



# Test and Installation of New sMDT Chambers in the ATLAS Muon Spectrometer

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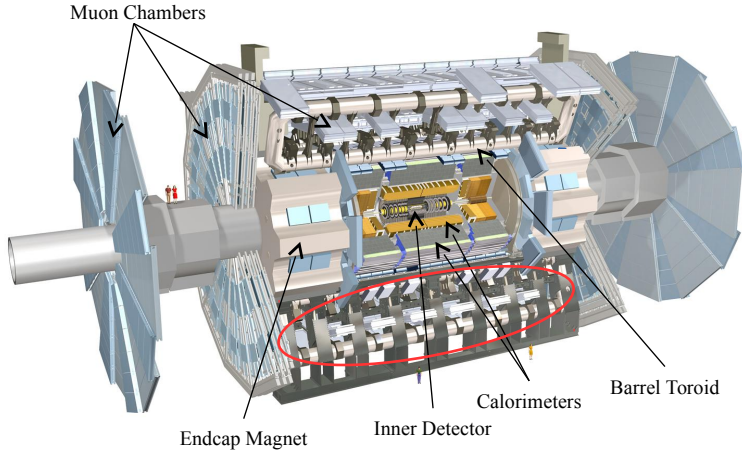
Max Planck Institute for Physics  
(Werner-Heisenberg-Institut)

29 Mar. 2017

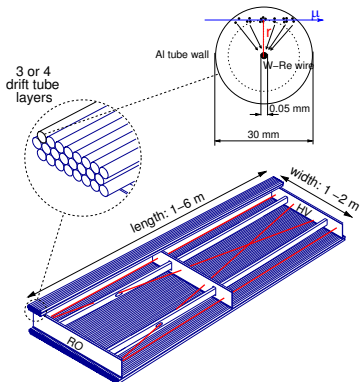


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# The ATLAS Experiment



## Standard Monitored Drift Tube (MDT) Specifications



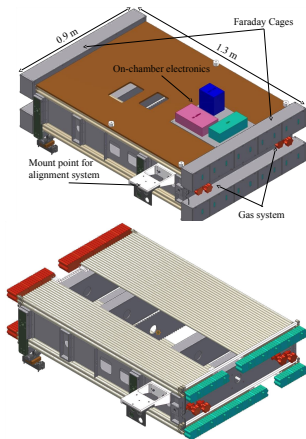
- 93% Ar, 7% CO<sub>2</sub> gas mixture
- 3 bar absolute pressure in the tubes
- HV of 3080 V
- Gas gain:  $2 \times 10^4$
- Wire position RMS:  $\Delta r < 20 \mu\text{m}$
- Tube diameter: 30 mm

Each chamber has 2 multilayers of tubes

Each multilayer has either 3 or 4 layers of tubes

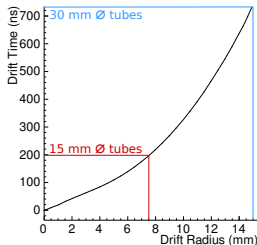
→ chamber resolution of  $40 \mu\text{m}$

## sMDT versus MDT chambers

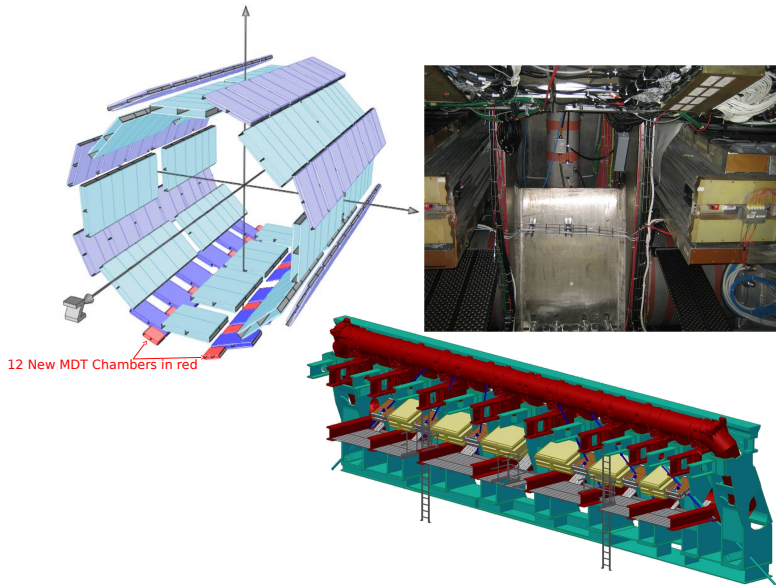


	MDT	sMDT
Diameter	30 mm	15 mm
Max. Drift Time	700 ns	185 ns
HV	3080 V	2730 V
Gas Gain	$2 \times 10^4$	
Chamber resolution	$\sim 40 \mu\text{m}$	

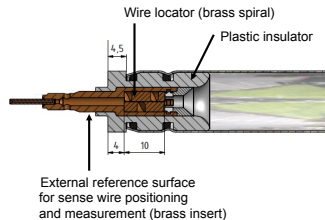
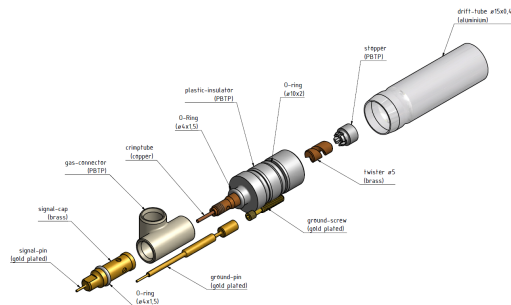
- Identical electric fields in sMDT vs. MDT
- Shorter drift time  $\rightarrow 10\times$  higher rate capability.
- Geometrically smaller to fit in smaller gaps.



# Location of New BMG Chambers

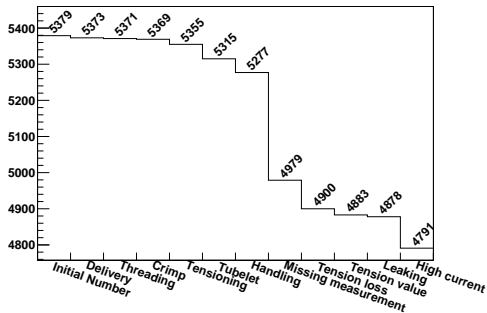


## Tube Endplug



- Brass insert is precision milled to be coaxial to the wire  
→ Gives precise location of wire inside the tube

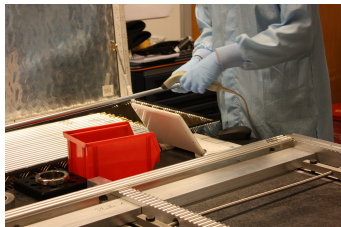
## BMG Tube Production Overview



- Any tube missing any test result is classified as "Missing measurement"
- The remainder have at most 1.71% loss of total tested tubes

5,379 Tubes	Total number
5,081 Tubes	Tested number
94.29%	OK
1.71%	High current
0.098%	Leaking
0.33%	Tension value
1.55%	Tension loss
0.75%	Handling
0.79%	Tubelet
0.28%	Tensioning
0.039%	Crimp
0.039%	Threading
0.12%	Delivery

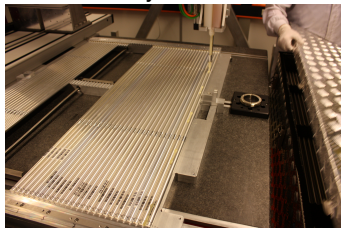
## BMG Chamber Assembly (I)



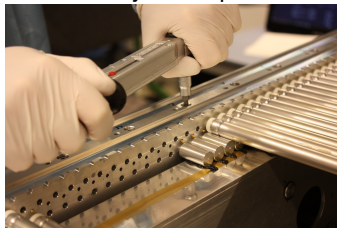
First layer of tubes



First layer completed



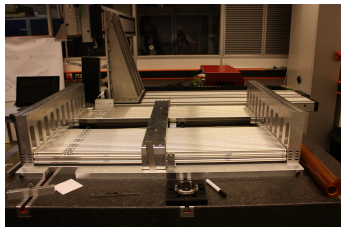
Epoxy for the second layer



Alignment comb closeup



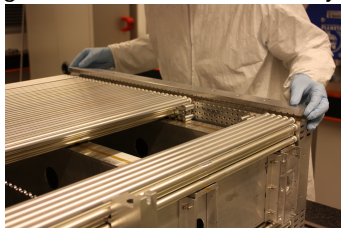
## BMG Chamber Assembly (II)



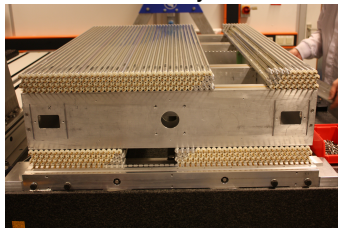
Alignment between the 2 multilayers



Second multilayer started



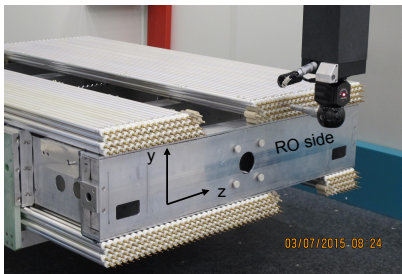
Second multilayer completed



Completed chamber

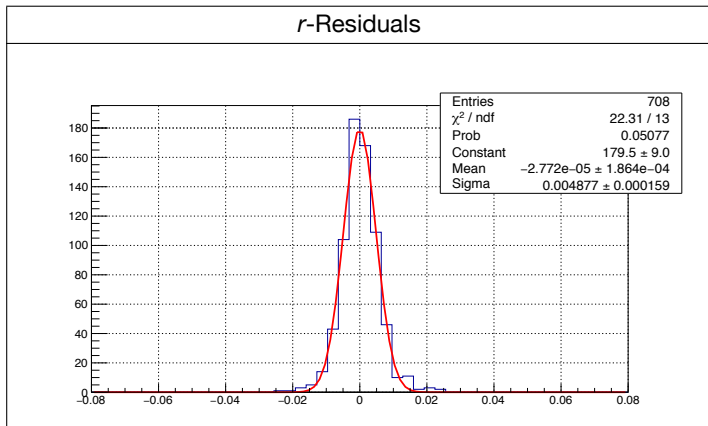
## Wire Position Measurement

- Wire positions recorded at both "Readout" (or "RO") and "HV" sides
- Measured positions are compared to optimum grid positions.
- A combined fit (both sides of the chamber) is also done
- Measurement done at  $20 \pm 1^\circ \text{C}$



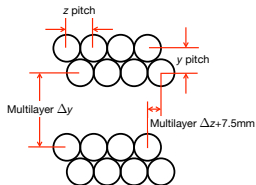
## BMG-6C-14

- Better than  $5 \mu\text{m}$  wire position precision (compared to  $20 \mu\text{m}$  requirement)
- Position measurement repeatability of the machine tested: differences have RMS of  $3 \mu\text{m}$ 
  - Added to the wire position measurement in quadrature



## BMG-6C-14 Chamber Geometry Parameters

All fits are within specifications. "Nominal" values are from comb measurements



BMG-6C-14	RO-Side	HV-Side	Nominal
z pitch [mm]	$15.0993 \pm 0.00001$	$15.0991 \pm 0.00001$	15.0990
y pitch [mm]	$13.079 \pm 0.0002$	$13.079 \pm 0.0001$	13.074
Multilayer $\Delta z$ [mm]	$-0.012 \pm 0.0002$	$-0.003 \pm 0.0004$	-0.008
Multilayer $\Delta y$ [mm]	$184.990 \pm 0.0004$	$184.989 \pm 0.0007$	184.970

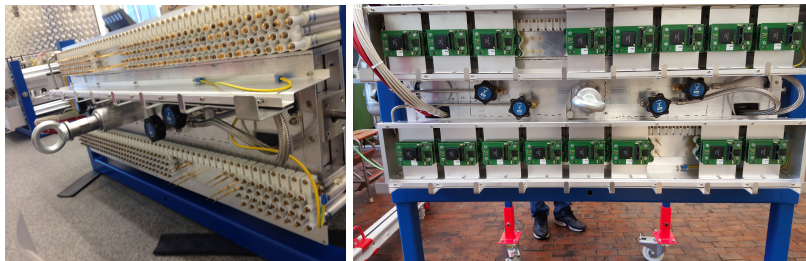
Overall ranges from RO, HV, and Combined measurements for all chambers:

z pitch [mm]: 15.099 to 15.0994      Multilayer  $\Delta z$  [mm]: -0.02 to 0.04

y pitch [mm]: 13.078 to 13.098      Multilayer  $\Delta y$  [mm]: 184.96 to 184.994

$\sigma_r$  [mm]: 0.004 to 0.016

## On-Chamber Component Installation



After wire position measurements, gas systems and electronics are installed

- Gas system and electronics mounted
- Systems test:
  - Chamber gas leak rate tested
  - Cosmic rays used to test electronic readout of chamber

## BMG Chamber Test Setup



Left shows chambers under test (red tape shows location of scintillators used for triggering)

Computer and crate in center with triggering, readout, HV, and gas systems

Right shows chambers which have been tested

- Photo from CERN. Similar to the setup used at MPI to test the chambers



# Gas Leak Rates

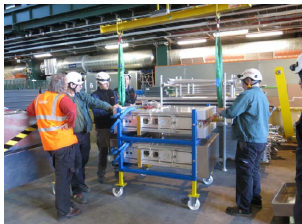
Measured gas leak rates at CERN

Chamber	Top Multilayer	Bottom Multilayer
BMG-2A-12	0.02	0.3
BMG-2A-14	6.6	2.8
BMG-2C-12	6.0	0.2
BMG-2C-14	1.7	3.0
BMG-4A-12	2.1	1.5
BMG-4A-14	0.5	0.1
BMG-4C-12	1.4	1.0
BMG-4C-14	2.4	2.7
BMG-6A-12	4.9	6.4
BMG-6A-14	4.4	0.9
BMG-6C-12	2.8	5.0
BMG-6C-14	3.5	2.0
Average	3.0	2.2

- Leak rate calculated from overnight pressure loss in a temperature controlled environment
- Leak rates in mbar/h
- ATLAS leak rate is 0.4 mbar/h
  - Achieved before electronics installation (< 0.2 mbar/h on all multilayers)
- Source of leaks due to stress on O-rings from Mezzanine cards
- Overall leak rate acceptable for chamber operation
  - passed for installation in ATLAS

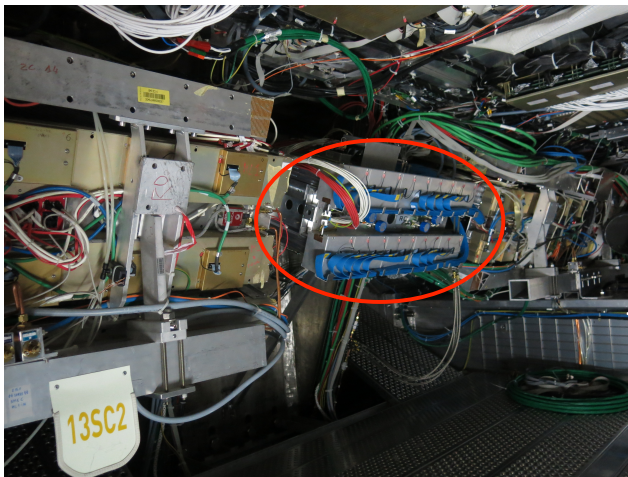


## BMG Chamber Installation in ATLAS





## BMG Chamber Installed in ATLAS



Installed chamber (BMG-2C-14) circled in red.



## Conclusions and Outlook

- 12 BMG chambers completed, installed during Winter Shutdown 2016 – 2017
- Testing shows all chambers OK for installation in ATLAS
  - These were the most precise wire precisions achieved!
- Next sMDT chambers for LS2 (2019 – 2020) have been started (BIS7/8 project)
  - 16 chambers will be constructed
  - After installation, 96 BIS chambers will be constructed to replace the barrel inner layer (Phase 2 upgrade)



# BACKUP

# Wire Specifications

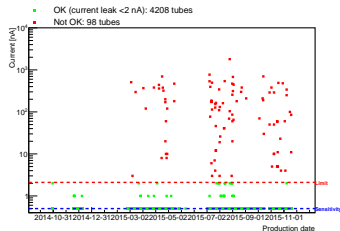
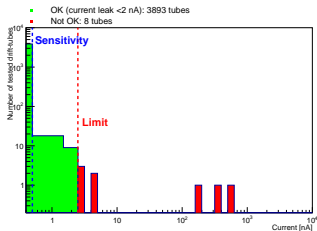


Wave velocity = $\sqrt{\frac{T}{m/L}}$	$\frac{m}{L} = \rho \times \pi r^2$	$f = \frac{v}{\lambda}$
$f = \frac{v}{2L} = \frac{1}{2L} \sqrt{\frac{T}{m/L}}$ $\rightarrow f = \frac{1}{2L} \sqrt{\frac{T}{\rho \pi r^2}}$		

$$T = L^2(2r)^2\nu^2\pi\rho/g$$

$\rho = 19.34 \text{ g/cm}^3$	$r = 25 \text{ } \mu\text{m}$	$L = 1642 \text{ or } 982 \text{ mm}$
Tensile strength: 6.28 – 6.67 N (640.38 – 680.15 g)		

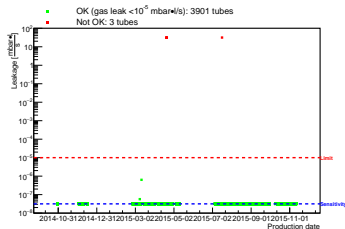
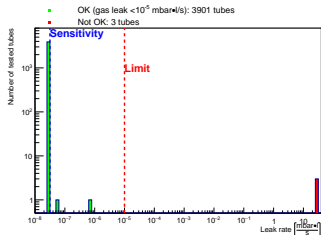
# BMG Tube Dark Current Test Results



- Red dotted line shows acceptable current limit ( $< 2$  nA)
- Blue dotted line shows sensitivity limit of the current measurement ( $0.5$  nA)

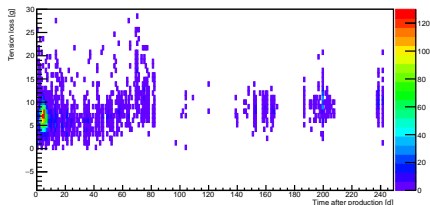
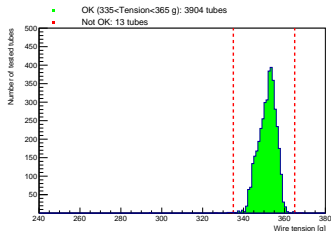


# BMG Tube Gas Leak Test Results



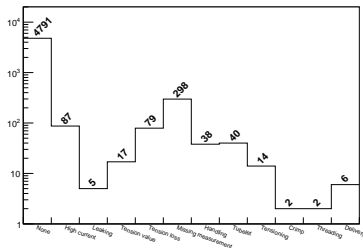
- Red dotted line shows acceptable leak rate limit ( $< 10^{-5}$  mbar·l/s)
- Blue dotted line shows sensitivity limit of the leak detector ( $3 \times 10^{-8}$  mbar·l/s)

# BMG Tube Tension Test Results



- Tension spec. ( $335 < T < 365$  g) shown in red
  - Corresponds to  $133.86 < \text{Hz} < 140.68$  for 1100 mm
  - Corresponds to  $89.67 < \text{Hz} < 94.24$  for 1642 mm
  - Corresponds to  $149.94 < \text{Hz} < 157.58$  for 982 mm
  
- Between 5 – 10 g loss over time

# BMG Tube Production Losses



5,379 Tubes

Total number

89.0686%

OK

1.62%

High current

0.093%

Leaking

0.32%

Tension value

1.47%

Tension loss

5.54%

Missing measurement

0.71%

Handling

0.74%

Tubelet

0.26%

Tensioning

0.037%

Crimp

0.037%

Threading

0.11%

Delivery



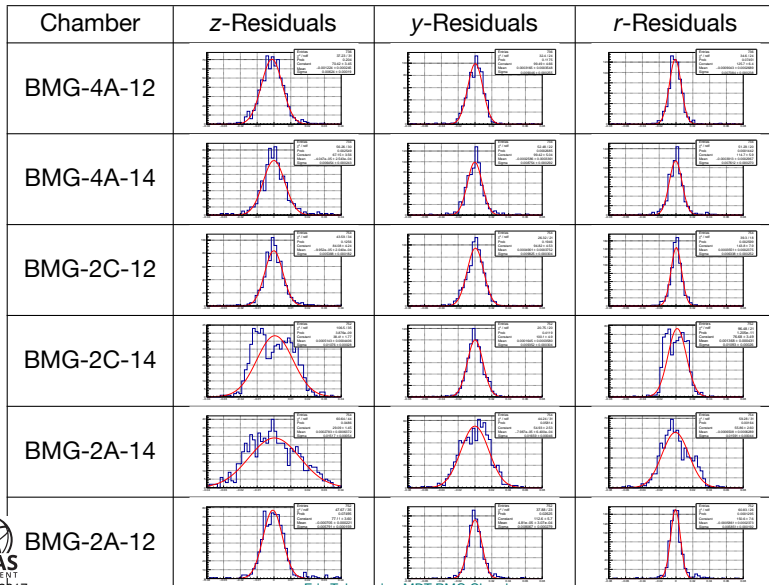


# z-, y-, and r-residuals for Wire Positions (I)

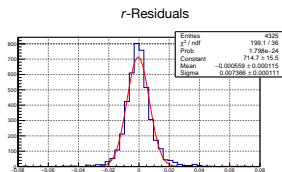
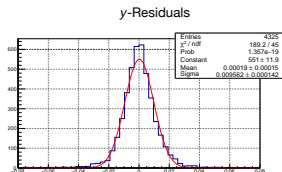
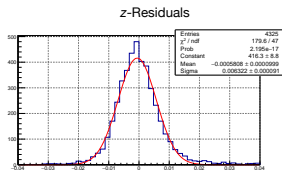
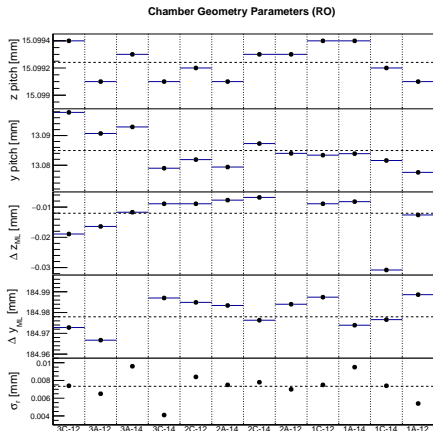
Chamber	z-Residuals	y-Residuals	r-Residuals
BMG-6C-12			
BMG-6A-12			
BMG-6A-14			
BMG-6C-14			
BMG-4C-12			
BMG-4C-14			



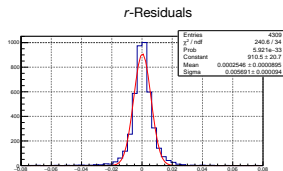
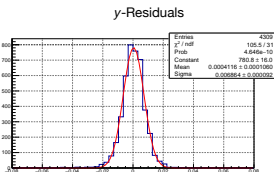
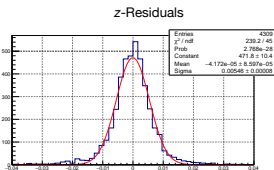
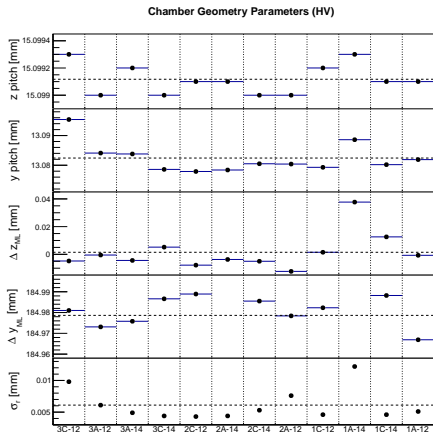
## z-, y-, and r-residuals for Wire Positions (II)



# RO Side Measurements from All BMG Chambers

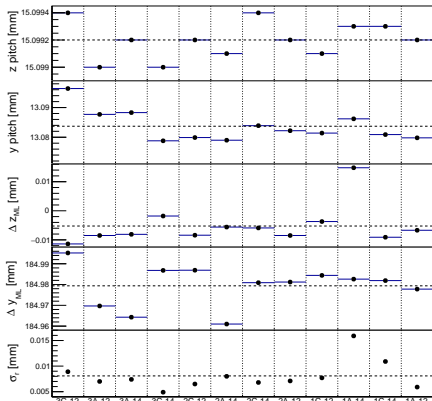


# HV Side Measurements from All BMG Chambers

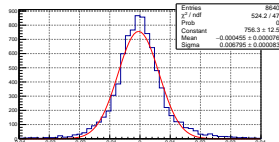


# Combined Measurements from All BMG Chambers

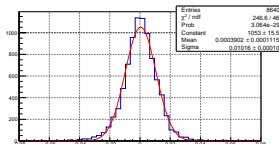
Chamber Geometry Parameters (RO and HV Common Fit)



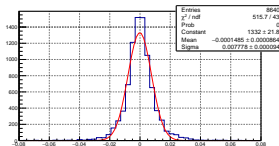
z-Residuals



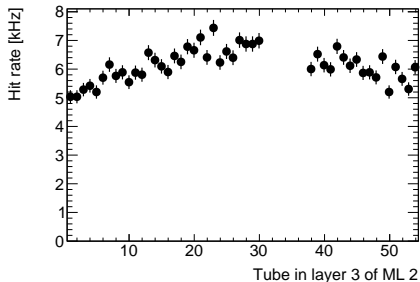
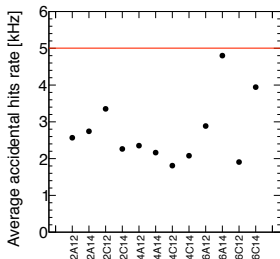
y-Residuals



r-Residuals



# Cosmic Ray Tests



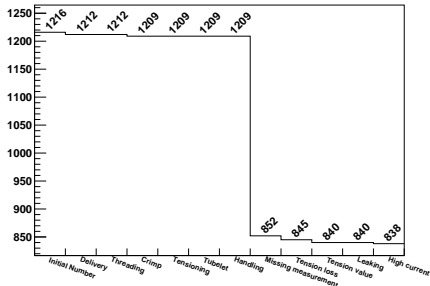
- Cosmic rays were used to check the response and noise in the chambers
- Average noise rates per chamber shown on left
  - Red line denotes limit of 5 kHz
  - Chambers are within acceptable rates
- Sample hit rate from one layer of one chamber on right
  - Plot from Layer 3, Multilayer 2, BMG-2A-12
  - All other layers and all other chambers show same characteristic shape
  - Gap corresponds to cutouts required for ATLAS alignment system

## BIS 7/8 Tube Production Overview

- Overall pass rate of the constructed tubes is 68.91%
  - This does not include tubes awaiting second tension test
  - 97.56% of those fully tested pass

For Module 0:

- Approx. 700 tubes of length 1660 mm are needed
  - 838 completed as of 16 Mar. 2017
- Approx. 50 tubes of length 1000 mm are needed
  - Construction of these tubes has started



# BIS Tube Production Losses

