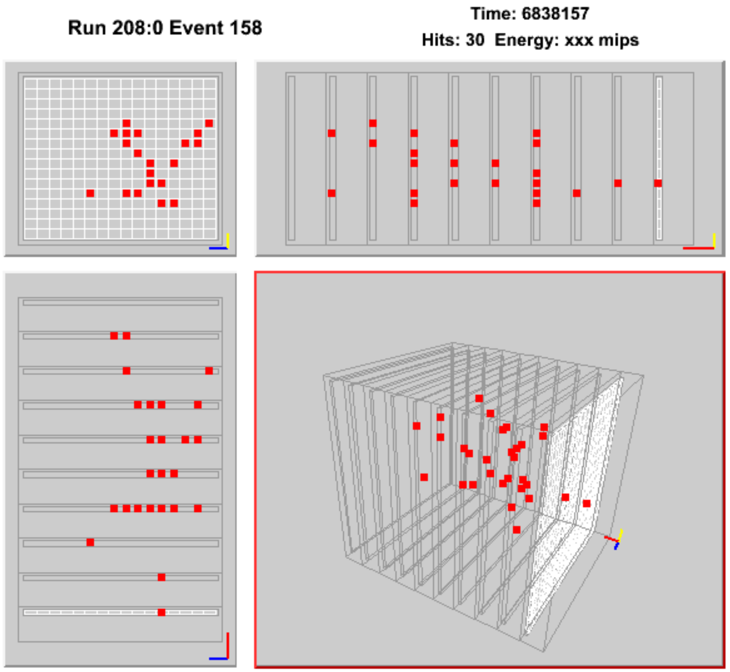
Simulation of a Digital Hadron Calorimeter



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Calorimeter for ILC

2009 Linear Collider Workshop of the Americas
September 29 – October 3, 2009
Albuquerque, New Mexico

Outline

I	Digital Hadron Calorimeter
II	Vertical Slice Test
III	Simulation strategy
IV	Calculating the rate capability
V	Simulating Muons
VI	Simulating Positron Showers
VII	Simulating Pion Showers
VIII	Studies of Larger Systems
IX	Conclusions

Monte Carlo Simulation = Integration of current knowledge of the experiment

Perfect knowledge → Perfect agreement with data
Missing knowledge → Not necessarily disagreement with data
Disagreement with data → Missing knowledge, misunderstanding of experiment
Perfect agreement with data → Not necessarily perfect knowledge

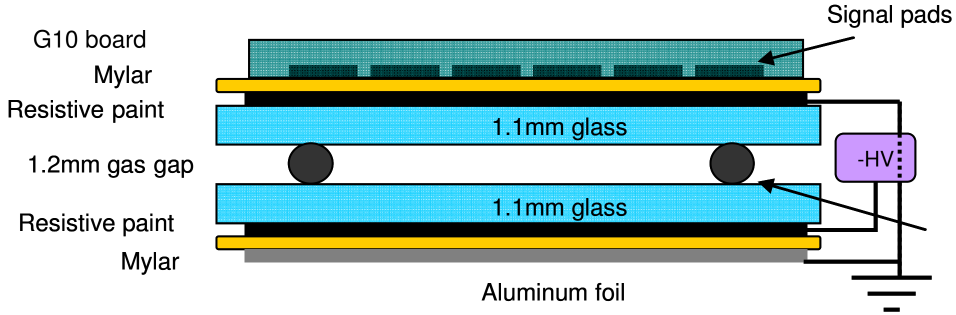
I Digital Hadron Calorimeter

Idea

Replace small number of towers with high resolution readout with large number of pads with single-bit (digital) readout

Energy of hadron shower reconstructed (to first order) as sum of pads above threshold

Concept provides high segmentation as required by the application of PFAs to jet reconstruction

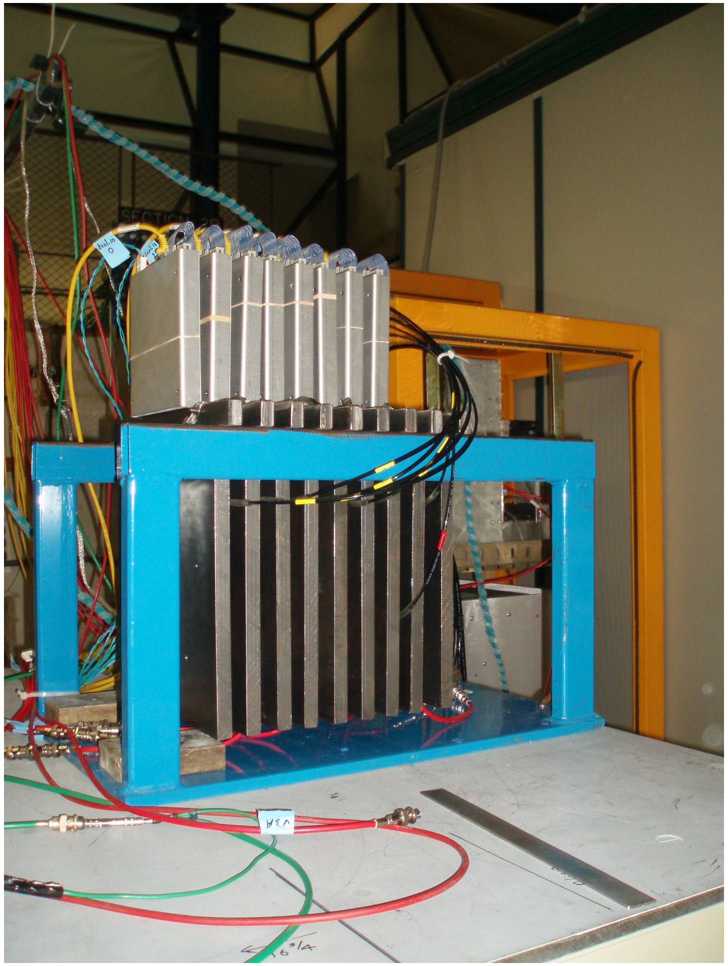


Active element

Resistive Plate Chambers

→ Simple in design
→ Cheap
→ Reliable (at least with glass as resistive plates)
→ Large electronic signals
→ Position information → segmented readout

II Vertical Slice Test



Small prototype calorimeter

Up to 10 RPCs, each 20 x 20 cm^2
(Up to 2560 channels)

RPCs

Used up to 10 RPCs for muons
Only used RPC0 – RPC5 in analysis of e^+, π^+
Only used RPC0 for rate capability measurments

Absorber

Steel (16 mm) + Copper (4 mm)

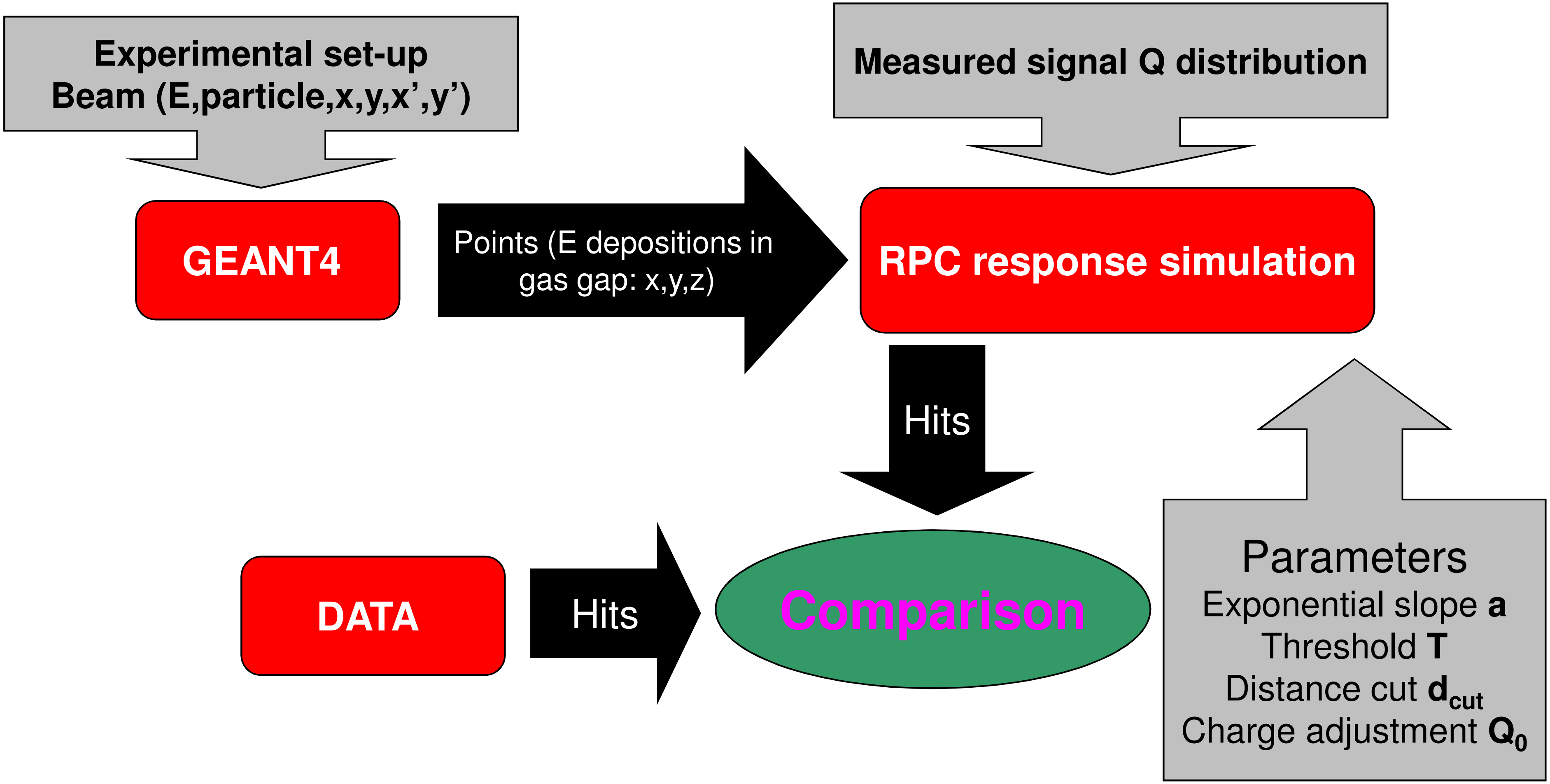
Test beam

Collected data in Fermilab's MT6 beam line
Used

- Primary beam (120 GeV protons) with beam blocker for muons
- Primary beam without beam blocker for rate measurements
- Secondary beam for positrons and pions at 1,2,4,8, and 16 GeV/c

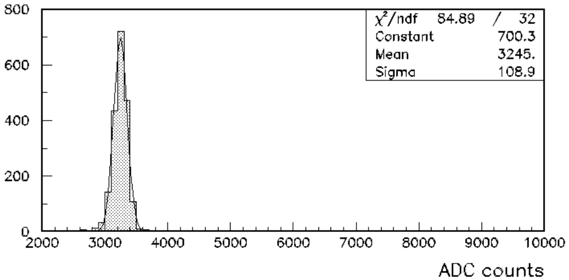
CALICE
Calorimeter for ILC

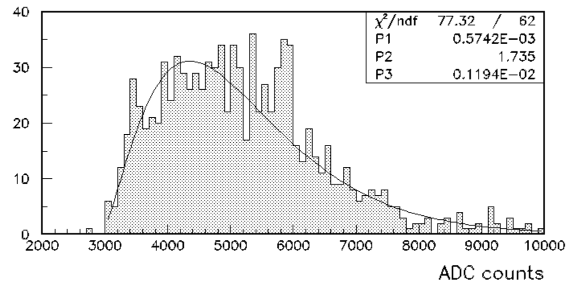
III Simulation Strategy



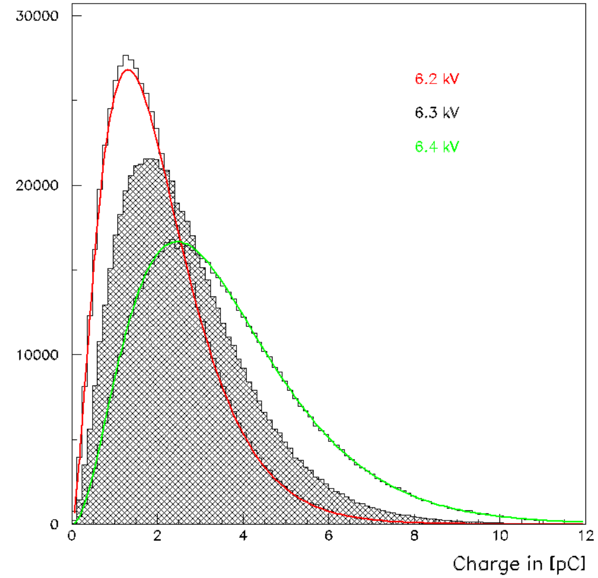
With muons – tune **a**, **T**, ($\mathbf{d_{cut}}$), and $\mathbf{Q_0}$
With positrons – tune $\mathbf{d_{cut}}$
Pions – no additional tuning

Measured charge distribution
for HV = 6.2 kV

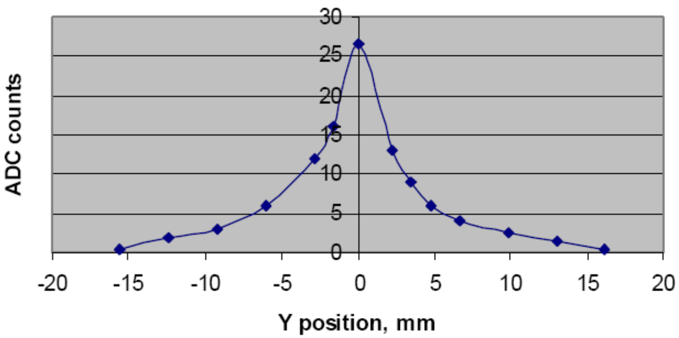




Generated charge distributions
for different HV settings

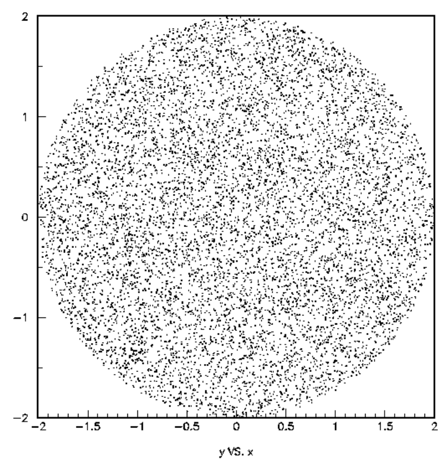


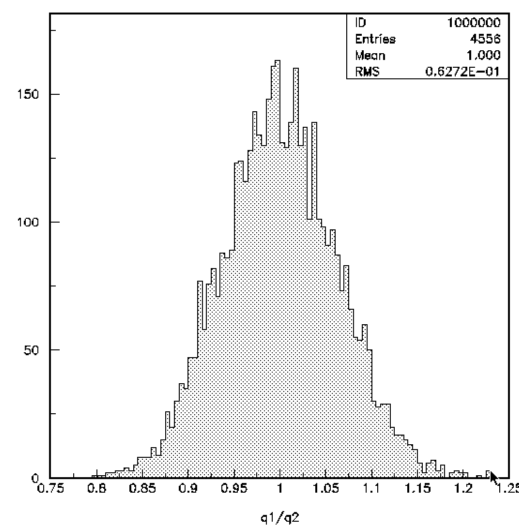
Measured charge distribution as
function of y in the pick-up plane



D.Underwood et al.

Throw 10,000 points in
x,y plane, calculate charge Q(r),
sum up charge on 1 x 1 cm^2 pads

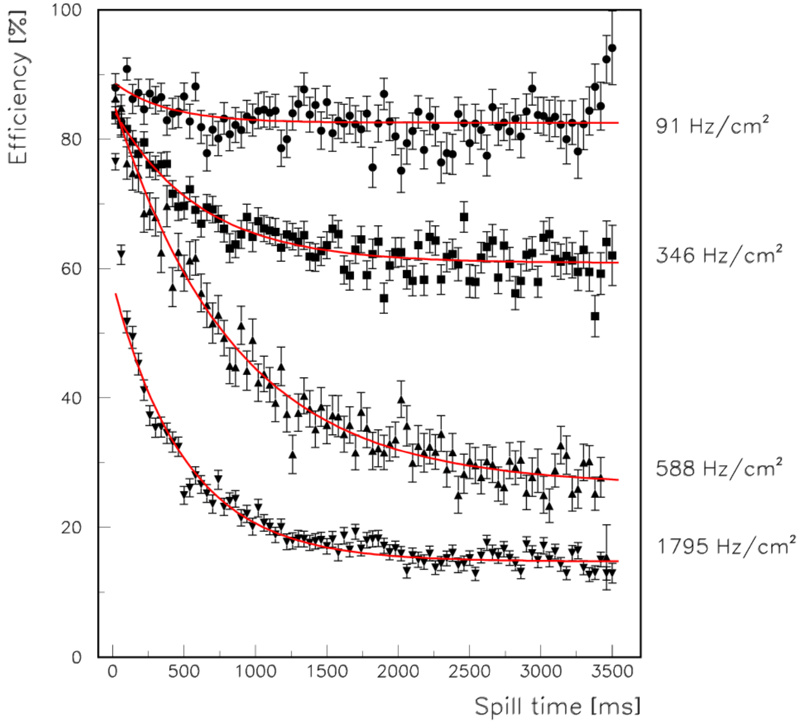




Overall reconstructed charge
with 10,000 throws

IV Calculating the Rate Capability

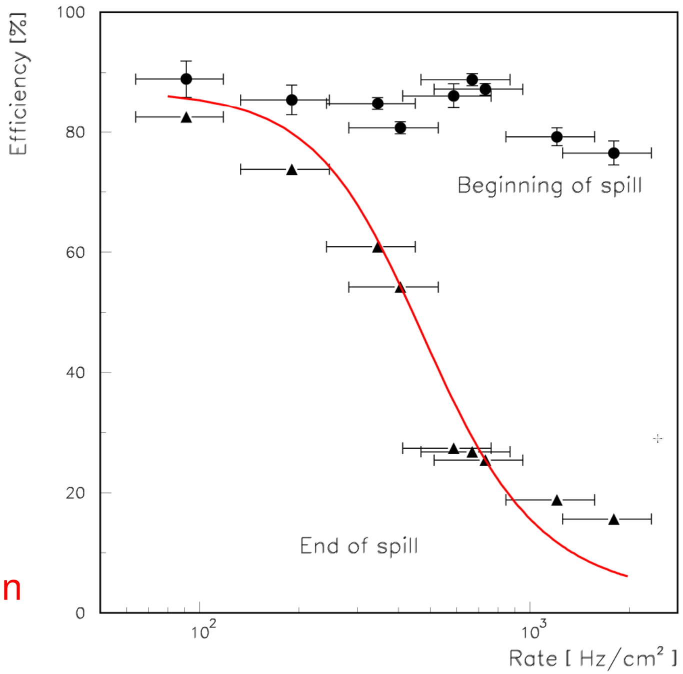
Measurements in FNAL test beam



Fits theoretically motivated

Developed analytical model to calculate drop in efficiency

Based on assumption of voltage drop due to current through RPC

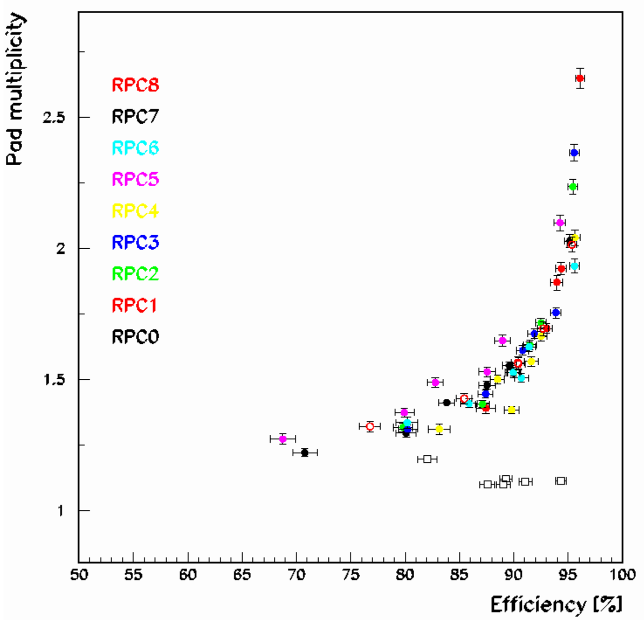


Analytical prediction

Effect not (yet) implemented in simulation

Published in 2009 JINST 4 P06003

V Simulating Muons



Broadband muons

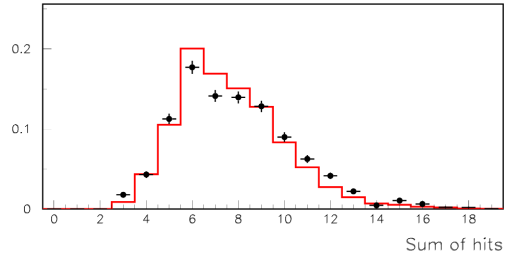
from FNAL testbeam (with 3 m Fe blocker)

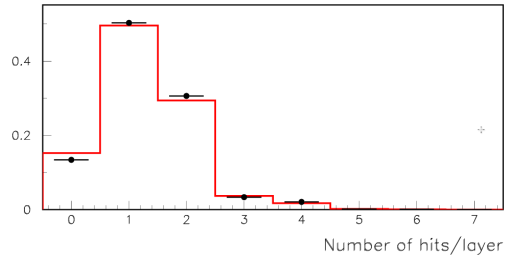
Used to measure efficiency and pad multiplicity of RPCs
→ calibration constants

Tuned

slope **a**
threshold **T**
charge adjustment $\mathbf{Q_0}$

→ reproduce the distributions of the sum of hits and hits/layer





Data

Monte Carlo simulations
after tuning

Published as B.Bilki et al., 2008 JINST 3 P05001
Published as B.Bilki et al., 2009 JINST 4 P04006

VI Simulating Positrons Showers

Positrons at 1, 2, 4, 8, 16, GeV

from FNAL testbeam (with Čerenkov requirement)

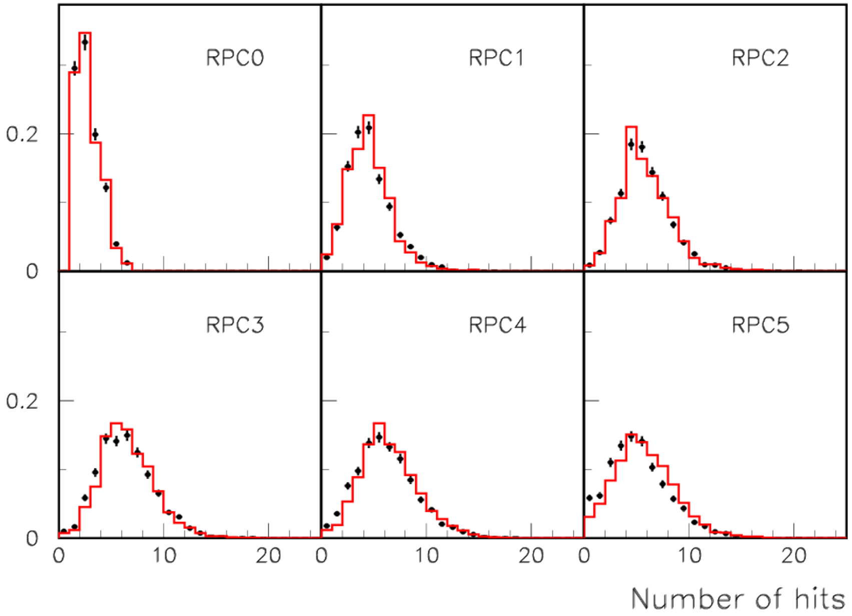
Tuned

distance cut $\mathbf{d_{cut}}$

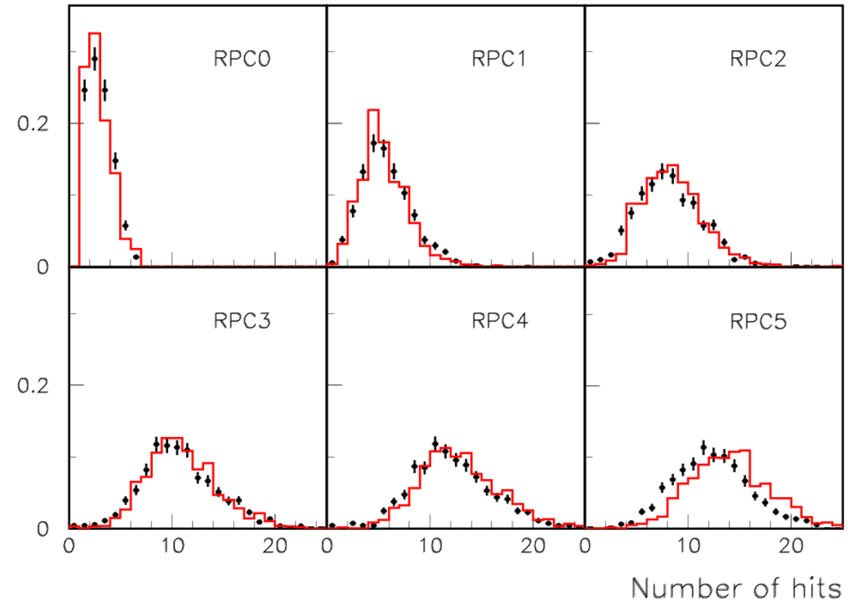
→ reproduce distributions in individual layers (8 GeV data)

Data
Monte Carlo simulations

2 GeV e^+

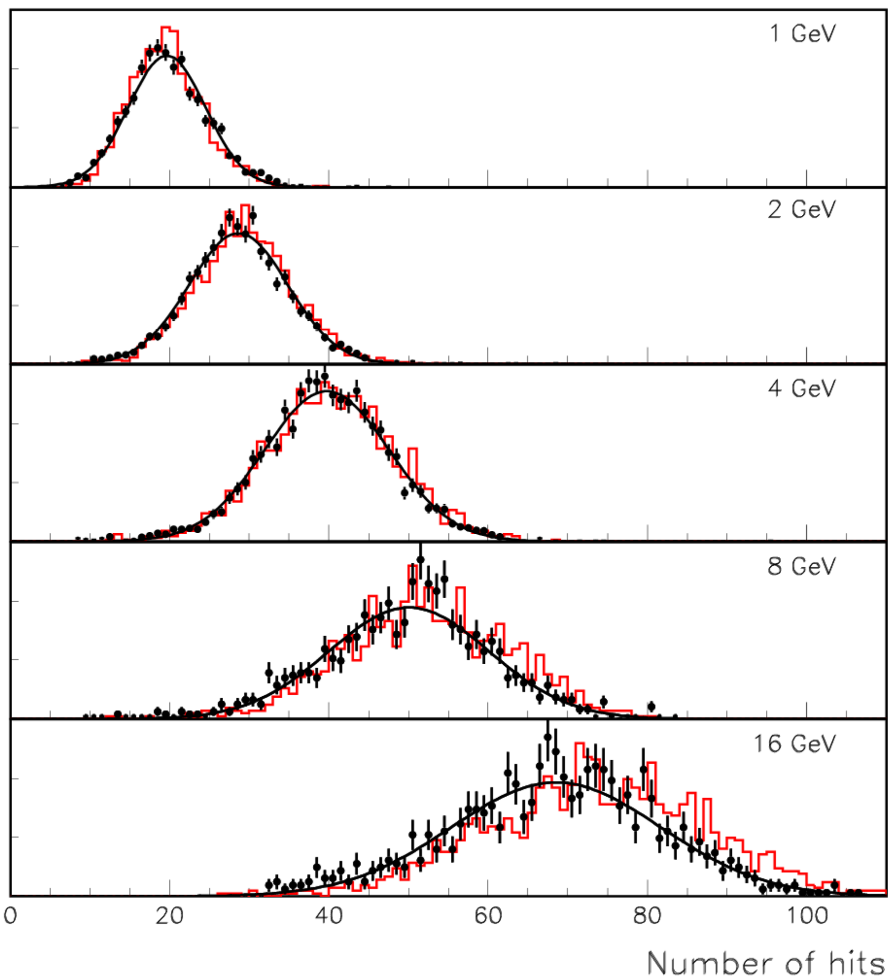


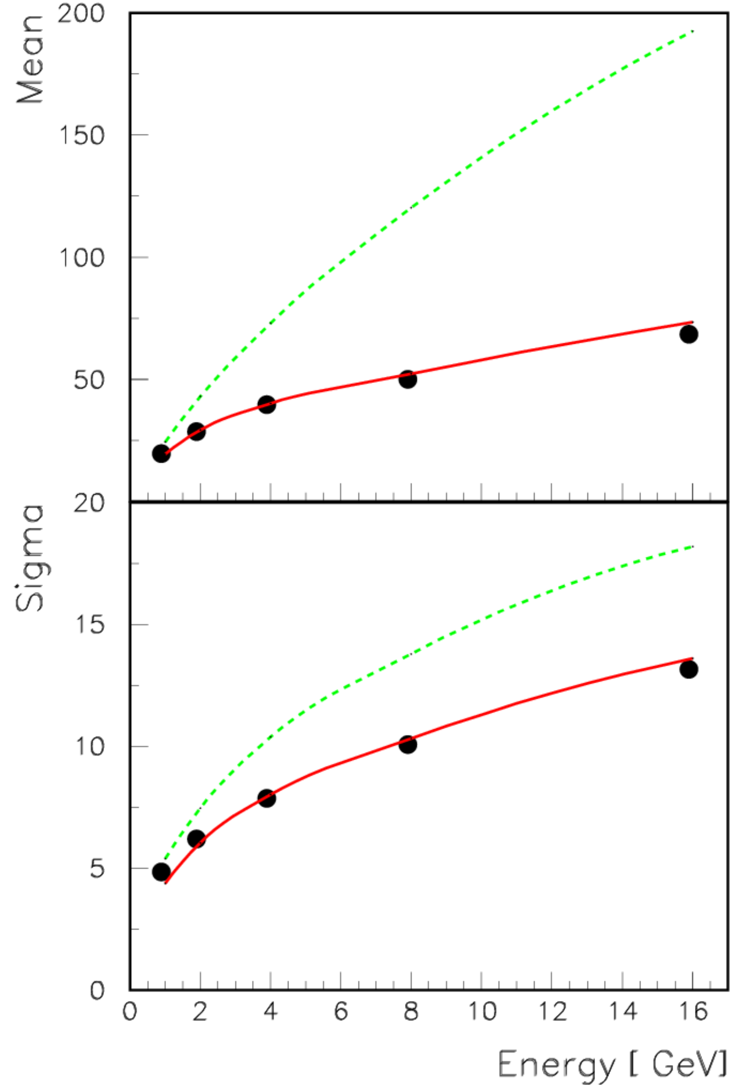
8 GeV e^+



Published as B.Bilki et al., 2009 JINST 4 P04006

Data
Monte Carlo simulations – 6 layers
Monte Carlo simulations – Infinite stack





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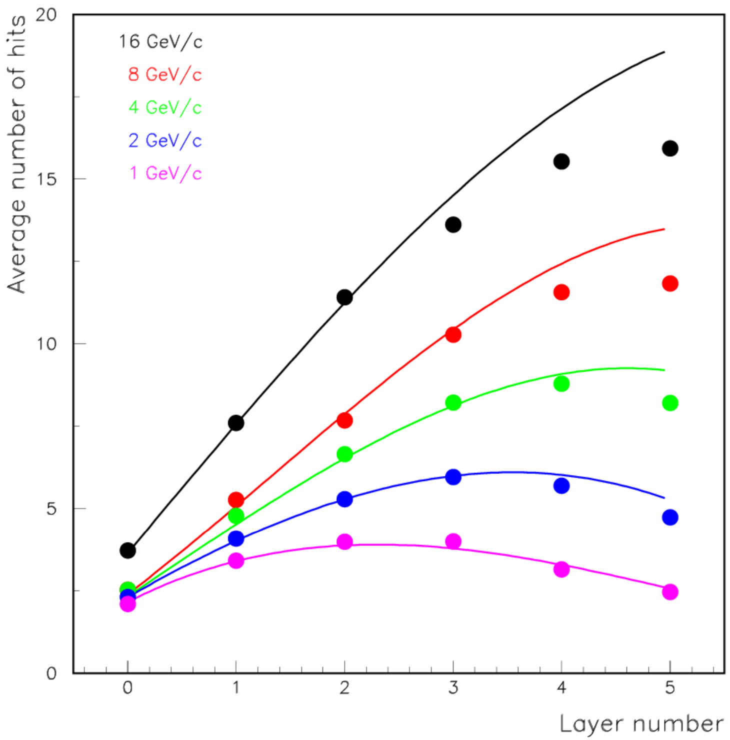
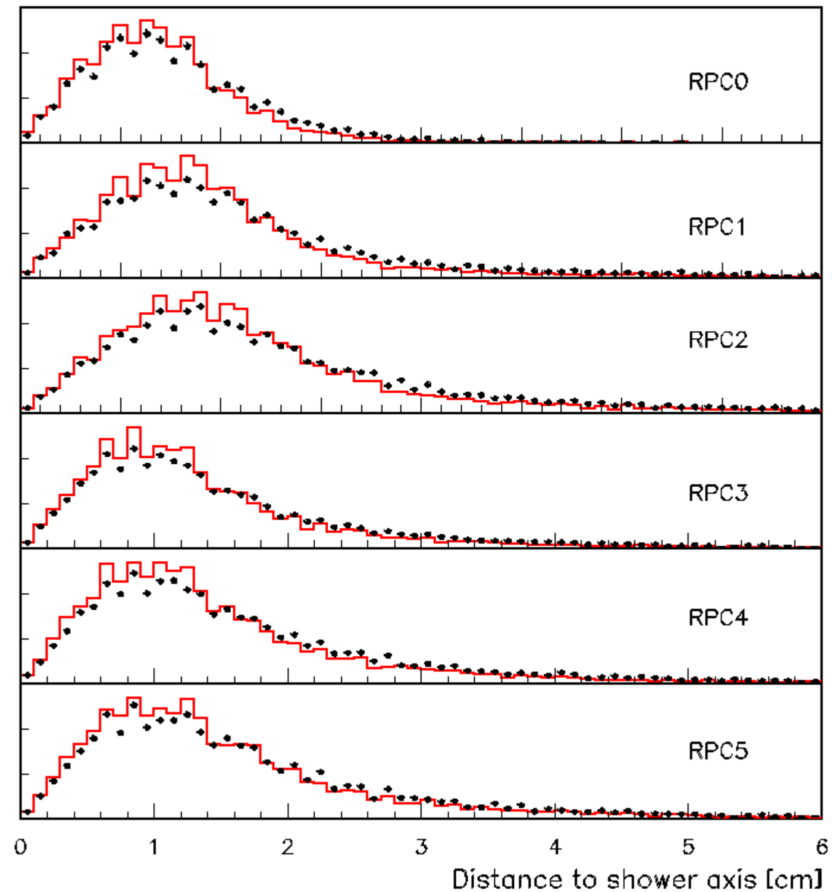
Longitudinal shower shape



Lateral shower shape for 2GeV e^+



Effects of high rates seen

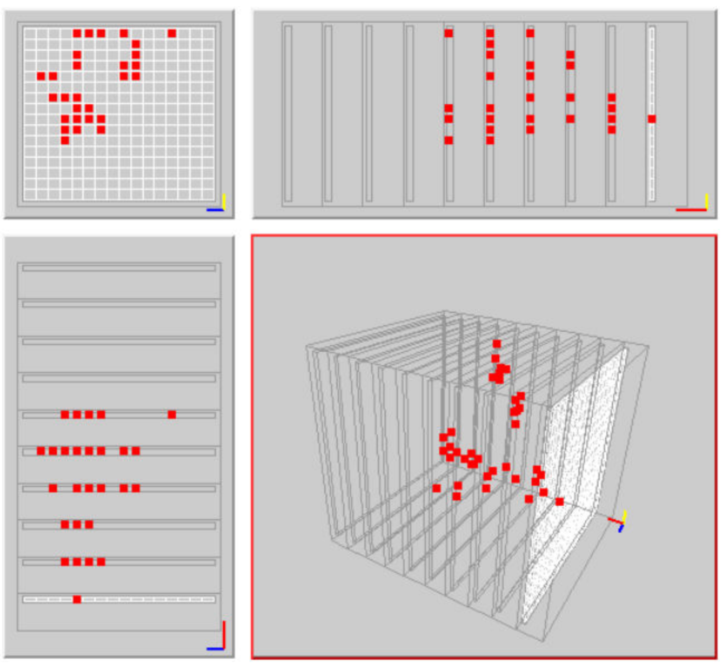
Published as B.Bilki et al., 2009 JINST 4 P04006

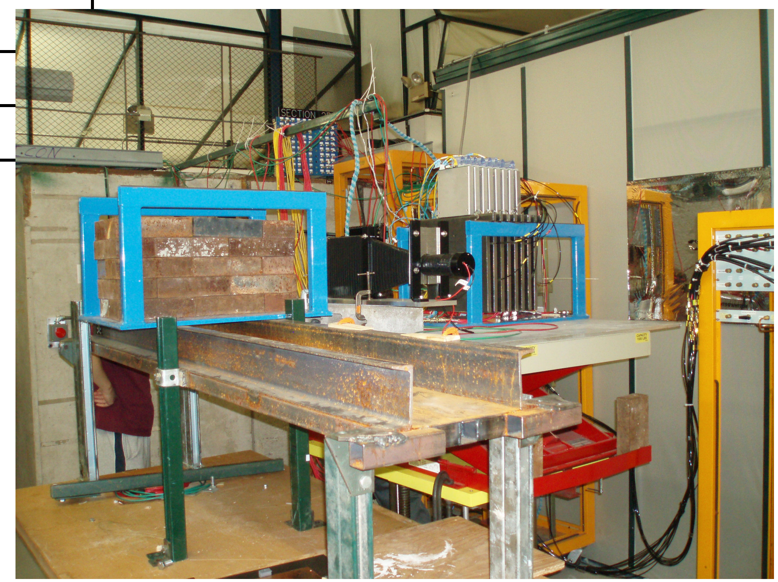
VII Simulating Pion Showers

Momentum [GeV/c]	Stack of iron bricks	Number of events	Beam intensity [Hz]	Fraction of events without veto from the Čerenkov counters[%]
1	No	1378	547	6.0
2	No	5642	273	5.9
	Yes	1068	80	57.3
4	No	5941	294	15.5
8	No	30657	230	24.6
16	No	29889	262	28.0

Trigger =

Coincidence of 2 scintillator paddels + veto from either Čerenkov counter





6 layer stack corresponding to 0.7 λ_I

Accepted for publication in JINST

Event Selection

Requirement		Effect
At least 3 layers with hits		Rejects spurious triggers
Exactly 1 cluster in the first layer		Removed upstream showers, multiple particles
No more than 4 hits in first layer		Removed upstream showers
Fiducial cut away from edges of readout		Better lateral containment
Second layer	At most 4 hits	**MIP selection**
	At least 5 hits	**Shower selection**

Accepted for publication in JINST

Brick data

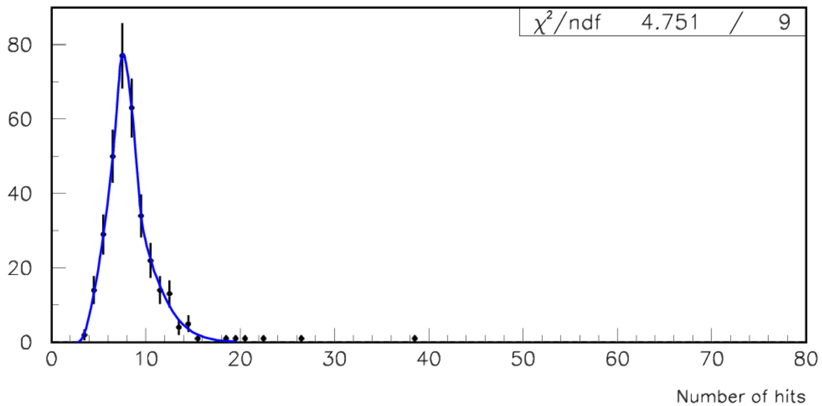
Calibration close to expected values
→ no corrections applied

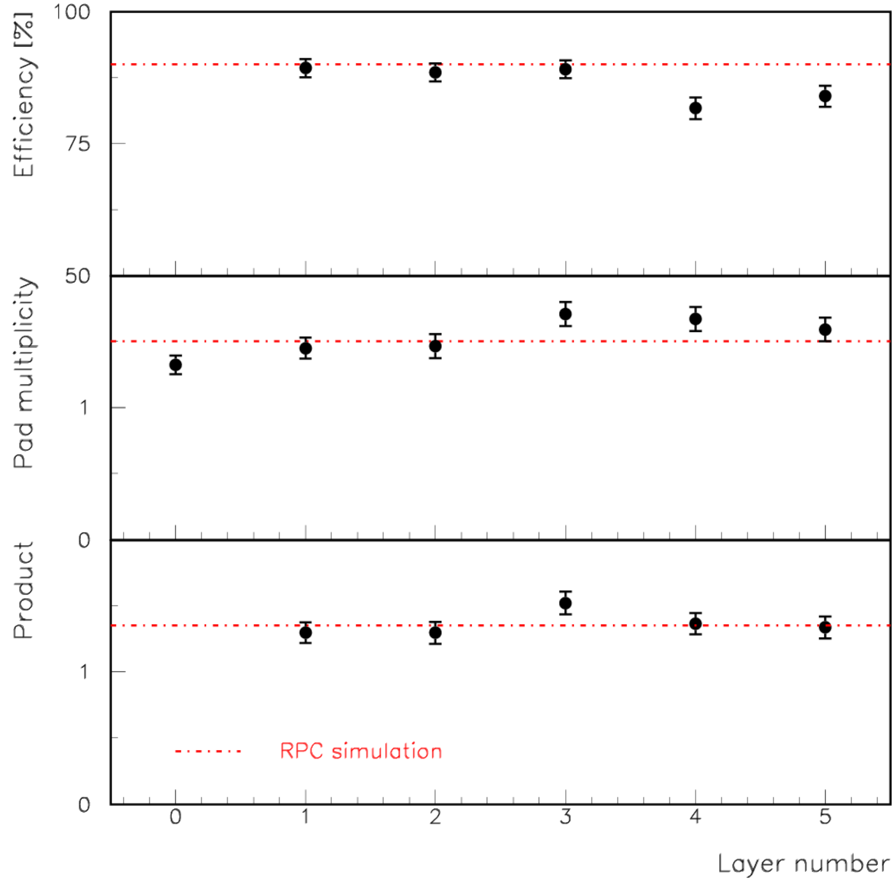
Secondary beam with +2 GeV/c selection

Fe blocks in front of RPCs

~ 50 cm deep corresponding to 3 λ_I
→ 97% of π interact
→ ΔE_μ ~ 600 MeV

Sum of hits in the DHCAL (RPC0 – RPC5)





→ Emperically fit to

$$\mathbf{y} = \alpha \mathbf{e}^{-\frac{1}{2}\left(\frac{\mathbf{x}-\beta}{\gamma}\right)^2} + \delta(\mathbf{x} - \mathbf{x}_0)^{\epsilon} \mathbf{e}^{\phi(\mathbf{x_0} - \mathbf{x})}$$

In the following this will be our μ signal shape

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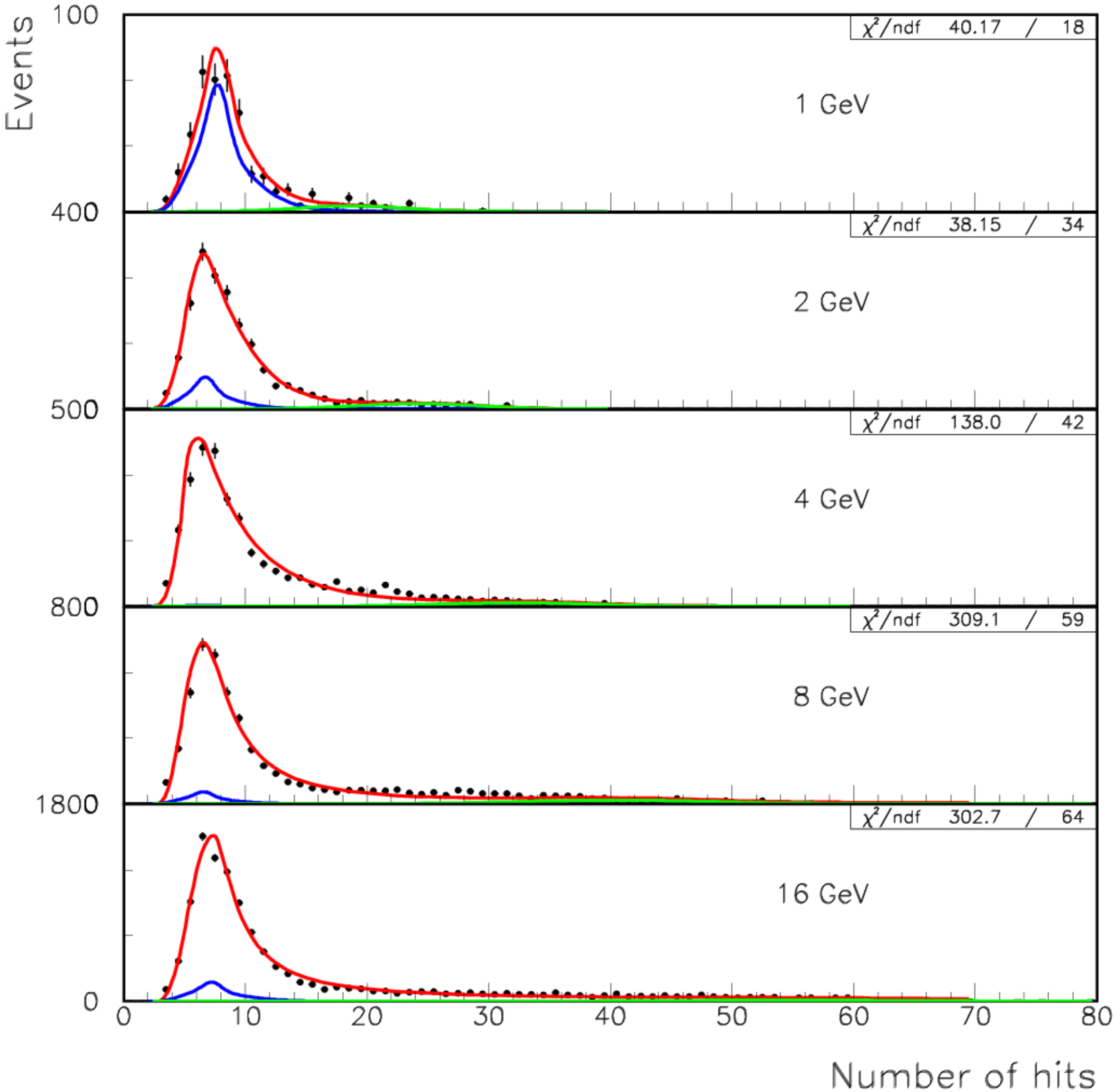
MIP Selection



Fit to 3 components

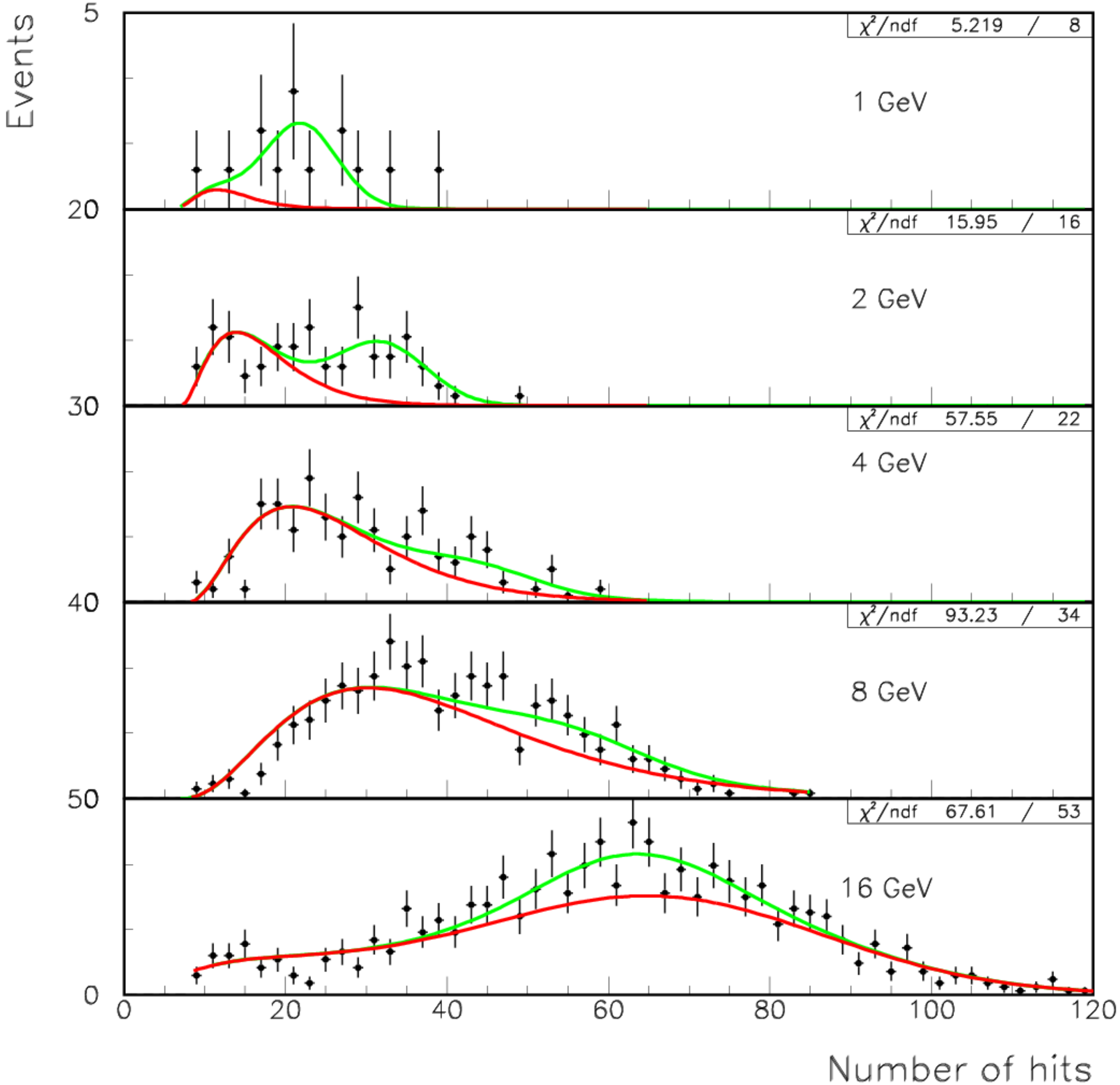
- **Muons** (from brick data)
- **Pions** (from MC, not shown)
- **Positrons** (from MC)

(red line sum of 3 components)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate)

Accepted for publication in JINST

Shower Selection



Fit to 2 components

- Pions (from MC)
- Positrons (from MC)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate) at 16 GeV (-9%)

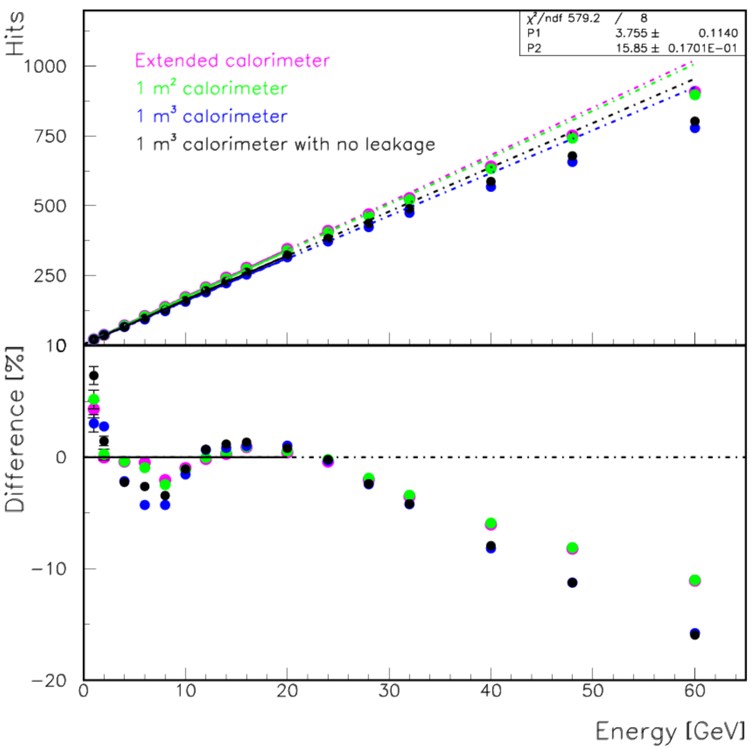
Reasonable description by simulation

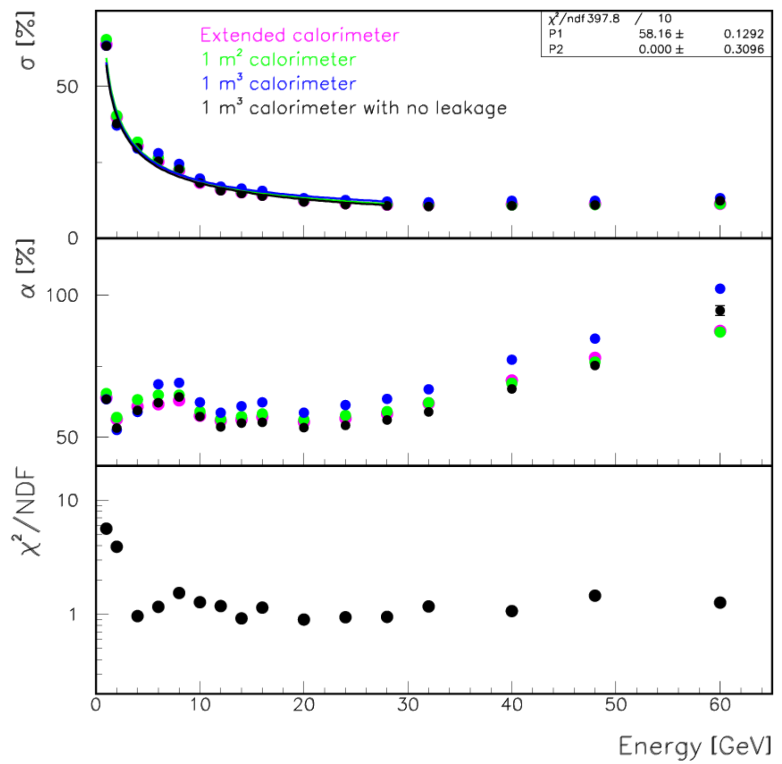
Positron contamination at low energies

Not many pions at low energies

Accepted for publication in JINST

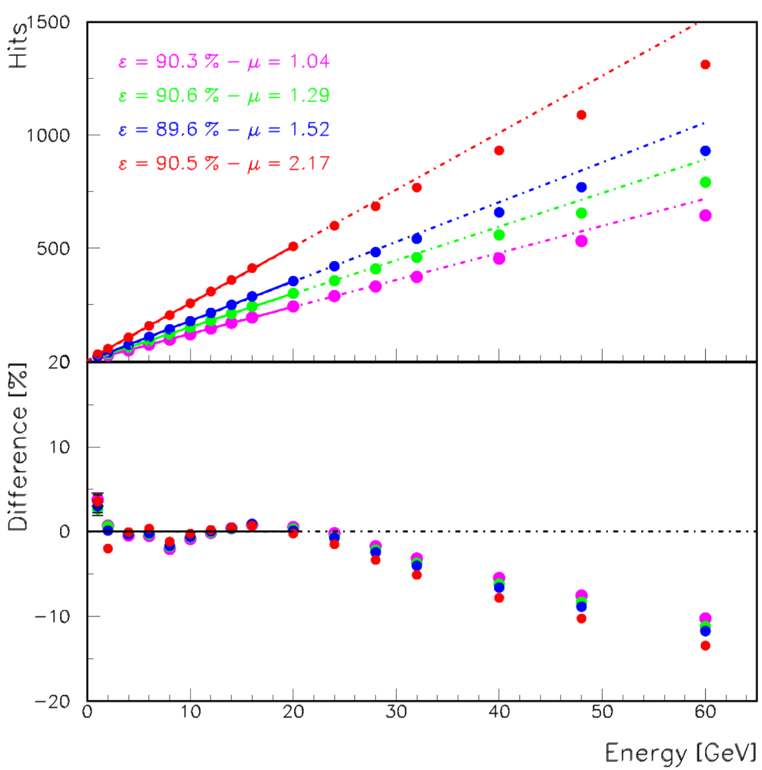
VIII Simulating Larger Systems

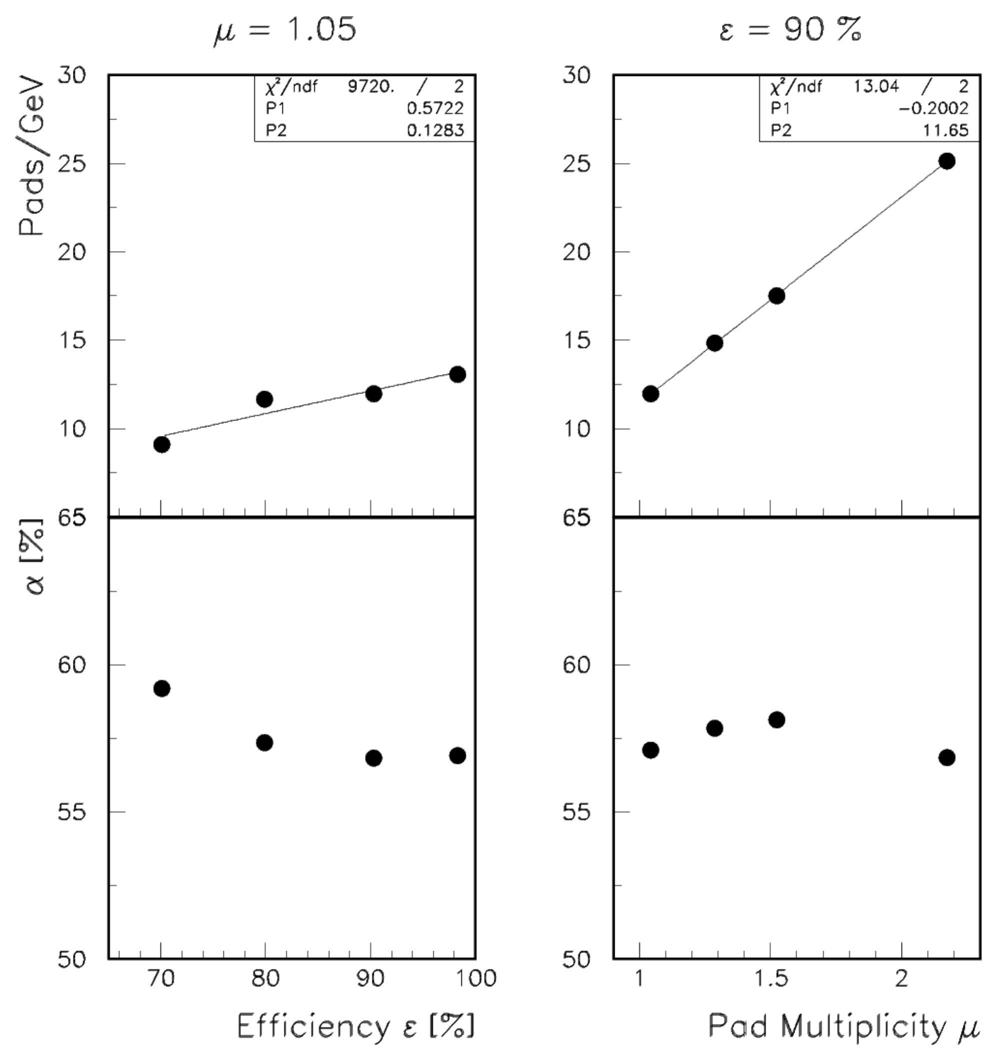




Reasonable Gaussian fits for E > 2 GeV
Discontinuity at E ~ 8 GeV (surprising, changes with physics list)
Non-linearity above E ~ 20 GeV (saturation)
Resolution ~ 58%/√E(GeV) (for E < 28 GeV)
Resolution degrades above 28 GeV (saturation)
Resolution of $1m^3$ with containment cut somewhat better than for extended calorimeter

Study of different extended RPC-based calorimeters





Efficiency and pad multiplicity have only minor effect on resolution (Small μ might be desirable for PFAs)

However values need to be known

Linear calibration corrections for ε,μ will work ($P_1 \sim 0$)

IX Conclusions

Analog RPC paper – published in **NIM**

Instrumentation paper – published in **IEEE Nuclear Transactions**

Muon calibration paper – published in **JINST**

Positron paper – published in **JINST**

First showers in a DHCAL, validity of concept, understanding of DHCAL response

Rate dependence paper – published in **JINST**

Unique contribution to understanding of RPCs, essential for operation of DHCAL

Pion paper – accepted for publication in **JINST**

Including predictions for larger prototype calorimeters

Environmental dependence paper – draft exists, plots (almost) finalized

Essential information for operation of DHCAL

Qingmin Zhang's talk

Have acquired detailed knowledge about RPCs

Developed MC program for the simulation of RPCs with segmented readout

Reasonable agreement between measurements in test beam and simulation

- Muons (used for tuning of the simulation)
- Positrons (1 additional parameter tuned)
- Pions (absolute predictions)

Simulation of larger system

- Reasonably linear response for pions
- Acceptable energy resolution ~ 58%/√E(GeV)
- To be compared to test beam data with 1 m^3 physics prototype

Study with different physics lists