Hadron energy measurement in the sampling calorimeter

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for CALOR2014 @ Giessen

event by event based analysis
with fine samplings
Hadron measurement

- H interaction length $\sim 10\text{cm}$
  $\gg X_0 \sim 1\text{cm}$ radiation length for EM interaction
- once a pi-zero produced
  EM shower emerges $E_{EM} \gg E_{\pi^{+}-}$
- nuclear interactions
  - photons and neutrons
  - $e^{-}$ evaporation / spallation
Hadron measurement

- H interaction length ~10 cm >> $X_0 \sim 1$ cm radiation length for EM interaction
- once a pi-zero produced EM shower emerges $E_{EM} \gg E_{\pi^+\pi^-}$
- nuclear interactions
  - photons and neutrons
  - e- evaporation / spallation
CALICE AH CAL

experimental data

• (steel 20mm + sc. 5mm) x 38 layers

• pions incident: 8 & 18 GeV

• **longitudinal** shower profile: \( z \)
  - FTFP_BERT model Geant4

• (1) **electrons from** \( \pi^0 \)

• (2) **protons**

• (3) **charged pions** ~ MIP
  - JINST 8, 2013, P07005
event data

- CALICE AHCAL events
- experimental data
- without selection

**Spike**

32GeV pions

layer \{(e)*(nevt==10001)\}

layer \{(e)*(nevt==10002)\}

spike

steel 20mm + sc. 5mm

layer num.
event by event

- **simulation**: longitudinally fine segmented calorimeter
- **QGSP_BERT**
- found spikes
- high dE in a layer
- due to protons

![Graph showing energy deposit in layers for different particle types at 5 GeV.](image)

- black: total
- green: proton
- cyan: heavy ion
- red: electrons
- blue: pi+-

Layer num.
event by event

- **simulation**: longitudinally fine segmented calorimeter
- **QGSP_BERT**
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5GeV $\pi^-$

layer num.

- black: total
- green: proton
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- red: electrons
- blue: pi+-

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CALOR2014
a spike in H-int.

- a simulated event
- **positive** charged recoil
- **proton** from np→pn
- spallation neutron
- timing ~0
- Tn~Tp~50MeV
a spike in H-int.

- a simulated event
- **positive** charged recoil
- **proton** from np→pn
- spallation neutron
- timing ~0
- Tn~Tp~50MeV
dE vs layer

- simulation dE/layer
- QGSP_BERT
- proton contribution
- makes spikes

Energy Deposit in layer

steel 20mm+sc.5mm
5GeV π-

black : total
green : proton
cyan : heavy ion
red : electron
blue : pi+-

Layers Number

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CALOR2014
proton energies

- $E_{\text{proton}}$ cut applied
- most of spikes are low $E$ from spallation

Esum in a event for particles

<table>
<thead>
<tr>
<th>Edep</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
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<tbody>
<tr>
<td></td>
<td>1000</td>
<td>25.89</td>
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dE/layer (sum)

T. Takeshita  Esum (MeV-MIP)  Esum (MeV)  CALOR2014
proton energies

- \( E_{\text{proton}} \) cut applied
- most of spikes are low \( E \) from spallation

\( E_{\text{proton}} > 1125 \text{MeV} \)
\( T_p > 200 \text{MeV} \)

Energy Deposit

E_{\text{sum}} \text{ in a event for par}

dE/layer
(sum)

energy deposit / layer
black: total
green: proton
cryan: heavy ion
red: electrons
blue: \( \pi^{+-} \)
spikes in liq./gas

- liq. Ar has spikes: spallation protons
- no spikes in gas detector

### Pb10+LiqAr5

Energy Deposit in layer

### Fe25+gasAr5

Energy Deposit in layer

- **5GeV π-**

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<th>RMS</th>
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<td>19.89</td>
<td>13.12</td>
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**Energy Deposit in layer**

<table>
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<tr>
<td>black: total</td>
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CALOR2014
how to avoid spikes

- a 5GeV pion event: 3 spikes from proton Pb10+sc.5mm

an event

![Energy Deposit in layer graph]

- 1 total
- 3 green; proton
- 7 air-blue: heavy ion
- 2 red; electrons
- 4 blue: pi+-

scintillator layer

EMshower at layer = 30
how to avoid spikes

- a 5GeV pion event: 3 spikes from proton Pb10+sc.5mm

graph:

- Energy Deposit in layer
- Cerenkov photon N:
  - Entries: 100
  - Mean: 33.11
  - RMS: 14.98

layers:

- EM shower at layer=30
- red~Nphotons in abs. layer
- EM shower indicator
Cerenkov light

- EM shower detection in absorber
- utilizing Cerenkov light det.
- good correlation low probability

5 GeV π⁻ into Pb10+sc.5 HCAI

~num. Cerenkov photon

dE in scintillator
summary & outlook

- hadrons make **spikes** in the sampling calorimeter
- by low energy protons due to Bragg peak
- makes large fluctuation in energy measurement
- to avoid them, Cerenkov in absorber can help
- need to develop technique to measure in sampling CAL.

An event

Energy [MeV]

~mips

Nlayer
spike rejection

- spikes could be avoided by
- fine lateral segmentation
- localized in a small unit
- find & remove a spike hit
- little effect to total energy measurement
**Figure 14.** Longitudinal energy profiles for 12 GeV $\pi^-$ data (shown as points), compared with simulations using different physics lists. The mean energy in MIPs is plotted against the depth after the initial interaction, in units of effective 1.4 mm tungsten layers. The total depth shown corresponds to $\sim 20 X_0$ or 0.8 $\lambda_{\text{int}}$. The breakdown of the Monte Carlo into the energy deposited by different particle categories is also indicated.

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HADRON CAL.
20GeV pi- with longitudinal segmentation

Energy Deposit in layer

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Layer Number
0 10 20 30 40 50 60 70 80 90 100

deposit Energy/ev/l [MeV]
0 20 40 60 80 100 120 140

3 green ; proton
7 air-blue: heavy ion
2 red ; electrons
4 blue : pi+-

simulation
Birks’ low

one event

Total proton !

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CALOR2014
HADRON CAL. 20GeV pi- with longitudinal segmentation

Energy Deposit in layer

- one event

- 3 green; proton
- 7 air-blue: heavy ion
- 2 red; electrons
- 4 blue: pi+-

Energy Deposit in layer

- one event

3 green; proton
7 air-blue; heavy ion
2 red; electrons
4 blue; pi+-

Simulation Birks’ low

One event

1000ev sum

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