High granularity tracker for the ND280-upgrade

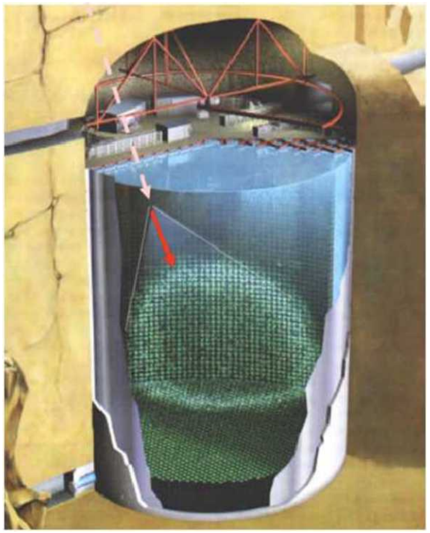
Benjamin Quilain (Kyoto University) on behalf of the ND280-upgrade taskforce

Worlshop on Neutrino Near Detectors based on gas TPCs (2016/11/08)

→ Presented by Yokoyama-san.

→ This talk : requirements for the target & central tracker/module.

Far detector, the number of observed events is :

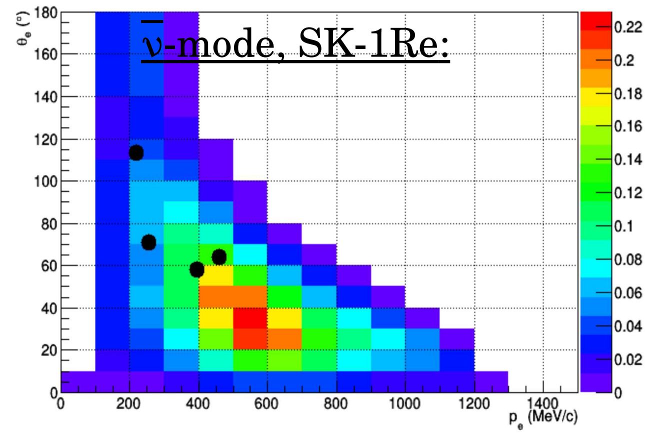


Observable	Flux	Cross section	Detector response	

$$N_{FD} \sim \Phi_{FD} \cdot \sigma_{FD} \cdot \epsilon_{FD} \cdot P_{Osc.}$$

Goal → Find $P_{osc}(E_\nu)$

1. Measure N_{FD}
2. Estimate Φ_{FD}, σ_{FD} & ϵ_{FD} with models



@SK : Measurement with lepton kinematics (p_μ, θ_μ)

The near detector is used to reduce the uncertainty on Φ_{FD}, σ_{FD} & ϵ_{FD} :

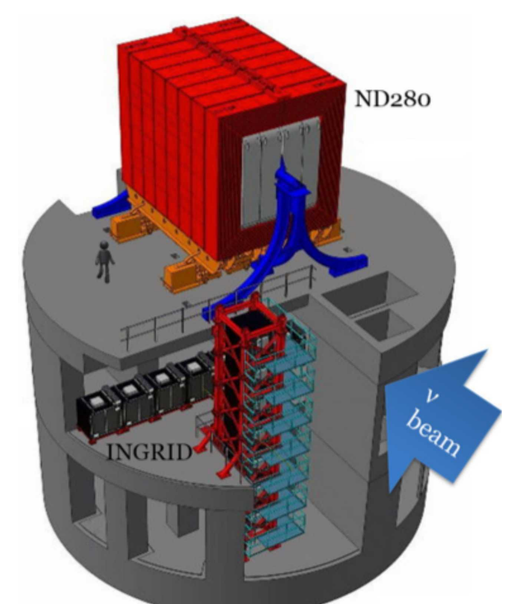
$$N_{ND} \sim \Phi_{ND} \cdot \sigma_{ND} \cdot \epsilon_{ND}$$

Goal :

Same fluxes : $\Phi_{FD} \sim \Phi_{ND}$

Same cross-section corrections : $\sigma_{FD} \sim \sigma_{ND}$

Same detector responses : $\epsilon_{FD} \sim \epsilon_{ND}$



But : Relative measurement does not cure all problems !

→ Even in the « ideal » situation (where $\Phi_{FD} = \Phi_{ND}$ + $\sigma_{FD}=\sigma_{ND}$ + same detector technology)

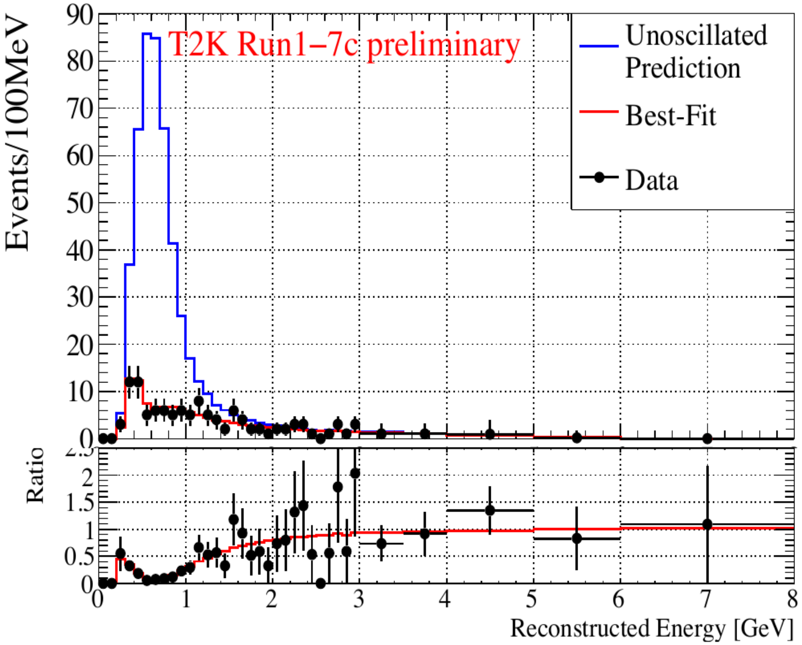
1. Solide angle : $\Phi_{FD} = \Phi_{ND}$ => ND smaller than FD

   → Since physics processes invariant between the 2 detectors : $\varepsilon_{FD} \neq \varepsilon_{ND}$

2. Absolute measurement of E_ν with high resolution :

   ν_e appearance : Depends on ν_μ spectrum @Near Detector → No FD/ND total cancellation !

   ν_μ disappearance : Δm^2_{32} measurement requires E_ν



Need a Near Detector that has:

1. H_2O target as Super-K : ~~cross-section models~~

2. 2π angle acceptance as SK (4π) for lepton kinematics : ~~Efficiency corrections~~

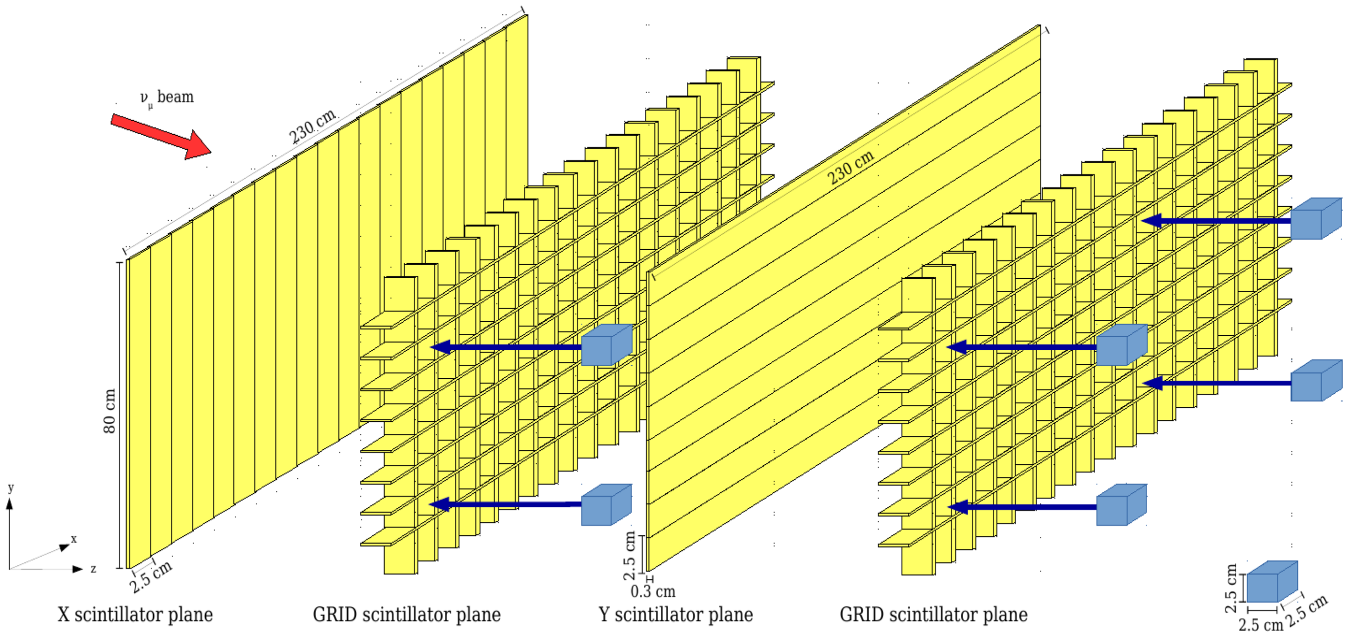
3. Excellent E_ν reconstruction → Detect most of the daughter particles & measure energy

→ High detection efficiency & energy resolution → « Active » target ! (High granularity)

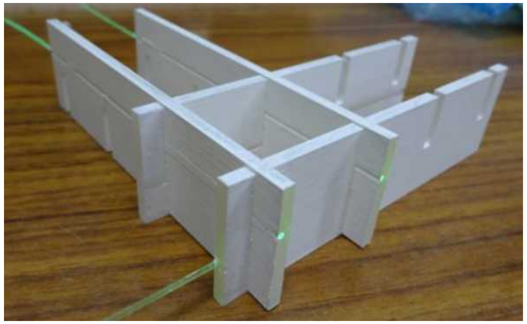
Motivations for WAGASCI tracker

Proposal : WAGASCI, a high granularity 2π scintillator tracker.

→ **WAGASCI tracker:** Alternance of XY planes & 3D grid scintillators.
→ ~2π angular acceptance
→ Good vertex resolution (even for large angle tracks)



GRID-like scintillators



High angle efficiency !

2 targets : 1 H_2O (& 1 plastic module → End of the talk).

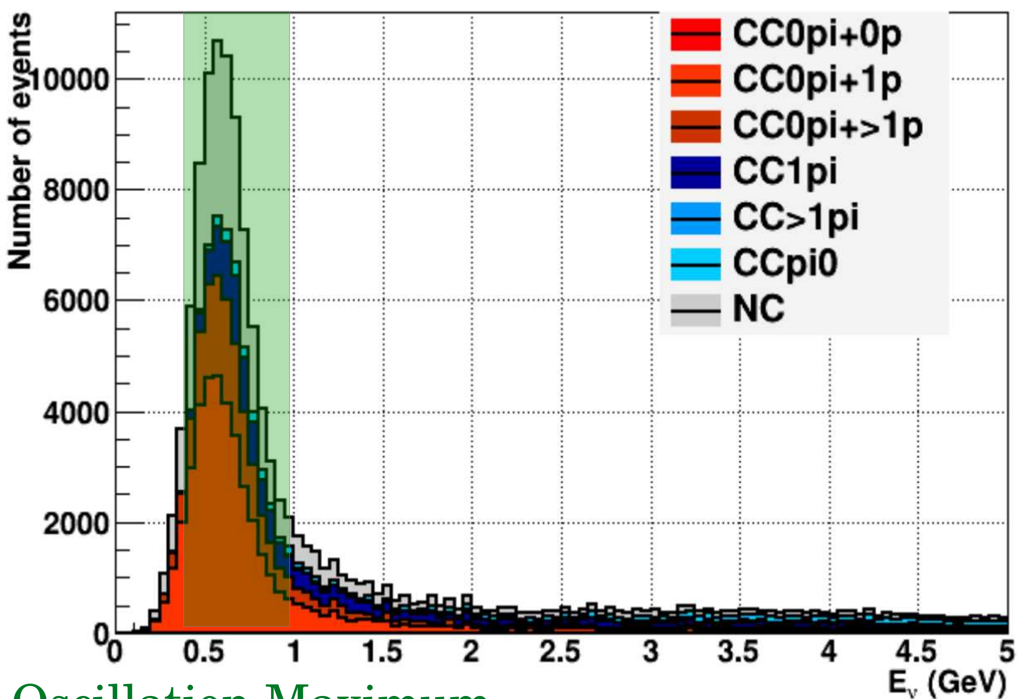
H_2O Module ID card :

Module size : 230 x 60 x 130 cm³ **~ 1.8 tons** (FGD ~ 2t).
Cell size (resolution) : 2.5x2.5x2.5 cm³ cells
Plastic background substraction : **H_2O:CH(Plastic)=7:3** in H_2O module (FGD2 is 4:6)

Expected number of events

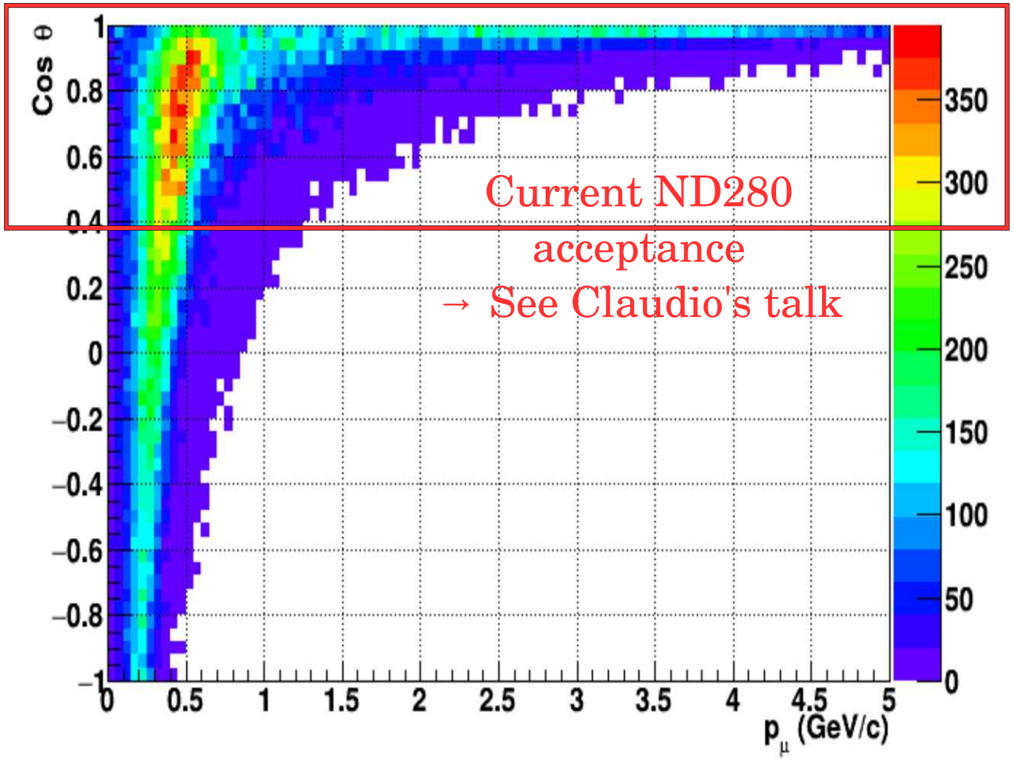
Number of true events : (Classification based on true information) for 10^{21} POT

As a function of neutrino energy :



Oscillation Maximum
~ 600-700 MeV

As a function of muon kinematics :

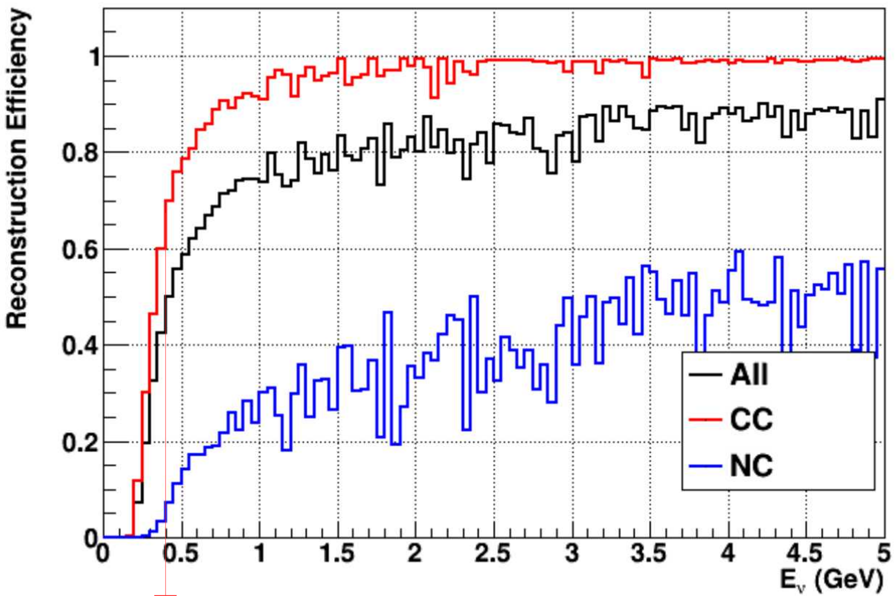


1. T2K, the signal + background E_ν > 300-400 MeV : Needs high efficiency for E_ν > 400 MeV
Both in the oscillation region (signal~ CC0π at 600MeV) & outside (background constraints)

2. Number of events at large angle : cos $\theta_\mu < 0.4$ → 32 % of the events !
Definitely need a high efficiency on the whole angular range 2π.

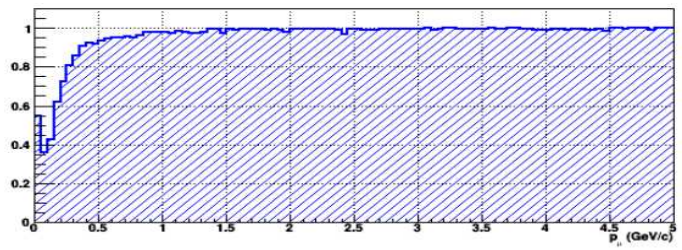
Reconstruction efficiencies

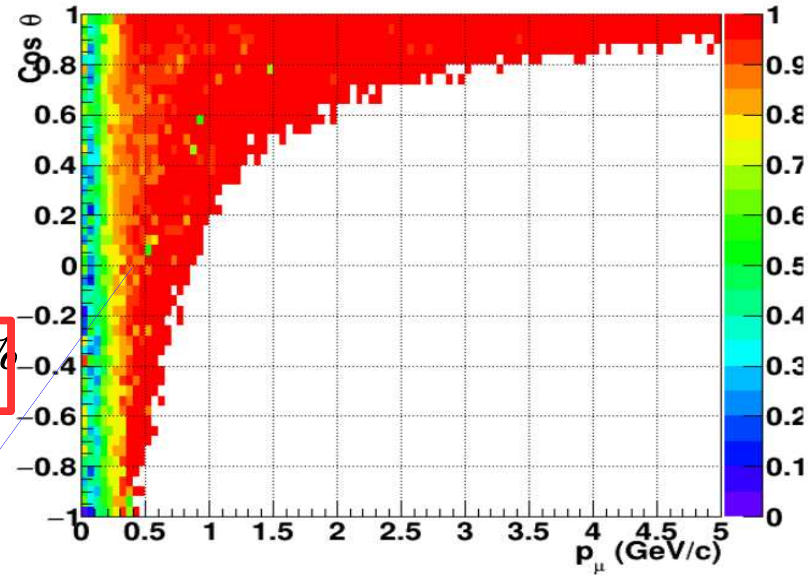
As a function of neutrino energy :

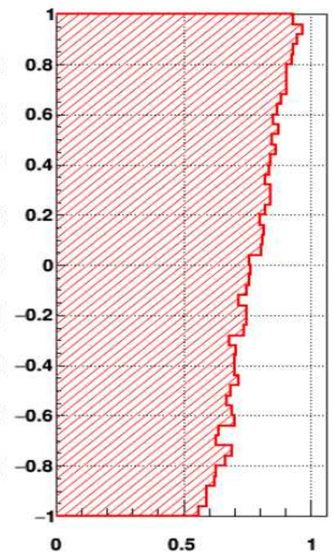


1. High efficiency for E_ν > 400 MeV: >70 %

As a function of muon kinematics :







2. High efficiency with p_μ :

ε > 80 % for p_μ > 300 MeV/c.

3. High efficiency on 2π range :

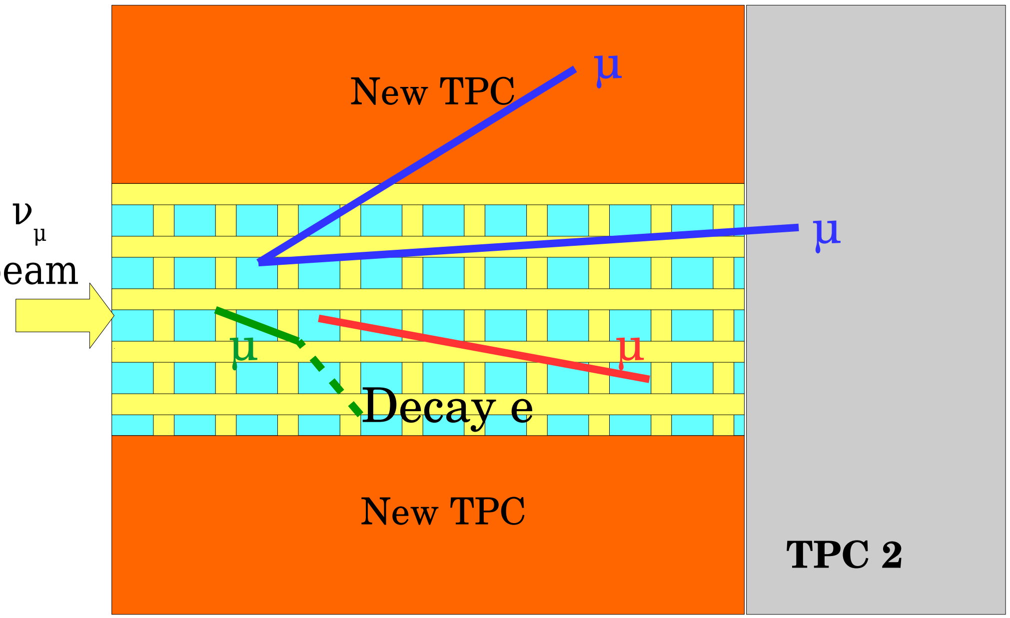
→ Efficiency is uniform with cos θ_μ.

	CC0π	All
Number of Interactions	54302	86361
Fraction	63 %	100 %
Reconstruction efficiency	85 %	68 %

No problem : due to NC

→ But p_μ decreases with cos θ_μ → ε=80% for cos θ_μ=0 → & ε=55% for cos θ_μ=-1.

Selection efficiency & purity



A particle is muon-like if :

Reaching TPC :

1. Is true μ/π & 1 hit in tracker

Not reaching TPC :

2. ⩾ 4 hits in tracker & Tracker PID > 0.15

Or

3. ⩾ 1hit in tracker & 1 decay-e

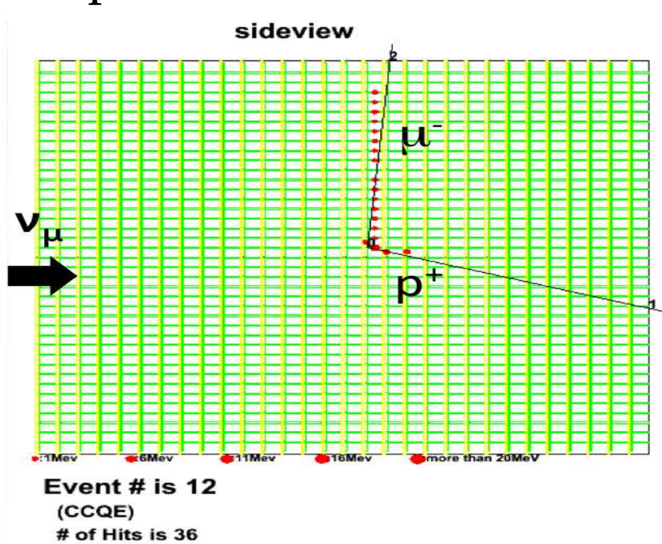
→ Else : particle is non muon-like

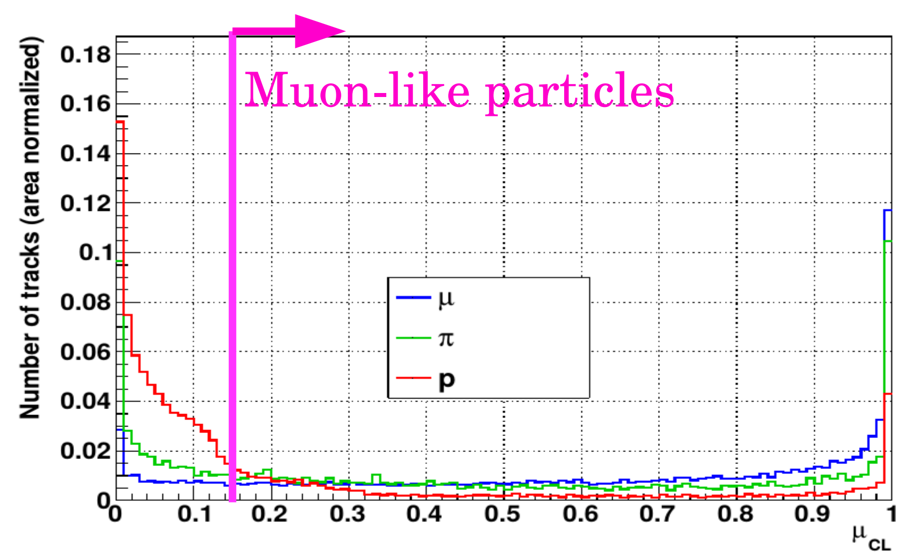
Large proportions of hadrons stopped in tracker:

→ Need a PID in the tracker PID !

→ Based on particle dE/dx :

True track type	μ	π	proton
Proportions of track stopping in tracker	6%	39%	56%





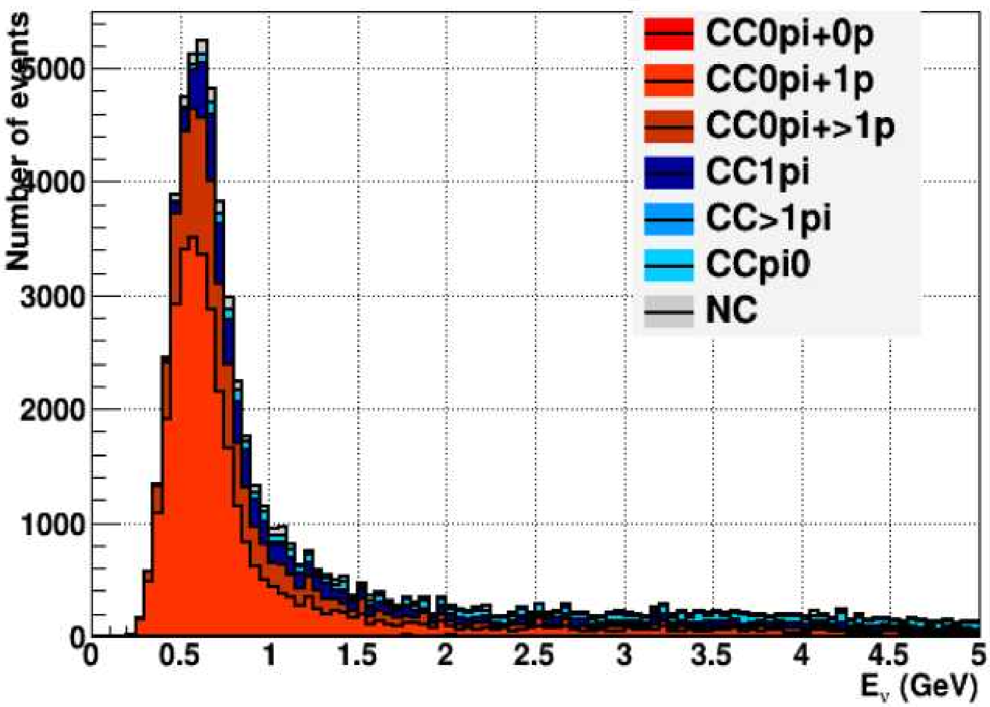
Selection efficiency & purity

Interactions are classified based on the number of mu-like tracks (M) :

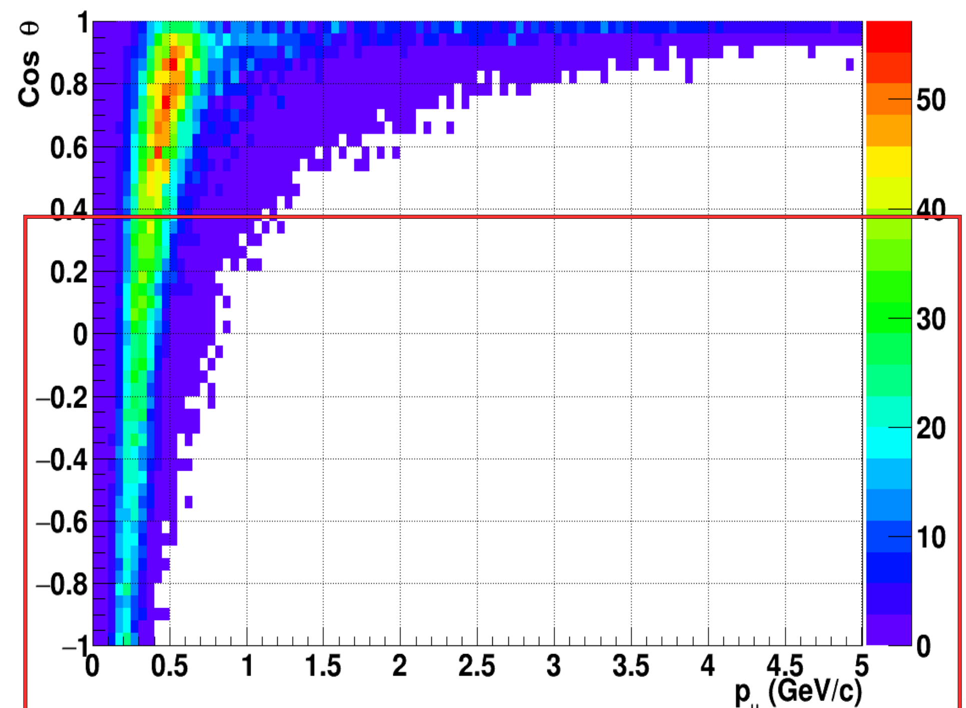
NC <=> M=0 CC0π <=> M=1 CC1π <=> M=2 CCOthers <=> M>2

	Purity	Efficiency	True CC1π	True CCOthers
Current ND280 (CC0π channel)	70 %	48 %	10 %	12 %
ND280 Upgrade (CC0π channel)	75 %	74 %	12 %	9 %

Selected CC0pi :



True CCQE :



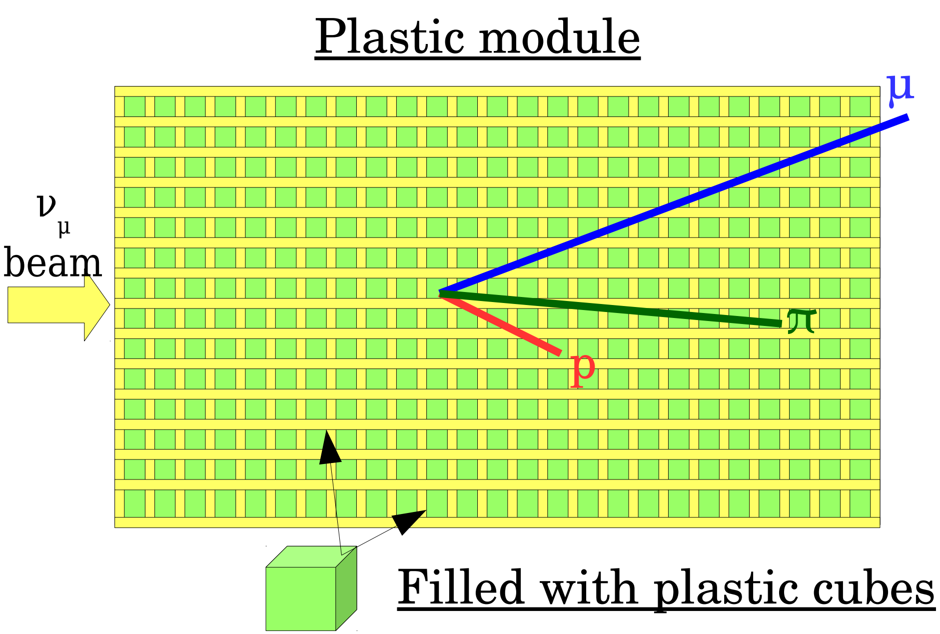
CC0π channel between current & upgraded ND280:

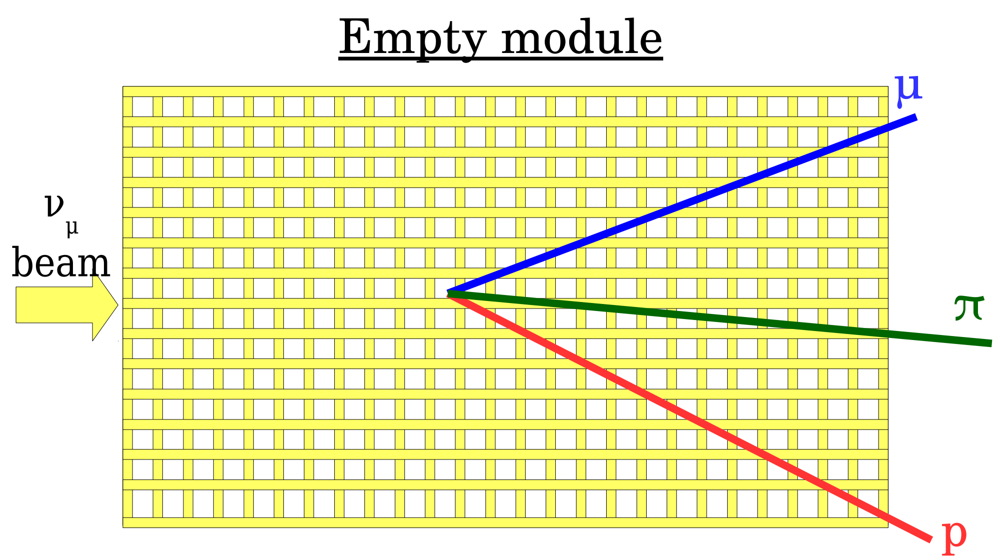
→ Purity increased from 70 % to 75 % with an efficiency increased from 48 % to 74 %!

→ Mostly comes from enlarged anular acceptance to 2π.

Neutrino interaction with scintillators (C8H8) → 30 % background that should be substracted

2 methods are proposed :





++ : Particle energy deposition = H_2O module.
High statistics.

- - : Little abilities to use proton kinematic (50 % of protons lost) → Small MEC/CCQE separation.

++ : Proton reconstruction threshold decreased to 250 MeV/c → Large MEC/CCQE separation (see slide 10 & back-up)

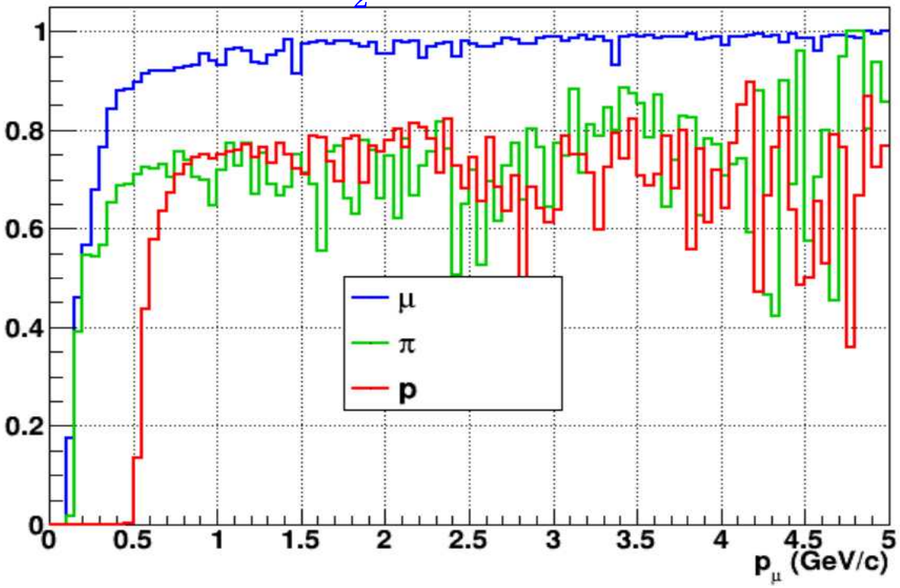
- - : -Particle energy deposition ≠ H_2O module → Efficiency corrections → Systematics !
-Smaller statistics (1/3 of H_2O module).

Empty module opens new possibilities for daughter hadron reconstruction & measurements.

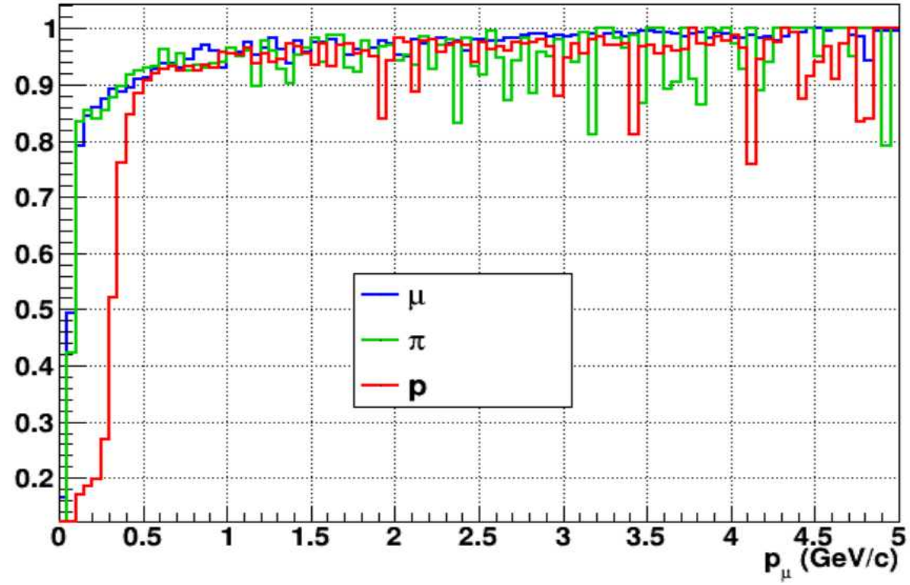
Empty module

Reconstruction efficiencies :

H_2O module



Empty module



Proton threshold : 550 → 300 MeV/c :

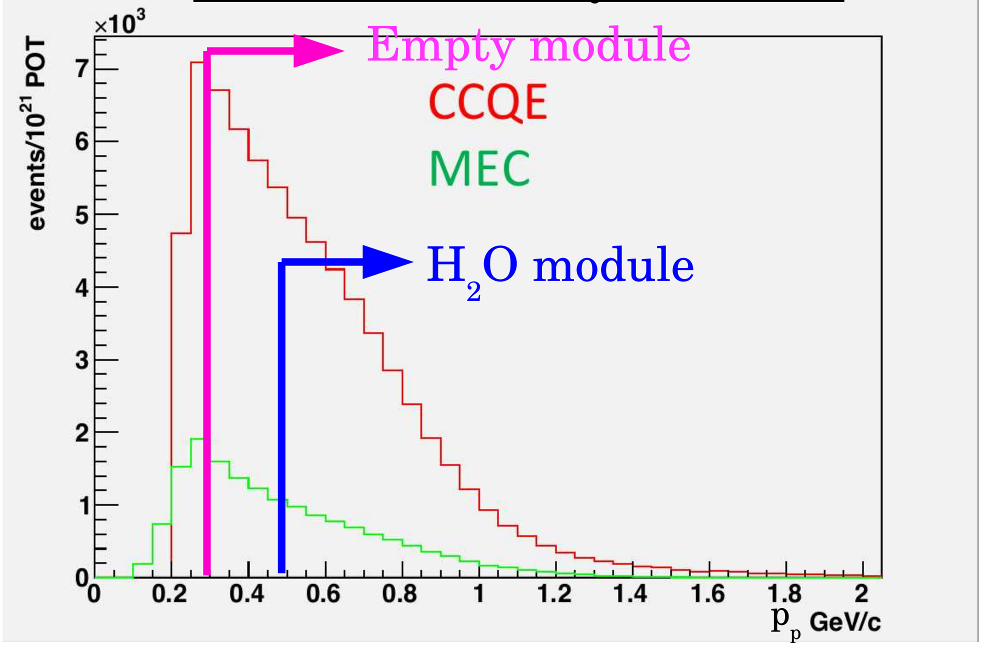
26 % →70 % of protons are reconstructed

MEC & FSI studies possible !

52 % → 87 % of pions reconstructed

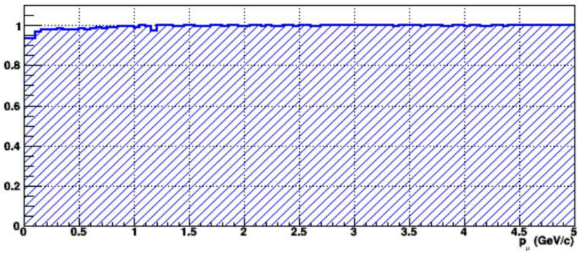
FV mass : 0.3 tons → 1/3 of current FGD

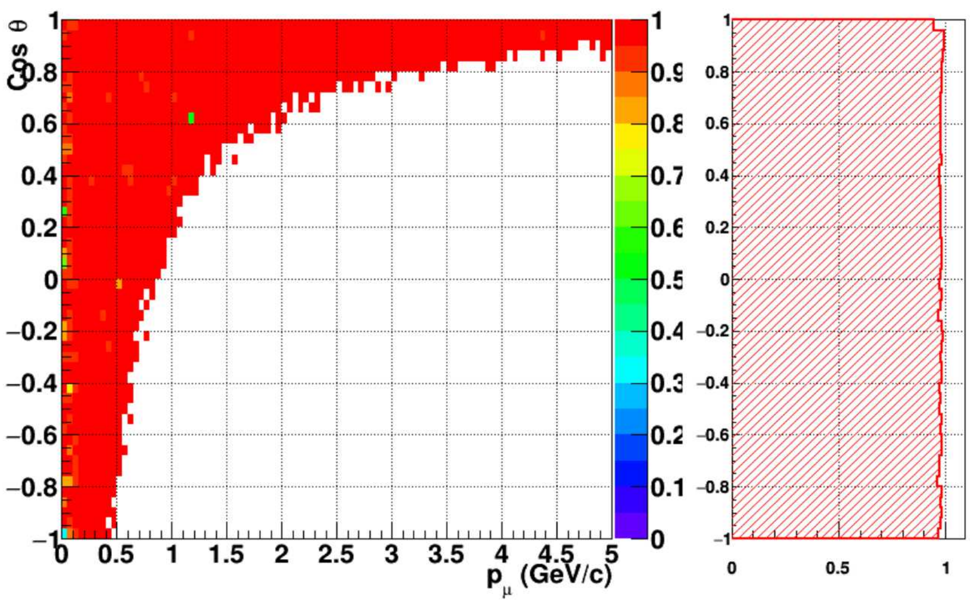
Protons from CCQE & MEC :



Empty module

1. Reconstruction efficiency > 90 % In the whole muon phase space.





	Number of selected events	Purity	Selection Efficiency
CC0π (H_2O module)	47383	75 %	74 %
CC0π (Empty module)	15013	79 %	79 %

1. Statistics is sufficient for ν_μ. Statistics for ν_e is a possible issue for this module.

2. Reconstruction efficiency > 90 % on the whole phase space !
→ Selection only limited by the PID.

3. Separation on CCQE & MEC effects (back-up) → Use proton counting & transverse variables →

[7] X-G. Lu, Measurement of nuclear effects in neutrino interactions with minimal dependence on neutrino energy, *Preprint* hep-ex/1512.05748.
[8] X-G. Lu *et al* , , Phys. Rev. D **92(5)**, 051302 (2015).

→ Ungoing WAGASCI : allow to estimate the systematics associated to the CH interaction substraction with an empty module.

Staging advantages : the WAGASCI Project

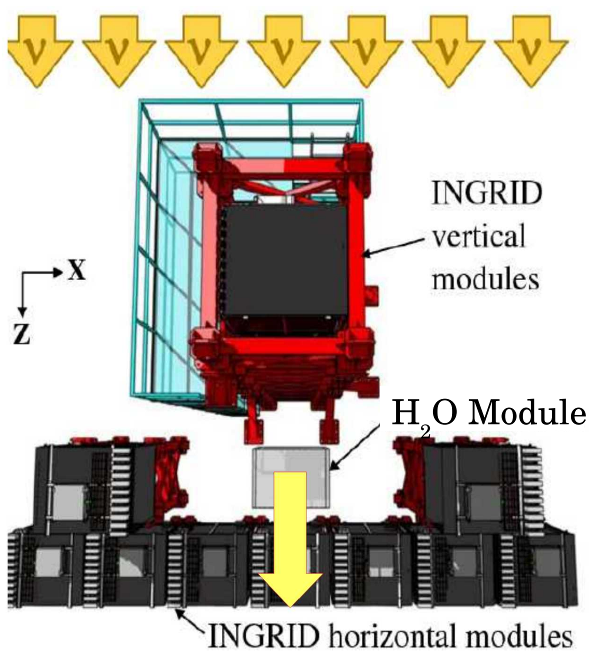
WAGASCI (T59 experiment) is an approved experiment at JPARC.

Goal : Measure the H_2O to C_8H_8 ratio with a 3 % accuracy.

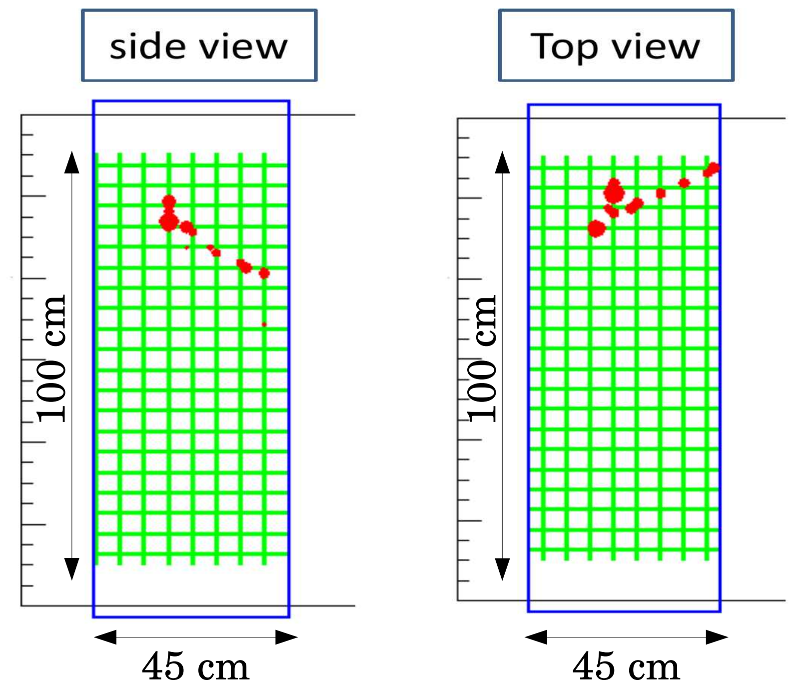
3 modules of 100x100x45cm : $2xH_2O + 1xC_8H_8$ with 5x5x2.5 cm³ cells → H_2O:CH=8:2

1. One H_2O module already installed & take data since 27 October 2016 ! → It works !

Prototype installed **on-axis :**



First neutrino event !

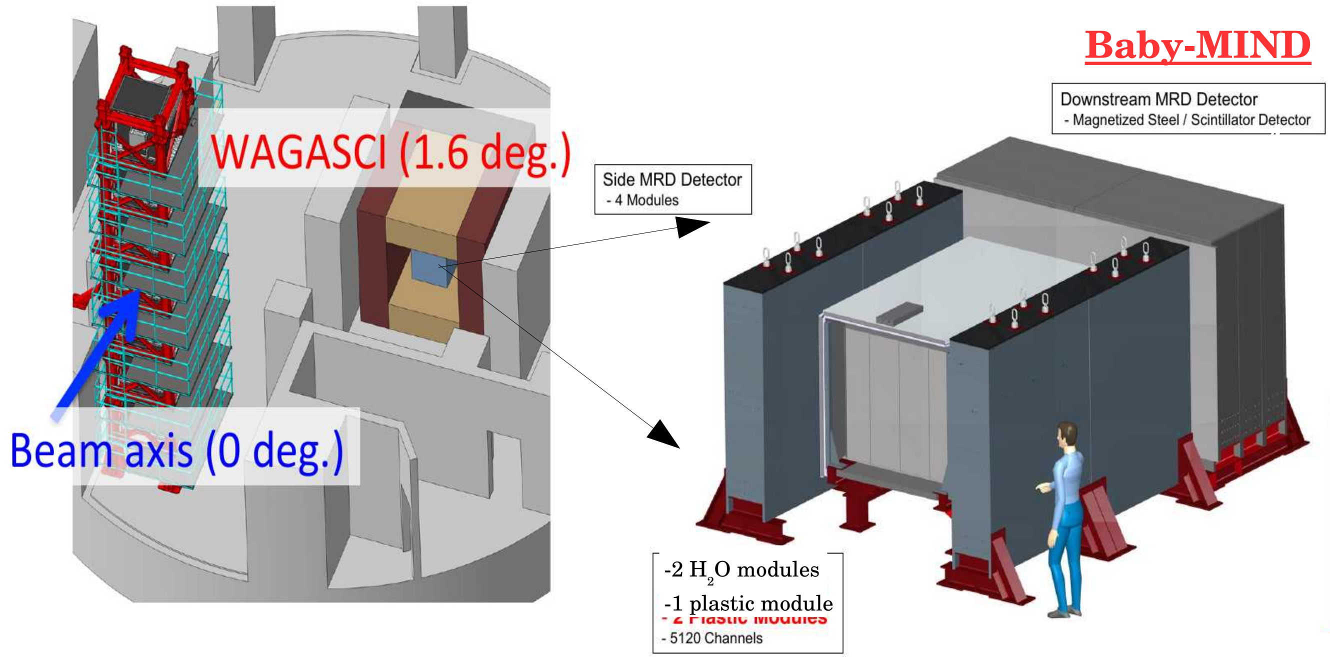


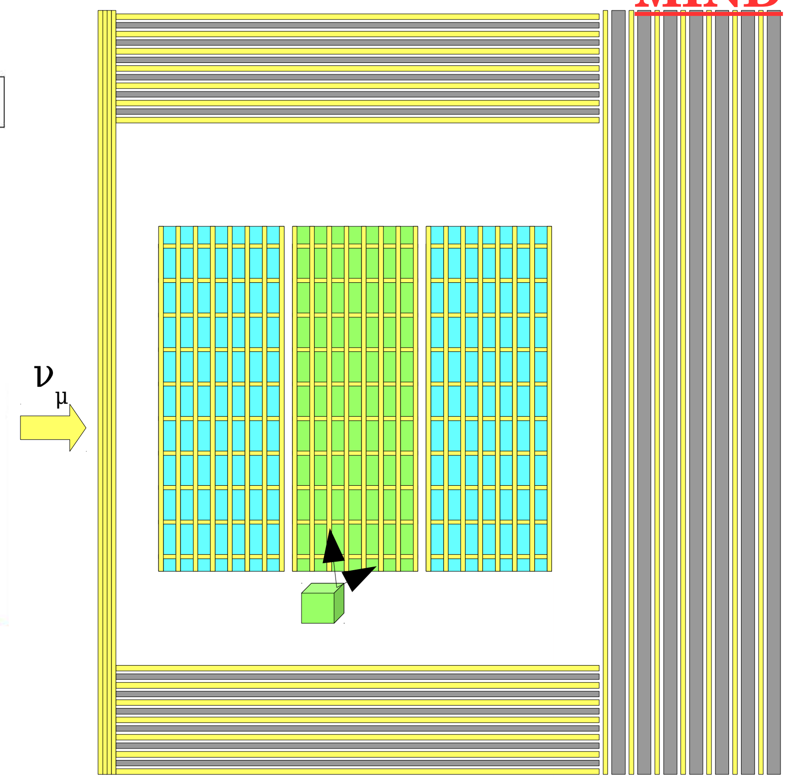
1st measurement on-axis in 2017 ! → Only for foward tracks !

1st systematics estimation using Empty Module (Proton Module) for CH interaction substract

2. 2xH_2O+1xC_8H_8 modules → Installed @1.6° → Autumn 2017

Baby-MIND





Baby-MIND : Magnetized downstream muon range detector (MRD) : Charge ID → ν / $\bar{\nu}$ separation

Side MRDs : ~2π acceptance → First H_2O/C_8H_8 measurement @ large muon angles.

1st high angle (2π) cross-section measurement in 2018 !

1st systematics estimation using Plastic Module for CH interaction substraction

Conclusions & schedule

1. Need a detector with the same target (**H_2O**) & angular acceptance (2**π**) as Super-K.

<u>2. WAGASCI provides excellent efficiency on the entire range of the neutrino flux :</u>

ε >70 % for E_ν > 400 MeV, ε > 80 % for p_μ > 300 MeV/c, ε > 55 % for cos θ_μ >-1.

→ Ideal detector to constrain not only the SK phase space, but also the whole flux !

3. Better purity (75 % for CC0pi) & <u>far higher efficiency (48 % → 74 %) than current ND280.</u>

→ Full simulation, reconstruction & PID packages are ready !

→ Impact on cross-section models & oscillation parameters under study (see Davide's talk)

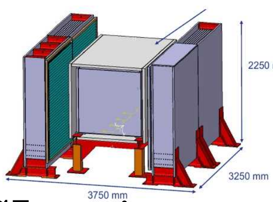
→ Mechanical constraint for the supporting structure are now tackled !

4. High separation between external tracks & backward going tracks than current ND280 !

→ Using reconstruction & timing.

<u>5. Empty module :</u> new era for understanding cross-section model using proton kinematics !

<u>**→staging :**</u> On-axis measurement (2017), High angle measurement @1.6° (2018).



<u>ND280 tracker → Based on experience & improvements from the whole WAGASCI project</u>

Reconstruction & PID improved by removing detector defaults (Hit efficiency, Light yield...)

Both plastic & empty module substraction systematics will be estimated.

Construction & Reconstruction & Analysis methods will be directly exported !

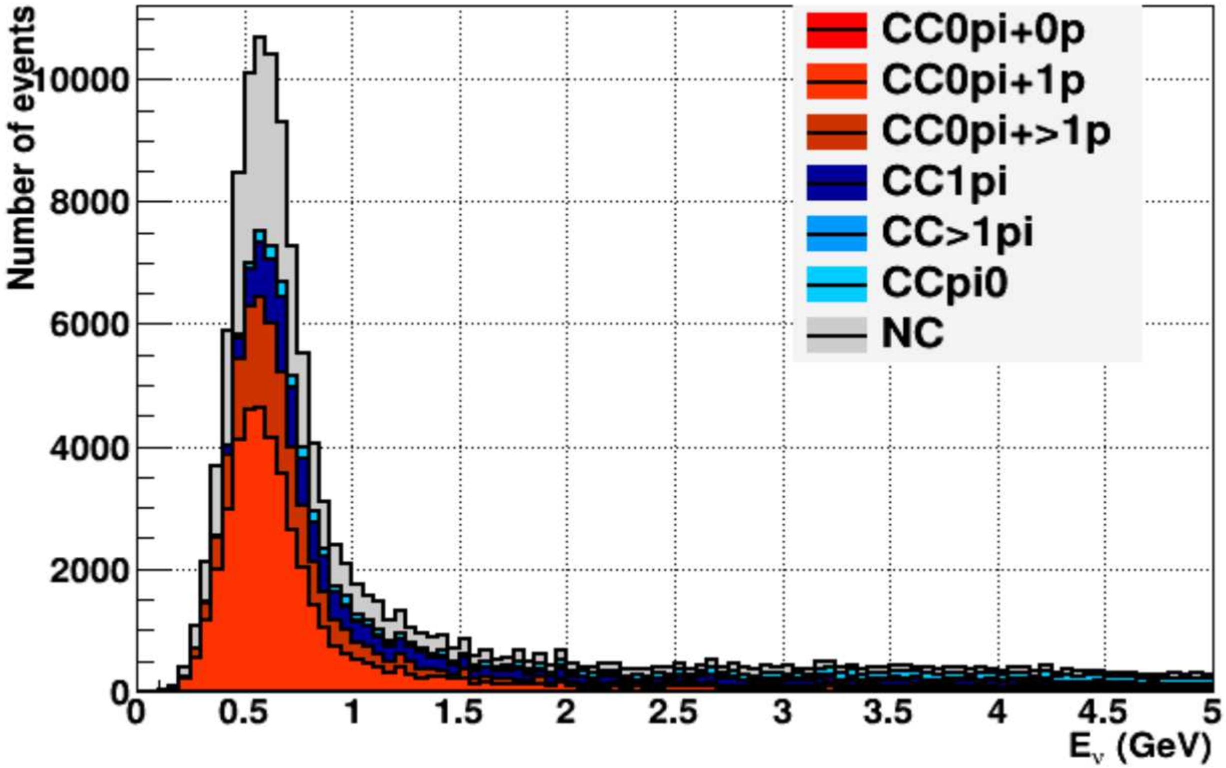
Additional slides

Expected number of events

FGD1 mass : (230x240x36.5 cm³) 2.0 T / WAGASCI water mass : (230x60x130 cm³) 1.8 T

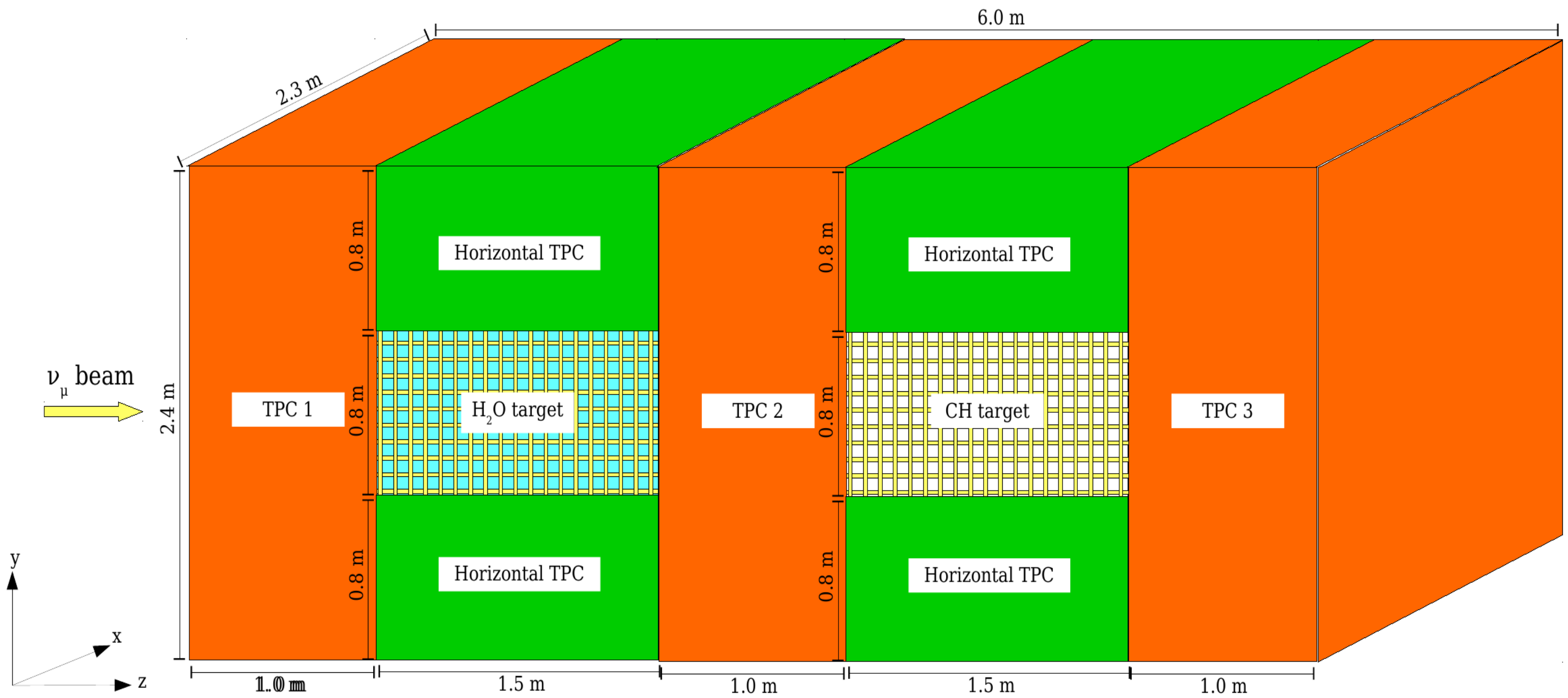
FGD FV cut : 175x175x31cm³ →0.9 T / WAGASCI FV cut : 166.4x40x110cm³ → 0.7 T

Number of true events : (Classification based on true information) for 10^{21} POT



	CC0π	CC1π	CCOthers	NC	All
Number of interactions	63834	16474	11029	35847	127185
Purity	50%	13%	9%	28%	100%

Checklist for the ND280-upgrade central detector



<u>Requirements for the near detector tracker/central module :</u>

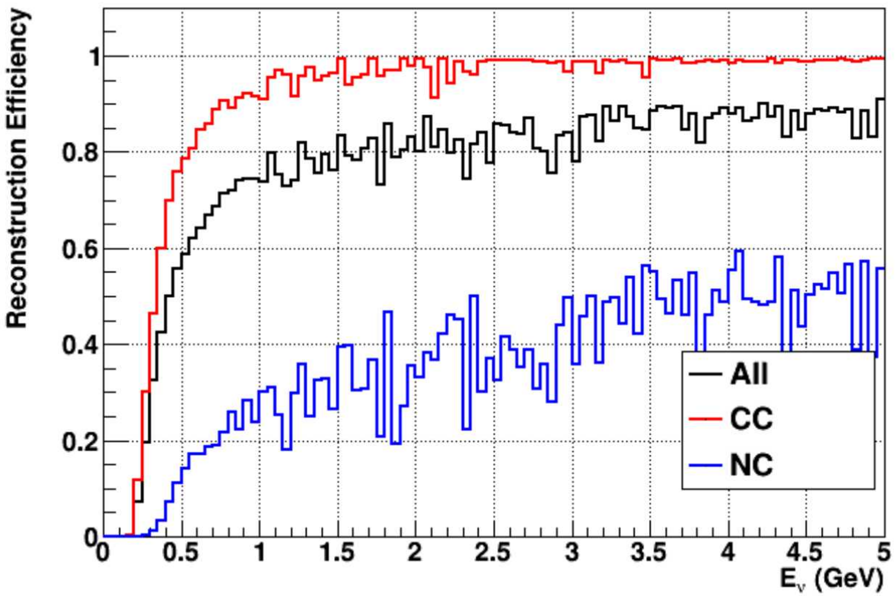
Reproduce SK target & acceptance → **H_2O target**

Cover SK momentum & angular phase space → **4π angle coverage**

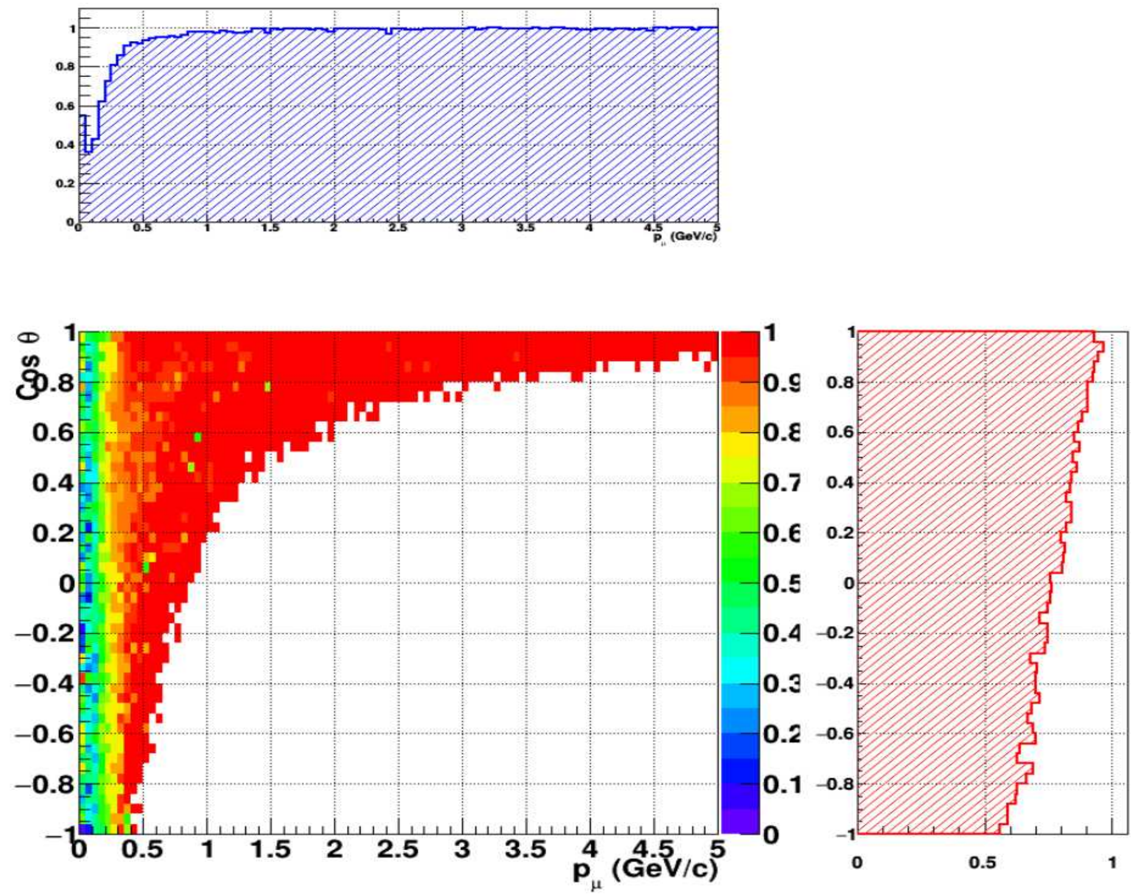
Do not degrade any other performances of the current ND280 → **High granularity** for tracking muons, but mainly pions & protons → Topology classification (CC0π, CC1π …) → Might try to enhance is also with the proton final states !

Reconstruction efficiencies

As a function of neutrino energy :



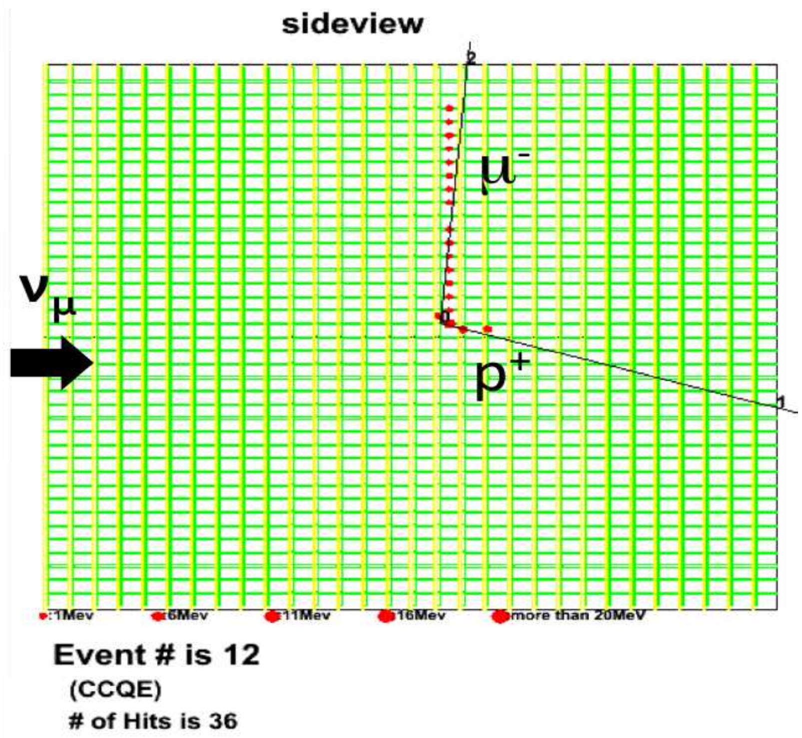
As a function of muon kinematics :

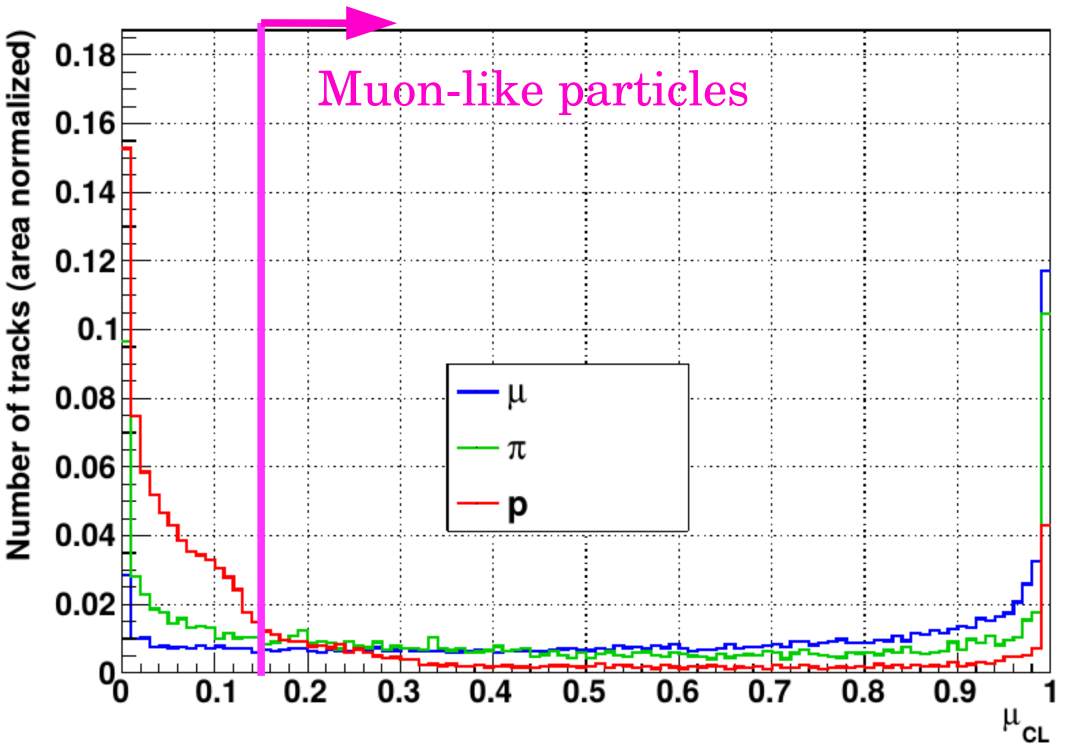


	CC0π	CC1π	CCOthers	NC	All
Number of Interactions	54302	14326	9985	7748	86361
Fraction	63 %	17 %	12 %	9 %	100 %
Reconstruction efficiency	85 %	87 %	91 %	22 %	68 %

2D plot → Consequence of smaller momenta in backward region.

Based on muon confidence level → Use particle dE/dx





<u>Summary of the PID efficiency & purity :</u>

	μ	π	p
Reconstruction Efficiency	79%	52%	26%
μ-like particle Efficiency	77%	45%	4%
Reconstruction Purity	56%	14%	31%
μ-like particle purity	77%	17%	7%
Momentum threshold	150 MeV/c	200 MeV/c	550 MeV/c

77 % of true μ = reconstructed & μ-like

45 % of true π = reconstructed & μ-like

4 % of true p = reconstructed & μ-like
→ 26 % only reconstructed
→ In these 26 %, 85 % are non μ-like

<u>→ Main issue comes from low pion reconstruction, not PID !</u>

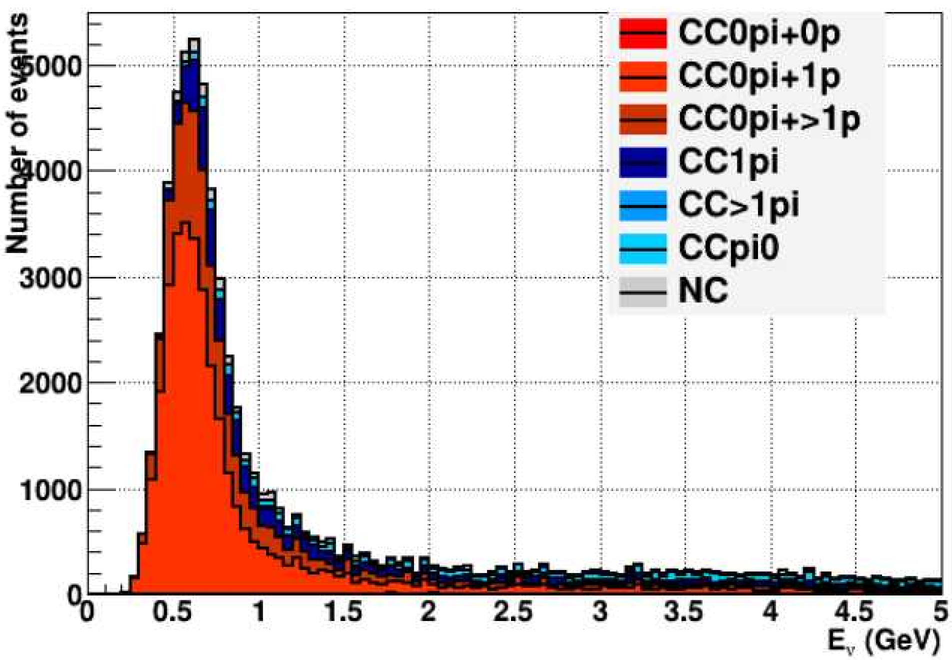
Selection efficiency & purity

Interactions are classified based on the number of mu-like tracks (M) :

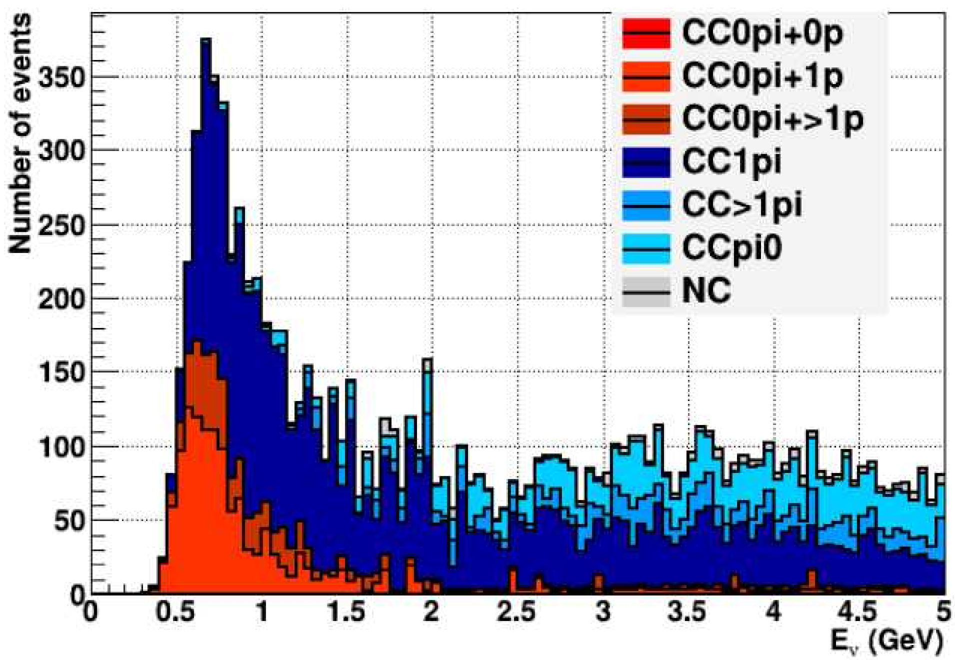
NC <=> M=0 CC0pi <=> M=1 CC1pi <=> M=2 CCOthers <=> M>2

	True CC0pi	True CC1pi	True CCOthers	Eff.
CC0pi	70 % → 75 %	10 % → 12 %	12 % → 9 %	48 % → 87 %
CC1pi	5 % → 20%	54 % → 50 %	28 % → 28 %	27 % → 36 %
CCOthers	5 % → 1 %	9 % → 21 %	73 % → 76 %	28 % → 11 %

Selected CC0pi :



Selected CC1pi :



Current limit → if π non-reconstructed → Forget « μ-like track »

→ 52 % π are not reconstructed & 7 % mis-ID → Migration to lower number of μ-like tracks !

3 Criteria are used :

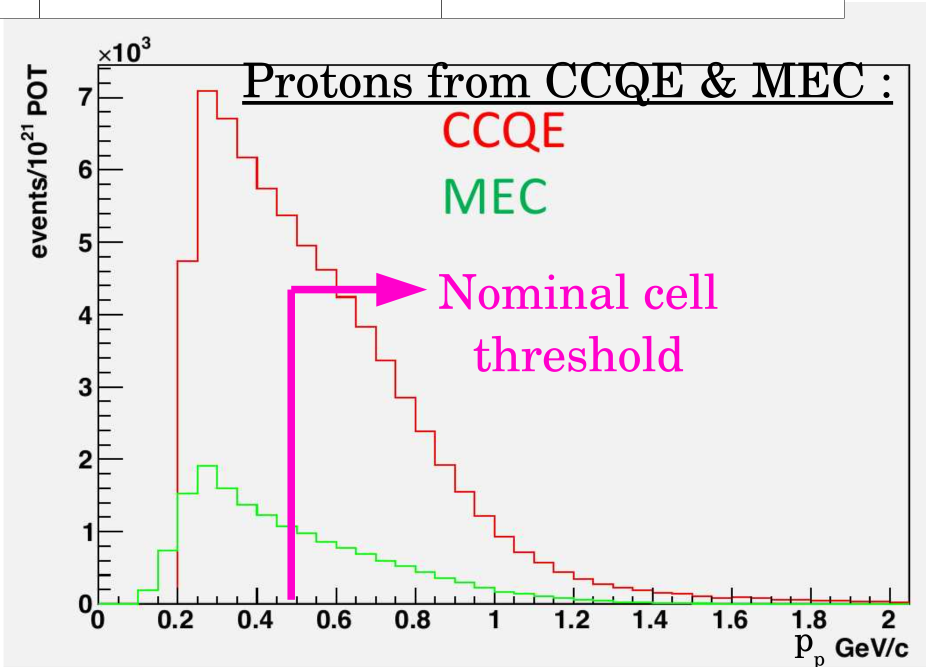
→ H_2O:CH ratio (background substraction) & H_2O mass (statistics)

→ Proton threshold : ability to distinguish interactions : assume 2 hits + muon track

→ Costs

	5x5x2.5 cm³	**2.5^3 cm³**	**2.0^3 cm³**	**1.0 cm³**
H_2O:CH	8:2	7:3	6:4	4:6 ~ FGD2
Proton threshold	500-550 MeV/c	400-450 MeV/c	~ 400 MeV/c	300 MeV/c
Costs (1 tank)	0.7 M$	0.9 M$	1.3M$	3.7 M$

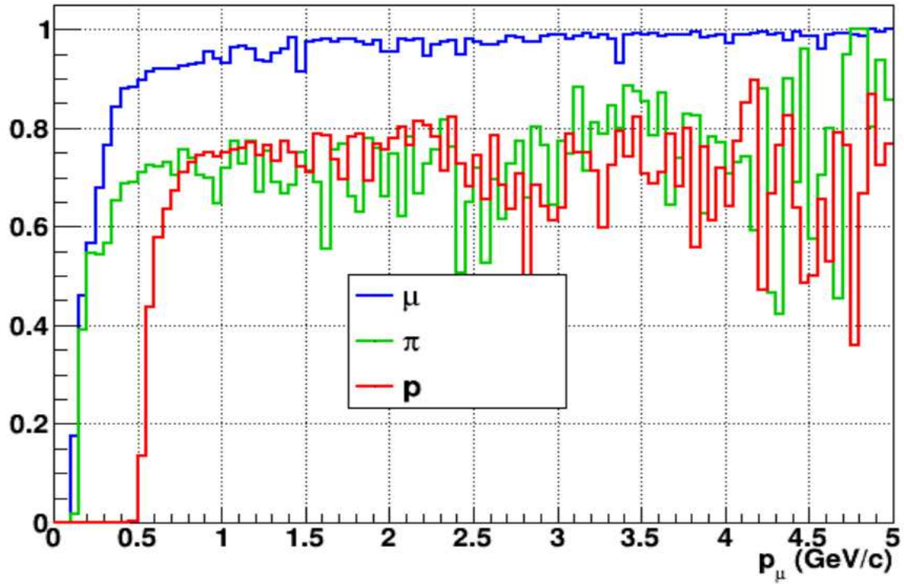
- **(FGD2-FGD1)/FGD1 analysis :** 2 % uncertainty
  → H_2O:CH >~ 4:6 seems enough
  → 1.0^3 cm³ seems ideal ! But costs are really high…
- The 2.5^3 cm³ cells seems more reasonable !
  → **Nominal design**
- … but loose ~50% of protons from MEC & CCQE !



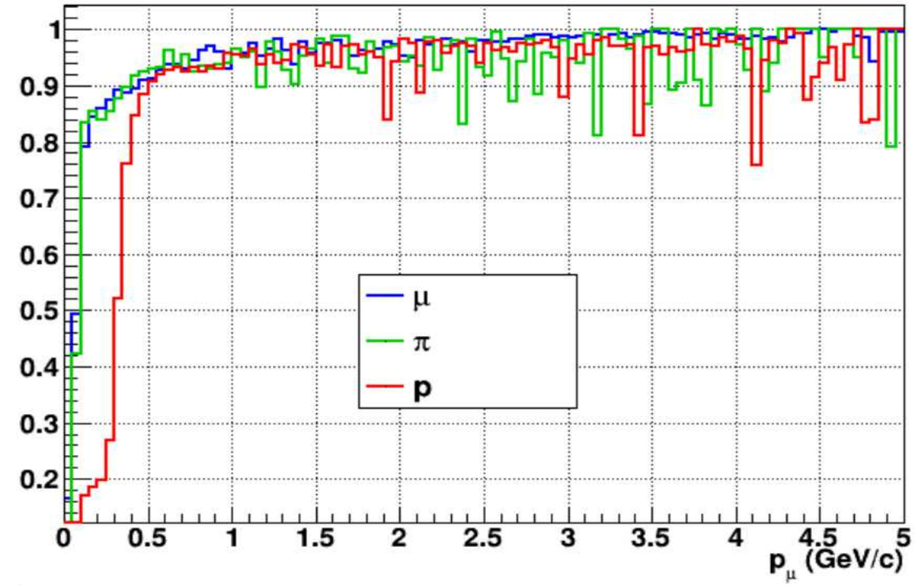
Empty module

Reconstruction efficiencies :

Water-in



Water-out



	μ	π	p
Reconstruction Efficiency	79%	52%	26%
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Reconstruction Purity	56%	14%	31%
μ-like particle purity	77%	17%	7%
Momentum threshold	150 MeV/c	200 MeV/c	550 MeV/c

	μ	π	p
Reconstruction Efficiency	90%	87%	70%
μ-like particle efficiency	89%	83%	9%
Reconstruction Purity	37%	13%	49%
μ-like particle purity	65%	23%	12%
Momentum threshold	50 MeV/c	50 MeV/c	300 MeV/c

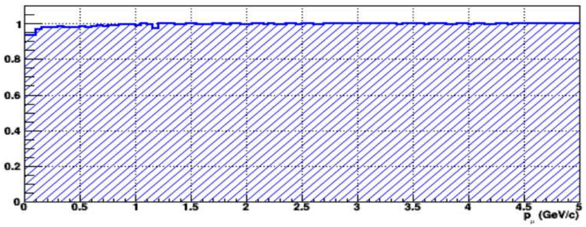
Proton threshold reduced from 550 MeV/c to 300 MeV/c

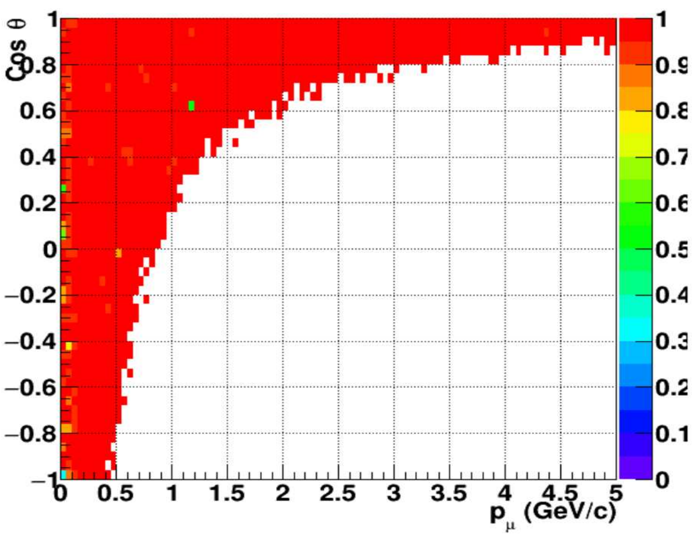
→ 26 % →70 % of protons are reconstructed → MEC & FSI studies possible !

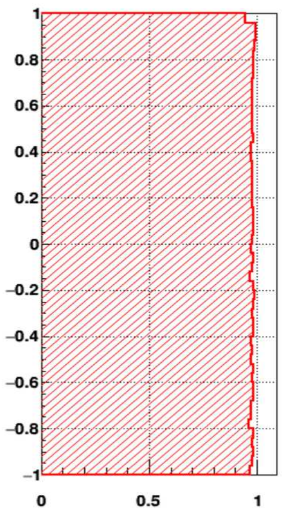
52 % → 87 % of pions reconstructed

FV mass : 0.3 tons → 1/3 of current FGD

Empty module







	CC0π	CC1π	CCOthers	NC	All
Selected CC0π					
Number of interactions	15013	1224	1349	1528	19114
Selection+reconstruction Efficiency	80%	25%	41%	28%	
Selection+reconstruction Purity	79%	6%	7%	8%	
Selected CC1π					
Number of interactions	2038	3324	1007	260	6628
Selection+reconstruction Efficiency	11%	67%	31%	5%	
Selection+reconstruction Purity	31%	50%	15%	4%	
Selected CCOthers					
Number of interactions	110	302	779	48	1240
Selection+reconstruction Efficiency	1%	6%	24%	1%	
Selection+reconstruction Purity	9%	24%	63%	4%	
Selected NC					
Number of interactions	1505	100	141	3541	5287
Selection+reconstruction Efficiency	8%	2%	4%	66%	
Selection+reconstruction Purity	28%	2%	3%	67%	

Reconstruction efficiency > 90 % In the whole muon phase space.

Statistics is enough for muons → It will be clearly problematic for electron.

<u>But main issue :</u>

what systematics can we expect from using a water-out module for background substraction
→ It will ultimately needs a full analysis before detector choice.

IV-Geometry tested for optimization

1. Decrease the detector size → Stastistics is decreased but proportions of pion in TPC higher → PID abilities are increased.

2. Decrease the cell size → Reconstruction threshold decrease but price increased.

Geometry tested :

Dimensions (x × y × z)	Cell volume	Weight	Costs	H_2O:CH	$p_\mu/p_{\pi^{+/-}}$ thresholds	p_p threshold
$186.4 \times 60 \times 130$ cm^3	2.5^3 cm^3	1.45 tons	0.69 M$	7:3	150 MeV/c	550 MeV/c
$186.4 \times 30 \times 130$ cm^3	2.5^3 cm^3	0.73 tons	0.60 M$	7:3	150 MeV/c	550 MeV/c
$186.4 \times 60 \times 65$ cm^3	2.5^3 cm^3	0.73 tons	0.46 M$	7:3	150 MeV/c	550 MeV/c
$186.4 \times 60 \times 130$ cm^3	2.0^3 cm^3	1.45 tons	0.9 M$	6:4	100 MeV/c	500 MeV/c
$186.4 \times 60 \times 130$ cm^3	1.0^3 cm^3	1.45 tons	2.5 M$	4:6	50 MeV/c	450 MeV/c

Status of the true pion (stopped, exiting, side escaping)

	Tracker stopped w/o decay-e	Tracker stopped w/ decay-e	Side escape	Enters TPC
Nominal	49%	21%	5%	25%
$186.4 \times 30 \times 130$ cm^3	41%	18%	4%	37%
$186.4 \times 60 \times 65$ cm^3	44%	21%	4%	31%
2^3 cm^3 cells	48%	21%	5%	26%
1 cm^3 cells	45%	20%	6%	28%

IV-Reduce the detector size

	Not reconstructed	Reconstructed not μ-like	Reconstructed and μ-like
Nominal	52%	7%	42%
$186.4 \times 30 \times 130$ cm^3	47%	5%	48%
$186.4 \times 60 \times 65$ cm^3	49%	6%	45%
2^3 cm^3 cells	45%	9%	46%
1 cm^3 cells	30%	11%	59%

Proportions of reconstruted & ID pions : from 42 % → 45/48 % when decreasing the detector size → Check effect on selection of interactions

Nominal :

	CC0π	CC1π	CCOthers	NC	All
Selected CC0π					
Number of interactions	47383	7799	5568	2725	63476
Selection+reconstruction Efficiency	87%	54%	56%	35%	
Selection+reconstruction Purity	75%	12%	9%	4%	
Selected CC1π					
Number of interactions	2088	5169	2769	251	10278
Selection+reconstruction Efficiency	4%	36%	28%	3%	
Selection+reconstruction Purity	20%	50%	27%	2%	
Selected CCOthers					
Number of interactions	15	306	1081	23	1425
Selection+reconstruction Efficiency	0%	2%	11%	0%	
Selection+reconstruction Purity	1%	21%	76%	2%	
Selected NC					
Number of interactions	4816	1052	567	4749	11183
Selection+reconstruction Efficiency	9%	7%	6%	61%	
Selection+reconstruction Purity	43%	9%	5%	42%	

186.4x30x130 cm³ :

	CC0π	CC1π	CCOthers	NC	All
Selected CC0π					
Number of interactions	12988	1938	1434	660	17019
Selection+reconstruction Efficiency	91%	53%	55%	32%	
Selection+reconstruction Purity	76%	11%	8%	4%	
Selected CC1π					
Number of interactions	485	1500	722	76	2783
Selection+reconstruction Efficiency	3%	41%	28%	4%	
Selection+reconstruction Purity	17%	54%	26%	3%	
Selected CCOthers					
Number of interactions	4	60	329	7	400
Selection+reconstruction Efficiency	0%	2%	13%	0%	
Selection+reconstruction Purity	1%	15%	82%	2%	
Selected NC					
Number of interactions	817	144	117	1333	2411
Selection+reconstruction Efficiency	6%	4%	5%	64%	
Selection+reconstruction Purity	34%	6%	5%	55%	

CC0pi : Efficiency increased only by 4 % & purity by 1 % → More pions reconstructed.
… But statistics / 5 (FV is too small for the 186.4x30x130 cm³ configuration)

Dimensions (x × y × z)	Cell volume	Mass	FV dimensions	FV Mass
$186.4 \times 60 \times 130$ cm^3	2.5^3 cm^3	1.45 tons	$166.4 \times 40 \times 110$ cm^3	0.73 tons
$186.4 \times 30 \times 130$ cm^3	2.5^3 cm^3	0.73 tons	$166.4 \times 10 \times 110$ cm^3	0.18 tons
$186.4 \times 60 \times 65$ cm^3	2.5^3 cm^3	0.73 tons	$166.4 \times 40 \times 45$ cm^3	0.30 tons
$186.4 \times 60 \times 130$ cm^3	2.0^3 cm^3	1.45 tons	$170.4 \times 44 \times 114$ cm^3	0.85 tons
$186.4 \times 60 \times 130$ cm^3	2.1^3 cm^3	1.45 tons	$178.4 \times 52 \times 122$ cm^3	1.13 tons

Conclusions :

→ Reduce detector size → enhance selection purity.

→ Reduce detector length → smaller impact on purioty but smaller reduction of FV (statistics) but

→ A 30 cm height is too small.

Optimal : Try to keep FV >~0.45tons (half of current FGD) → higher reduction on length than height → Try Total Volume : 186.4 x 50 cm x 110 cm^3 → FV mass = 0.45 tons.

IV-Reduce the cell size

	Not reconstructed	Reconstructed not μ-like	Reconstructed and μ-like
Nominal	52%	7%	42%
$186.4 \times 30 \times 130$ cm^3	47%	5%	48%
$186.4 \times 60 \times 65$ cm^3	49%	6%	45%
2^3 cm^3 cells	45%	9%	46%
1 cm^3 cells	30%	11%	59%

Proportions of reconstruted & ID pions : from 42 % → 46/59 % when decreasing cell size → Check effect on selection of interactions

Nominal (2.5 cm³ cells):

	CC0π	CC1π	CCOthers	NC	All
Selected CC0π					
Number of interactions	47383	7799	5568	2725	63476
Selection+reconstruction Efficiency	87%	54%	56%	35%	
Selection+reconstruction Purity	75%	12%	9%	4%	
Selected CC1π					
Number of interactions	2088	5169	2769	251	10278
Selection+reconstruction Efficiency	4%	36%	28%	3%	
Selection+reconstruction Purity	20%	50%	27%	2%	
Selected CCOthers					
Number of interactions	15	306	1081	23	1425
Selection+reconstruction Efficiency	0%	2%	11%	0%	
Selection+reconstruction Purity	1%	21%	76%	2%	
Selected NC					
Number of interactions	4816	1052	567	4749	11183
Selection+reconstruction Efficiency	9%	7%	6%	61%	
Selection+reconstruction Purity	43%	9%	5%	42%	

1cm³ cells :

	CC0π	CC1π	CCOthers	NC	All
Selected CC0π					
Number of interactions	72203	9872	7458	6034	95566
Selection+reconstruction Efficiency	80%	41%	46%	32%	
Selection+reconstruction Purity	76%	10%	8%	6%	
Selected CC1π					
Number of interactions	7140	11603	4816	790	24349
Selection+reconstruction Efficiency	8%	48%	30%	4%	
Selection+reconstruction Purity	29%	48%	20%	3%	
Selected CCOthers					
Number of interactions	166	1073	2865	118	4222
Selection+reconstruction Efficiency	0%	4%	18%	1%	
Selection+reconstruction Purity	4%	25%	68%	3%	
Selected NC					
Number of interactions	10494	1806	1013	11645	24957
Selection+reconstruction Efficiency	12%	7%	6%	63%	
Selection+reconstruction Purity	42%	7%	4%	47%	

CC0pi : Efficiency decreased by 7 % & purity increased by 1 % → More pions reconstructed but not well ID→ Migration towards « natural purities of CC0pi, CC1pi... »

IV-Reduce the cell size

Conclusions :

→ Reduce the cell size : clearly enhance reconstruction efficiency.

→ But does not necessarily increase purity : the current PID of the tracker limits the purity enhancement ! → It is important to consider the analysis tool before selecting the final cell size !

→ Imagining this PID were the final one (it is not) : I would recommend to keep the 2.5^3 cm^3 cells considering the purity decrease smaller cell size creates + price increase

→ A 30 cm height is too small.

To do : seriously consider the PID improvement before selecting the final detector geometry !

First estimation for detector granularity

3 Criteria are used :

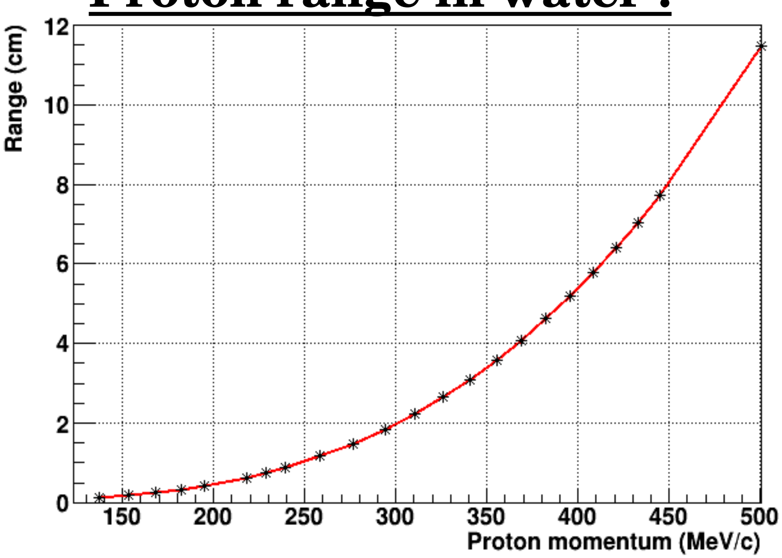
→ H_2O:CH ratio (background substraction) & H_2O mass (statistics)

→ Proton threshold : ability to distinguish interactions : assume 2 hits + muon track

→ Costs

	5x5x2.5 cm³	**2.5³ cm³**	**2.0³ cm³**	**1.0 cm³**
H_2O:CH	8:2	7:3	6:4	4:6 ~ FGD2
Proton threshold	500-550 MeV/c	400-450 MeV/c	~ 400 MeV/c	300 MeV/c
Costs (1 tank)	0.7 M$	0.9 M$	1.3M$	3.7 M$

Proton range in water :



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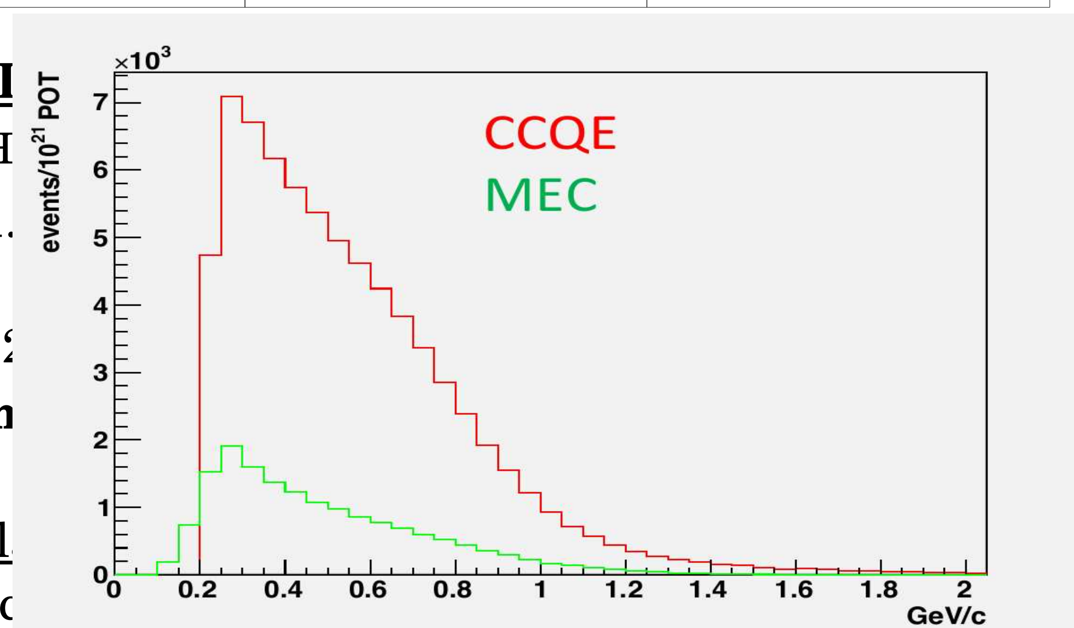
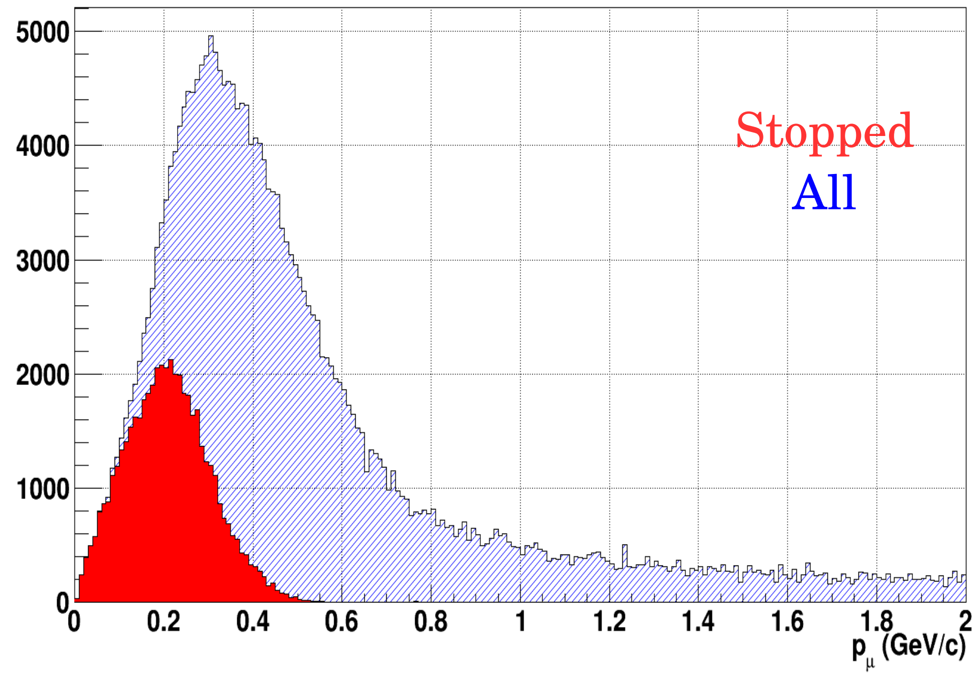
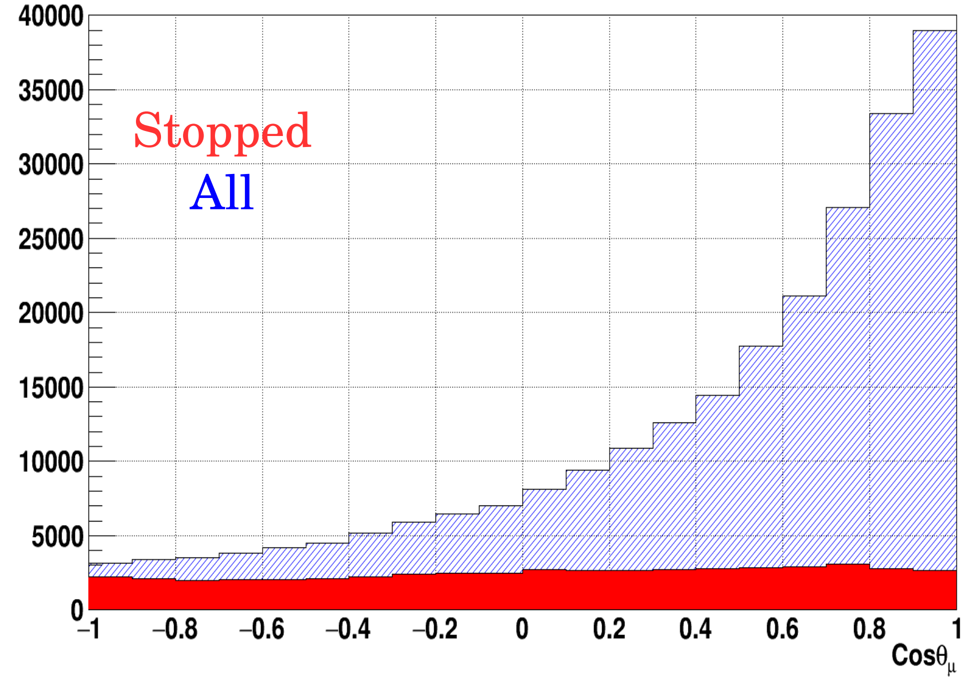


IV-Criteria for tuning : the muon case…

- Proportions of interactions whose muons is stopped in the tracker: 21 %





	CC0pi	CC1pi	CCother	Total
Proportions of stopped	18.4 %	32.7 %	17.7 %	20.8 %

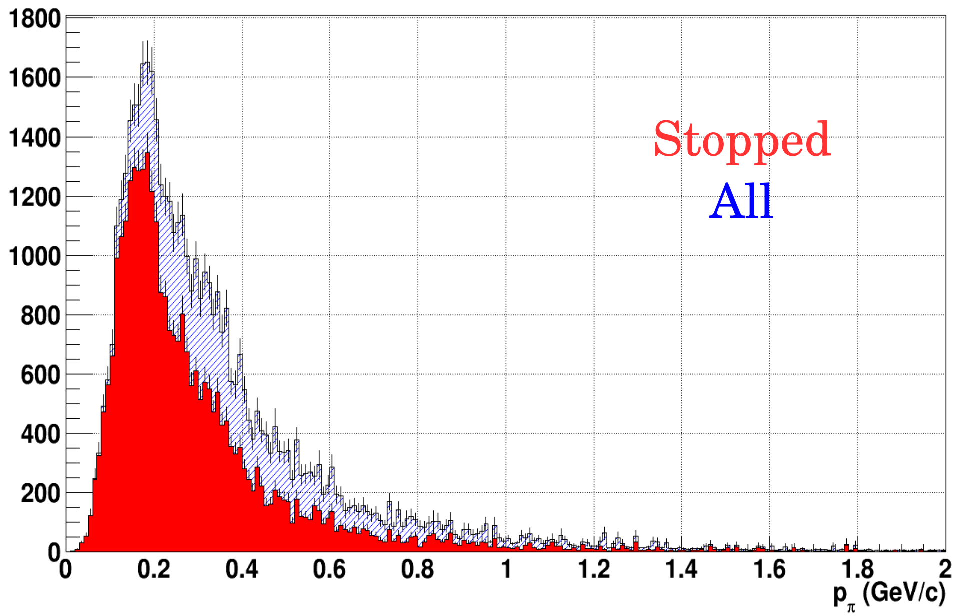
- Requiring the muon to go to the TPC → what is the threshold :
  → In momentum : ~200 MeV/c (1000 events for 10^{21} POT) ~ SK
  → In angle : no threshold → The detector external size is compatible with 4pi measurement

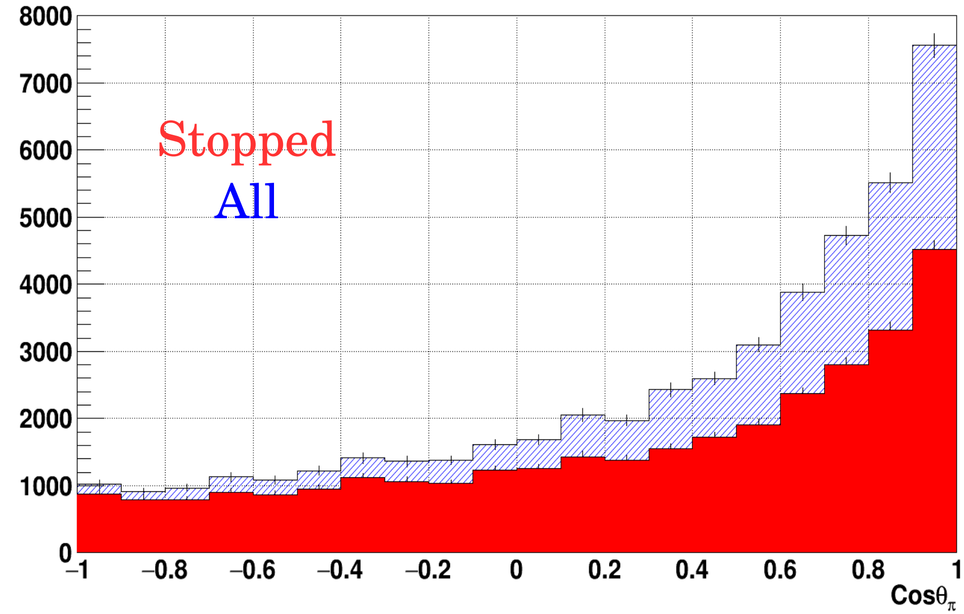
Conclusion : the muons are definitely not a problem for the current detector

- Today, I will focus only on the contamination in the CC0pi channel (dominant)

- Main contamination comes from CC1pi → study pions of CC1pi interactions.

- Proportions of CC1pi which pions stopped in the tracker : 67 %



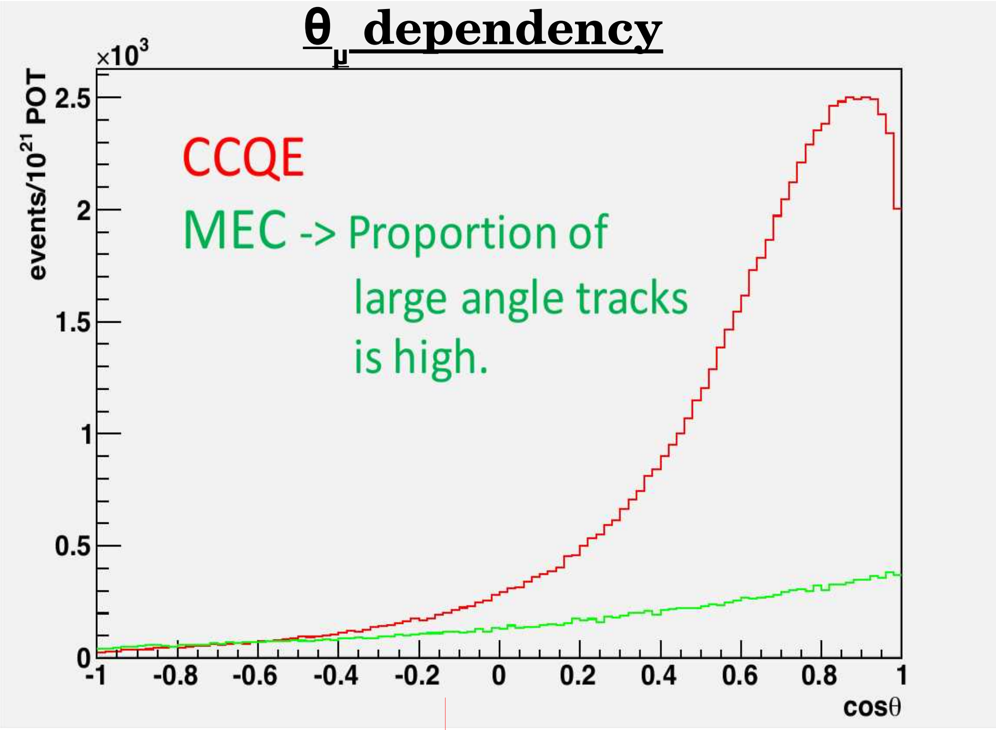


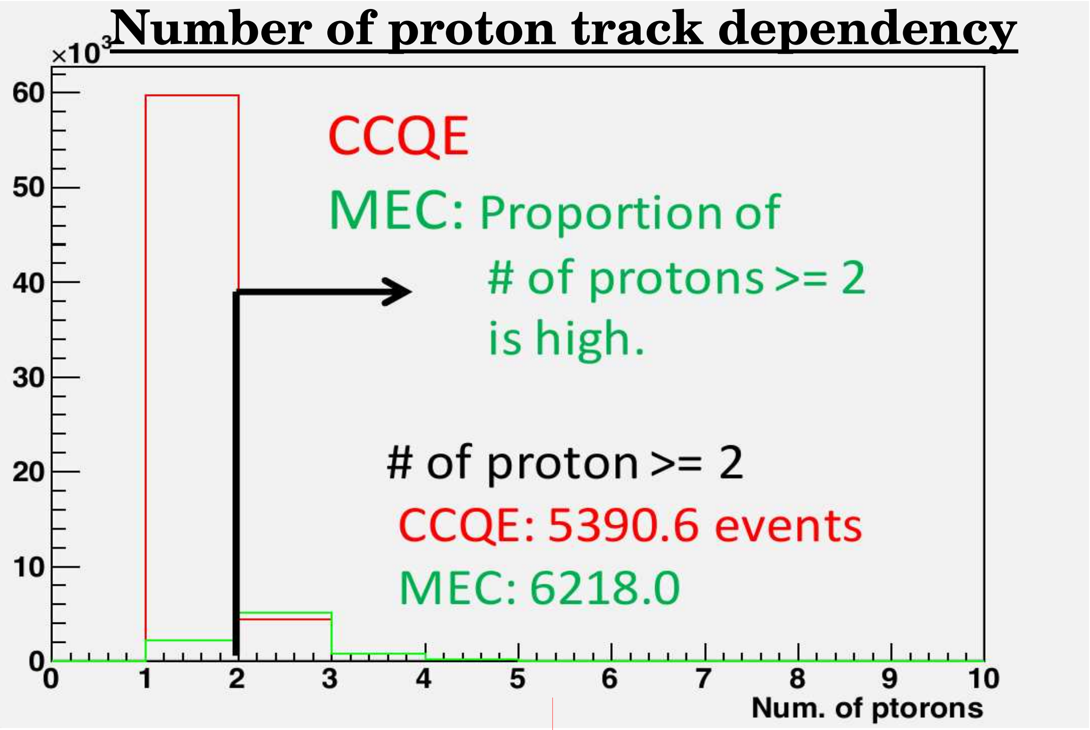
- Majority of the pions are stopped. It affect mainly the low momenta/large angle pions (that low momenta in average)

- → Reconstruction, and then, identification of these pions will be crucial.
  Contamination happens when : -Pion not reconstructed
  -Pion seen as a proton

CCQE & 2p-2h separation

- **Goal :** separate CCQE from 2p-2h interaction to constrain the later !





Additional motivation for a 4π detector

Should be able to reconstruct proton tracks !
(Next slide : 2 proton tracks momentum)

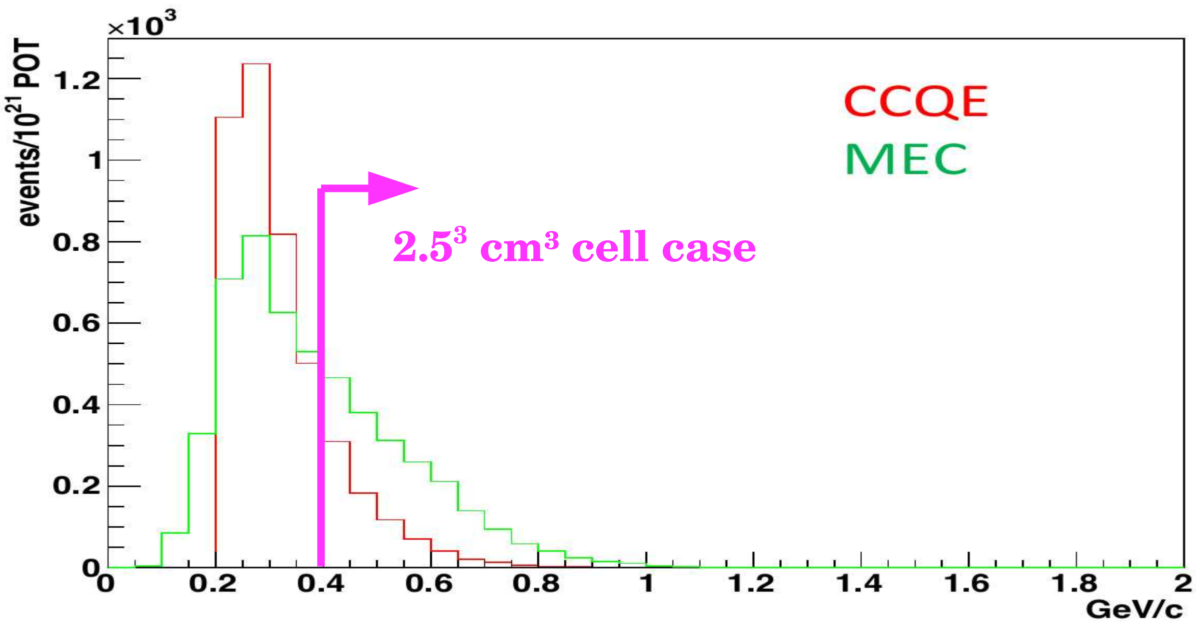
→ Let's select the 2 proton track sample !

Benjamin Quilain

CCQE & 2p-2h separation : 2p tracks

- Can we separate this sample from 1 proton track sample ?

Momentum distribution for the proton having the lowest momentum



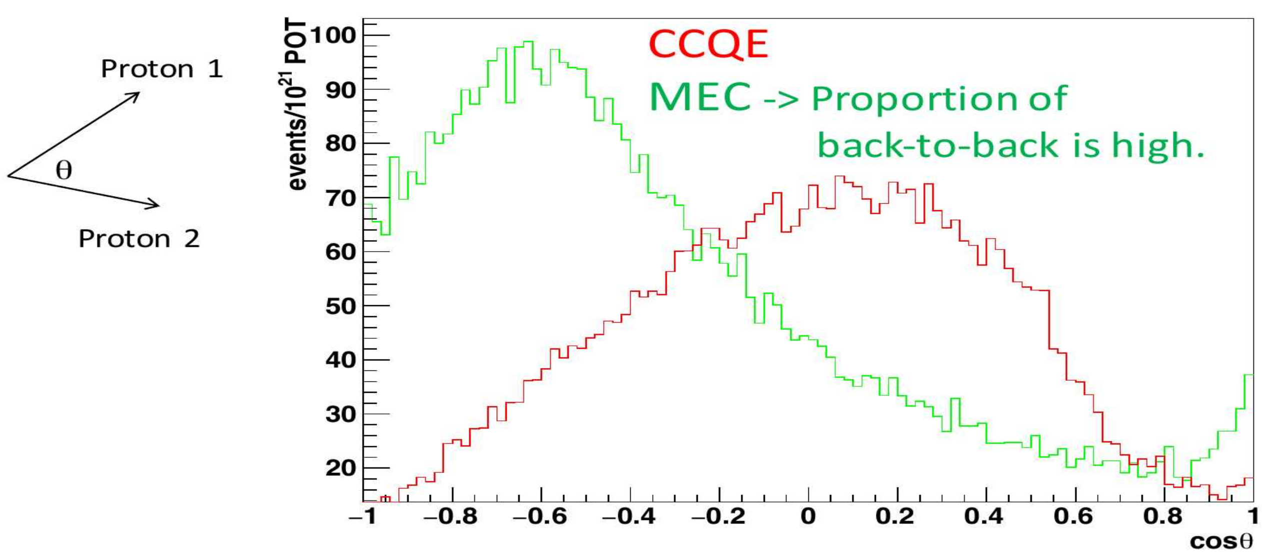
→~1/2 of the proton tracks lost : low statistics !

→ Loose more CCQE : seems ok **if this model is correct** …

→ Ideal: 200 MeV threshold (i.e .5 cm resolution)

→ Check quantitatively (apply reconstruction)

Proton opening angle distribution :



→ High separation power btw CCQE & 2p-2h …

→ … but requires more than p-track reconstruction : good momentum resolution

→Check w/ granularity !

→Check model dependency !