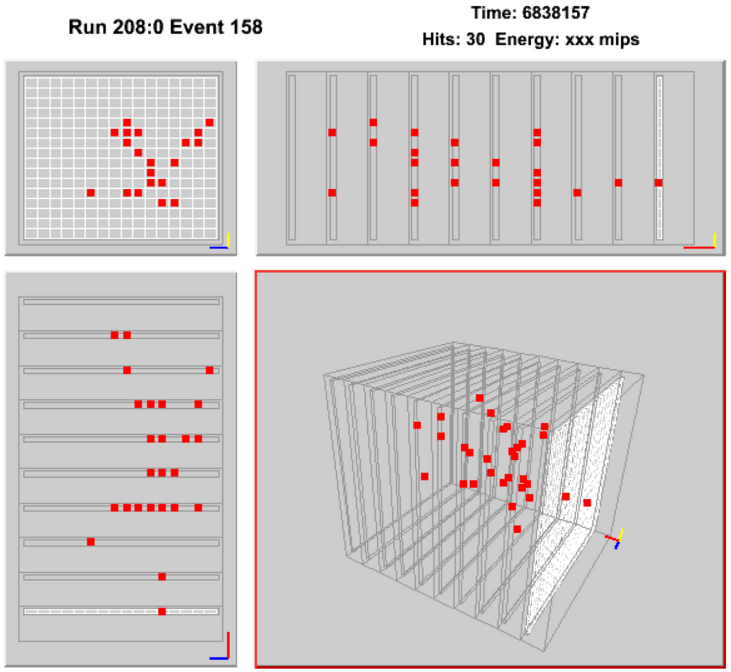
Analysis of Test Beam Data from the Vertical Slice Test of the Digital Hadron Calorimeter



José Repond
Argonne National Laboratory

Linear Collider Workshop LCWS 2008
University of Illinois at Chicago
November 16 - 20, 2008

Outline

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 Vertical Slice Test

Test of whole system with

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

RPCs

Up to 9 2-glass designs
1 1-glass design
Only use RPC0 – RPC5 in analysis of e^+, π^+
Only use RPC0 – RPC3 for rate dependence

Absorber

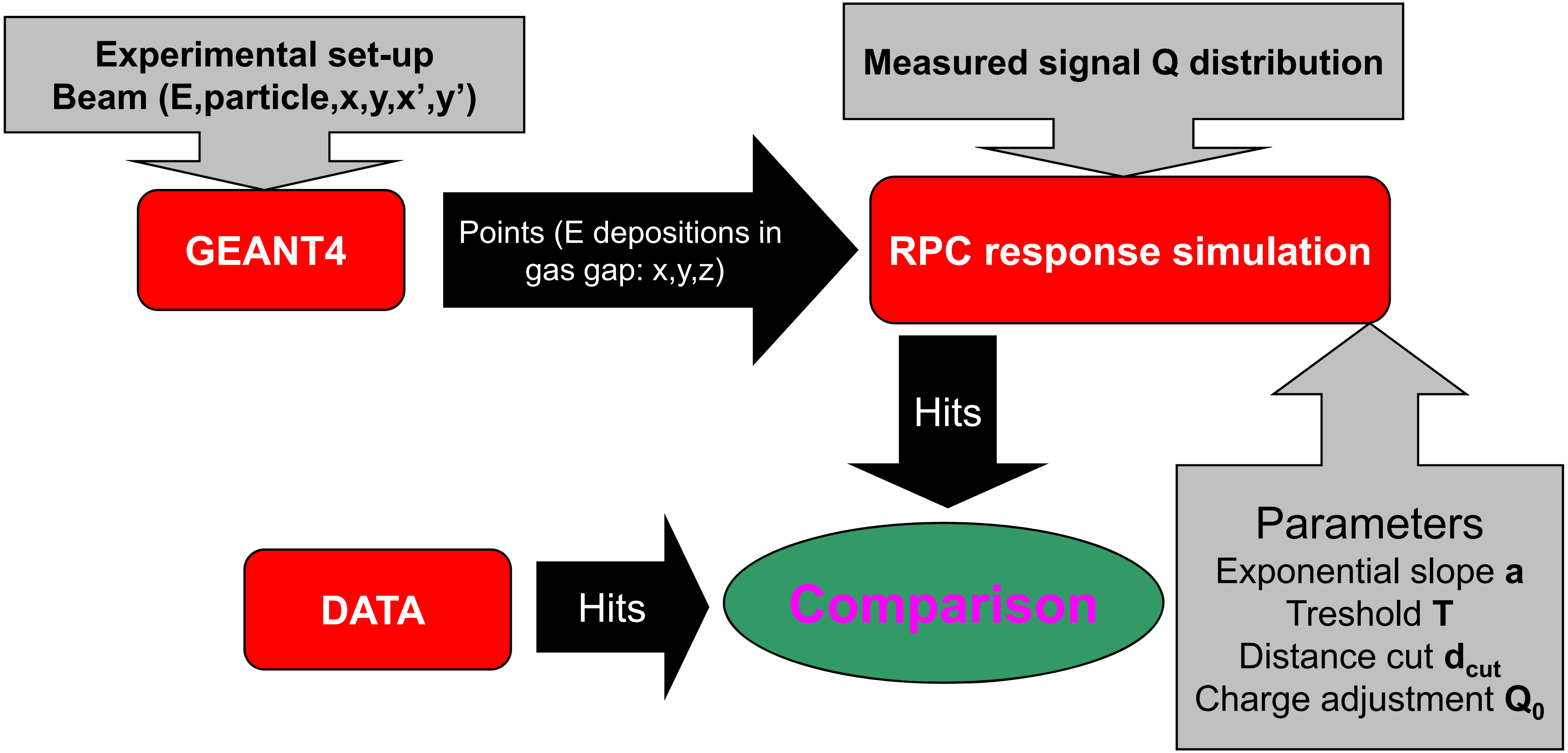
For cosmic rays, muon, pions, electrons: Steel (16 mm) + Copper (4 mm)
Rate capability measurement (120 GeV protons): 16 mm PVC with whole cut out in center

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

Calorimeter for ILC

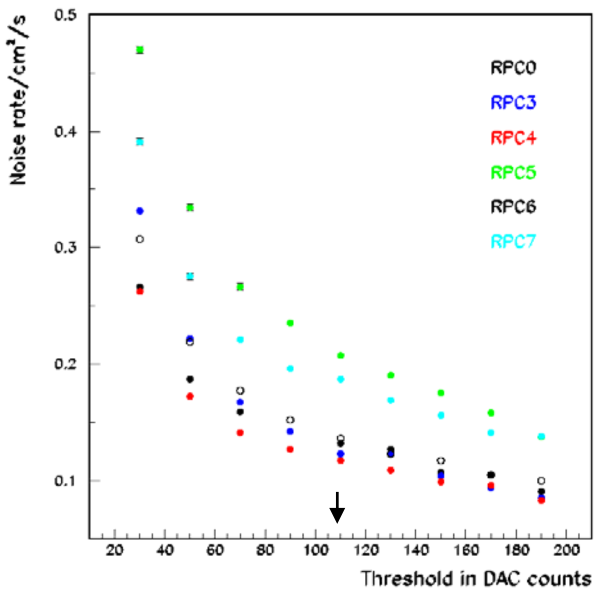
II Simulation Strategy

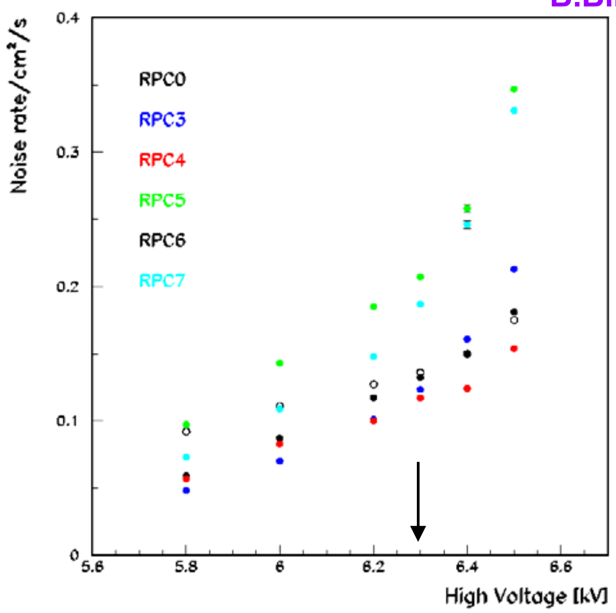


With muons – tune a, T, (d), and Q_0
With positrons – tune d
Pions – no additional tuning

III Measurement of Noise Rates

B.Bilki et al., 2008 JINST 3 P05001





At the default setting the rate measures

~ 0.1 Hz/cm²

For a $5 \cdot 10^7$ channel calorimeter this rate corresponds to 1 hit in a 200 ns gate

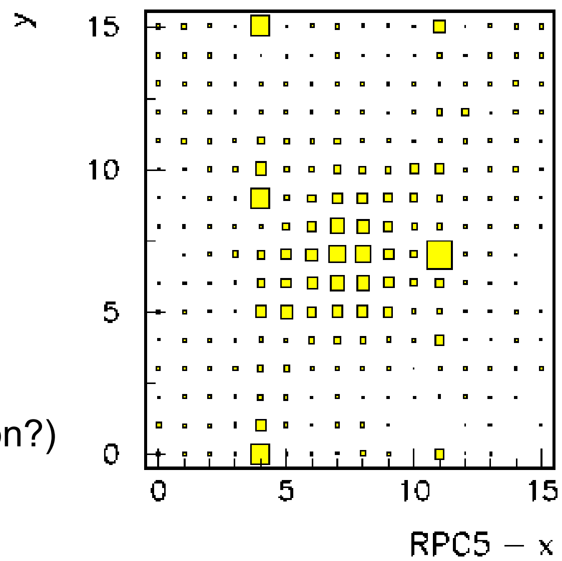
Noise rates

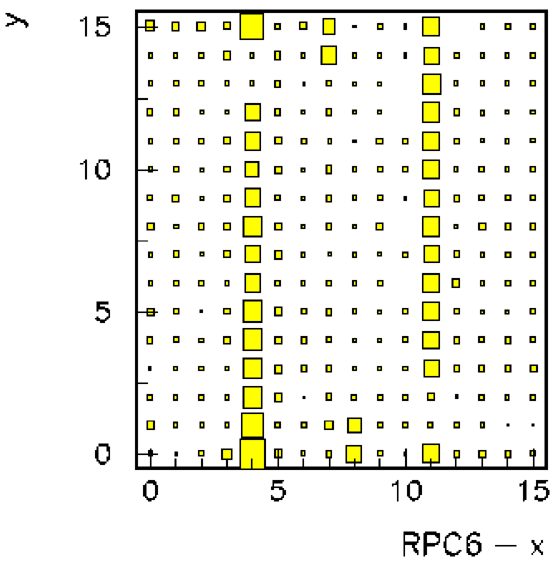
Decrease with increasing threshold
Increase with increasing high voltage

x – y map

Noise rates higher around location of spacers (fishing lines)

Somewhat higher in center (beam activation?)



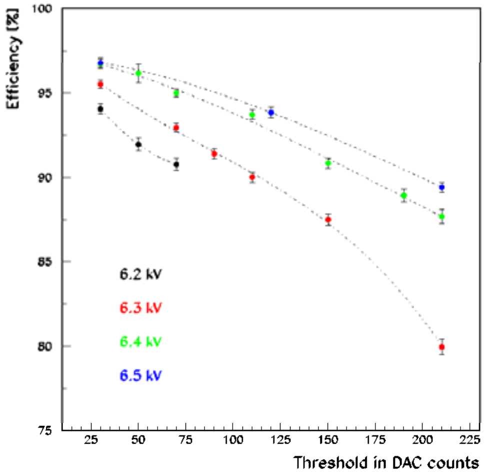


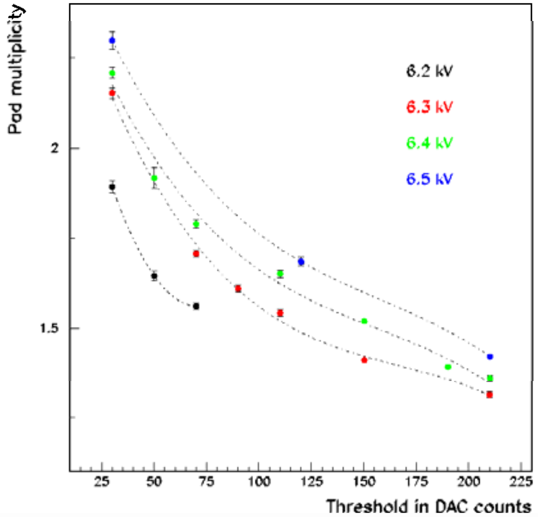
IV Analysis of Muon data

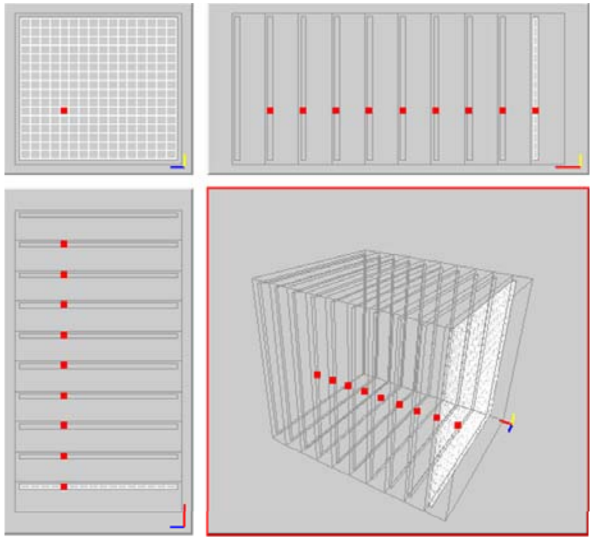
Explored operating space

Dependence on threshold & HV

Results confirmed earlier studies



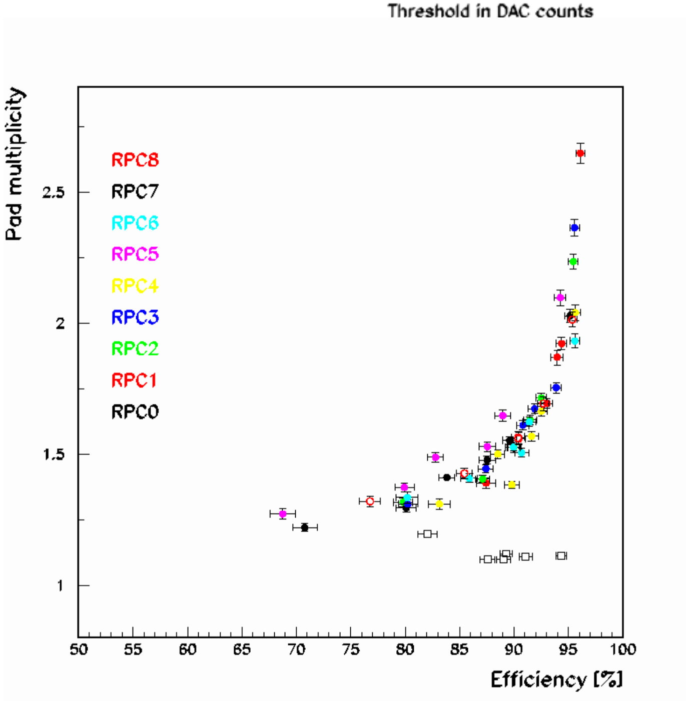




Efficiency vs. pad multiplicity

2-glass RPCs: results on
common curve

1-glass RPC: constant $\mu^{MIP} \sim 1.1$



Chose as default operating point

HV = 6.3 kV, THR = 110

$$\varepsilon^{MIP} \sim 90\%$$
$$\mu^{MIP} \sim 1.5$$

B.Bilki et al., 2008 JINST 3 P05001

CALICE Calorimeter for ILC

Data selection (minimal)

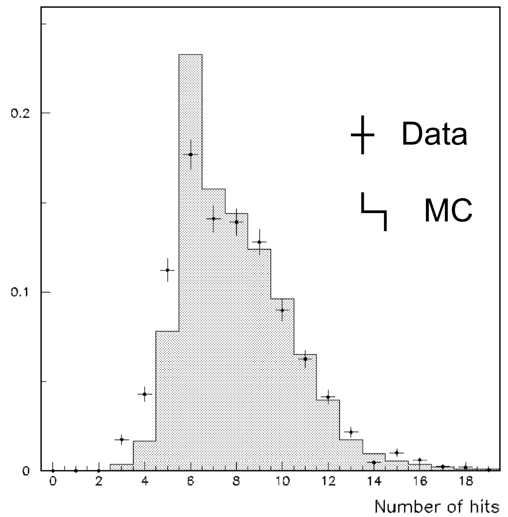
At most 1 cluster/layer
Fiducial cut around border of RPCs
At least 3/6 RPCs with hits

Plots considered for tuning

Sum of all hits
Average number of hits/layer

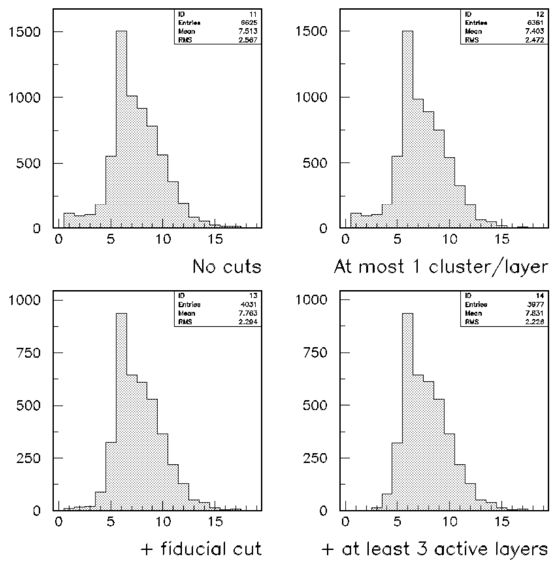
Simulation looks ~OK

Now let's tune the parameters

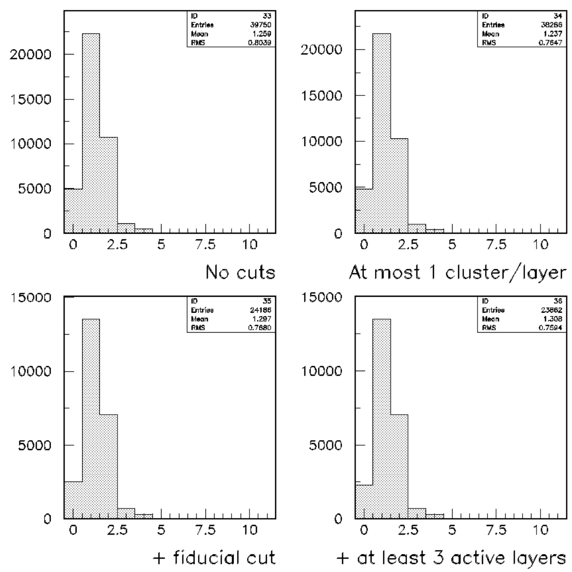


Simulation

Number of hits

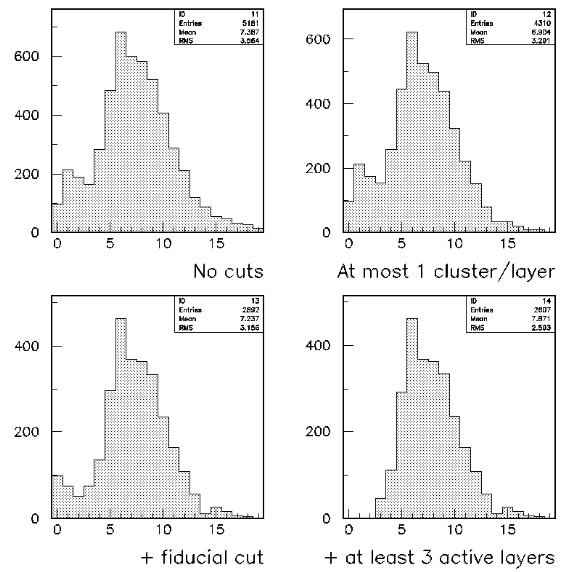


Number of hits/layer

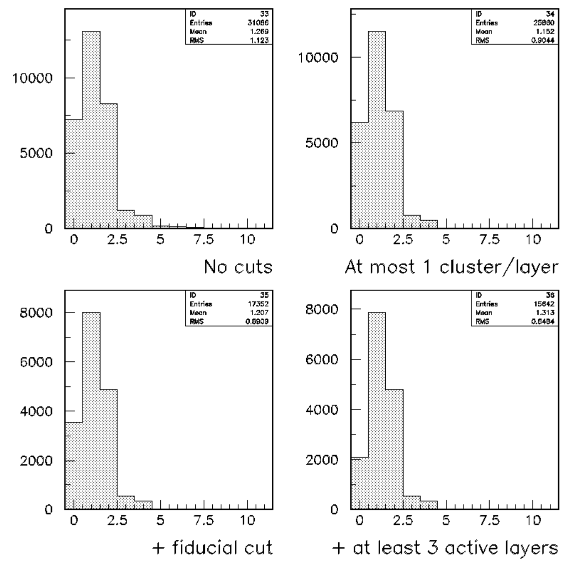


Data

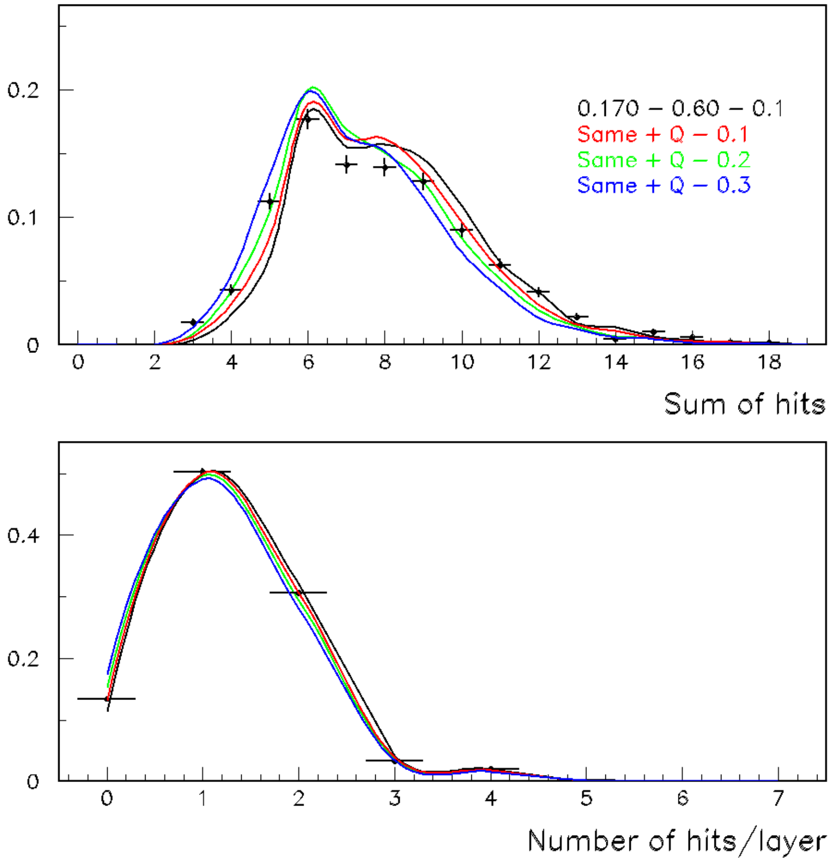
Number of hits



Number of hits/layer



Hit distributions after tuning of simulation

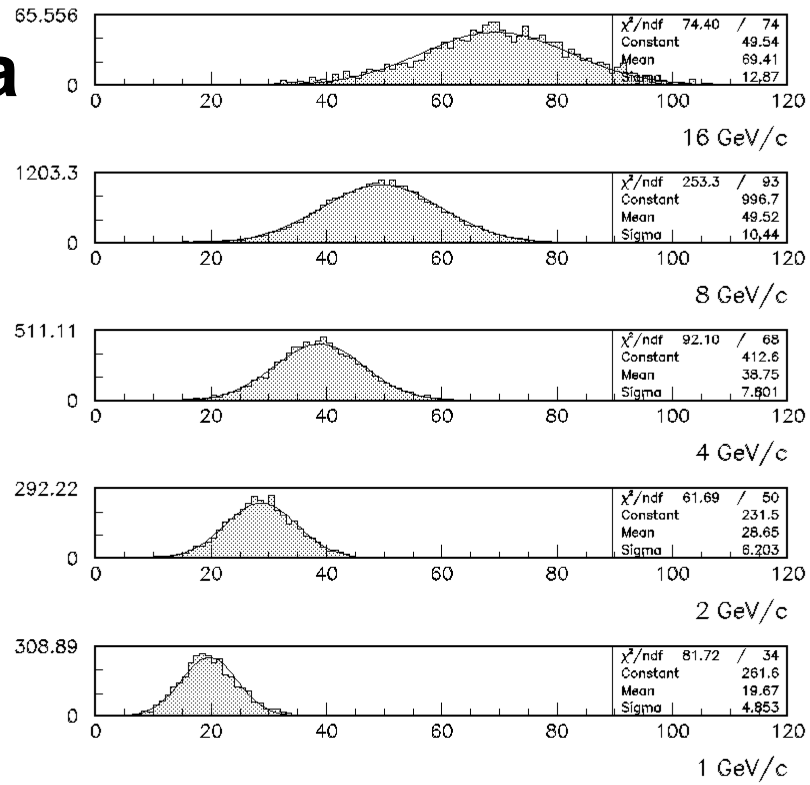


Best parameters

Slope **a**	0.170 cm
Threshold **T**	0.60 pC
Inefficiency distance d_{cut}	0.1 cm
Charge offset Q_0	-0.2 pC

Not perfect, but hopefully good enough

V Analysis of Positron Data

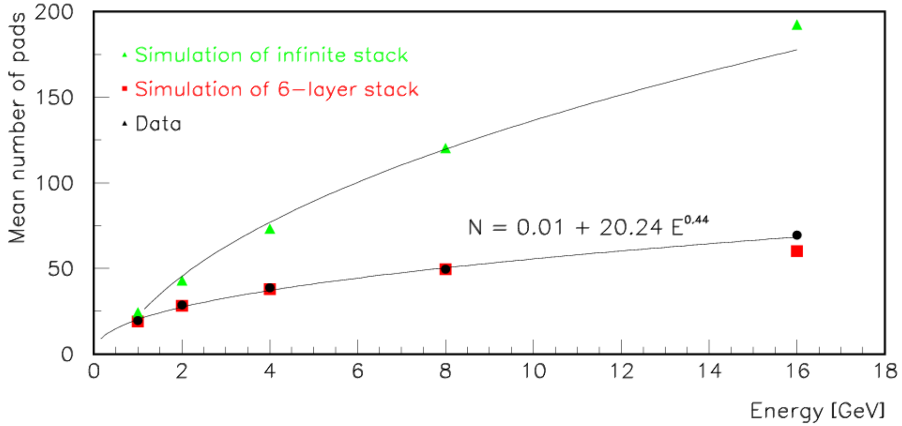


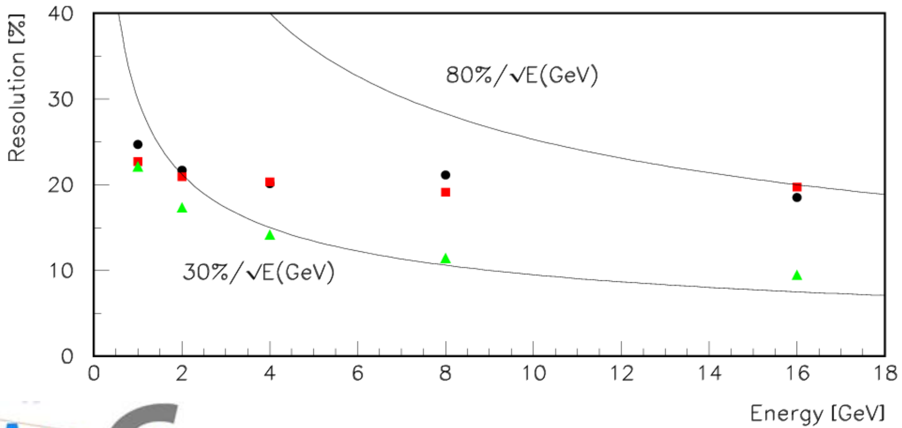
Data at

1, 2, 4, 8, 16 GeV (electrons selected by Čerenkov)

Response well fit by Gaussian

Accident!





Monte Carlo simulation

Both mean and sigma well reproduced

Large non-linearity

Dominated by leakage out the back (only 6.8 X_0)
Infinite stack – non-linearity due to overlaps in pads

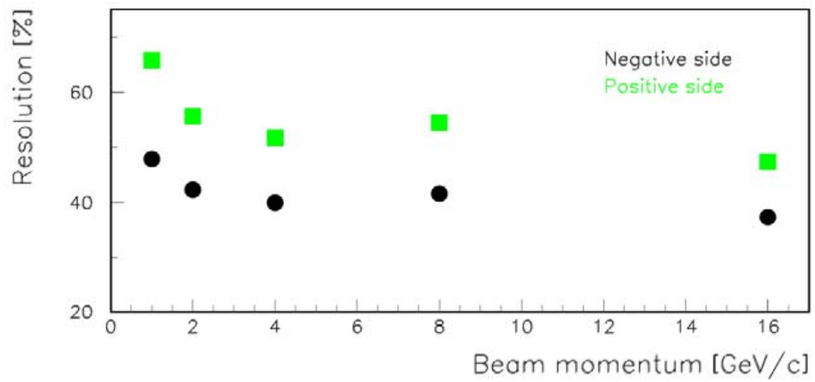
Resolution

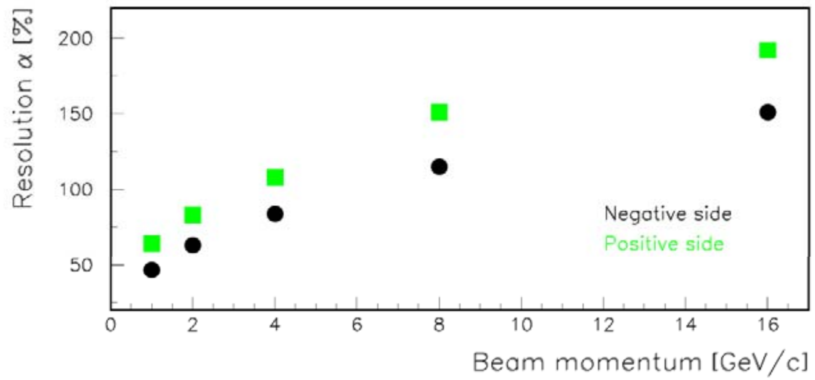
Effect of non-linearity ignored in this plot
Infinite stack – should reach 30%/√E at least

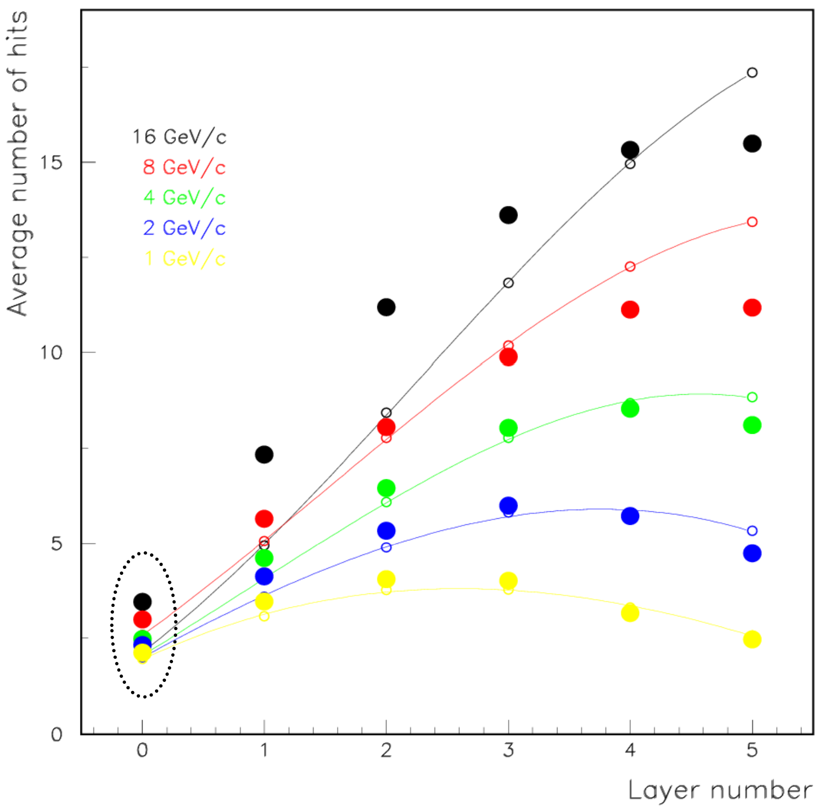
Calorimeter for ILC

Resolution values corrected for non-linearity

Remember → Dominated by leakage
Effect of overlaps (saturation) secondary







Measurement of longitudinal shower shape

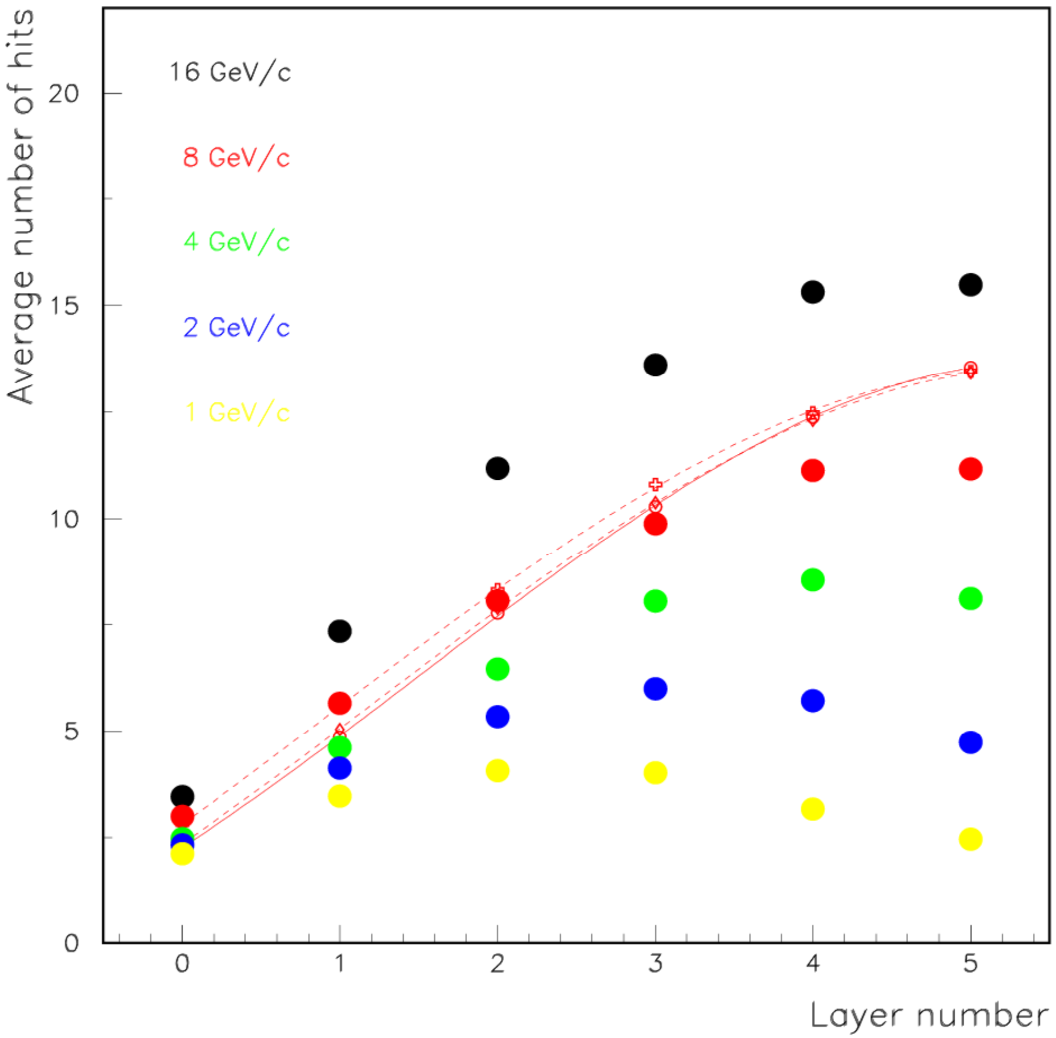
Agreement with simulation adequate (at best)
Simulation - Requires additional material in beam line

CALICE
Calorimeter for ILC

Longitudinal shower shape

Extra material in beam helps first layers

Deficit in last layers
→ need to check efficiency
using pion data with same
beam set-up



● Data

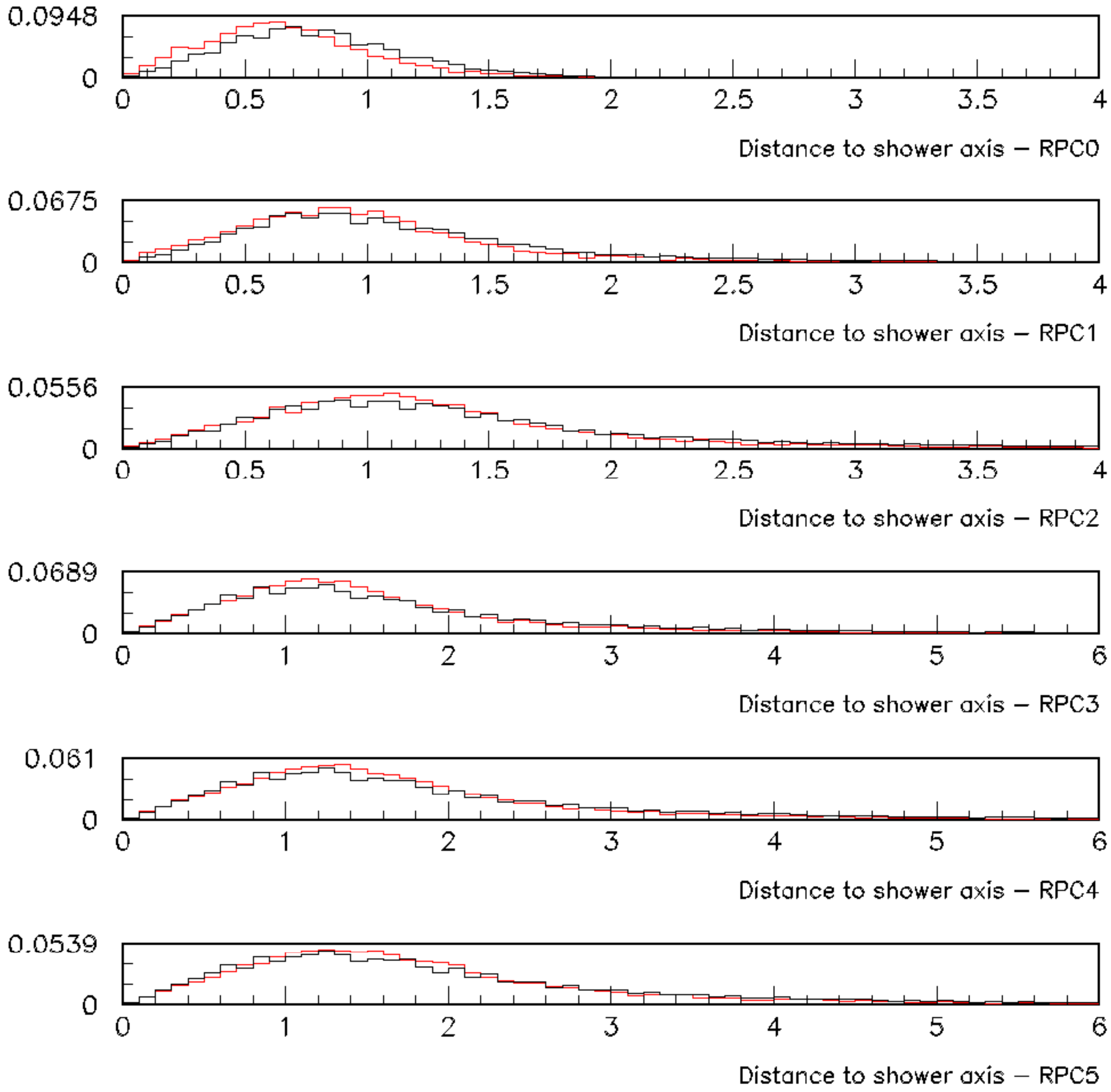
○ MC: No material in beam
▽ MC: Reasonable material in beam
✚ MC: Lots of material in beam (1/4 X_0)

Lateral shower profile

Without material in beam

First layer too narrow

Subsequent layers OK



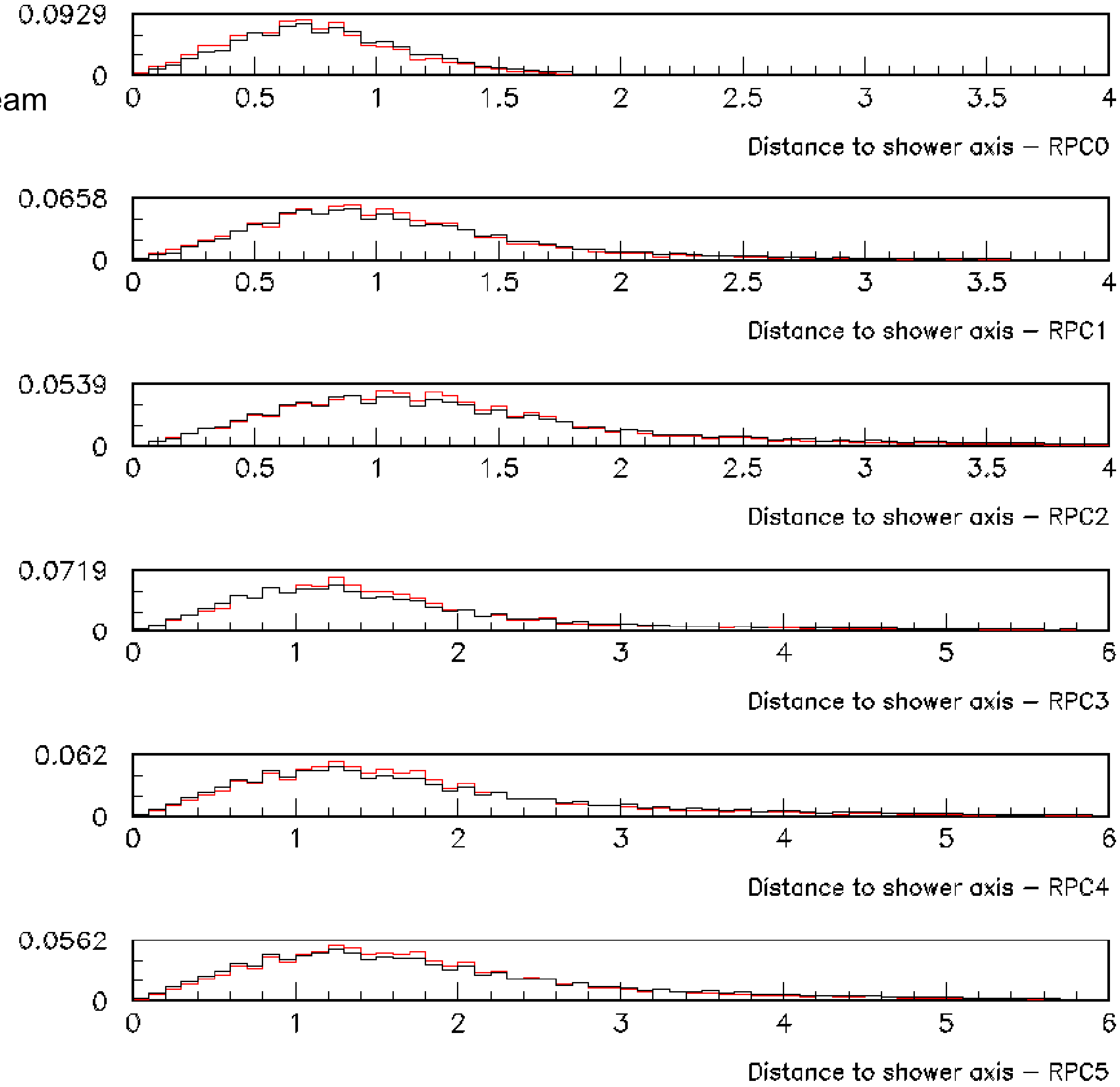
Data

Simulation

Lateral shower profile

With lots of material (1/4 X_0) in beam

Looks good everywhere



Data

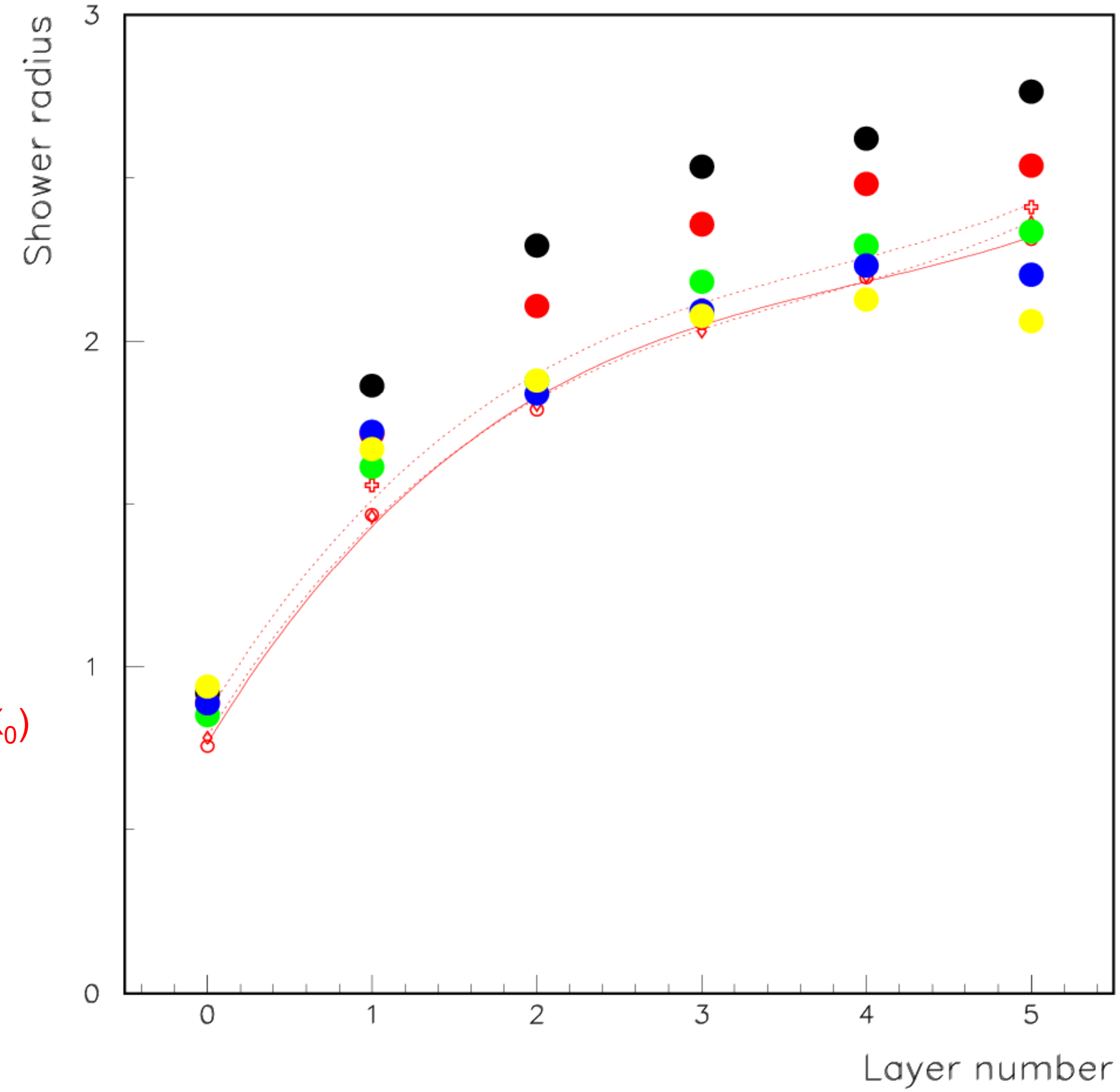
Simulation

Lateral shower profile

Extra material helps, but not enough

More outliers in data

Still under investigation…



● Data

○ MC: No material in beam

▽ MC: Reasonable material in beam

✚ MC: Lots of material in beam (1/4 X_0)

VI Response to Pions

Data at

1, 2, 4, 8, 16 GeV (electrons rejected by Čerenkov)

6 layer stack corresponding to 0.7 λ_I

Analysis separates

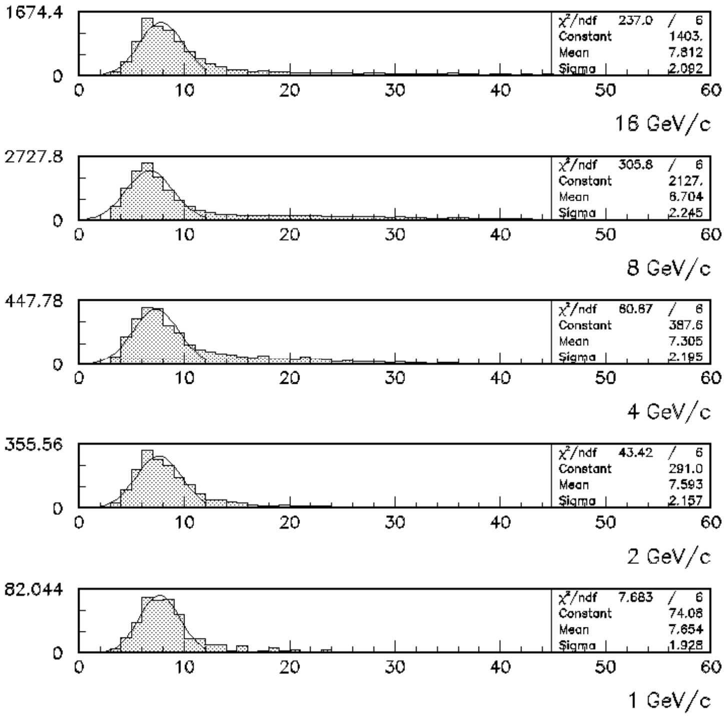
- Non-interacting pions/muons
- Pions interacting in first layers
- Pions interacting later (rejected)

Criteria:

- Exactly one cluster in first layer
- Distance R< 5
- Number of hits in **first** layer <5

MIP selection

Number of hits in **second** layer < 5

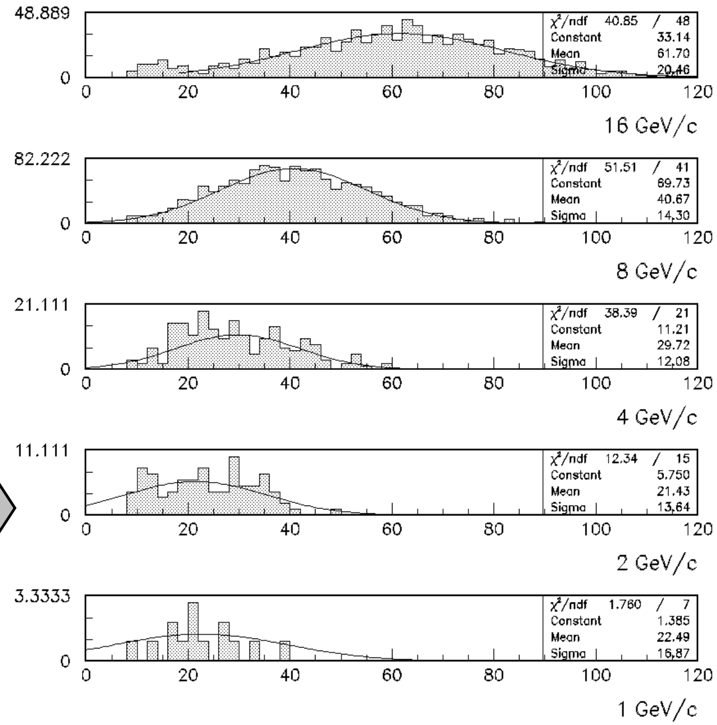


Nice MIP peaks

Gaussian distributions

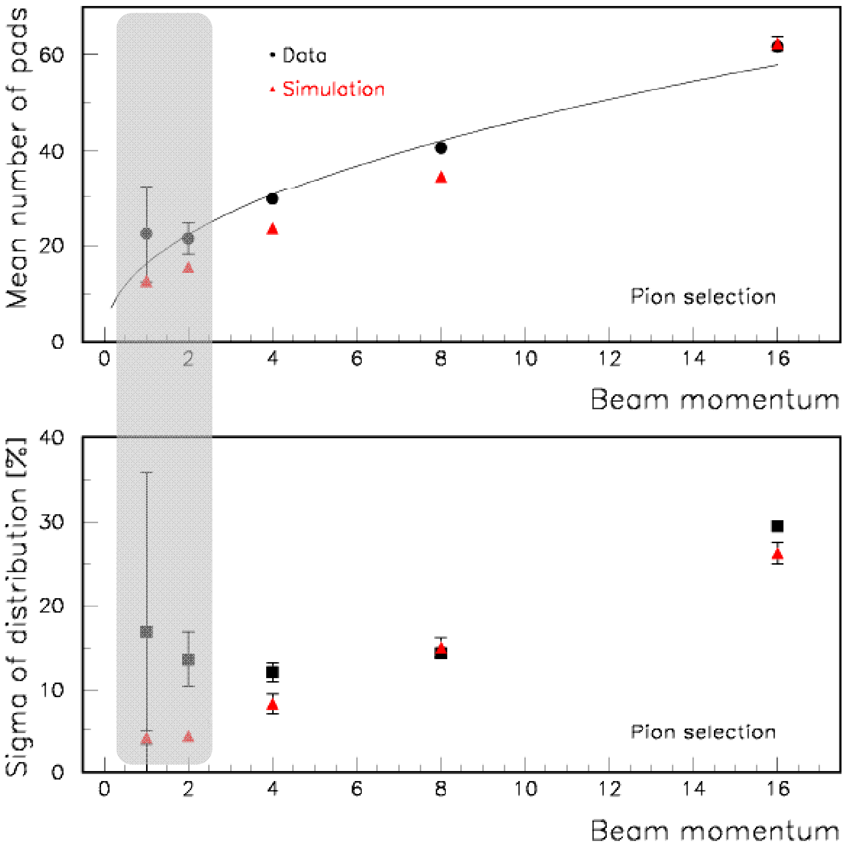
Pion selection

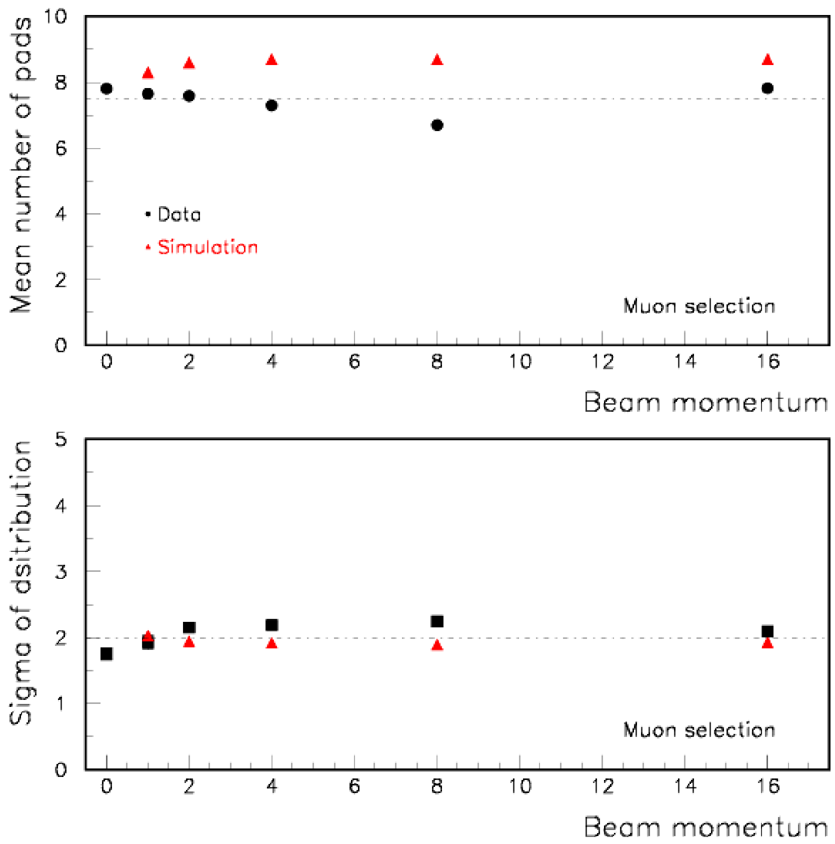
Number of hits in **second** layer ≥ 5



MIP selection

Mean and sigma ~independent of beam momentum
Mean not very well reproduced by simulation
→ Beam contains muons, simulation does not
(data are cleaner !!!)
Width of distributions adequately reproduced





Pion selection

Measurements at 16, 8 and 4GeV/c
Not sufficient statistics at 2, 1 GeV/c
Non-linearity due to leakage
Adequate agreement with simulation

VII RPCs' Rate Dependence

RPC's recovery

RPCs are inefficient at high rates
Typical acceptable rates are ~ 1 Hz/cm^2 in streamer and ~ 100 Hz/cm^2 in avalanche mode

Rate dependence measurement

Measure MIP detection efficiency at different rates
Look for 2 effects

- Drop of efficiency after a hit as function of time difference between the hits
- Drop of efficiency as function of rate on chamber

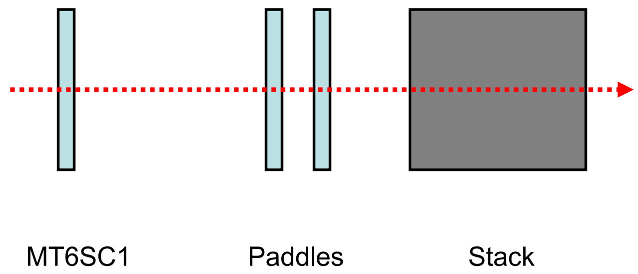
Very tricky measurements

Experimental set-up

Stack without absorber plates

7 RPCs in total

6 Default, 1 Exotic
Default High voltage and threshold setting
Problems with grounding → good data on only 4 RPCs

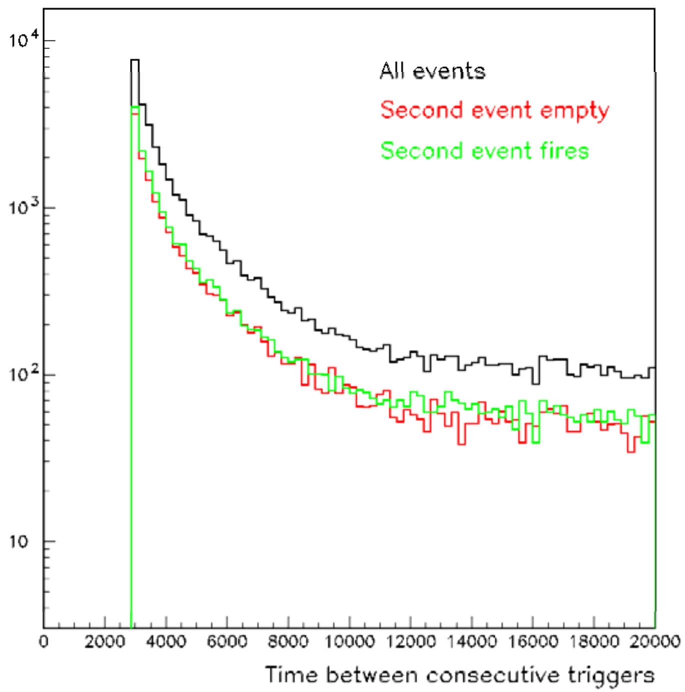


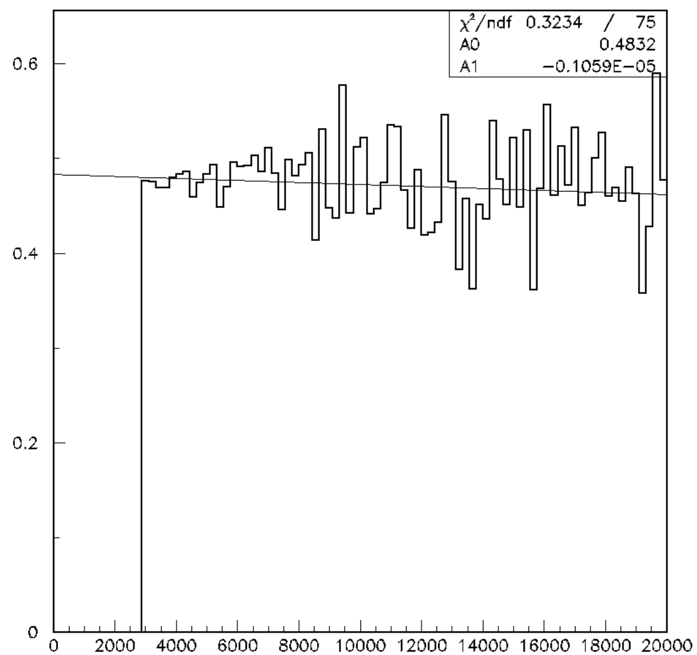
120 GeV proton beam at variable rates

Trigger → Coincidence of 2 (19 x 19 cm^2) paddles with 1.0 (0.3) ms DAQ veto

Deadtime after hit?

Select events with hits in RPC0
Check if next event has hits or not in RPC0
Calculate time difference Δt between these consecutive events
Minimum time difference given by 0.3 ms DAQ veto (only used during VST)



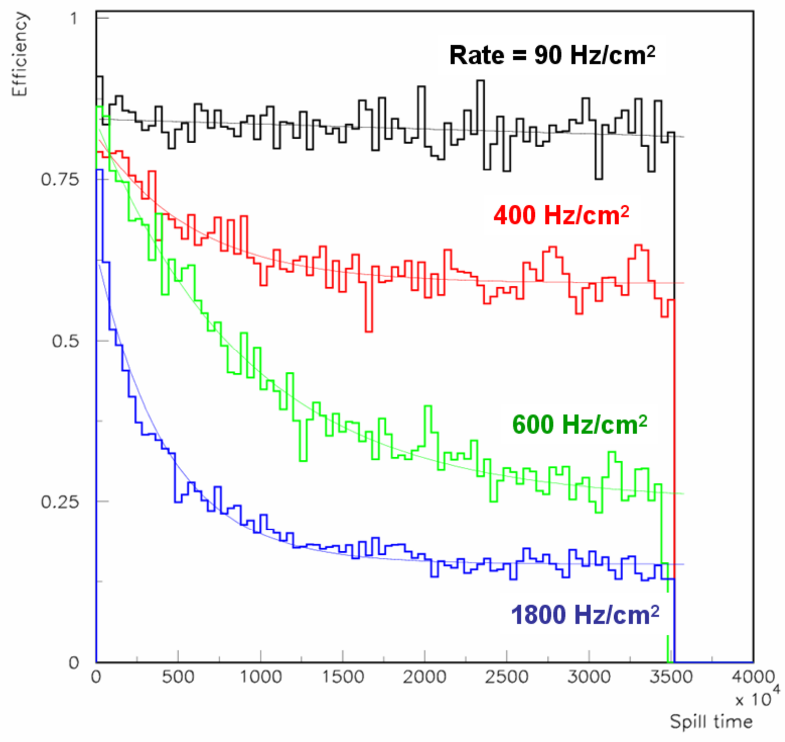


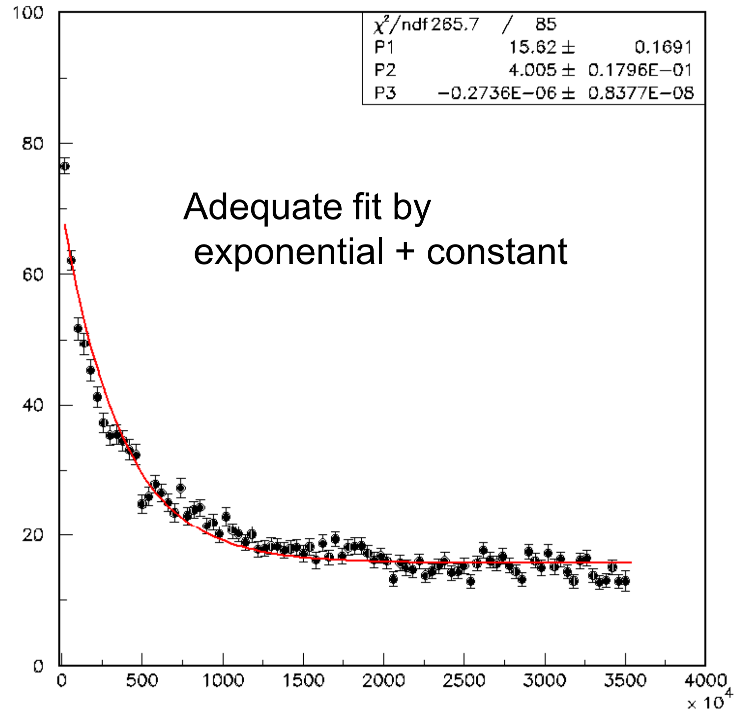
No depletion of events with hits at short Δt

Good news: deadtime < 0.3 ms

Study of the efficiency

Only use RPC0 (minimum bias from interactions)
Fermilab test beam spills last 3.5 seconds
Efficiency plotted versus time within spills





Efficiency drops for rates ≥ 100 Hz/cm²

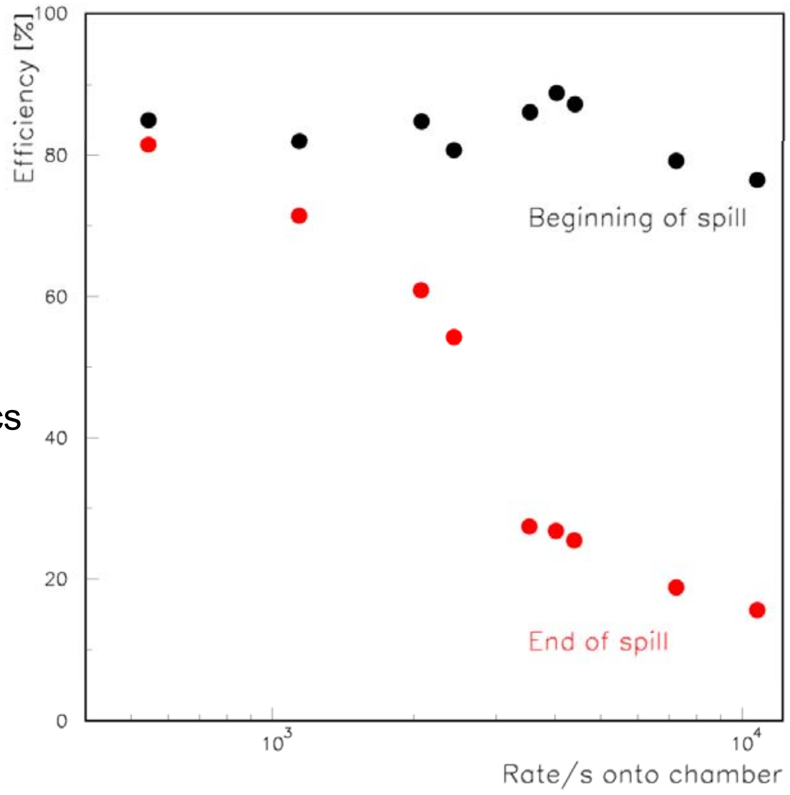
In agreement with previous measurements with sources

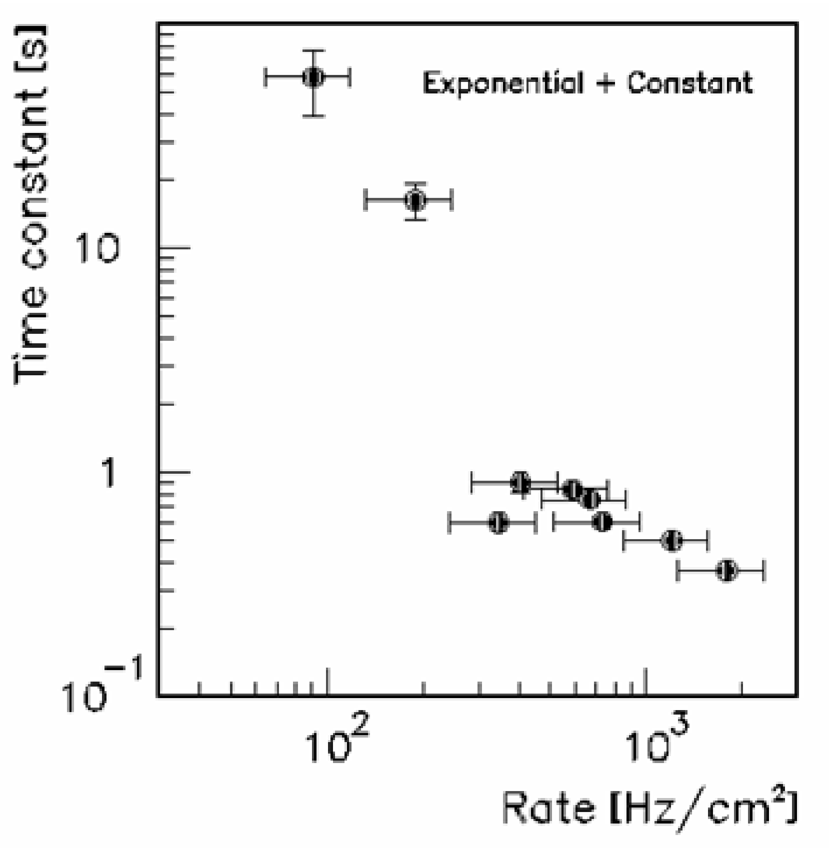
Efficiency at beginning of spill

Independent of rate
Perhaps slight decrease at high rate (fast decrease)

Efficiency at end of 3.5 second spill

Efficiency decrased at rates > 100 Hz/cm^2
This effieicny remains constant for times longer than 3.5 secs





Time constant of exponential decrease

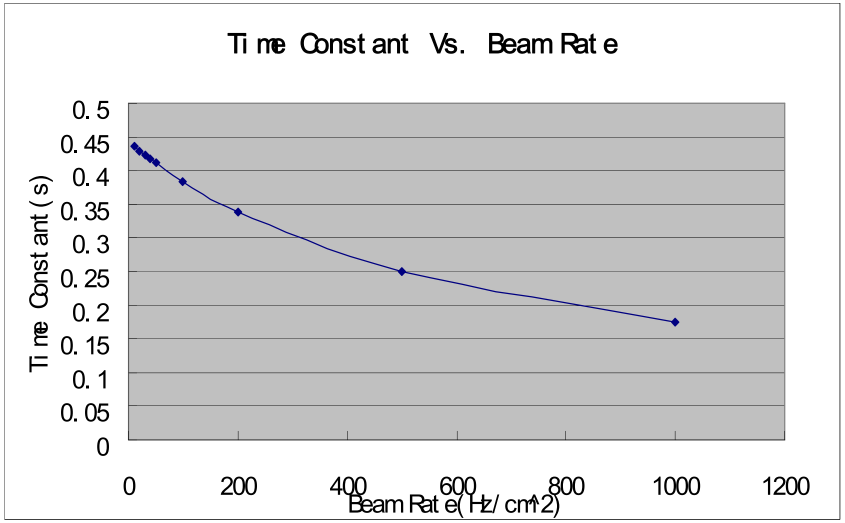
Time constant < 1 seconds at high rates

Calorimeter for ILC

Calculation of the gap voltage as function of rate

Definitions

Rate	f (Hz/cm^2)
Signal charge	q (pC)
Avalanche turn on voltage	U_0 (V)
Applied high voltage	U_{all}, U_{gap}, U_{glass} (V)
Charge density	s(/)
Current density in the glass	I(A/cm^2)
Glass resistivity	$\rho(\Omega cm^2)$
Gap thickness	d



Relationships and assumptions

$U_{all} = U_{gap} + 2\ U_{glass}$
s = const. x U_{gap}
Assume glass is Ohmic device $i = U_{glass}/\rho$
Assume signal charge $q = J_0 \times (U_{gap} - U_0)$
Charge conservation $ds/dt = q \times f - i$

$$U_g(t) = \frac{fJ_0(U_t - U_0)}{fJ_0 + \frac{1}{2\rho d}} \exp\left(\frac{-t}{\frac{\varepsilon_r \varepsilon_0}{2dJ_0 f + \frac{1}{\rho}}}\right) + \frac{fJ_0 U_0 + \frac{U_t}{2\rho d}}{fJ_0 + \frac{1}{2\rho d}}$$

Results

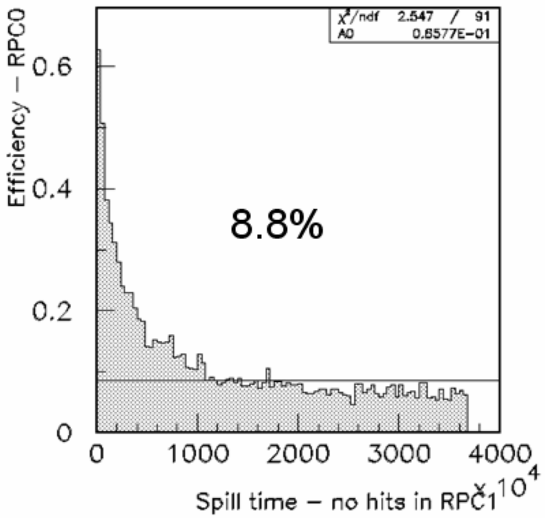
Exponential change of $U_g(t)$
Time constant shorter with higher rates

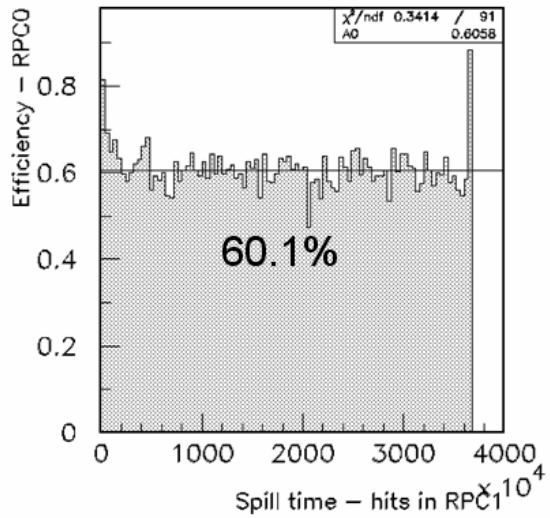
Agrees qualitatively with data

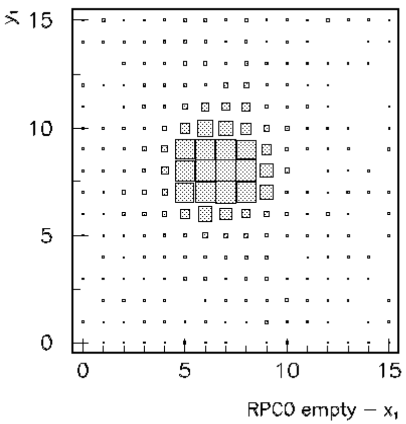
Caveat: $U_g(t) \neq \varepsilon(t)$

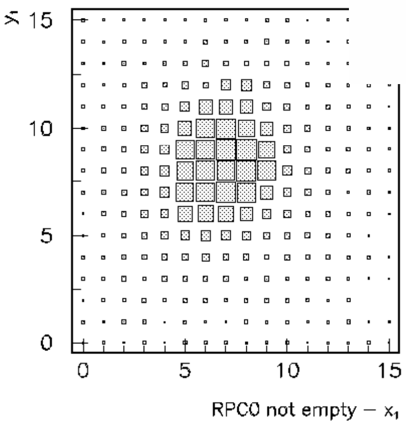
Study of the correlation between chambers

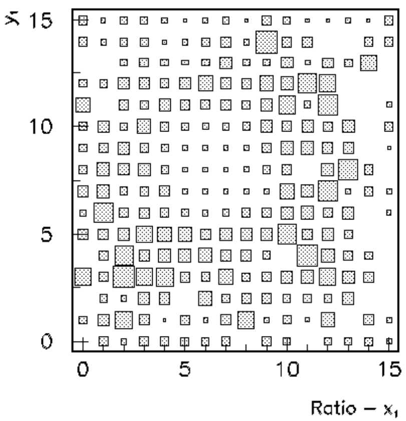
Efficiency in RPC0 for hits/no hits in RPC1
Strong correlation observed











No telescope information available (at the moment)
Can only extract position information, if efficient

Plot x,y in RPC1 for hits/no hits in RPC0

Inefficiency local to high rate region of RPCs

VIII Conclusions

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

Muon calibration paper – published in **JINST**

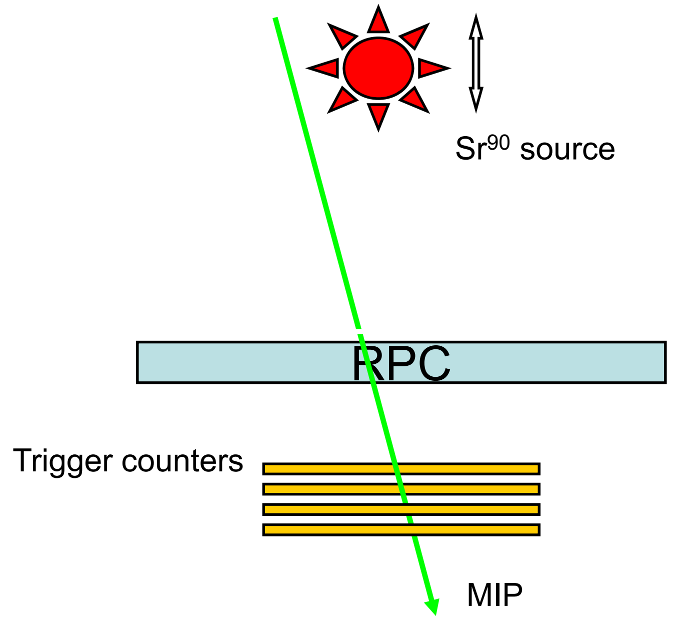
Positron/pion paper – to be published as soon as simulation satisfactory

Rate dependence paper – Studies almost completed – paper soon

Environmental dependence paper – **QingMin Zhang's** talk this morning
almost all the data for publication

Backup slides

Rate Capability…



Cosmic Rays and Sources

Efficiency for MIPS

Measurement triggered by scintillation counters

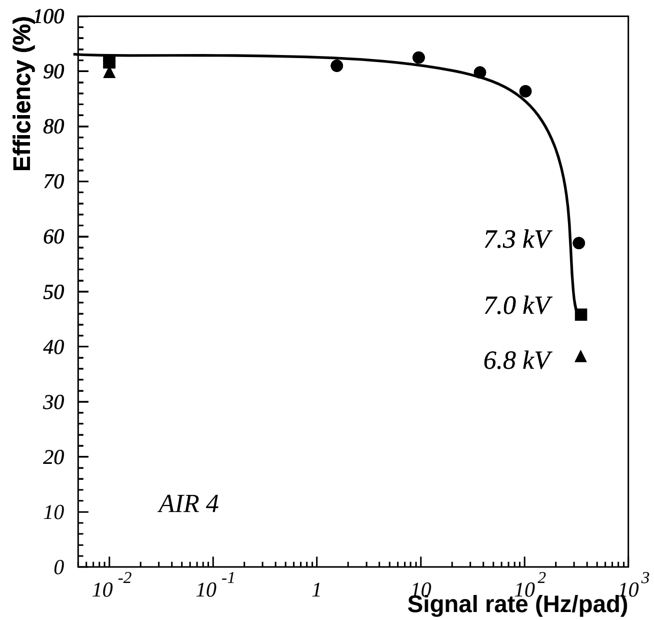
Variable rates

Measurement
Self-triggered

Problems with this method

- Rates from source not uniform over area
- Efficiency drop affects rate measurement
- Source provides e^-, not MIPs
- Cosmic ray trigger contaminated

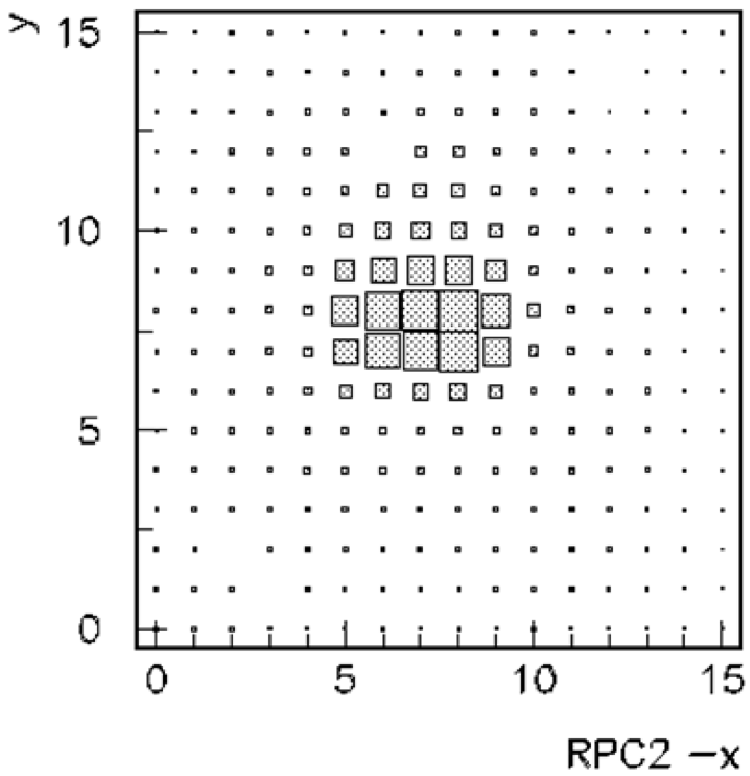
Rate capability at least 50 Hz/cm^2



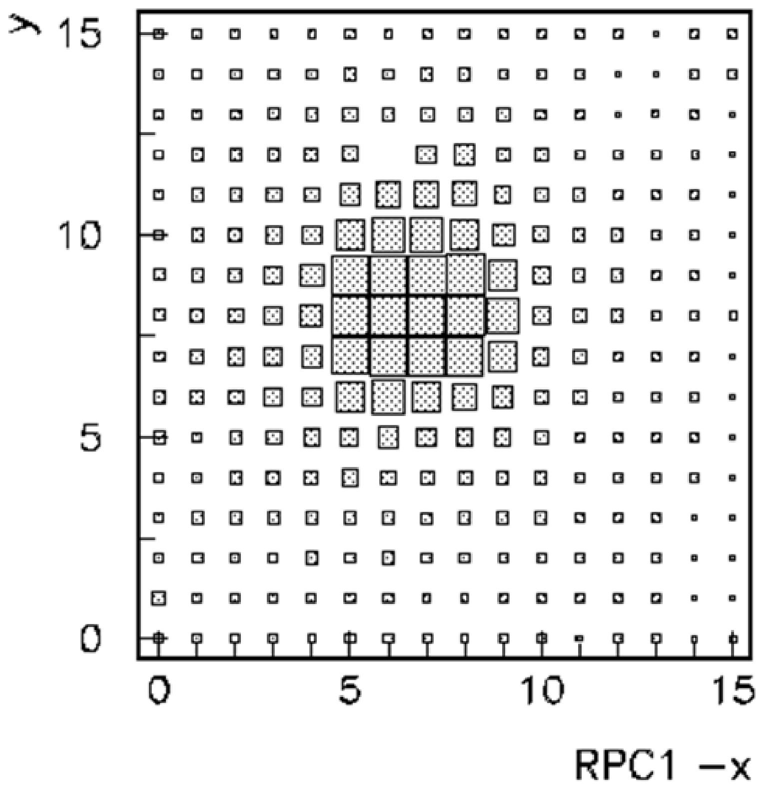
Beam profile

Pretty collimated beam
Area ~ 2.5 x 4 cm^2 = 10 cm^2
Gets a bit wider at higher rates: effect of inefficiency?

Low rate

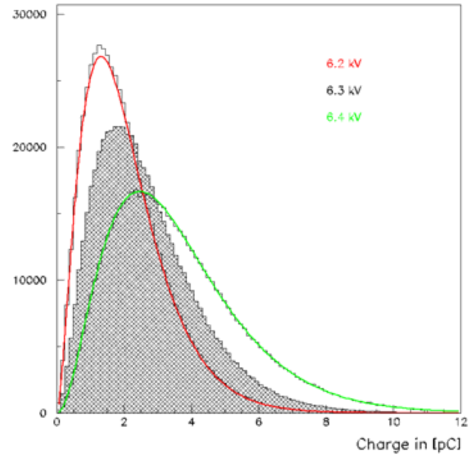


High rate



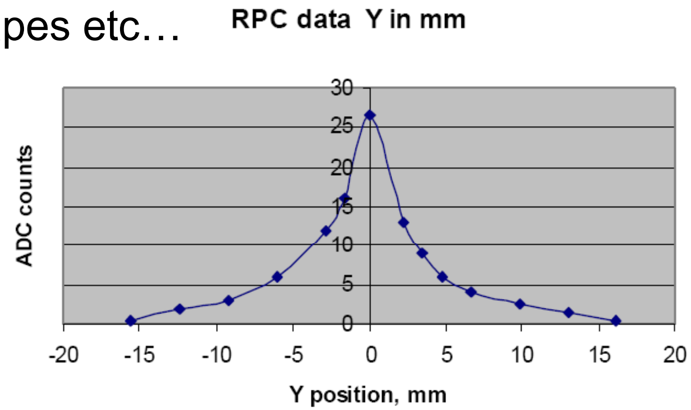
II Simulation Strategy

- Generate **muons** (at some energy) with GEANT4
  (with same x-y distribution and slope as in the data)
- Get x,y,z of each energy deposit (point) in the active gaps
- Generate charge from measured charge distribution for each point
  (according to our own measurements)
- Introduce charge offset $\mathbf{Q_0}$ for flexibility
- Introduce $\mathbf{d_{cut}}$ to filter close-by points (choose one randomly)
  (RPCs do not generate close-by avalanches)
- Noise hits can be safely ignored



- Distribute charge according to exponential distribution with slope **a**
- Apply threshold **T** to flag pads above threshold (hits)
- Adjust **a**, **T**, $\mathbf{d_{cut}}$ and $\mathbf{Q_0}$ to reproduce measured hit distributions

- Generate **positrons** at 8 GeV with GEANT4
  (with same x-y distribution and slope as in the data)
- Introduce material upstream to reproduce measured shapes etc…
- Re-adjust $\mathbf{d_{cut}}$ if necessary
  (Muon data not very sensitive to d_{cut})



- Generate predictions for other beam energies
- Generate **pions** at any beam energy