W-AHCAL data analysis

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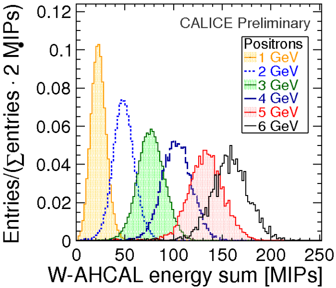
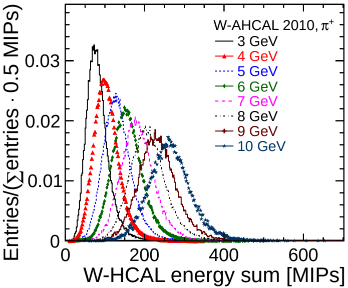
on behalf of the CALICE W-AHCAL group

2010 data: CERN PS, 1-10 GeV

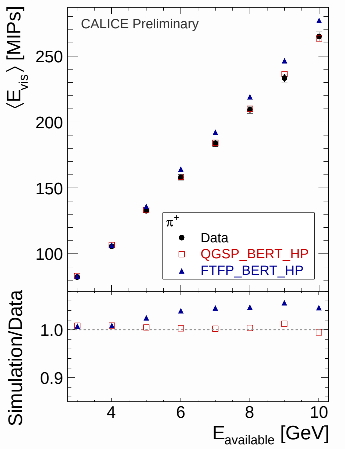
- May 2012: CALICE analysis note ‣ CAN-036
  Shower development of particles with momenta from 1 to 10 GeV in the CALICE Scintillator-Tungsten WHCAL
- Particle ID based on Cherenkov triggers
- To increase samples purity, additional selection cuts using calorimeter's high granularity





2010 data

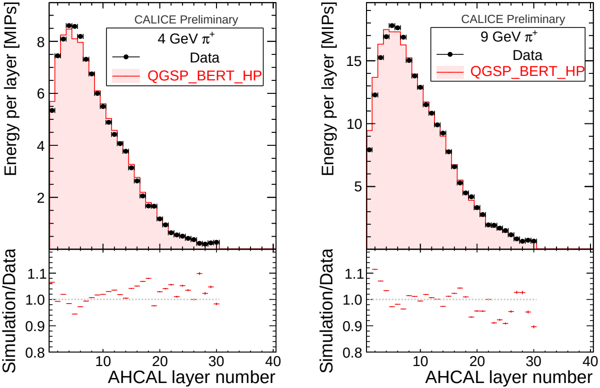
- Compared data with simulation models including the high precision (HP) package, which describes neutron interactions with $E < 20$ MeV
- At low beam energies, the energy available for deposition in calorimeter is important: $\pi: \; E_{available} = \sqrt{p_{beam}^2 + m_\pi^2}$
- *QGSP_BERT_HP* is found to give very good agreement for both pions and protons (better than 97% for most of the studied variables)



- Data: $\langle E_{vis} \rangle = a + b \cdot E_{available}$

a [MIPs]	4.64 ± 1.92
b [MIPs/GeV]	25.61 ± 0.37
χ^2/ndf	$2.7/6$

2010 comparison with simulation: longitudinal profiles

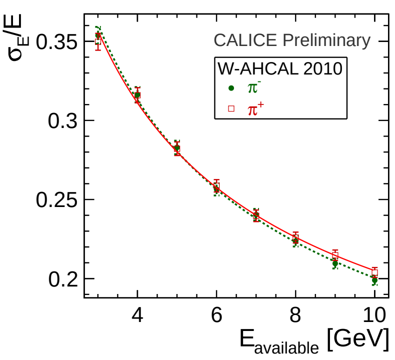


- In general agreement better than 95%, with the exception of the first layer

2010 π^+/π^- energy resolution

- Energy spectra of low energy hadrons are non-Gaussian

  $\Rightarrow$ Energy resolution measured as: $\frac{\sigma_E}{E} = \frac{RMS}{Mean}$



- Fit function:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E[\mathrm{GeV}]}} \oplus b \oplus \frac{c}{E[\mathrm{GeV}]}$$

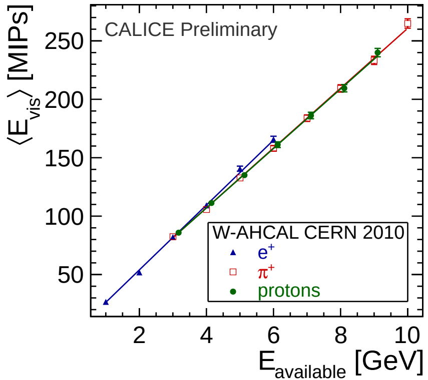
Parameter	π^-	π^+
a [%]	61.9 ± 1.0	60.3 ± 1.1
b [%]	4.2 ± 2.2	7.5 ± 1.3
c [MeV]	71	72
χ^2/ndf	3.3/6	3.2/6

backup

Calorimeter response

- e^+: mean visible energy obtained from Novosibirsk fit
  - slightly different slope compared to hadrons
- π^+, *protons*: statistical means

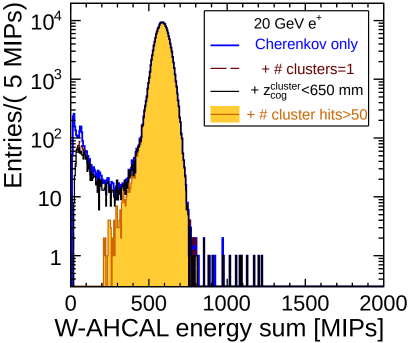
Calorimeter response is similar for all 3 particle types in the analyzed low energy range ($1\ \mathrm{GeV} \leq p_{beam} \leq 10$ GeV)



2011 e^+/e^- selection

Disclaimer: all 2011 figures show work in progress (i.e. not final results)

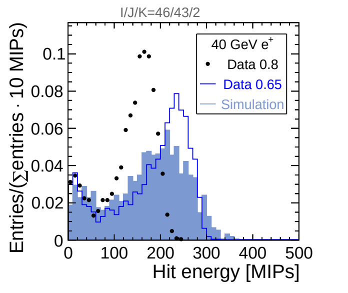
- CERN SPS, e^+/e^- with energies from 10 to 40 GeV
- Electromagnetic showers in W-AHCAL have small lateral size (∼few tiles) and deposit most of their energy in the first 5 layers
- Selection based on clusters (algorithm developed by B. Lutz, DESY-THESIS-2010-048): number of clusters, *z*-position of cluster, minimum number of hits in the cluster



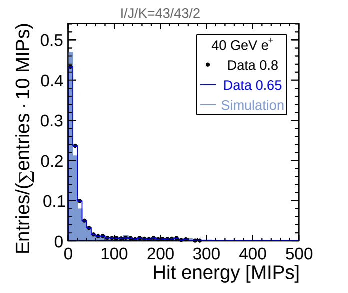
2011 e^+ comparison with simulation

- To correct for saturation, measured SiPM response curves are scaled by a factor of 0.8 by default $\rightarrow$ This results in disagreement between data and Monte Carlo
- Comparison of energy spectra for individual channels with simulation show that different factors are needed, i.e. 0.65 for channel $I/J/K = 46/43/2$

Central tile



Neighbouring tile



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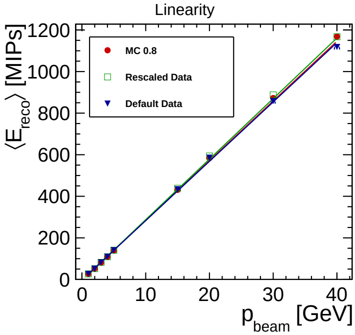
e^{+} analysis



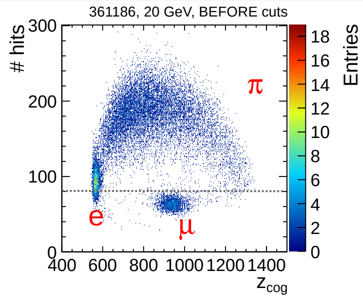
- Default data: global scaling of 0.8 for all channels
- Rescaled data: 0.65 for $I/J/K = 46/43/2$, 0.8 for other channels
- E_{reco} is the mean of Novosibirsk fit
- Linear fitting parameters: $a \cdot x + b$

	a [MIPs]	b [MIPs/GeV]	χ^2/ndf
MC	28.73 ± 0.13	-3.03 ± 0.32	7.2
Rescaled data	29.13 ± 0.13	-3.61 ± 0.33	9.0
Default data	28.54 ± 0.13	-2.71 ± 0.32	6.9

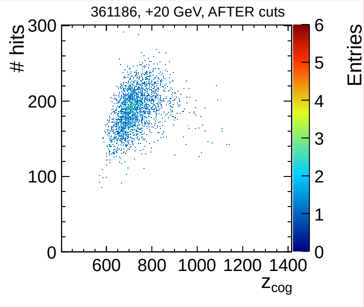
2011 hadron selection

- CERN SPS, mixed beam: electrons, pions, kaons and protons; energies from 10 to 180 GeV
- Electron rejection: based on clusters
- **Events with early showers**, i.e. shower start in the first 3 calorimeter layers
- Example for run 361186 (+20 GeV): 8 mm Pb absorber in beamline ⇒ still significant fraction of electron events
- Note: most runs taken with **18 mm Pb absorber in beamline**

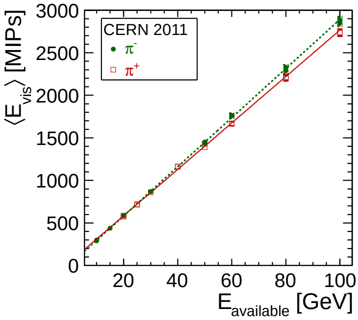
Before selection

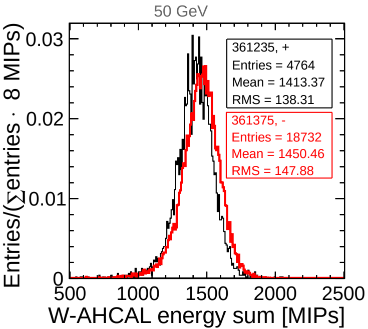


After selection



π^+/π^- analyses



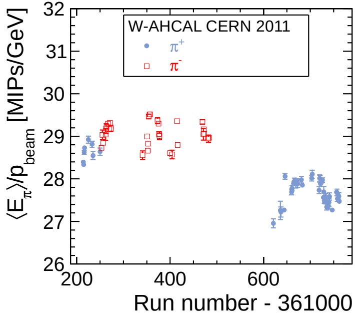


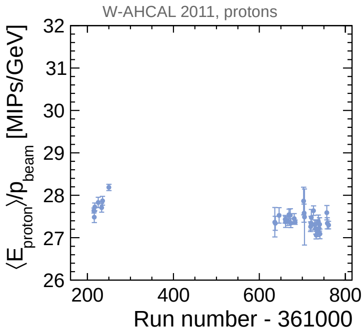
- Significant differences between π^- and π^+
- Temperature variations ≤ 5 deg. C
- Temperature correction not good enough?

- But even runs with same temperature show differences
- To be able to compare several energies, look at E_{hadron}/p_{beam} ratio, but only up to 100 GeV (to limit leakage effects)

$\pi^+/\pi^-/proton$ analyses

- Drop in calorimeter response to pions (about 5%) for runs taken in Sept./Oct. 2011 (run number > 361600)
- Decrease not visible in proton data (same runs, just different Cherenkov selection)

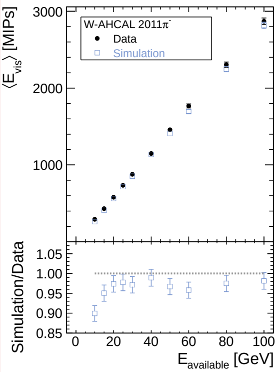




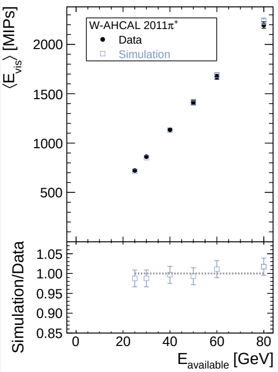
2011 comparison of data with simulation

- Simulation: *QGSP_BERT_HP*

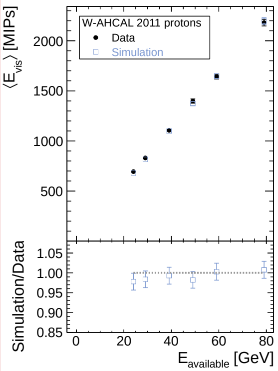
π^-



π^+

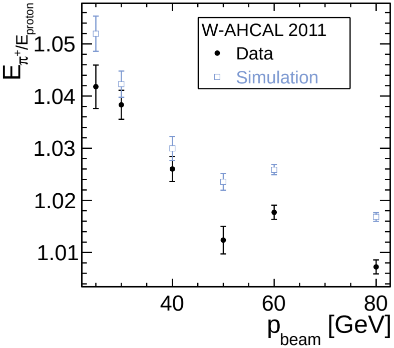


Protons



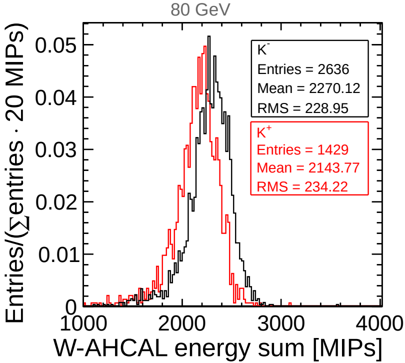
$\pi^+/proton$ ratio

- For a non-compensating calorimeter ($e/h > 1$), expect $E_{\pi^+} > E_{proton}$
  - baryon number conservation favours production of leading baryons $\Rightarrow \pi^0$ ($\rightarrow \gamma$) production is, on average, smaller in proton induced showers



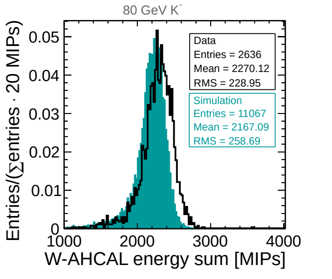
- Agreement between data and simulation not perfect, but same trend observed
- $E_{\pi^+}/E_{proton} \lesssim 1.05$

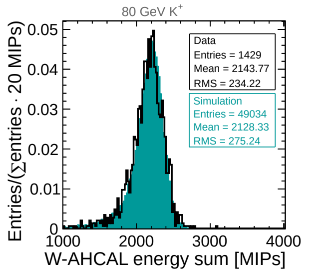
K^- vs. K^+



- Differences between K^- and K^+
- Let's see what Monte Carlo predicts

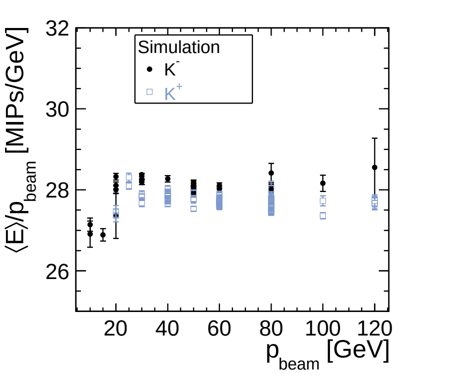
Data vs. simulation



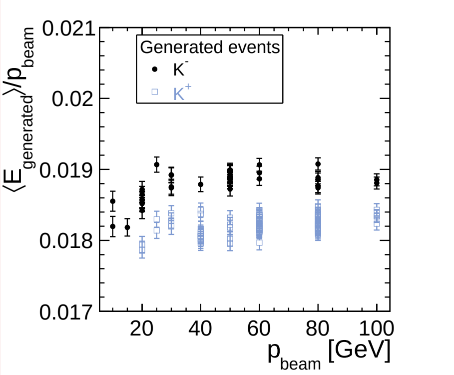


Simulation: K^- vs. K^+

Reconstructed MC



Generated MC



- Markers corrrespond to different runs
- Simulation predicts a small difference between K^+ and K^-
- Not due to detector effects, but present already in GEANT4, maybe due to $\sigma_{K^- nucleon} > \sigma_{K^+ nucleon}$

backup

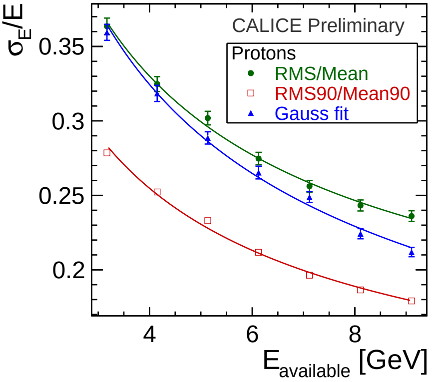
Conclusions

- **2010** data: CALICE analysis note CAN-036
- **2011** data:
  - e^+/e^-: studies of scaling factors for the SiPM response to obtain a better agreement between data and Monte Carlo
  - π^+/π^-: significant differences in calorimeter response, depending on time (ongoing work to identify the source)
  - K^+/K^-: small statistics, about 1500 events for 60/80 GeV, but with tight cuts
- For many more details: here you can follow our (almost) weekly meetings on indico

Backup slides

2010 data: comparison of methods to measure hadronic energy resolution

- **RMS90**: RMS of the region containing 90% of the statistics
  - overestimates the energy resolution
- **Gauss fit**: $\frac{\sigma_E}{E} = \frac{\sigma_{Gauss}}{\mu_{Gauss}}$
  - similar to RMS method



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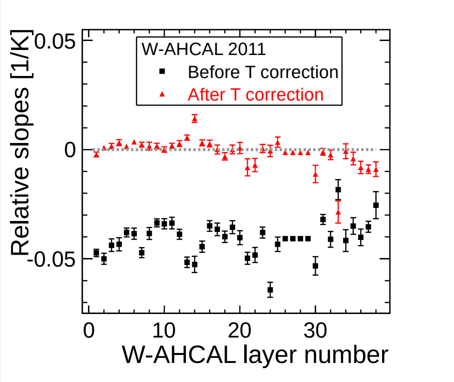
2011 MIP temperature correction

- Idea: use a slope per layer (as for 2010 data)
- Method:
  - find muon hits in hadron runs, using Lars' track finder
  - fit hit energy spectra of hits in a given layer and measure corresponding slope

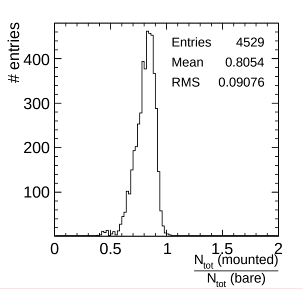
- Before T correction: average slope -4.1%/K
- After T correction: average slope -0.1%/K
- A few layers show no muon peak: their slope is set to average

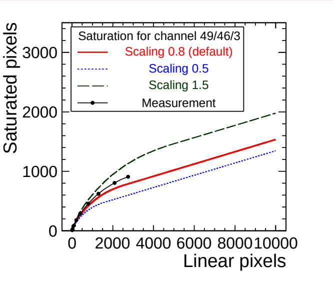


SiPM response curves

- SiPM signal $= \sum N_{fired\ pixels}$
- But: limited number of pixels (1156) and finite pixel recovery time (20–500ns) ⇒ **non-linear** response curve (i.e. saturation)

- Ratio of maximum number of fired pixels, N_{tot}(mounted), measured with SiPM mounted on a tile to N_{tot}(bare) measured directly with bare SiPMs (from arXiv:1012.4343)
- The measured saturation curves are scaled with a global factor of 0.8 (average)





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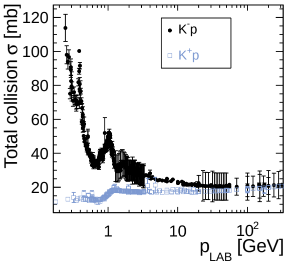
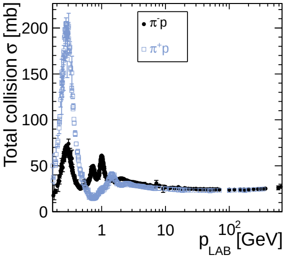
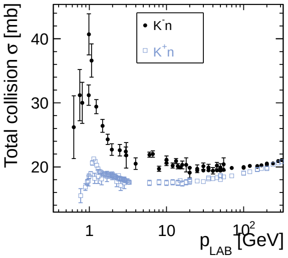
Simulation: K^- vs. K^+







- Cross-sections from
  http://pdg.lbl.gov/2012/hadronic-xsections/
- Small difference for K^-/K^+
- π^+/π^- the same (for $p_{LAB} > 1$ GeV)

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