GLACIER:
physics and software tools

28th April 2009 - GDR Neutrino - Paris

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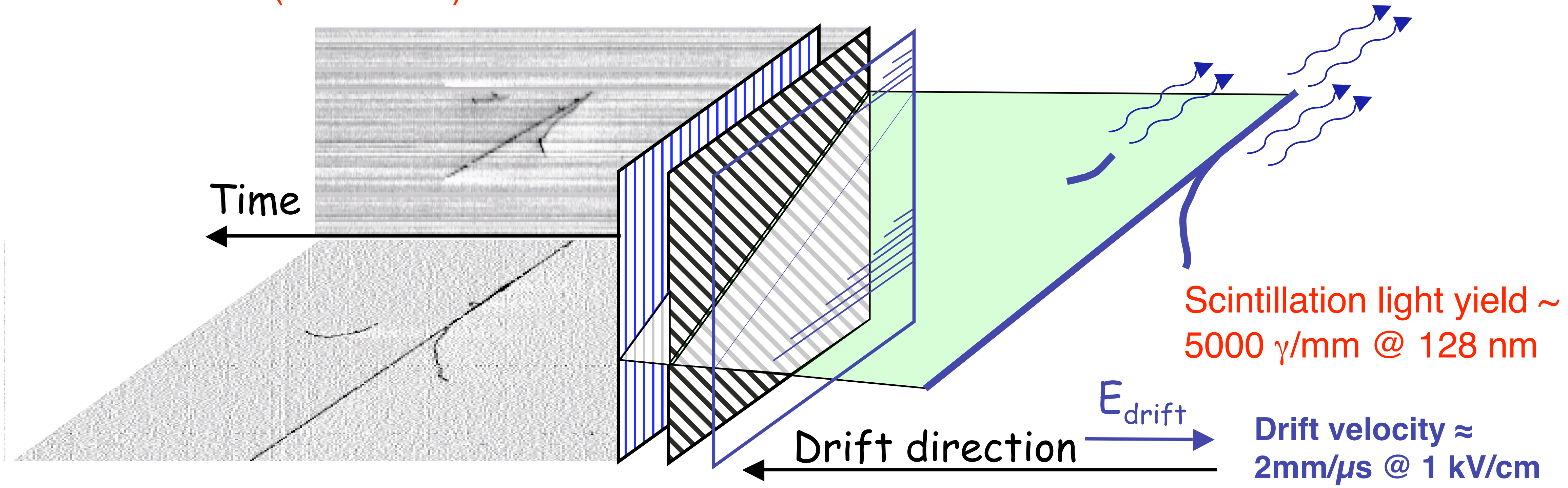
The LAr TPC principle

Charge yield ~ 6000 electrons/mm (~ 1 fC/mm)

Charge readout planes: Q

UV Scintillation Light: L



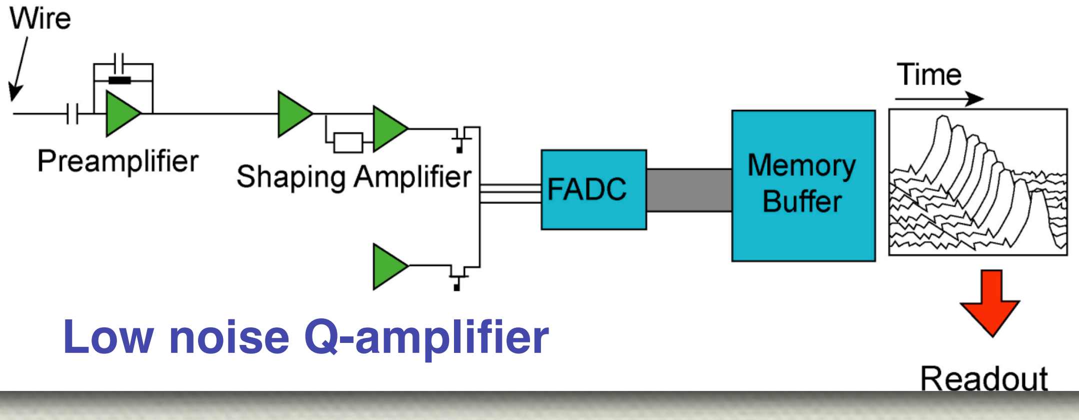
Scintillation light yield ~ 5000 γ/mm @ 128 nm

Drift velocity ≈ 2mm/μs @ 1 kV/cm

Drift electron lifetime:

$$\tau \approx 300\mu s \times \frac{1\,ppb}{N(O_2)}$$

Purity < 0.1ppb O_2-equiv.

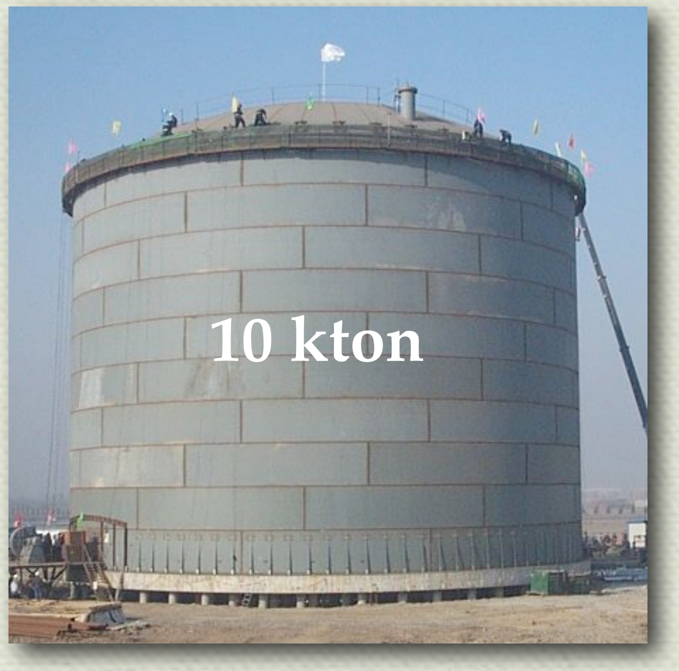


Low noise Q-amplifier

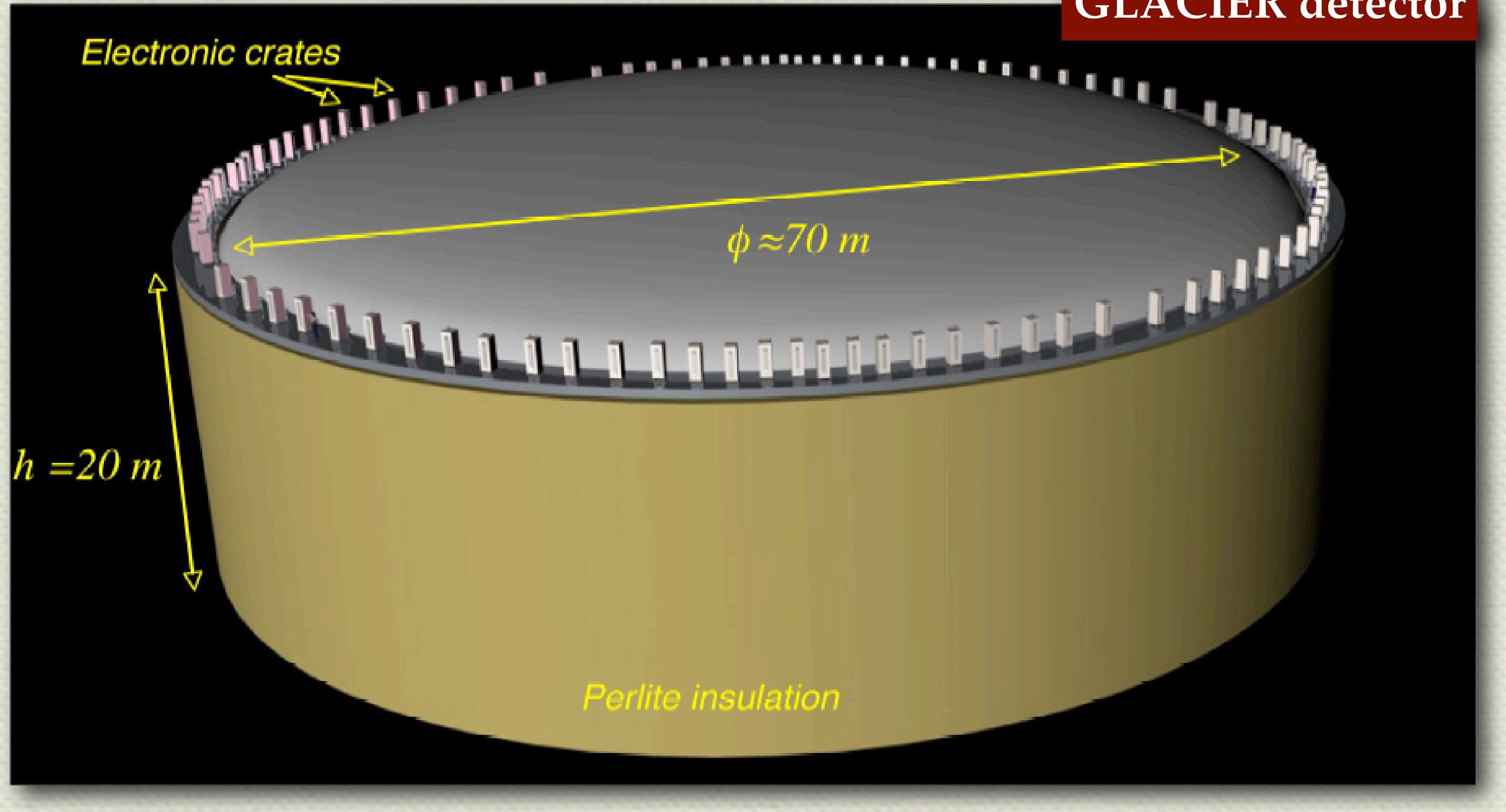
Continuous waveform recording → image

GLACIER: the detector (1)

- GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment) is a 100 kton LAr TPC.
- It could play an important role in neutrino and astroparticle physics in particular in the discovery of θ_{13}, CP-violation in the leptonic sector, in the determination of the mass hierarchy and in the proton decay search.
- The detector design profits from the experience of the ICARUS collaboration but it is different under many aspects.
- The detector could be built as a single module tanker based on industrial LNG technology.



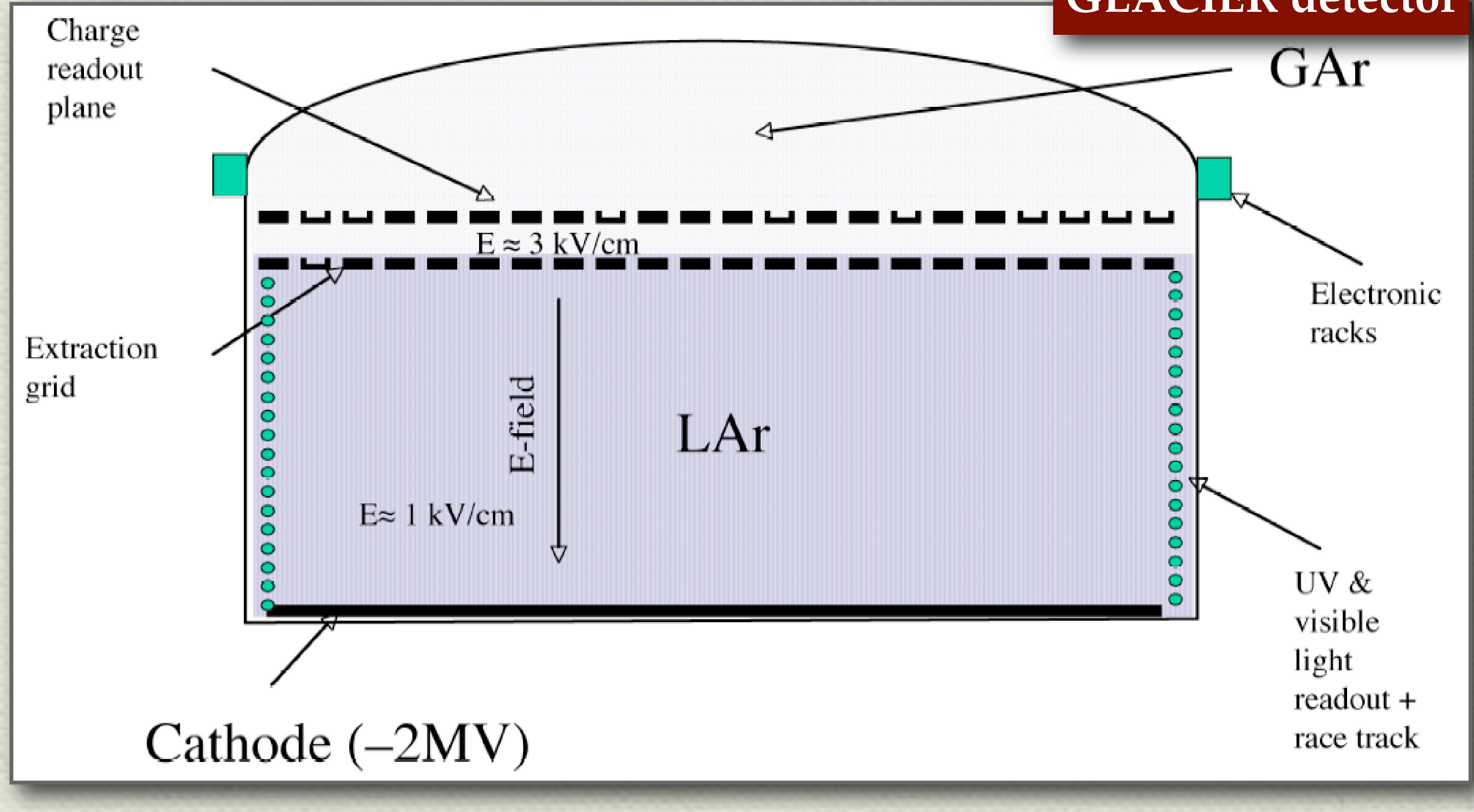
GLACIER detector



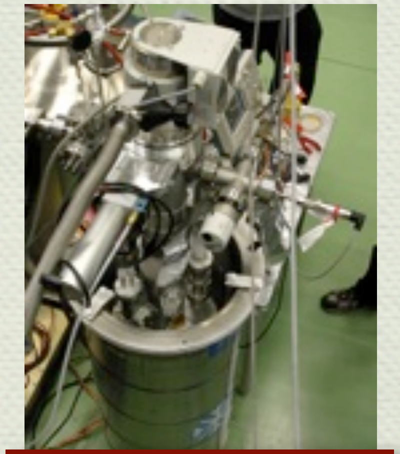
GLACIER: the detector (2)

- The drift is 20 m long compared to the 1.5 m of the ICARUS detector.
- Wires are not suitable for such dimensions (70 m diameters) because of the technical difficulties related to the construction and the large noise/signal ratio.
- The idea is to have a double phase detector: electron drift in liquid and multiplication in gas.
- The readout will be carried out using LEMs.
- A new high voltage supply is needed since it is very difficult to bring in 2 MV with standard feed-through method.
- All the needed R&D will be carried out in the and ArDM and ARGONTUBE project.

GLACIER detector



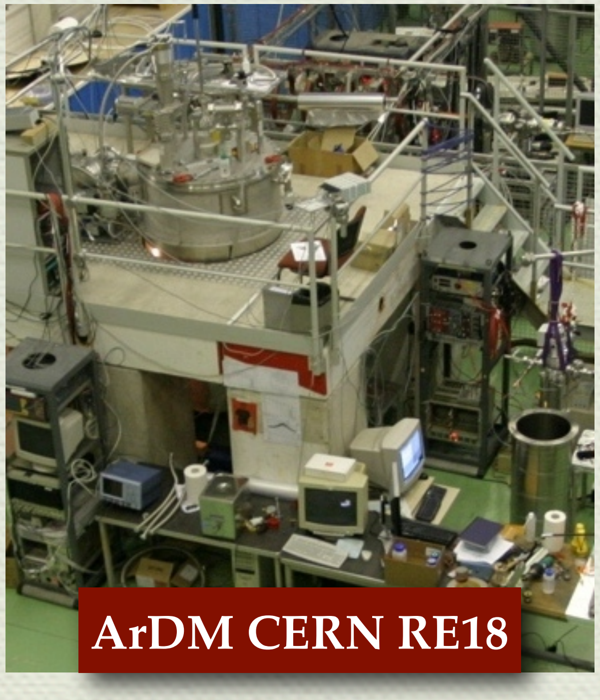
Steps towards GLACIER



LEM-TPC ETHZ

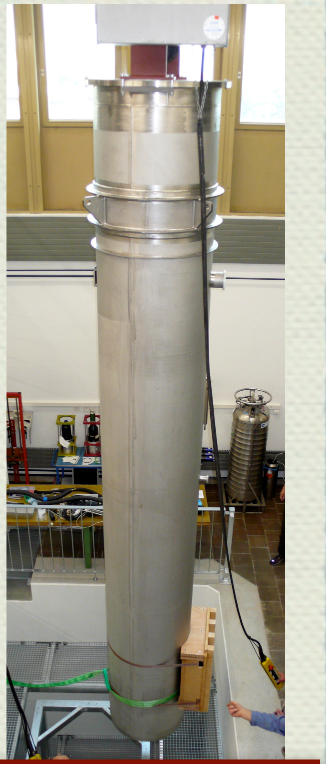
proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m^2 scale

LEM readout on 1x1 m^2 scale UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)



ArDM CERN RE18

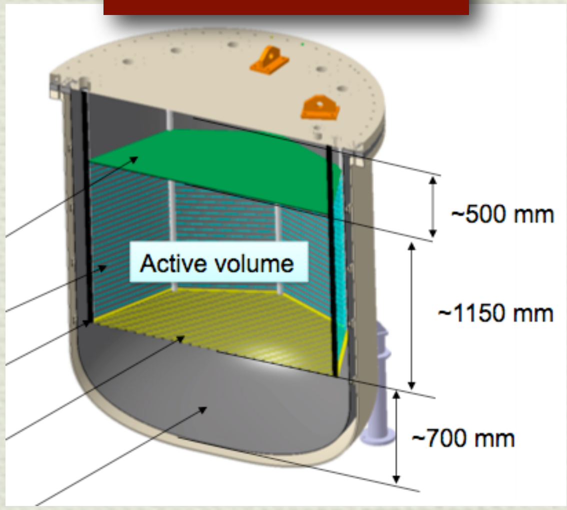
direct proof of long drift path up to 5 m



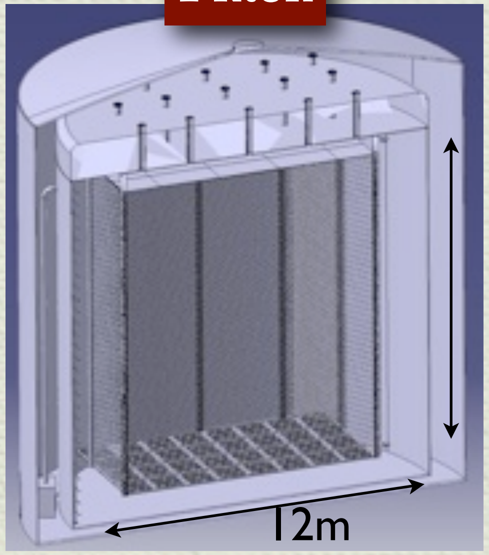
ARGONTUBE

Application of LAr LEM TPC to neutrino physics: particle reconstruction & identification (e.g. 1 GeV e/μ/π), optimisation of readout and electronics, possibility of neutrino beam exposure

TEST BEAM
1 to 10 ton scale



1 kton

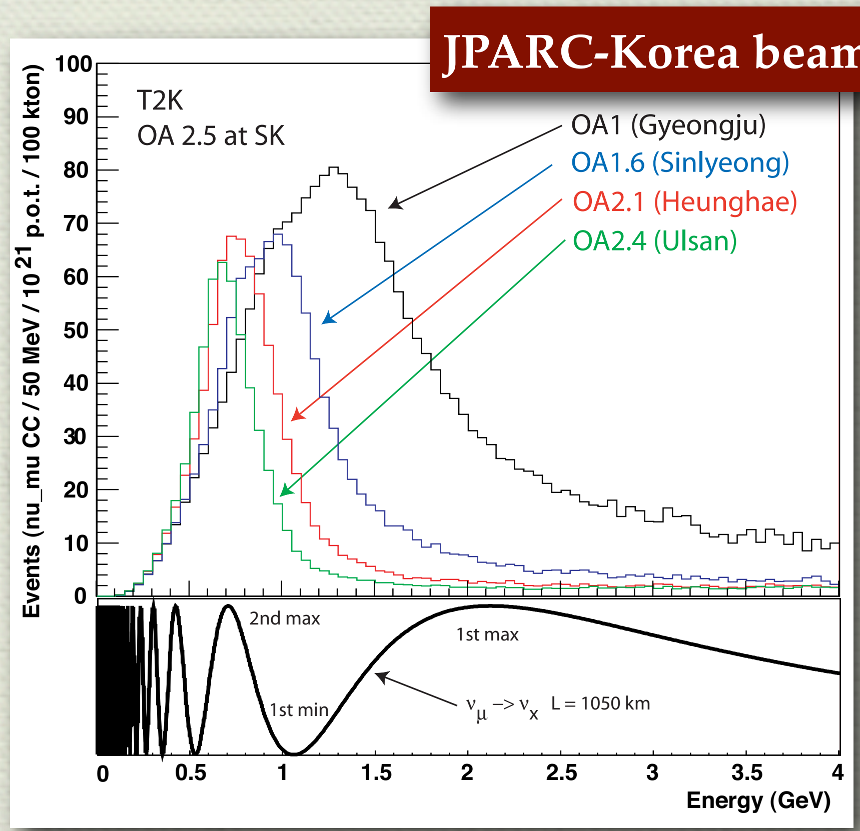


full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, …

Physics goals: neutrino oscillations (1)

- Future long baseline neutrino experiments will aim at the discovery of θ_{13}, and possibly at the determination of CP violation and mass hierarchy.
- Using the GLoBES software, we studied the performance of GLACIER when operated on future neutrino beams in particular at upgraded versions of the CNGS and T2K beams with baselines of about 1000 km (**JHEP 0611:032,2006 ; arXiv:0801.4035**).
- The off-axis technique was used and the beam tuned in order to best cover the first and second maximum and first minimum of oscillation in order to disentangle CP-violation and matter effects.

JPARC-Korea beam spectrum



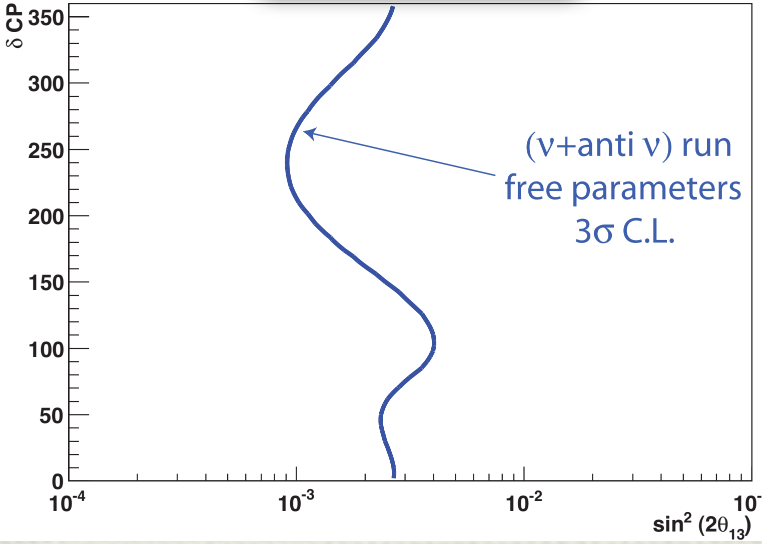
Beam parameters

	T2K		CNGS	
	Upgraded	Baseline	Upgraded	Baseline
Proton energy	40 GeV/c		400 GeV/c	
Protons per pulse (x 10^{13})	>33	33	14	4.8
p.o.t. per year (x 10^{19})	700	100	33	7.6
Running (days/year)	130		200	
Efficiency	1		0.83	0.55
Beam power (MW)	4	0.6	1.2	0.3
Energy x p.o.t. (x 10^{22} GeV x p.o.t/year)	28	4	13.2	3

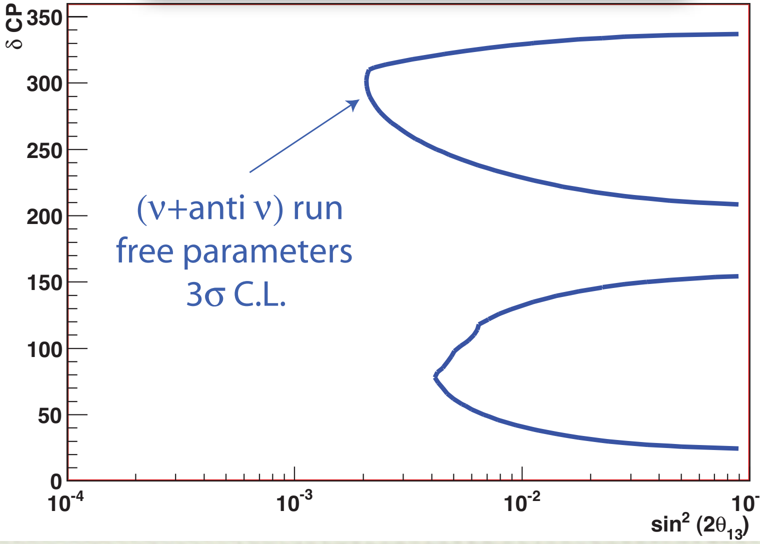
Physics goals: neutrino oscillations (2)

JPARC - Korea results

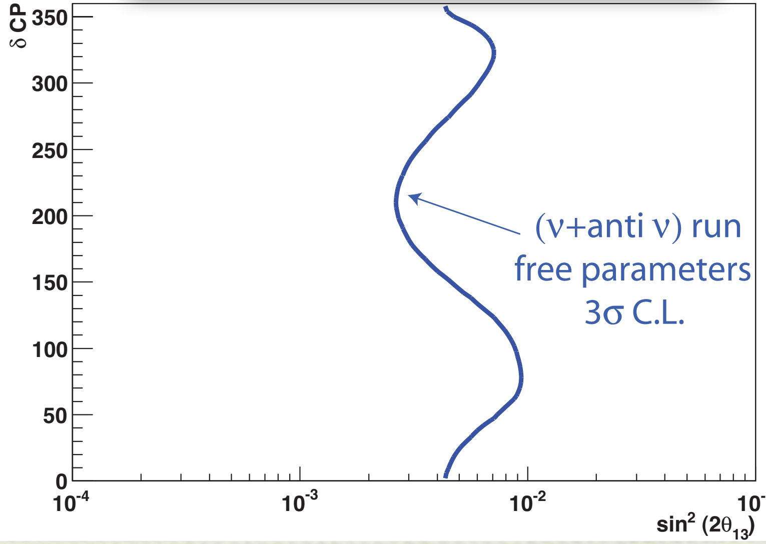
θ_{13} Discovery



CP-Violation Discovery



Mass Hierarchy exclusion

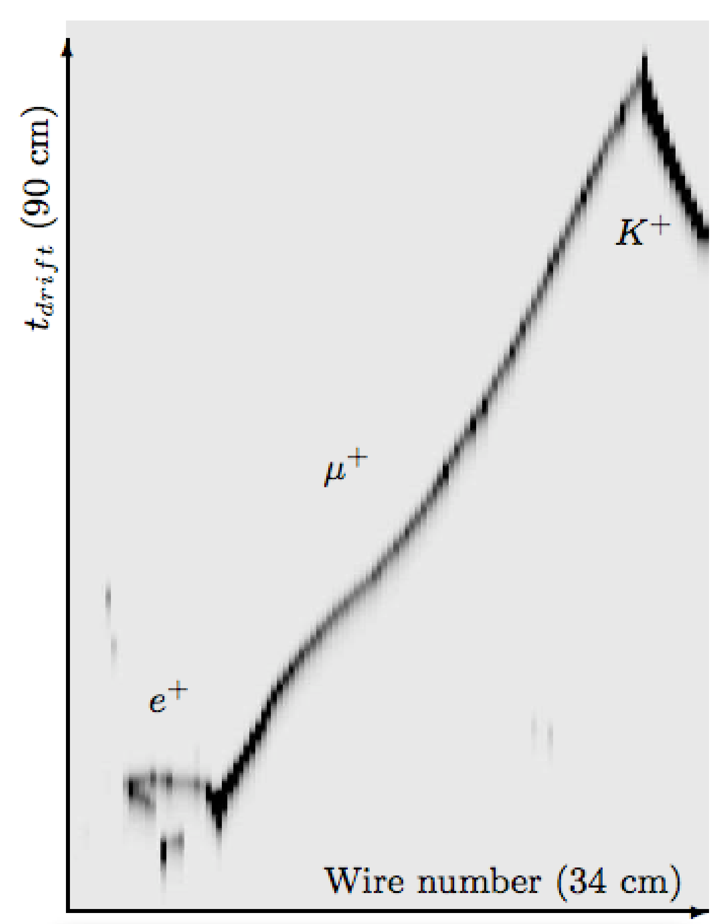


Summary	Best sensitivity (3σ) $\sin^2(2\theta_{13})$	Maximal coverage (3σ) $\sin^2(2\theta_{13})$
θ_{13}	$\sim 1\times10^{-3}$	100% coverage at $\sim 4\times10^{-3}$
CP-Violation	$\sim 2\times10^{-3}$	~70% coverage at 1×10^{-1}
Mass Hierarchy	$\sim 2\times10^{-3}$	100% coverage at $\sim 1\times10^{-2}$

NOTE that CNGS results yields similar limits

Physics goals: proton decay (1)

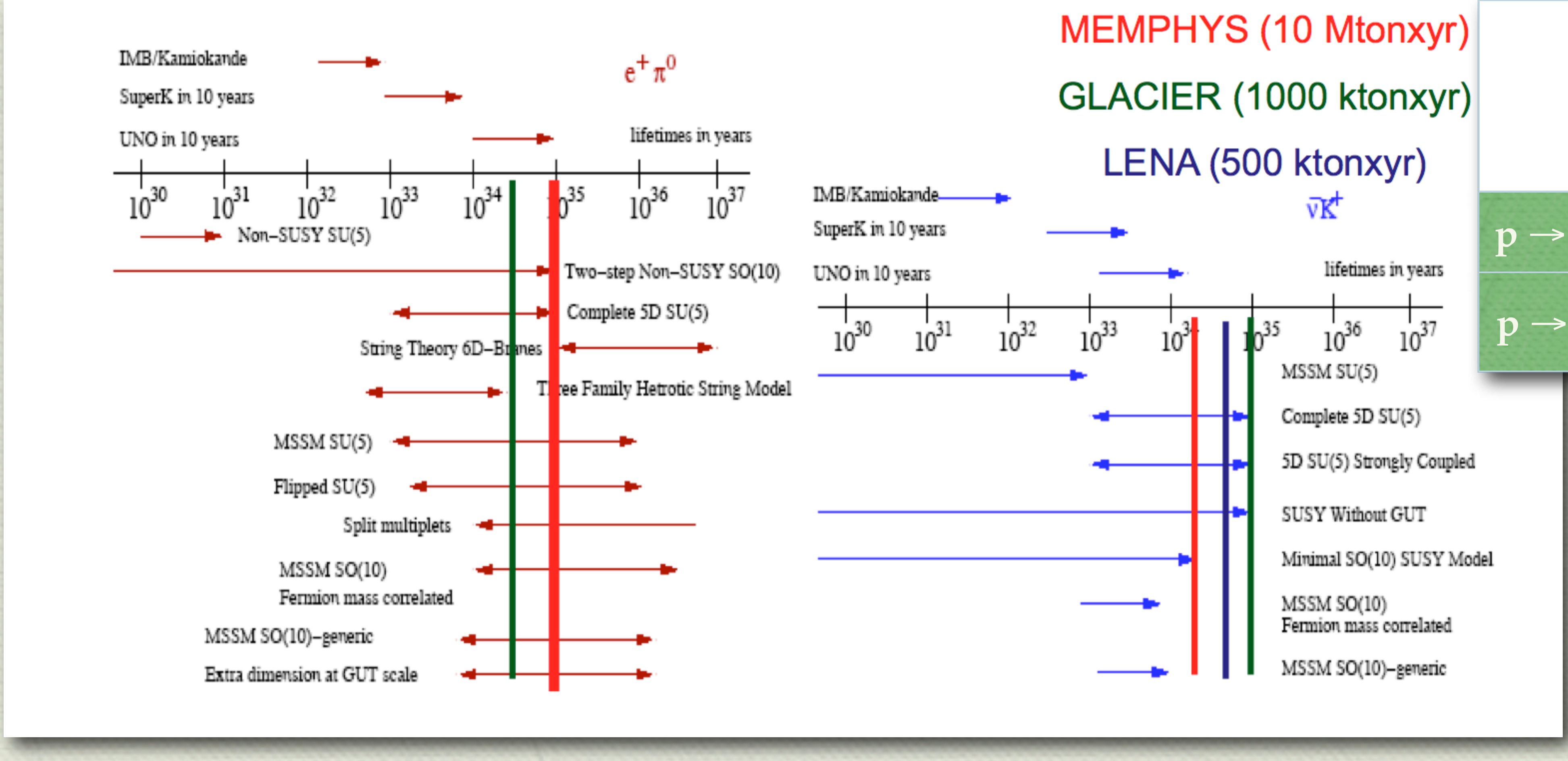
- The proton decay is one of the most important and unsolved problems of particle physics since the direct observation of baryon number violation would be the most convincing experimental evidence of Grand Unification.
- The sensitivity of GLACIER for such a search was investigated studying different decay channels (**JHEP 0704:041,2007**).
- Particular care was taken in the simulation of the cosmic induced background (studied with different simulation programs such as FLUKA and GEANT4) in order to assess how much underground the detector should be located.
- We found that with the implementation of large RPC planes veto to tag muons very good sensitivities (order of 10^{34} - 10^{35} according to the decay channel) could be reached at shallow depth i.e. 200 m underground (about 600 m water equivalent).



$p \rightarrow K^+ \bar{\nu}$ MC simulation

Physics goals: proton decay (2)

- With respect to Water Cerenkov detector, the channels involving kaons have a sensitivity of one order of magnitude better.



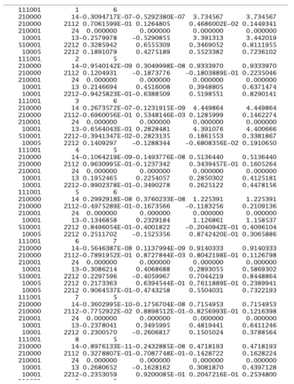
	LAr efficiency	WC efficiency
$p \rightarrow e^+ \pi^0$	45%	45%
$p \rightarrow K^+ \bar{\nu}$	97%	14%

Sensitivity to many theoretical models

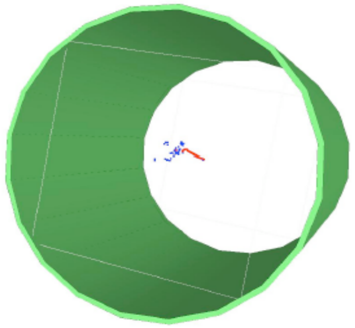
Software tools

- Neutrino fluxes are calculated using full simulations in Geant3/Geant4 of the beam lines starting from the parent protons (conventional neutrino beam).
- Neutrino interactions are simulated with neutrino generators (NUX/NEG/NEUT/NUANCE/GENIE ...).
- Particles from the primary interaction are traced in the detector geometry described using Geant4 simulations.
- The deposited energy released by Geant4 is digitised by "ad hoc" software that fully simulate the response of the detector. In our case this is done in the **fullreco** library.
- Once the fluxes and the detector response are known, sensitivity curve can be calculated using for example the GLoBES software.

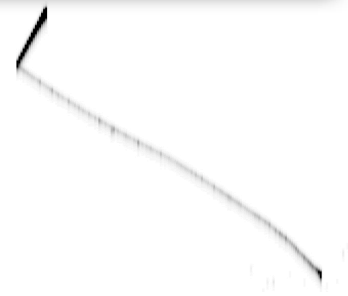
Simulation chain



Input File.txt from NUX/NEG/NEUT/NUANCE neutrino generator



Geant4 simulation of the event with a .g4root output file

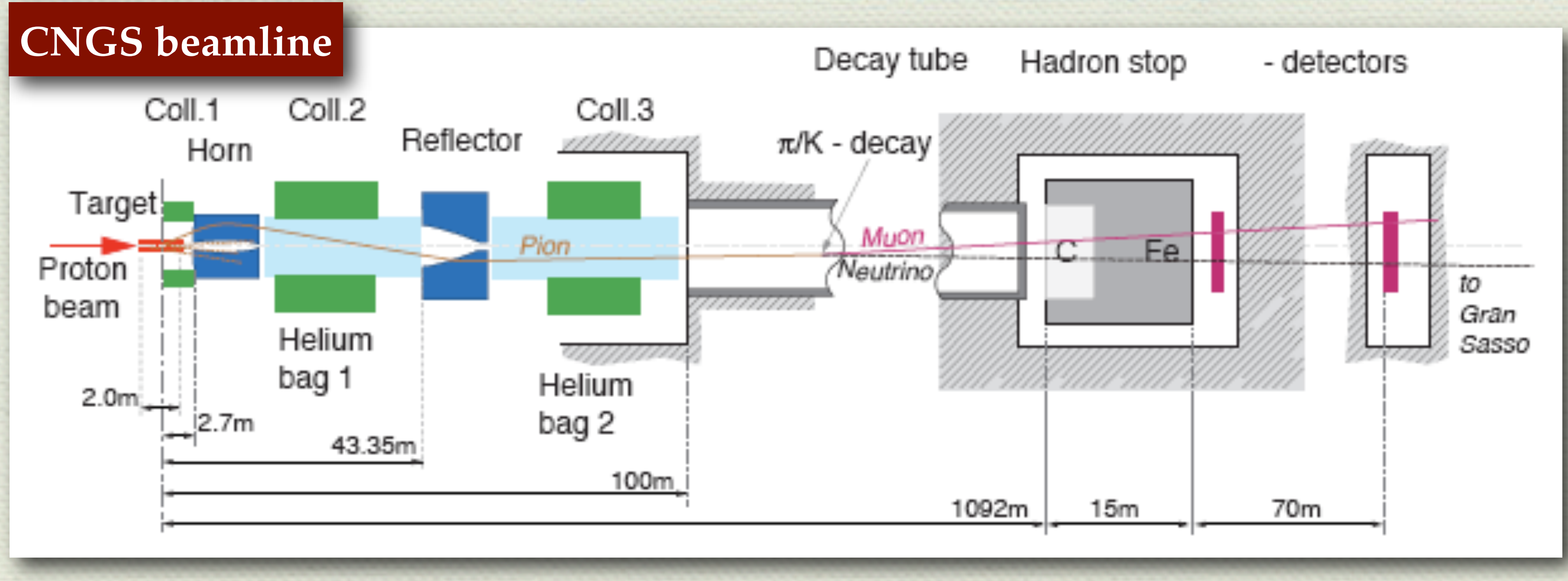


Reconstruction of the event using Fullreco from the .g4root file

Neutrino flux

- Starting from protons at a given energy colliding on a target (e.g. Be or Graphite) the spectra of secondary mesons (π^-, π^+, K^+, K^-, K^0_L) are computed.
- The mesons are generated inside the target and reinteractions are taken into account.

CNGS beamline

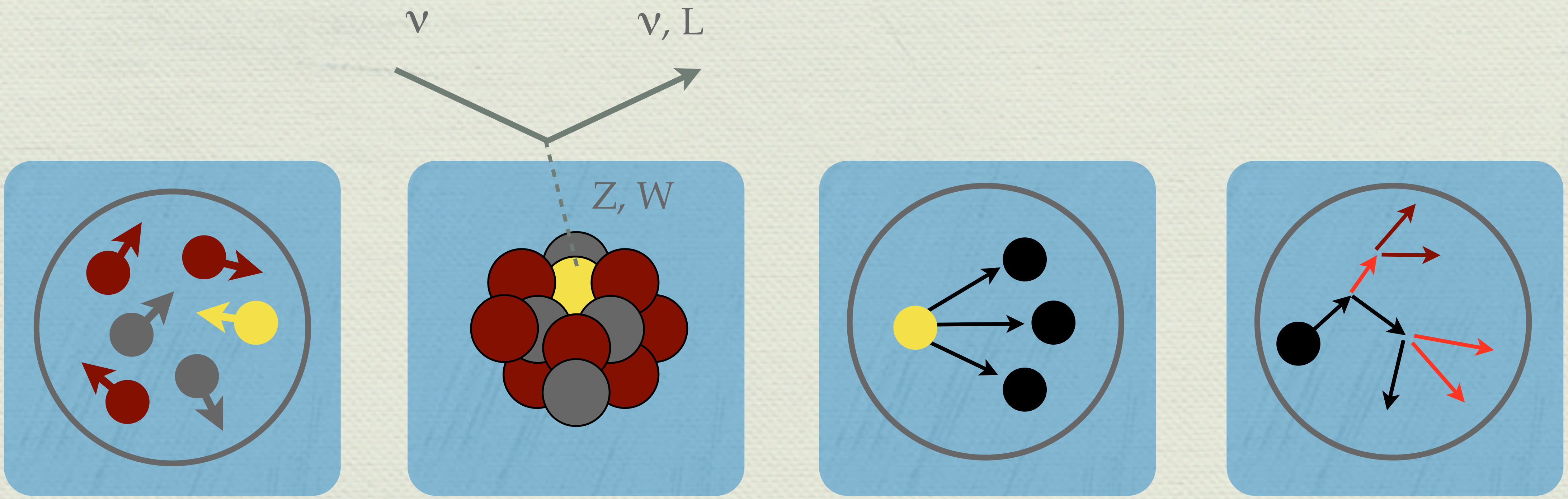


- The phase-space and normalisation of mesons exiting the target are a critical point if you need very low systematics on the knowledge of the neutrino beam (see the need of NA61 for T2K).
- The mesons that exit the target are tracked in the beam line simulation in particular to the horns focusing system.
- Each meson is forced to decay according to its decay length and the relevant decay modes are taken into account according to the branching ratio.
- In order of having enough statistics for detector at long baselines, the neutrinos are forced to cross the detector volume and a weight that accounts for such a probability is considered (For more details: **Eur.Phys.J.C20:13-27,2001**).

Neutrino event generator

- Once the neutrino flux is generated, we need to simulate neutrino interactions in the detector: this is the task of dedicated software such as NUX, NEG, NUANCE, NEUT, GENIE, etc.

- Neutrino interaction modelling can be ideally divided in 4 steps:



Nuclear model	**Primary interaction**	**Hadronisation**	**Intranuclear hadron transport**
↓	↓	↓	↓
Fermi Gas model, Pauli blocking	Cross section model	Different models according to invariant mass W	Different models for hadrons reinteractions

G4 event simulation

- The particles exiting the nucleus are then simulated in Geant4 and tracked through the detector active volume, registering the **energy deposited** and the **coordinates**.
- These two pieces of information are used by the "*fullreco*" library to simulate the event in a "LAr-like" format in the following way:

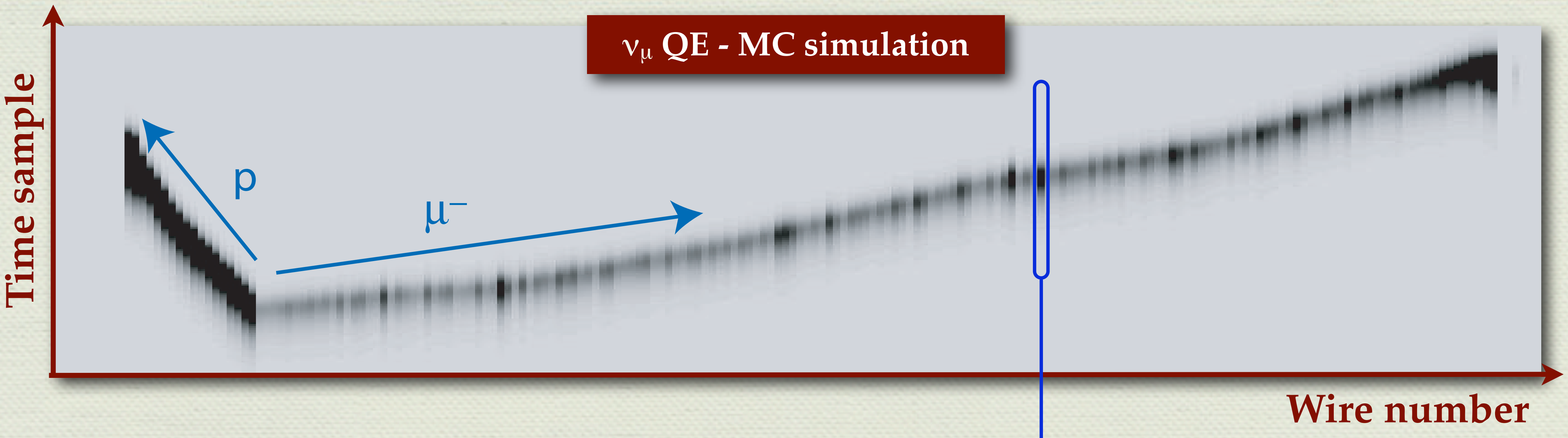
x,y,z → wire number, drift time → Function of geometrical setup and parameters such as electric field.

Energy corrected for quenching → Function of the dE/dx of the particle and of the electric field.

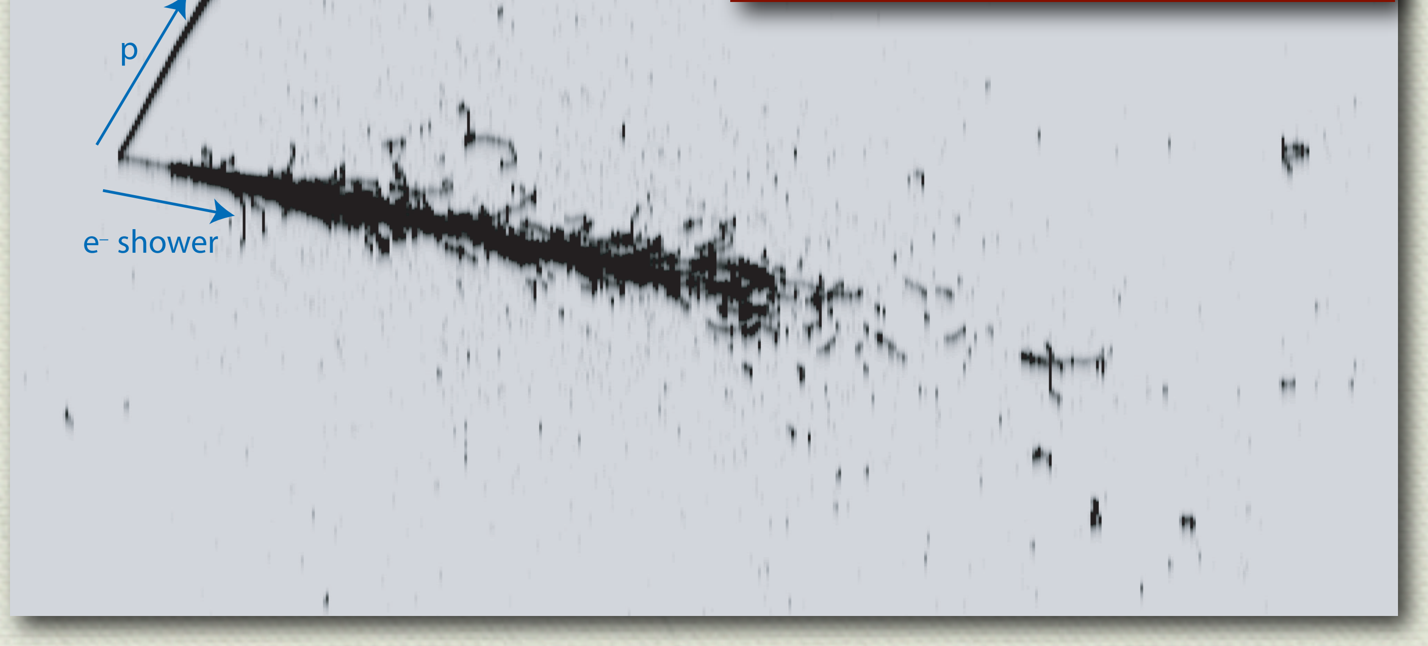
Energy corrected electron lifetime → Function of the LAr purity and the drift distance

Electronic signal simulation → Function of the energy and of the real ICARUS electronics

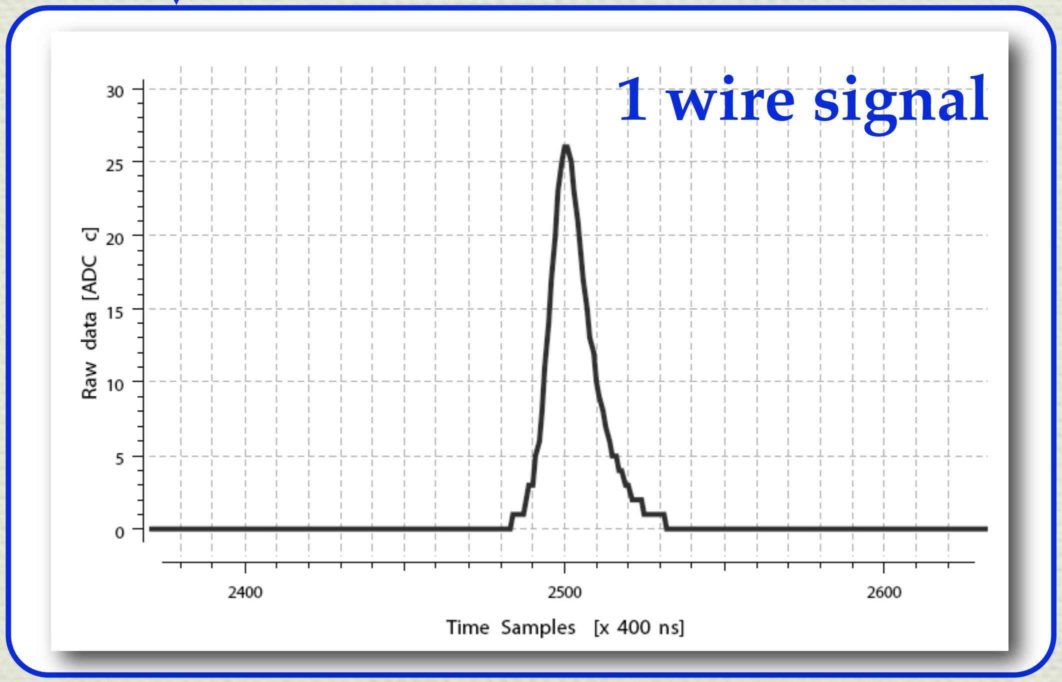
Event examples



ν_μ QE - MC simulation



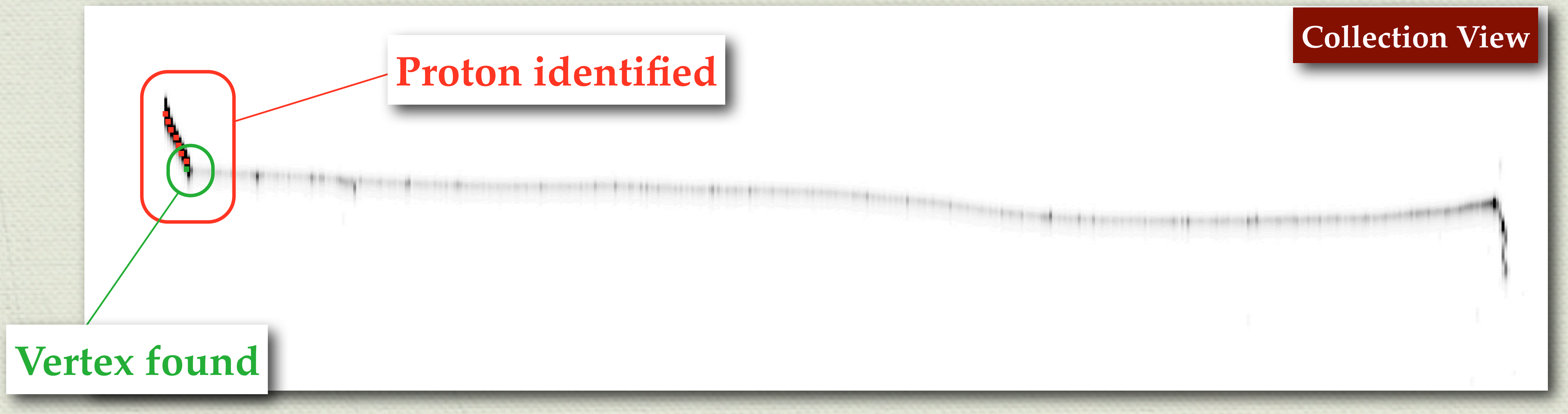
ν_e QE - MC simulation



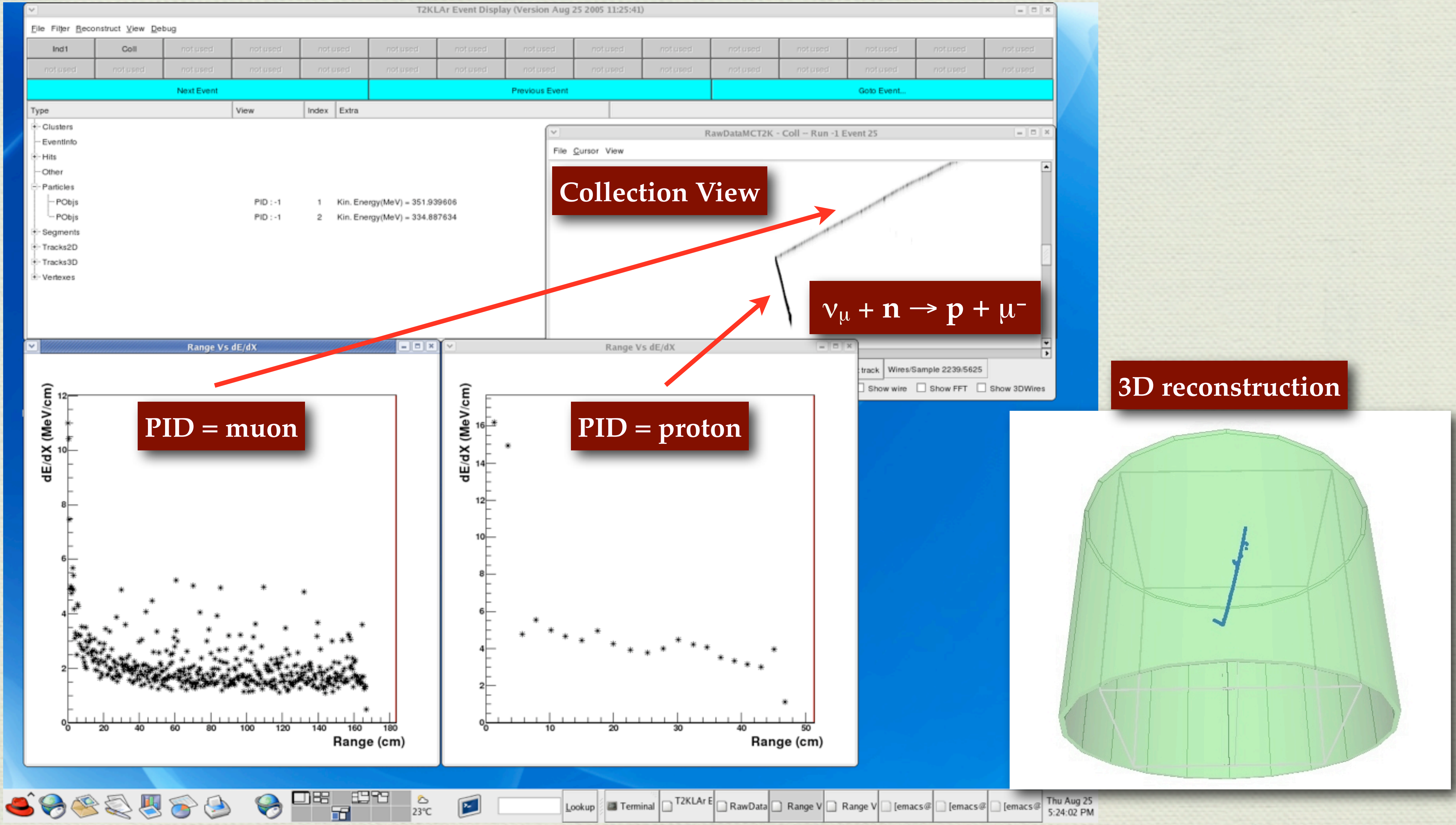
1 wire signal

Event reconstruction

- Each wire signal is fitted to reconstruct the **charge** and the **drift time**.
- In each 2D view **automatics algorithms** reconstruct 2D tracks and the vertex.
- Using the common coordinate (i.e. the drift time) the 3D tracks are reconstructed.
- Using dE/dx Vs. range information the PID is performed.
- The algorithms are ready, however tuning and improvements on the different topologies should be performed on real data.



GUI



PObjs PID : -1 1 Kin. Energy(MeV) = 351.939606

PObjs PID : -1 2 Kin. Energy(MeV) = 334.887634

Collection View

$\nu_\mu + n \rightarrow p + \mu^-$

PID = muon

PID = proton

3D reconstruction

Conclusions

- LAr TPCs are likely to play an important role in the future of neutrino physics.
- Physics reach of a 100 kton LAr TPC (GLACIER) has been investigated in terms of neutrino oscillations physics and proton decay.
- Software tools for simulation and reconstruction of events in LAr have been presented.
- Automatic algorithms exists and they are just waiting for real data for further tuning and development.