The University Of Sheffield.

Measurements of muon-induced neutrons at Modane

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On behalf of the EDELWEISS Collaboration

Expérience pour **DE**tecter **L**es **W**imps **En** **SI**te **S**outerrain

Outline

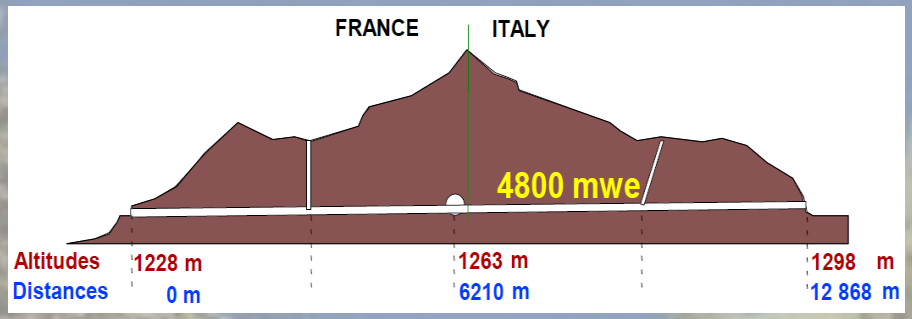
- Neutron counters at Modane.
- Neutron detection principle.
- Calibrations.
- Data and simulations: time distributions, energy spectra, multiplicity.
- Results and conclusions.

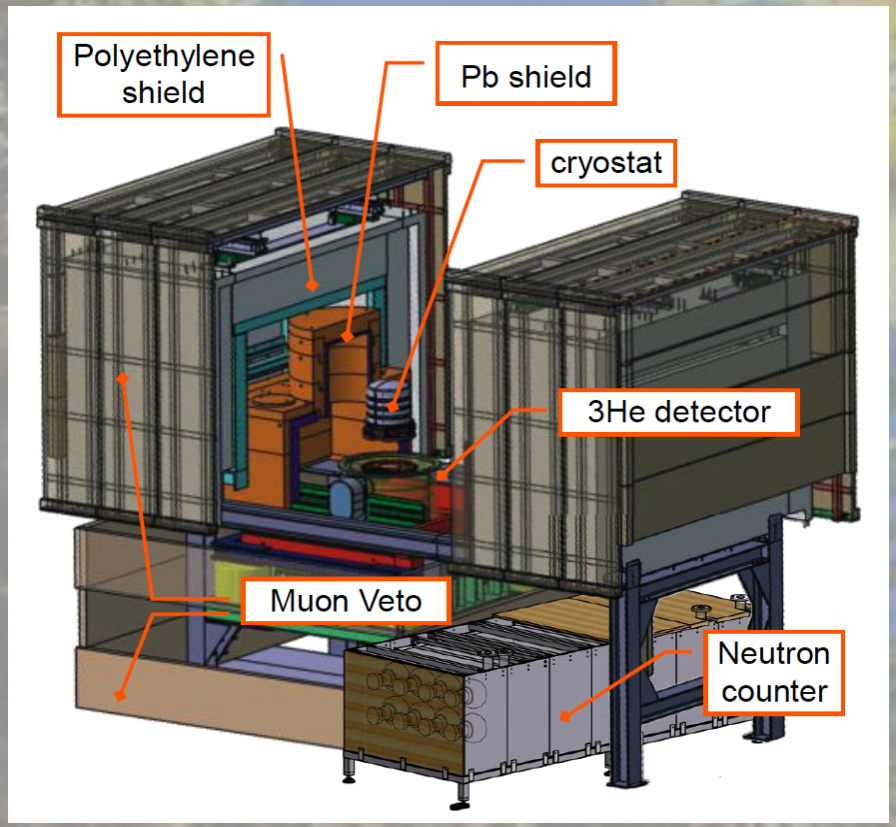
The EDELWEISS Collaboration:

- CEA, Saclay (IRFU, IRAMIS)
- CSNSM, Orsay (CNRS/IN2P3, U. Paris Sud)
- IPN, Lyon (CNRS/IN2P3, Univ. Lyon 1)
- Institut Néel, Grenoble (CNRS/INP)
- Laboratoire Souterrain de Modane
- Karlsruhe Institute of Technology (IEKP, IKP, ITP)
- JINR, Dubna
- University of Oxford
- University of Sheffield

Karlsruhe - September 2011

EDELWEISS setup



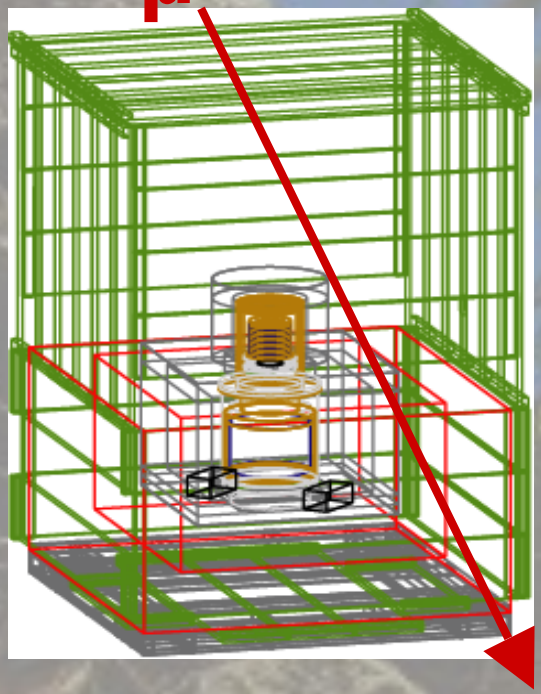


- LSM - deepest working lab in EU:
  - ~4 μ/m²/day (through a thin horizontal detector);
  - ~10^{-6} n/cm²/s (E > 1 MeV) - measurements (radioactivity).
- Gamma-ray and neutron shielding - 20 cm Pb + 50 cm of PE.
- Muon veto (>98% geometrical efficiency).
- Neutron detectors.
- Muon-induced neutron studies using 1-tonne Gd-loaded scintillator:
  - Coincidences between muon veto and Ge detectors (direct link to DM searches)
  - Coincidences between veto and n-captures in liquid scint.
  - Several neutron captures.

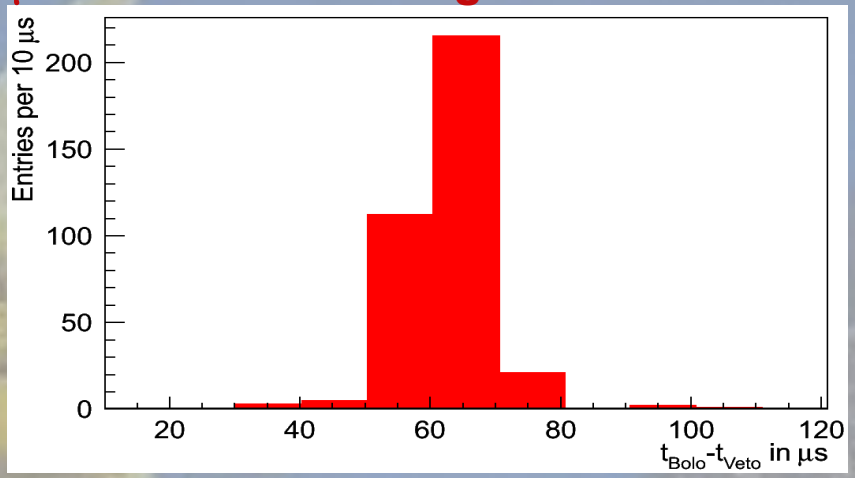
μ-induced neutrons in Ge bolometers

- **Neutrons from muons:**
  - 100 m² of active veto (42 BC412 plastic scintillator modules);
  - Almost full coverage;
  - Muon track reconstruction.

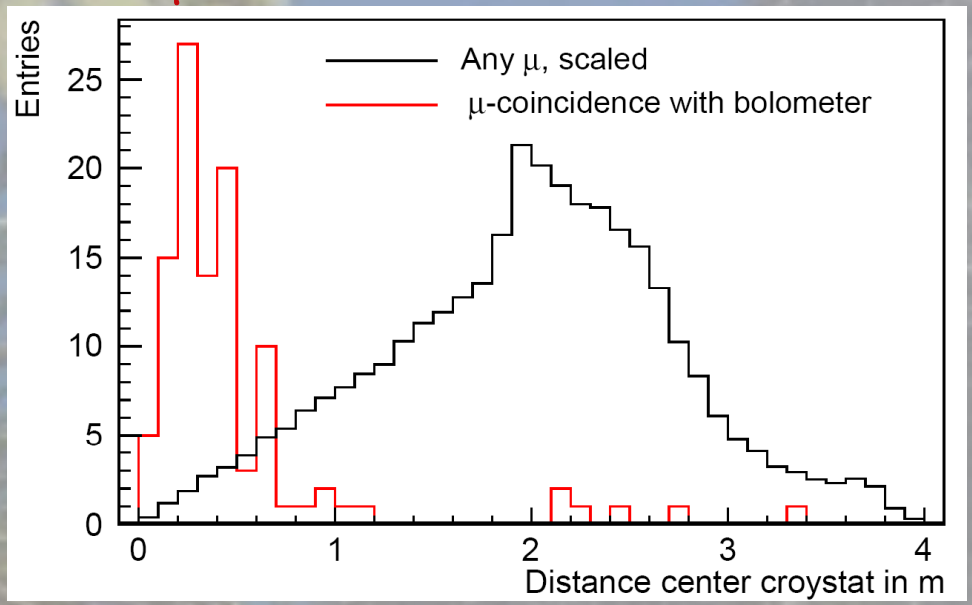
μ



μ – bolometer timing

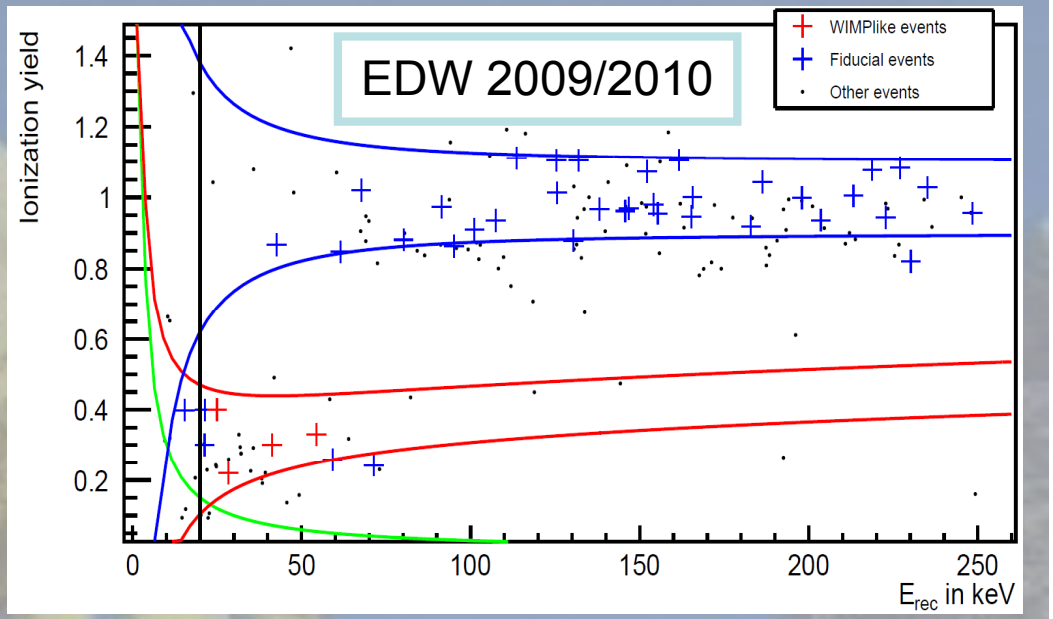


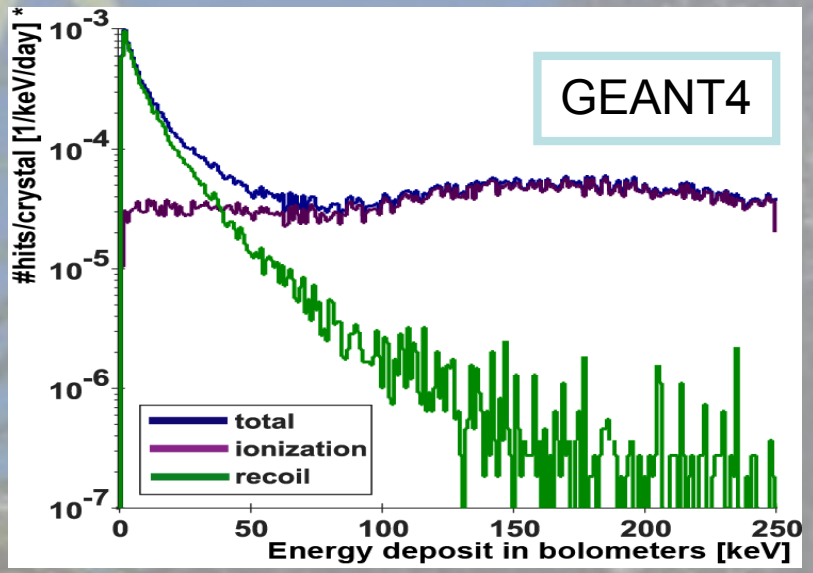
μ track reconstruction



μ-induced neutrons in Ge bolometers

- 534 kg×d - 234 *μ*-bolo coincidences.
- 4 evts. in WIMP-RoI (*Q*, 20<E<250keV).
- R = 0.008 ± 0.004 n/kg/d.
- Muon detection efficiency:
  - Select m(bolo)>1, *E*(bolo)>7MeV:
  - 31 “gold-plated” μ´s.
  - All seen by μ veto.
  - *ε*(*μ*-veto) ≥ 92,8% (90%CL)
- All numbers limited by small statistics

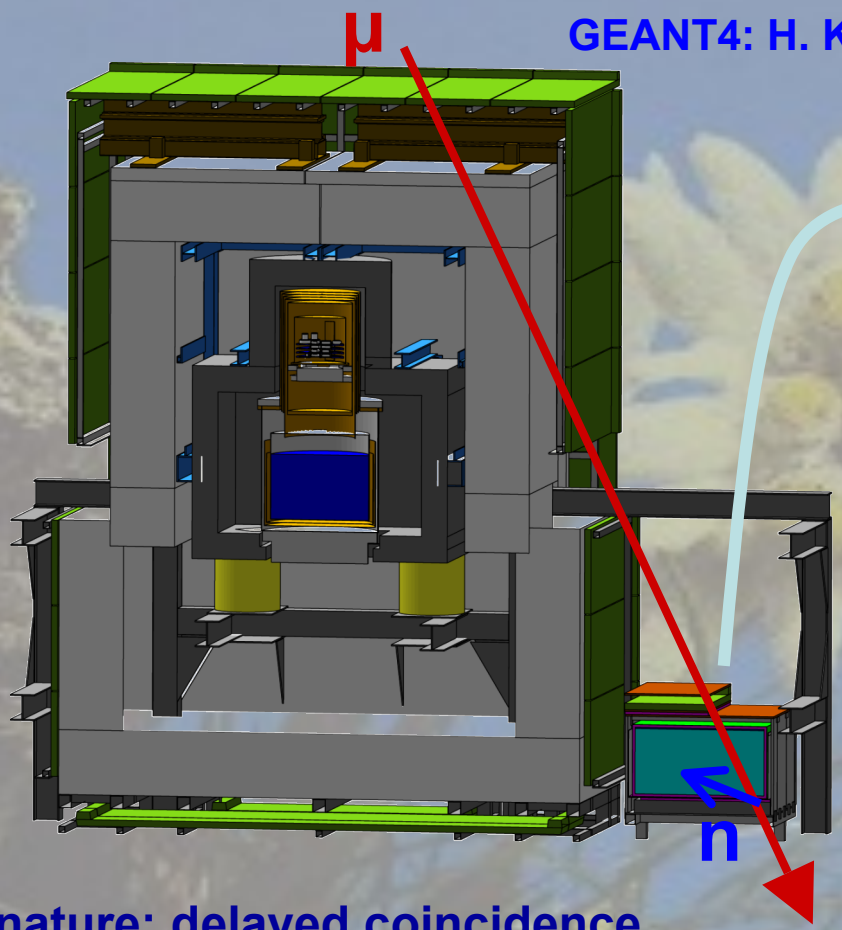


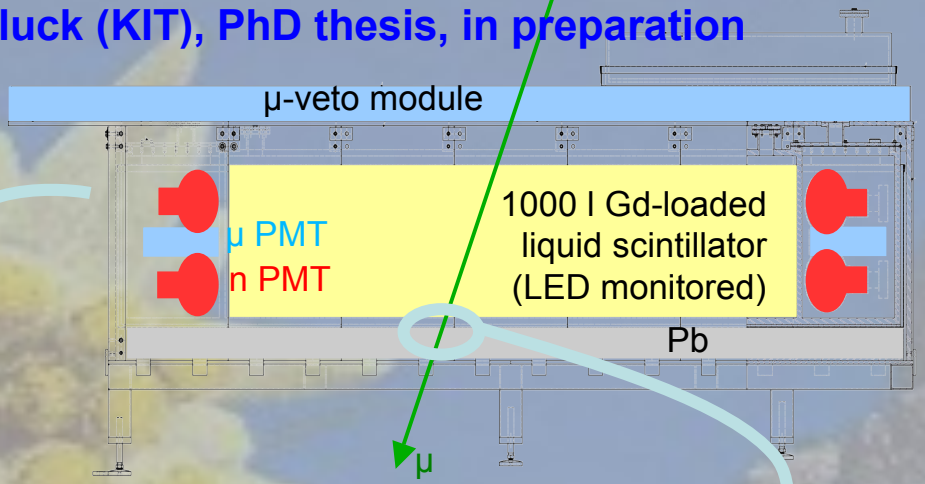


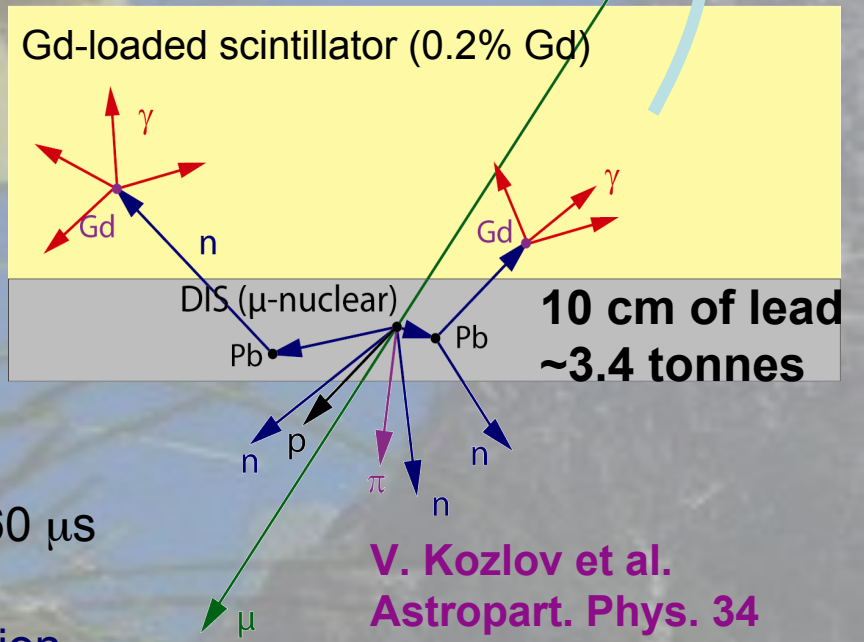
μ-induced energy deposition in Ge crystals; M Horn. PhD thesis (KIT, 2007).

μ-induced neutrons in LSM: setup

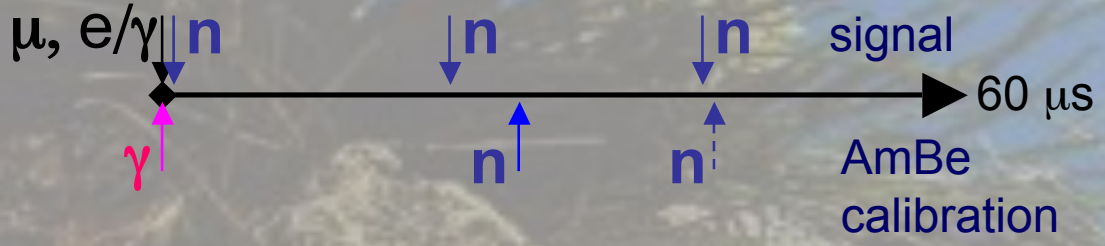
GEANT4: H. Kluck (KIT), PhD thesis, in preparation







Signature: delayed coincidence



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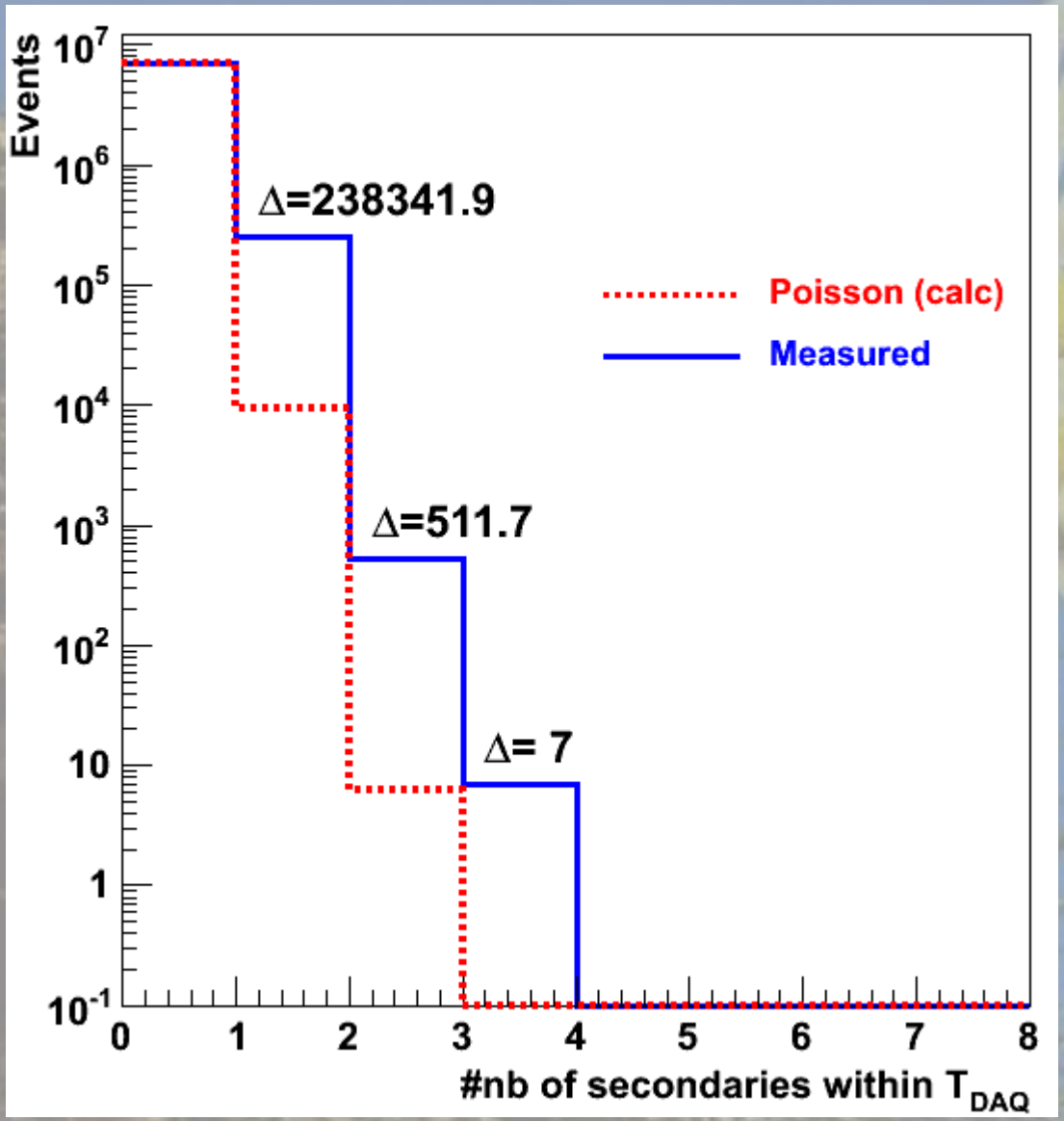
AmBe calibrations: multiplicity

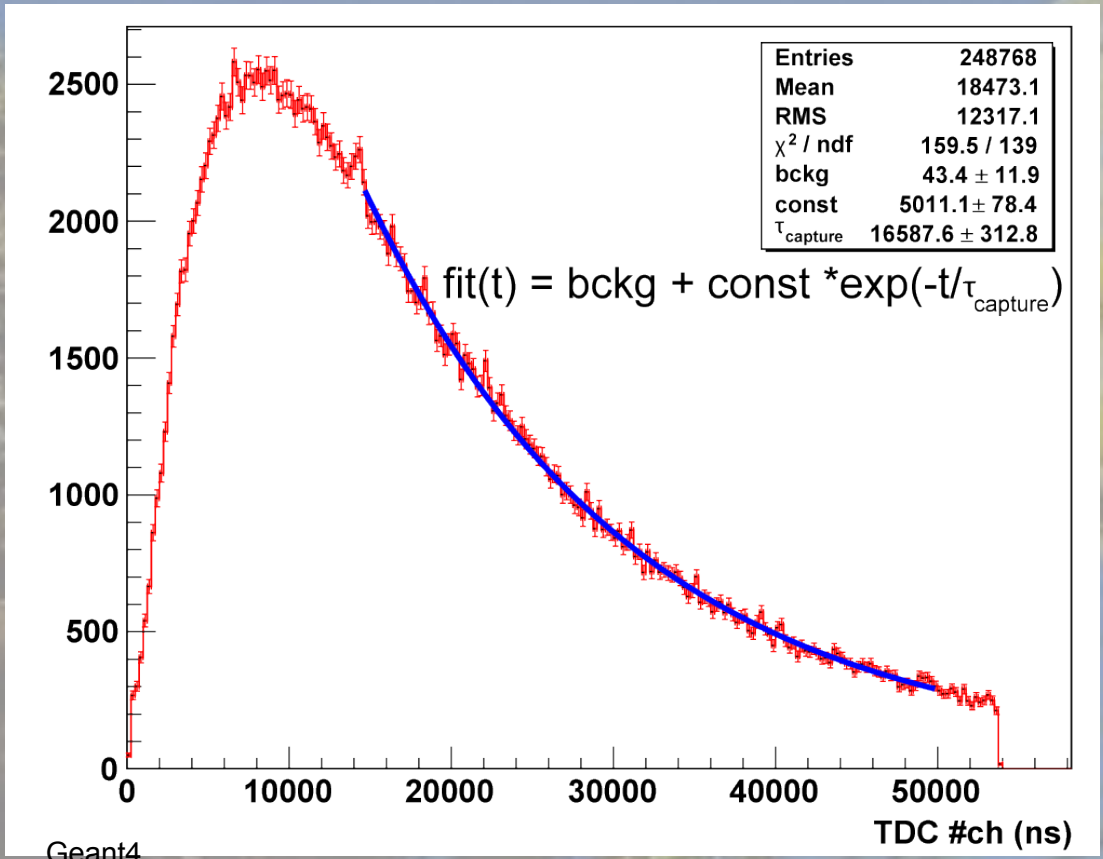


~3.94 days

Neutron source ~20 n/s,

T_{daq}=53.4 μs

AmBe calibrations: time delay



Geant4

Gd content, %	0.18	0.19	0.20	0.21	0.22
$\tau_{capture}$, ns	17800	17100	16290	15600	15000
$\Delta\tau_{capture}$, ns	±100	±100	±90	±80	±80

- AmBe source: ~20 n/s.
- E_n up to ~11 MeV, mean energy at ~4 MeV.
- Mean capture time on Gd: 19 μs.
- Capture time constant: 16.6 ± 0.3 μs.
- Agreement with GEANT4 (G4 9.2.p01).

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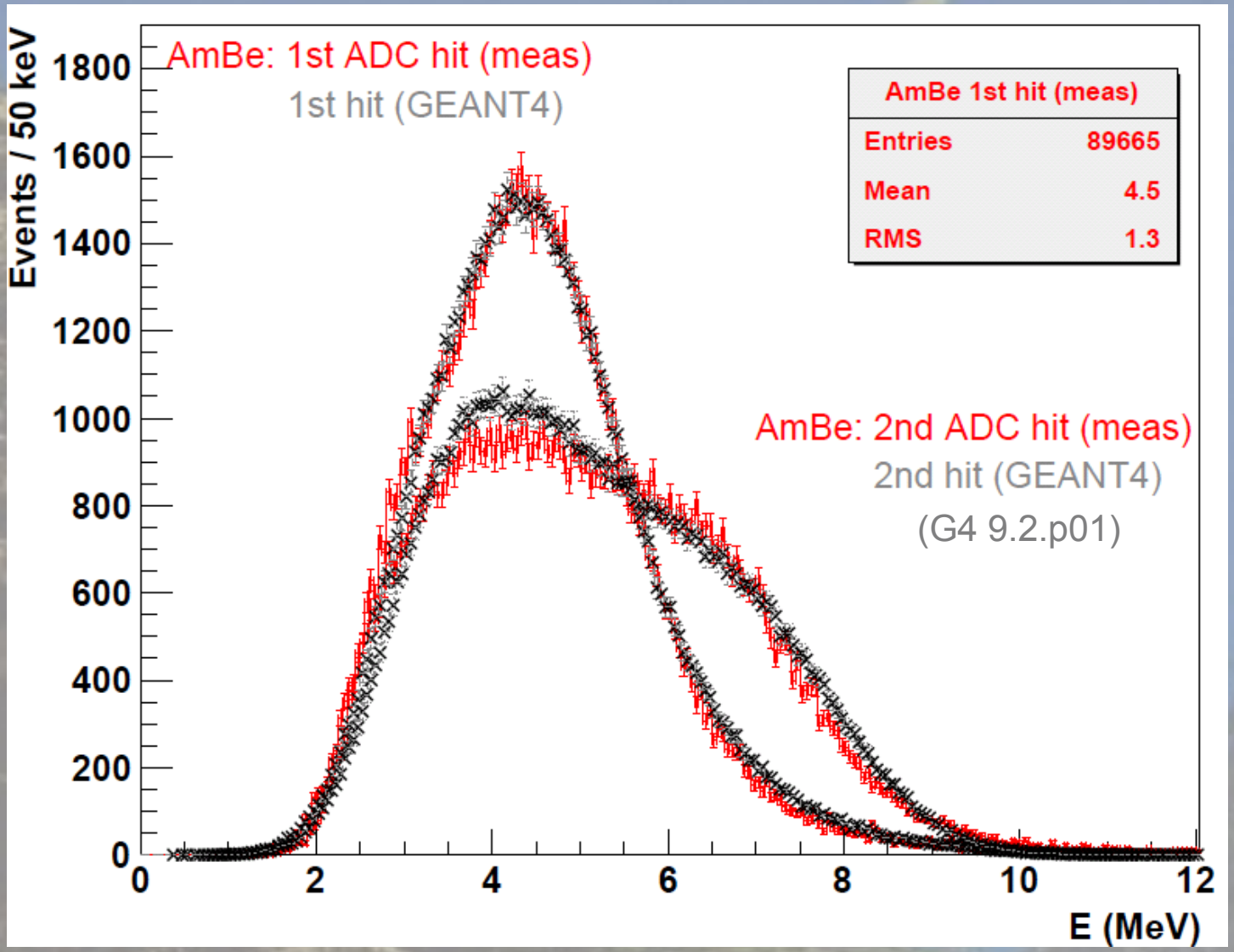
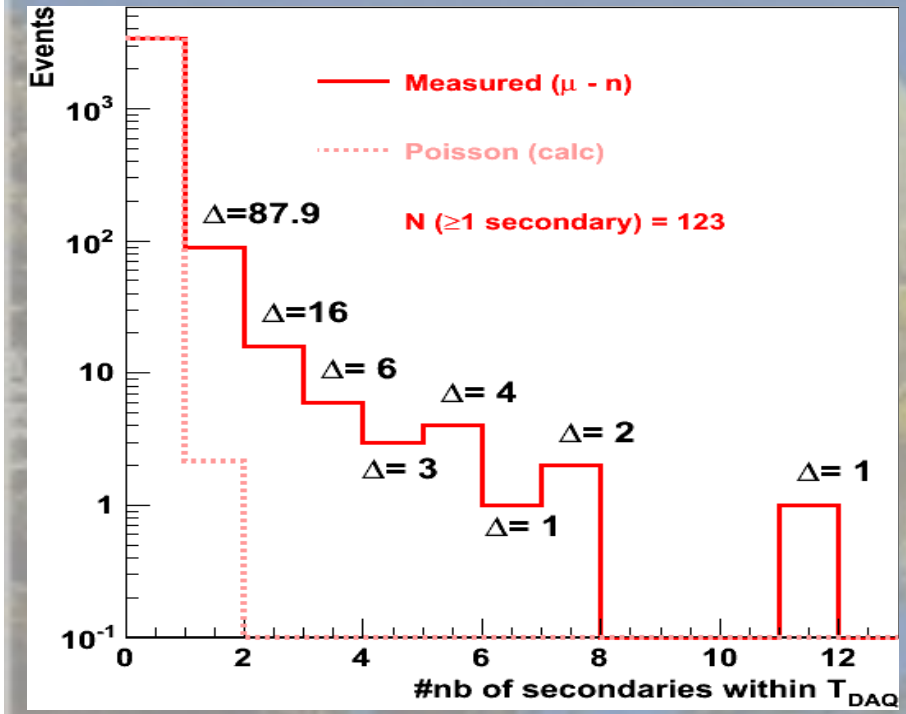
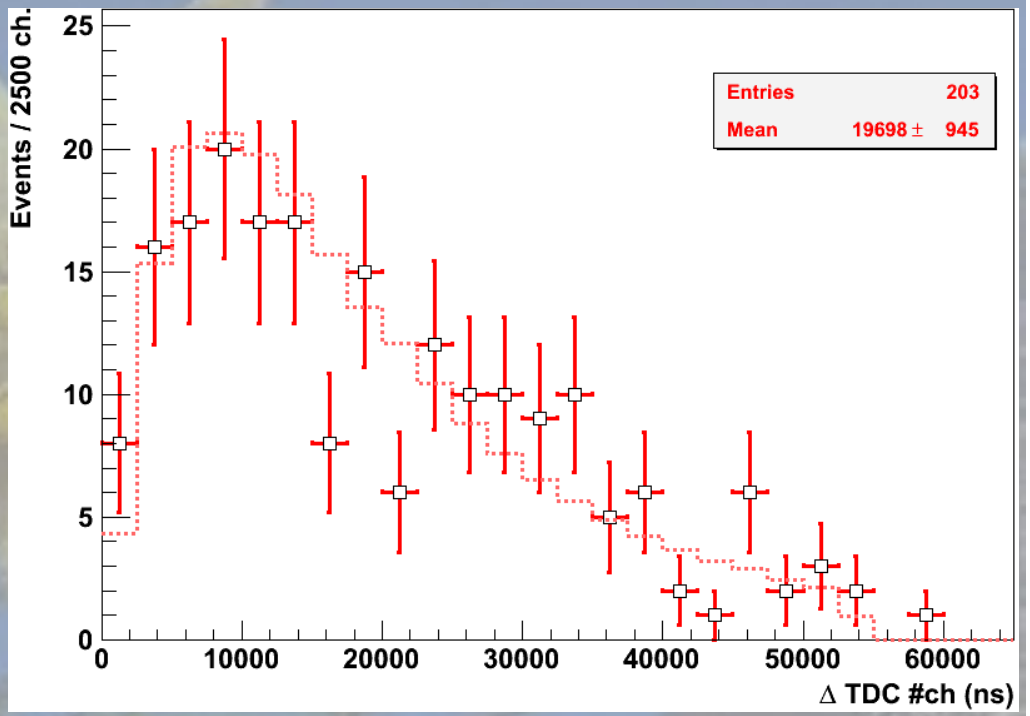
AmBe calibrations: energy spectra



Data: multiplicity and time delay





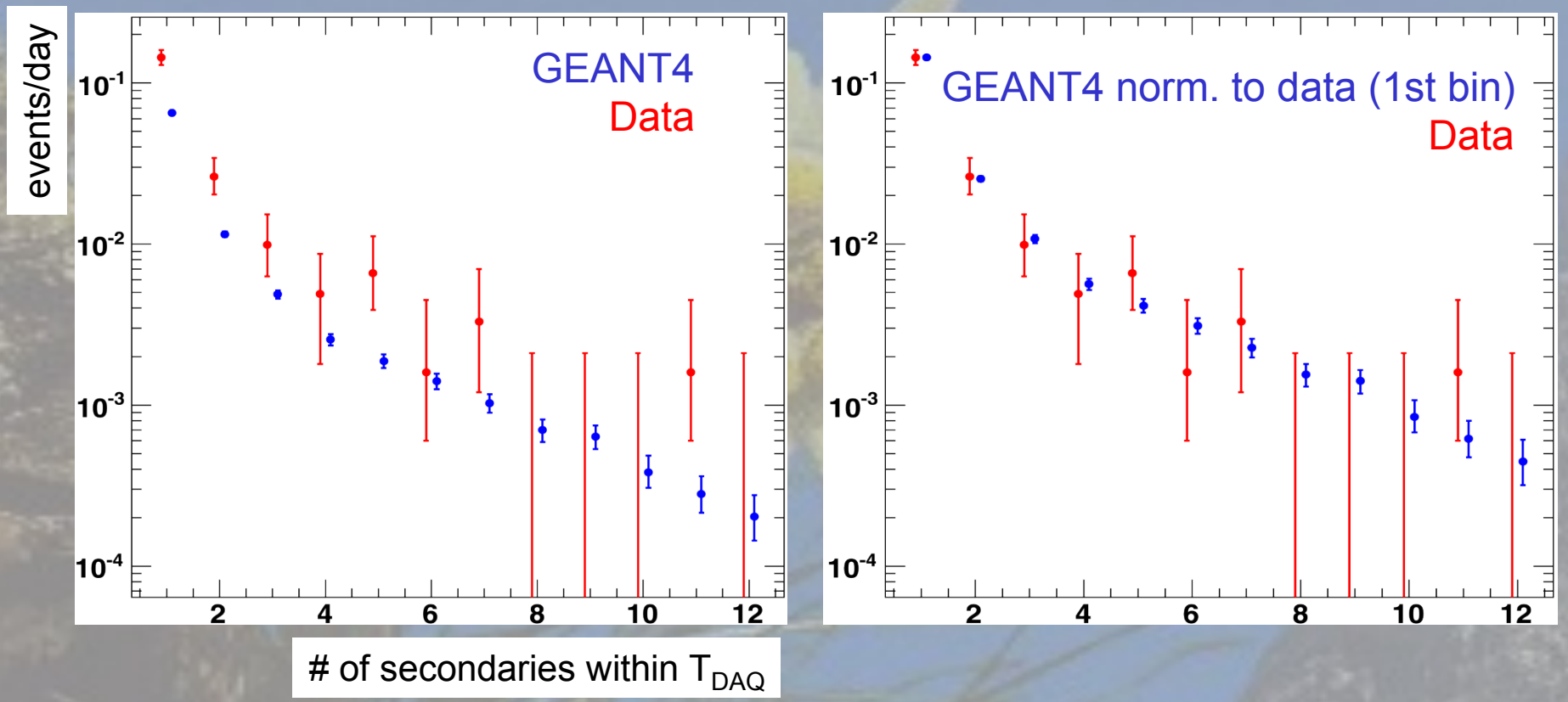
- T_{DAQ}=60 μs
- 04/09 - 08/11: ~608 live days
  μ candidates: 3507
  N_{event} (≥1 secondary) = 123
  $N_{secondaries}$ = 203

——— $\langle\Delta t_{sec}\rangle$ (data) = 19.7 μs

----- $\langle\Delta t_{sec}\rangle$ (AmBe) = 19.0 μs

- 13% probability for the same parent distribution (K-S test)

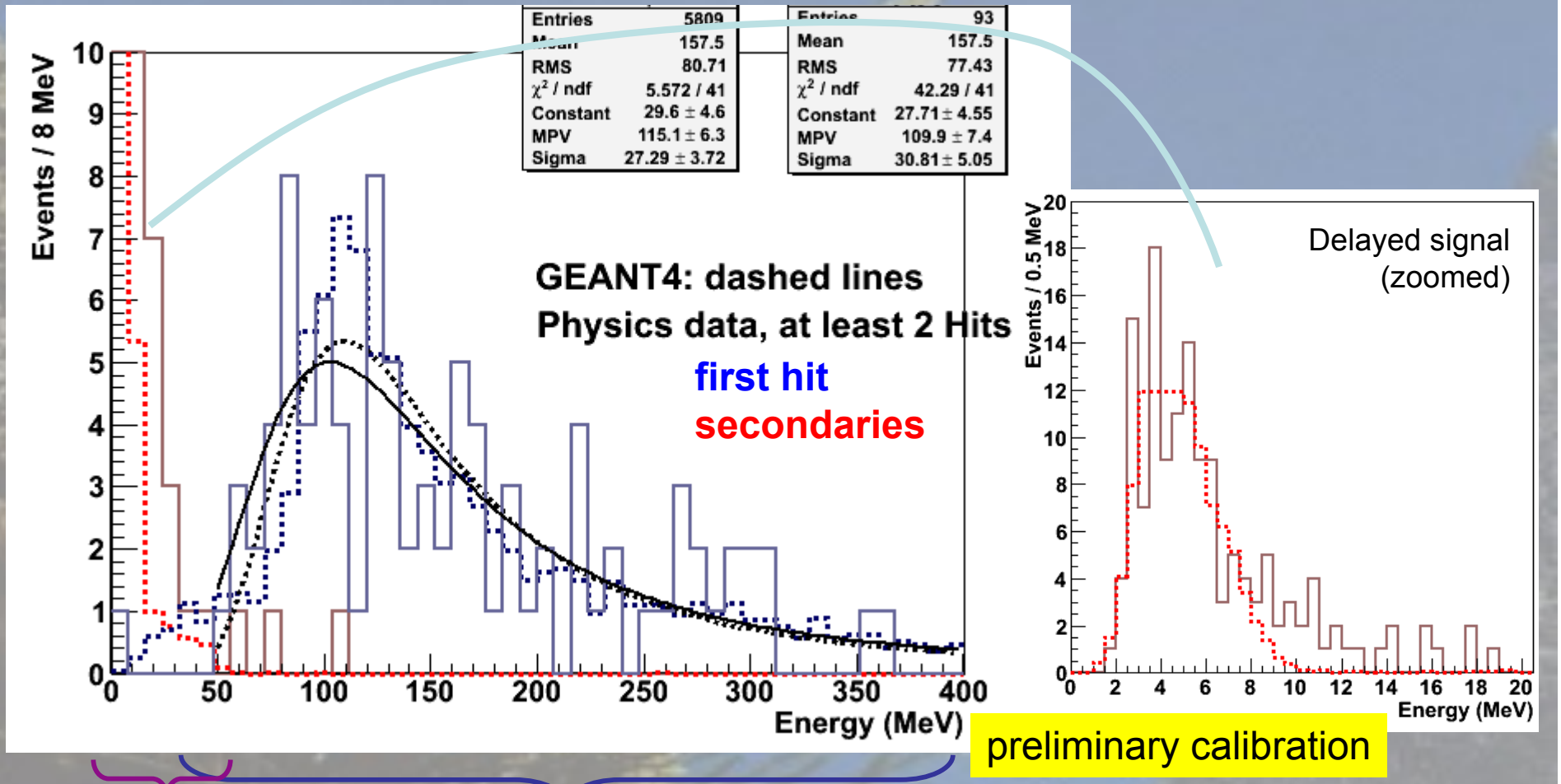
Data: multiplicity



$P_{\mu\text{-n coinc}}$ (≥1 secondary) = 0.2 /day

Almost no background.

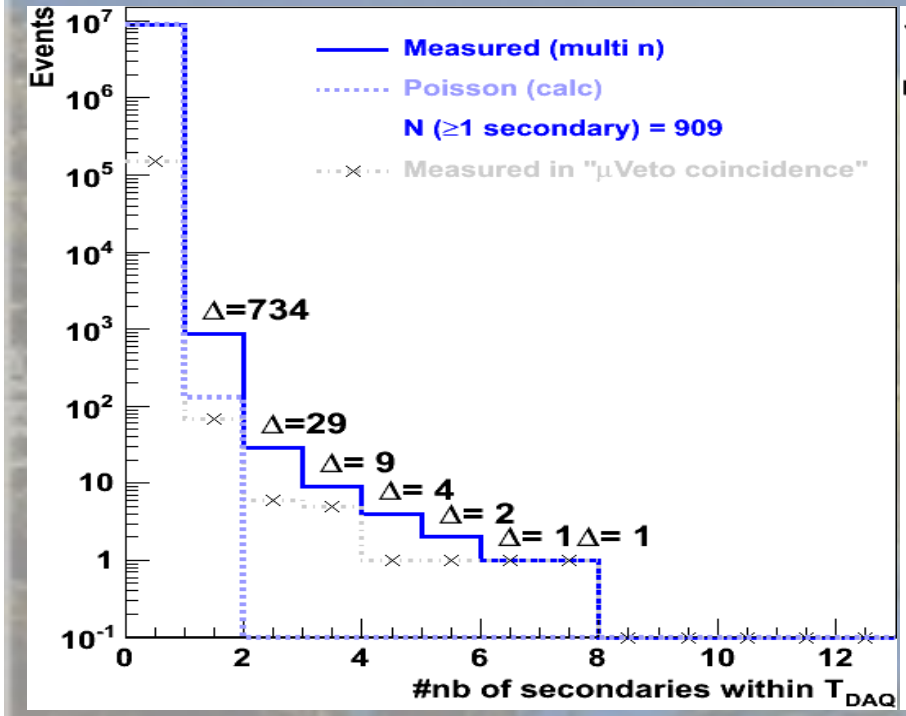
Data: energy spectra

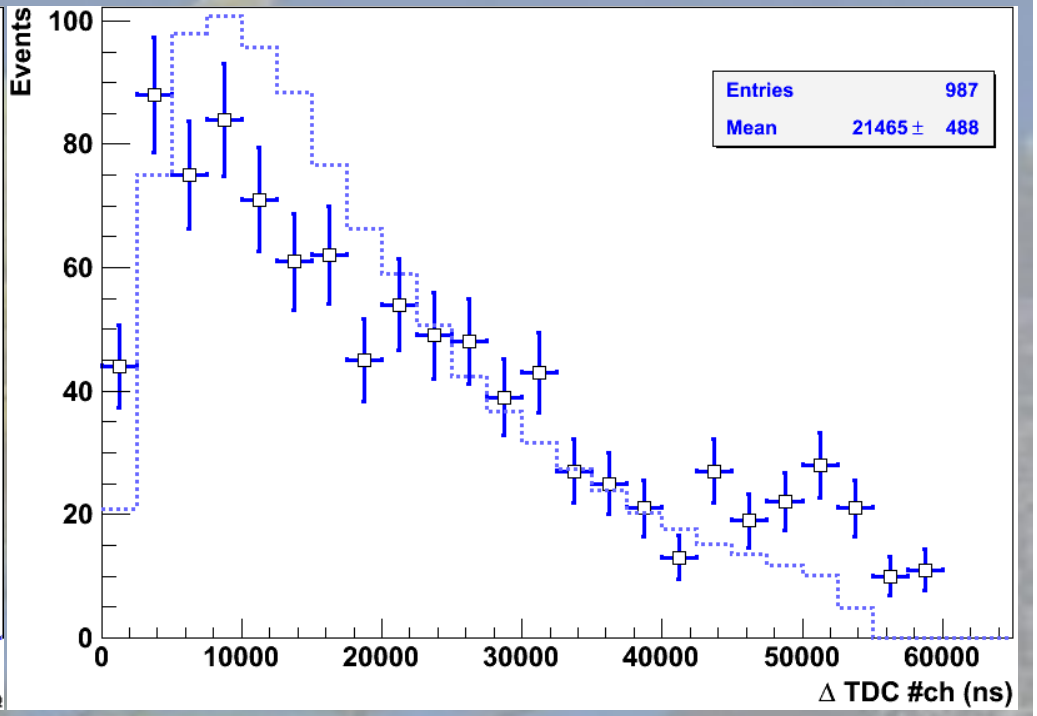


delayed n's: predominantly small energy deposit

prompt μ's: E_{dep} ~100MeV

Data: several neutrons (no muons)





- 06/09 - 08/11: ~636 live days
  N_{event} (≥1 secondary) = 909-129$_{acc}$=780
  $N_{secondaries}$ = 987-129$_{acc}$=858
- Multiplicity = 1 dominated by ambient neutron background?

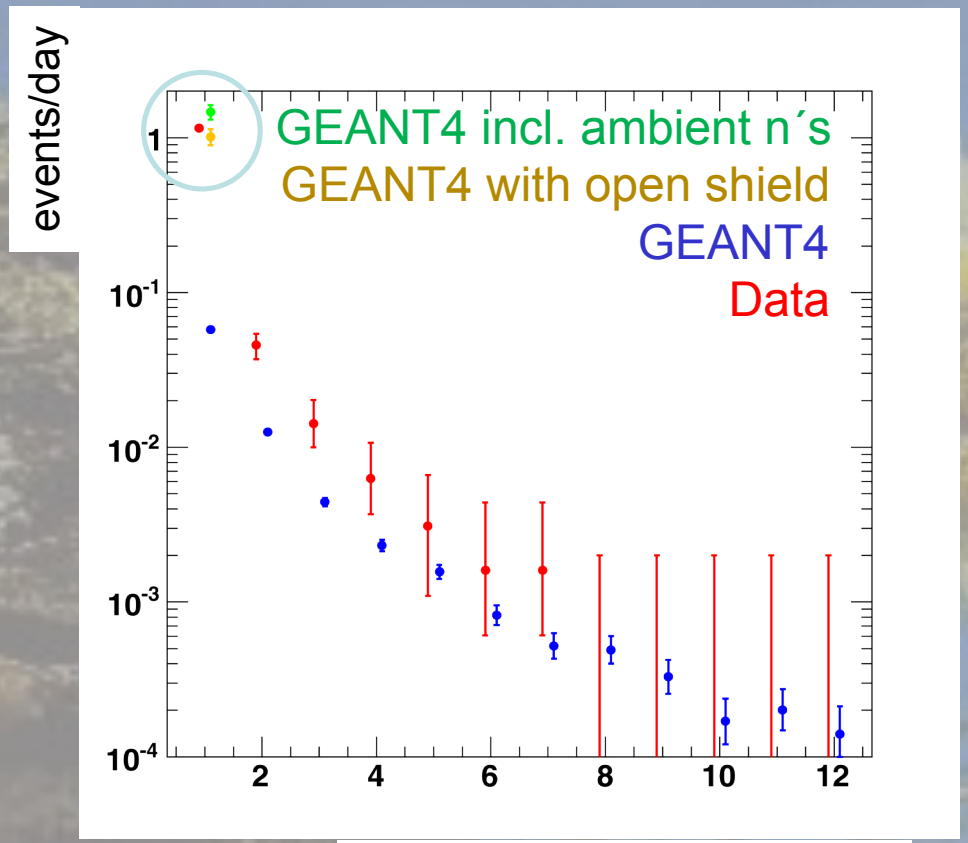
——— <Δt_{sec}> (data) = 21.5 μs

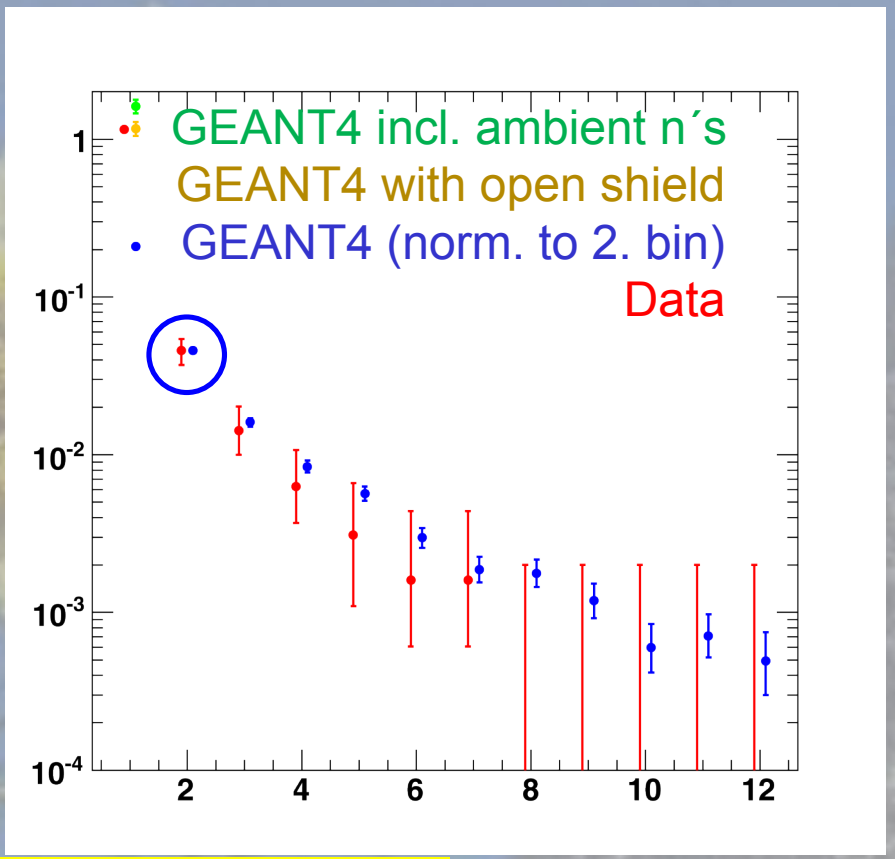
----- <Δt_{sec}> (AmBe) = 19.0 μs

→ background?

preliminary analysis

Data: several neutrons (no muons)





- **N(secondaries) = 1 dominated by ambient neutron background.**
- **Without normalisation: measured neutron rate is higher than predicted by ~2 for multiplicities ≥2 (preliminary).**

Preliminary results

Detected neutrons		GEANT4 results		G4 scaling
$R_{n,\,data}$	$= 0.33 \pm 0.02\ d^{-1}$	$R_{n,MC}$	$= 0.189 \pm 0.003\ d^{-1}$	1.8 ± 0.2
$R_{n,\,data}/\mu$	$= 0.057 \pm 0.004$	$R_{n,MC}/\mu$	$= 0.031 \pm 0.001$	1.8 ± 0.2
$\langle n_n \rangle$	$= 1.7 \pm 0.2$	$\langle n_n \rangle$	$= 2.00 \pm 0.05$	0.8 ± 0.1

➔ G4 underestimates neutron yield by ~2

preliminary analysis

- These are preliminary results.
- Only statistical errors are quoted.

Conclusions

- Dedicated neutron monitoring systems are running at LSM in connection with the EDELWEISS experiment.
- Neutron flux (from radioactivity) is monitored outside and inside the neutron shield (not discussed here).
- Muon-induced neutrons have been measured and preliminary results indicate that the measured rate of neutron events exceeds GEANT4 (v9.2) predictions by about a factor of 2.
- The measurements are ‘setup specific’ (depend on the geometry, trigger conditions etc).
- Systematic uncertainties are under study.
- Active muon veto system allows the efficient rejection of muon-induced neutrons producing nuclear recoils in Ge bolometers.
- EURECA: efficient rejection of muon-induced events with water Cherenkov veto system even if the neutron yield is higher than predicted by GEANT4.