Luis Labarga
24/10/2006

The ATLAS experiment

OUTLINE:

- about the LHC, about multipurpose HEP experiments
- the ATLAS machinery; the electromagnetic calorimeter
- online / offline

this talk tries to summarize the work by many people during many years

35 countries
≈135 institutes

≈1650 physicists
many engineers
many technicians

ZEUS:
16 countries
53 institutes
456 physicists

Widely agreed "NEXT" in experimental HEP

Around the known:

- origin of mass at the EW scale
- characteristics of the top quark
- non abelian structure of the EW interaction
- CP violation in the SM
- QCD, high E_T jet production …

Around the unknown:

- SUSY
- Dark Matter
- Extra Dimensions

A glance to the cross sections:

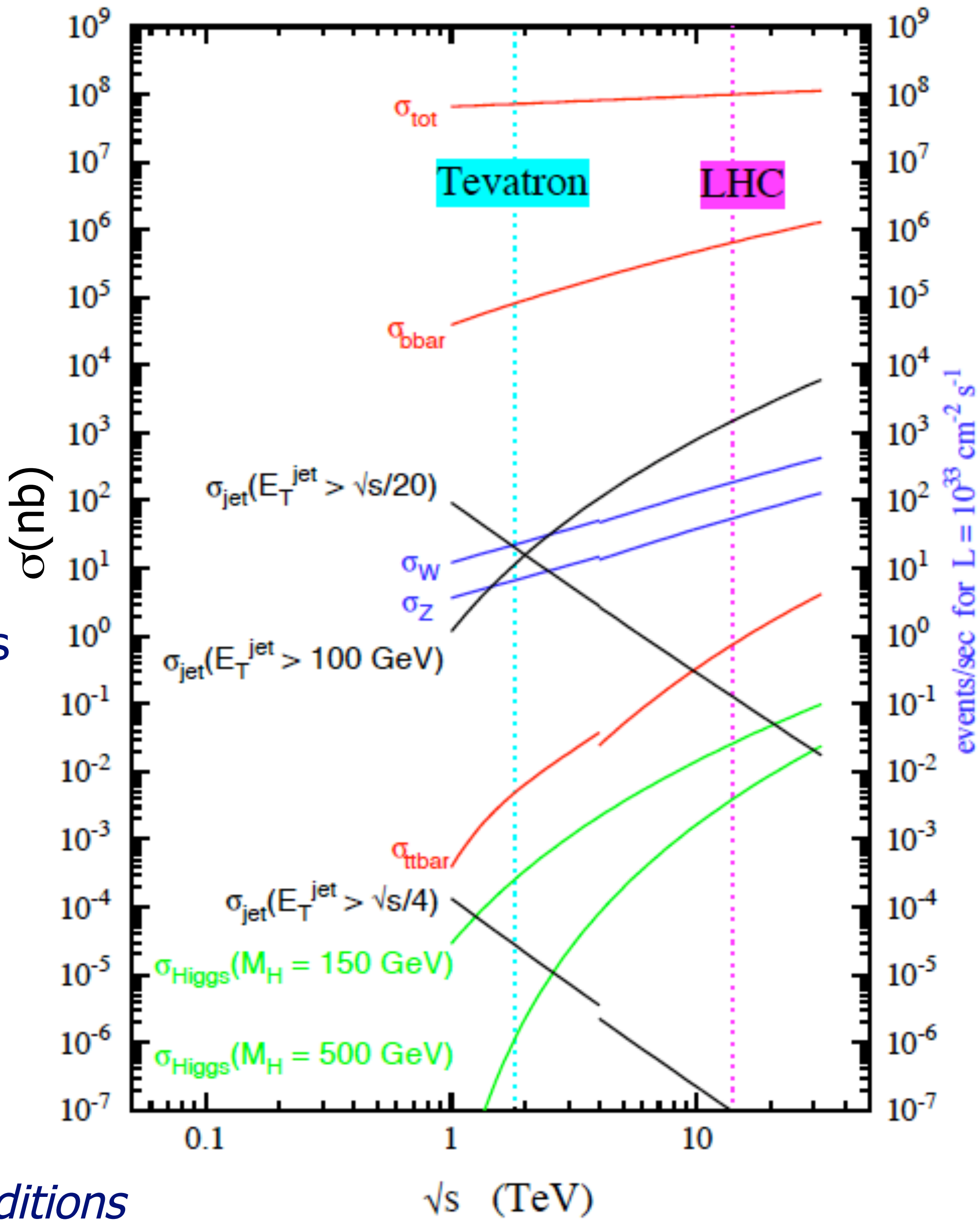
→ High Energy needed

→ many fb-1 needed to produce desired reactions

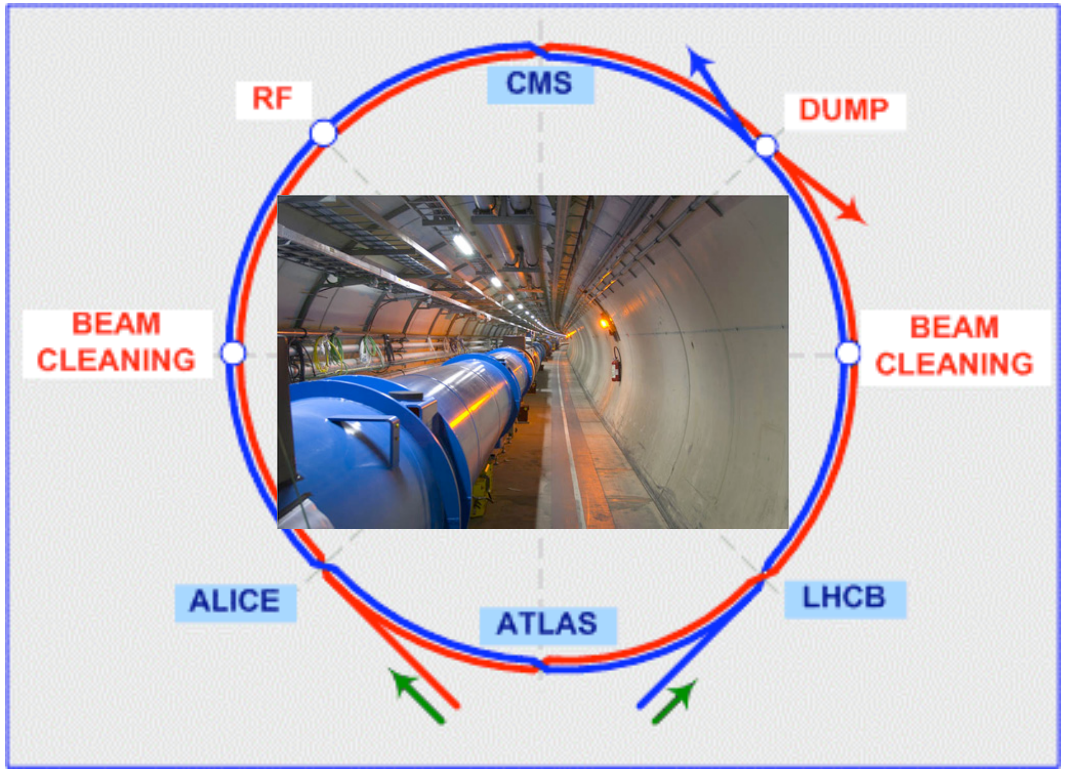
⇒ for the time being only a pp accelerator is able to provide it

but non-interesting/dirty pp interaction have huge cross sections

⇒ *painful experimental conditions*



Relevant LHC facts and some of their consequences



Proton energy: 7 TeV

Peak Luminosity: $1x10^{34}$ cm^{-2} s^{-1}
(100 fb-1/year)

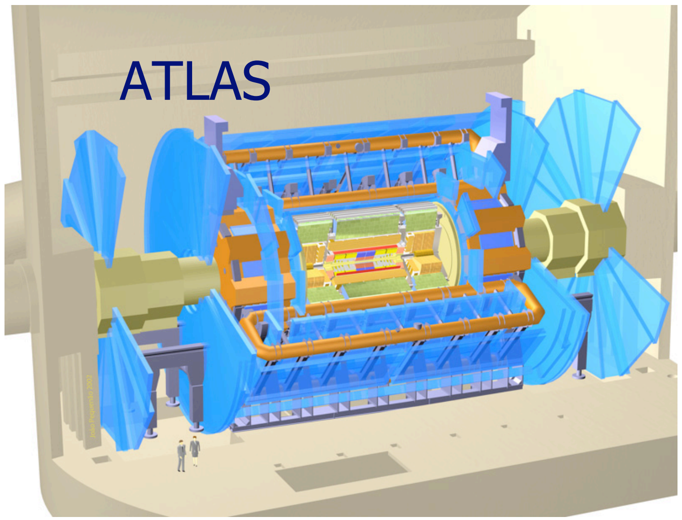
No. particles/bunch: $1{,}15x10^{11}$

No. bunches: 2808

Stored Energy: 362 MJ

Time between collisions: 25ns

Half crossing angle: 0,143 mrad
(vertical plane)



σ(inelastic) ≈ 70 mb

Events/crossing ≈ 20

Charged particle multiplicity≈200

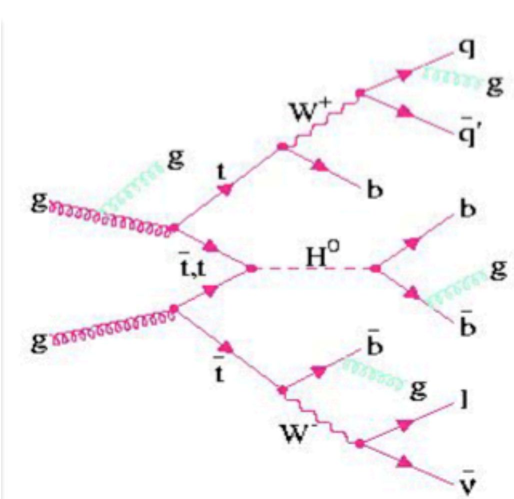
Some relax:

RMS bunch length: 7,55 cm

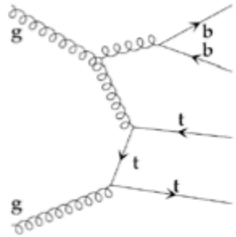
RMS bunch trans. size: 0,017 mm

What is what we can direct detect/measure ?

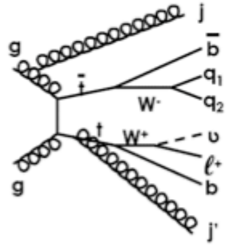
⇒ particles stable within the detector volume



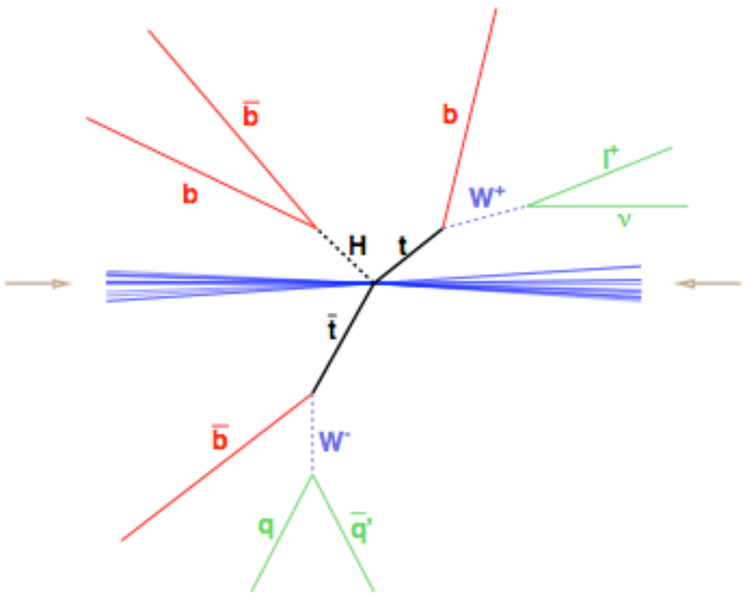
$t\bar{t}H$, $H \to b\bar{b}$ signal



$t\bar{t}b\bar{b}$ background



$t\bar{t}jj$ background



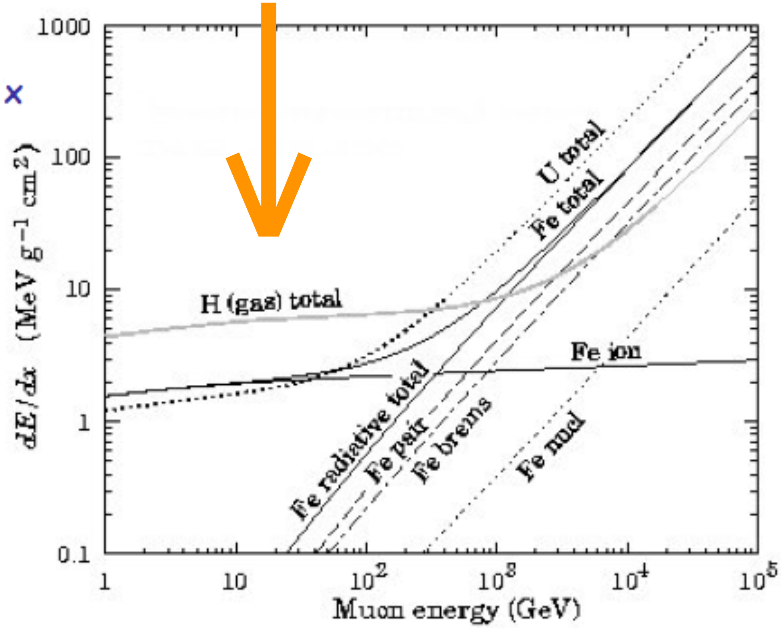
I.e. the only known particles to which we have a direct access are:

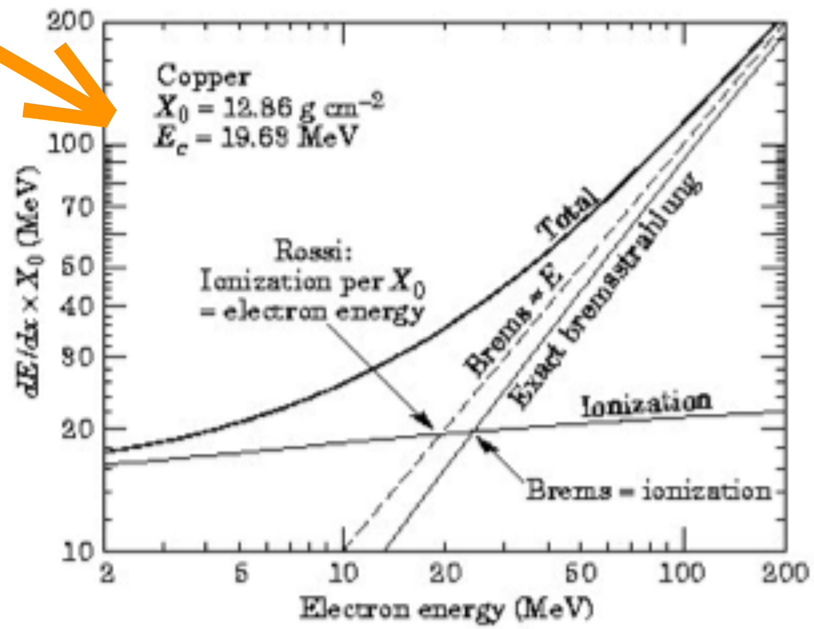
- → e^+, e^-, γ
- → μ^+, μ^-
- → π^+, π^-, K^+, K^-, p, $\bar{p}$
- → K^0_L, n
- → Neutrinos

Basics of interaction radiation-matter (at high energy)

e^+, e^- : ionisation, bremsstrahlung + pair creation
γ : pair creation + bremsstrahlung

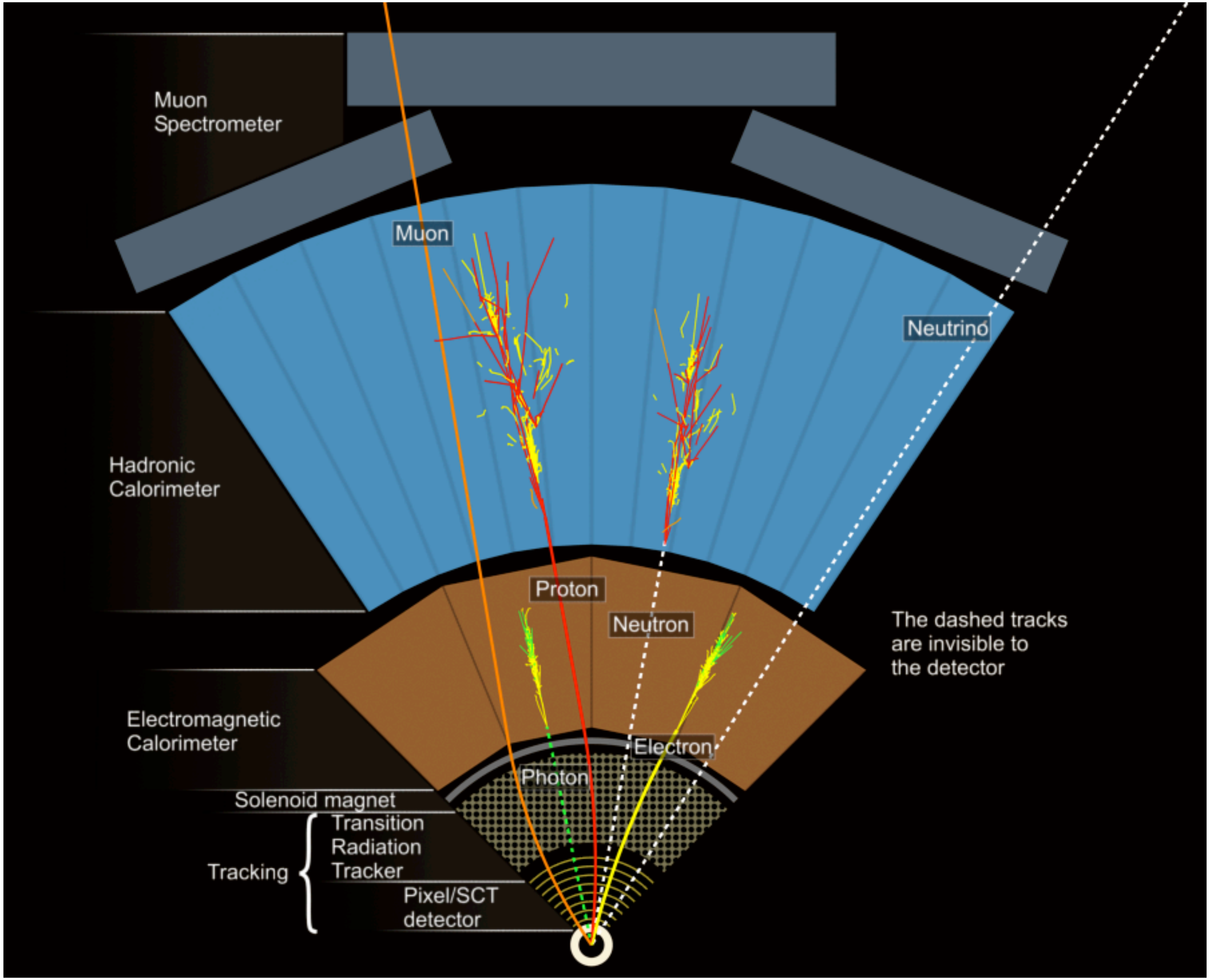
μ^+, μ^-: ionisation [for the same energy is σ(brems.) $\propto m^{-2}$]





charged hadrons : nuclear interactions …
[π^{+-}, K^{+-}, p^{+-}] + ionisation
neutral hadrons : nuclear interactions …
[K^0_L, n]

ATLAS has the typical structure of multipurpose detectors:



But we need to reconstruct/measure many others

$\Rightarrow$ always from those direct-measured !

- invariant mass techniques
- secondary vertices
- flavour tagging

- jet reconstruction

A non easy example: measuring the τ lepton

How to identify them ?

Leptonic decay modes (35 %)

$\tau \rightarrow \nu_\tau + \nu_e + e$ (17.4%)

$\tau \rightarrow \nu_\tau + \nu_\mu + \mu$ (17.8%)

→ 1 e^{+-} or 1μ^{+-}
→ missing E, P_T …

Hadronic decay modes (65 %)

1 prong

~77 %

$\tau \rightarrow \nu_\tau + \pi^\pm$ (11.0%)

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0$ (25.4%)

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0$ (10.8%)

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0 + \pi^0$ (1.4%)

$\tau \rightarrow \nu_\tau + K^\pm + n\pi^0$ (1.6%)

→ 1 charged track
→ impact parameter
→ CAL shower shape
→ EM-HAD *E* sharing

τ jets

3 prong

~23 %

$\tau \rightarrow \nu_\tau + 3\,\pi^\pm + n\pi^0$ (15.2%)

→ 3 charged tracks
→ impact parameter
→ secondary vertex
→ CAL shower shape
→ EM-HAD *E* sharing

… which is only an intermediate step towards the physics of interest:

SM physics

$Z \rightarrow \tau^+ \tau^-$

$W^{+-} \rightarrow \tau^{+-} \nu_\tau$

(also important for commissioning)

HIGGS physics:

SM

$q\,q\,H \rightarrow q\,q\,\tau^+ \tau^-$, $t\,t\,H \rightarrow t\,t\,\tau^+ \tau^-$

MSSM

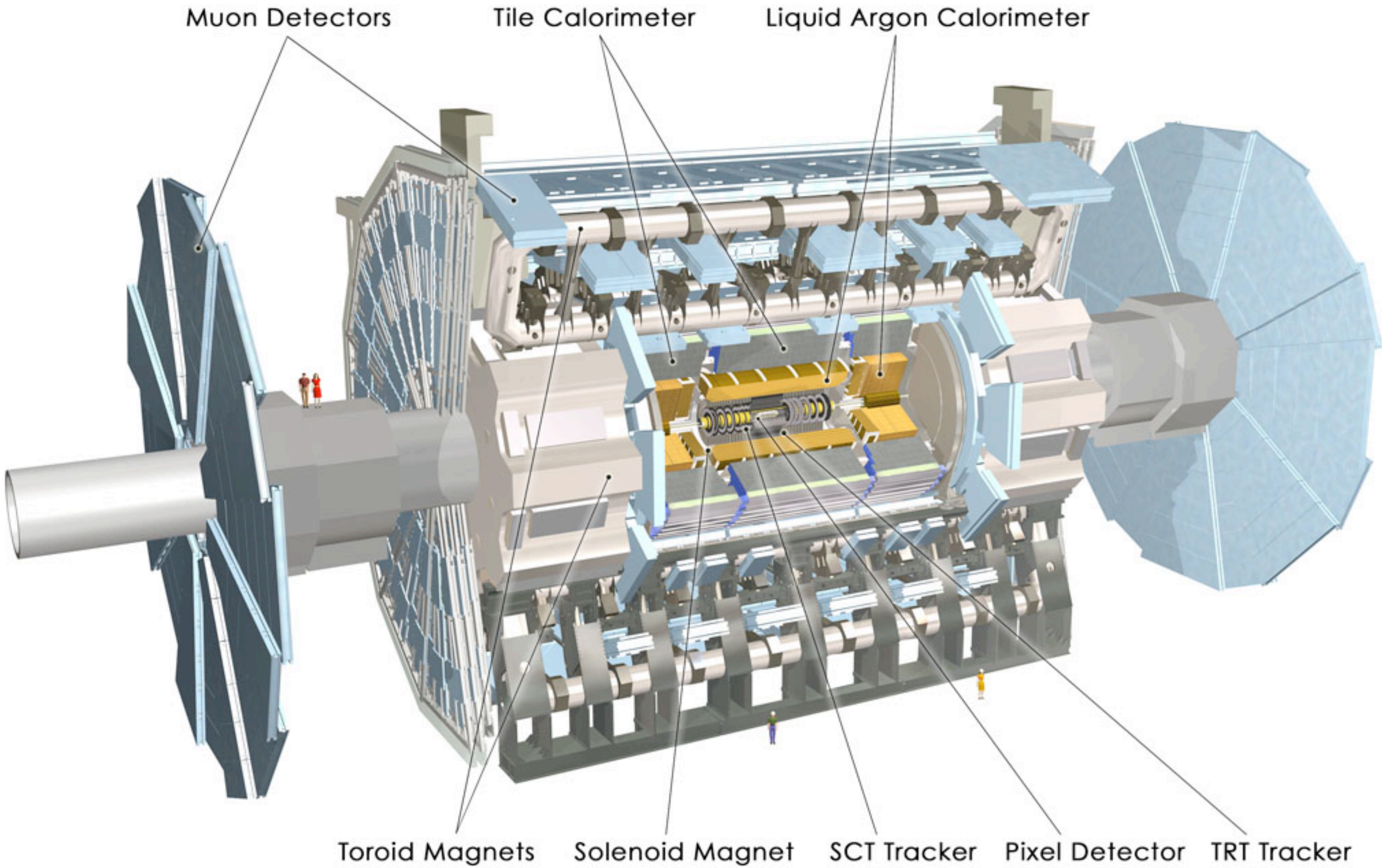
$A\,/\,H \rightarrow \tau^+ \tau^-$, $H^+ \rightarrow \tau^+ \nu_\tau$

Exotics process:

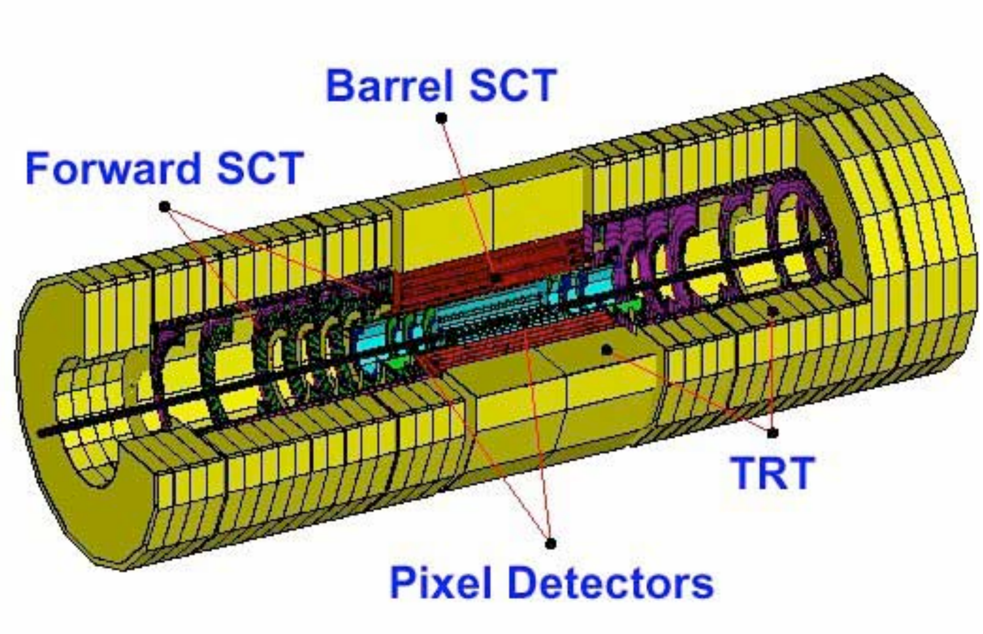
SUSY with τ^+, τ^- in the final state

….

The ATLAS detector: schematics



The TRACKING system



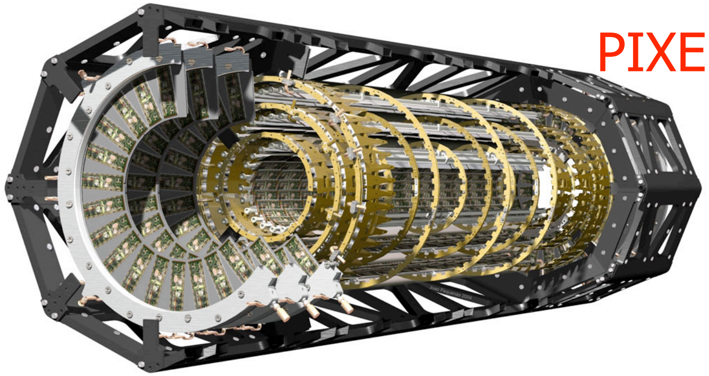
How to reconstruct trayectories, measure p_T, reconstruct secondary vertices in such dense events ?

Precision tracking:
> Pixel *detector*,
> *Semi-Conductor Tracker* (SCT)

Long range tracking for pattern recognition and e^{+-} ID:
> *Transition Radiation Tracker* (TRT)

→ Inside a 2 T solenoid field
→ $|\eta|<2.5$ coverage

Momentum resolution:
$\sigma(p_T)/p_T = 0{,}05\%\ p_T(\mathrm{GeV}) \oplus 1\%$
(ZEUS: $0{,}6\%\ p_T \oplus 0{,}7\% \oplus 0{,}14\% / p_T$)



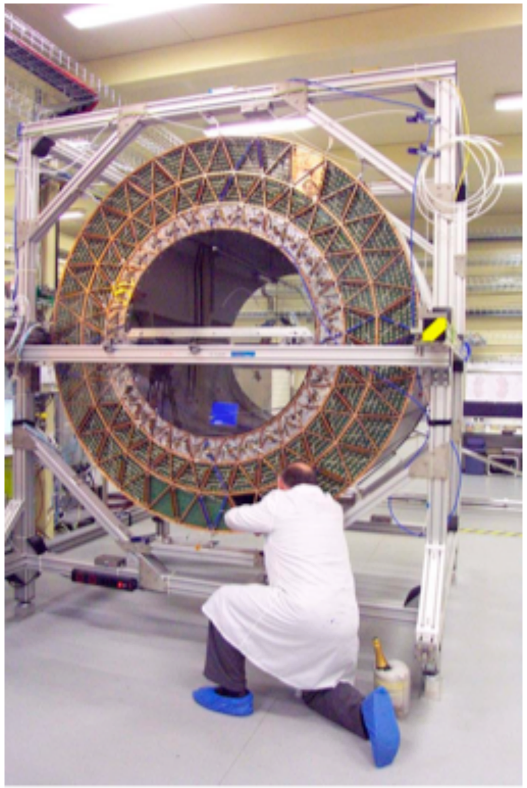
PIXEL

3 layers/disks of Si pixels in Barrel/EC; 8 x 10^7 channels

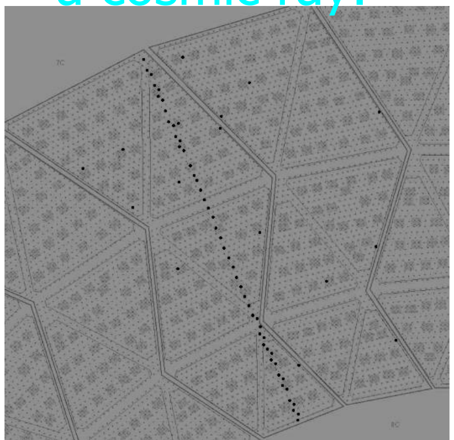
SCT

4 layers / 9 disks of 2 x [Si μ-strip det.] in barrel / End-Cap; 6 x 10^6 channels

TRT *(barrel module shown)*



a cosmic ray:



3 layers of multi-layer straw-tube modules in Barrel / 14 m-layer straw-tube disks in End-Cap; 4 x 10^5 ch.

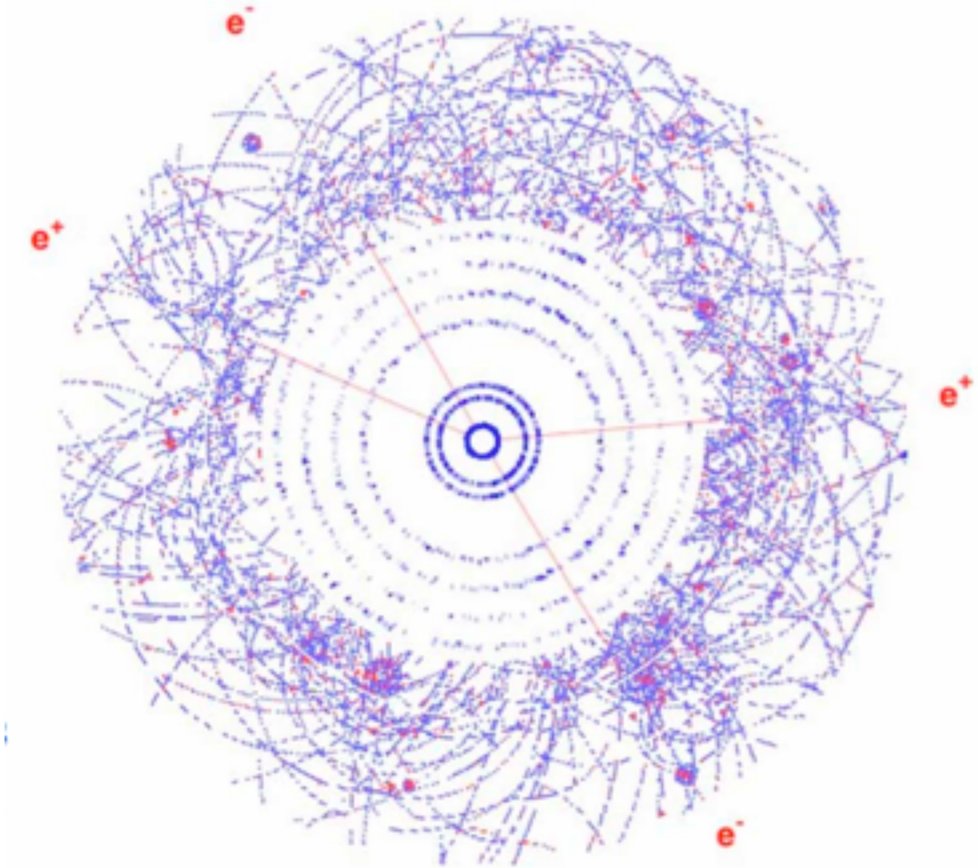
Spatial resolutions

	points	$\sigma(R\varphi)$ (μm)	$\sigma(Rz)$ (μm)
pixel	3	12	60
SCT	4	17	580
TRT	36	170	-

typical multiplicities may be very large

judge by eye:

pp -> H X -> 4e X



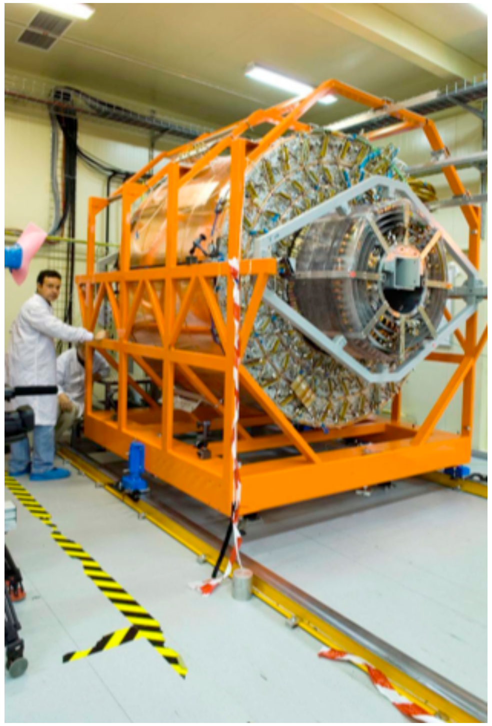
At peak luminosities:

- > more than 200 tracks
- > 15-20 secondary vertex candidates

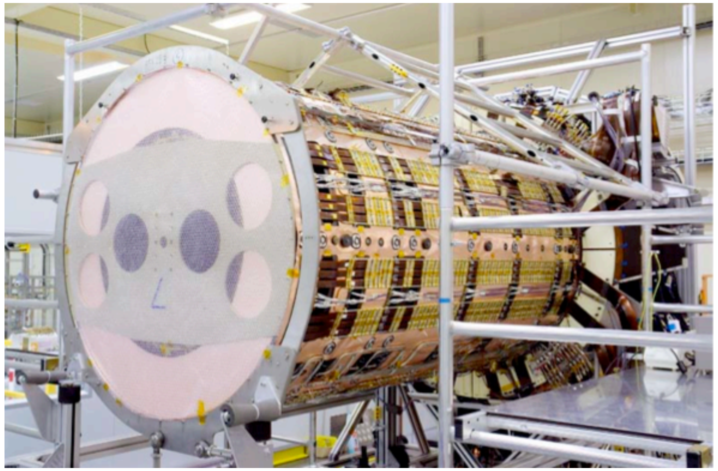
quick online raw tracking for triggering will be rather complex

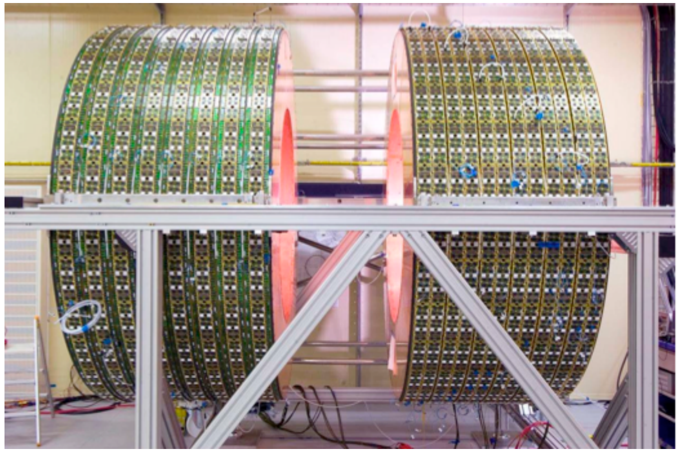
offline precise pattern recognition will be rather CPU-time consuming (and complex)

TRT+SCT barrel already in

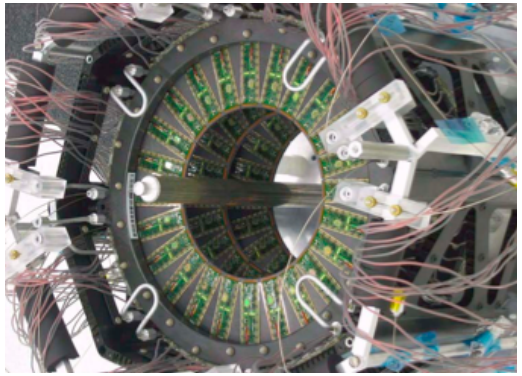


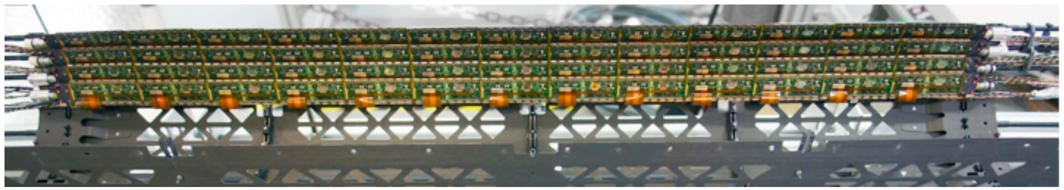
TRT+SCT End-Caps to be integrated at end of Year



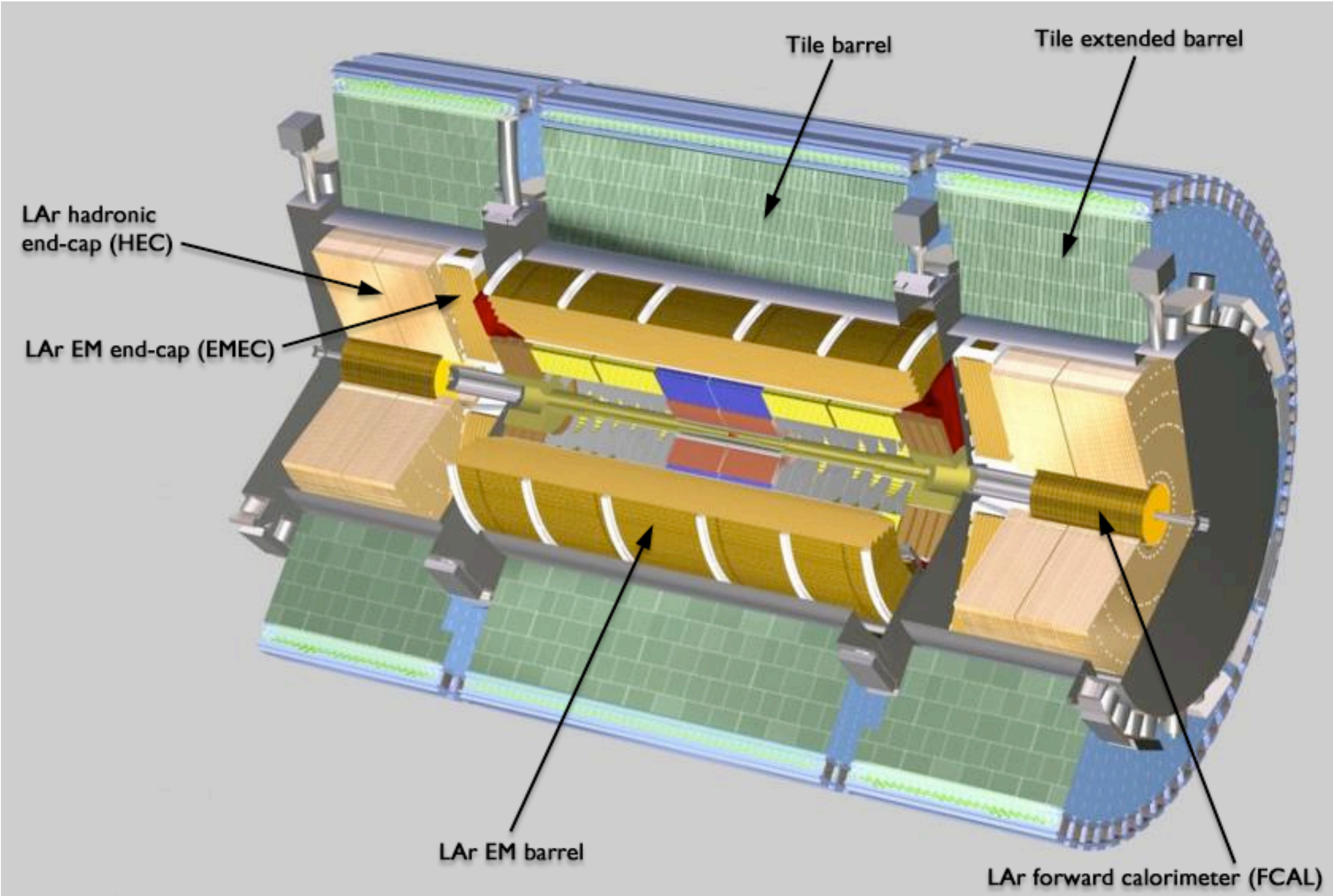


Pixel: problems have delayed readiness by spring 07





The calorimetric system



Electro Magnetic
→ $|\eta|<3$
→ $\sigma(E)/E \approx 10/\sqrt{E} \oplus 0.7\ \%$
ZEUS: $17/\sqrt{E} \oplus 1\%$

Hadronic
→ $|\eta|<3$
→ $\sigma(E)/E \approx 50/\sqrt{E} \oplus 3\ \%$
ZEUS: $35/\sqrt{E} \oplus 2\%$

Forward jet tag
→ $3<|\eta|<5$
→ $\sigma(E)/E \approx 100/\sqrt{E} \oplus 10\ \%$

- Excellent measurement of high energy E.M. particles
- Hermetic hadronic energy measurement + forward jet tag
- High granularity and fast electronics

The Electromagnetic Calorimeter

Design driven mostly by the measurement of an intermediate mass SM Higgs

$H \to \gamma\,\gamma$, $H \to Z\,Z \to e^+ e^- e^+ e^-$

[from LEPII limit of ≈114 GeV to $2m_Z$ ≈180 GeV]

> significance proportional to rapidity coverage

> $\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b$ already high energy; a small constant term b is mandatory $b \leq 0.7\%$

→ superb mechanics uniformity/reproducibility

→ superb electronics calibration stability/uniformity

→ time measurement (minimize pile-up effects)

> excellent linearity, ≤ 0.1% [also m_W measurement]

→ presampler for dead material

→ electronics calibration

> particle separation e^{+-}/jet, γ/π^0 : Rej. > 3 at p_T≈50 GeV

> angular measurement $50\sqrt{E}$ mrad

→ segmentation lateral + longitudinal

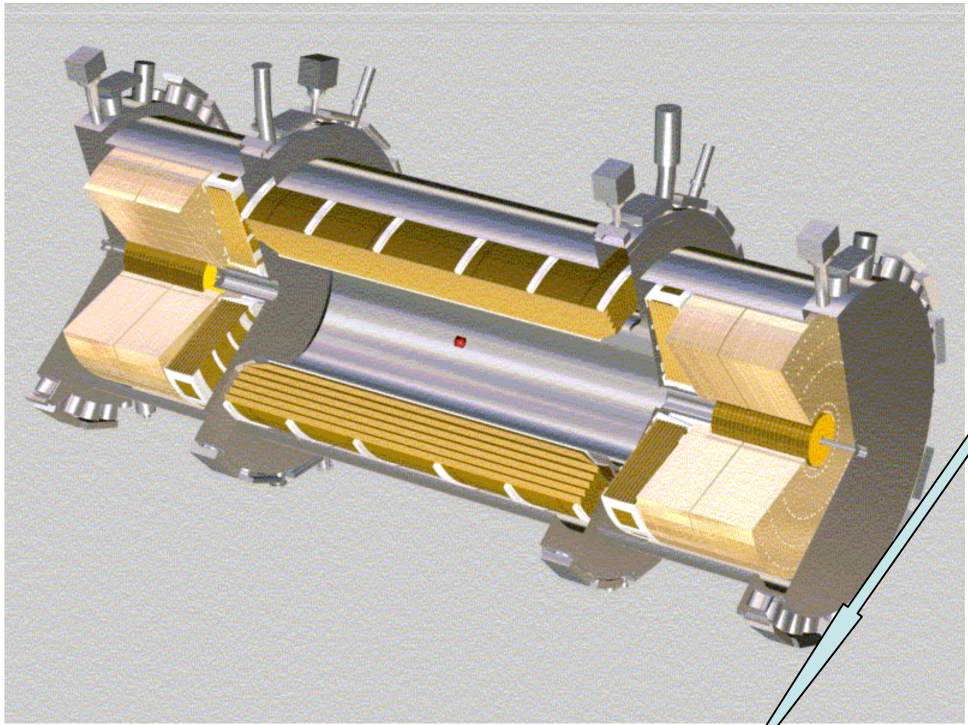
Being able to measure all the available phase space for EM particles

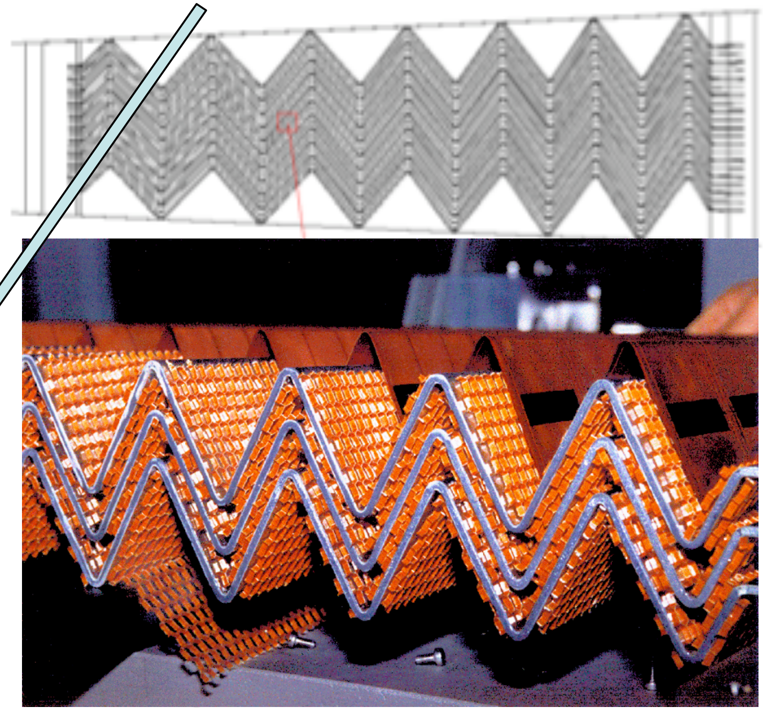
> large dynamic range: 20 MeV → 2 TeV

→ non trivial read-out electronics

Solution chosen by ATLAS:

Liquid-Argon/Lead sampling calorimeter with accordion-like geometry





- → full azimuthal coverage
- → $|\eta|<3$
- → high granularity (> 2×10^5 ch.)
- → 3 longitudinal samples
- → presampler for $|\eta|<1.8$
- → radiation hard

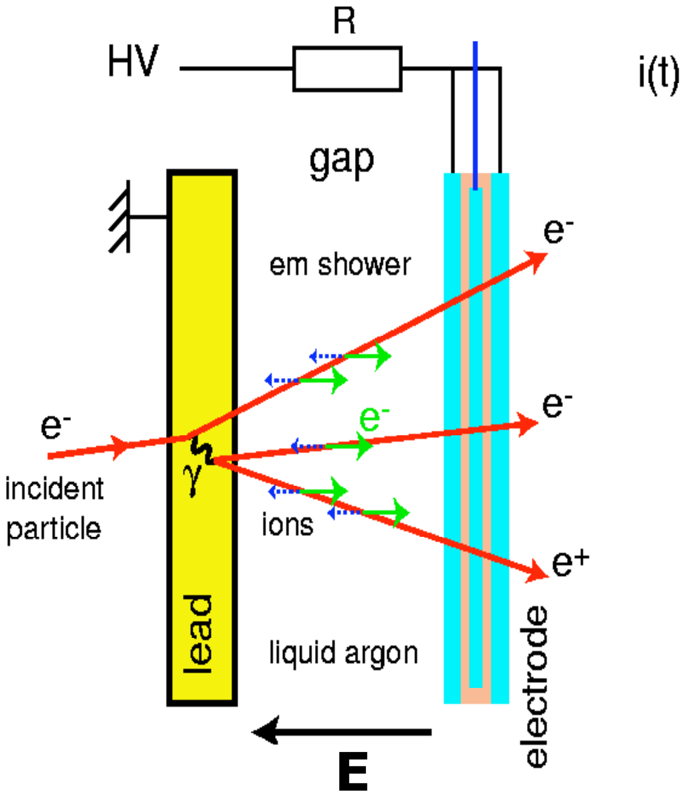
Sampling Unit (S.U.):

......

lead absorber
honey-comb spacer
Cu-Kapton flexible PCB electr.
honey-comb spacer
lead absorber

......

Signal Collection:

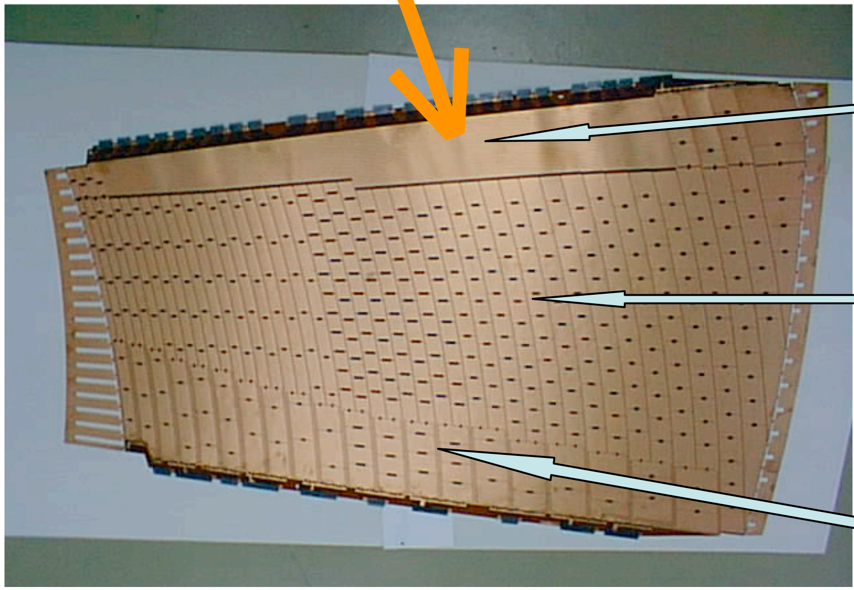


The calorimeter signal depends on:

- lead/argon thicknesses
- High Voltage (E field map)
- Temperature
- Attachment, Ions build up …

Read-out granularity

particles from I.P.



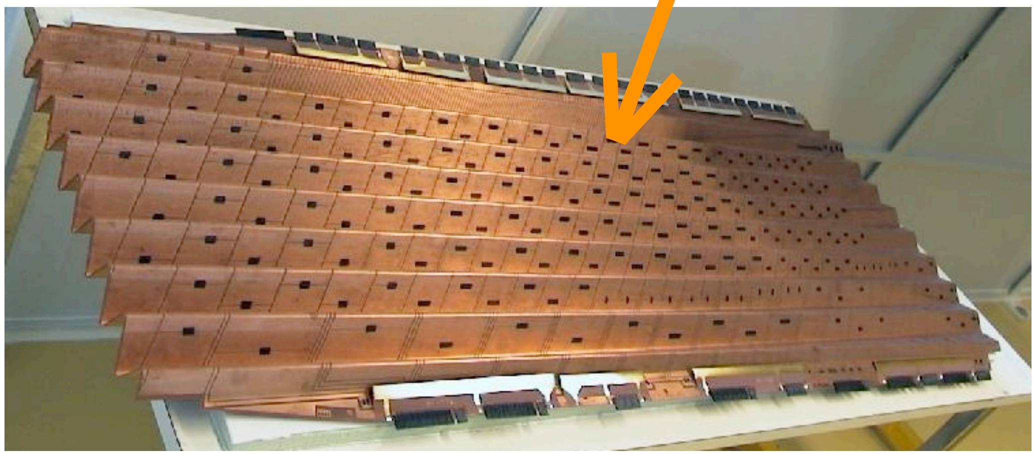
End-Cap read-out electrode
before bending

First sampling:
high granularity in η for γ/π^0 separation
and first point for angular measurement

Second sampling:
large containment for precise energy
measurement and second angular point

Third sampling:
monitoring of shower depth

particles from I.P.



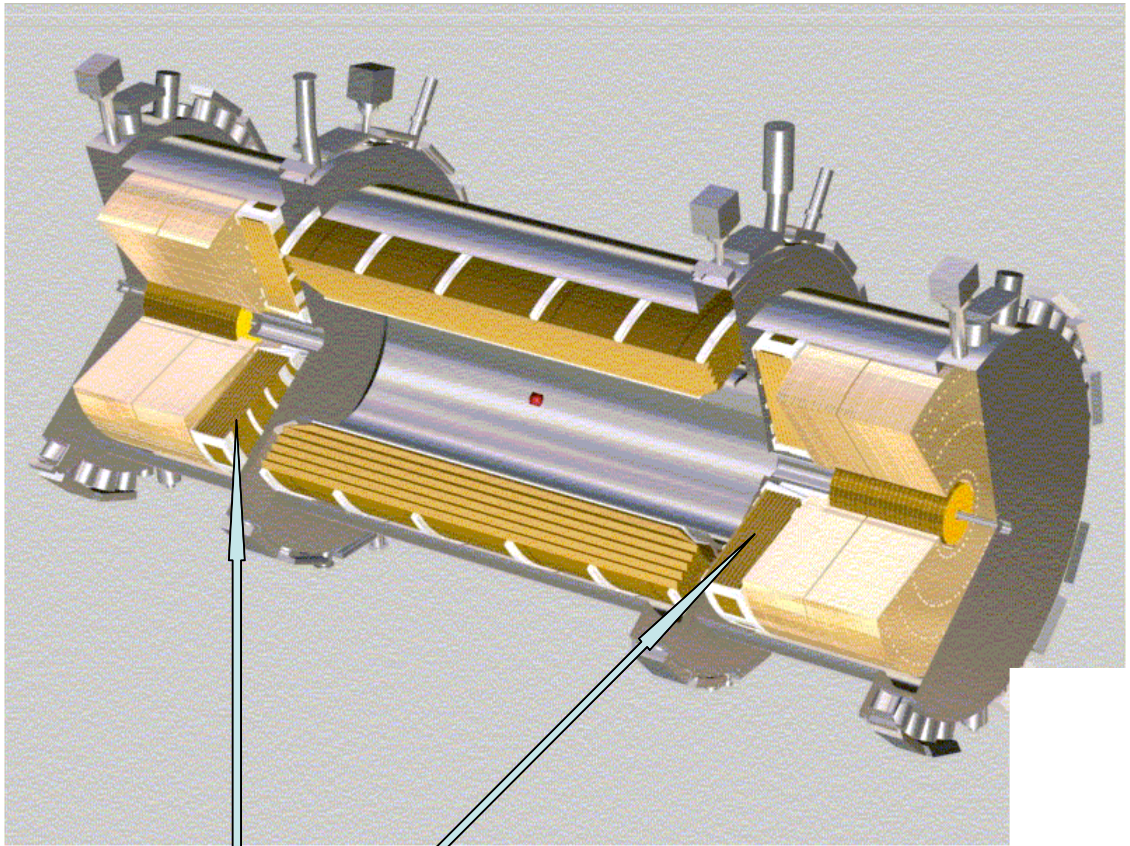
End-Cap read-out electrode
after bending

INTERLUDE

The construction of the ATLAS Electro Magnetic Calorimeter (End-Cap) by the UAM

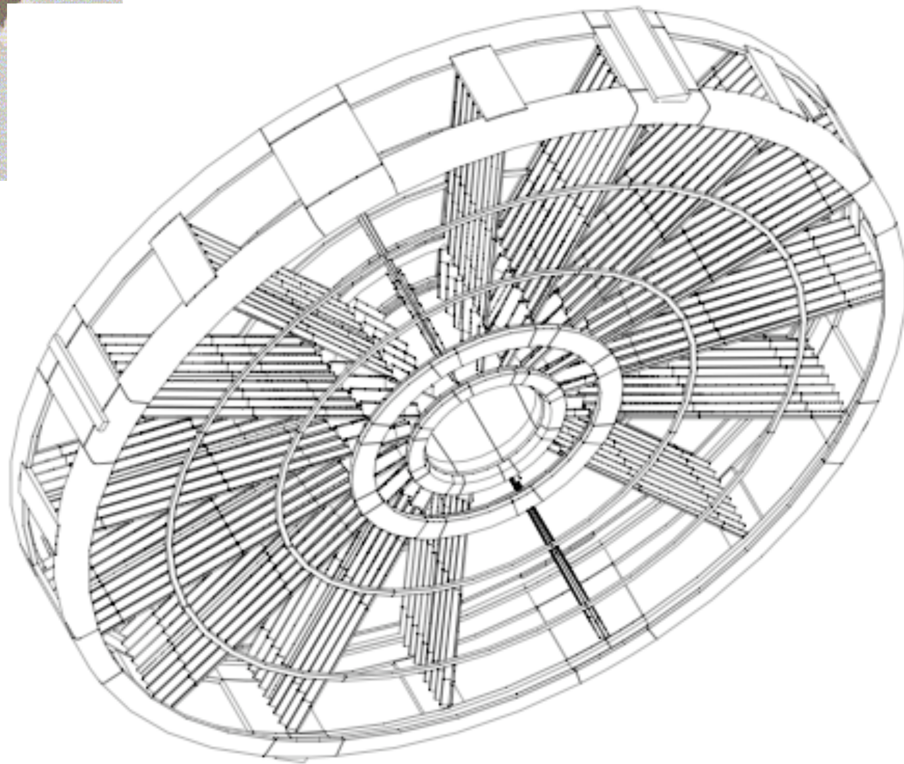
4 Thesis presented:

C. Oliver (Oct. 2006, *del Peso*)
Uniformity of the Electromagnetic End-Cap Calorimeter of ATLAS
S. Rodier (Oct. 2003, *Barreiro, del Peso*)
The ATLAS Liquid Argon Electromagnetic Calorimeter: Construction and Tests
P. Romero (Oct. 2000, *Labarga*)
On the design and construction of the End-Cap Liquid Argon Electromagnetic Calorimeter for the ATLAS experiment
G. García (Apr. 2000, *Labarga*)
Two different cases of calorimetry in High Energy Physics: the ATLAS Liquid Argon Electromagnetic End Cap and the ZEUS Forward Plug Calorimeter

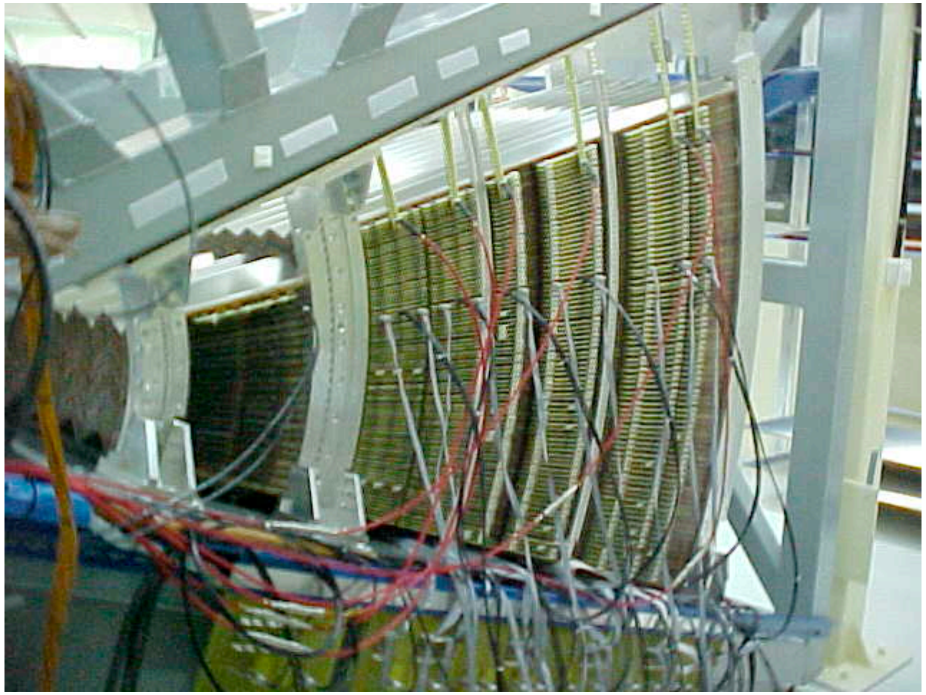


E.M. End-Cap Calorimeters

Schematics of mechanical structure:



- each End-Cap is divided into 8 modules
- each End-Cap is divided into 2 concentric wheels: Inner / Outer
- total no. of S.U. are 512 / 1536



All components vary with R:
- HV settings, capacitances
- fold angle, distances within S.U.

Electromagnetic calorimetry: $$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b$$

- if large E, σ(E)/E dominated by *b*
- *b* is built by non uniformities in reactions / perfomances
- as a result: in order to keep σ(E)/E < 0.7 % the contribution to *b* from geometrical non uniformities must be, b_{mec} < 0.3 %

⇒ a rather demanding mechanical project

Absorbers: the key of E resolution

-> 1.7 / 2.2 mm thick lead protected and rigidified by 0.2 mm thick s. steal plates; pre-preg layers are used for sticking together

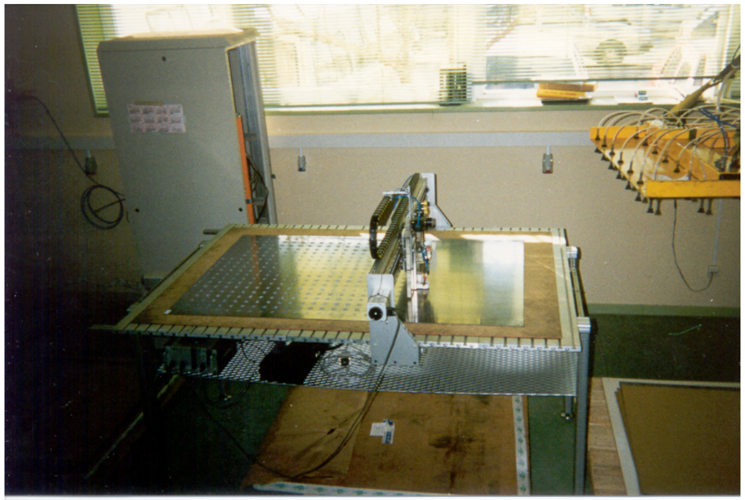
To achieve b_{mec} < 0.3 % :

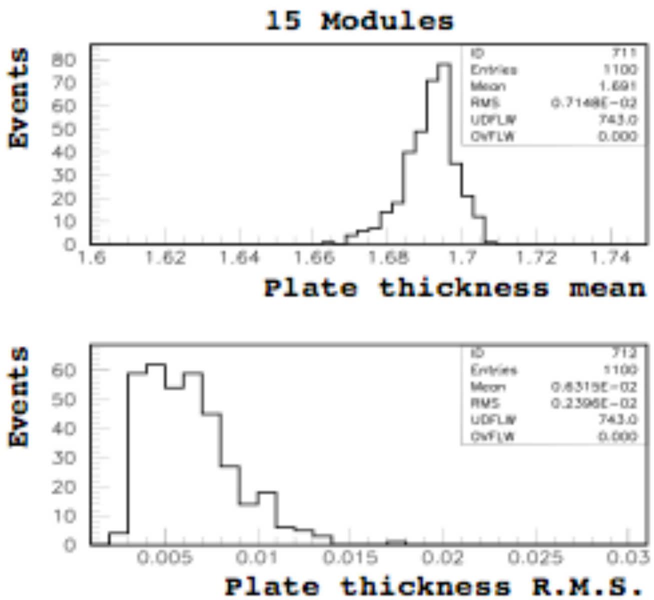
-> lead thickness uniform to 1% [17 / 22 μm RMS]

-> LArg. thick. uniform to 3% [abs. geometry reproducible to ≈ 150 μm RMS]

The lead was laminated in a standard foundry; with an online control of its thickness by a custom X-ray setup Rohr-GmbH, (Krefeld, Germany)

Ultra-sound thickness mapping at UAM:

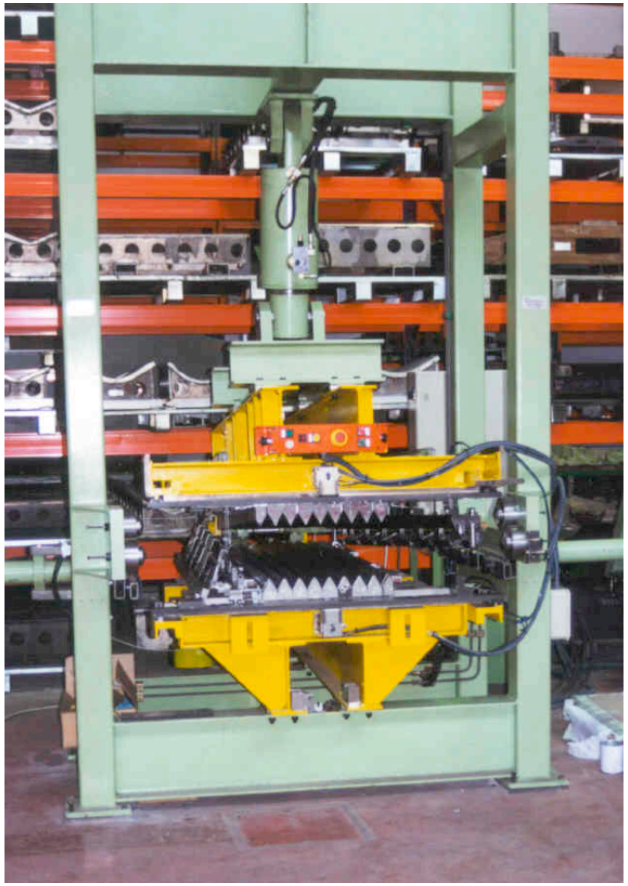


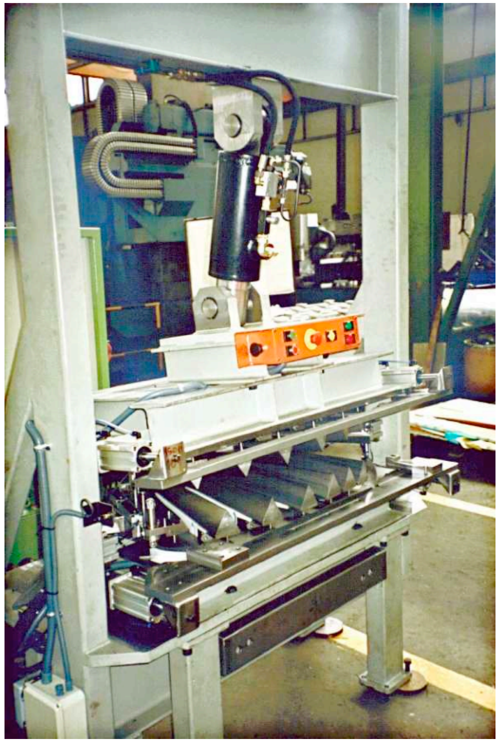


Thickness uniformity achieved: < 9 μm RMS

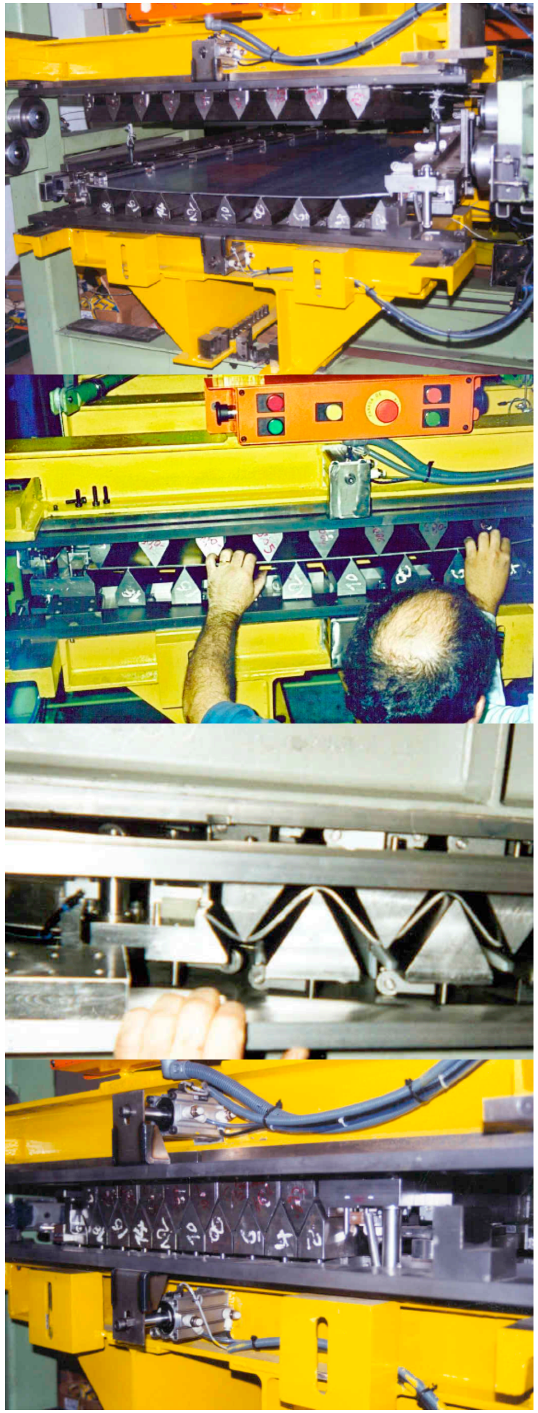
Absorbers: flat sandwich to accordion shape

2 presses built:





PROCESS:

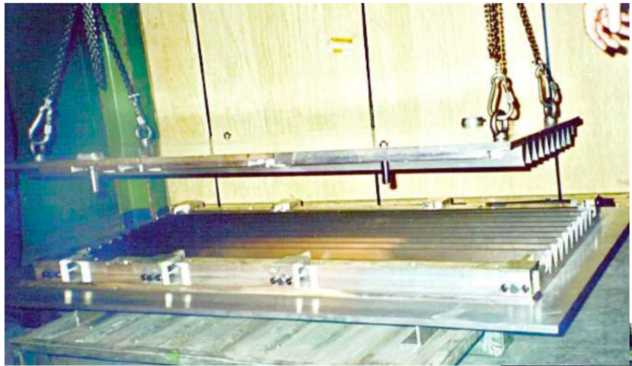


Mechanical tolerances of ≈150 μm along distances of ≈ 2 m *Talleres Arantz (Vitoria, Spain)*

The lead keeps its thickness unchanged (except at fold) ⇐

Absorbers: moulding and curing to precision shape

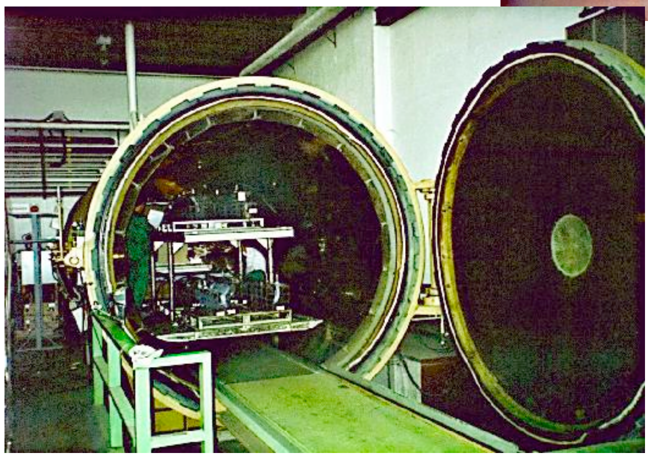
PROCESS: *Fibertecnic (Vitoria, Spain)*



Precision mould

Vacuum bag

Autoclave
P-T cycle (8 h.)



Logistics ⊗ economy:

⇒ autoclave cycles of 10 Outer and 4 Inner Absorbers

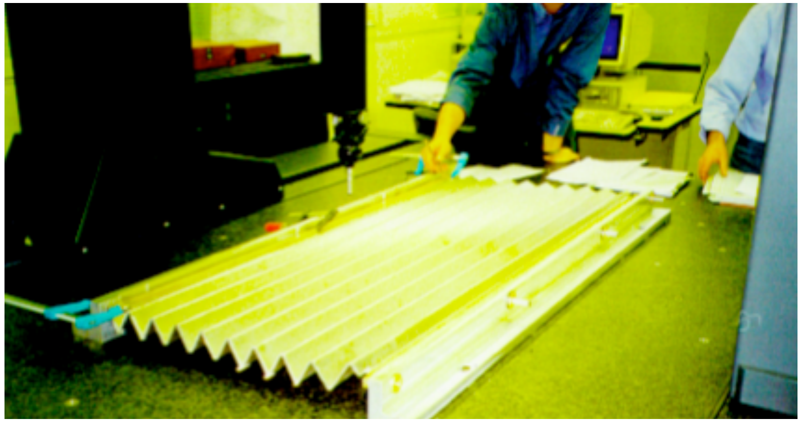
⇒ needed 10 OA + 4 IA moulds

⇒ mechanical reproducibility a must

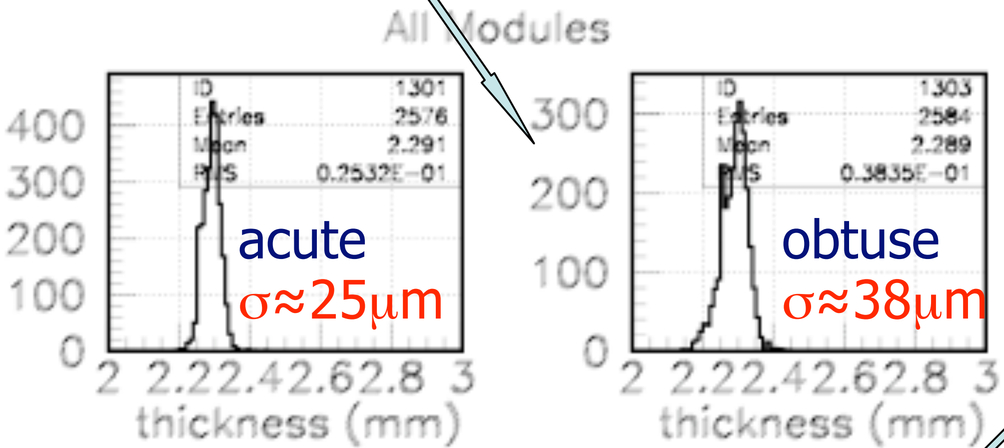
The dispersions achieved are only ≈ 25 % of the tolerances of the absorbers (≈ 40 μm)

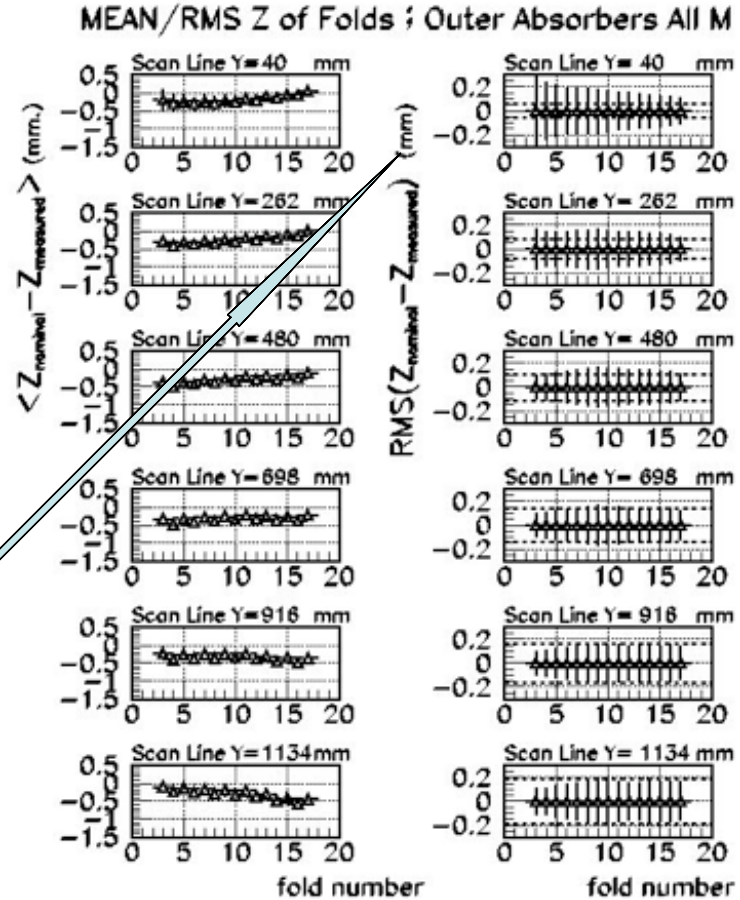
Talleres Arantz (Vitoria, Spain)

Absorbers: control (mass production)



to 100 % of absorbers:
- visual inspection
- thickness and widths at predetermined positions

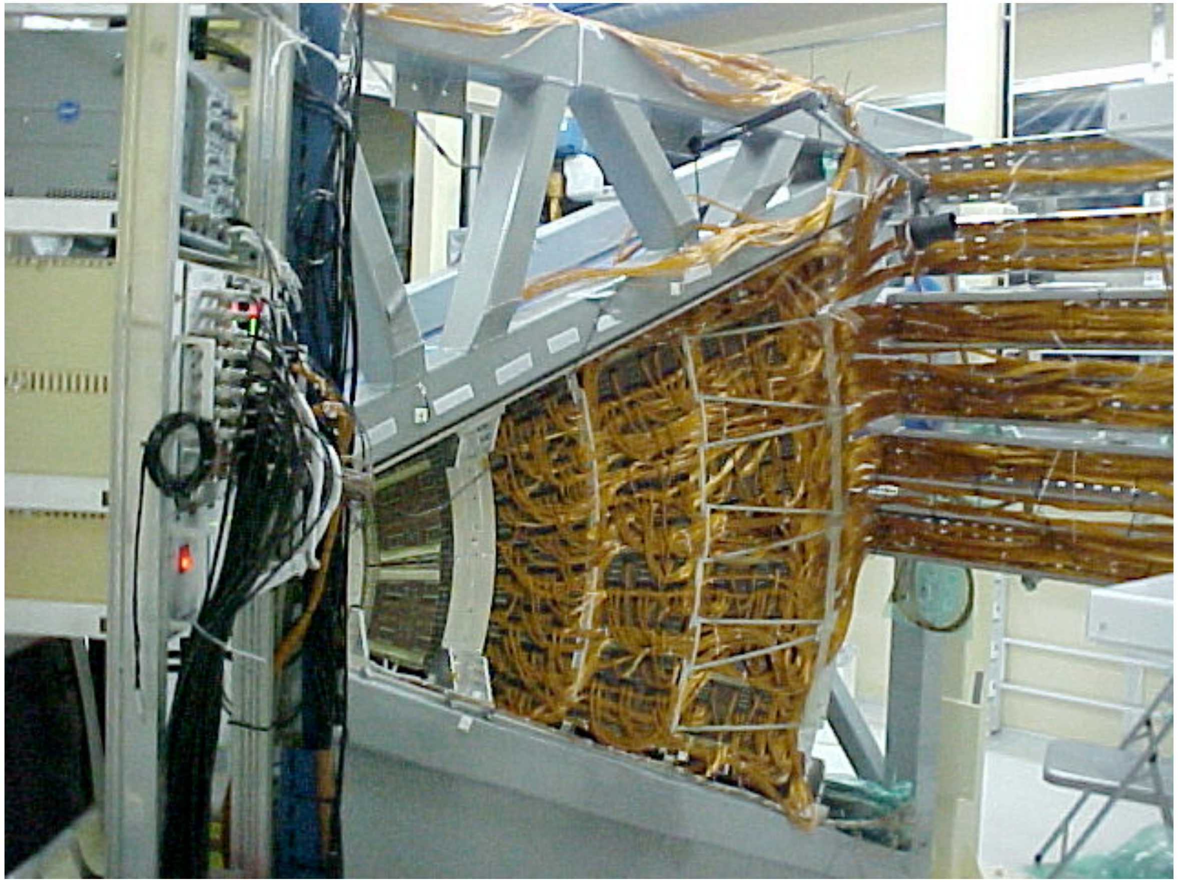




to selected 10 % of absorbers:
- complete 3D map in custom jig

Reproducibility achieved: 40 to 200 μm

The modules were stacked at CPPM (Marseille) and UAM

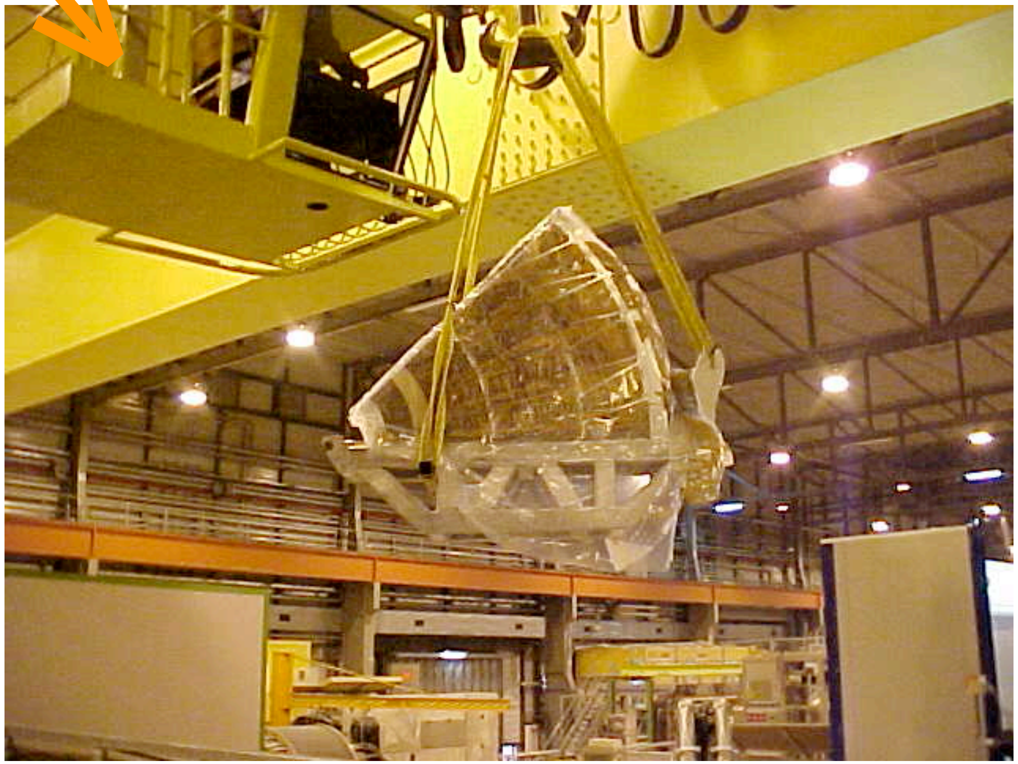


Module transport to CERN

Removal from stacking frame

At CERN´ test beam hall

In transport/storage frame to truck:

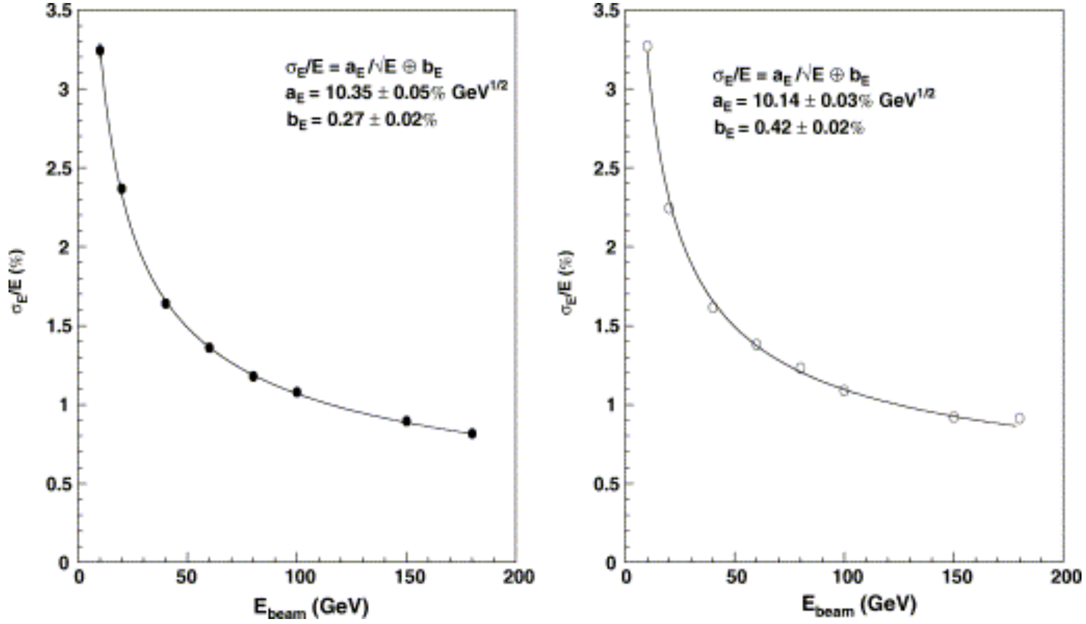


Test program at CERN (NA31 cryo.)

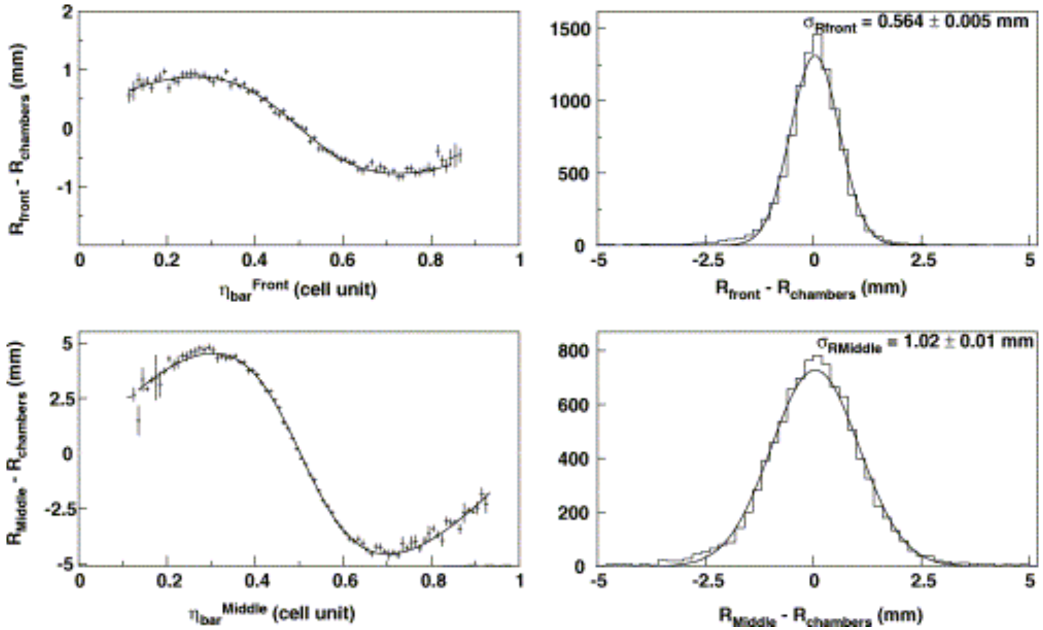
at Cold
(all the modules)
- Charge injection
- Calibration; gain calculations
- Performance under HV

10-200 GeV e^+ beams (H6 line)
(2 prototypes, 3 modules)

Energy resolution



Position reconstruction

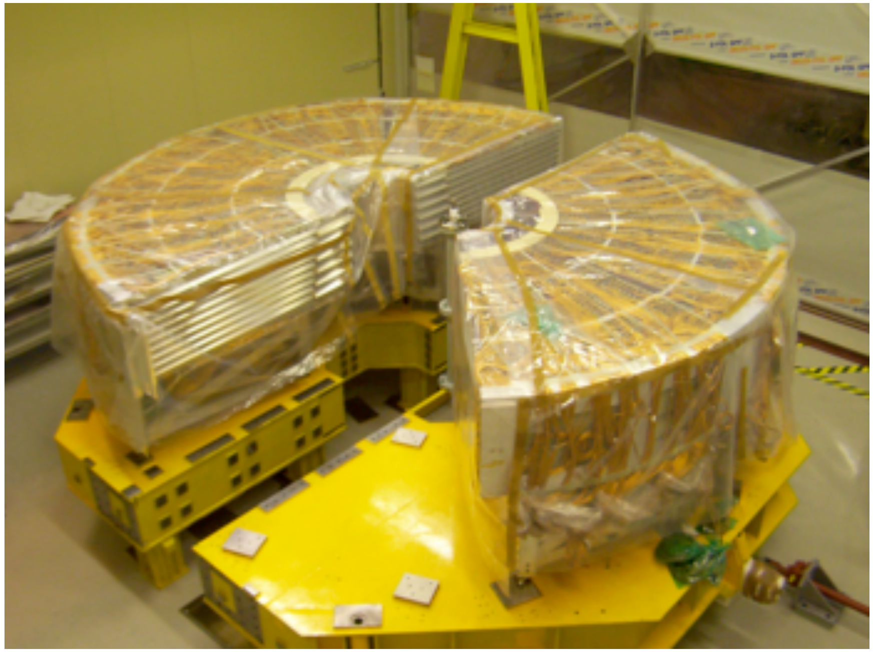


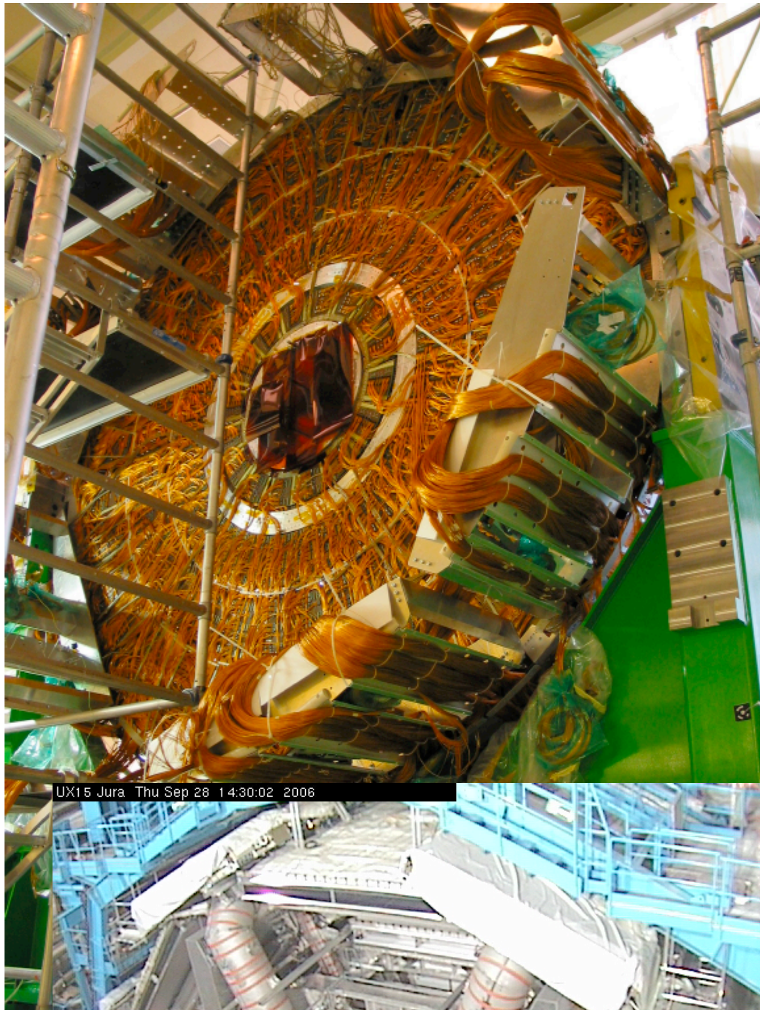
Uniformity
(deviations to)

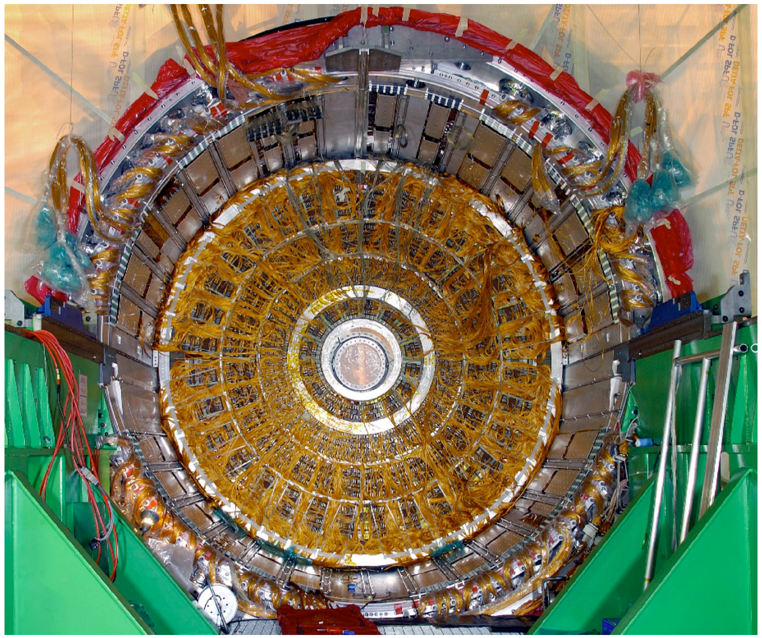
Module	ECC0	ECC1	ECC5
$\sigma / < E >$	0.57±0.02%	0.51±0.02%	0.50±0.02%
$\sigma_\eta / < E >$	0.42±0.02%	0.49±0.02%	0.43±0.02%
$\sigma_\phi / < E >$	0.47±0.02%	0.43±0.02%	0.38±0.02%

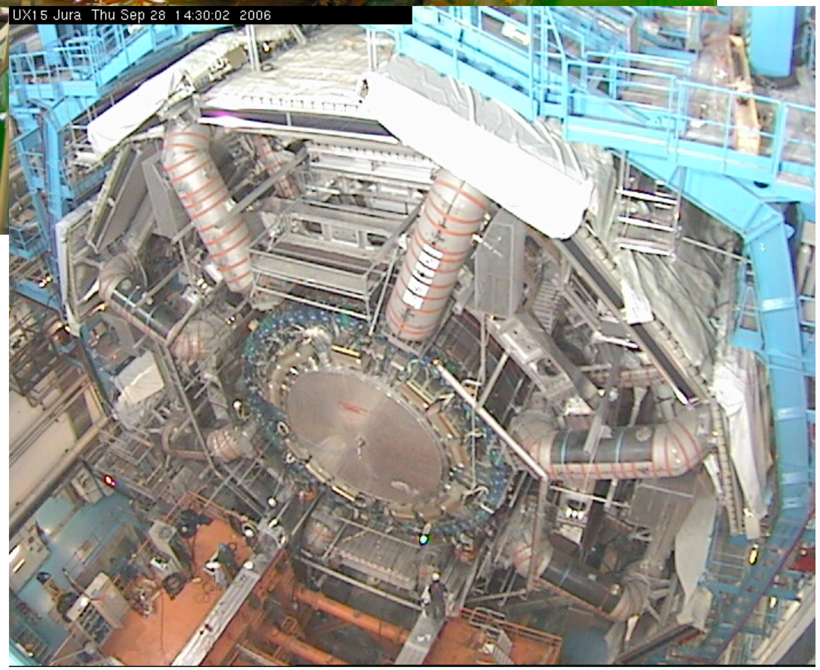
Consistent with b < 0.7 % !

… into ATLAS







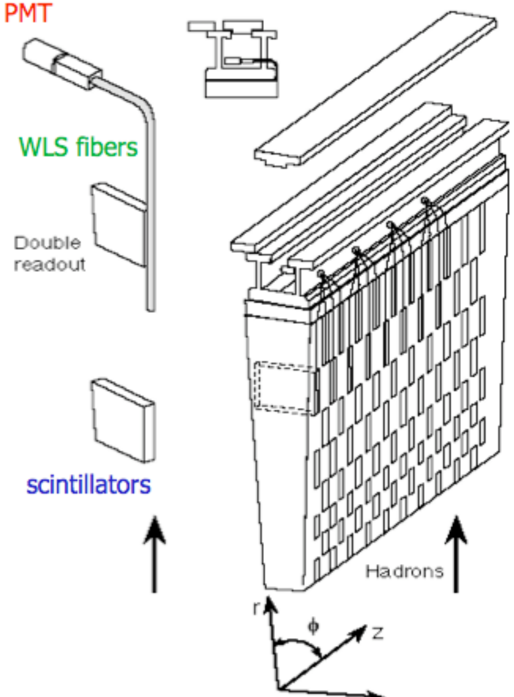


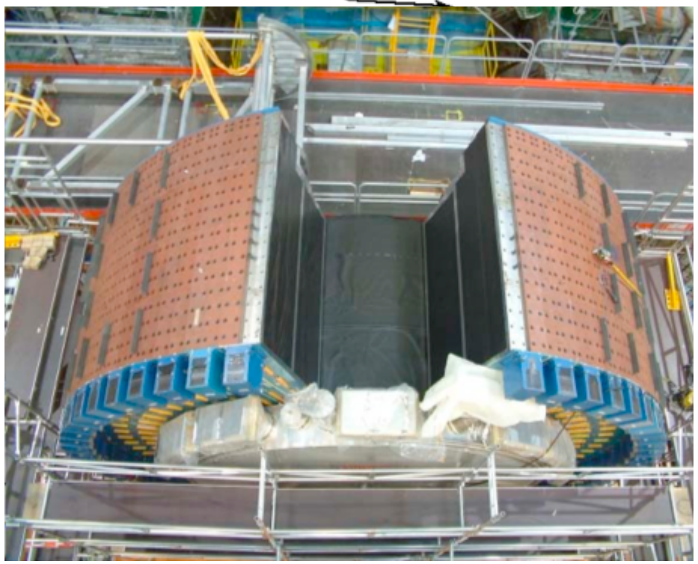
END of INTERLUDE

back to main flow ....

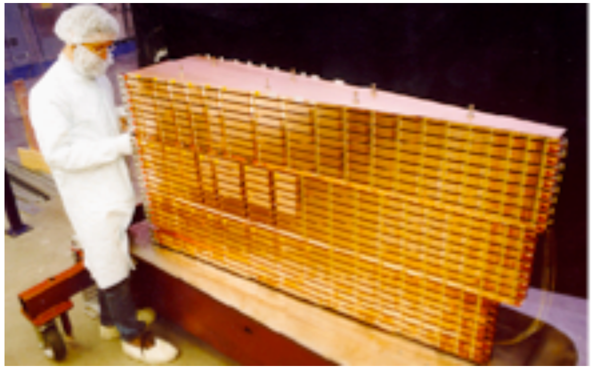
The Hadronic Calorimeters

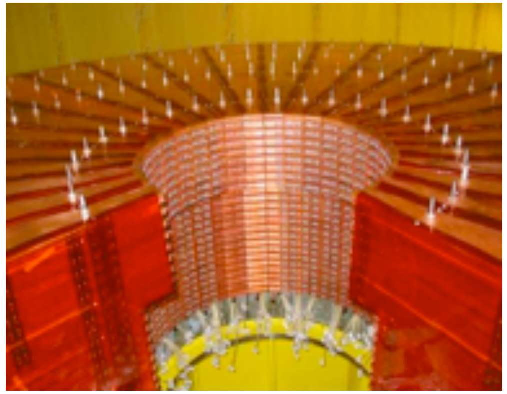
The tile calorimeter (barrel)

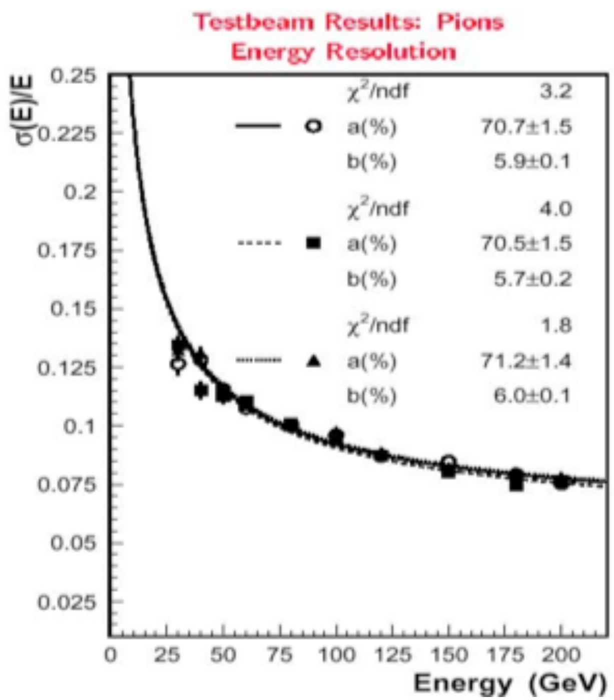




The Hadronic End-Cap (HEC) goes inside the EC cryostates



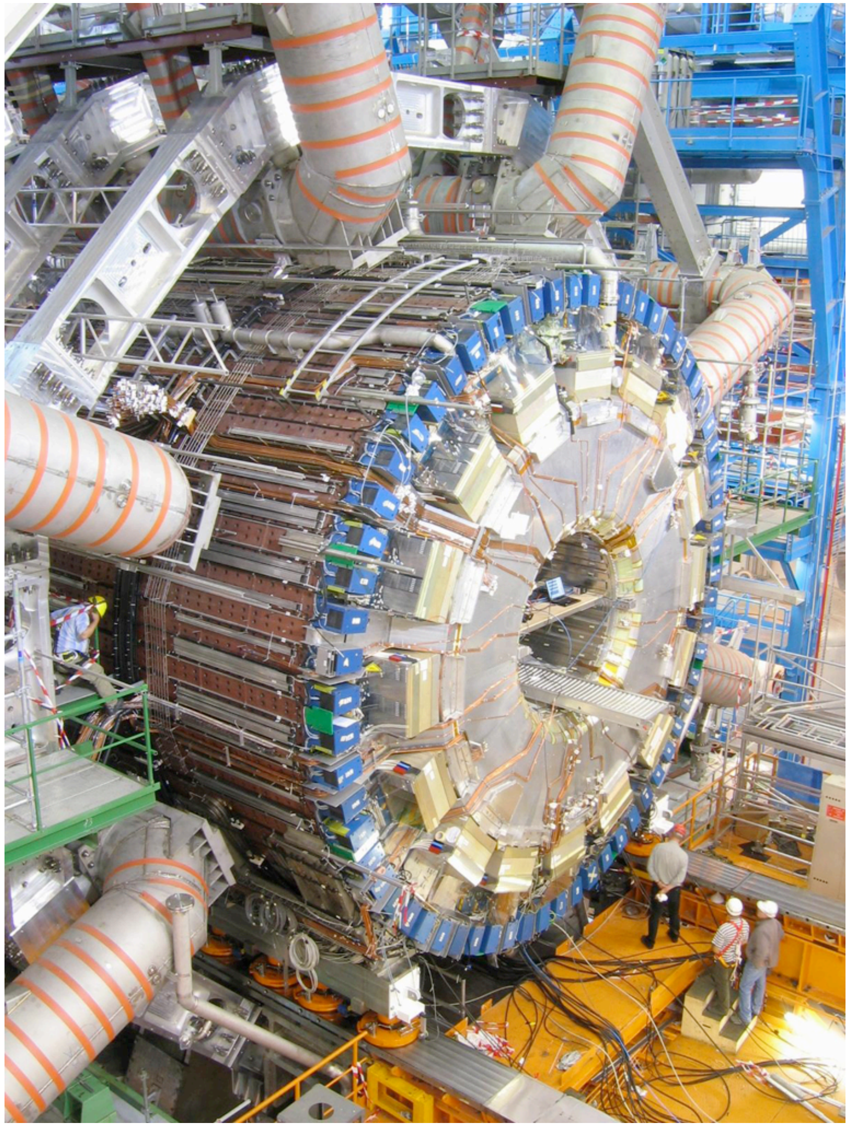


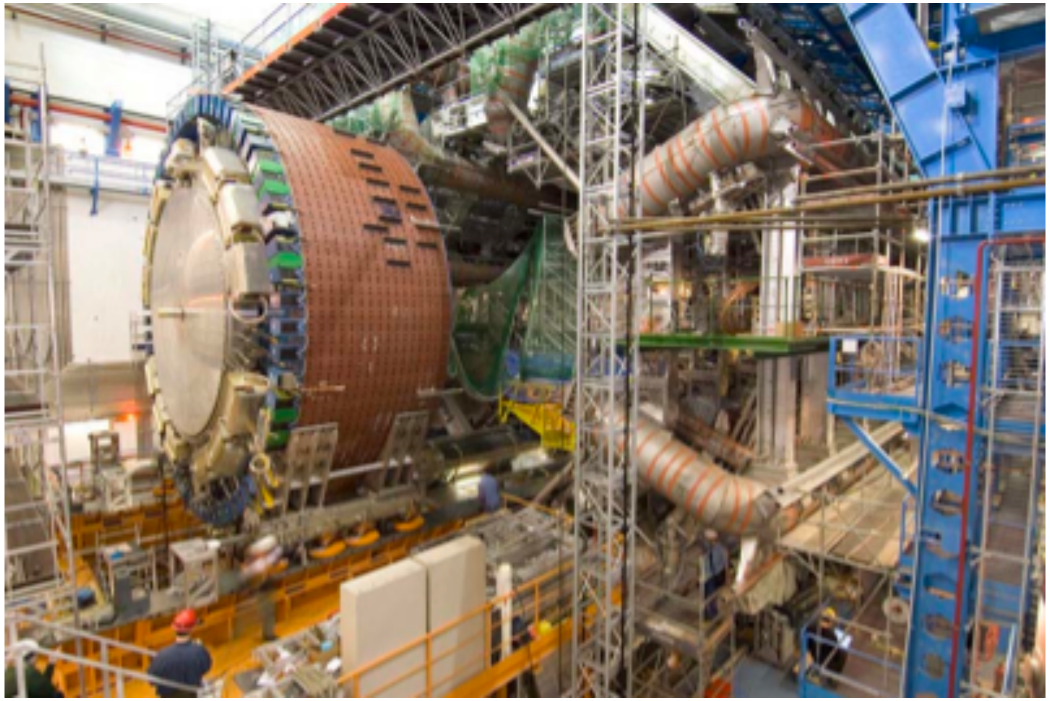


All the Calorimeters:

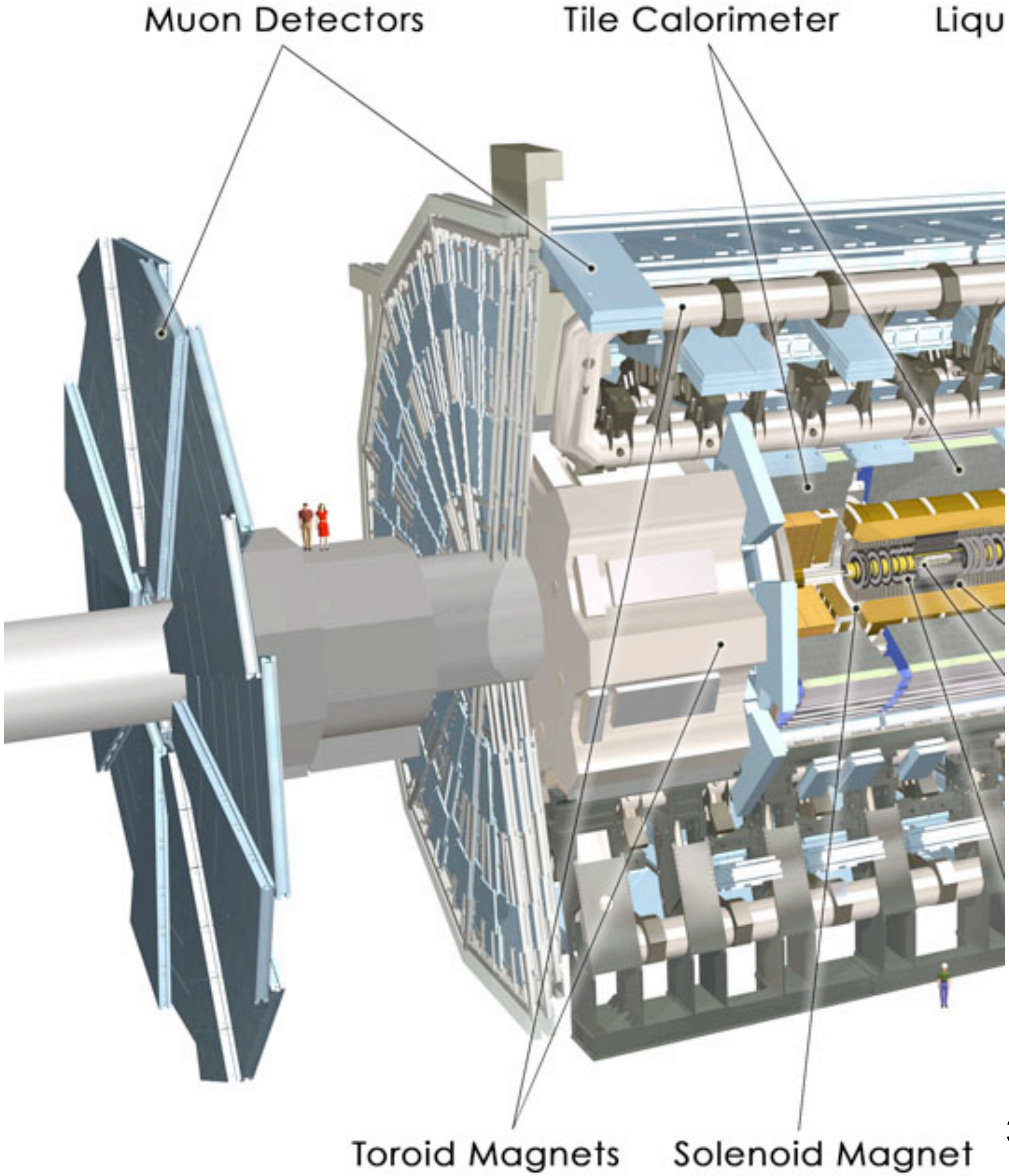
→ barrel Larg-EM, Tile; End-Cap Larg-EM, Larg-Had, Forward ←

are already in





The MUON system



Capable of standalone muon reconstruction

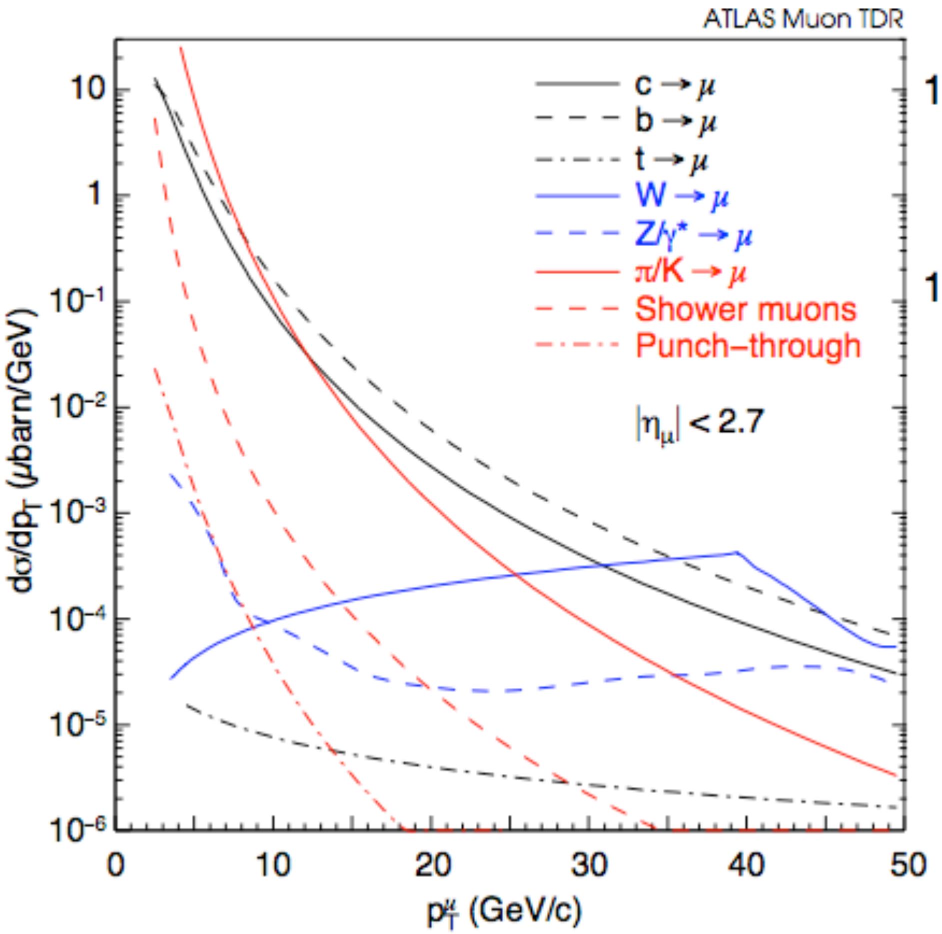
Minimization of multiple scattering: air toroid

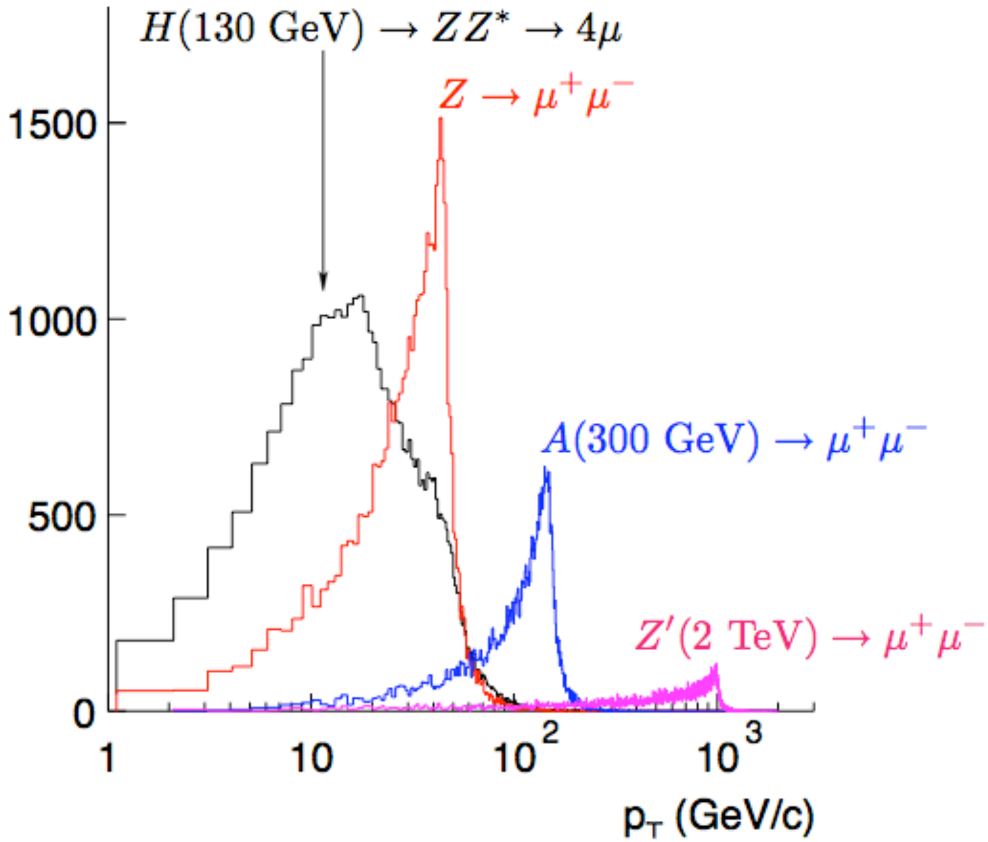
Barrel by sept. 06
EC toroid by Dec. 06
Full EndCap by April 07

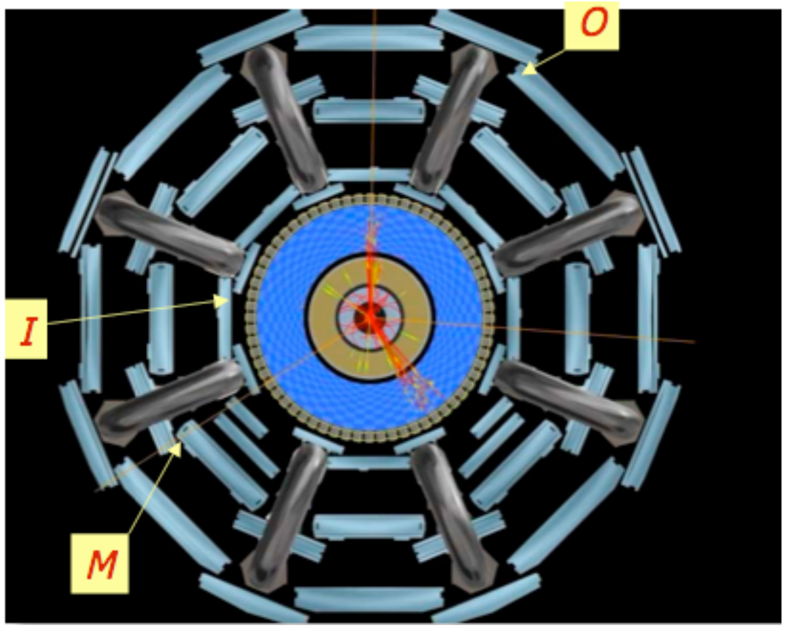
Spectra of MUONS at the LHC

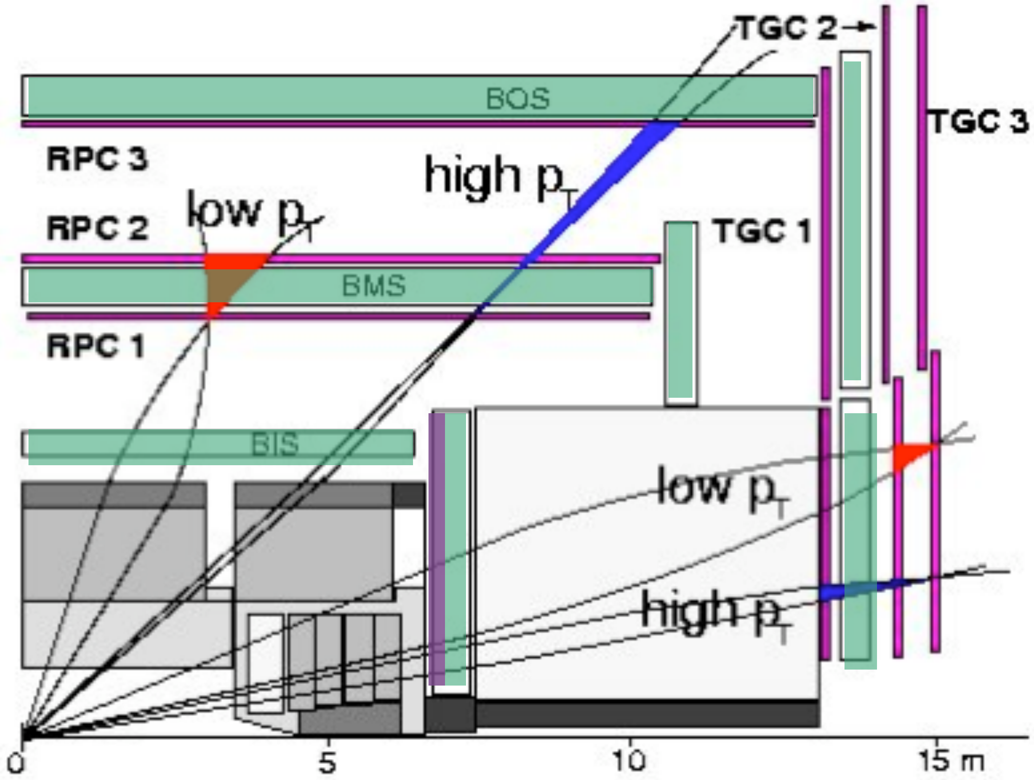
$p_T(\mu)$ spectra at characteristic reactions:

$p_T(\mu)$ inclusive spectra:





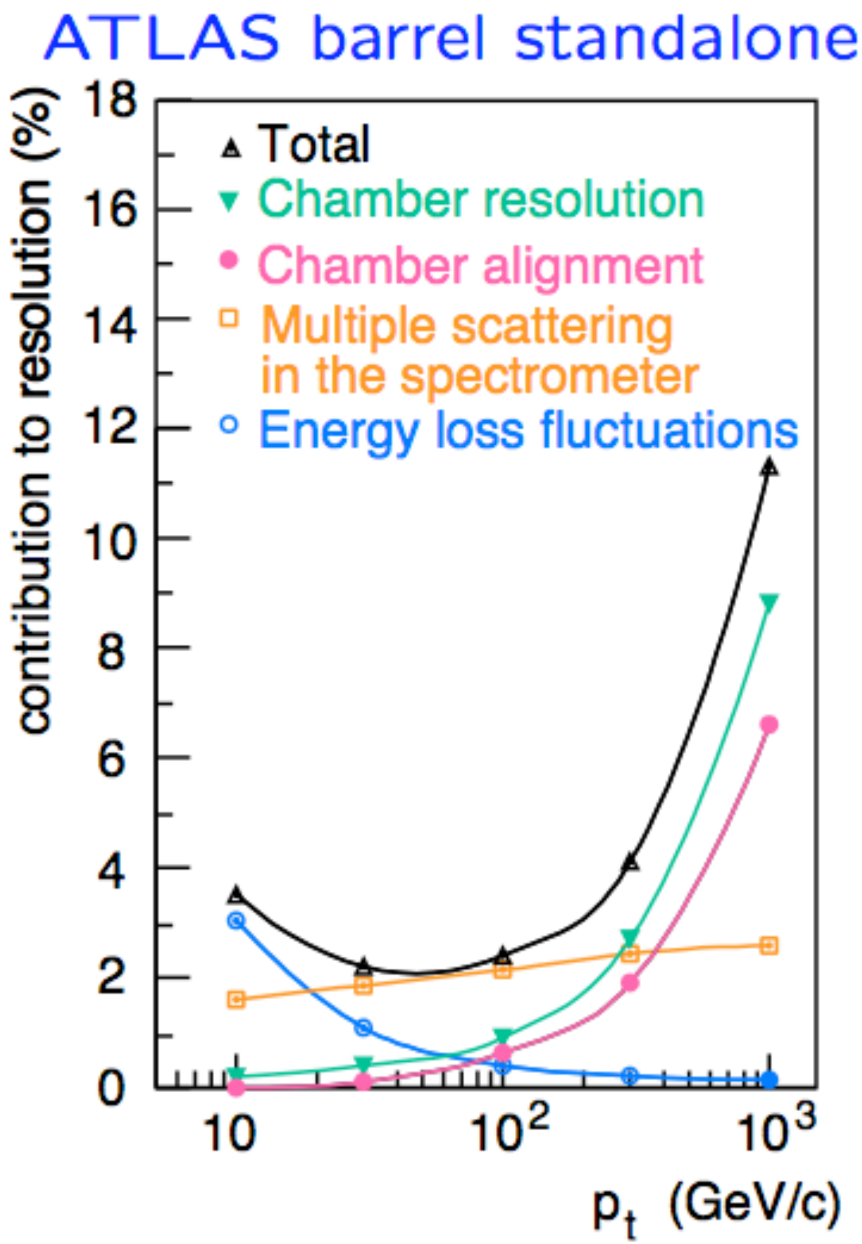




3 stations of precision chambers [drift tubes]
interleaved with Trigger chambers of fast response (< 25 ns)

LV1 Trigger Chambers:
Lower rate area (barrel): Resistive Plate Chambers (RPC)
Higher rate area (forward): Thin Gap Chambers (TGC)

$p_T(\mu)$ resolution:



similar results for:

- End Cap standalone
- Combined with tracking system [slightly better resolution for intermediate $p_T(\mu)$]

Efficiency:

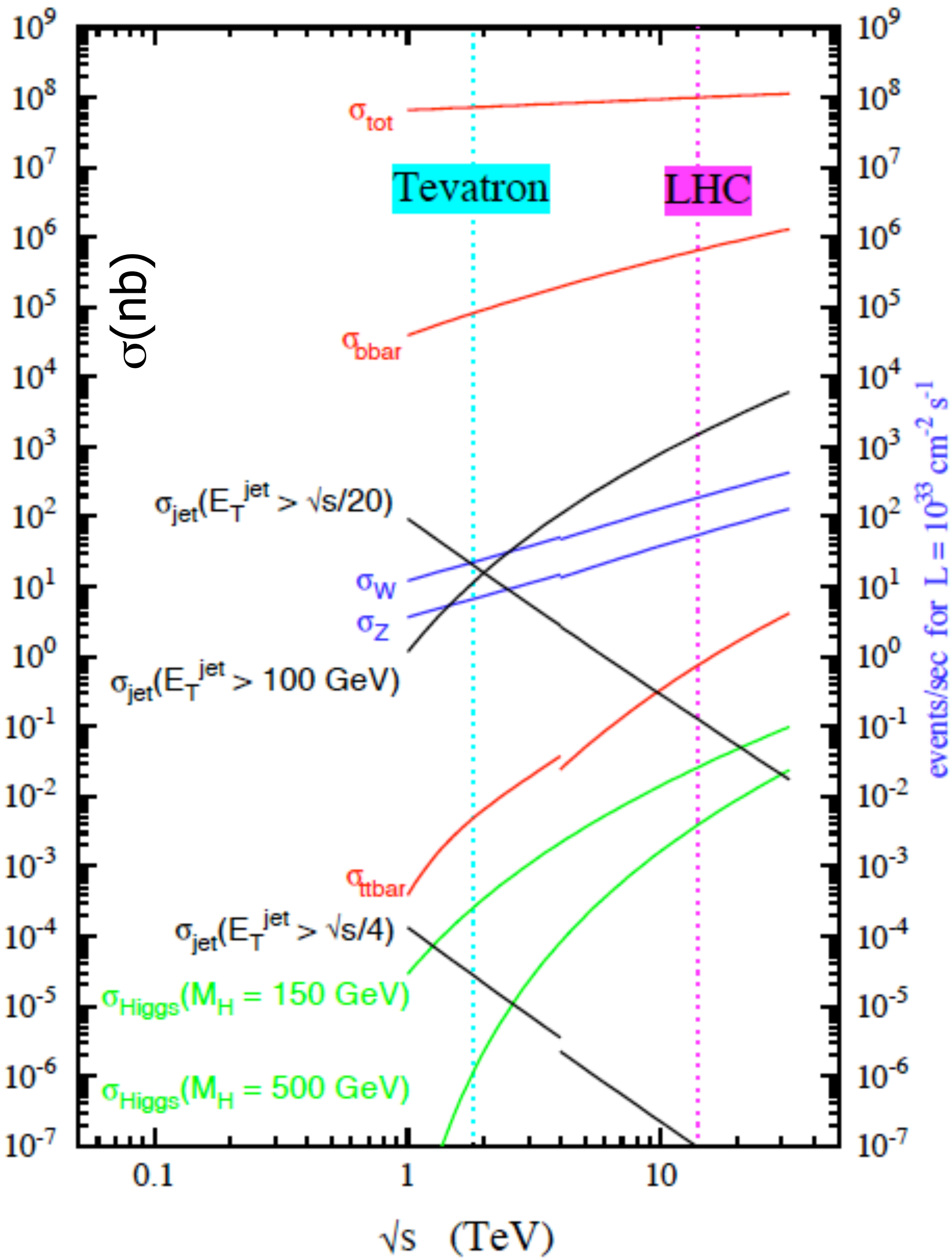
$> 96\%$ for $p_T(\mu) > 20$ GeV

$\approx 80\%$ for $p_T(\mu) = 5$ GeV

TGC1 sectors

Installation is a puzzle of logistics
but it is going ≈ on time

Trigger and DAQ



Trigger and DAQ

Impossible (and non-desired !) to record more than 100 ev./s.

But 10^8 ev/s are produced total

Trigger/DAQ systems-strategies should be capable of:

> correctly flag and record all interesting events of very low cross section (p.e. Higgs, tt)

> flag, pre-scale[small] & record (only pre-scaled) interesting ev. of intermediate σ (p.e. W, Z)

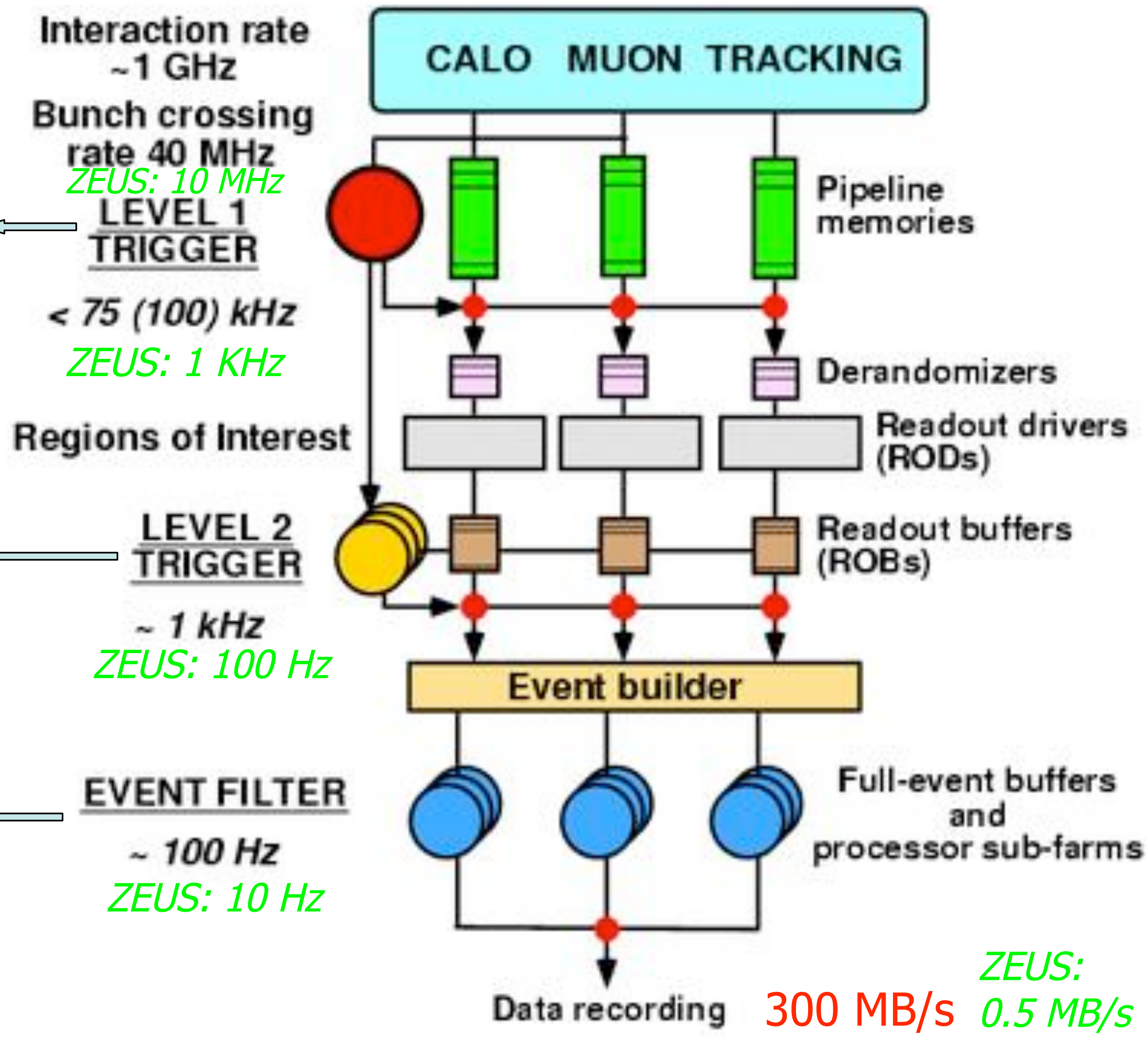
> flag, pre-scale[large] & record (only pre-scaled) interesting ev. of large σ (p.e. bb)

The trigger and DAQ systems

Only info[rough] from CAL and Muon tracker
[2.5 μs]

Computations only performed for the identified RoI
[10 ms]

An almost offline event analysis
[1 s]

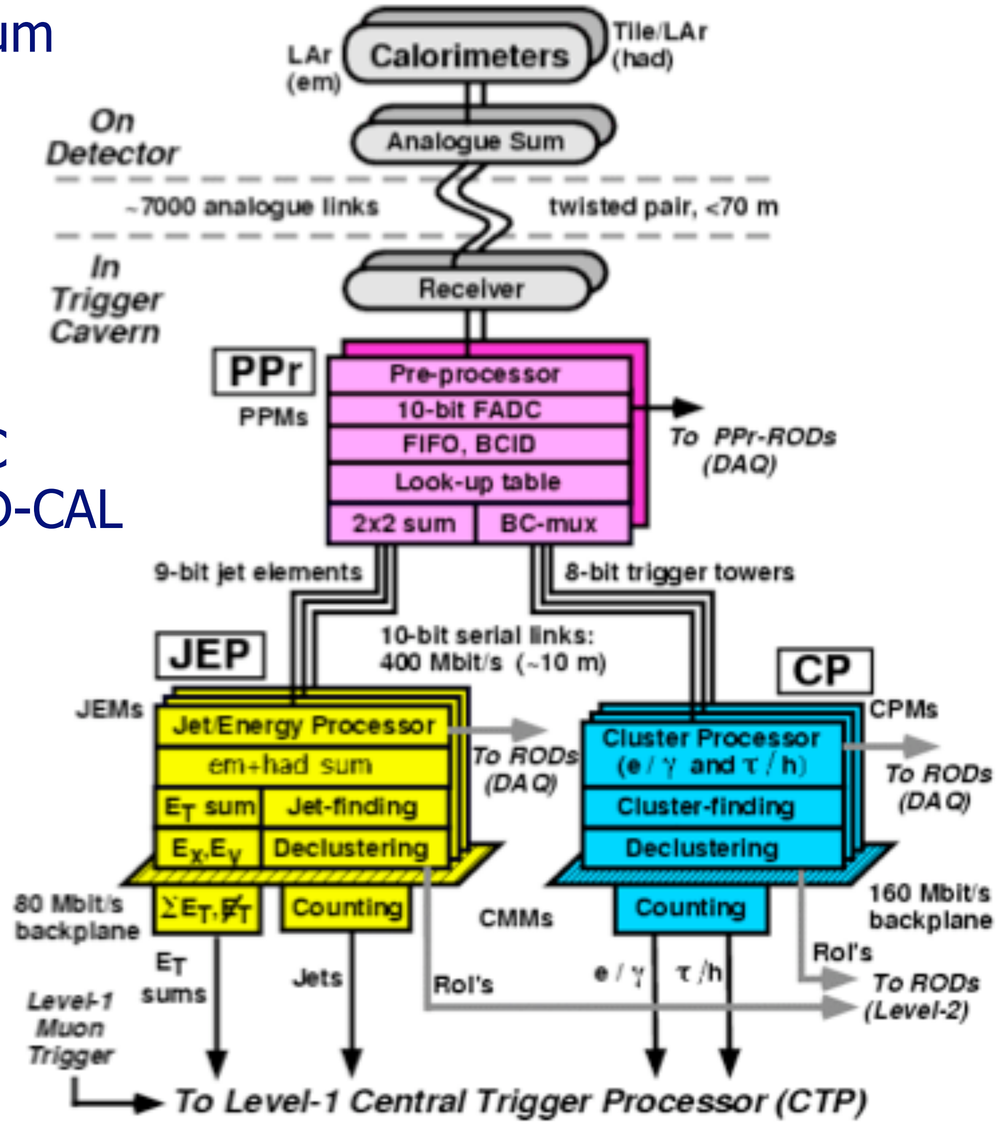


For instance: LVL1 calorimeter trigger

analogue electronics on det. sum signals to form trigger towers

signals digitised and processed to measure E_T per tower for BC
→ E_T matrix for EM-CAL & HAD-CAL

Tower data transmitted to processor and processed:
→ rough E_T, jets, e^{+-}/γ …



[for decision taken]

LVL1 muon trigger

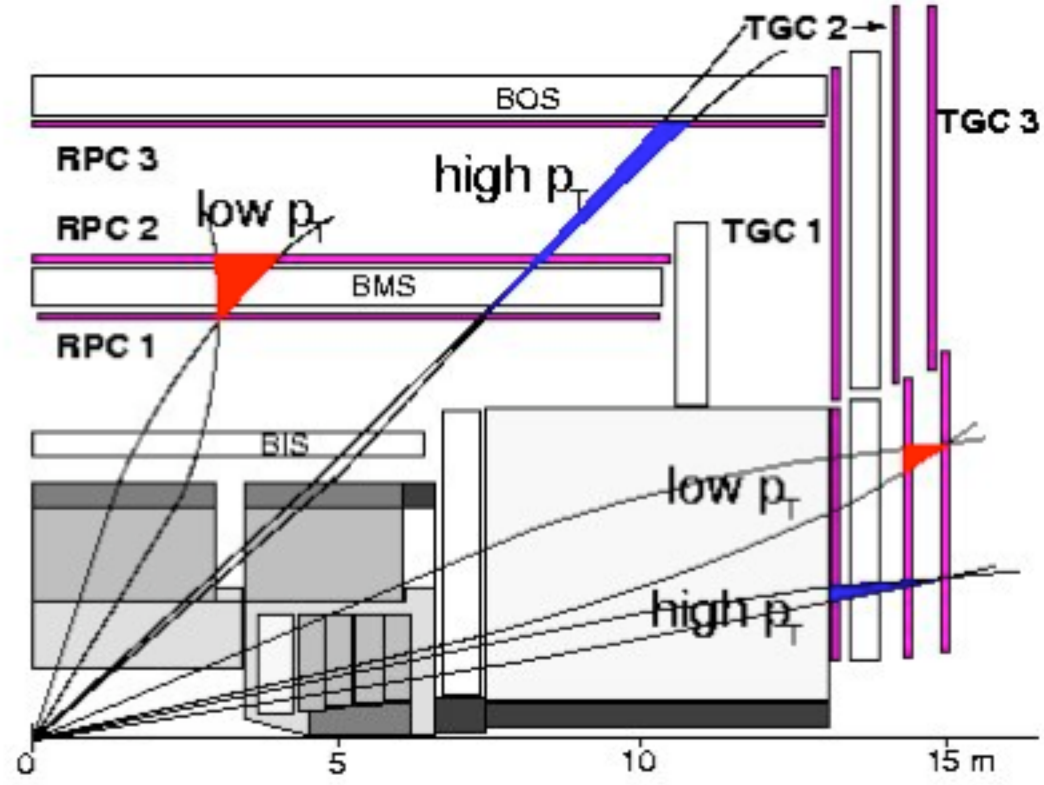
> hit in RPC1

> extrapolate straight line
VX-RPC1 to RPC2

> if coincidence hit at
RPC2+window ⇒ low-p_T μ

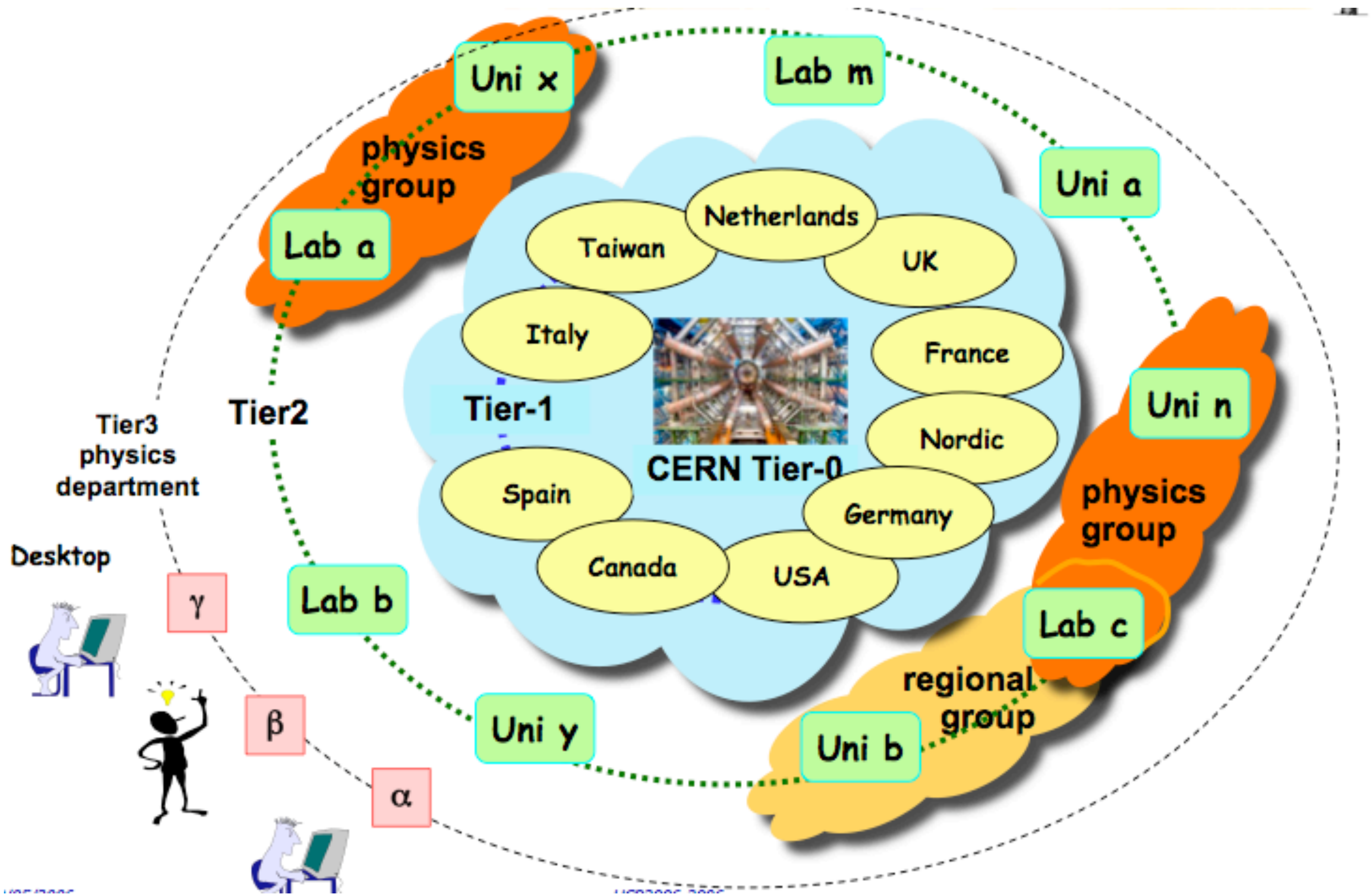
> extrapolate straight line
VX-RPC1 to RPC3

> if coincidence hit at
RPC3+window ⇒ high-p_T μ



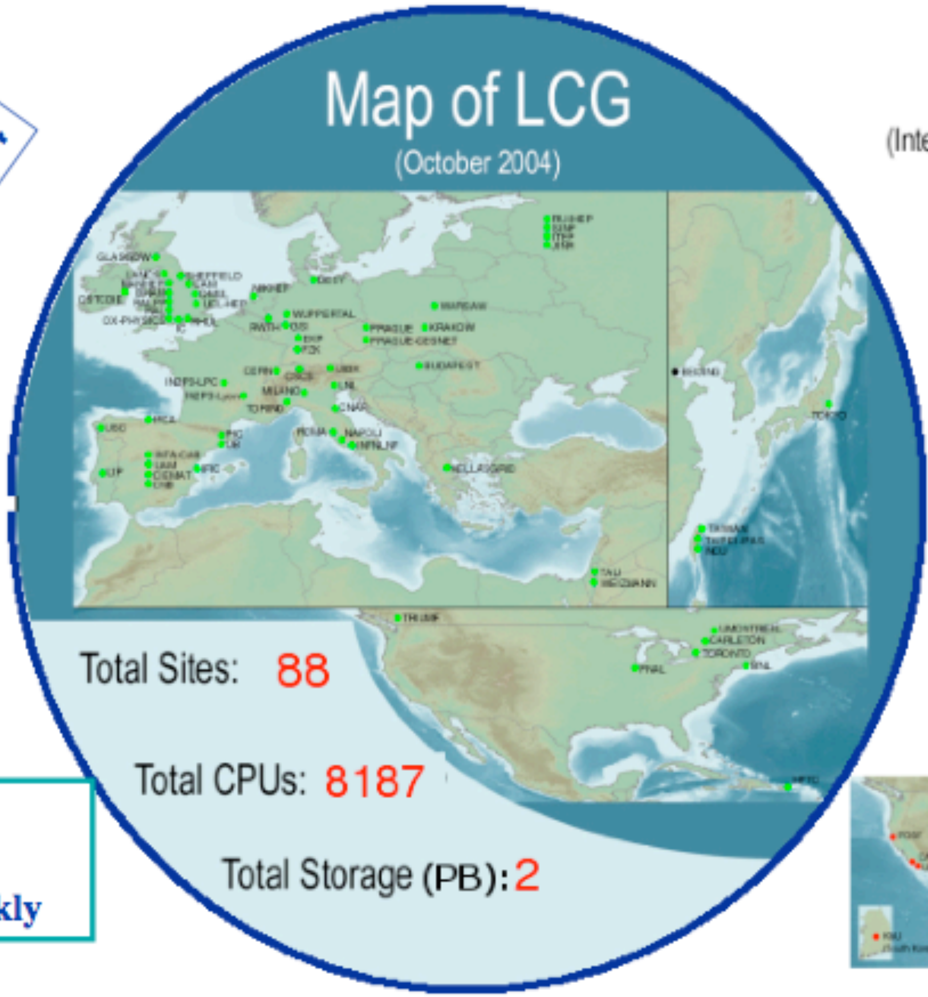
OFF-line computing

Worldwide LHC Computing Grid (WLCG)



The 3 Grid flavors: LCG-2

ATLAS DC2
Autumn 2004



NorduGrid
(Interoperating with LCG)

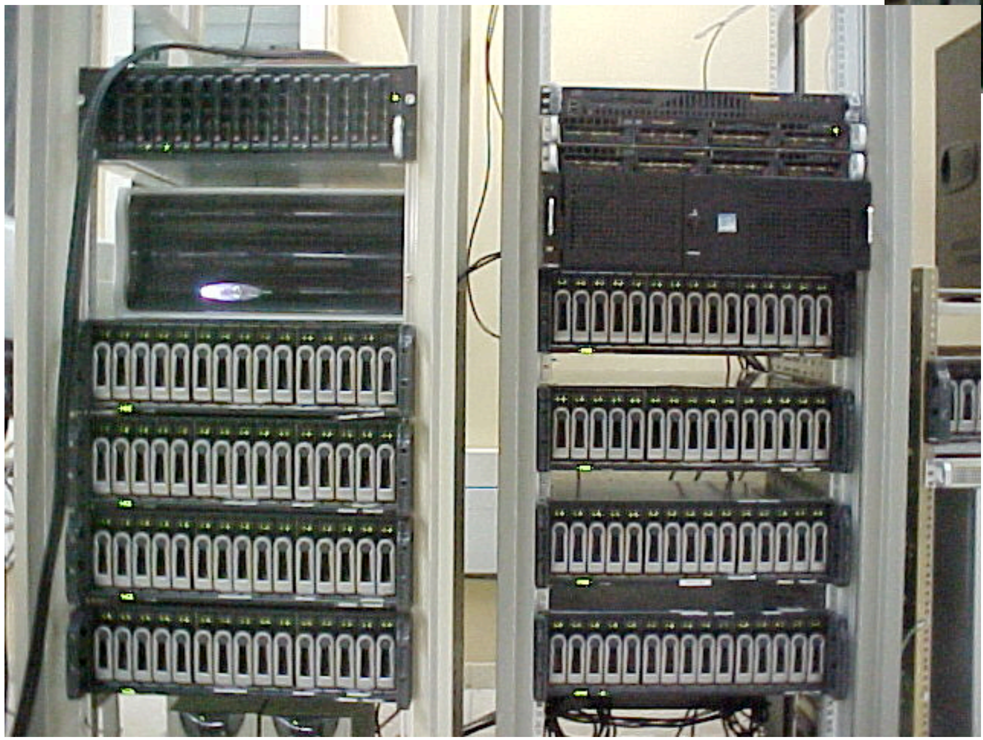
Grid3
(Interoperating with LCG)

Number of sites; resources are evolving quickly

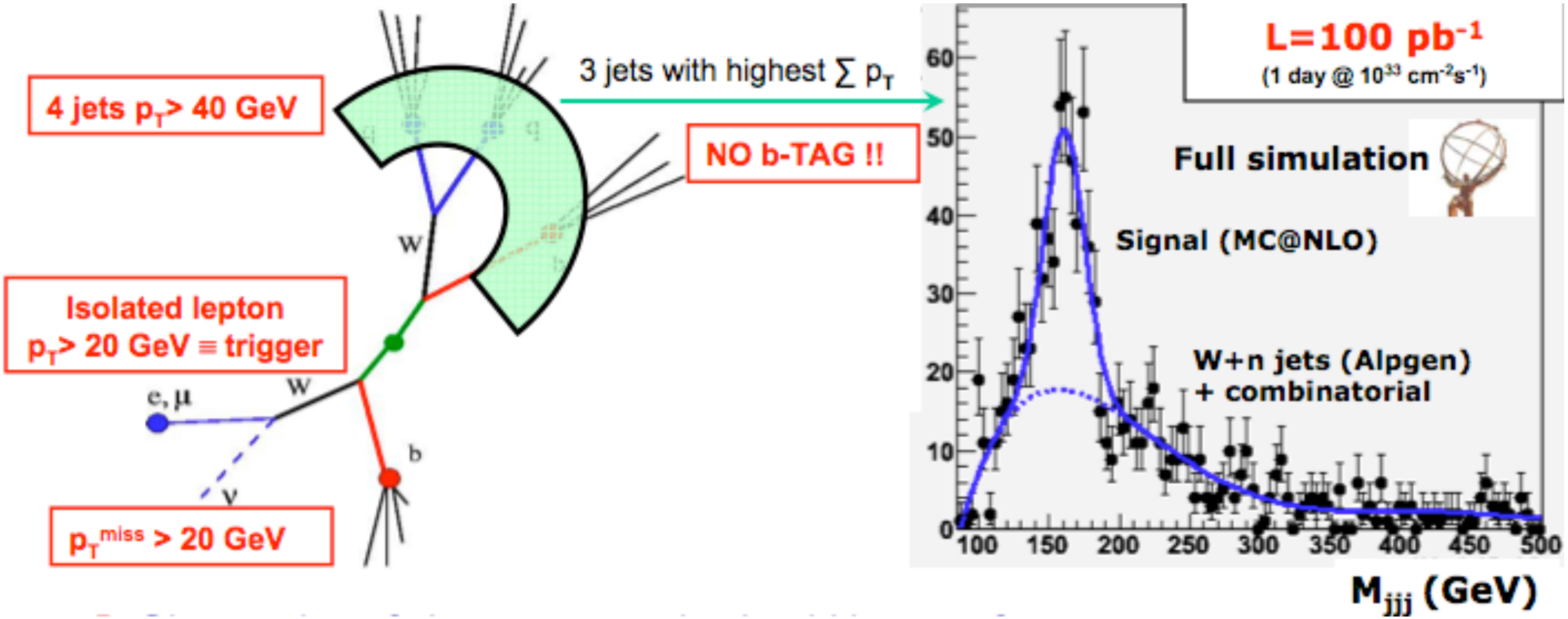
The Spanish ATLAS tier-2:
IFAE-IFIC-UAM

U.A.M. node

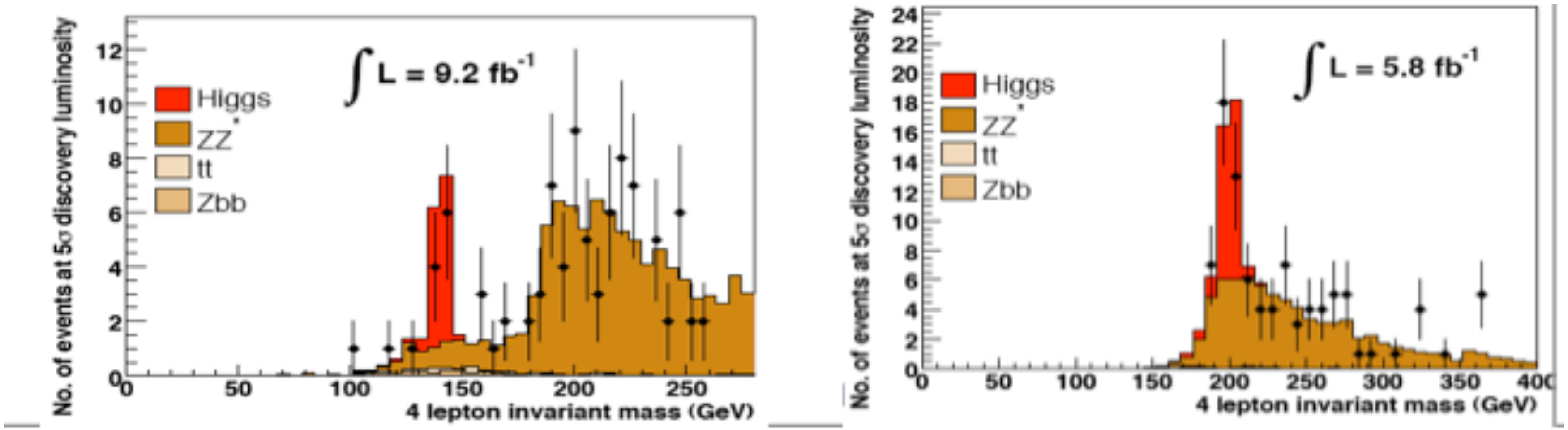
currently	foreseen
150 cpu,s	500 cpu,s



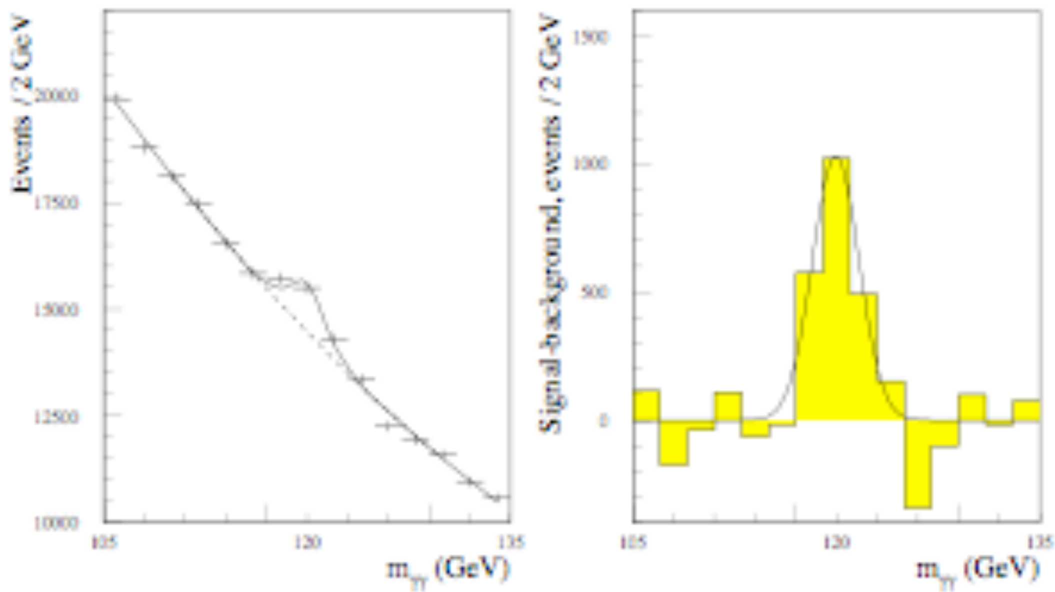
Top reconstruction with first luminosity



$H \rightarrow ZZ \rightarrow 4l$, 4l:[$e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$] early signals



$H \rightarrow \gamma\gamma$ with $100 fb^{-1}$



A bit of summary
A bit of conclusions

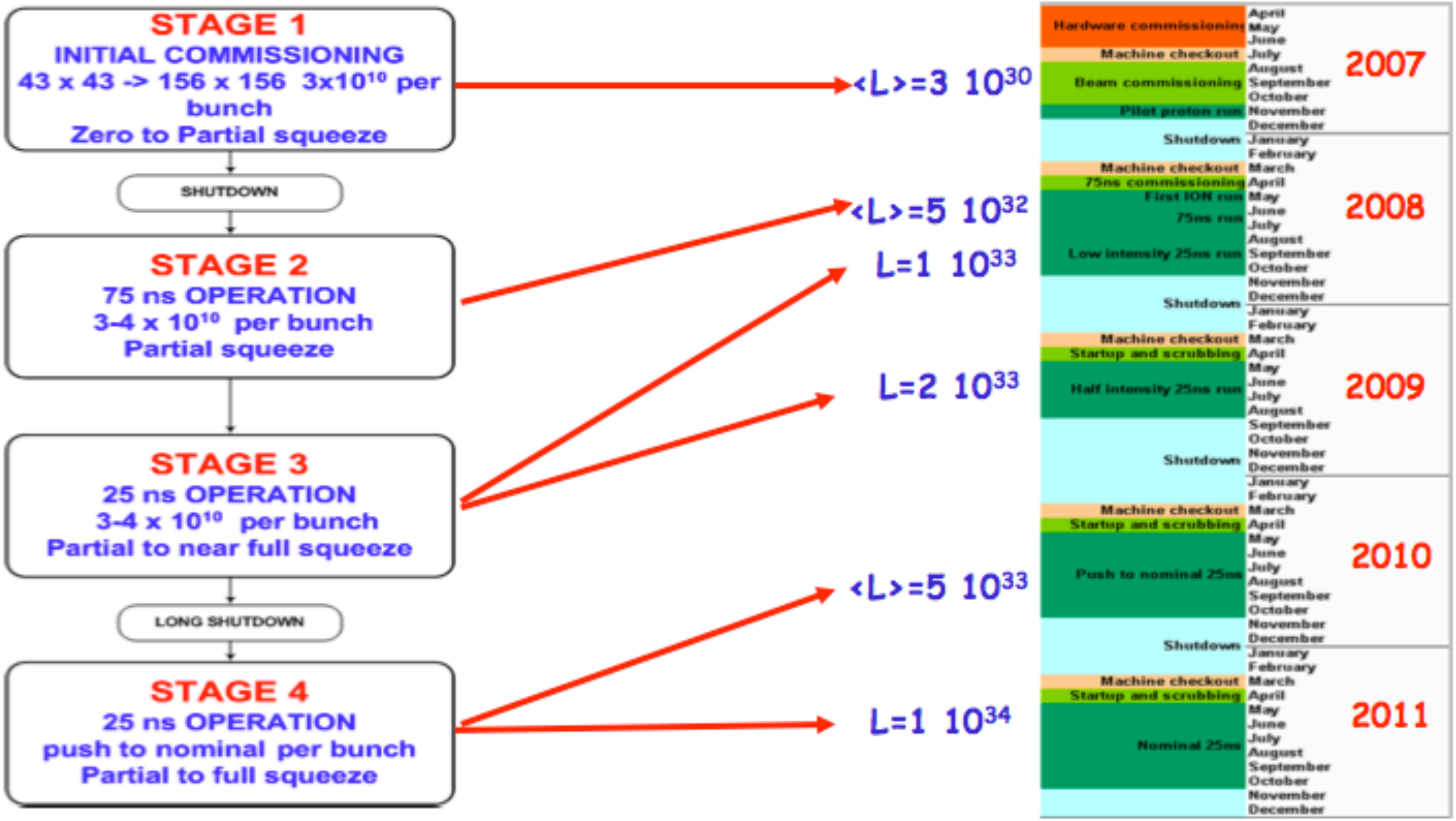
A detector to be capable of carrying out the LHC physics program is necessarily a very large and complicated piece of machinery

as it is ATLAS, even though its design concept / performances are "conservative".

ATLAS will be operational (≈ 100%) by the first LHC Luminosity.

Additional Information

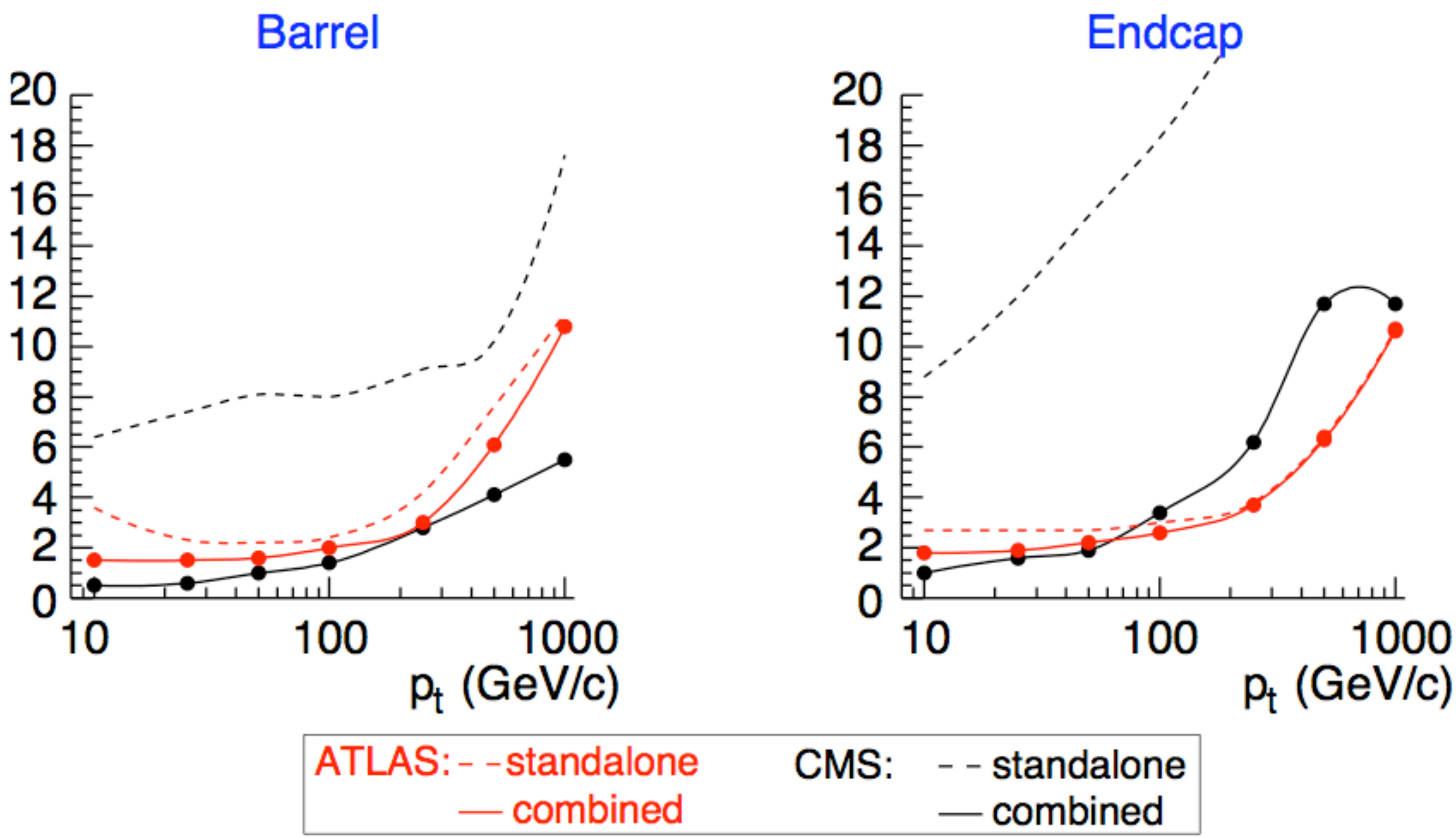
LHC planning



	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 $\sigma/p_T \sim 5\mathrm{x}10^{-4}\ p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\mathrm{x}10^{-4}\ p_T \oplus 0.005$
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

Straw tube diagram

Momentum resolution for μ^+, μ^- by ATLAS and CMS



particulas detectables
reconstruccion de objetos: masas invarintes, taus, jets, bs,
cantidades fisicas: higgs discovery, top couplings ….

-the trigger system
-the offline/data processing system