BDX tests

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- Cosmogenic background
- Results from MC simulations
- Measurements @ LNS-CT

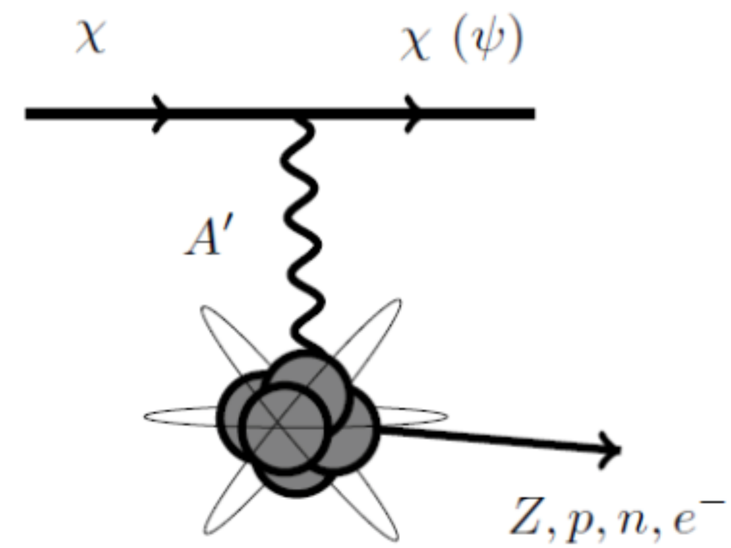
What next LNF: Perspectives of fundamental physics at the Frascati Laboratory

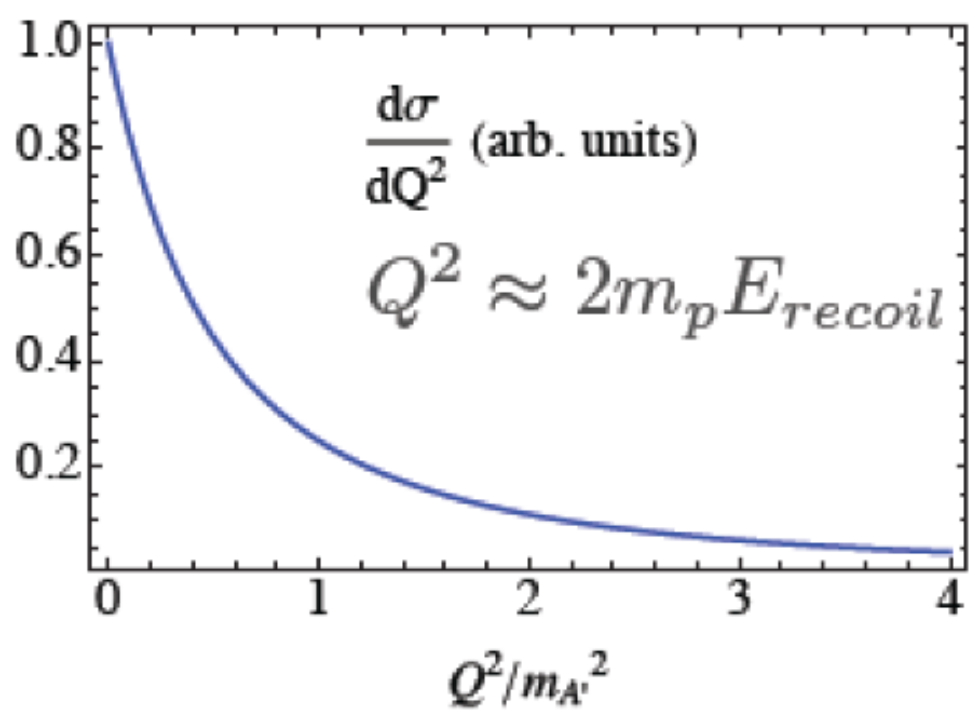
10-11 November 2014 *INFN - Laboratori Nazionali di Frascati*
Europe/Rome timezone

The cosmogenic background issue

ϰ detection: elastic scattering on nucleon

ϰ scatters elastically on a nucleon (p) in the detector producing a visible recoil (~ MeV)





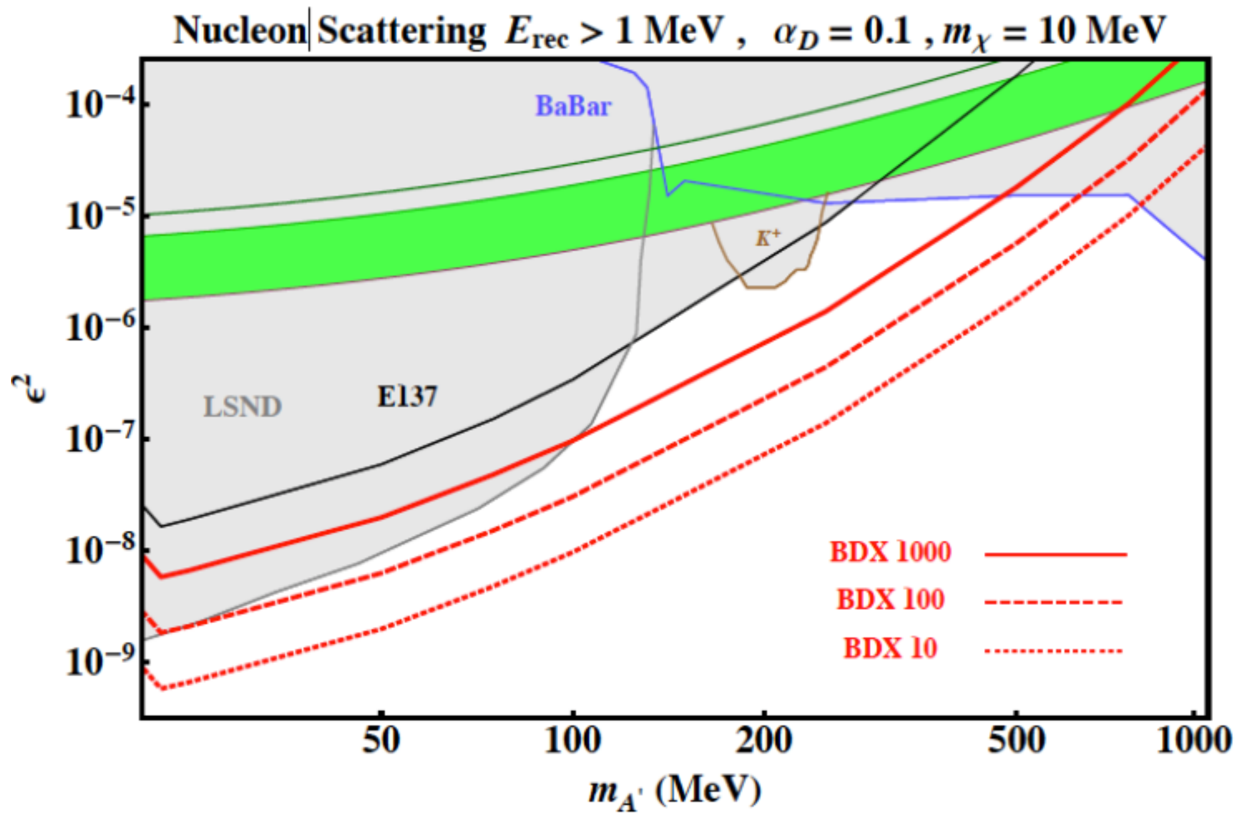
Experimental requirements:

- Sensitivity to ~ MeV nucleon recoil (low detection thresholds)
- Low energy backgrounds rejection capability

The cosmogenic background issue

Backgrounds matter !

Particles that mimic the $\varkappa$ interaction in the detector producing a low energy signal limit the BDX reaches



Beam-related background **see R. De Vita talk**

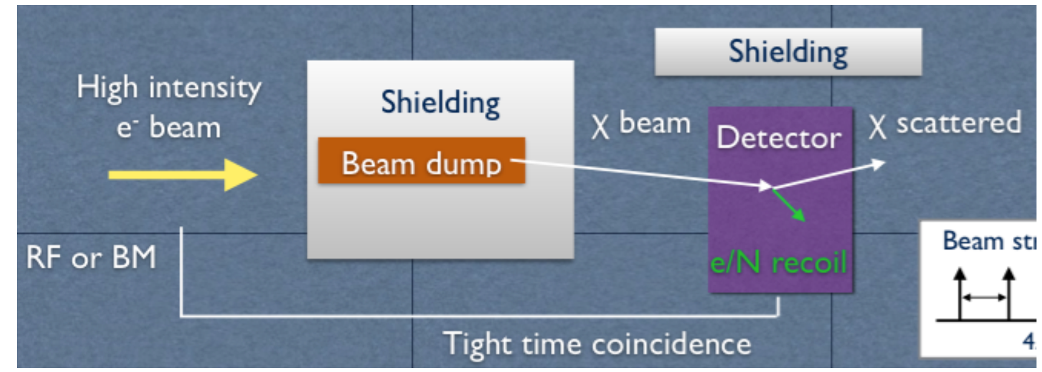
Cosmogenic background is the main limiting factor

Beating down the cosmogenic background is crucial for BDX

Reducing cosmogenic background

Time correlation

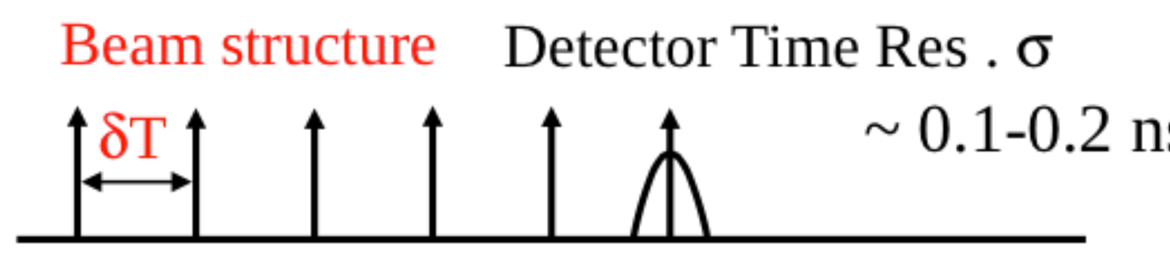
Beam-uncorrelated background can be rejected by requiring a time coincidence between the RF signal and the event recorded by the detector.



Continuous beam - time resolution is critical

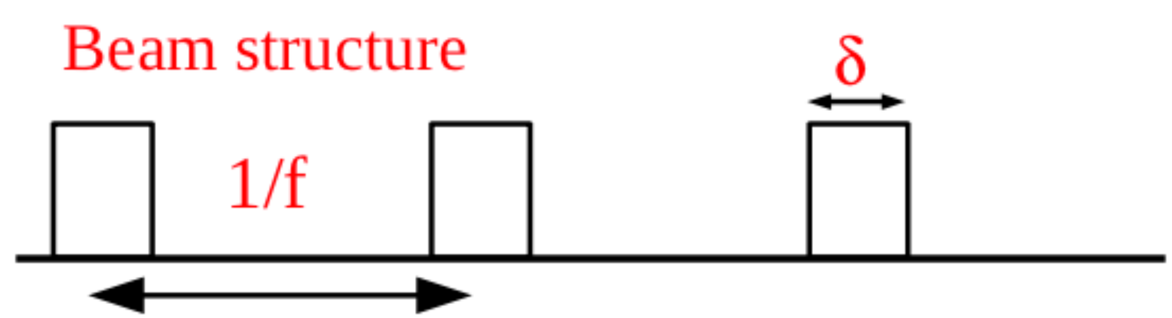
ment.

Reduction factor $R \simeq \frac{\delta T}{3\sigma} < \simeq 100$



Pulsed beam - allows to take full advantage of this technique

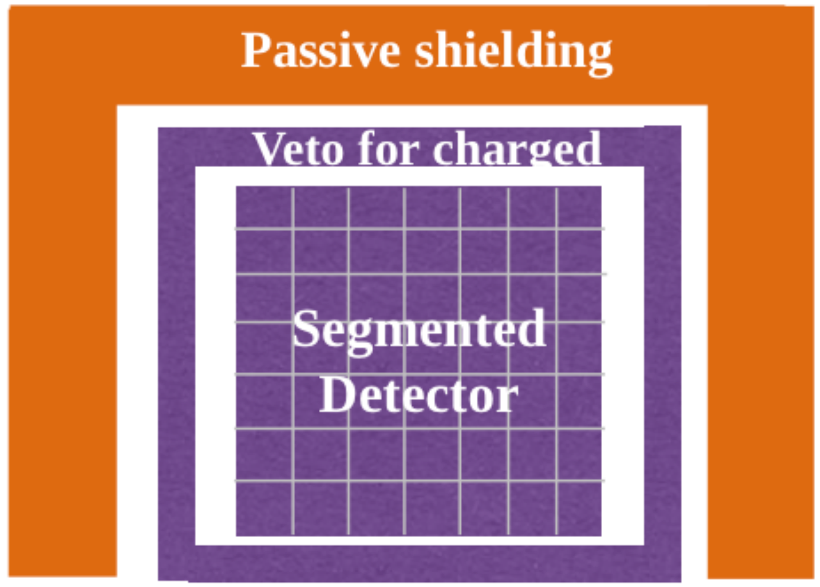
$$R = \frac{1}{f \cdot \delta} = 2 \cdot 10^5 @\, 50\, Hz, 100\, ns$$



significant reduction but not enough

Reducing cosmogenic background

Passive shielding + Active Veto



Passive shielding and active veto are crucial for reducing the cosmogenic background

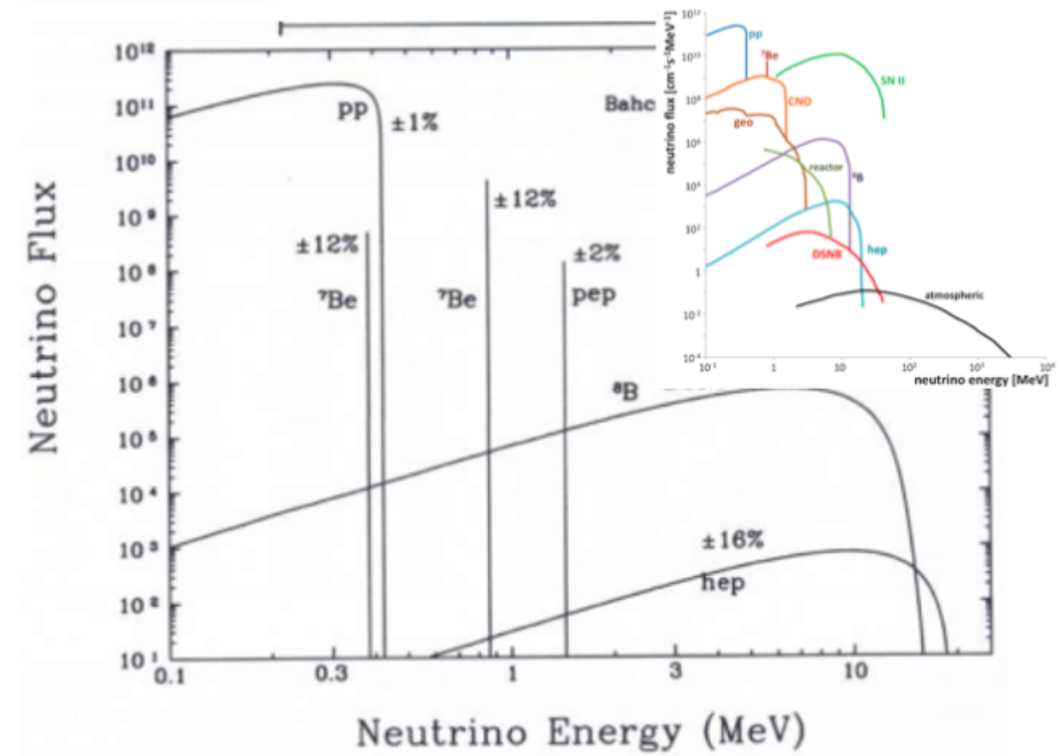
is BDX a feasible experiment ?

MC simulations to estimate cosmogenic background rates for different possible contributions (neutrinos, neutrons and muons)

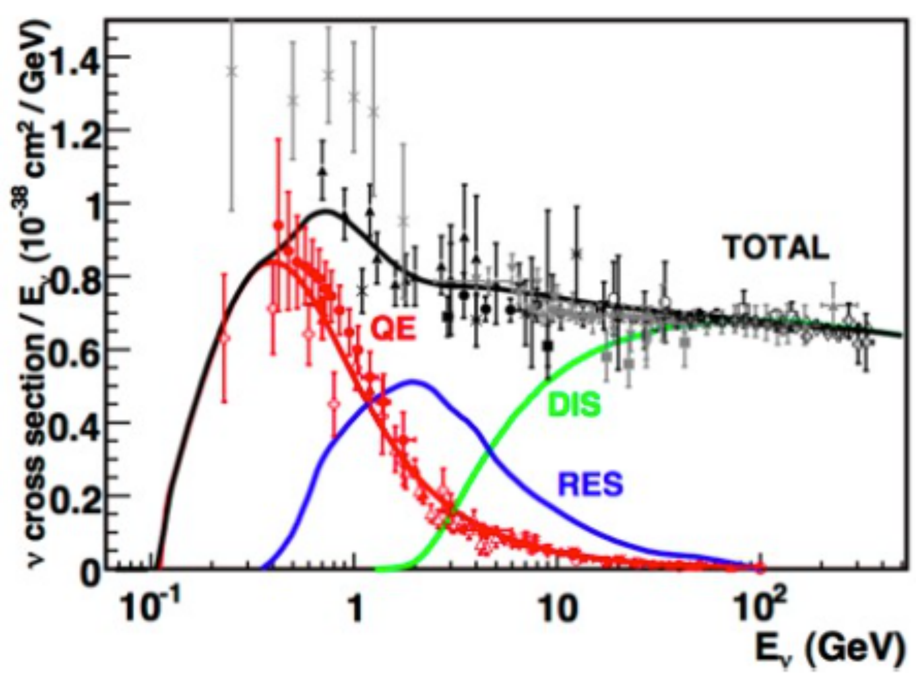
Beam un-related background

Neutrinos

Neutrinos can interact with protons in the detector mainly by inverse beta decay ($\bar{\nu} p \rightarrow e^{+} n$), producing a positron that could mimic a **ϰ** interaction.



Considering flux, interaction cross-sections and thresholds the contribution is **negligible**



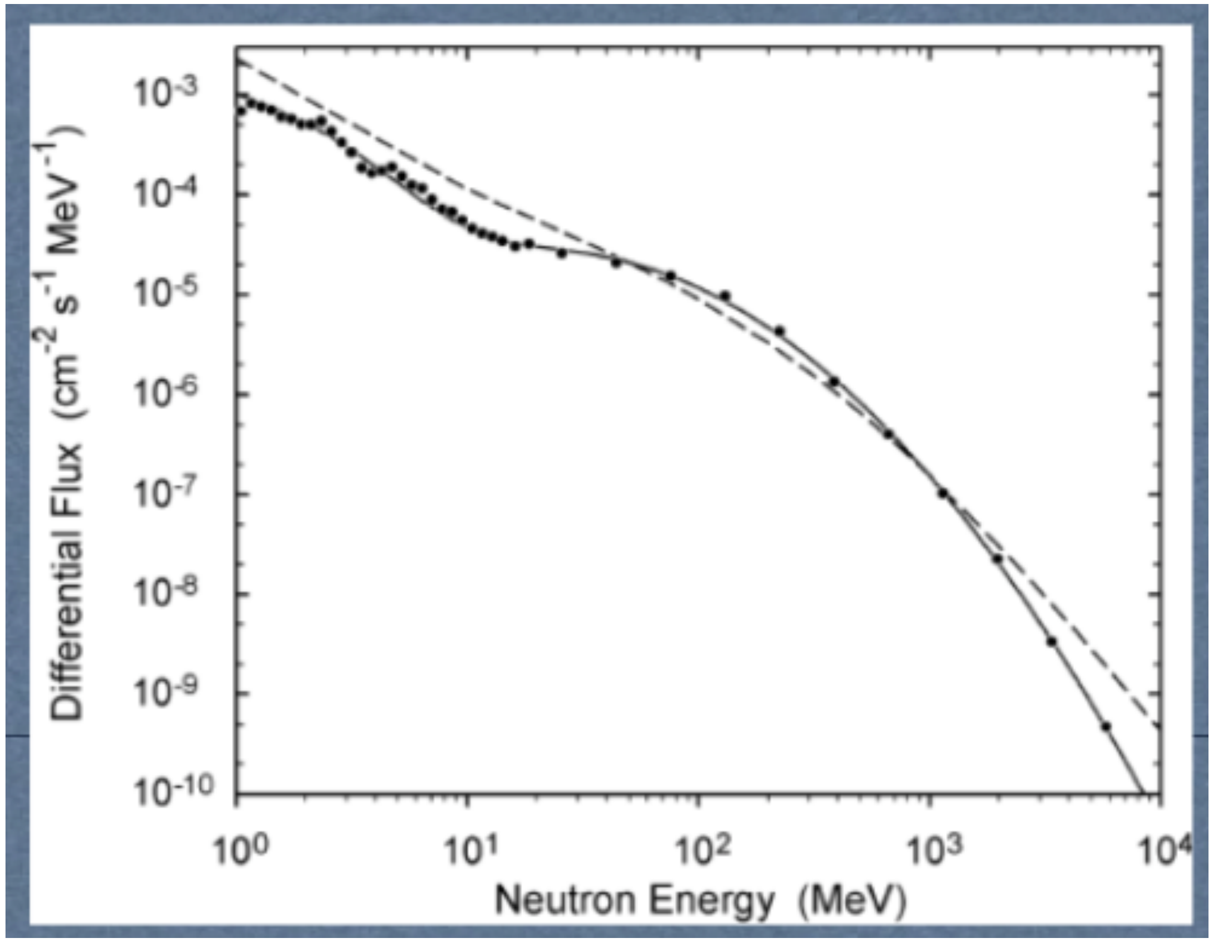
Beam un-related background

Neutrons

1 m iron shielding + 1 MeV detection threshold introduce an energy cut-off on the primary spectrum ~ 50 MeV

High-energy neutrons can penetrate the shielding and interact inside the detector, mimicking a $\varkappa$-N interaction

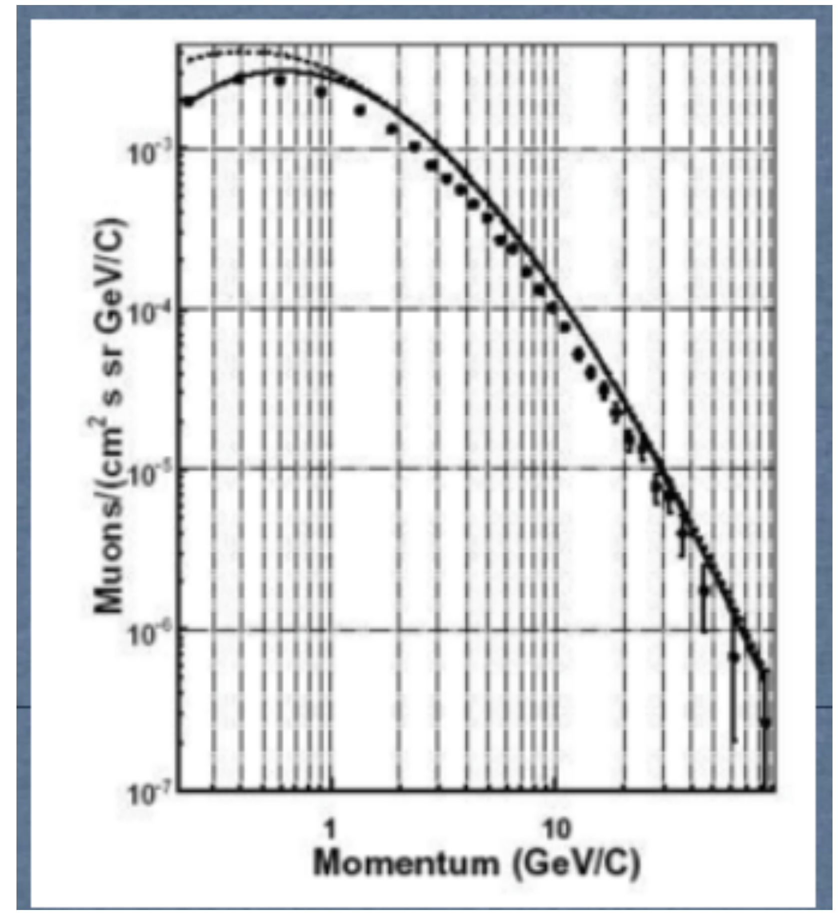
Contribution **sizeable**



Beam un-related background

Muons

1 m iron shielding + 5 cm thick lead suppress muons with momentum <1.45 GeV/c



Different contributions:

Crossing muons

Muons decaying inside the detector

Muons decaying inside the lead shielding

Some of them are missed by the veto due to detection inefficiencies

Contribution **sizeable**

Cosmogenic Background rates

Estimated background rates

http://arxiv.org/abs/1406.3028

	Rate $_{Thr=1\mathrm{MeV}}$ (Hz)	Rate $_{Thr=10\mathrm{MeV}}$ (Hz)
B-unrel ν	$2.0\ 10^{-6}$	$2.0\ 10^{-7}$
B-unrel neutron	$2.7\ 10^{-3}$	$0.6\ 10^{-3}$
Crossing muons	$3.3\ 10^{-3}$	$3.5\ 10^{-3}$
Captured μ^+	$1.4\ 10^{-3}$	$2.4\ 10^{-3}$
Decaying μ^- (CORM)	$2.9\ 10^{-3}$	$4.8\ 10^{-3}$
Stopped μ in lead	$7.0\ 10^{-3}$	$4.3\ 10^{-3}$
μ^- rare decay	$2.0\ 10^{-5}$	$8.0\ 10^{-6}$
Total Beam-unrelated bg	$1.7\ 10^{-2}$	$1.5\ 10^{-2}$

with some assumed quantities:

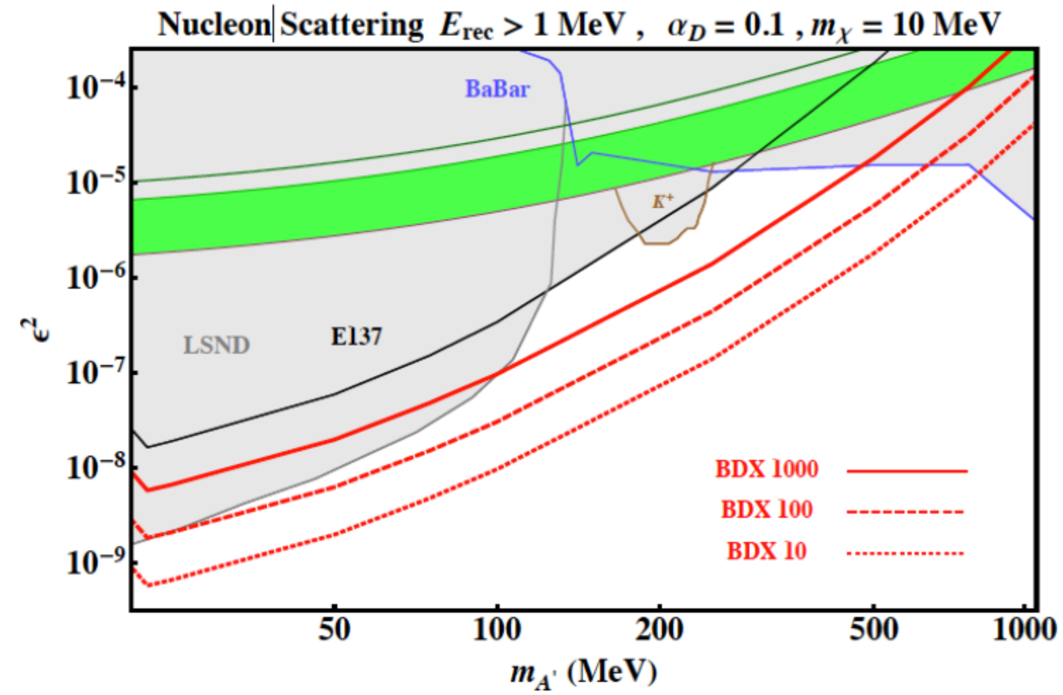
detection efficiencies

detector thresholds

veto inefficiencies

…..

1 ton detector, 10^{22} EOT



The estimated background rates suggest for BDX orders of magnitude better sensitivity to light dark matter than any previous experiment

these numbers are a key ingredient to predict the final BDX sensitivity: they need to be <u>experimentally proved</u>

Measurements at LNS

We are preparing a campaign of cosmogenic background measurements at LNS-CT

- Validate MC results
- Background vs energy threshold
- Test different veto solutions and measure detection efficiencies
- Optimize shielding
- Test the performances of plastic scintillators and different crystals (we are working on both options for the full detector design)

Plastic scintillator vs crystals

Heavy crystals has a density 5-8x wrt plastic (compact detector)
Easy EM shower detection (X-e- scattering channel)
Similar LY and Timing as for plastic

Physics: is the X scattering on a free N equivalent to a quasi-free on heavy nuclei ?
Detection: light quenching ?
Minimum proton momentum detectable ?

Considering LY, Timing, Cost, Availability …. Candidates for the LNS tests

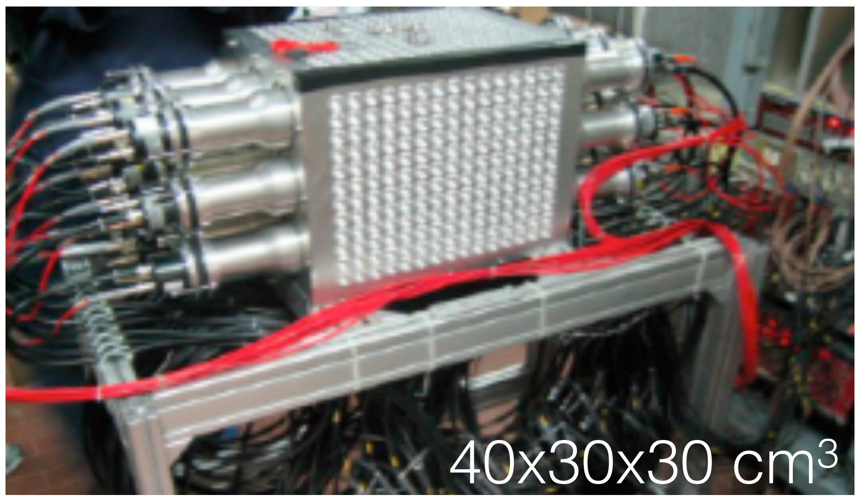
	PbWO	BGO Bi4Ge3O122	BSO Bi4Si3O12	LuAG:Ce	BaF2	CsI:Tl0.1%	Plastic
density (g/cm^3)	8.3	7.1	6.8	6.7	4.9	4.5	1
LY (N_γ/MeV)	120 (0.3 %NaI)	6 10^3 (15%NaI)	100/200/1.4 10^3 (0.25/0.5/3.4 %NaI)	8 10^3 (20 %NaI)	1.4 10^3/15 10^3 (3.4/36 %NaI)	75 10^3 (105/60 %NaI)	
Decay time (ns)	10	300	2.4/26/99	70	0.9/630	680/3340	1.8
Radiation length (cm)	0.9	1.12	1.15	1.4	2.03	1.85	42.5
Emission peak (nm)	420	480	480	530	220/300	565	410
Light Quenching (T_p=10MeV)		0.5	0.5			0.5	0.5
cost ($) 30x30x40$cm^2$	750k 450x (2x2x20)	crystals from L3	600k 600x (2x2x15)		540k 120x (10x10x20)	crystals from BaBar	9k 36x (5x5x30)
cost ($) 30x30x1000eq	2.25M L=1.2m	0.3M L=1.5m	2.4M L=1.5m		2.75M L=2m	0.3M L=2.25m *	0.3M L=10m
Full cost (cal+veto+shield)	2.5M	0.5M	2.6M		2.85M	0.5M	2.0M

* Reuse of 810 CsI(Tl) crystals from BaBar the instrumented volume would be 60x45x225 cm3

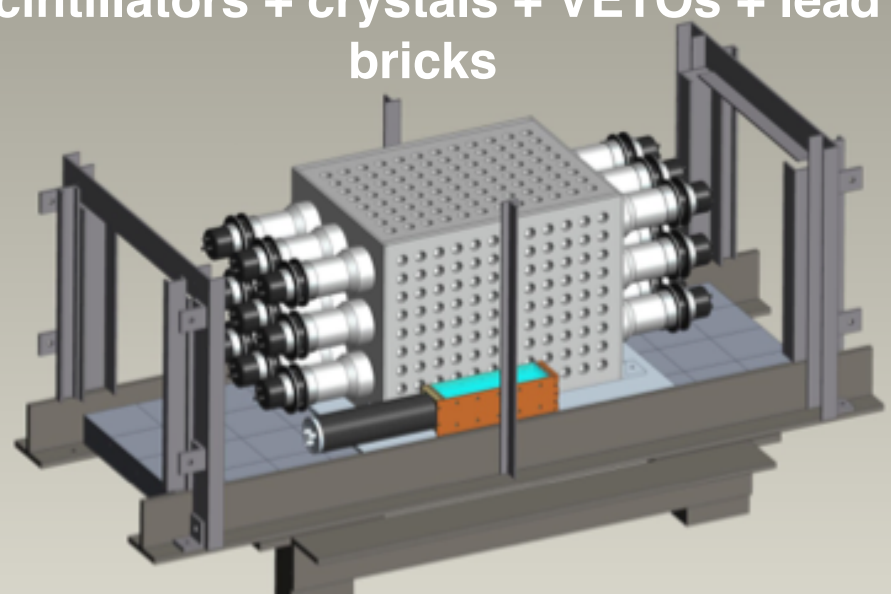
Experimental setup: inner detector

Different solutions for the inner detector will be tested

Plastic scintillator (NE110) bars
read at both ends by PMTs



Mechanical support for plastic scintillators + crystals + VETOs + lead bricks



V. Vigo, F. Parodi

Crystals

CsI (Tl) from BaBar

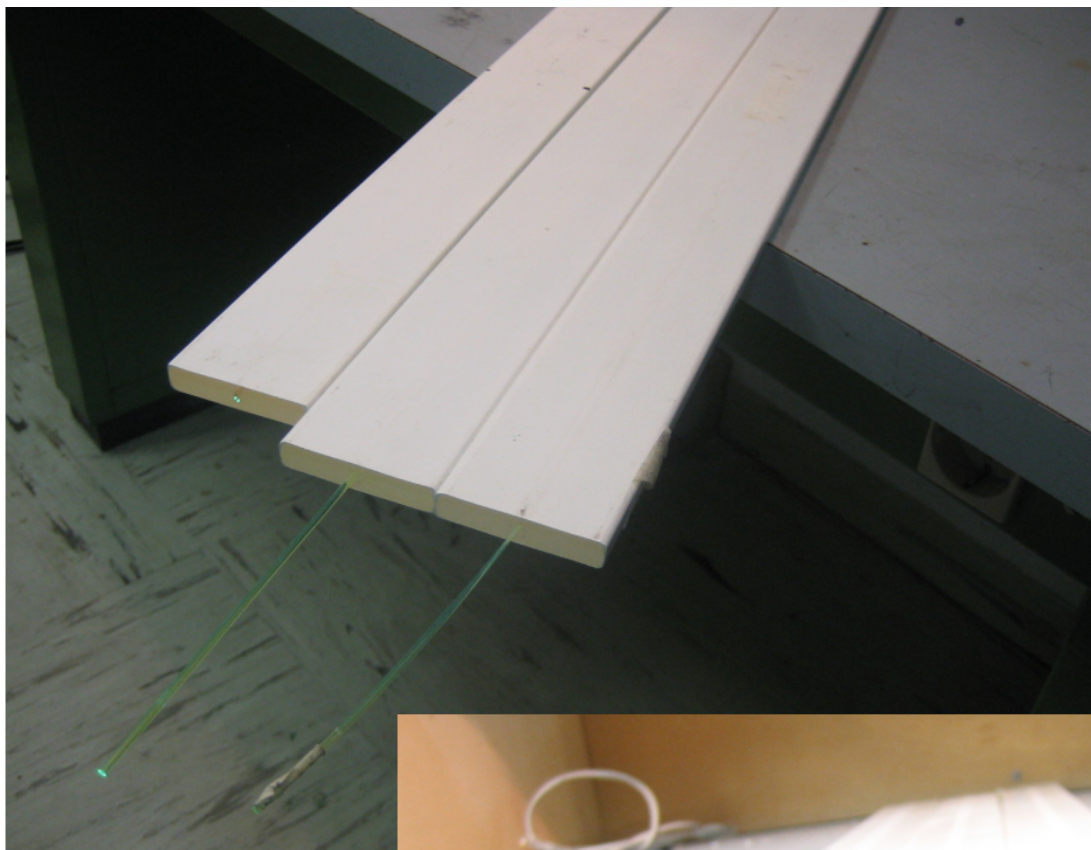
BSO-BGO

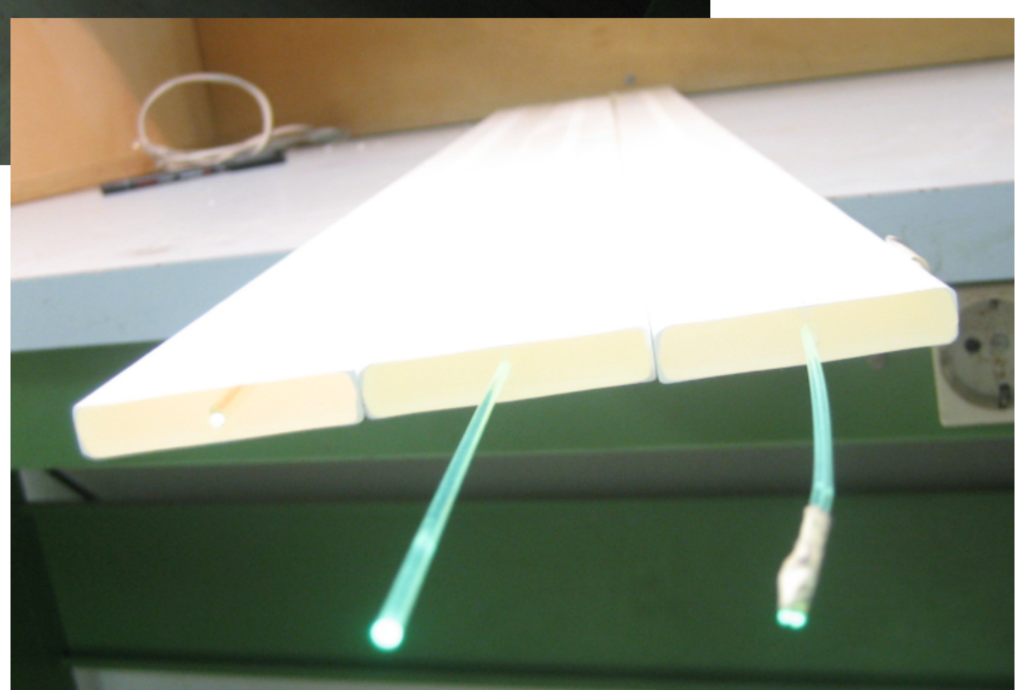
LuAG:CE

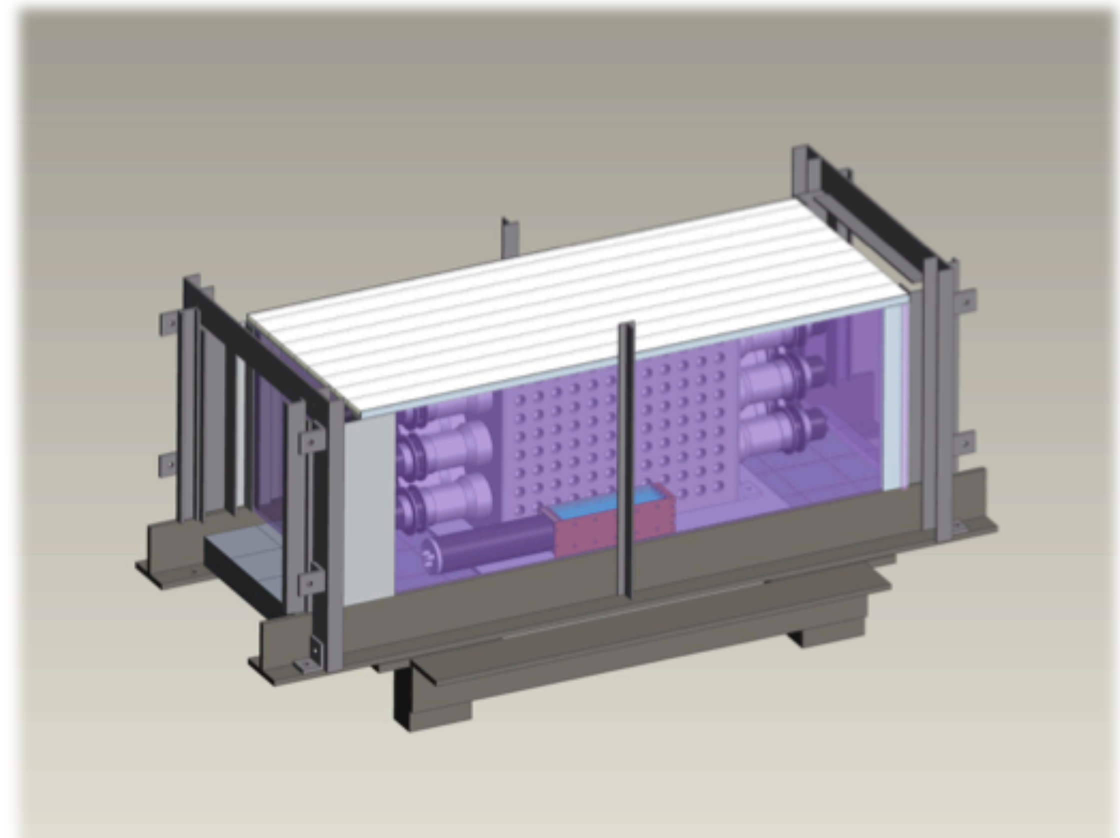
Experimental setup: inner veto

Active veto between the inner detector and the lead shielding

extruded plastic scintillator paddles + WLS fibers + single sipm readout

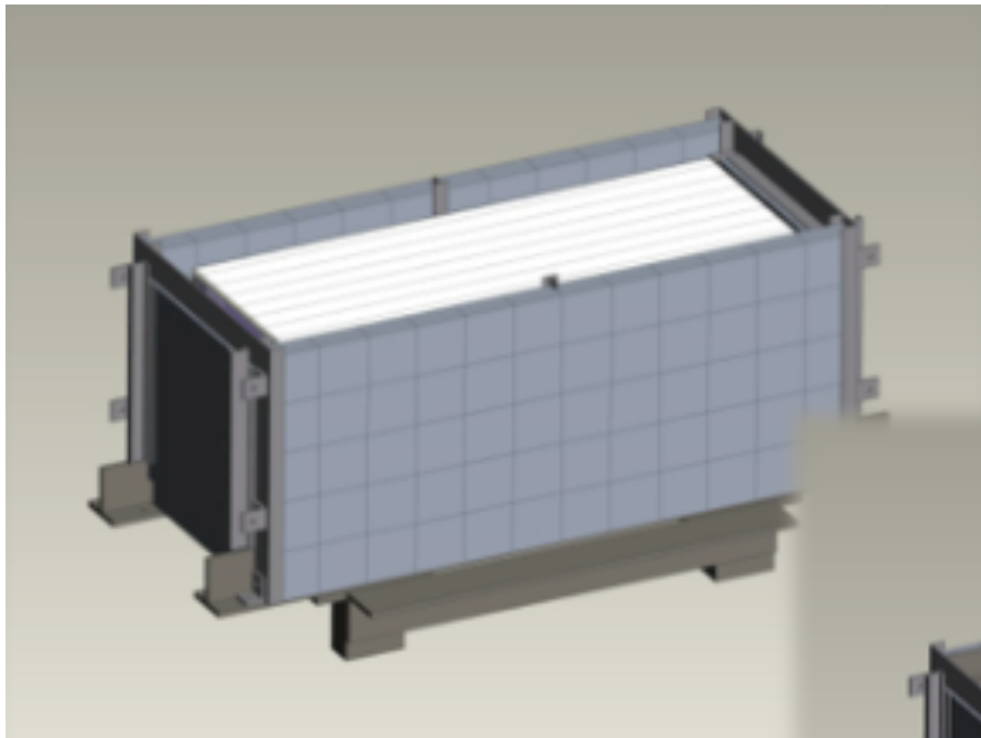


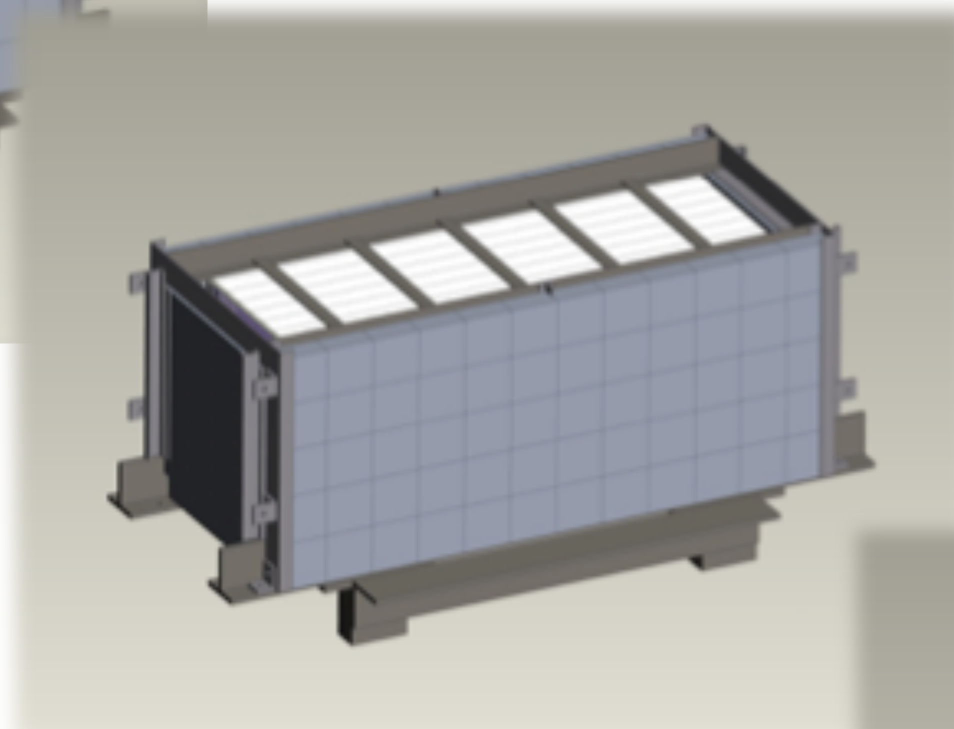


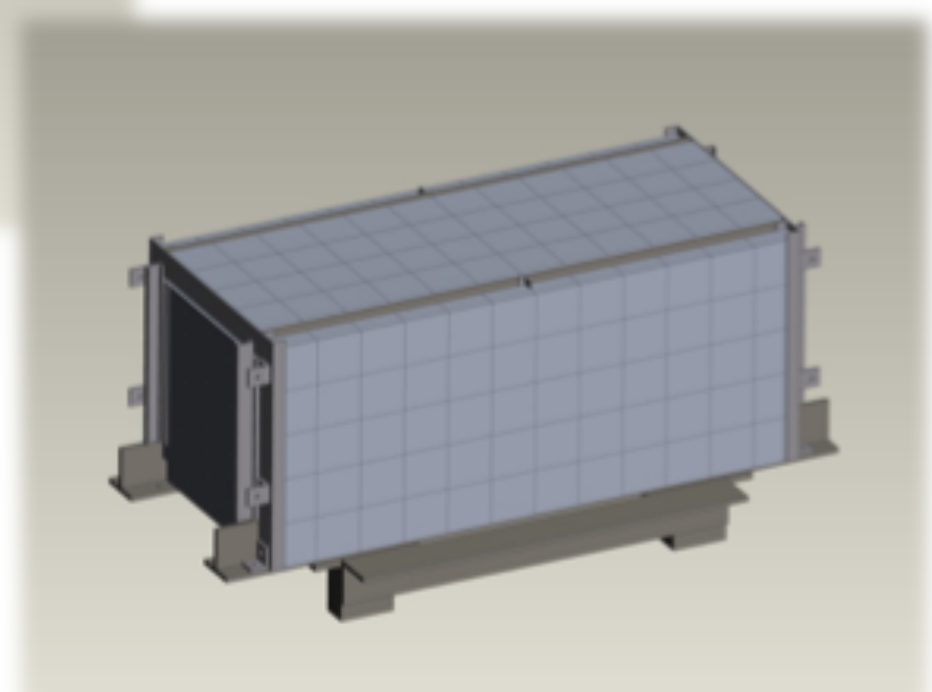


Experimental setup: passive shielding

Passive shielding 5cm-thick lead bricks

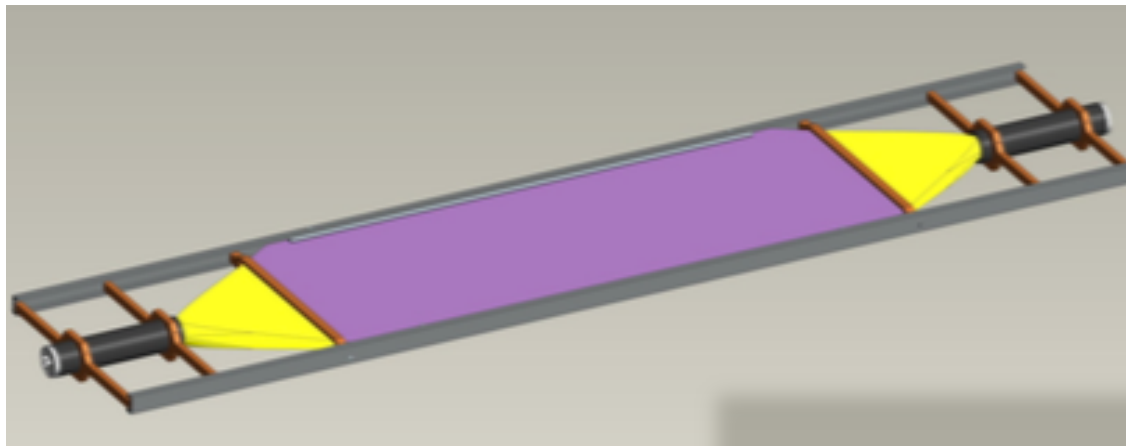


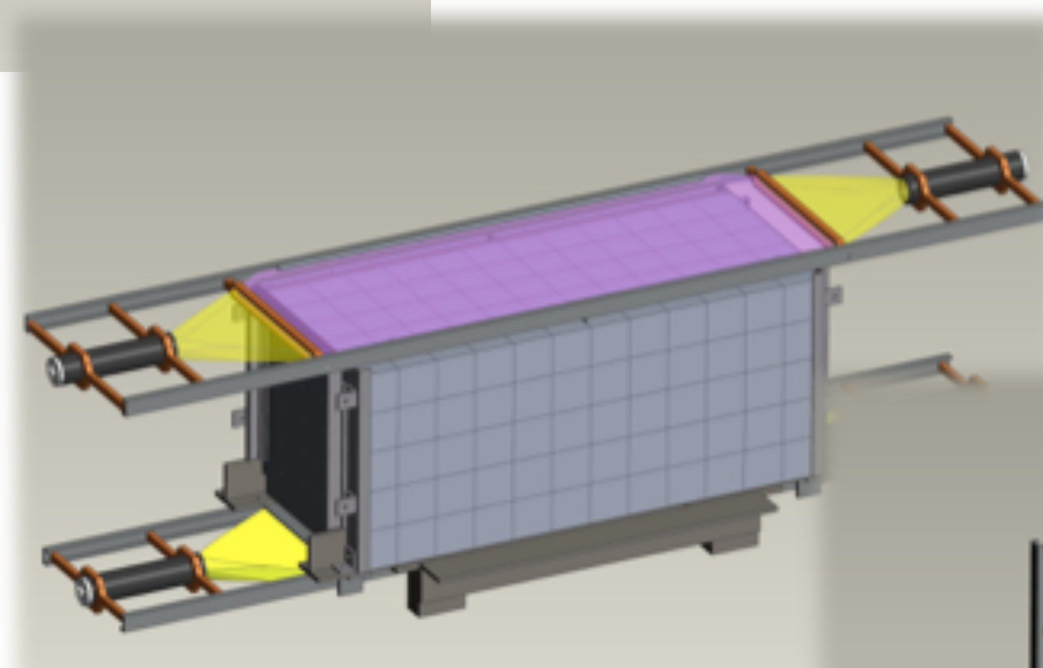


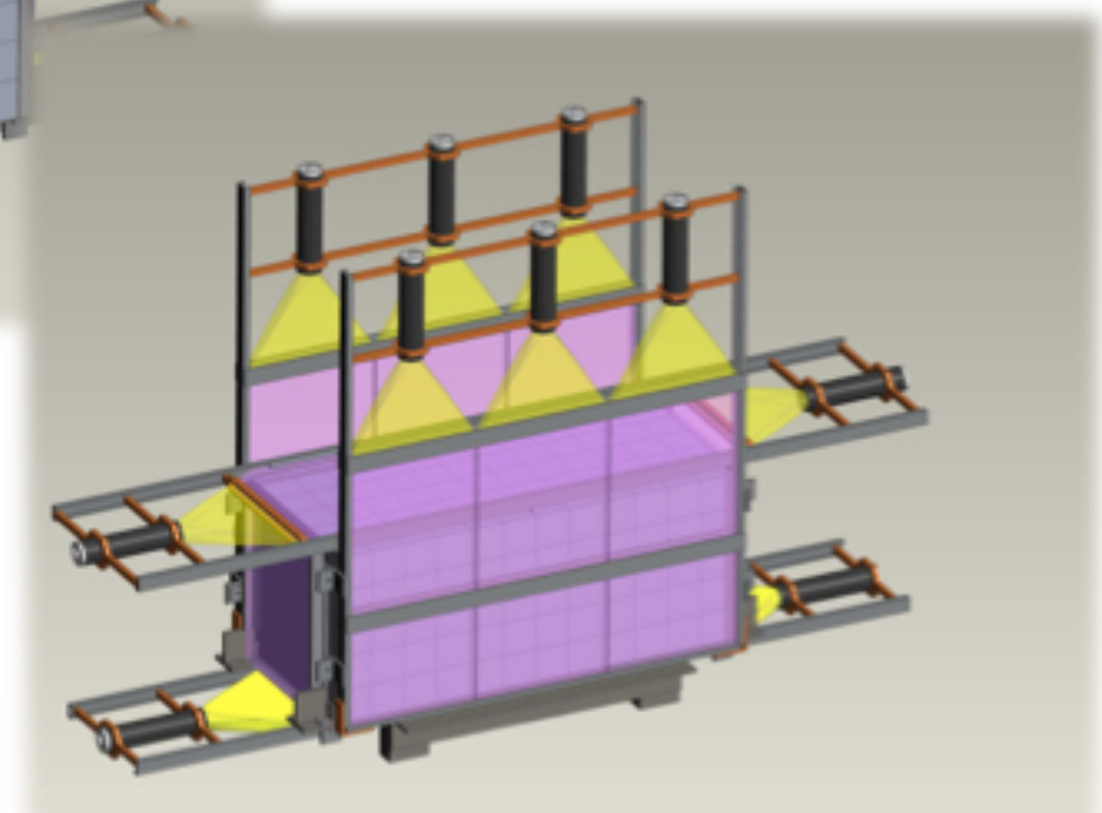


Experimental setup: external veto

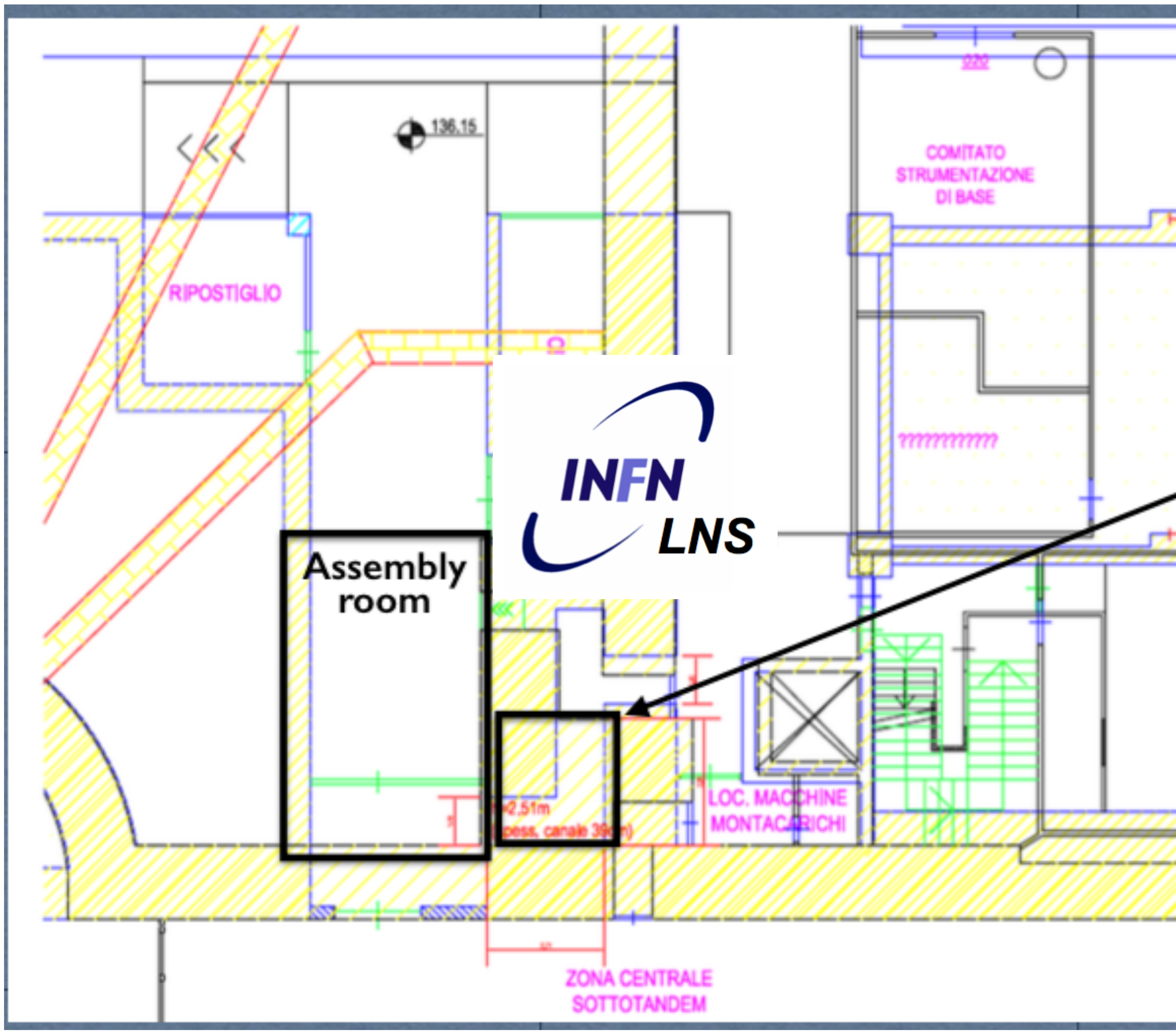
Plastic scintillator paddles 2 cm thick
+ single side PMT readout







BDX-prototype alcove at LNS



Suitable location

Known shielding (~6 m concrete)

Full services (AC, power network)

Fine for log (~ 6 months) installation

Conclusions

Statistical uncertainties of cosmogenic background are the main limiting factor for the BDX reaches in the X-N scattering channel

The ability of rejecting cosmogenic backgrounds was studied with MC simulations

The estimated background rates suggest orders of magnitude better sensitivity to light dark matter than any previous experiment

In preparation to the BDX experiment, a campaign of cosmic background measurements at LNS will start at the beginning of the next year

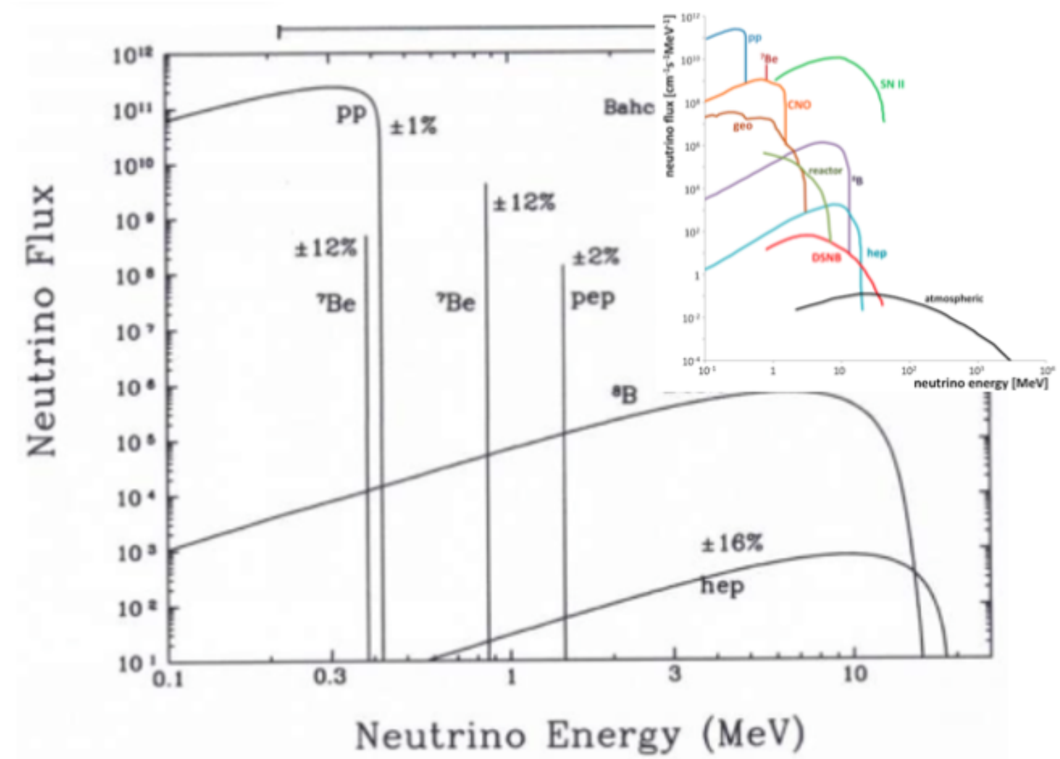
Validate MC simulations + veto system + shielding + test of different detector solutions

Optimize the BDX final design at the end of these measurements

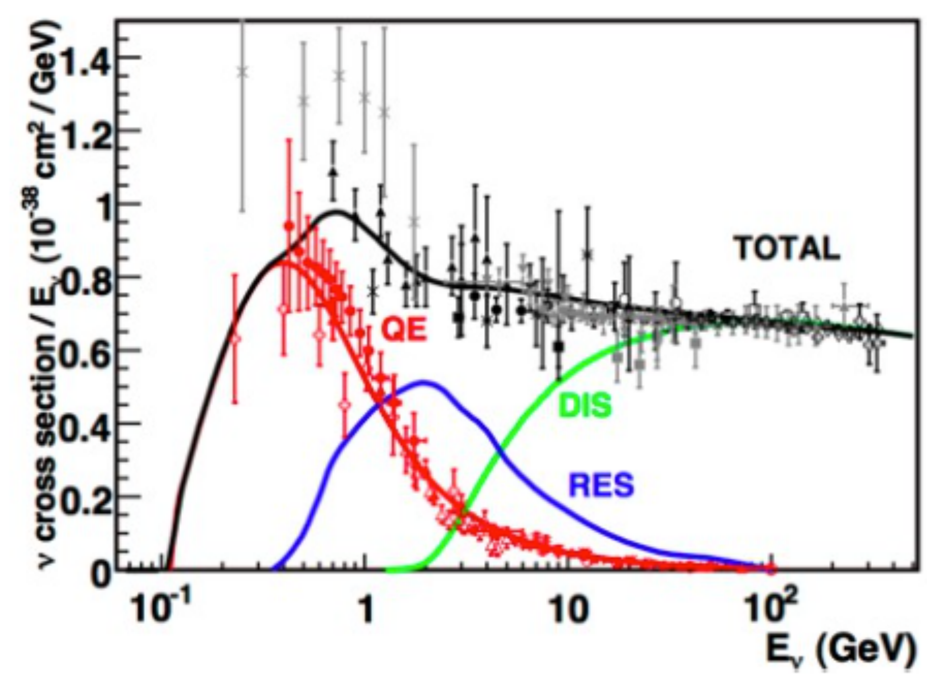
Beam un-related background

Cosmic neutrinos **negligible**

The only sizeable flux we need to consider is for solar neutrinos with energy below 10 MeV



Low energy neutrinos (E_ν <10 MeV) interact with protons in the detector mainly by inverse beta decay ($\bar{\nu} p \rightarrow e^+ n$), producing a positron that carries almost all the neutrino energy and could mimic a χ interaction.



The background rate, considering the volume of CORMORINO and assuming a detection efficiency of $\varepsilon_{e+detection}$ = 50% with 1 MeV thresholds (and 5% for 10 MeV threshold), is given by:

$$R^{\nu}_{Bg} = R^{Cosmic\nu}_{E_\nu<10MeV}\ \sigma_{\bar{\nu}p}\ 1/AN_{Avogadro}\ \rho_{plastic}\ L_{CORMORINO}\ \epsilon_{e^+detection} = 10^{-6}\text{Hz}\ \ (10^{-7}\text{Hz})$$

the cosmic neutrino background is negligible with respect to the other sources.

Beam un-related background

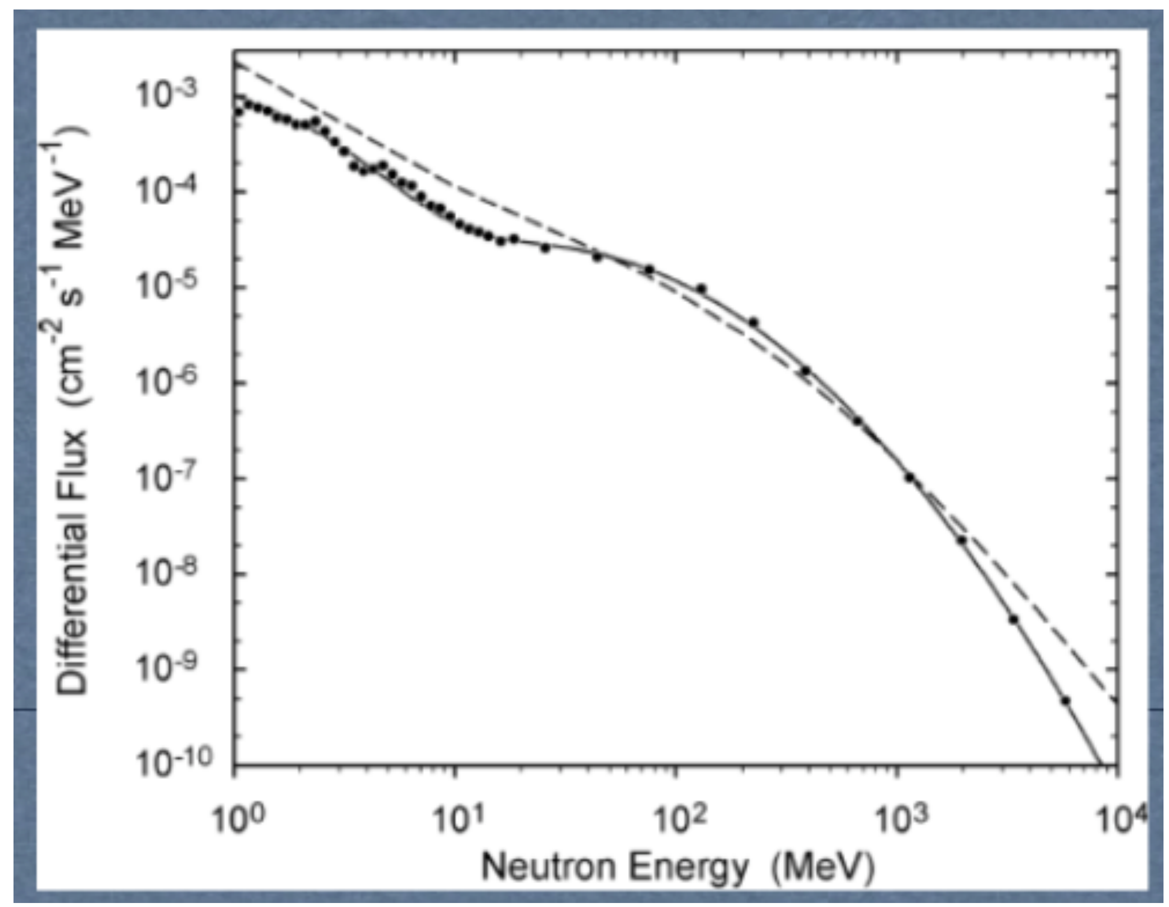
Cosmic neutrons **sizeable**

A cosmic neutron interacting with CORMORINO can produce a signal over the trigger threshold identical to a χ hit. Considering the typical interaction length of neutrons in plastic, the 2 cm thick active veto has a small chance to detect the incoming neutrons.

1 m iron shield + detector energy threshold introduce a neutron energy cutoff (detection efficiency = 0) for E_n<50 (100) MeV

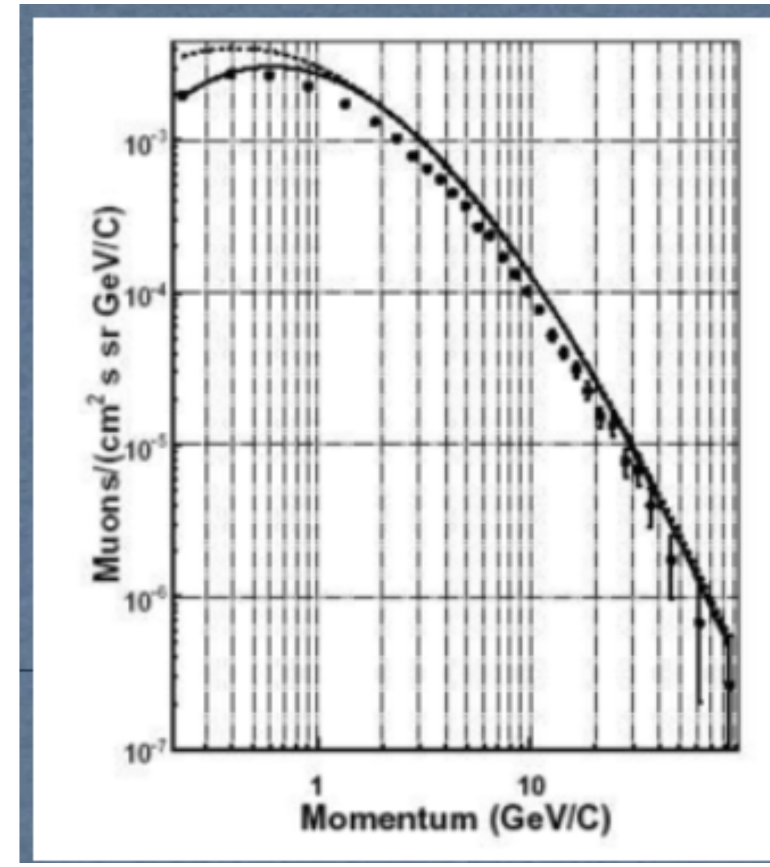
Thus, the overall visible rate for a detection threshold of 1 MeV (10 MeV) is :

$$R^n_{Bg} = 2.7\ 10^{-3}\mathrm{Hz}\ \ (0.6\ 10^{-3}\mathrm{Hz})$$



Beam un-related background

Cosmic muons **sizeable**



The effect of 1 m iron shielding and 5 cm thick lead is to suppress muons with momentum <1.45 GeV/c

Crossing muon **sizeable**

usually provides 2 hits on the veto detector and ≥1 hits in CORMORINO. To misidentify a crossing μ as a χ it is necessary that both hits in the veto counter are missed and only one CORMORINO bar records the hit.

Assuming the veto counter inefficiency to be 5% $(1-\epsilon_{veto})$

$\alpha^{Crossing\ \mu}_{Single\ hit}$=32% 1 MeV threshold (36% 10 MeV threshold)

rate of misidentified charged muons $R^{Crossing\ \mu}_{Bg} = R^{All\ \mu}\,\alpha^{Crossing\ \mu}_{Single\ hit}\,(1-\epsilon_{veto})^2 = 3.3\ 10^{-3}\text{Hz}\ (3.5\ \ 10^{-3}\text{Hz})$

Muons decaying inside CORMORINO **sizeable**

Muons stopping inside the detector cross one side of the veto. Negative muons, not detected in the Veto and providing a single hit in CORMORINO, contribute to the background.

$\alpha^{\mu\ inside\ capture}_{Single\ hit}$=24% 1 MeV threshold (39% 10 MeV threshold)

$$R^{\mu^{-}\ inside\ capture}_{Bg} = R^{\mu^{-}\ inside\ capture}\,\alpha^{\mu\ inside\ capture}_{Single\ hit}\,(1-\epsilon_{veto}) = 1.4\ 10^{-3}\text{Hz}\ \ (2.4\ 10^{-3}\text{Hz})$$

Positive muons stopping and decaying (at rest) generating a single hit in CORMORINO

$$R^{\mu^{+} inside\ decay}_{Bg} = 2\ R^{\mu^{+}\ inside\ dec}\,\alpha^{\mu\ inside\ dec}_{Single\ hit}\,(1-\epsilon_{veto}) = 2.9\ 10^{-3}\text{Hz}\ \ (4.8\ 10^{-3}\text{Hz})$$

Beam un-related background

Muons decaying inside lead shielding **sizeable**

$\alpha^{\mu\ lead}_{Single\ hit} \sim 0.46$ 1 MeV threshold (0.43 10 MeV threshold)

$$R^{\mu^-\ lead}_{Bg} = R^{\mu\ lead}\ \alpha^{\mu\ lead}_{Single\ hit}\ (1-\epsilon_{veto}) = 7.0\ 10^{-3}\mathrm{Hz}\ \ (4.3\ 10^{-3}\mathrm{Hz})$$

Muons decaying between iron shielding and veto **negligible**

For the usual decay, the few e^+ escaping the iron have a good chance to be detected by the veto and fully absorbed by the lead shielding between the veto and CORMORINO and therefore their contribution to the background is negligible.

The rare $\mu^- \rightarrow e^- \bar{\nu}_\mu \nu_e \gamma$ decay (BR~ 1.5%) produces a 20-50 MeV gamma that can enter in CORMORINO bypassing the veto. The leads shielding between the detector and the veto produces an overall attenuation of ~ 4 10^{-3}.

$\alpha^{\mu\ between\ dec}_{Single\ hit} \sim 0.5$ 1 MeV threshold (0.210 MeV threshold)

$$R^{\mu;\ rare\ dec}_{Bg} = R^{\mu\ between\ dec}\ BR\ Att\ \alpha^{\mu\ between\ dec}_{Single\ hit} = 2\ 10^{-5}\mathrm{Hz}\ \ (0.8\ 10^{-5}\mathrm{Hz})$$