# Track Segments within Hadronic Showers using the CALICE AHCal

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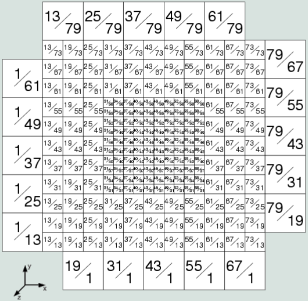
# The CALICE Analog Hadron Calorimeter (AHCal)

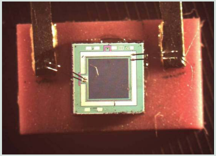
## AHCal Properties

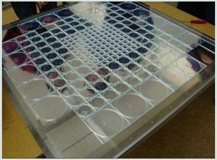
- similar to scintillator HCal of the ILD
- testbeams at DESY, CERN and FNAL
- highly granular ("imaging") calorimeter
- scintillator tiles with SiPM readout
- tile size: $3 \times 3\,\mathrm{cm}^2$ to $12 \times 12\,\mathrm{cm}^2$
- 38 layers of steel absorber $\Rightarrow \approx 5.3\,\lambda$

## layer structure



## SiPM / AHCal layer

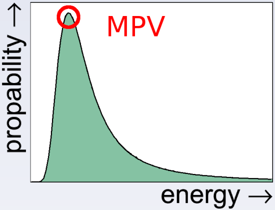




# Calibration of HCal

## Passage of MIPs through thin matter

- Energy deposition: Landau distribution.
- Most Probable Value (MPV) can be used for calibration



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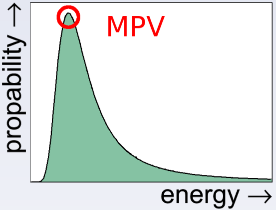


## Classical Approach

Calibration using $\mu$ data (cosmics)

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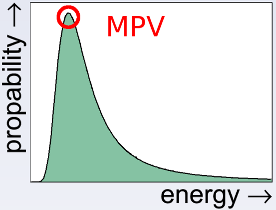


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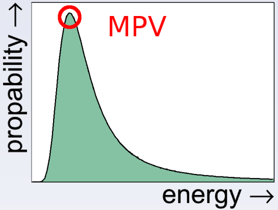


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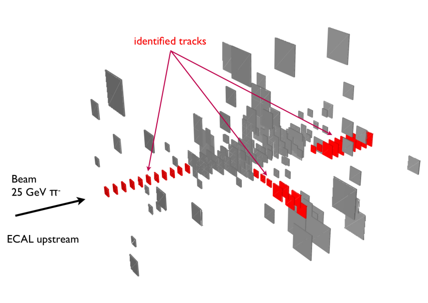
## Idea

- Search for track segments of isolated particles (MIP) in hadronic showers

$+$ Powerful tool sensitive to spatial structure of hadronic showers

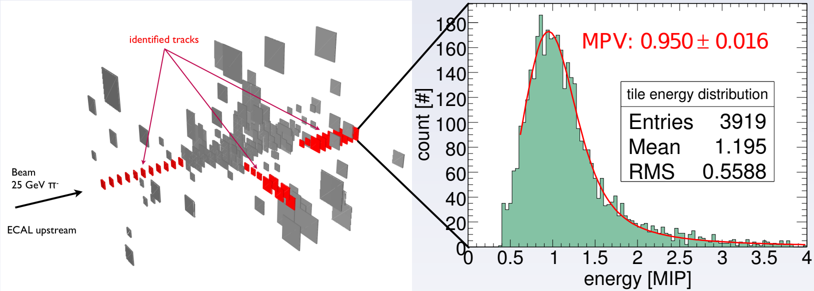
# Isolated track segments in hadronic showers




## Hadronic showers are broad and sparse

- ⇒ Many MIPs leaving the shower core
- ⇒ Many cells only hit by isolated particle
- ⇒ Identfication of track segments possible
  CALICE: $B = 0 \Rightarrow$ non-curved track segments

# Search for track segments within hadronic showers




## Properties of hadronic track segments

- Isolated hits: $\Rightarrow$ MIP $\Rightarrow$ Landau-Distribution
- Sensitive to spatial structure (shower tail)
- Applications:
  - Detector studies (e.g. SiPM temperature dependency)
  - Transport of calibration constants
  - Comparison of Monte-Carlo simulation to testbeam data

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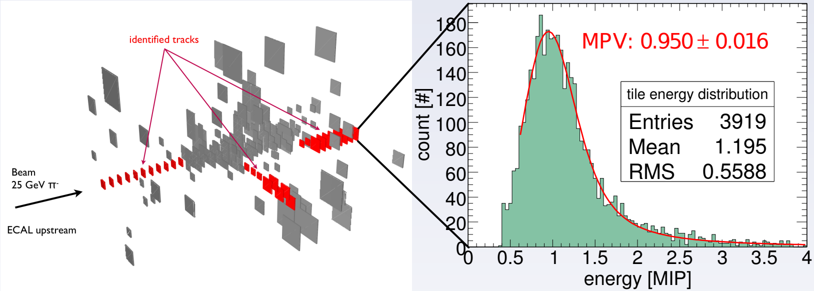


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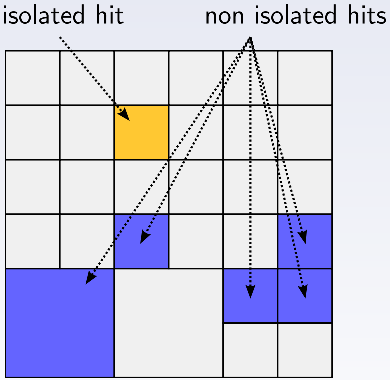
# Searching for MIP tracks: "Follow-Your-Nose"

## Algorithm

1. Find all isolated hits / layer (to reject cells hit by more than 1 particle)



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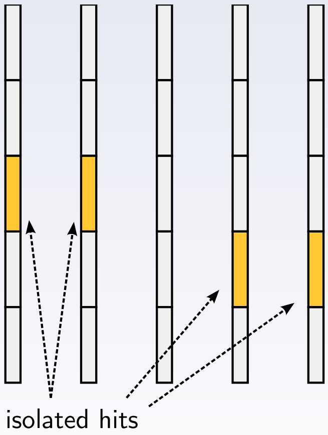

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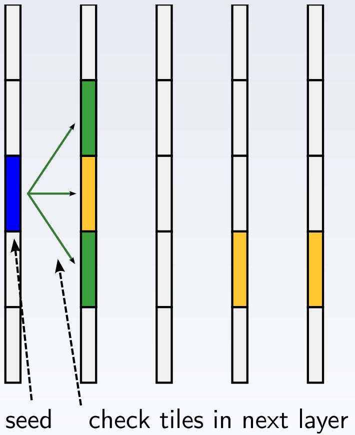

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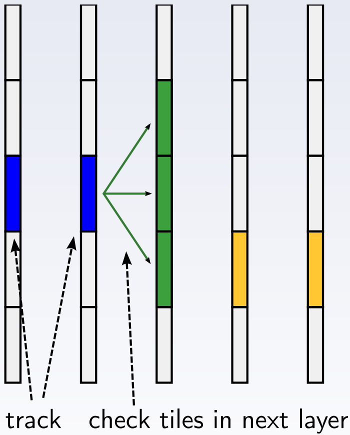

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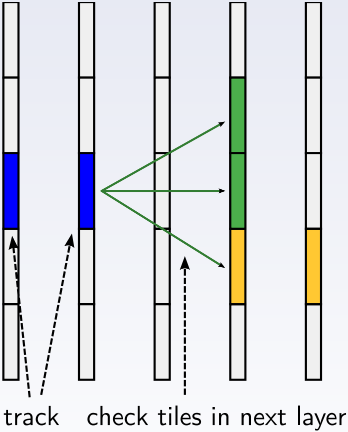

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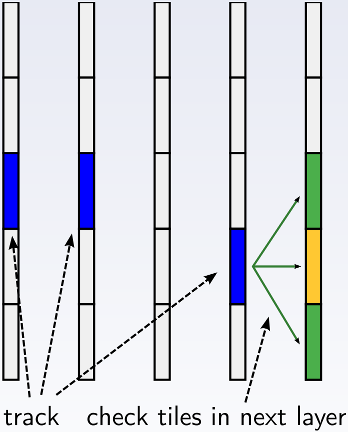

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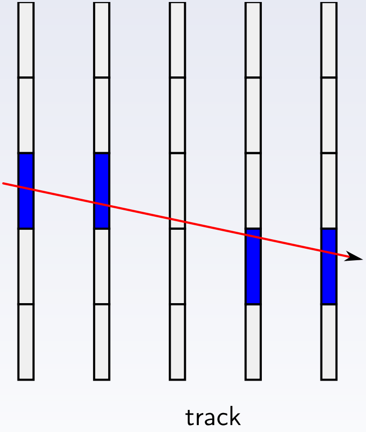
4. Redo until no continuation hit can be found
   ⇒Finished track



# Application example: Transport of Calibration Constants

## Scenario: Calibration of complete detector

- Challenges:
  - Underground location / power pulsing (active: 0.5% of time)
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- Install module into detector
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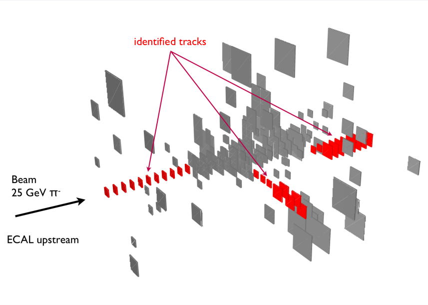
## CALICE Test Scenario

- Use calibration constants from FNAL 2008
- Use data from CERN 2007
- Transform FNAL calibration to CERN conditions ($T$, $U$, ...)
- Reprocess CERN 2007 data with new calibration constant set

# Use tracking to maintain module intercalibration

## Method

1. Search for tracks



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## Method

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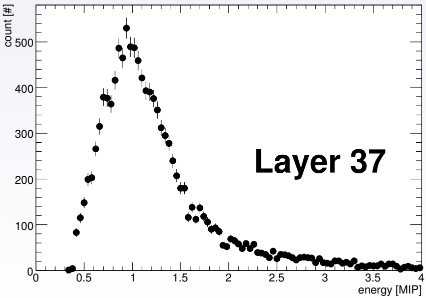
2. Create a single histogram for the energy deposition per module
   $\Rightarrow$ Increase statistics by factor of $\approx 150$



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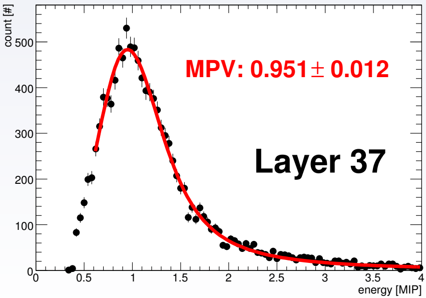

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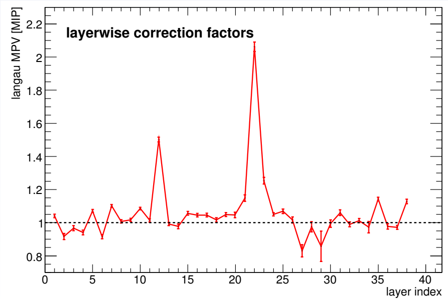
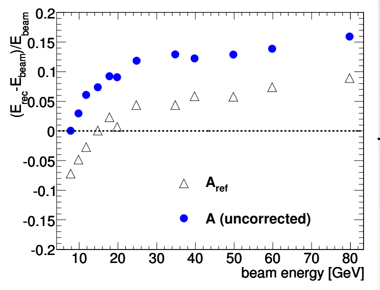
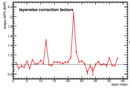


# Relative deviation of reconstructed energy from beam energy




apply module correction




Requirement of full containment of showers in HCal lead to non-linear energy response

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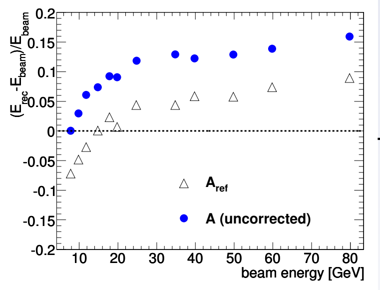


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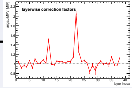
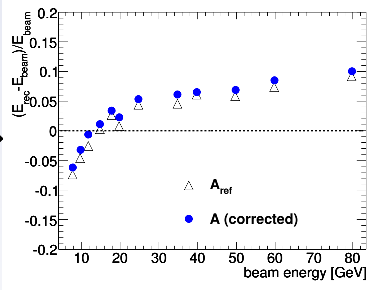



Requirement of full containment of showers in HCal lead to non-linear energy response

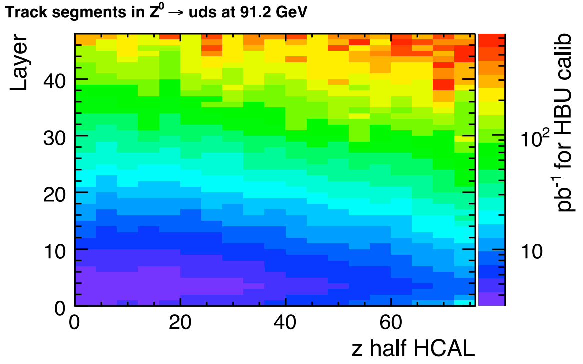
## Conclusion

- Correction decreased the reconstructed energy deviation

⇒ track based module-to-module intercalibration possible

⇒ cell-to-cell intercalibration stable and temp correction under control

# Luminosity needed for Tracking Based Calibration at ILD




⇒ done within a few days plot by S. Lu

| Luminosity | 91 GeV | 500 GeV |
|---|---|---|
| layer module to 3% to layer 20 | $1\,\mathrm{pb}^{-1}$ | $1.8\,\mathrm{fb}^{-1}$ |
| layer module to 3% to layer 48 | $10\,\mathrm{pb}^{-1}$ | $20\,\mathrm{fb}^{-1}$ |
| HBU to 3% to layer 20 | $20\,\mathrm{pb}^{-1}$ | $36\,\mathrm{fb}^{-1}$ |

# Application example: Monte Carlo - Data comparison

## Monte Carlo simulations

- Predictions of hadronic interactions difficult
- Different models exist for various energy regions
  $\Rightarrow$ Combination of models necessary (“physics list”)
- Until now: Use only the shower shapes to compare to data
  $\Rightarrow$ Good agreement

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## Using track finding algorithms

+ More detail on spatial structure
  ⇒ Track properties can be used as comparison observable
- Tracks consist of hits from single MIP like particles
  ⇒ Sensitive to shower tail

# Application example: Monte Carlo - Data comparison

## Simulation: Mokka/Geant4 with physics lists:

- QGSP_BERT
- QGSP_BERT_TRV
- QGS_BIC
- LHEP
- FTF_BIC
- FTFP_BERT

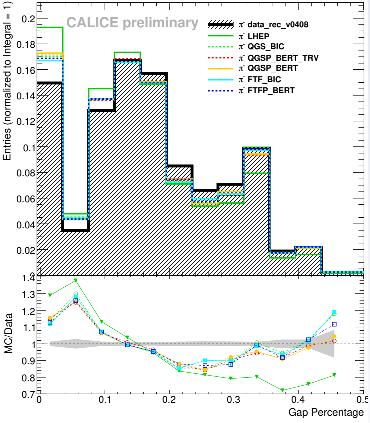
## comparison observables

- track gap ratio: sensitive to correct digitization
- track multiplicity: density and width of shower
- track angle: width of shower
- track length: shower length

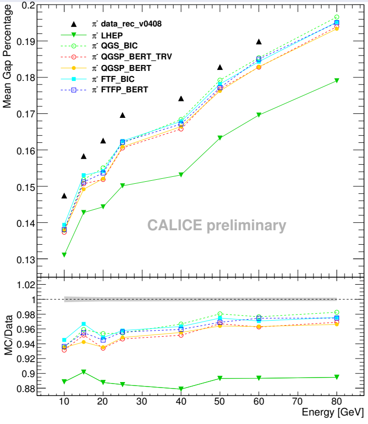
Influence on PFA performance!

# Monte Carlo - Data Comparison: track gap ratio

25 GeV:



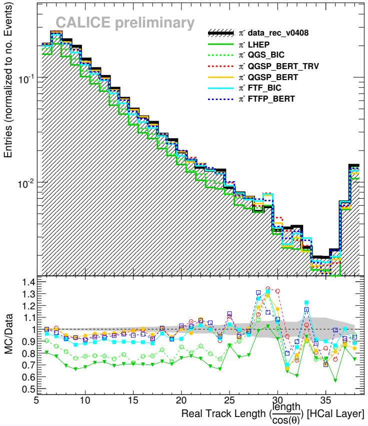

mean value for 10 GeV to 80 GeV:




- Non intuitive structure reproduced in all cases
- Too few gaps in all cases $\Rightarrow$ missing effect in digitization?
- Greatest discrepency for `LHEP`

# Monte Carlo - Data Comparison: track length

25 GeV:

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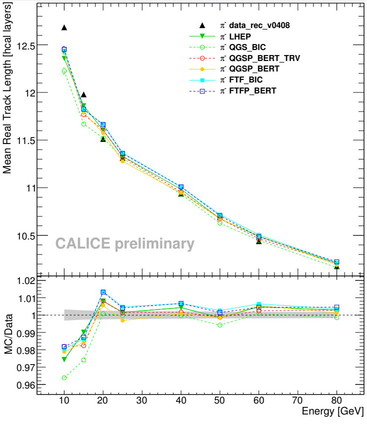
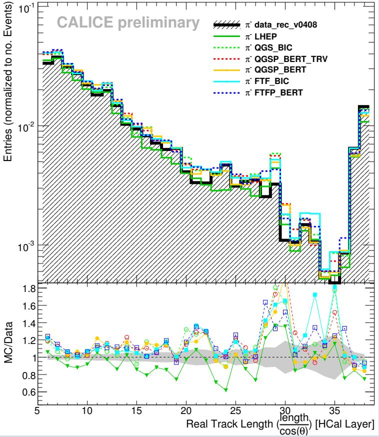


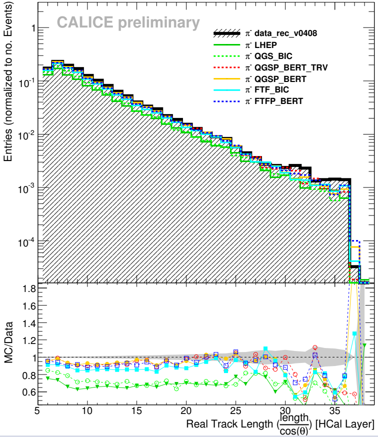

- All physics lists close to each other
- Good modelling of beam composition, well reproduced by all lists
- Discrepencies for low energies and for layer 30
- Exception: `QGS_BIC` and `LHEP`

# Monte Carlo - Data Comparison: track length - Details

## Starting layer 1+2: primary particles



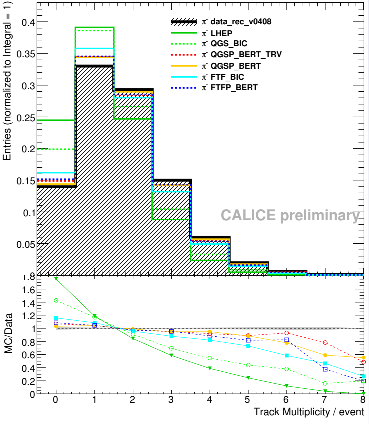

## Starting layer ≥ 3: secondary particles



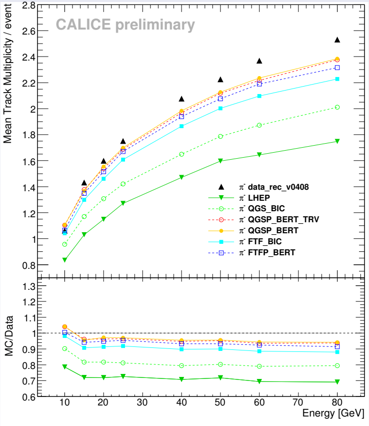

- primary particles: jump in layer 30 ⇒ different geometry
- secondary particles: sensitive to cross section for high $E$ particles
  ⇒ exponential decrease modelled well by all physics list

# Monte Carlo - Data Comparison: track multiplicity

25 GeV:



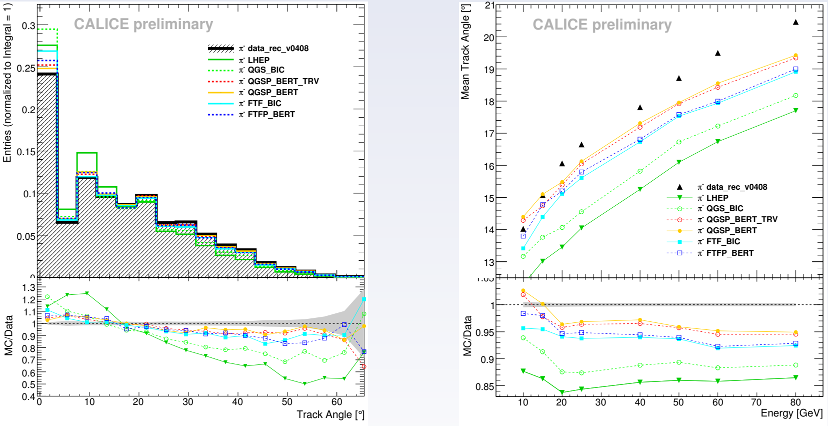

mean value for 10 GeV to 80 GeV:




- All physics lists create too few tracks at high energies
- Group: `QGSP_BERT` , `QGSP_BERT_TRV` , `FTF_BIC` , `FTFP_BERT`

# Monte Carlo - Data Comparison: track angle

25 GeV: mean value for 10 GeV to 80 GeV:




- Too low inclination for tracks of all physics lists
- Same grouping as with mulitplicity
- Biggest discrepency for `LHEP` and `QGS_BIC`

# Comparison Data - Monte Carlo

## Conclusion

- Grouping of QGSP_BERT , QGSP_BERT_TRV , FTF_BIC and FTFP_BERT
  - No big discrepencies to testbeam data
  - mean value compares better than actual distribution
  - Choice of "best" physics lists difficult (QGSP_BERT(_TRV) ?)
- QGS_BIC and LHEP with great discrepencies in track multiplicity and angle
- possible missing effect in digitization

# Conclusion

- Working track finding algorithm:
  - Follow-Your-Nose
- Transport of calibration constants possible
  - ⇒ Presented solution was well recieved by IDAG
- Found tracks provide observables for MC-Data comparison:
  - Sensitive to shower tails
  - Grouping of `QGSP_BERT` , `QGSP_BERT_TRV` , `FTF_BIC` and `FTFP_BERT`
  - `LHEP` and `QGS_BIC` provide too few tracks with too low angles
  - ⇒ Impact on Particle Flow performance

# BACKUP

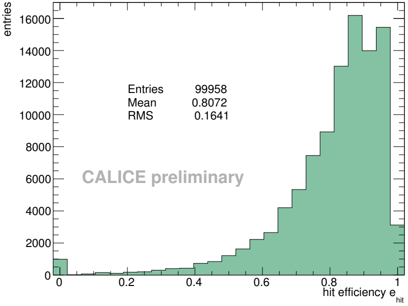
# Efficiency

## Efficiency determination

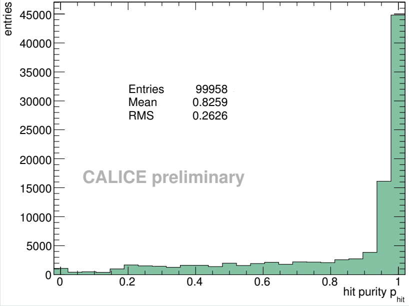
- Based on MC with $\mu$

$\Rightarrow$ Comparison of tracks found with real MC position

### Efficiency




### Purity



# Efficiency

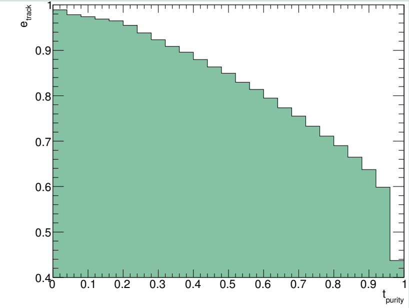
## Efficiency determination

- Based on MC with $\mu$

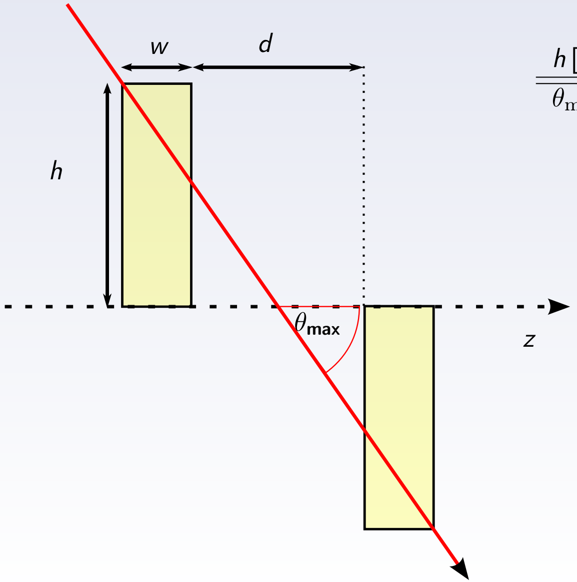
⇒ Comparison of tracks found with real MC position

- Efficiency in identifying parts of the muon track: 98,9%

## Efficiency in Identification of muon tracks with purity $p > t_{\text{purity}}$

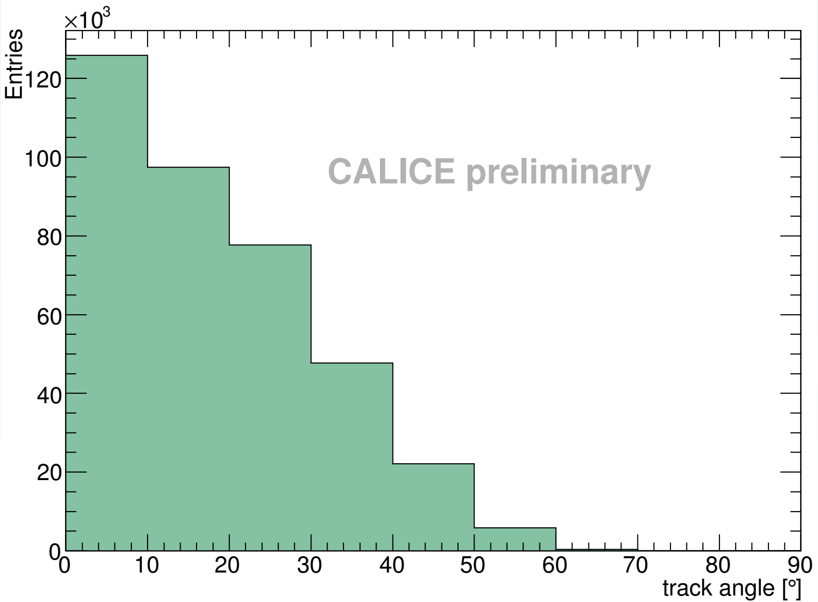


# FYN: max angle

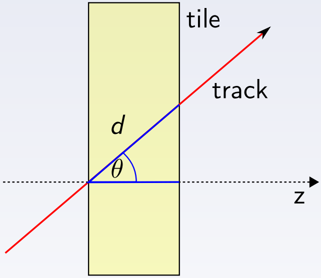



| $h$ [mm] | 30 | 60 | 120 |
|---|---|---|---|
| $\theta_{\max}$ [°] | 58 | 72 | 81 |

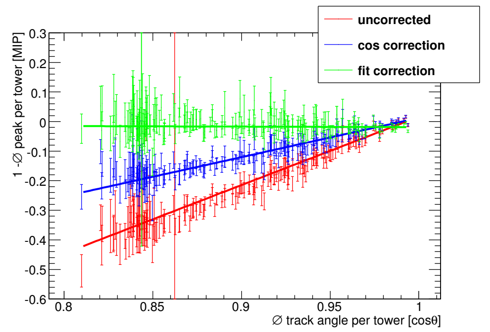
# angle distribution



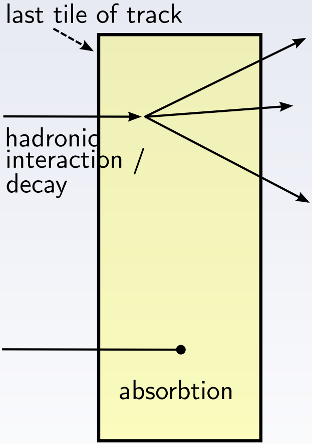
# angle correction

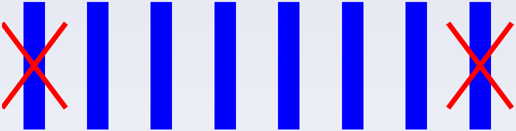


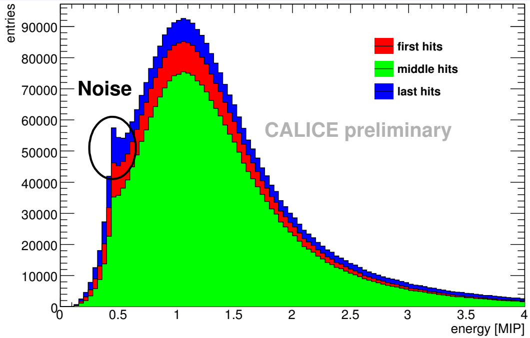

$$E_{\text{used}} = \cos\theta \cdot E_{\text{deposited}}$$



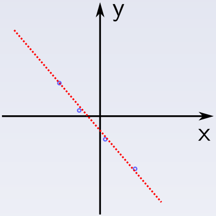
# no first/last hit correction



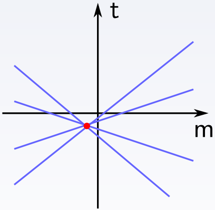


# Hough Transformation based tracking

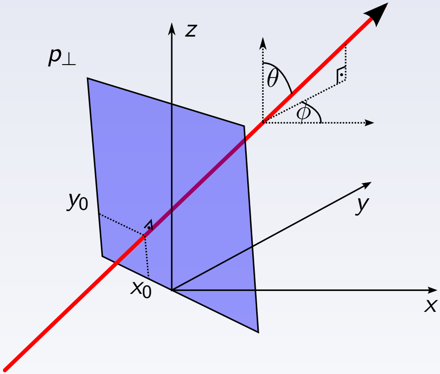



$$y = mx + t \qquad (1)$$

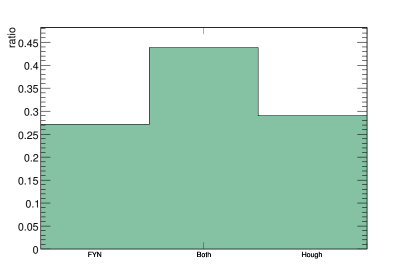
$$\Downarrow$$

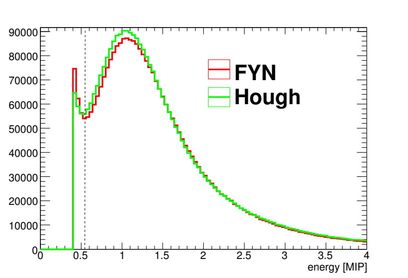


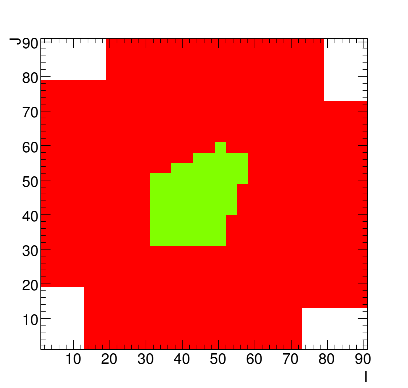

$$t = y - mx \qquad (2)$$

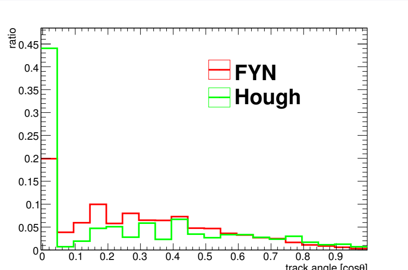


# Differences FYN to Hough

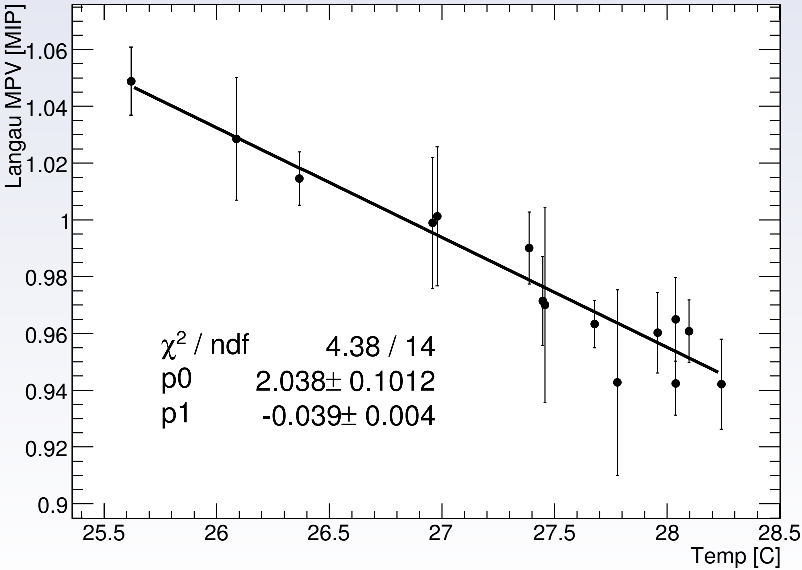


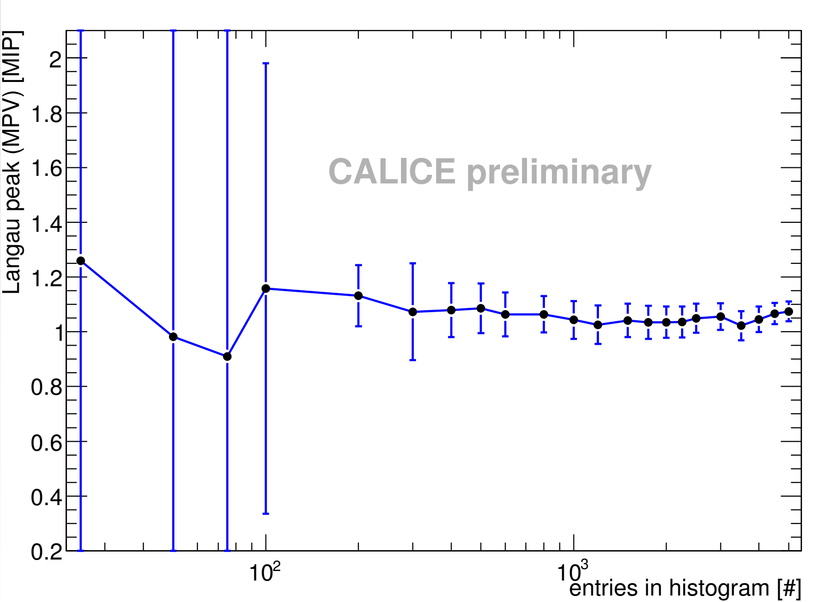



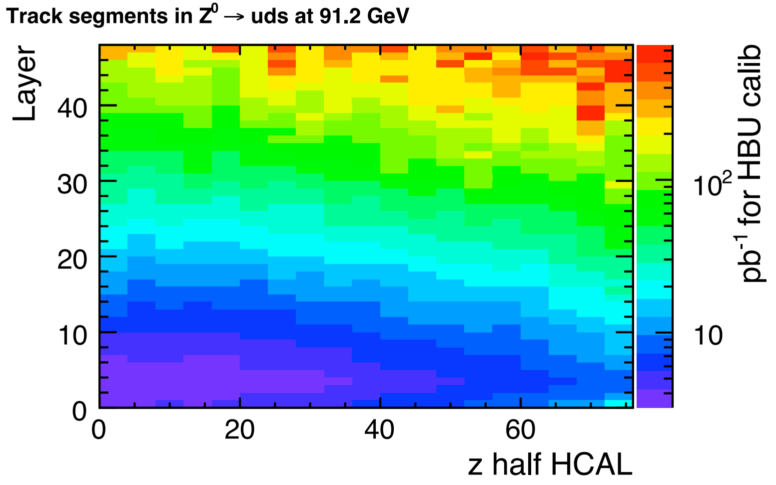
# SiPM temperature dependence



# Langau: statistical fit errors



# Luminosity needed for Tracking Based Calibration at ILD




⇒ done within a few days plot by S. Lu

# Calibration Constant Transportation Calculation

2 possibilities:

$$\begin{aligned} A(\text{TU corr}) &= A_{\text{FNAL}} + \frac{dA}{dT}\Delta T + \frac{dA}{dU}\Delta U \\ A(\text{G corr}) &= A_{\text{FNAL}} + \frac{dA}{dG}\Delta G \end{aligned} \tag{3}$$

- $A$ Calibration constants
- $T$ Temperature
- $U$ SiPM applied Voltage
- $G$ SiPM Gain

# Monte Carlo - data comparison

## used parameters

- FYN algorithm with default settings
  - min length: 6 layers
  - max gap size: 1 layer
- GEANT4 version `4.9.3`
- Mokka version `0703-p01`
- Mokka model `TBCern0707_p0709`

# Geant4 hadronic models and physics lists

- high energy ($E > 20\,\mathrm{GeV}$)
  - QGS: Based on Quark-Gluon-String theory model
  - FTF: Fritiof like theory model
- low energy ($E < 10\,\mathrm{GeV}$) cascade models
  - Bertini
  - Binary
- $E < 10\,\mathrm{MeV}$: Chiral Invariant Phase Space (CHIPS)
  - photo-nuclear and electro-nuclear
  - stopping negatively charged particles at rest in nuclei
- nucleus dexcitation: precompound model
- parametrized models: LEP and HEP $\rightarrow$ LHEP
  - Based on GHEISHA from Geant3
  - Fast, but not as accurate as theory driven models
  - Used as backup if other models don't provide data