

Pile-up simulation studies with cosmic-ray data and toy Monte Carlo simulation

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Outline

- Motivation
- Data-based simulation
- Toy MC
- Results
- Conclusions

Introduction and motivation

- The pile-up of low energy background hits is expected to be an important source of noise limiting the low energy resolution of the ECL
- The cumulation of these background hits modifies the baseline and peak of the signal hits, changing the value of the measured amplitude. The fluctuation on this change adds in quadrature to the electronics noise and the other fluctuations on the energy measurement
- We study the effect using
 - cosmic-ray data
 - toy MC simulation

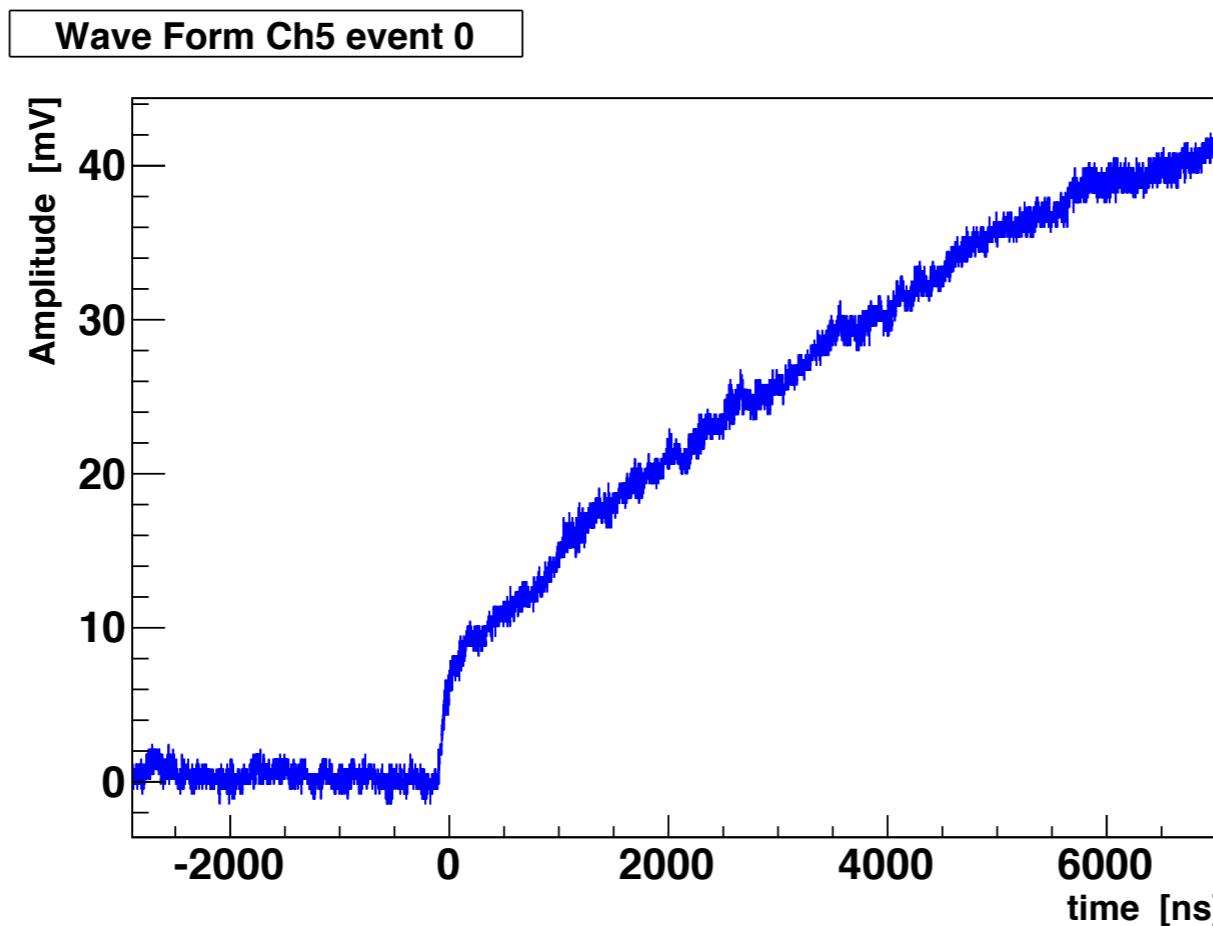
Cosmic-ray Data Sample

Results in this talk are obtained from cosmic-ray (CR) data collected with:

- a Belle CsI(Tl) crystal with PIN diode and standard Belle preamp readout, which we used for irradiation tests
 - ✓ time window of $12\mu\text{sec}$ @ 500MSa/s (6000 samples total).
 - ✓ most probable energy loss of CR track = **40 MeV**
 - ✓ *this crystal got a total irradiated dose of 250Gy ($\sim 25\%$ light loss)*
- a pure CsI crystal with LA Hamamatsu APDs + CREMAT preamp
 - ✓ time window of $10\mu\text{sec}$ sampled at 1GSa/s (10000 samples)
 - ✓ most probable energy loss of CR track = **30 MeV**

Pile-up simulation using cosmic-ray data

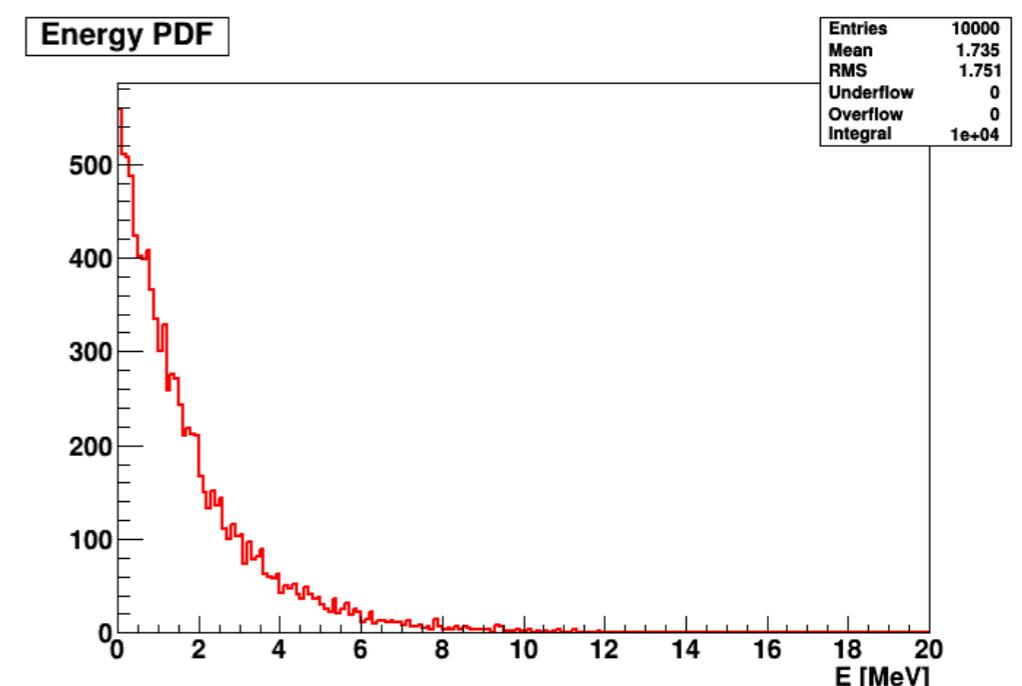
- Pile-up hits are simulated using *real waveforms* buffered from previous events.
 - require amplitude to be $> 2.0\text{mV}$ (CsI(Tl)) or 0.5mV (CsI) to have a non-empty background event



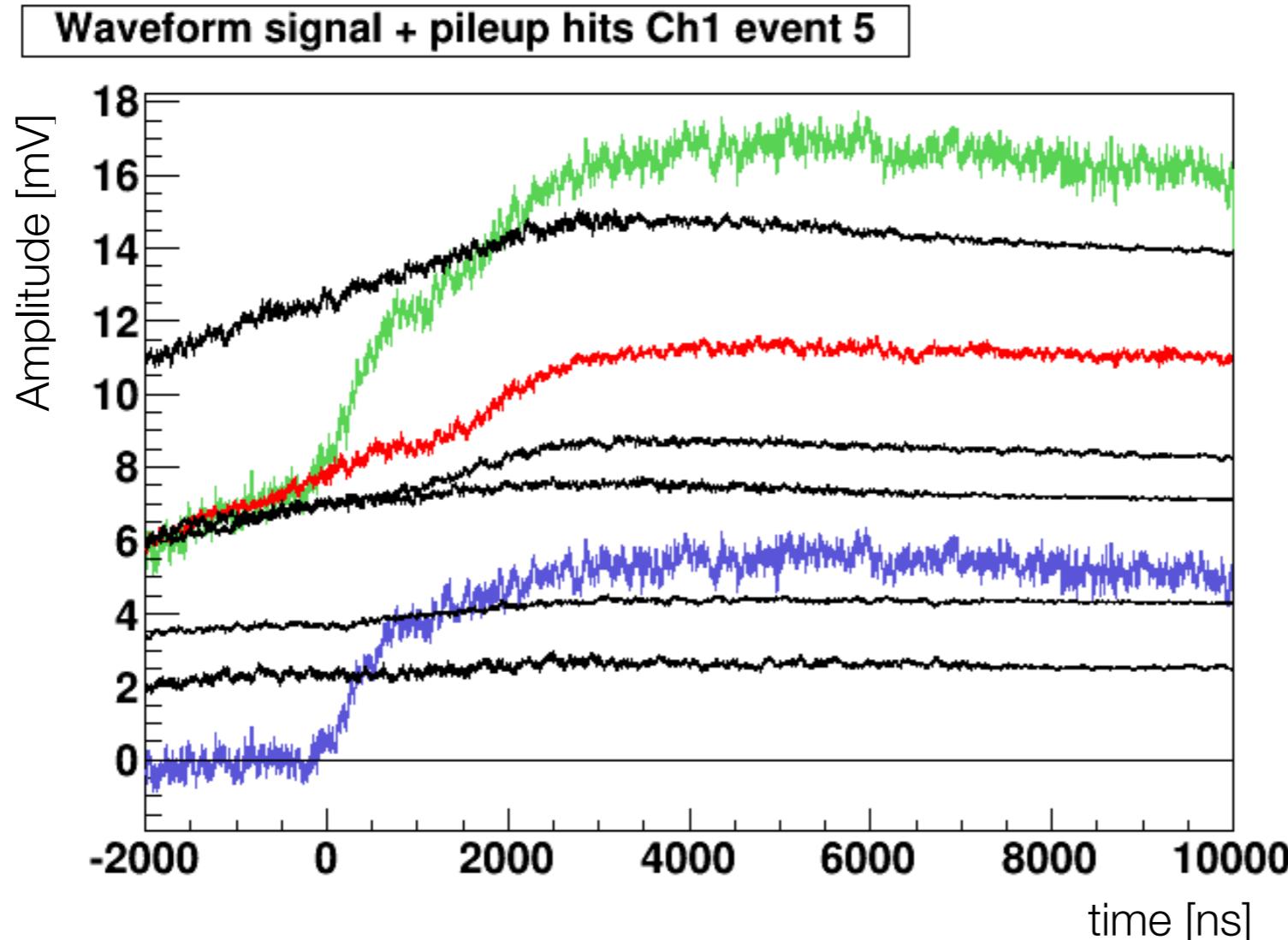
- Amplitude of buffered event is rescaled to obtain amplitude of background hit

Pile-up simulation using cosmic-ray data (II)

- Background hits from MC simulation show an exponential energy distribution
 - use mean $\lambda = E_{\text{average}}/\text{nhits}$
- Flat time distribution in the interval [-2,10] μs
- Using numbers from a sample crystal in ring #2: 5.1MeV/ μs in 3hits, we would add on average $5.1 \times 12 = \mathbf{61 \text{ MeV}}$ in $3 \times 12 = \mathbf{36 \text{ hits}}$ to each 12 μs long waveform

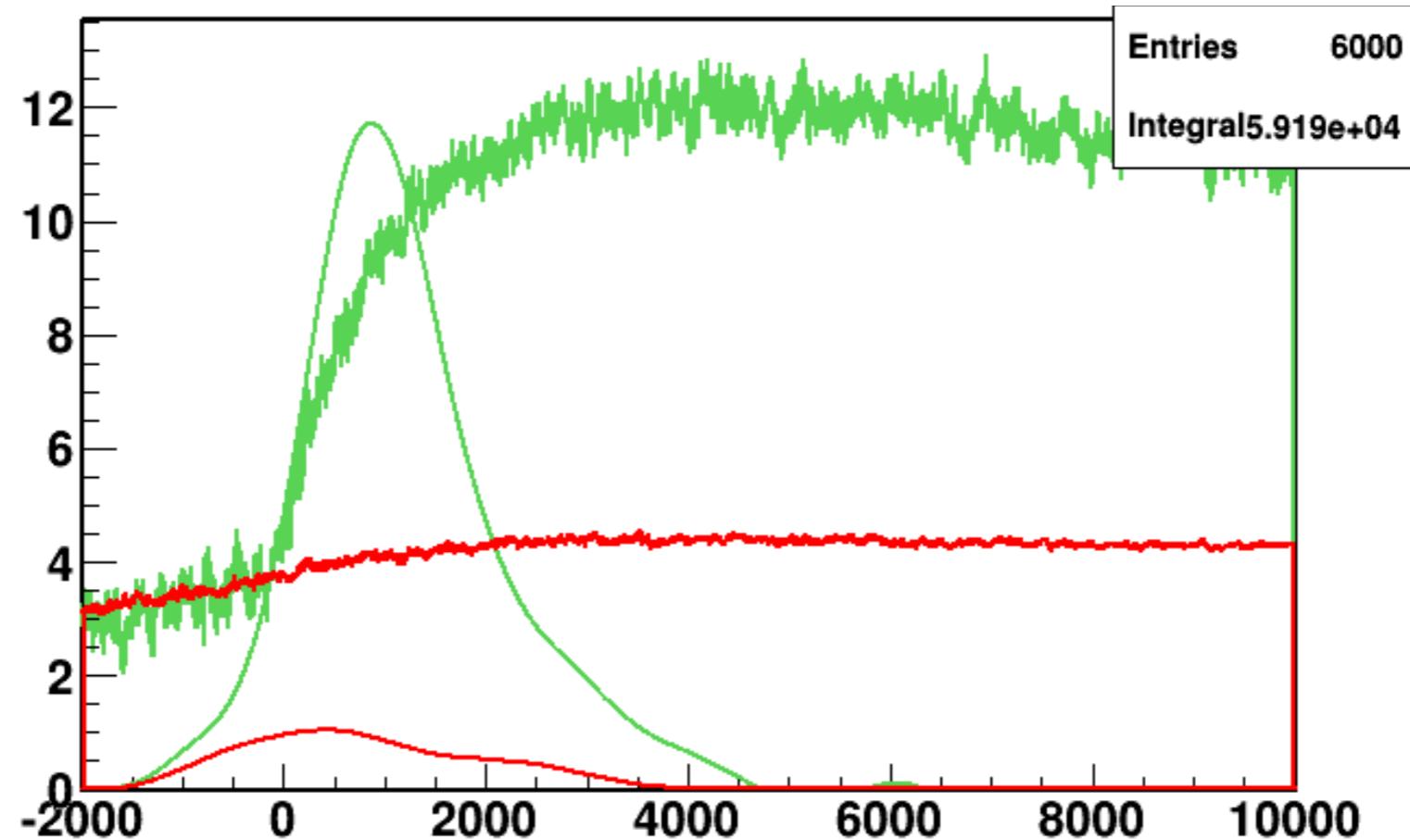


For illustration - Signal + background hits



Indigo waveform is the original signal, **red** waveform is the background resulting from the algorithm, **green** waveform is the sum. More background samples from other events are shown by the **black** curves. Large fluctuations in background size and shape are observed.

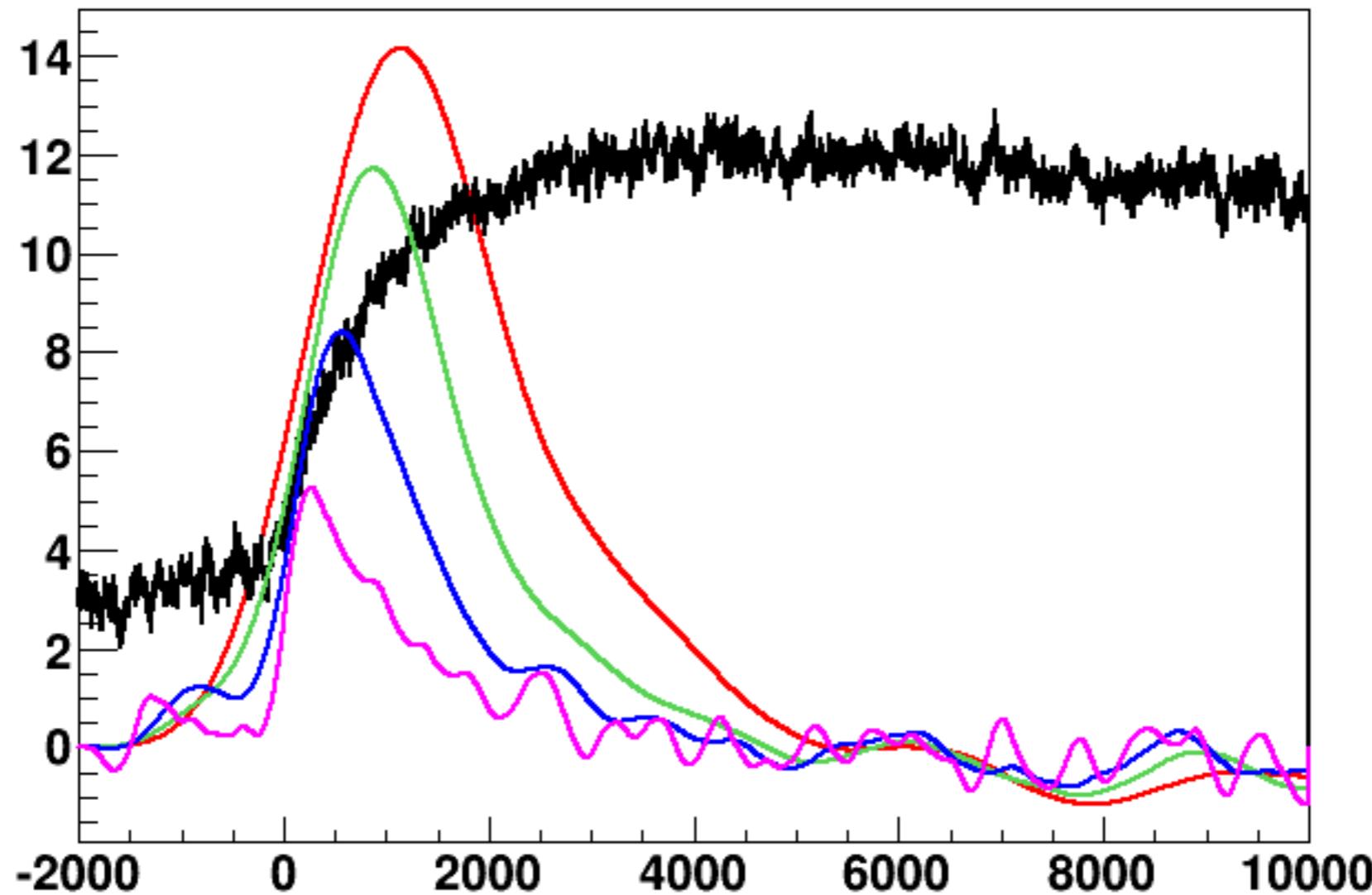
CR-(RC)⁴ shaping



Shaping CR-(RC)⁴ with tau=500ns applied to “signal+background”
and “background only”

CR-(RC)⁴ shaping

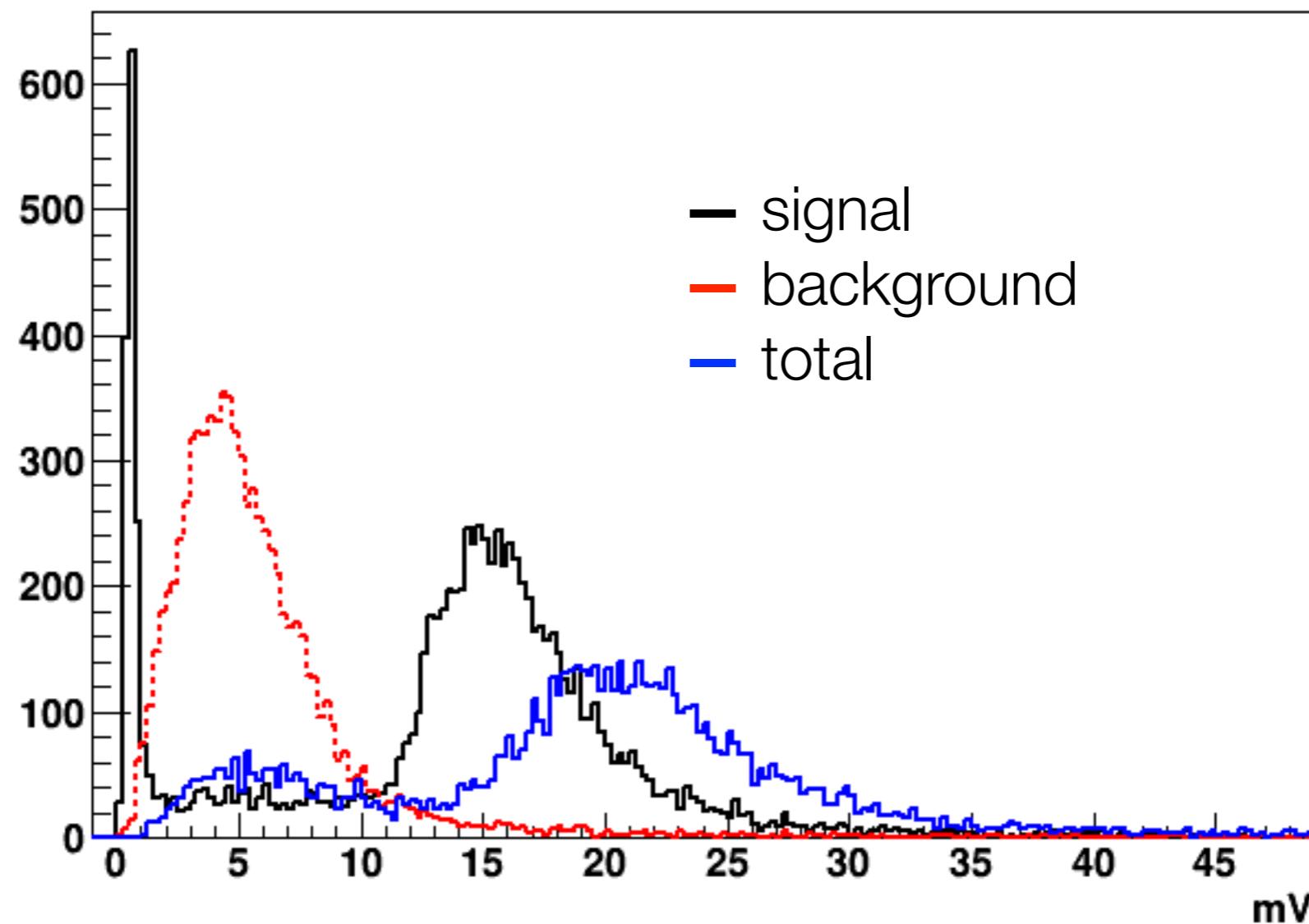
CRRC4-shaped waveform signal + pileup hits Ch1 event 3



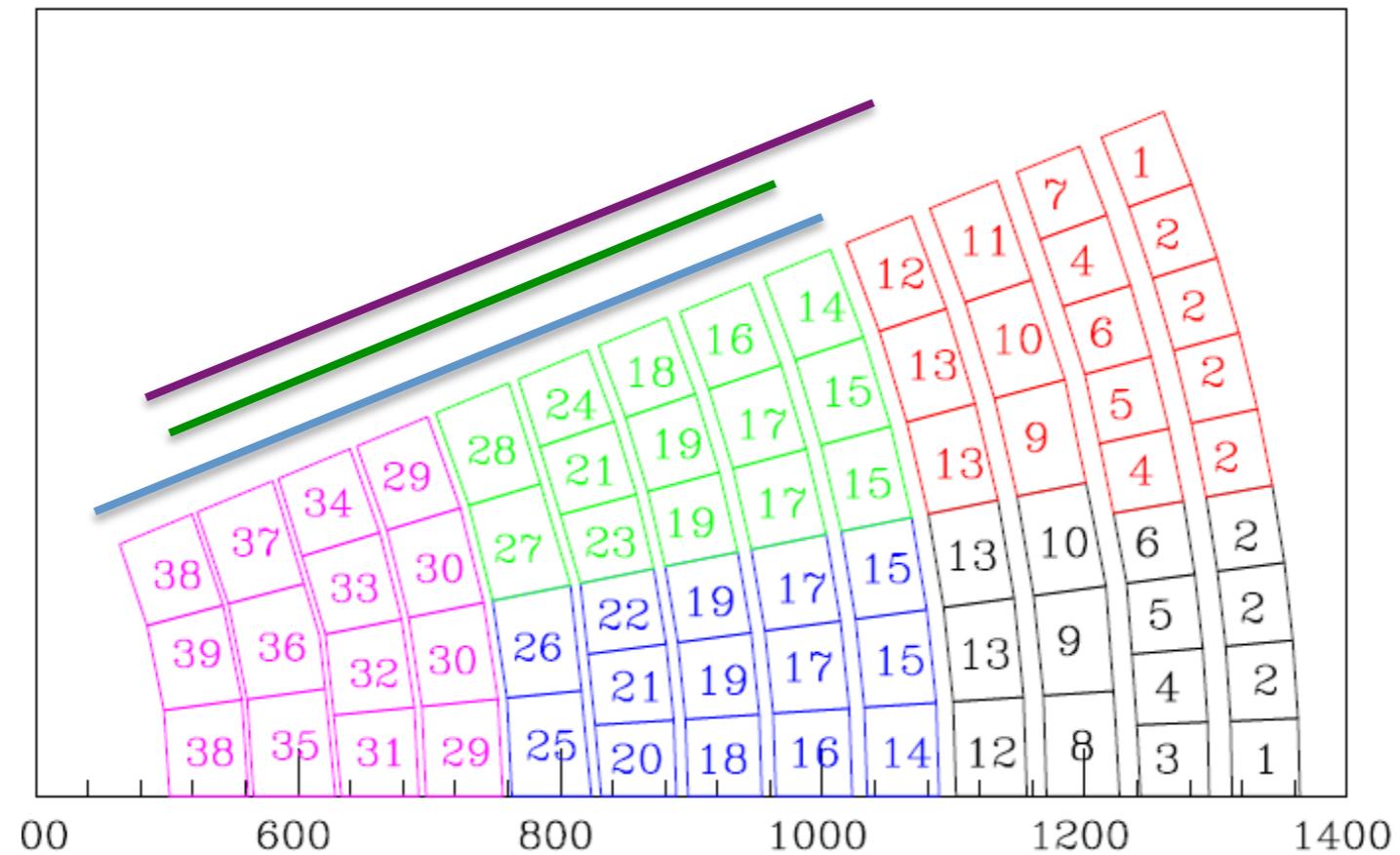
Shaping CR-(RC)⁴ with tau= **700**, **500**, **300**, **150** ns

Amplitudes

aMaxCRRC4[0]+aMaxCRRC4[1]



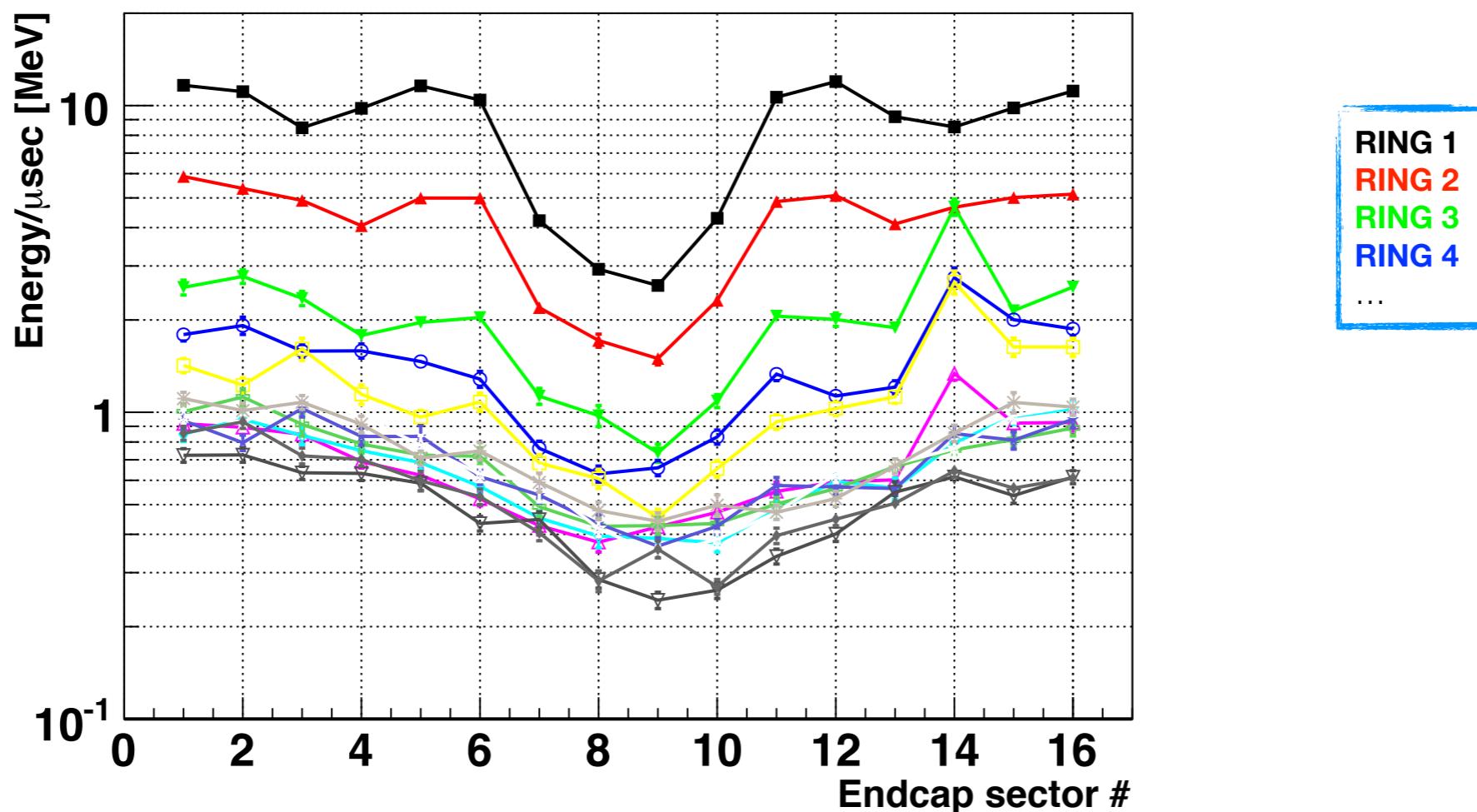
Background Simulation MC Campaign #11



Total energy per microsecond

Average on endcap sectors

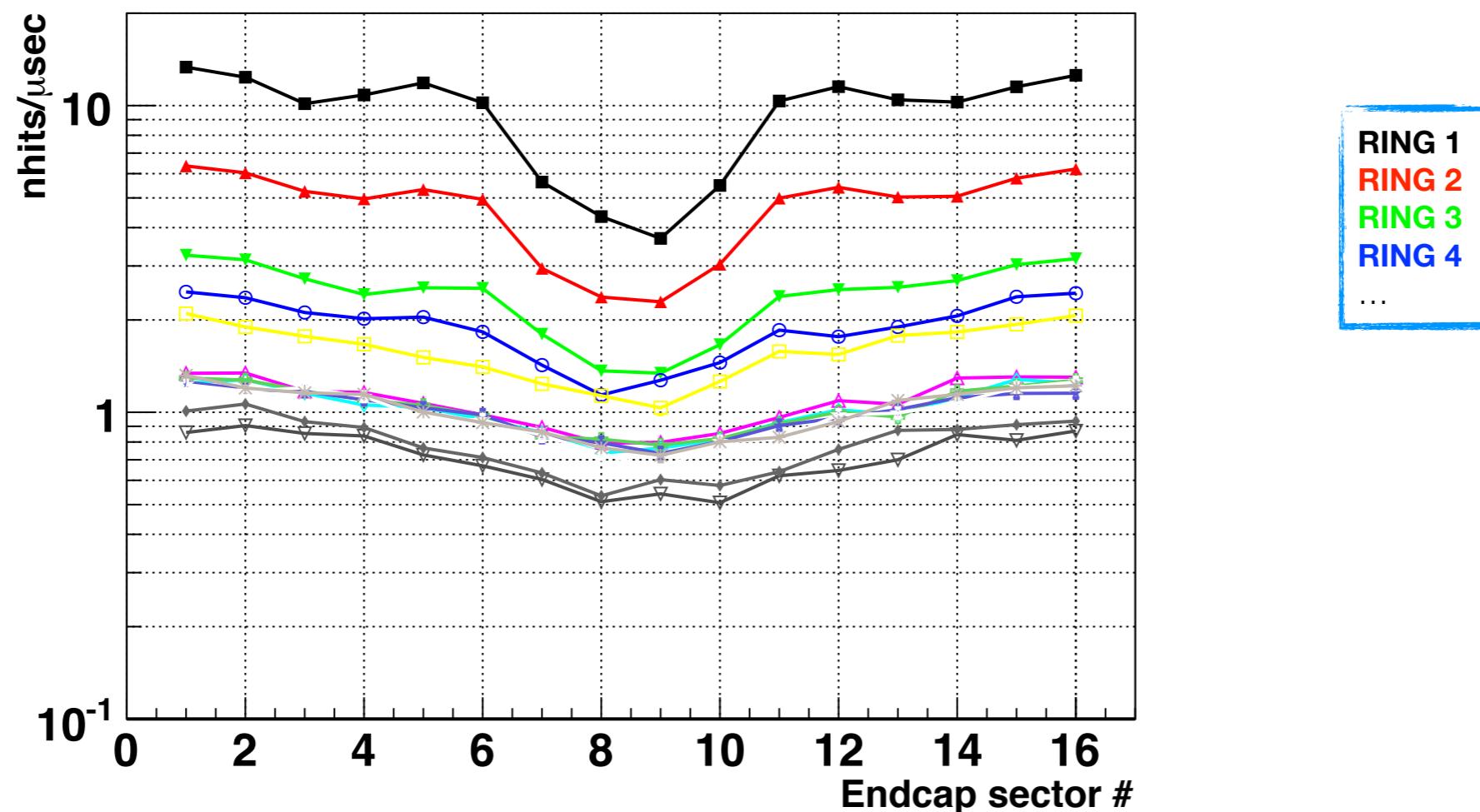
- 13 rings, 16 sectors per ring
- 11th MC campaign



Number of background hits per microsecond

Average on endcap sectors

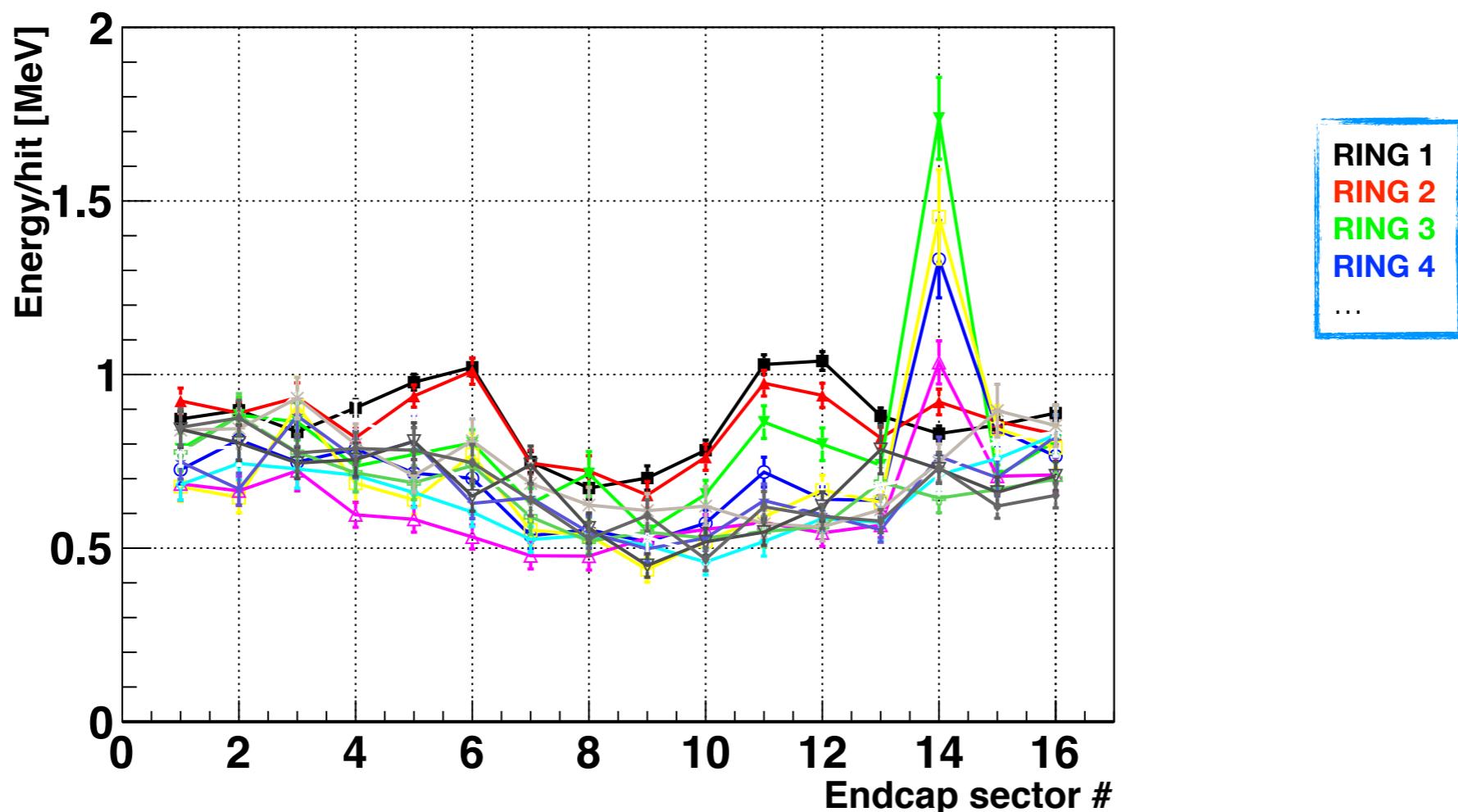
- 13 rings, 16 sectors per ring
- 11th MC campaign



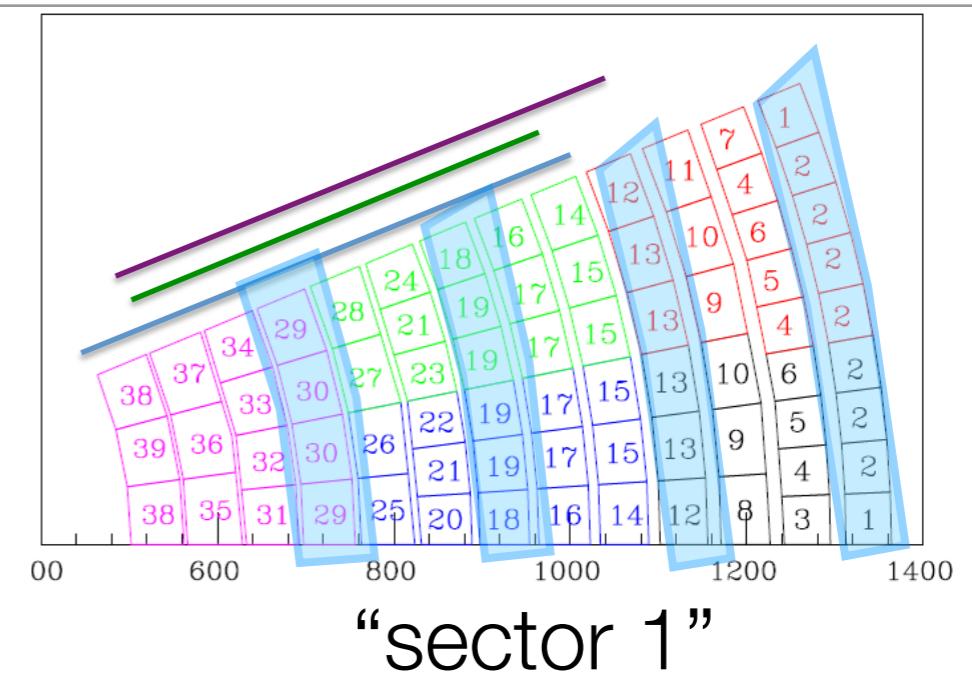
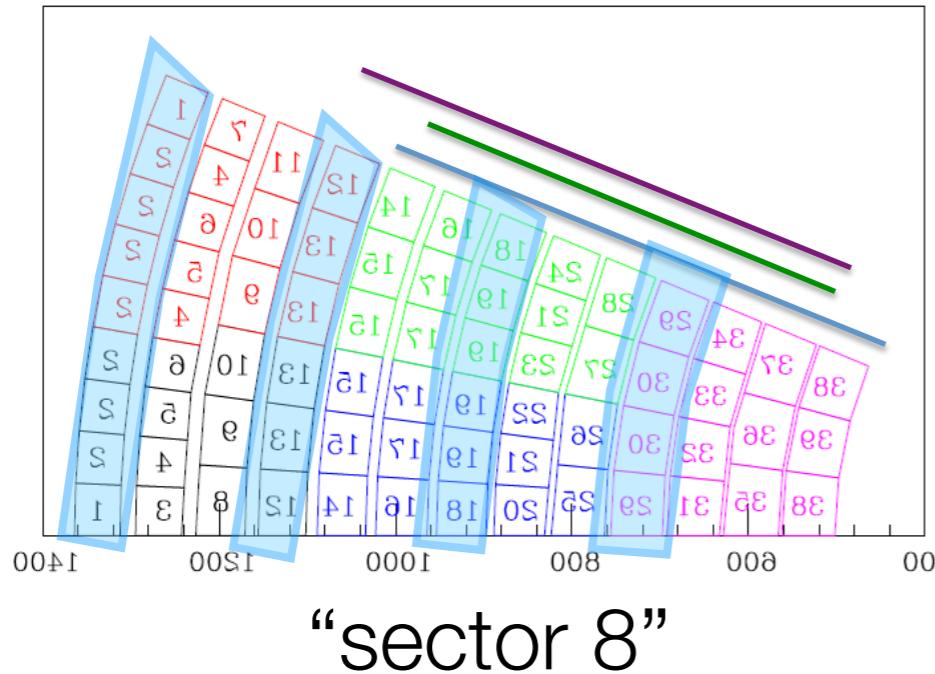
Energy per hit

Average on endcap sectors

- 13 rings, 16 sectors per ring
- 11th MC campaign



Benchmark regions



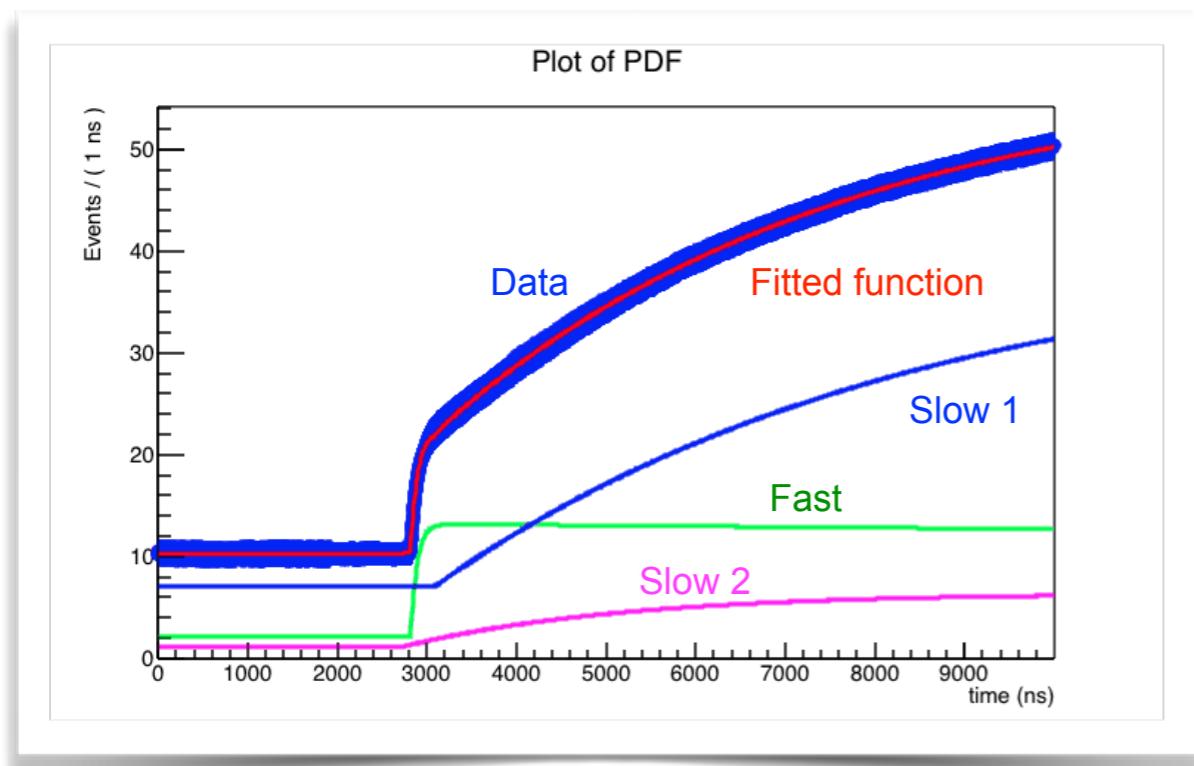
RING	SECT.	E/ μ s (MeV)	hits/ μ s	E/hit (MeV)
4	1	1.792 \pm 0.084	2.469 \pm 0.077	0.726 \pm 0.041
4	8	0.630 \pm 0.038	1.139 \pm 0.052	0.553 \pm 0.042
7	1	0.849 \pm 0.047	1.244 \pm 0.045	0.683 \pm 0.045
7	8	0.395 \pm 0.034	0.736 \pm 0.034	0.537 \pm 0.052
10	1	0.969 \pm 0.052	1.231 \pm 0.044	0.787 \pm 0.051
10	8	0.418 \pm 0.025	0.736 \pm 0.034	0.569 \pm 0.043
13	1	0.855 \pm 0.045	1.009 \pm 0.033	0.848 \pm 0.053
13	8	0.282 \pm 0.022	0.534 \pm 0.024	0.527 \pm 0.047

Use as benchmark the background level in rings actually used in cluster reconstruction ($i\Theta\geq 4$):

Pile-up toy simulation

- Simulate the pile-up of signals coming from background photons inside a pure CsI crystal with a function whose parameters are obtained from a fit to cosmic ray data
- Exploit the long time constant of the CREMAT CR-110 preamplifier we used to read out the LAAPDs, which preserves the features of the slower components of scintillation light in pure CsI crystals
 - A study using data collected with CsI with photo-pentode readout was presented by C.Hearty

Toy MC - Fit & pile-up simulation



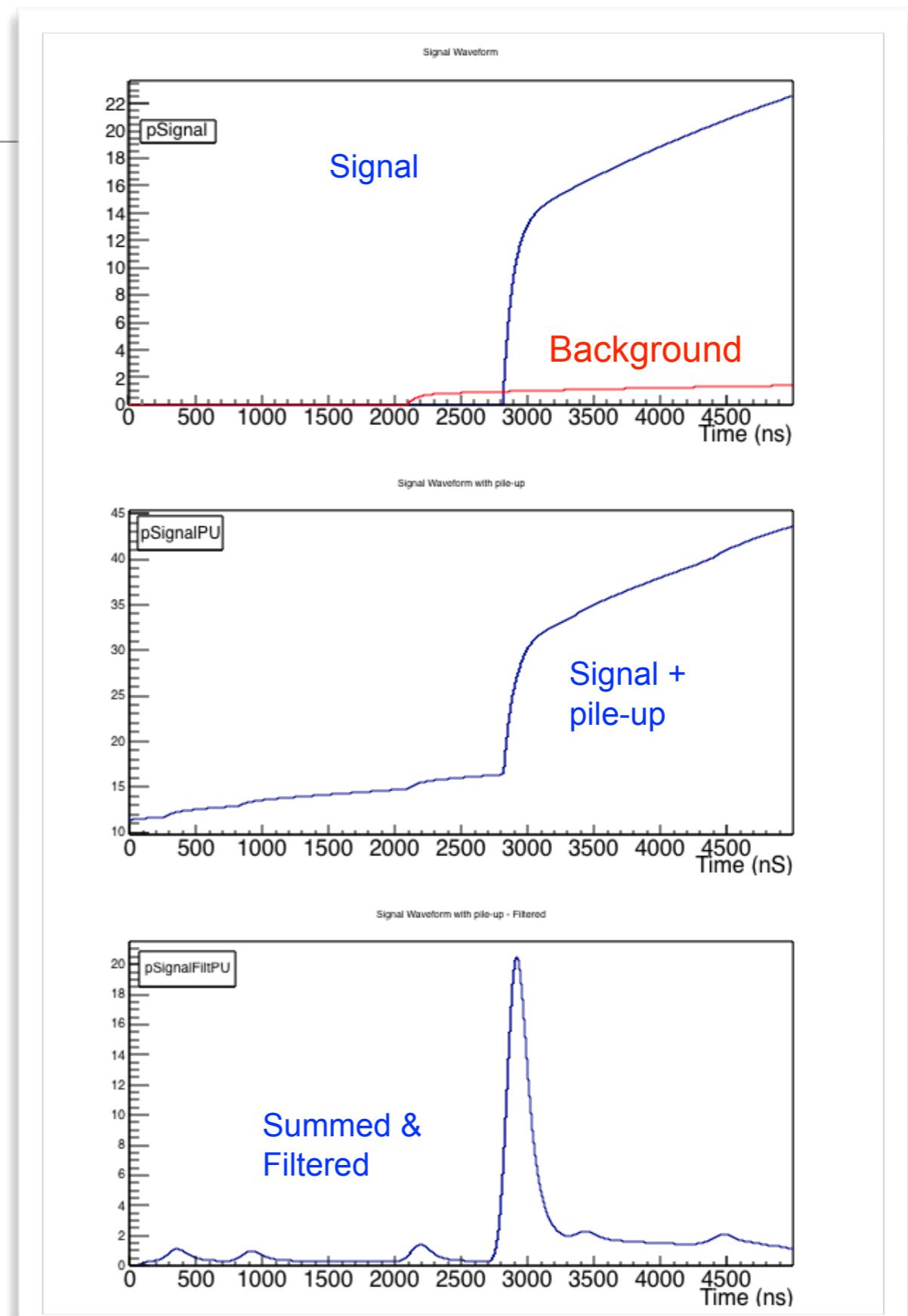
Fit three components

$$\tau_F = 70 \pm 2 \text{ ns } (*)$$

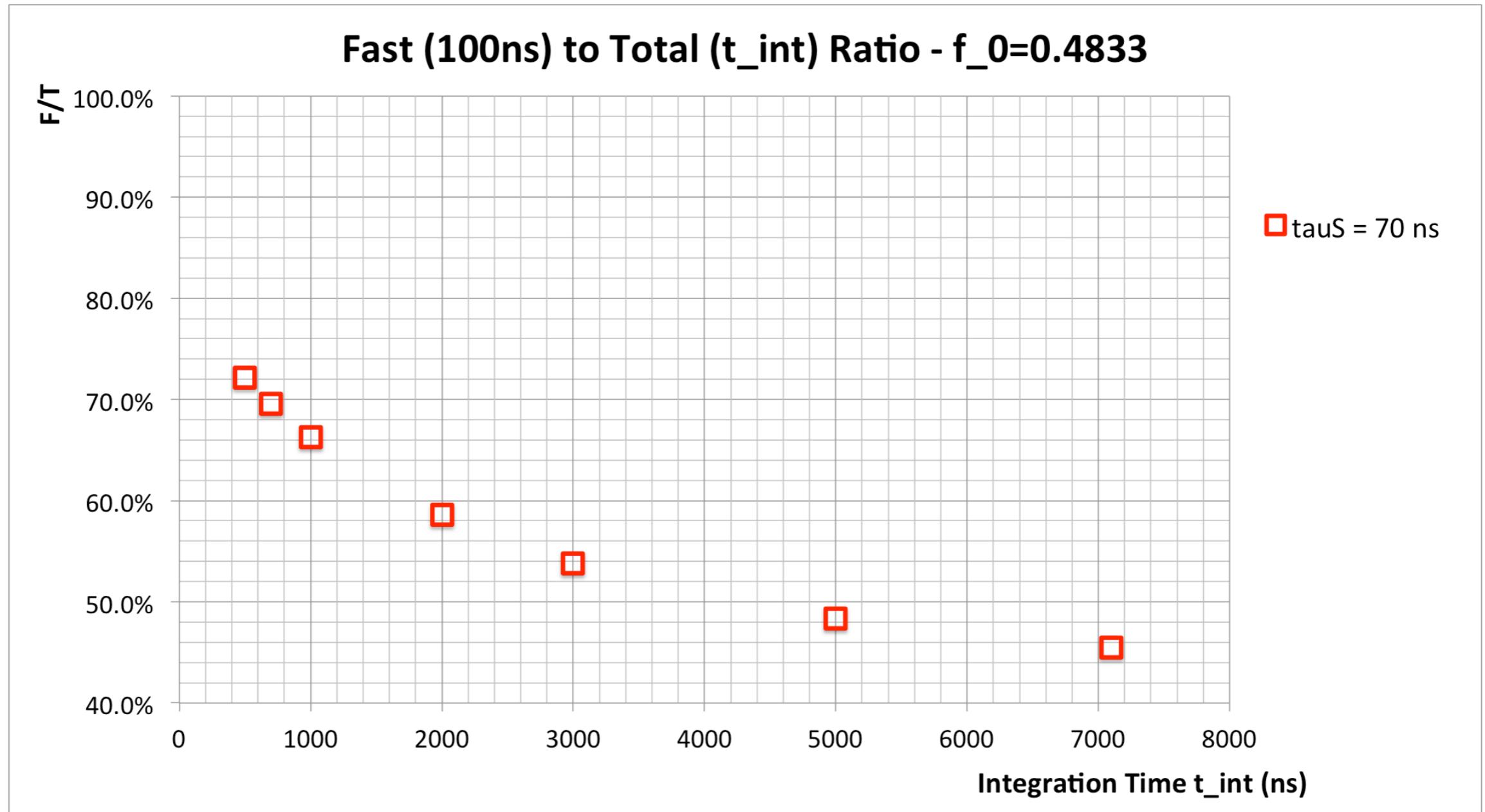
$$\tau_{S1} = 2.8 \pm 0.6 \mu\text{s}$$

$$\tau_{S2} = 6.5 \pm 1.0 \mu\text{s}$$

(*) Also affected by APD+preamp



Fraction of fast component in pure CsI

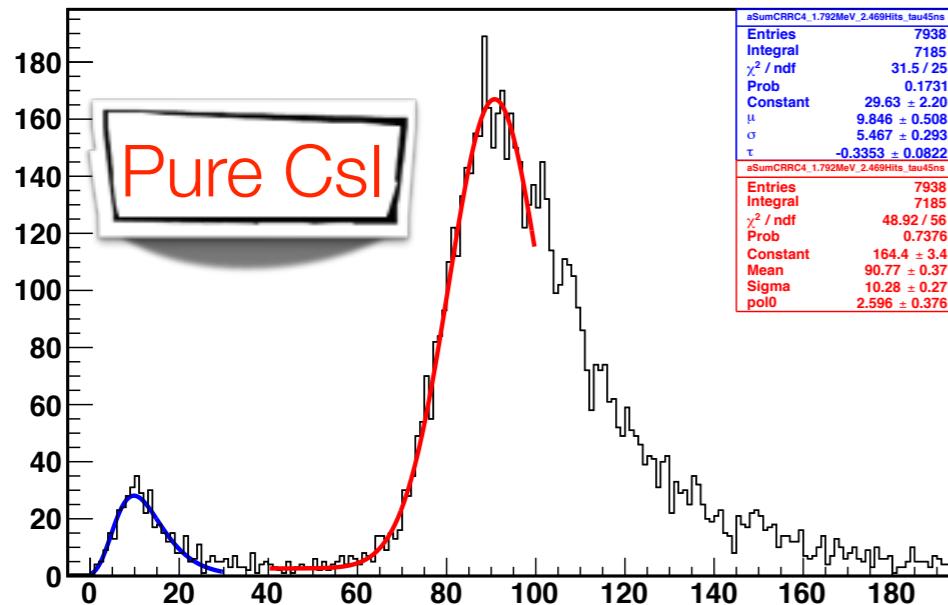


Compilation or results on CsI(Tl) and pure CsI

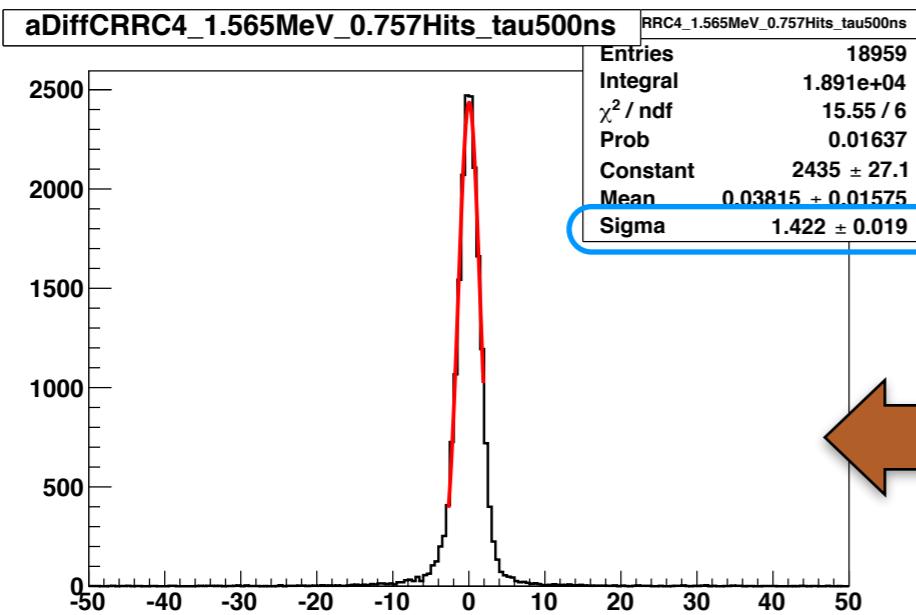
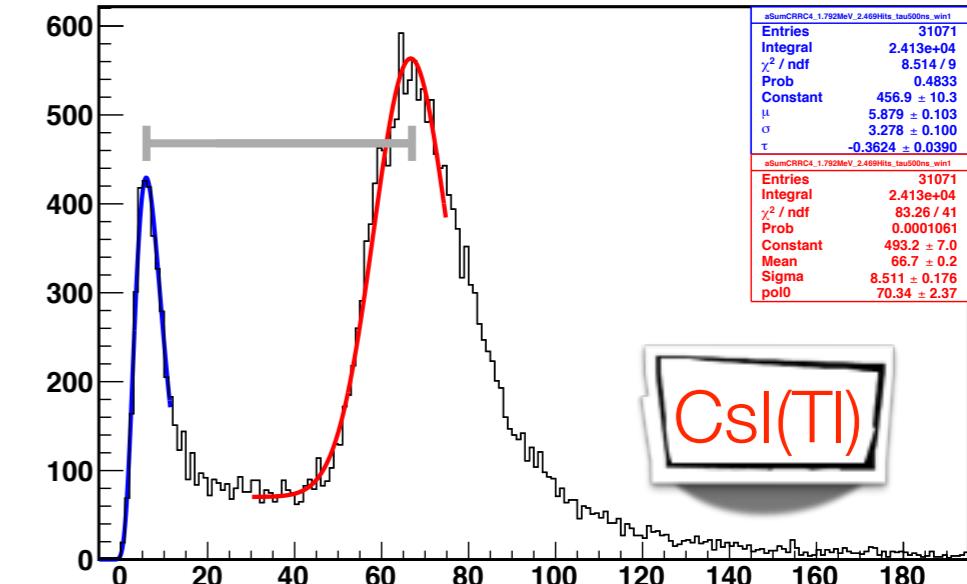
- We performed two separate analyses to compare the results obtained with the method outlined above
- In the following slides a compilation of results is presented, using the background level of the hottest sector (#1) in the innermost ring (#4) which can be used for a cluster seed
- Conclusion is that the two analyses on data and the toy MC simulation (on pure CsI only) do compare well

Determination of ENE and σ_E/E

aSumCRRC4_1.792MeV_2.469Hits_tau45ns



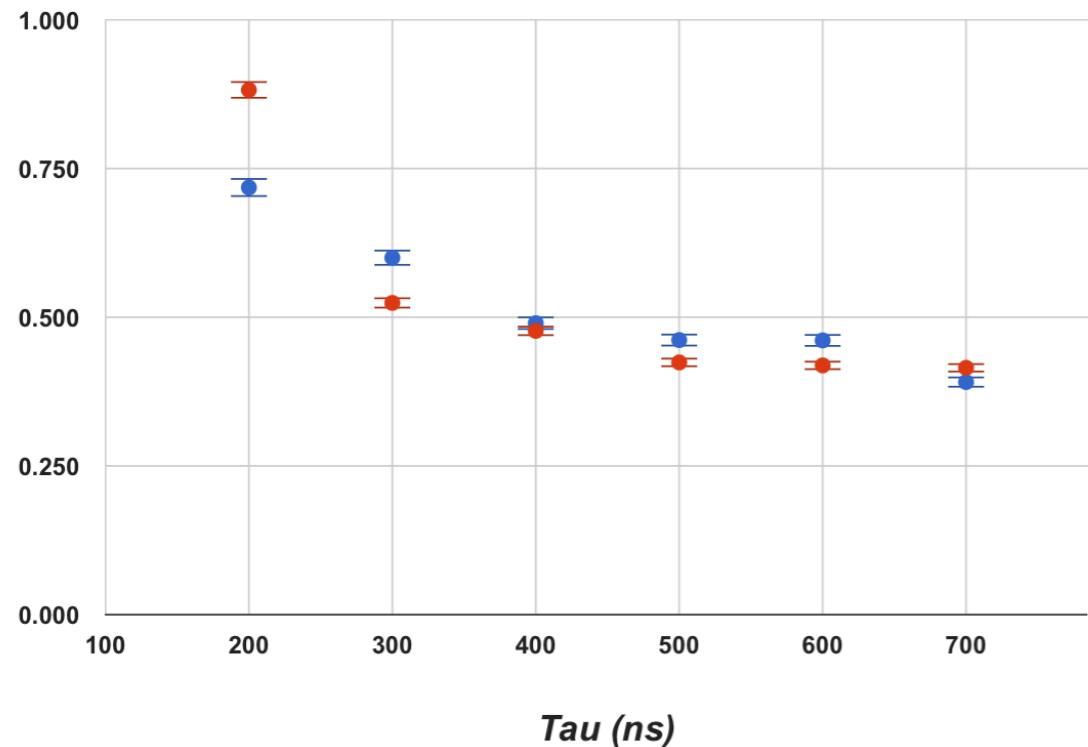
aSumCRRC4_1.792MeV_2.469Hits_tau500ns_win1



- Track length and Landau fluctuations cancel out in the difference of amplitudes of the two photosensors
- Remaining spread mainly related to photo-statistics
- Normalize to MPV signal to measure relative resolution

ENE comparison for CsI(Tl)

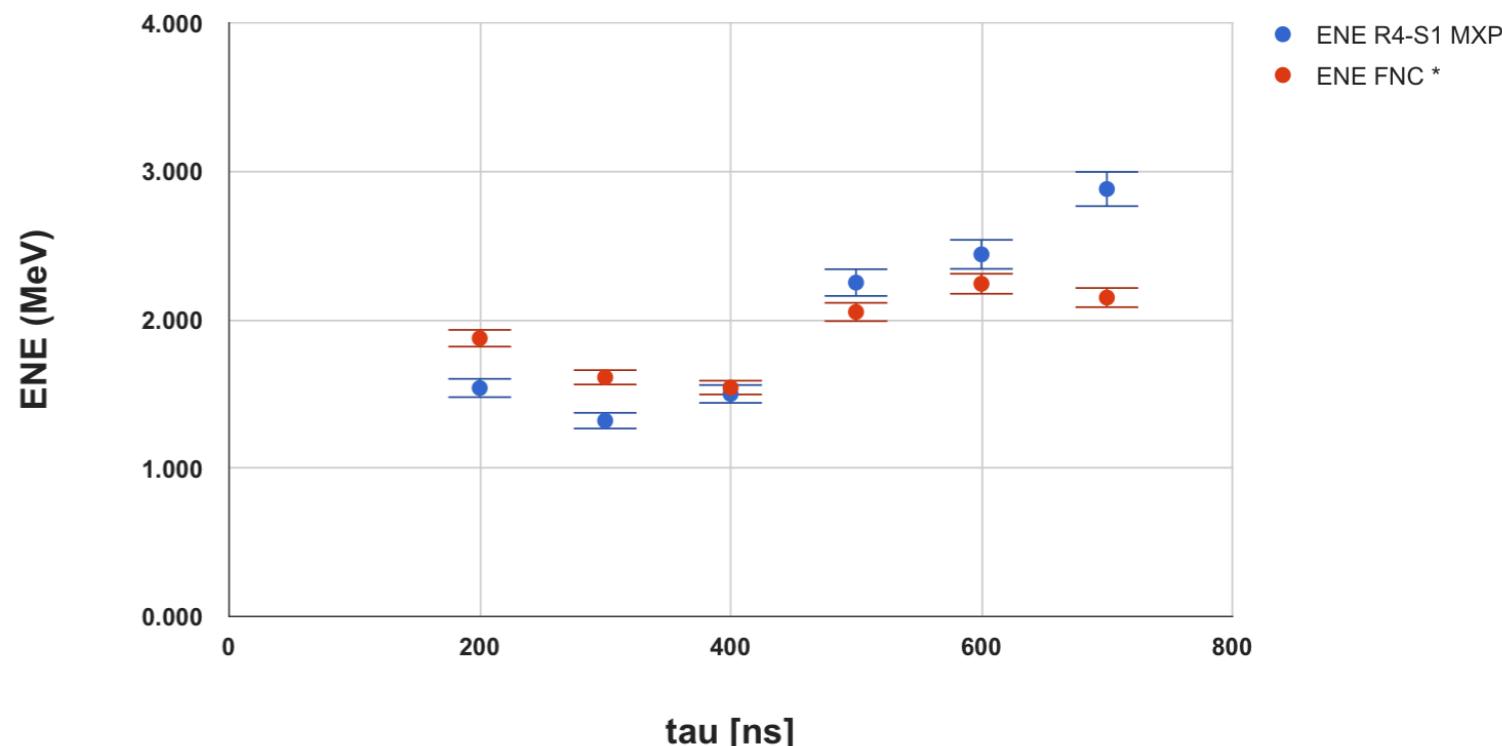
ENE CsI(Tl) No Pile Up



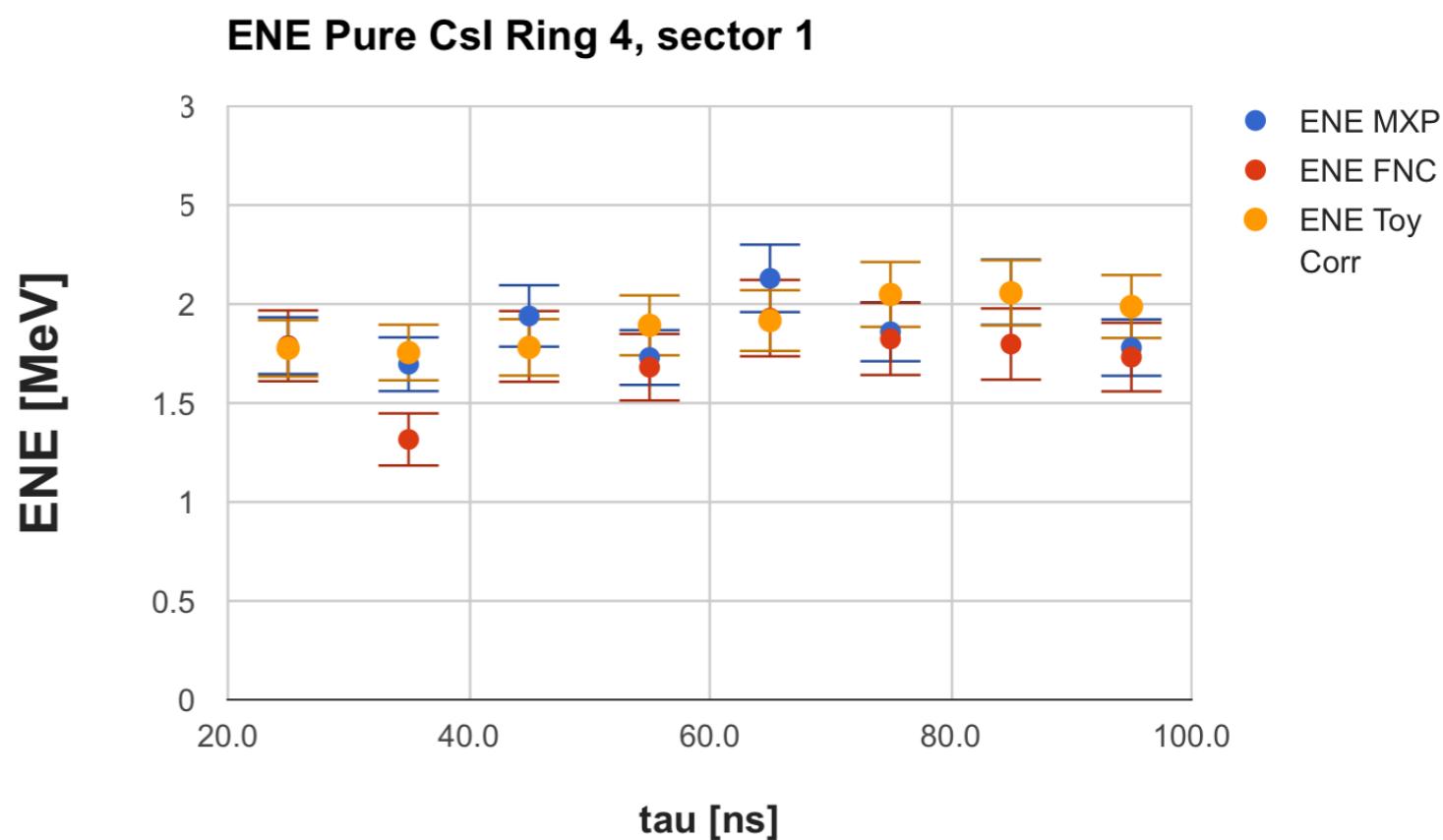
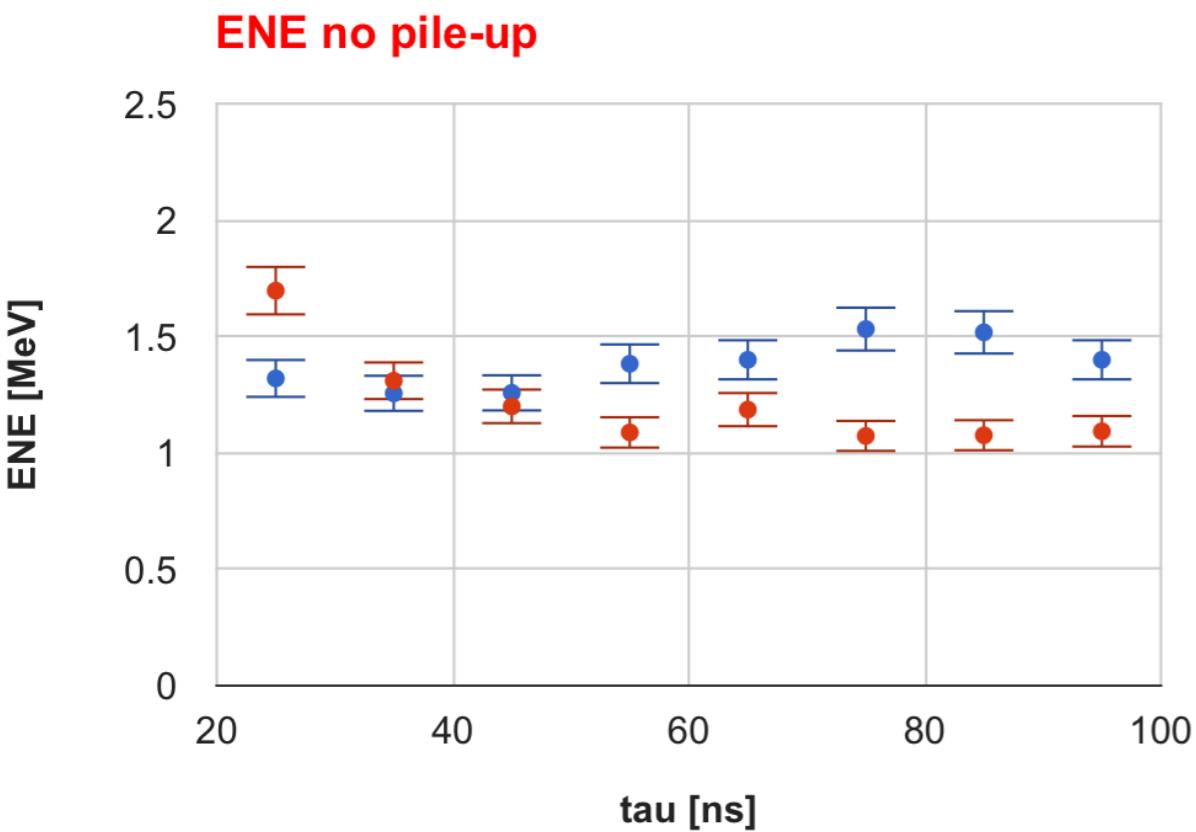
- ENE no pileup
MXP
- ENE no pileup
FNC

- ✓ Error bars are the fit statistical errors
- ✓ We estimate systematic uncertainty of changing the fit limits, parameter initialisation, background shape etc $\sim 10\%$

ENE CsI(Tl) (Ring 4, Sector 1)

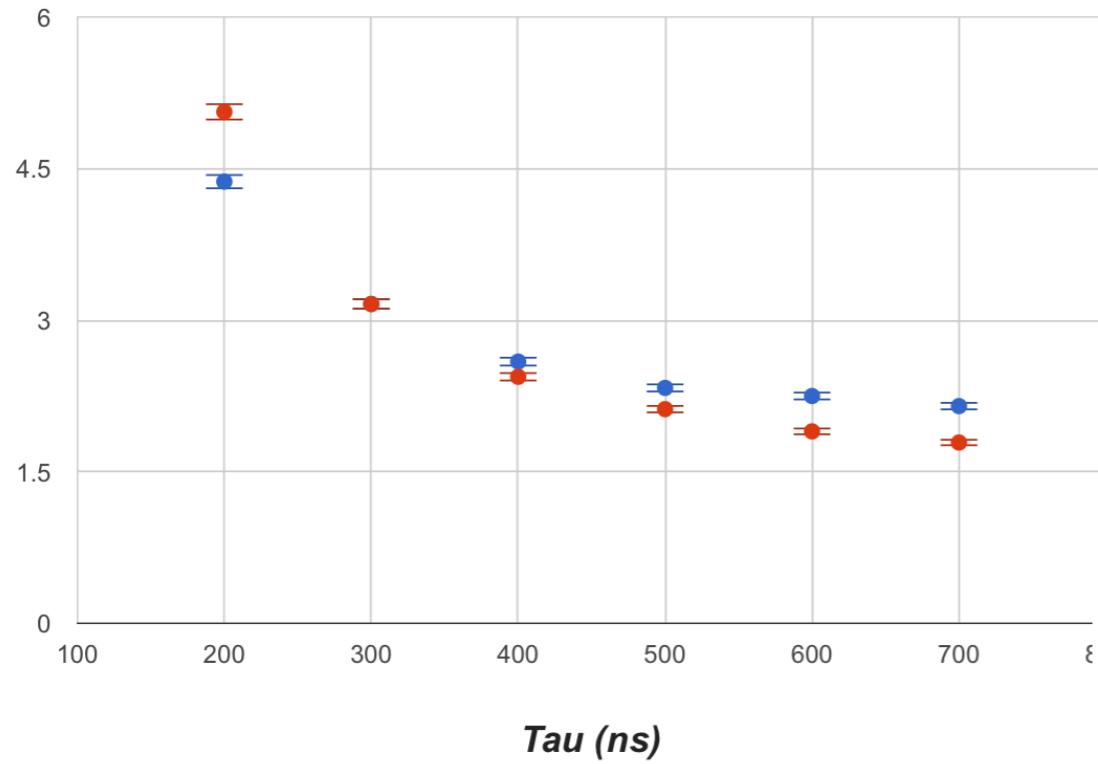


ENE comparison for pure CsI

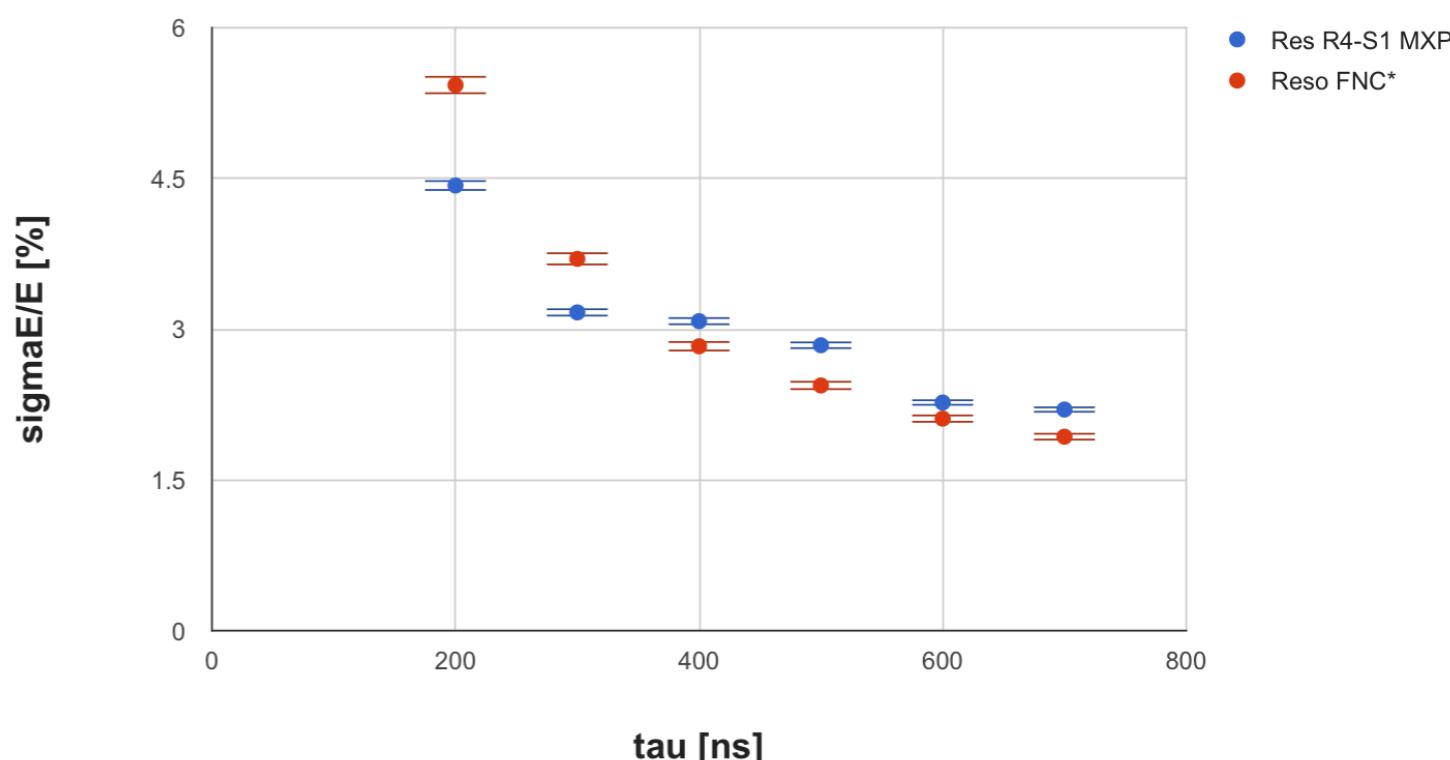


$\sigma(E)/E$ (at 40MeV) comparison for CsI(Tl)

Resolution CsI (Tl) No Pile Up

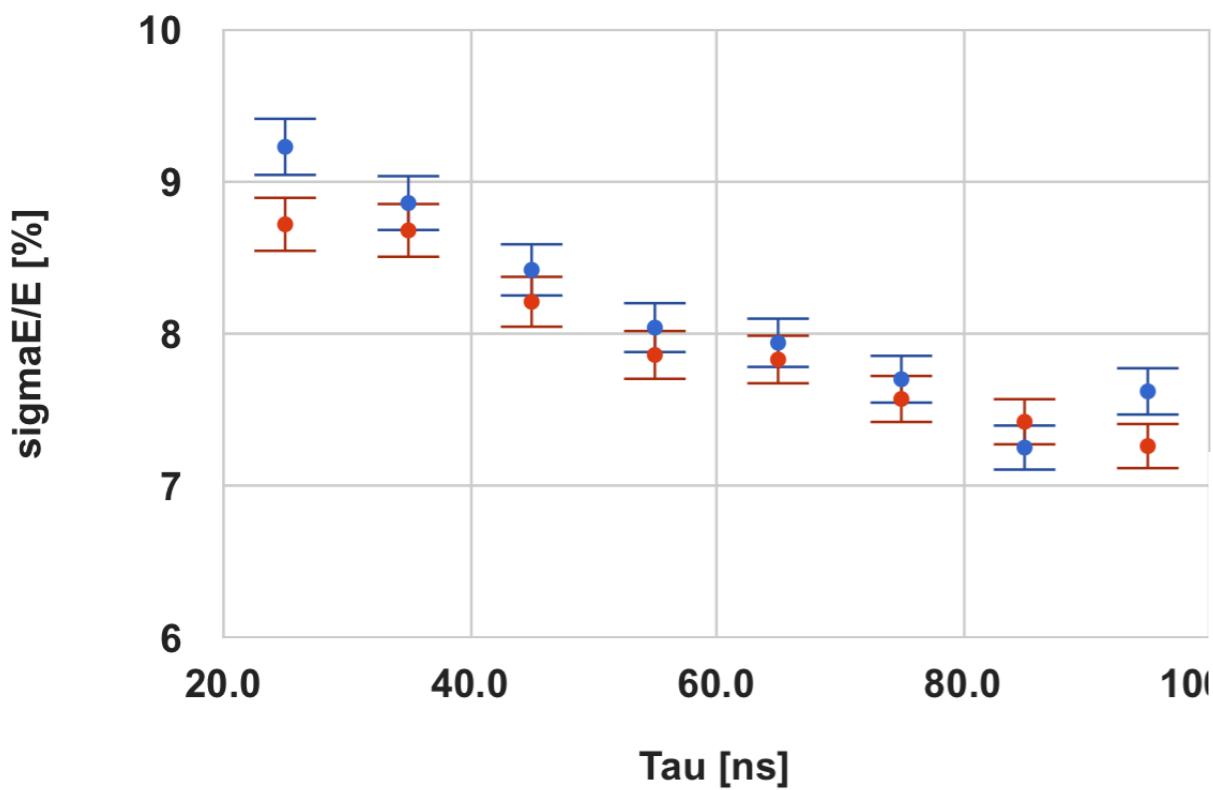


Reso CsI(Tl) (Ring 4, Sector 1)



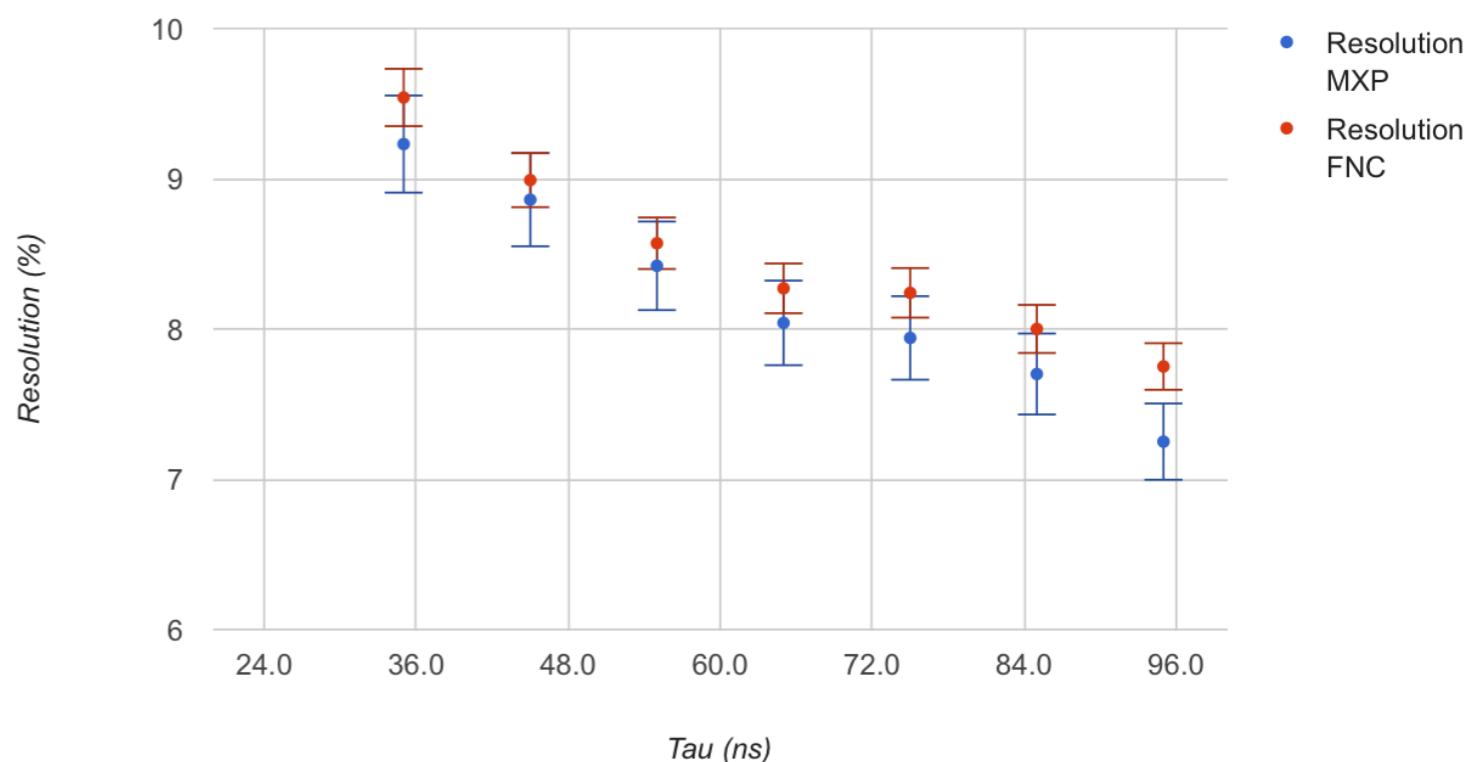
$\sigma(E)/E$ (at 30MeV) comparison for pure CsI

Energy resolution vs. tau No pile-up



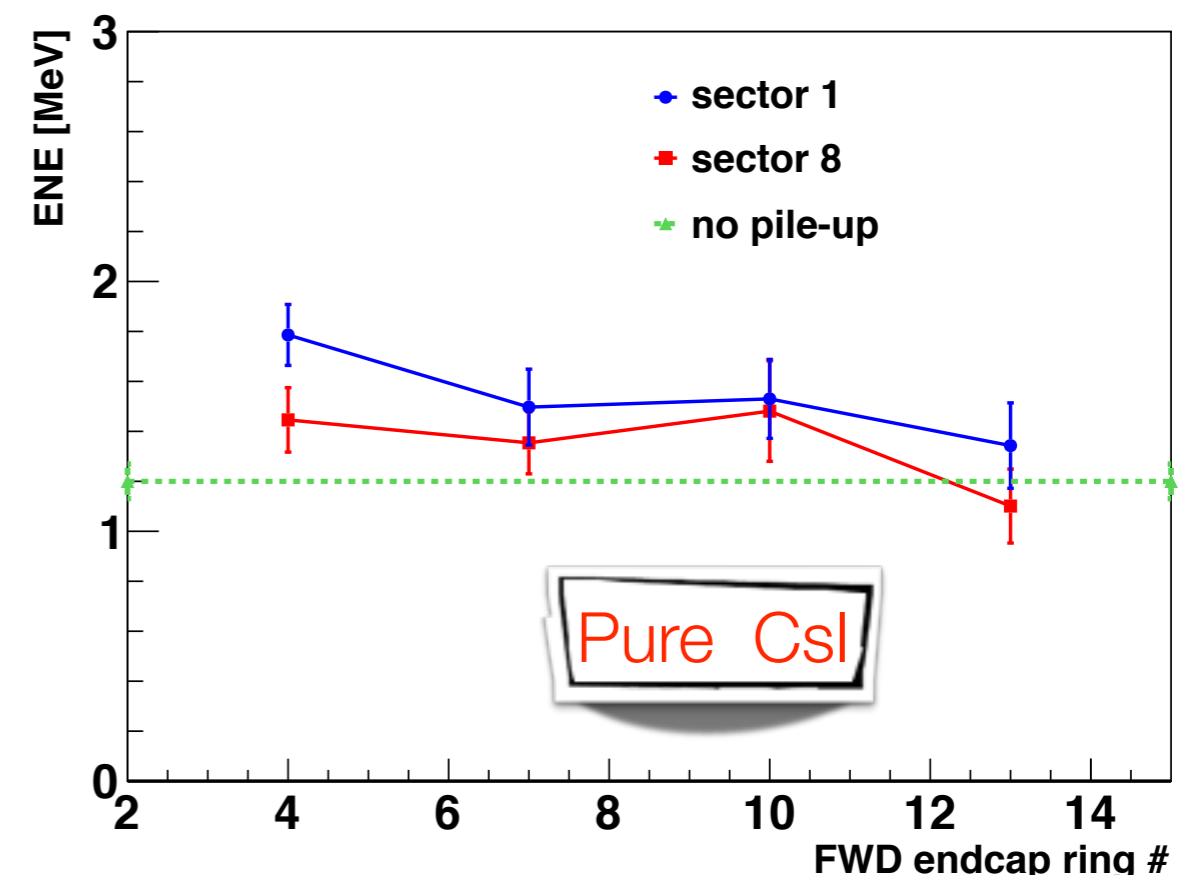
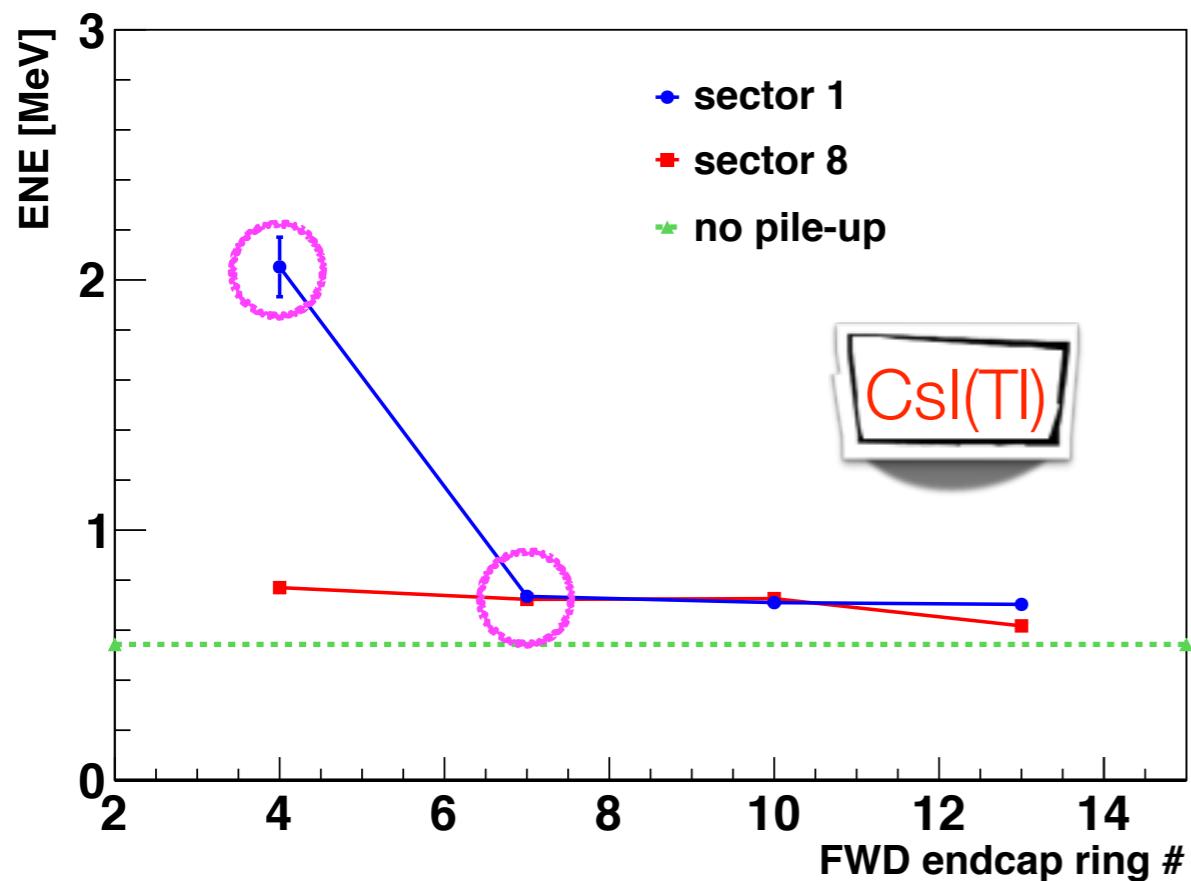
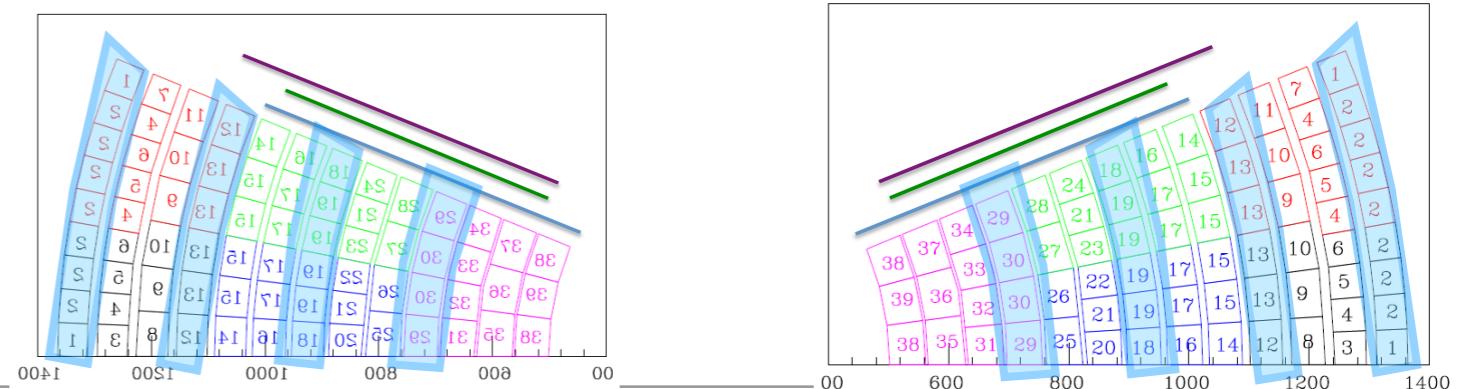
- Resolution MXP
- sigmaE/E FNC No pile-up

Resolution CsI Pure (Ring 4, Sector 1)

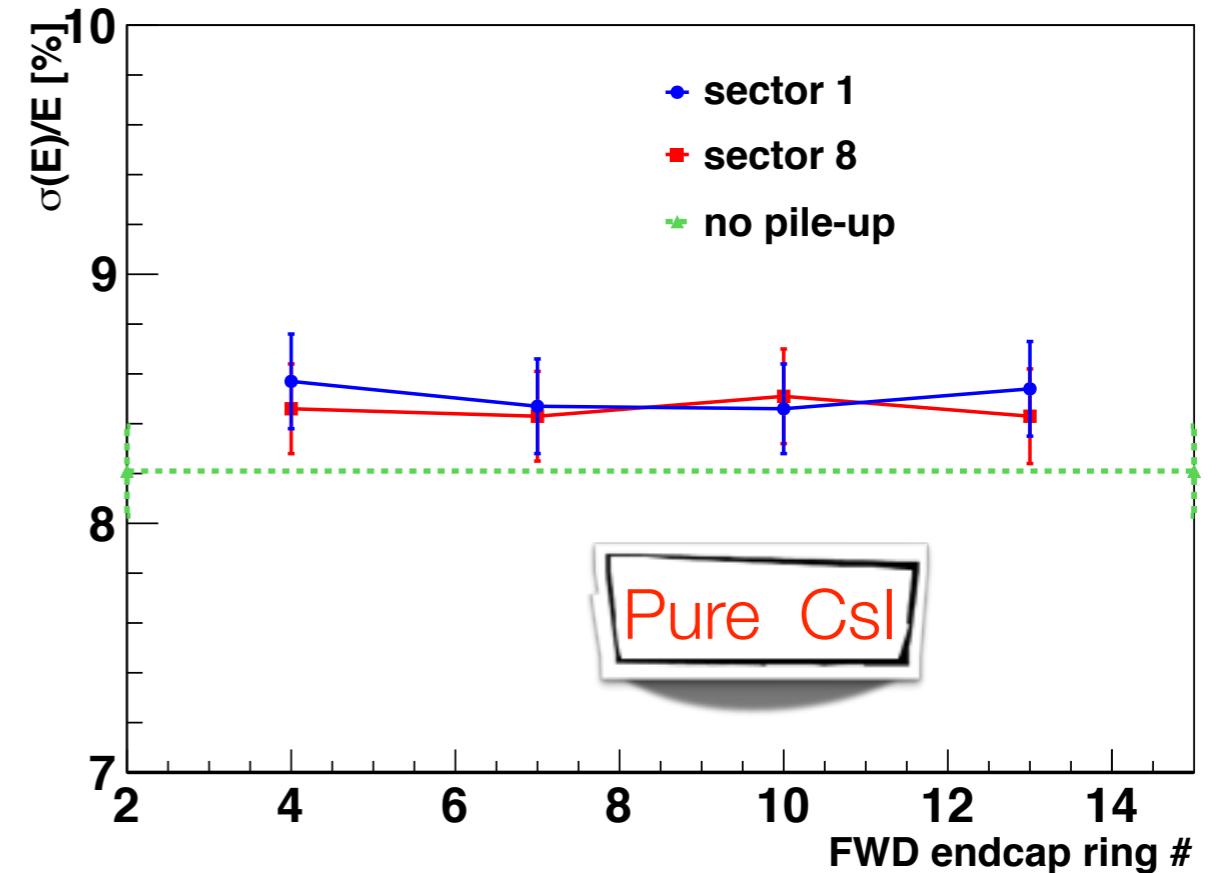
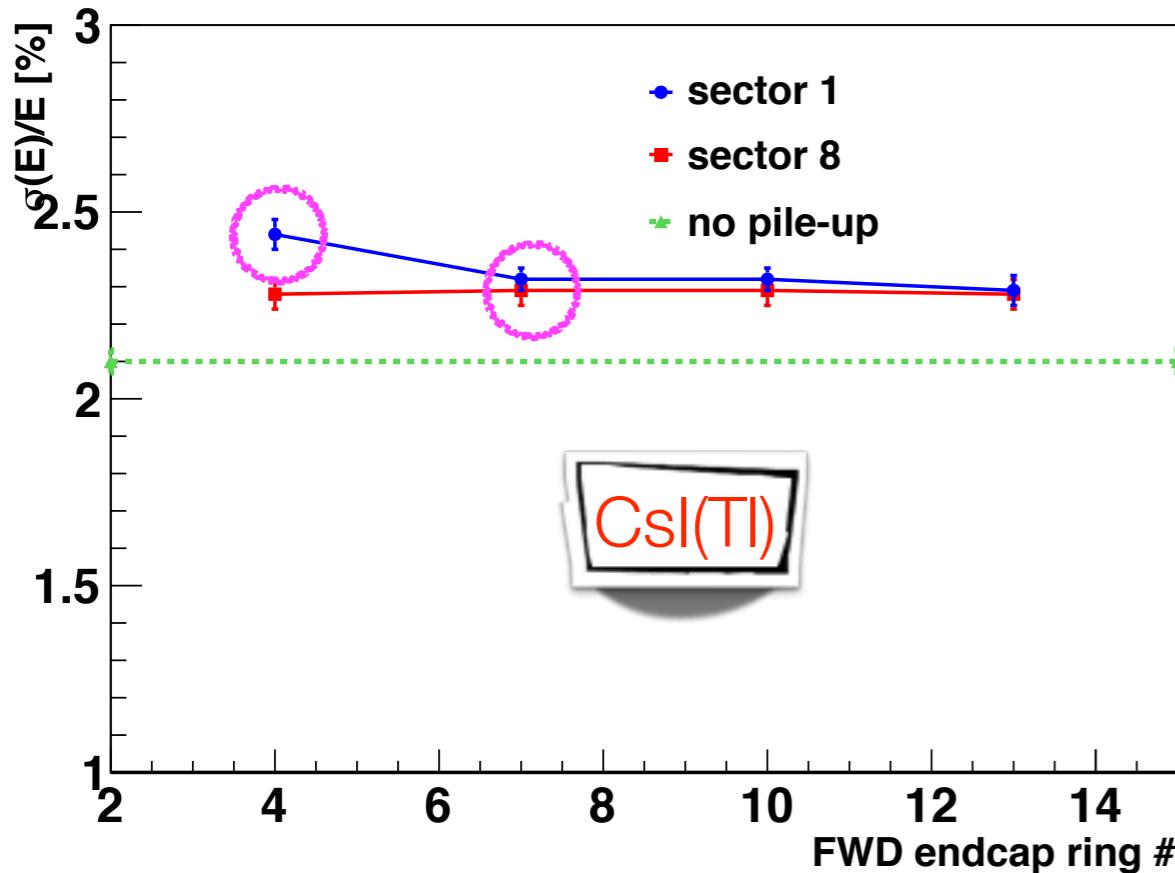


- Resolution MXP
- Resolution FNC

ENE vs ring/sector

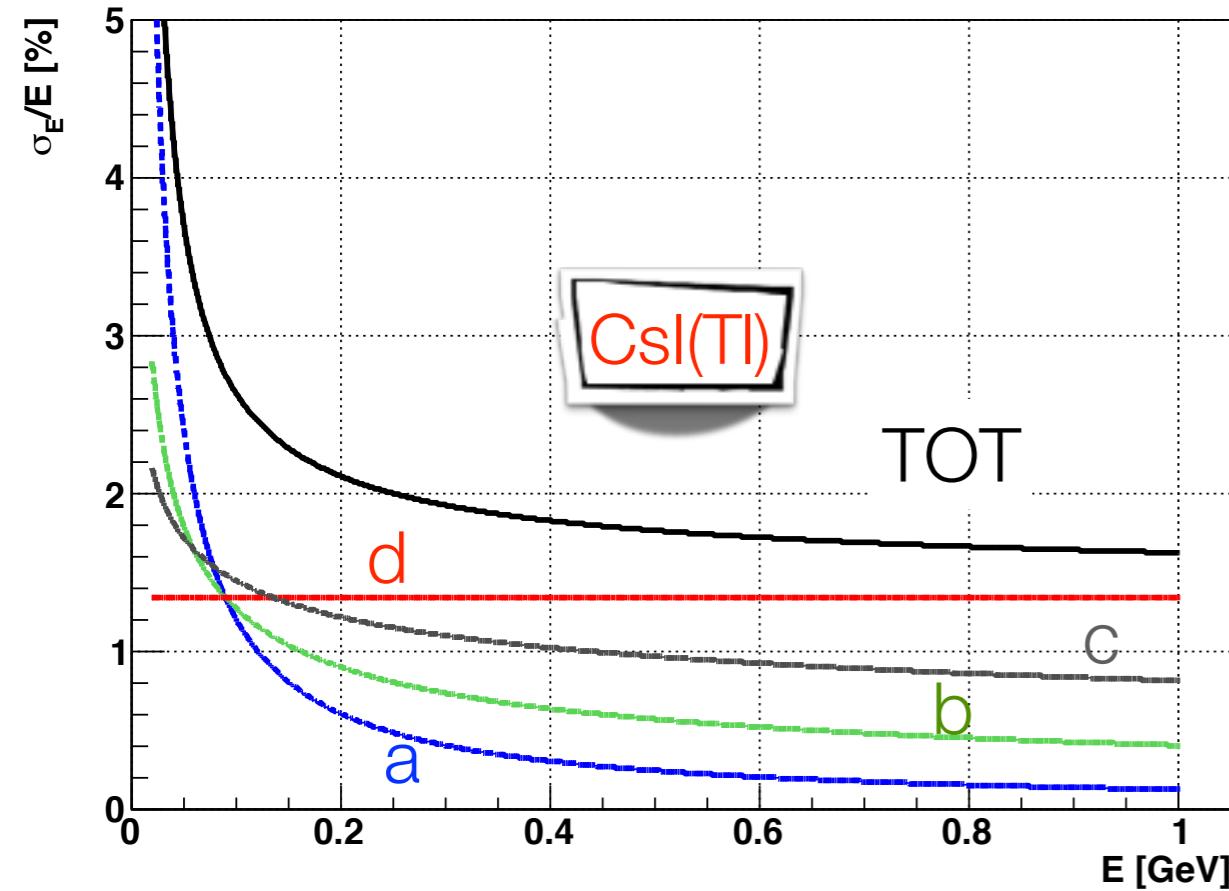


$\sigma(E)/E$ vs ring/sector



Relative energy resolution

$$\sigma/E = a/E \oplus b/\sqrt{E} \oplus c/\sqrt[4]{E} \oplus d$$



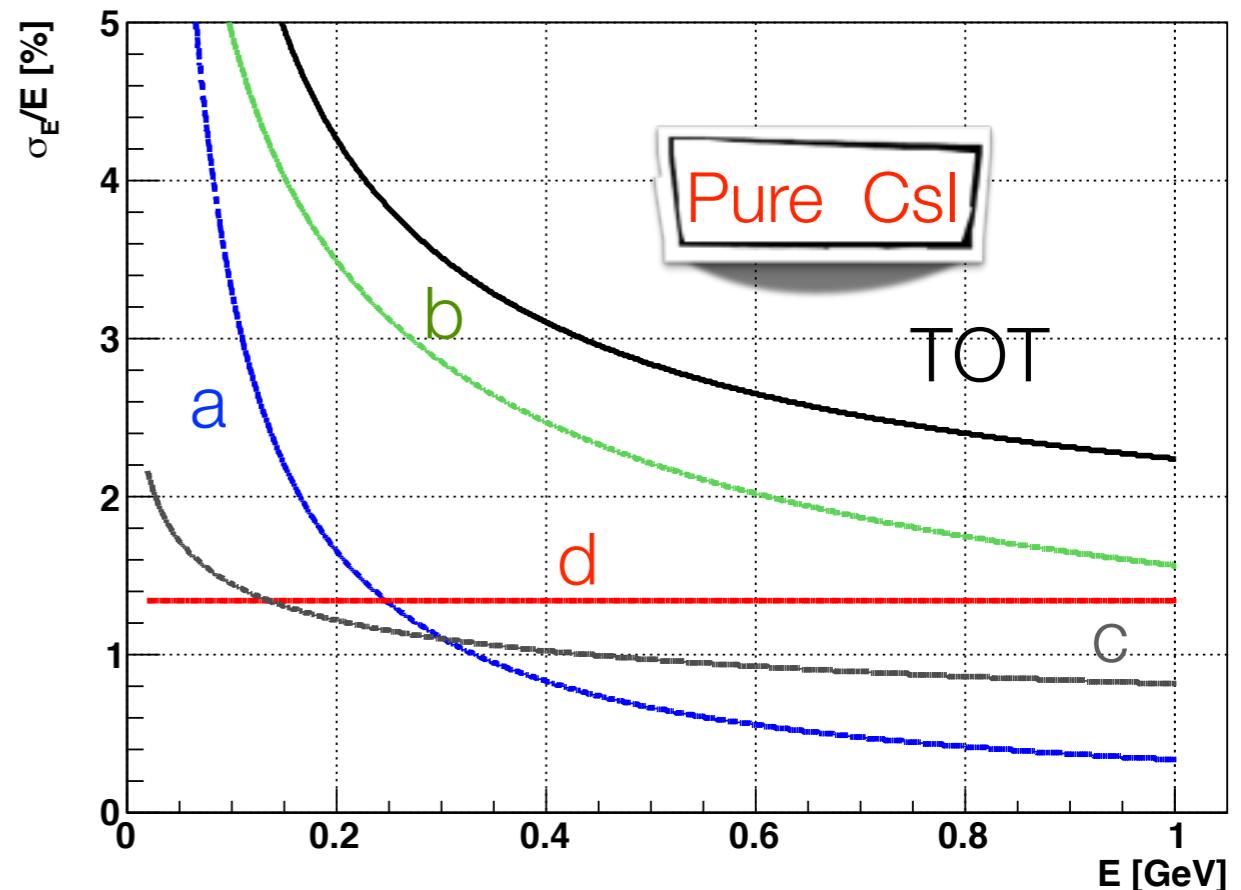
The stochastic term **b** in CsI(Tl) is negligible w.r.t. the shower shape fluctuation **c**.

Viceversa in pure CsI.

In the following **c** and **d** (calibration term) are assumed equal for CsI(Tl) and pure CsI.

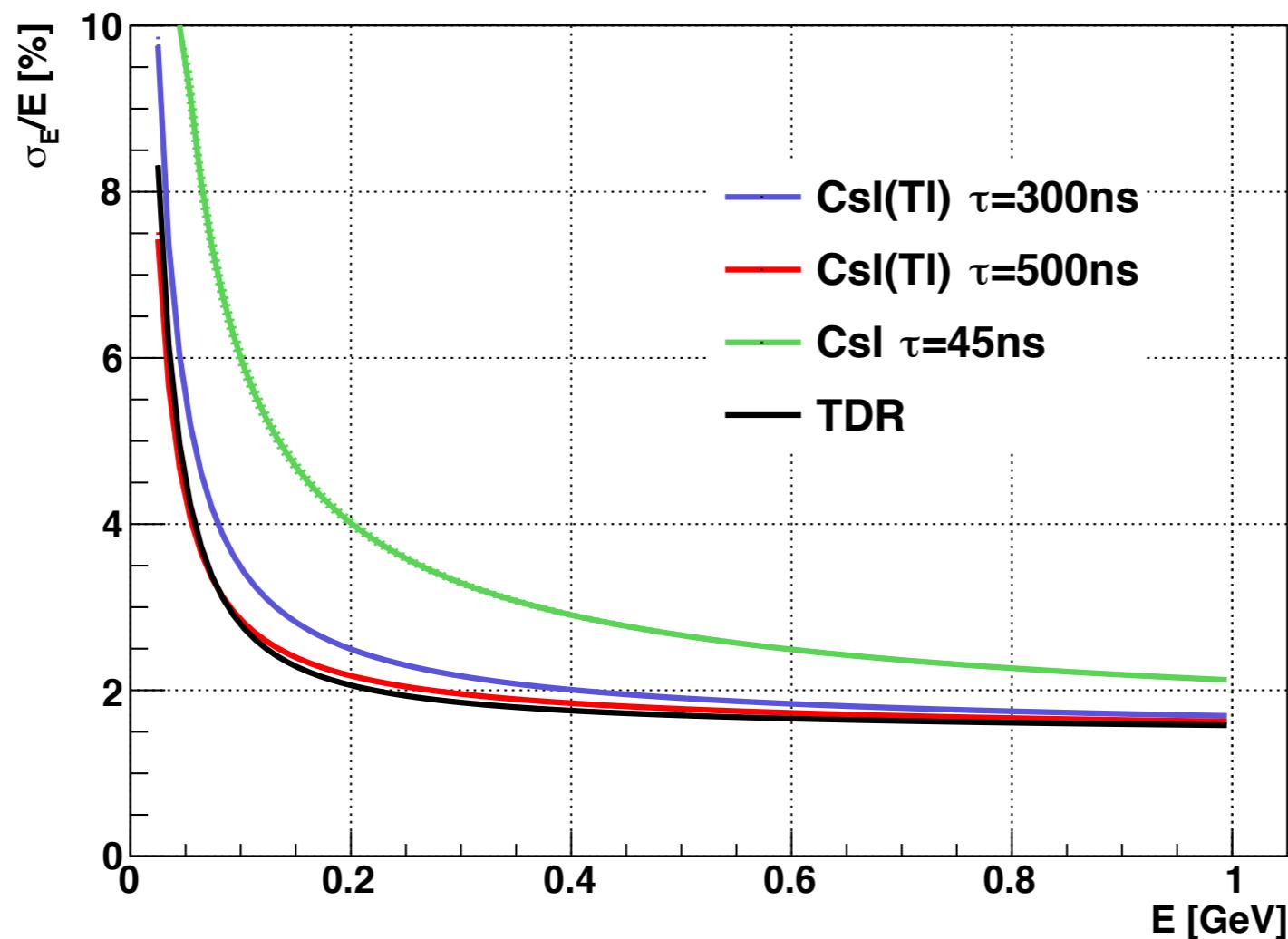
It is not clear however if one can keep the APD readout stability at the same level of PIN diodes and therefore 1.34% is adequate for APD as well

a → ENE
b → stochastic
 Bellell TDR: **c=0.81%** ~shower shape
d=1.34% ~calibration

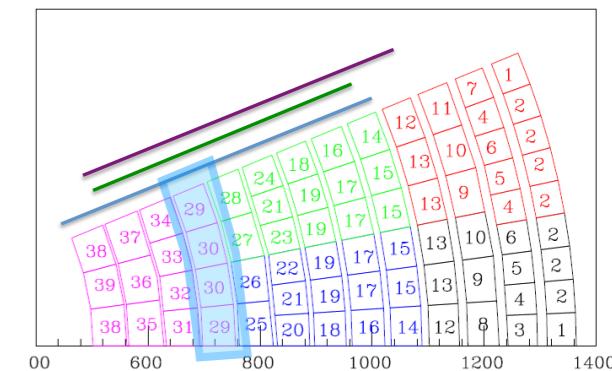


Relative energy resolution *no pile-up*

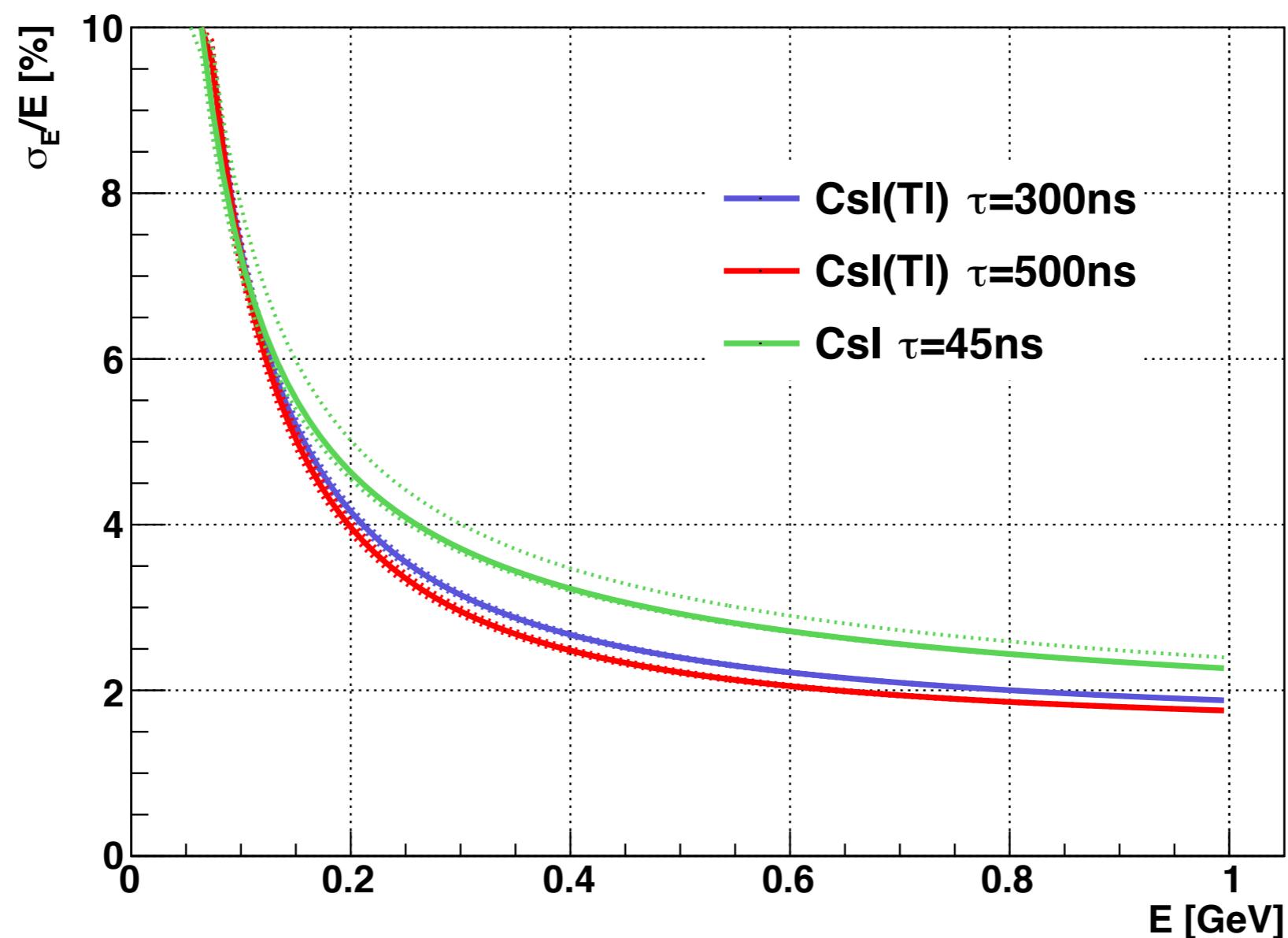
3x3 Matrix



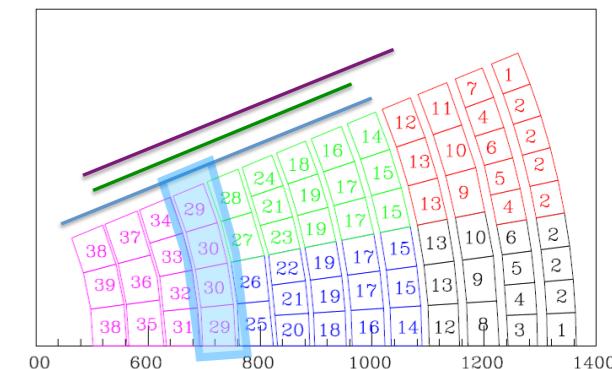
Relative energy resolution Ring 4 sector 1



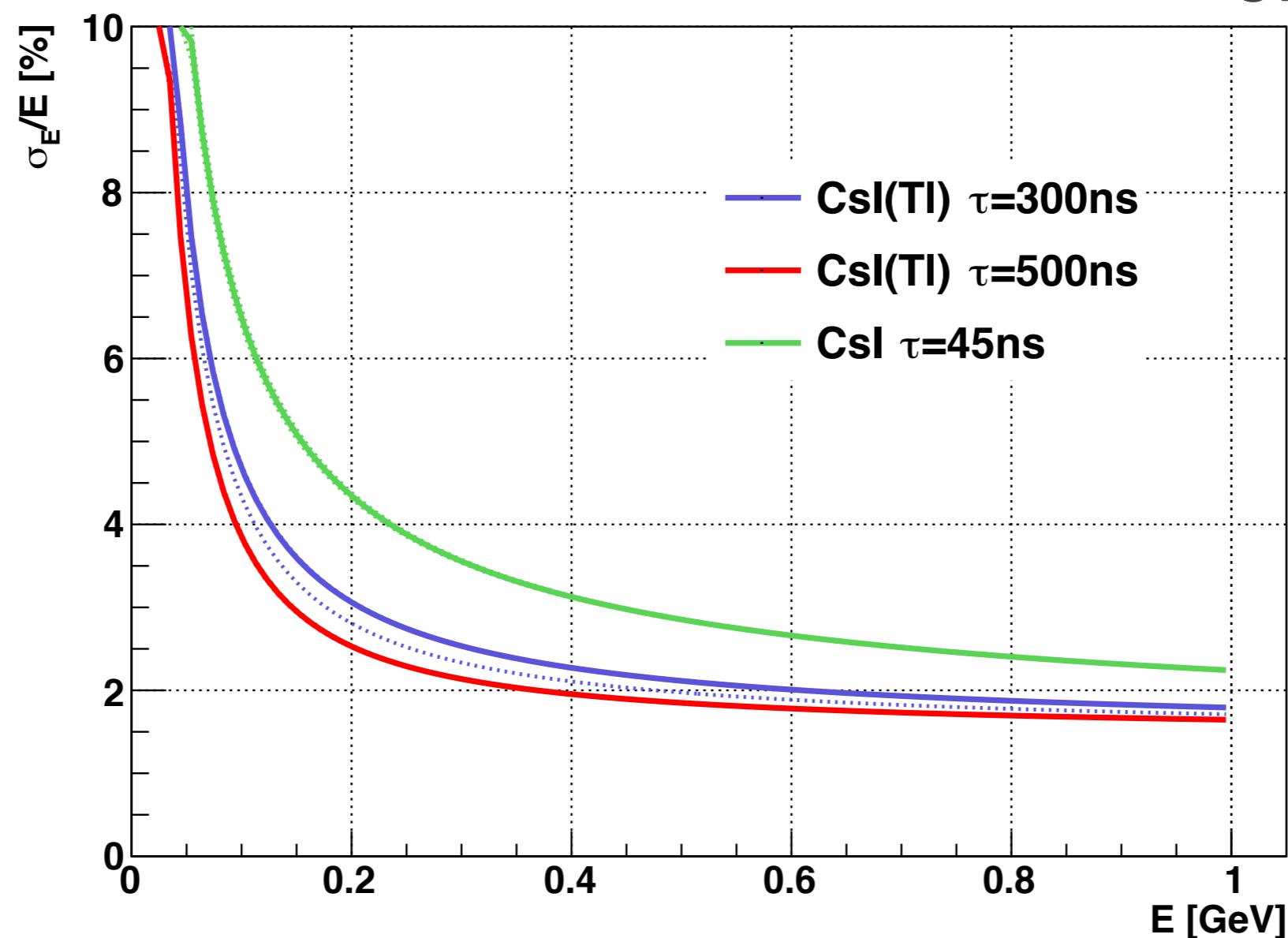
3x3 Matrix



Relative energy resolution Ring 7 sector 8

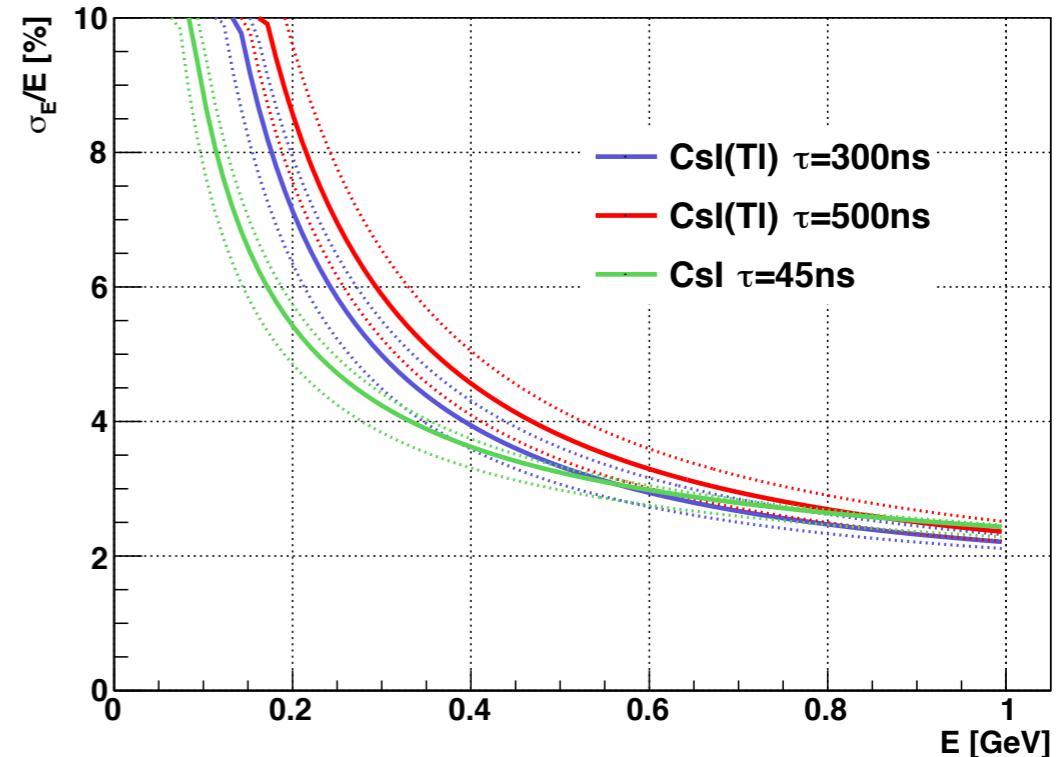
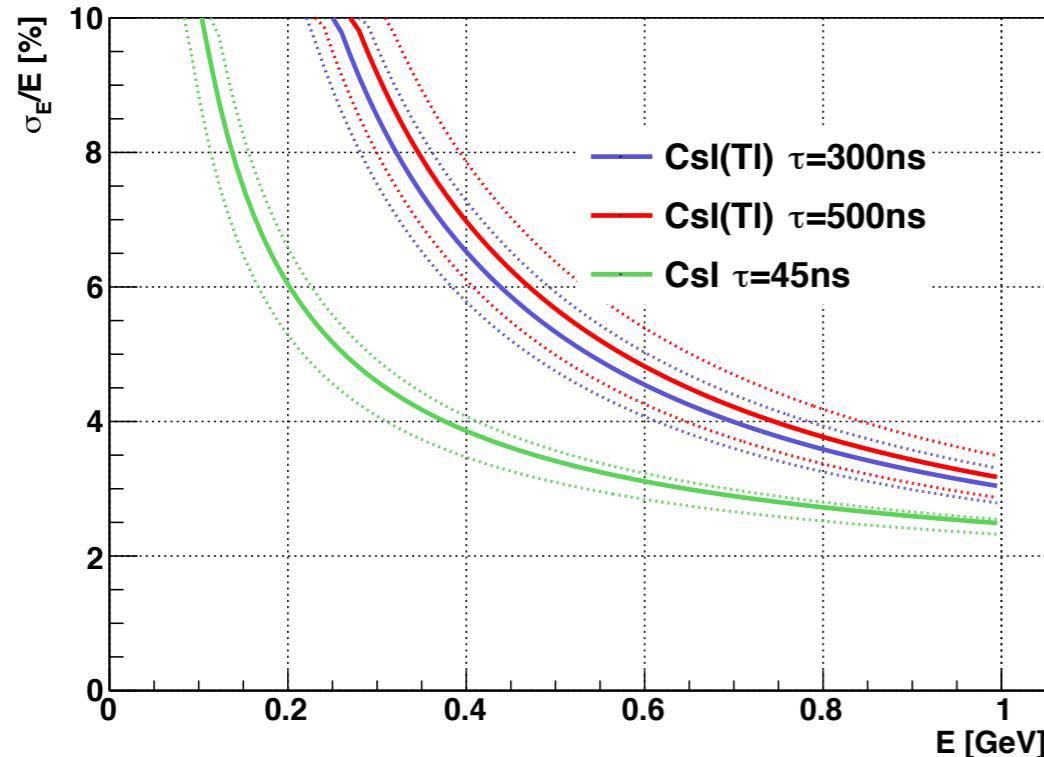


3x3 Matrix



FONDI ESTREMI

safety factor 3x E/μsec (ring 4 sect 1)



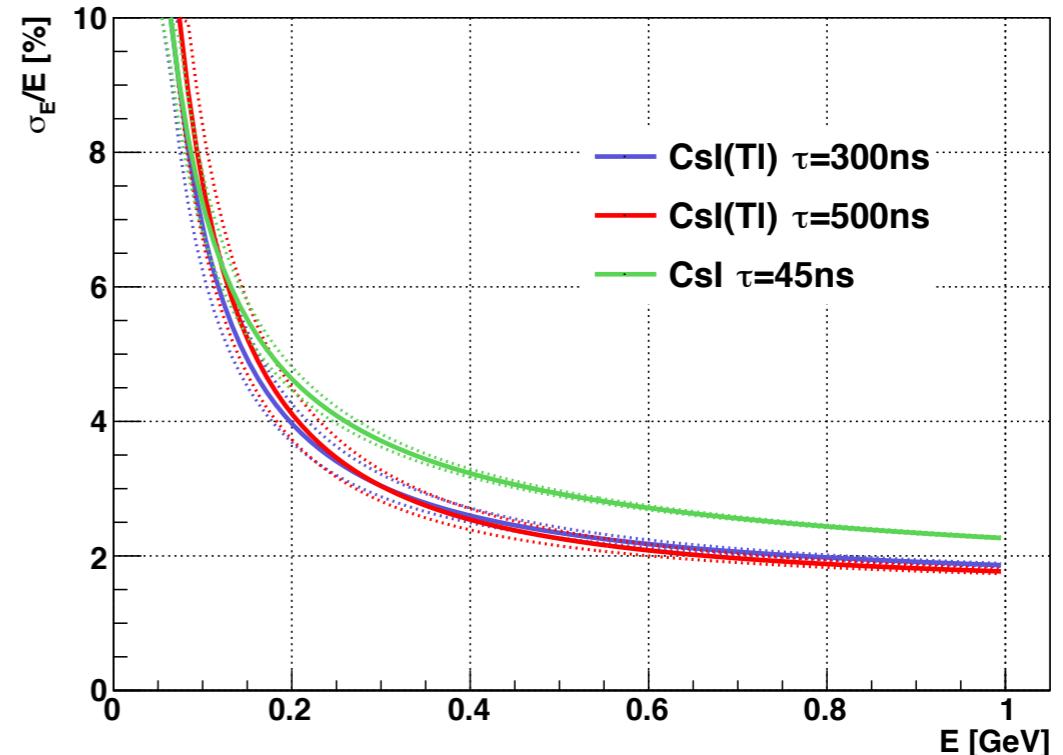
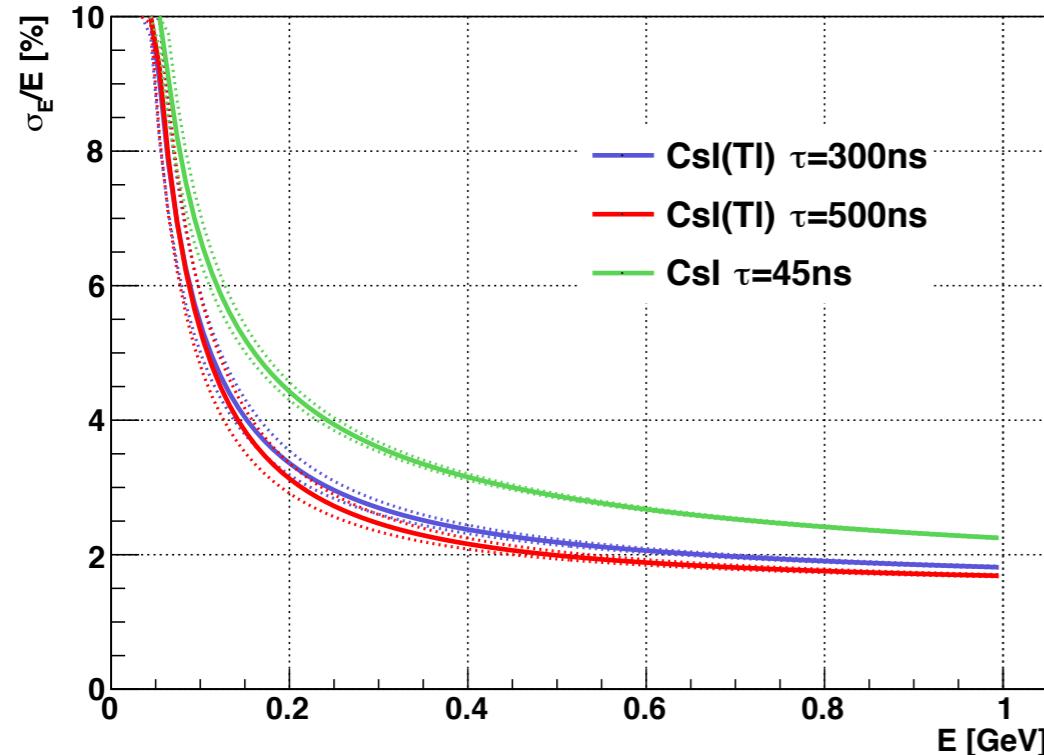
- ✓ E/μsec x 3
- ✓ hit/μsec nominale
- E/hit x 3

- CsI puro CsI(Tl) - CsI puro nettamente meglio nel caso **E/hit x 3**, marginalmente nel caso **E/hit costante**
- Non (mi) e' ovvio *in che modo* MC 11 potrebbe essere ottimistico (E/hit costante o x3?)

- ✓ E/μsec x 3
- ✓ hit/μsec x3
- E/hit nominale

FONDI ESTREMI -

safety factor 3x E/μsec (ring 7 sect 8)



- ✓ $E/\mu\text{sec} \times 3$
- ✓ hit/ μsec nominale
- $E/\text{hit} \times 3$

- ✓ $E/\mu\text{sec} \times 3$
- ✓ hit/ $\mu\text{sec} \times 3$
- $E/\text{hit} \text{ nominale}$

- Anche nel limite MC11 con $E/\text{hit} \times 3$ il $\text{CsI}(\text{TI})$ appare avere performance migliori

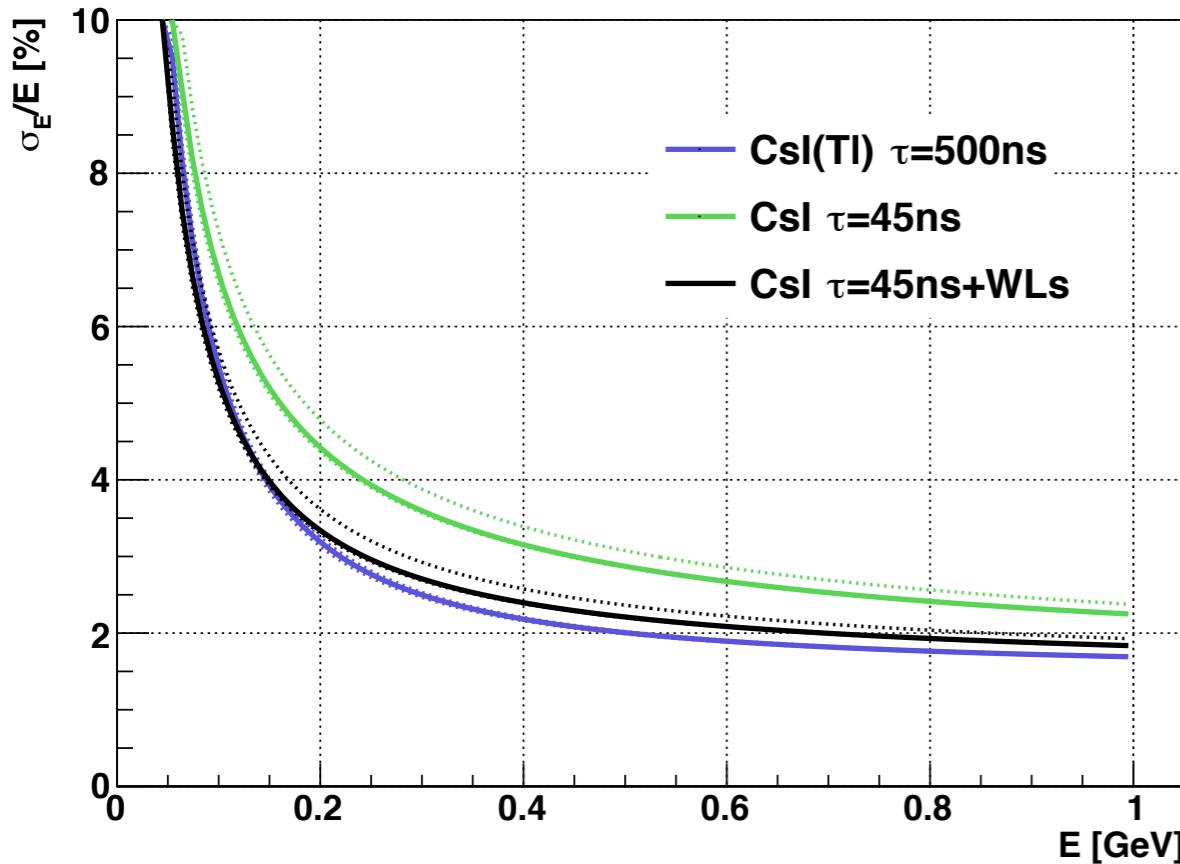
Concludendo

- Abbiamo studiato l'effetto del pile-up sulle performance del calorimetro e.m. di Belle II utilizzando dati reali
 - La simulazione del pile-up con i dati di raggi cosmici su singoli cristalli è stata validata confrontando due implementazioni completamente indipendenti, e con toy MC
- Si osserva l'atteso peggioramento delle performance dell'attuale calorimetro a causa del pile-up, mentre il CsI puro è più robusto soprattutto in condizioni estreme

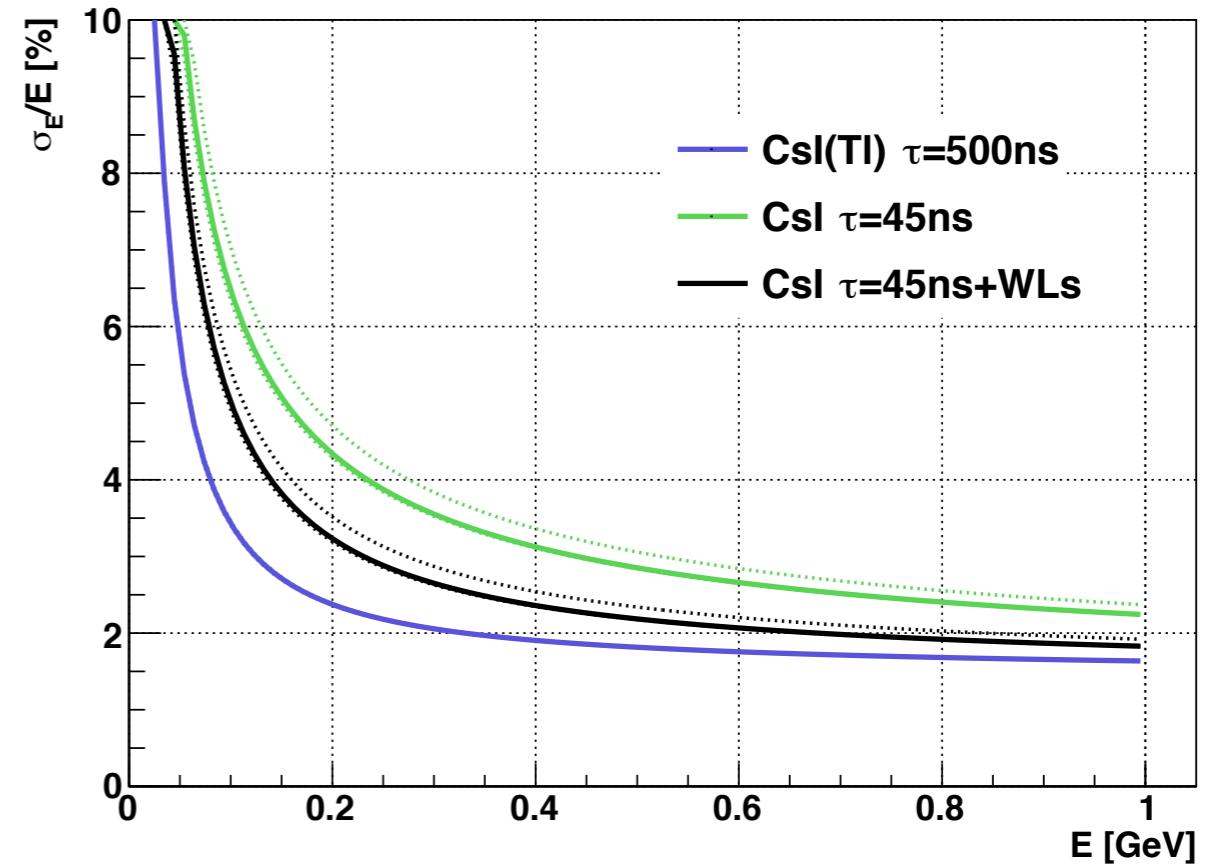
Concludendo

- Dati i livelli di fondo predetti dal MC, non c'e' tuttavia una chiara evidenza che un upgrade con CsI puro + APD migliorerebbe la situazione
 - CsI puro ha prestazioni migliori sono nella configurazione R4_S1 con fondo nominale x3
- Abbiamo in programma (a gennaio?) di studiare il pile-up con *cosmici + sorgente*
- Possibile aumentare il numero di p.e./MeV nel CsI + APD usando wavelength shifters (talk di Alessandro)
 - Aumenterebbe la resa di luce ma *non migliorerebbe* il contributo del pile-up!!

Relative energy resolution con WLS (3x segnale)



Ring 4 sector 1

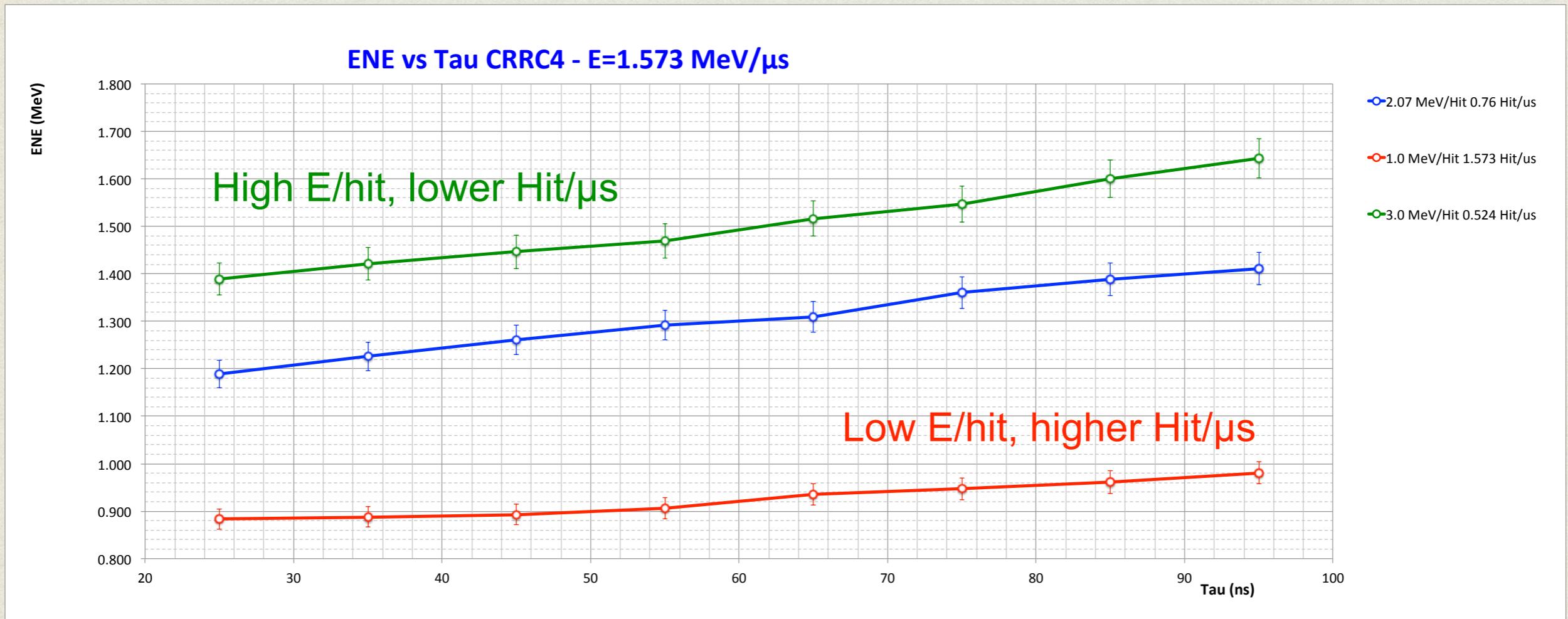


Ring 7 sector 1

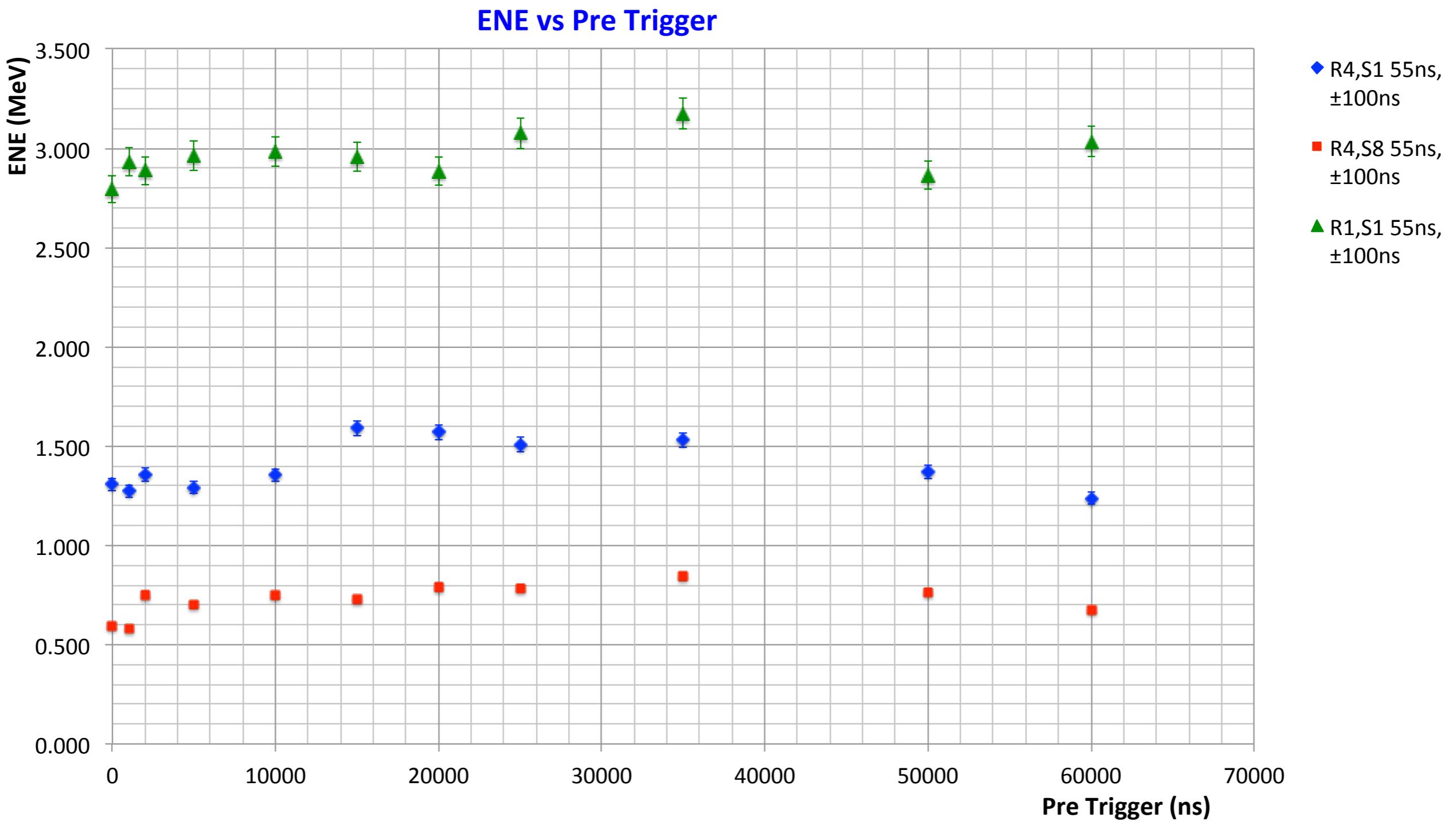
Backup slides

ENE VS ENERGY OF HITS

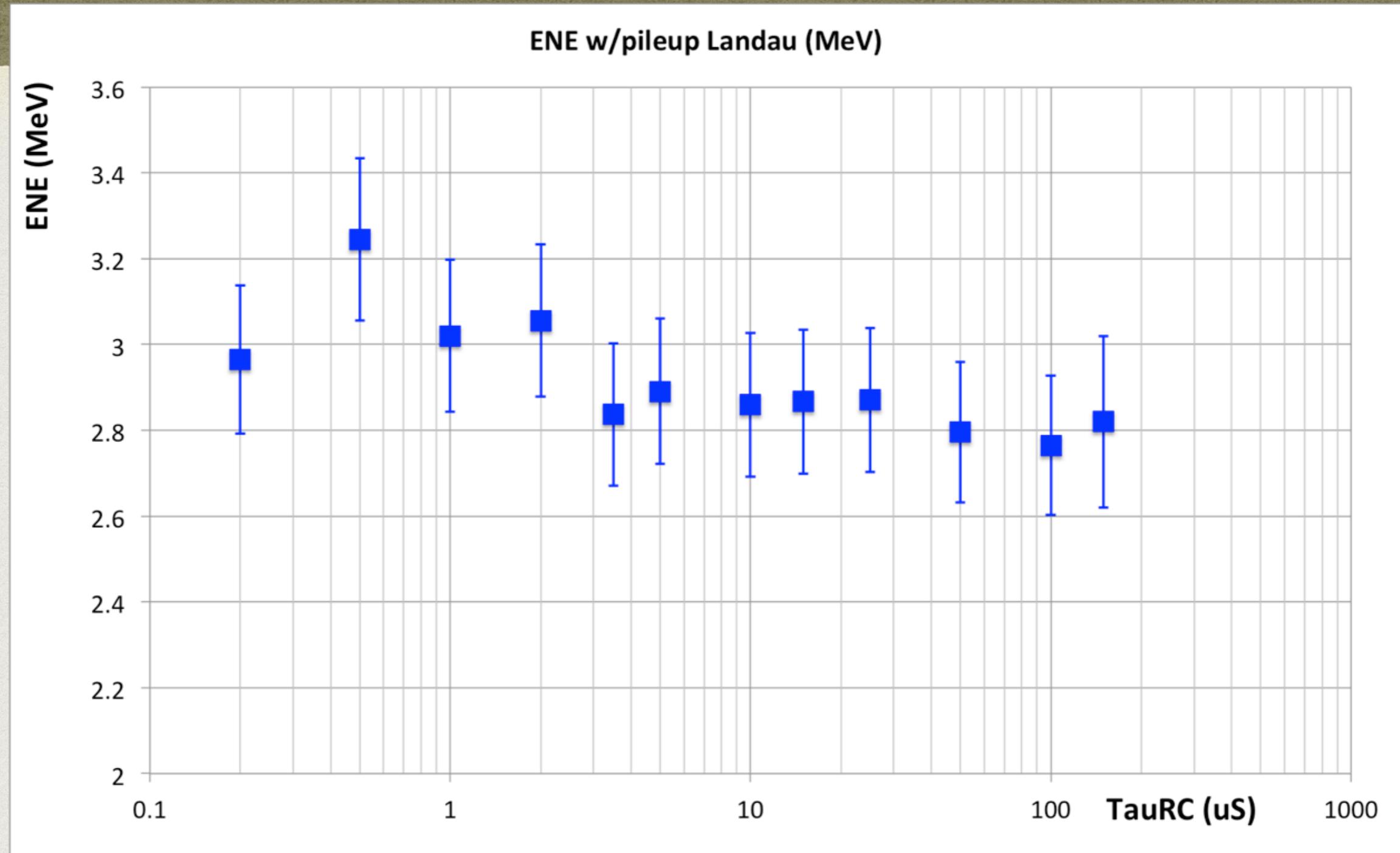
Total background energy fixed, change frequency/energy of hits



ENE VS PRE-TRIGGER



ENE VS TAURC



Little dependence observed