Measurement of the cosmogenic ^{11}C background with the Borexino Counting Test Facility

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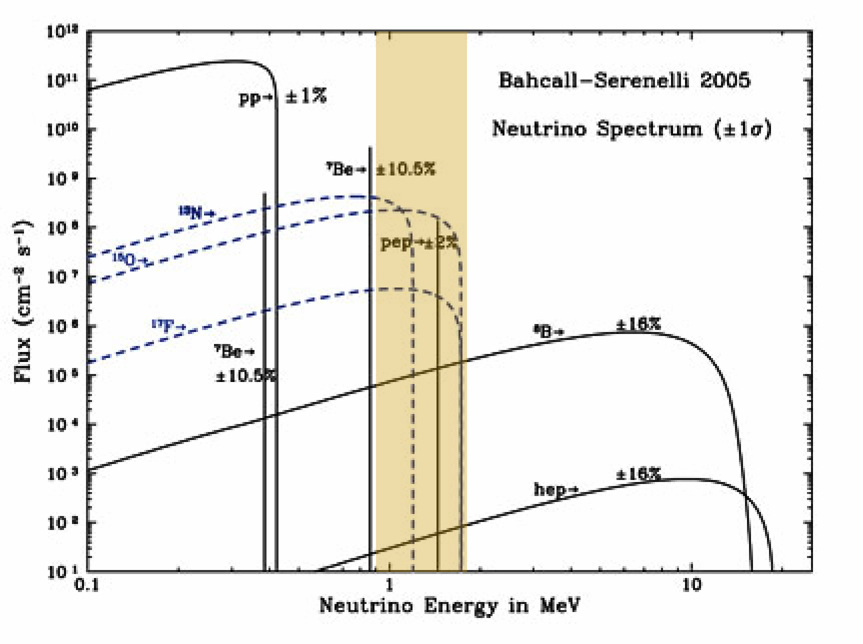
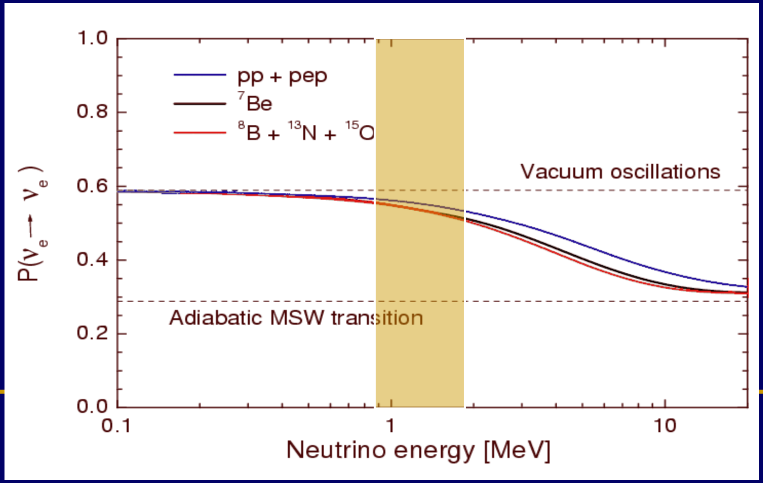
Outline

- *pep* and CNO neutrino physics in deep underground liquid scintillator detectors
- Main background contaminants
- The ^{11}C problem and the three-fold coincidence technique
- Measurement of the ^{11}C production rate with CTF
- How to open a window to the pep and CNO neutrino flux measurement in large scintillator detectors

pep and CNO neutrinos

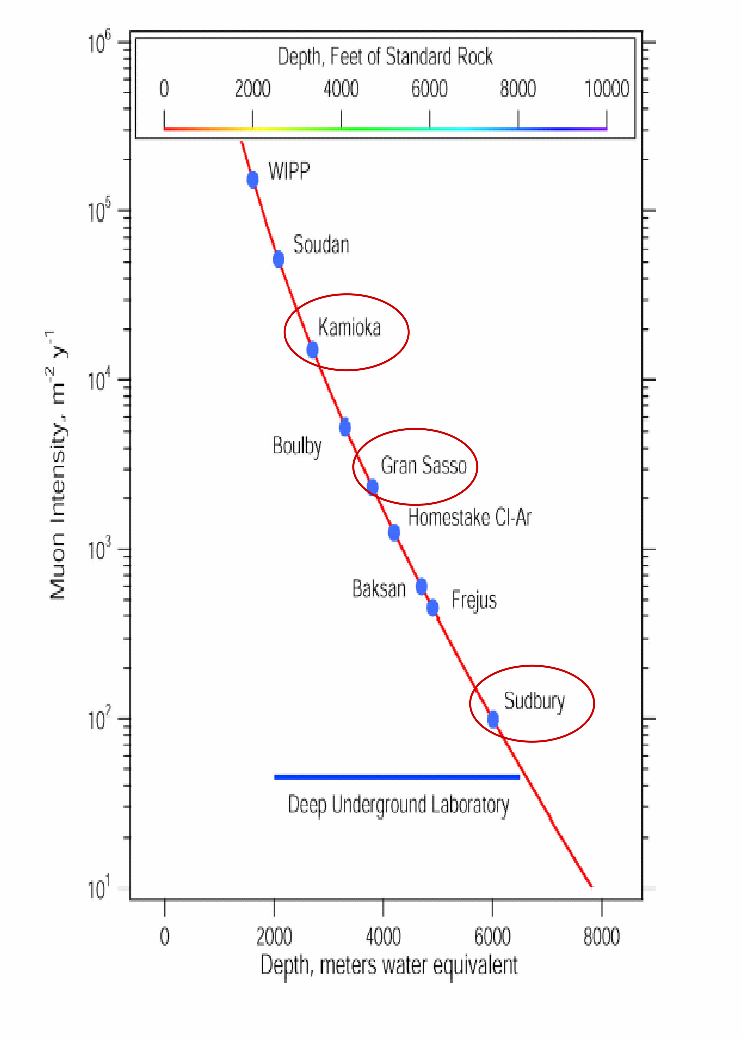




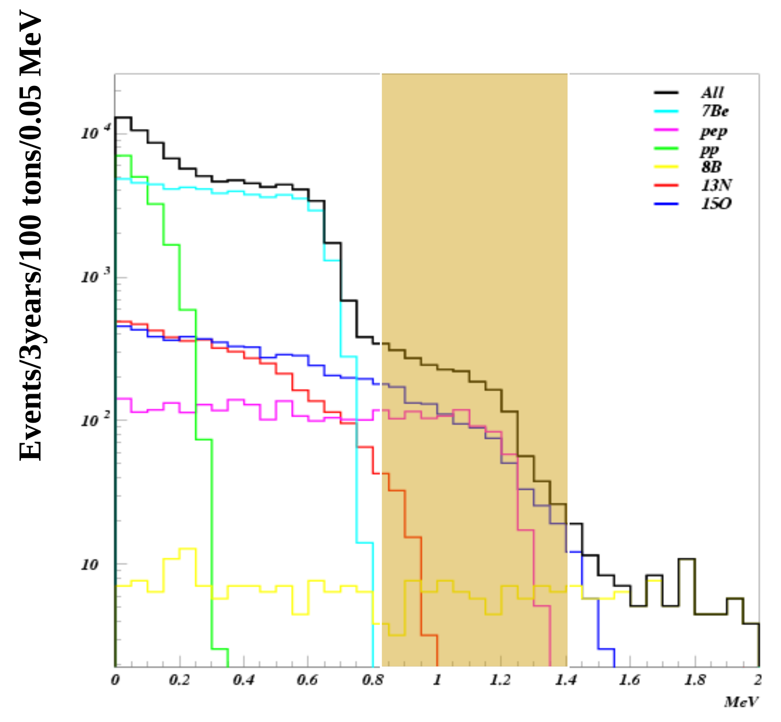
- Ideal sources for probing the transition between matter and vacuum dominated oscillations (MSW-LMA)
- Directly related with the *pp* fusion reaction in the Sun
- Improves our knowledge of the solar neutrino luminosity
- Helpful in the age estimation of the Globular Clusters
- Non-standard interactions, mass-varying neutrinos, CPT violation,large θ_{13} sterile neutrino admixture….

Organic liquid scintillator detectors

	KamLAND	BOREXino	SNO+
Scintillator	Dodecane (80%) + Pseudocumene 20%)	Pseudocumene	linear alkylbenzene
Mass	1 kt	0.3 kt	1 kt
Depth	2700 mwe	3800 mwe	6000 mwe
μ–Rate	26,000 d^{-1} (26 d^{-1} t^{-1})	1,500 d^{-1} (5 d^{-1} t^{-1})	70 d^{-1} (0.07 d^{-1} t^{-1})
$<E_\mu>$	285 GeV	320 GeV	350 GeV



Detection signature in liquid organic scintillator



- Energy resolution: 380 p.e./MeV
- LMA-BP2004-LUNA
- 3 years statistics in 100 tons of scintillator

- Neutrino elastic scattering off electrons
- Energy range of observation:
  - 0.8 – 1.4 MeV
- Expected flux in BOREXino-like scintillator (BP2004+LUNA+LMA):
  - *pep*-ν: 9x10^{-3} d^{-1} ton^{-1}
  - CNO-ν: 6x10^{-3} d^{-1} ton^{-1}

Expected background contamination

Trace contaminations:

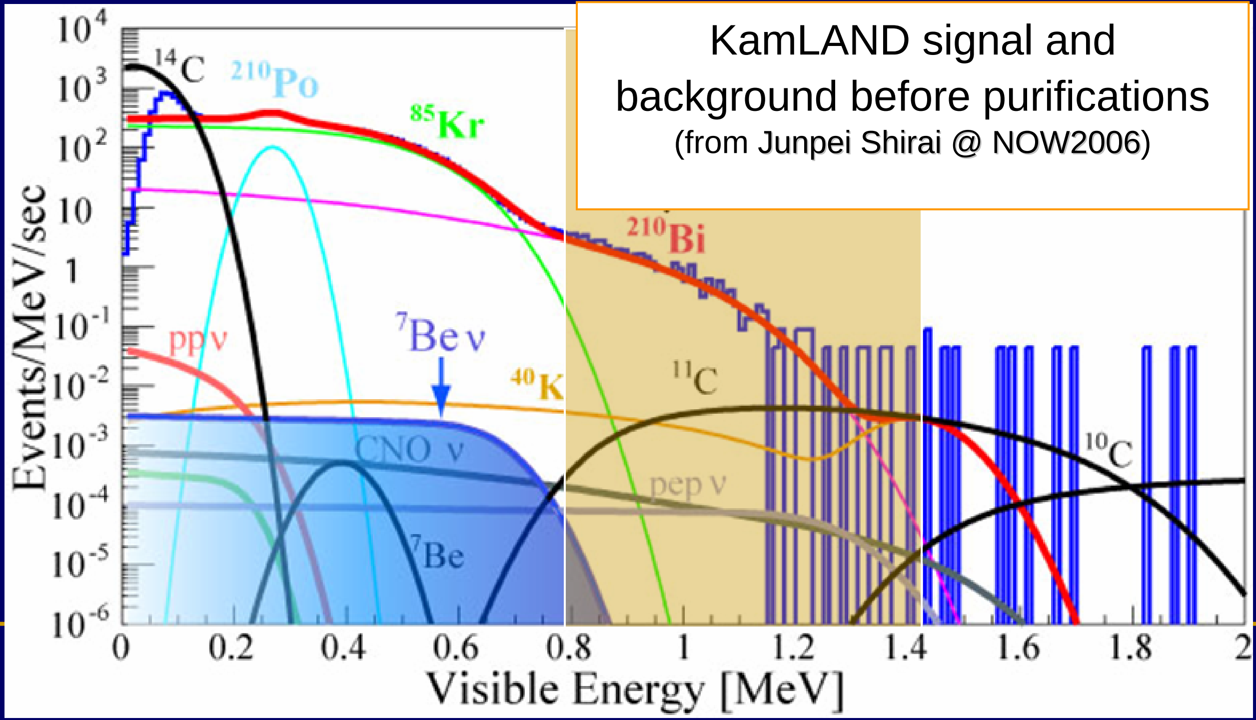
- ^{210}Bi (Q_β = 1.16 MeV)
- ^{214}Bi (Q_β = 3.27 MeV)
- ^{212}Bi (Q_β = 2.25 MeV)
- ^{40}K (Q_β = 1.32 MeV Q_{EC} = 1.51 MeV)

Cosmogenic background:

- ^{11}C (Q_β = 1.98 MeV)

For the pep and CNO flux measurement, BOREXino require:

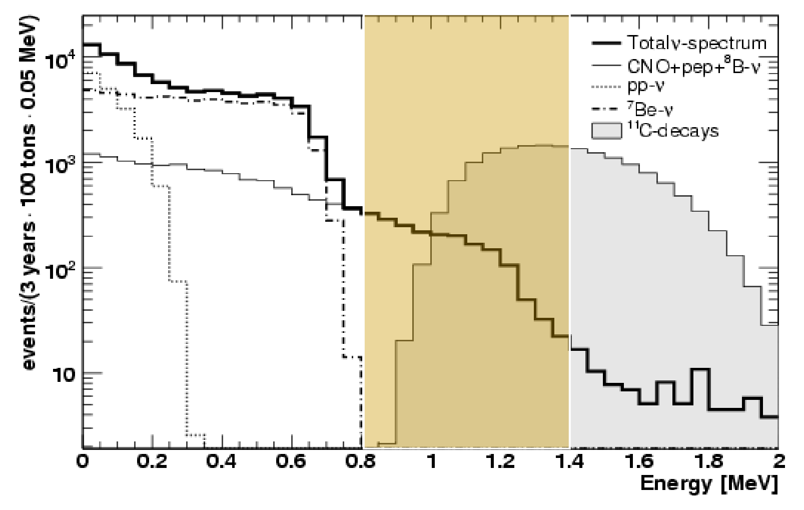
- ^{238}U @ 10^{-17} g/g
- ^{232}Th @ 10^{-17} g/g
- ^{nat}K @ 10^{-15} g/g



KamLAND signal and background before purifications

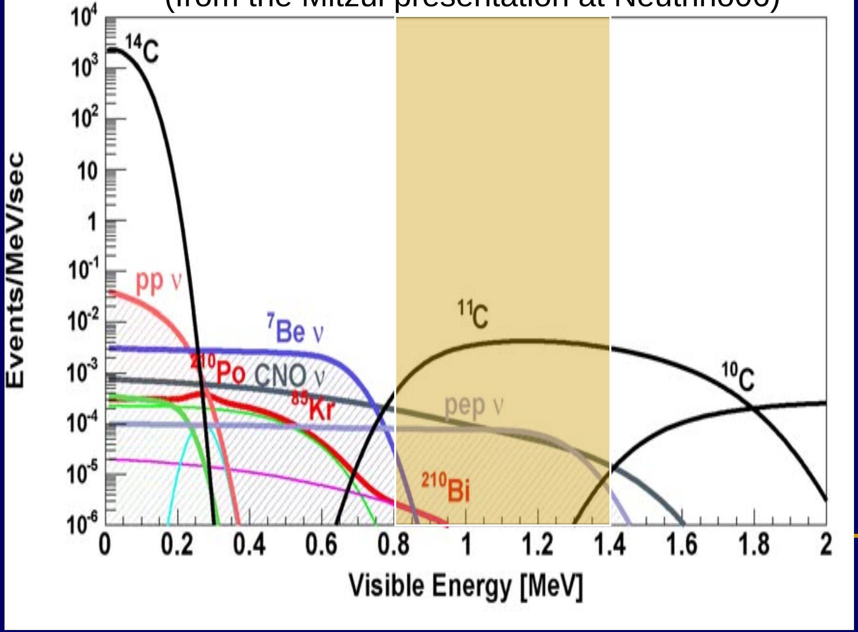
(from Junpei Shirai @ NOW2006)

BOREXino



KamLAND

(from the Mitzui presentation at Neutrino06)



NA54 @ CERN: 100 and 190 GeV muon beams on a ^{12}C target: ^{11}C represents 80% of all the muon-induced contaminants and more than 99% in the CNO pep-ν energy window

Hagner et al., Astropart. Phys. ***14****, 33 (2000)*

^{11}C Rate (cts / day / 100 tons)		
	All energy	0.8 – 1.4 MeV
KamLAND	107	55
BOREXino	15	7.4
SNO+	0.15	0.074

The BOREXino Case

- Energy range: [0.8 – 1.4] MeV
- Expected n-rate (BP2004+LUNA+LMA):
  - *pep*-ν: 9x10^{-3} d^{-1} ton^{-1}
  - CNO-ν: 6x10^{-3} d^{-1} ton^{-1}
- Internal background : 6x10^{-3} d^{-1} ton^{-1} (assuming 10^{-17} g/g of U and Th)
- In situ production muon-induced ^{11}C Rate:
  - R_{11C} = 7.5x10^{-2} d^{-1} ton^{-1} (R_{11C} = 14.6x10^{-2} d^{-1} ton^{-1} in the whole energy spectrum)*

The goal:

to reach a signal-to-background ratio 1, we require a reduction factor

$$f > R_{11C} / R_\nu = 8$$

^{11}C production and decay

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

n + p $\rightarrow$ d + γ

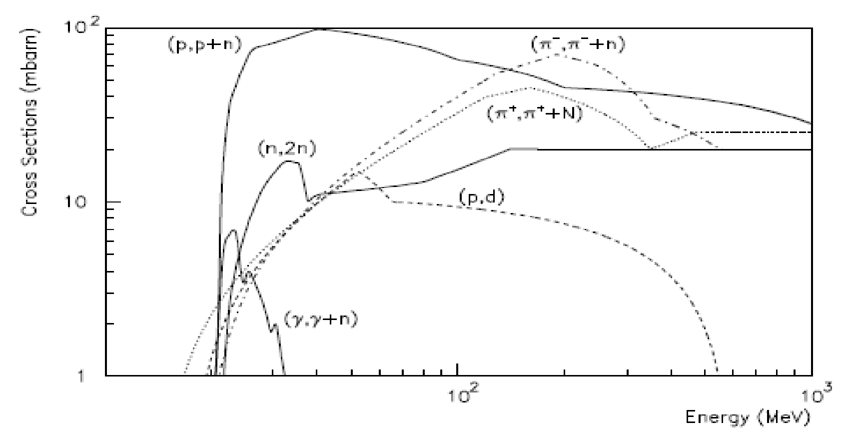
^{11}C $\rightarrow$ ^{11}B + e^+ + ν_e

PROBLEMS!!!!

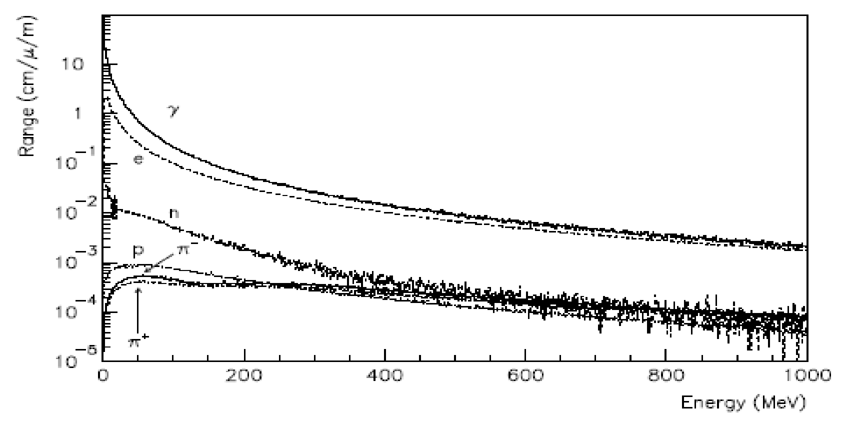
Coincidence among:

- cosmic muon:
  - rate at LNGS (3700 mwe): 1.16 hr^{-1} m^{-2}
  - average energy: 320 GeV
- gamma from neutron capture:
  - energy: 2.2 MeV
  - capture time: 250 μs
- positron from ^{11}C decay:
  - deposited energy between 1.022 and 1.982 MeV
  - mean life: 30 min

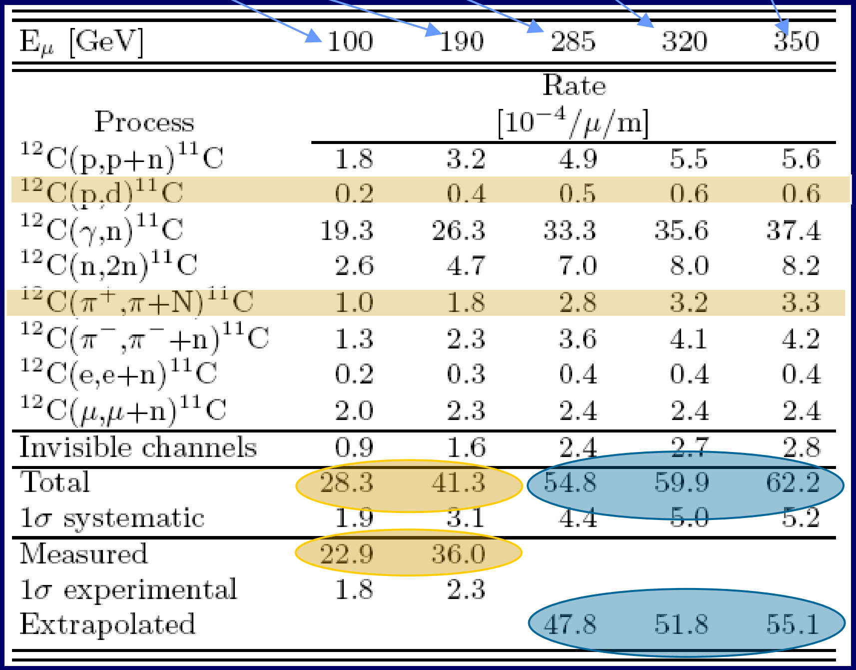
Cross sections for ^{11}C production from ^{12}C as a function of energy



Cumulative range of μ-induced secondaries



NA54 Kamioka LNGS SNOLab



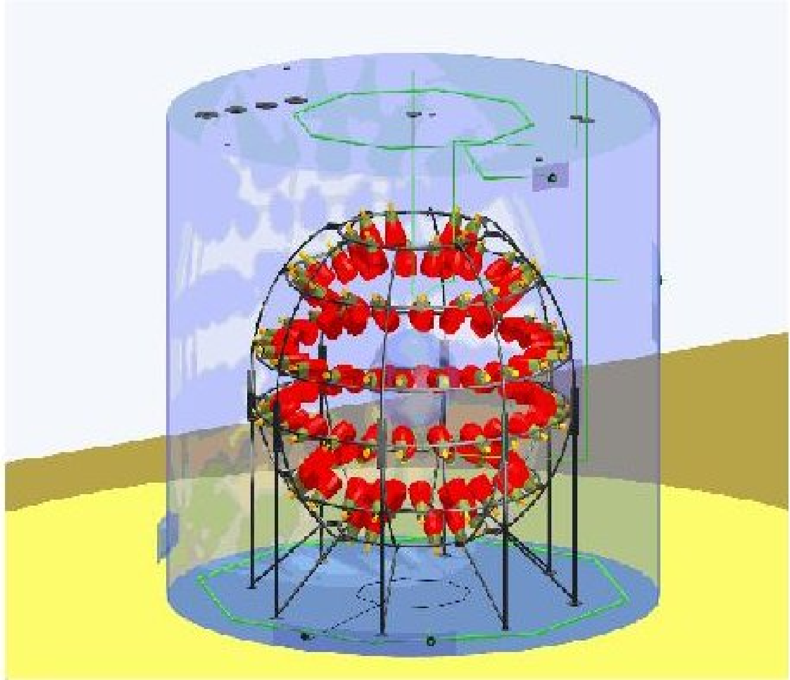
E_μ [GeV]	100	190	285	320	350
Process	Rate $[10^{-4}/\mu/m]$				
$^{12}C(p,p+n)^{11}C$	1.8	3.2	4.9	5.5	5.6
$^{12}C(p,d)^{11}C$	0.2	0.4	0.5	0.6	0.6
$^{12}C(\gamma,n)^{11}C$	19.3	26.3	33.3	35.6	37.4
$^{12}C(n,2n)^{11}C$	2.6	4.7	7.0	8.0	8.2
$^{12}C(\pi^+,\pi+N)^{11}C$	1.0	1.8	2.8	3.2	3.3
$^{12}C(\pi^-,\pi^-+n)^{11}C$	1.3	2.3	3.6	4.1	4.2
$^{12}C(e,e+n)^{11}C$	0.2	0.3	0.4	0.4	0.4
$^{12}C(\mu,\mu+n)^{11}C$	2.0	2.3	2.4	2.4	2.4
Invisible channels	0.9	1.6	2.4	2.7	2.8
Total	28.3	41.3	54.8	59.9	62.2
1σ systematic	1.9	3.1	4.4	5.0	5.2
Measured	22.9	36.0			
1σ experimental	1.8	2.3			
Extrapolated			47.8	51.8	55.1

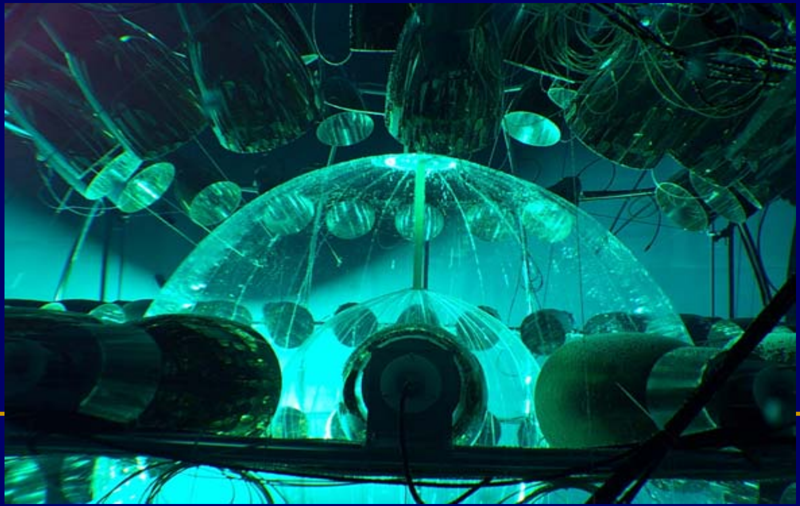
C. Galbiati et al., Phys. Rev. C **71**, 055805 (2005)

Neutrons are produced in association with 95.5% of the muon-induced ^{11}C

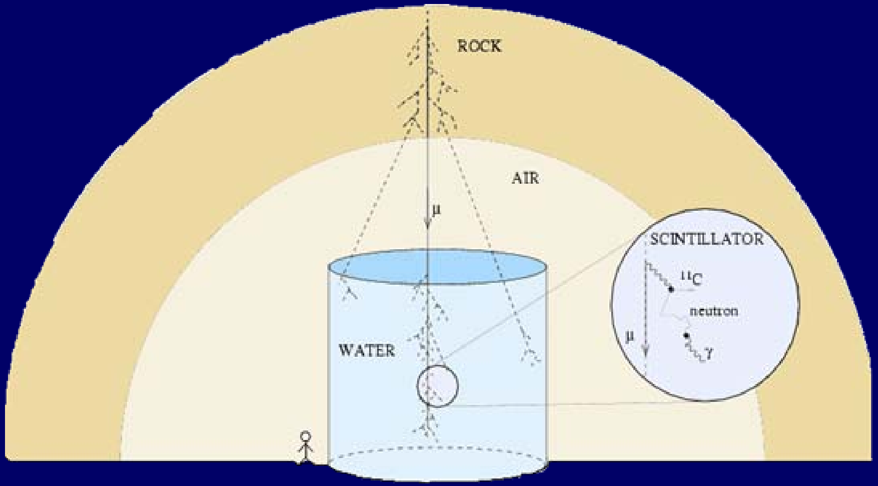
Test of the coincidence technique with the Counting Test Facility

- 4 tons of scintillator
- 1 m radius vessel housing the scintillator
- 2 m radius "shroud"
- 3.6 p.e./PMT for 1 MeV electron
- Muon veto
- 100 PMT (OC: 21%)
- Buffer of water
- Energy saturation: 6 MeV





Data selection



Muon selection

- cut on the number of photoelectrons detected by the muon-veto

Neutron selection

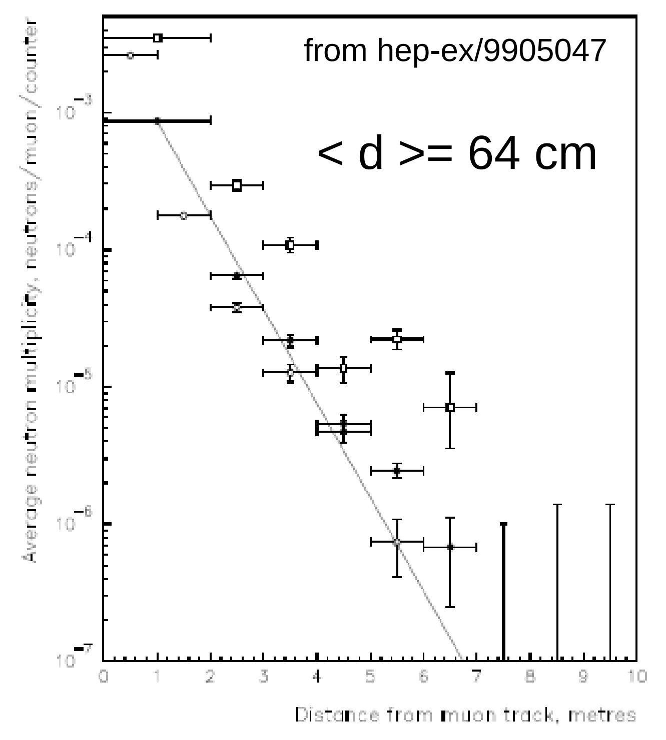
- For each detected μ, the following event in the time window $T_n = [20, 2000]$ μs is selected as a candidate event for a neutron capture γ
- $E < 2.6$ MeV

^{11}C selection

- After each μ–γ coincidence, ^{11}C candidates are selected in a subsequent time window $T_w = 300$ min, 10 times the ^{11}C mean life.
- Optimal energy range: $1.15 < E < 2.25$ MeV
- Distance between ^{11}C event and gamma < 35 cm

Muon induced neutrons

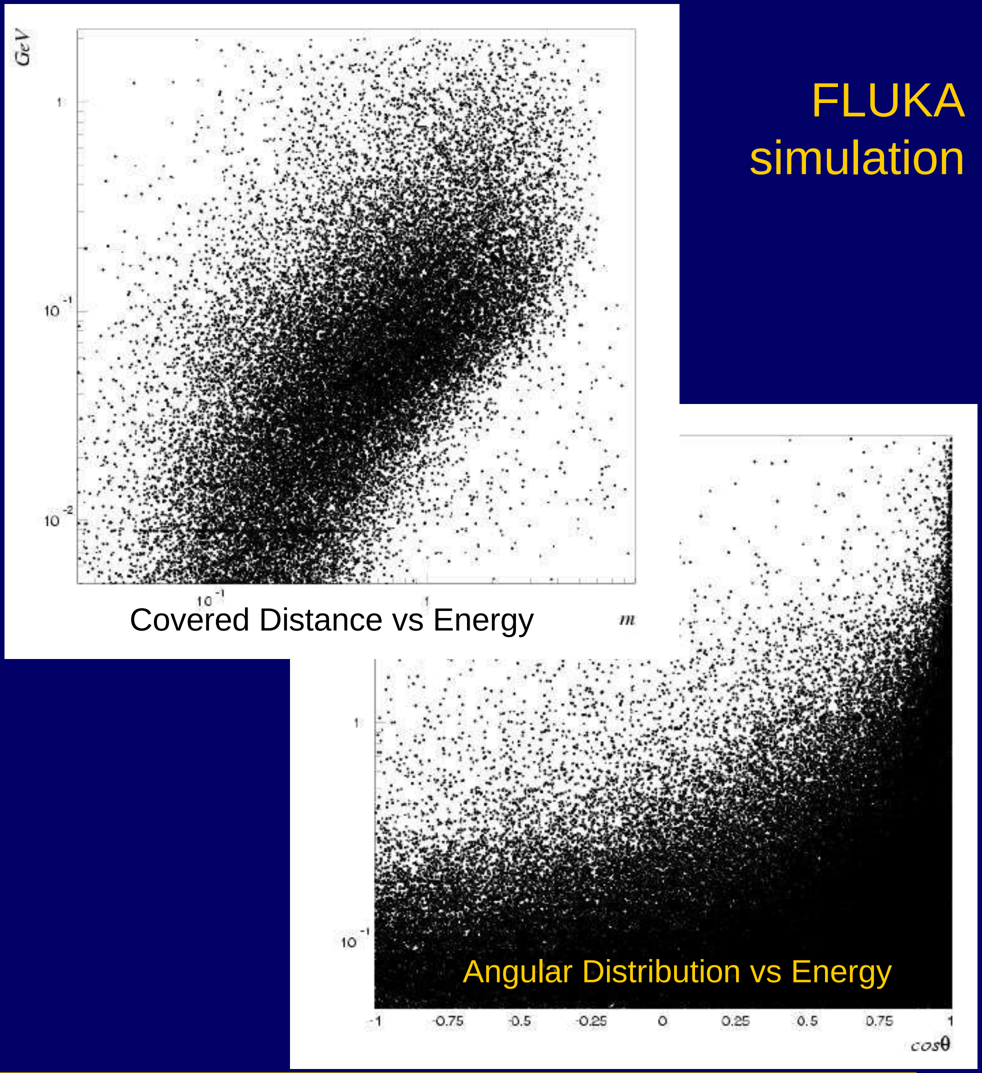
LVD measurement: neutron multiplicity as function of the distance from the muon track



from hep-ex/9905047

< d >= 64 cm

FLUKA simulation

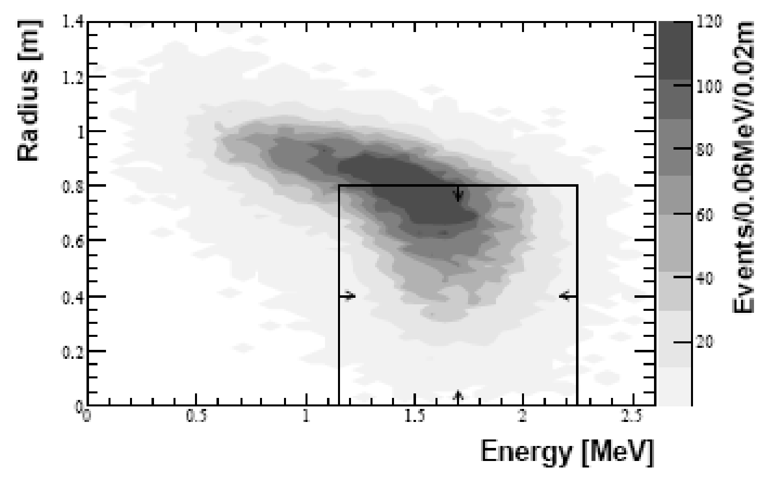


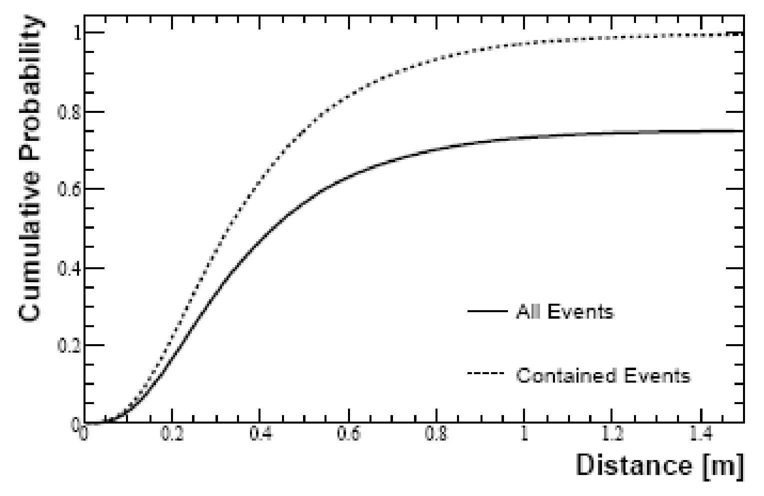
Covered Distance vs Energy

Angular Distribution vs Energy

$< N >= (1.5 \pm 0.4) \cdot 10^{-4}$ neutrons/(muon event)/(g/cm^2)

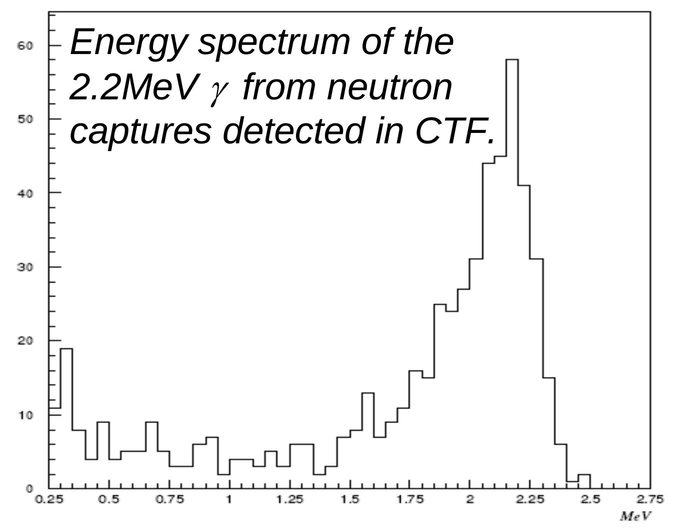
CTF detection efficiency from MC



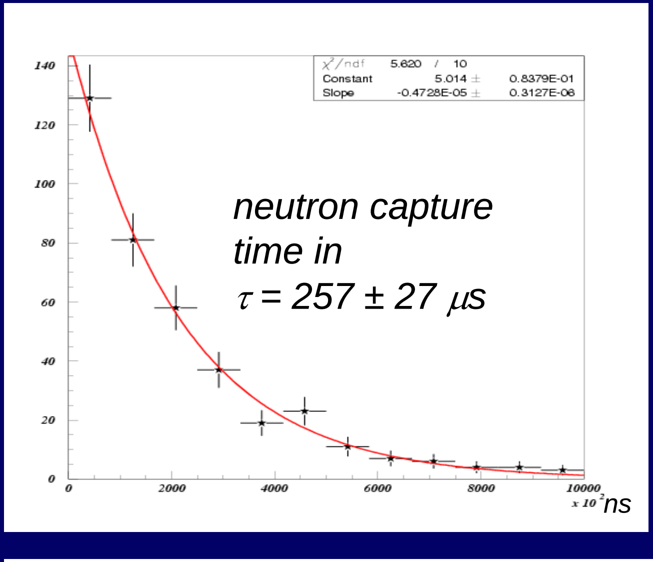


Efficiency in CTF		Value
ε_{vis}	Visible channels	0.955
ε_{end}	End of run during the time window T_w	0.990
ε_t	Time window T_n neutron selection	0.925
ε_{escape}	Neutrons contained in the vessel	0.732
ε_c	^{11}C energy cut Neutron capture gamma energy > 0.2 MeV ^{11}C-γ distance < 35 cm	0.563
Total		0.360

CTF results



Energy spectrum of the 2.2MeV γ from neutron captures detected in CTF.



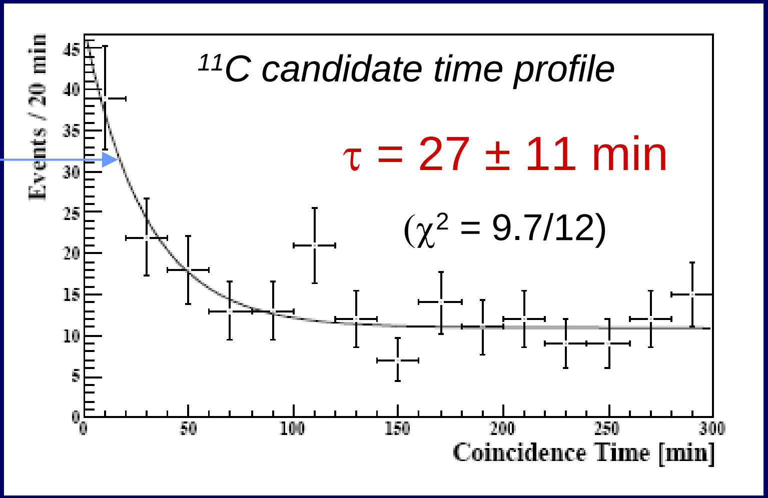
neutron capture time in
$\tau = 257 \pm 27\ \mu s$

$$F(t) = \frac{N}{t} \cdot e^{t/\tau} + B$$

$n =$ number of events

$\tau =$ 11C lifetime

$B =$ random coincidences



^{11}C candidate time profile

τ = 27 ± 11 min

(χ^2 = 9.7/12)

Measured ^{11}C production rate

$$R(^{11}C) = \frac{N}{\frac{4}{3}\pi r^2 \rho T} \cdot \frac{1}{\varepsilon_{vis} \cdot \varepsilon_{end} \cdot \varepsilon_t \cdot \varepsilon_{escape} \cdot \varepsilon_c}$$

$r =$ fiducial volume radius (0.8 m)

$\rho =$ scintillator density (0.88 g/cm^3)

$T =$ detector live time (611 days)

Main systematic sources:

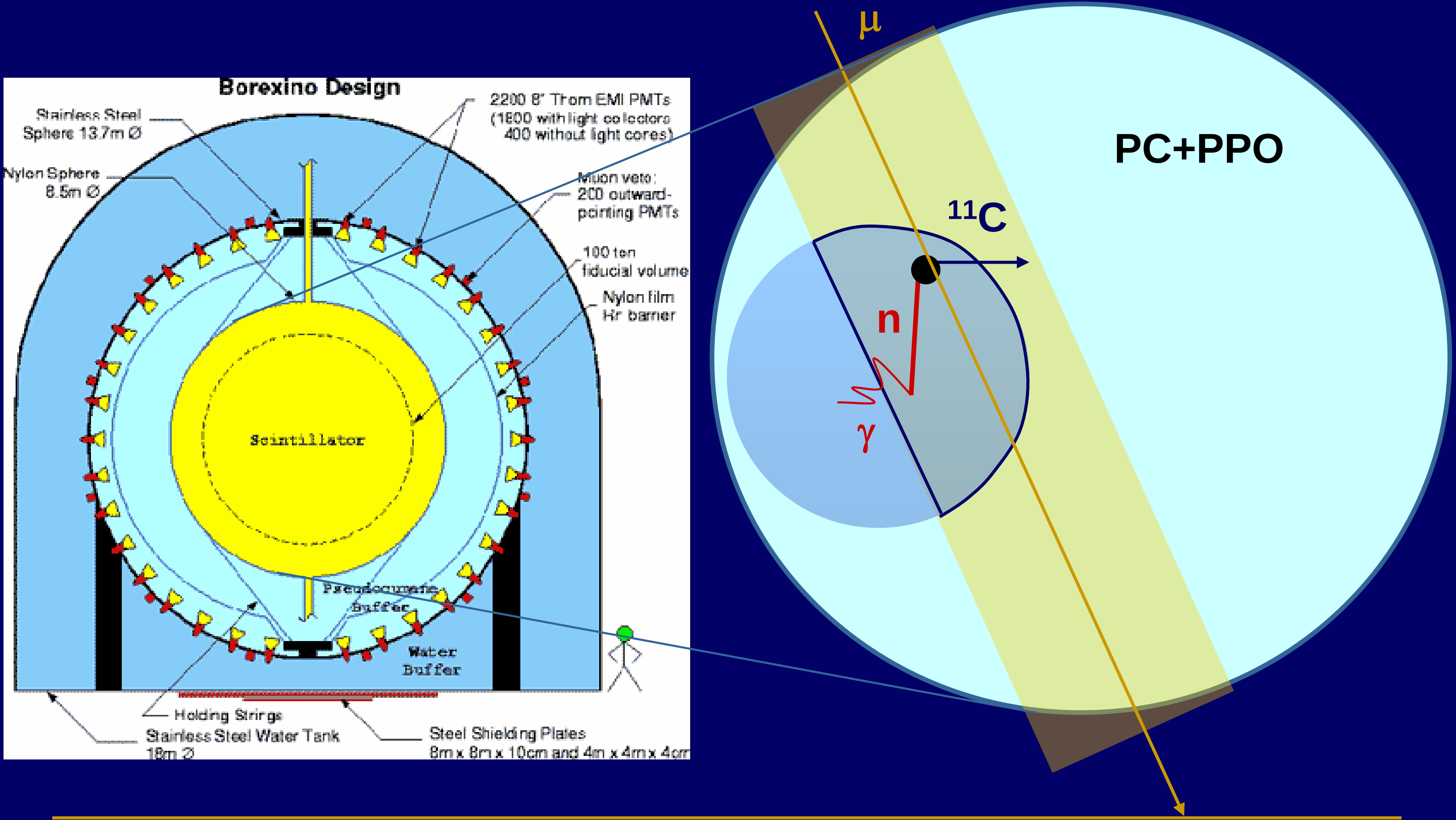
- position reconstruction: 1.5%
- light yield: 8.5%

$$R(^{11}C) = [13.0 \pm 2.6(\text{stat}) \pm 1.4(\text{syst})] \times 10^{-2}\ \text{d}^{-1}\ \text{ton}^{-1}$$

$$\frac{\text{Measured Rate}}{\text{Expected Rate}} = 0.89 \pm 0.20$$

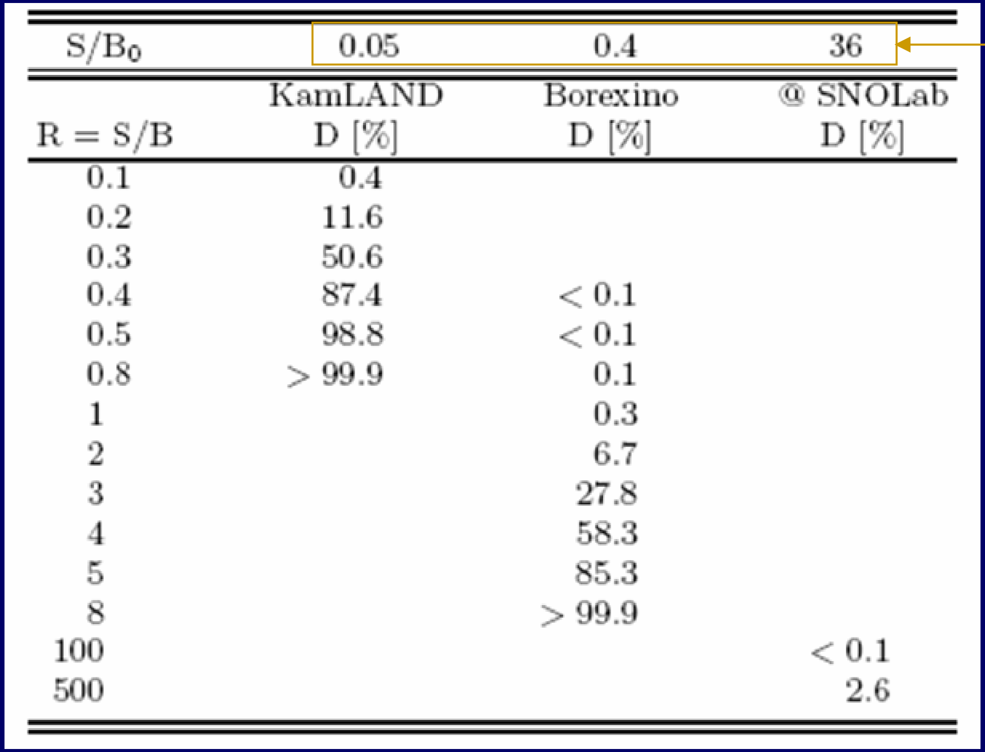
Goal reached!

Large scintillator detector potential



Large scintillator detector potential

Assuming efficiency 1 and only the spherical cut



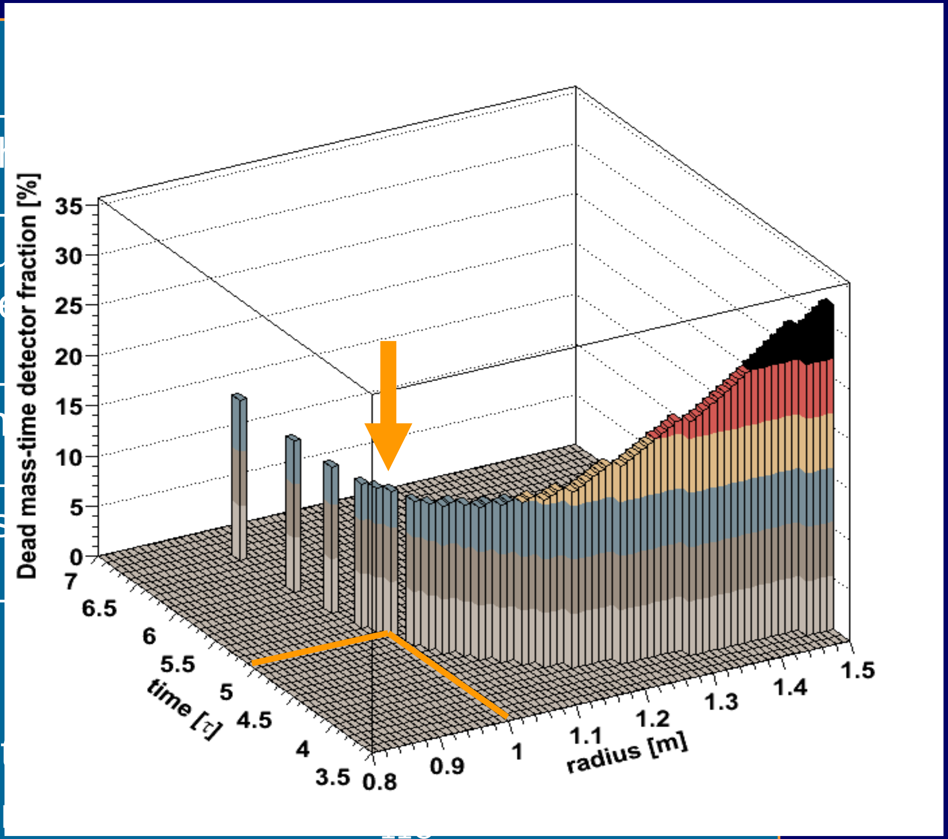
S/B_0	0.05	0.4	36
	KamLAND	Borexino	@ SNOLab
$R = S/B$	D [%]	D [%]	D [%]
0.1	0.4		
0.2	11.6		
0.3	50.6		
0.4	87.4	< 0.1	
0.5	98.8	< 0.1	
0.8	> 99.9	0.1	
1		0.3	
2		6.7	
3		27.8	
4		58.3	
5		85.3	
8		> 99.9	
100			< 0.1
500			2.6

S/B ratio before the cuts

D = detector mass-time fraction loss

BOREXino rejection efficiency

Efficiency in BOREXino		
ε_{vis}	Visible ch	
$\varepsilon_{\cancel{end}}$	End of ru for ^{11}C se	
ε_t	Time win	
$\varepsilon_{\cancel{escape}}$	Neutrons	
ε_c	Neutron MeV ^{11}C-γ dis ^{11}C-γ coi	
Total		0.880



To reach
S/B = 1

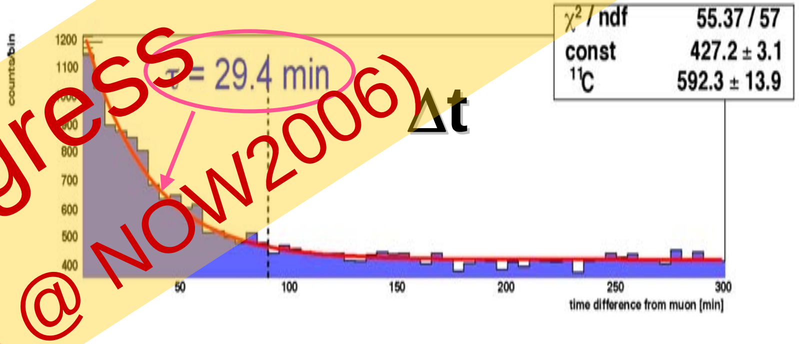
D = 14%

Remove ^{11}C by 3-fold coincidence

~95% of ^{11}C production is accompanied by neutron

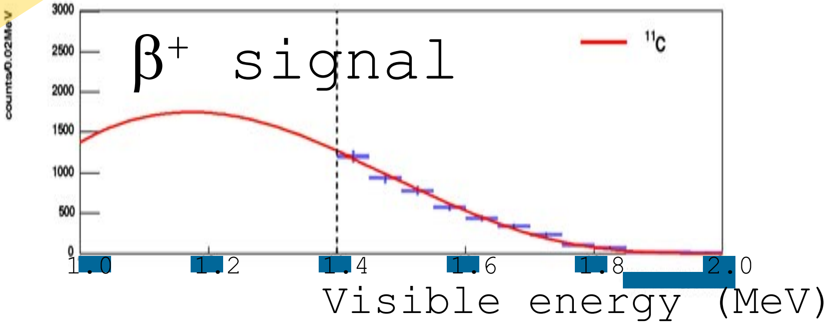
$^{12}C+X \rightarrow ^{11}C+n+Y+\ldots$

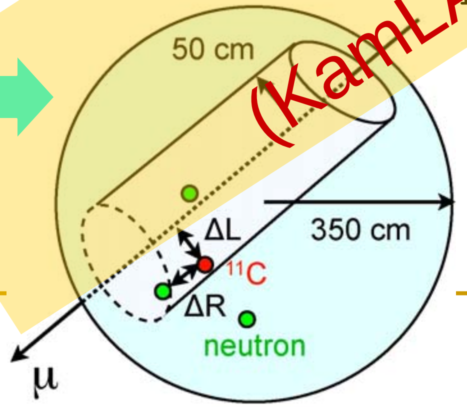
$X=\gamma,n,p,\pi,e,\mu$



Take 3-fold coincidence:

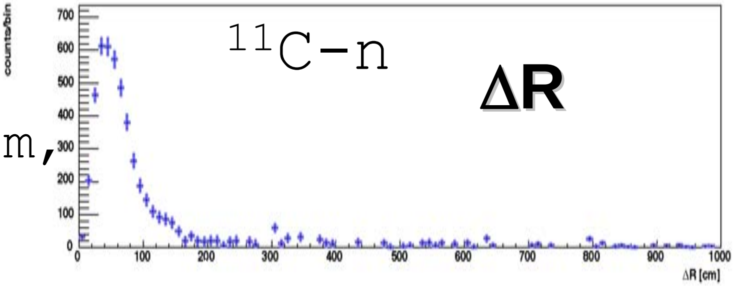
1) Muon
2) Neutron (2.2MeV γ after ~200μs)
3) ^{11}C decay(τ=29.4m)





KamLAND ^{11}C detection

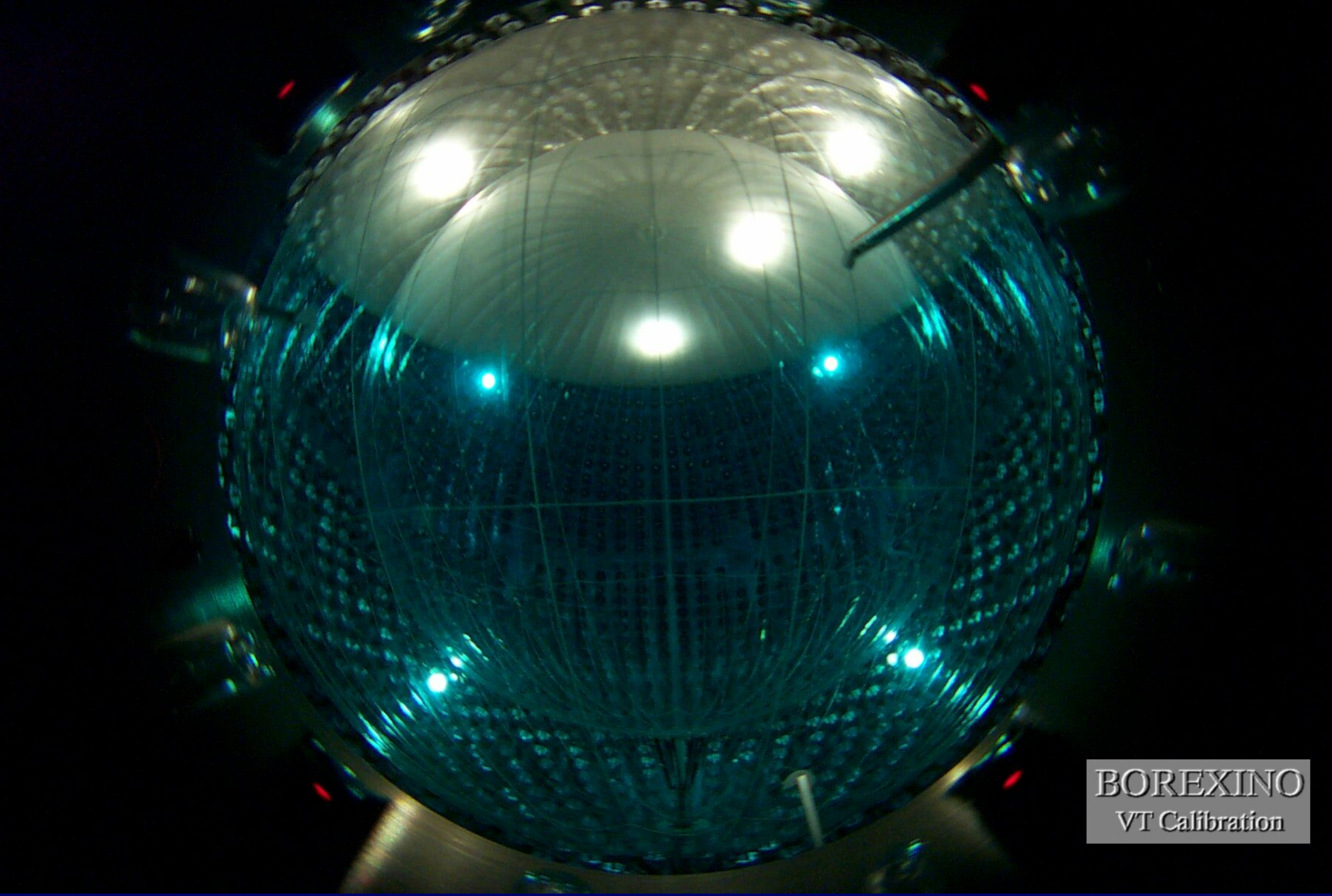
(select ΔL<50cm, $\#n_{detected}>0$)



KamLAND progress
(KamLAND presentation @ NOW2006)

Conclusions

- The CTF measurement has demonstrated that the three-fold coincidence technique is powerful in localizing in space and time ^{11}C decays
- ^{11}C can be removed by blinding detector volumes around it
- Waiting SNO+, BOREXino and KamLAND can open a window to *pep* and CNO neutrino spectroscopy


BOREXINO
VT Calibration