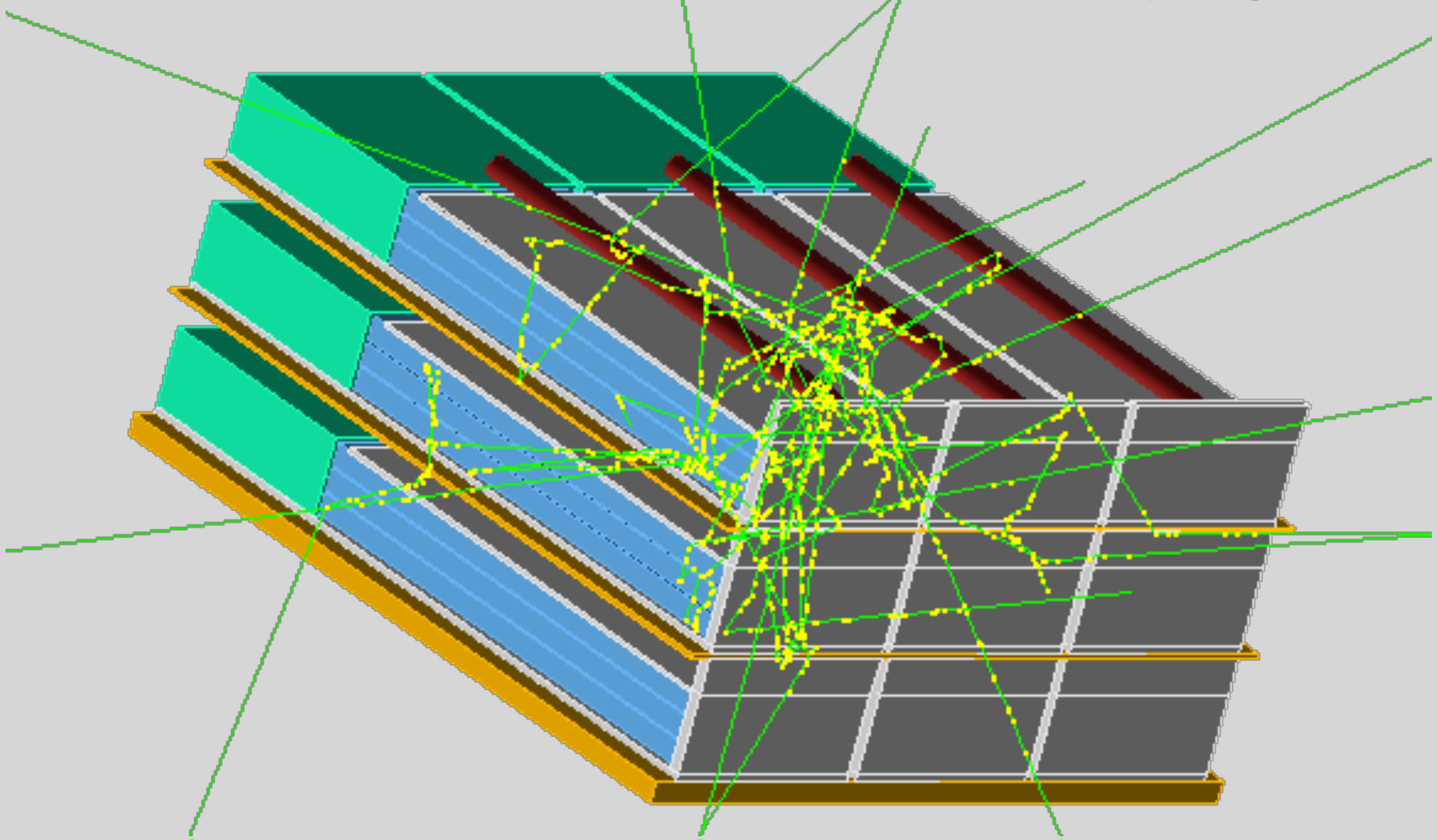
CALOR 2010, 10-14 May, Beijing



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

NEUCAL Experiment

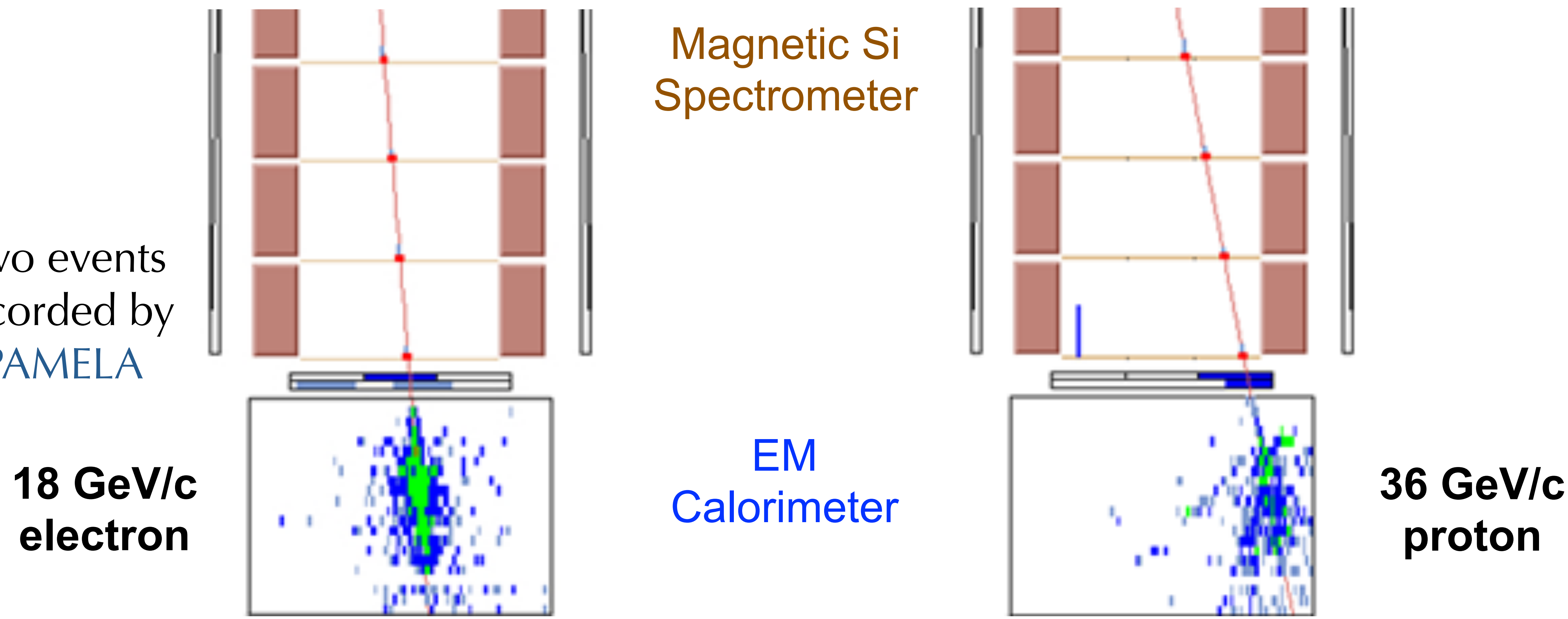
O.Adriani[1,2], L.Bonechi[1,2], M.Bongi[2], S. Bottai[2], M.Calamai[2,4], G.Castellini[3], R.D'Alessandro[1,2], M.Grandi[2], P.Papini[2], S.Ricciarini[2], G.Sguazzoni[2], G.Sorichetti[1]

1 University of Florence, 2 INFN Section of Florence, 3 IFAC–CNR Florence, 4 University of Siena

e/hadron discrimination in HEP

Important requirement: crucial in Astroparticle Physics / **EM calorimeters**: very good discrimination capability in a wide energy range / **Depth, weight, power constraints in space missions**.

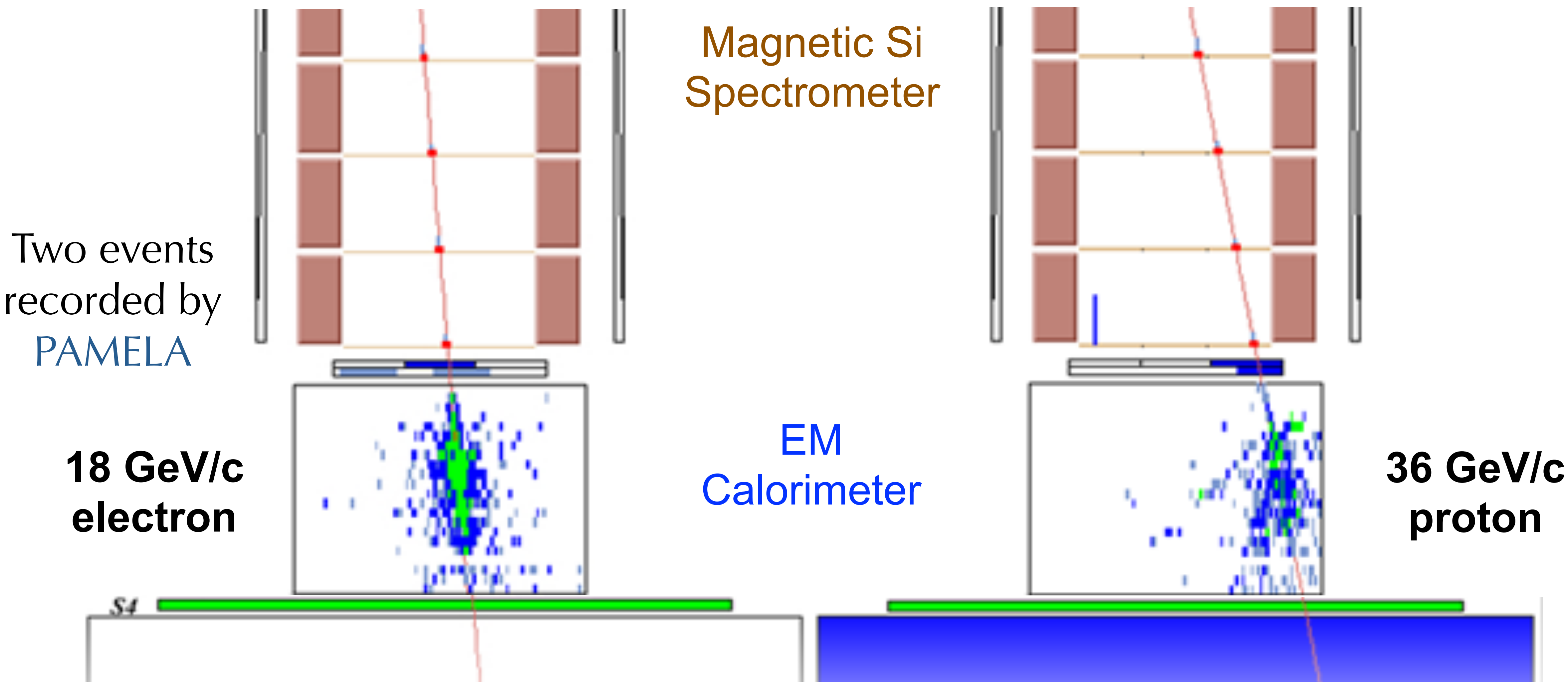
Two events recorded by PAMELA



Shallow calorimeters (circa ~$0.6\lambda_I$, a la PAMELA detector) / **protons can be tagged as electrons**: very extensive leakage; similar energy release; similar shower development.

The neutron counting handle...

Neutron production for hadronic showers (hadronic interaction, nuclear excitation) larger than EM showers (Giant Resonances only).



PAMELA's way: use a **neutron counter** beyond the calorimeter

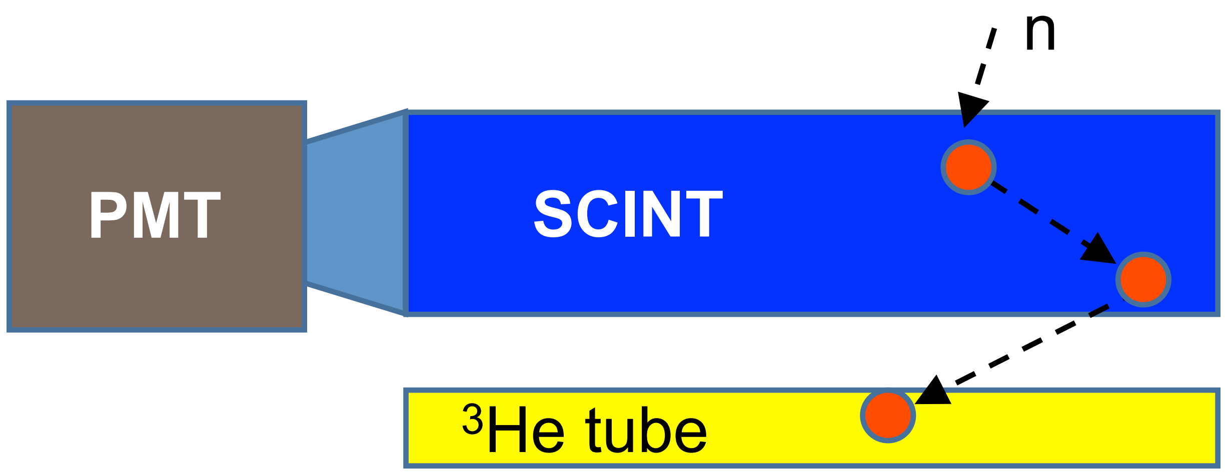
Moderation: polyethylene layers

Signal: ^{3}He proportional tubes

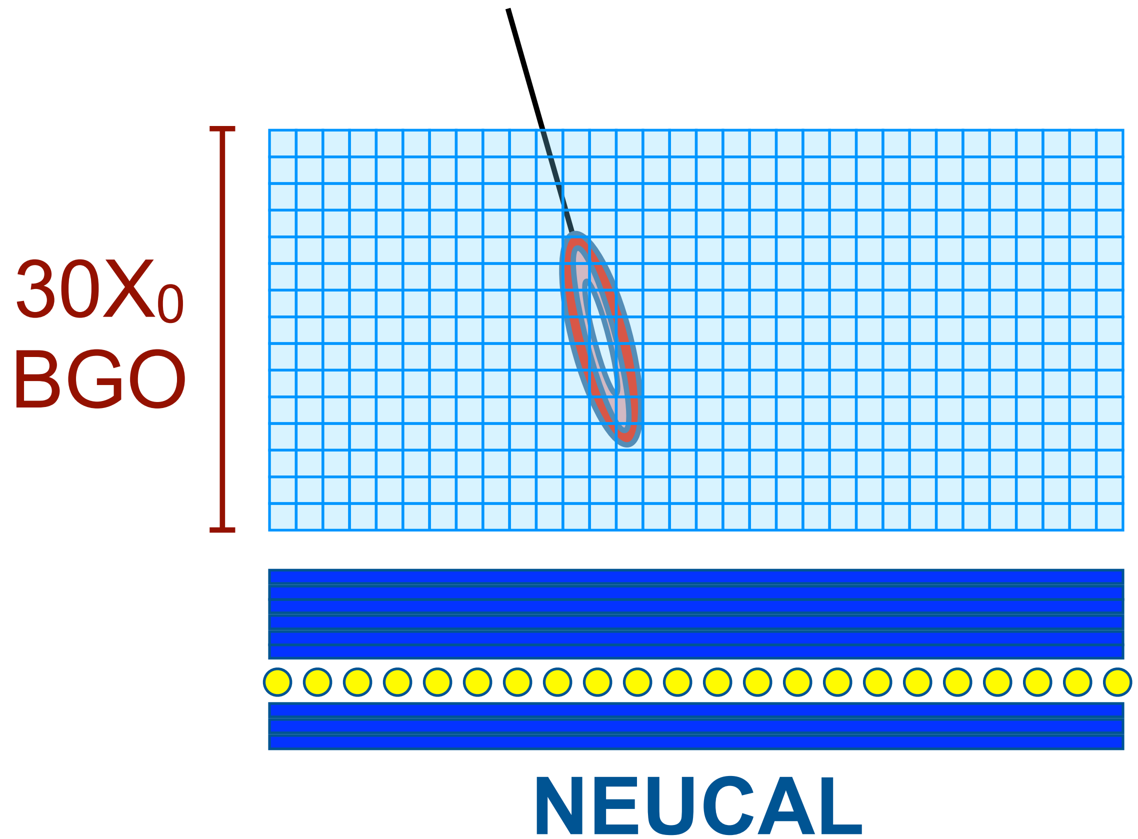
$n + {}^3He \rightarrow {}^3H + p$ (Q=0.764MeV)

NEUCAL: concept and implementation

NEUCAL = new idea: study of the moderation phase using plastic scintillators (rich in hydrogen) as active moderator (signals from neutron scattering). Standard ^{3}He-tubes to complement and validate.



NEUCAL design: detector geometry based on FLUKA simulations (cross check with GEANT4)
Use case: NEUCAL downstream a $30X_0$ homogeneous BGO calorimeter (i.e. CALET experiment).

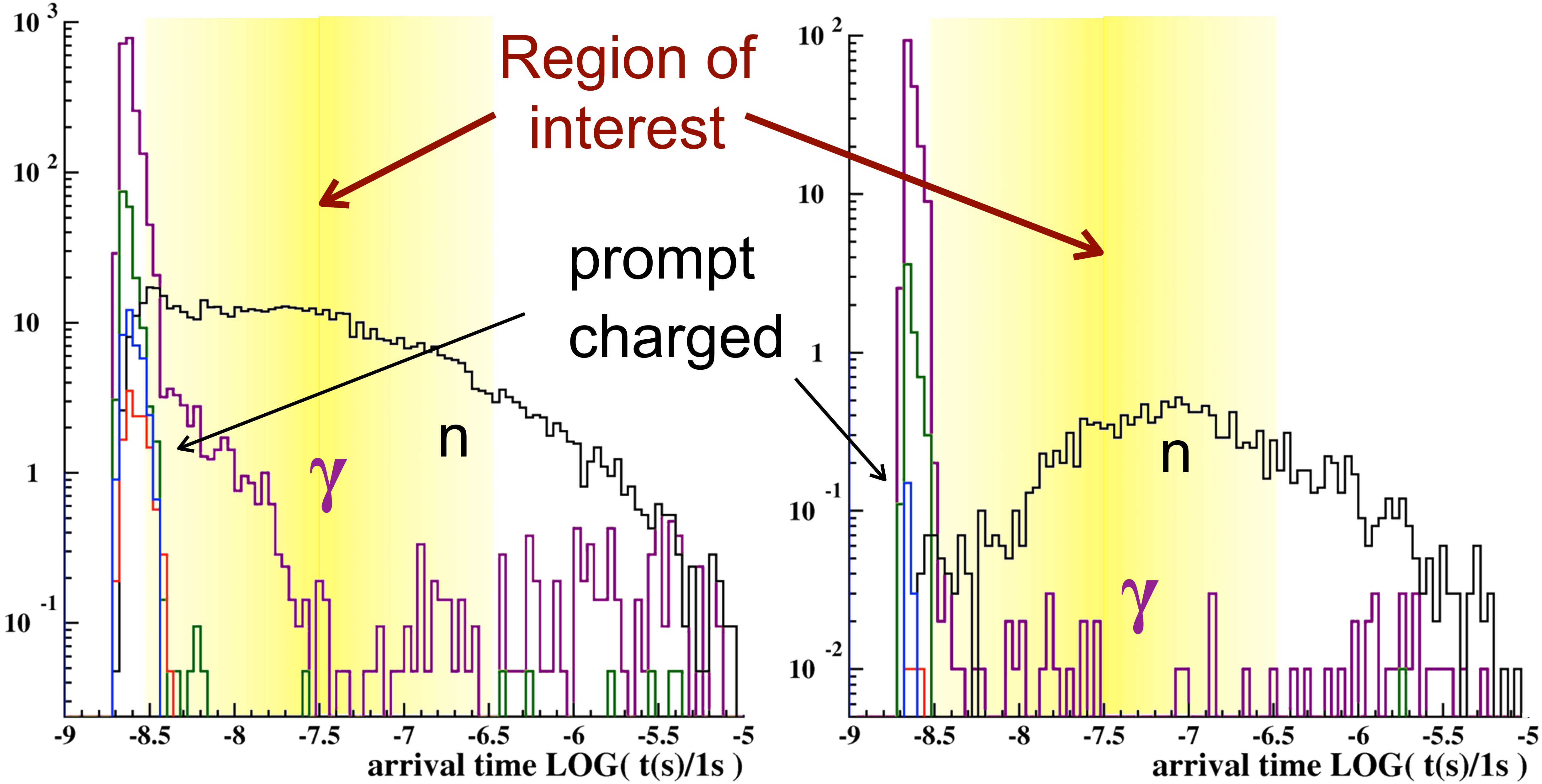


Neutron yield at high energies

Neutron per event vs. time

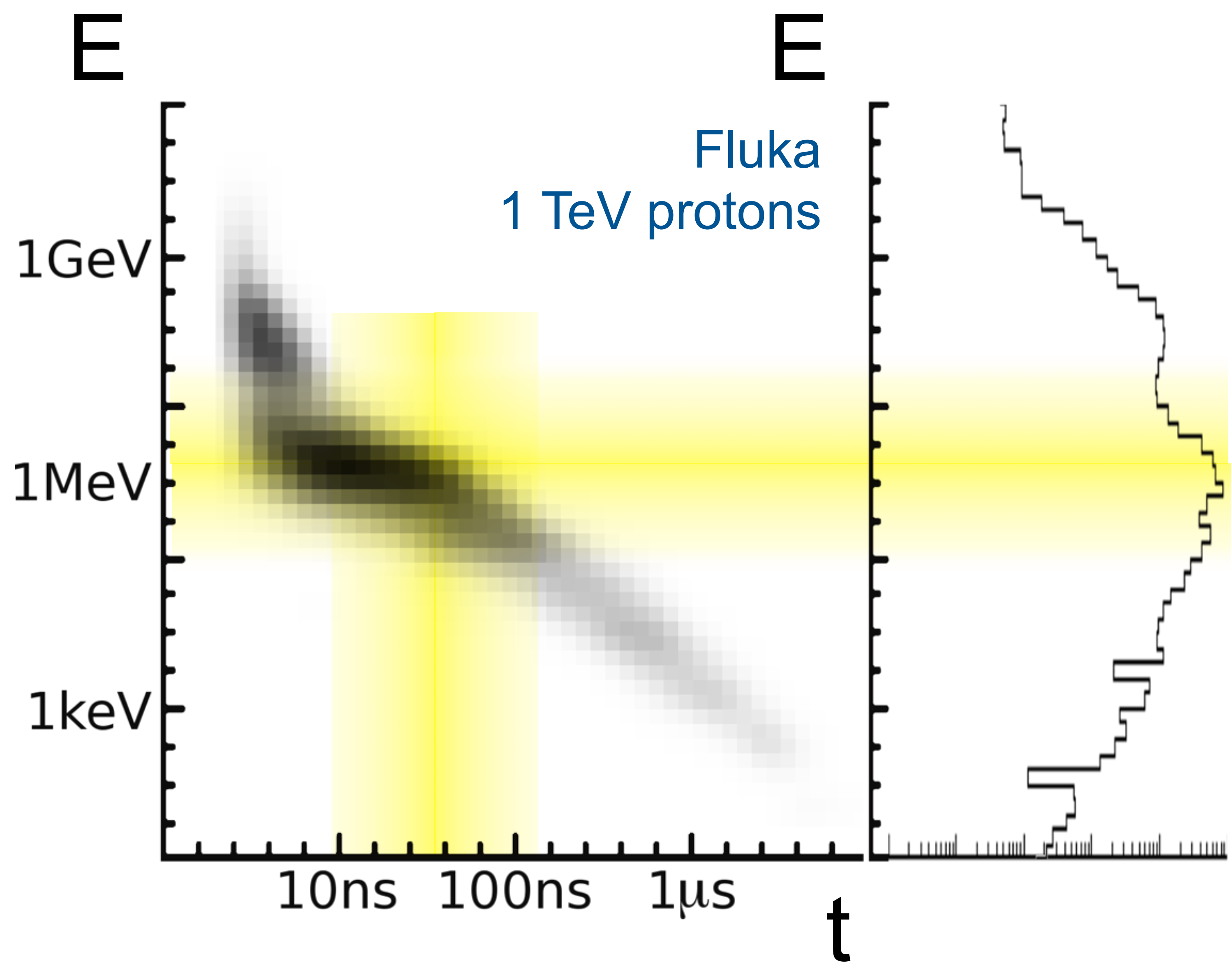
Protons 1TeV / Electrons 400GeV (similar deposited energies)

Possible discrimination region:10-100ns / Different vertical scale!

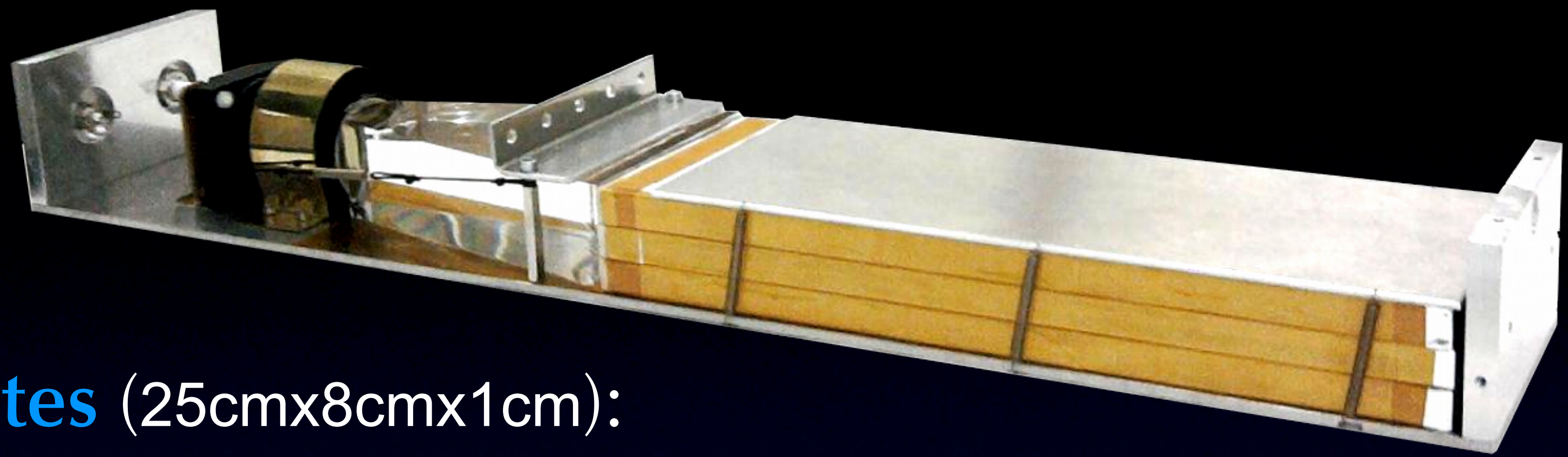


Neutron arrival time vs. energy

GeV <10ns	Shower Hadronic Interaction
MeV <100ns	**Nuclear excitation** **Scint. active moderation**
keV ~1μs	Upstream moderation ^{3}He tubes



Design of Neucal for the Test Beam



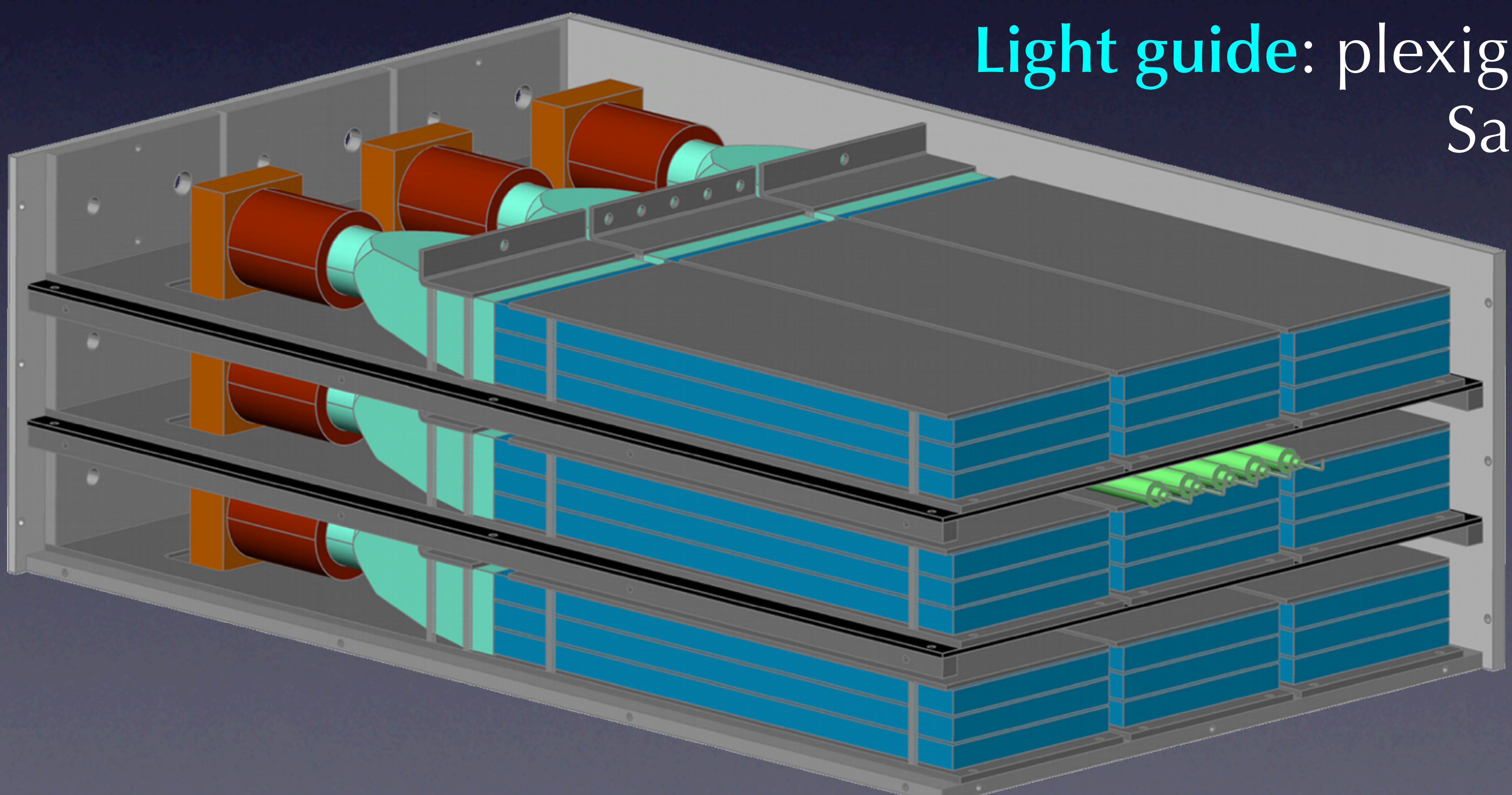
3x3 Modules.

Each **module**:

3x Fast Scintillator plates (25cmx8cmx1cm):
ELJEN TECHNOLOGY, EJ-230 Polyviniltoluene (BC-408)

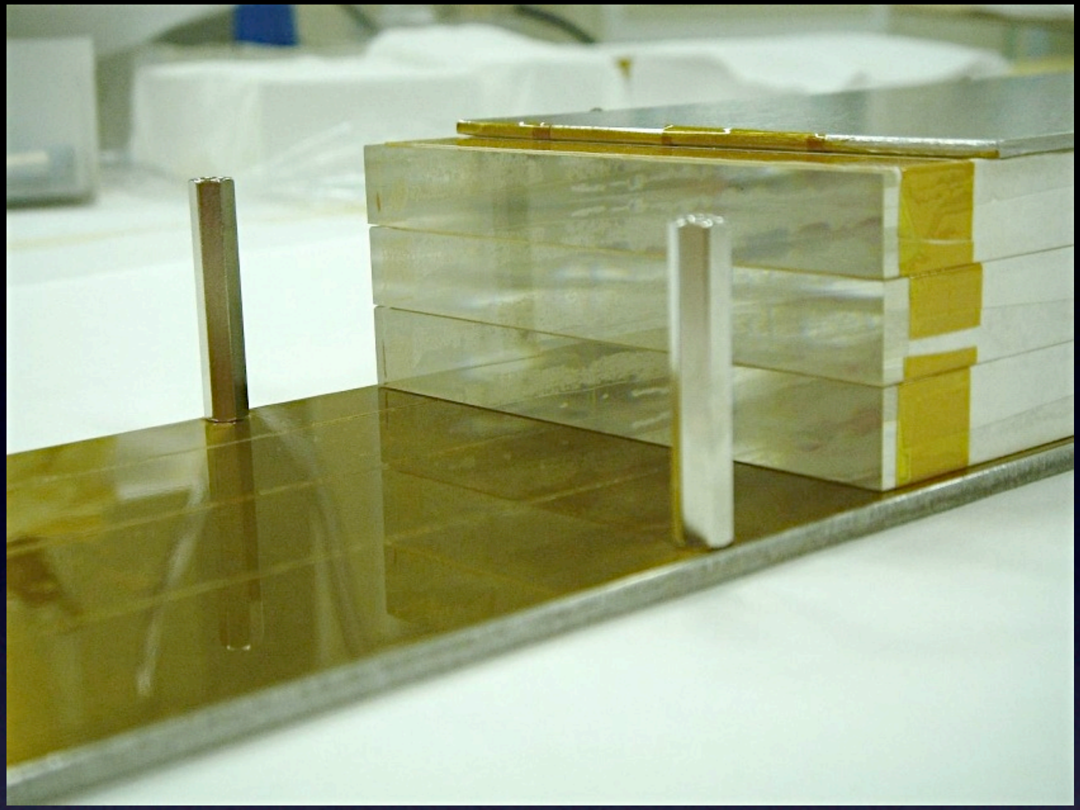
PMT: Hamamatsu R5946

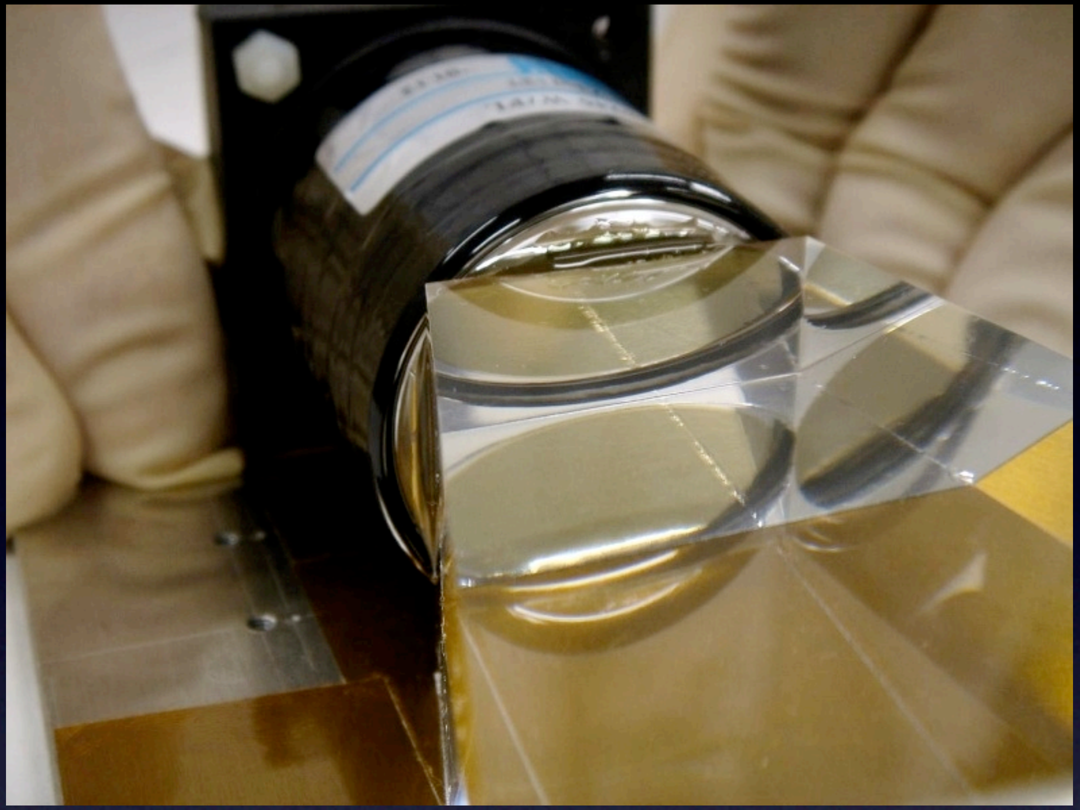
Light guide: plexiglas / Optical grease
Saint Gobain BC-630

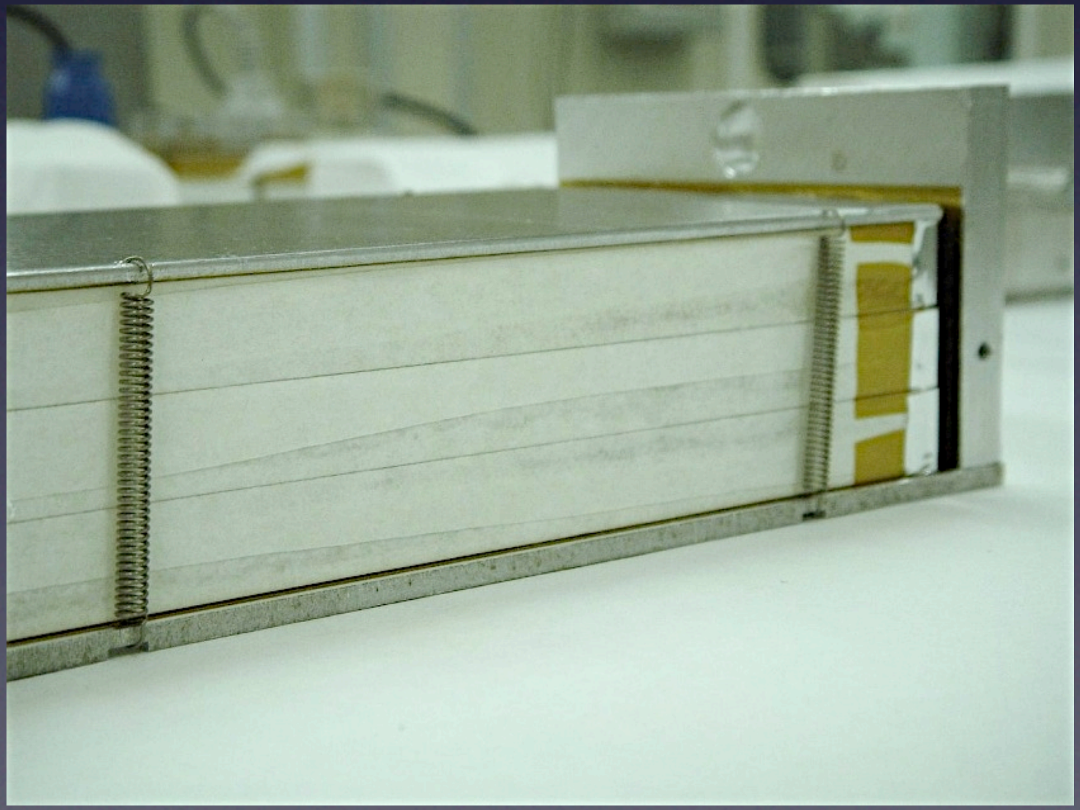


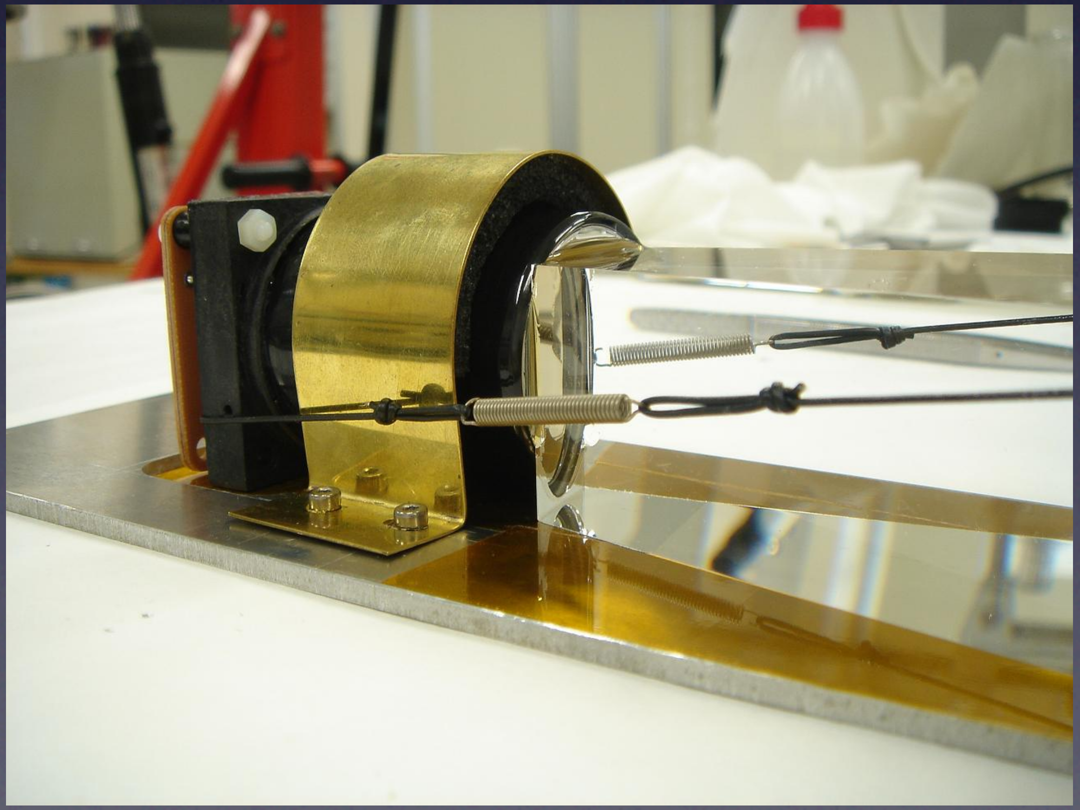
5x ^{3}He tubes:
Canberra
12NH25/1

Pictures from the assembly



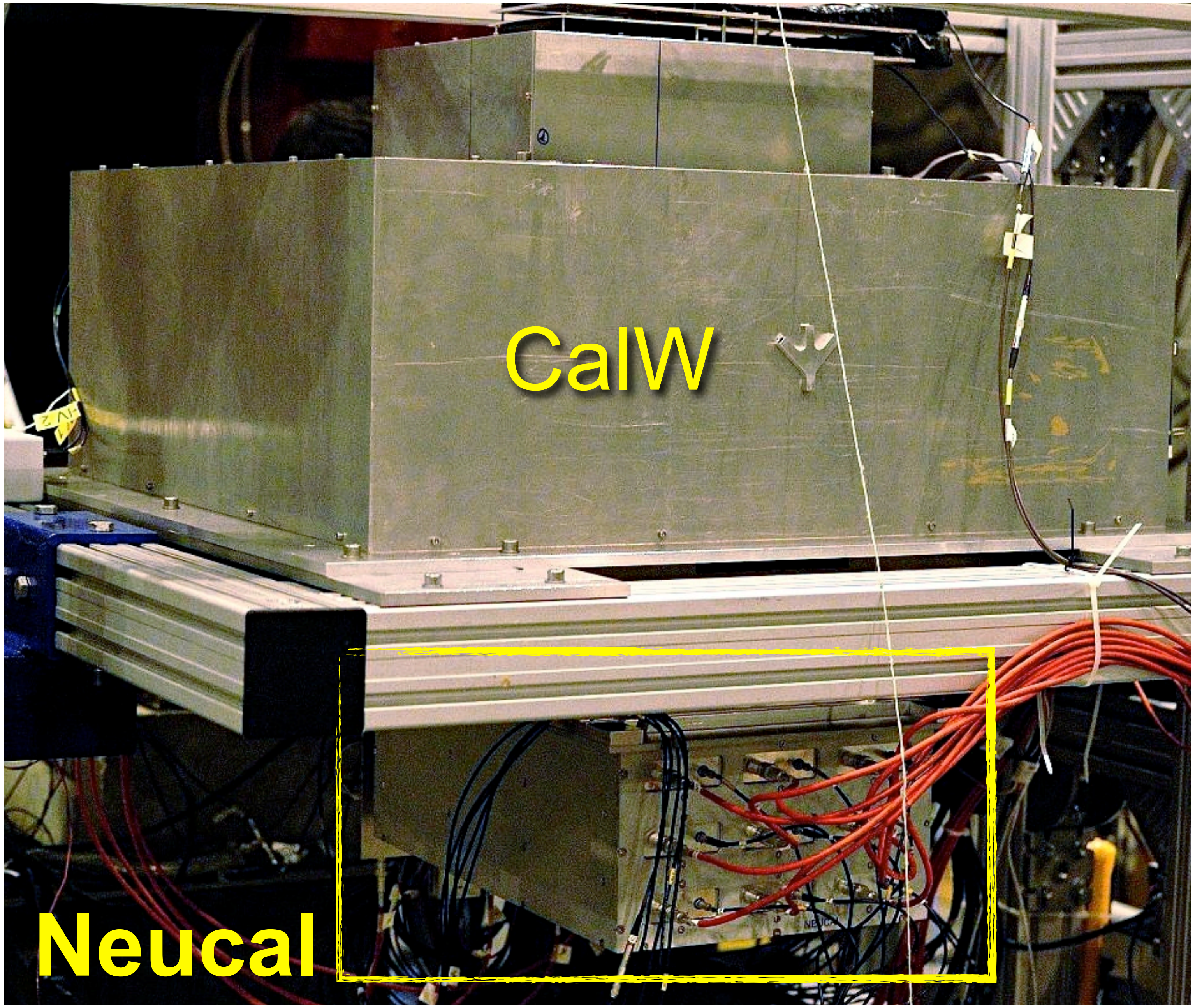






NEUCAL Test Beam for MC validation

Goal: validate the Monte Carlo simulations.
CERN SPS, line H4
π^- 350 GeV (230k events)
e^+ 100GeV (240k events)
e^+ 150GeV (50k events)



NEUCAL:
- **Parasitic**
- **Separate readout**

Shallow tungsten calorimeter (**CalW**);
CREAM2 prototype:
- $16X_0$
- Tungsten, fibres.

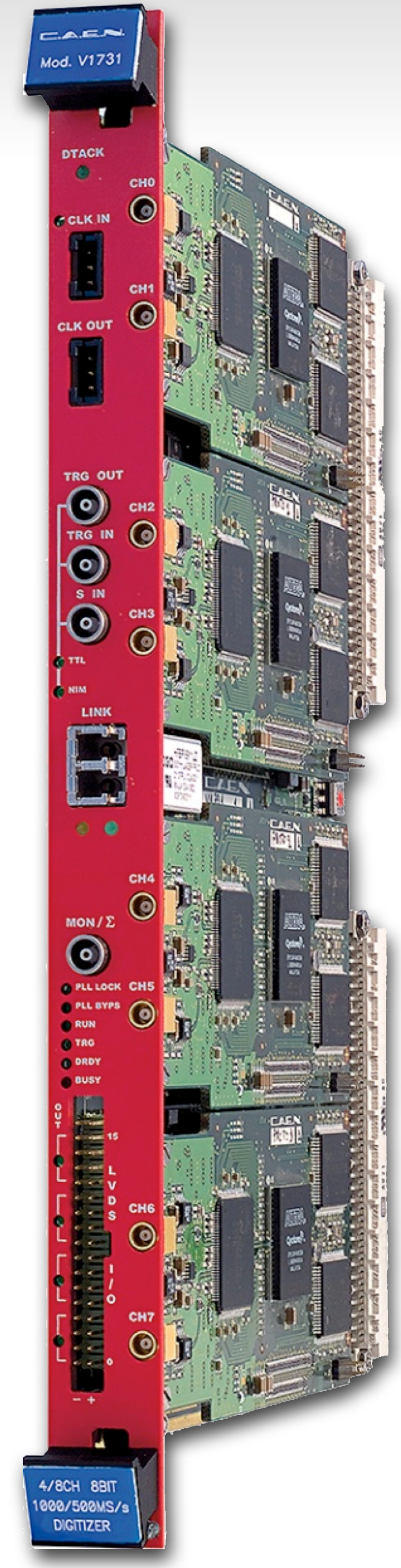
Readout electronics...

...to capture a **long time exposure** of the detector after the trigger, looking for neutron signals for up to **1ms**.

CAEN V1731	**CAEN V1720**
VME standard 8 ch	
500MSample/s	250MSample/s
8 bit ADC	12 bit ADC
2MB/ch memory	
16ns jitter	32ns jitter
On-board **Zero Suppression, ZS**	

Need to operate in ZS to avoid huge data size and read-out time / **Firmware bug in ZS mode**, fast signals not recognized: passive filters to "slow" the signals / Reflections introduced / **Blind below ~1µs**.

Small sample of data without ZS and no filters!

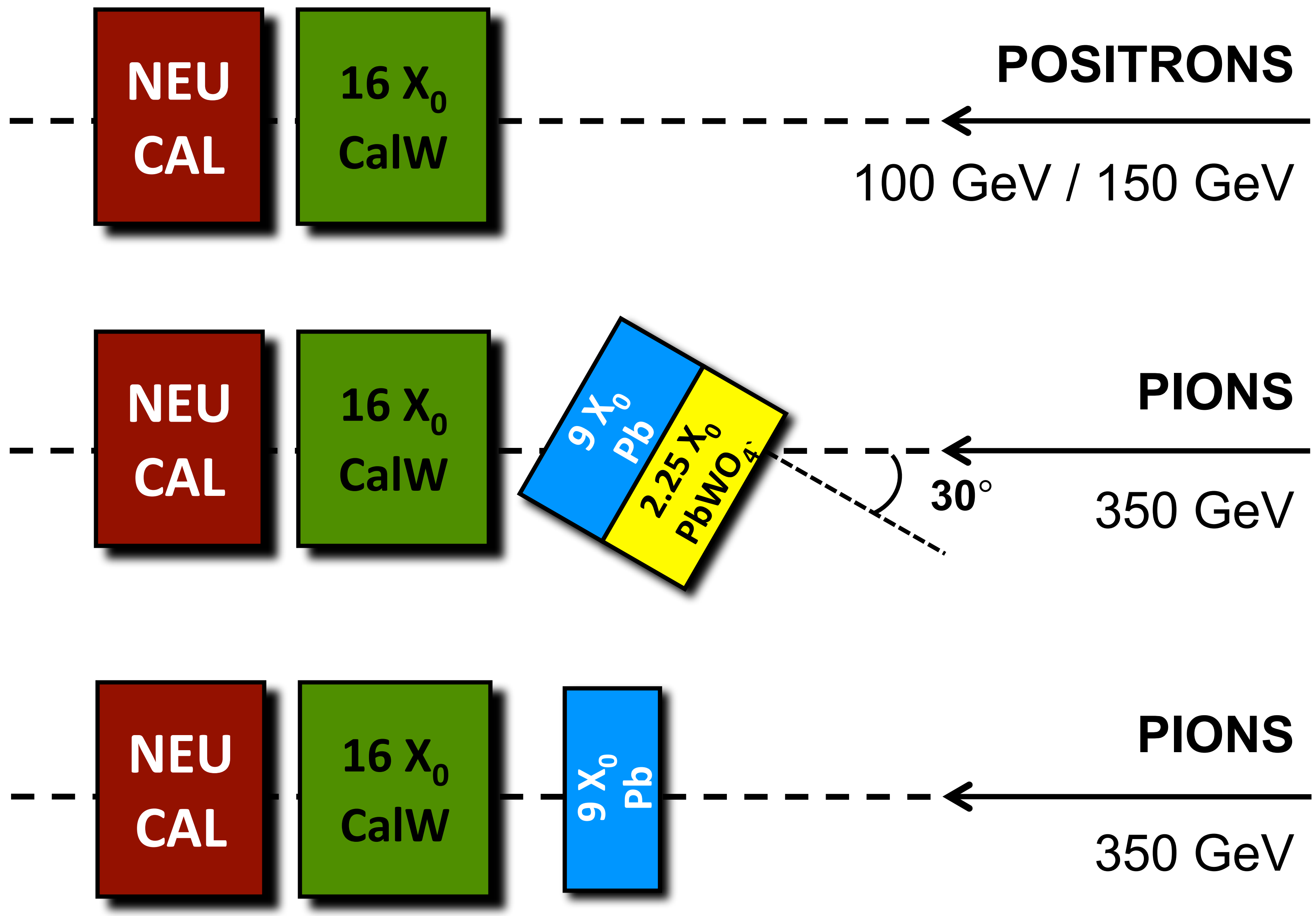


Test Beam Configurations

CFG 0
16 X_0

CFG 3b
$(16+13)X_0$, $\sim 1\lambda_I$

CFG 2b
$(16+9)X_0$, $\sim 0.8\lambda_I$



Data collected in different configurations: scan of detector (beam impact point), different working parameters, PMTs and tubes voltages
Digitizer boards parameters (thresholds, data compression…)

Monte Carlo samples

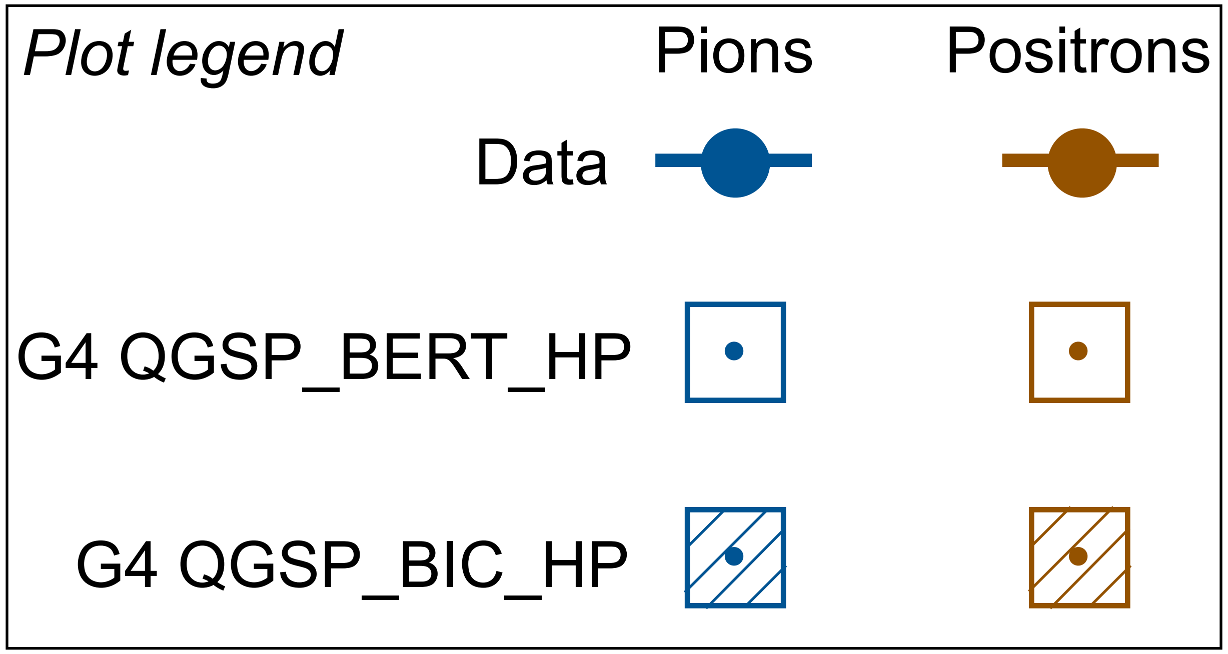
GEANT4 simulation of the Test Beam setup: readout chain response not implemented; comparison on scintillator energy and ^{3}He-counter pulses versus time.

Physics lists (HE hadronic showers with low energy neutron transportation):

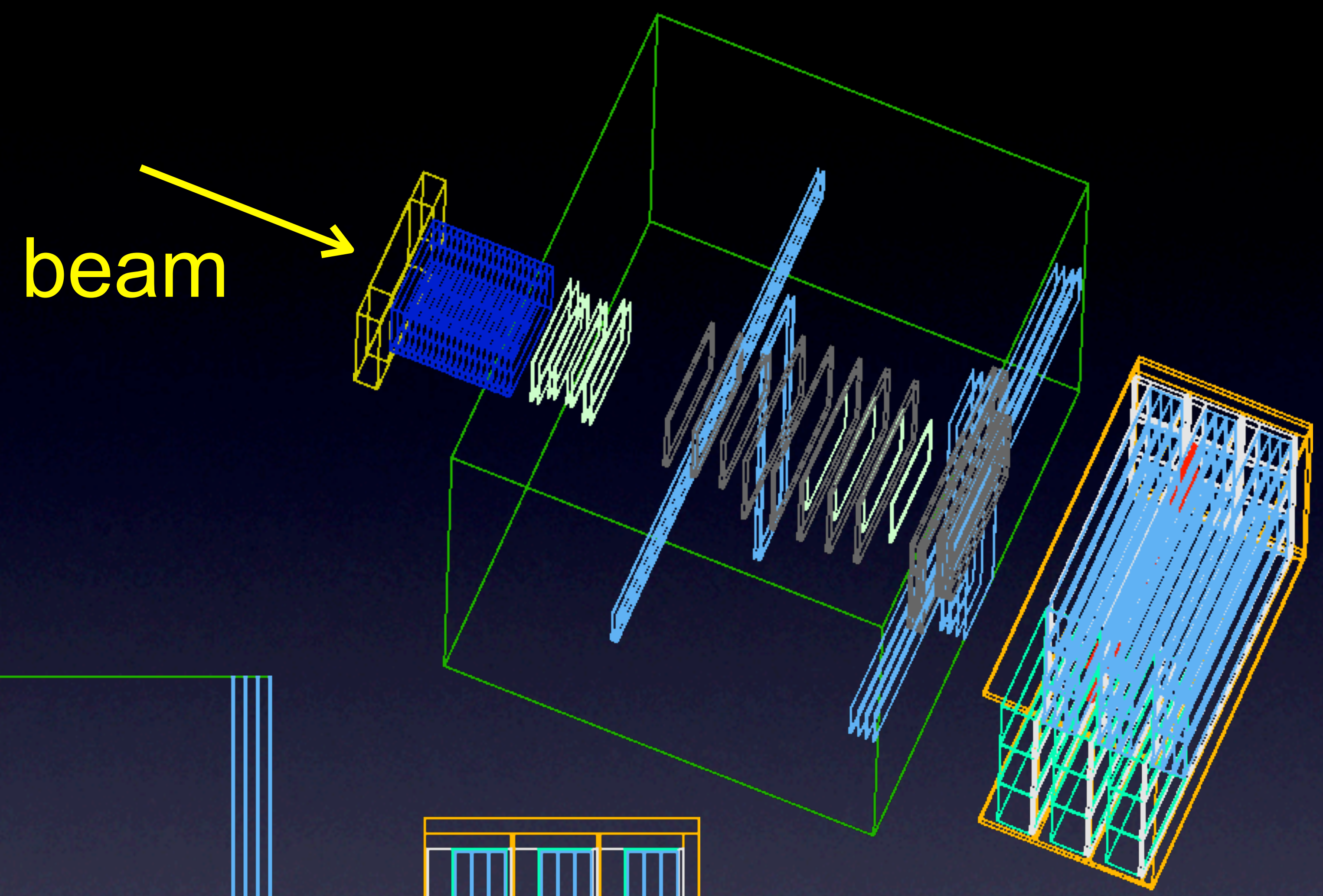
QGSP_BERT_HP *Quark-Gluon String Precompound, Bertini model, low energy neutrons*

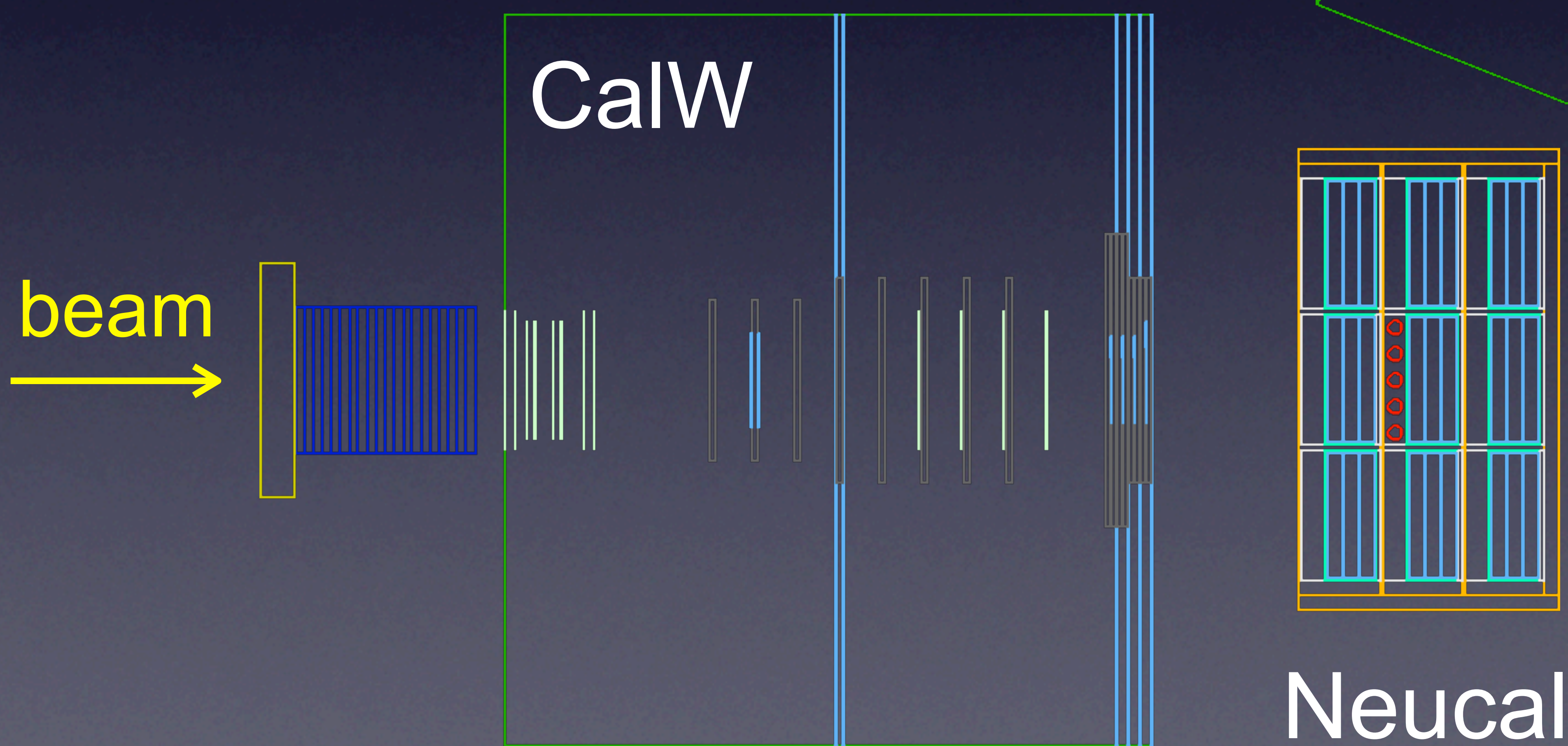
QGSP_BIN_HP *Quark-Gluon String Precompound, Binary cascade model, low energy neutrons*

Typical sample size:
20k for pions;
80k for positrons.



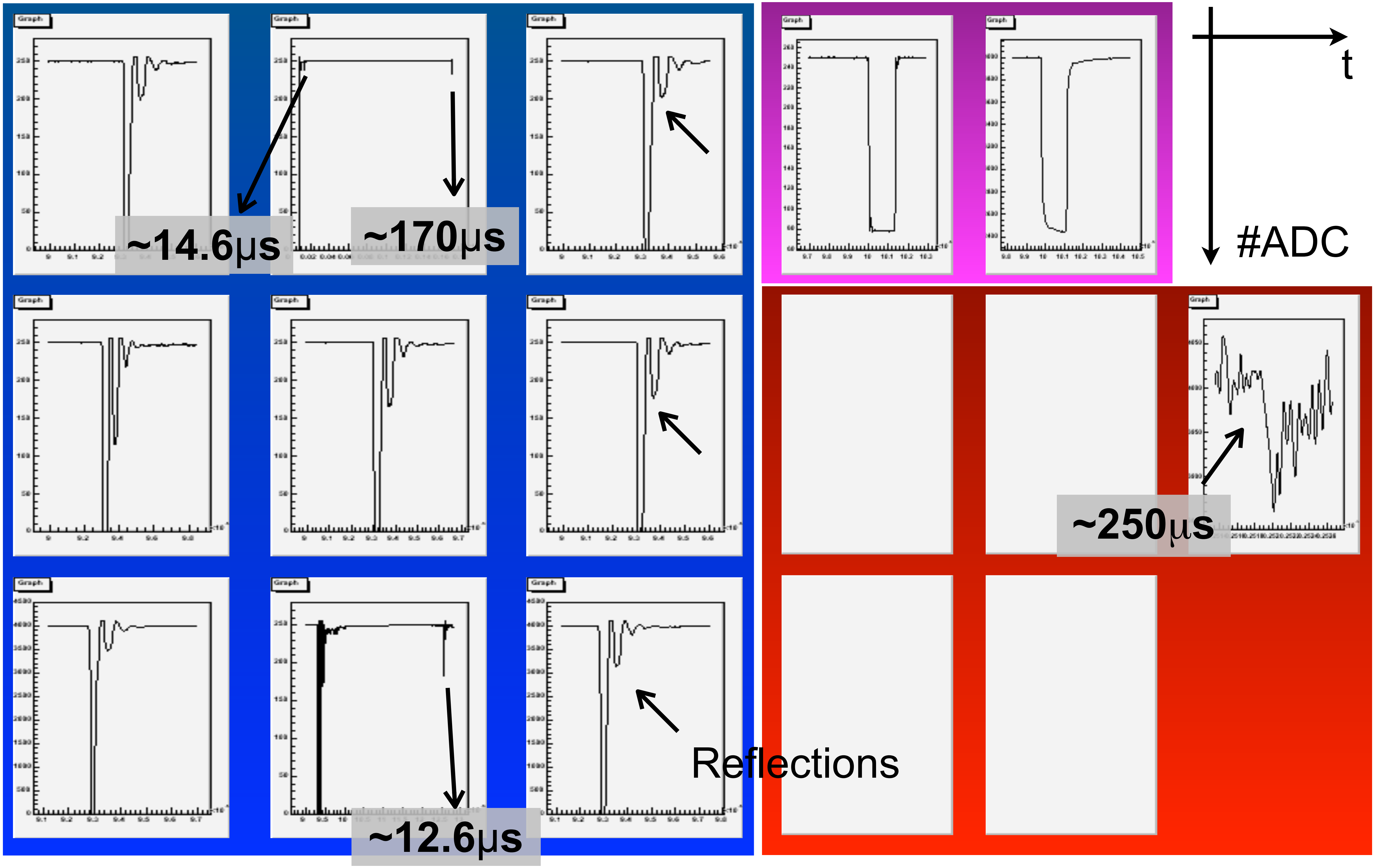
G4 description of Neucal & TB setup





Pion event display

9x scintillator views, 2x triggers, 5x ^{3}He tubes

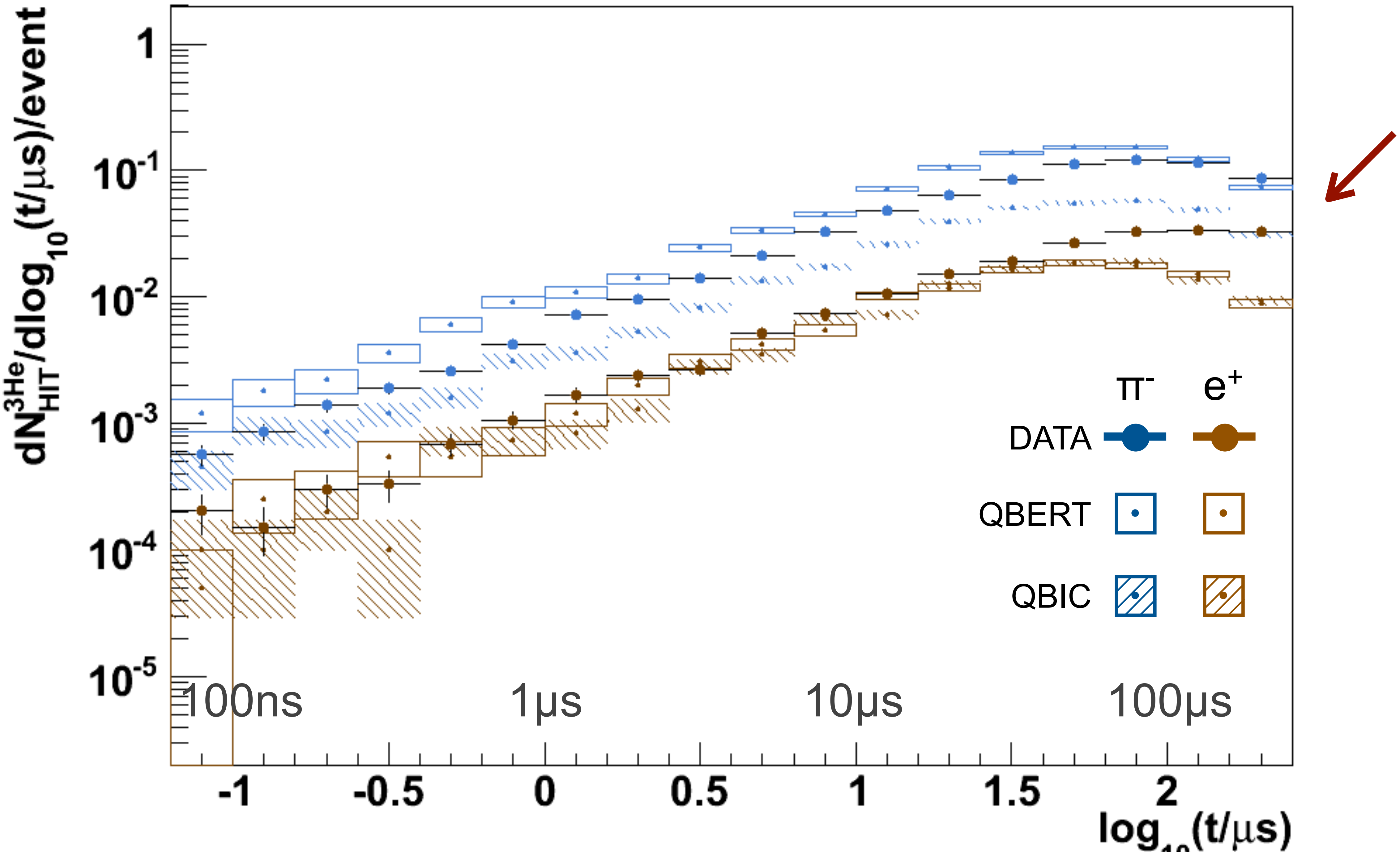


^{3}He-counters

Countings/ev vs. $\log_{10}$(t/μs)

Significant difference between QBERT and QBIC for pions

e^+: ***contamination*** *(beam) at t>30-100μs*



Scintillator data analysis

LATE	**1μs<t<1ms**	ZS	e^+ 100GeV CFG0 (39k)	π^- 350GeV CFG3b (76k)
EARLY	**t<1μs**	no ZS	e^+ 150GeV CFG0 (7k)	π^- 350GeV CFG2b (18k)

Signal (=n candidate): **single isolated pulse** (**HIT**), **E_{HIT}>0.3MeV**

Backgrounds	**Rejection**
Filter reflections (ZS)	Veto of specific time delays
Off trigger particles	No coincidences
Saturation phenomena	No abnormally long signals

Background is generally larger for positrons (EM shower = larger strain).

Energy calibration: lab measurements with cosmics of all 9 modules
Time synchronization: of Data vs. MC / t_0 = arrival of the shower

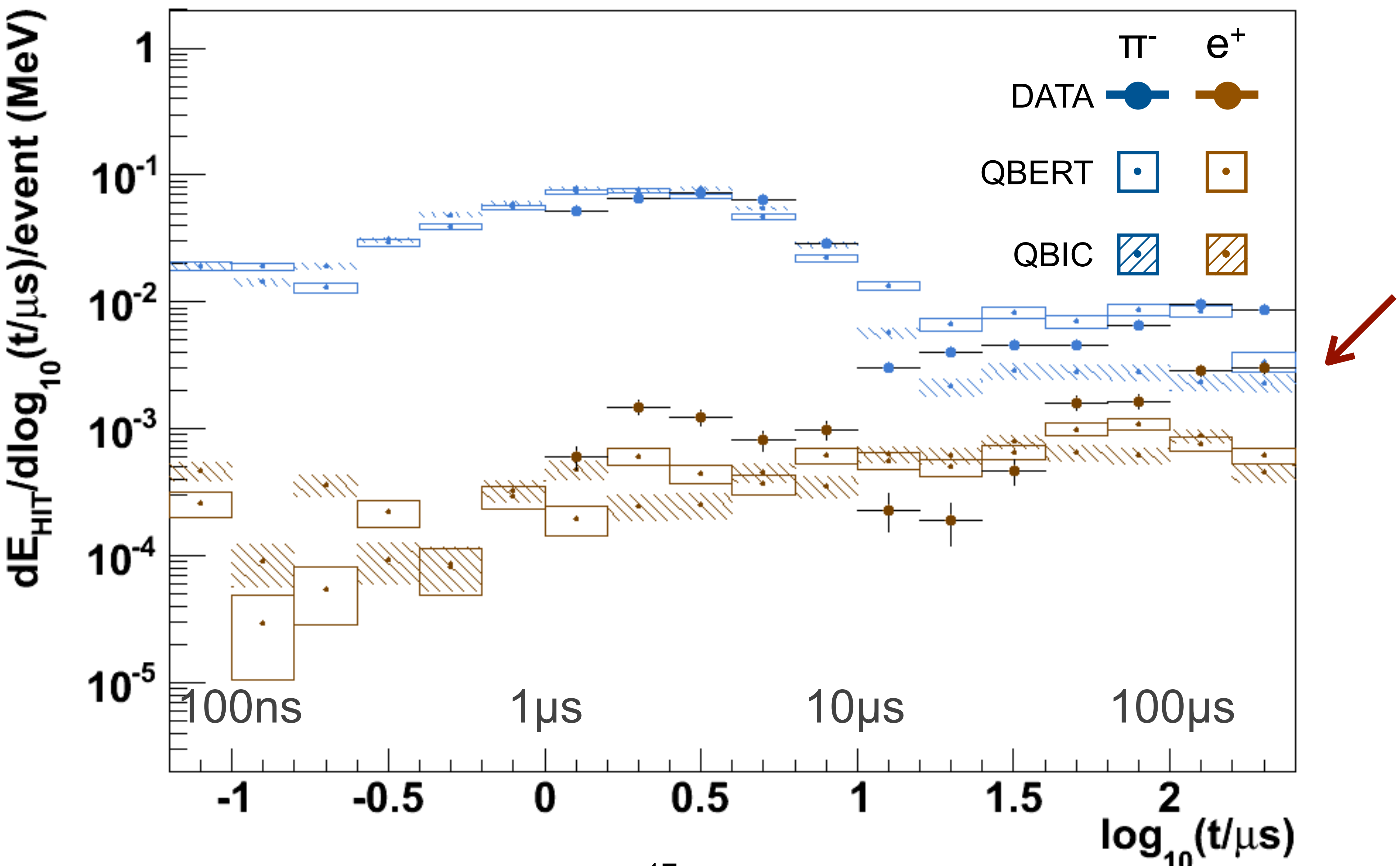
*All plots normalized to the number of showered events (*1e^+, ~0.6π^-*).*

Late ZS

E_{HIT}/ev [MeV] vs. $\log_{10}$(t/μs) - Module #3

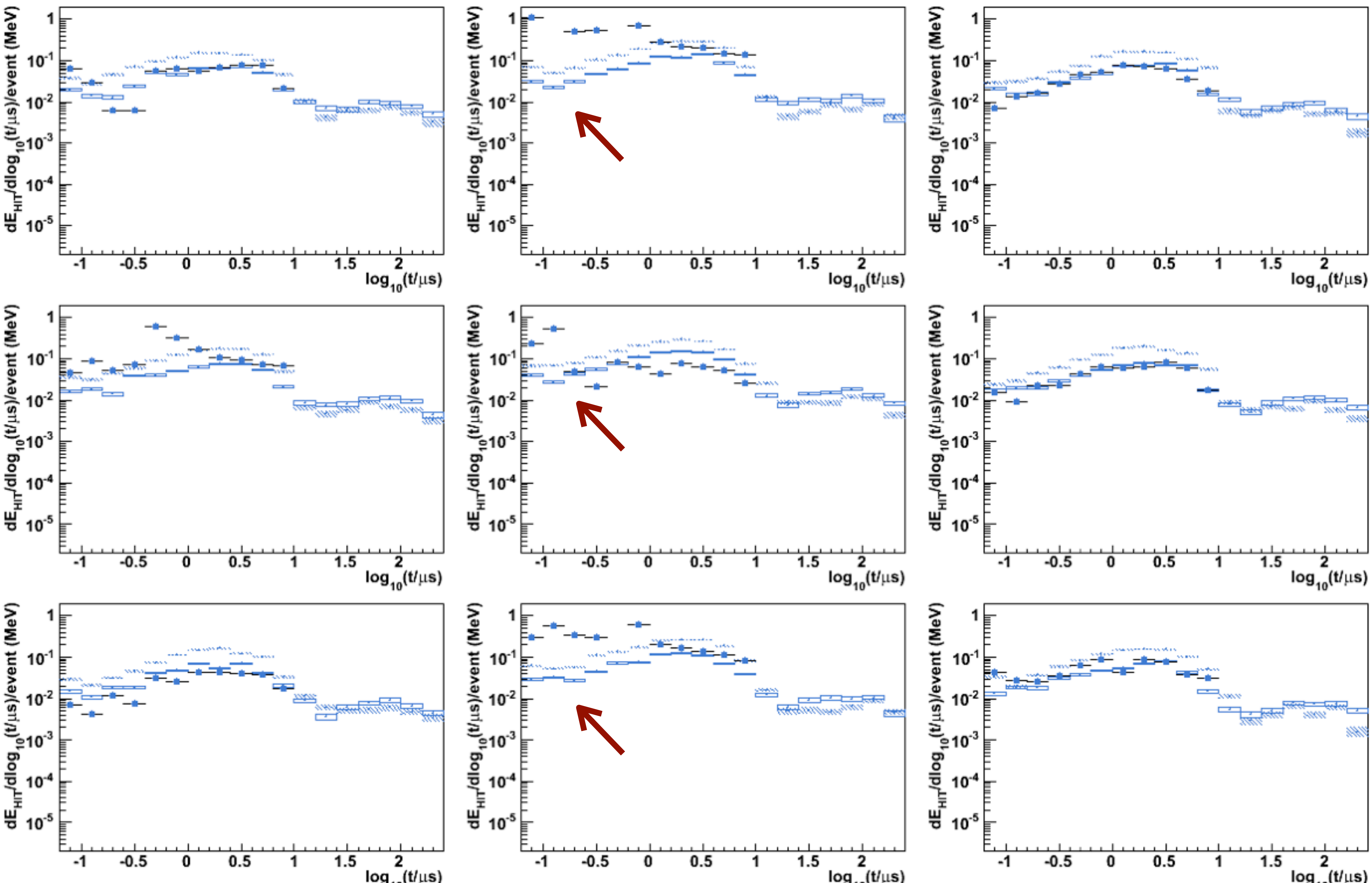
Other modules similar / Residual contamination at large t

Possible future development: late (1-10 μs) n- signals (nucleus captures)



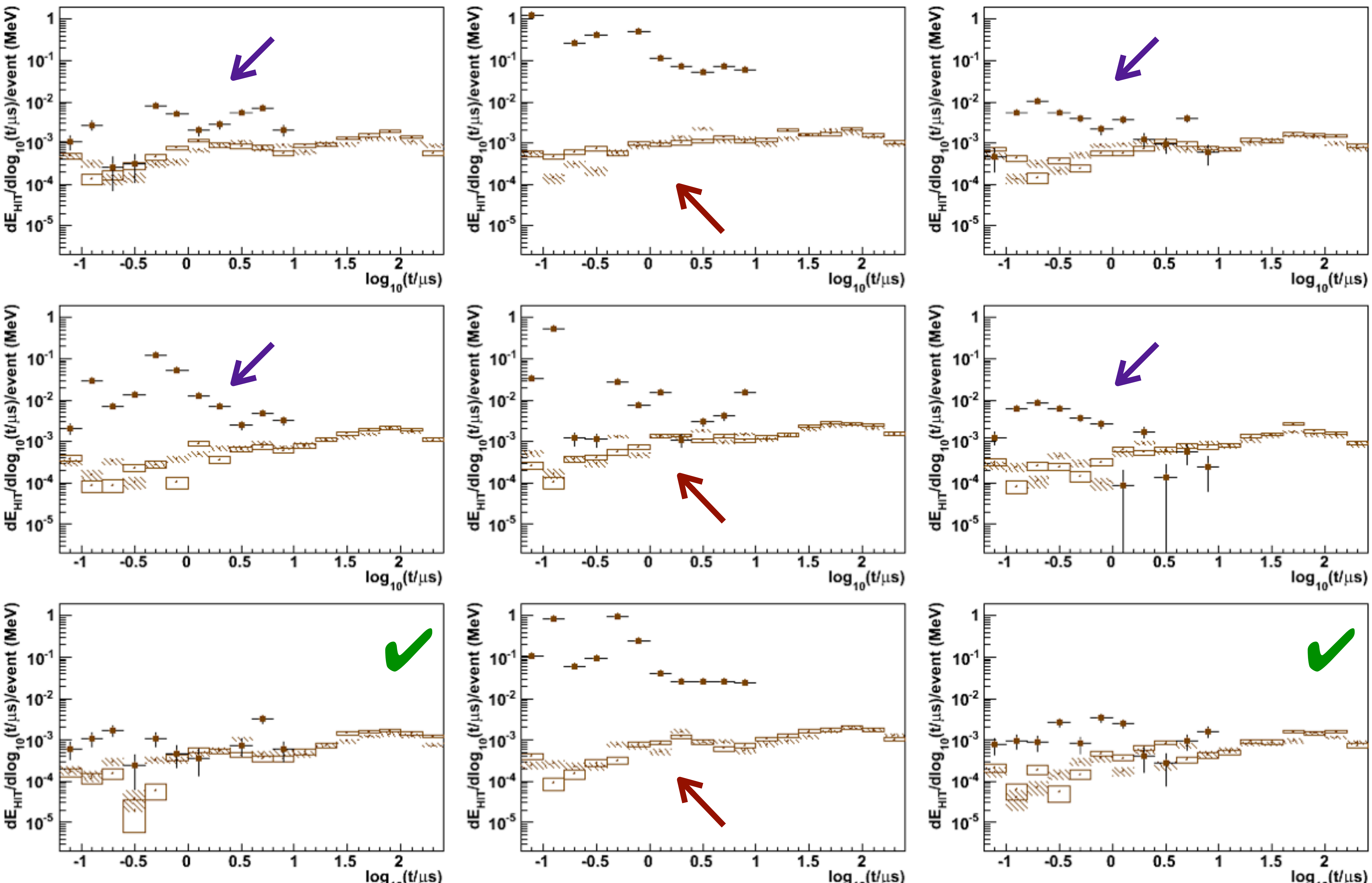
Early: pions all modules

E_{HIT}/ev [MeV] vs. $\log_{10}(t/\mu s)$ / *Side: ~OK; Central: shower contamination*



Early: e+ all modules

E_{HIT}/ev [MeV] vs. $\log_{10}$(t/μs) / ***Side 12bits: ~OK*** / *Side 8bits: saturation*

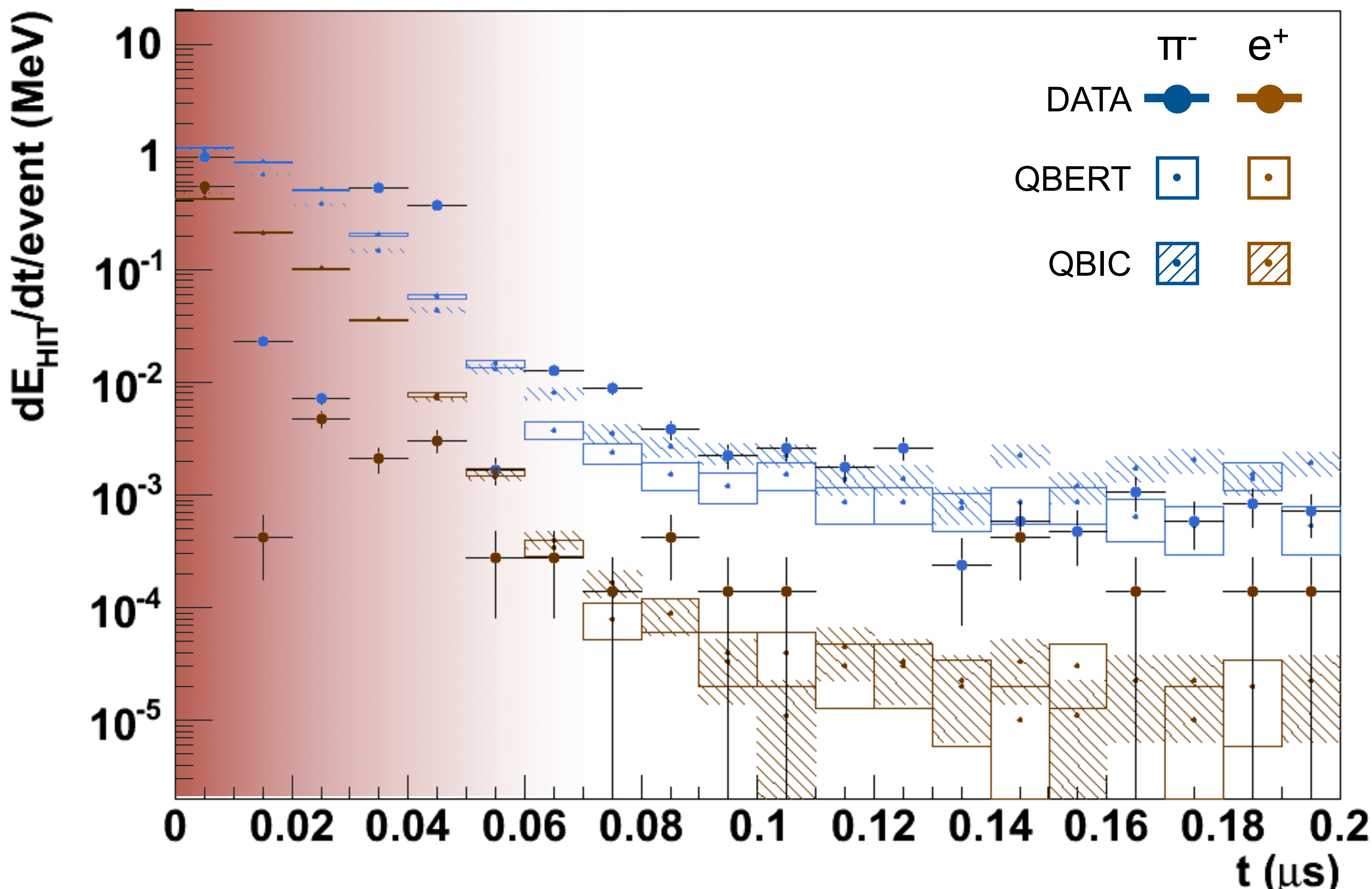


Bottom-Side 12bit ADC counters t<200ns

E_{HIT}/ev [MeV] vs. t [μs] - Module #7 & #9

t<30-40ns : shower contamination,

to be investigated in better conditions



Conclusions

A novel technique for **neutron detection** for hadron/electron discrimination consisting of **active moderation** investigated.

Prototype (**Neucal**) designed and assembled; use case: astroparticle physics application.

Test beam at CERN SPS with π and e^+ beams beyond a calorimeter.

Difficult measurement. A lot of lessons learned.

Results encouraging, but not conclusive. Refinements needed to keep instrumental and beam effects under control.

Next future:

-- analysis of **data collected at nTOF** (CERN neutron spallation facility);

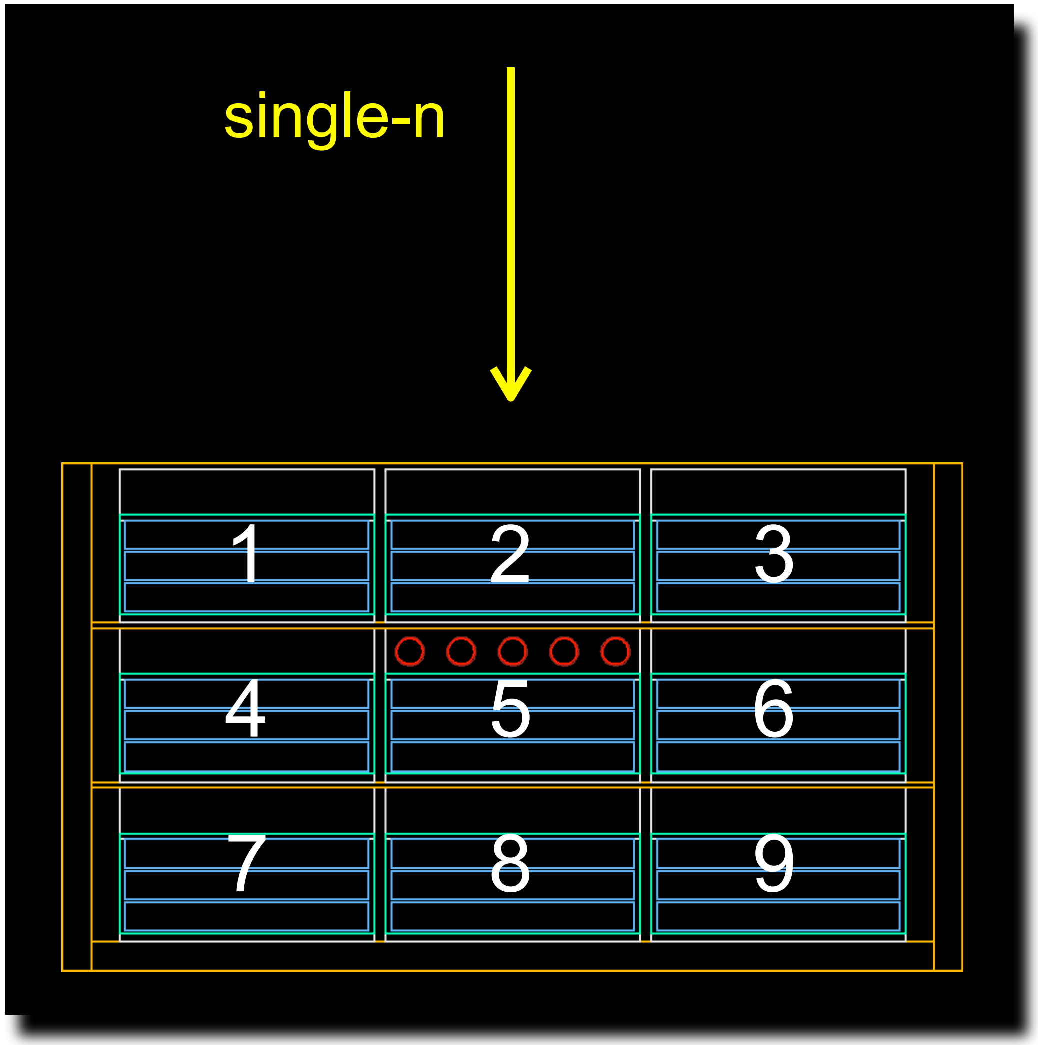
-- **new test beam with new apparatus and improved DAQ**.

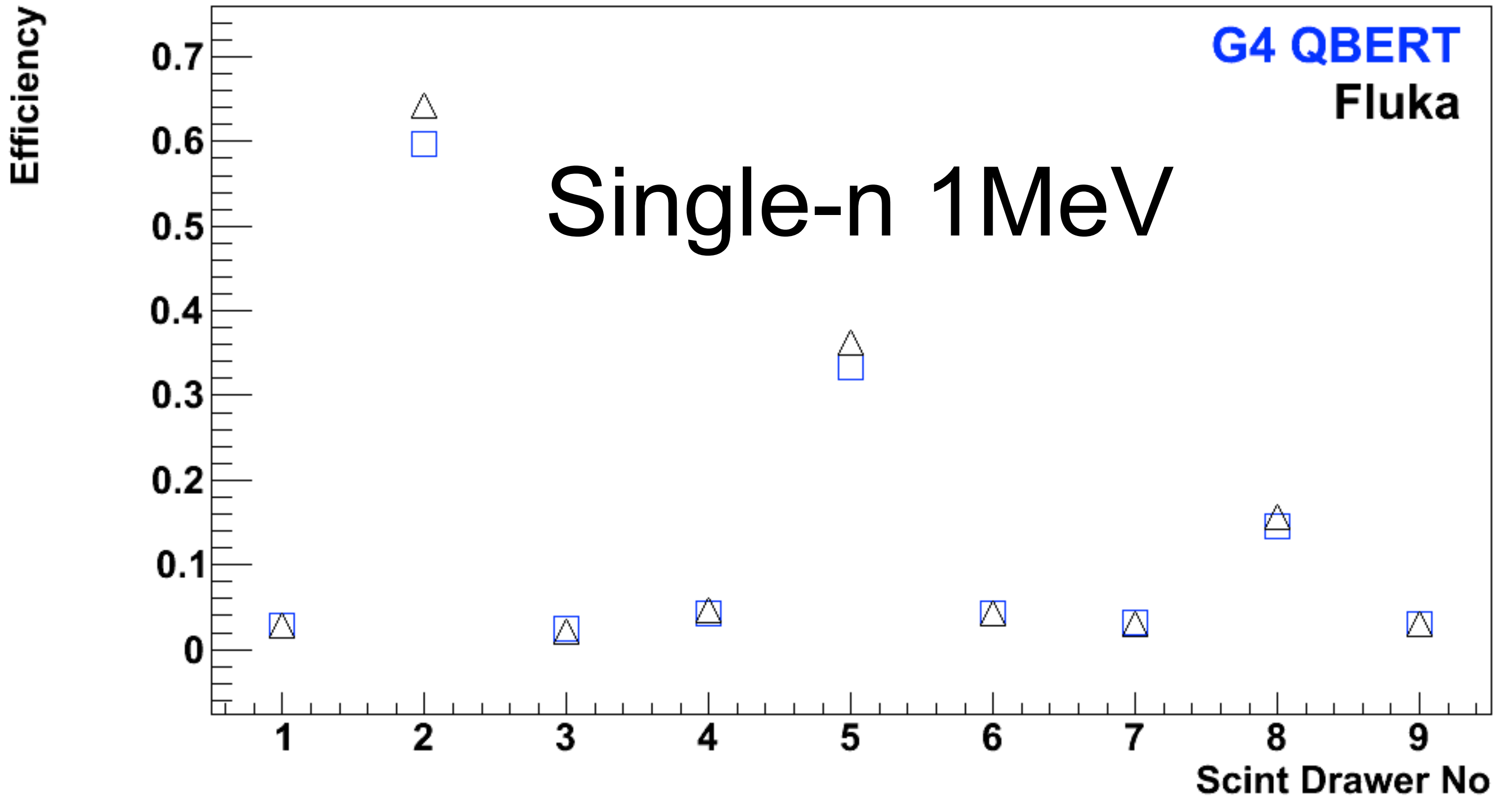
Extra slides

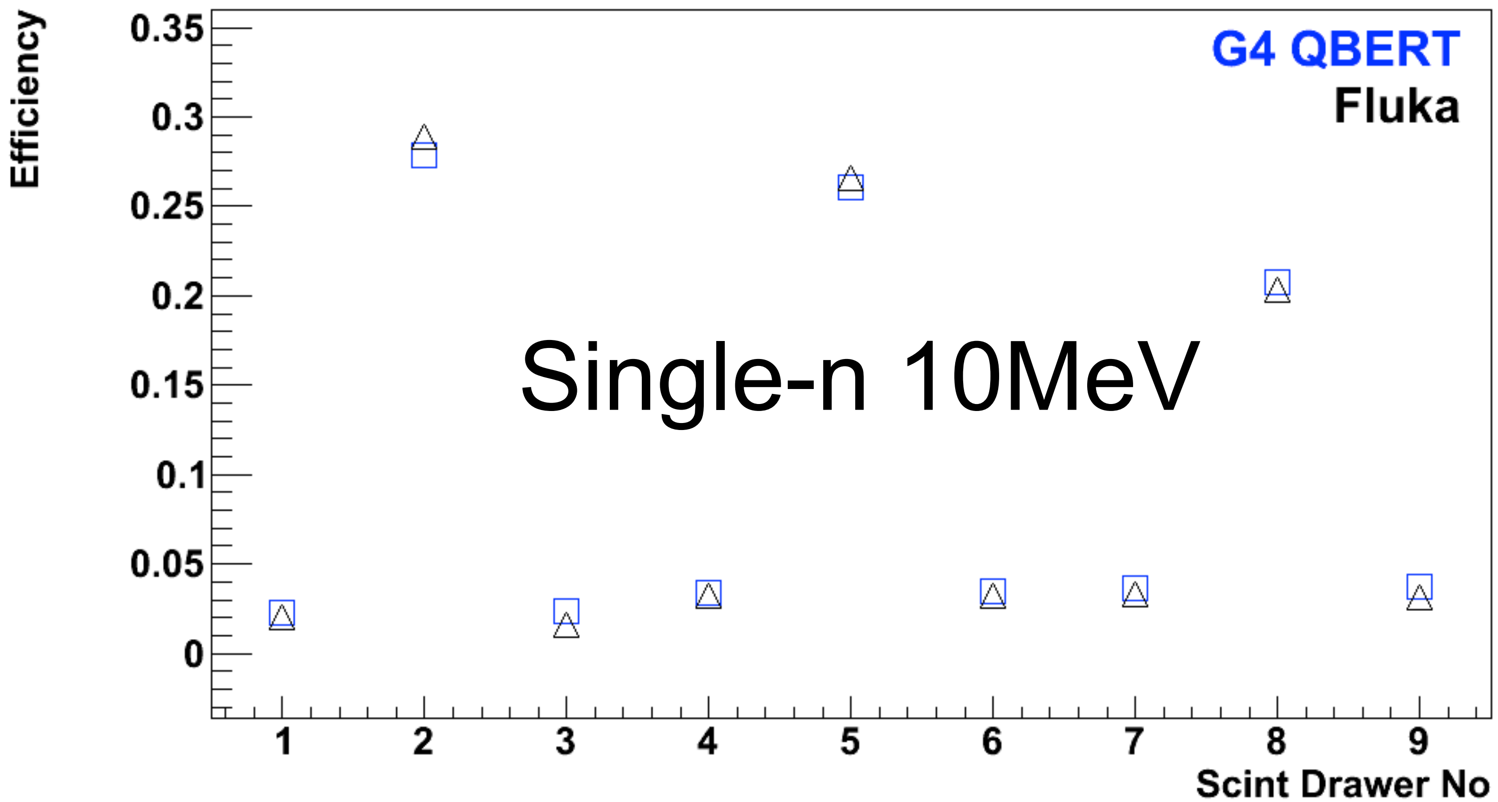
Fluka vs. G4: NEUCAL single-n efficiency

Efficiency of NEUCAL moderation counters for single neutrons.

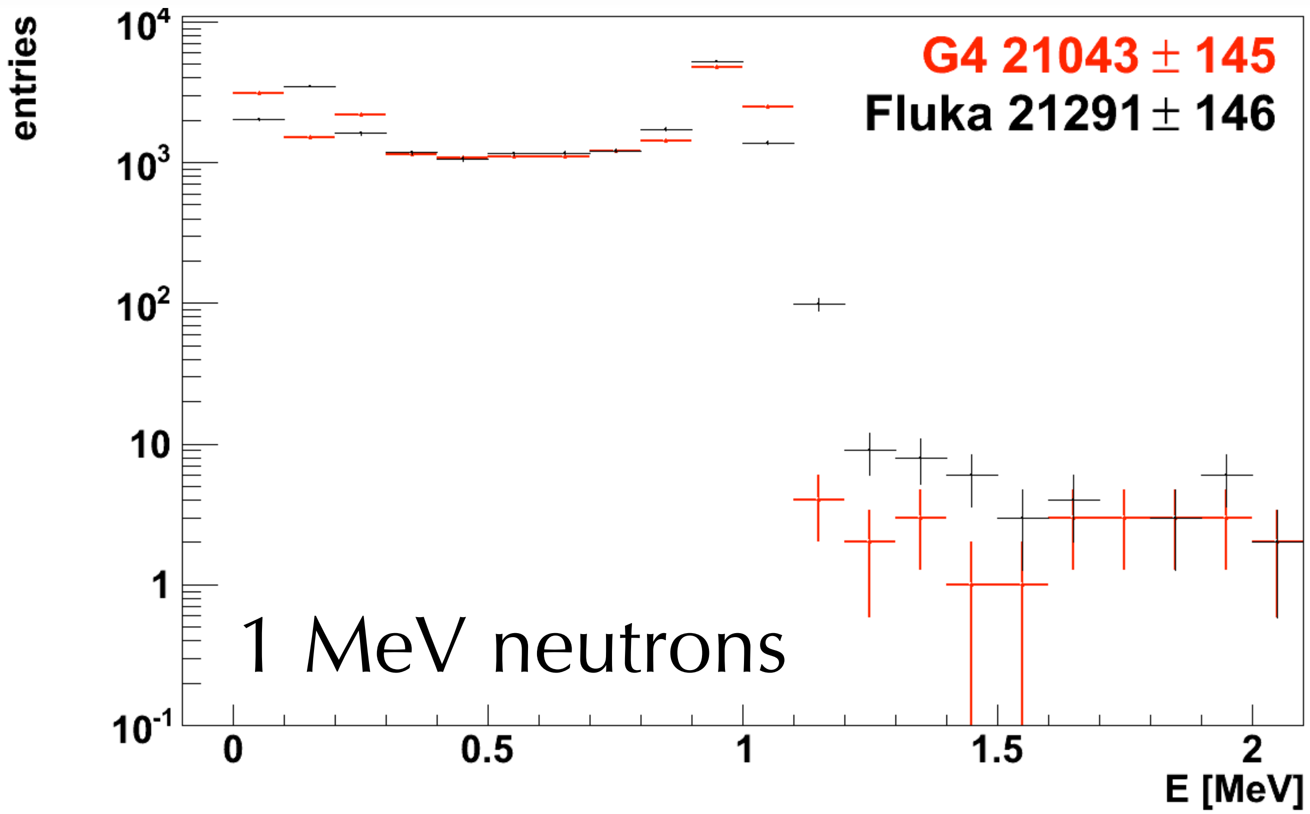
Assumption: a neutron is recorded by a module if the energy deposited in its scintillators within 1ms exceeds 100keV.

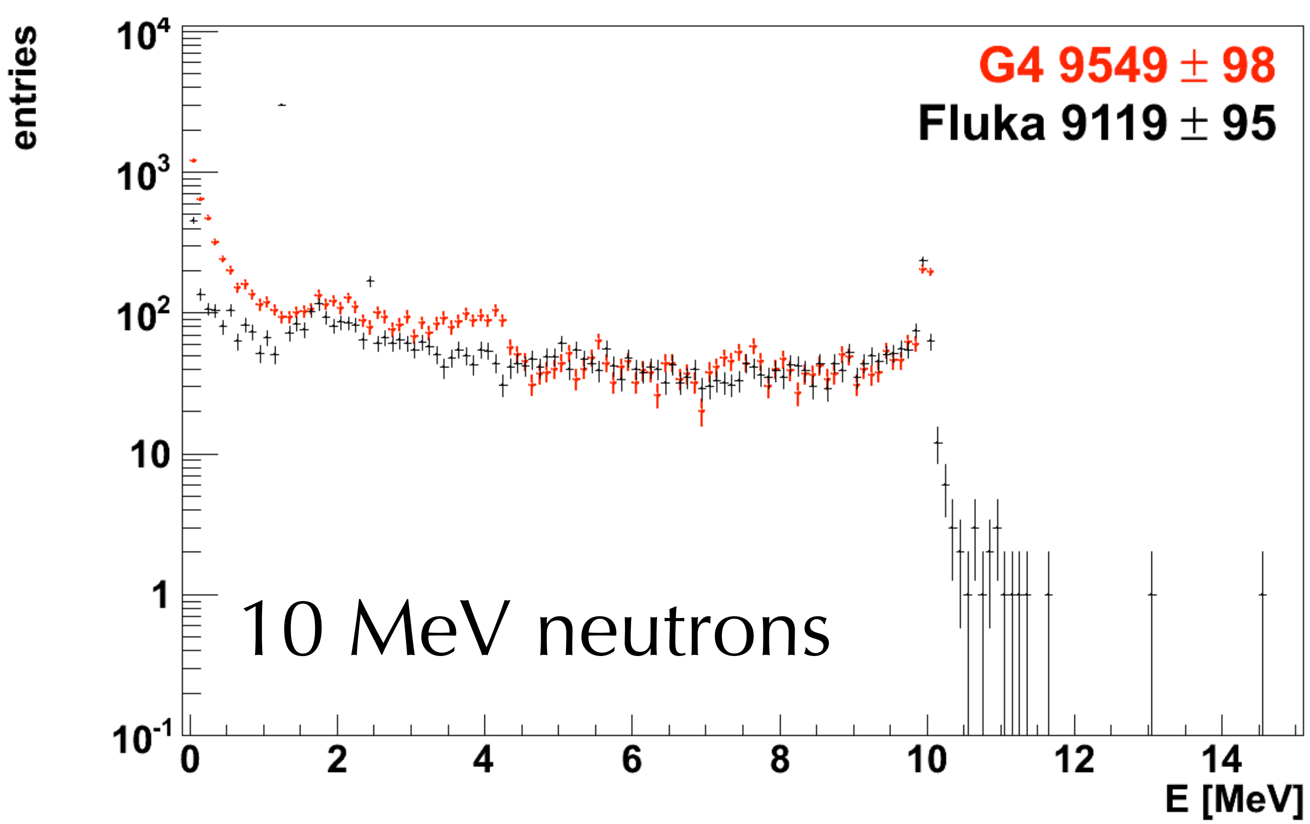






Single-n Fluka vs. G4 comparison



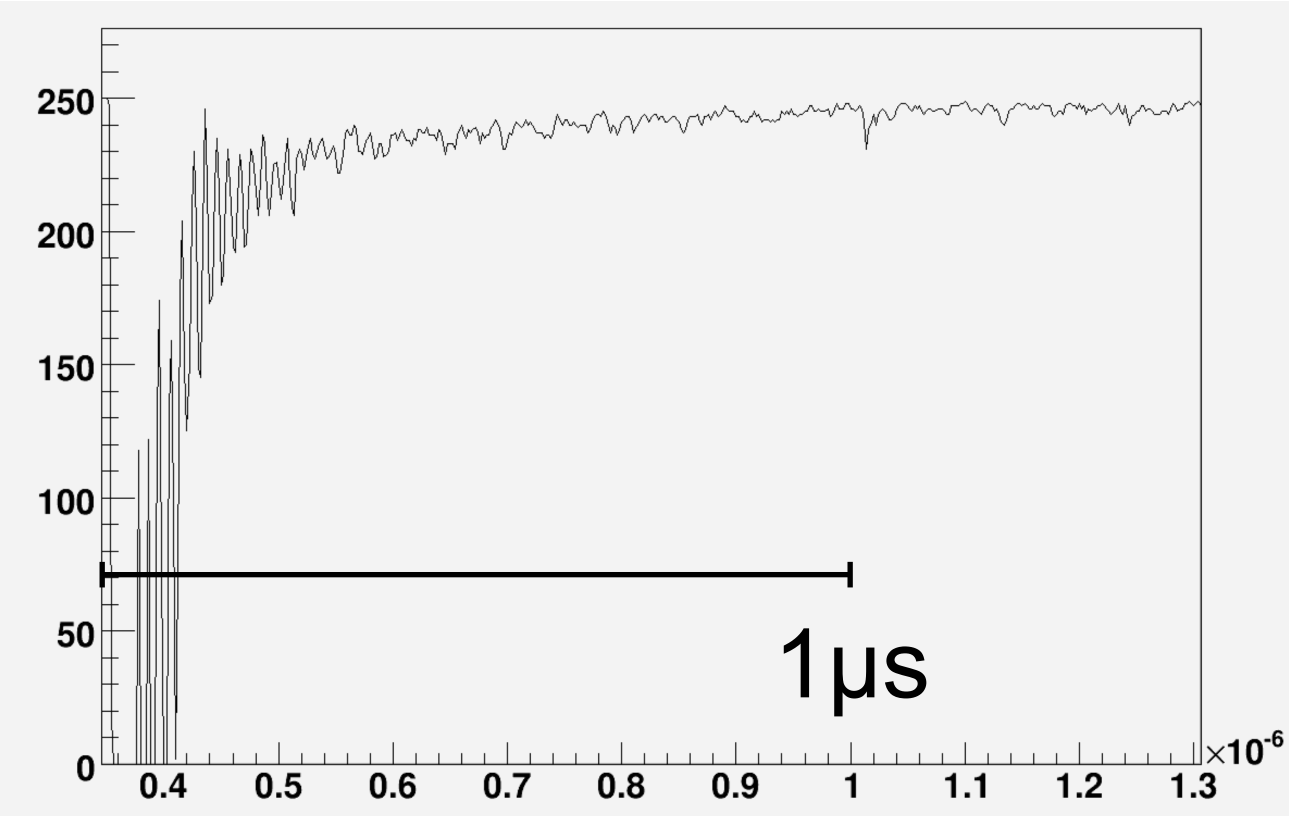


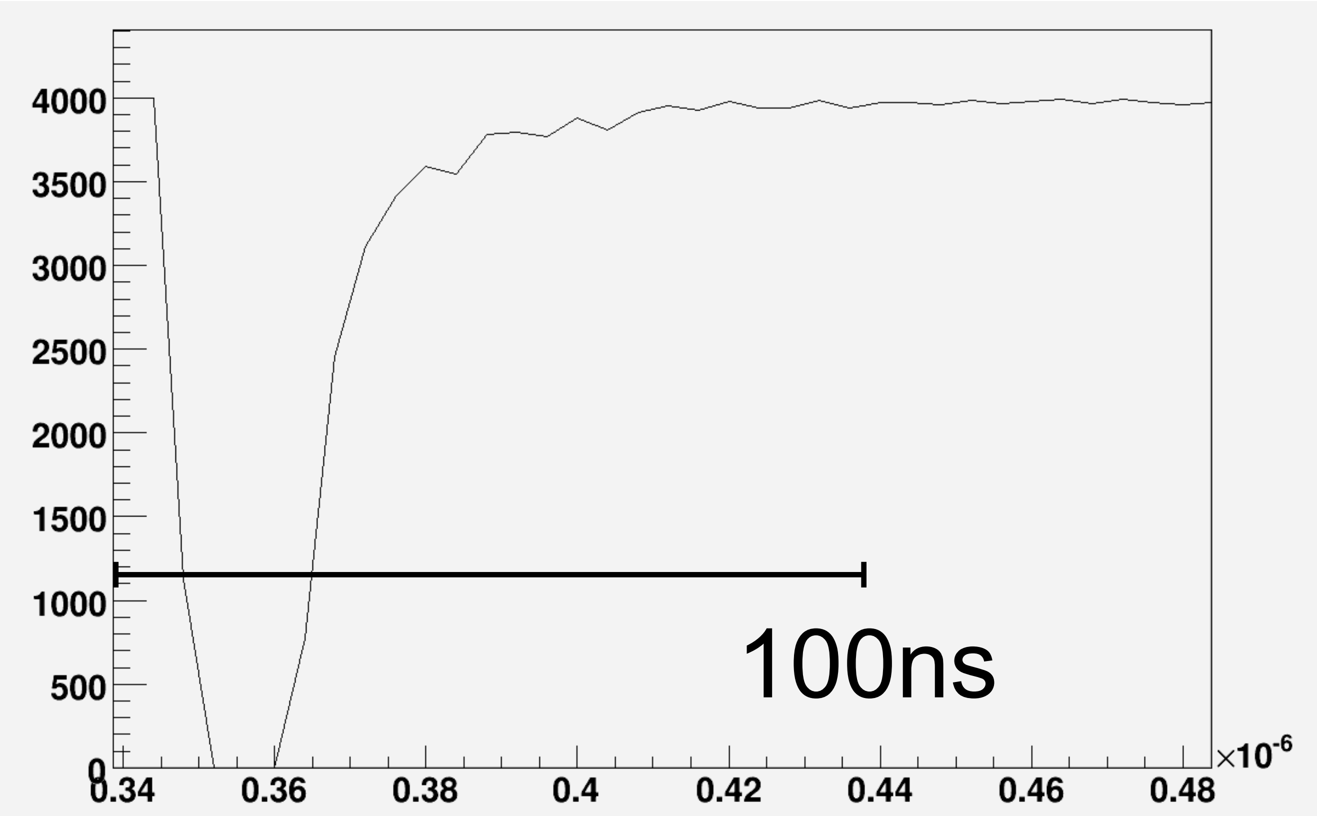
Simulated energy release inside one scintillator layer

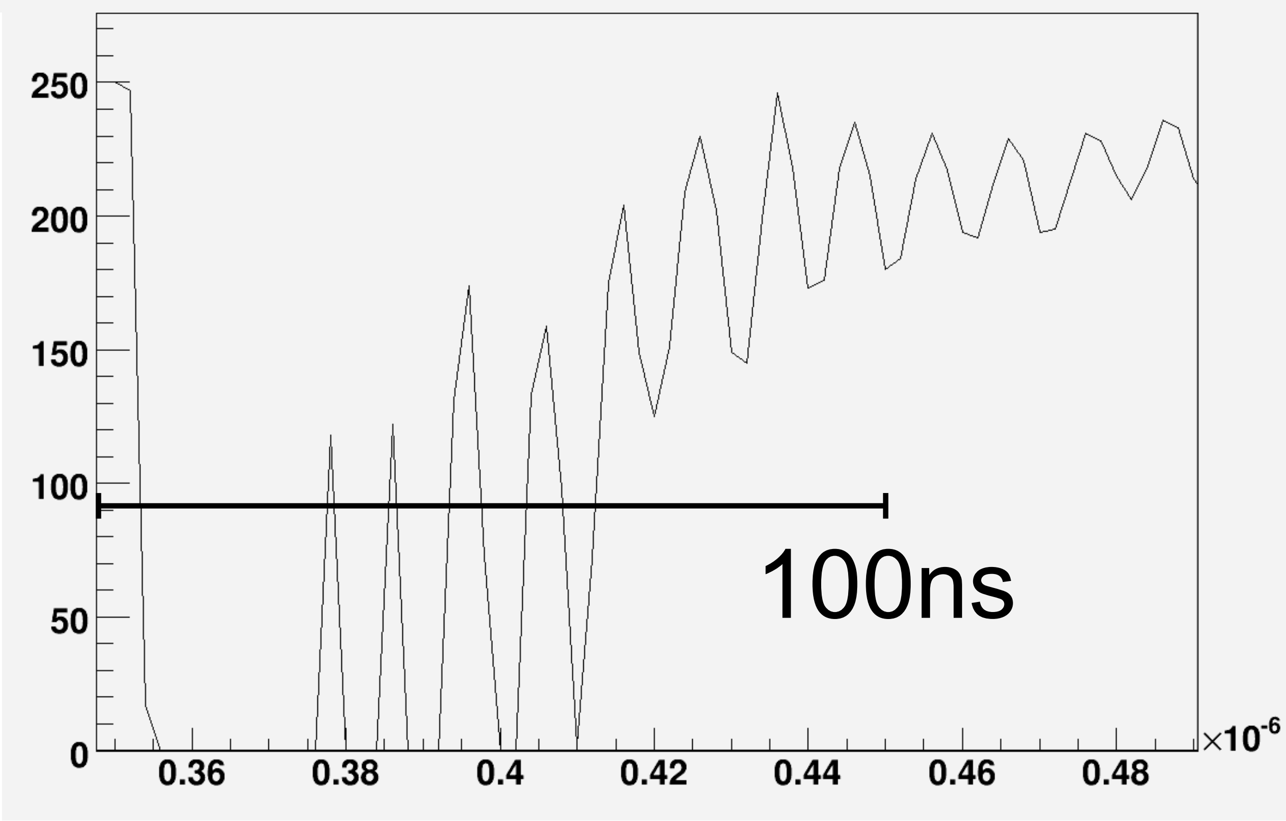
Fluka vs. **Geant4** comparison.

No ZS (no filter) pulse shapes

8bits ADC / 12bits ADC

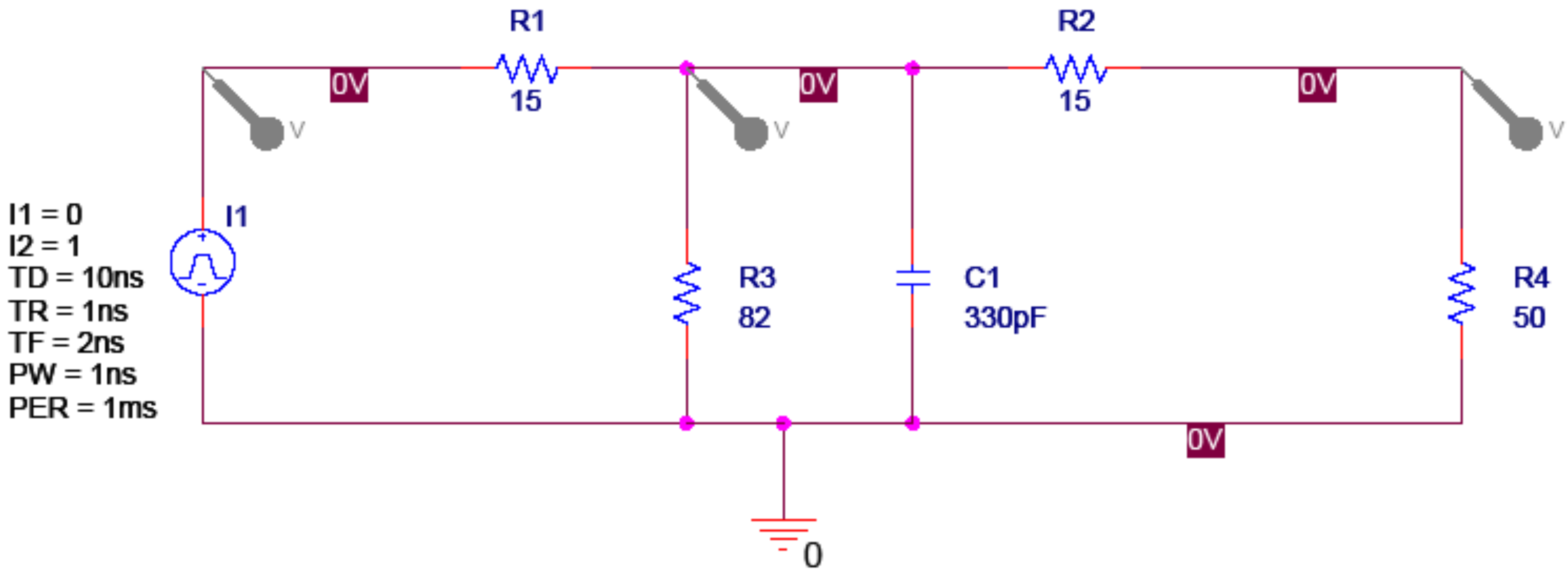






Filter

Passive filter implemented to get around the firmware problem of CAEN V1731 and CAEN V1720.



Late signal composition

// 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