Precision Muon Drift-Tube Detectors for High Radiation Rates at Super-LHC

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Particle Physics School Colloquium - December 2009

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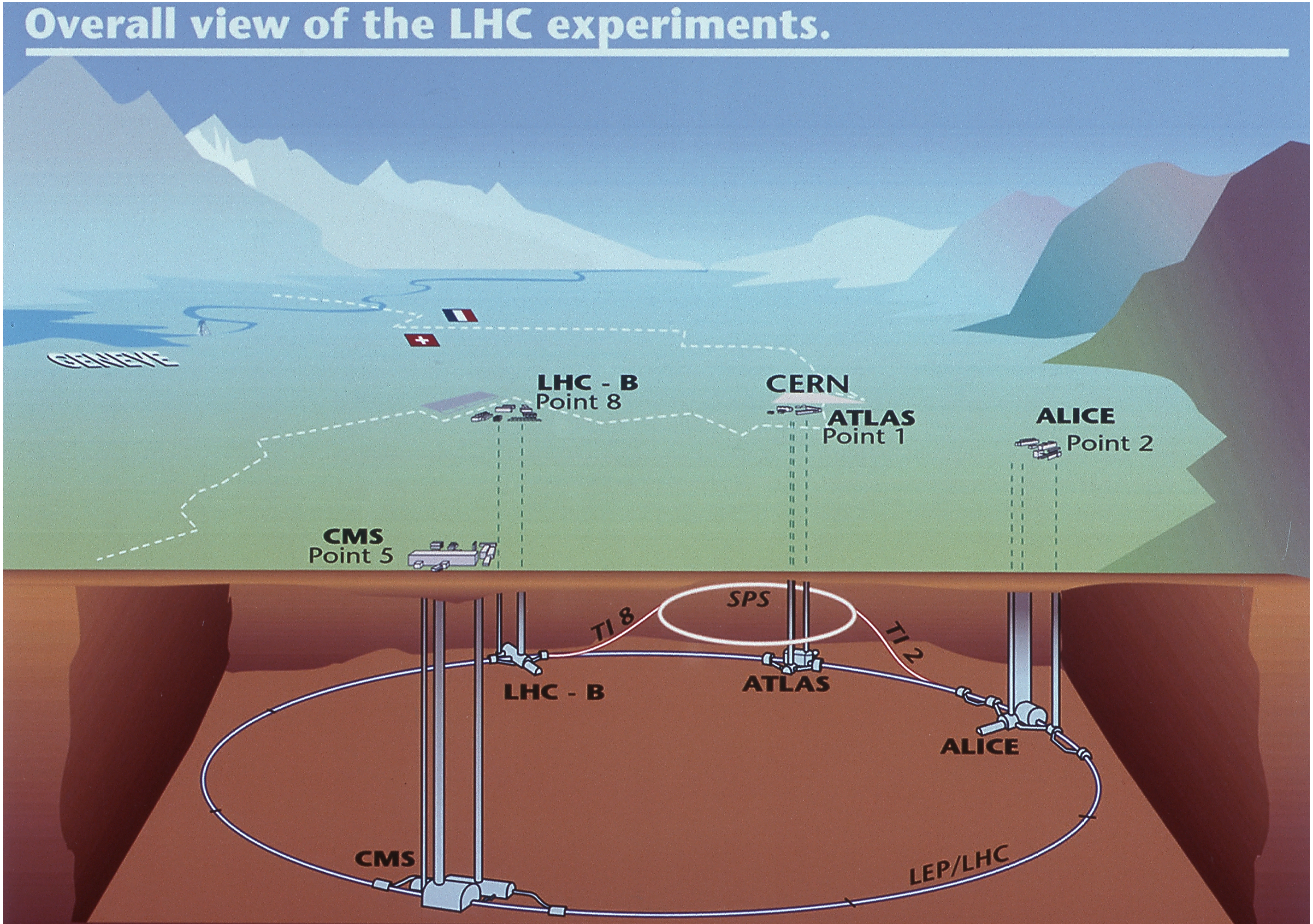
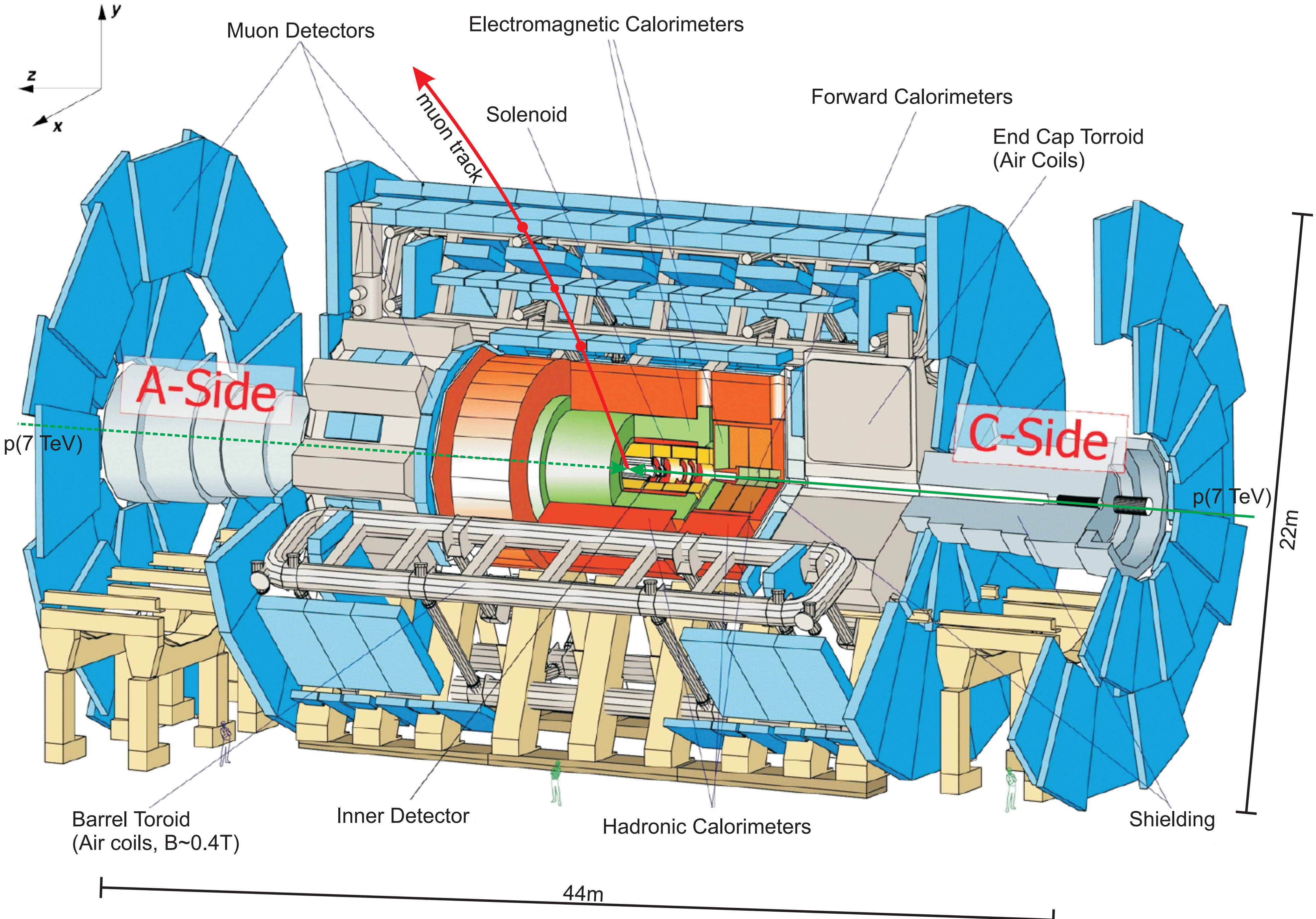
FSP 101 ATLAS

Outline

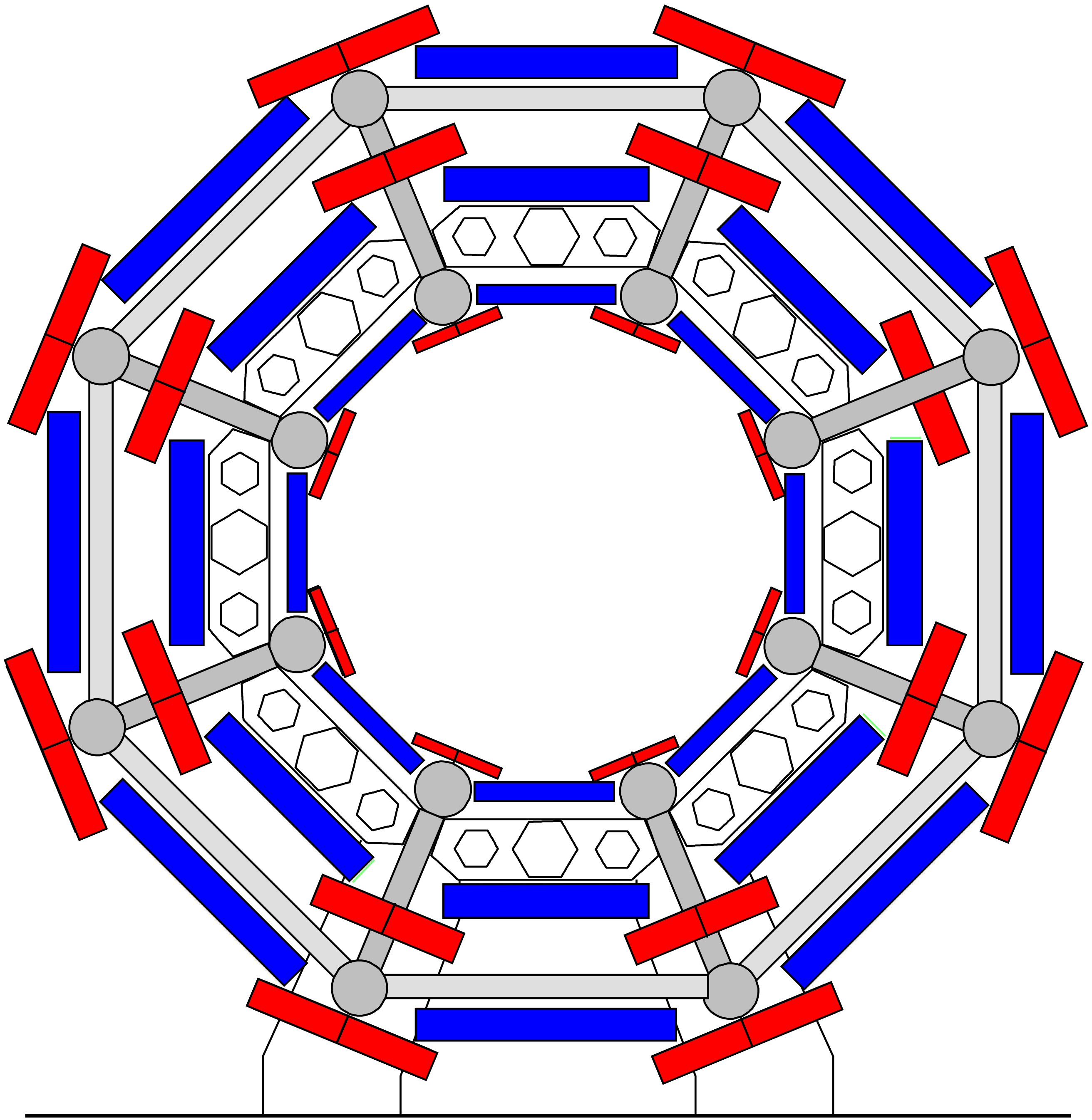
LHC and its Experiments



The ATLAS Detector at the LHC

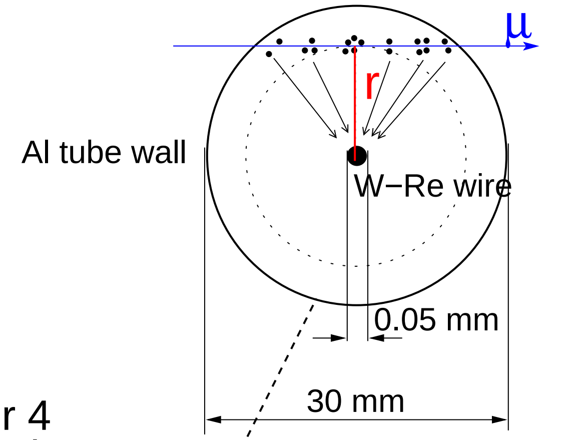


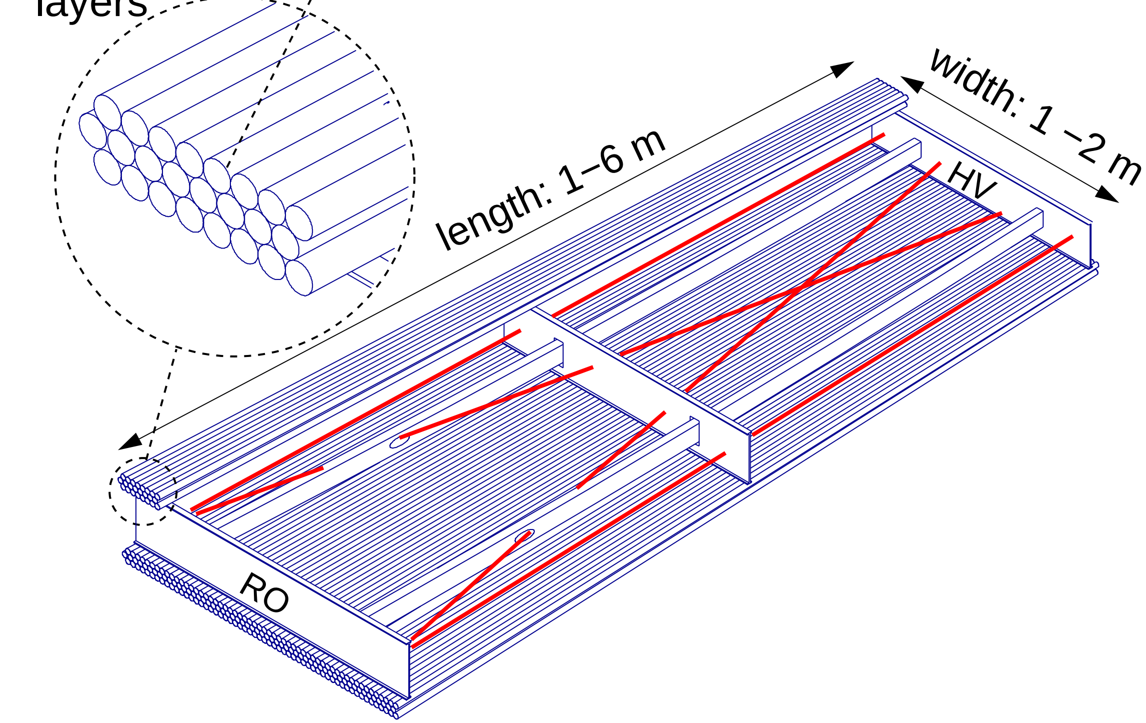
The ATLAS Muon Spectrometer

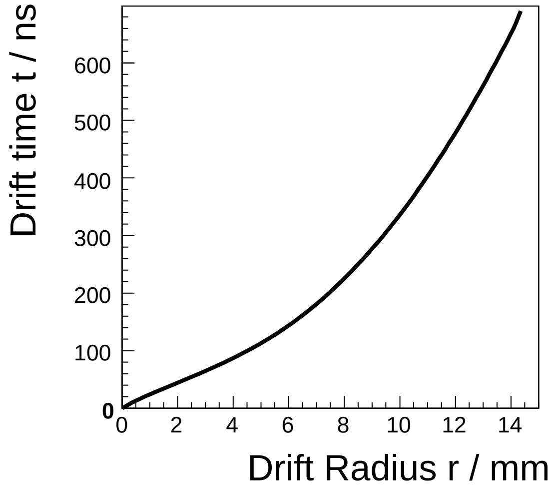


- Toroidal magnetic field with $B\mathrm{d}l \approx 0.4$ Tm
- Momentum determination via three layers of high resolution drift tube chambers
- Very fast detectors for triggering and second coordinate

Current Design for the Muon Drift Tube Chambers



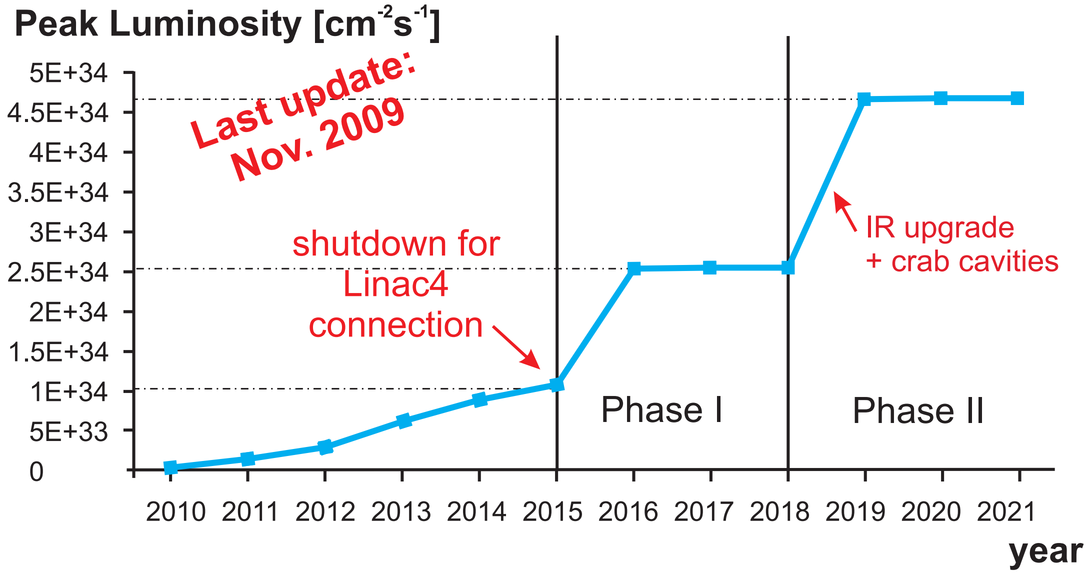




- Gas mixture: $Ar/CO_2 = 93/7$
- Gas gain: $2 \cdot 10^4$
- Max. drift time: ≈ 700 ns
- Single tube resolution: 80 μm
- Mechanical accuracy: 20 μm
- Track reconstruction accuracy: 35 μm
- Optical system to ensure this high accuracy

$\Rightarrow$ Very good momentum resolution for high p_T muons (10% for 1 TeV/c)

Timetable for LHC & SLHC



July 2009: CERN council approved the budget for the next three years of SLHC development

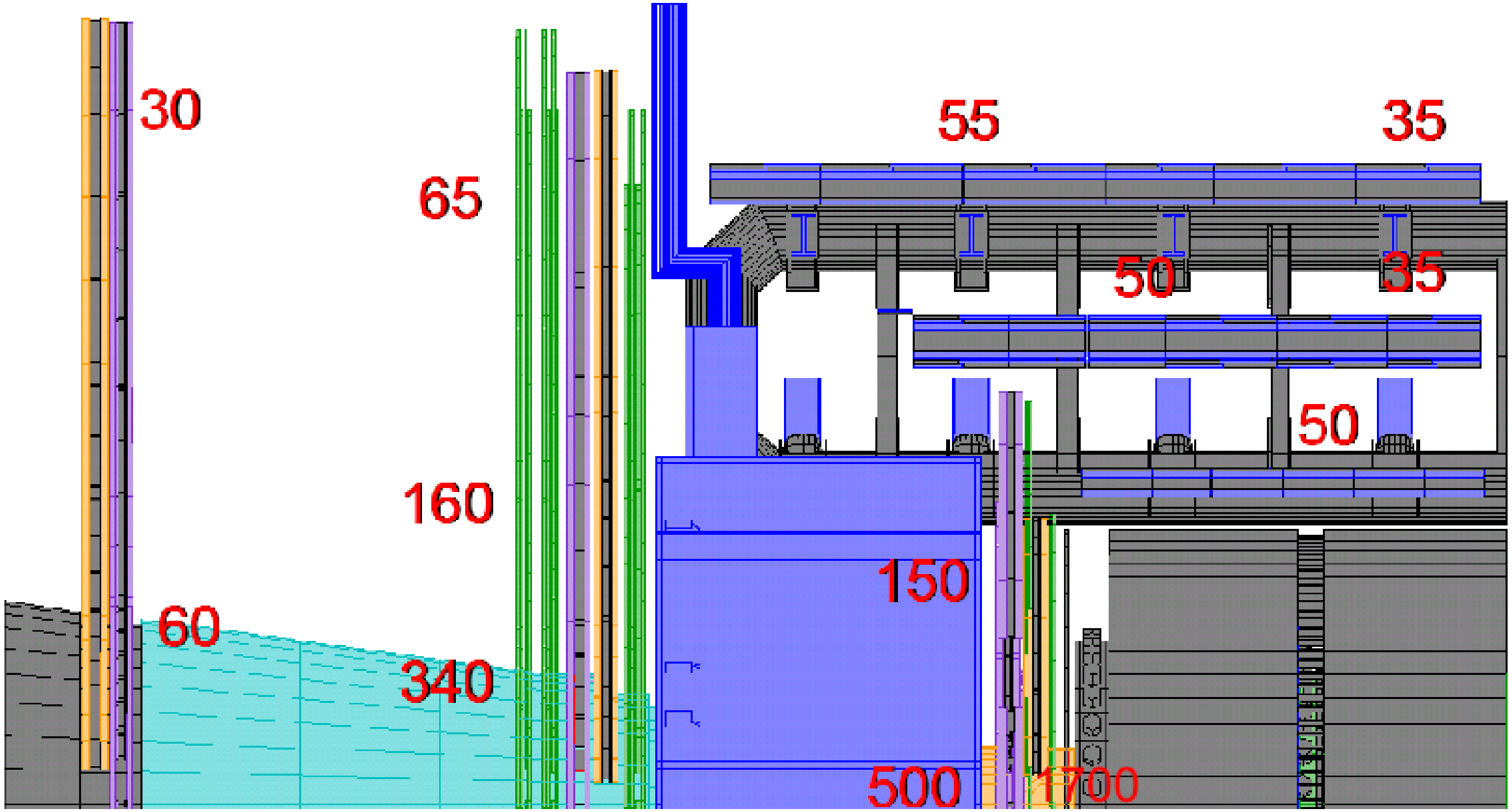
- **Phase 1** (6-8 month shutdown, ~2015):
  Upgrade of the ATLAS pixel detector
  Replacement of the innermost layer of MDT chambers in the forward region ($2.0 < \eta < 2.7$) with new technology
- **Phase 2** (2-3 years shutdown, ~2018):
  Replacement of the MDT chambers in critical regions with new technology
  New Electronics may also be necessary

There will be a new meeting about the LHC upgrade in January $\Rightarrow$ a new schedule

Background Rates in the Muon Spectrometer

Consists mainly of photons and neutrons (E≈1 MeV) from secondary reactions in the calorimeters, shielding, beam pipe and other structures.

Expected rates [Hz/cm^2] for nominal LHC luminosity ($\mathcal{L} = 10^{34}$ cm^{-2}s^{-1}):



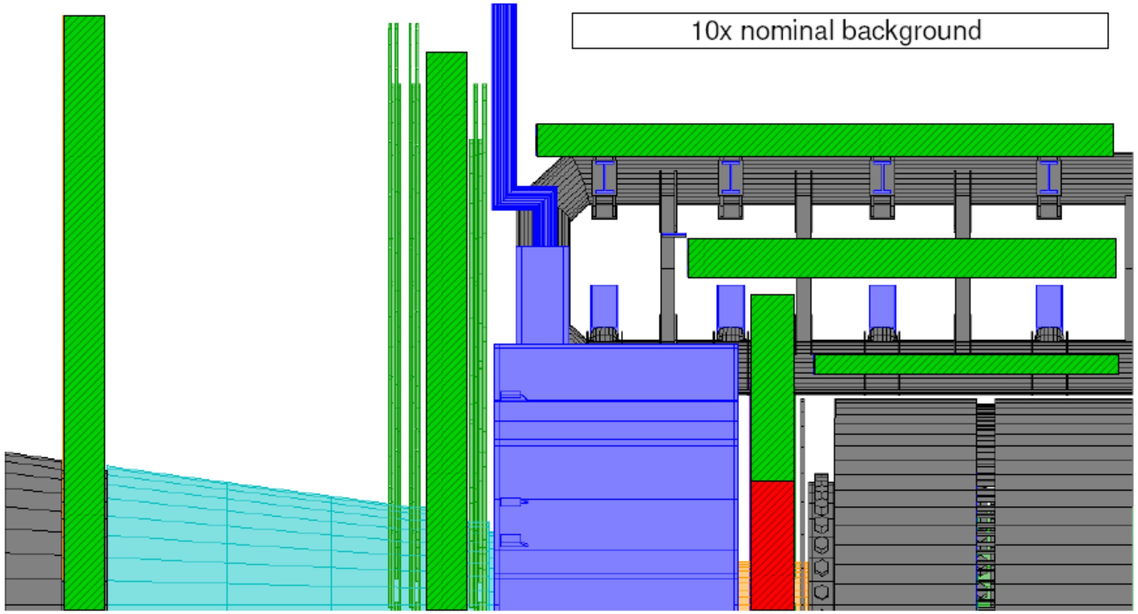
Huge uncertainties in the simulations ⇒ Calculations include a safety factor of 5

Rates at the SLHC are higher by a factor of 5!

Especially in the forward regions we expect very high rates (up to 1.7 kHz/cm^2)!

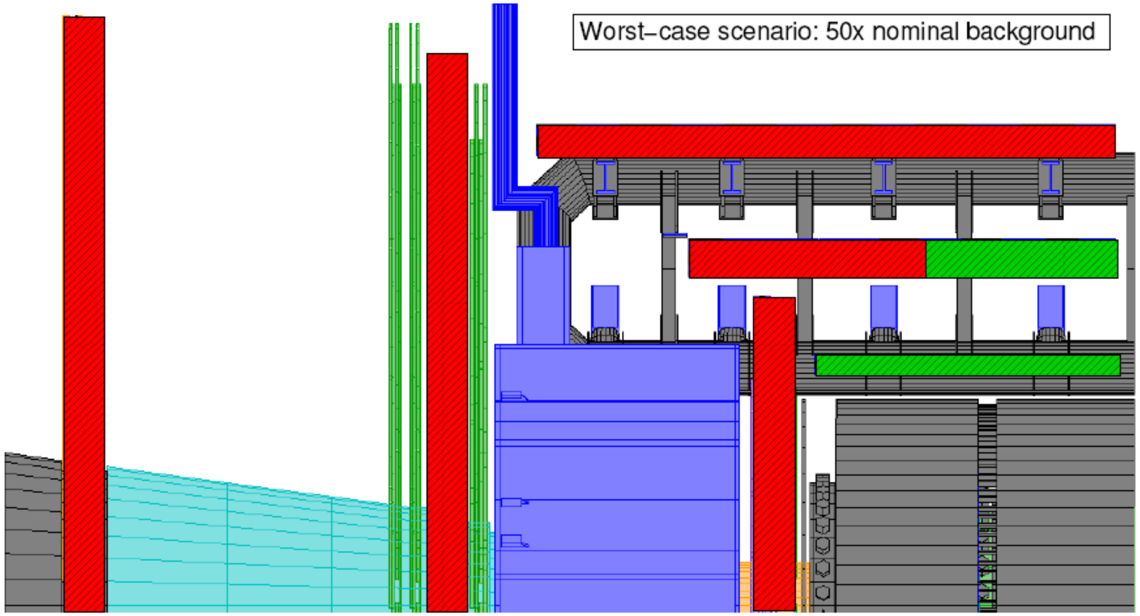
Occupancy of the MDT Chambers at SLHC Luminosity

Good track reconstruction efficiency for occupancy's less than 30% (green)



Scenario 1: Safety factor was unnecessary

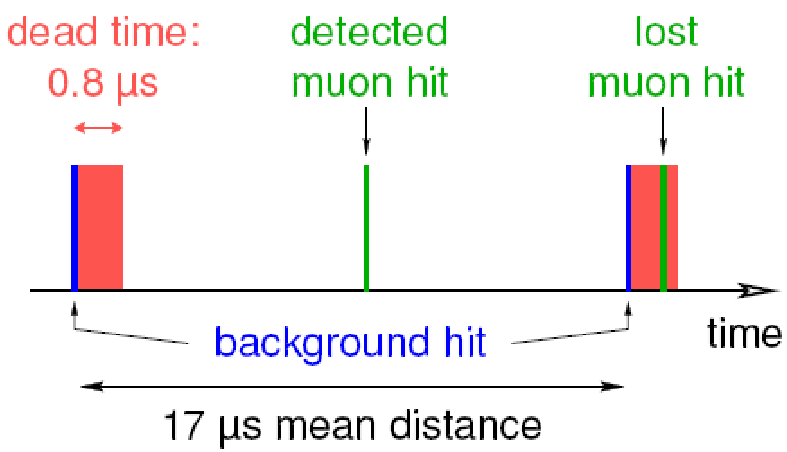
- Only small fraction of chambers have to be replaced (red parts)
- Electronics can be kept



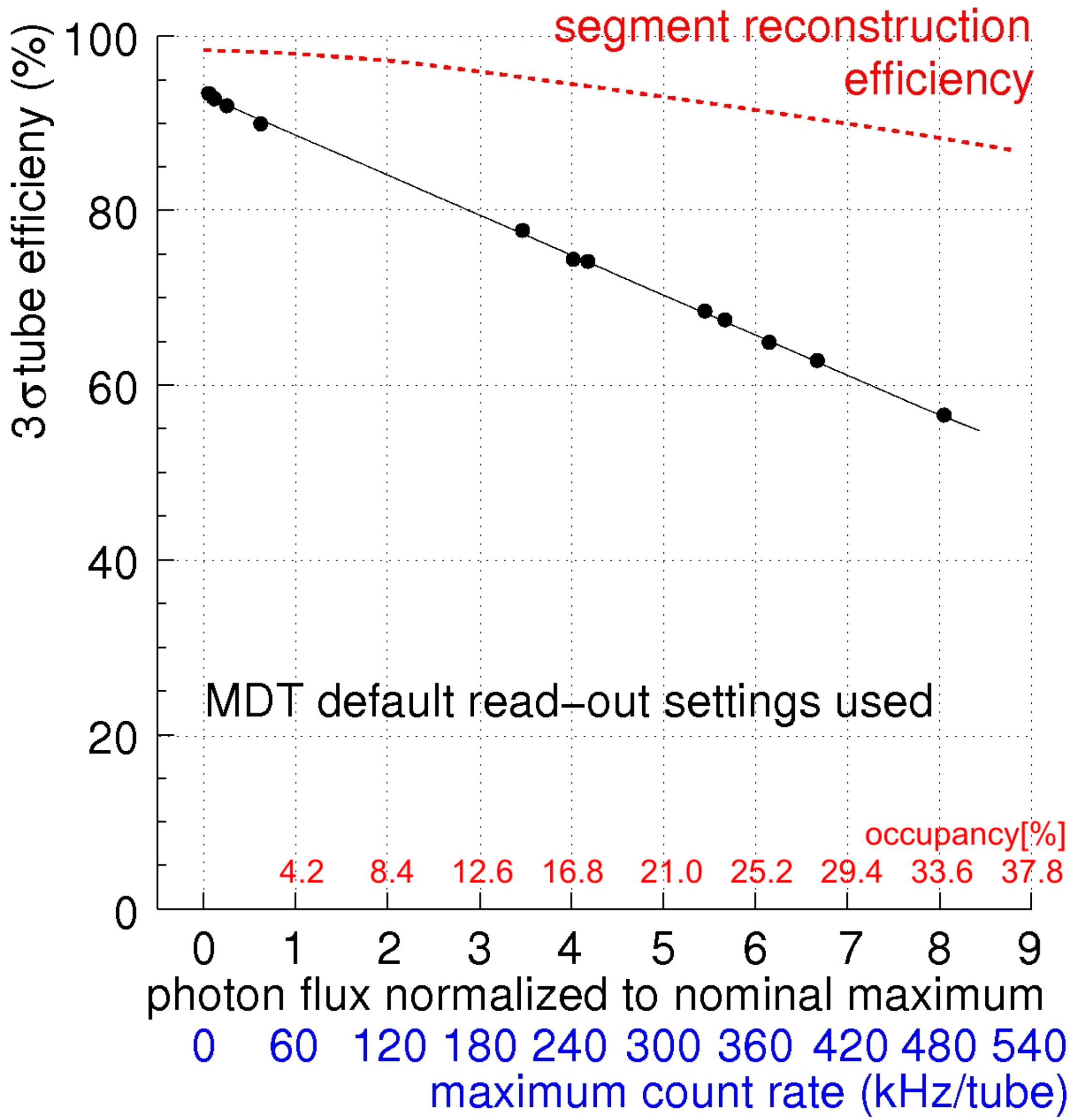
Scenario 2: Safety factor of 5 was necessary

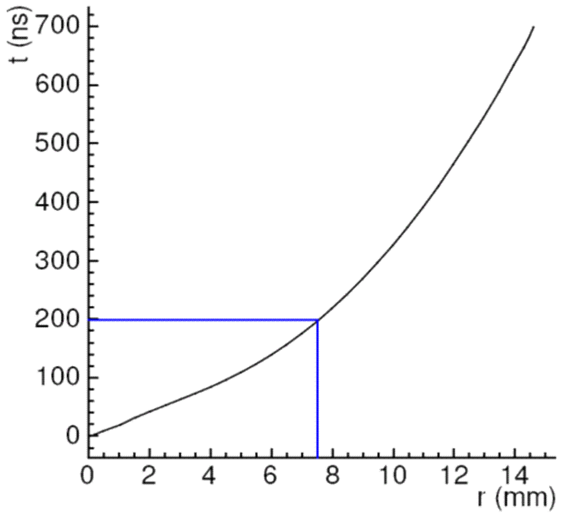
- 70% of the MDT chambers have to be replaced
- The electronic components must become more resistant to radiation

Efficiency problems at high background rates



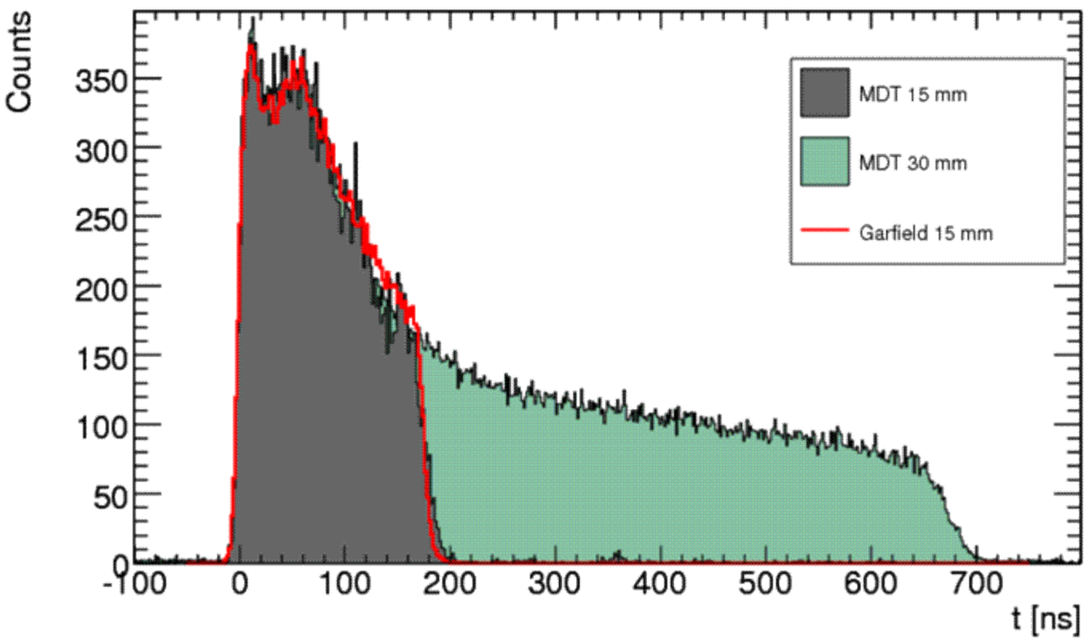
Some muon hits are masked by background events. But the track reconstruction efficiency is still good ($\approx$ 90%) up to an occupancy of 30% beacause of the redundant measurement by 6 tube layers.





By reducing the tube diameter from 30 to 15 mm we get a shorter maximal drift time and a more linear space drift time relation

- Maximal drift time is shorter by a factor of 3.5 (700 ns $\rightarrow$ 200 ns)
- Smaller diameter also results in 2x less background hits (smaller area per tube)



An occupancy of 30% is reached at 10 kHz/cm^2 (for 1 m tubes)

The tube density is doubled $\Rightarrow$ better track reconstruction because of more redundant track points

Parameters and Expectations for 15 mm tubes

Tube ⌀	**15 mm**	**30 mm**
Gas	93:7 Ar/CO_2	93:7 Ar/CO_2
Pressure	3 bar	3 bar
Wire	50 μm W-Re	50 μm W-Re
Tube wall	0.4 mm Al	0.4 mm Al
HV	2730	3080
Max. drift time	200 ns	700 ns

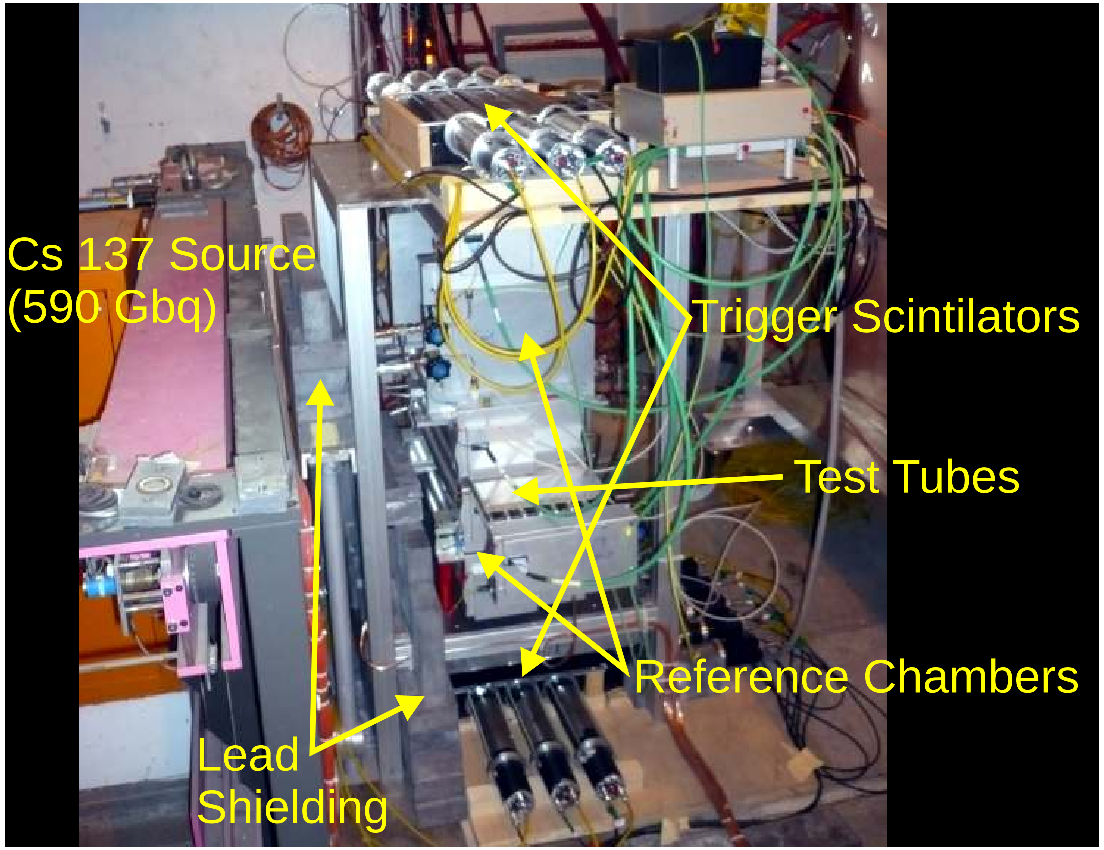
- Keep as many parameters as possible to ease integration in old systems
- Well known operating parameters with many reference measurements

Expected occupancy and rate for different background rates

Luminosity $[cm^{-2}s^{-1}]$	Background rate $[kHz/cm^2]$	Counting rate 1m tubes [Hz]	Occupancy	Occupancy	Year
Tube ⌀	15 mm	15 mm	15 mm	30 mm	
1×10^{34}	1.7	250	2.5%	35%	2015
2×10^{34}	3.4	500	5%	60%	2016
3×10^{34}	5.0	750	7.5%	95%	2017
5×10^{34}	8.5	1250	12.5%	100%	SLHC

Tests with 6 tubes in the GIF at CERN

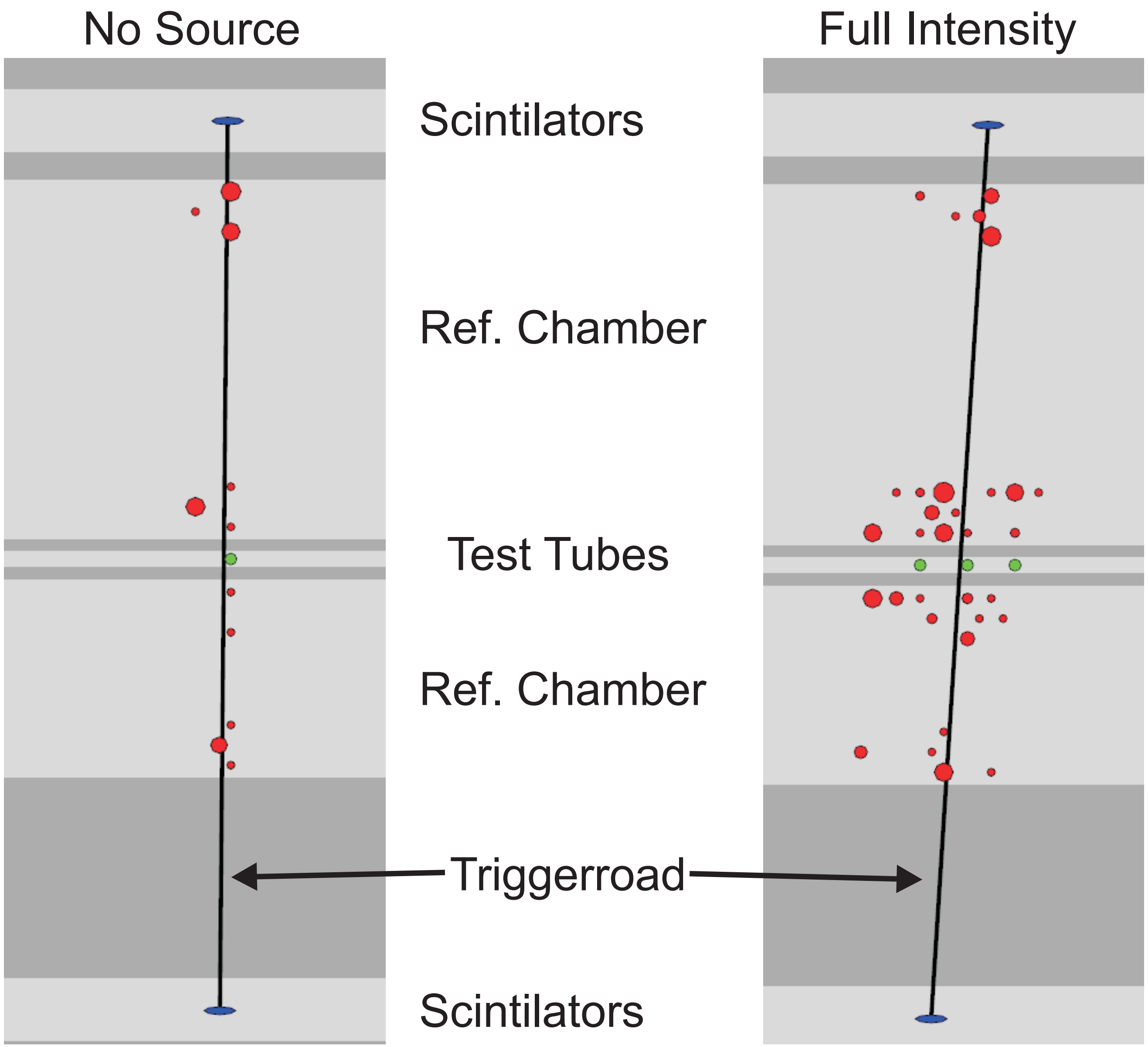
Simulation of the background radiation with a very intense γ source (end of April until mid of July '09)



- Tests with different HV and discriminator settings
- Background rates up to 5.3 kHz/cm^2 (800 kHz/tube)
- Muon tracks are determined with (shielded) 30 mm tube chambers
- First results show a very good agreement with the simulations

Data analysis still in progress . . .

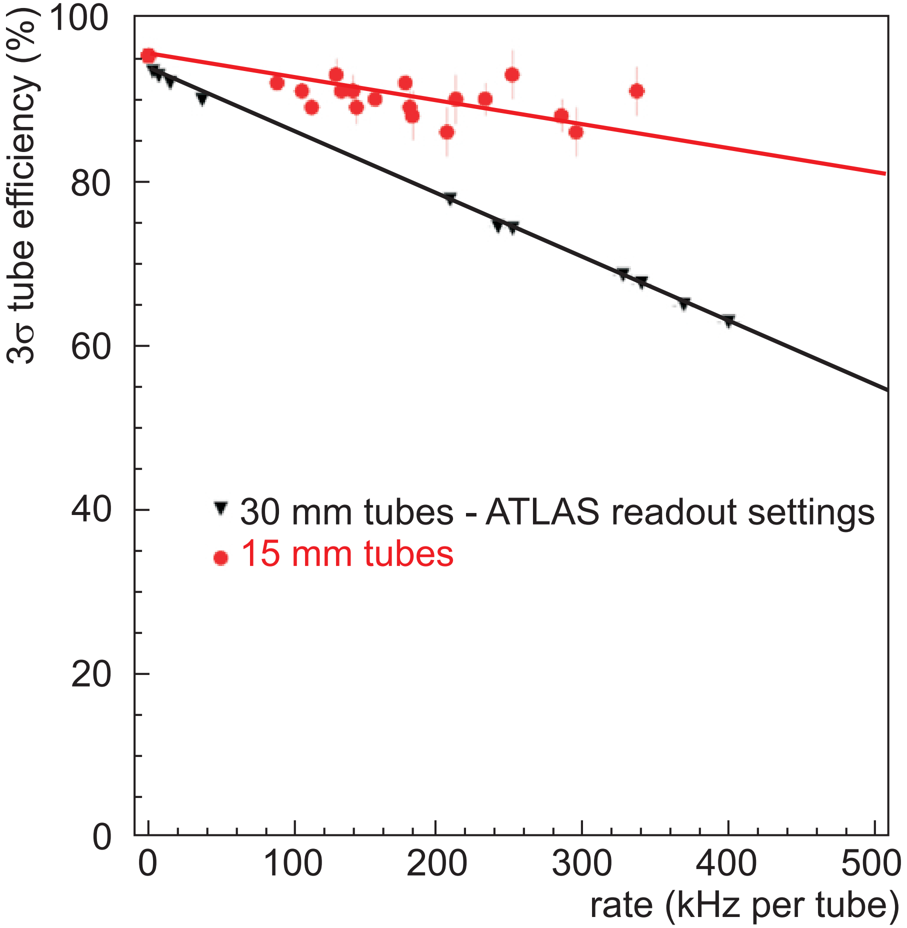
Sample event displays with and without γ irradiation



- Uppermost and lowermost layers of the reference chambers are shielded $\Rightarrow$ good track reconstruction possible
- Middle layers are not shielded $\Rightarrow$ bad efficiency in the 30 mm tubes and track hits are hard to find
- Locating potential track hits with the trigger road given by the hodoscope

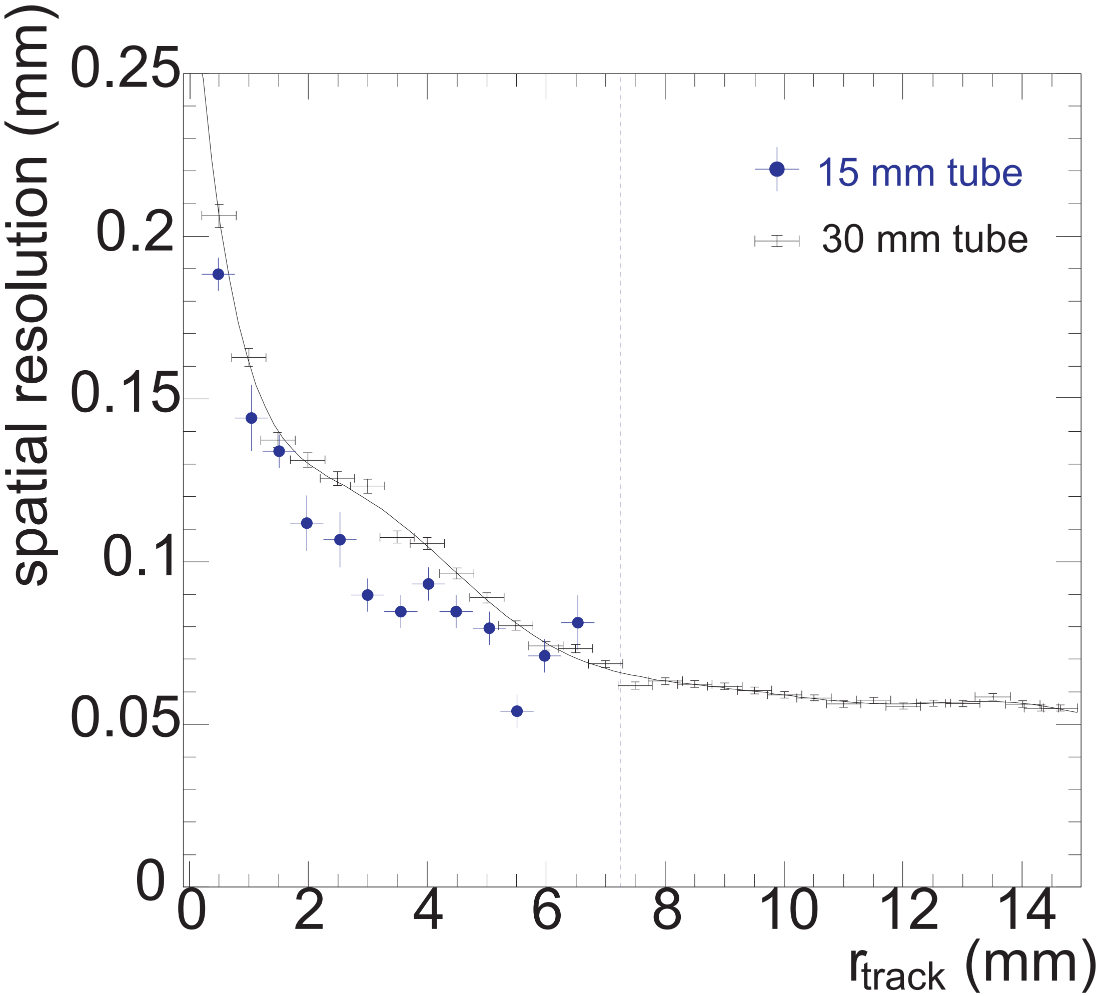
Results from the GIF Tests

Single-tube efficiency



Measured single-tube efficiency in agreement with expectation (red line).

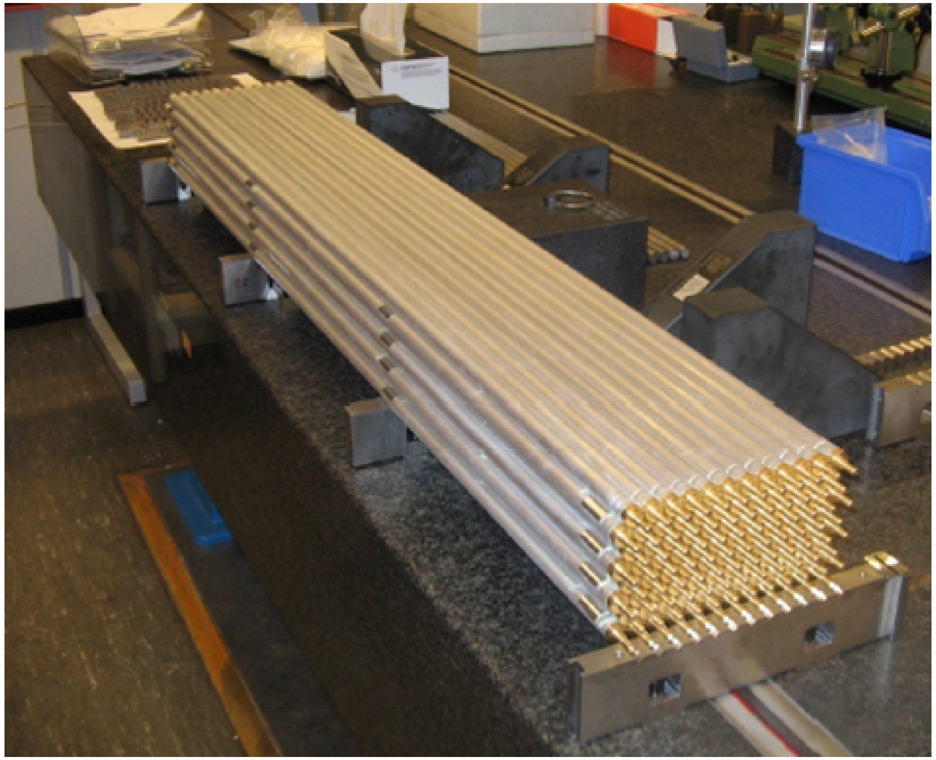
Resolution



Spatial resolution slightly better than expected.

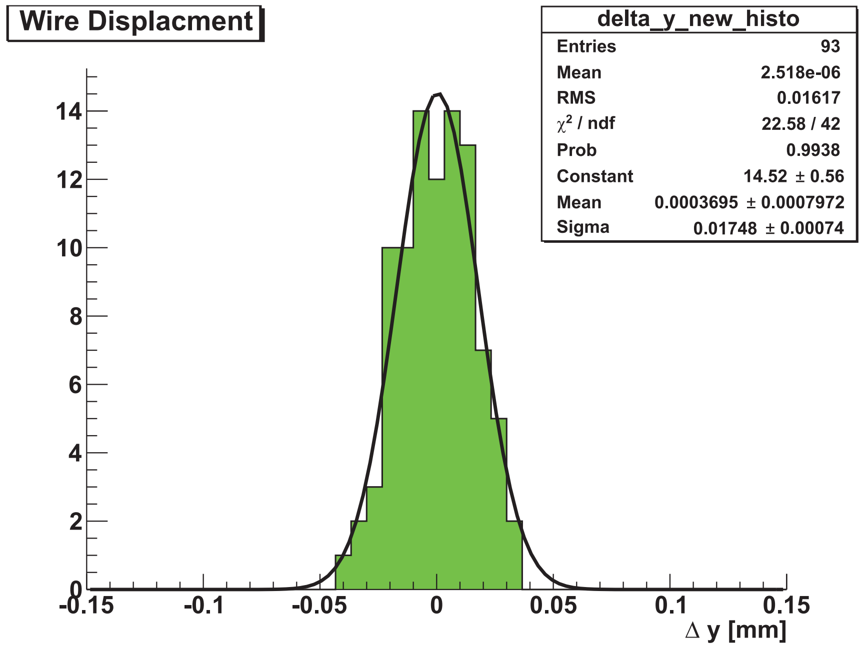
Building a first Prototype with 96 Tubes

Construction of a 8x12 tube bundle



- Usage of standard MDT electronics
- All services are connected via tubes/cables until the final design for all parts is finished

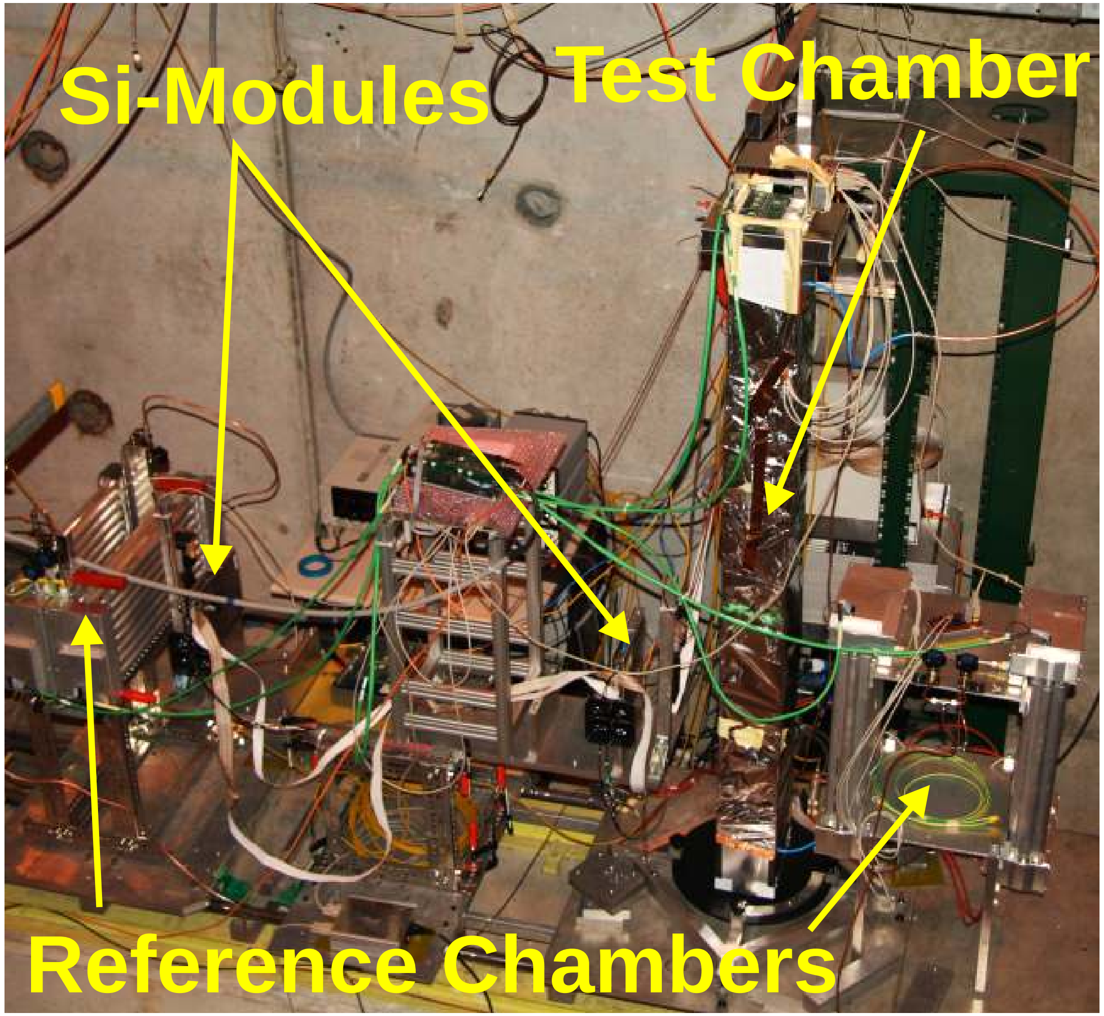
Position accuracy tests



- Construction accuracy better than 20 μm
- The grid spacing is the same for all layers (differences < 10 μm)
- No outliers $\Rightarrow$ very homogeneous grid

Tests with a 96 tube bundle in a high p_T beam at CERN

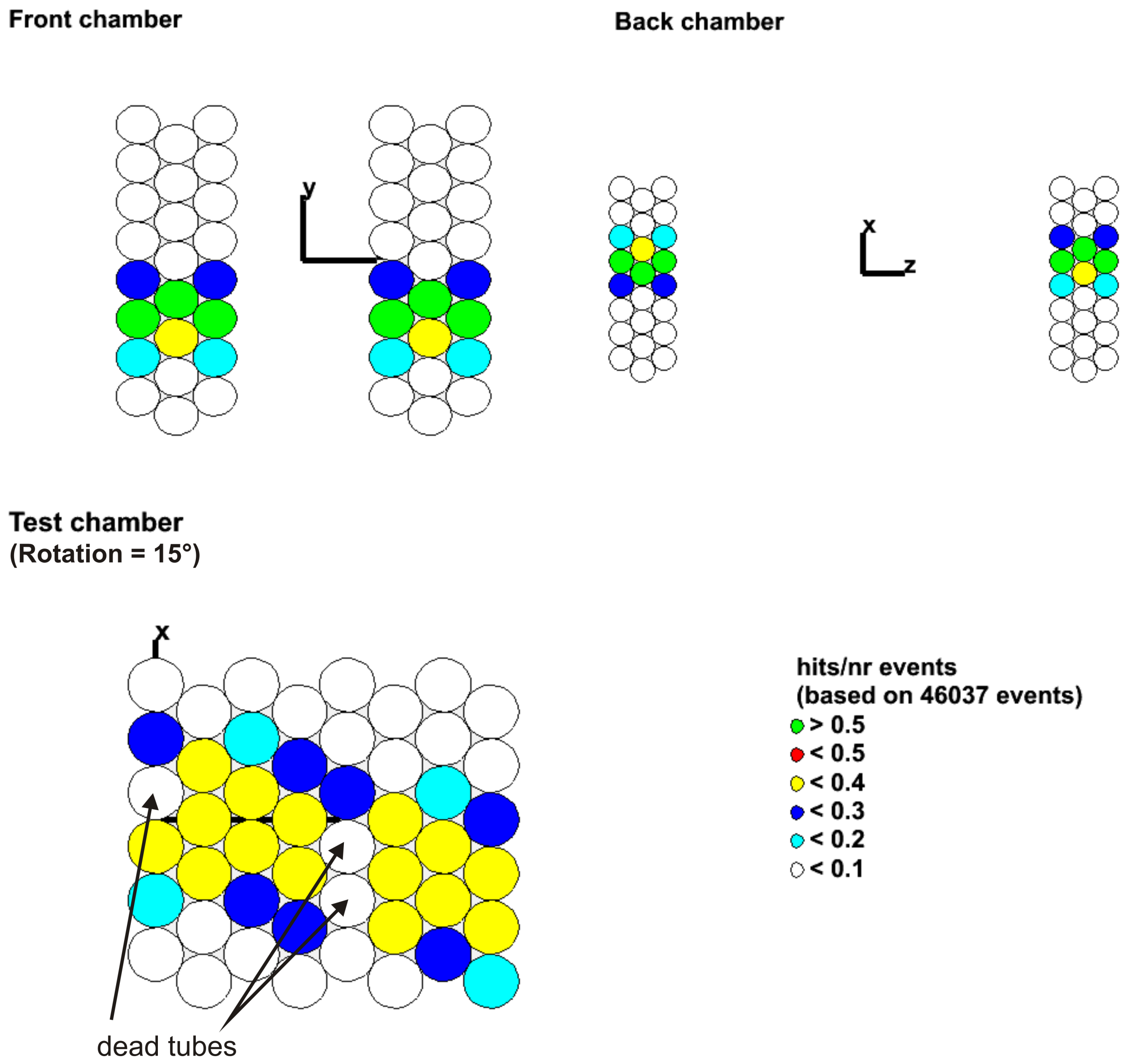
The prototype bundle was tested in a high energetic muon beam (∼180 GeV) in August ’09



- Pivot-mounted test chamber to examine different track angles
- Silicon strip detector for a very precise track reconstruction
- Reference chambers for additional track points and for comparison with the test chamber

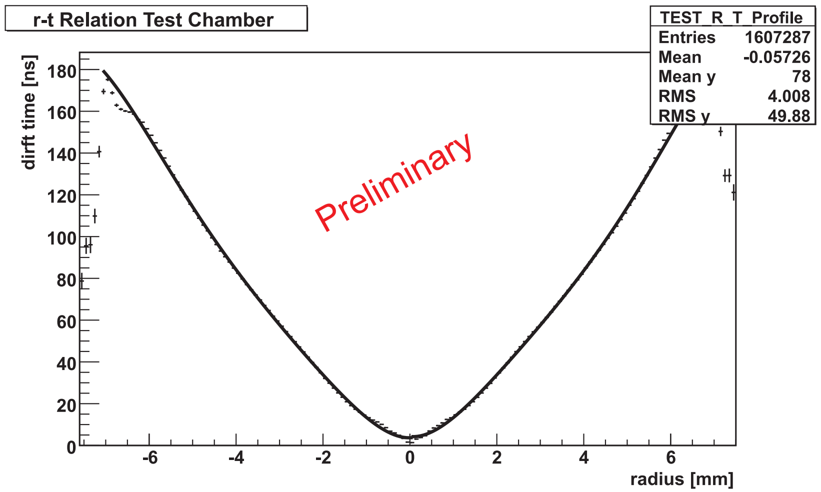
Analysis still on going . . .

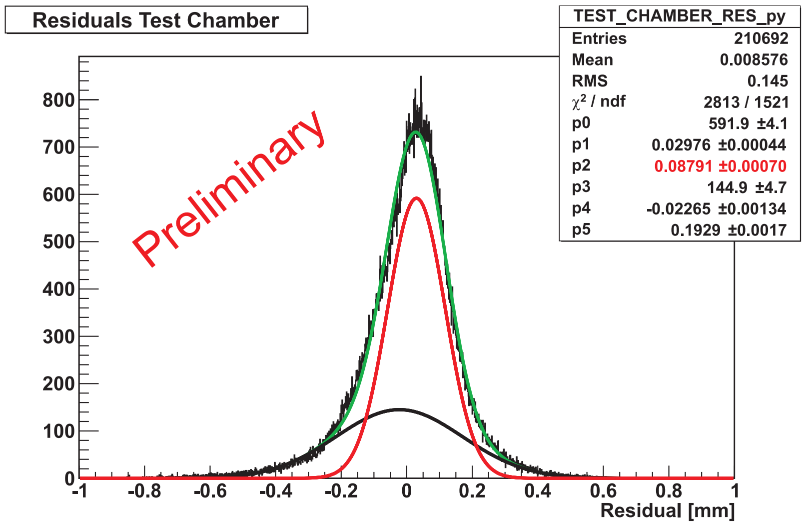
Occupancy and Hit Distributions in the Tubes



- Occupancy of the 15 mm tubes is clearly lower than for the 30 mm tubes
- Very well focused muon beam ($\sim$ 7 cm wide)
- Unfortunately we had a few dead tubes due to loose cables after the transport

First Results from the Test Beam



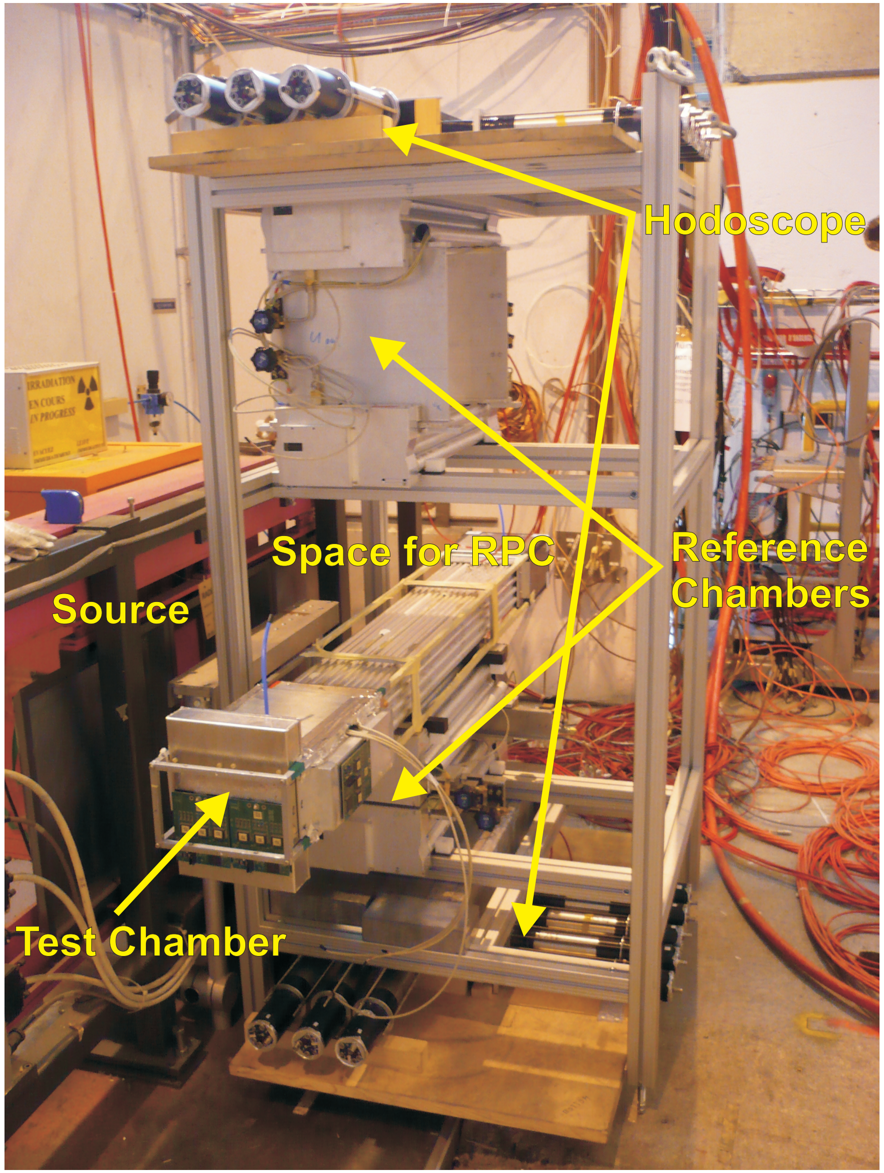


- *r*-*t* relation almost linear
- Calibration is working fine
- Deviations at the tube walls are under investigation

- Better resolution than in the GIF due to a higher muon momentum ($\approx$90 μm vs $\approx$110 μm)

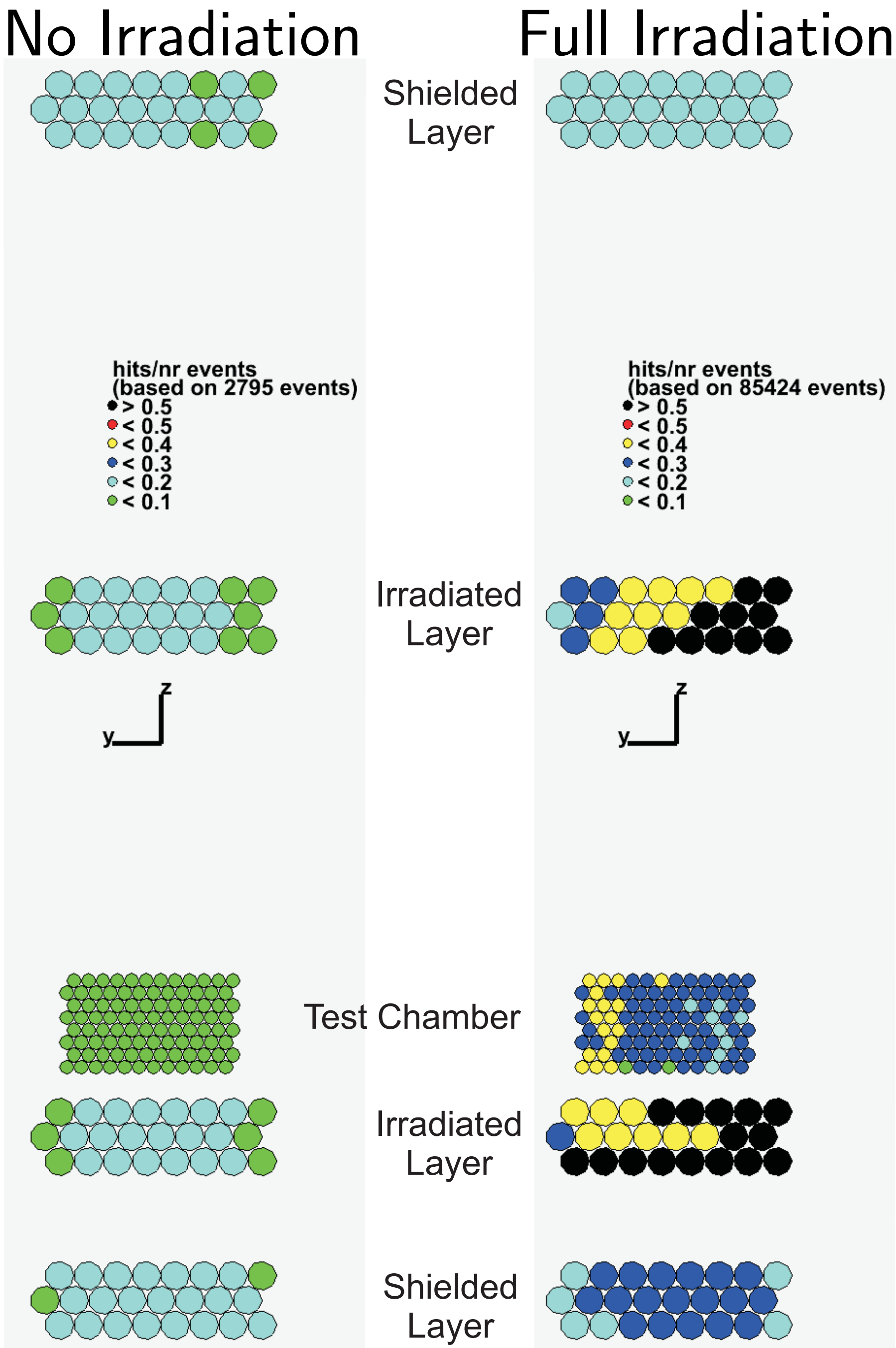
Not the final results, analysis still ongoing!

New GIF tests with the 96 Tube Chamber



- Basically same setup as in spring '09
- The 6 small tubes are replaced by the 96 tubes prototype
- Space for an additional test chamber (RPC upgrade for SLHC, installed on Wednesday)
- Possible to test the tracking performance of the chamber in a high background environment

Hit distribution with and without γ irradiation



- Uppermost and lowermost layers of the reference chambers are shielded $\Rightarrow$ good track reconstruction possible
- Middle layers are not shielded $\Rightarrow$ bad efficiency in the 30 mm tubes and track hits are hard to find
- The lower occupancy in the test chamber (closest to the source) is clearly visible

Conclusions and Outlook

Plans

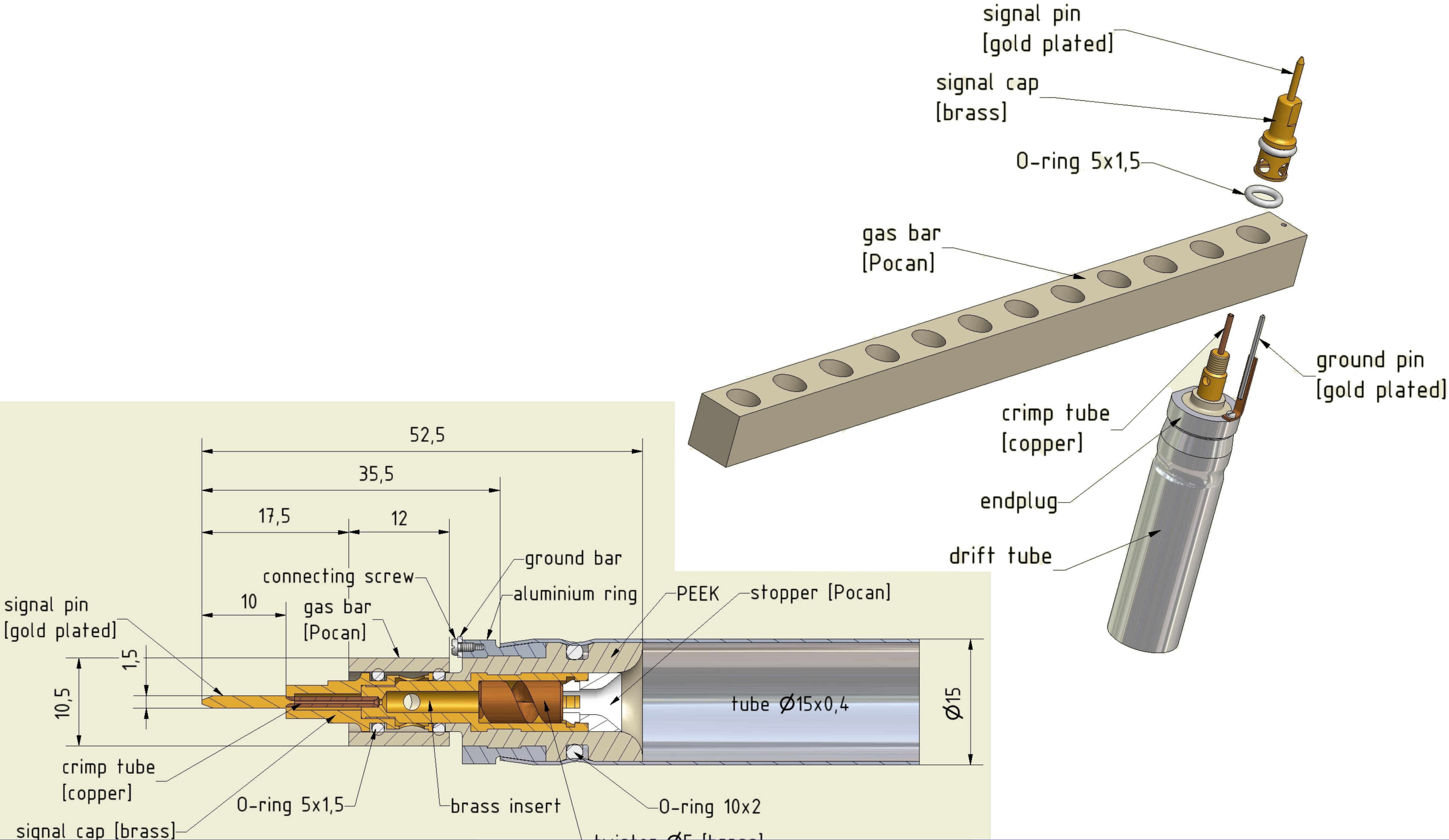
- Finish the analysis of all datasets
- Finish the tests in the GIF until February 2010
- Develop and test all necessary components for a fully operational full size prototype (gas connections, electronic components, support etc.)

Conclusions

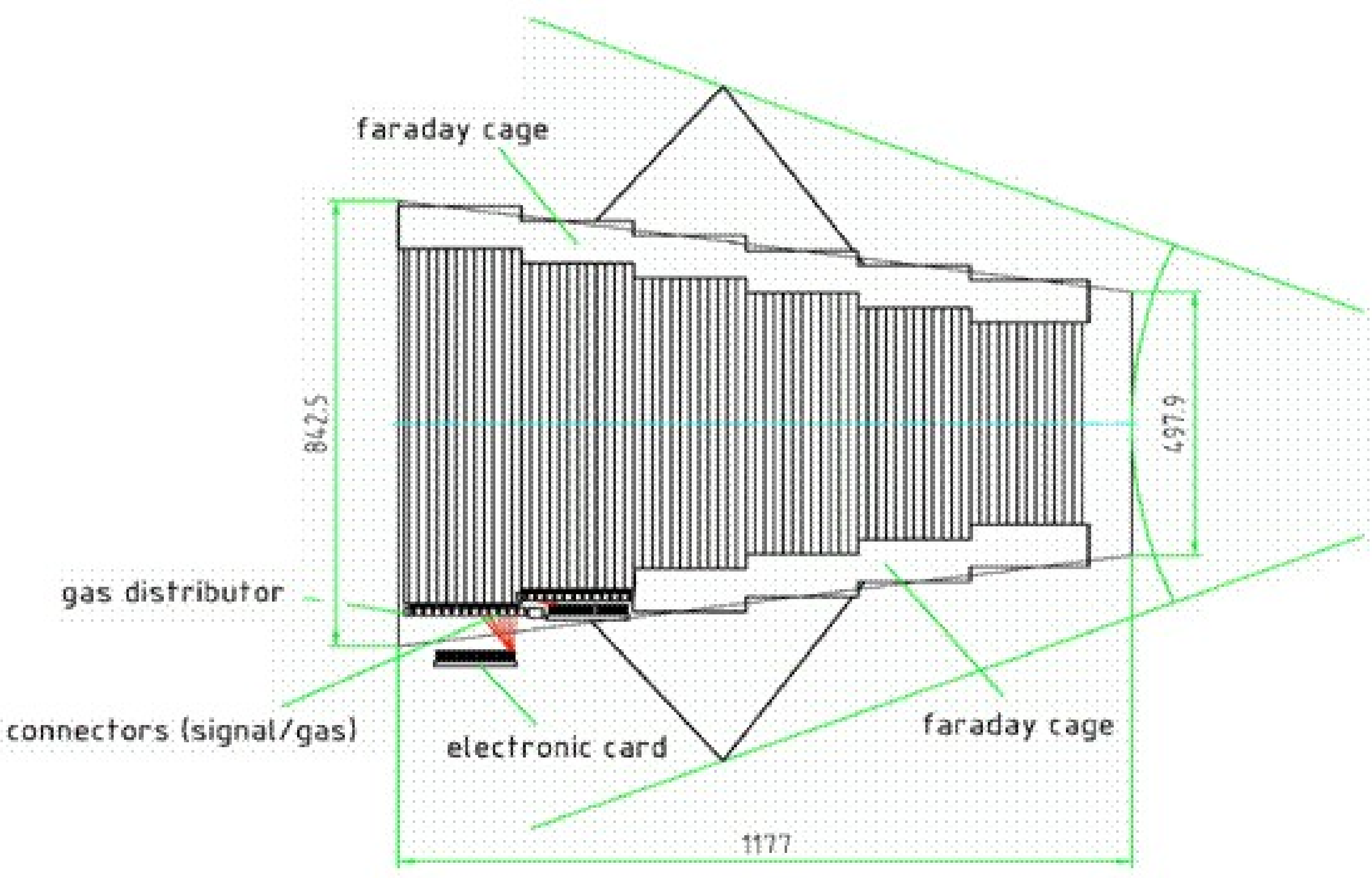
- New detector technologies must be available in a few years (exact time is given by a very unreliable LHC schedule)
- The 15 mm tubes can work safely in a "Worst case Scenario" in all areas of the ATLAS muon spectrometer
- Data shows a very good agreement with Simulations $\Rightarrow$ we understand our detectors!
- **Advantages:** Technology is very well understood and we have experience with it, reasonable costs, suitable for large areas, limited number of channels

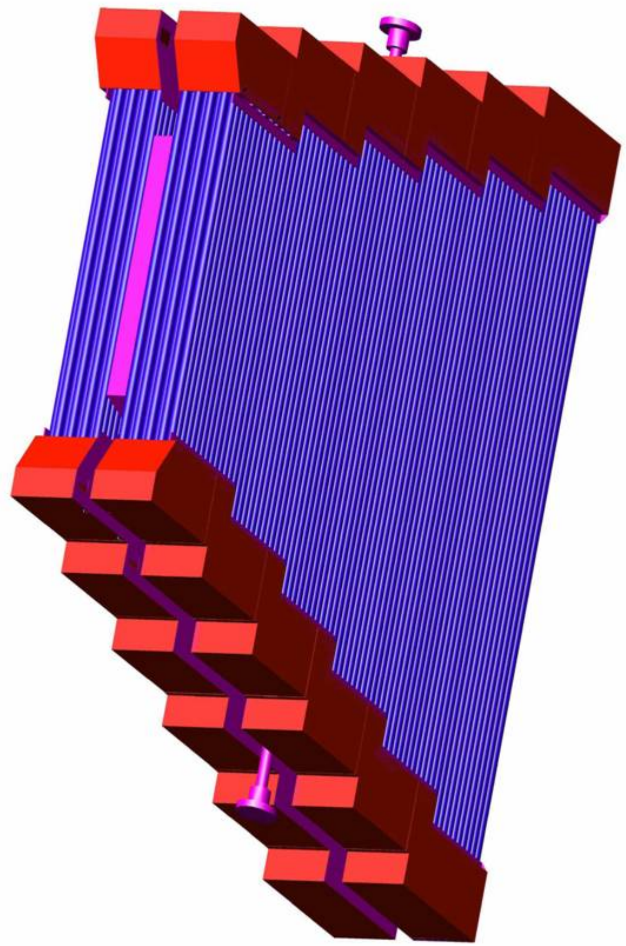
Backup

Erste Studien für das Design der Rohrenden und der Gasverteilung



Entwurf für eine (ganze) Kammer





Eine Kammer besteht aus zwei Multilagen mit je 8 Lagen 15 mm Rohren. Der stufenförmige Aufbau ergibt sich aus der Position im Myonenspektrometer.