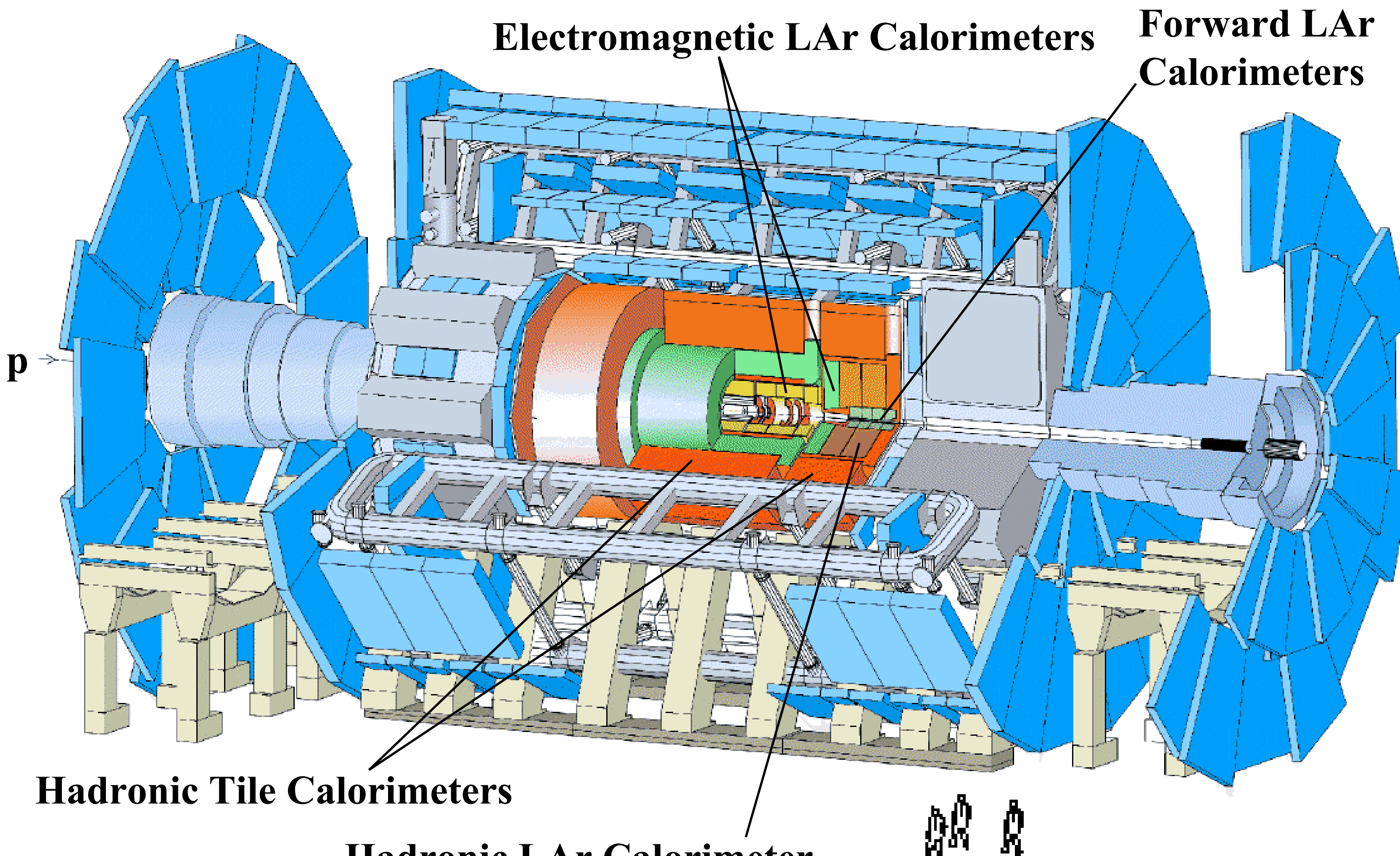
An Overview of the ATLAS Liquid Argon Calorimetry

VII International Conference on
Calorimetry
in High Energy Physics

November 9-14
University of Arizona
Tucson, Arizona

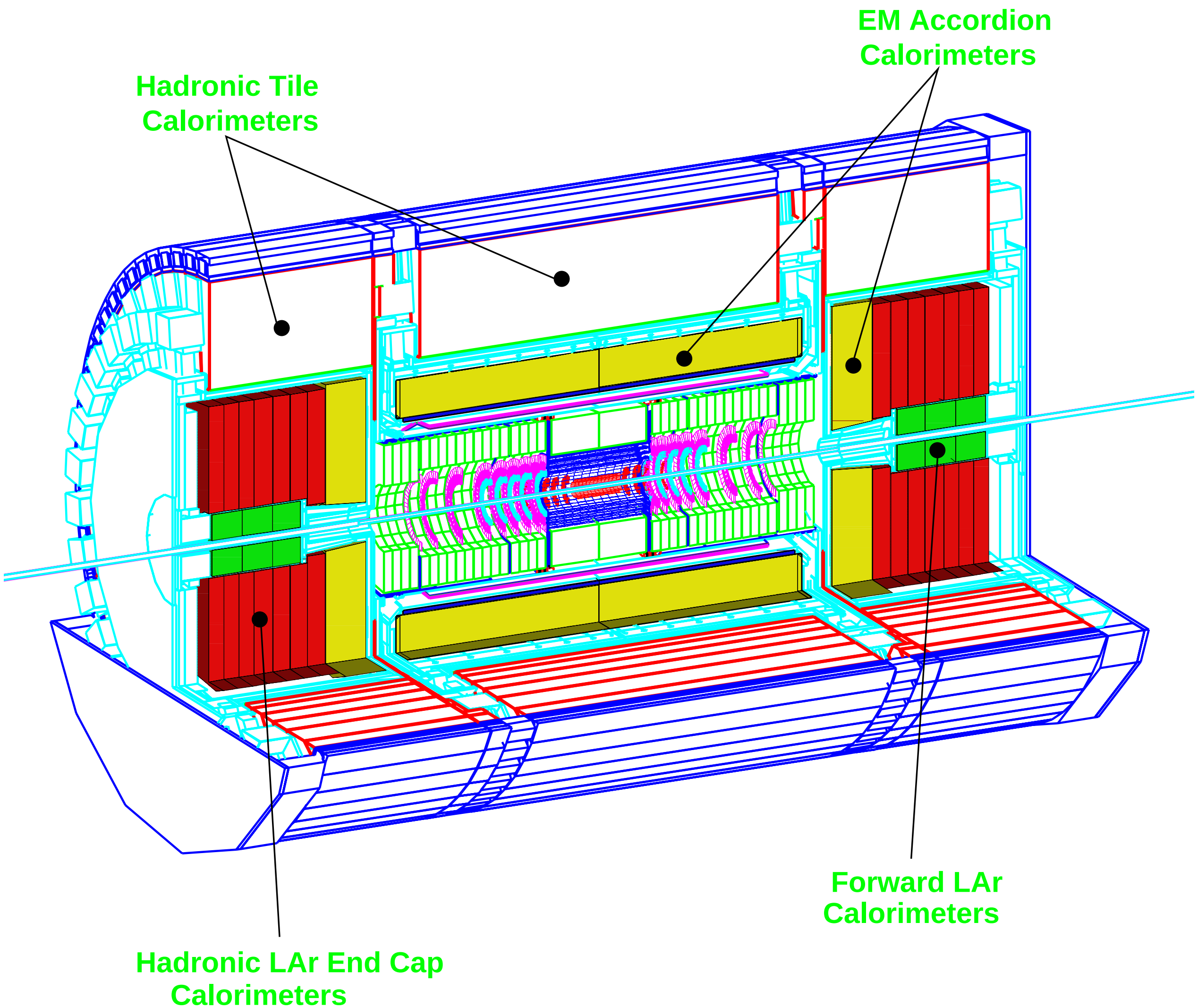
Michel Lefebvre
University of Victoria
British Columbia, Canada

The ATLAS Detector



ATLAS Calorimetry

Liquid argon calorimetry for R<2m, divided into 3 cryostats



ATLAS Liquid Argon Calorimetry

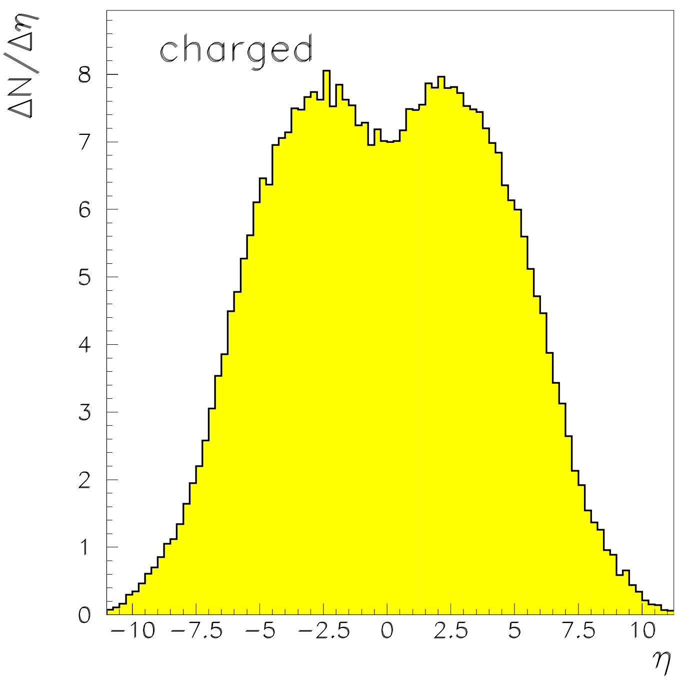
- **Azerbadjan Republic:** **Baku**
- **Brazil:** **Sao Paulo**
- **Canada:** **Alberta, British Columbia, Carleton, Montreal, Toronto, TRIUMF, Victoria**
- **CERN**
- **France:** **Annecy, Grenoble, Marseille, Orsay, Paris 6/7, CEA Saclay**
- **Germany:** **Heidelberg, Mainz, MPI, Wuppertal**
- **Italy:** **Milano**
- **Kazakhstan:** **Almaty**
- **Morocco:** **Rabat**
- **Russia:** **ITEP, Lebedev, Novosibirsk, Protvino**
- **JINR:** **Dubna**
- **Slovak Republic:** **Kosice**
- **Spain:** **Madrid**
- **Sweden:** **KTH Stockholm**
- **United States of America:** **Arizona, BNL, Nevis, Pittsburgh, Rochester, Dallas**

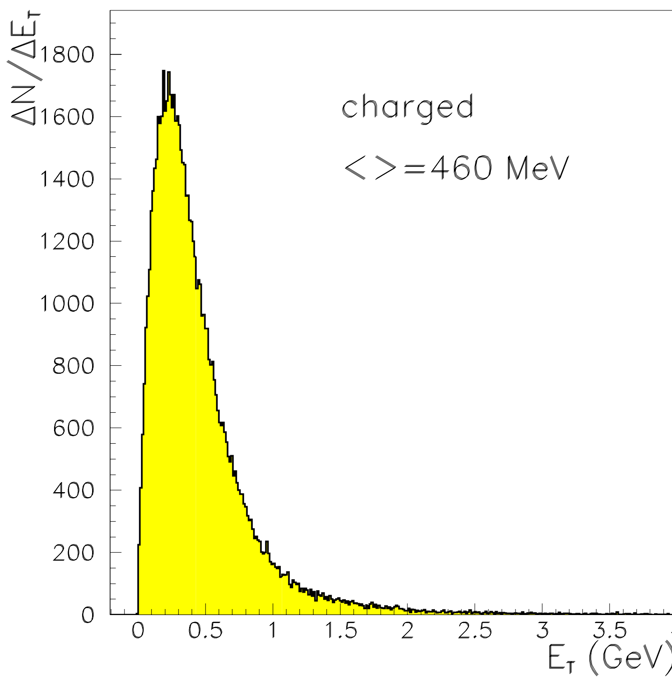
37 Institutions, 426 scientists

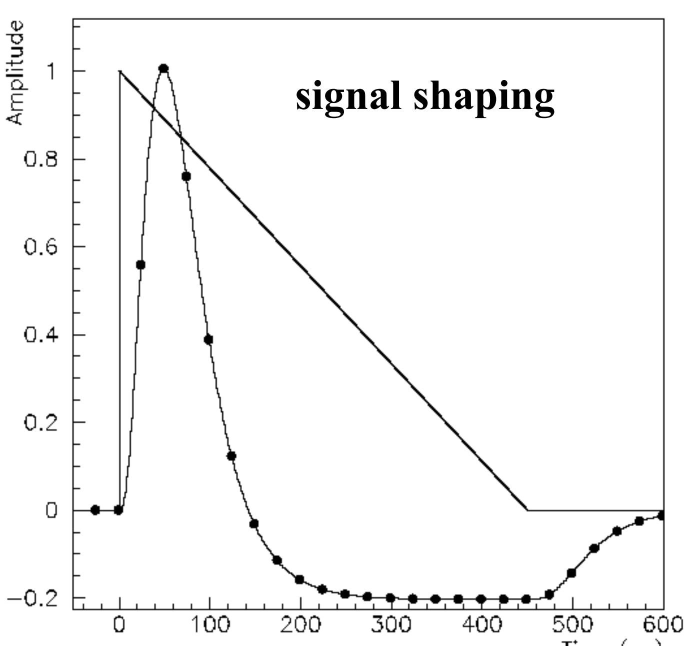
Shaping, Pileup and Electronic Noise

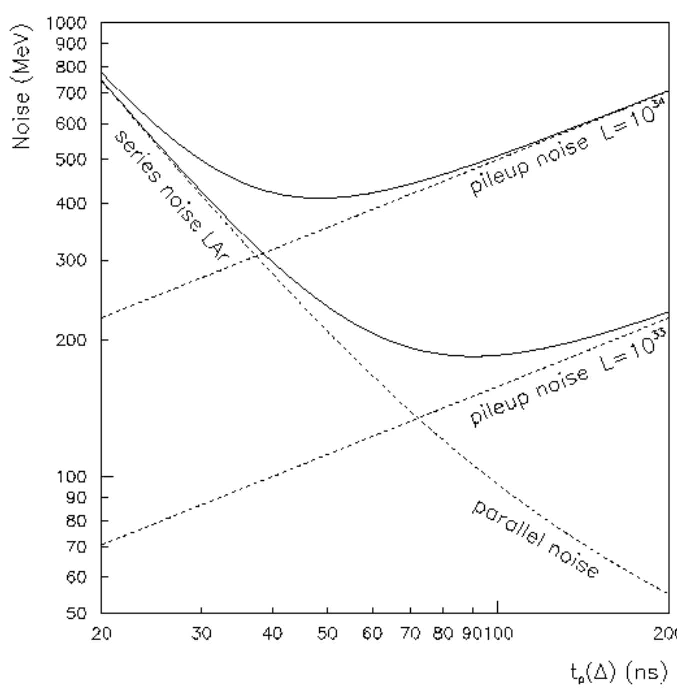
Inelastic pp cross section 70 mb
Average luminosity of 10^{34} $cm^{-2}s^{-1}$
2835 active bunches over 3564 LHC clock cycles

23 inelastic events per crossing

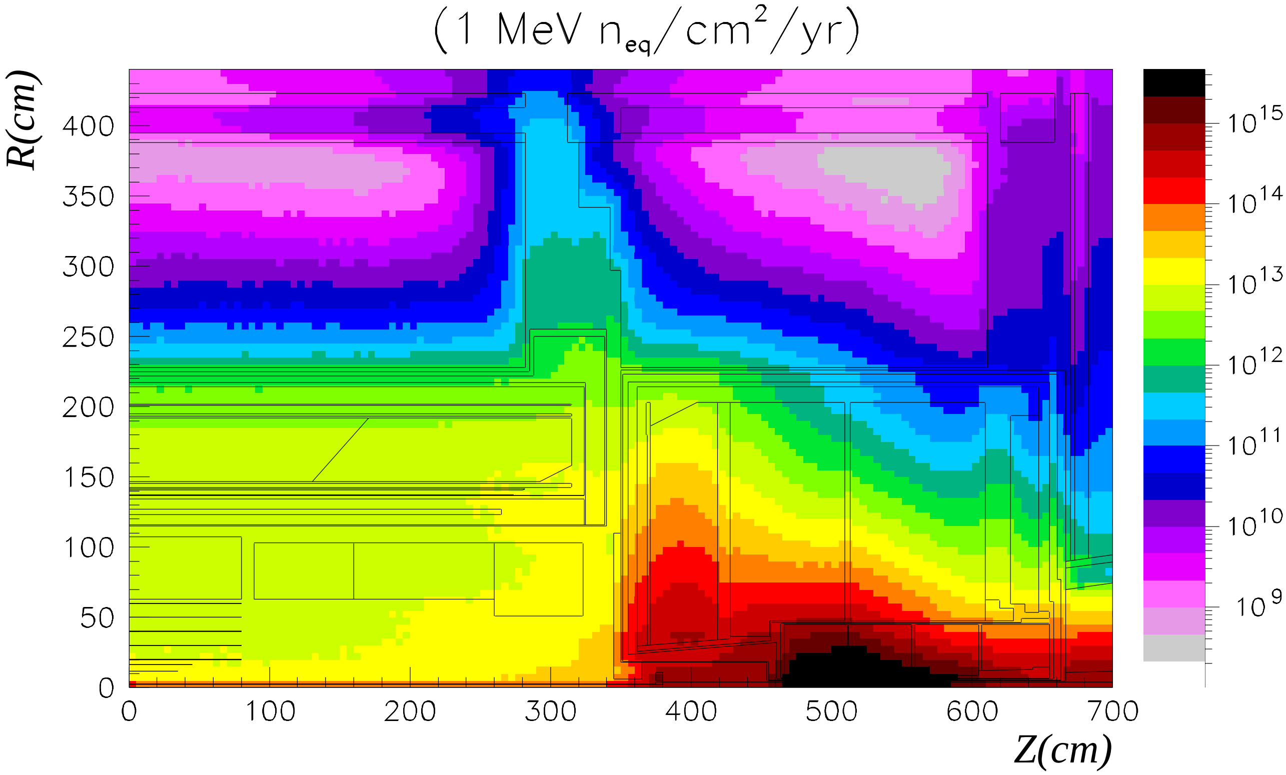




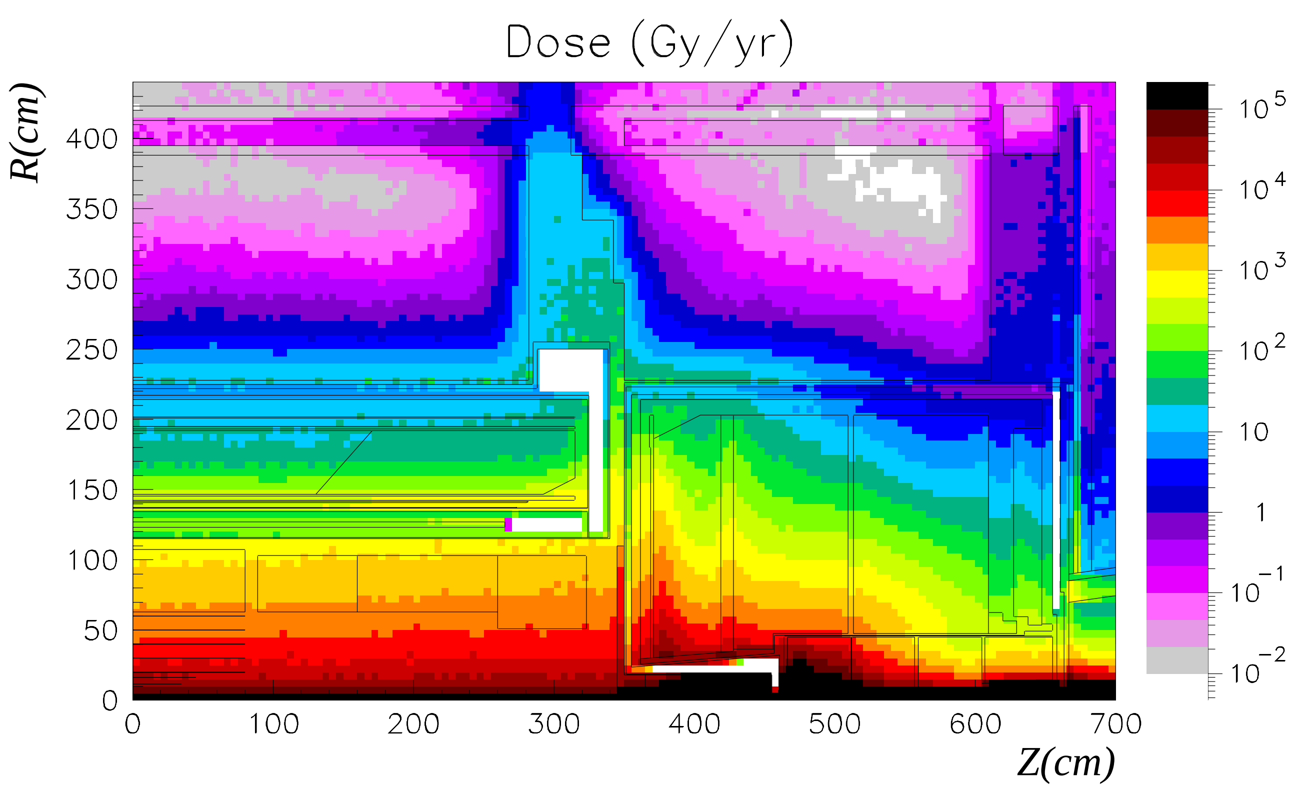




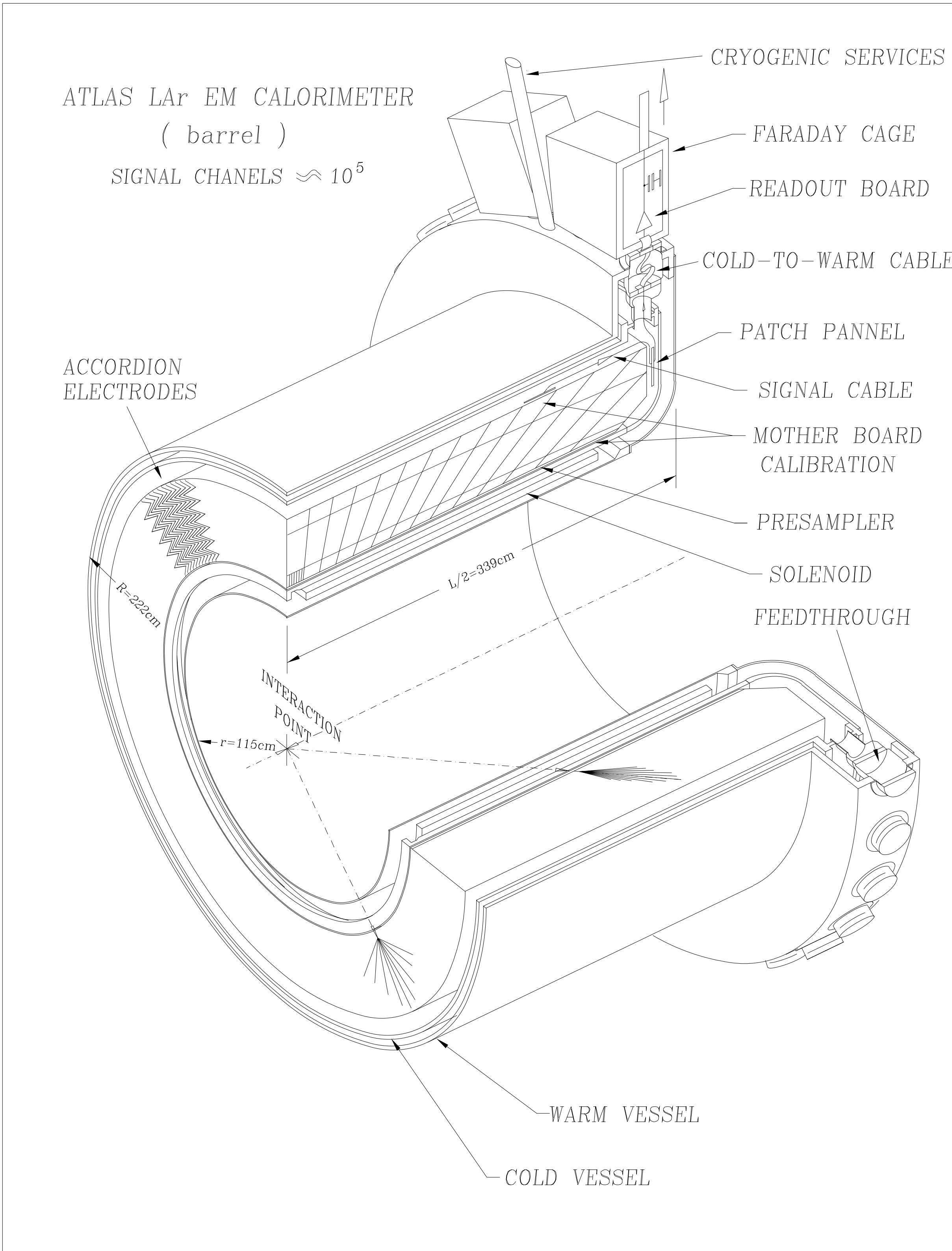
Radiation Environment



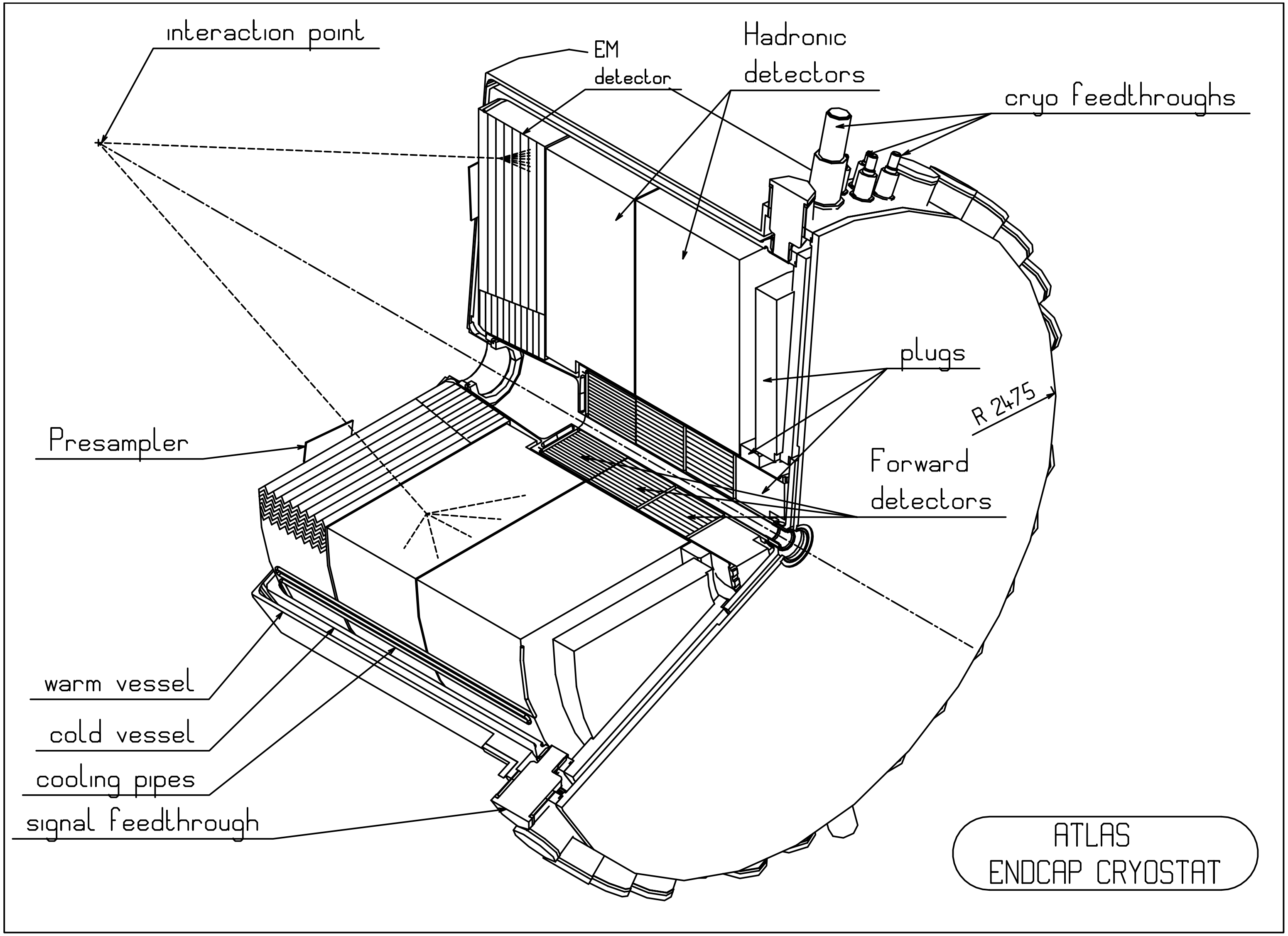
- Up to 10^{16} n/cm²/yr and $2x10^6$ Gy/y in the FCAL
- Less than 10^{12} n/cm²/yr and 20 Gy/y at the EM electronics location
- Less than $5x10^{12}$ n/cm²/yr and 50 Gy/y at the Hadronic Endcap electronics location



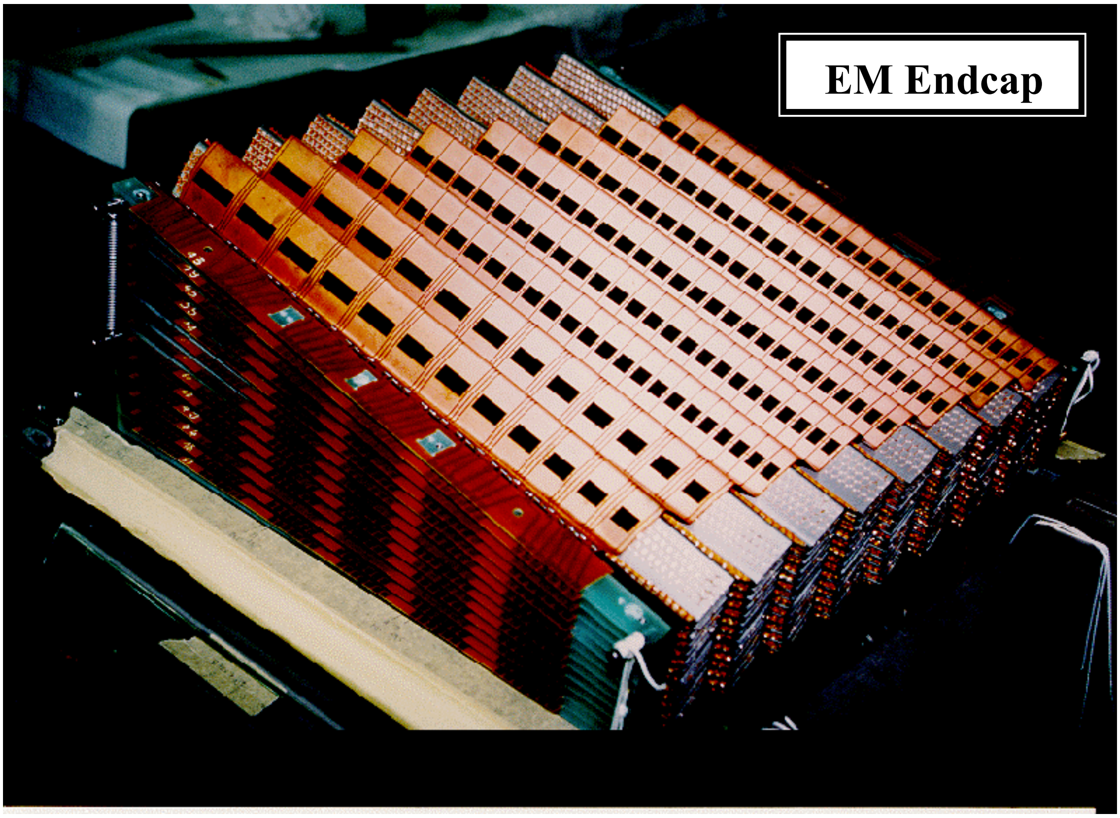
EM Barrel Calorimeter and Cryostat

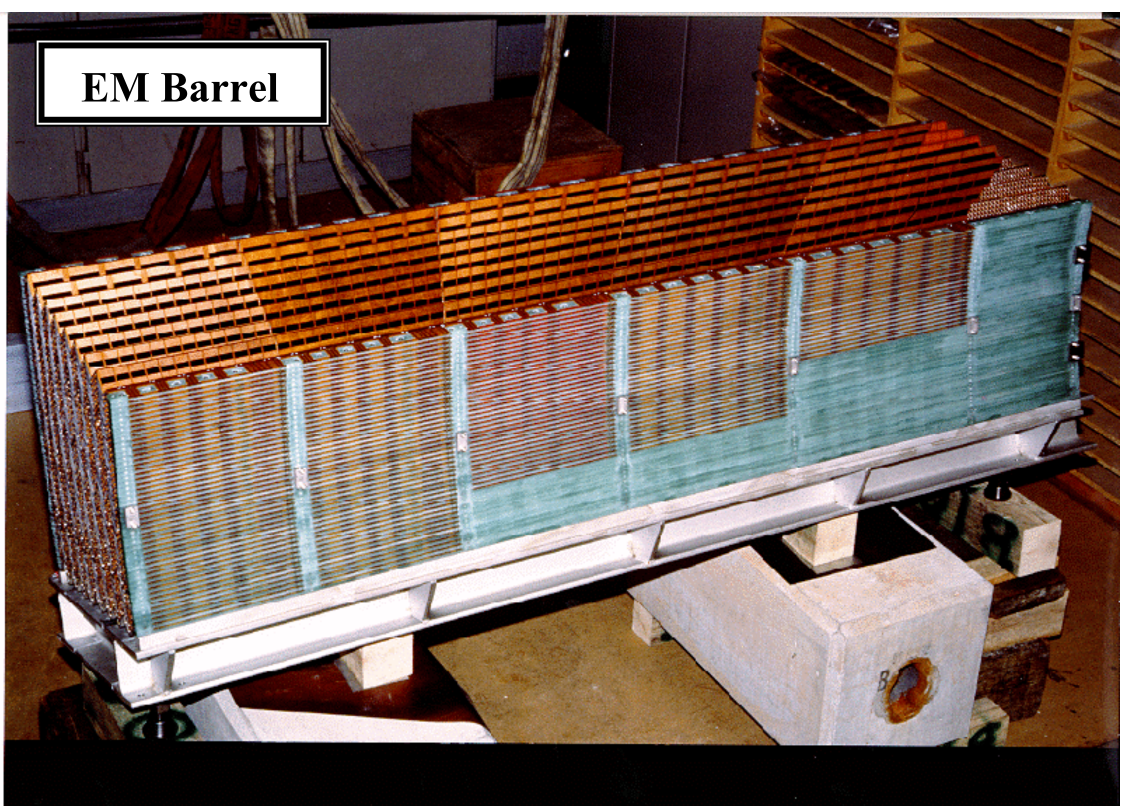


Endcap Calorimeters and Cryostat

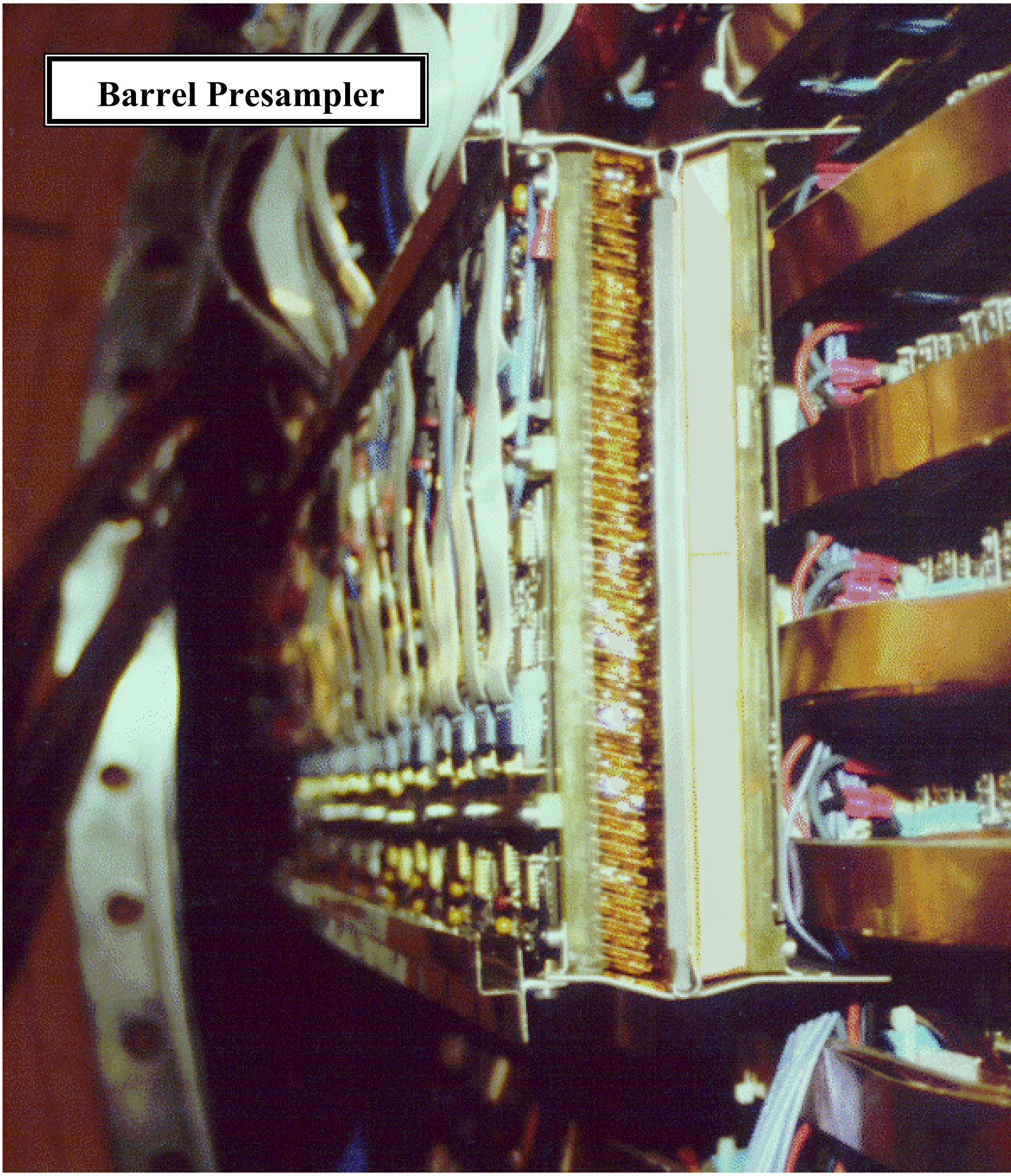


Prototypes

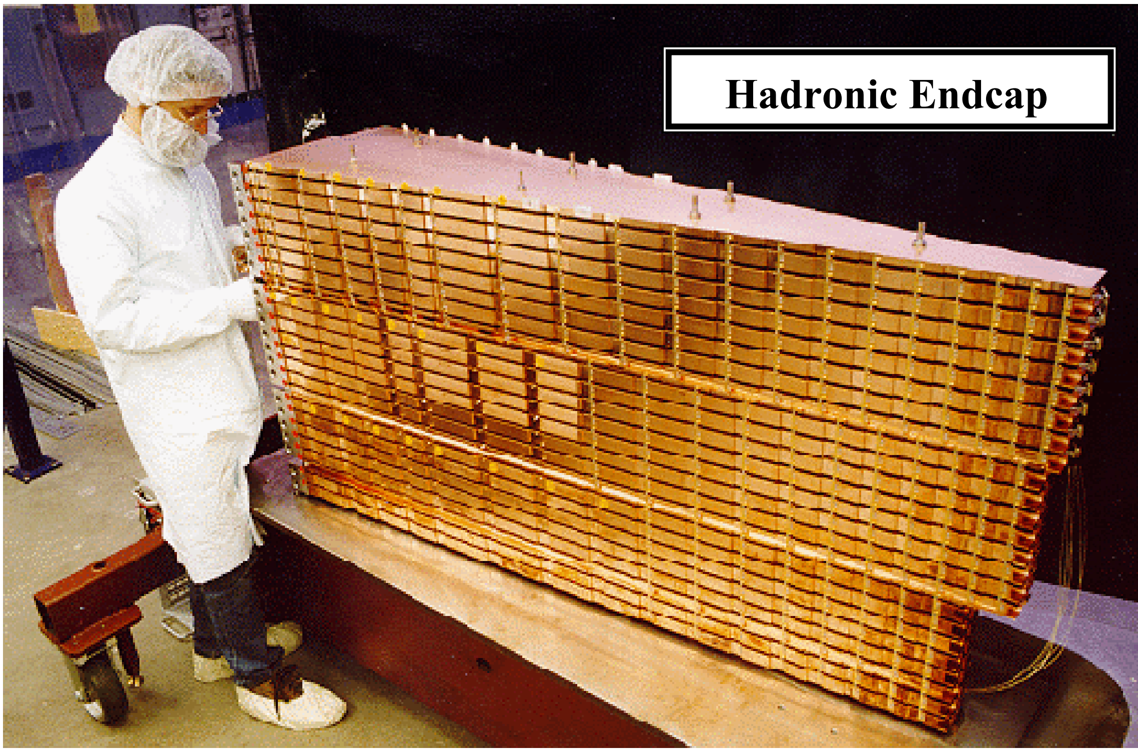


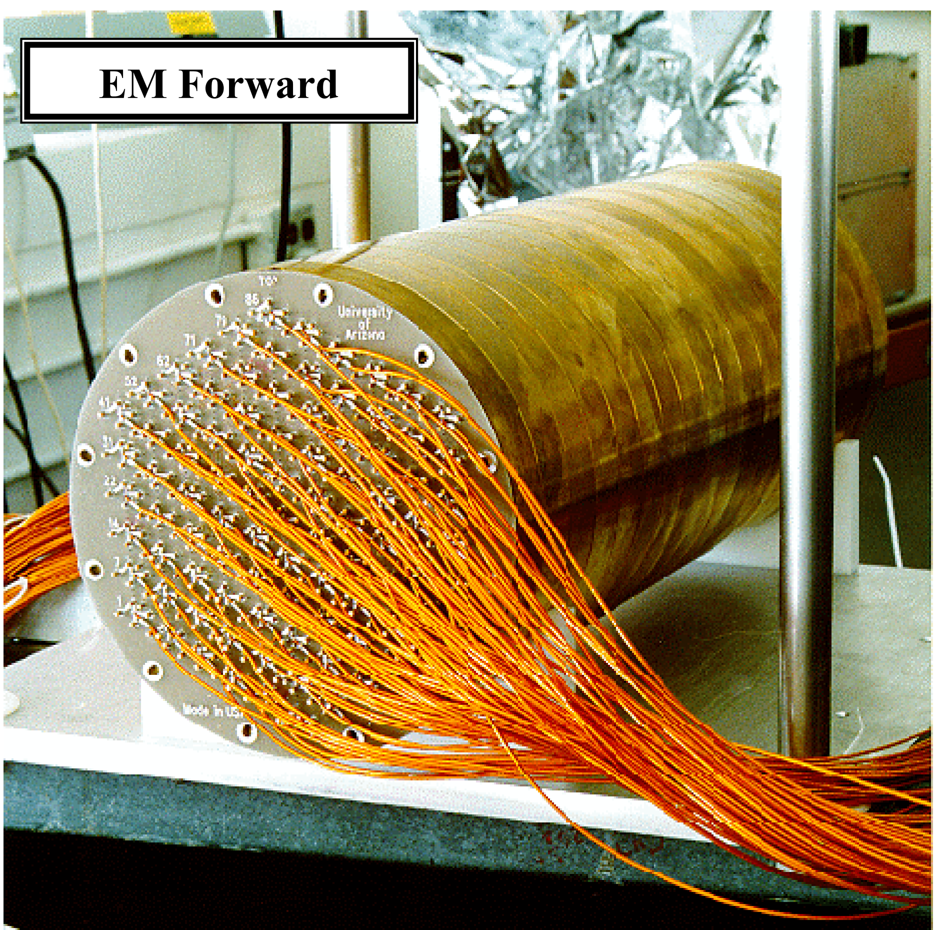


Prototypes

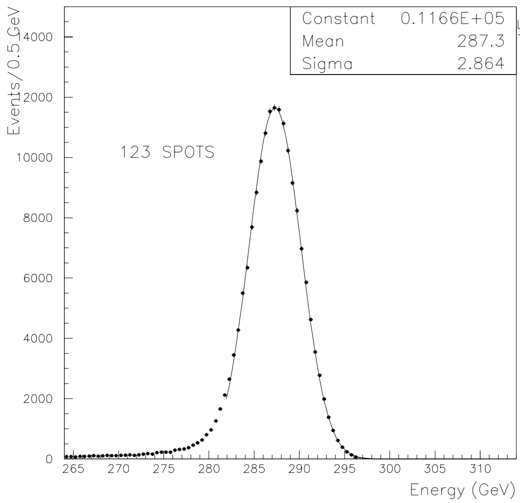


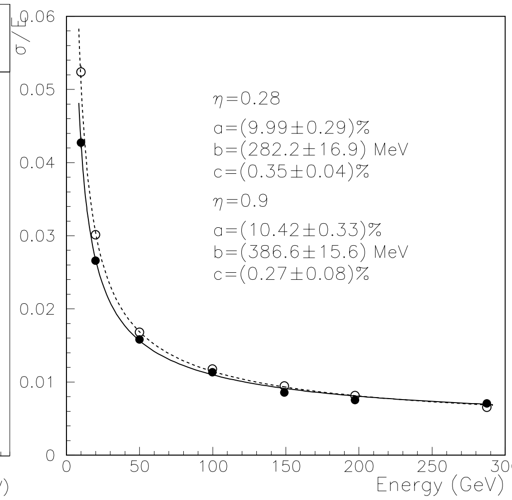
Prototypes

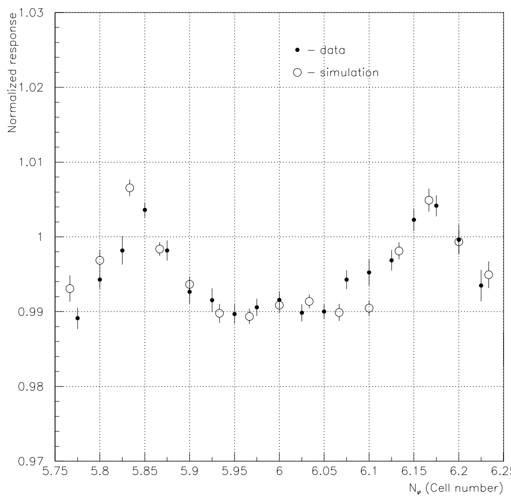

Hadronic Endcap

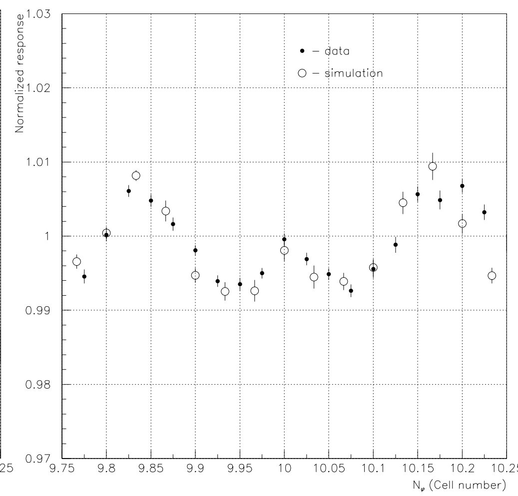

EM Forward
University of Arizona
Made in USA

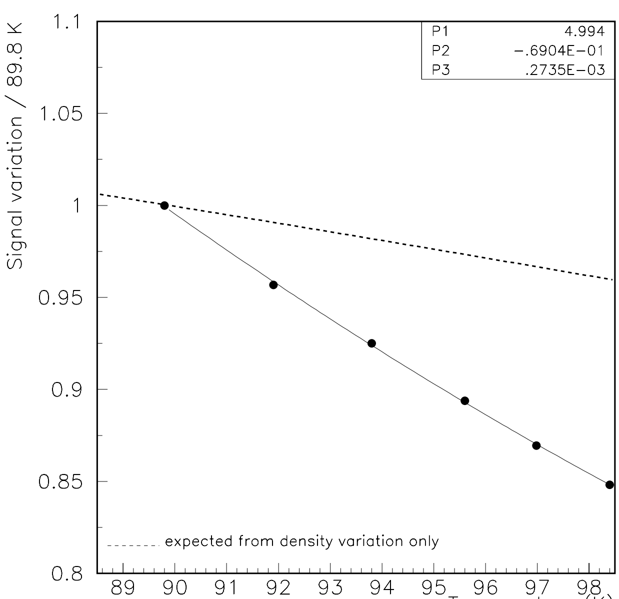
EM Calorimeter Prototypes Testbeam Results

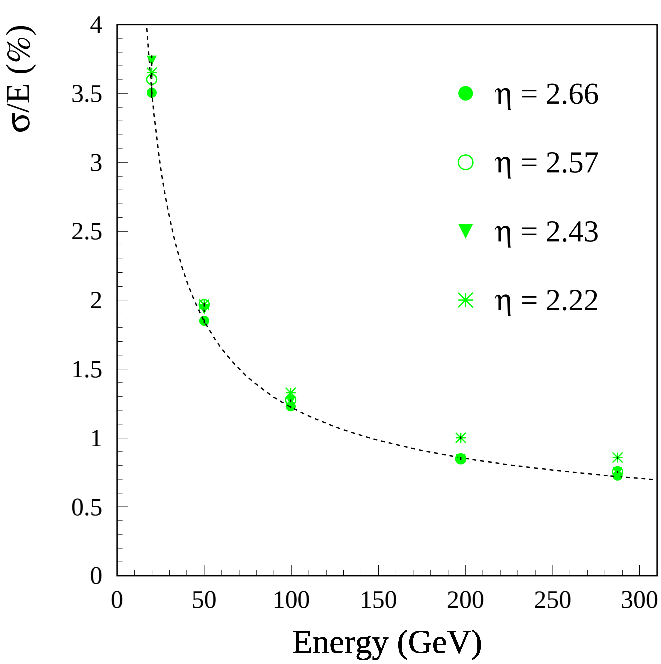






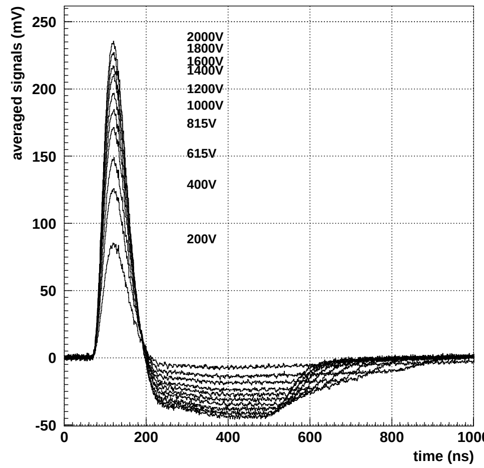


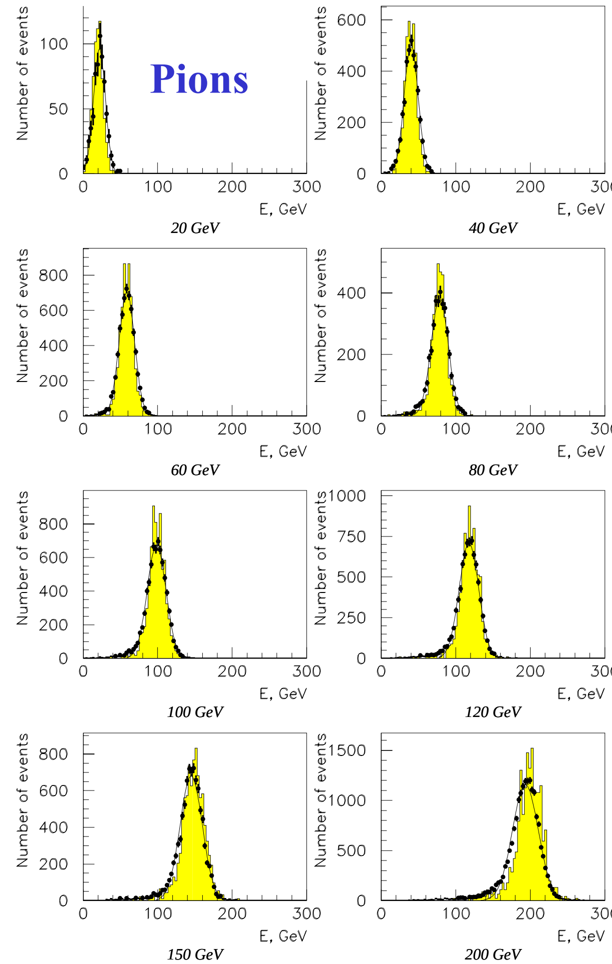




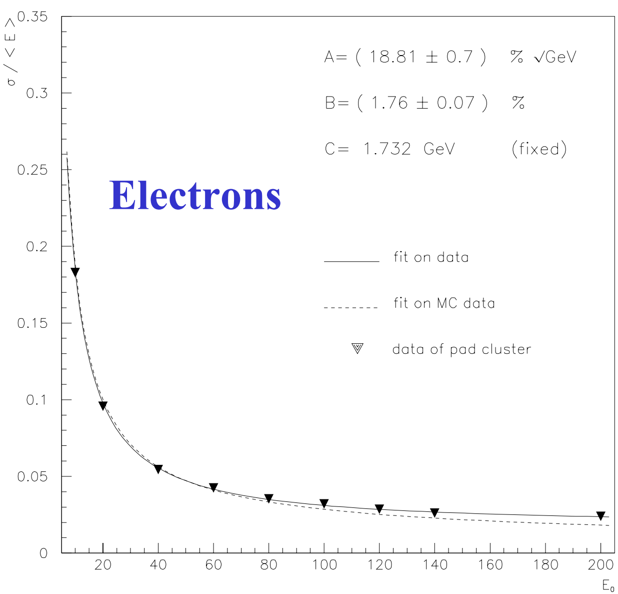
Hadronic Endcap Prototype Testbeam Results

Signal Shapes

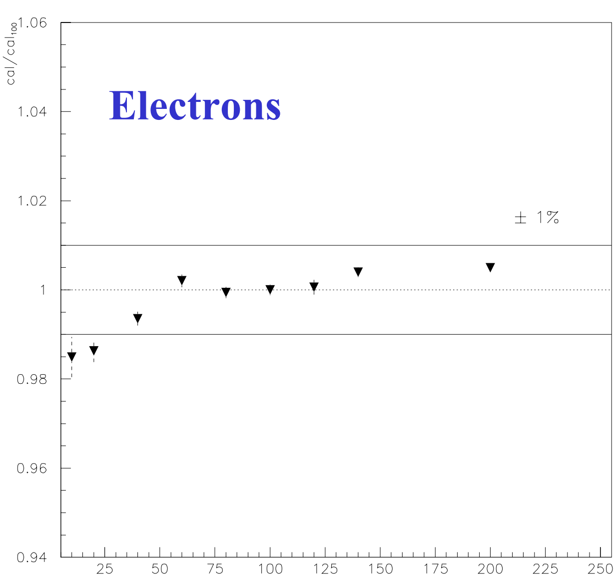


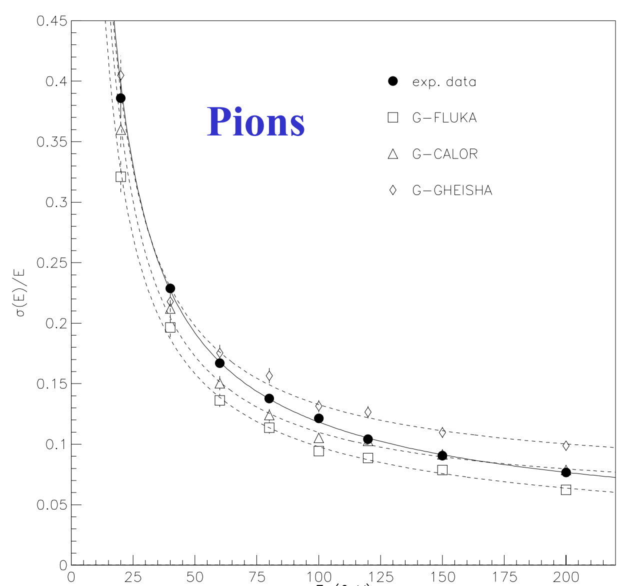


Resolution of HEC (pad cluster)



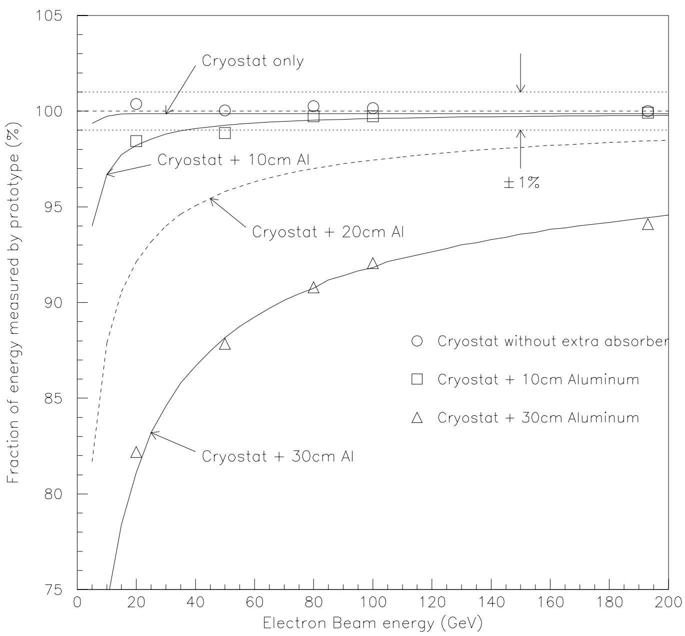
Linearity of HEC (pad cluster)



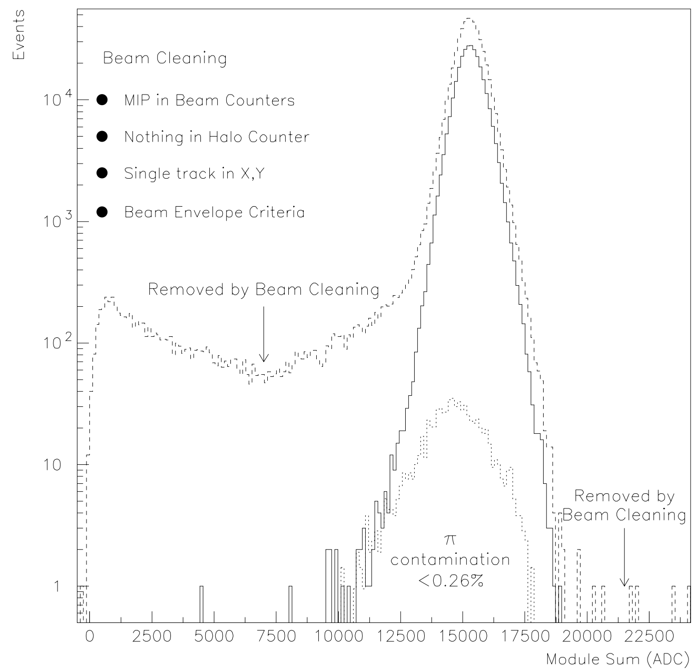


EM Forward Prototype Electron Testbeam Results

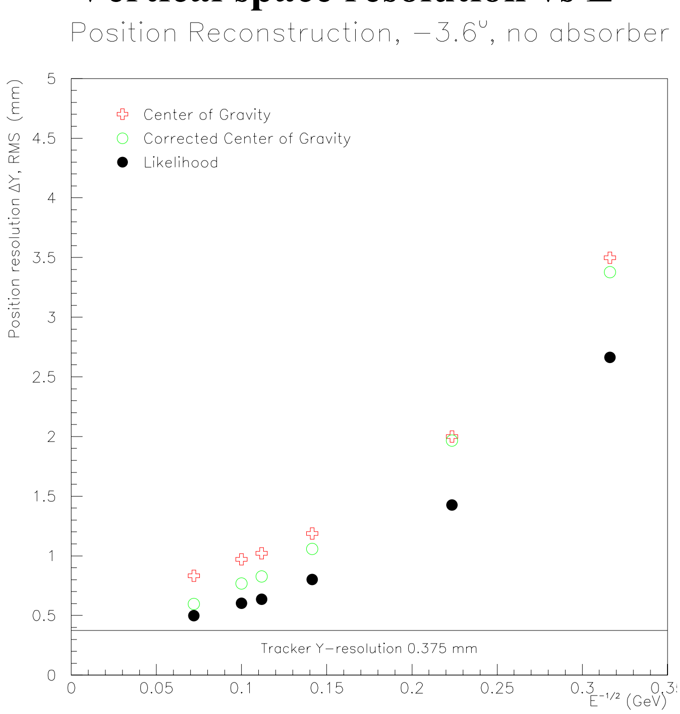
Effect of material in front of calorimeter (data and simulation)



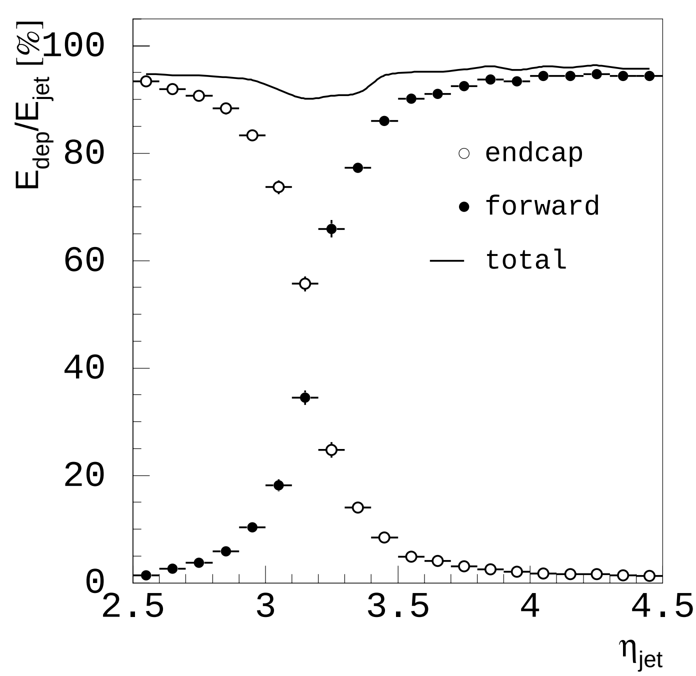
Electron resolution profile



Vertical space resolution vs $E^{-1/2}$

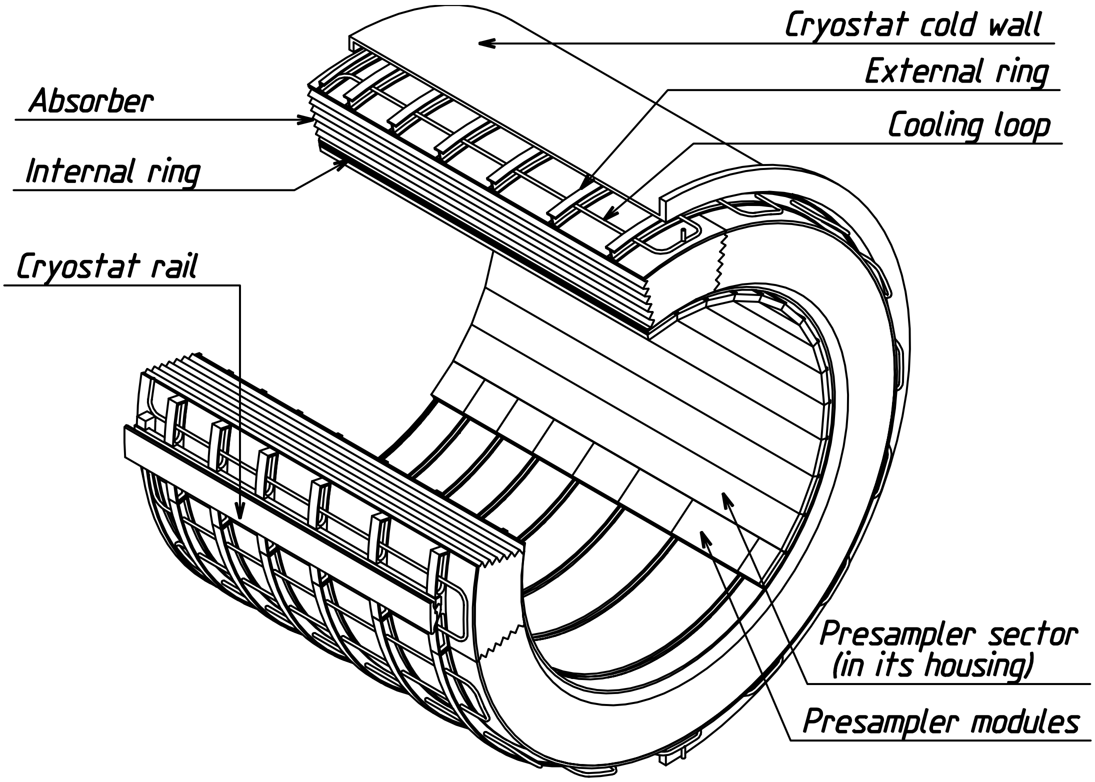


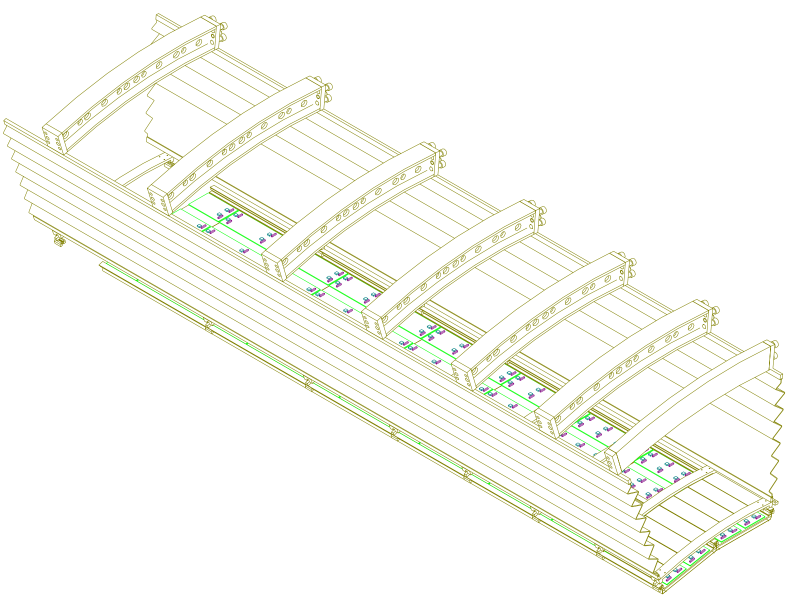
Result from simulation



Michel Lefebvre (Victoria) CALOR97 November 10-14 1997

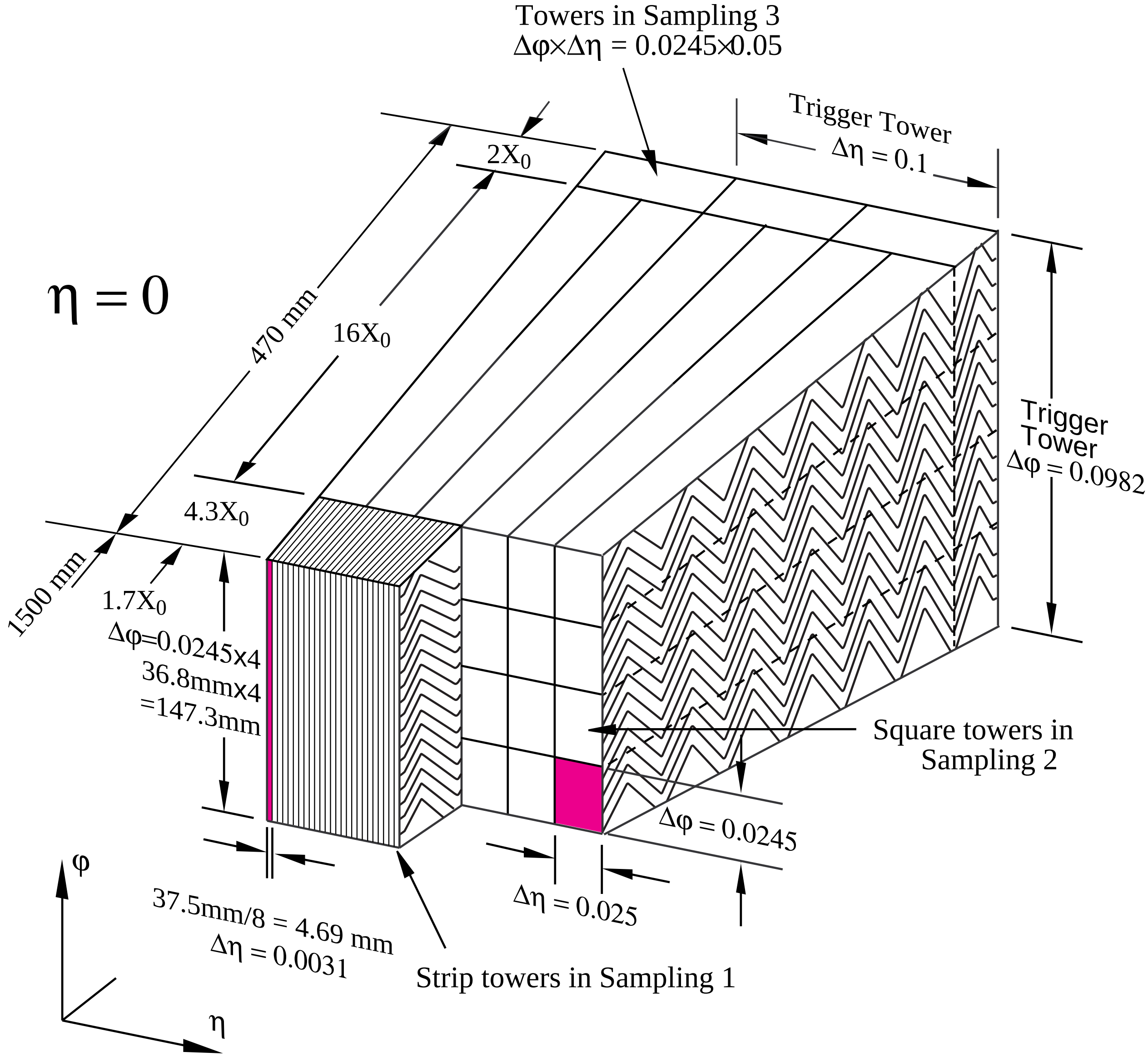
EM Barrel Calorimeter





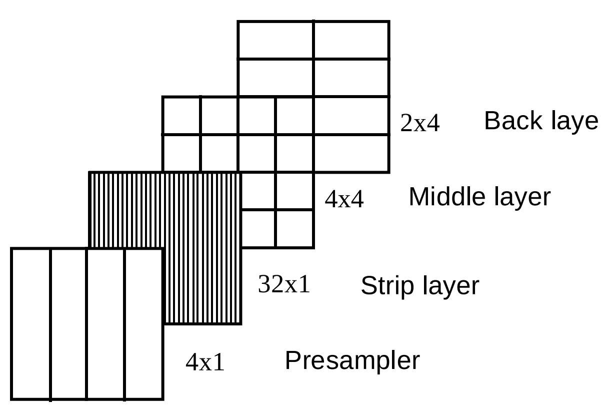
- **2 half barrels**
- **16 modules in each**
- **55 tons per half barrel**
- **Deformations < 4mm**
- **Tolerance on liquid argon gap better than 50 μm**
- **1024 absorbers per half barrel screwed onto 7 SS rings**
- **Rings placed close to every η = 0.2 to ease cabling of electronics**

EM Barrel Calorimeter Accordion Structure

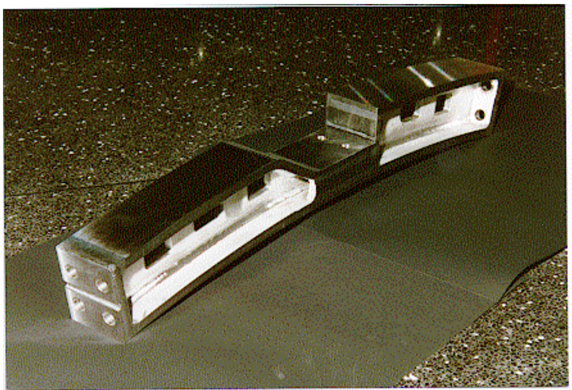


Channel count	
Presampler	**7808**
Strips	**57344**
Middle	**28672**
Back	**14336**
End	**2048**
Total	**110208**

Trigger tower ΔηxΔϕ = .1x.1



EM Barrel External Rings



Aim to get an accuracy of 0.1mm on the internal radius and 0.5mm on the external radius

Rail ring piece

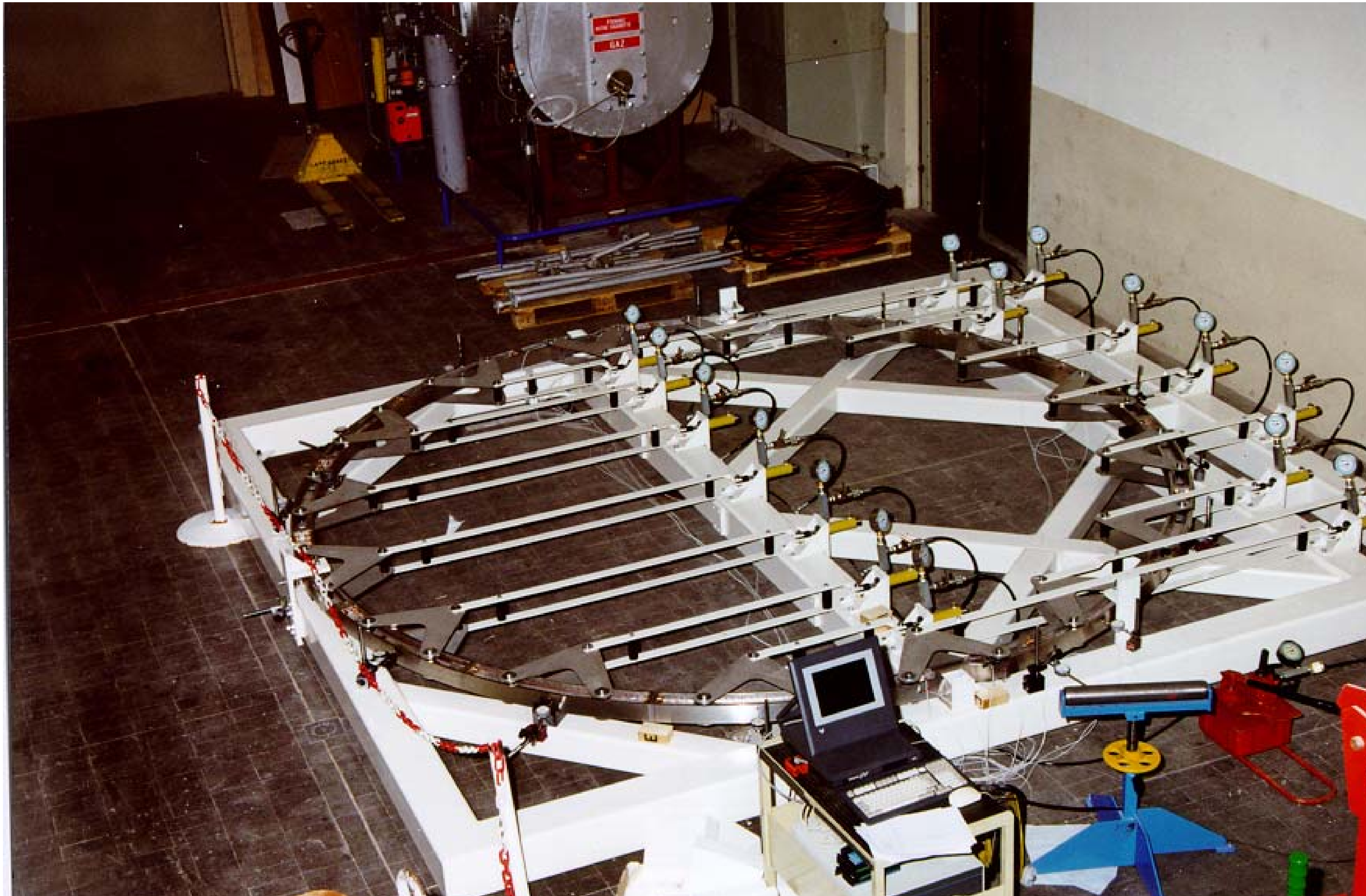
Standard ring piece

Prototype ring

EM Barrel External Rings

Measurement of radii, deformations and stresses
Deformations agree with predictions

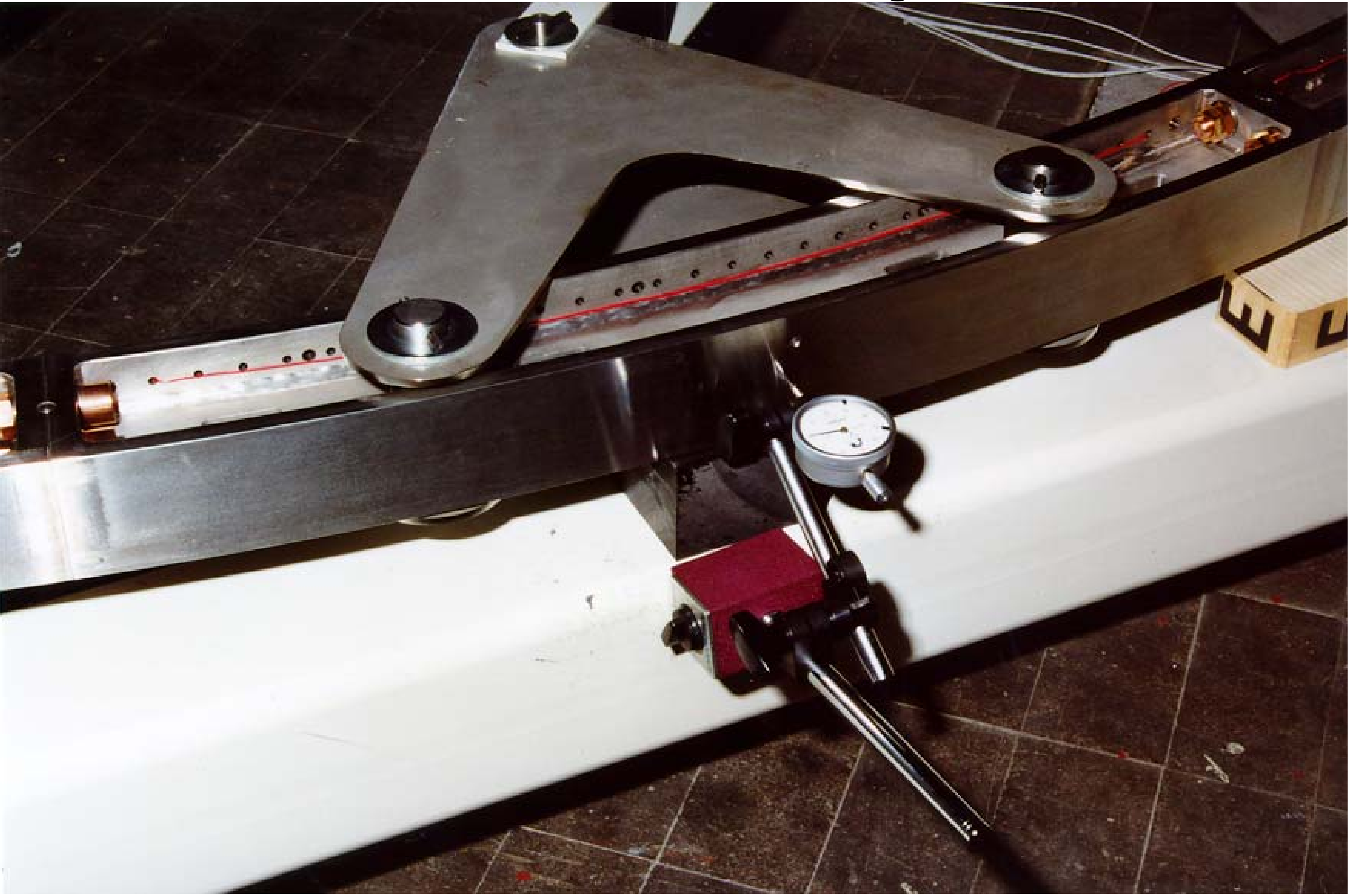
EM Barrel External Ring



EM Barrel External Ring

EM Barrel External Ring

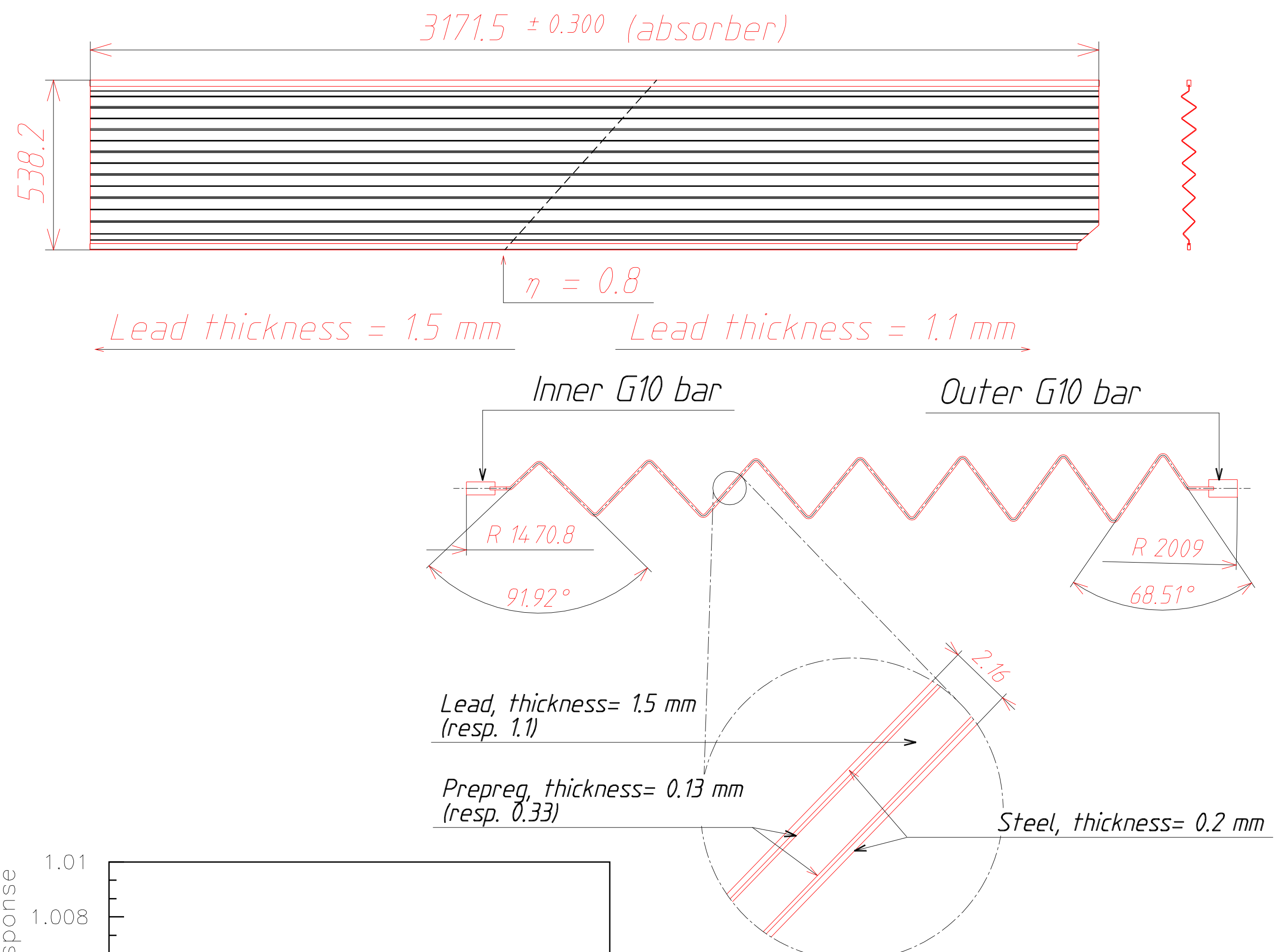
EM Barrel External Ring

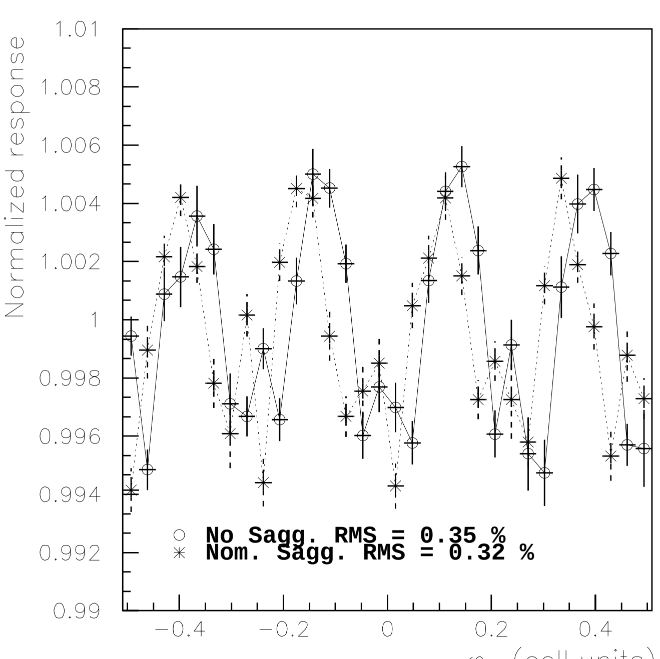


EM Barrel External Ring

EM Barrel Absorbers

- **Constant absorber thickness; change of lead thickness at η = 0.8**
- **Attention paid to: change of geometry between warm and cold**
  reducing mechanical deformation
  control of the absorber thickness



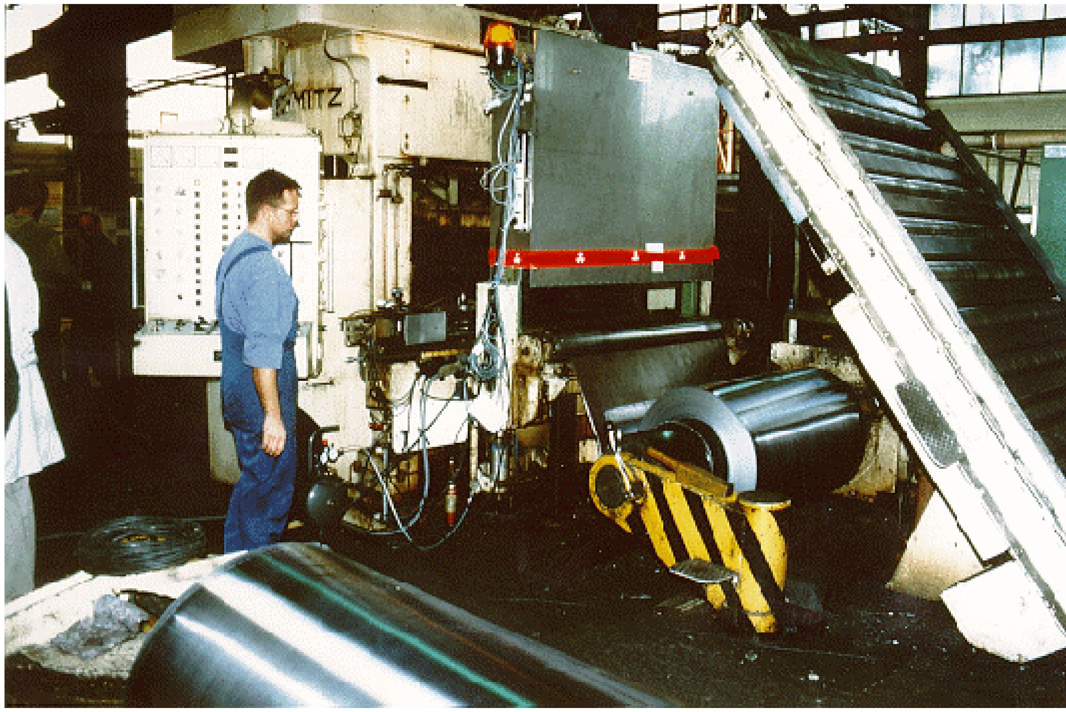


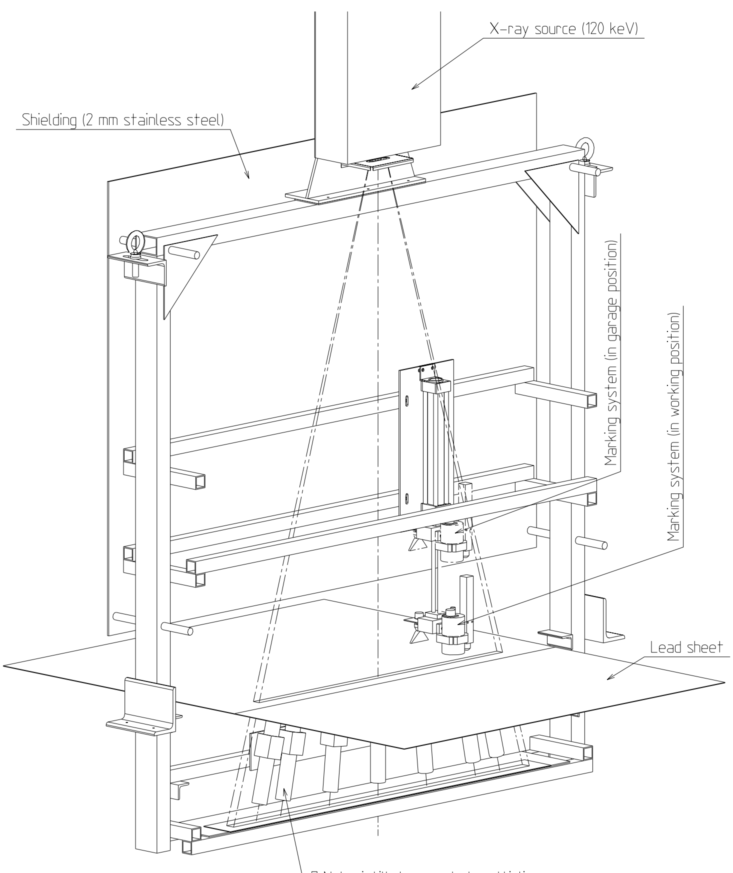
- **A straight line from the vertex crosses 4 absorbers in ATLAS (3 in RD3).**
- **Reduces φ modulations**
- **1mm sagging has negligible effect**

EM Lead Absorber Thickness

A 10 μm increase in lead thickness produces a 0.4% decrease in signal

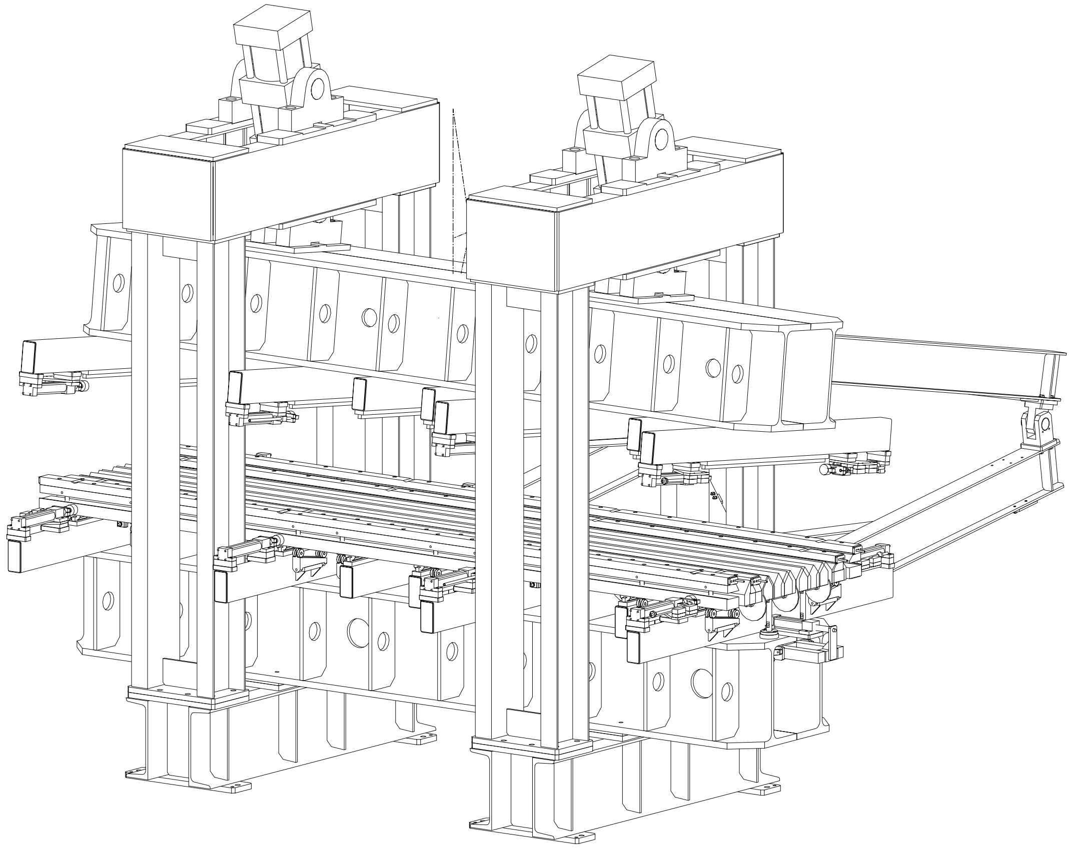
Lead for module 0 produced end of 1996

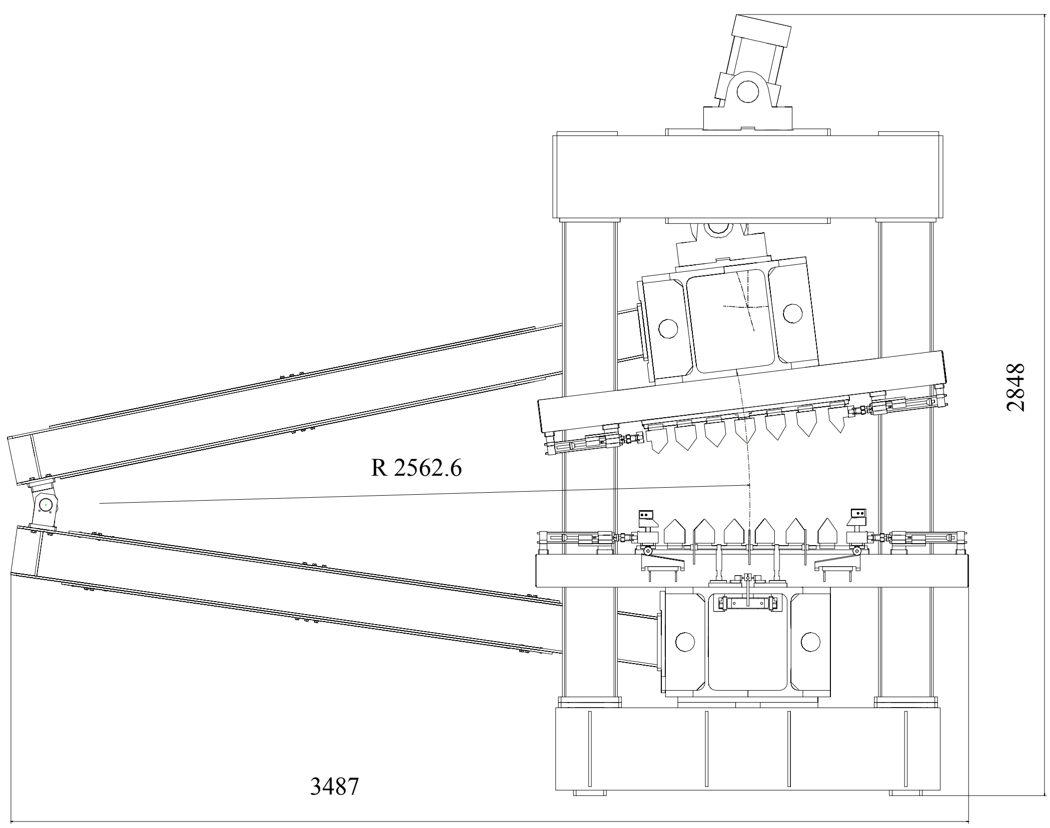




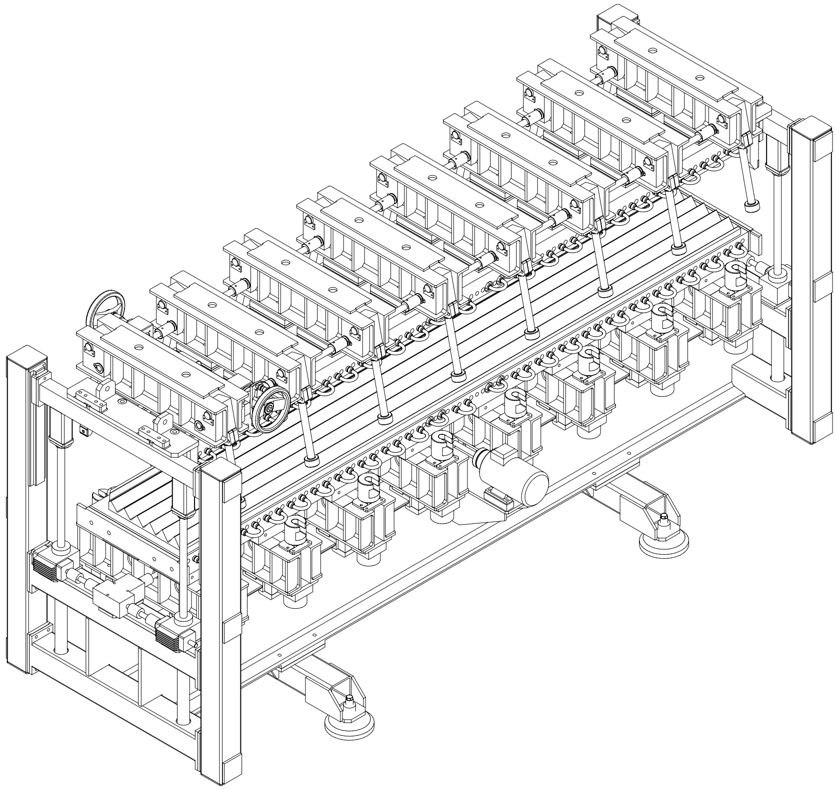
- **Thickness controlled online**
- **Reproducibility of the online measurement is 5μm**
- **5μm dispersion within a typical plate**
- **Overall dispersion is 9μm rms**
- **Online measurements repeated offline (ultrasonic probes)**
- **Plates will be sorted to guarantee the required uniformity**

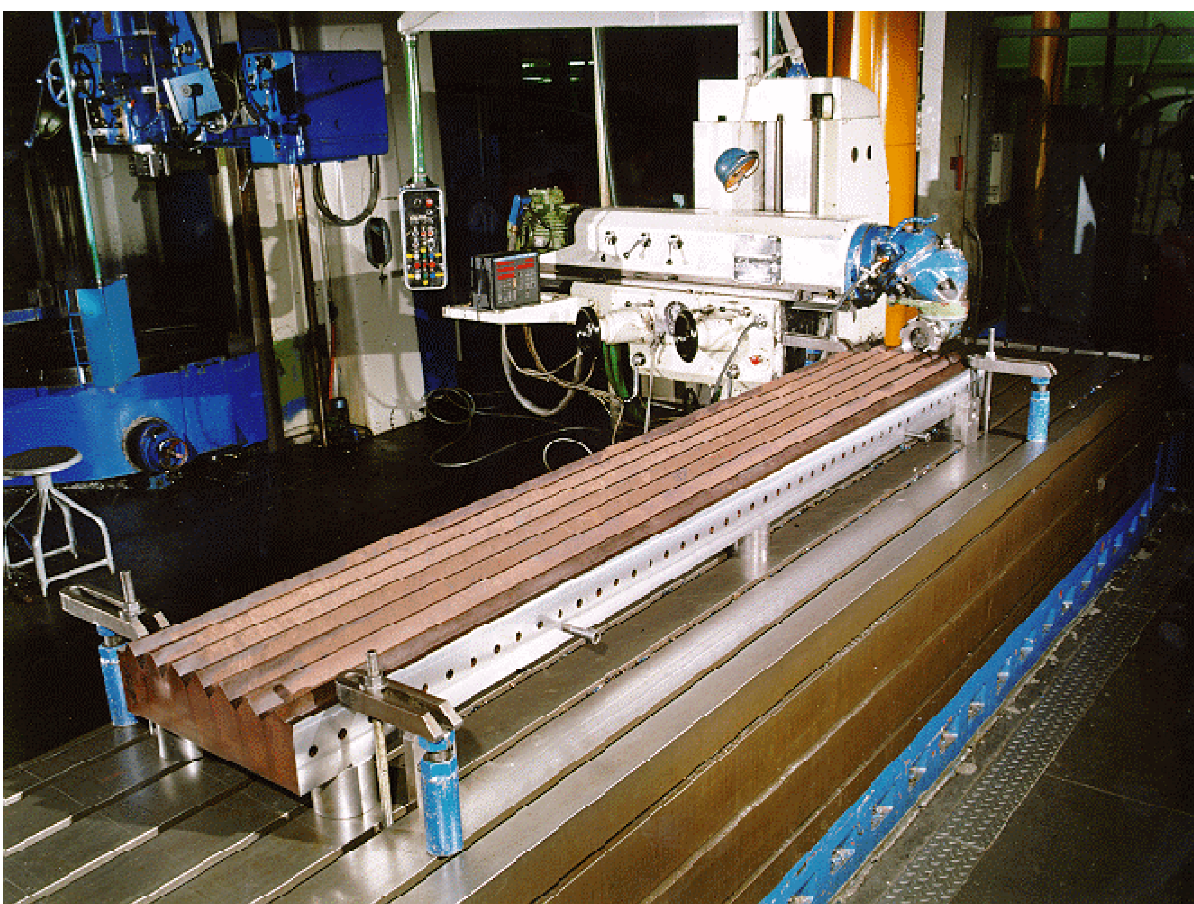
EM Barrel Absorber Bending Press



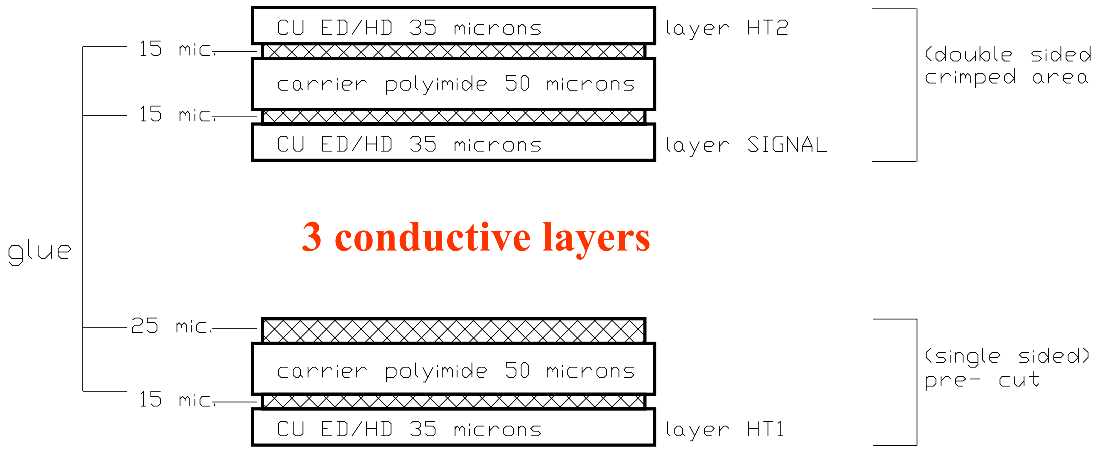


EM Barrel Absorber Gluing Press



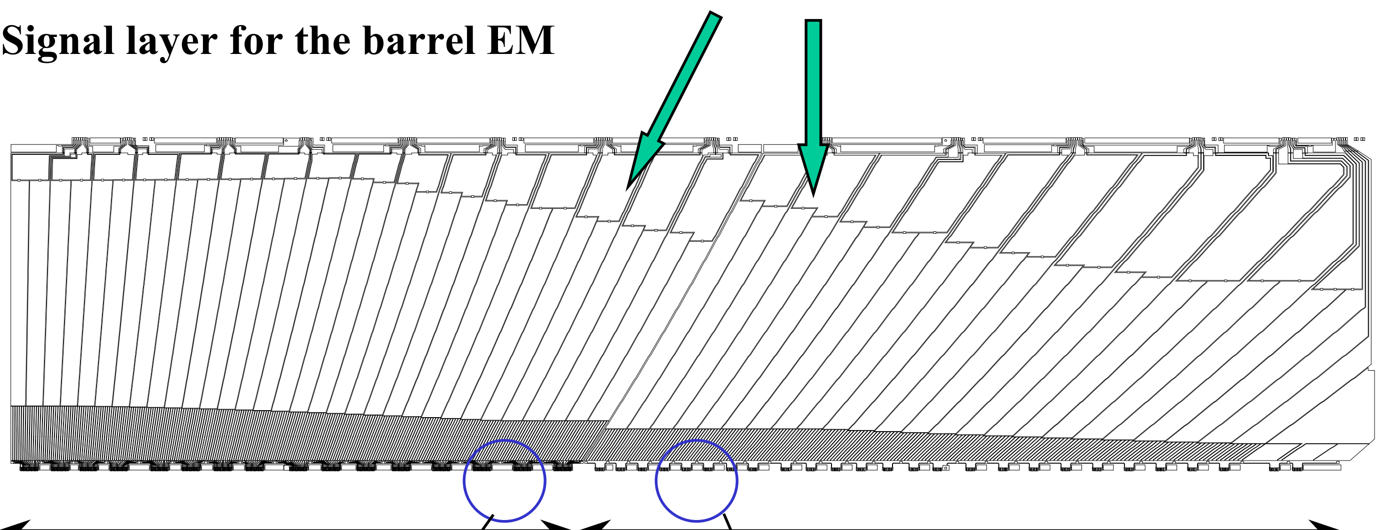


EM Barrel Readout Electrodes



Middle layer tappered at 24Xo:
enough for energy containment below about 50 GeV

Signal layer for the barrel EM

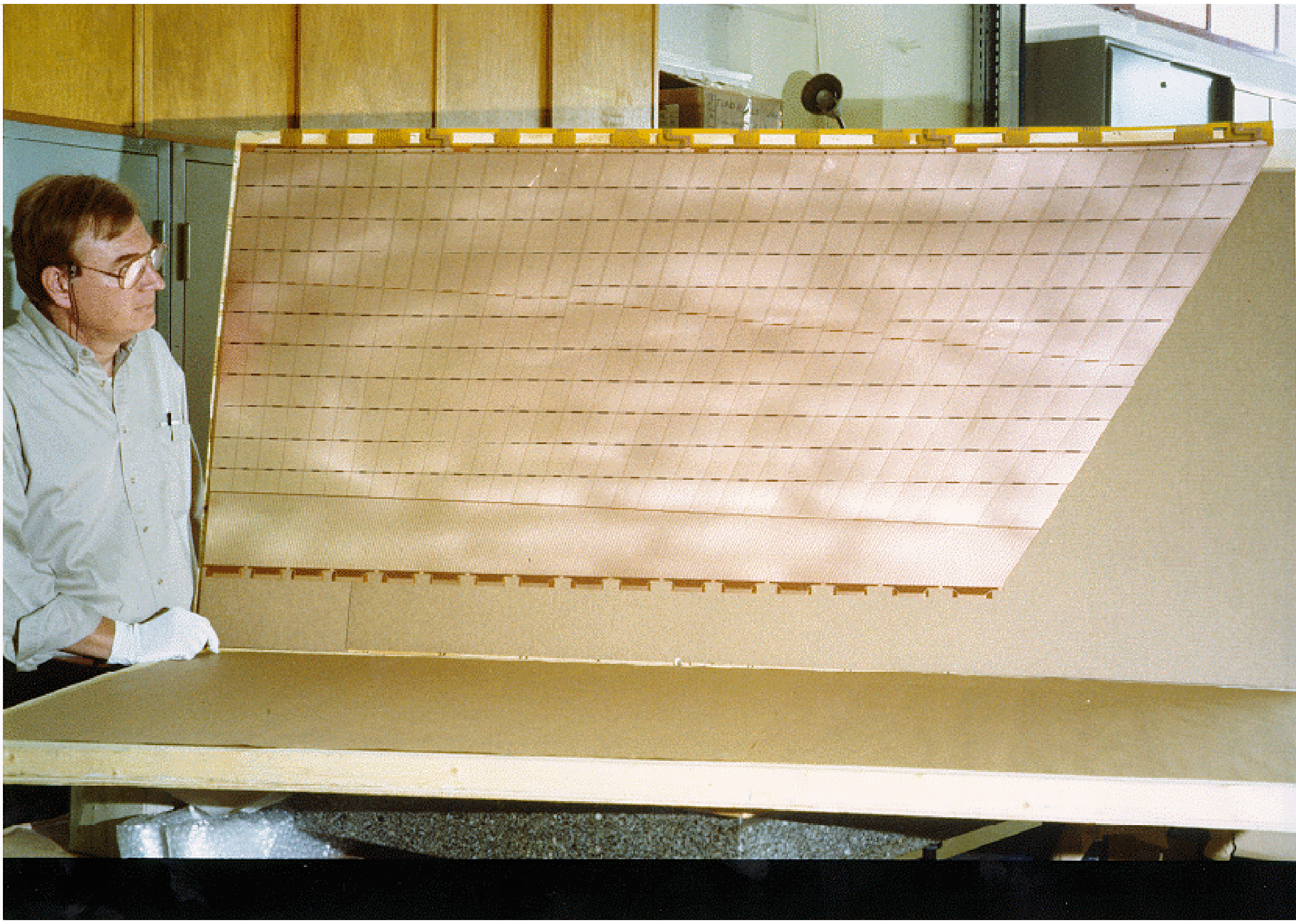


$0 < \eta < 0.8$ **$0.8 < \eta < 1.475$**

Crimped pins
2 per cell at the back for increased reliability

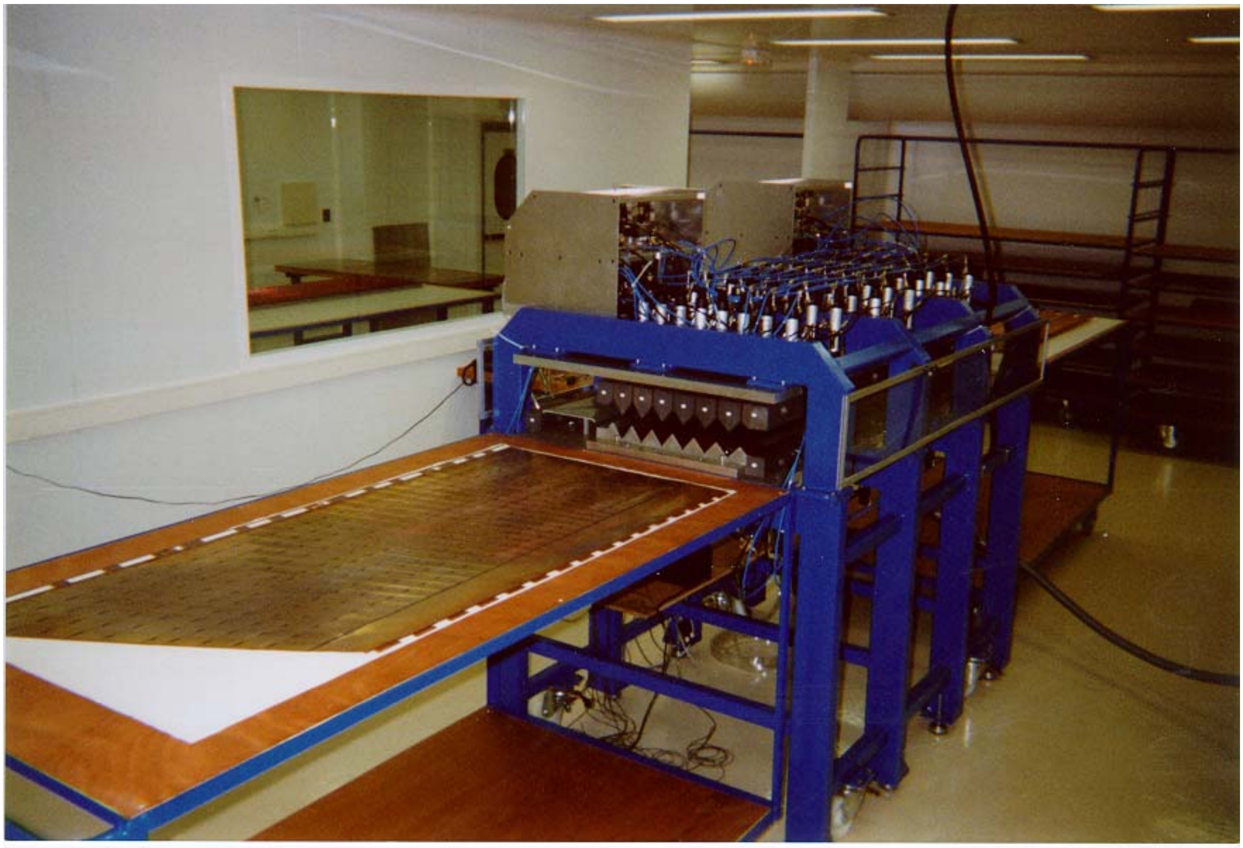
Strips for γ/π^0 identification and pointing (using middle layer)

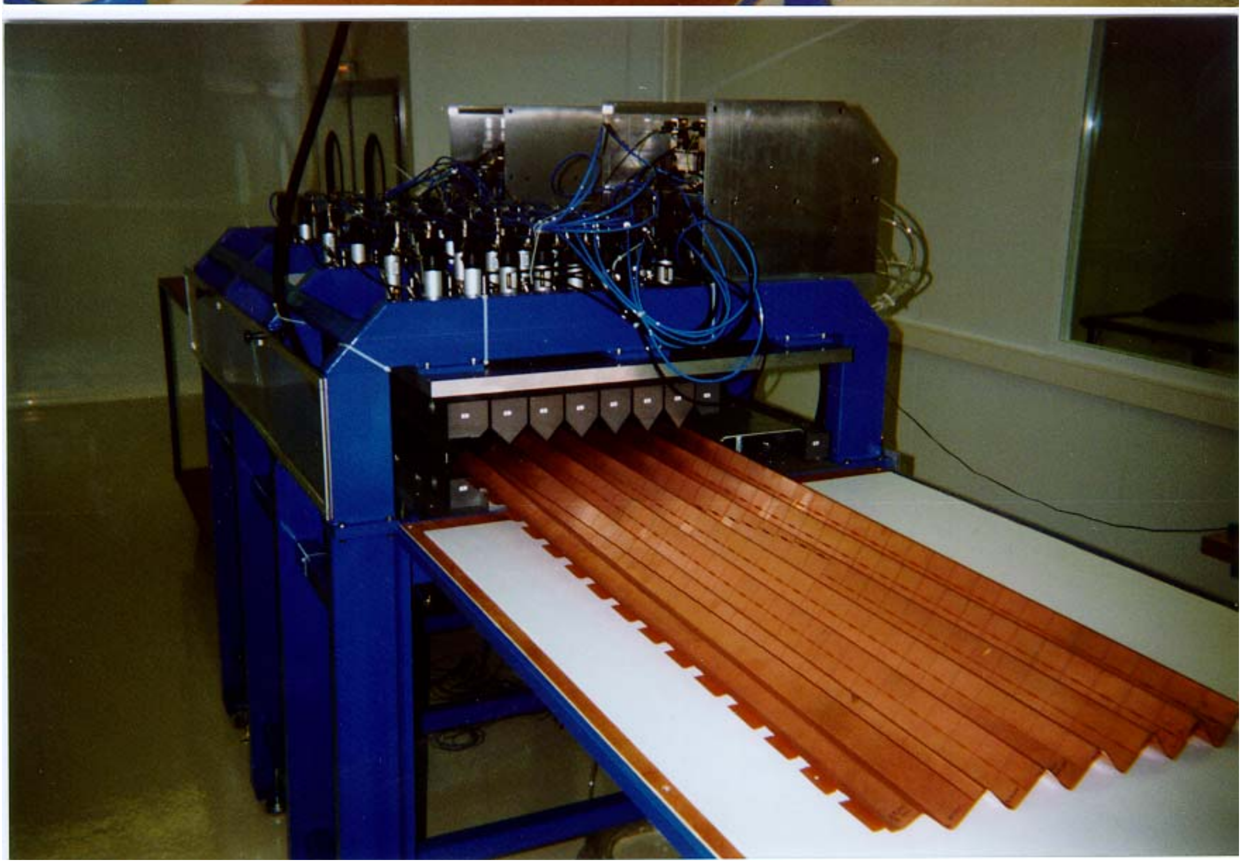
EM Barrel Readout Electrodes



- Large size electrodes have been developed to improve on response uniformity   2 elements in barrel: $0 < \eta < 0.8$ and $0.8 < \eta < 1.475$
- Kapton "E" selected to minimize differences in thermal expansion coefficients. Epoxy glue to bound the layers for good radiation resistance

EM Barrel Electrode Bending Press



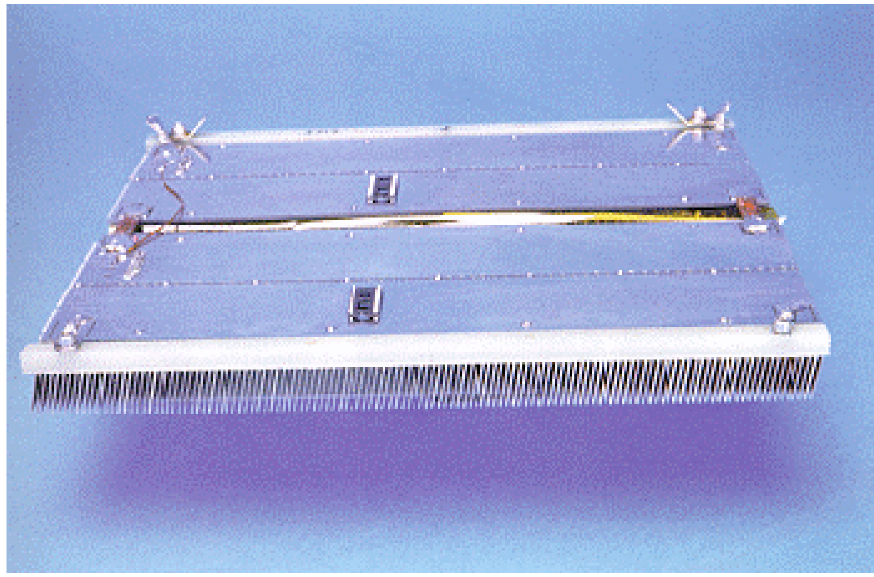


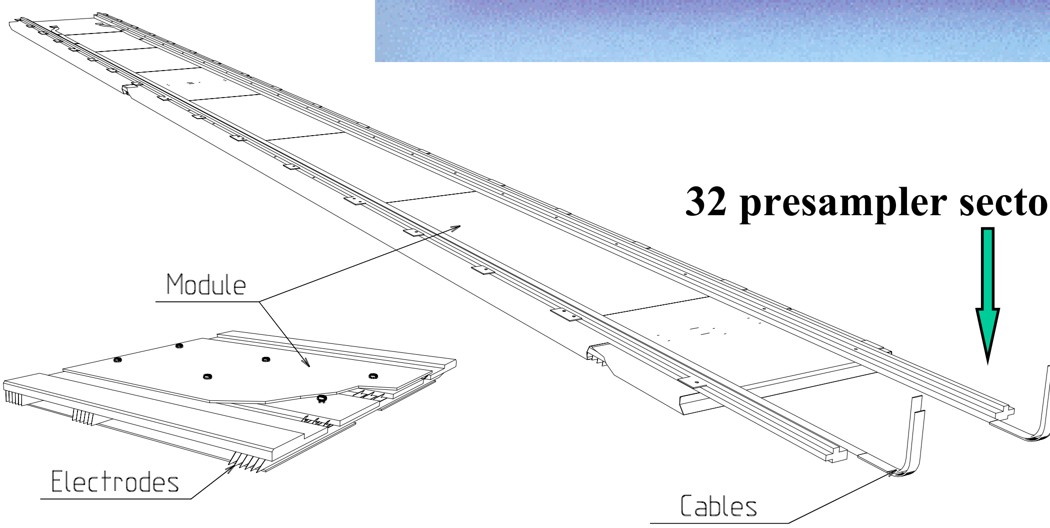
Presampler

- 21mm total thickness
- 11mm active liquid
- granularity of

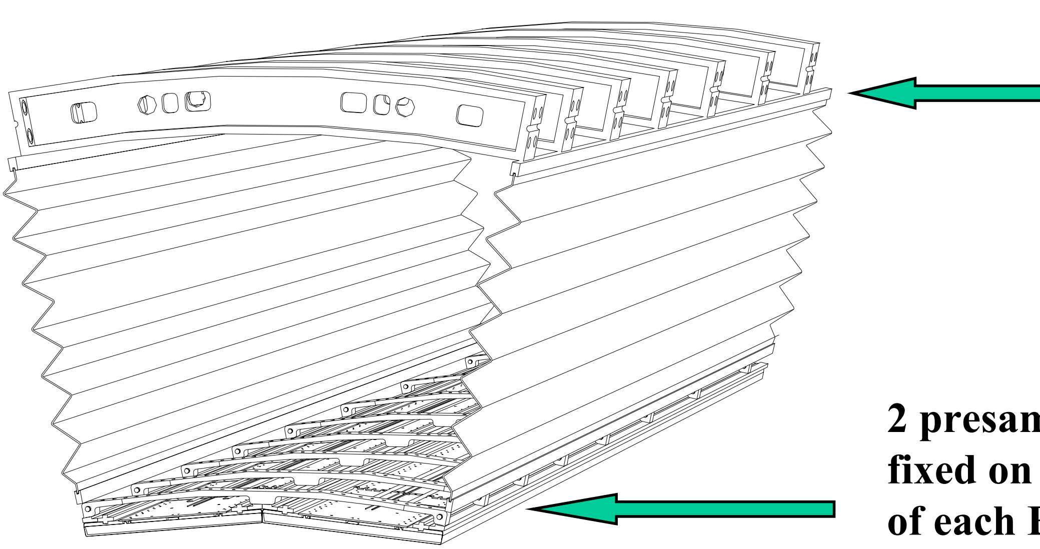
□ $\Delta\eta \times \Delta\varphi = 0.025 \times 0.1$

- sector assembly





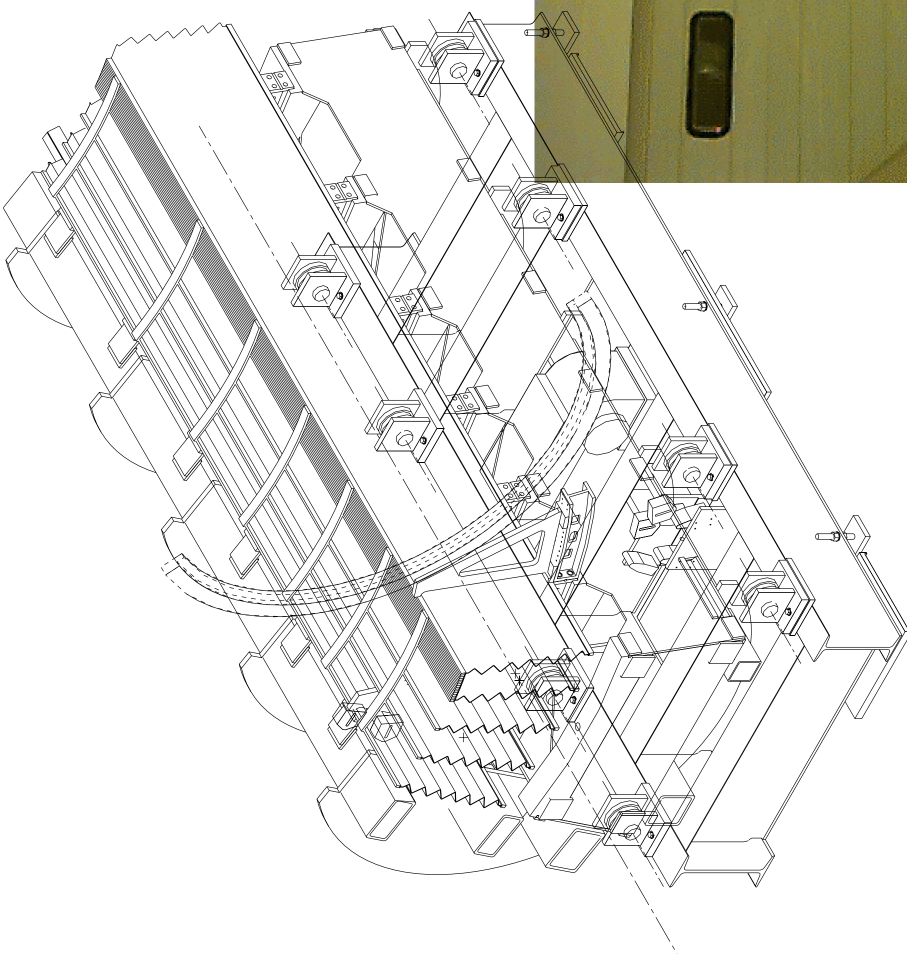
32 presampler sectors in φ



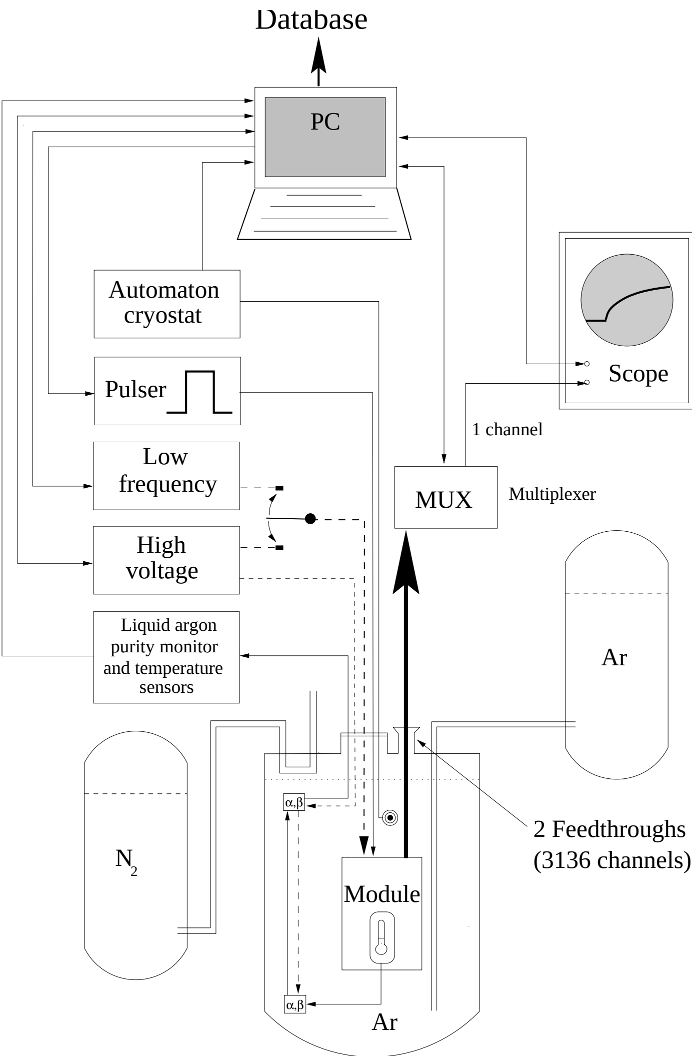
16 EM Barrel modules in φ

2 presampler sectors fixed on the inner rings of each EM module

EM Barrel Module Assembly Jig and Assembly Backbone

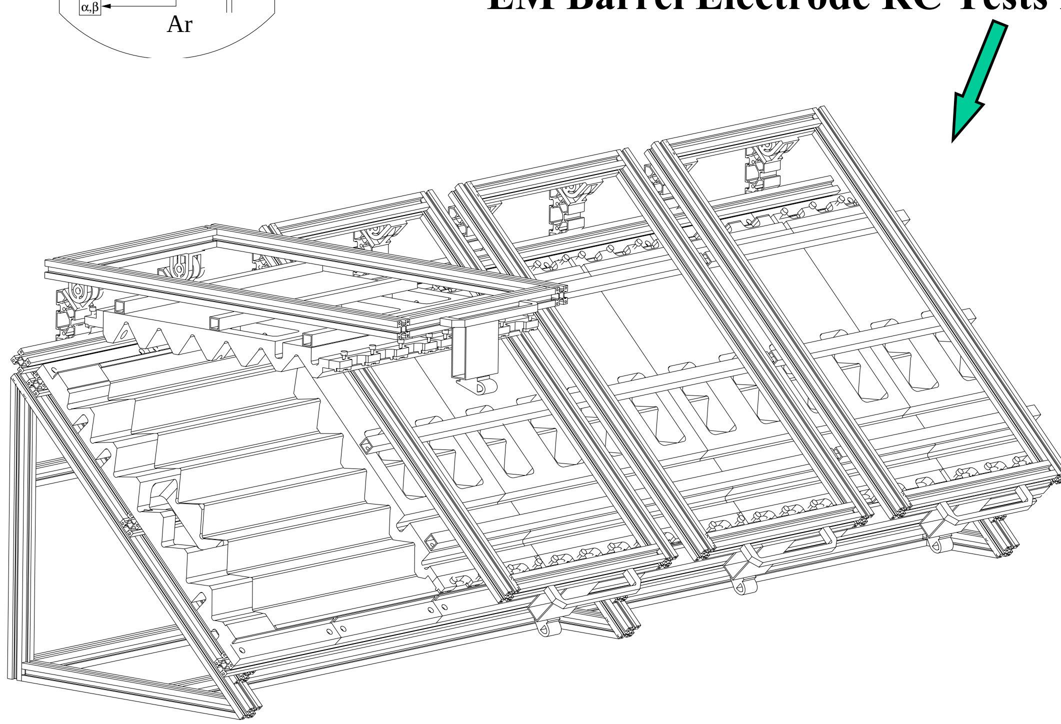


EM Barrel Module Tests



- A complete electrical testing
  - HV
  - capacitance measurement
  - pulsing and reading out all channels
- Every module will be cold tested in the labs or at CERN
- A fraction only (about 1/6) will be beam tested at CERN

EM Barrel Electrode RC Tests Fixture

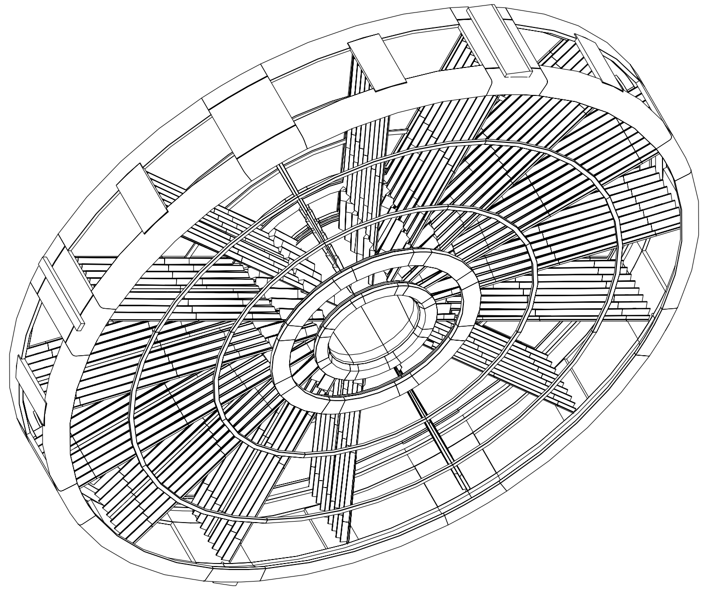


EM Barrel Module 0 Status

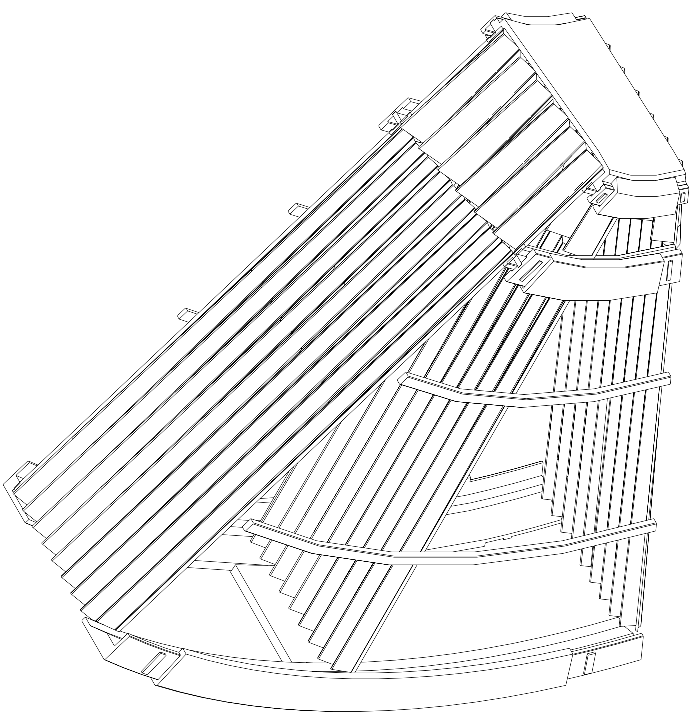
- **Absorbers**
  - **Lead delivered, thickness measured (9μm rms)**
  - **Stainless steel delivered, cleaned**
  - **First absorbers (17) bent and glued**
  - **Production tooling ready for production**
  - **Module 0 production starts December 97**
- **Spacers**
  - **Production tooling ready for production**
  - **30μm rms on 2mm gap thickness**
- **Readout boards**
  - **Module 0 electrodes expected spring 98**
- **External rings**
  - **Ring 0 constructed**
  - **Loading tests agree with predictions**
- **Assembly**
  - **Jig currently being assembled**
- **Quality control**
  - **Test procedure established**

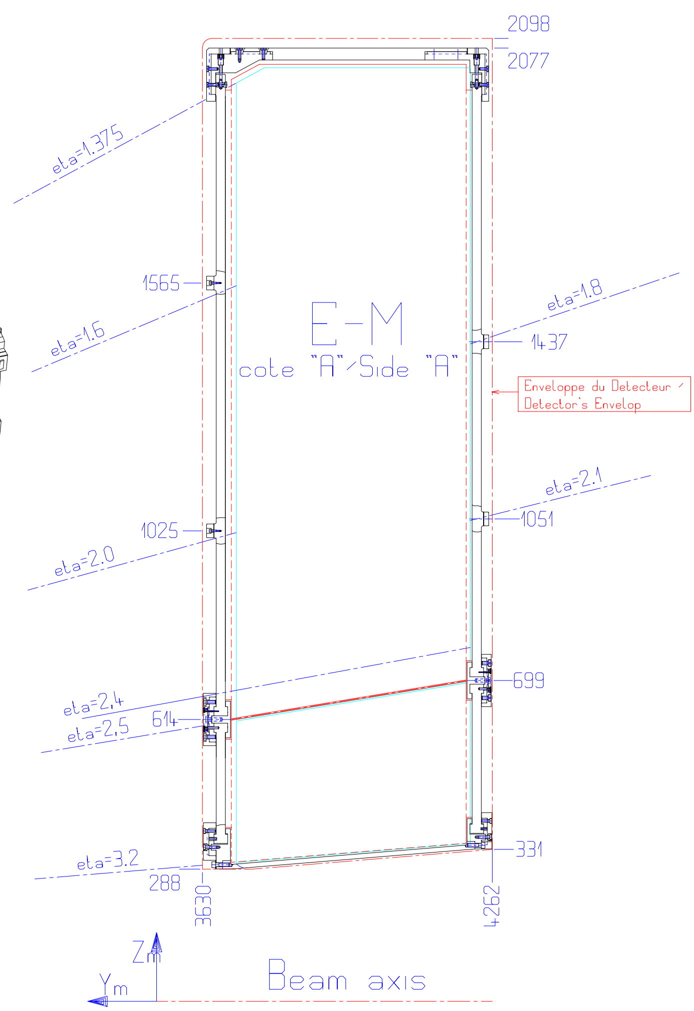
EM Endcap Calorimeter

- **2 concentric wheels**
- **8 modules in azimuth**
- **24 tons**
- **Deformations < 1.1 mm**
- **Six support rings**
- **Outer wheel 1.4 < η < 2.5**
  768 absorber
  1.7 mm lead
- **Inner wheel: 2.5 < η < 3.2**
  256 absorbers
  2.2 mm lead



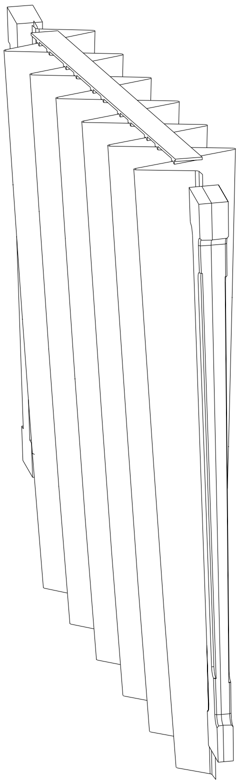
One EM endcap module



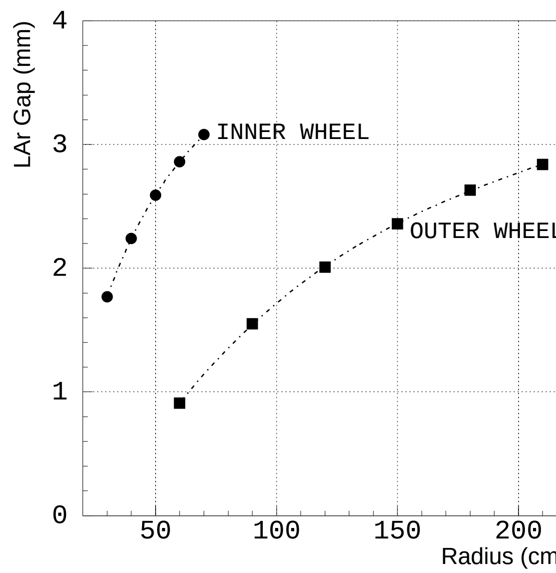


EM Endcap Absorbers

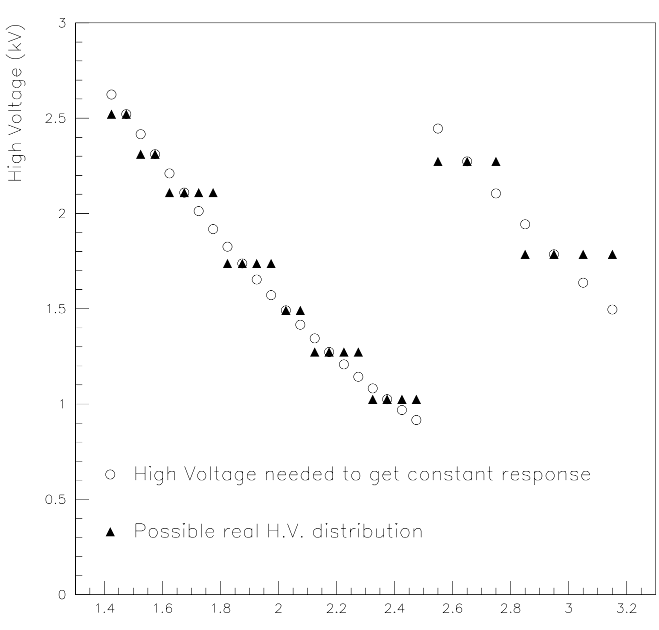
Inner wheel absorber

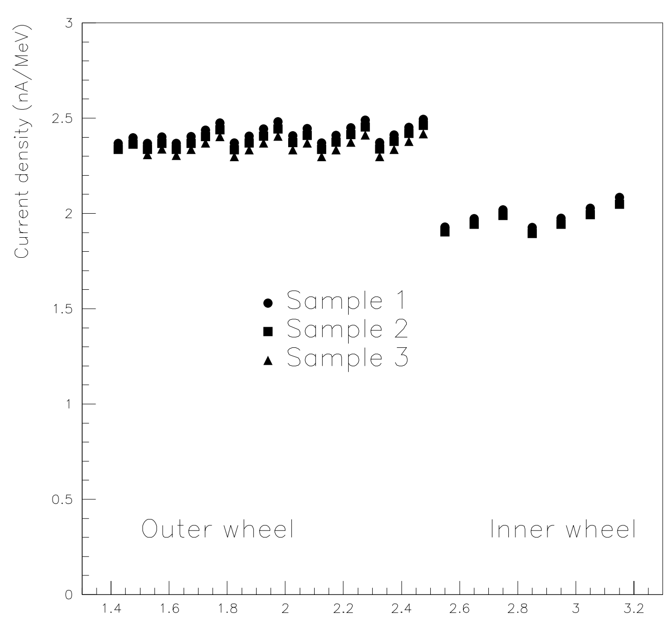


varying liquid gap

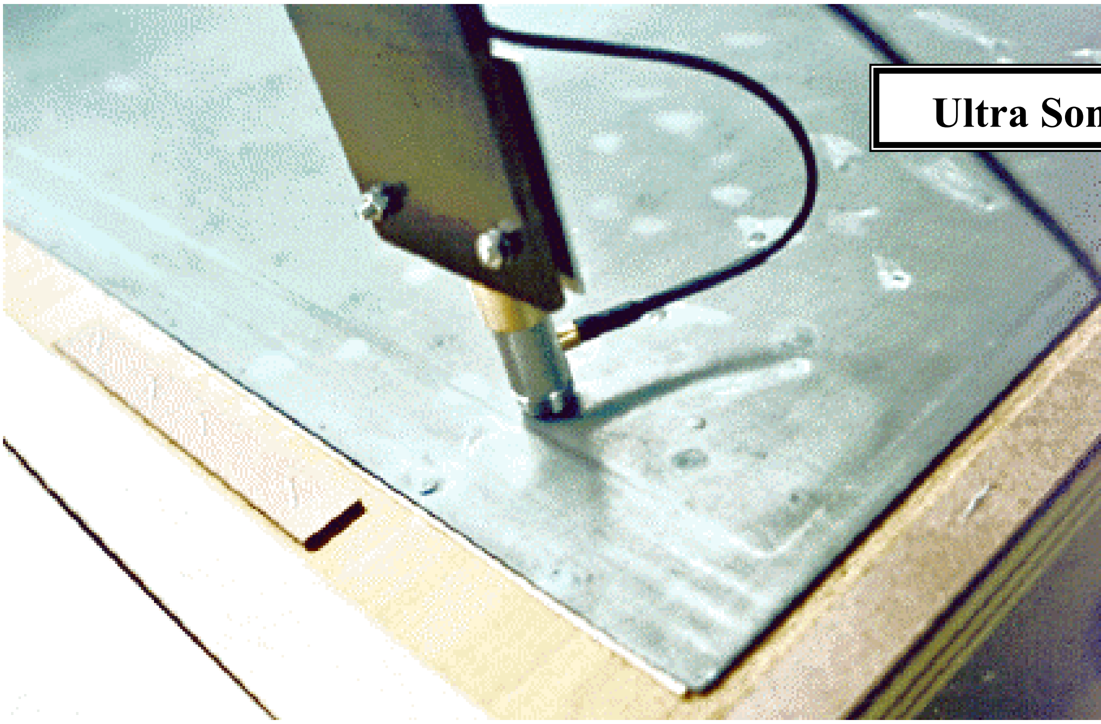


varying HV to keep current constant



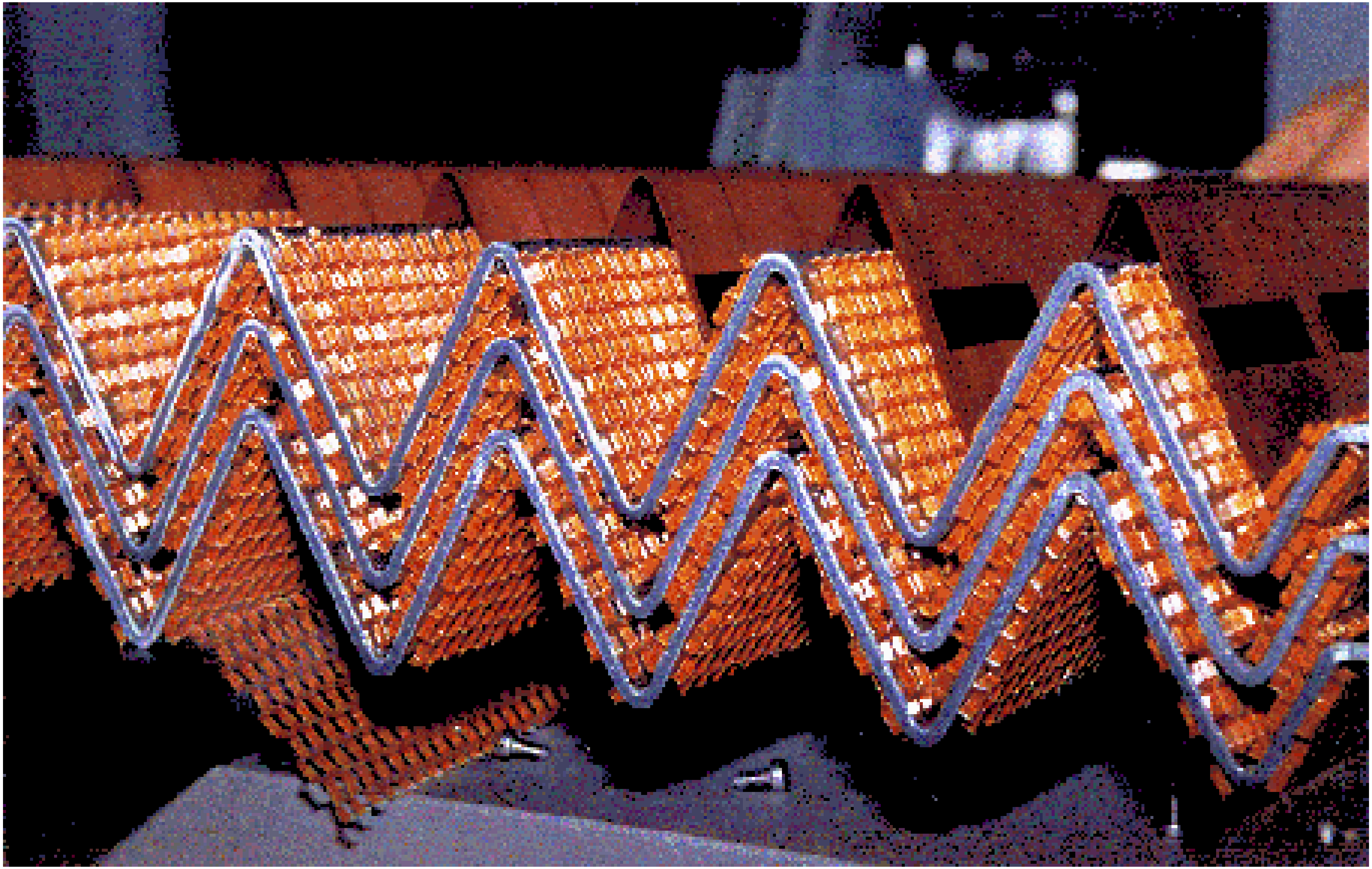


EM Endcap Absorber



EM Endcap

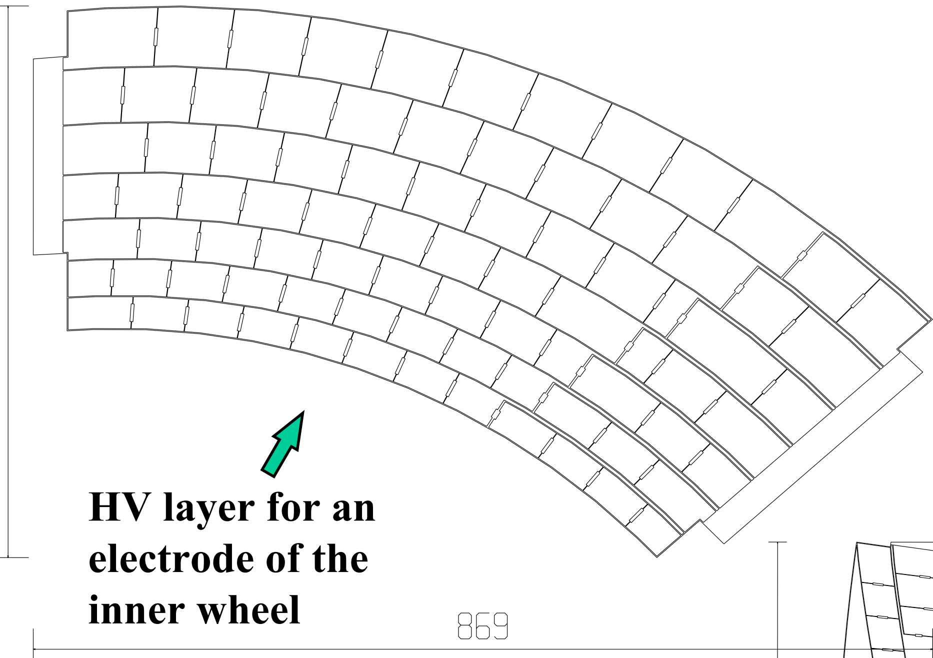
EM Endcap Absorber and Electrodes



EM Endcap Electrodes

Channel Count (both ends)

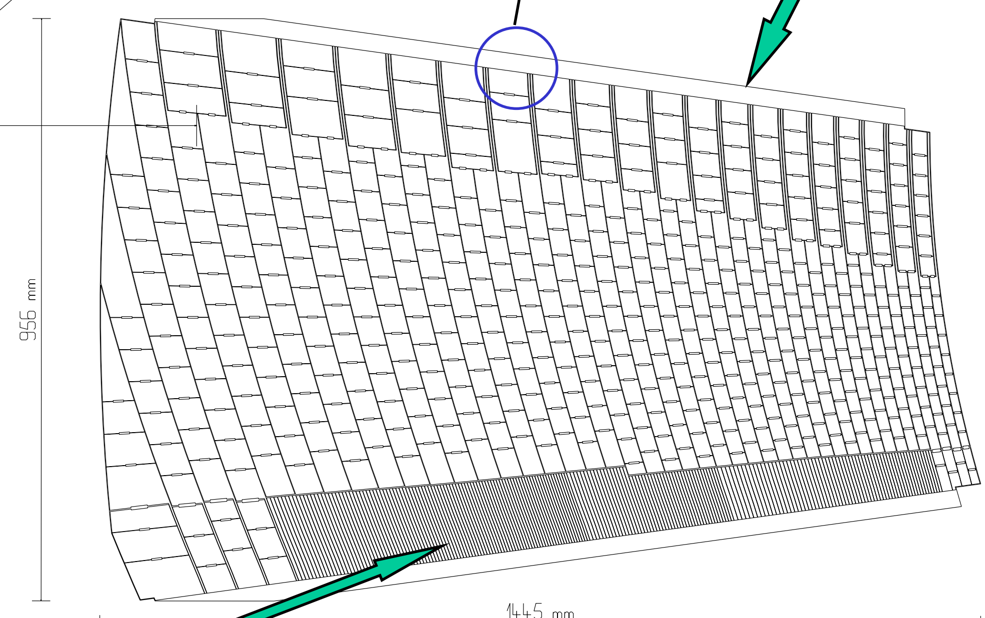
Presampler	1536
Strips	27136
Middle	21888
Back	13184
Total	63744



HV layer for an electrode of the inner wheel

HV layer for an electrode of the outer wheel

HV feed from back

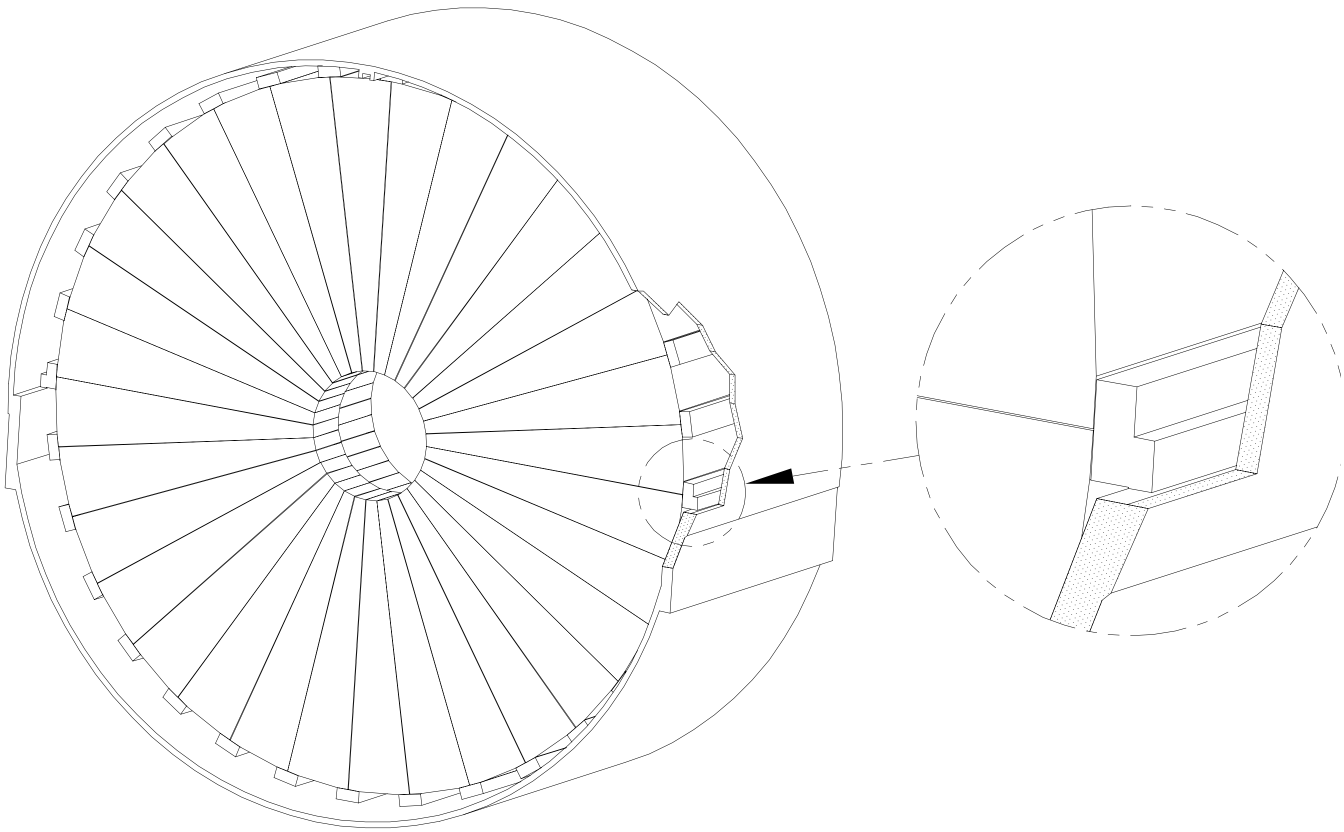


Small pads to limit the energy discharged into the readout in case of a spark

Note change in strip granularity

Hadronic Endcap Calorimeter

LAr-Cu sampling calorimeter covering 1.5 < η < 3.2



Composed of 2 wheels per end, 32 modules per wheel

Front wheel: **67 t**
25 mm Cu plates

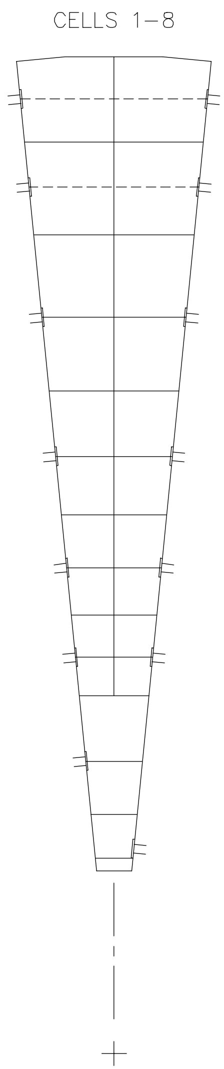
Back wheel: **90 t**
50 mm Cu plates

Channel count for both endcaps

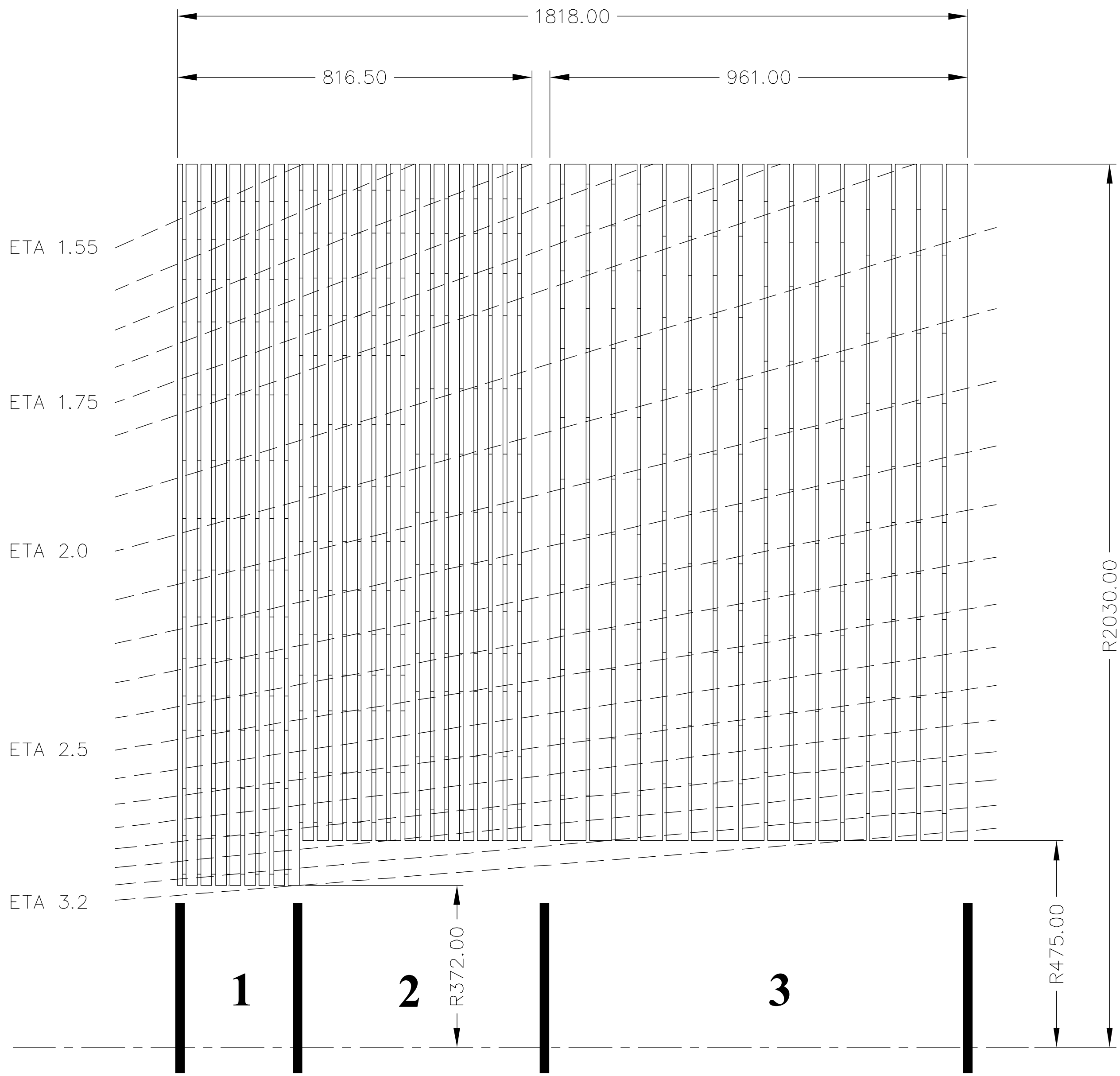
Front	1536
Middle	1472
Back	1408
Total	4416

Hadronic Endcap Calorimeter Segmentation

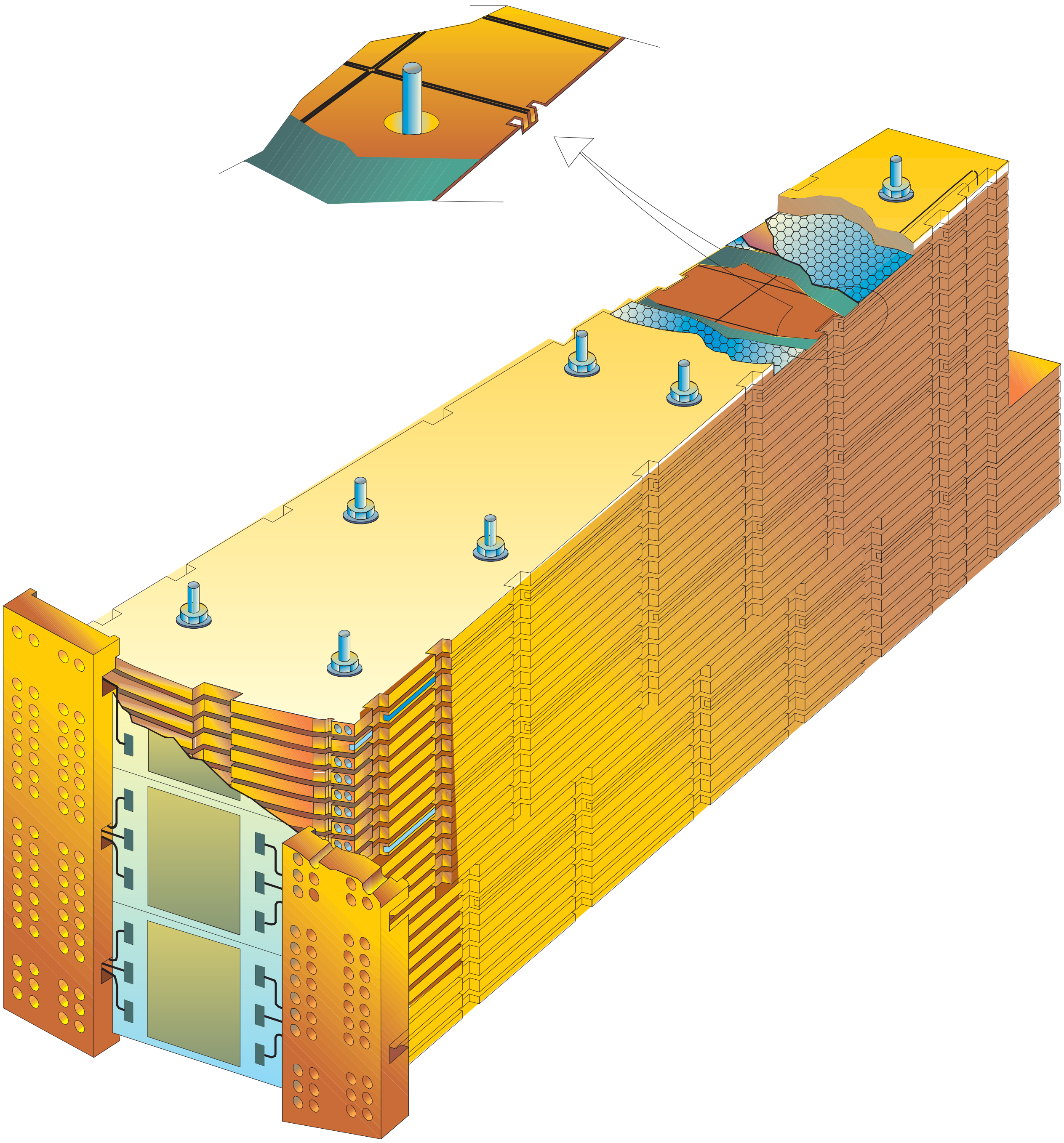
Readout Segment



3 Readout Depths



Hadronic Endcap Module



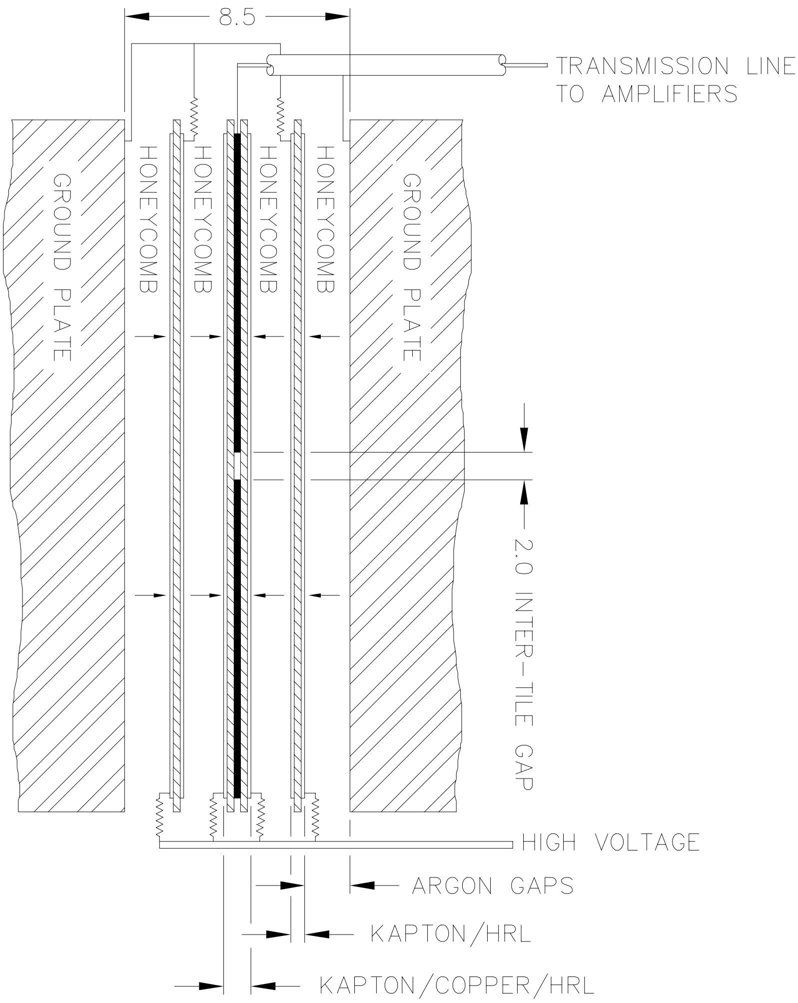
Gap between Cu plates: 8.5 mm

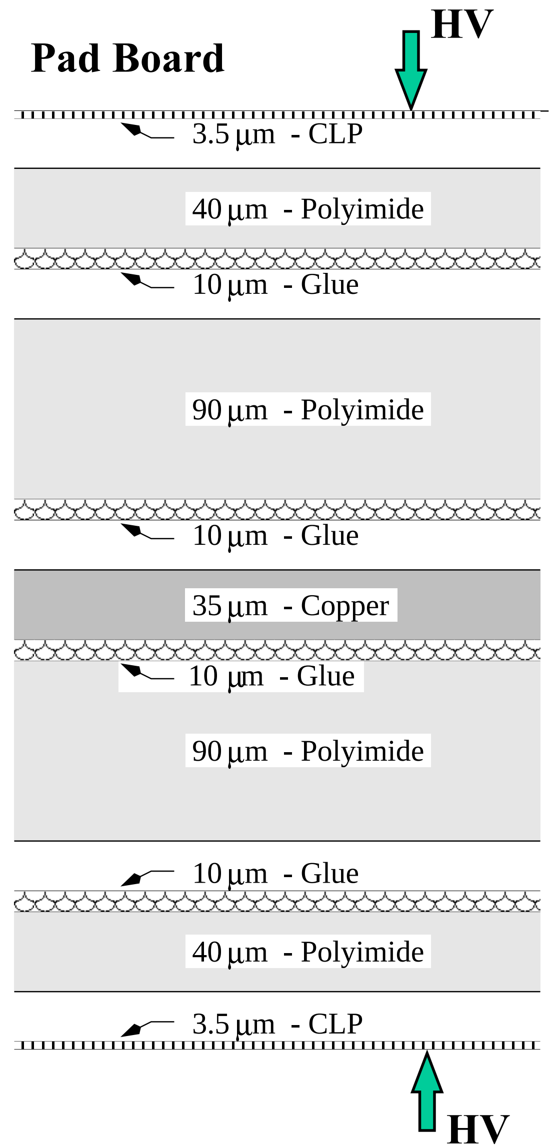
Front wheel module: 2103 kg
25 mm Cu plates

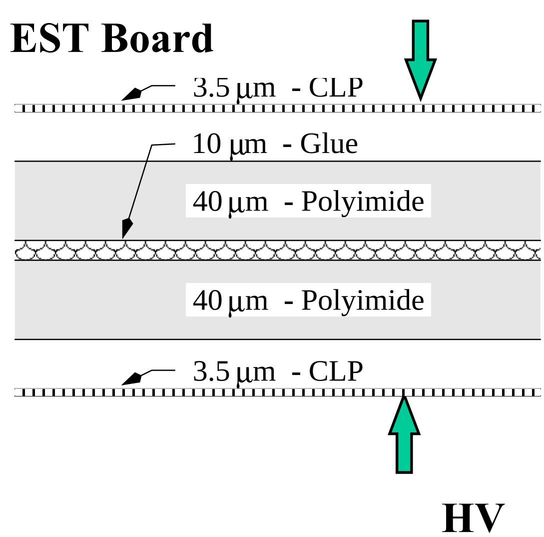
Back wheel module: 2811 kg
50 mm Cu plates

Hadronic Endcap Readout Structure

Electrostatic Transformer (EST) Readout





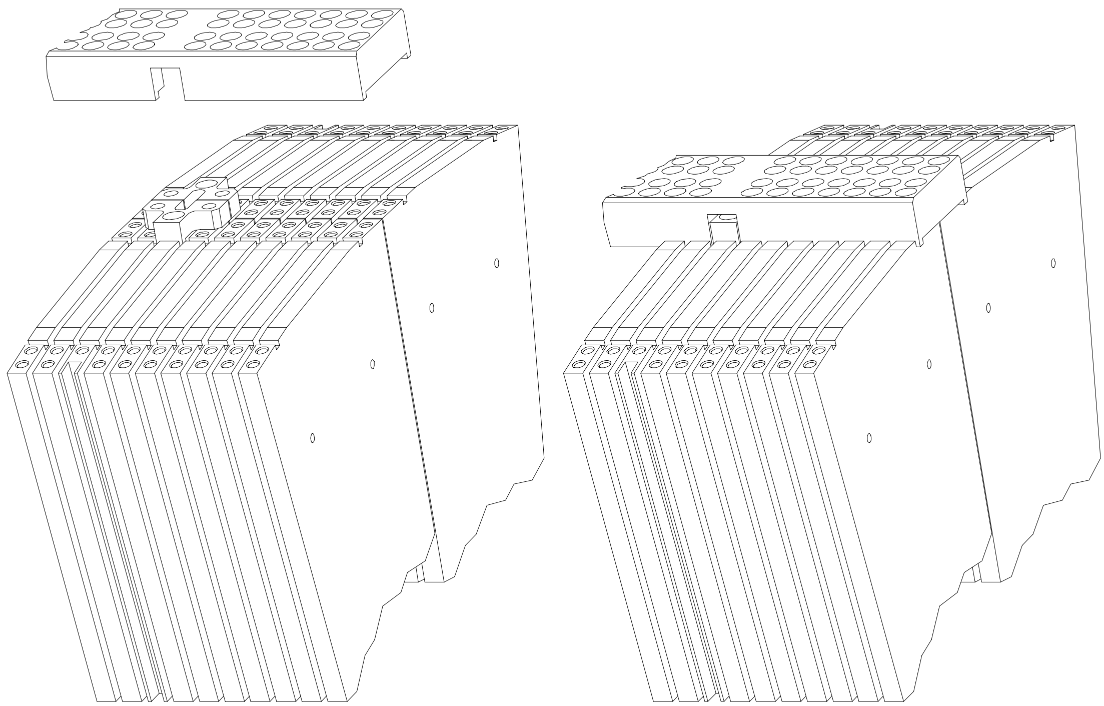


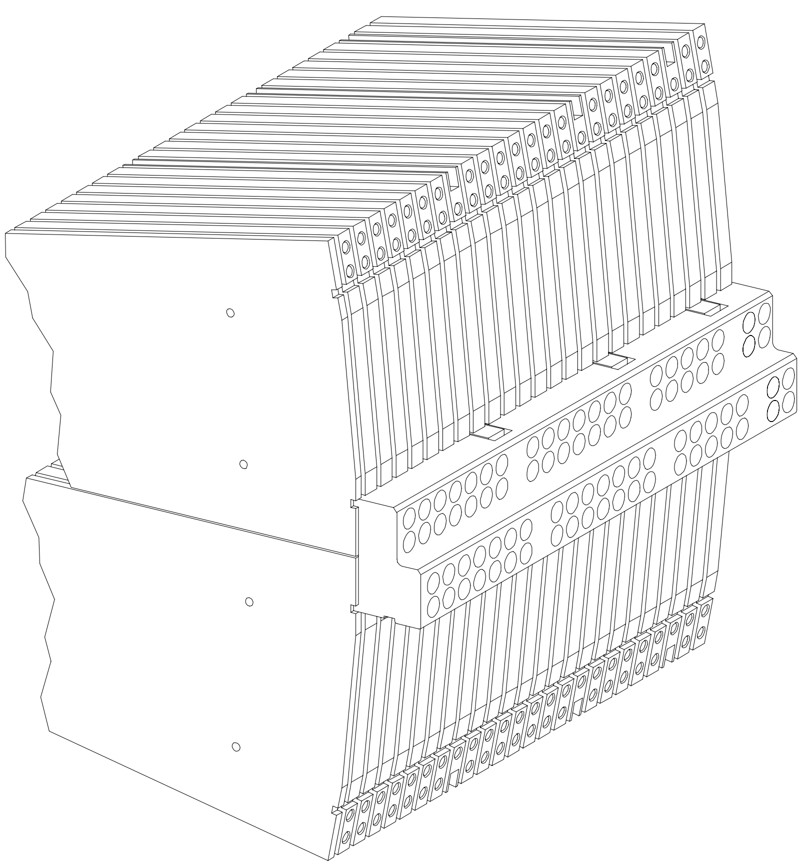
For the Carbon-loaded paint scenario:

Distance between Cu plates	**8.5 mm**
Liquid argon gaps	**1.954 mm**
Honeycomb thickness	**1.774 mm**
Pad and EST board thickness	**0.685 mm**

Hadronic Endcap Module Connection

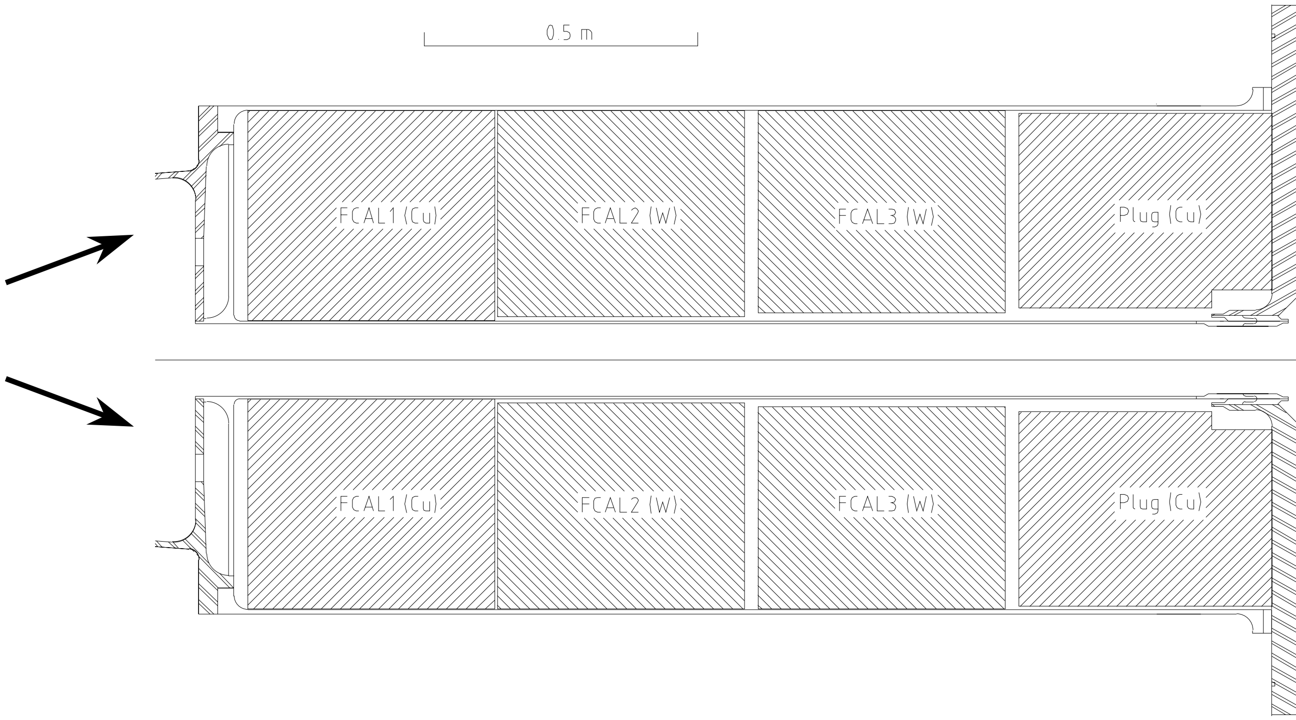
Inter-module clamping bar





At rail location, the inter-module clamping bar is replaced by a slider

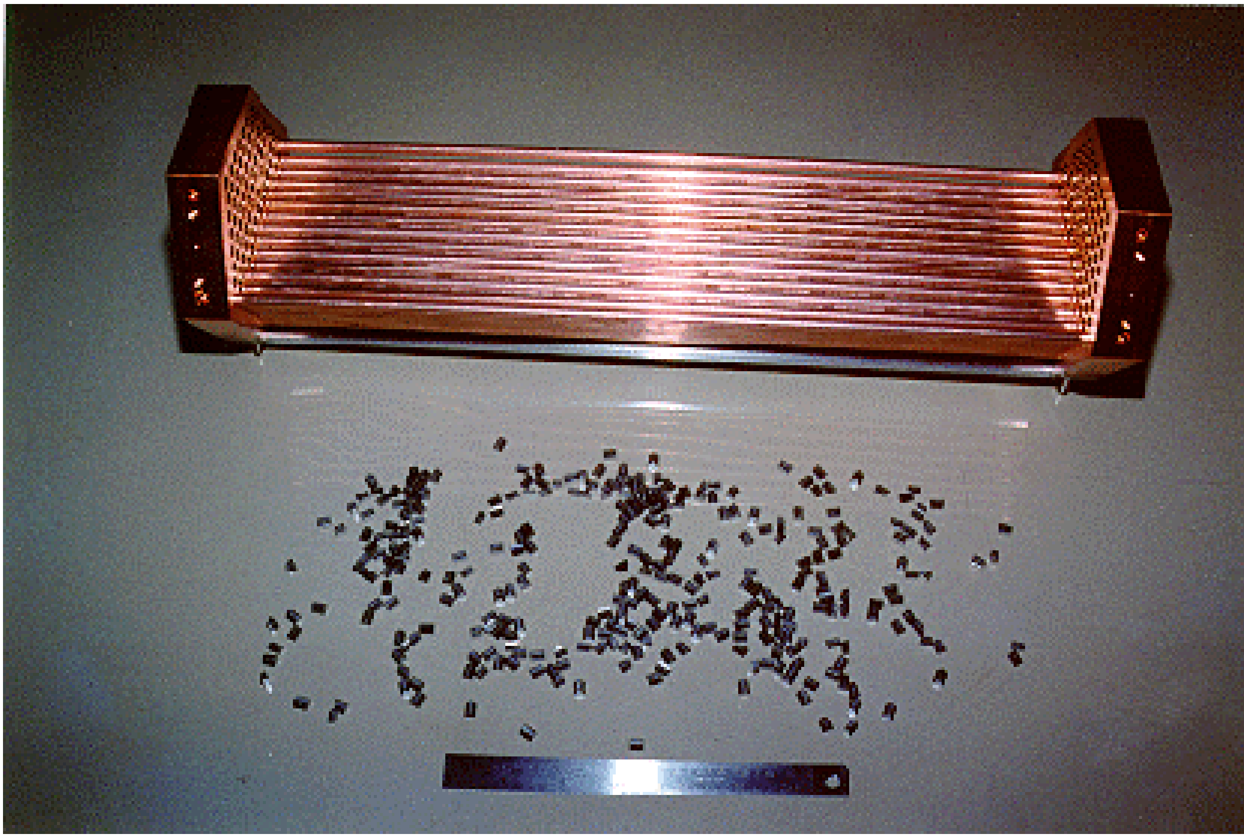
Forward Calorimeter

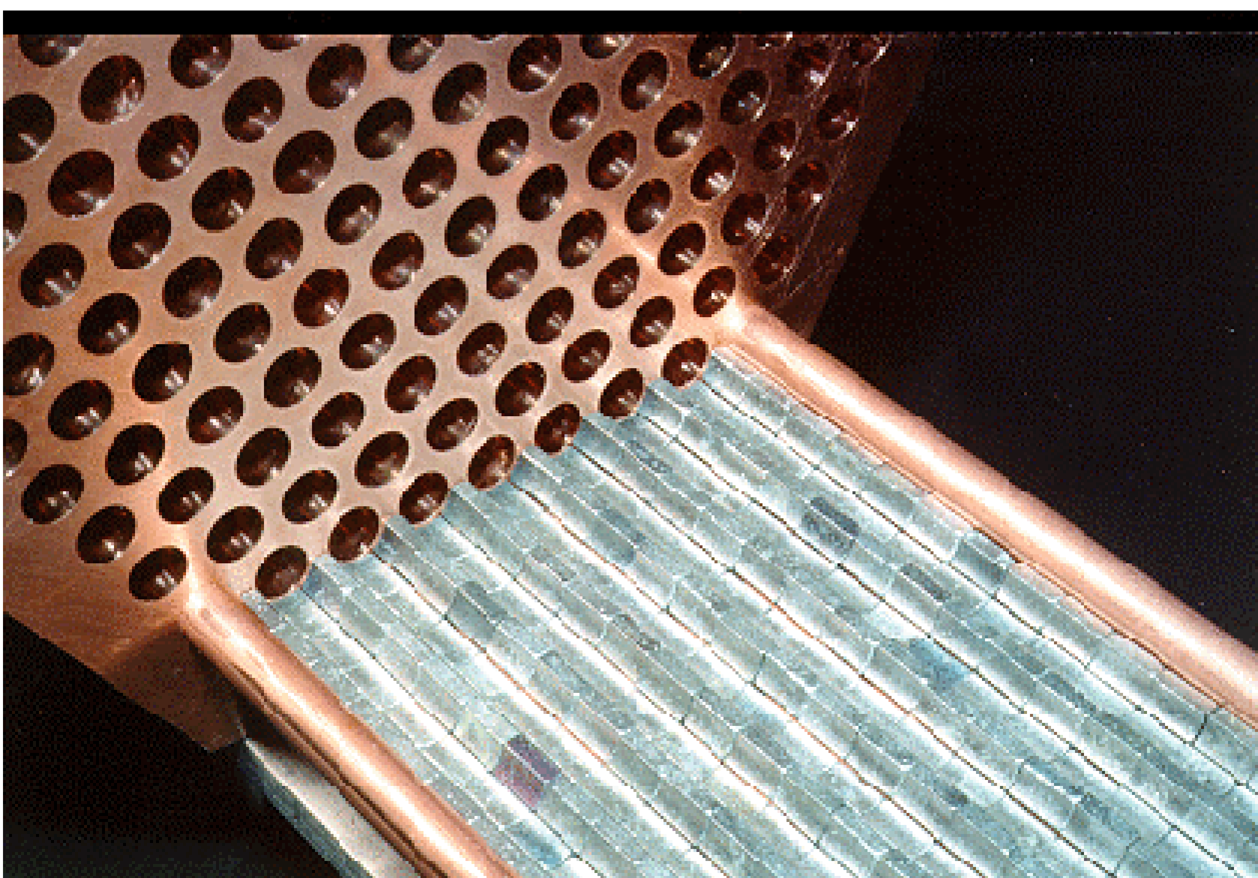


	FCAL1	FCAL2	FCAL3
η_{min}	3.0	3.1	3.2
η_{max}	4.9	4.9	4.9
Absorber material	Cu	W	W
Mass (t)	2.3	4.1	4.0
dE/dx sampling %	1.49	1.36	1.68
Depth (λ)	2.6	3.5	3.4
Gap width (mm)	0.25	0.375	0.50
Drift time (ns)	50	75	100

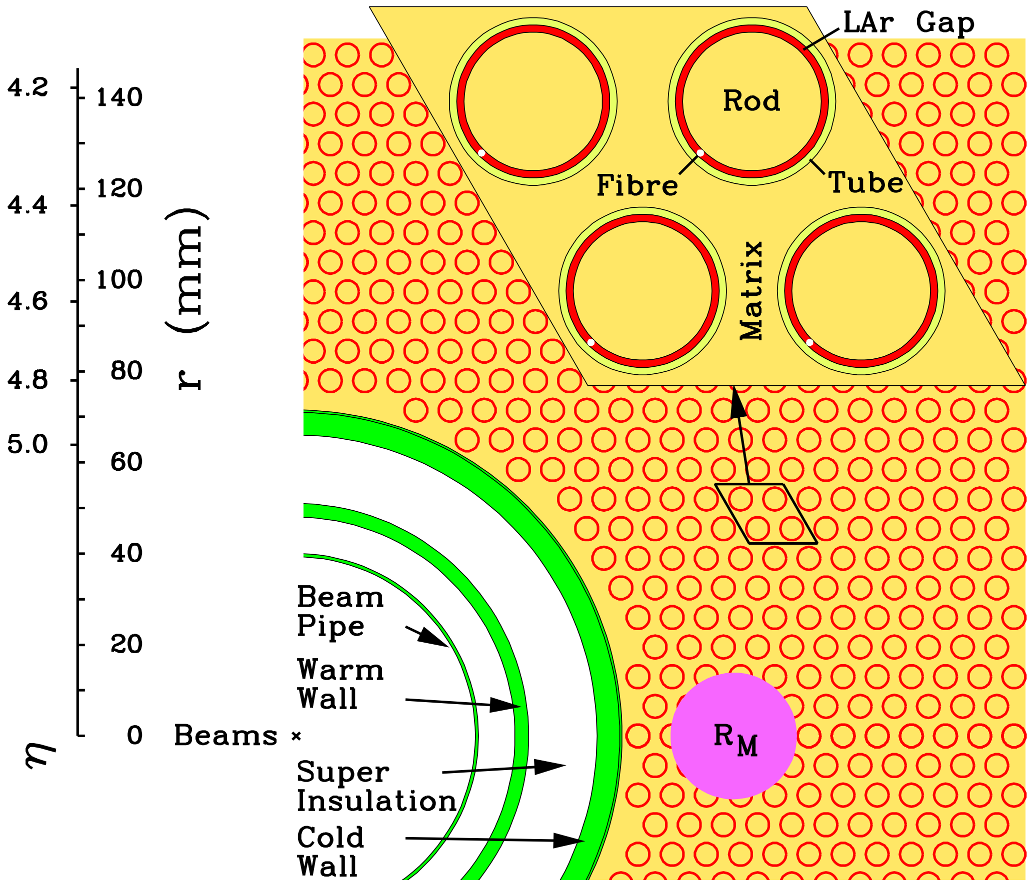
Channel count for both ends: 2822

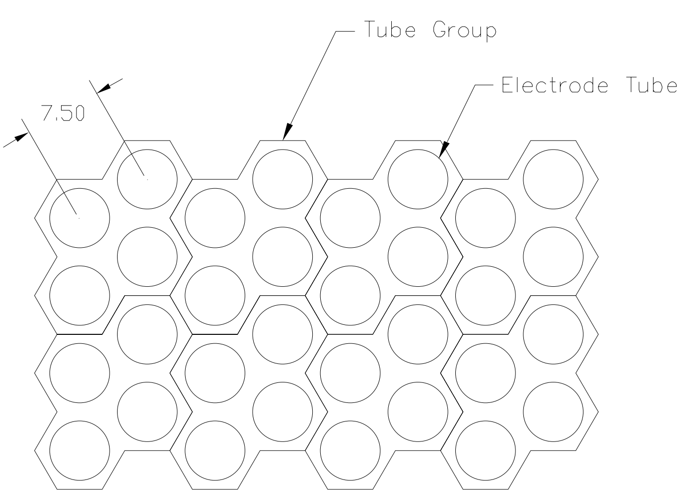
Hadronic Forward Calorimeter Maquette

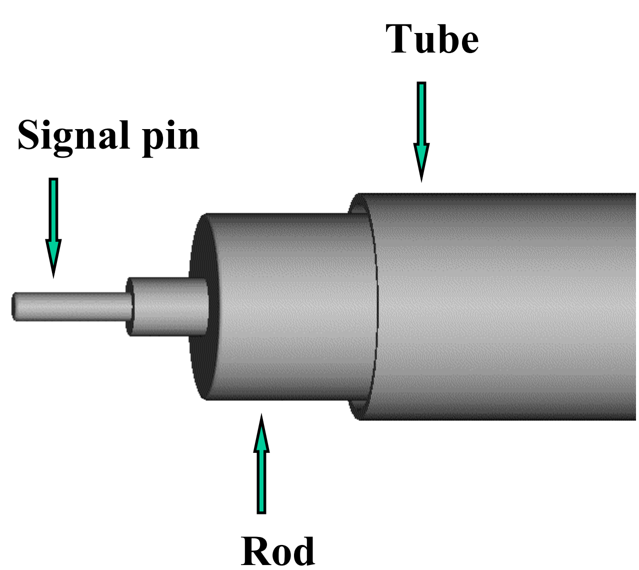




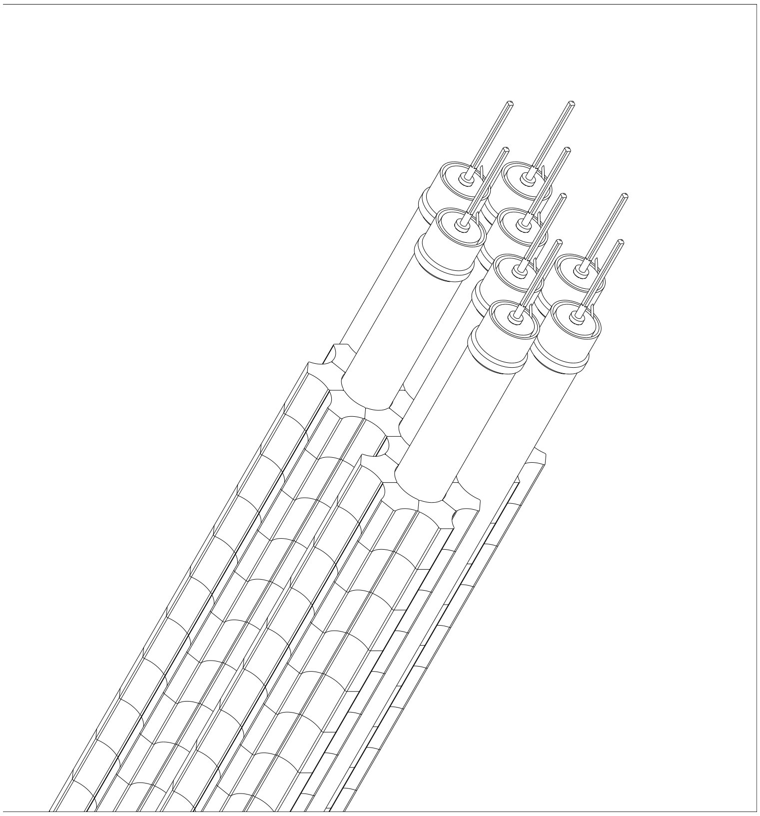
EM Forward Calorimeter Principle







Hadronic Forward Calorimeter Principle

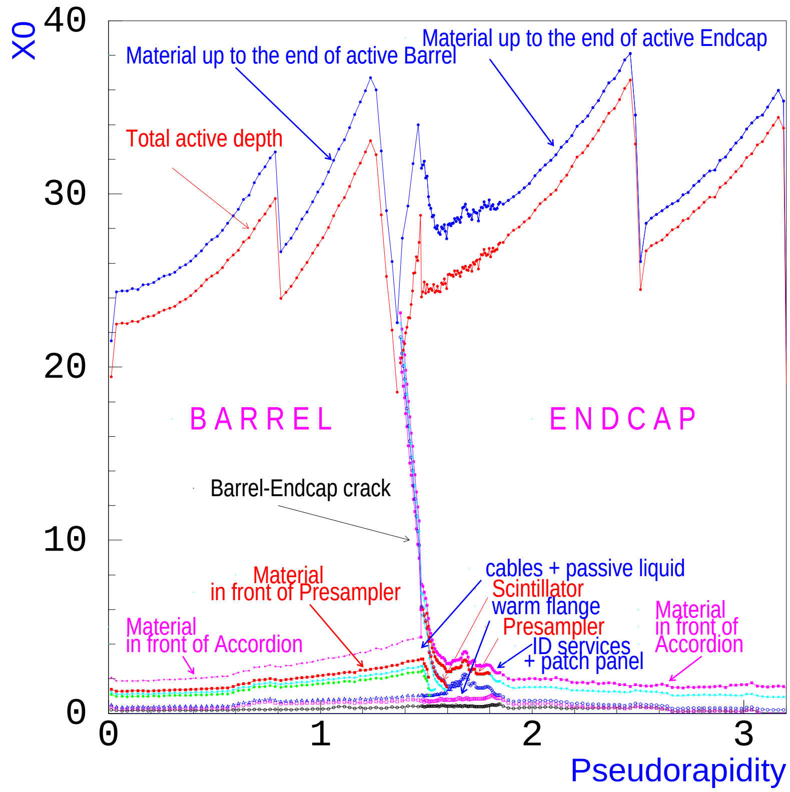


Matrix built of tungsten slugs

Forward Calorimeter Status

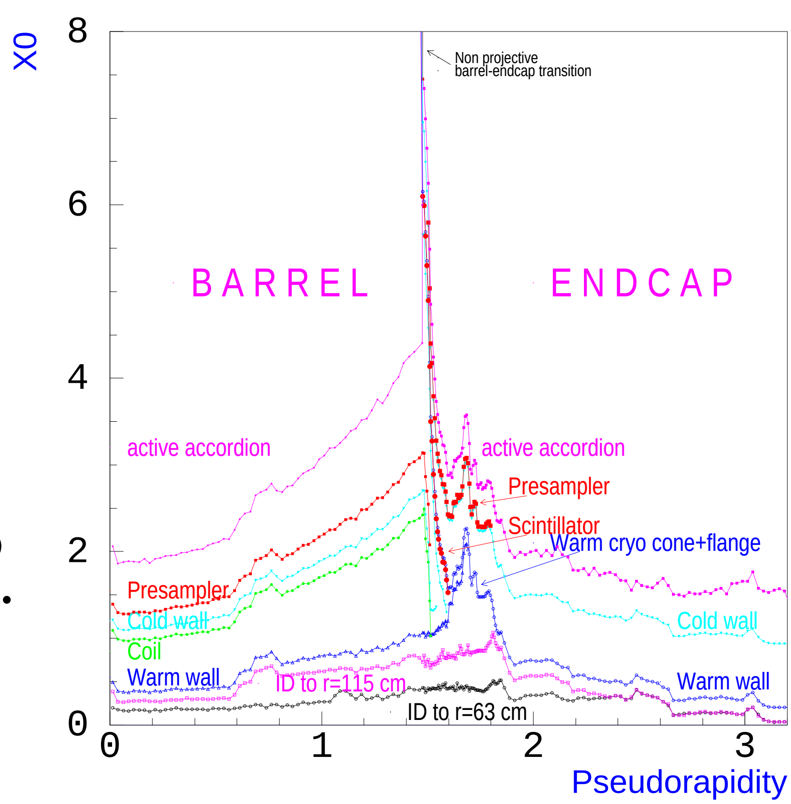
- **Components for FCAL1 and FCAL2 modules re-engineered**
- **Heat loading studies performed**
- **Radiation tests of components have been performed**
- **Module 0 prototype by December 97**
- **Testbeam simulation work ongoing**

Material Budget



More than 24Xo to minimize leakage fluctuation.

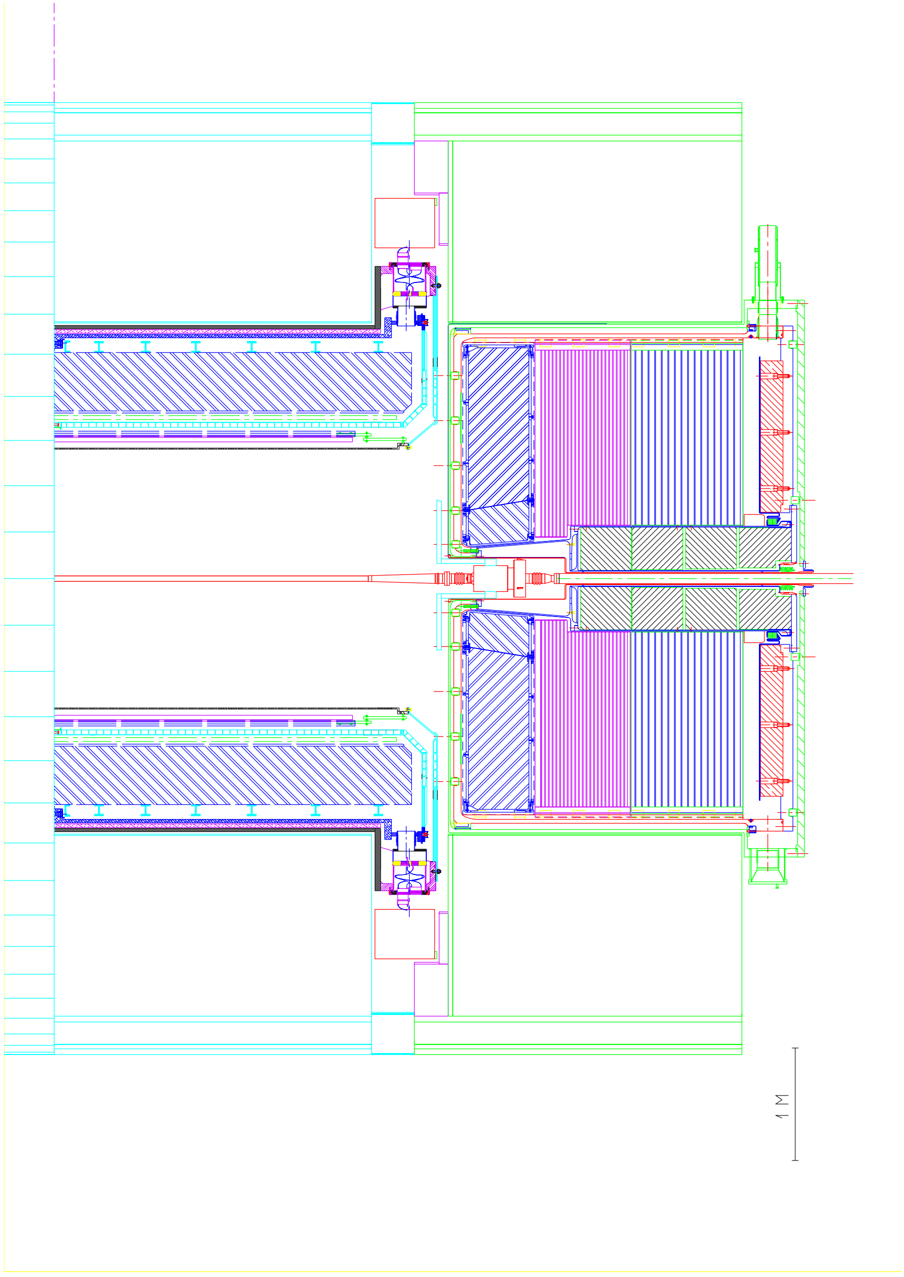
(<0.3% at 1 TeV)



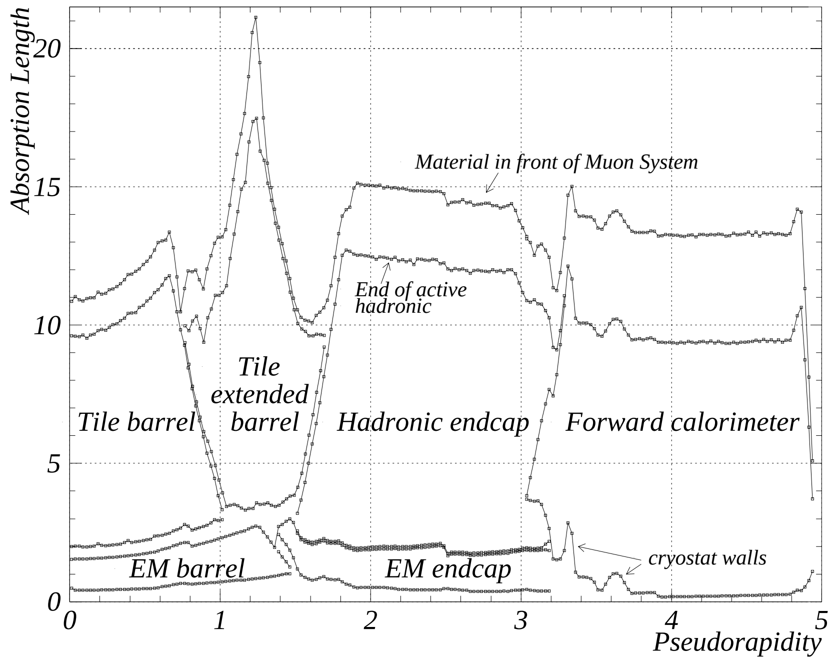
Presampler if more than 2.5 Xo in front of EM:

barrel: 0<|η|<1.51
endcap:1.5<|η|<1.8

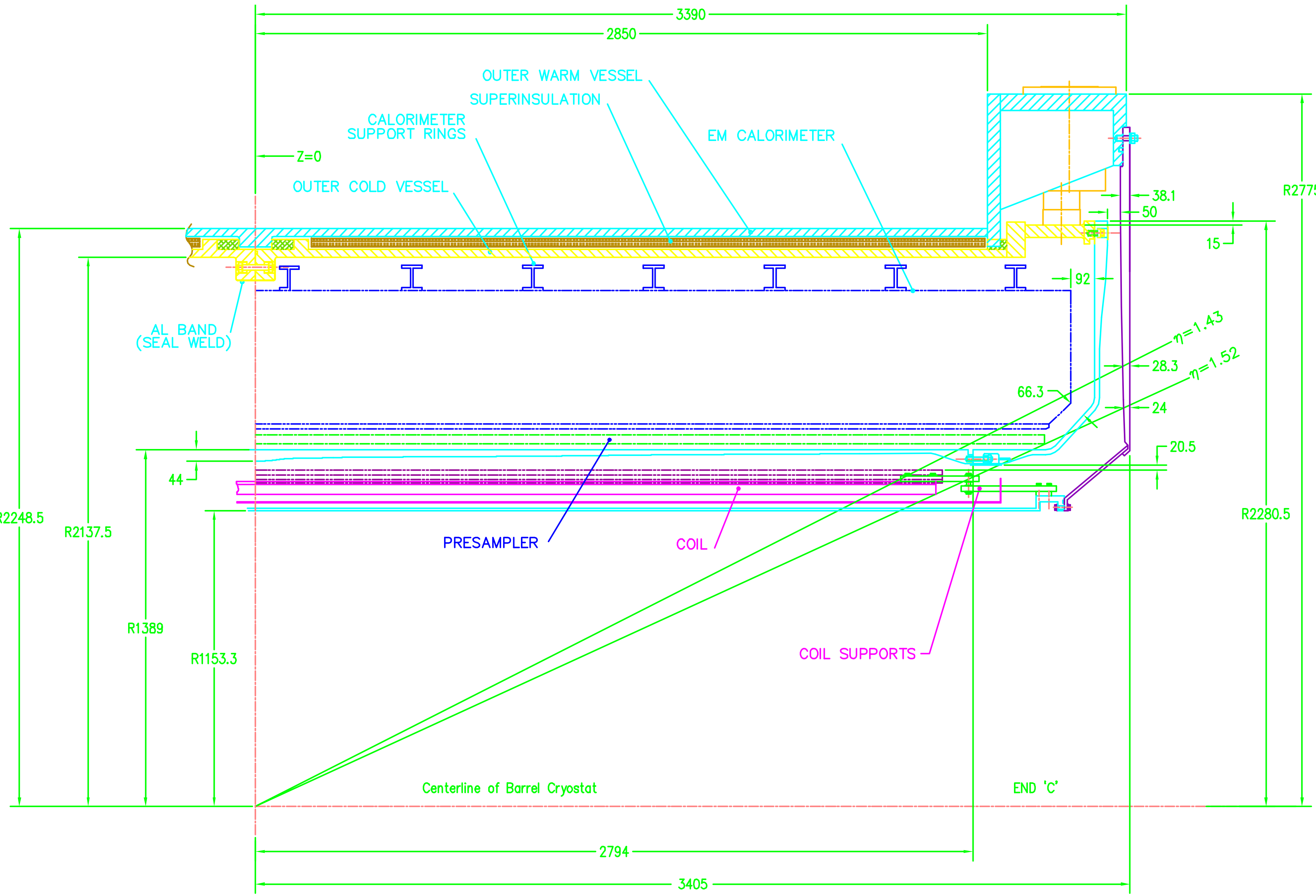
Careful Barrel/Endcap transition optimization.



Material Budget



Barrel Cryostat (longitudinal view)

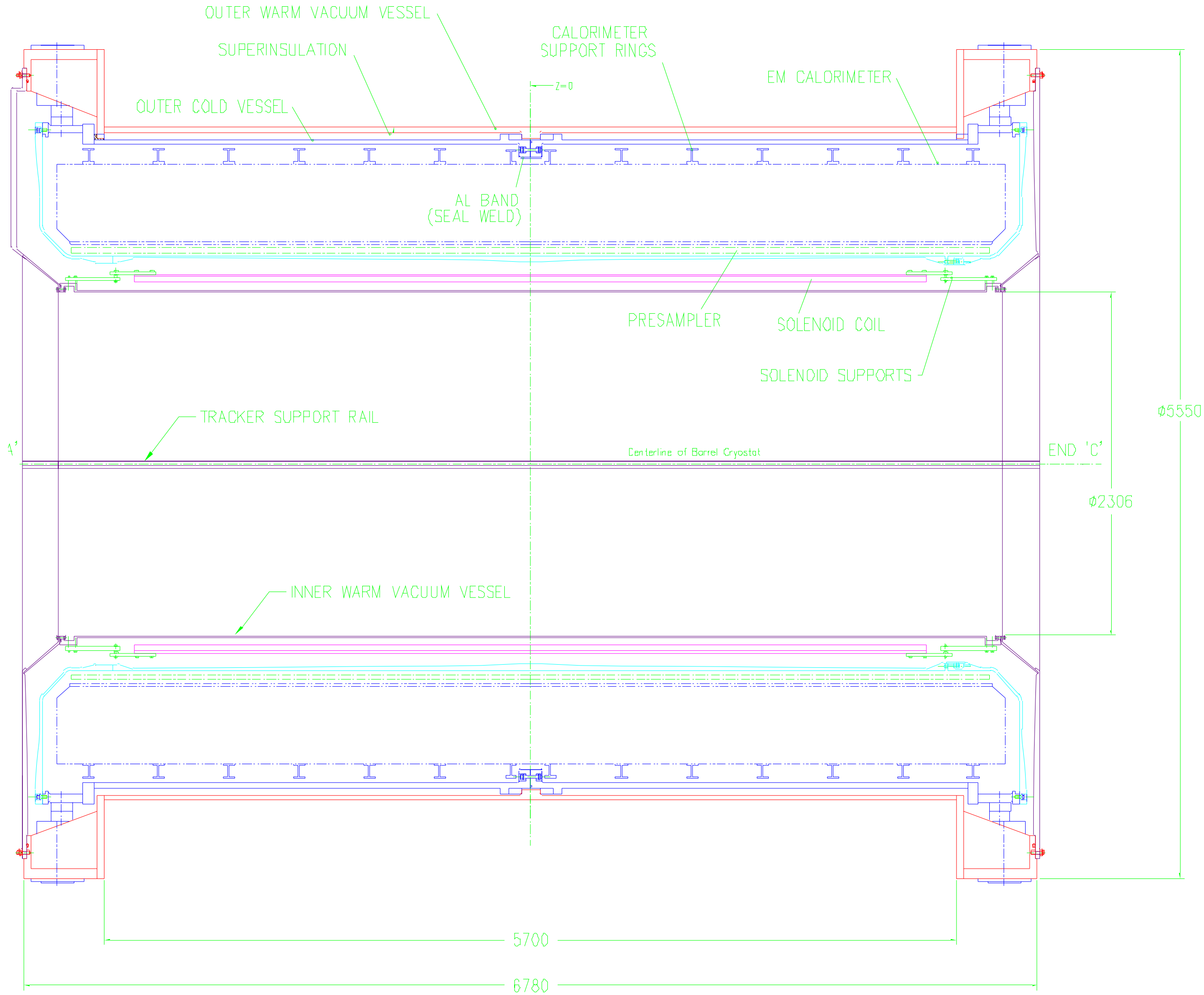


CRYOSTAT VERTICAL AXIS QUARTER-SECTION

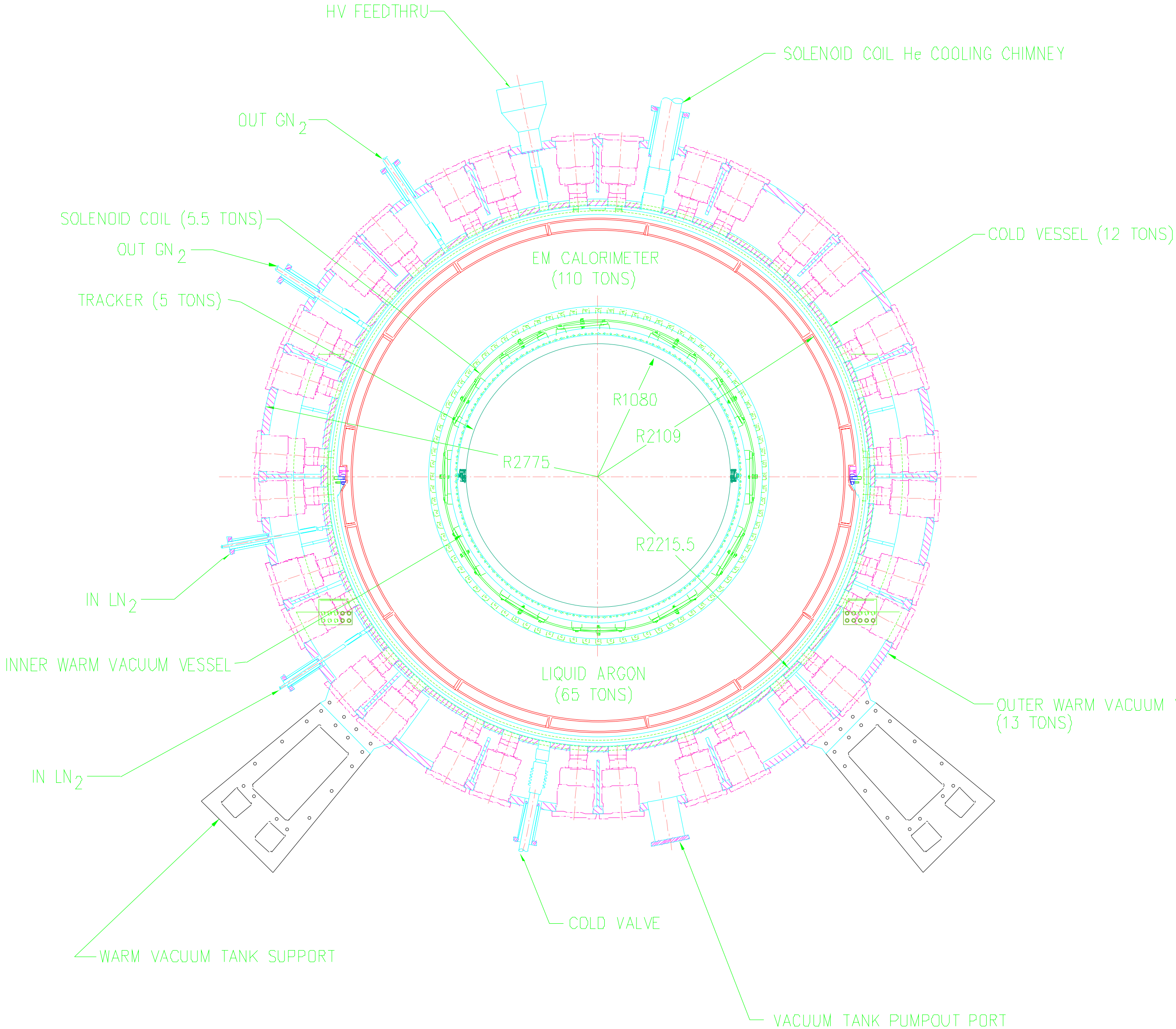
(RADIAL DIMENSIONS ARE NOMINAL VALUES)

qtr-101.dwg
10/1/97

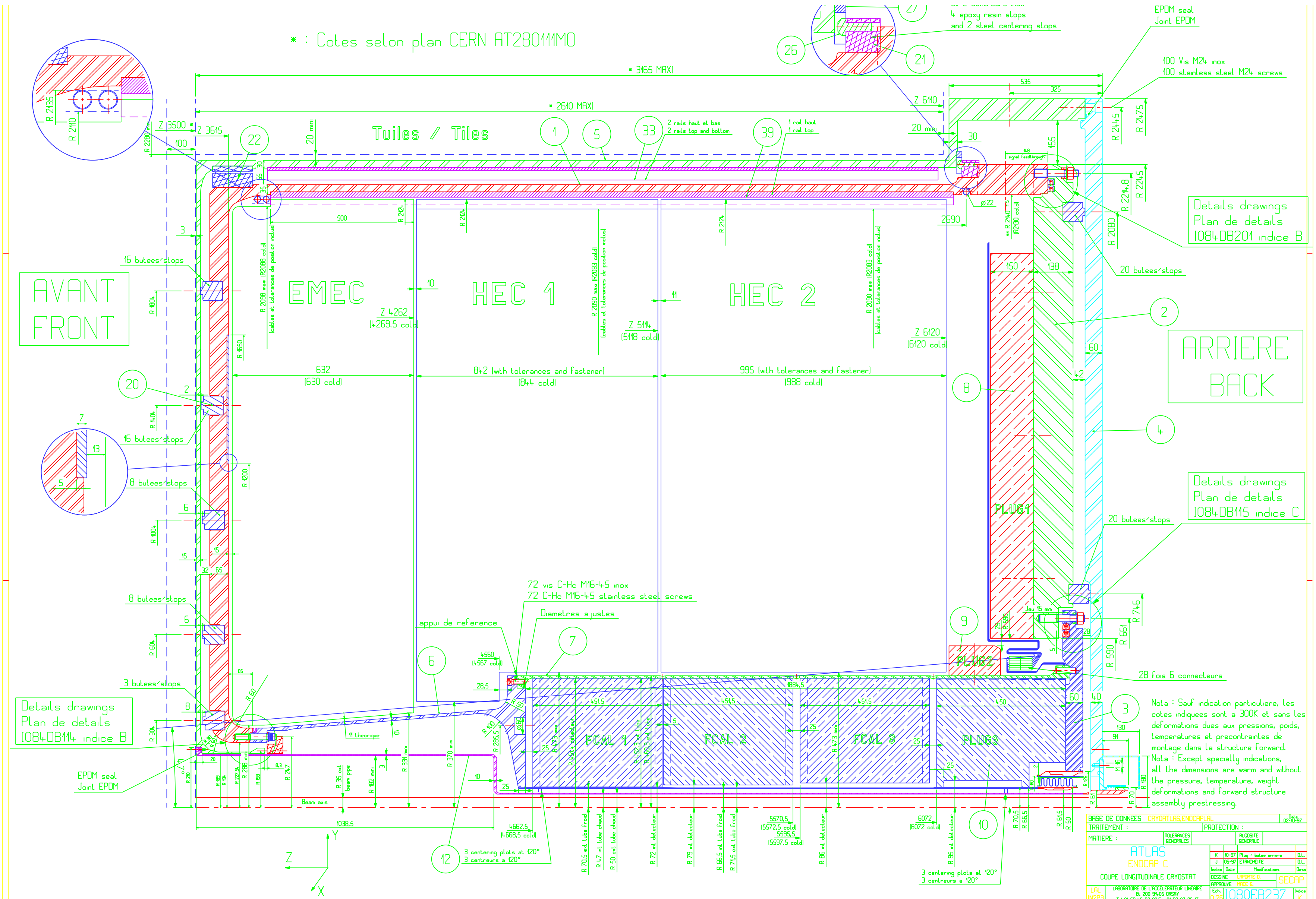
Barrel Cryostat (longitudinal view)



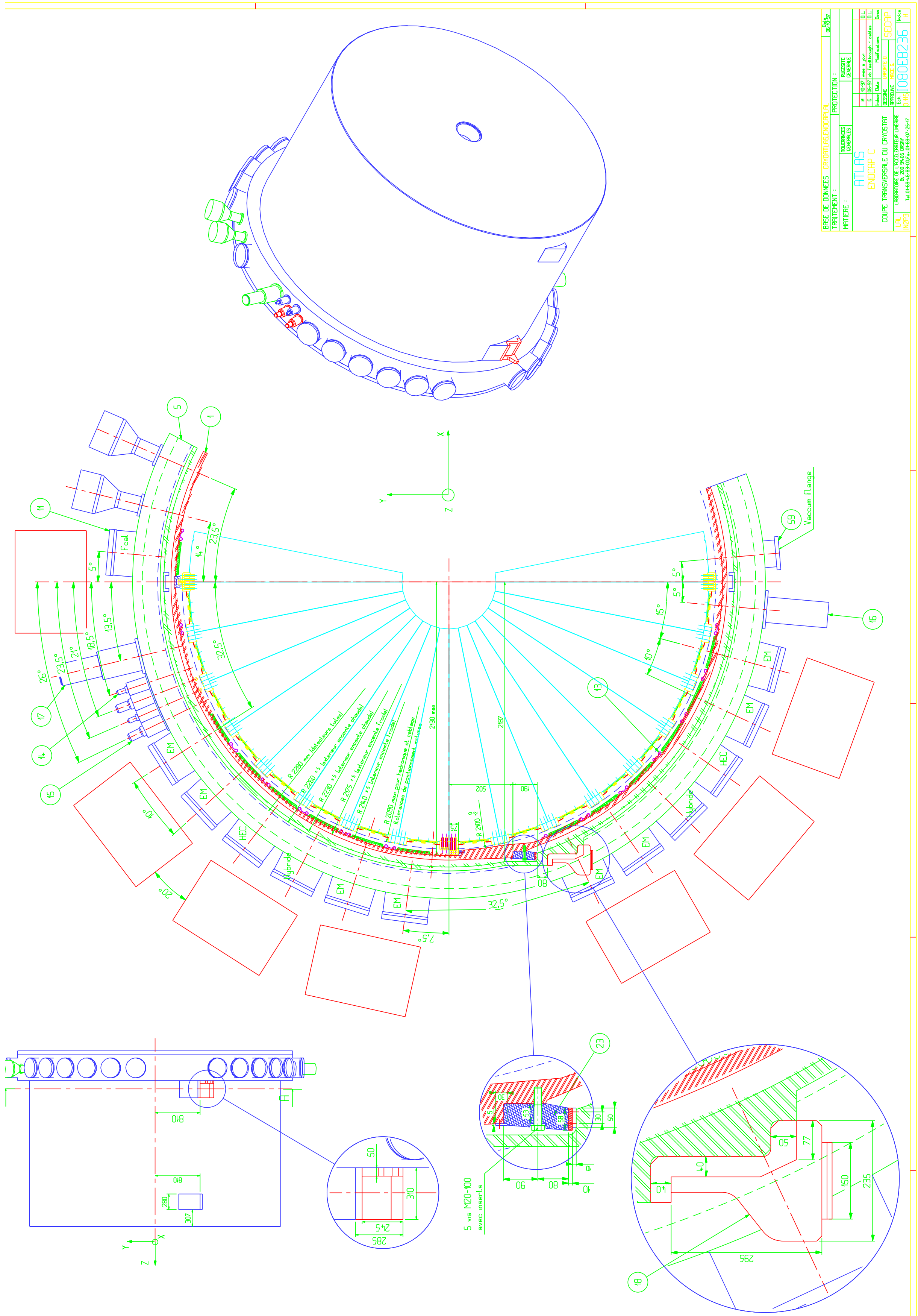
Barrel Cryostat (transverse view)



Endcap Cryostat (longitudinal view)



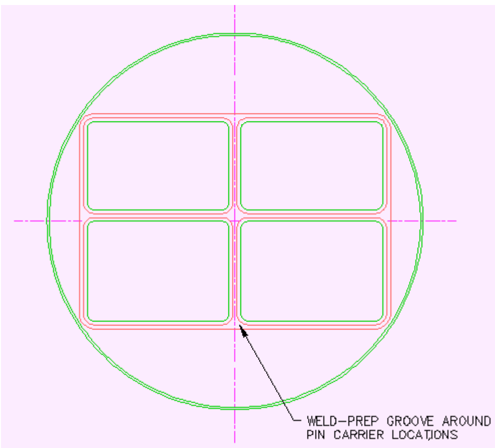
Endcap Cryostat (transverse view)

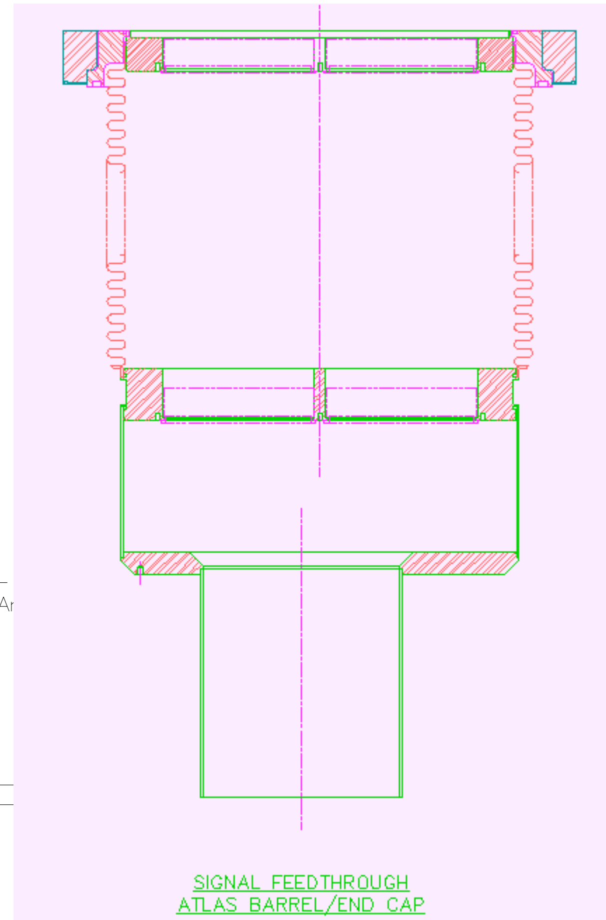


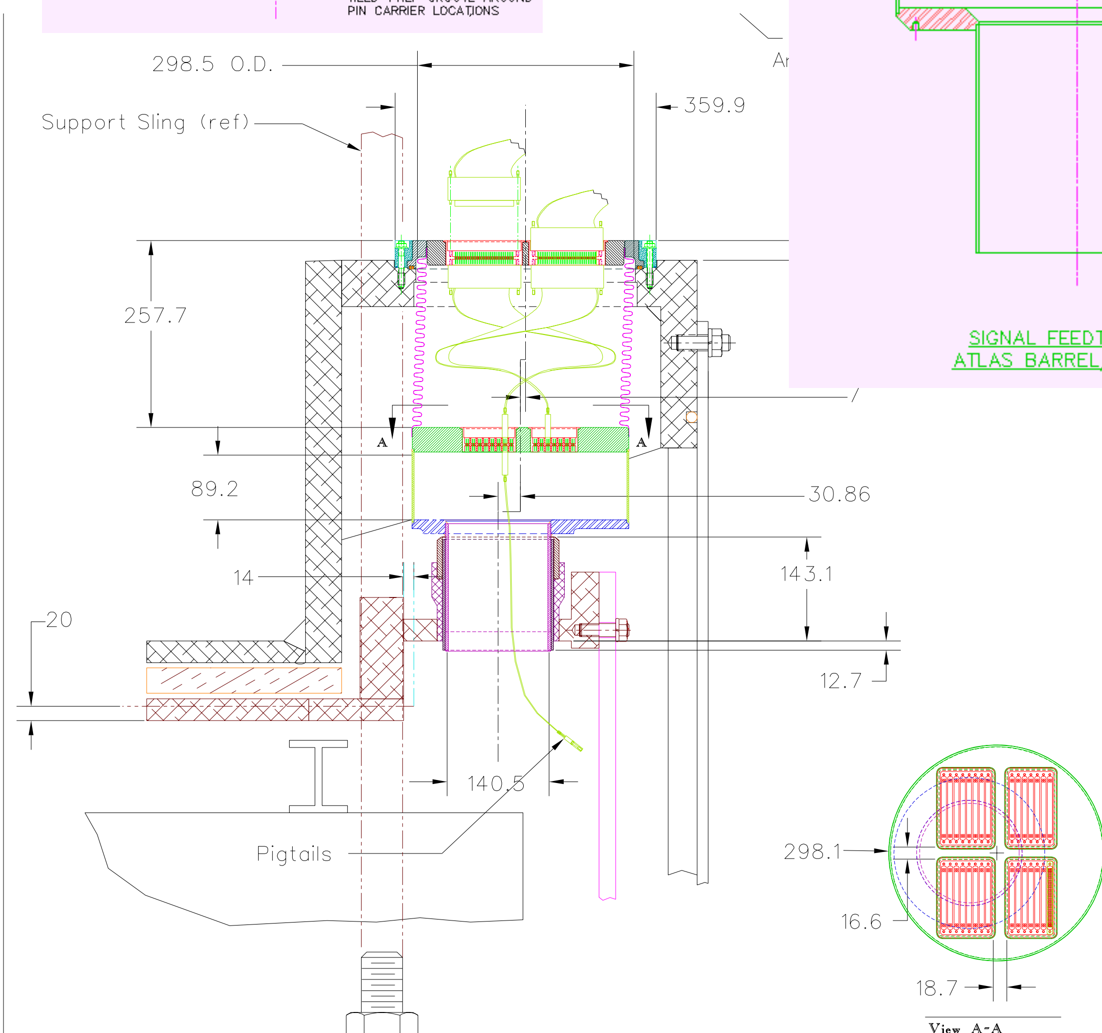
Signal Feedthroughs

Over 180k signal channels in the LAr calorimetry

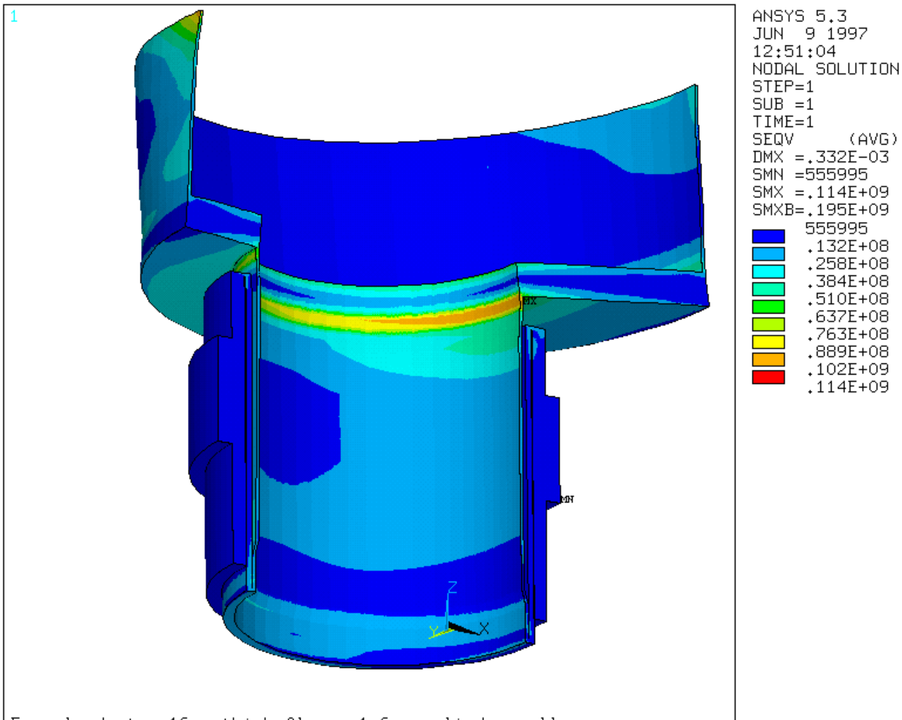
High density and reliability required:
1920 pins per feedthrough unit
barrel: 64 units
endcaps: 50 units total



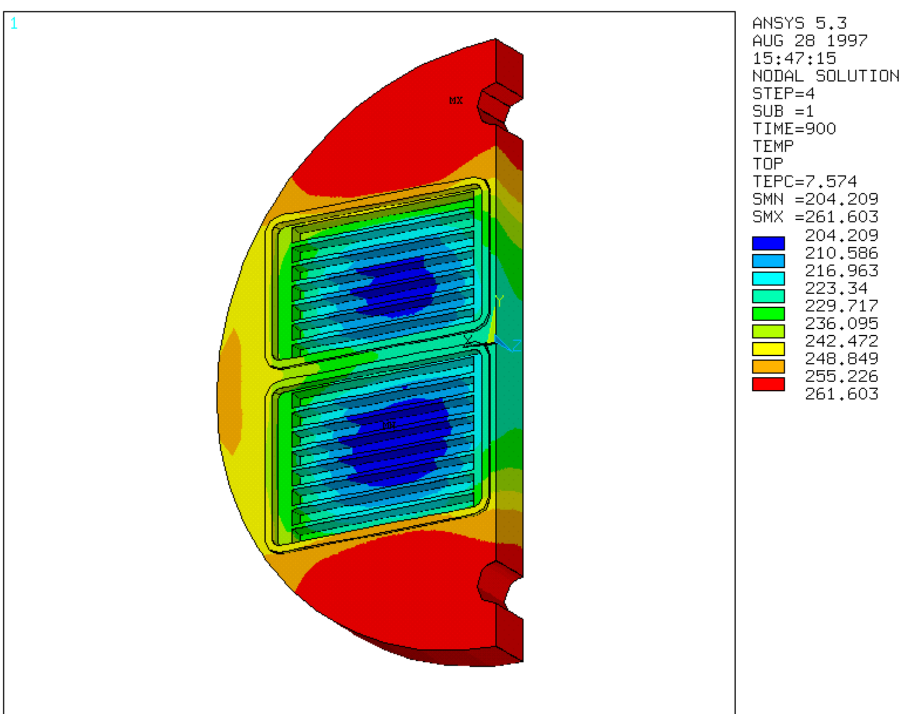




Signal Feedthroughs

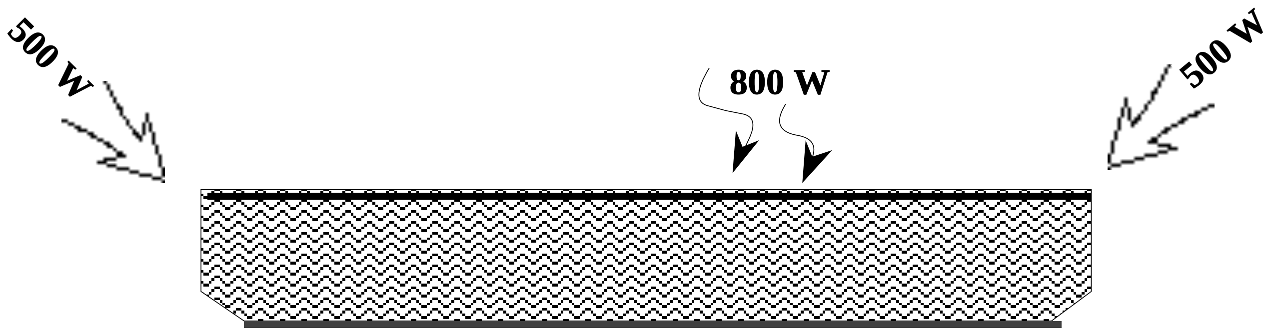


Funnel adaptor,16mm thick flange,1.6mm cylinder walls.



Ambient signal flange cooled by convection in nitrogen gas at 80K

Heat Input

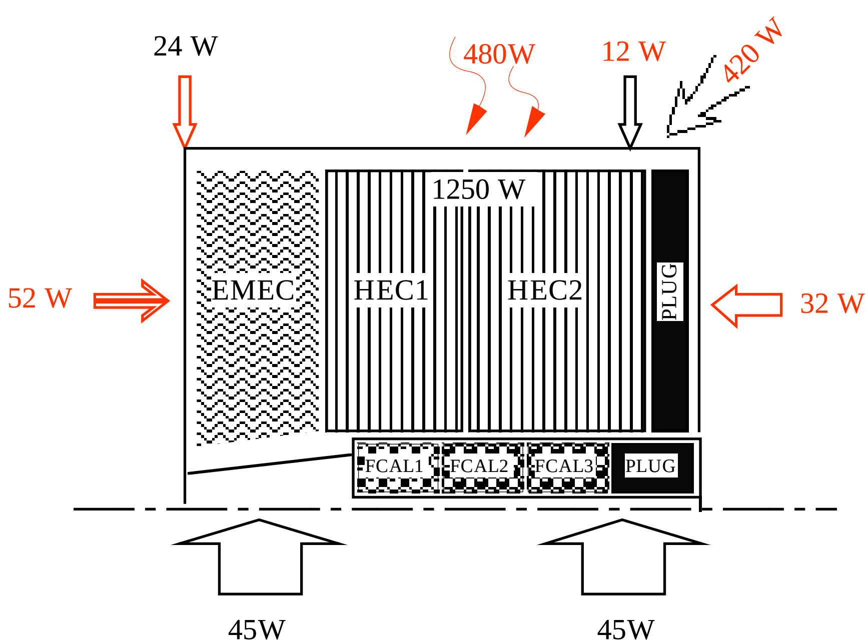


Barrel Heat Leaks (W)

Supports		
	suspensions	30
	stoppers	8
Radiation		796
Feedthroughs		960
Electronics		
Total		**1794**

Endcap Heat Leaks (W)

Supports		
	axial rails	90
	spacers	84
	stoppers	36
Radiation		690
Feedthroughs		420
Electronics		1250
Total		**2570**



Cryogenic System

Cryostats	Barrel	Endcap
Cold vessel volume (m^3)	58	43
Liquid argon volume (m^3)	45	19
Cold vessel weight (t)	12	14
Detector weight (t)	110	219
Full cryostat weight (t)	203	269

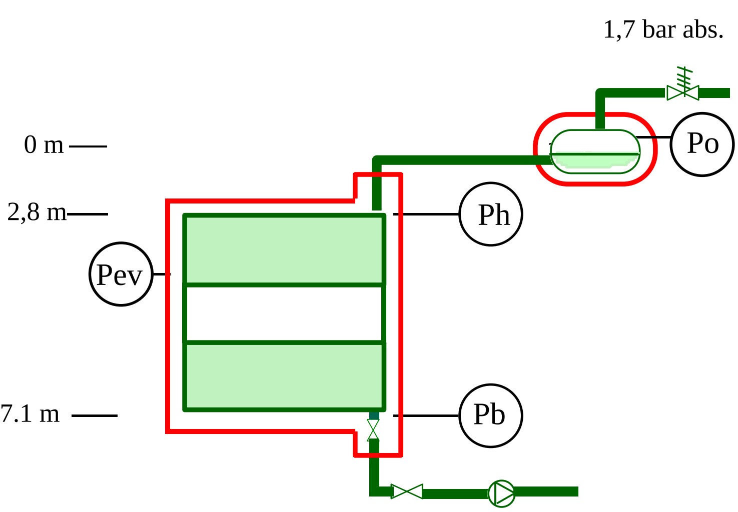
Thermal Balance (kW)

Cryostats	7
Cryolines	2
Dewars, valves	2
Pumps	1
Total heat load	12

Max Pressure (bar abs.)

normal conditions

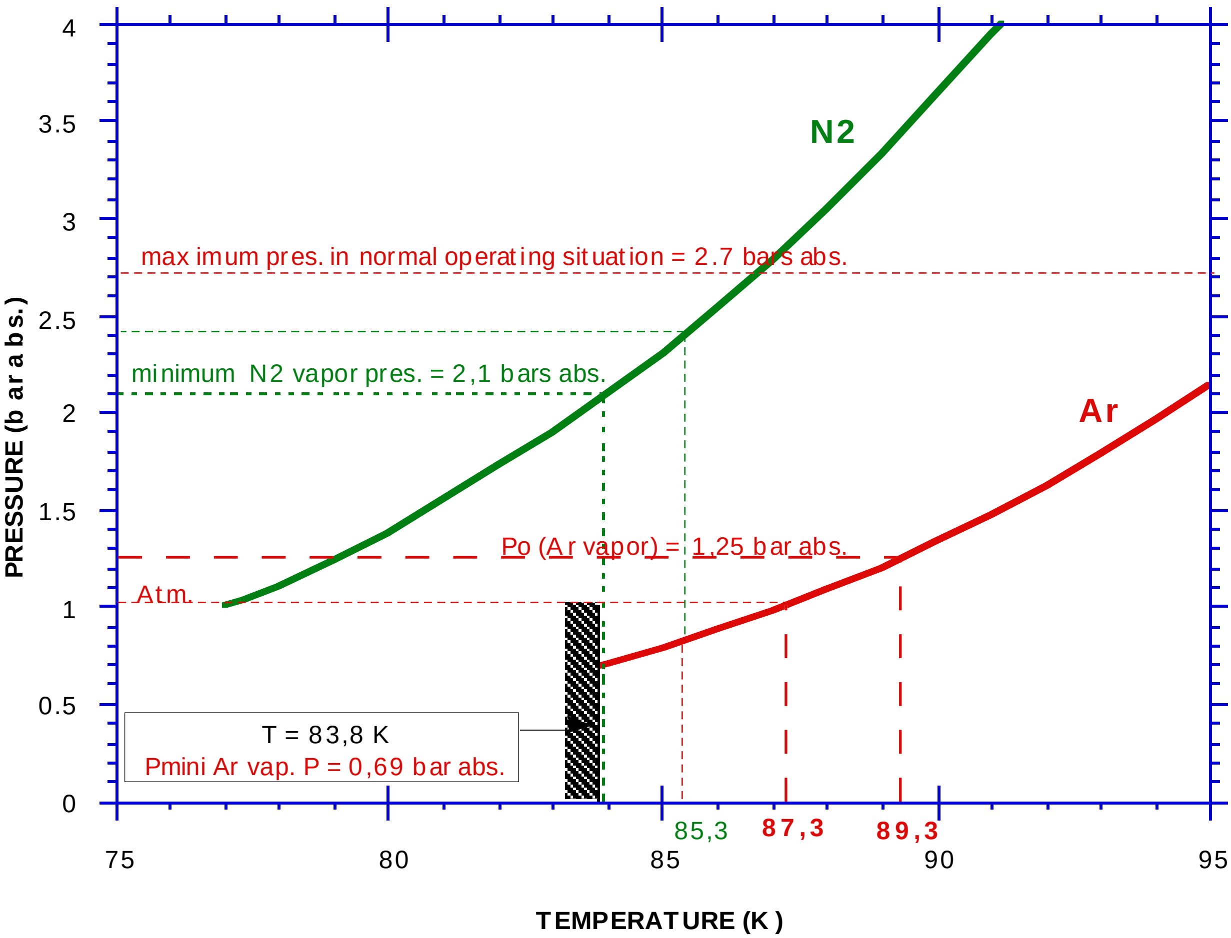
	Barrel	Endcap
Po	1.7	1.7
Ph	2.2	2.1
Pb	2.8	2.8

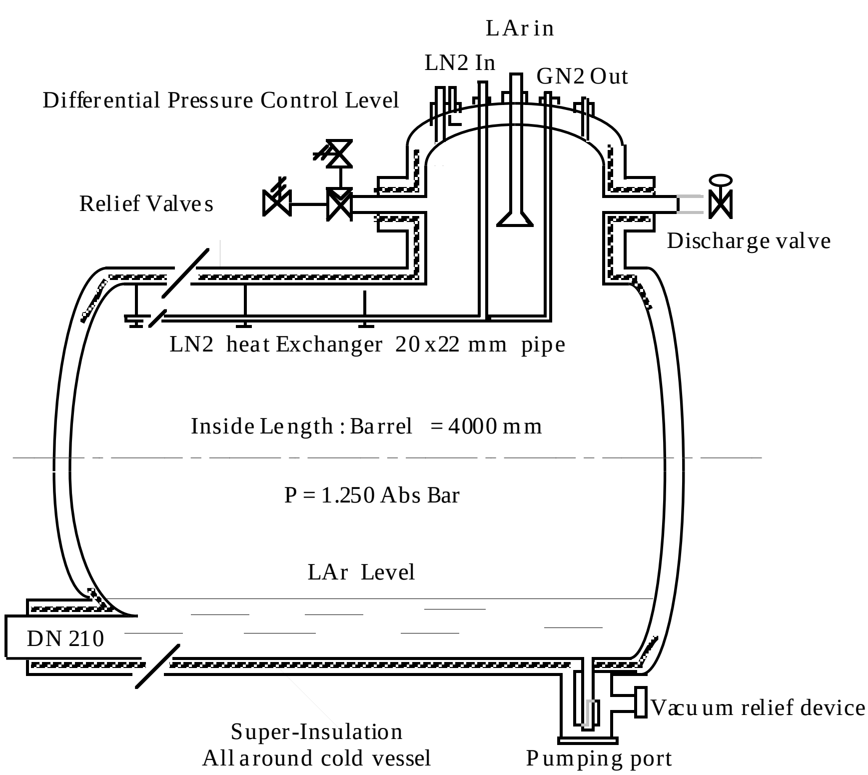


LAr at 1.7 bars

Temperature	92.5 K
Pressure	1.7 bar
Liquid density	1360 kg/m^3
Gas density	9.3 kg/m^3
Vaporization heat	160 kJ/kg
Viscosity	2.2×10^{-4} Pa.s

Heat Exchanger





LN_2 in exchanger:

87.3K @ 2.8bars

LAr in overflow bath:

89.3K @ 1.25bars

LAr set pressure at safety valve:

92.5K @ 1.7bars

Summary

- Liquid Argon calorimetry plays a central role in ATLAS
    - EM barrel and presampler
    - EM endcap and presampler
    - Hadronic endcap
    - Forward
- Over 7 years of succesful R&D
- ATLAS calorimetry TDR approved:
  ATLAS is now in its construction phase!
- Modules 0 construction and tests progressing
    - Hadronic Endcap already has 2 modules in beam
- Cryostat designs being finalized