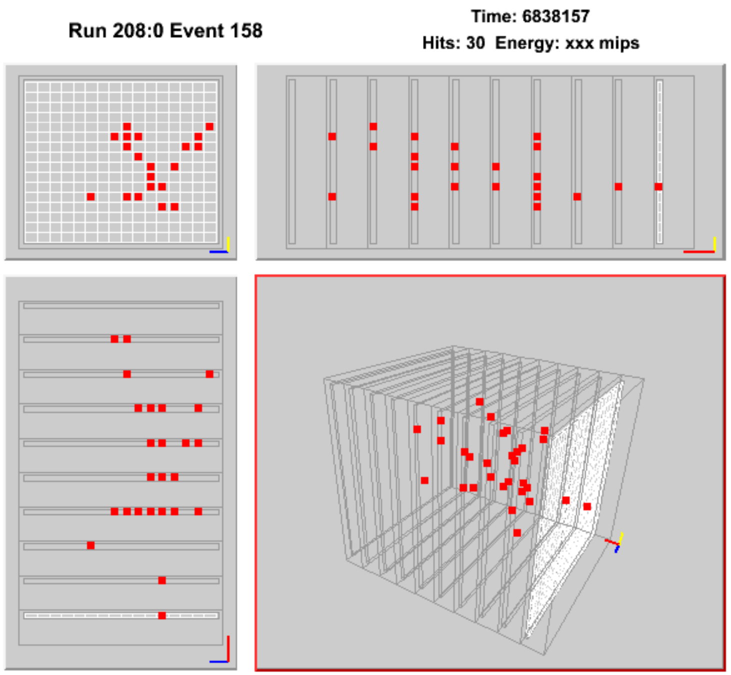
Analysis of the DHCAL Vertical Slice Test Data



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CALICE Meeting, Manchester, September 8 – 10, 2008

Outline

I	Vertical Slice Test
II	Simulation strategy
III	Simulation of Muon data
IV	Simulation of Positron data
V	Measurement of RPCs’ rate dependence
VI	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 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

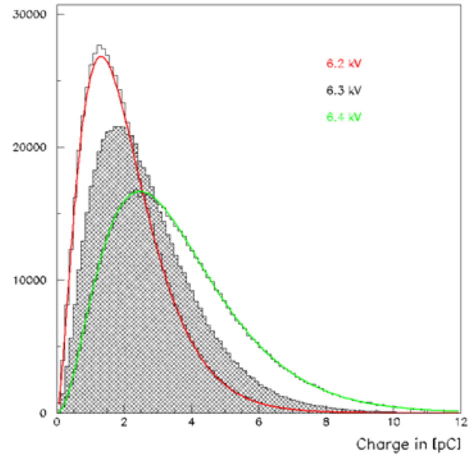
For cosmic rays, muon, pions, electrons: Steel (16 mm) + Copper (4 mm)
Rate capability measurement (120 GeV protons): 16 mm PVC with whole cut out in center

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

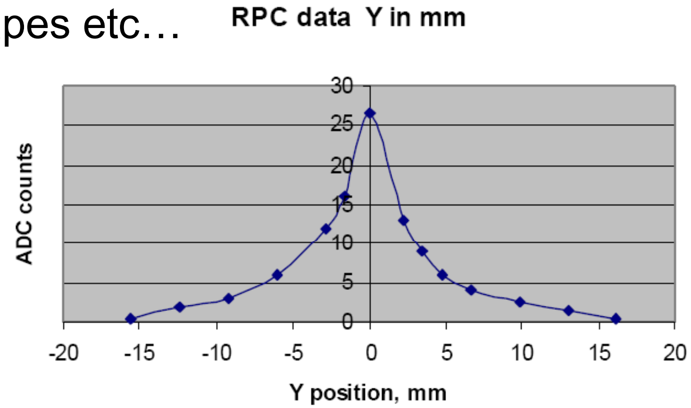
II Simulation Strategy

- 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

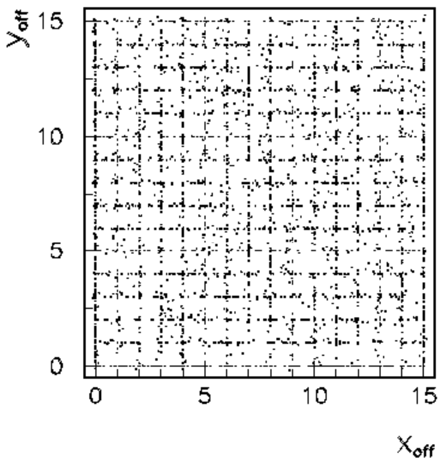
- Generate **positrons** at 8 GeV with GEANT4
  (with same x-y distribution and slope as in the data)
- Introduce material upstream to reproduce measured shapes etc…
- Re-adjust $\mathbf{d_{cut}}$ if necessary
  (Muon data not very sensitive to d_{cut})

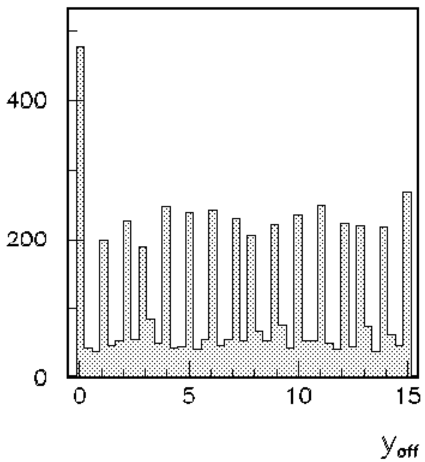


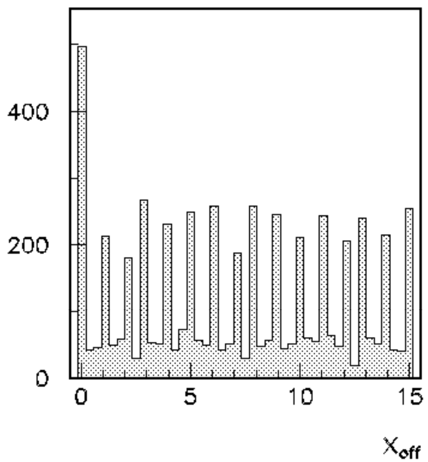
- Generate predictions for other beam energies
- Generate **pions** at any beam energy

III Simulation of Muon Data

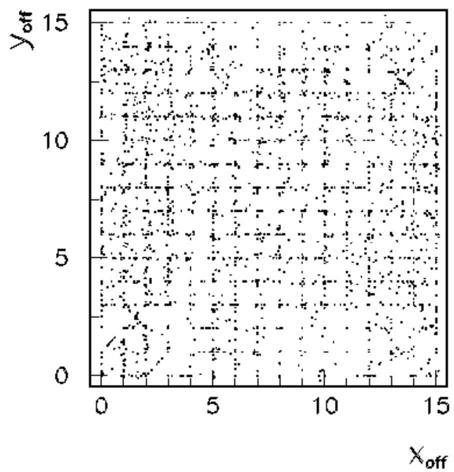
x – y position of cluster in first layer

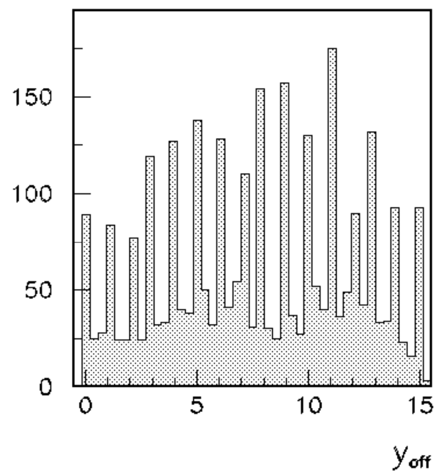


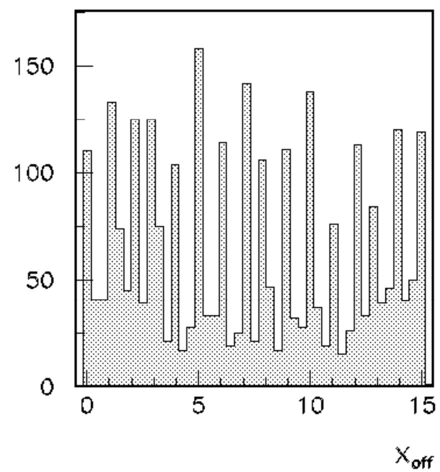




Simulation



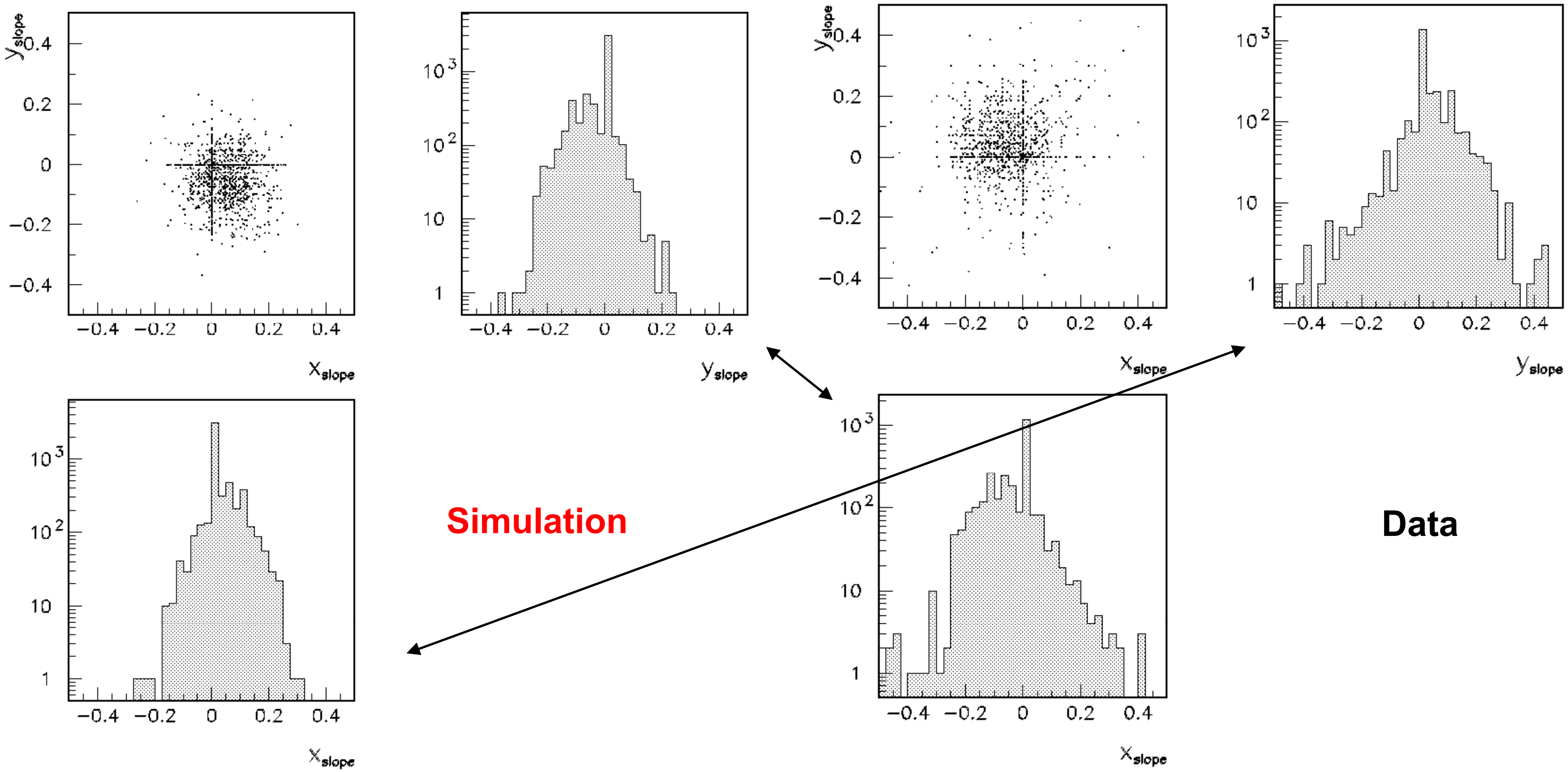




Data

Slope of reconstructed muon tracks

Obtained from fit to straight line through all layers
Inverted axes (later fixed)



Data selection

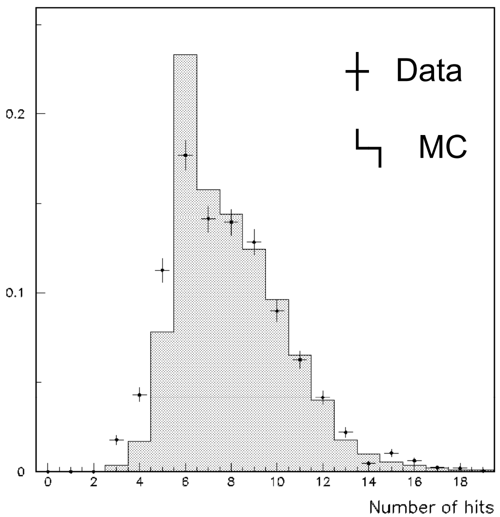
At most 1 cluster/layer
Fiducial cut around border of RPCs
At least 3/6 RPCs with hits

Plots used for tuning

Sum of all hits
Average number of hits/layer

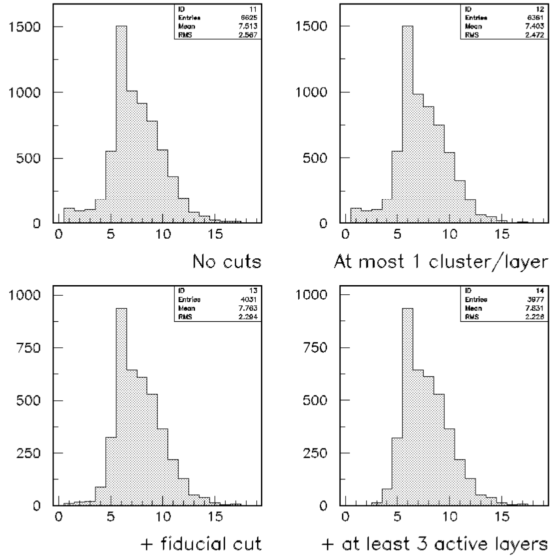
Simulation looks ~OK

Now let's tune the parameters

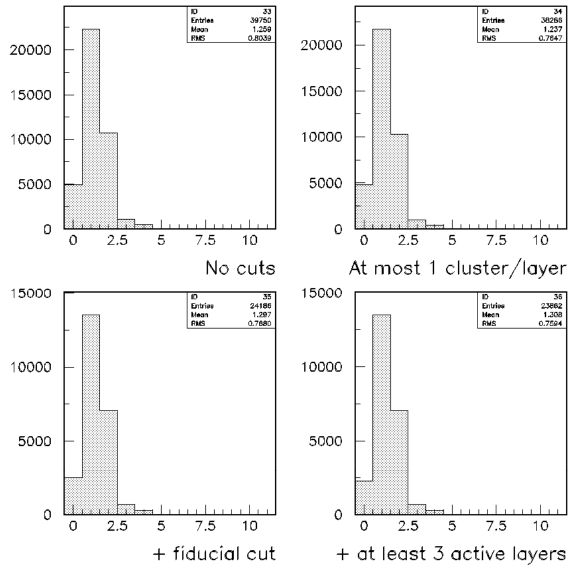


Simulation

Number of hits

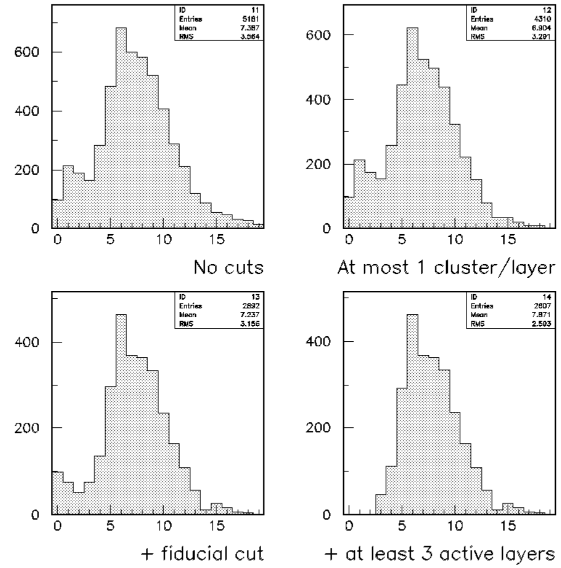


Number of hits/layer

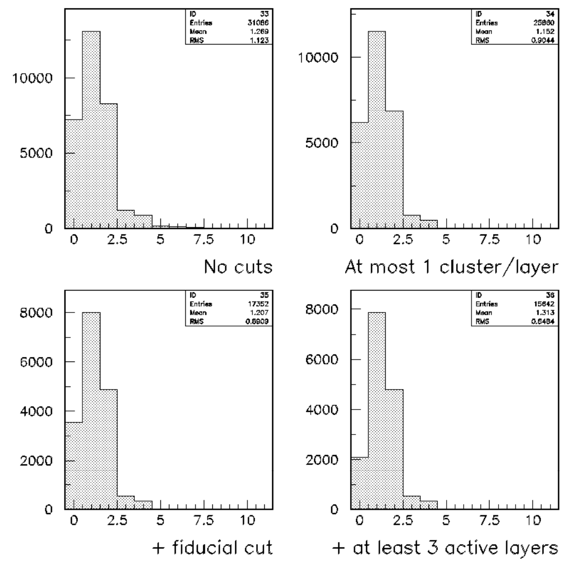


Data

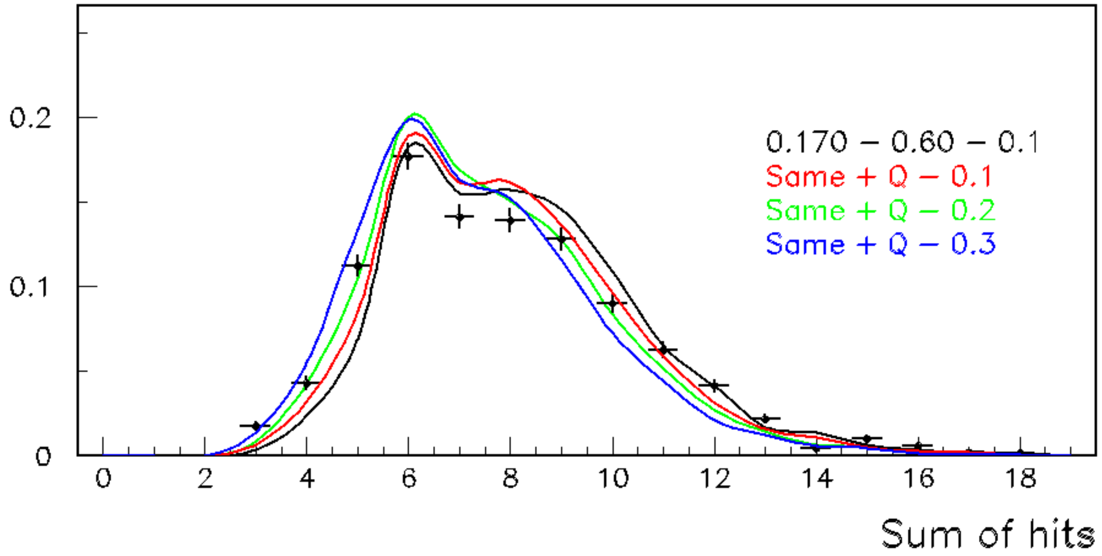
Number of hits

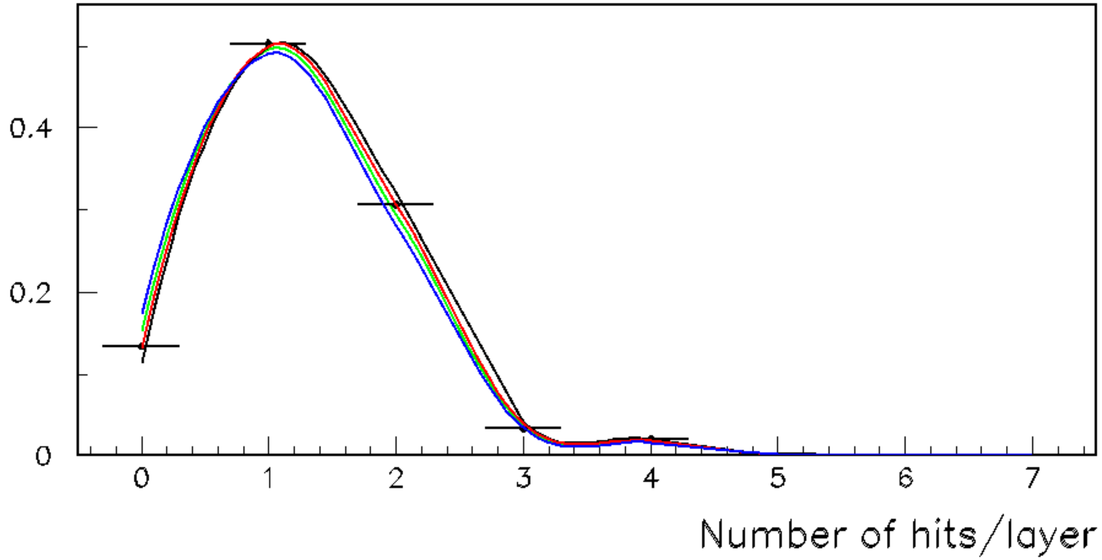


Number of hits/layer



A long time later….





Best parameters

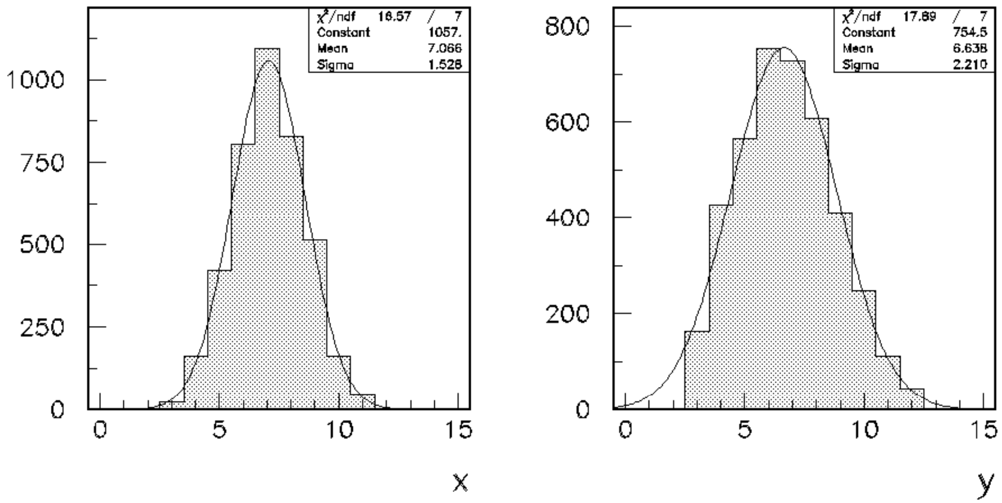
Slope **a**	0.170 cm
Threshold **T**	0.60 pC
Inefficiency distance $\mathbf{d_{cut}}$	0.1 cm
Charge offset $\mathbf{Q_0}$	-0.2 pC

Not perfect, but hopefully good enough

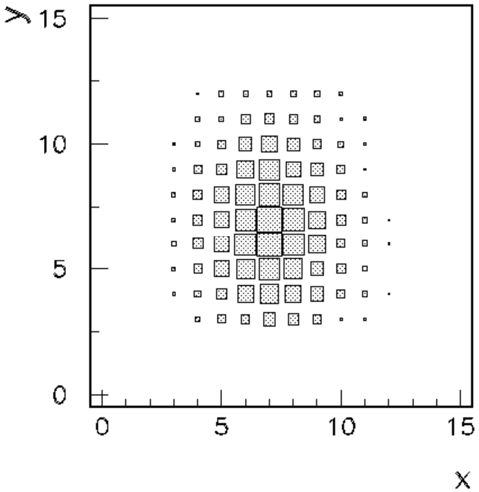
IV Simulation of Positron Data

Concentrate on 8 GeV data for the moment

Position of cluster in layer 0



Good enough…



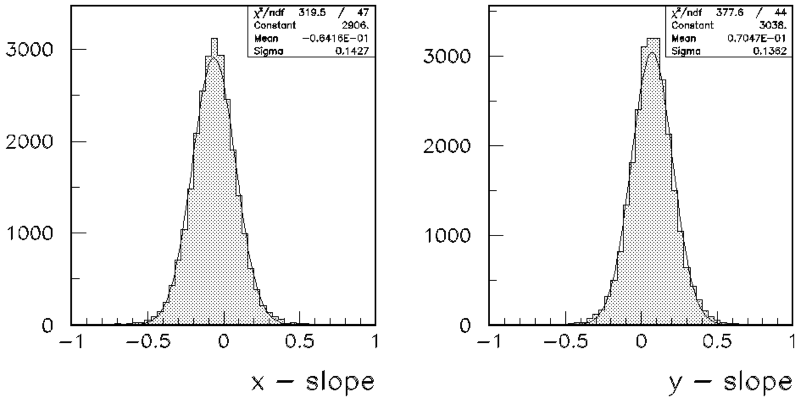
Momentum	Mean – x	Sigma – x	Mean - y	Sigma - y
16	6.94	2.43	6.50	2.94
8 – data	6.91	1.45	6.35	2.28
8 – MC	7.07	1.53	6.64	2.21
4	7.90	2.28	7.60	2.97
2	8.24	3.59	6.11	4.50
1	8.47	5.36	7.69	5.26

Slope of shower

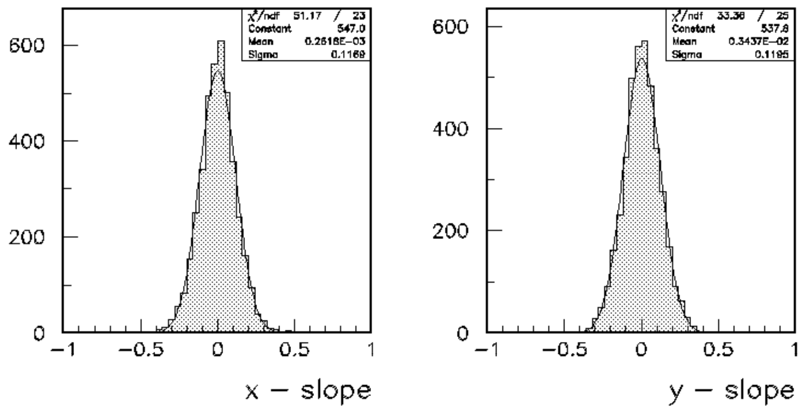
Fit of cluster positions to straight line

	μ_x	σ_x	μ_y	σ_y
Data	-0.064	0.143	-0.070	0.136
Simulation	0.000	0.117	0.003	0.120

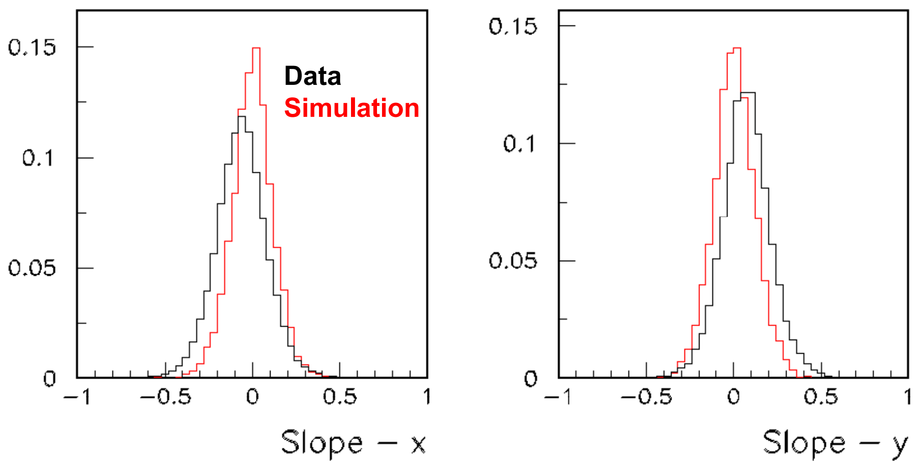
Data



Simulation



Good enough…



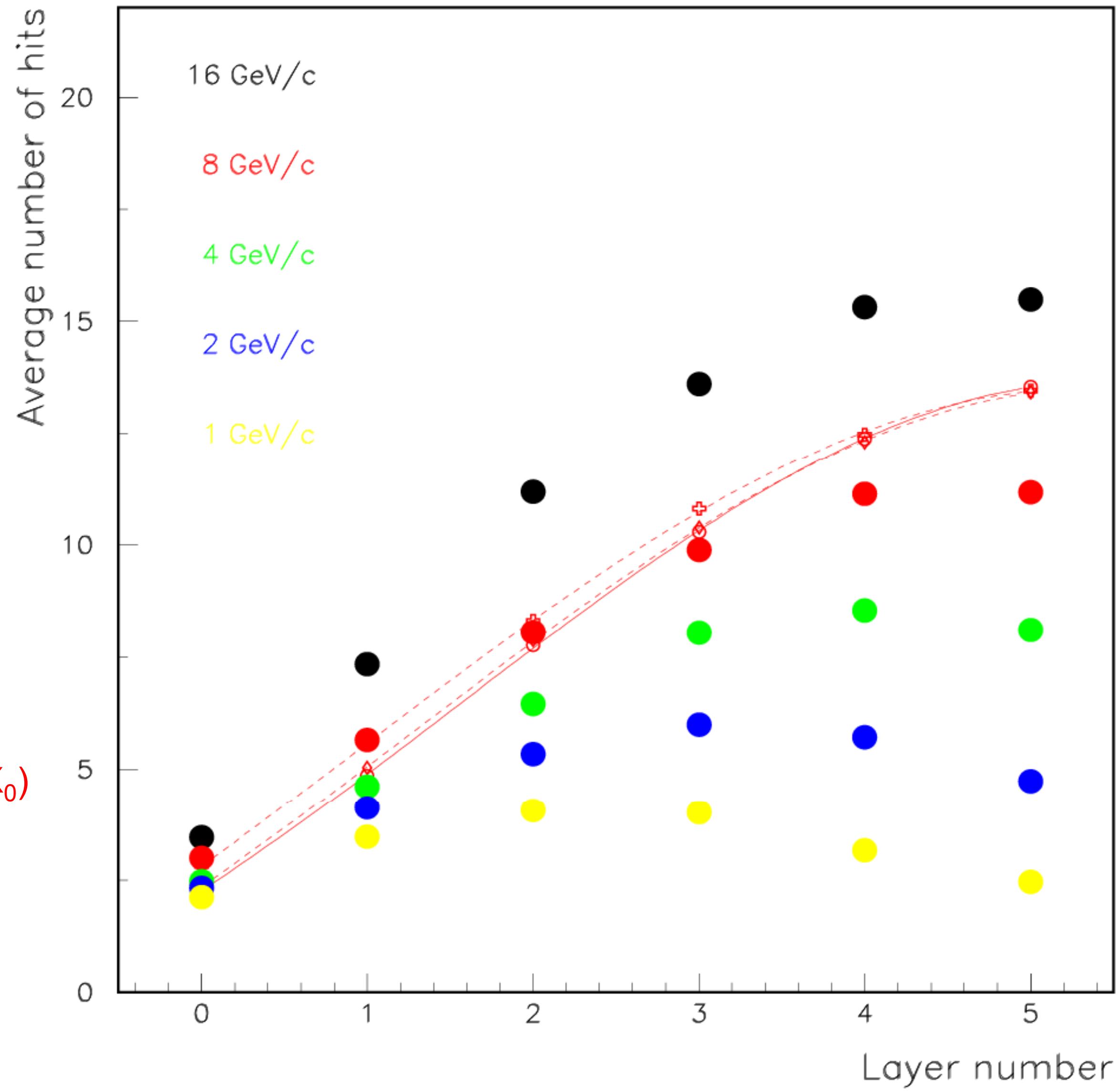
Longitudinal shower shape

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)

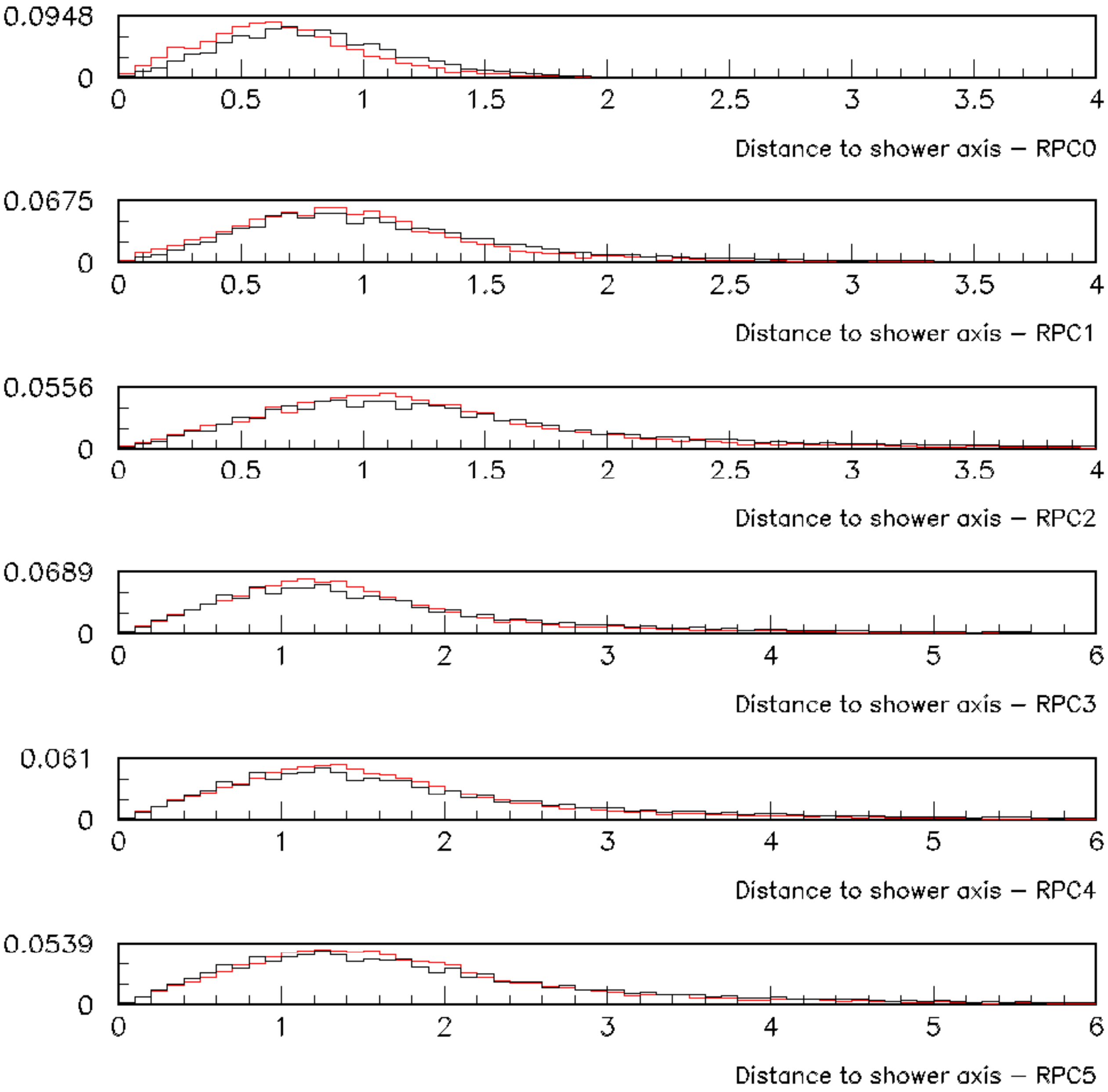


Lateral shower profile

Without material in beam

First layer too narrow

Subsequent layers OK



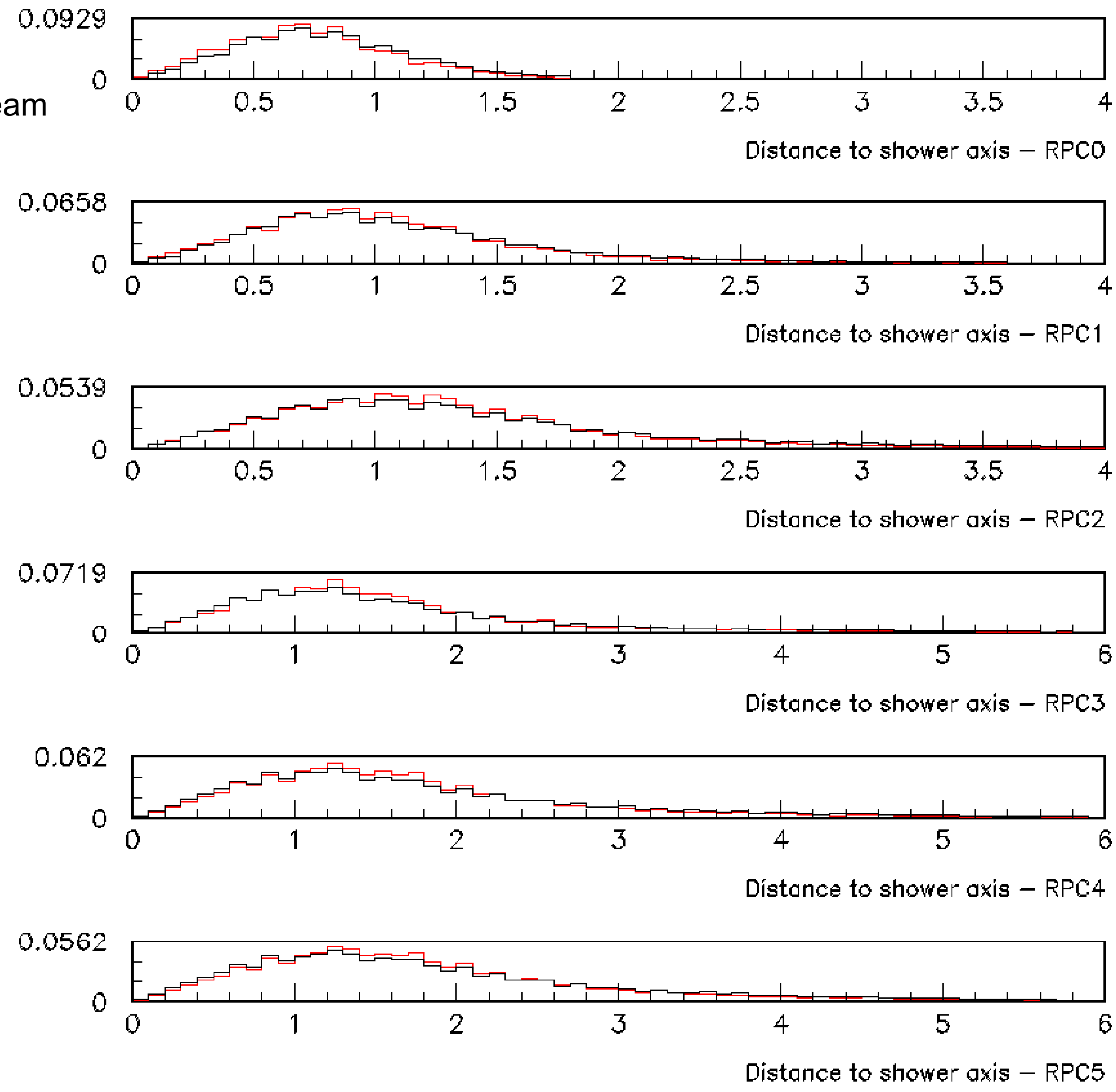
Data

Simulation

Lateral shower profile

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

Looks good everywhere



Data

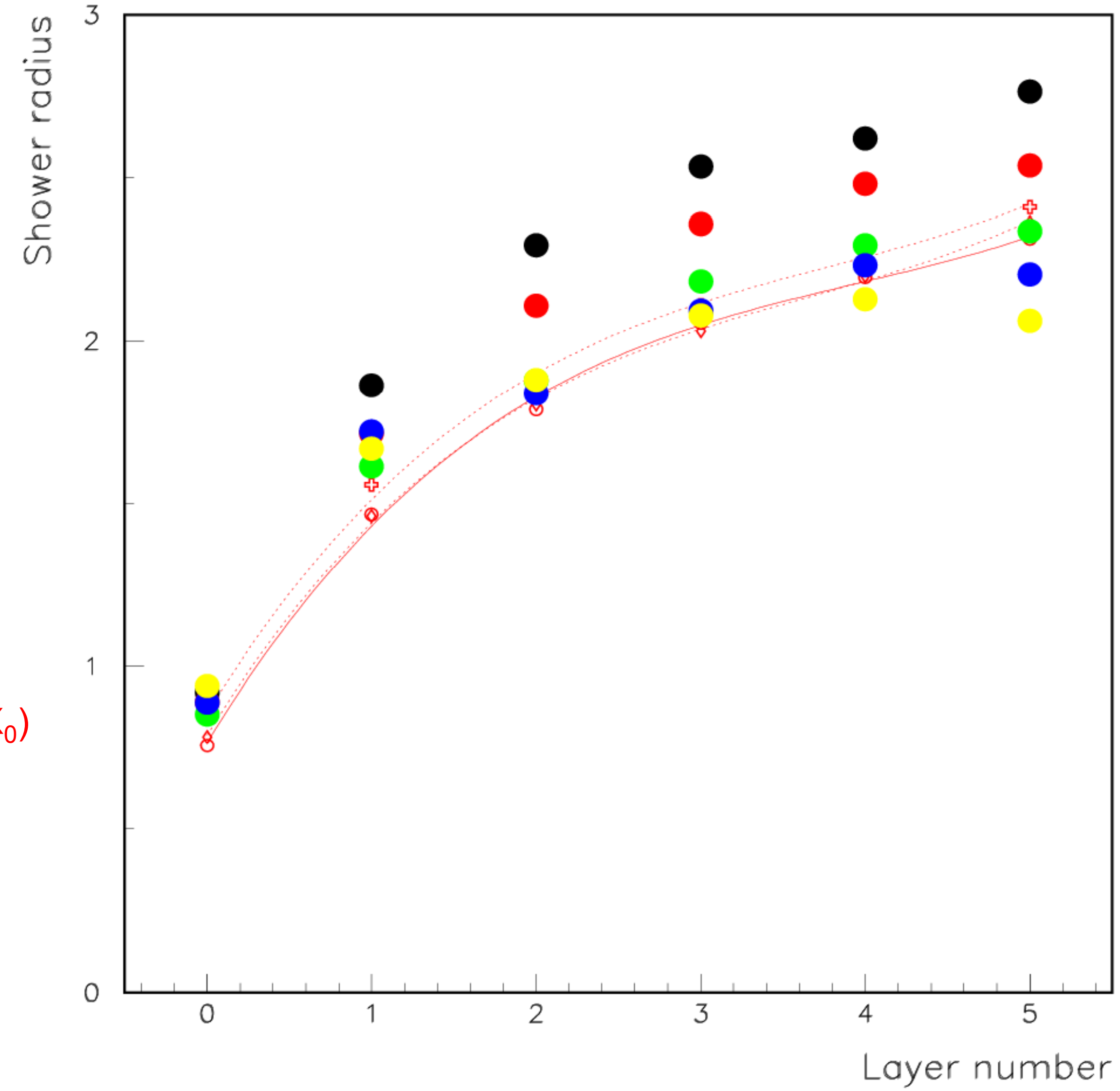
Simulation

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)

V RPCs' Rate Dependence

RPC's recovery

RPCs are inefficient at high rates
Typical acceptable rates are ~ 1 Hz in streamer and ~ 100 Hz 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

Very tricky measurements

Experimental set-up

Stack without absorber plates

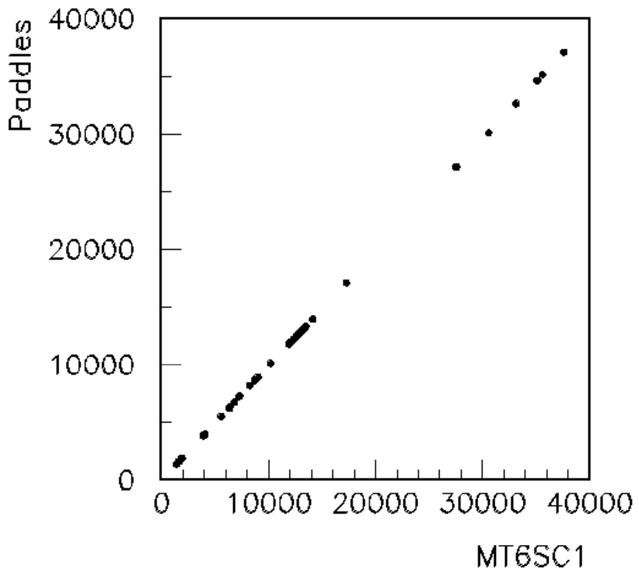
7 RPCs in total

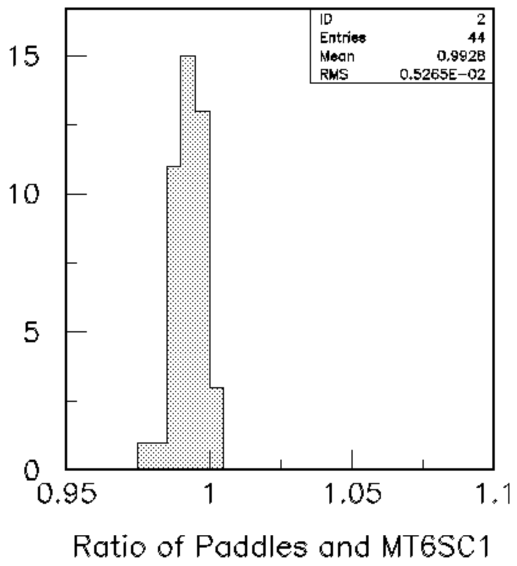
6 Default, 1 Exotic
Default High voltage and threshold setting
Problems with grounding → good data on only 4 RPCs

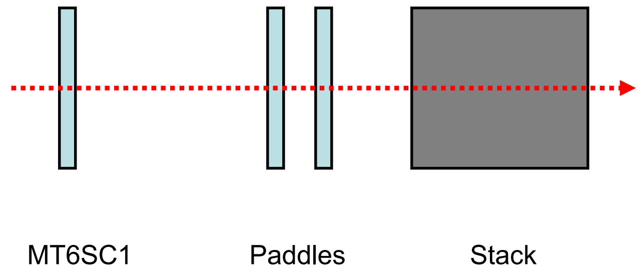
120 GeV proton beam at variable rates

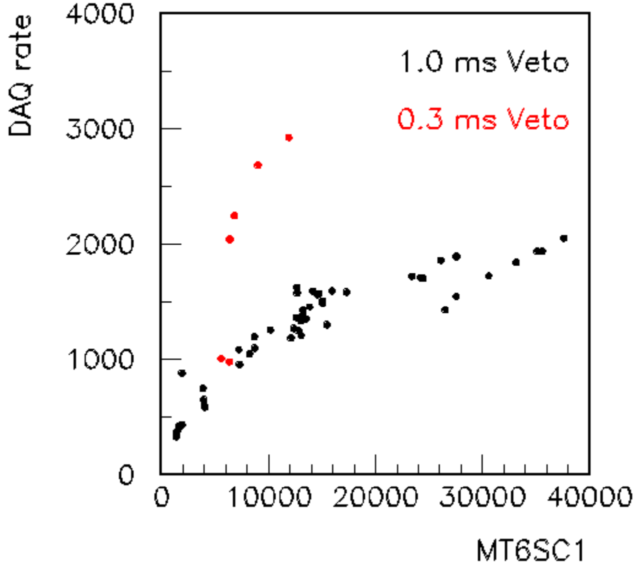
Trigger → Coincidence of 2 (19 x 19 cm^2) paddles with 1.0 (0.3) ms DAQ veto

Rate of scintillation counters / spill









Ratio of Paddles and MCSC1 close to unity

Paddles cover front face of RPCs → Measurement of beam rate
Rates between 200 and 40,000 per spill (~4 seconds)

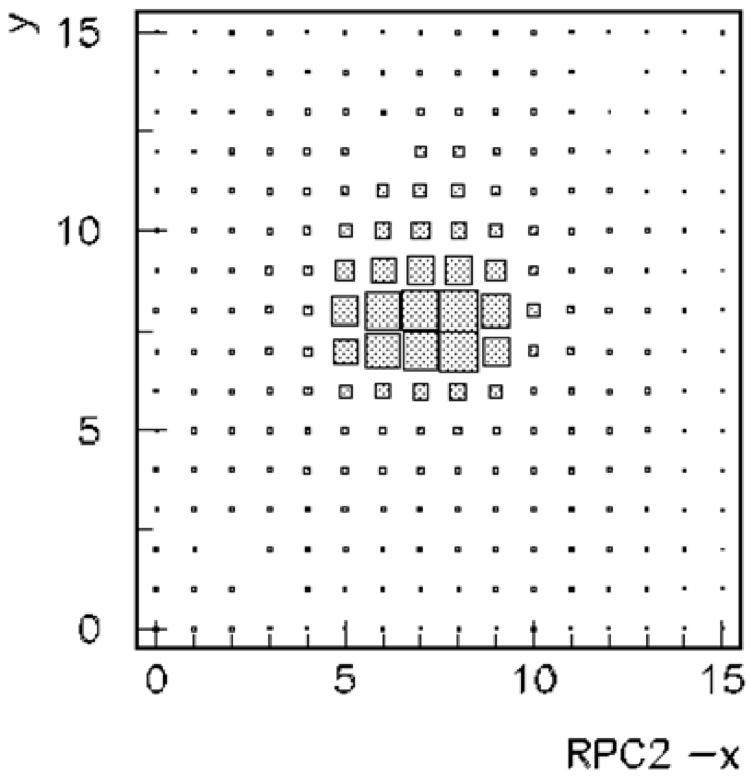
DAQ rate depends strongly on Veto

Veto thought to be necessary when running in debug mode (7 samples/trigger)
Data without veto available, but not looked at yet

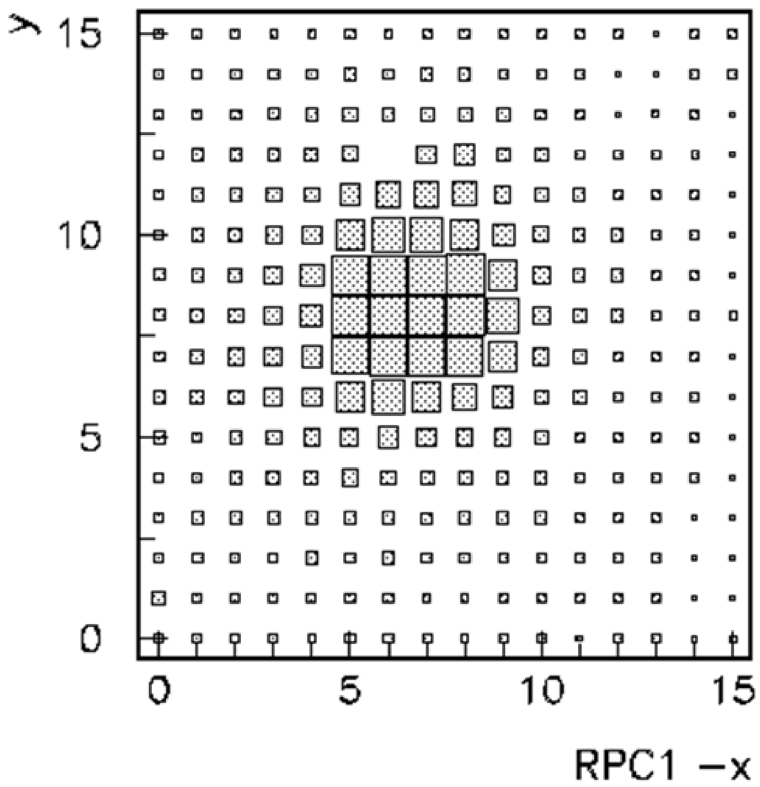
Beam profile

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

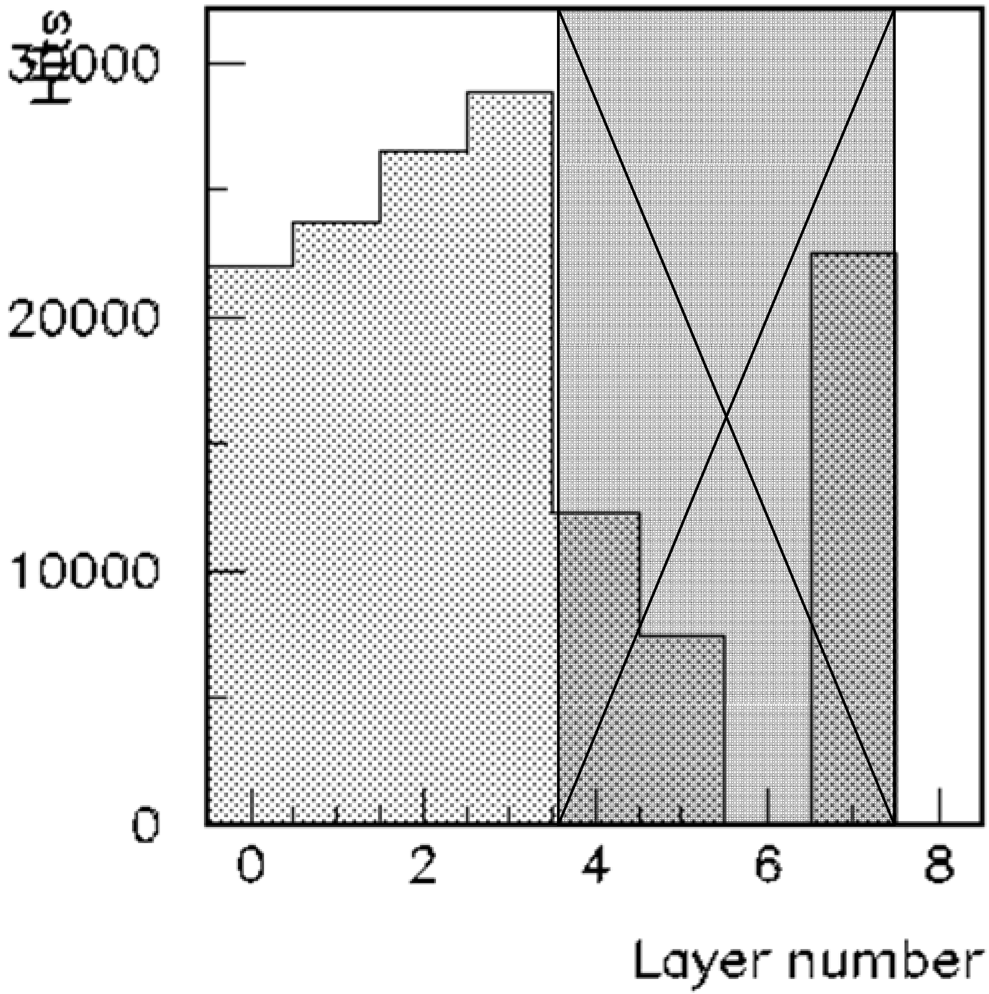


High rate



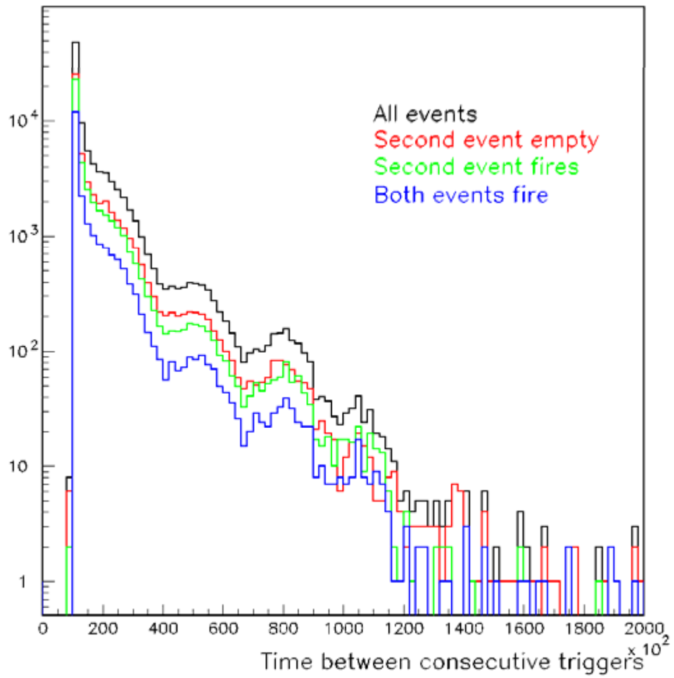
Number of hits versus layer number

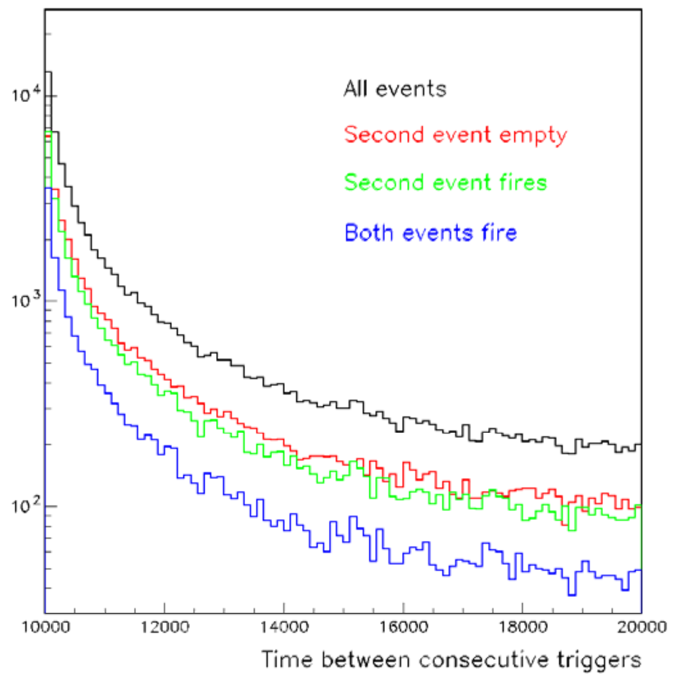
Layers 4 – 7 have grounding problems → ignore, problems have been solved in the meantime
Slowly increasing numbers in layers 0 – 3 → due to interacting protons (?)



Effect of consecutive hits

Each event has time stamp with 100 ns resolution
Use time difference to previous event





Shape of distribution independent of selection

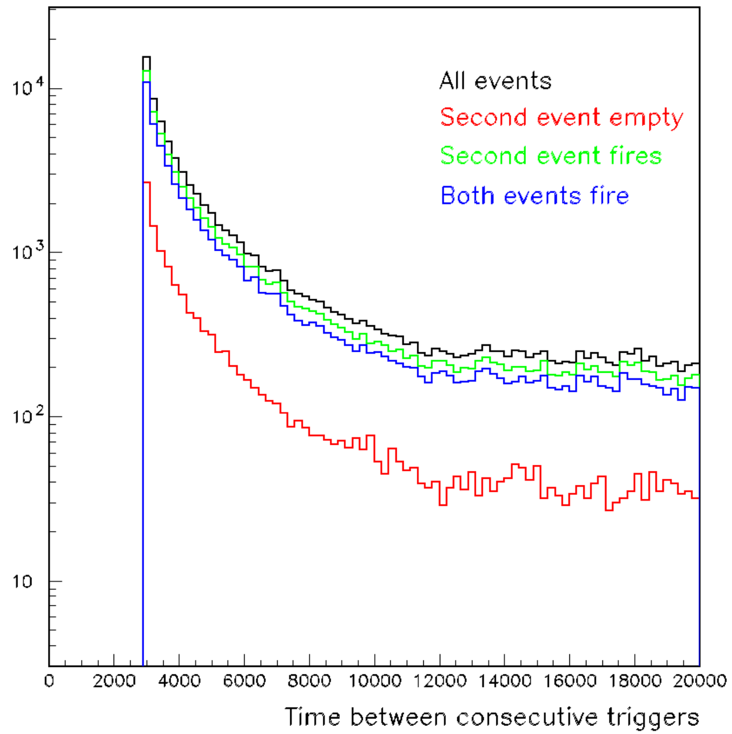
→ no evidence of short time effect

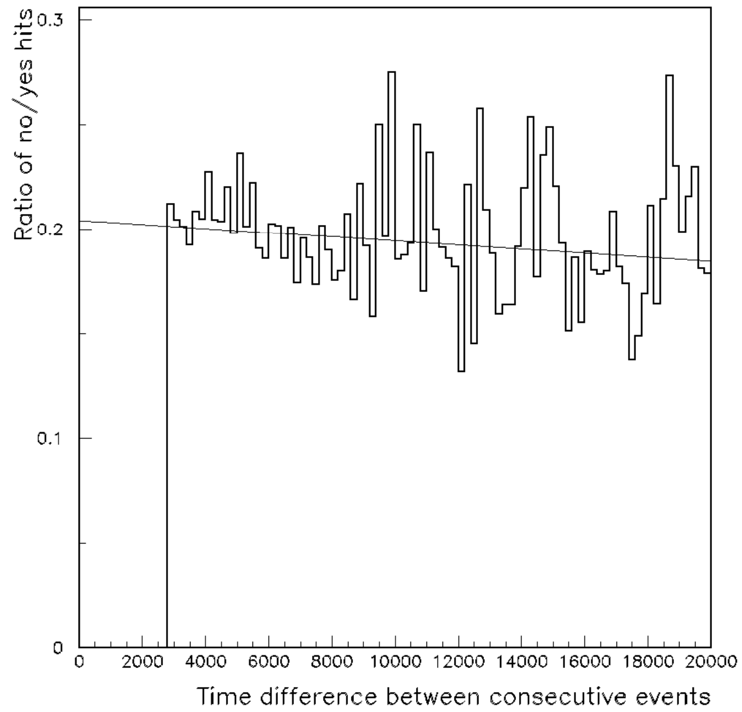
No events with Δt < 10,000, due to 1.0 ms DAQ veto

Structure with 3 ms periodicity ???

Run with 0.3 ms DAQ Veto

→ no visible effect





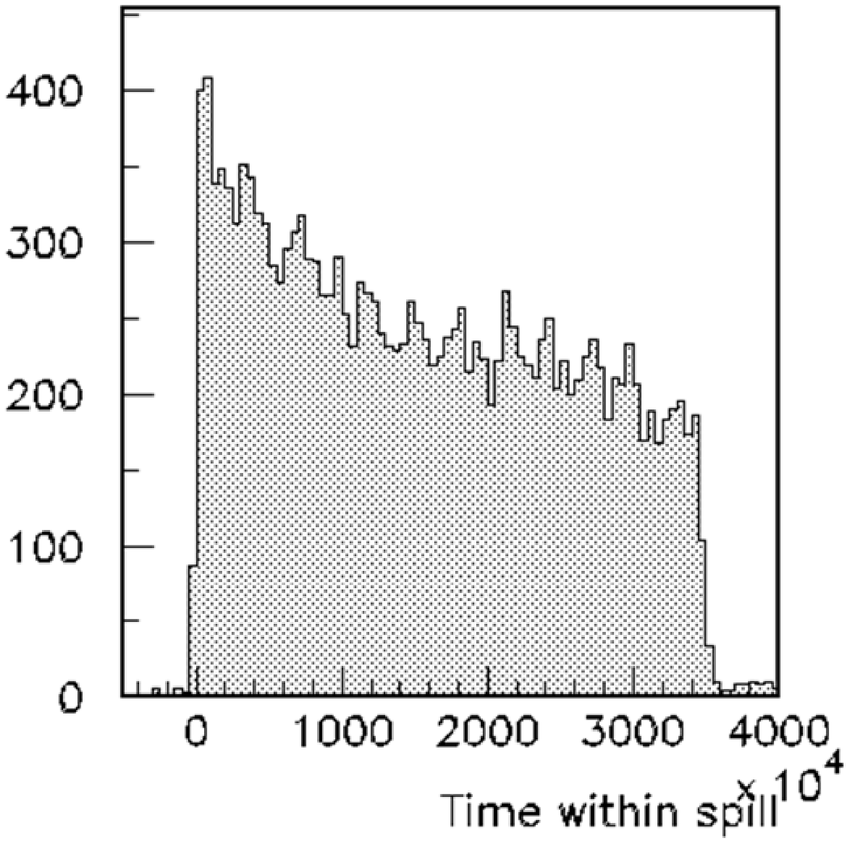
If this holds up without DAQ Veto….

Good news: only the average rate matters

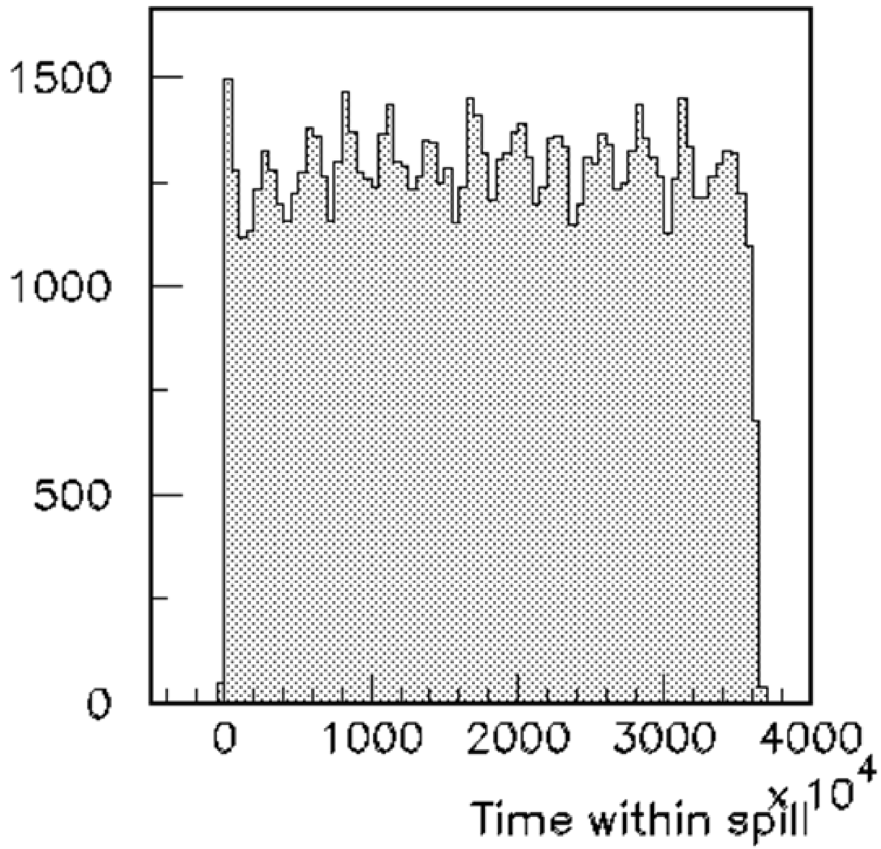
Triggers versus time within spill

Use time stamps to reconstruct time within a spill
At high rate → constant rate over spill (good)
At low rate → decreasing rate over spill (not so good)

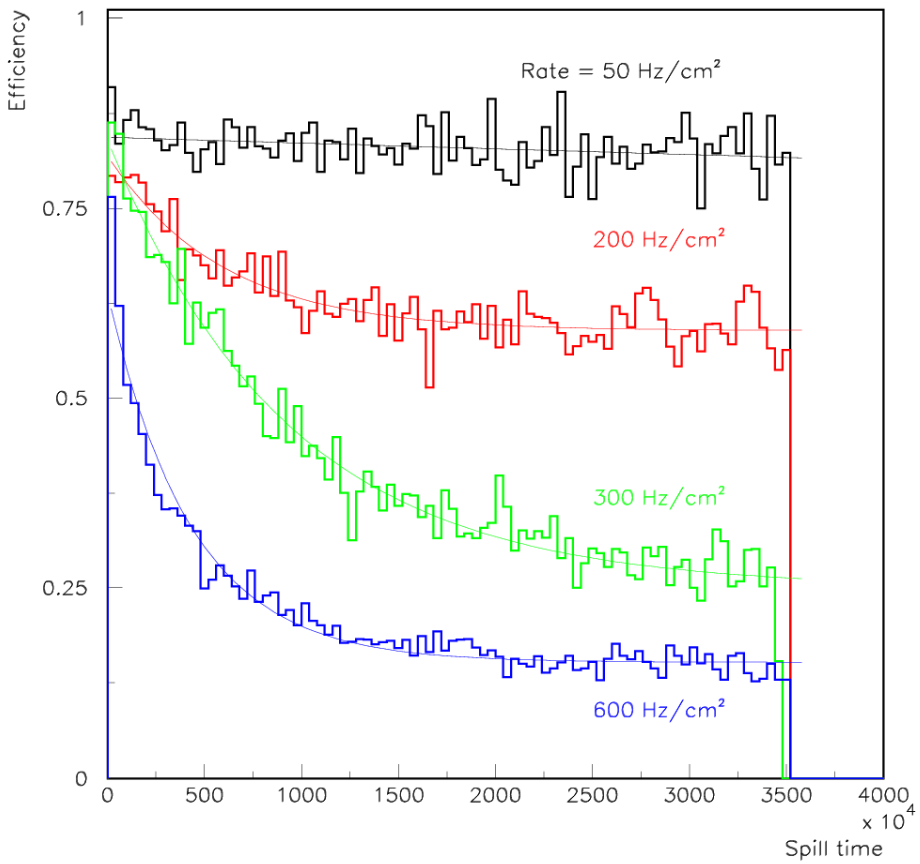
Low rate



High rate



Efficiency = $\frac{\text{Events with hits in RPC}}{\text{All triggers}}$



At high rate efficiency drops and then levels out

Fits to exponential + constant appear adequate

Time constant for efficiency drop shorter at higher rate (as expected)

Efficiency drops for rates ≥ 100 Hz/cm²

In agreement with previous measurements with sources

Future rate studies

Analyze data without DAQ veto to look for consecutive hit effect

Look for correlations between RPCs

Calculate the time dependence of the efficiency loss

…..

VI 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 – more studies needed before publication

Environmental dependence paper – needs more data