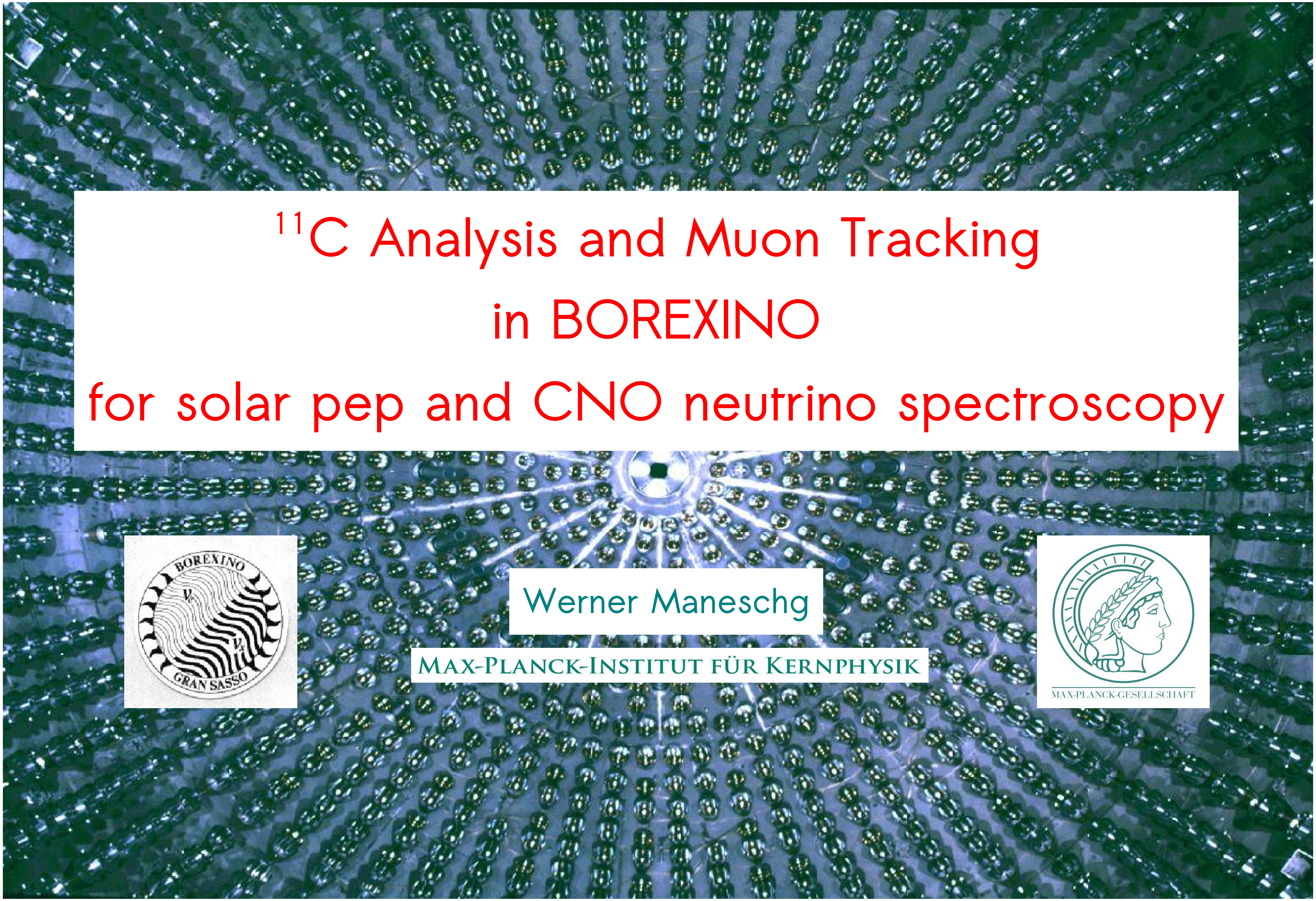
^{11}C Analysis and Muon Tracking in BOREXINO for solar pep and CNO neutrino spectroscopy

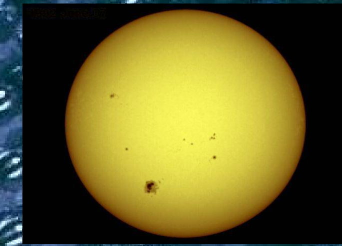


Werner Maneschg

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

DPG Spring Meeting, Munich, 13th March 2009

Overview



Introduction

- Solar pep and CNO neutrinos
- Detection with Borexino

pep and CNO neutrino Analysis

- General strategies for different backgrounds
- External background
- Shortlived cosmogenics
- ^{11}C and the threefold coincidence

Muontracking

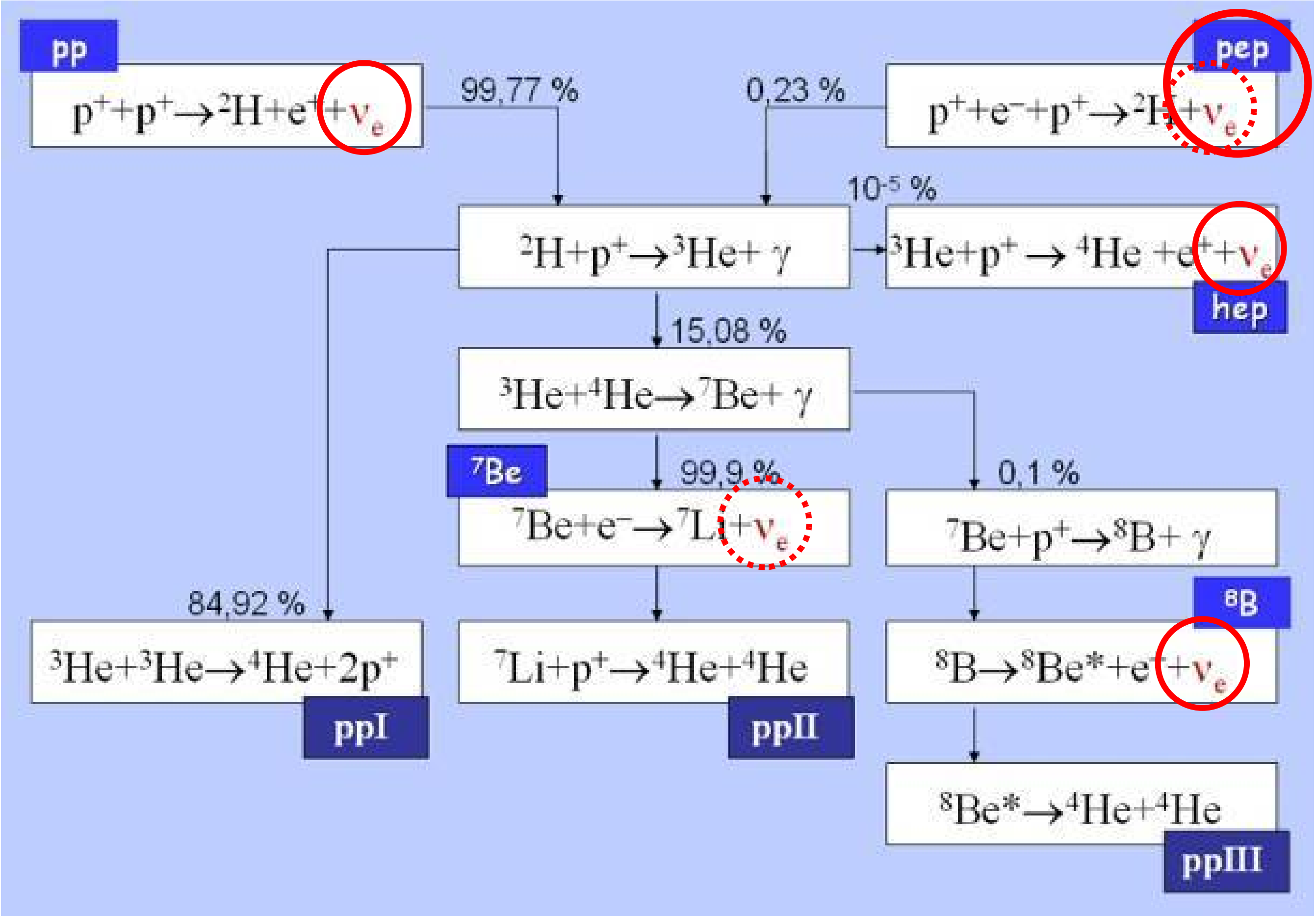
- Reconstruction of muontrack points and global fitter
- Testing the algorithms

Outlook & Conclusions

Solar fusion processes: Part 1

Proton-Proton chain:

Overall reaction: $4p \rightarrow \alpha + 2e^+ + 2\nu_e + 26.7MeV$



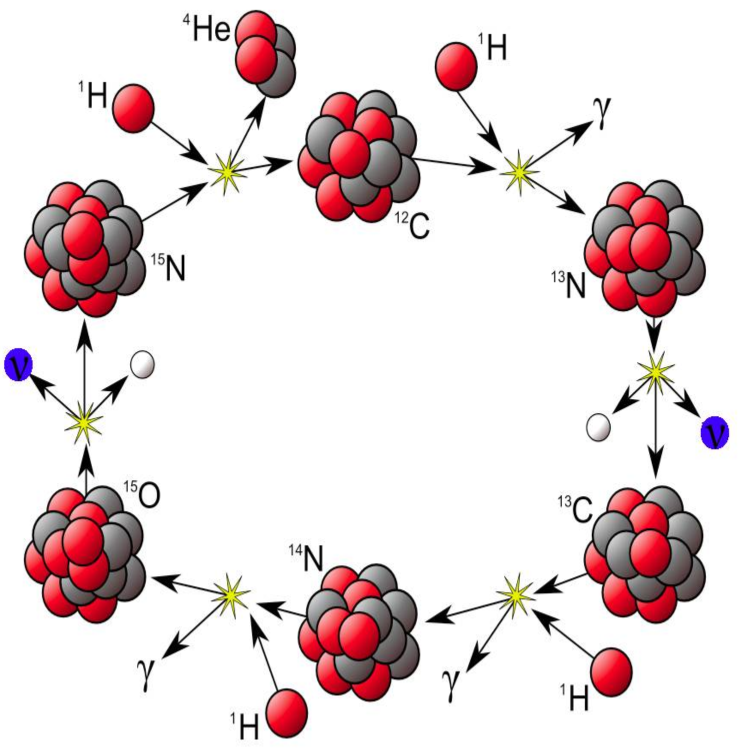
pep neutrinos:

directly related to the pp ν-flux, which has the highest contribution to the total ν-flux

Solar fusion processes: Part 2

CNO-cycle

Invented by H. A. Bethe 70 years ago



- *In our Sun:*
  pp-chain is the dominating process

- *Theoretical expectation for the Sun:*
  CNO: 1.5% of solar ν- luminosity

Nuclear reactions:

$^{12}C + p \rightarrow {}^{13}N + \gamma$

$^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

$^{13}C + p \rightarrow {}^{14}N + \gamma$

$^{14}N + p \rightarrow {}^{15}O + \gamma$

$^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

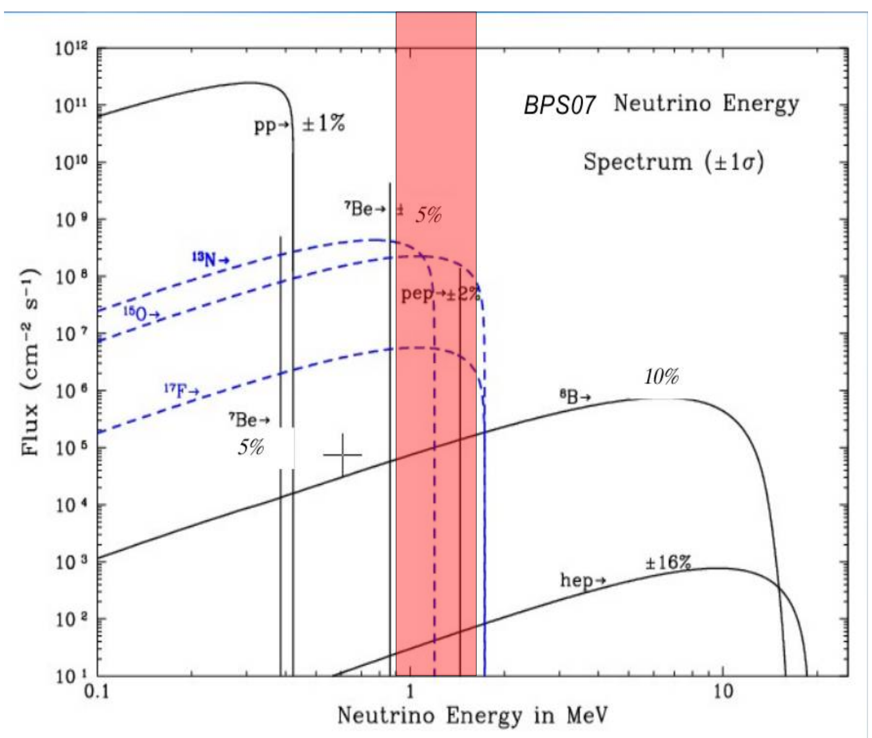
$^{15}N + p \rightarrow {}^{12}C + \alpha$

Overall reaction (as for pp-chain):

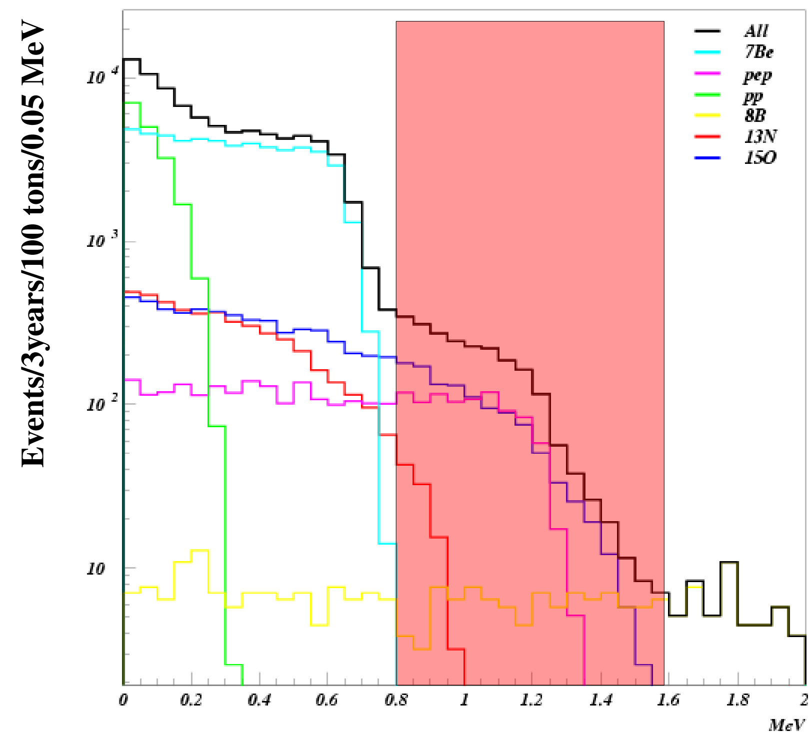
$4p \rightarrow \alpha + 2e^{+} + 2\nu_e + 26.7 MeV$

Detection of pep and CNO neutrinos with Borexino

Theor. pred. solar neutrino fluxes



Expected detection signiture in Borexino



3 years statistics in 100 tons of scintillator

Removal of backgrounds

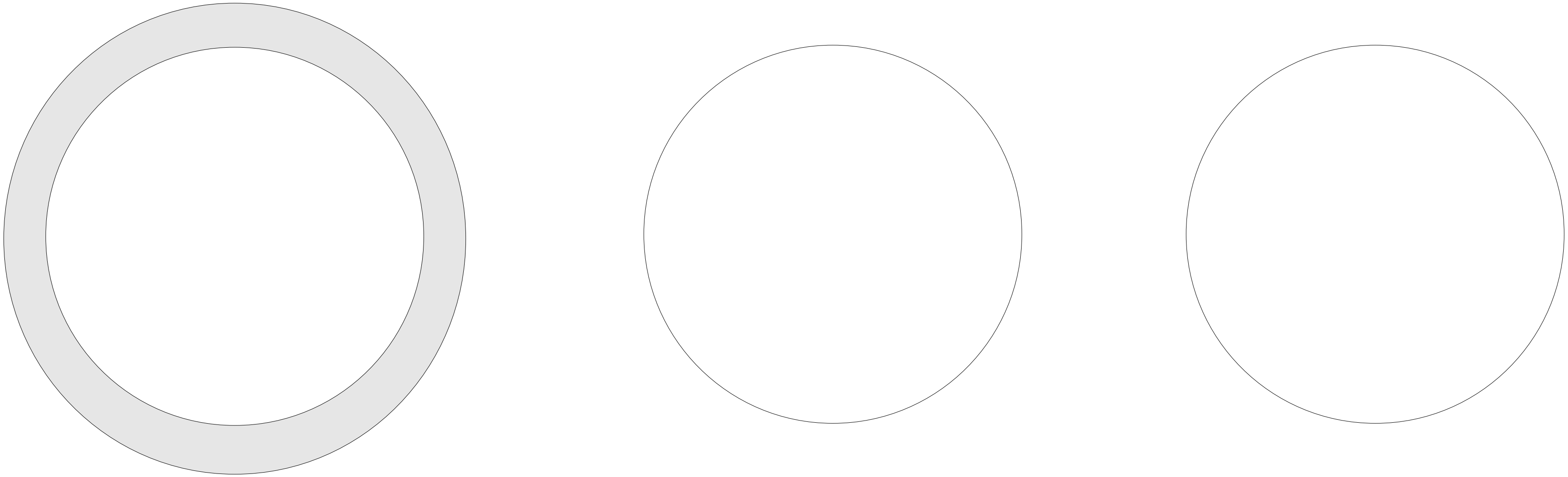
Expected rate for combined fluxes of
pep & CNO neutrinos in energy-window [0.8, 1.4] MeV: ~ 1.5 cts/(d*100 ton)

Backgrounds in [0.8, 1.4] MeV:

1. Gamma-radiation from IV and outer parts of the detector
2. Short lived cosmogenic radionuclids
3. Longlived cosmogenic ^{11}C: <u>Main background!</u> Rate:

Techniques

1.



i) Space: Radial cut->Fid.Vol.
ii) Time: For all live time

Removal of backgrounds

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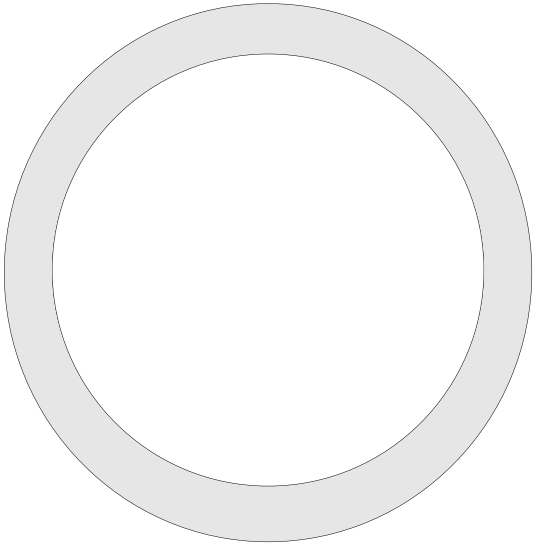


i) Space: Radial cut->Fid.Vol.
ii) Time: For all live time

2.

i) Space: All Fiducial Volume
ii) Time: very short (~sec), after each muon

Removal of backgrounds

Expected rate for combined fluxes of pep & CNO neutrinos in [0.8, 1.4] MeV: ~ 1.5 cts/(d*100 ton)

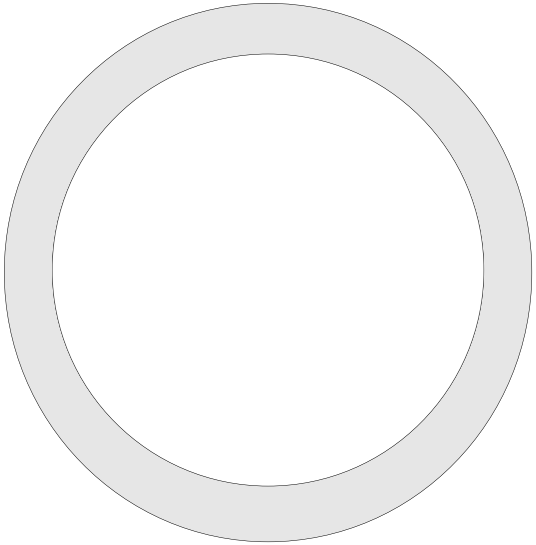
Backgrounds in [0.8, 1.4] MeV:

1. Gamma-radiation from IV and outer parts of the detector
2. Short lived cosmogenic radionuclids
3. Longlived cosmogenic ^{11}C: Main background! Rate: ~ 13 cts/(d*100 ton)

S/B ~1/9

Techniques

1.



i) Space: Radial cut->Fid.Vol.
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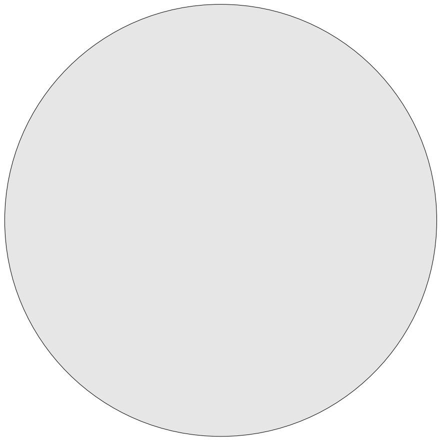
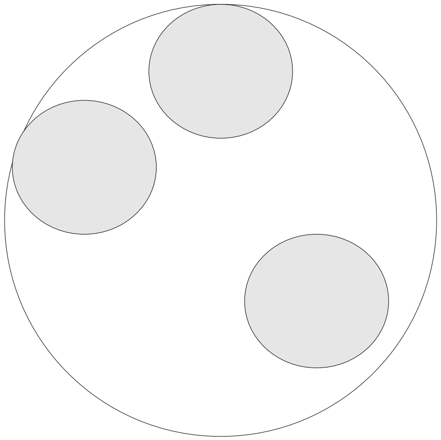


i) Space: All Fiducial Volume
ii) Time: very short (~sec), after each muon

3.

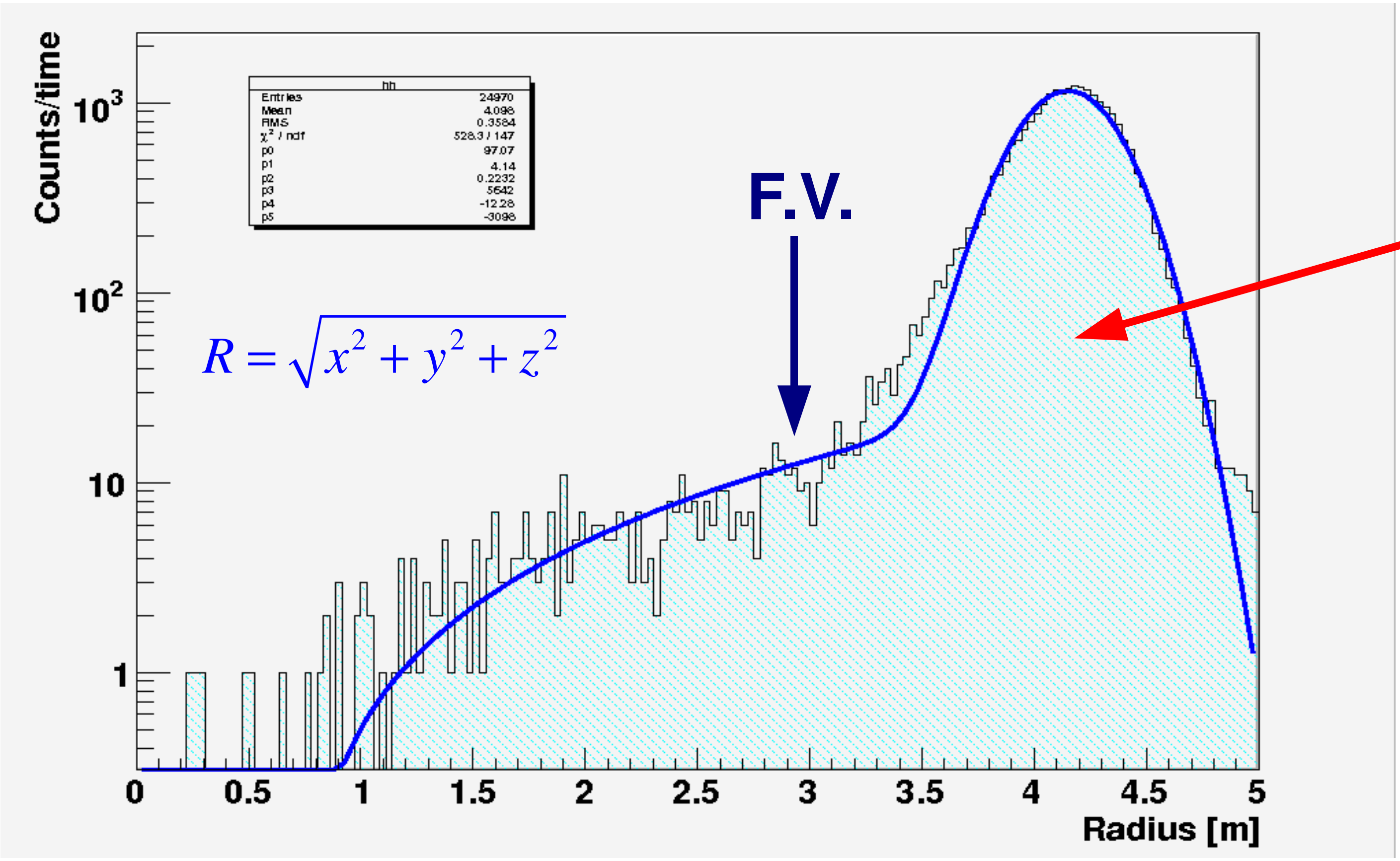


„3-fold-coincidence“

i) Space: rel. „Small spheres“
ii) Time: rel. long (up to hours)

External Background

Radial distribution of neutrino-like-events in the energy-window [0.8, 1.4] MeV



Contamination from nylonvessel and gamma radiation from outer parts of detector (i.e. SSS and PMTs)

Fiducial volume cut: (F.V.) Examples:

1. R<2.5m → Targetmass: 57.3 tons
2. R<3.0m → Targetmass: 99.1 tons
3. R<3.5m → Targetmass: 157.3 tons

Short-lived cosmogenics

Definition: Muoninduced radioisotopes = „cosmogenics“

Isotopes	τ	Q [MeV]	Decay	σ [μbarn]	E_μ [GeV]
Short-lived ($\tau < 2s$)					
^{12}B	0.03 s	13.4	β^-	$\sim$4500	320
^{9}Li	0.26 s	13.6	β^-	<2	190
^{8}Li	1.21 s	16.0	β^-	5	320
^{8}He	0.17 s	10.6	β^-	<2	190
^{6}He	1.17 s	3.5	β^-	23	320
^{9}C	0.19 s	16.5	β^+	5	190
^{8}B	1.11 s	18.0	β^+	11	320
Long-lived ($\tau > 2s$)					
^{7}Be	76.9 d	0.9	β^+	373	320
^{11}Be	19.9 s	11.5	β^-	<2	190
^{11}C	29.4 min	2.0	β^+	1303	320
^{10}C	27.8 s	3.6	β^+	159	320

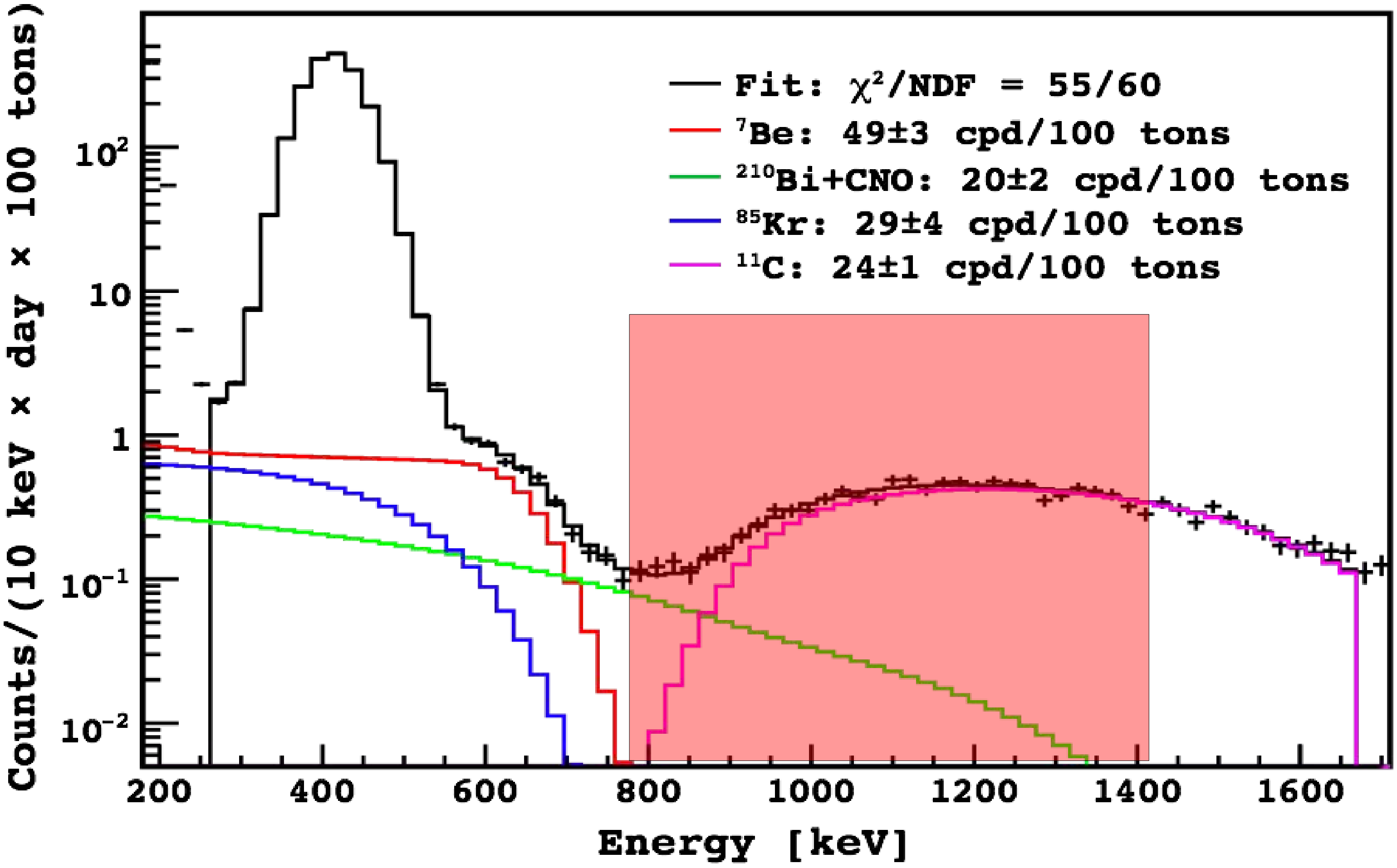
Muonrate in Inner Vessel: **~1muon/20sec**

Example for timecuts after each muon to reduced shortlived cosmogenics

Δt = 5sec → 4.3 τ (^{6}He) → Efficiency: 98.7 %

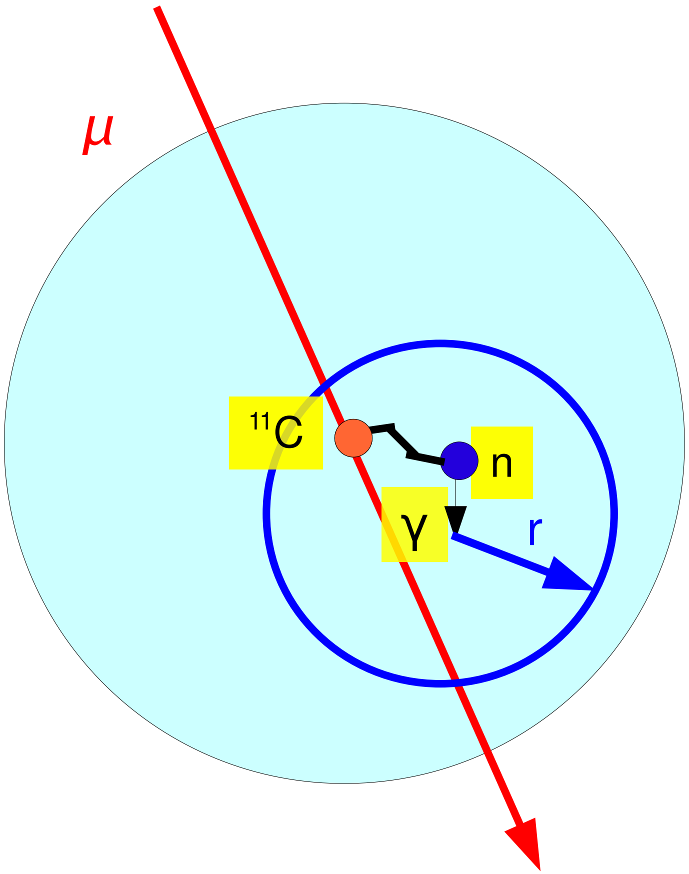
→ Loss of statistics: ~25 %

Muoninduced ^{11}C



^{11}C: Threefold coincidence

Tagging of ^{11}C via a **threefold-coincidence:**



Reactions involved:

1. Muons-interaction:

muon, which passed ID, can create ^{11}C by interaction with the scintillator:

^{11}C: $\mu + {}^{12}C \rightarrow {}^{11}C + n + \mu$

(95% of ^{11}C is produced on this way!)

2. Neutron captured by protons:

$n \rightarrow \gamma$ (2.2 MeV)

$\tau \sim$ (260-270) μsec

3. ^{11}C-decay:

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

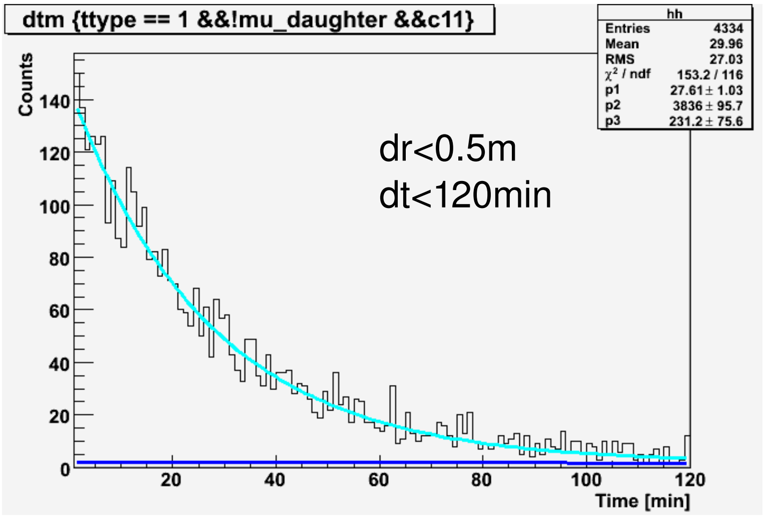
τ = 29.4 min

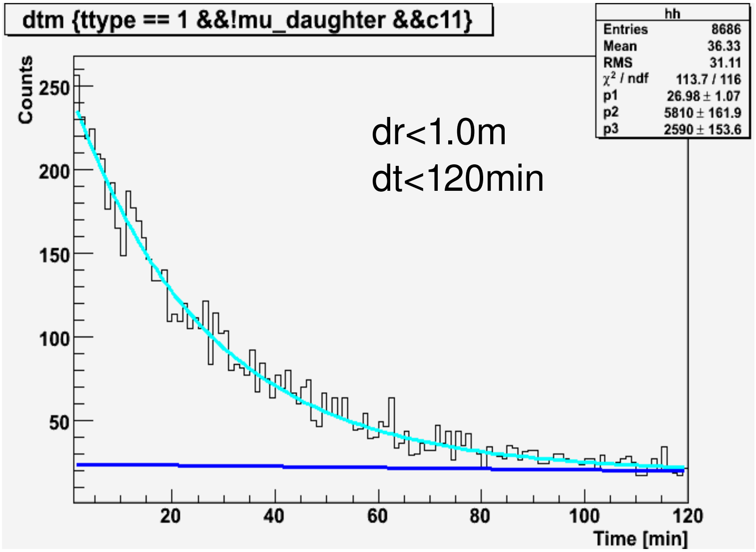
$E_{\beta\ min}$ = 0.96 MeV; $E_{\beta\ max}$ = 1.98 MeV

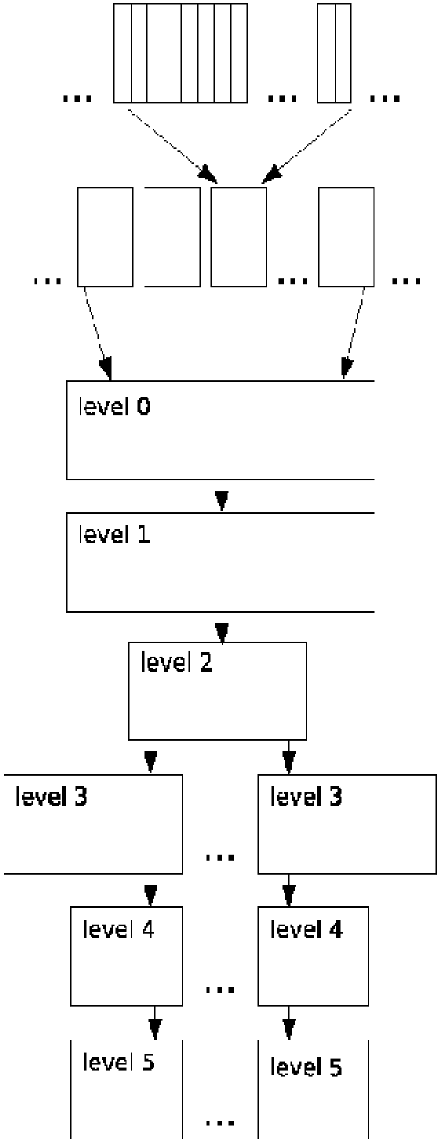
Goals: 1. Define the spectral shape of the ^{11}C
2. Remove the tagged ^{11}C from the global energy spectrum

→ Optimisazion of time-volume-cuts

^{11}C: Selection of optimal cuts







Processed single Runs (typical run duration: 6 h)

DST-Rootfiles (one/week)

Initial data-set: Selection of events of interest in a given timeperiod

Tagging of aftermuons

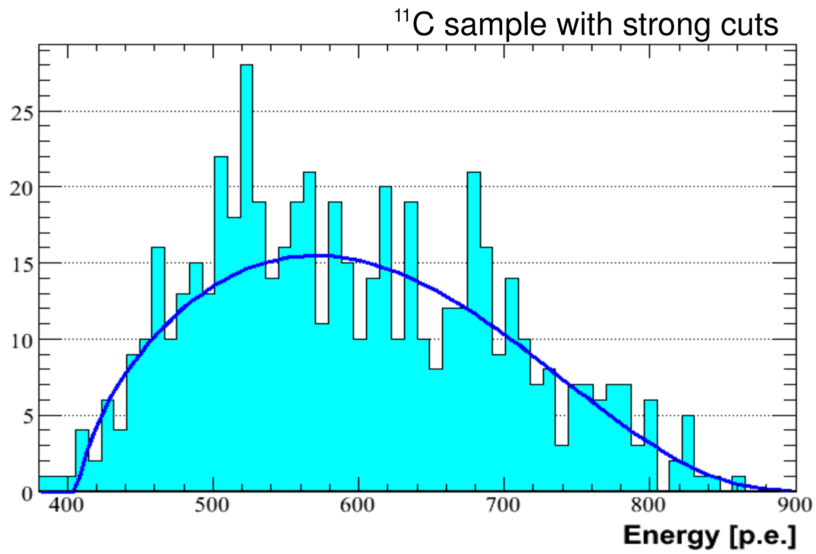
Rejection of muons

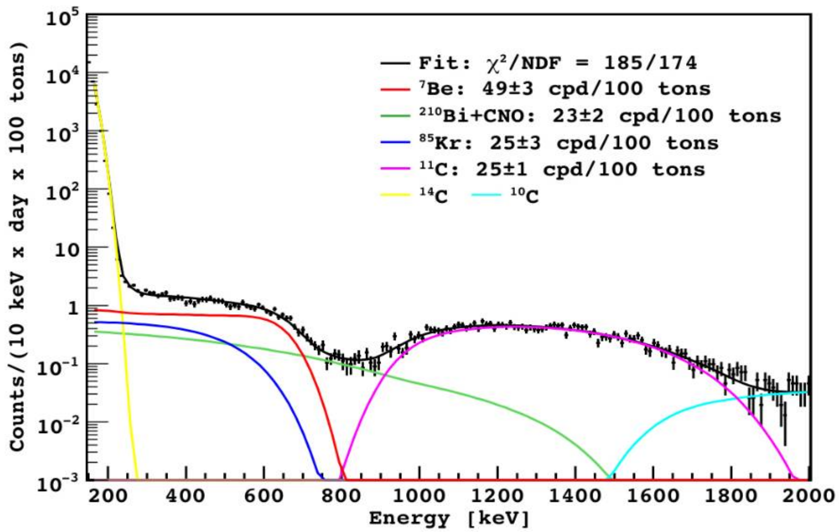
Tagging of 11C (application of different time-volume-cuts)

Rejection of muon daughters and neutrons

Estimation of 11C-multiplicity

^{11}C tagging: preliminary results





^{11}C-Rate estimated via 3-fold-coincidence:

Rate without corrections of efficiencies:

R = (20.2 +/-1.5) cts/d/100ton

Correcting for the efficiencies:

- 3-fold-coincidence: 0.95
- time-cut in ^{11}C-tagging: 0.92
- hardware-time-cut of neutrontrigger: 0.94
- cluster-efficiency of neutrontrigger ξ: unknown

R_{tot} = (24.5 +/-2.0) cts/d/100 ton/ξ

^{11}C rate estimated from global fit of the energy spectrum:

R_{tot} = (25 +/-2$_{stat}$ +/-2$_{syst}$) cts/d/100 ton

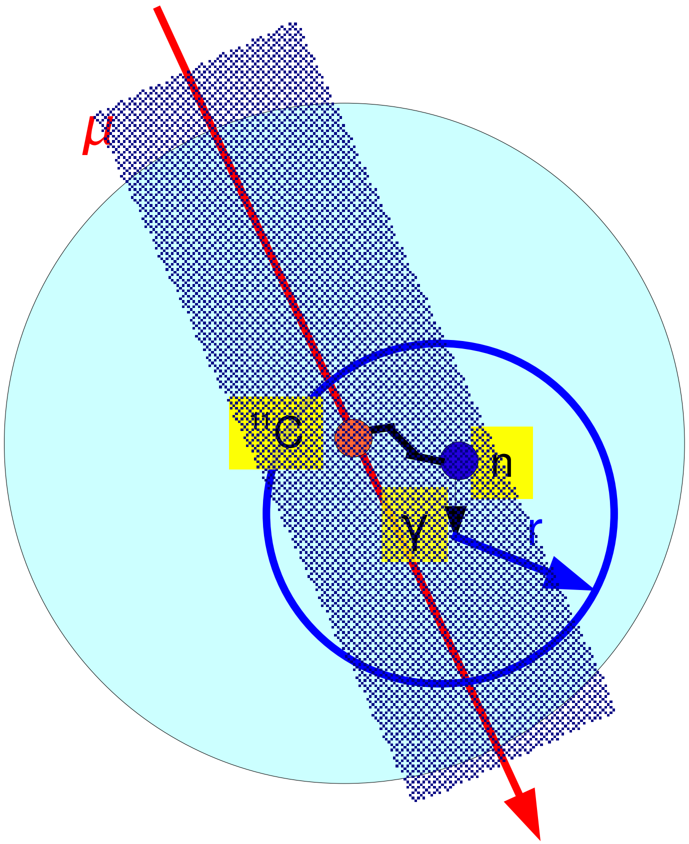
→ ^{11}C-Tagging-efficiency very high!

→ Cluster-efficiency of neutrontrigger might be also very high!

Muontrack: Improving 3-fold coincidence

Improvement in tagging ^{11}C:

threefold-coincidence combined WITH muontrack-reconstruction

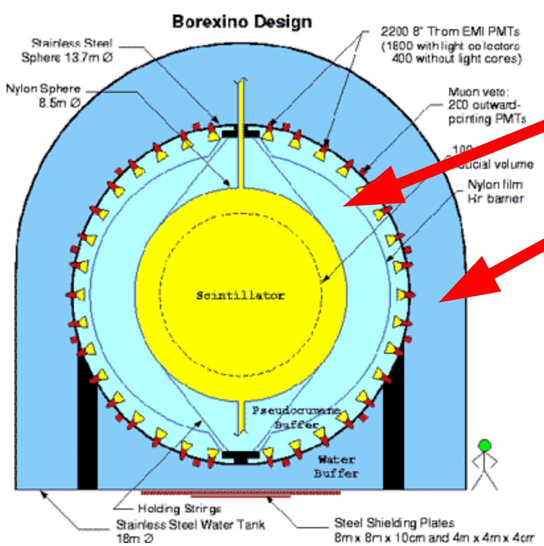


Spherical time-volume cut overlapping with cylinder around reconstructed muontrack

1. **Detect the 11C via threefold-coincidence**
2. **Define the muontrack of associated muon**
3. **Overlap of muontrack-tube with spherical time-volume cut**

→ *Loss of statistics is reduced !*

Muontracking: reconstruction of points

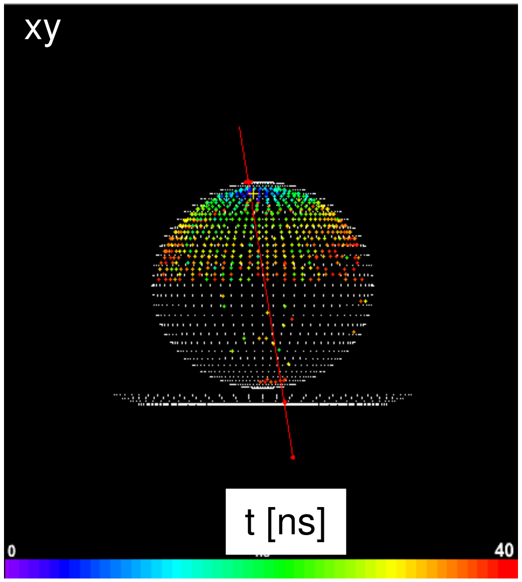


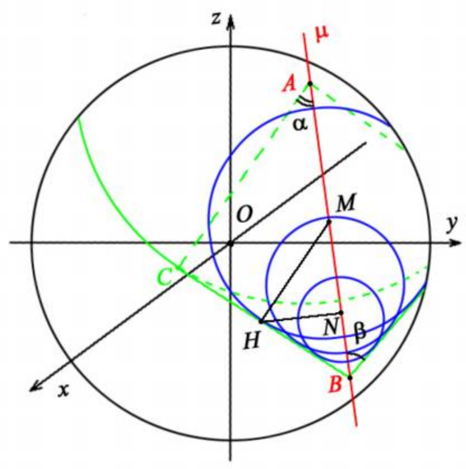
Inner Detector

Outer Detector

Techniques:
- Charge-information (only for Outer D.)
- TOF-information

Number of reconstructed points (ideal case):
- One entrypoint in Inner D., Outer D. each
- One exitpoins in Inner D. and Outer D. each
- A new point is going to be implemented:
  → 2^{nd} algorithm for the exit point in the Inner D.





Scheme of model

Example: 2^{nd} algorithm for exit point in Inner D.
- use TOF-information of propagating scintillation light
- needs information of reconstructed entry points
- Deduce recursively the exit-point for given TOF-profil assuming the illustr. model

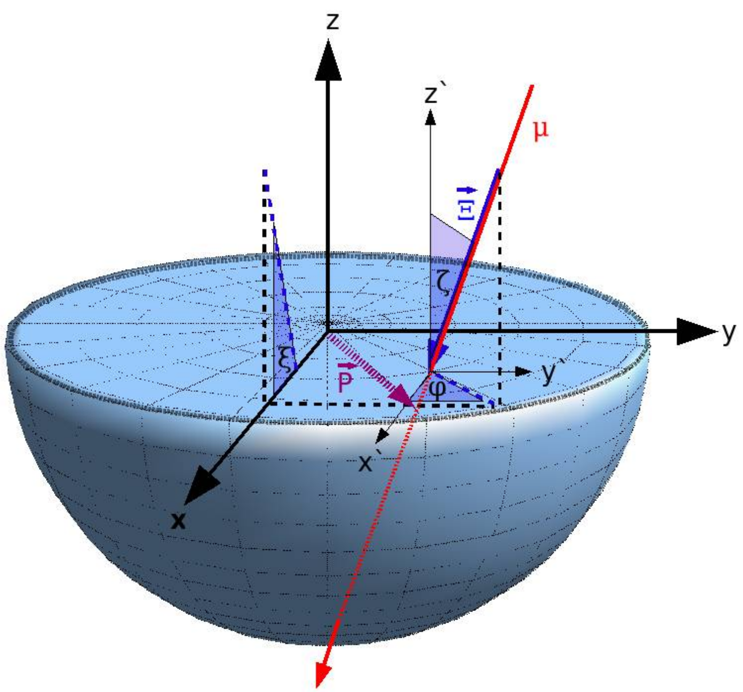
Muontrack: Global fit

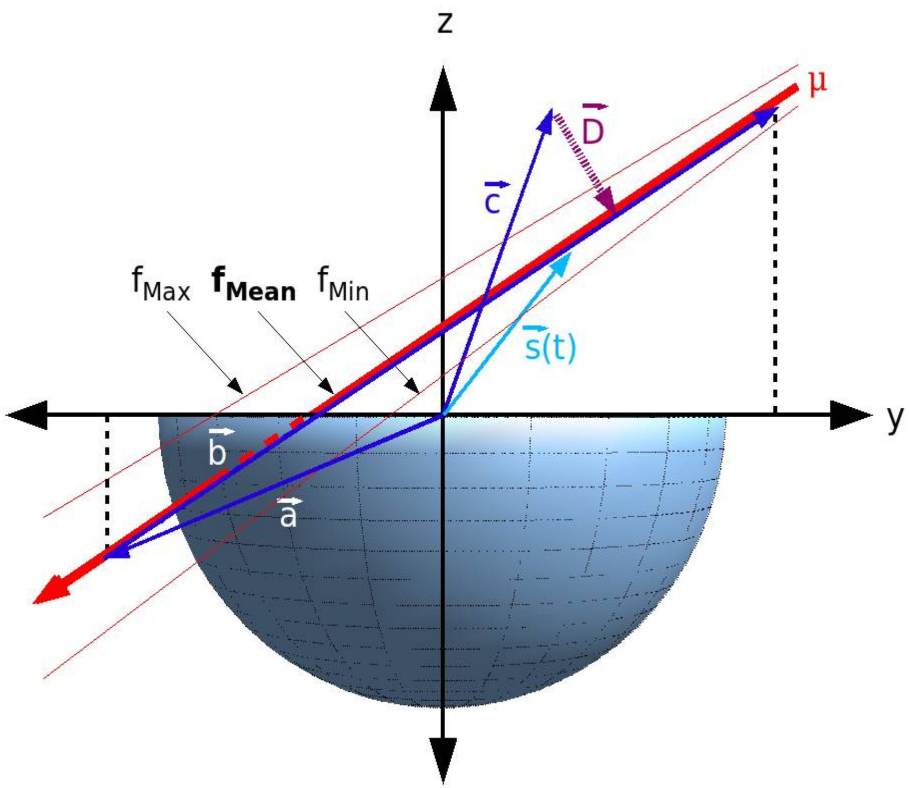
1. part of algorithm:

3D-Fitting through reconstructed muontrack points, which have 3D uncertainties

2. part of algorithm:

Calculation of distance from global muontrack fit to an arbitrary position in the Inner Detector



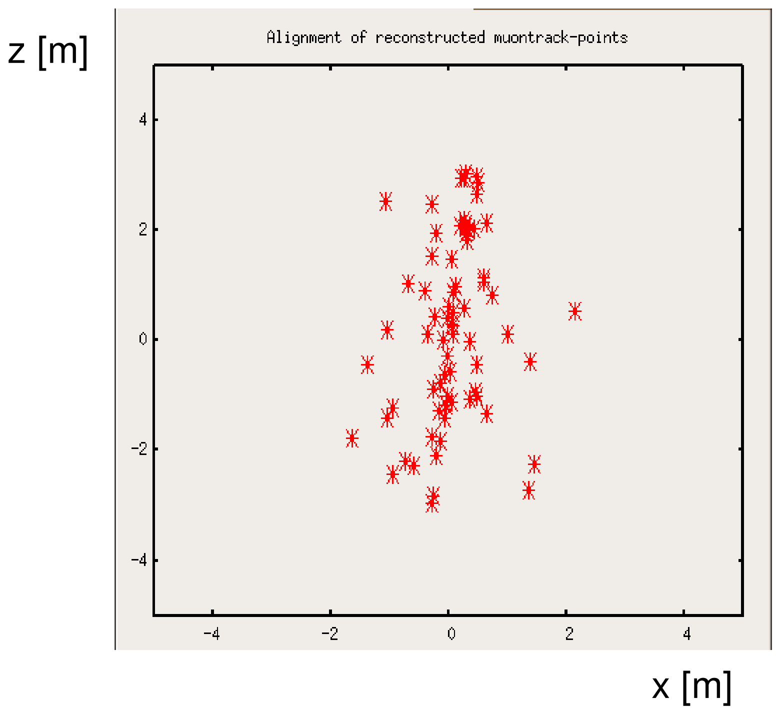


Testing muontrack: methods & examples

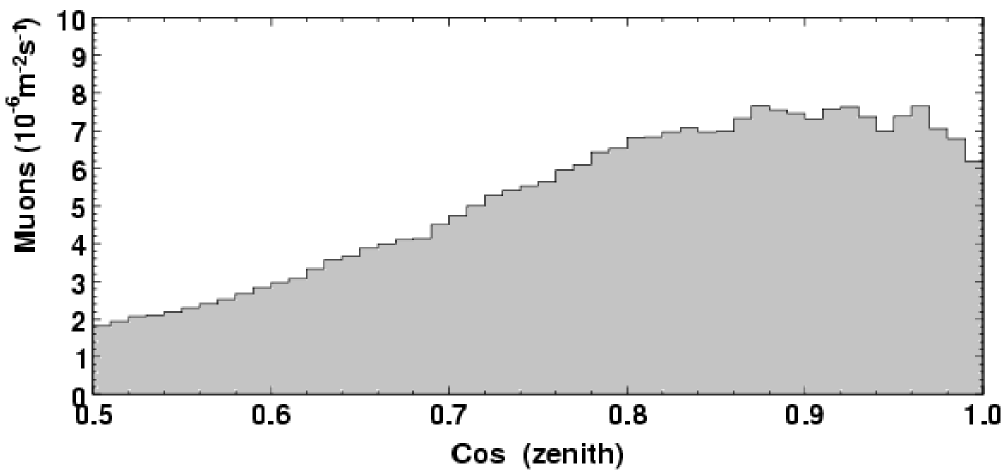
Strategies:

1. Goodness of fit (χ^2/n.d.f.), (<u>event by event</u>)
2. ^{11}C-burst/neutron-bursts: sometimes aligned around the muontrack
3. Calculation of distance of neutrons from tracks
4. Angular distribution of fitted tracks (<u>general behavior</u>)
5. Ultimative test: MC-simulation of all signal chain in O.D. and I.D.

Example:
^{11}C-burst



Example:
Angular distribution: cos(τ), where $\tau \equiv$ zenith-angle



(Very similar to results from MACRO)

Conclusions & Outlook

- Borexino has the potential to detect solar pep and CNO neutrinos

- Impact on solar physics, astrophysics, cosmology

- Requirement for successful pep and CNO neutrino analysis

- High statistics (several years)
- Identification and subtraction of different backgrounds

- Main background ^{11}C

- The 3-fold coincidence method is a powerful method to reject the main background
- Improvement of this method via inclusion of muontrack-reconstruction (loss of statistics reduced)

- Status of our work

- Study and defininition of optimal cuts for shortlived and longlived cosmogenics: on-going
- Study of muons, muoninduced neutrons, ^{11}C and other cosmogenics: on-going
- Finalisation of tests of the muontrack-reconstruction: on-going
- Combination of all information to obtain the pep and CNO neutrino flux: in near future