Measurement of ^{7}Be(n,α) and ^{7}Be(n,p) cross sections for the Cosmological Li problem in EAR2@n_TOF

M. Barbagallo, A. Musumarra, L. Cosentino, N. Colonna,
P. Finocchiaro, A. Pappalardo and the n_TOF Collaboration

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Outline

- Physics case
- The n_TOF experimental program on ^{7}Be
  - **^{7}Be(n,p) measurement (2016)**
  - **^{7}Be (n,α) measurement (currently ongoing)**
- Conclusions

Big Bang Nucleosynthesis

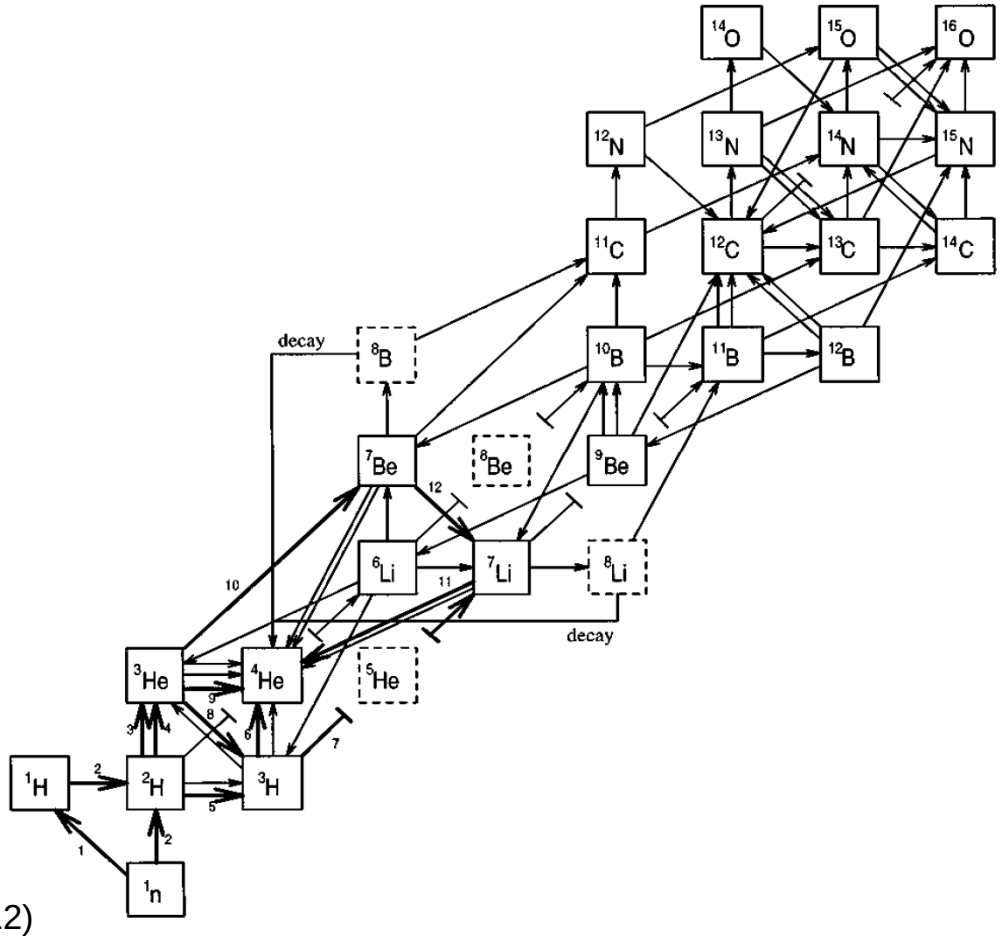
Big Bang Nucleosynthesis (BBN), together with Hubble expansion and Cosmic Microwave Background Radiation is one of the cornerstones for Big Bang Theory.

BBN gives the sequence of nuclear reactions leading to the synthesis of light elements up to Na* in the early stage of Universe (0.01-1000 sec)

At his first formulation, it depended on 3 parameters:

- -the baryon-to-photon ratio η,
- -the number of species of neutrino ν,
- -the lifetime of neutron τ.

Nowadays **BBN is a parameter free theory****, being the **cross-sections** of reactions involved the only input to the theory.



* A.Coc et al., The Astrophysical Journal, 744:158 (2012)

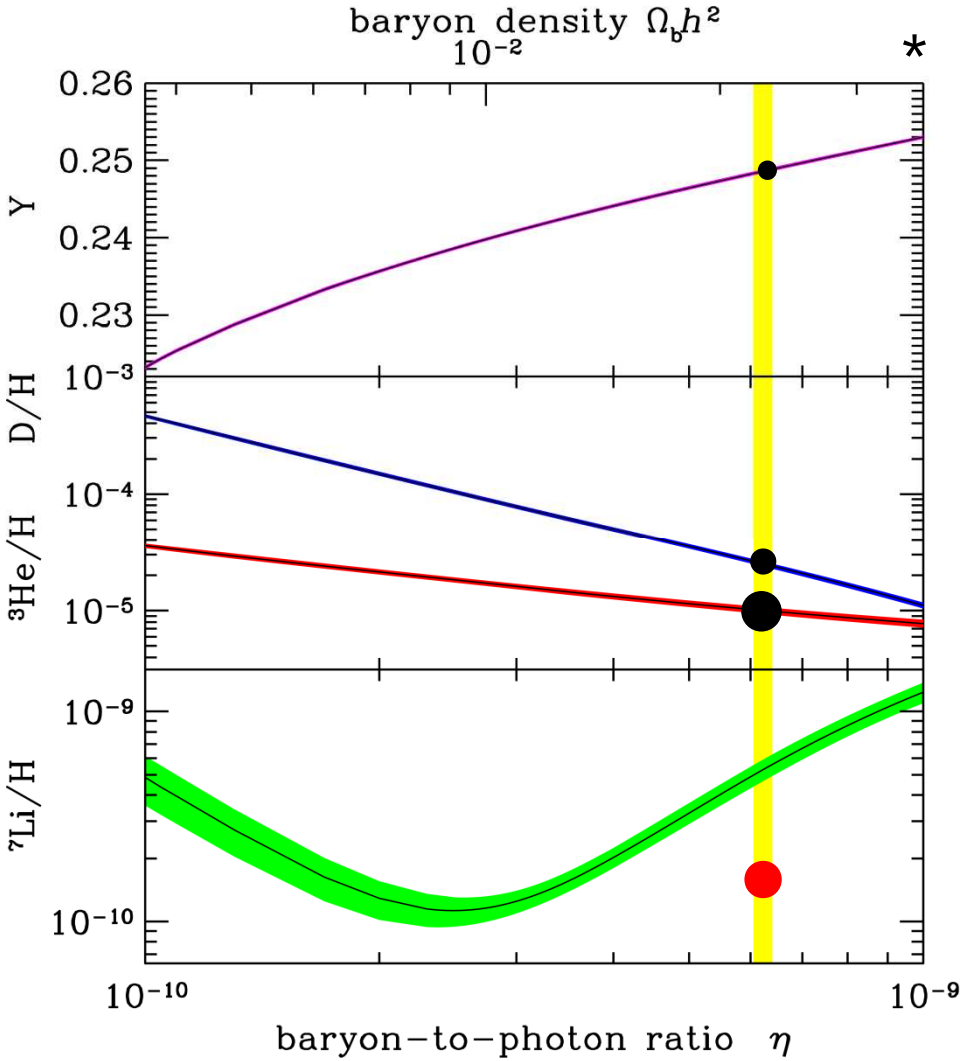
**D.N. Schramm and T.S Turner, Rev. Mod. Phys 70 (1998) 303

The Cosmological Lithium Problem

BBN successfully predicts the abundances of primordial elements such as ^{4}He, D and ^{3}He.

A serious discrepancy **(factor 2-4)** between the predicted abundance of **^{7}Li** and the value inferred by measurements (Spite et al, many others.)

Cosmological Lithium Problem (CLiP)



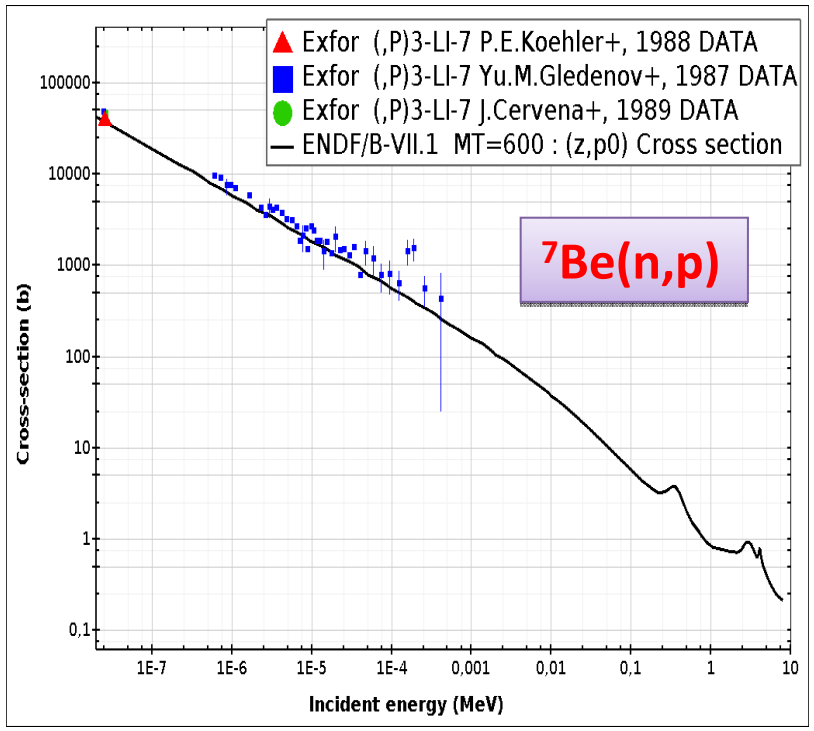
* R.H.Cyburt et al., Journal of Cosmology and Astroparticle Physics 11 (2008) 012

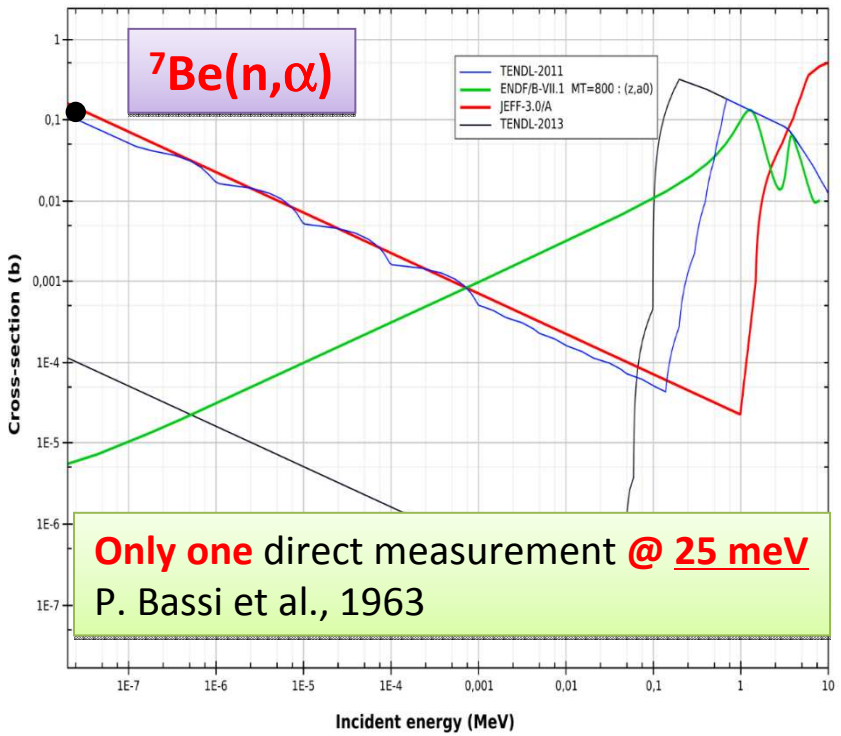
** A.Coc et al., The Astrophysical Journal, 744:158 (2012)

Solution to Clip?

Approximately 95% of primordial **^{7}Li** is produced from the electron capture decay of **^{7}Be** (**$T_{1/2}$=53.2 d**).

^{7}Be is destroyed via (n,p) and (p,x), (d,x), (^{3}He,x), … reactions
Very small contribution of the (n, α) reactions according to **estimated** cross section.



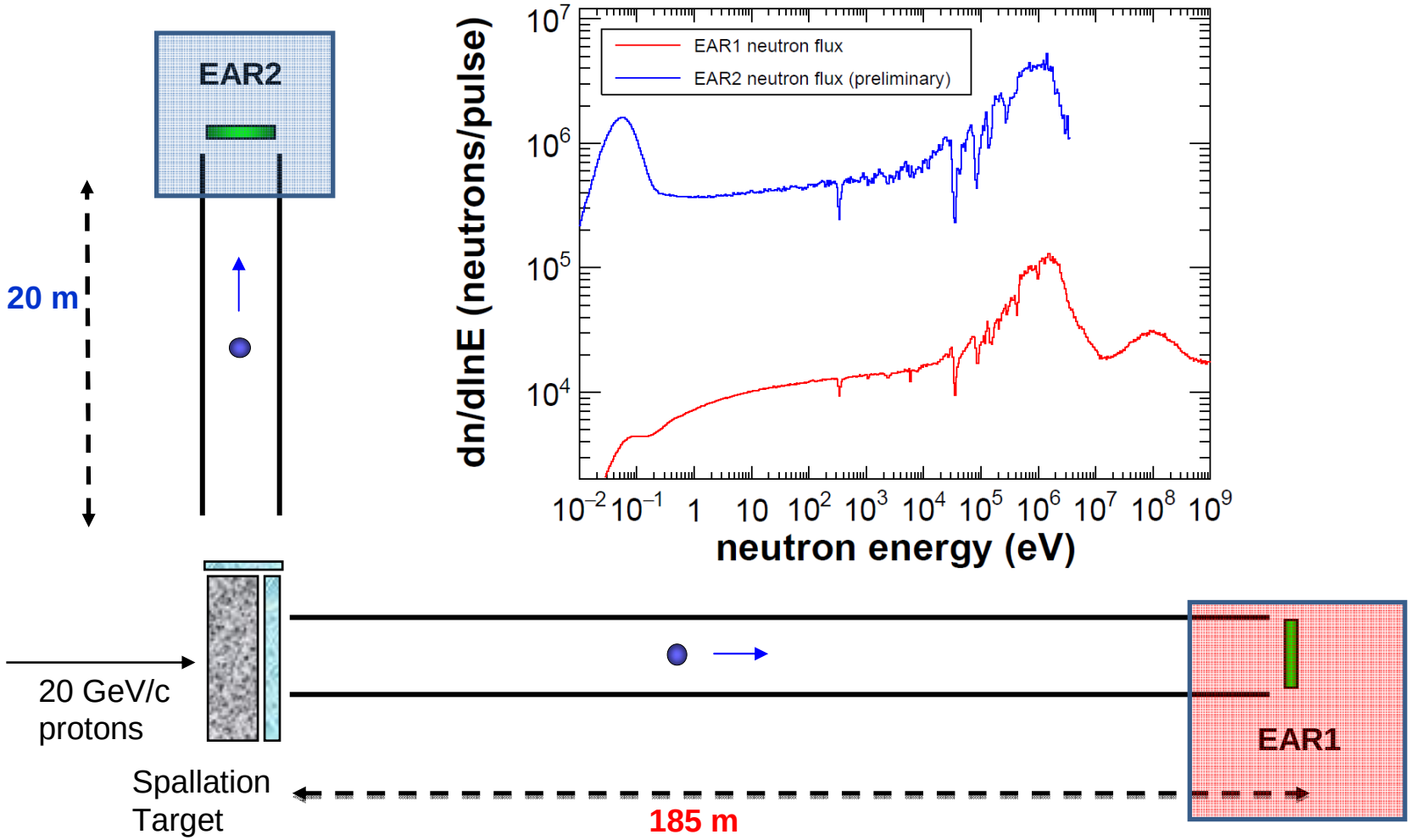


Only one direct measurement **@ 25 meV**
P. Bassi et al., 1963

The n_TOF facility

^{7}Be(n,α)

Two beam lines and experimental areas available at n_TOF, **EAR1** and **EAR2**



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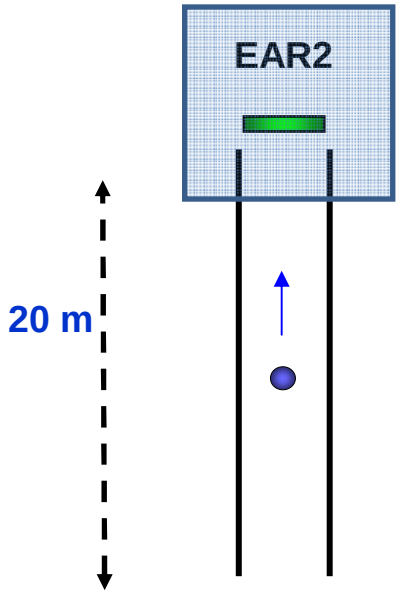
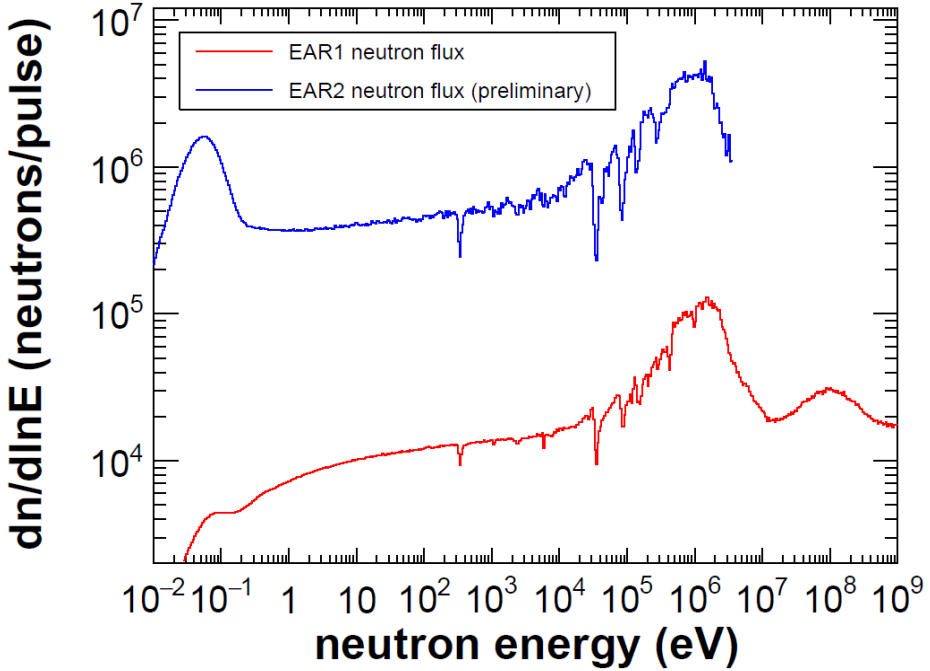


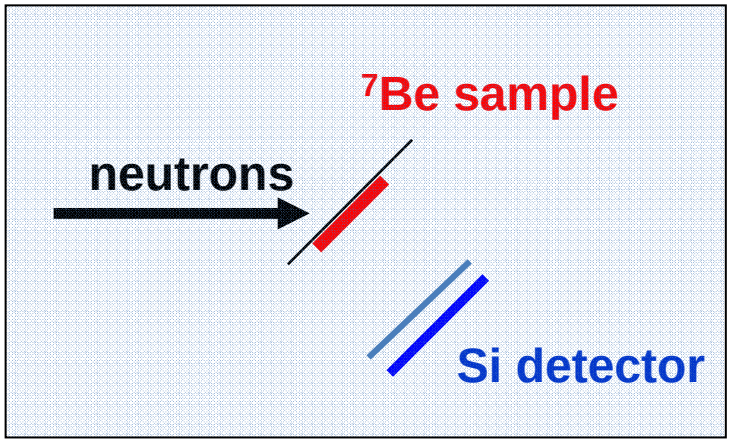


The much higher flux in EAR2 allows to:

- measure samples of **very small mass (<1 mg)**
- measure **short-lived radioisotopes** (down to a few weeks)
- collect data on a much **shorter time**
- **measure (n,charged particle)** reactions with **thin samples**

Experimental setup for ^{7}Be(n,p)

2 Silicon detectors (5x5 cm^2 area, 20 μm and 300 μm thickness) to detect 1 MeV and 1.4 MeV protons. Telescope Technique

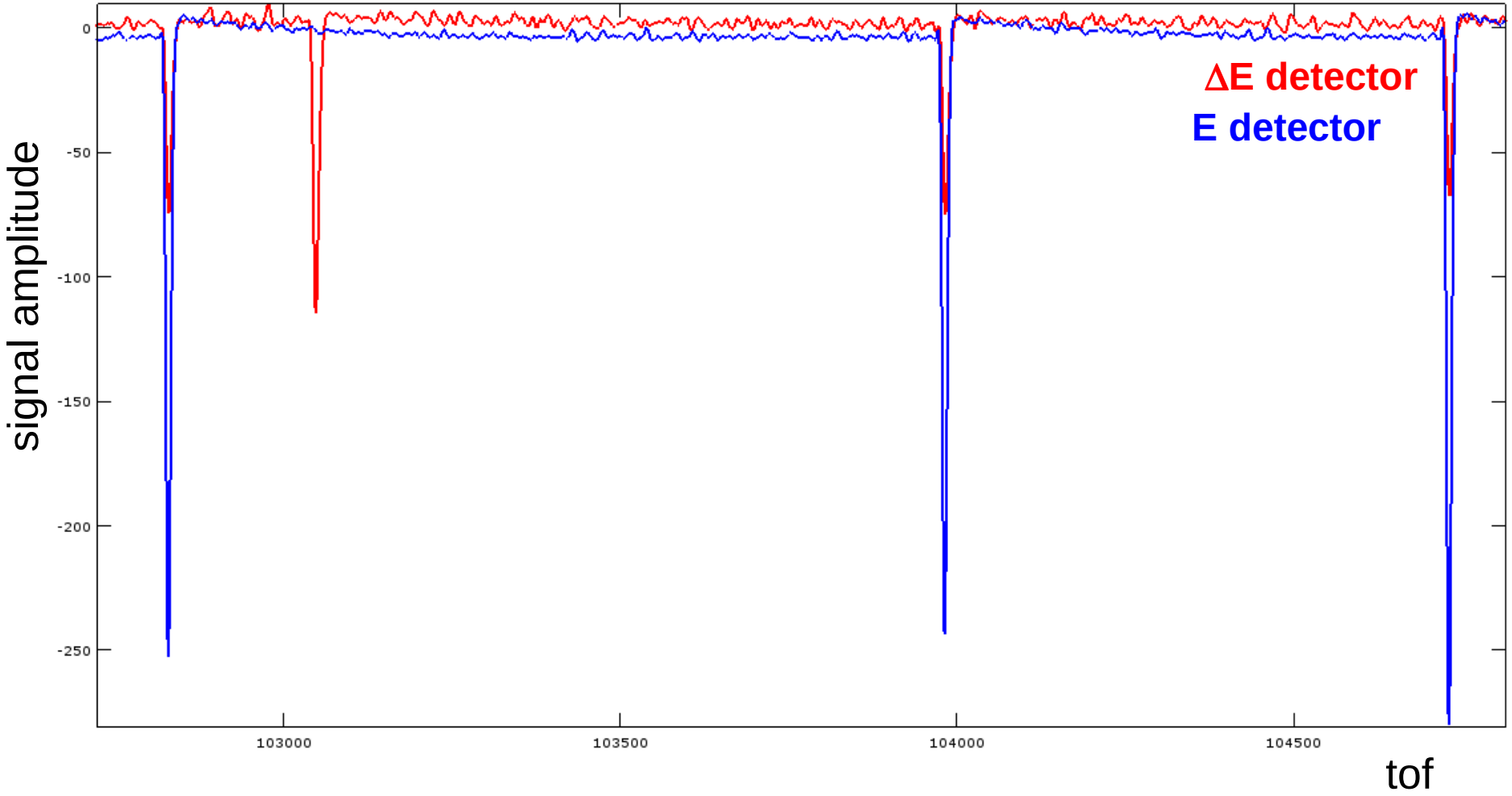


Purification of sample needed: ISOLDE

- 100 ng of ^{7}Be (material from water cooling of SINQ spallation source at **PSI**)
- Offline mass separation required at ISOLDE **≤1 day** (starting from 100 GBq of $^{7}BeNO_3$)
- Implantation on C backing

Experimental setup for ^{7}Be(n,p)

The commissioning of the setup for ^{7}Be(n,p) measurement shows the feasibility of the technique in EAR2



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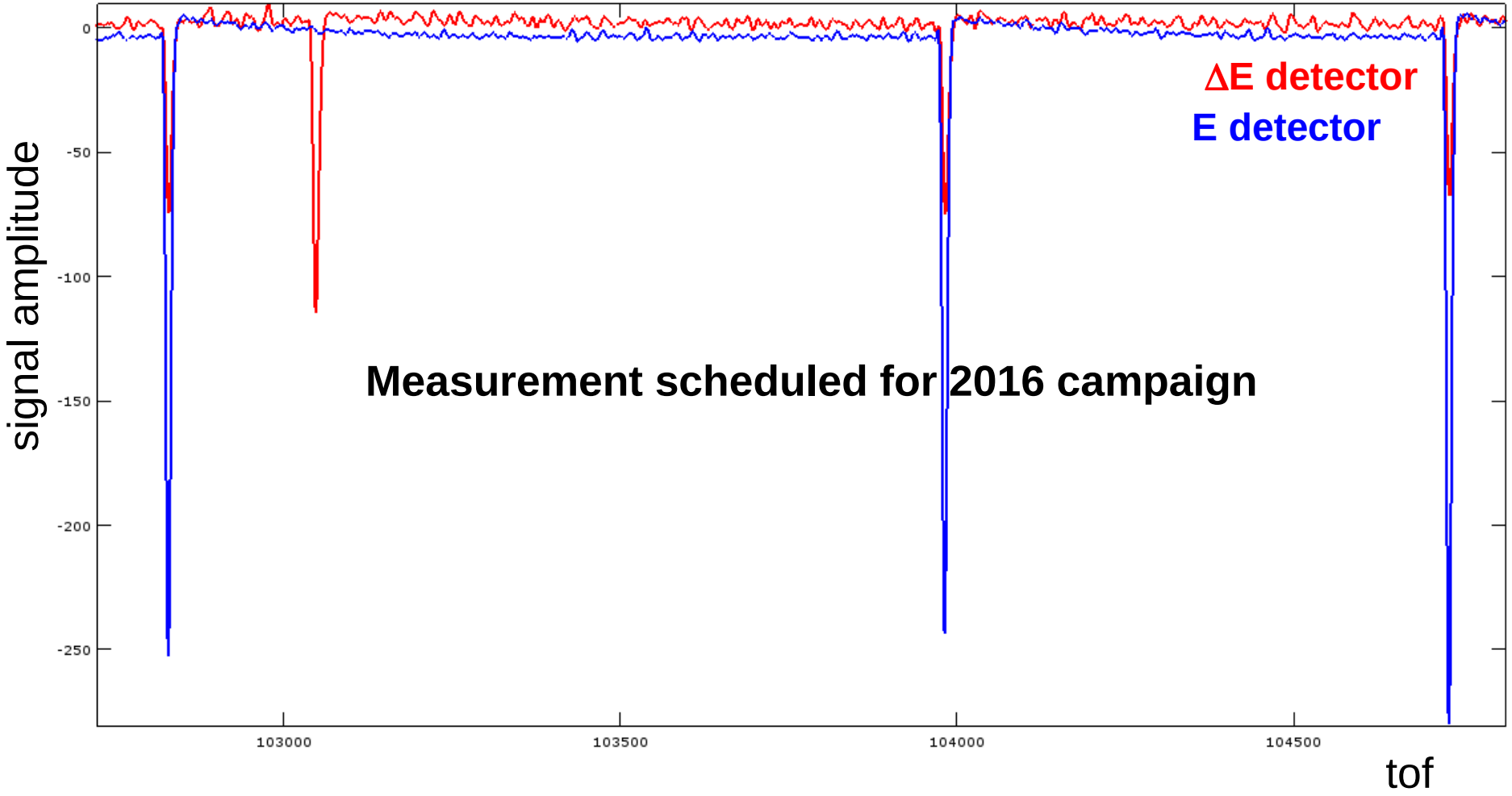
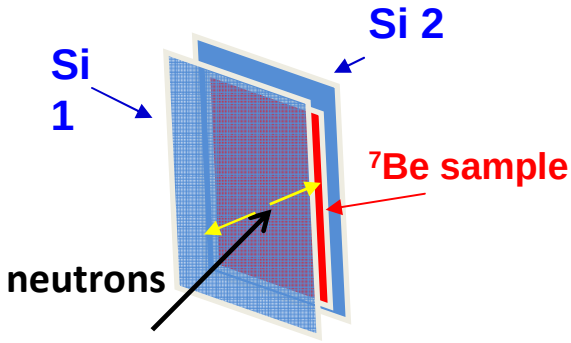


Measurement of ^{7}Be(n,α) at n_TOF-EAR2

The (n,α) reaction produces **two a-particles** emitted back-to-back with **several MeV energy** (Q-value=19 MeV)

2 Sandwiches of **silicon detector** (140 μm,3x3cm^2) with ^{7}Be sample in between **directly inserted in the neutron beam**

Coincidence technique: strong background rejection



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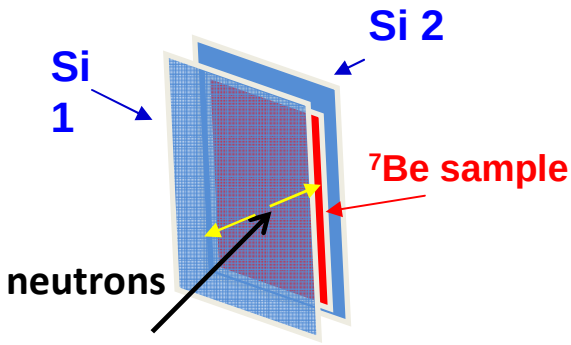

Biggest challenge related to the sample:

- For a reasonable count-rate, a **few μg of ^{7}Be** are needed
- The short half-life of ^{7}Be (53.2 d) → **very large specific activity** (~1.3 GBq/μg of 478 keV g-rays
- Difficult to find and handle

At n_TOF:

- Up to 10 μg of ^{7}Be from cooling water of SINQ spallation target at PSI (Zurich)
- Chemically purified before depositing (on polyethilene and Al backing)
- Complex mechanics and procedure for mounting in the hot-cell

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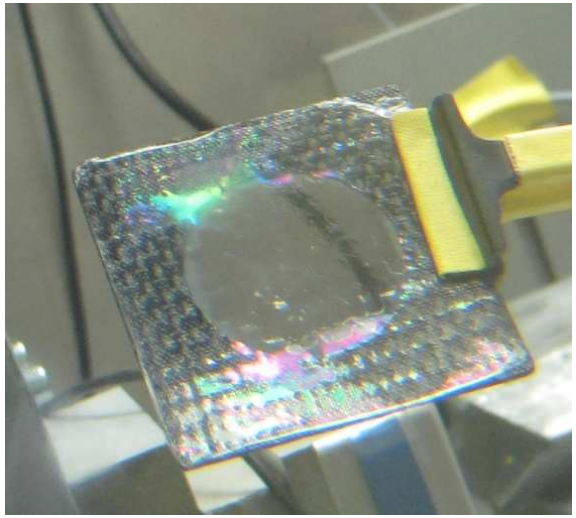

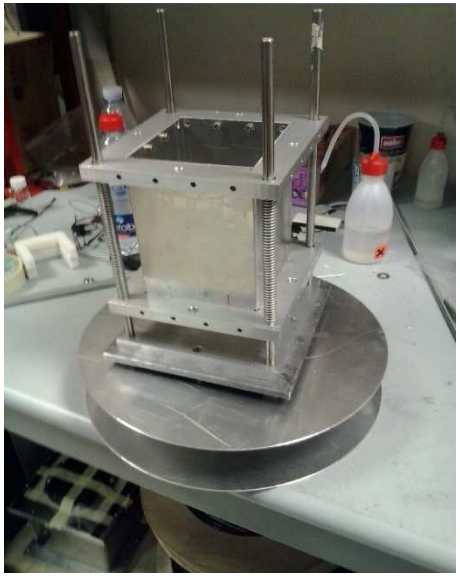

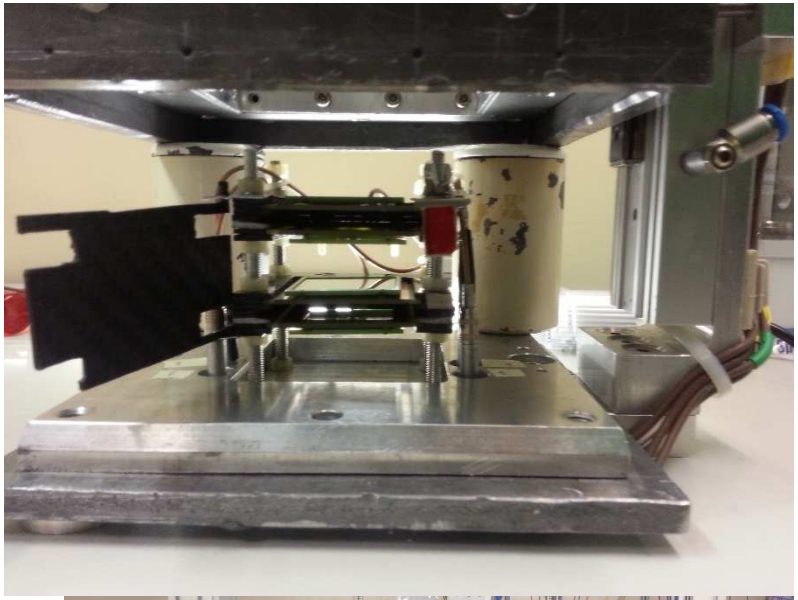

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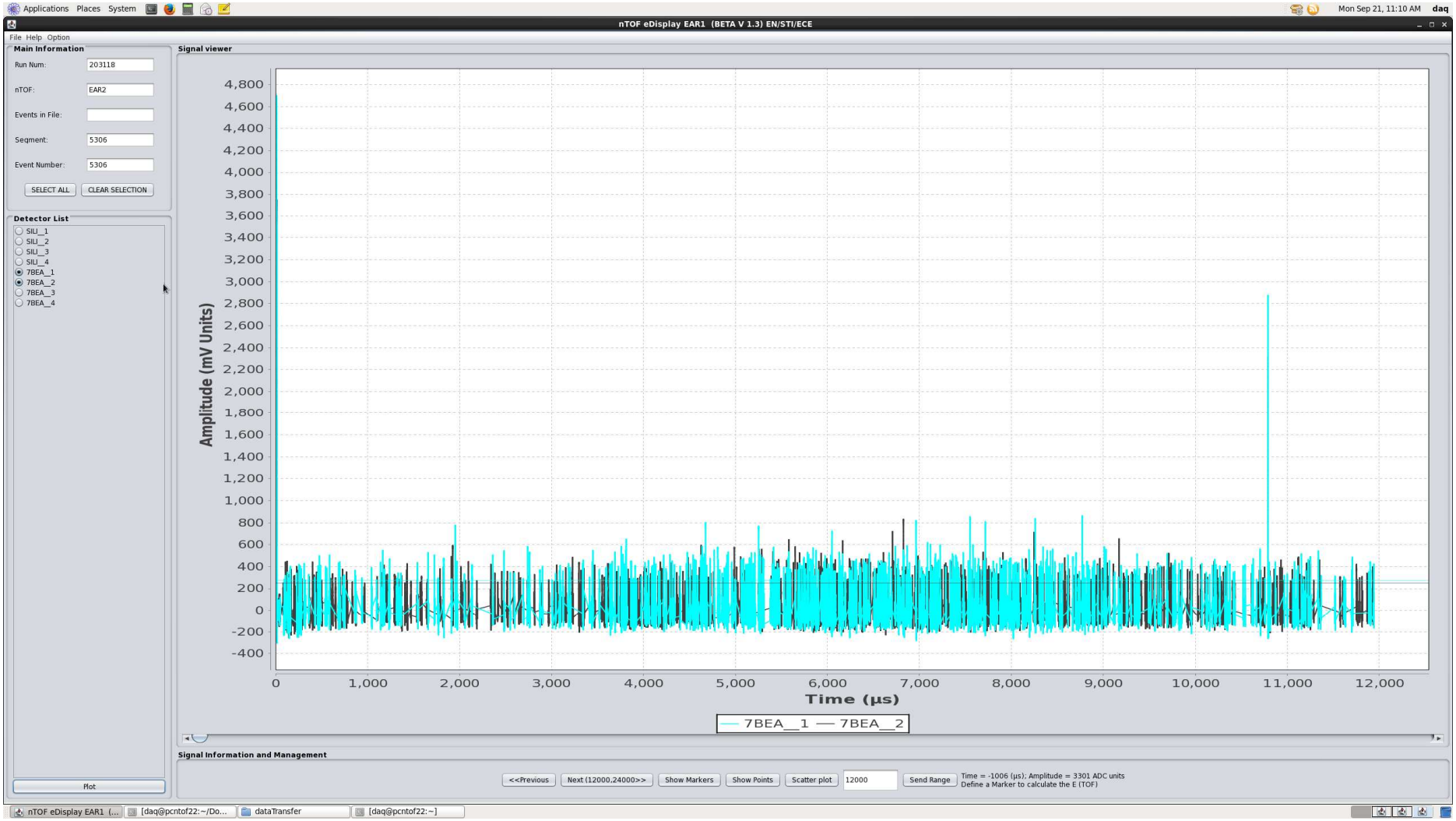
Raw signals from one of the sandwich (det1&det2)



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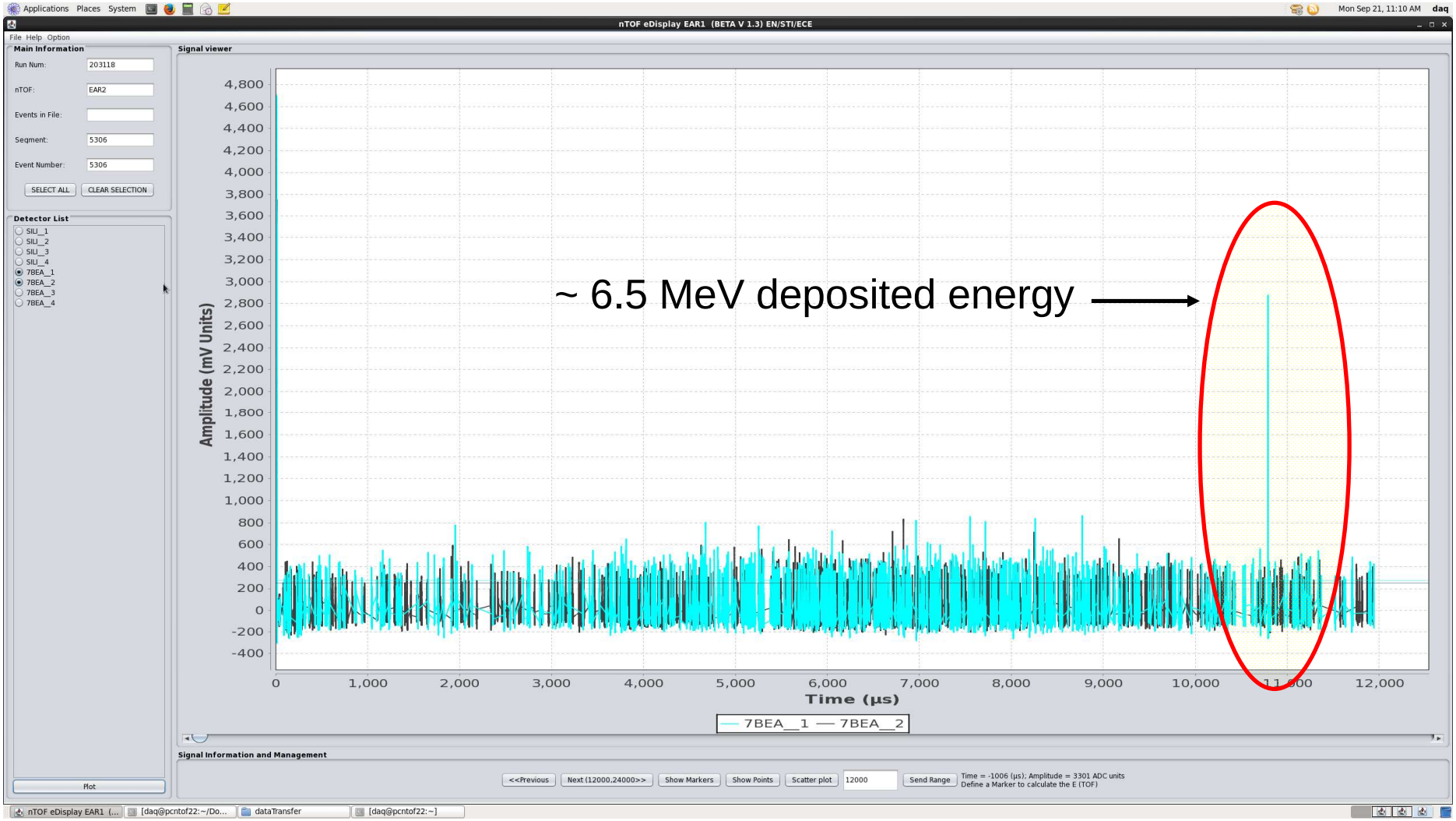

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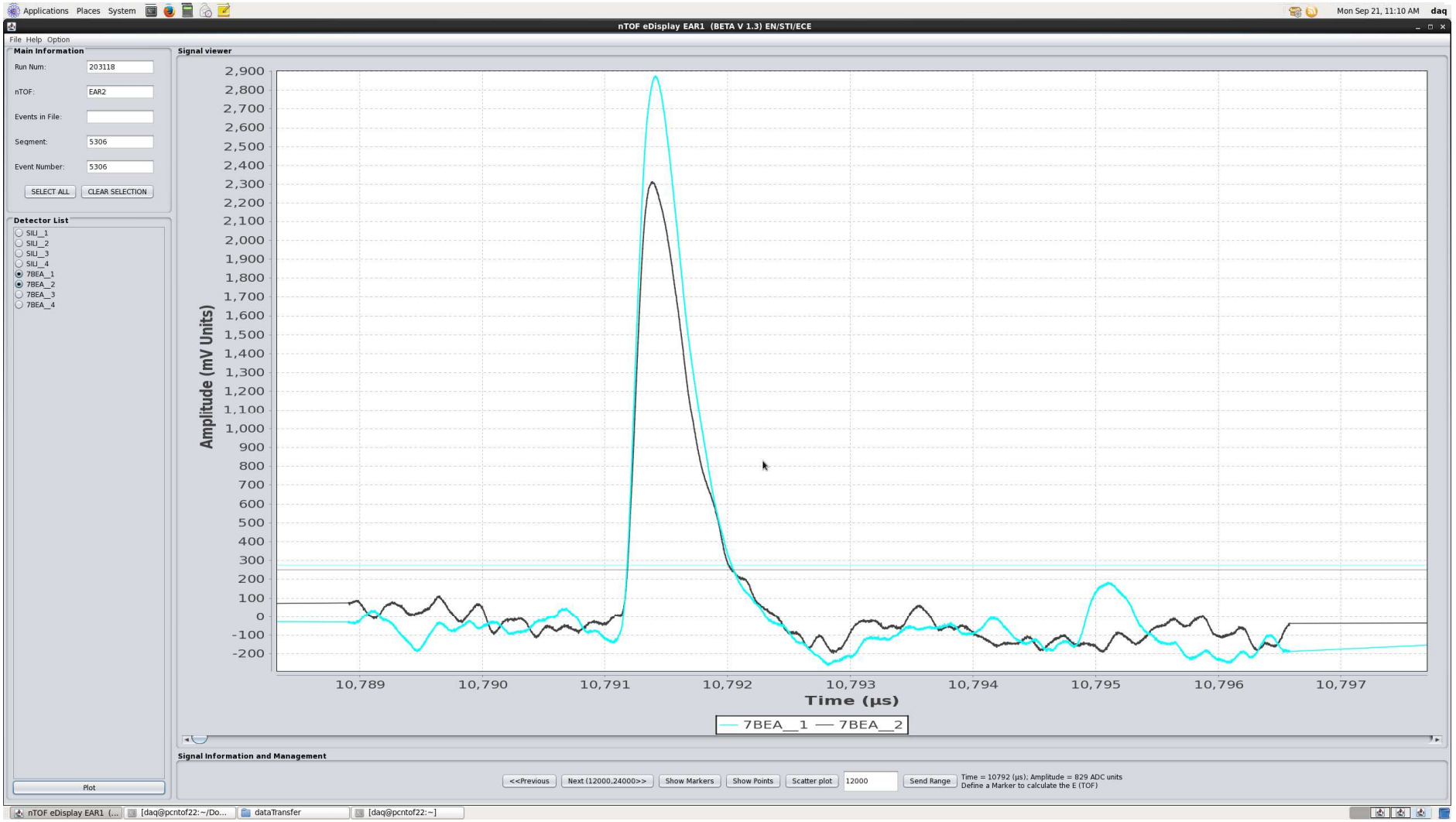

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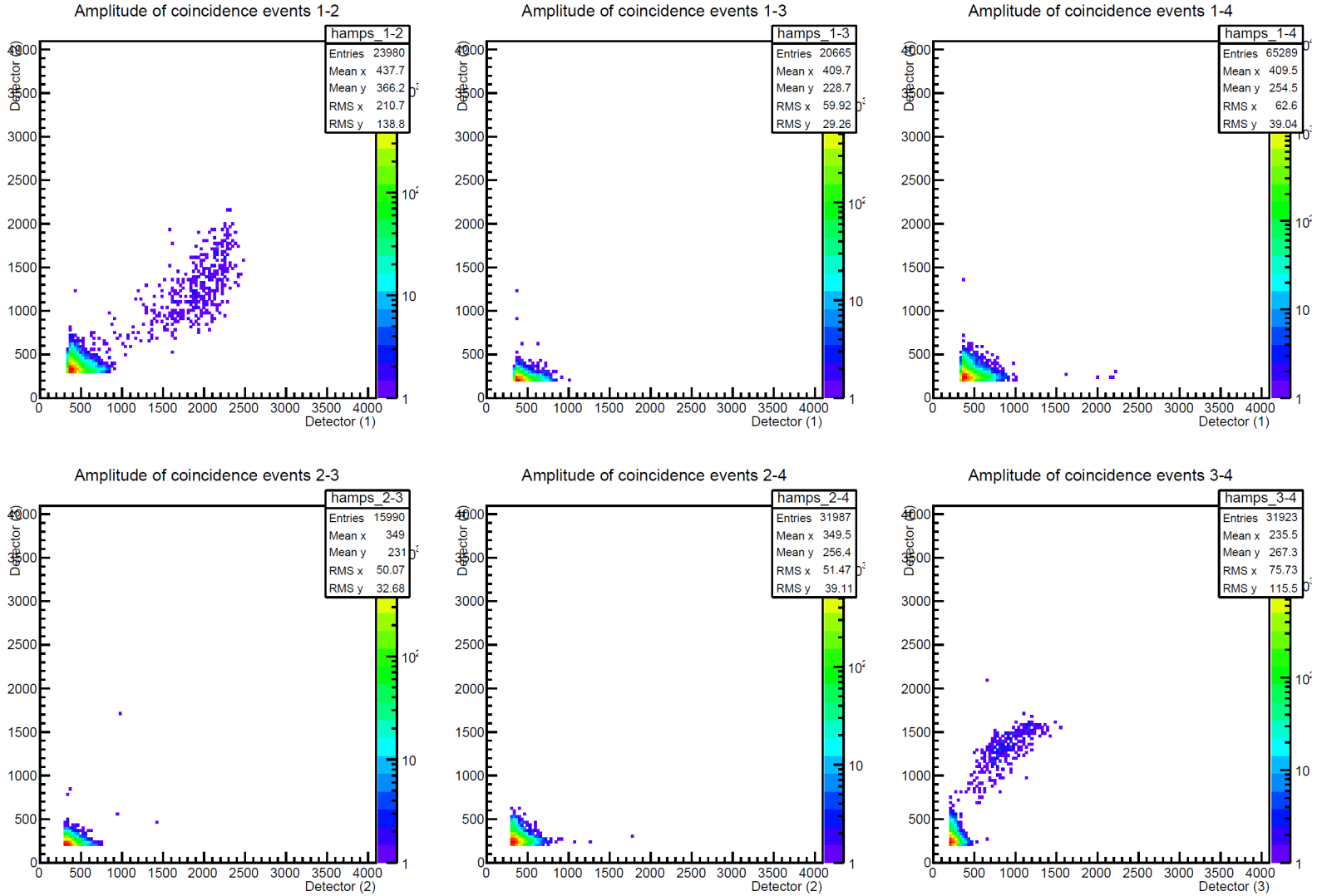
Amplitude distribution of coincidence events



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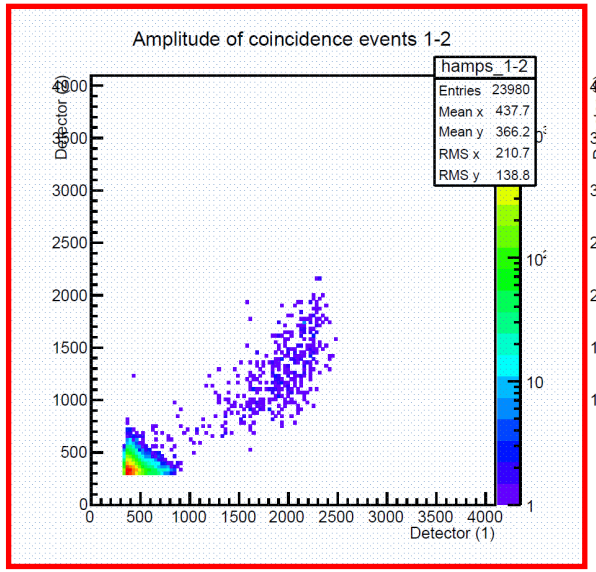
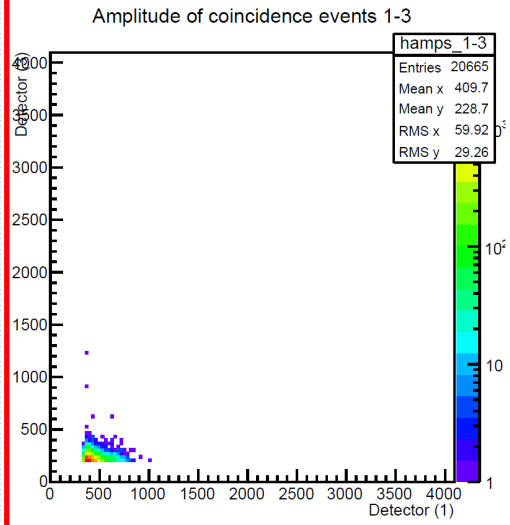
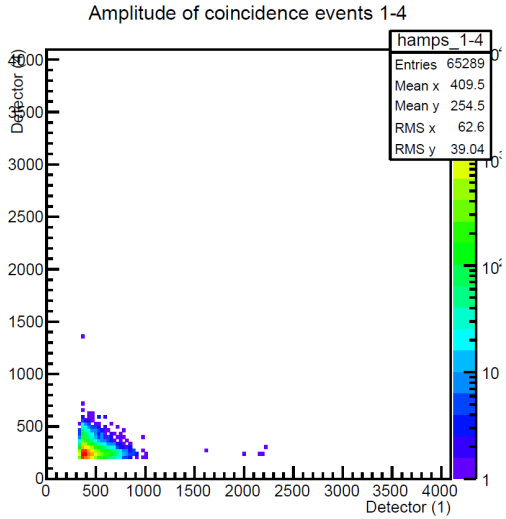
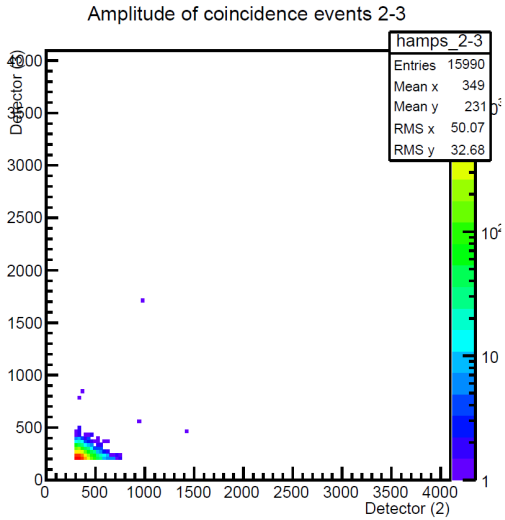
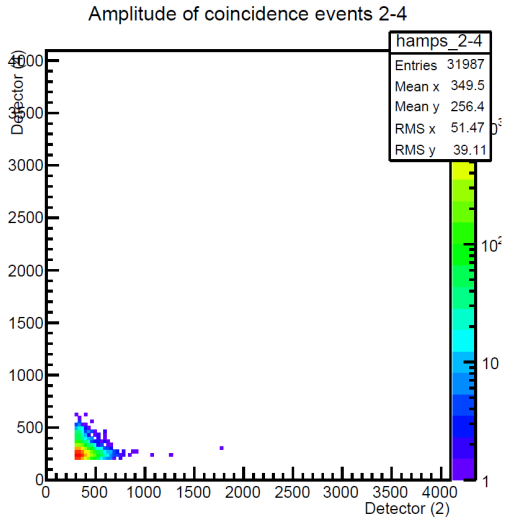
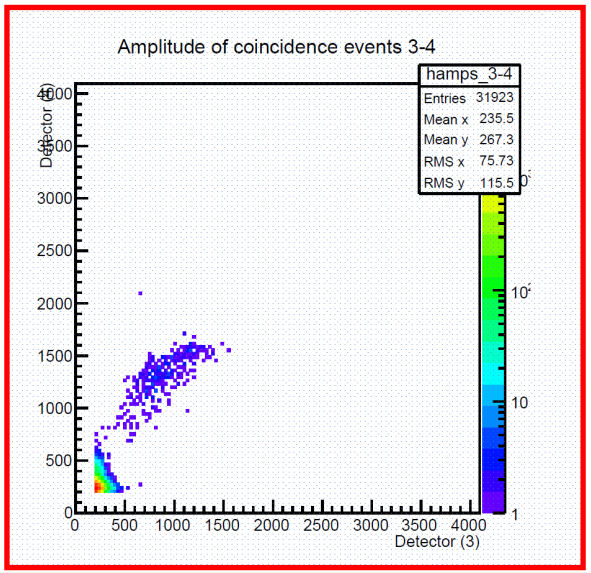




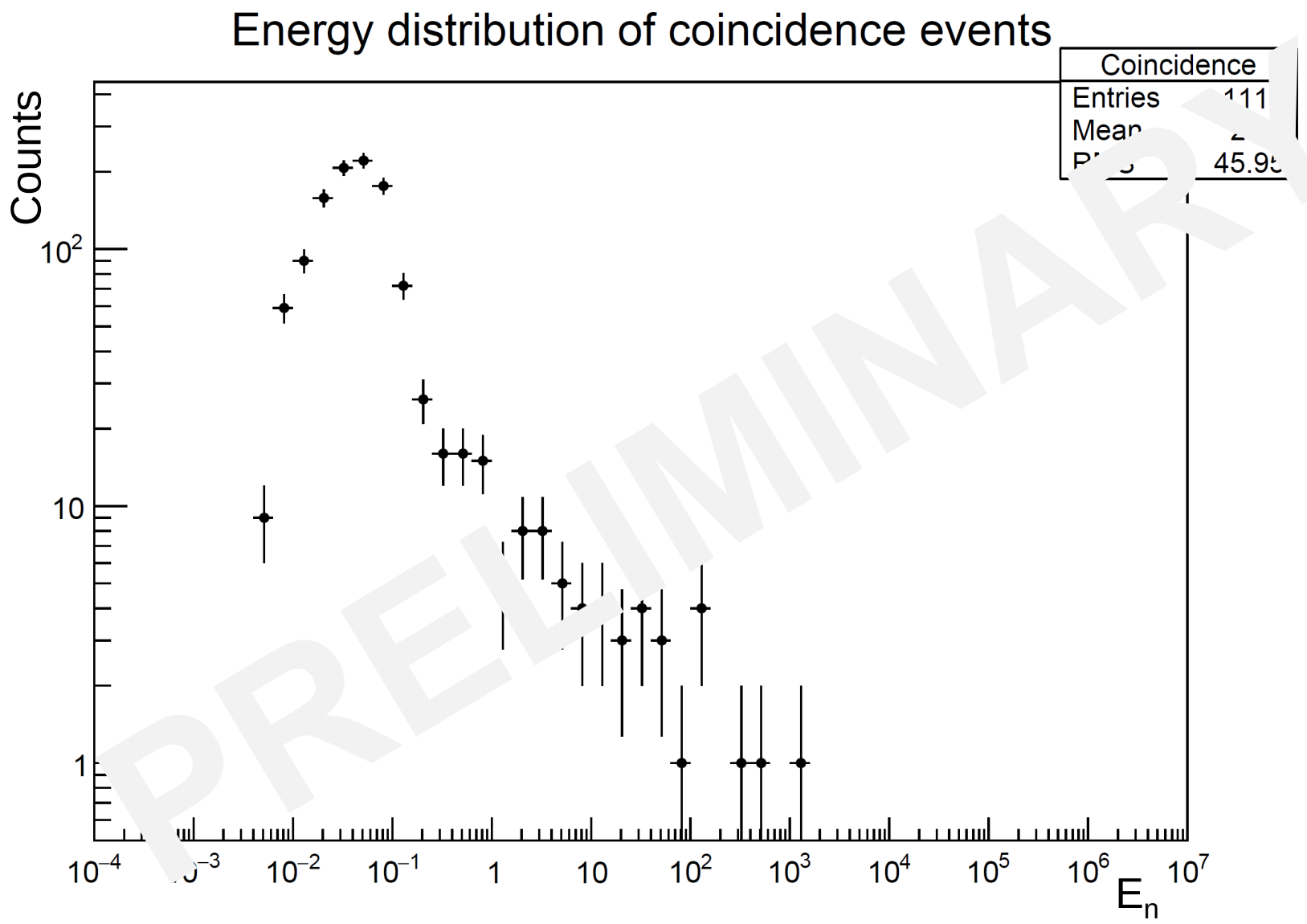








Preliminary results



Conclusions

• Uncertainties in nuclear data strongly affect the Big Bang Nucleosynthesis calculations for the abundance of ^{7}Li and could probably explain (at least partially) the **C**osmological **Li**thium **P**roblem.

• Experimental program aiming at measuring at n_TOF-EAR2 **for the first time** the **^{7}Be(n,p) and ^{7}Be(n,α)** cross sections in the whole range of interest for BBN, with the aim of reducing uncertainties in nuclear data used in calculations, thus setting stronger constraints to BBN theory and on CLiP.

• Taking advantage of the well suited features of the facility (high instantaneous neutron flux, work sector type A):

- The measurement of **^{7}Be(n,p)** reaction cross-section is scheduled for **2016 in EAR2**
- The measurement of **^{7}Be(n,α)** reaction cross-section is **currently ongoing** and preliminary results are extremely encouraging.