Analysis of 2006 Hadron Data

- comparison of data and Monte Carlo -

Outline:

- Introduction
- Experimental Setup in 2006
- Data Set and Event Reconstruction
- Simulation and Digitisation
- Event Selection
- Energy Response and Resolution
- Hadron Shower Profiles
- Conclusions

Introduction

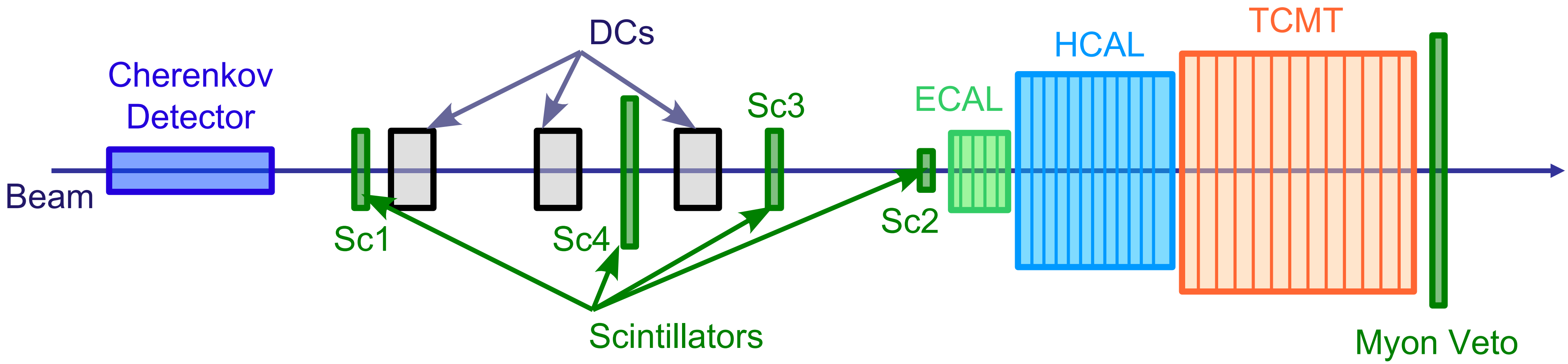
Goal: compare results from CALICE test-beam(s) with Geant4 simulations

- AHCAL → focus on hadron data
- several physics lists in Geant4 → differ in their predictions especially for hadrons
- ➔ validate and/or choose physics list
- use well defined variables (response, resolution, shower shape parameters, etc.)

How to achieve that?

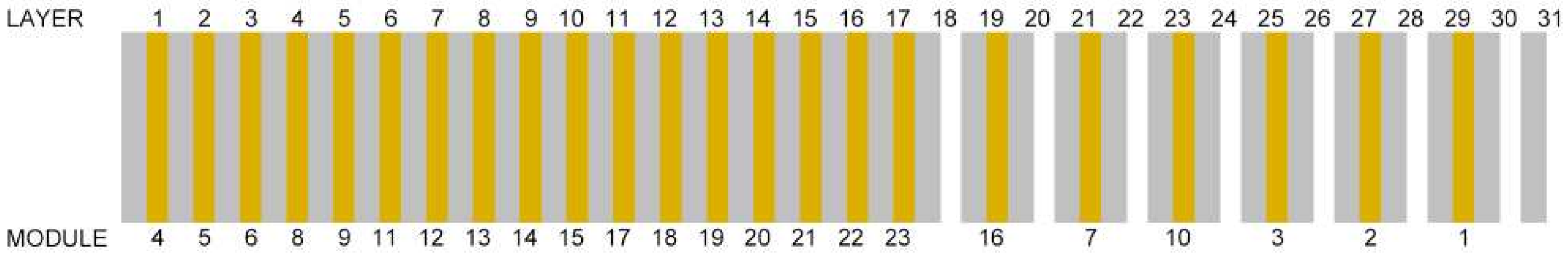
- reconstructed data + digitised Monte Carlo → detector effects (saturation, x-talk, ...)
- full set of hadron energies (6 to 80 GeV)
- compare π^+ and π^- runs at corresponding energies
- official CALICE software system (for data reconstruction and digitisation)

Experimental Setup in 2006



- H6 beam line SPS test beam area at CERN
- several particle types (μ, e, π), large range of energies with high precision (<1%)
- beam instrumentation: Cherenkov, Coincidence Trigger, Drift Chambers, Muon Veto

Experimental Setup in 2006



- H6 beam line SPS test beam area at CERN
- several particle types (μ, e, π), large range of energies (6 to 80 GeV) with high precision (<1%)
- beam instrumentation: Cherenkov, Coincidence Trigger, Drift Chambers, Muon Veto
- ECAL and TCMT full set of sensitive layers
- AHCAL: 23 active layers installed, 2 samplings, reduced calorimeter depth (approx. 3.7 λ total depth in HCAL)
- ECAL:1 λ in front of HCAL, TCMT with approx. 5.7 λ

Data Set and Event Reconstruction

<u>in this talk:</u> focus on π^+ runs (approx. 5.5 M events)

run number	particle type	momentum [GeV/c]	statistics [kEvts]
300587, 300588, 300598	π^+	6.0	~ 450
300579, 300580, 300593	π^+	10.0	~ 700
300585, 300594, 300595	π^+	15.0	~ 700
300546, 300586, 300599, 300600	π^+	20.0	~ 800
300696, 300718, 300720	π^+	30.0	~ 580
300697, 300712, 300724	π^+	40.0	~ 750
300568, 300698, 300725	π^+	50.0	~ 760
300702, 300715, 300726	π^+	80.0	~ 900

Event Reconstruction:

- official Calice reconstruction chain for ECAL, HCAL and TCMT
- for HCAL: including scaled saturation correction and temperature correction
- 3 reconstructed data sets with different gain values (high, nominal, low)

→ correlated systematic error caused by gain variations

Simulation and Digitisation

Simulation:

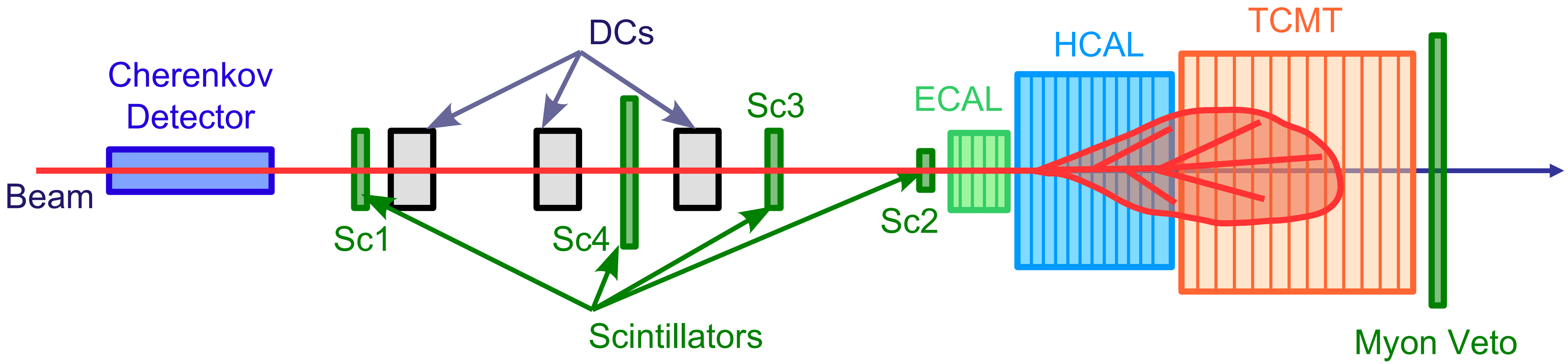
- Mokka-06-05-p02 (Geant4.9.2.b01), detector model: TBCern1006_01_dchxy_new
- Birks Law included for all scintillators, coefficient for G4_POLYSTYRENE
- electronics 'gate time cut' of 150 ns (default value)
- G4 particle gun on front of Cherenkov detector, Gaussian beam profile in x and y ($\sigma_{x,y}$ = 25 mm), no direction and momentum smearing
- 6 Geant4 physics lists (LHEP and 5 QGS types):
  → LHEP, QGSP, QGSC, QGSP_BERT, QGSP_BERT_HP and QGSP_BIC
- simulation with high statistics (approx. data statistics)
  → 200 k events for each run, 600k events for each energy
  → 29 M events in total for simulation of π^+ runs

Simulation and Digitisation

Digitisation:

- official Calice reconstruction chain for ECAL, HCAL and TCMT
- for HCAL: including finite number of pixels, light cross talk, overlay of random trigger events from data, ...
- event reconstruction for digitised Monte Carlo **identical** to data reconstruction

Event Selection



Selection of Pion shower contained in HCAL+TCMT, mip track in ECAL:

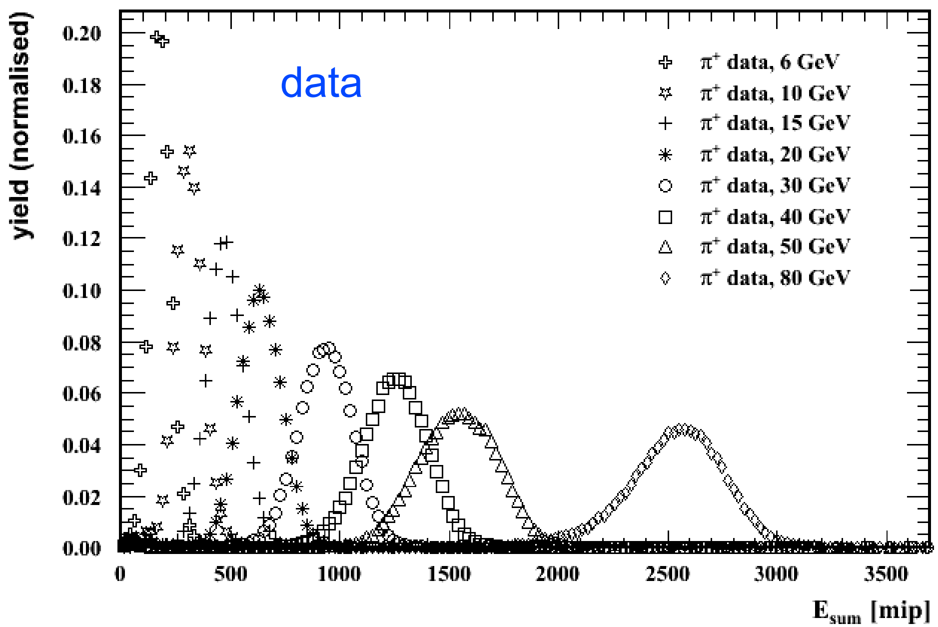
- trigger: spill, coincidence in Sc1 and Sc3 and no trigger in muon veto
- 0.5 mip cut in ECAL, HCAL and TCMT
- ECAL: $20 < N_{hits} < 42$ and $25 < E_{sum} < 70$ mip (≈250 MeV energy loss in ECAL)
- topological search for mip tracks in HCAL and cuts on TCMT ($N_{hits} < 32$ and $E_{sum} < 35$ mip) to reject muons further
- flag events with more than 3 hits in last 3 layers of TCMT (event with leakage)

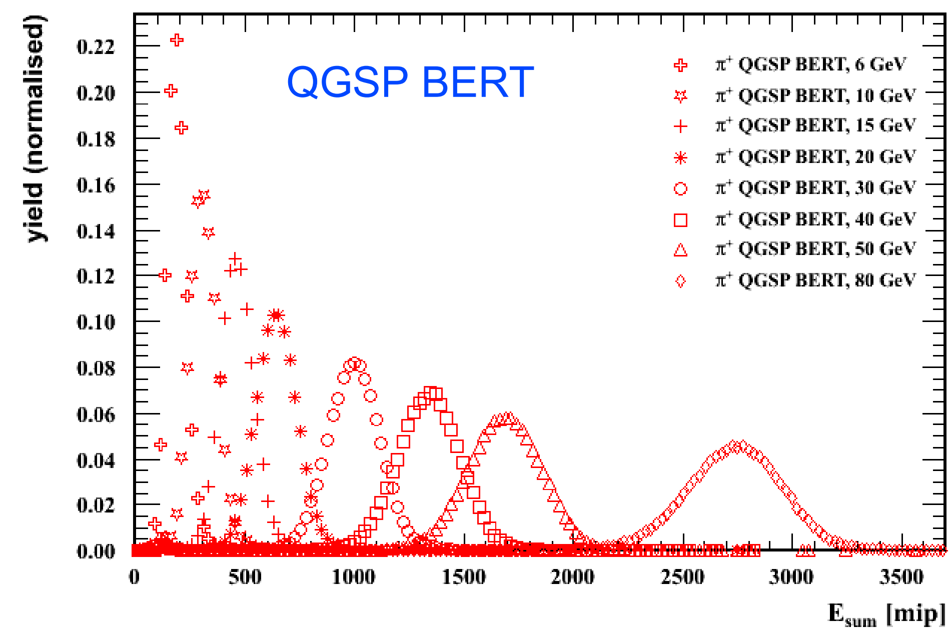
➔ showers contained in HCAL and TCMT with high purity but low efficiency (≈20%)

➔ identical selection for data and Monte Carlo

Energy Response and Resolution

- reconstructed energy sum HCAL+TCMT of selected events
- comparison of π^+ data with 6 Monte Carlos

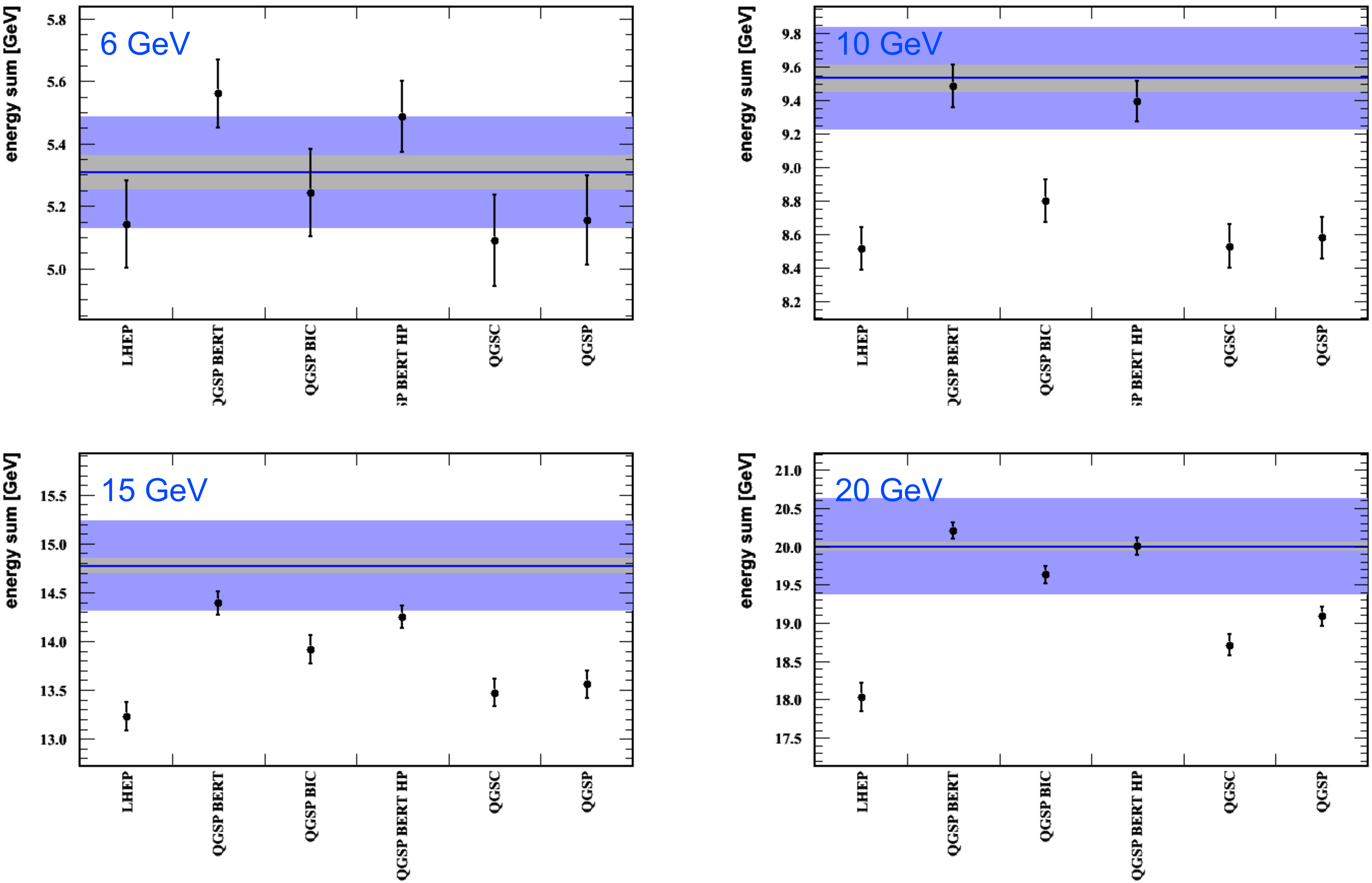




- Gaussian fit on the selected energy sum
- extract mean and width to calculated energy response and resolution
- variation of fit range contributes to (uncorrelated) systematic error
- correlated systematic error introduced by gain variation and uncertainty on mip scale of 3 % (indicated by shaded (blue) area)

Energy Response and Resolution

reconstructed energy sum HCAL+TCMT, π^+ data and 6 Monte Carlos



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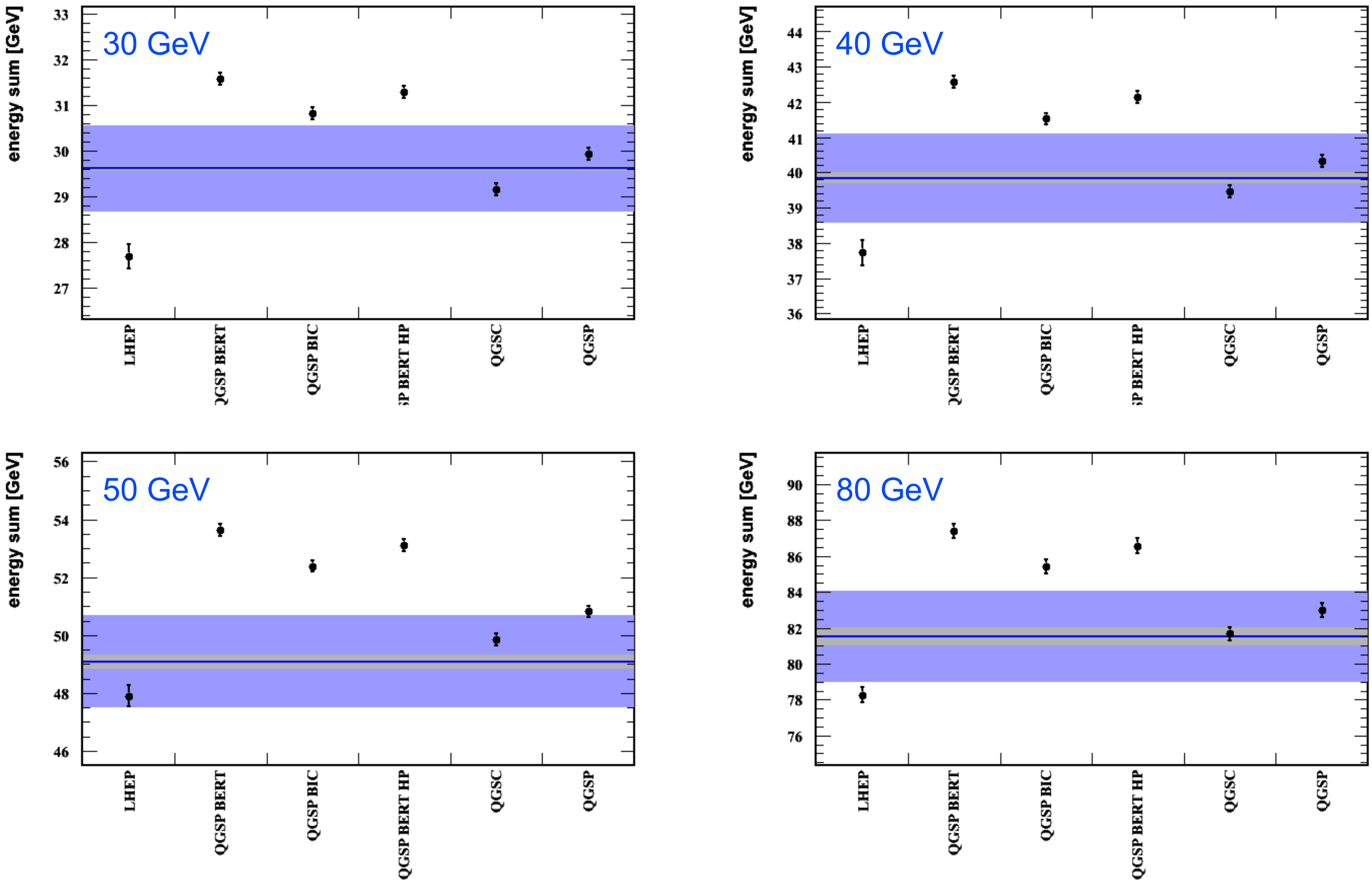

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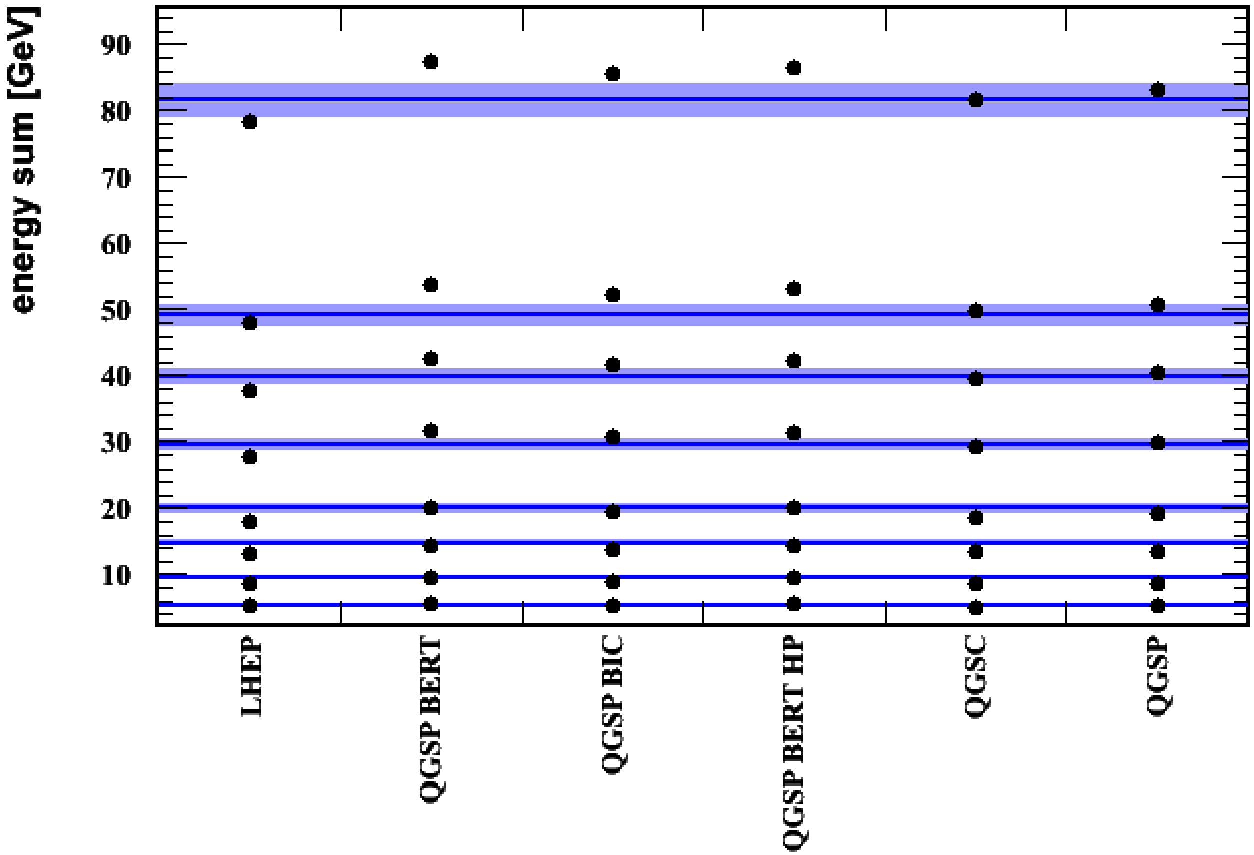
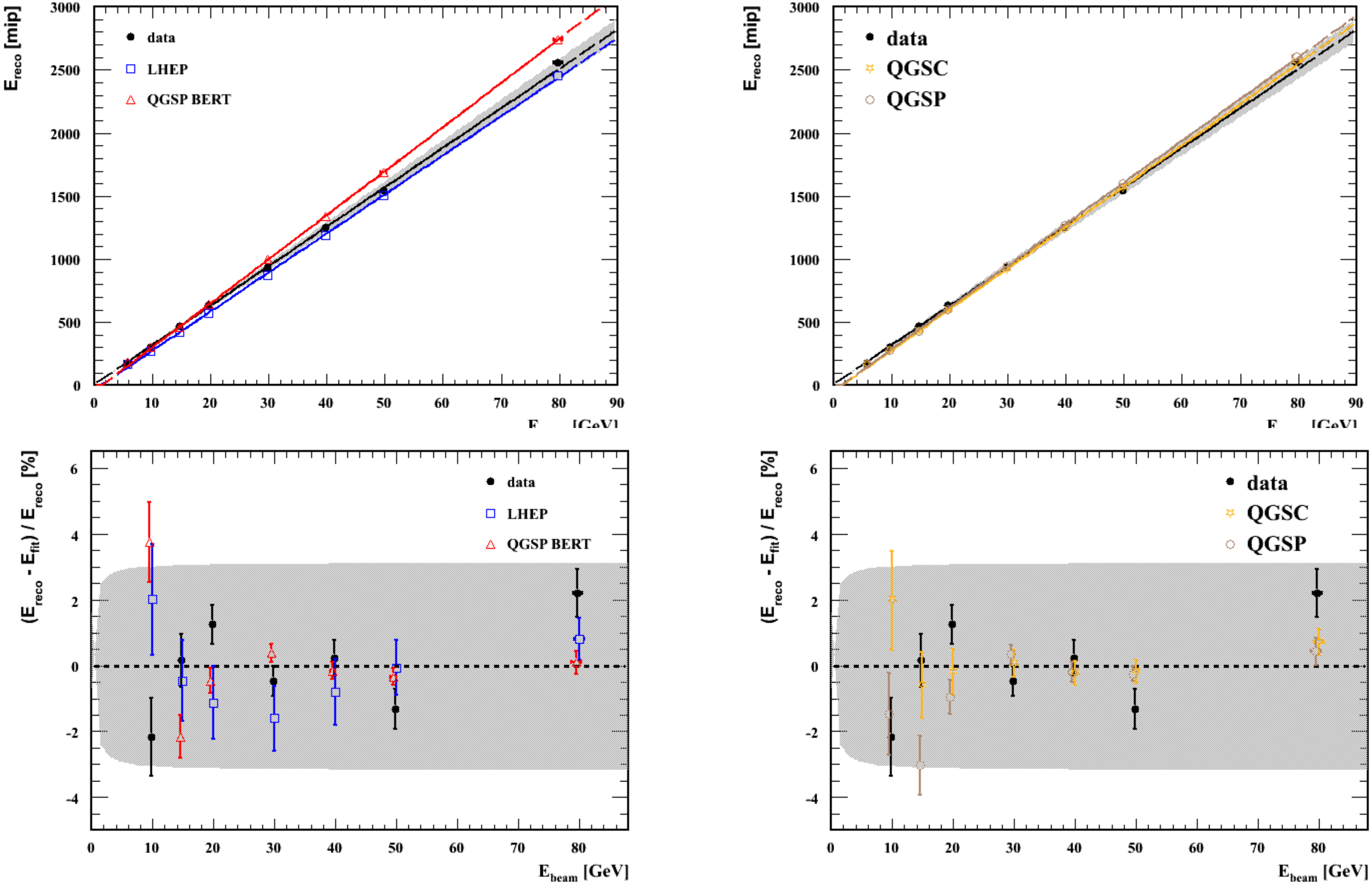


- LHEP predicts too small energy for all energies, LHEP and QGSP BERT differ most
- QGSP BERT describes well the data for < 20 GeV, above 20 GeV too high energy
- HP package has no major impact
- energy scale in agreement with 2007 analysis

Energy Response and Resolution

linearity for HCAL+TCMT, π^+ data and 4 example Monte Carlos



Energy Response and Resolution

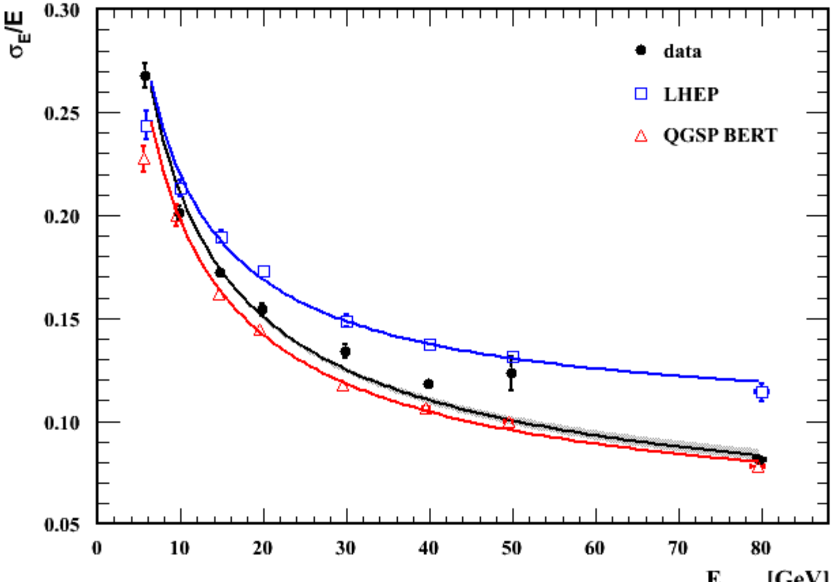
- unexpected linear behavior on the whole range for data and Monte Carlo
→ data approx. 2% deviation from linearity, Monte Carlo approx. 4%
- slope of LHEP agrees best with data, but different offset
- to compare, perform linear fit in energy range, results:

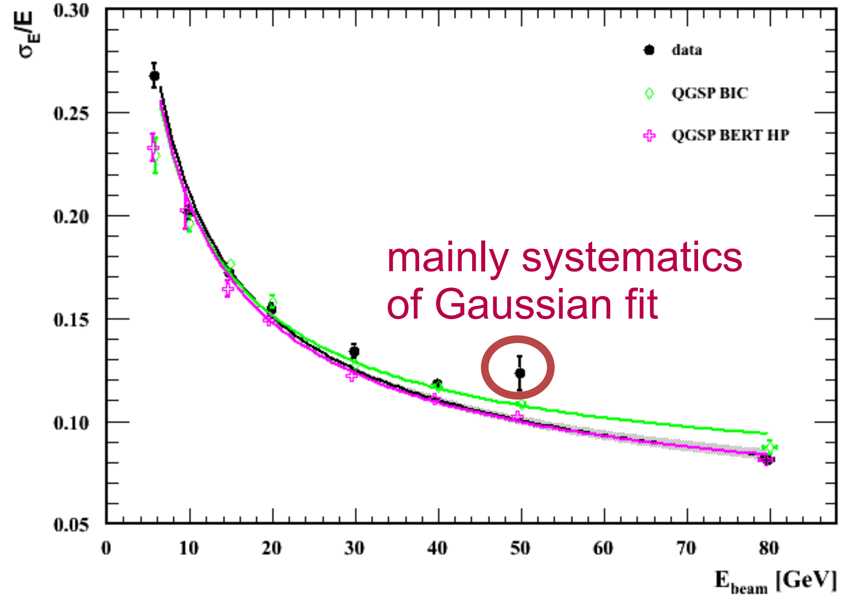
	slope [mip/GeV]	offset [mip]
data	31.291	9.184
LHEP	30.972	-31.728
QGSP BERT	34.943	-45.721
QGSP BIC	34.164	-48.735
QGSP BERT HP	34.590	-46.370
QGSC	32.520	-46.316

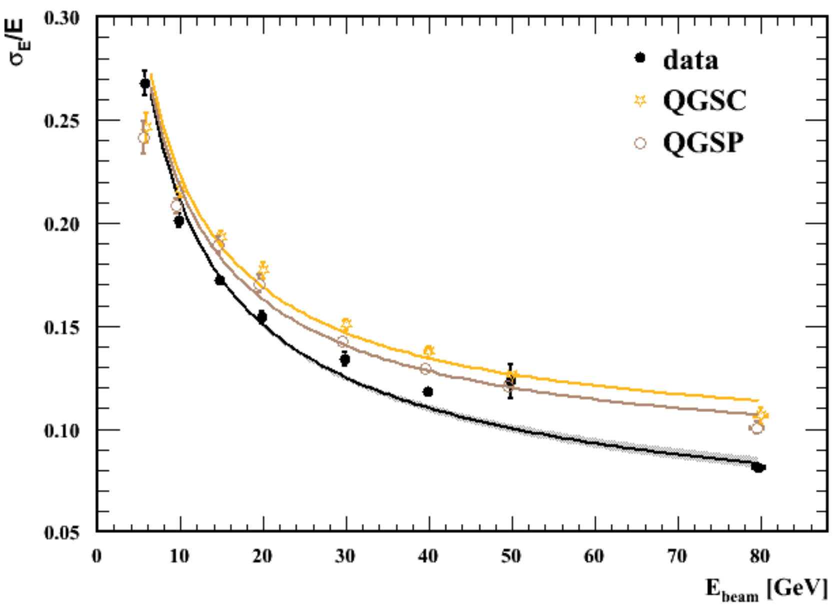
- uncertainties on fit small, systematic uncertainty not covered in table
- energy sum of random trigger events: mean 18.5 mip, RMS 9.3 mip
- QGS models show significant larger slopes
- different offsets in data and Monte Carlos → remaining issue in digitisation (noise) ?

Energy Response and Resolution

resolution for HCAL+TCMT, π^+ data and 4 example Monte Carlos







- noise term is fixed to 9.3 mips
- ➔ RMS of the energy sum in random trigger events

Energy Response and Resolution

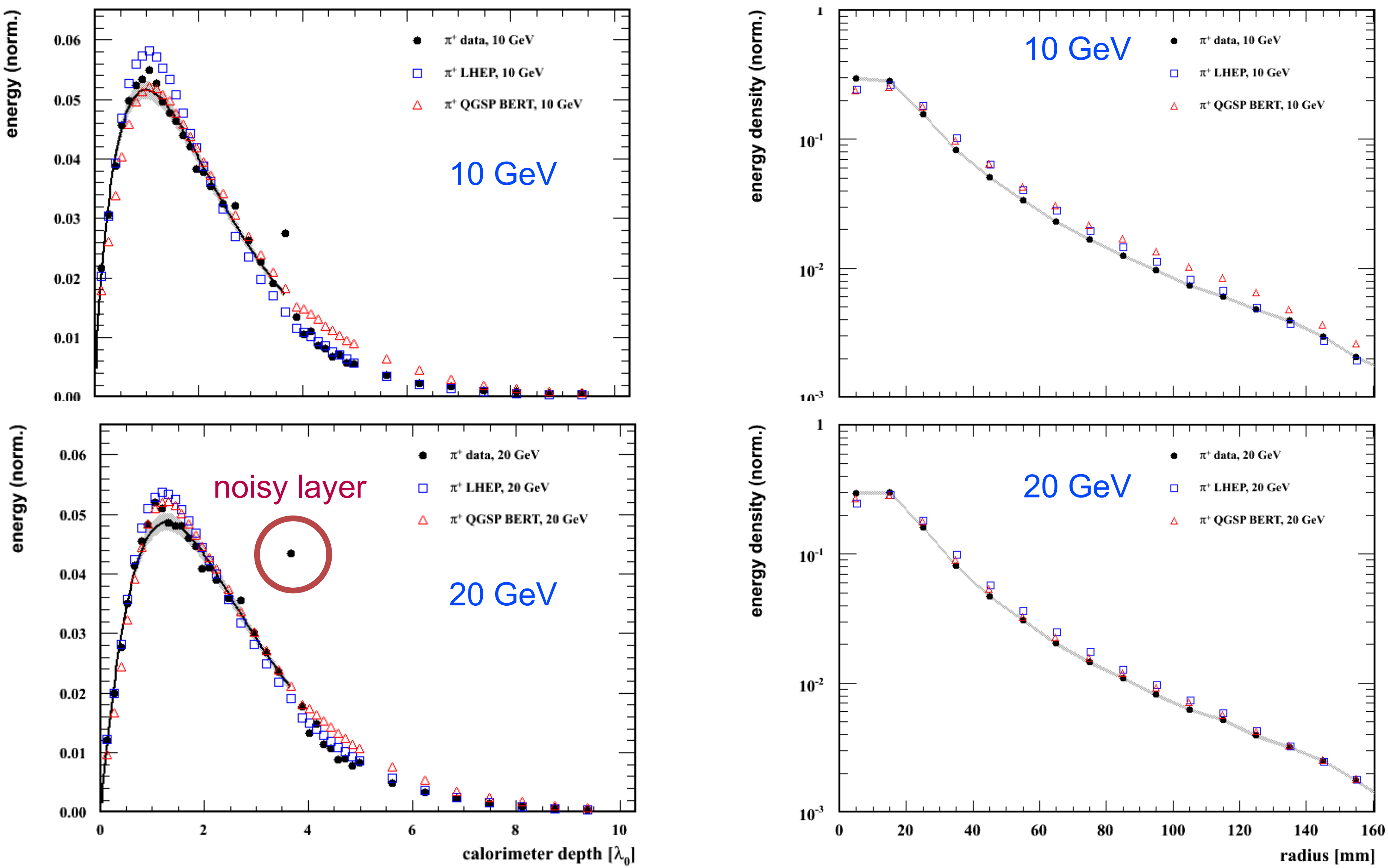
- for 6 GeV resolution deteriorates → effect of 0.5 mip cut ?
- → to compare, perform fit in energy range, results:

	a [1/sqrt(E/GeV)]	g [1]
data	0.643	0.042
LHEP	0.612	0.097
QGSP BERT	0.599	0.044
QGSP BIC	0.608	0.064
QGSP BERT HP	0.625	0.046
QGSC	0.639	0.088

- systematic uncertainty of fit result not covered in table
- QGSP BERT models show best agreement in this observable

Hadron Shower Profiles

- data corrected for detector effects, fit in HCAL depth only



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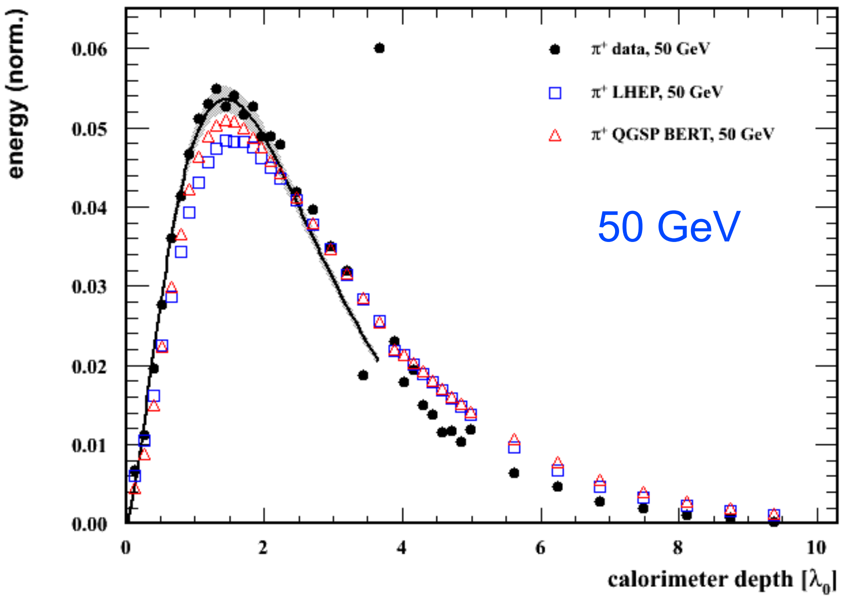
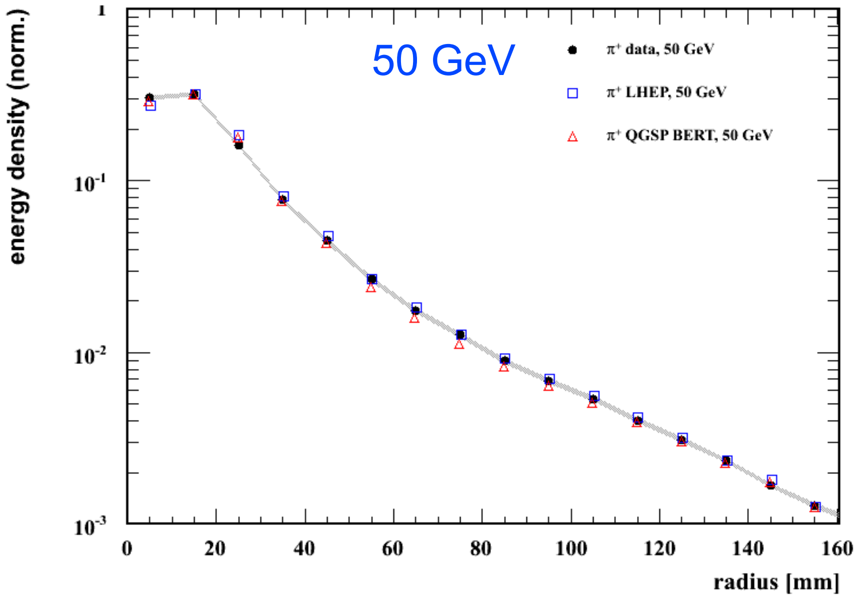


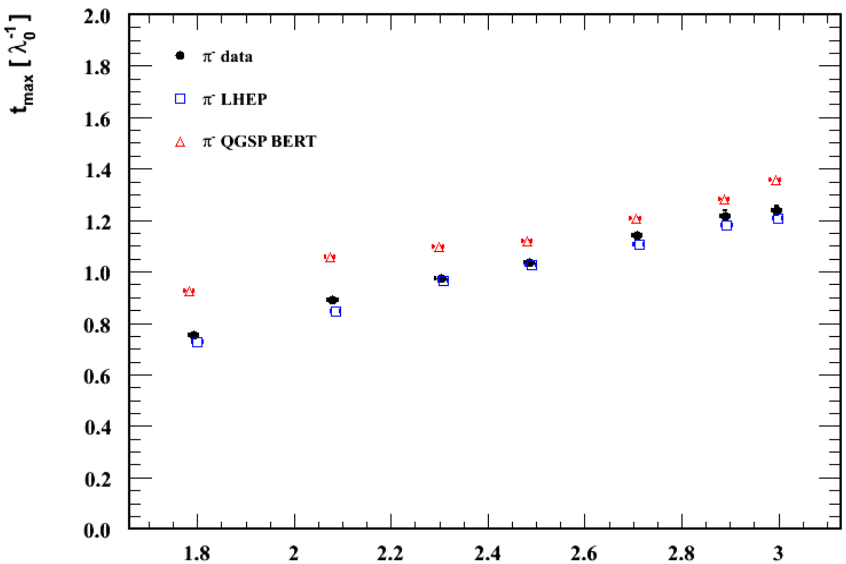


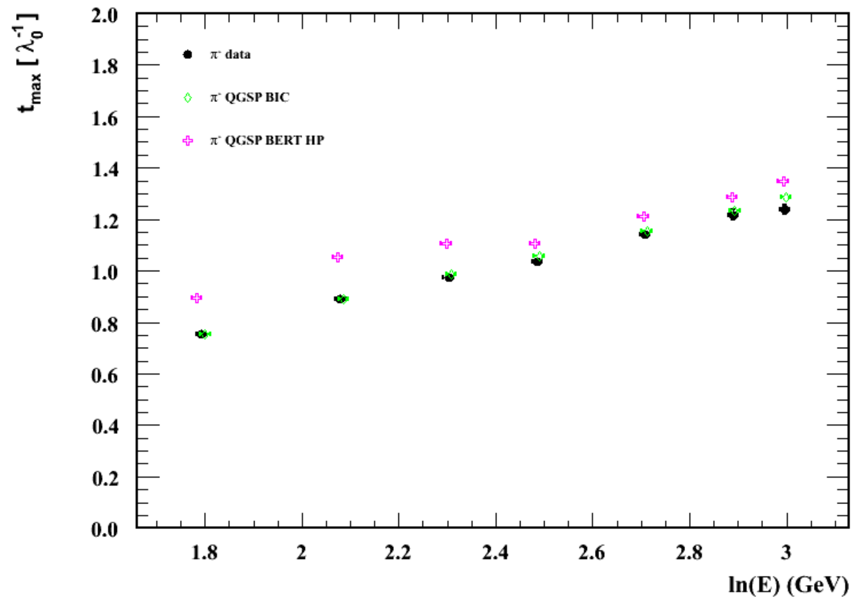
- containment cut of the TCMT released, leakage out of the TCMT 'allowed'
- LHEP seems to have a 'earlier' shower start for small energies, for higher energies this seems to be inverted
- QGSP BERT agrees better with longitudinal profile of data
- the lateral profiles seem to be better described by LHEP

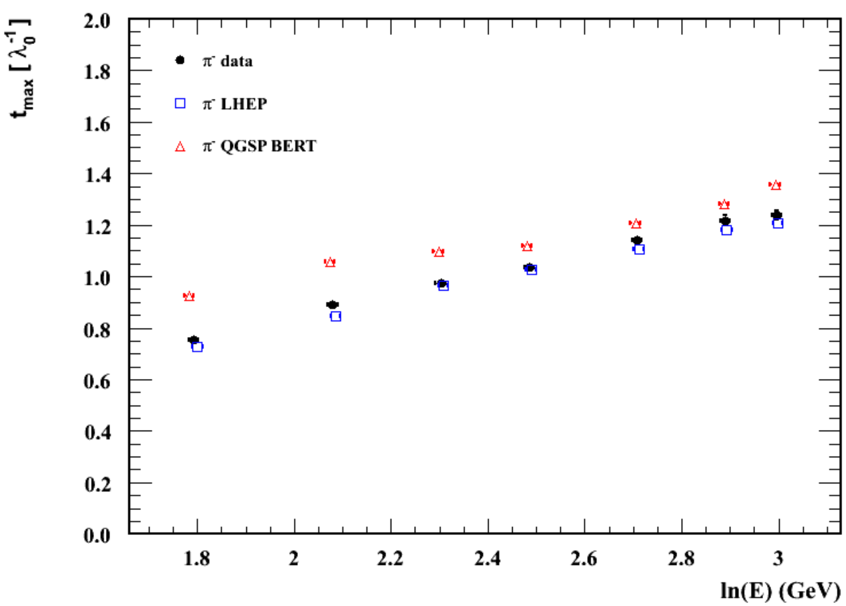
o ➔ fit longitudinal profiles and look at t_{max} and attenuation parameter as function of ln(E)

Hadron Shower Profiles

t_{max} as function of ln(E):



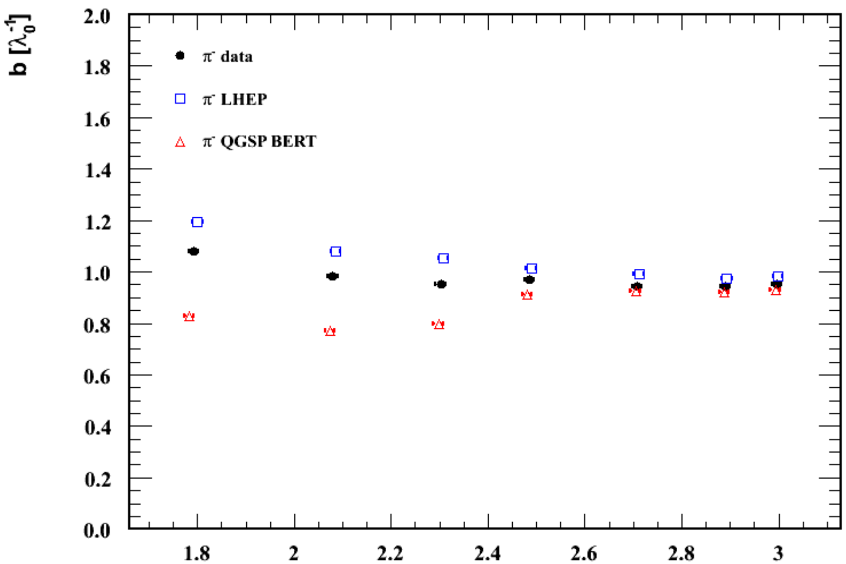


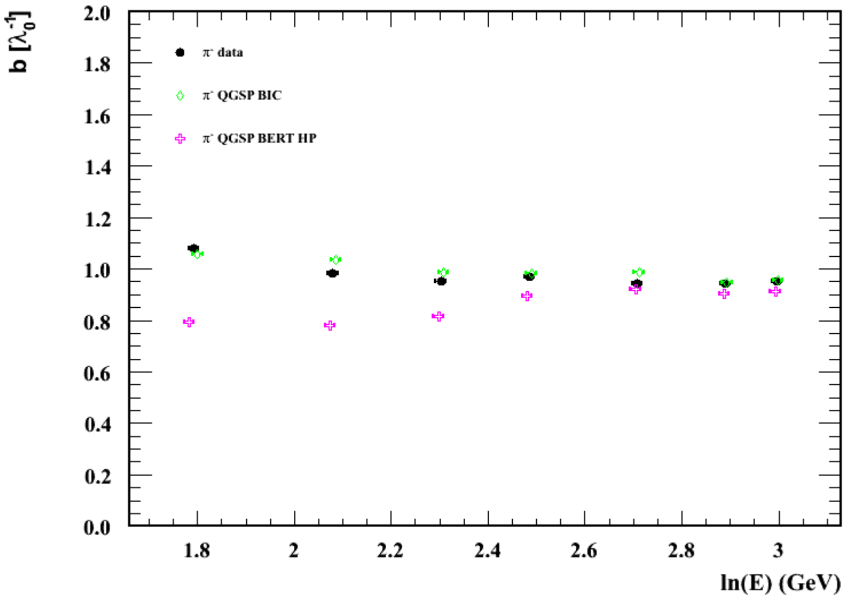


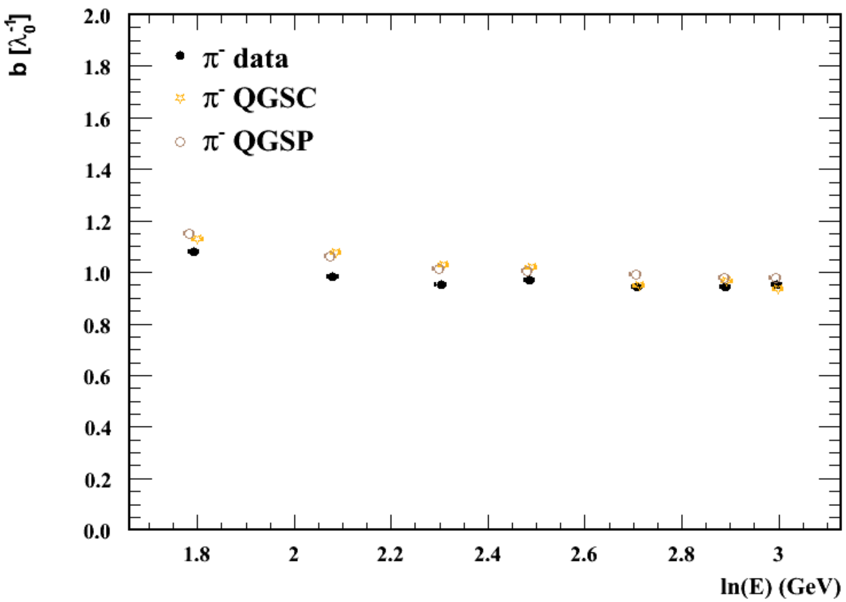
- energy dependence of shower maximum position well reproduced by most models
- except QGSP BERT (HP)

Hadron Shower Profiles

attenuation parameter as function of ln(E):







- significant discrepancies between data and Monte Carlos (and also among the Monte Carlos) for small energies
- for higher energies they more or less agree

➔ caveat: longitudinal fit only in the HCAL

Conclusions

Technically:

- data reconstruction chain based on official Calice software established
- Geant4 mass production including Birks and electronic gate time cut on GRID
- digitisation of all detectors on GRID
- full analysis chain available, including

➔ event selection, ROOT tree writer and analysis software to calculate systematics, produce plots, ...

Data Analysis:

- data and Monte Carlo comparison based on well defined observables available
- potential to validate Monte Carlos
- *but:* still open issues in the analysis of electro-magnetic data, no perfect agreement of data and Monte Carlo, might lead to a shift in the energy scale

backup slides ...