External gamma background al LNGS

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External gamma bkg estimate

1. Radioactivity measurement in the rock:
   - Measure the background with a NaI detector in Hall B and Hall C
     ➔ Calibrate spectrum and extract experimental resolution
   - Use a GEANT4 simulation of the experimental setup to generate radioactive decays in the rock
   - Apply the experimental resolution to MC
   - Deconvolve the experimental spectrum to obtain radioactivity in the rock
     ➔ comparison with literature when possible

2. Estimate the gamma background for SABRE
   - Use a GEANT4 simulation of the SABRE setup to generate radioactive decays in the rock
   - Normalize with radioactivity measurements from step 1
     ➔ Prediction of the background for SABRE and shielding attenuation

Analysis documented in an internal note available on SABRE wiki page.

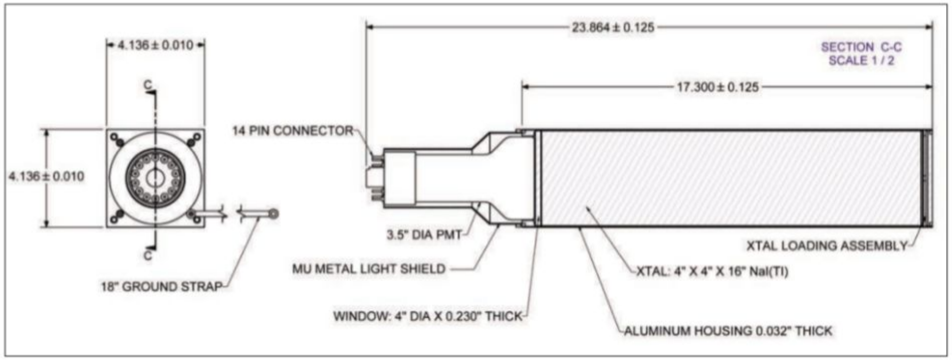
External gamma measurements

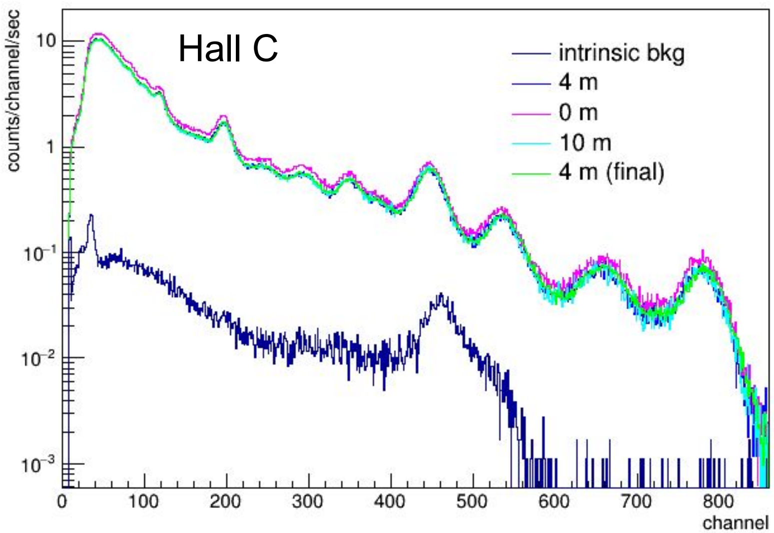
4”x 4”x 16” NaI(Tl) crystal coupled to a 3.5” diameter photomultiplier tube (PMT) inside aluminium case.

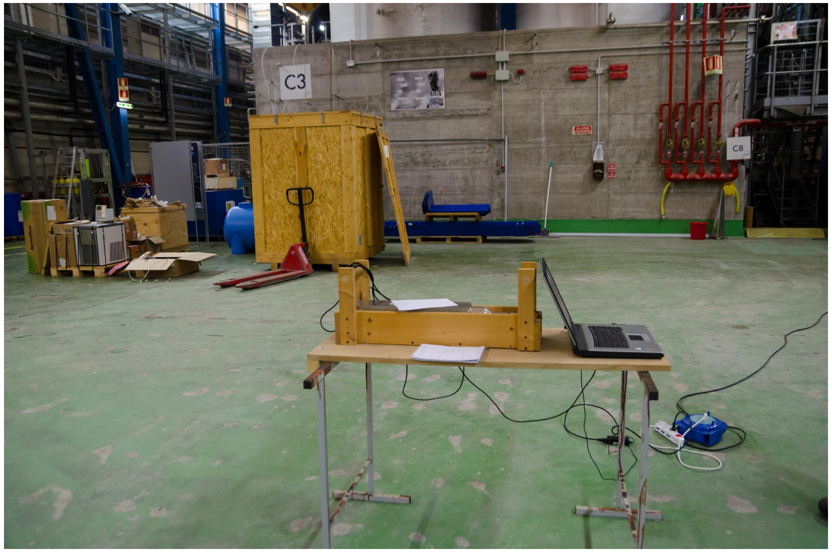
- Hall B : measurements at different height done in 2015
- Hall C : measurements at different distance from Borexino wall (0,4,10 m), done in 2017
  ➜ no significant difference observed between different configurations

NaI(Tl) scintillation detector series 905-16, Ortec

905-16 NaI Scintillation Detector, 4- x 4-in. crystal, 3-in. tube

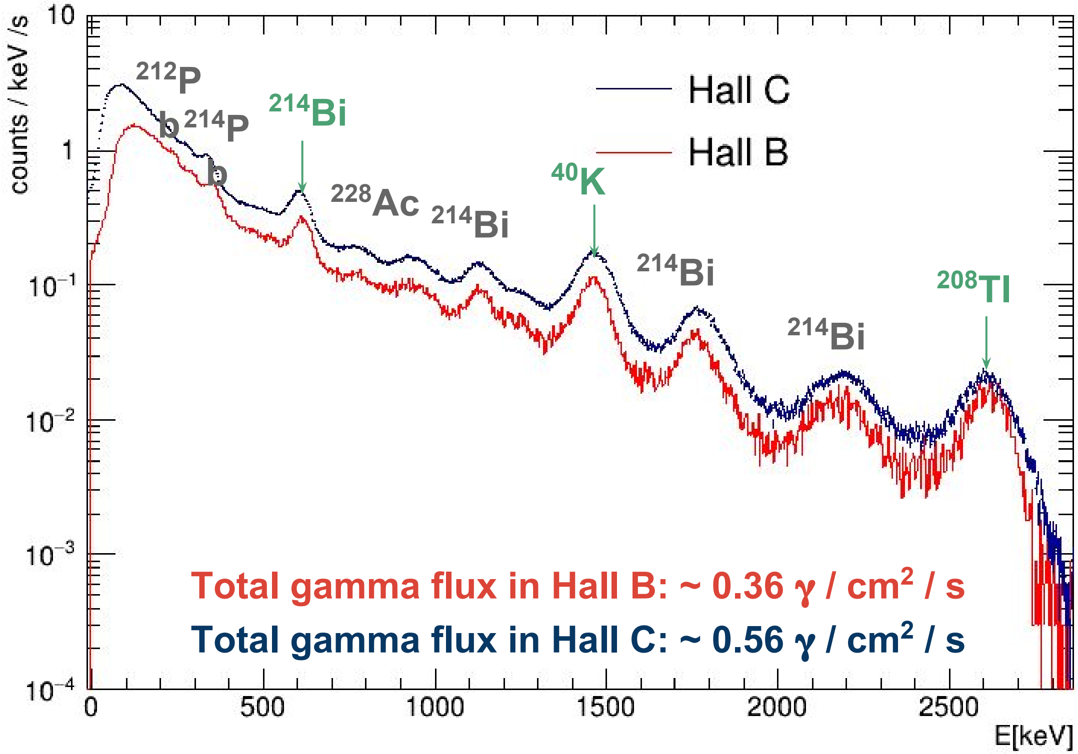




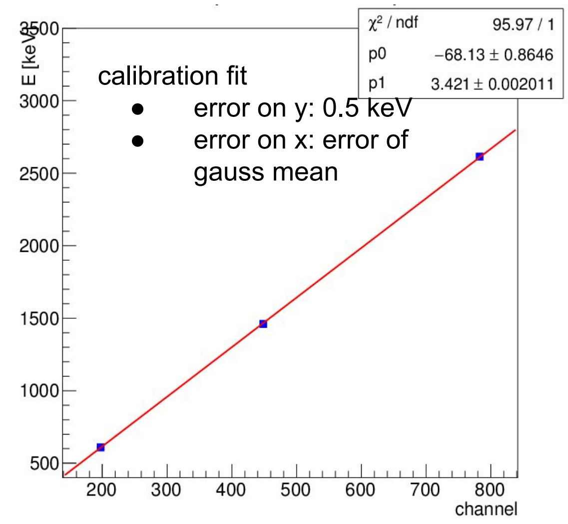


Hall B and Hall C calibrated spectra

- Gammas mostlly from **K, U** chain and **Th** chain
- The spectrum has been calibrated using 609 (^{214}Bi), 1461 (^{40}K), 2615 (^{208}Tl) keV lines
- The resolution is slightly different between the Hall B and C measurements because the NaI detector was not the same
- For the second crystal (Hall C measurement) we also made a measurement of intrinsic background ➡ background subtraction



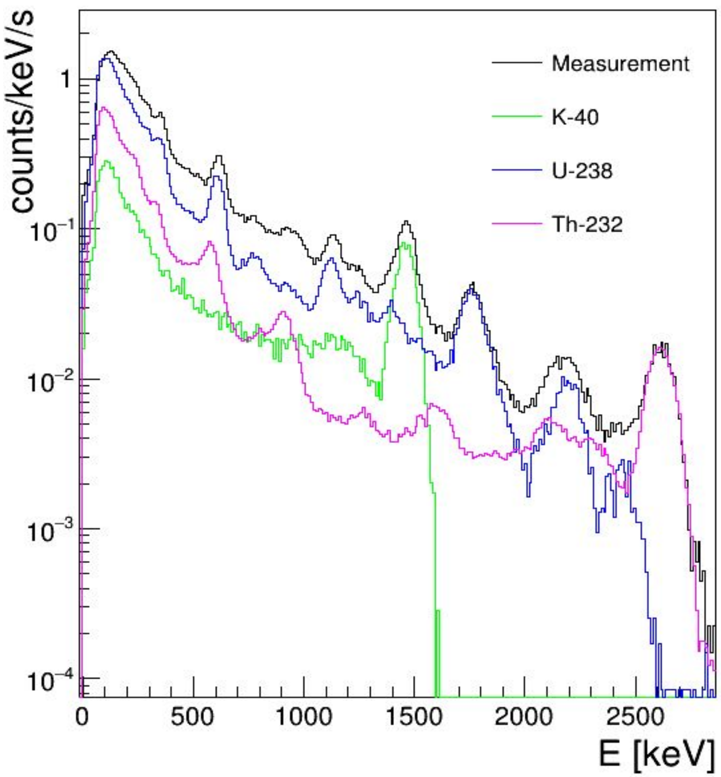
Calibration fit for Hall C spectrum



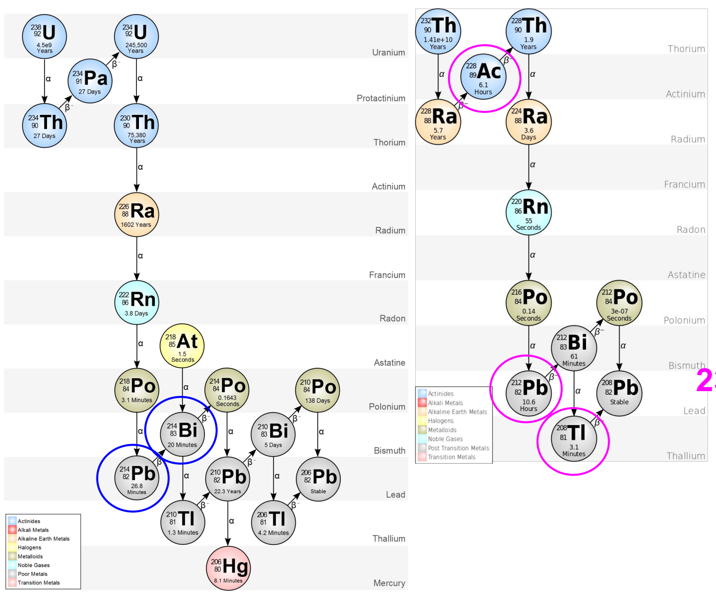
Deconvolution of the measured gamma spectrum

$$f(E) = c_K \times f_K(E) + c_U \times f_U(E) + c_{Th} \times f_{Th}(E)$$

f ➔ templates from simulation
c ➔ normalization, free parameters of fit
Experimental resolution of the NaI detector is applied to Monte Carlo



We simulate only the isotopes of U and Th chains that produce most intense gammas



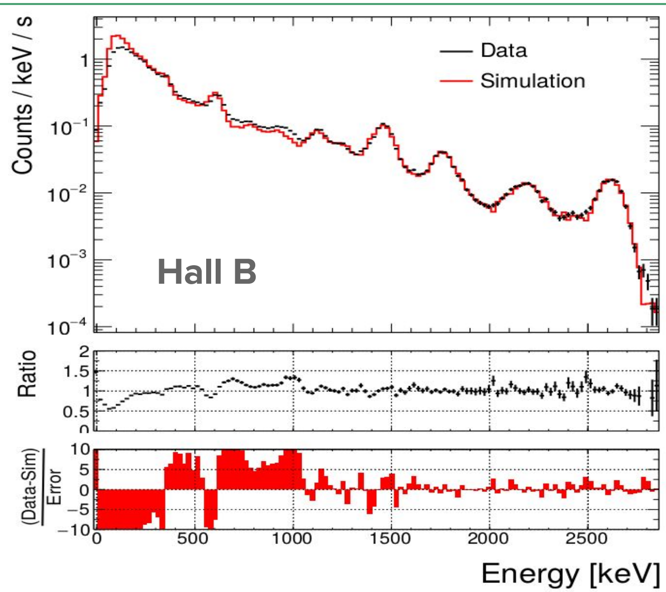
^{40}K

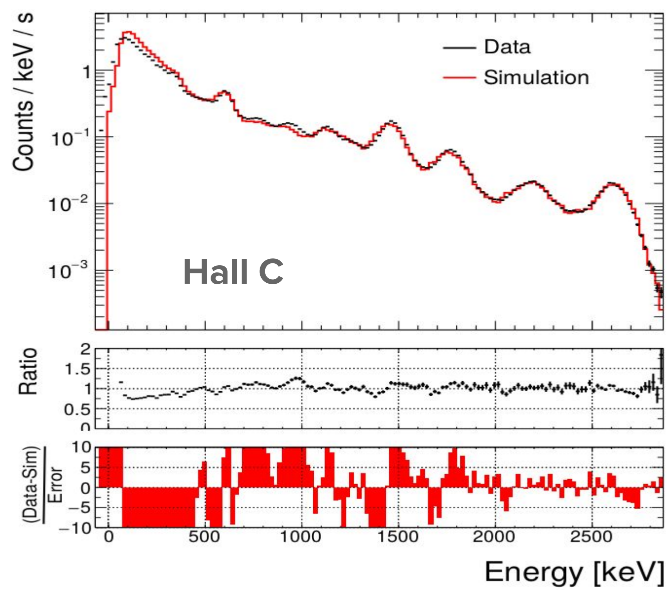
^{238}U: ^{214}Bi, ^{214}Pb

^{232}Th: ^{208}Tl, ^{228}Ac, ^{212}Pb

Spectrum fit

$$f(E) = c_K \times f_K(E) + c_U \times f_U(E) + c_{Th} \times f_{Th}(E)$$

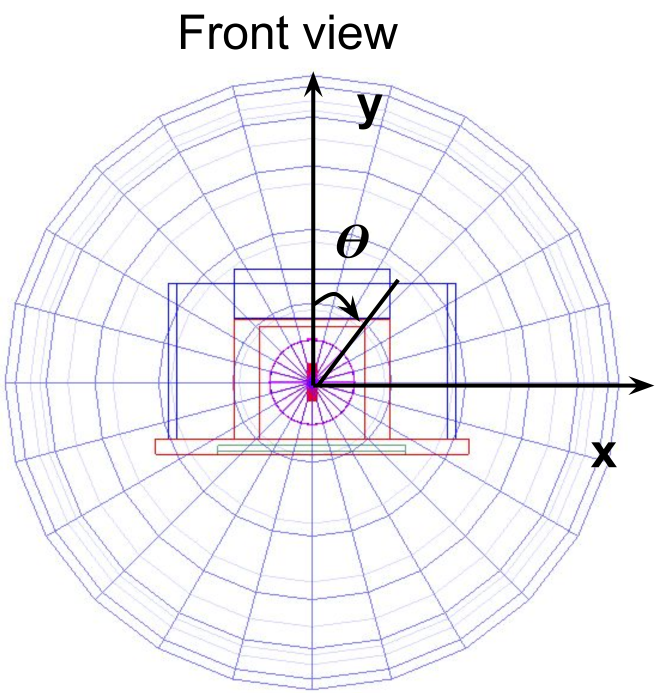


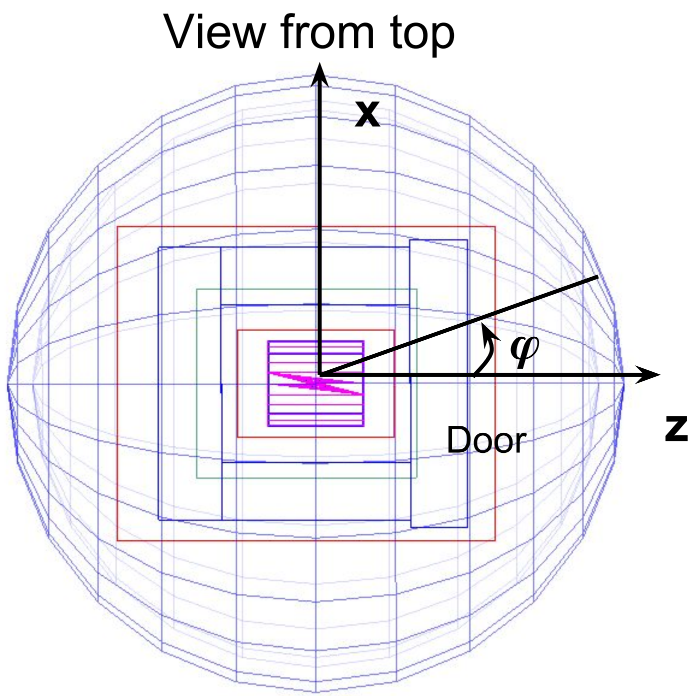


	Measurements		H. Wulandari et al. Astroparticle Physics 22 (2004) 313–322			
	Hall B [ppm]	Hall C [ppm]	Hall B [ppm]		Hall C [ppm]	
			Rock	Concrete	Rock	Concrete
K	7068 ± 90	12780 ± 70	10272	5377	10272	5377
U	0.56 ± 0.01	0.966 ± 0.004	0.42	0.66	0.66	0.66
Th	0.54 ± 0.01	0.840 ± 0.006	0.062	1.05	0.066	1.05

SABRE simulation

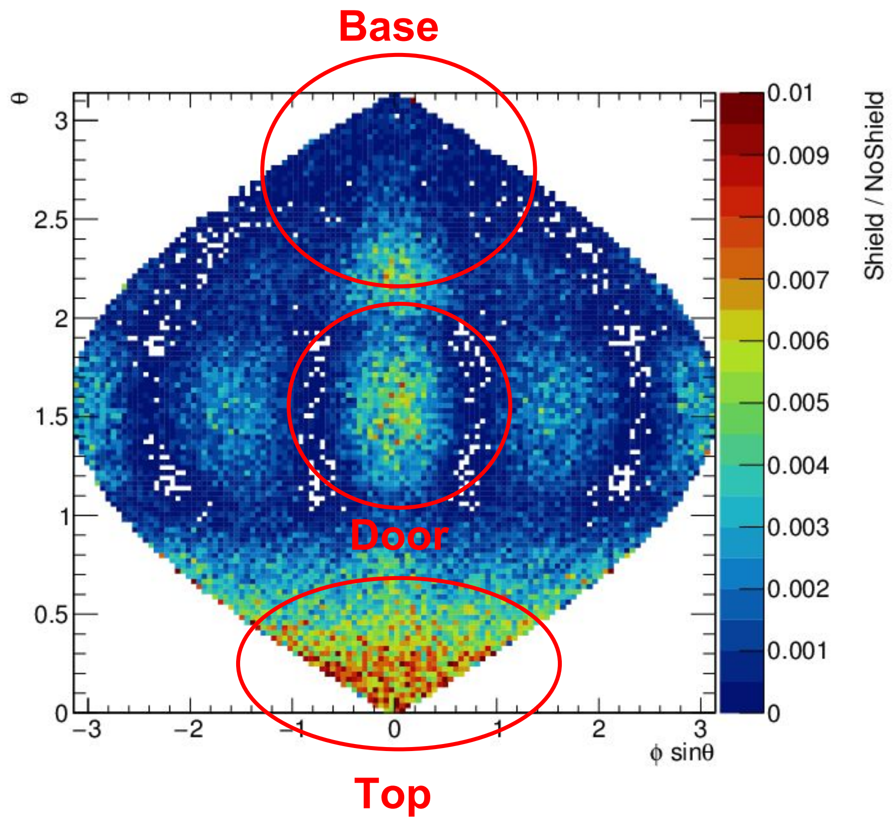
- Used SABRE MC official simulation
- Shielding design not the very final one but about the same amount of material
- Rock cavern simplified
  ➔ rock spherical shell of 40 cm thickness and 4.5 m internal radius in order to contain the shielding
- Input contaminations of ^{40}K, ^{238}U and ^{232}Th in the rock shell from previous slide



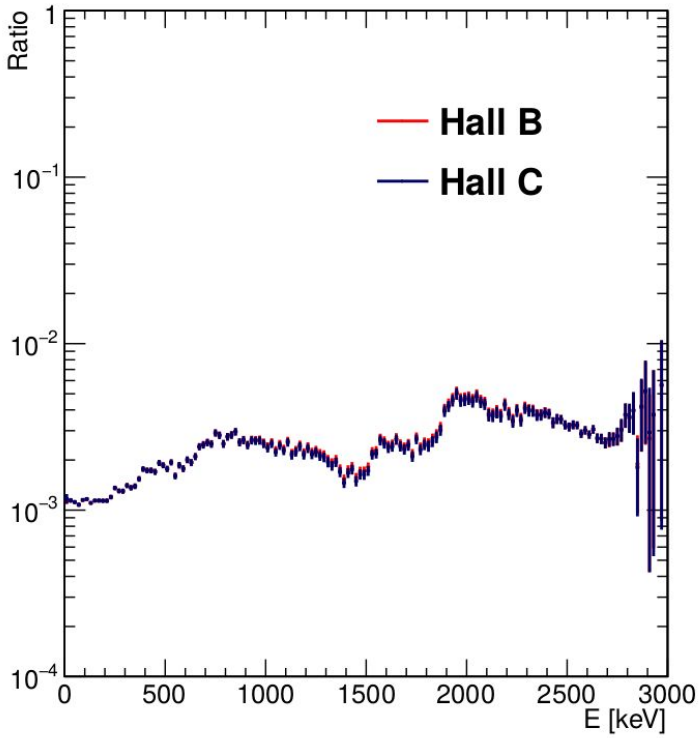


Shielding attenuation

Position of generated isotopes that deposit some energy > 0 in the liquid scintillator

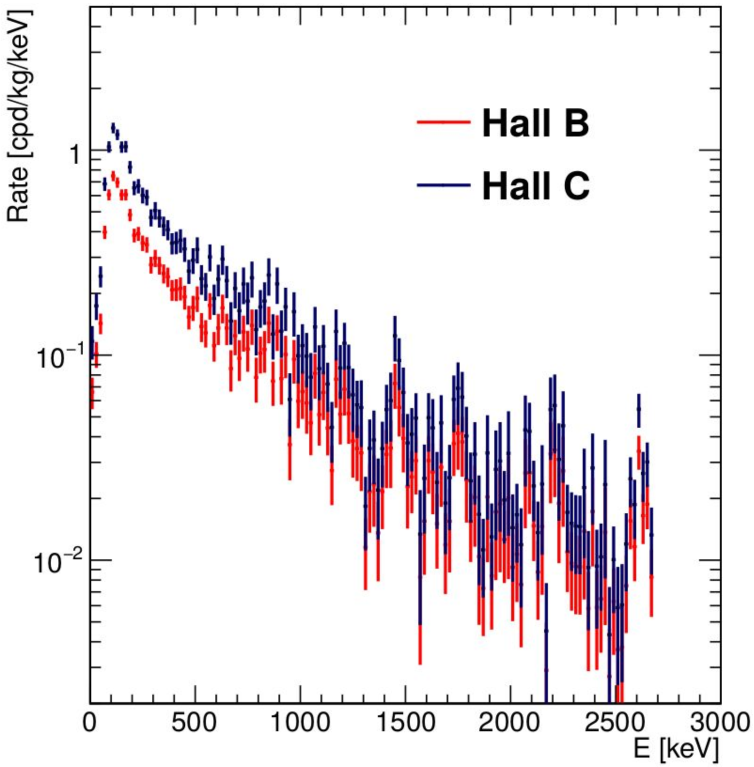


Shielding attenuation vs Energy is estimated from the ratio of spectra in liquid scintillator with and without shielding



External gamma background for SABRE

- We didn't produce sufficient statistics to simulate the spectrum in SABRE crystal with the shielding
- The shielding attenuation obtained from the LS is applied to the crystal spectrum without shielding

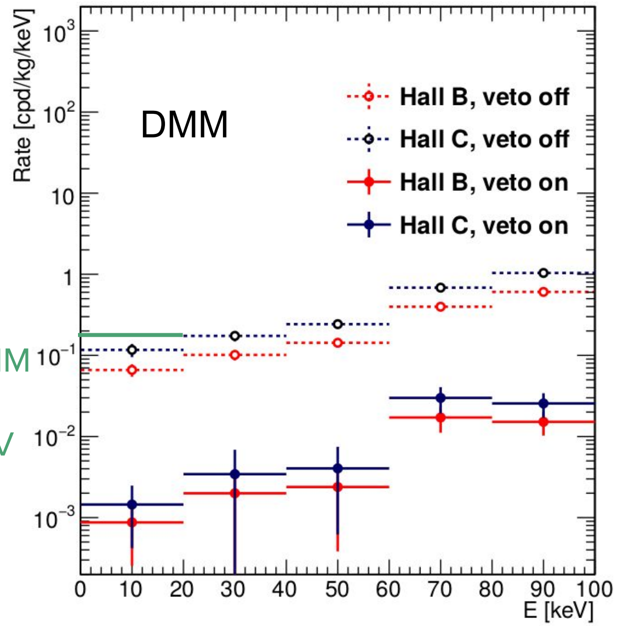


SABRE background using veto

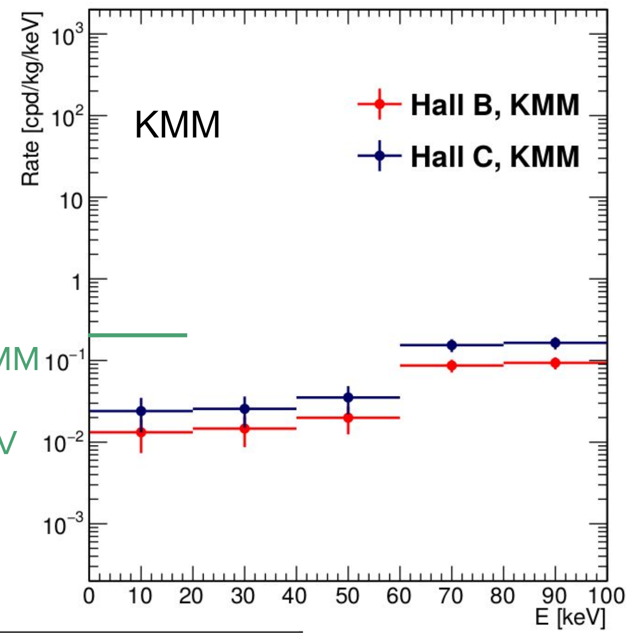
We can apply also the veto effect to obtain the background level for dark matter measurement mode (DMM) and for the K measurement mode (KMM)

veto: E(Scintillator) > 100 keV
E(Crystal) ∈ [2,6] keV

E(Scintillator) ∈ [1280,1640] keV
E(Crystal) ∈ [2,4] keV



Tot. internal background DMM in [2-6] keV
0.20 cpd/kg/keV
(see backup)



Tot. internal background KMM in [2-4] keV
0.19 cpd/kg/keV

	Hall B [cpd/kg/keV]	Hall C [cpd/kg/keV]
KMM	$(1.37 \pm 0.41)\ 10^{-2}$	$(2.40 \pm 0.55)\ 10^{-2}$
DMM	$< 4.0\ 10^{-3}$ (99% CL)	$< 5.4\ 10^{-3}$ (99% CL)

Conclusions

- Measured the external gamma spectrum in Hall B (temporary site for SABRE vessel) and Hall C (final site for SABRE PoP)

- Obtained a measurement of contamination in the LNGS rock
  ➜ compared with literature when possible and found compatible results
  ➜ Hall C has a higher gamma flux (0.56 γ/cm^2/s) than Hall B (0.36 γ/cm^2/s)

- Obtained a prediction for the SABRE external gamma background
  ➜ shielding attenuation between 10^{-2} to 10^{-3}
  ➜ last design of the shielding door (from 10 to 65 cm of PE) should improve the door shielding attenuation

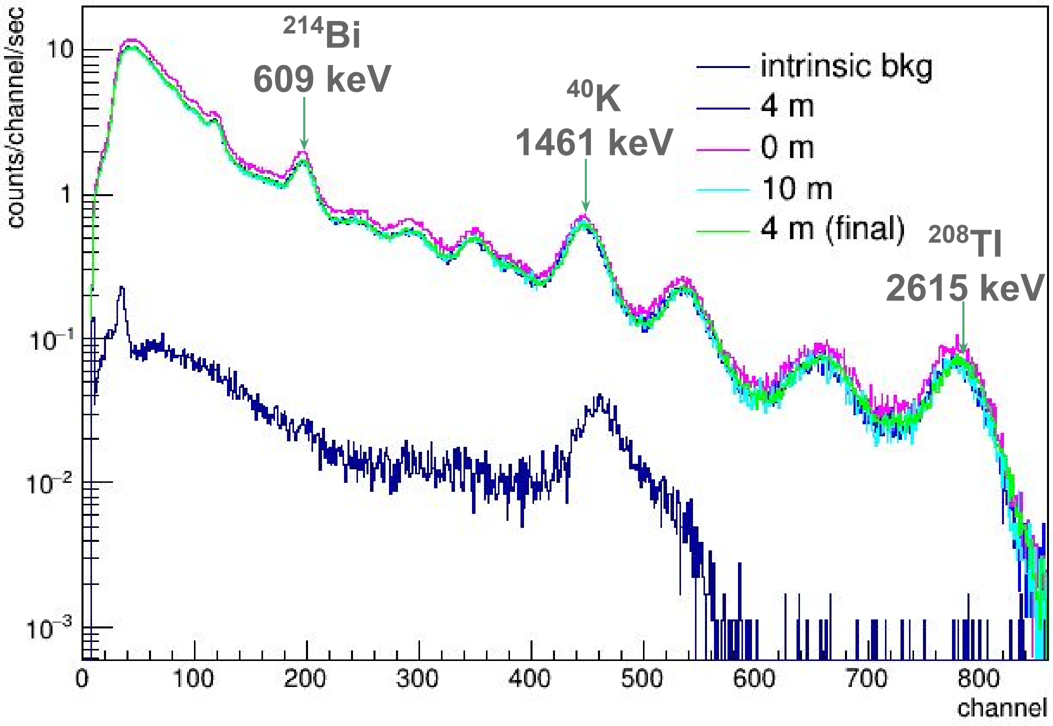
- The expected background for SABRE crystal is factor ~50 below the other internal backgrounds for Dark matter measurement mode

Backup slides

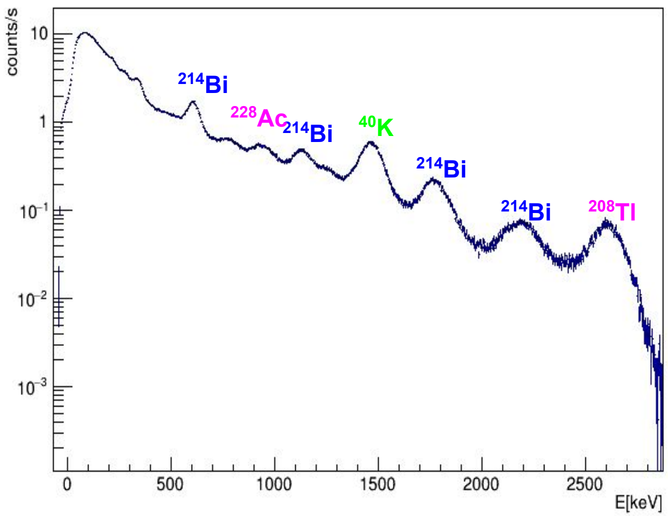
Spectrum calibration

Overlapped spectra taken at different distances and intrinsic background

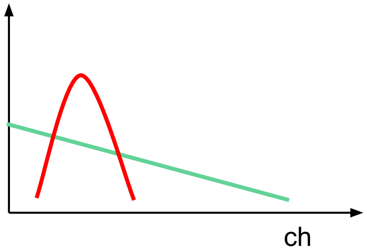
- intrinsic counts, 10 cm Pb shielding (30 min)
- 4 m from Borexino wall (30 min)
- close to Borexino wall (30 min)
- 10 m from Borexino wall (30 min)
- 4 m from Borexino (90 min)



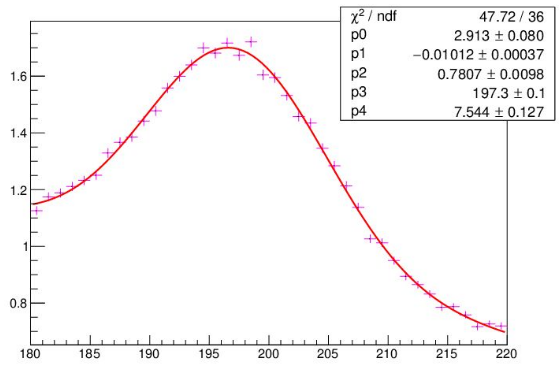
Calibrated spectrum

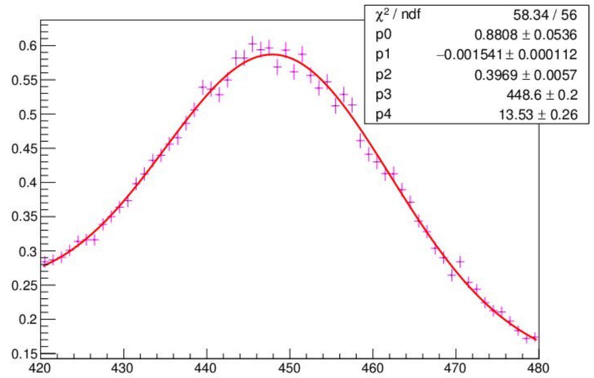


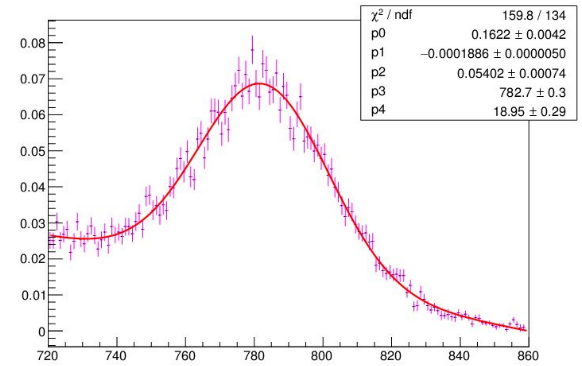
Spectrum calibration

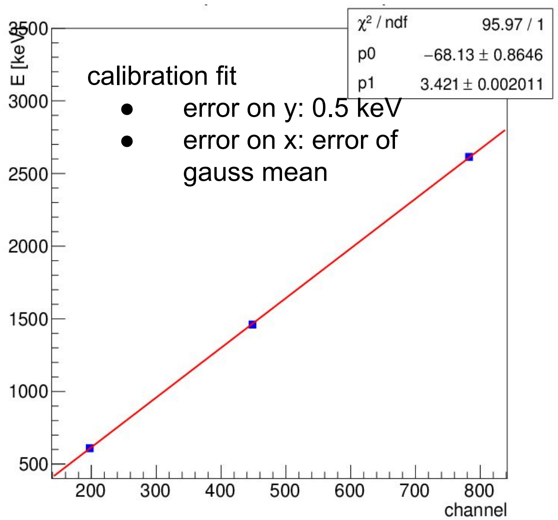


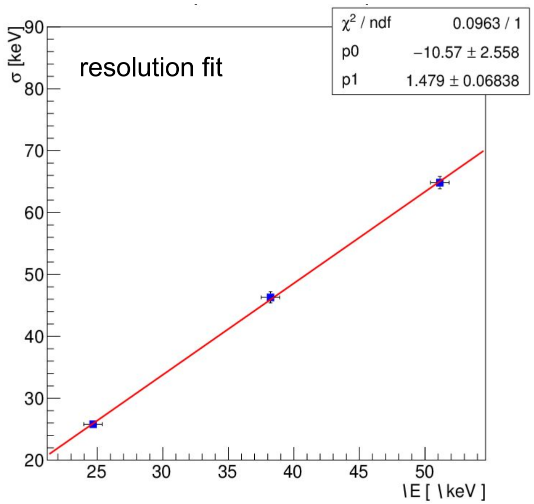
- Slope + gauss fit to 609, 1461, 2615 keV lines
- Extract gauss mean and sigma using long run (90 min)
    - Mean ➔ calibration fit
    - Sigma ➔ resolution fit









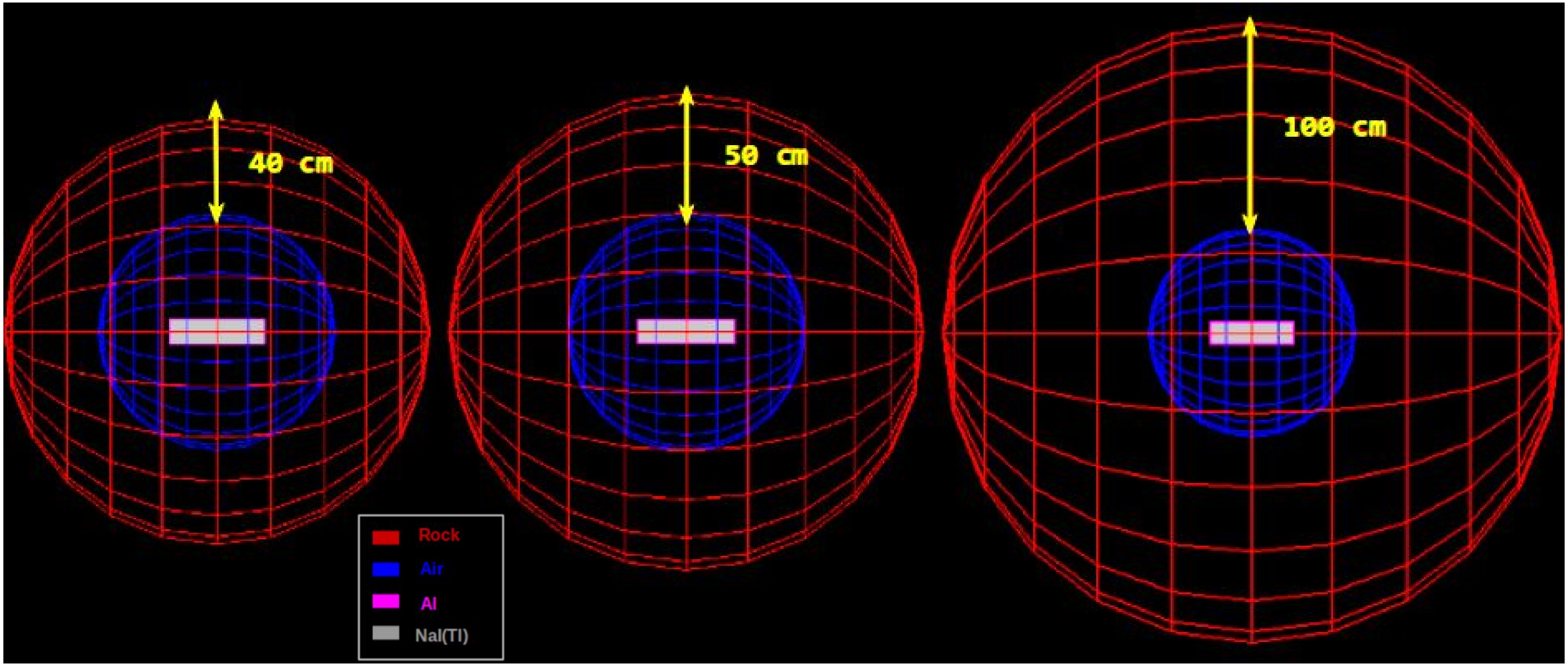


Resolution of the NaI detector is 1.47/sqrt(E[keV])

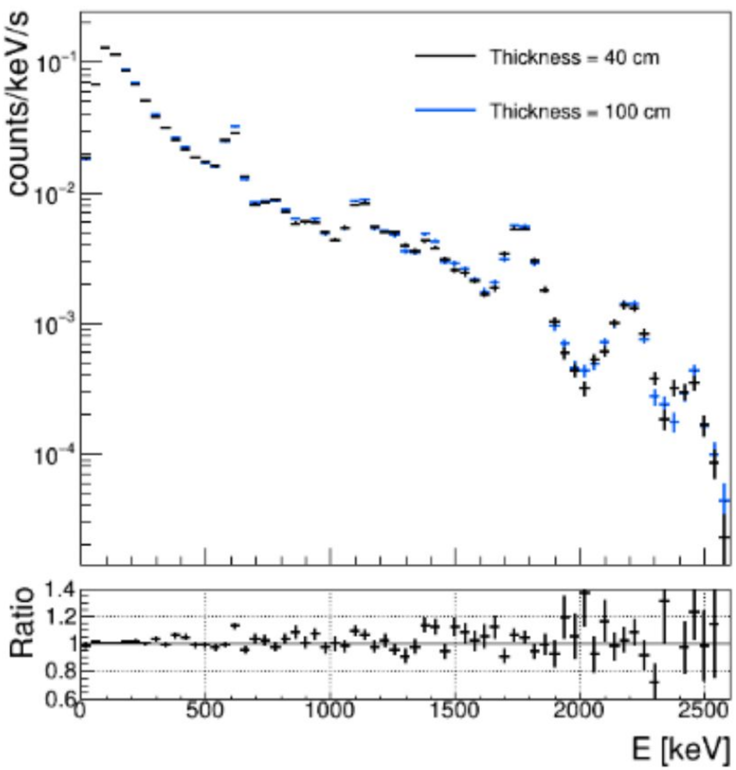
Previous studies of hall B spectrum (made by Ambra) indicated a smaller resolution (~1.1/sqrt(E[keV]))
➔ not the same crystal

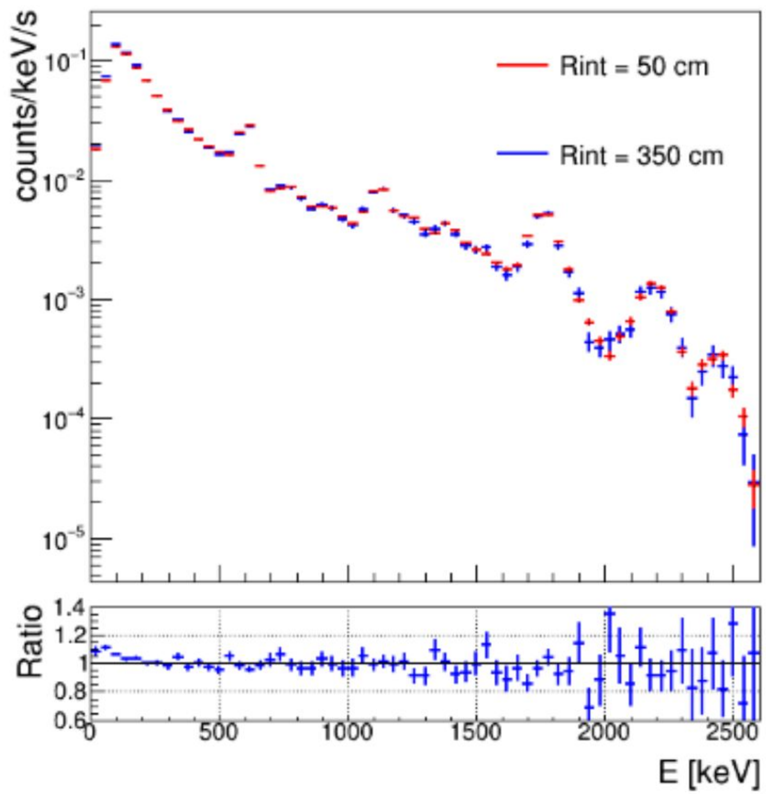
NaI simulation

- Rock spherical shell
- NaI crystal of 4"× 4"×16" in aluminium case
- Test of spectrum dependency vs thickness and internal radius in order to maximize statistics
  ➜ difference between configurations within 10%
  ➜ use R_{int} = 50 cm and thickness = 40 cm



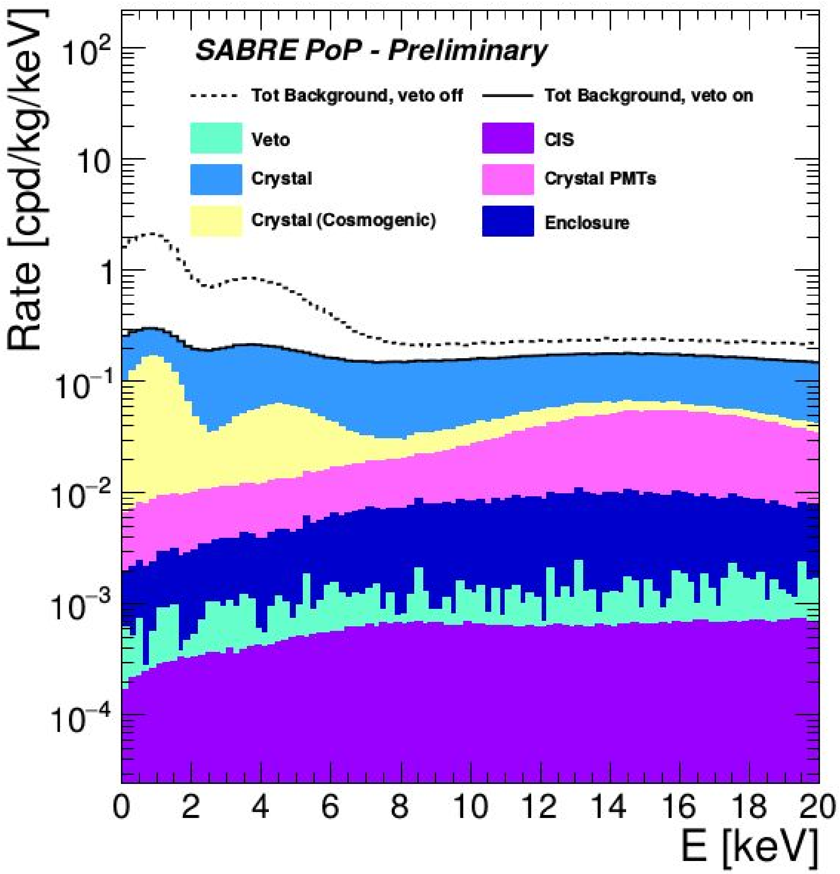
Simulated spectrum vs rock thickness and internal radius





Total internal background for DM measurement

Internal note MC



veto: E(Scintillator) > 100 keV
E(Crystal) ∈ [2,6] keV

	Rate, veto OFF [cpd/kg/keV]	Rate, veto ON [cpd/kg/keV]
Veto	$3.0 \cdot 10^{-2}$	$5.7 \cdot 10^{-4}$
CIS(*)	$3.7 \cdot 10^{-3}$	$4.6 \cdot 10^{-4}$
Crystal	$3.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-1}$
Crystal Cosmogenic(*)	$3.0 \cdot 10^{-1}$	$3.9 \cdot 10^{-2}$
CrystalPMTs	$1.3 \cdot 10^{-2}$	$8.3 \cdot 10^{-3}$
Enclosure(*)	$9.5 \cdot 10^{-3}$	$3.6 \cdot 10^{-3}$
Total	$7.1 \cdot 10^{-1}$	$2.0 \cdot 10^{-1}$

(*) after 180 days underground

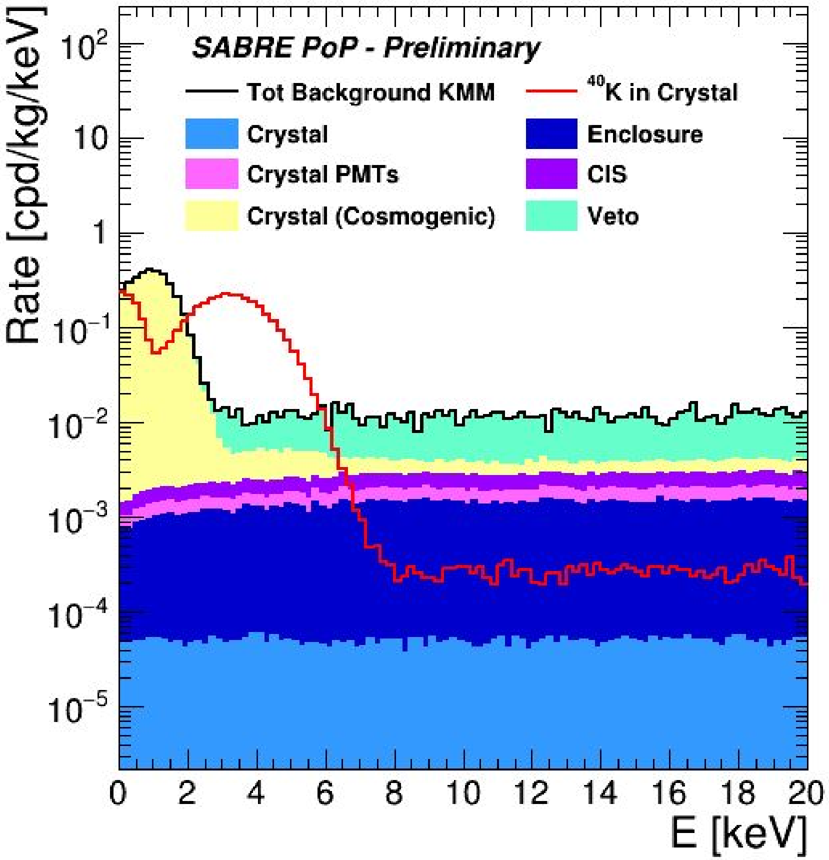
- Expected BKG **0.2 cpd/kg/keV in the ROI**
- Total veto rejection of internal bkg: **factor 3.5**
- **Crystal is the main source** of background
  - contaminations in the crystal measured with ICP-MS
  - dominant bkg ^{40}K → measured independently with ICP-MS at Seastar and PNNL
  - other bkg do not change the overall picture

Total internal background for K measurement

Internal note MC

- **Target ^{40}K electron capture** (3 keV e$^-$/x-rays + 1.46 MeV γ) in the crystal and other processes with large energy deposits in the scintillator
- Coincidences Cystal+Scintillator allow to study other intrinsic BKGs that give a energy release in the scintillator

E(Scintillator) ∈ [1280,1640] keV
E(Crystal) ∈ [2,4] keV



	Rate KMM [cpd/kg/keV]
Veto	$6.2 \cdot 10^{-3}$
CIS(*)	$7.7 \cdot 10^{-4}$
Crystal	$5.1 \cdot 10^{-5}$
Crystal Cosmogenic(*)	$1.8 \cdot 10^{-2}$
CrystalPMTs	$4.3 \cdot 10^{-4}$
Enclosure(*)	$1.3 \cdot 10^{-3}$
Total	$2.7 \cdot 10^{-2}$
Crystal ^{40}K	$1.9 \cdot 10^{-1}$

(*) after 60 days underground

- Largest bkg contribution from **^{22}Na mostly below threshold of 2 keV**