Experiment ATLAS v CERN

Komplexní soustava (sub)detektorů
univerzálního zaměření
na urychlovači LHC

Úvod

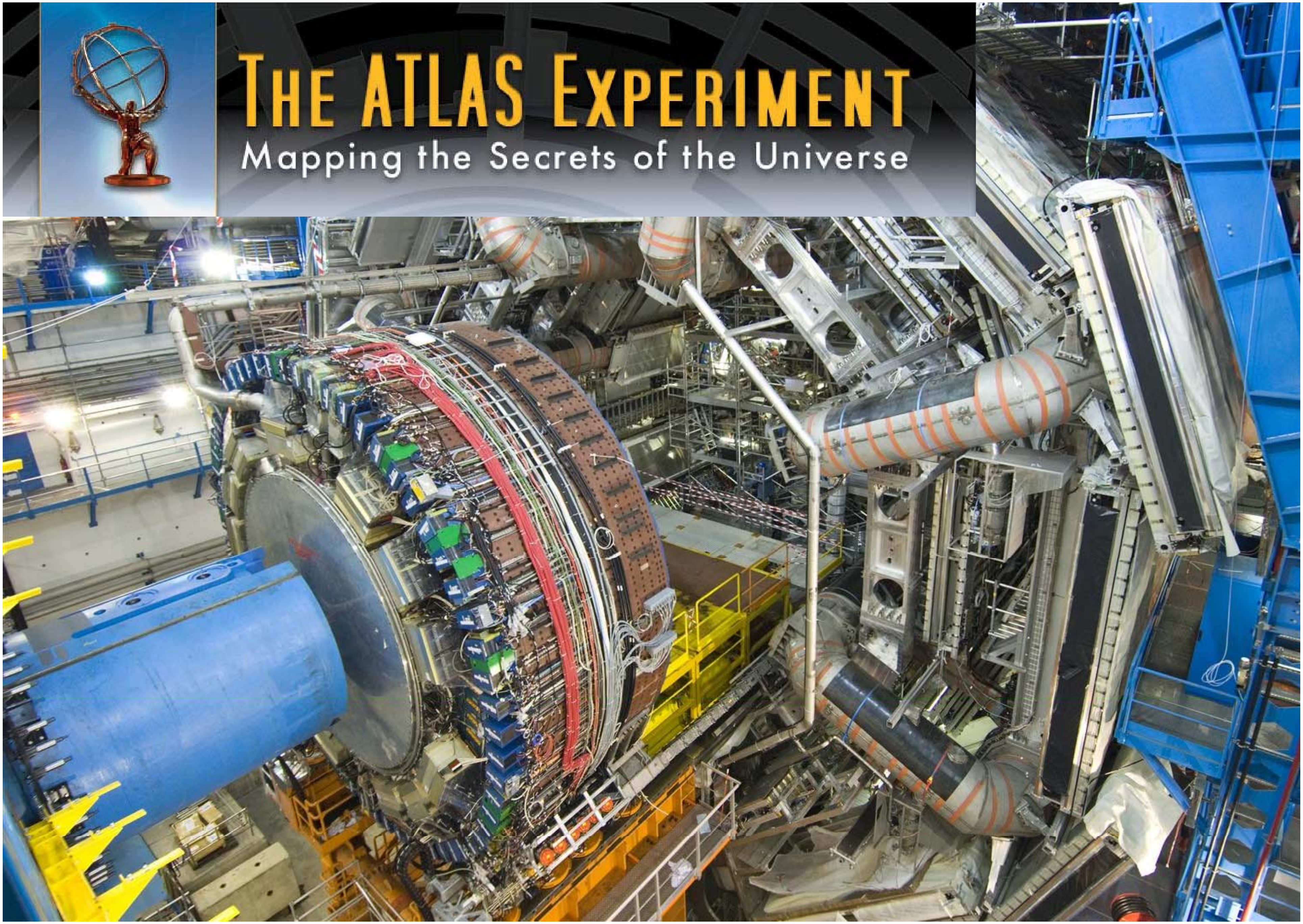
- Co, Kde, Kdy

- Fyzikální motivace (Proč)
  - Standardní model je neúplný
  - Narušení elektroslabé symetrie
  - Existují další kvarky? Mají kvarky strukturu?

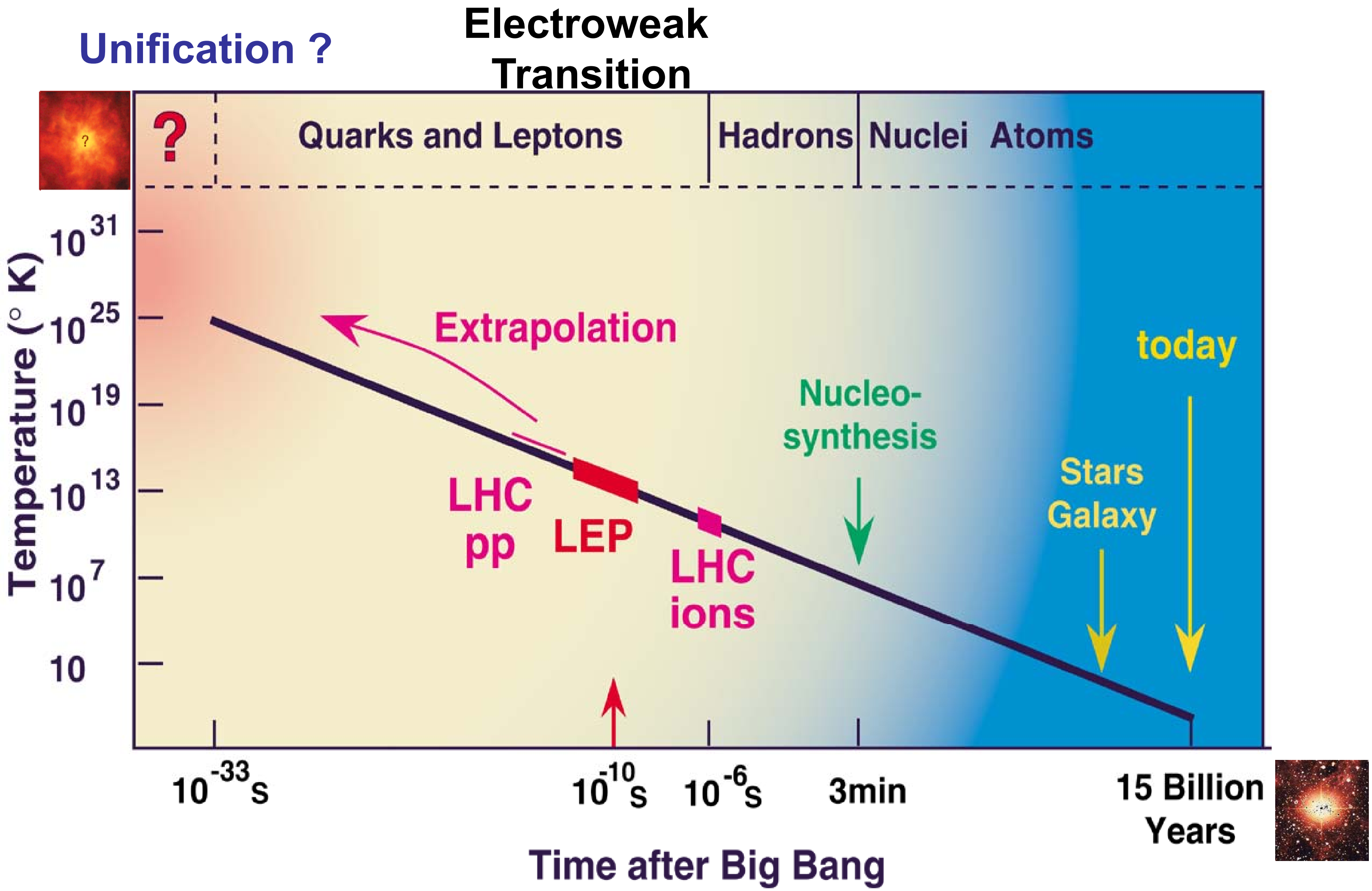
- www-ucjf.troja.mff.cuni.cz/**dolejsi**/textbook/LHC_CZ.ppt

THE ATLAS EXPERIMENT

Mapping the Secrets of the Universe



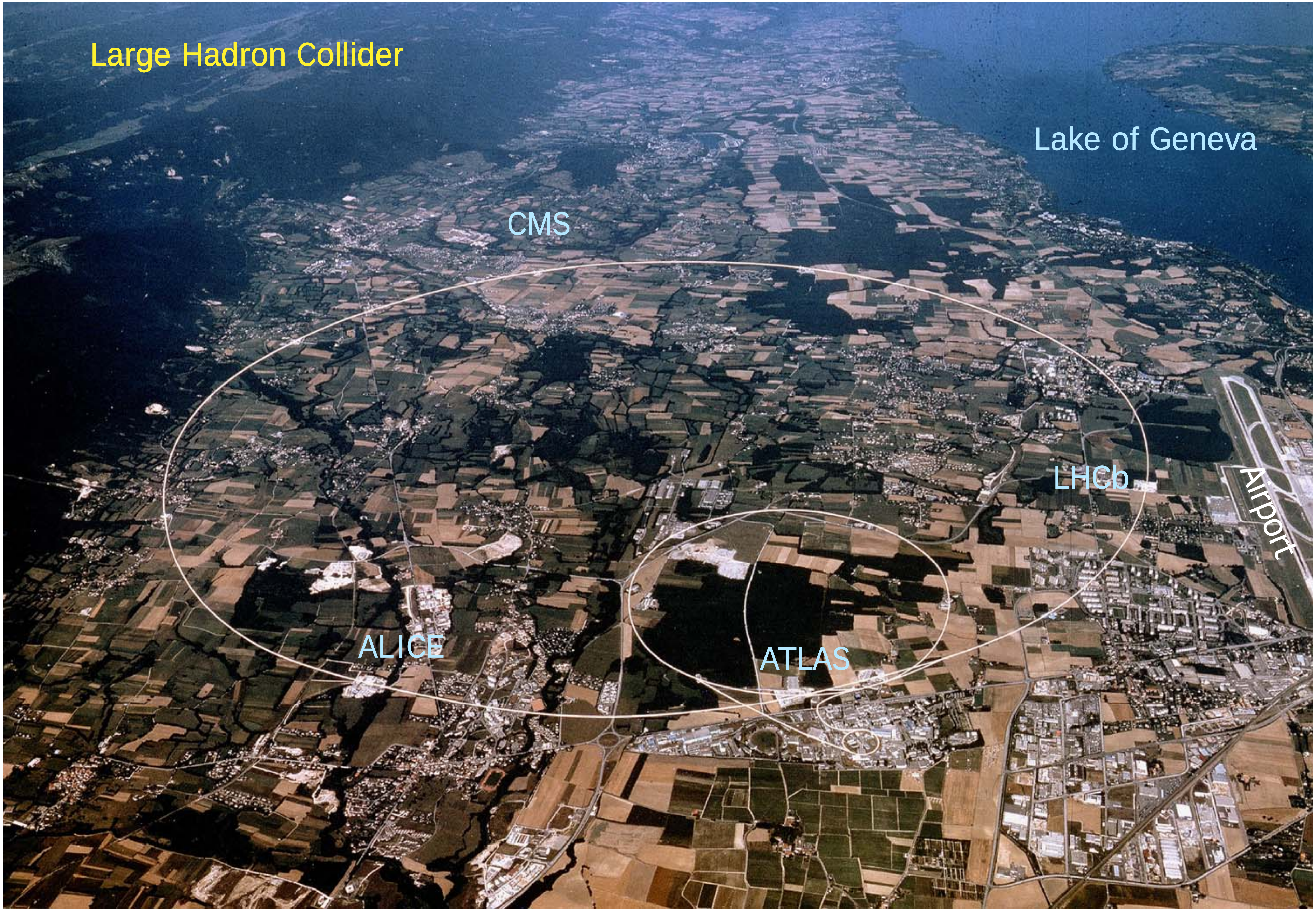
Understanding the Universe …



Experiment ATLAS v CERN

- A Toroidal LHC ApparatuS (= ATLAS)
- Large Hadron Collider (= LHC)
- Conseil Européenne pour la Recherche Nucléaire (= CERN)
  - (1954: Conseil → Organisation)
  - Dnes: Evropská Laboratoř Částicové Fyziky

Large Hadron Collider



LHC

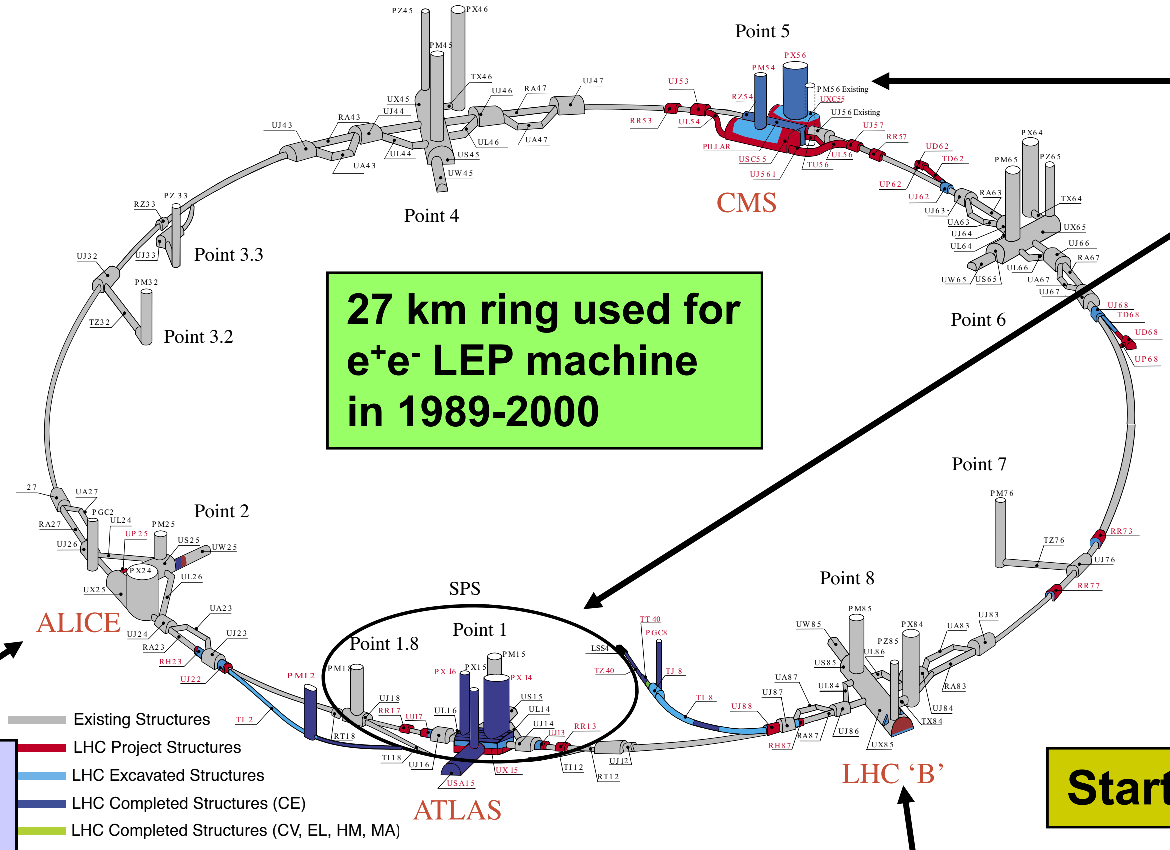
pp

- $\sqrt{s}$ = 14 TeV (7 krát víc, než dosud existující TEVATRON)

  → hledání nových těžkých částic až do hmoty m ~ 5 TeV

- $L_{design} = 10^{34}$ cm^{-2} s^{-1} (~ 100 krát víc než na Tevatronu)

  → hledání vzácných procesů malé σ ($N = L\sigma$)



27 km ring used for e^+e^- LEP machine in 1989-2000

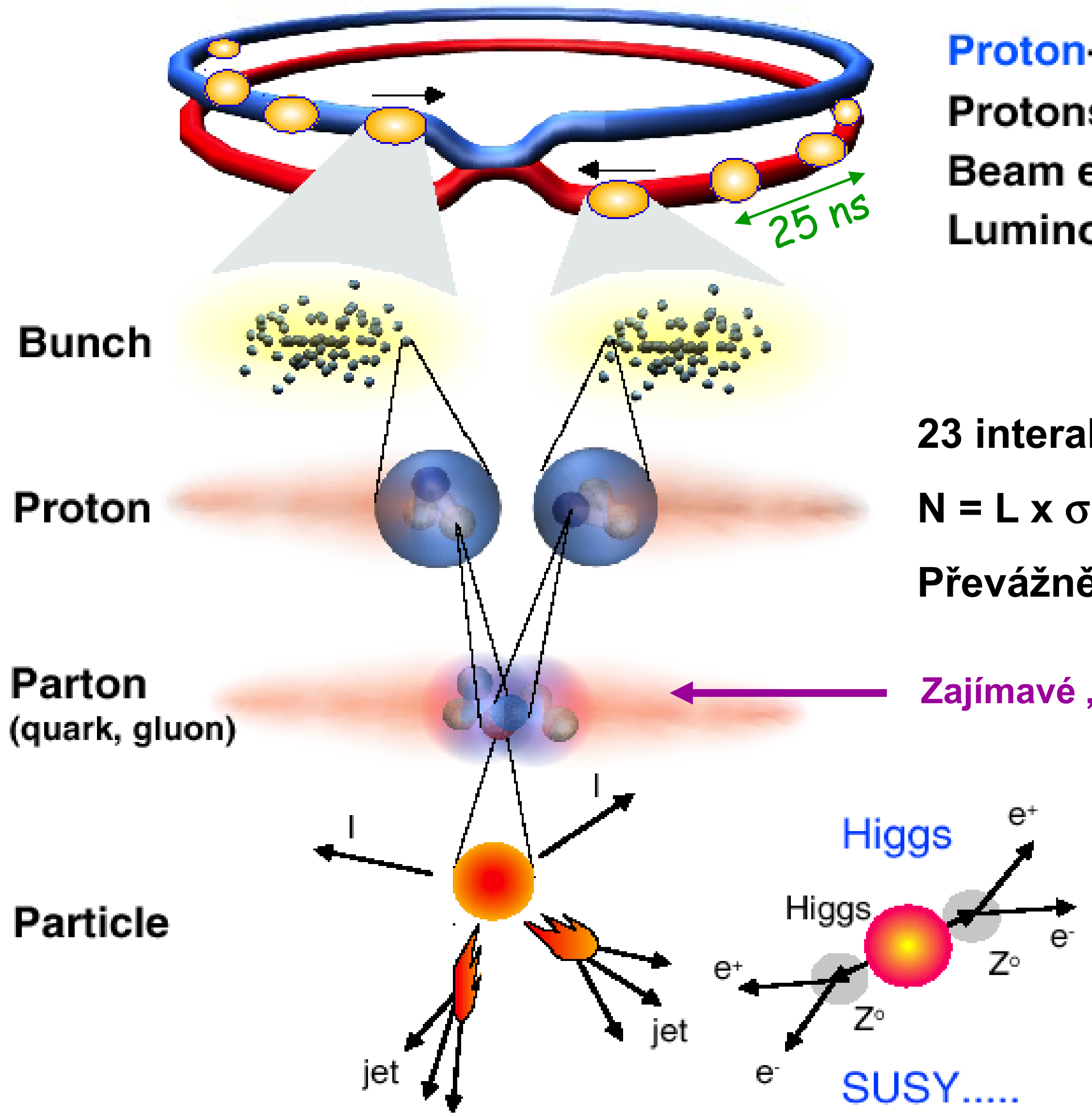
ATLAS and CMS :
pp, general purpose

ALICE :
heavy ions

LHCb :
pp, B-physics

Start : Spring 2008

V LHC se sráží protony



Bunch = Metro vlak

Proton-Proton	
Protons/bunch	**10^{11}**
Beam energy	**7 TeV (7×10^{12} eV)**
Luminosity	**10^{34} cm^{-2} s^{-1}**

23 interakcí při každé srážce „vlaků“ :

N = L x σ (pp) ≈ 10^9 interakcí/s

Převážně „měkké“ (low p_T) případy

Zajímavé „tvrdé“ (high-p_T) případy jsou vzácné

Selection of 1 in
10,000,000,000,000

→ Potřeba velmi sofistikovaného detektoru

Hlavní cíle pp fyziky na LHC

Hledání chybějícího článku Standardního Modelu (SM) = Higgsova bosonu v oblasti hmot $\sim 115 < m_H < 1000$ GeV

Hledání Fyziky za SM (Supersymmetry, q/ℓ compositeness, leptoquarks, W'/Z', heavy q/ℓ, Extra-dimensions, ….) až do TeV-ové oblasti

Přesná měření :

- **W hmoty**
- **top hmoty, vazbových konstant a rozpadových vlastností**
- **Higgs hmoty, spinu, vazbových konstant (když se Higgs najde)**
- **B-fyzika (doplněk k LHCb): CP violation, rare decays, B^0 oscillations**
- **QCD účinné průřezy pro jety, α_s**
- **atd. ….**

Studium fázového přechodu na plasmu nevázaných kvarků a gluonů při velkých hadronových hustotách (doplněk k experimentu ALICE).

A další …..

ATLAS

- Spolupracující instituce z celého světa

- Tři hlavní součásti detektoru
  - Vnitřní detektor
  - Kalorimetry
  - Mionový spektrometr s toroidálním magnetem

- Měření hybnosti mionů

ATLAS Collaboration
(Status October 2007)

37 států
167 Institucí
2000 celkem vědeckých autorů
(400 studentů)

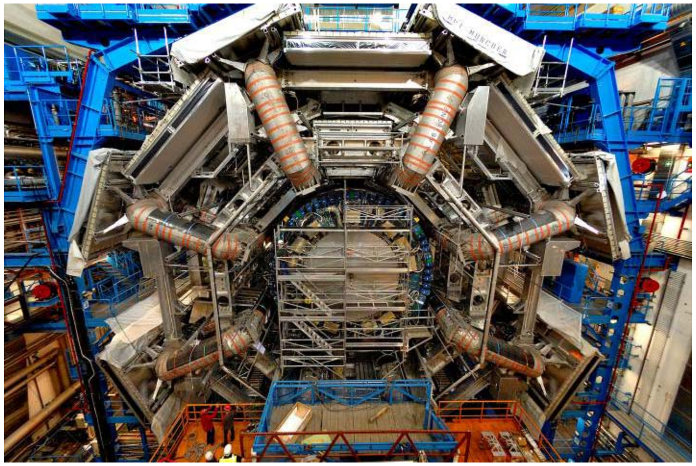
Nově přijatí členové :
Santiago (PUC)/ Valparaíso (UTFSM), Chile
Bogotá (UAN), Colombia

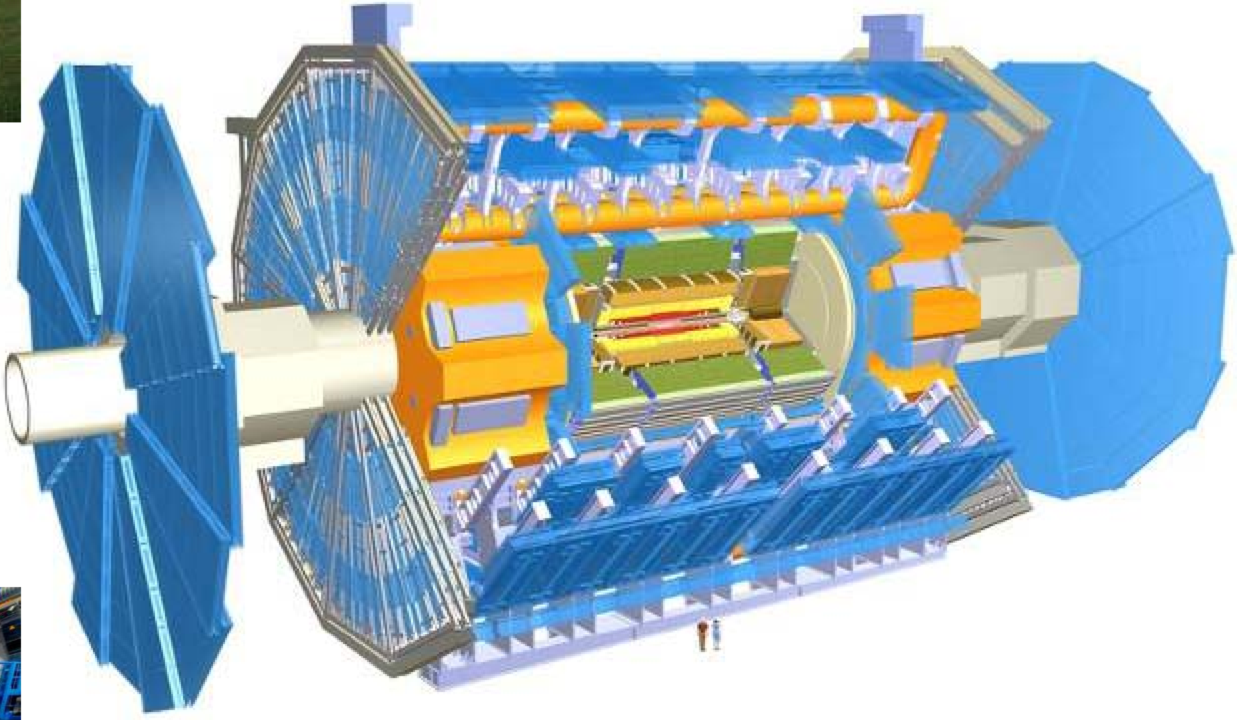
Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

ATLAS v číslech a představách

ATLAS vestavěný do budovy 40
(první magnet už tam leží..)





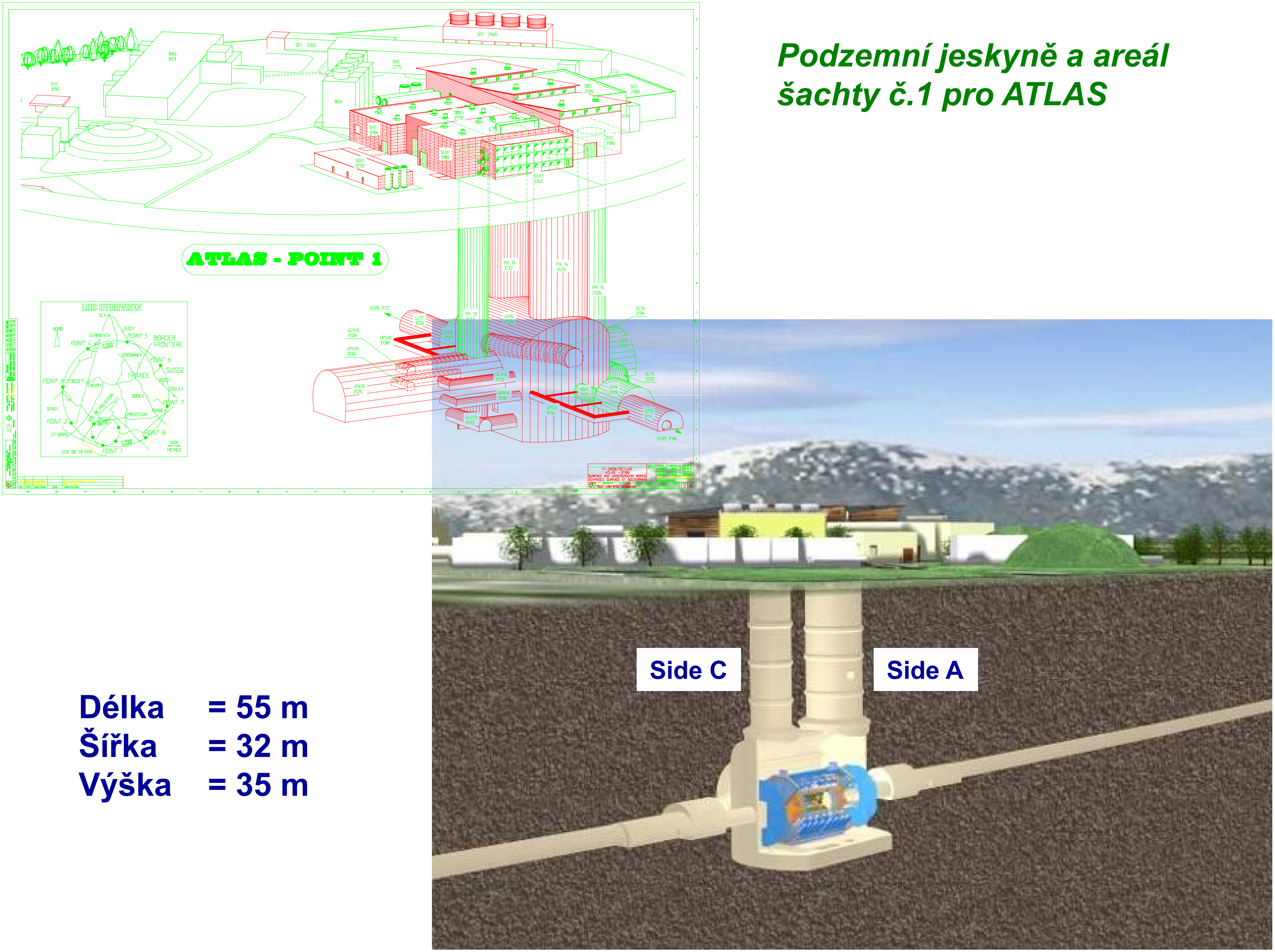
Průměr	*25 m*
Délka toroidálního magnetu	*26 m*
Vzdálenost krajních mionových komor	*46 m*
Celková váha	*7000 tun*

Letecký pohled na areál ATLASu (PIT_1)

Vlajky

Budova přímo nad podzemní jeskyní

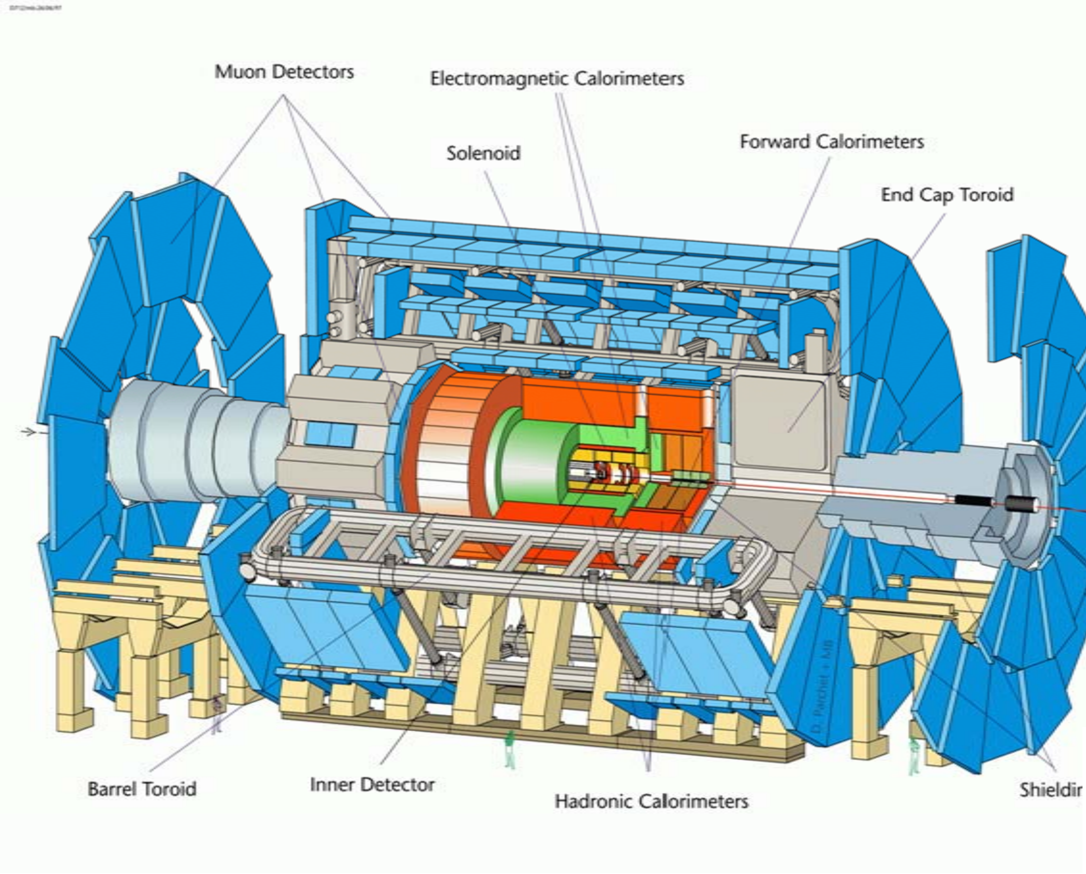
Podzemní jeskyně a areál šachty č.1 pro ATLAS



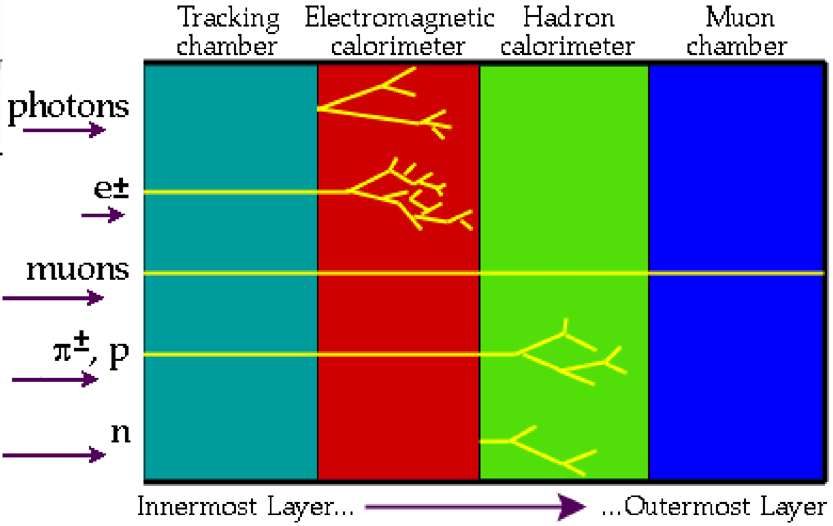
Délka = 55 m
Šířka = 32 m
Výška = 35 m

..vysvětlit během prohlídky…
.. [: Válec+Disk struktura :]

ATLAS



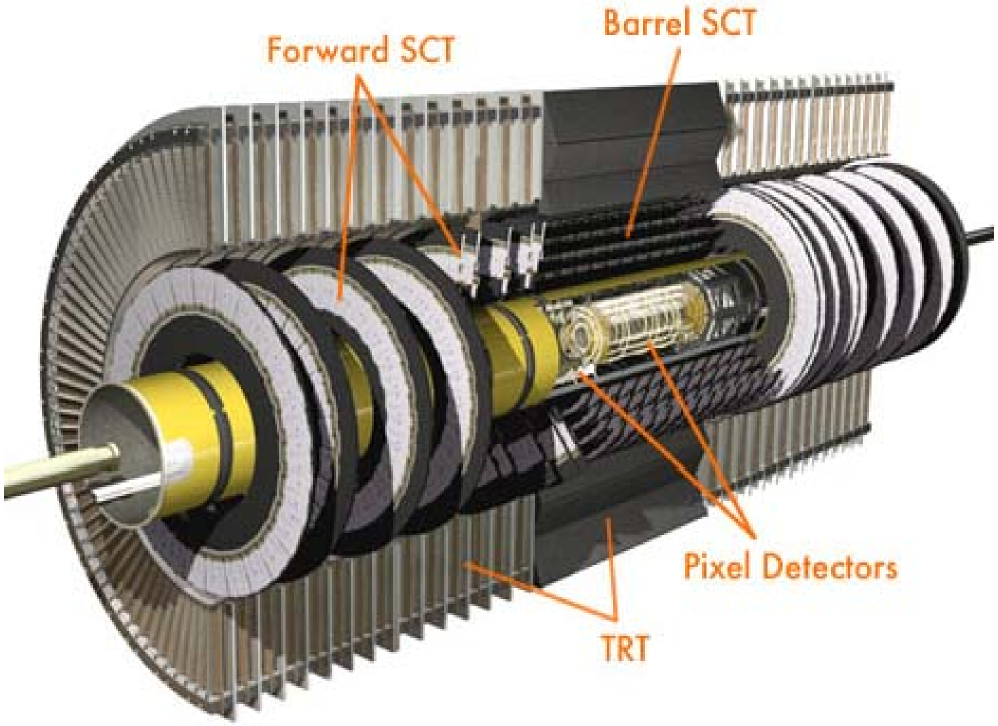
- **Tracking (|η|<2.5, B=2T)** :
  - -- **Si pixels and strips**
  - -- **Transition Radiation Detector (e/π separation)**
- **Calorimetry (|η|<5)** :
  - -- **EM : Pb-LAr**
  - -- **HAD: Fe/scintillator (central), Cu/W-LAr (fwd)**
- **Muon Spectrometer (|η|<2.7)** :
  air-core toroids with muon chambers

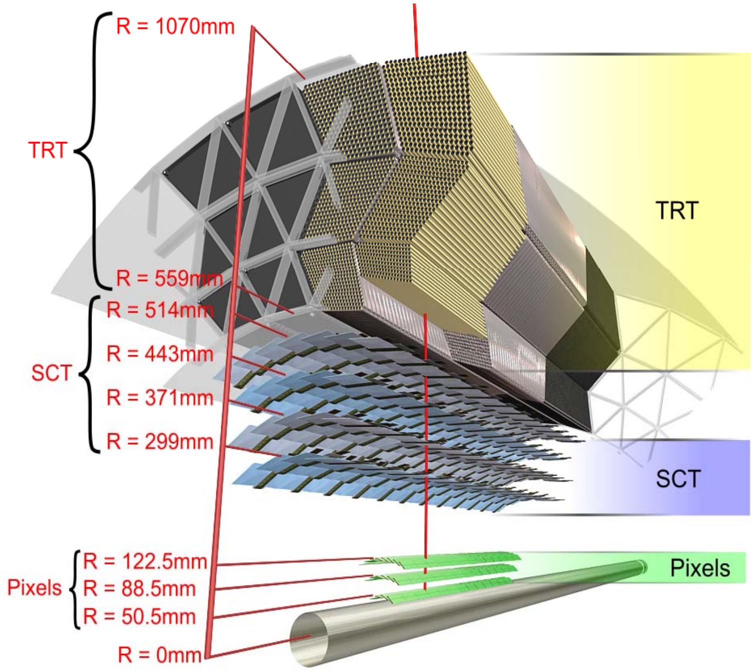


ATLAS / ID

- Vnitřní detektor (ID = barrel + end cups)
  - 7 přesných (10um) bodů + ~30 TRT bodů pro rekonstrukci dráhy v mg.poli = hybnost částic, druhotné vrcholy; separace pionu/elektronu
- Tři součásti ID barelu
  - pixely (40x500 um) …. 3 válce
  - stripy (stereo 80 um) .. 4 válce
  - TRT (hodně bodů, menší přesnost, IDENTIFIKACE částic)

The Inner Detector

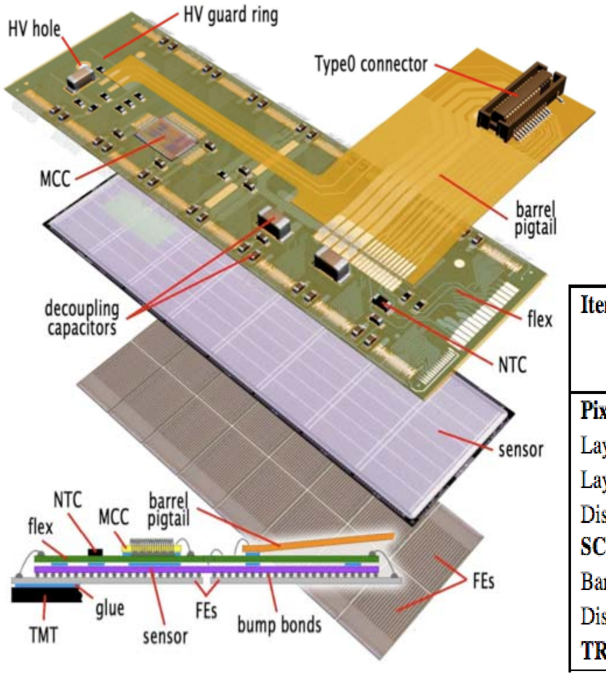




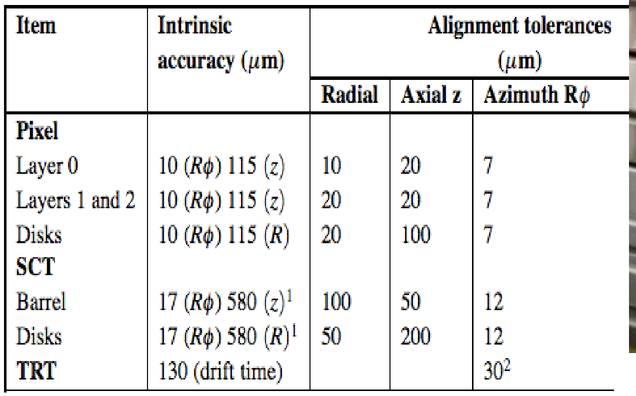
✓ All cables and pipes installed, SCT and TRT fully connected

✓ Pixel detector cables and pipes installed, pixel connection waiting for SCT sign off

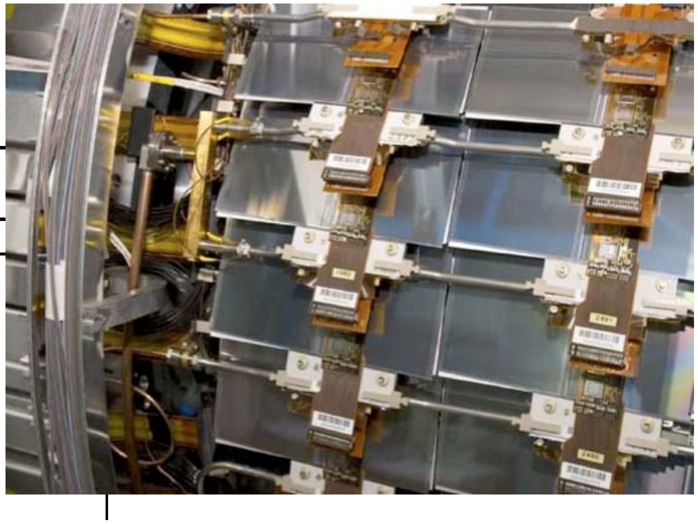
ID Si-sensors



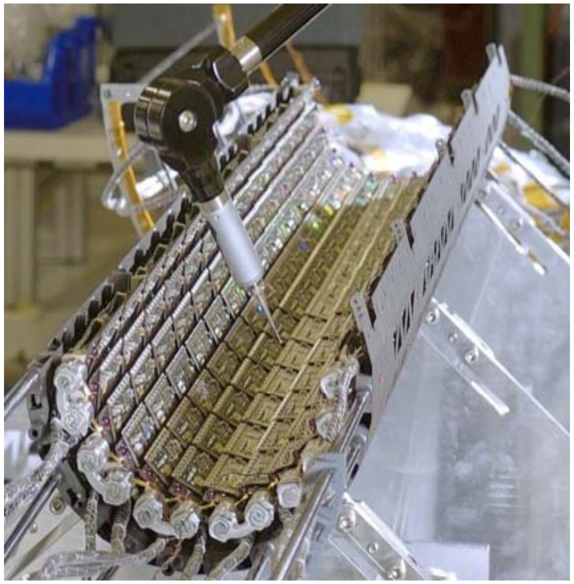
1744 modules, min 50x400 μm²

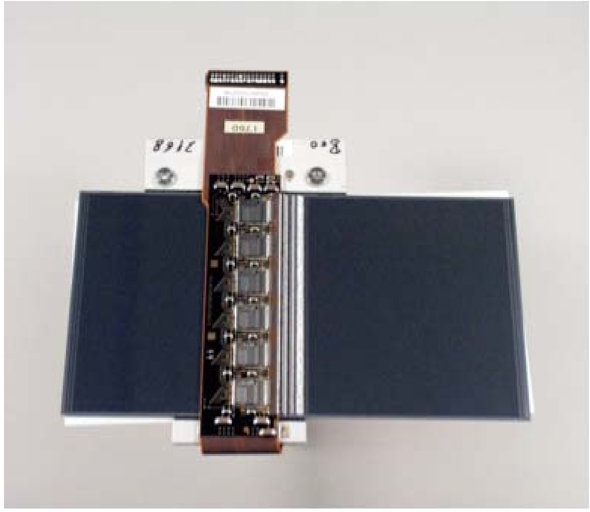


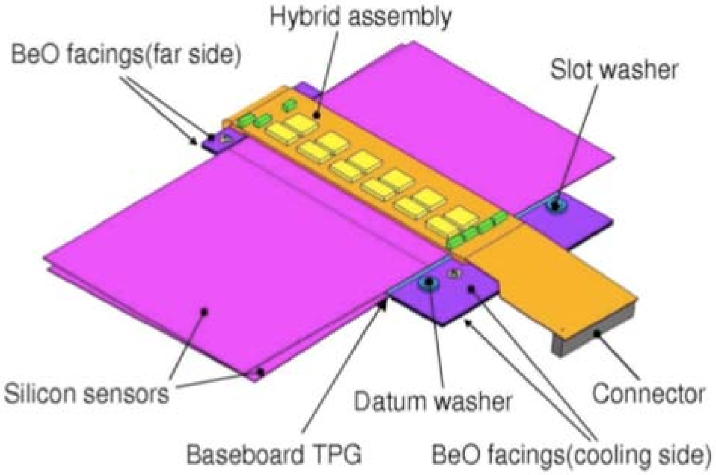
Item	Intrinsic accuracy (μm)	Alignment tolerances (μm)		
		Radial	Axial z	Azimuth Rϕ
Pixel				
Layer 0	10 ($R\phi$) 115 (z)	10	20	7
Layers 1 and 2	10 ($R\phi$) 115 (z)	20	20	7
Disks	10 ($R\phi$) 115 (R)	20	100	7
SCT				
Barrel	17 ($R\phi$) 580 (z)^1	100	50	12
Disks	17 ($R\phi$) 580 (R)^1	50	200	12
TRT	130 (drift time)			30^2



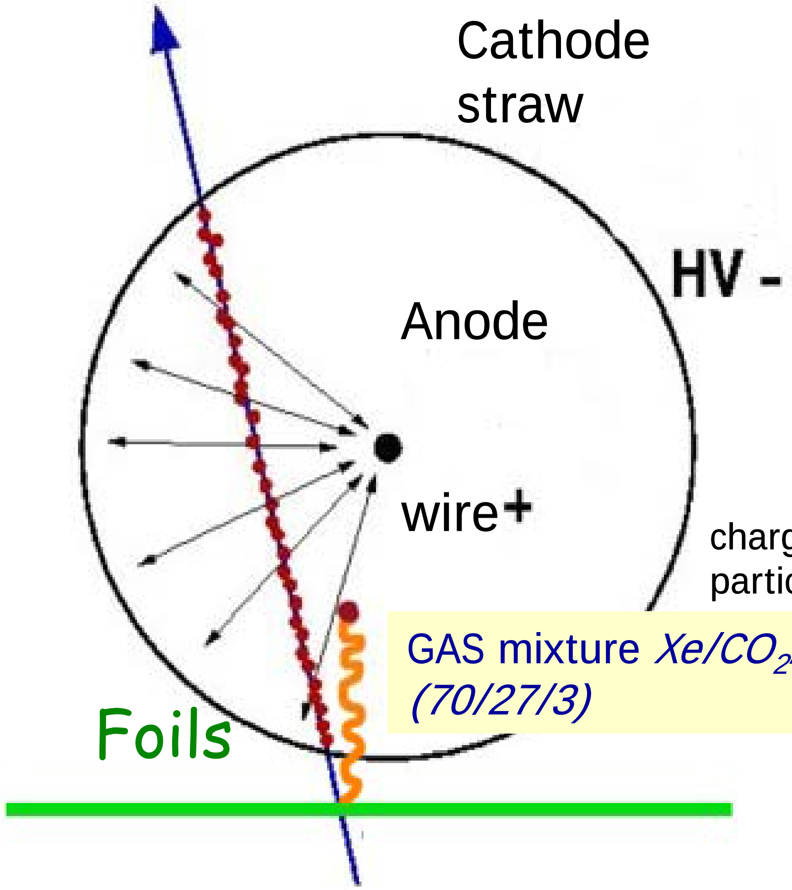
4088 modules, 80 μm micro-strips





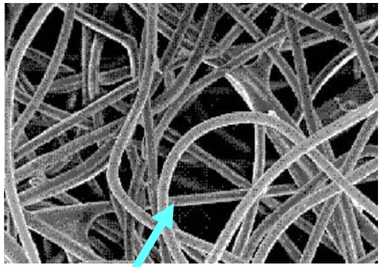


The TRT (Transition Radiation Tracker)

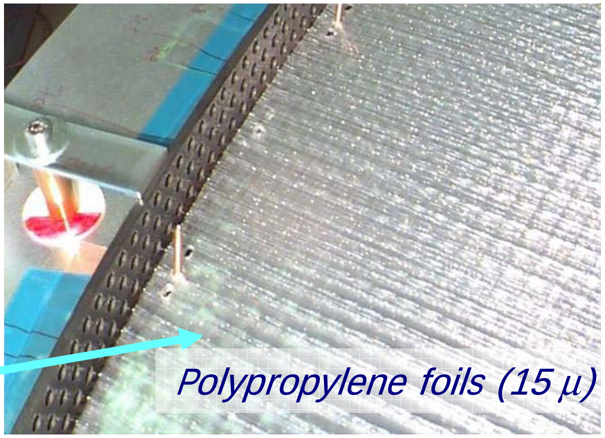


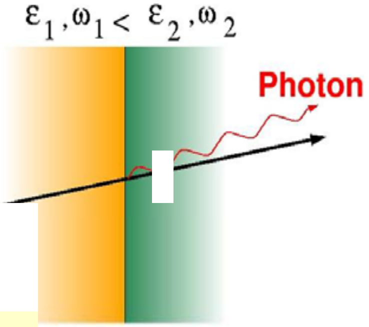
GAS mixture *$Xe/CO_2/O_2$ (70/27/3)*

radiator

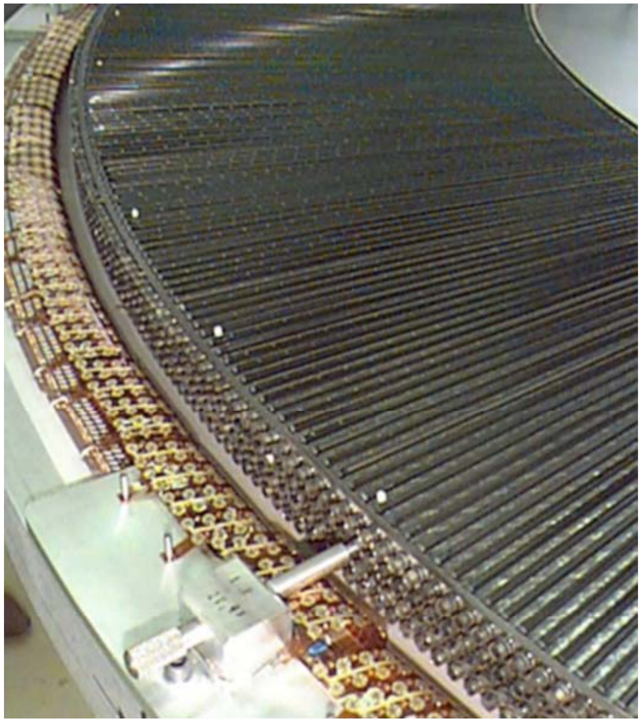


Barrel end-cap



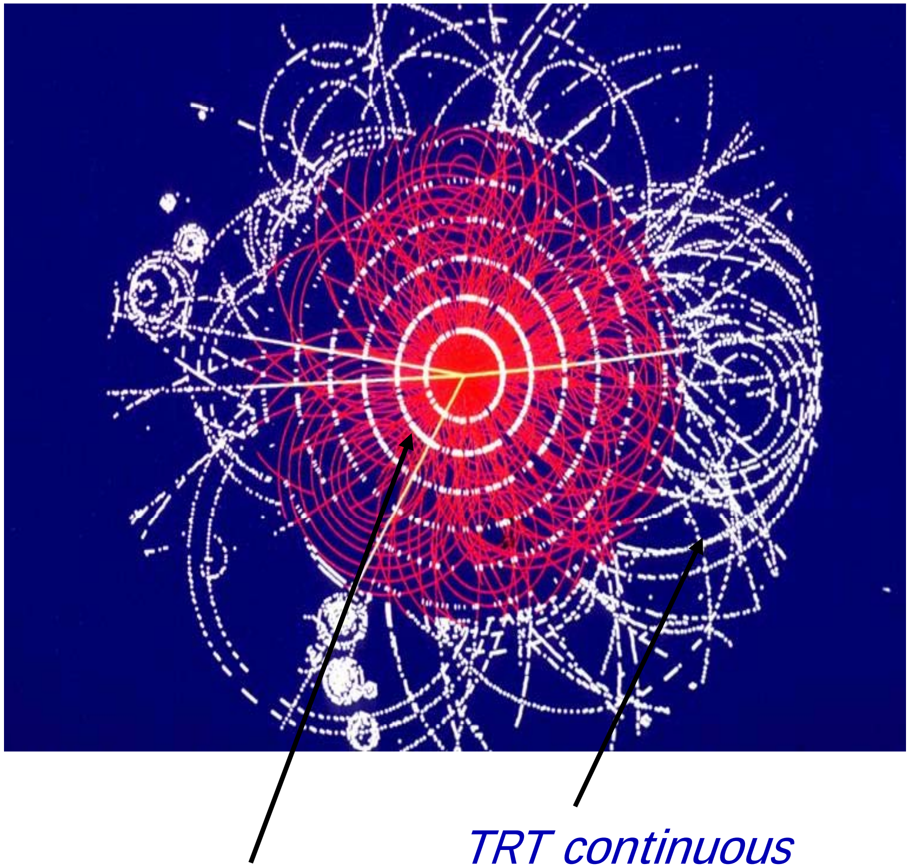


charged particles



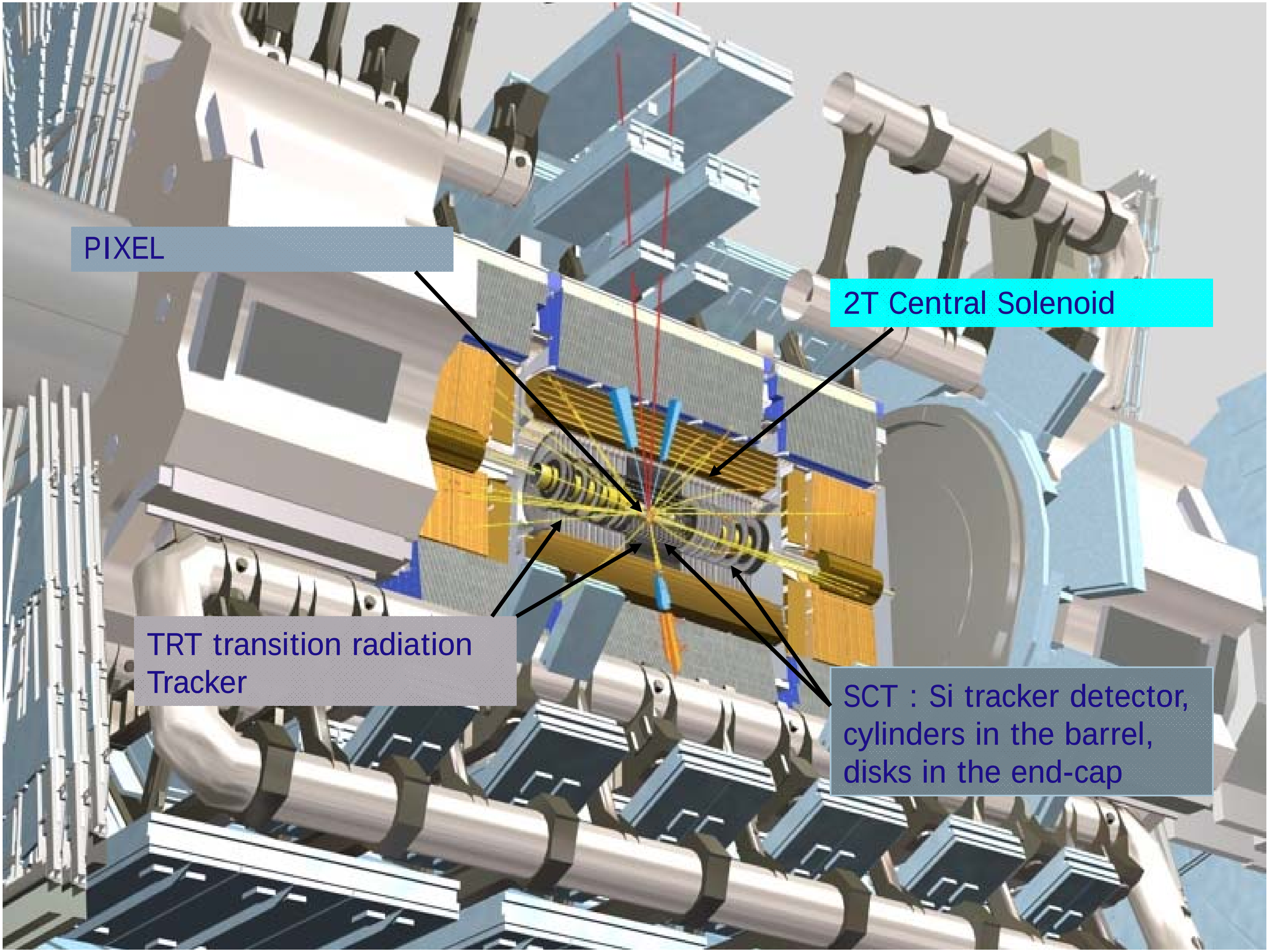
The Inner Detector (ID) challenge

- *Patter recognition challenging: high track density*
  - ✓7 precision points/track (3 pixel+4 SCT)
  - ✓Each r-ϕ and z (40 mrad stereo in SCT)
  - ✓Up to 36 TRT straw hits
  - ✓Continuous tracking... optimised for tracking performance, not TR e-
  - ✓π rejection up to 100 for 80% e-efficiency
- Needs to operate up to an integrated dose between 10 and 60 Mrad
- Hermetic coverage up to $|\eta|=2.5$
- B-tagging capability



Pixel, SCT precision tracking

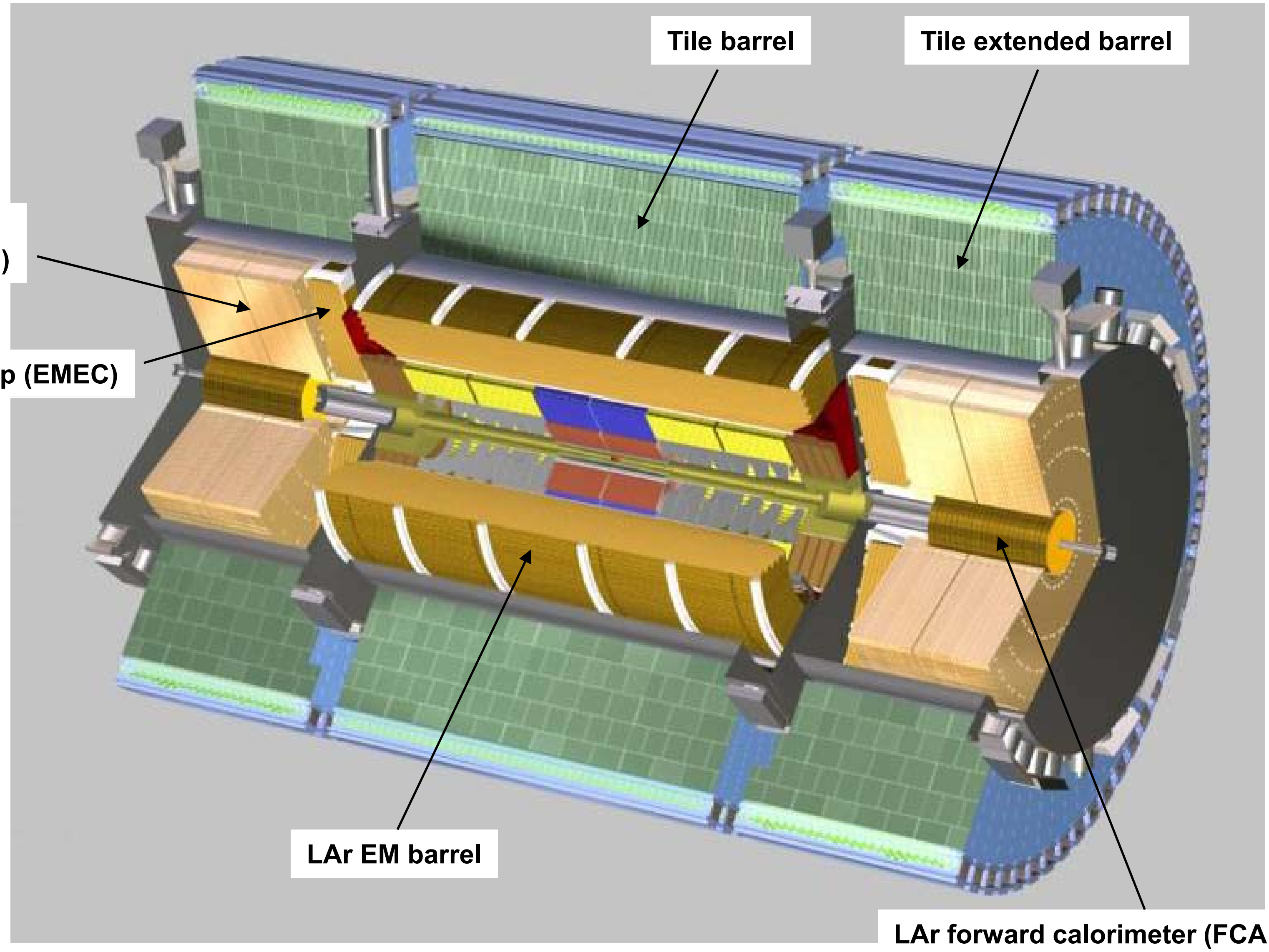
TRT continuous tracking


PIXEL
2T Central Solenoid
TRT transition radiation Tracker
SCT : Si tracker detector, cylinders in the barrel, disks in the end-cap

Kalorimetry v ATLASu

- Úkoly
  - Pohlcují všechny částice kromě mionů a neutrin
  - Měří jejich energii vzorkováním:
    absorbátor = W,Pb,Cu,Fe +
    aktivní část = Kapalný Argon(LArg), scintilátor
  - Rychlá informace z nich umožňuje spuštění celého ATLASu (trigger L1CALO)
  - Umožňují identifikaci e/jety/fotony, separaci neutrálního pionu/fotonu
- Dělení
  - válcový / diskový (EC) / dopředný (FCAL)
  - elektromagnetický (EM) / hadronový (H)
  - Larg (3 kryostaty) / Tile
- Průchod všech kabelů, kapalin,.. pro vnitřní detektor rozděluje válcovou část na fixní „barrel“ a pohyblivé „extended barrels“

LAr and Tile Calorimeters



Tile barrel

Tile extended barrel

LAr hadronic end-cap (HEC)

LAr EM end-cap (EMEC)

LAr EM barrel

LAr forward calorimeter (FCAL)

Electromagnetic Calorimeters

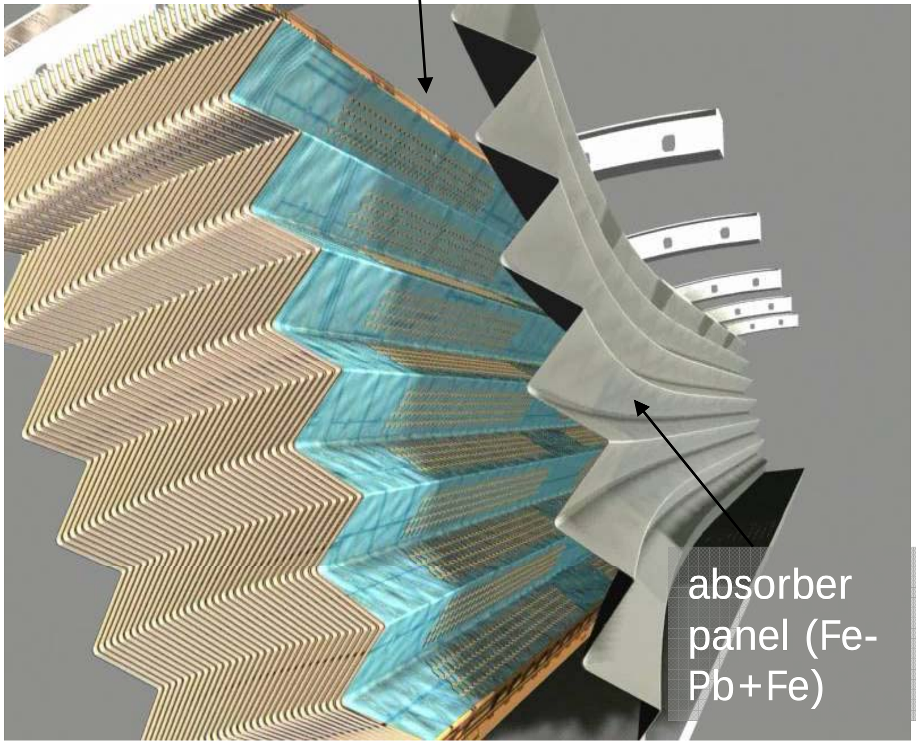
LAr sampling calorimeter

accordion geometry

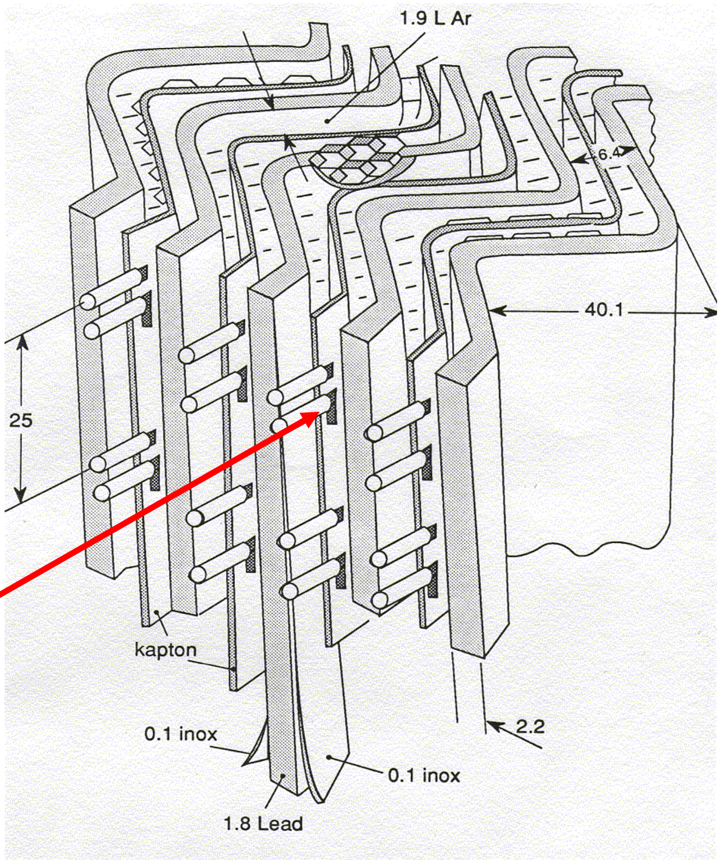
readout panel

LAr gap

NOVINKA = struktura HARMONIKA

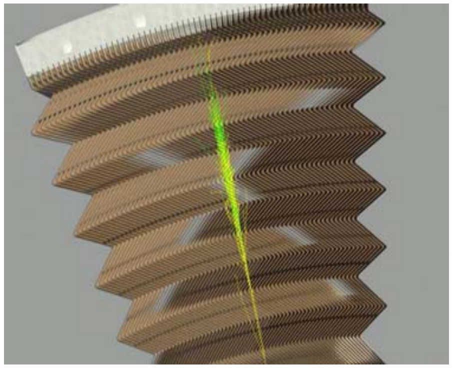


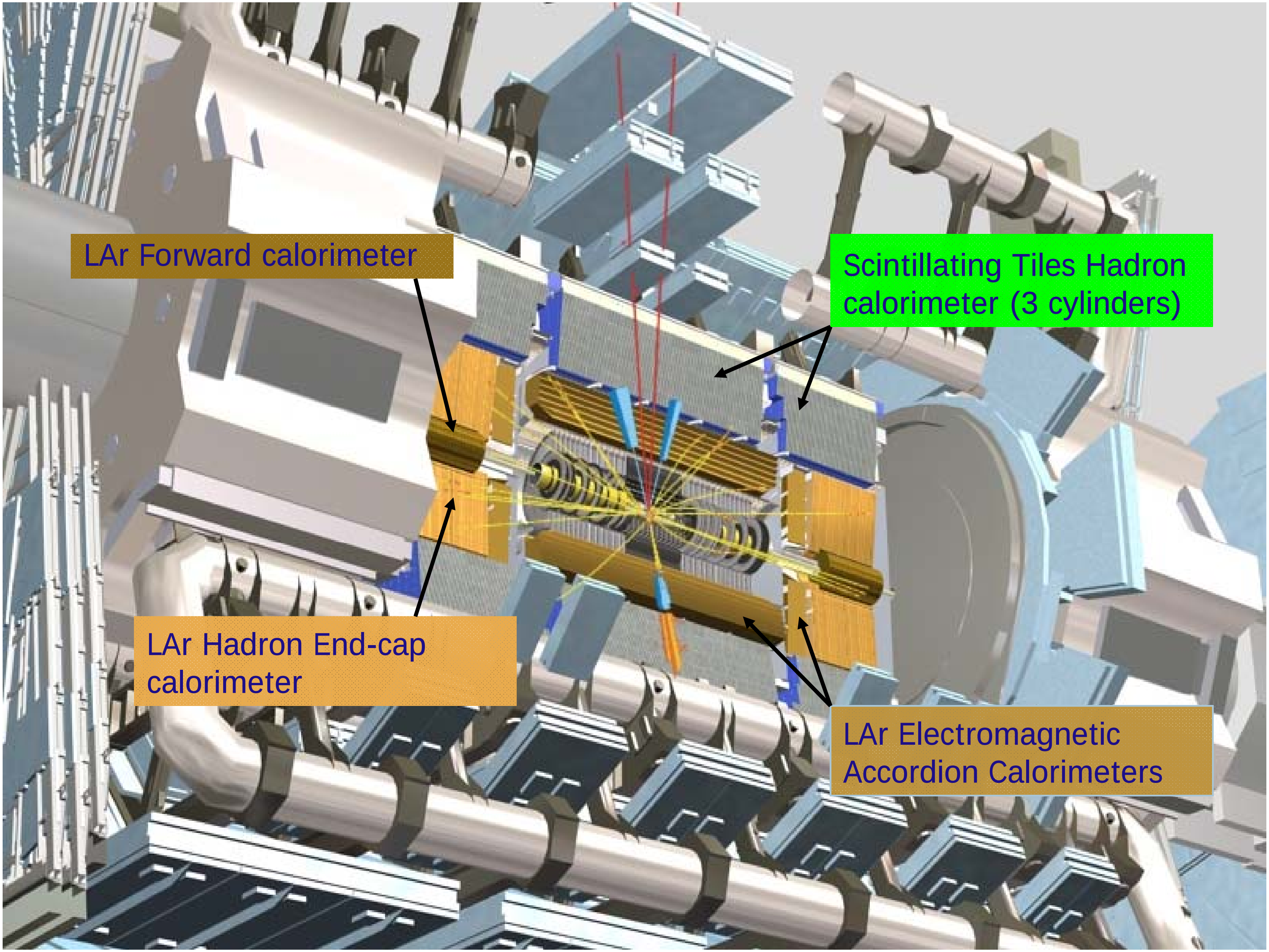
absorber panel (Fe-Pb+Fe)



Why ?

- readout speed
- radiation hard
- electronically inter-calibrated
- allows longitudinal segmentation
- hermetic in phi
- good energy, angular resolution





LAr Forward calorimeter

Scintillating Tiles Hadron calorimeter (3 cylinders)

LAr Hadron End-cap calorimeter

LAr Electromagnetic Accordion Calorimeters

Kalorimetr TileCAL

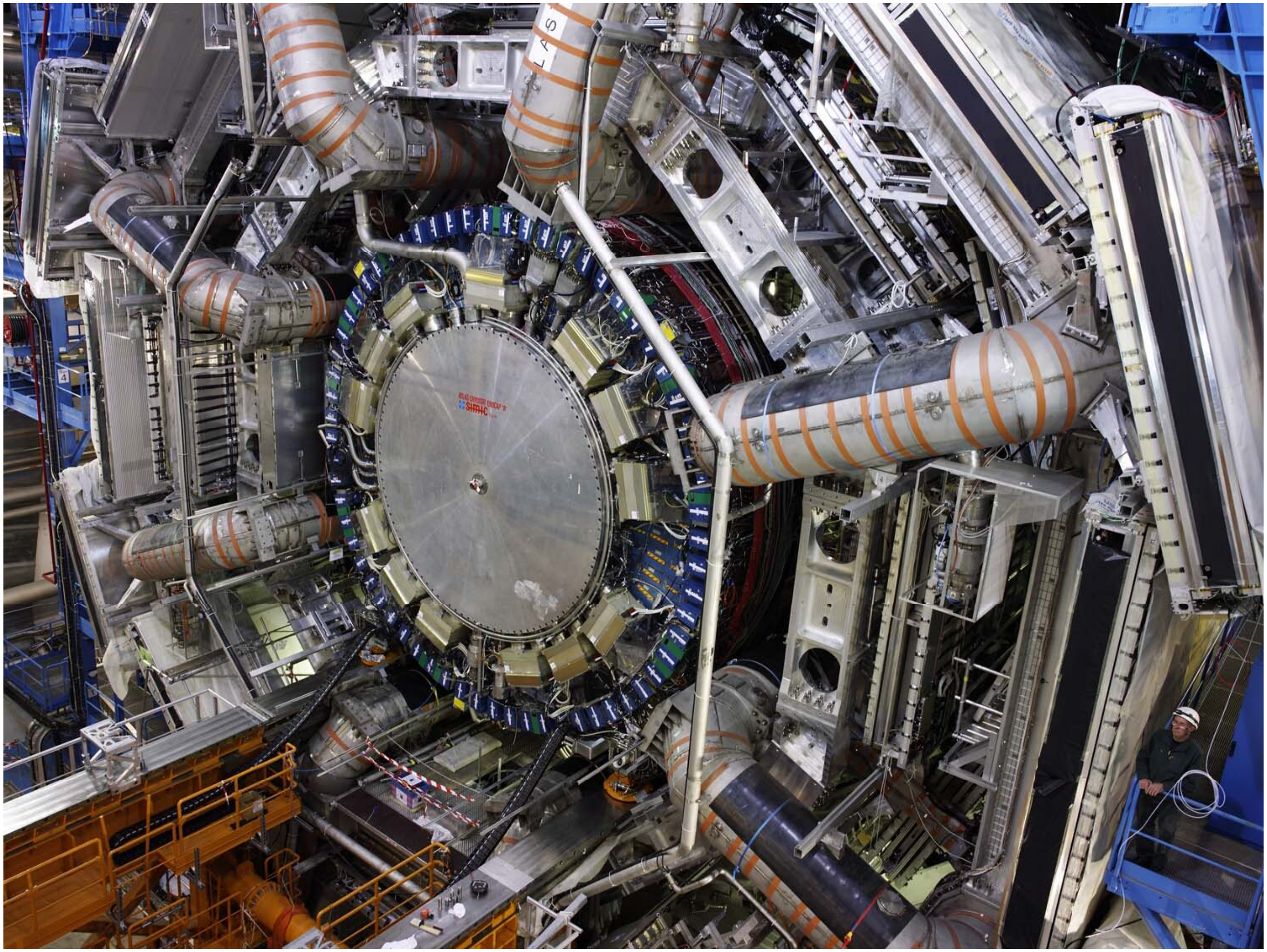
15 years of fruitful collaboration with our Czech friends... !

Some 8 years ago …

Some 7 years ago …

Some 3 years ago …

Kryostat s diskovými (EM+H) a dopřednými kalorimetry během zasunování

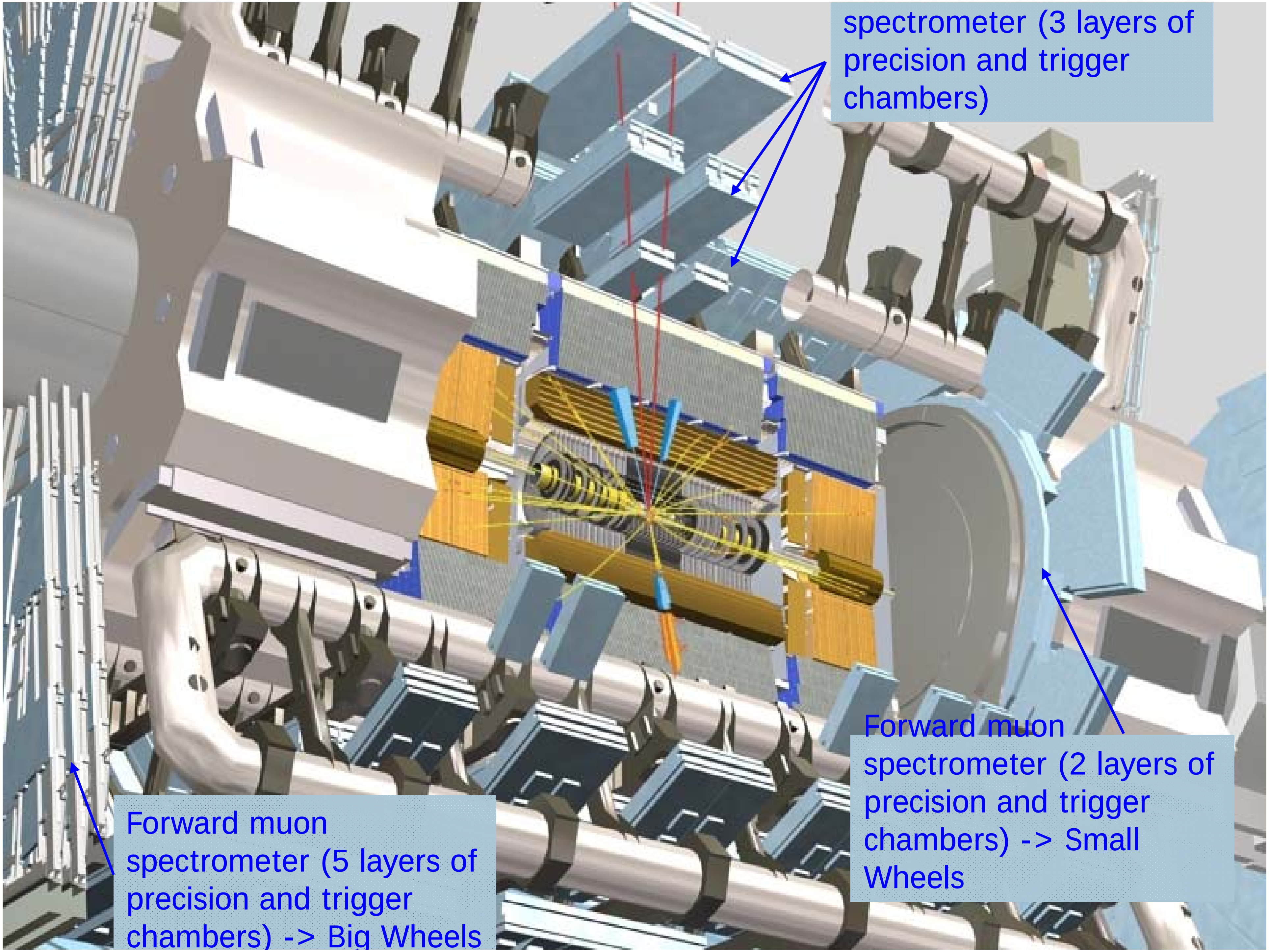


ATLAS side A (with the calorimeter end-cap partially inserted, the LAr end-cap is filled with LAr)

ATLAS / mionový spektrometr

- Úkoly
  - Rychlá informace z něho umožňuje spuštění celého ATLASu (LVL1 muon trigger)
  - Měří (i samostatně) velmi přesně hybnost mionů = rekonstrukce dráhy v mg. poli
- Dělení
  - válcový =vnitřní, střední a vnější vrstva / diskový = malá a velká kola + fixní komory na zdech jeskyně
  - přesné měření souřadnice (80um) = MDT + CSC / přesné měření času (4ns) = RPC, TGC

MDT = monitorované driftové trubky
RPC = Resistive Plate Chamber
CSC = Cathode Strip Chambers
TGC = Thin Gap Chambers

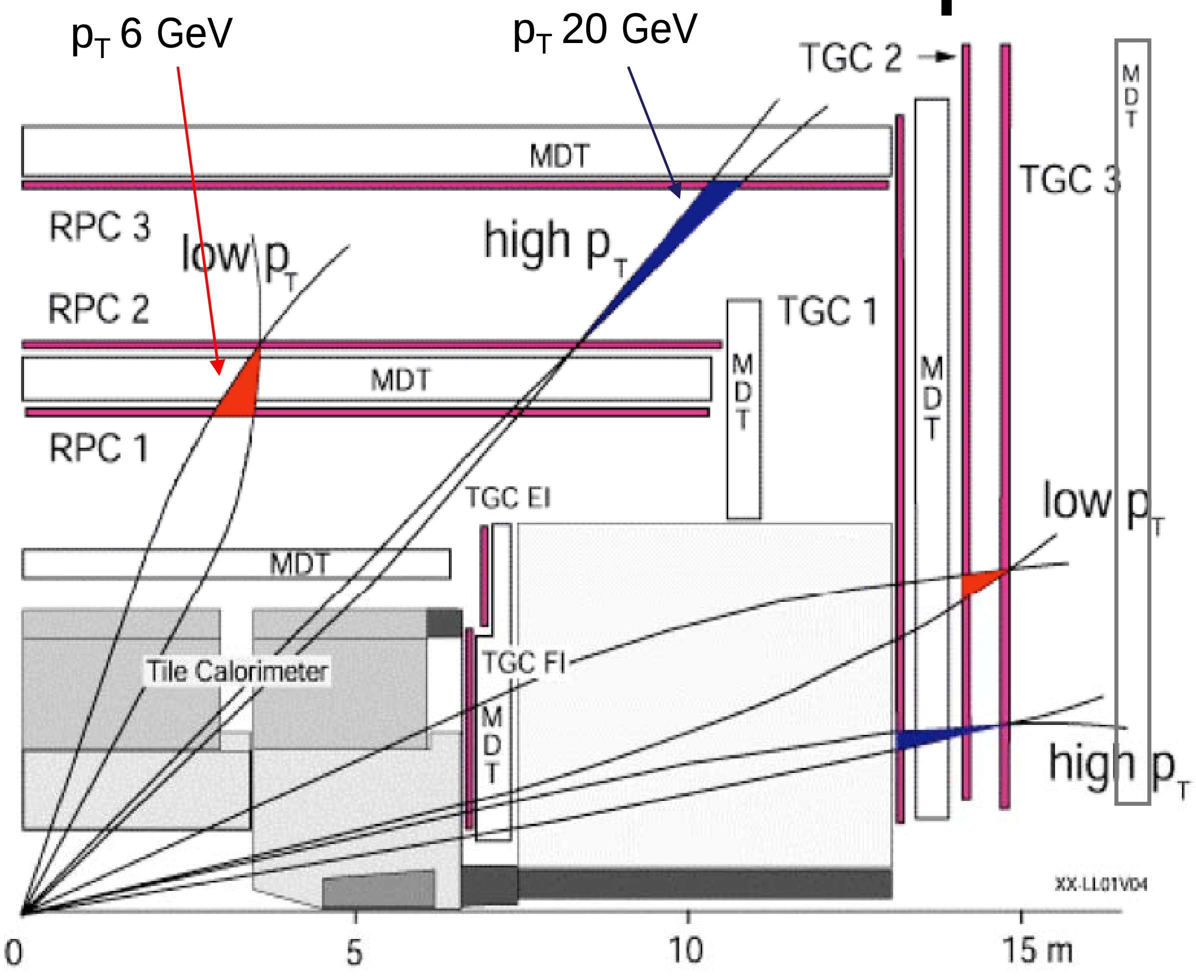


spectrometer (3 layers of precision and trigger chambers)

Forward muon spectrometer (2 layers of precision and trigger chambers) -> Small Wheels

Forward muon spectrometer (5 layers of precision and trigger chambers) -> Big Wheels

The Muon Spectrometer



Precision chambers :

MDT : monitored drift tubes

1108 chambers, 339 k channels

CSC : cathode strip chambers

32 chambers, 31 k channels

Trigger chambers (LVL1):

RPC : resistive plate chambers

560 chambers, 359 k channels

TGC : thin gap chambers

3588 chambers, 318 k channels

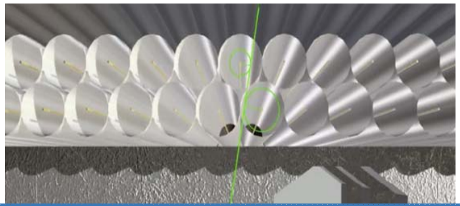
$\Delta p_T / p_T \sim 3\%$ for $p_T = 10\text{–}100$ GeV in standalone mode

Total : ~12’000 m^2, ~ 1.1 M channels

Barrel Stations

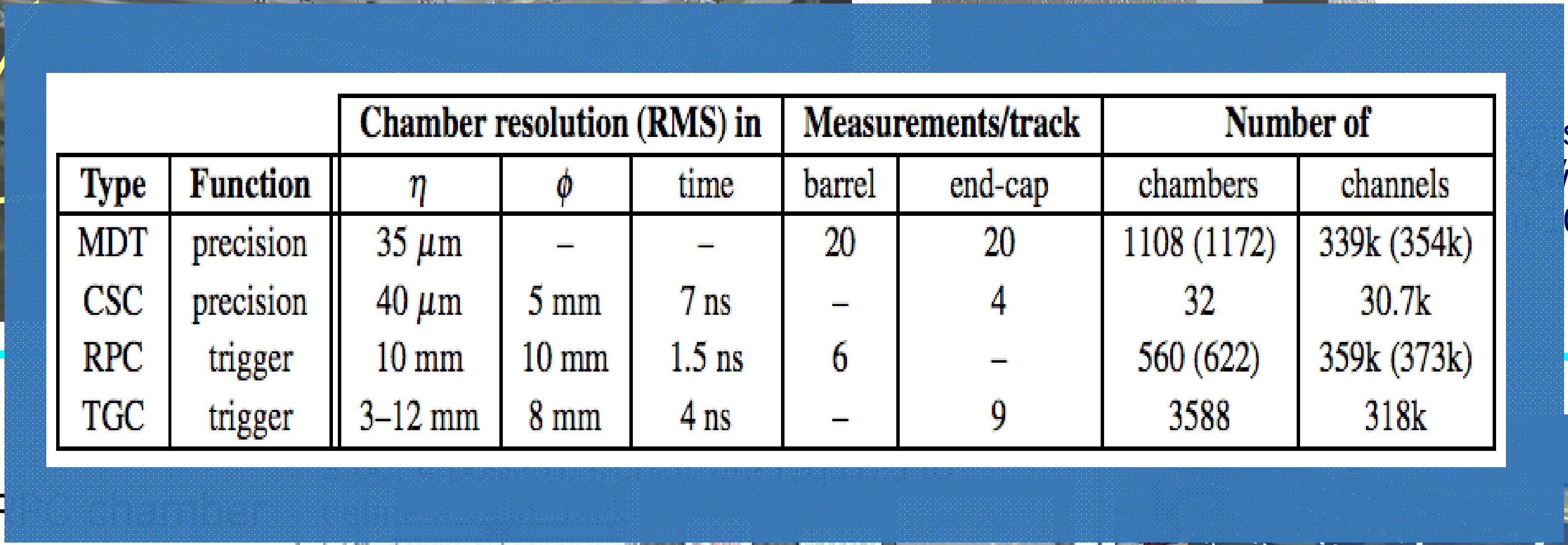
Two MDT layers (2 x 3 planes)

Two (M-layer), One (O-layer) RPC chambers



3 layers of tubes (4 layers inner ch.)

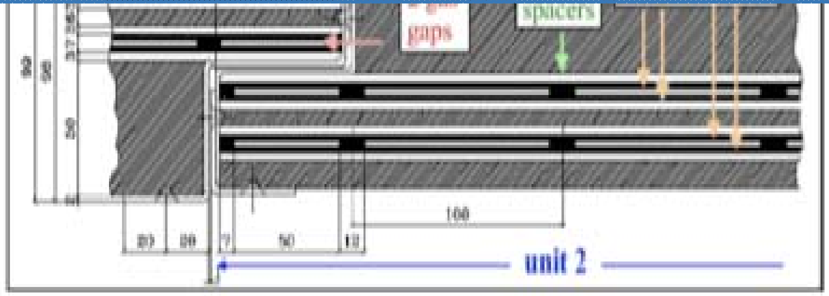
s of
ire
0µm)



		Chamber resolution (RMS) in			Measurements/track		Number of	
Type	**Function**	η	ϕ	time	barrel	end-cap	chambers	channels
MDT	precision	35 μm	–	–	20	20	1108 (1172)	339k (354k)
CSC	precision	40 μm	5 mm	7 ns	–	4	32	30.7k
RPC	trigger	10 mm	10 mm	1.5 ns	6	–	560 (622)	359k (373k)
TGC	trigger	3–12 mm	8 mm	4 ns	–	9	3588	318k

Each R
consists of 2 times
2 gas volumes
(units)

Each unit delivers
2 coordinates (η, ϕ)



Trigger chambers (RPC) rate capability ~ 1 kHz/cm^2

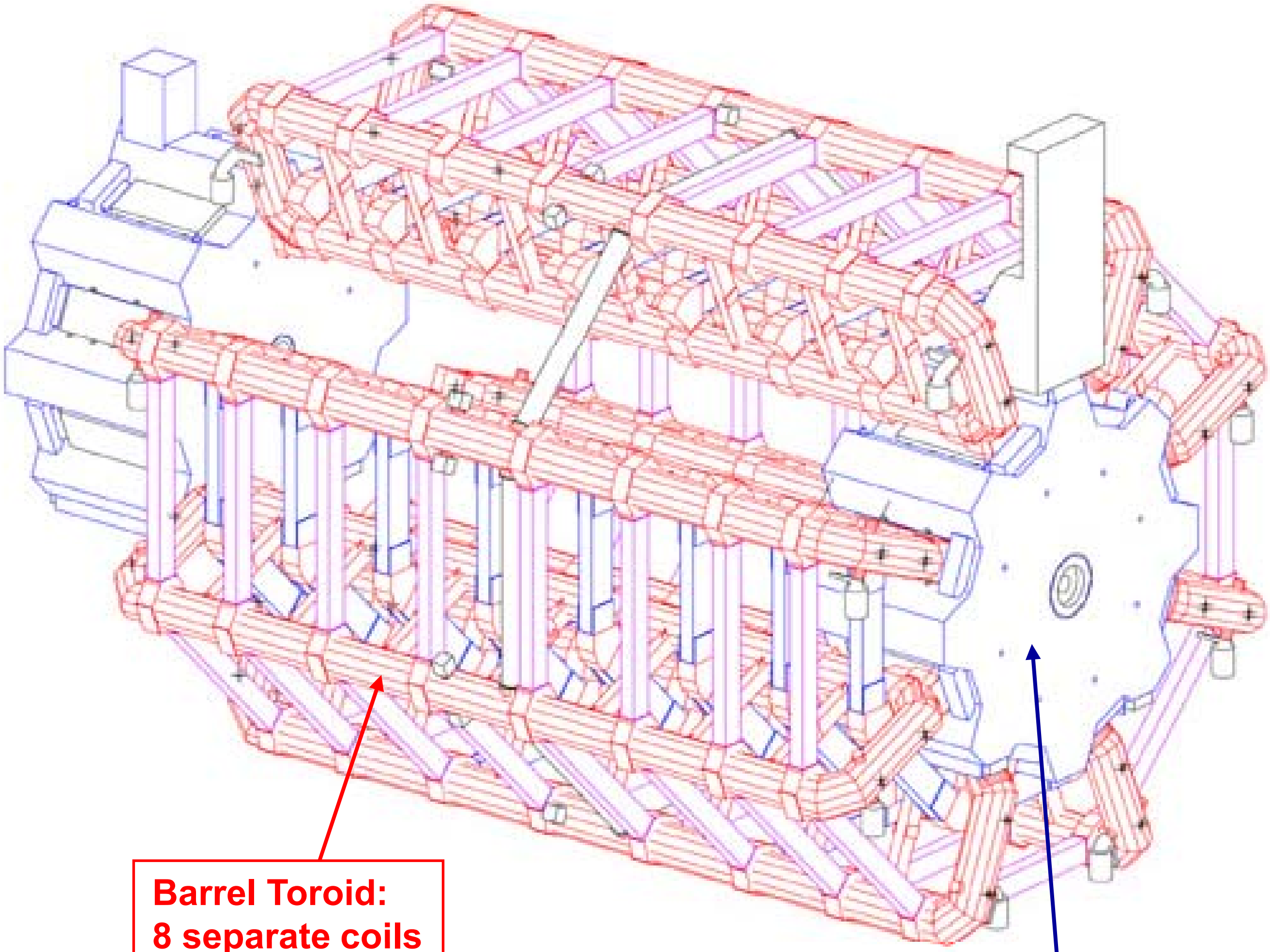
Toroid system

Barrel Toroid parameters

25.3 m length
20.1 m outer diameter
8 coils
1.08 GJ stored energy
370 tons cold mass
830 tons weight
4 T on superconductor
56 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

End-Cap Toroid parameters

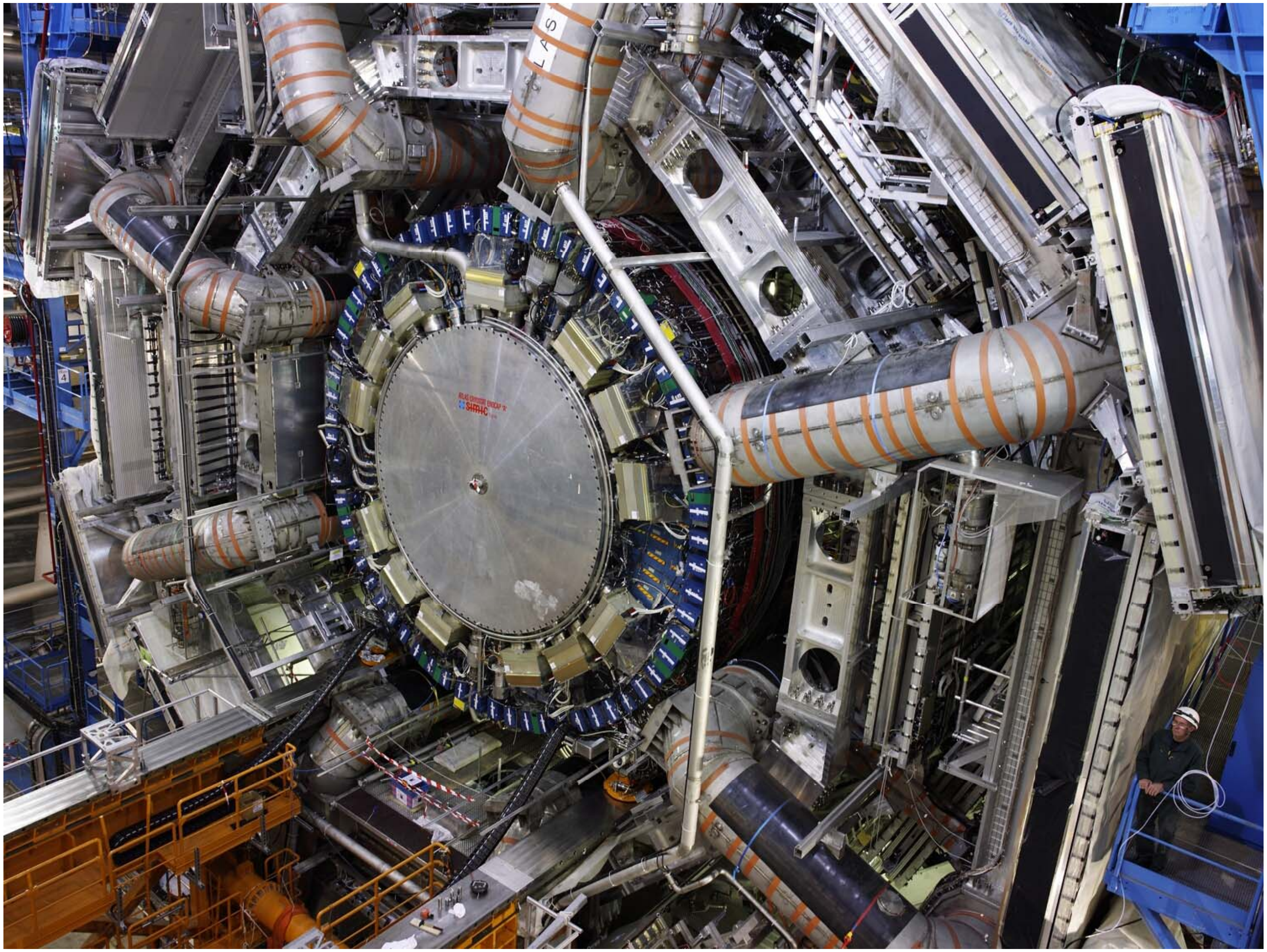
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point



Barrel Toroid:
8 separate coils

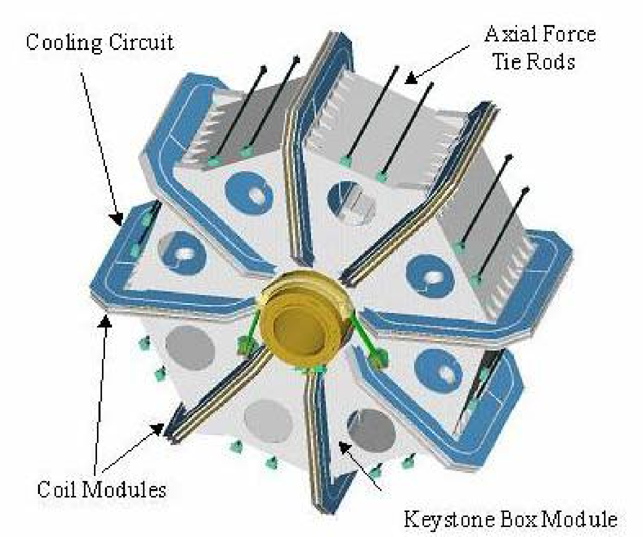
End-Cap Toroid:
8 coils in a common cryostat

Toroidální magnet: čela sedmi z osmi cívek jsou dobře vidět



ATLAS side A (with the calorimeter end-cap partially inserted, the LAr end-cap is filled with LAr)

End-Cap Toroids



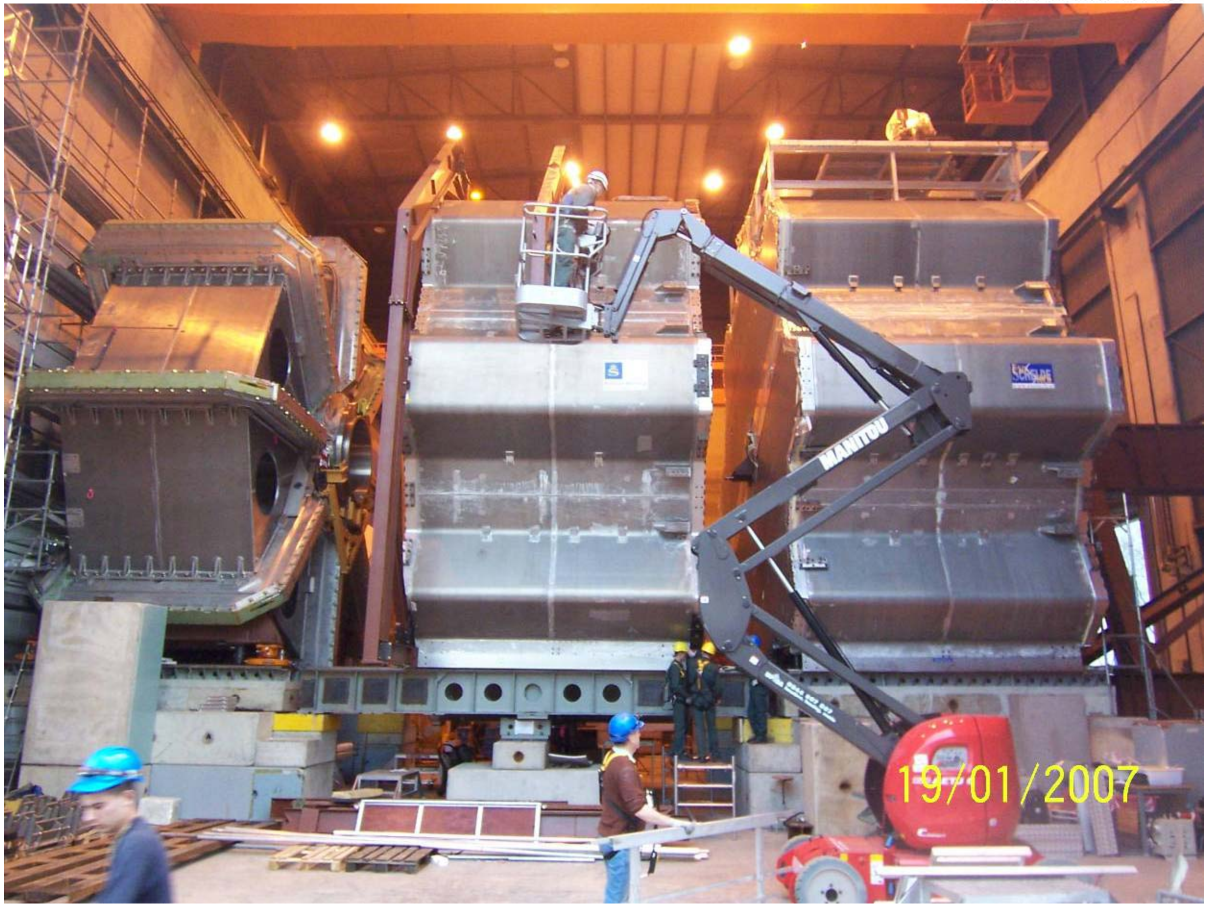
All components were fabricated in industry, and the assembly done at CERN

The ECTs are tested at 80 K on the surface, before installation and excitation tests in the cavern

The first ECT will move to the pit in June 2007, the second one in July 2007

Uzavření magnetického pole v podstavách
Válce toroidálního magnetu

The picture shows the first of the two ECT cold masses inserted into the vacuum vessel, and the second one assembled as well




Friderici
special s.a.

Měření mionů / hmoty Higgse

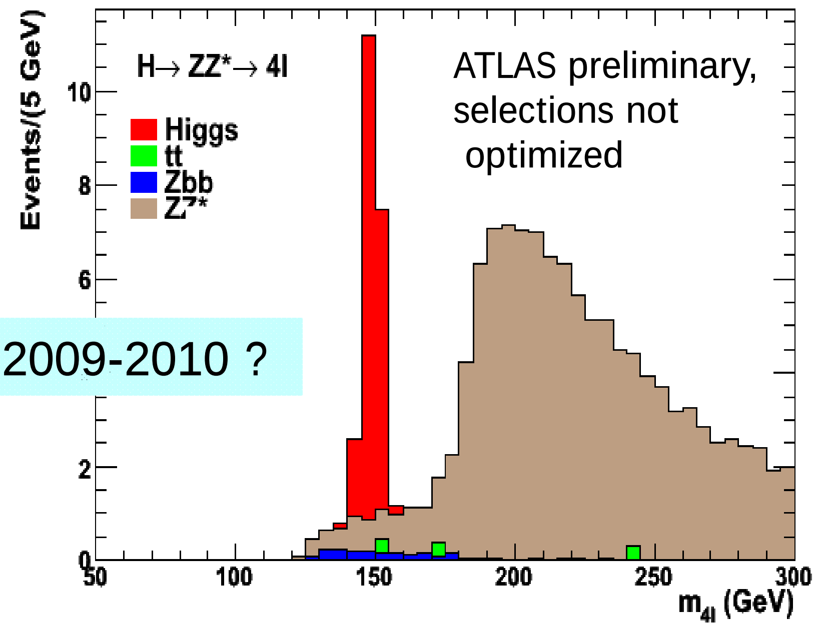
- Průhyb dráhy mionu (E ~ 1 TeV) v mg.poli (4T) = pouze 500 um + rekonstrukce hmoty Higgse: potřebujeme přesnost měření průhybu alespoň 50um

- Chybu ovlivňuje:
  - neurčitost při měření souřadnice pomocí MDT
    - Testy s mionovými svazky na povrchu ukázaly dostatečnou přesnost
  - znalost vzájemné polohy komor
    - (laser, zrcadla + CCD = RASNIK systém měří neustále aktuální polohu) => chyba 20um
  - znalost průběhu magnetického pole, požadavek na odchylky < 1 až 2 mT
    - Hallovy sondy měří s přesností 0,5mT z měření se nejdříve určí přesná poloha cívek a pole se dopočítá v celém objemu
    - Procedura vyzkoušena, čeká se na kompletní test magnetů v uzavřeném ATLASu v dubnu

M_H > 130 … is easier

m_H > 130 GeV : $H \rightarrow ZZ^{(*)} \rightarrow 4l$ (gold-plated), $H \rightarrow WW^{(*)} \rightarrow l\nu\ l\nu$

$H \rightarrow ZZ^* \rightarrow 4l$, 10 fb^{-1}



2009-2010 ?

May be observed with 3-4 fb^{-1}

$H \rightarrow 4l$: low-rate but very clean : narrow mass peak, small background

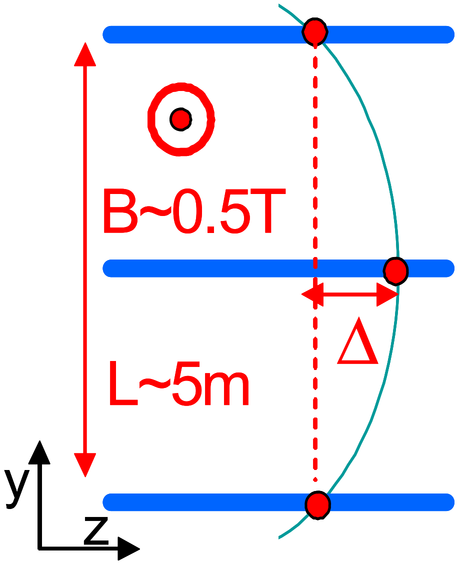
- requires:
  - ~ 90% e, μ efficiency at low p_T
  - σ / m ~ 1%, tails < 10% → good quality of E, p measurements in ECAL and tracker
- background dominated by irreducible ZZ production (tt and Zbb rejected by Z-mass constraint, and lepton isolation and impact parameter)

→ $WW \rightarrow l\nu l\nu$: high rate (~ 100 evts/expt) but no mass peak

→ not ideal for early discovery …

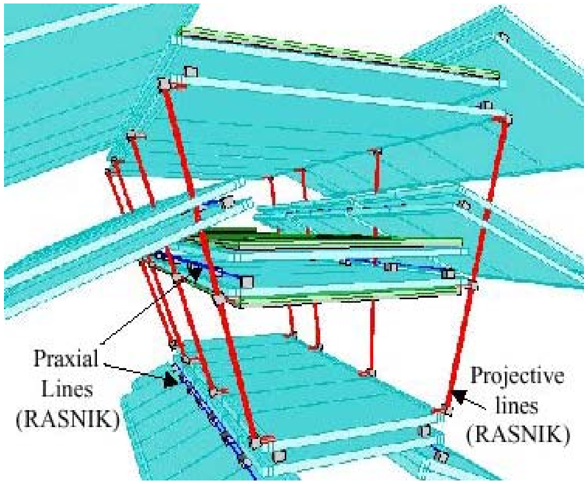
Muon Spectrometer Strategy

σ/p < 10% for Eμ ~ TeV needed to observe a possible new resonance X→ μμ as a “narrow” peak



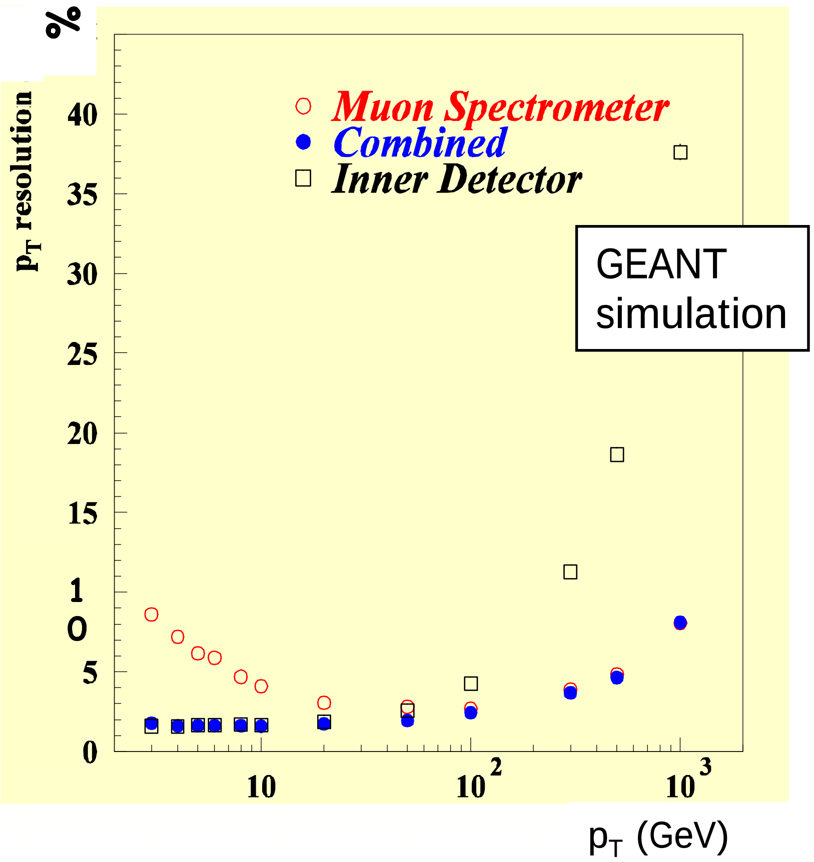
$E_{\mu} \sim 1\ \mathrm{TeV} \Rightarrow \Delta \sim 500\ \mu\mathrm{m}$

$\sigma/p \sim 10\% \Rightarrow \delta\Delta \sim 50\ \mu$



alignment accur
to ~30 μm

Muon momentum resolution

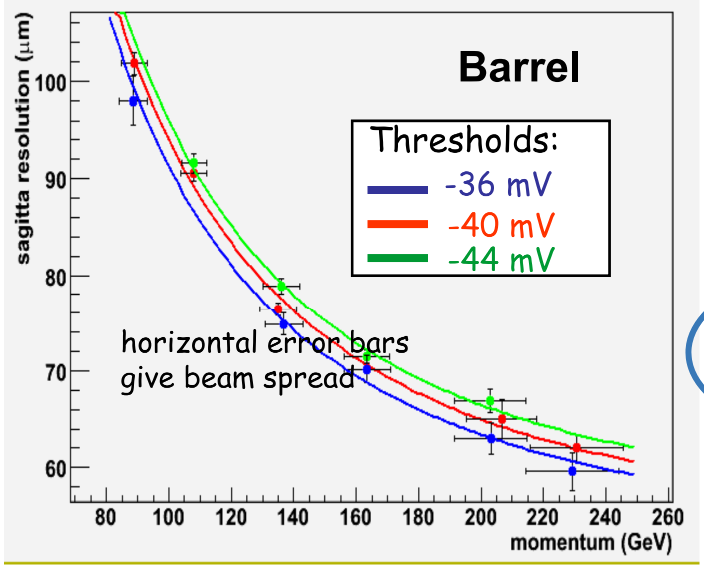


GEANT simulation

Can we achieve such a precision ?

1) Showing that we master the intrinsic resolution of the MDT chambers (monitored drift tubes)

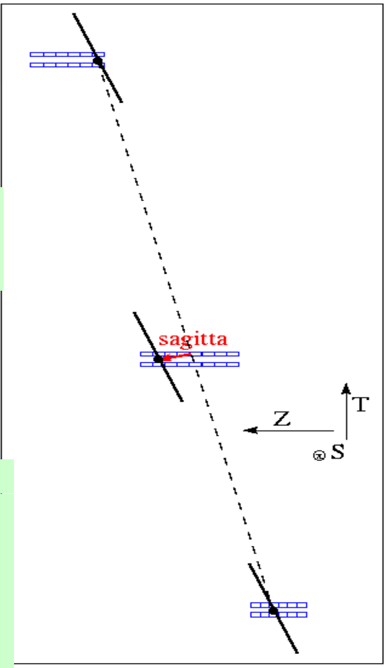
Sagitta resolution measured in the 2004 combined test beam



Data fitted with: $\sigma = \sqrt{K_1^2 + (K_2/p)^2}$

- p = muon momentum from beam magnet
- K_1 = intrinsic resolution
- K_2 = multiple scattering

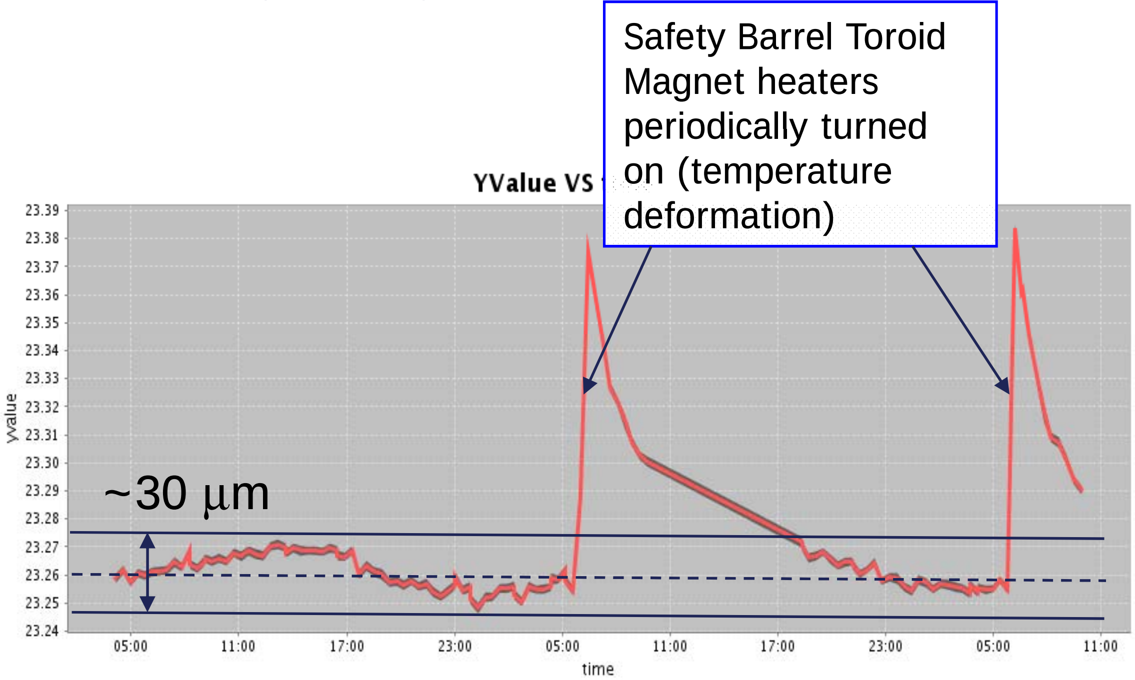
Data	Simulation
K_1 = 50.7±1.5 µm	K_1 = 40±3 µm
0.29±0.01 X_0	0.32 ±0.02 X_0



All this might sound obvious but it is not: think of wire positioning, tubes mechanical properties, straightness, gravitational sag, gaps between tubes, traceability, mass production in many different locations, ...

Can we achieve such a precision ?

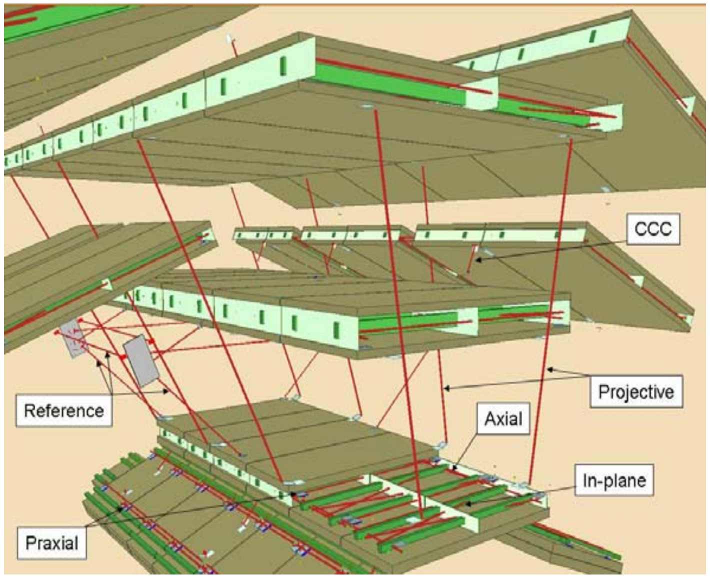
2) Showing that we know the geometrical position of all chambers in time, using a sophisticated alignment system

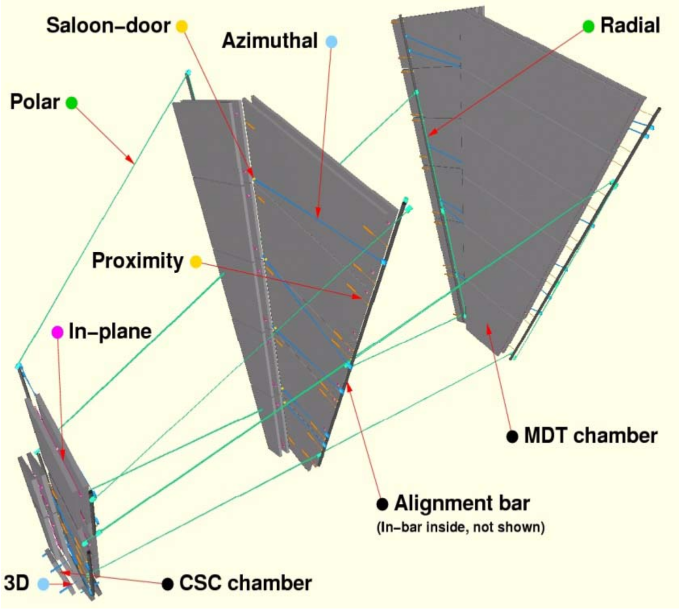


Safety Barrel Toroid Magnet heaters periodically turned on (temperature deformation)

Example of one projective line stability

We demonstrated an alignment precision of ±20 µm with the test beam setup already

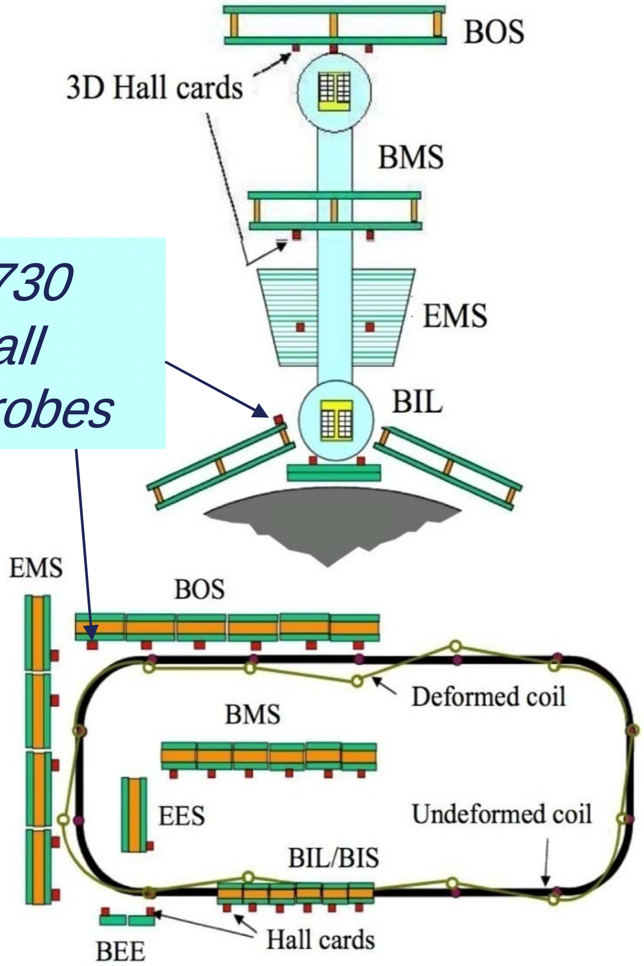




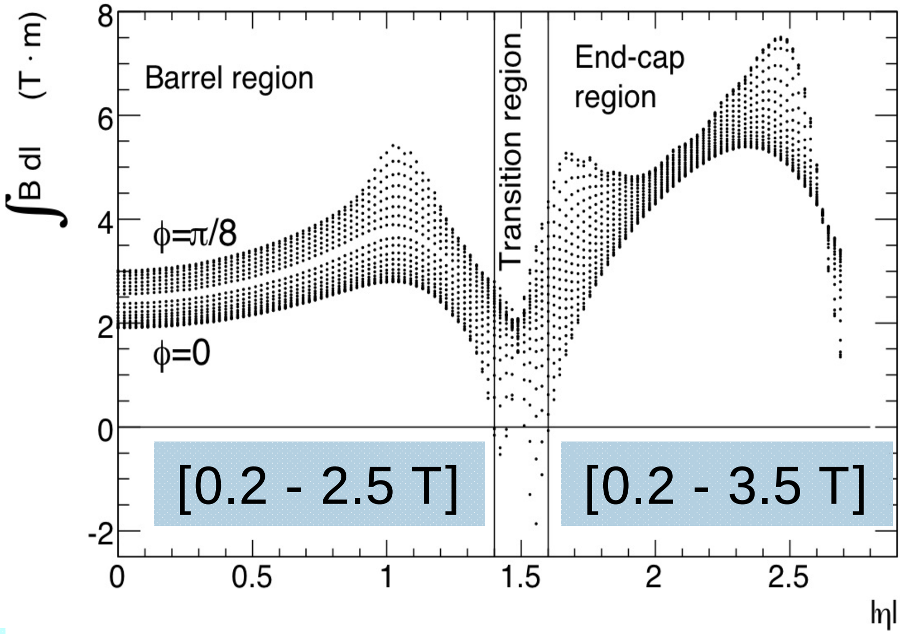
Can we achieve such a precision ?

3) By controlling and knowing the B-field properties of the spectrometer

Accuracy goal: | ΔB | ~ 1-2 mT



1730 Hall probes



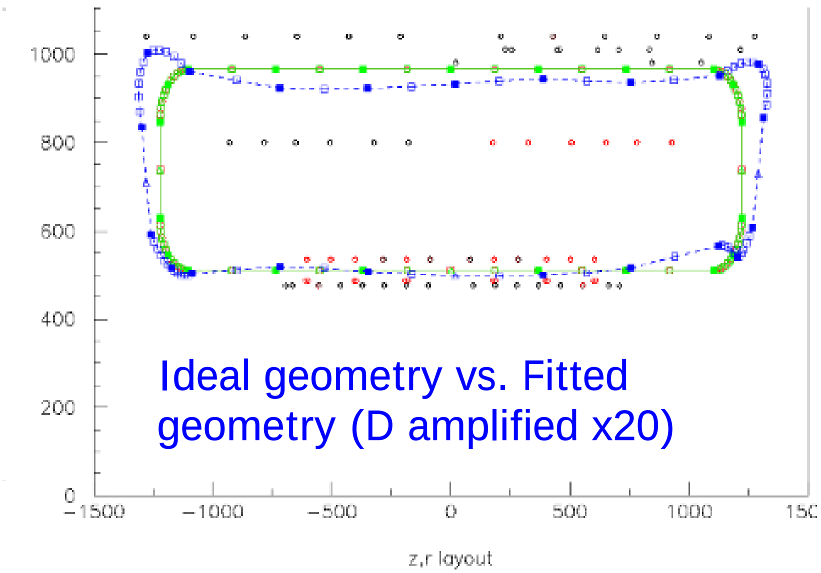
[0.2 - 2.5 T]

[0.2 - 3.5 T]

Strategy:

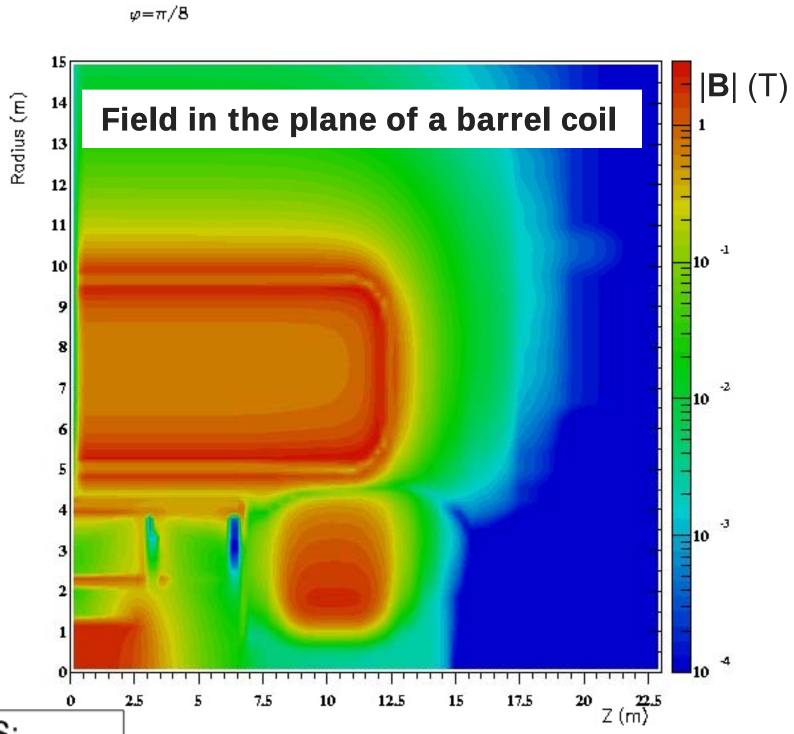
- Measure the B-field vector ($B_{x,y,z}$) to < 0.5 mT with ~ 1800 sensors (3-D Hall cards) positioned (2mm, 3 mrad) at places where the field gradient is large
- Use the B-sensor readings after correcting for the magnetic pollution predicted for known regions, to fit the position (and shape) of each toroid coil
- Once the geometry is known, compute B numerically everywhere

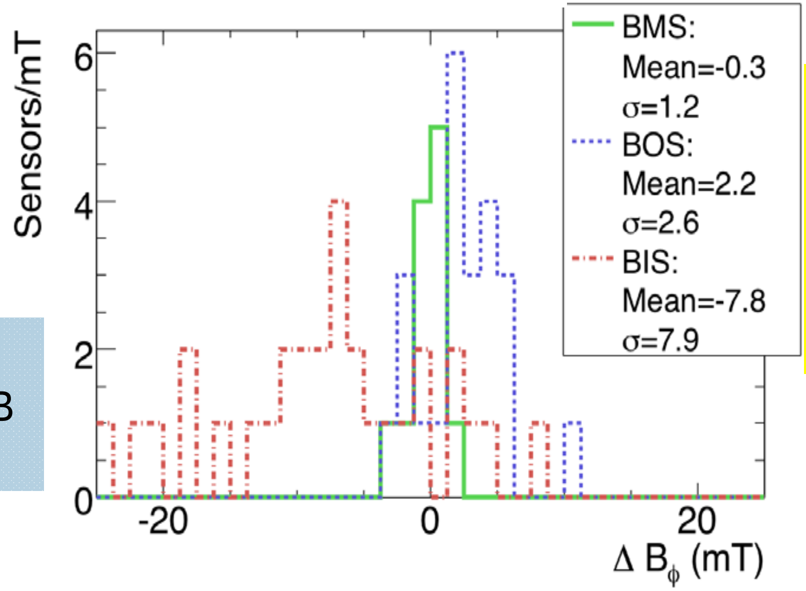
Can we achieve such a precision ?



Ideal geometry vs. Fitted geometry (D amplified x20)

Comparison of ***ideal*** *coil geometry, with that reconstructed from B-sensor data*





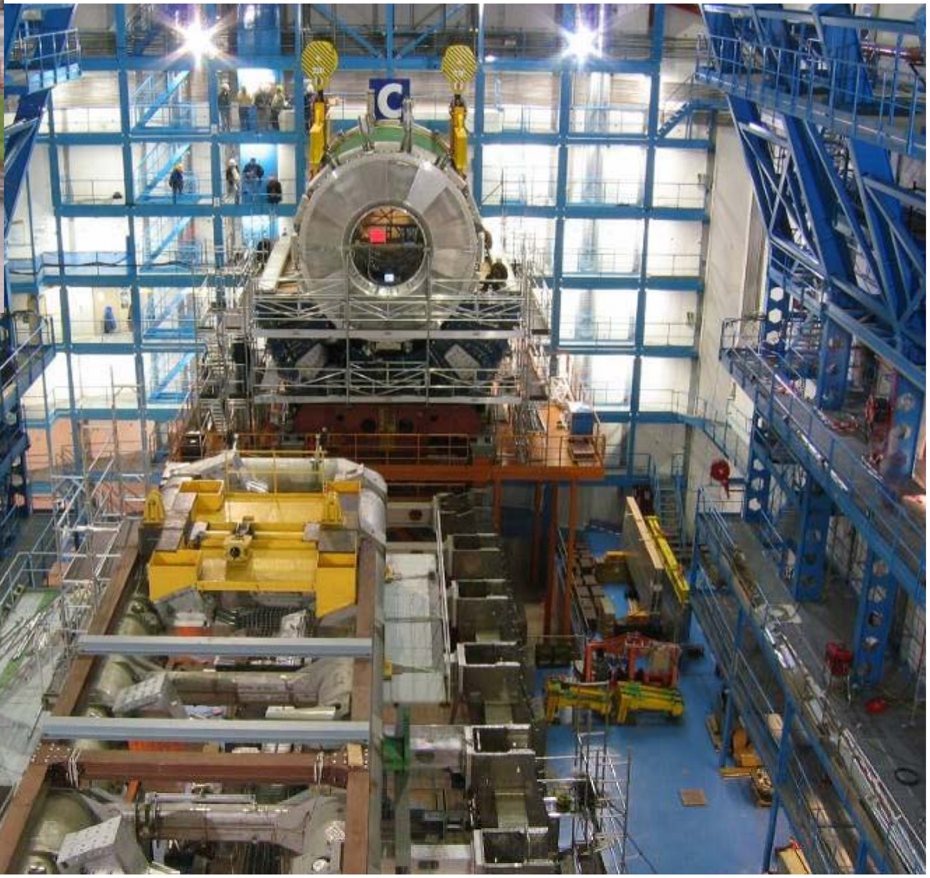
Field reconstruction residual ΔB_ϕ , in mT, for a middle (green, solid), outer (blue, dashed) and inner (red, dot-dashed) MDT layer.

By comparison, the accuracy goal is $< \Delta B > = 0$, $\sigma(\Delta B) \sim 1\text{-}2$ mT

First results now waiting for final B test in 2008

Pojďte se podívat do podzemí

End of October 2004 the cryostat was transported to the pit, and lowered into the cavern



The first coil was installed in October 2004

The last coil was moved into position on 25th August 2005