Production and suppression of ^{11}C in the solar neutrino experiment Borexino

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Technische Universität München

On behalf of the Borexino Collaboration

Low Radioactivity Techniques,
Sudbury, August 29th 2010

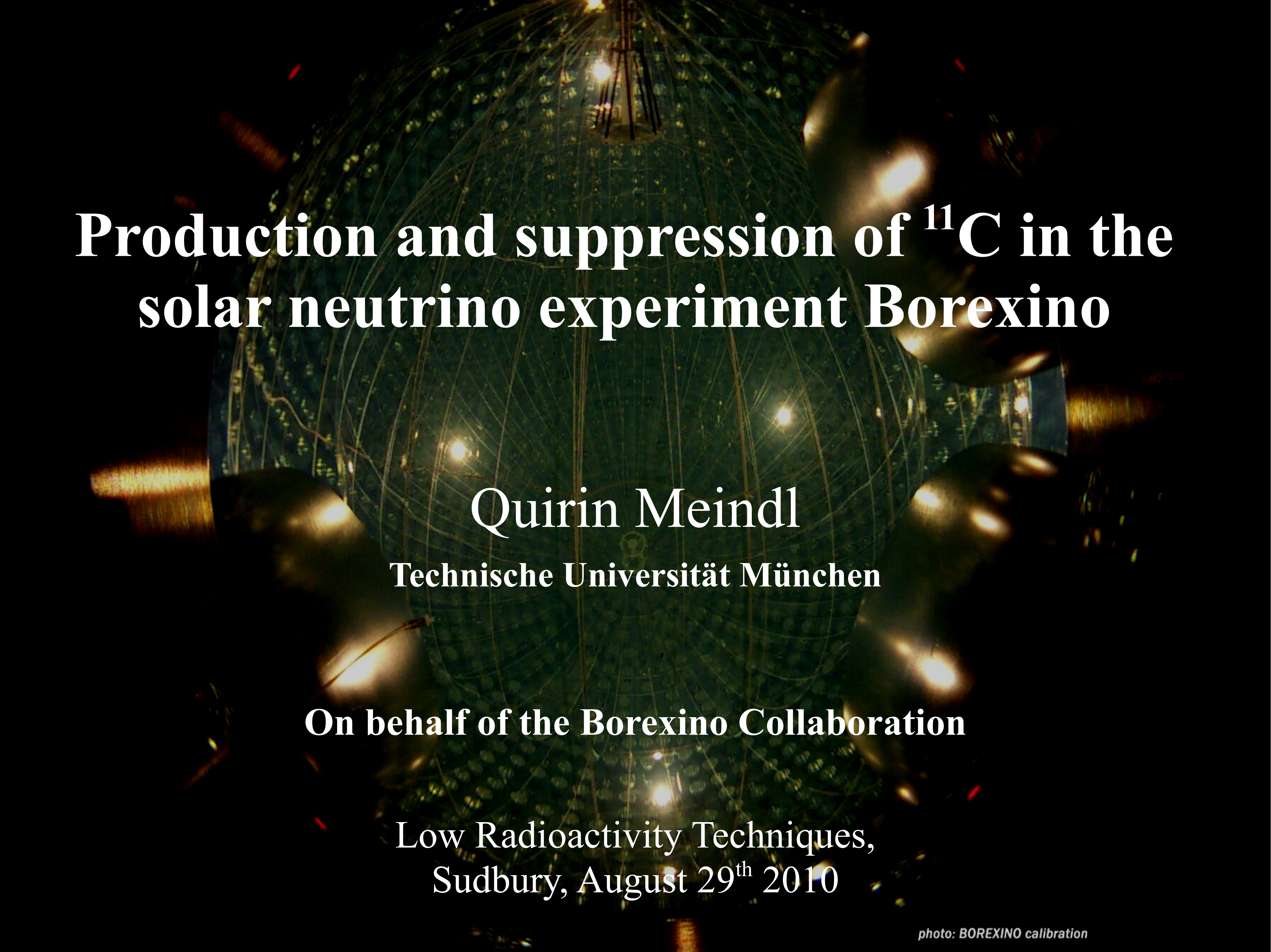


photo: BOREXINO calibration

The Borexino collaboration

INFN

Genova

Perugia

Milano

APC Paris

Princeton University

Virginia Tech. University

LNGS Laboratori Nazionali del Gran Sasso – Istituto Nazionale di Fisica Nucleare INFN

Dubna JINR (Russia)

Kurchatov Institute (Russia)

Jagiellonian U. Cracow (Poland)

Max-Planck-Institut für Kernphysik

Heidelberg (Germany)

Technische Universität München

Munich (Germany)

The Borexino Experiment

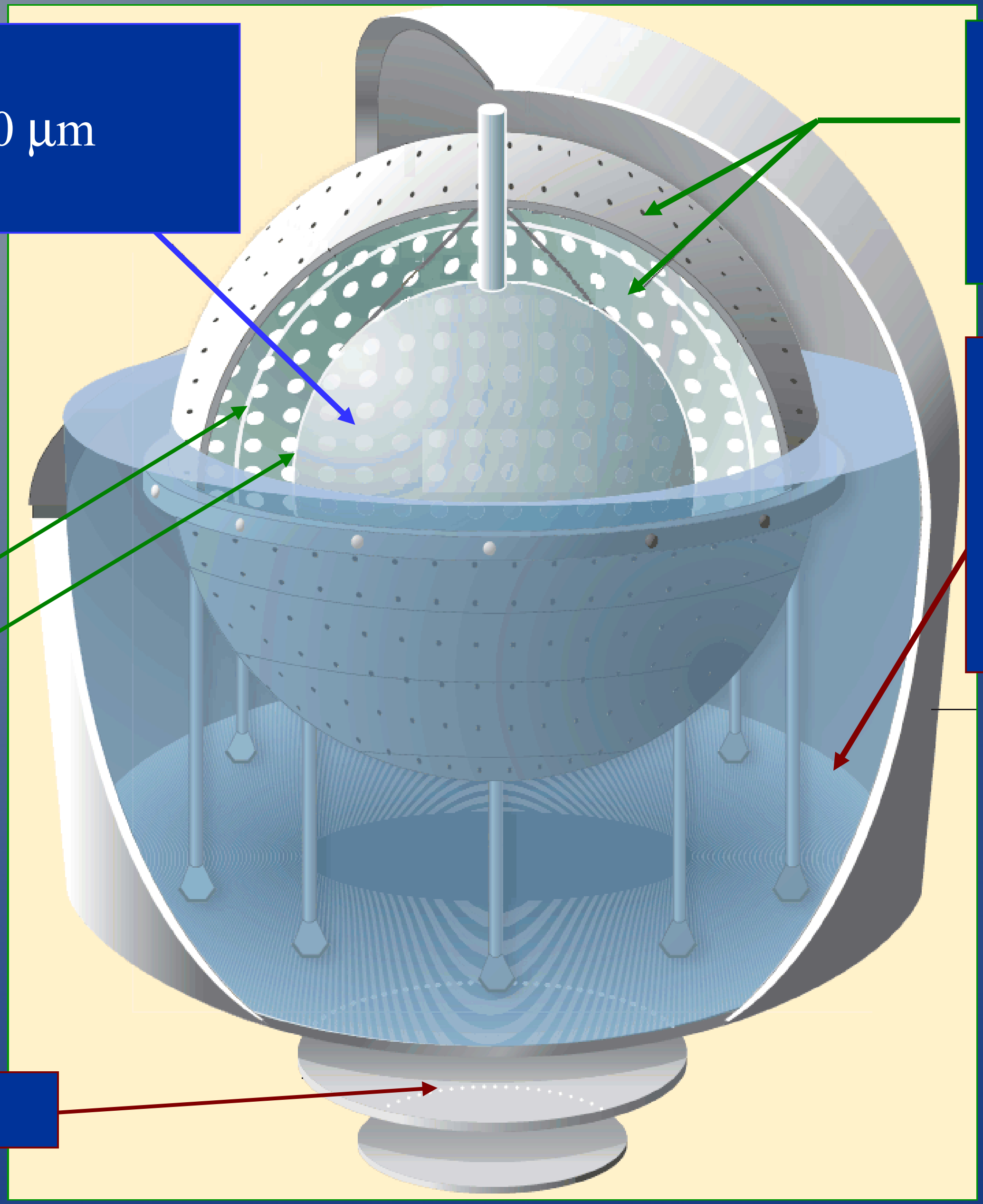
Neutrino electron scattering: $\boldsymbol{\upsilon\ e \rightarrow \upsilon\ e}$

- Liquid scintillator technology (300 t)
- Low energy threshold: ~ 60 keV
- Good energy resolution: ~ 4.5% @ 1 MeV
- Extreme radiopurity
- Sensitivity on sub-MeV neutrinos
- Data taking since May 16th 2007

The Borexino Experiment

Scintillator:
270 t PC+PPO in a 150 μm thick nylon vessel

Nylon vessels:
Inner: 4.25 m
Outer: 5.50 m



Carbon steel plates

Stainless Steel Sphere:
2212 PMTs + concentrators
1350 m^3

Water Tank:
γ and n shield
μ water Č detector
208 PMTs in water
2100 m^3

Excellent ***shielding*** of external background

Increasing ***purity*** from outside to the central region

The Borexino Experiment

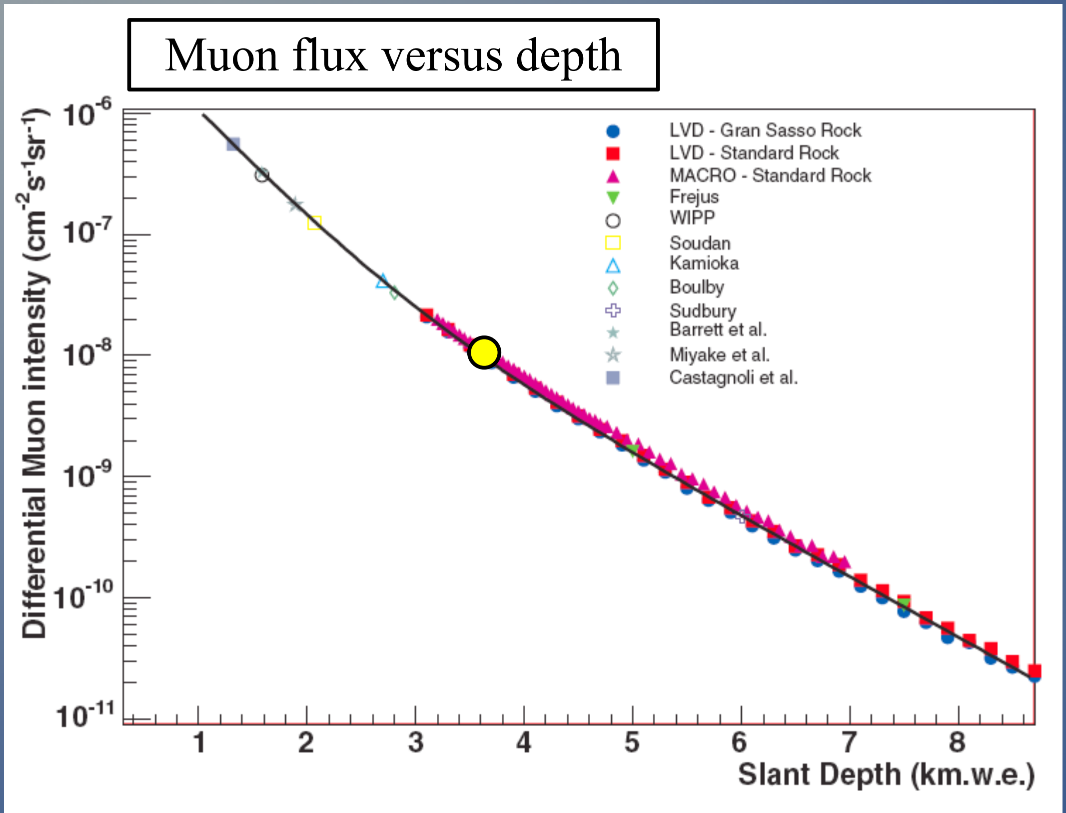
- **Internal background**

^{238}U	$\sim 2 \times 10^{-17}$ g/g
^{232}Th	$\sim 5 \times 10^{-18}$ g/g
^{210}Po	~ 10 counts / (d t)
^{85}Kr	~ 0.30 counts / (d t)
^{210}Bi	~ 0.15 counts / (d t)

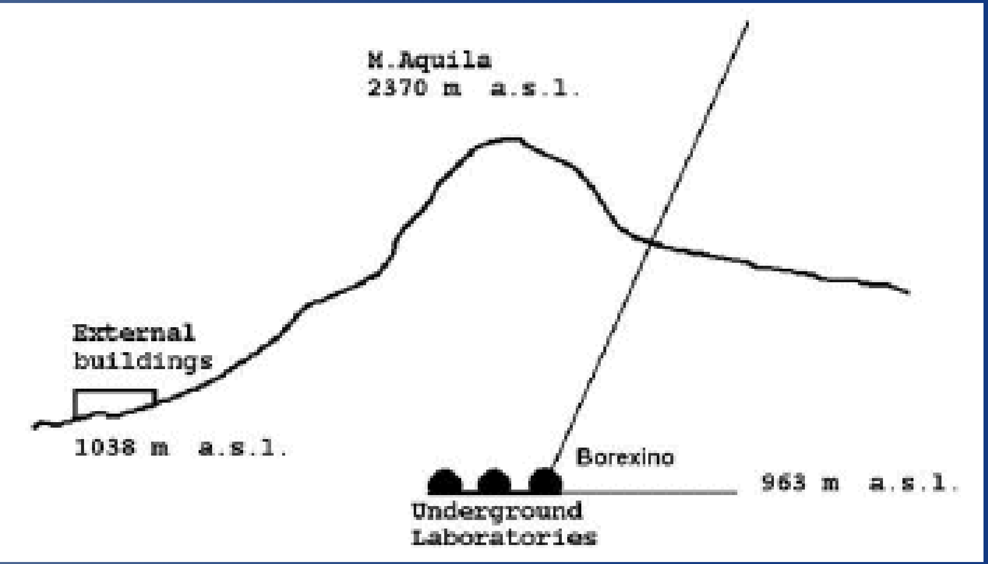
Ultrahigh radiopurity!

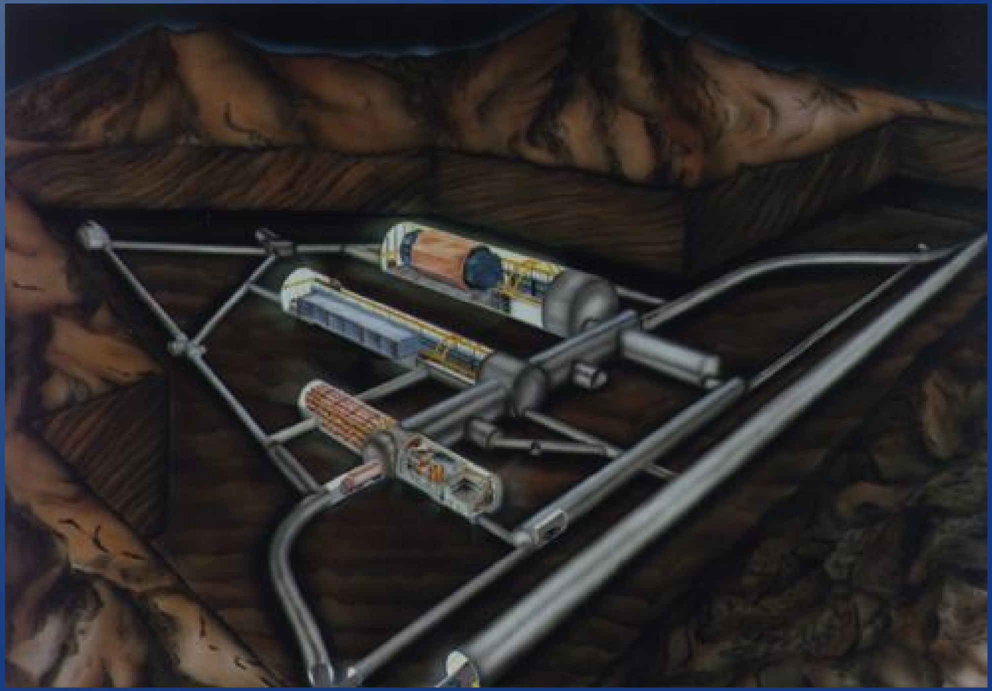
- **Muons**
  Muon shielding requires an underground site

Shielding of atmospheric muons



Kudryavtsev, Talk at JRA1 meeting 10/07/2006





Laboratori Nazionali del Gran Sasso

Shielding provided by rock coverage:
~ 3800 m.w.e.

Residual μ-rate: 1.16 m^{-2} h^{-1}
Mean μ-energy: 320 GeV

Muon-induced secondaries and radionuclides

Residual μ produce secondaries in electromagnetic and hadronic showers within the detector: Gammas, pions (π^+,π^-), protons, electrons and neutrons

Isotope	Expected rates $counts\ day^{-1}\ (100\,t)^{-1}$
$^8He + {}^9Li$	0.034 ± 0.007
^9C	0.077 ± 0.025
^8B	0.11 ± 0.02
^6He	0.26 ± 0.03
^8Li	0.070 ± 0.017
^{11}Be	< 0.34
^{10}C	1.95 ± 0.21
^{11}C	14.55 ± 1.49
^7Be	0.34 ± 0.04

The μ and its secondaries can produce in-situ radionuclides in the organic liquid scintillator by interacting with ^{12}C.

Measurement of production rates of muon-induced radionuclides by the Borexino collaboration at CERN (NA54 Experiment)

T. Hagner, PhD Thesis, Technische Universität München

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Most prominent cosmogenic radionuclide is ^{11}C (τ = 29.4 min).

Decays: $^{11}C \rightarrow {}^{11}B + e^+ + \upsilon$

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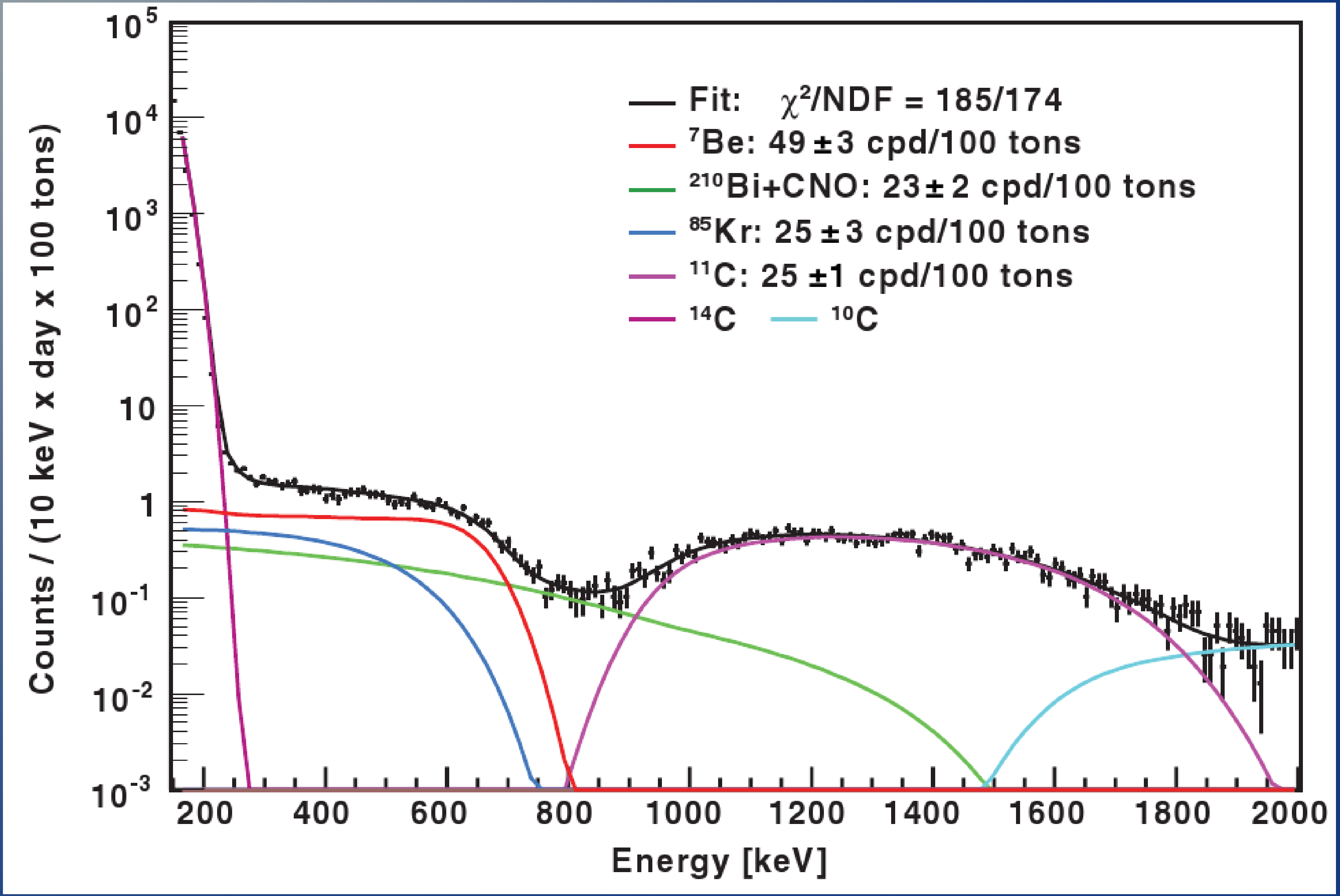
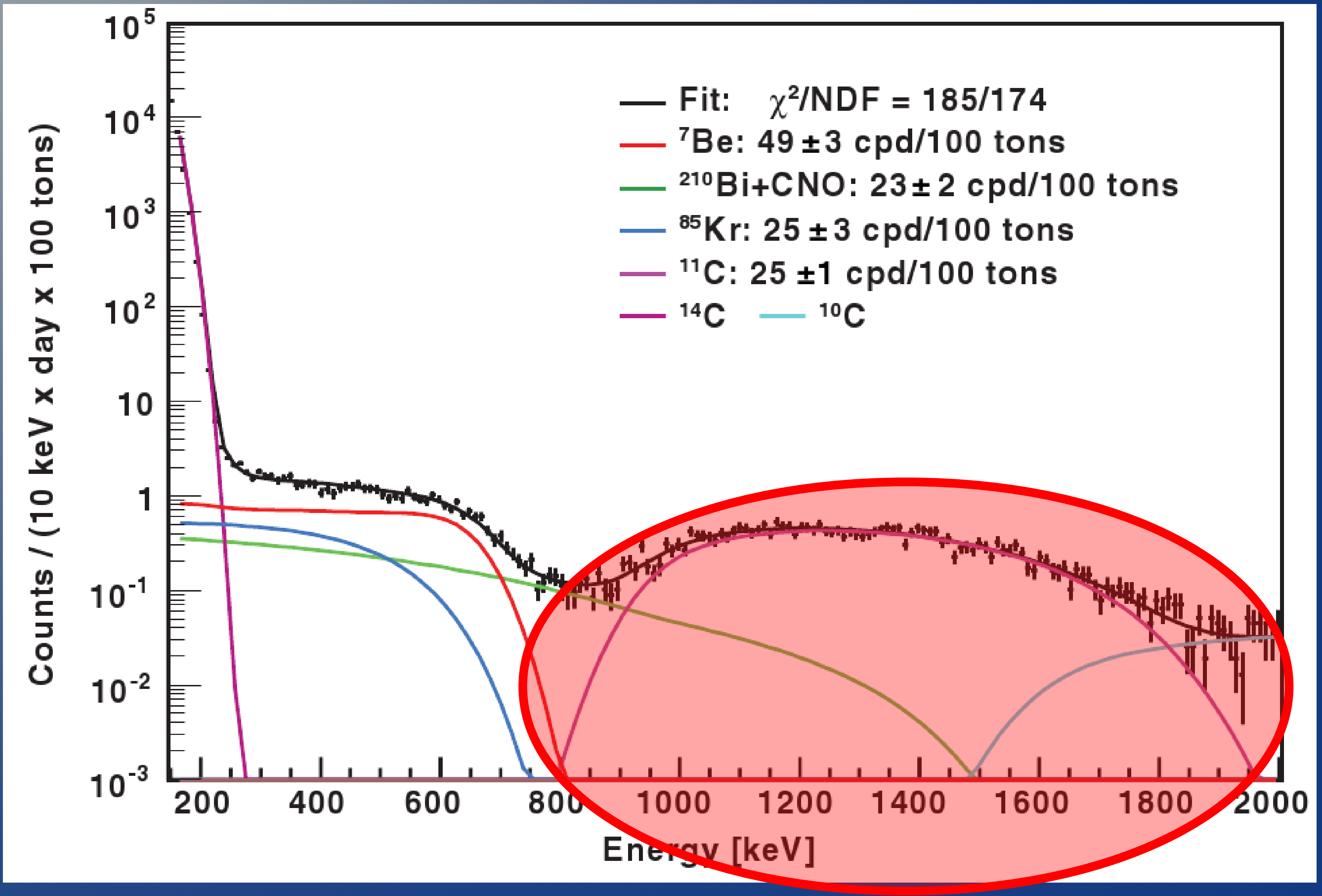


Fit of the Borexino energy spectrum

Muon-induced secondaries and radionuclides



Fit of the Borexino energy spectrum

Production of ^{11}C by muons

E_μ (GeV)	100	190	285	320	350
Interaction	Rate ($10^{-4}/\mu/m$)				
$^{12}C(p,p+n)^{11}C$	1.8	3.2	4.9	5.6	5.7
$^{12}C(p,d)^{11}C$	0.2	0.4	0.5	0.6	0.6
$^{12}C(\gamma,n)^{11}C$	19.8	27.0	34.1	46.6	38.4
$^{12}C(n,2n)^{11}C$	1.4	2.6	3.8	4.4	4.6
$^{12}C(\pi^+,\pi+N)^{11}C$	1.0	1.8	2.8	3.2	3.3
$^{12}C(\pi^-,\pi^-+n)^{11}C$	1.3	2.3	3.6	4.1	4.2
Invisible	0.9	1.6	2.4	2.7	2.9
Total	25.4	37.3	49.7	54.4	57
Measured	22.9±1.8	36.0±2.3			

FLUKA simulations of ^{11}C production channels

D. Franco, PhD Thesis, Universita degli studi di Milano

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=> 95% of all ^{11}C is produced with at least 1 free neutron in the final state

Tagging of ^{11}C
The Three-Fold Coincidence

Production of ^{11}C by atmospheric μ out of ^{12}C

$\mu(+\text{secondaries}) + {}^{12}C \rightarrow \mu(+\text{secondaries}) + {}^{11}C + n$

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Free neutrons get captured on Hydrogen:

$n + p \rightarrow d + \gamma$	$E_\gamma = 2.2$ MeV
Range of free neutron:	few dozen cm
Mean neutron capture time:	~250 μs

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Coincidence of μ and neutron-capture flags production of ^{11}C isotopes (and of many cosmogenic radionuclides in general).

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This so-called Three-fold Coincidence (TFC) of muon, neutron and ^{11}C decay can be used to reject ^{11}C from data.

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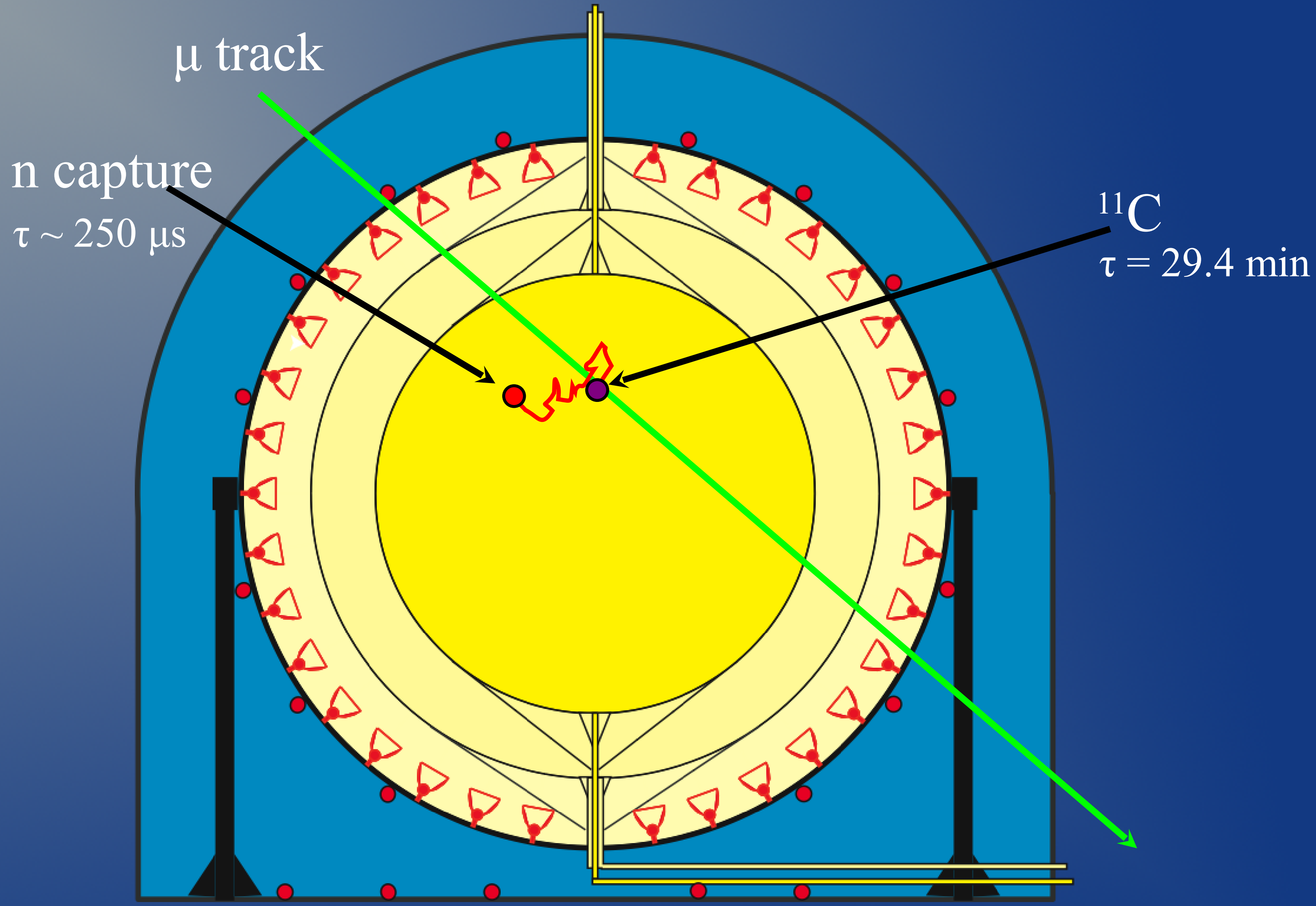
The Three-Fold Coincidence



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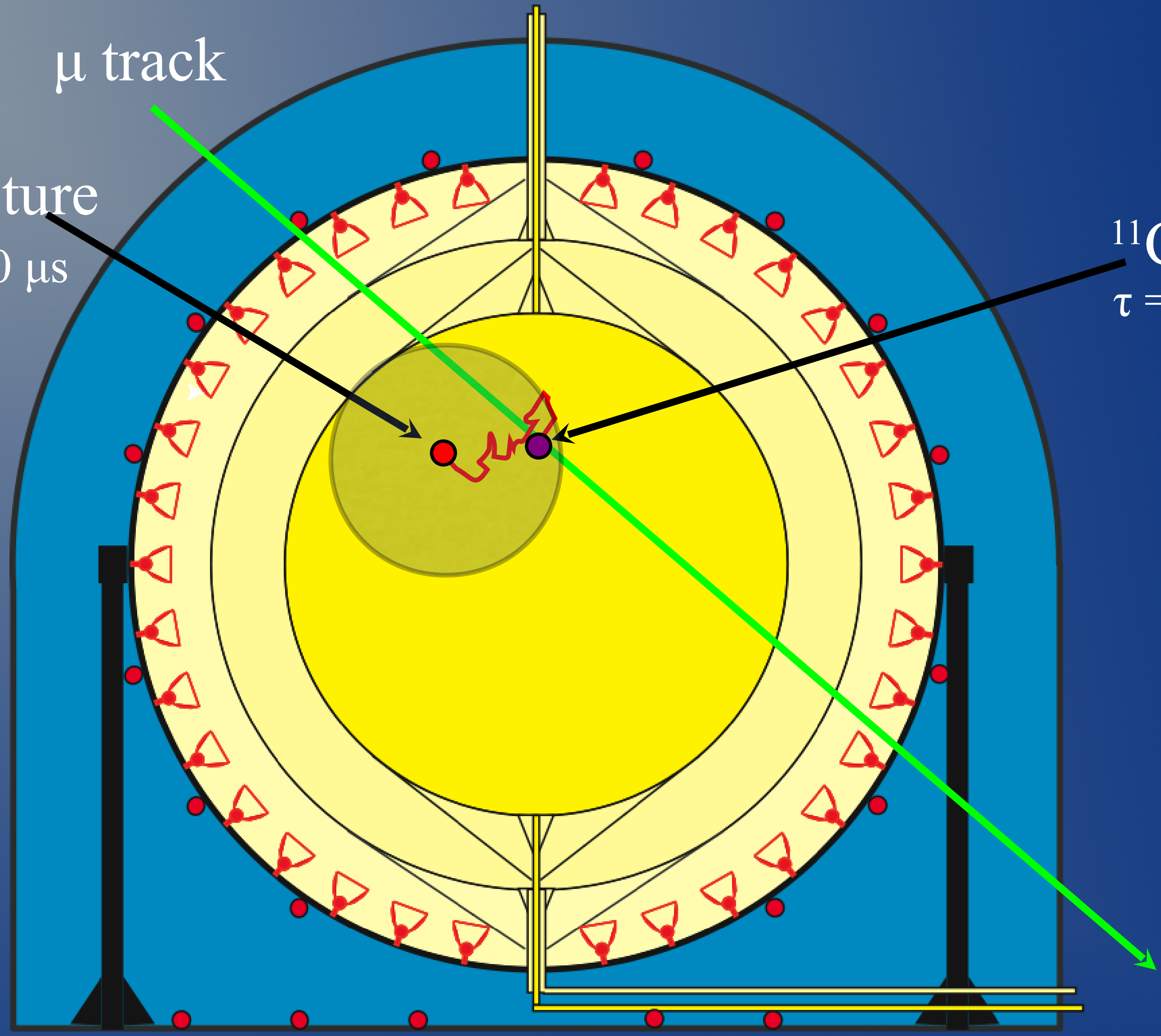

^{11}C can be rejected with proper cuts in space and time around the neutron.

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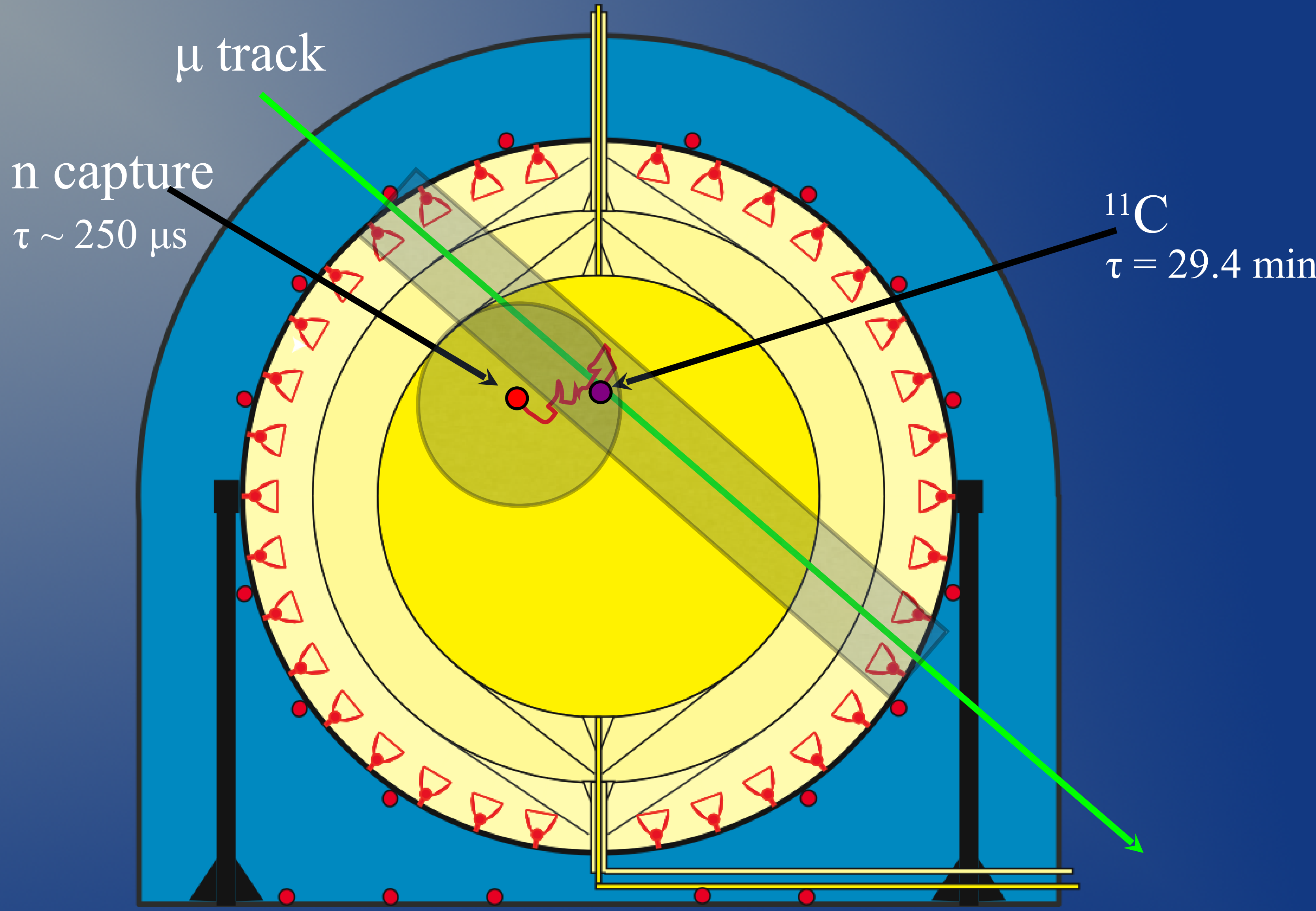

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Using also the muon: target-mass-time loss can be reduced.

Tagging of ^{11}C
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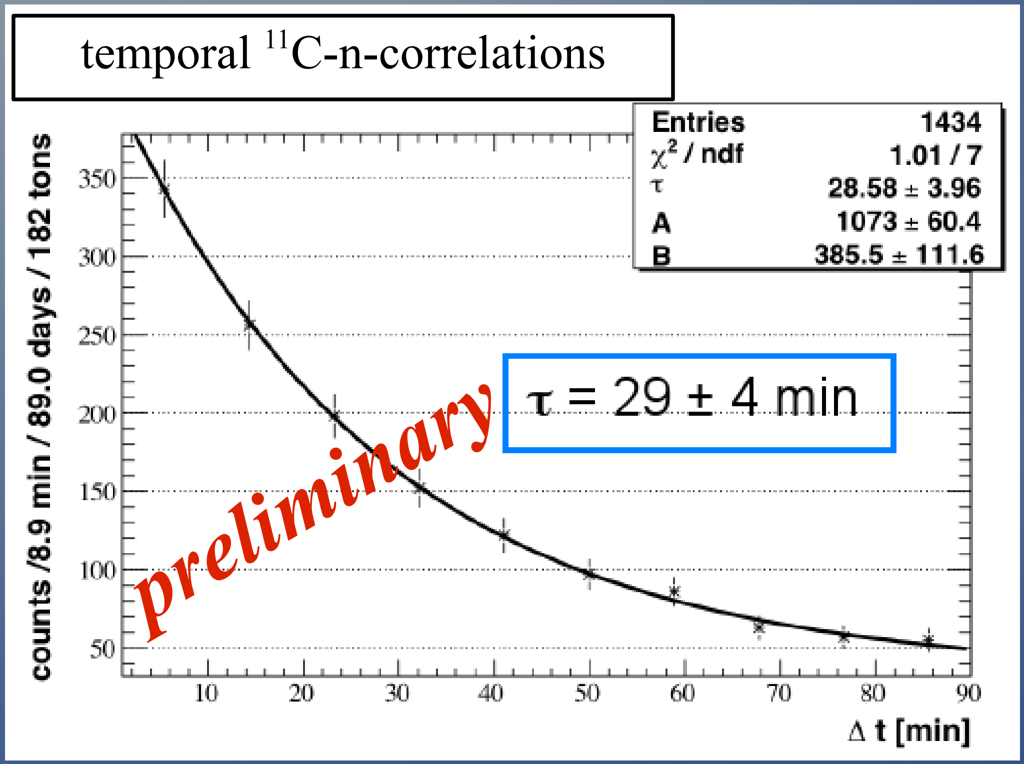

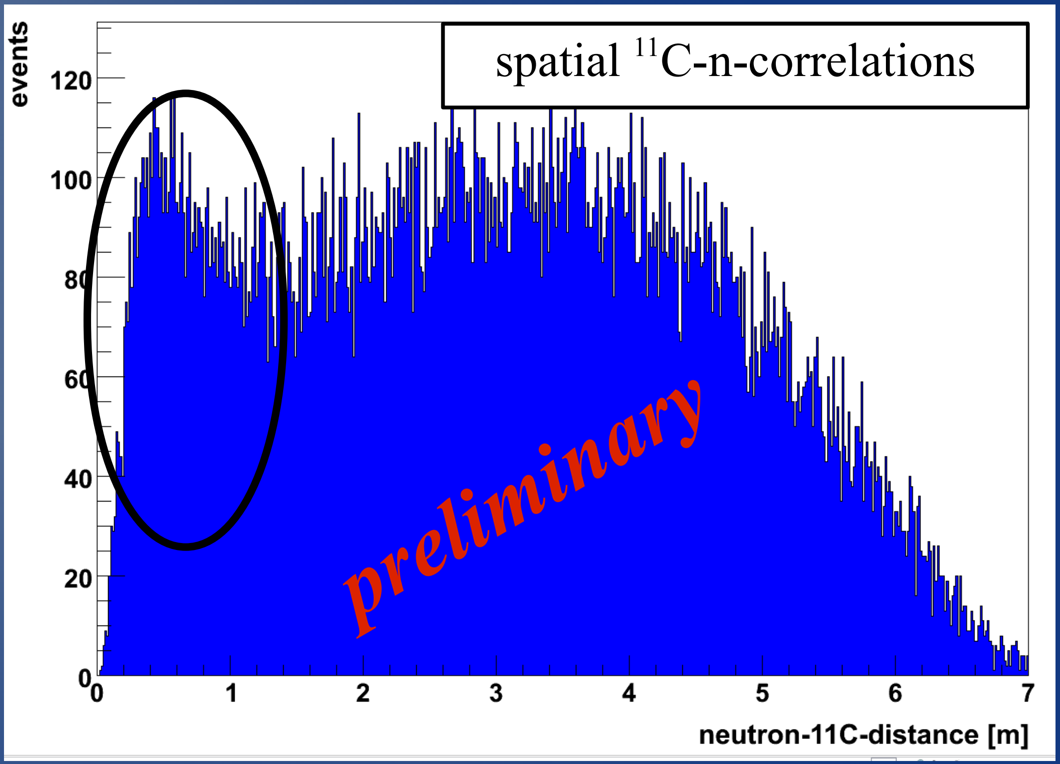

Temporal correlations

Literature value : $\tau(^{11}C) = 29.4$ min

Spatial correlations

Strong correlations in space and time

Tagging of ^{11}C
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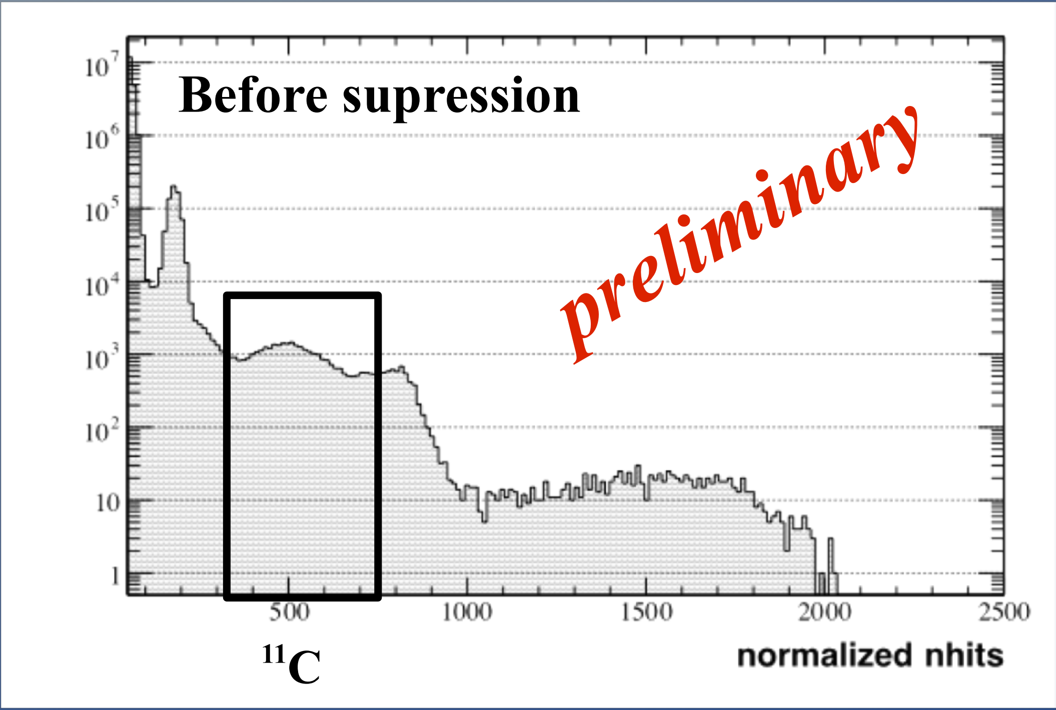
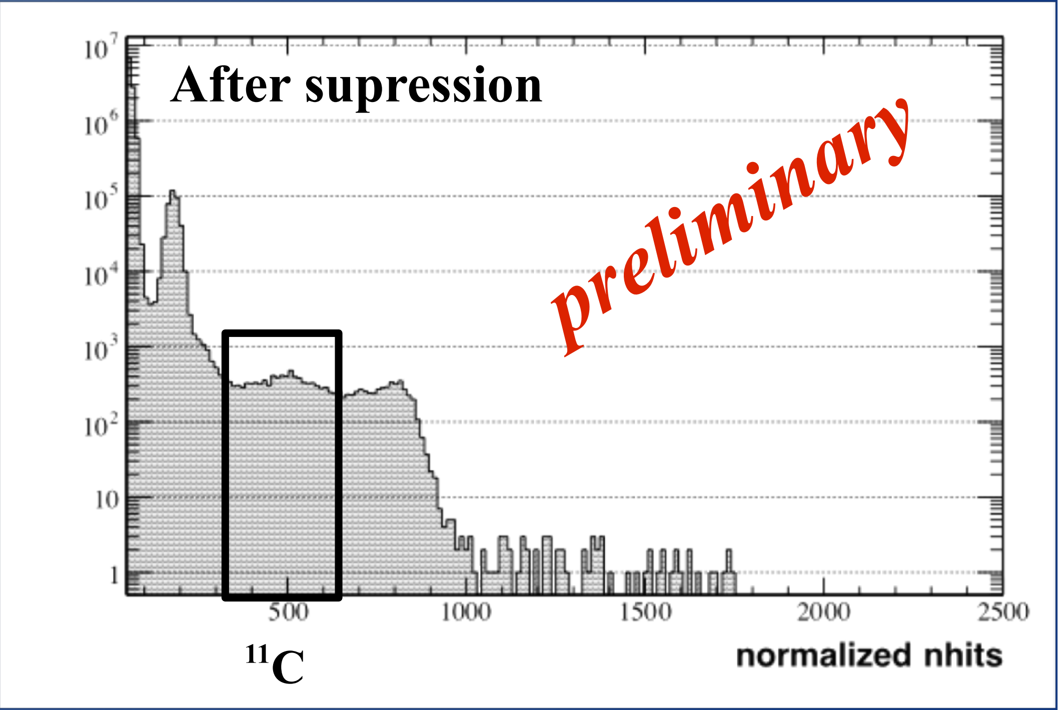
Example of ^{11}C supression:
Reject events within 90min and 1m to a cosmogenic neutron





Supression efficiencies:

^{11}C ($\tau = 29.4$min) :	~ 60%
Reduction of the target-mass-time:	~ 16%

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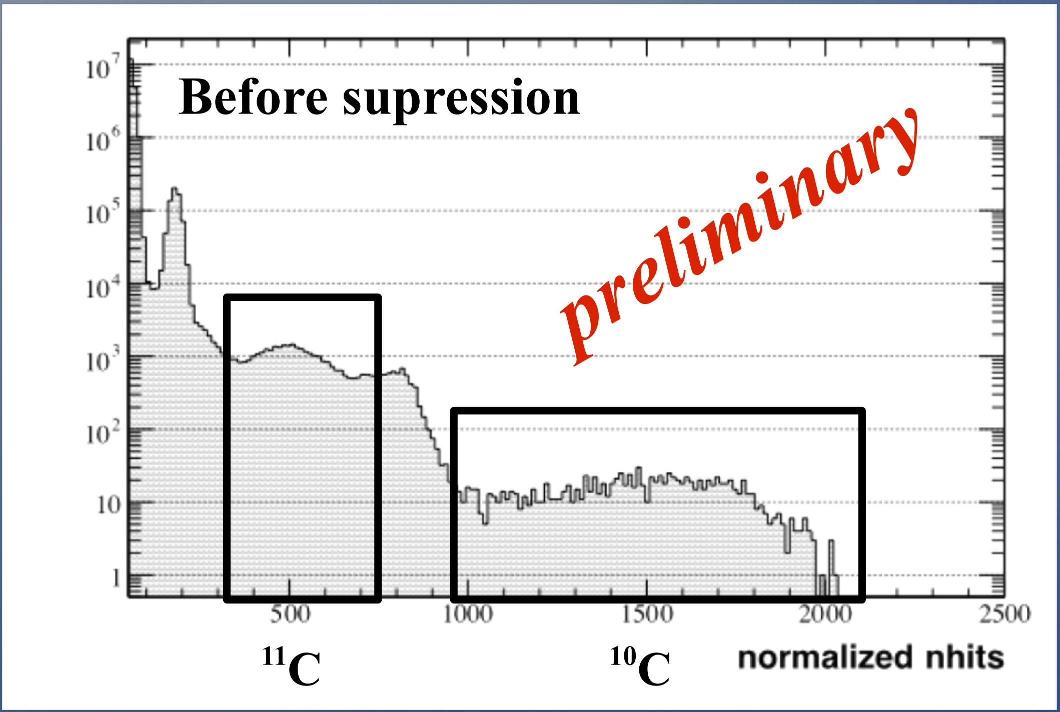

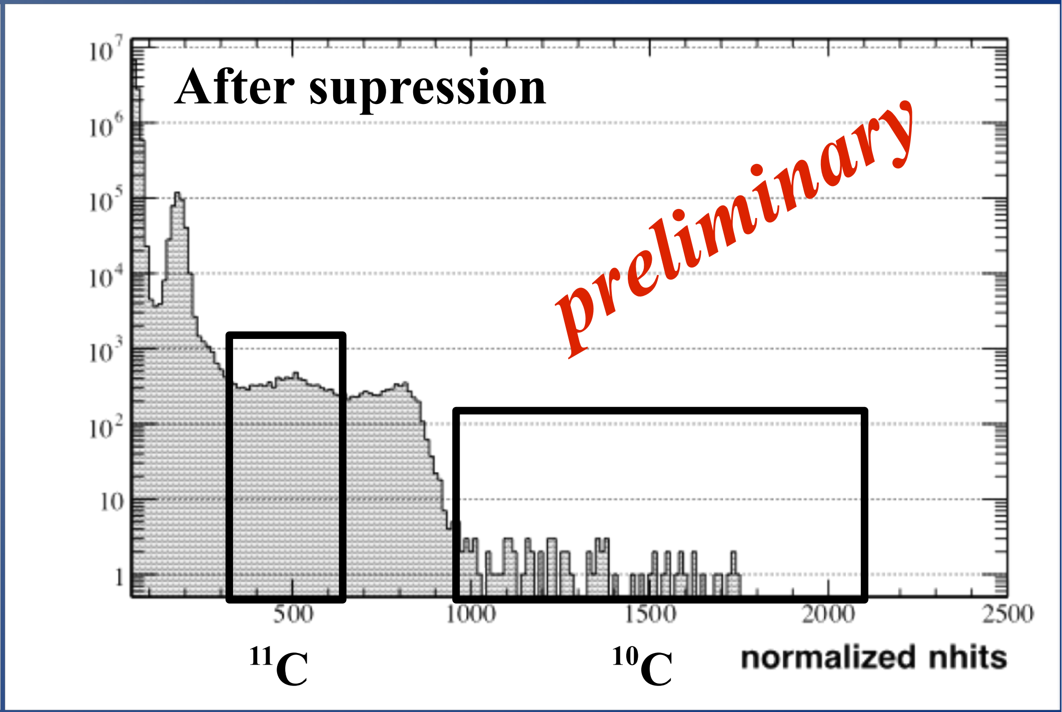

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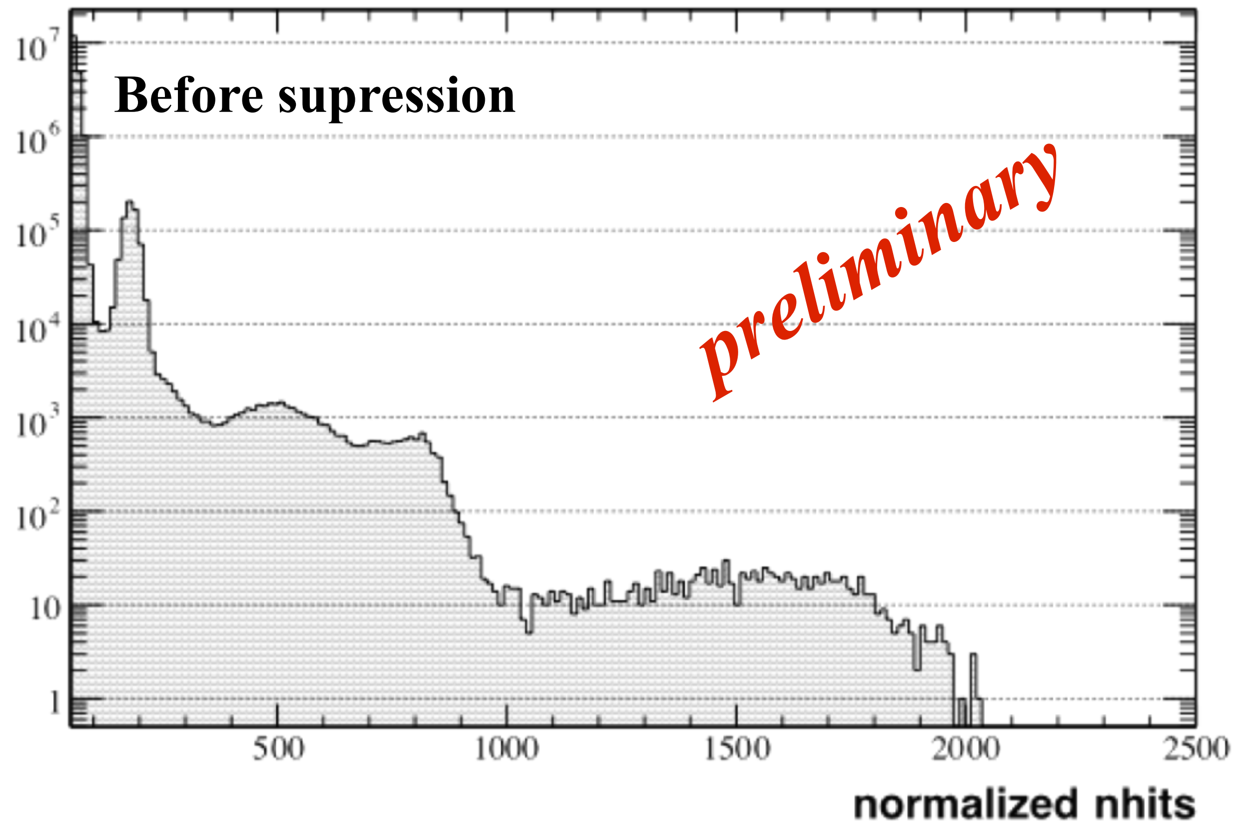
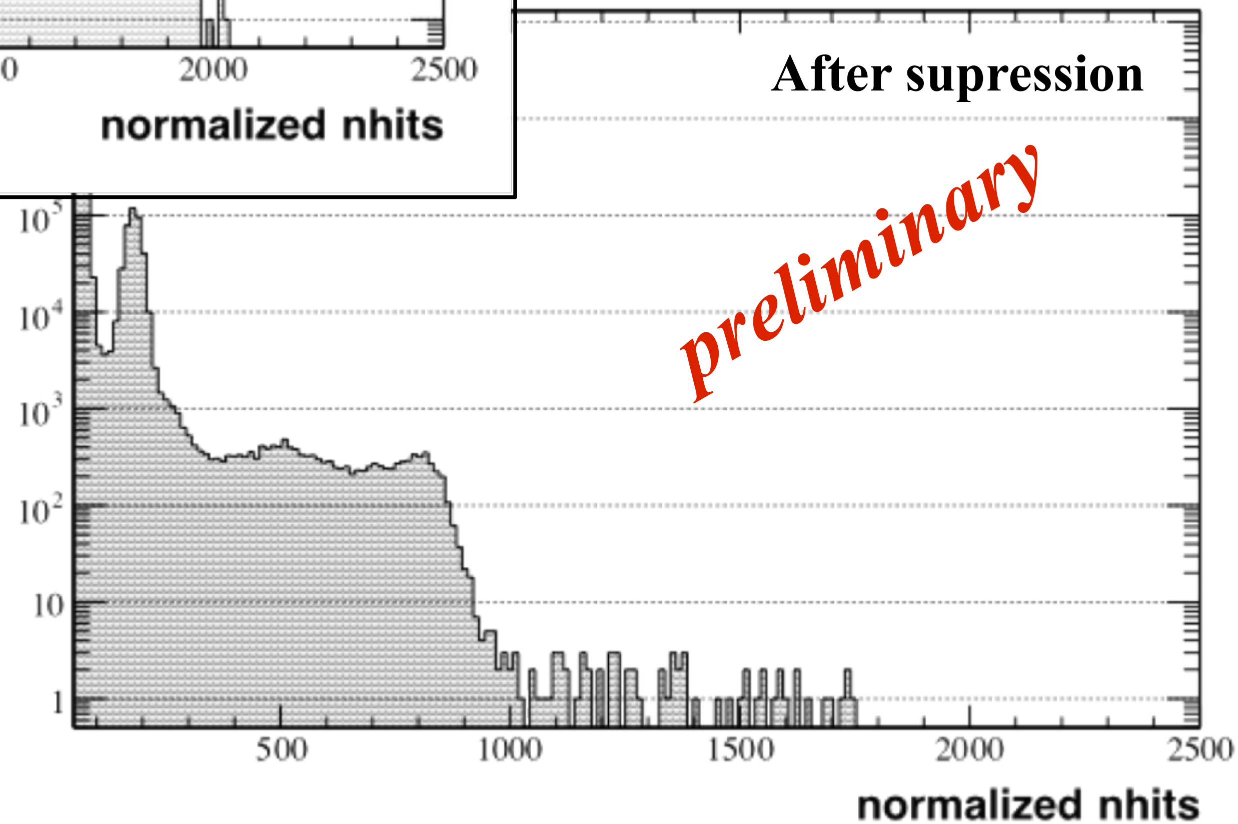

Before supression
preliminary
10^7
10^6
10^5
10^4
10^3
10^2
10
1
500
1000
1500
2000
2500
normalized nhits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Outlook
Advanced TFC

Muon track
Vetoing only the intersection of the muon track cylinder and the neutron spheres
=> less target-mass-time reduction

Run start
Maintenance or calibration runs interrupt normal data taking
=> muon/neutrons of ^{11}C production are not detected
=> ^{11}C decay is untaggable
This ^{11}C can be rejected by vetoing the first 30min of a run after a long data taking interruption.

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Full supression capability of Borexino still under investigation!
However, tagging efficiencies of up to 88% seem feasable!

Summary

- The Borexino Experiment
- Muon-induced secondaries and radionuclides
- Tagging of ^{11}C: The Three-Fold Coincidence
- Advanced Three-Fold Coincidence

Thank you for your attention!

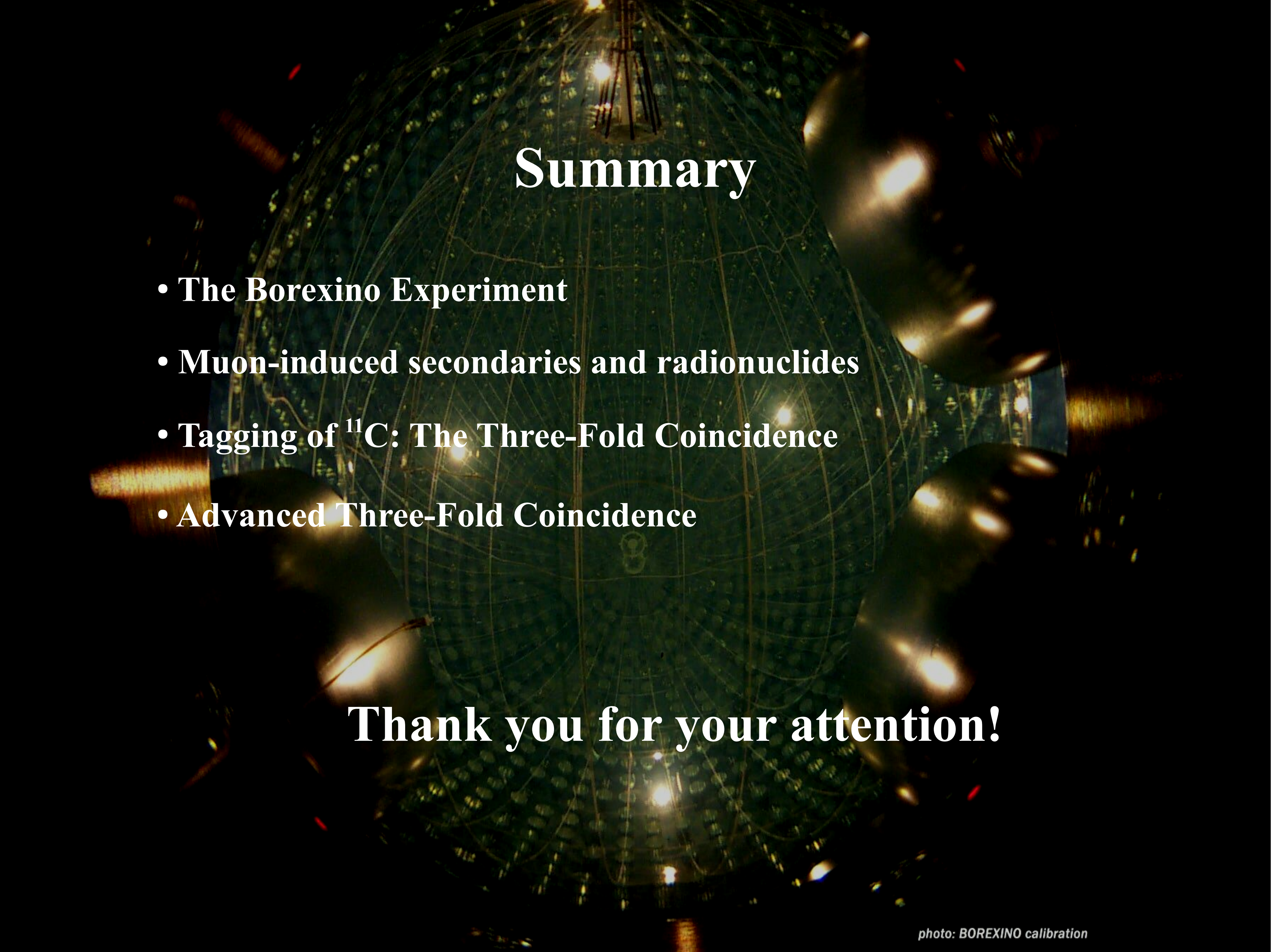

photo: BOREXINO calibration