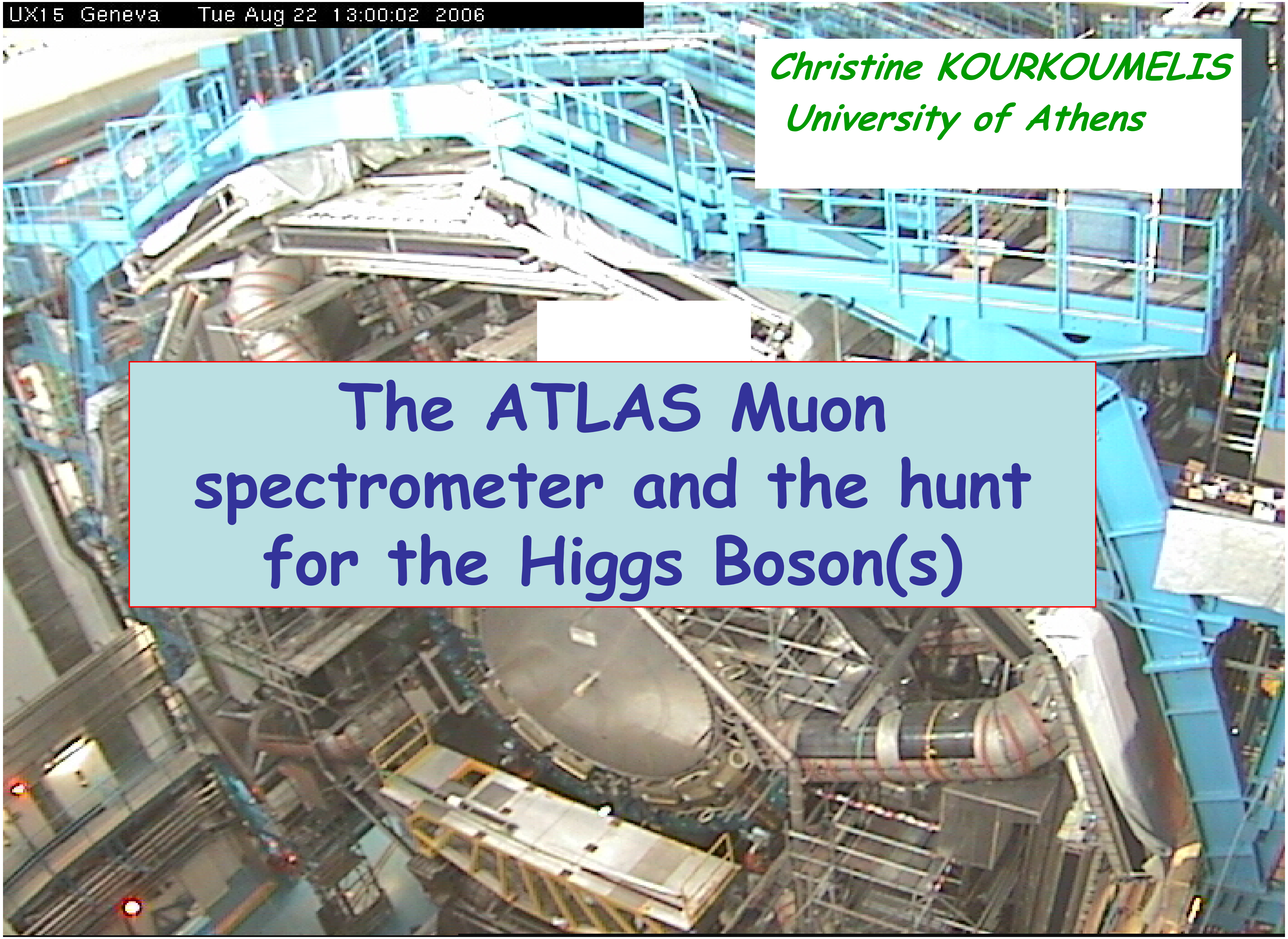
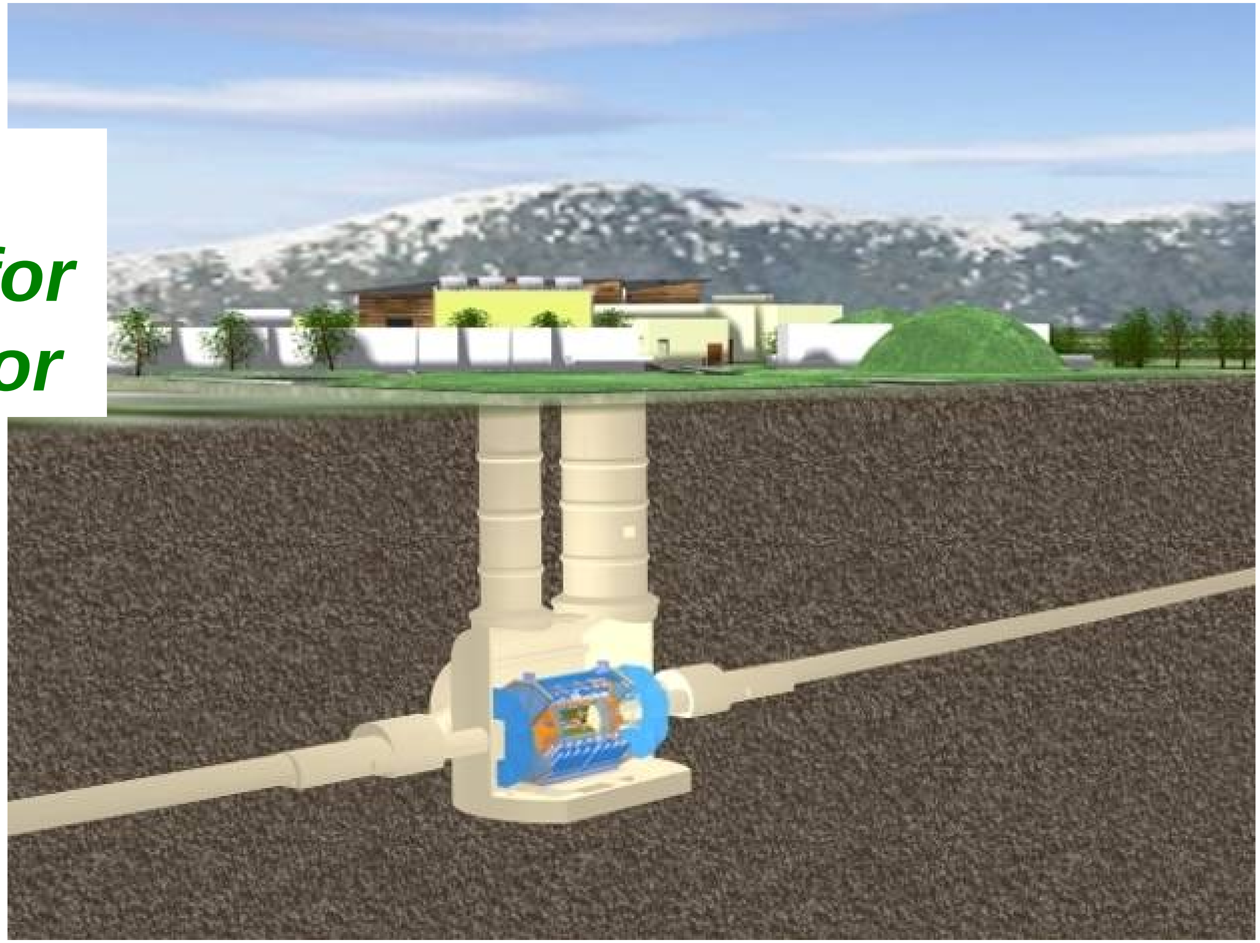


Christine KOURKOUMELIS
University of Athens

The ATLAS Muon spectrometer and the hunt for the Higgs Boson(s)

- LHC pp collisions @ $\sqrt{s}$=14 TeV
- ATLAS (+CMS) detector optimised for l's,γ's, b-jets,jets,measurements with the SM and beyond
  - Rapidity : $|\eta|$< 2.5 (l's, γ's) $|\eta|$< 5 (jets)
  - Momenta : soft to 5 TeV

The underground cavern at point-1 for the ATLAS Detector



Length = 55 m
Width = 32 m
Height = 35 m

Milestones for the machine

Last magnet delivered*	**October 2006**
Last magnet tested	**December 2006**
Last magnet installed**	**March 2007**
Machine closed	**31 August 2007**
First collisions	**November 2007**

(Presented by CERN to SPC and Council 23-6-06)

Full commissioning to 7 TeV during shut-down of winter 2007/8

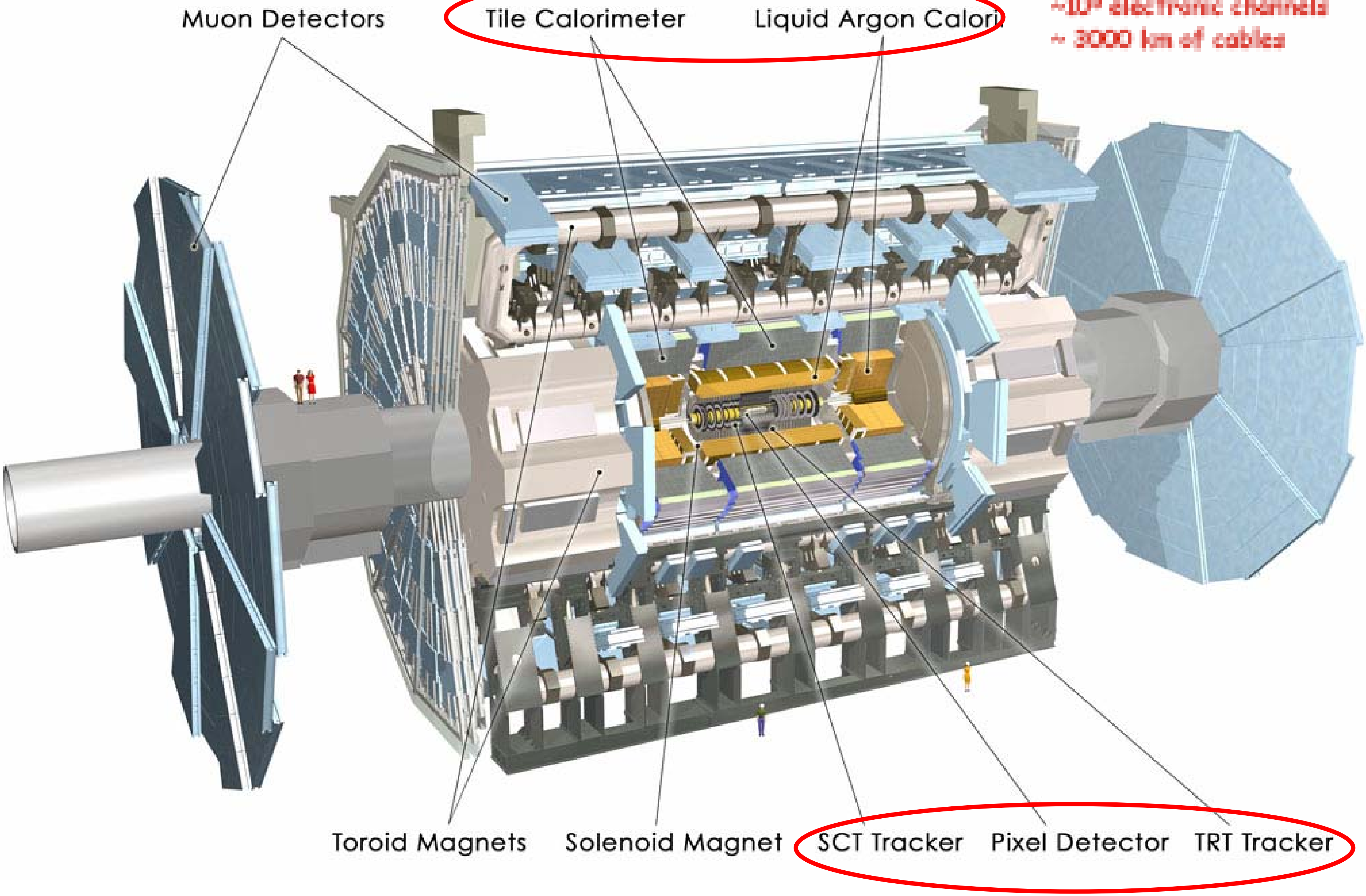
Physics Run @ $\sqrt{s}$ =14TeV : Spring 2008

* >90% of magnets already delivered

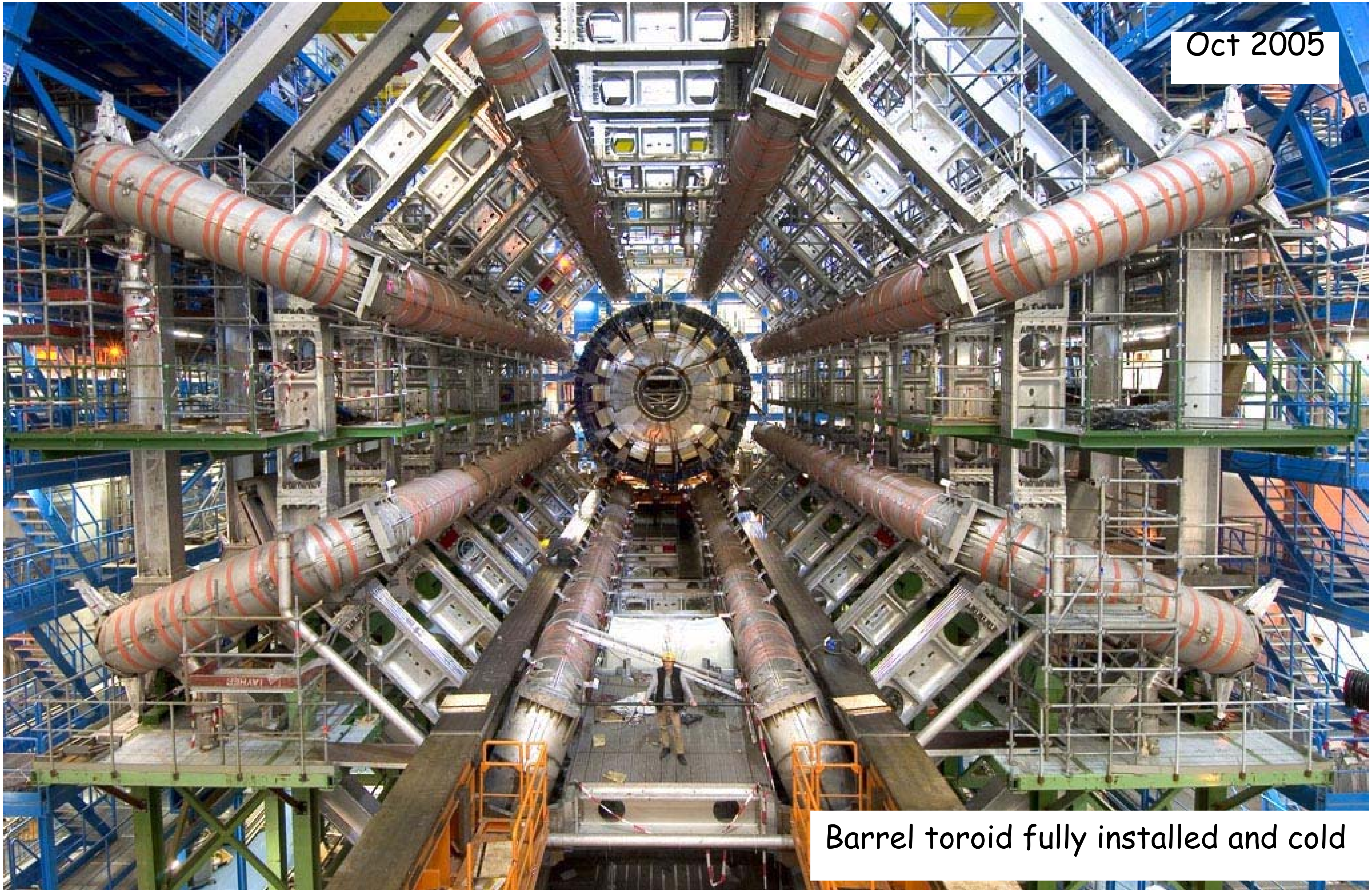
**half magnets installed July 2006

The ATLAS Detector

Length : ~46 m
Radius : ~12 m
Weight : ~ 7000 tons
$\sim 10^8$ electronic channels
~ 3000 km of cables



Most spectacular magnet



More magnets…

Barrel Solenoid
Installed,cold,and
operational

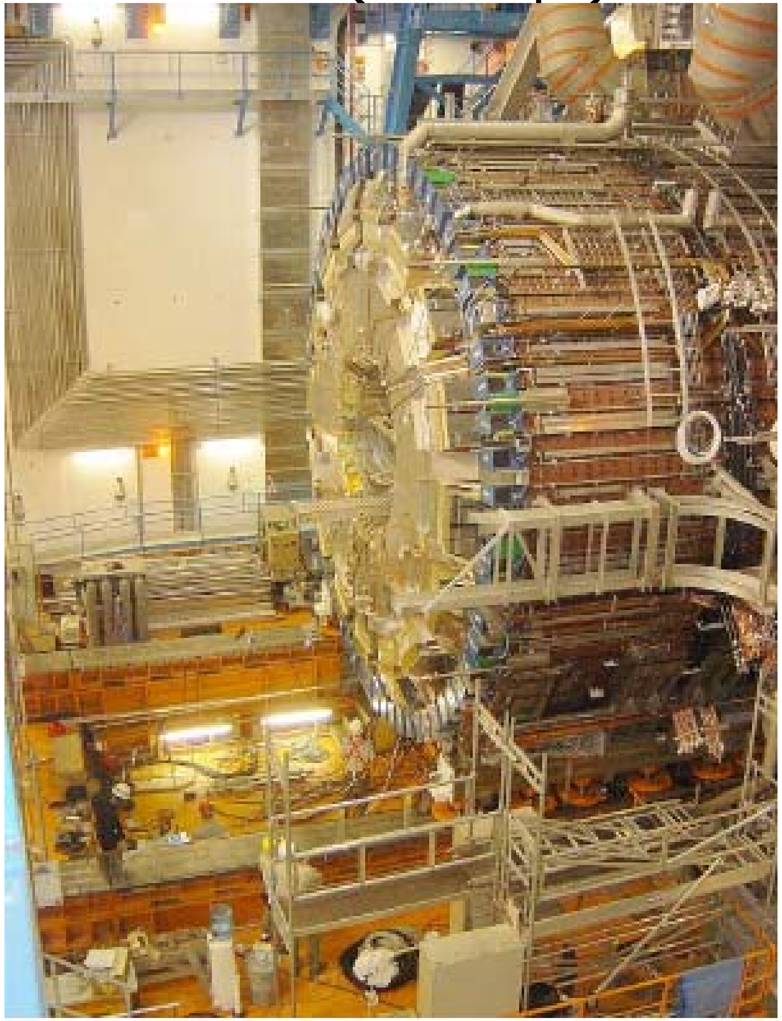
End-cap toroid(s)
To be installed
end 2006 (A) & beg 2007(C)

Calorimeters :

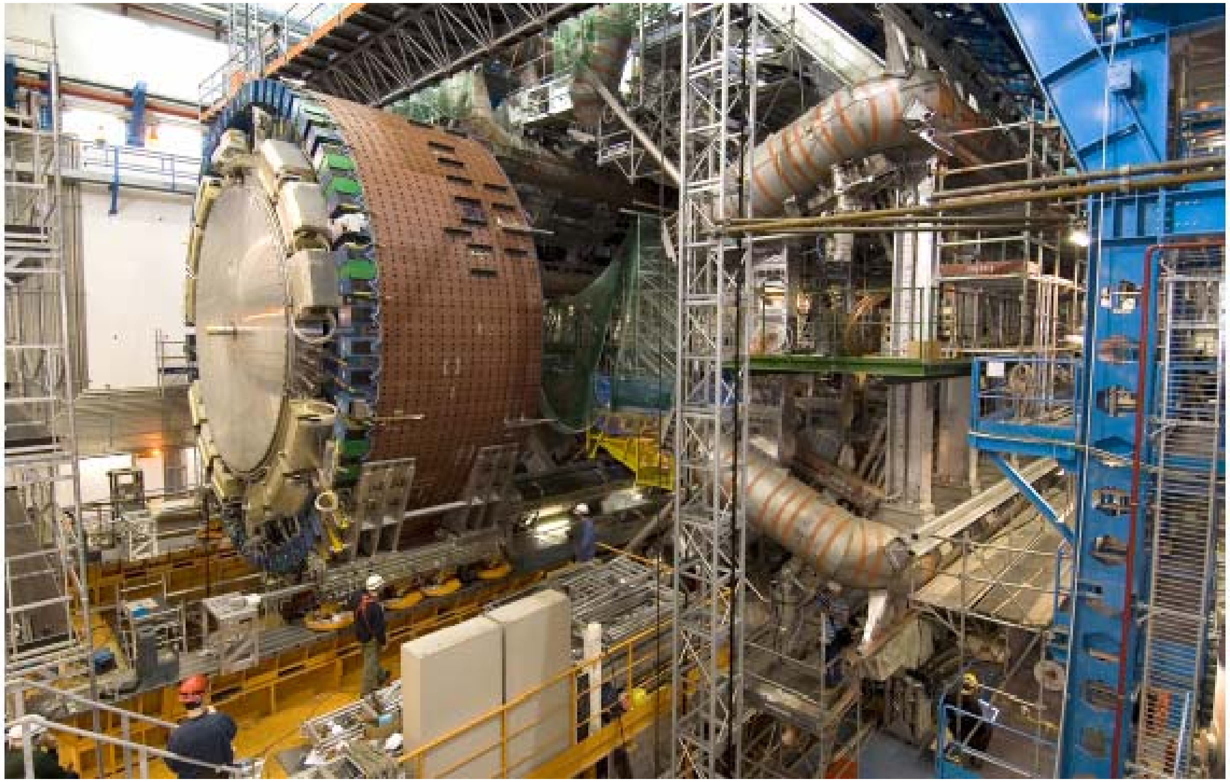
EM: Pb-Ar (barrel) (filled with 45kl LAr)

Hadronic: Fe/Tiles (barrel)

Cu/W-LAr (end-caps)

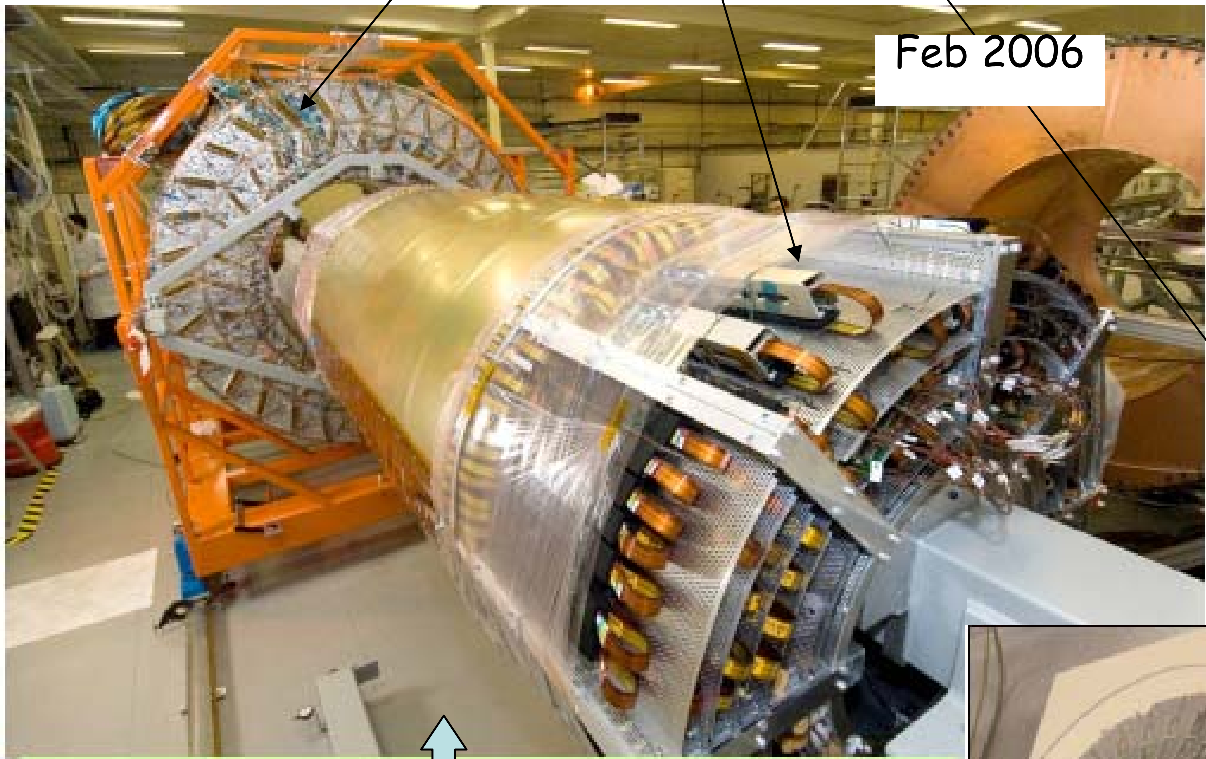


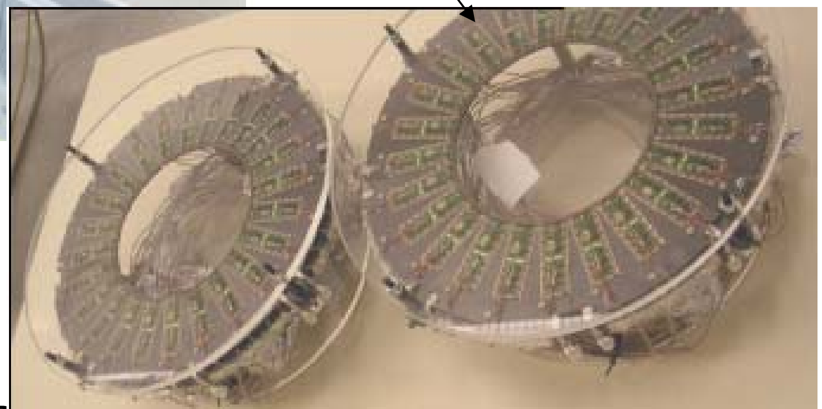
End cap calorimeter



Inner detector (tracking)

SCT + Si pixels +
TRD with straws for e/π discrimination

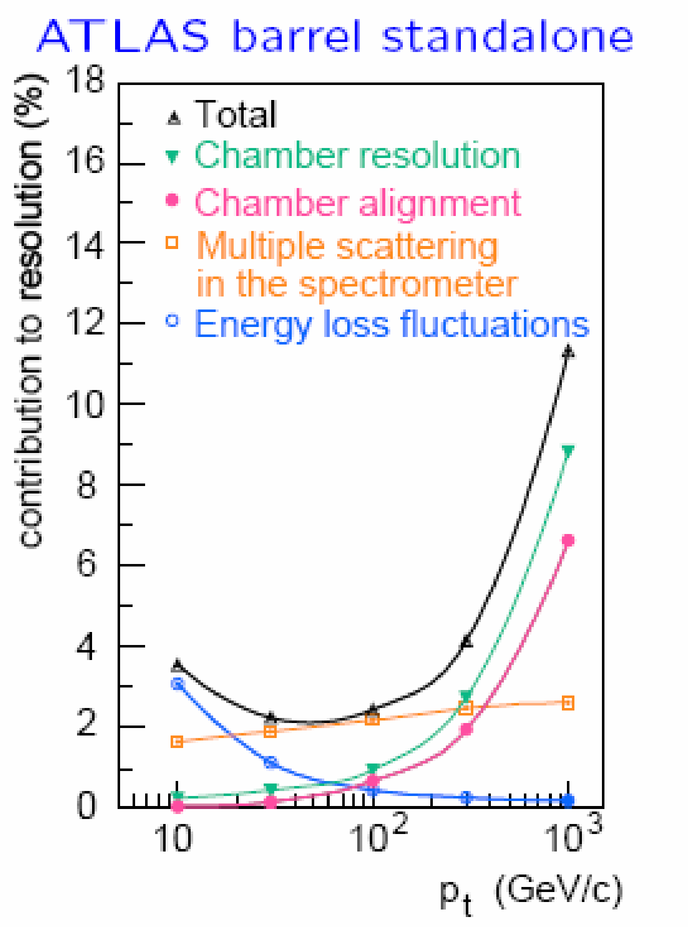




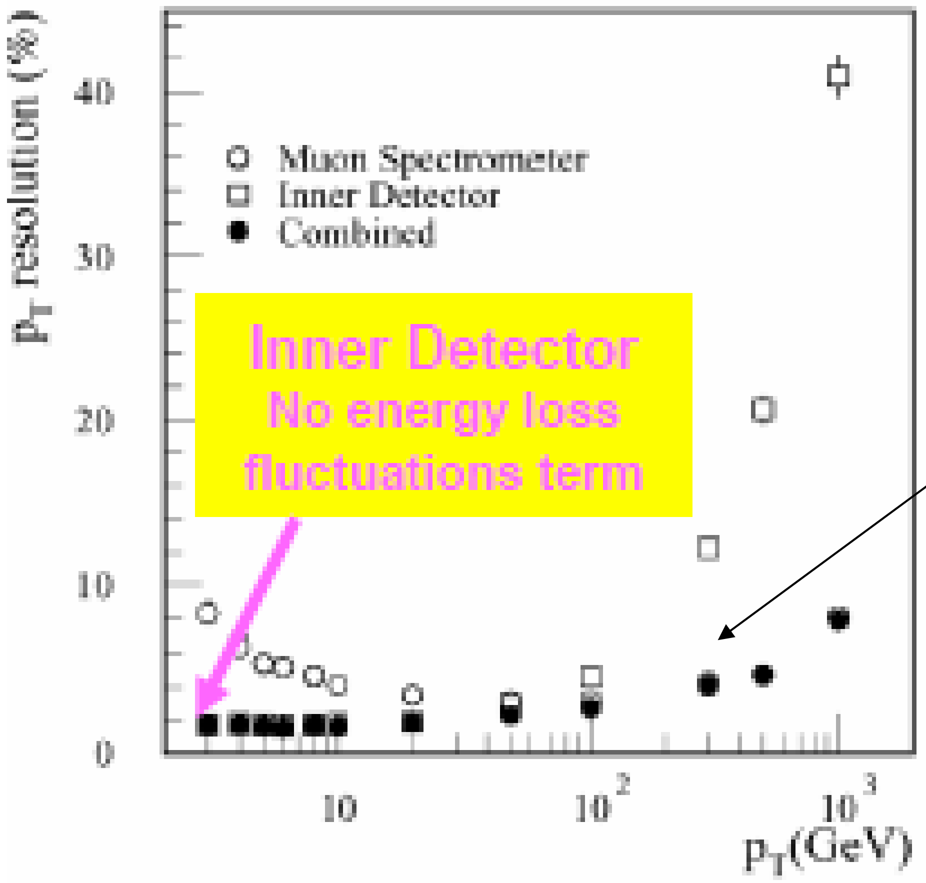
Took cosmics
To be installed in the pit soon

Muon Spectrometer:What for?

- Measure momenta from ~5 GeV to few TeV
- Trigger on muons (+BC)
- Identify muons
- Physics channels:
  - $H \to ZZ^* \to \mu\mu\ell\ell,$
  - $A \to \mu\mu,$
  - $Z' \to \mu\mu.$

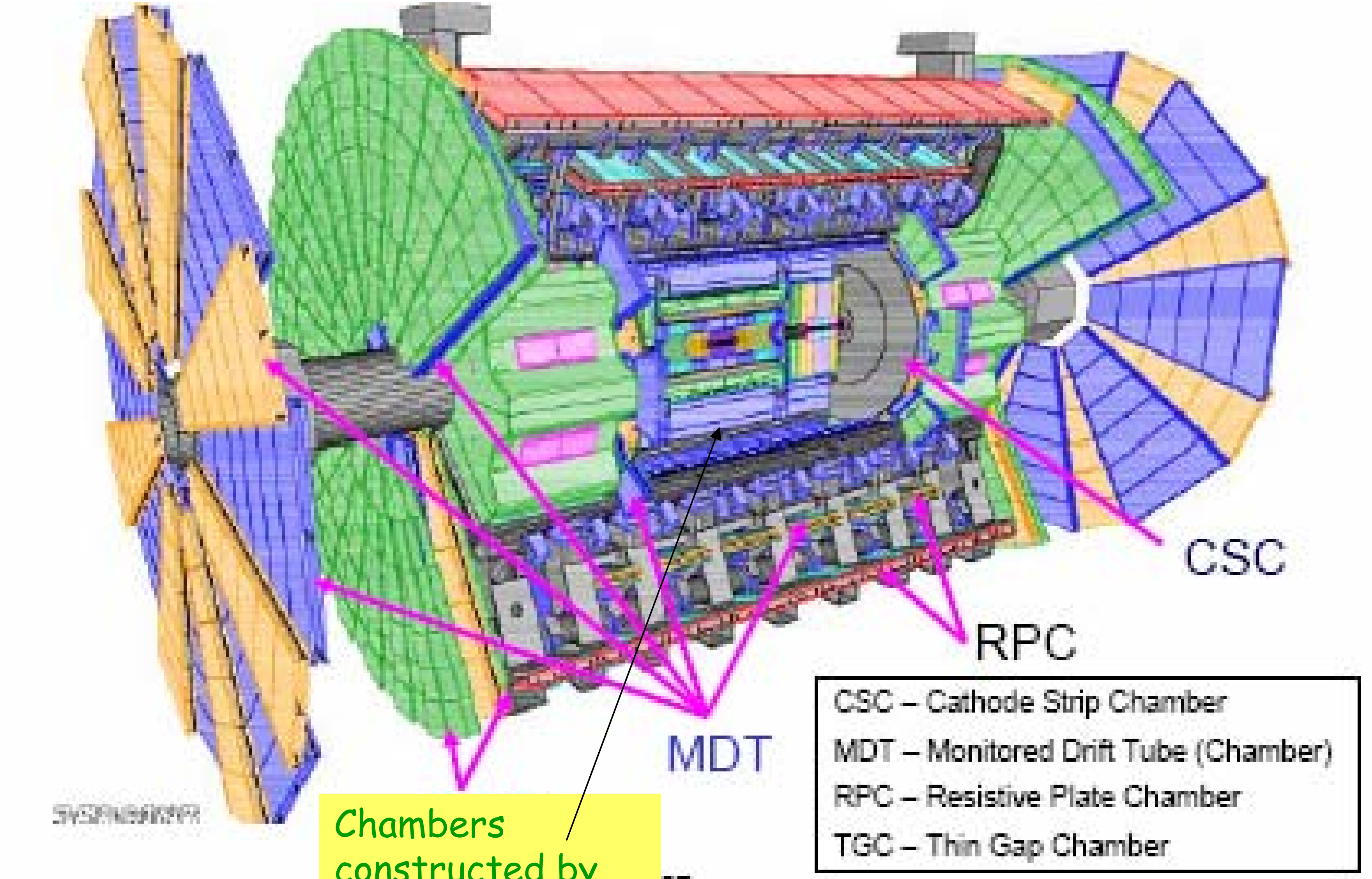


Muon spectrometer +Inner detector



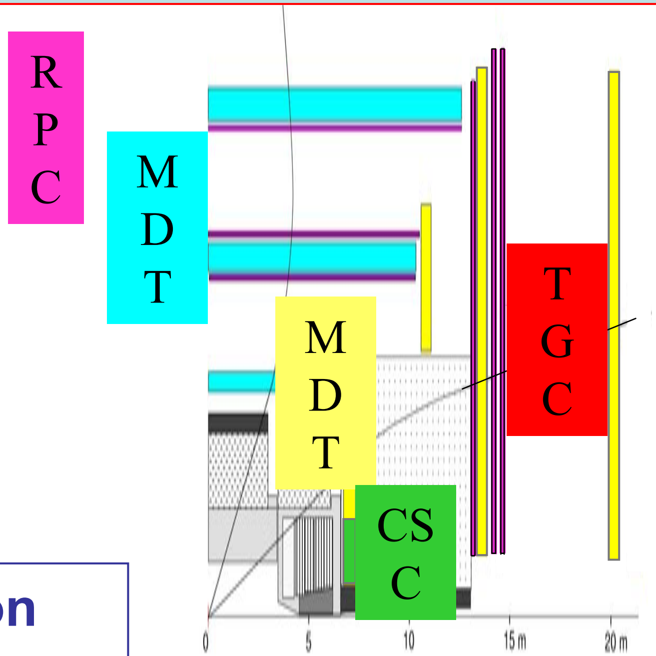
$\Delta p/p$ <10%
up to 1 TeV

The different technologies of Muon chambers



Chambers constructed by the three Greek institutions

ATLAS: Muon Chambers



Precision chambers

Trigger chambers

Monitored Drift Tubes $(|\eta| < 2)$

with a single wire resolution of 80 μm

1194 chambers, 5500m^2

GREECE constructed 12%

Cathode Strip Chambers $(2 < |\eta| < 2.7)$

at higher particle fluxes

32 chambers, 27 m^2

Resistive Plate Chambers $(|\eta| < 1.05)$

with a good time resolution of 1 ns

1136 chambers, 3650 m^2

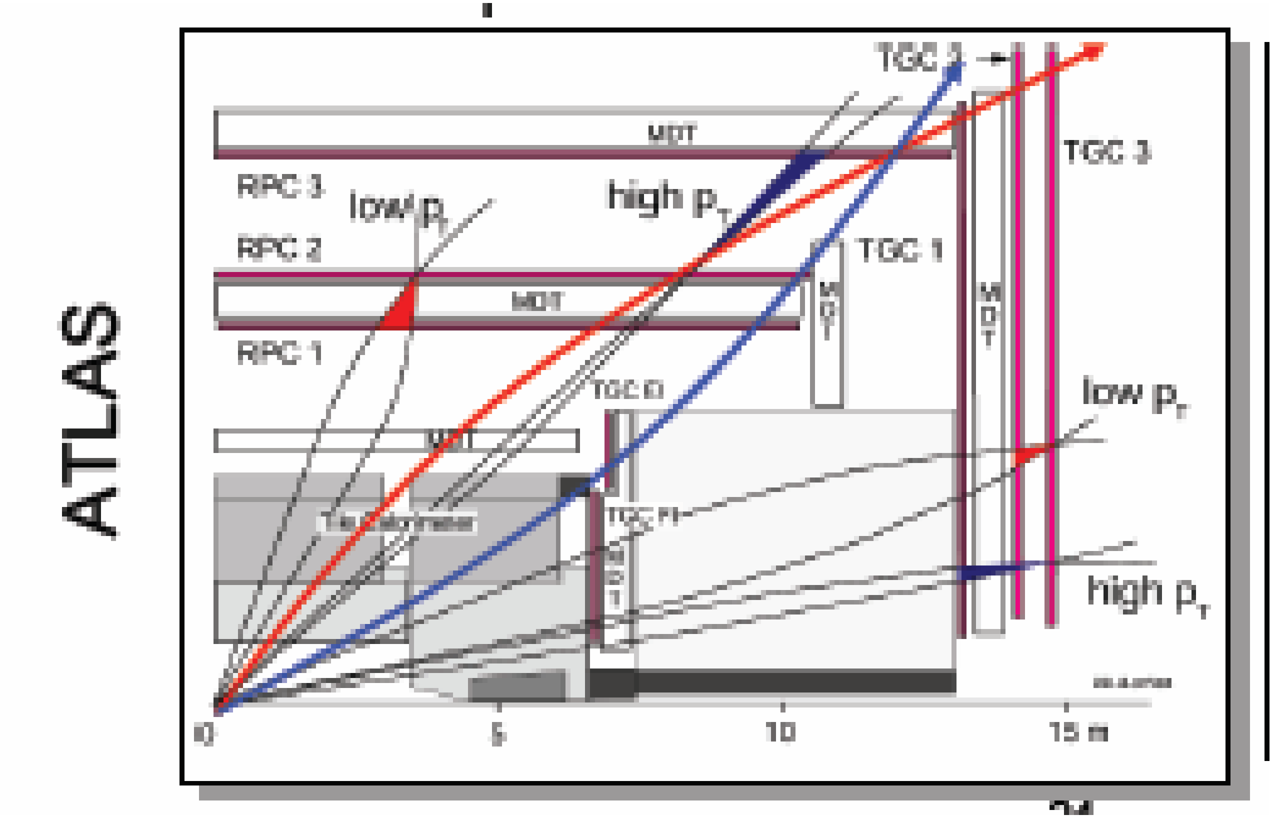
Thin Gap Chambers $(1.05 < |\eta| < 2.4)$

at higher particle fluxes

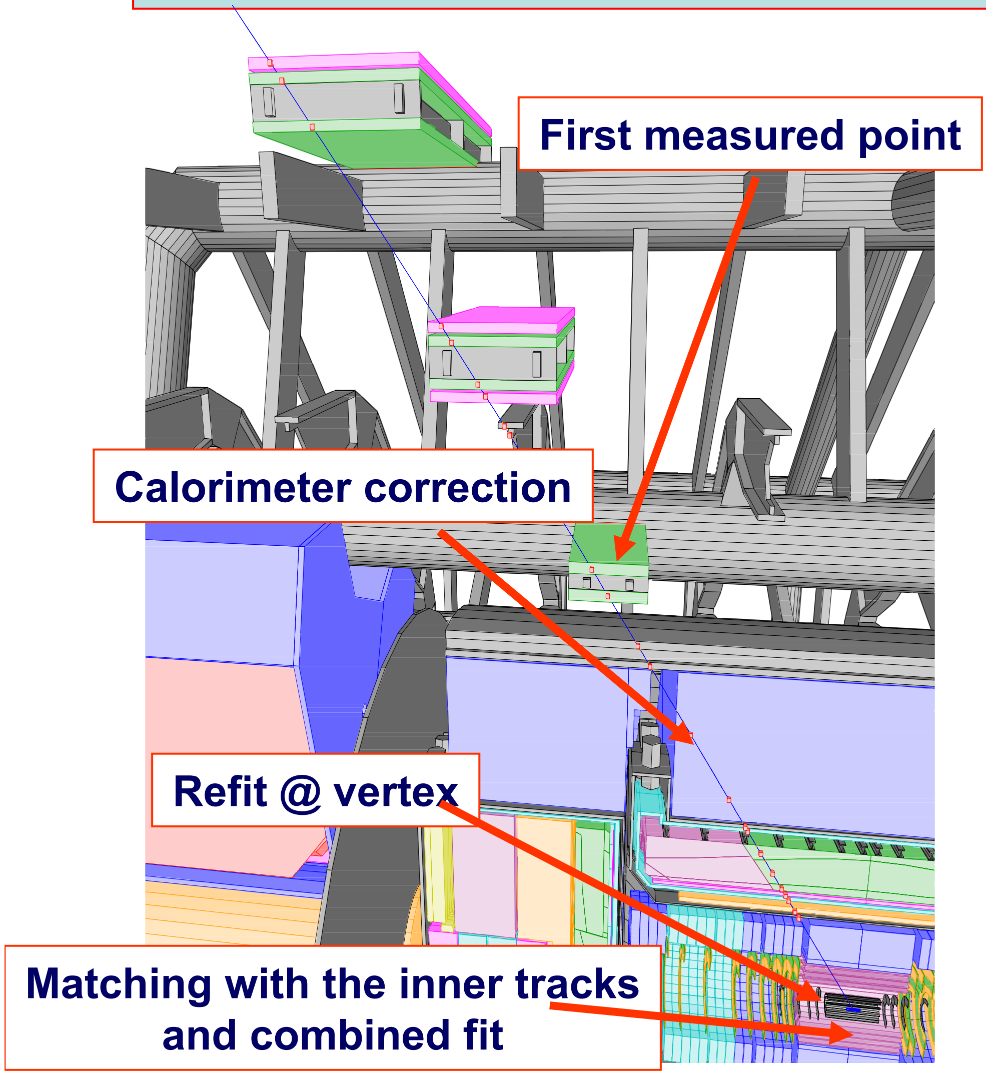
1584 chambers, 2900 m^2

Overview of muon trigger

Determine Trigger segments ROI in η,φ of width (δη,δφ)



Overview of muon identification



I Muon system as tracker

- standalone Muon system
- combination of muon and ID track
- Eloss-calorimeter

II Muon system as tagger

- starting point is ID track
- muon identification by extrapolation and matching to muon segments/hits

III Calorimetry tagging

PRECISION CHAMBERS (380,000 MTD tubes)+CSC's

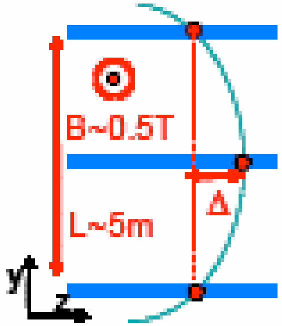
Challenge was the construction accuracy and the constant monitoring

ATLAS Muon Spectrometer:

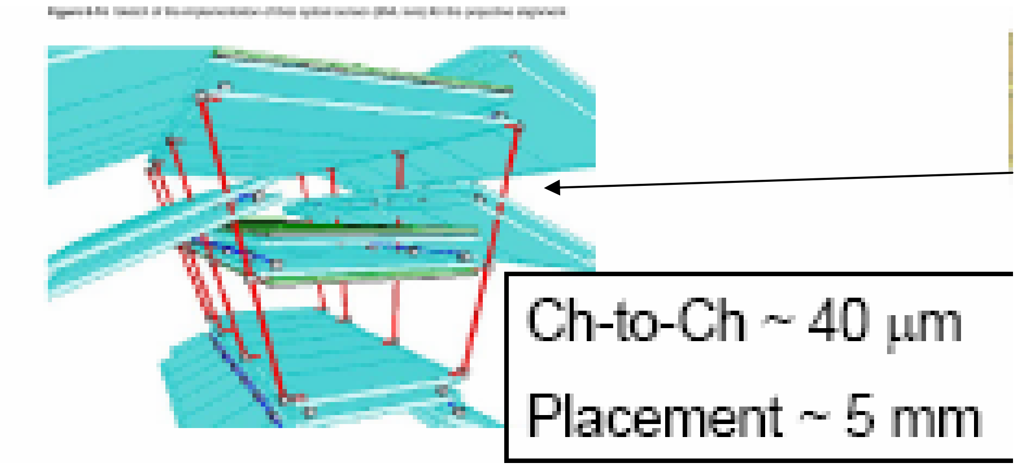
$E_\mu \sim 1$ TeV $\Rightarrow \Delta \sim 500\ \mu m$

⬇

- $\sigma/p \sim 10\% \Rightarrow \delta\Delta \sim 50\ \mu m$
- alignment accuracy to $\sim 20\ \mu m$



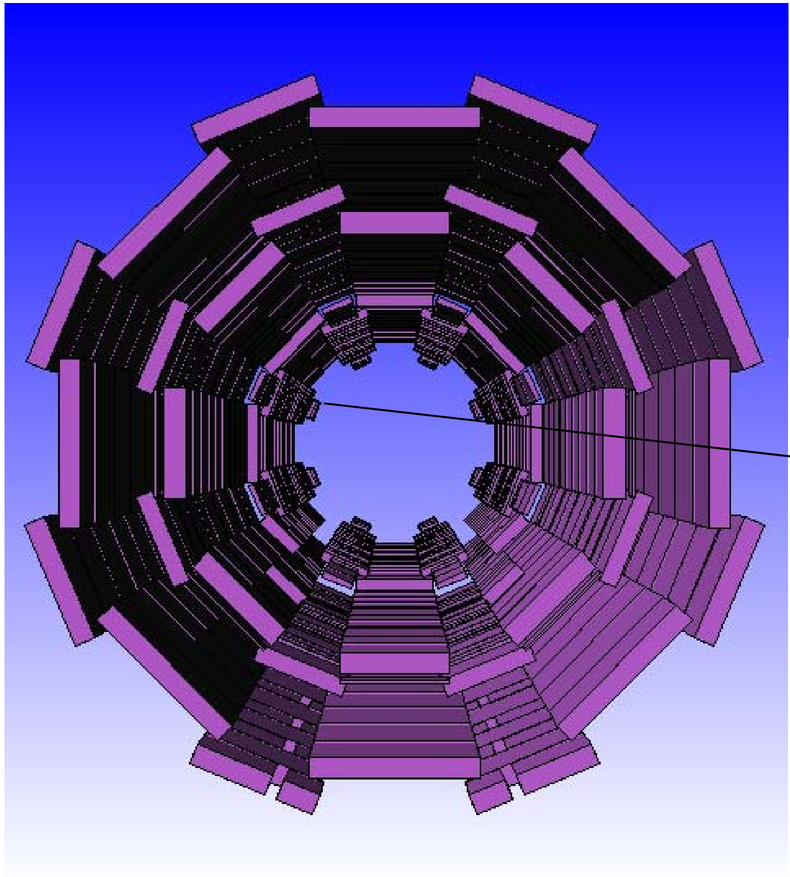
The sagitta story



Barrel alignment

The Greek Tracking Muon Chambers (BIS)

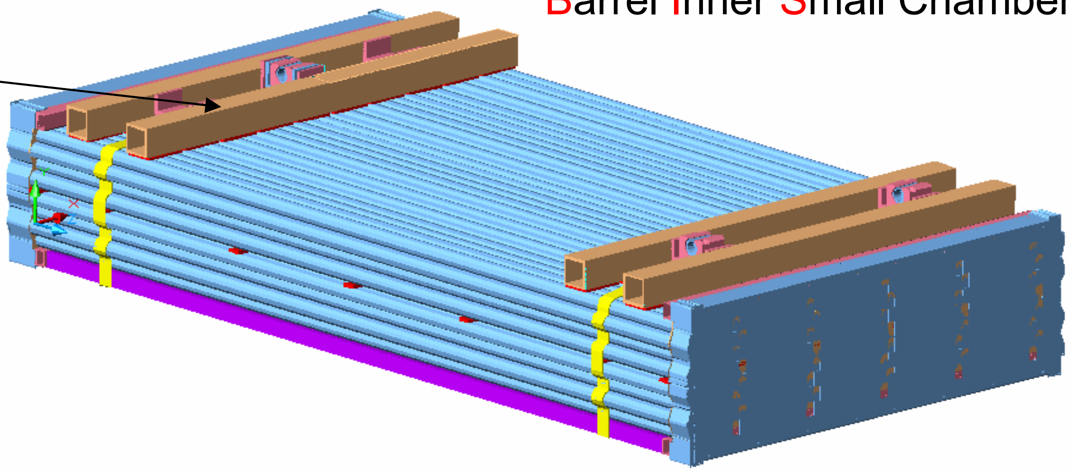
Transverse view of the Muon Spectrometer



The three Greek Laboratories:

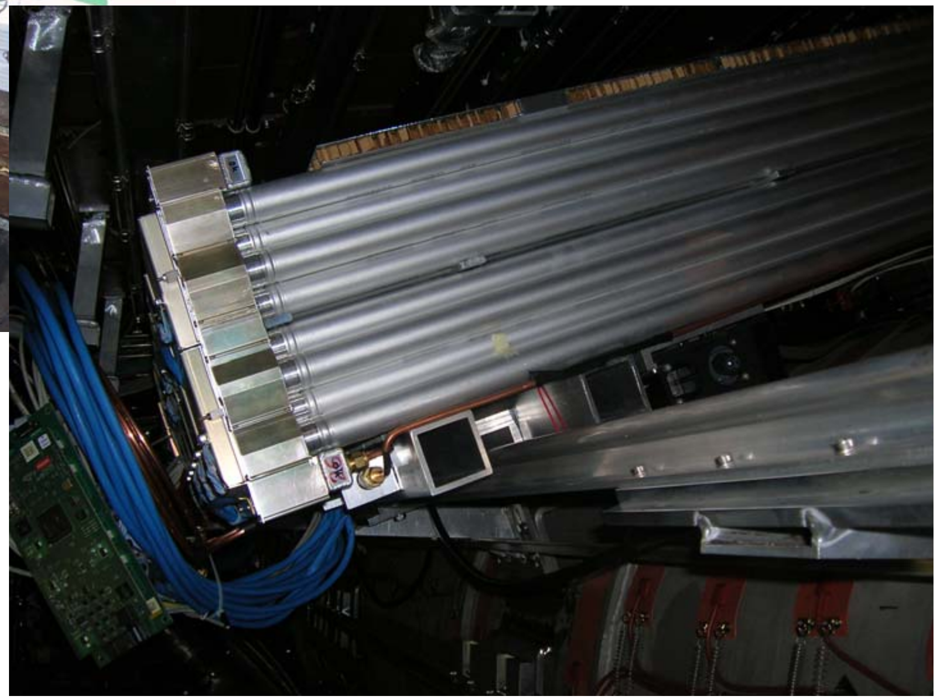
- University of Athens (UoA)
  MDT tube assembly
- National Technical University of Athens(NTUA)
  Quality Assurance/Quality Control of MDT tubes
- Aristotle University of Thessaloniki (AUTh)
  MDT chamber assembly and test

Barrel Inner Small Chambers



The tube wiring table at UoA (start 1998)

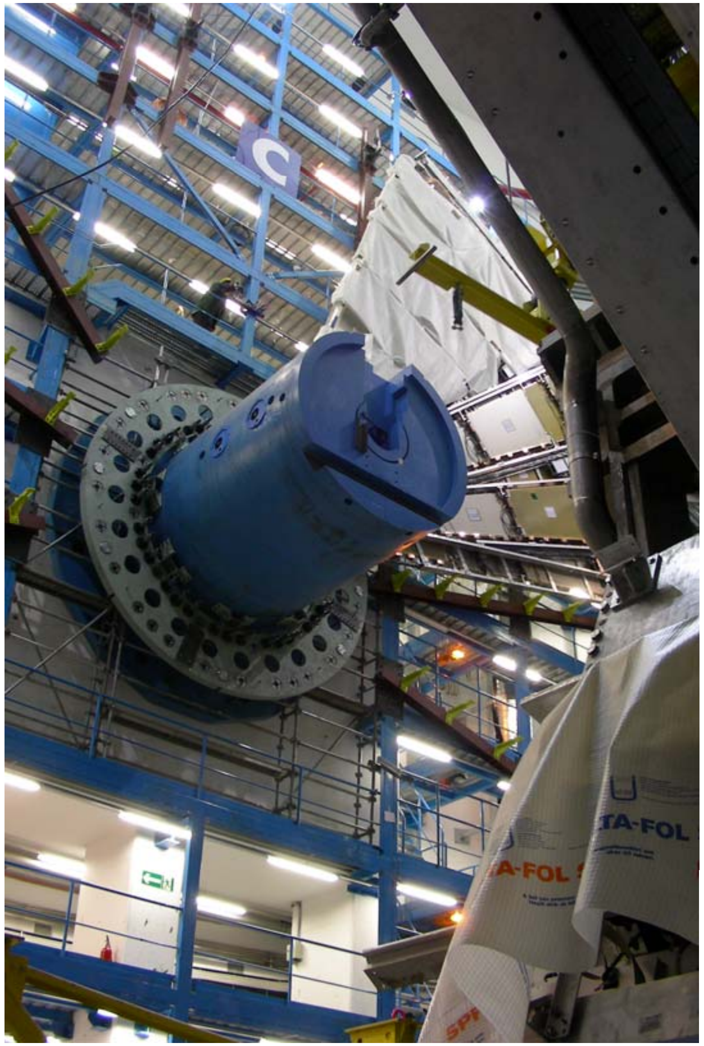
The finished product!!
Installed at the pit
(summer 2006)

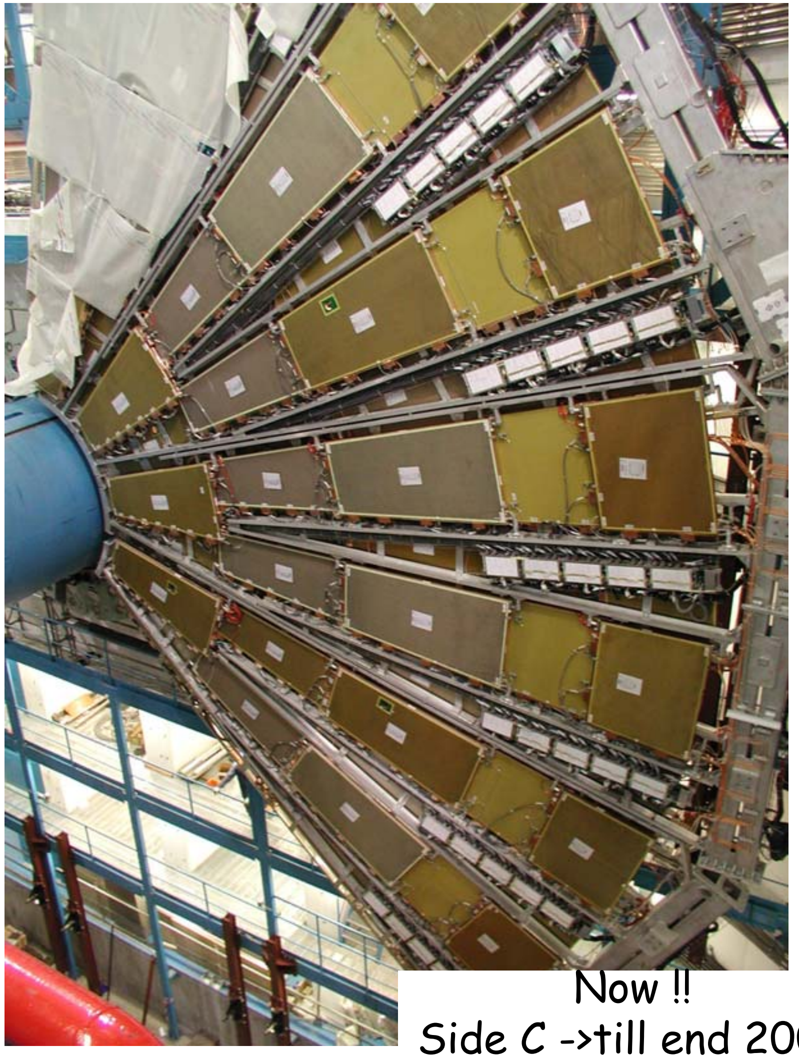


Barrel Muon Installation

Barrel chamber installation (to be almost completed at end of August)

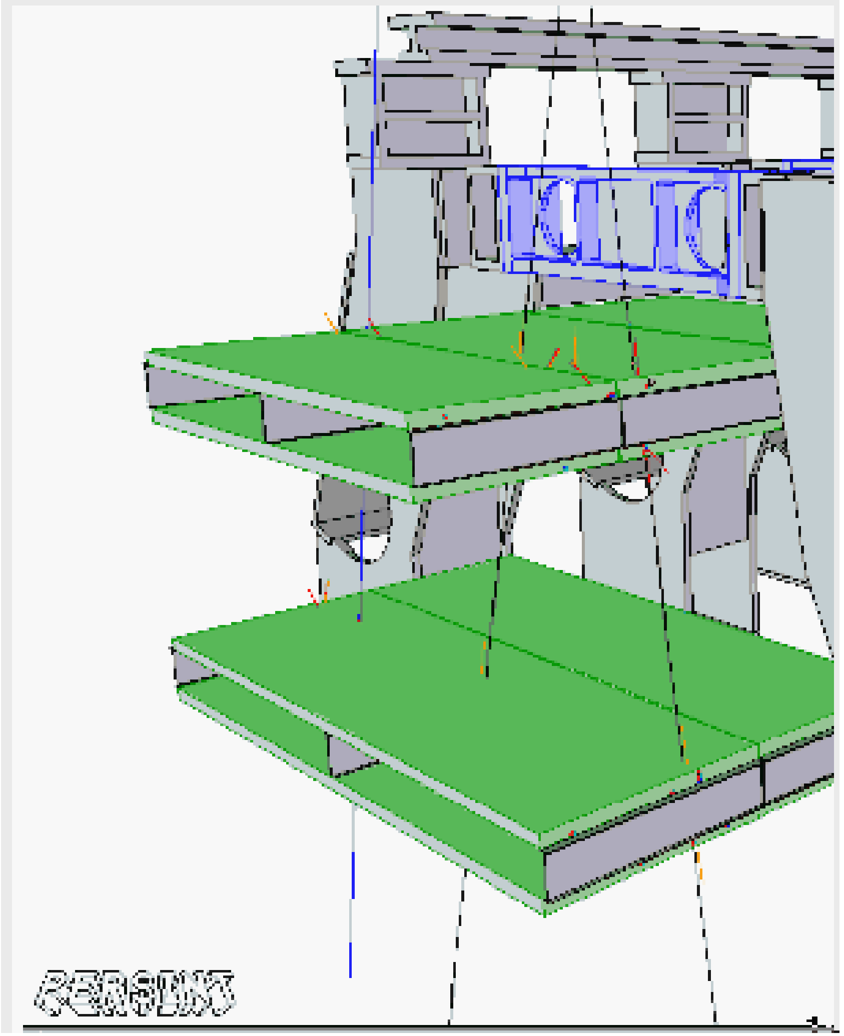
Big-Wheel Sectors' installation

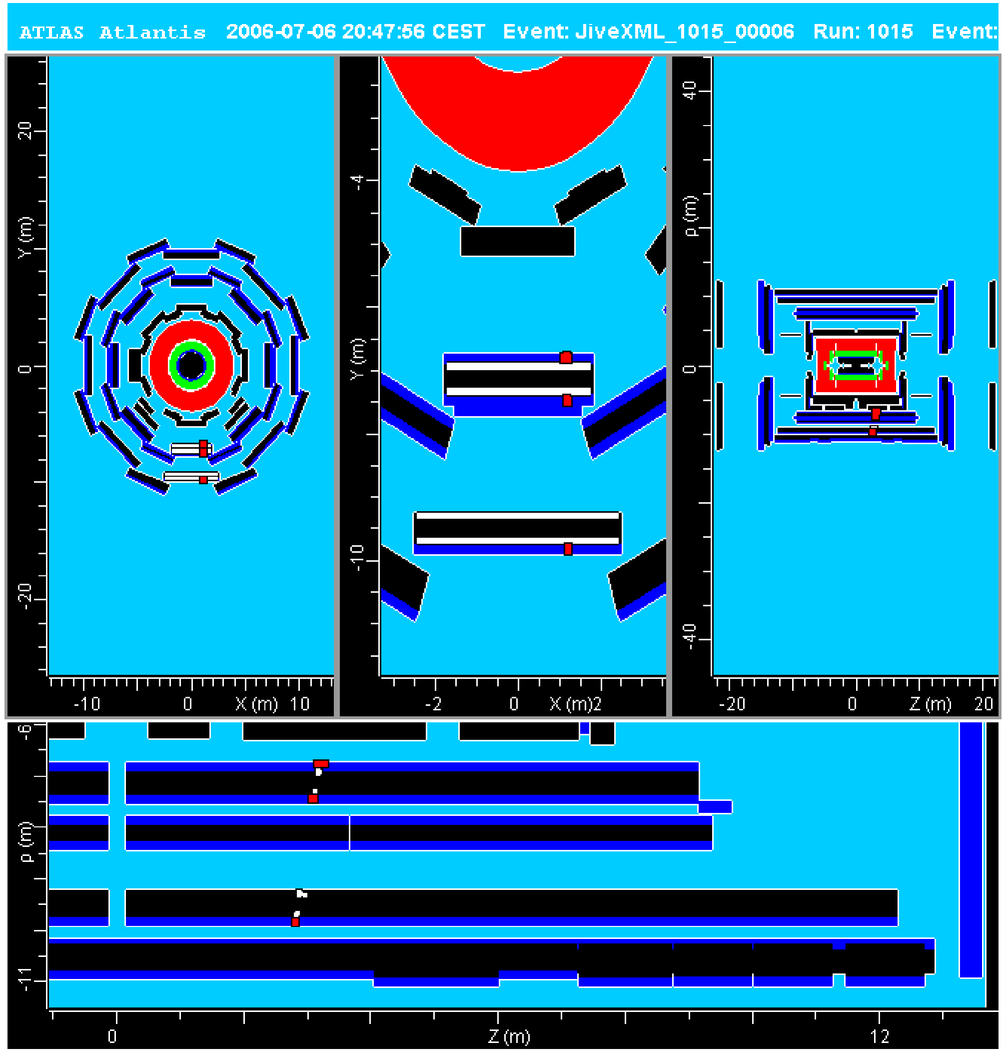




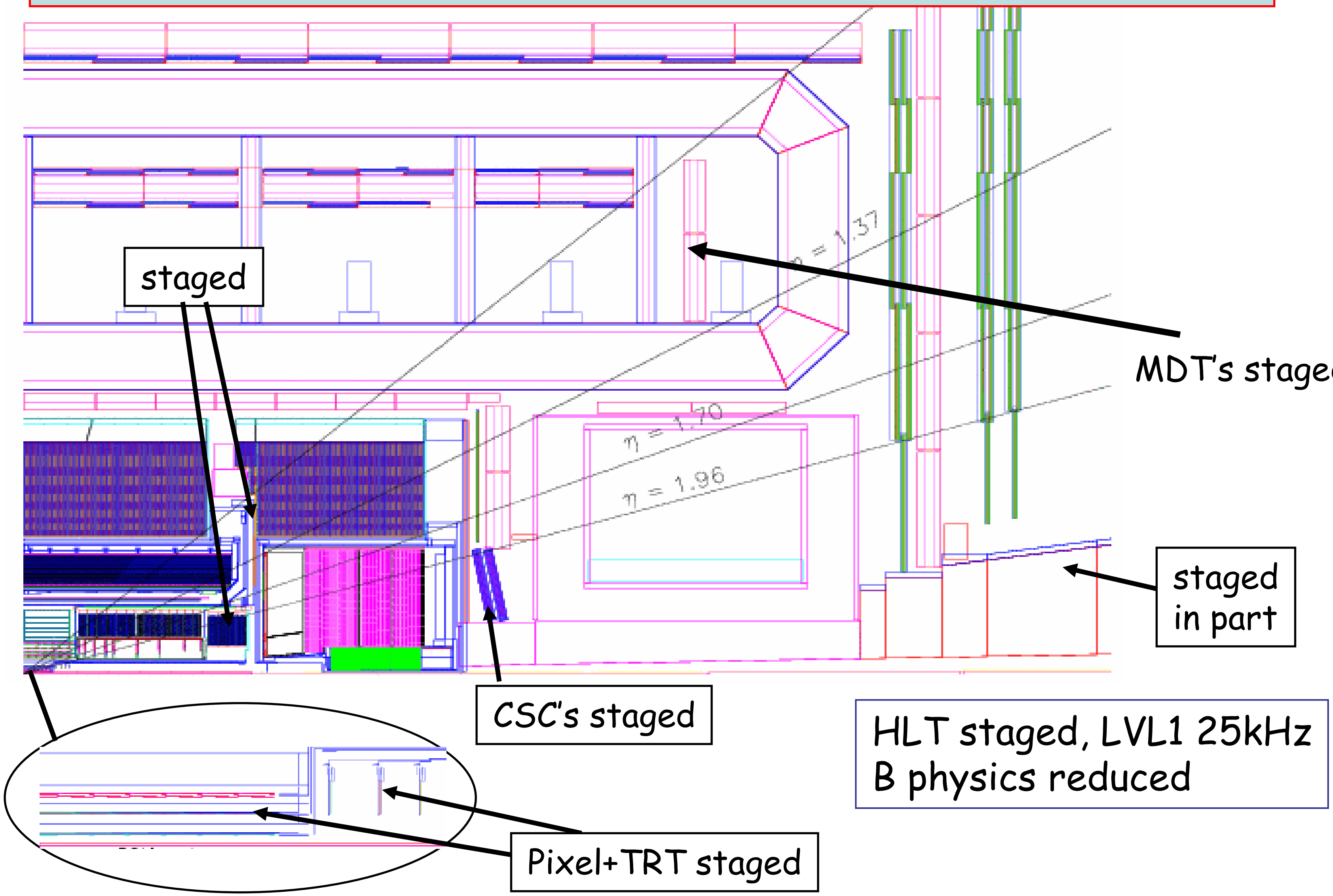
Now !!
Side C ->till end 2006

Cosmic rays at station 13 (feet)





Staged detector/trigger in the first year



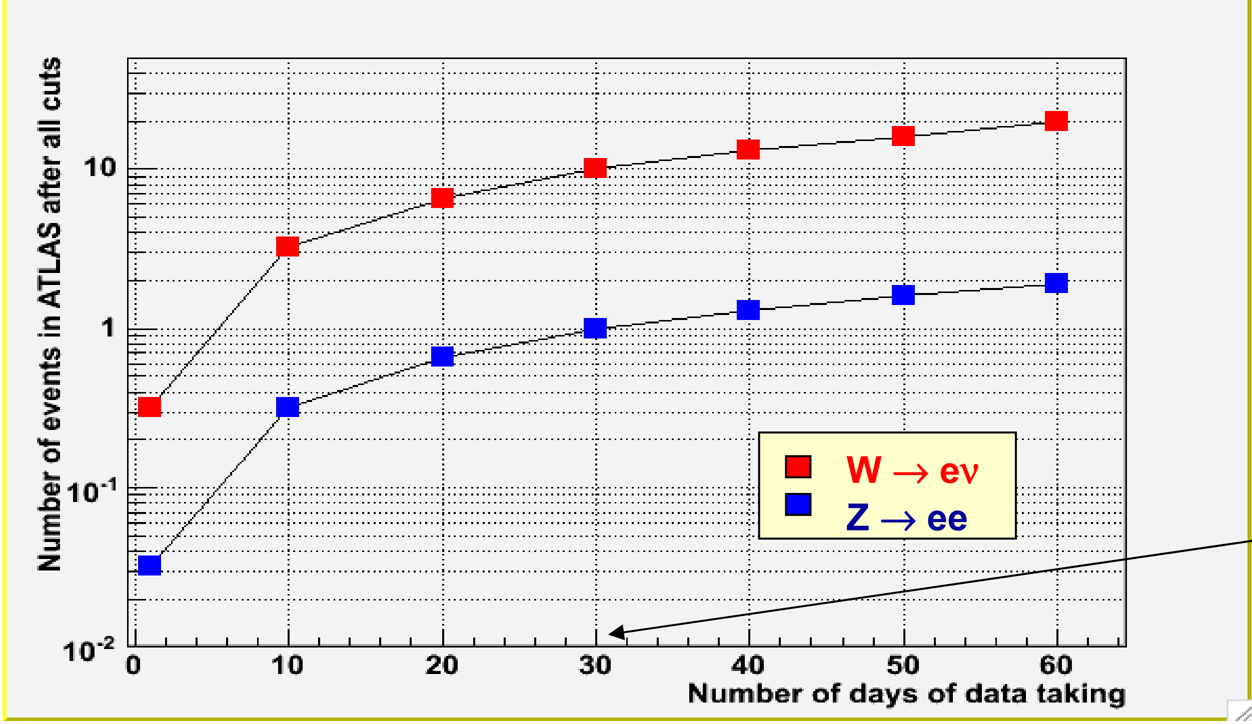
Now:
Let’s look at some examples of expected physics performance during the first years

LHC machine scenario:

Nov 2007 : pp collisions at $\sqrt{s}$= 900 GeV @ 10^{29} $cm^{-2}sec^{-1}$
April 2008 : two beam-collisions (low luminosity)
End 2008 : accumulate few fb^{-1}

Assume: 10 pb^{-1} /month @10^{30}
100pb^{-1}/few days @ 10^{32} (eff~50%)
1-10 fb^{-1}/year
Assume: $6*10^{6}$ sec/year (duty factor 20%)
L~ few*10^{33} $cm^{-2}sec^{-1}$ up to 2009

End 2007 running :pp collisions @ $\sqrt{s}$=900 GeV $L \sim 10^{29} cm^{-2} s^{-1}$

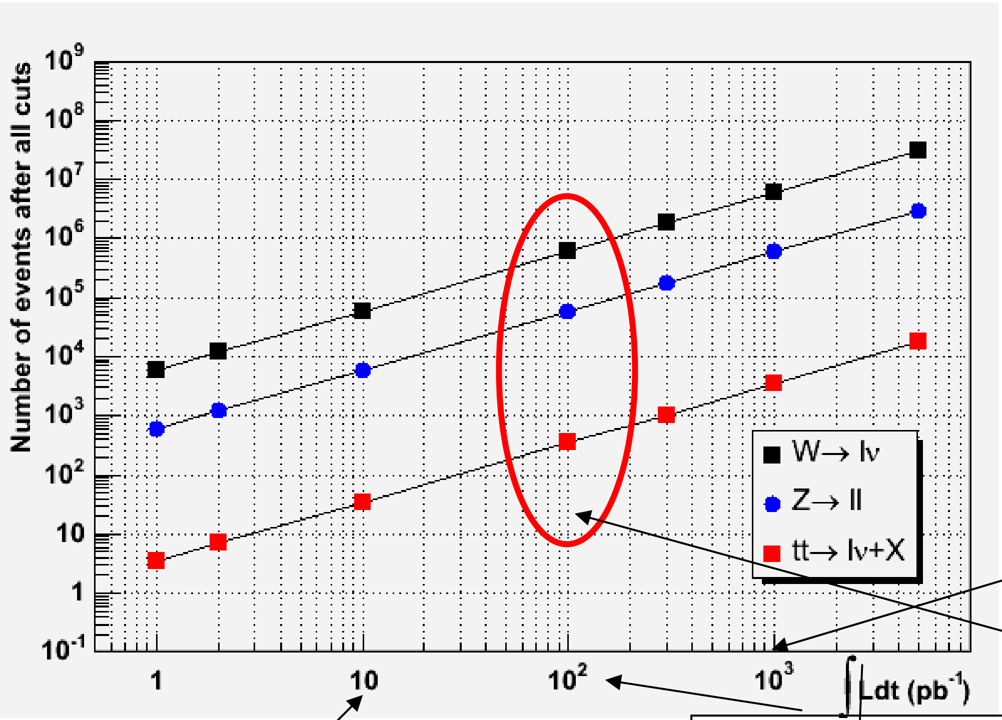


30% data taking efficiency included (machine+detector)

100 nb^{-1}

Very few W, Z's, **mainly detector commissioning**, min bias events (1M/day),UE, compare to SppS data, trigger rate 1-2kHz

2008 running : pp collisions @ $\sqrt{s}$= 14TeV $L \sim 10^{30 \to 32}$ $cm^{-2}s^{-1}$



- MB
- QCD jets
- Z's
- W's
- top

6 months @10^{32} (50%eff)

One month @10^{30}

Few days @10^{32}

Statistics of Tevatron now

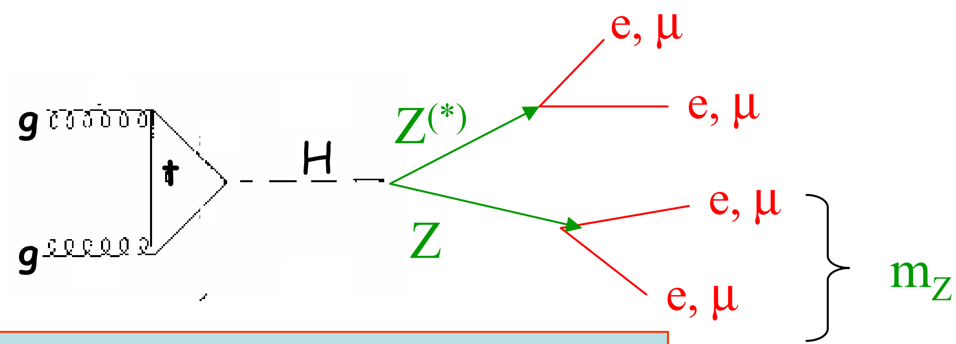
Expect few fb^{-1} at the end of 2008

End 2008??

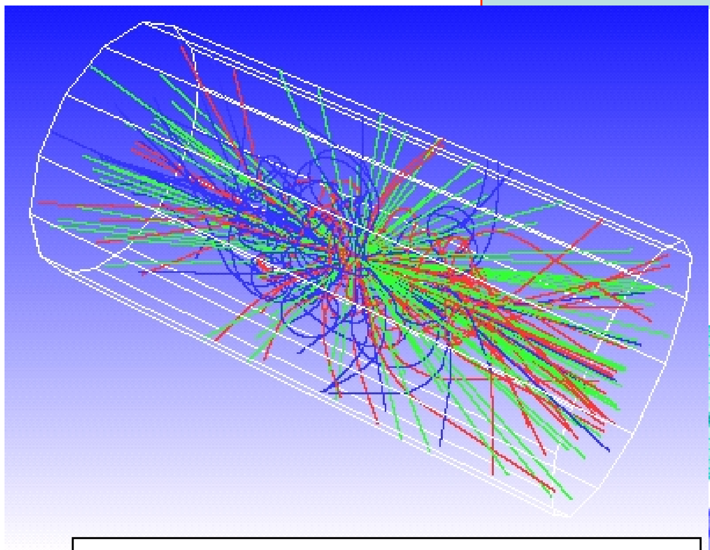
Process	Events/s	Events for 1 fb^{-1}	Events for 10 fb^{-1} (one year)
$W \to e\nu, \mu\nu$	15	$7*10^6$	$7*10^7$
$Z \to ee, \mu\mu$	1	$\sim 10^6$	10^7
H m=130 GeV	10^{-2}	$6*10^3$	$6*10^4$
H m=180 GeV	10^{-4}	60	$6*10^2$
$\tilde{g}\tilde{g}$ m=1 TeV	10^{-3}	10^2-10^3	10^3-10^4
$tt \to WbWb \to \mu\nu + X$	1	$8*10^4$	$8*10^5$
$bb \to \mu\nu + X$	10^3	10^6	10^7
Minimum bias	10^8	10^6 } $*10^{-2}$	10^7 } $*10^{-2}$
QCD jets p_T>150 GeV	10^2	10^6	10^7

$H \rightarrow ZZ^{(*)} \rightarrow$ 4 leptons

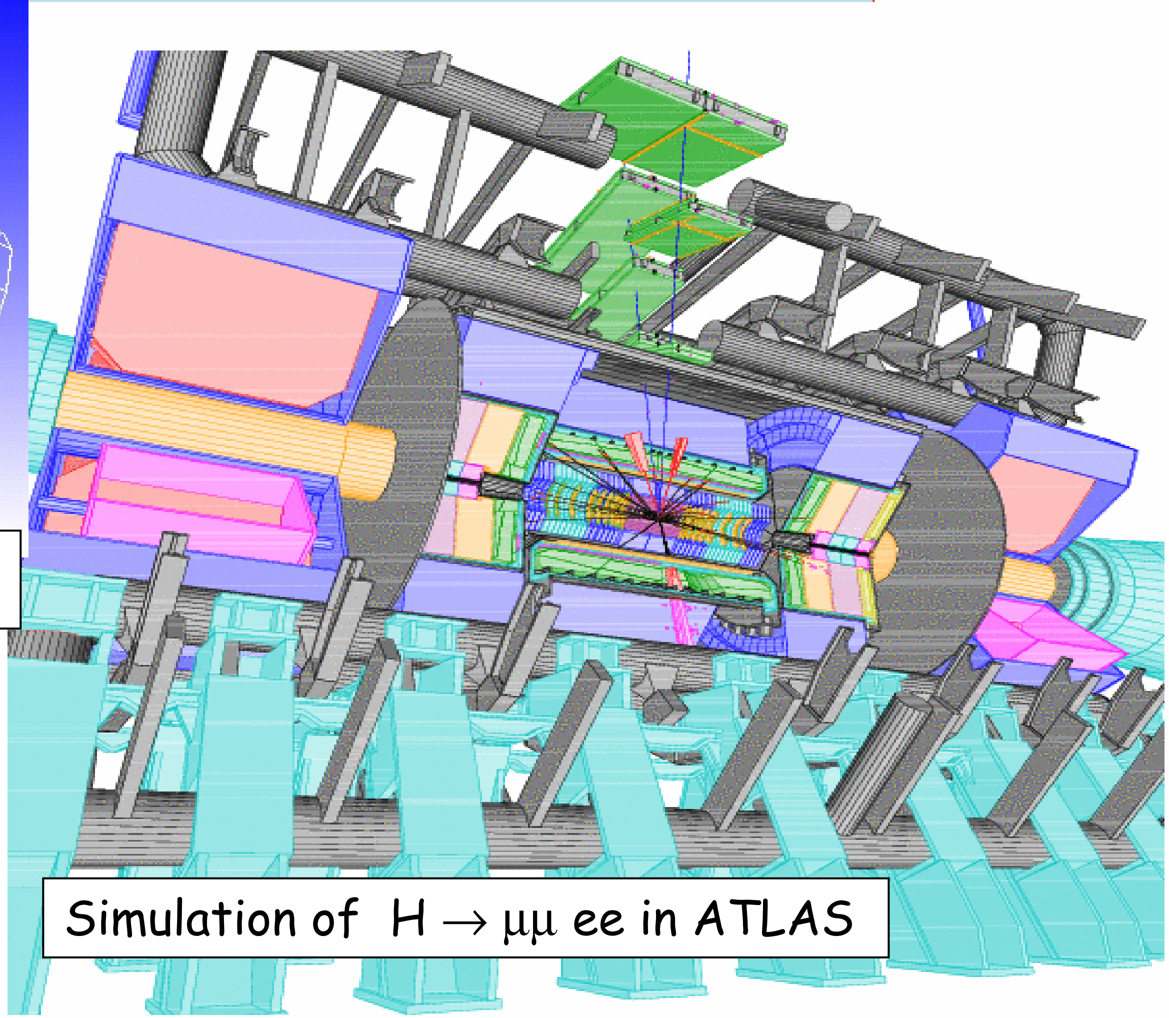
$120 \leq m_H < 700$ GeV



"**golden channel**" for the Higgs discovery at LHC



Simulation of $H \rightarrow \mu\mu\mu\mu$



Simulation of $H \rightarrow \mu\mu\, ee$ in ATLAS

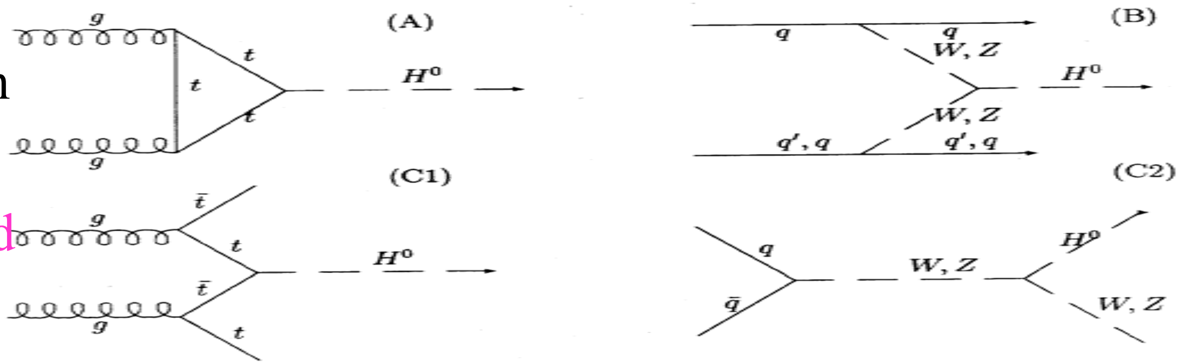
SM Higgs at the LHC (several production/decay channels)

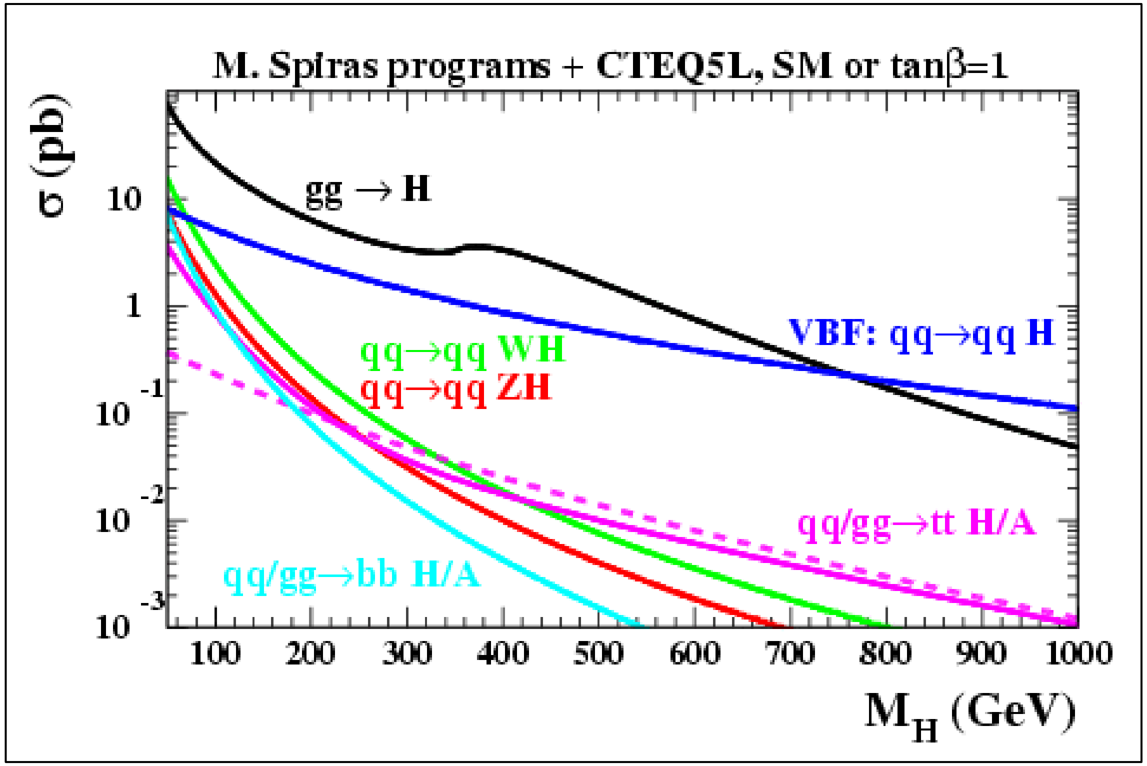
gg fusion

VBF WW/ZZ fusion

associated $t\bar{t}H$

associated WH, ZH





LOW MASS

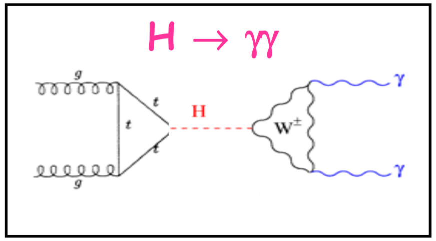
Difficult region !!!

- For the mass range $m_H \sim 115\text{-}130$ GeV

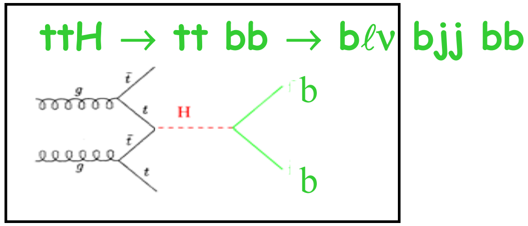
three channel combination (each about 2σ)

1. $H \rightarrow \gamma\gamma$ $S/B \sim 10^{-2}$ (excellent calorimetry)

   $\sigma/m < 1\%$

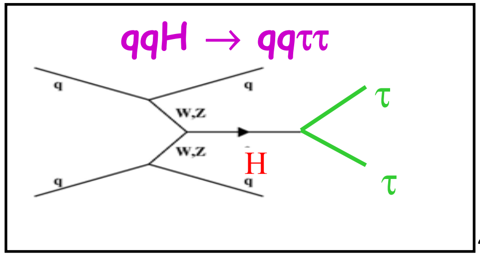


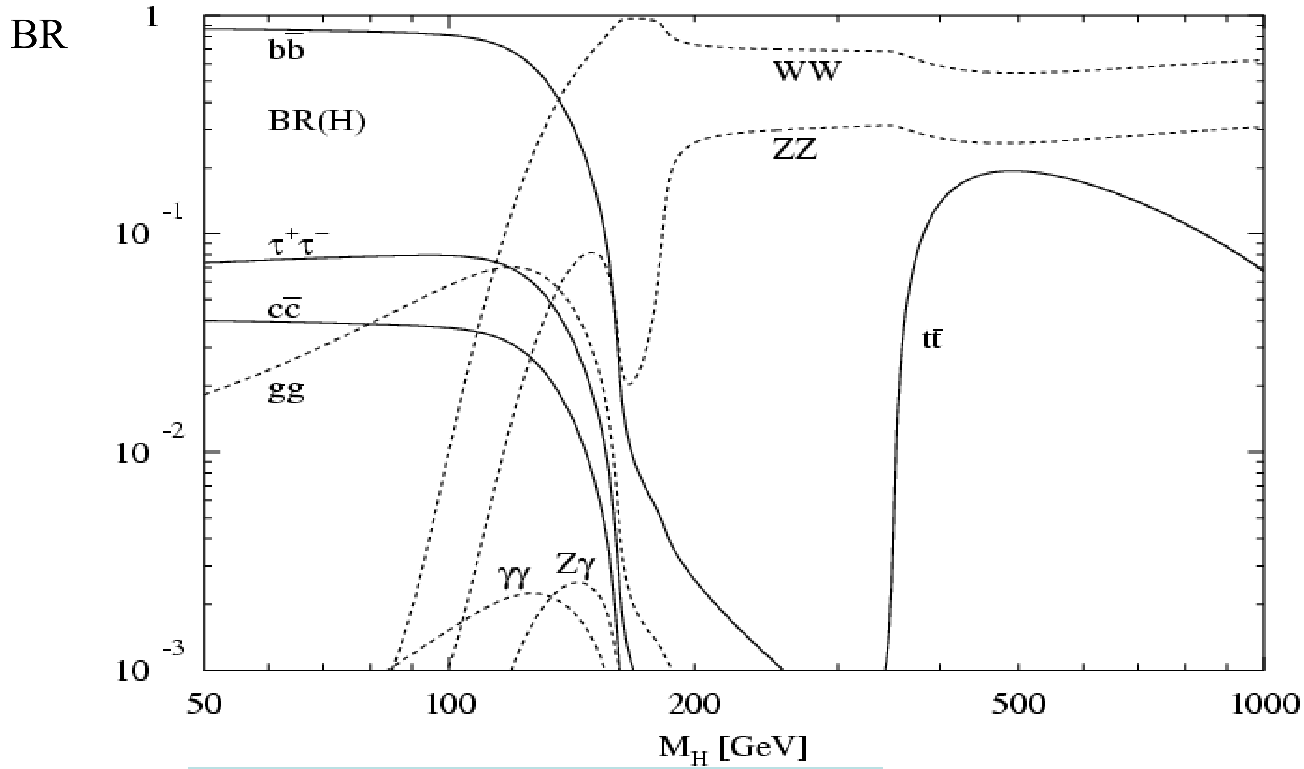
2. $H \rightarrow ttH$ (WH,ZH) with $H \rightarrow bb$ (b-tagging, 4 b jets) hadronic transverse mass resolution



Total $S/\sqrt{B}$ ~4 for $10fb^{-1}$

3. $qqH \rightarrow qq\tau\tau$ VBF (jets over $|\eta| < 5$ forward jet tag +central jet veto τ ID)





SM Higgs Decay channels

(A.Djouadi et al)

INTERMEDIATE MASS

m=130GeV @10fb^{-1} each 3σ

total $S/\sqrt{B}$ ~ 6 σ

- For the mass range $130 < m_H < 180$GeV, the Higgs decays to:
  - $H \to W W^* \to ll \nu \nu$ (E_T^{miss})
  - $qqH \to qq\tau\tau$ (ll+ l-had)
  - $H \to ZZ^* \to 4l$ (clean signature and rather low background)
- For $m_H < 2m_Z$, Higgs is narrow $\Rightarrow$ good detector resolution in e,μ is essential

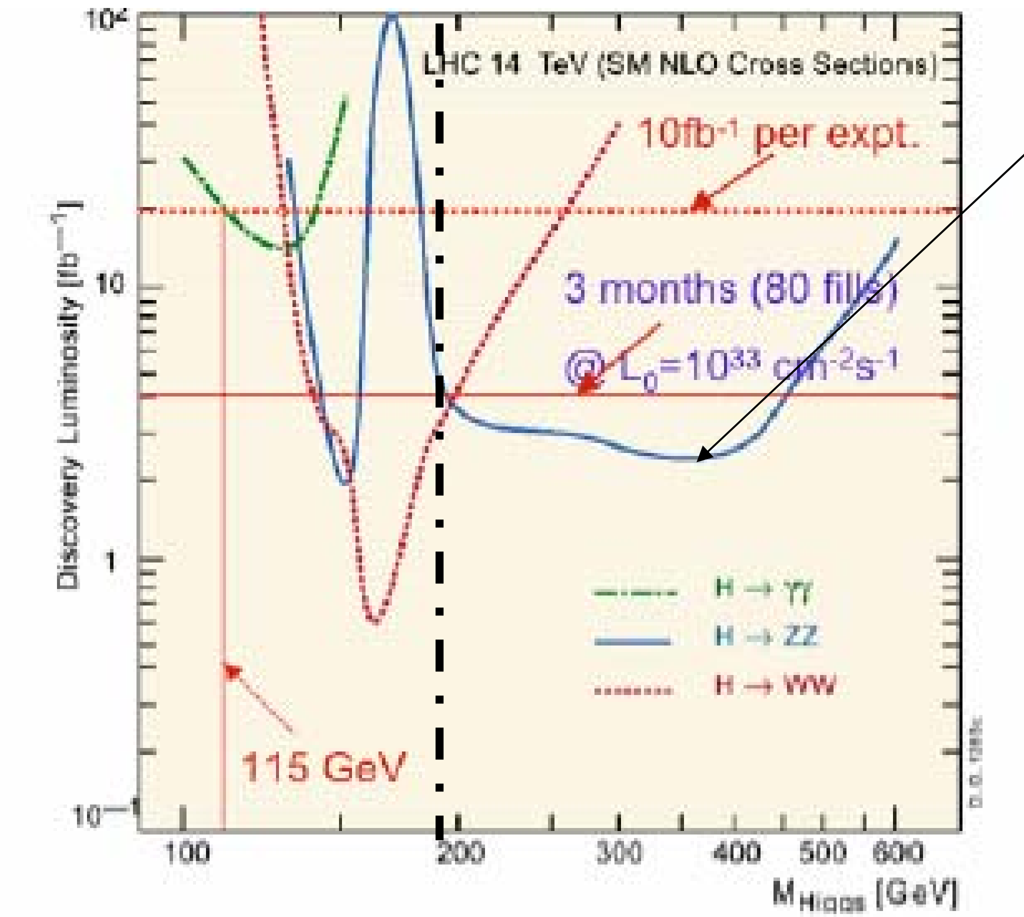
HIGH MASS

Keep in mind that according to SM m_H<166 GeV (Moscow conference)!!!

NEW!!

For $m_H > 2m_Z$ early discovery with:

CMS+ATLAS



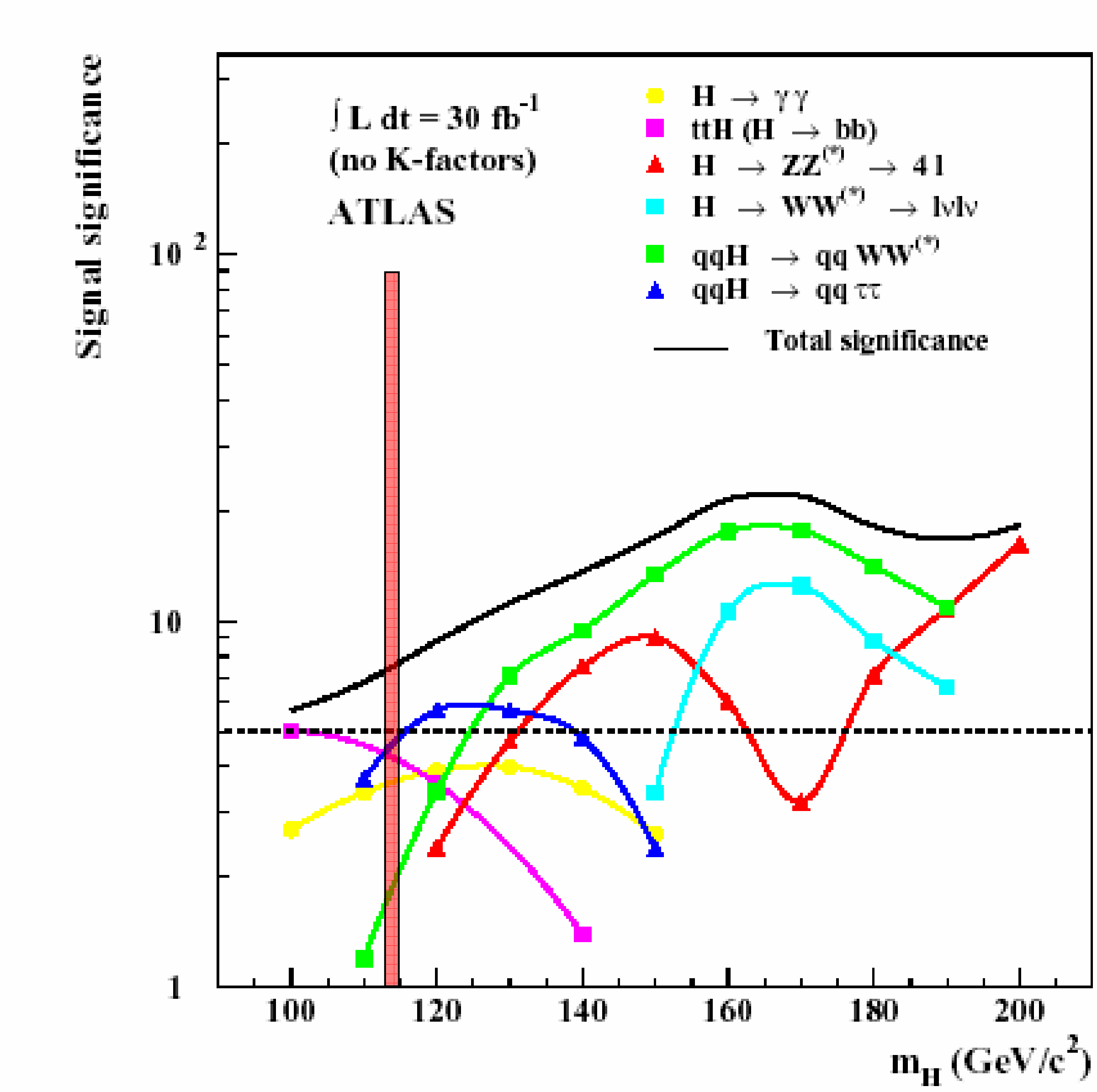
$H\rightarrow ZZ\rightarrow 4l$
"gold plated channel"
(low-rate BUT very clean)
Good lepton efficiency +good mass resolution

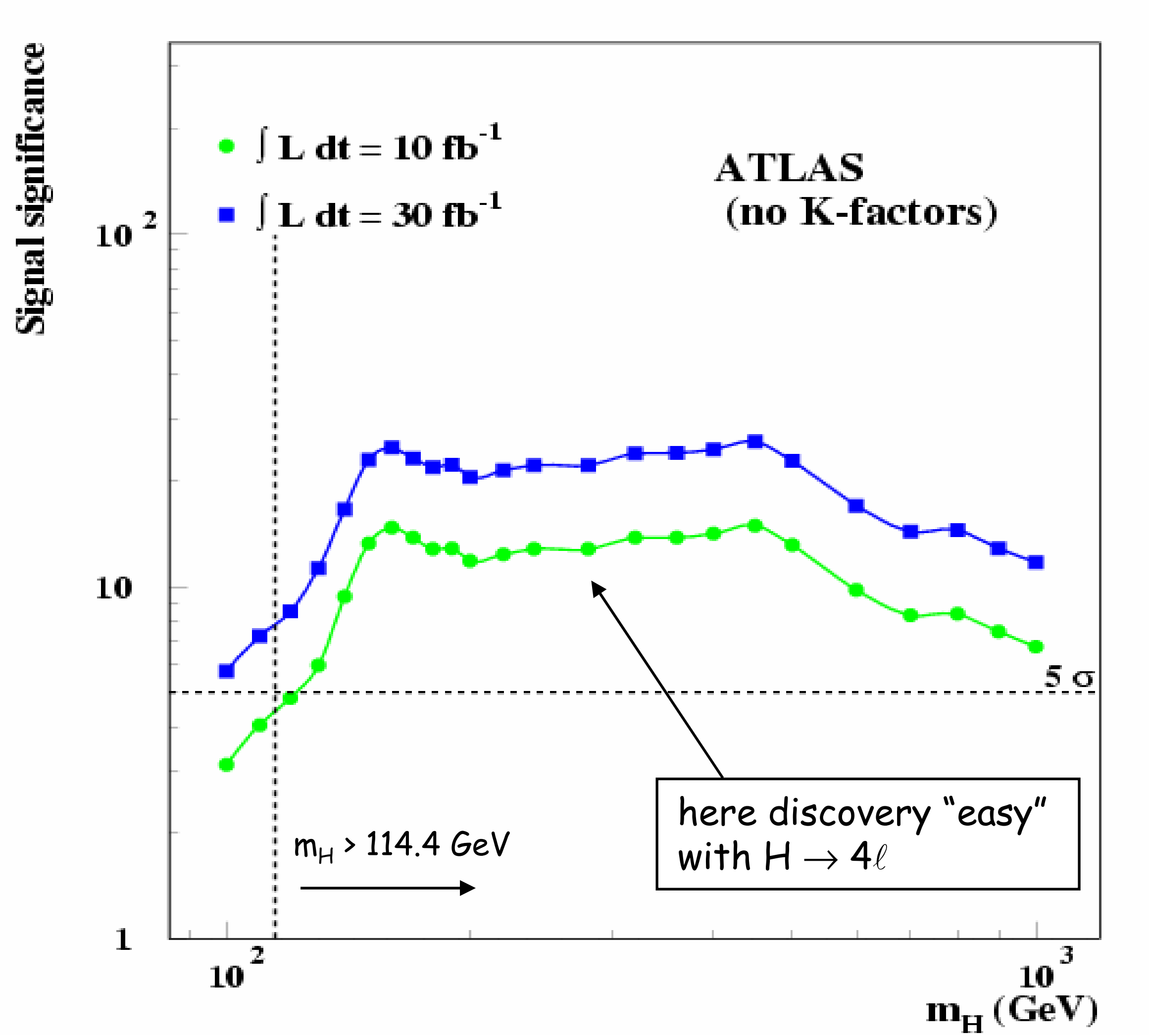
other:
$H\rightarrow W W\rightarrow l\nu l\nu$ (counting)

$H \to 4\mu$ BR*σ (fb)

$gg \to H \to 4\mu$ (m=130 GeV)	0.535	0.682 (gg fusion+VBF)
$gg \to H \to 4\mu$ (m=150 GeV)	1.02	1.325 (gg fusion+VBF)
$gg \to H \to 4\mu$ (m=180 GeV)	0.573	0.759 (gg fusion+VBF)
Irreducible $qq \to (Z/\gamma^*)(Z^*/\gamma^*) \to 4\mu$	17.6	22.88 (1.3 factor account for missing $gg \to ZZ$)
Irreducible $qq \to (Z/\gamma^*)(Z^*/\gamma^*) \to 2\mu 2\tau$	35.2	45.76 (1.3 factor account for missing $gg \to ZZ$)
Reducible : $gg \to (Z/\gamma^*)bb$, with $(Z/\gamma^*) \to 2\mu$	22.4 $\times 10^3$	22.4 $\times 10^3$
Reducible : $gg, qq \to tt \to WbWb$, with $W \to \mu\nu$	5.73 $\times 10^3$	5.73 $\times 10^3$

ATLAS discovery potential in 3 yrs low L





ONE YEAR
Covers almost
all mass region
(if detector known…)

What do we need fast? (1)

Understand the detector

- Dead/hot channels, dead material
- Calibration and alignment tracker (20μm few months)+ μ chambers

➢ Run beforehand with cosmics, single beam
(10^{6}events/3 months, beam-gas 10^{7}events/2months)

➢ Muon energy scale ($Z \to \mu\mu$) (5*10^4 needed $\to$ few days @10^{32})

➢ Electron energy scale ($Z \to ee$) EM calorimeter (10^{5}events +uniformity)

➢ Jet energy scale ($tt \to WbWb \to bl\nu\ bjj$) hadron calorimeter

➢ Measure cross-sections : minimum bias, underlying event,
QCD jets, DY,W,Z,tt ~ 10-20% (10% from L)

➢ Measure t mass (~few GeV)

➢ B-tagging from top decays (4 high p_T jets)

What do we need fast?(2)

Statistics available:

100 Hz events to tape ⟹ 10^7 events to tape /3 days

10^3events/day after cuts

1 PB of data /year/experiment

Measure standard SM processes to get to understand the detector and get an estimate of background "today's physics is tomorrow's background (top,bb,W/Z)

Need $\sigma/m \sim 1\%$ on e,μ and small tails

90% e, μ efficiency even at low p_T

$\sigma/m \sim 10\%$ for jets

b-tagging

Understanding of background

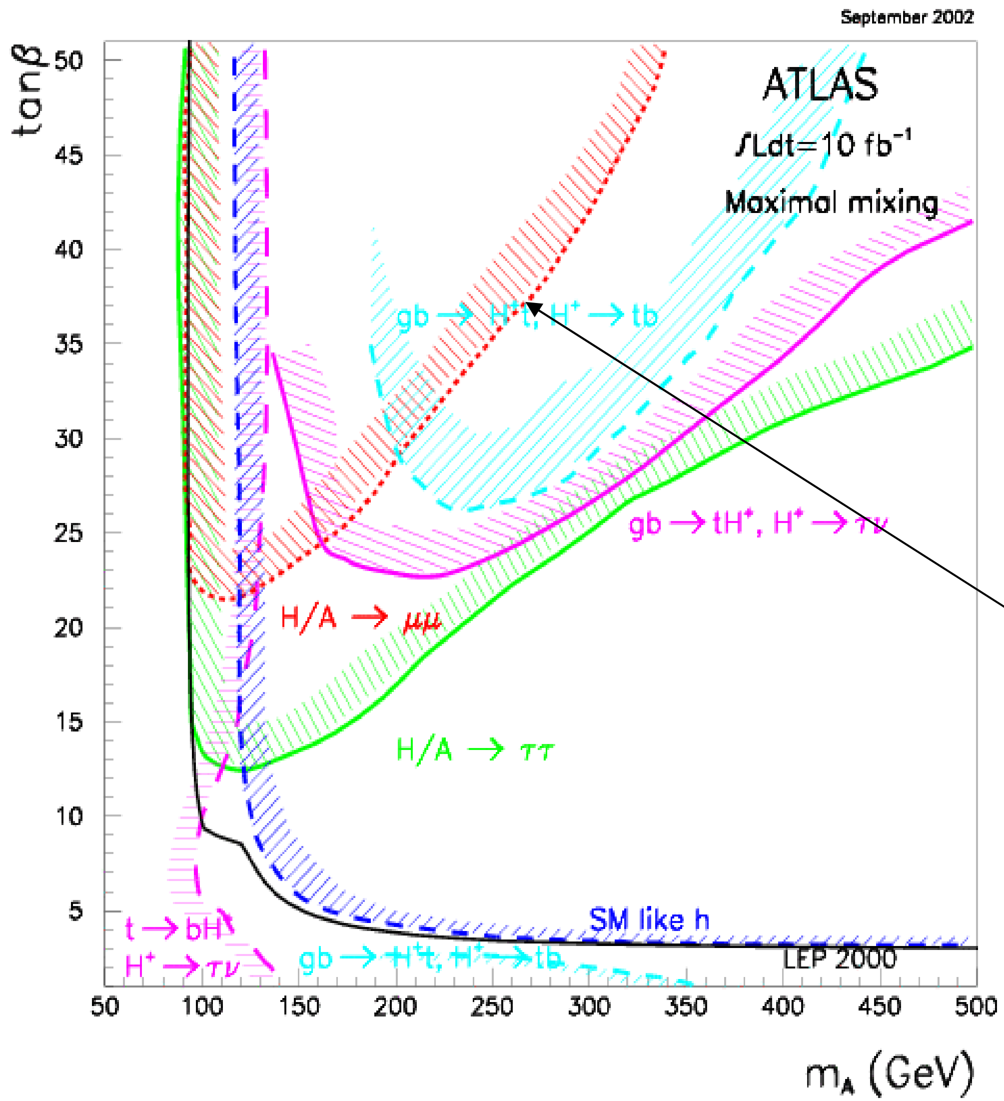
Forward jet/central veto

When all this has been done (after one year…)

- Get better accuracies (mass scales etc)
- Look for more rare processes

How about MSSM Higgs (h,H,A)??
A large variety of channels (M_{SUSY}>1TeV)

m_h< 135 GeV
$m_A \sim m_H$ at large m_A



Minimal mixing m_h<116 GeV fully explored by LEP

H/A → μμ :Very clean for first year(s)
(see talk of M.Milosavljevic)

Full exploitation requires 100fb^{-1}

Difficult region :
3<tanβ<10 and 120<M_A<220 GeV
Intermediate tanβ region :
only h detectable

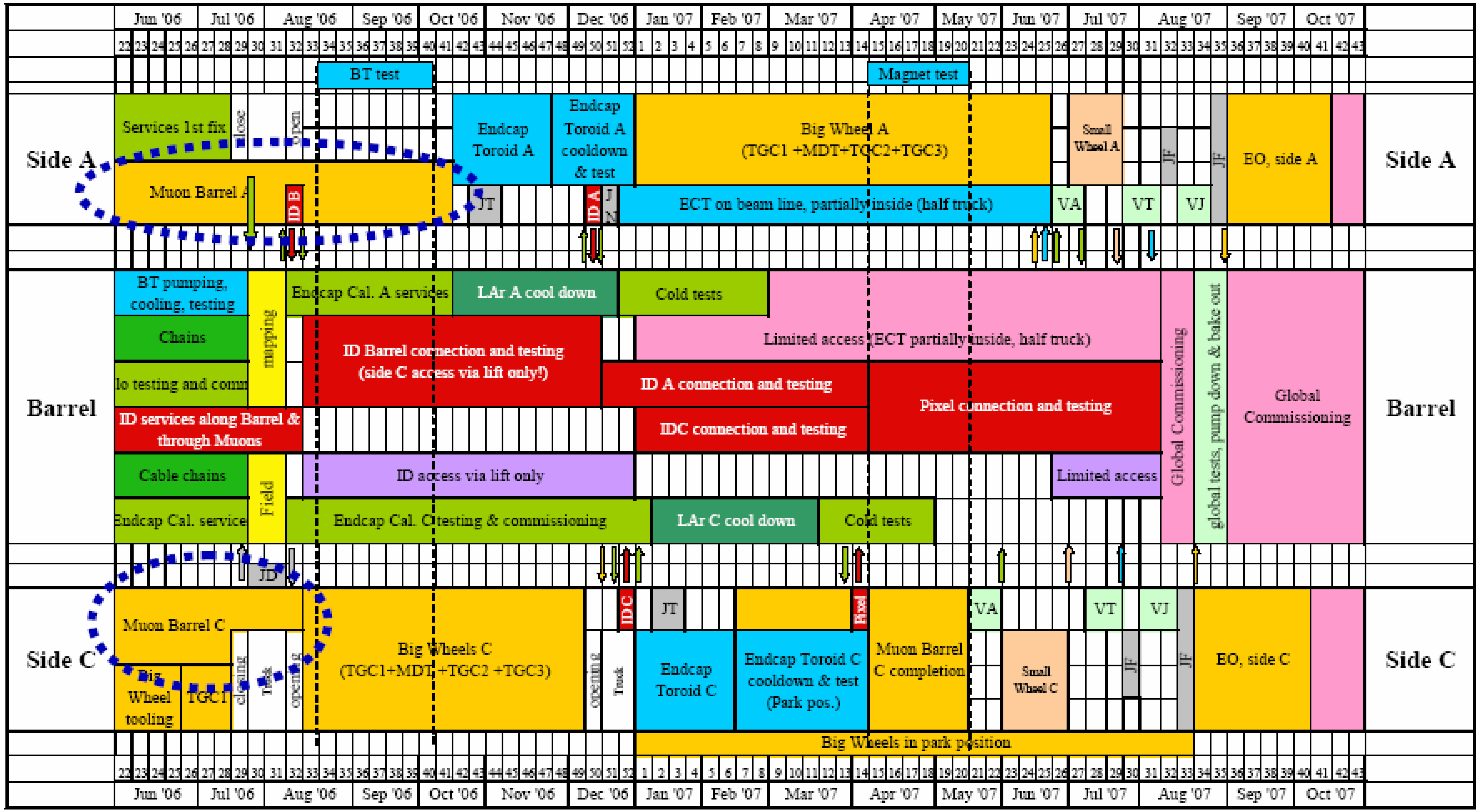
Conclusions

With a bit of luck and a lot of hard work everything will be under control (experiments + machine)

with ~ 1fb^{-1}

- The intermediate Higgs mass region will be covered
- 1 TeV SUSY will show up (if any)
- 1 TeV Z' will be discovered (if any)
- etc etc
- suprises ??

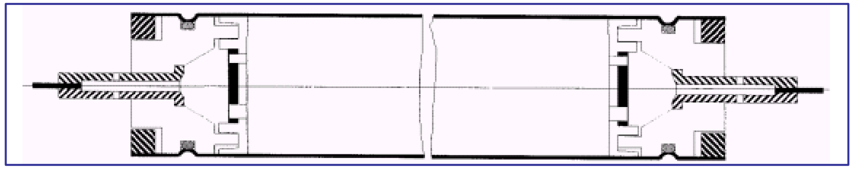
Back-up slides

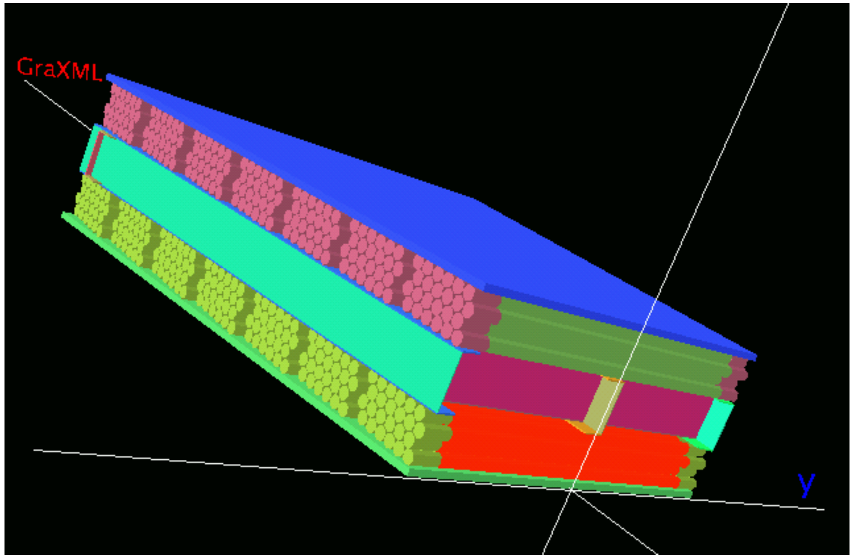

Side A
Barrel
Side C
BT test
Magnet test
Services 1st fix
Muon Barrel A
Endcap Toroid A
Endcap Toroid A cooldown & test
Big Wheel A (TGC1 +MDT+TGC2+TGC3)
ECT on beam line, partially inside (half truck)
EO, side A
BT pumping, cooling, testing
Chains
Endcap Cal. A services
LAr A cool down
Cold tests
ID Barrel connection and testing (side C access via lift only!)
Limited access (ECT partially inside, half truck)
ID A connection and testing
Pixel connection and testing
ID services along Barrel & through Muons
IDC connection and testing
Cable chains
ID access via lift only
Limited access
Endcap Cal. C testing & commissioning
LAr C cool down
Global Commissioning
global tests, pump down & bake out
Muon Barrel C
Big Wheels C (TGC1+MDT+TGC2+TGC3)
Endcap Toroid C
Endcap Toroid C cooldown & test (Park pos.)
Muon Barrel C completion
EO, side C
Big Wheels in park position

	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5\text{x}10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\text{x}10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 7$ % at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker

ATLAS: MDT's

Monitored Drift Tubes
width (tube length) : 83-494 cm
length : 90-216 cm





Tube : Al, 30 mm φ, 0.4 mm wall

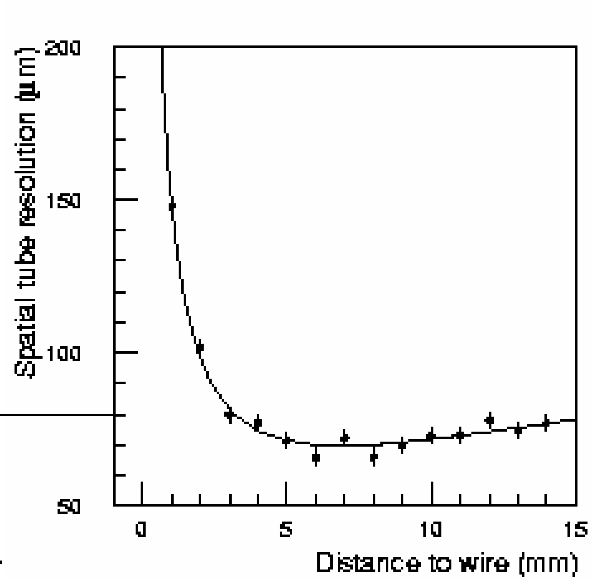
Wire : 50 μm, W/Re alloy (97/3)

Gas : Ar/CO_2 (93%/7%) at 3 bar

Gas gain : $2x10^4$ at 3080 V

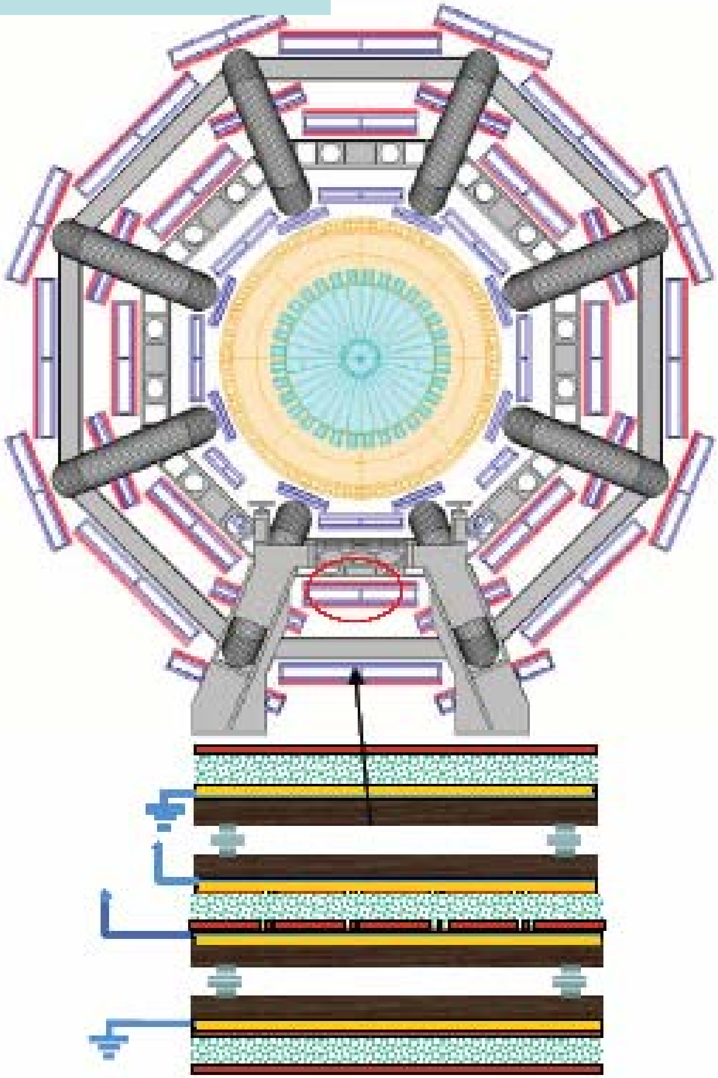
Maximum drift time : ~ 700 ns

Resolution : 80 μm



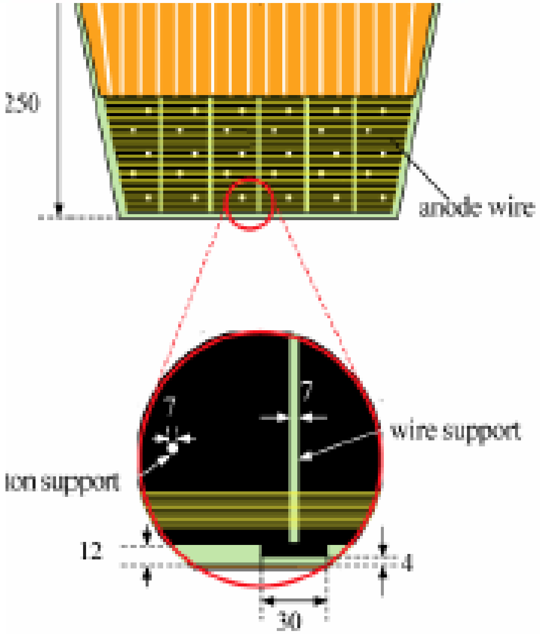
RPC's :Trigger in Barrel

- Three RPC detector layers:
  - 2 in the middle station, 1 in the outer (380 MDT/RPC stations)
- Each layer:
  - 2 gas gaps and 4 readout planes for each detector element
  - Eta and Phi read-out copper strips panels, pitch ranging from 26.4 to 33.9 mm
- Each gap:
  - 2 mm gas gap with plastic laminate electrodes
  - plate resistivity : ~ 1- 4x10^{10} Ωcm
  - Gas mixture: ($C_2H_2F_4$) 94.7% - (C_4H_{10}) 5% - (SF_6) 0.3%
- Performance:
  - RPCs working in avalanche mode
  - Efficiency: > 98%
  - Time resolution: ~ 1-2 ns
  - Spatial resolution: 5-10 mm
  - Rate capability: ~ 1000 Hz/cm^2



T controlled, gas controlled

TGC's Trigger in forward regions



- Basic structure a MWPC with graphite cathode
- Signal is read from both anode wires and cathode strips
- Gap between ano-cath is 1.4 mm
- Wire spacing is 1.8 mm
- 50 μm tungsten wire
- Gas CO_2:n-Pentane (55 : 45)
- Efficient 25 ns tag

G. Mikenberg – Weizmann/CERN

CSC's

Gas: Ar:CO_2 80:20

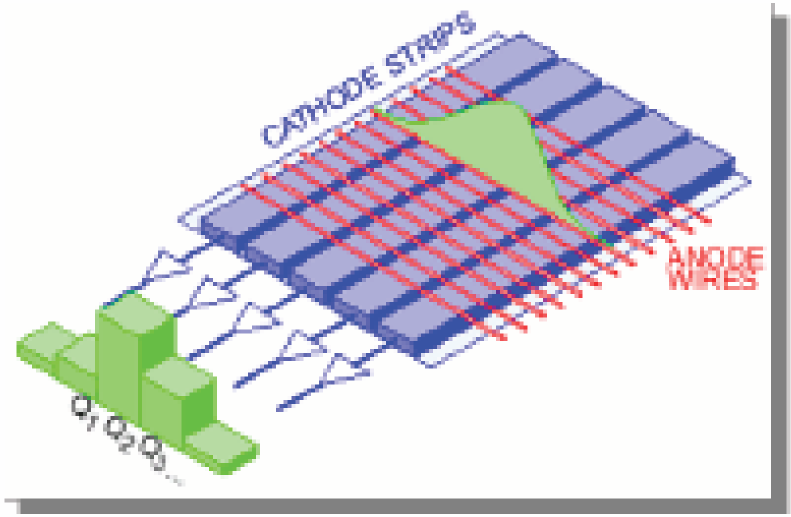
ATLAS

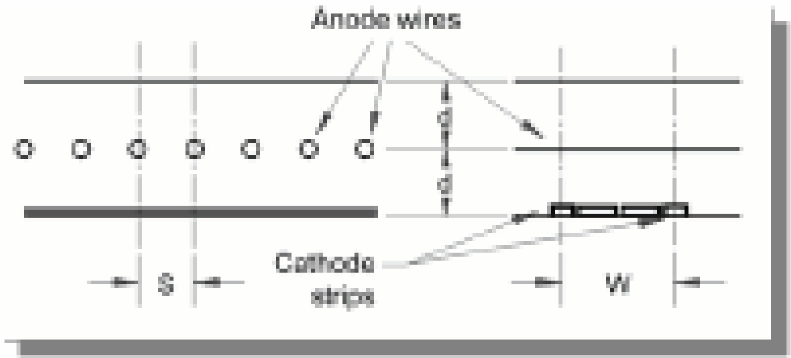
s = d = 2.54 mm

W = 5.6 mm

V. Polychronakos-BNL ATLAS

- Determine muon position by interpolating the charge on 3 to 5 adjacent strips
- ΣQ_i ~ Landau Distribution
- 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.





Technology & Layouts – ATLAS & CMS

Chamber Technology	ATLAS	CMS
Inner Tracker		
Outer radius of Tracker	107 cm	110 cm
Technology	Silicon & Straw Tubes	Silicon
Min (X/X_0) $\eta \sim 0$	0.3	0.4
Max (X/X_0) $\eta \sim 1.7$	1.2	1.5
Drift Tubes	MDT	DT
Coverage	$\lvert\eta\rvert < 2.0$ inner, $\lvert\eta\rvert < 2.7$ middle & outer	$\lvert\eta\rvert < 1.2$
Number of chambers	1.170	250
Number of channels	354.000	172.000
Function	Precision Measurement	Precision Measurement, Trigger
Cathode Strip Chambers (CSC)		
Coverage	$2.0<\lvert\eta\rvert < 2.7$ inner layer	$1.2<\lvert\eta\rvert < 2.4$
Number of chambers	32	468
Number of channels	31.000	500.000
Function	Precision Measurement, 2nd Coordinate	Precision Measurement, Trigger
Resistive Plate Chambers (RPC)		
Coverage	$\lvert\eta\rvert <1.05$	$\lvert\eta\rvert < 2.1$
Number of chambers	1.112	912
Number of channels	374.000	160.000
Function	Triggering, 2nd Coordinate	Triggering
Thin Gap Chambers (TGC)		
Coverage	$1.05<\lvert\eta\rvert < 2.4$	
Number of chambers	1.578	
Number of channels	320.000	
Function	Triggering, 2nd Coordinate	

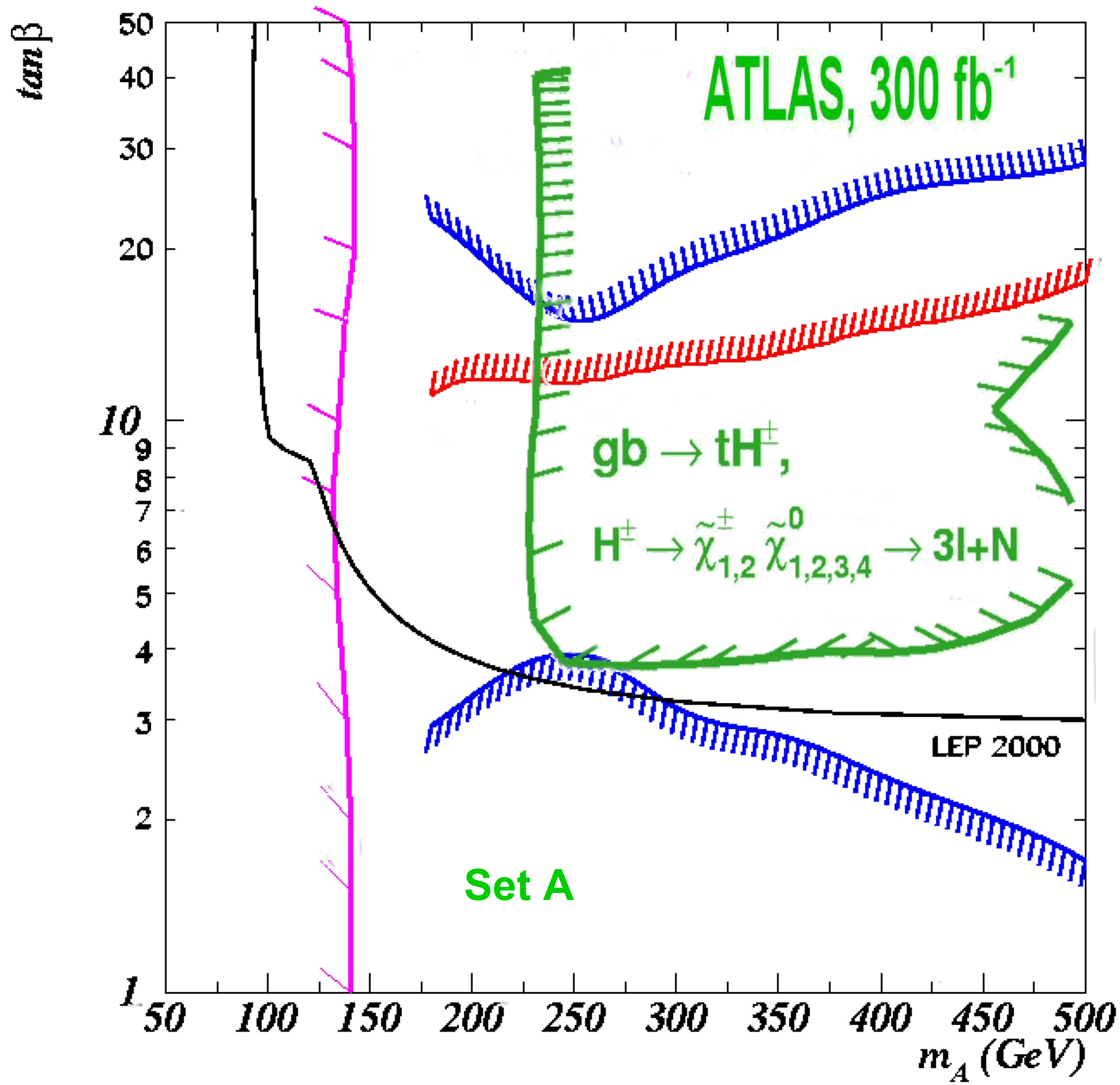
Physics Impact of Staging ATLAS components

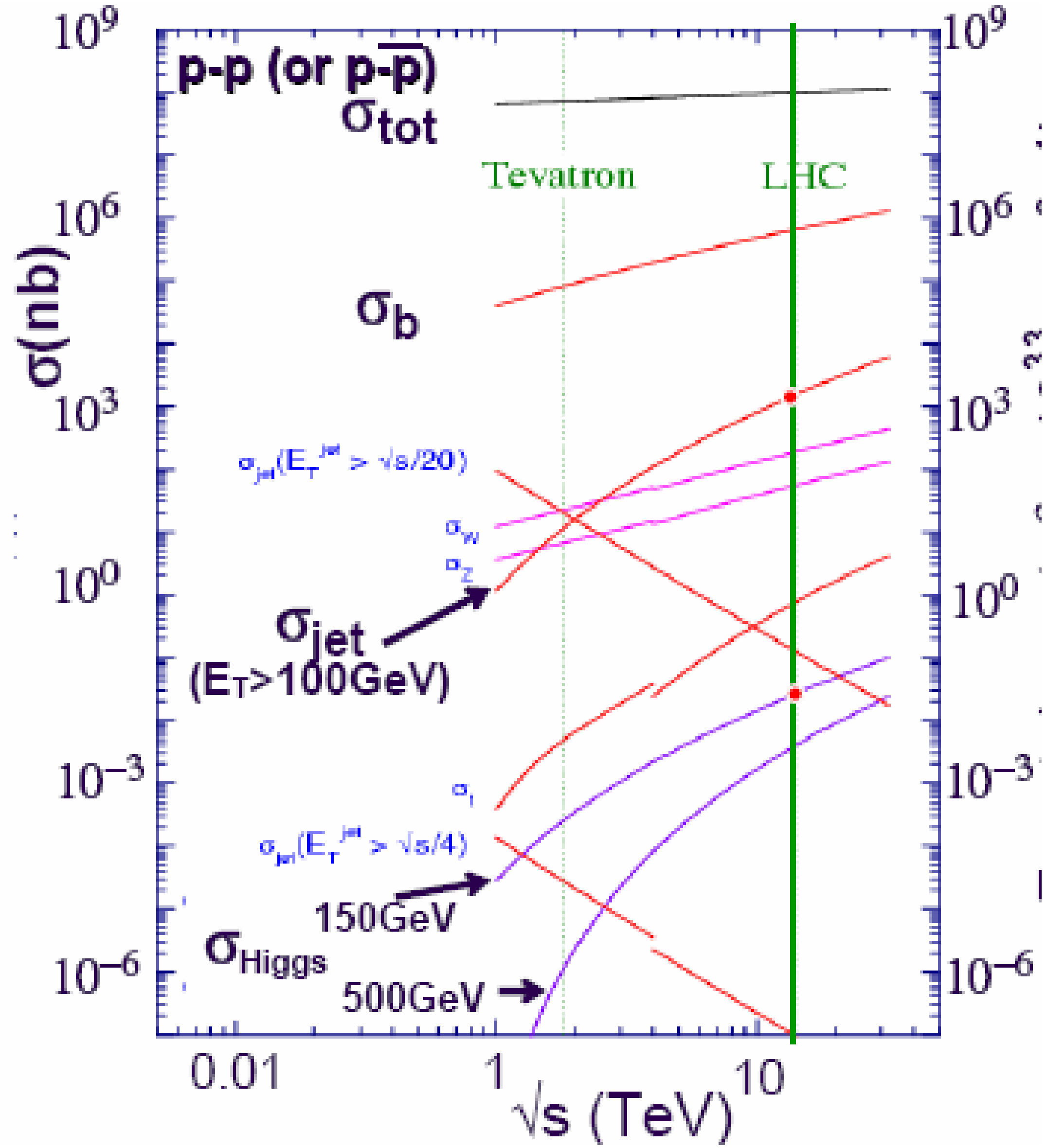
ATLAS RRB-D 2001-118
F.Gianotti and P.Jenni

Staged items	Main impact expected	Effect (loss in significance)
1 pixel layer	ttH $\rightarrow$ttbb	~8%
Cryostat Gap scintillator	H $\rightarrow$4e	~8%
TRT wheels + CSC's	H $\rightarrow$4μ	~7%
MDT's	A/H $\rightarrow$4μ	~10% for m=300GeV
HLT (trigger)	B-physics + High-p_T physics	dangerously cut

Need 20% more L

5-σ Discovery Contour for H^+





p-p (or p-p̄)
σtot
Tevatron
LHC
σb
σ(nb)
σjet(ETjet > √s/20)
σW
σZ
σjet
(ET>100GeV)
σt
σjet(ETjet > √s/4)
150GeV
σHiggs
500GeV
10^9
10^6
10^3
10^0
10^−3
10^−6
0.01
1
10
√s (TeV)