THE 12TH VIENNA CONFERENCE ON INSTRUMENTATION

FEB 15-20, 2010

Enhancement of hadron electron discrimination in calorimeters by detection of the neutron component.

NEUCAL Experiment:

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2) *INFN Section of Florence*
3) *IFAC – CNR, Florence*

Introduction

- Motivations
- Simulations
- First prototype
- Simulations
- Test beams
- Some results

- *Astroparticle physics*
- *Fluka - Geant 4*
- *Fast scintillators*
- *^{3}He tubes*
- *Pions, electrons*
- *Neutrons*

Astroparticle physics

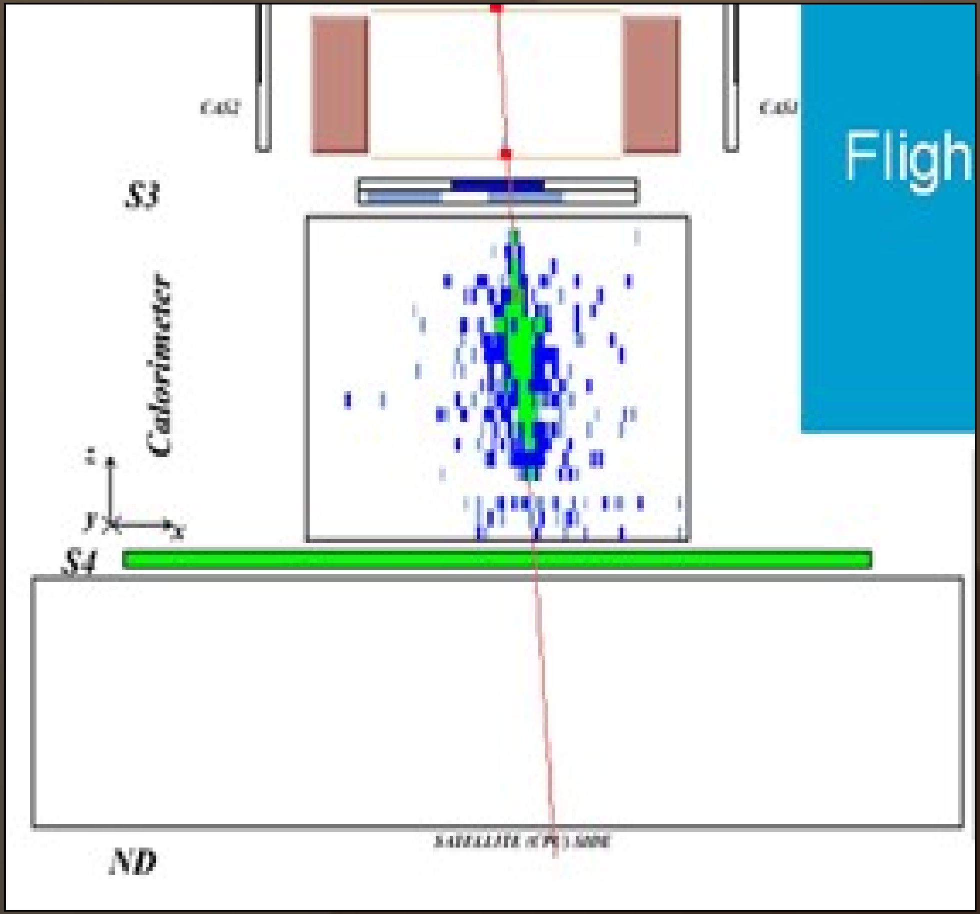
- Discrimination between protons and electrons/positrons is extremely important.
- Recent results, like the positron spectra measured by the PAMELA collaboration, attest to this fact.
- Adriani et al., Nature 458, 607-609 (2 April 2009)

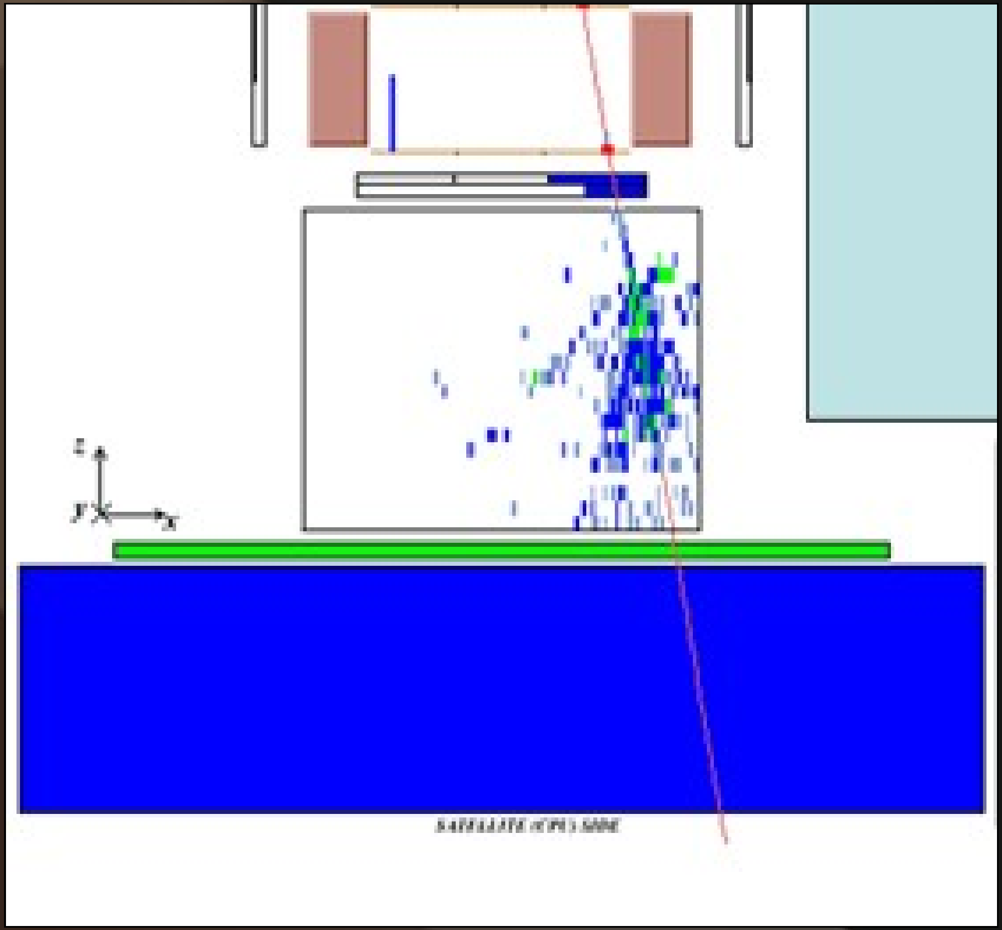
- *The calorimeter is the main detector used for this task.*
- *Best results are obtained with long depths and high granularities.*
- *This is not always possible, i.e. on a space based experiment.*

Electron-Hadron discrimination.

Pamela detector

- 18 GeV electron
- 36 GeV proton





Problems with the calorimetric approach.

- In shallow calorimeters (circa 0.6 λ_I) of the type used in the PAMELA detector, interacting protons can be tagged as electrons.
- Very extensive leakage.
- Similar shower development to electrons.
- Complementary detectors, do not provide a smoking gun solution, (trackers, TRD, Cherenkov).

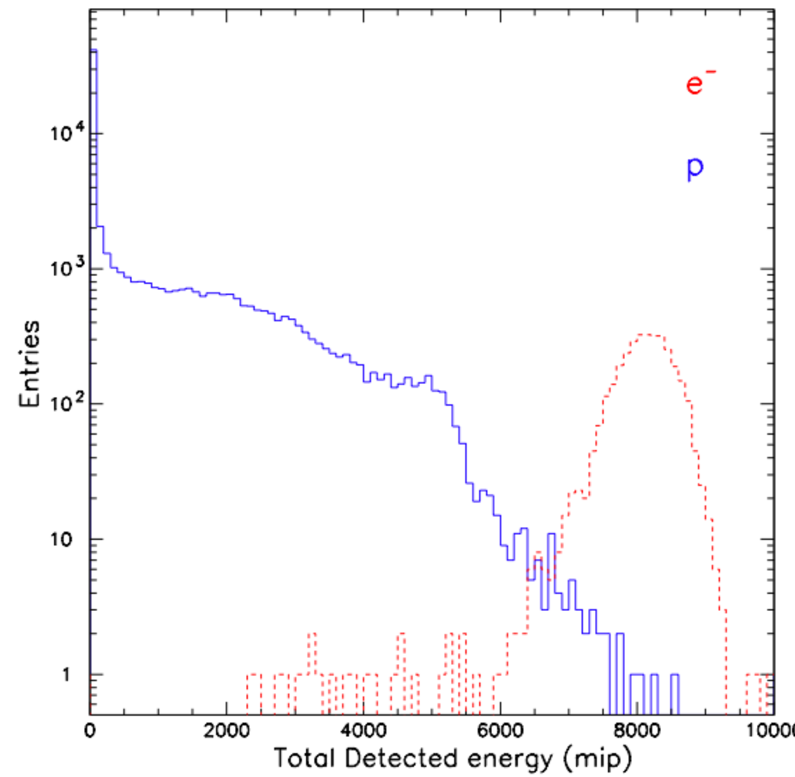


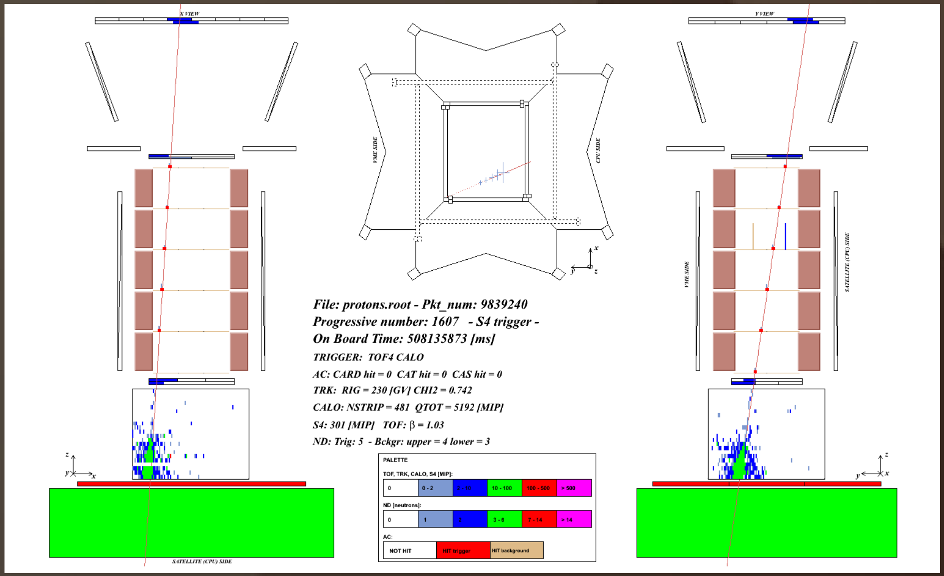
Fig. 4. An illustration of electron–proton separation using a simple total deposited energy variable. The test beam data were collected for particles of momentum 50 GeV/c. After a cut placed at 7300 mip 14 protons (99.98% reduction) and 3197 electrons (4.3% reduction) remain.

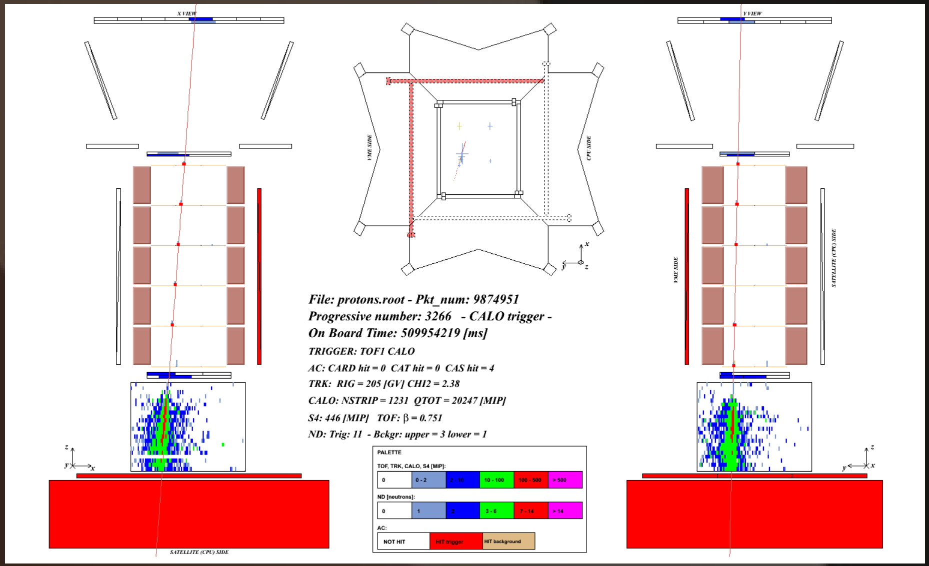
Boezio et al., Astroparticle Physics 26 (2006) 111–118

High energy protons

- Easy case
- Late interaction
- Easily identified

- Problematic case
- Interacts within the first 3 layers.
- Could be misidentified.



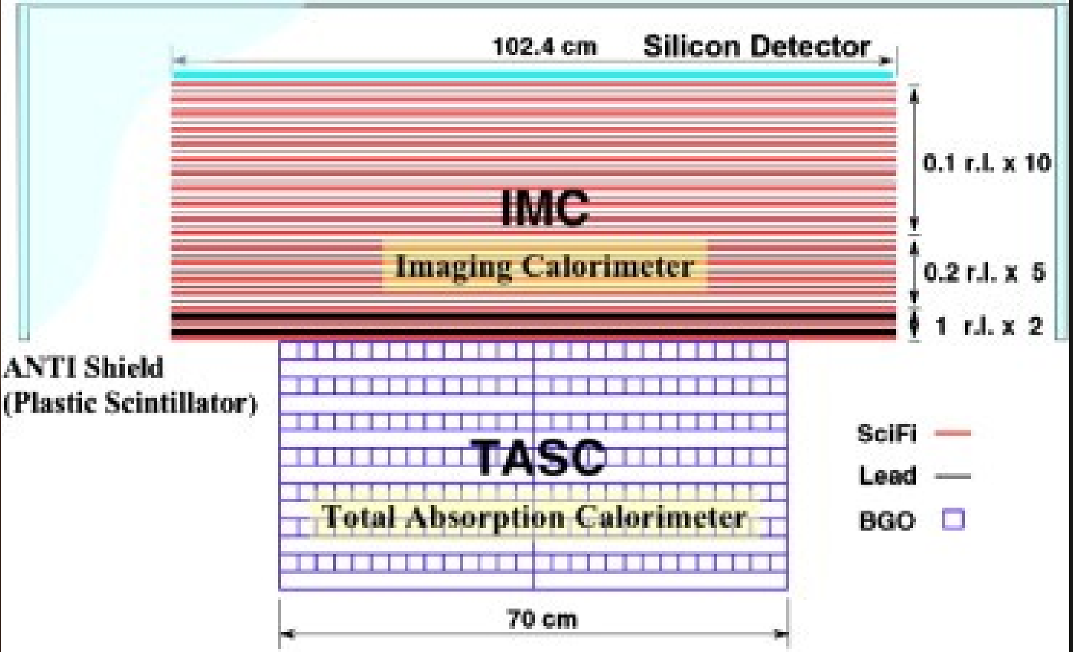


Neutron detection

- Neutron production:
  - Protons: nuclear excitation, hadronic interaction and Giant Resonance mechanism
  - Electrons: only through Giant Resonance
- Expect different yields for e.m. or hadronic showers.
- PAMELA uses a neutron counter as the final stage of the apparatus (after the calorimeter)
- Standard detector:
  - Moderation of neutrons by means of passive moderator (polyethylene layers)
  - ^{3}He proportional tubes react with thermal neutrons and detect signals given by the ionization products inside the gas
  - $n + {}^{3}He \rightarrow {}^{3}H + p$ (Q = 0.764 MeV)

Simulations

- BGO electromagnetic calorimeter simulation
  - CALET proposal for the space station
  - Circa 35 rad. lengths
  - 400 GeV electrons
  - 1 TeV protons

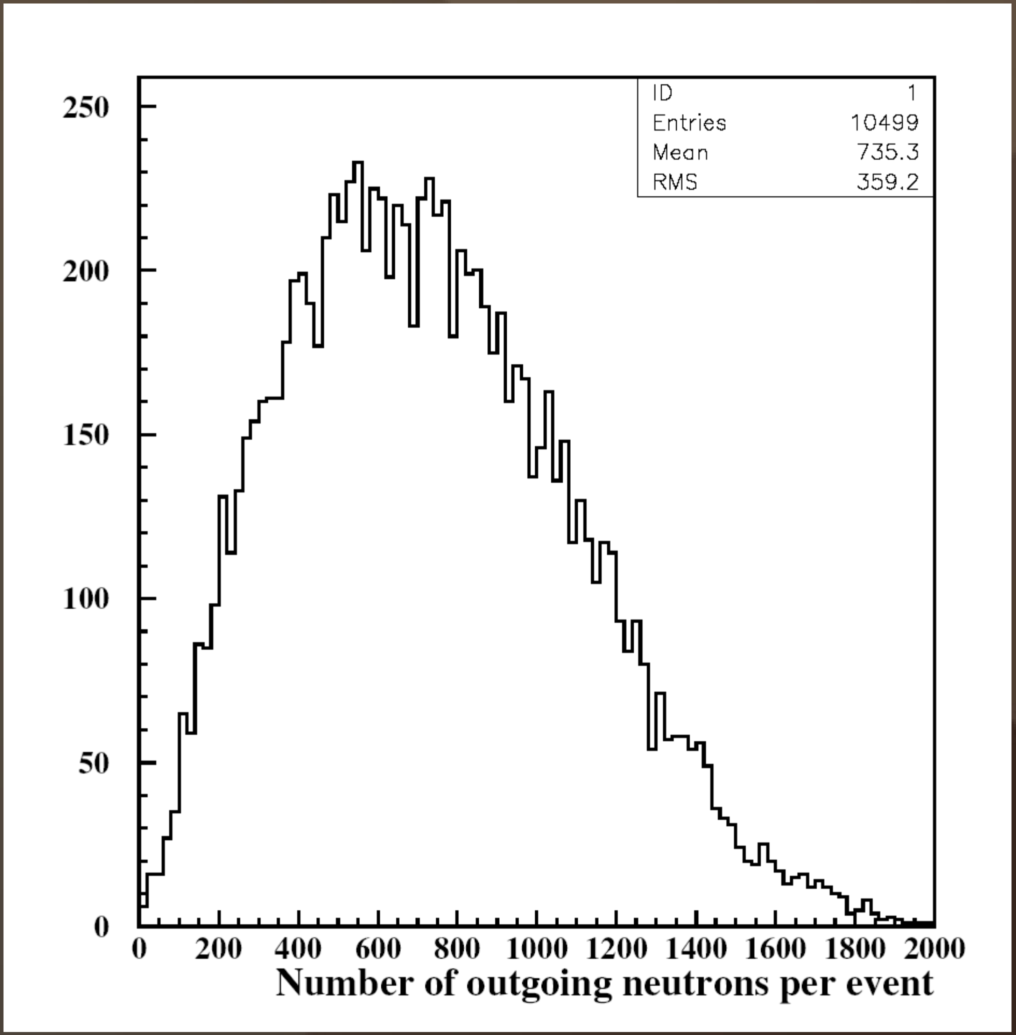


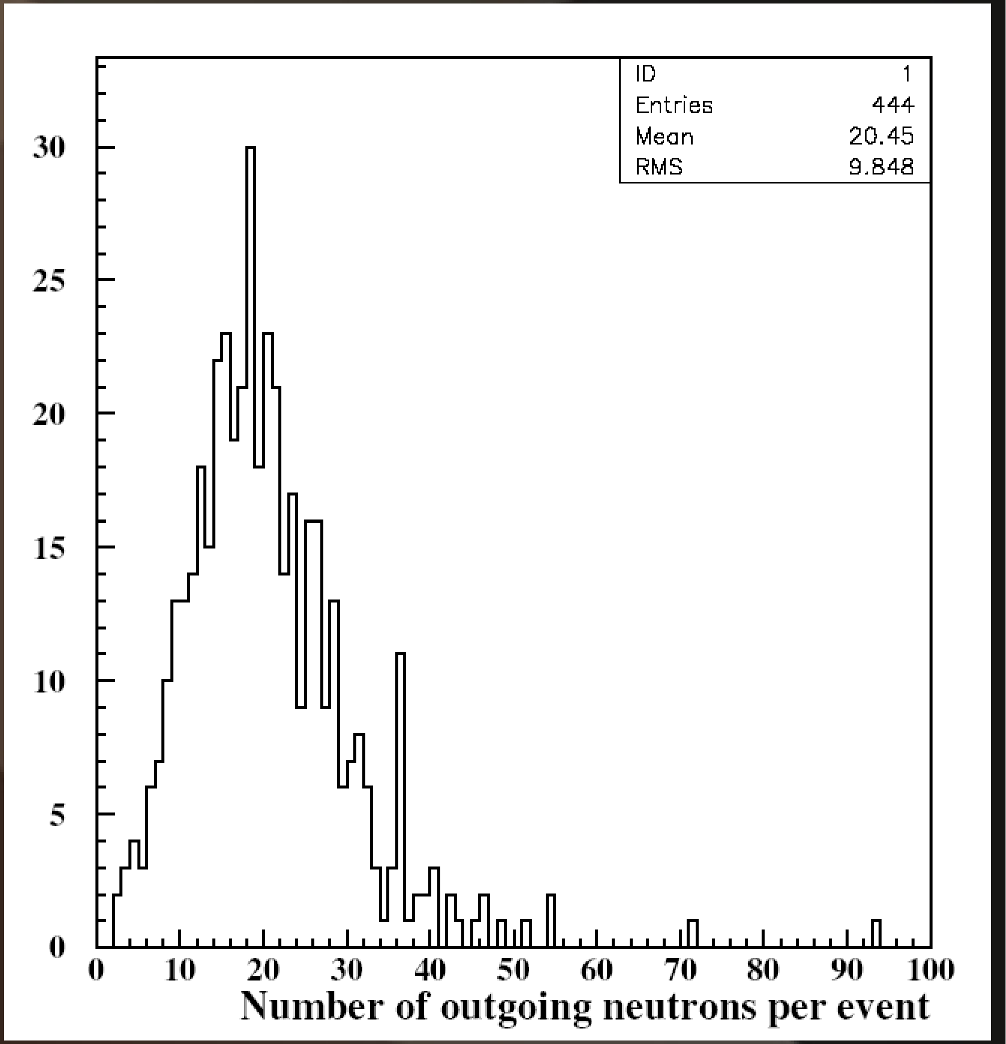
  - Roughly same energy deposit in TASC (when interaction takes place in IMC)

Simulations

- 1 TeV protons (Fluka)
- 400 GeV electrons (Fluka)

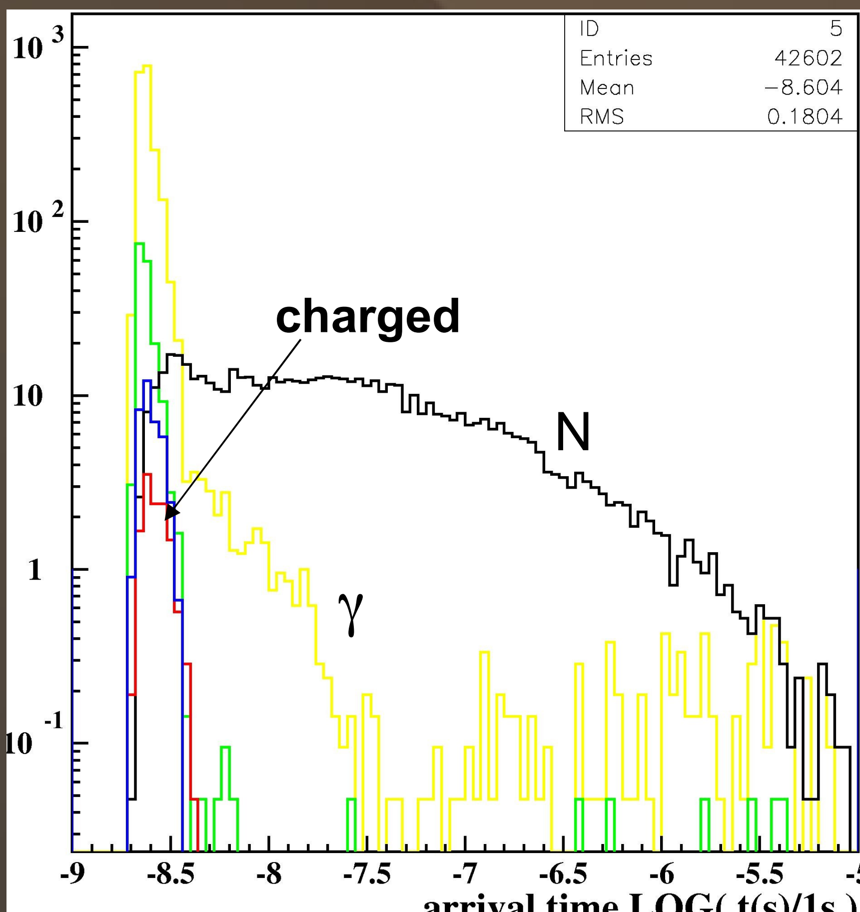
release the same energy .... as



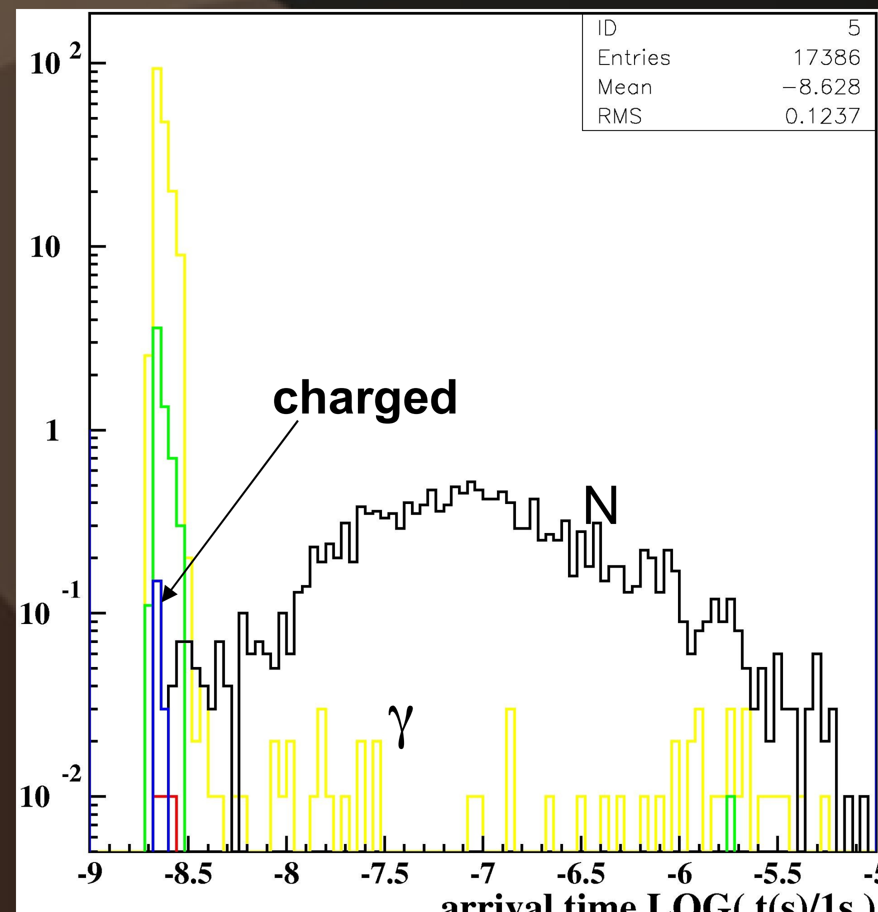


Shower components

- 1 TeV proton



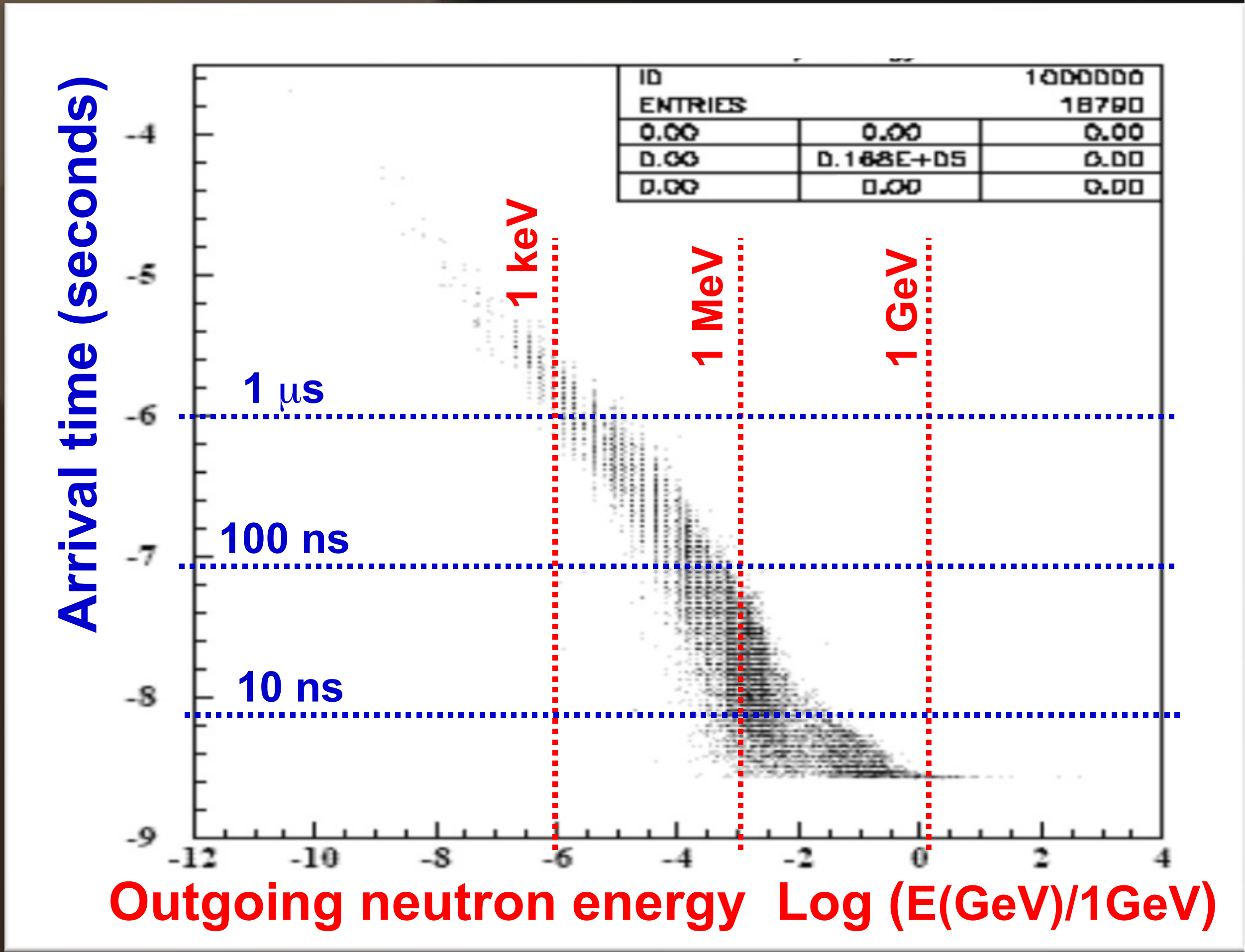
- 400 GeV electron



Simulations

- Well developed hadronic showers (interaction in the first layers)
- Many more neutrons released
- Harder spectra than with electromagnetic showers
- Very strong correlation between arrival time and energy.

- 1 TeV proton showers



NEUCAL

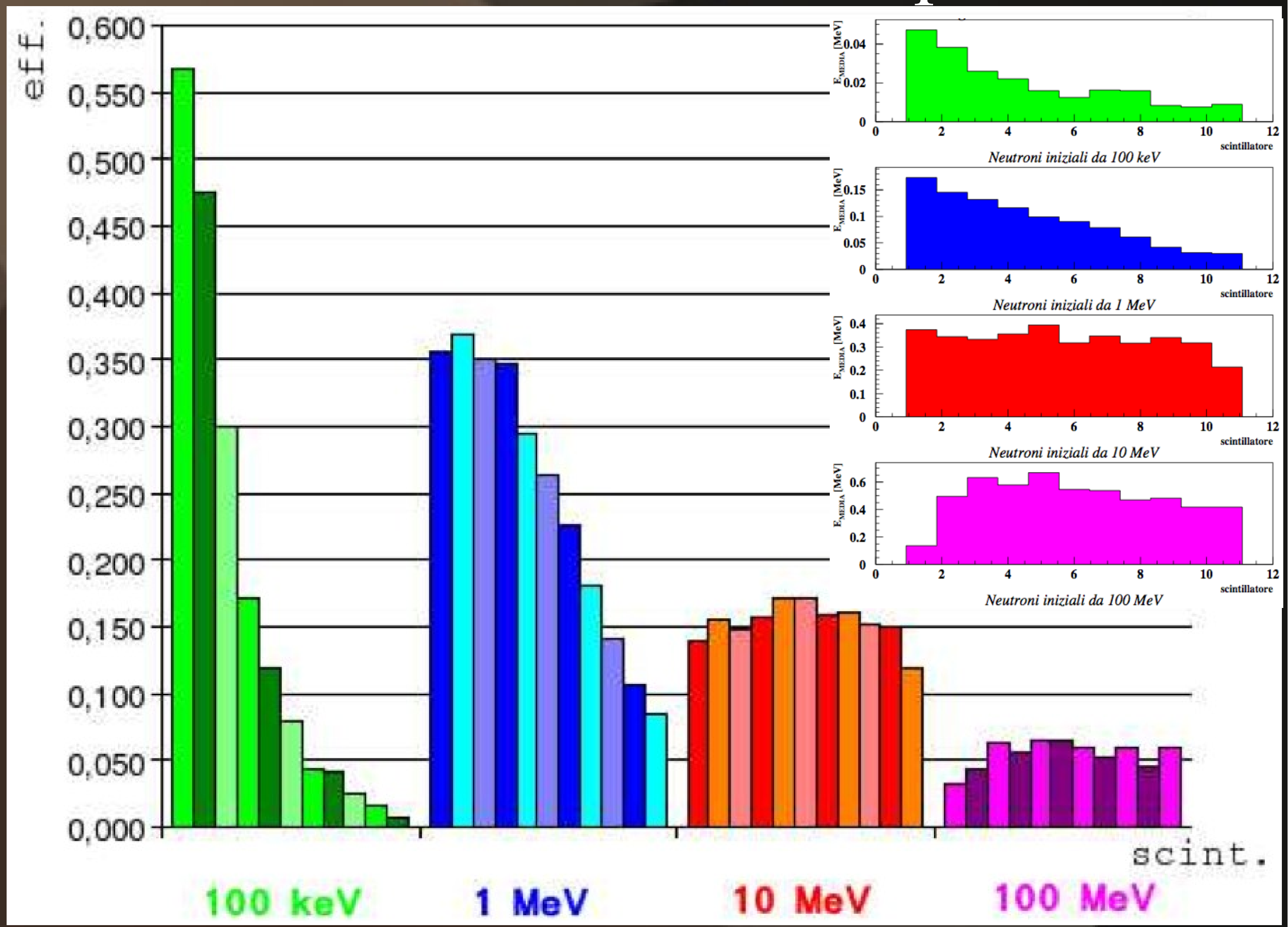
- Almost all neutrons exit from the calorimeter within a few microseconds, but thermalization inside the neutron detector can take hundreds microseconds
- Sensitivity also to energetic neutrons.
- Detect neutron signals during moderation by using standard organic scintillators.
- Fast photomultiplier readout.
- Complement with ^{3}He tubes.

Energia [MeV]	σ^H_{tot} [barn]	σ^C_{tot} [barn]	ℓ_{Antr} [cm]	ℓ_{Stil} [cm]	$\ell_{EJ\text{-}230}$ [cm]	$\ell_{NE\text{-}213}$ [cm]
0.1	13	4.4	1.2	1.4	1.1	1.2
1	4.2	2.6	2.9	3.6	2.9	3.2
10	0.93	1.2	8.8	11	9.6	11
100	0.075	0.47	32	41	39	45

Number of layers.

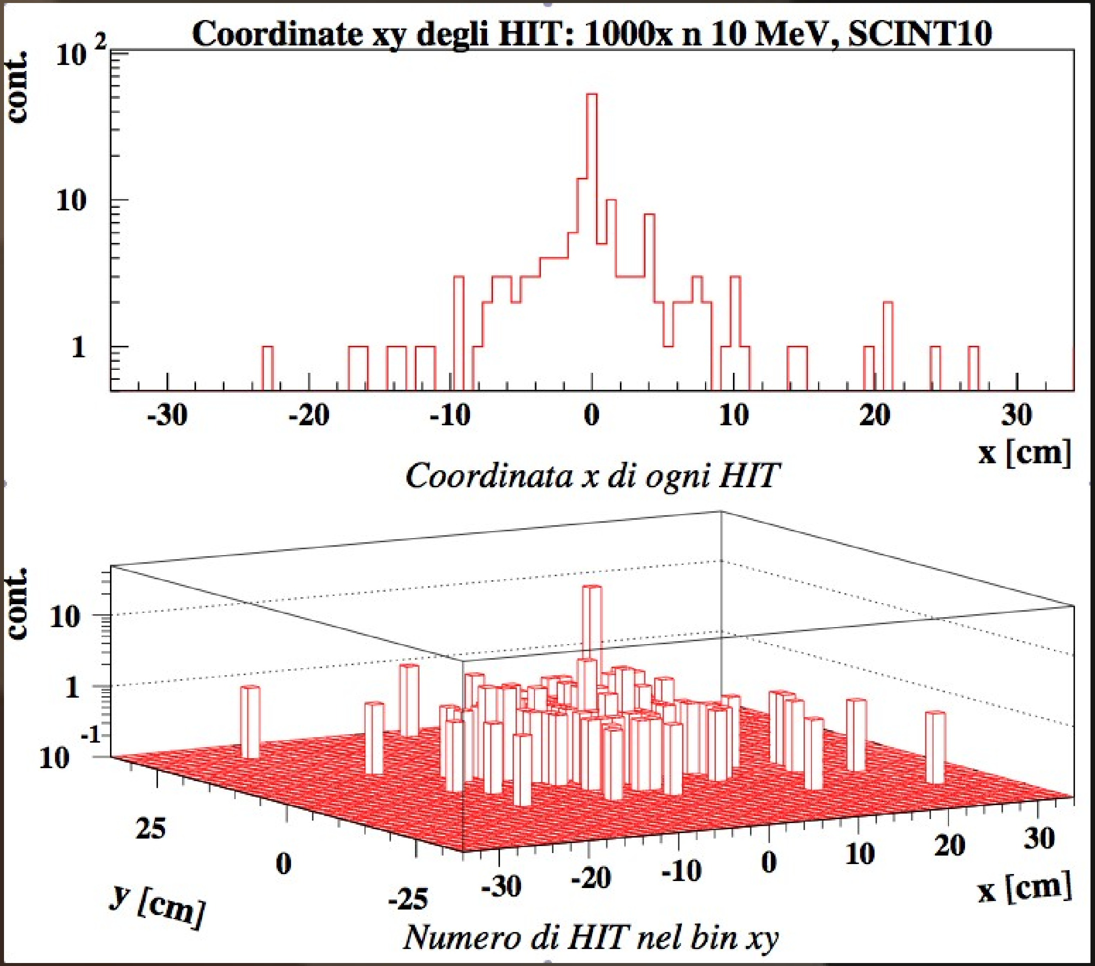
- At least 1 hit required.

- For low energy (100 KeV) neutrons 2-3 layers are sufficient.
- At 10-100 MeV efficiency drops and more layers are needed.



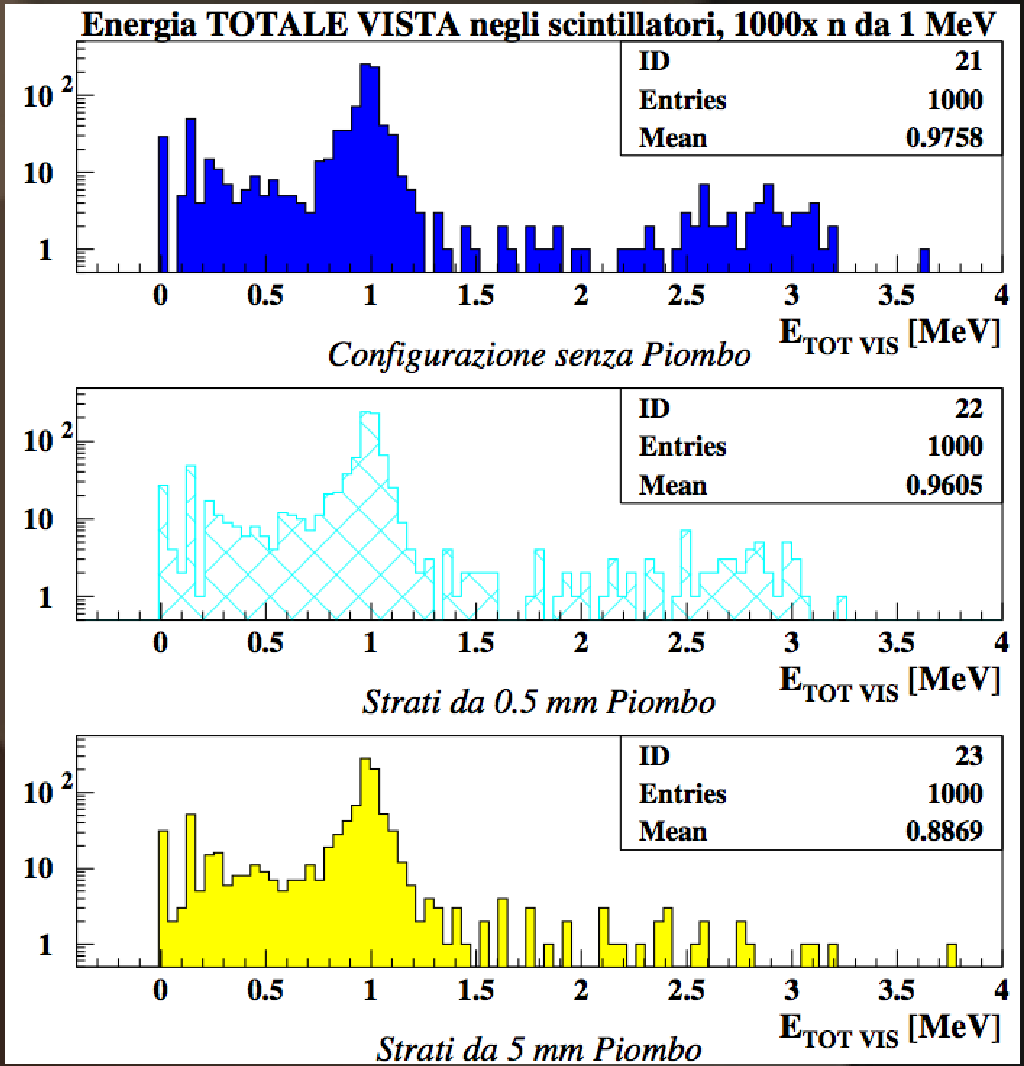
Dimensions

- From simulations:
- neutrons from the showers interact mostly within a radius of 20 cm from the shower centre.
- there is a lot of straggling and depending on the energy little or no interaction



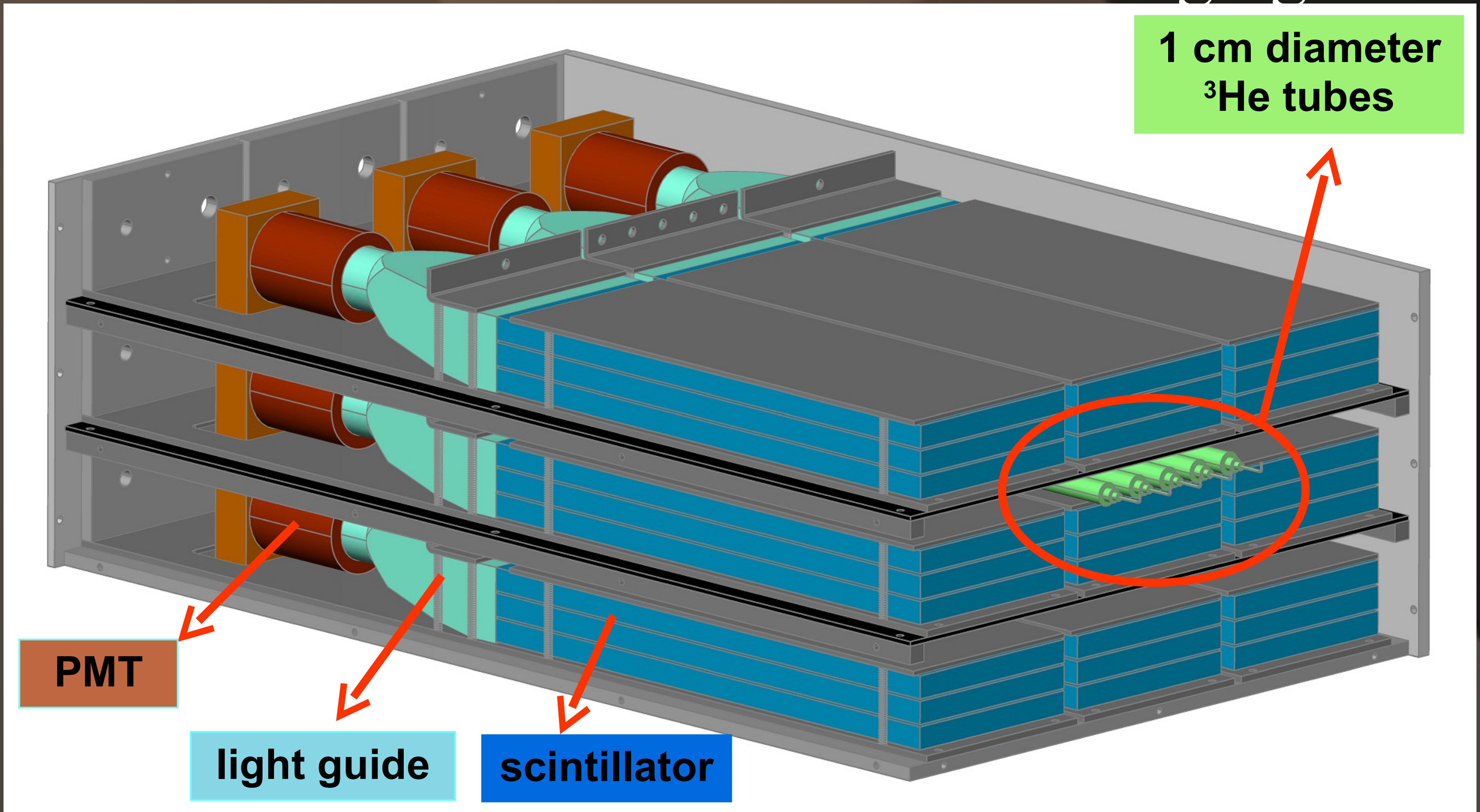
Lead foils

- KLOE calorimeter study.
- Simulations show a modest gain for high energy neutrons.
- Left as an option the possibility of inserting a .5 mm sheet.



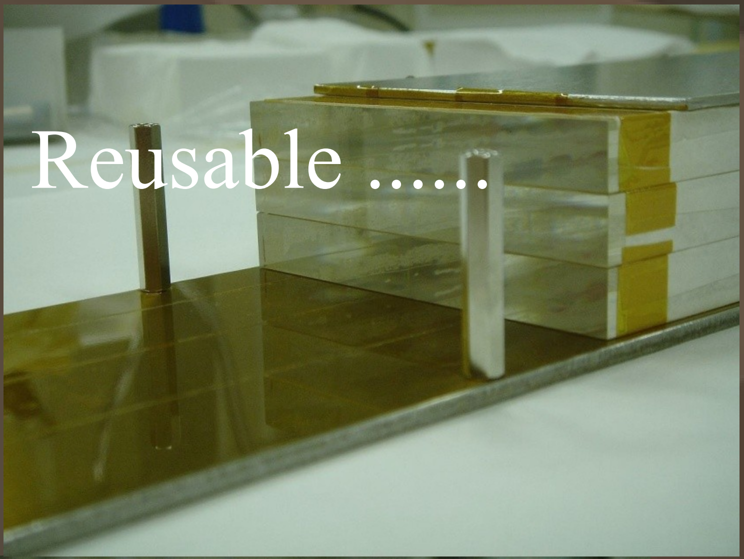
Detector

- Scintillator plates
- ^{3}He tubes
- Photomultipliers, very fast.
- Slow high gain electronics

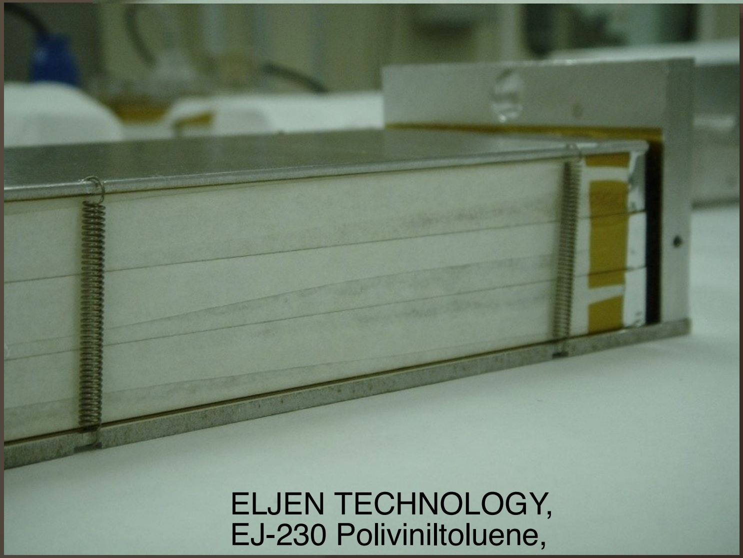


Simple build

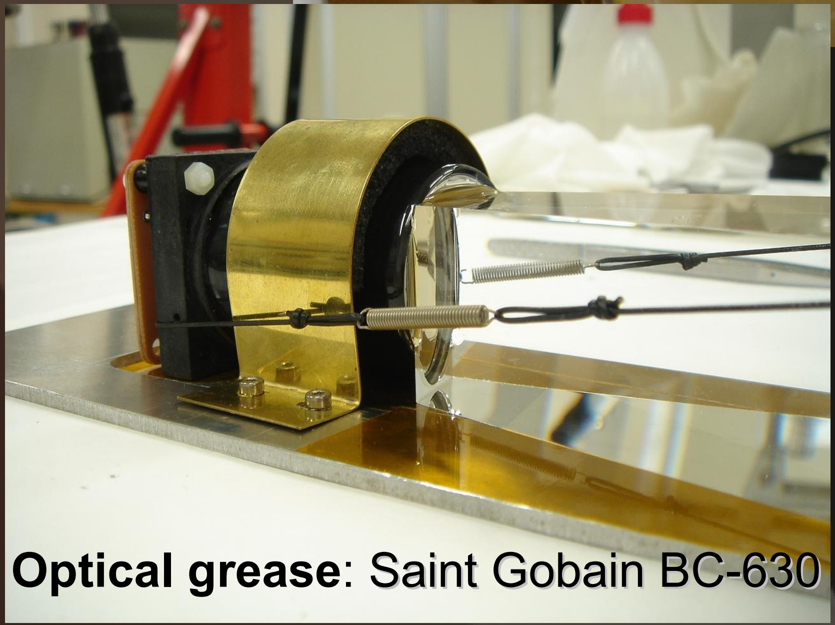
- Reusable ......
- A lot of borrowing ....



PMT
Hamamatsu
R5946

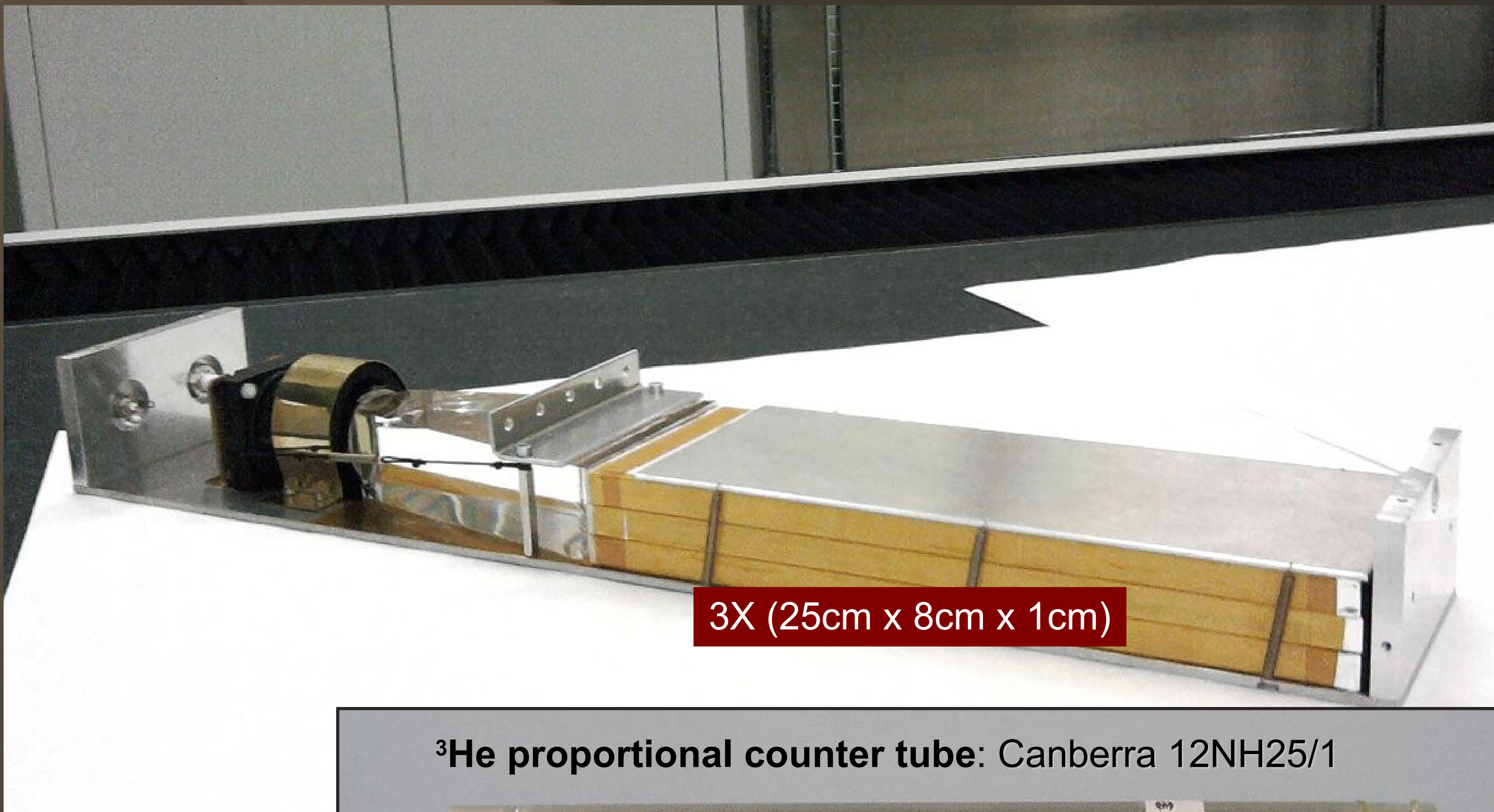


ELJEN TECHNOLOGY,
EJ-230 Poliviniltoluene,



Optical grease: Saint Gobain BC-630

A detection module



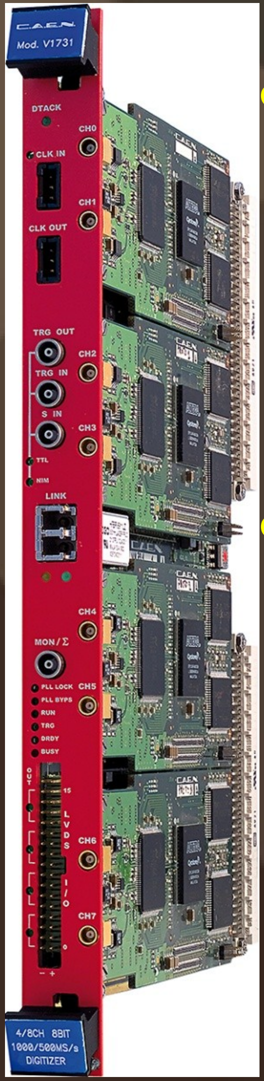
^{3}He proportional counter tube: Canberra 12NH25/1

1 cm diameter

Readout electronics

CAEN V1731 / V1720 board

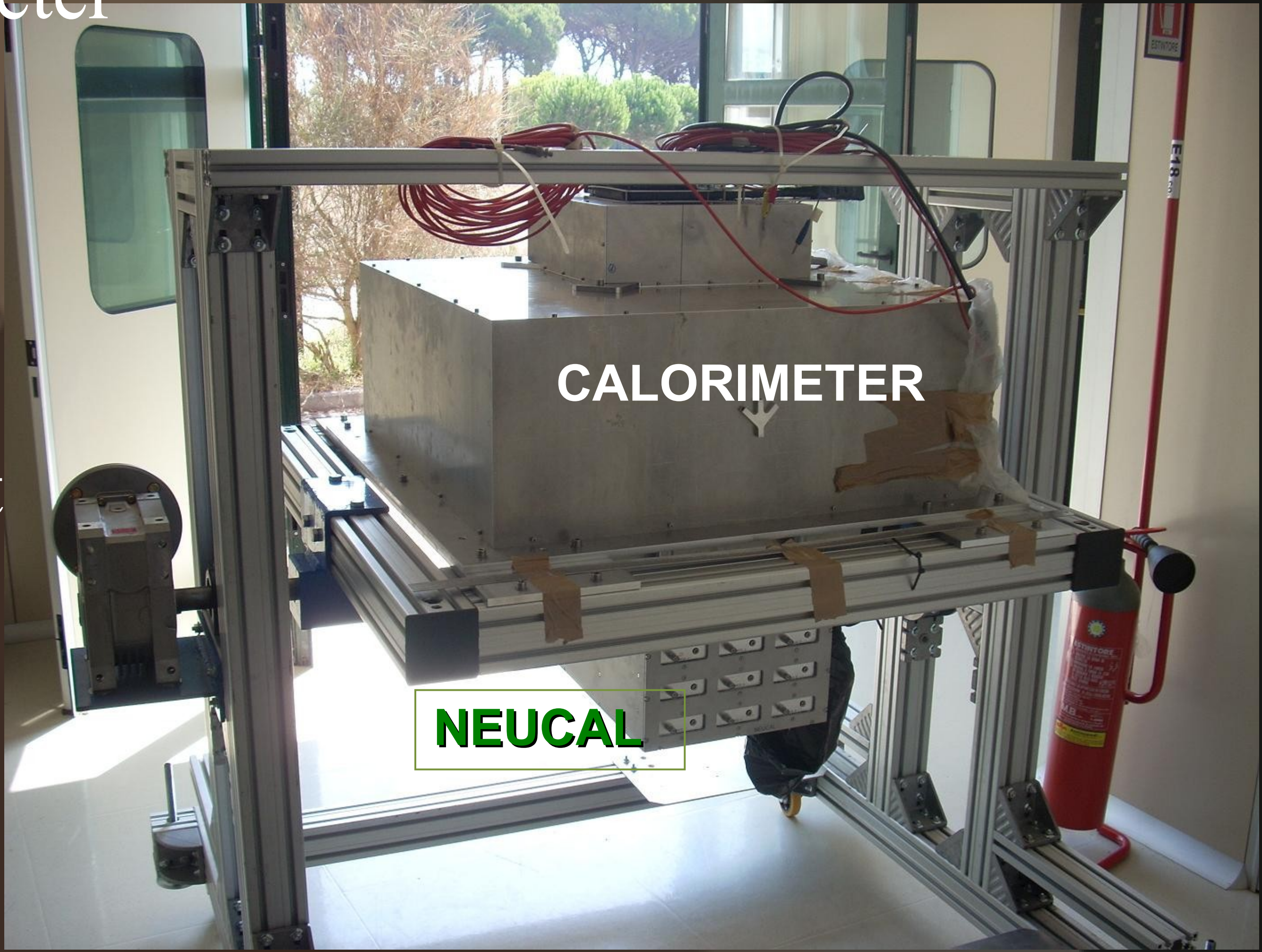
- **VME standard**
- **8 ch, 500MS/s, 250MS/s**
- **8, 12 bit ADC**
- **2MB/ch memory (few ms digitization)**
- **16, 32 ns jitter**
- **On-board data compression (Zero Suppression Encoding)**



- The idea is to capture a long “time exposure” of the detector after the trigger.
- Looking for neutron signals for up to a millisecond after the shower has ended.

Test beam SPS

- Shallow calorimeter scenario. $16X_0$.
- Tungsten, fibres.
- Parasitic
- Separate readout



Test beam conditions

- CERN SPS, line H4 (one week test)
- Beam type – energy - # of events:
  - **Pions** 350 GeV (230000 events)
  - **electrons** 100 GeV (240000 events)
  - **electrons** 150 GeV (50000 events)
  - **muons** 150 GeV (130000 events)
- Data collected in different configurations:
  - scan of detector (beam impact point)
  - different working parameters
    - PMTs and tubes voltages
    - Digitizer boards parameters (thresholds, data compression…)
    - 16 X_0 for electrons, 29 X_0 with pions ....

Signals

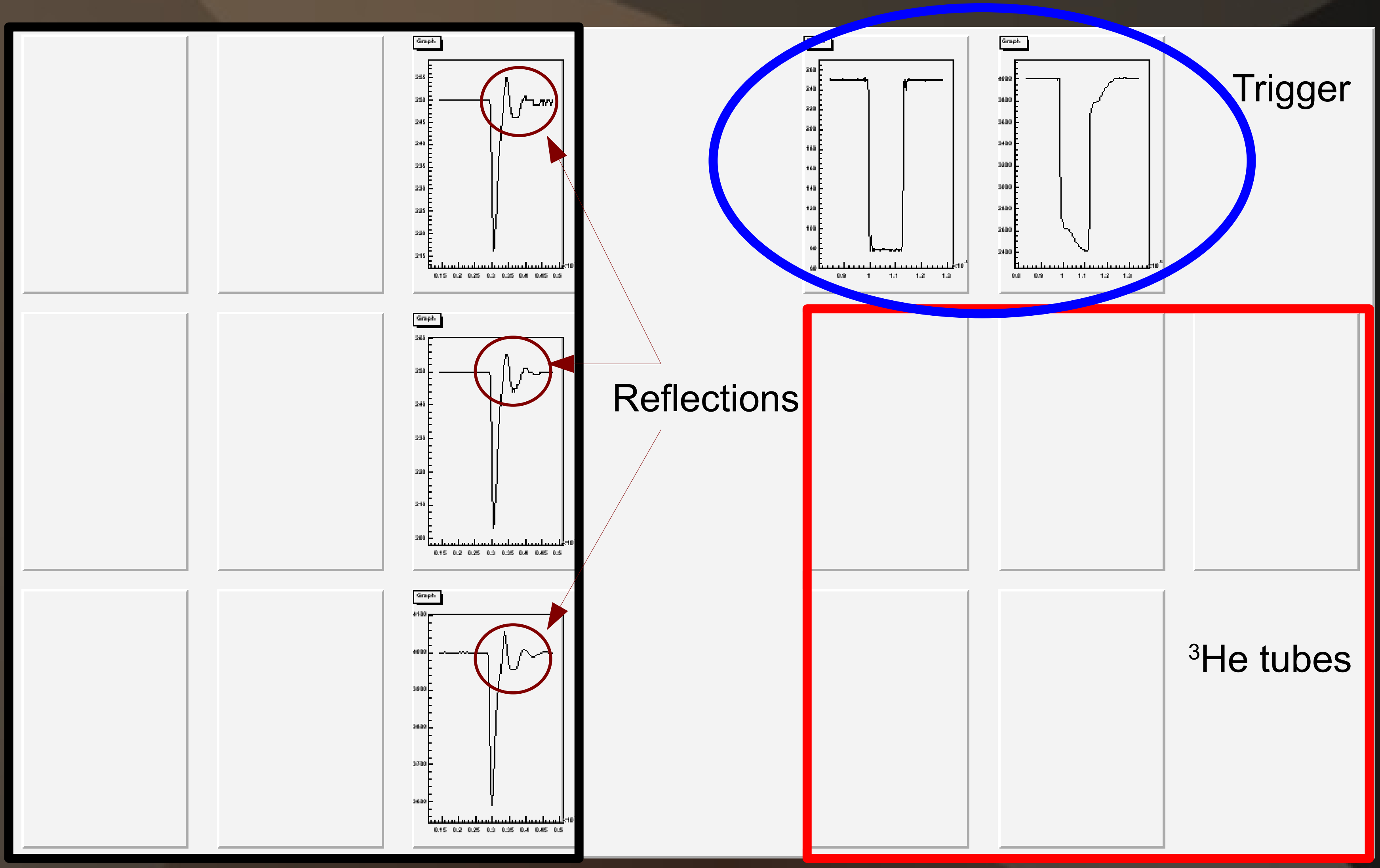
- Expect single pulses coming after the main shower core has passed.
- After the trigger, a prompt signal appears on all scintillators, the result of the showering process.
- As the film unrolls other signals may show up. Traversing hadrons will give a visible signal on more than one scintillator (2-4 ns resolution of the system comes into play).
- <u>A single isolated pulse is considered as a neutron candidate.</u>

Caveats

- NEED to operate in zero suppression mode!
  - Huge data frame otherwise
  - Enormous read-out time (seconds !)
- Due to a firmware bug, our fast signals were not recognised even though below threshold.
- Ad hoc solution using passive filters to “slow” the signals.
  - Reflections introduced
  - Took a small sample of data without zero suppression (without filters).

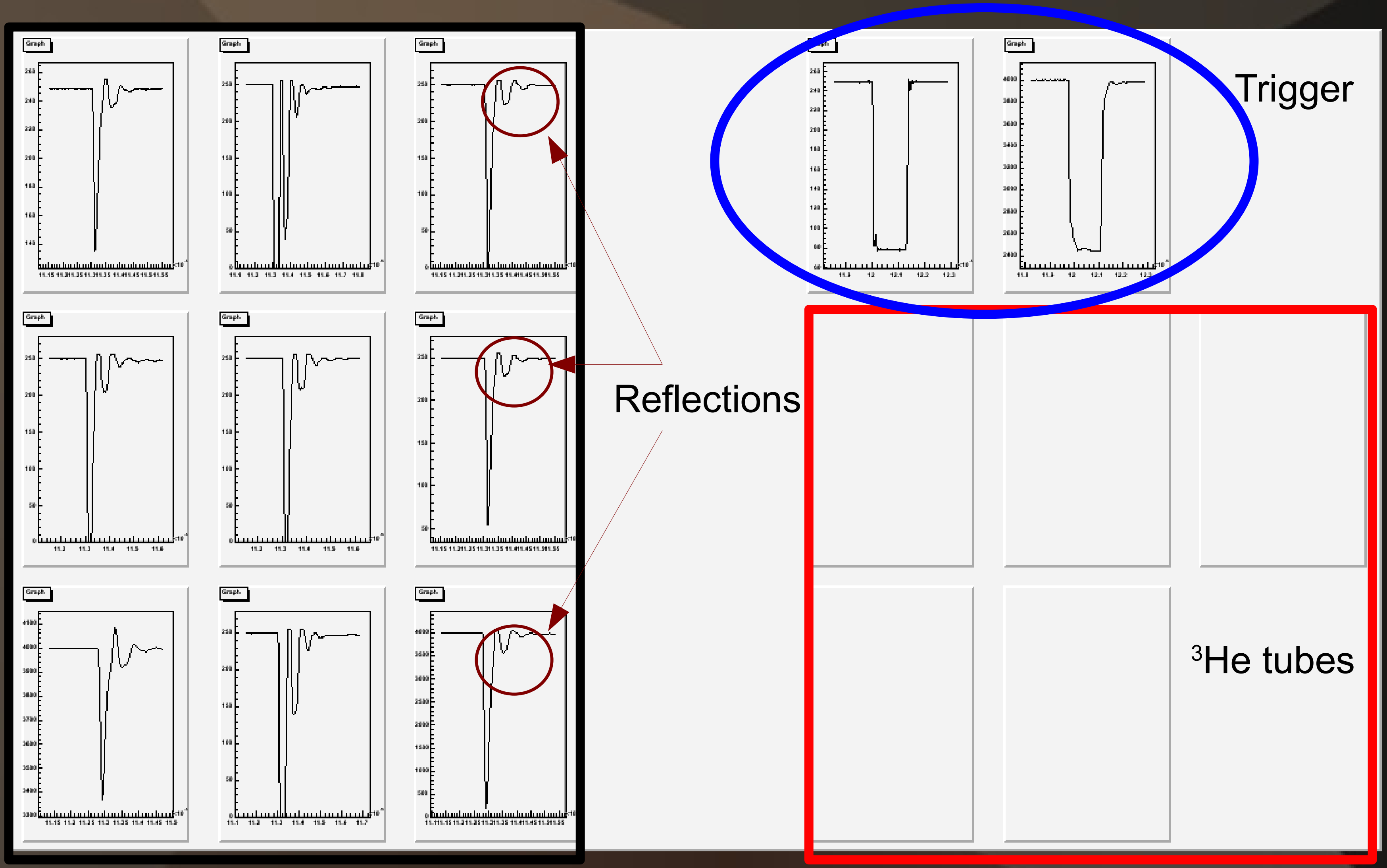
Muon example

- 9 scintillator views, 2 trigger views, 5 ^{3}He views.



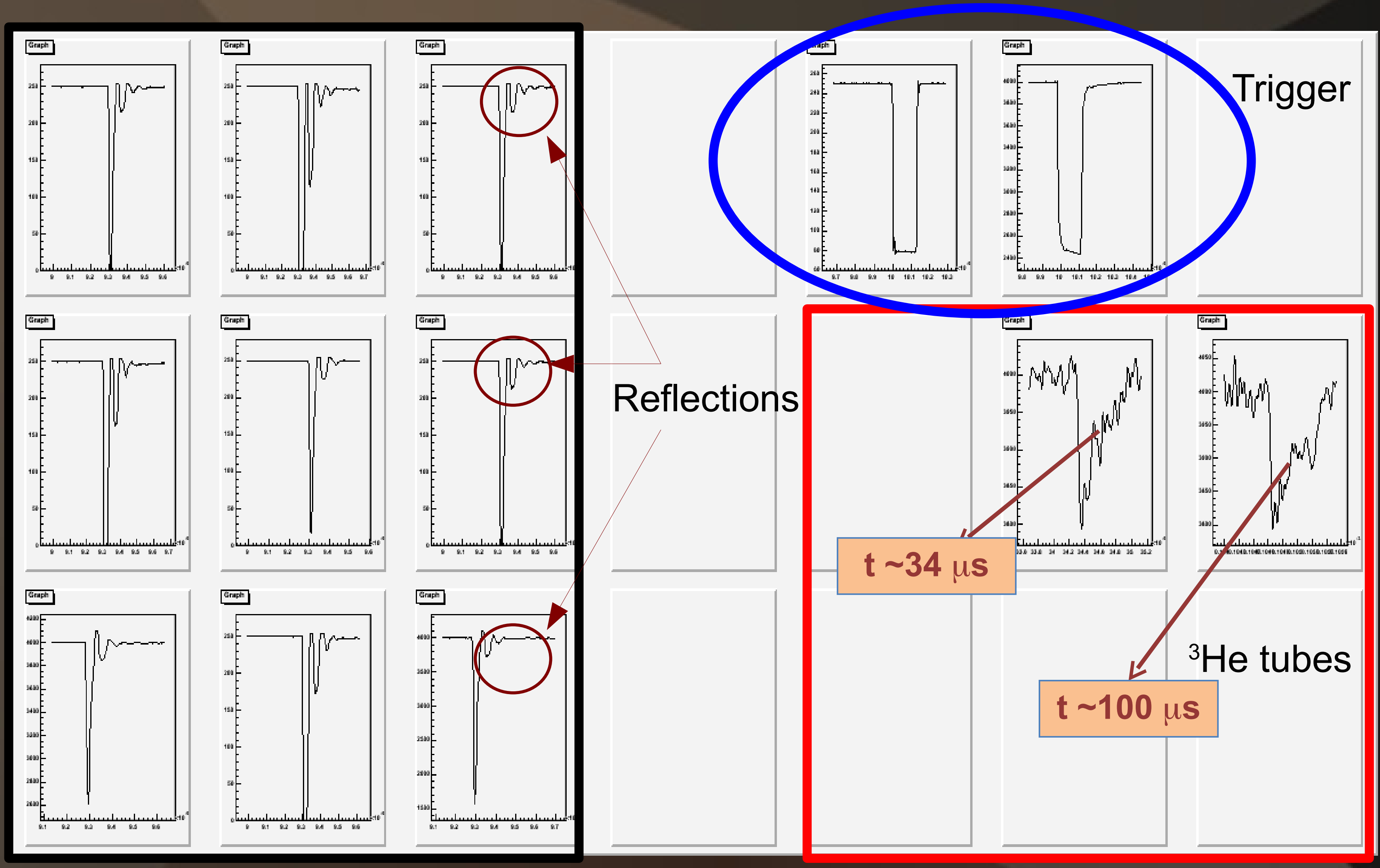
Electron example

- 9 scintillator views, 2 trigger views, 5 ^{3}He views.



Pion example

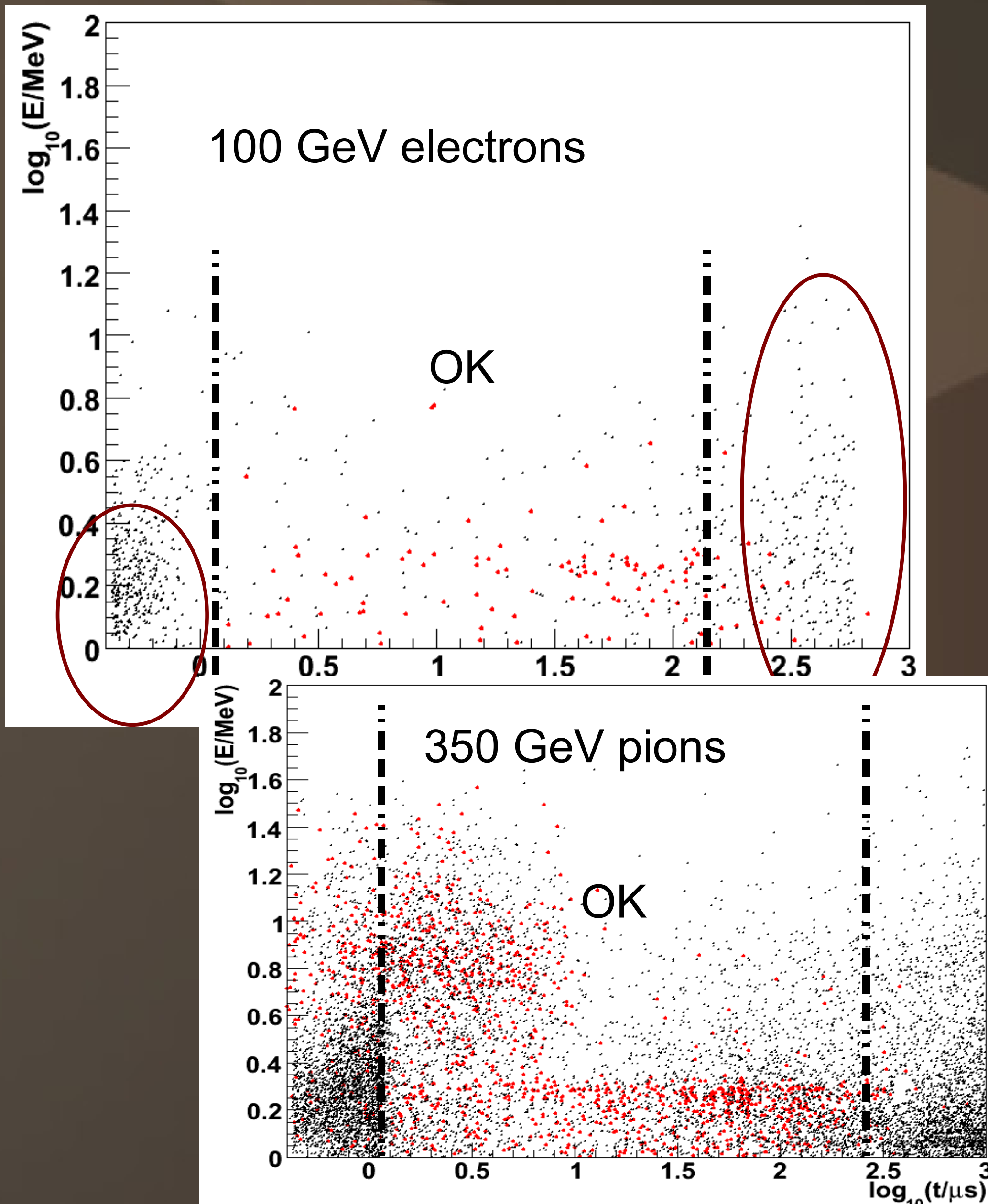
- 9 scintillator views, 2 trigger views, 5 ^{3}He views.



Pion example

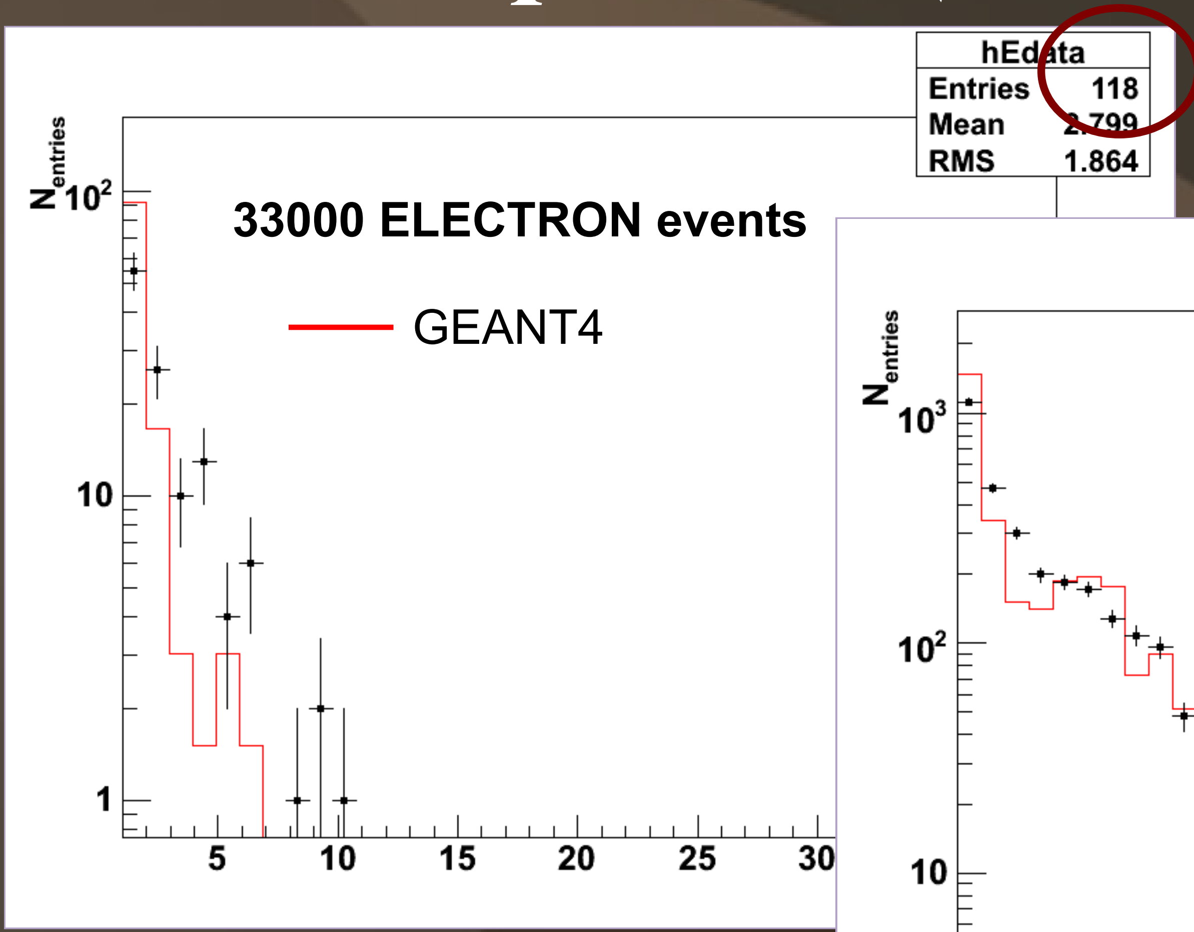
- 9 scintillator views, 2 trigger views, 5 ^{3}He views.

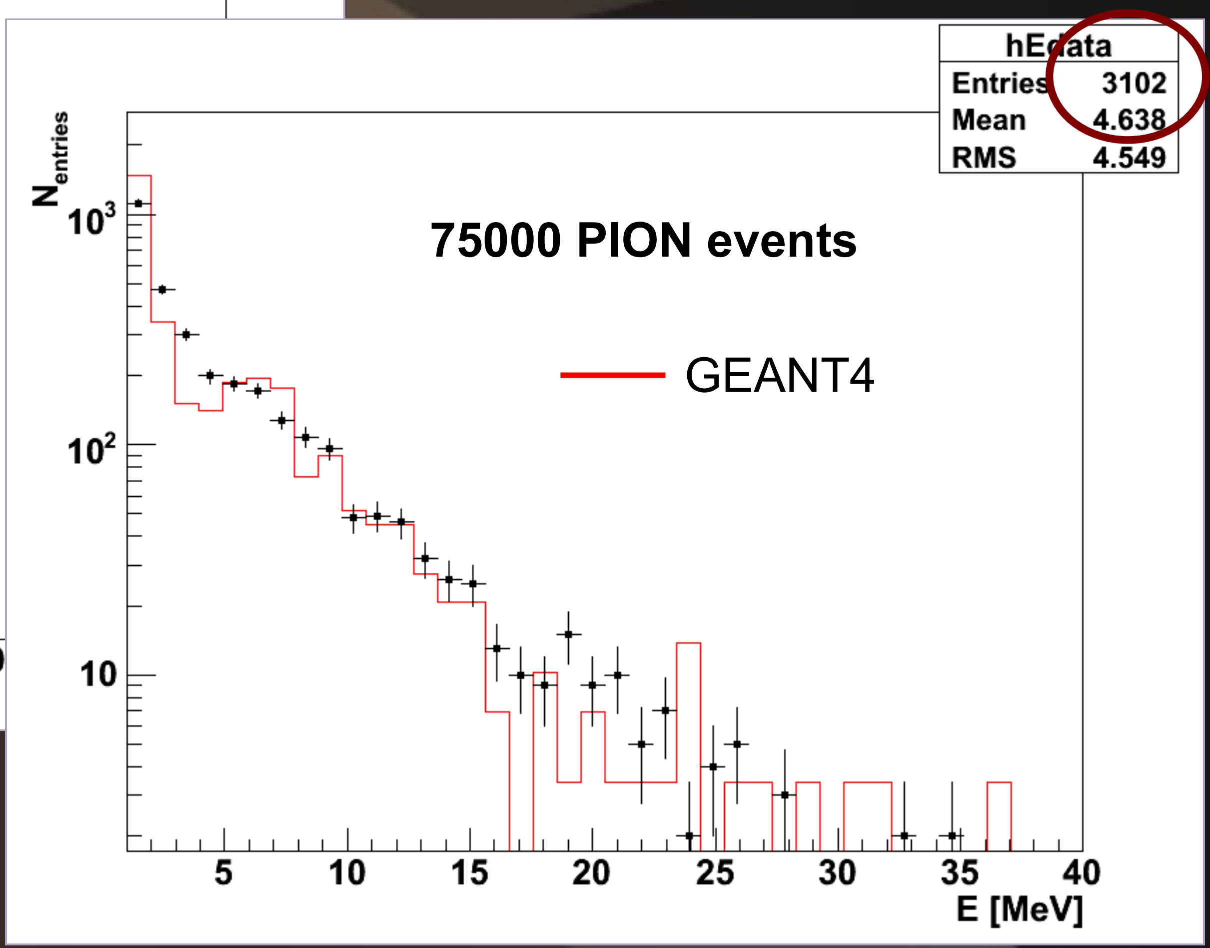
Geant 4 simulation of test beam set up



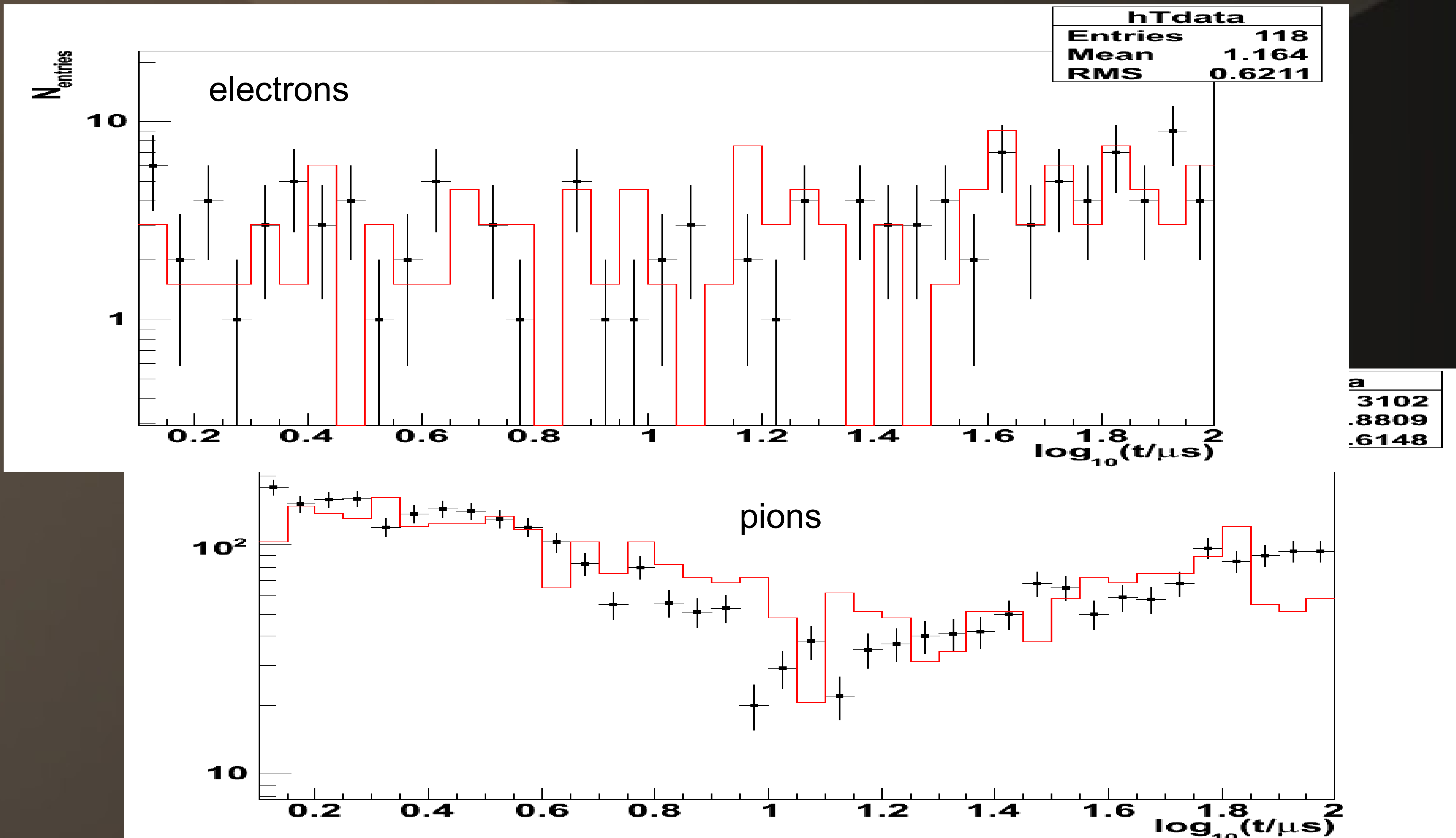
- Calorimeters simulated as passive absorber blocks.
- Energy calibration from muons
- Reflections, spurious signals (high intensity spill).

Comparison (Data after 1 μs!)



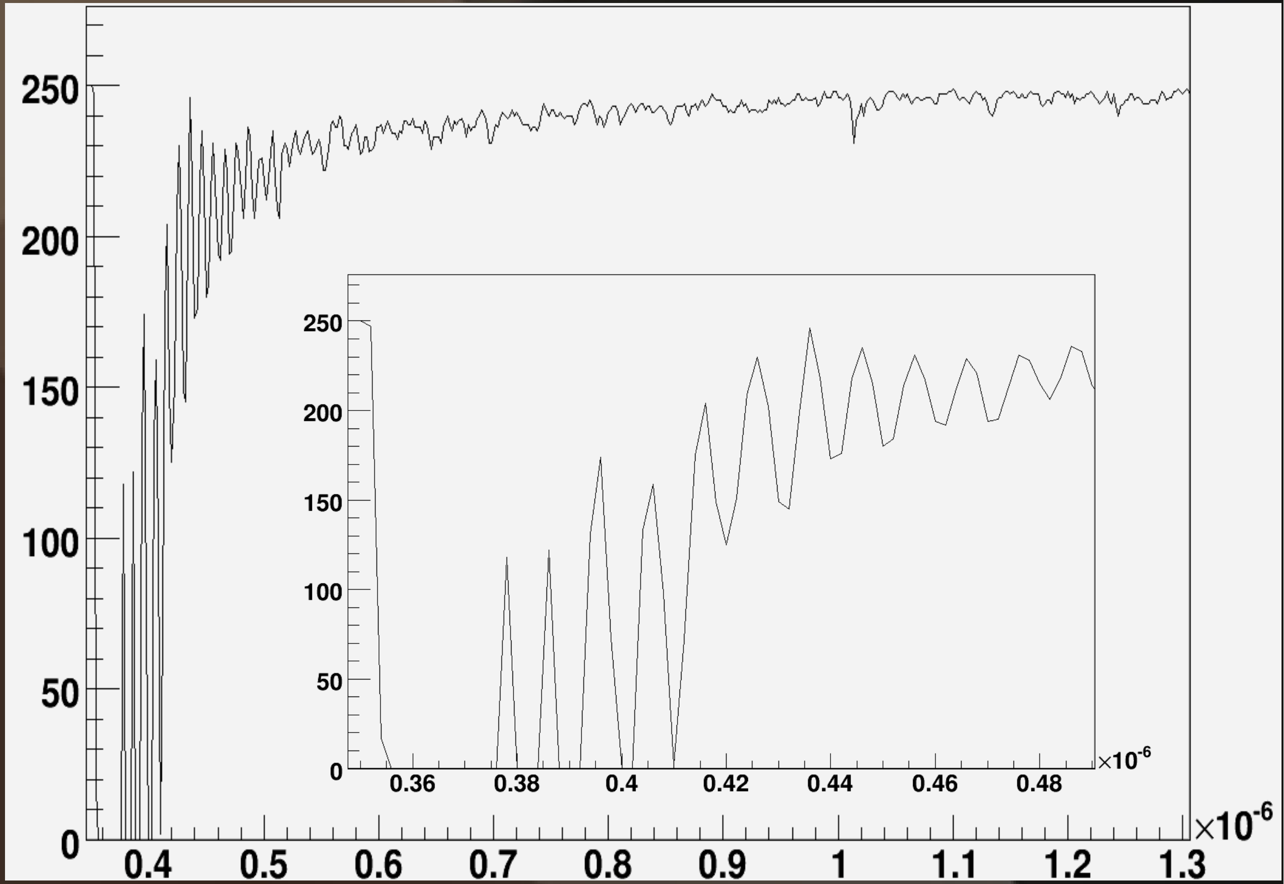


Comparison (2)



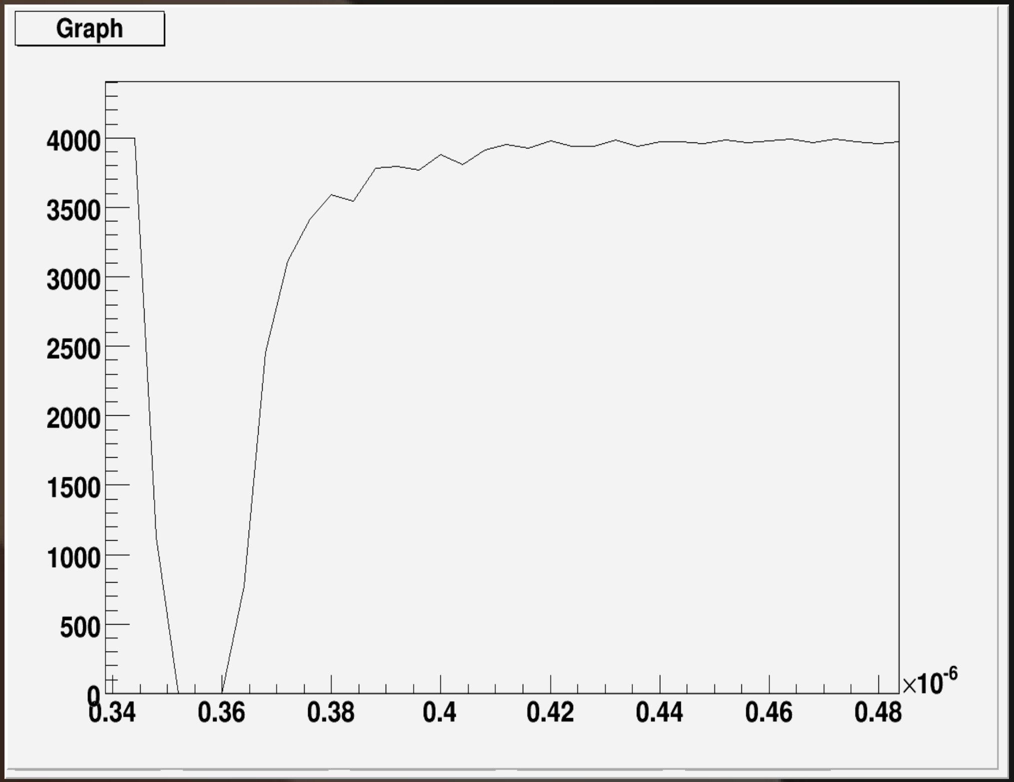
Before 1μs ?

- Cannot use zero suppressed data sets because of reflection problems.
- Very little data without filters.
- Saturation problems.
- 8 bit ADCs



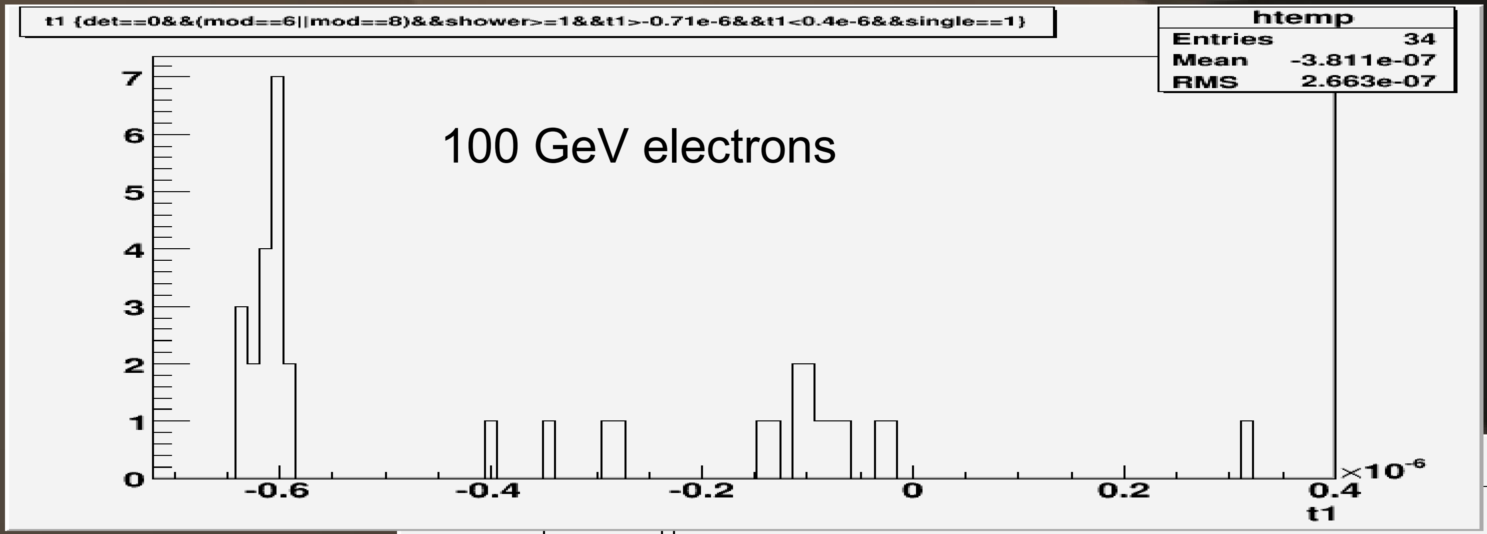
All is not lost

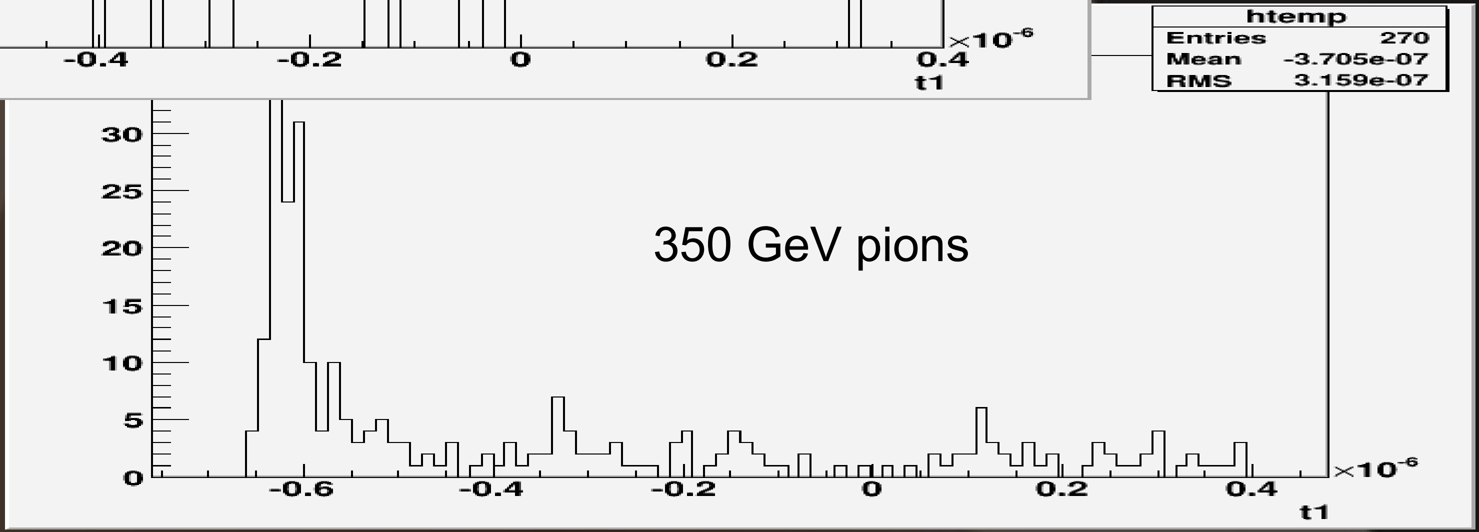
- Two scintillator blocks were read out by a slower 12 bit ADC.
- They are not in the immediate path of the shower.
- Some signals have been extracted using procedures similar to the ones outlined before.



Again a significant difference

- There are more "single" signals for pions than electrons.

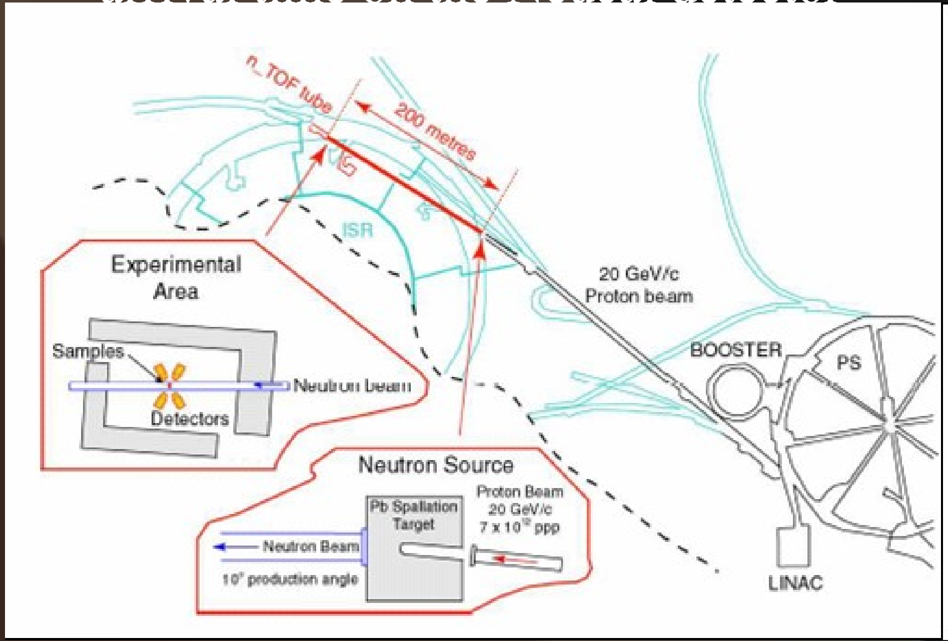




Response to neutrons

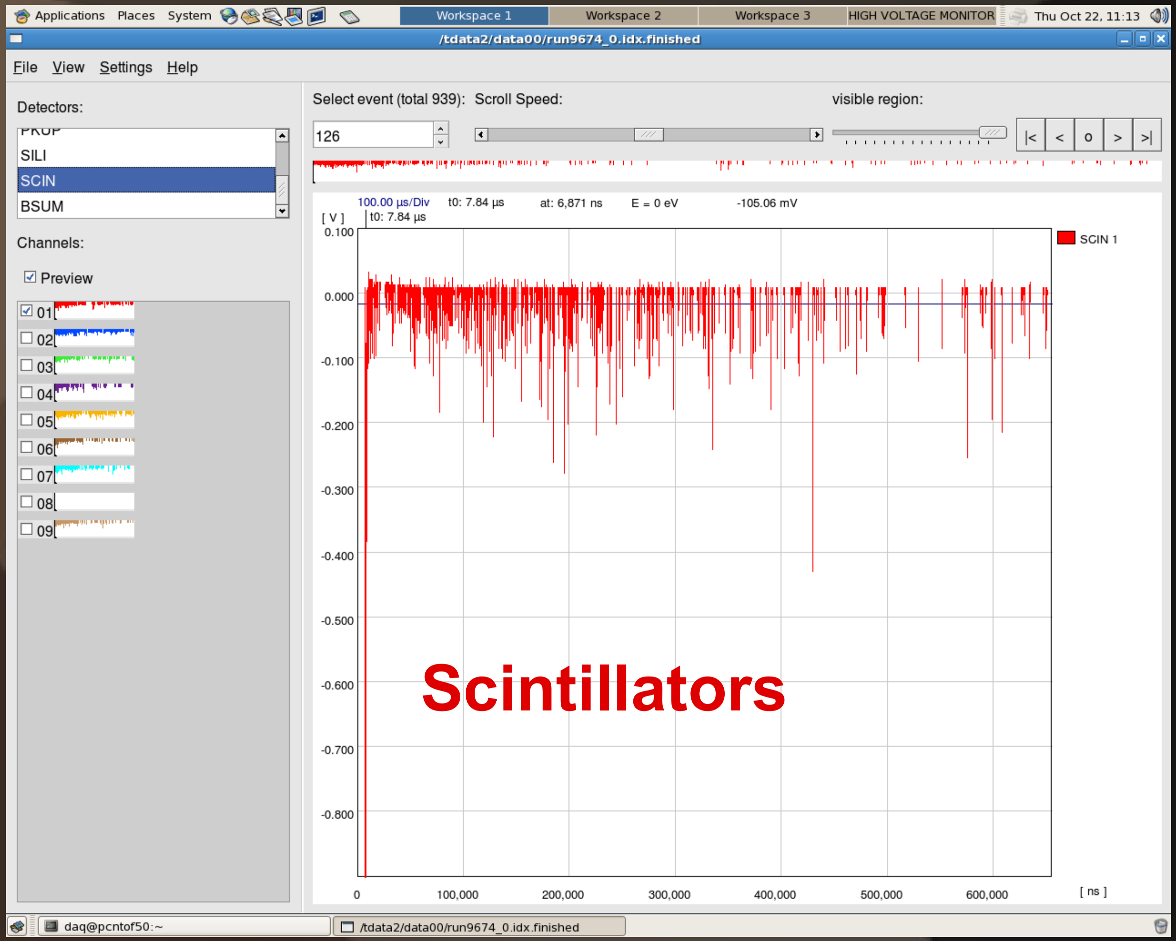
- Had the opportunity to sit on the nTOF beam in November.
- We placed our detector at the end of the beam line and collected data.
- The analysis has still to start.

- Very intense p beam (20 GeV, 10^{12} p per spill)
- …But with very short spill (5 ns)
- …And very small duty cycle (5 ns/few ms)
- Neutrons are produced in the target with different energies
- Neutrons travel along the 200 m line
- The energy of the neutron is inferred from the arrival time on the Neucal detector

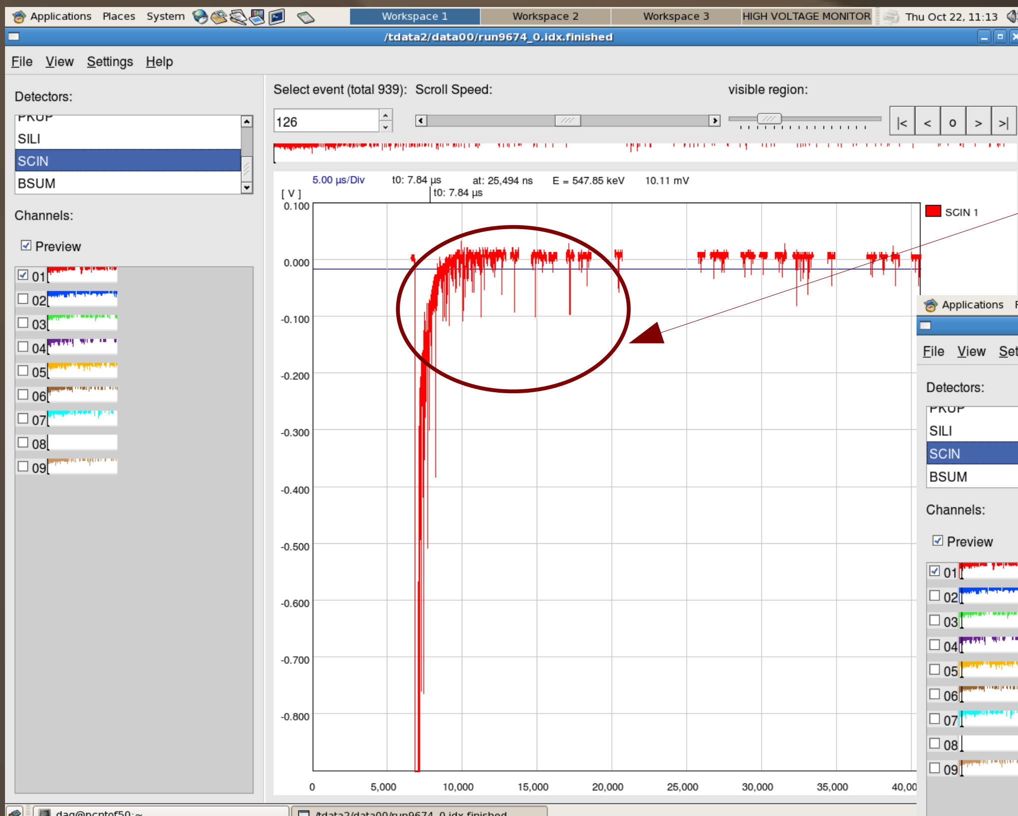


Signals

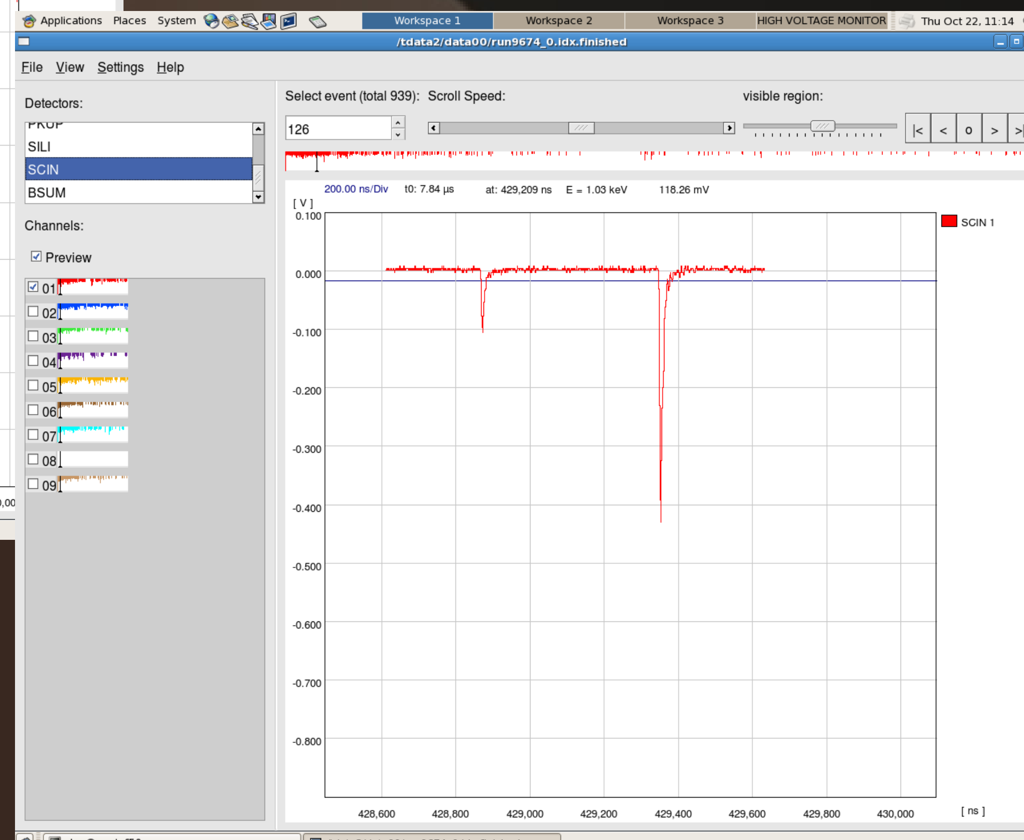
- By knowing the neutron spectrum (both in shape and absolute normalization) we can measure the single neutron efficiency as function of the neutron energy
- Analysis is complex.



Signals

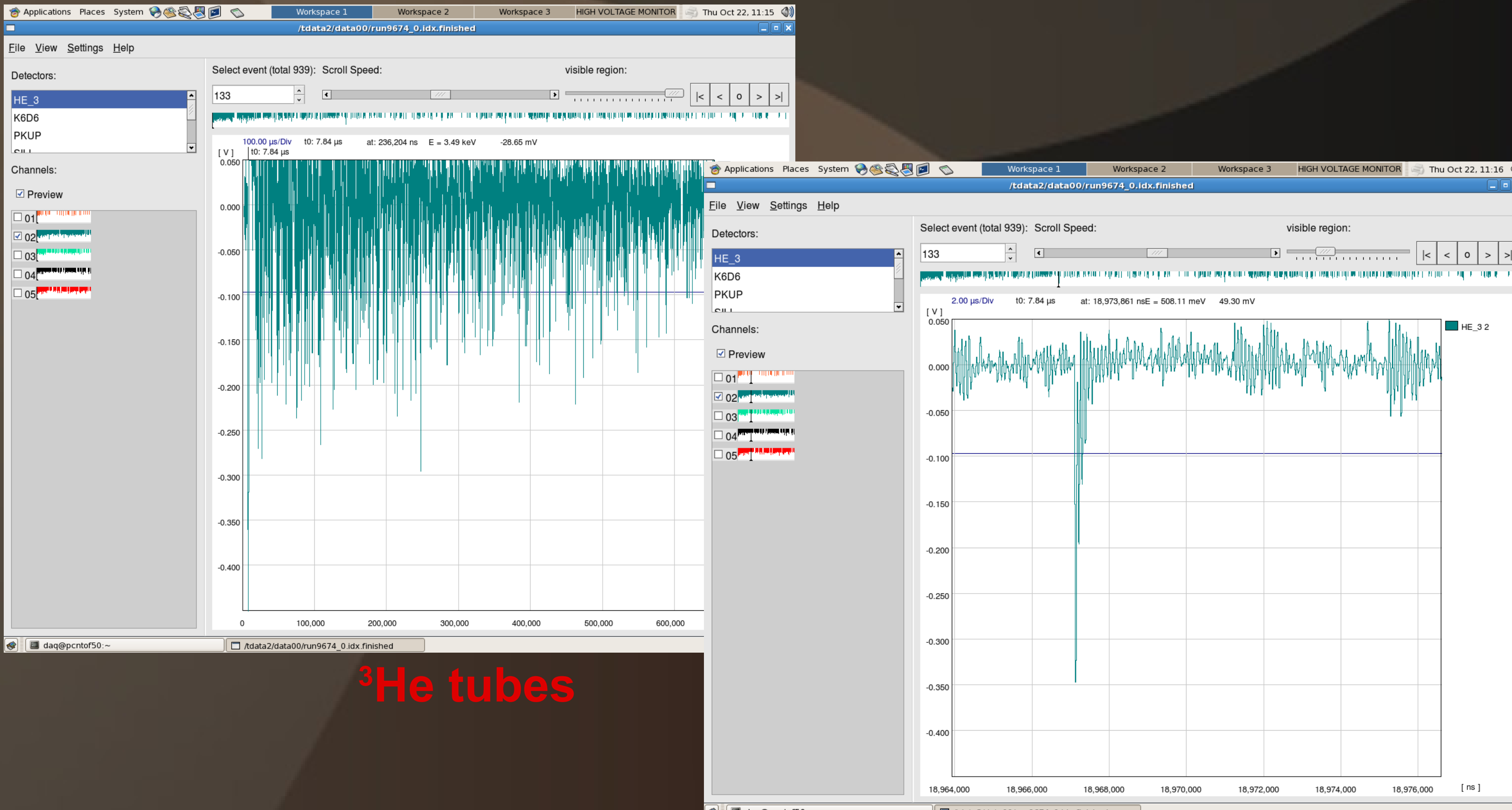


Saturation effects



Scintillators

Signals

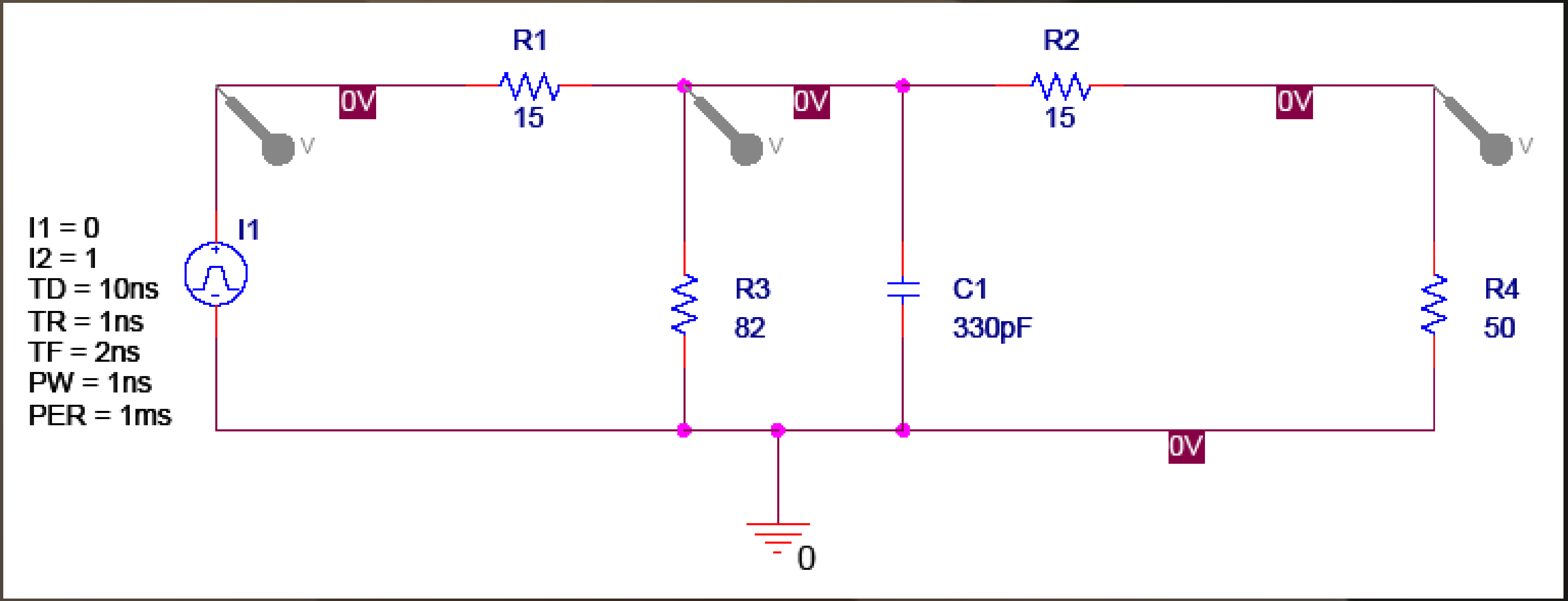


^{3}He tubes

Conclusions

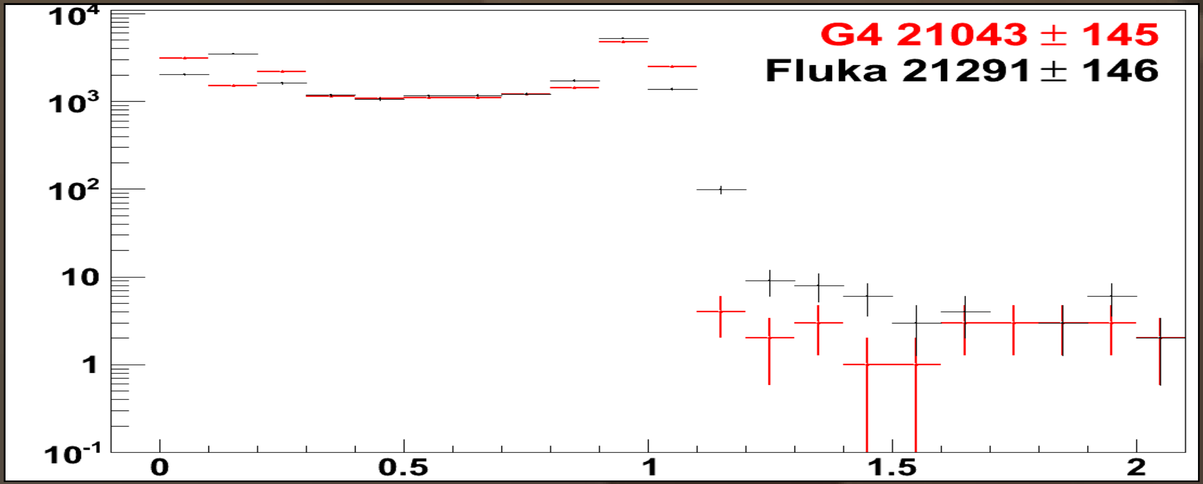
- A new approach to hadron/electron separation is being pursued.
- Advantages are the possibility of achieving the same performance with lighter more compact calorimeters
- Results are very encouraging, and entice us to repeat the tests with more adequate electronics and with better calorimeter control.
- We thank the nTOF collaboration for their support and especially Marco Calviani who will collaborate with us on the analysis of the nTOF data.

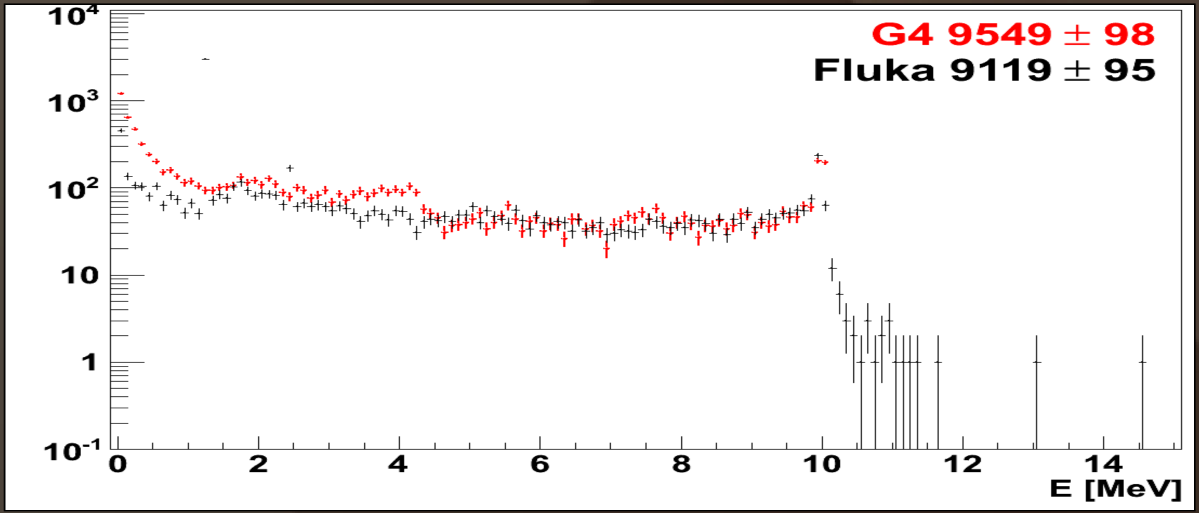
Backup 1


R1
15
R2
15
0V
0V
0V
0V
V
V
V
I1 = 0
I2 = 1
TD = 10ns
TR = 1ns
TF = 2ns
PW = 1ns
PER = 1ms
I1
R3
82
C1
330pF
R4
50
0

Backup 2

- Simulated energy release inside one scintillator layer





- Fluka, Geant4 comparison.
- 1 MeV neutrons
- 10 MeV neutrons

Backup 3

- 100k single 1MeV neutron events.
- Look for late produced (t>100ns) particles with E_{KIN}>10keV.
- Two categories: soft E_{KIN}<3MeV, hard E_{KIN}>3MeV.
- particles originating in the active ^{3}He counters volume ignored.

	Note	particle	number	per 1k N	process	material
SOFT <3MeV	**Charged** [not due to photons: no compton, no conversions, no photoelectric]	p	62	0.62	NeutronInelastic	Air
		^{14}C	28	0.28		Air
		^{16}O	4	0.04	hElastic	Air
		^{14}N	2	0.02		Air
	Neutrals [no eBrems, no annihil]	gamma	5441	54.41	nCapture	Scintillator
			531	5.31		Al
			135	1.35		NiCu
			1	0.01		Air
HARD >3MeV	**Neutrals** [no eBrems, no annihil]	gamma	377	3.77		Al
			103	1.03		NiCu
			74	0.74		Scintillator
			5	0.05		Air