# Muon detection at SuperColliders

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**INFN ELOISATRON PROJECT**

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# Outline

- Physics capabilities at a future Hadron Collider and detector challenges
- Experimental conditions at the VLHC
- Muon detection and required momentum resolution for multiTev muons
- The ATLAS and CMS muon systems at the Large Hadron Collider
- A possible VLHC muon spectrometer
- Review of muon chamber technologies

# Next in Particle Physics

- Open questions of the Standard Model :
  - Higgs boson mass
  - Naturalness or hierarchy problem
    - **The Higgs boson mass is generally not protected against quantum corrections to become of the order of the largest physical mass ($M_{planck} = 10^{19}$ GeV).**
  - Known solutions:
    - New strong forces at the TeV scale, Technicolor: strongly disfavoured by LEP/Tevatron data;
    - Supersymmetry in the TeV region: compatible with LEP and Tevatron data; candidate for cold dark matter;
    - Additional space dimensions, “strong” fundamental gravity, lowering gravity scale from **$M_{planck} \sim 10^{19}$ GeV** to $M_D \sim$ 1TeV.
- The LHC should give us some hints in a few years from now !

# Search for physics beyond the SM

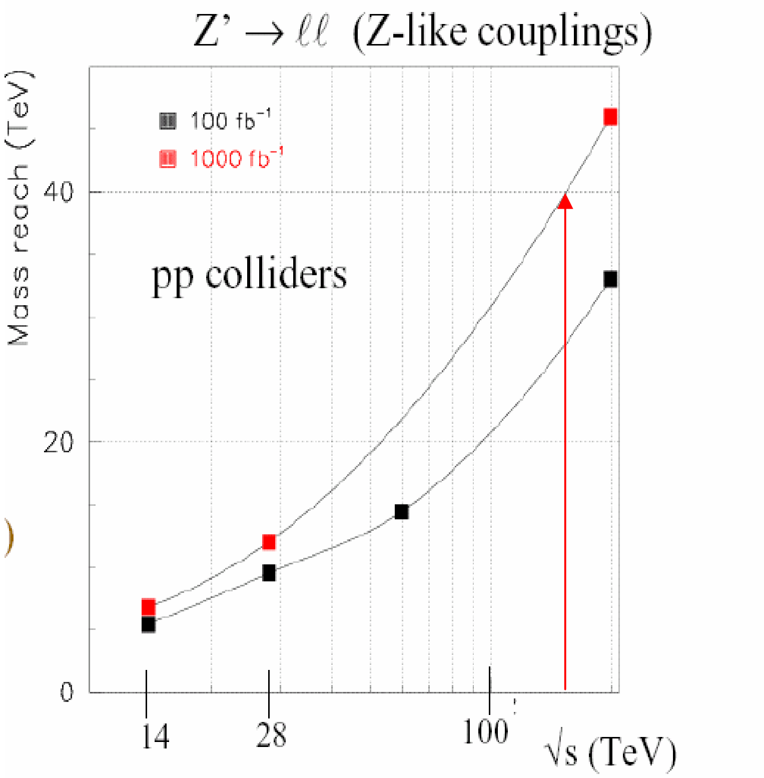
- But the LHC will most likely not answer all outstanding questions….
- New accelerator projects:
  - Lepton Colliders (LC) :
    - $e^+e^-$ $\sqrt{s} = 0.5 \div 1.0$ TeV TESLA, NLC, JLC (2015)
    - $e^+e^-$ $\sqrt{s} = 3 \div 5$ TeV CLIC (2025)
    - $\mu^+\mu^-$ $\sqrt{s} < 4$ TeV Muon Colliders
  - Precision measurements of Higgs physics but direct observation limited to the few TeV scale
- A new Hadron Collider ($40 < \sqrt{s} < 200$ TeV) is the only in-principle-feasible machine which can explore directly the multiTeV (10-100) energy range

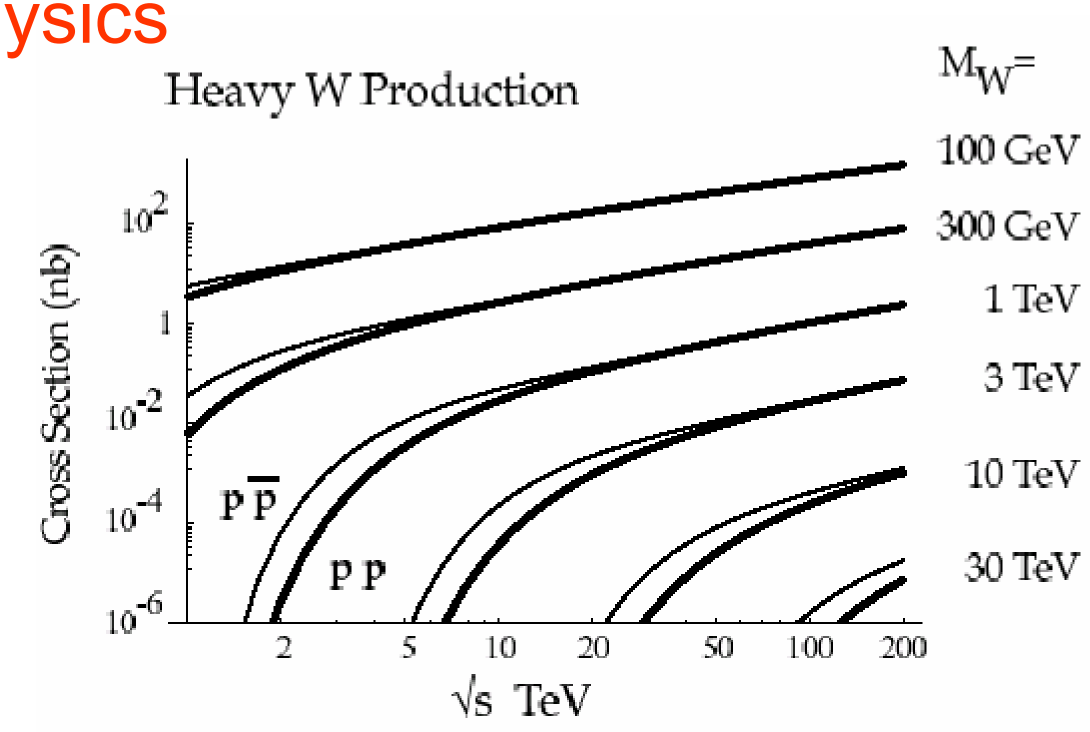
# The MultiTeV Frontier

- Considering the long time for an accelerator project it is important to start R&D for a VLHC
- Existing projects:
  - INFN/ELN
    - $\sqrt{s}$ =100-200 TeV L =$10^{34}$-$10^{35}$ $cm^{-2}$ $s^{-1}$
  - US Very Large Hadron Collider
    - two stage machine (233Km tunnel)
      - $\sqrt{s}$ =40 TeV at L = $10^{34}$ $cm^{-2}$ $s^{-1}$
      - $\sqrt{s}$ =175 TeV at L = 2x $10^{34}$ $cm^{-2}$ $s^{-1}$
- Physics
  - $\sqrt{s}$ = 200 TeV corresponds to E=2x$10^{19}$ eV for fixed target experiment
    - Collisions at energy equivalent to the GZK cut-off in cosmic ray!!!!

# Physics

- The main reason to build the VLHC is not to test SM but the search for new physics



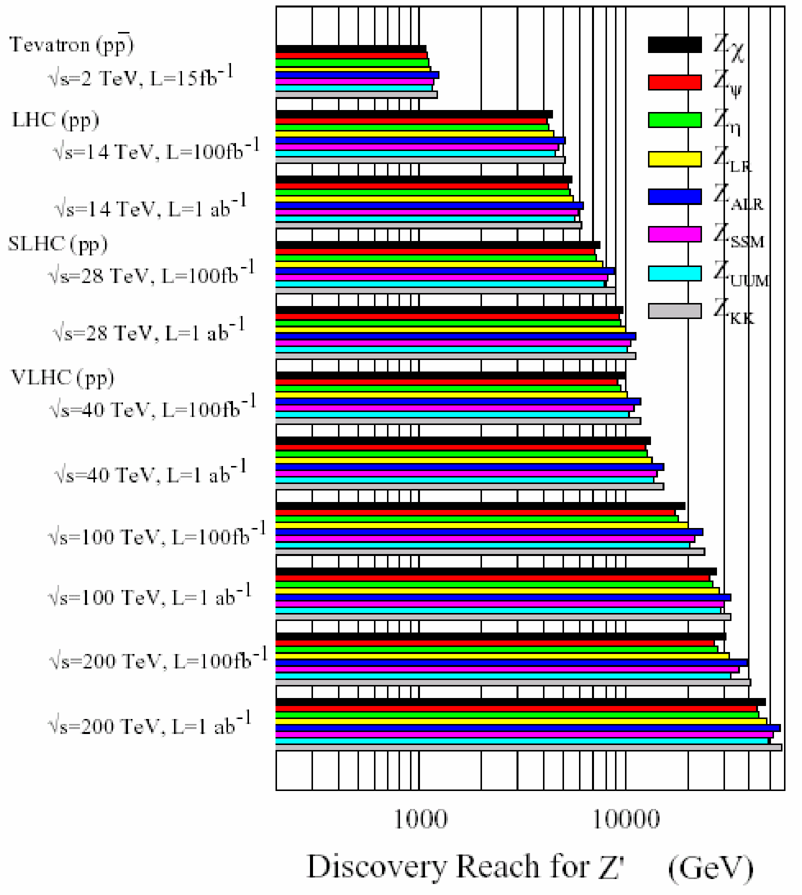


- ➢ explore the ~ **10 TeV** energy scale
- ➢ mass reach **up to ~30-40 TeV**

- ➢ Heavy particles (Z',W') produced with small σ :
  - ➔ high luminosity required

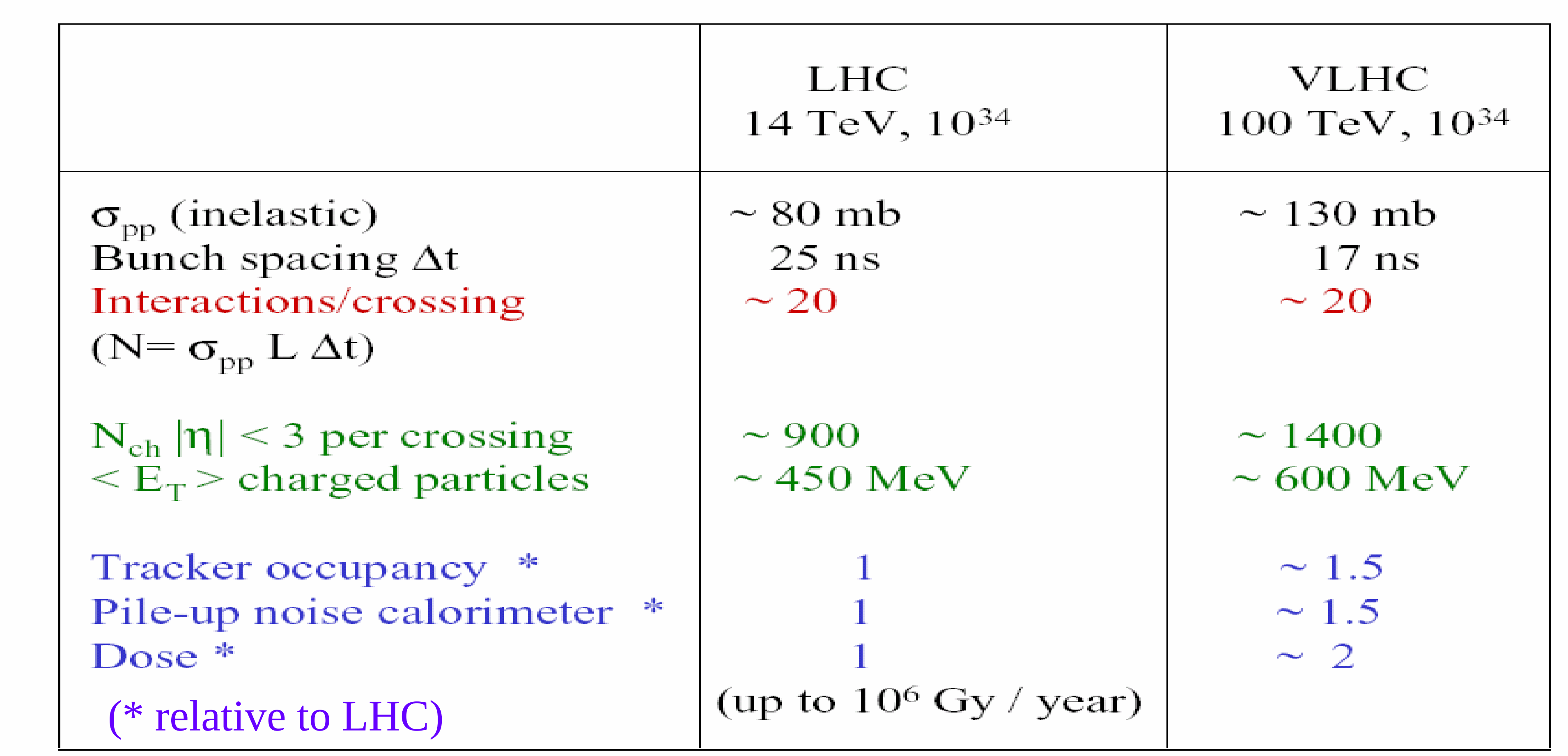
# Physics at a future hadron colliders

- Physics goals for a VLHC
  - New gauge bosons
  - Higgs physics studies
  - Compositness
  - Extradimensions
  - Supersymmetry
  - No Higgs: strong electroweak symmetry breaking

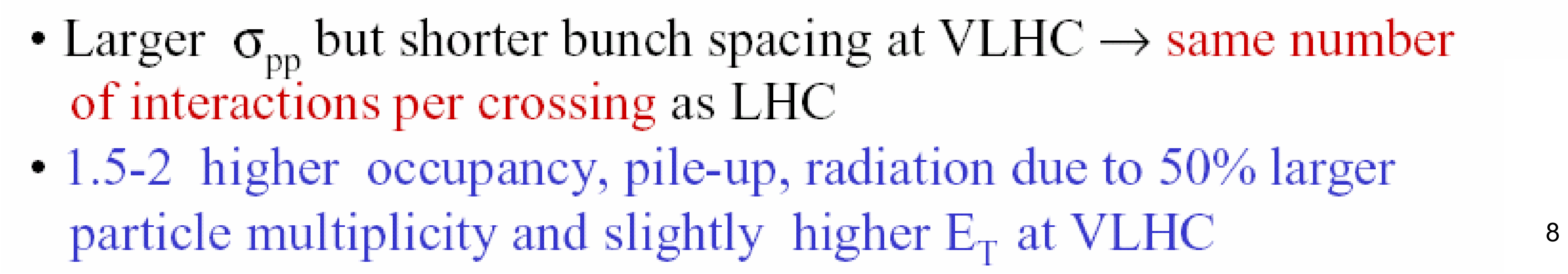


**Discovery limit for extra neutral gauge bosons for a variety of models**

# The experimental enviroment at $L=10^{34}$ cm$^{-2}$ s$^{-1}$



| | LHC<br>14 TeV, $10^{34}$ | VLHC<br>100 TeV, $10^{34}$ |
|---|---|---|
| $\sigma_{pp}$ (inelastic) | ~ 80 mb | ~ 130 mb |
| Bunch spacing $\Delta t$ | 25 ns | 17 ns |
| Interactions/crossing<br>($N = \sigma_{pp}\, L\, \Delta t$) | ~ 20 | ~ 20 |
| $N_{ch}$ $\lvert\eta\rvert < 3$ per crossing | ~ 900 | ~ 1400 |
| $< E_T >$ charged particles | ~ 450 MeV | ~ 600 MeV |
| Tracker occupancy * | 1 | ~ 1.5 |
| Pile-up noise calorimeter * | 1 | ~ 1.5 |
| Dose * | 1<br>(up to $10^6$ Gy / year) | ~ 2 |
| (* relative to LHC) | | |



- Larger $\sigma_{pp}$ but shorter bunch spacing at VLHC → same number of interactions per crossing as LHC
- 1.5-2 higher occupancy, pile-up, radiation due to 50% larger particle multiplicity and slightly higher $E_T$ at VLHC

# Experimental conditions @ 100 TeV and L > $10^{34}$ cm$^{-2}$ s$^{-1}$

- Smaller bunch crossing separation
- More multiple interactions per bunch crossing

  → fast, higher granularity detectors, faster level 1 trigger

- Higher radiation level in the experimental hall

  → more radiation hard electronics

  → high rate capability of the detectors

  → careful study of detectors ageing

  → higher occupancy of tracking detectors

# Muon detection

- Muons are unique as charged particles in their great penetrating power. Crucial signature for many low rate physics processes
  - Higgs production, new heavy Z and W bosons,high mass DY,Supersymmetry etc)
- After sufficient material of the calorimeters particles rates are low enough
  - Enable trigger and momentum measurements up to the highest luminosity

❖ Emphasis on the talk will be on high energy muon measurement outside the central tracking

# Muon detection at the VLHC (1)

- Challenging performance in muon detection at the VLHC:
  - charge measurement:
    - Massive new particles (W',Z') charge asymmetry
  - momentum measurement with:
    - dp/p < 10% up to 10 TeV muons
    - dp/p ≈ 50% for 10 TeV muons in ATLAS and CMS at LHC

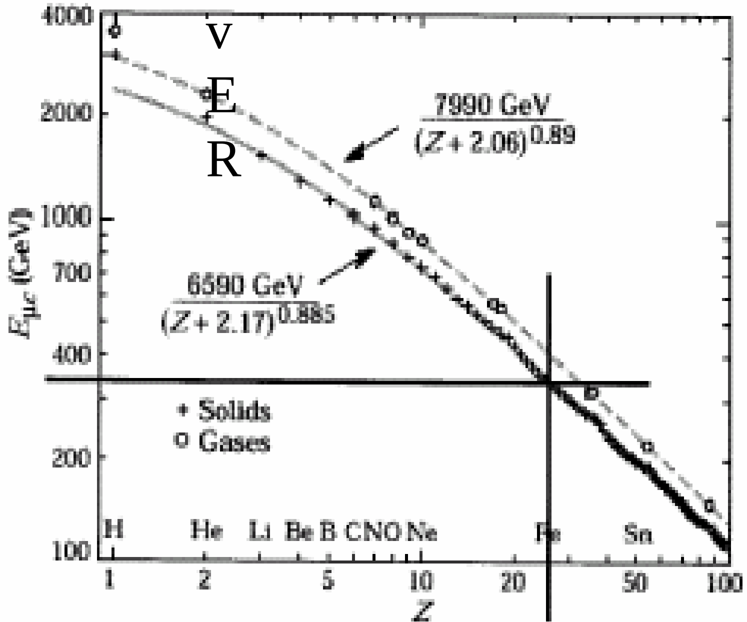
      ->Need a factor 5 improvement
  - If the muons are measured, $E_T^{miss}$ measurements could be done:
    - crucial for studying strong WW scattering, supersymmetric particle searches

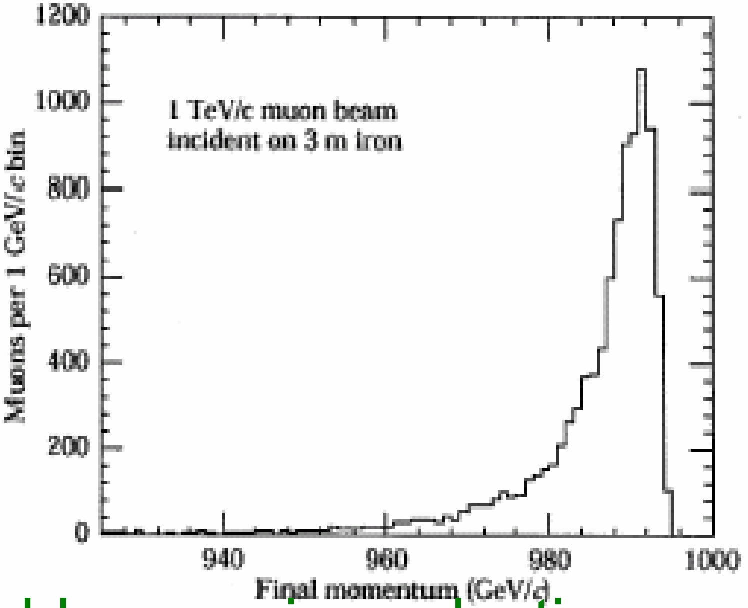
# Muon detection at the VLHC(2)

- Muon detector requirements:
  - Muon identification
  - Charge assignment
  - Muon trigger at Level1 and Level 2
  - Beam crossing identification
  - Good muon momentum measurement up to ~10 TeV
- Source of muon backgrounds:
  - π and K decay in the central tracking
  - Punchtrough
  - Low energy background (neutrons and photons) in the detector hall -> shielding in the forward region
- MultiTeV energy muon: “catastrophic” energy losses

# Muon energy loss in dense materials

- Very high energy muons behave like electrons at low energy





- Large energy losses (bremsstrahlung, pair productions, nuclear interactions) in calorimeters and a possible iron yoke of the muon spectrometer ($E_{critical}$ =330 GeV in iron) produce:
  - incorrect muon momentum measurements
  - position measurement difficult (overlap between muon tracks and e.m.showers in muon detectors )

# Muon momentum measurements

- Muon detector in a magnetic field B
- Momenta are reconstructed by measuring the sagitta s
  - $s = 0.3\ B\ L^2 / 8\ p$ for a track at 90° to the beam
    s(meter), B(Tesla), p (GeV/c)
- For a good momentum resolution
  - B and L must be made large

# Muon momentum resolution

- Parameterization of muon momentum resolution
  - $ds/s = dp/p = \sqrt{(ap)^2 + b^2}$
- The term b depends from multiple scattering

  ➔Limits the resolution at low momentum
- The term a is determined by systematic alignment errors and intrinsic muon chamber spatial resolution

  ➔Limits high momentum measurements

# Muon momentum resolution

$$p = 0.3 \cdot B \cdot \rho \Rightarrow \left\{ \begin{array}{l} B : Tesla \\ \rho : m \\ p : Gev / c \end{array} \right\}$$

**(a)** $$(\Delta p / p)_{Meas} = \Delta s / s = \sqrt{96} \cdot \frac{p}{0.3 \cdot B \cdot L^2} \cdot \sigma = 0.33 \cdot 10^{-4} \cdot \frac{p}{B \cdot L^2} \cdot \sigma(\mu m)$$

**(b)** $$(\Delta p / p)_{MS} = (\Delta s / s)_{MS} = 0.186 \cdot \frac{1}{B \cdot L} \cdot \sqrt{\frac{x}{X_0}}$$

**Excellent chamber spacial resolution**

Large magnetic volume required

Minimize the material

# ATLAS & CMS at the LHC

- The LHC muon systems are a good starting point to design a muon system for at least a stage-I VLHC:
  - ATLAS muon spectrometer
    - stand alone air-core toroids
  - CMS muon spectrometer
    - compact solenoid with iron yoke

# Toroidal B field

- Good:
  - Larger rapidity coverage with respect to a solenoid field
  - Field line perpendicular to the particle trajectories
  - Bending power increases as $\int B dl \propto 1/\sin\theta$
  - Bending power follows the increasing p for forward rapidity at fixed $p_T$
  - Closed field->no need for massive iron for flux return
- Bad:
  - Field free-region around the vertex ( need an additional solenoid to measure momentum in the inner tracker)
  - Design of tracking chambers complicated by the coils that surround the field volume

# Solenoidal B field

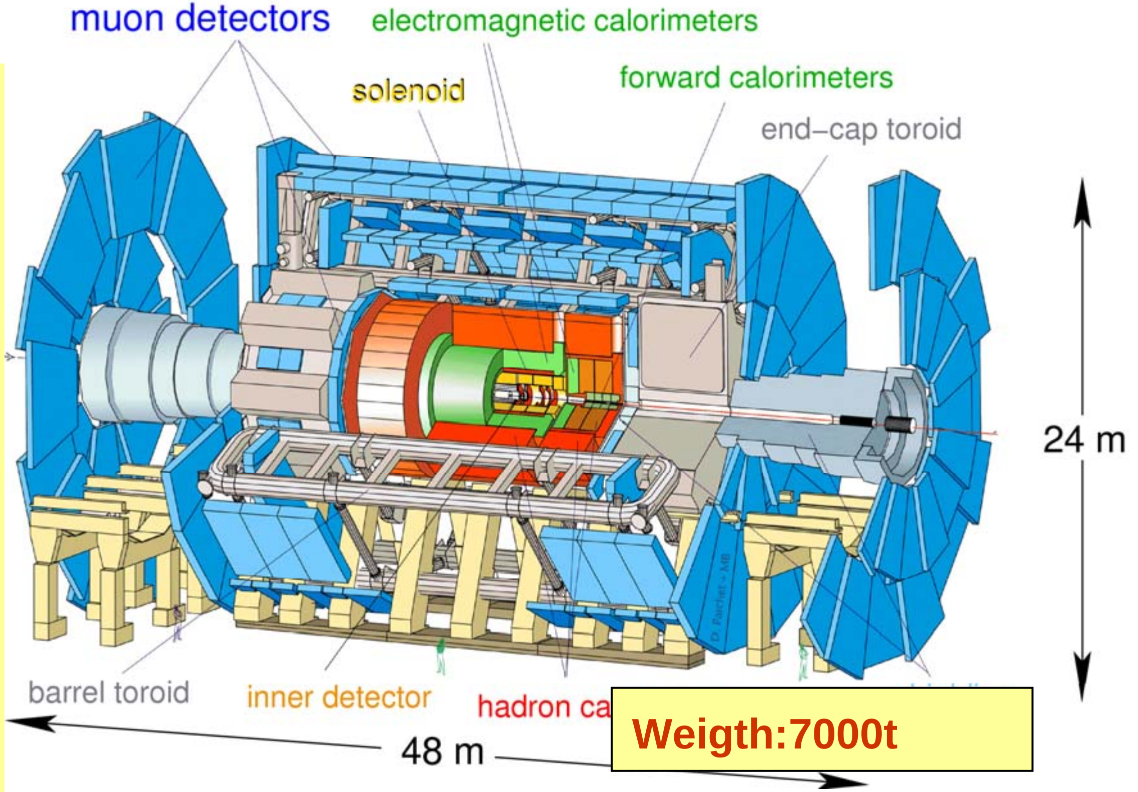
- Good:
  - A solenoidal field configuration provides azimuthal symmetry and simplifies detector construction
- Bad:
  - The transverse bending power decreases in the forward region once the particles no longer traverse the total field volume
  - Large mass of iron to return the flux

# The ATLAS Muon Spectrometer

**ATLAS at LHC:** multi-purpose detector to search for Higgs and new physics

## Muon Spectrometer:

- toroidal magnetic field: <B> = 0.4 T
  ⇒ high $p_t$-resolution independent of the polar angle
- size defined by a large lever arm to allow high stand-alone precision
- air-core coils to minimise the multiple scattering
- 3 detector stations
  - cylindrical in barrel
  - wheels in end caps
- coverage: $|\eta| < 2.7$



**Weigth:7000t**

**Muon technologies:**

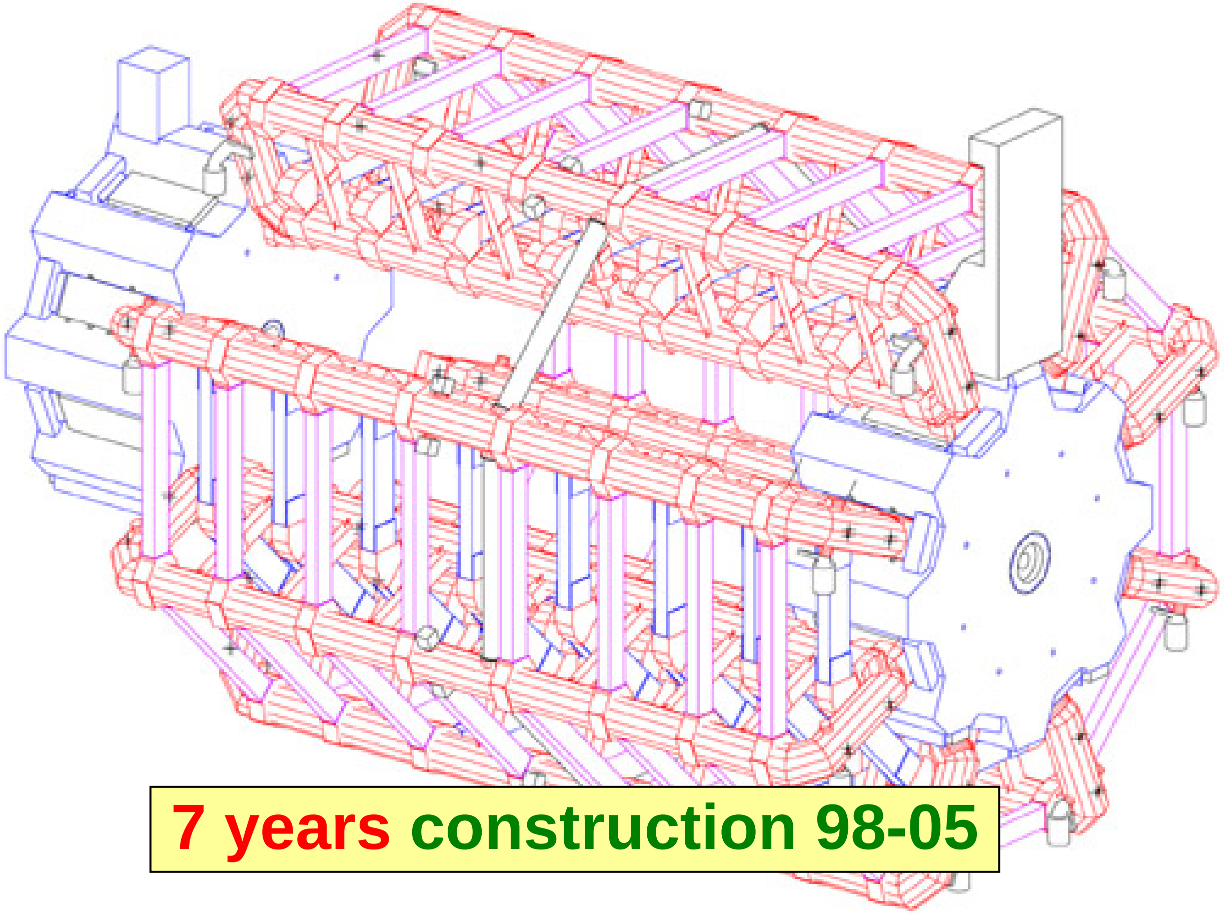
- **fast trigger chambers: TGC, RPC**
- **high resolution tracking detectors: MDT, CSC**

# The ATLAS magnetic system

- Superconducting central Solenoid for momentum measurement in the ID
- 3 superconducting air toroids for stand-alone momentum measurement

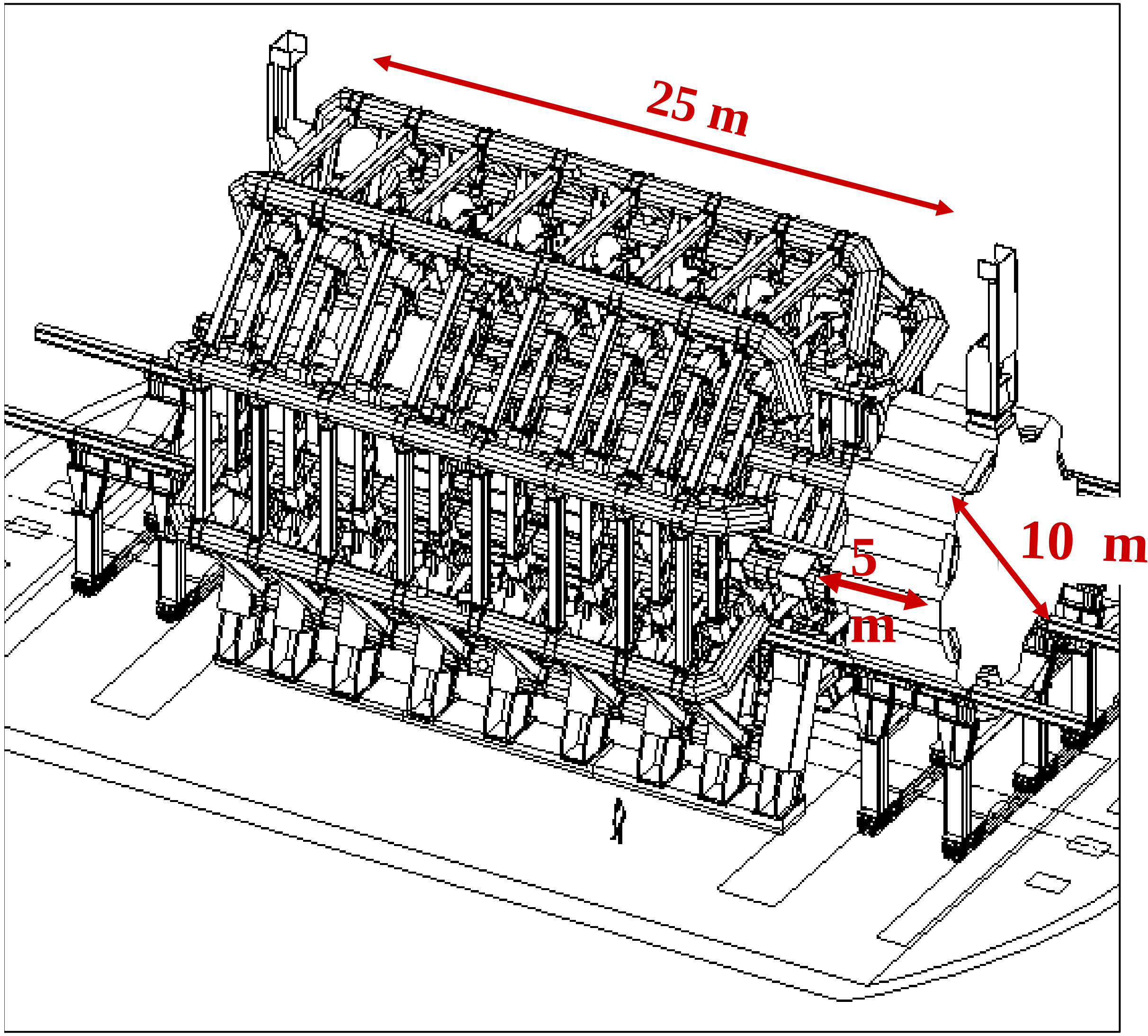
**BT Parameters** :

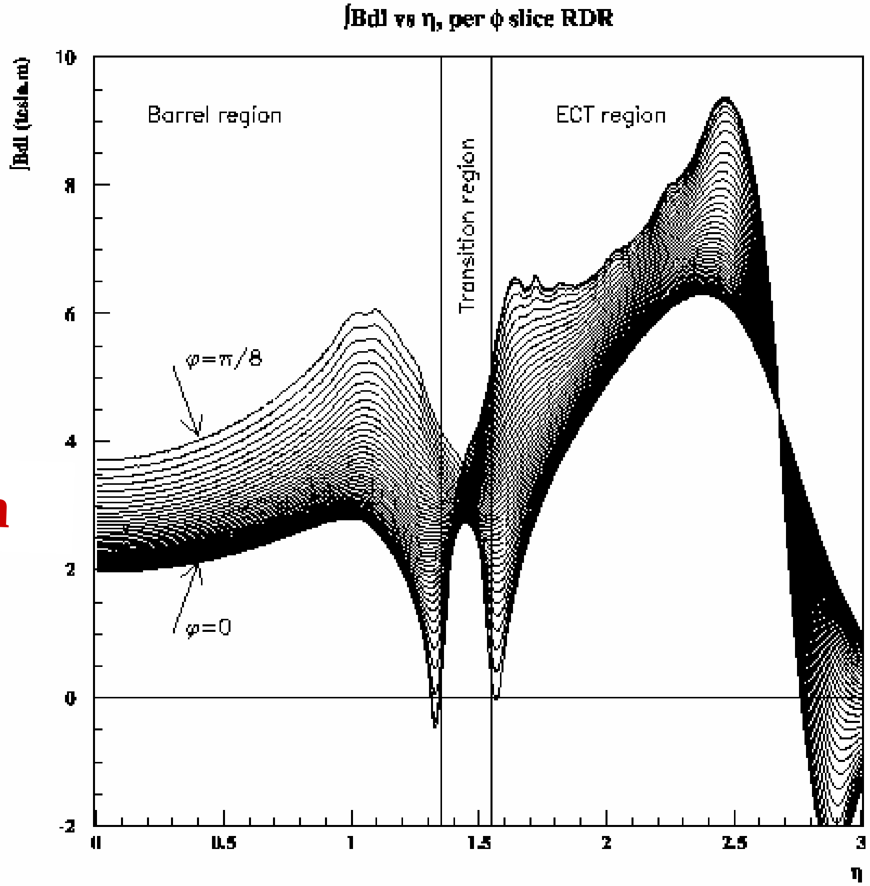
- 25.3 m length
- 20.1 m outer diameter
- 8 coils
- 1.08 GJ stored energy
- 370 tons cold mass
- 830 tons weight
- 56 km Al/NbTi/Cu conductor
- conductor cooled at 4.7 K



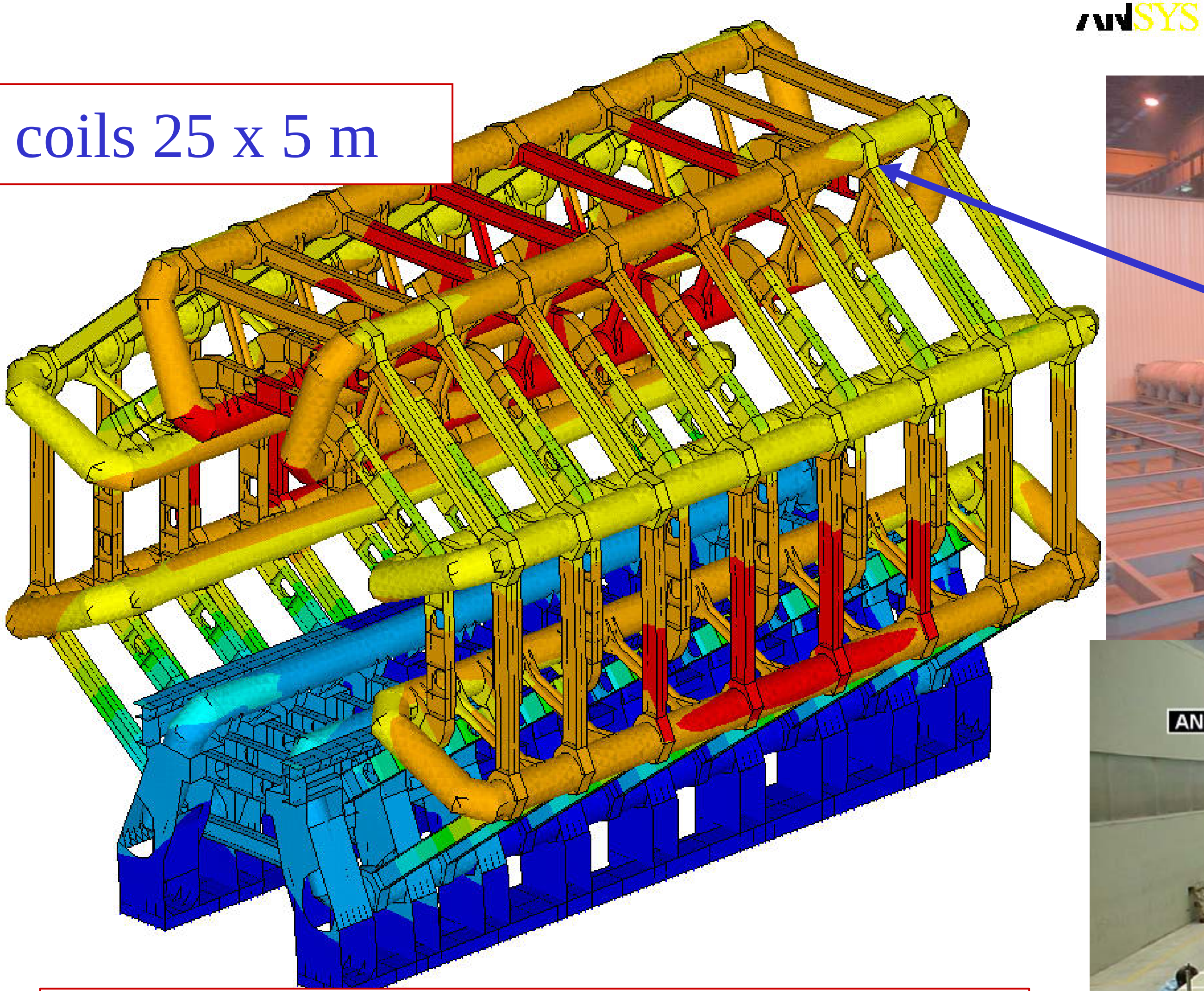
7 years construction 98-05

# Superconducting Toroids

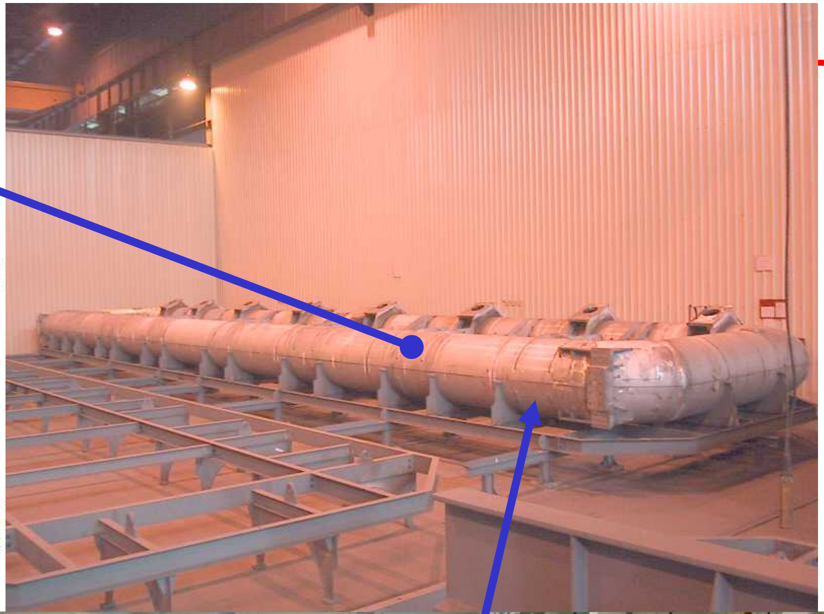




# Barrel Toroid



8 coils 25 x 5 m

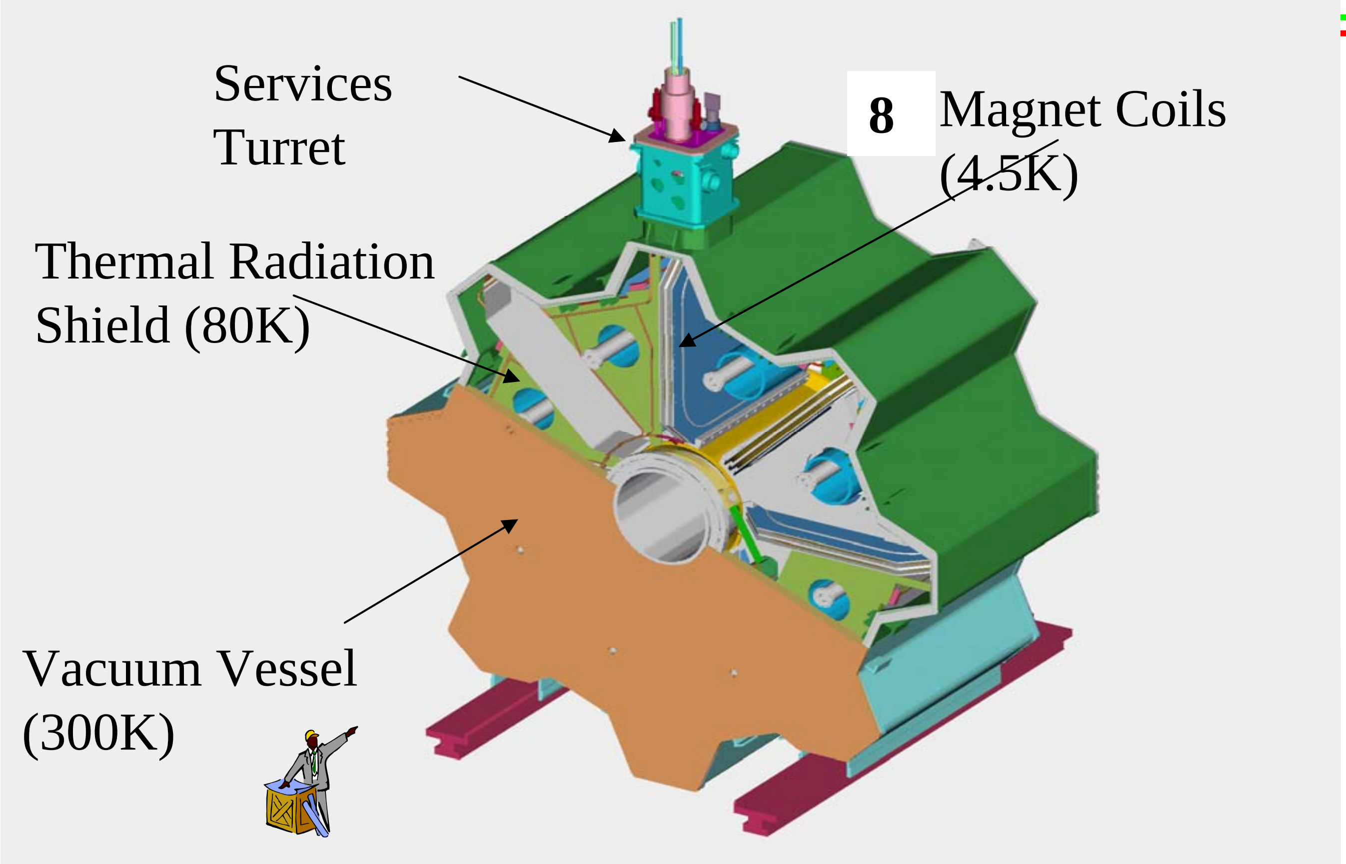


$$(\Delta p / p)_{Meas} = 0.33 \cdot 10^{-4} \cdot \frac{p}{B \cdot L^2} \cdot \sigma_{MDT}(\mu m) \approx 1.0 \cdot 10^{-4} \cdot p$$

$B L^2 \sim 15$ T m$^2$ $\sigma_{MDT} = 50$ µm

$\Delta p/p \sim 30\%$ at 3 Tev/c

# End-Cap Toroid



Services Turret

**8** Magnet Coils (4.5K)

Thermal Radiation Shield (80K)

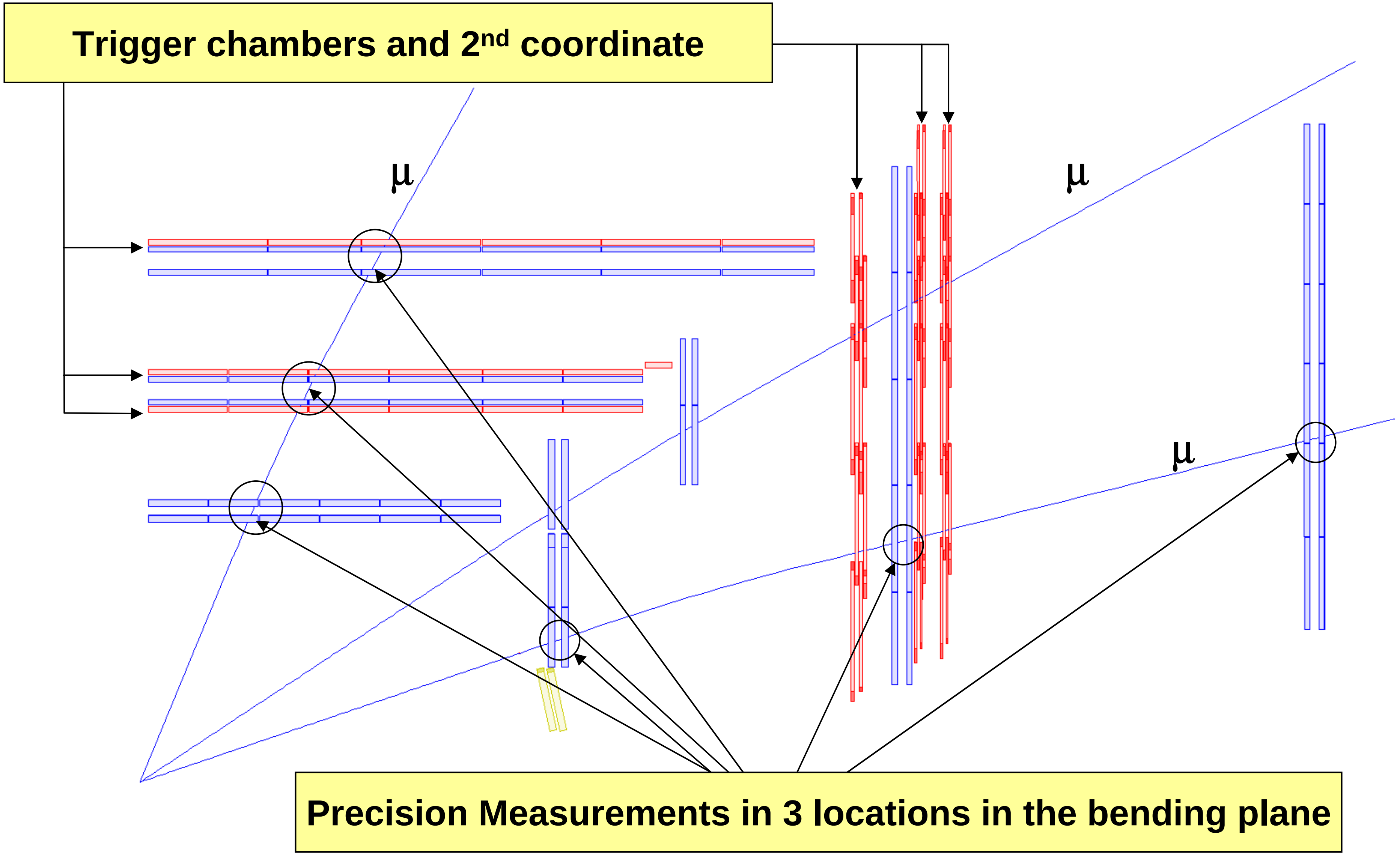
Vacuum Vessel (300K)

$$(\Delta p / p)_{Meas} = 0.33 \cdot 10^{-4} \cdot \frac{p}{B \cdot L^2} \cdot \sigma_{MDT}(\mu m) \approx 0.7 \cdot 10^{-4} \cdot p$$

$B\,L^2 \sim 25\ \mathrm{T\,m^2}$ $\sigma_{MDT} = 50\ \mu\mathrm{m}$

$\Delta p/p \sim 21\%$ at 3 Tev/c

# The muon momentum measurement

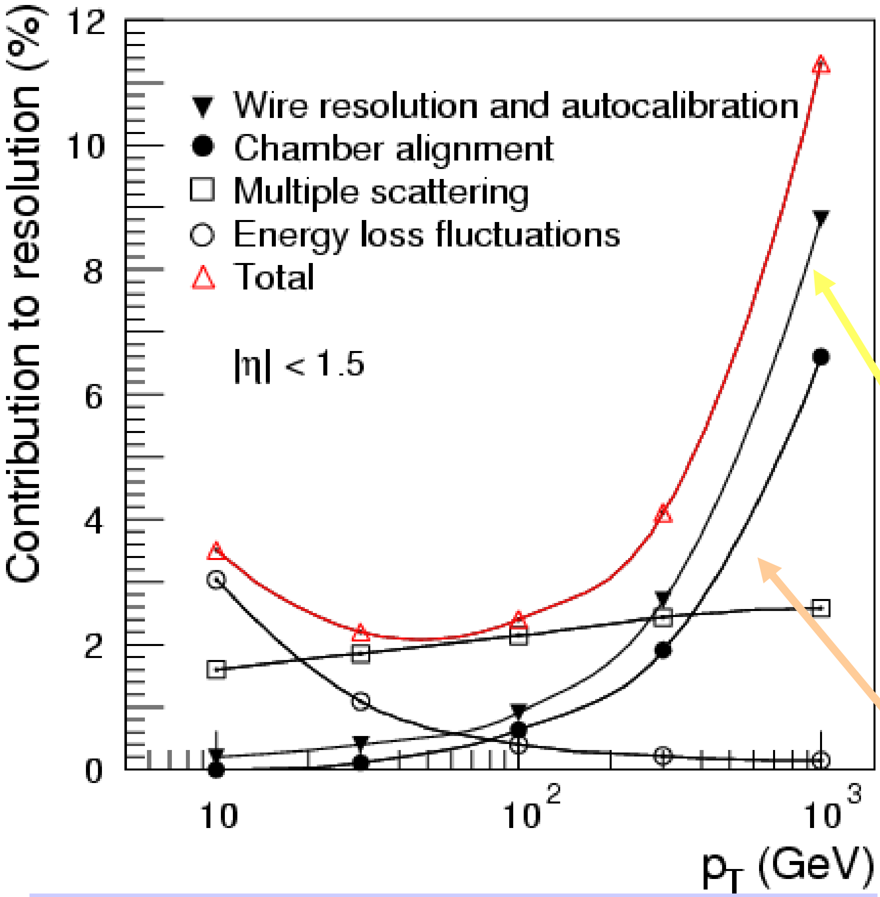


**Trigger chambers and 2nd coordinate**

**Precision Measurements in 3 locations in the bending plane**

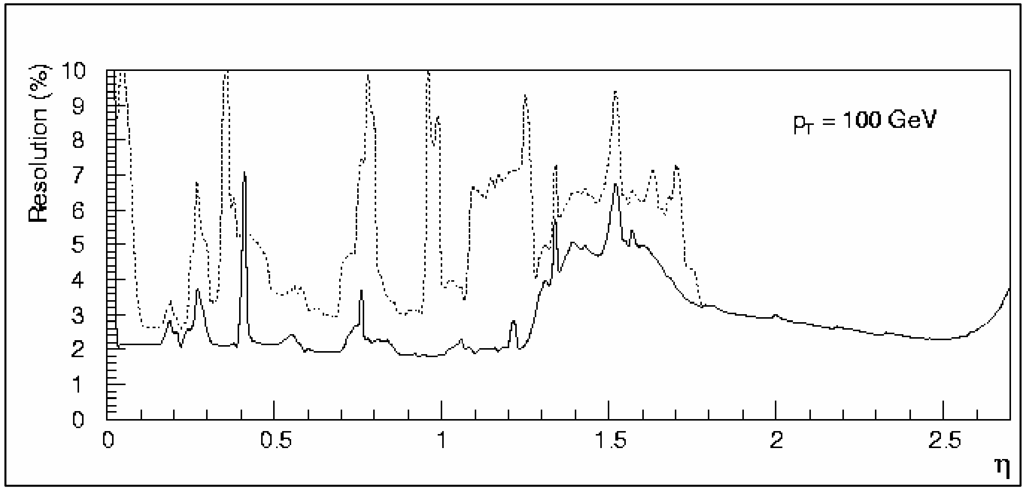
# Performance

## Momentum resolution vs $p_T$



**at 1TeV:**
**dp/p = 10% ⇔ sagitta = 500 μm**

## Momentum resolution vs η



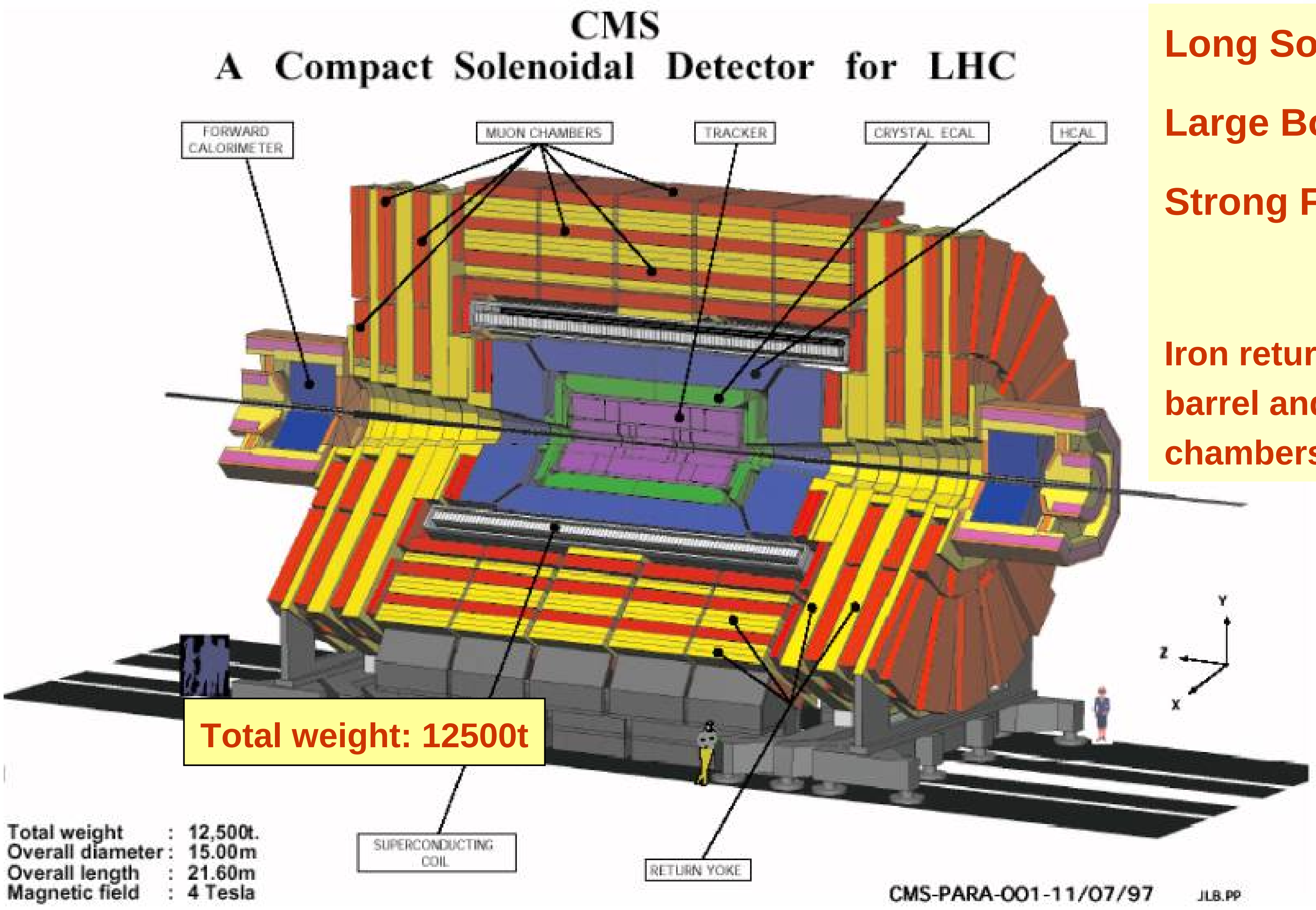
chamber resolution: ***50 μm***

⇨ monitoring of high mechanical precision during production

alignment

⇨ elaborate optical system to monitor chamber deformations and displacements

# CMS:a Compact Solenoidal Detector



**Total weight: 12500t**

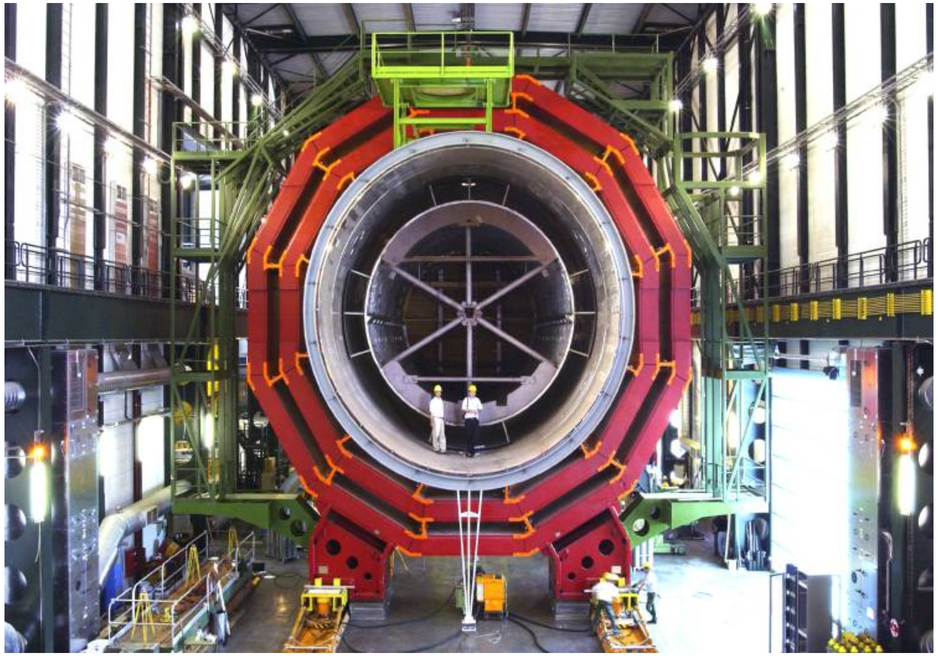
**Long Solenoid L =13m**

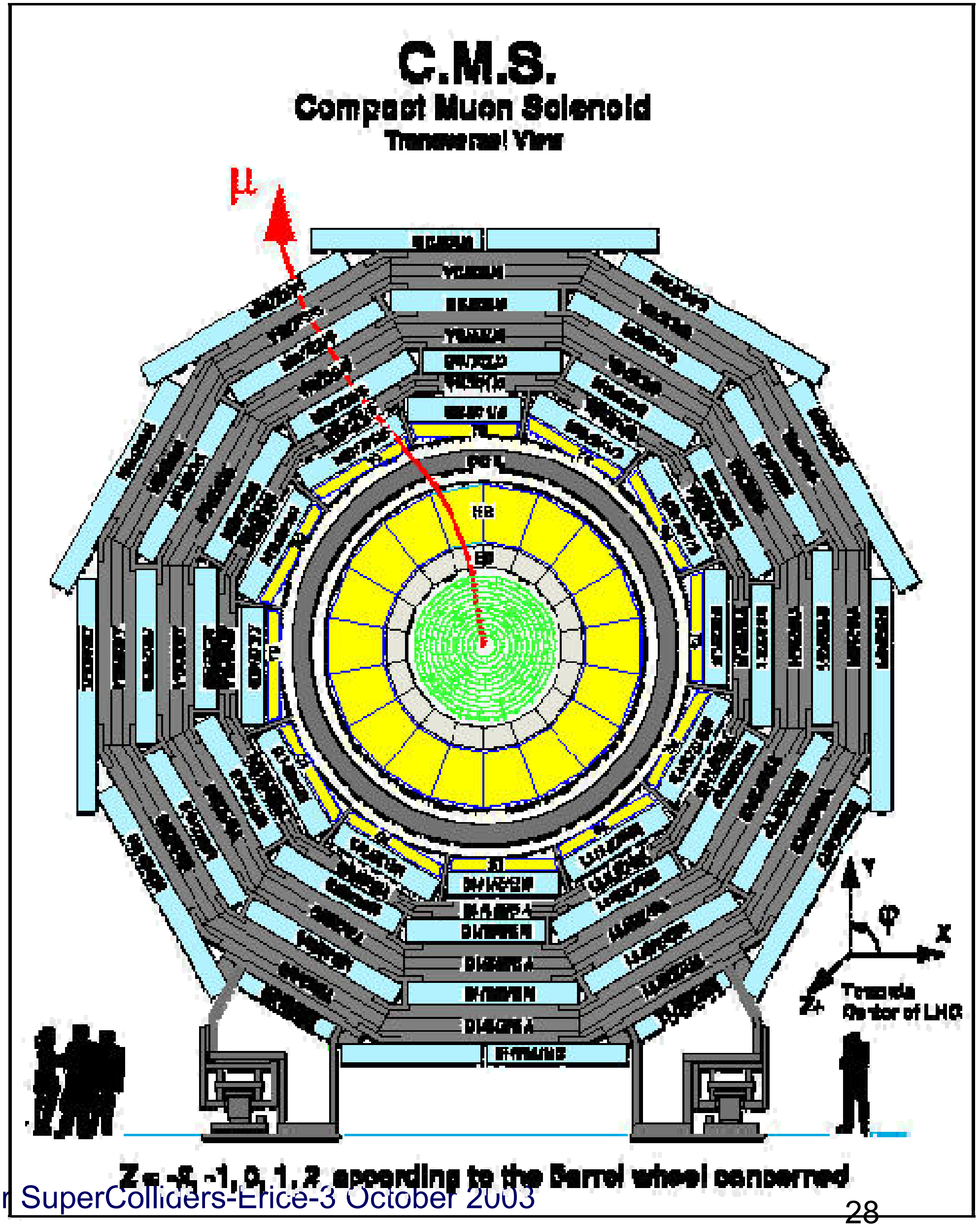
**Large Bore R = 2.95m**

**Strong Field B =4 T**

**Iron return yoke houses the barrel and the endcap muon chambers**

# Barrel CMS compact muon solenoid

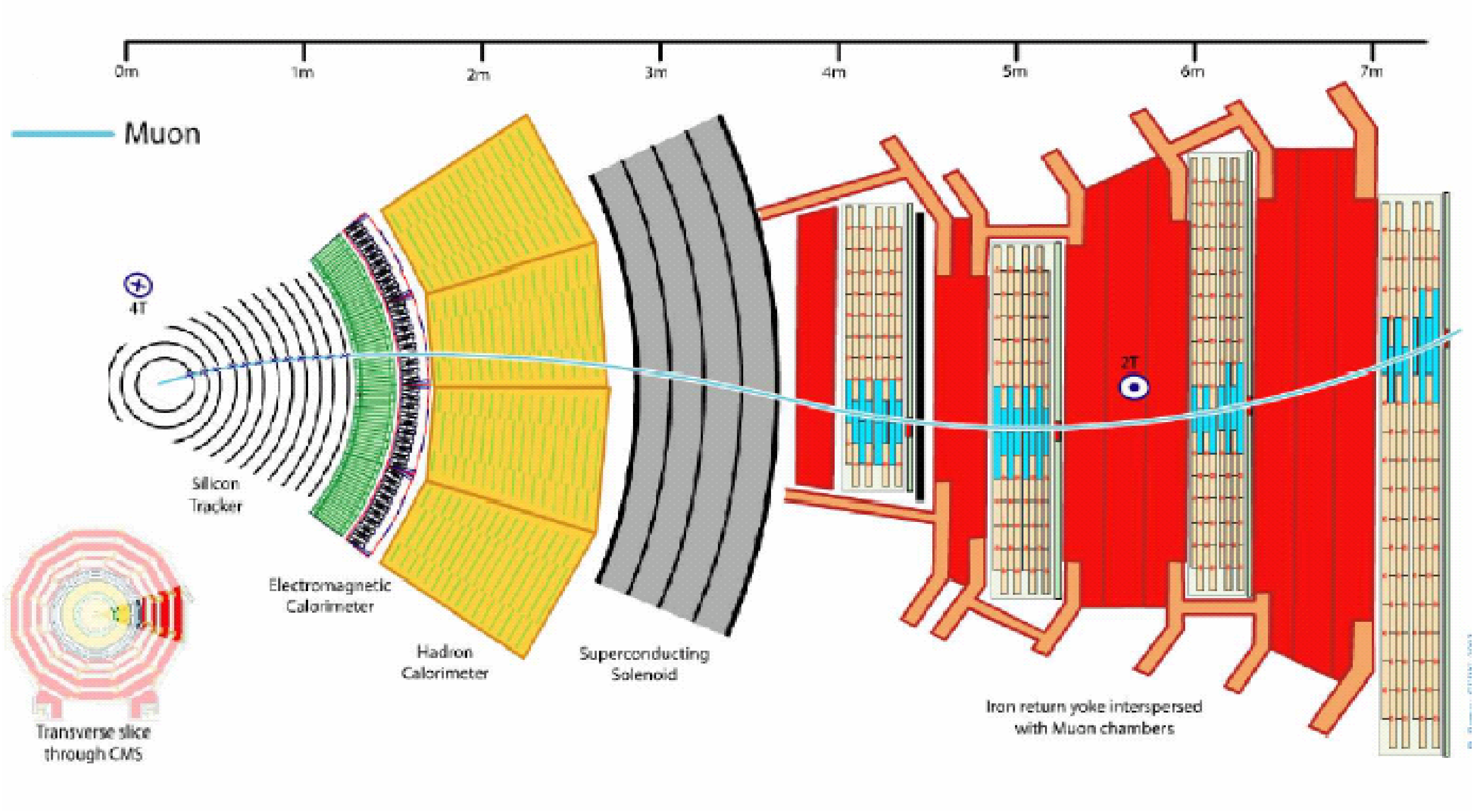




5 wheels with 4 muon stations located in the pockets of the iron magnet return yoke.

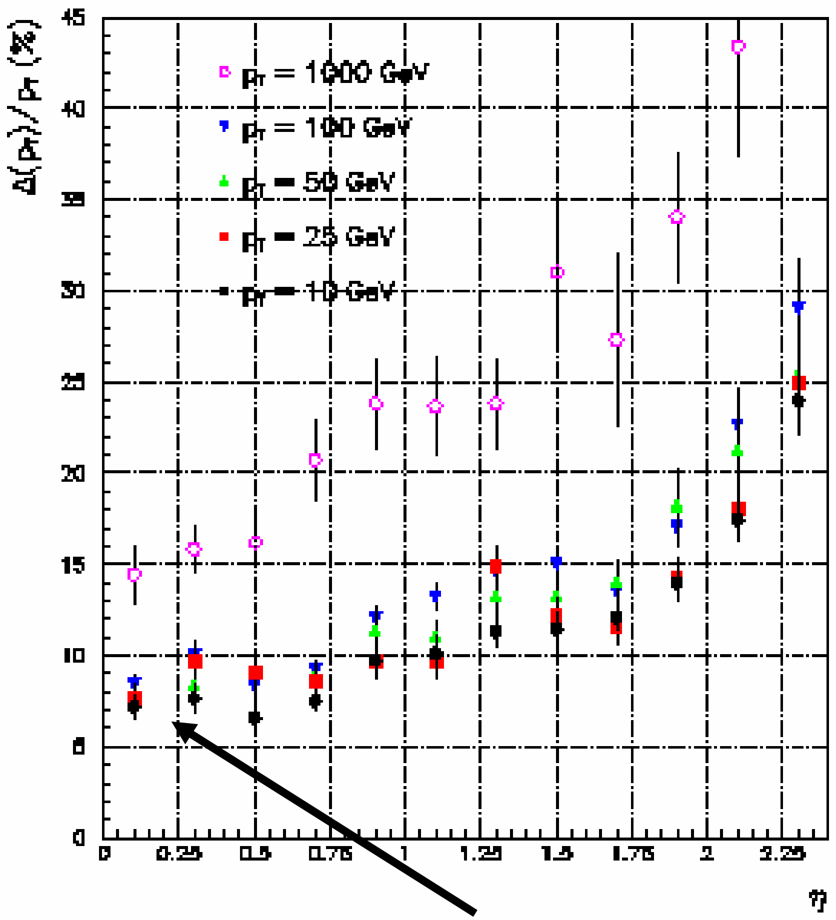
Each station is made by
- 1 DT and 2 RPCs on MB1,MB2, and
- 1 DT and 1 RPC on MB3,MB4

# Muon reconstruction

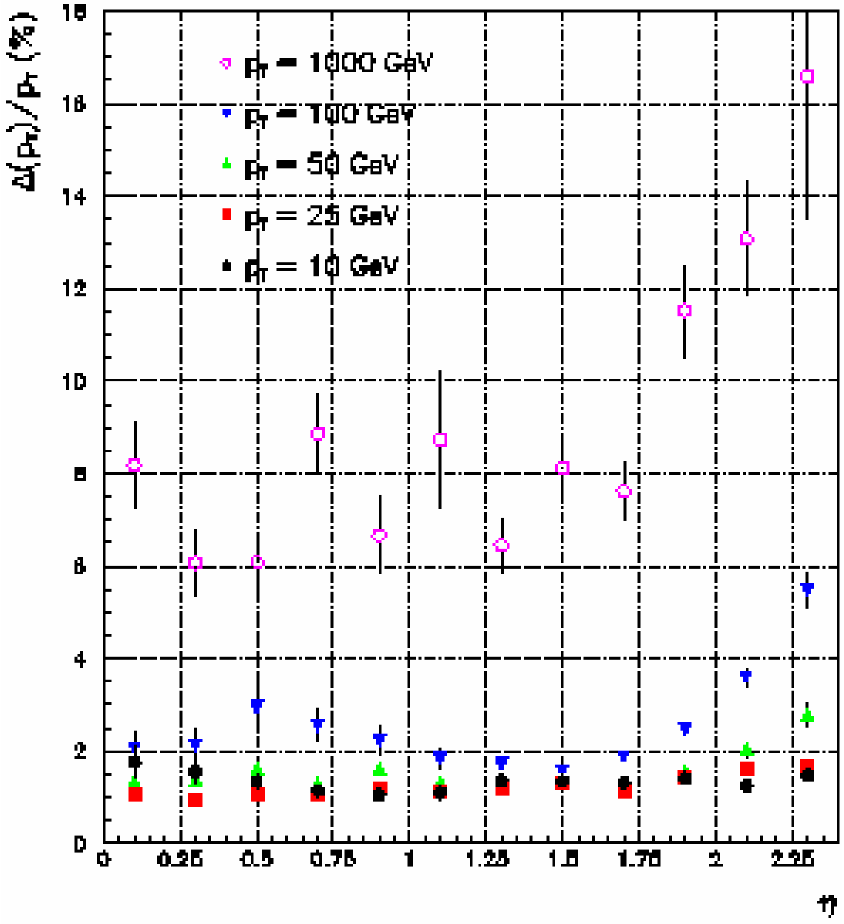


# CMS muon momentum resolution

**Stand-alone momentum resolution with vertex constraint**

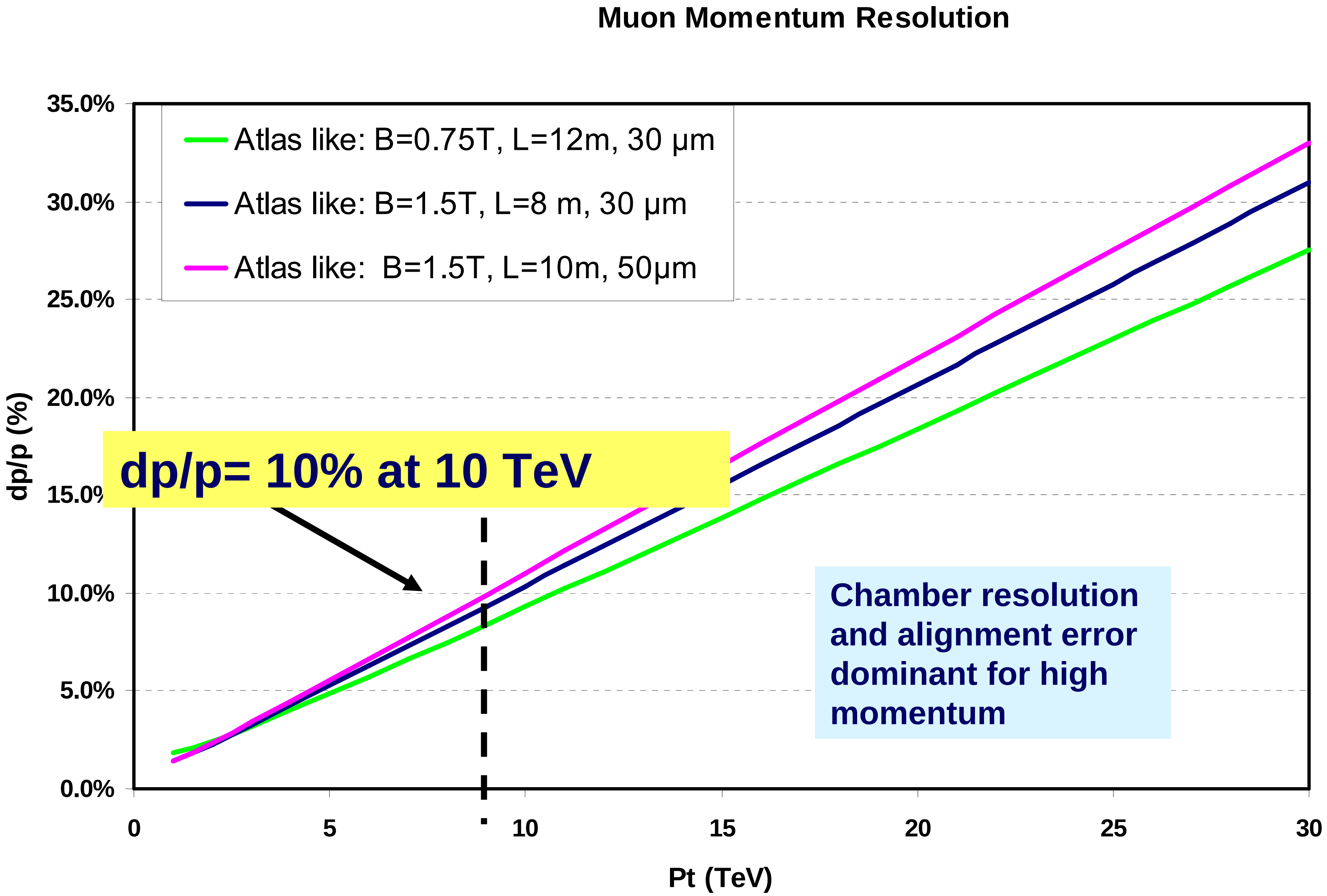


**Muon system with inner tracker**



**Dp/p dominated by multiple scattering in iron**

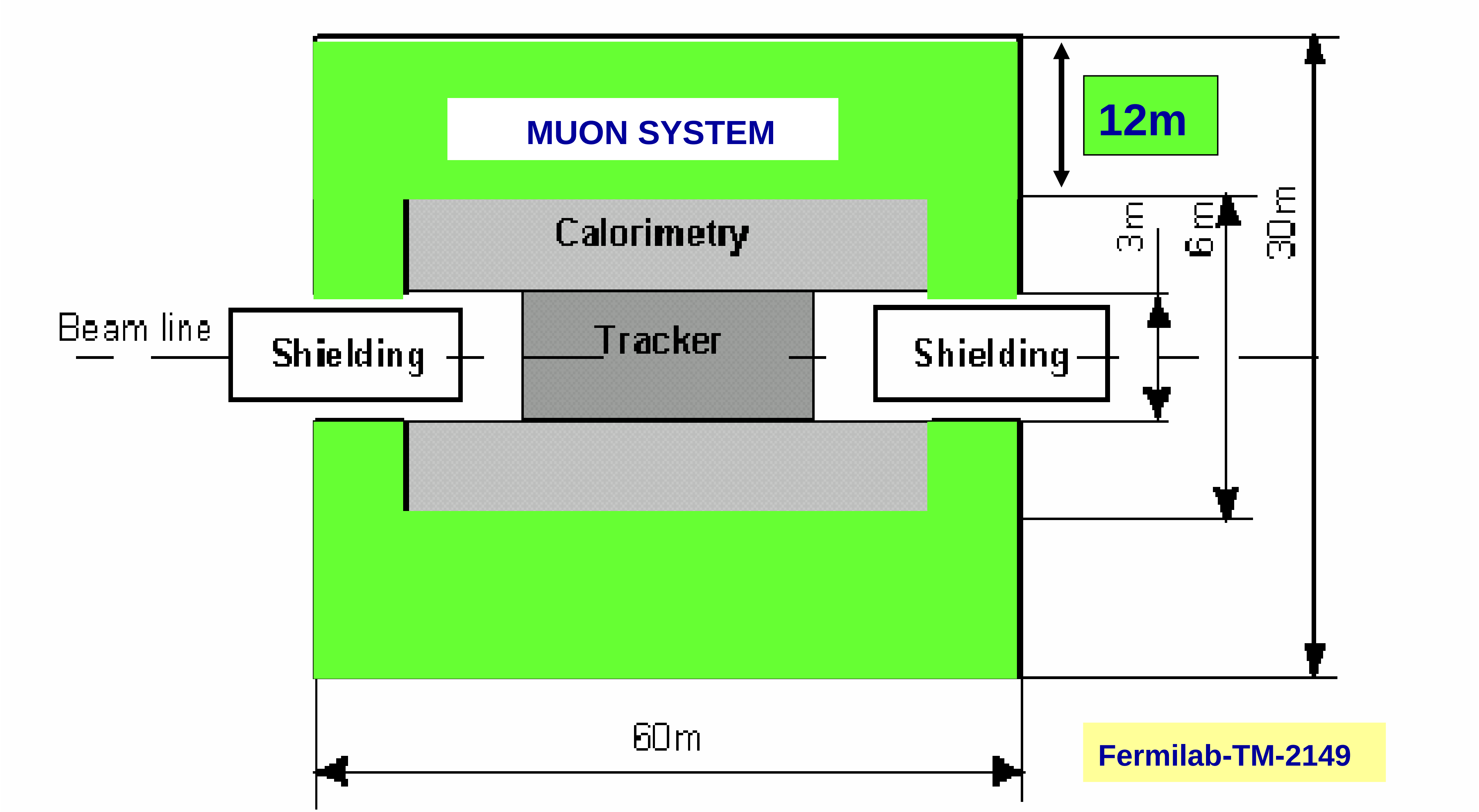
# Extrapolating ATLAS muon system for a VLHC



**dp/p= 10% at 10 TeV**

**Chamber resolution and alignment error dominant for high momentum**

# A possible VLHC detector



Fermilab-TM-2149

# A possible VLHC muon spectrometer

- A larger muon system (8-12m radius ) could reaches a muon momentum resolution of 10% for 10 TeV muons using present muon detectors
  - A spectrometer similar to ATLAS could in principle be used for a VLHC experiment
  - CMS design is not optimal for the reasons:
    - Muon chamber detection in iron problematic ->large energy losses
    - Large amount of iron needed as return yoke
- A large solenoid with muon chambers inside (as for the LEP-L3 experiment) could in principle reach the design goal with:
  - A ~30 m diameter solenoid (i.e. with B=0.75T and L=12m) plus a huge external iron return yoke (>100.000t of iron!)

# Muon technologies

ATLAS muon detectors

- Tracking Chambers :
  - MDT,CSC
- Trigger Chambers
  - RPC,TGC

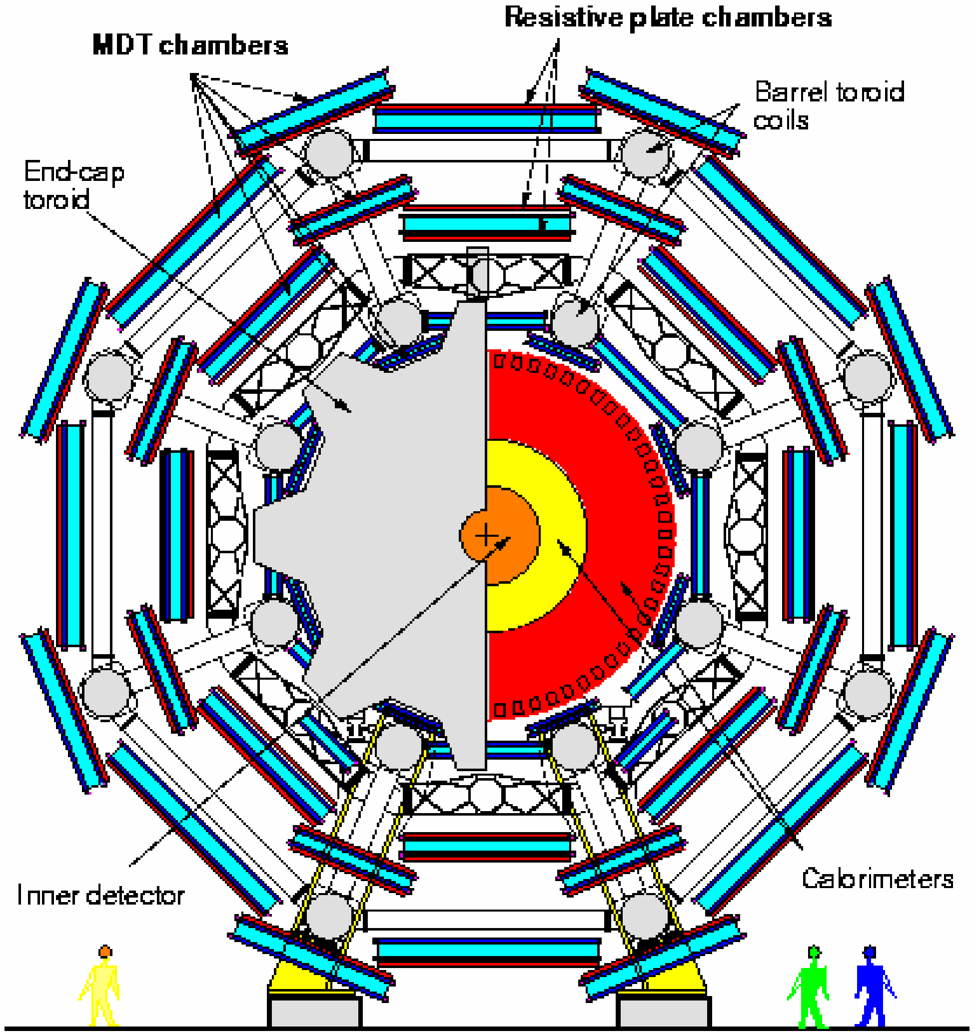
CMS muon detectors

- Tracking chambers
  - DT,CSC
- Trigger chambers
  - DT,RPC,CSC

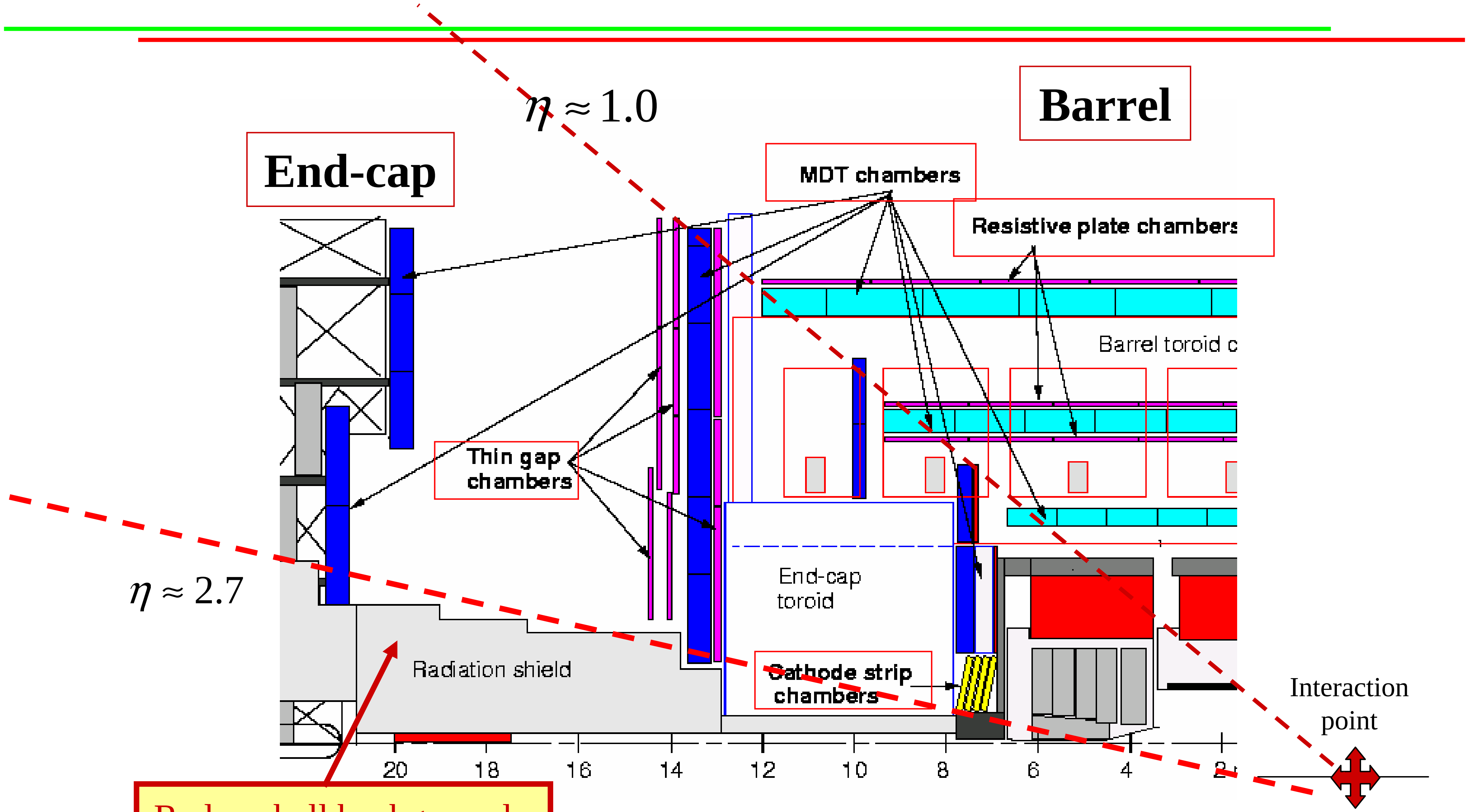
# The ATLAS muon Spectrometer-Front view

**4 technologies**

- **Trigger**
  - **RPC** barrel region
  - **TGC** forward
- **Precision chambers**
  - **MDT** $|\eta| < 2.0$
  - **CSC** $2.0 < |\eta| < 2.7$



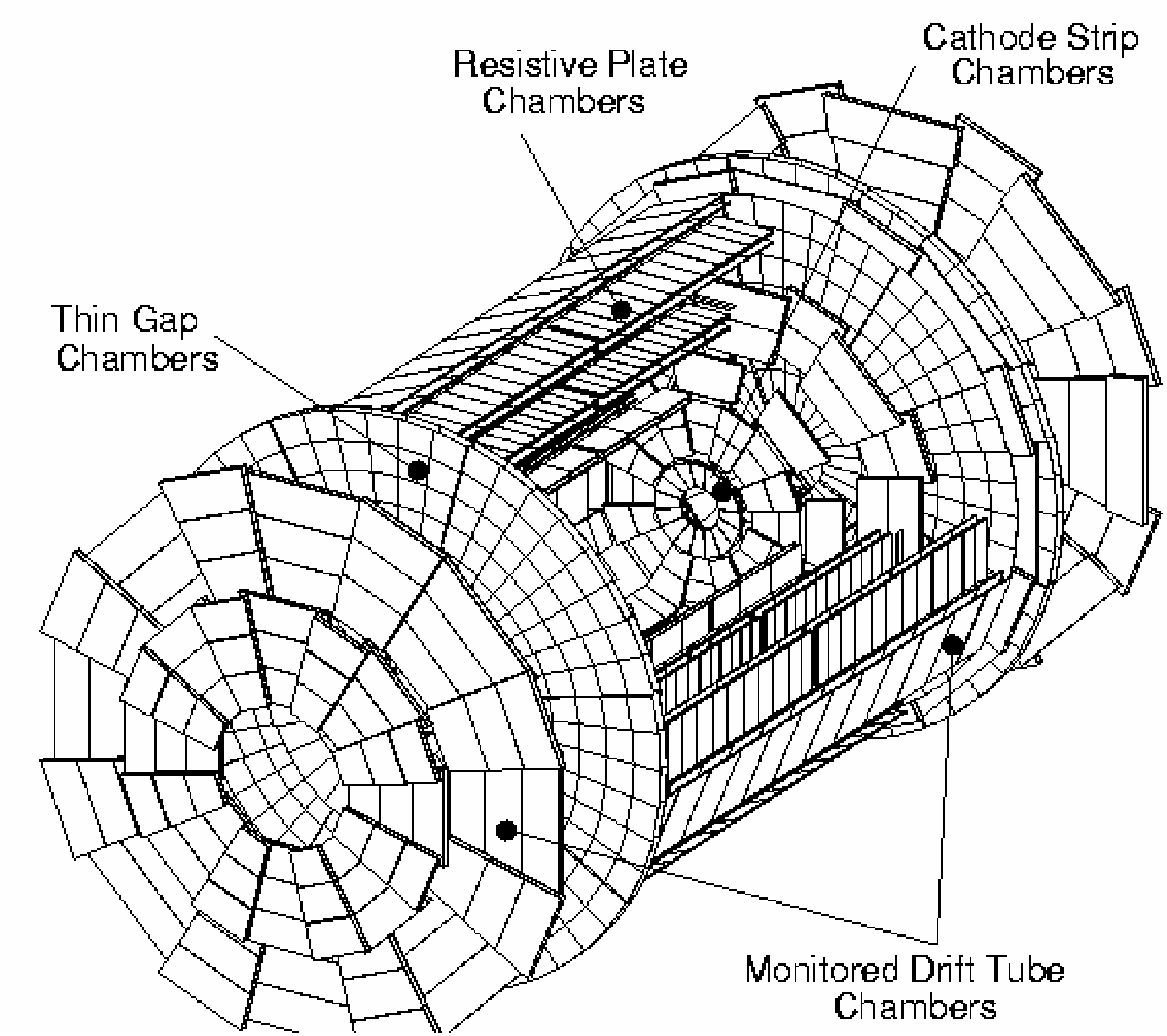
# The ATLAS muon Spectrometer-Side view



Reduce hall background

**d from int. point (m)**

# The ATLAS muon detector 3D view



**MDT: 5500 m$^2$**

**RPC: 3650 m$^2$**

**TGC: 2900 m$^2$**

**CSC: 29 m$^2$**

**-----------------------------**

**12079 m$^2$**

# Monitored Drift Tubes

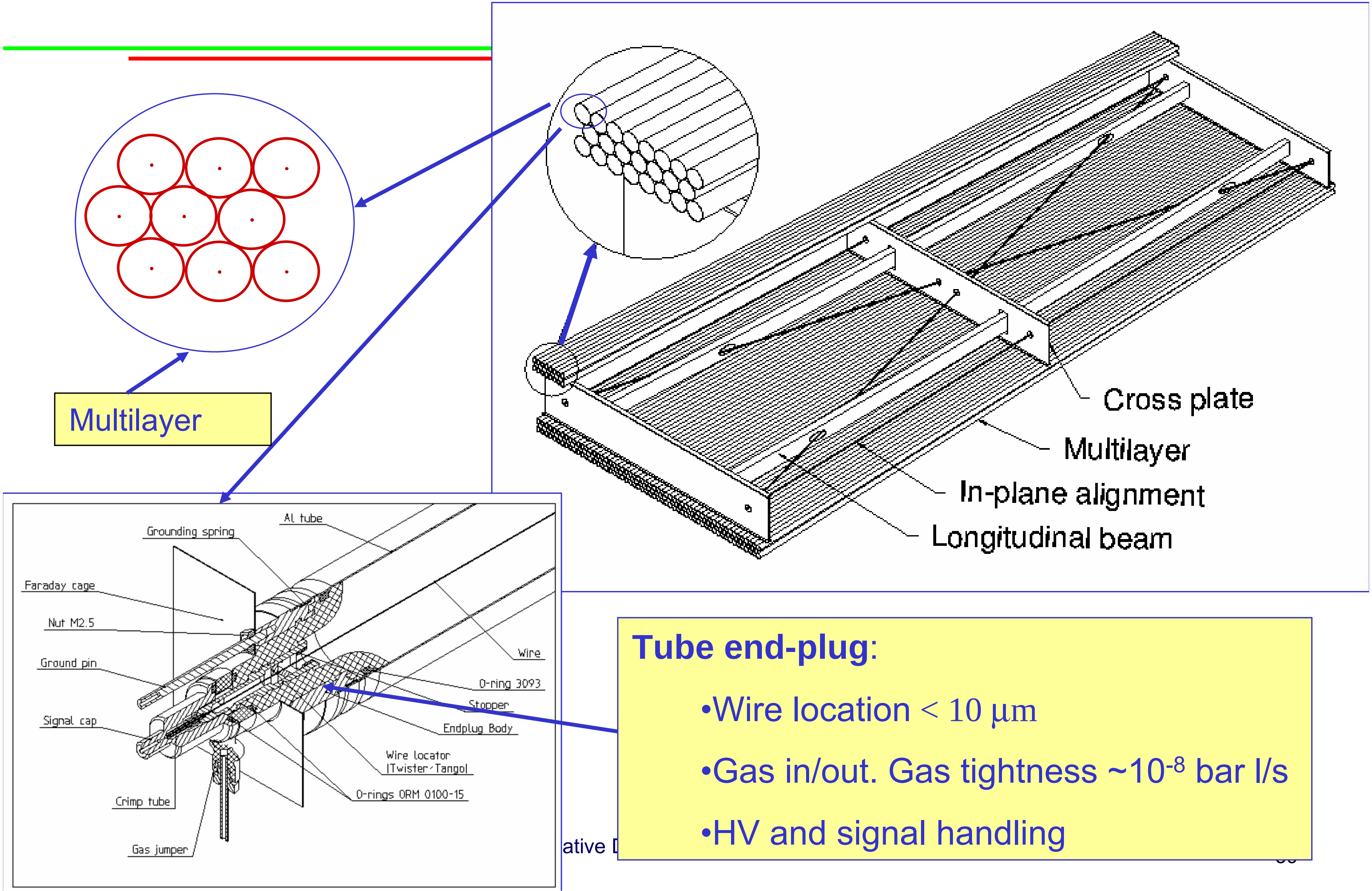
**Specifications of the ATLAS spectrometer tracking system:**

- ✓3 point measurements (3 muon stations); $\sigma$ = **50 $\mu$m/station**
- ✓Moderate radiation length (0.1-0.2 x/X0)
- ✓Fast (< 1ms ) and with high rate capability (> 100 Hz/cm$^2$)
- ✓Low ageing ( survival time > 10 years of operation in the LHC background)

**MDT detector:**

- ➢Drift tube: **3 cm** diameter, l =1.5-5.0m. Al wall 400 $\mu$m thick.
- ➢2 multilayers of tubes with 20-30 cm separation, 3-4 layers of tubes each.
- ➢Gas : Ar-CO$_2$ (93-7%) at **3 bars** absolute (~700 ns drift; ~70-80 $\mu$m space resolution/tube, G=2 10$^4$) 30% occupancy max.

# Monitored Drift Tubes



**Tube end-plug**:

- Wire location $< 10\ \mu m$
- Gas in/out. Gas tightness ~$10^{-8}$ bar l/s
- HV and signal handling

# Monitored Drift Tube: Mechanical construction

Contribution to the error: required precision/station → $\sigma = 50\ \mu\mathrm{m}$

✓ Intrinsic single tube space resolution ~ $100 \div 70\ \mu\mathrm{m}$

3x2 tubes → $\frac{70\mu m}{\sqrt{6}}$ → $40\ \mu\mathrm{m}$ $\oplus$

✓R-t relation from autocalibration → $10\ \mu\mathrm{m}$ $\oplus$

✓Mechanical precision on wire location → $20\ \mu\mathrm{m}$ $\oplus$

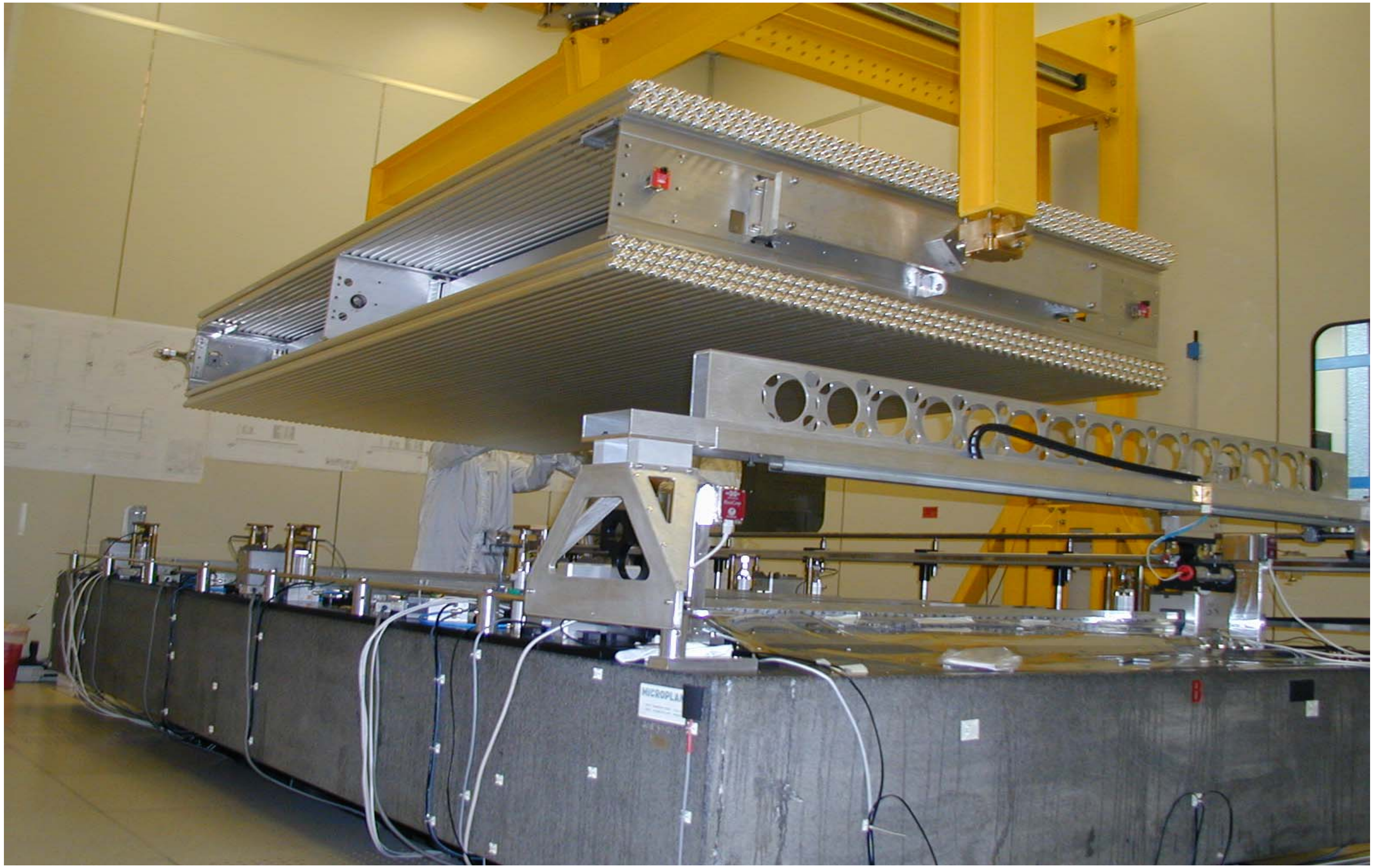
✓MDT location in space (alignment) → $20\ \mu\mathrm{m}$

**50 μm**

Assembly procedure must guarantee 20 μm wire location at the two tube ends.

Wire tension control at % level → ~ 5 μm uncertainty on wire gravitational sag.

# MDT Chamber

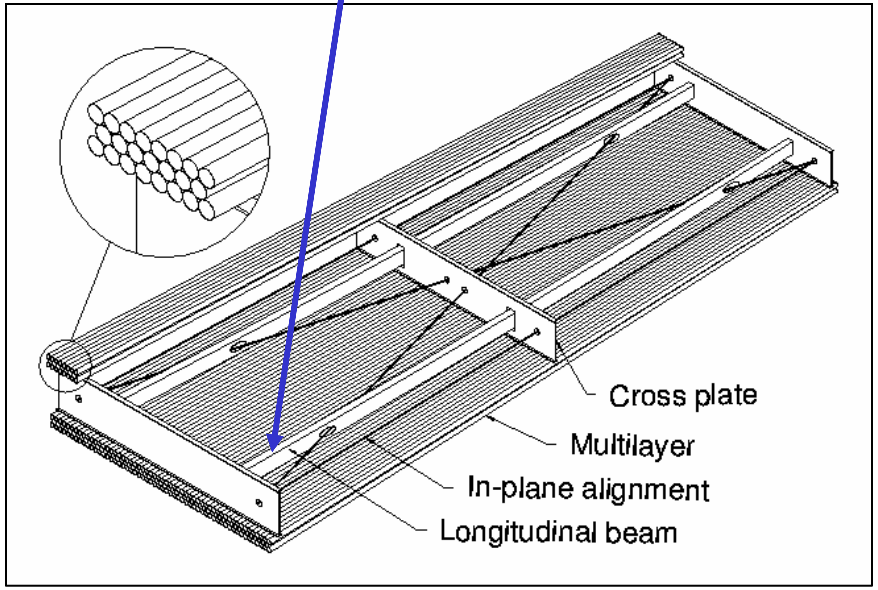


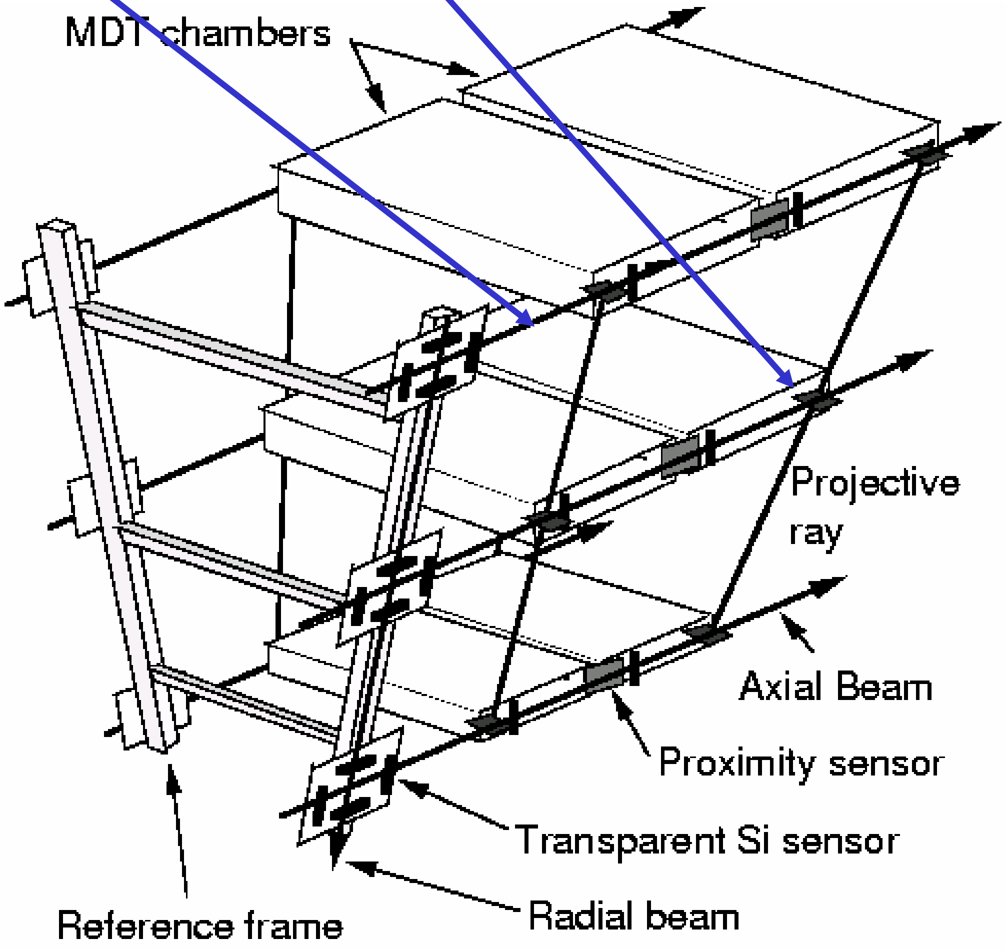
# Alignment system

✓**Designed to correct for 3D movements of the chambers after installation.**

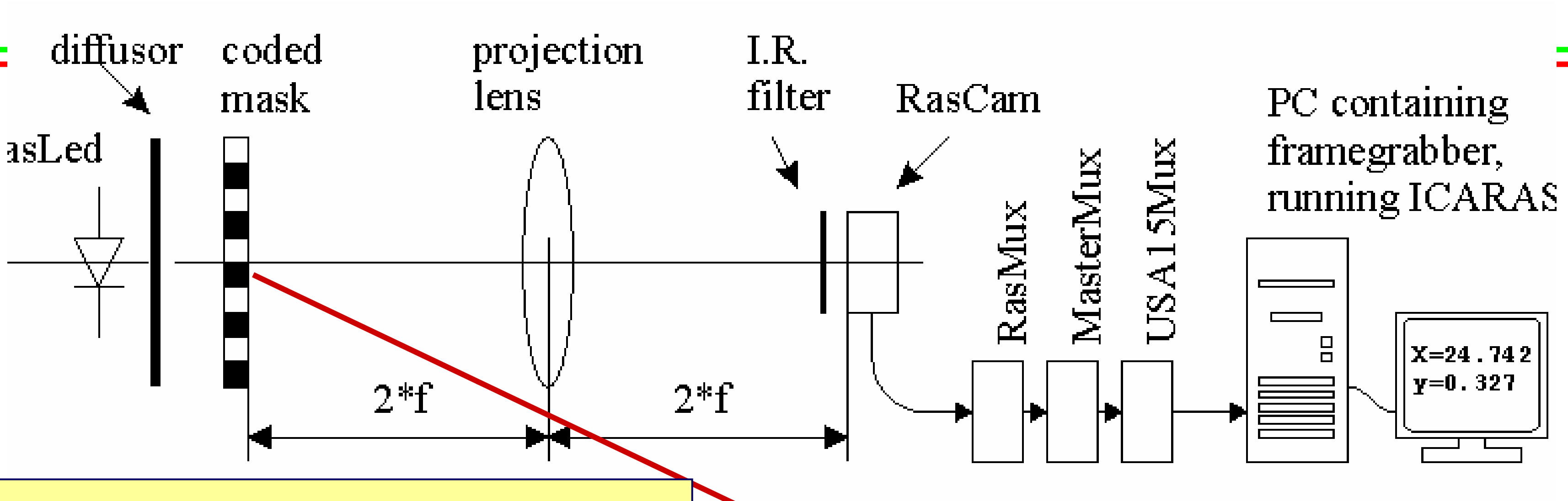
✓**Based on straightness monitors Rasnik with ~ 1 $\mu$m accuracy**

**1) in-plane** **2) axial** **3) projective**





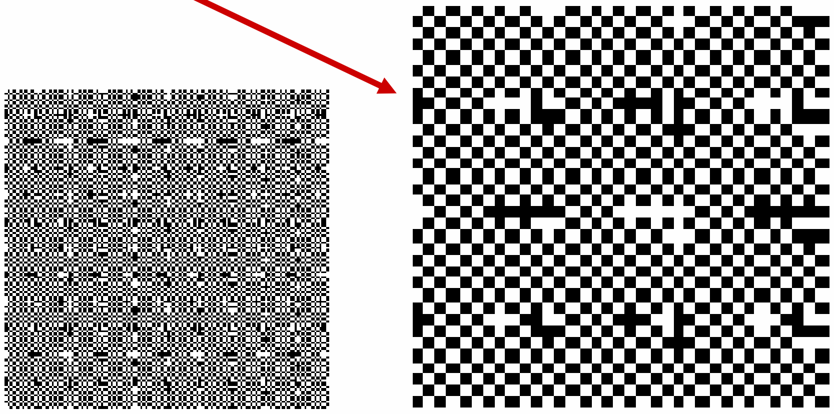
# Alignment system: Rasnik



✓ **Projective aligment:**

- ✓ **Mask in inner station**
- ✓ **Lens in middle station**
- ✓ **Camera in outer station**
- ✓ **Monitor the image of the mask in regular interval and store on a PC**
- ✓ **$1\mu m$ precision**

Figure 3: **RasNiK Coded Mask showing modified 'Chessboard Pattern'.**

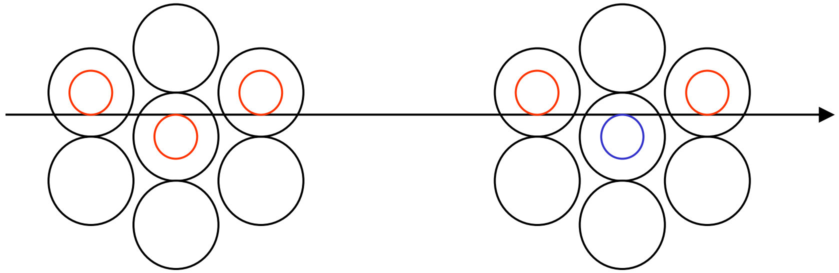


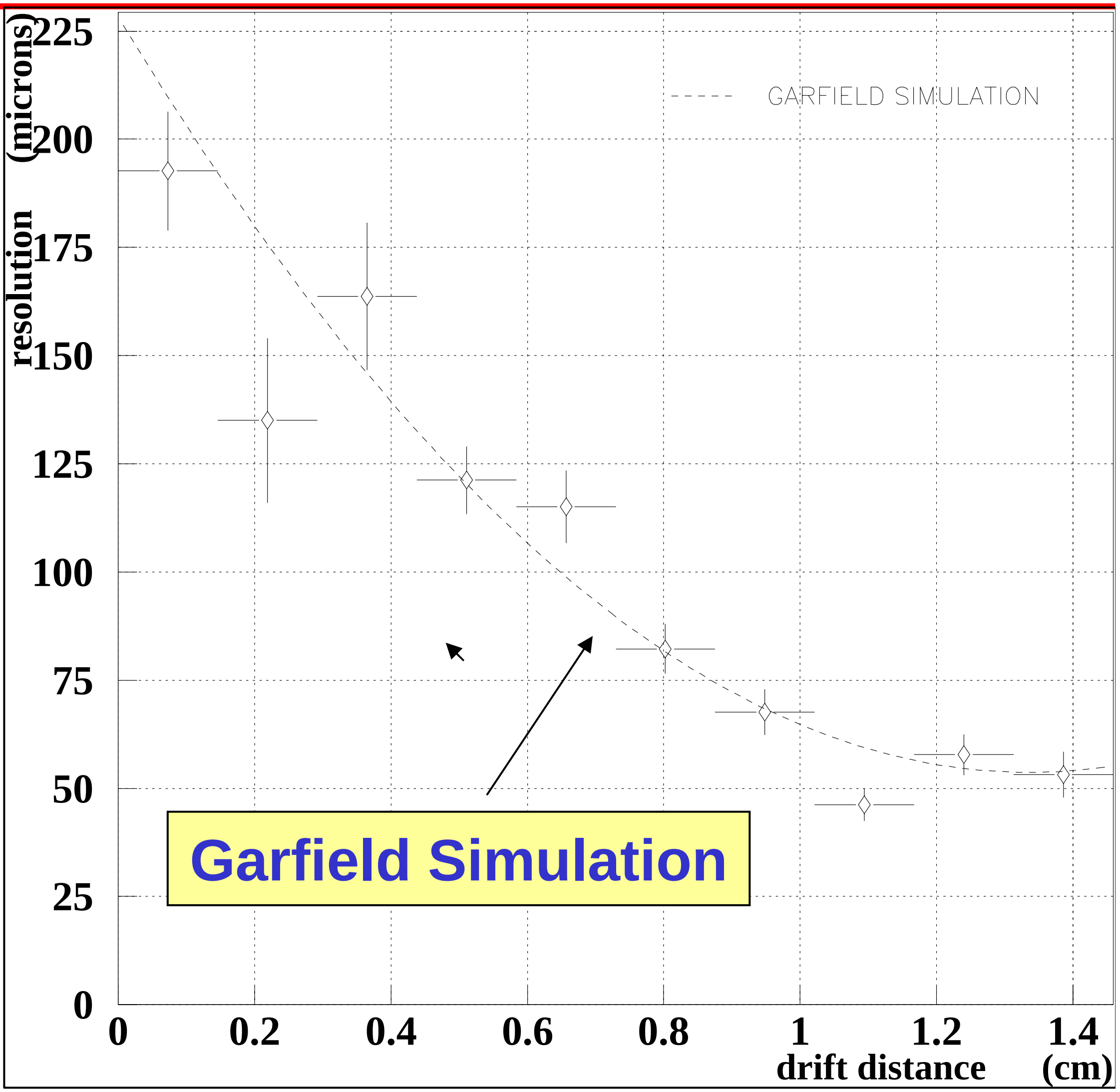
Full Mask & Detail

The field size (basic square) depends on the system: InPlane ❑ = 120µm

# Single tube:Measured Resolution

Fit tracks using 5 out of 6 measured points.
Extrapolate the tracks to the tube not used in the fit
Define the residual for this tube as $Res=R_{fit}-R_{measued}$



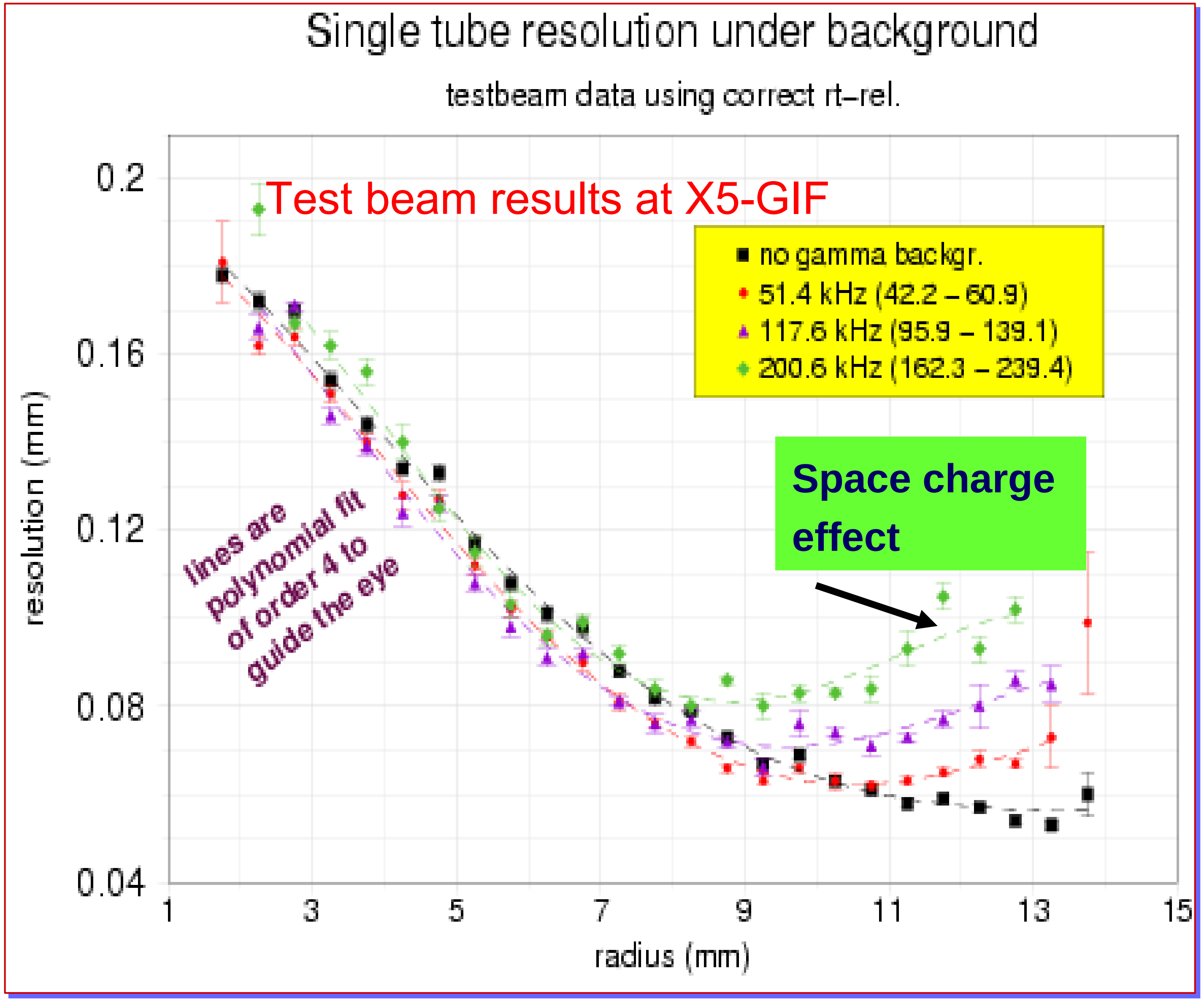


Garfield Simulation

- Single Tube averaged resolution:

**70 µm → 100 µm**

# MDT  Resolution with background rate



Test beam results at X5-GIF

**Space charge effect**

lines are polynomial fit of order 4 to guide the eye

- degradation of the resolution for large drift radii

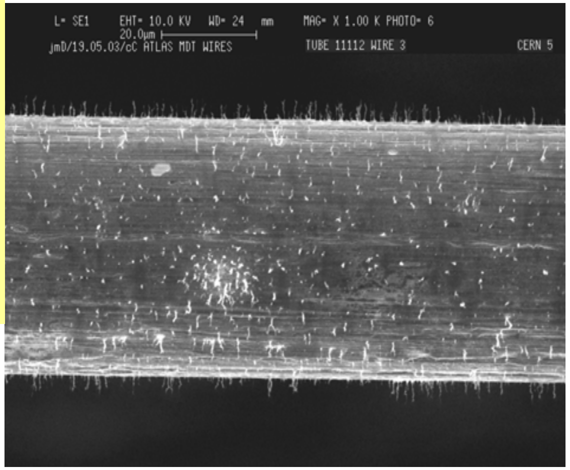
Improve MDT resolution for the VLHC

- smaller radius tube
- faster gas

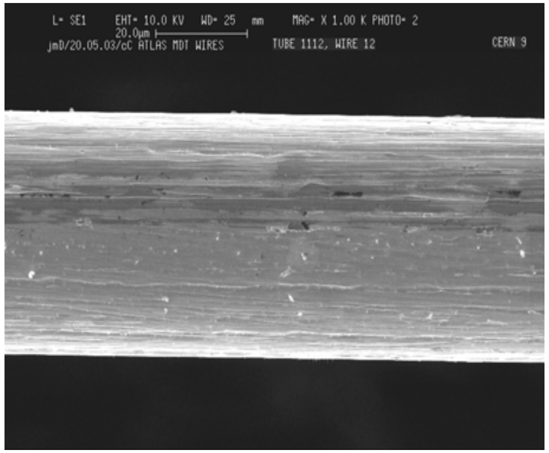
# MDT ageing

- A MDT operated with gas circulation after a long-term irradiation showed large reduction in pulse height within the first ~30 cm from gas input side already for accumulated charge ~ 40 mC/cm (Atlas spec: 0.6 C/cm)

**L = 30 cm from gas inlet**

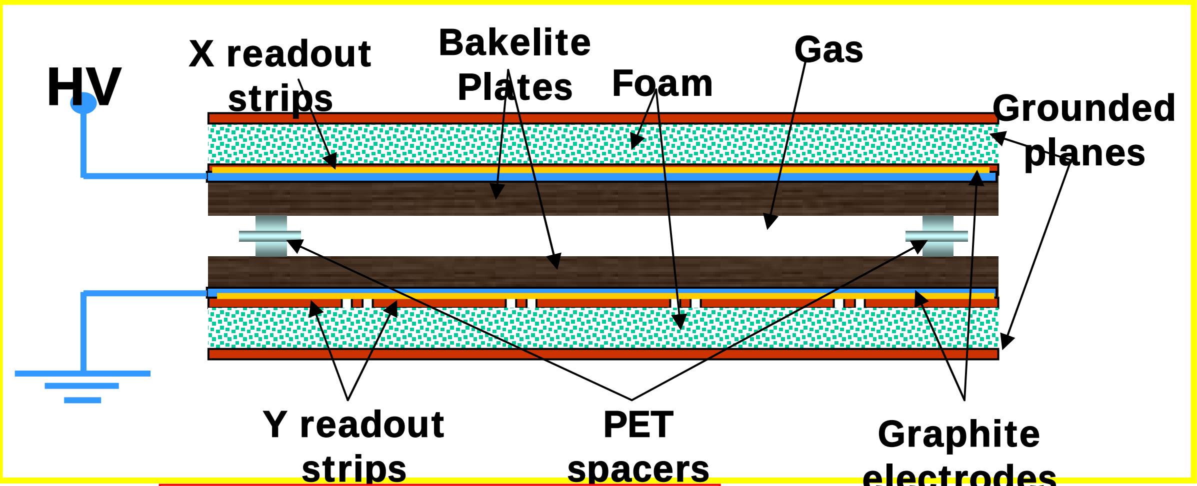


**furthest away from gas inlet (L=130 cm)**



- Electron microscopy of the wire surface:silicon deposit on wire near the gas input
- Silicone grease found in the gas system components
- Strictly quality control needed for the installation of the MDT gas system

# Resistive Plate Counters



## RPC operating conditions:

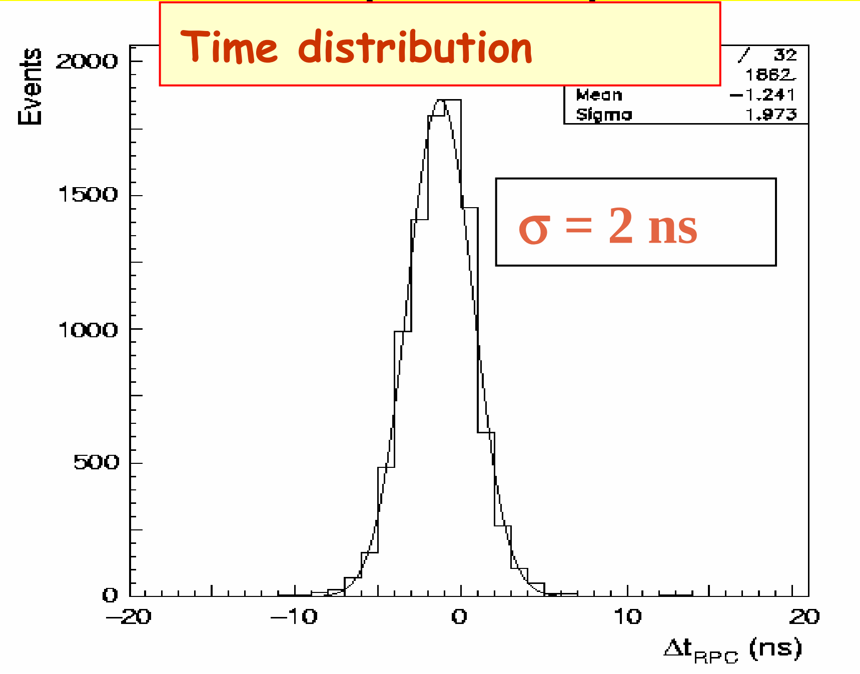
•Gas gap: 2 mm E ~ 4.5 KV/mm

•Bakelite plates: 2 mm, $\rho \sim 2 \times 10^{10}\ \Omega \times \text{cm}$

•Gas working mode: avalanche

•Gas mixture:

•94.7%$C_2H_2F_4$+ 5%iso$C_4H_{10}$+ 0.3%$SF_6$



## Performance:

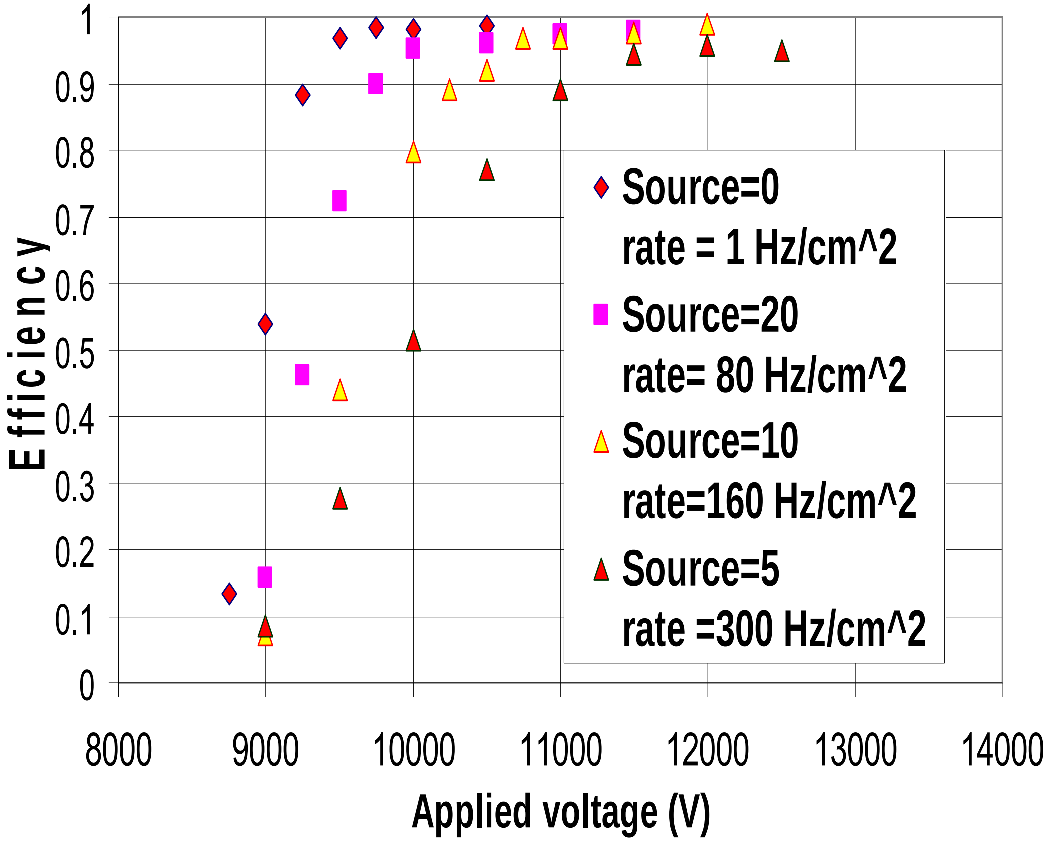
- Single gap efficiency (with spacers ): ε = 97%
- **Time resolution ~ 1.5-2.0 ns → b.x. identification**
- Rate capability <1 KHz/cm2 after ageing of 10 ATLAS years → reduced rate capability (~ 200-300Hz/cm$^2$)
- (x,y strip readout ) → 2nd coordinate measurement

# RPC ageing test at X5-GIF

**Efficiency vs HV after Q = 0.35 C/cm²**

**(>10 ATLAS years + safety factor 5-10)**

**Source: 740 GBq $^{137}$Cs E γ = 0.662 MeV**

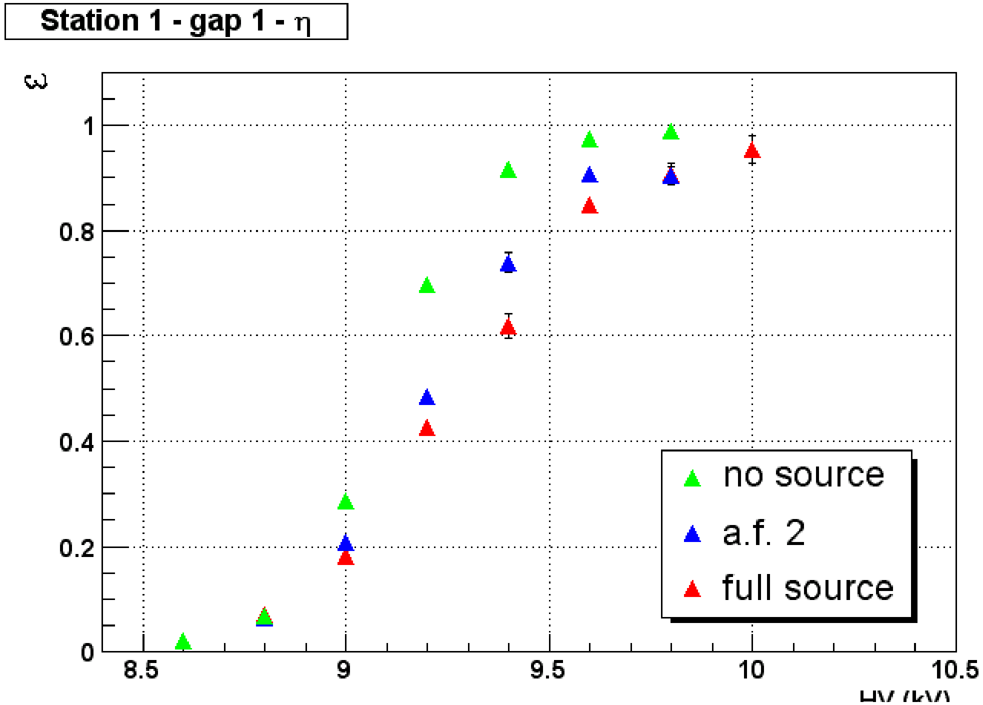


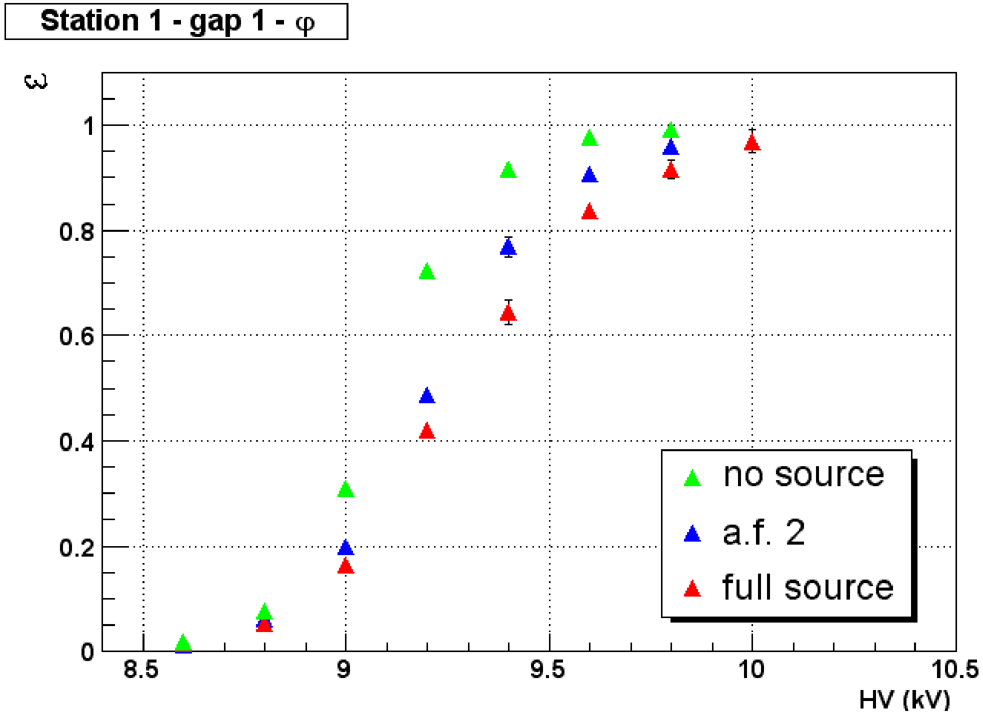
- **The RPC module-0 after ageing (>10 Atlas year +safety factor 5-10) shows a rate capability of ~ 200-300Hz/ cm² (expected rate 10-20 Hz/cm²)**
- **The ageing effect can be described in term of an increase of the operating voltage, due to an increase of the electrode total resistence**
- **An ageing study on 4 production chambers is now going on at the CERN GIF facility**

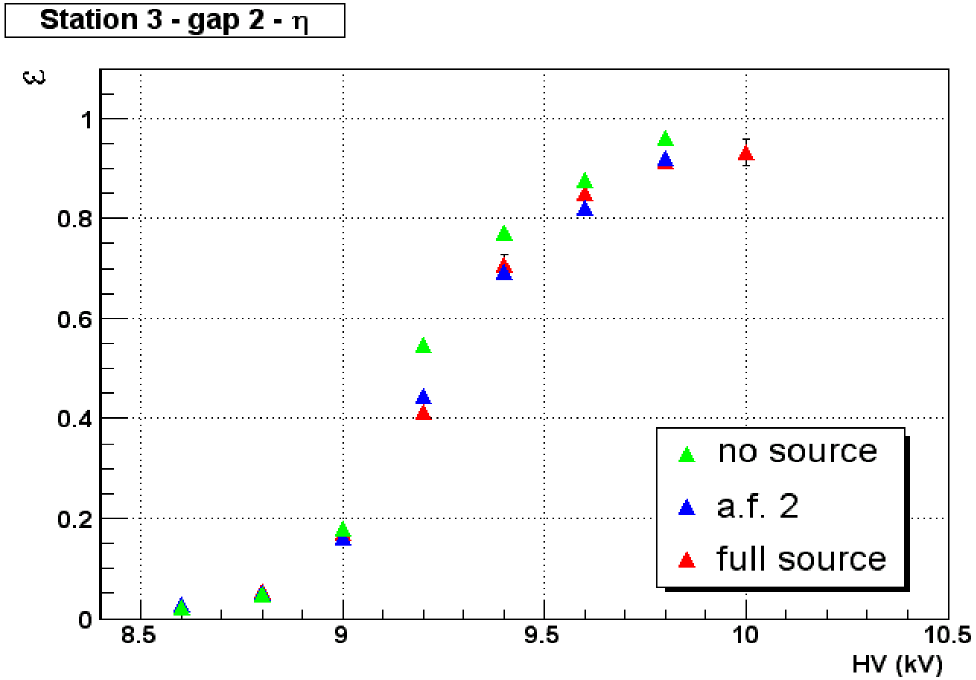
# X5 Ageing test status

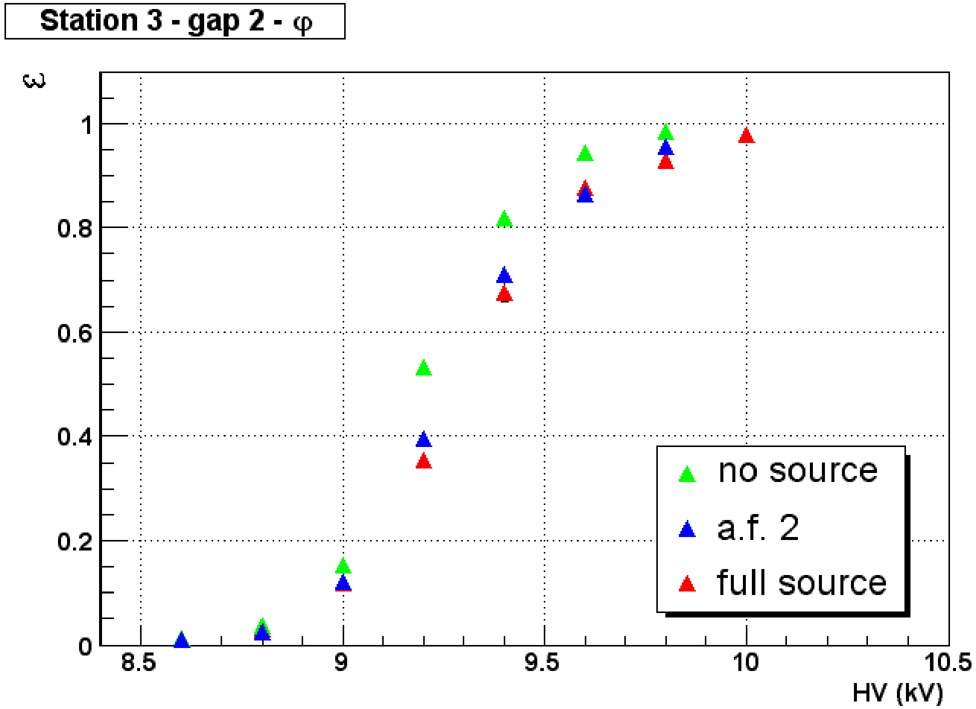
- Present integrated ageing is 4.1 ATLAS years.
- After 3.5 ATLAS years (about 100 mC/cm2 integrated charge, including a safety factor of 5) all the gas gaps under test show very good detection efficiency even at fully open source.
- A moderate increase of the resistivity was observed as expected. The rate capability remains much above the ATLAS requirements
- At the beginning  of July the gas closed loop was introduced on 4 out of the 6 tested gas gaps. The gas recirculated fraction is 50% so far and was increased last week to 95%.
- Since last January all the gas volumes are operated with average 30% RH gas mixture to test the effect on the long term stability of the bakelite resistivity. No negative effects where detected until now.

# RPC beam tests at X5(3.5 years)

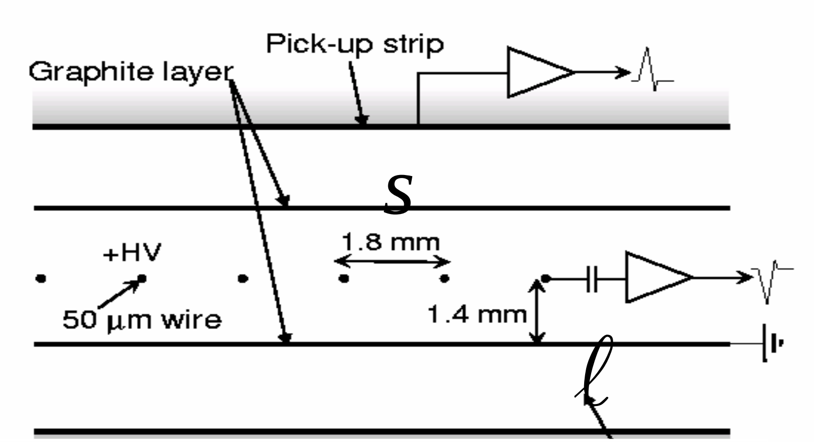


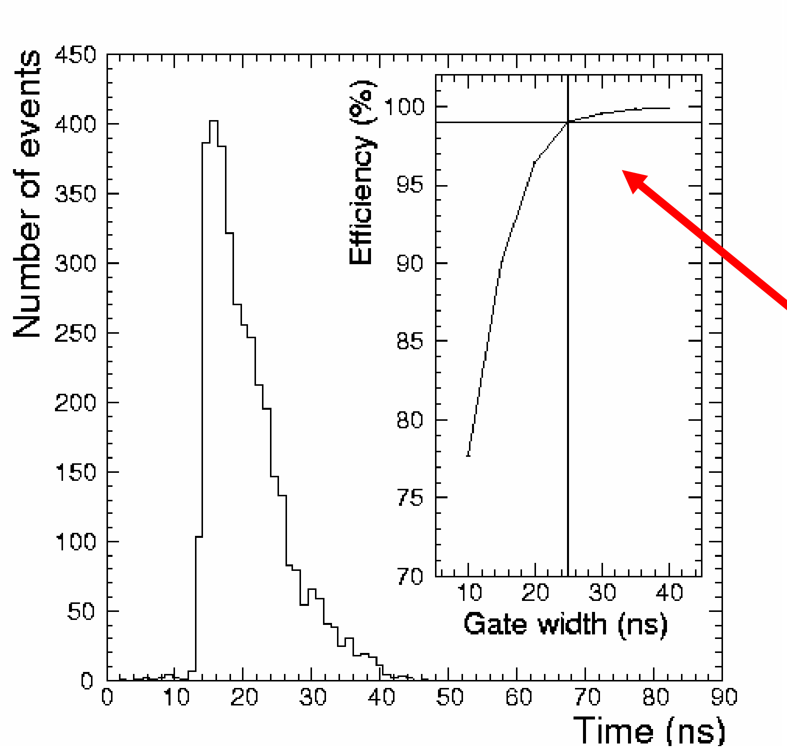






# Thin Gap Chambers





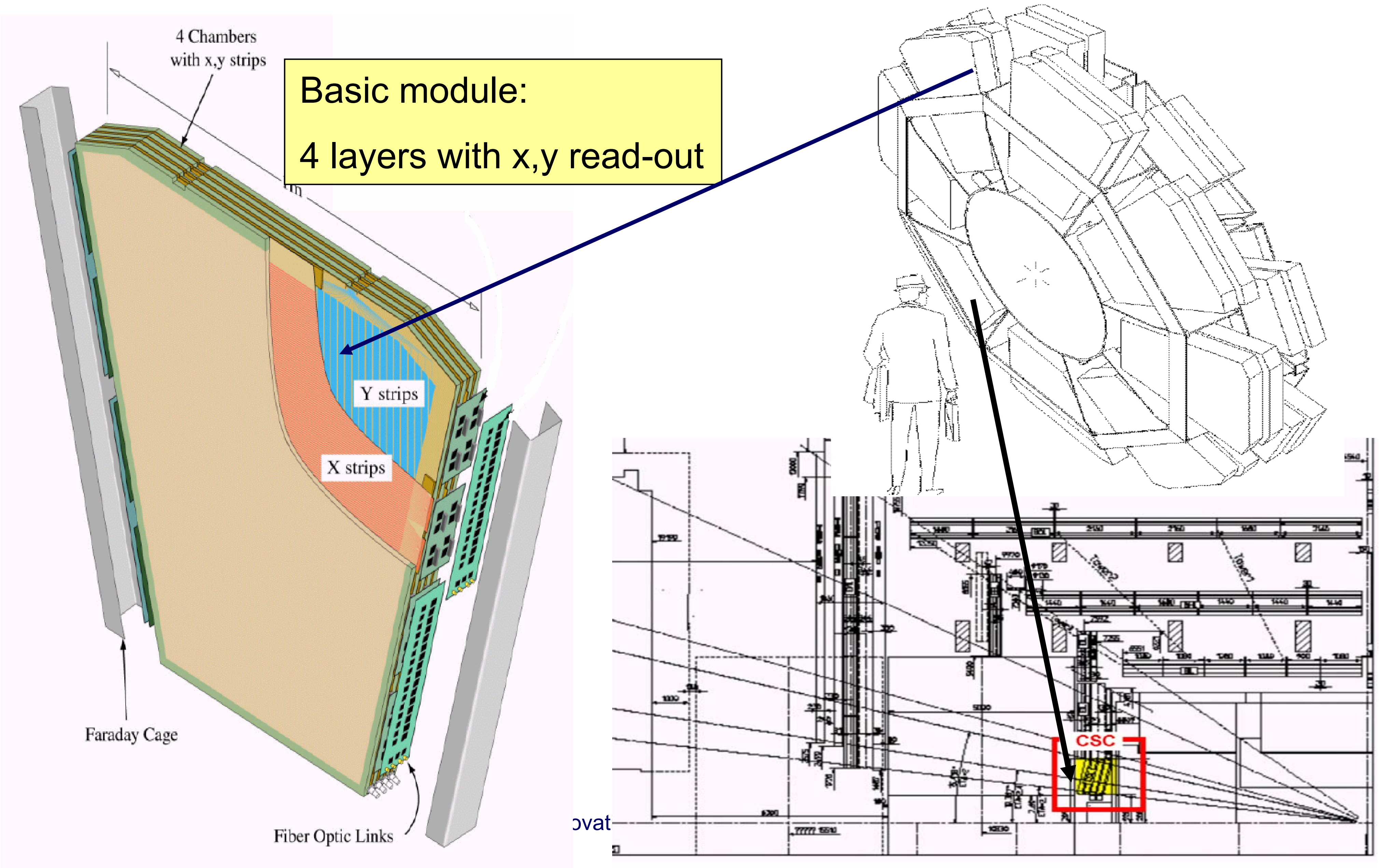
**TGC: MWPC with small cathode-cathode distance**

- **Anode pitch: 1.8 mm**
- **Anode-Cathode dist: 1.4 mm**
- **Cathode-Cathode dist: 2.8 mm**

**Operating conditions**

- **Gas : 55 % $CO_2$ , 45 % N-Pentane**
- **HV: 3.1 KV**
- **Saturated avalanche mode**
- **Very short drift time due to the thin gap ensures the good time resolution needed for Bunch Crossing ID( 99% efficiency with a 25 ns gate)**
- **Wire signals used to provide the trigger, strip(15-40mm) signals used for the second coordinate**

# Cathode Strip Chambers



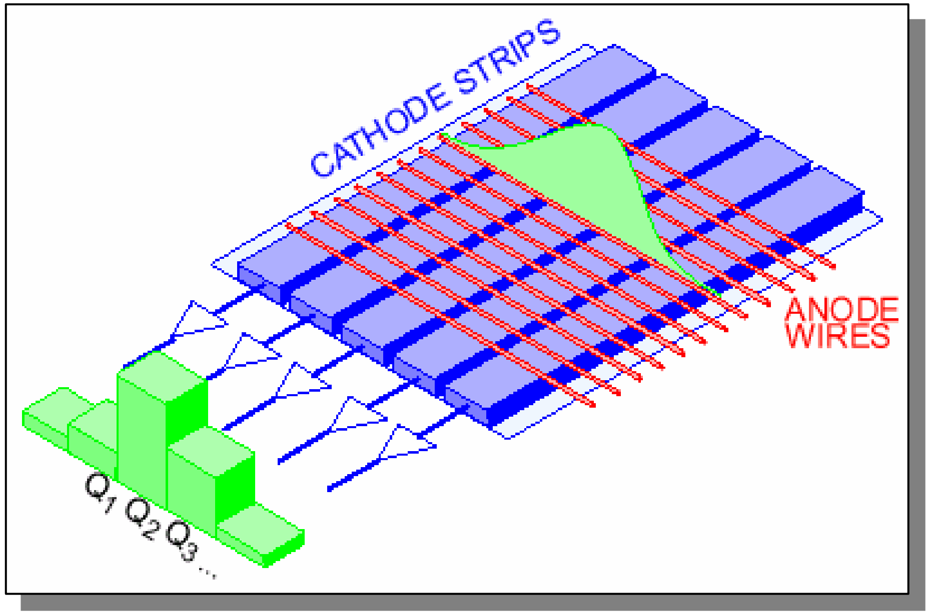
Basic module:

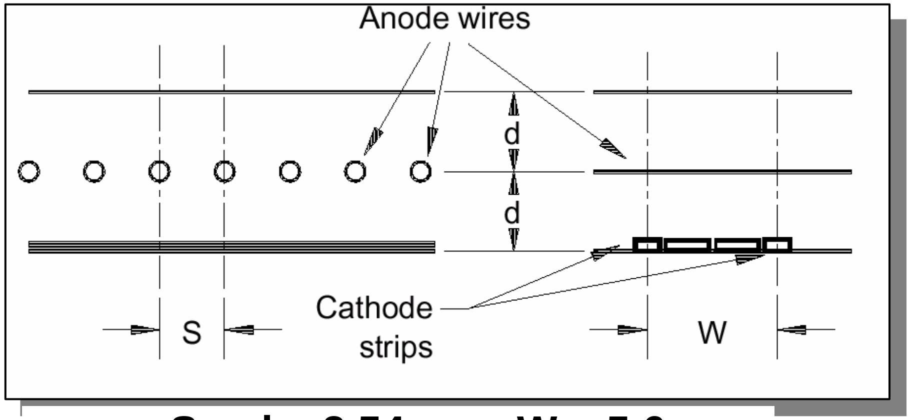
4 layers with x,y read-out

# Cathode Strip Chambers

**CSC:MWPC with analog strip read-out**

- **Gas mix :Ar-$CO_2$ (80/20 %)**
- **Gain $10^4$; HV 2.6 KV**
- **Muon position determined by interpolating the charge induced on 3 to 5 adjacent strips**
- **Precision (x-) strip pitch ~ 5.6 mm**
- **Measure Q1, Q2, Q3… to get $s_x$ ~ 60 μm.**
- **Second set of y-strips measure transverse coordinate to ~ 1 cm.**
- **7 ns time resolution,good two track resolution.**
- **High rate capability (>>1KHz/$cm^2$).**
- **Low sensitivity to background n ($10^{-4}$), small ageing**

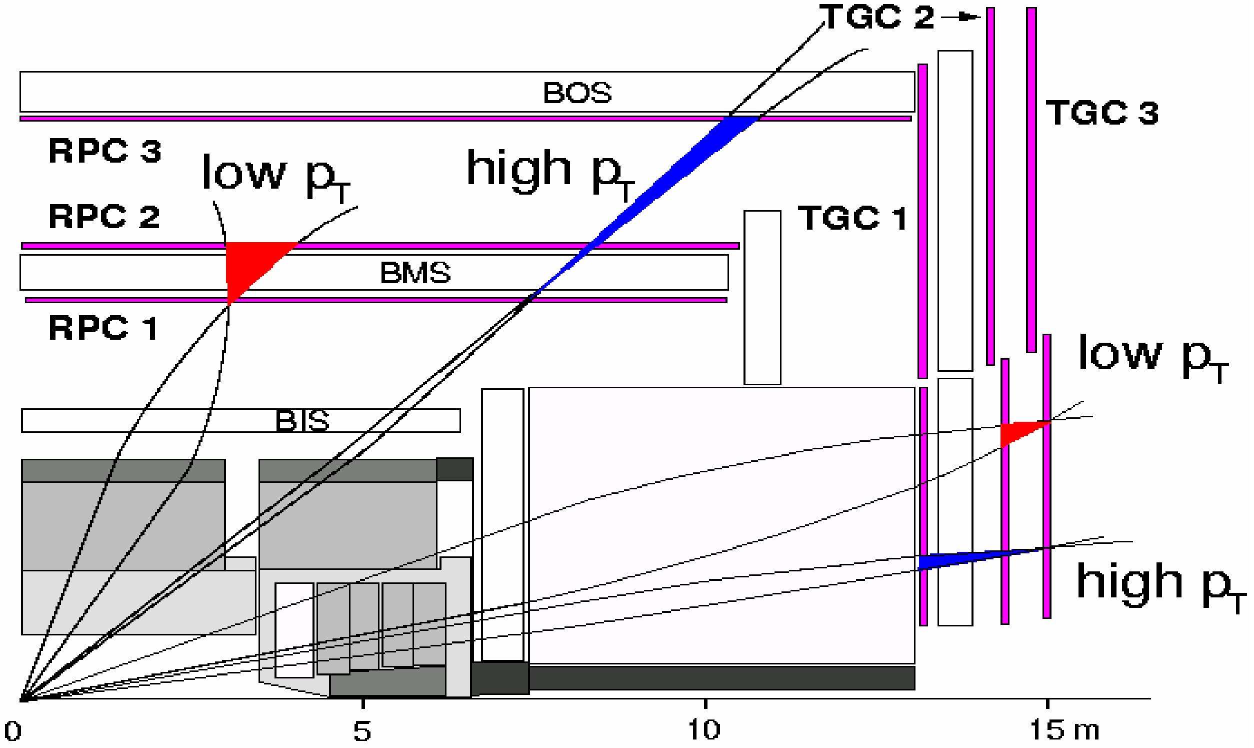




**S = d = 2.54 mm W = 5.6 mm**

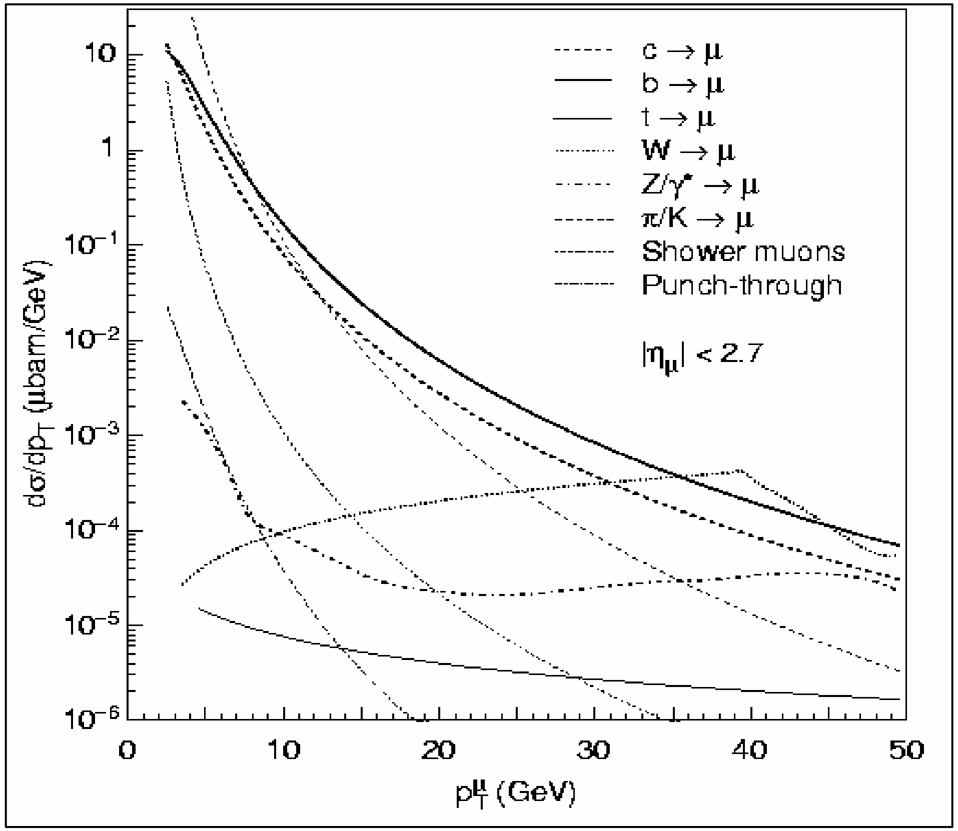
# Level 1 Muon Trigger

- Trigger selection performed both in the bending and non-bending plane to reduce fake trigger rate due to the high background level.
- Window size in the bending plane defines the accepted $p_T$ interval; in the non-bending plane defined by multiple scattering.
- Two trigger thresholds : Low pt (6 GeV/c threshold) and High pt (20-40 GeV/c threshold)

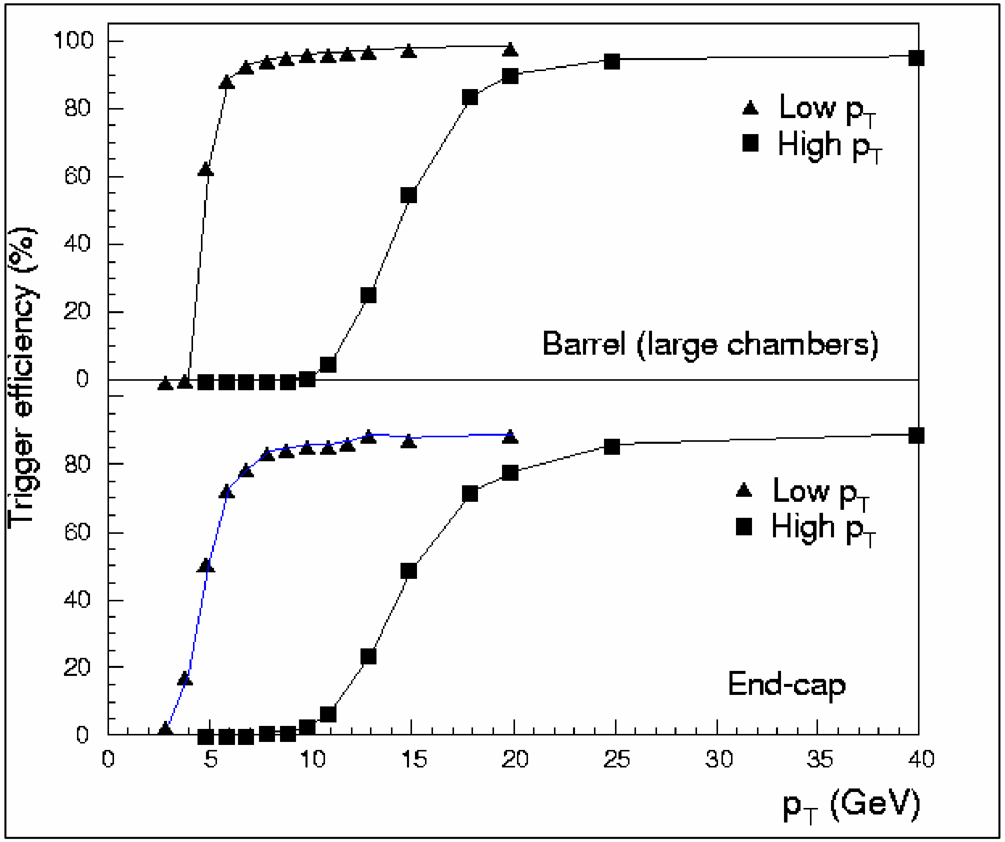


# Trigger performance

## Cross sections for prompt muons and punchtrough

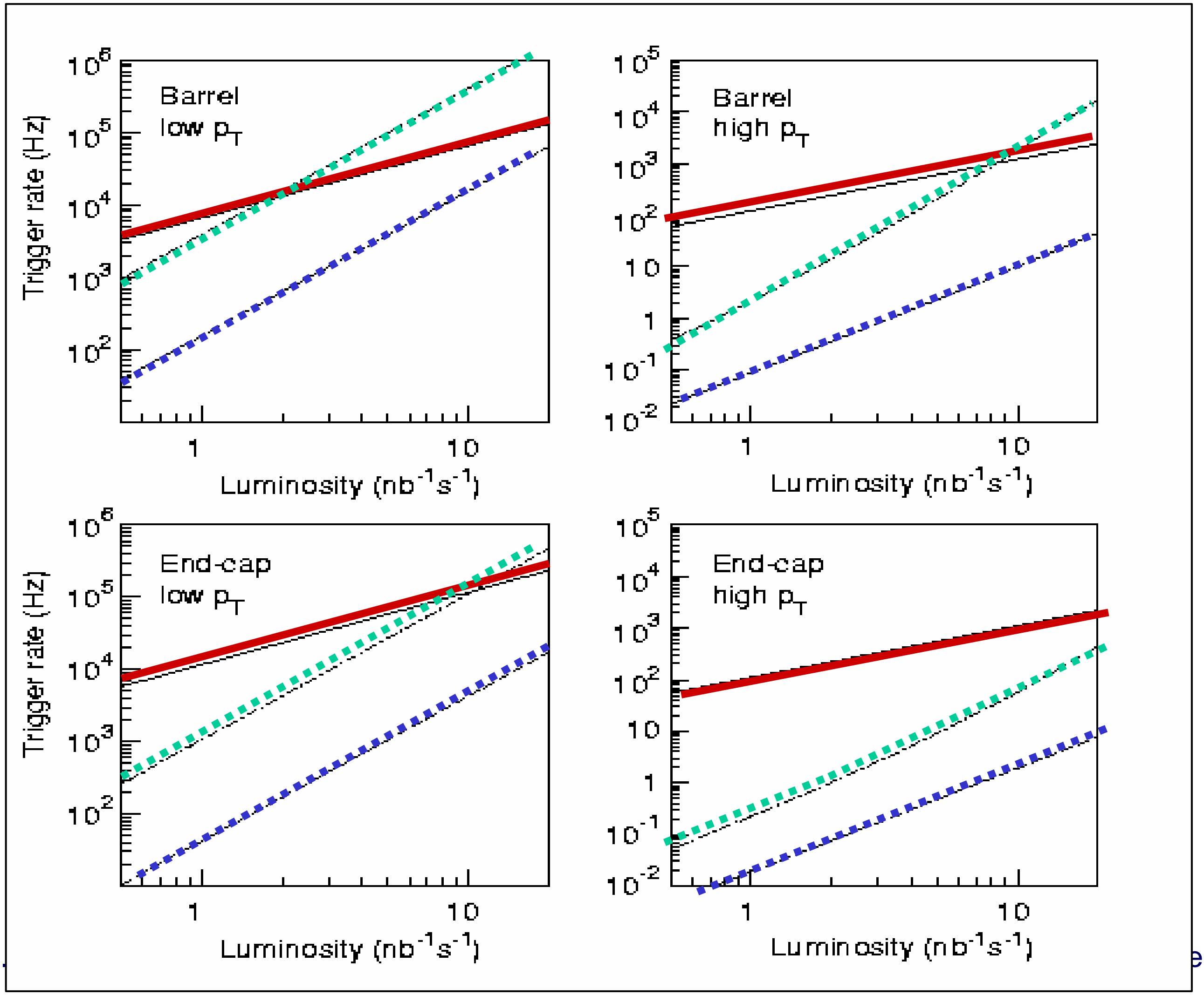


## Trigger efficiency



# Fake trigger rate

Background hits in trigger detectors → accidental triggers



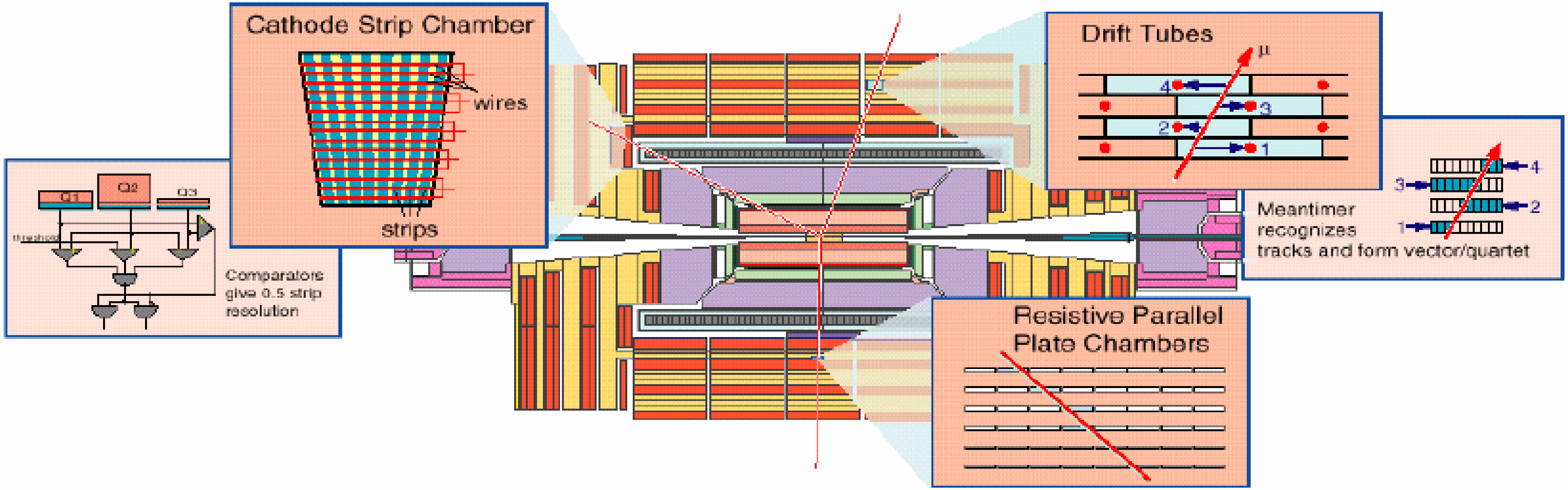
▬ Prompt muons

⋯⋯ Accidentals rate (nominal background)

⋯⋯ Accidentals rate (background x 10 )

**Good safety margin over accidental trigger rate**

# The CMS Muon Detectors



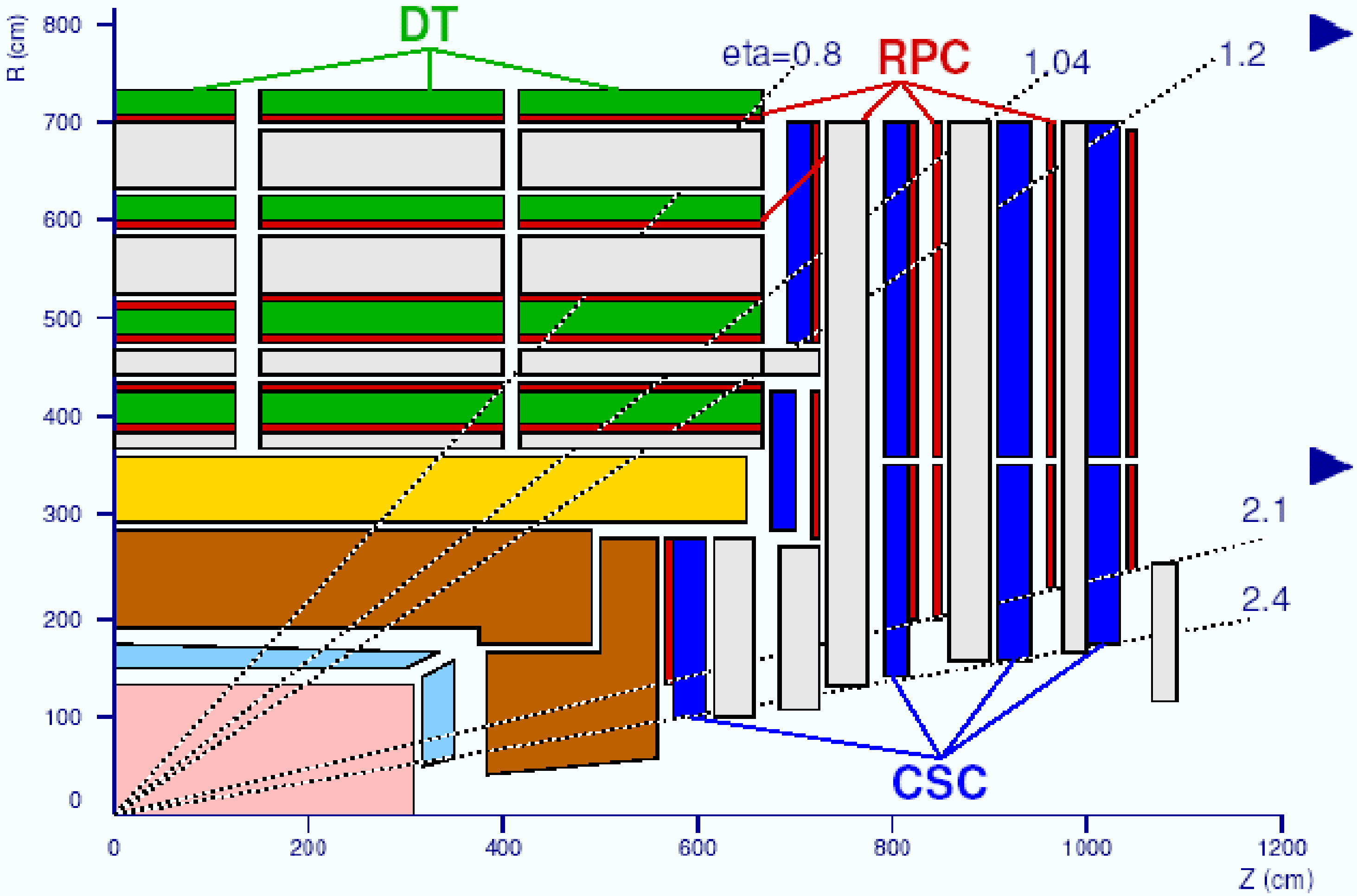
**Muon Barrel**

- **Drift Tube chambers with Bunch crossing identification (DTBX)**
- **Resistive Plate Chambers (RPC)**

**Muon Endcap**

- **Cathode Strip Chambers (CSC)**
- **Resistive Plate Chambers (RPC)**

# CMS:longitutinal view

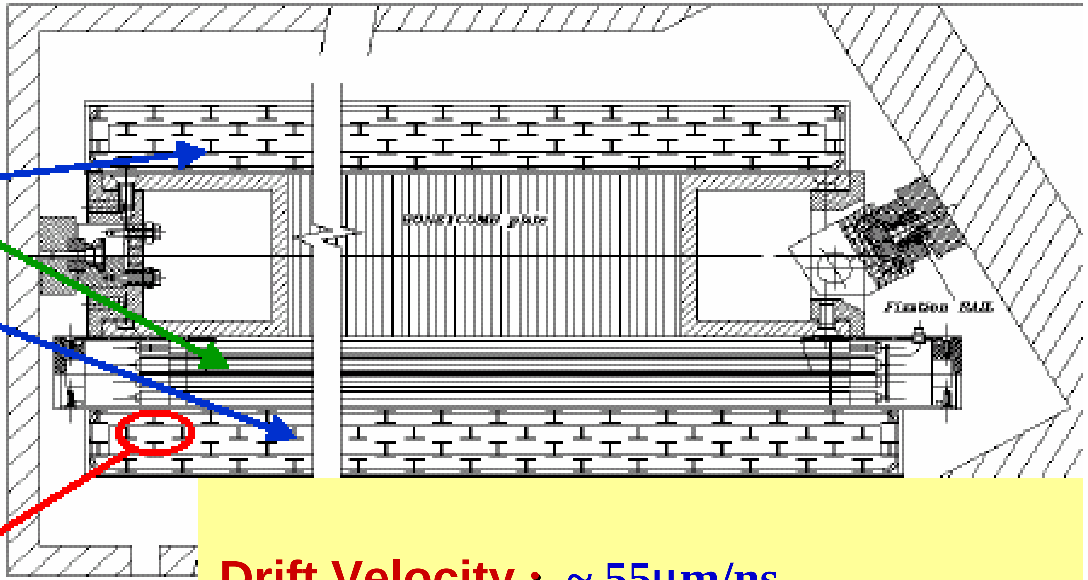


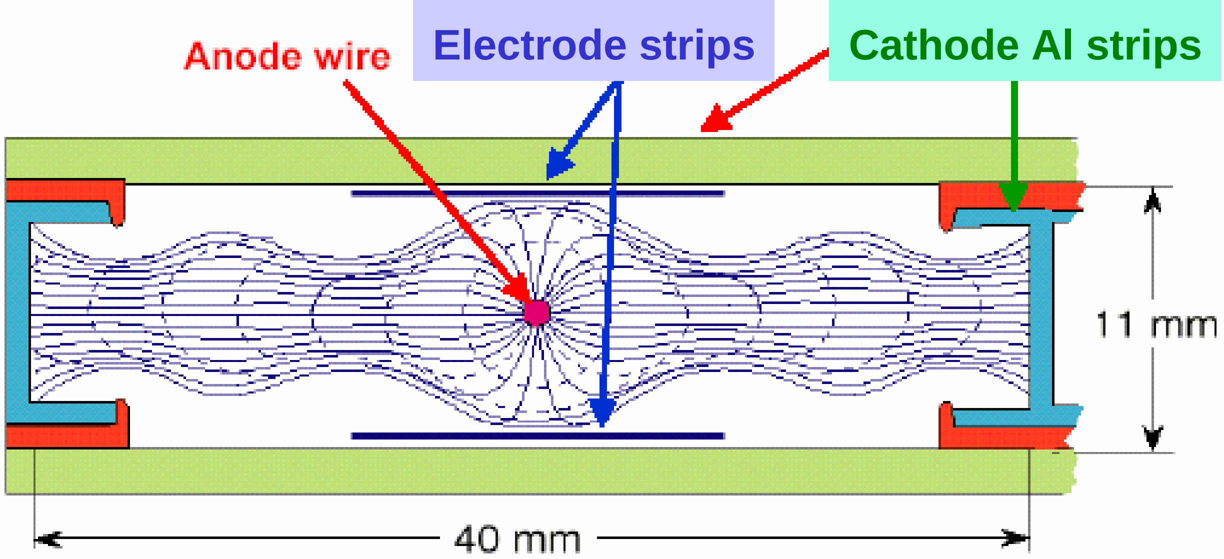
- 4 stations of DT's, interleaved with the iron of magnet yoke, self triggering and bx identification,
- 4 stations of CSC's with same capabilities, interleaved with iron disk yoke, up to $|\eta| < 2.4$,
- 6 –Barrel– or 4 –Endcaps– station of RPC's up to $|\eta| < 2.1$,
- L1 trigger up to $|\eta| < 2.1$

# MUON DT Chambers

Each DT Chamber comprises
4 layers of DT cell in r-φ, 4 in r-z and
further 4 in r-φ

(No r-z layer in the fourth station)





**Drift Velocity :** ~ 55µm/ns
**Single Wire Resolution :** < 300 µm

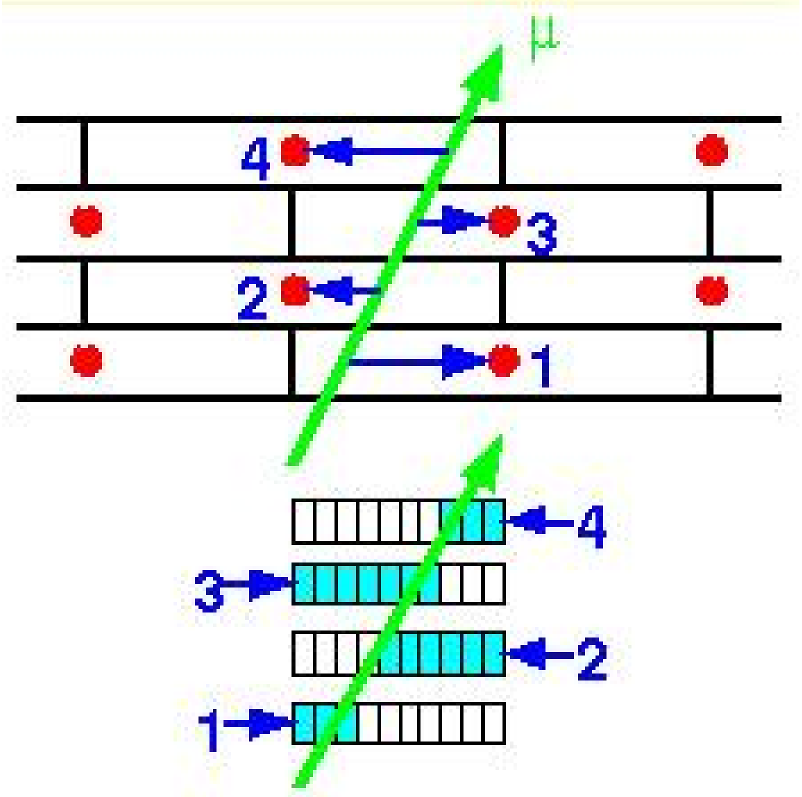
100 µm Φ ,150 µm Θ

**Nominal Operating Parameters**

| | |
|---|---|
| • Nominal Mixture | Ar - CO$_2$ (85% -15%) |
| • Nominal voltages | strips at 1800V,<br>wires at 3600,<br>I-Beams at -1800V |
| •Gain (nominal) | 9.10$^4$ |
| •Typical charge | 1pC |

# DT Local Trigger-Bunch and track Identifier

DT Meantimer technique allows bunch-crossing identification and measurements of track parameters



**3 out of 4 hits in a SL:**

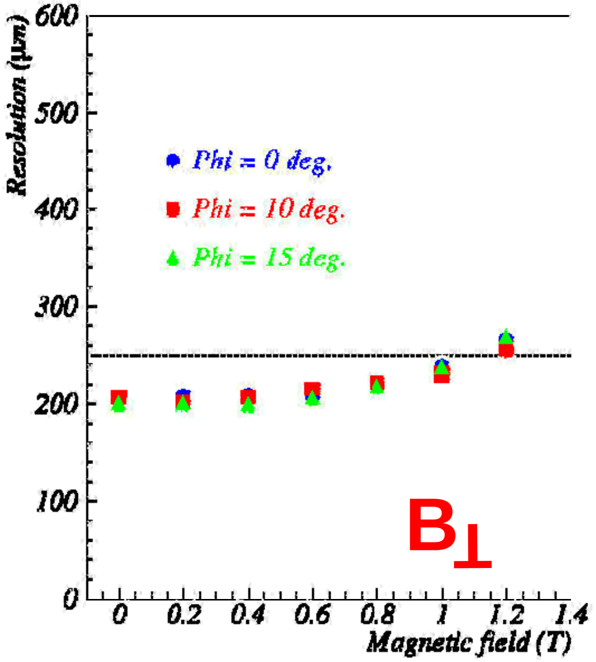
**MT1 = 0.5 * (T1 + T3) + T2**

**MT2 = 0.5 * (T2 + T4) + T3**

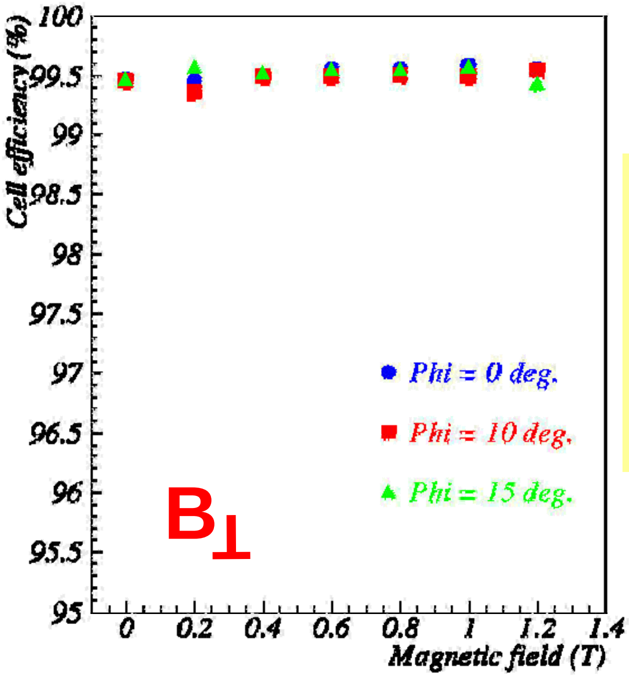
- **MT = $T_{driftmax}$ independent on the track angle and position**
- **True alignment occurs in a shift register at a fixed time ->allow bx identification**
- **Track and angle position are given by the alignment of the hits**

# DT Performance in magnetic field

**Resolution**



**Efficiency**



Resolution < 300 μm
Efficiency > 99%
(for B field conditions expected in CMS)

- This detector is suitable for a muon spectrometer in iron (large multiple scattering)

->but for the VLHC needed a better chamber resolution

# Conclusions

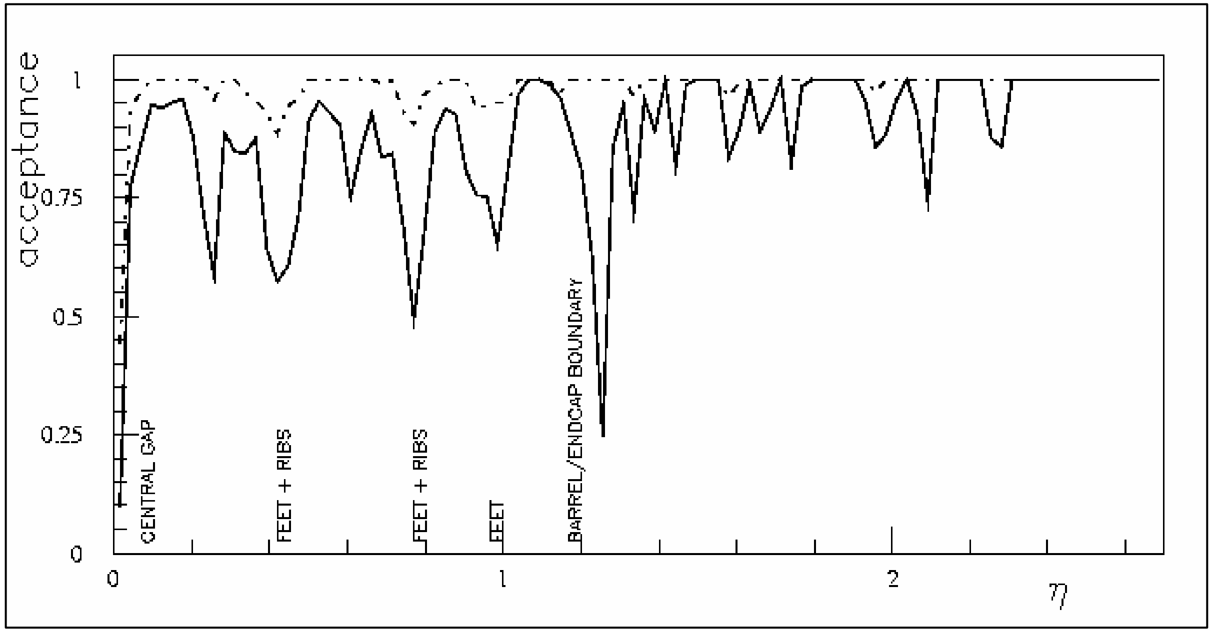
- The technology used for the LHC muon detectors and their successful use is a good starting point for the VLHC.
- At the VLHC an improvement of the momentum resolution dp/p of a factor 5 is required

  -> $BL^2 \sim 150$ Tesla $m^2$ needed
- We need a specific R&D programme for:
  - ✓Extensive ageing studies
  - ✓More precision resolution detectors
  - ✓Faster
  - ✓Cheaper (large surface to cover!!)
- Current LHC detector technologies were chosen after a successful detector R&D programme launched in early 90's

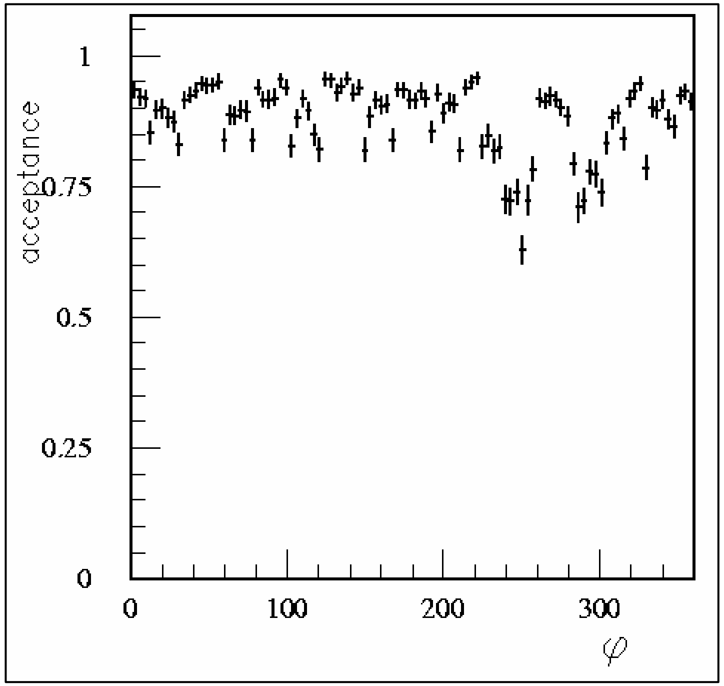
# Spectrometer performances

- Geometrical acceptance:
  - Trigger system | η |<2. 4 : low pt =93% high pt=92%
  - Tracking system | η |<2.7, 3 points/track : 89.6% (fake tracks ~0.1%)

**Tracking efficiency vs eta**

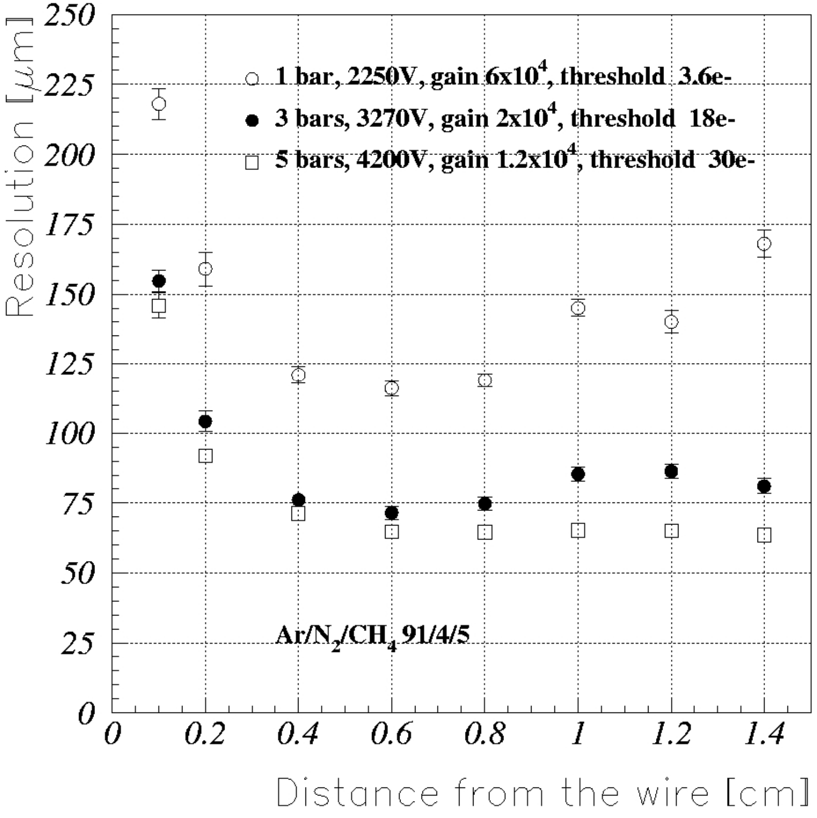


**Tracking efficiency vs phi**



# Dependence of the Resolution on the Pressure

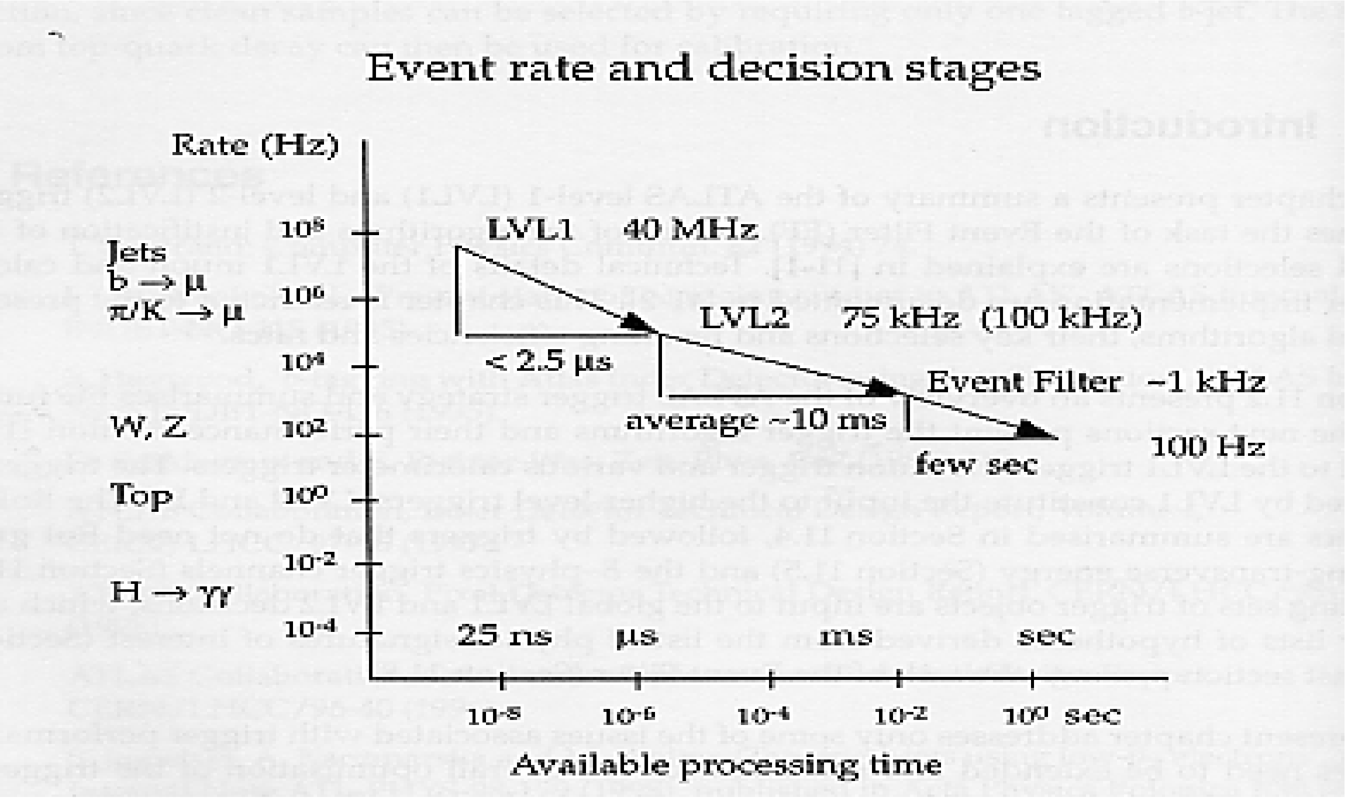
- Resolution improves with higher pressure
  - diffusion contribution decreases
  - smaller cluster position fluctuations (more clusters)
  - smaller contribution of charge fluctuations (higher threshold)
- Gas pressure of 3 bars chosen
  - big improvement 1 → 3bars
  - marginal improvement 3 → 5bars
  - with higher pressures maximum ion drift time grows → more space charge (3 → 5bars 30% more)



Different gas pressures compared

keeping the signal/noise ratio constant

# Trigger system



- ❖ **Three levels of trigger to reach the final output rate of ~ 100Hz**
  - ❖ **Level 1 : bunch crossing identification→trigger detectors time resolution << 25 ns**
  - ❖ **Level 1 latency time fixed to 2.5 μs**
  - ❖ **Level 1 must provide Region Of Interest (ROI) to level 2**

# RPC Ageing Studies

**A 15 months ageing test performed on module-0 at the GIF – X5 CERN irradiation facility.**

**GIF-X5:**
**Uniform irradiation with low energy gamma**

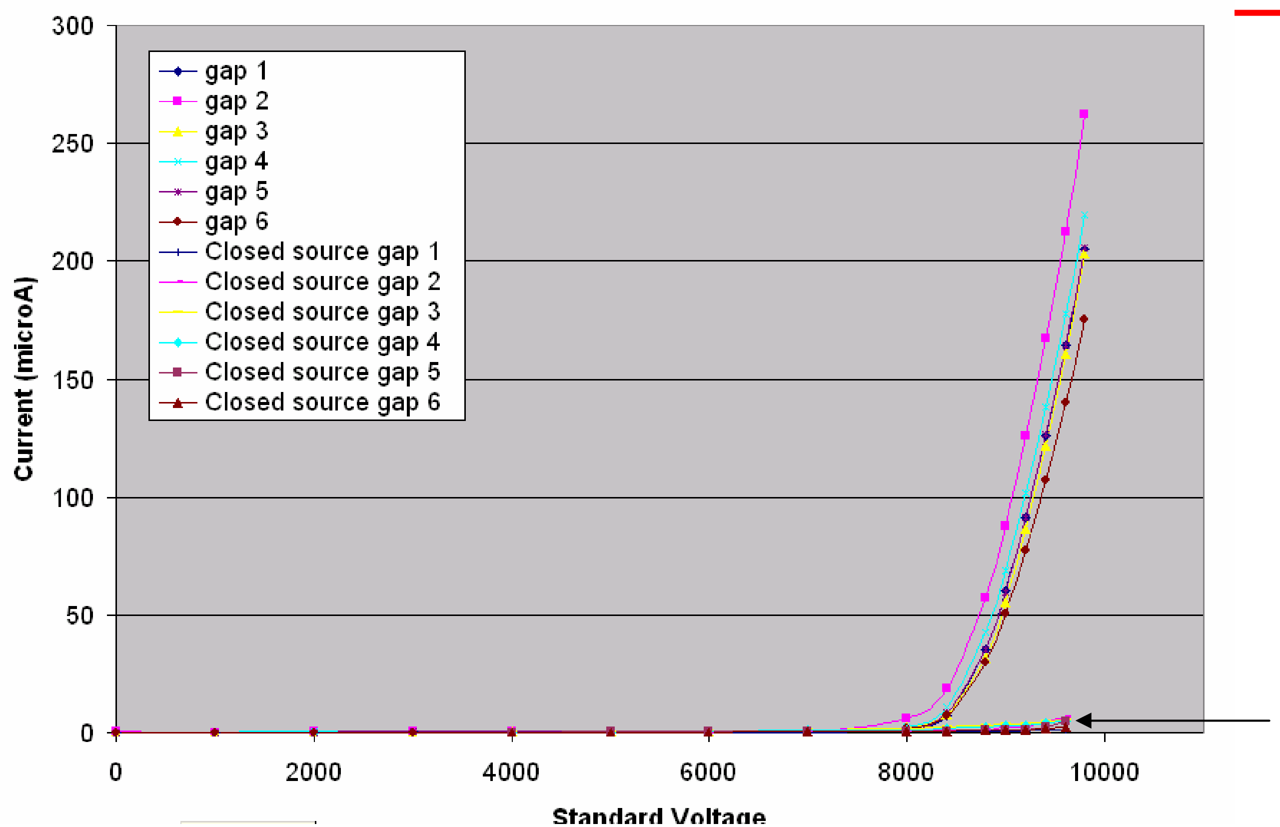
**Source:**
**740 GBq $^{137}$Cs**

**$E_\gamma$ = 0.662 MeV**

**RPC module-0**

- **Average expected counting rate in the ATLAS barrel ~100 Hz/cm$^2$ ( including a safety factor ~ 10)**
- **Total counts expected in 10 ATLAS years: $10^{10}$/cm$^2$**
- **Total delivered charge: 0.3 C/cm$^2$**

# Full source and source off operating currents



23.2°C-5/9/2003

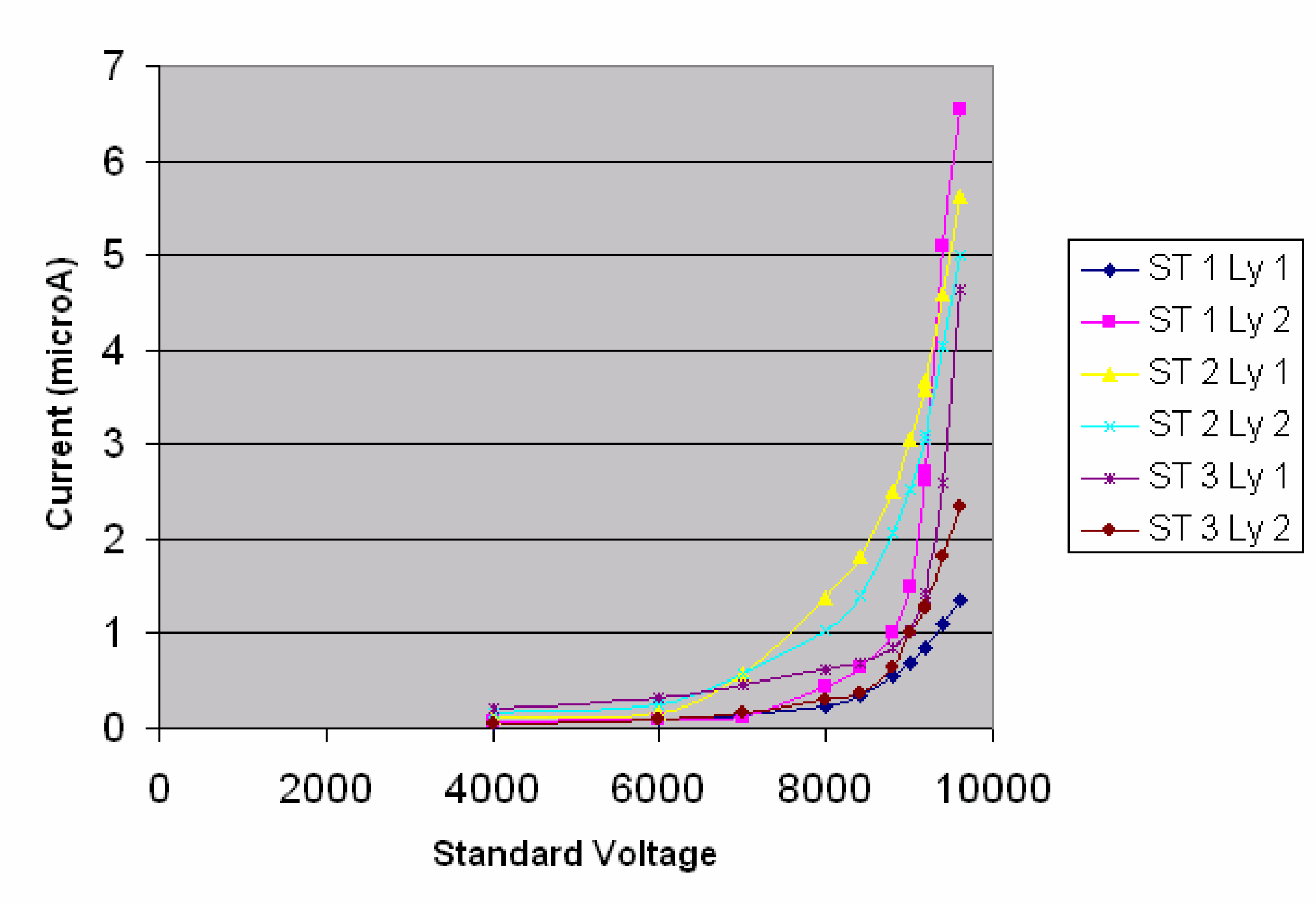
Closed source

- The source-off currents show also a modest increase which is to a large extent related to the temperature, however, part of this increase is an indication of ageing, which is still irrelevant for the detector performance

- This ageing effect, due to the extreme conditions of the test (about 40 times the nominal Atlas rate), has been shown to be amplified by high temperature operation (around 30 C) and lower gas flow (< 1 Vol/2hours)

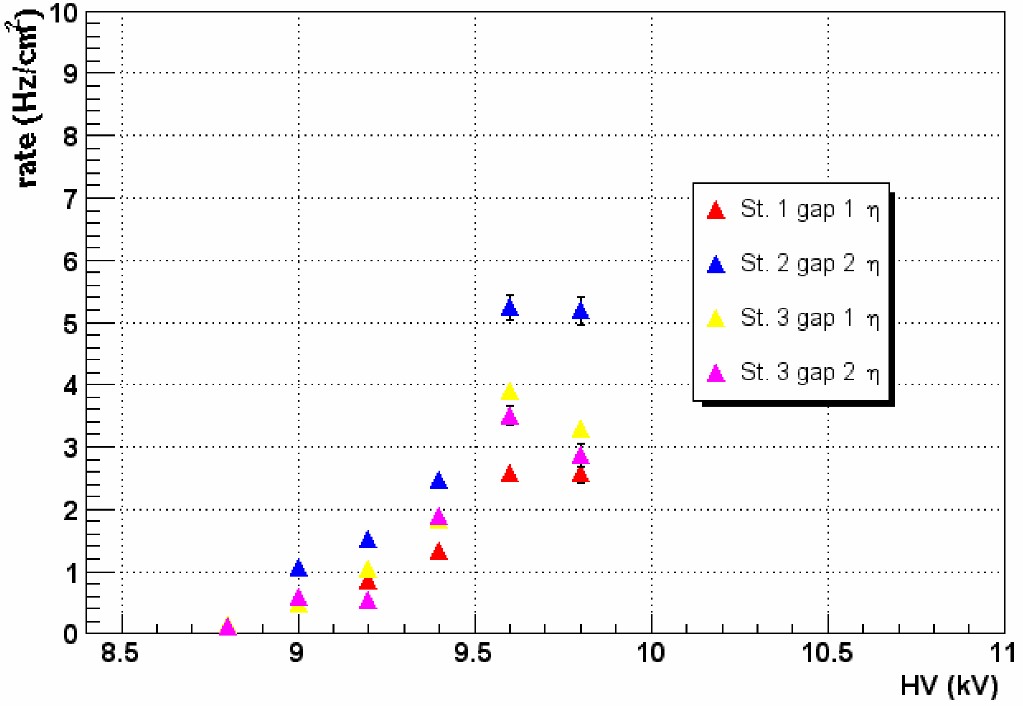
- We are now observing a very significant decrease of the closed source currents that we correlate to the reduced ageing rate (in the last 2 months) and to the decreasing temperature

# Closed source current



# Counting rate
# Open vs. closed source

no source



full source