Status report on the GLACIER project and a proposal for a electron/π^0 test beam for ISS-FP7

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ISS meeting, CERN, July 3th 2006

GLACIER list (≈40 people, 12 institutions)

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D. Kielczewska

UW Warszawa (Poland)

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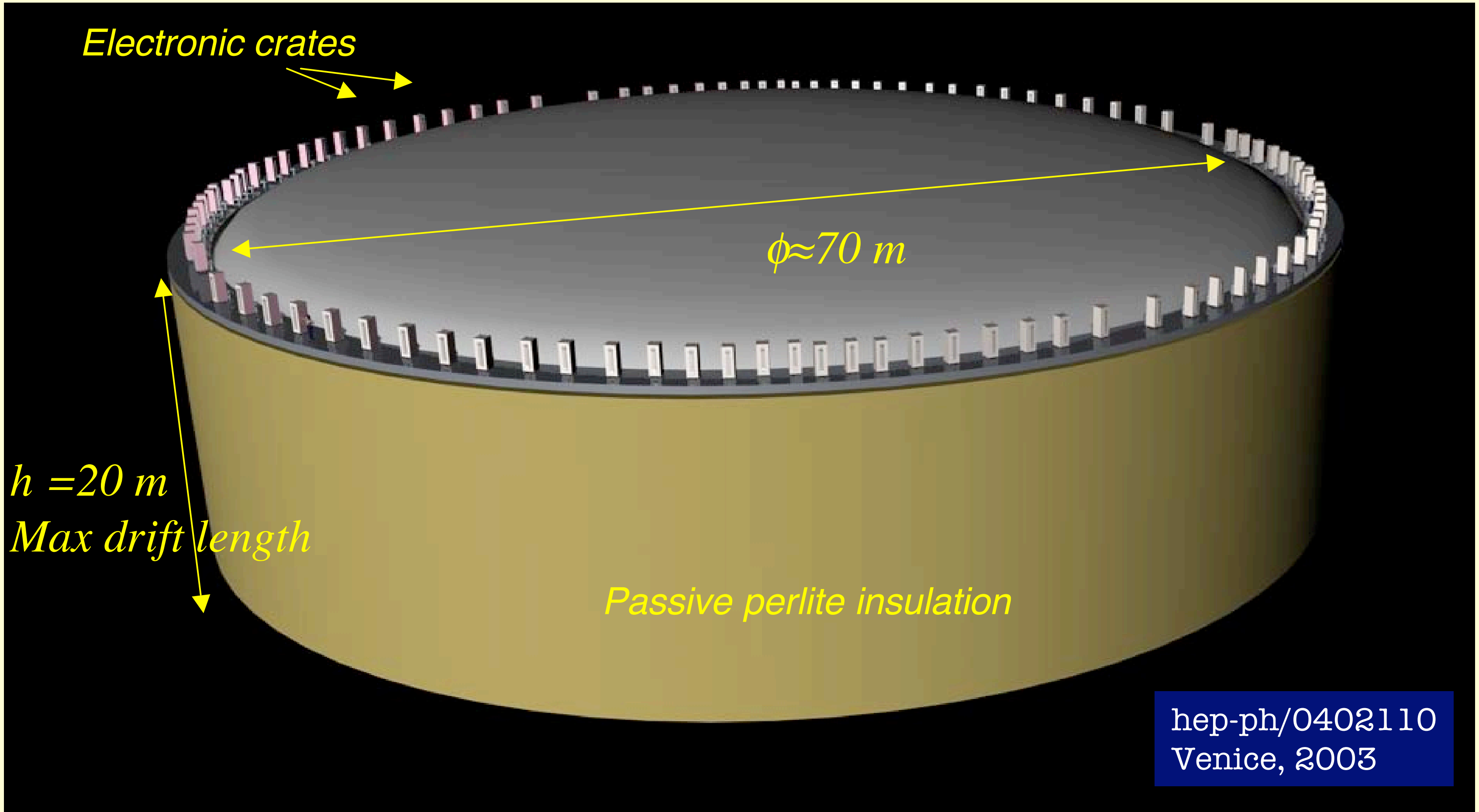
The goal: a 100 kton liquid Argon TPC detector



A scalable design, up to 100 kton, limited by liquid Argon & cooling power cost

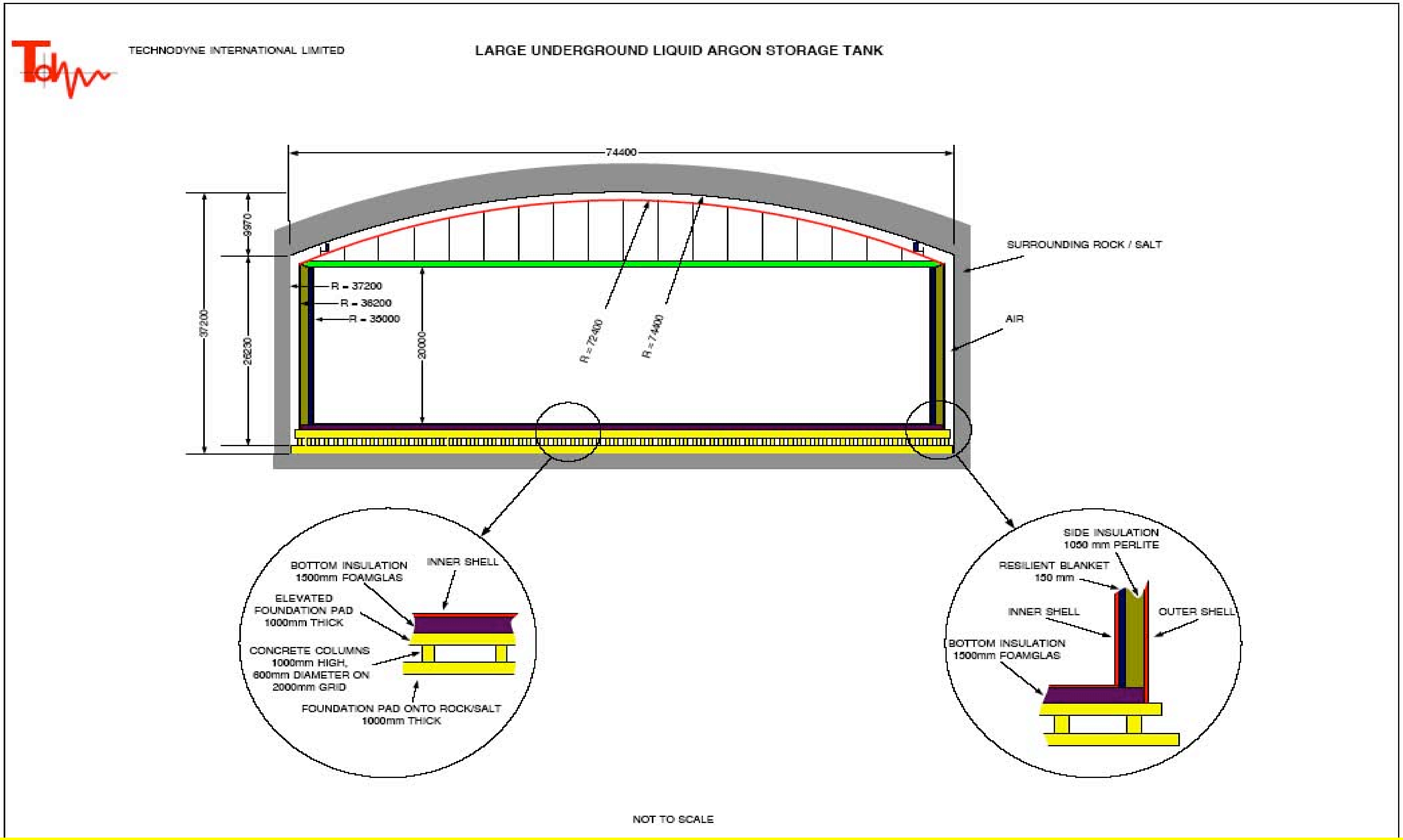
A "general-purpose" detector for superbeams, beta-beams and neutrino factories with broad non-accelerator physics program (SN ν, p-decay, atm ν, …)

The concepts for the scalable design

- ***LNG tanker***
  - ➥*Proven LNG tanker with standard aspect ratio*
  - ➥*Vertical electron drift for full active volume*
- ***Double-phase with LEM readout***
  - ➥*A new method for readout to allow for a very long drift path and cheaper electronics*
  - ➥*To avoid use of readout wires, which can be hardly mechanically and electrically scaled (S/N) and with disfavored use in conjunction with magnetic fields (induction).*
  - ➥*A path towards pixelized readout for 3D images.*
- ***Voltage multiplier***
  - ➥*Extend drift voltage by additional of stages, w/o VHV feed-through*
- ***Very long drift path***
  - ➥*Minimize channels by increasing active volume with longer drift path*
- ***Light readout on surface of tanker***
- ***Immersed superconducting solenoid for B-field***

The tanker

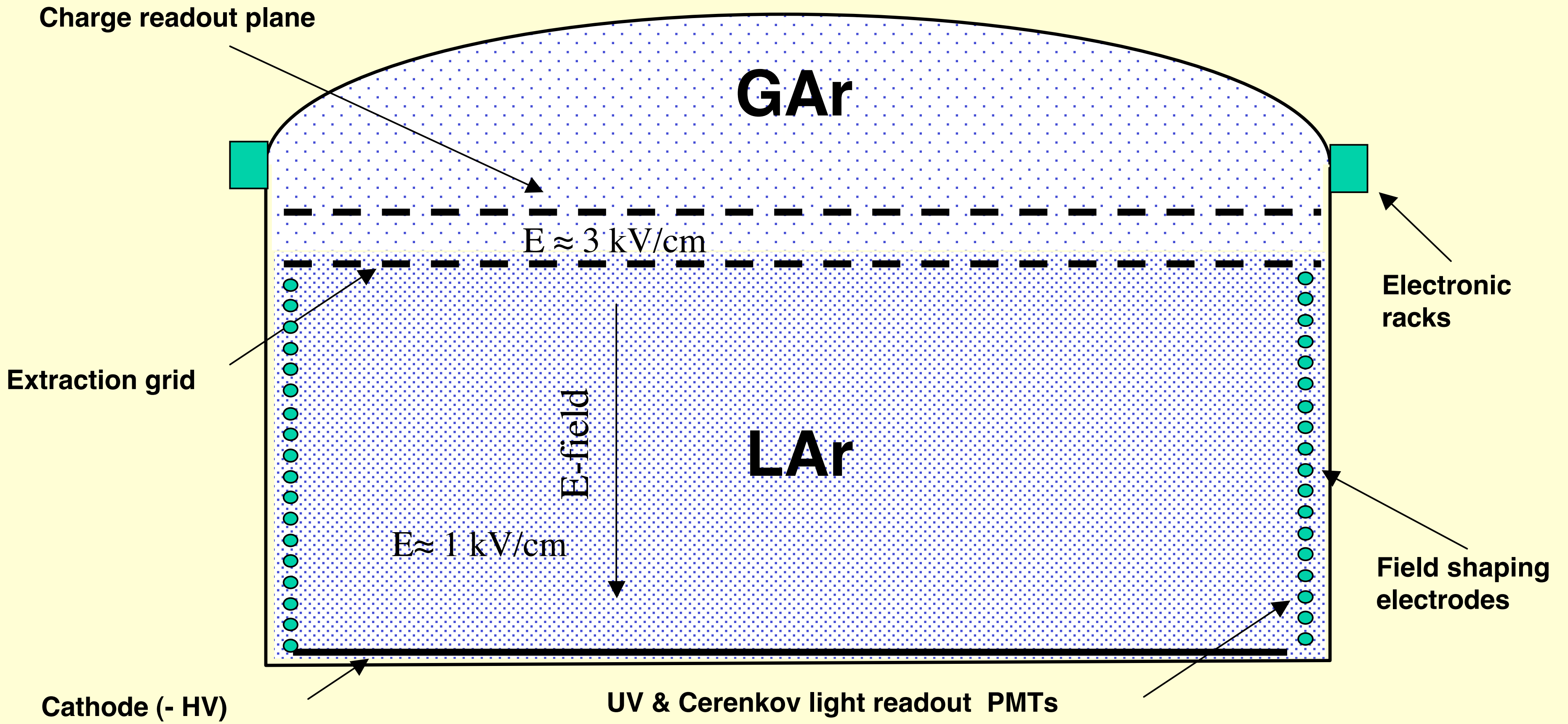
The technology of long term storage of cryogen has been mastered by the petrochemical industry. In Collaboration with Technodyne Ltd (Eastleigh, UK), expect in this field, we have shown that extrapolation from the LNG technology to LAr is possible



The detector layout

Single detector: charge imaging, scintillation, possibly Cerenkov light

Dewar	φ ≈ 70 m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc φ ≈70 m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability



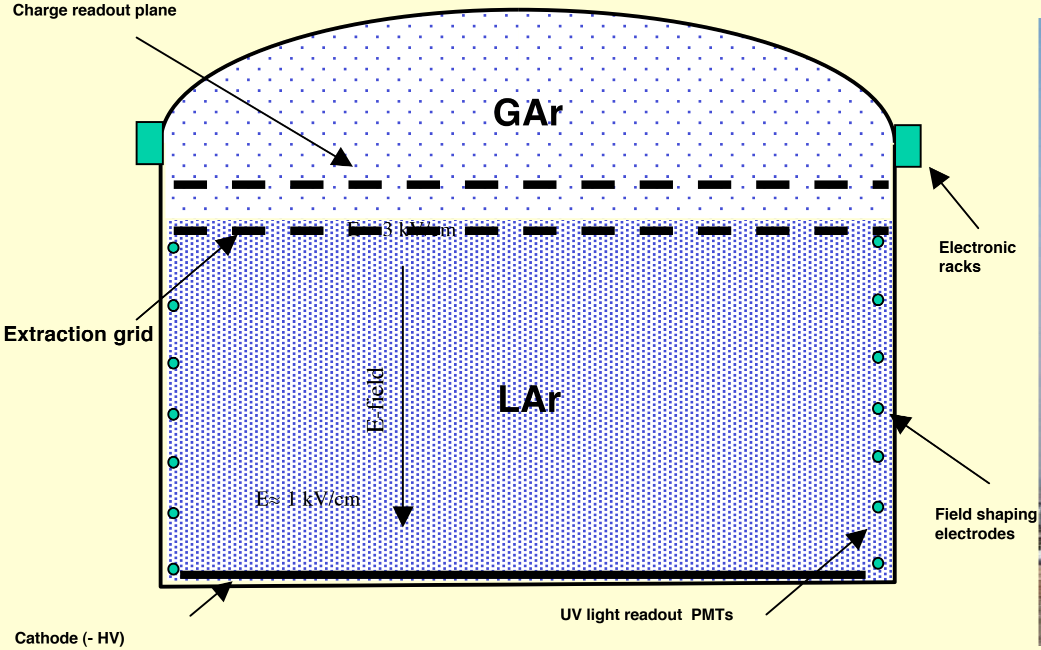
A scalable design: 10 kton prototype

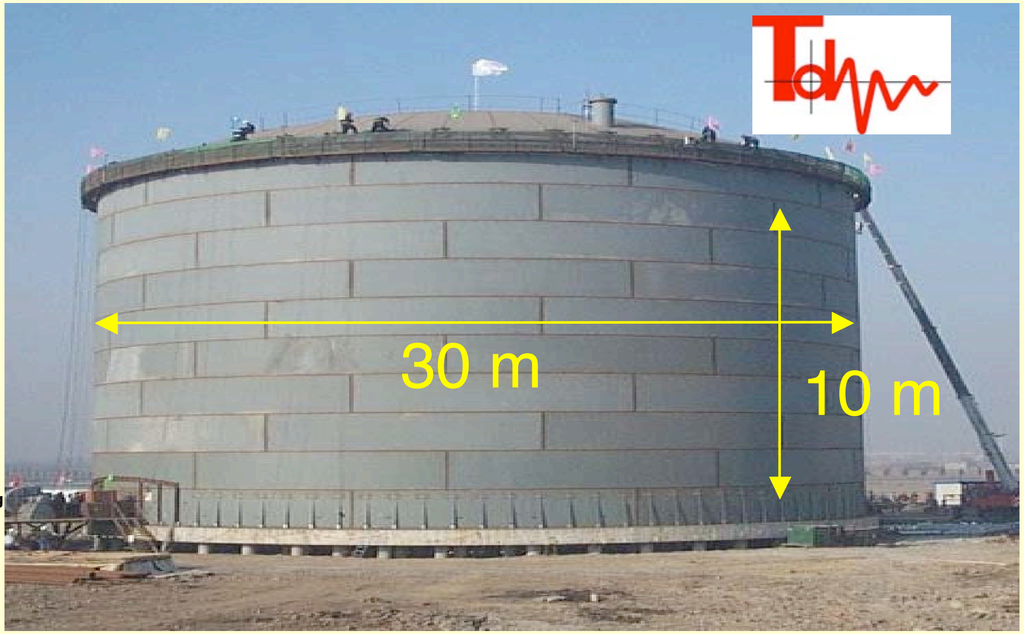
- 10% full-scale prototype
- Shallow depth
- **Physics program on its own**

(e.g. sensitivity for $p \rightarrow \nu K$: $\tau > 10^{34}$ yrs for 10 years running)

•Complementary to SuperK

Dewar	$\phi \approx 30$ m, height ≈ 10 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	7000 m^3, ratio area/volume $\approx$ 33%
Argon total mass	9900 tons
Hydrostatic pressure at bottom	1.5 atmospheres
Inner detector dimensions	Disc $\phi \approx 30$ m located in gas phase above liquid phase
Charge readout electronics	30000 channels, 30 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 300 immersed 8" PMTs with WLS



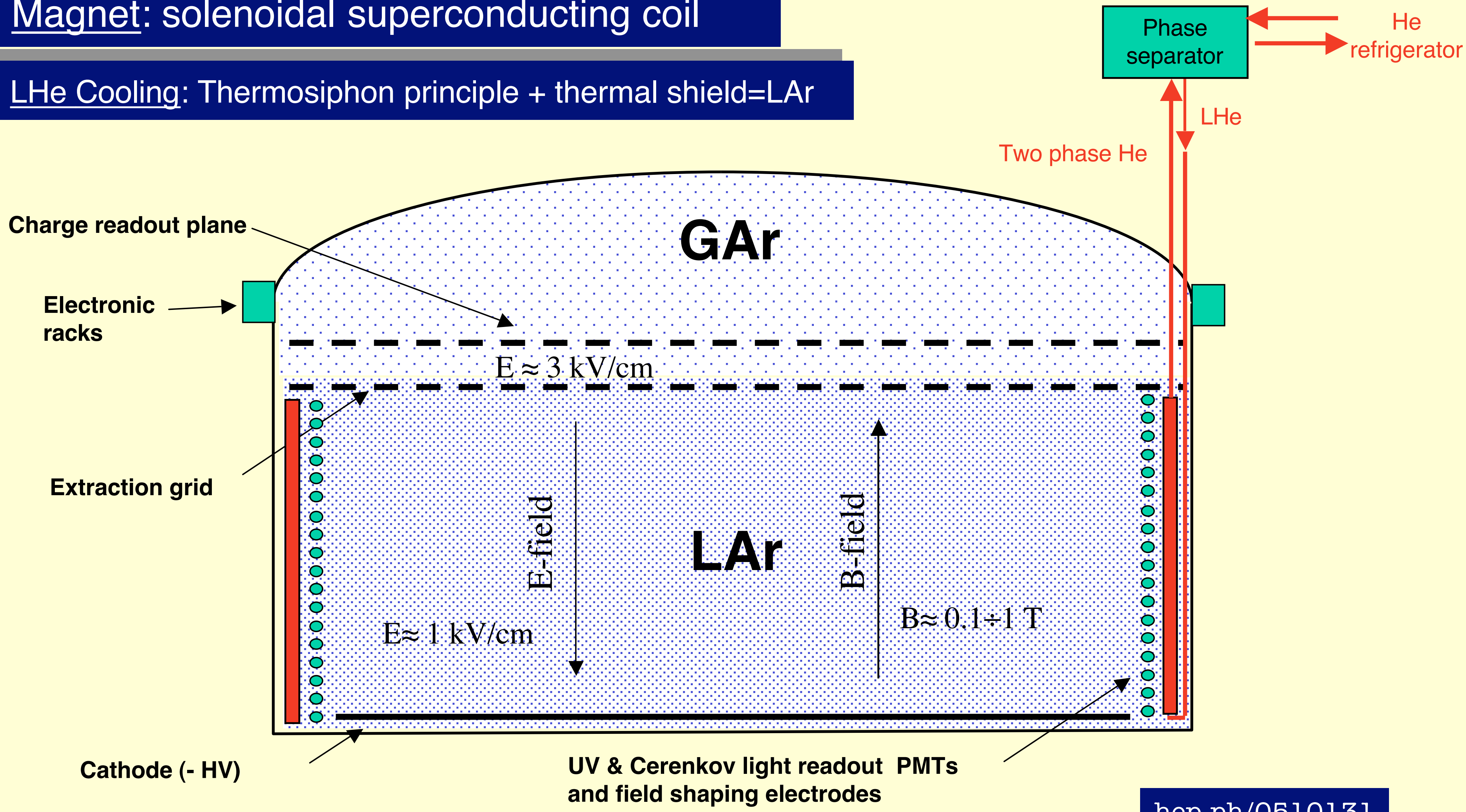


- 1% prototype: 1 kton engineering detector, $\phi \approx 10$m, h $\approx$ 10m, shallow depth?

Tentative layout for a magnetized detector

Magnet: solenoidal superconducting coil

LHe Cooling: Thermosiphon principle + thermal shield=LAr



(Magnet: HTS coil also considered)

hep-ph/0510131
Frascati, 2005

First operation in magnetic field

A possible improvement of the LAr TPC technique ?

Operation of the LAr TPC embedded in a magnetic field

Nucl. Phys. B 631 239;
Nucl. Phys. B 589 577;
hep-ph/0402110;
hep-ph/0106088

The possibility to complement the features of the LAr TPC with those provided by a magnetic field has been considered and would open new possibilities (a) charge discrimination, (b) momentum measurement of particles escaping the detector (e.g. high energy muons), (c) very precise kinematics, since the measurement precision is limited by multiple scattering. These features are mandatory at a NF.

Momentum measurement:

$$\frac{\Delta p}{p} \approx \frac{0.14}{B(Tesla)\sqrt{(x(m))}\ \cos\lambda}$$

x=track length

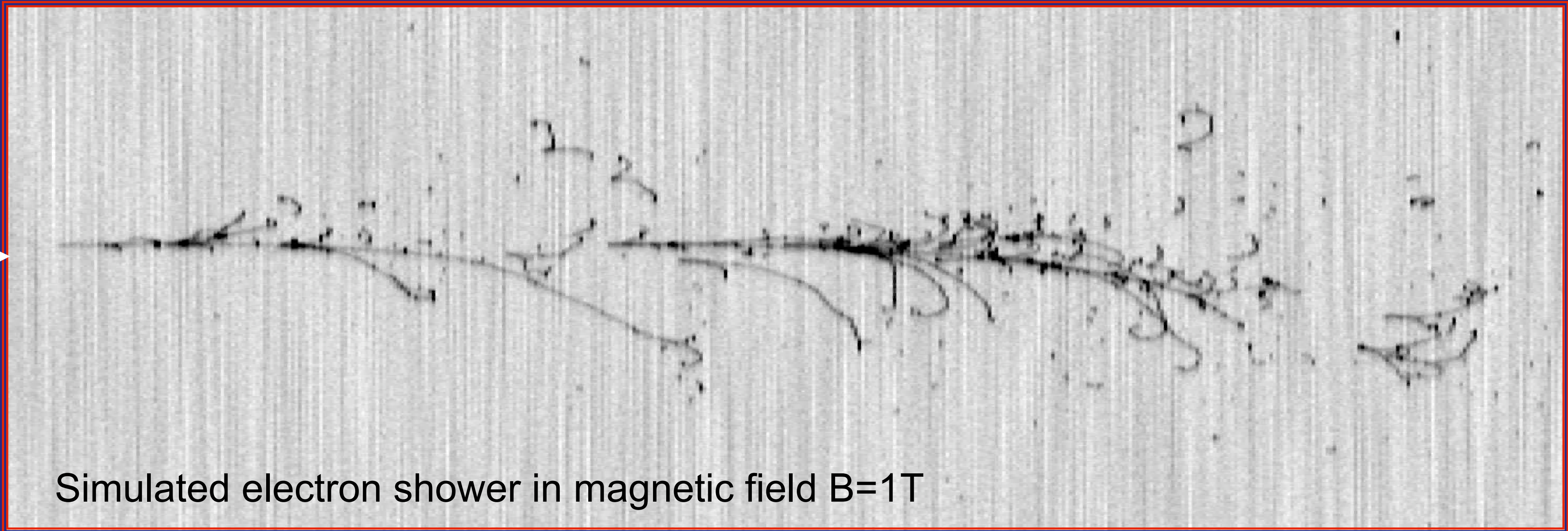
λ=pitch angle

Required field for 3σ charge discrimination:

$$B \geq \frac{0.2\ (Tesla)}{\sqrt{x(m)\ \cos^3\lambda}}$$

e⁻

2.5 GeV

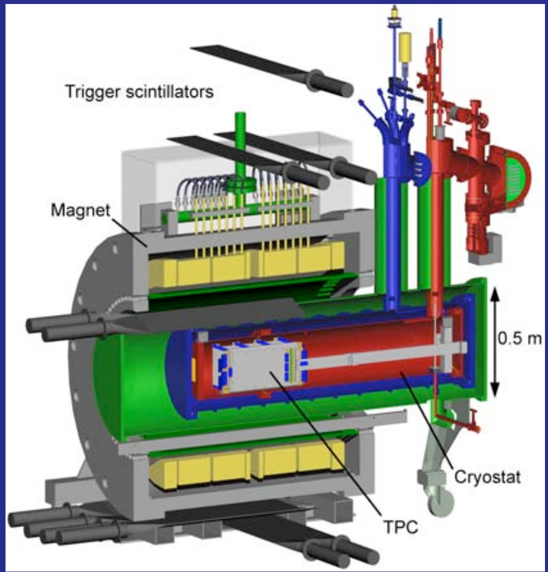


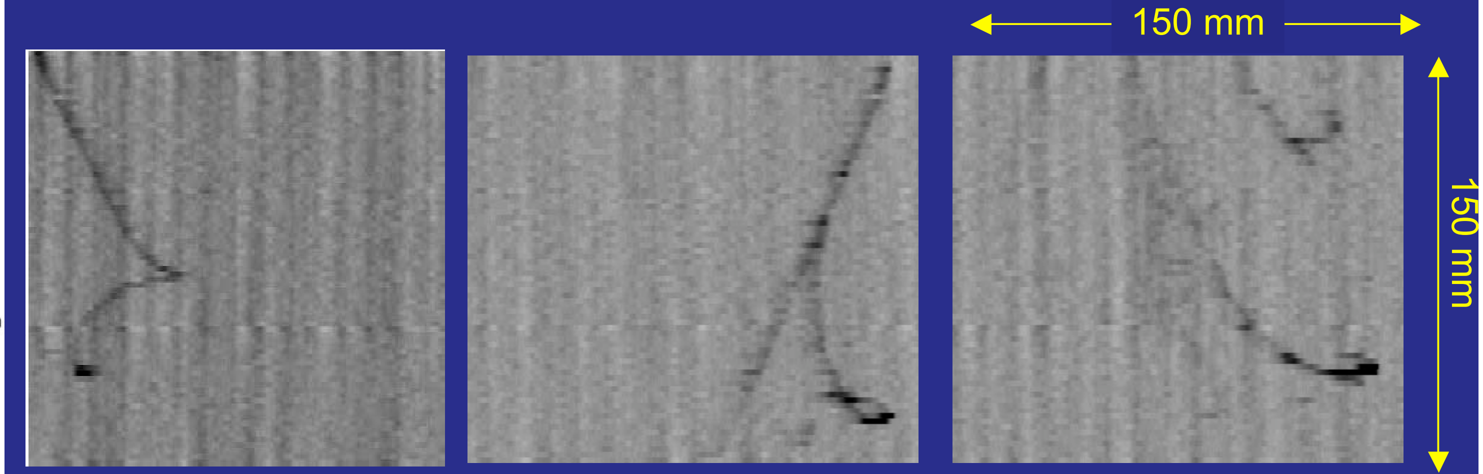
Simulated electron shower in magnetic field B=1T

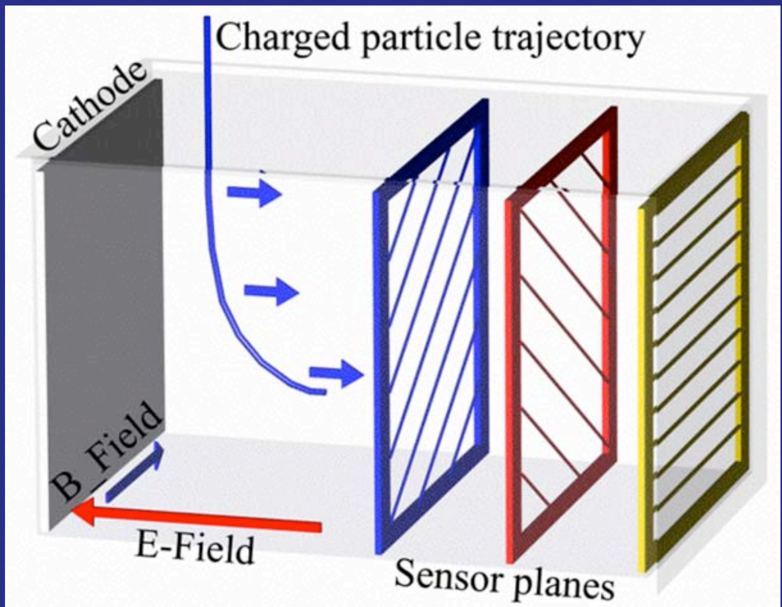
First operation of a 10 lt LAr TPC embedded in a B-field

First real events in B-field (B=0.55T):

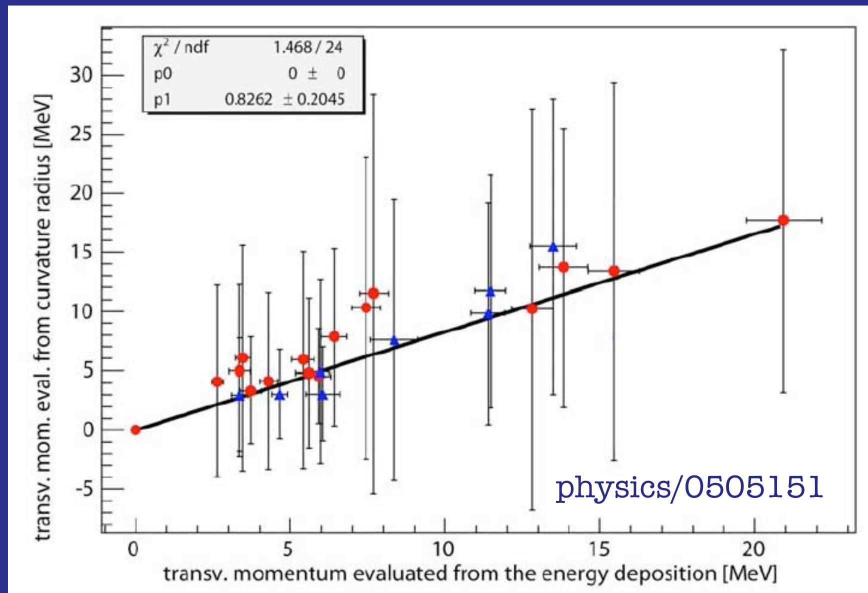
New J. Phys. 7 (2005) 63
NIM A 555 (2005) 294

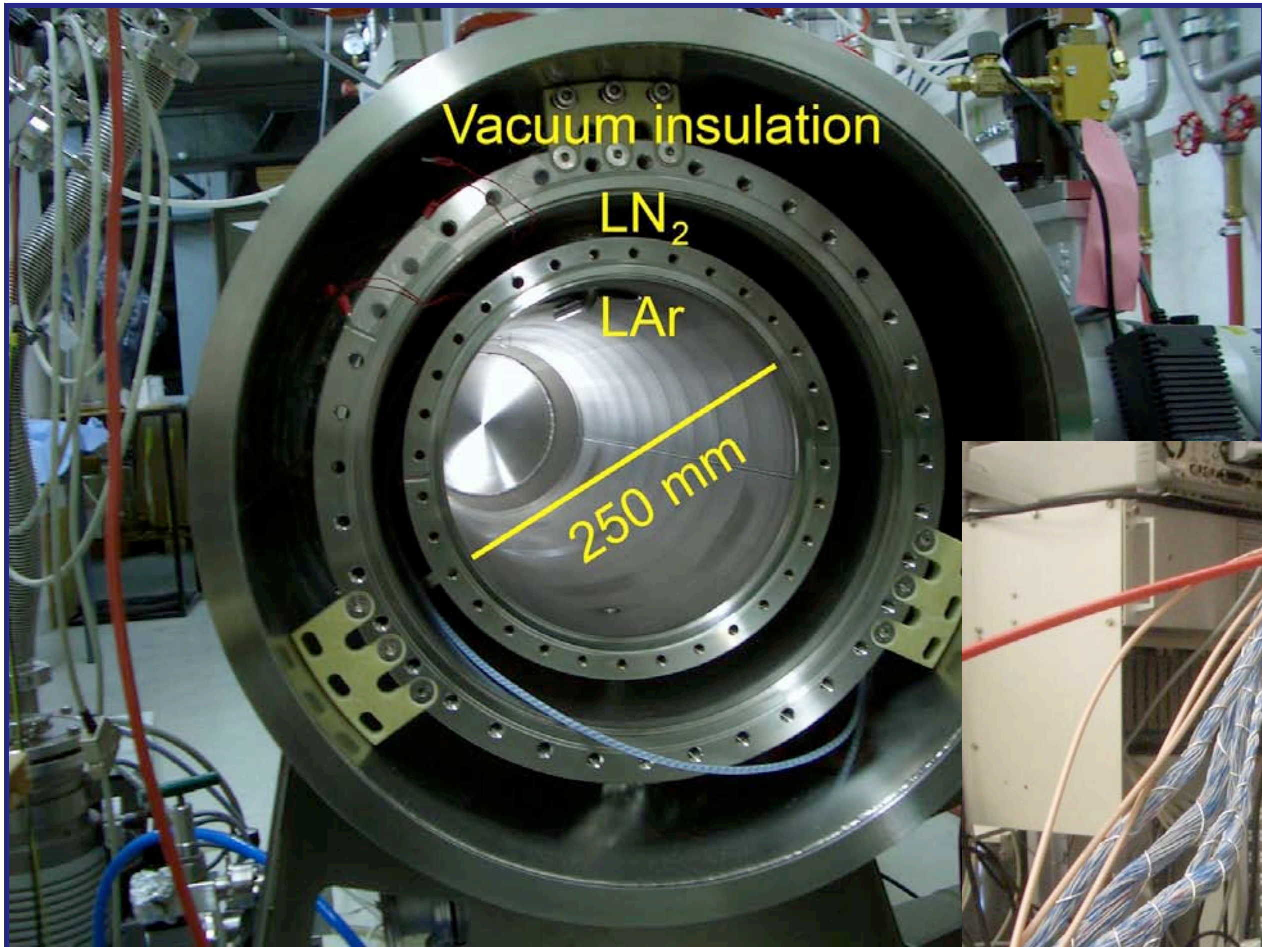




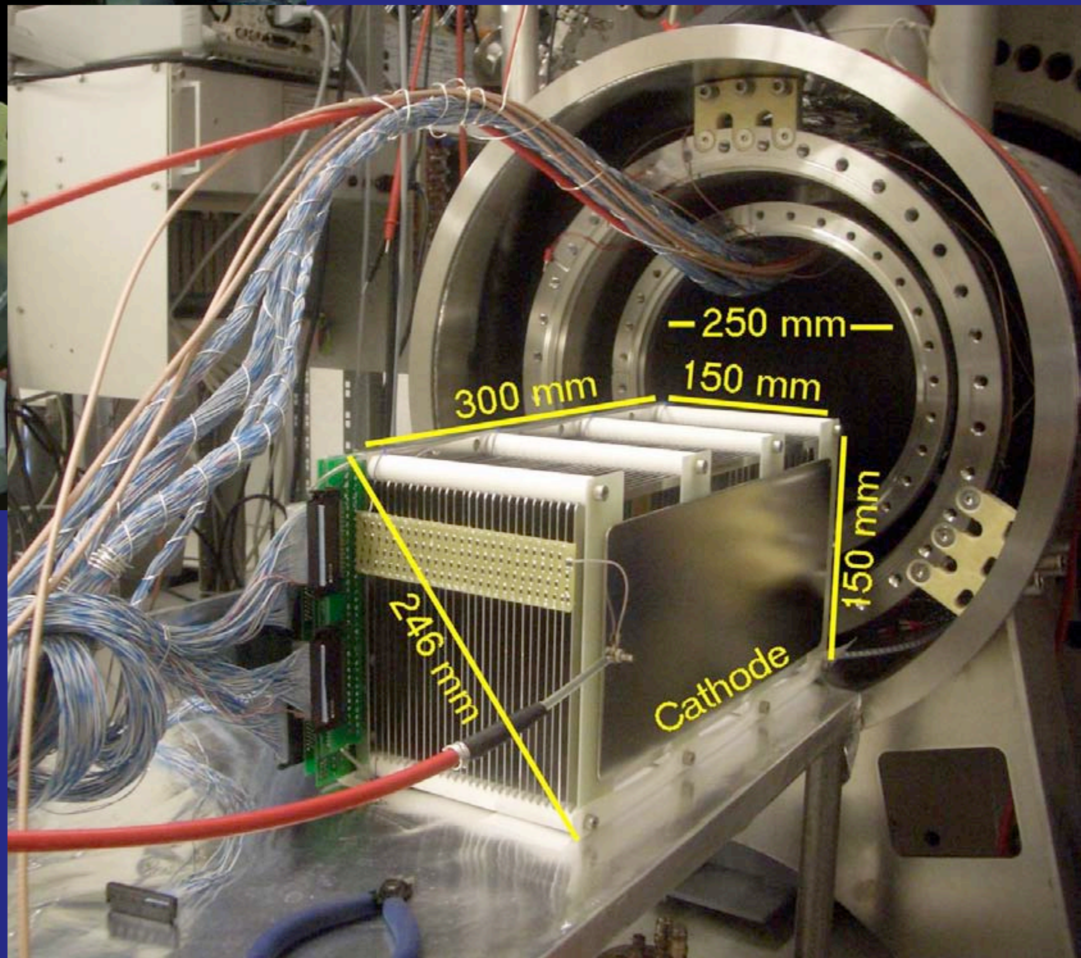


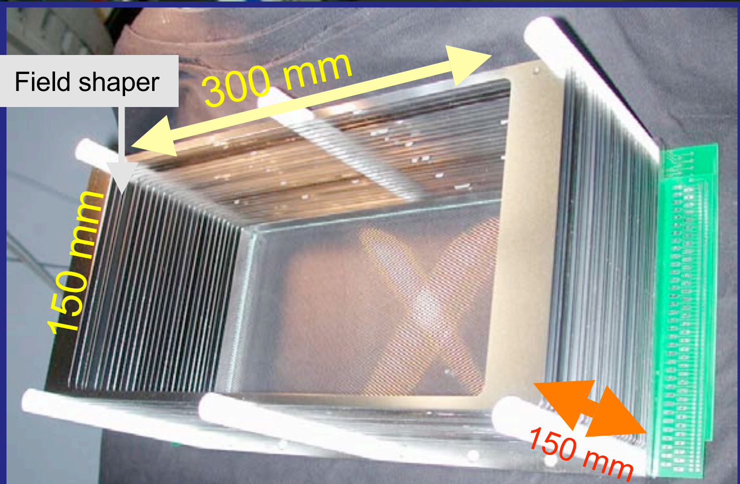
Correlation between calorimetry and magnetic measurement for contained tracks:





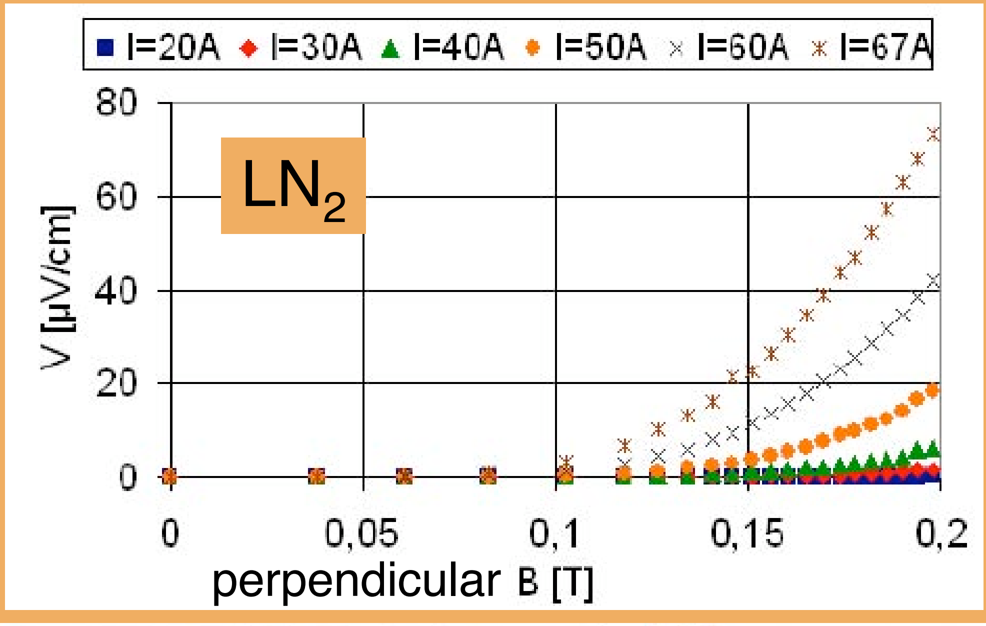
NIM A 555 (2005) 294

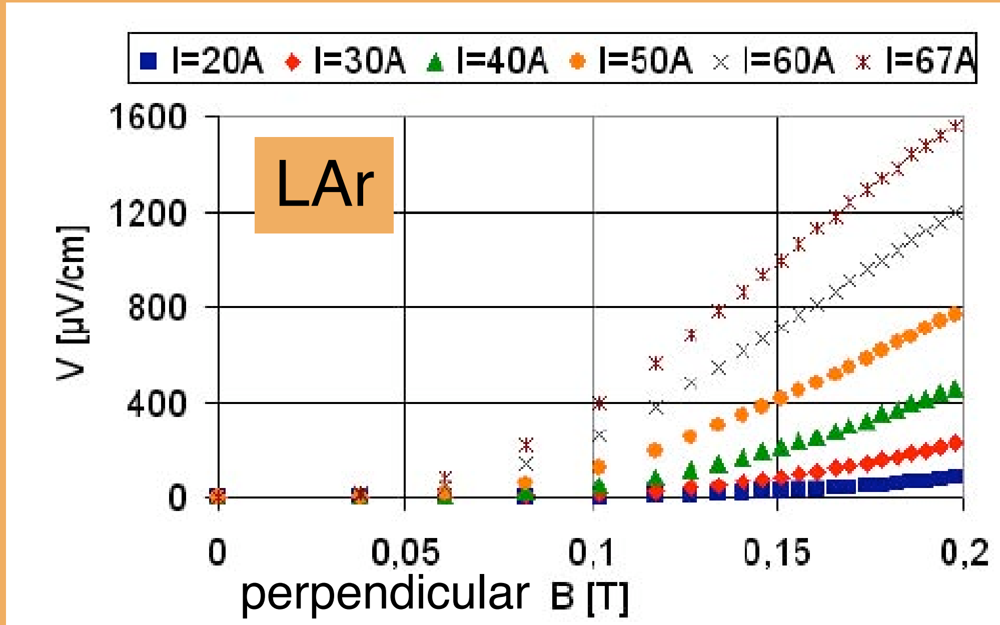


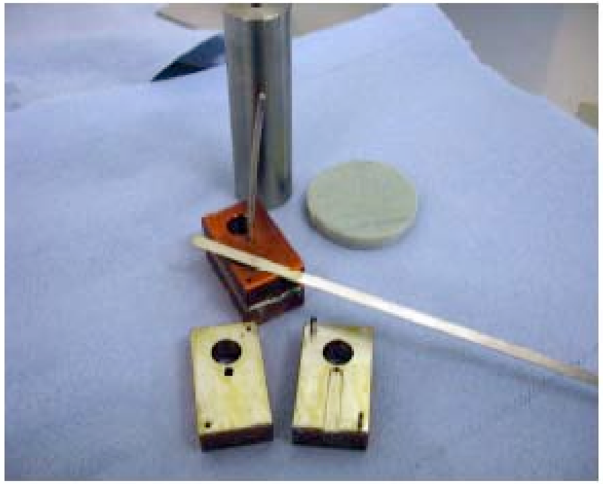


First tests of HTS conductor in Liquid Argon

- We have performed first tests with BSCCO HTS superconductor by American Superconductor (www.amsuper.com) in order to compare critical currents and influence of stray-field at LAr temperature (rather than LN_2).



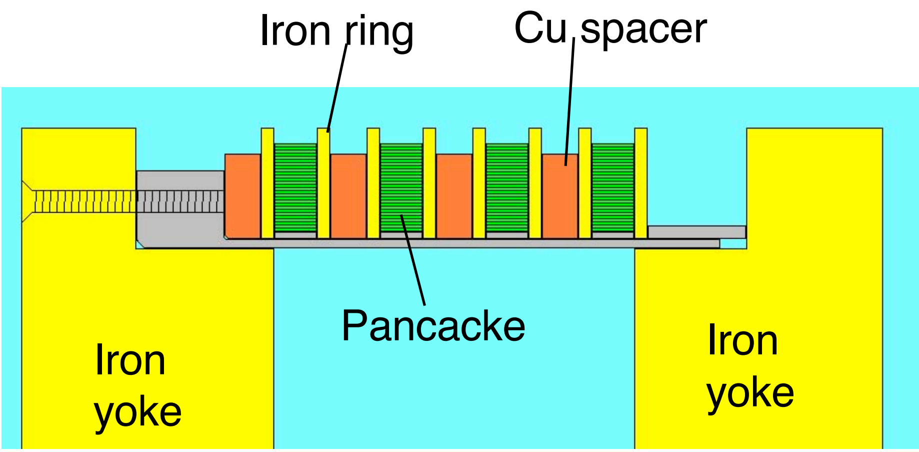


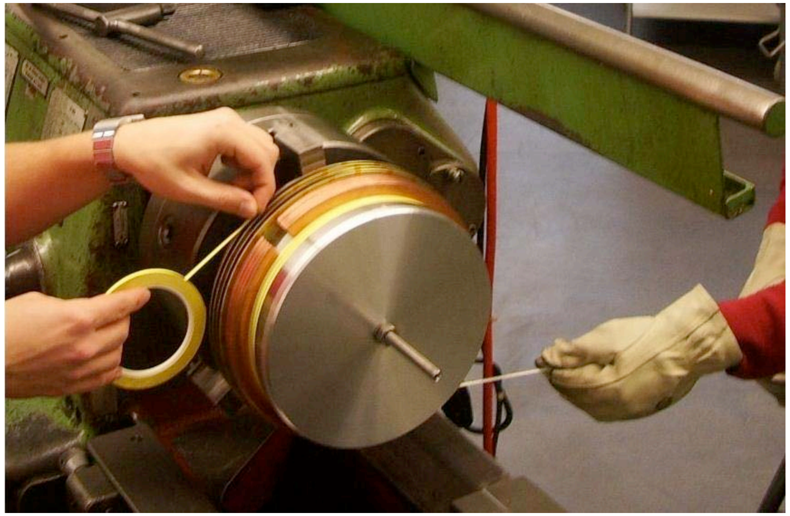


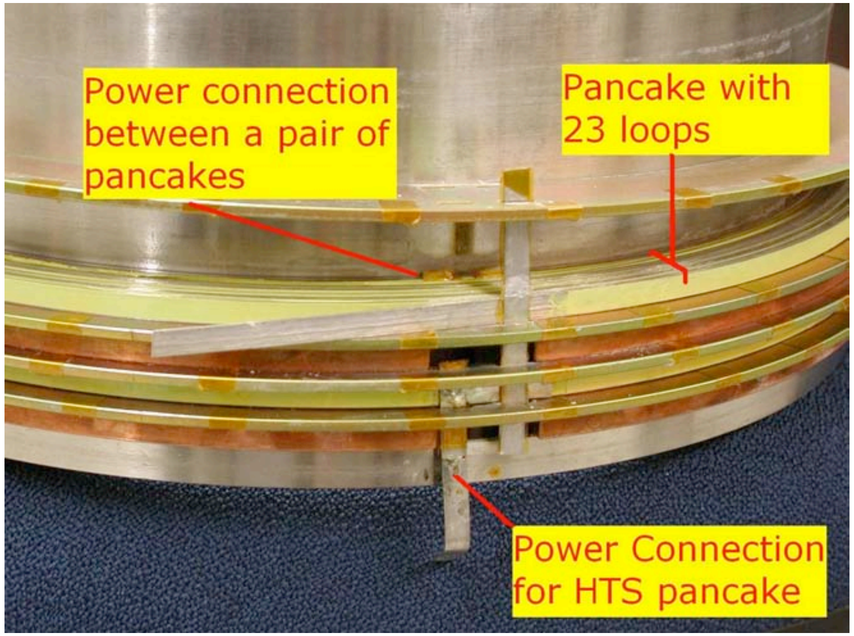
Diploma student
T.Strauss

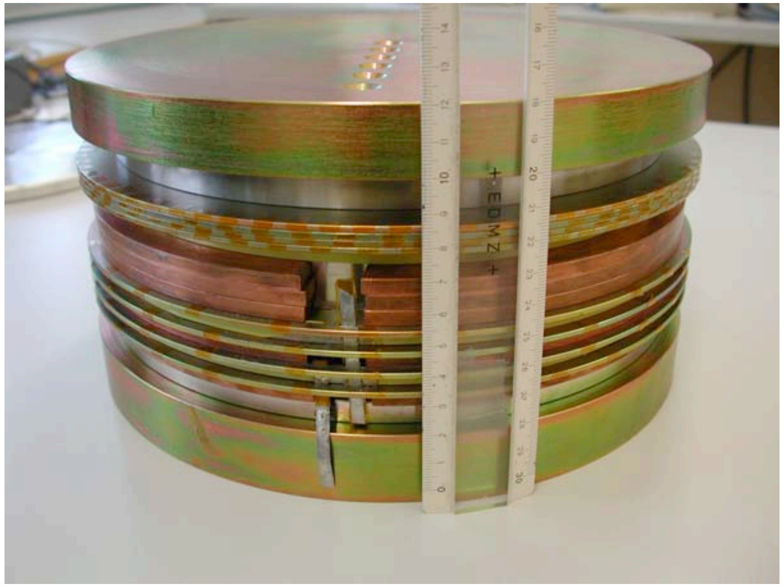
Small test solenoid built wit HTS wire

Consists of 4 pancakes, total HTS wire length: 80m





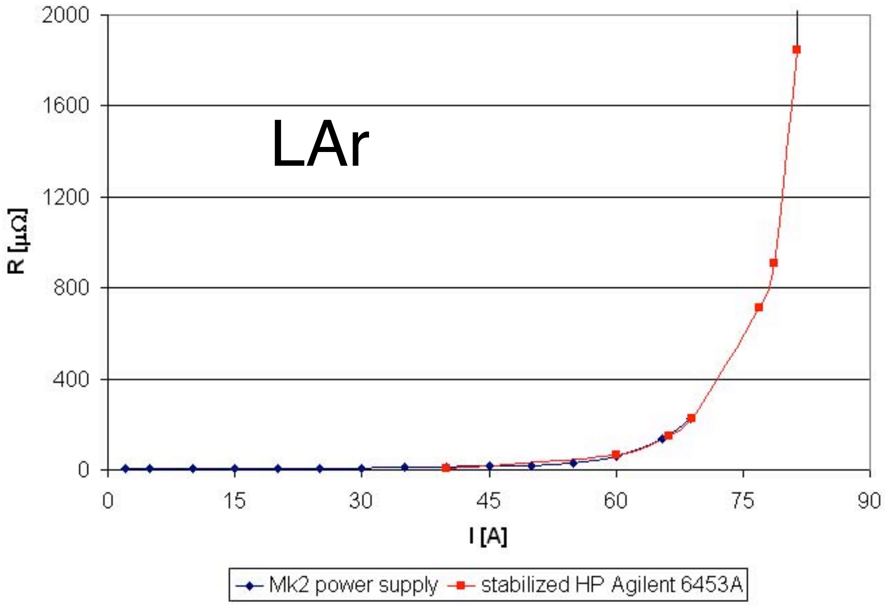


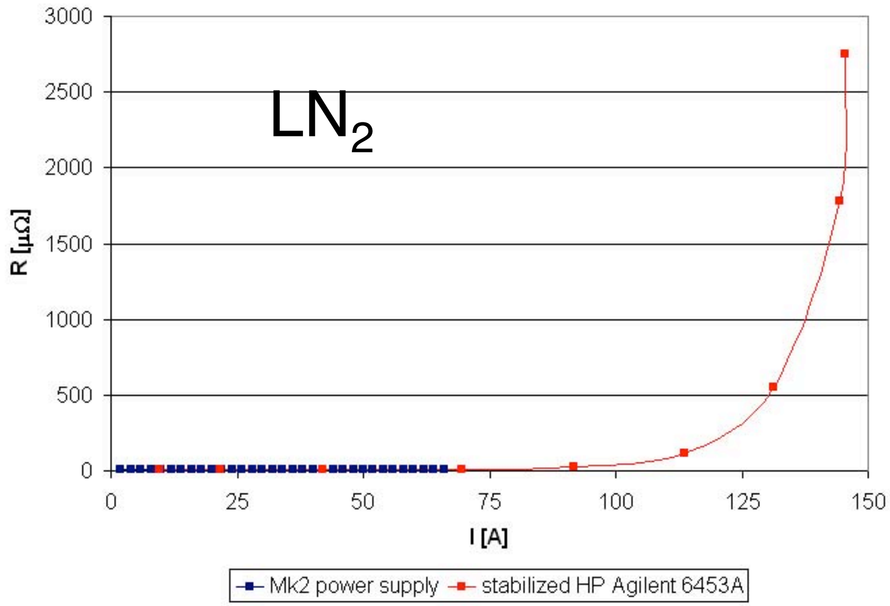


Results obtained with the small HTS solenoid

Coil resistance as a function of the applied current

Total HTS wire length: 80 m





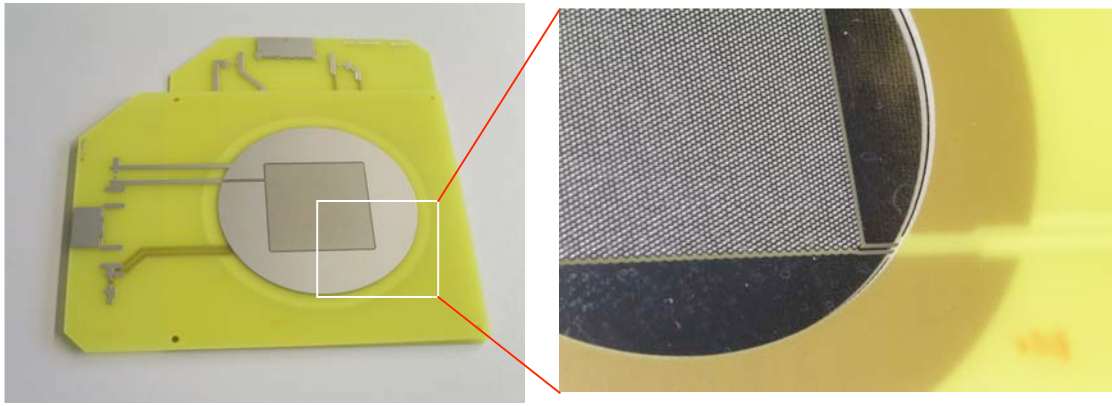
Temperature	LN_2 (77K)	LAr (87K)
Max. applied current	145 A	80 A
On-axis B-field	0.2 T	0.11 T
Coil resistance at 4A	6 µΩ	6 µΩ

New method of charge readout

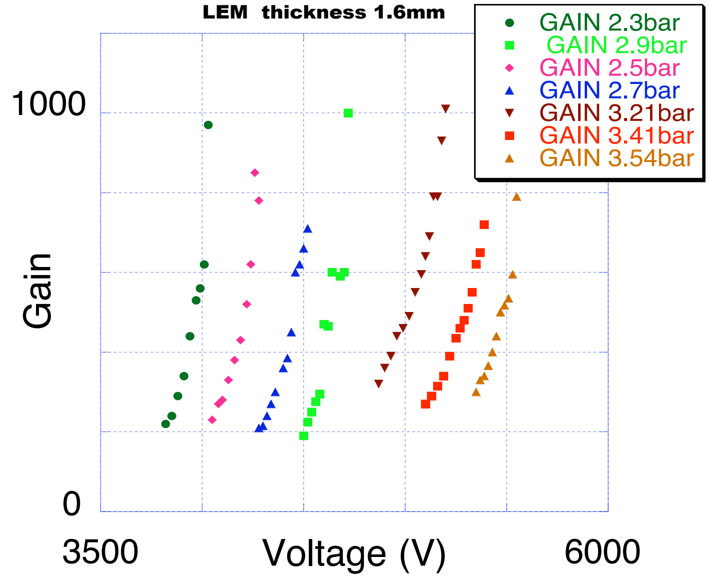
Charge readout: Thick Large Electron Multiplier (LEM)

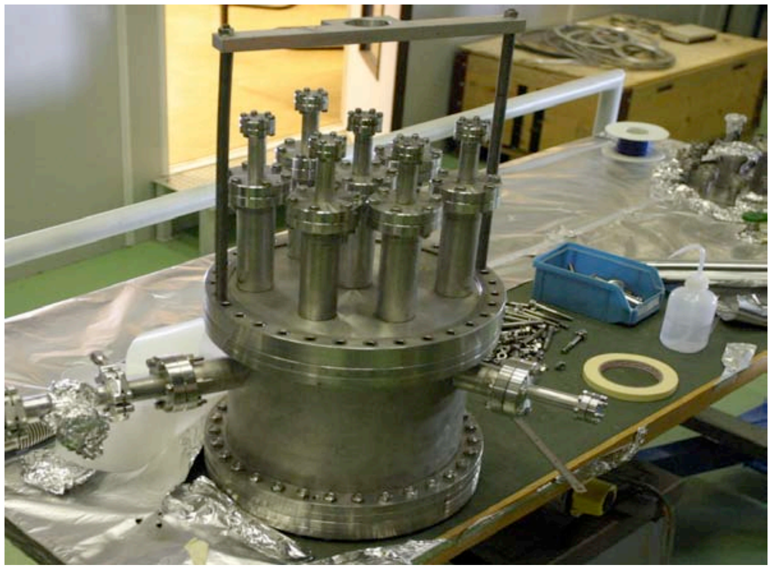
Thick-LEM: Vetronite with holes, coated with copper

→ macroscopic GEM
→ easier to operate at cryogenic temperatures
→ hole dimensions: 500 μm diameter, 800 μm distance



High gain operation of LEM in pure argon at high pressure





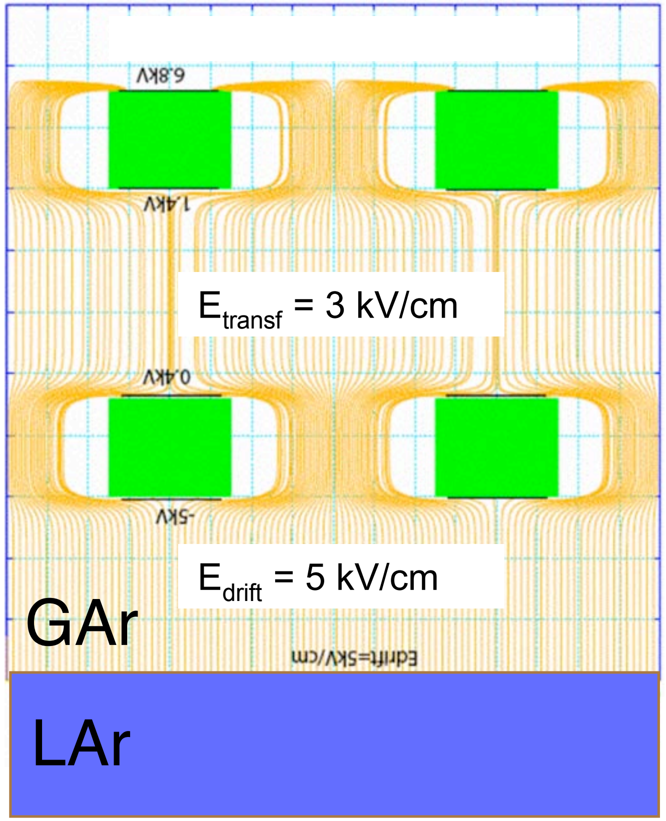
→ The level of the liquid argon is placed just below a LEM readout system

→ Each extracted electron creates an avalanche which is detected on the anode.

→ Gain up to ≈ 800 possible even at high pressure (good prospects for operation in cold)

→ The segmented LEM readout facilitates event localization

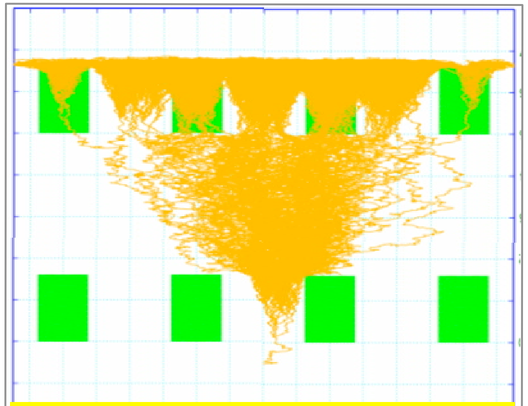
Two-stage LEM



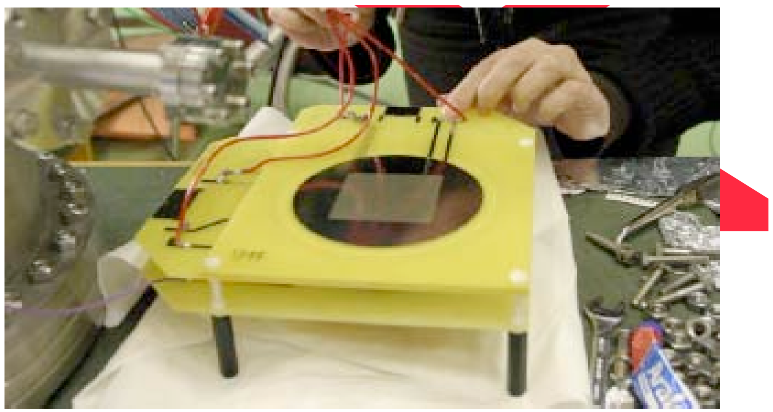
→ Distance between stages: 3 mm

→ Avalanche spreads into several holes at second stage

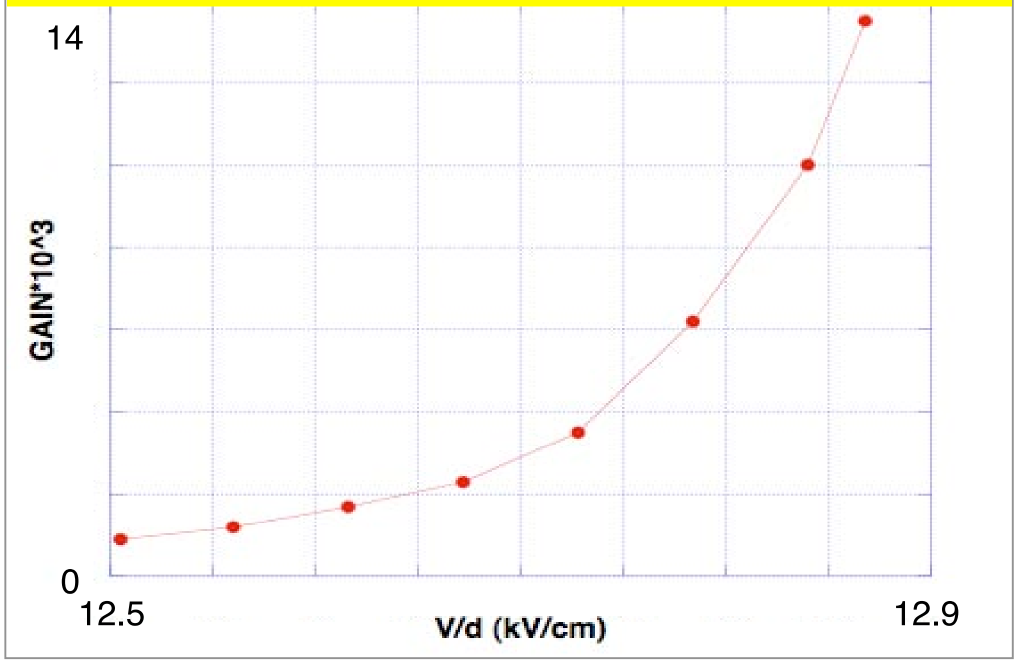
→ Higher gain reached as with one stage, with good stability



Simulation of avalanche

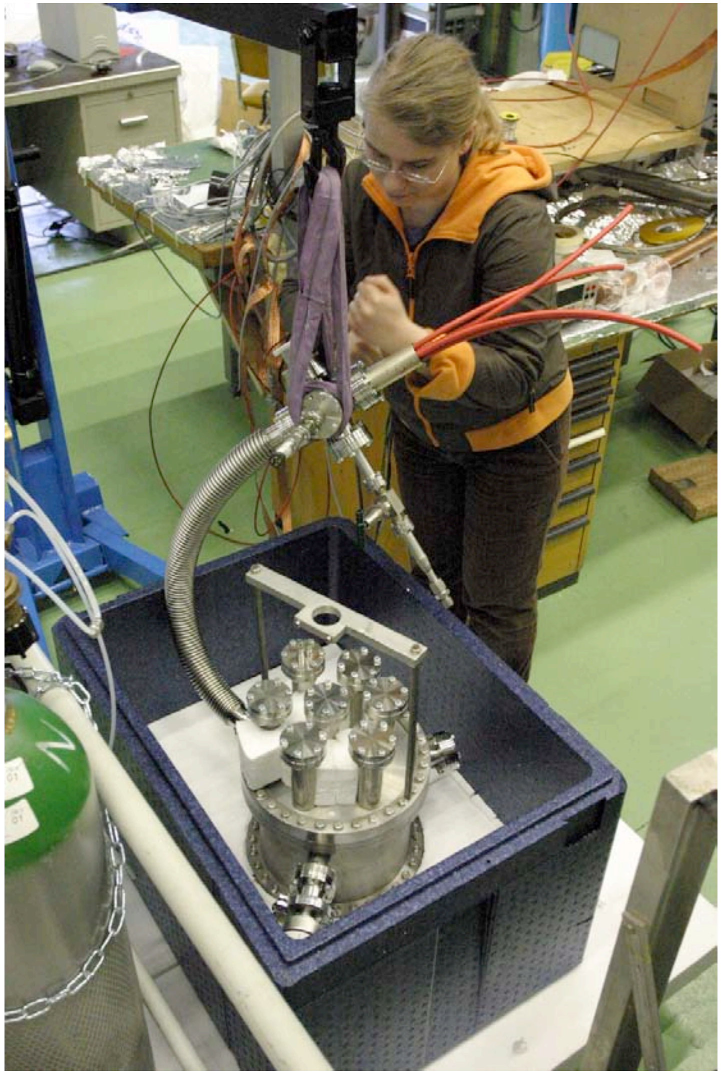


A stable gain of 10^4 has been measured

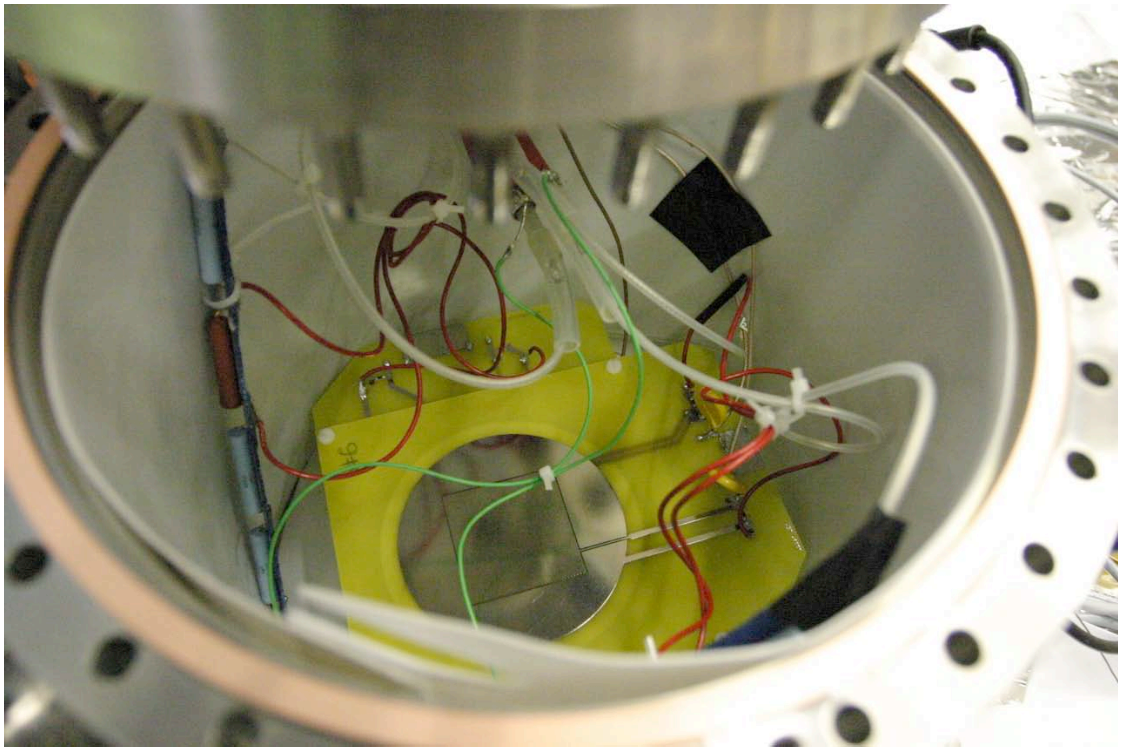


LEM test setup

(The LEMs will be fully tested in the ArDM experiment: CIEMAT - ETHZ - Granada - Sheffield - Warszawa – U. Zurich)



Test LEM in cold Ar gas

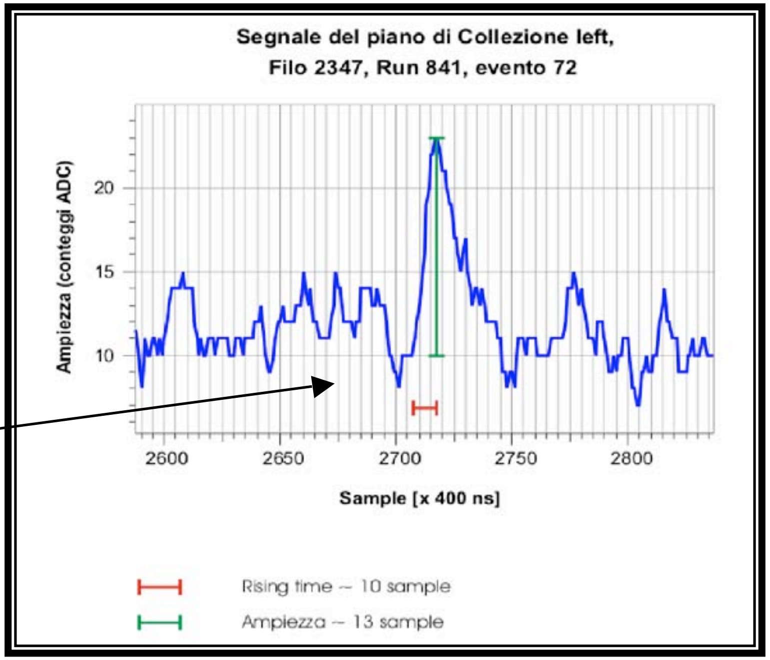


Two-stage LEM: measurements (preliminary)

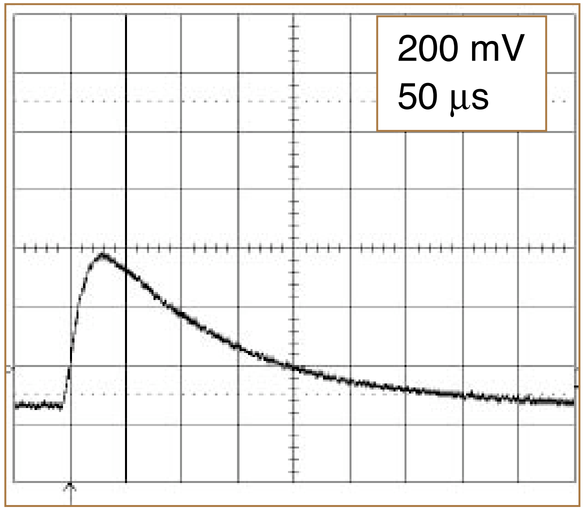
Shapes from Fe^{55} radioactive source (5.8 keV, event rate about 1kHz) of the signals from double-stage LEM system have a very clean S/N ratio.

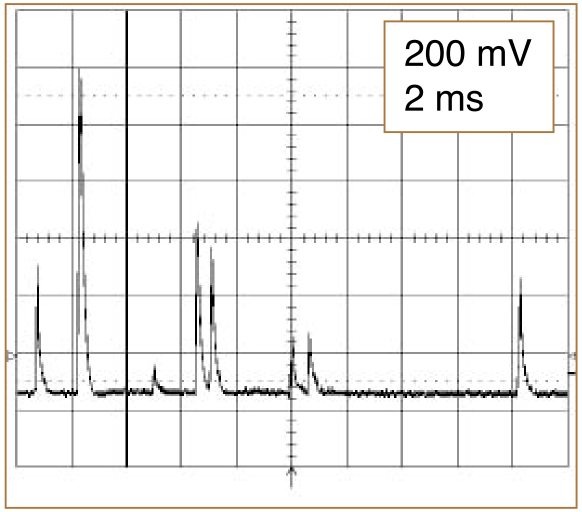
This technique solves the non-scalability of the traditional wire readout used in ICARUS
E.g. MIP signal @ ≈2 MeV/cm has poor S/N !

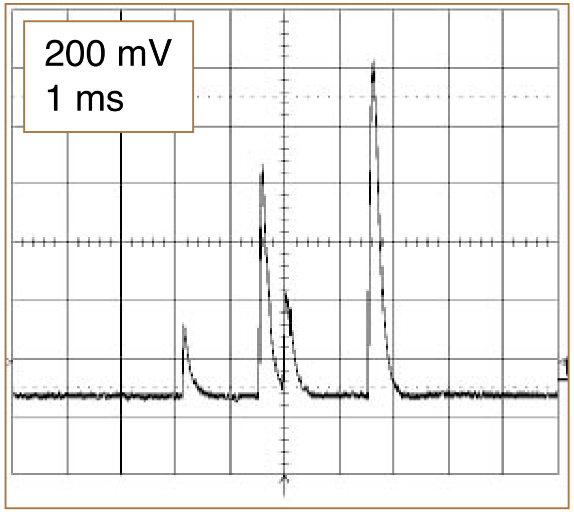
MIP signal in ICARUS T300



Average signal rise time: 12μs.



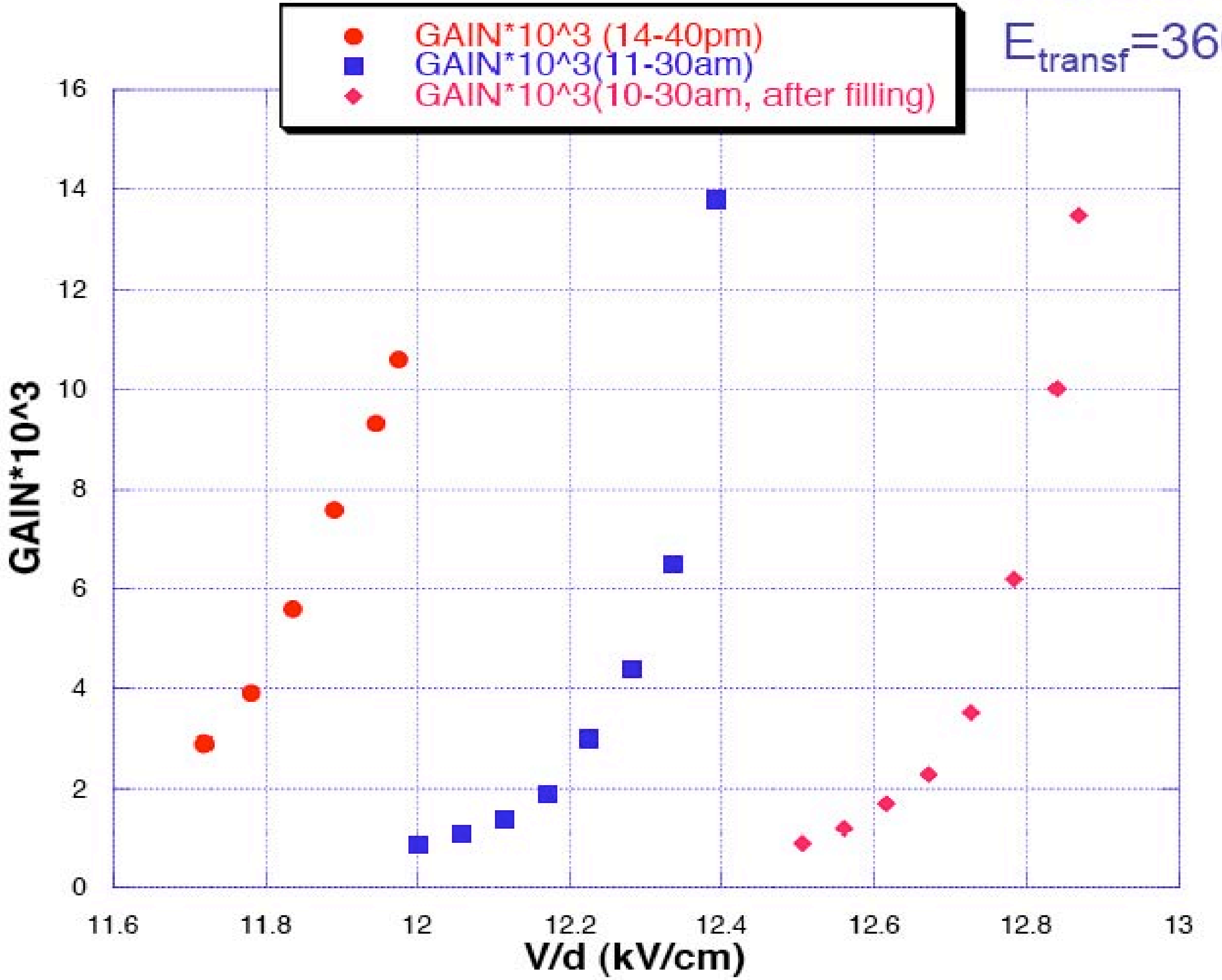




Gain at room temperature

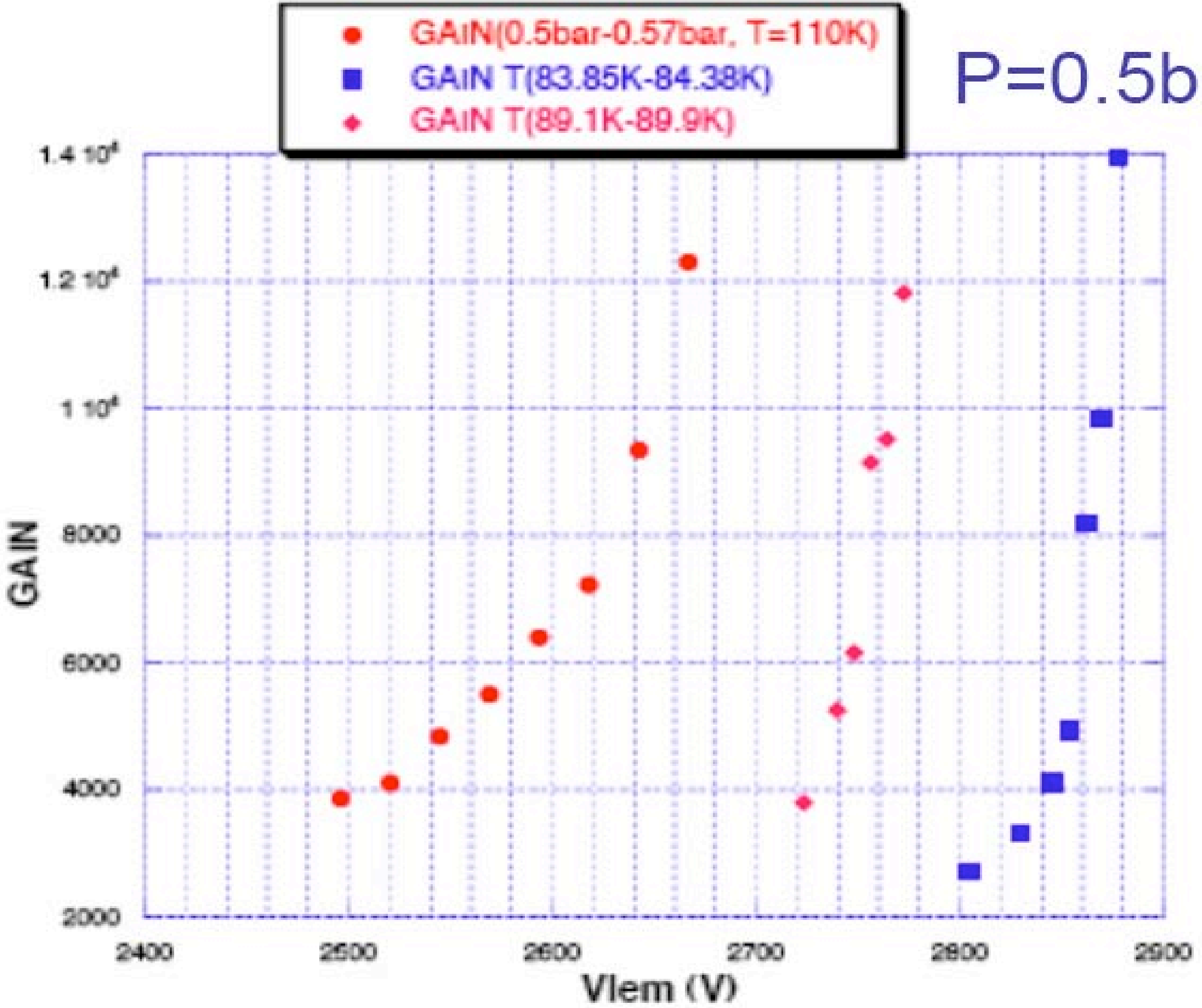
Gain curves at atmospheric pressure and room temperature

Transfer field:
E_{transf}=360V/cm

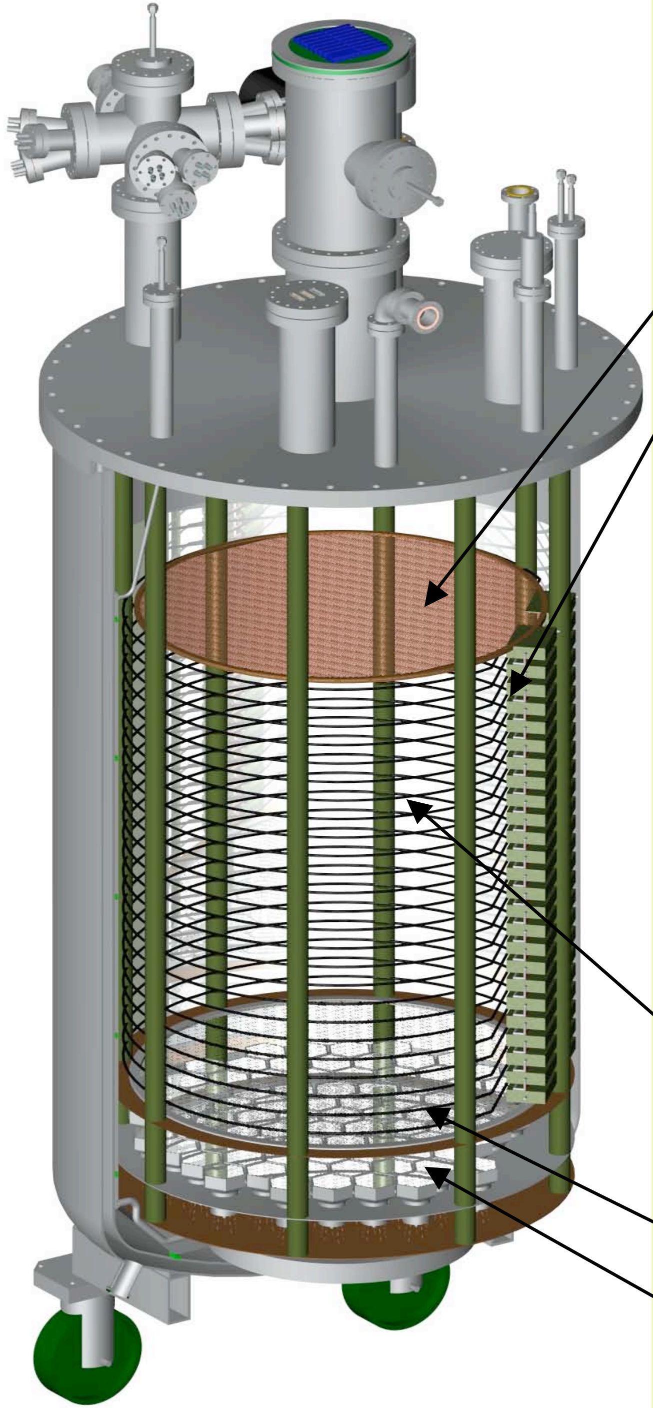


Gain at LAr temperature

P=0.5bar



Prototype layout



Two-stage LEM for electron multiplication and readout

Greinacher chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV

Field shapers are needed to provide a homogeneous electric field, but are thin enough to permit the scintillation light to be reflected from the container walls

Transparent cathode

~85 PMTs below the cathode to detect the scintillation light

ASSEMBLY AT CERN

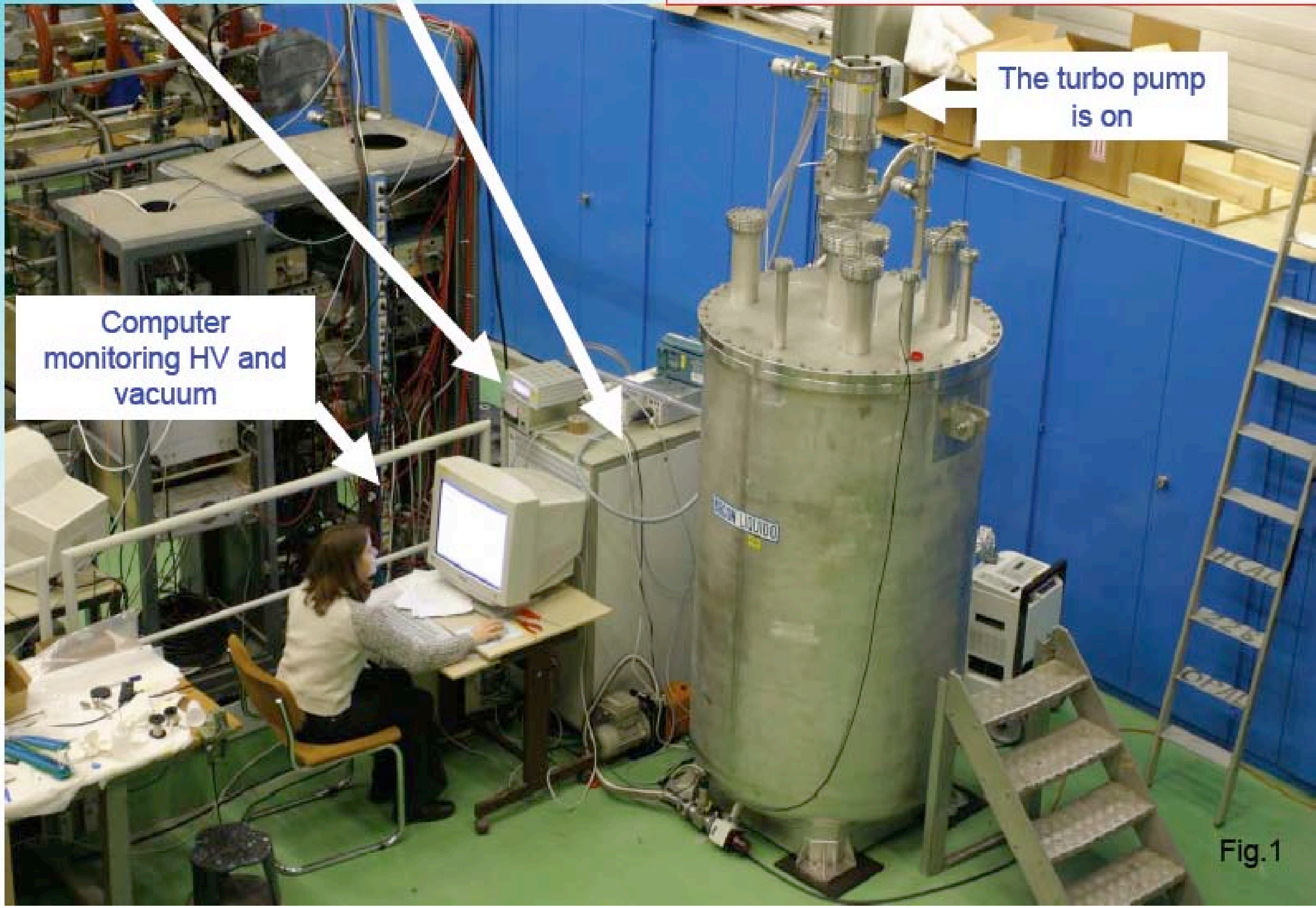
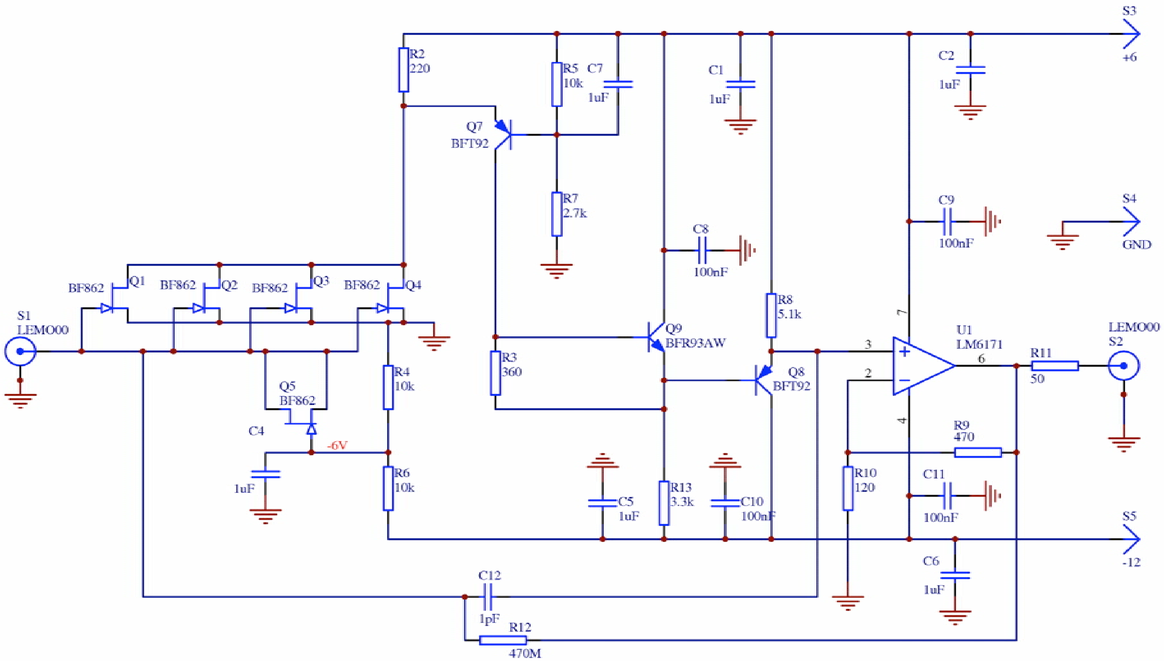


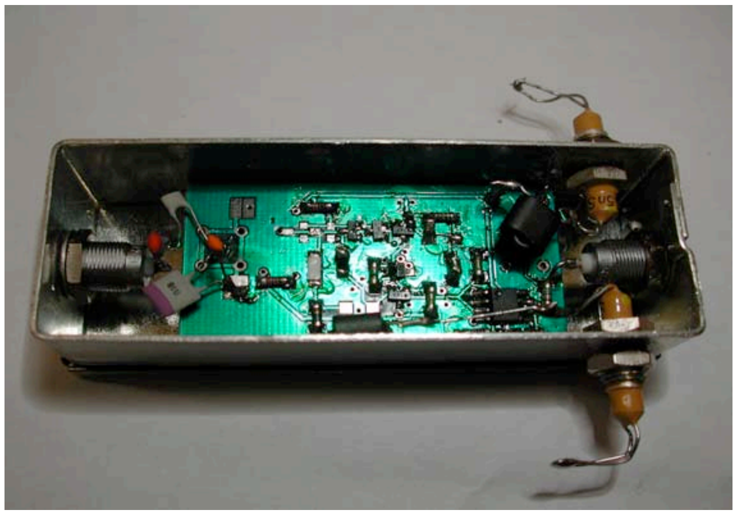
Fig.1

New method of DAQ

Custom made front-end preamplifier



1) C. Boiano et al., IEEE Transact. on Nucl. Science, Vol. 51, No. 5 Oct. 2004



- **Preamplifier circuit inspired from C. Boiano et al. INFN [1]:**
  - Modern junction FET's are used: BF862
  - 4 matched FET's in parallel
  - Different feedback paths

- Modifications:

-The base of Q7 has no resistor in series, but a capacitor to GND

-The Gate voltage of the protecting FET Q5 has been changed from -12V to -6V

Characteristics:

-Bandwidth: 9MHz

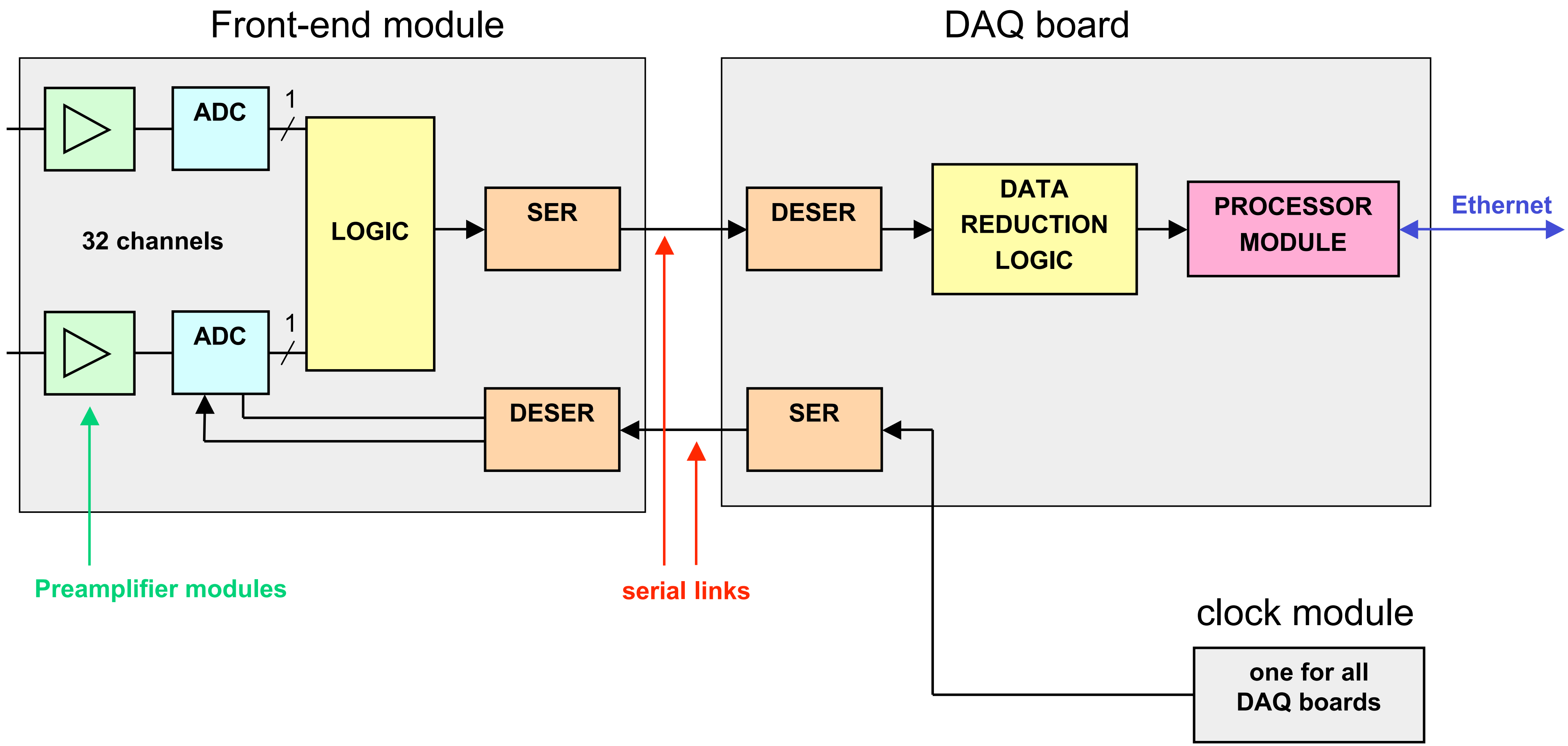
-Amplitude Outp: +4V, -5V

-Input Noise:

$5*10^{-18}$ C $Hz^{-1/2}$ @0pF

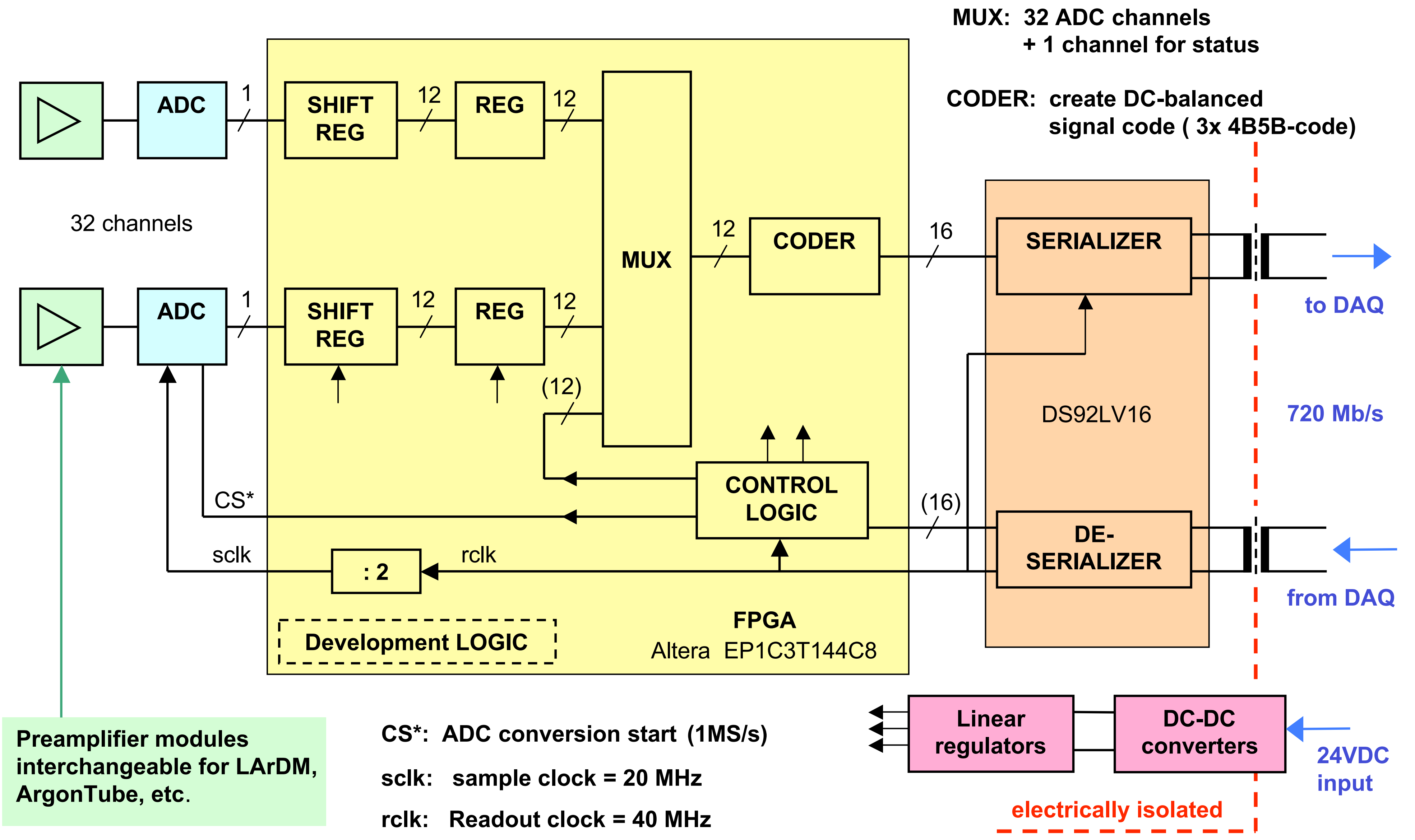
$2.1*10^{-17}$ C $Hz^{-1/2}$ @200pF

Data Acquisition System



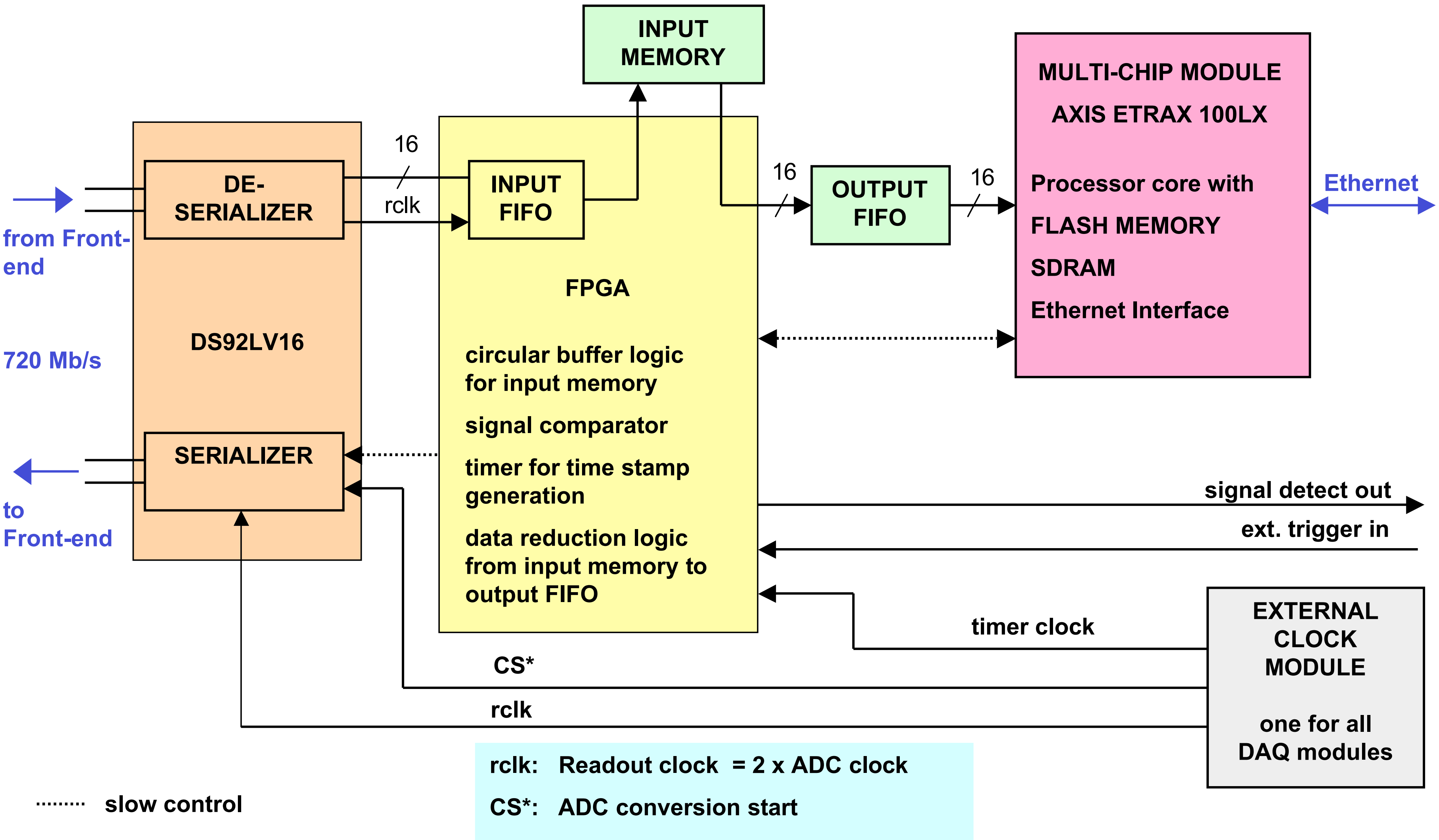
6.06.2006 Max Hess

Front-end module



26.06.2006 Max Hess

Data Aquisition board



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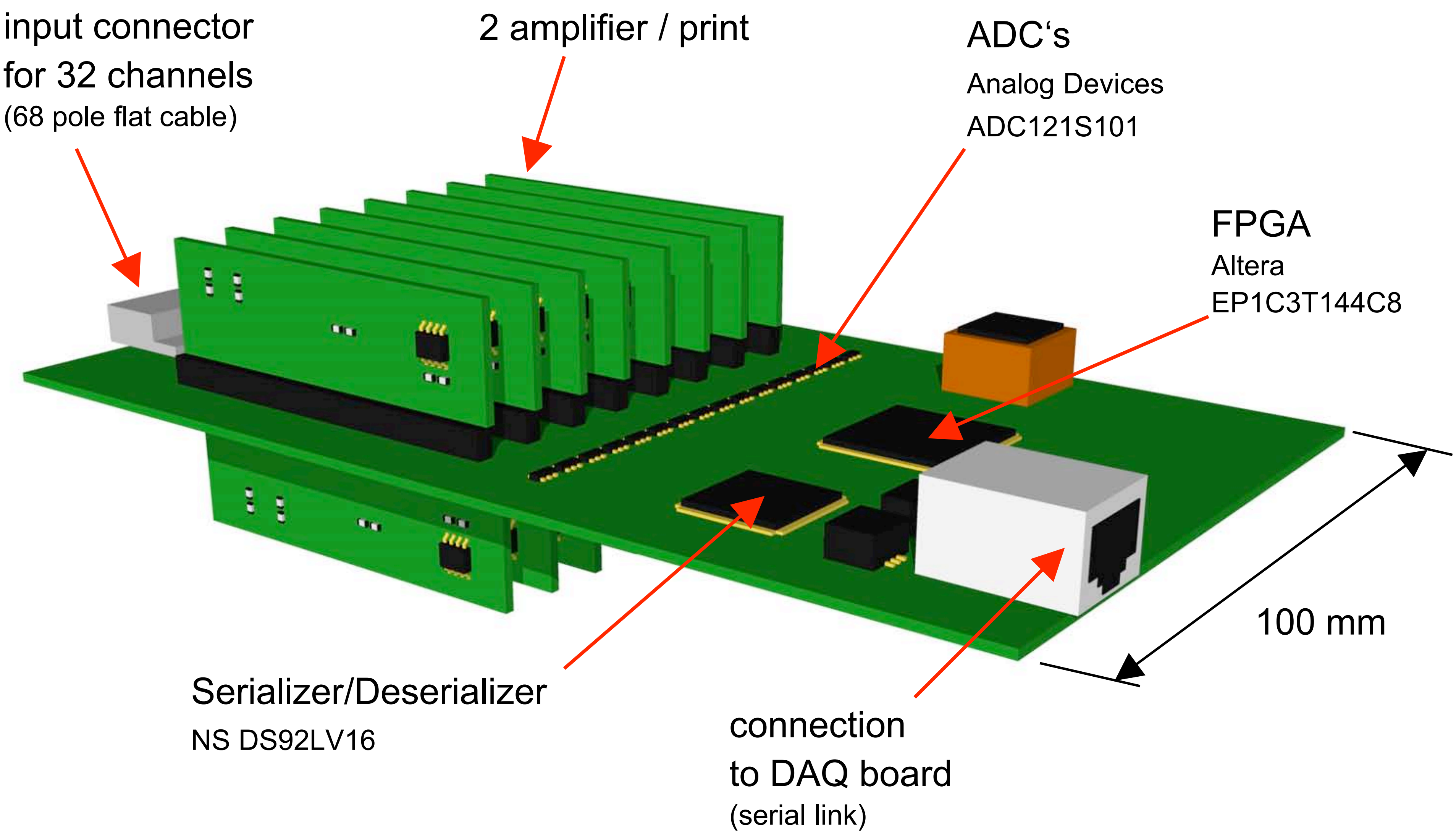
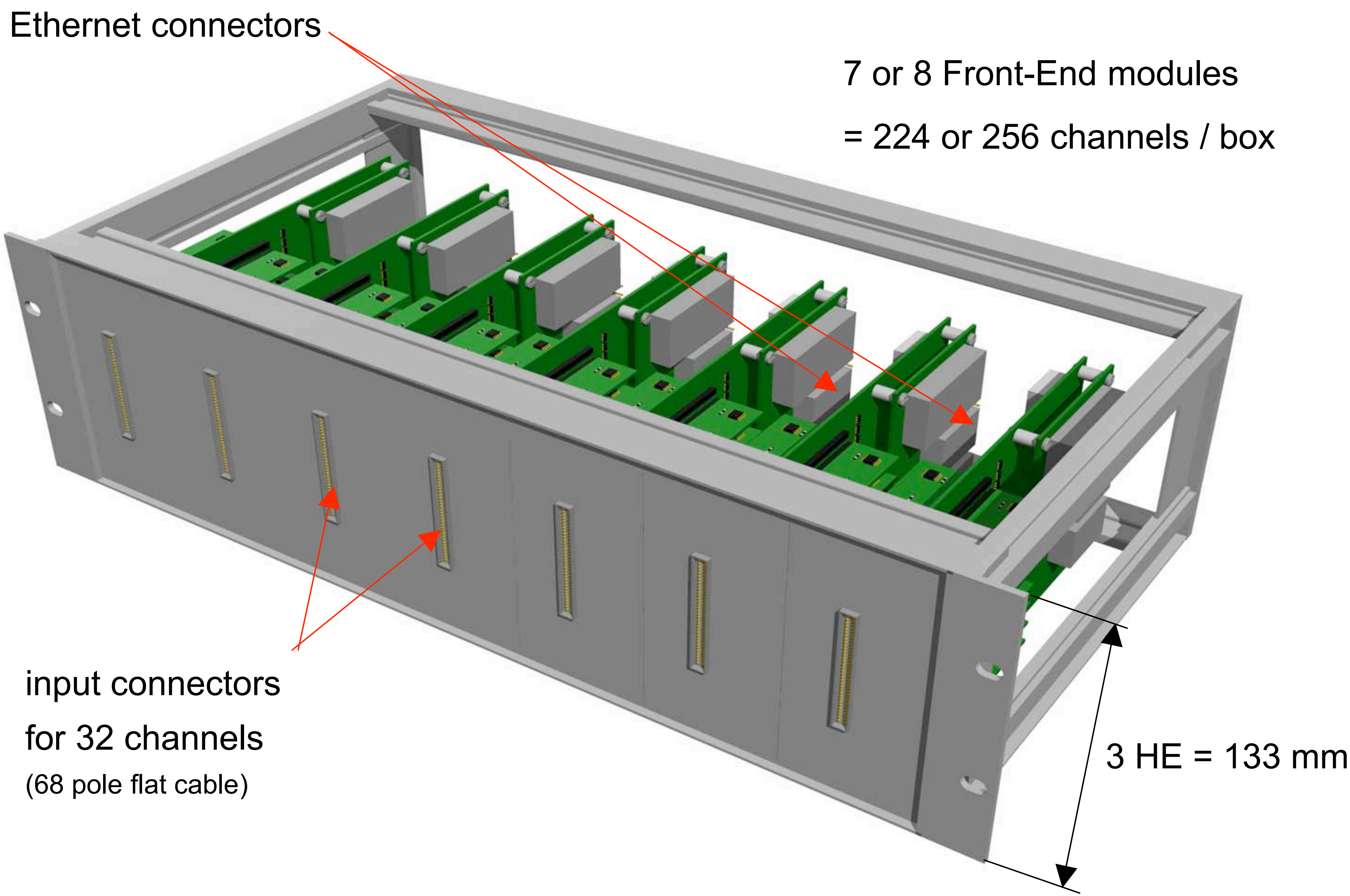
Front-end module



Front-end box

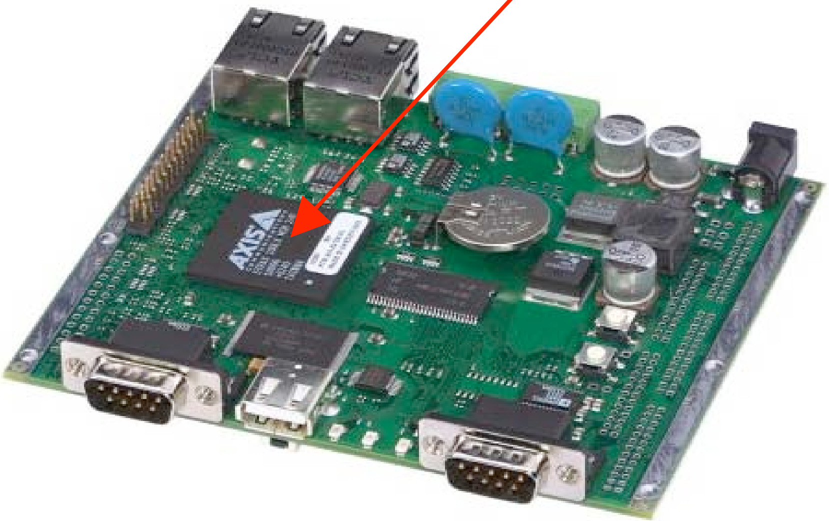


26.06.2006 Max Hess

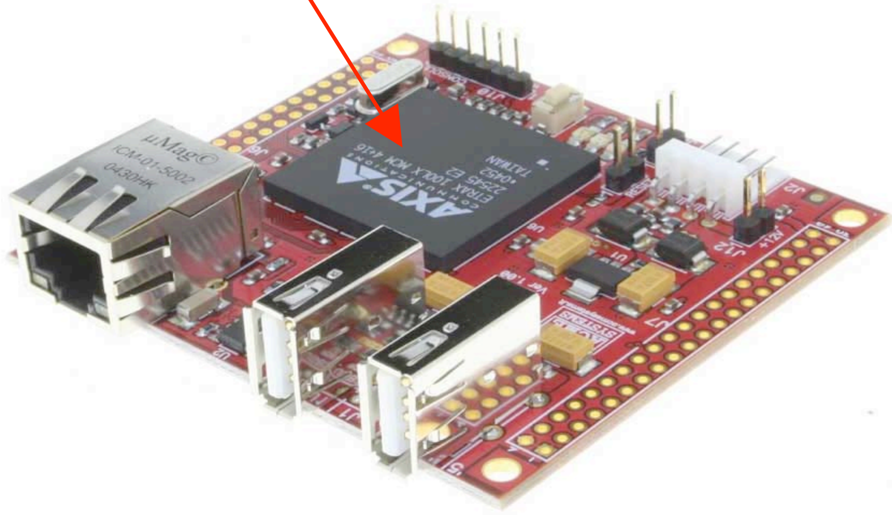
A complete Linux system on a small board

Scheme successfully implemented in OPERA (IPN Lyon)

ETRAX 100LX MCM 4+16



AXIS 82+ Developer Board
www.developer.axis.com

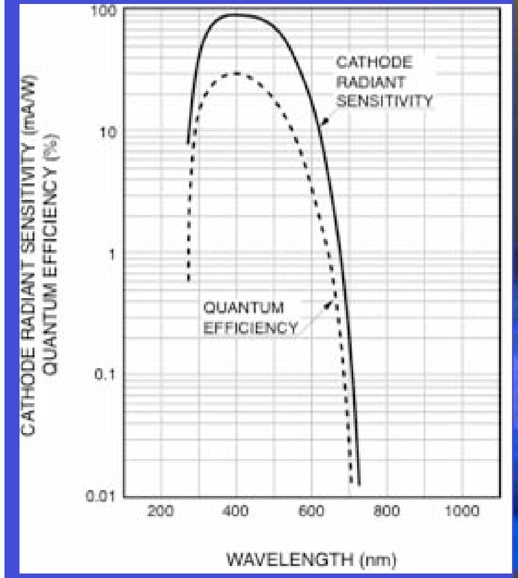


FOX Board
www.acmesystems.it

New method of light readout

WLS-coated PMT Hamamatsu 6237mod

Scintillation light detection via WLS-coated PMTs:
Polymer and Tetra-Phenyl-Butadiene (TPB) compound coated on PMT window shifts the DUV light (128 nm) to 430 nm
Efficiency of wavelength shifting: 20% to 30%
PMTs: array of 85 photosensors at bottom of detector, hexagonal shape
Quantum efficiency at 430 nm: ≈ 20%

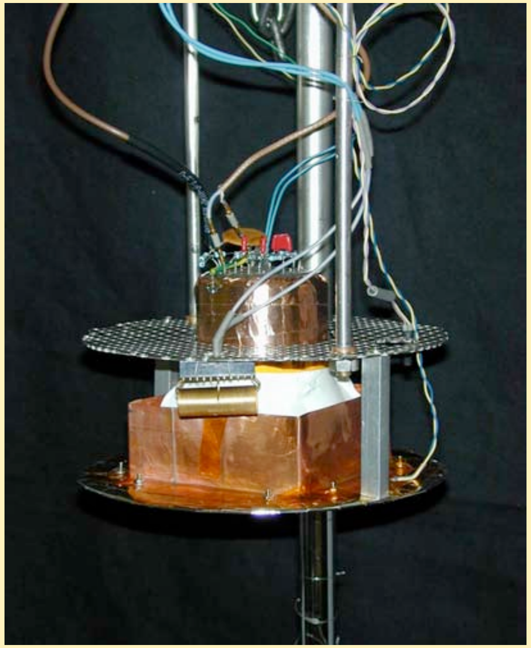


Type: R6237-01MOD
- Pt underlay
- QE ~ 20%
- Bi-Alkali type
- 7.6 x 7.6 cm²
- 8 dynodes, G~3x10⁶

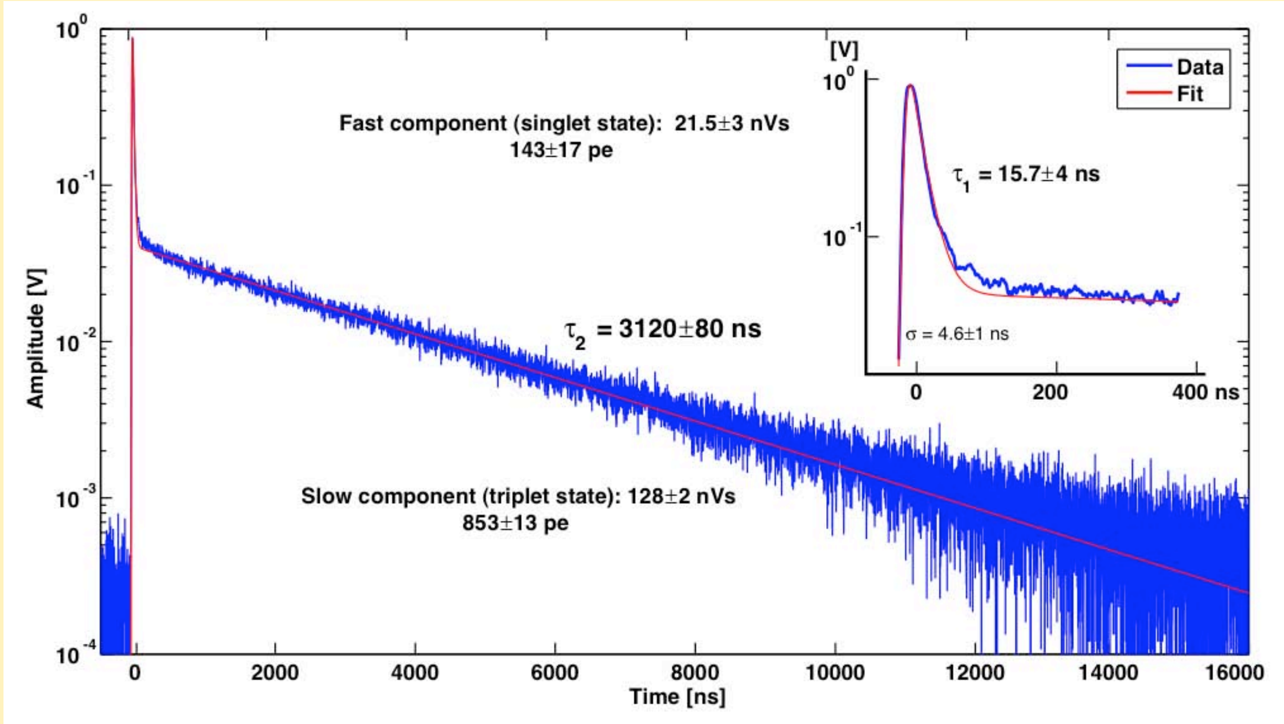
- open leads

Wavelength-shifter TPB:PS

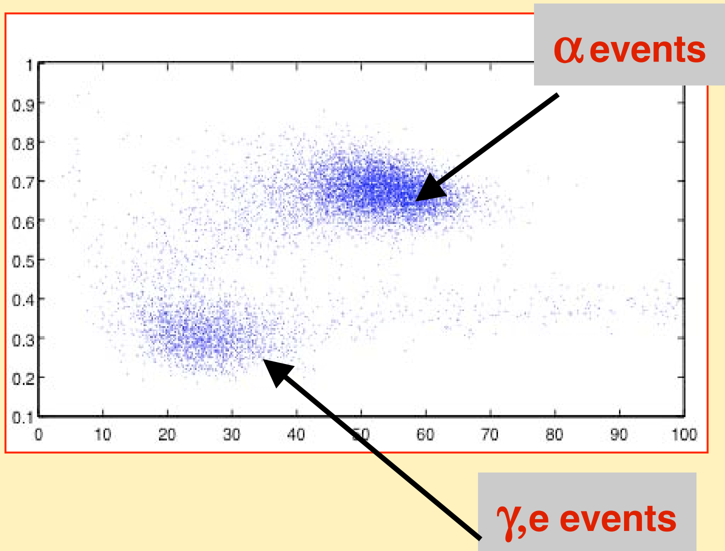
Measurements of scint. Light (in collab. with Zurich Univ)



Low Temp LAPM w wavelength shifter
Single photon = 0.140nVs
Collected photons (total) ~750
Collected photons from Slow comp. ~630
Collected photons from Fast comp. ~ 120



Particle discrimination



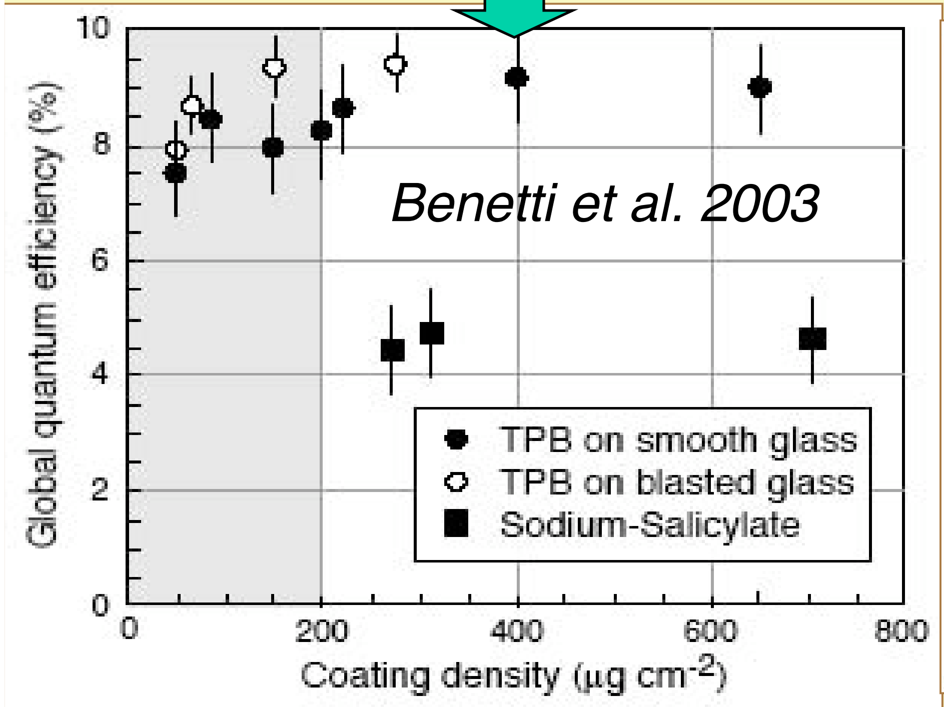
Also: development of highly reflecting DUV surfaces

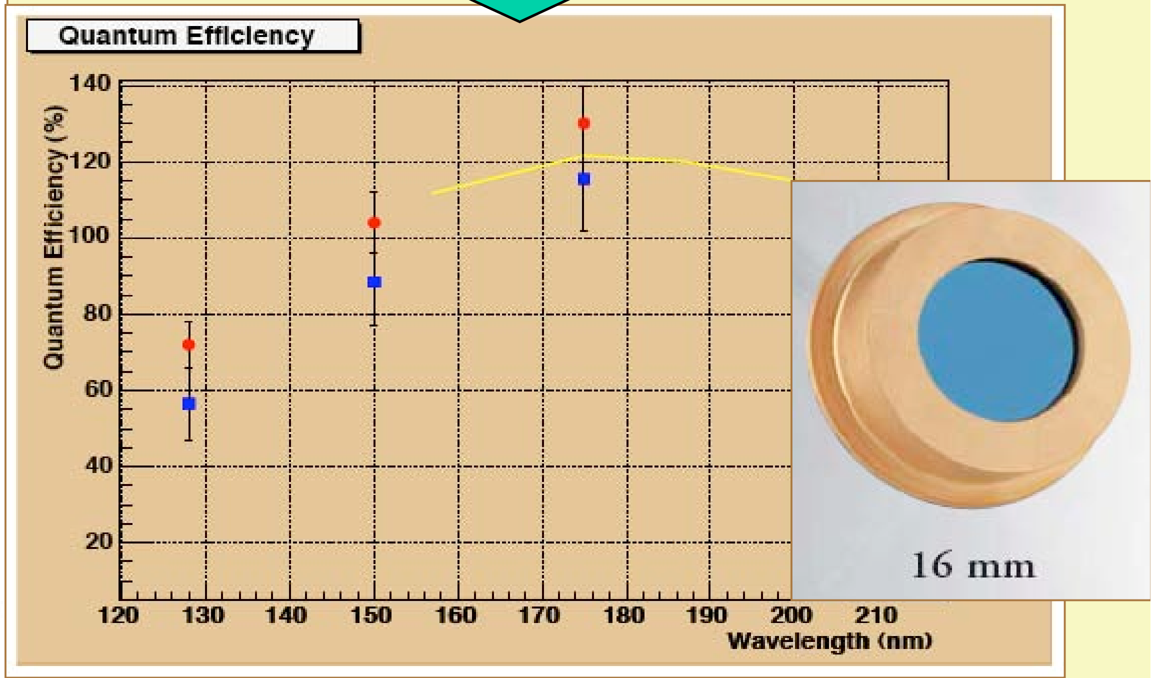
The Detection of 128nm UV light with LAAPDs

PMT+TPB

Windowless DUV-APD

NIMA546:426-437,2005



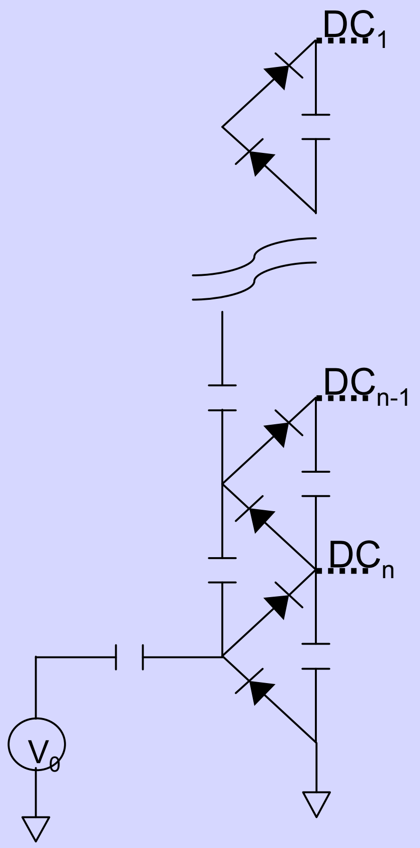


- Current detection threshold ≈ 1000 photons
- Cooling increases APD gain and reduces noise

⇨ By cooling detection of smaller photon numbers possible. Single γ ? Study in progress!

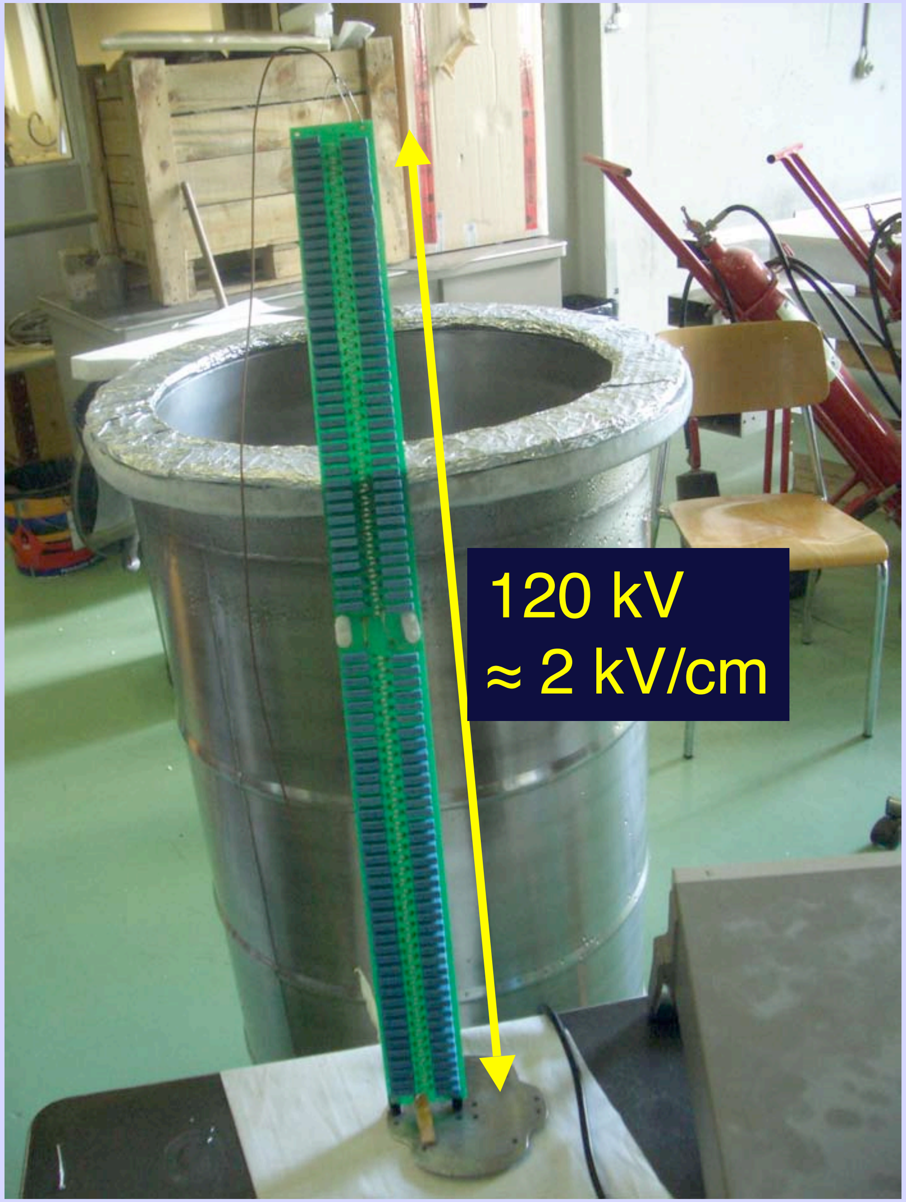
New method of HV

Drift very high voltage: Greinacher circuit



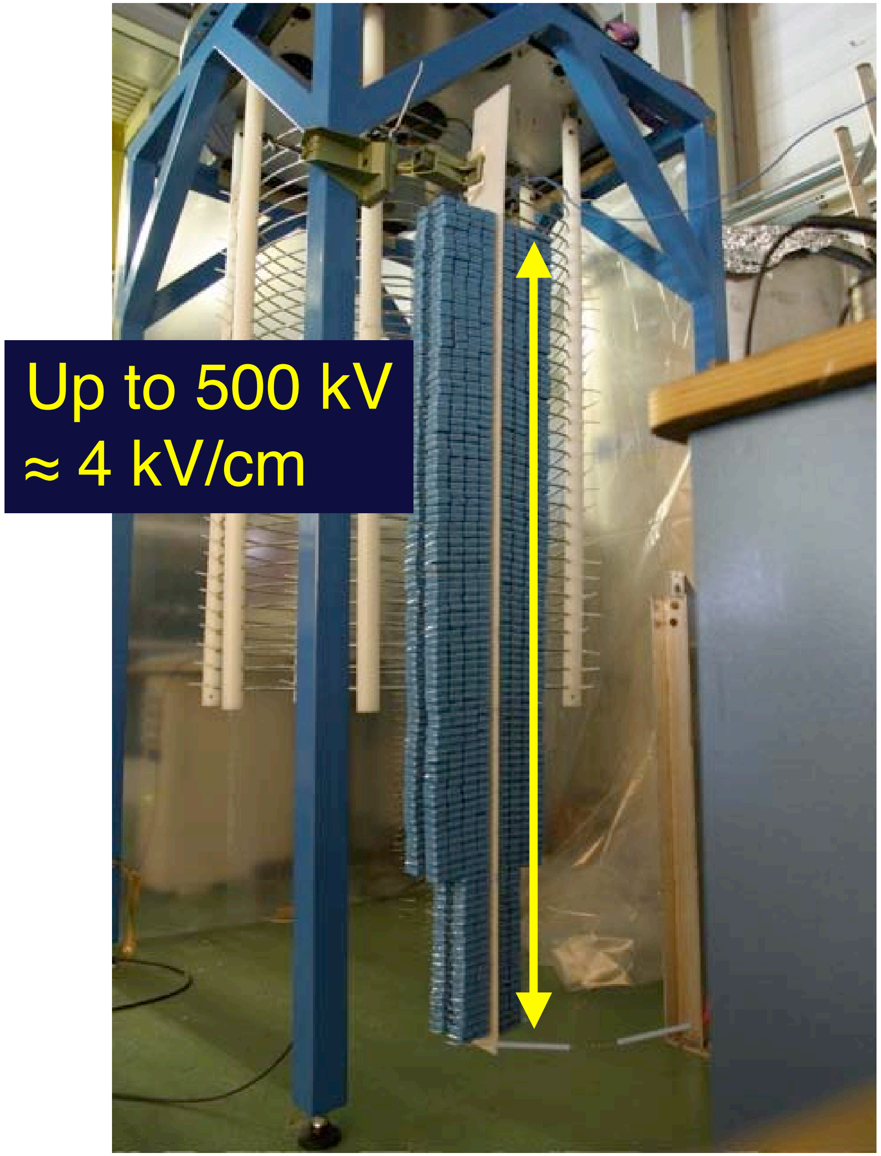
Greinacher or Cockroft/Walton voltage multiplier

- No load to avoid resistive ripple
- Low frequency (50-500 Hz) to induce noise with a spectrum far from the bandwidth of the preamplifiers used to read out the wires or strips
- Possibility to stop feeding circuit during an event trigger

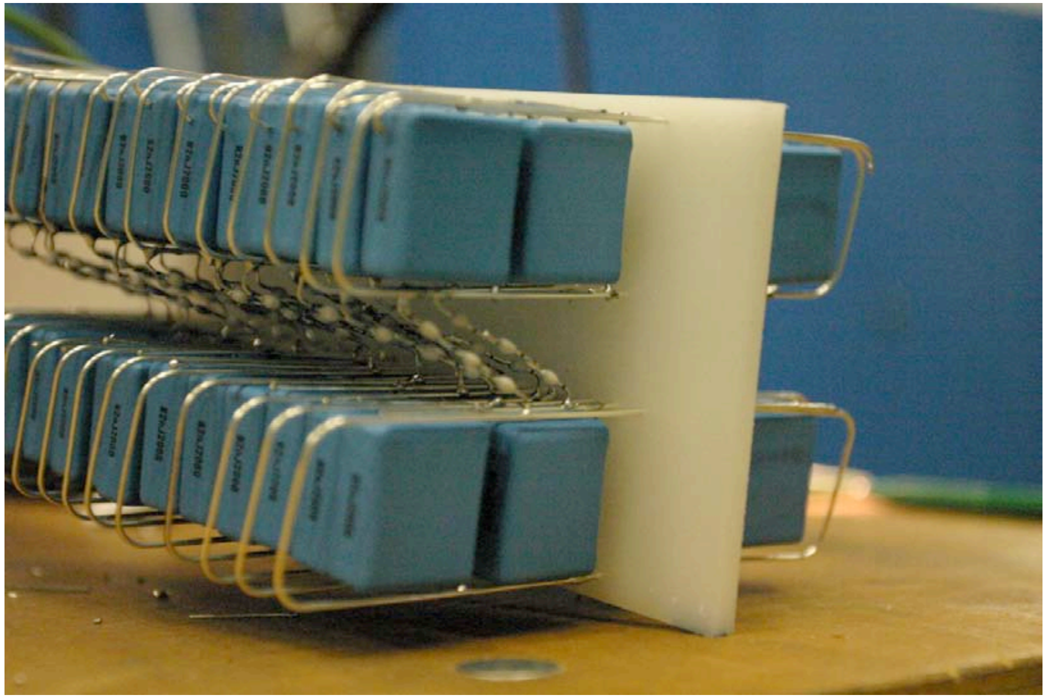


A Greinacher circuit will be fully tested in the ArDM experiment

CIEMAT – ETHZ – Granada – Sheffield – Warszawa – U. Zurich

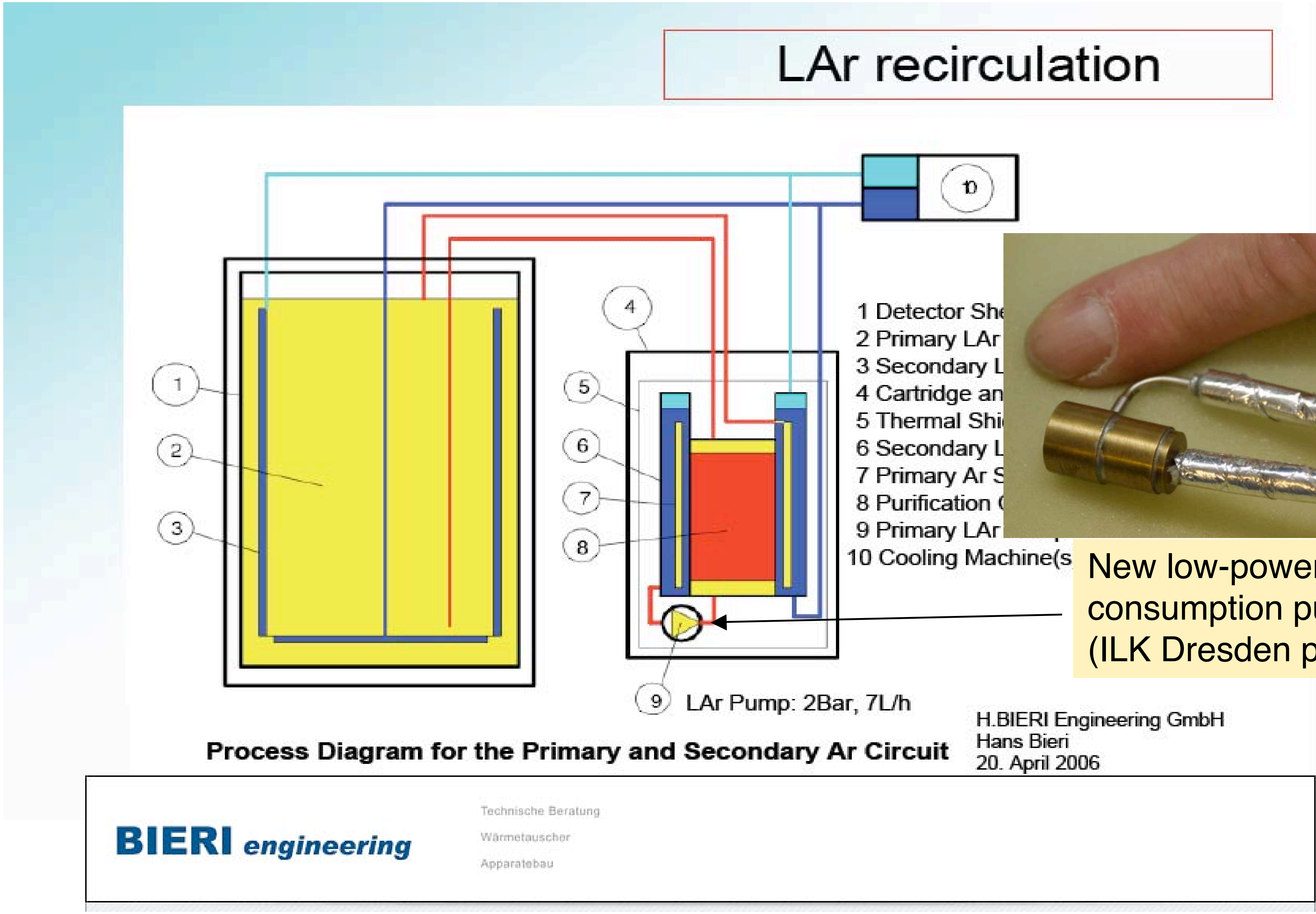


- The total voltage we aim to reach is V_{tot} = 500 kV, i.e. ≈ 4 kV/cm
- Tests in liquid nitrogen have been performed



New systems for cooling and purification

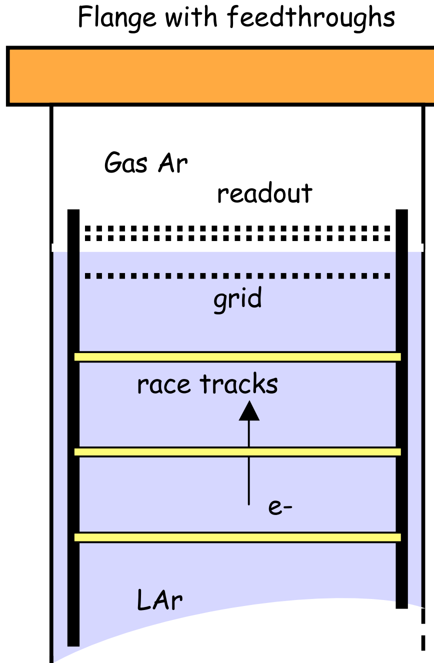
LAr purificaton for the ArDM experiment CIEMAT – ETHZ – Granada – Sheffield – Warszawa – U. Zurich

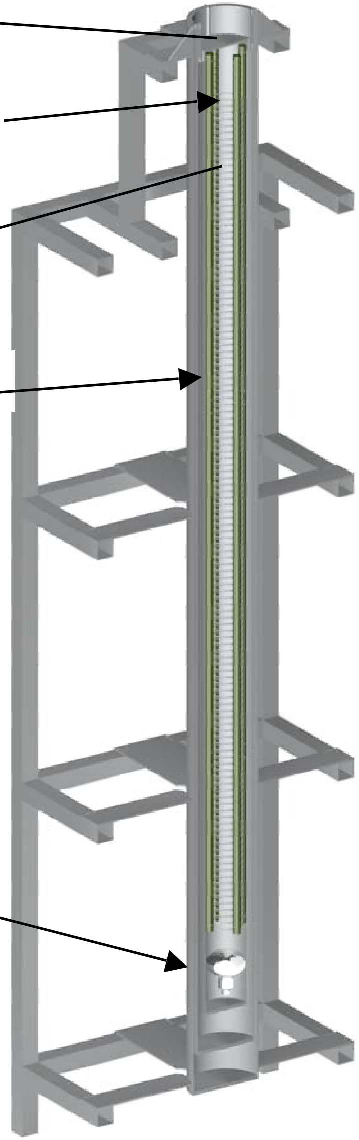


New low-power consumption pump (ILK Dresden patent)

Very long drift paths

Long drift, extraction, amplification: "ARGONTUBE"





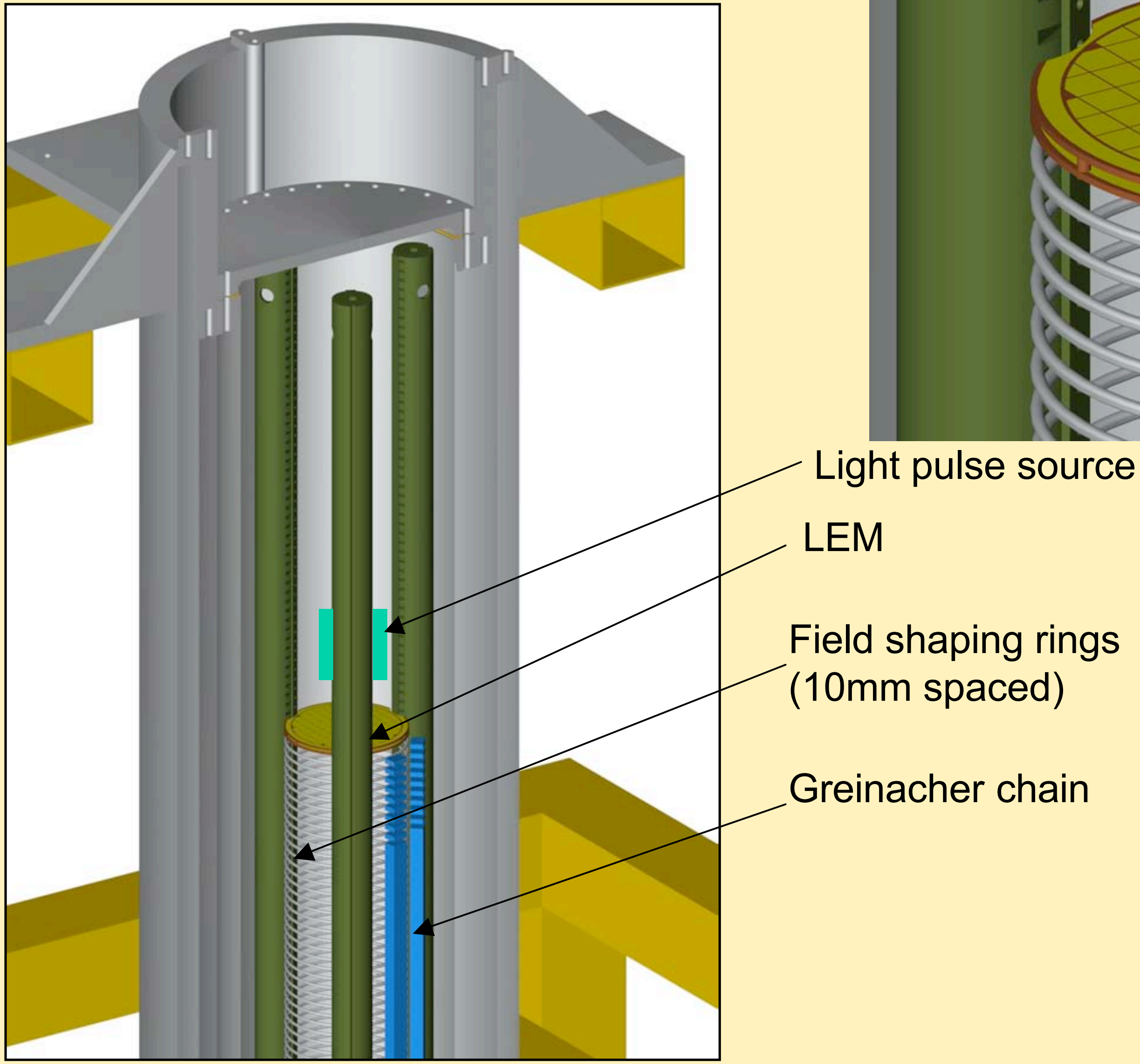
5 meters

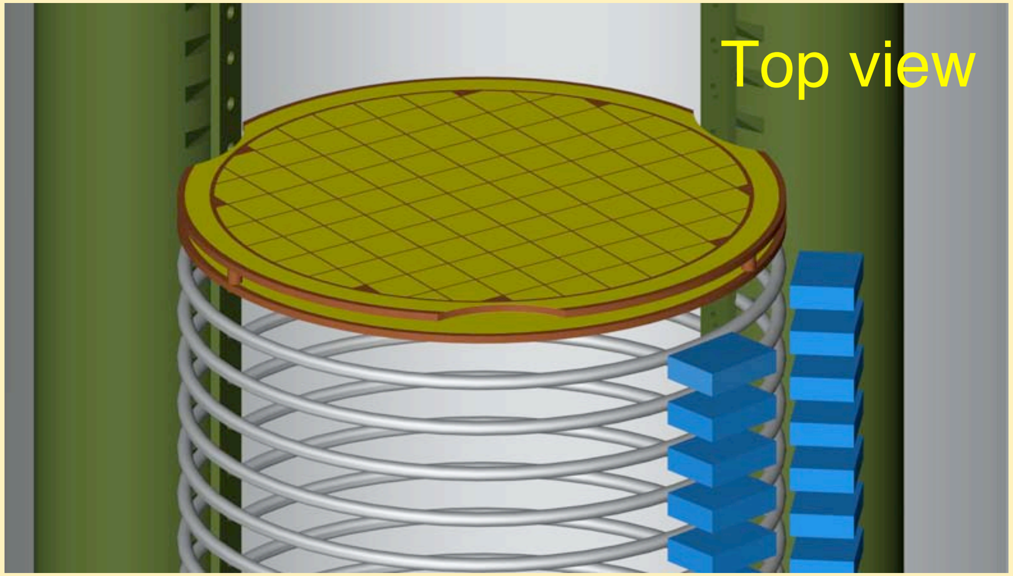
- Full scale measurement of long drift (5 m), signal attenuation and multiplication
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Measurement Rayleigh scatt. length and attenuation length vs purity
- Design & assembly:

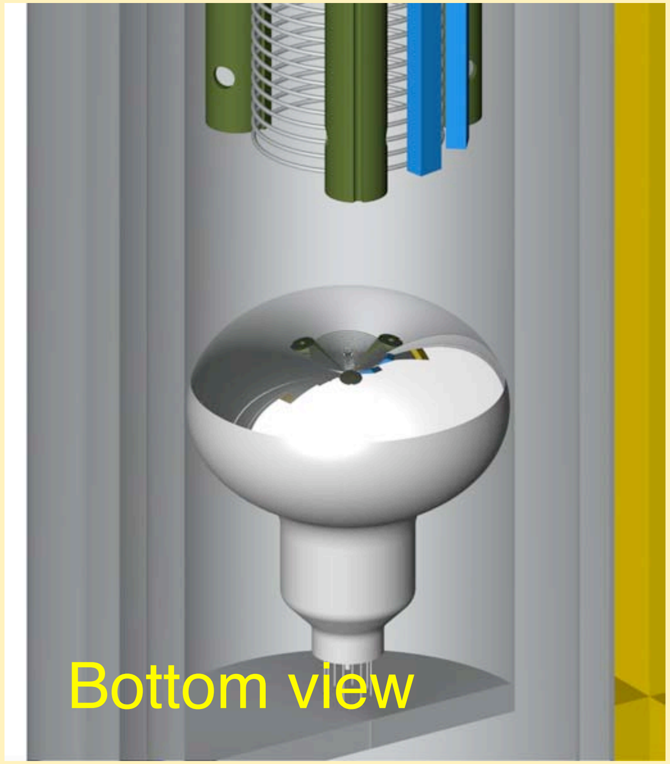
completed: external dewar, detector container

in progress: inner detector, readout system, …

Inner detector design





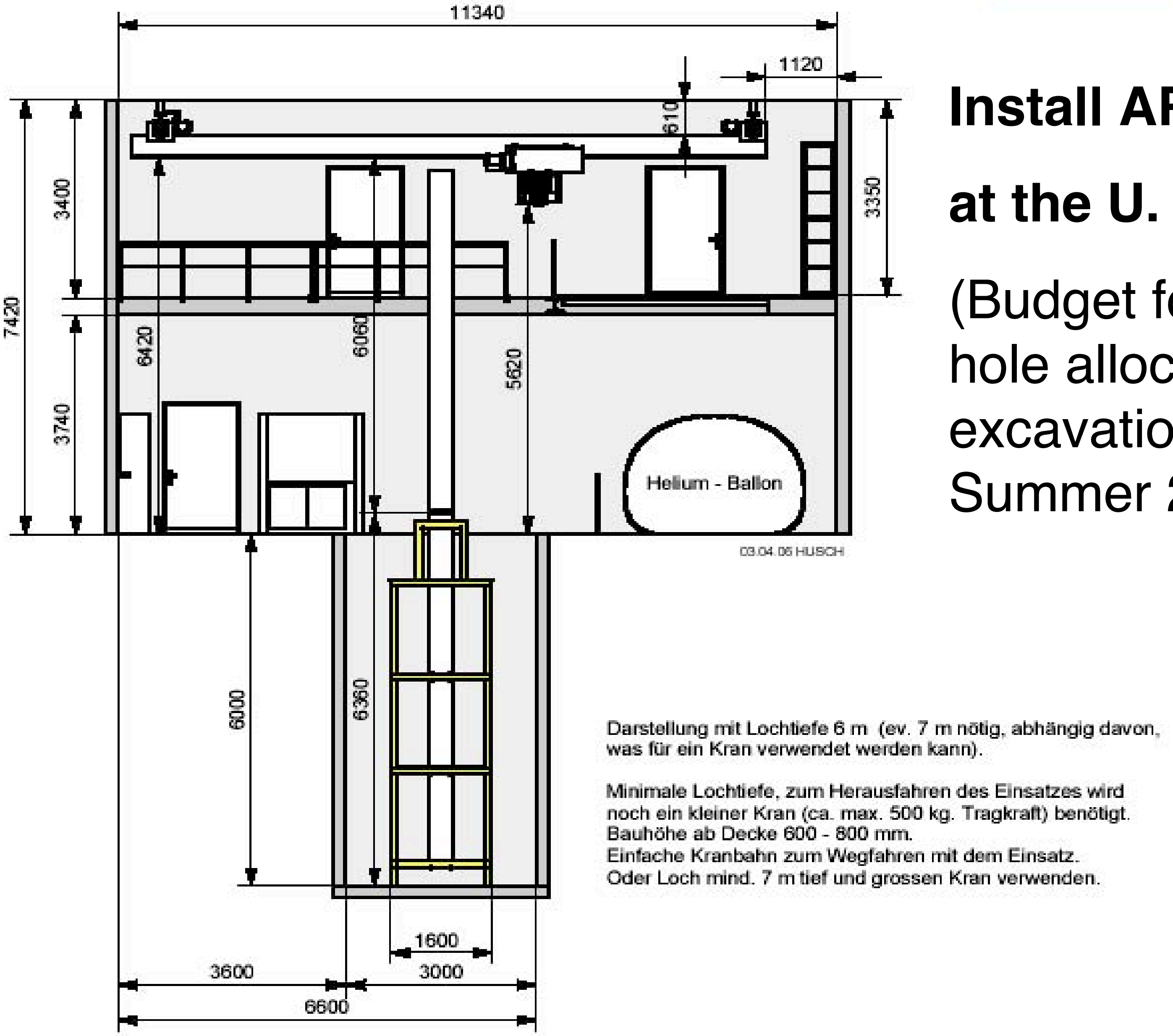


In Collaboration between Univ. Bern & ETHZ & Granada

Install ARGONTUBE

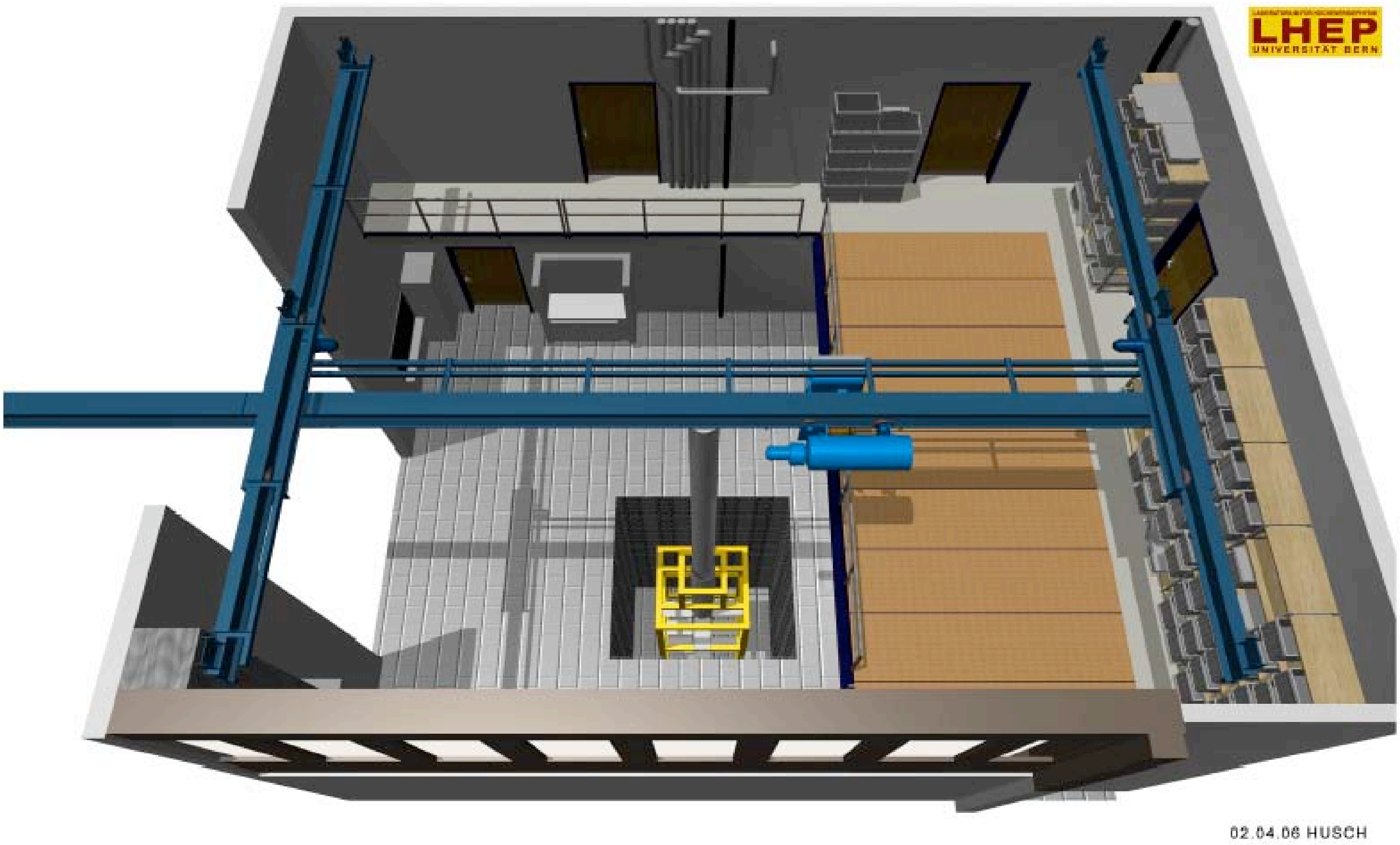
at the U. of Berne

(Budget for digging hole allocated, excavation during Summer 2006!)



Install ARGONTUBE at the U. of Berne

Budget for digging hole allocated, excavation during Summer 2006!



A clean sample of e/π^0

Motivation for the test: calorimetry and shower reconstruction

- The liquid Argon TPC can ideally be considered as an homogenous full-sampling calorimeter. However, in an imaging device, deviations from this ideal situation will occur from the difficulty to reconstruct the total deposited charge from rather complicated event topologies induced by electromagnetic showers.

- This effect will become more severe with increasing energy.

- In addition, the properties of the readout, including the performance of the electronics, will affect the performance because it will determine the minimum amount of detectable energy in the medium and the resolution
  - ➥ In the ICARUS T300 surface test, the minimum amount of energy detectable was about 200 keV, limited by the electronic noise. When the ionization charge is amplified before is readout like in the scheme we are proposing, it could be less.

- NB: within the ICARUS R&D program, a small chamber with a drift gap of 24 cm was exposed to a charged pion beam to study the detection of delta-rays (S.Bonetti et al., Nucl. Instrum. Meth. A286, 135 (1990)). No result on response to high-energy electrons has been reported.

Motivation for the test: e/π^0 reconstruction, separation

- In future neutrino experiments, a very important reaction will be $\nu_\mu \rightarrow \nu_e$
- The liquid argon TPC should provide the better conditions for observing this reaction, compared to other detector technologies. In particular, electron reconstruction and e/π^0 separation should have excellent performance.
- NB: We note that a proposal to study this reaction simultaneously in Water Cerenkov and Liquid Argon TPC (in the same beam and the same location) has been put forward at T2K 2km.
- We believe that a dedicated test beam with clean electron and pion samples would provide an important milestone, before similar analysis are performed in the more complicated neutrino beam environment.
- Given the radiation length of LAr (X_0=14cm), the test beam requires a much smaller detector than for the neutrino beam.
- Since future neutrino factories will require magnetized detectors, we also consider this test in a magnetized LAr TPC.

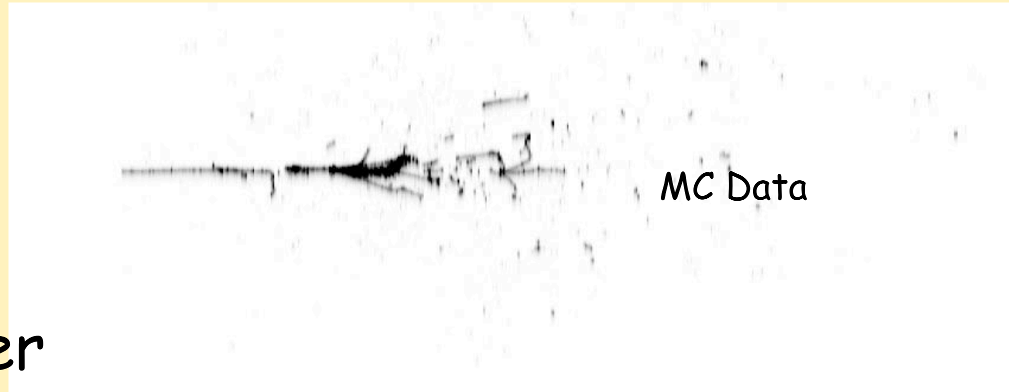
ν_e Appearance : the important reactions in LAr

- ν_e CC reaction:

  (ν_e appearance signal)

$$\nu_e + n \longrightarrow e^- + p$$

e^- $\longrightarrow$ electromagnetic shower



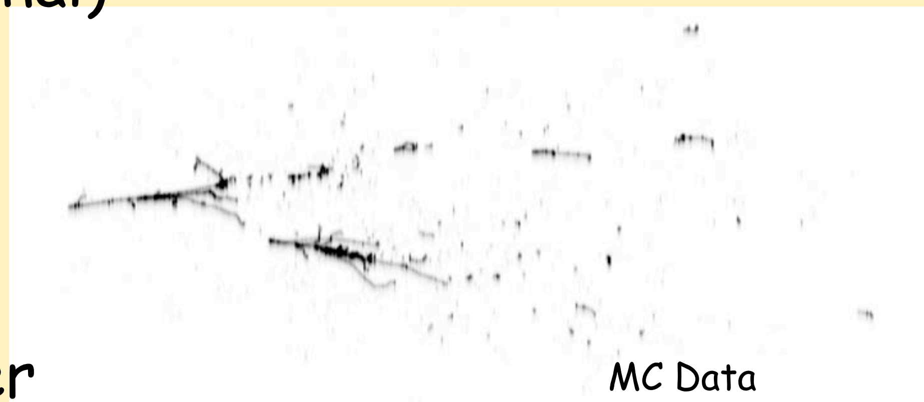
- ν_μ NC reaction:

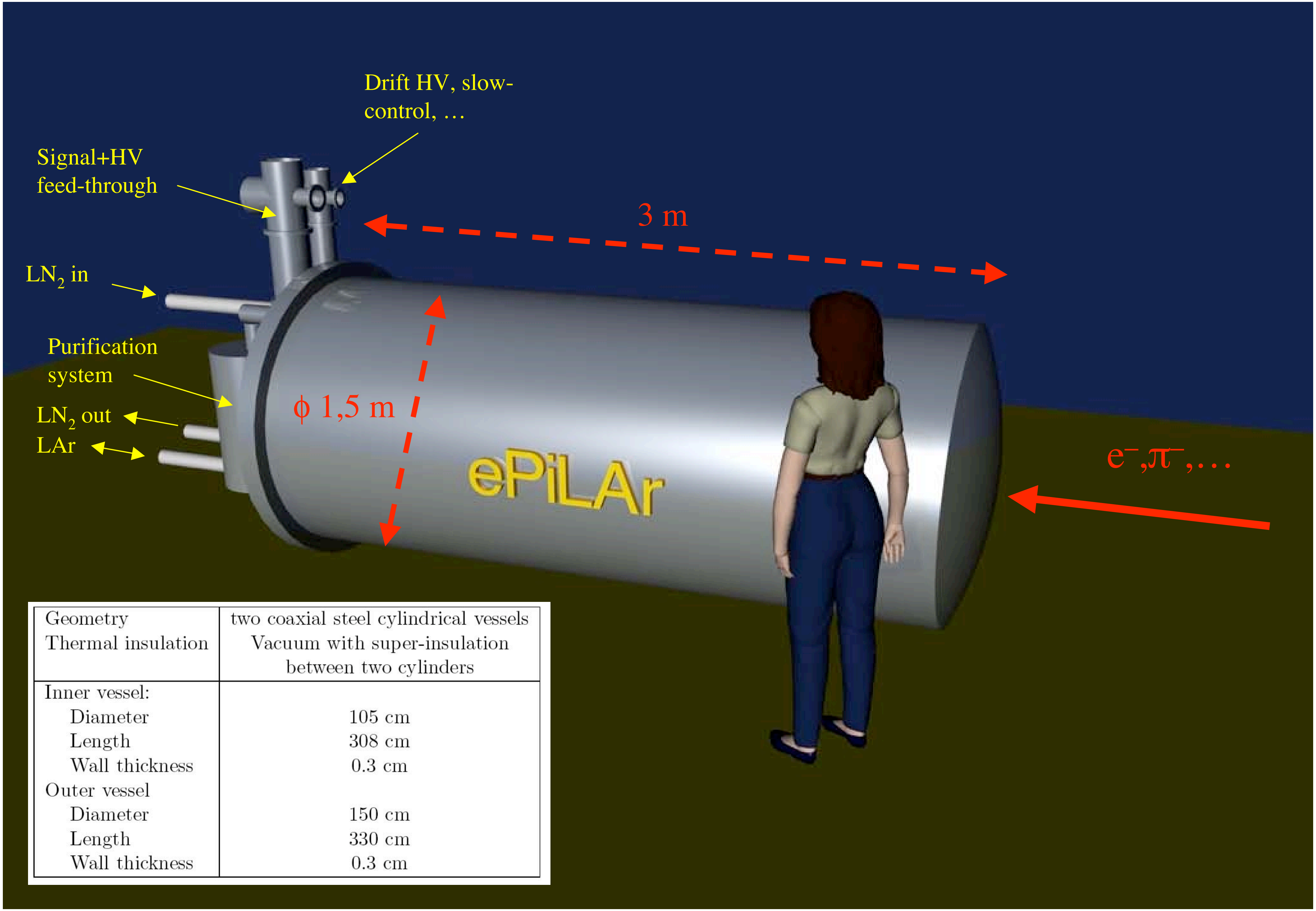
(background for ν_e appearance signal)

$$\nu_\mu + n \longrightarrow \nu_\mu + \pi^0 + X$$

Decay: $\pi^0 \longrightarrow \gamma\gamma$

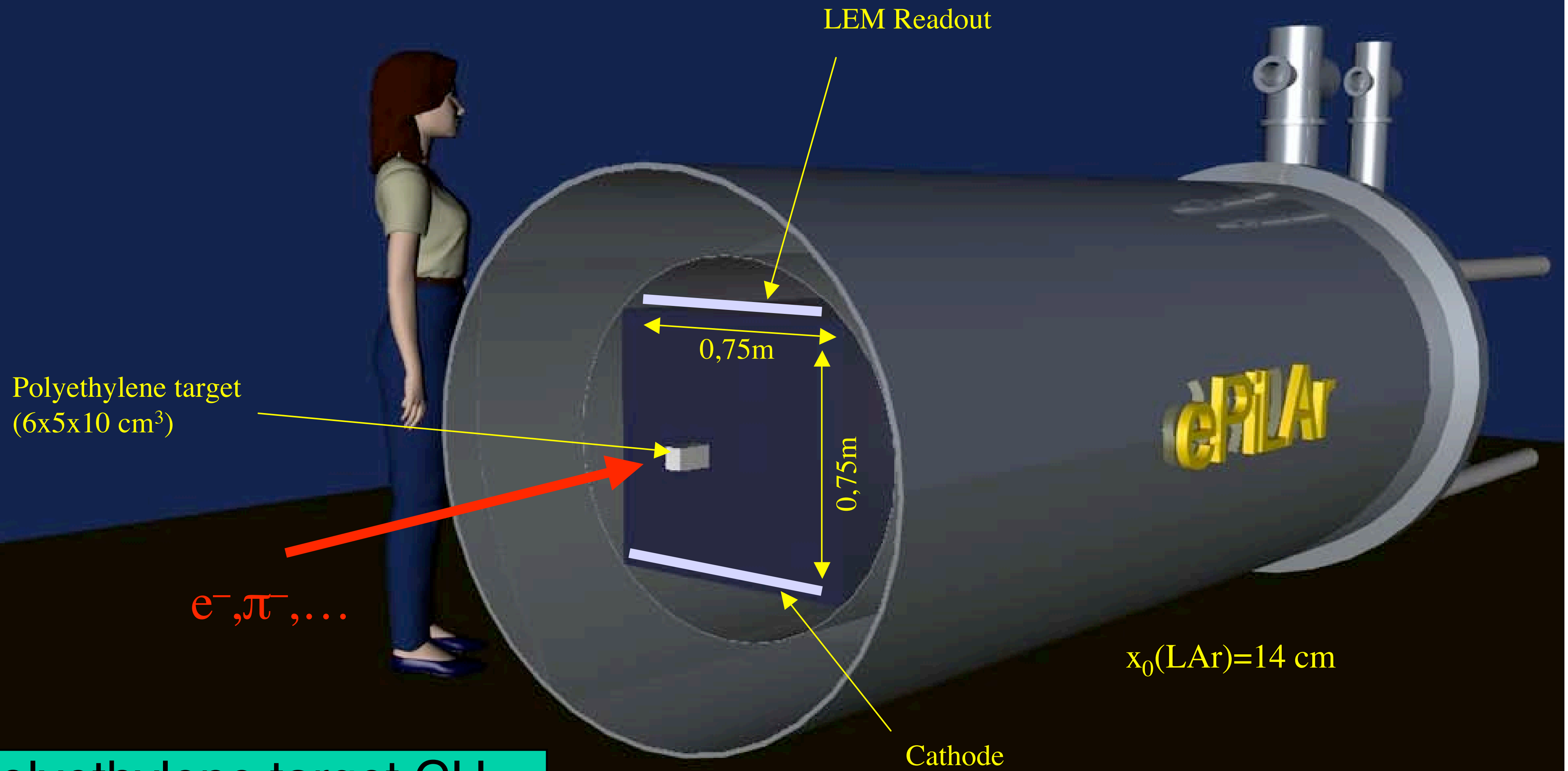
γ $\longrightarrow$ electromagnetic shower





Geometry	two coaxial steel cylindrical vessels
Thermal insulation	Vacuum with super-insulation between two cylinders
Inner vessel:	
Diameter	105 cm
Length	308 cm
Wall thickness	0.3 cm
Outer vessel	
Diameter	150 cm
Length	330 cm
Wall thickness	0.3 cm

Electron and π^0 samples:



Polyethylene target CH_2

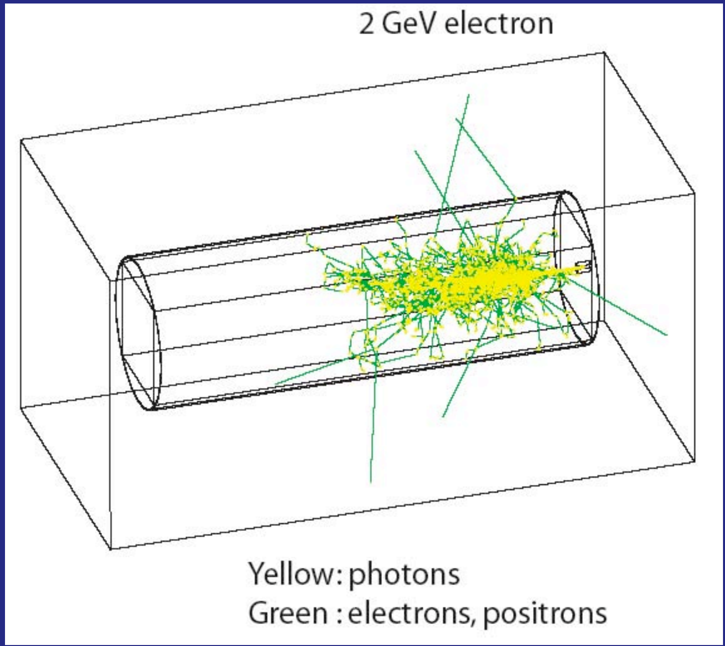
$\pi^- + p \rightarrow \pi^0 + n$

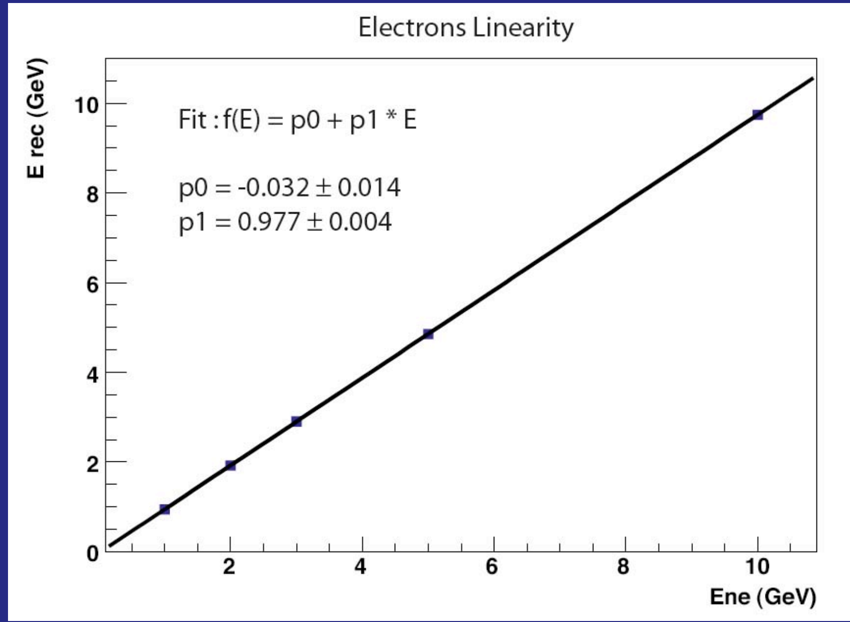
$\sigma_{CH2} \approx 30 \times \sigma_{Ar} \approx 10^{-3} \sigma_{inel,\, CH2}$

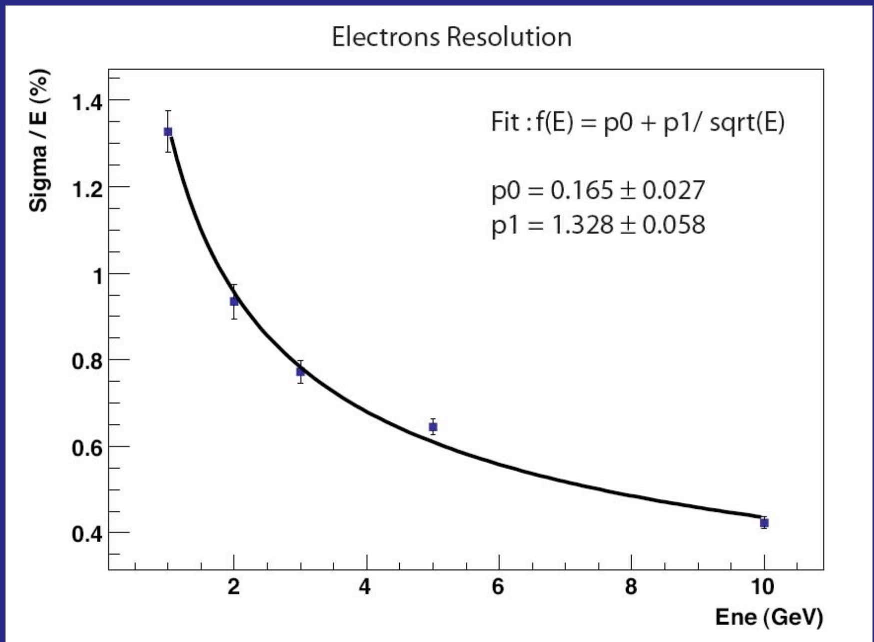
Drift time @ 1 kV/cm ≈ 375 μs

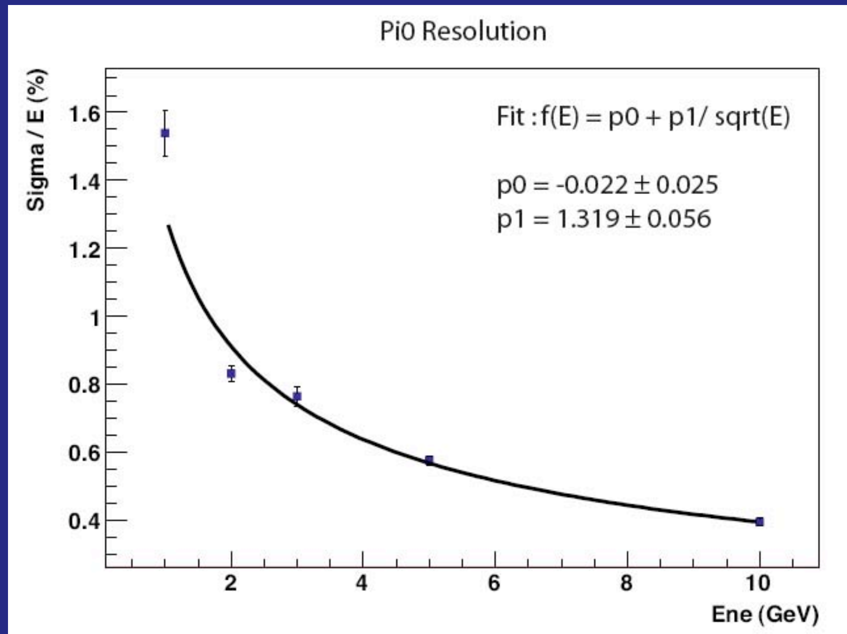
Max rate/350 ms≈ 1000 particles

Expected shower containment (GEANT4)

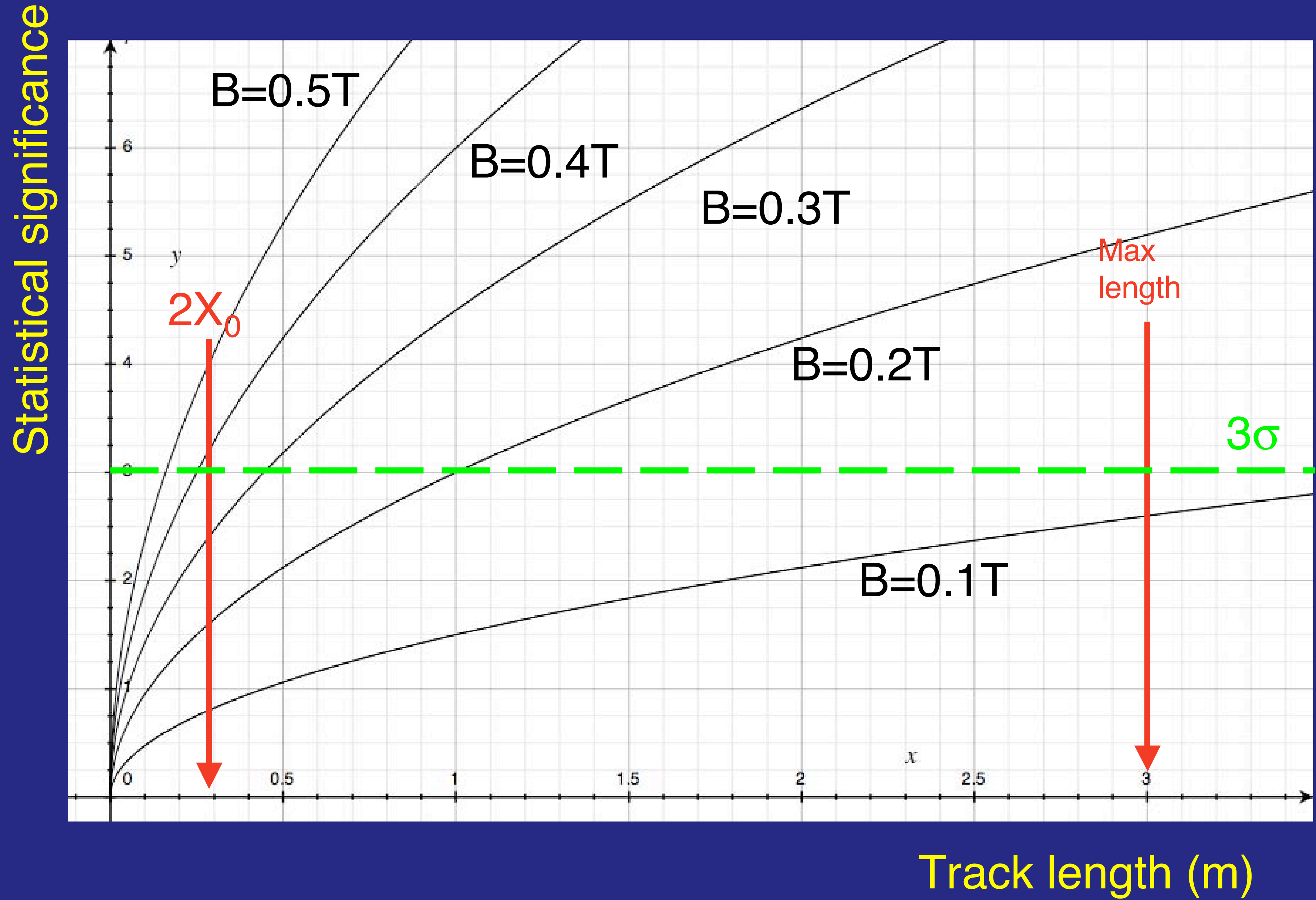




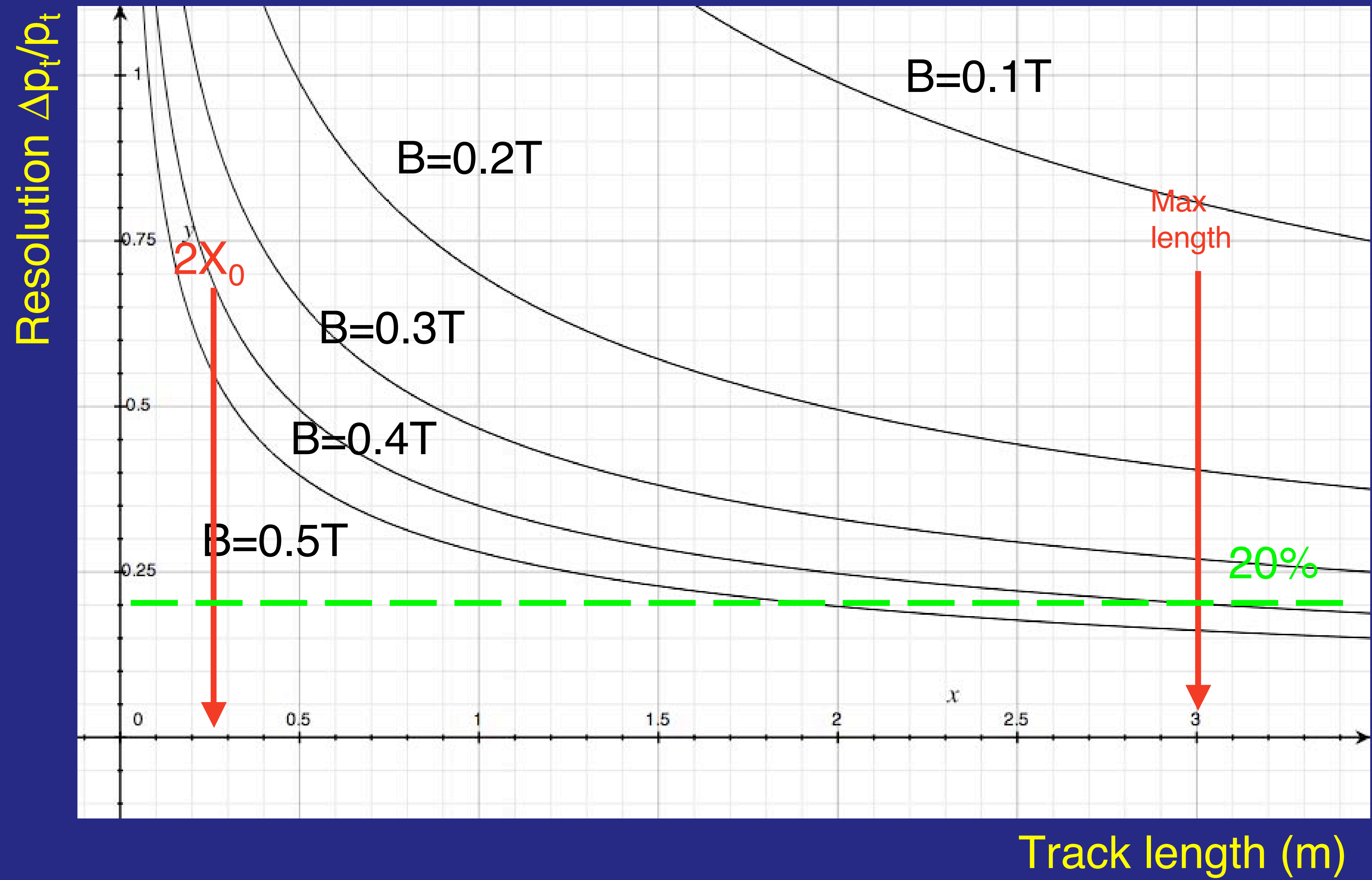




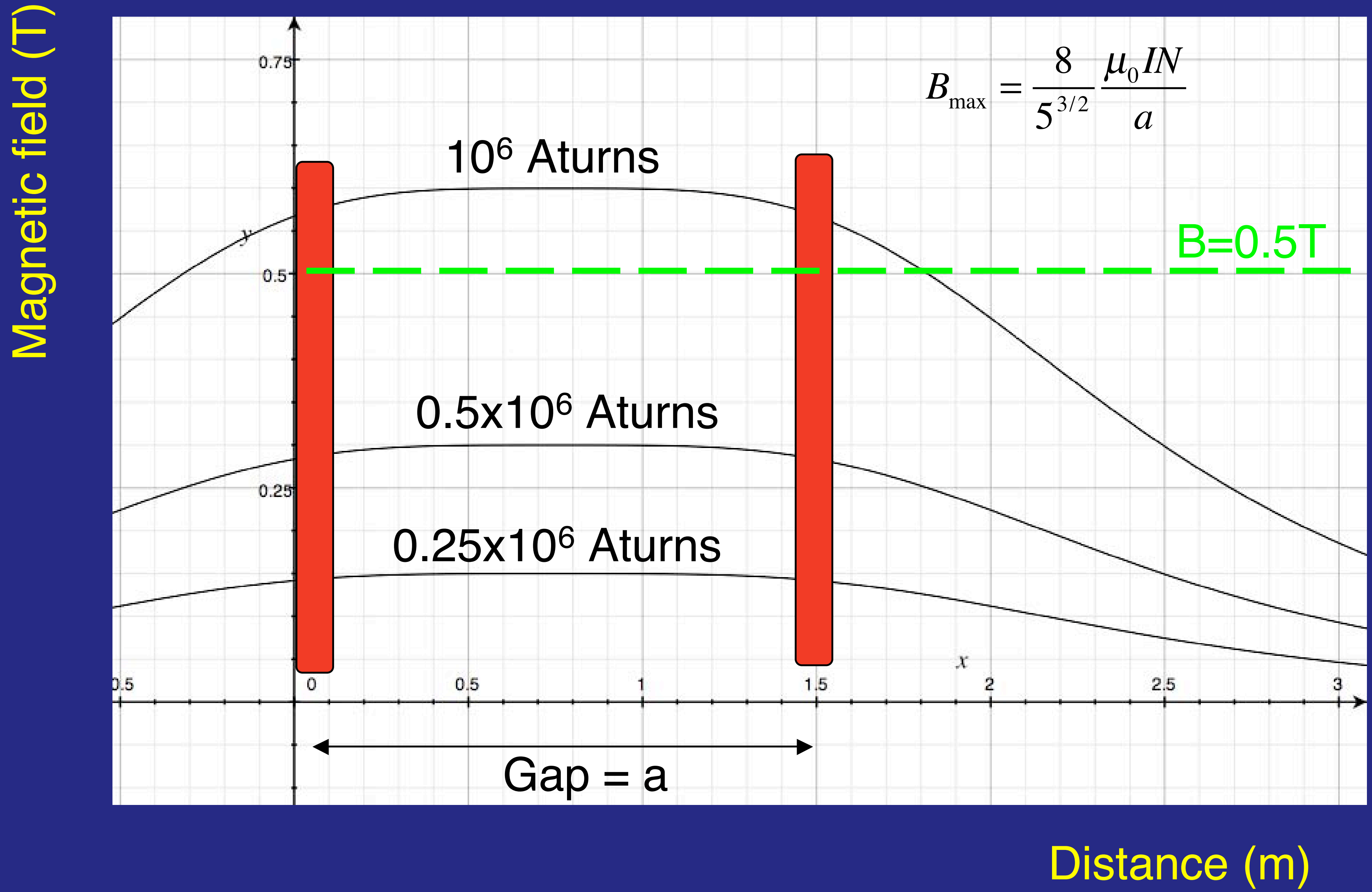
Charge separation as function of track length



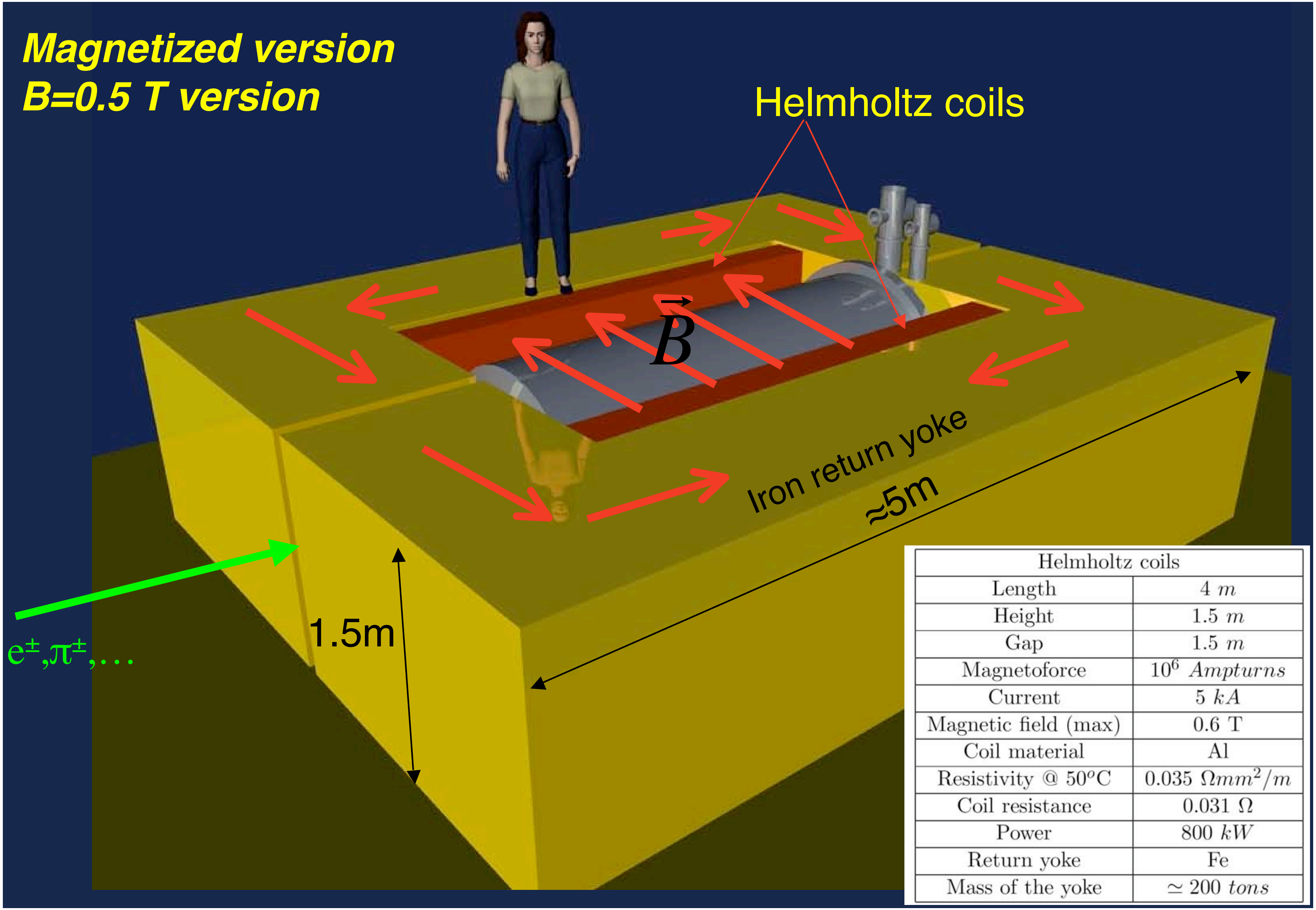
Expected transverse momentum resolution



Magnetic field with Helmholtz coils



Magnetized version
B=0.5 T version



Helmholtz coils	
Length	4 m
Height	1.5 m
Gap	1.5 m
Magnetoforce	10^6 $Ampturns$
Current	5 kA
Magnetic field (max)	0.6 T
Coil material	Al
Resistivity @ 50^{o}C	0.035 $\Omega mm^2/m$
Coil resistance	0.031 Ω
Power	800 kW
Return yoke	Fe
Mass of the yoke	$\simeq$ 200 $tons$

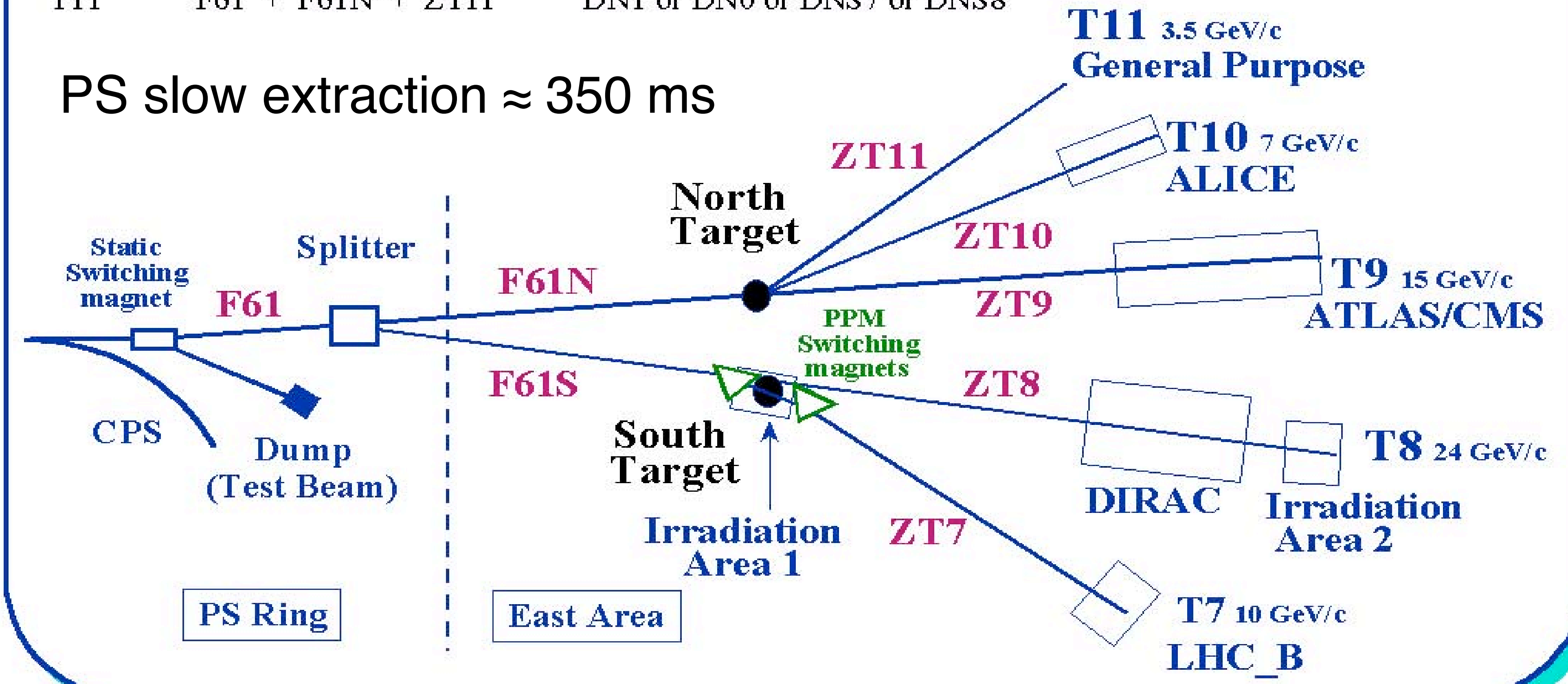
East Area - Schematics of Beam Lines

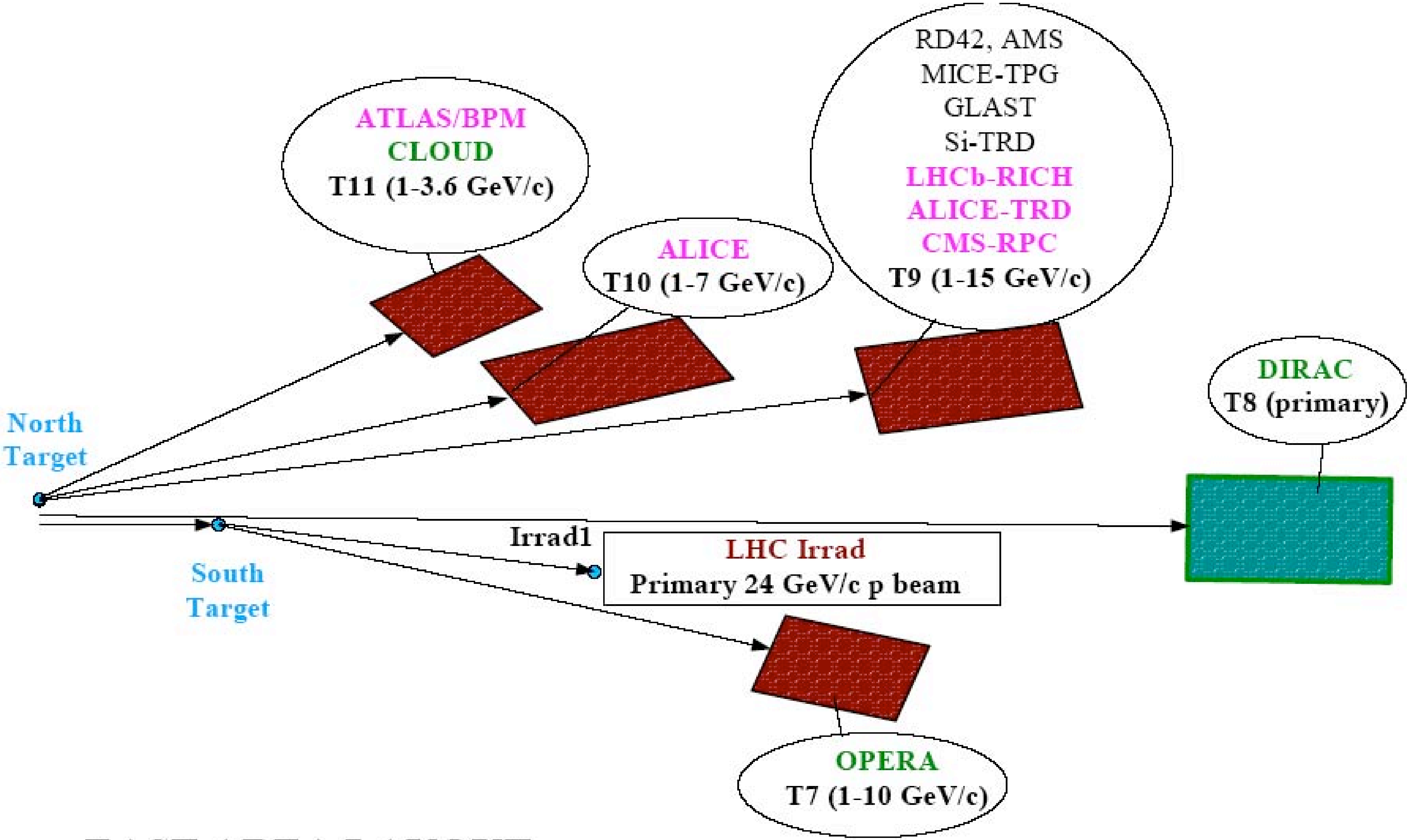
Beam Line	Beam transport involved	PS "Destinations" on which beam is provided
T7	F61 + F61S + ZT7	DS7 or DNS7
T8	F61 + F61S + ZT8	DS8 or DNS8
T9	F61 + F61N + ZT9	DN1 or DN0 or DNS7 or DNS8
T10	F61 + F61N + ZT10	DN1 or DN0 or DNS7 or DNS8
T11	F61 + F61N + ZT11	DN1 or DN0 or DNS7 or DNS8

Key for "Destination"

S : South only
N : North only
NS : Sharing North/South

PS slow extraction ≈ 350 ms





EAST AREA LAYOUT

(2006 Situation)

Need very low intensity ≈ 1000 /spill

Particle intensities

2x10[11] p @ 24 GeV

$$N_S = N_p \eta \Omega \Delta p Y_i e^{-L/\lambda_i}$$

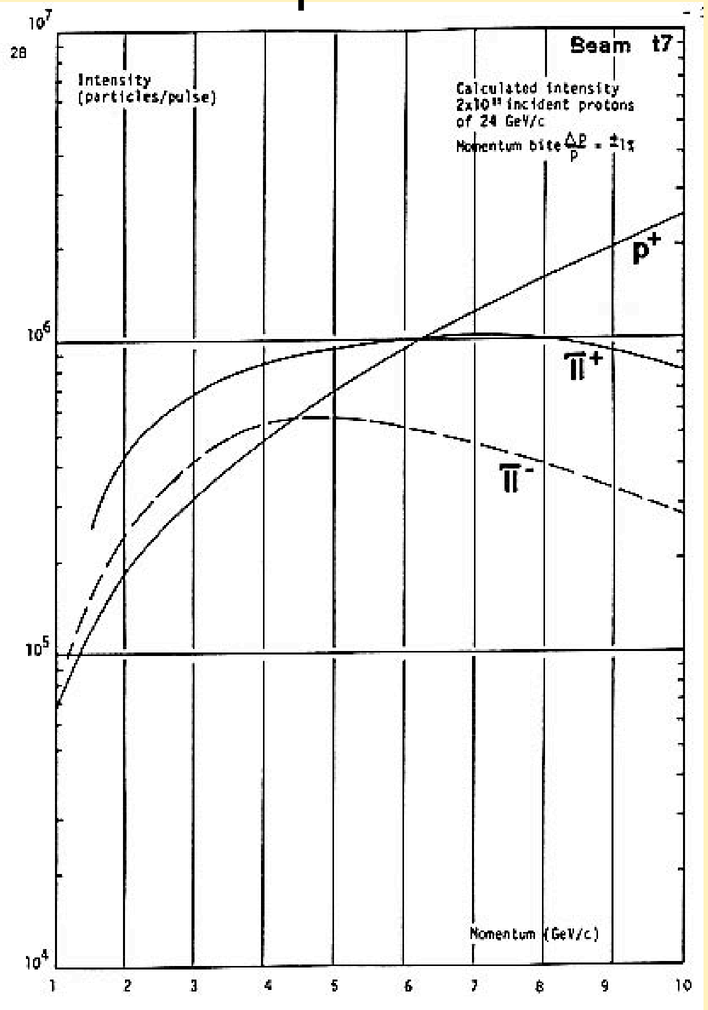


Fig. 13 Calculated intensity at the reference focus of t7.

Negative focus

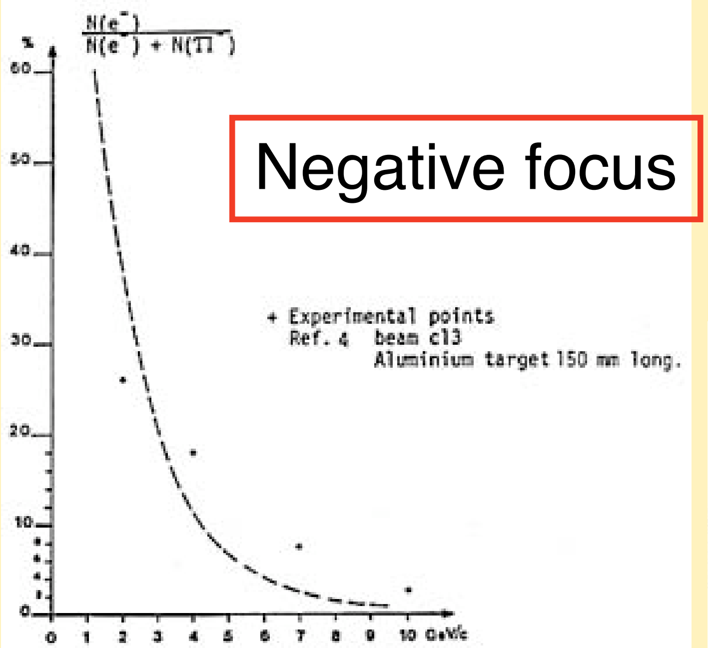


Fig 4.
Percentage of e⁻ in a negative beam calculated in Ref. 5 (zero degree production angle).

Positive focus

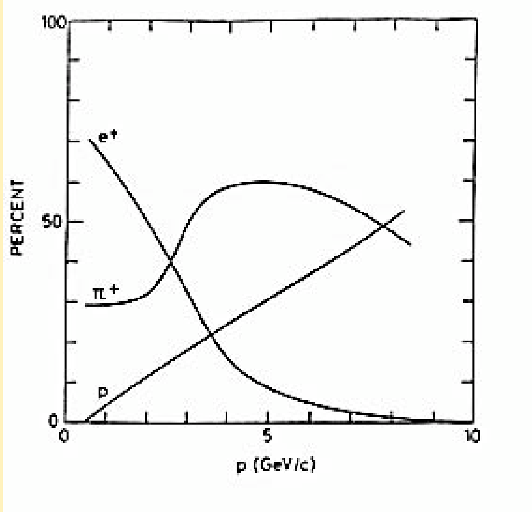


Fig. 14 Relative distribution of protons, pions and positrons in the t7-beam, as measured by PS188 (Ref. 6,7)

Need to talk to L. Gatignon to reach low intensities ≈ 1e3/spill

4 Year R&D Plan
(very preliminary estimated manpower and funding requests)

Bid request in kEuros

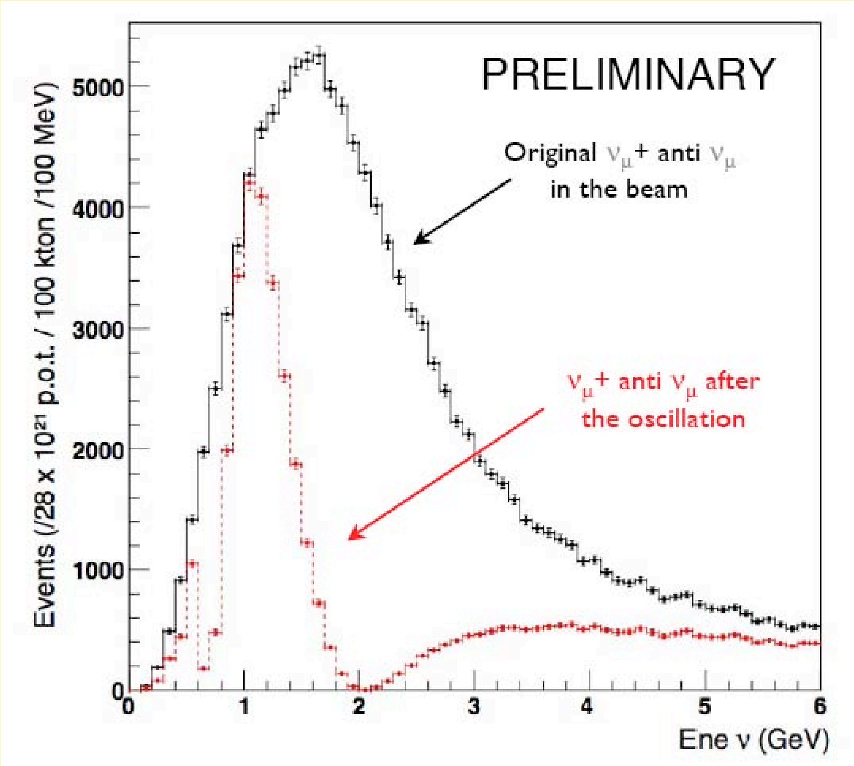
	2007	2008	2009	2010	Total (kEuro)
Liquid Argon Detectors	1105	830	280	280	2495
Equipment					1375
Inner detector	200	150	0	0	350
Readout electronics	75	100		0	175
Cooling + recirculation	150	100	0	0	250
Magnet	400	200			600
Manpower	280	280	280	280	1120
Students	2	2	2	2	
Postdoc	1	1	1	1	
Engineer	1	1	1	1	

Software & physics

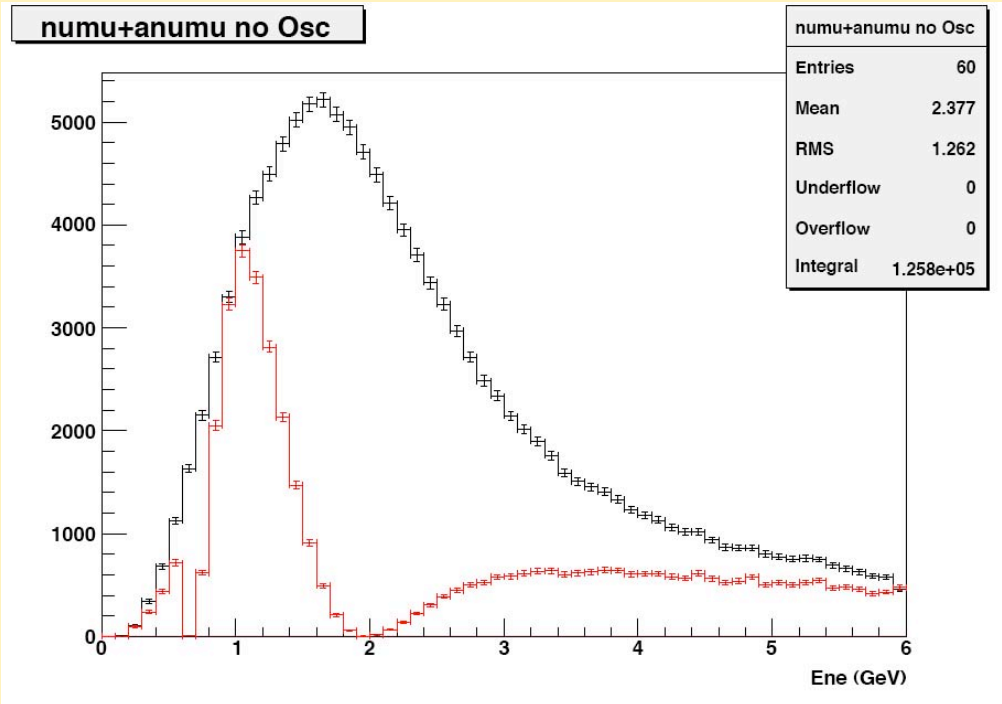
Liquid Argon in GLOBES (work in progress)

- Effort by K. Satalecka, A. Zalewska, A. Meregaglia, A. Rubbia
- Reproduce T2K-Korea results presented at 1st Workshop in Nov05
  - ➥ Fluxes, normalizations, …
  - ➥ ≈20% differences due to cross-sections, otherwise the same

Private code



GLOBES 2006

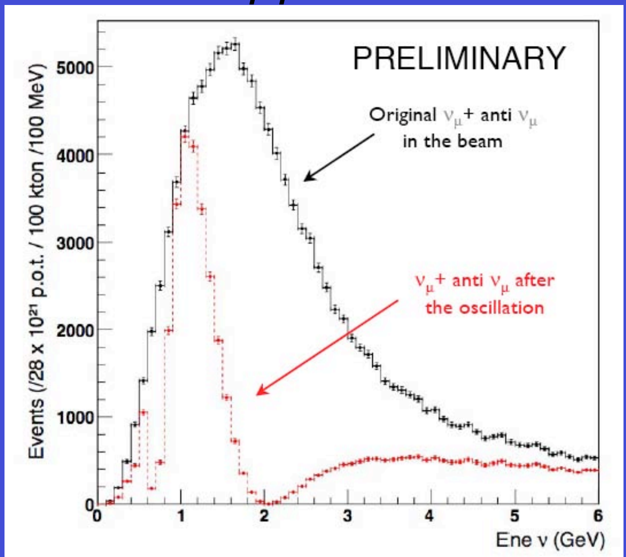


Overview physics reach

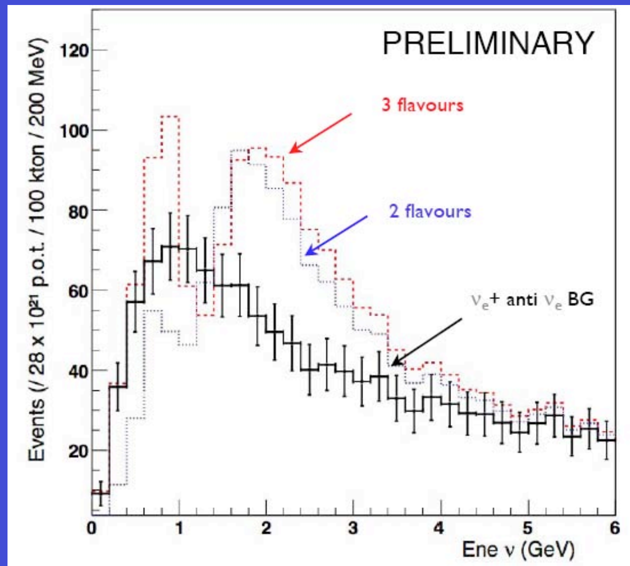
A.R., Workshop on a Far Detector in Korea for the J-PARC Neutrino Beam, Nov 2005, Seoul, Korea

- 28e+21 p.o.t. , 100 kton LAr detector at 1000 km. Beam OA 0.5 degrees.
- $(\sin^2(\theta_{23}) = 0.5$, $\sin^2(2\theta_{13}) = 0.01$, $\Delta m^2_{23} = +2.5e\text{-}3$ eV2, $\tan 2(\theta_{12}) = 0.45$, $\Delta m^2_{21} = +7e\text{-}5\ eV^2$, $\delta = 0)$

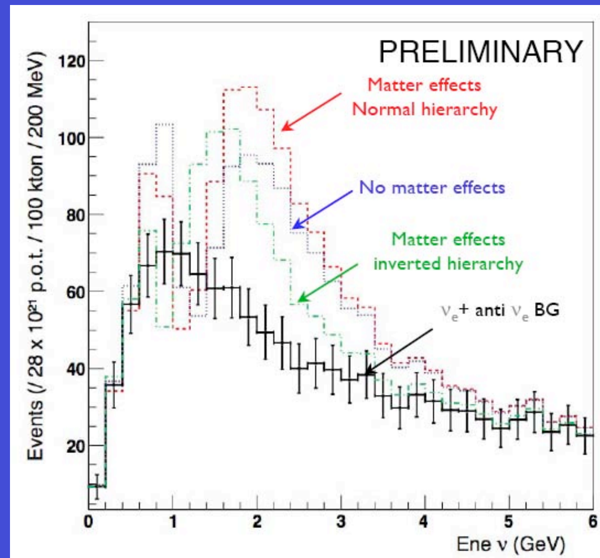
Disappearance

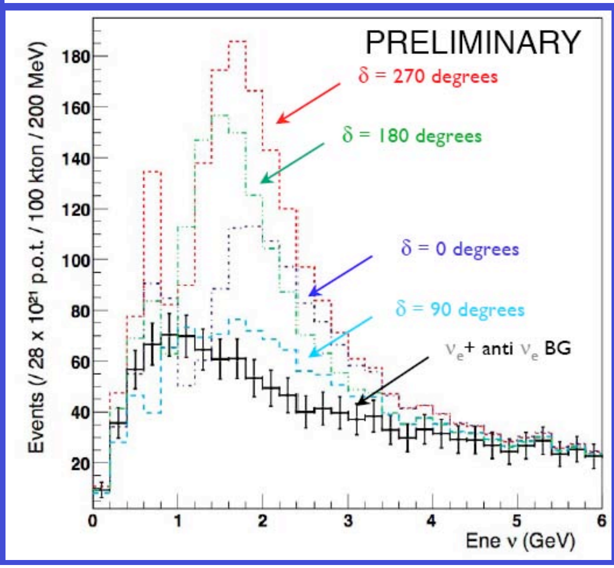


Appearance - solar terms



Appearance - matter eff.





After 4 years, J2K would have the statistical power to

- ✓Search for $\sin^2 2\theta_{13} < O(0.001)$ @ 90 C.L.
- ✓Study matter effects (determine mass hierarchy)
- ✓Look for non-vanishing δ-phase (for $\sin^2 2\theta_{13} \approx 0.01$)

***Next workshop**: July 2006 (after T2K general meeting)*

Appearance - CP phase

Outlook

- We continue with our R&D program, necessary to extrapolate liquid Argon TPC concept to O(100 kton) detectors. The state of the art of our conceptual design has been presented. It relies on
  - ➥ (a) industrial tankers developed by the petrochemical industry (no R&D required, readily available, safe) and their extrapolation to underground LAr storage. At this stage we do not see an extended physics program in a potential surface operation.
  - ➥ (b) improved detector performance for very long drift paths w e.g. LEM readout
  - ➥ (c) new solutions for drift very HV
  - ➥ (d) a modularity at the level of 100 kton (limited by cavern size)
  - ➥ (e) the possibility to embed the LAr in B-field (conceptually proven). Magnetic field strength to be determined by physics requirements.

- We presented the possibility to perform a dedicated test beam to study clean samples of electrons and π^0's.

- On the medium-term, a coordinated T2K-LAr effort will be fundamental for the understanding of neutrino interactions on Argon (and possibly water) target and will represent an important and very high statistics milestone for the liquid Argon technology.