Low energy measurement with Radioactive Sources

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Why radioactive sources?

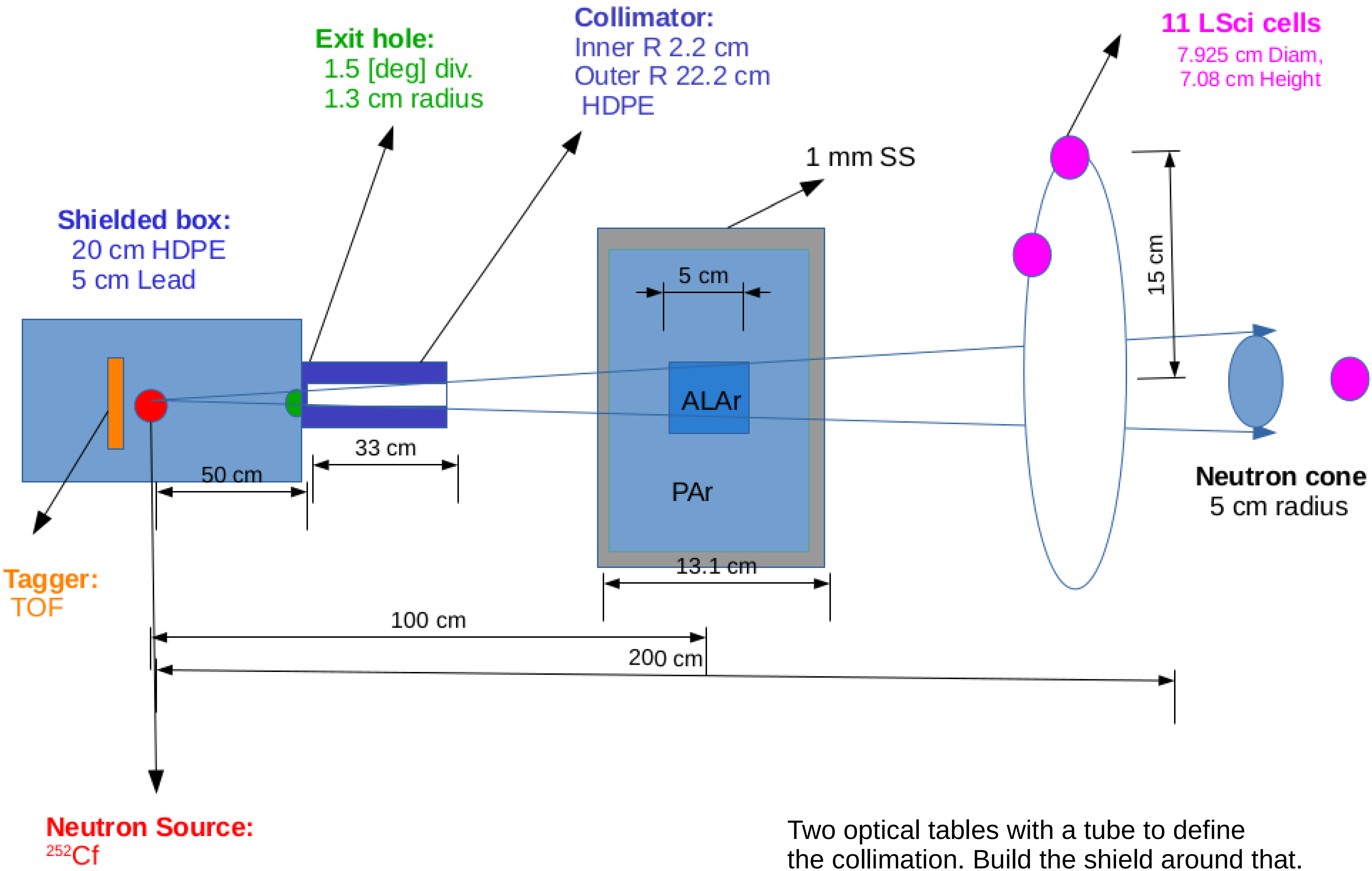
- **Beam stability:** for low energy, event rate can be as low as 0.01 Hz. Long runs spanning several days are necessary.
- **Simpler experimental set-up:** more compact.

Problems?

- **Neutron energy spectrum:** for low energy (1-10 keV energy deposition), the neutron speed does not change substantially, so per event neutron energy measurement based on TOF is plausible. The usual requirement of a mono-energetic beam is not necessary.
- **Neutron angular distribution:** most sources are isotropic, so the neutron beam needs to be collimated This means the need of a shield around the source.

The TPC accidental background with a shielded source can be made smaller than in accelerator hall (different spatial locations where the background is originated compared to a cm size object).

Remember: in the current LNS set-up we have 2 kHz of accidental background in TPC for 1 nA on Target, i.e 0.1 events per full drift time.



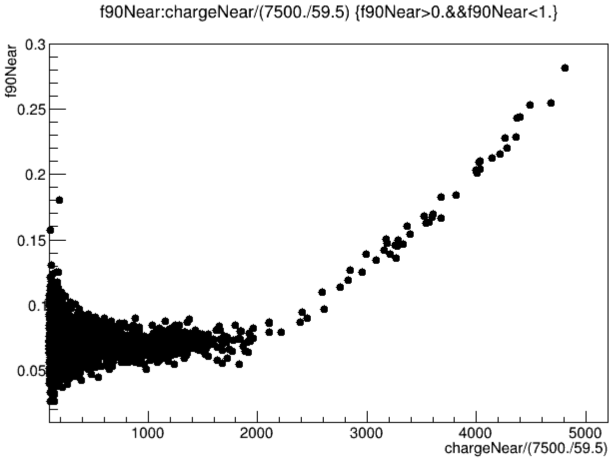
Two optical tables with a tube to define the collimation. Build the shield around that.

A lead cap on the collimator cylinder might be appropriate. Needs to be studied.

Requirements for a clean measurement

- **Neutron speed 1-10 MeV is 1.4-4.3 cm/ns:** 200 cm source to LSci -> 46-144 ns TOF should guaranteed good neutron energy resolution and clean prompt gamma separation.
- **Neutron beam collimation:** important that *golden events* (neutrons depositing 1-10 keV in TPC and >100 keVee in LSCi with neutron PSD) are mostly due to neutrons that do not scatter in the shield (to *minimize neutron energy biases*).
- **The tagger:** important that tagger has ~1-2 ns accuracy and accidental tagging as close to 0 as possible, i.e. every single tagged event corresponds to a prompt neutron.

  The source will be inside a shield aiming to stop all neutrons and gammas. The *shield box* will be filled with gammas and neutrons delayed and not delayed (e.g. neutron inelastic scattering, neutron capture).
  This suggest that tagging with gammas is not clean. G4DS simulations in progress to make the statement quantitative.
- **The accidental background rate (most of the tagged neutrons will not exit through the hole):**
  $R = R_{tag}$ [Hz] x TOF_{window} [s] x R_{LSci} [Hz]
  $TOF_{window} = 10^{-7}$ [s]
  R_{tag} = 20 [kHz] (for a 0.01 Hz signal rate, see later)
  R_{LSci} [Hz] = 0.00013 [Hz] (at LNS, run 80, 15376 s, PSD>0.15, E>100 keVee)



The case of a AmBe source

--> ^{241}Am decays to ^{237}Np producing α and gammas (~60 keV dominant channel).

--> (α , n) reaction in ^{9}Be produces:

- 36% : 1 neutron.
- 61% : 1 neutron + 1 4.4 MeV γ-ray.
- 3% : 1 neutron + 2 γ-rays (4.4 MeV and 3.2 MeV)

Clean tagging can only proceed through the 4.4 MeV γ-ray

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Tagging fast neutrons from an $^{241}Am/^{9}Be$ source

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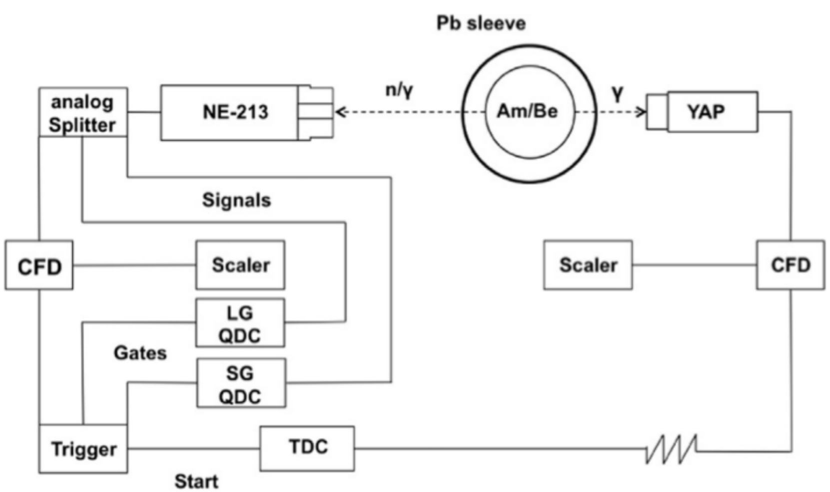
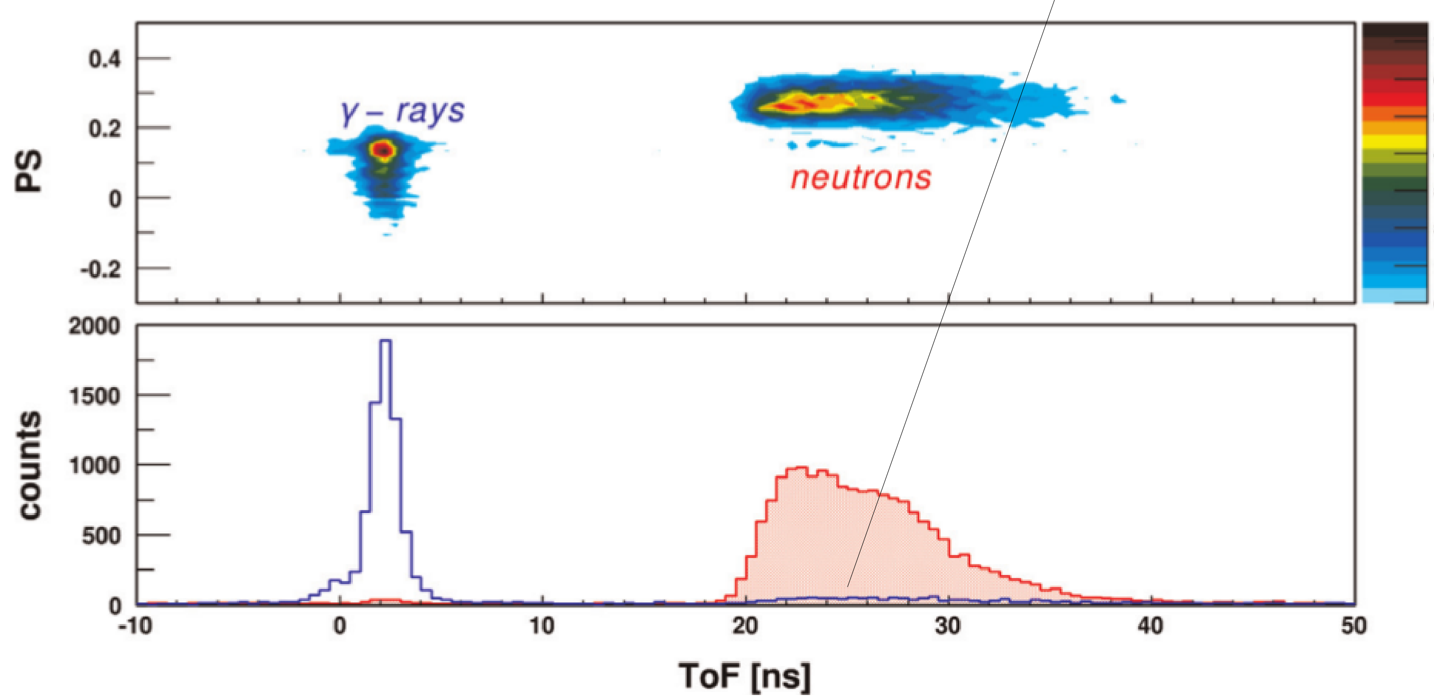


Tagger (YAP:Ce detector) mostly 4.4 MeV gamma. Insensitive to neutrons. Threshold 350 keVee.
Neutron Detector (NE-213), threshold 250 keVee
5 cm distance.

But, this is a **naked source....** (1 γ/μs)

Neutron inelastic scattering.

Source: 1 n/μs



The beauty of ^{252}Cf

^{252}Cf :
- α-particle emission (96.908%)
- Spontaneous fission (3.092%): neutron emission

Tagging can proceed with Fission fragments

^{252}Cf: neutron multiplicities in correlation with fission-fragment mass and energy ☆

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Nuclear Physics A578 (1994) 77–92

A 12 cm diameter cylindrical opening through the center of the detector sphere contains an evacuated chamber. Therein, fission fragments from ^{252}Cf spontaneous fission are assayed with two ORTEC surface-barrier detectors, each with 300 mm^2 active area. The distance between fission source and fission detectors is set to 13 mm, thus giving an efficiency of ca. 20% for the detection of fission fragments. The detection of at least one fission fragment opens a 40 μs gate for the registration of fission neutrons. A more complete description of the experimental setup has been published elsewhere [5,12].

Table 1
Parameters for primary fragment mass A, post-neutron fragment energy E and post-neutron TKE distribution from this work compared to data of Weissenberger et al. [14] and Schmidt–Henschel [16], respectively

	This work	Weissenberger et al.	Schmidt–Henschel
$\langle A_L \rangle$ (amu)	108.9 ± 0.5		108.55
$\langle A_H \rangle$ (amu)	143.1 ± 0.5		143.53
$\sigma(A_L)$ (amu)	7.6 ± 0.1		7.16
$\sigma(A_H)$ (amu)	7.6 ± 0.1		7.16
$\langle E_L \rangle$ (MeV)	103.5 ± 0.5	102.61	105.9 ± 0.7
$\langle E_H \rangle$ (MeV)	78.3 ± 0.5	78.42	80.4 ± 0.5
$\langle$TKE$\rangle$ (MeV)	181.8 ± 0.7	181.0	186.3 ± 1.2
$\sigma\langle E_L \rangle$ (MeV)	5.8 ± 0.1		6.52
$\sigma\langle E_H \rangle$ (MeV)	8.5 ± 0.1		8.92
$\sigma\langle$TKE$\rangle$ (MeV)	12.9 ± 0.1		12.27

We do have surface barrier silicon detectors

Tagging fast neutrons from a ^{252}Cf fission-fragment source

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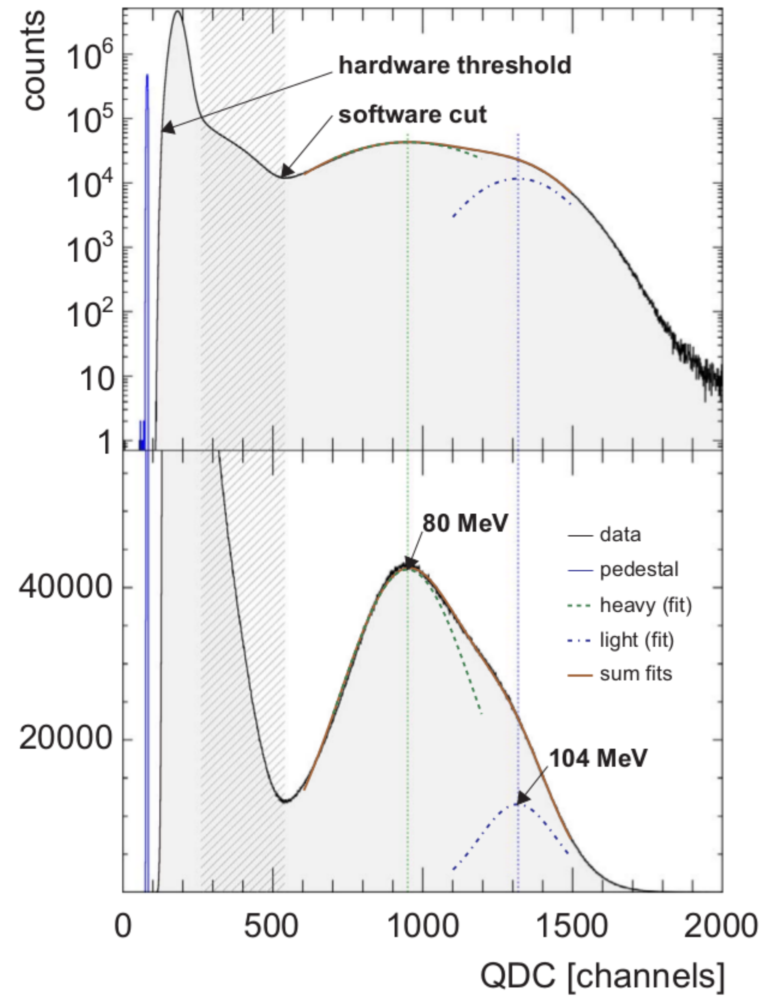
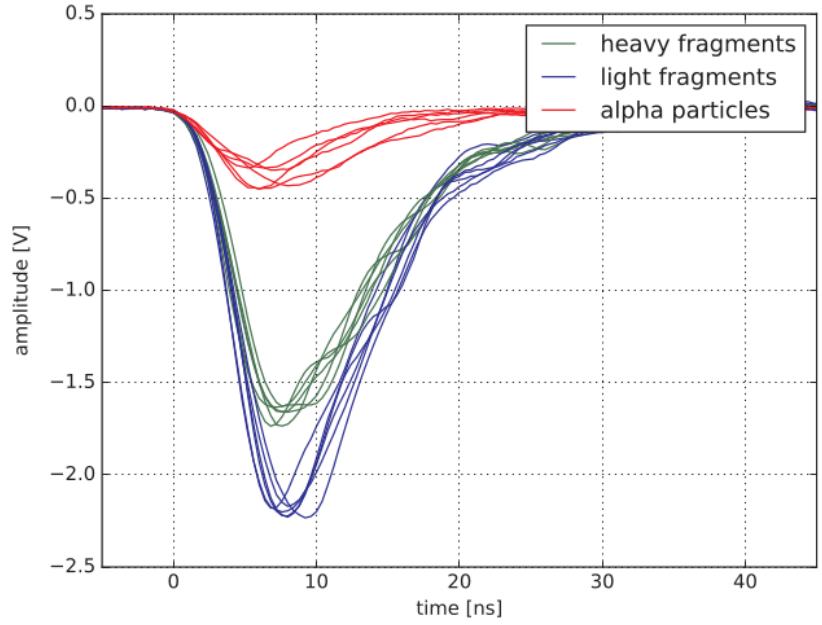
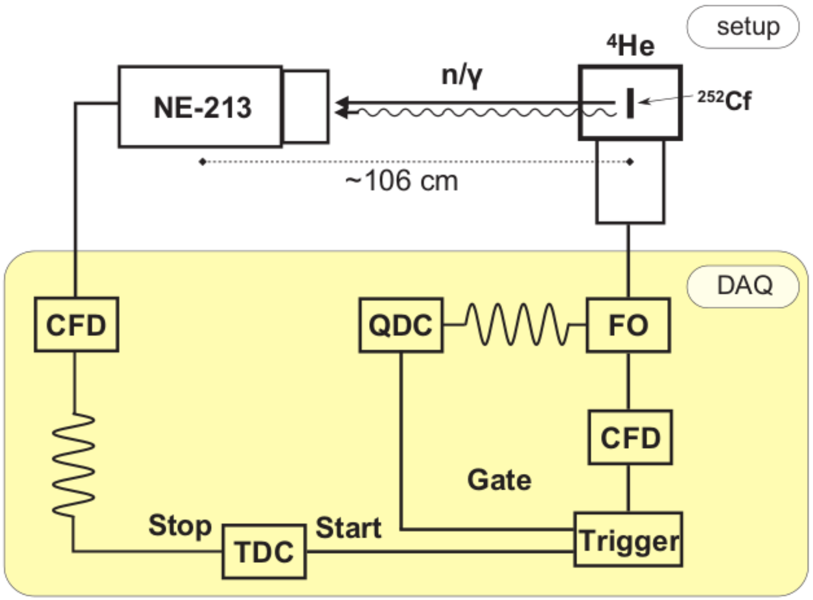
Applied Radiation and Isotopes 128 (2017)

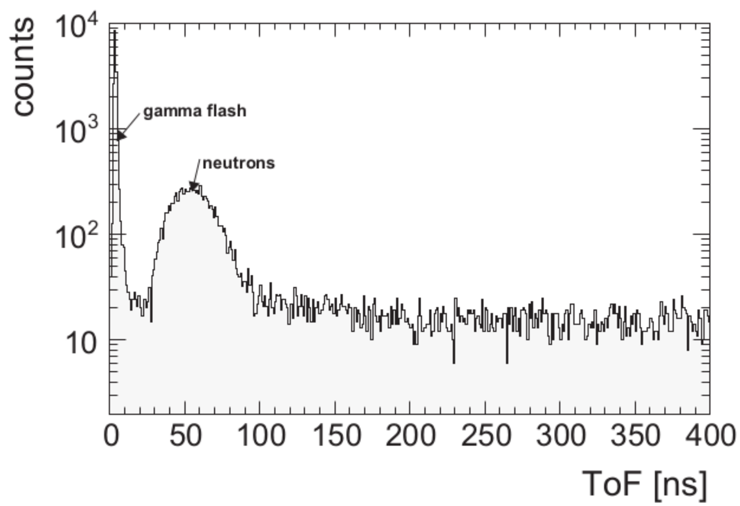
Tagging with a ^{3}He cell



Fission fragment and alpha spectra







No PSD

Accidental Background in signal region (25-100 ns) is given by:

10^5 SF/s x R_{acc} [Hz] x 10^{-7} [s]

I estimate 1 kHz of accidental in NE-213 (neutrons and gamma)

Naked source

3.7 MBq, 4 x 10^5 n/s, 0.1 SF/μs

106 cm distance --> 220 n/s through NE-213

NE-213 150 keVee threshold

Detailed investigation on the possibility of using EJ-299-33A plastic scintillator for fast neutron spectroscopy in large scale experiments

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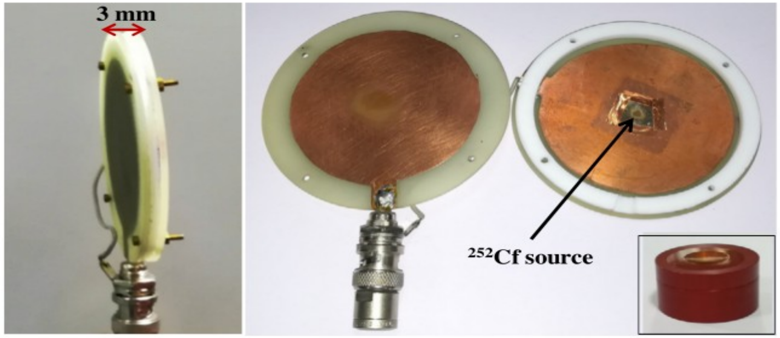
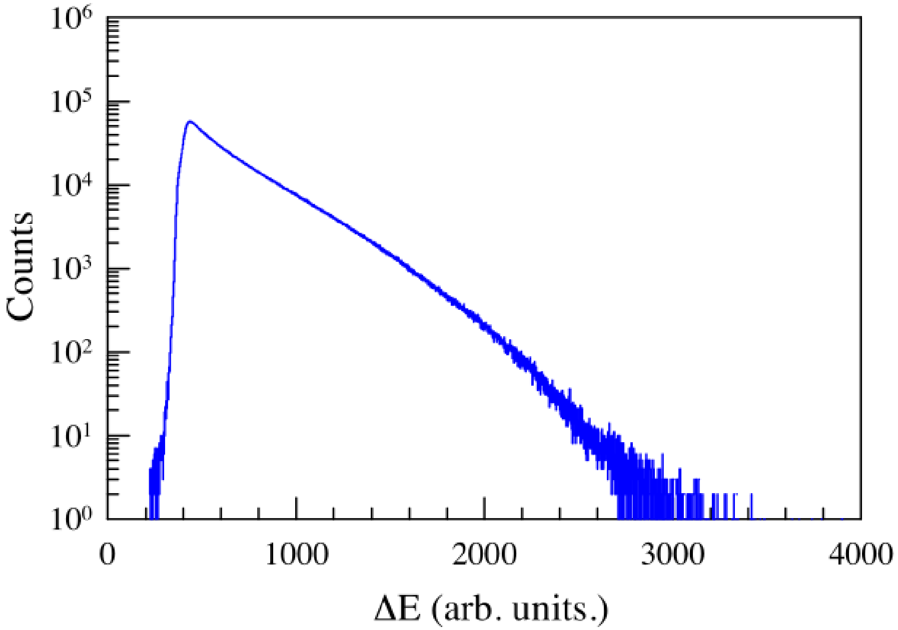
Tagging with a Fission Chamber





Fission fragment and alpha spectra

^{252}Cf : prompt gammas

Prompt Fission Gamma-ray Spectra and Multiplicities for Various Fissioning Systems

Physics Procedia 59 (2014) 89 – 94

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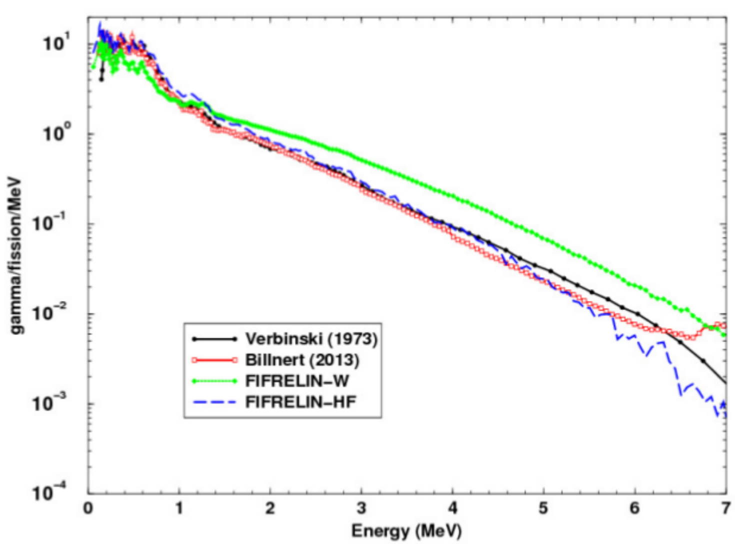
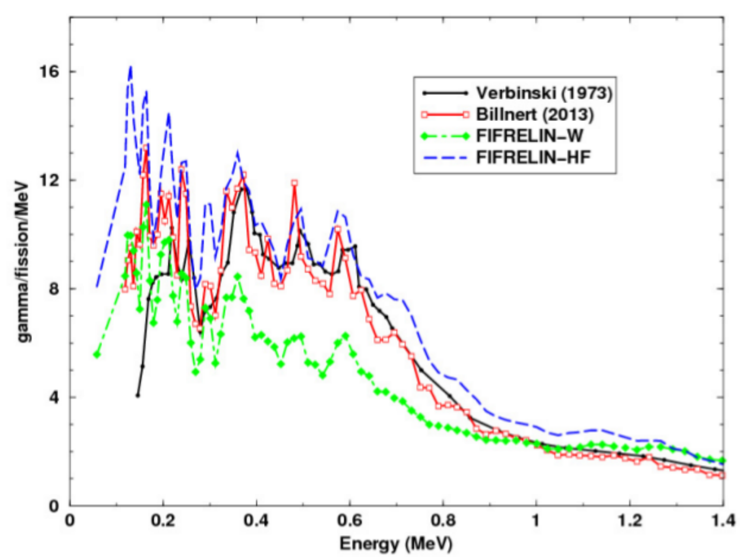
Multiplicity

Total energy

Table 1. Average quantities related to prompt fission gamma rays for spontaneous fission of ^{252}Cf(sf)

^{252}Cf(sf)	R_T^{min}	R_T^{max}	k_{rig}	$\overline{\sigma}_L$ ($\hbar$)	$\overline{\sigma}_H$ ($\hbar$)	$\overline{\nu}_L$	$\overline{\nu}_H$	$\overline{\nu}$	$\overline{M}_\gamma$	$< \epsilon_\gamma >$ (MeV)	$< E_\gamma^{tot} >$ (MeV)	E_{th} (MeV)	Δ_t
(Vorobyev et al., 2004)	(target observables)					2.051	1.698	3.76					
(Smith et al., 1956)									10.3	0.79	8.2	0.040	0.3 μs
(Skarsvag, 1980)									9.76±0.40	0.72	6.99±0.30	0.114	12 ns
(Billnert et al., 2013)									8.30±0.08	0.80±0.01	6.64±0.08	0.100	3 ns
(Verbinski et al., 1973)									7.80±0.30	0.88±0.04	6.84±0.30	0.140	10 ns
(Pleasonton, 1972)									8.32±0.40	0.85±0.06	7.06±0.35	0.085	
(Chyzh et al., 2012)									8.14±0.40	0.94±0.05	7.65±0.55	0.150	10 ns





Prompt gammas will have a hard time to mimic a **golden event**:

- Compton scatter in the TPC.
- Pass PSD LSci cut.
- Pass TOF cut.

G4DS quantitative studies in progress.
Delayed gammas also, but relative strength is smaller.

Plausible roadmap if we follow the Californium avenue

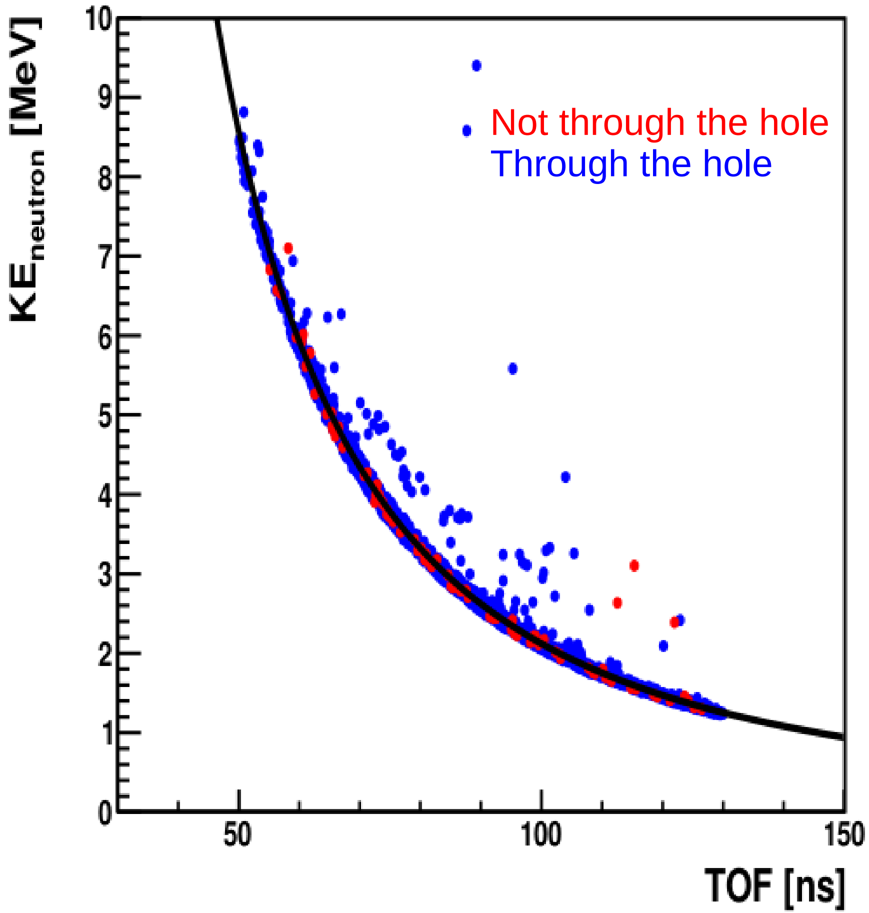
- **Experimental set-up to measure the Fission Fragments**: source preparation in thin-film attached to ORTEC. Small vacuum chamber.
- **Repeat the LSCi calibration done a few weeks ago with the new tagger:** no shield
- **Prepare a shield and measure background with the wheel and a central LSCi.**

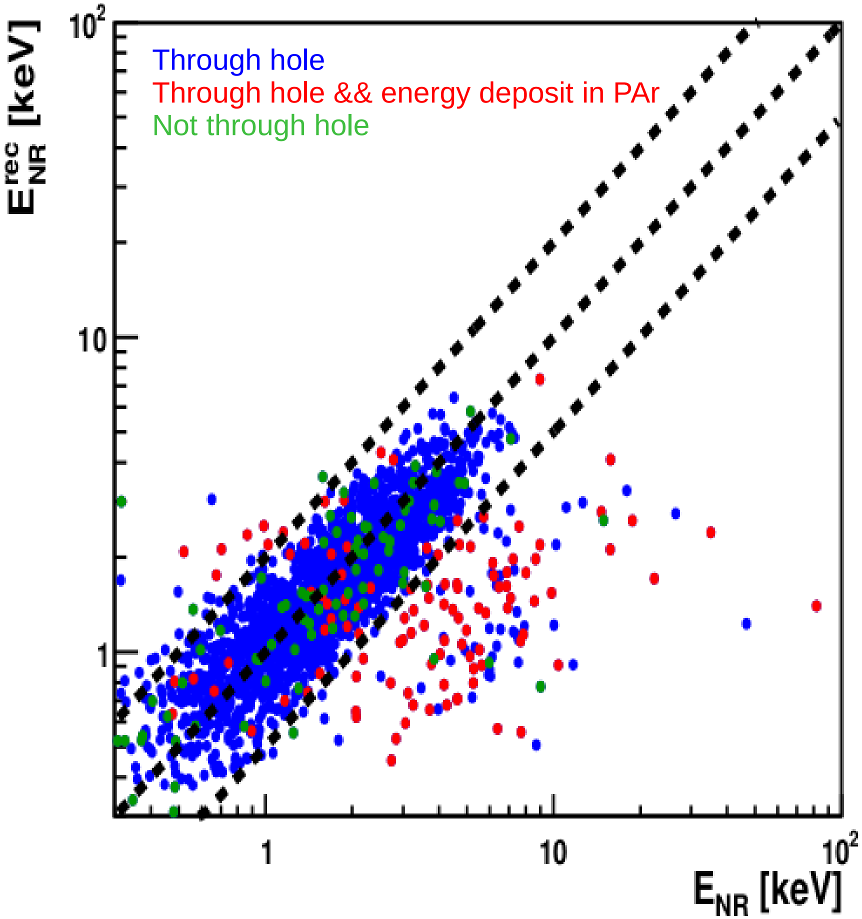
I do not recommend doing the shield studies with a Fast PS or LSCi as a tagger,
we already observed a large pile up with a naked source due to the use of a gamma sensible tagger. We probably do not learn anything out of that.

Performance of the set up in slide 3

(neutrons in a +-3 [deg] cone around hole, hole is +-1.5 [deg])

10 million neutrons

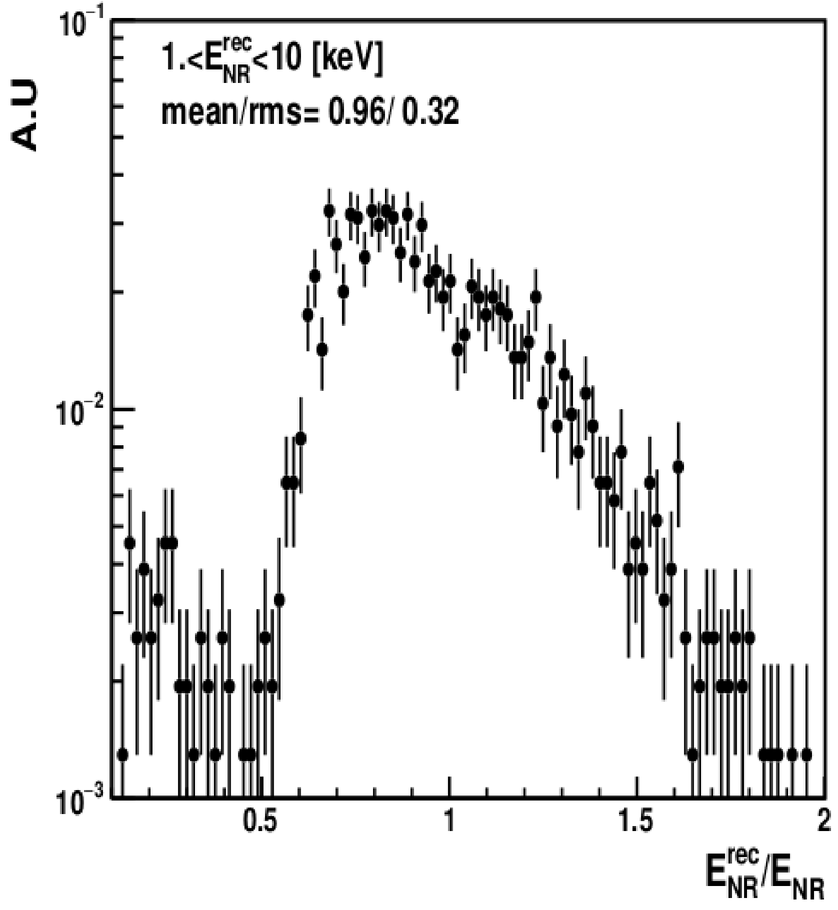


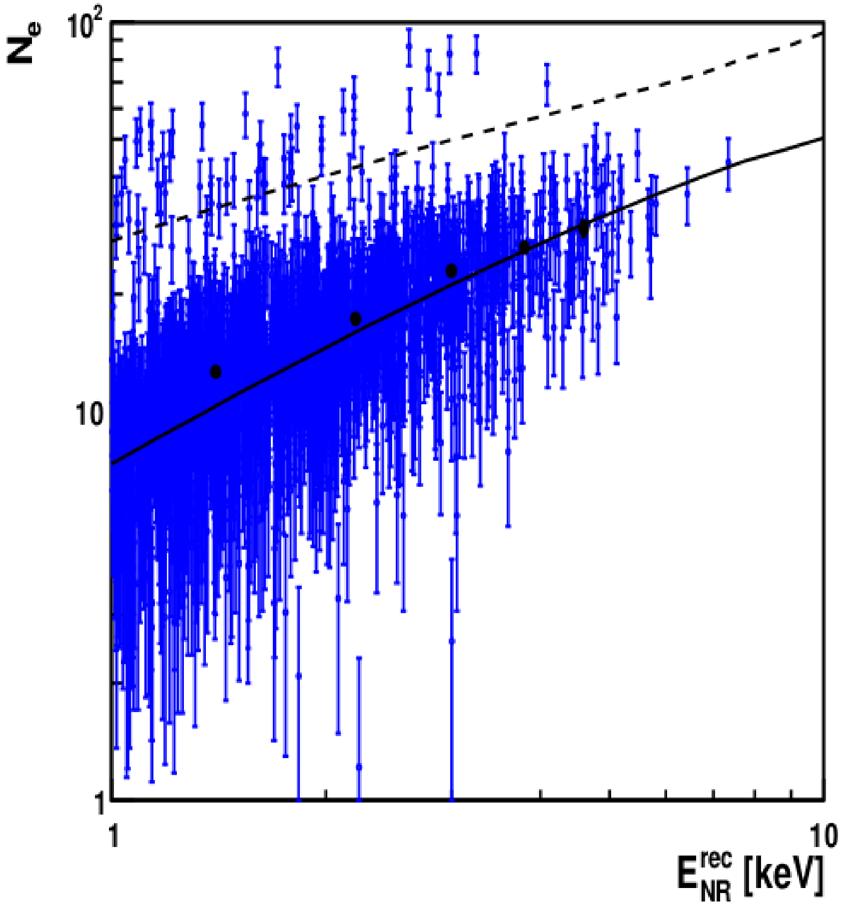


Neutron energy reconstruction

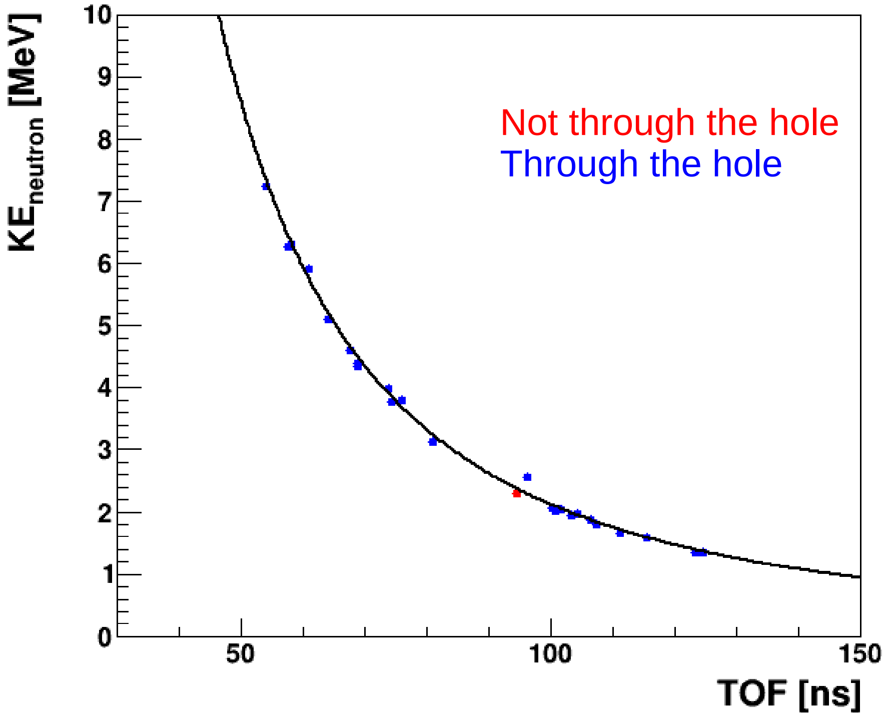
Neutron Recoil energy reconstruction

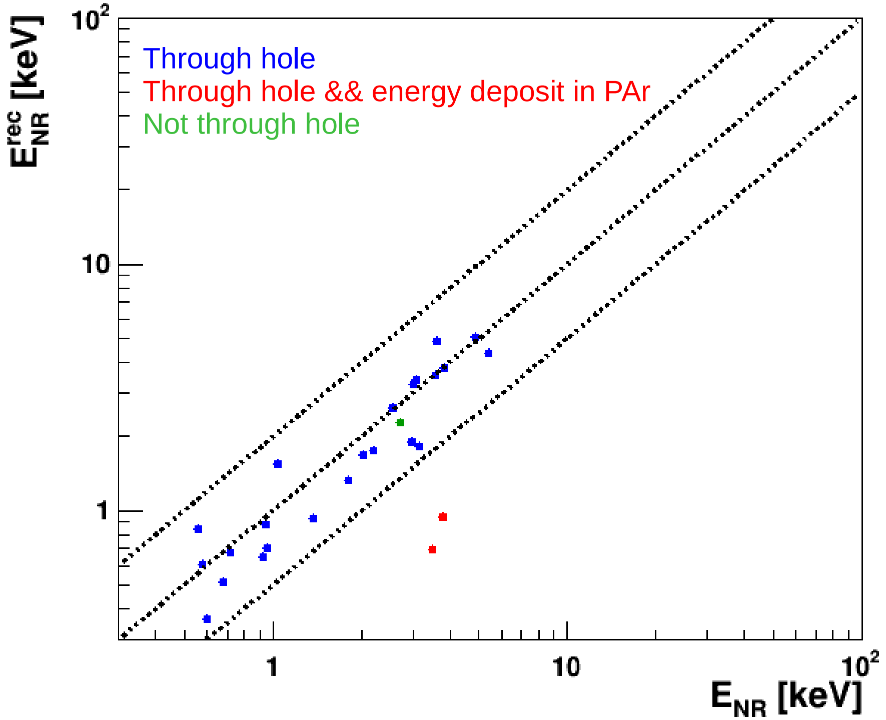
N_e (rec) vs E_{NR} (rec)



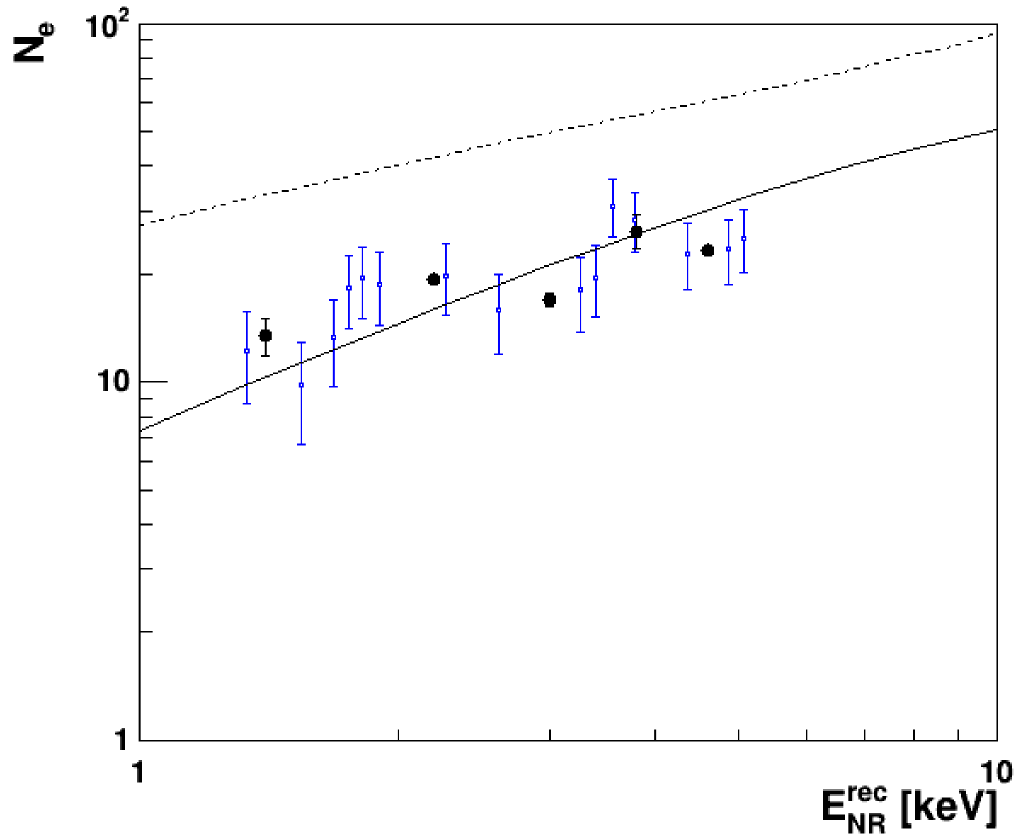


200 million isotropic neutrons





1 golden event out 26 is due to a neutron that scatter slightly in the Shield.
Collimation is working.



N_e
10^2
10
1
1
10
E_{NR}^{rec} [keV]

Table 1: The probabilities of *okTPC*, *okLSci* and *okEvent* for neutrons generated in a 3 [deg] cone around different directions, see text for more details.

	sr $[10^{-3}]$	N_{MC}	okTPC	okLSci	okEvent
Positive x, *inner*	2.153	2.5e6	475301 / 0.20	7045 / 2.8e-3	2005/ 8.e-4
Positive x, *outer*	6.457	7.5e6	20103 / 2.7e-3	1309 / 1.7e-4	80 / 1.e-5
Negative x, *inner*	2.153	2.5e6	16/ 6.4e-6	2/ $\sim$1e-6	1/ $\sim$1.e-7
Negative x, *outer*	6.457	7.5e6	31/ 4.1e-6	0/ $\sim$1e-7	0/ $\sim$1.e-7
Positive z	8.611	10e6	0/ $<$1e-7	1/ $\sim$1e-7	0/ $<$1.e-7

20 kHz of SF is required for a 0.01 Hz of Golden Events, about 1 MBq ^{252}Cf

Work in progress to estimate:
The TPC and LSci background rate under the presence of the shielded source (i.e. the source should induce an increase in the overall background, not correlated with the time tag).

No show stopper has been found so far.

The neutron camera would be also very usefull in this set-up:

- Neutron beam characterization.
- Measurement.

2 Inch LSci would also improve the results.