Optimization Of The Emulsion Detector For LDM And Tau Neutrino Physics

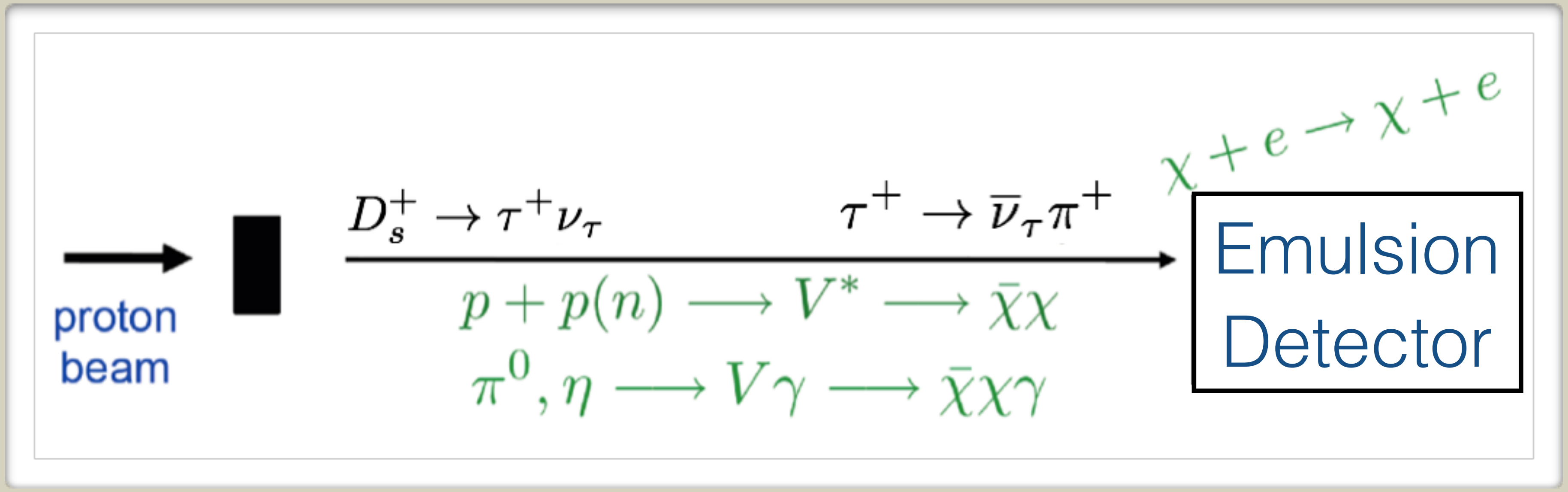
A. Di Crescenzo

University of Naples and INFN
Italy

9^{th} SHiP Collaboration Meeting
November 24^{th}, 2016

MOTIVATION

- Search for exotic particles can be performed through the observation of their **interaction** with nuclei/electrons
- Emulsion detector ideally suited for Light Dark Matter search thanks to:
  1) micrometric position resolution
  2) high electron identification efficiency
  3) capability of measuring the electron energy through calorimetric technique
  4) background reduction by observing large angle and low energy fragments produced in neutrino interactions



Optimization Of Emulsion Detector For LDM Search

Improvement of SHiP sensitivity in LDM search requires a dedicated optimization of the emulsion detector, concerning:

1) Data analysis tools

- electromagnetic shower identification
- electron energy measurement

2) Detector layout:

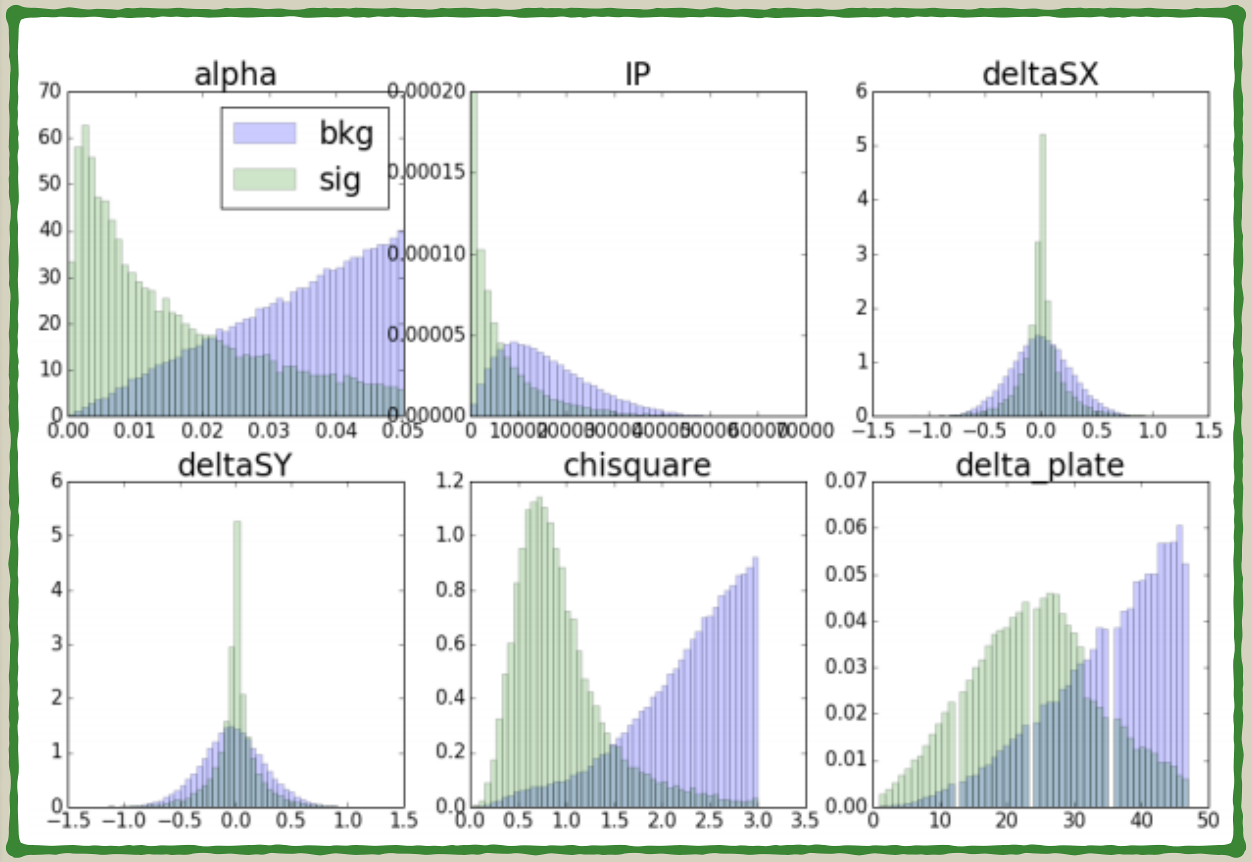
- increase the detector mass
- structure and material of ECC

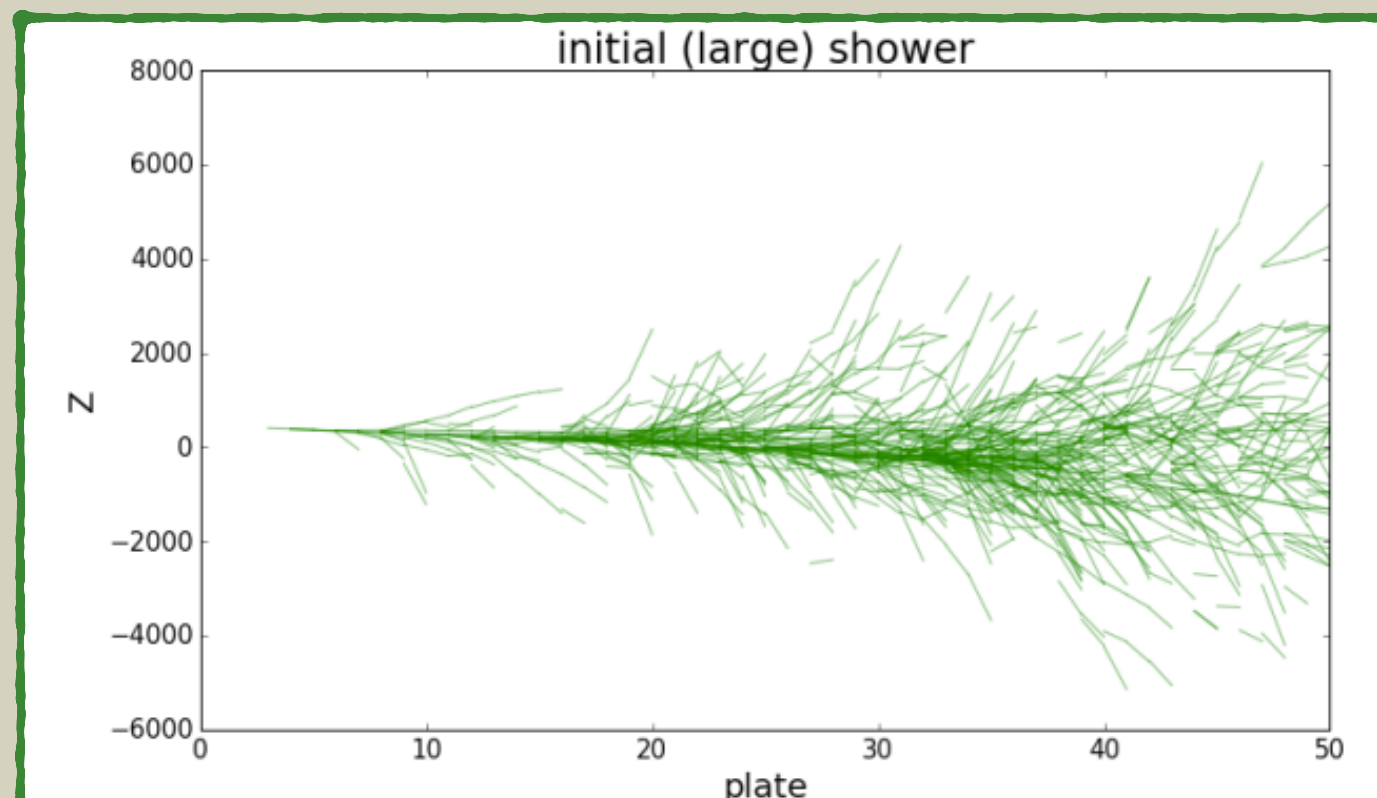
Data Analysis Tools

Yandex School of Data Analysis involved in development of software tools for electron identification and energy measurement

Machine learning-powered searches of EM-showers in the Emulsion Cloud Chamber data

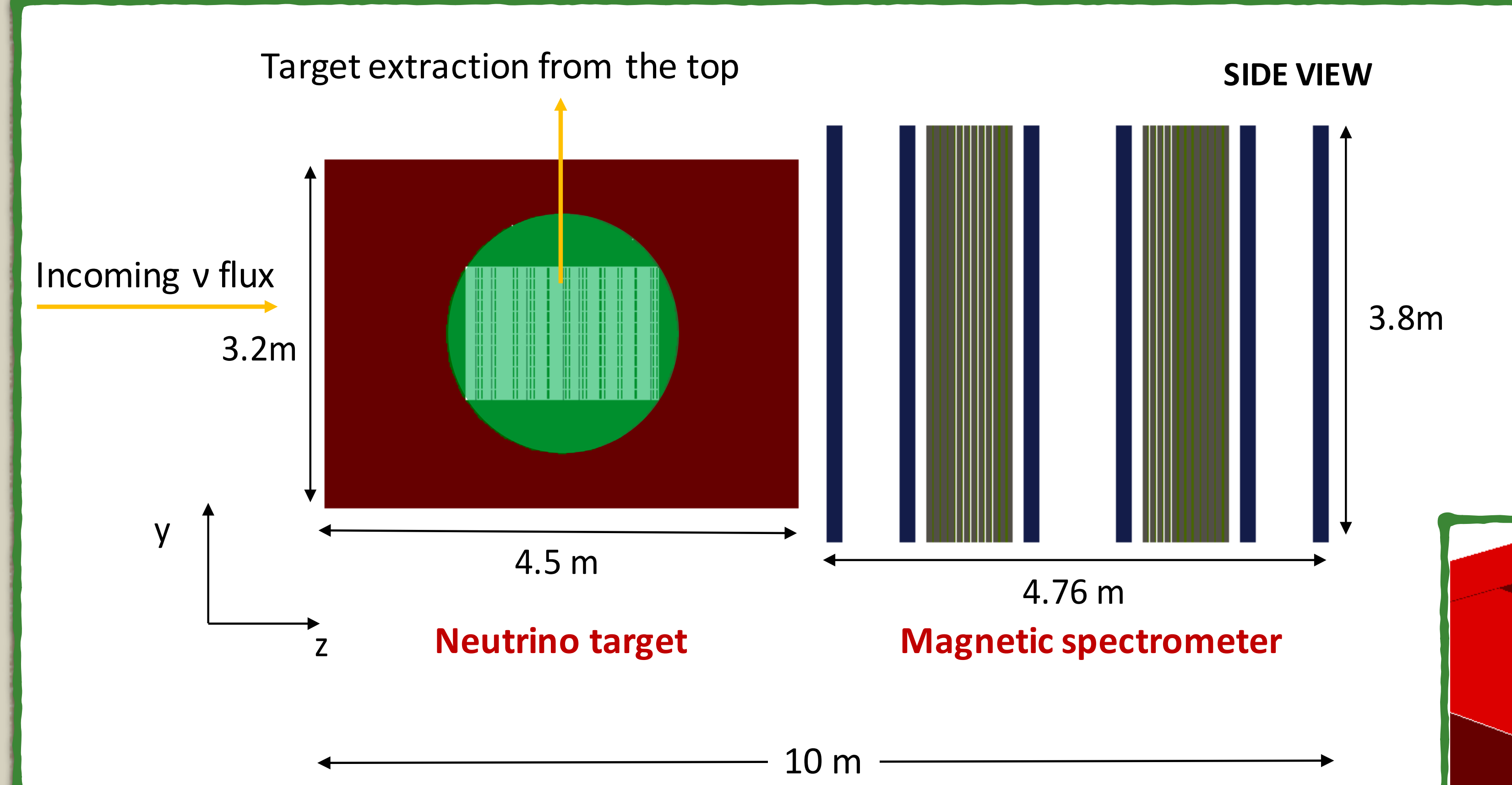
Andrey Ustyuzhanin
Alex Rogozhnikov





Current Layout Of Emulsion Detector

(details in A. Buonaura's presentation on 23/11)



MAGNETIC SPECTROMETER

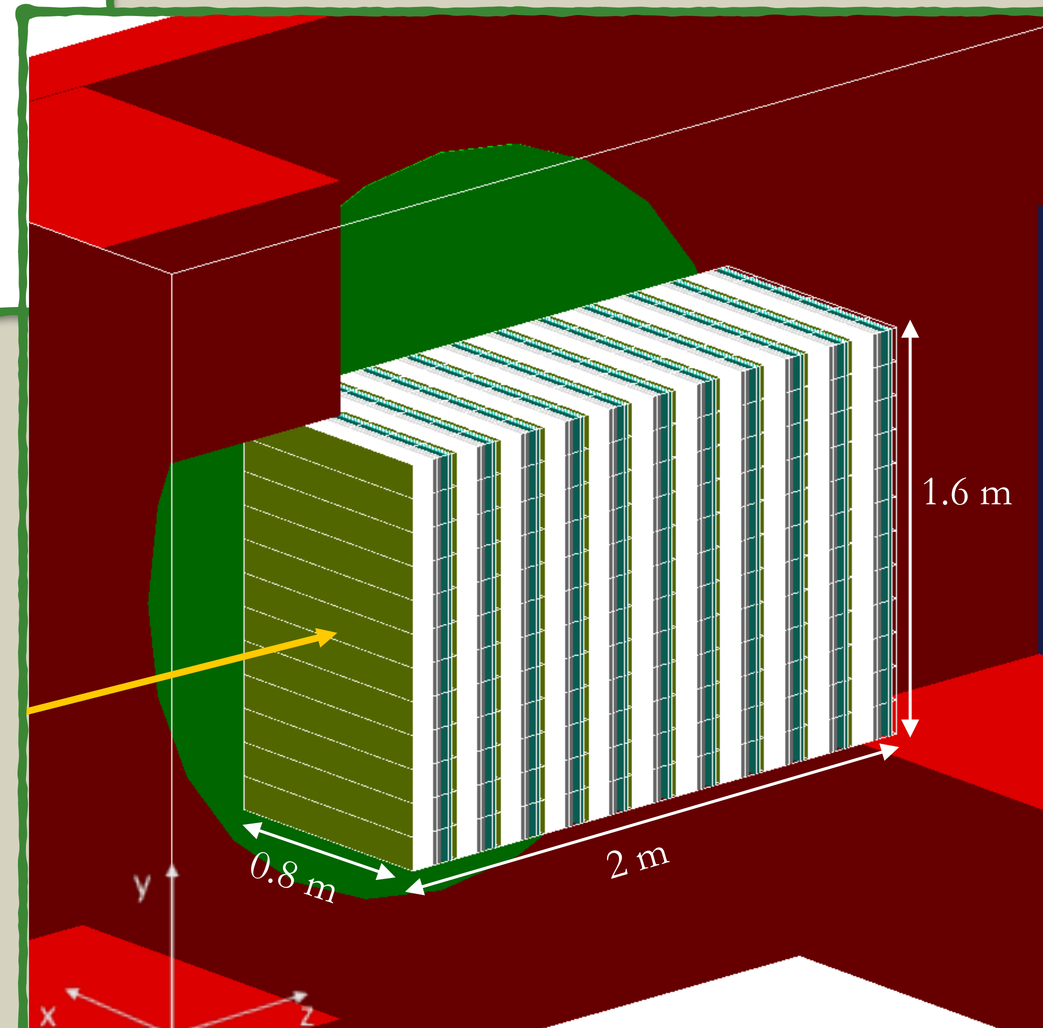
- 2 magnetized arms: 12 iron layers interleaved with RPCs
- 6 High Precision Trackers (HPT)

Target

- 6 columns (along x direction)
- 14 rows (along y direction)
- 11 walls (along z direction)
- 12 layers of Target Trackers

Total dimensions: 0.8x1.6x2 m³

Total number of bricks: 924



Mass Increase VS Target Magnetization

MASS INCREASE

Pros

1) increase in the LDM sensitivity

2) increase in neutrino statistics

3) CES not needed anymore: simplification of the target, further increase in target mass

4) Avoid multiple scattering in magnet iron

Contra

1) CES not needed anymore: charge measurement of hadrons not possible

2) only muonic tau channel (Br 17%) used for ν_τ/anti-ν_τ separation

3) momentum measurement for hadron rely only on MCS in the brick

TARGET MAGNETIZATION

Contra

1) poor sensitivity in LDM search

2) target volume limited by the magnetized region

3) Multiple scattering in magnet iron

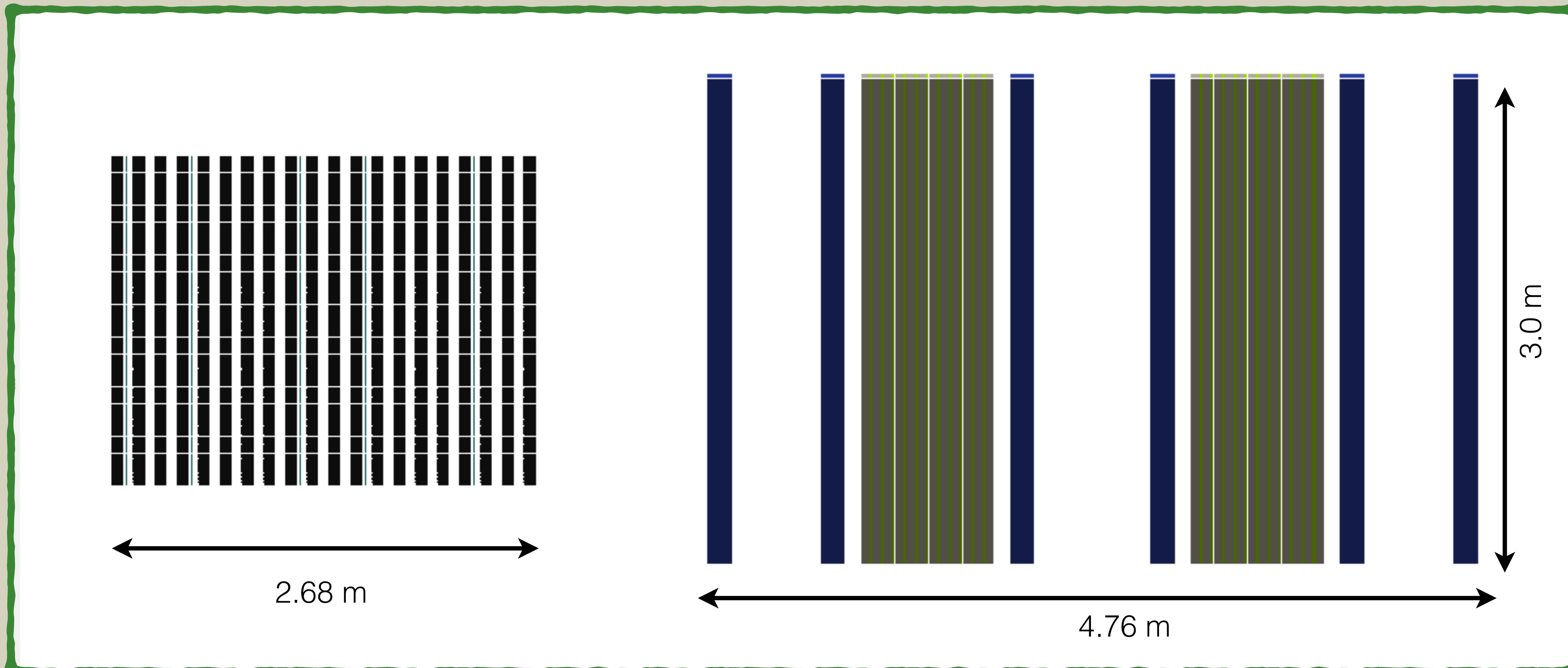
Pros

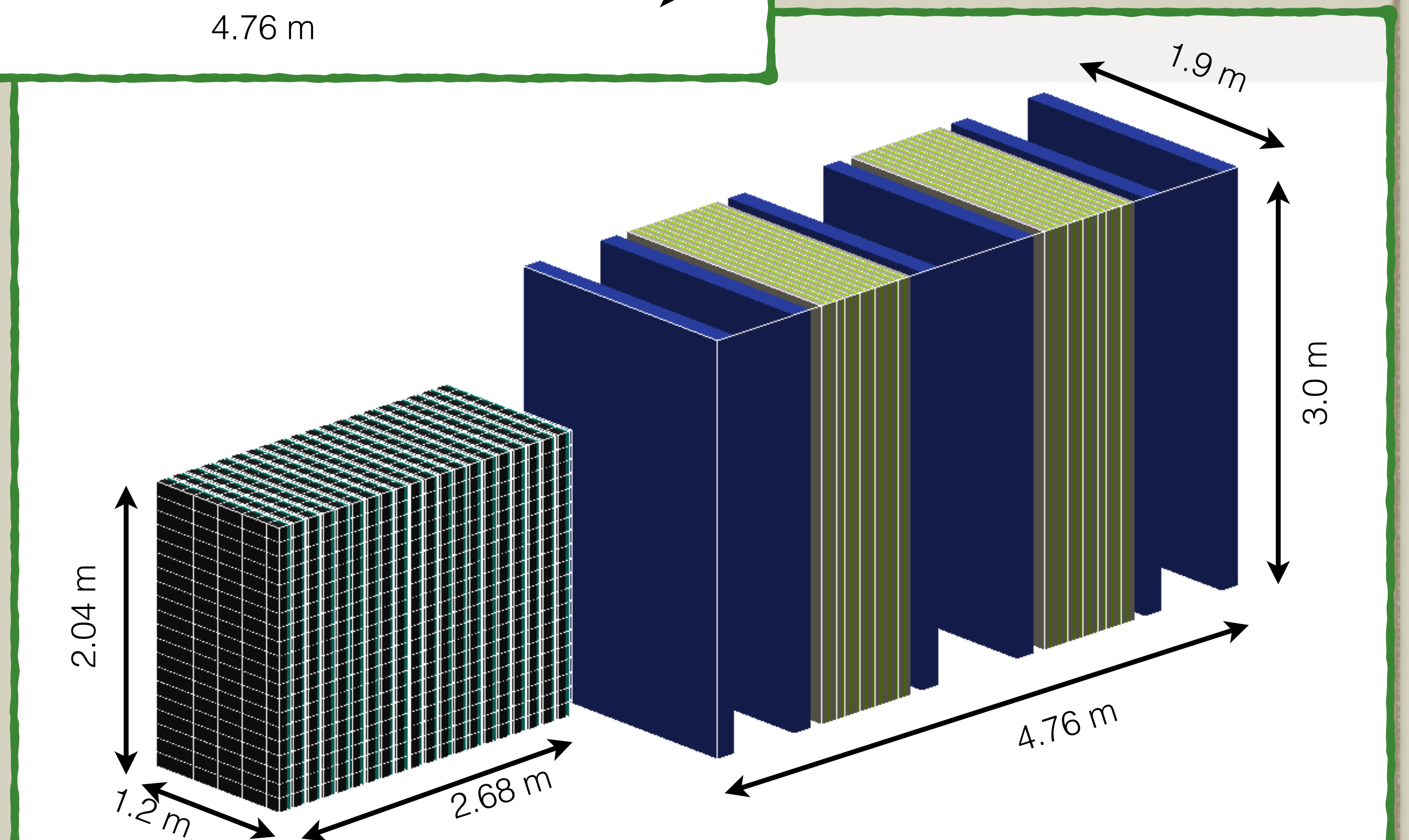
1) hadronic (Br 65%) and muonic (Br 17%) tau decay channels used for ν_τ/anti-ν_τ separation

2) momentum measurement for hadrons per formed with MCS algo in the brick and with sagitta method in CES

- emulsion production is an issue ***(M. Komatsu on 23/11)***
- time required for emulsion scanning and analysis increases linearly with the target mass ***(V. Tioukov on 23/11)***

EMULSION TARGET W/O MAGNET





Target

- 10 columns (along x direction)
- 20 rows (along y direction)
- 20 walls (along z direction)

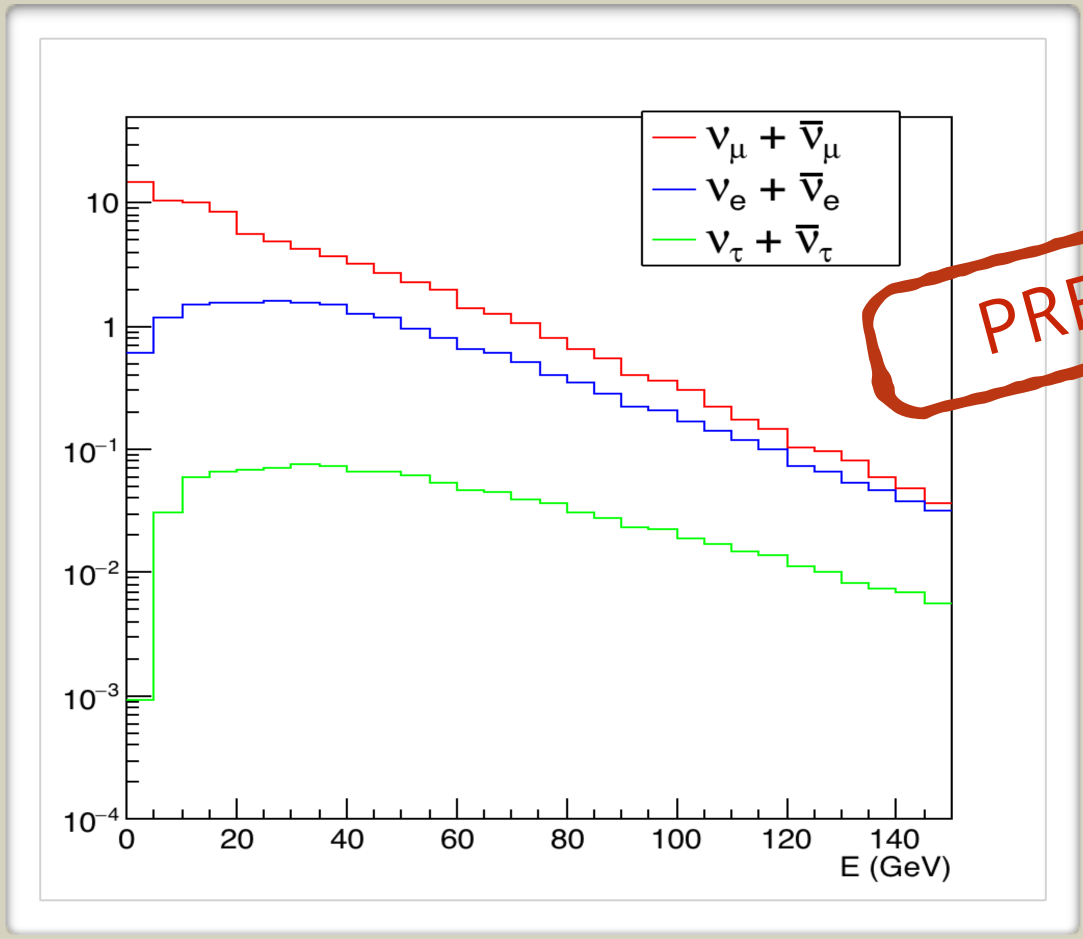
Total number of bricks: 4000
(increase x4 in the target mass)

Monte Carlo Simulation

Neutrinos of different species interacting in the target ***(A. Buonaura)***

Charm cascade included

WITHOUT MAGNET



Expectations in 5 years run (2×10^{20}pot)

PRELIMINARY

	<E> (GeV)	CC DIS interactions
N_{ν_μ}	27	7.2×10^6
N_{ν_e}	45	1.7×10^6
N_{ν_τ}	43*	7.6×10^4
$N_{\bar{\nu}_\mu}$	24	2.8×10^6
$N_{\bar{\nu}_e}$	36	6.5×10^5
$N_{\bar{\nu}_\tau}$	61*	5.5×10^4

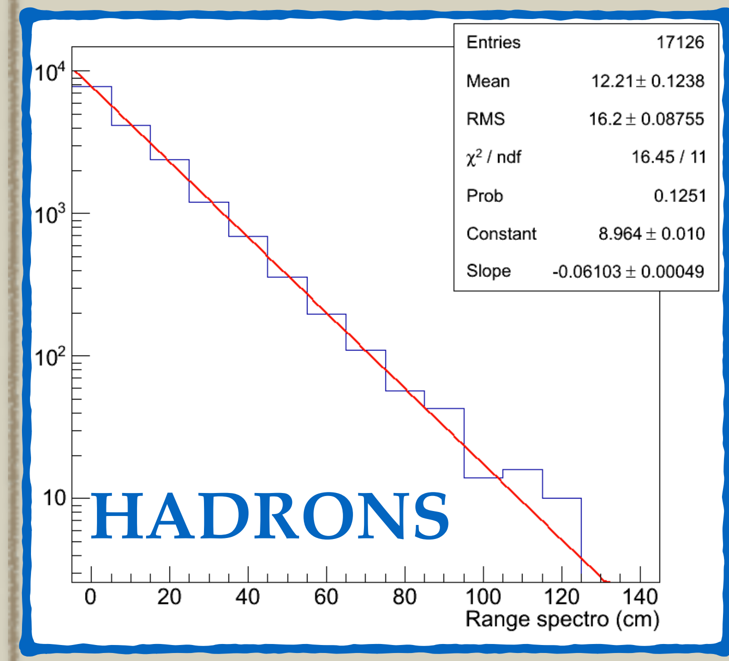
*average ν_τ and anti-ν_τ energies under investigation

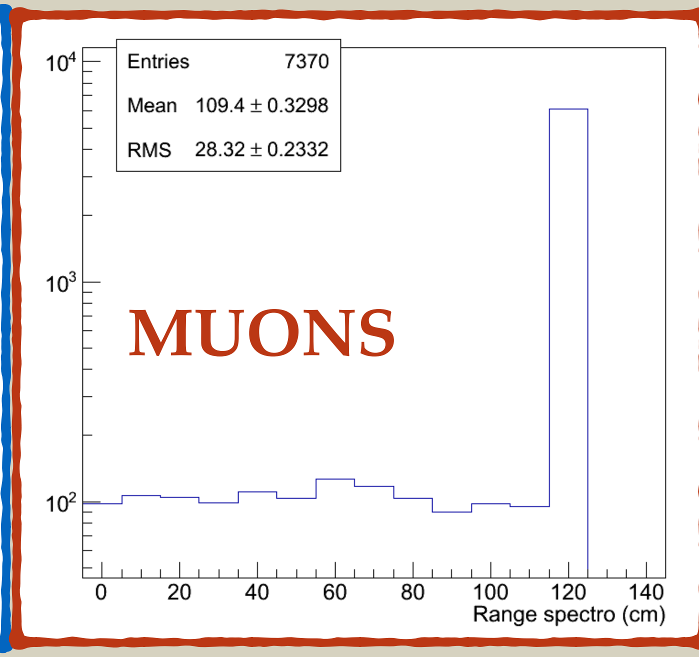
CAVEAT: neutrino vertices distributed uniformly in the target

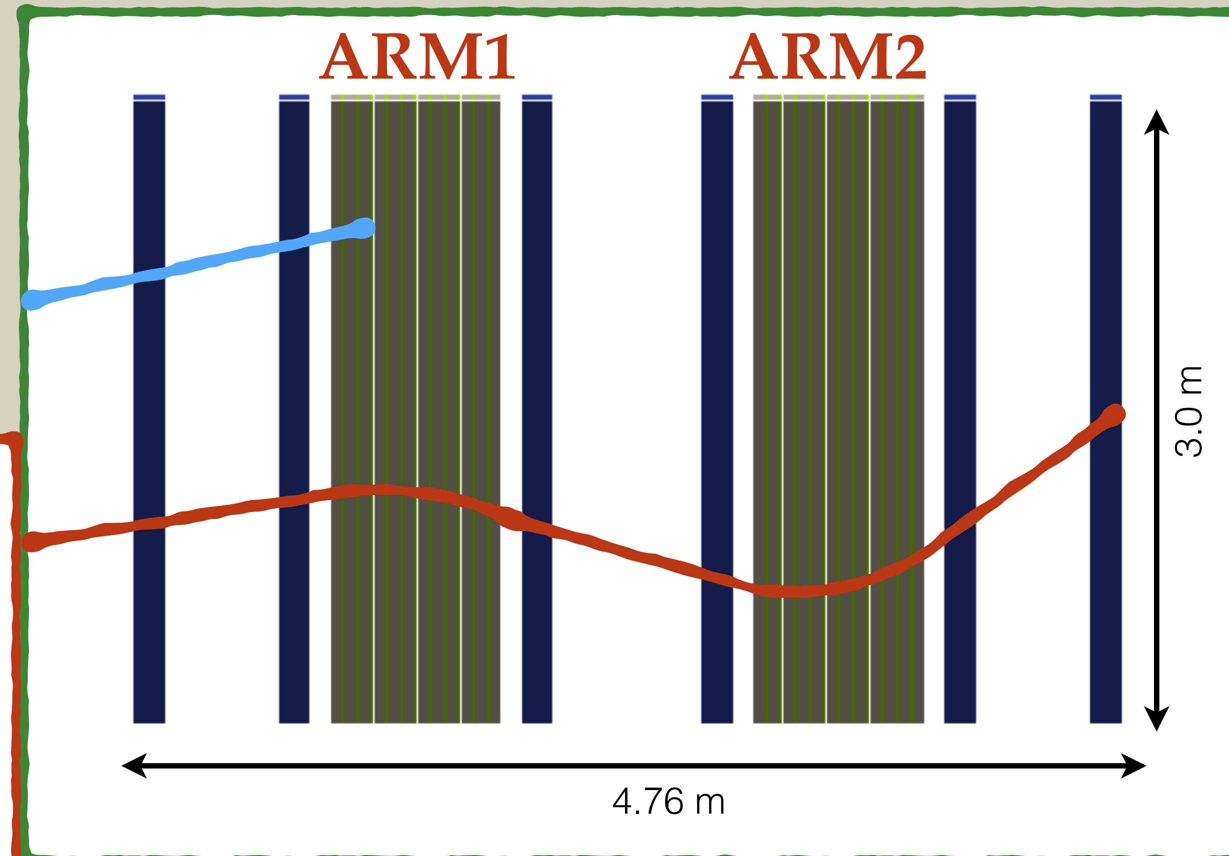
PERFORMANCES: MUON ID

Muon identification performed with the Muon Spectrometer, relying on the amount of crossed material

Requirement: $N_{RPC} > 3$







Particle range in the Spectrometer Iron

Muon identification efficiency

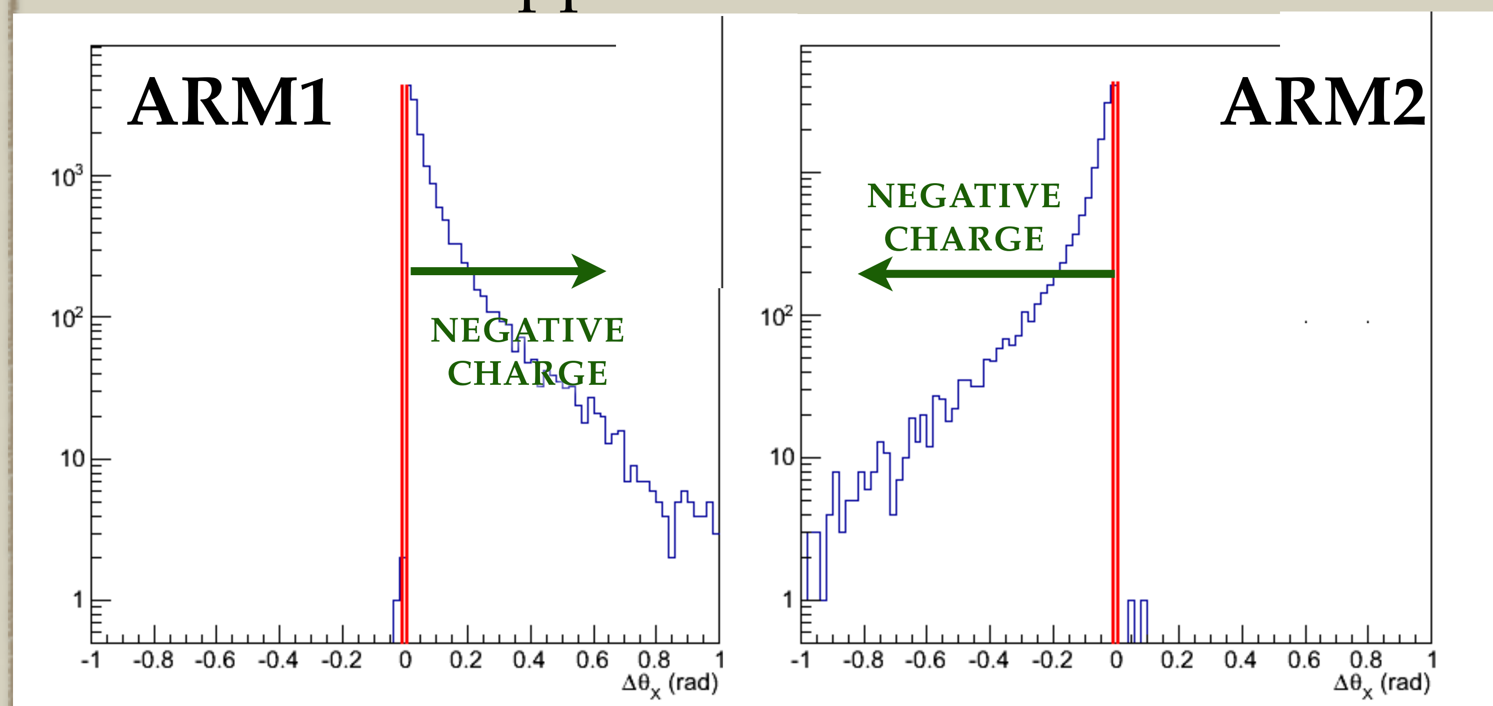
$\boxed{\mu^- \text{ in } \nu_{\mu cc}^{charm}}$ $\varepsilon^{\text{charm}}{}_{\mu\text{ID}} = 78 \pm 1\ \%$

$\boxed{\tau^- \rightarrow \mu^-}$ $\varepsilon^{\tau}{}_{\mu\text{ID}} = 81 \pm 1\ \%$

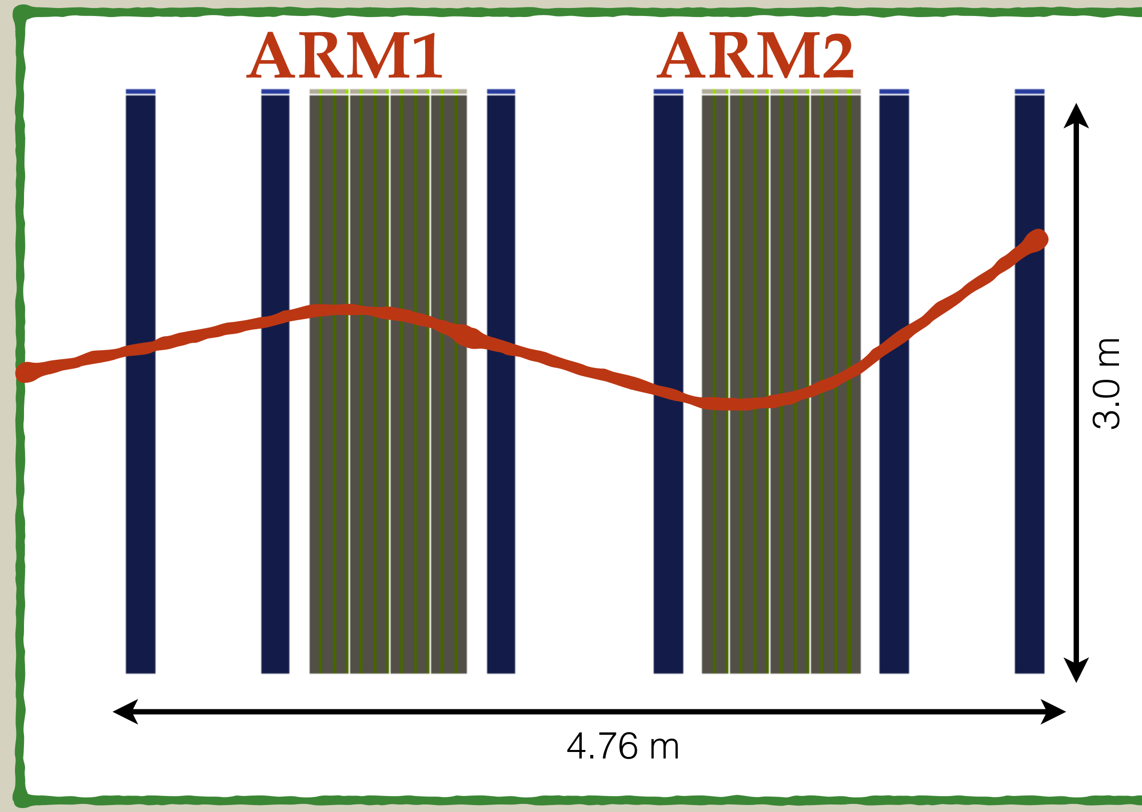
Performances: Muon Charge

Opposite magnetization
in the two arms

Two opposite curvatures



MC simulation: muons from ν_μ^{CC} interactions



Momentum Measurement

$$\frac{\Delta p}{p} \approx \frac{\Delta\theta}{\theta} = \frac{1}{eBd}\sqrt{6\left(\frac{\varepsilon p}{a}\right)^2 + \frac{d}{X_0}\left(\frac{14\,\mathrm{MeV}}{c}\right)^2}$$

Momentum resolution better than 25%

Muon charge measurement efficiency

$\boxed{\mu^- \text{ in } \nu_{\mu cc}^{charm}}$ $\qquad \varepsilon^{charm}_{charge} = 90 \pm 1\ \%$

$\boxed{\tau^- \rightarrow \mu^-}$ $\qquad \varepsilon^{\tau}_{charge} = 91 \pm 1\ \%$

Signal and Background Expectation

Detected neutrino interactions **W/O** lepton number measurement

PRELIMINARY

CURRENT CONFIGURATION

decay channel	$\nu_\tau + \overline{\nu}_\tau$		
	N^{exp}	N^{bg}	R
$\tau \to \mu$	3700	300	12
$\tau \to h$	6400	800	8
$\tau \to 3h$	1500	350	4
$\tau \to e$	4000	300	13
total	15600	1750	9

WITHOUT MAGNET
& increase in mass x4

decay channel	$\nu_\tau + \overline{\nu}_\tau$		
	N^{exp}	N^{bg}	R
$\tau \to \mu$	10000	1600	6
$\tau \to h$	28000	6000	5
$\tau \to 3h$	10000	4000	2
$\tau \to e$	11000	1600	7
total	59000	13000	4

Detected neutrino interactions **WITH** lepton number measurement

decay channel	ν_τ			$\overline{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \to \mu$	1700	80	12	2040	200	9
$\tau \to h$	2914	200	8	3500	600	6
$\tau \to 3h$	700	90	4	800	250	3
total	5300	360	14	6400	1100	6

decay channel	ν_τ			$\overline{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \to \mu$	5700	400	14	4100	1100	4

* Background considered: charmed hadrons produced in ν_e and ν_μ CC interactions where primary lepton not identified

SENSITIVITY TO F_4 AND F_5

$$\frac{d^2\sigma^{\nu(\bar\nu)}}{dx\,dy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Bigg(\left(y^2 x + \frac{m_\tau^2 y}{2E_\nu M}\right) F_1 + \left[\left(1-\frac{m_\tau^2}{4E_\nu^2}\right) - \left(1+\frac{Mx}{2E_\nu}\right)\right] F_2 \pm \left[xy\left(1-\frac{y}{2}\right) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\Bigg),$$

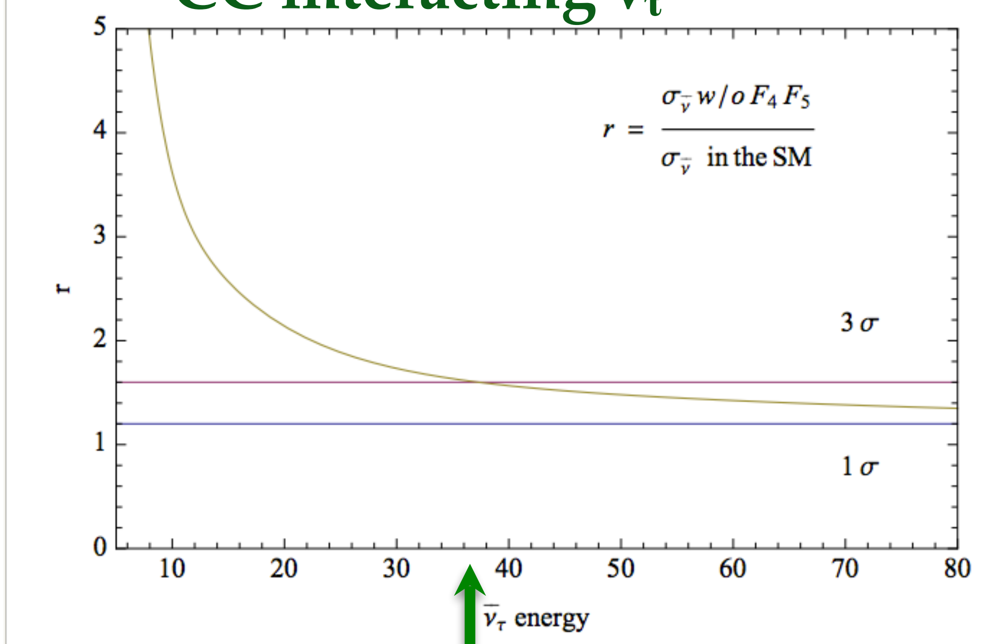
$F_4 = F_5 = 0$ hypothesis

→ increase of the ν_τ and anti-ν_τ CC DIS cross sections

→ increase of the number of expected ν_τ/anti-ν_τ interactions

- Sensitivity to F_4 and F_5 F can be performed with anti-ν_τ only and with ν_τ+anti-ν_τ

CC interacting $\overline{\nu}_\tau$



E(anti-ν_τ) < 38 GeV

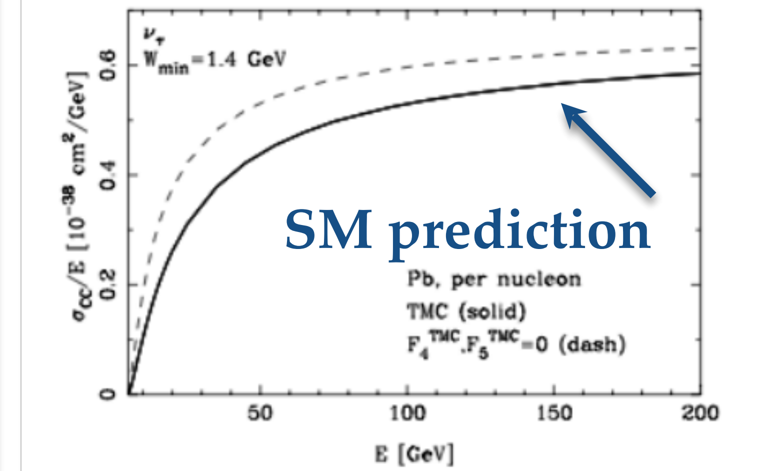
(~ 2000 observed events expected)

r *= ratio between the cross sections in the two hypotheses*

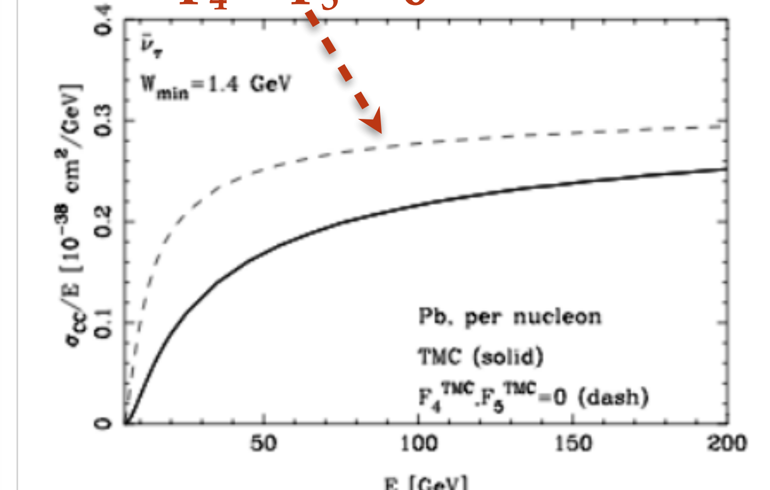
* ***study reported in TP***

r>1.6
evidence for non-zero values of F_4 and F_5

ν_τ CC DIS cross-section



$F_4 = F_5 = 0$



anti-ν_τ CC DIS cross-section

CHARM PHYSICS

- Fraction of neutrino-induced charm events:

ν_μCC

$$f(charm) = \frac{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_\mu}}\right) dE}{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} dE} \approx 3.5\%$$

ν_eCC

$$f(charm) = \frac{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_e}}\right) dE}{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} dE} \approx 5.5\%$$

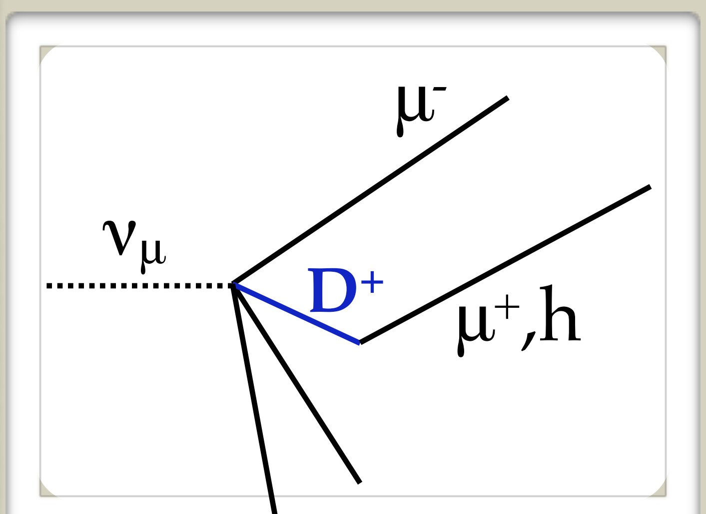
PRELIMINARY

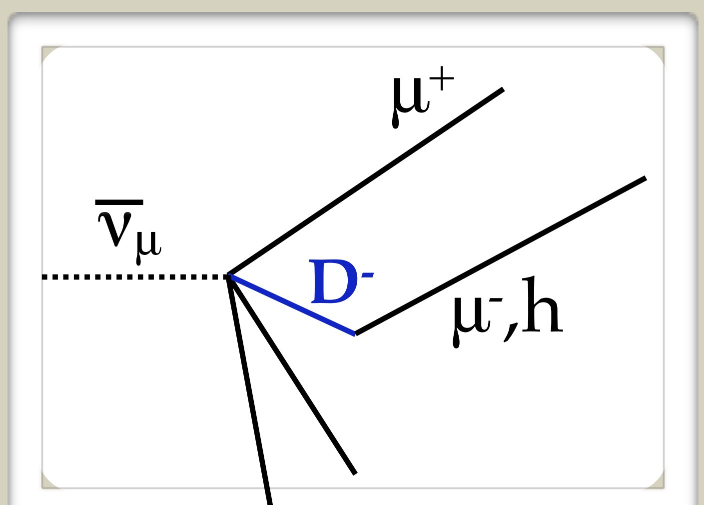
	Expected events
ν_μ	2.7 x 10^5
ν_e	1.0 x 10^5
$\bar{\nu}_\mu$	3.3 x 10^4
$\bar{\nu}_e$	1.0 x 10^5
total	6.0 x 10^5

(A. Buonaura)

- Charmed hadron identification based on lepton identification at the primary vertex
- Charge of primary muon needed to distinguish charmed hadron produced in ν_μ from anti-ν_μ interactions

Used for estimation of strange quark content of the nucleon



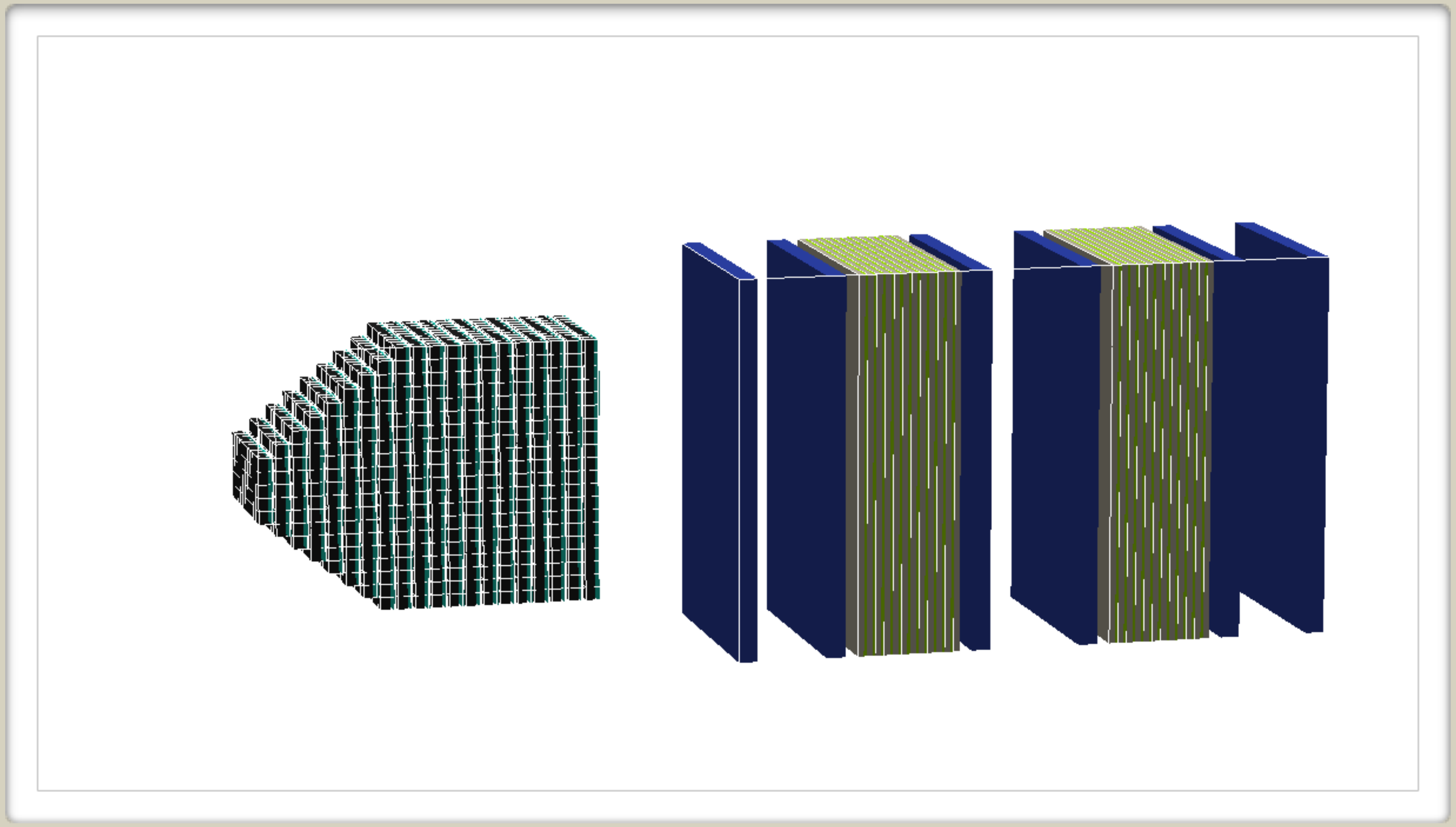


- The measurement of muon charge allows to get a large sample of anti-ν_μ interactions
- Not measuring the charge of secondary hadrons increases the hadronic-background contamination

TO BE EVALUATED

FURTHER OPTIMIZATIONS

- Options under study:
  - Tungsten option as passive material in emulsion brick (instead of Lead): smaller X_0 for a better EM shower containment in the brick
  - tune the thickness of passive material layers to improve the electron identification efficiency
  - conical shape of the emulsion target: make uniform the geometrical acceptance for muons in the Muon Spectrometer



Conclusions

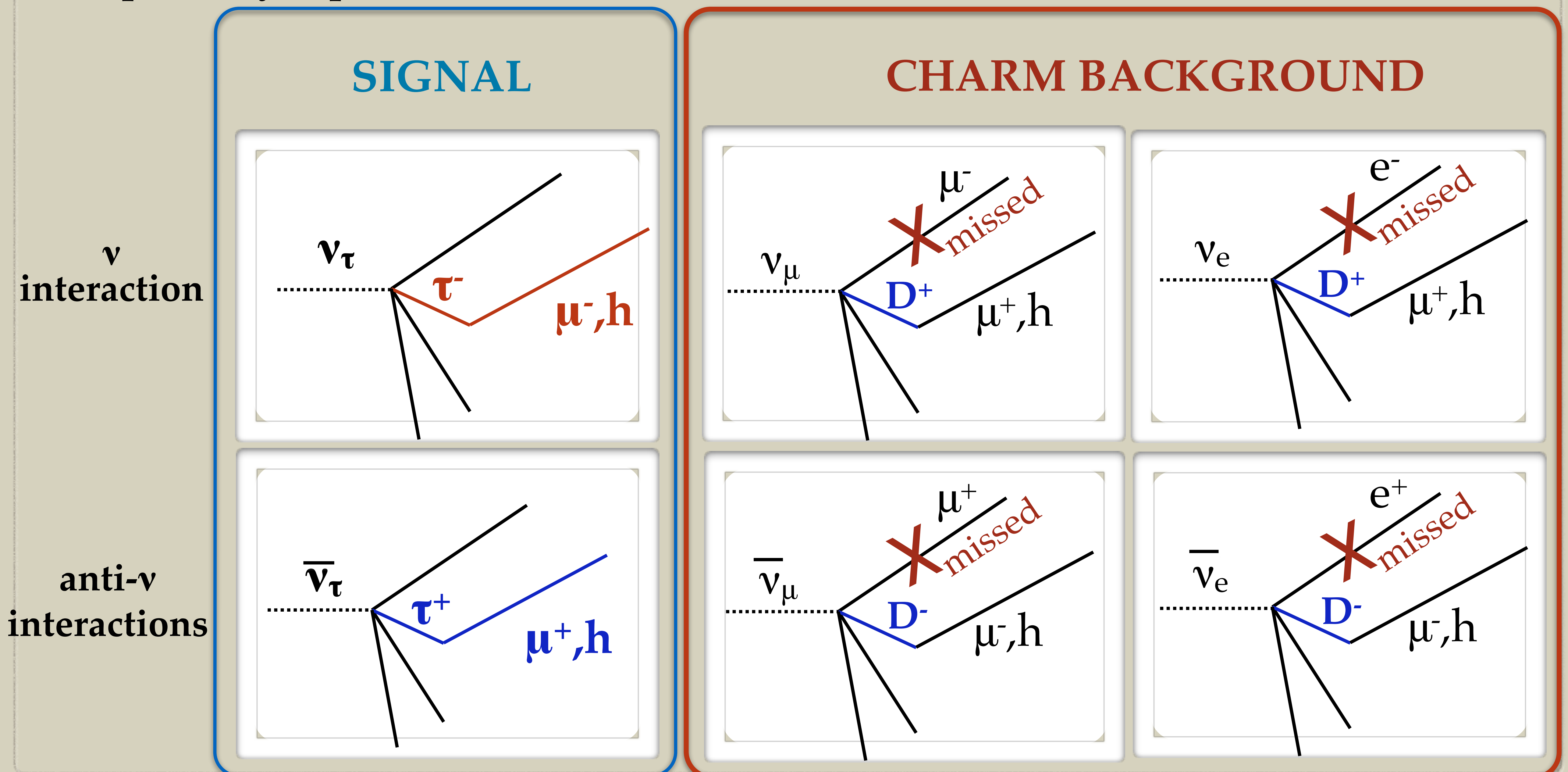
- Emulsion excellent position resolution and electron identification capabilities makes the SHiP Emulsion Detector suited for **Light Dark Matter** search
- Improvement of SHiP sensitivity in LDM search requires a dedicated optimization of the emulsion detector
  - Yandex School of Data Analysis developing new tools to improve electromagnetic shower identification and energy measurement
  - Two options under study: **mass increase VS magnetized target**
  - Pros and cons of both options to be considered

- Perspectives:
  - Further optimization of the Emulsion Detector layout
  - All background sources for both neutrino and charm studies to be included
  - Evaluation of SHiP **sensitivity to LDM**

Backup

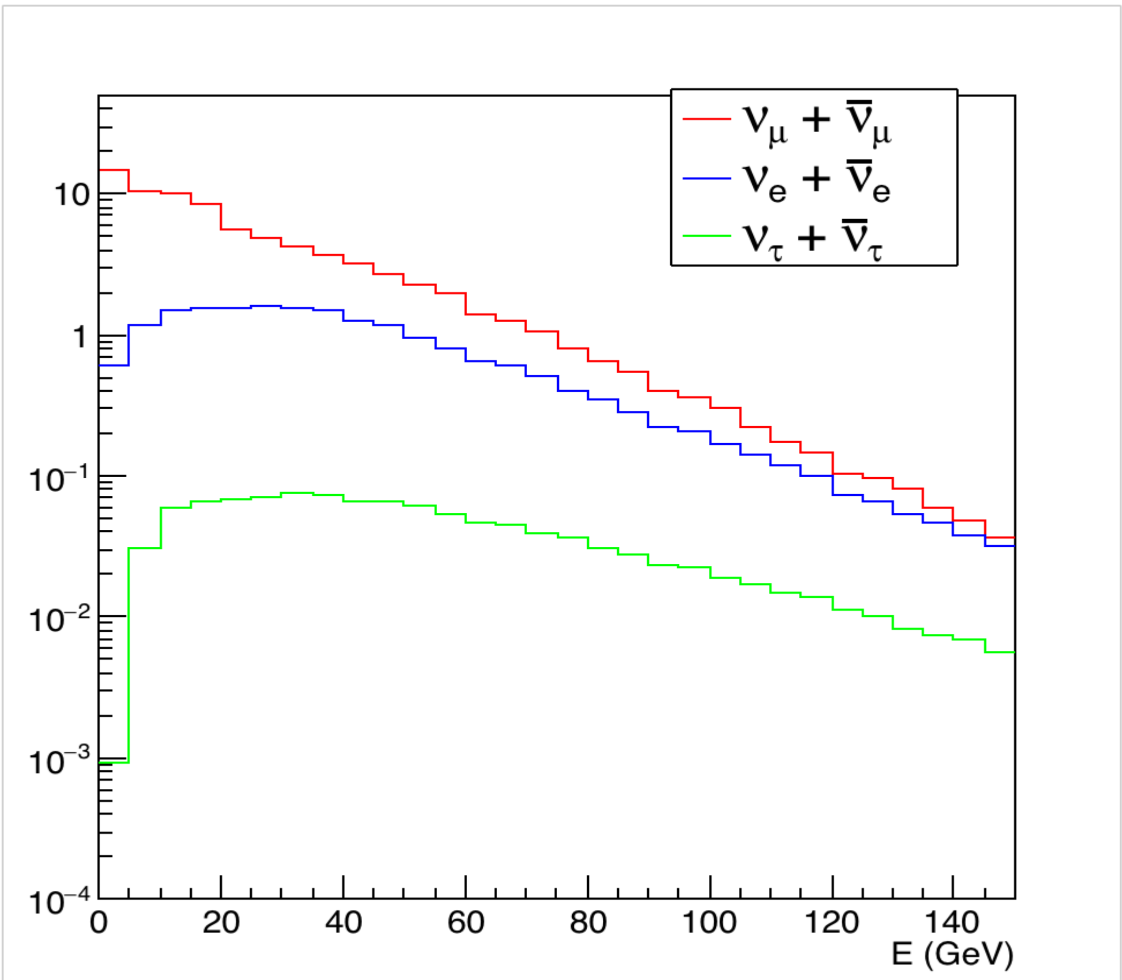
Background Sources

- The main background source in ν_τ and anti-ν_τ searches is the charm production in ν_μ^{CC} (anti-ν_μ^{CC}) and ν_e^{CC} (anti-ν_e^{CC}) interactions, when the primary lepton is not identified



Monte Carlo Simulation

Neutrinos of different species interacting in the target ***(A. Buonaura)***
Charm cascade included



CURRENT CONFIGURATION

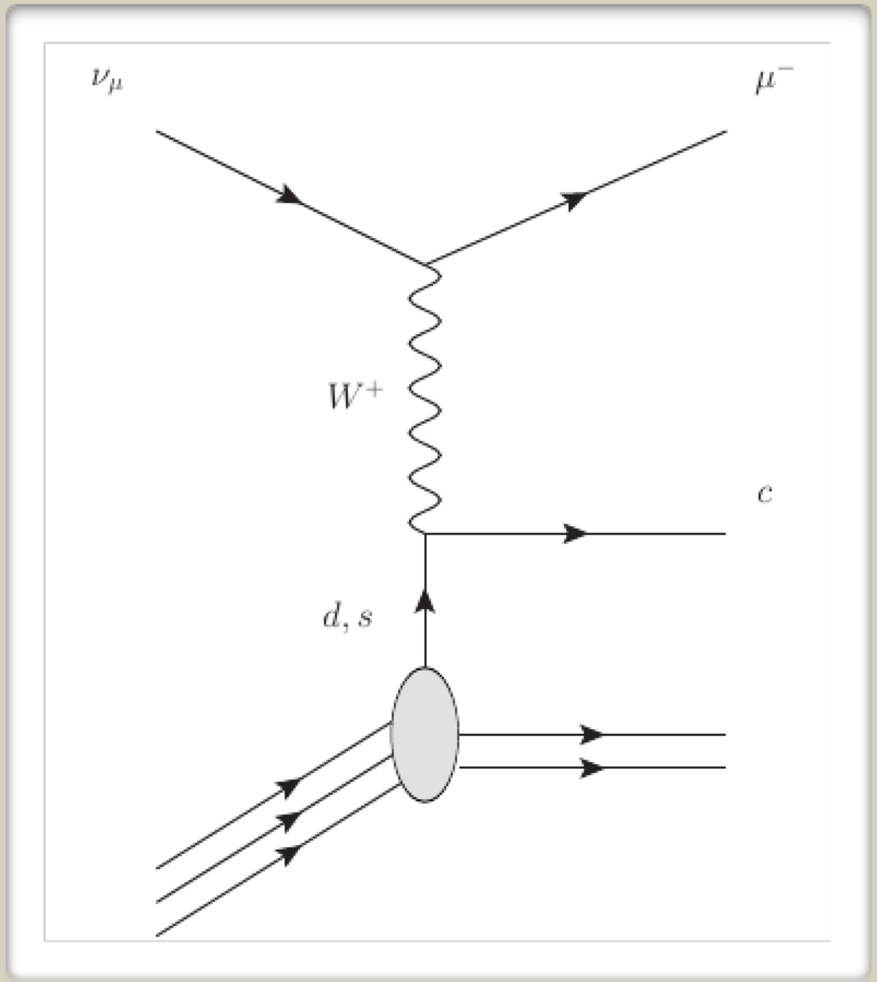
Expectations in 5 years run ($2x10^{20}$pot)

	<E> (GeV)	CC DIS interactions
N_{ν_μ}	31	$2.3x10^6$
N_{ν_e}	50	$6.3x10^6$
N_{ν_τ}	45	$2.0x10^4$
$N_{\bar{\nu}_\mu}$	26	$8.6x10^5$
$N_{\bar{\nu}_e}$	38	$2.2x10^5$
$N_{\bar{\nu}_\tau}$	73	$2.4x10^4$

CAVEAT: neutrino vertices distributed uniformly in the target.
Angular dependence non considered in the present study

Charm Physics @SHiP

- Large charm production in ν_μ^{CC} and ν_e^{CC} interactions
- Process sensitive to strange quark content of the nucleon



- Charm production with electronic detectors tagged by di-muon events (high energy cut to reduce background)
- Nuclear emulsion technique: charmed hadron identification through the observation of its decay
- Loose kinematical cuts → good sensitivity to the slow-rescaling threshold behavior and to the charm quark mass

Charm Physics @SHiP

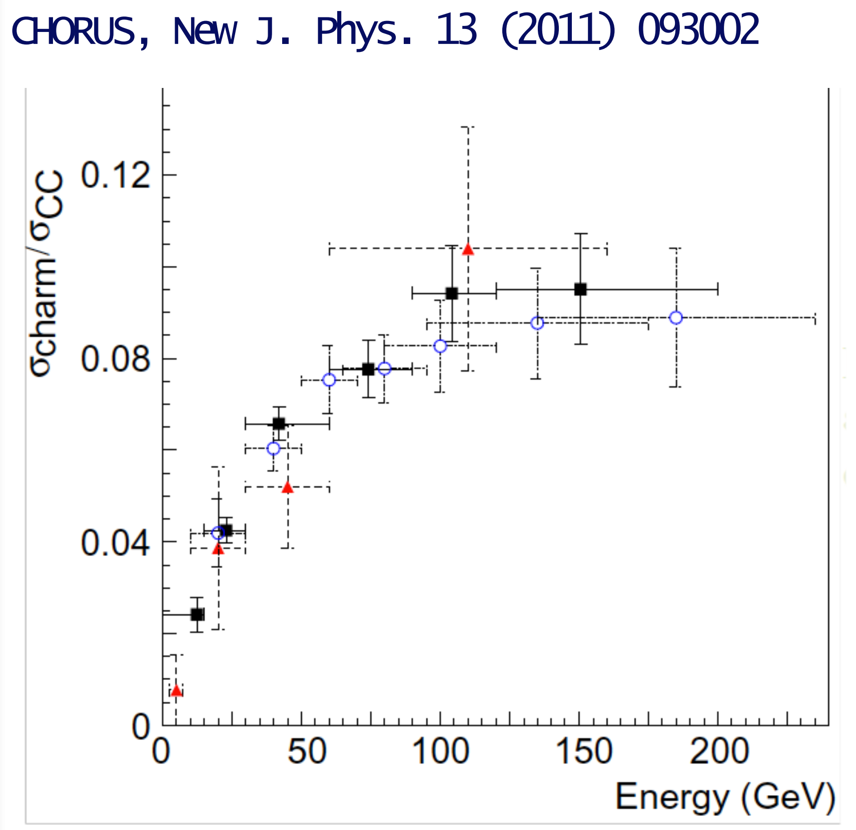
- Fraction of neutrino-induced charm events:
- Convolution of CHORUS data with SHiP spectrum

ν_μCC

$$f(charm) = \frac{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_\mu}} \right) dE}{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} dE} \approx 4\%$$

ν_eCC

$$f(charm) = \frac{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_e}} \right) dE}{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} dE} \approx 6\%$$



- Expected charm yield exceeds the statistics available in previous experiments by more than one order of magnitude

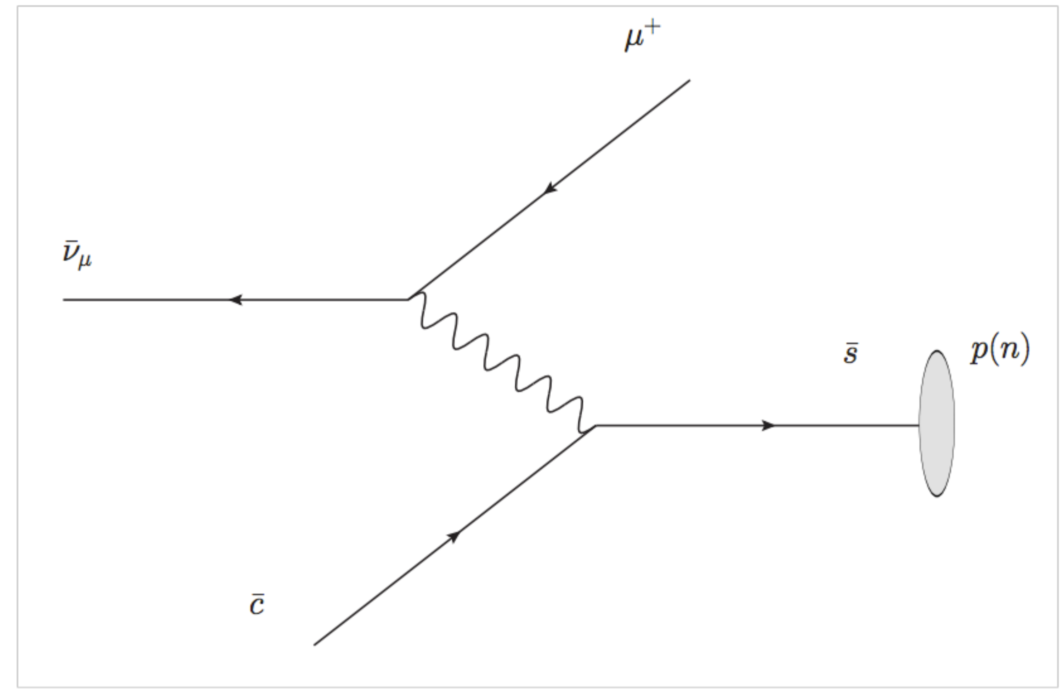
	Expected events
ν_μ	$6.8 \cdot 10^4$
ν_e	$1.5 \cdot 10^4$
$\bar{\nu}_\mu$	$2.7 \cdot 10^4$
$\bar{\nu}_e$	$5.4 \cdot 10^3$
total	$1.1 \cdot 10^5$

In NuTeV ~5100 ν_μ
~ 1460 anti-ν_μ
In CHORUS ~ 2000 ν_μ
32 anti-ν_μ

No charm candidate from ν_e and ν_τ interactions ever reported!

Strange Quark Nucleon Content

- Charmed hadron production in anti-neutrino interactions selects anti-strange quark in the nucleon
- Strangeness important for precision SM tests and for BSM searches



- Improvement achieved on s^+/s^- versus x
- Significant gain with SHIP data (factor two)