First test-beam experience with the CALICE tungsten A-HCAL prototype

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Outline

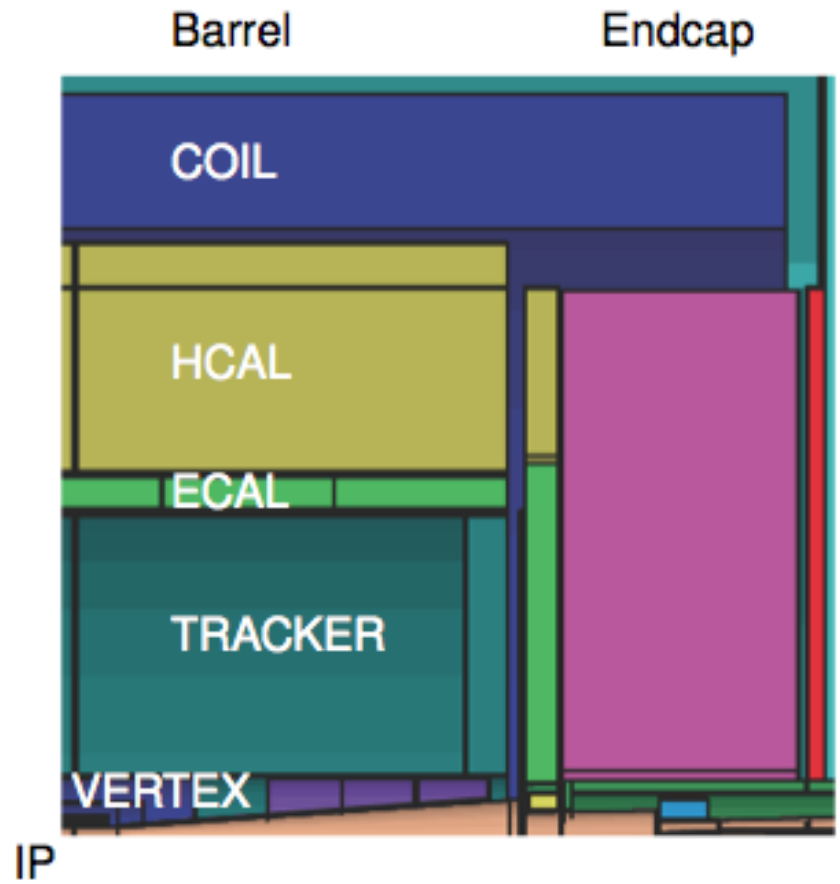
- Tungsten for hadronic calorimetry
- W-AHCAL test-beam setup
- Calibration and particle identification
- Data quality assessment

Hadronic calorimetry at 3 TeV

- Resolution of hadronic calorimetry driven by:
  - Intrinsic resolution
  - Leakage (number of λ_i)

- To maximize number of λ_i:
  - Increased depth
  - Denser absorber

- Depth severely constraint by:
  - Feasible coil size for large B-field
  - Size of tracker needed for good momentum resolution



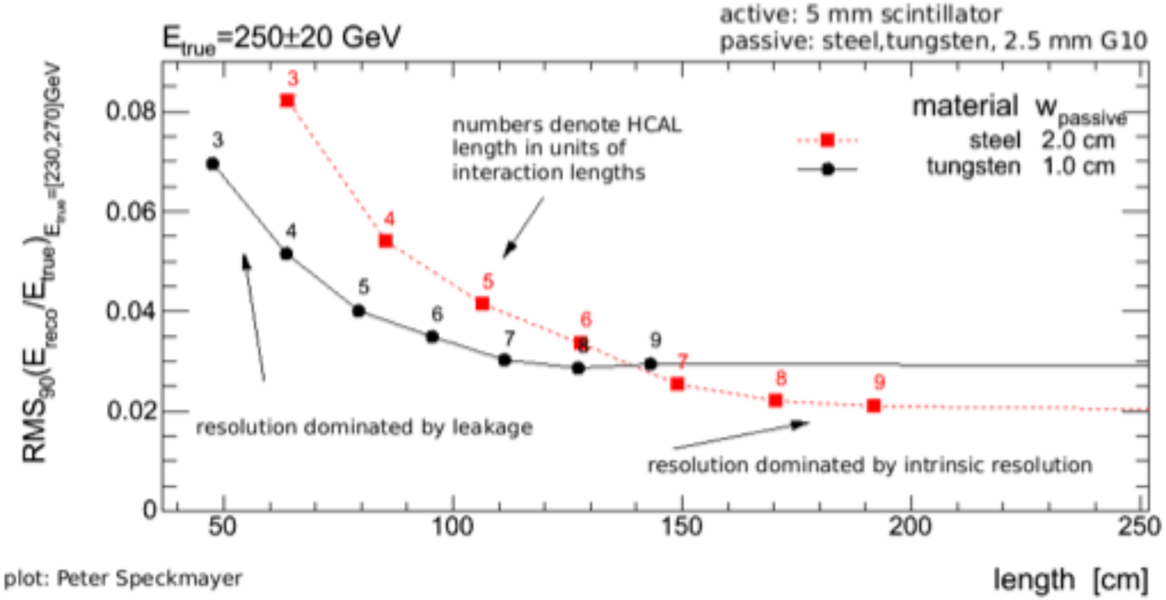
→CALICE investigates dense absorbers for hadronic calorimetry

Simulation results at 3 TeV

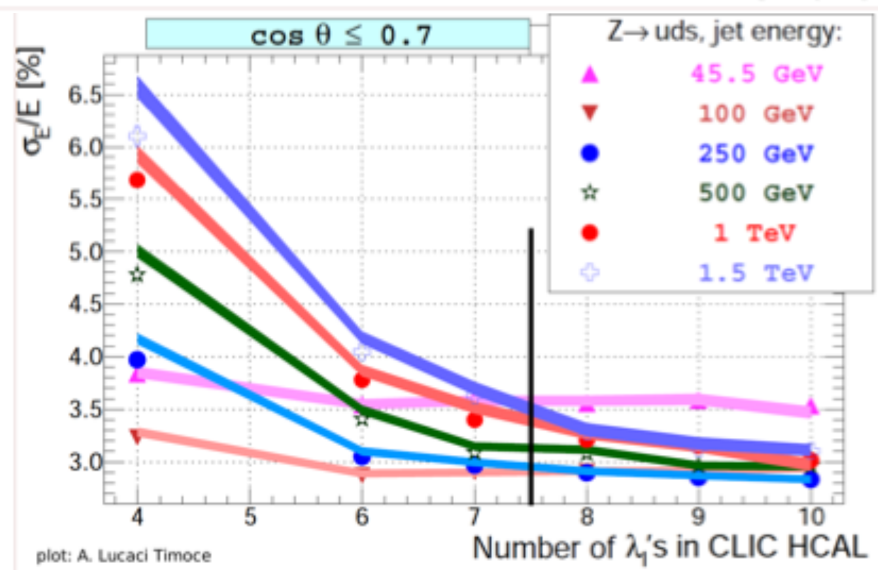
- Shorter HCal leads to:
  - more leakage
  - worse resolution

- Flat region reached at smaller depth for **tungsten** than for **steel** absorber

Energy resolution for single π, reconstr. with neural network:



- For E_{jet}<50 GeV: resolution constant, dominated by intrinsic resolution
- For E_{jet}>100 GeV: leakage dominates resolution



→Aim for HCAL depth of 7.5 λ_i (+1 λ_i from ECAL)

Tungsten as absorber material

- Expected benefits of tungsten absorber vs. iron:
  - λ_i(W) = 10 cm; λ_i (Fe) = 17 cm

  → Less leakage for same depth → more showers contained

  → Smaller shower diameter → better separation

- However: little experience with tungsten for hadronic calorimetry
  - So far: tungsten used for EM calorimetry (~1 λ_i)
  - No experience with tungsten in HCALs (4-9 λ_i)
  - Simulation of hadronic showers in tungsten not validated
    - No data/MC comparisons
    - In particular: no validation with high granularity
    - Low-energy spallation neutrons increased, less ionization

      → Late component of shower more important, making time stamping more challenging

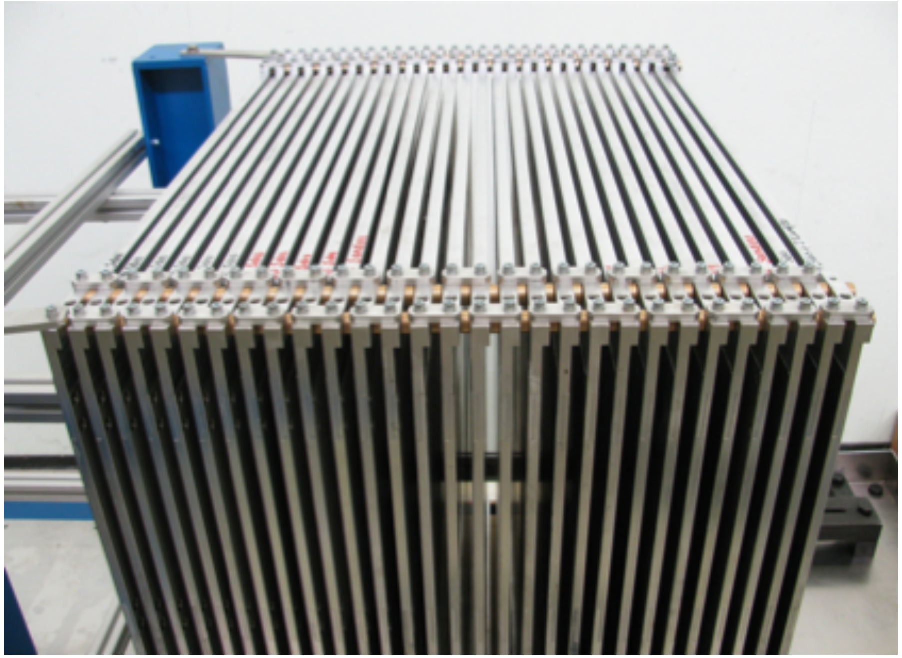
- Goal of CALICE test-beam program with tungsten absorber:
  - Validate particle-flow based calorimetry for CLIC conditions
  - Help to improve/validate Geant-4 simulation models

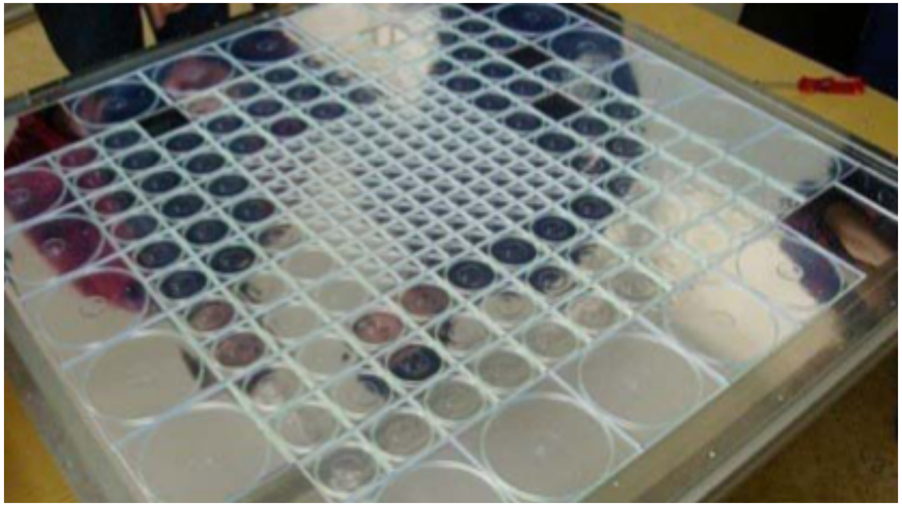
W-AHCAL prototype

- Tungsten Absorber:
  - 30 plates of 10 mm thickness
    1 x 1 m^2 surface
- Active material:
  - Scintillator tiles of
    3 x 3 cm^2 (center) and
    6 x 6 cm^2 (edges)
- Total depth incl. supports: ~3.8 λ_i

- Readout:
  - Light collection via WLS fibres,
    readout with multi-pixel SiPMs
  - MICROMEGAS in last readout layer
  - T3B high-precision timing meas.
    behind last readout layer
    (cf. talk by F. Simon tomorrow)

→will concentrate on SiPM readout in the following





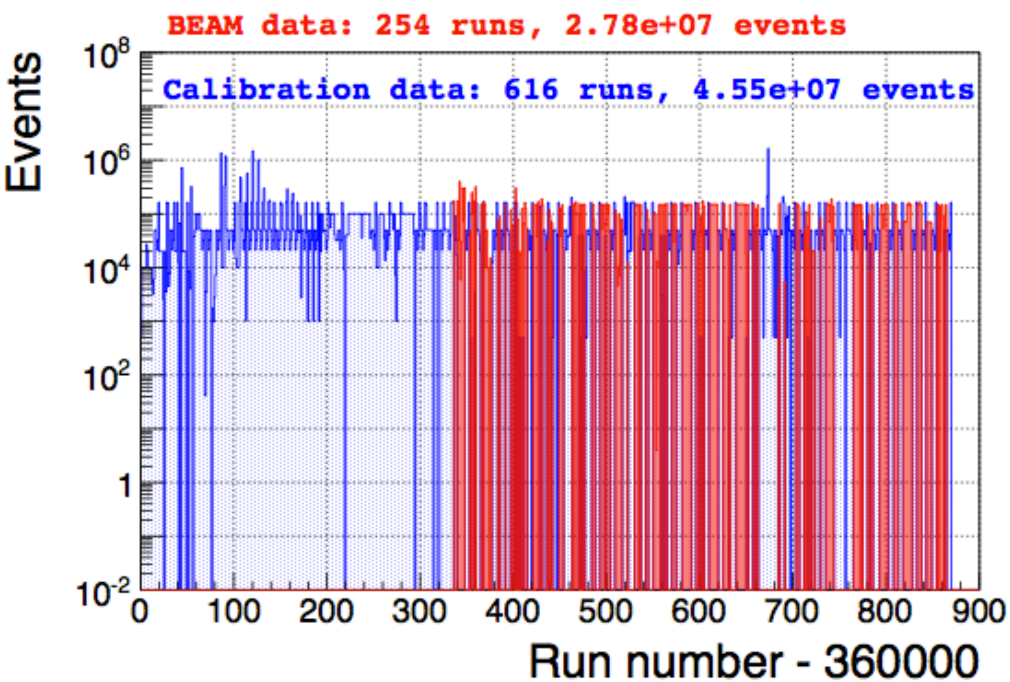
Test beam at CERN-PS

•Several weeks of low-intensity μ runs in T7, to obtain MIP calibration

•19 days of beam time in T9 area of CERN-PS

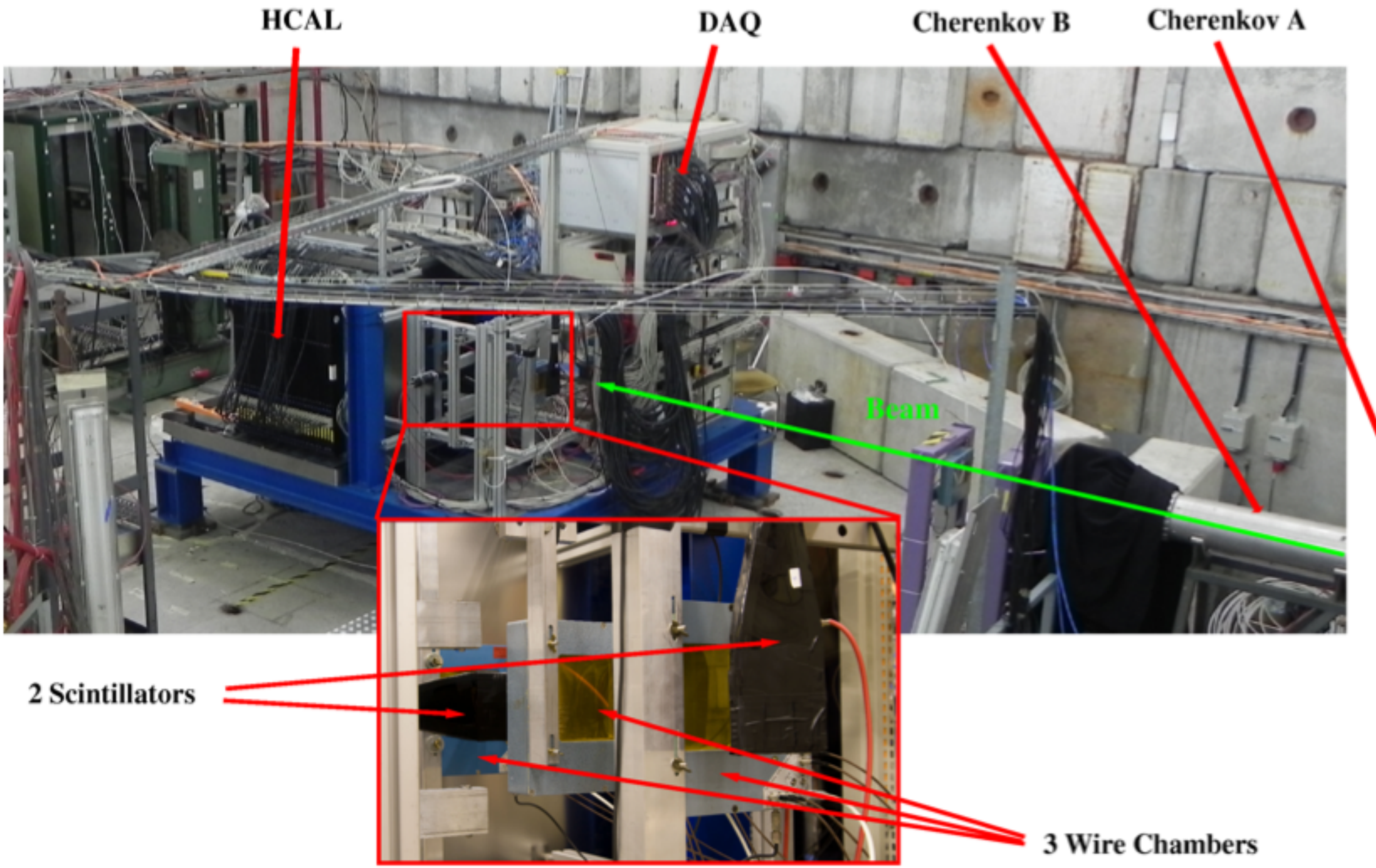
- •Typically 2-3 spills / 45 s, 24-33 Hz DAQ rate
- •28 million events in total:

  e^{+-}, μ^{+-}, π^{+-}, p^{+-} from 1 to 10 GeV in steps of 1 GeV

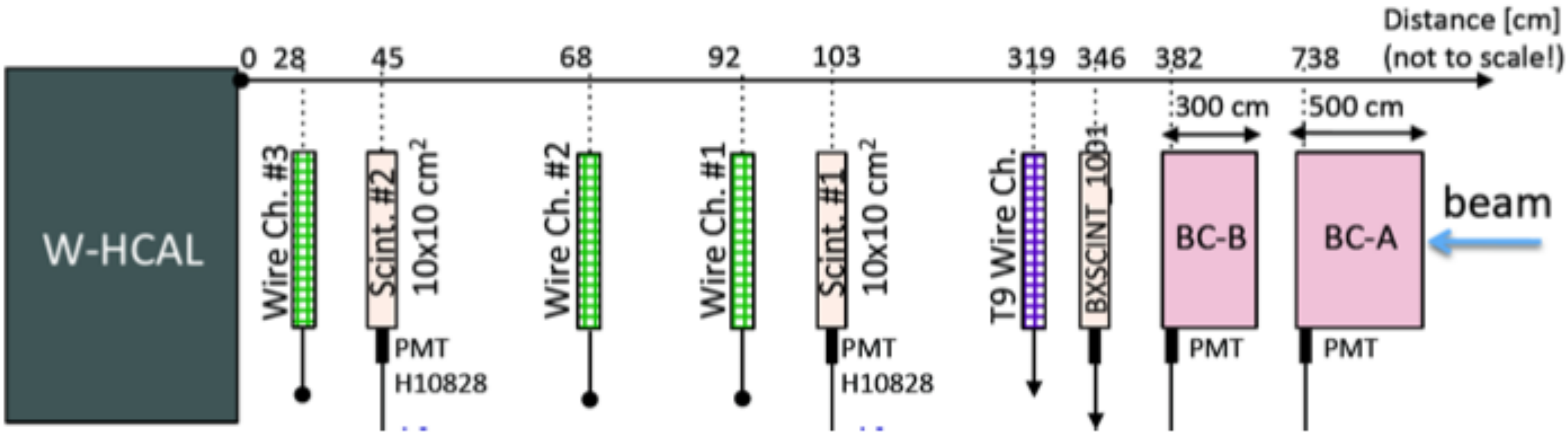


Particle Mix in T9			
p(GeV/c)	e^+ [%]	π^+ [%]	p [%]
2	55	30	15
3	30	50	20
4	15	60	25
5	10	60	30
6	5	55	40
7	5	50	45
8	0	45	55
9	0	40	60
10	0	40	60

Test beam setup



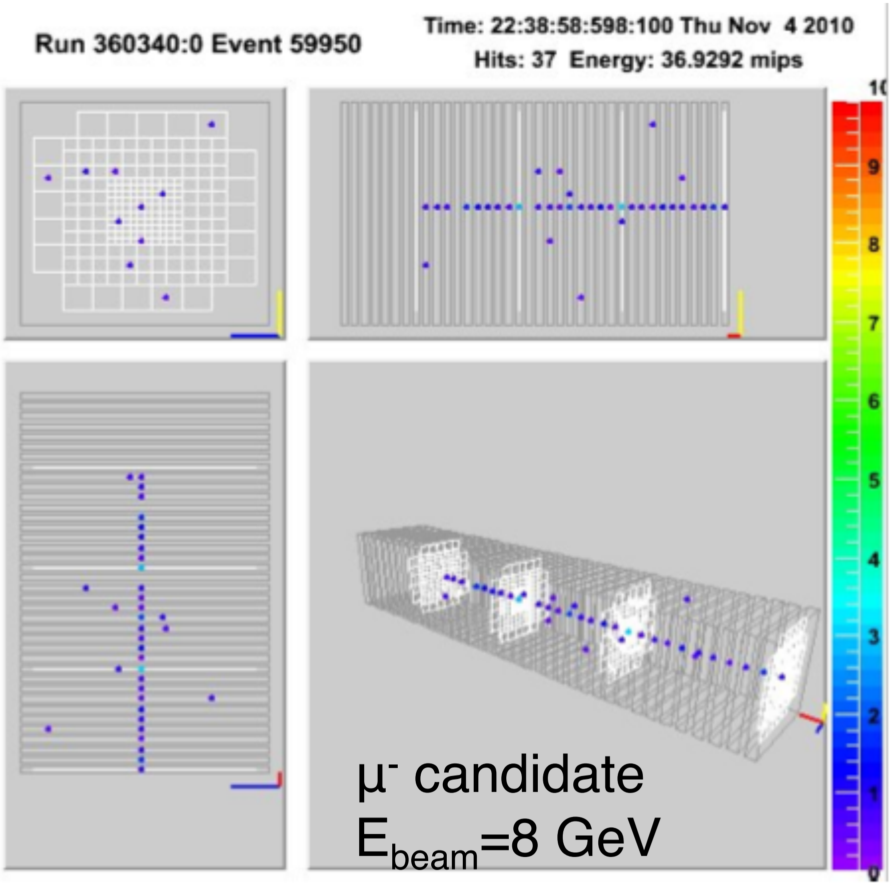
Beam instrumentation

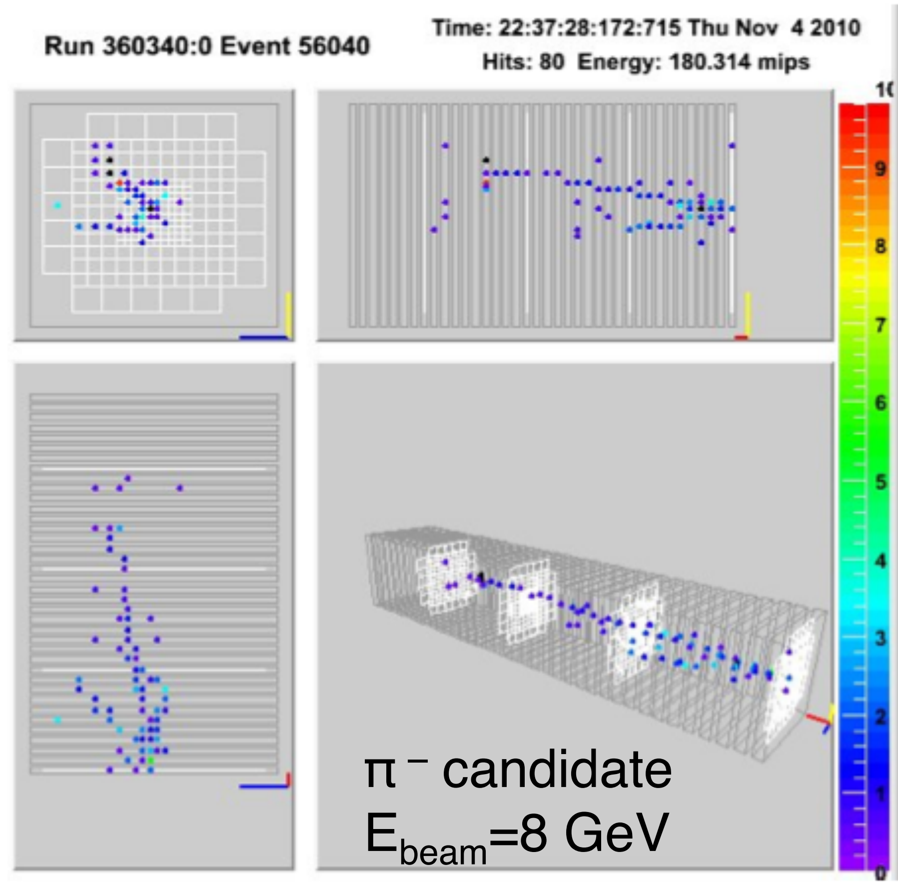


- Trigger:
  - Coincidence of 2 scintillators + PMT in front of W-AHCAL
- Tracking:
  - 3 delay-line wire chambers with x/y planes in front of W-AHCAL
  - Resolution of predicted impact point on W-AHCAL surface ~0.5 mm
- Particle ID:
  - 2 Cherenkov counters filled with CO_2 at $\sim 0 < p_{abs} < 3$ bar
  - PMT+Scintillator+Discriminator → Cherenkov bit: on/off
  - Used offline to separate electrons, muons, pions, protons

Event displays

- Online reconstruction of events using calibration from 2007
- (layers 31-38 missing in 2010 setup)





Calibration procedure

- Dead/noisy channels
  - Dead/noisy channels monitored during data taking
  - Number of problematic channels ~constant
  - Flagging for offline analysis handled by new software package

- Temperature monitoring/correction
  → See following slides

- Gain calibration
  → See following slides

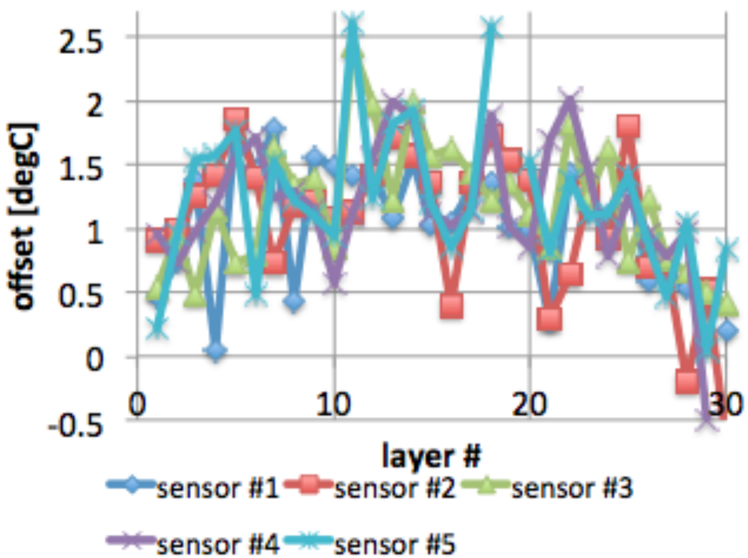
- Intercalibration
  - Ratio of readout response between physics+calibration mode
  - Probed with LED runs
  - Good agreement with previous calibration (FNAL 2008)

- MIP calibration
  → See following slides

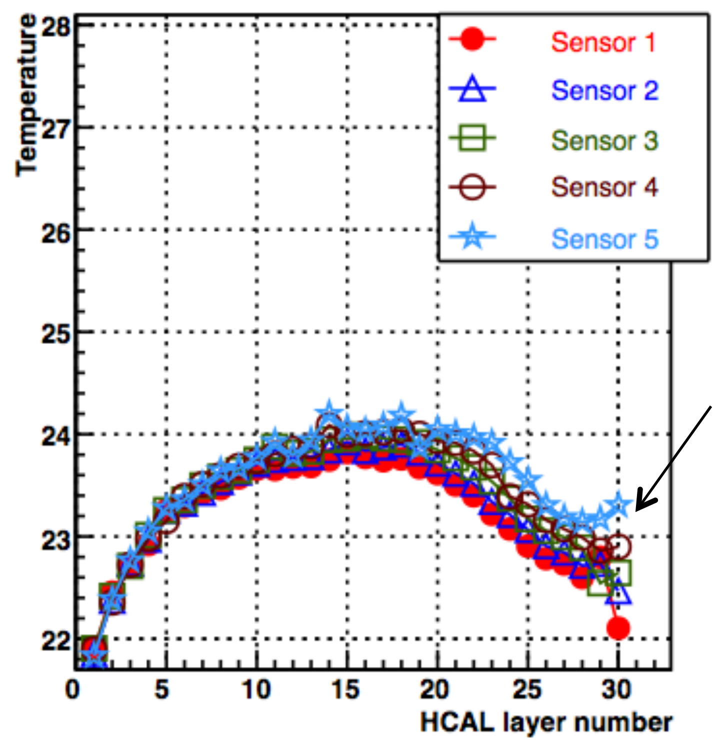
Temperature monitoring

- SiPM properties depend on ambient temperature:
  - Gain decreases with 1.7% / K
  - Breakdown voltage increases with 65 mV / K
  - Response decreases with 3.7% / K
- Continuous temperature monitoring with 5 sensors per readout plane
- Corrections for gain/response are applied offline during calibration procedure

Calibration offsets for temp. sensors:



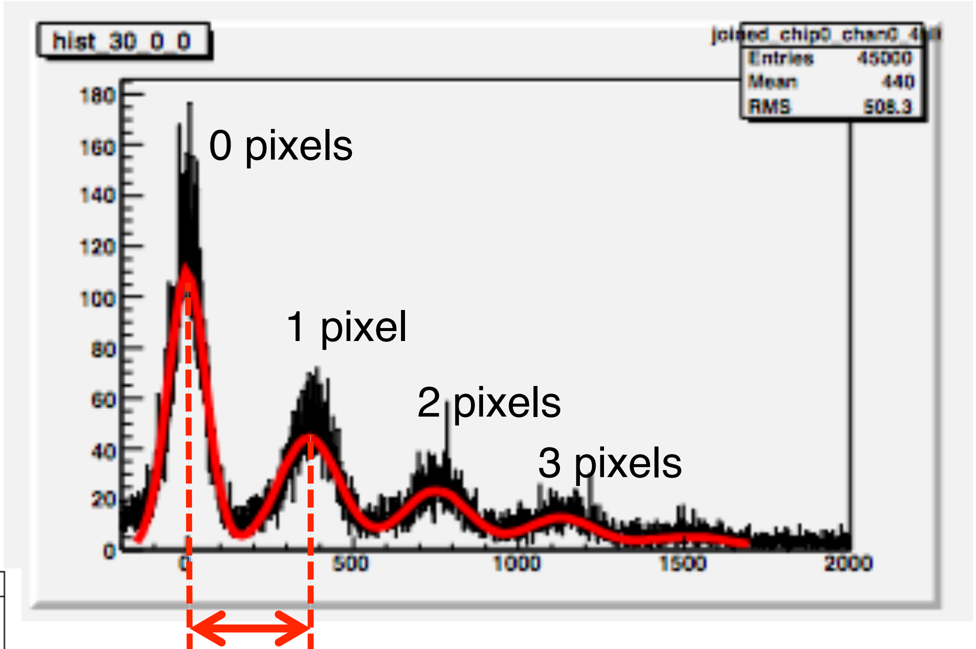
Temperature profile during run:



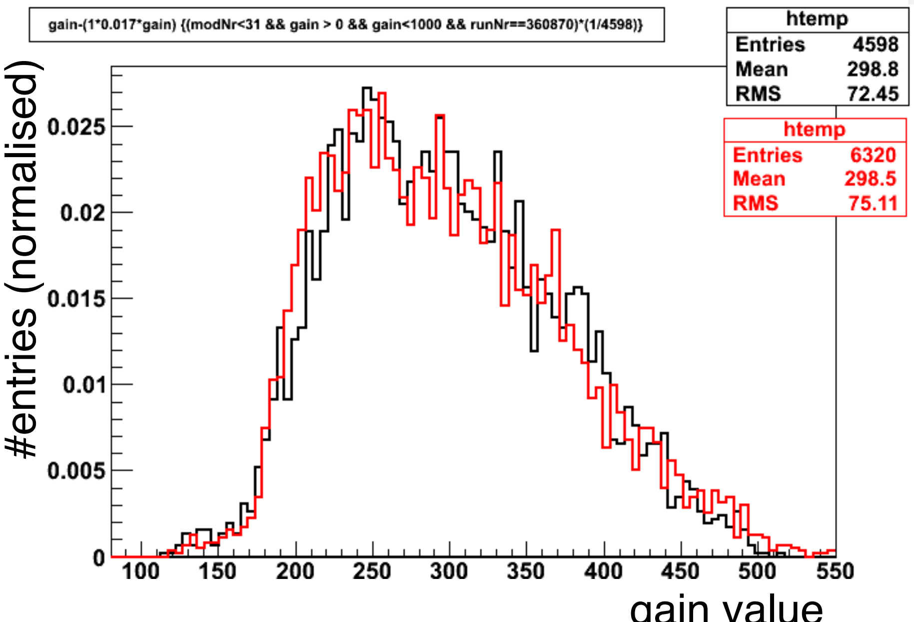
Additional heat sources next to last layers, originating from alternative readout modules → larger spread

Gain calibration

- Gains (ADC counts per pixel) obtained from periodic low-intensity LED-pulser calibration runs during data taking
- Efficiency for extracting gain constants is used for data-quality monitoring



Gain = ADC counts per SiPM pixel (modulo correction for difference between calibration and physics readout mode)

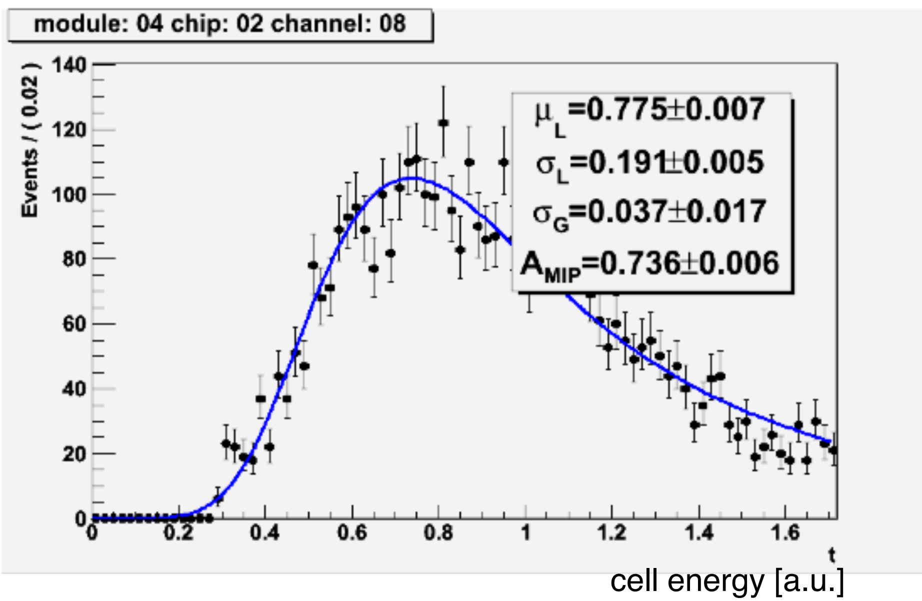


Good agreement between gains for FNAL 2008 data (red) and gains for CERN 2010 data (black) (after preliminary temperature correction)

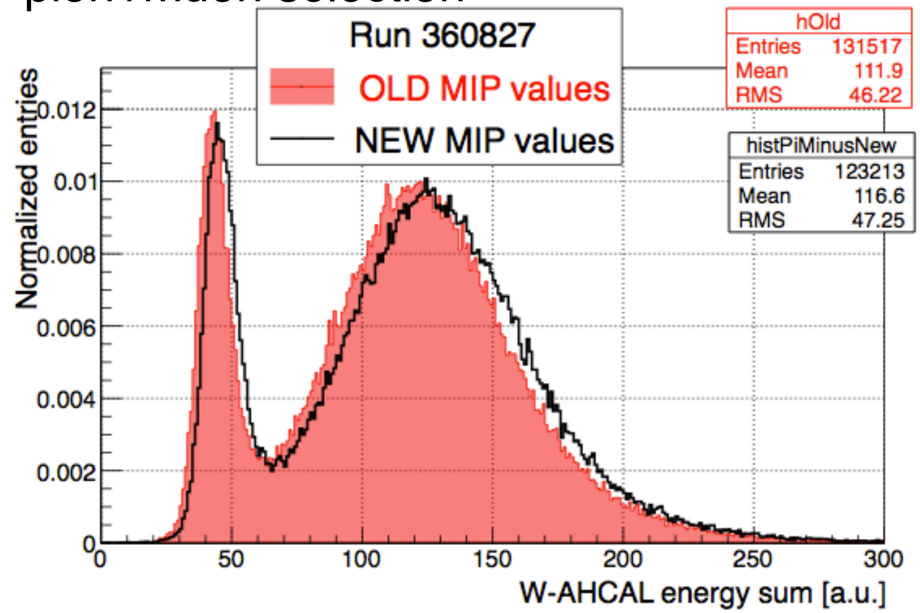
MIP calibration

- ADC-to-MIP calibration performed with long low-intensity μ runs
- Fit ADC distributions per channel with Gauss+Landau
- MPV of Landau gives MIP value for corresponding channel (at reference temperature given by the average temperature of the corresponding runs)

Example of MIP fit for one channel:



Comparison old / new MIP calibration:
Energy response for -5 GeV run with pion+muon selection



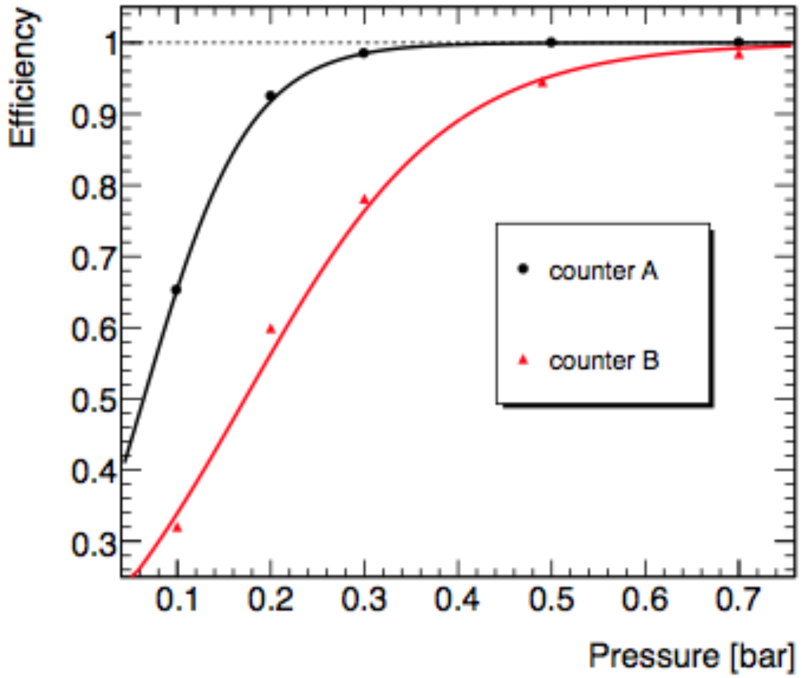
Particle-ID using Cherenkov counters

- Use Cherenkov counters offline to select / veto various types of particles
- Becomes difficult at low energy (limited by p_{max}=3.0 bar)

Momentum (GeV/c)	Cherenkov threshold (atm) electron	muon	pion	kaon	proton
1.00	0.0004	13.23	23.02	348.82	880.9
2.00	0.0001	3.31	5.78	76.13	248.1
3.00	0.0000	1.47	2.57	33.06	113.3
4.00	0.0000	0.83	1.45	18.45	64.4
5.00	0.0000	0.53	0.93	11.76	41.4
6.00	0.0000	0.37	0.64	8.15	28.8
7.00	0.0000	0.27	0.47	5.98	21.2
8.00	0.0000	0.21	0.36	4.58	16.3
9.00	0.0000	0.16	0.29	3.61	12.9
10.00	0.0000	0.13	0.23	2.93	10.4

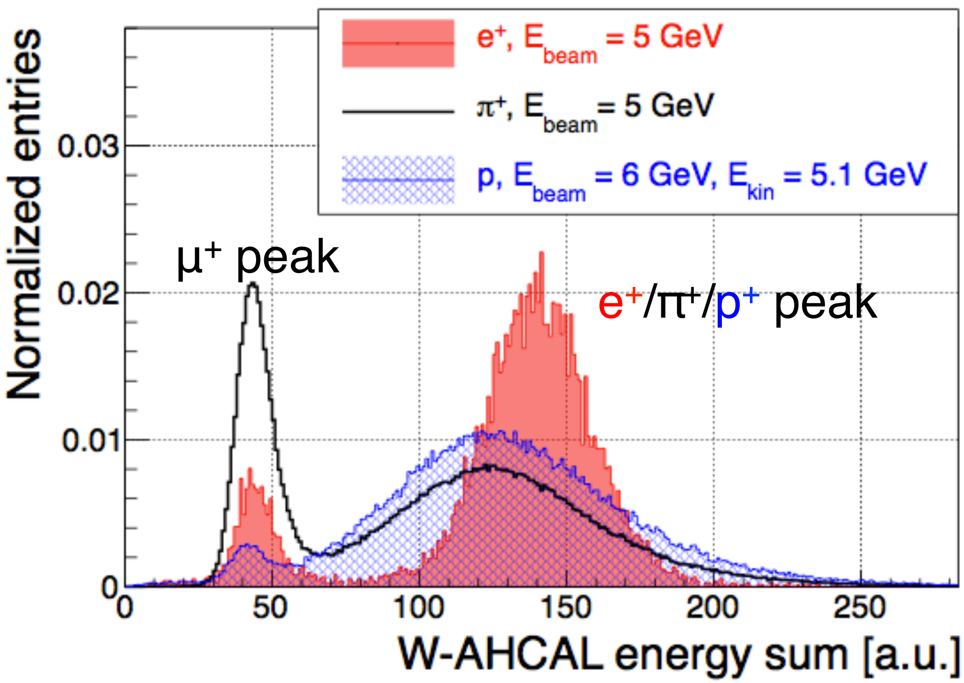
- Efficiency of Cherenkov selection limited by discrimination threshold of PMT readout
- Pion purity limited by in-flight pion decays
- Optimized pressure settings for each energy point, to allow for selecting exclusive sample of sufficient size

Electron efficiency (tag and probe):

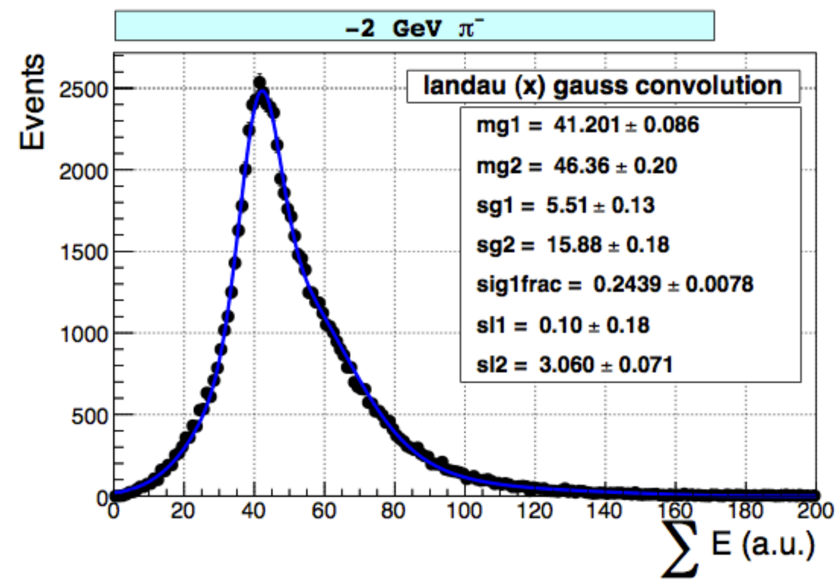


Response to e, μ, π, p

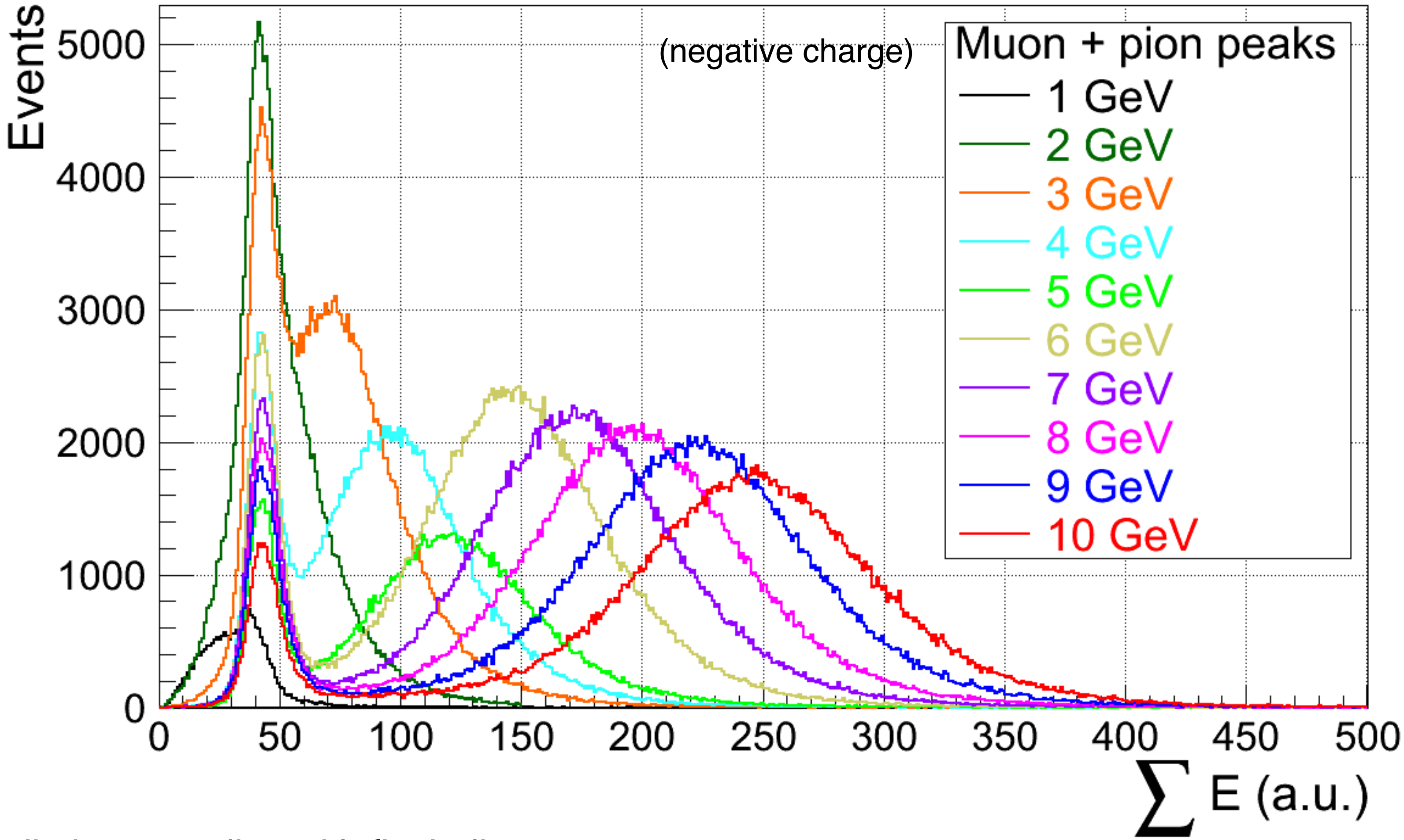
- Use CERN 2007 (Fe) calibration for now, to study global quantities (e.g. total energy sum and resolution)
- Obtain particle types per event from Cherenkov counters
- μ contamination at all energies, as expected from in-flight π decays and Cherenkov cross-efficiencies
- μ separation difficult for low energies, where e, π, p also look like MIPs
- However: at low energies combined fits still allow to obtain individual mean and sigmas from the inclusive selections



- μ+π peak at -2 GeV:



μ and π response at different energies



- Preliminary studies with fits indicate:
  - EM resolution slightly worse than for Fe (lower sampling fraction for X0)
  - Hadronic resolution similar to Fe
  - e/π stable vs. energy

Summary/Conclusions

- Successful first W-AHCAL test beam at CERN PS
- 28 million events collected: e, μ, π, p from 1 to 10 GeV
- Calibration and data-quality studies show satisfactory results
- Final calibration and simulation in progress

Outlook

- 2 test beam campaigns planned in 2011 at CERN SPS (H8):
  - Hadrons, electrons and muons from 9 to 350 GeV
  - 1^{st} period: will add 8 additional tungsten layers
  - 2^{nd} period: will add also tail catcher

Backup slides

Simulation

- Geant-4 simulation for AHCAL setup implemented in Mokka framework
- Comparison of data with different Geant-4 physics lists ongoing
- Expect differences for shower shapes and timing between:
  - QGSP_BERT → high neutron content
  - QGSP_BERT_HP → in addition: high precision neutron tracking