Passive Shielding in CUORE

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on behalf of the

CUORE Collaboration

2nd Topical Workshop in Low Radioactivity Technique

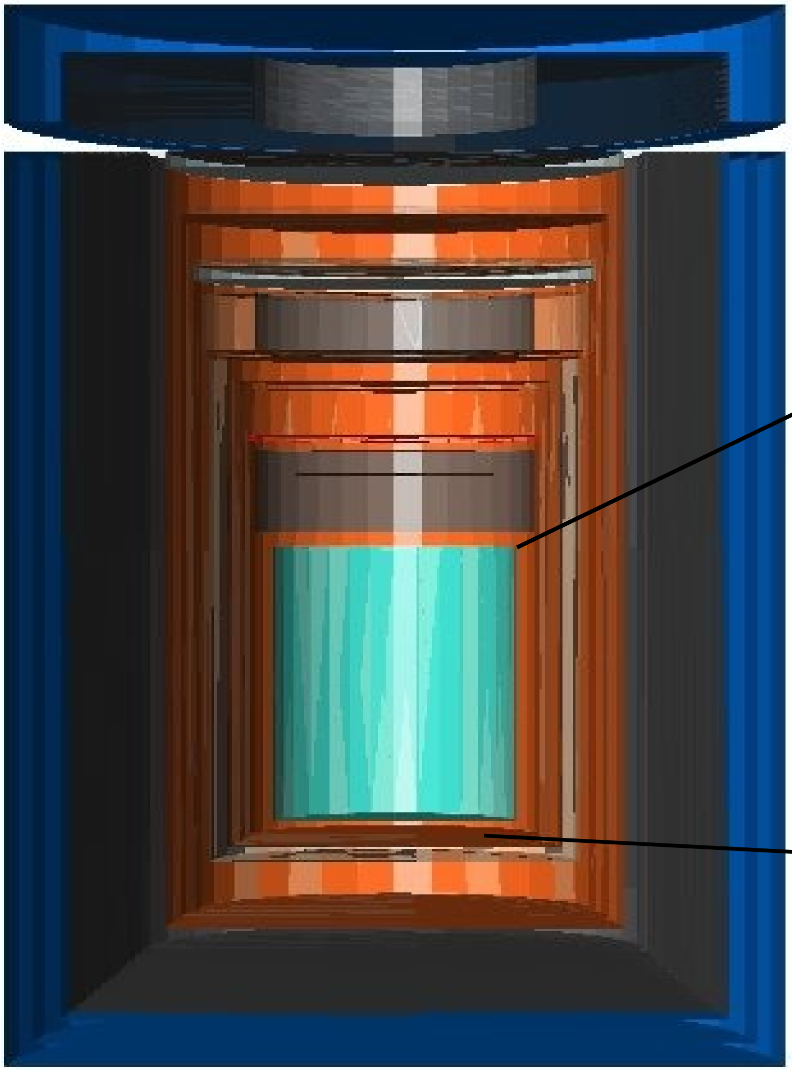
Aussois, France, Oct. 01-04, 2006

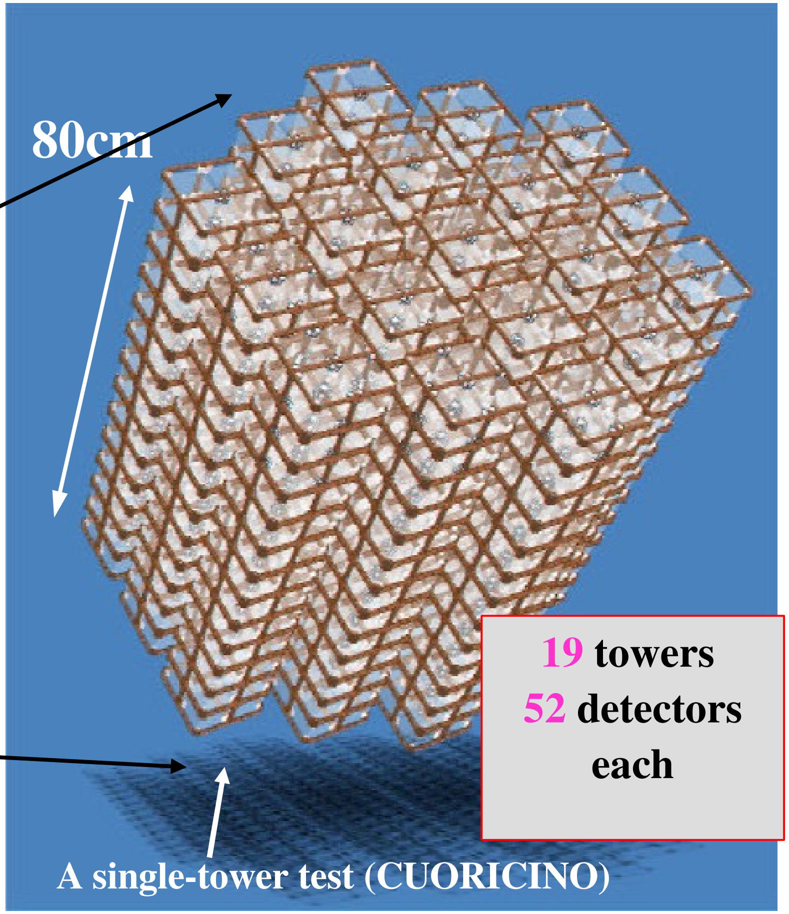
Cryogenic Underground Observatory for Rare Events

Single dilution refrigerator ~10 mk

- $\beta\beta0\nu$, Cold Dark Matter searches

  proposal hep/ph 0501010





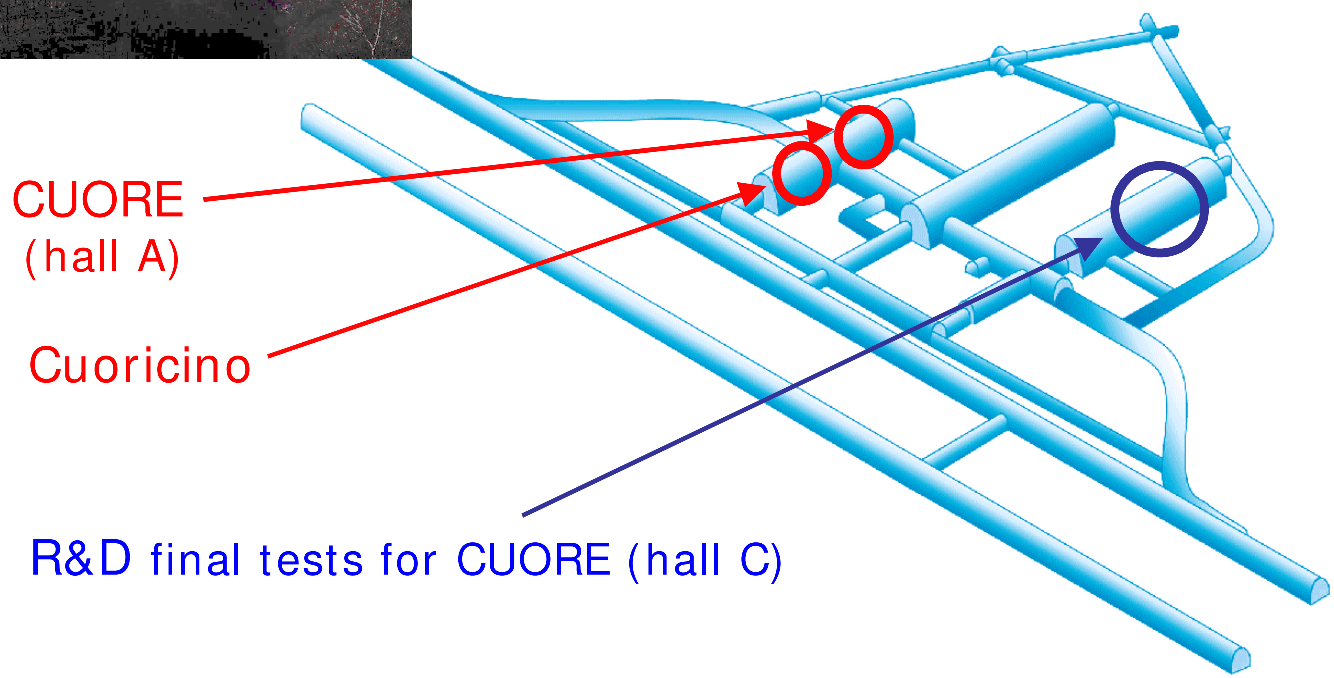
Closed packed array of 988 TeO_2 5x5x5 cm^3 crystals ⇒741 kg TeO_2 ⇒ 204kg ^{130}Te

CUOR(ICINO) @ LNGS

Cuoricino experiment is installed in the

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

the mountain providing a **3500 m.w.e. shield** against cosmic rays



Background challenge

CUORE ββ0ν sensitivity will depend strongly on the bkg level and detector performance

detector mass [kg] • measuring time [y]

$$S^{\beta\beta 0\nu} \propto a \cdot \epsilon \cdot \left(\frac{M\,T}{\Gamma\,b} \right)^{1/2}$$

energy resolution[keV] •bkg [counts/keV/kg/y]

isotopic abundance • detector efficiency

mass, efficiency & resolution almost fixed

sensitivity depends on T and background

In 5 years of data taking

b(c/keV/kg/y)	Γ (keV)	$T^{0\nu}_{1/2}$ (y)	$\vert\langle m_\nu \rangle\vert$ (meV)
0,01	10	$1{,}5\times10^{26}$	23 - 118
0,01	5	$2{,}1\times10^{26}$	19 - 100
0,001	10	$4{,}6\times10^{26}$	13 - 67
0,001	5	$6{,}5\times10^{26}$	11 - 57

CUORE GOAL:

test inverse hierarchy: 19-50 meV

Background reduction

BKG SOURCES

- Radioactive contaminations in the detector materials, on the detector surfaces
- Radioactive contaminations of the set-up – shielding included
- Neutrons
- Muon induced neutrons

THE SOLUTION

- Select construction materials according to their contamination (ICPMS, n-activation, HPGe)
- Avoid contaminated materials (use Cu, Pb and TeO_2 where you can)
- Avoid activation (cosmogenic isotopes ->reduce exposure above grounds)
- Build thick efficient gamma and neutron shields
- Build (eventually) a muon veto to tag muon-induced neutrons

CUORE background prediction based on
Cuoricino experience – Cuoricino bkg model
+ specific measurement with a dedicated detector (RAD – HallC)

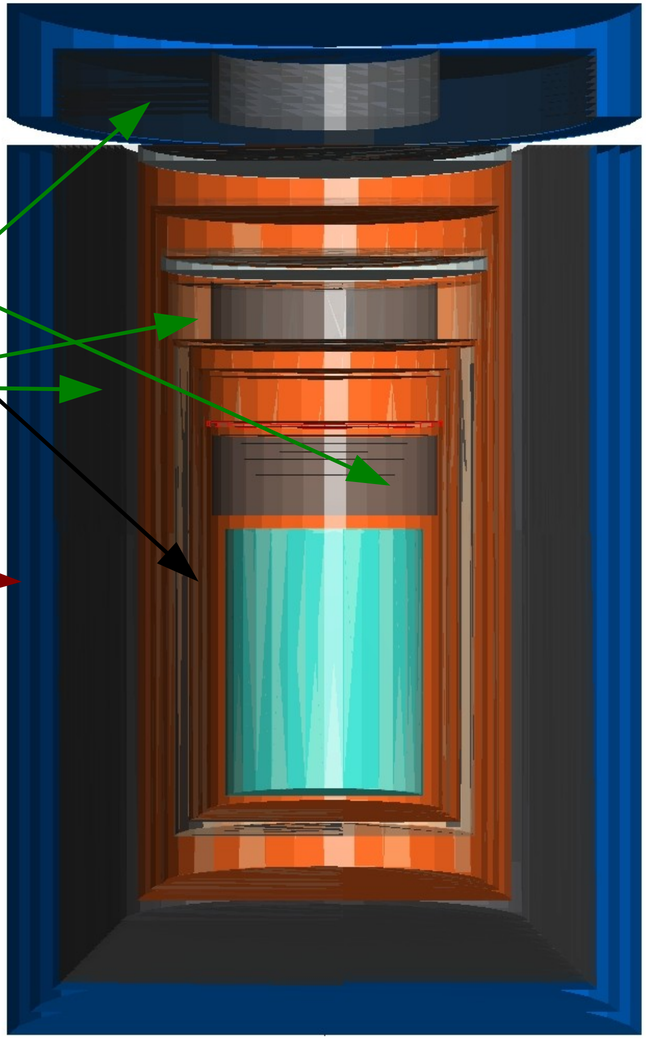
Cuoricino: 0.18 ±0.01 counts/keV/kg/y → 70% interpreted as surface bkg; 30 % ^{208}Tl from ^{232}*Th* in *cryostat shield*

hall C: < 2.5-3•10^{-2} counts/keV/kg/y

CUORE Shielding

CUORE will be Installed in a dilution refrigerator shields:

- 6 cm Roman Pb inner shield on the side ($<$4mBq/kg ^{210}Pb)
- 35 cm Pb inner shield on top (16±4 Bq/kg ^{210}Pb)
- 25 cm Pb external shield (16±4 Bq/kg ^{210}Pb)
- Neutron shield:
  18 cm Borated(10%)-polyethylene
- Anti-radon box: nitrogen overpressure



Other geometries simulated

- internal shield: 3cmCu+ 3m Roman Pb
- different Boron concentration in n-shield
- borated Polyethylene internal to Pb shields

FLUKA vs GEANT

- **Studies and comparisons in literature:**

  Araujo et al. hep-ex/0411026
  Wang et al. hep-ex/0101049
  Kudryavtsev, Spooner, McMillan hep-ex/0303007
  Mei, Hime astro-ph /0512125
  Wulandari et al, hep-ex/ 0401032

- **Different neutrons productions for em and had cascades in GEANT4 and FLUKA**

- **Muon spallation in GEANT4 disagree with experimental results**

- **In Pb: a factor 2 less neutrons in GEANT4**
  Neutron production material dependent: $\langle n \rangle \sim A^{0.81}$
  Neutron production muon energy dependent: $\langle n \rangle \sim E_{\mu}^{0.75}$
  Poor data in Pb, reasonable agreement except Bergamosco (a factor ~3 less in MC)

- **Use FLUKA to compute neutron energy spectrum**

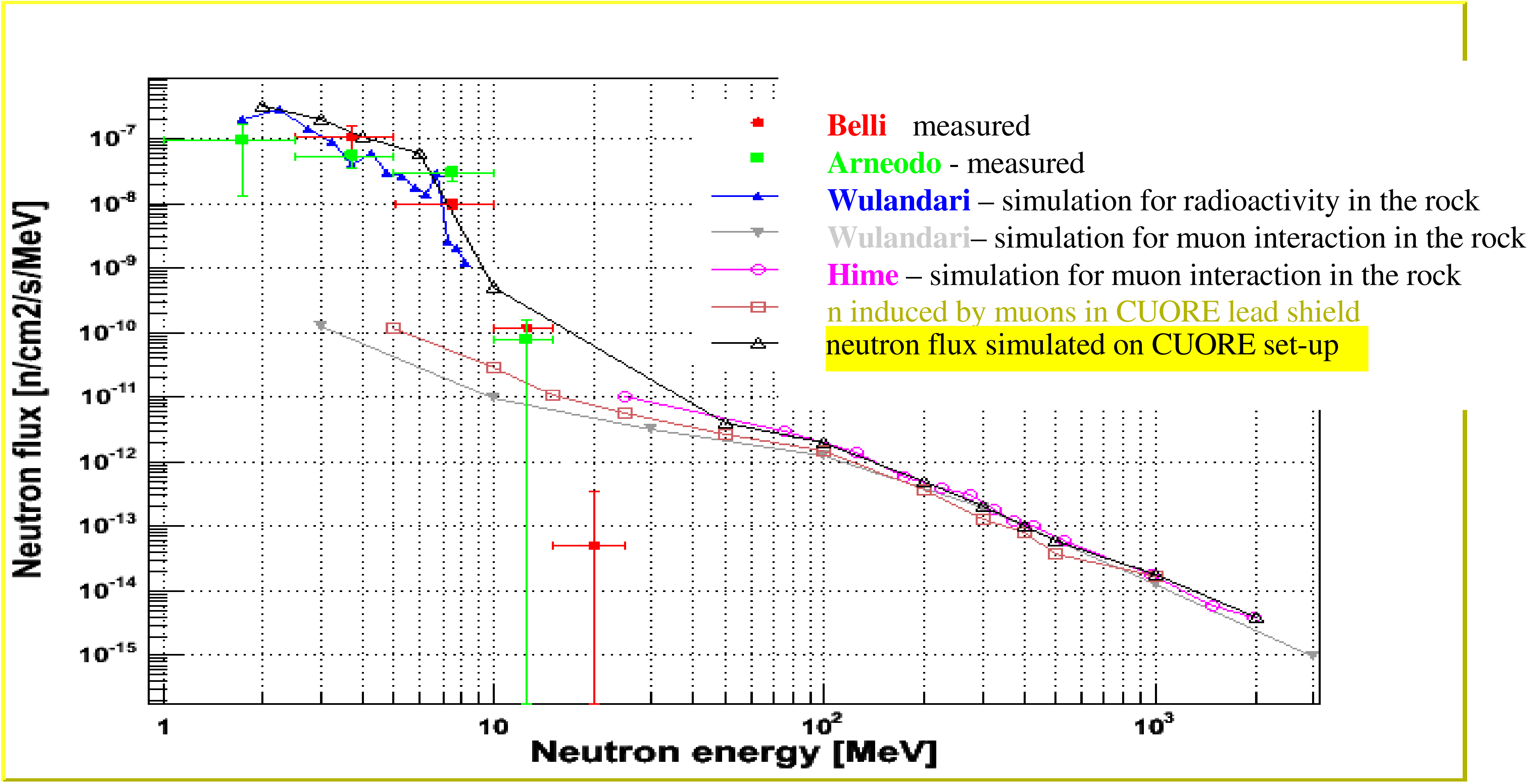
- **Use this spectrum as input for GEANT4 for the CUORE DBD background estimate**

- **Measurements with neutron source for MonteCarlo validation(..up to 10 MeV)**

External Neutrons sources

- (α,n) reactions from U and Th contaminations and spontaneous ^{238}U fission in rock, concrete, setup-materials (E_n<10MeV)
- Muon-induced neutrons in rock:

0.1% of neutrons from local radioactivity but hard to shield, very energetic neutrons (up to several GeV) can travel far from the μ track before being thermalized and captured.



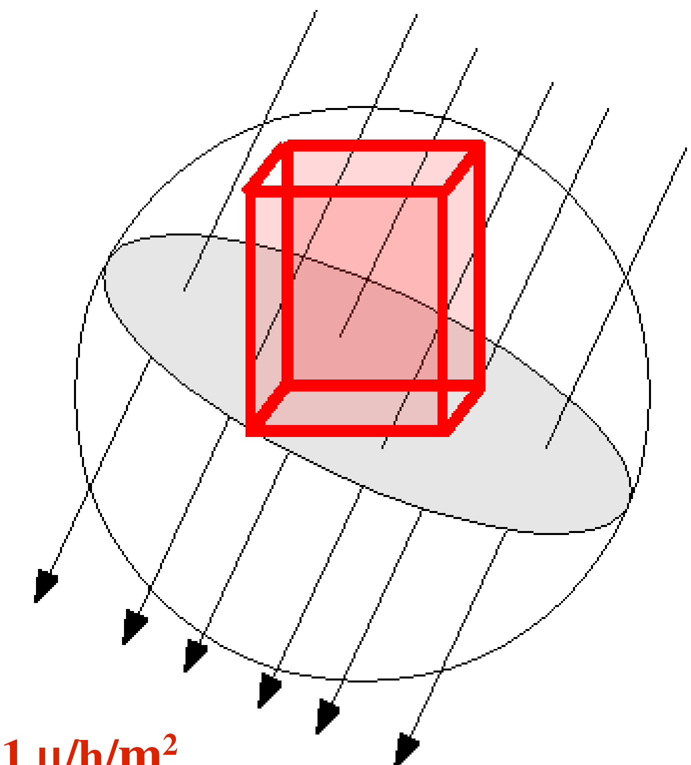
Muons generation

- **Muon flux** measured by **MACRO** experiment **(Hall B)** as a function of **polar (18º per bin)** and **azimuthal (~10º per bin) angle**

Thanks to G Battistoni

- **Angular distribution: generate uniform flux inside a 5 m radius sphere and use MACRO maps (hit or miss technique) to tailor underground muon flux**

- **Energy spectrum: parametrized from ground level flux (well know) and transported underground taking into account, for each given direction, amount and shape of overburden rock**



Muon generated with underground energy: E<2000GeV

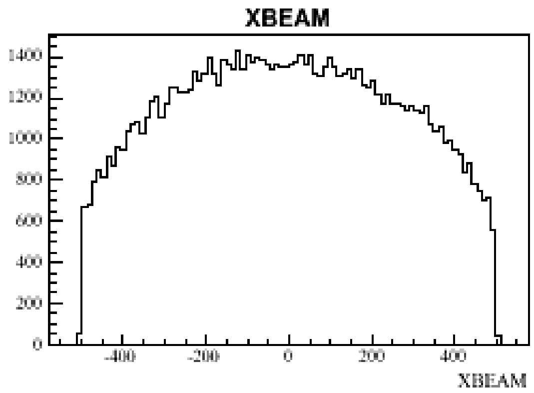
- **Used muon flux:** $\Phi = (3.2+0.2) \bullet 10^{-4}\ \mu/s/m^2$

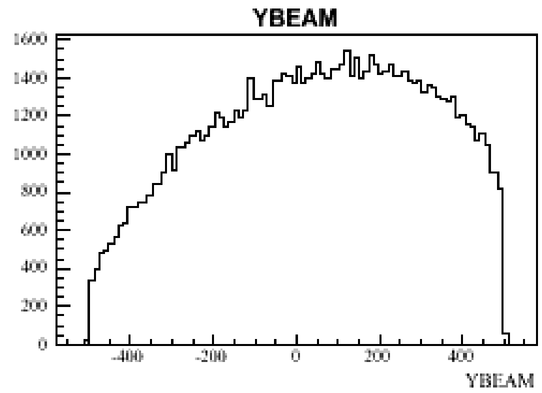
M. Cribier et al. (Gallex Col.)
Astron. Part. Phys. 6, 129 1997

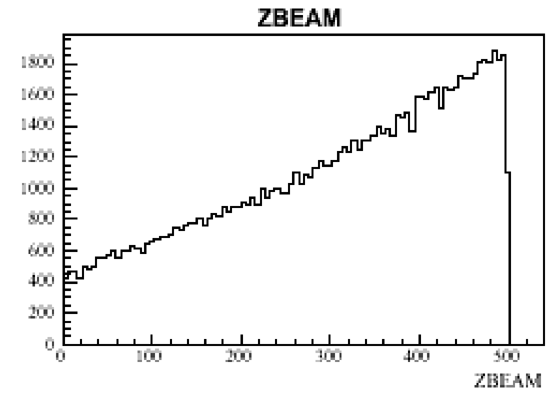
note: this is the highest in literature

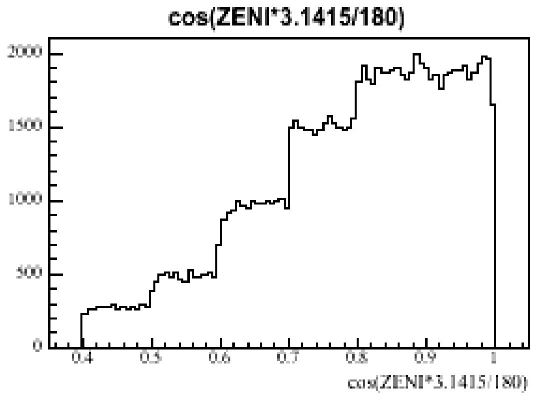
- *Mei, Hime astro-ph /0512125 :* $\Phi = (2.58+0.3) \bullet 10^{-4}\ \mu/s/m^2$
- *Wulandari et al, hep-ex 0401032:* $\Phi = (2.78+0.2) \bullet 10^{-4}\ \mu/s/m^2 \sim 1\ \mu/h/m^2$

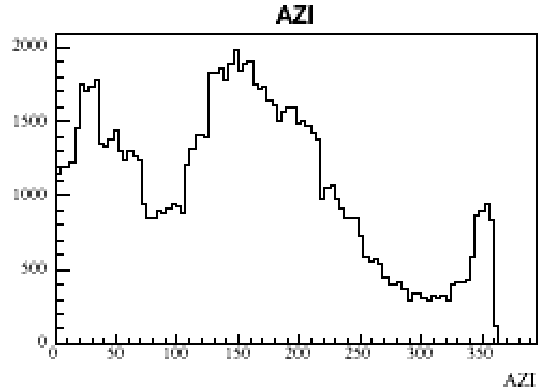
Muon distributions

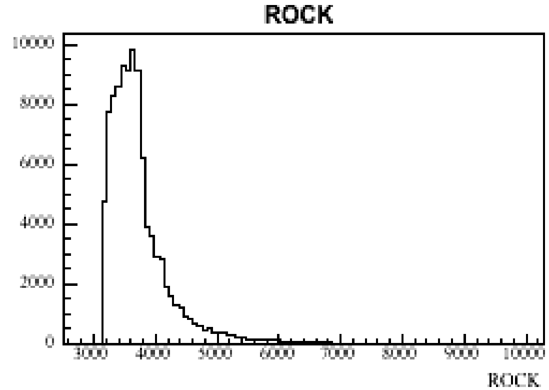


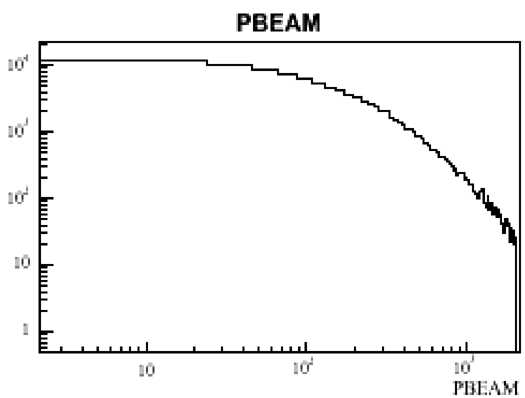








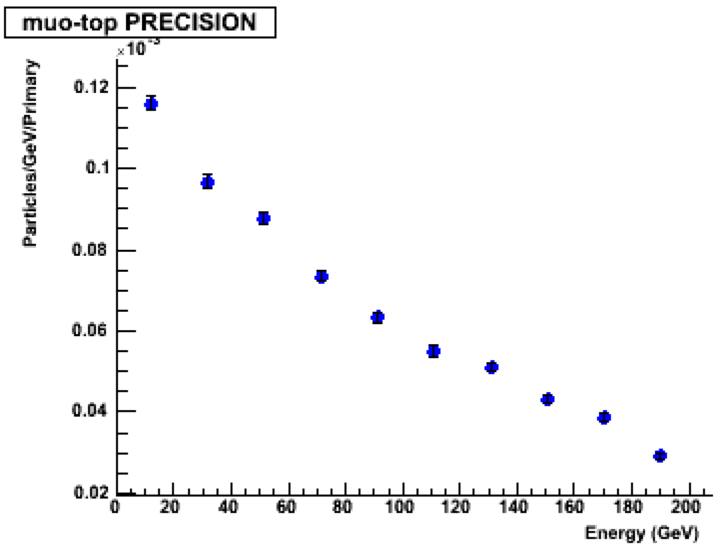


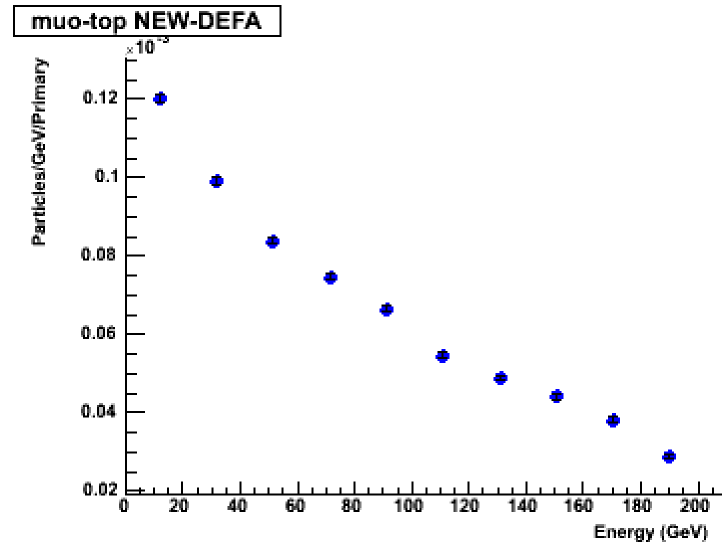


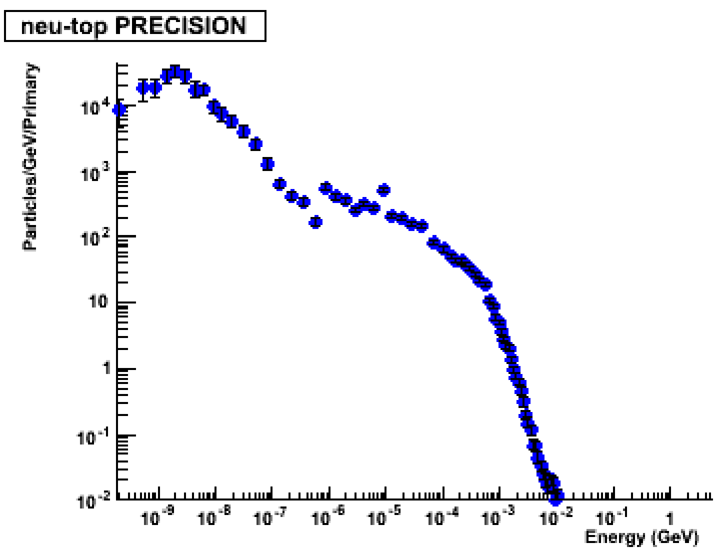
Thanks to
G Battistoni

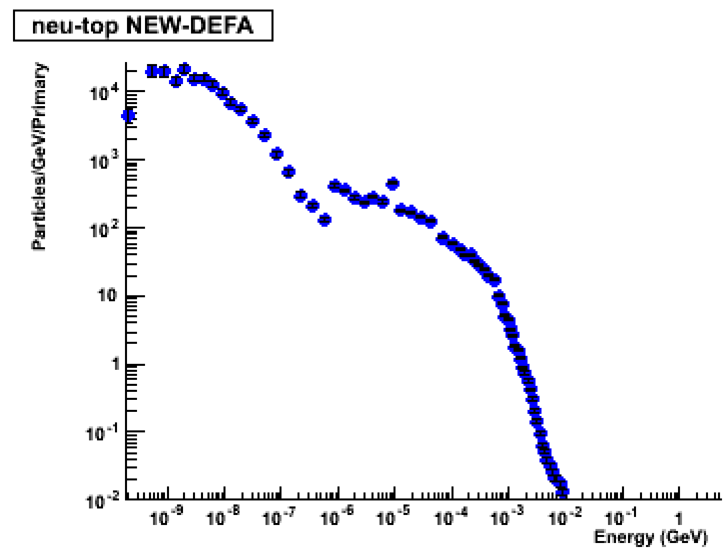
Fluka Physics Cards

	Precision card	New-Default card
transport	fully analogue	biased neutron (8 times faster)









Muon-induced neutron flux on detector

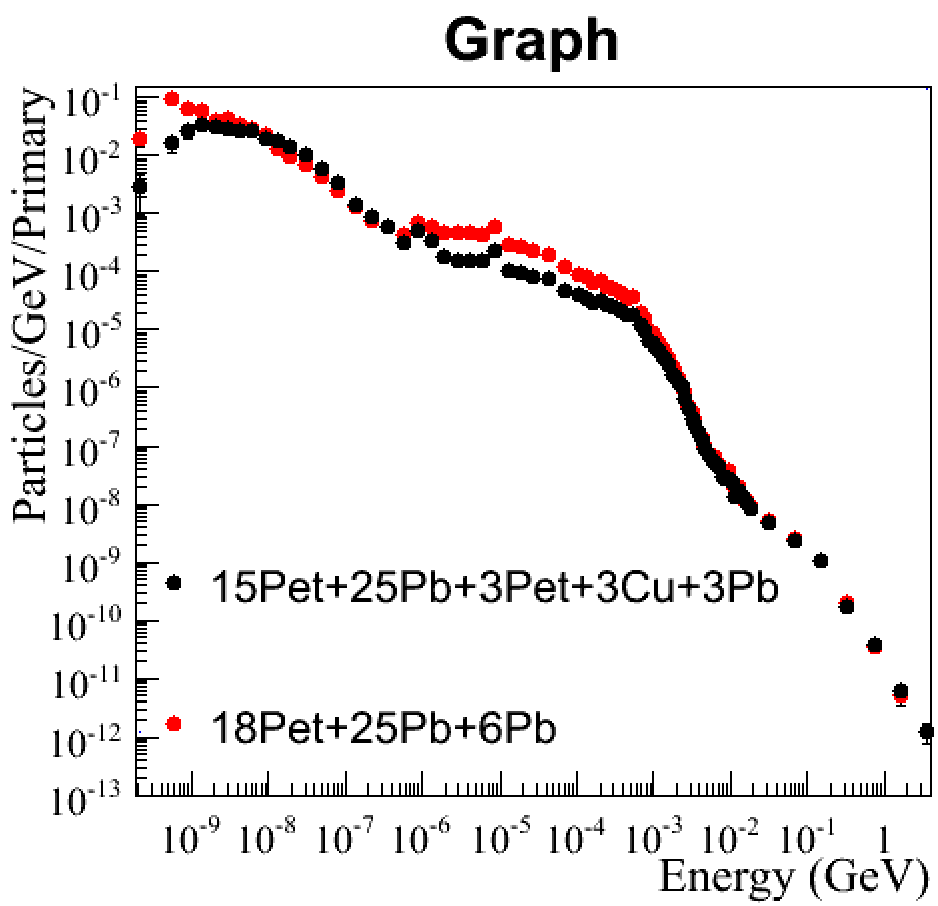
"Extreme" configuration:

ext shield:
18 cm (1%B)n shield + 25 cm Pb

int shield: 6 cm Roman Pb

ext shield:
15cm (10%B) +25 cm Pb + 3cm (10%B)

int shield: 3cm Cu + 6 Roman Pb



$\Phi=(57.7 \pm 3.6)\cdot 10^{-9}$ n/s/cm^2 $\Phi=(29.4 \pm 1.9)\cdot 10^{-9}$ n/s/cm^2

Environmental neutron flux contribution: 1 order of magnitude less

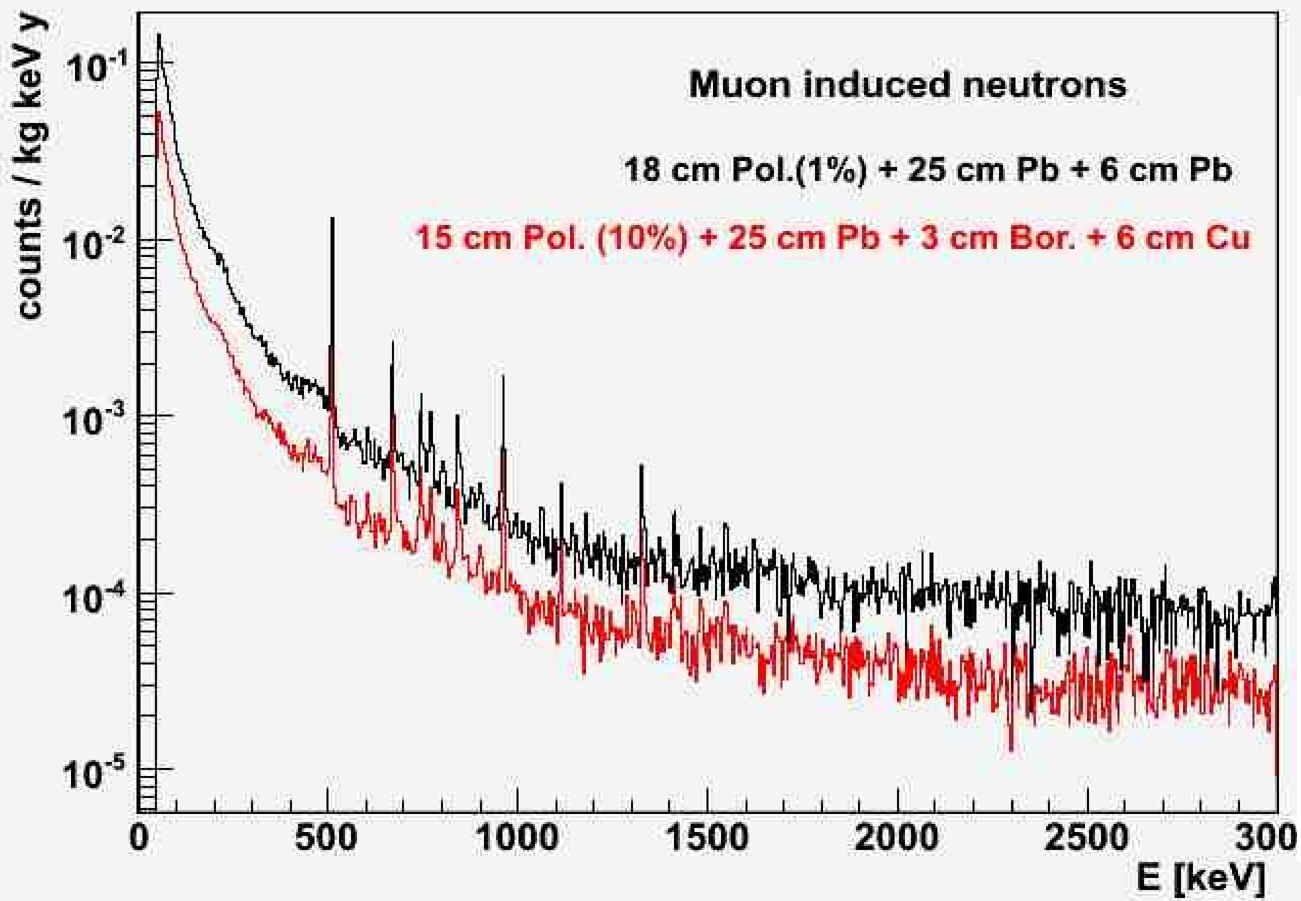
$\Phi=(7.6 \pm 0.7)\cdot 10^{-9}$ n/s/cm^2 $\Phi=(3.6 \pm 0.4)\cdot 10^{-9}$ n/s/cm^2

note:induced γ not included ...work in progress

Background in DBD region (GEANT4)

Preliminary results

Anti-coincidence spectrum



Anti-coincidence bkg:
(FWHM:5keV, ROI: 5 σ around 2530 keV, 10 ms)

(1.5±0.3)•10^{-4} counts/keV/y/kg
(5.6±1.2)•10^{-5} counts/keV/y/kg

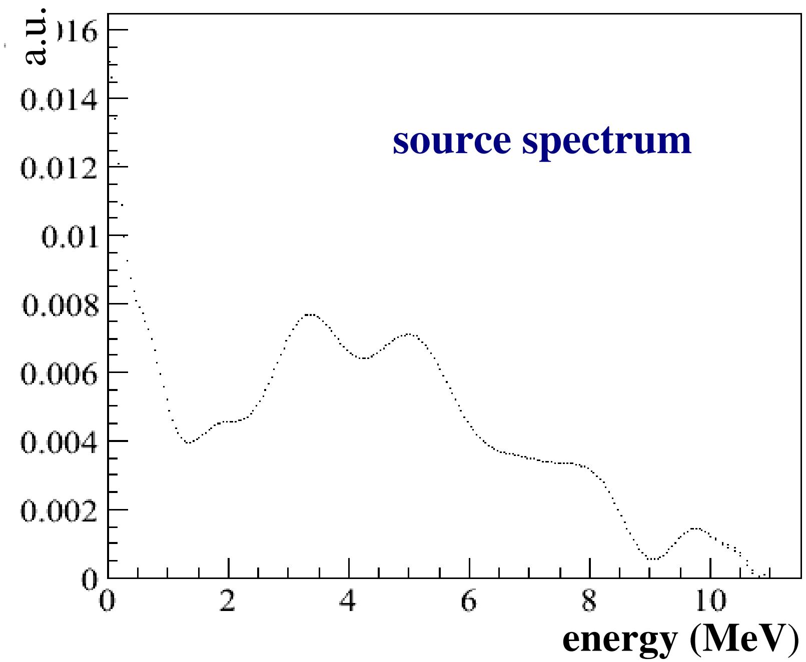
Total bkg:
(2.4±0.2)•10^{-3} counts/keV/y/kg
(9.8±0.8)•10^{-4} counts/keV/y/kg

Environmental neutron flux contribution: one order of magnitude less

note:induced γ not included ...work in progress

Measurement with neutron source

Am-Be source: ~2200 n/s



hall C shielding:

10 cm Pb + 7cmPet+2cmCB_4+10cm Pb

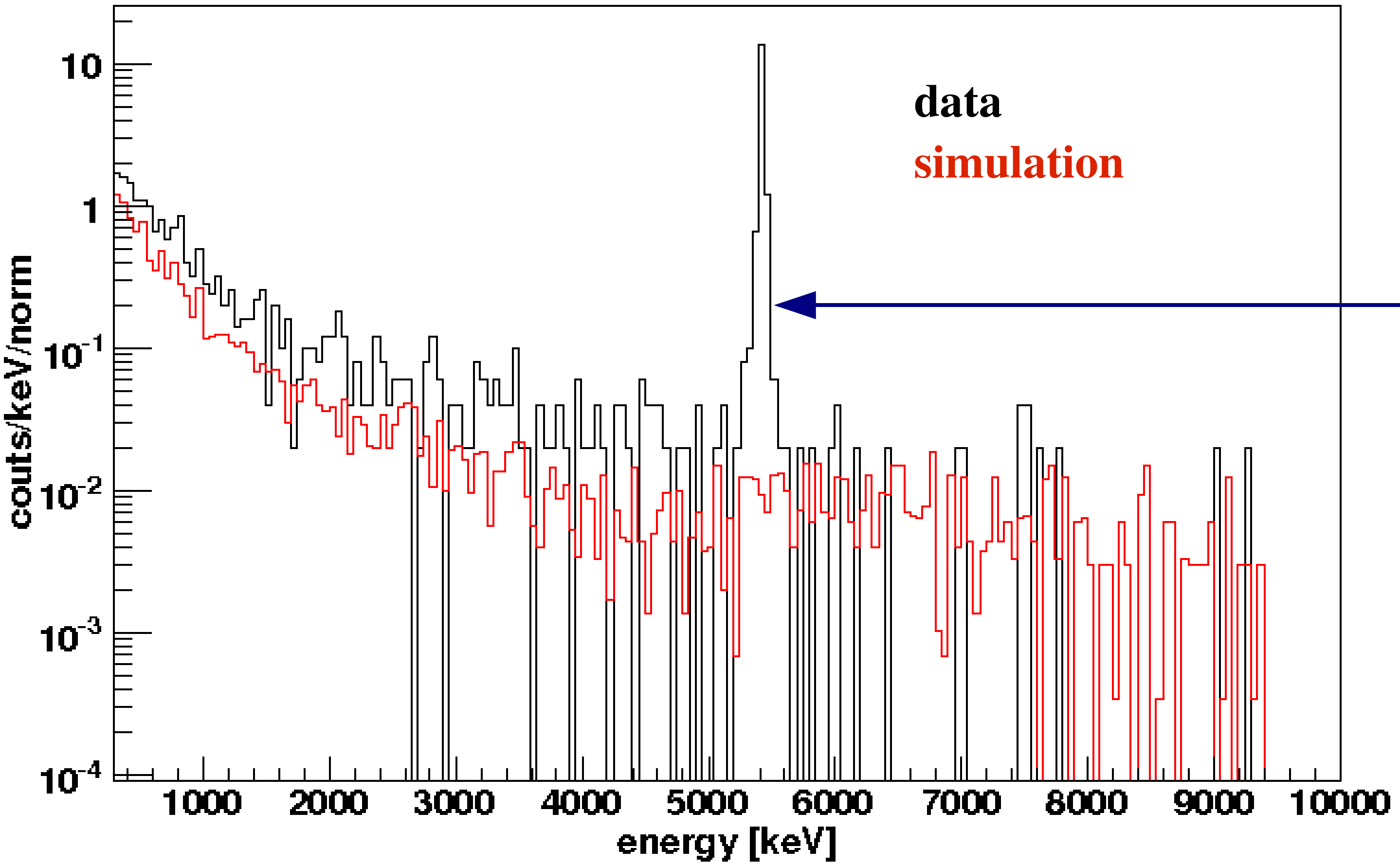
4 different measurements

- standard set-up
- source in a 30 cm PET box
- without internal n-shield and different source position

Measurement with neutron source

Preliminary results

configuration:
source in 30 cm PET box



5400 keV line due to ^{210}Po crystal contamination

Simulation seem to underestimate neutron flux

n and muon-induced neutron not included -> minor contribution expected

γ background

External radiation: $\Phi = 7.7 \cdot 10^6 \gamma$/d/cm^2 measured with Ge detector and used as input for GEANT

bkg= $1.5 \cdot 10^{-5}$ counts/kg/keV/y with 24 cm external Pb shield

- Cryostat ^{232}Th bulk contamination contribution reduced by properly shielding in CUORE cryostat

\+ selection of construction material

bkg = < 10^{-3} c/keV/kg/y

- External Pb shield contamination: 100 μBq/kg

bkg = $2.4 \cdot 10^{-4}$ counts/kg/keV/y

- Internal shield
  - Roman lead contamination (6cm Pb):

60±17 μBq/kg	bkg = $6 \cdot 10^{-3}$ counts/keV/y/kg	need to measure
<71 μBq/kg	bkg < $7 \cdot 10^{-3}$ counts/keV/y/kg	again?

  - DownRun Pb   <22 μBq/kg   bkg < $2 \cdot 10^{-3}$ counts/keV/y/kg

    (but ^{60}Co contamination & 27 Bq/kg ^{210}Pb)

  - Cu shield contamination : <12 μBq

    bkg < $2.4 \cdot 10^{-3}$ counts/keV/y/kg

    (better for Th contamination.. worse for ^{60}Co contamination and neutron activation)

CUORE background estimate

source	10-3 counts/keV/y/kg
external gamma	<1
external apparatus	<1
detector structure bulk	<1
crystal bulk	<0.1
detector surfaces	~20-40
crystal surfaces	<3
neutrons	~0.01
muon induced neutrons	~0.1

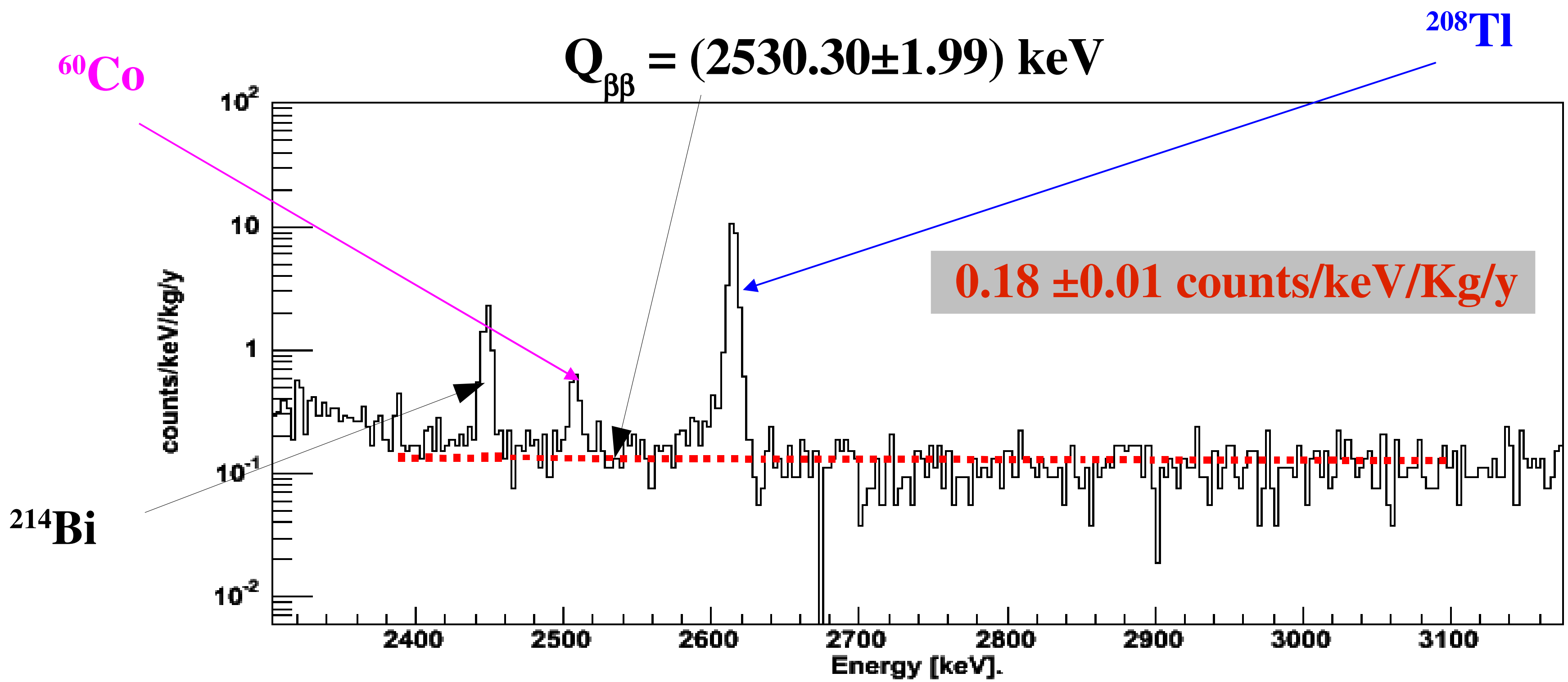
→ The limiting factor up to now (detector surfaces)

Next Steps

- **Double check simulation and add statistics**
- **Validate simulation with neutron source**
- **Include Isotope activation**
- **Include muon background and gamma induced background**
- **Evaluate background also in dark matter region**
- **Understand correlation with muons & study veto system for muons tagging**
- **Publish results soon**

Cuoricino bkg knowledge

- In $0\nu\beta\beta$ region:
  - 30 ± 10% ^{208}Tl (2614.5 keV line) via multi-Compton events from *^{232}Th* in *cryostat shields*
  - 10 ± 5% from crystals surface *^{238}U and ^{232}Th contamination*
  - 50 ± 20% from degraded α produced by ^{238}U and ^{232}Th contaminations of *mounting structure* main candidate the *copper surface*
  - negligible contribution from 2505 (1173γ+1332γ) keV ^{60}Co tail due *Cu cosmogenic activation*

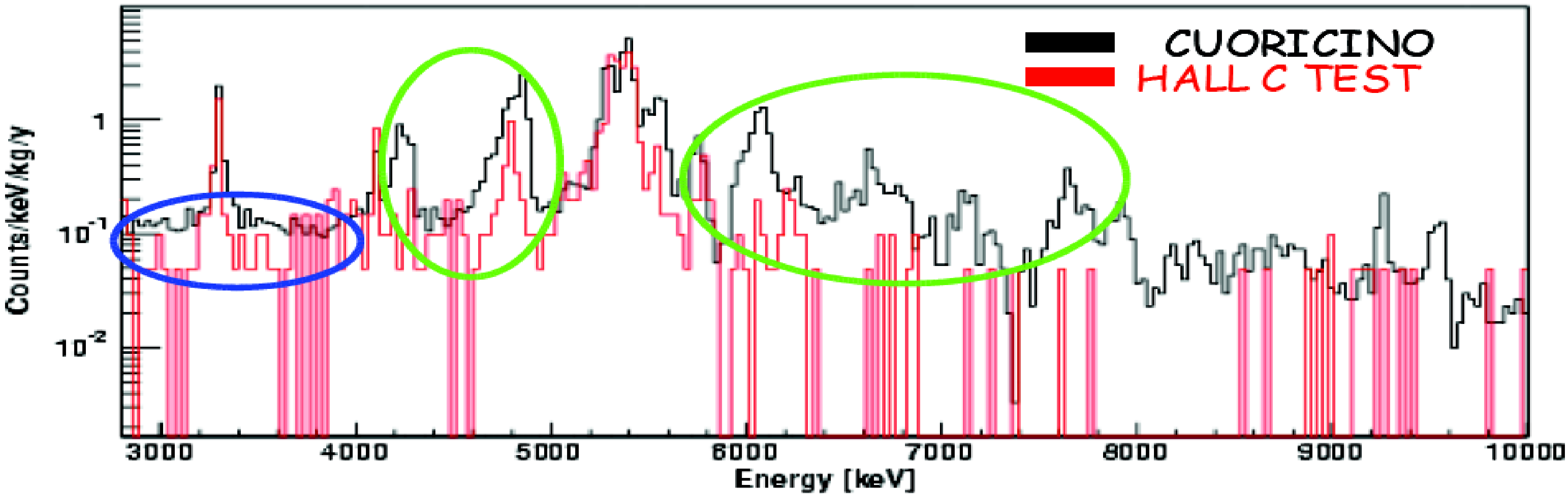


Background reduction

- Surface contribution:
  - test wih new crystals surface cleaning (etching, lapping with 2µm SiO_2 clean powder)

    reduction of a factor 4
  - test wih new Cu cleaning (etching, electro-polishing, passivation) and complete coverage of Cu facing the crystal with ~50µm PET film

    reduction of ~40% of flat continuum background



The extrapolated contribution to CUORE are

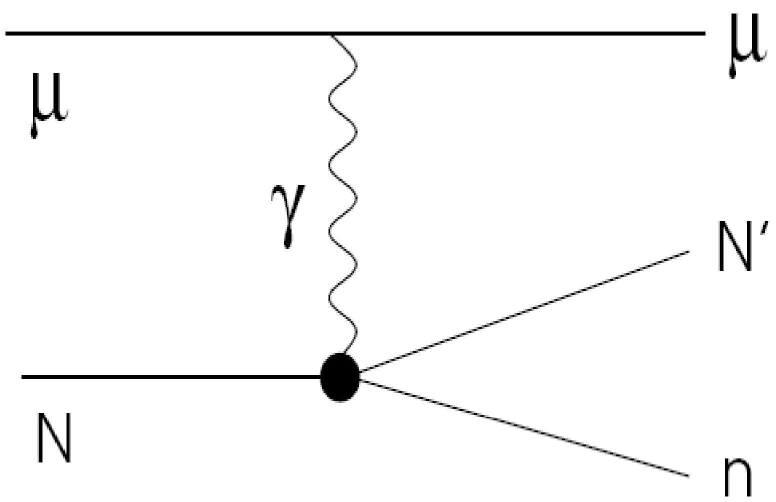
- Crystal Surface contamination contribution <3•10^{-3} counts/kg/keV/y
- Copper Surface contamination contribution <5•10^{-2} counts/kg/keV/y
- New structure with reduced Cu amount is being tested right now

MC simulation Cu contribution < 2.5•10^{-2} counts/kg/keV/y

Muon-induced neutrons

Muon-induced neutrons in shields (mainly in Pb, <n>~ $A^{0.81}$)
Not shielded, can be tagged by a muon veto

- Muon energy spectrum undreground: from simulation or measured
- Material geometry and composition ($\sigma_\mu^{em} \sim Z^2/A$, $\sigma_\mu^{had} \sim A^{0.76}$)
- Physical process
  - μ spallation,
  - μ elastic scattering with bound n,
  - μ induced em cascades,
  - μ induced hadronic cascades,
  - negative μ capture,
  - secondary neutron production



Neutron production material dependent <n>~$A^{0.81}$
Neutron production muon energy dependent <n> ~$E_\mu^{0.75}$

Mei, Hime
astro-ph /0512125