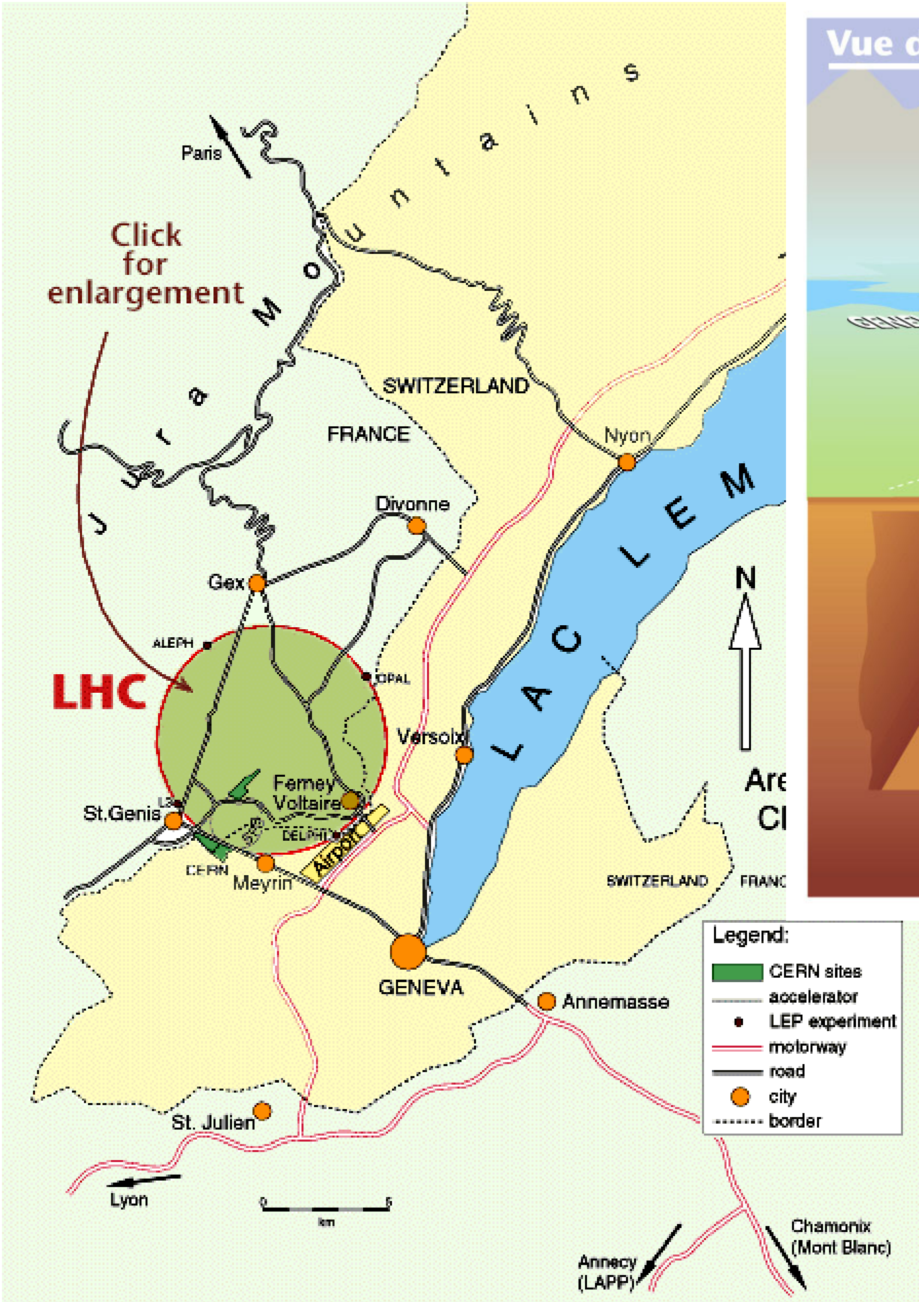
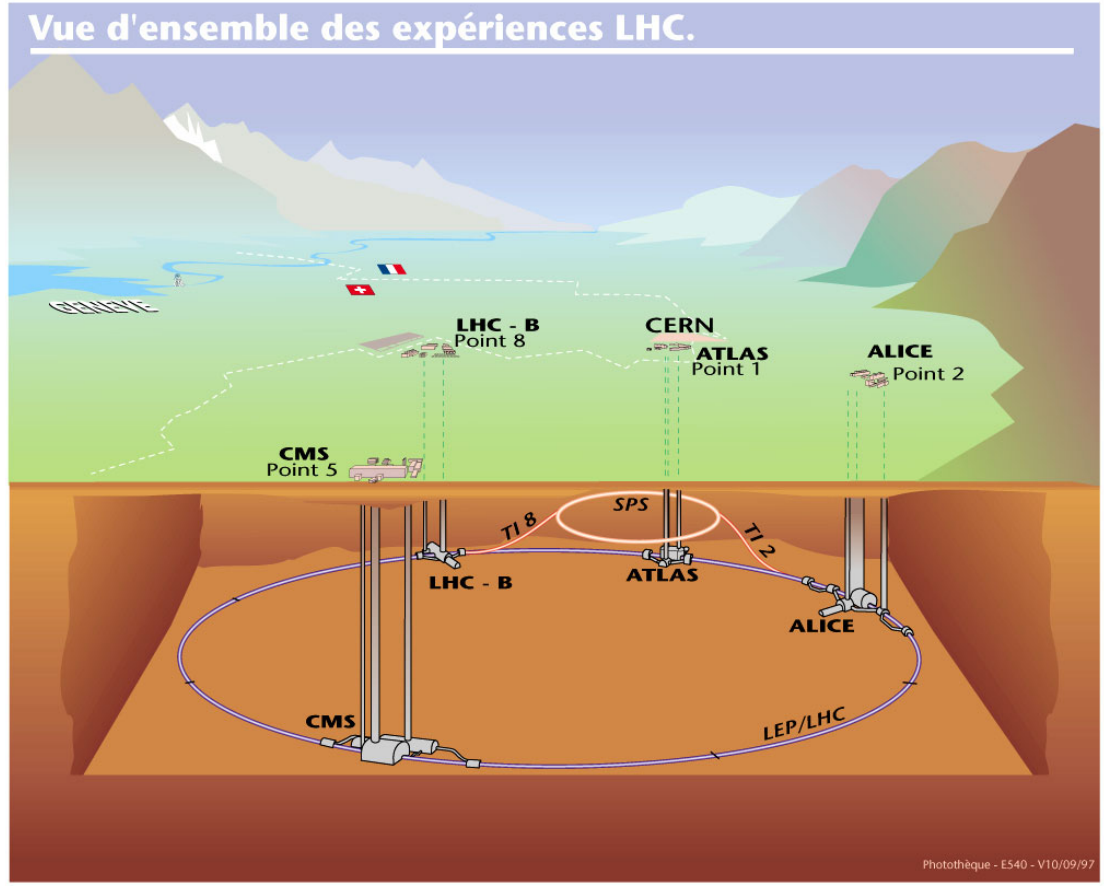
The ATLAS Muon Detector

V. Polychronakos, Physics

Overview

- The Large Hadron Collider – A Brief Overview
- The ATLAS Experiment
  - Physics Goals – Why do this?
  - Description of the Experiment
- The Muon System
- The four different muon detectors
- The Monitored Drift Tube Chambers
- Cathode Strip Chambers
- Electronics
- Concluding Comment





Ring inclined 1.23 deg towards
The lake in order to reduce depth
At the Jura side

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Key LHC Parameters

LHC General Parameters		
Energy at collision	7	TeV
Energy at injection	450	GeV
Dipole field at 7 TeV	8.33	T
Coil inner diameter	56	mm
Distance between aperture axes (1.9 K)	194	mm
Luminosity	1	E34 $cm^{-2}s^{-1}$
Beam beam parameter	3.6	E-3
DC beam current	0.56	A
Bunch spacing	7.48	m
Bunch separation	24.95	ns
Number of particles per bunch	1.1	E11
Normalized transverse emittance (r.m.s.)	3.75	µm
Total crossing angle	300	µrad
Luminosity lifetime	10	h
Energy loss per turn	7	keV
Critical photon energy	44.1	eV
Total radiated power per beam	3.8	kW
Stored energy per beam	350	MJ
Filling time per ring	4.3	min

0.9

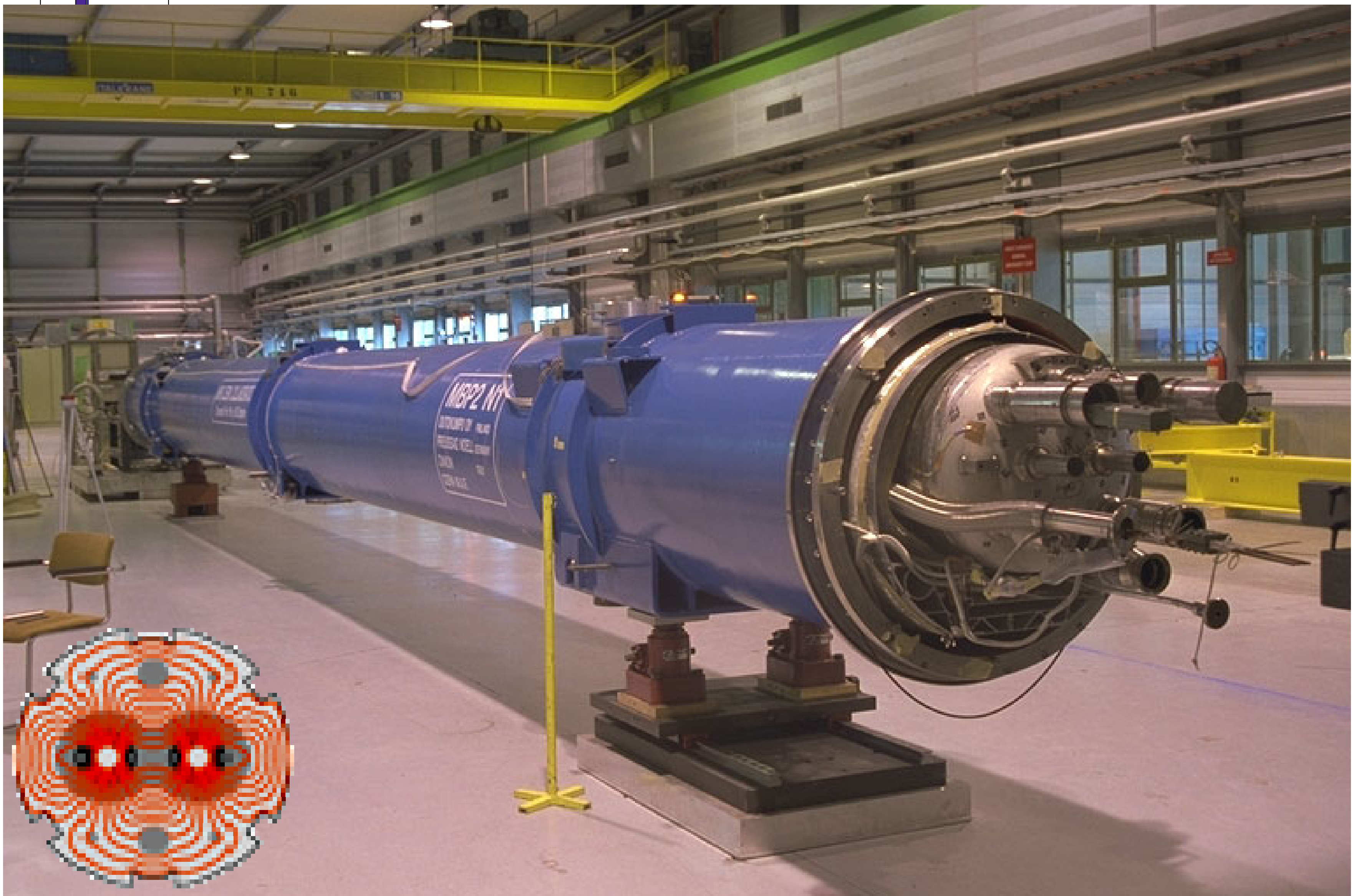
0.021

What would 1e9 Joules of Stored Energy compare to?

Approximate energy in joules associated with various events and phenomena

Description	Energy
Big Bang	10^{68}
Radio energy emitted by the Galaxy during its lifetime	10^{55}
Rotational energy of the Milky Way	10^{52}
Energy released in a supernova explosion	10^{44}
Oceans' hydrogen in fusion	10^{34}
Rotational energy of the earth	10^{29}
Annual solar energy incident on the earth	5×10^{24}
Annual wind energy dissipated near earth's surface	10^{22}
Annual global energy usage by humans	3×10^{20}
Annual energy dissipated by the tides	10^{20}
Annual U.S. energy usage	8×10^{19}
Energy release during Krakatoan eruption of 1883	10^{18}
Energy release of 15-megaton fusion bomb	10^{17}
Annual electrical output of large generating plant	10^{16}
Thunderstorm	10^{15}
Energy released in burning 1000 kg of coal	3×10^{10}
Kinetic energy of a large jet aircraft	10^{9}
Energy released in burning 1 litre of gasoline	3×10^{7}
Daily food intake of a human adult	10^{7}
Kinetic energy of a home run in baseball	10^{3}
Work done by a human heart per beat	0.5
Turning this page	10^{-3}
Flea hop	10^{-7}
Discharge of a single neuron	10^{-10}
Typical energy of a proton in a nucleus	10^{-13}
Typical energy of an electron in an atom	10^{-18}
Energy to break one bond in DNA	10^{-20}

Superconducting (2 in 1) Dipoles



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Experiments at the LHC

- Four Experiments being constructed:
- "General Purpose" ATLAS and CMS
  - 4-pi Geometry
  - Electroweak Symmetry Breaking (Higgs Boson)
  - Supersymmetry
  - Compositness
  - New Vector Bosons?
  - Extra Dimensions?
  - ……
- ALICE – Heavy Ion Experiement (akin to PHENIX)
- LHCb – Dedicated "b-physics" Experiement (CP violation in the b sector

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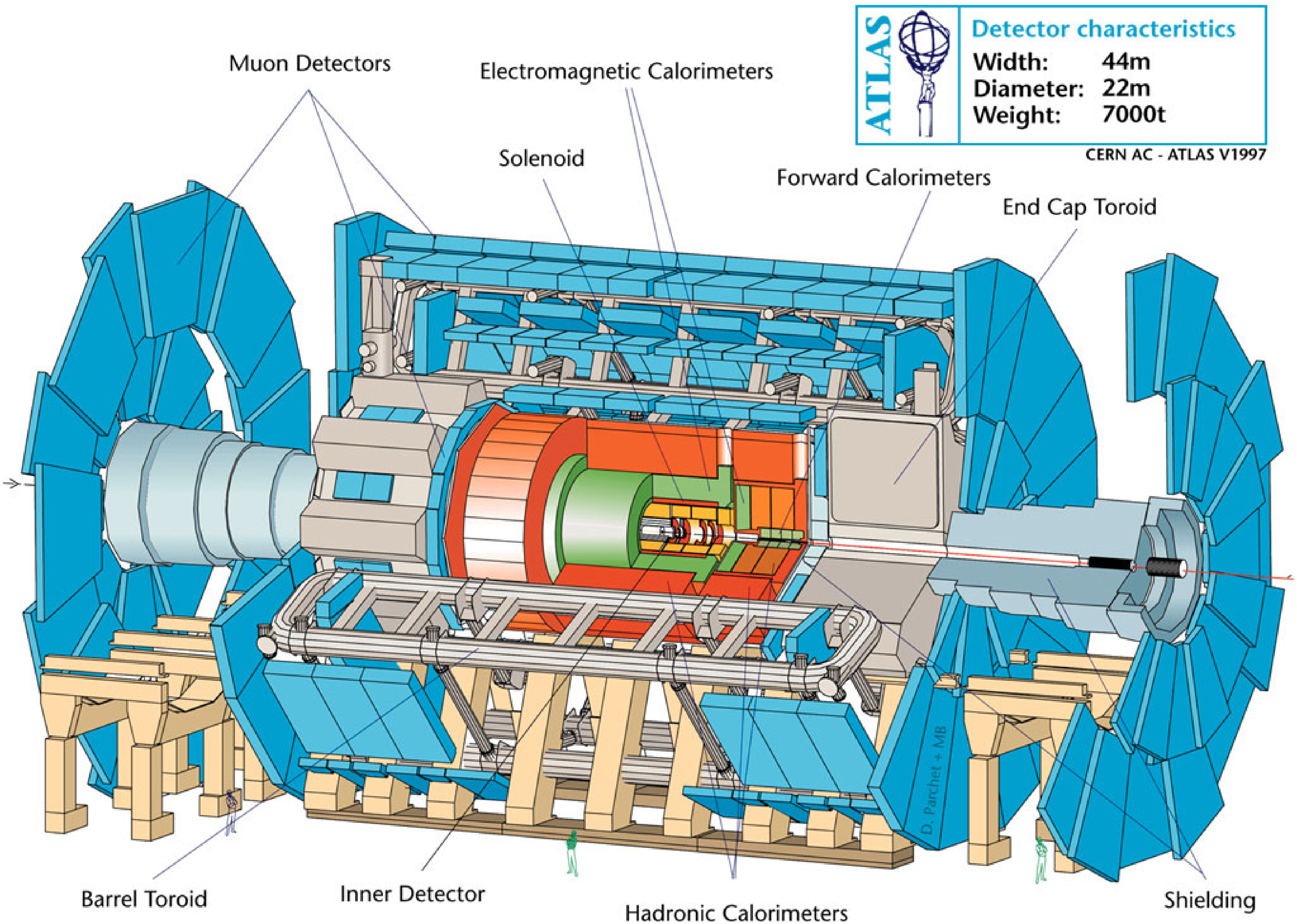
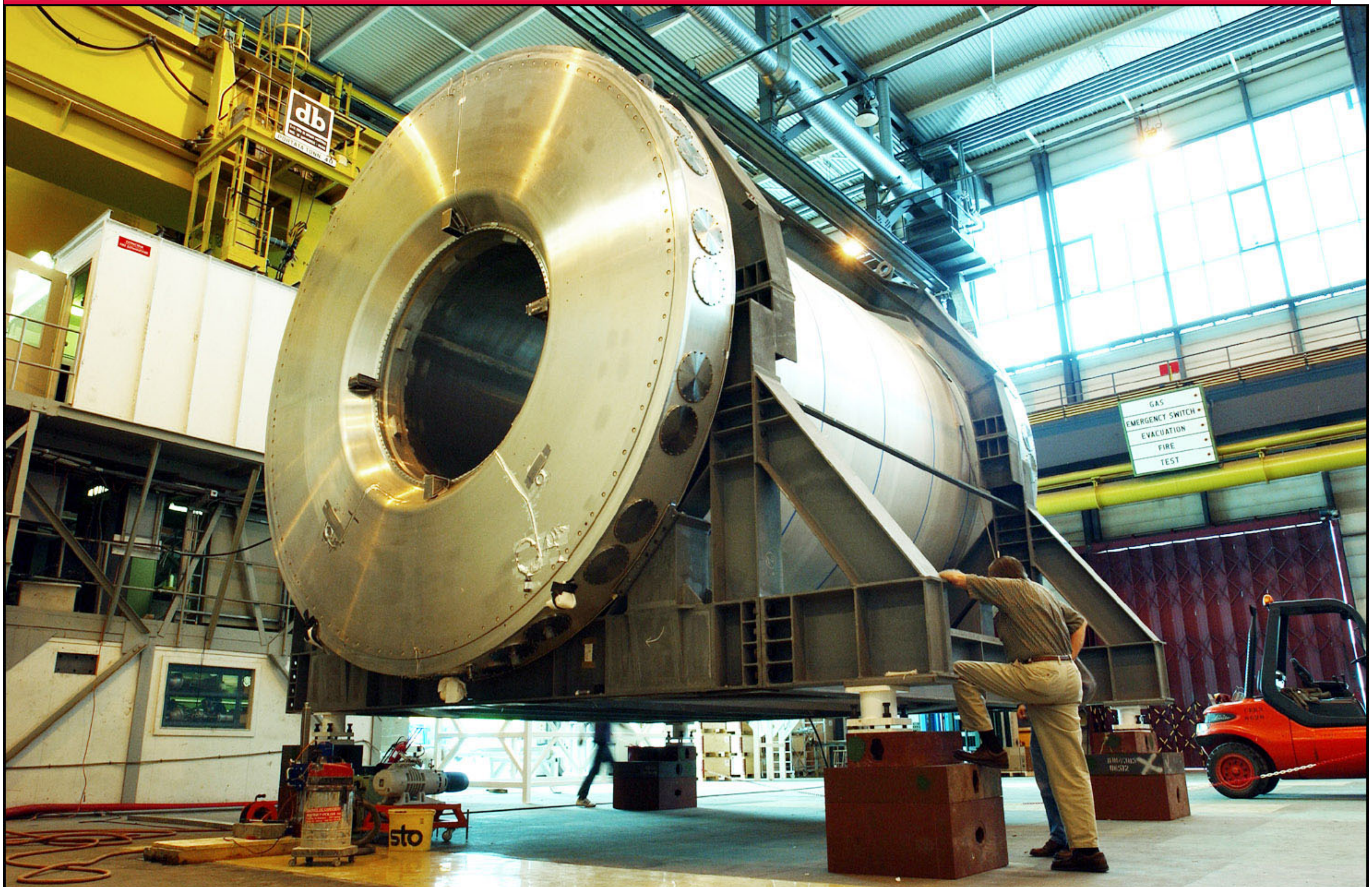
The ATLAS Detector



The Electromagnetic Calorimeter Cryostat

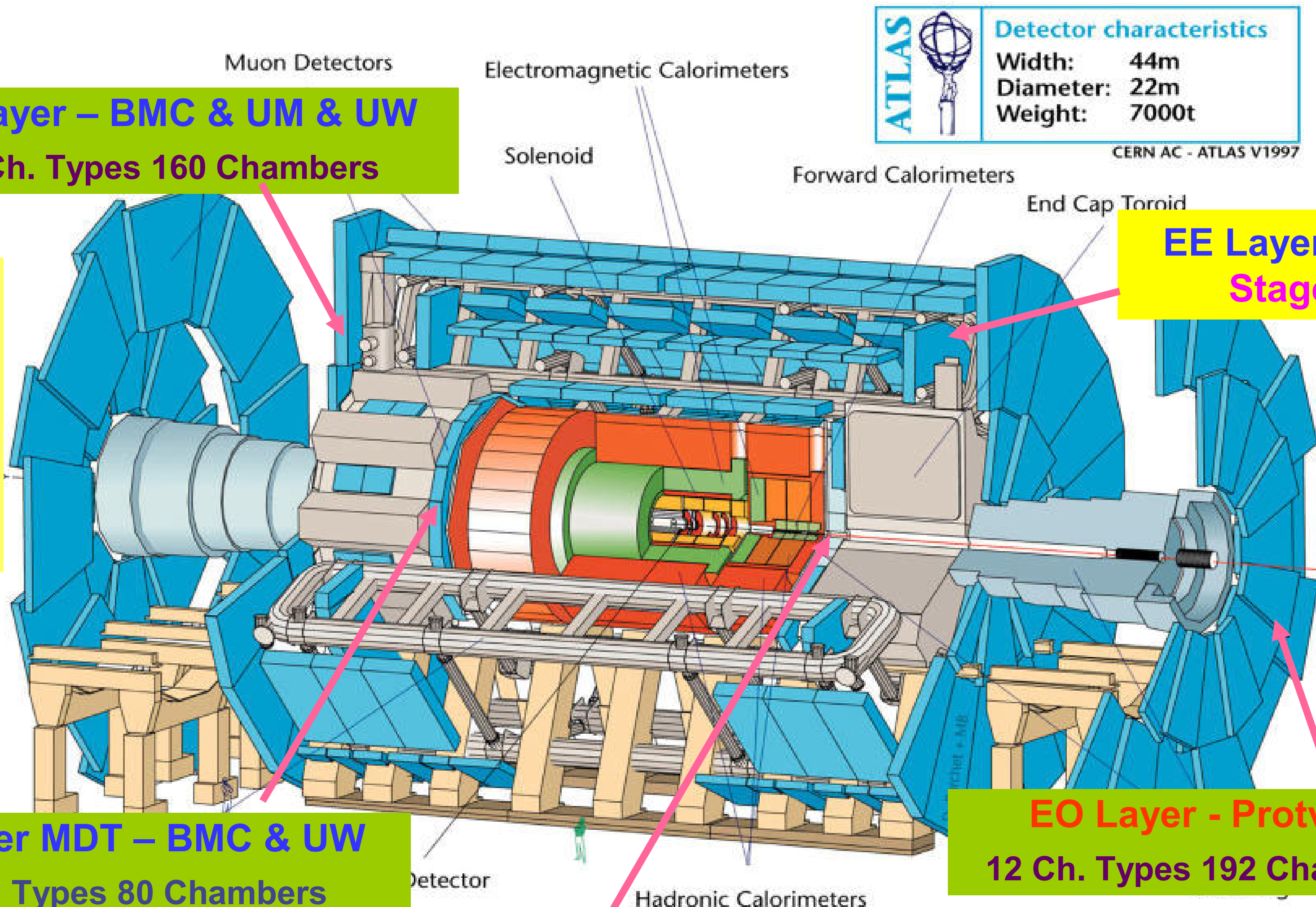


ATLAS Muon Endcap System

EM Layer – BMC & UM & UW
10 Ch. Types 160 Chambers

BMC
- Boston
- Brandeis
- Harvard
- MIT
- Tufts

EE Layer – US
Staged



EI Layer MDT – BMC & UW
5 Ch. Types 80 Chambers

EI Layer CSC – BNL & UCI
2 Ch. Types 32 Chambers

EO Layer - Protvino
12 Ch. Types 192 Chambers

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U.S. ATLAS Muon Collaboration

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University of Washington at Seattle

*** Institute Contact Person**

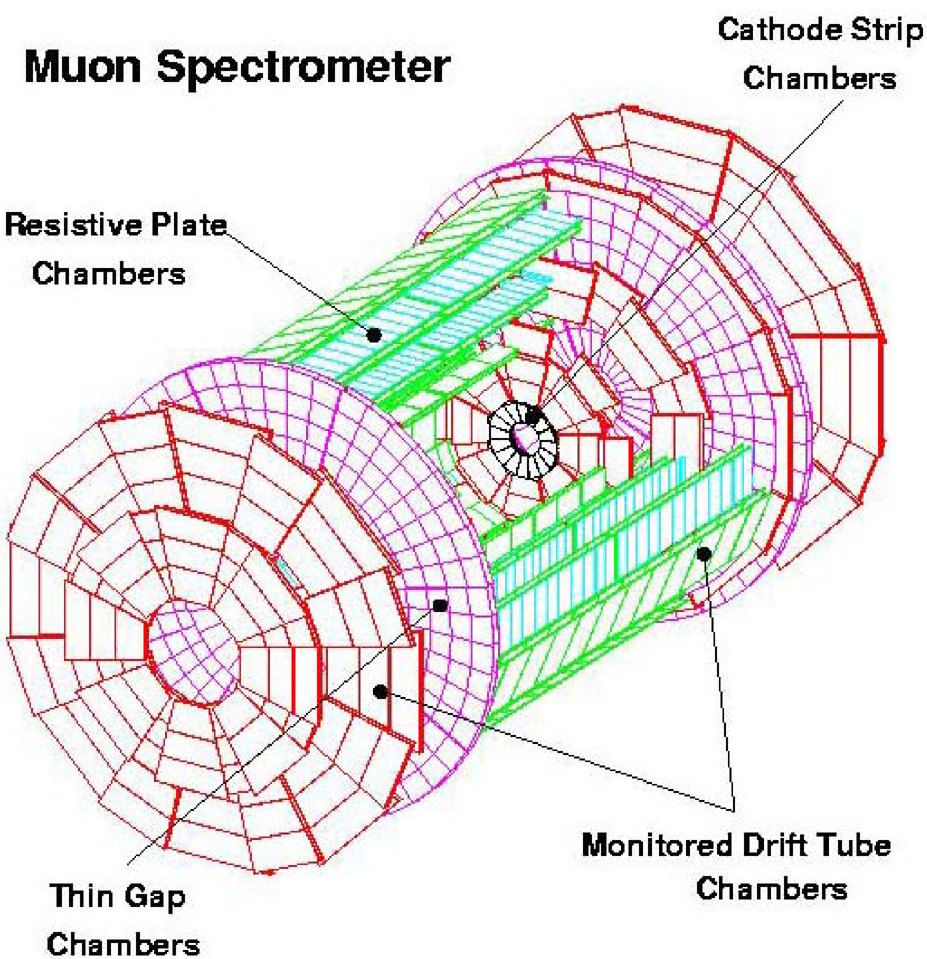
The importance of leptons (e,μ) for the Higgs search

- Mass of the Higgs Boson not a priori constrained by theory (but < ~700 Gev/c^2)
- LEP experiments → M_H > 114 GeV /c^2, most likely value $170 > M_H > 120$
- H likes to decay into the heaviest possible particles, hence $H \rightarrow Z^0 Z^0$

```
      |   |_> μ+μ–
      |____> μ+μ–
```

- Of course H decays into electrons at about the same rate (measured by the EM Calorimeter - most important BNL contribution to ATLAS)
- P_T of μ(e) 5-50 GeV/c, easy to trigger

The ATLAS Muon System



- Trigger Chambers, fast timing resolution ~2 ns, ~ 1 cm spatial resolution
  - Resistive Plate Chambers (RPC) in Barrel
  - Thin Gap Chambers (TGC) in the Endcaps
- Momentum measurement chambers (Precision Chambers, ~80 micron spatial resolution)
  - Monitored Drift tubes (MDT) in most of the solid angle
  - Cathode Strip Chambers (CSC) in the most forward (high rate) Endcap region

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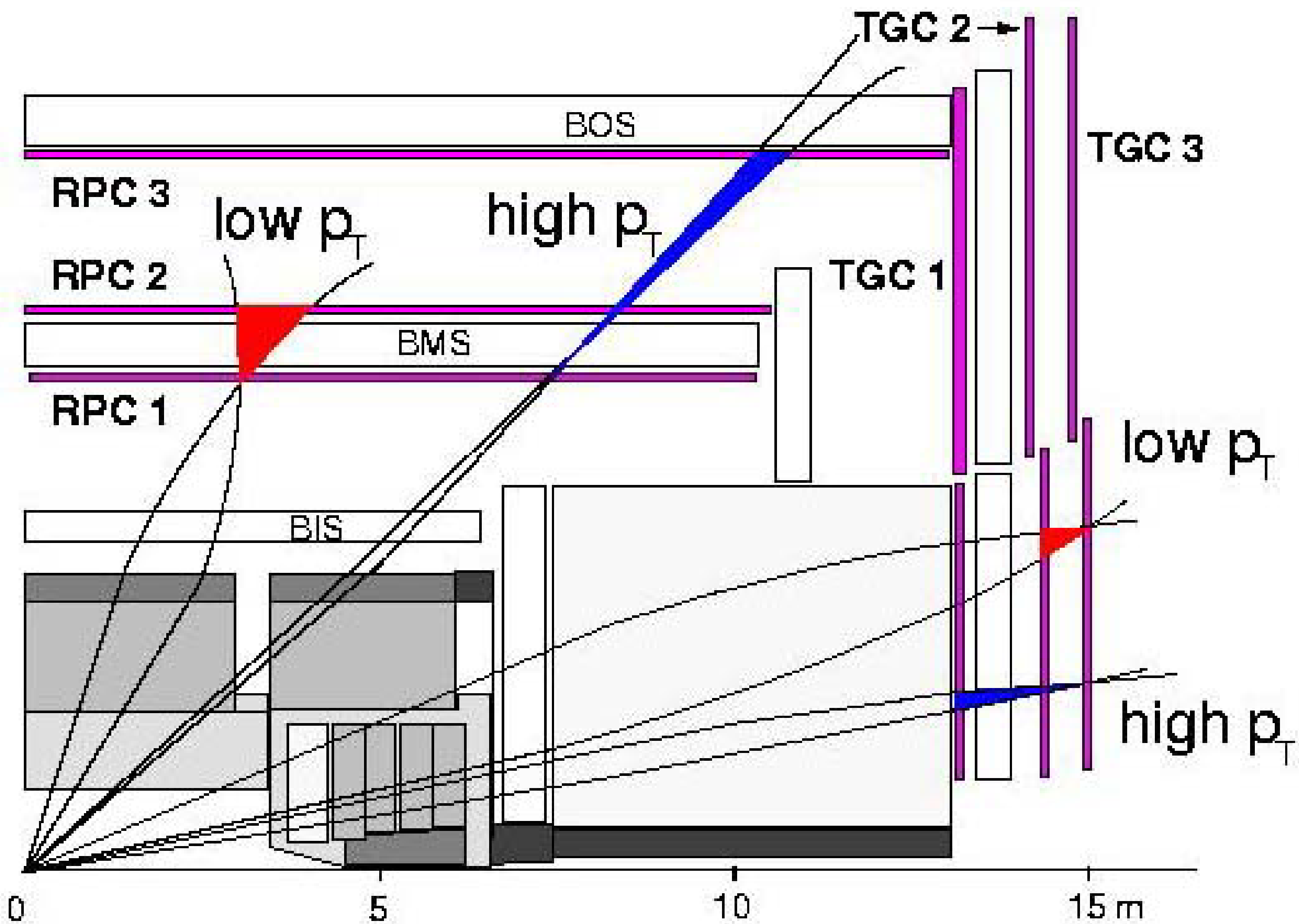
Triggering and Measuring Muons



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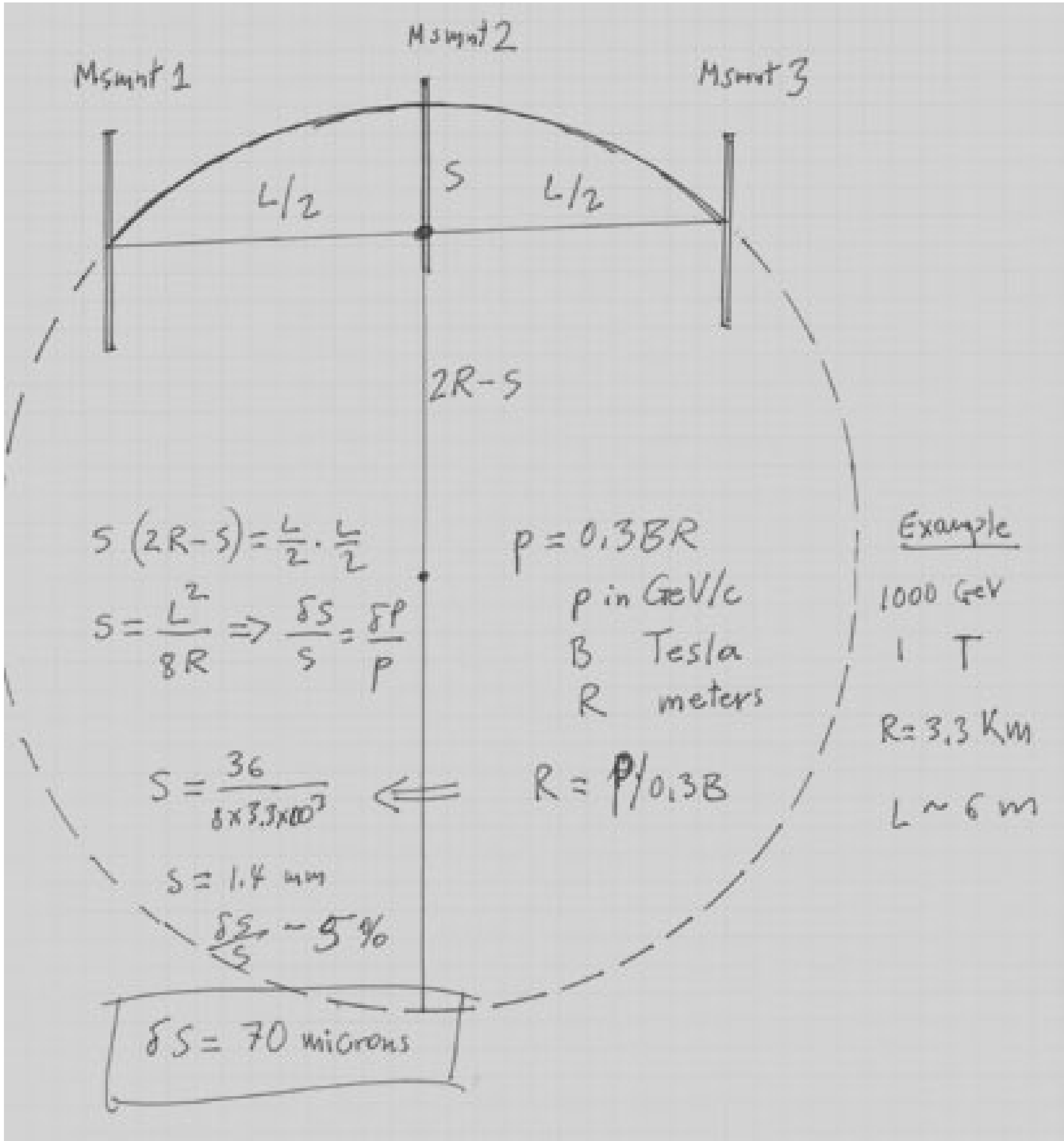
What dictates Size and Precision



Sagitta for 1 TeV/c muon in a typical Spectrometer (B = 1 Tesla
L = 6 m)

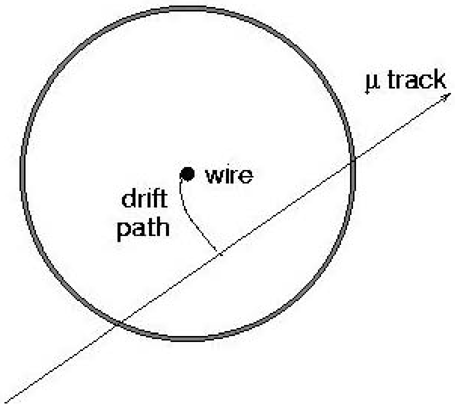
S = 1.4 mm

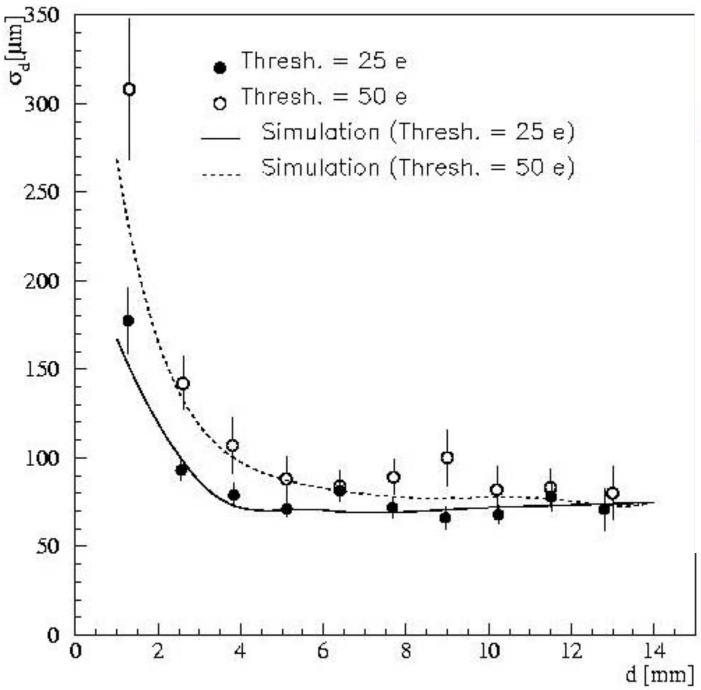
If we want to measure p to 5%

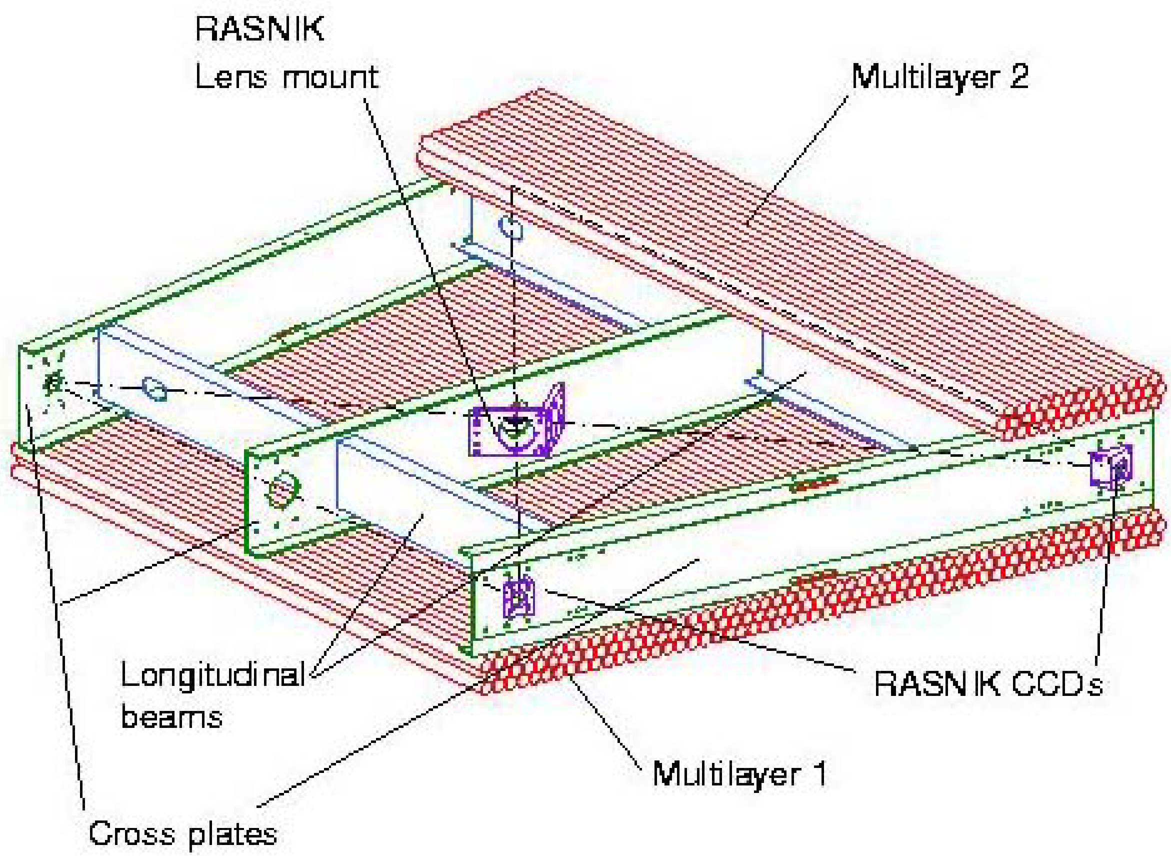
ds = 70 microns

→Large area, high precision detectors

The Monitored Drift Tube Chamber







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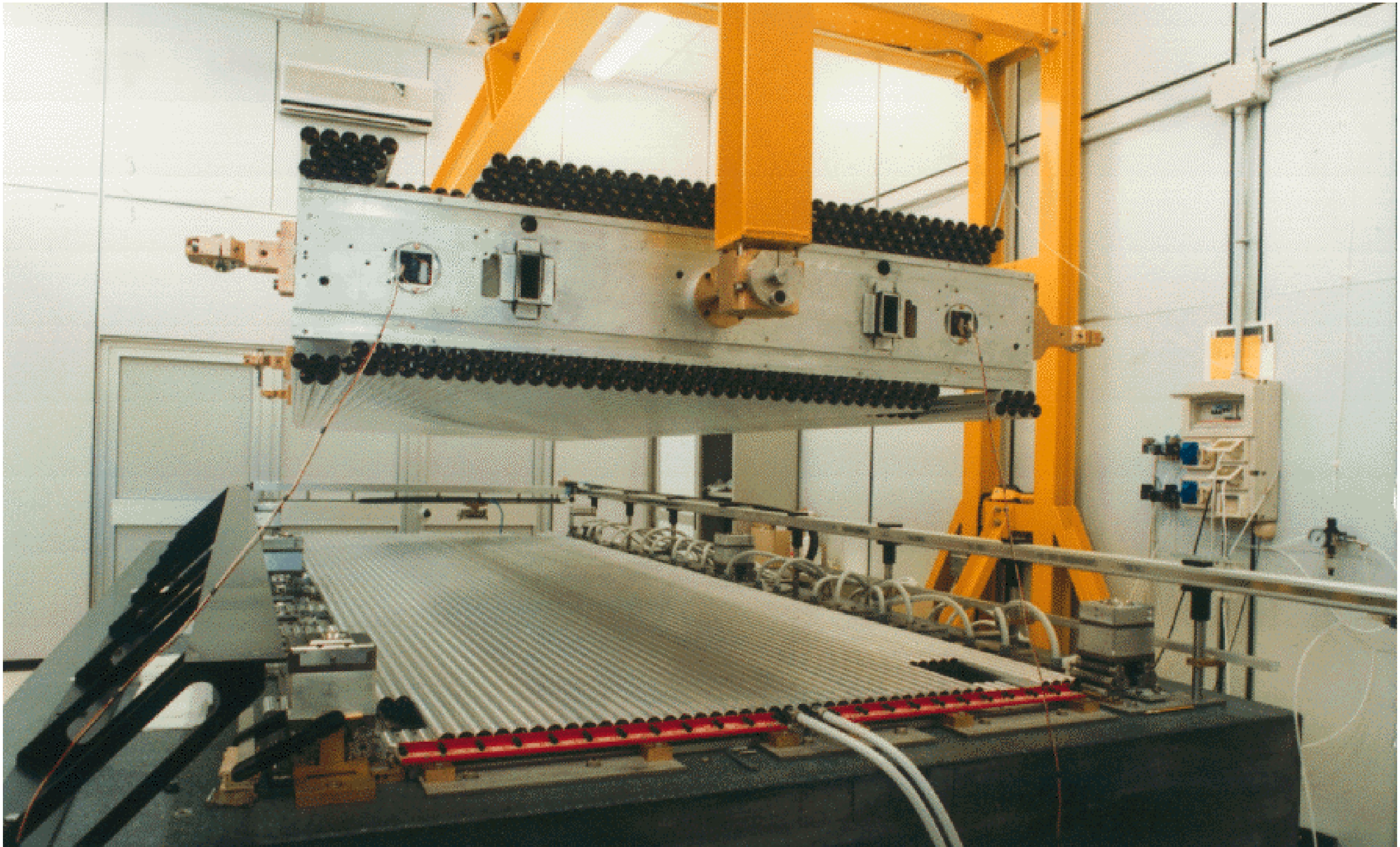
Assembly of MDT Chambers (Frascati, IT)



An Orthogonal (Barrel) Chamber (EMS, U. Michigan)

Barrel Chamber (MPI, Munich)

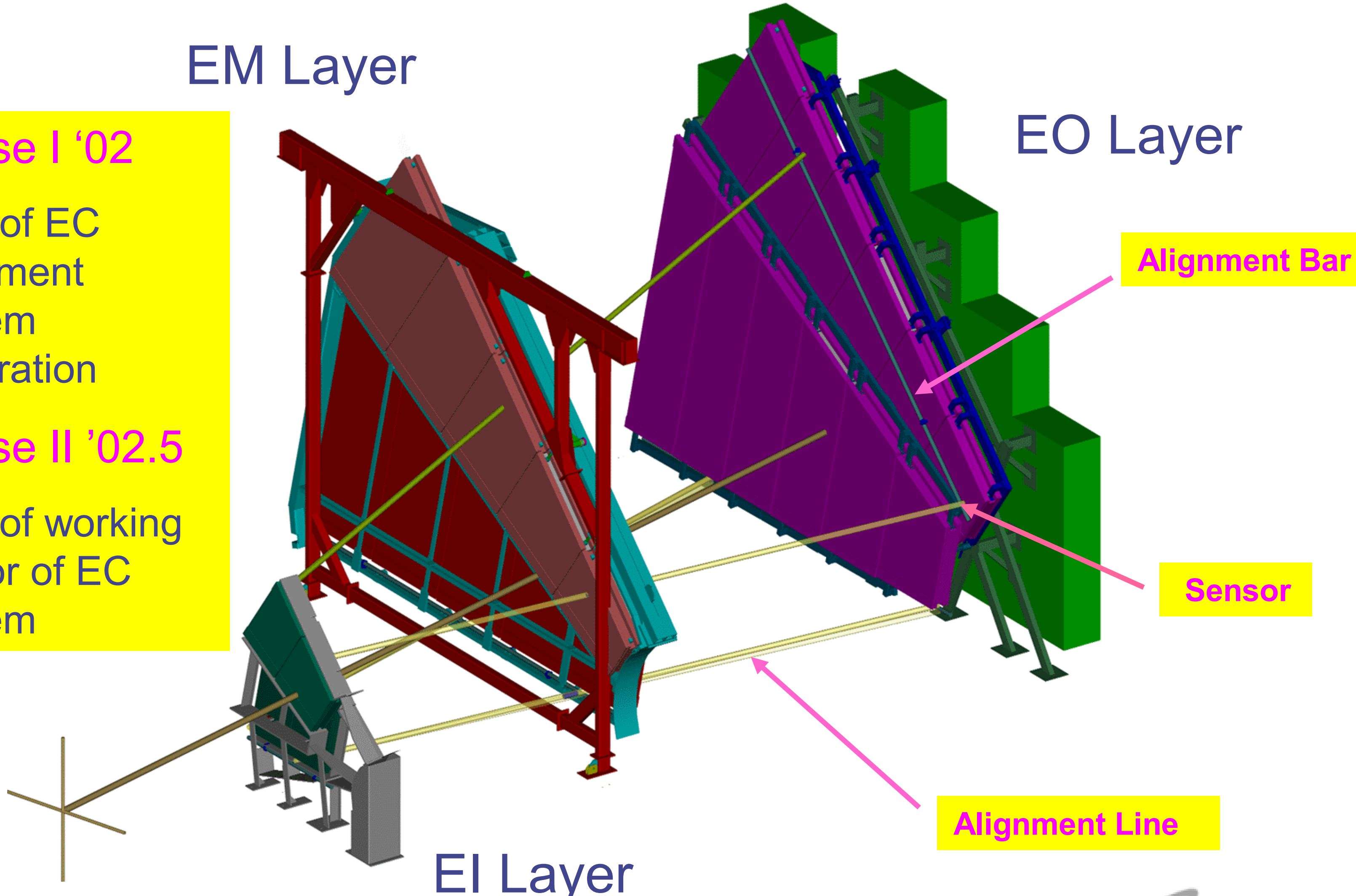
H8 Alignment System Test

Phase I '02

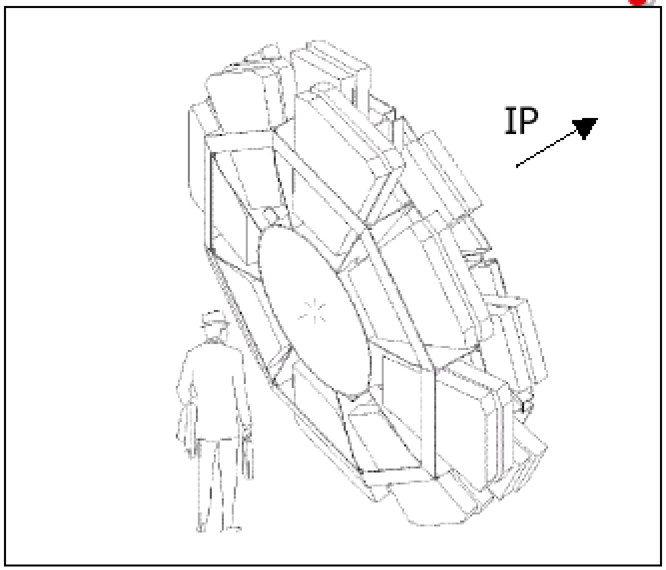
Test of EC alignment system integration

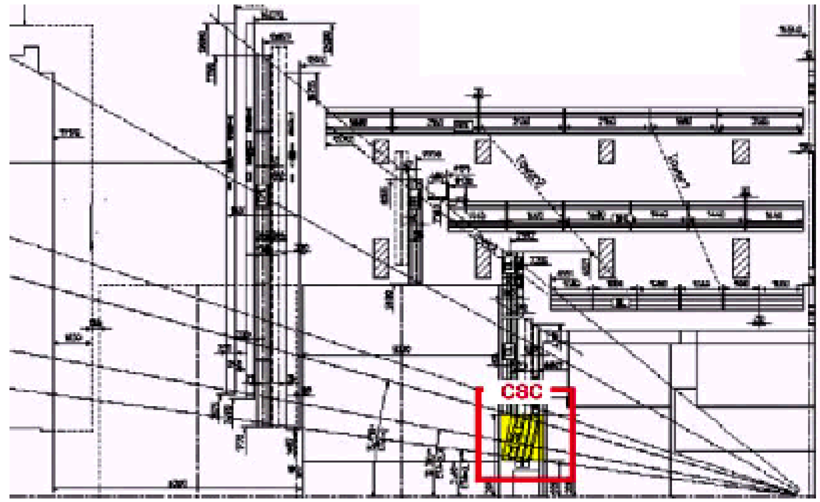
Phase II '02.5

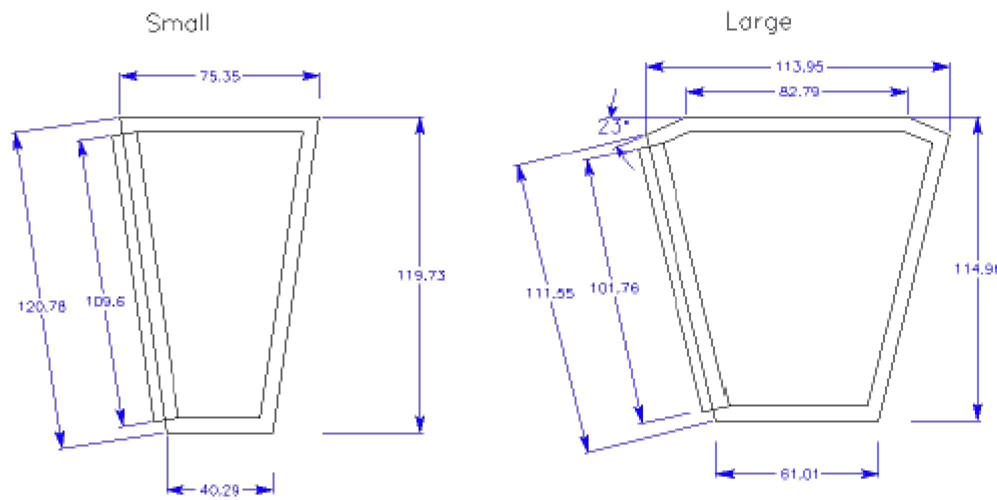
Test of working sector of EC system



CSCs are the forward precision muon system of ATLAS







32 four-layer chambers

$2.0 < |\eta| < 2.7$

$|Z| \sim 7\text{m}, 1 < r < 2$ m

4 gas gaps per chamber

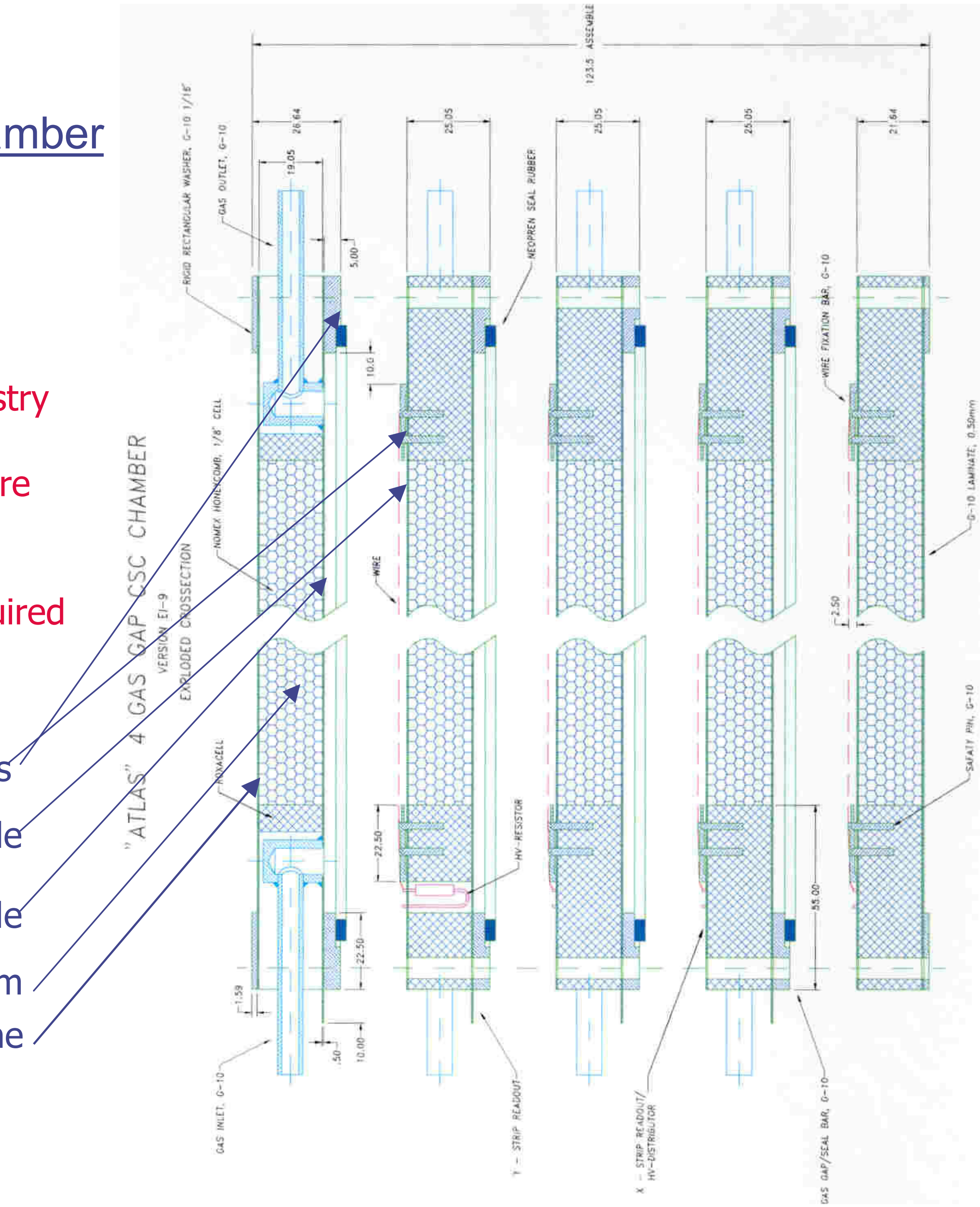
31,000 channels

Exploded View of a CSC Chamber

Cathodes, Spacers, Core foam, and Ground Planes are produced in Industry

All edge trimming and all the holes are made by the vendors.

No further work on components required



Principle of operation

Determine muon position by interpolating the charge on 3 to 5 adjacent strips

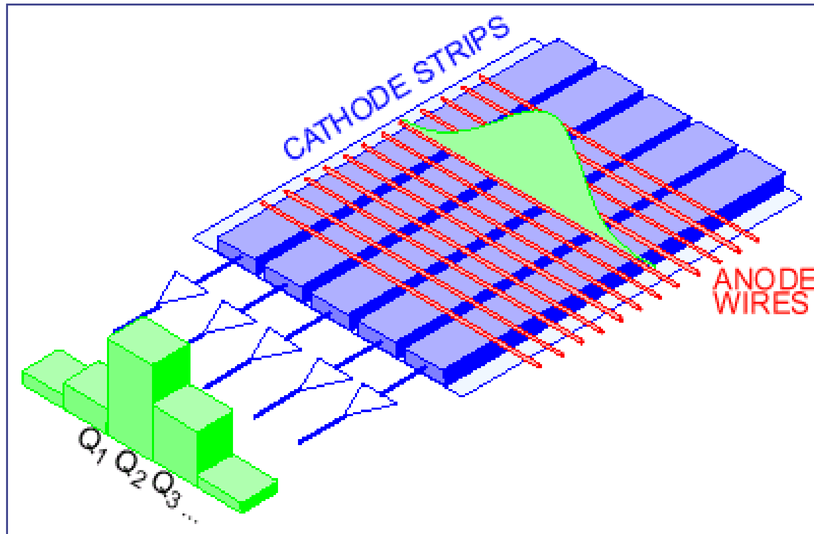
Precision (x-) strip pitch ~ 5.6 mm

Measure Q1, Q2, Q3… with 150:1 SNR to get σ_x ~ 60 μm.

Second set of y-strips measure transverse coordinate to ~ 1 cm.

Position accuracy unaffected by *gas gain* or *drift time* variations.

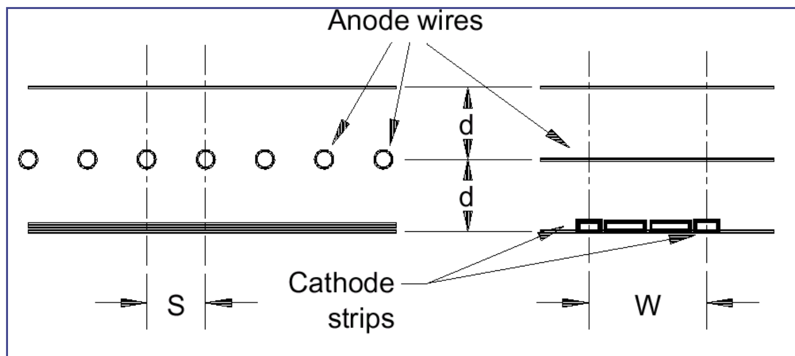
Accurate *intercalibration* of adjacent channels essential.



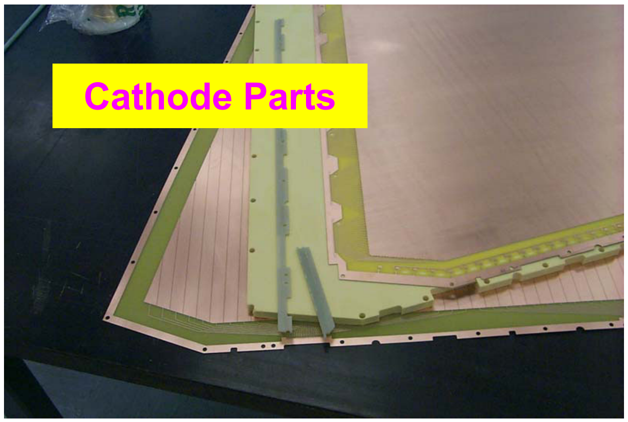
Design derives from E814 Pad Chambers
Graham Smith
Bo Yu

S = d = 2.54 mm

W = 5.6 mm

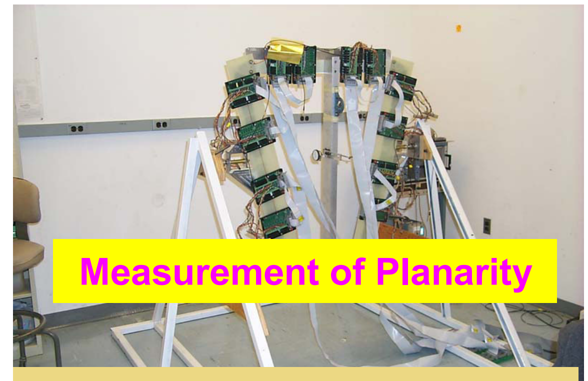


CSC Fabrication @ BNL



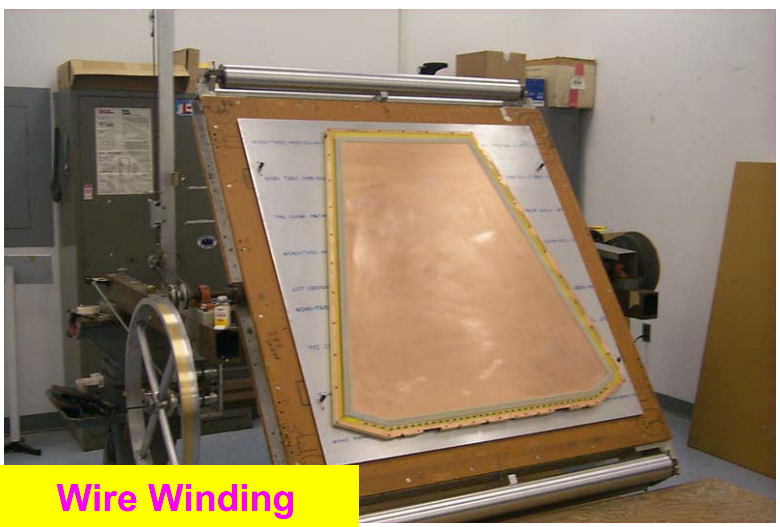
Cathode Parts

Cathode Panel Lamination

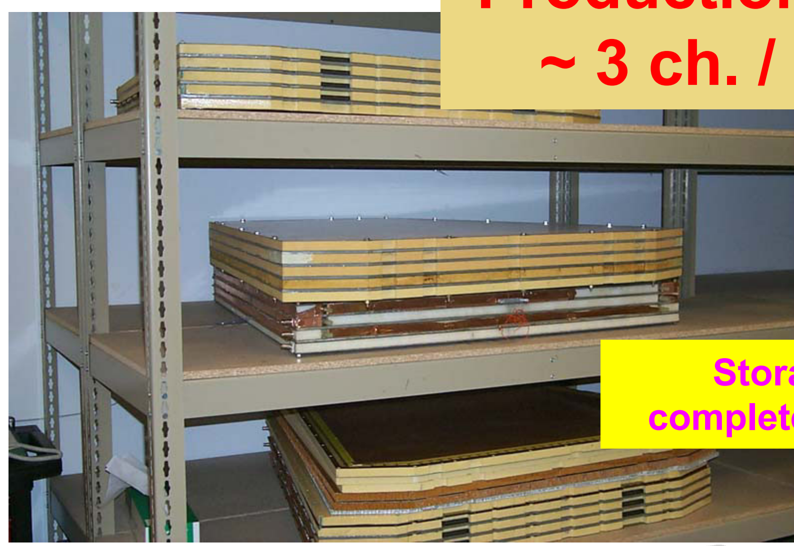


Measurement of Planarity

Estimated Production Rate ~ 3 ch. / mo.



Wire Winding



Storage of completed panels

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The CSC Team

BNL:

- **T. Corwin**
- J. Fried
- A. Gordeev
- V. Gratchev
- S. Junnarkar
- A. Hoffmann
- A. Kandasamy
- W. Licciardi
- T. Muller
- P. O'Connor
- V. Polychronakos
- D. Rahm
- K. Sexton
- K. Wolniewicz

UCI:

- A. Lankford
- D. Stoker
- M. Schernau
- S. Pier
- D. Hawkins
- N. Drego
- J. Dailing
- B. Toledano

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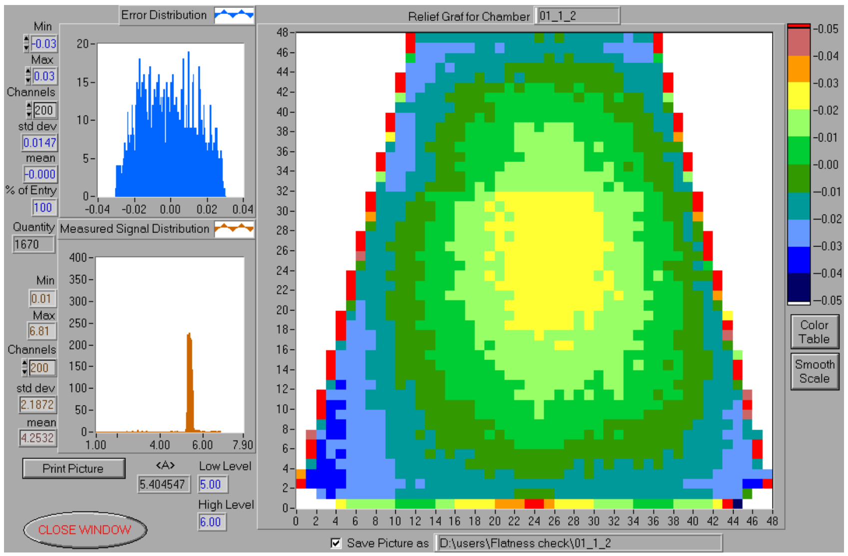
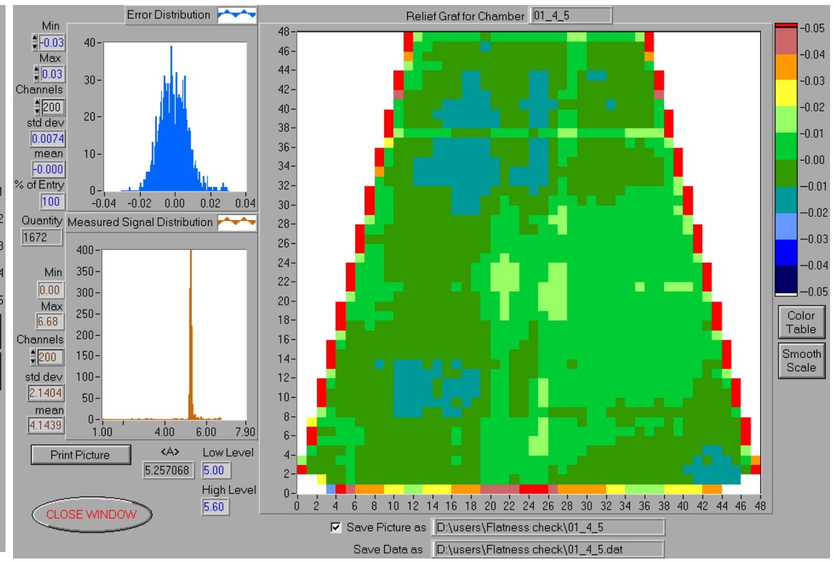
Panel Flatness Measurements





Early Panel while still developing technique

Min to Max variation ~6-7 %

One of the later panels

Min to Max variation ~4%

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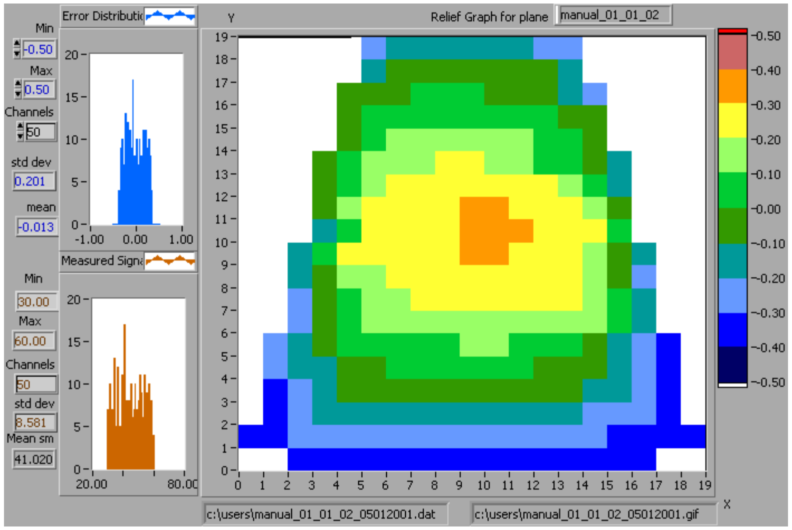
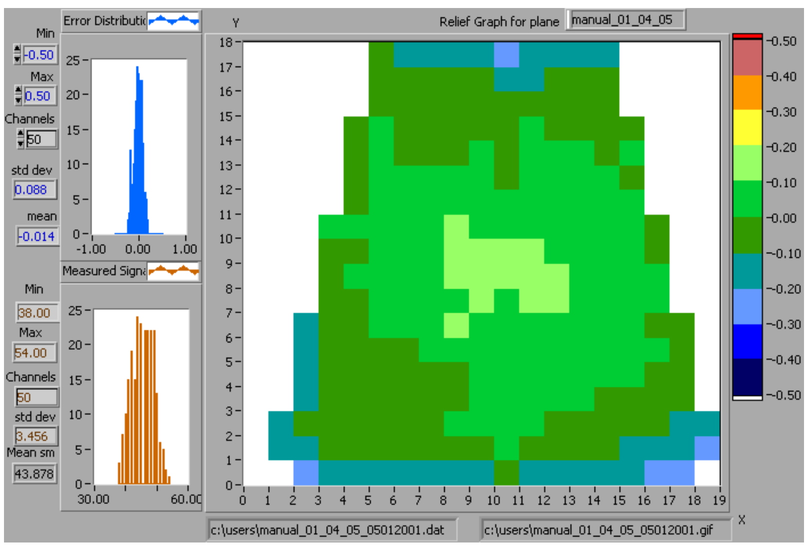
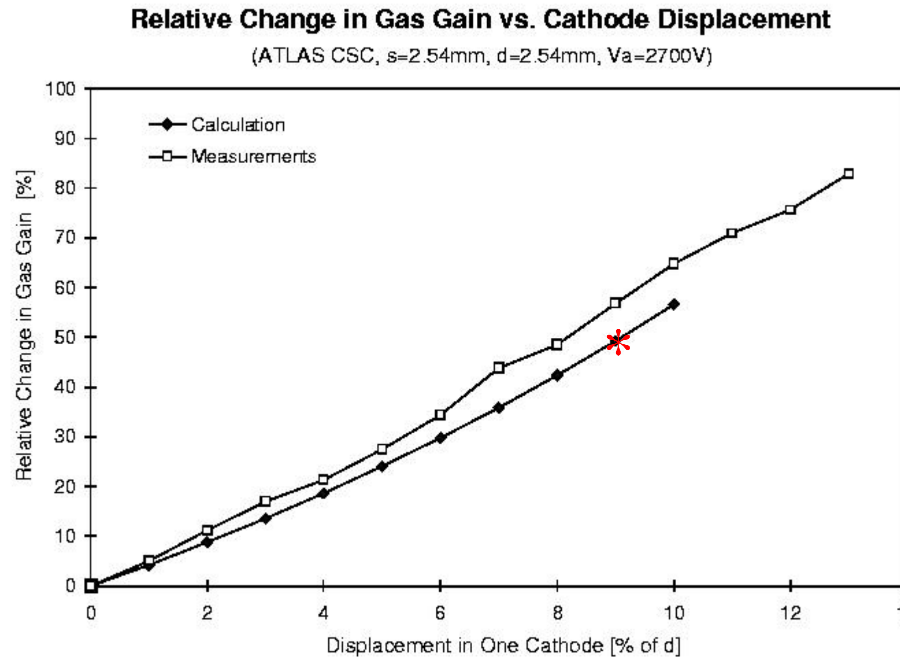
Corresponding Gas Gain Variation







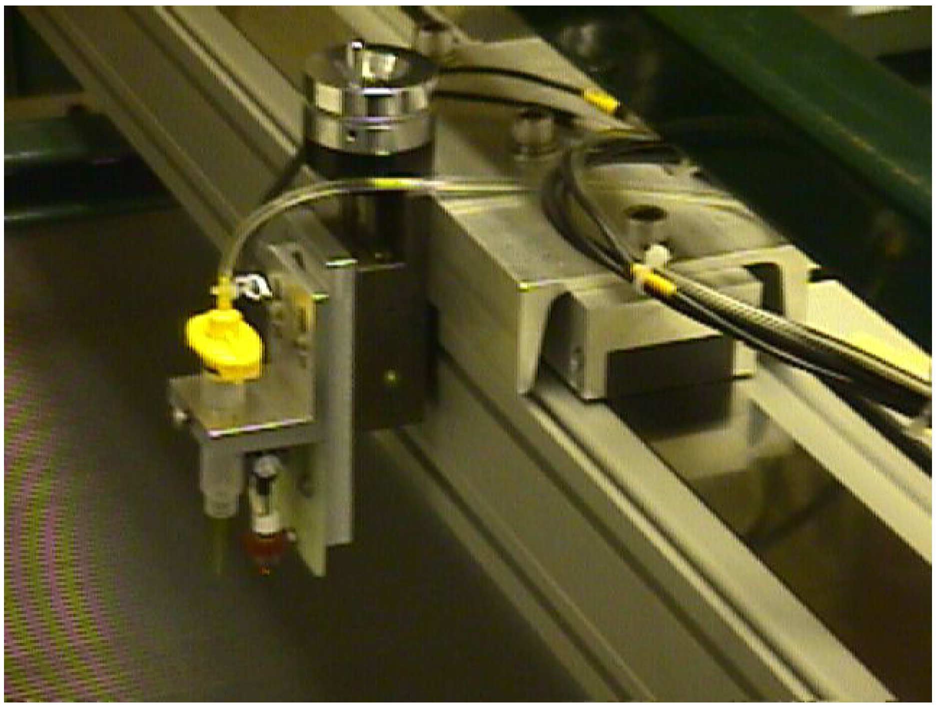
Gas Gain Variation tracks well anode-cathode gap variation

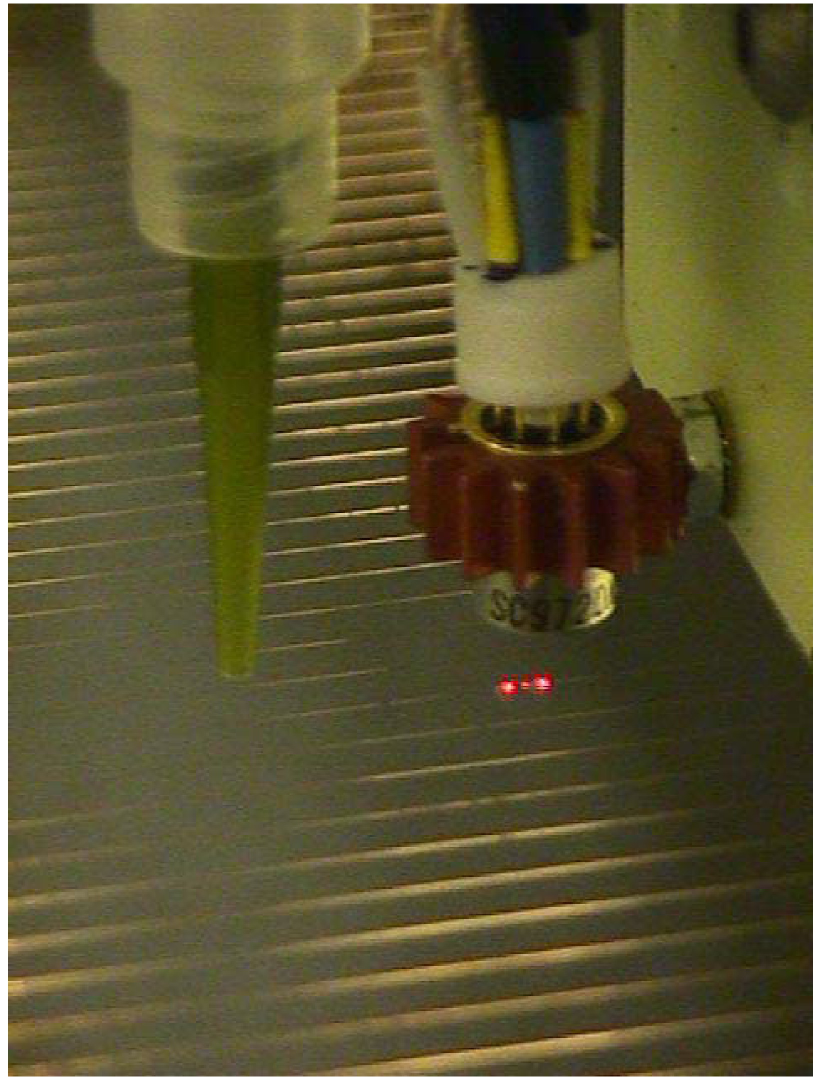
Agrees well with calculations

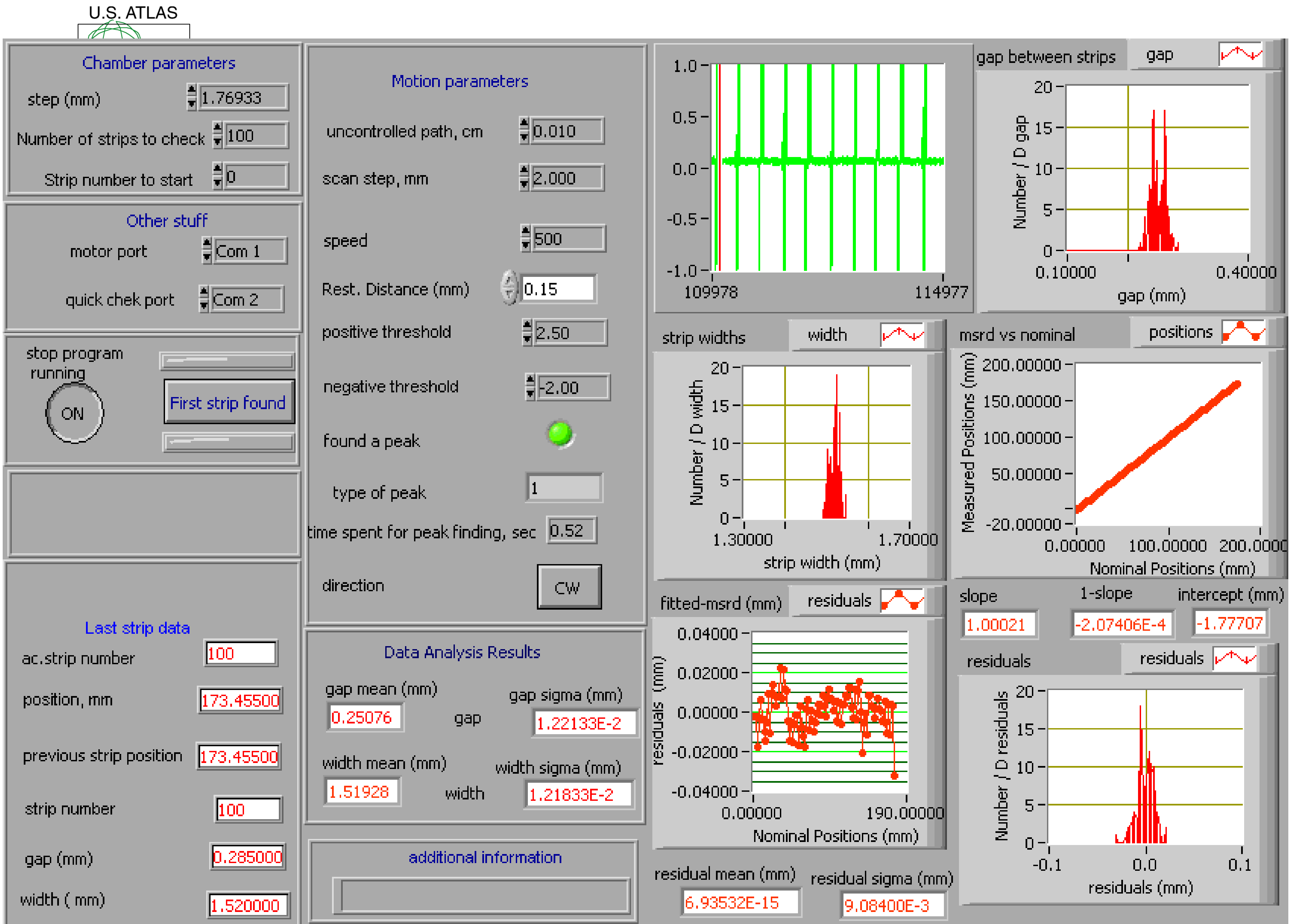
Confidence for robust operation

Wire Tension and Spacing Measurement

- Wire tension and spacing are automatically measured without touching the anode wires
(inheritance from PHENIX, Achim Franz)



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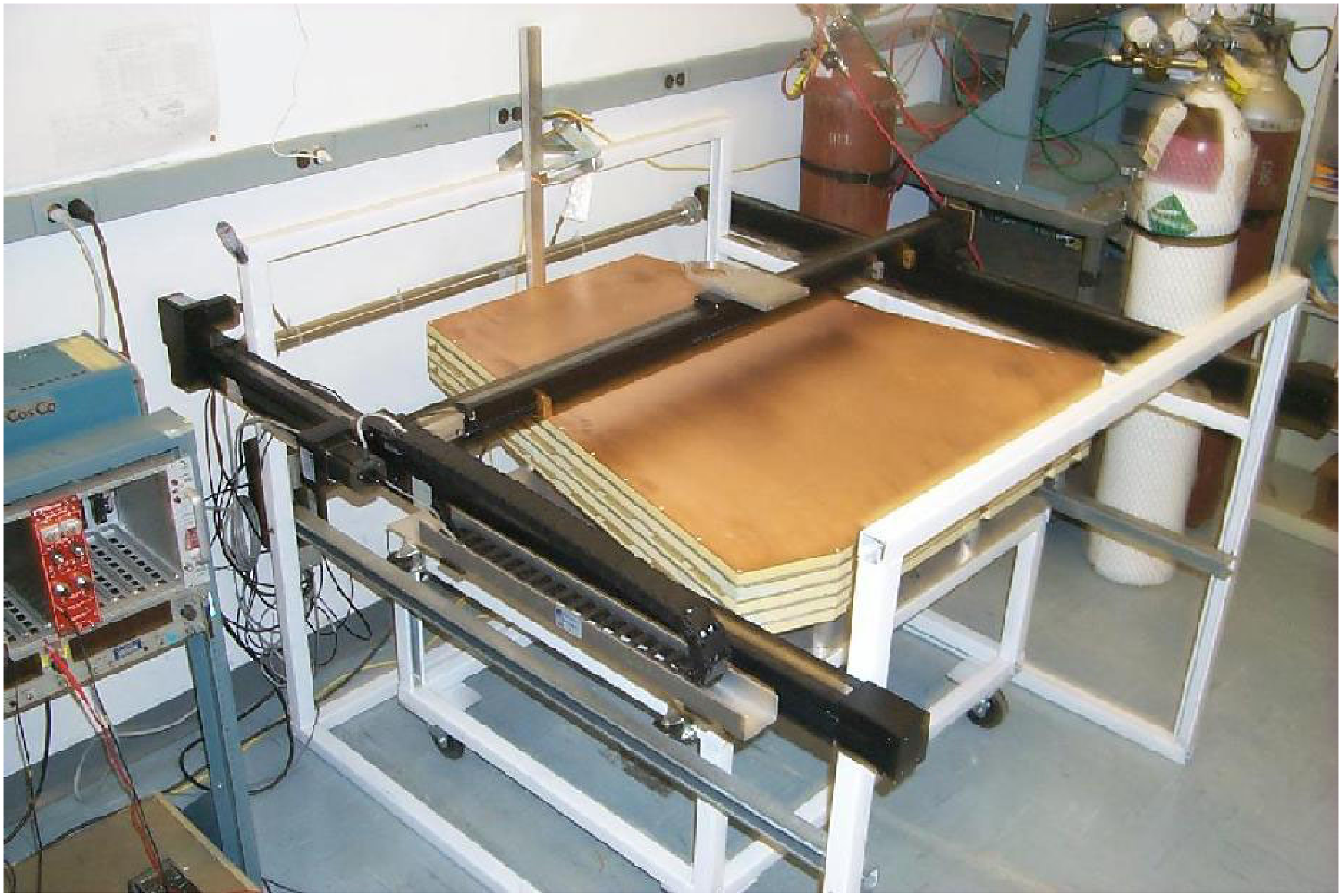
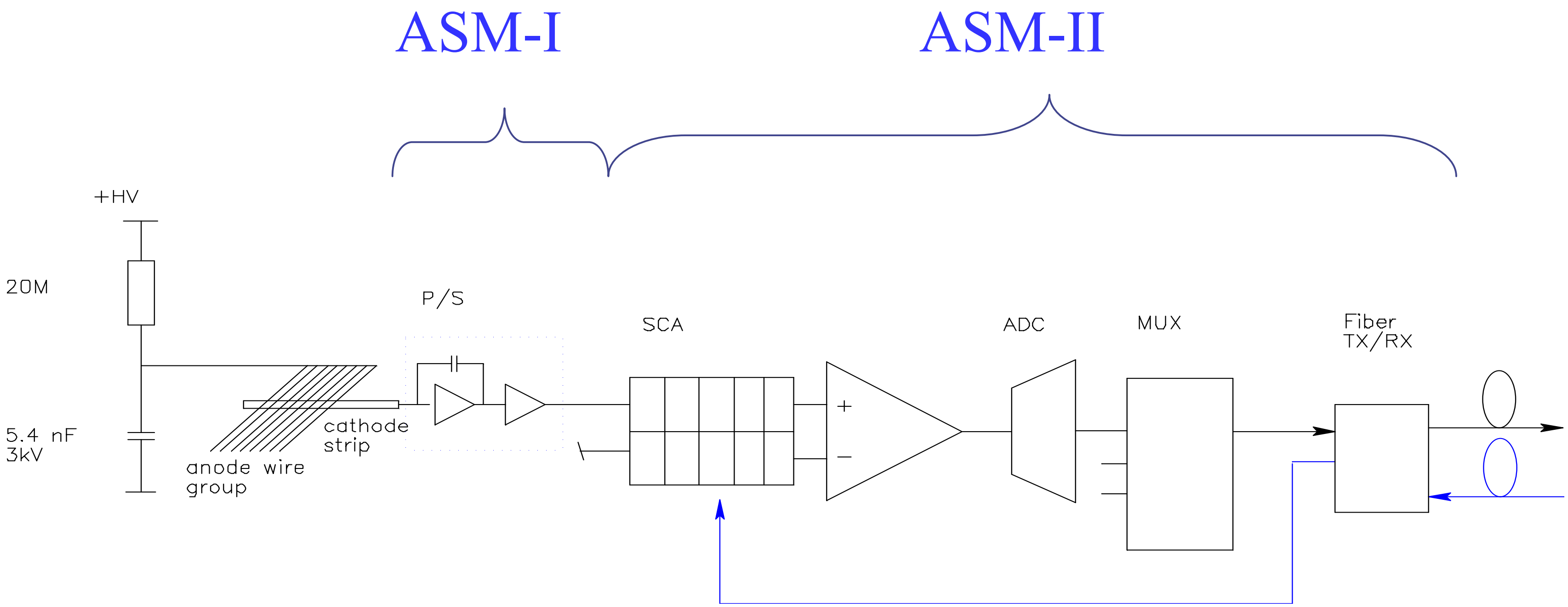
Chamber parameters
step (mm) 1.76933
Number of strips to check 100
Strip number to start 0
Other stuff
motor port Com 1
quick chek port Com 2
stop program running
ON
First strip found
Last strip data
ac.strip number 100
position, mm 173.45500
previous strip position 173.45500
strip number 100
gap (mm) 0.285000
width (mm) 1.520000
Motion parameters
uncontrolled path, cm 0.010
scan step, mm 2.000
speed 500
Rest. Distance (mm) 0.15
positive threshold 2.50
negative threshold -2.00
found a peak
type of peak 1
time spent for peak finding, sec 0.52
direction CW
Data Analysis Results
gap mean (mm) 0.25076
gap
gap sigma (mm) 1.22133E-2
width mean (mm) 1.51928
width
width sigma (mm) 1.21833E-2
additional information
1.0
0.5
0.0
-0.5
-1.0
109978
114977
gap between strips
gap
Number / D gap
gap (mm)
0.10000
0.40000
strip widths
width
Number / D width
strip width (mm)
1.30000
1.70000
msrd vs nominal
positions
Measured Positions (mm)
Nominal Positions (mm)
200.00000
150.00000
100.00000
50.00000
-20.00000
0.00000
100.00000
200.0000
fitted-msrd (mm)
residuals
residuals (mm)
0.04000
0.02000
0.00000
-0.02000
-0.04000
0.00000
190.00000
Nominal Positions (mm)
slope 1.00021
1-slope -2.07406E-4
intercept (mm) -1.77707
residuals
Number / D residuals
residuals (mm)
-0.1
0.0
0.1
residual mean (mm) 6.93532E-15
residual sigma (mm) 9.08400E-3

Gain measurement station



CSC Readout Principle



- Amplifiers, analog pipeline memory, digitizer, fiber-optic links
- 192-channel "ASM-Pack"
- 2 board types: ASM-I and ASM-II
- 3 custom ICs: Preamp/shaper, SCA, digital MUX

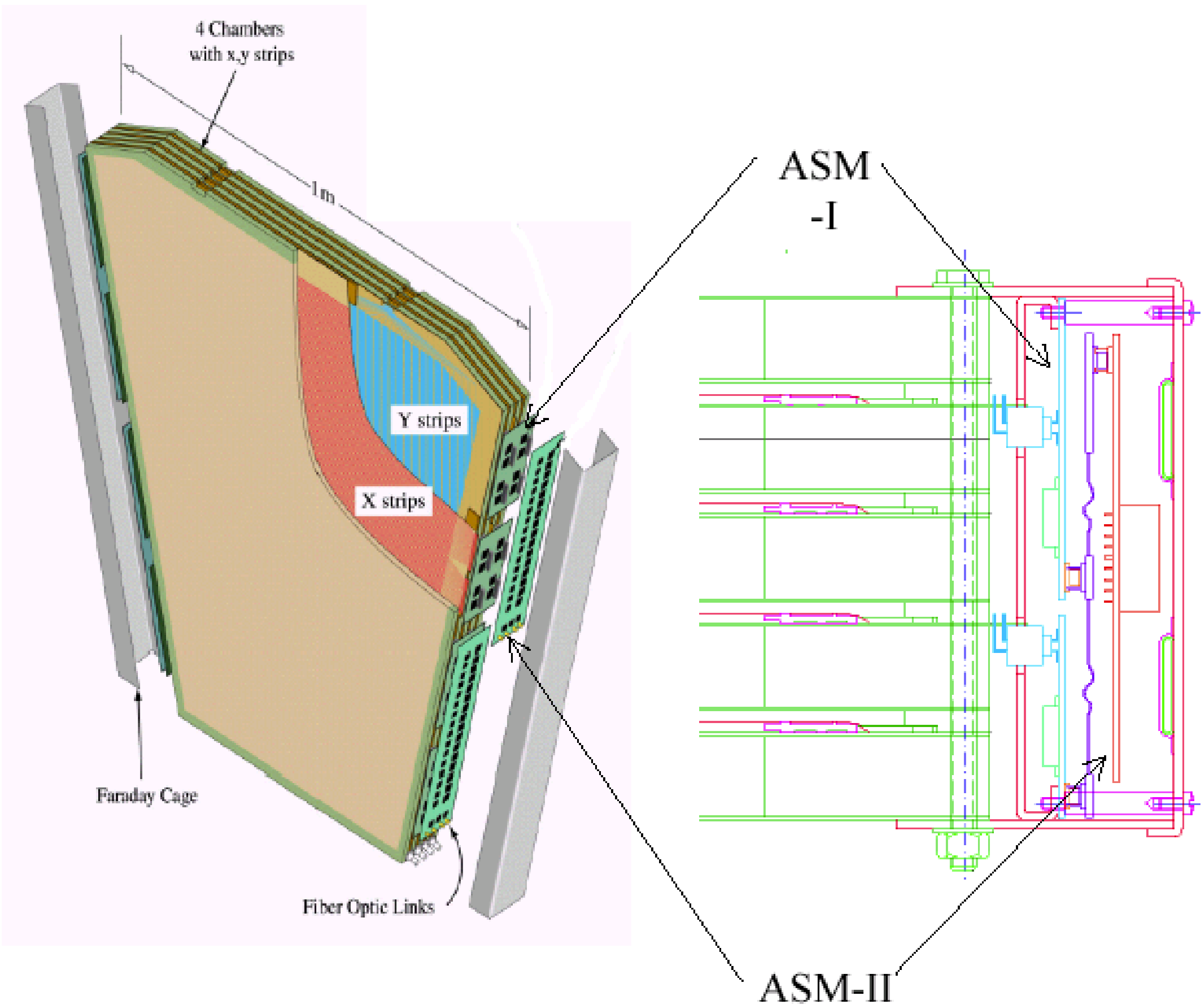
Readout Philosophy

- CSCs reside in a high occupancy region and hostile radiation environment.
- Goal: <0.1% data lost to hard or soft failures
- Details:
  - All intelligence resides off-detector.
  - Minimal parts list on-chamber: ~10 components
  - On-chamber electronics has no:
    - configuration registers
    - programmable logic
    - FIFOs
    - RAM
    - Counters
    - State machines
  - Thorough radiation test of all components
  - ESD protect inputs of chips & boards
  - Extra attention to amplifier stability
  - Follow ATLAS grounding & shielding policy
  - Minimal monitoring **(no DCS)**

ASICs and much of the front end Work at Instrumentation (Paul, Anand, Sachin)

- Strategy: on-chamber electronics as simple and robust as possible

Electronics Location in Faraday Cage



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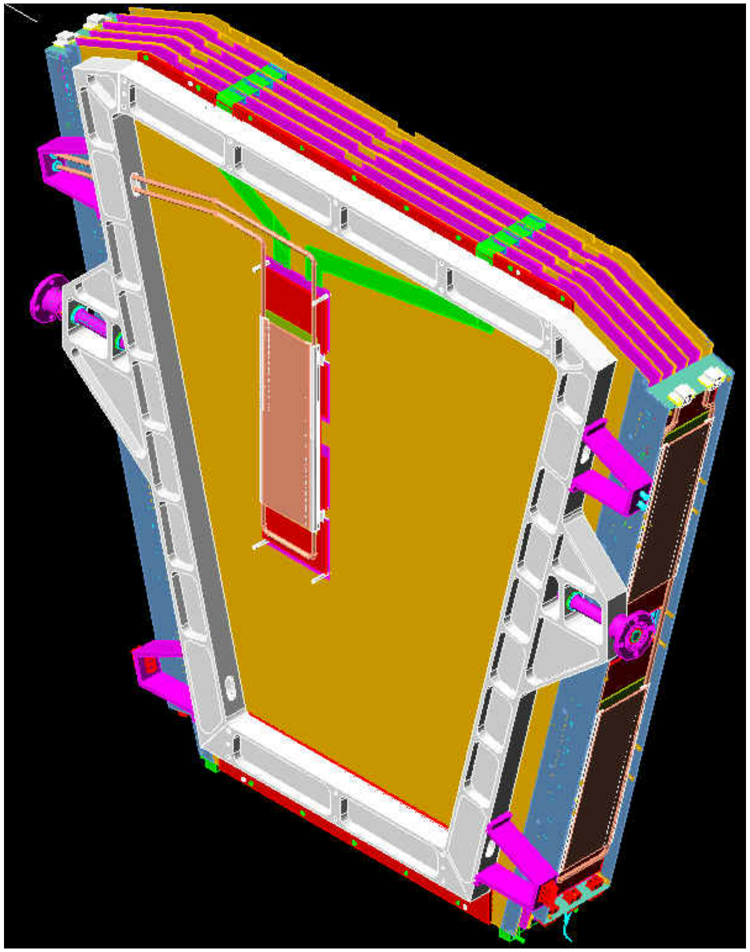
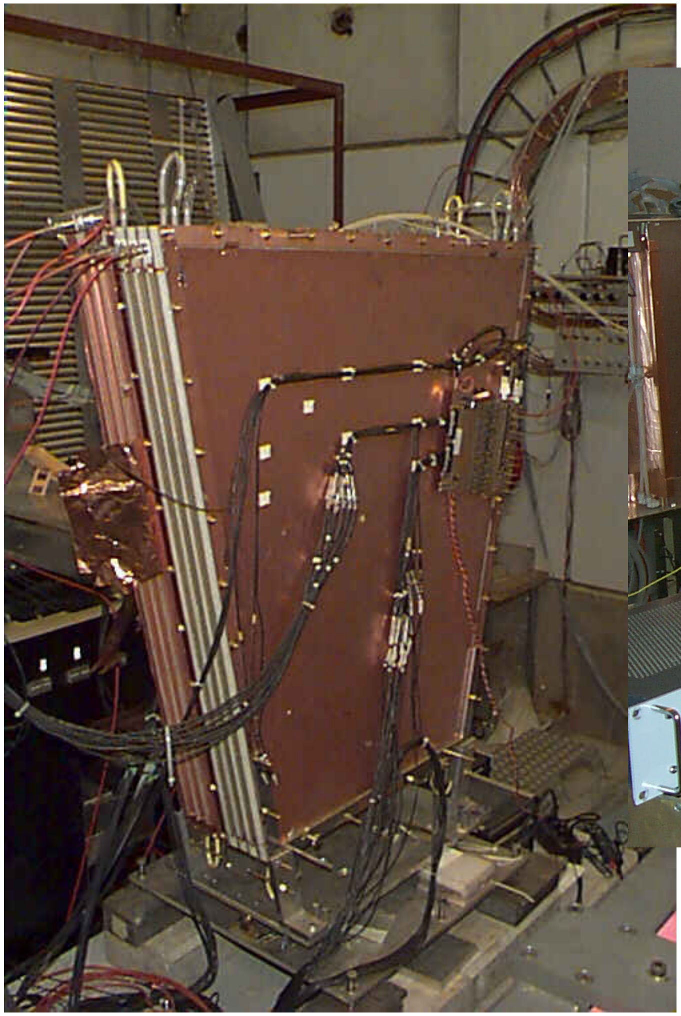
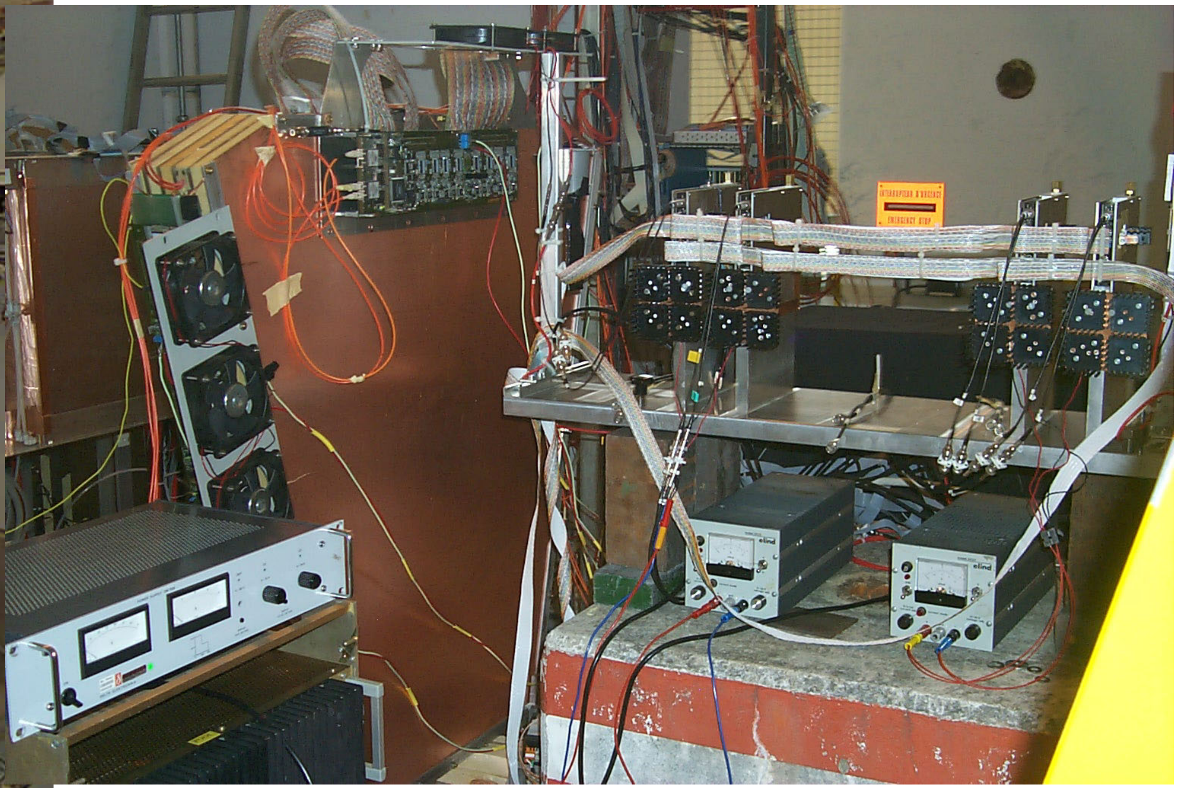
Support frame, y-strip readout location, Faraday cages



Prototype at the X5 Beam at CERN



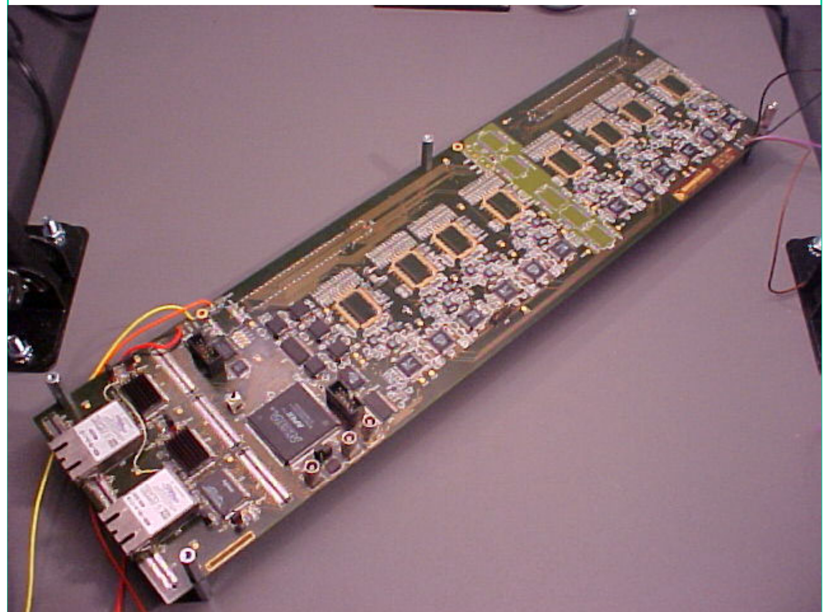


ASM-II board

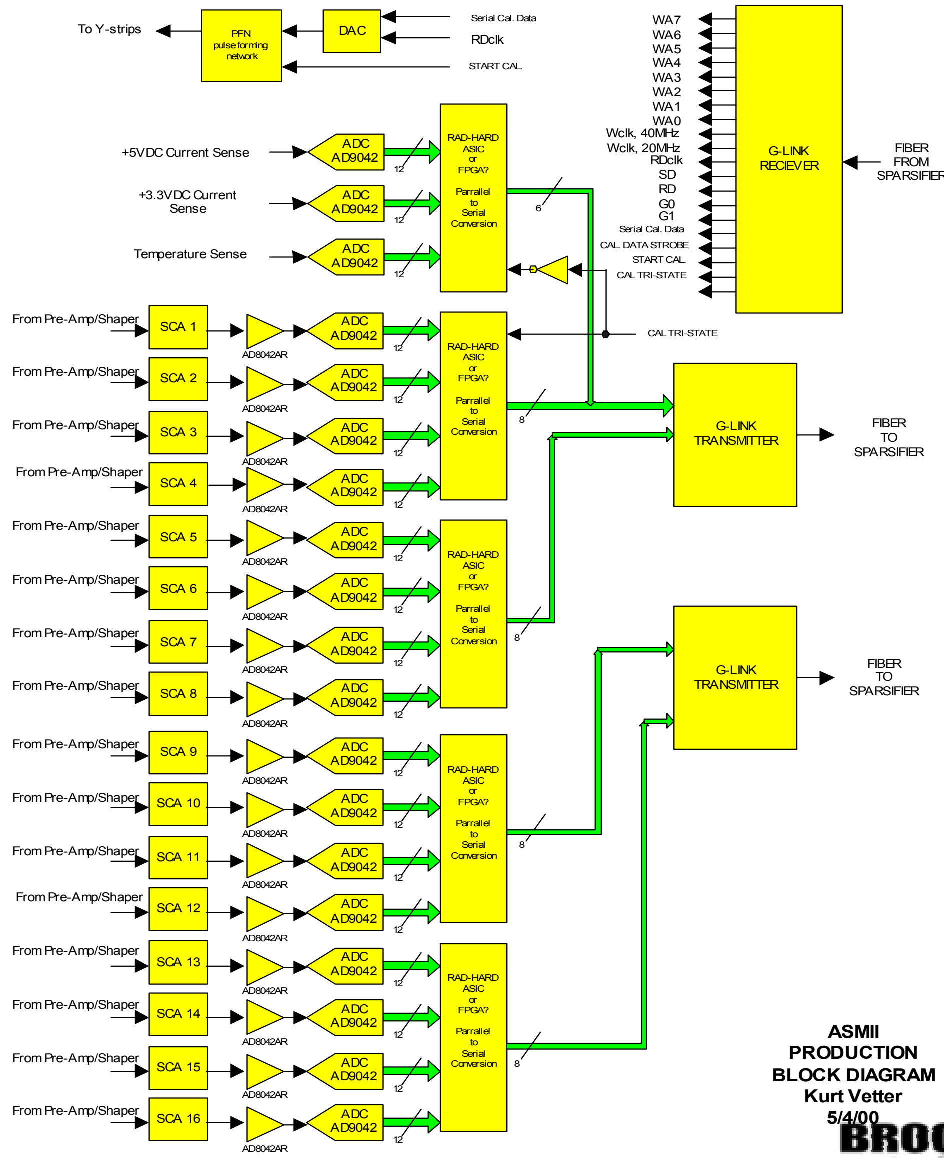
- **Function:**

  analog pipeline, digitization, optical link
- **No. of channels: 192**
- **No. of boards: 160 (320)**
- **120 *x* 430 mm^2 board, 46w, plugs onto ASM-I**
- **Design responsibility: BNL Instrumentation**
- **12-chan proto (ASM-IIa) tested successfully**
  - on-board SCA controller, optical mezzanines
  - measured gain, linearity, noise, pedestal dispersion
  - verified i/f to P/S, >5MHz Read Clock rate, G-link
- **192-chan proto (ASM-IIb) under test now**
  - digital multiplexer, on-board or remote SCA control
  - AC-coupled P/S to SCA to use full range of SCA
  - will be used in 2002 beam test
- **Next iteration will be "Module 0"**
  - will be ready by end of year
- **Production planned for early 2003.**

ASM-IIb: prototype 192-channel ASM

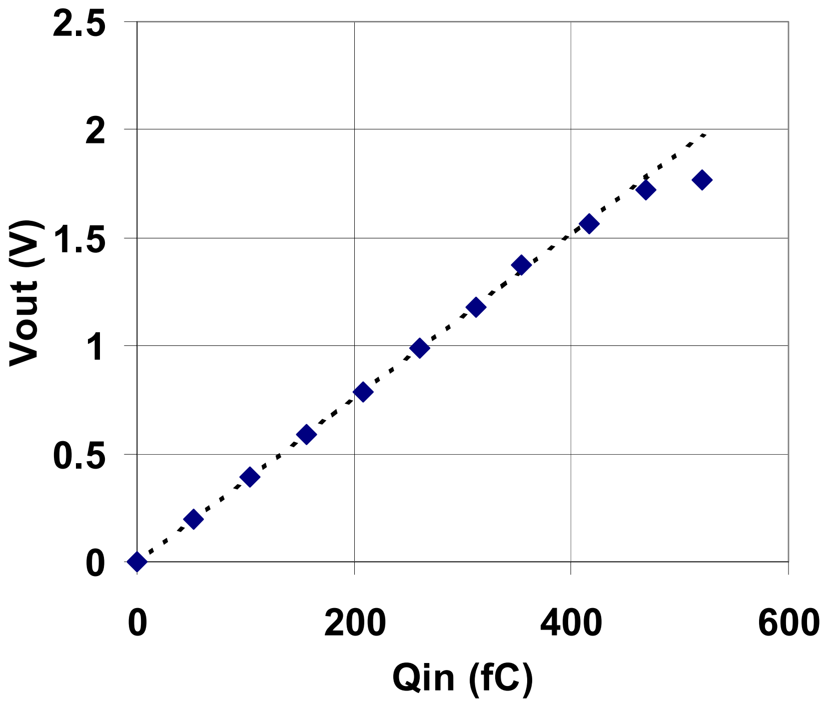


ASM-II block diagram

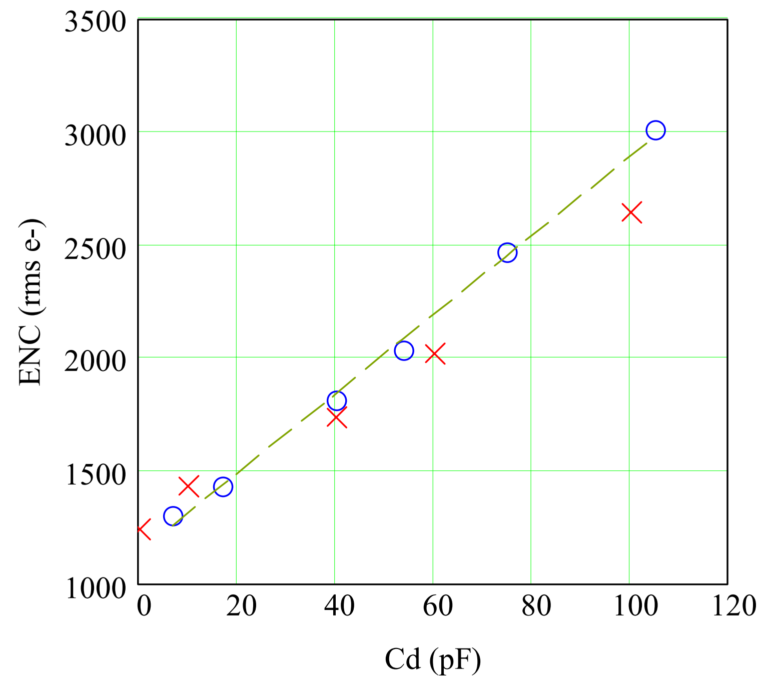


Front End Performance

Linearity



Noise vs. capacitance

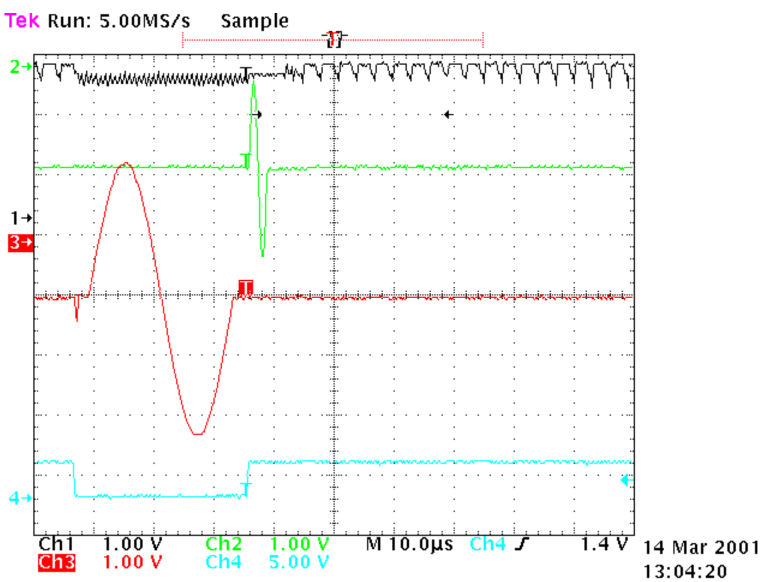


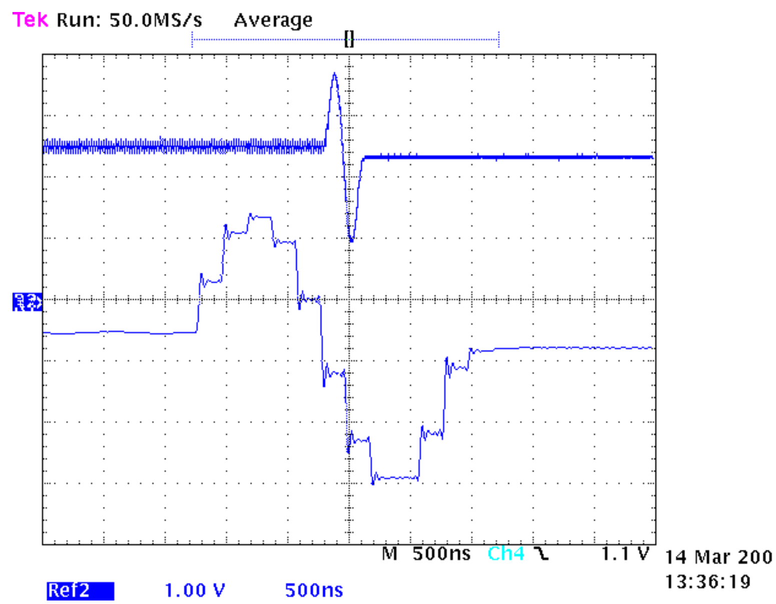
Simulated: □

Measured: ○

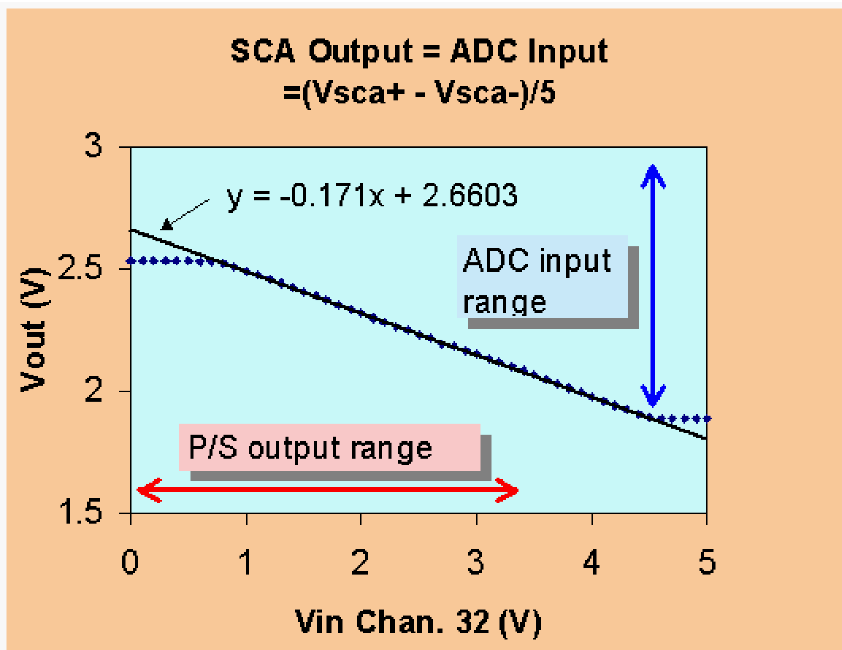
U.S. ATLAS

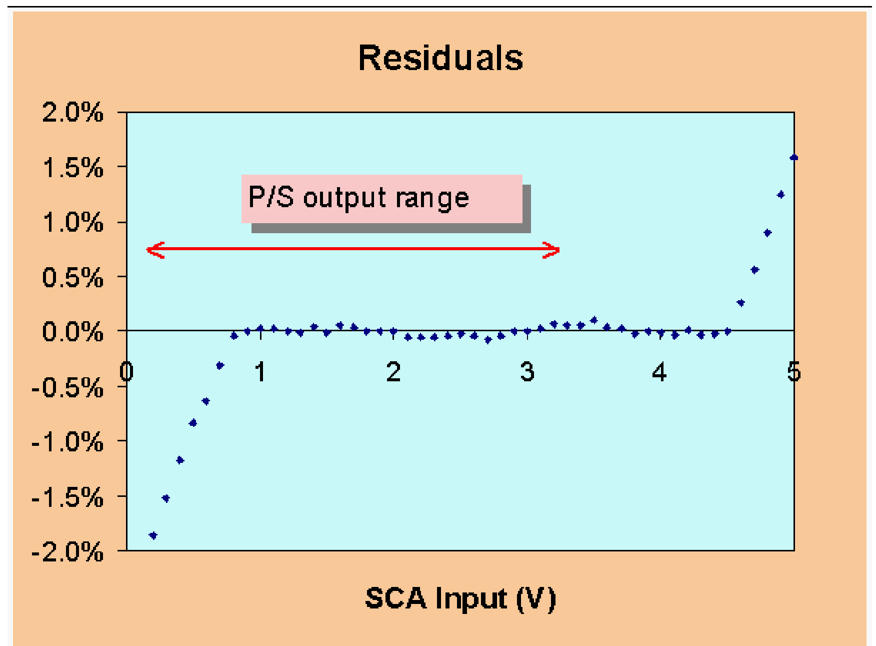
ASM-2a waveforms





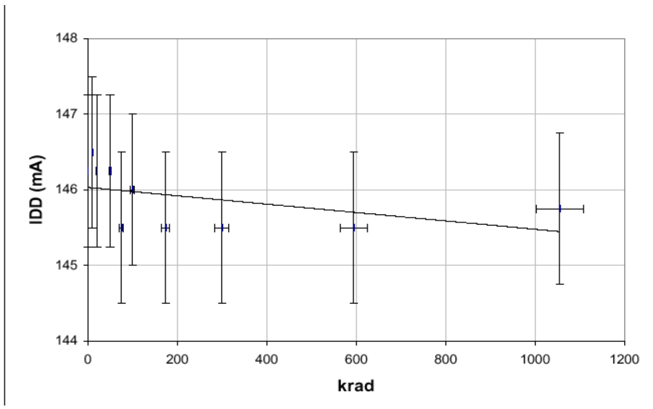
ASM-2a Gain and Linearity



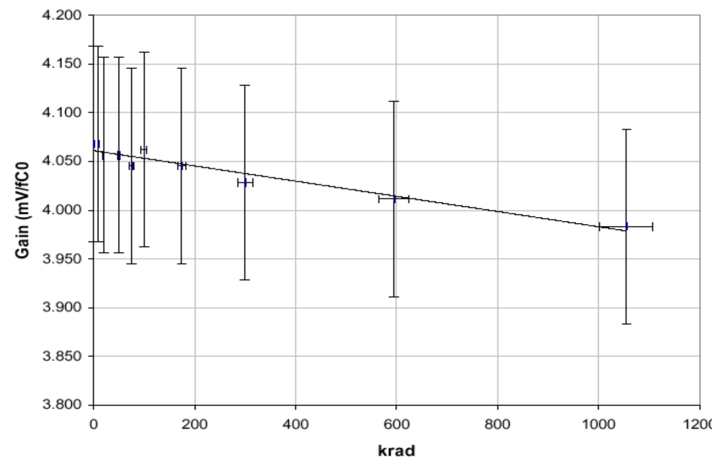


Preamp/shaper ^{60}Co irradiation results

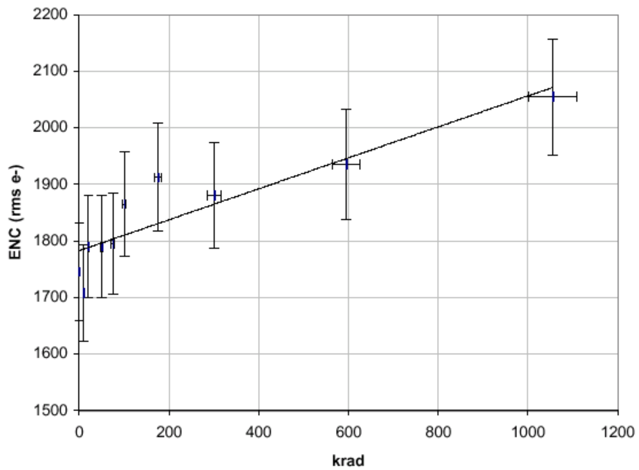
Supply current



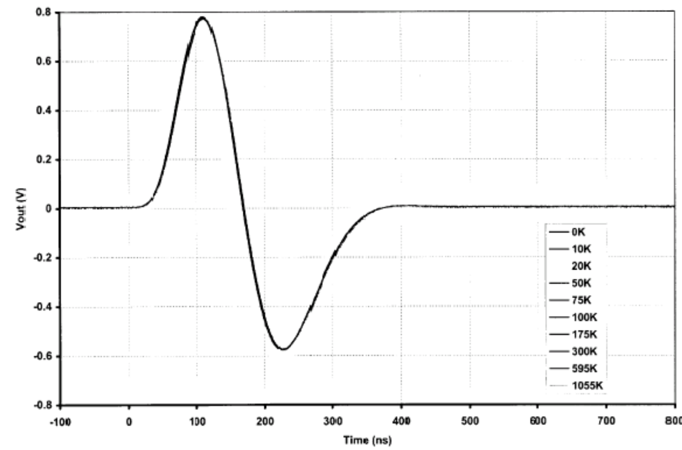
Gain



Noise



Waveform



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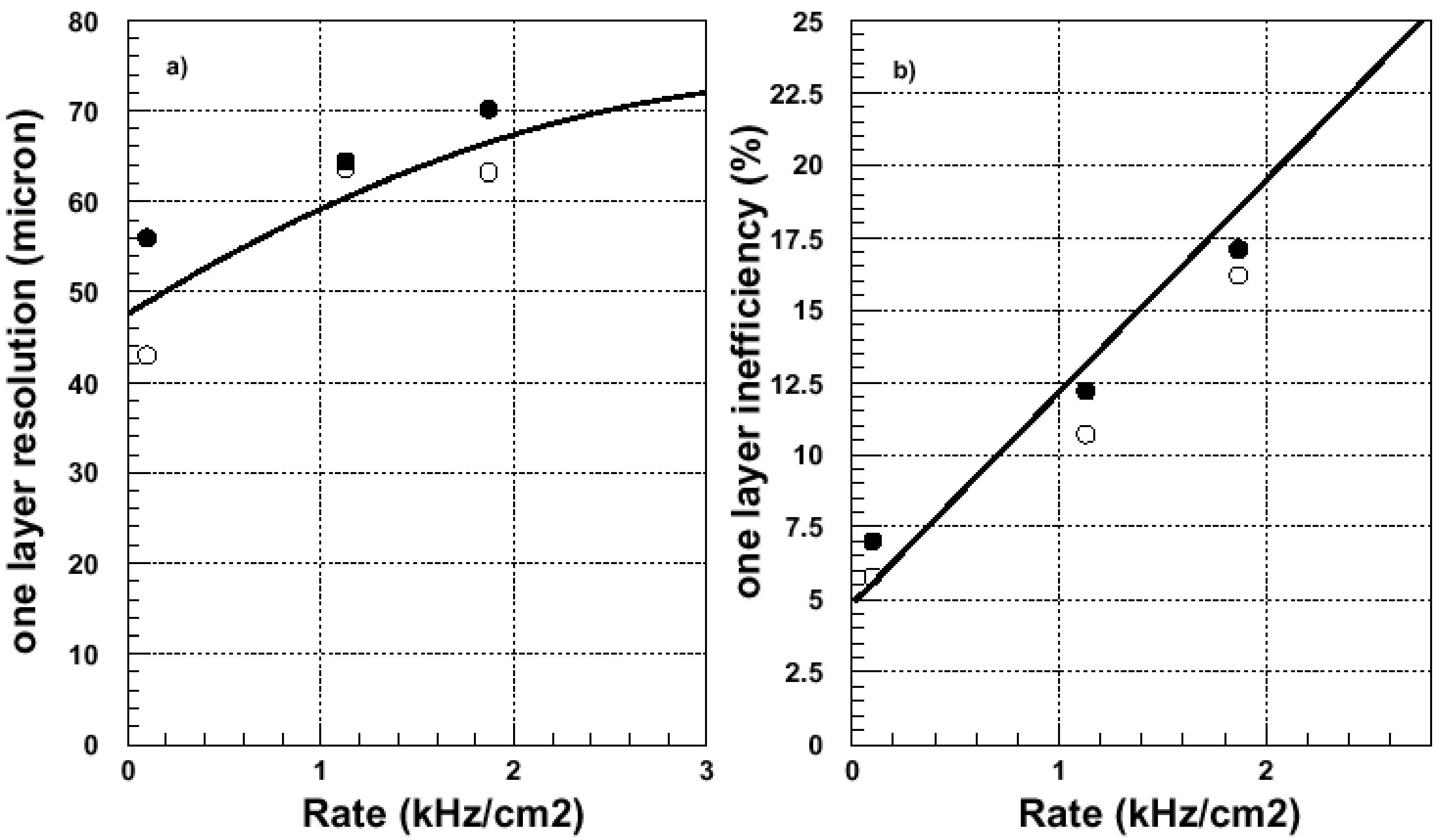
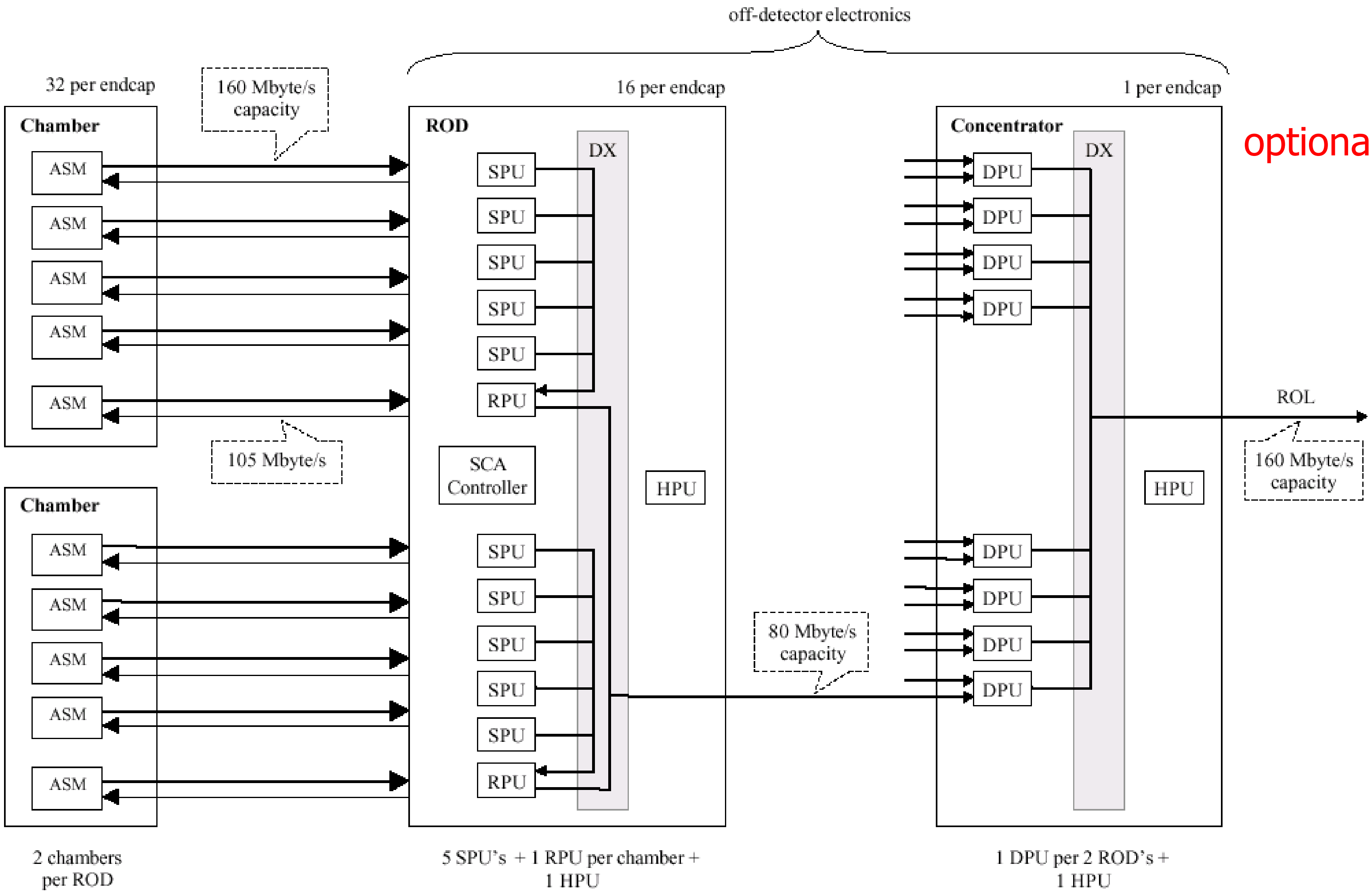
Beam Test Measurments



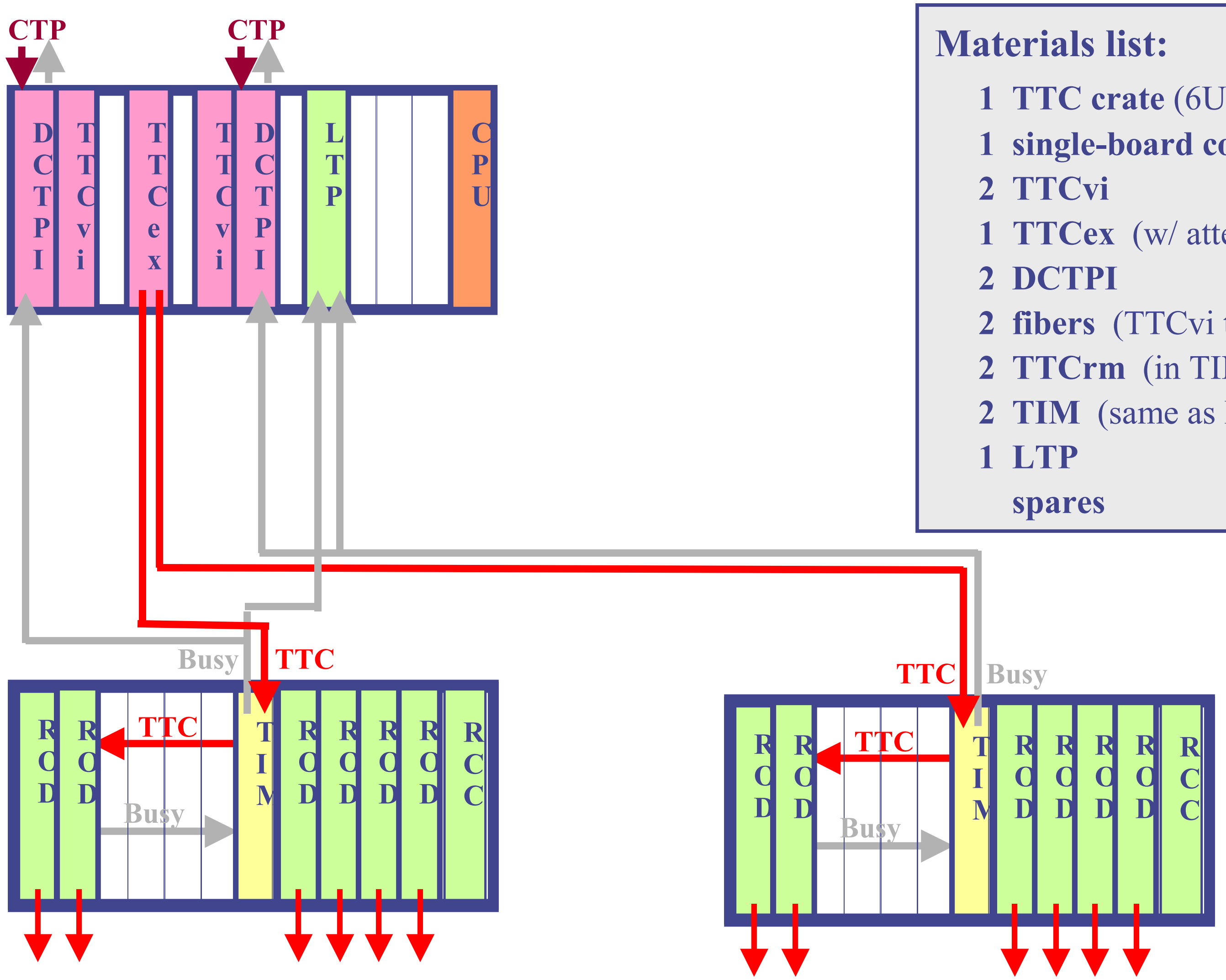
CSC Off-detector electronics



ROD

- Functions:
  - Generate control signals and transmit to chambers
  - Receive and process raw chamber data
  - Assemble events and transmit to Concentrator
  - Calibration and monitoring
  - ROD serves 2 chambers (1920 channels, 12.8 Gbit/s)
- 9U VME plus 220 mm Transition Module, 100W
- Modular design using TI DSP-based daughterboard (GPU)
  - 70 x 70 mm, 3W
  - > 100 Mword/s data BW
  - Component cost ~ $300
  - 12 GPUs per ROD

CSC TTC subsystem: Layout of TTC modules



Materials list:

- 1 **TTC crate** (6U VME)
- 1 **single-board computer**
- 2 **TTCvi**
- 1 **TTCex** (w/ attenuators)
- 2 **DCTPI**
- 2 **fibers** (TTCvi to TIM)
- 2 **TTCrm** (in TIMs)
- 2 **TIM** (same as Pixel/SCT)
- 1 **LTP**
- **spares**

Prototype Recirculating Gas System

Design and Construction by L.Kotchenda (PNPI) and his crew at BNL

System design similar to final

Will be used in test beams

Important for long term aging tests foreseen using X5/GIF

Our Extrapolation into the Future

(Or some facts that a lot of colleagues sometimes forget)

- Comparing ATLAS to the highest luminosity pp collider experiments we are making the following extrapolations:

  - Sqrt(s) (also $$$) 10
  - Luminosity 100, relvant factor for occupancies in other detectors
  - Background 1000, this is why Muons drive shielding

"The Future ain't what used to be"

Yogi Bera

Our Extrapolation into the Future

(Or some facts that a lot of colleagues sometimes forget)

- Comparing ATLAS to the highest luminosity pp collider experiments, we are making the following extrapolations:
  - Sqrt(s) [Center of Mass Energy, also $$$] x10
  - Luminosity [Relevant to rates seen by most detectors x100
  - Background rates [Muon rates, shielding] x1000

"The Future ain't what used to be"

Yogi Bera