Ideas for a possible Swiss contribution to T2K

NU-CHIPP meeting
Université de Neuchatel

June 21, 2004

André Rubbia (ETH Zürich)

Swiss Institute of Particle Physics

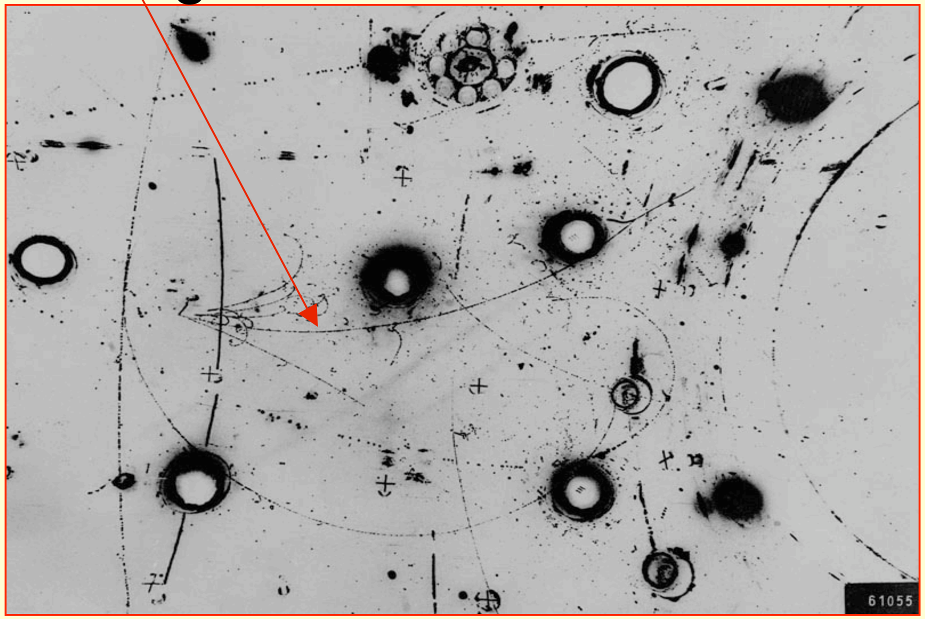
Abstract

- The liquid Argon TPC imaging has reached a high level of maturity thanks to many years of R&D effort conducted by the ICARUS collaboration.
- The ICARUS experiment, which acts as a sort of observatory for the study of neutrinos and the instability of matter, is starting to come together. In the summer of 2001, the first module of the ICARUS T600 detector passed brilliantly a series of tests. The year 2004 should see the detector's installation at the Underground Gran Sasso Laboratory and first data-taking should follow afterwards.
- In this talk, I will discuss possible independent application of the technique to a near site position in a future long baseline project, in particular at the approved T2K experiment.

Liquid Argon TPC: an electronic bubble chamber

Bubble diameter ≈ 3 mm
(diffraction limited)

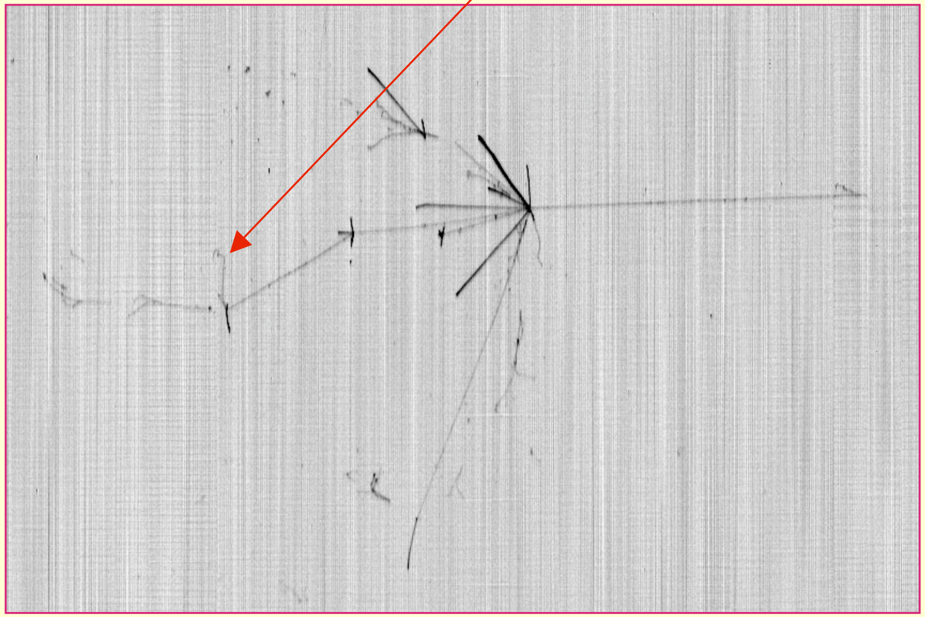
Gargamelle bubble chamber



Medium	*Heavy freon*	
Sensitive mass	3.0	ton
Density	1.5	g/cm^3
Radiation length	11.0	cm
Collision length	49.5	cm
dE/dx	2.3	MeV/cm

Bubble size ≈ 3x3x0.4 mm^3

ICARUS electronic chamber



Medium	*Liquid Argon*	
Sensitive mass	Many ktons	
Density	1.4	g/cm^3
Radiation length	14.0	cm
Collision length	54.8	cm
dE/dx	2.1	MeV/cm

Liquid Argon medium properties

	Water	Liquid Argon
Density (g/cm^3)	1	1.4
Radiation length (cm)	36.1	14.0
Interaction length (cm)	83.6	83.6
dE/dx (MeV/cm)	1.9	2.1
Refractive index (visible)	1.33	1.24
Cerenkov angle	42°	36°
Cerenkov $d^2N/dEdx$ (β=1)	≈ 160 eV^{-1} cm^{-1}	≈ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold (p in MeV/c)	120	140
Scintillation (E=0 V/cm)	No	Yes (≈ 50000 γ/MeV @ λ=128nm)
Long electron drift	Not possible	Possible (μ = 500 cm^2/Vs)
Boiling point @ 1 bar	373 K	87 K

When a charged particle traverses LAr:

1) Ionization process

$W_e = 23.6 \pm 0.3$ eV

2) Scintillation (luminescence)

$W_\gamma = 19.5$ eV

UV "line" (λ=128 nm ⇔ 9.7 eV)

No more ionization: Argon is transparent

Only Rayleigh-scattering

3) Cerenkov light (if relativistic particle)

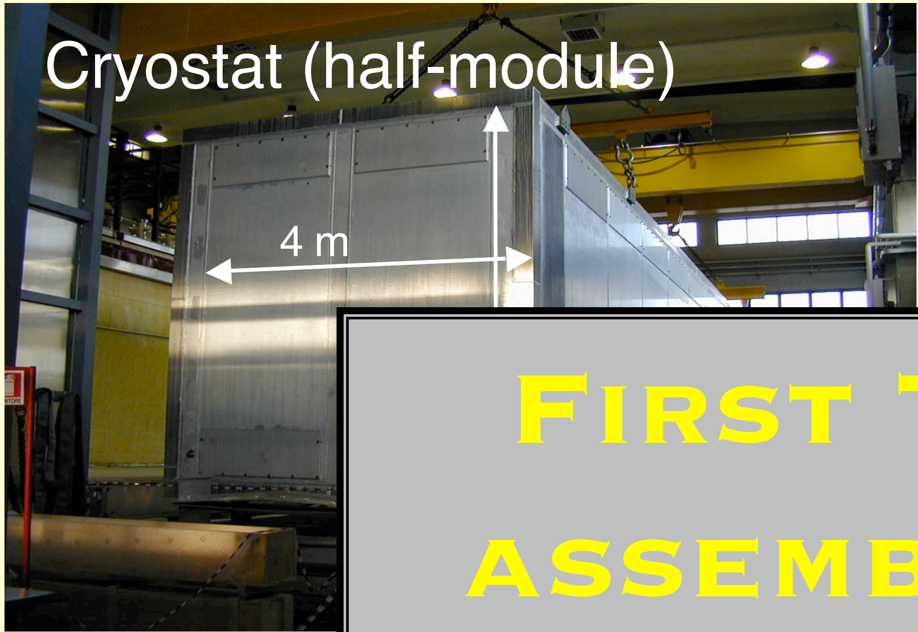
☞ **Charge**

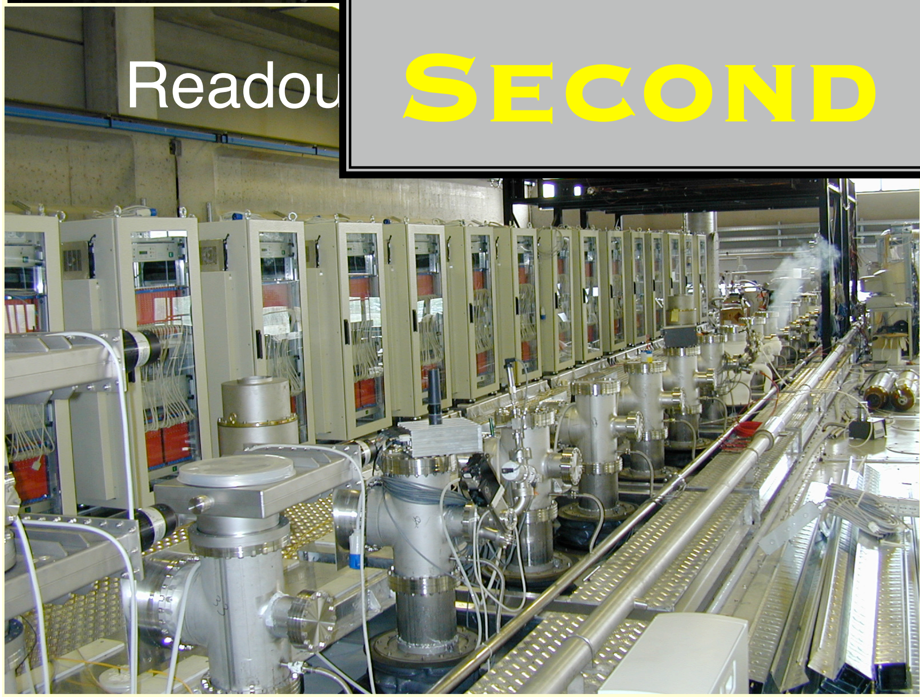
☞ **Scintillation light (VUV)**

☞ **Cerenkov light (if β>1/n)**

Scintillation & Cerenkov light can be detected independently !

ICARUS T300 detector

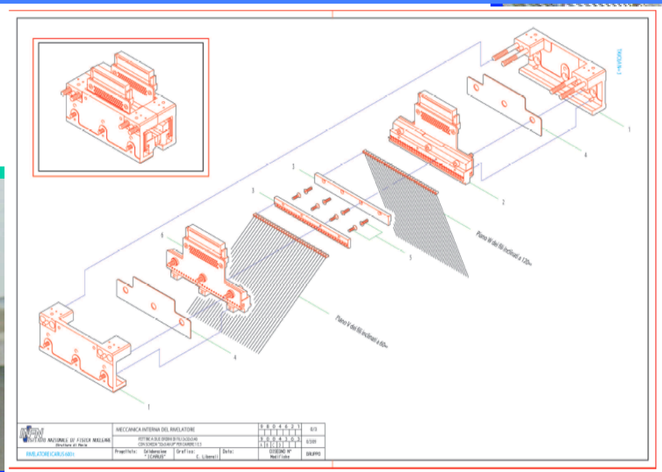




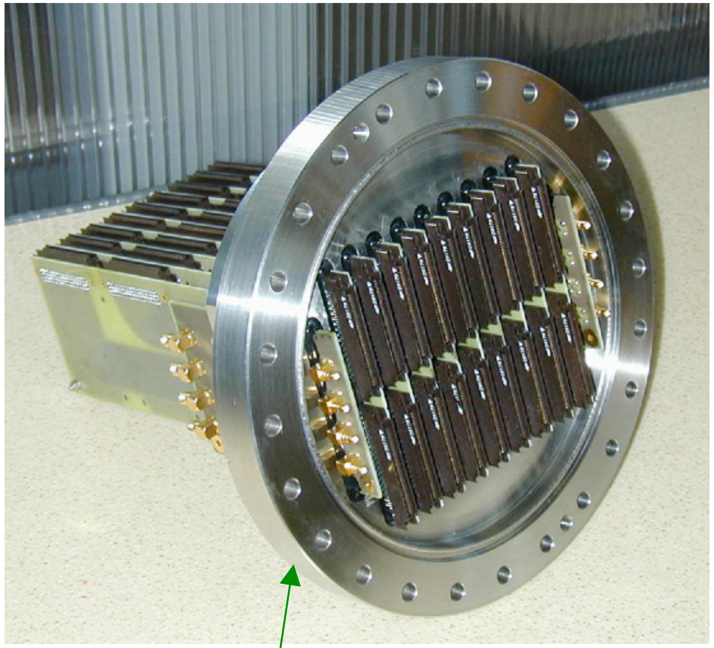
First T300 Fully assembled in 2001

Second T300 in 2002

ICARUS wiring

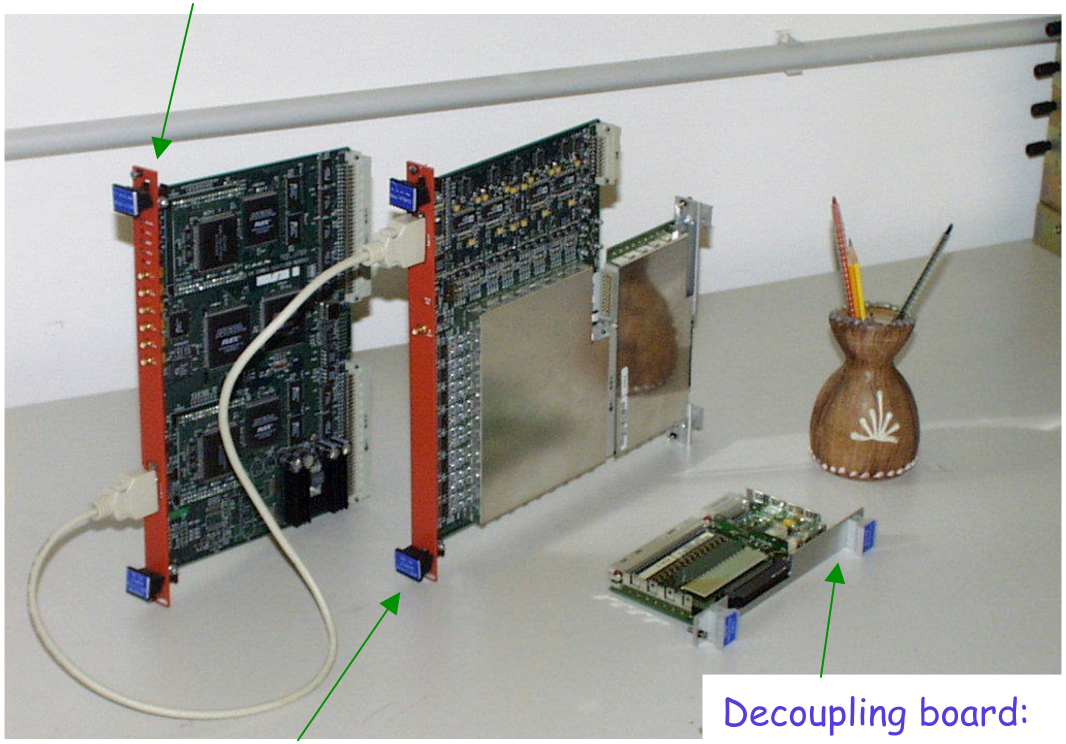


Read-out chain



Signal UHV feed-through:
576 channels (18 connectors x 32)
+ HV wire biasing

CAEN-V789 board: 2 Daedalus VLSI * 16 input channels (local self-trigger & zero suppression) + memory buffers + data out on VME bus

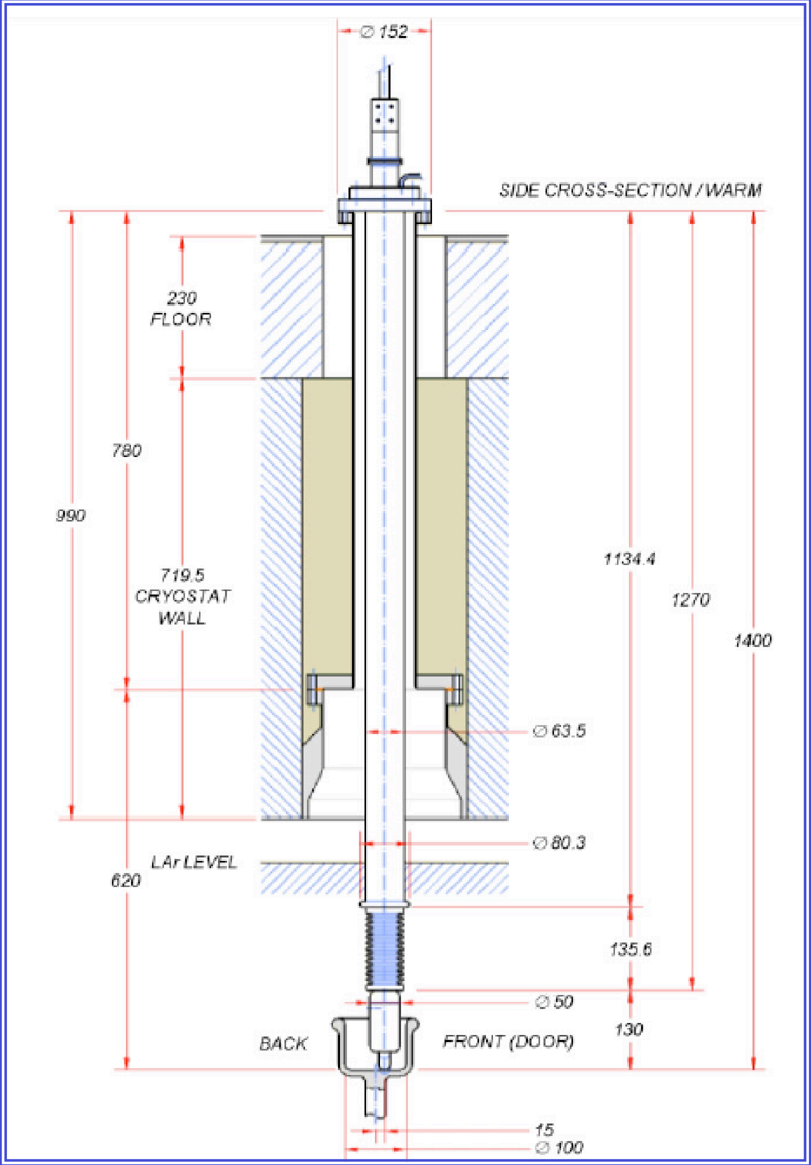


CAEN-V791 board: 32 pre-amplifiers +
4 multiplexers (8:1) + 4 FADC's (10 bits - 20 MHz)

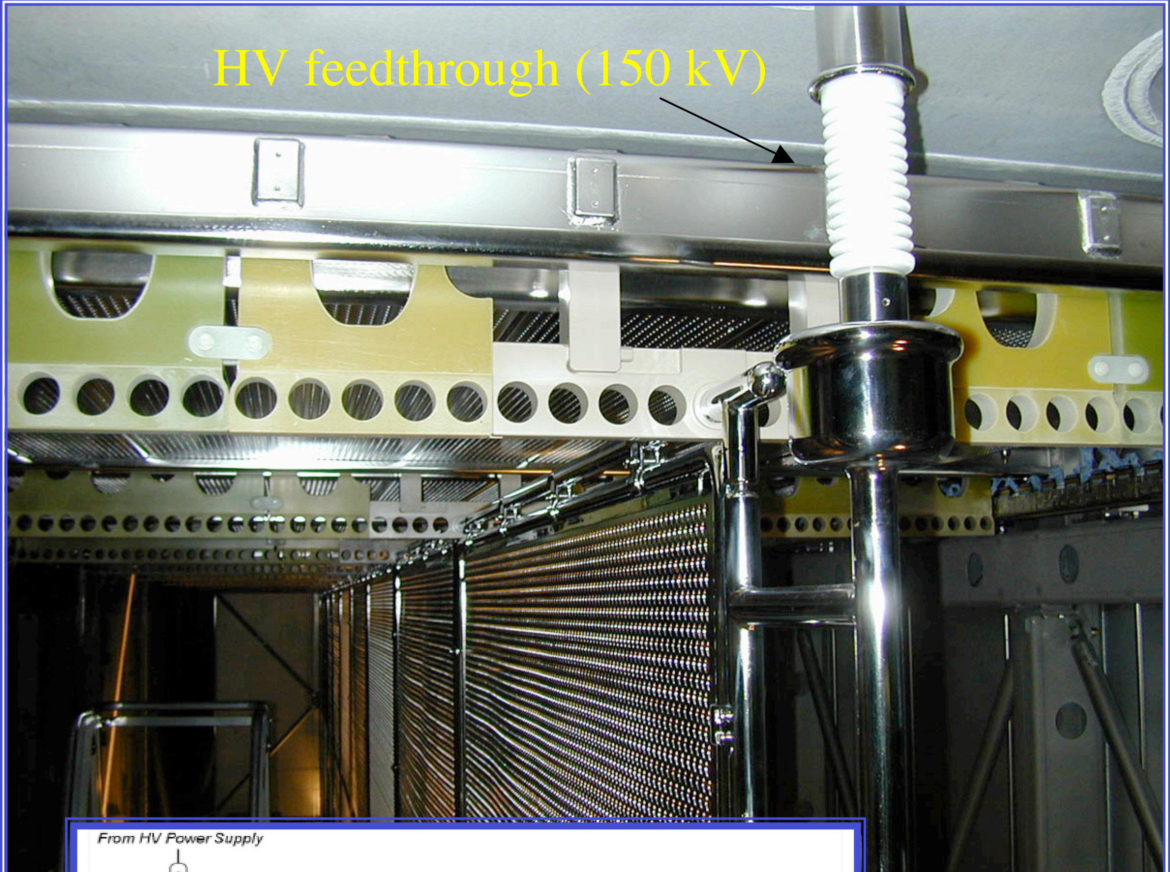
Decoupling board:
HV distribution
and signal input

commercially available

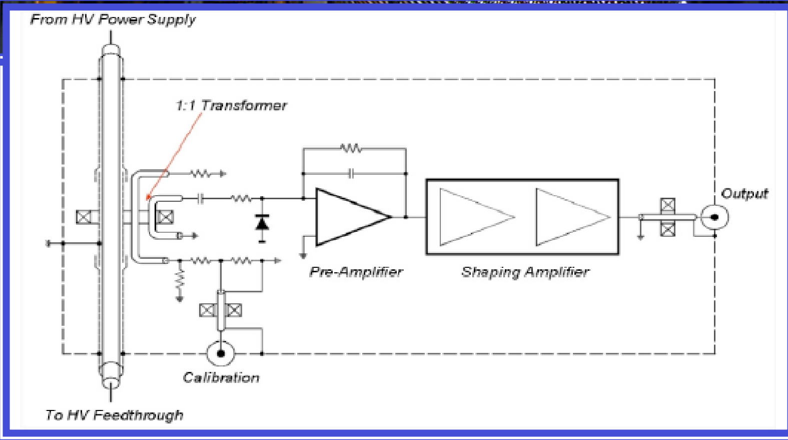
ICARUS H.V.



∅ 152
SIDE CROSS-SECTION / WARM
230
FLOOR
780
990
719.5
CRYOSTAT
WALL
1134.4
1270
1400
∅ 63.5
∅ 80.3
LAr LEVEL
620
135.6
∅ 50
130
BACK
FRONT (DOOR)
15
∅ 100

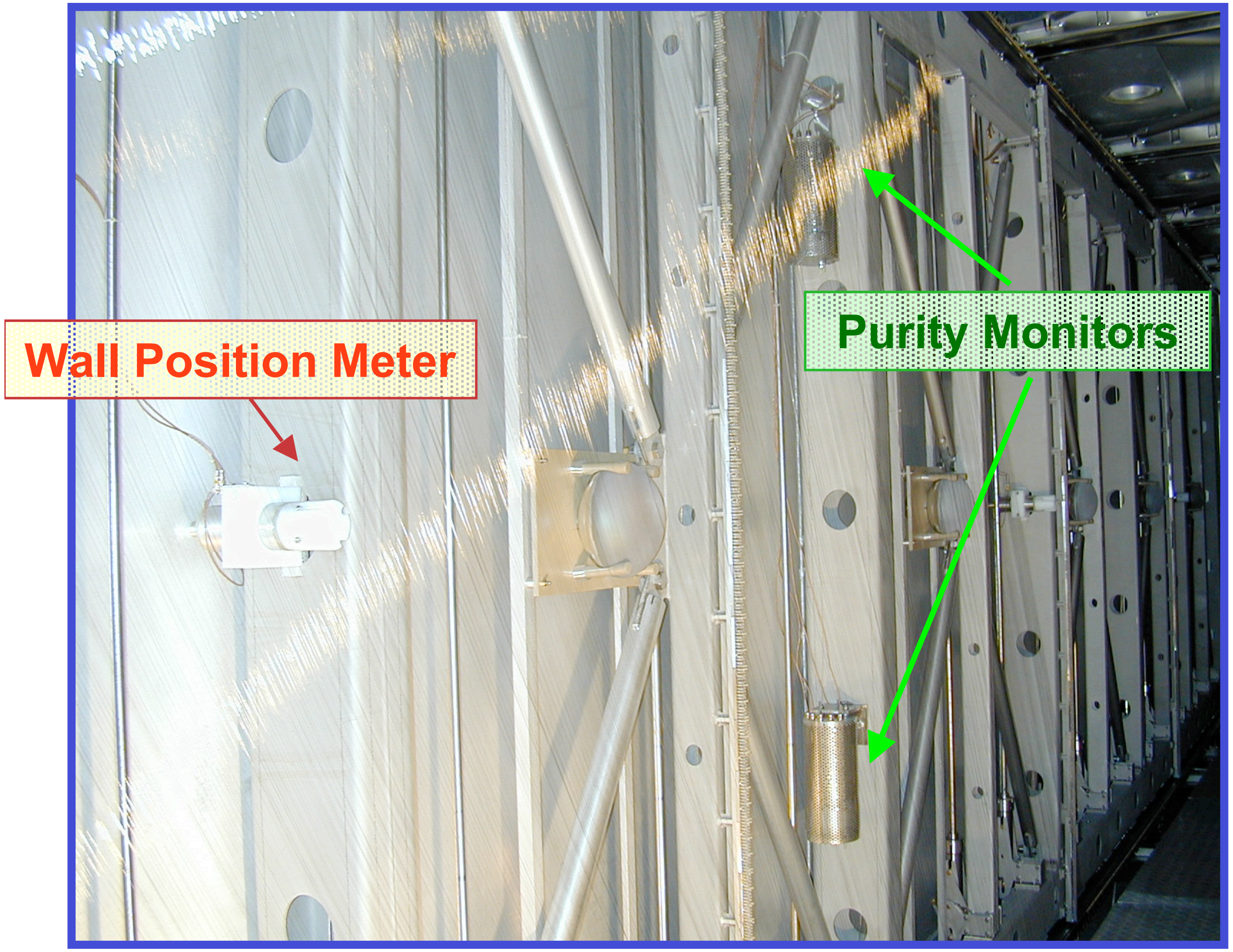


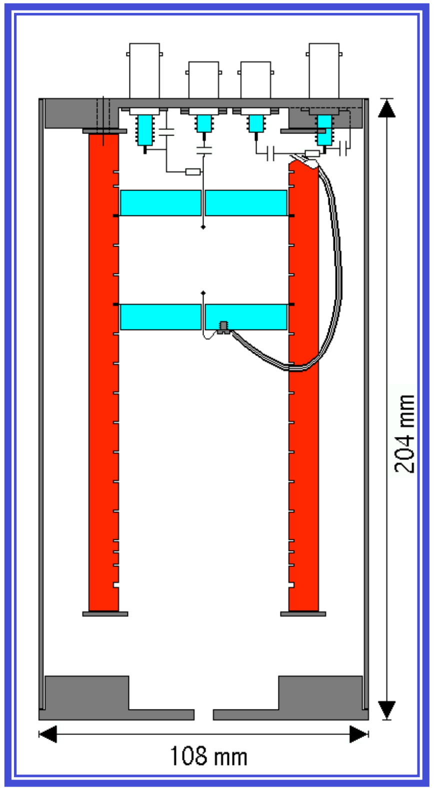
HV feedthrough (150 kV)

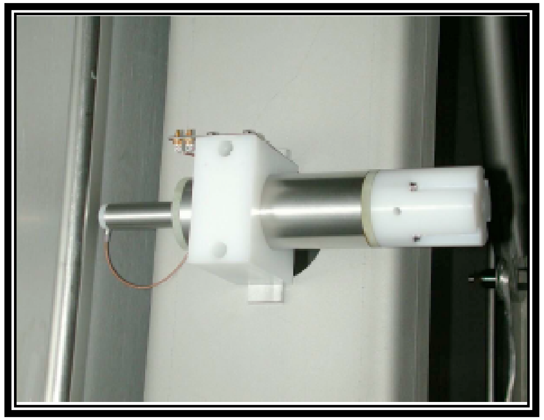


From HV Power Supply
1:1 Transformer
Output
Pre-Amplifier
Shaping Amplifier
Calibration
To HV Feedthrough

ICARUS slow control



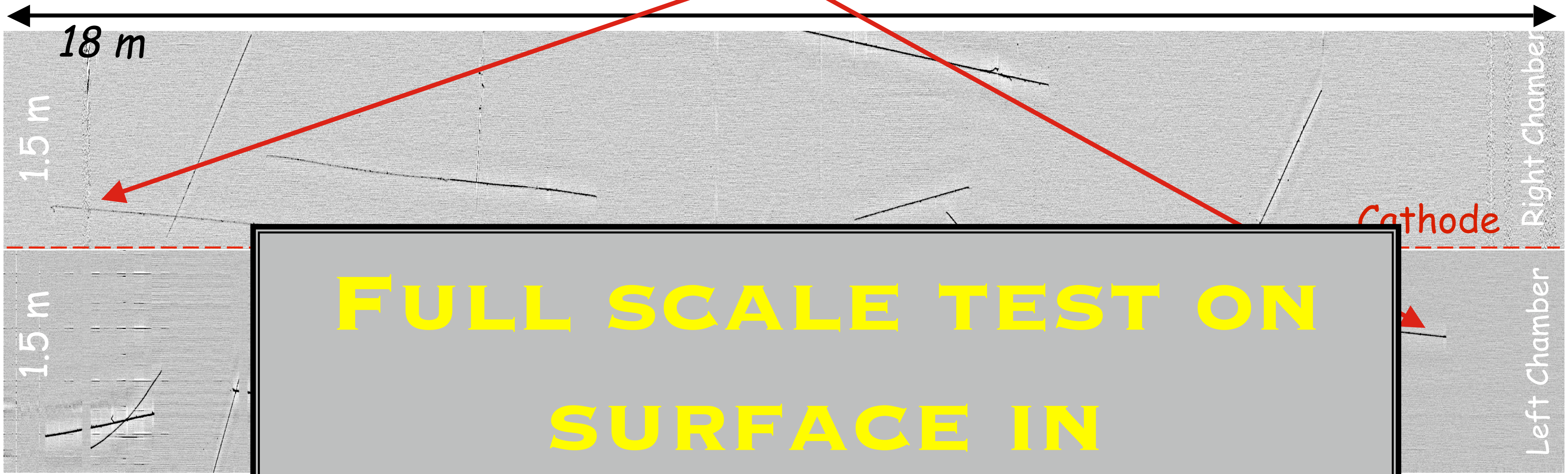


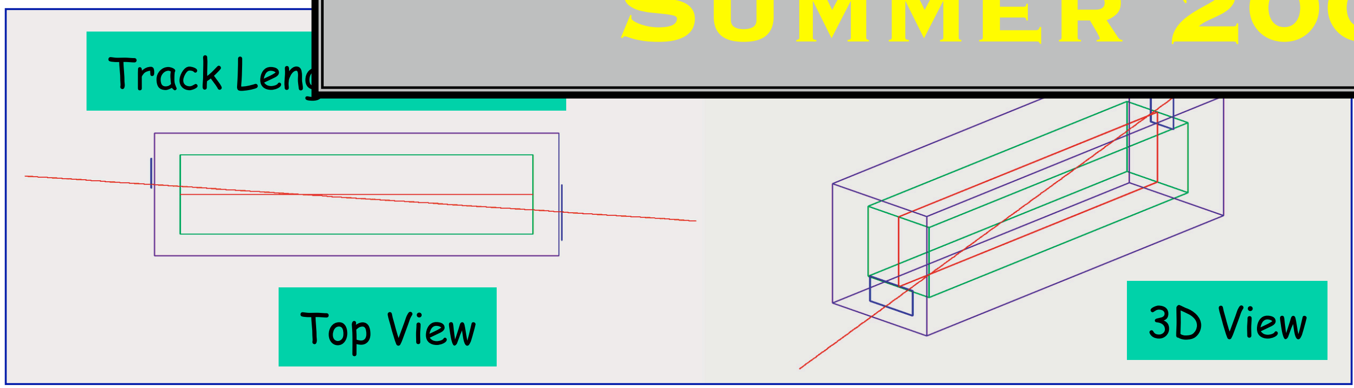


purity monitors, level meters, wire position meters, wall position meters, temperature probes

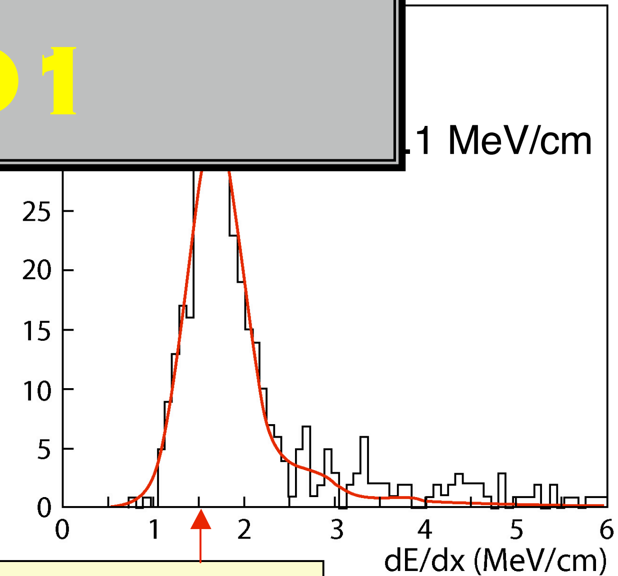
Long longitudinal muon track crossing the cathode plane

Full scale test on surface in Summer 2001





3-D reconstruction of the long track

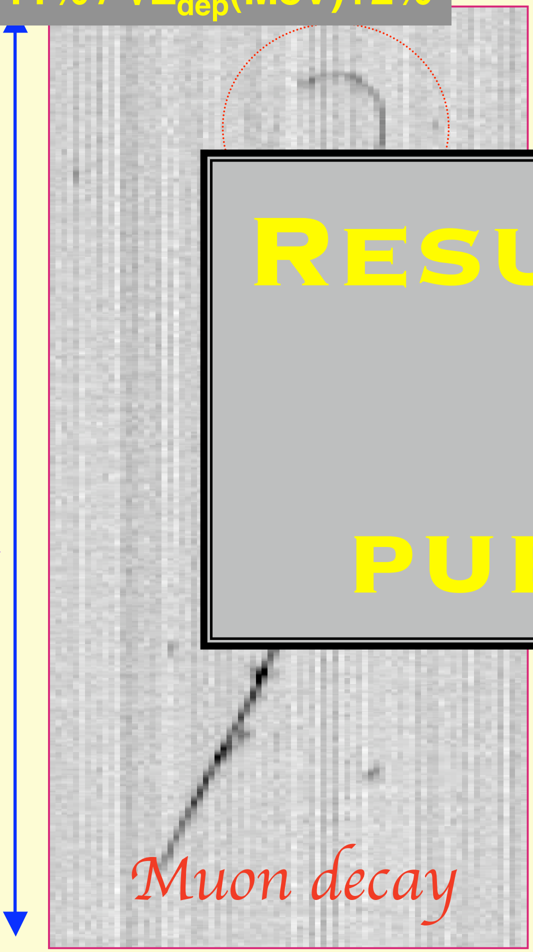


dE/dx distribution along the track

Cosmic rays events in the ICARUS T300

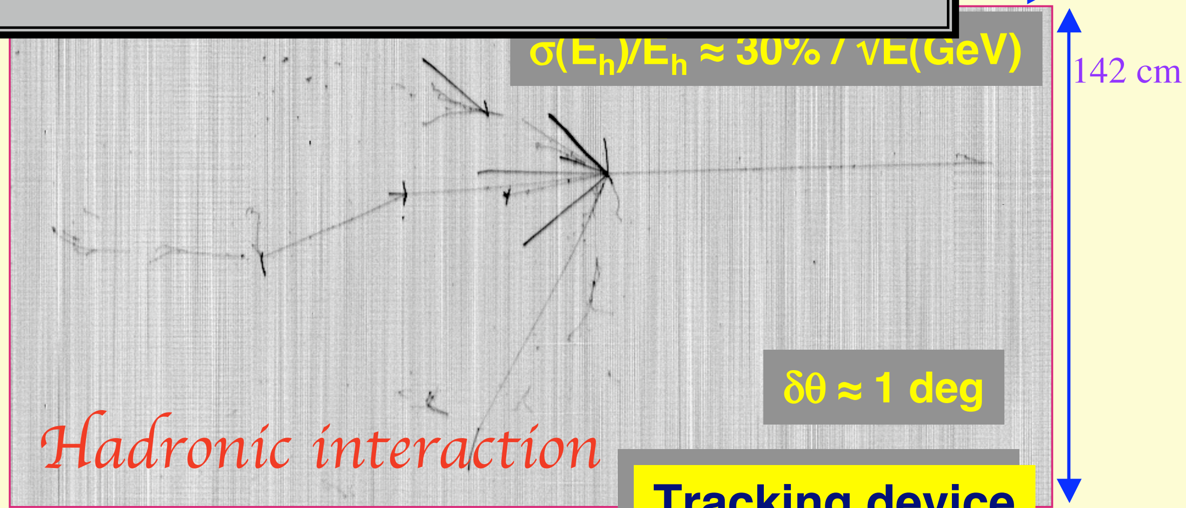
Stopping tracks:

$\sigma(E_{dep})/E_{dep} = 11\% / \sqrt{E_{dep}(MeV)} + 2\%$



Run 960, Event 4 Collection Left

Measurement of local energy deposition dE/dx



$\sigma(E_h)/E_h \approx 30\% / \sqrt{E(GeV)}$

$\delta\theta \approx 1$ deg

Run 308, Event 160 Collection Left

Tracking device

RESULTS DOCUMENTED IN 6 PAPERS PUBLISHED IN 2003

Liquid Argon TPC: the big picture

physics calls for applications at two different mass scales

100 ton

- Precision studies of ν interactions
- Calorimetry
- Near station in LBL facilities

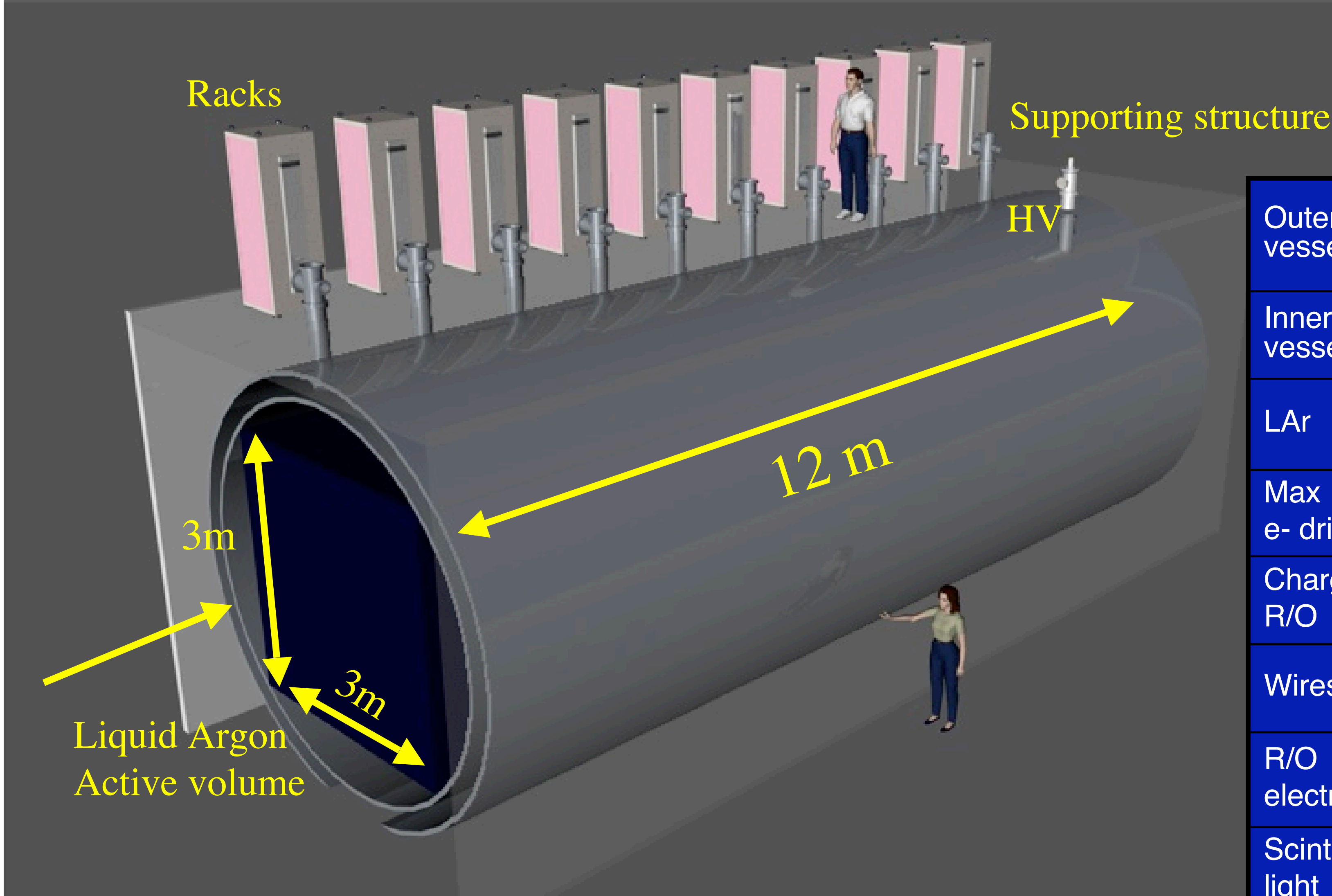
100 kton

- Ultimate nucleon decay searches
- Astroparticle physics
- CP violation in neutrino mixing

Strong synergy and high degree of interplay

Need to coherently develop conceptual ideas within the international community

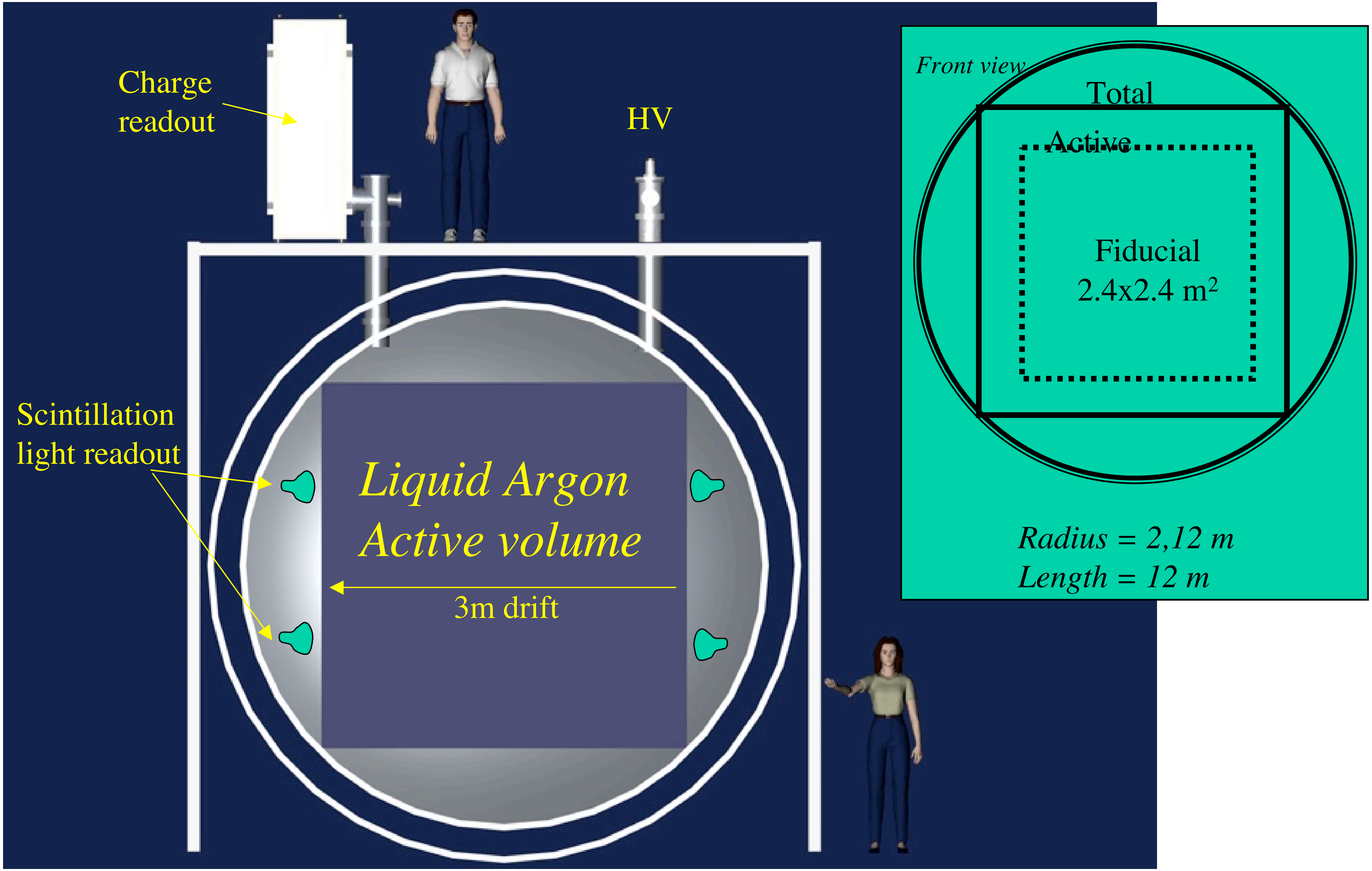
Conceptual design of a ~100 ton LAr TPC for a near station in a LBL facility:



Outer vessel	$\phi \approx$ 5m, L≈13m, 15mm thick, weight ≈ 22 t
Inner vessel	$\phi \approx$ 4,2 m, L ≈ 12 m, 8 mm thick, ≈ 10 t
LAr	Total ≈ 240 t Fiducial ≈ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	≈10000 (7000) ϕ = 150 μm
R/O electr.	on top of the dewar
Scintill. light	Also for triggering
B-field	possible

Ideas for future liquid Argon detectors
A.Ereditato, A.Rubbia, to appear in Proc. of NUINT04, LNGS, March 2004

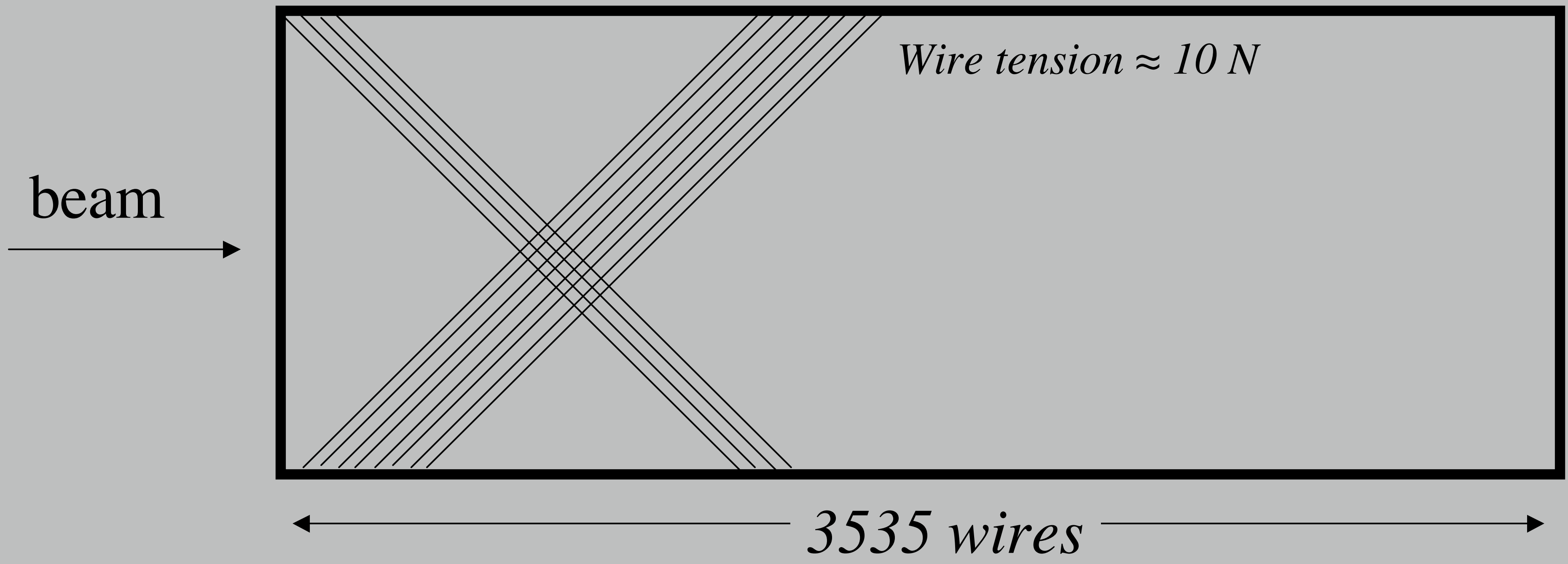
Conceptual design study of a ≈100 ton active LAr detector:



Readout chamber

Baseline assumptions:

Two wire planes, ±45°, ***3 mm pitch****, ϕ 150 μm*



7071 wires in total

2121 long
1414 short

221 units of 32 wires

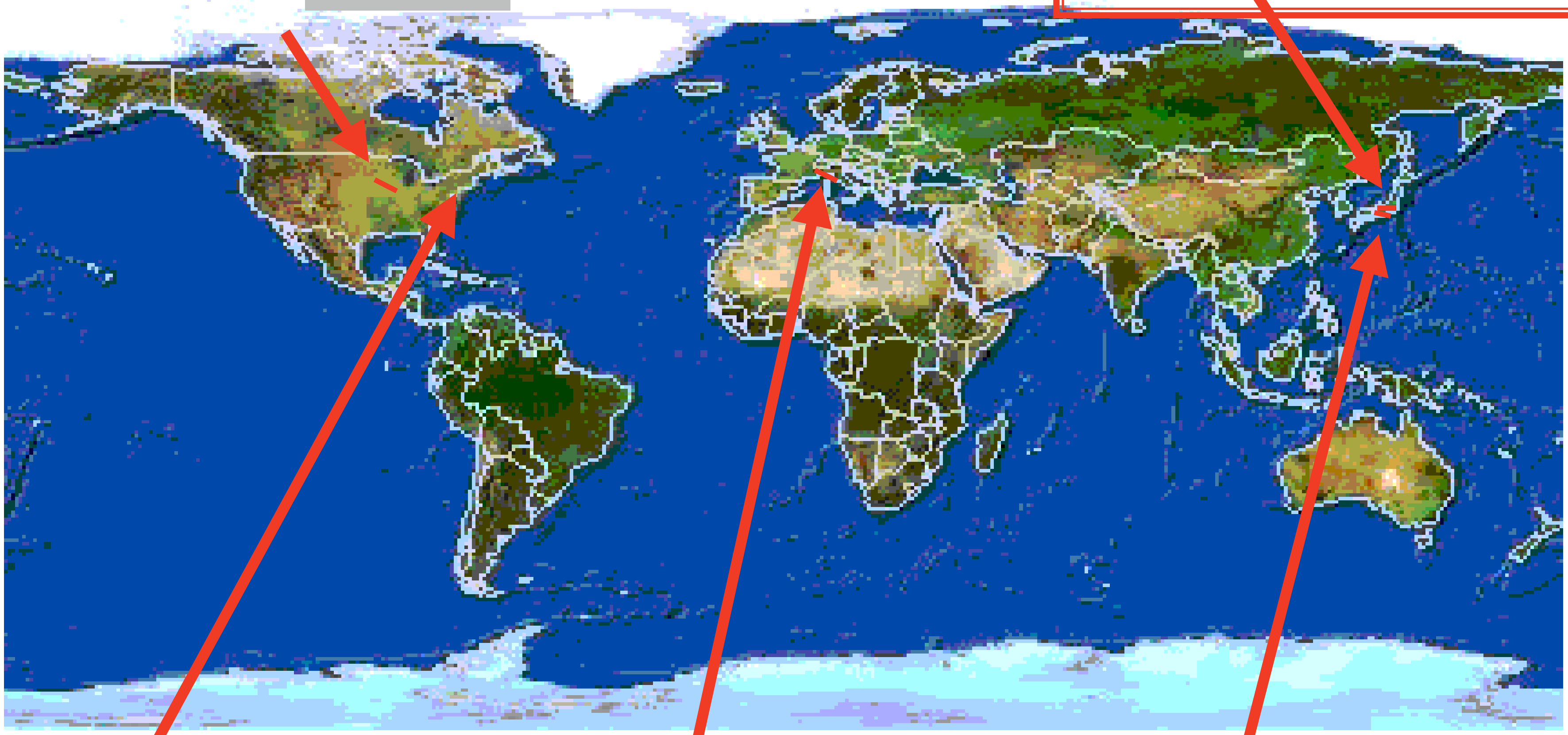
100 ton detector: milestones

- **Nov 2003: JHF-Europe working group meeting at CERN / Venice Workshop**
  - Physics is calling for next generation high granularity neutrino detector
  - Basic concepts of a 100 ton detector for JHF program
- **March 2004: NUINT04 Workshop**
  - Identification of a global strategy: synergy between ‘small’ and ‘large’ mass LAr TPC
  - Intent to define a coherent International Network to further develop the conceptual ideas
  - High statistics, precision physics will require a ≈100 ton detector in a neutrino beam (near site)
  - Approved or planned LBL programmes can profit from a 100 ton liquid Argon detector in an intermediate station
- **June 2004 : CH-neutrino meeting**
  - Plan to develop a prototype in Europe as an initial step
  - Ideal device to test electromagnetic & hadronic calorimetry (calibration) in a charged particle beam

Location of current/planned neutrino beams

FNAL
120 GeV Main Injector
NUMI (0.4MW)
8 GeV booster
BOONE

JAERI
50 GeV PS
J-PARC (0.75MW)
(under construction, ν-beam>2009)



BNL
24 GeV AGS

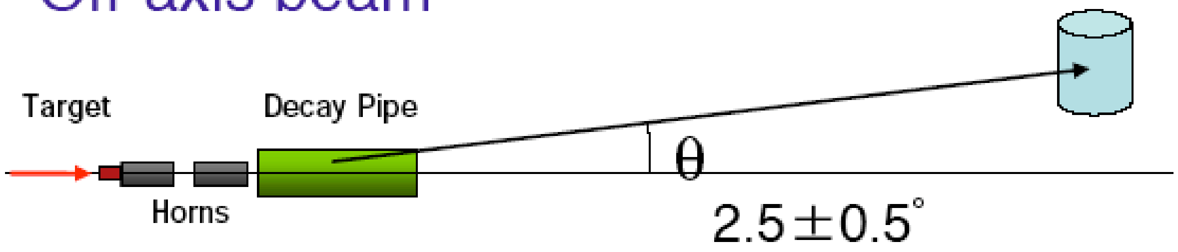
CERN
400 GeV SPS
CNGS (0.3MW)

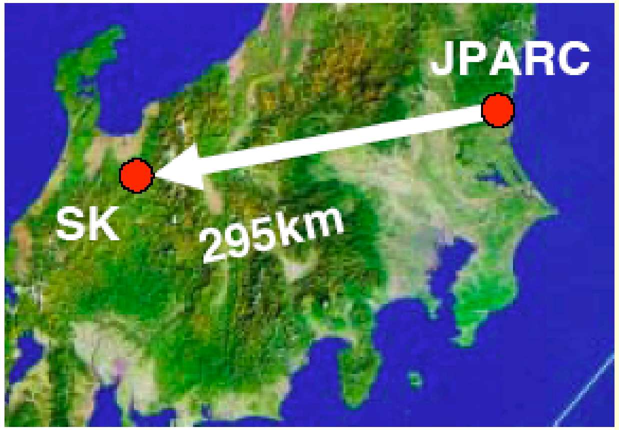
KEK
12 GeV PS
K2K 0.005 MW

JPARC neutrino project = T2K

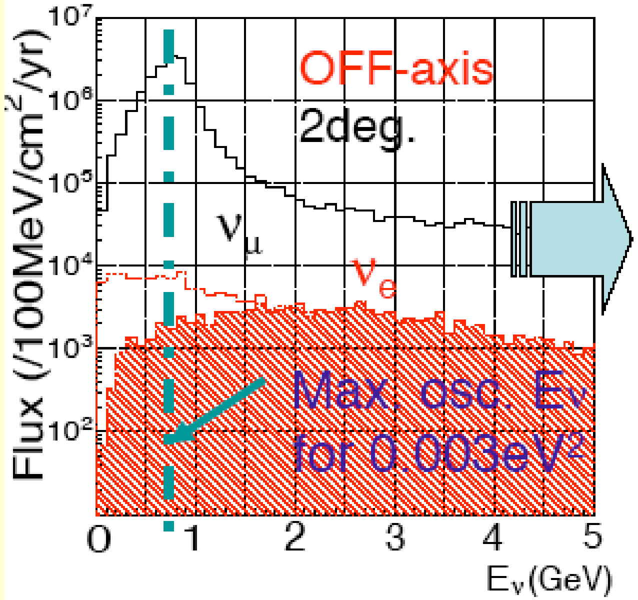
APPROVED IN DECEMBER 2003

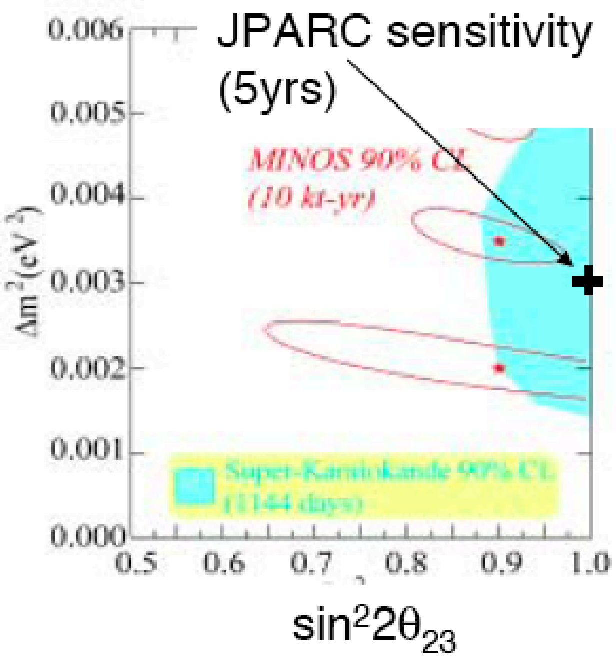
Off-axis beam

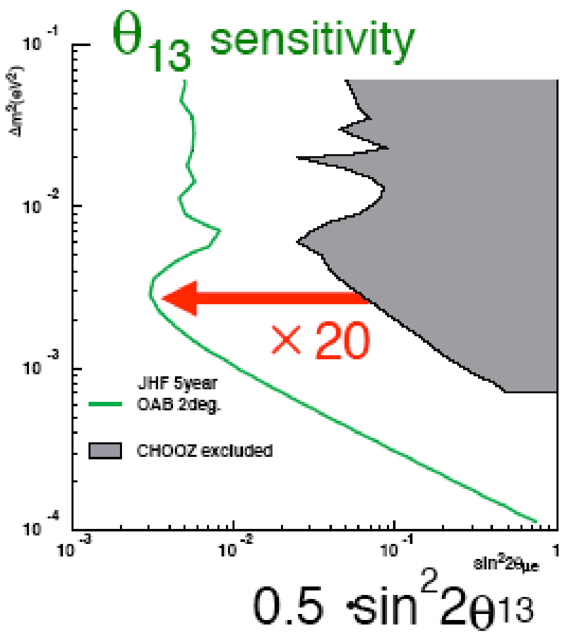




×100 more intensity than K2K, Eν < 1GeV

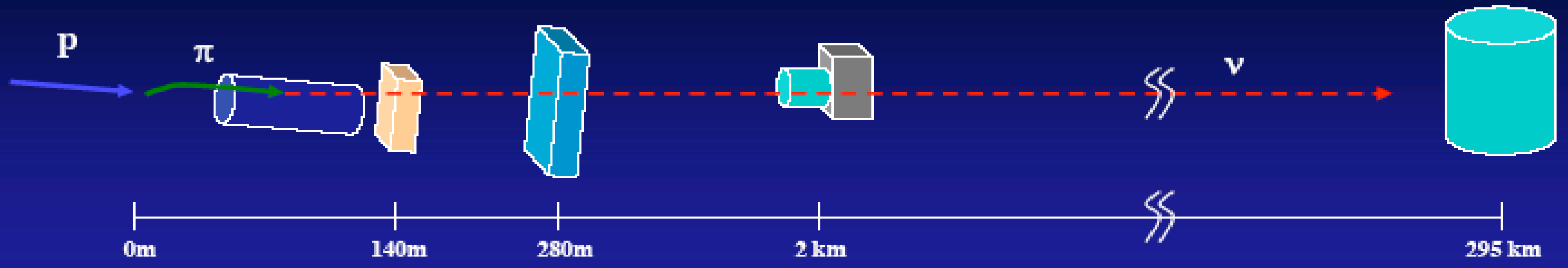




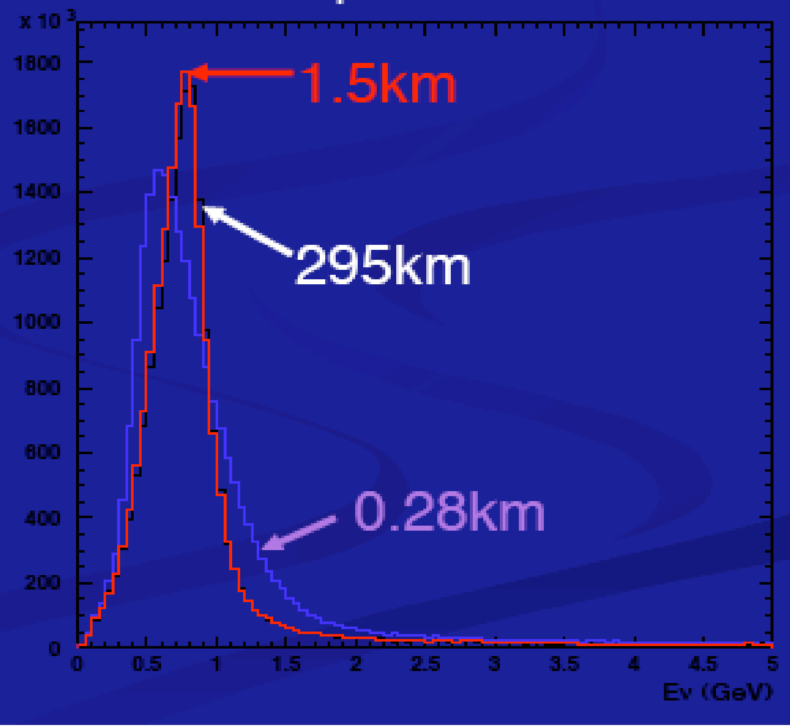


A wide physics program and the next logical step in accelerator neutrino physics

Front Detectors

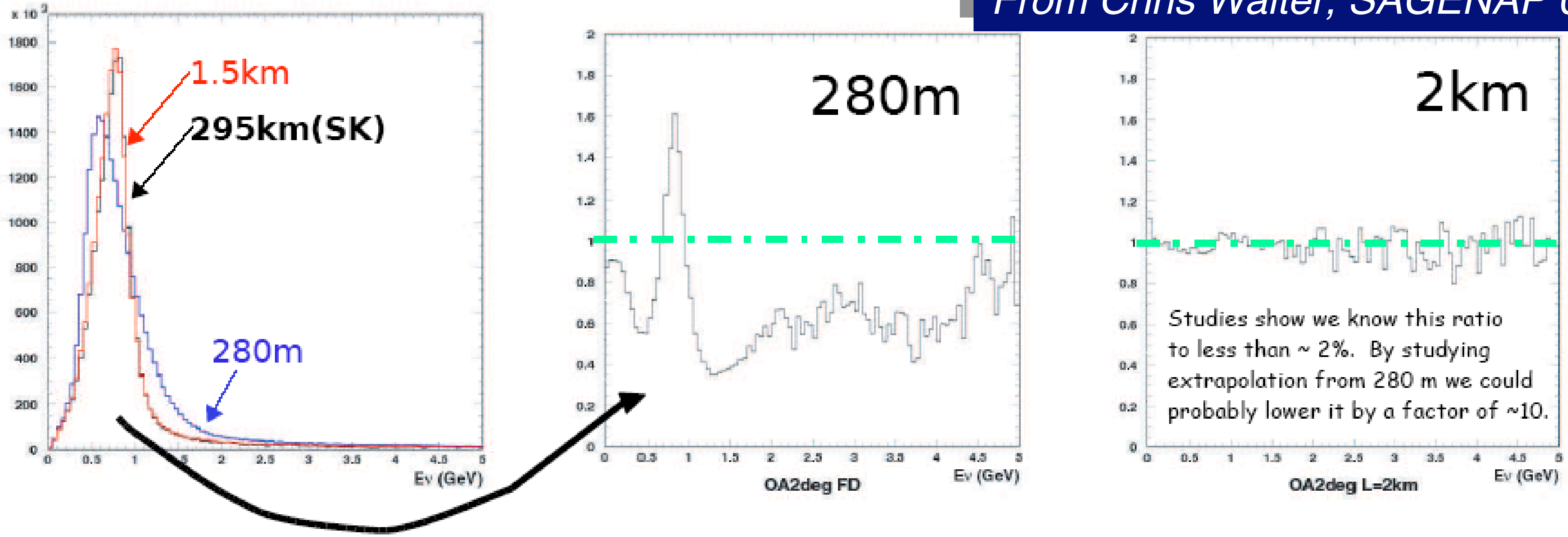


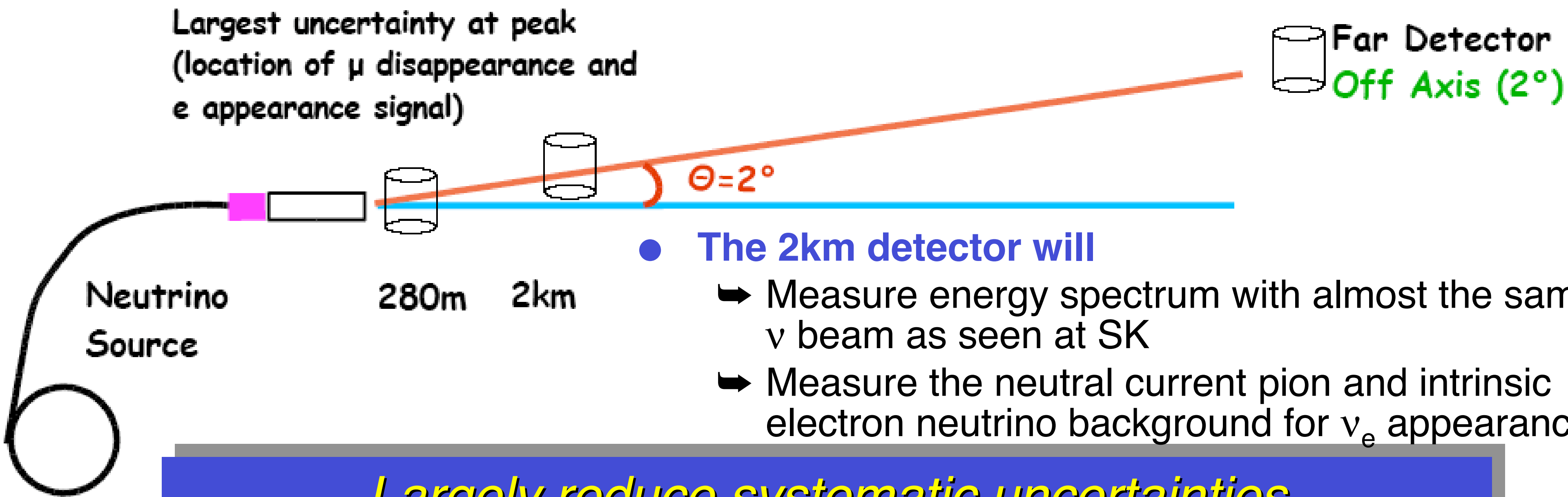
- Muon monitors @ ~140m
  - Fast (spill-by-spill) monitoring of beam direction/intensity
- First Front detector @280m
  - Neutrino intensity/direction
- Second Front Detector @ ~2km
  - Almost same E_ν spectrum as for SK
  - Water Cherenkov can work
- Far detector @ 295km
  - Super-Kamiokande (50kt)



Far/Near ν Flux Ratio vs. Detector Distance

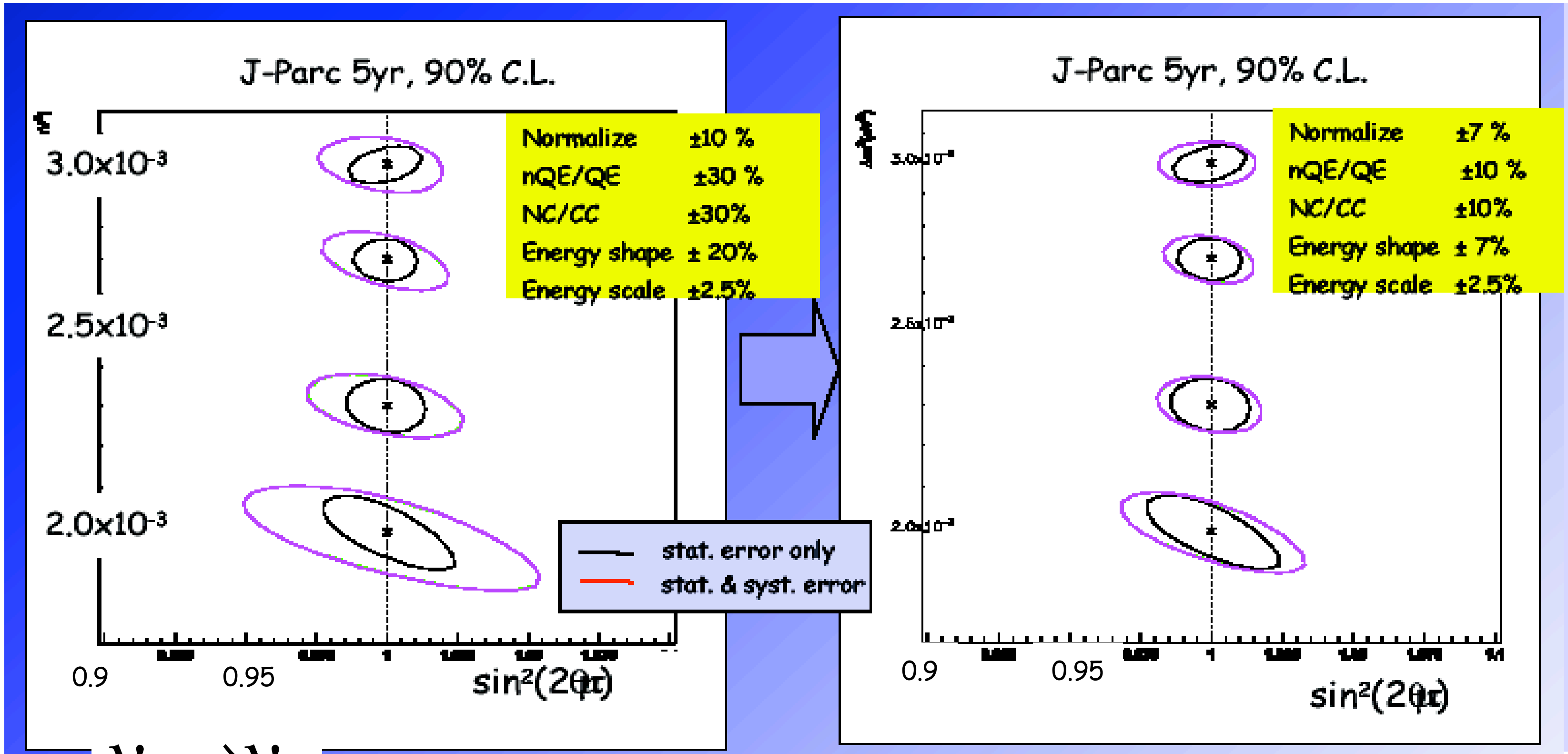
From Chris Walter, SAGENAP 04/04





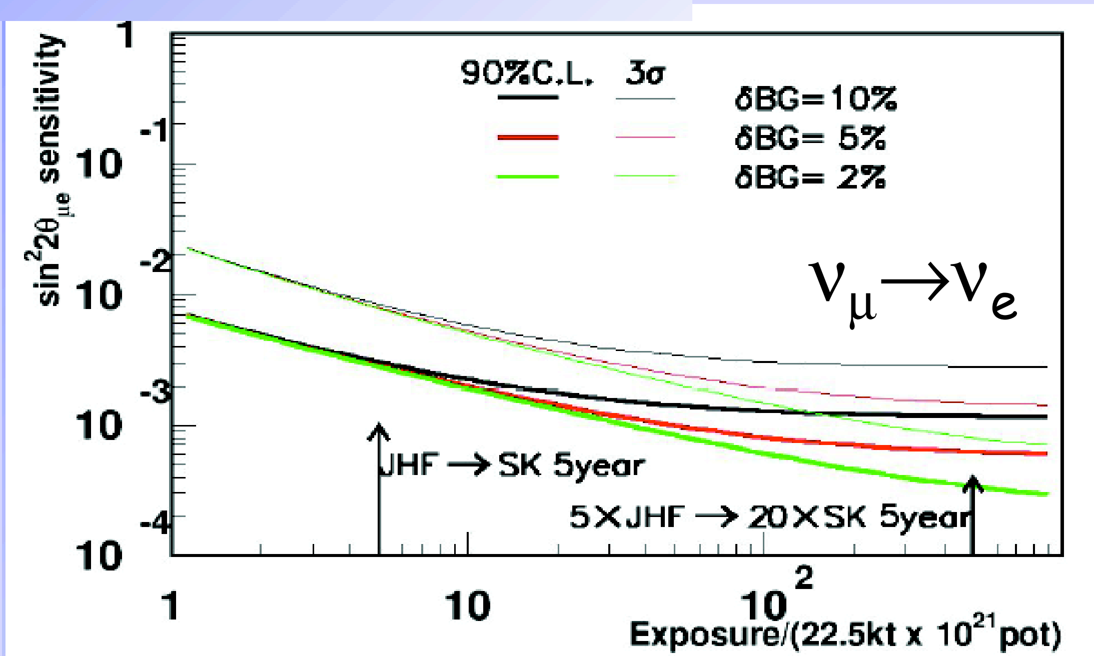
- **The 2km detector will**
  - ➥ Measure energy spectrum with almost the same ν beam as seen at SK
  - ➥ Measure the neutral current pion and intrinsic electron neutrino background for ν_e appearance

Largely reduce systematic uncertainties



$\nu_\mu \rightarrow \nu_\tau$

Impact of systematic errors on the T2K sensitivity



Rationale of 2 km position (personal comments)

- **We think that the necessity for a 2 km station rests on at least two points**

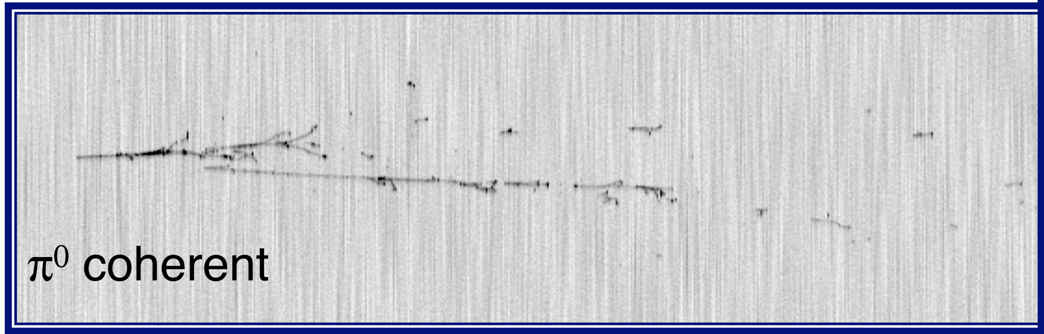
- **(A) It appears natural that a conservative approach to the first ever performed off-axis experiment with the goals of measuring very precisely the oscillation parameters will require some level of redundancy.**
  - ➥ At 280 m from the source, an angle of 1 degree corresponds to a displacement of 5 m. A movable detector could be hosted in the 280 m position in order to measure both on- and off-axis fluxes. The combination of the two can be used to predict the neutrino flux at 295 km in absence of oscillations. The 2 km position provide a way to directly access this flux in absence of oscillation!

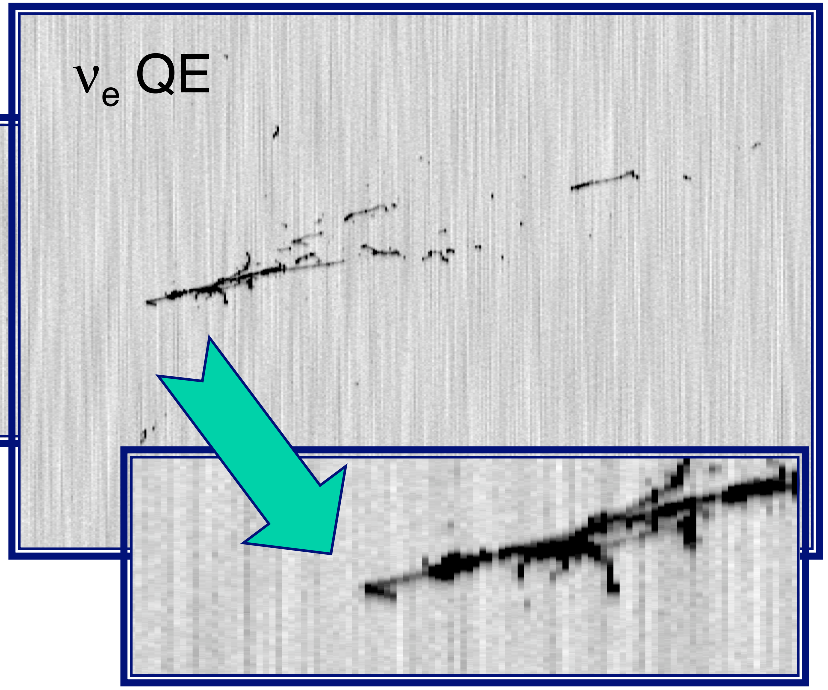
- **(B) The precise measurement of the π^0 yield requires the same neutrino flux as the far detector. For example, for neutral current events it is not possible to correct for the incoming neutrino energy on an event-by-event basis.**

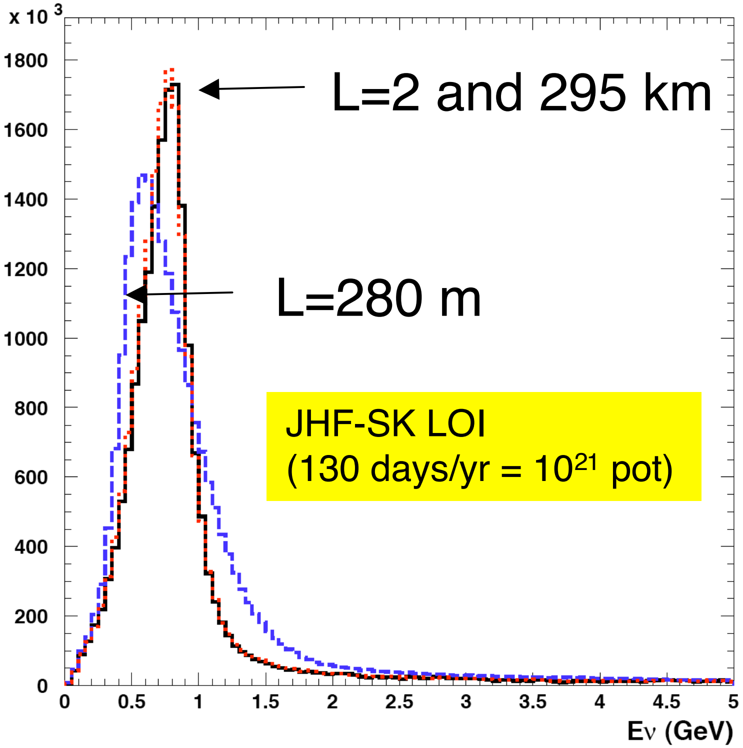
The 2 km position requires a fine-grain detector in the 100 ton range. The liquid Argon TPC is unique in this context.

The liquid Argon TPC allows for large detectors with very high granularity (sampling rate ≈ $0.02X_0$)

full simulation, digitization, and noise inclusion





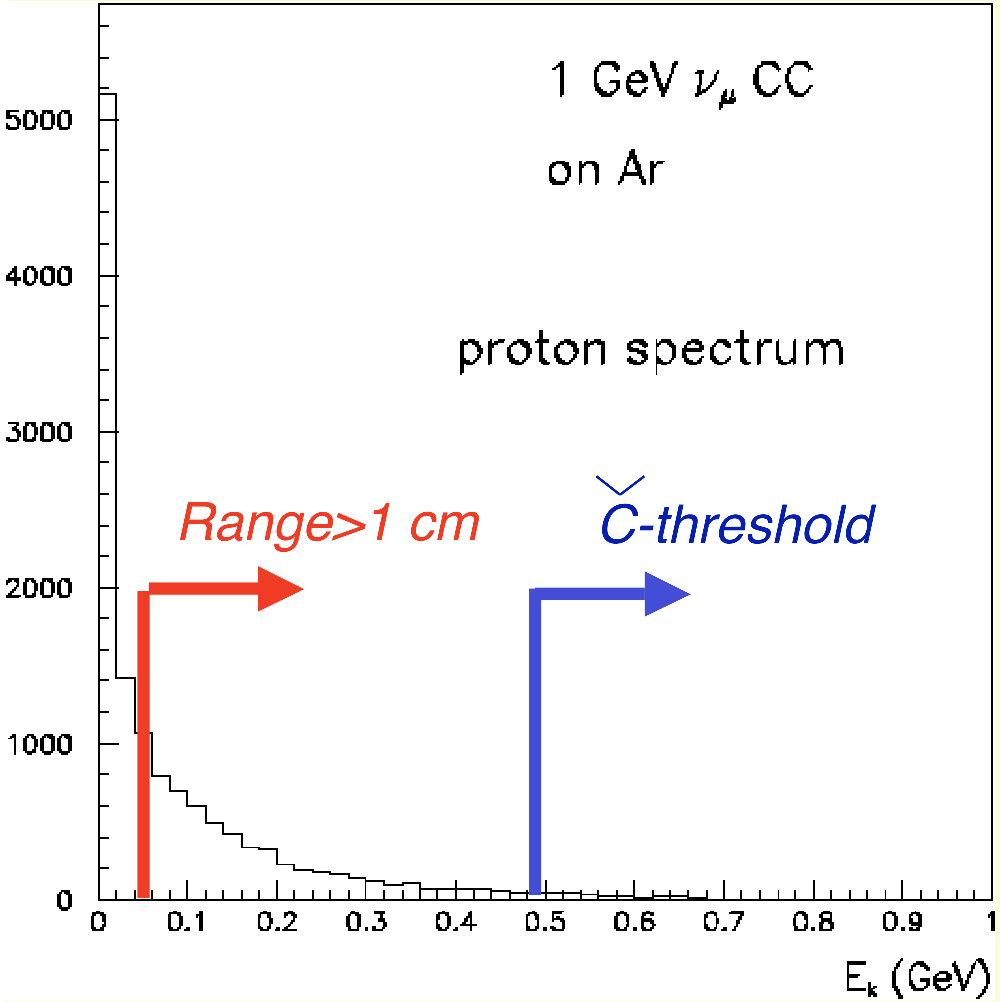


For example: 100 ton @ L=2000 m

Beam	E_{peak}(GeV)	ν_μ	ν_e
OA2	0.7	300000/yr 0.1/spill	5800/yr 45/day

High granularity: Example of proton detection thresholds

E_ν = 1 GeV (MC)



Protons

Kinetic energy T (MeV)	Momentum p (MeV/c)	Range in LAr (cm)
10	43	0.14
40	280	0.93
70	370	4.19
100	446	7.87
300	813	51.9
500	1094	116

Particle	Cerenkov thr. in H_2O MeV/c	range in LAr cm
e	0.6	0.07
μ	120	12
π	159	16
K	568	59
p	1070	110

Ongoing studies and initial R&D strategy

Engineering studies, dedicated test measurements, detector prototyping, simulations, physics performance studies in progress:

1) **Geometry and physics optimization**

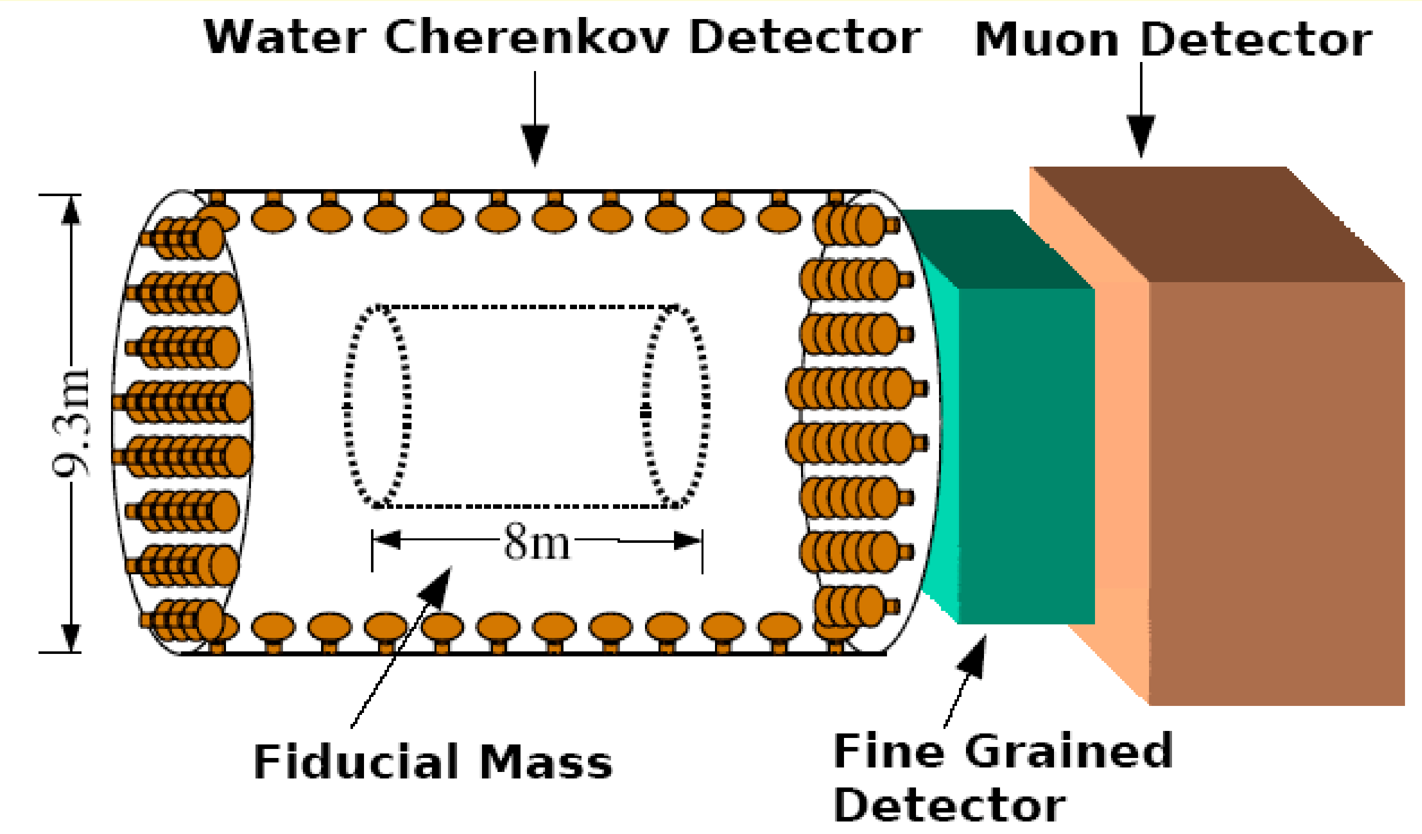
2) **Design of a prototype**

3) **Offline reconstruction of events**

4) **Possible addition of a magnetic field**

1) Geometry and physics optimization

- **Geometry and physics optimization of a potential liquid Argon TPC acting as a fine grain detector at the 2km position of the T2K project**
  - ➥ Preliminary work in collaboration with Chris Walter
    - ☛ Optimization acceptance of tracks and showers from the water target (within space available in the planned hall)
    - ☛ Aim for GEANT4 results within the fall 2004



2) Design of a prototype

- **The safe and stable underground operation of a cryogenic liquid argon detector essentially relies on the capability to reach stable thermodynamical conditions.**
- **This implies that**
  - ➥ The thermal insulation must be as good as possible in order to reduce heat input (this effect improves with increased volume, since area over volume ratio improves)
  - ➥ The cryogenic liquid must be ideally stored at atmospheric pressure (with as small as possible overpressure)
  - ➥ The small evaporation of the liquid must be compensated by a small input of cold just sufficient to liquefy the produced vapor.
  - ➥ The purification system (liquid recirculation, mandatory to obtain high purity levels) needs to be as reversible as possible in order to prevent any losses and unnecessary heat input

R&D in cryogenic technique required to develop further these items

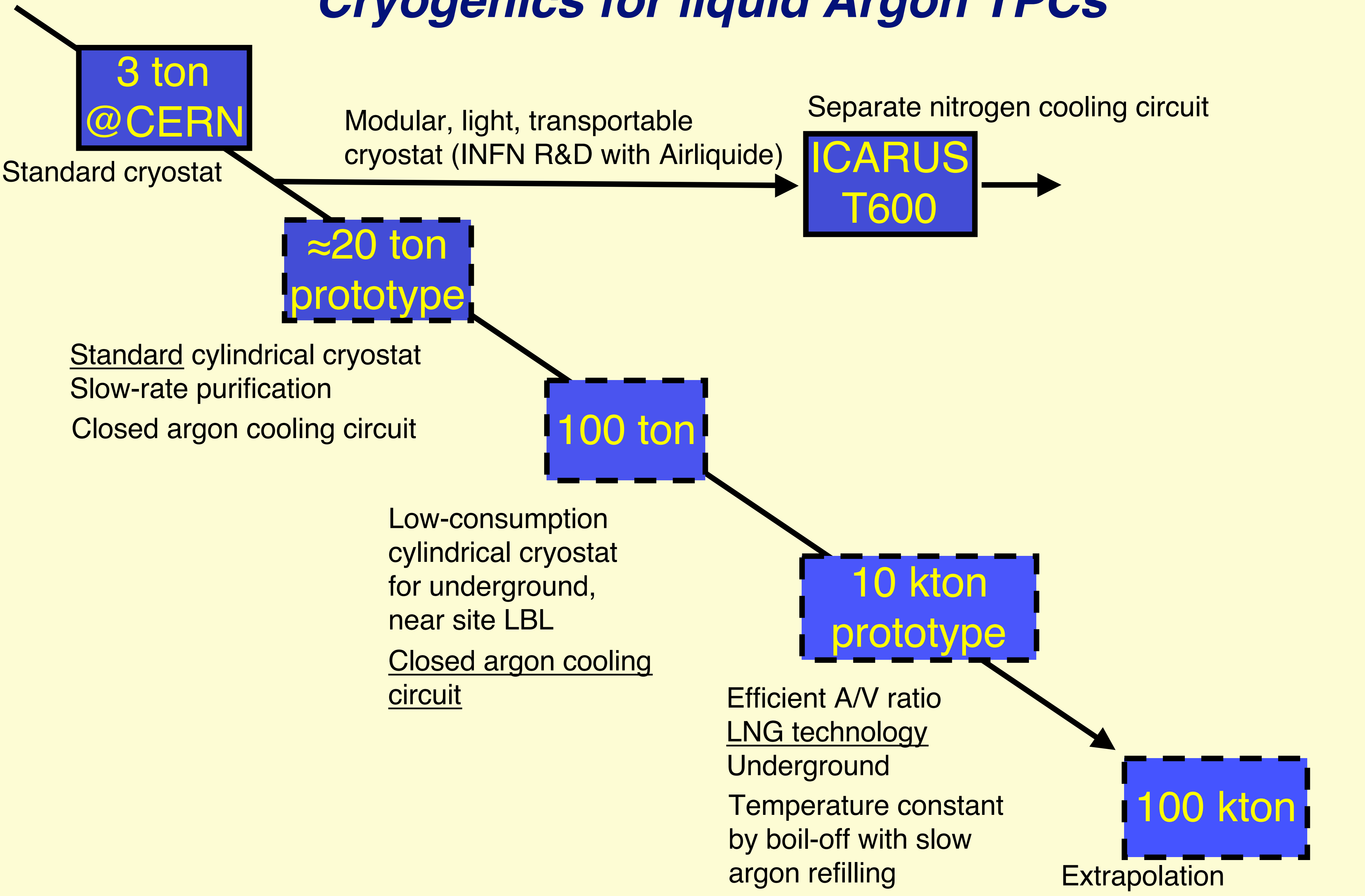
↓

Prototype

↓

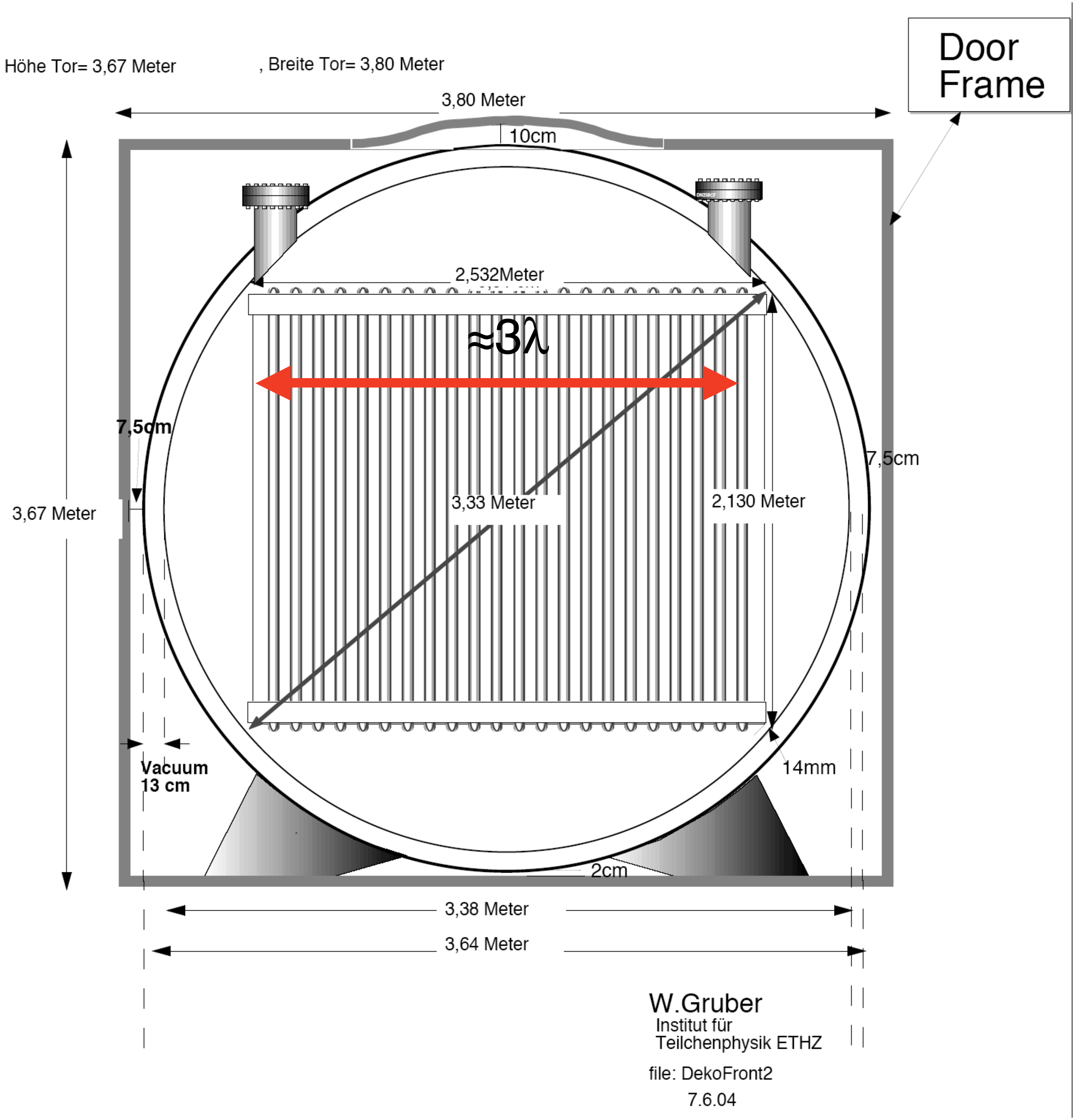
Interesting by-product: the prototype will also be a tool to study calorimetric response (electromagnetic and hadronic calibration)

Cryogenics for liquid Argon TPCs

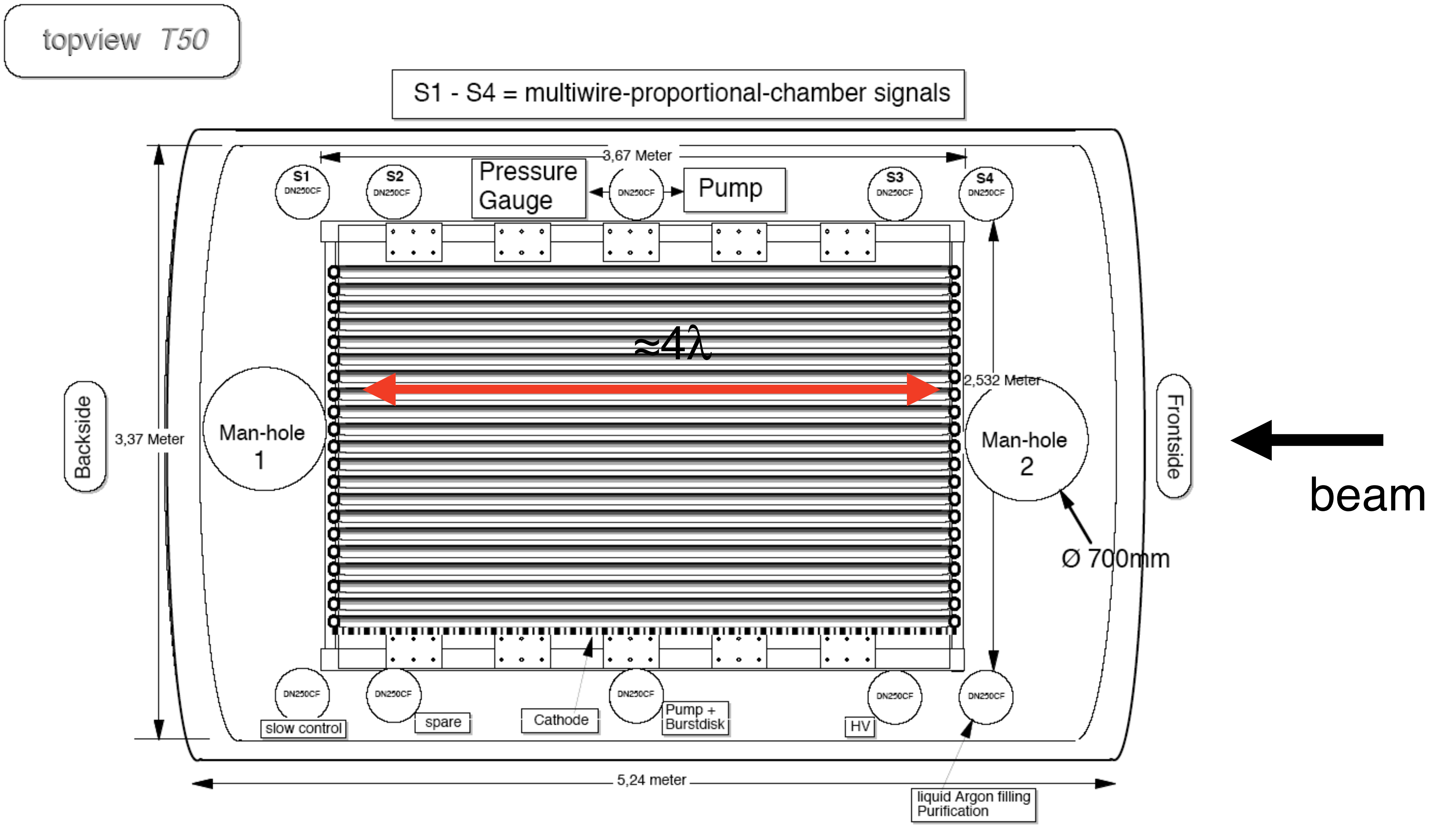


Preliminary design:

The help of PSI would be very valuable in this phase of the design of the cryogenics



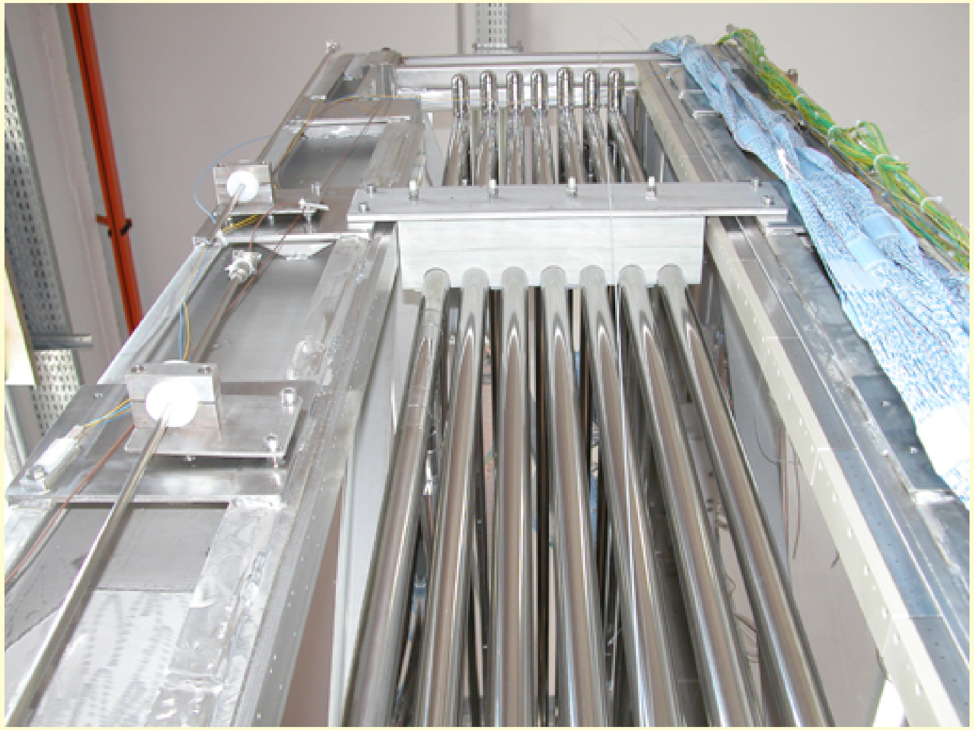
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

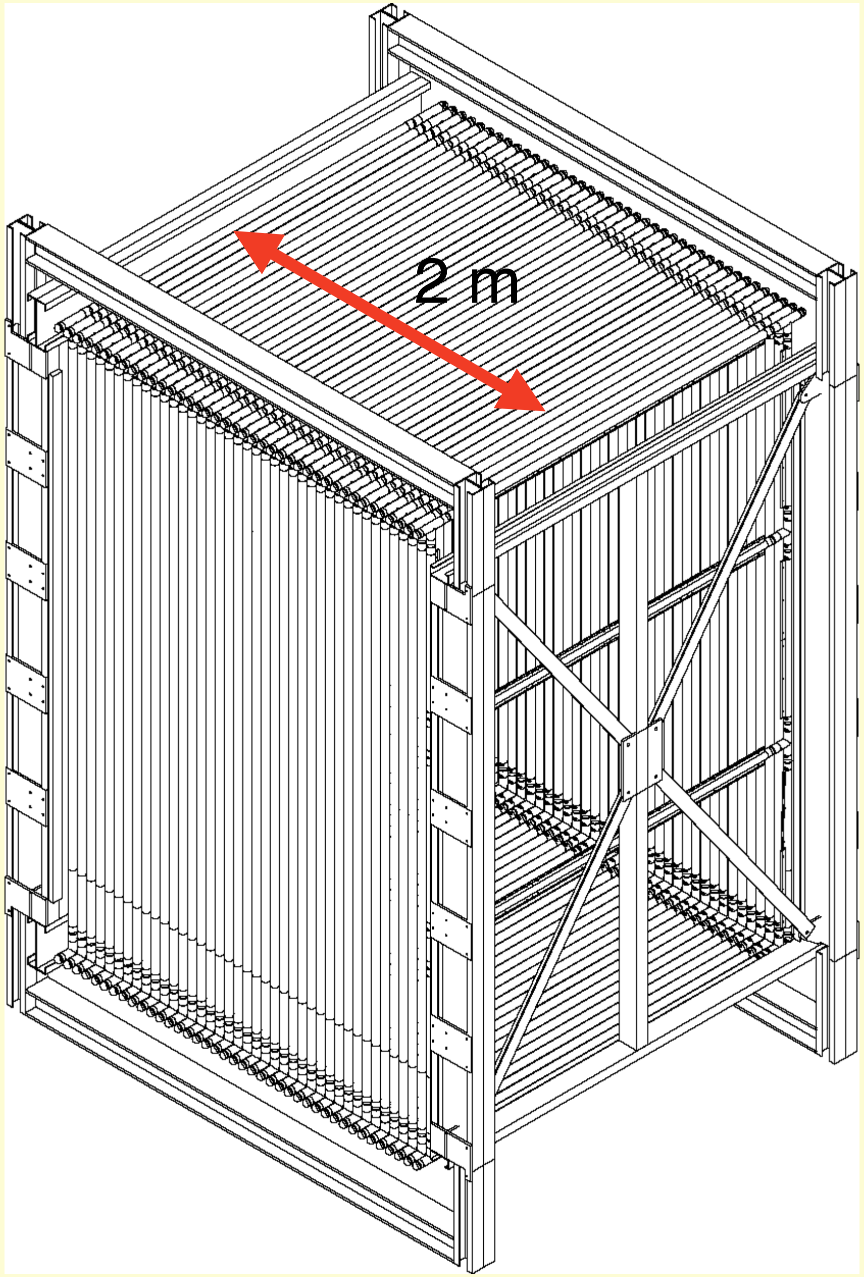


file. topview2
8.6.04
W.Gruber
Teilchenphysik
ETHZ

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Inner detector for prototype (tentative solution)



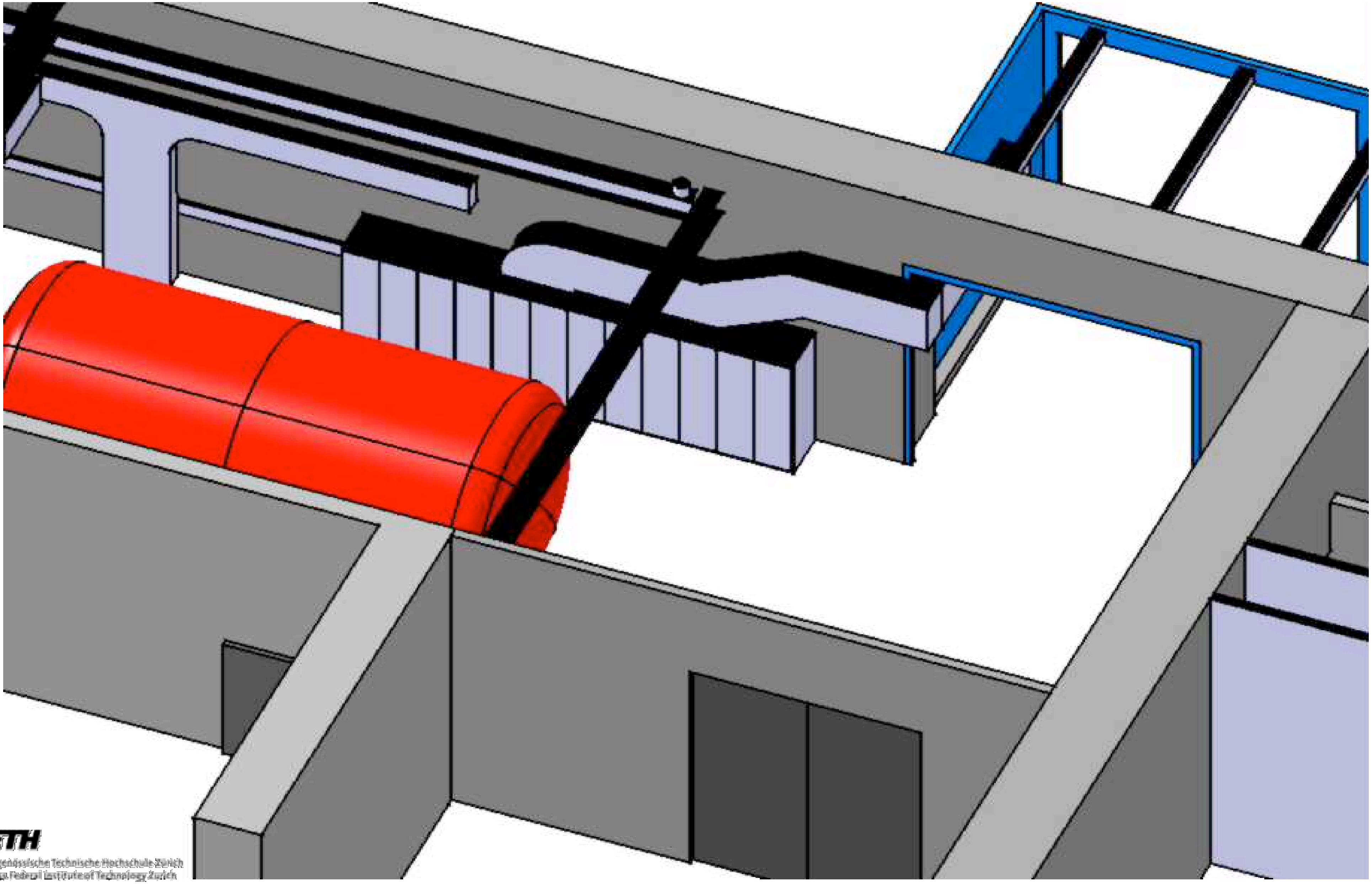


Extend drift length of an existing chamber.

Active volume 3 x 2 x 2 m^3 = 12 m^3

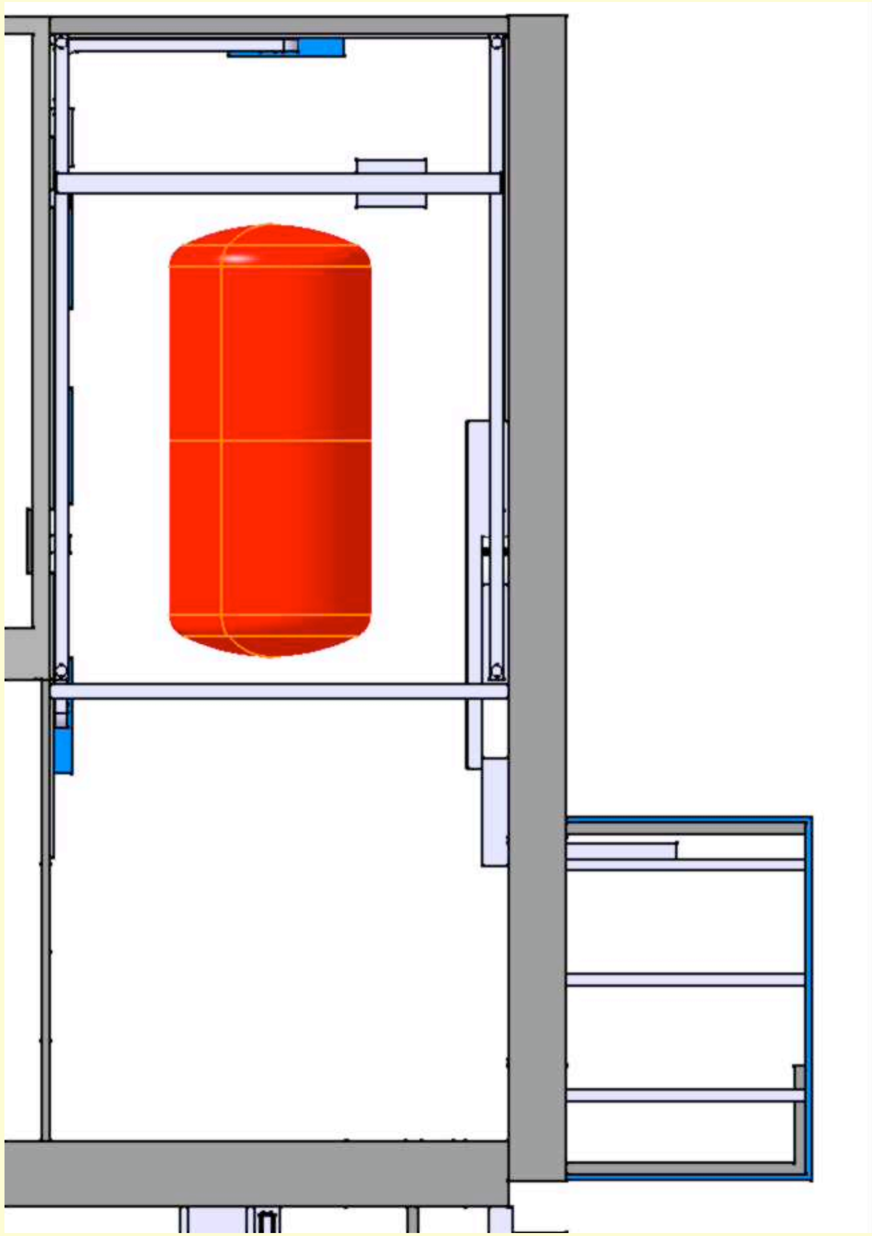
Mass = 17 tons

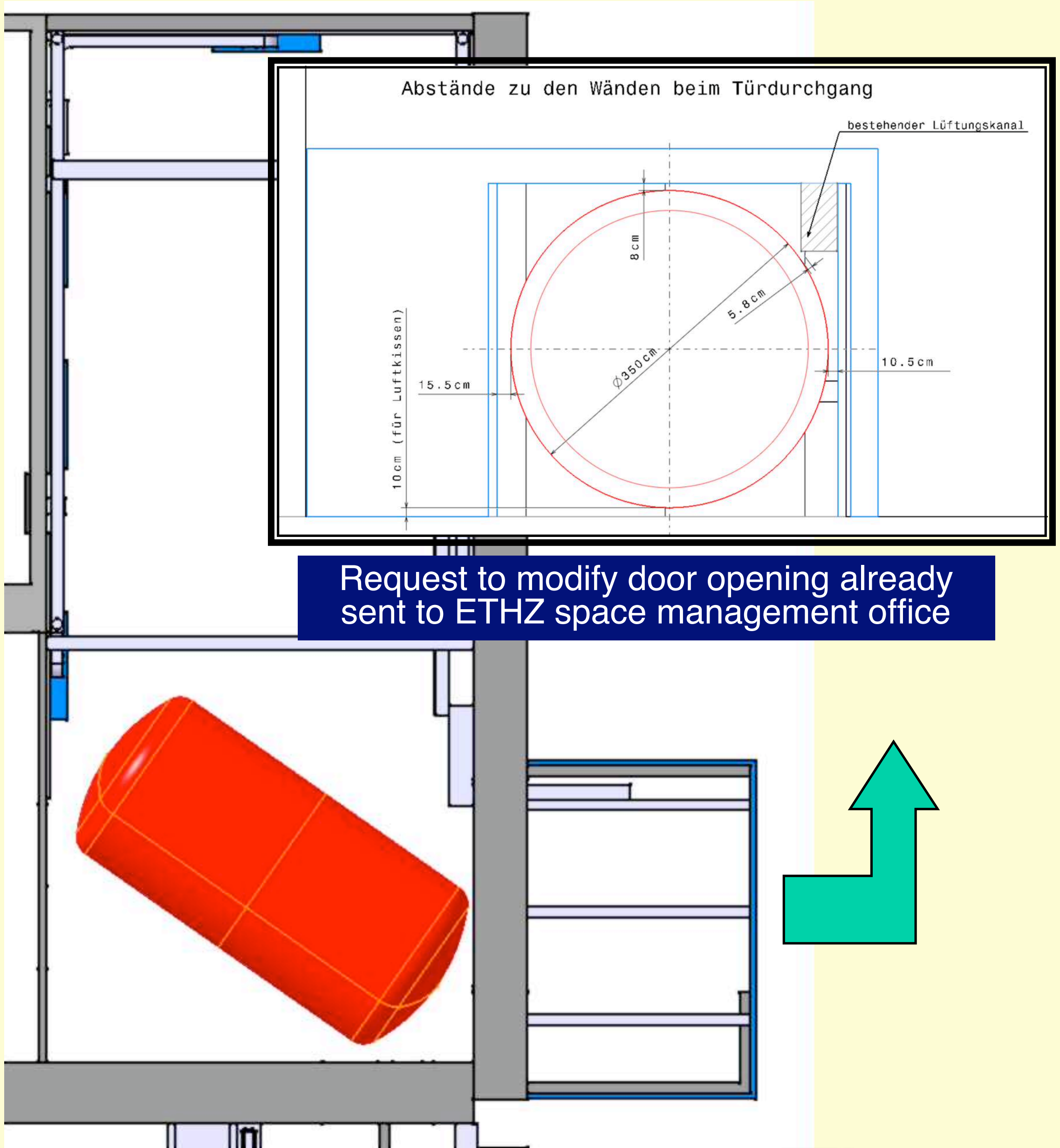
Possible assembly in ETHZ clean room



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Possible assembly in ETHZ clean room

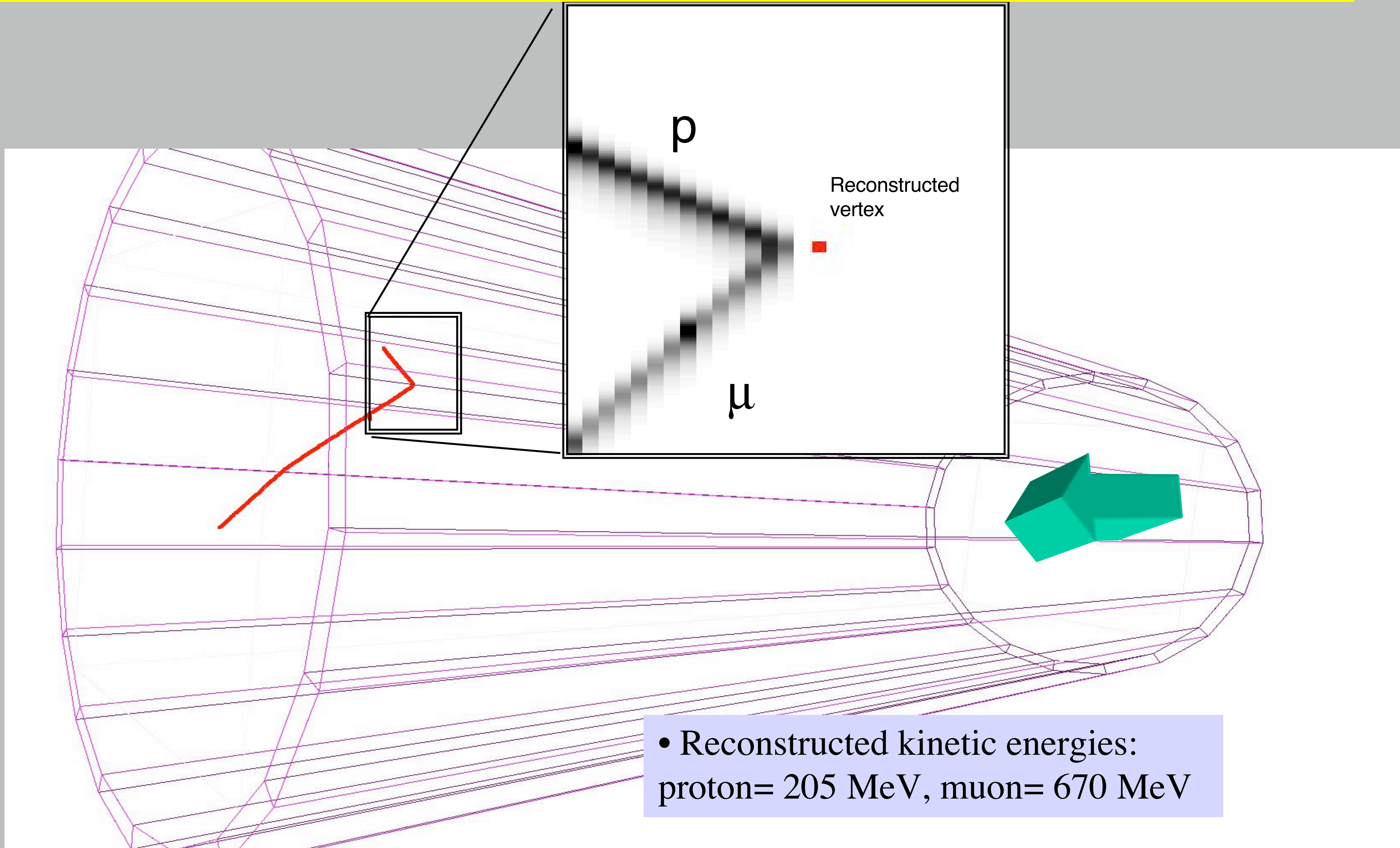




Request to modify door opening already sent to ETHZ space management office

3) Offline reconstruction of events

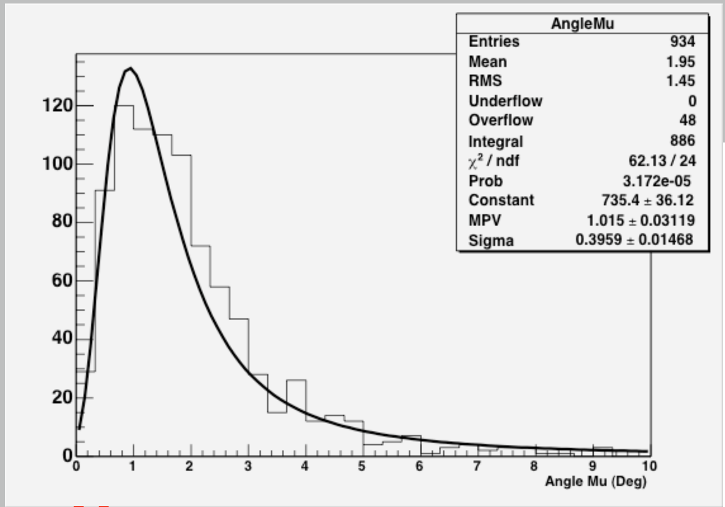
Work in progress to develop fully automatic event reconstruction ⇒ ***high statistics experiment !***



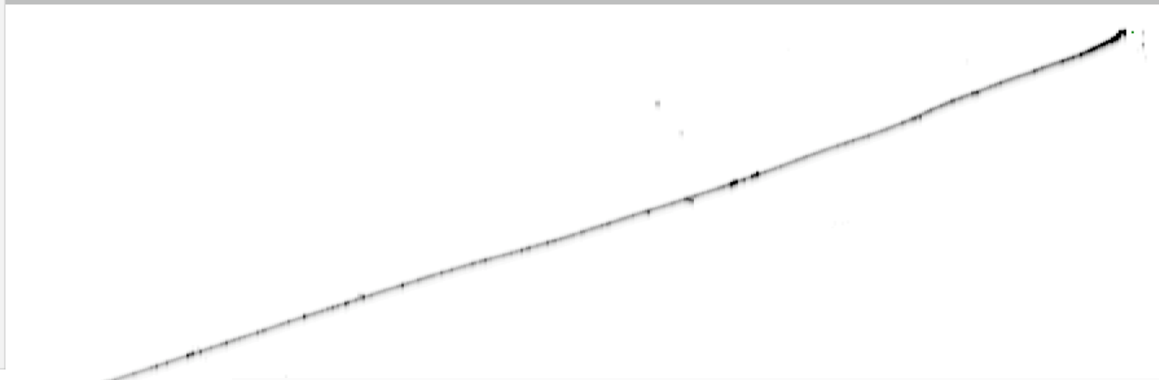
• Reconstructed kinetic energies:
proton= 205 MeV, muon= 670 MeV

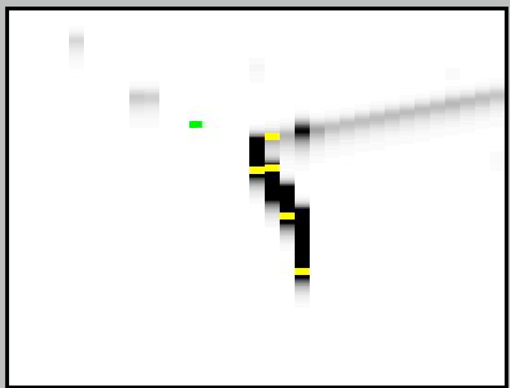
Automatic reconstruction: benchmark

Work in progress

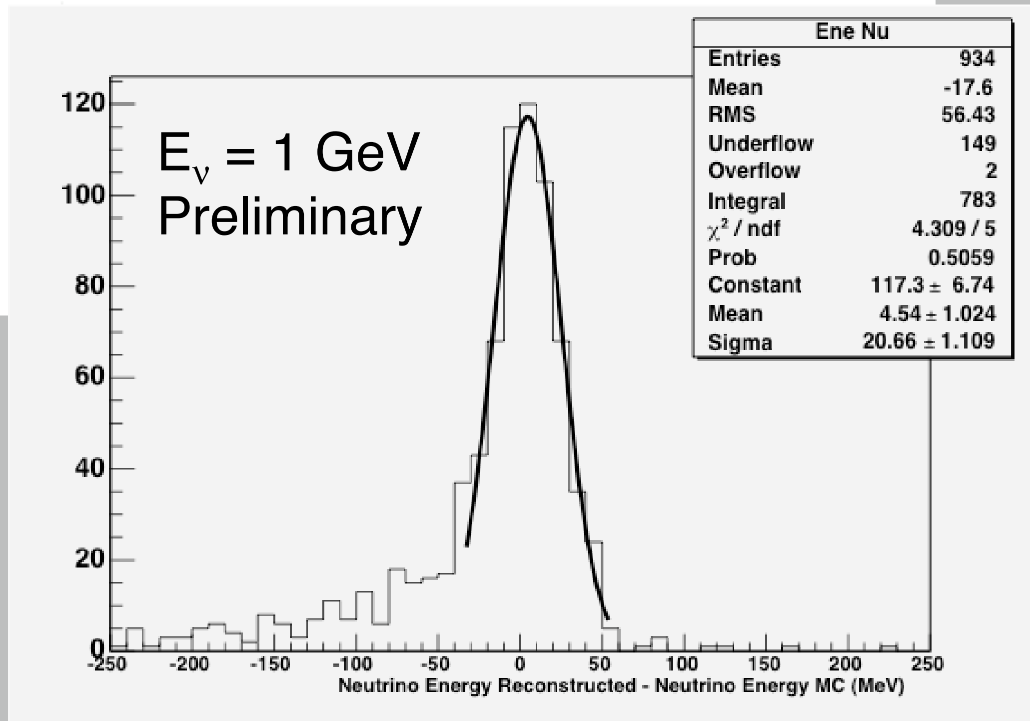


Muon angle resolution





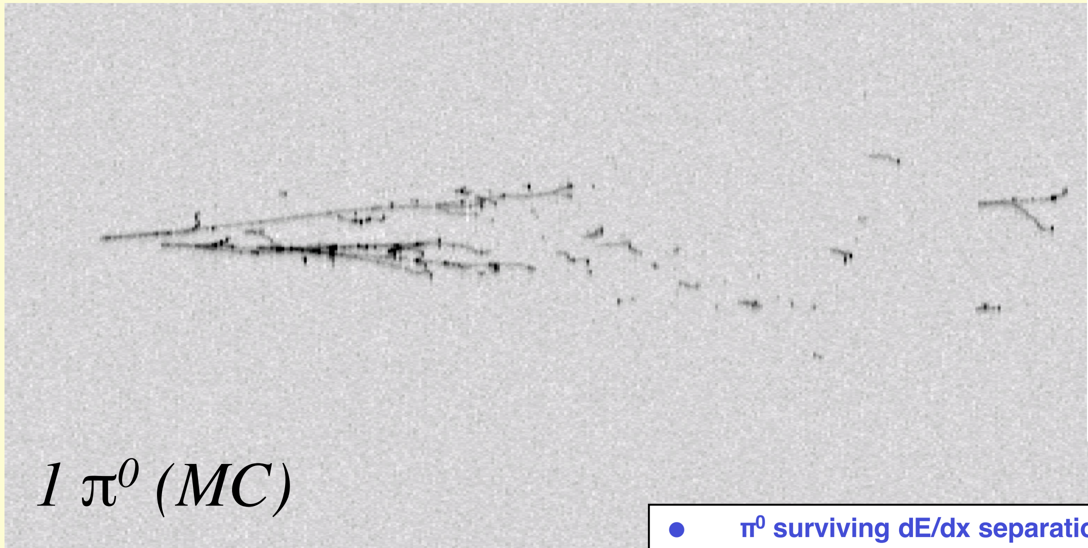
Primary vtx

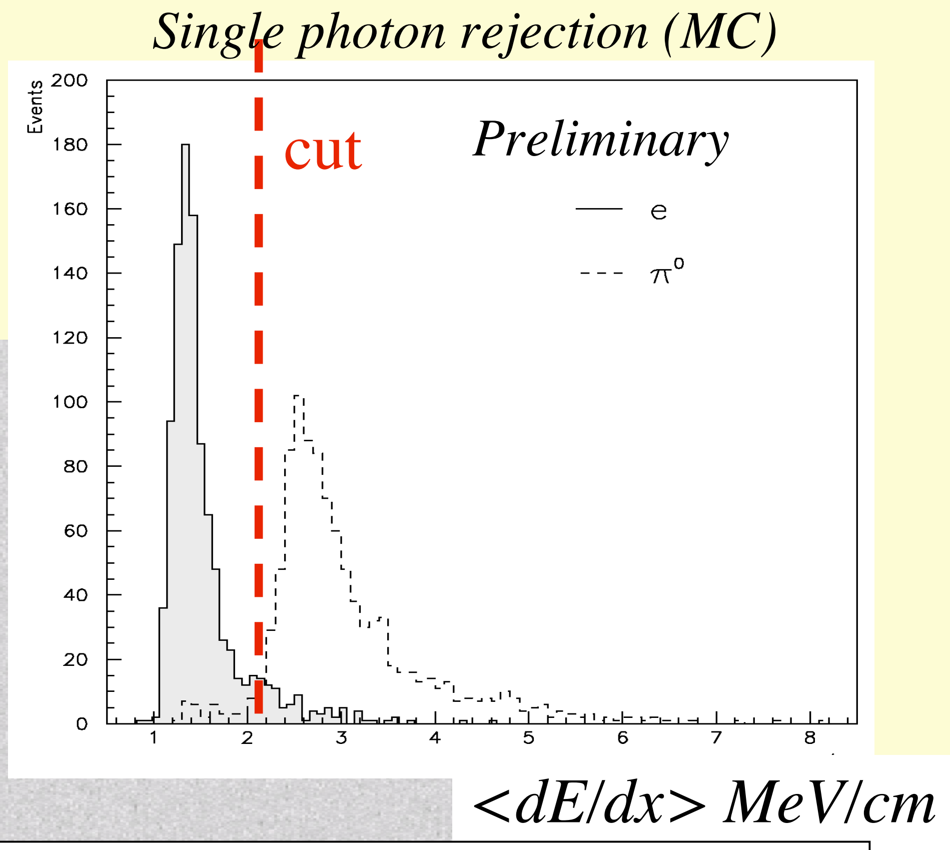


Neutrino energy resolution

Example: Rejection π_0 based on imaging

- **Algorithm: cut for 90% eff. electrons**
  1. Events with vertex: conversion within 1cm (3 wires) of vertex $R_1 \approx 19$
  2. Single/double mip $R_2 \approx 30$ (preliminary)





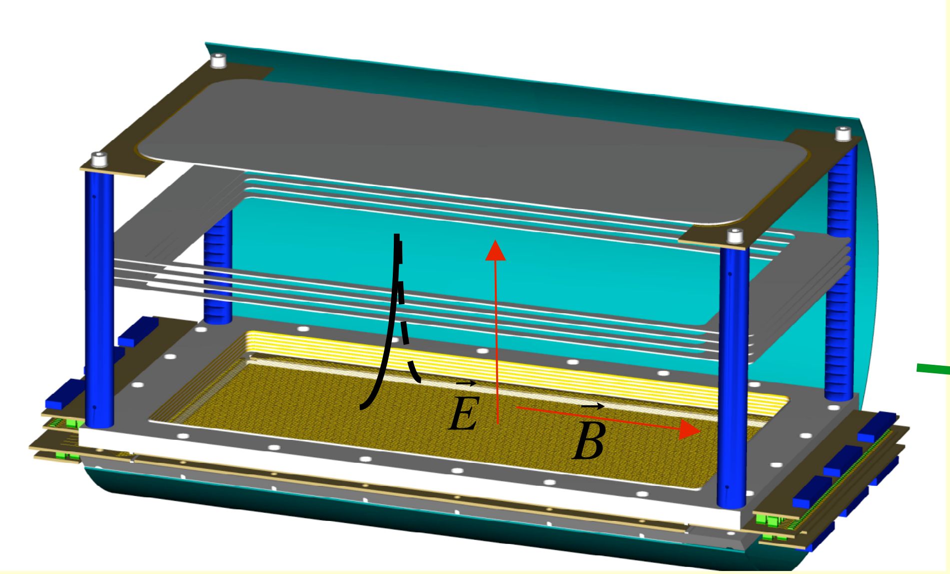
- **π^0 surviving dE/dx separation cut (total 31 events out of 1000 1GeV π^0)**
  - ➥ 21 events: Compton scattering
  - ➥ 5 events: Asymmetric decays (partners have less than 4 MeV)
  - ➥ 2 events: positron annihilation immediately
  - ➥ 1 event: positron make immediate Bremsstrahlung taking >90% of energy
- **π^0 rejection improves with energy: 5% @ 0.25 GeV, 4% @ 0.5 GeV, 3% @ 1 GeV, 2% @ 2 GeV**

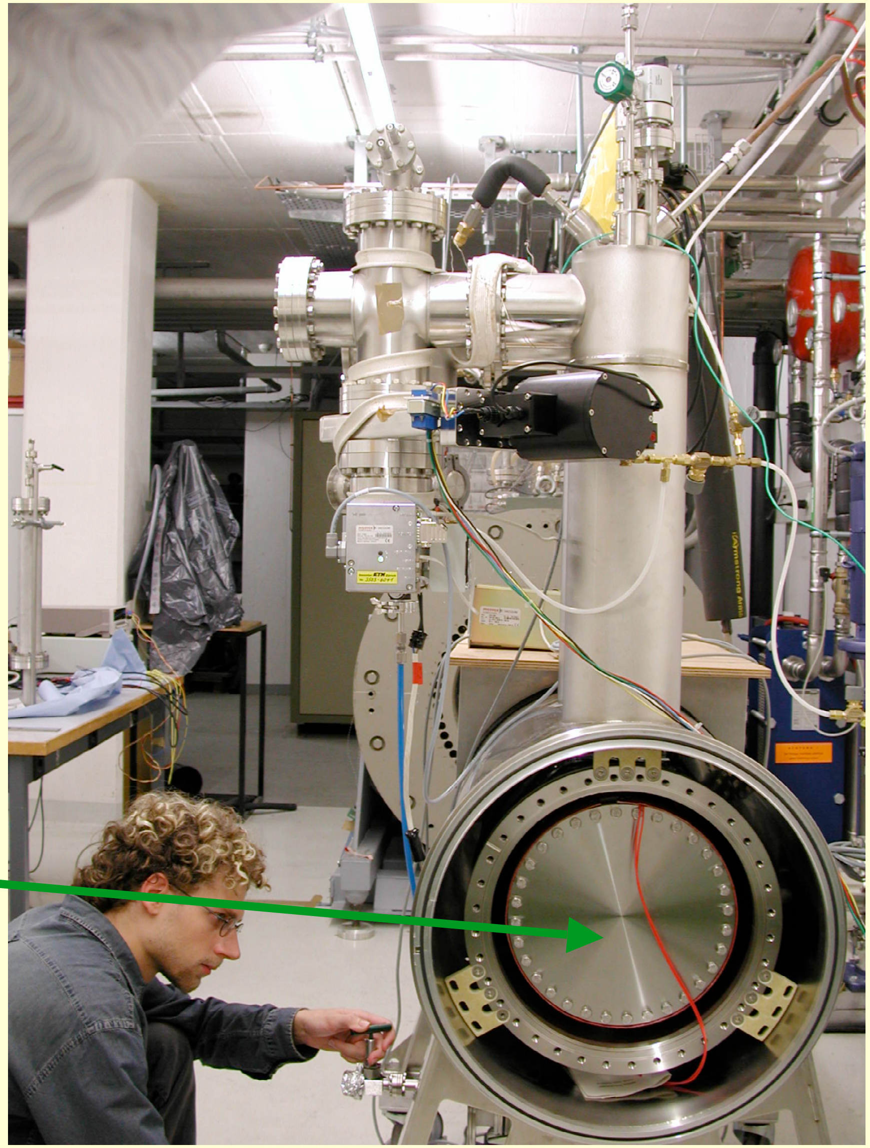
IMAGING PROVIDES $\approx 2\times10^{-3}$ EFFICIENCY FOR SINGLE π_0

- **Further rejection by kinematical cuts (depends on actual beam energy profile)**
  - ➥E.g. $\nu p \rightarrow \nu \pi^0 p$: momentum cut, angle, mass reconstruction, …

4) Test of liquid Argon imaging in B-field

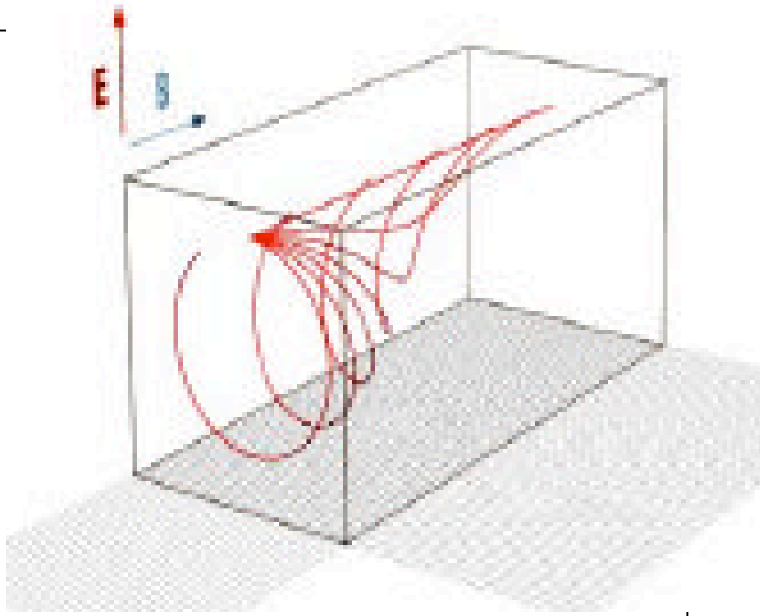
- **Small chamber in SINDRUM-I recycled magnet up to B=0.5T (230KW) given by PSI, Villigen**
- **Test program:**
  - Check basic imaging in B-field
  - Measure traversing and stopping muons bending
  - Charge discrimination
  - Check Lorentz angle ($\alpha \approx 30$mrad @ E=500 V/cm, B=0.5T)
- **Results expected in 2004**





Width 300 mm, height 150 mm, drift length 150 mm

R&D for liquid argon in magnetic field



- **Opens new possibility**
  - ➥ Charge discrimination
  - ➥ Momentum measurement of particles escaping detector (e.g. muons)
  - ➥ MS dominated ($\Delta p/p \approx 4\%$ at L=12m, B=1T)
- **Orientation of the field**
  - ➥ Bending in the direction of the drift where resolution is the best
    - ☛ Point resolution : ≈400 μm
  - ➥ B-field perpendicular to E-field
  - ➥ Lorentz angle small in liquids $\alpha \approx 30$mrad @ E=500 V/cm, B=0.5 T
- **Required magnetic field strength for charge discrimination (*x=path in LAr*)**

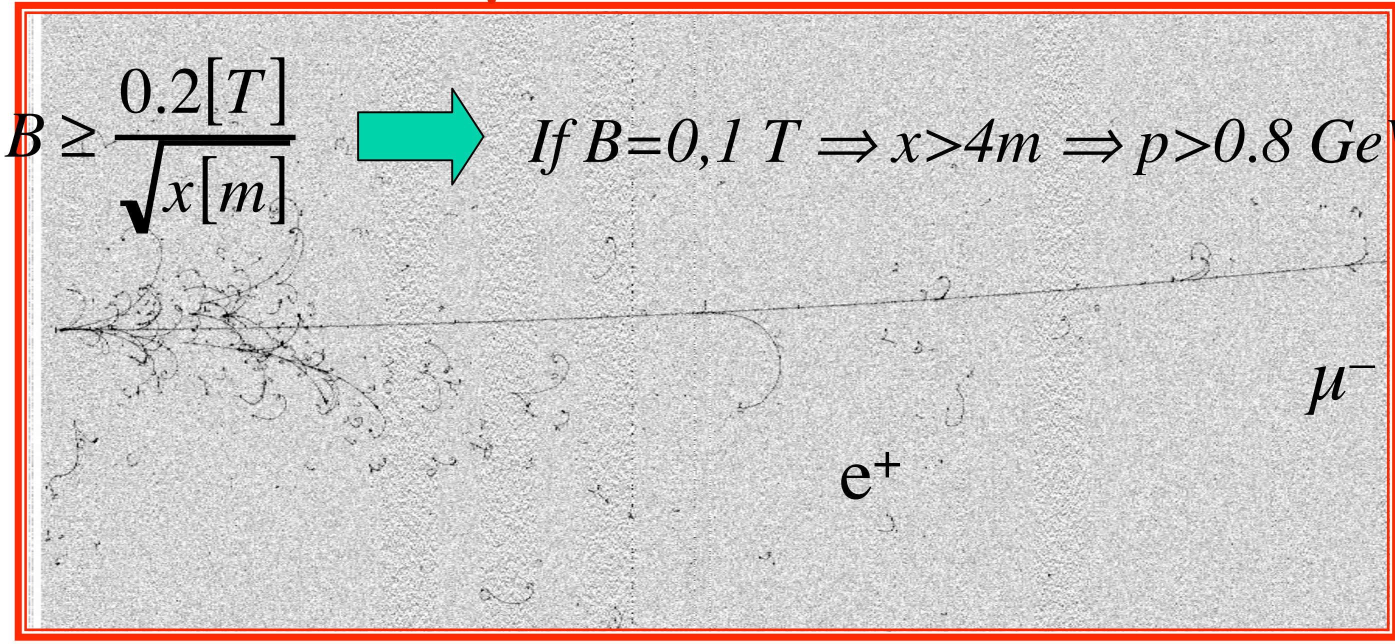
$$b \approx \frac{l^2}{2R} = \frac{0.3B[T](x[m])^2}{2p[GeV]}$$

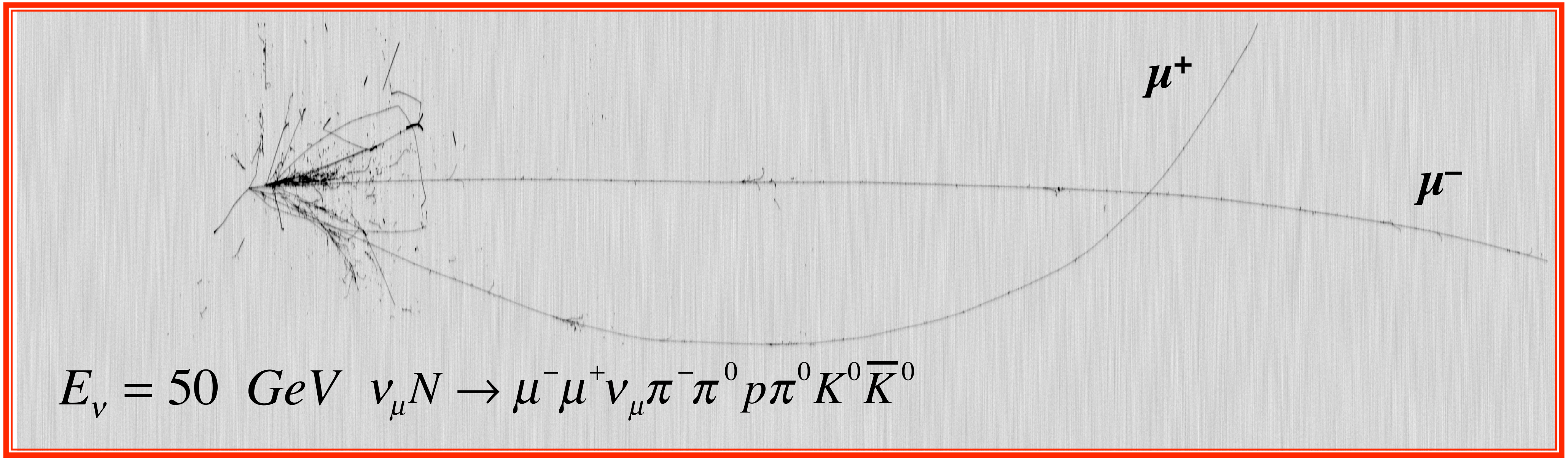
$$MS \approx \frac{0.02(x[m])^{3/2}}{p[GeV]}$$

3 sigmas discrimination:

$$b^+ - b^- = 2b > 3\,MS \quad \Rightarrow \quad B \geq \frac{0.2[T]}{\sqrt{x[m]}}$$

Simulated ν_μ CC events in B=0.2 T





Outlook

- **The liquid Argon TPC imaging has reached a high level of maturity thanks to many years of R&D effort conducted by the ICARUS collaboration.**

- **Today, physics is calling for applications at two different mass scales:**
  - **≈ 100 kton: proton decay, high statistics astrophysical & accelerator neutrinos**
  - **≈ 100 ton: systematic study of neutrino interactions, near detectors at LBL facilities**

- **The T2K project is the next logical step in accelerator neutrino physics, after the current round of experiments (K2K, NUMI-MINOS, CNGS)**
  - ➥ The project has been approved in December 2003. Planned for 2009.
  - ➥ The commitment of the Japanese funding agencies reflects the importance of this program in the field of neutrino physics. Time is approaching to undertake discussions with T2K Collaboration.

- **We think that a visible Swiss (+ European) contribution to this project will be a unique opportunity to participate in this very important project**
  - ➥ We can bring a technology well matched to the fine grain detector at the 2 km position