudinal segmentation
- Summary

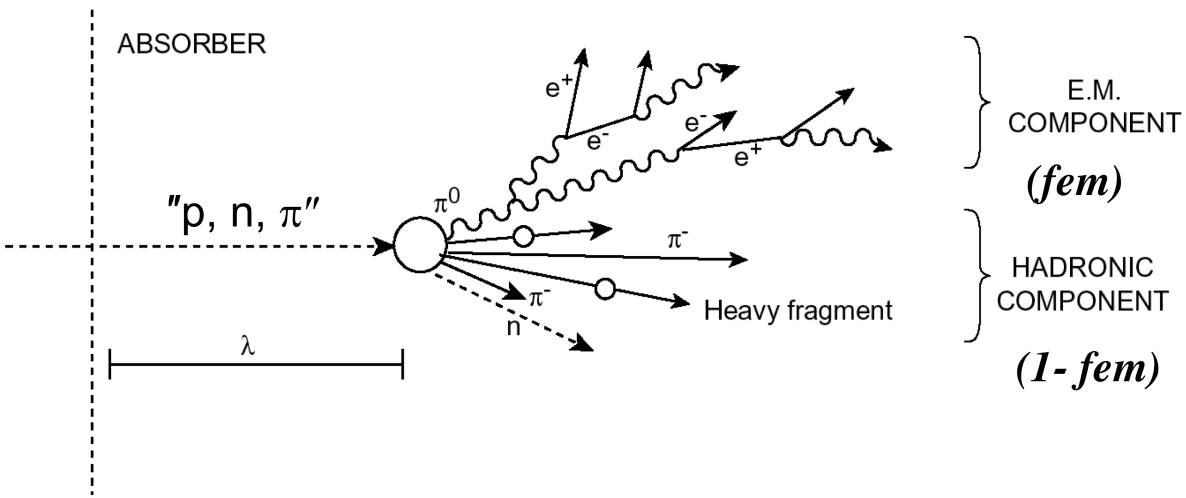
Reminder: why dual readout?

- Precision physics at e^+e^- collider calls for high-resolution hadronic calorimetry





The curse of hadronic calorimetry



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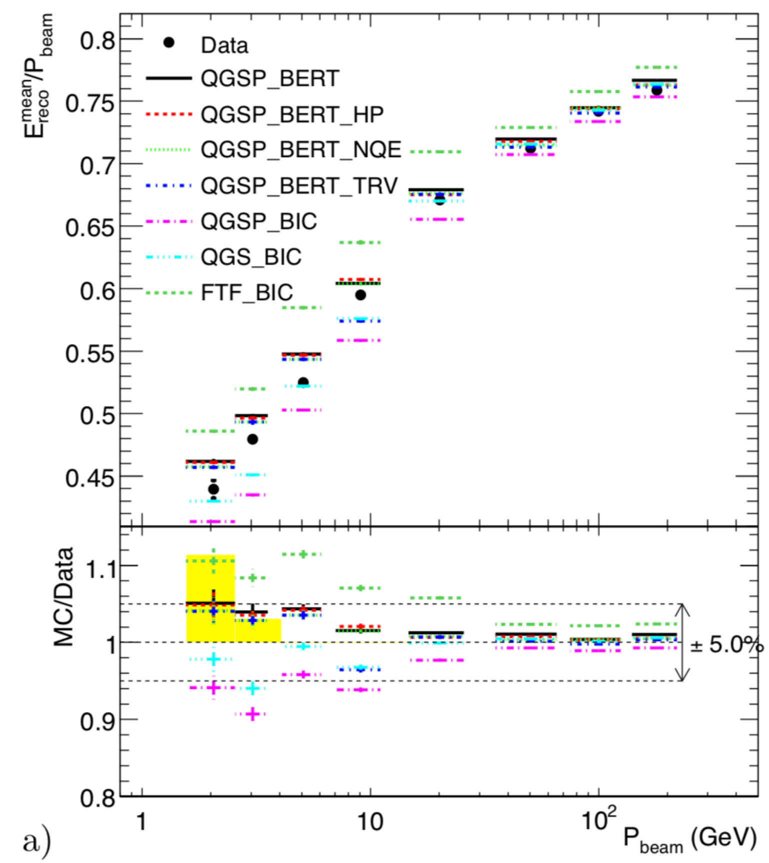


- Non-compensating calorimeter: response to em part different from that to non-em part. h/e < 1

- <f_{em}> energy dependent —> Non-linear calorimeter response to hadrons

$$E_{\mathrm{meas}} = E\left(f_{\mathrm{em}} + \frac{h}{e}\left(1 - f_{\mathrm{em}}\right)\right)$$

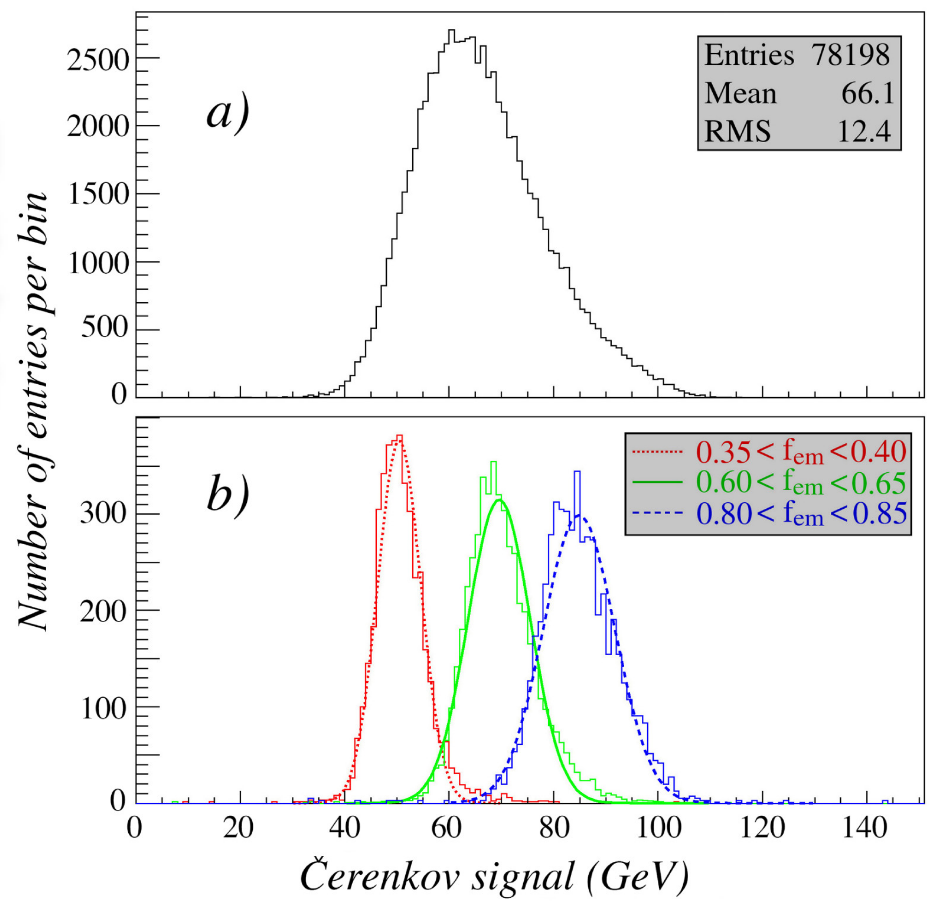
The curse of hadron calorimetry (2)

- f_{em} fluctuations dominate the hadronic calorimeter resolution

- Dual Readout:
  - Scintillation (all particles) and Cherenkov (electrons) signals have different h/e $\Longrightarrow$ allow the event-by-event extraction of f_{em}

$$\frac{S}{C} = \frac{fem + \left(\frac{h}{e}\right)_s (1 - fem)}{fem + \left(\frac{h}{e}\right)_c (1 - fem)}$$

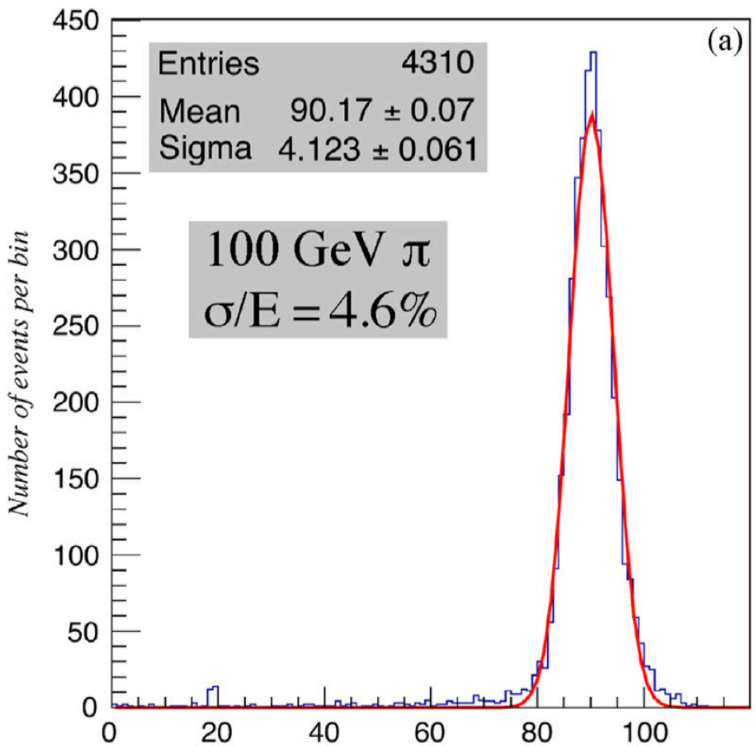
$$E = \frac{S - \chi C}{1 - \chi} \qquad \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}$$

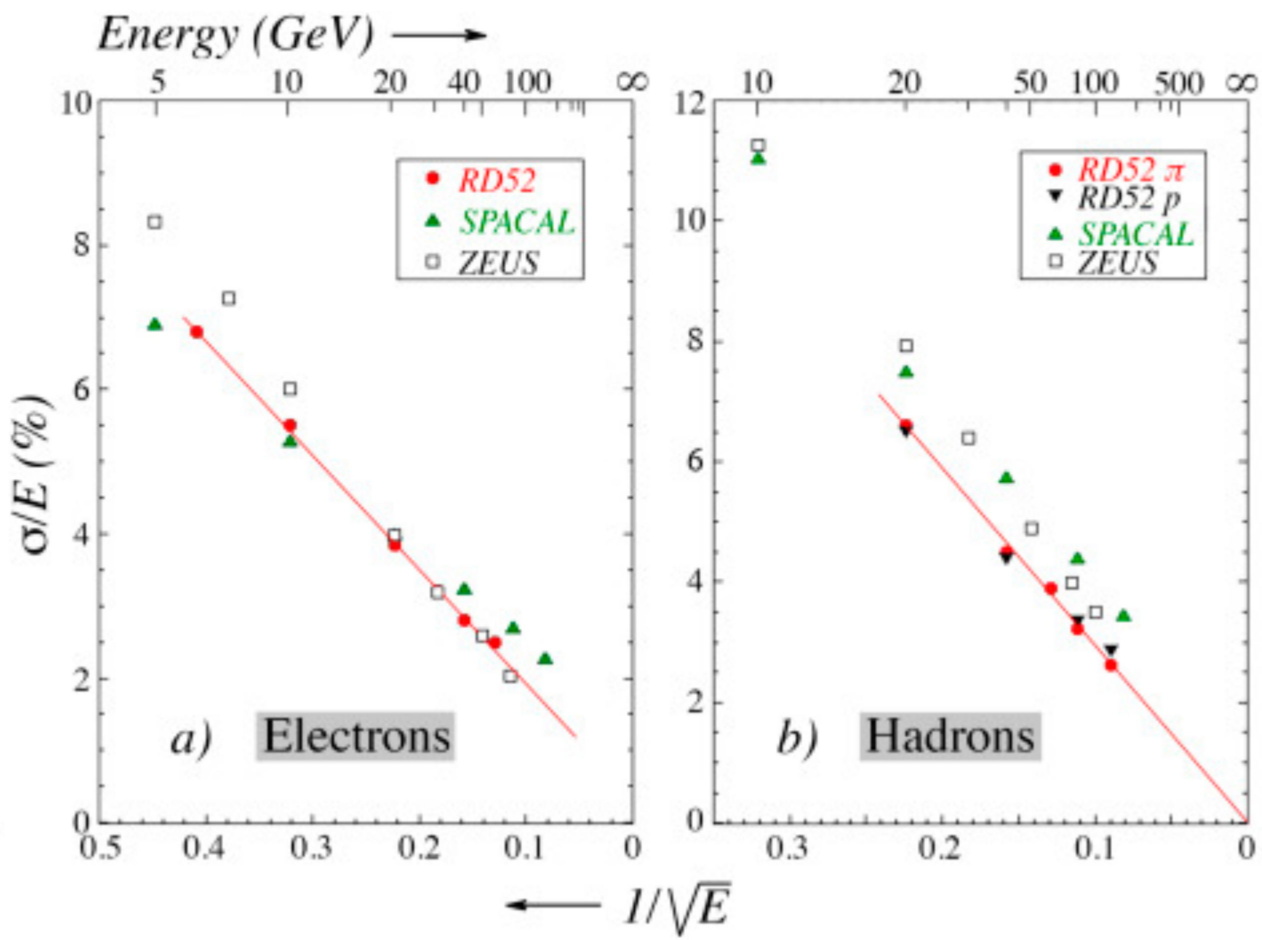


Performance of Dual Readout

- Hadronic resolution comparable to compensating calorimeters.

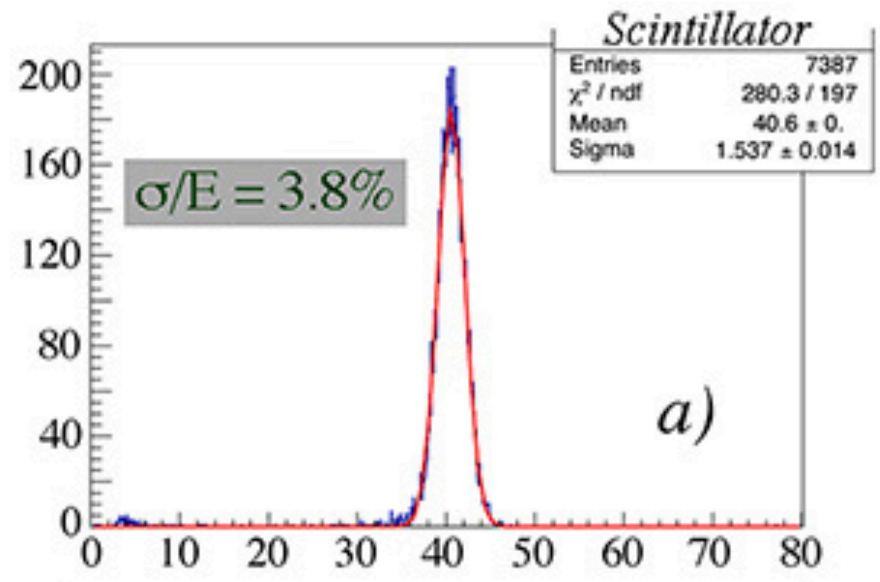
See https://doi.org/10.1016/j.ppnp.2018.07.003

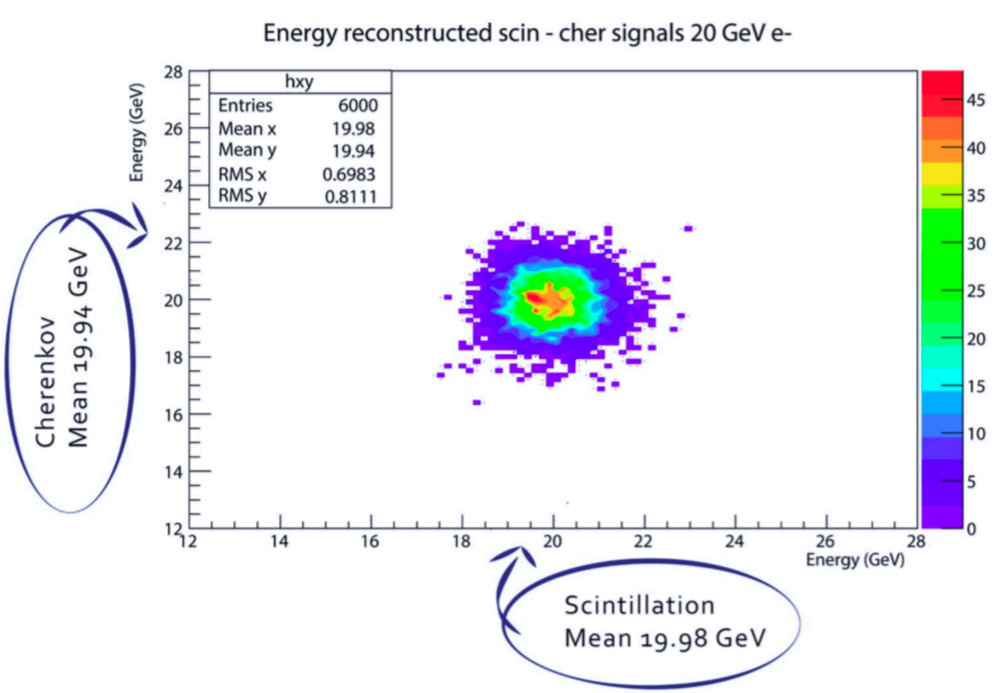


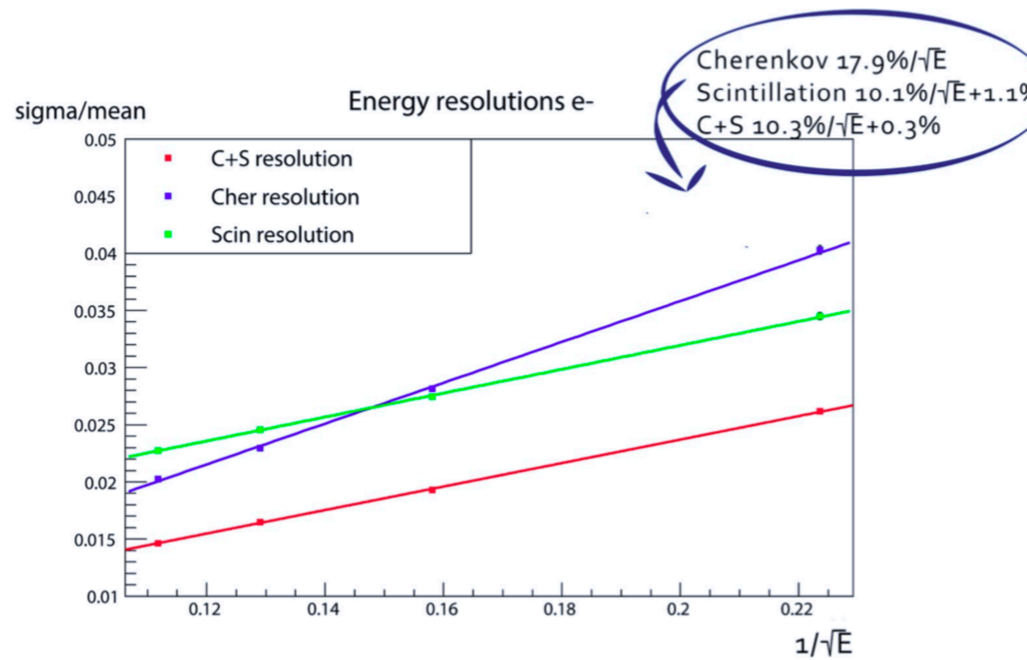


EM performance

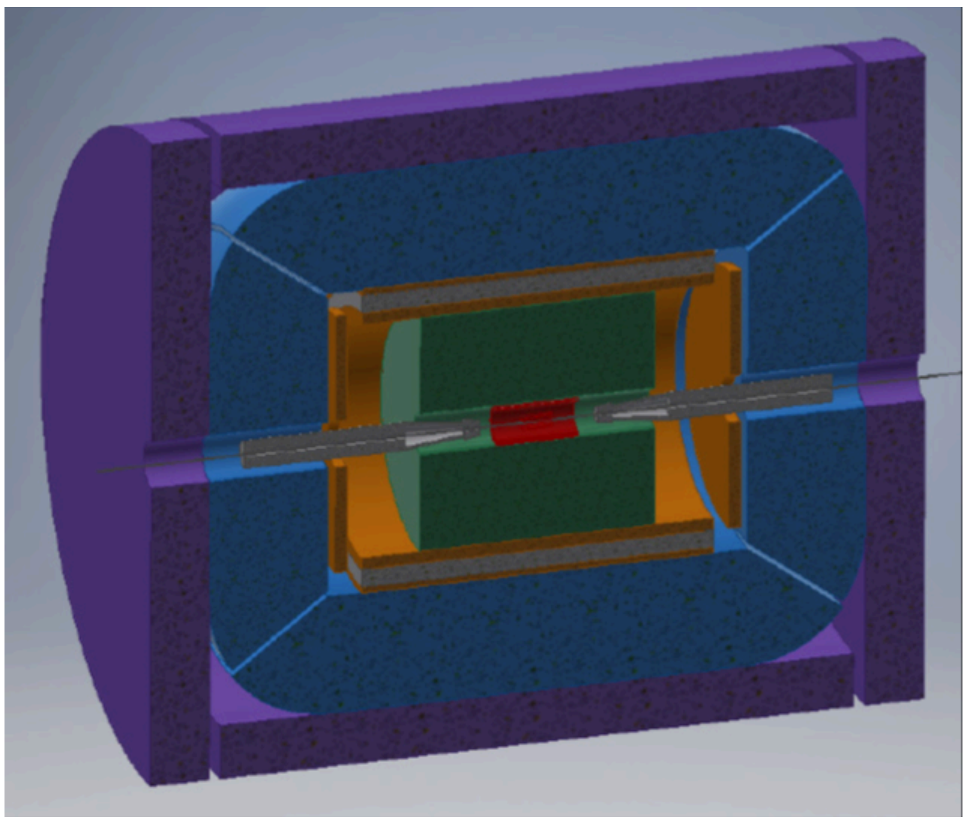
- Excellent e and γ calorimeter performance thanks to high sampling fraction.
  - EM and HAD calorimetry in one device.

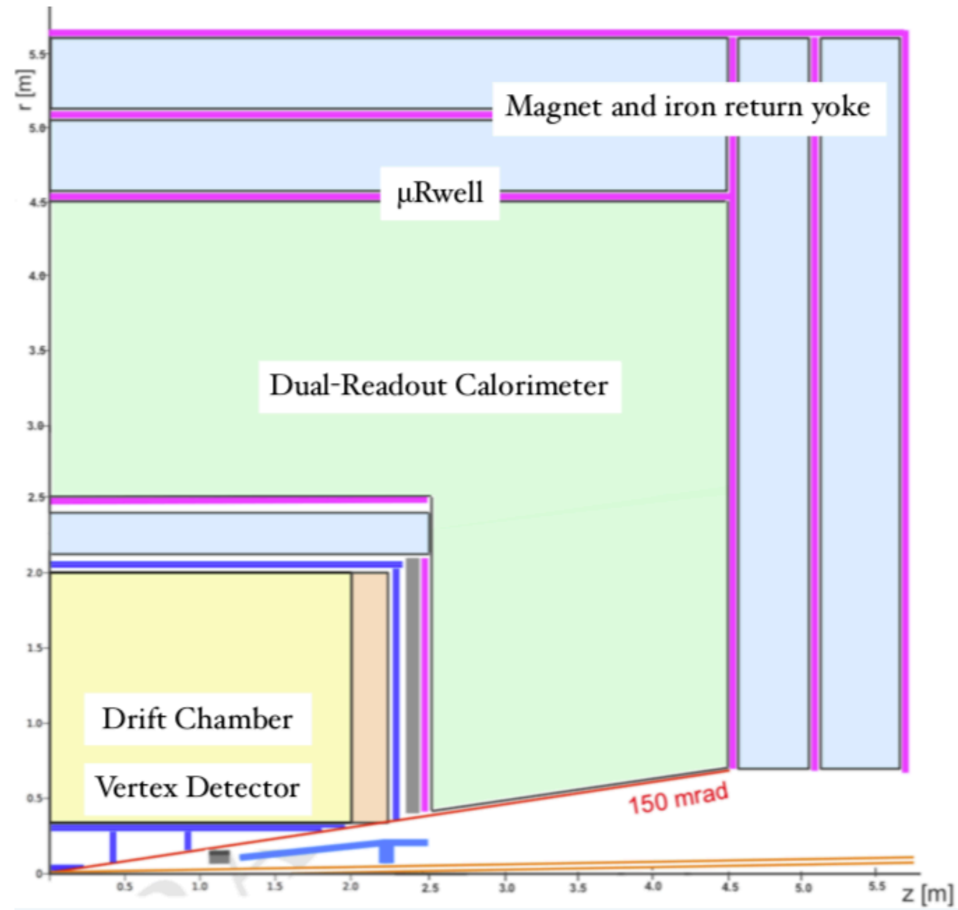






A practical implementation: IDEA



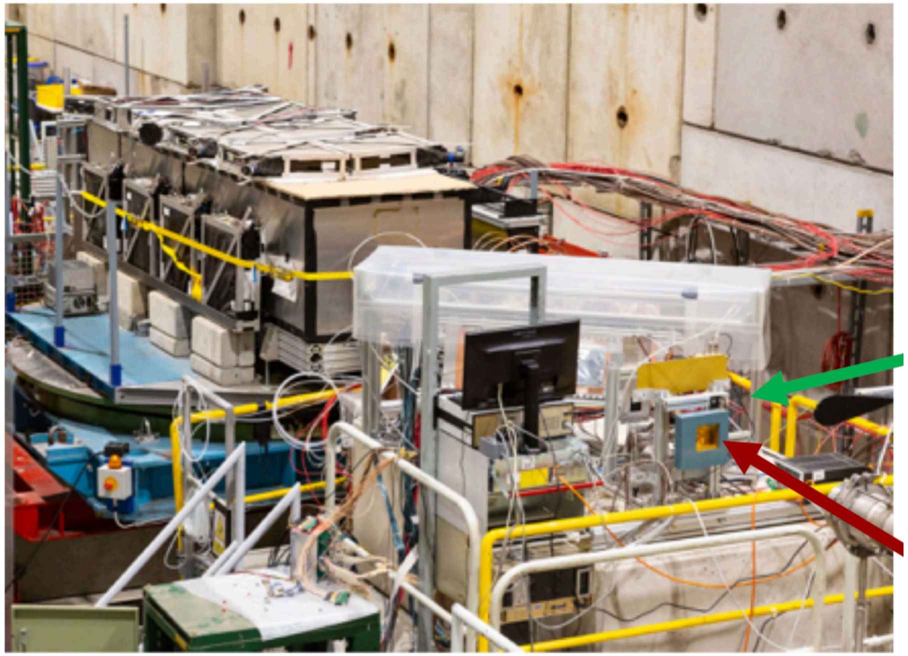


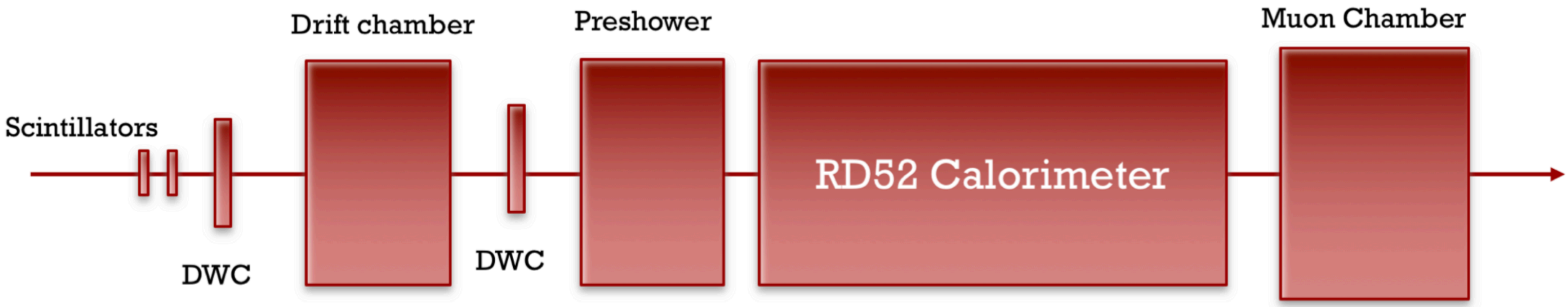
The structure of the IDEA detector and its overall dimensions

See here for additional information

IDEA slice on beam (2018)

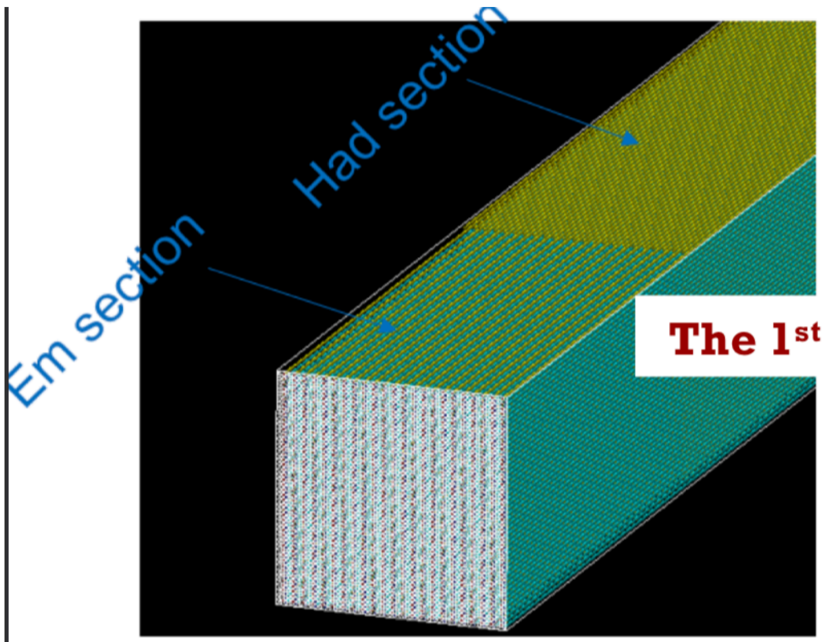
- A full combined test of IDEA:
  - Drift chamber prototype
  - GEM as preshower + µRWell for µ detection
  - Several calorimeter options tested on beam
  - See, e.g., talk from R. Santoro here



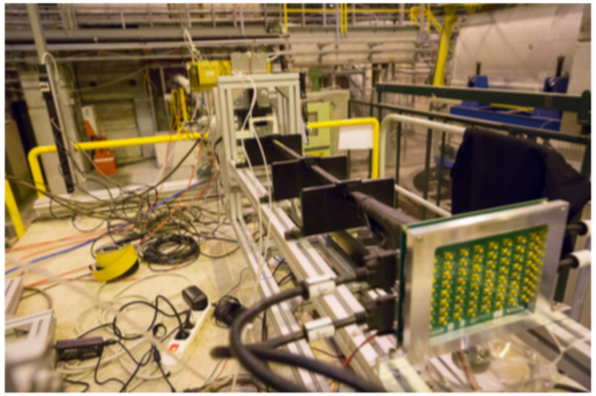


Calorimeter options used during TB

- RD52 module (combined data taking with other sub detectors)
- SiPM-based readout (standalone)
- Staggered module (standalone)



The 1st time on beam

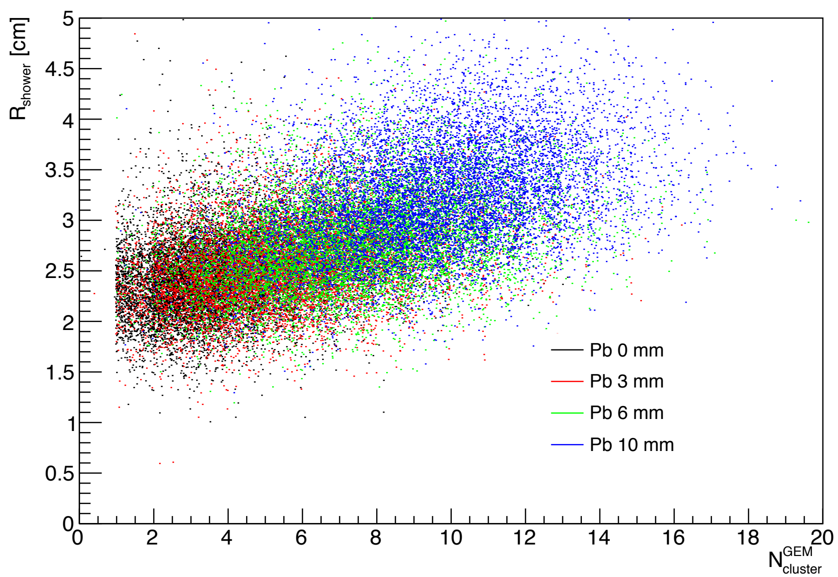


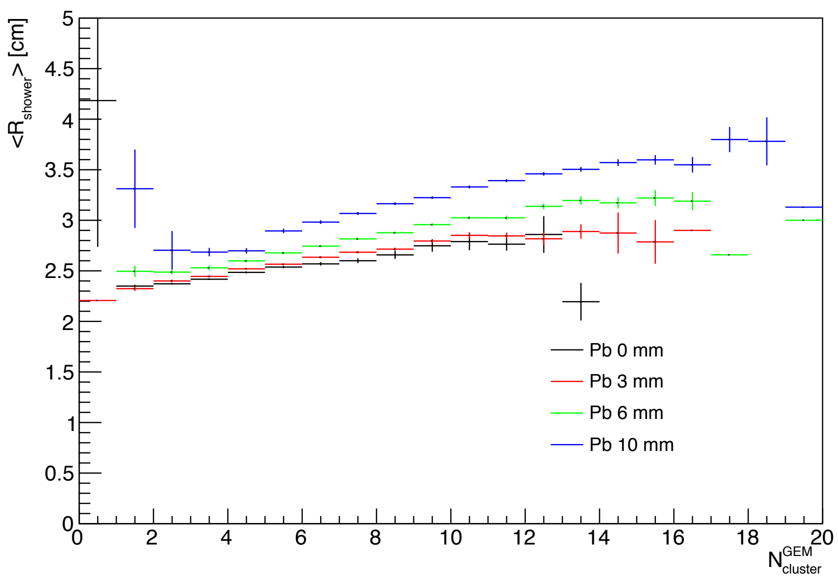
Combined measurements (RD52)

- RD52 performance studied in detail elsewhere
  - Focus on DAQ combination and combined runs with GEM-based preshower

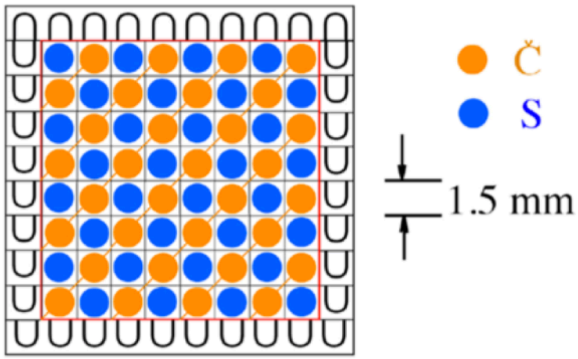
$$R_{\mathrm{shower}} = \frac{\sum_{\mathrm{ch}} E_{\mathrm{ch}} \cdot \sqrt{x_{\mathrm{ch}}^2 + y_{\mathrm{ch}}^2}}{\sum_{\mathrm{ch}} E_{\mathrm{ch}}}$$

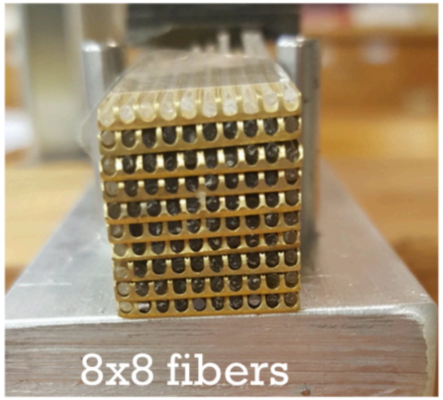
Shower width from 5 mm Pb + additional material correlates with number of clusters in GEM preshower

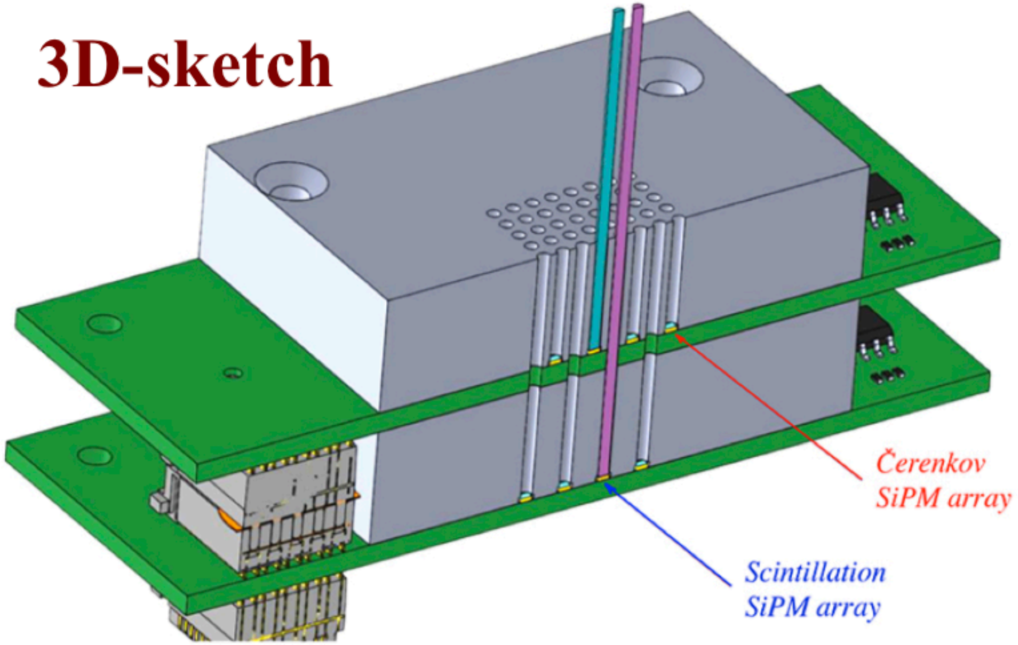




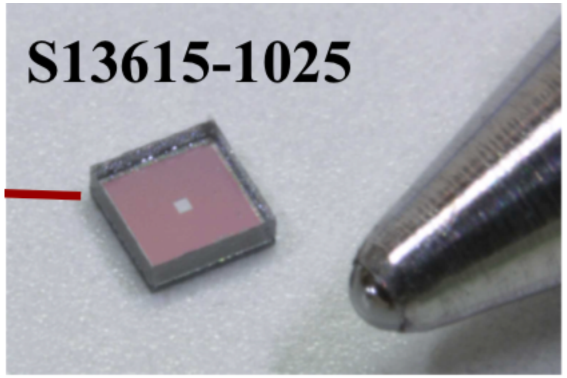
SiPM dual readout (standalone test)



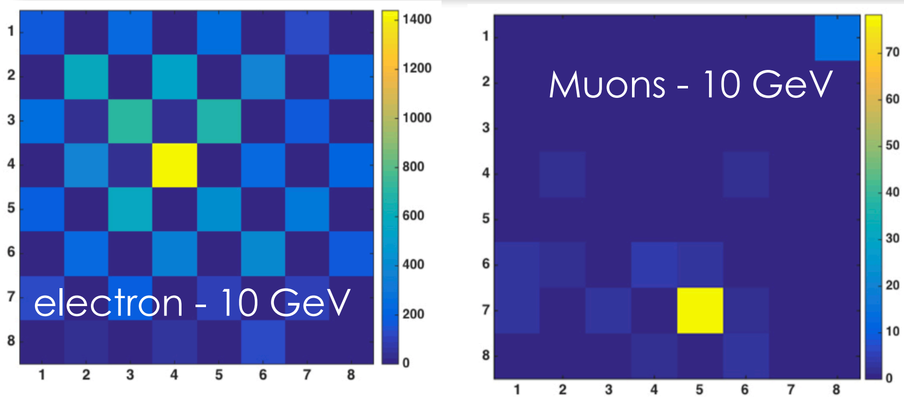


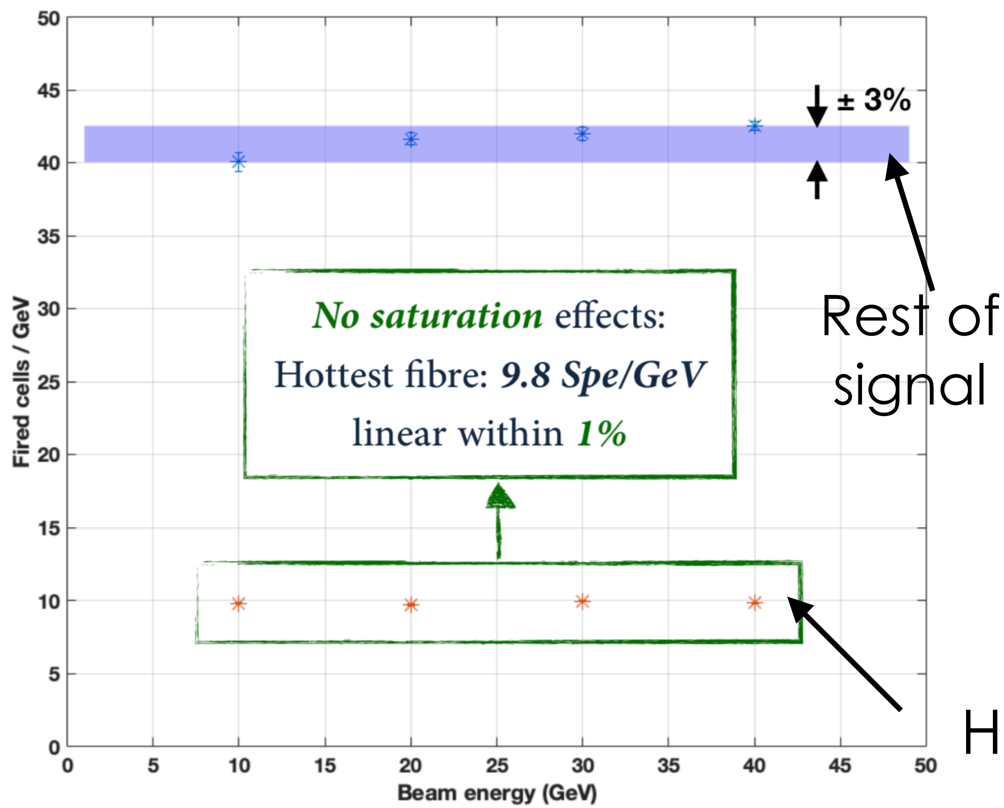


- Single fibre readout with HAMAMATSU SiPM
- Readout for Cherenkov and Scintillation light separated to minimise cross talk (the latter expected to be ~ 50 times larger)



SiPM dual readout (linearity)





Operating with 5.7 V_{OV} - PDE ~ 22%

Cherenkov light yield ~ a factor 2 larger than what measured with PMT

(Filtered) scintillation light yield under control.

EM stochastic term ~ 10% is achievable

Result could still be improved with SiPM with larger dynamic range

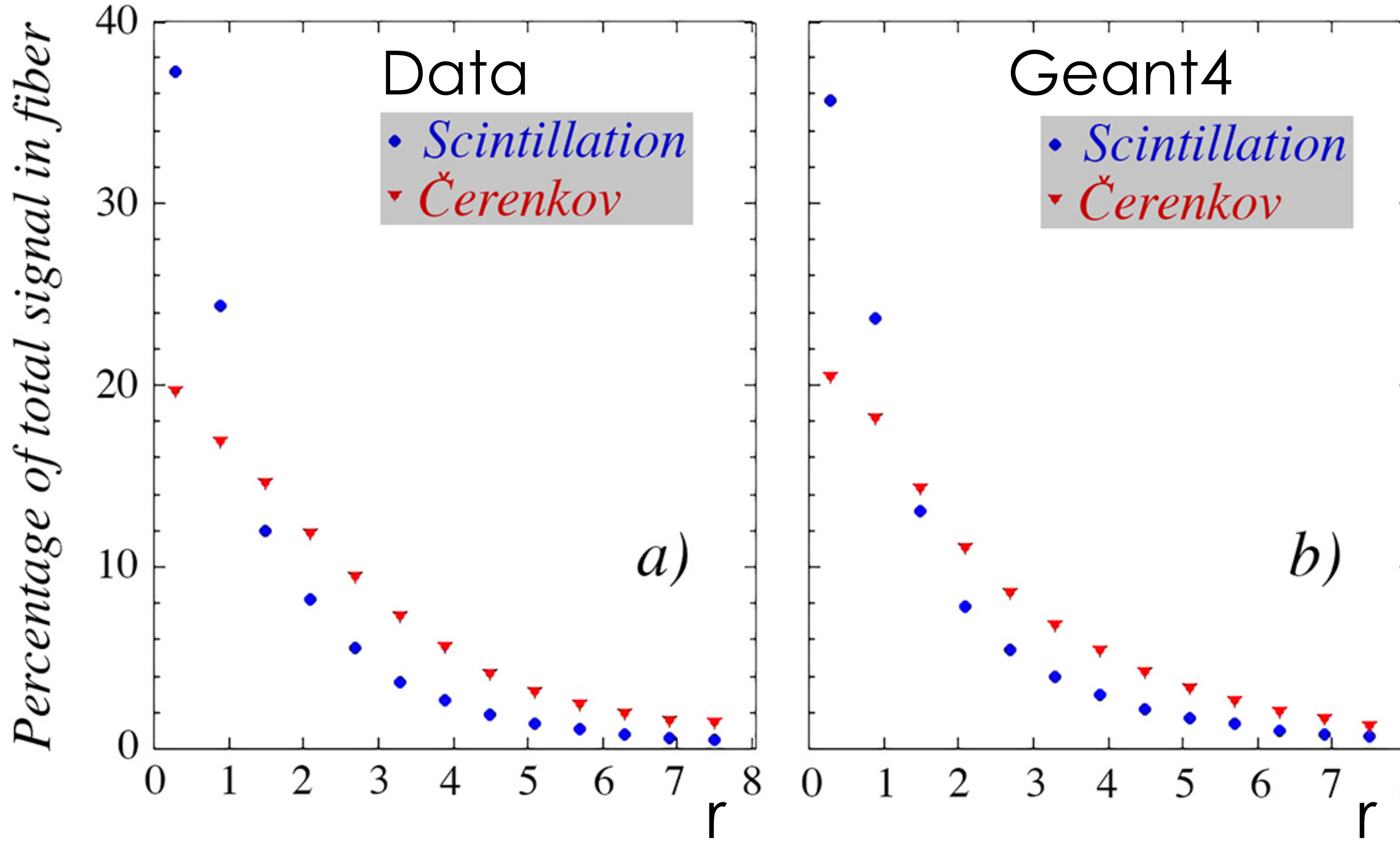
SiPM dual readout (shower shape)

- Readout of single fibre gives unprecedented lateral segmentation
- Em lateral shower shape measured with ~ 1 mm precision.

Doi:10.1016/j.nima.2018.05.016

$$\bar{x} = \frac{\sum_i x_i E_i}{\sum_i E_i}; \bar{y} = \frac{\sum_i y_i E_i}{\sum_i E_i}$$

$$r = \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}$$

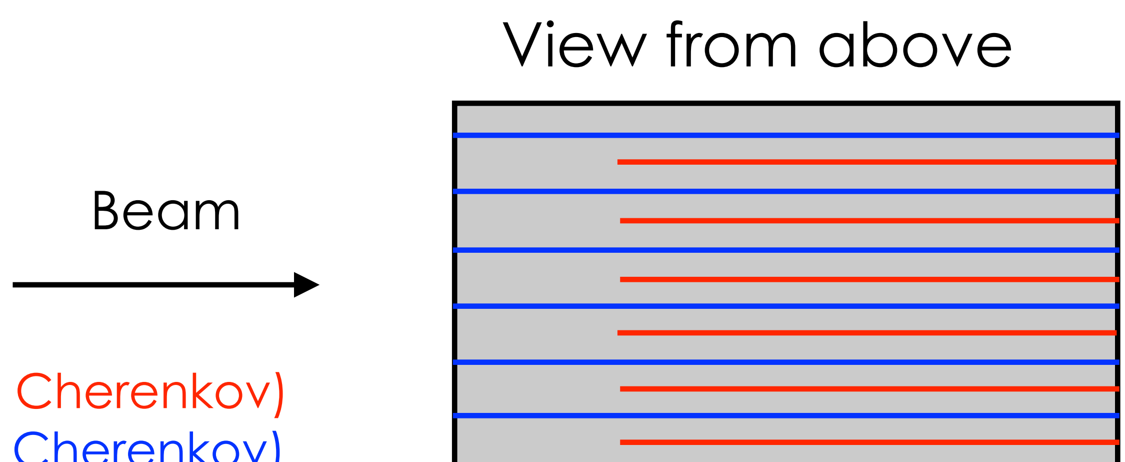


Longitudinal segmentation (standalone test)

- Particle identification (e.g. hadronic tau decay) may benefit from longitudinal segmentation.
- Staggered option tested on beam

“HAD” section: E(short fibres)
“EM” section: E (long fibres) - E (short fibres)

- Challenge: calibration of the short section.

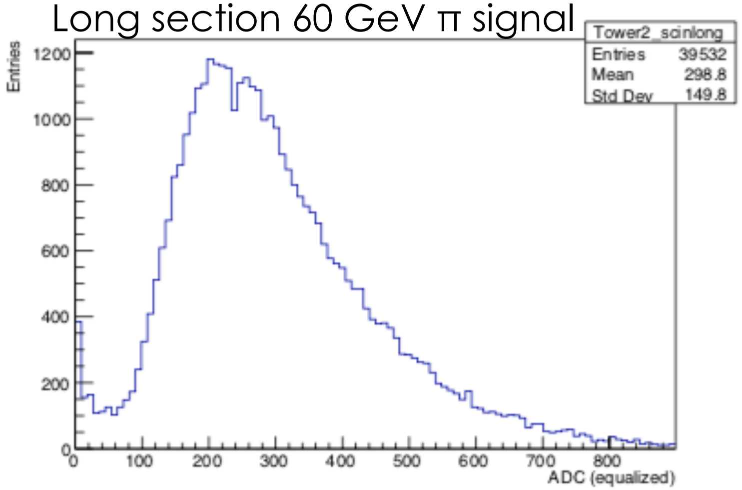


Red: short fibres (scintillation and Cherenkov)
Blue: long fibres (scintillation and Cherenkov)

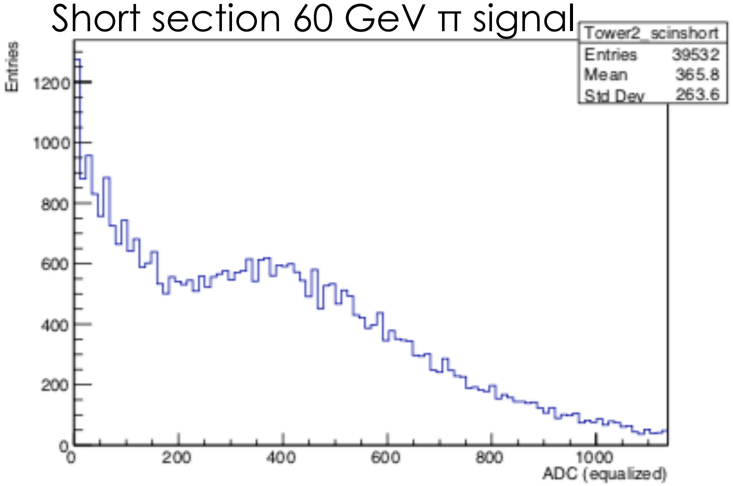
Longitudinal segmentation

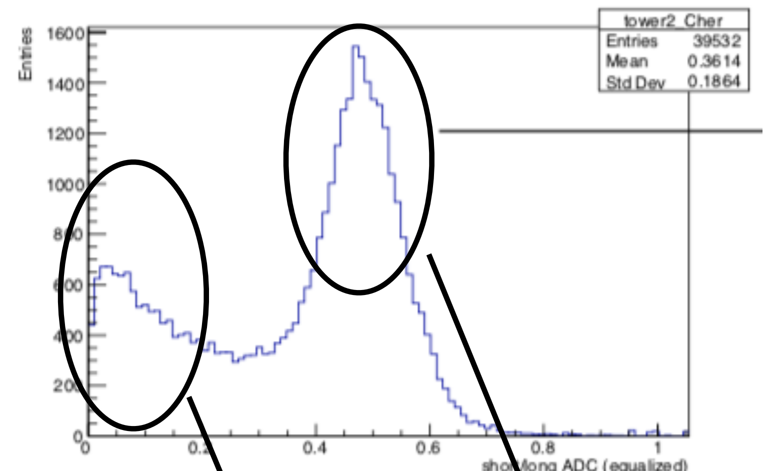
- Problem: how do we calibrate short section?
  - Idea: propagate calibration from long section using hadrons.

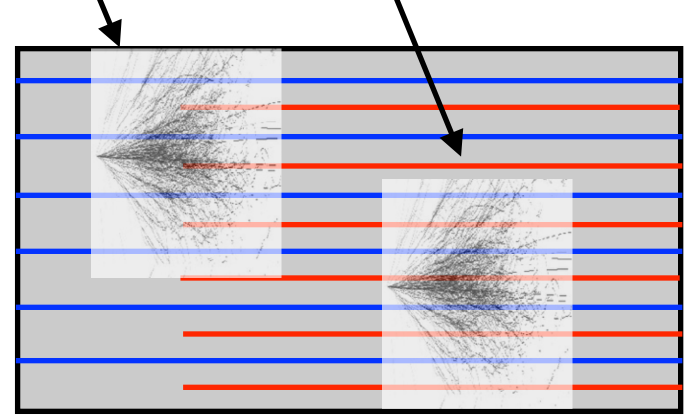
Long section 60 GeV π signal



Short section 60 GeV π signal







Summary

- Dual readout:
  - Excellent EM and HAD native resolution
  - Could be combined with pflow approach if need be.
- 2019 combined test beam + standalone calorimetry:
  - SiPM readout offers potential excellent transverse segmentation
  - Options to introduce longitudinal segmentation being investigated
    - Promising results on calibration

Backup