Canada and the ATLAS Experiment

TRIUMF

May 21st 1998

The future Large Hadron Collider (LHC) at CERN will provide 14TeV centre-of-mass proton-proton collisions. The ATLAS detector, currently under construction, is designed to take full advantage of the LHC discovery potential. The ATLAS detector and its experimental programme will be briefly reviewed, with emphasis on its Canadian content.

Michel Lefebvre
University of Victoria
Physics and Astronomy

Physics Motivation

Large Hadron Collider at CERN

Allow to perform experiments

at constituent energies in the 1-2 Tev region

using

14 TeV pp collisions

Understand the Physical Origin of the

Electroweak Symmetry Breaking

and the

Origin of Mass

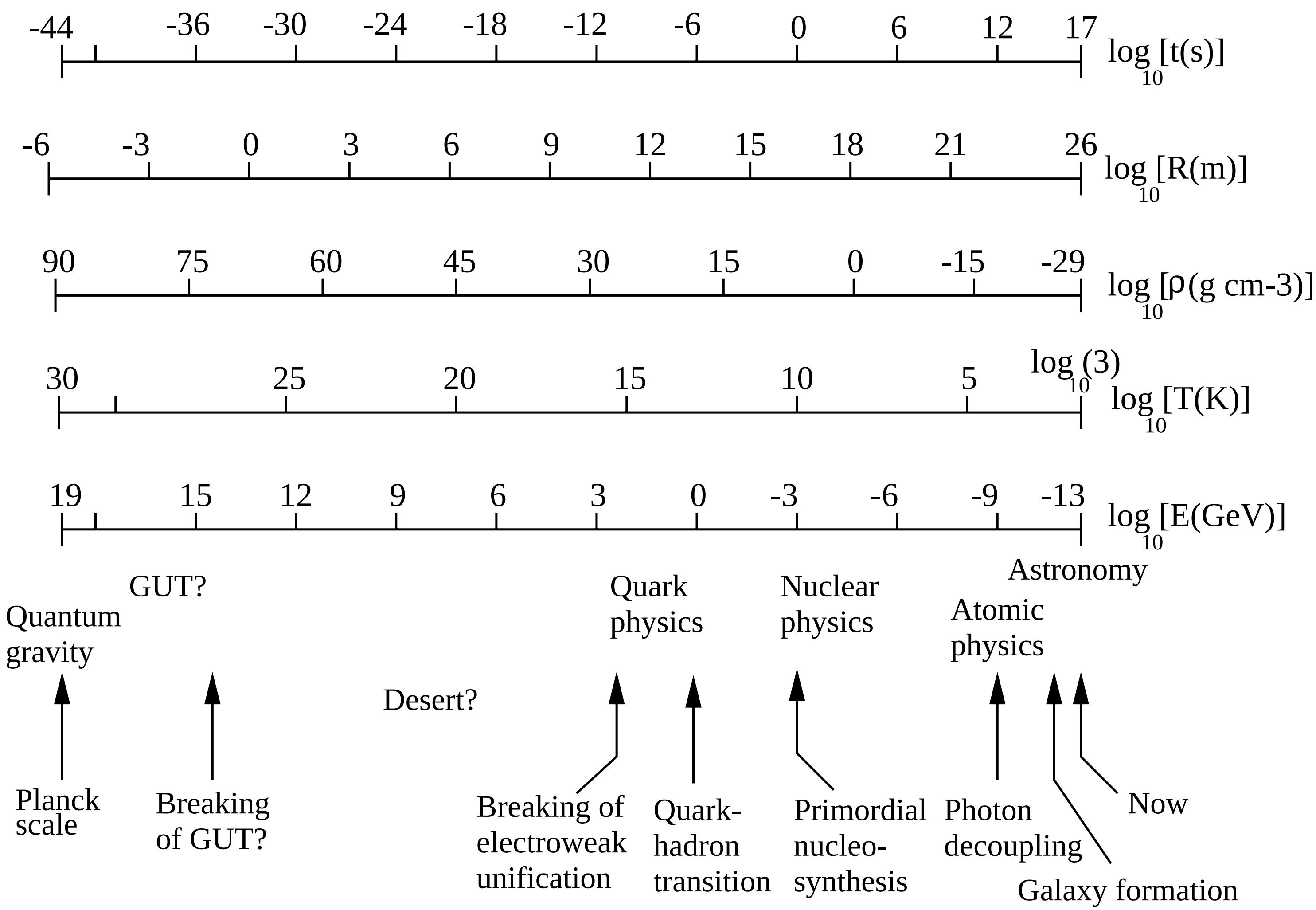
Higgs to be found below $\approx$ 1 TeV

and/or

New Physics beyond the Standard Model

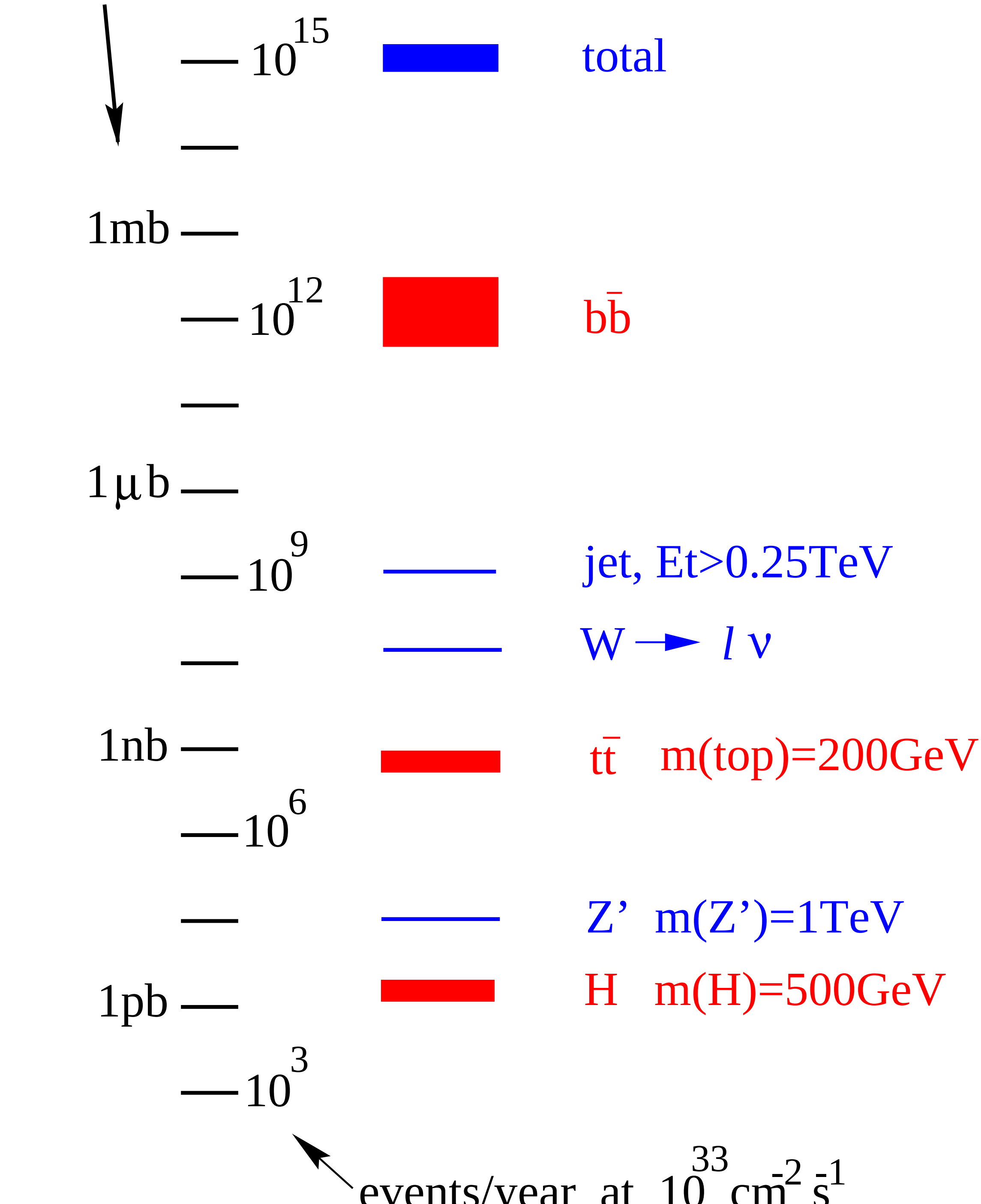
Space, Time and Energy Frontier

The "History" of the Universe from the Planck time to the present, showing how the size of the presently observable universe R, the average density ρ, the temperature T, and the energy per particle kT, have varied with time t according to the hot big bang model.



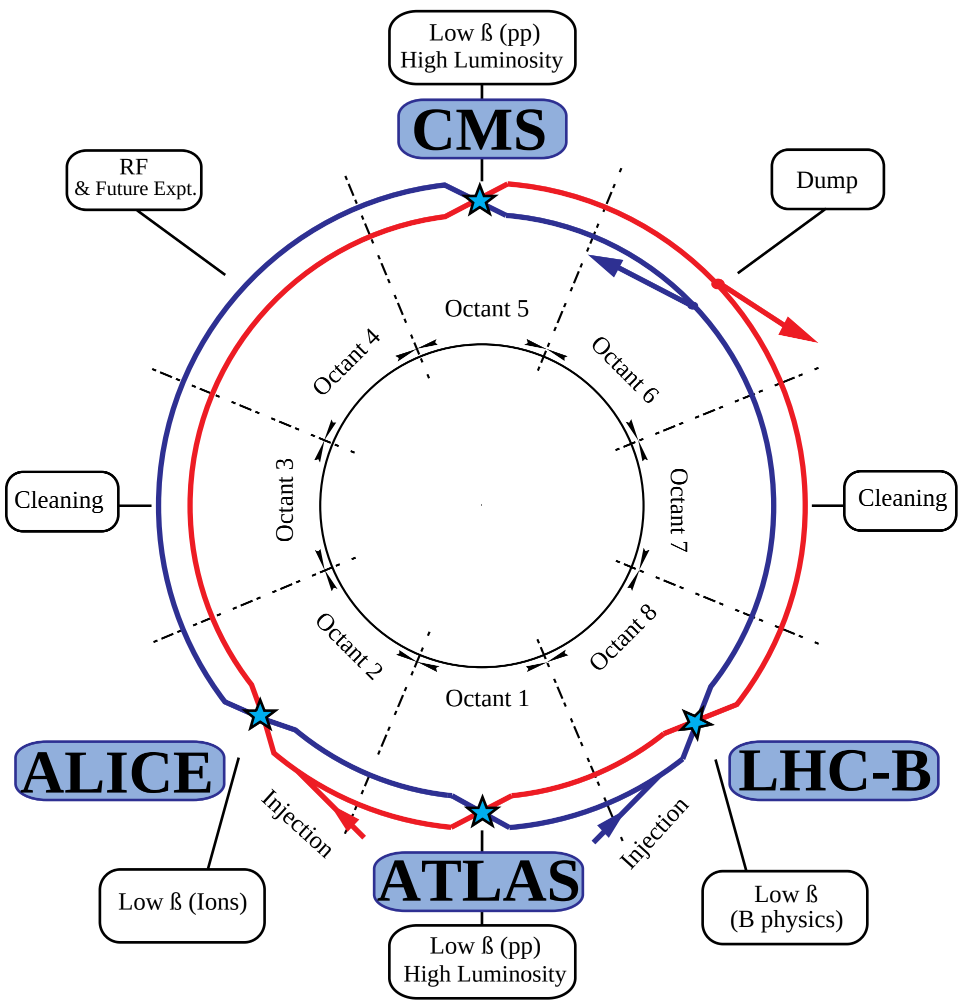
PP Cross Section

- High Luminosity needed
- Large background to overcome

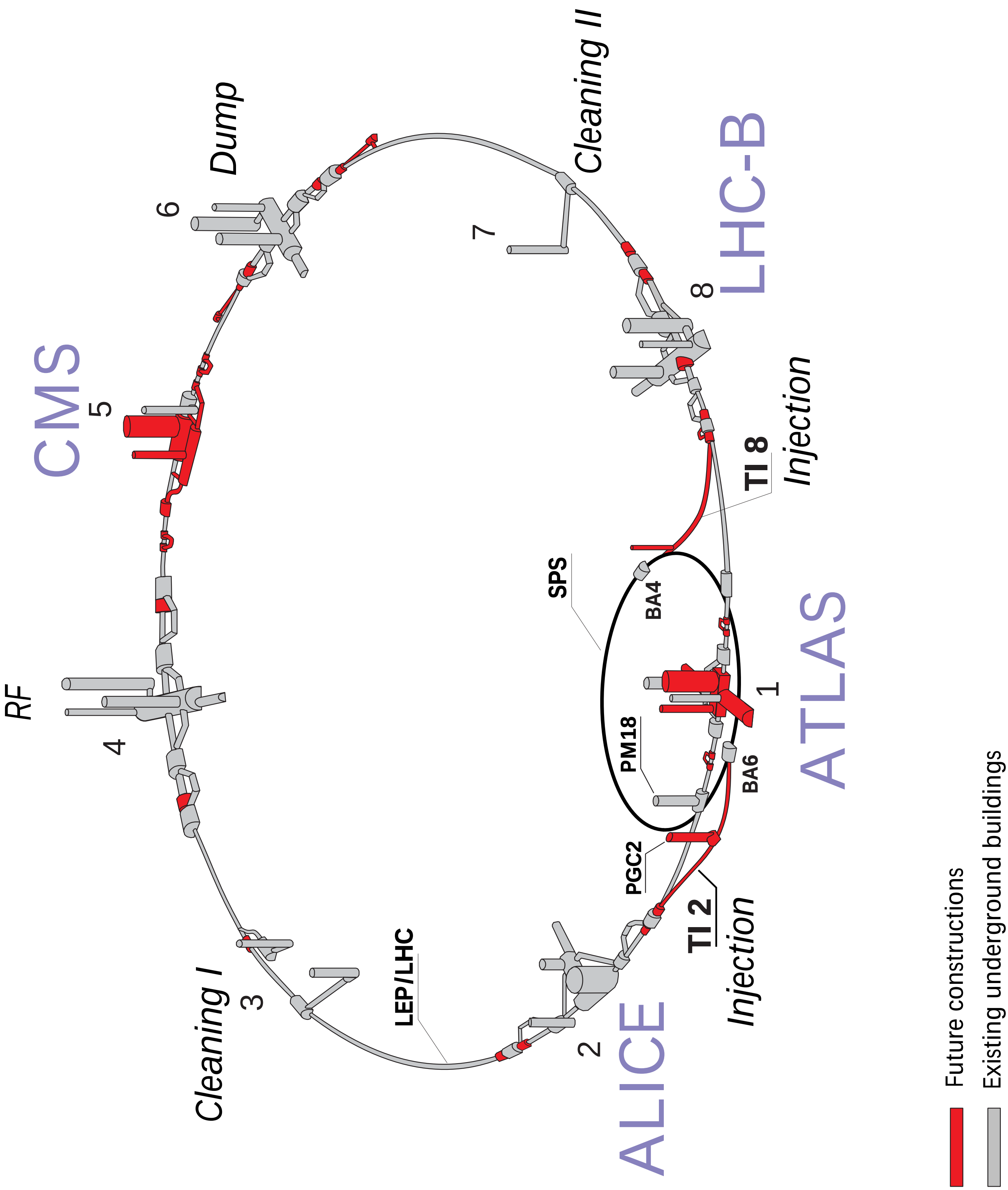


LHC Parameters

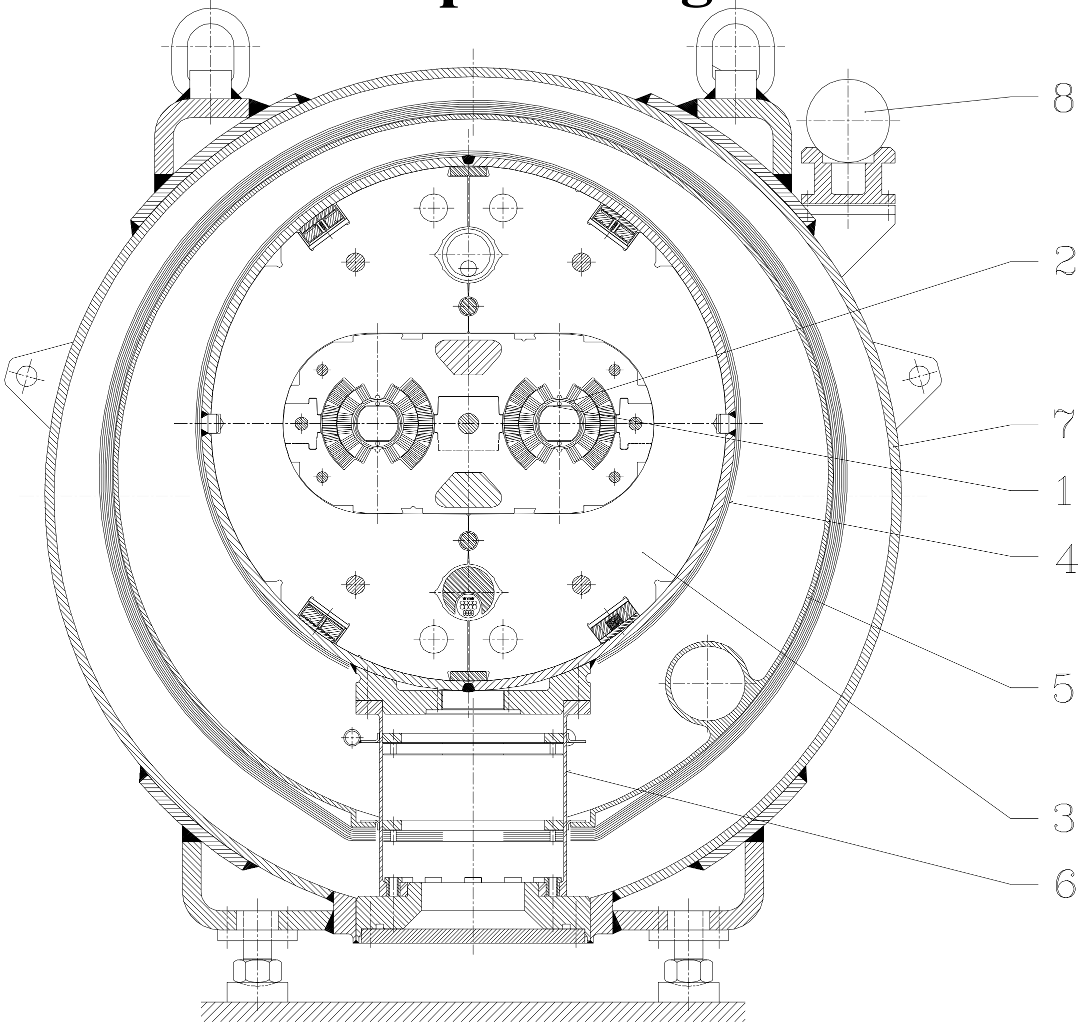
Circumference C	26659	m
Energy E	7	TeV
Dipole field B	8.4	T
Bunch spacing s	25	ns
Bunch population N	10^{11}	
Bunch radius $\sigma_x = \sigma_y$	16	μm
Bunch length σ_s	75	mm
Beam-beam parameter ξ	0.0034	
Luminosity L	10	$\text{nb}^{-1}\text{s}^{-1}$
Distance to nearest quadrupole ℓ_Q	± 23	m
Events/collision n_c	19	



LHC Engineering

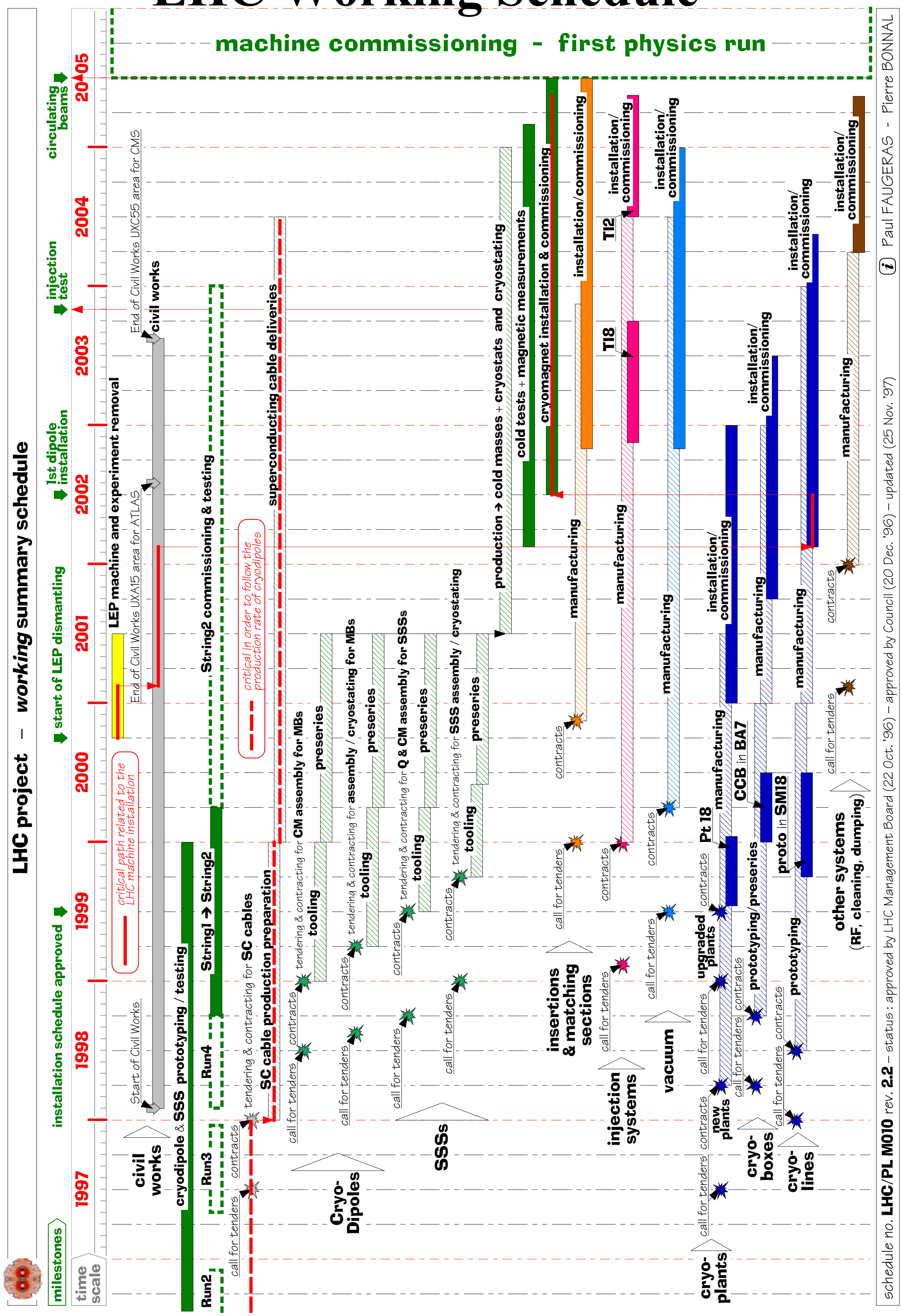


LHC Dipole Magnet

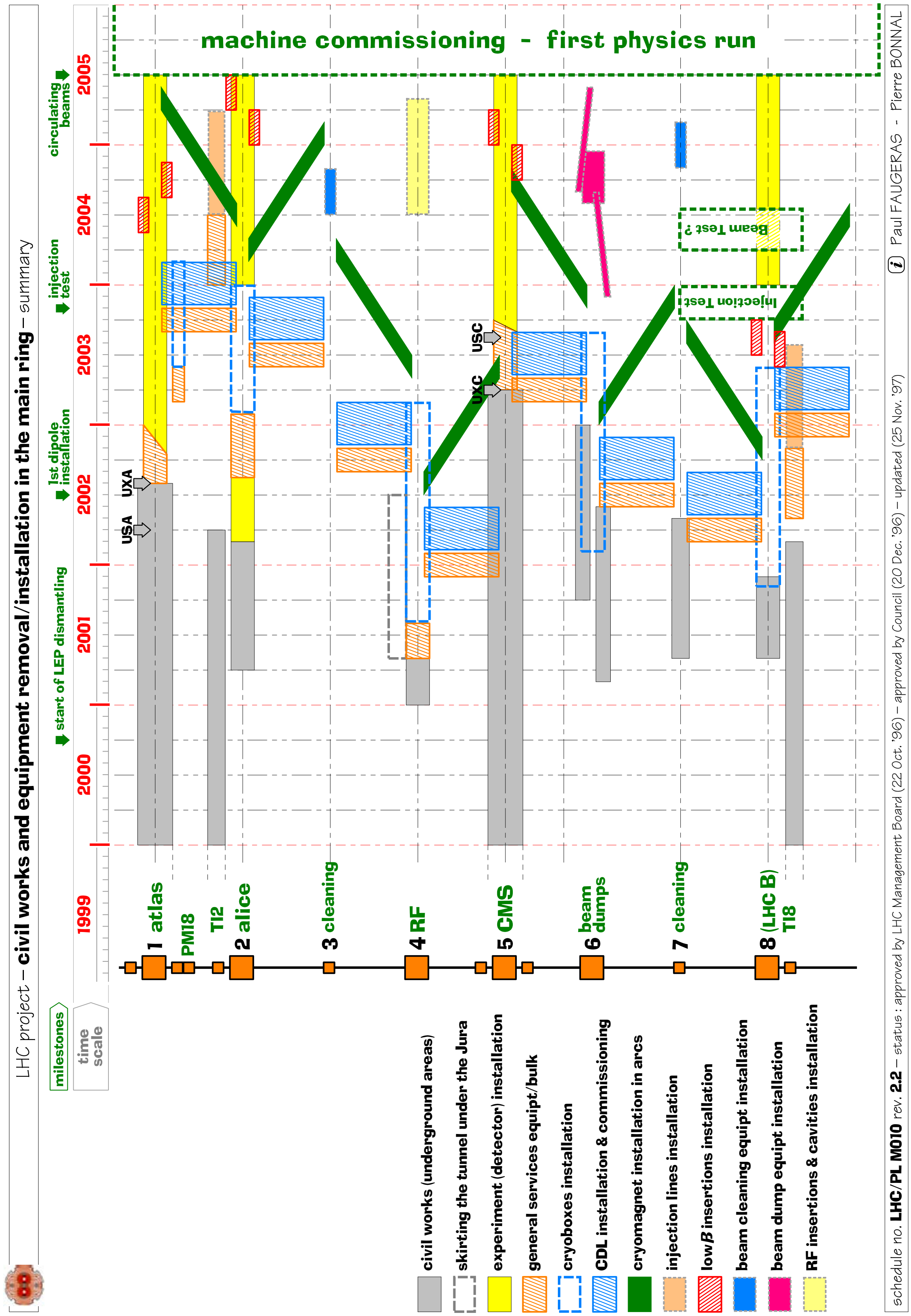


1- Beam Screen
2- Cold Bore
3- Cold mass at 1.9K
4- Radiative insulation
5- Thermal shield at 55 to 75K
6- Support post
7- Vacuum vessel
8- Alignment target

LHC Working Schedule



LHC Installation Schedule



ATLAS

General-purpose pp detector

designed to exploit the full discovery potential of the LHC

Designed to operate at

high luminosity

$10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

and at initial lower luminosities

Designed to be sensitive to many signatures

$\mathrm{e}, \gamma, \mu, \mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{b}$ - tagging,...

and to more complex signatures

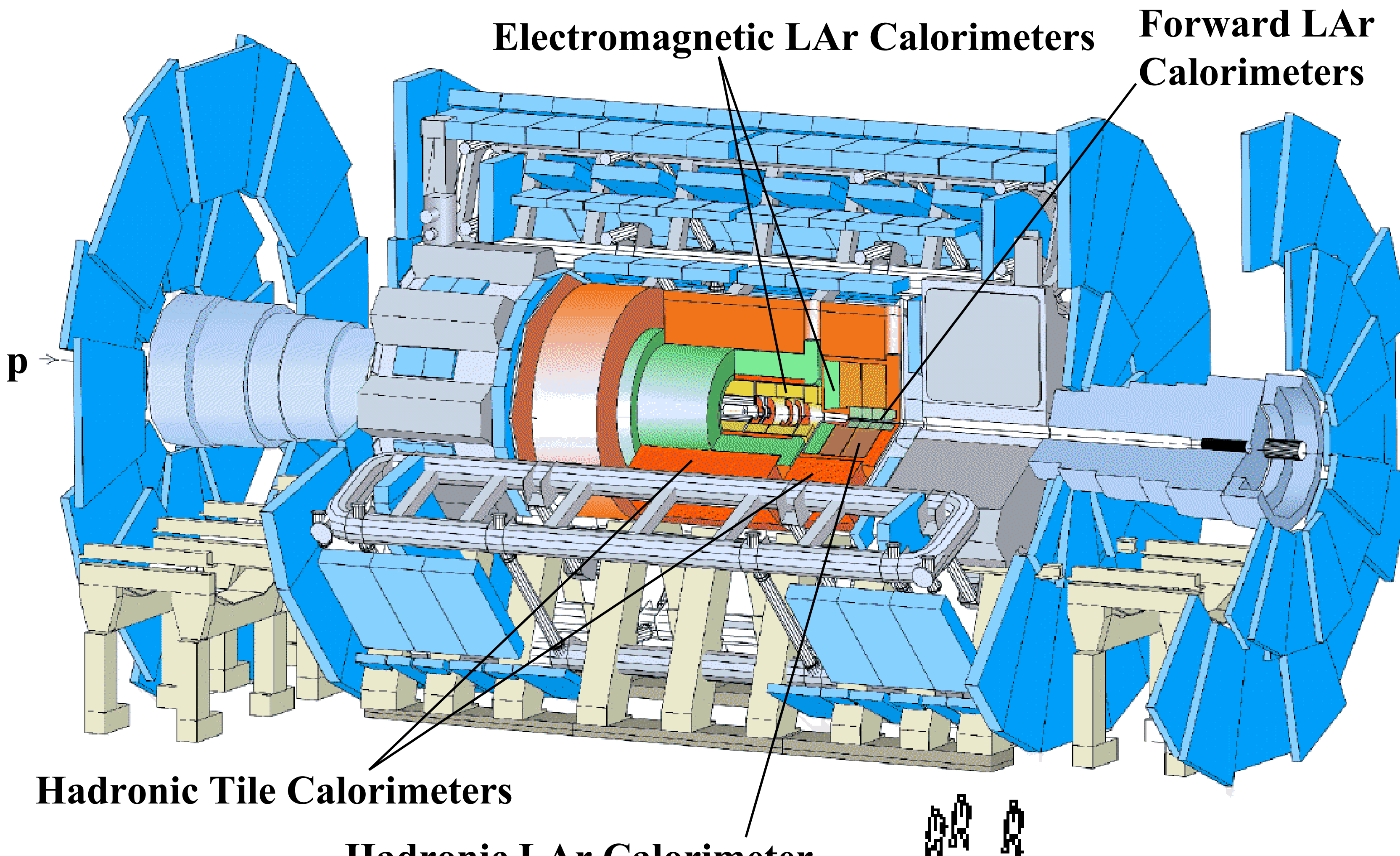
τ and heavy flavour from secondary vertices

ATLAS Collaboration

144 Institutes, 37 Funding Agencies

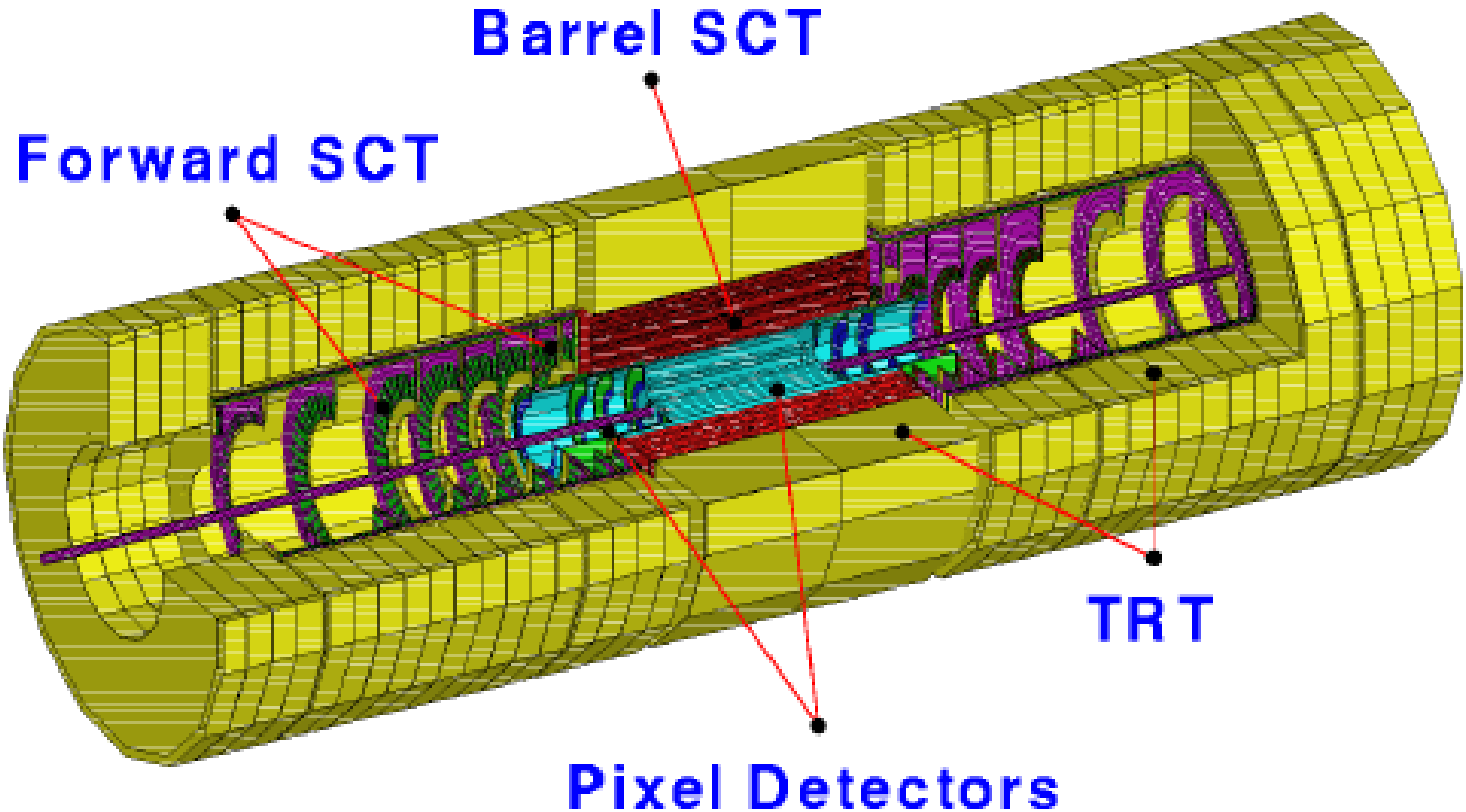
Mar 92 Expression of Interest
Oct 92 Letter of Intent
Jun 93 Green light to proceed towards a Technical Proposal
Dec 94 Technical proposal
Jan 96 ATLAS approval
97 Start of construction
Jul 05 First collisions

The ATLAS Detector



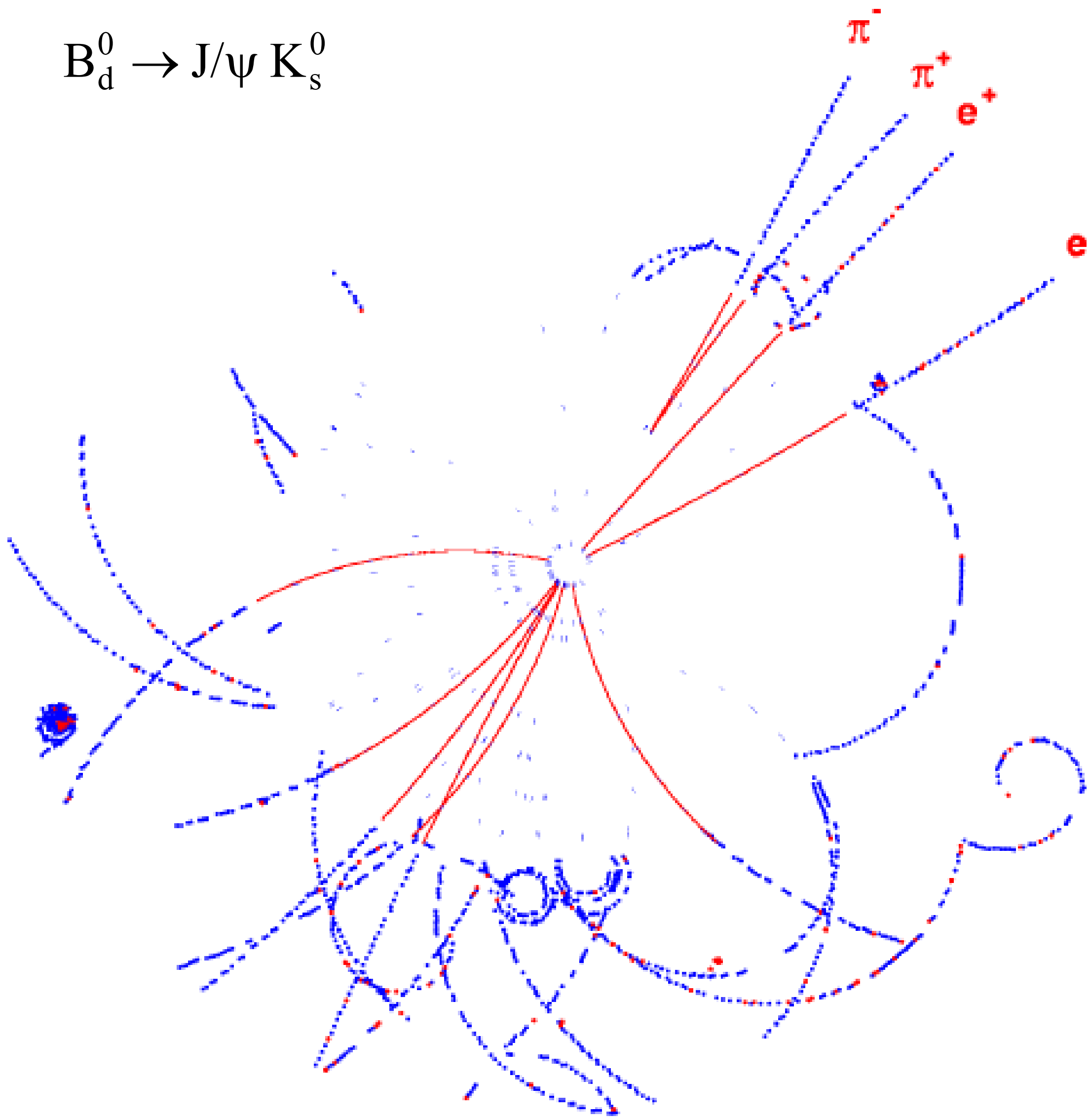
Inner Detector

R < 115 cm



Inner Detector

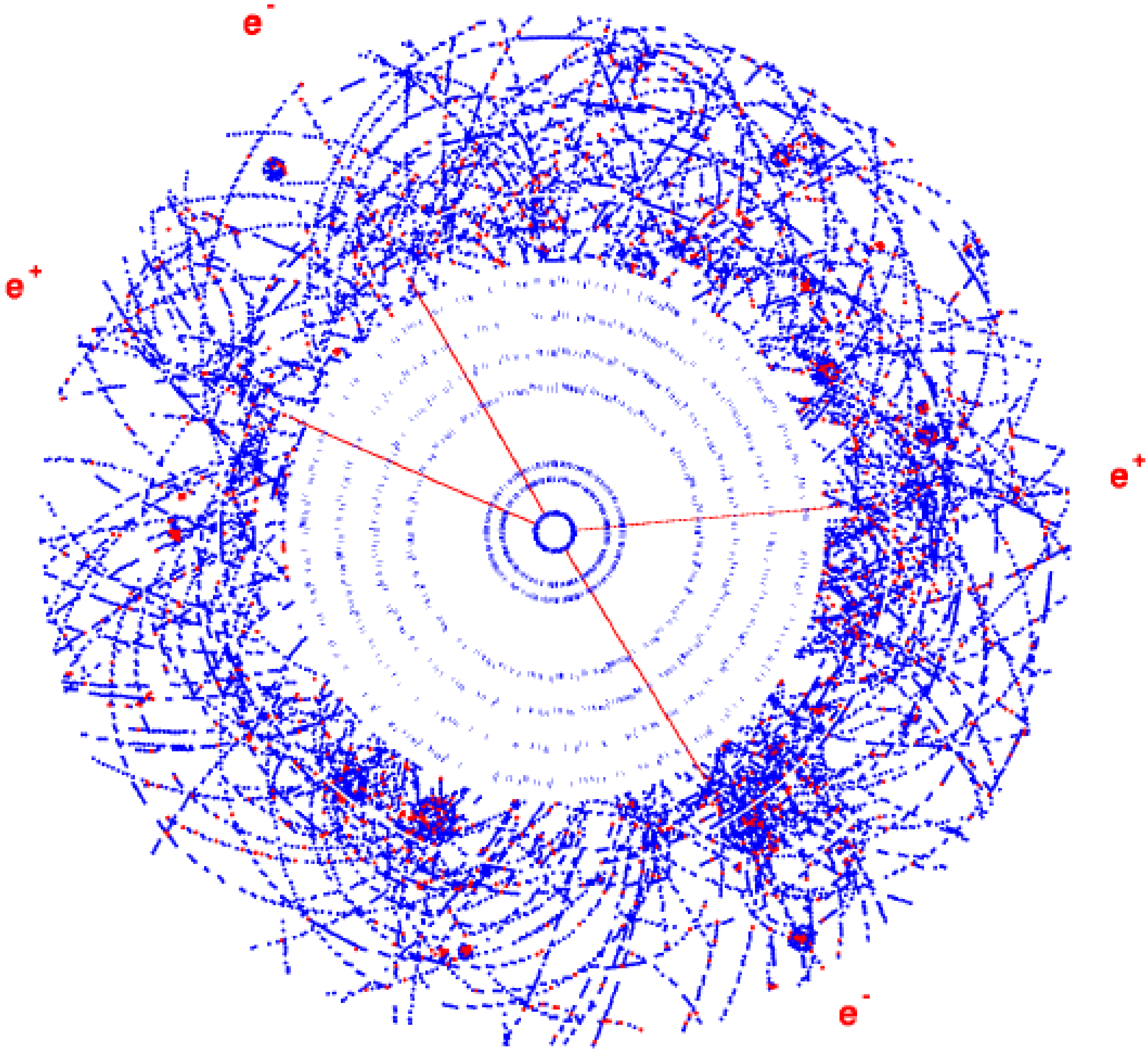
$B_d^0 \rightarrow J/\psi\, K_s^0$



Low luminosity simulation. Precision hits are shown for $0 < \eta < 0.7$; TRT hits are shown in barrel for z > 0; high threshold transition radiation hits are shown as red points. Fitted tracks (red), with $p_T > 0.5\,\mathrm{GeV}$ and $0 < \eta < 0.7$, are shown just in the precision tracker so as not to obscure the TRT hits.

Inner Detector

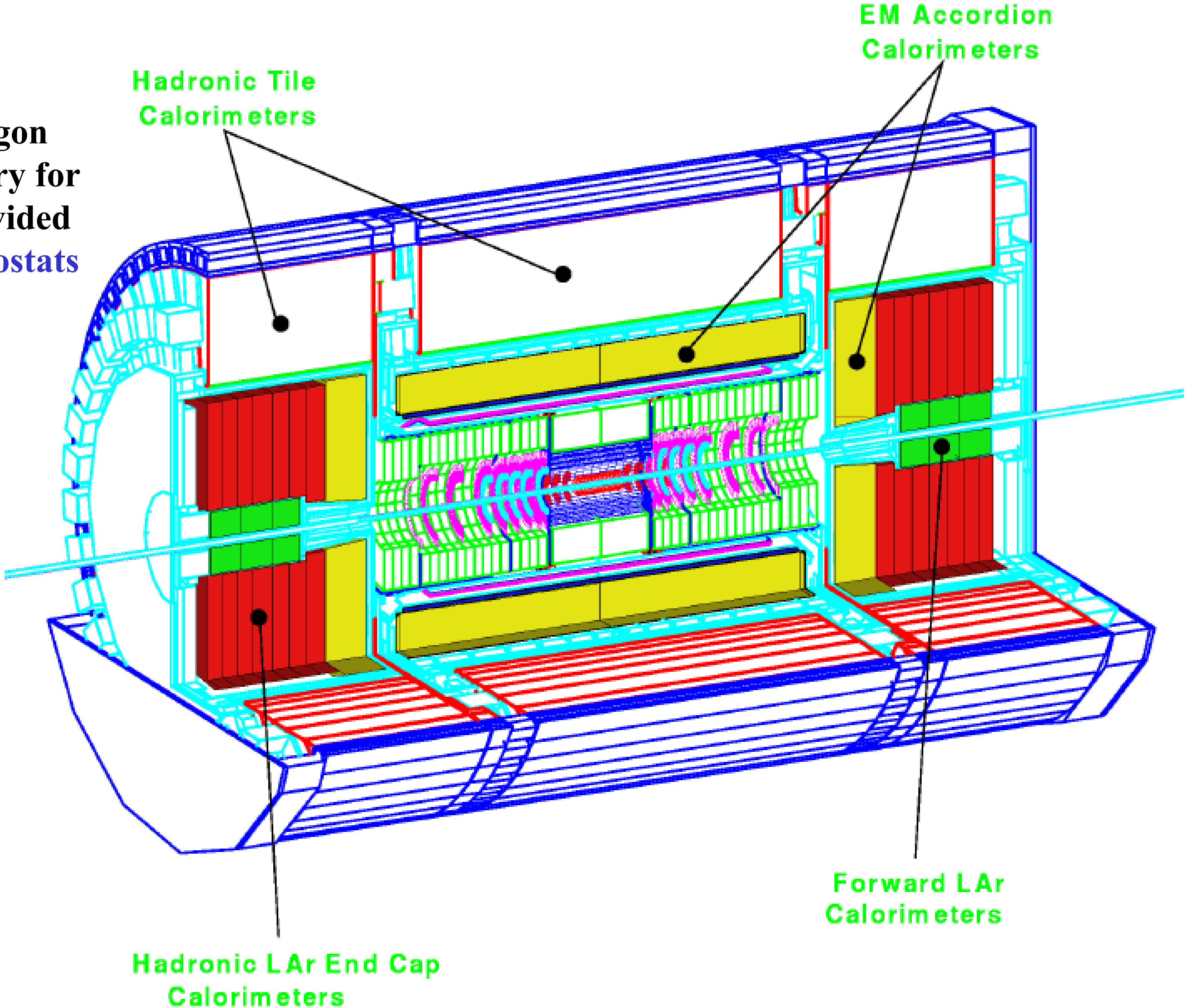
$H \rightarrow ZZ^{*} \rightarrow e^{+}e^{-}e^{+}e^{-}$ $(m_{H} = 130\,\mathrm{GeV})$



High luminosity simulation. Precision hits are shown for $0 < \eta < 0.7$; TRT hits are shown in barrel for z > 0; high threshold transition radiation hits are shown as red points. Fitted tracks (red), with $p_{T} > 5\,\mathrm{GeV}$ and $0 < \eta < 0.7$, are shown just in the precision tracker so as not to obscure the TRT hits.

ATLAS Calorimetry

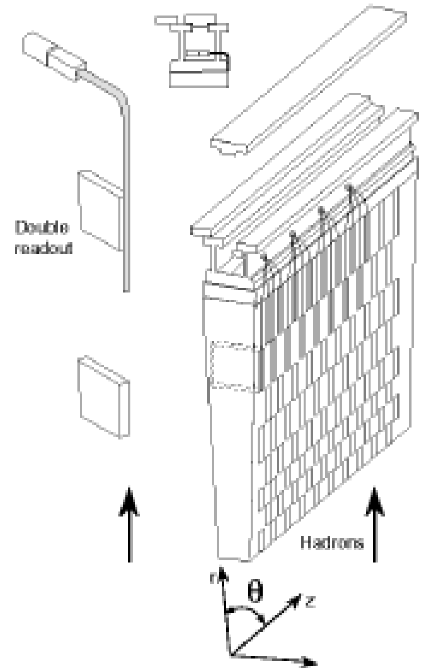
Liquid argon calorimetry for R<2m, divided into 3 cryostats



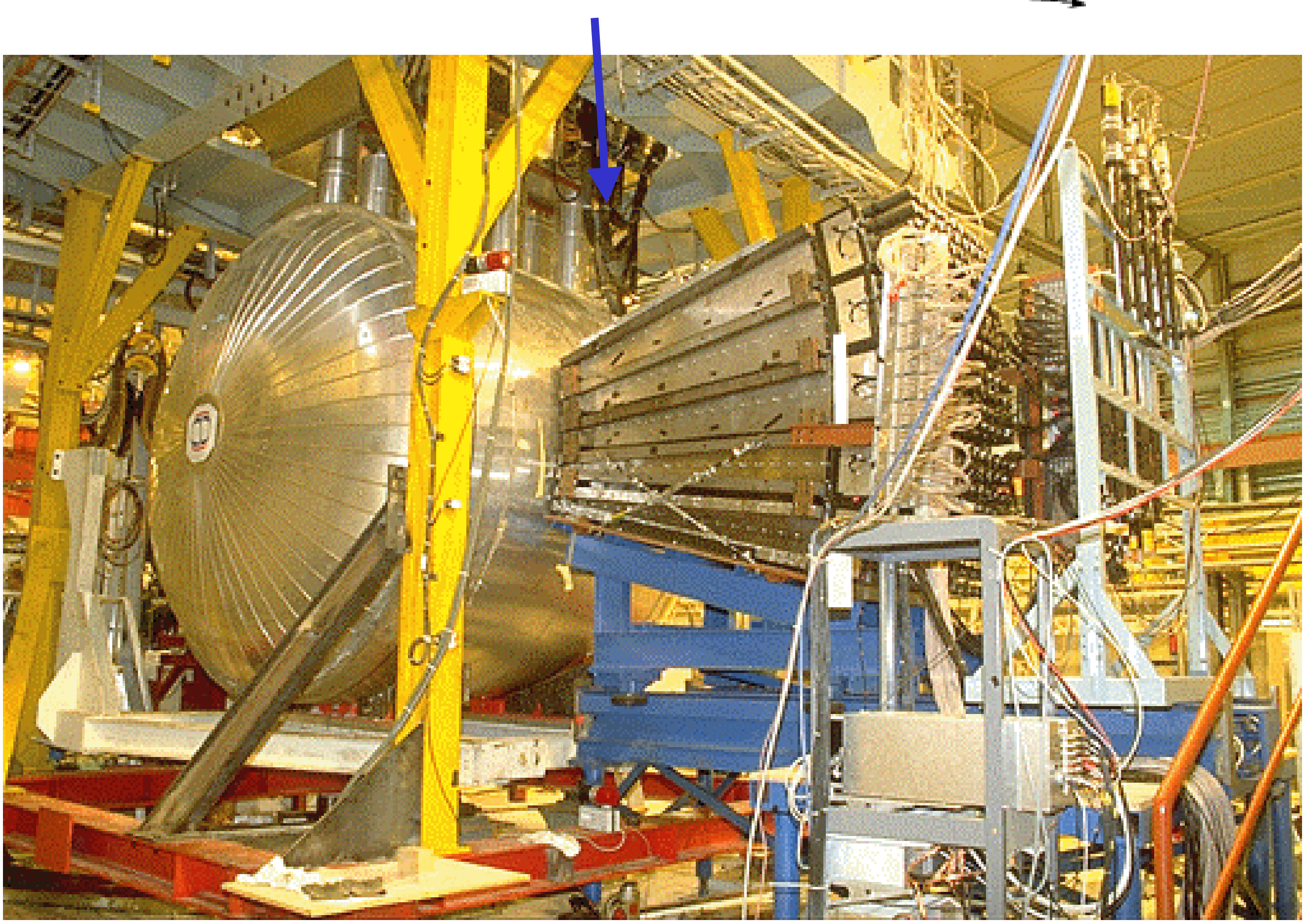
Tile Calorimeter

Sampling calorimeter made of steel and scintillating tiles.

The laminated structure of the absorber allows for channels in which the light collecting fibres run.



Combined tests with EM barrel



LAr Calorimetry

Physics Requirements

Reconstruction → P_e , P_γ , P_{jet} , E_T^{miss} , (P_μ), bunch

Separation → γ / π^0 , e/π

General Requirements

Fast readout scheme
Radiation hard
High segmentation
Uniformity of response
Dynamic range (from 1 mip to 5 TeV)
Hermiticity down to $|\eta| \approx 5$
Long term stability
"Ease" of calibration
Cost
Mechanics consideration: modular construction
installation in ATLAS

Design Goals

EM Calorimeters ($0 \le |\eta| \le 3.2$) and Presampler ($0 \le |\eta| \le 1.8$)

$$\frac{\sigma}{E} \le \frac{10\%}{\sqrt{E(\mathrm{GeV})}} \oplus 0.7\% \oplus \frac{0.27}{E(\mathrm{GeV})} \qquad \sigma_\theta \le \frac{40\ \mathrm{mrad}}{\sqrt{E(\mathrm{GeV})}} \qquad \sigma_{\vec{r}} \le \frac{8\ \mathrm{mm}}{\sqrt{E(\mathrm{GeV})}}$$

Hadronic Endcap ($1.5 \le |\eta| \le 3.2$)

$$\frac{50\%}{\sqrt{E(\mathrm{GeV})}} \oplus 3\% \le \frac{\sigma}{E}(\mathrm{jets}) \le \frac{100\%}{\sqrt{E(\mathrm{GeV})}} \oplus 10\%$$

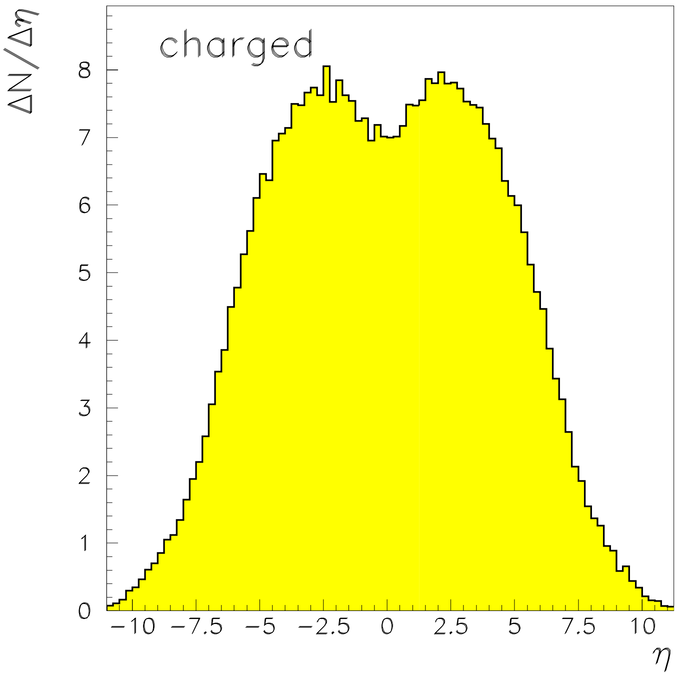
Forward Calorimeter ($3 \le |\eta| \le 5$)

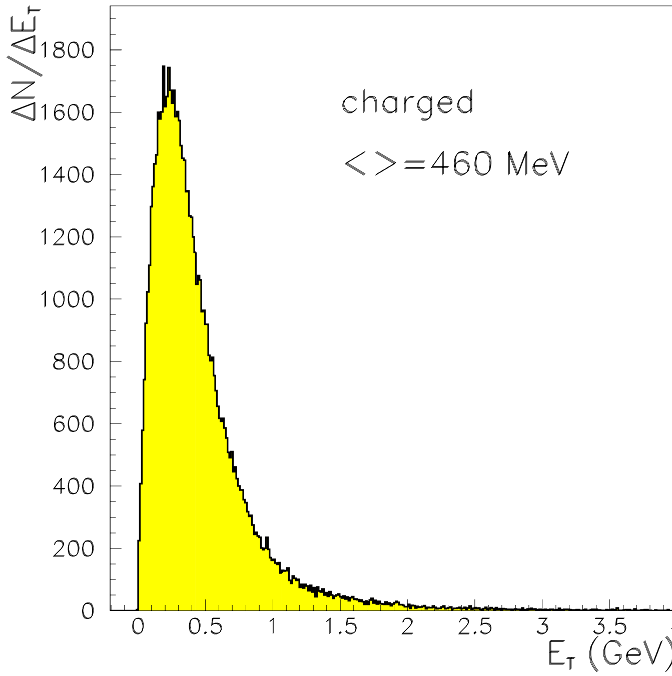
$$\frac{\sigma}{E}(\mathrm{jets}) \le \frac{100\%}{\sqrt{E(\mathrm{GeV})}} \oplus 10\%$$

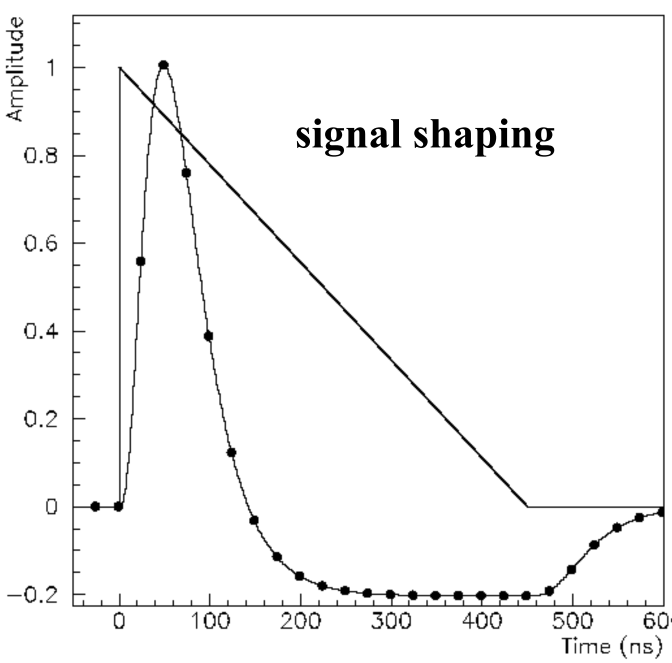
Shaping, Pileup and Electronic Noise

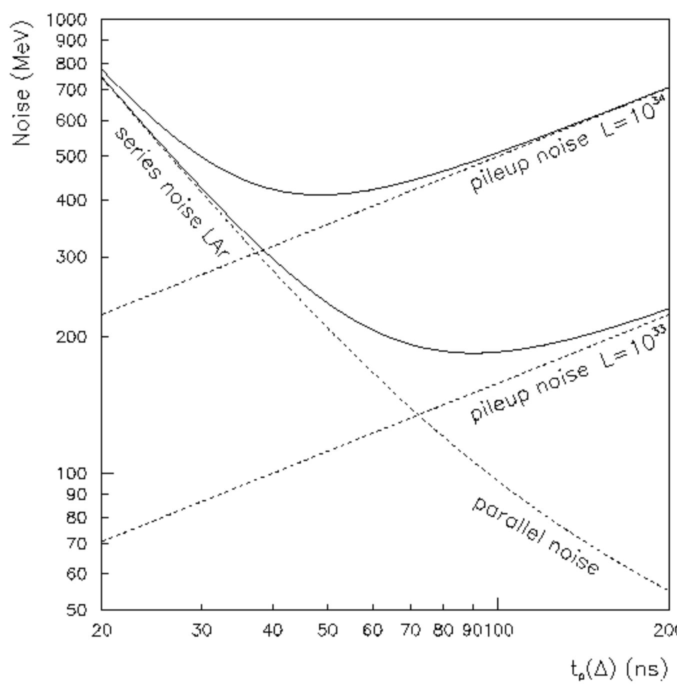
Inelastic pp cross section 70 mb
Average luminosity of 10^{34} cm^{-2}s^{-1}
2835 active bunches over 3564 LHC clock cycles

} **23 inelastic events per crossing**

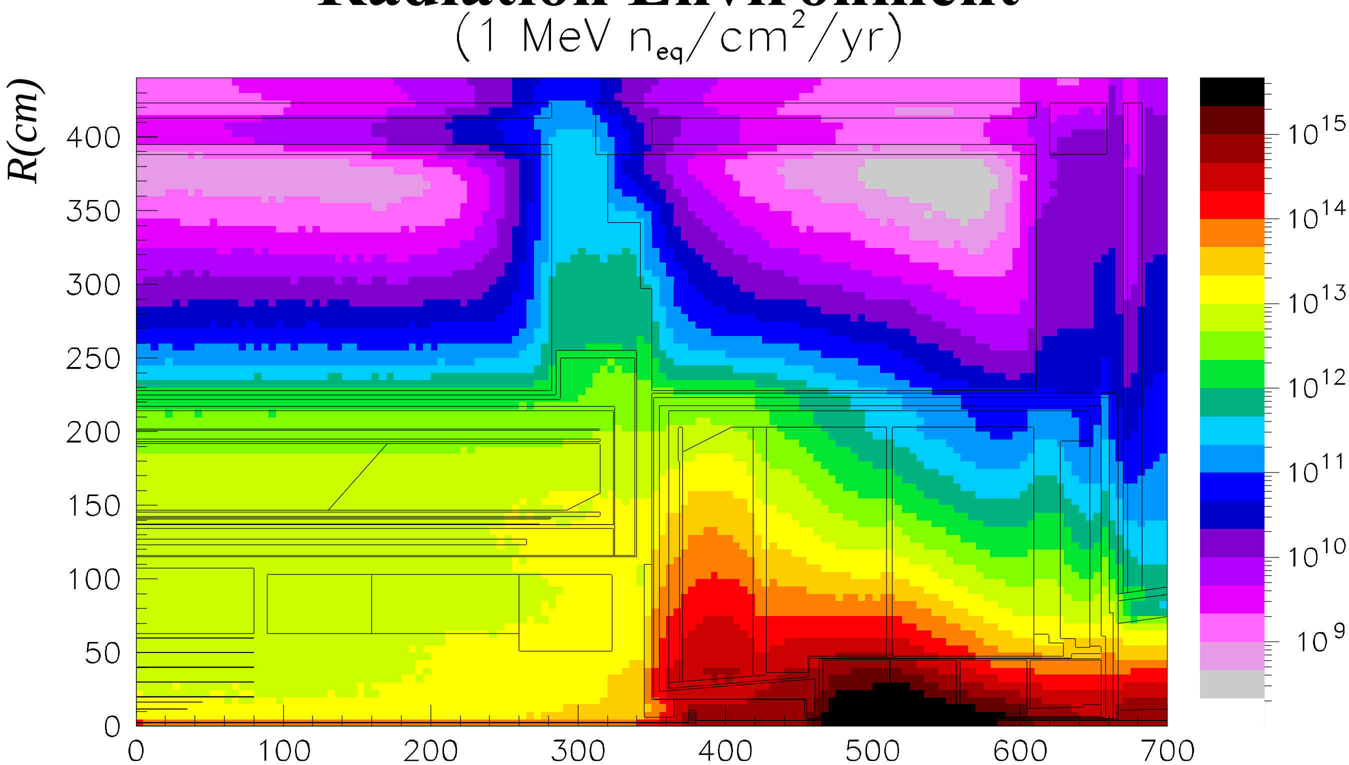




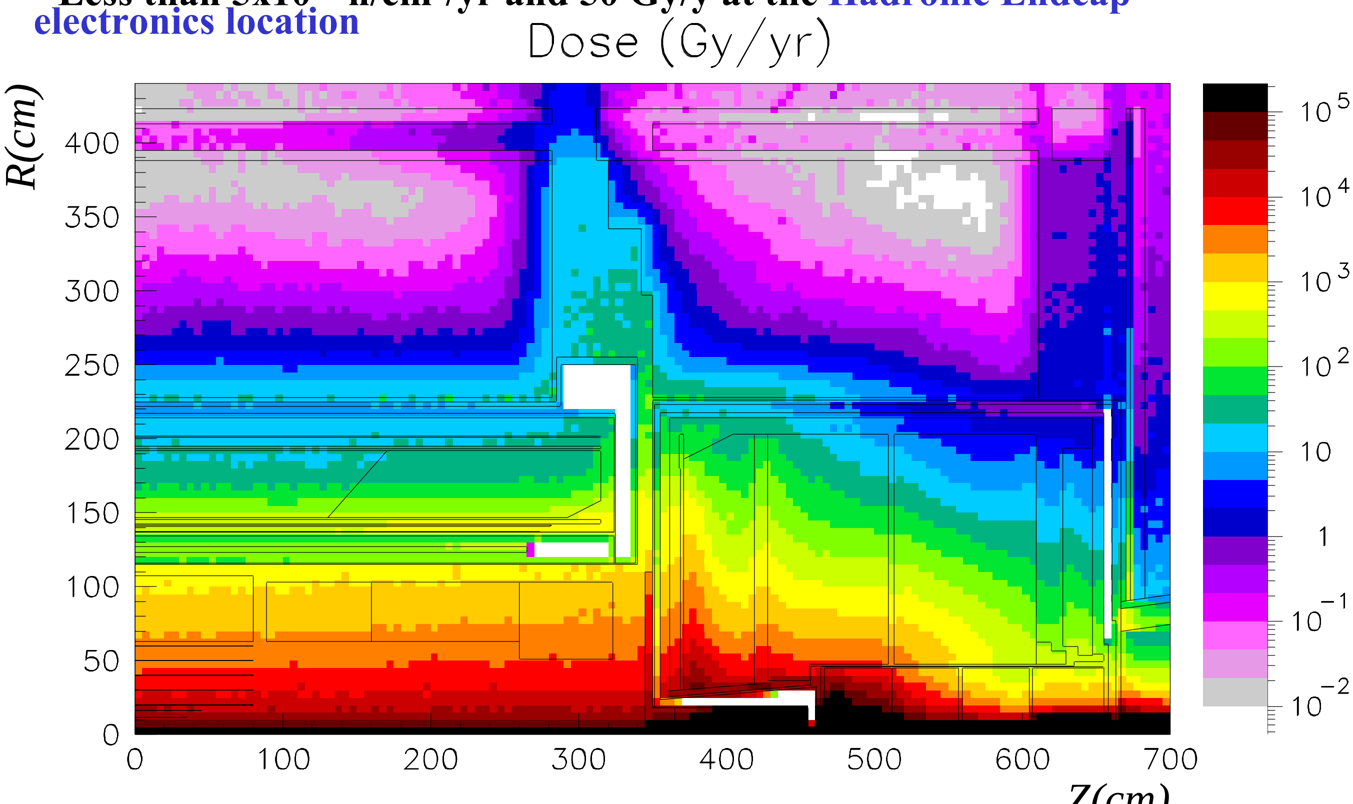




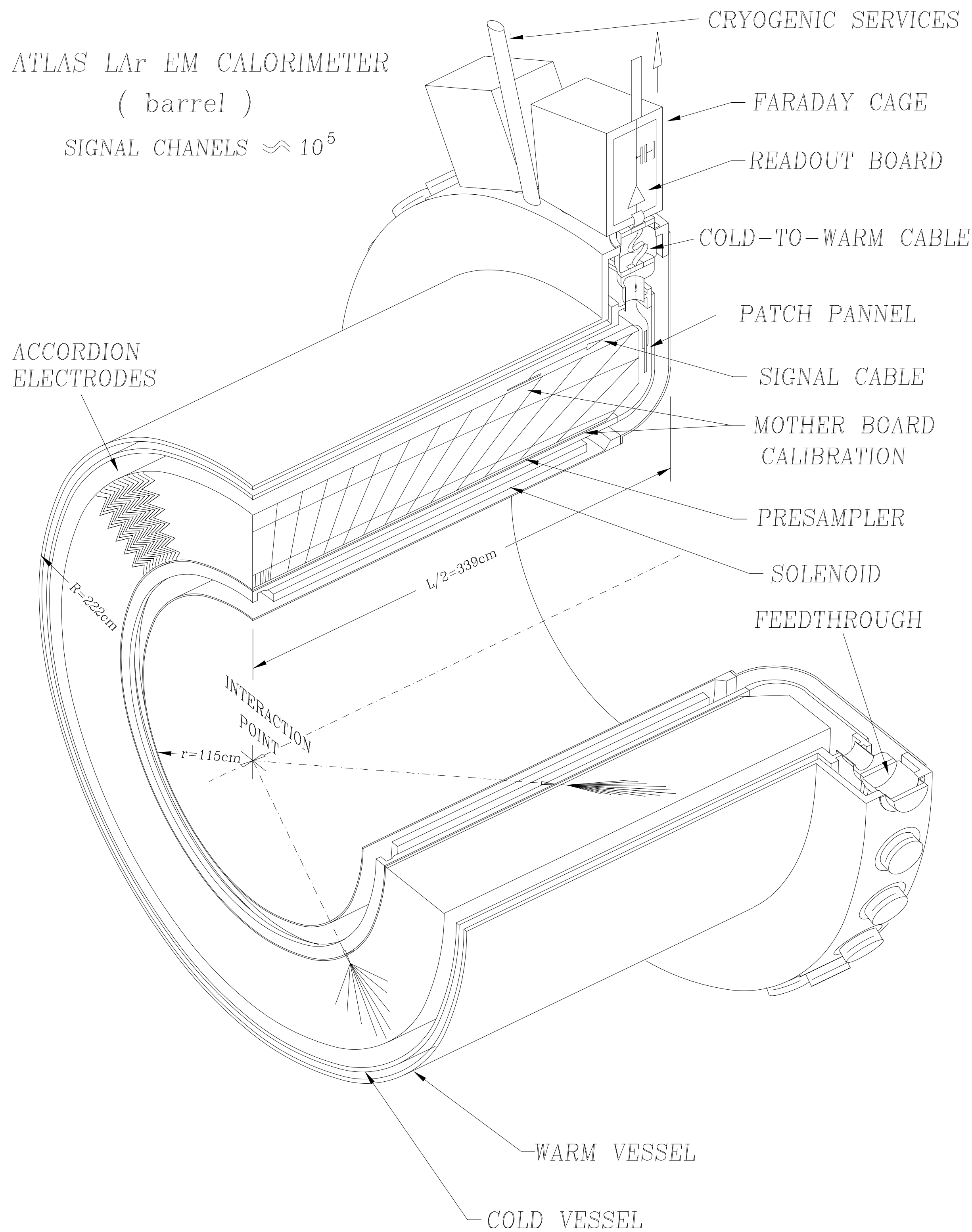
Radiation Environment



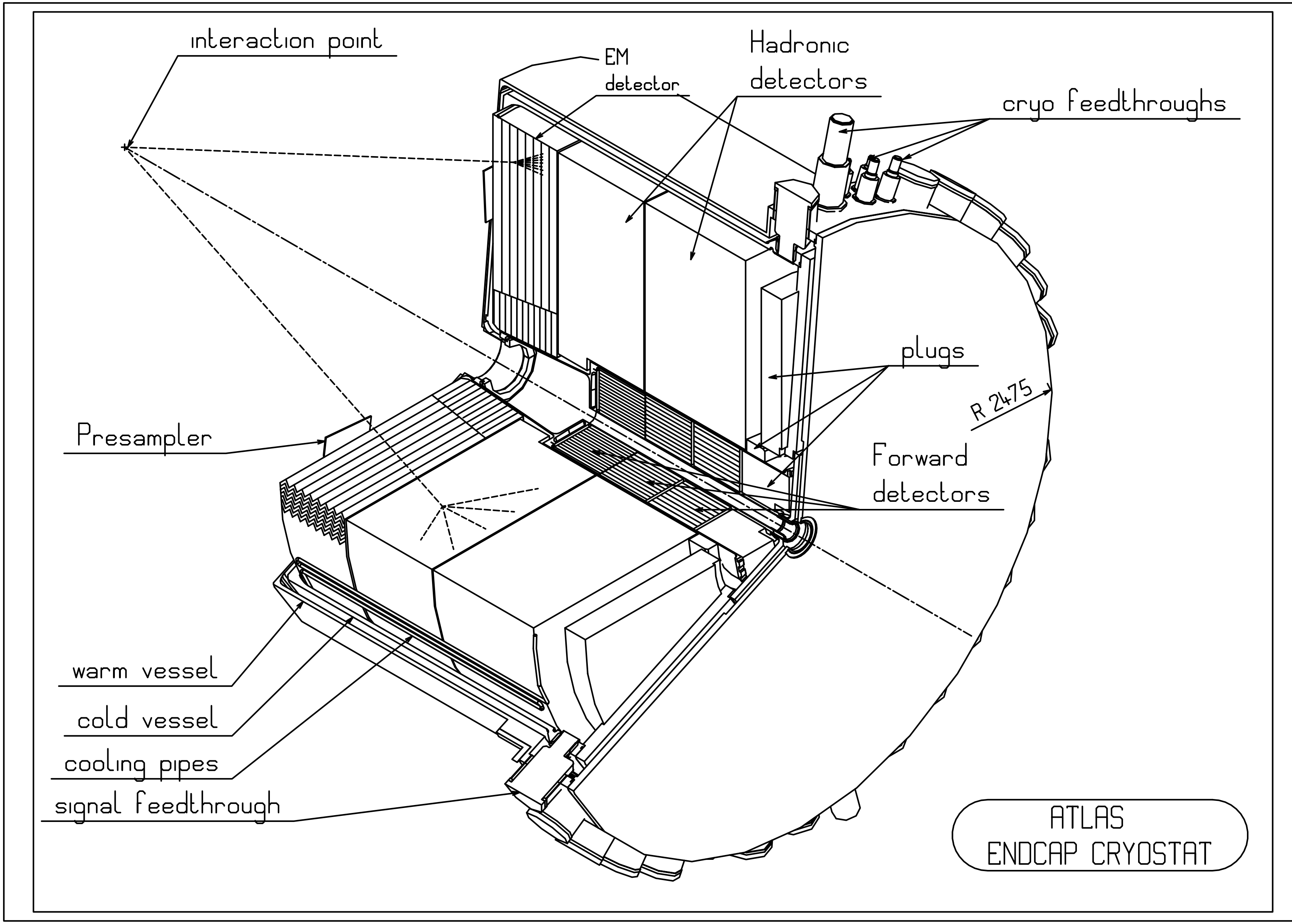
- Up to 10^{16} n/cm²/yr and 2×10^6 Gy/y in the **FCAL**
- Less than 10^{12} n/cm²/yr and 20 Gy/y at the **EM electronics location**
- Less than 5×10^{12} n/cm²/yr and 50 Gy/y at the **Hadronic Endcap electronics location**



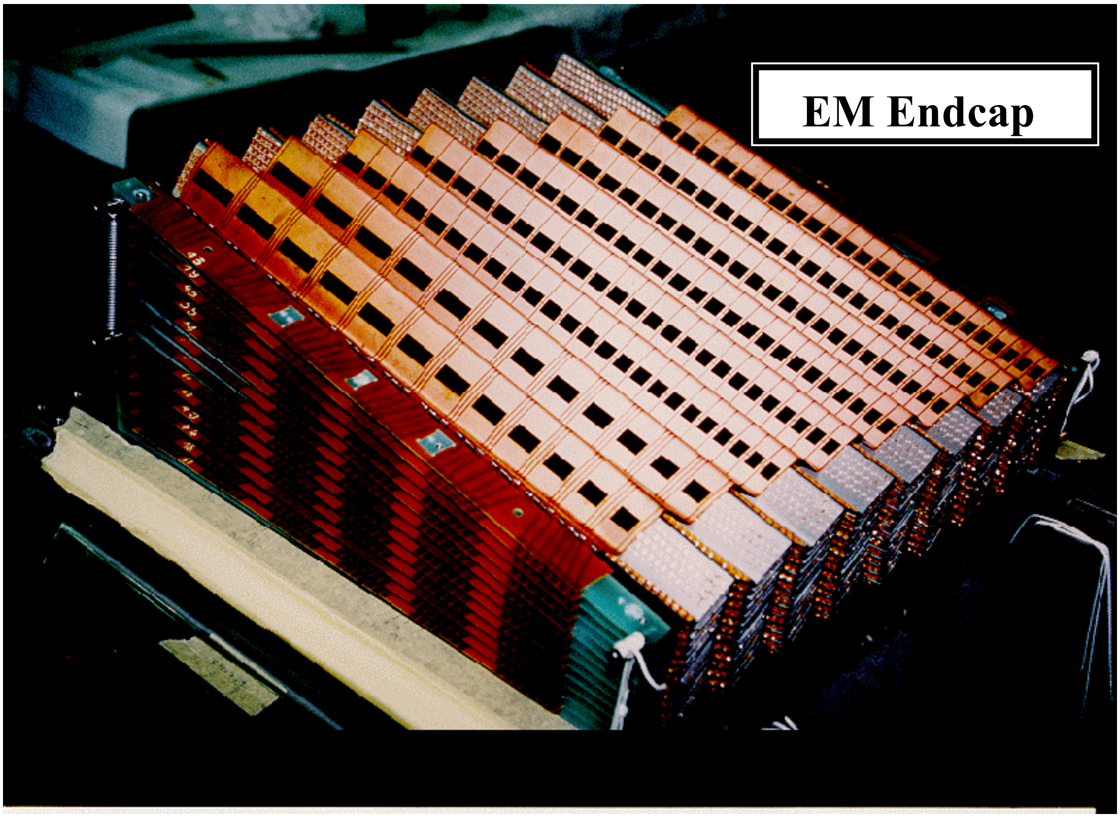
EM Barrel Calorimeter and Cryostat

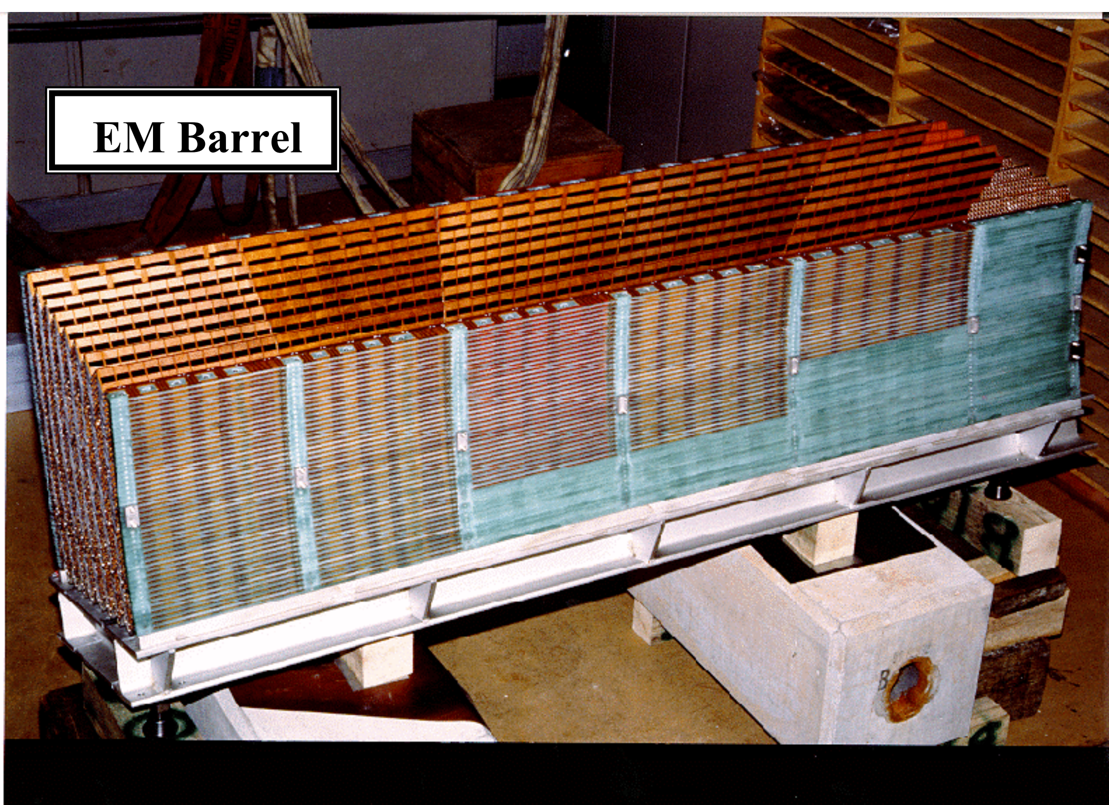


Endcap Cryostat and Calorimeters



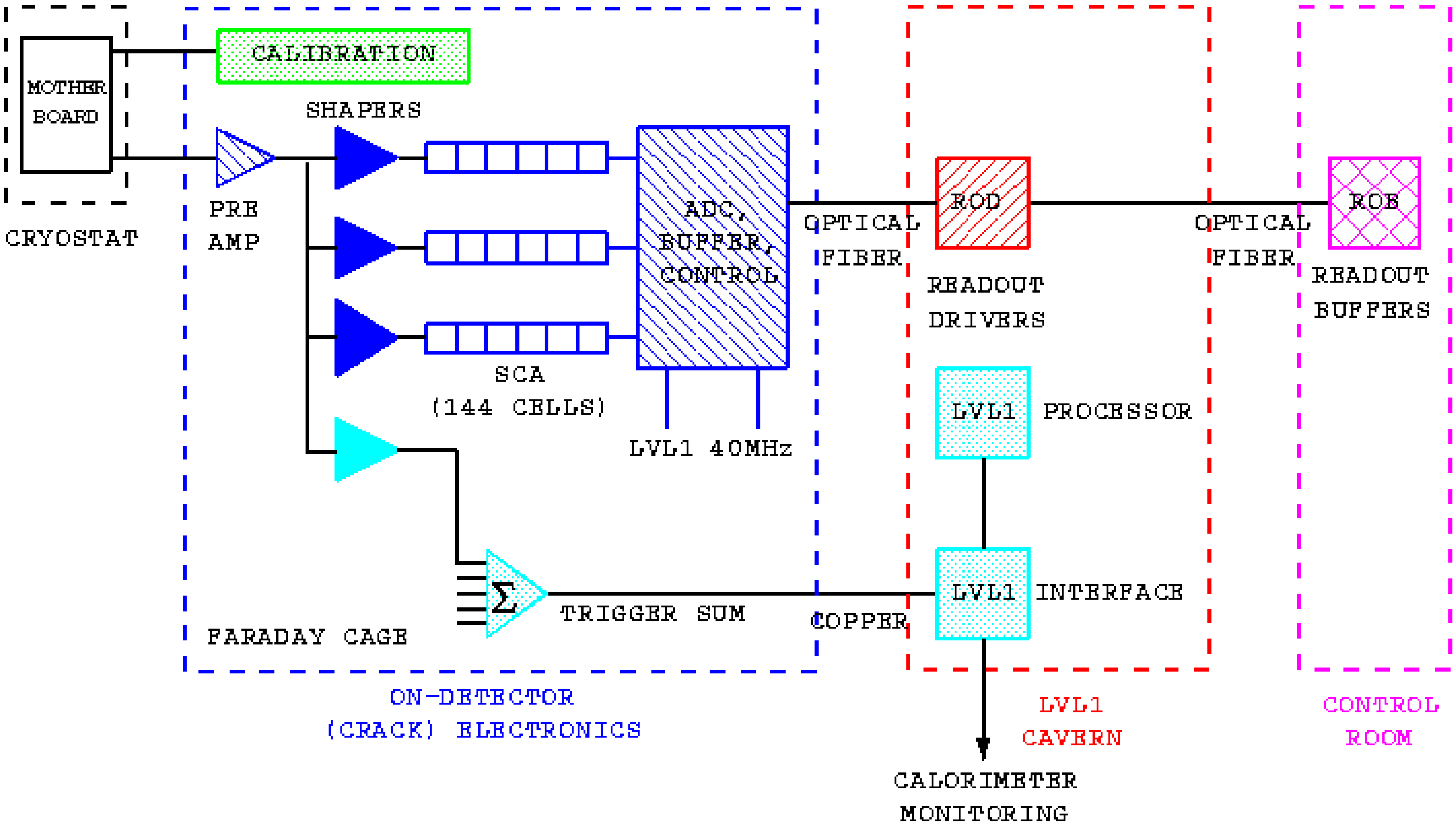
EM Calorimeter Prototypes





LAr Front-End-Board

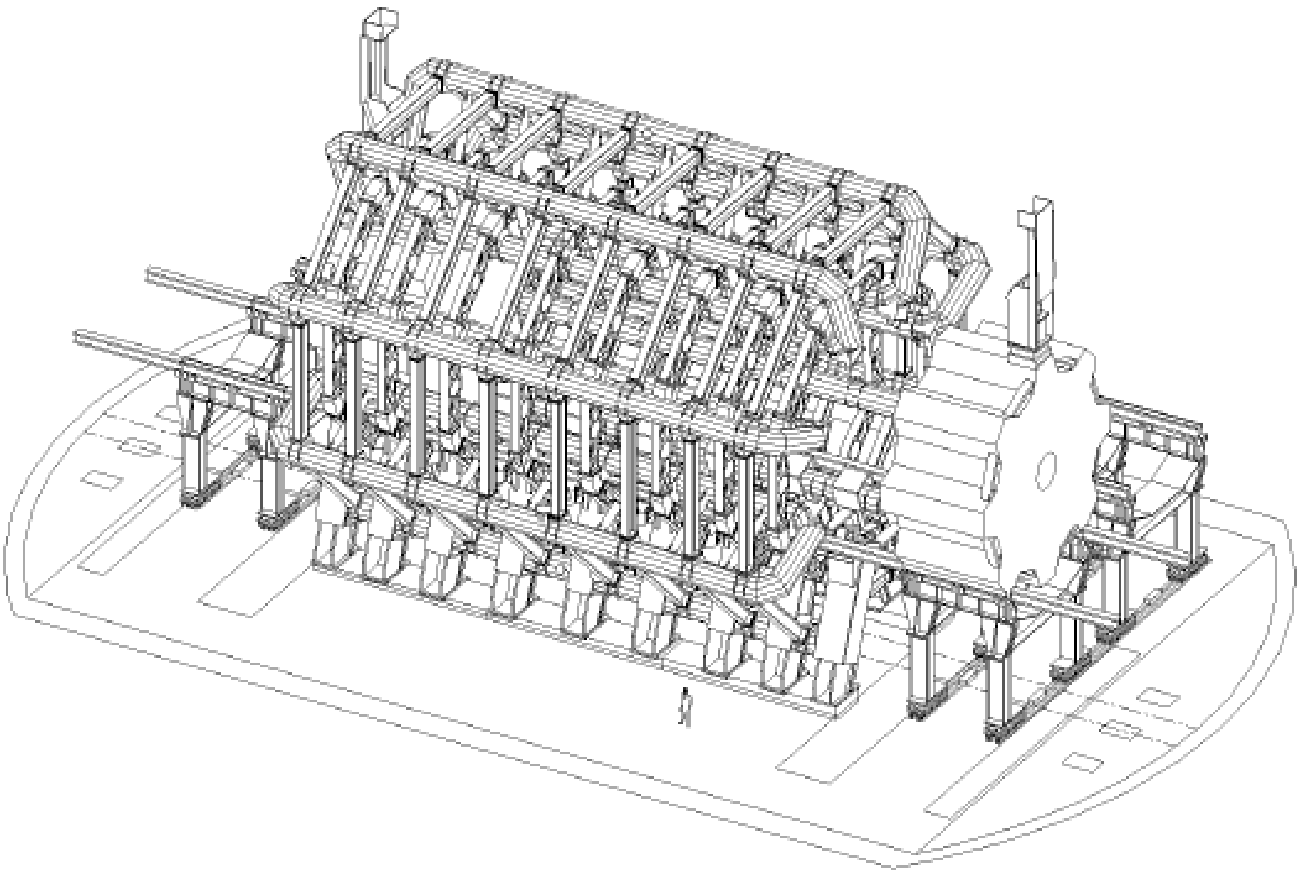
Readout Architecture

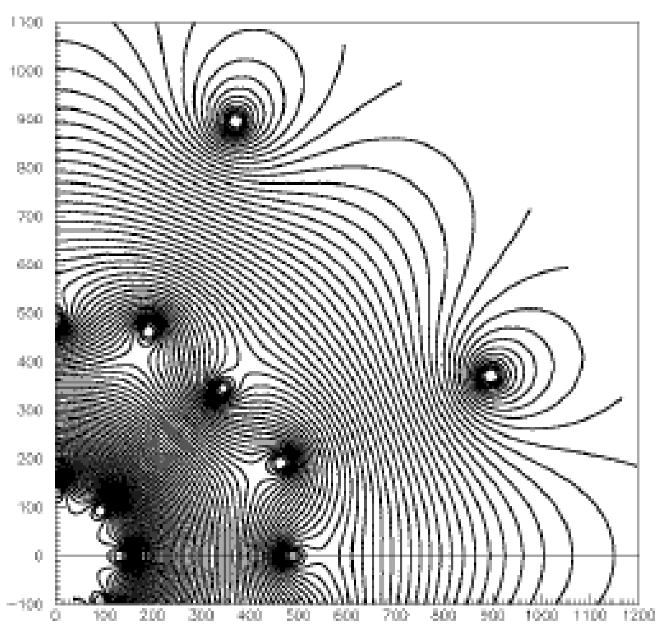


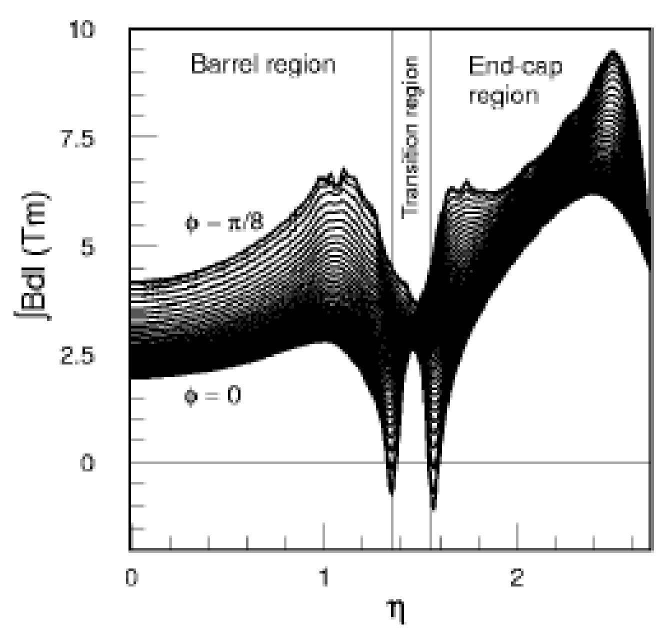
LeCroy: 28-29 May 1997

D.M. Gingrich

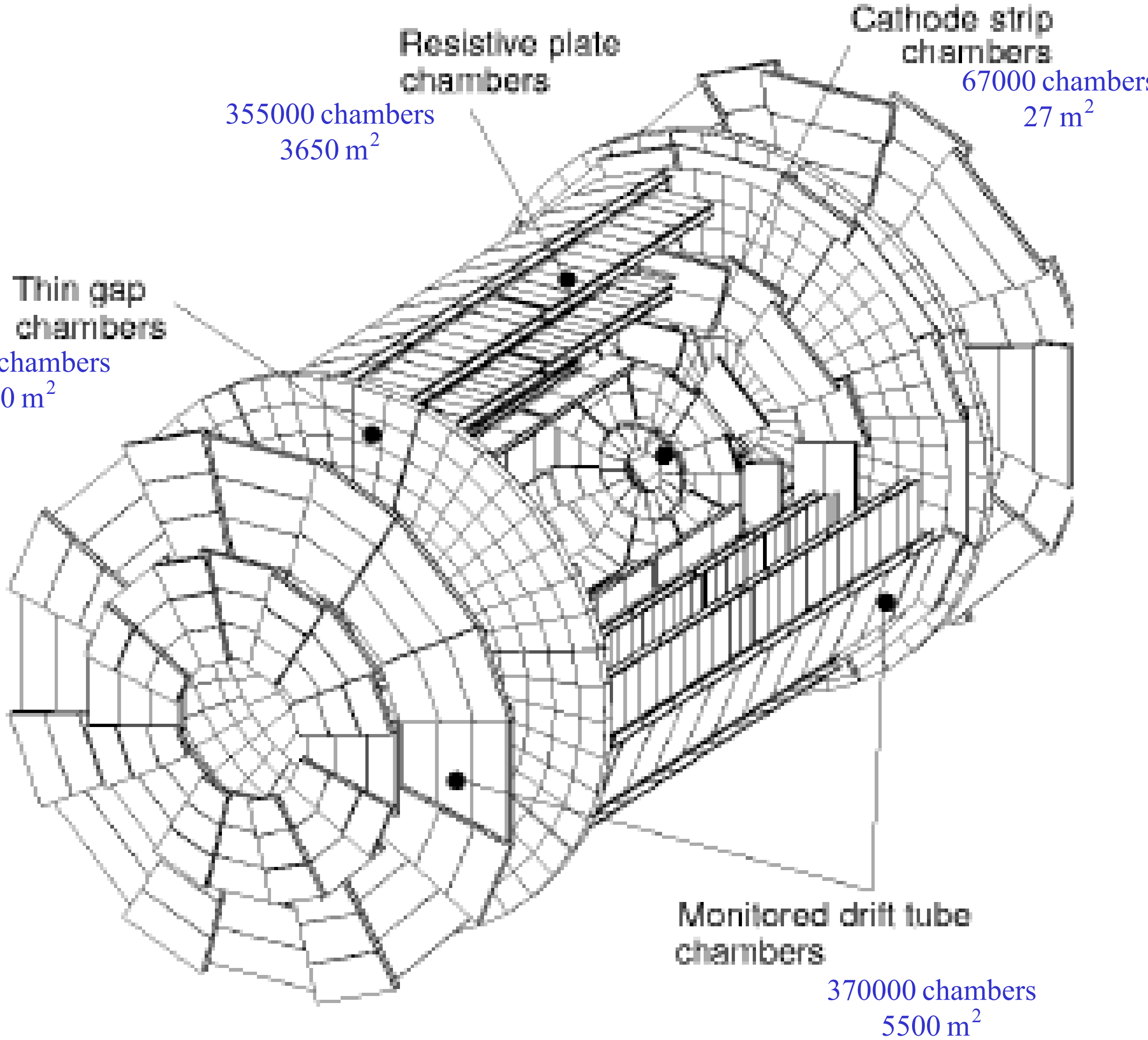
Muon System: Air-Core Toroid Magnets

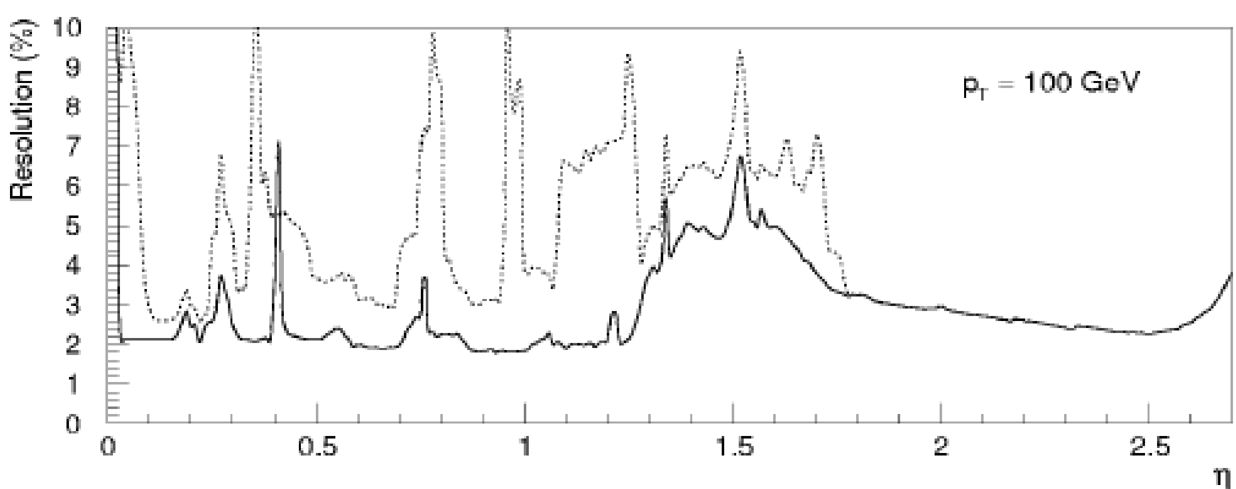




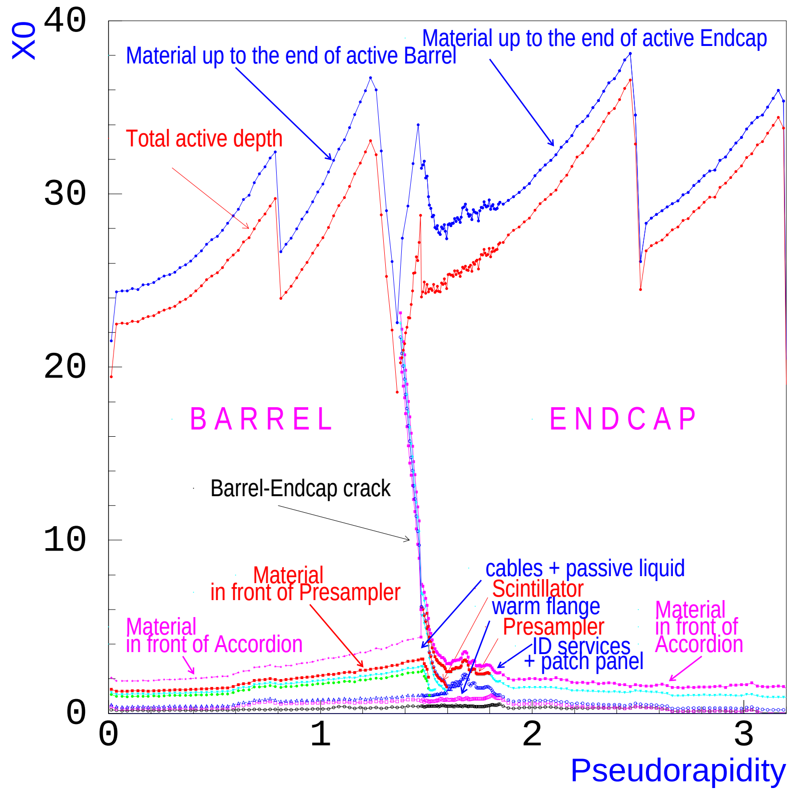


Muon System: Detector Layout



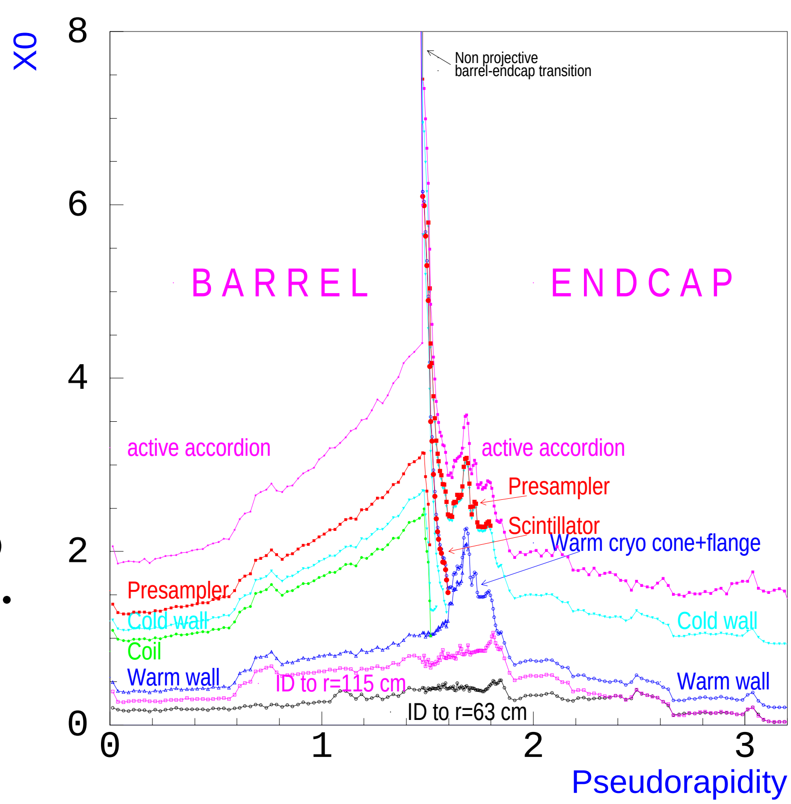


Material Budget



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

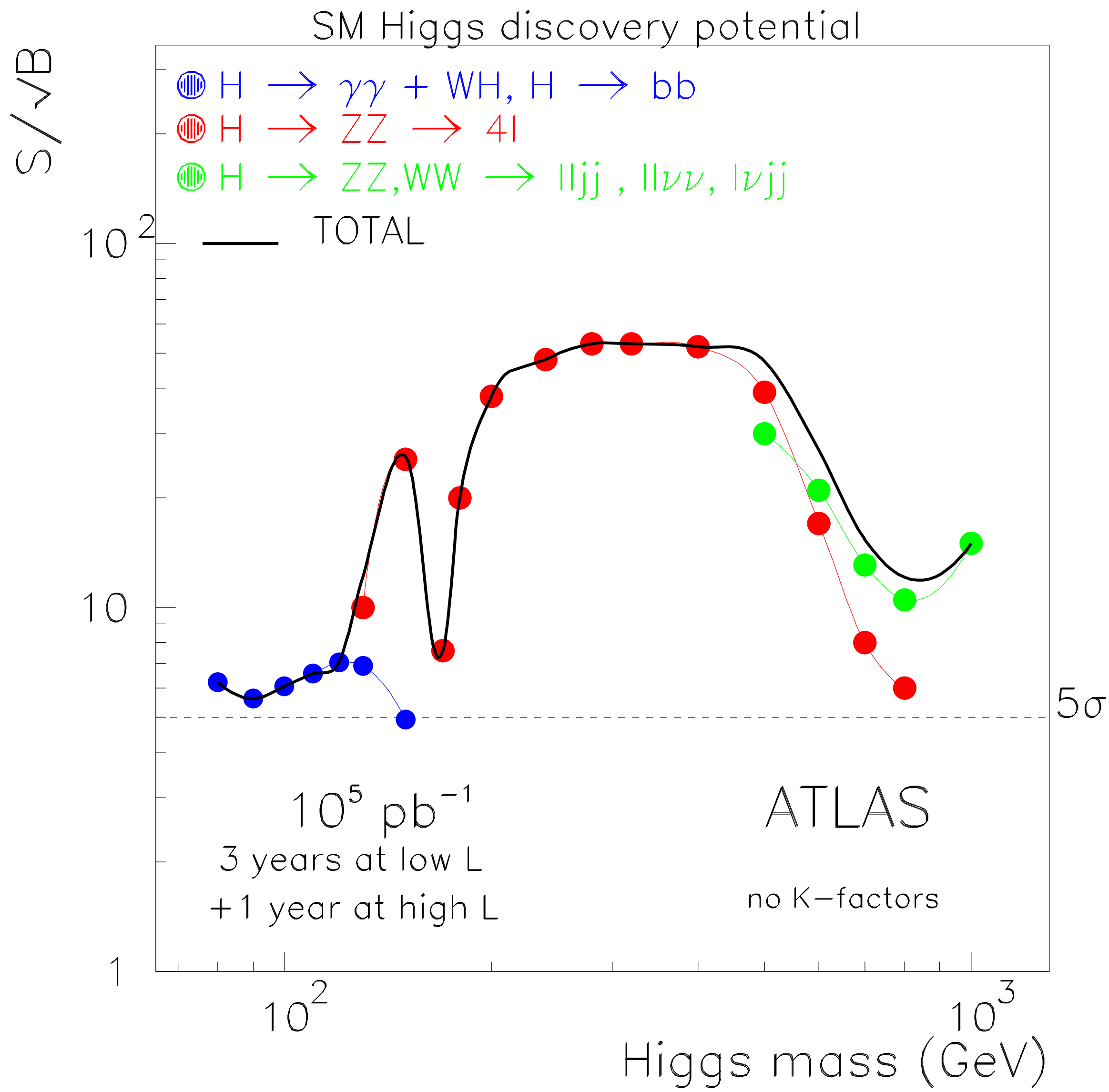
Careful Barrel/Endcap transition optimization.

IMPORTANT PHYSICS PROCESSES

	Luminosity Low	Luminosity High	Mass (TeV) reach
$H \rightarrow b\bar{b}$	√		0.08 to 0.14
$H \rightarrow \gamma\gamma$		√	
$H \rightarrow WH \rightarrow \ell\gamma\gamma + X$		√	
$H \rightarrow ZZ^{*} \rightarrow 4\ell$	√	√	0.13 to 0.18
$H \rightarrow ZZ \rightarrow 4\ell$	√	√	0.18 to 0.70
$H \rightarrow ZZ \rightarrow \ell\ell\nu\nu$	√	√	0.50 to 0.80
$qqH \rightarrow ZZ \rightarrow \ell\ell qq$	√		0.50 to 1.0
$qqH \rightarrow WW \rightarrow \ell\nu qq$	√		
SUSY $\rightarrow E_T^{miss} + n$jets	√	√	$\sim$ 1.0
SUSY $\rightarrow$ same-sign dileptons	√	√	
$h \rightarrow \gamma\gamma$		√	
$t \rightarrow bH^{+}$	√		
$A \rightarrow \tau\tau$	√		
$h \rightarrow \tau\tau$	√		
CP violation in B decays	√		
$t\bar{t} \rightarrow \ell + X$	√		
$t\bar{t} \rightarrow \ell\ell + X$	√	√	
Inclusive jet cross section	√	√	$\sim$ 15
$Z' \rightarrow ee, \mu\mu, jj$	√	√	$\sim$ 1.5
$W' \rightarrow e\nu, \mu\nu, jj$	√	√	$\sim$ 6
$\rho_{TC}\ (W_L\ Z_L) \rightarrow \ell\ell\ell + E_T^{miss}$		√	$\sim$ 1.5
$\omega_{TC}\ (Z_L\gamma) \rightarrow \ell\ell\ell$		√	$\sim$ 2.0
pp $\rightarrow$ leptoquarks $\rightarrow \ell j \ell j$	√	√	$\sim$ 1.5

ATLAS Physics Workshop, Grenoble March 29th to April 4th 1998

Standard Model Higgs



ATLAS Canada Collaboration

Alberta
Carleton
CRPP
Montréal
Toronto
TRIUMF
UBC
Victoria
York

33 grant-eligible physicists
Over 80 people, including Engineers, Technicians, Students

Activities focused on LAr Calorimetry

4 Major Projects Funded by a Major Installation Grant

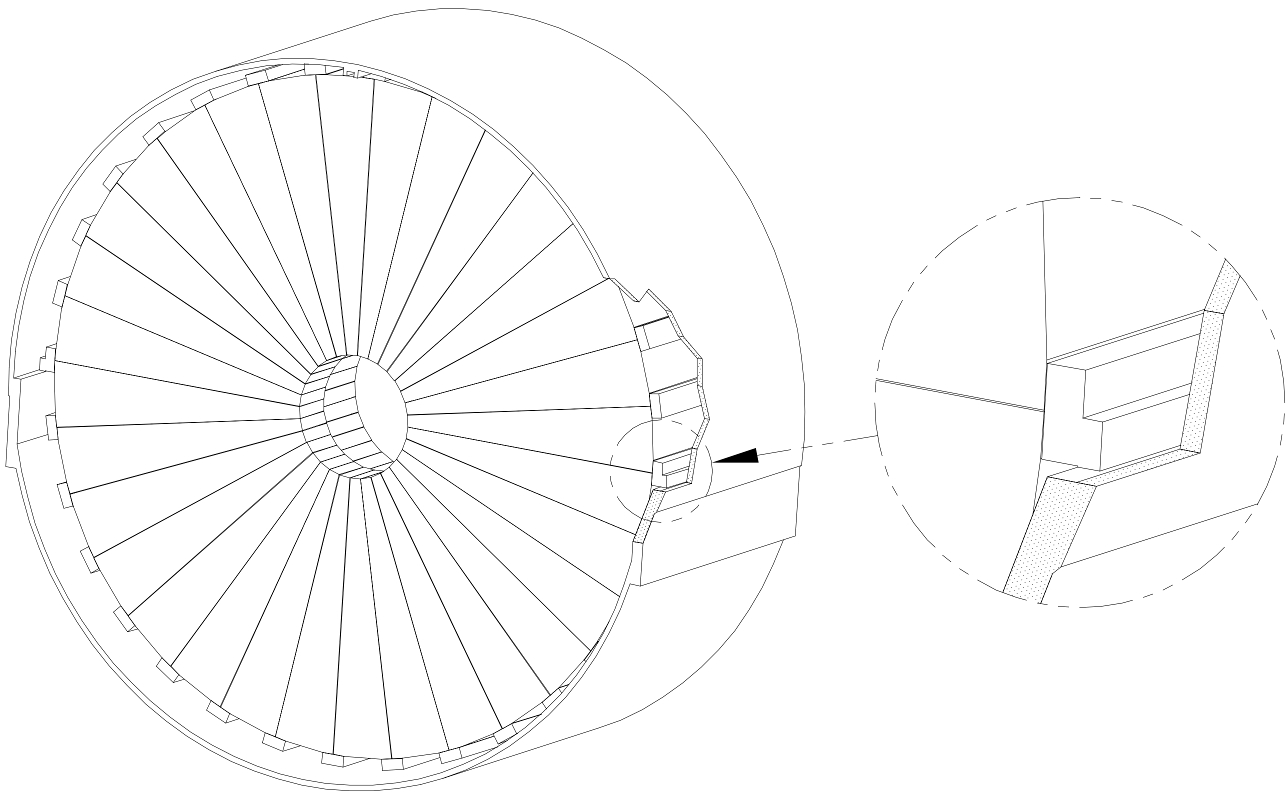
- **Endcap Hadronic Calorimeter**
- **Forward Hadronic Calorimeter**
- **Front-End-Board Electronics**
- **Endcap Signal Cryogenics Feedthroughs**

Important Activities

- **Radiation Hardness Studies**
- **Physics Studies**

Hadronic Endcap Calorimeter

LAr-Cu sampling calorimeter covering $1.5 < \eta < 3.2$



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	

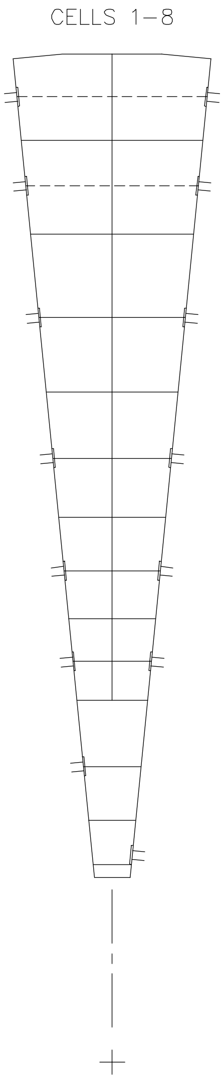
Channel count for both endcaps

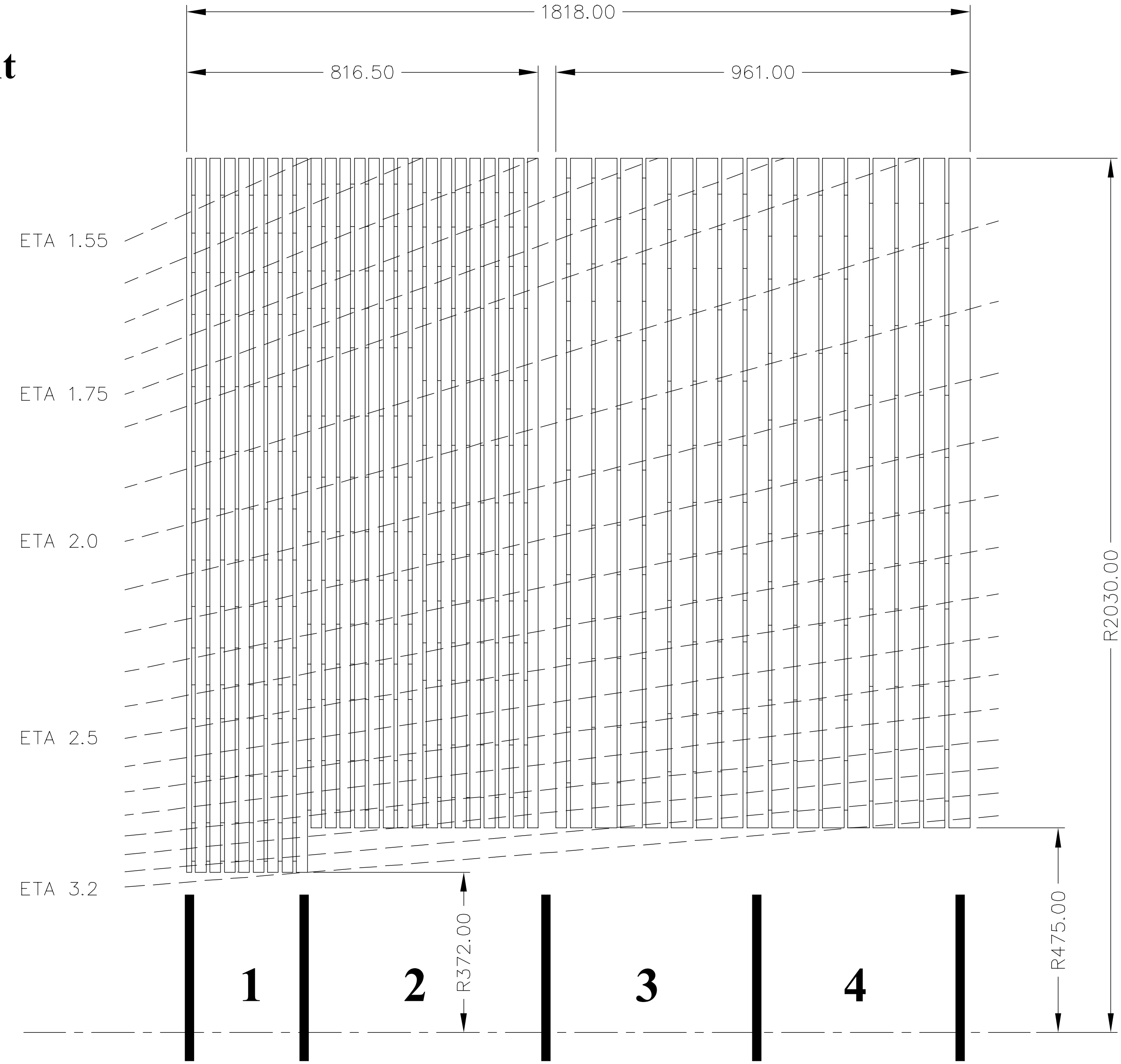
Front	**1536**
Middle	**1472**
Back	**1408**
Total	**4416**

Hadronic Endcap Calorimeter Segmentation

4 Readout Depths

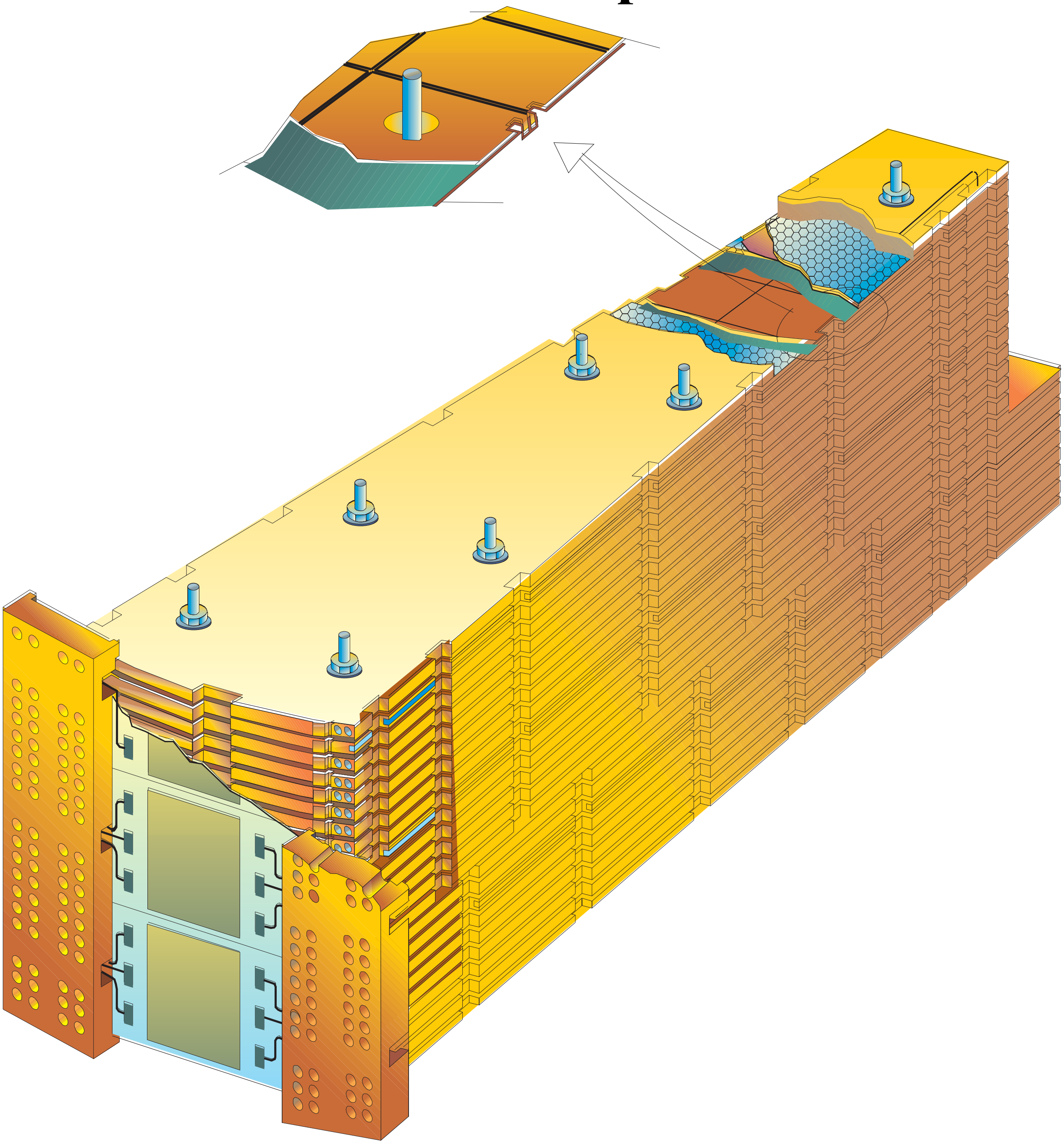
Readout Segment





TRIUMF May 21st 1998
Michel Lefebvre (Victoria)

Hadronic Endcap Module



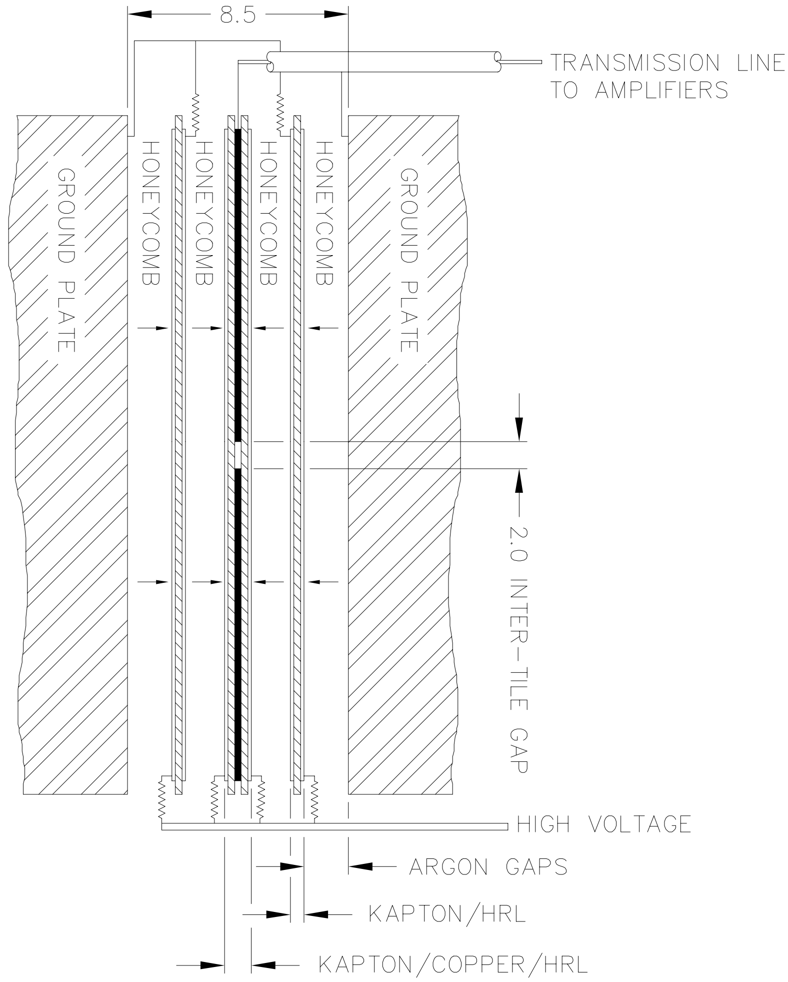
Gap between Cu plates: **8.5 mm**

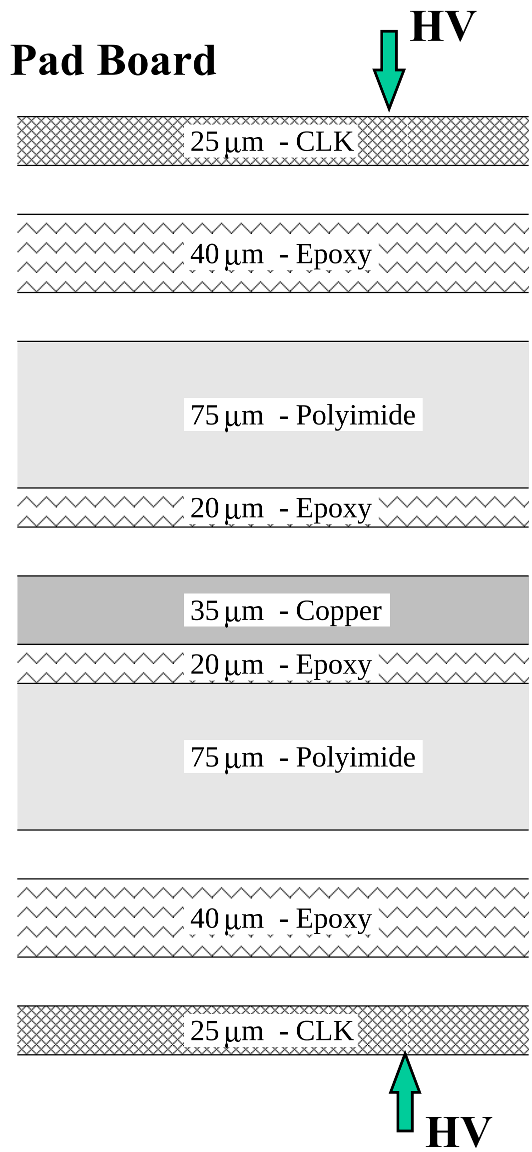
Front wheel module: **2103 kg**
25 mm Cu plates

Back wheel module: **2811 kg**
50 mm Cu plates

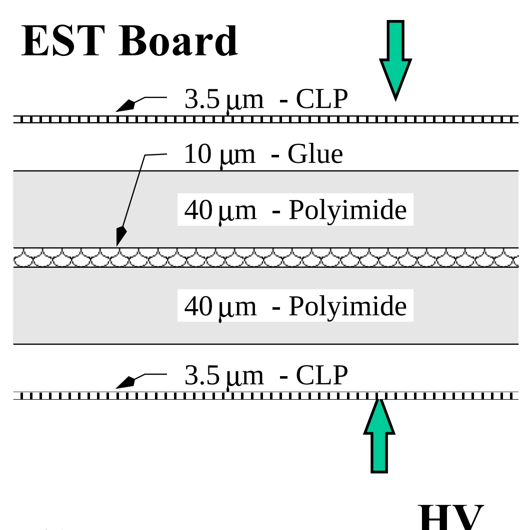
Hadronic Endcap Readout Structure

Electrostatic Transformer (EST) Readout



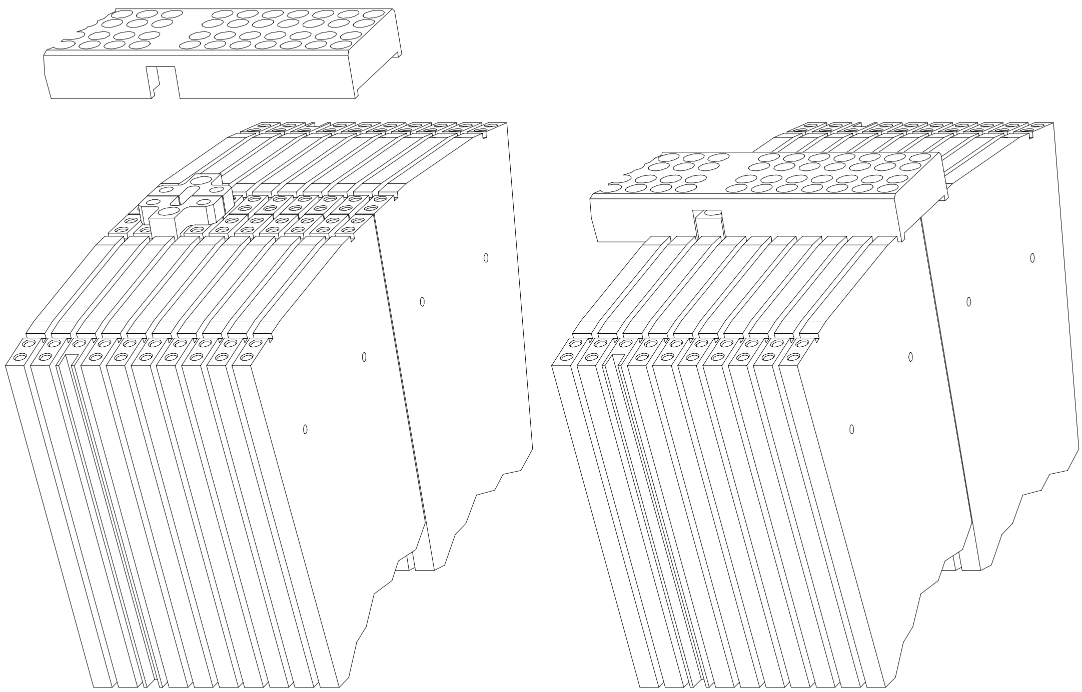


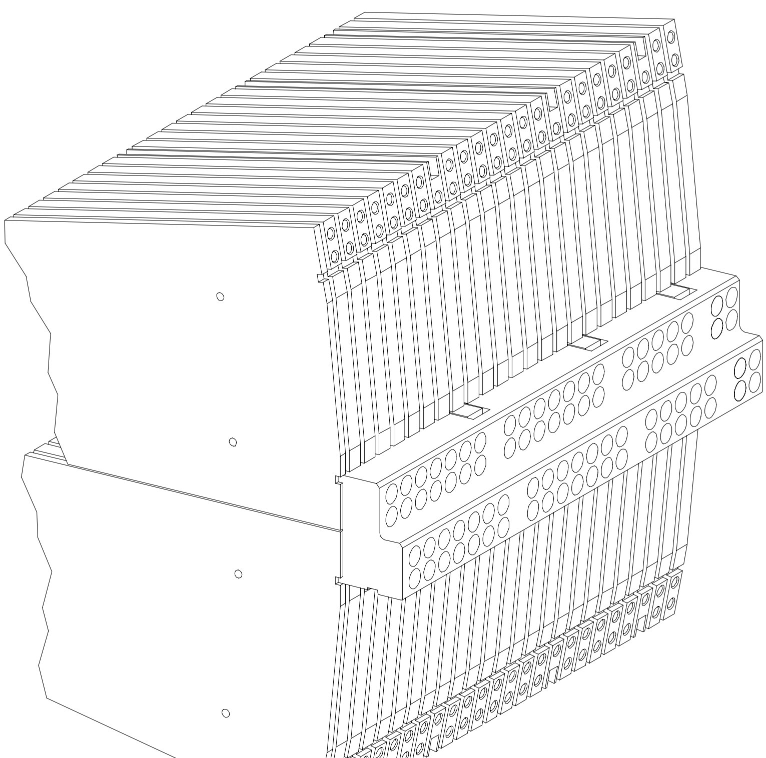
Distance between Cu plates	**8.5 mm**
Liquid argon gaps	**1.954 mm**
Honeycomb thickness	**1.774 mm**
Pad and EST board thickness	**0.685 mm**



Hadronic Endcap Module Connection

Inter-module clamping bar





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

Michel Lefebvre (Victoria)

Endcap Hadronic Calorimeter Responsibilities

Project Leaders: H. Oberlack (MPI), C. Oram (TRIUMF)

Mechanical Design: Canada (T. Hodges and R. Langstaff)

Electronics: MPI, Munich

Construction:

Canada (Alberta, UBC, Montréal, TRIUMF, Victoria)

Europe (Germany, Russia, Slovak Republic)

Testbeam:

Cryogenics, trigger, DAQ, calibration: Europe

Testbeam software: Canada (Victoria)

Endcap Hadronic Calorimeter Schedule

Module 0 (2 full modules) in beam tests in 1998 (April and August). First occasion at full hadronic shower containment. Preliminary analysis of April data done.

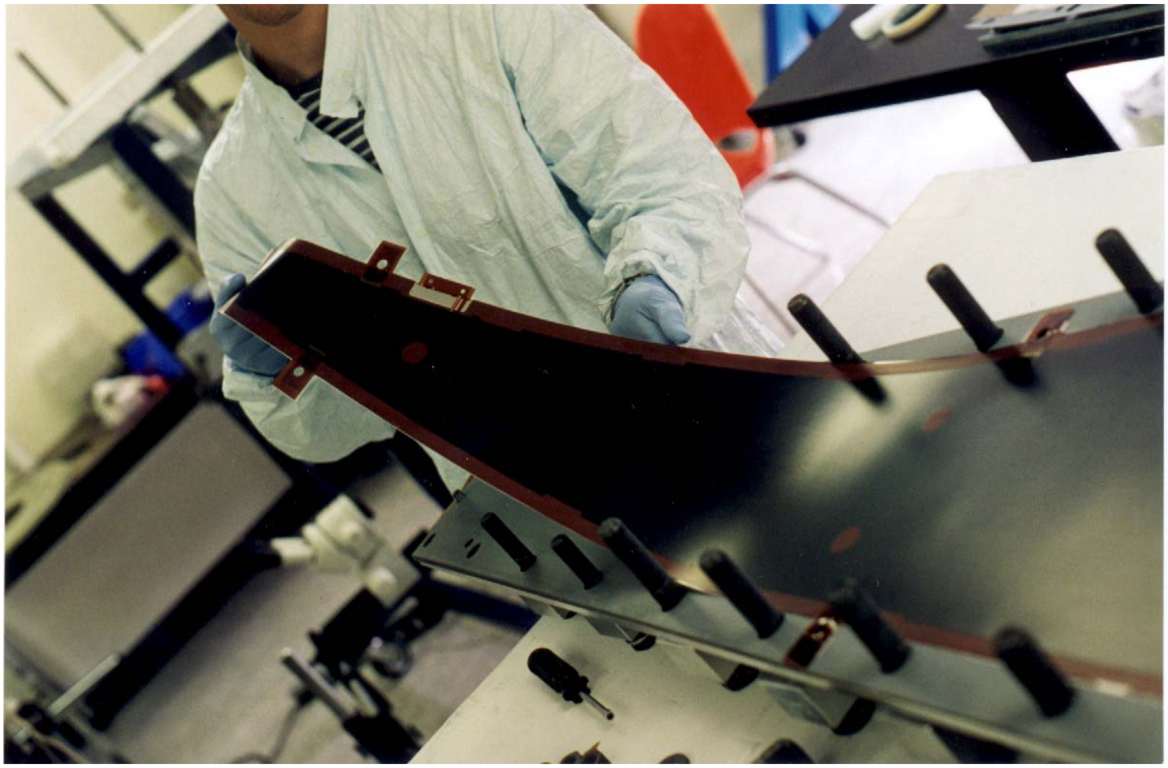
Production Readiness Review successfully completed May 4th

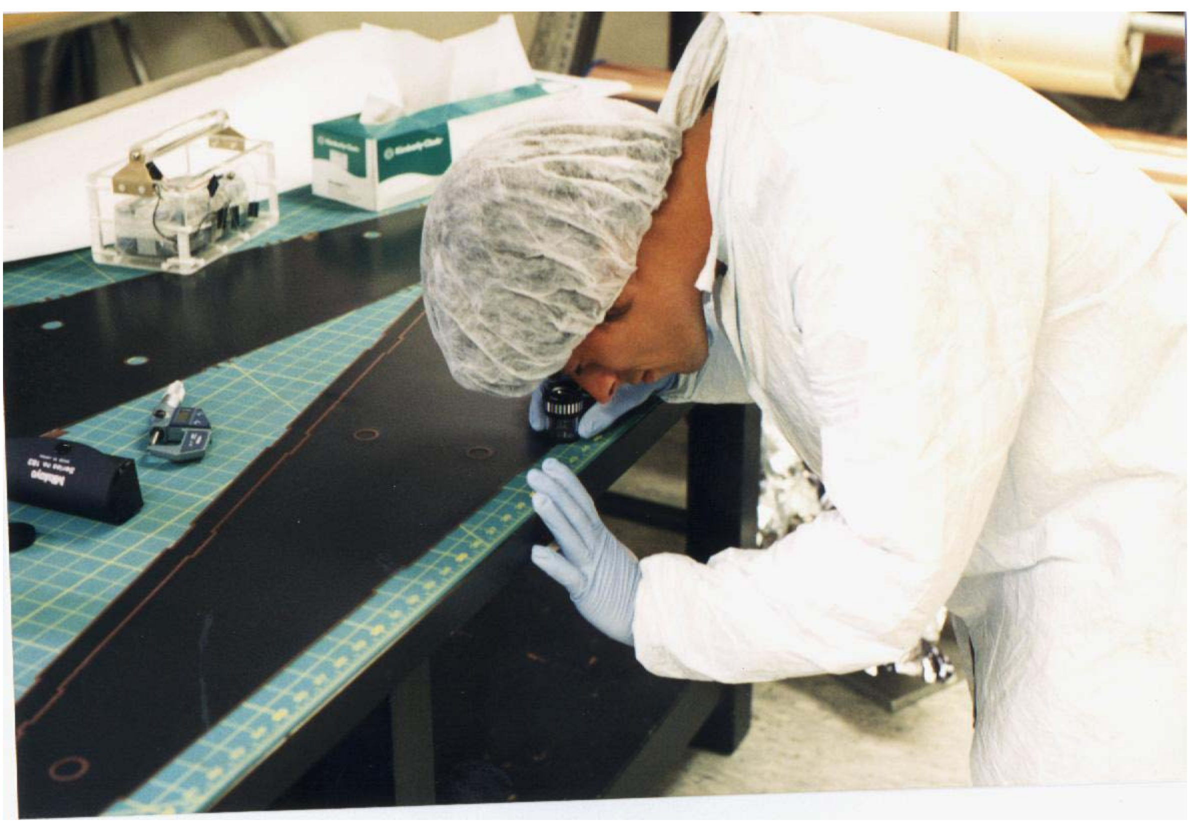
Series module production started:

> **Raw material procurement initiated (Cu plates, glue, polyimide, Cu clad poliymide, honeycomb, stainless steel parts). Attempt to obtain Cu from China.**
>
> **Tooling upgrade and construction started. This includes improvements to the TRIUMF cleanrooms, and construction of a cleaning facility (TRIUMF).**
>
> **First series production module to arrive in CERN early in 1999. All modules to be cold tested at CERN. Up to 1/8 of the modules will be beam tested at CERN.**

Wheel assembly to start mid to late 2000 in CERN.

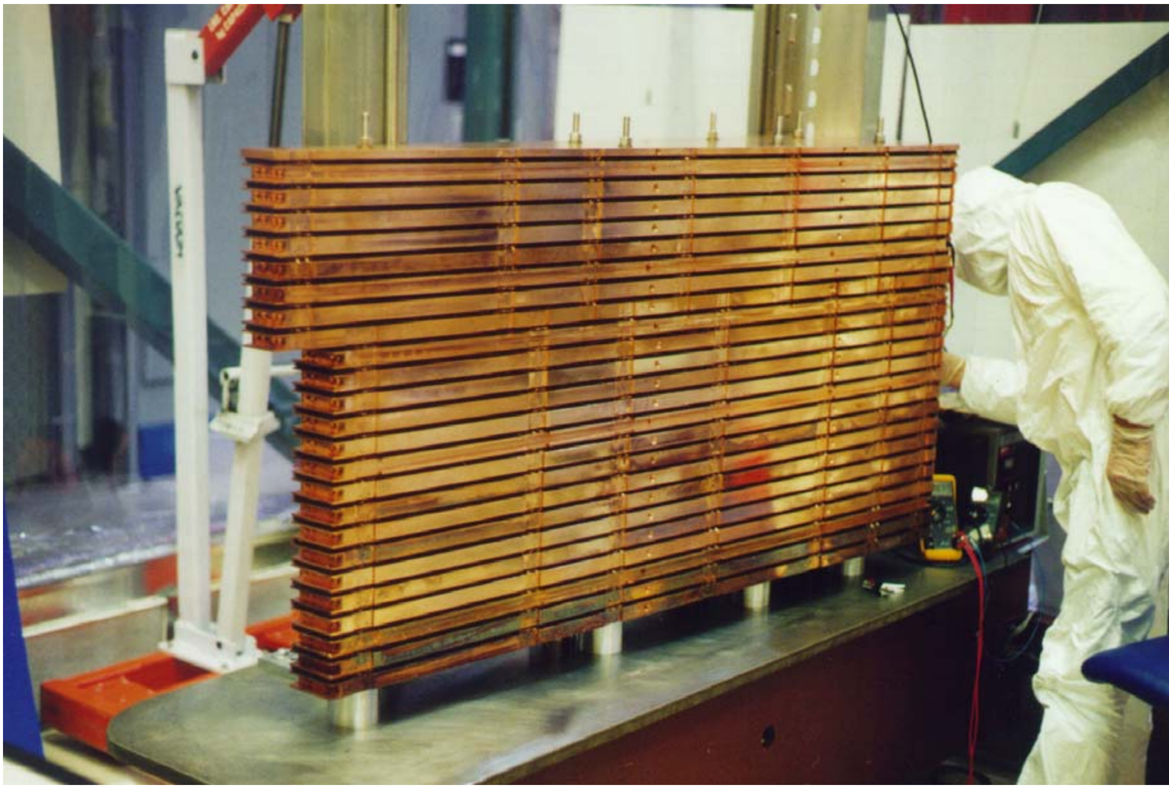
Endcap Hadronic Module 0: Foils

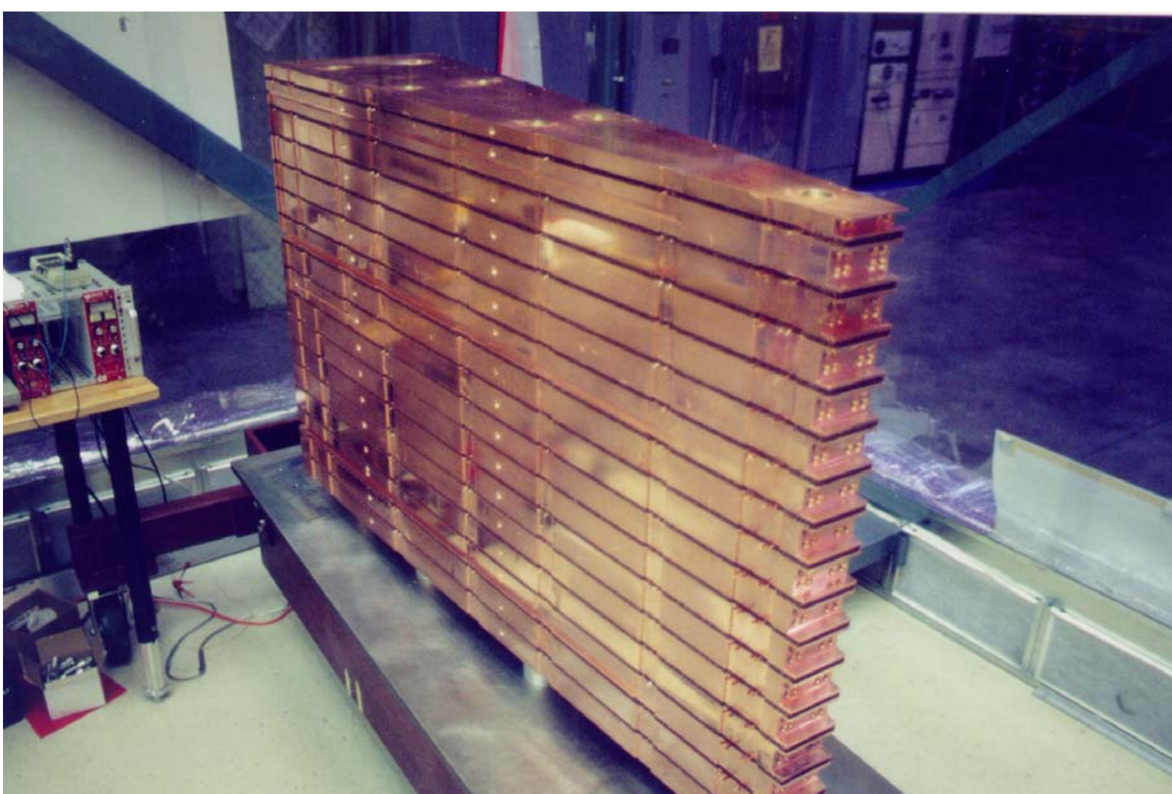




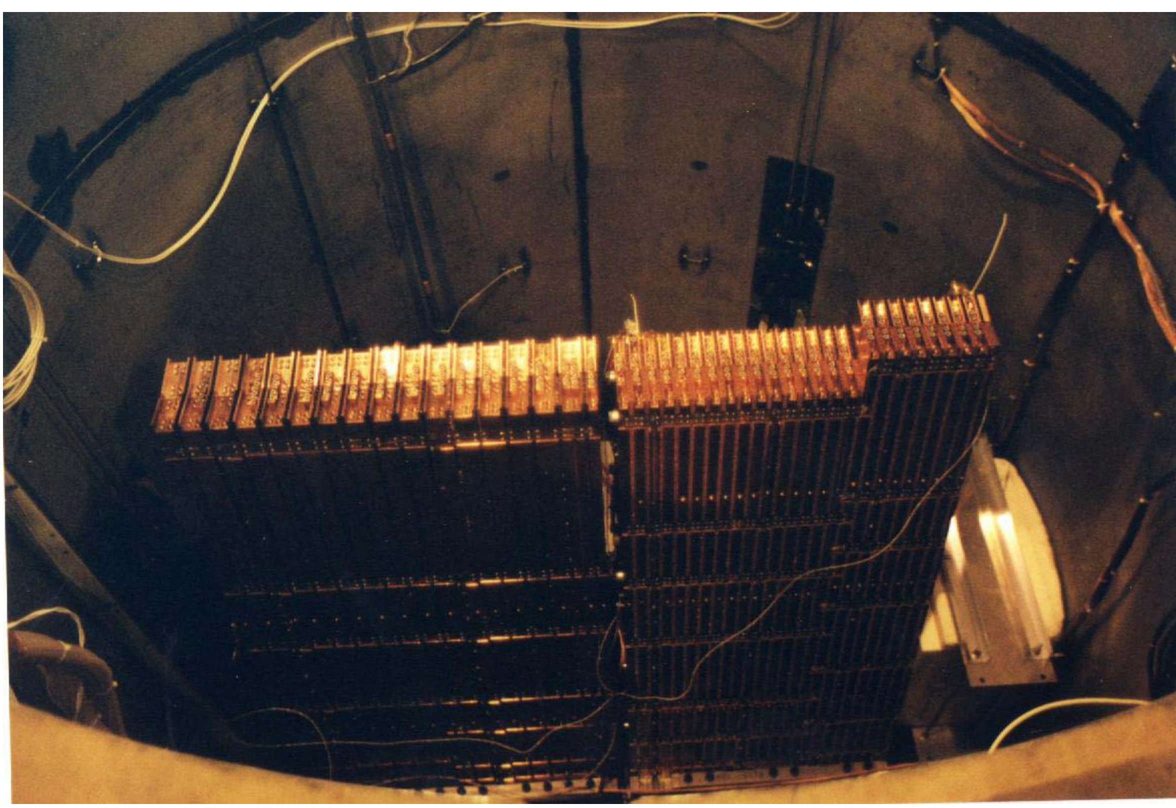
Endcap Hadronic Module 0: Stacking

Endcap Hadronic Module 0





Endcap Hadronic Modules 0: CERN

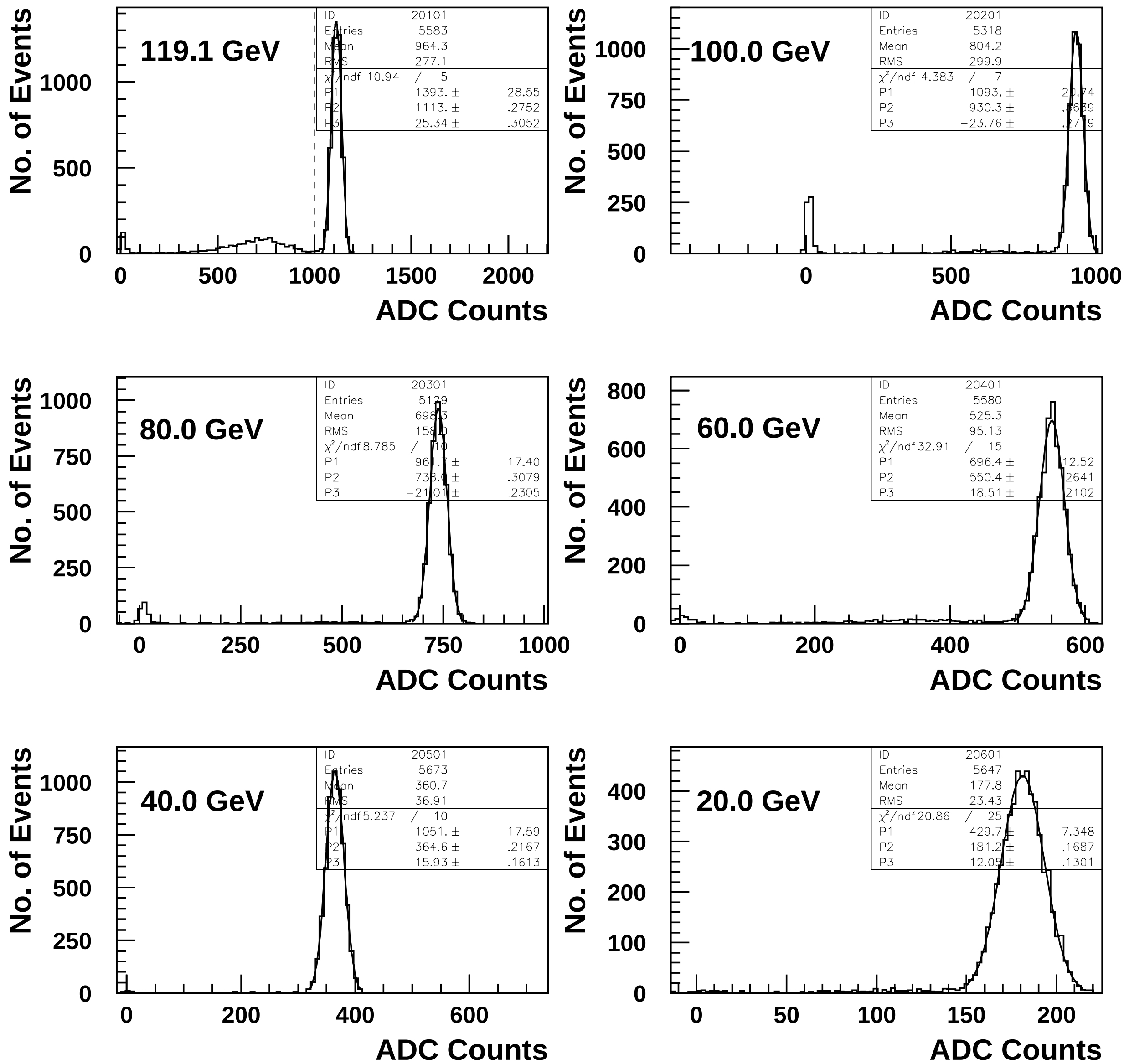


Endcap Hadronic Modules 0: CERN

Endcap Hadronic Modules 0: Beam Tests

HEC Testbeam, April 1998

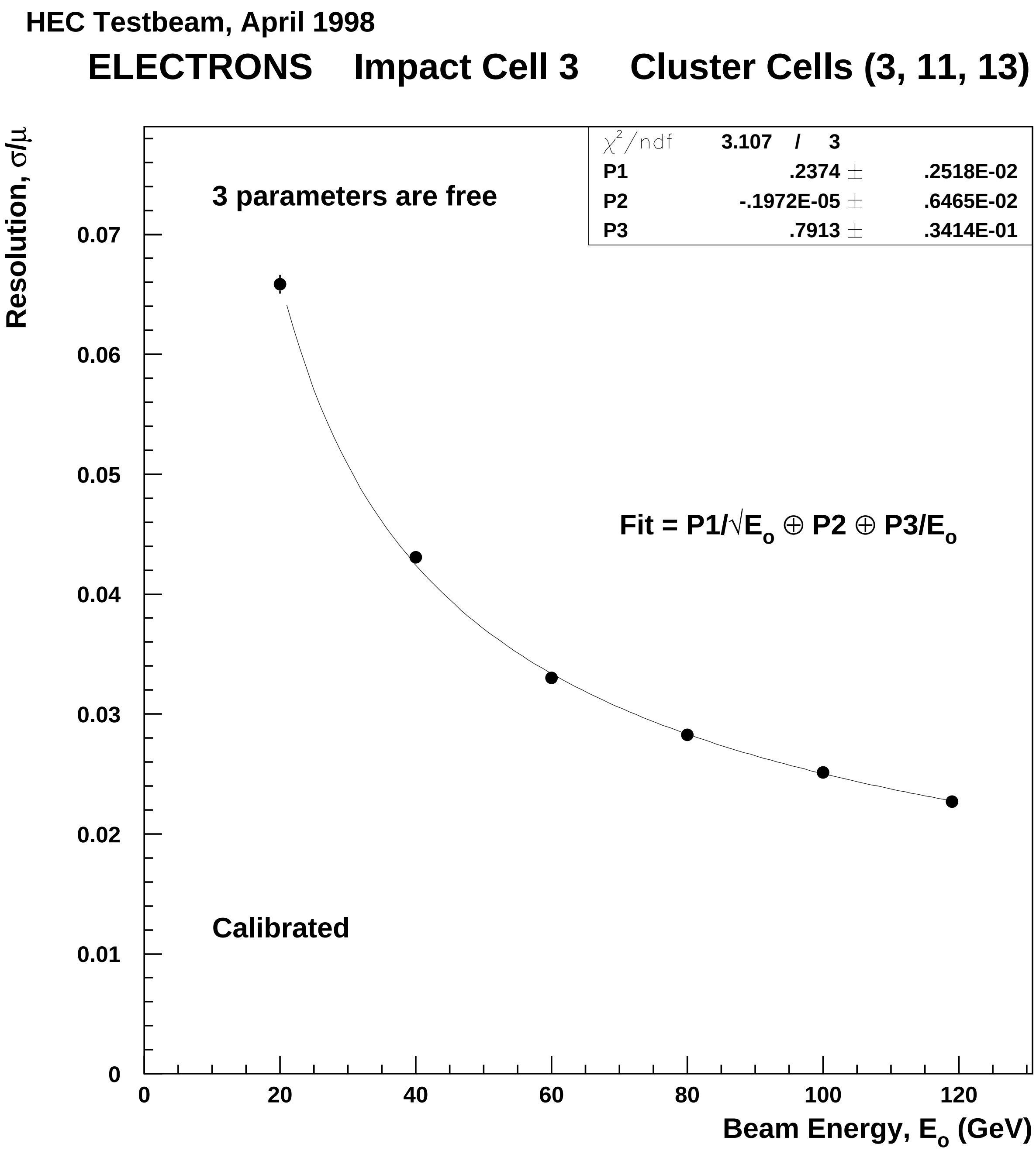
ELECTRONS   Impact Cell 3   Cluster Cells (3, 11, 13)



α_{em}= 0.108 GeV/ADC

$$\frac{\sigma}{E} = \frac{24\%}{\sqrt{E(\mathrm{GeV})}} \oplus 0.0\% \oplus \frac{0.8}{E(\mathrm{GeV})}$$

Endcap Hadronic Modules 0: Beam Tests



$$\frac{\sigma}{E} = \frac{24\%}{\sqrt{E(\mathrm{GeV})}} \oplus 0.0\% \oplus \frac{0.8}{E(\mathrm{GeV})}$$

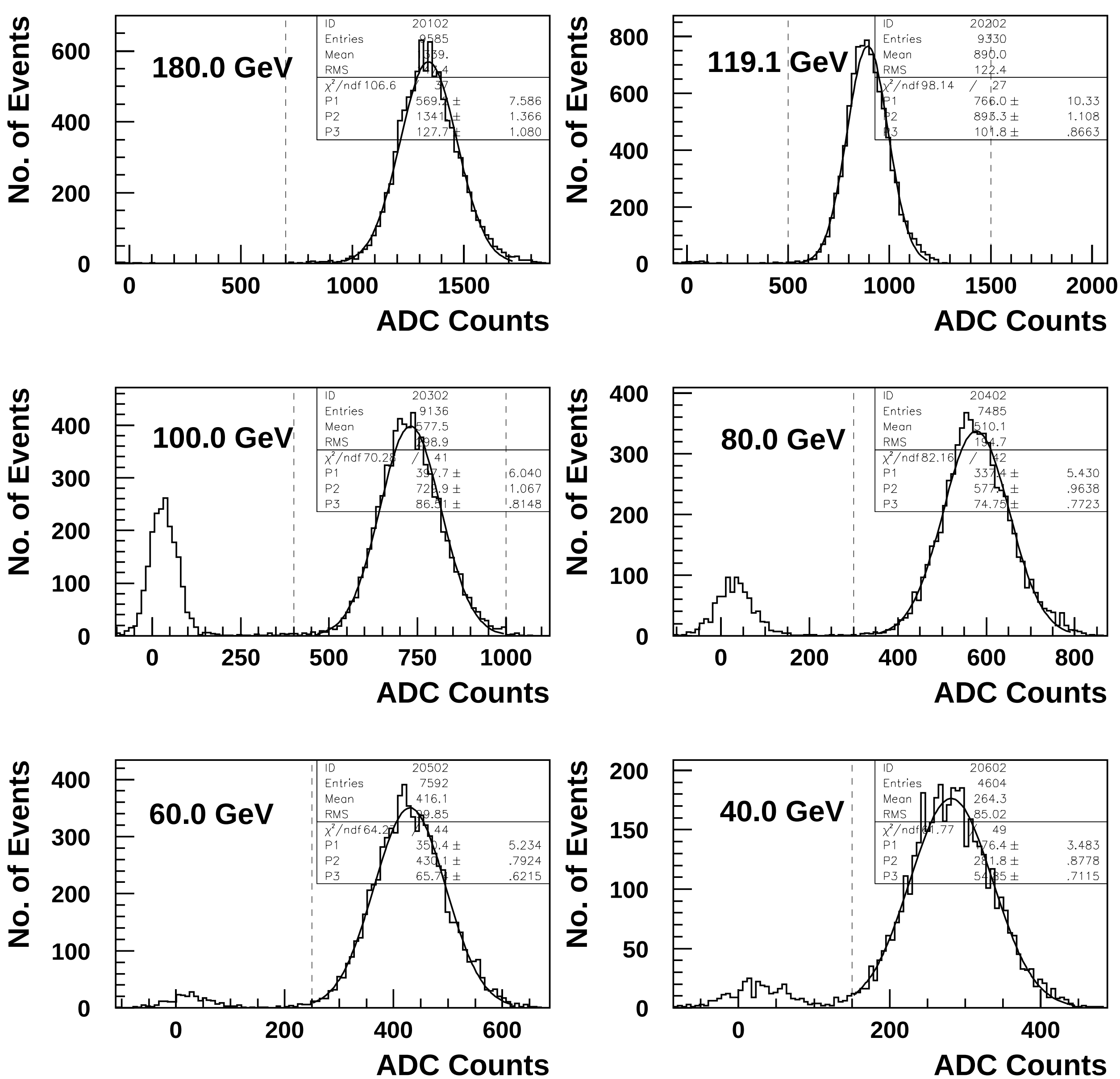
Endcap Hadronic Modules 0: Beam Tests

Preliminary analysis of pion data.

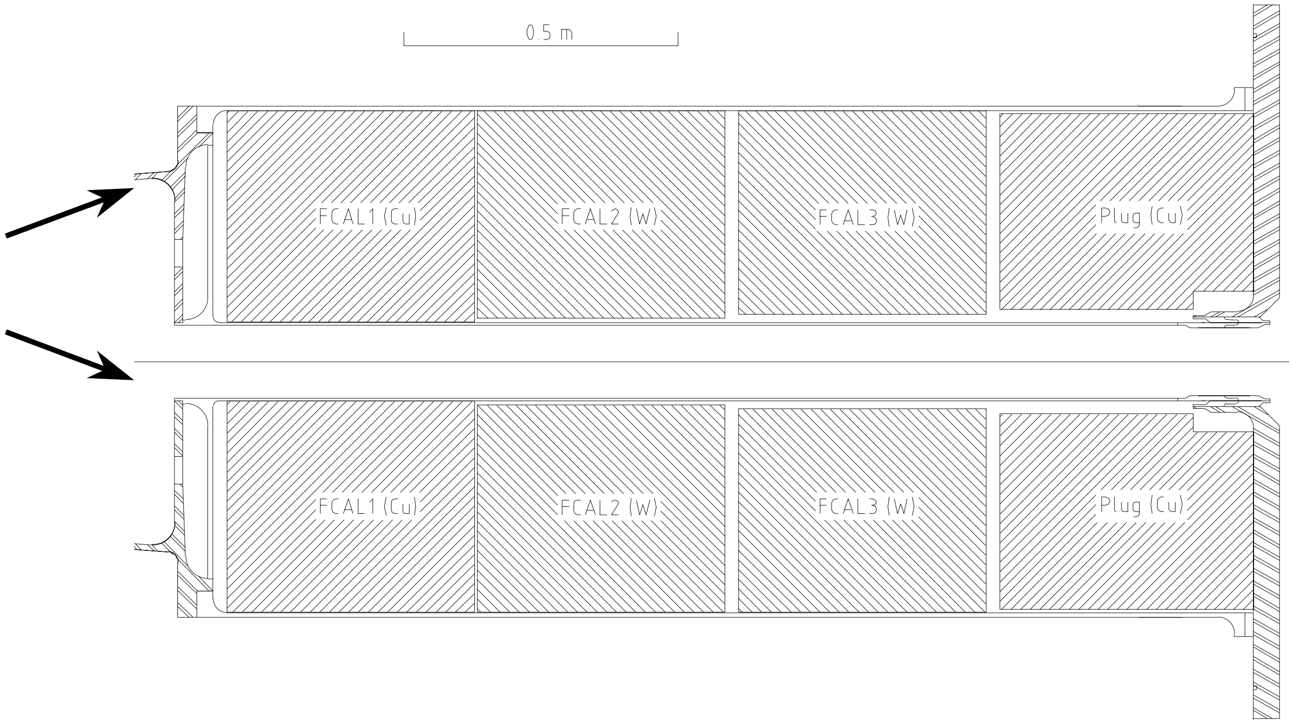
Need to better understand the low signal multiple time sampling treatment

HEC Testbeam, April 1998

Impact Cell 3, Depth Weighted Nineteen Cell Cluster



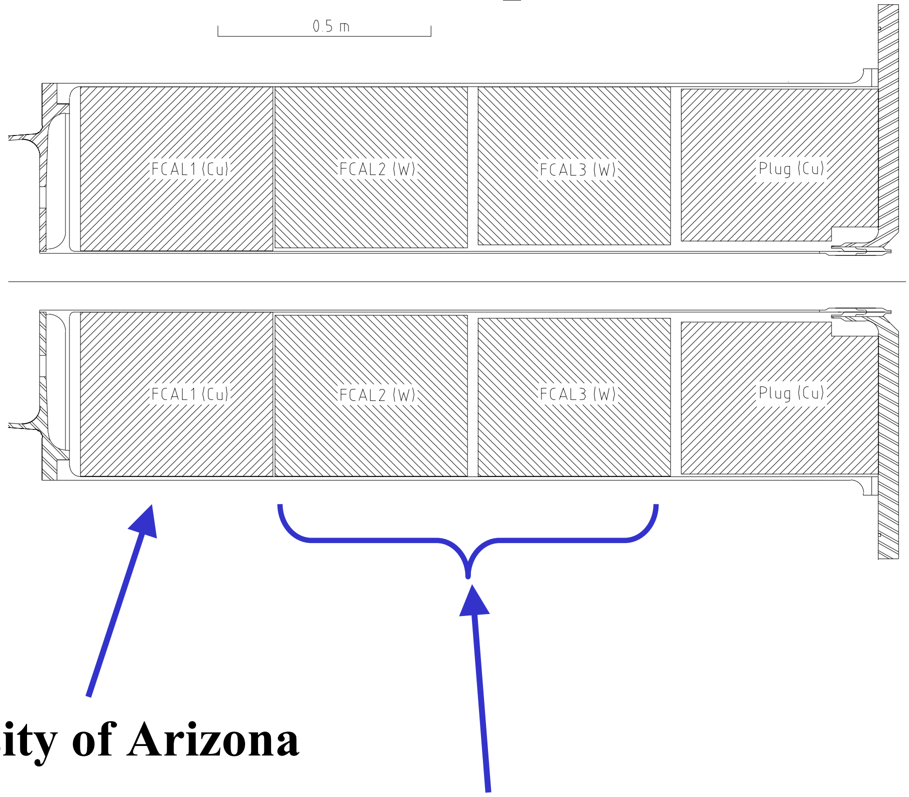
Forward Calorimeter



	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

Forward Calorimeter Responsibilities



FCAL1: University of Arizona

FCAL2 and 3: Canada (Carleton, CRPP, Toronto)

Tungsten rods from Moscow (ITEP)

Module 0 (quadrant) tests during summer 1998

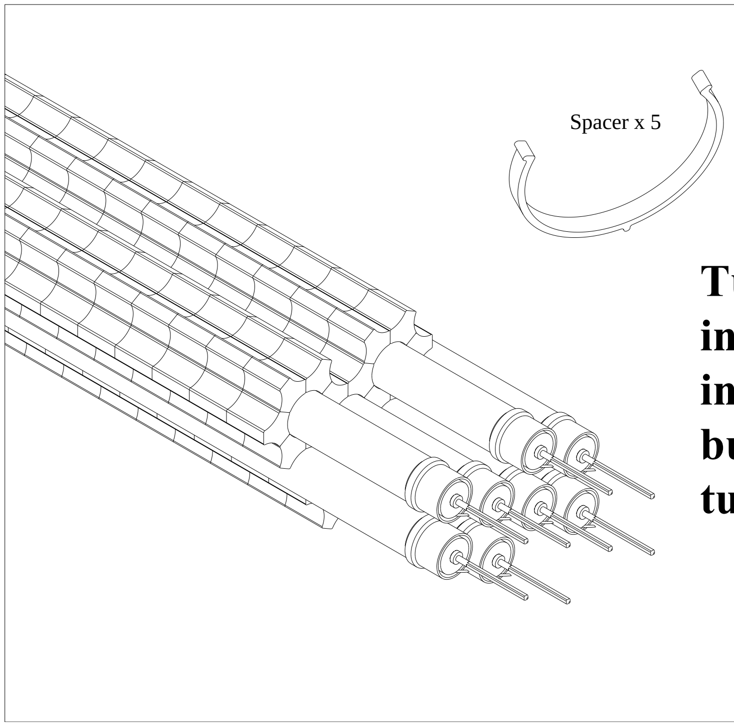
FCAL1 and FCAL2

full containment of hadronic showers

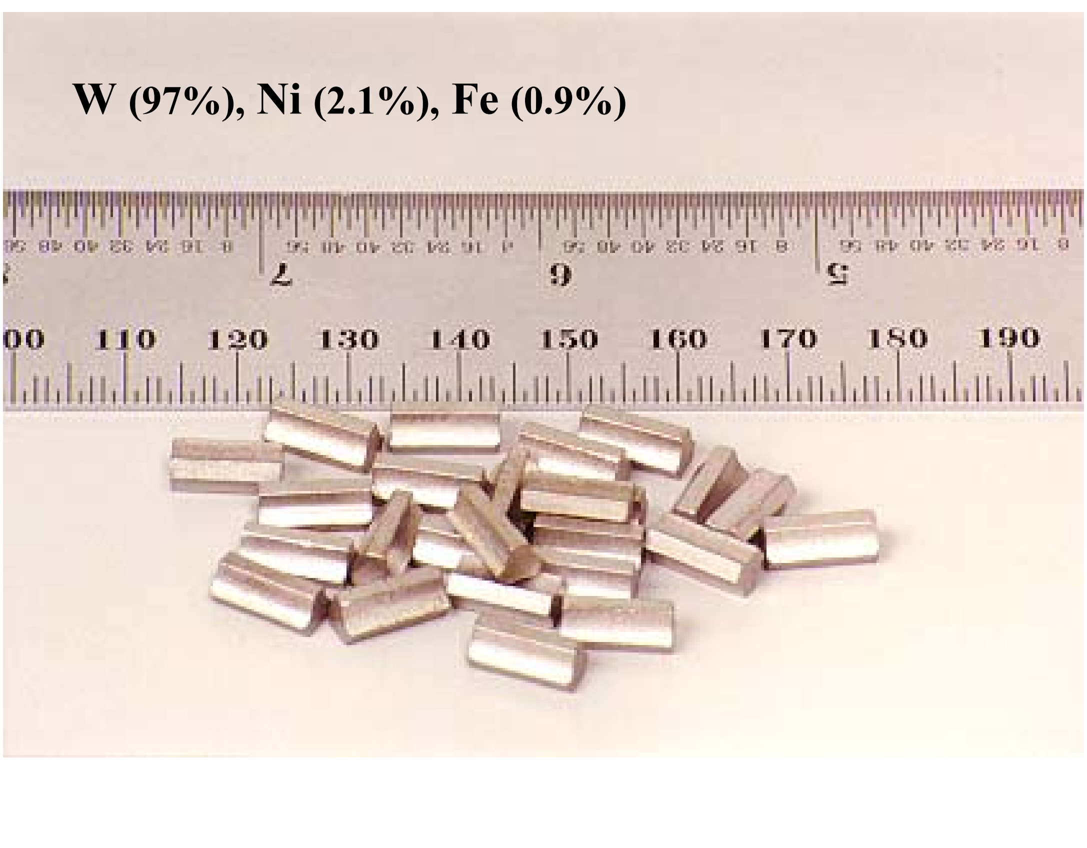
Final modules construction from mid 19999 to mid 2001

Final assembly and installation at CERN in 2001 to end 2003

Hadronic Forward Calorimeter Principle



Tungsten rods in copper tubes in a matrix built of tungsten slugs



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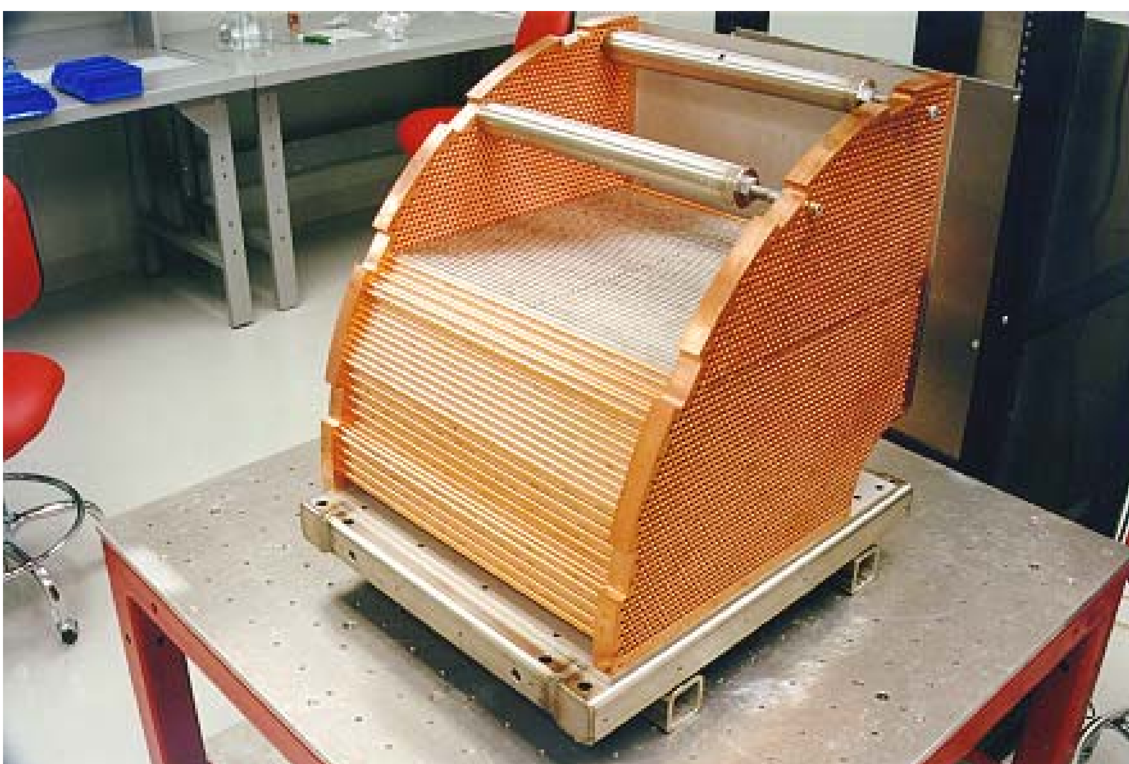
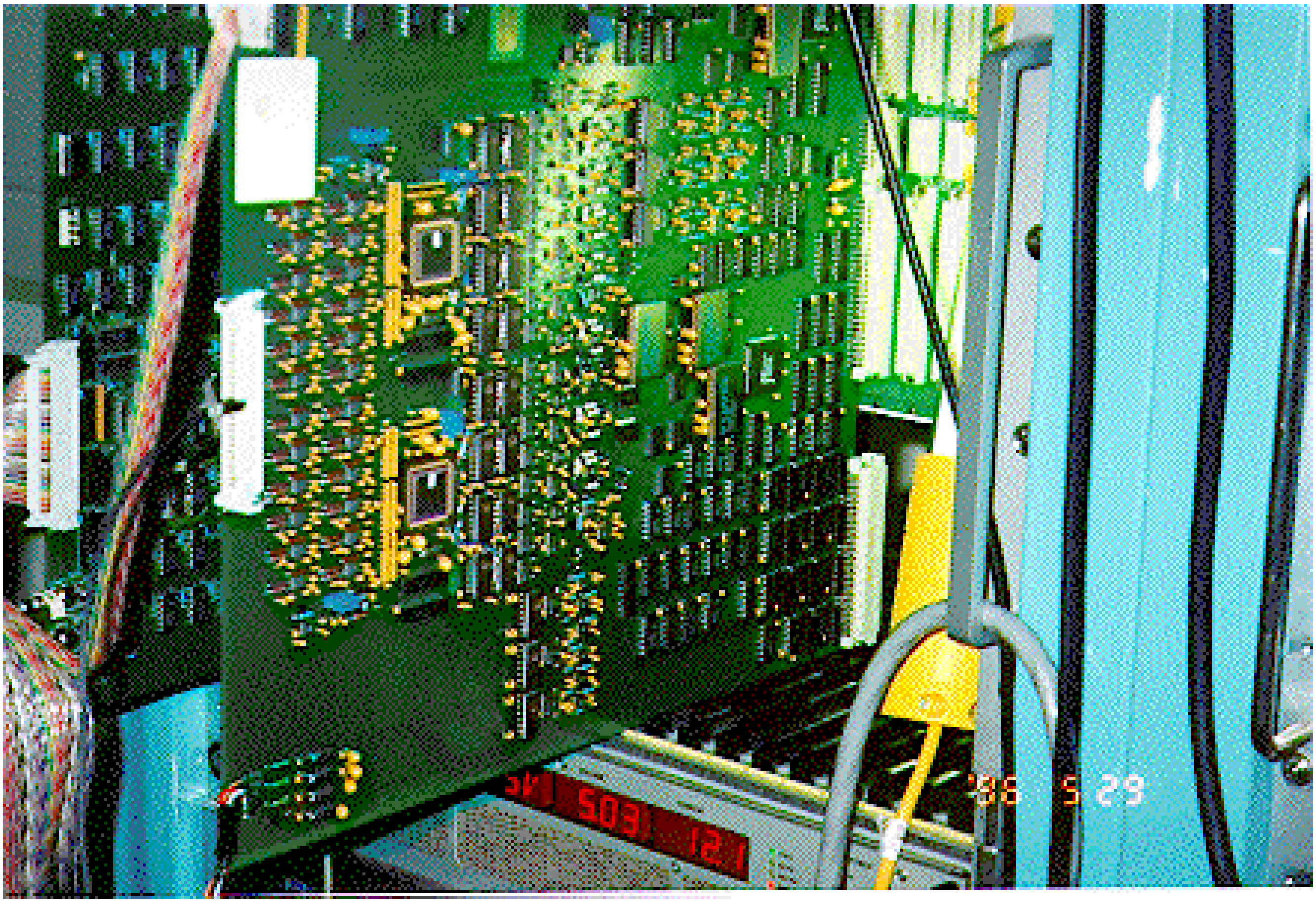
FCAL2 Module 0



FCAL2 Module 0

FCAL2 Module 0

LAr Front-End-Board



1996: ATLAS opts for analog pipeline

Canada (Alberta) responsible for SCA controller

1997: SCA controller successfully tested with module-0 SCA

1998: SCA controller successfully tested with module-0 front-end-board

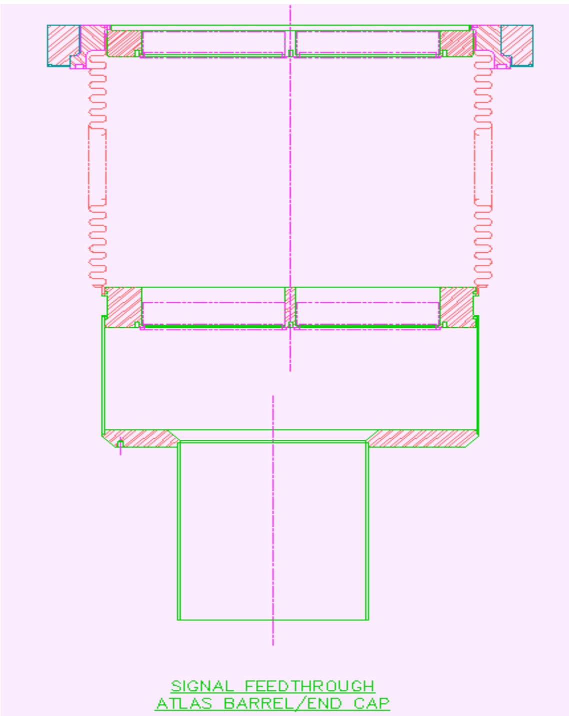
First 4 module-0 FEB's at CERN mid July

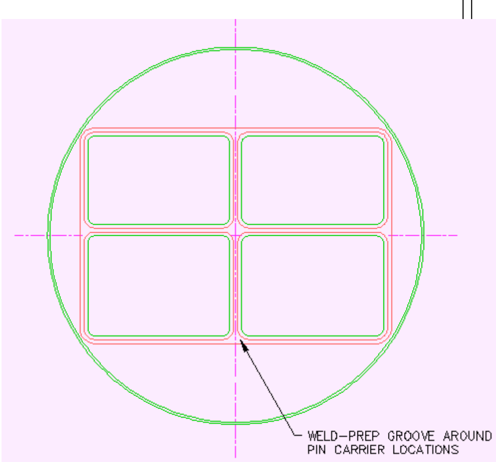
Calorimeter tests in H8 at CERN

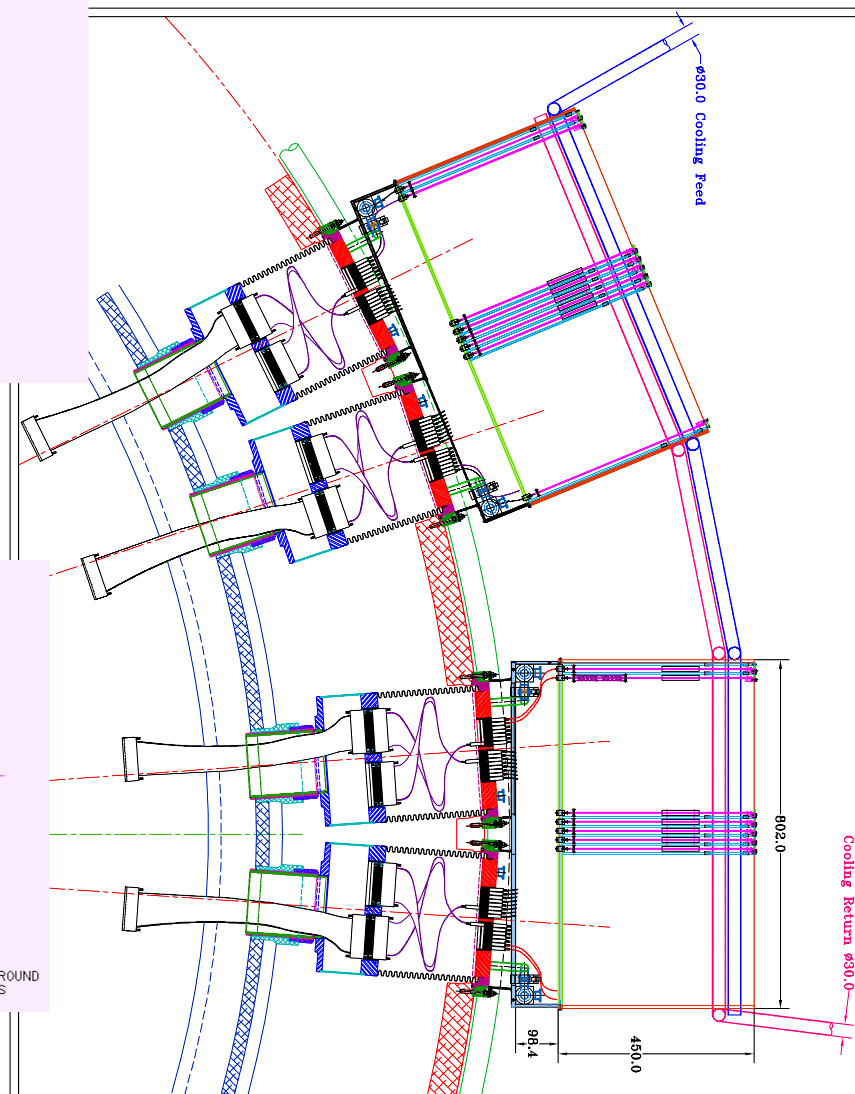
Signal Feedthroughs

Over 180k signal channels in the LAr calorimetry

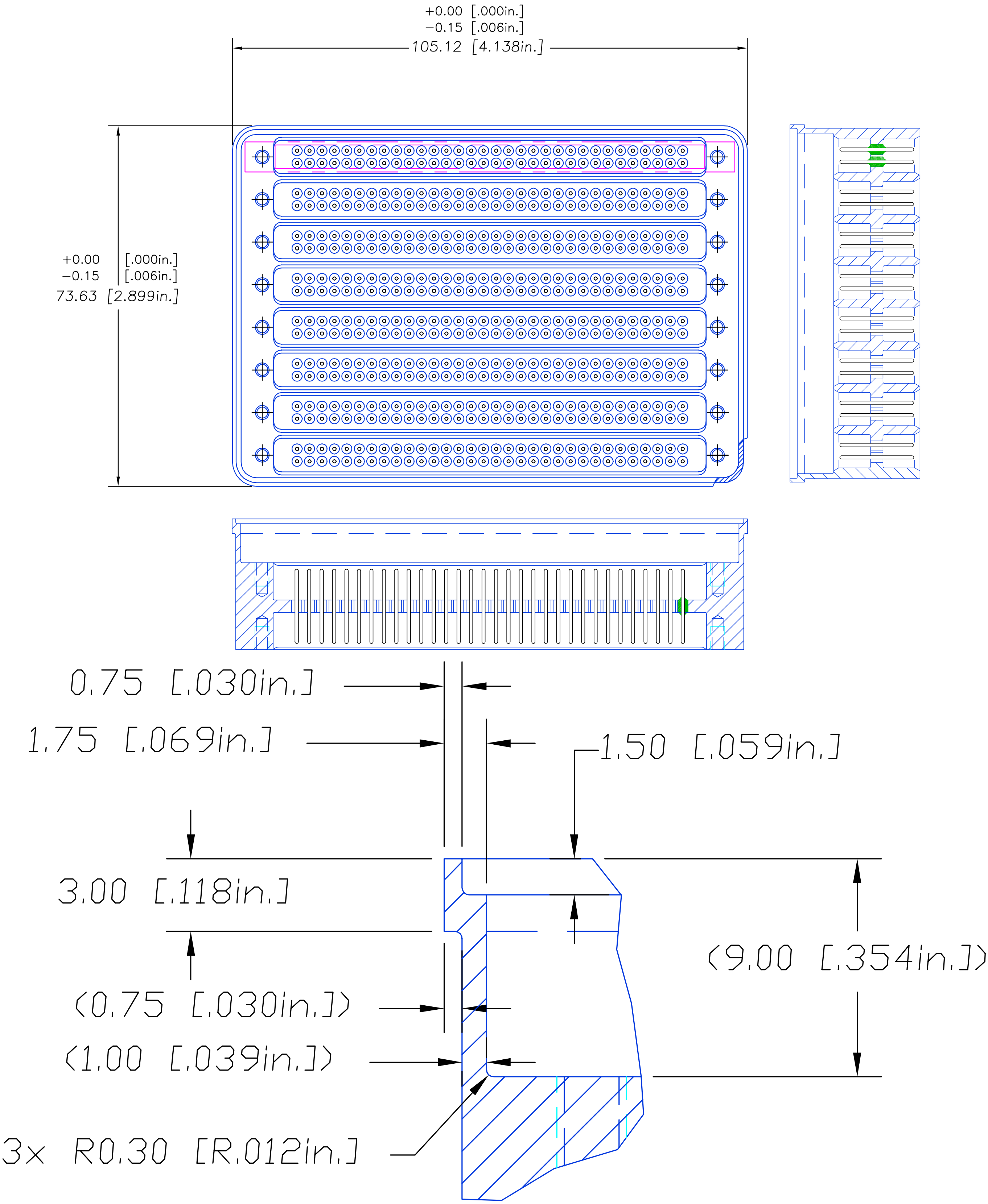
High density and reliability required:
1920 pins per feedthrough unit
barrel: 64 units
endcaps: 50 units total ← **Canada (Victoria, TRIUMF)**







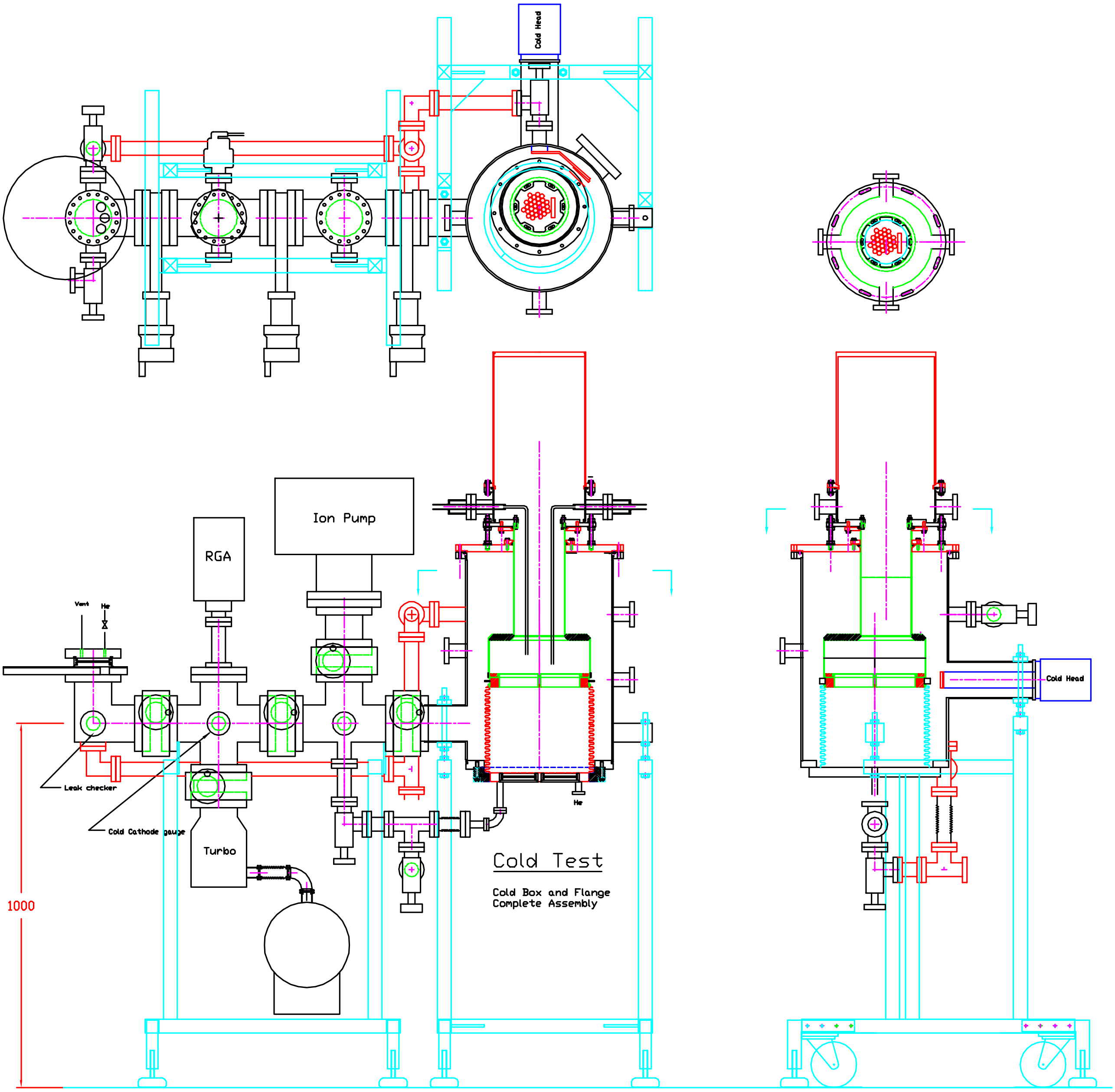
Pin Carrier Design



TRIUMF May 21st 1998

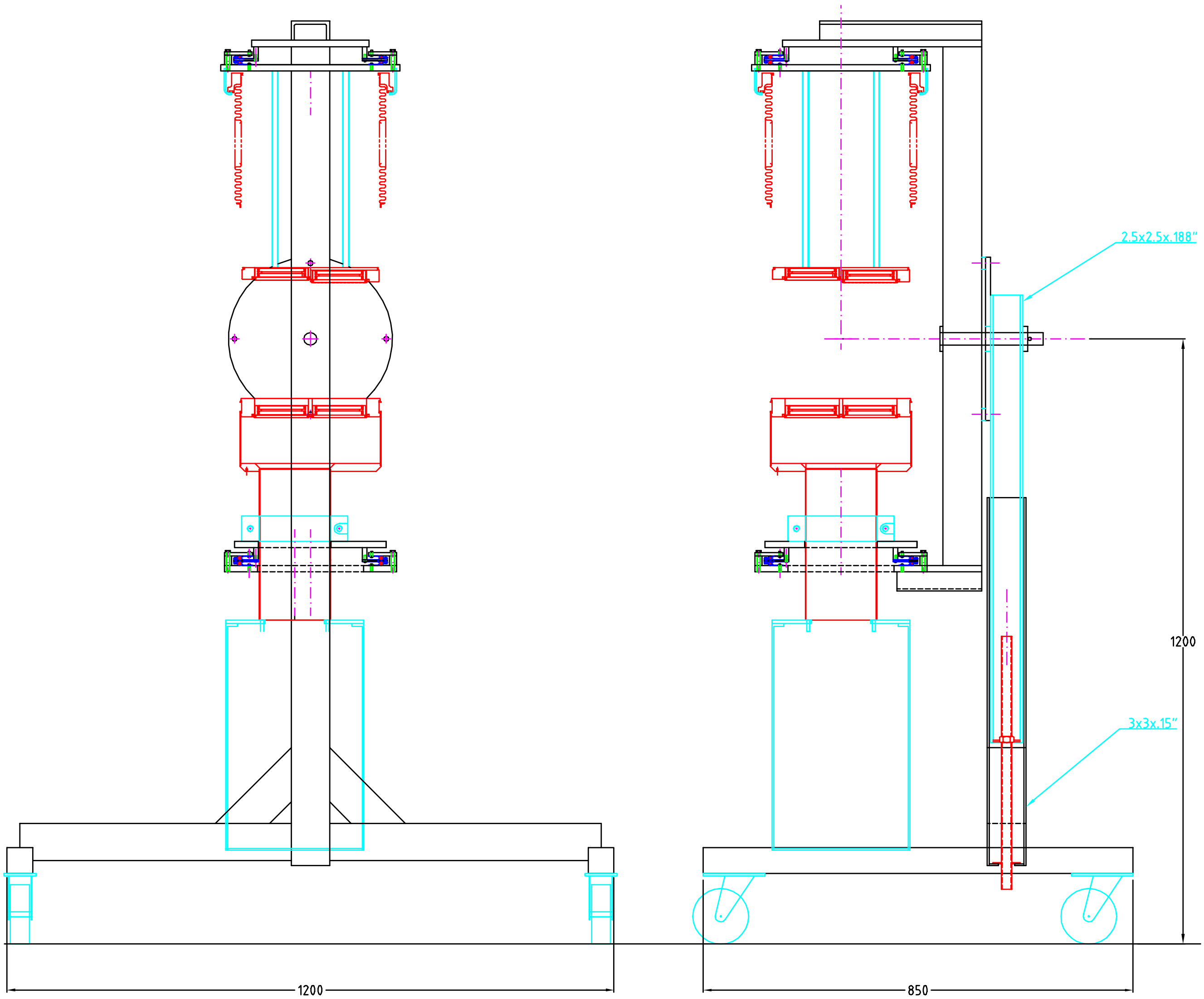
Michel Lefebvre (Victoria)

Leak Test Setup in Victoria



- Leak detection using He leak detector supported by an RGA
- Leak detector services warm and cold test stations
- Cooling by cryo-cooler or LN_2
- Fully assembled; commissioning started.

Assembly Jig in Victoria



- Rotation about horizontal and vertical axis possible
- Various assembly scenarios under study
- Under construction

Physics Studies

Canadian active in ATLAS physics studies

- Heavy Higgs searches

$H \to WW \to l\nu jj$

$H \to ZZ \to lljj$

$H \to ZZ \to ll\nu\nu$

- Technicolour searches

$\rho_T \;,\; \pi_T \;,\; \omega_T \;,\; \eta_T$

$\rho_T^{\pm} \to W^{\pm}Z \to l^{\pm}\nu l^{+}l^{-}$

$\rho_T^{\pm} \to \pi_T^{\pm}Z \to bql^{+}l^{-}$

$\eta_{8T} \to t\bar{t}$

$\omega_T \to \gamma\pi_T^{o} \to \gamma b\bar{b}$

- Top physics

single top production

$t\bar{t}$ production

top couplings, mass, width

- Three gauge boson couplings

$\gamma W^{+}W^{-}$ in $pp \to W\gamma$

$ZW^{+}W^{-}$ in $pp \to ZW$ or WW

Summary

Large Hadron Collider at CERN

- 14 TeV center-of -mass pp collisions (2005)
- very exciting programme!

ATLAS

- Successful R&D phase closing
- Construction phase starting
- Exploit the full discovery potential of the LHC

ATLAS Canada

- Successful Canadian involvement in ATLAS
- Canada's involvement in ATLAS will grow as start up date approaches
- Canada is already considering other contributions to ATLAS, beyond its major hardware responsibilities (DAQ, Inner detector)
- It is important, necessary, to consolidate and increase our impact on the ATLAS physics programme
- TRIUMF's role in this programme is crucial, both for IPP and TRIUMF's future