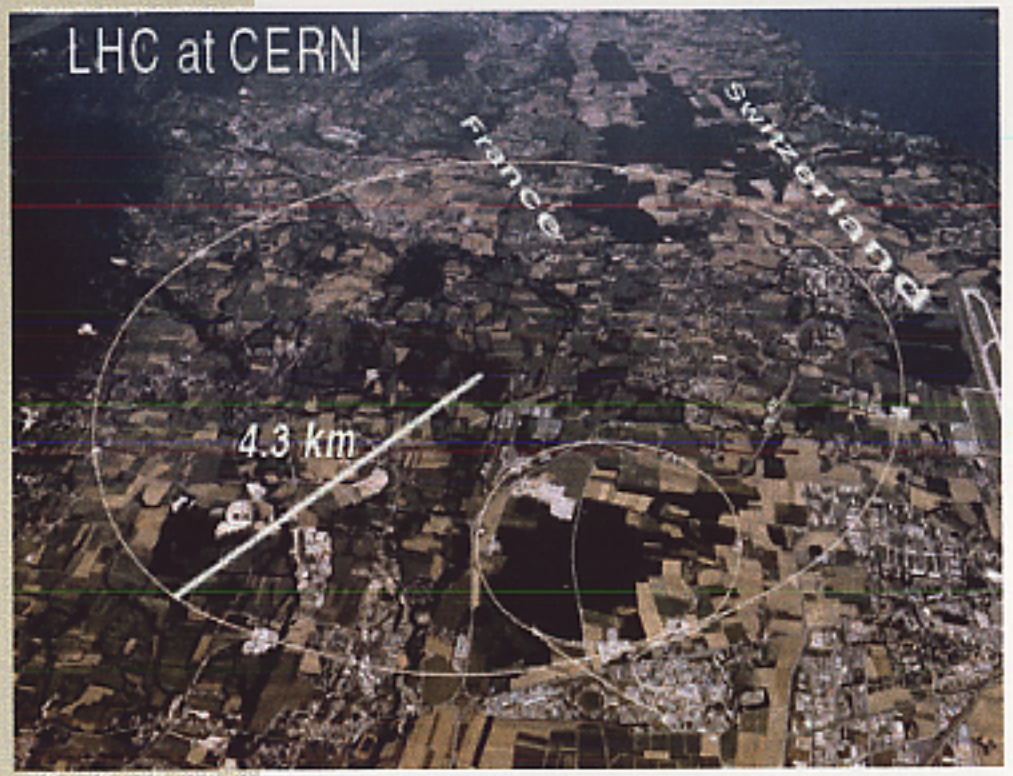
LHC Experiment

田中秀治
KEK IPNS

LHC実験の概要

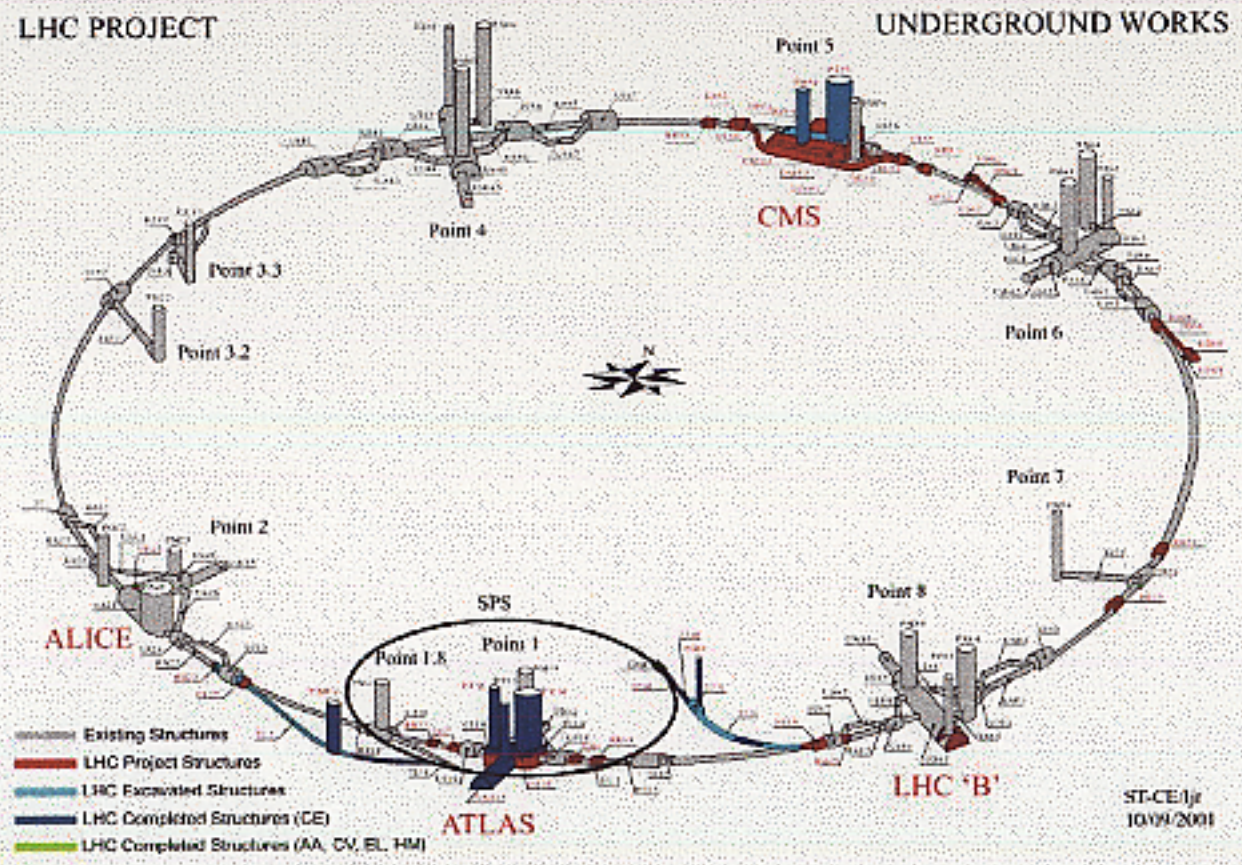
- 世界最高エネルギーでの陽子・陽子衝突実験
  - Higgs粒子存在の可否の判定 (～TeV)
  - SUSYの可能性の検証
  - SM の検証
  - B physics (CP violation)
  - Top quark study
  - 未発見粒子の探索など

LHC加速器



- 周長 26.6 km
- E(Proton) 7 TeV
- Lumi. $10^{34}cm^{-2}s^{-1}$
- Bunch crossing 25ns
- Beam Lifetime 22 hours

LHC加速器の概要

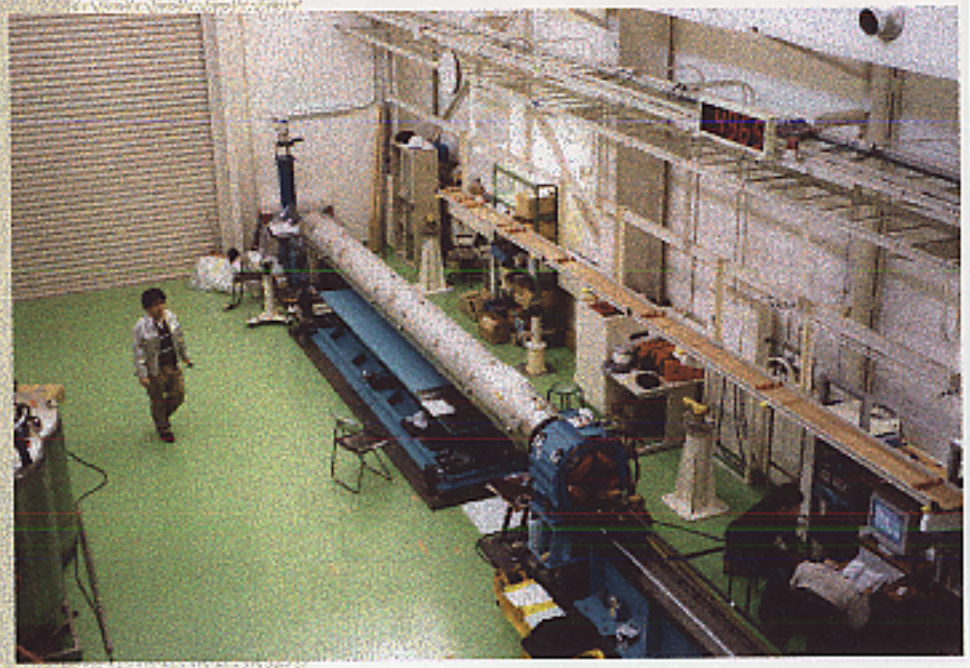


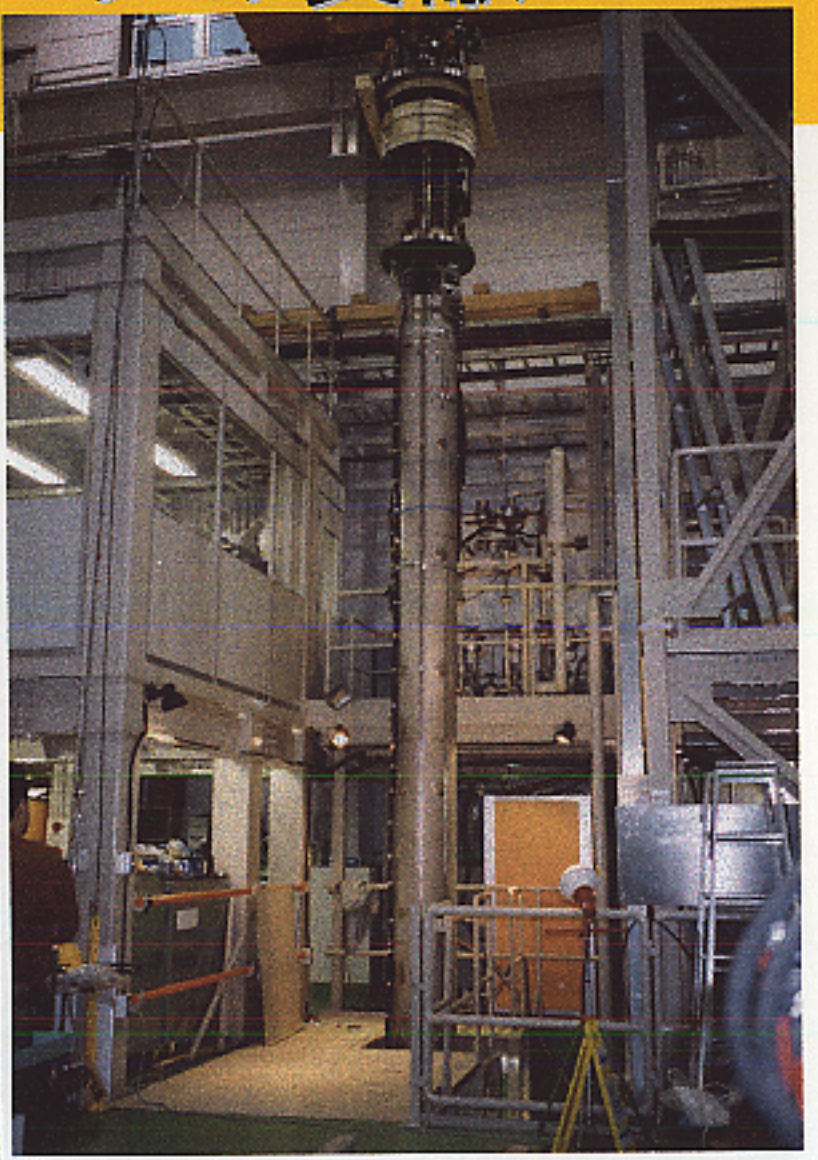
Proton Linac
(50MeV)
↓
PS Booster
(1.4 GeV)
↓
PS(24 MeV)
↓
SPS(450GeV)
↓
LHC(7TeV)

日本グループの貢献

Operating Gradient field = 215T/m
長さ ＝ 6.3m

Quadrupole magnet
（衝突点でのビームの収束）





CERN
CH-1211 Geneva 23
Switzerland

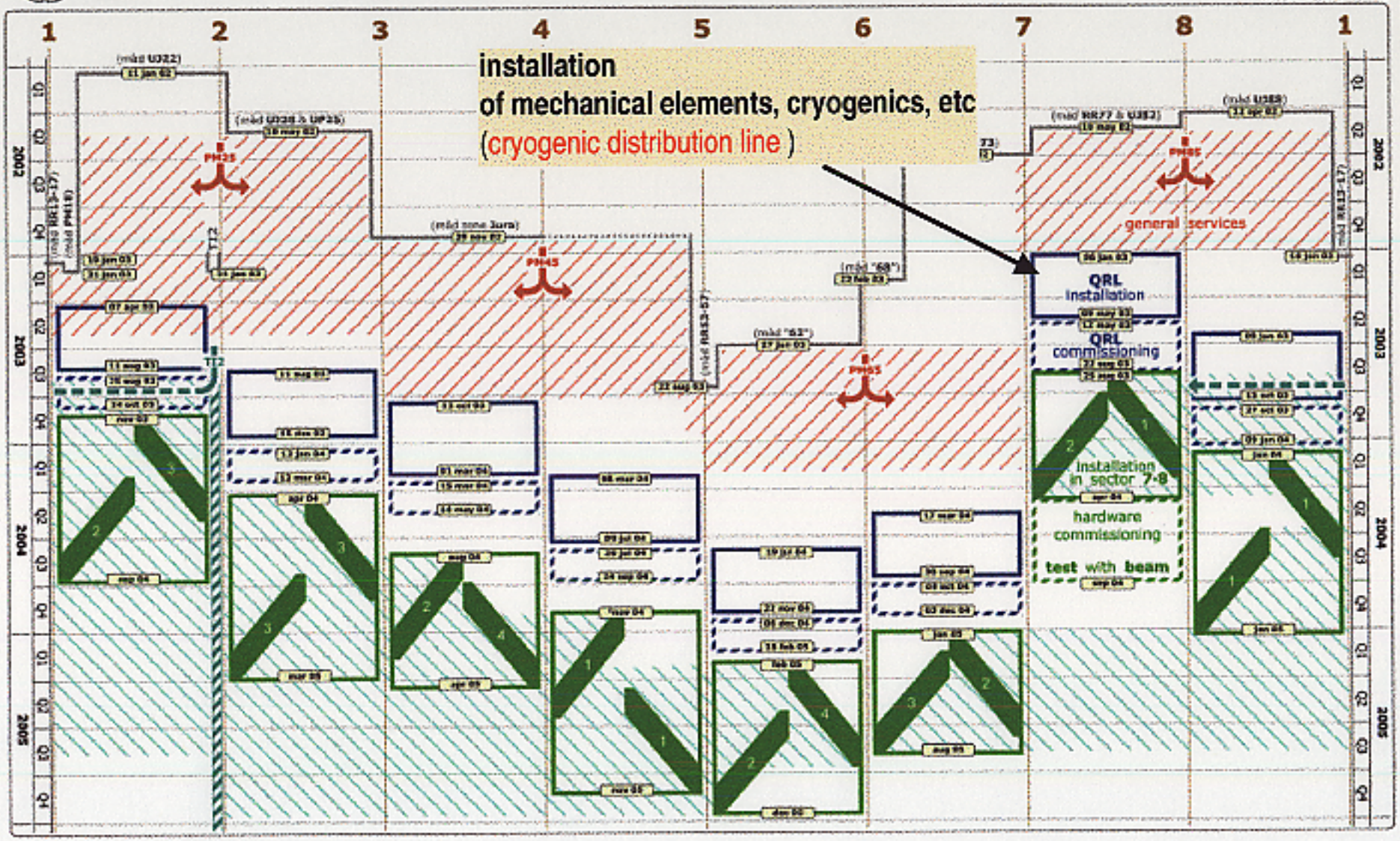
the Large Hadron Collider project

LHC Project

Summary Installation Schedule

LHC-PM-MS-0009 rev. 2.0
AC/TCP
311826

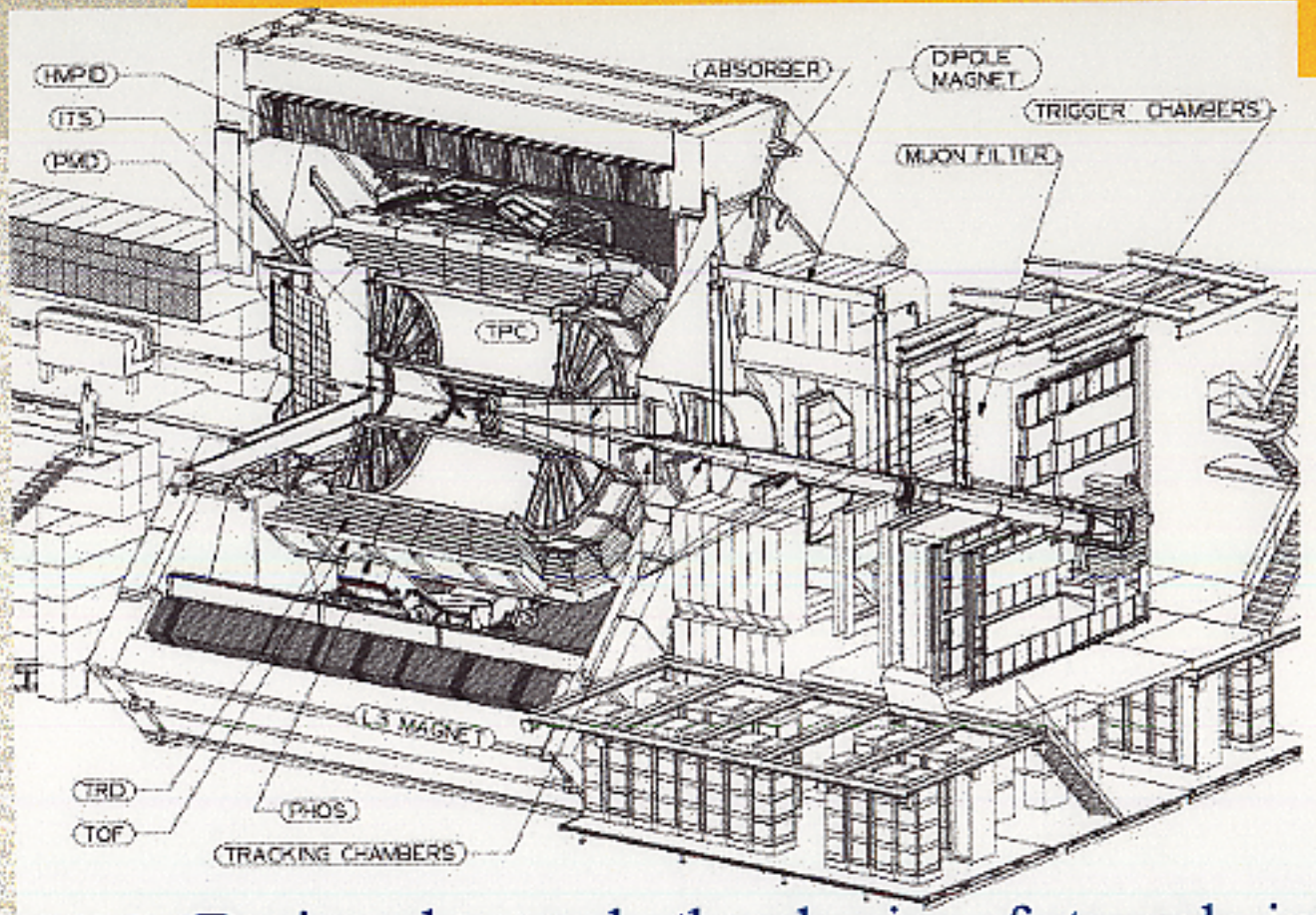
Date : 2001-05-23



LHCを用いた実験

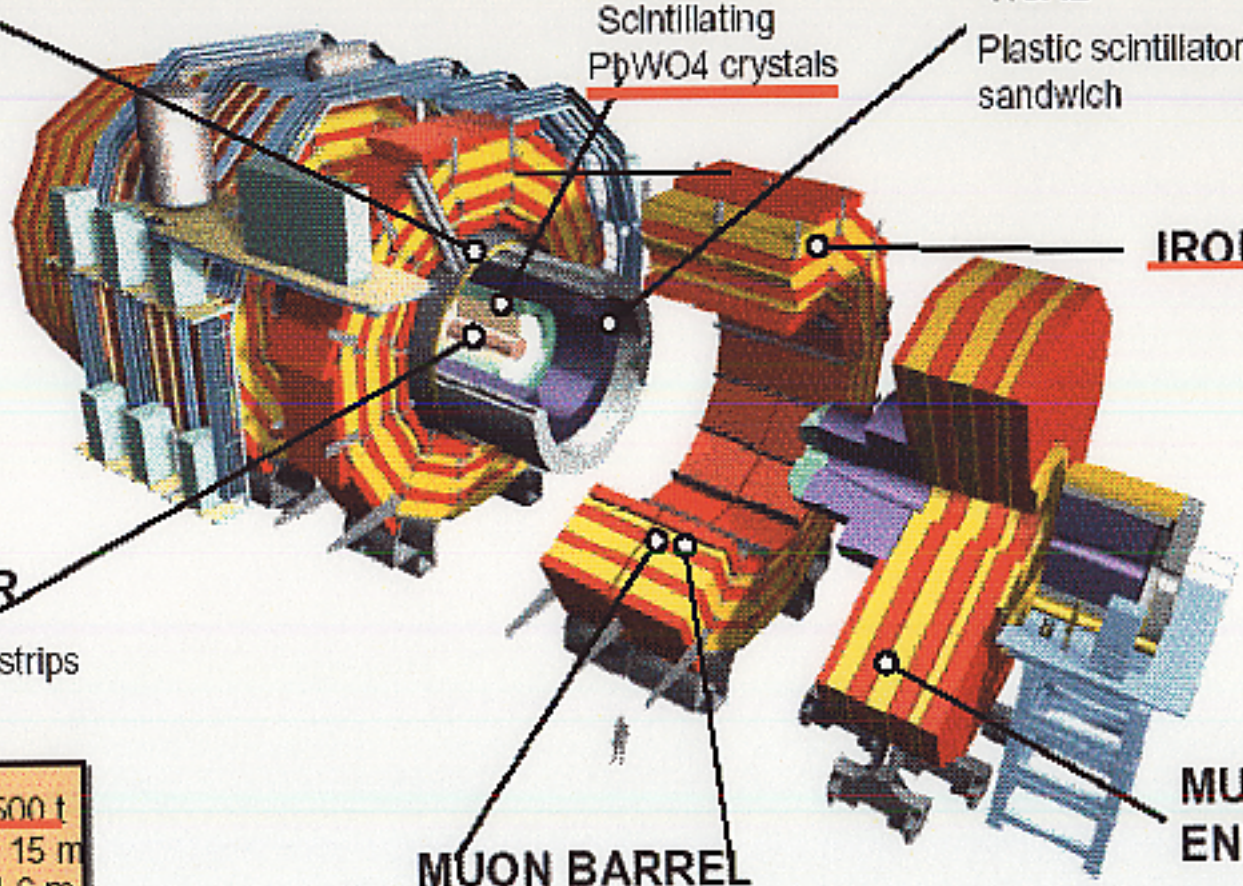
- **ATLAS** (汎用実験グループ)
- **CMS**（汎用実験グループ）
- **LHCb**（主にB physics)
- **ALICE** (重イオンビーム衝突実験)
- (TOTEM)（Total cross section の測定等）

ALICE Detector



Designed to study the physics of strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions at the LHC.

The CMS Detector



SUPERCONDUCTING COIL

CALORIMETERS

ECAL
Scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE

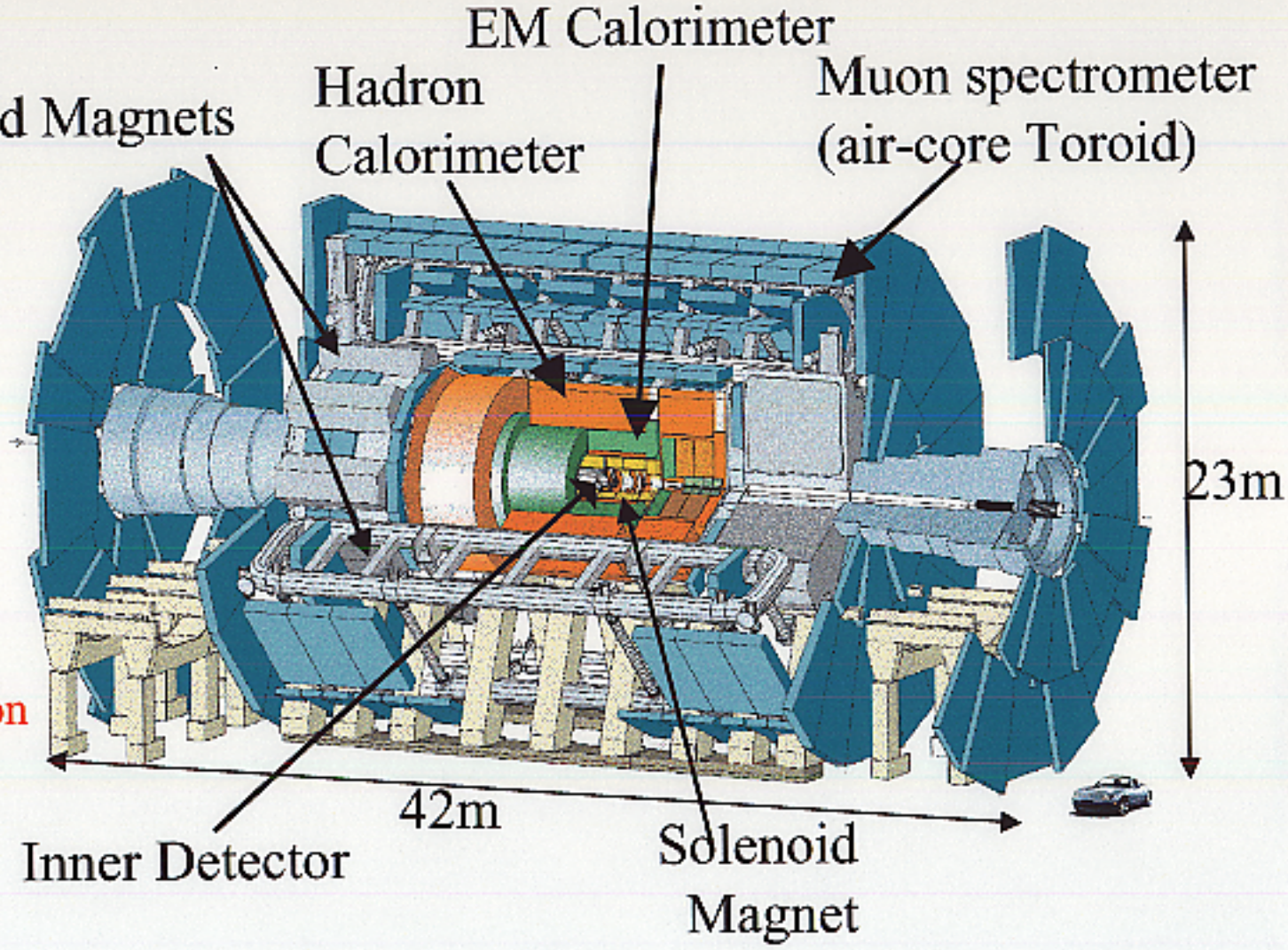
TRACKER
Silicon Microstrips
Pixels

MUON BARREL
Drift Tube Chambers (**DT**)
Resistive Plate Chambers (**RPC**)

MUON ENDCAPS
Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Total weight : 12 500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

ATLAS Detector



Weight=7000ton

2001/11/5

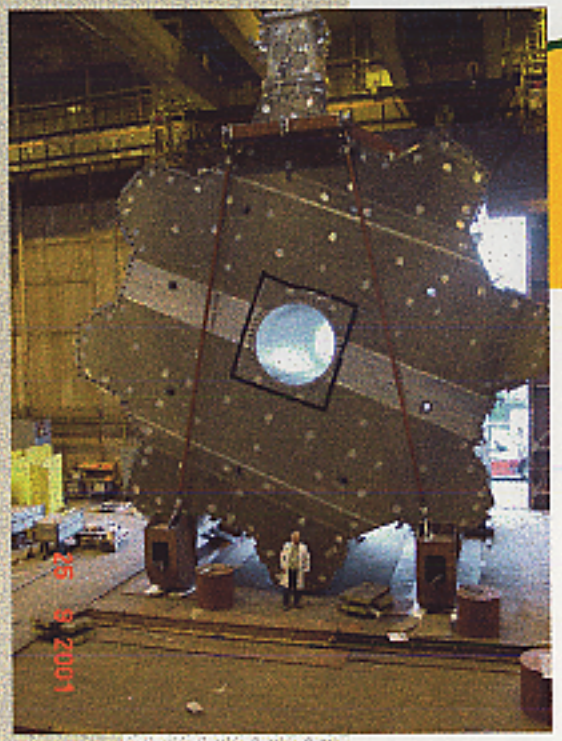
ATLAS Collaboration

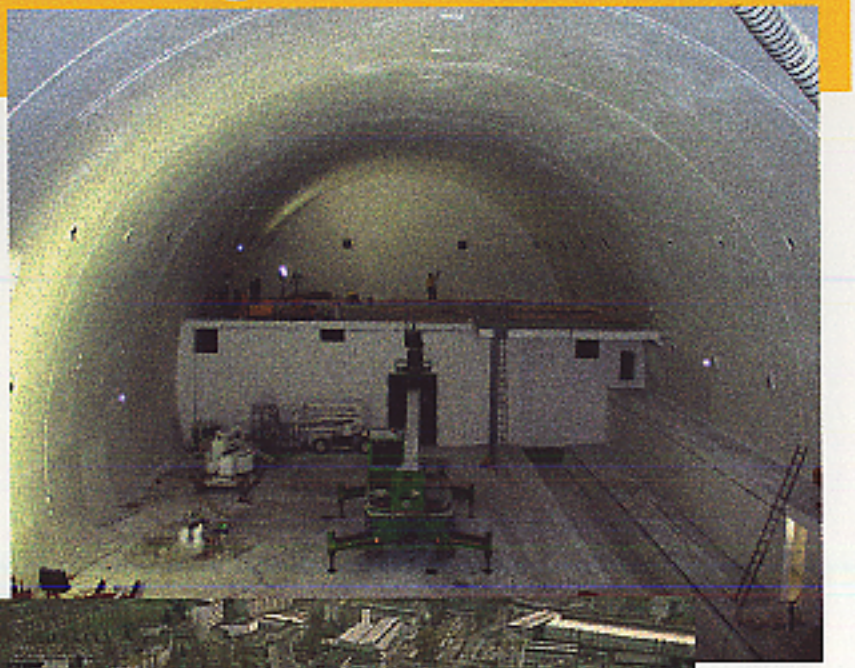
(Status October 2001)

Albany, Alberta, NIKHEF Amsterdam, Ankara, Ann Arbor, LAPP Annecy, Argonne NL, Arizona, Arlington UT, Athens, NTU Athens, Baku, IFAE Barcelona, Bergen, Berkeley LBL and UC, Bern, Birmingham, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Bucharest, Cambridge, Carleton/CRPP, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, INP Cracow, FPNT Cracow, Dortmund, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Fukui, Geneva, Genoa, Glasgow, ISN Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Helsinki, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, MIT, Melbourne, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Naples, Naruto UE, New Mexico, Nijmegen, Northern Illinois, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, LAL Orsay, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Southern Methodist, NPI Petersburg, Stockholm, KTH Stockholm,Stony Brook, Sydney, AS Taipei, Tbilisi, Tel-Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo UAT, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yerevan

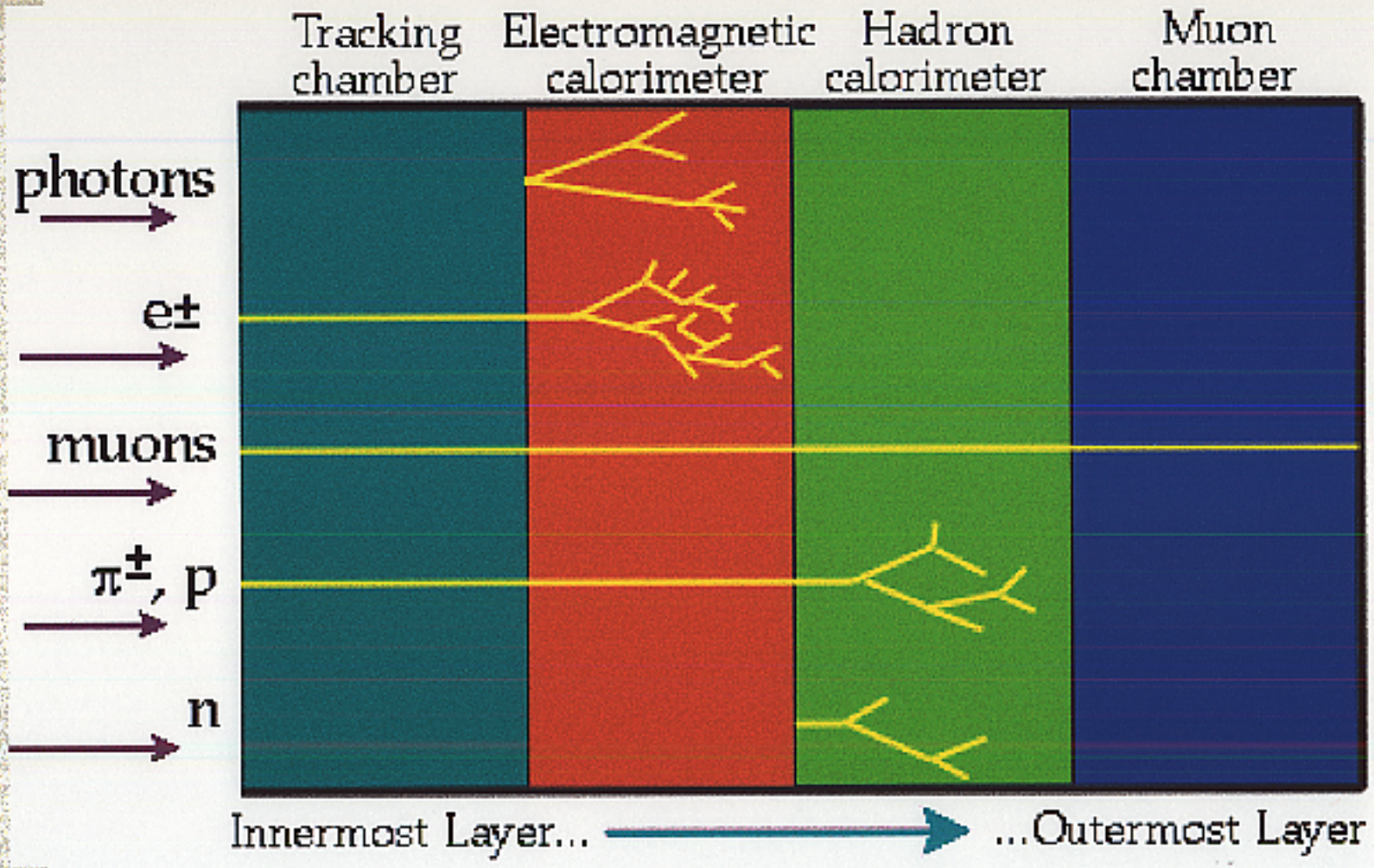
(149 Institutions with about 1850 authors)

Civil engineering Now (Hall)



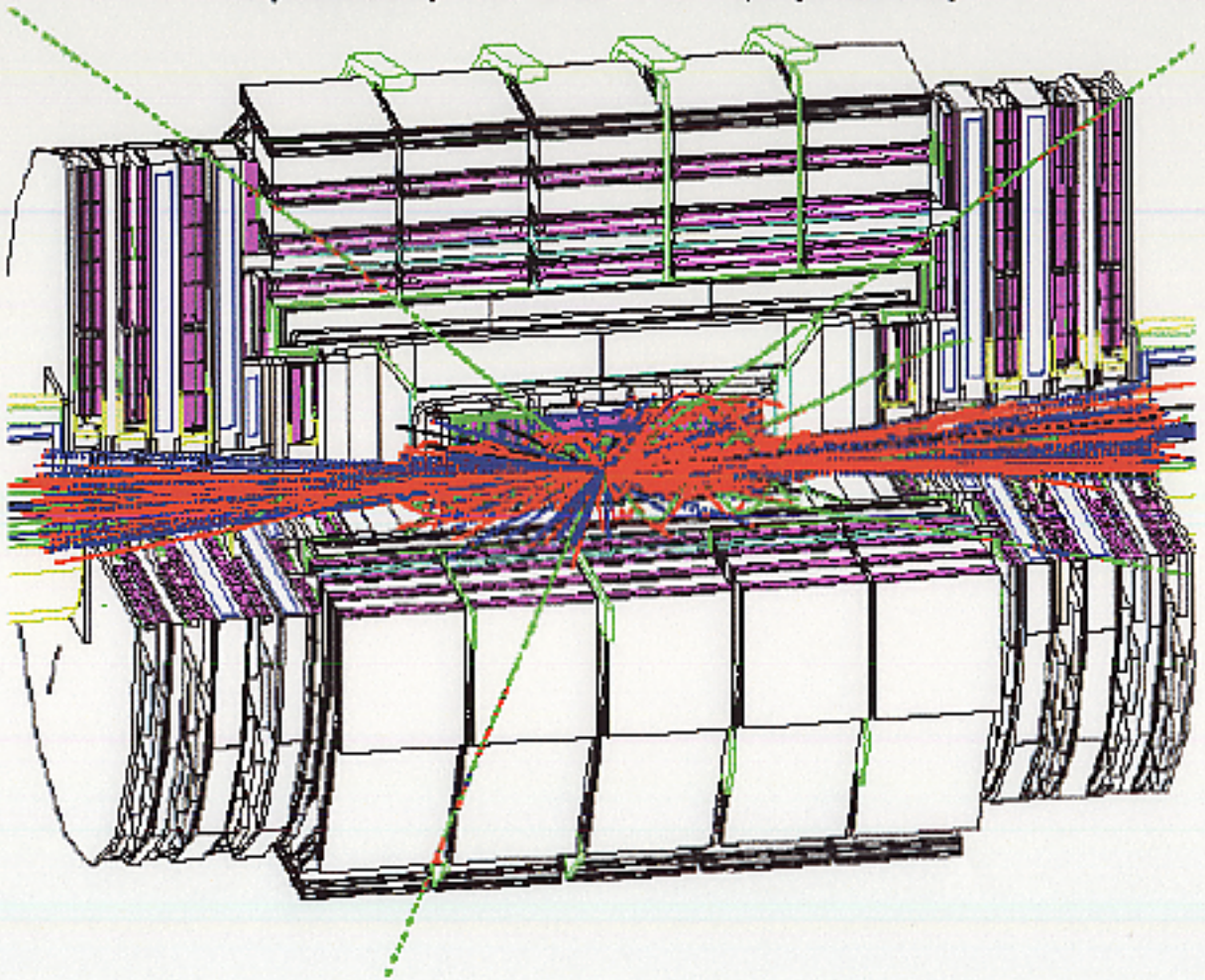


How to identify particles?



Higgs event into four Muons

H(150GeV) → Z^0Z^{0*} → 4μ (event 8)

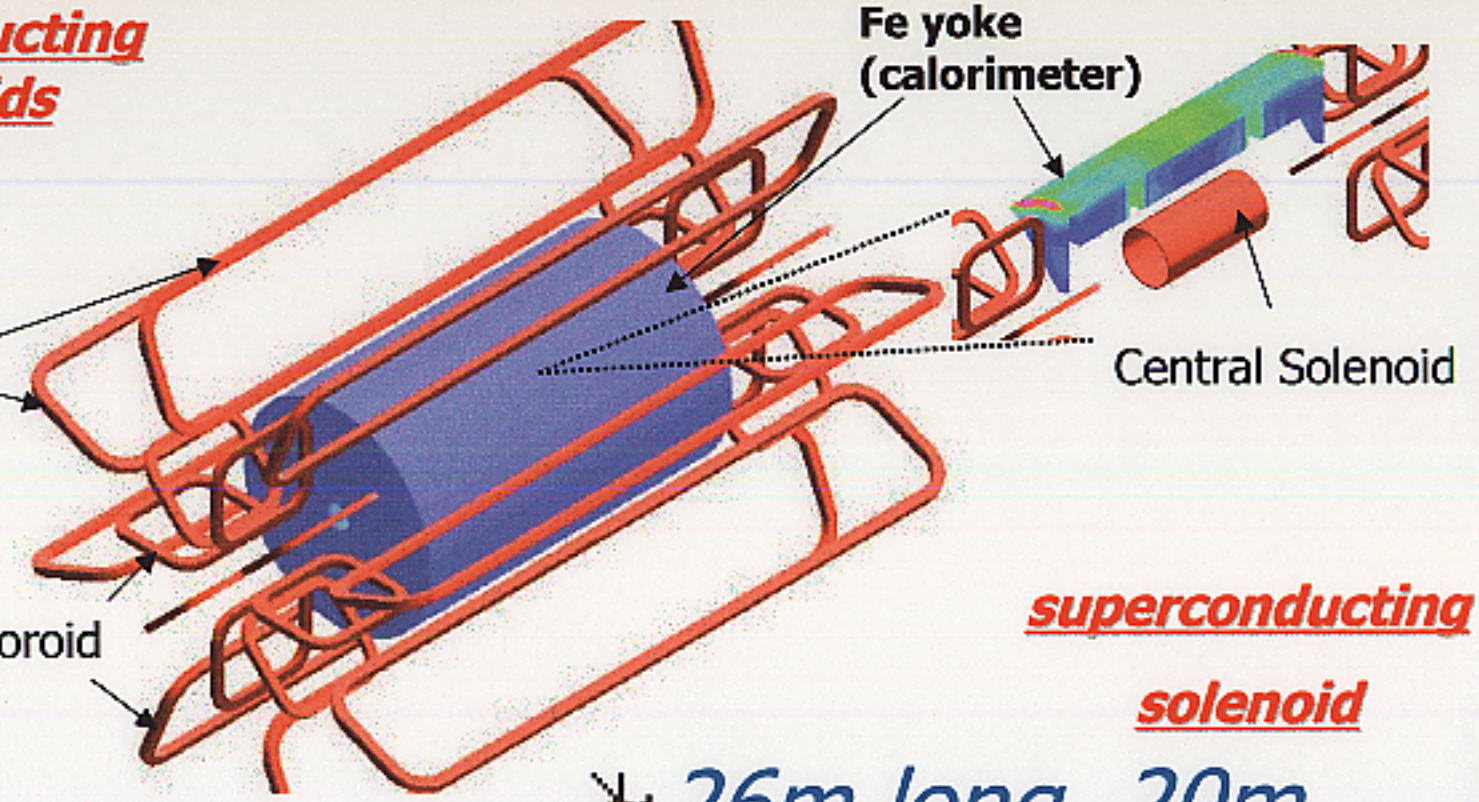


Sub-detectors (ATLAS)

Detector	Required Characteristics	η coverage
Inner Det.	30% at Pt=500GeV	$\pm$2.5
	Electron ID	$\pm$2.5
	T and b tagging	$\pm$2.5
	Secondary vertex detection	$\pm$2.5
EM Cal.	$10\% / \sqrt{E} + 0.7\%$	$\pm$3.0
Hadron Cal.	$50\% / \sqrt{E} + 3\%$	$\pm$3.0
Forward Cal.	$100\% / \sqrt{E} + 10\%$	3-5
Muon	10% at Pt =1TeV	$\pm$3.0

The ATLAS Magnet System

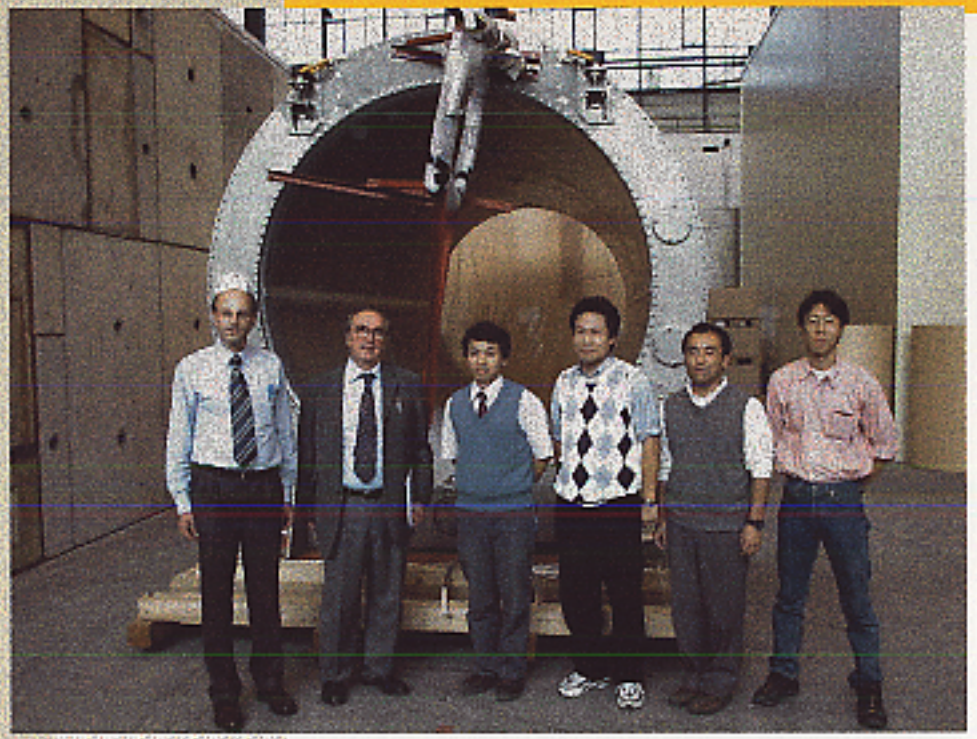
3 superconducting air core toroids



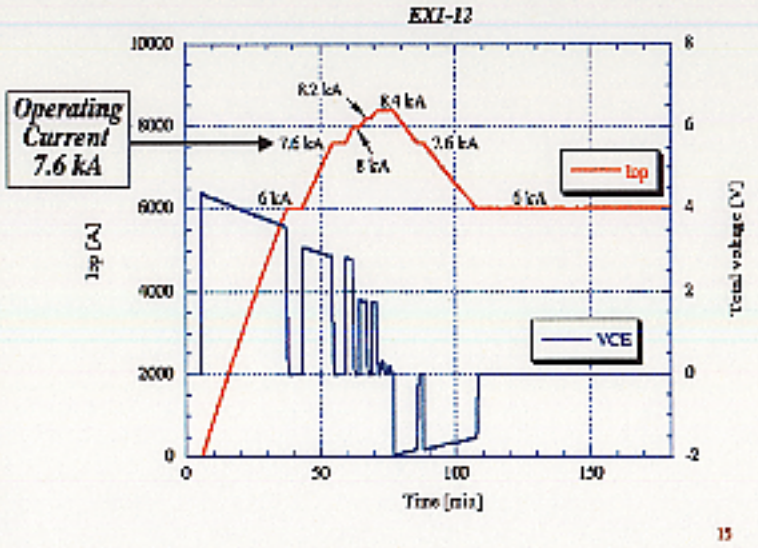
superconducting solenoid

- *26m long, 20m outer diameter*
- *1350 tons*

The Central Solenoid



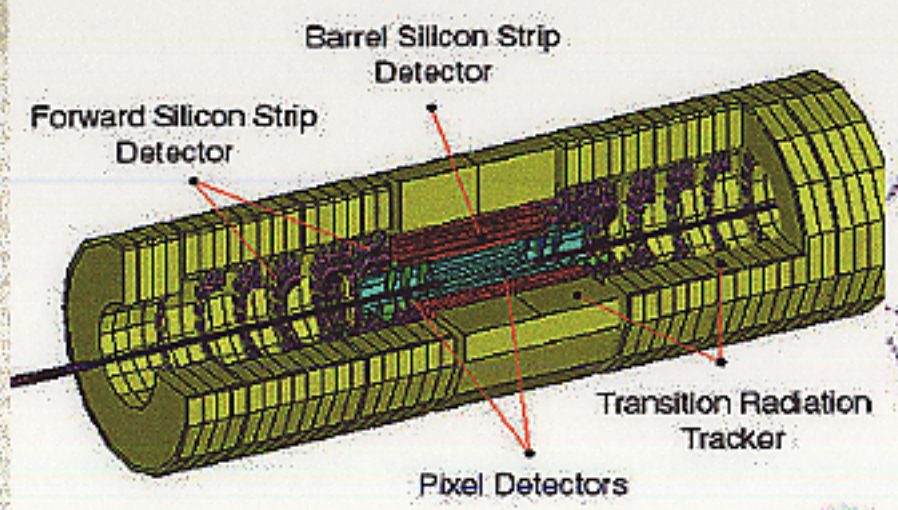
Excitation to 8.4 kA and hold at 6 kA

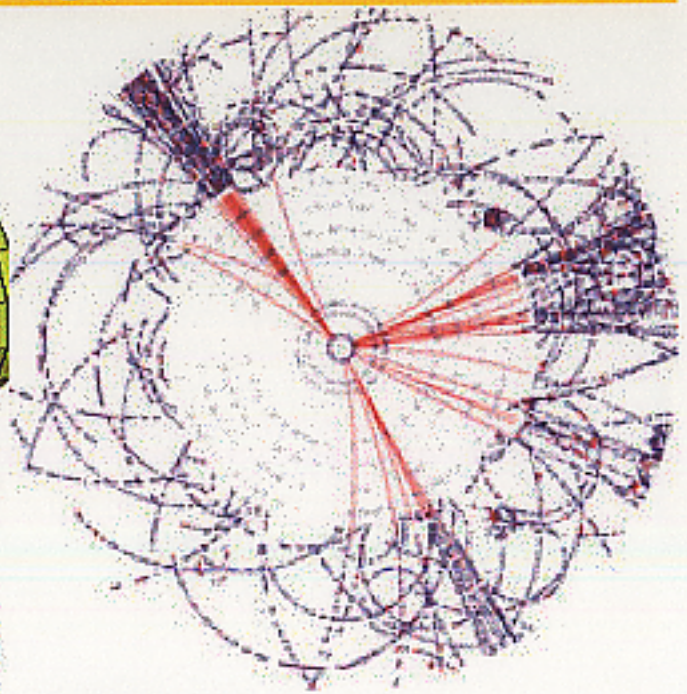


Solenoid field 2T with a stored energy of 38 MJ

The solenoid is an in-kind contribution from Japan and has been fabricated under the responsibility of KEK at Toshiba

Inner Detector

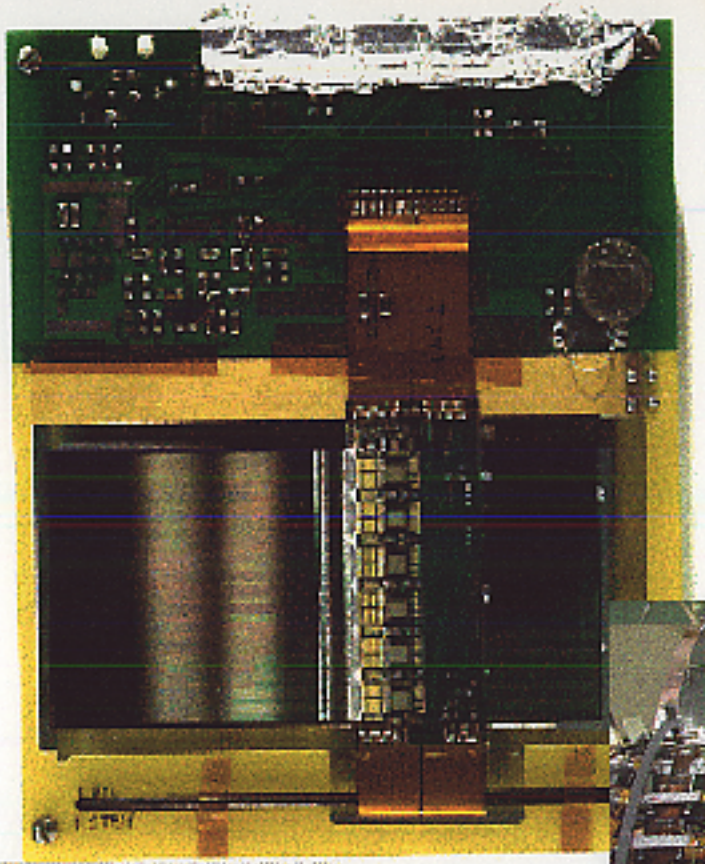


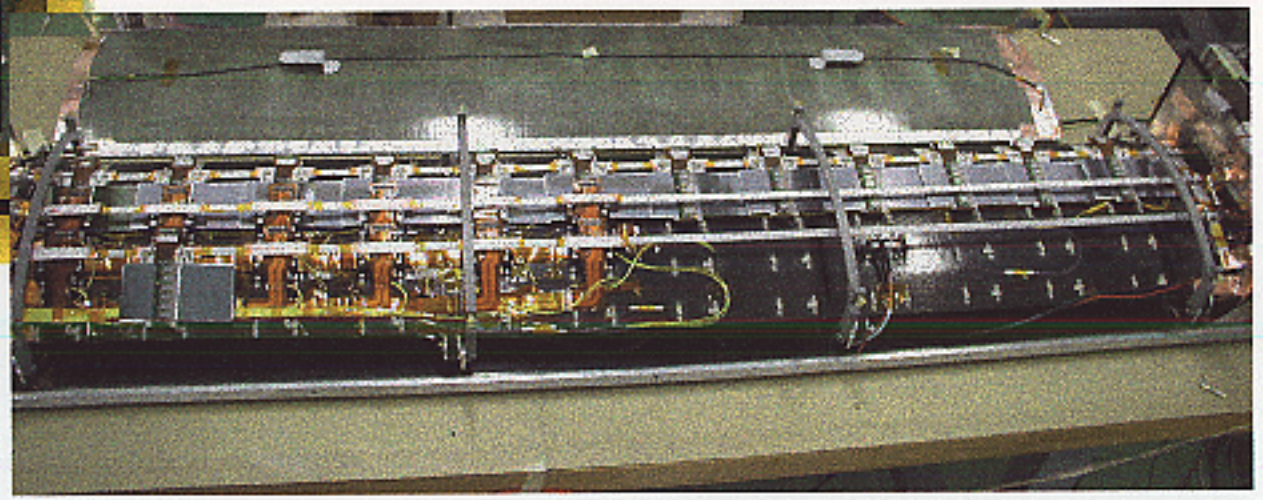


Inner Tracker
Position Resolution= 30% at Pt=500GeV

- **Solenoid Magnet (2T field) →Completed**
- Pixel Detectors $\sigma(r\phi)=12\mu m$ (~10^8channels)
- Strip Detectors $\sigma(r\phi)=16\mu m$ (~5* 10^5 channels)
- Transition Radiation Tracker $\sigma(r\phi)=170\mu m$/straw

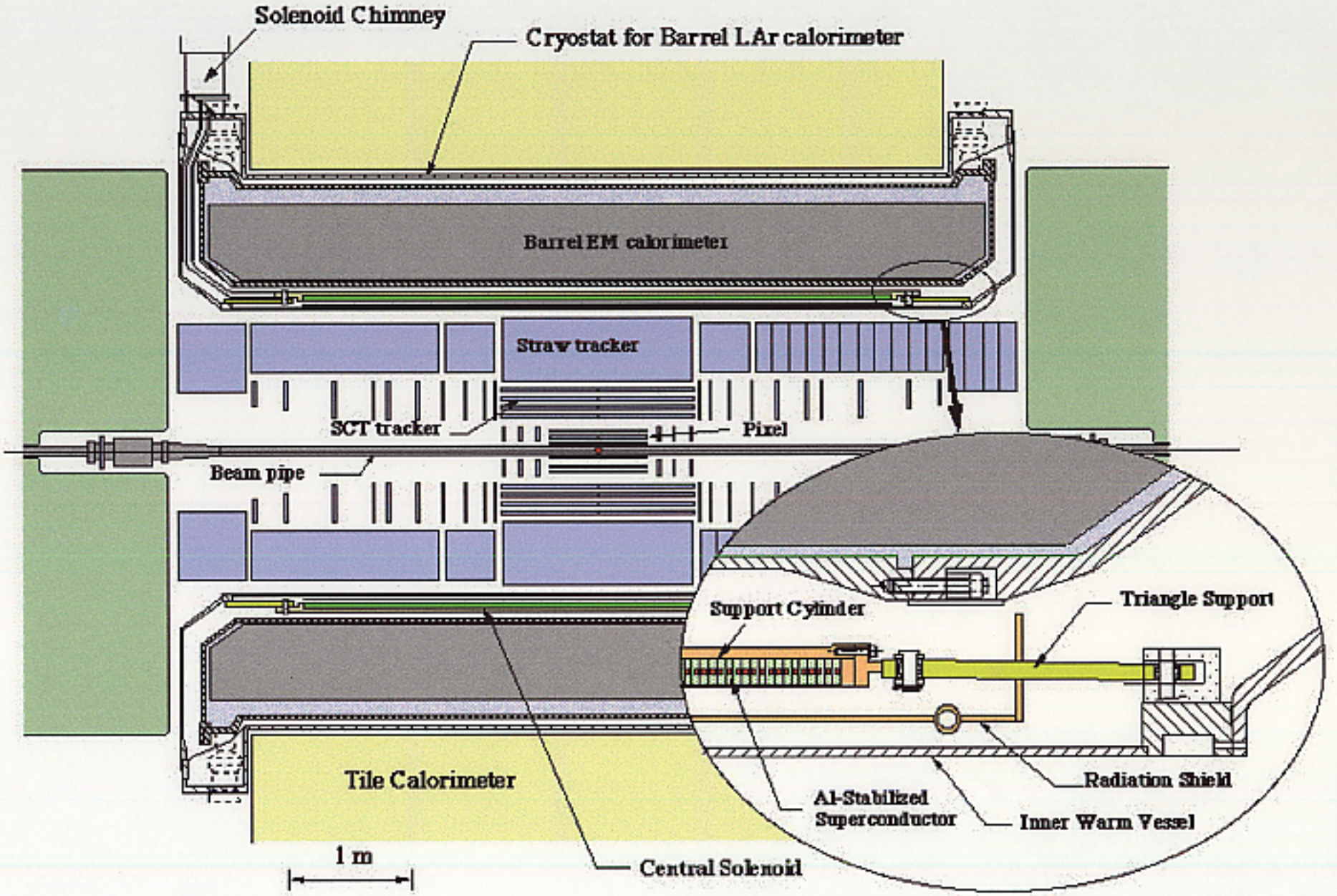
Silicon micro-strip tracker



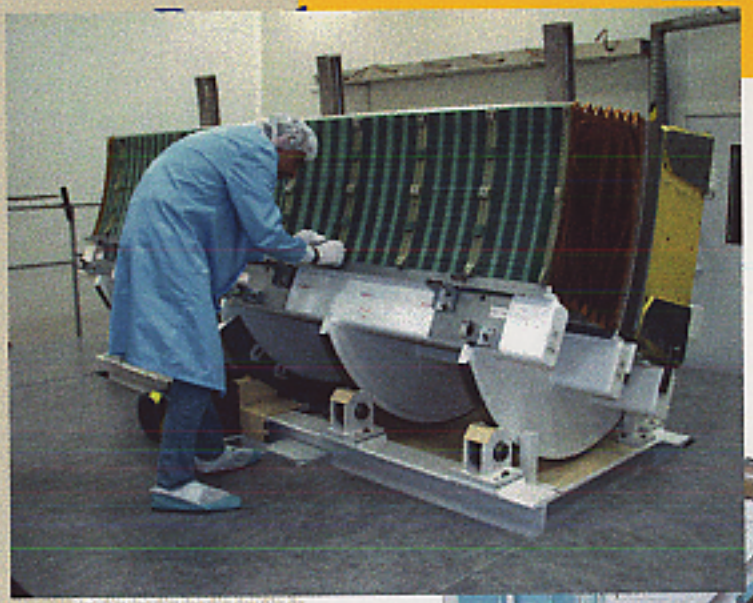


SCT barrel system test

2001/11/5

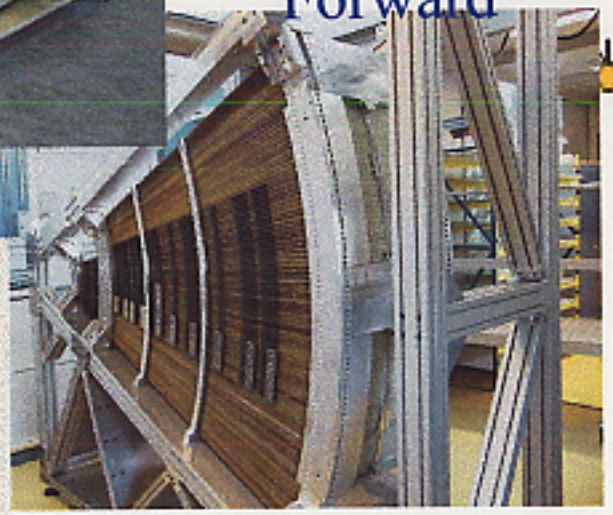

Solenoid Chimney
Cryostat for Barrel LAr calorimeter
Barrel EM calorimeter
Straw tracker
SCT tracker
Pixel
Beam pipe
Support Cylinder
Triangle Support
Tile Calorimeter
Al-Stabilized Superconductor
Radiation Shield
Inner Warm Vessel
1 m
Central Solenoid

EM Calorimeter

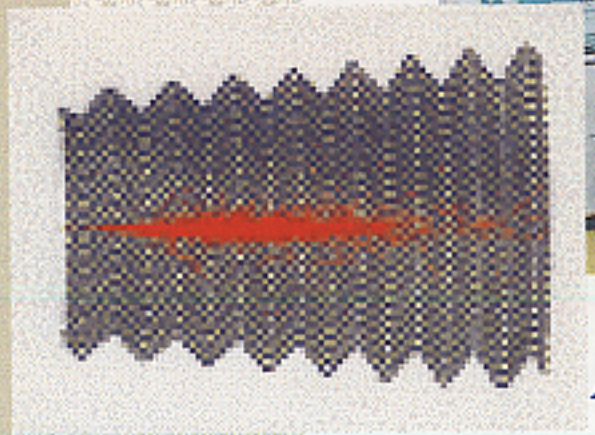


Liquid Argon detector
with accordion shape

Forward



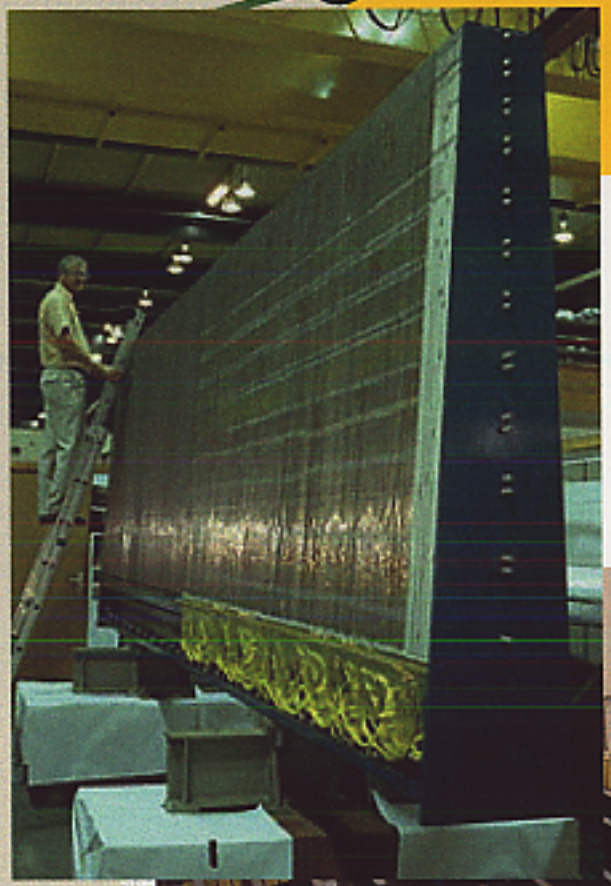
Total 190,000ch

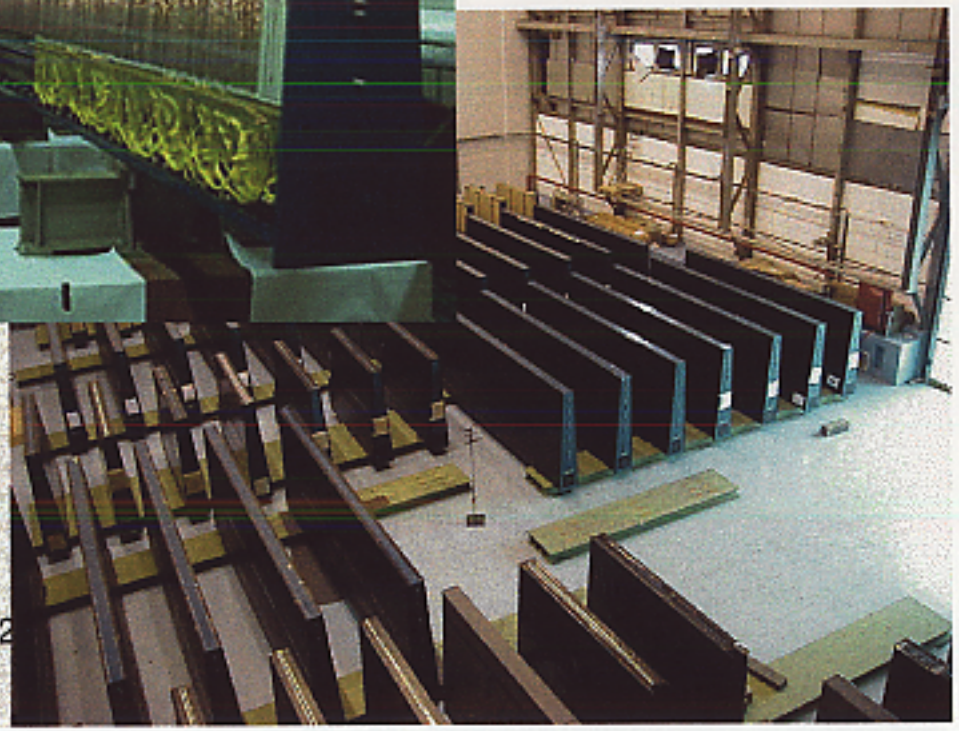


- Energy res.<
  $10\%/\sqrt{E}$
  ↑
  $H \rightarrow \gamma\gamma$,
  $H \rightarrow 4e$

All modules will be finished early 2003.

Hadron Calorimeter





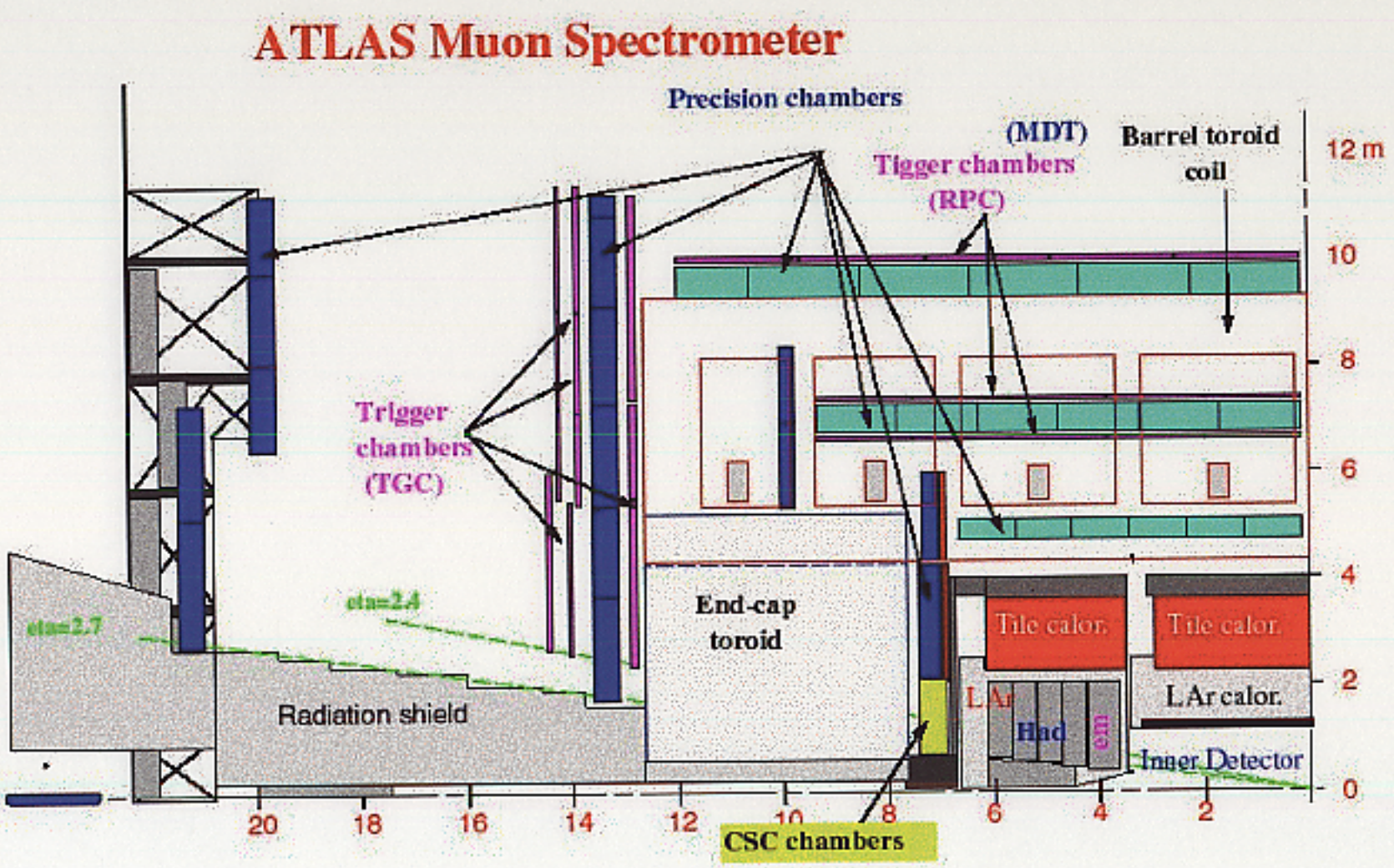
Tile Calorimeter (Barrel)
(Scinti.+ lead sandwich)

LAr Calorimeter(forward)

- $\Delta E / E = 50\% / \sqrt{E}$
- Granularity: $\Delta\eta\Delta\phi = 0.1 \times 0.1$ for $|\eta| < 3$

Almost Modules have already produced (Tile).

Muon Detector



Muon Detector Concept

For reconstructed mass resolution (ex. $H \rightarrow 4\mu$, $Z \rightarrow 2\mu$)

Momentum resolution for a reconstructed track :

~2% for 5-100 GeV Pt

For CP-violation and B physics

Trigger selectivity :

High Pt (~20 GeV) and Low Pt (~ 6 GeV)

For the track reconstruction

Second-coordinate measurement : ~10 mm

For bunch-crossing identification

Time resolution : < 25 ns

⇒

- standalone muon system
- dedicated chambers for tracking and triggering
- air-core superconducting toroid magnet

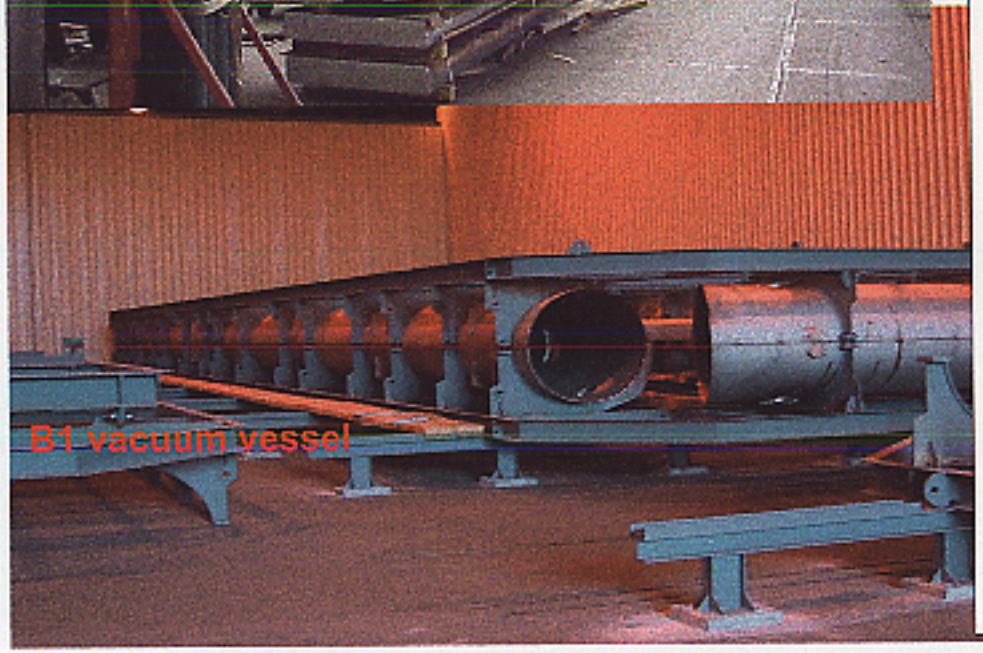
BT Components in Construction

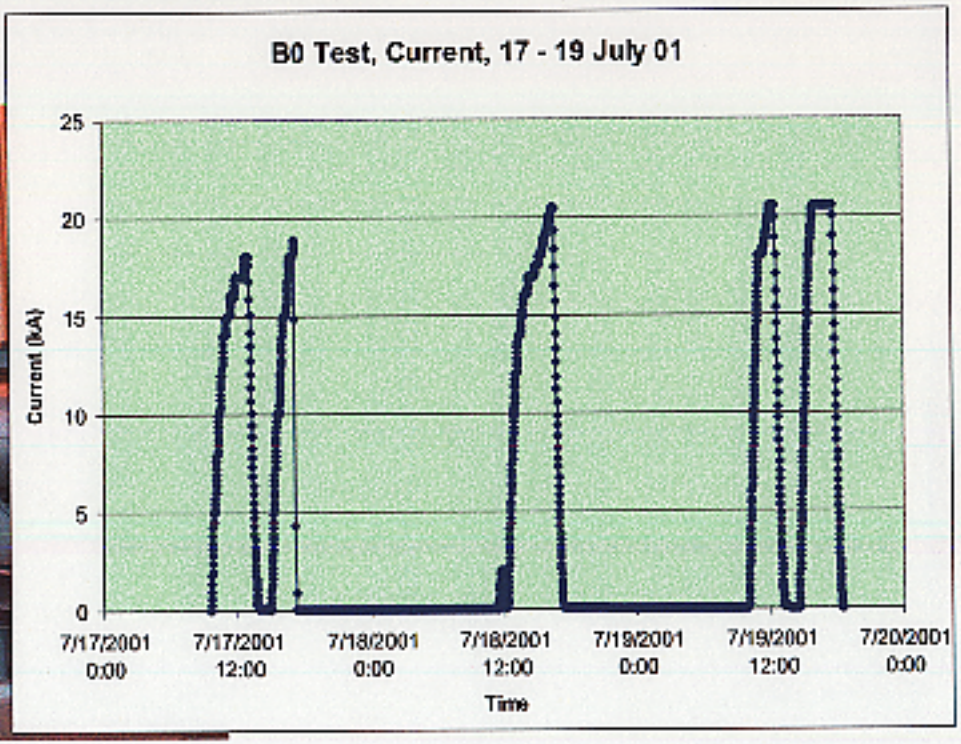
B1 coil casing after welding, ready for Transport to machining factory

Current=20.5kV

25.3 m length

4 T on superconductor

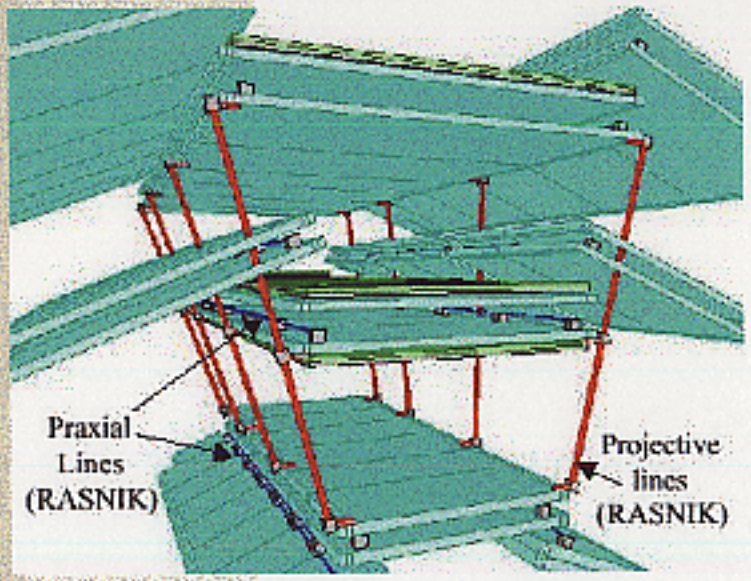


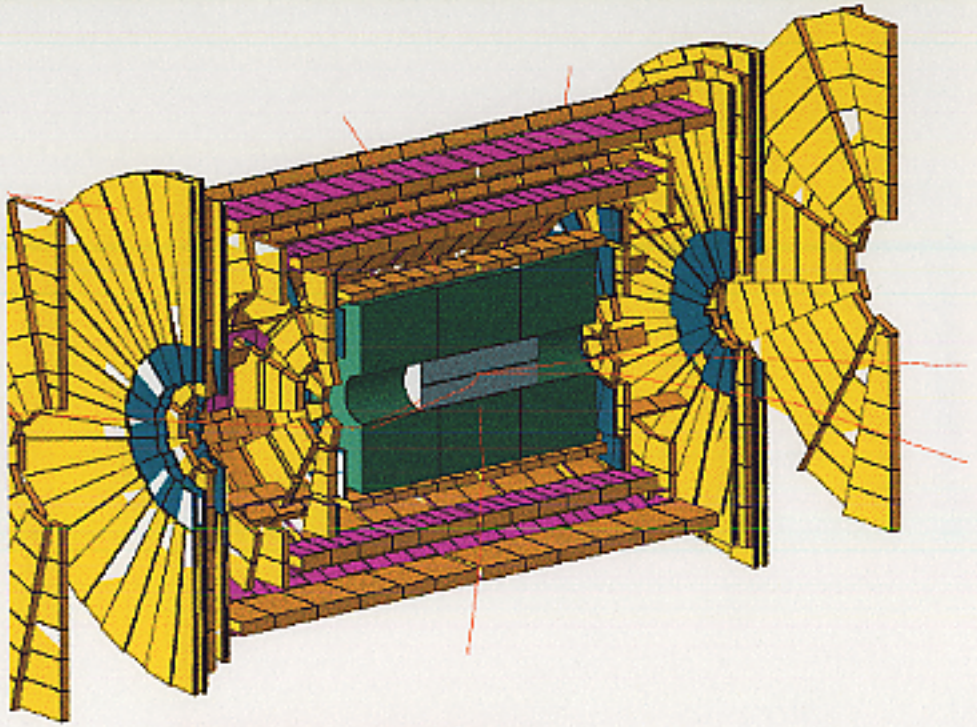


Muon Spectrometer Instrumentation

The ATLAS Muon Spectrometer is instrumented separately with precision chambers and fast trigger chambers

Alignment system in a barrel sector





Precision chambers:
MDTs in the barrel and end-caps
CSCs at large rapidities in the innermost end-cap stations

Trigger chambers:
RPCs in the barrel
TGCs in the end-caps

Muon Detectors

MDT Barrel

width (tube length) : 830-4940 mm
length : 900-2160 mm

MDT Endcap

width (tube length) : 810-6220 mm
length : 480-1920 mm

RPC Barrel

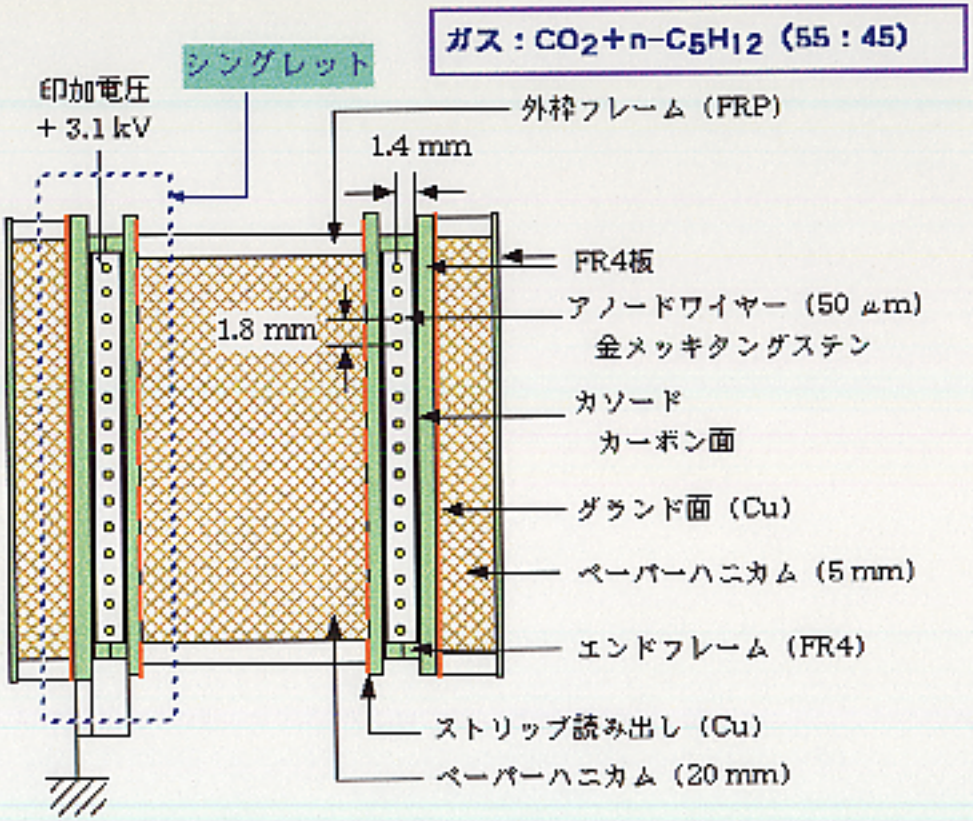
width(gas volume) : 1060-2960 mm
length(gas volume) : 310-1190 mm

TGC Endcap

width : 520-1690 mm
length : 1250-2280 mm

2001/11/5

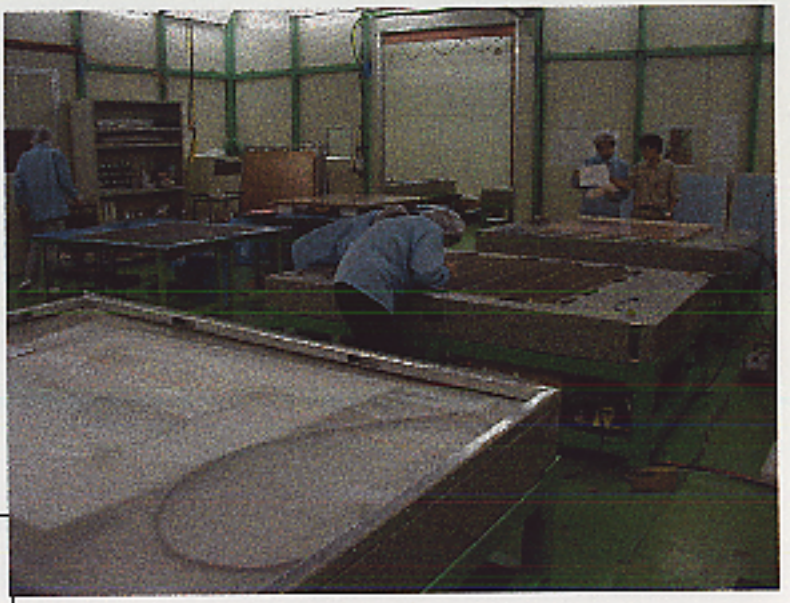
TGCの構造

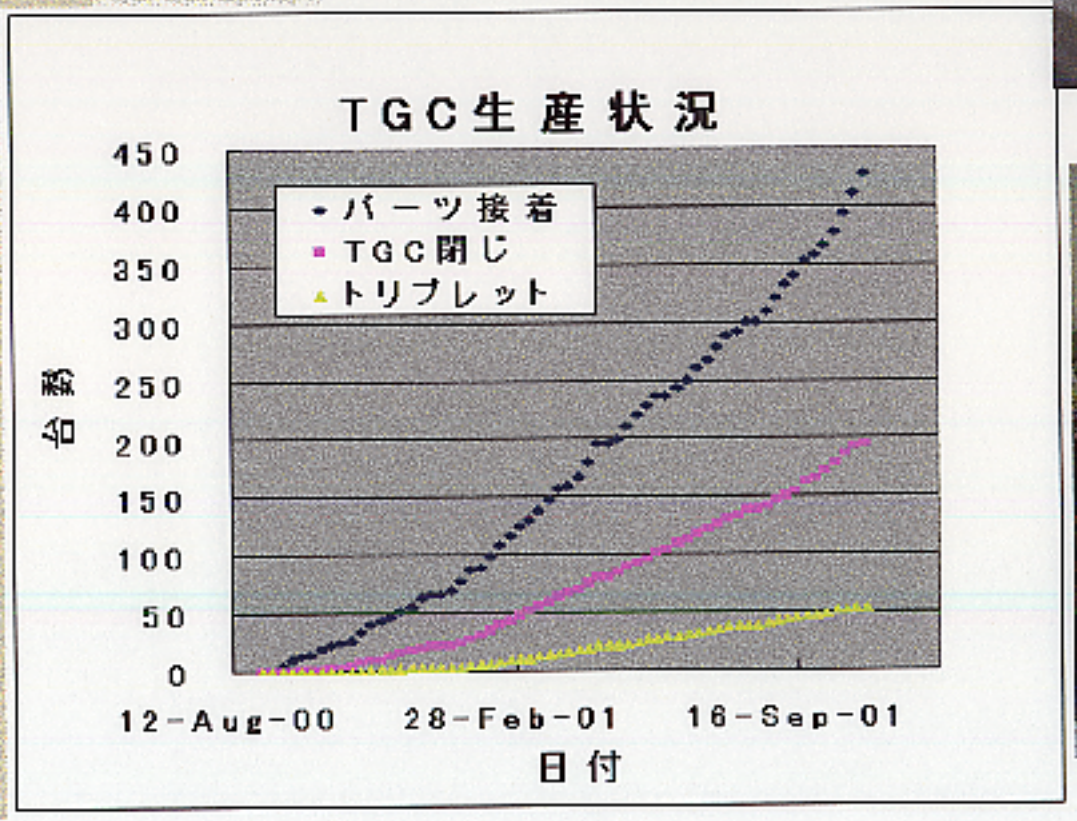

ガス：CO_2+n-C_5H_{12} (55 : 45)
シングレット
印加電圧
+ 3.1 kV
外枠フレーム（FRP）
1.4 mm
FR4板
アノードワイヤー（50 μm）
金メッキタングステン
1.8 mm
カソード
カーボン面
グランド面（Cu）
ペーパーハニカム（5 mm）
エンドフレーム（FR4）
ストリップ読み出し（Cu）
ペーパーハニカム（20 mm）

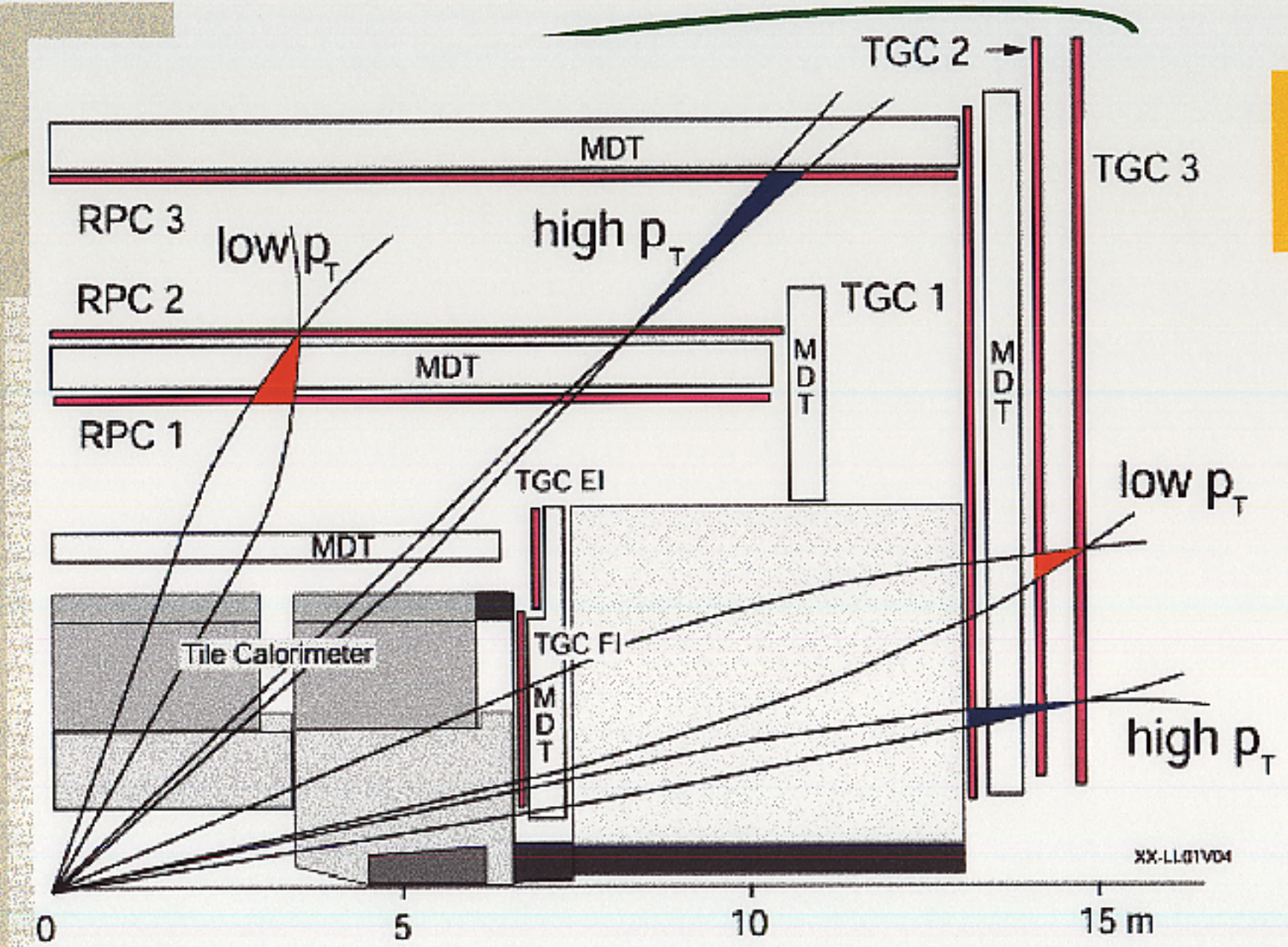
TGCの生産(@KEK富士)

生産台数:1056台

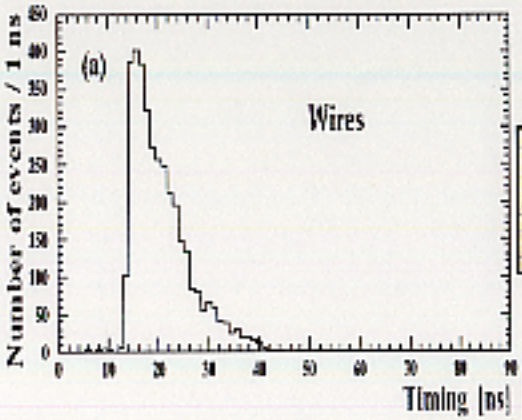
ICEPP,KEK,神戸大、信州大が参加。

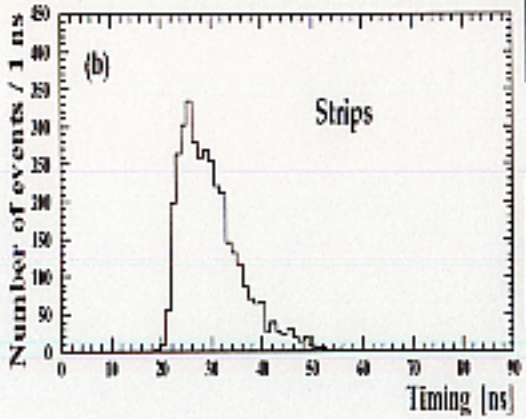





TGC 2
MDT
TGC 3
RPC 3
low p_T
high p_T
RPC 2
TGC 1
MDT
MDT
MDT
RPC 1
TGC EI
low p_T
MDT
Tile Calorimeter
TGC FI
MDT
high p_T
XX-LL01V04
0
5
10
15 m

ATLAS Trigger Architecture





Beam Crossing

40MHz

LEVEL1 Synchronous	**Custom made hardware pipelined trigger processors**	2μs fixed

100kHz

LEVEL2 Asynchronous	**Commercial DSPs RISCs, etc.**	1 – 10ms variable

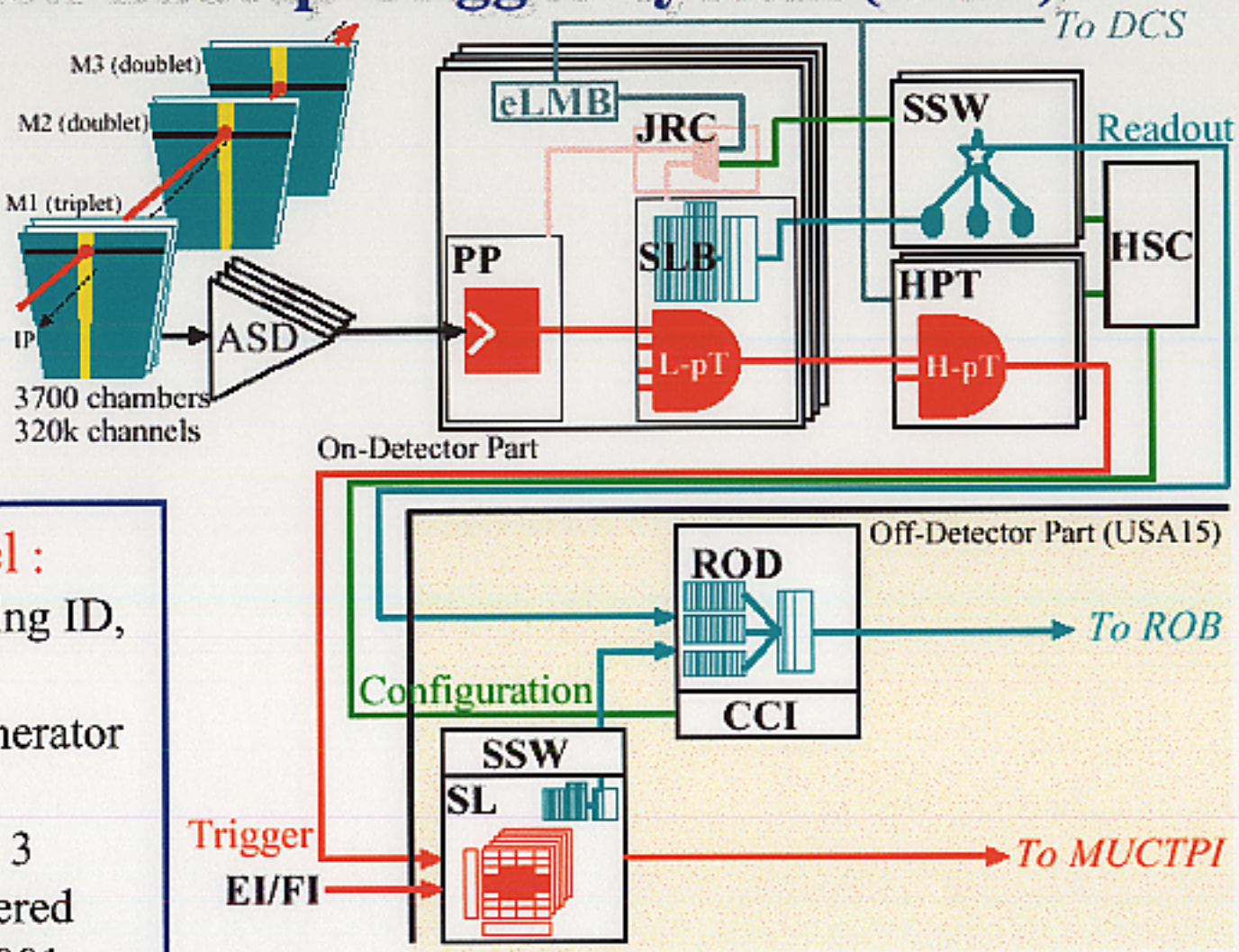
1kHz

LEVEL3 Asynchronous	**Farms of RISCs, Workstations, etc.**	1 s variable

10-100Hz

Raw data size ~ 2Mb/event

Muon Endcap Trigger System (TGC)



Patch Panel :

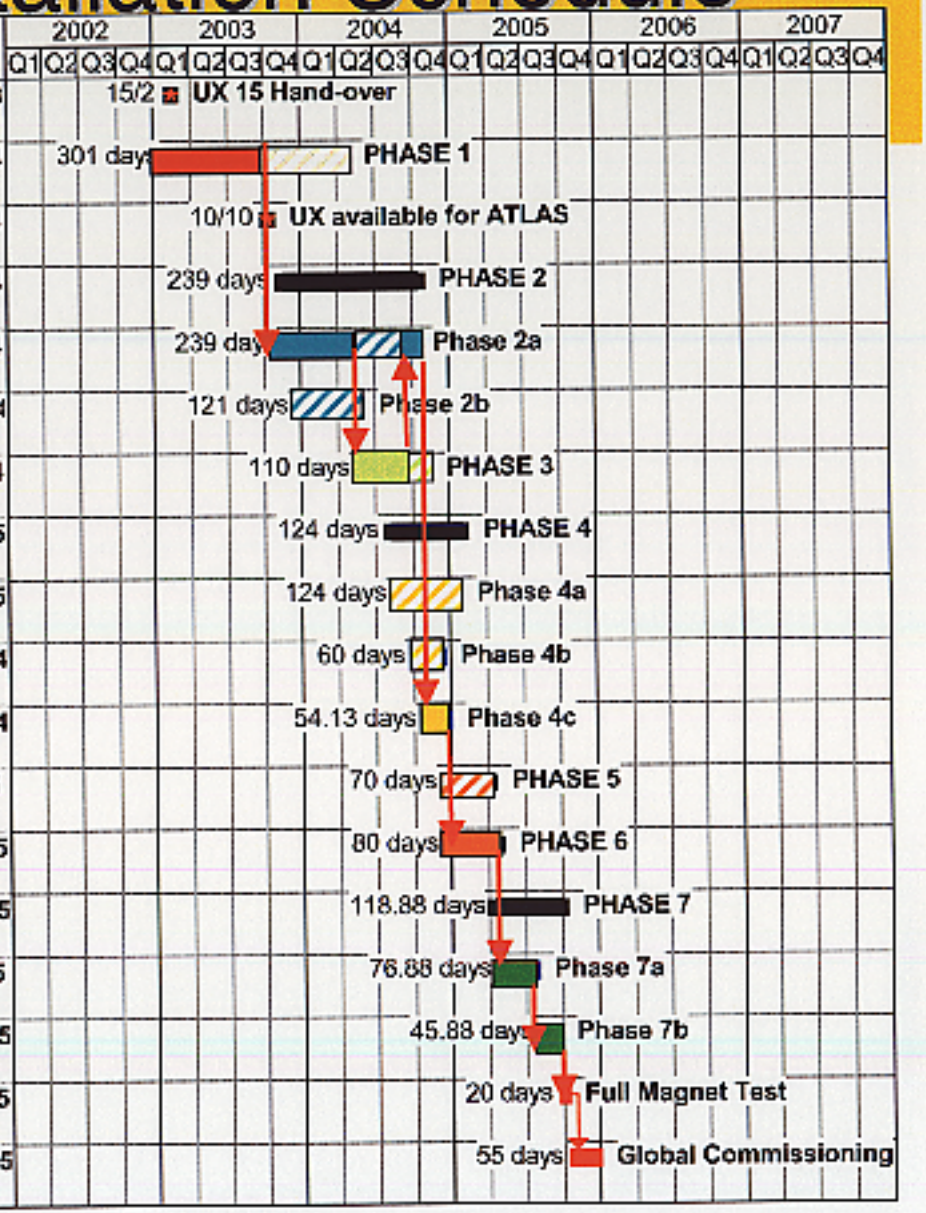
Bunch-crossing ID,
fine delays,
test pulse generator
for ASDs
→ PPIC ver. 3
will be delivered
in October 2001

ATLAS CORE cost estimate

Sub system	CORE Cost [kCHF]	Japan [kCHF]
Inner Detector	80,340	6,859
Liquid Argon Cal.	75,905	--
Tile Cal.	16,720	--
Muon Detector	43,025	6,802
Trigger/DAQ/DCS	46,745	4,525
Common project	208,700	14,000
GRAND TOTAL	474,800	32,100

ATLAS Installation Schedule

Task Name	Start	Finish
UX 15 Hand-over	15 Feb '03	15 Feb '03
PHASE 1: Infrastructure	17 Feb '03	12 Apr '04
UX available for ATLAS	10 Oct '03	10 Oct '03
PHASE 2: Barrel Toroid & Barrel Calorimeters	17 Nov '03	14 Oct '04
Phase 2a: Barrel Toroid	17 Nov '03	14 Oct '04
Phase 2b: Barrel Calorimeter	12 Dec '03	31 May '04
PHASE 3: Services & End-cap Calorimeter C	31 May '04	29 Oct '04
PHASE 4: Muon Barrel & End-cap Calorimeters	6 Aug '04	27 Jan '05
Phase 4a: End-cap Cal. C connections & Muon Barrel	6 Aug '04	27 Jan '05
Phase 4b: End-cap Cal. A assembly & Muon Barrel C	23 Sep '04	16 Dec '04
Phase 4c: Solenoid field mapping	15 Oct '04	31 Dec '04
PHASE 5: Small Wheels	28 Dec '04	5 Apr '05
PHASE 6: Inner Detector Barrel & Big Wheels	31 Dec '04	22 Apr '05
PHASE 7: ID and Torold End-Caps & Beam Vacuum	15 Apr '05	28 Sep '05
Phase 7a: End-Cap Torolds & Inner Detector End-Cap	15 Apr '05	1 Aug '05
Phase 7b: Beam Vacuum	27 Jul '05	28 Sep '05
Full Magnet Test	19 Sep '05	14 Oct '05
Global Commissioning	14 Oct '05	31 Dec '05



Physics Impact of the Initial Detector

The initial detector configuration for the first physics run consists of the following elements

Magnet system

A meaningful detector needs the full magnet system,

Furthermore the construction of the barrel toroid is critical for the schedule, as it will condition the installation for all the other detector components

Inner Detector

The following components will be deferred (staging/upgrades):

- Part of the Pixel system (3rd point)

- Part of the RODs

- Potentially some TRT electronics

- TRT end-cap wheels type C

Muon instrumentation

The following components will be deferred (staging/upgrades) for the low luminosity phase:

- EEL and EES MDT chambers, electronics and supports
- Half of the CSC chamber layers (mechanics and electronics)

The following component can appear as partially staged item:

-Part of the end-wall MDT chambers

High Level Trigger and DAQ

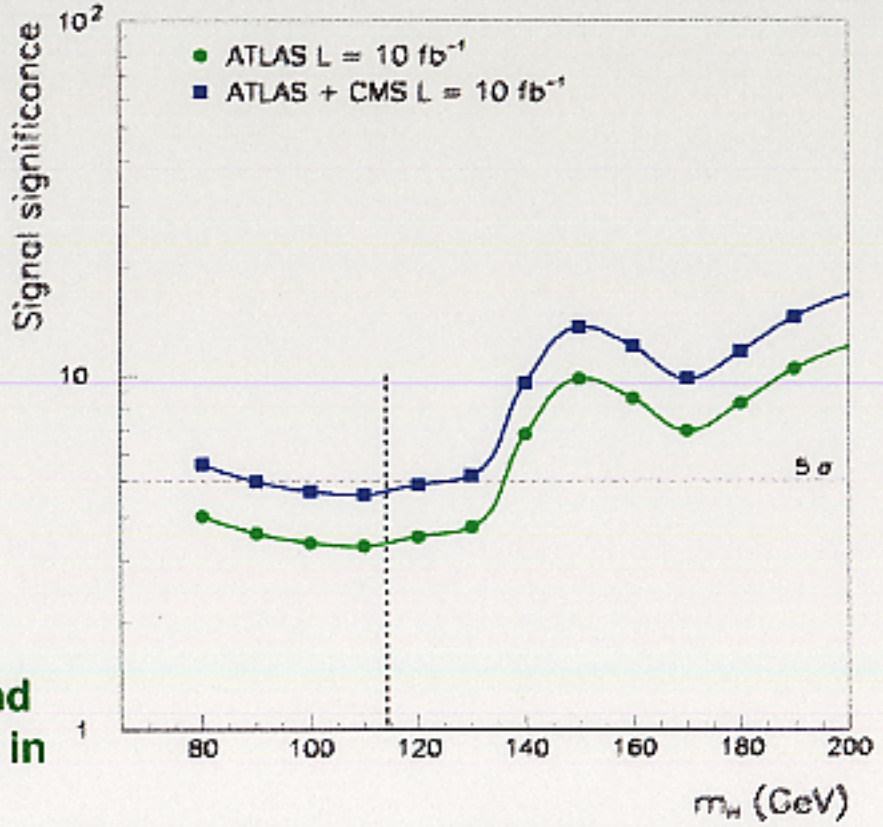
The system needs to be designed to cost in a way that it can be easily upgraded

Reduced processors from Common Projects

Shielding

A limited part of the high-luminosity shielding can be deferred by about one year

The physics implication of the initial detector configuration has been studied for the test case of the low mass Higgs discovery potential during the first physics run (10 fb^{-1})



The figure shows the SM Higgs signal significance for the complete (TDR) ATLAS detector and for combining ATLAS and CMS

Expected number of signal and background events, and significance, for m ~ 115 GeV in ATLAS alone

	$H \rightarrow \gamma\gamma$	$ttH \rightarrow tt\ bb$	Both channels
S	150	15	
B	3900	45	
S/B	0.04	0.3	
$S/\sqrt{B}$	2.4	2.2	3.2

The main impact of the initial detector configuration is that the discovery potential for the Higgs signal in several final states will be degraded by about 10% (meaning that 20% more integrated luminosity is required to compensate)

Possible penalties on the pattern recognition performance from the less robust tracking systems are not included in these results

Staged items	Main impact expected on	Loss in significance
One pixel layer	$ttH \rightarrow ttbb$	~ 8%
Outermost TRT wheels + MDT	$H \rightarrow 4\mu$	~ 7%
Cryostat Gap scintillators	$H \rightarrow 4e$	~ 8%
MDT	$A/H \rightarrow 2\mu$	~ 10% for m ~ 300 GeV

(The studies are documented in ATLAS RRB-D 2001-118)

Conclusions

LHC 実験に向け加速器、実験装置の建設が急ピッチでするめられている。

現在 4実験が準備中(ATLAS, CMS、LHCb、ALICE)。

2006年始めから加速器の運転を開始予定でphysics run は夏ごろから始まる。

日本が参加するATLAS実験は各検出器の性能評価、Production Review等を終え検出器量産を行っている段階である。(2003年よりinstallationを開始)

最初のphysics run(10fb-1)でATLAS+CMSのデータを用いるとlow mass Higgsを発見可能である。