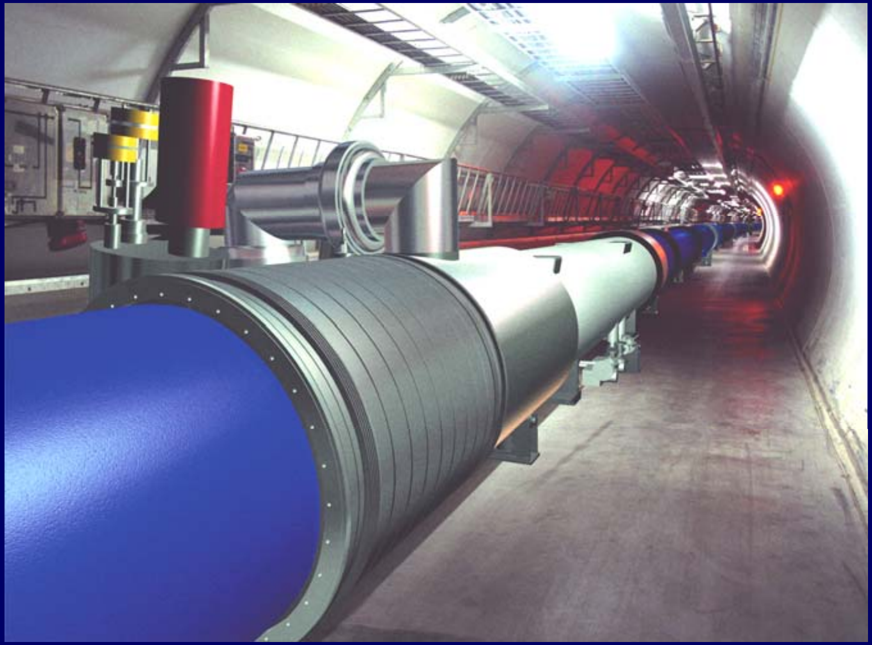
Modern experiments - ATLAS

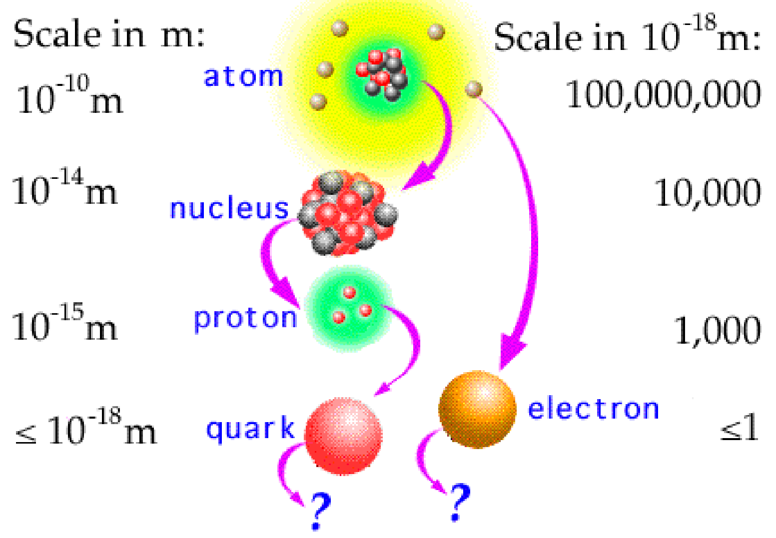


Paula Eerola, paula.eerola [at] hep.lu.se, 046-222 7695
FYST17/FKF050, 7 Mar 2008

Outline

- Introduction – why new experiments?
- The next generation of experiments: ATLAS at the Large Hadron Collider
- Physics basics – luminosity, cross-sections, trigger
- Physics examples – Higgs, B-physics, black holes
- ATLAS – current status
- Lund activities in ATLAS
- Student possibilities

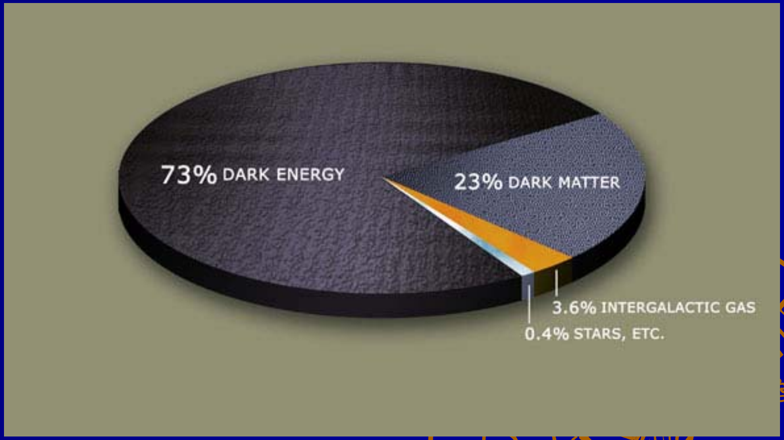
Why do we need yet a bigger accelerator? Particles…



We know that there are 6 quarks and 6 leptons, but…

there are OPEN QUESTIONS:

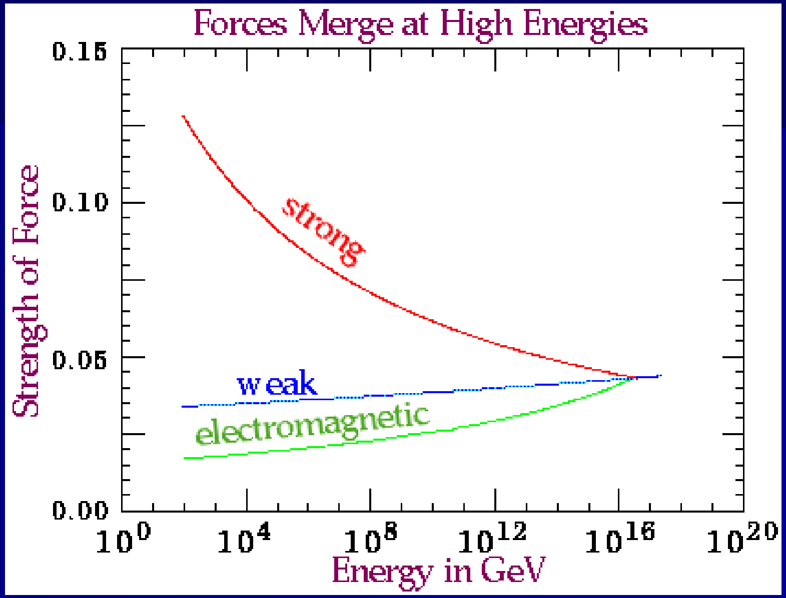
- How do particles obtain masses? Through the Higgs mechanism?
- Why does the Universe consist of almost exclusively of matter, not antimatter?→ CP violation
- The Dark Matter in the Universe makes 23 % of the matter-energy contents of the Universe, while only 4 % is known matter. Is Dark Matter made of Supersymmetric Particles?

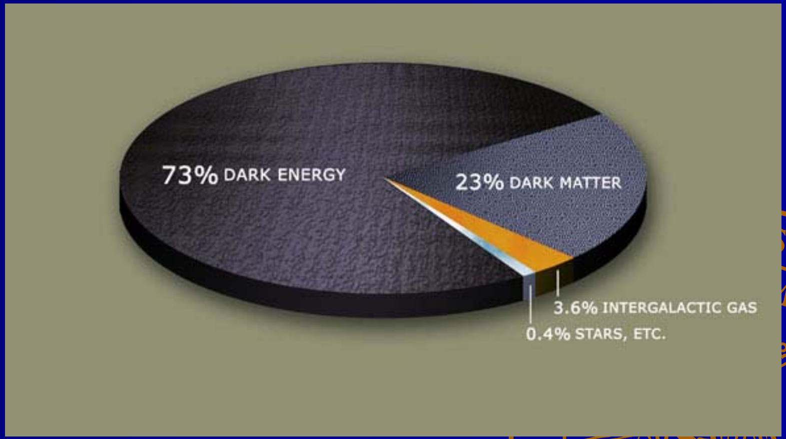


...and forces

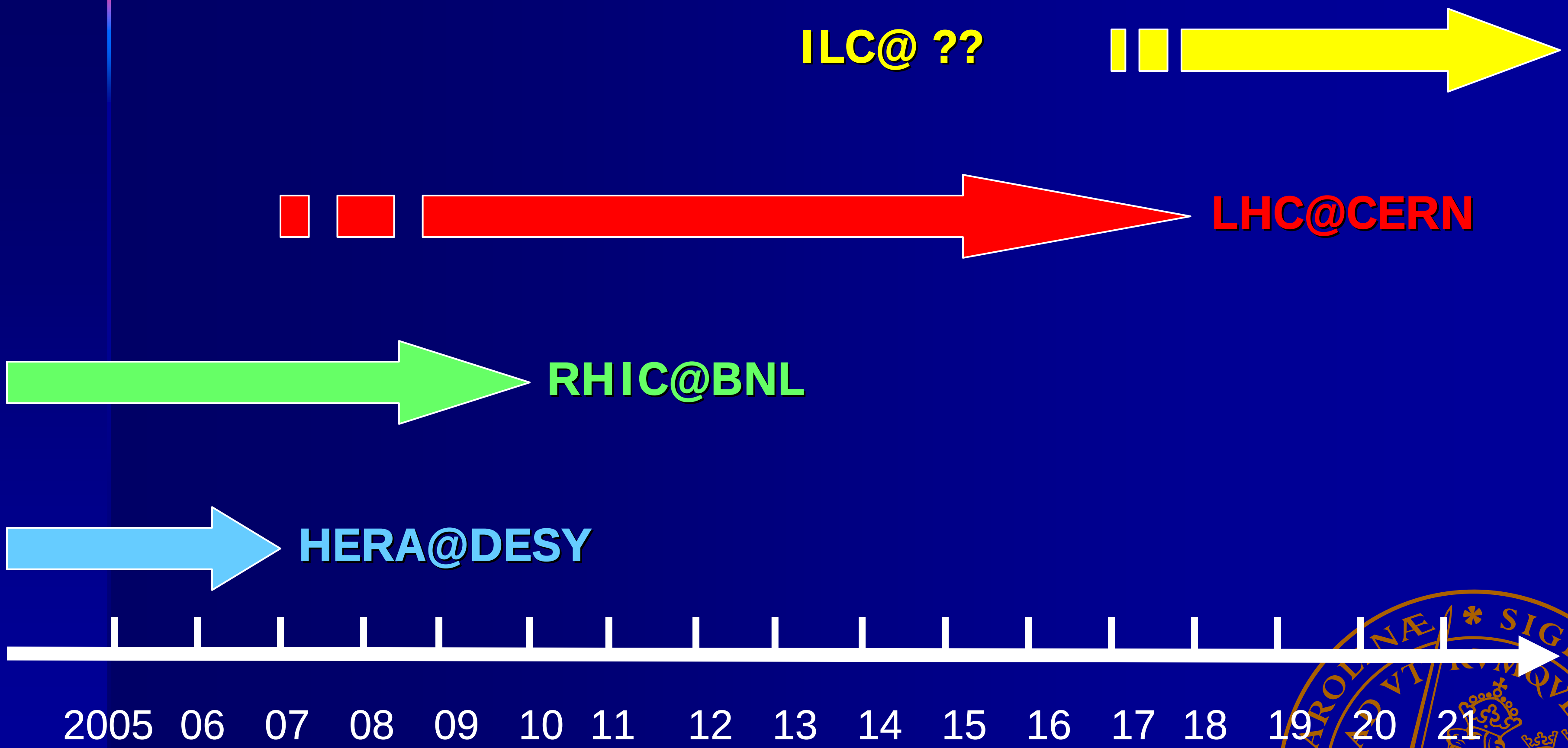
We know that there are four forces, but...

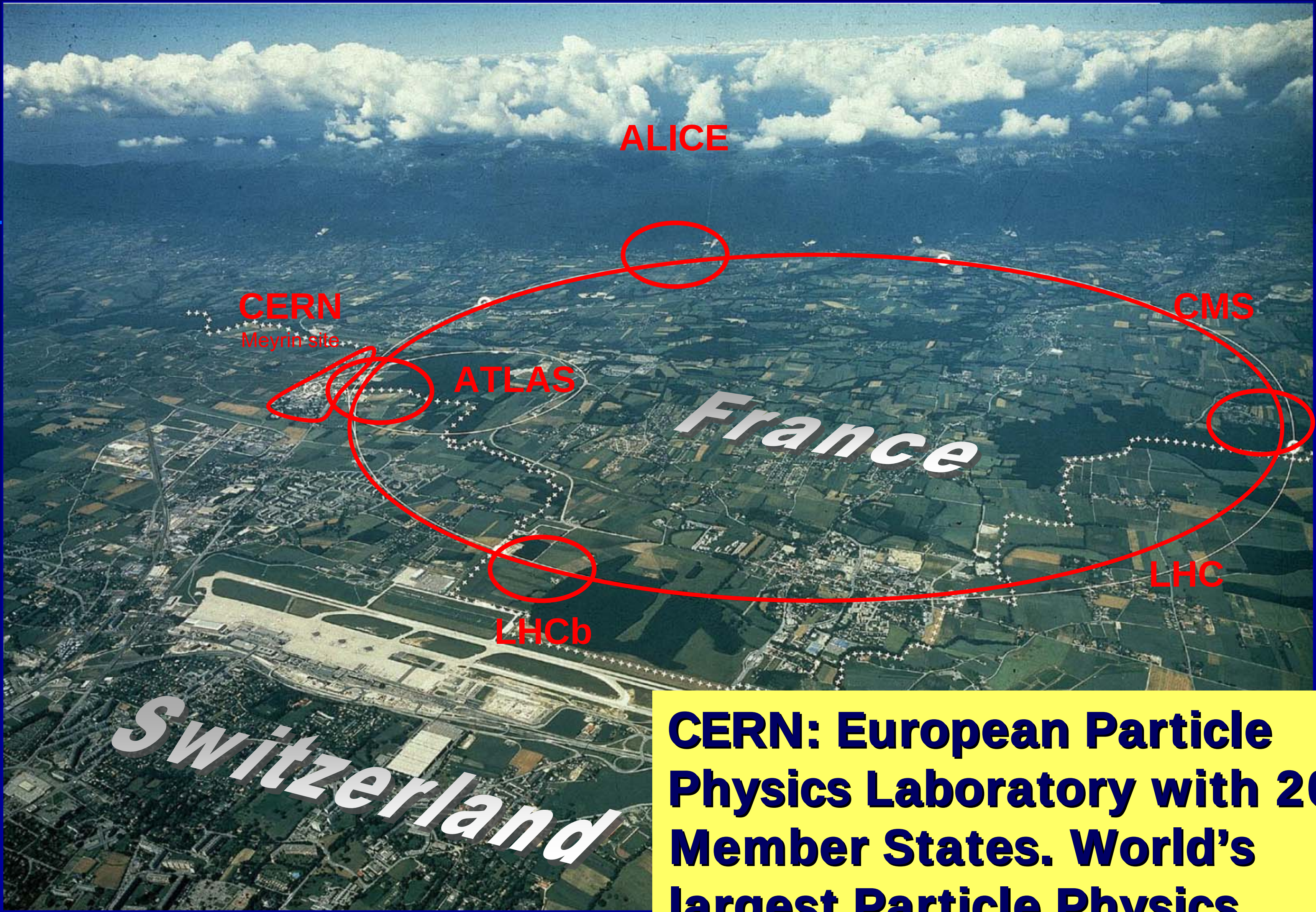
- Can we unify all the 4 forces into one theory?
- Can we unify gravity and quantum mechanics?
- What is Dark Energy which dominates the matter-energy contents of the Universe?





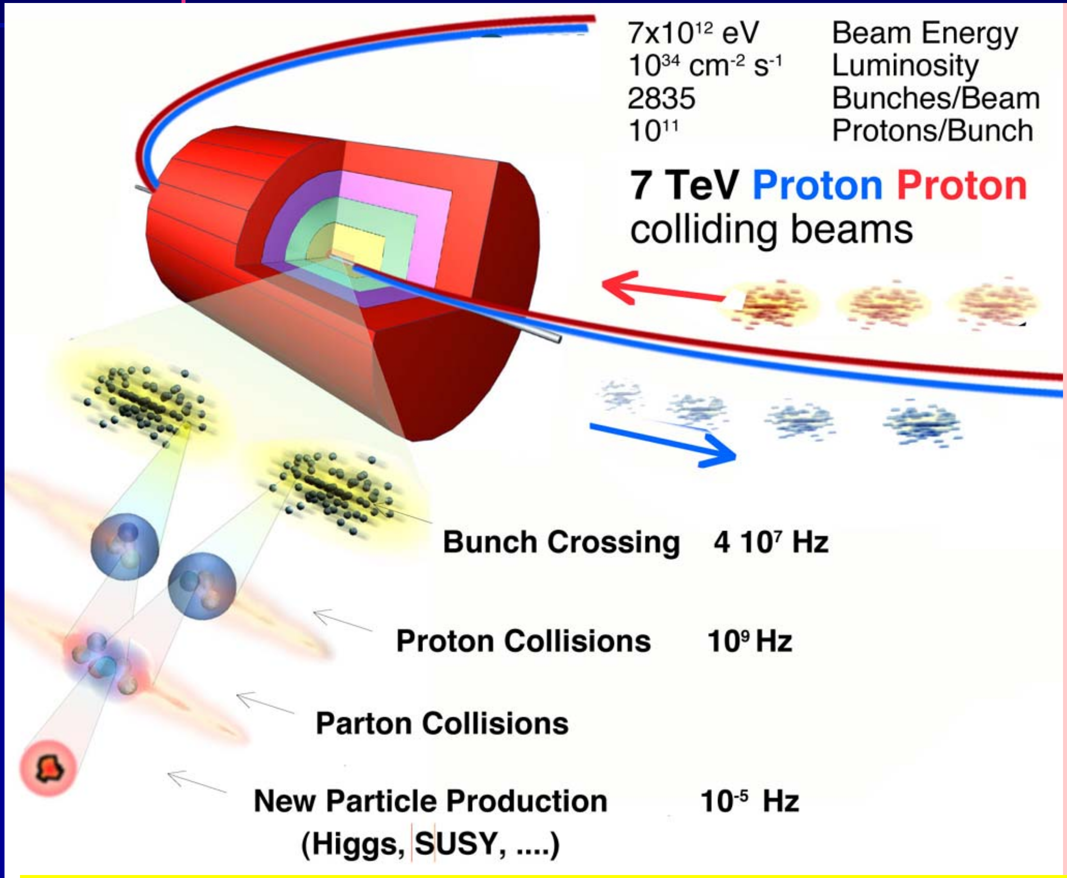
Particle accelerators





CERN: European Particle Physics Laboratory with 20 Member States. World's largest Particle Physics Laboratory.

The Large Hadron Collider, LHC

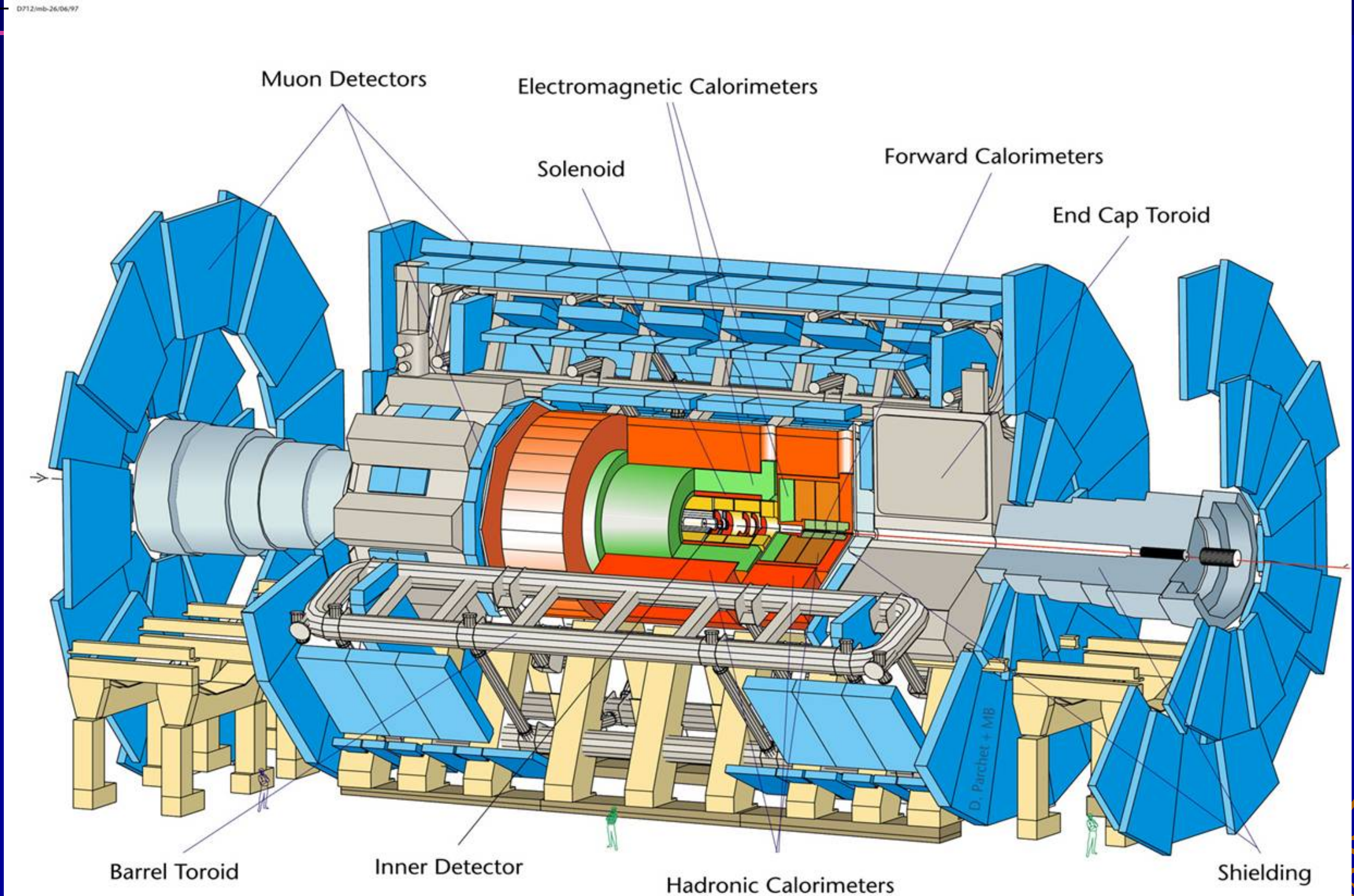


Proton-proton collisions:

- Length 27 km
- Protons are accelerated to E = 7 TeV
- Total energy in collisions 2 x 7 TeV = 14 TeV
- 10^{11} protons in a bunch, 2808 bunches in a beam
- Proton beams are held in a circular track with superconducting dipole magnets (B=8 T, T= 1.9 K).

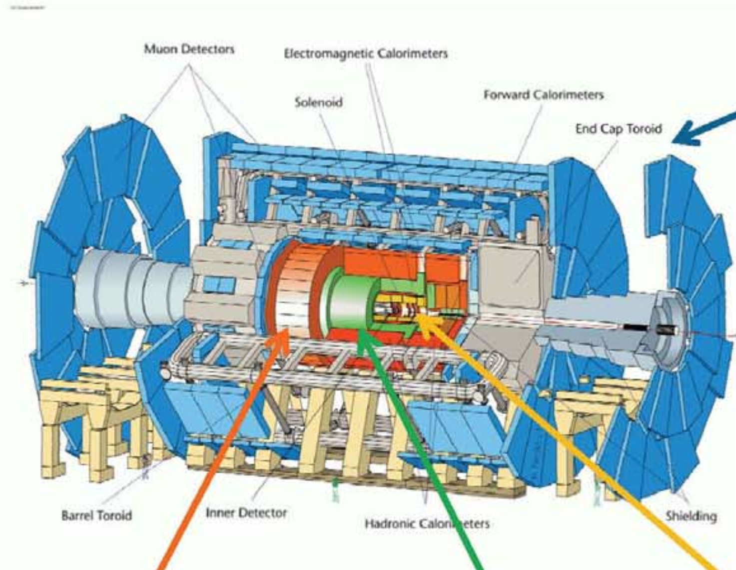
- **Start autumn 2008.**
- **Experiments are close to being ready and collect cosmic data.**

The ATLAS experiment



http://atlasexperiment.org/

The ATLAS detector at LHC

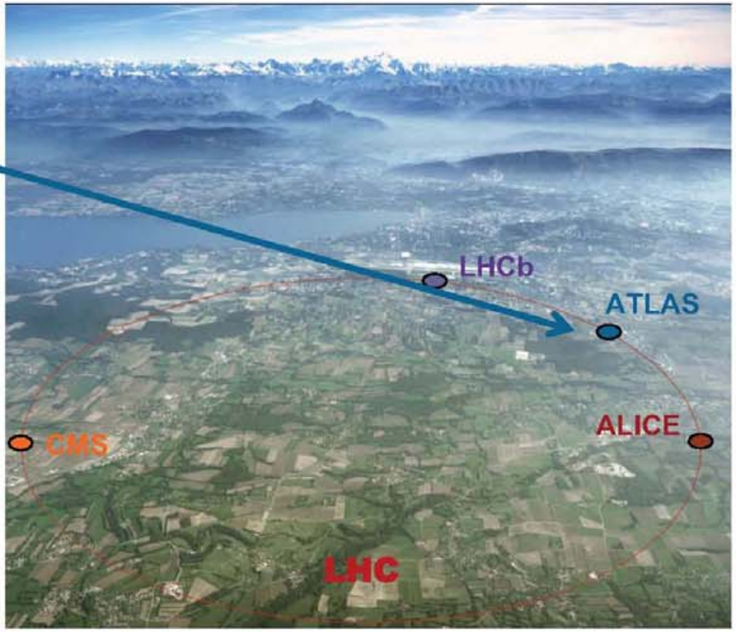


Muon Spectrometer

Air-core toroid, Precision drift and Trigger chambers

P_T resolution:~10% at P_T = 1 TeV (standalone)

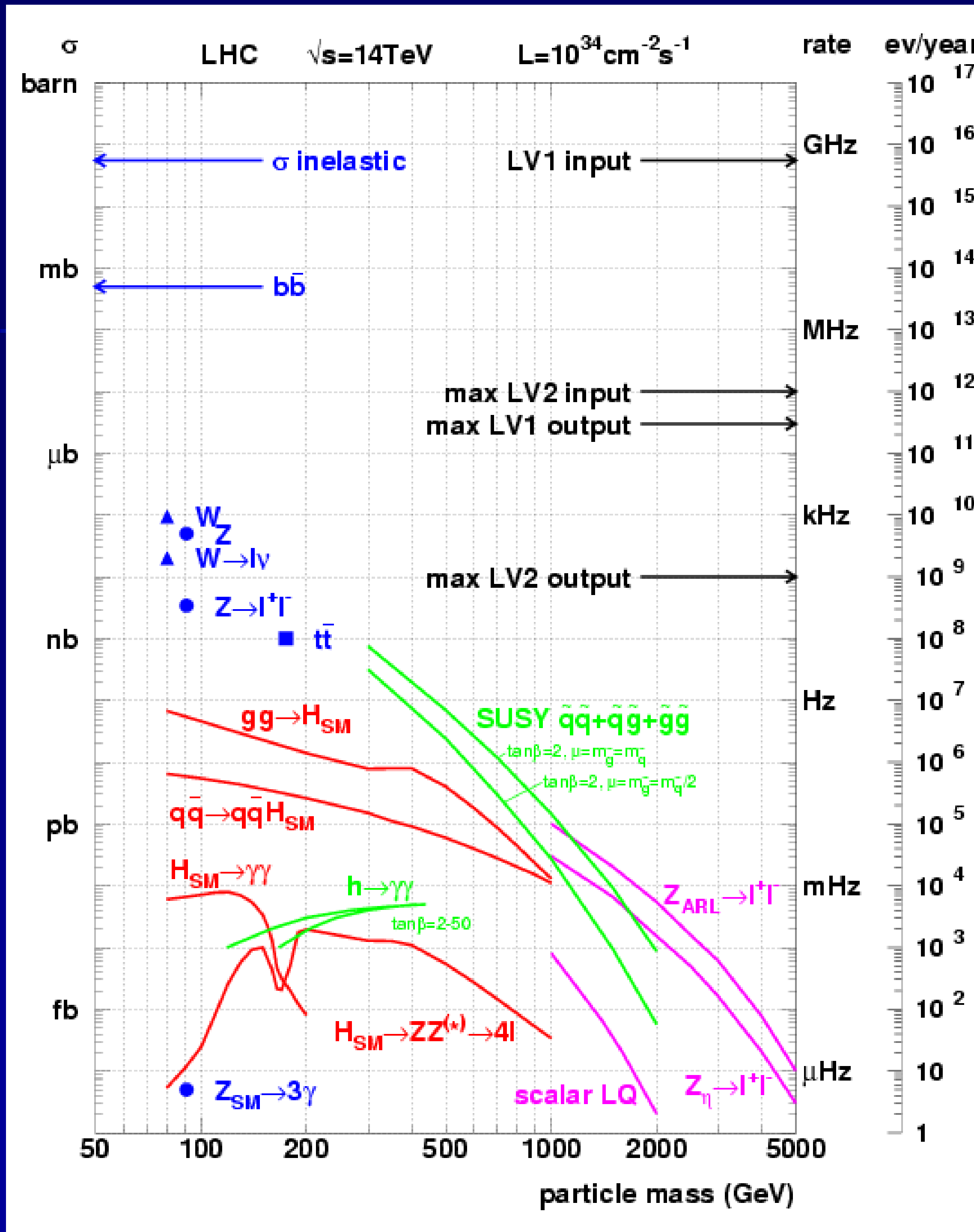
~2.3% at P_T = 50 GeV (combined)



Hadron Calorimetry	**E/M Calorimetry**	**Inner Detector**
Fe/Sci + Cu/LAr	Pb/LAr	2 T solenoid
$\sigma/E \sim 60\%/\sqrt{E} \oplus 3\%$	$\sigma/E \sim 10\%/\sqrt{E}$	Si (Pixels + Strips)
		Transition
		Radiation Tracker

ATLAS status in talk by M. Bellomo

Current LHC Plan : 1st June beam-pipe close and bake-out, 1st injection ~mid-June, 1st collisions ~end of summer, pilot physics run (~1.1×10^{32}cm^{-2}s^{-1}) looks possible for 2008.



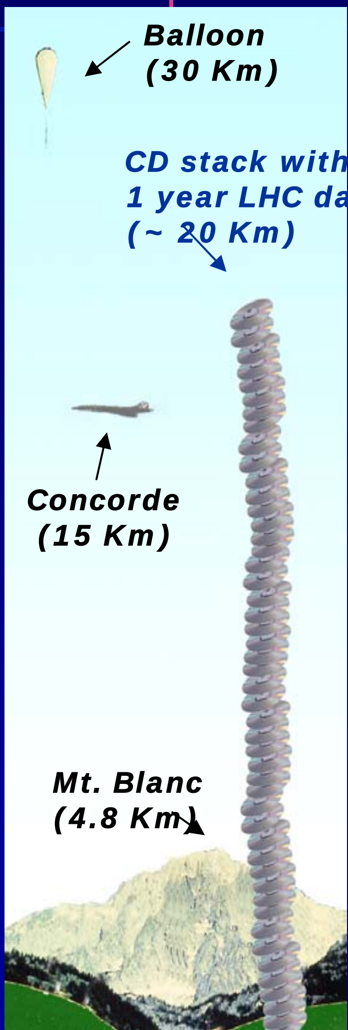
$N = \sigma \times L$

- Instantaneous luminosity $L = 10^{34}\ cm^{-2}s^{-1}$
- $t = 10^7$ s (about 1/3 of a year)
- Integrated luminosity $L = 10^{34}\ cm^{-2}s^{-1} \times 10^7\ s = 100\ fb^{-1}$
- Number of bbbar events per year: $500\ \mu b \times 100\ fb^{-1} = 5 \times 10^{13}$ events
- Number of Higgs events per year (Higgs to 4 leptons, $m_H = 200$ GeV) $= 20\ fb \times 100\ fb^{-1} = 2000$ events
- Number of SUSY events per year (with m = 300 GeV and some model parameters) $= 500\ pb \times 100\ fb^{-1} = 50$ million events

Trigger

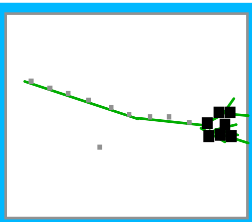
- BUT…we cannot collect all this data!
- Data can be written on disk/tape at a rate of max 100-200 Hz → max 10^8-10^9 events per year
- TRIGGER = online selection of events which tries to keep as many as possible of the interesting ones, and throw away the non-interesting ones
- Trigger signatures: for example high-p_T leptons, high-E_T jets, missing energy,…
- Caveat: how can we define in beforehand what is interesting and what is not?

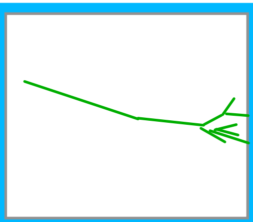
High-energy physics analysis

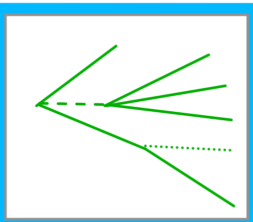


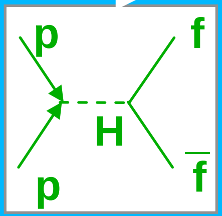
From raw data to physics results

2037	2446	1733	1699
4003	3611	952	1328
2132	1870	2093	3271
4732	1102	2491	3216
2421	1211	2319	2133
3451	1942	1121	3429
3742	1288	2343	7142









Raw data
Convert to physics quantities

Detector signals
Calibration, Geometry, Alignment

Hits/Tracks
Pattern, recognition, Particle identification

Event
Parent particle, Event plane

Physics results
Signal, Background

Reconstruction

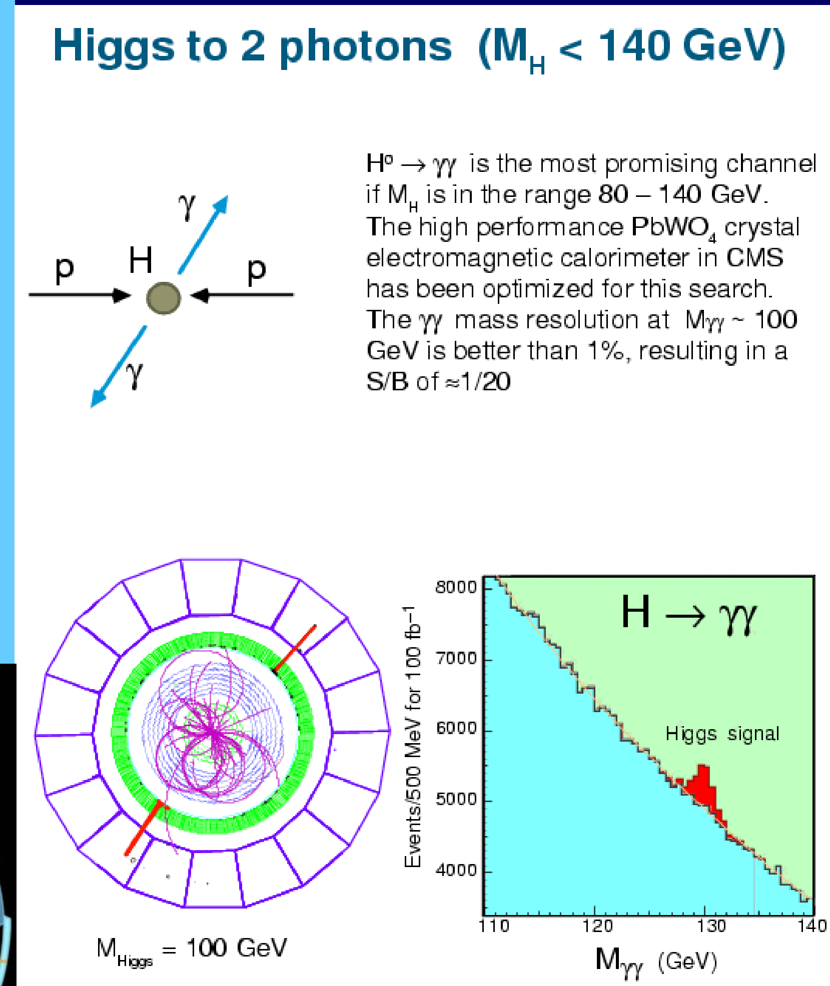
Analysis

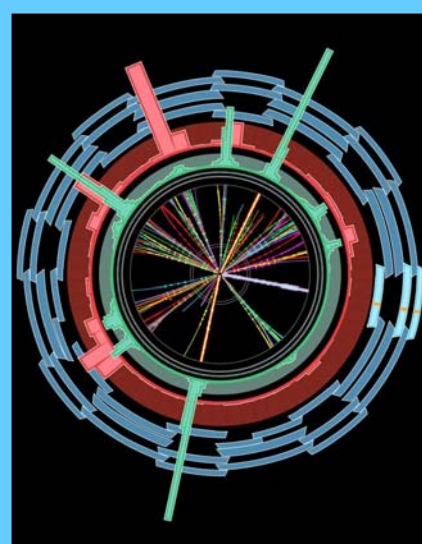
Simulation (Monte-Carlo)

Heavy use of computers: programming and software

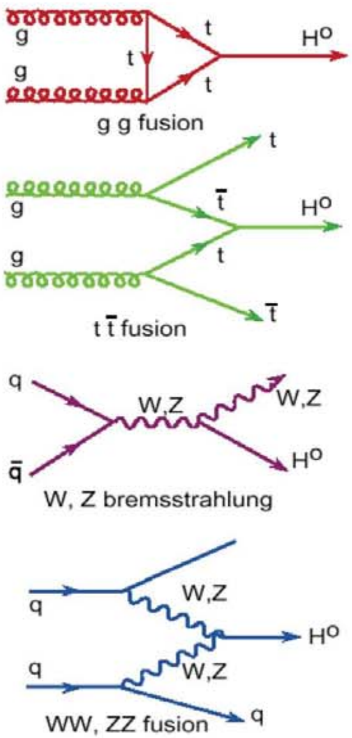
Higgs physics

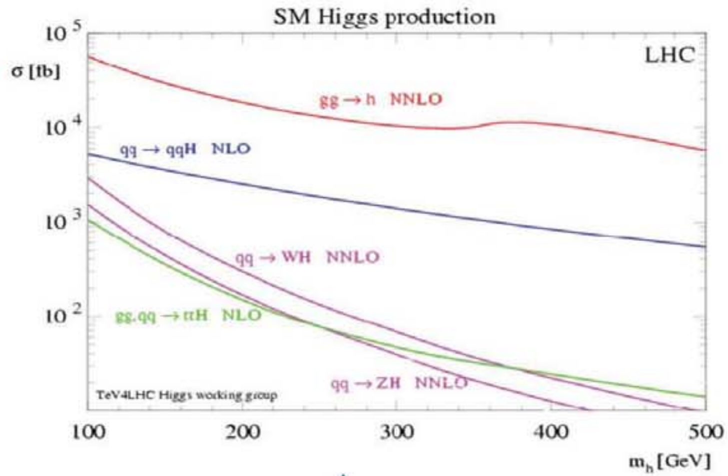
- The Higgs mechanism (or something similar) is required to generate particle masses
- Higgs particle has not been found yet!
- Present tests: Higgs must be heavier than 115 GeV
- LHC: Higgs can be found if mass is 115-1000 GeV
- Decay channels: e.g. $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons





SM Higgs Production and Decay at LHC

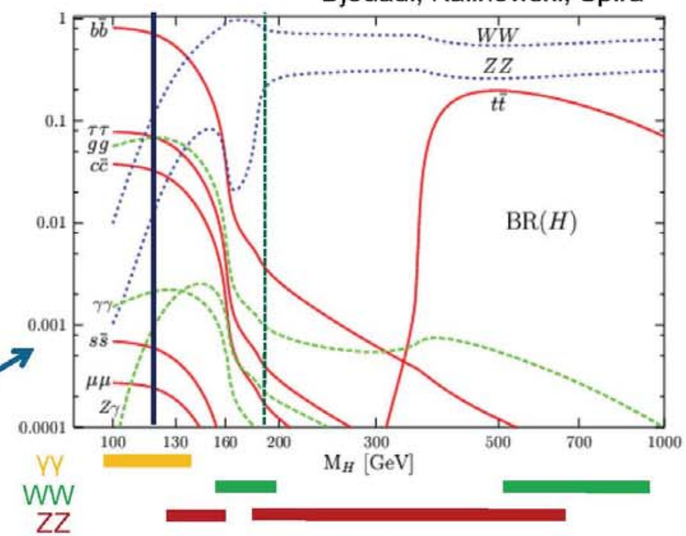




Typical uncertainties

- gg 10-20% (**NNLO**)
- ttH ~10% (**NLO**)
- WH,ZH <5% (**NNLO**)
- VBF <10% (**NLO**)

Djouadi, Kalinowski, Spira



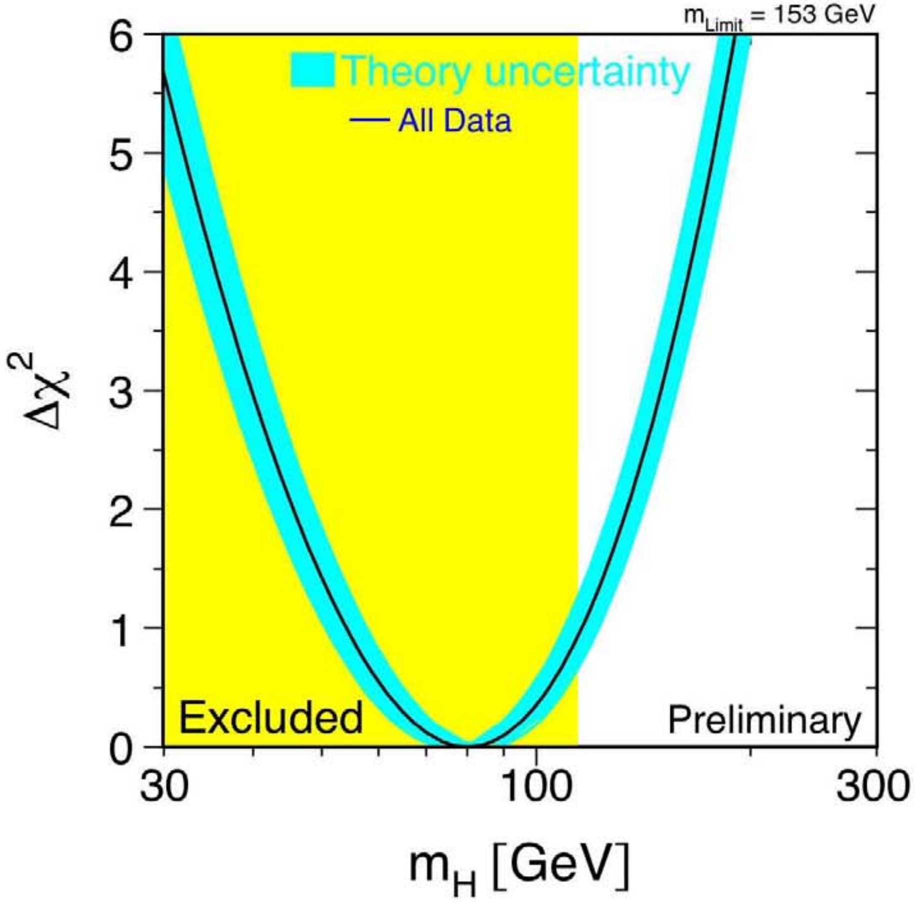
Branching Ratios

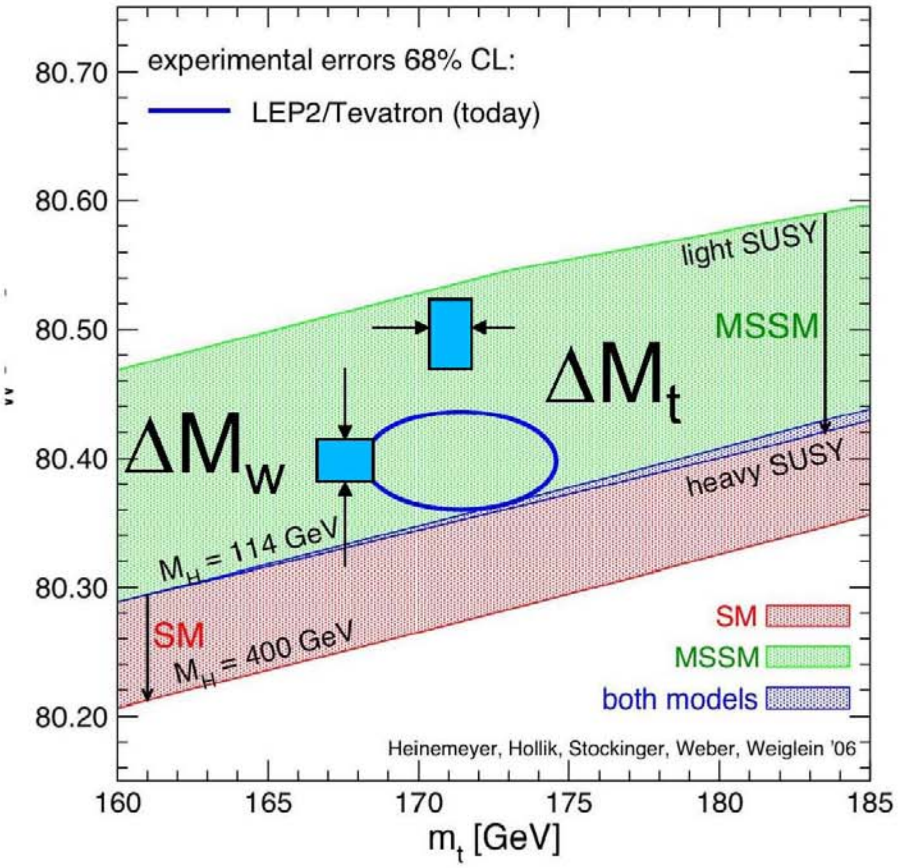
known to NLO few % uncertainty

Virtual Measurement:Mar 07

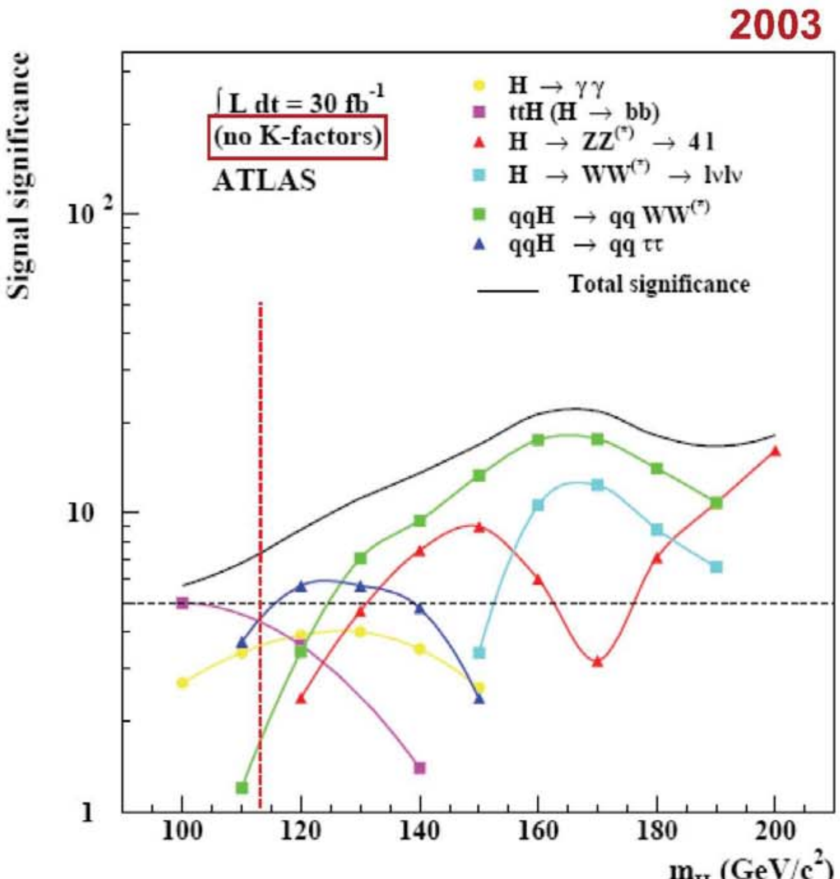
M_h =80 GeV 68%CL (most probable value)

M_h <153 GeV 95% CL





Expected Significance



H→ ZZ → 4l dominates for

200 GeV < M_H < 600 GeV

RECENT PROGRESS

K-factors

pile-up/cavern background

trigger performance

as-installed detector ← complete material, misalignments, miscalibrations

cut optimization

multivariate techniques

statistics treatment with systematics

background extraction from sidebands

NEW

expected significance / exclusion limits

for summer conferences 2008

Discovery already possible from few fb^{-1}

e.g. for M_H = 150 GeV and M_H>200 GeV

ATLAS B-physics goals: precision measurements and new physics

- **CP-violation parameters**
- **B-hadron parameters: masses, lifetimes, widths, oscillation parameters, couplings, b-production, etc.**
- **Search for New Physics effects: very rare decay modes, forbidden decays/couplings, etc.**

CP violation	$B_d \to J/\psi K_s^0(\pi\pi)$ $J/\psi \to \mu\mu/ee$	$\sin(2\beta) + \Phi_{NP}$
Measurement of B_s properties	$B_s \to D_s\pi; B_{s,d} \to D_s a_1$ $B_s \to J/\psi(\mu\mu)\phi(KK)$ $B_{s,d} \to J/\psi(\mu\mu)\eta(\gamma\gamma)$	Δm_s, $\Delta\Gamma_s$, Γ_s, the weak phase ϕ_s
B_c mesons	$B_c \to J/\psi\pi; B_c \to J/\psi\mu\nu$	B_c mass, τ, QCD/EW interplay
Λ_b polarization measurements	$\Lambda_b \to J/\psi(\mu\mu)\Lambda(p\pi)$	Asymmetry parameter α_b, P_b, life-time measurements
Rare decays	$B_{s,d} \to \mu^+\mu^-; B_d^0 \to K^{*0}\mu\mu$ $\Lambda_b \to \Lambda\mu\mu; B_s^0 \to \phi^0\mu\mu$	Precise measurements of the branching ratios and asymmetries

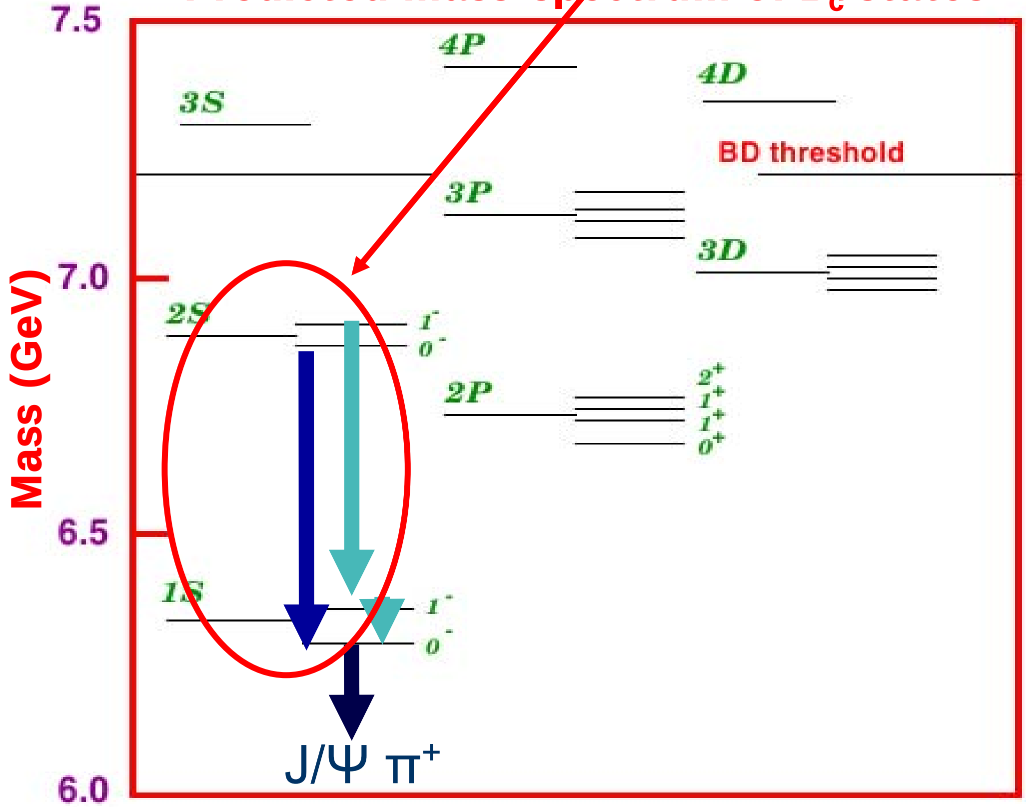
Lifetime measurements with small statistics

The reconstructed masses and lifetimes of the well-known control channels are sensitive tests of those detector features which have a strong impact on B-physics measurements.

	Decay	Statistics 100 pb^{-1}	Statistical error on lifetime	World av today (stat + syst)
B^+	$B^+ \to J/\psi K^+$	17 000	1.5 %	0.4 %
B^0	$B^0 \to J/\psi K^{0*}$	8 700	2.2 %	0.5 %
B_s	$B_s \to J/\psi \phi$	900	6 %	2 %
Λ_b	$\Lambda_b \to J/\psi \Lambda$	260	8 %	5 %

B_c decays

- ***Motivation 1:*** **B_c is a newly discovered particle (about 60 at CDF) → precision measurement of mass and lifetime**
- ***Motivation 2:*** **Precision reconstruction of B_c ground and excited states can be used to constrain strong potential models.**
- **Easiest to find hadronic B_c* decays.**



Predicted mass-spectrum of B_c states

- Possible decay modes:

$B^*_c(2^1S_0) \rightarrow B_c(1^1S_0)+\pi^+\pi^-$

↓

$J/\Psi\ \pi^+$

- $B^*_c(2^1S_1) \rightarrow B^*c(1^1S_1)+\pi^+\pi^-$

↓

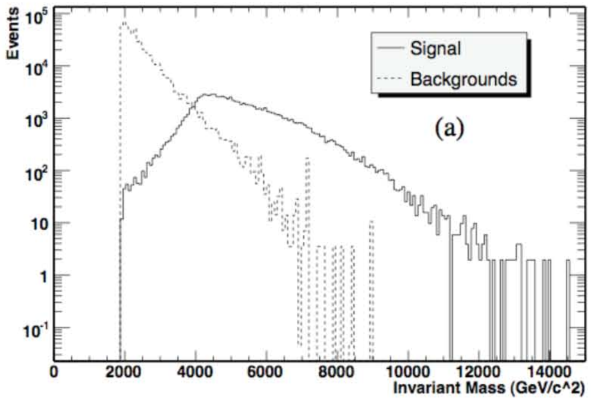
$B_c(1^1S_0)+\gamma$

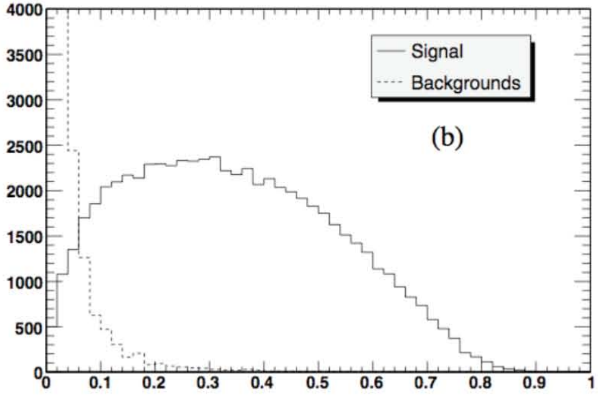
↓

$J/\Psi\ \pi^+$

Exotic Processes (Mini Black Holes)

- Models with extra dimensions and a reduced Planck scale may allow the production of mini black holes
  - Parton-parton impact parameter less than Schwarzschild radius
- The black holes evaporate via Hawking radiation
  - Spherical emission of all types of particles
- Example for 2 TeV Planck scale and $M_{BH} > 2$ TeV

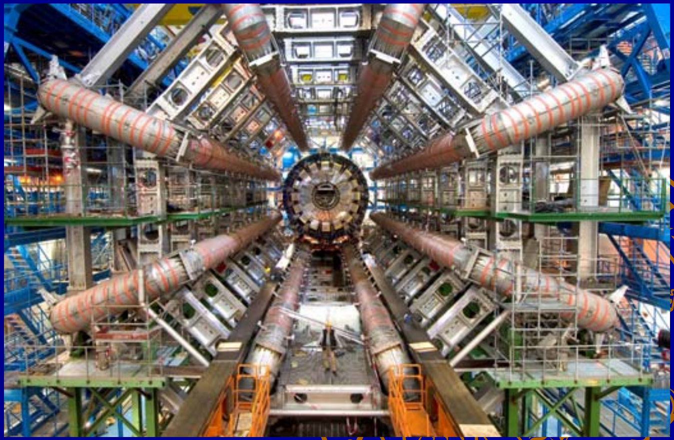


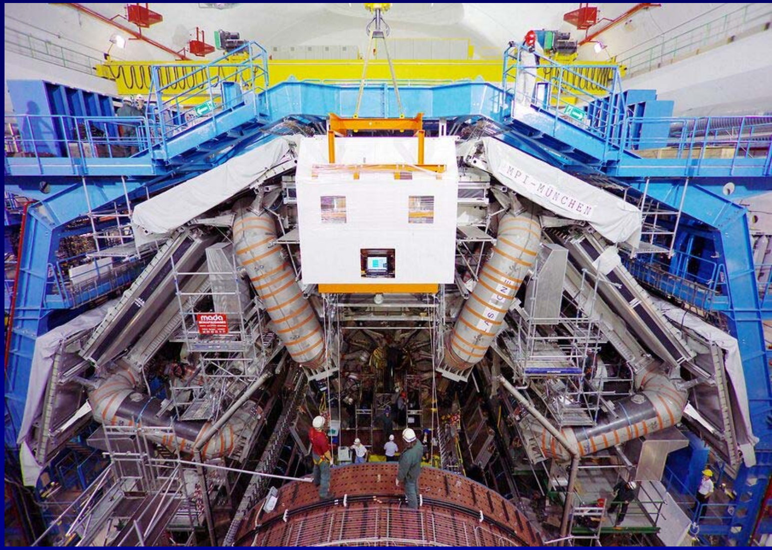


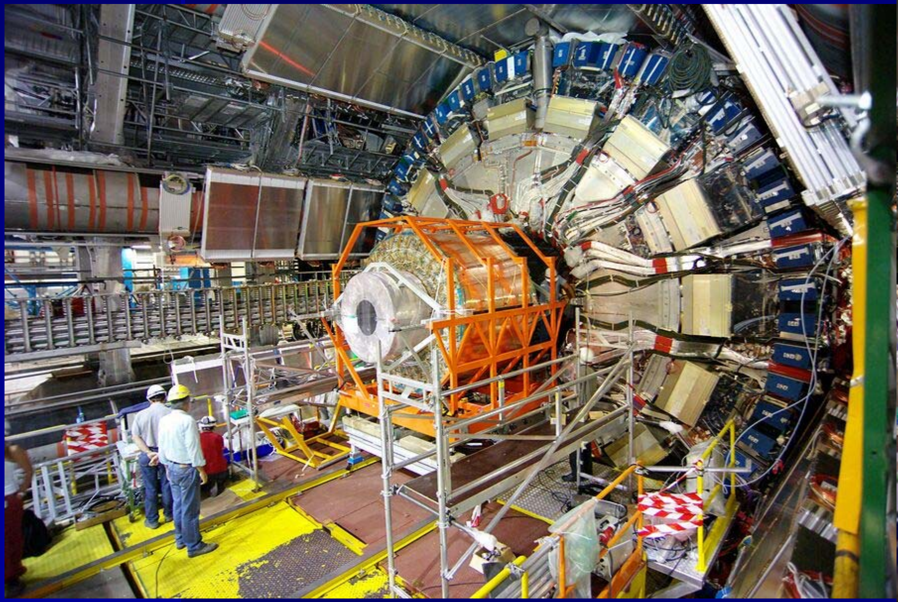
Event Sphericity

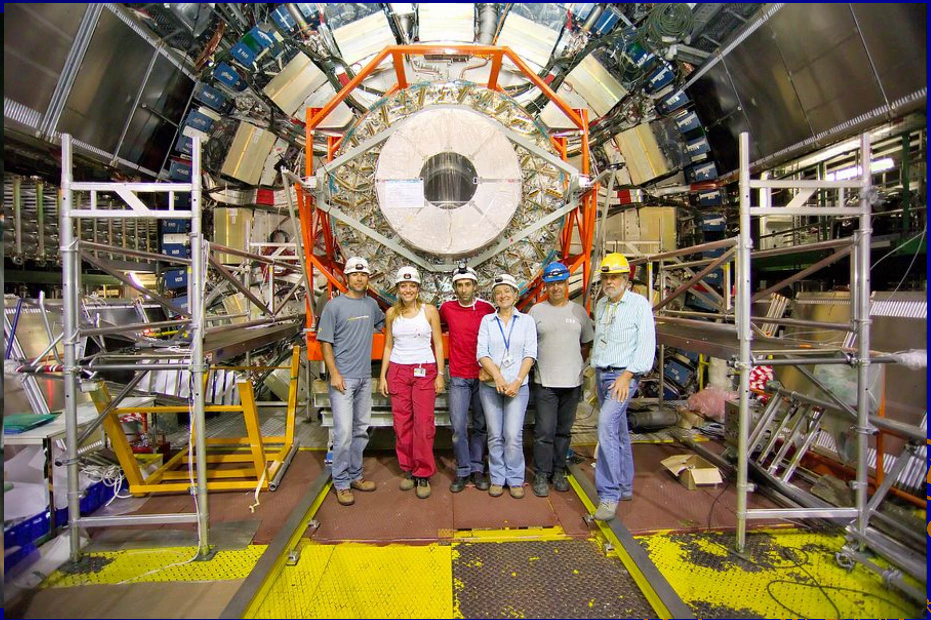
ATLAS installation

Toroid magnets

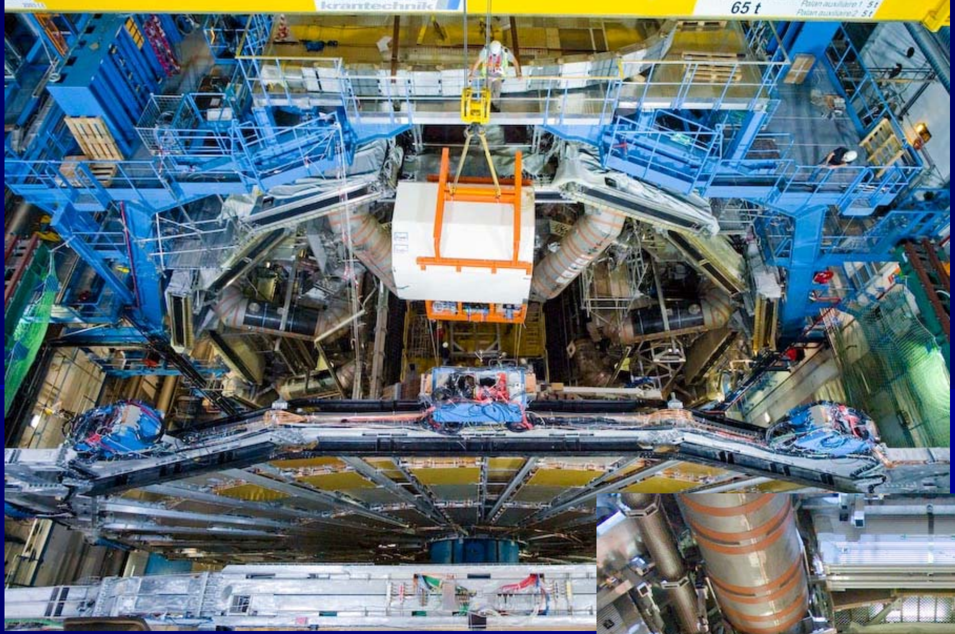


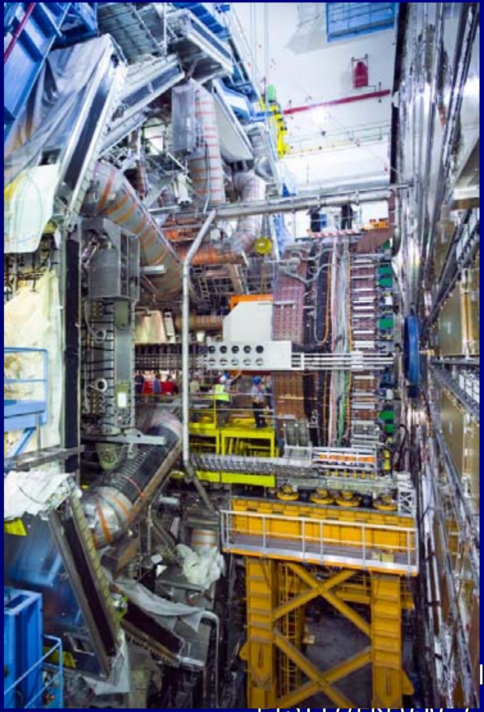


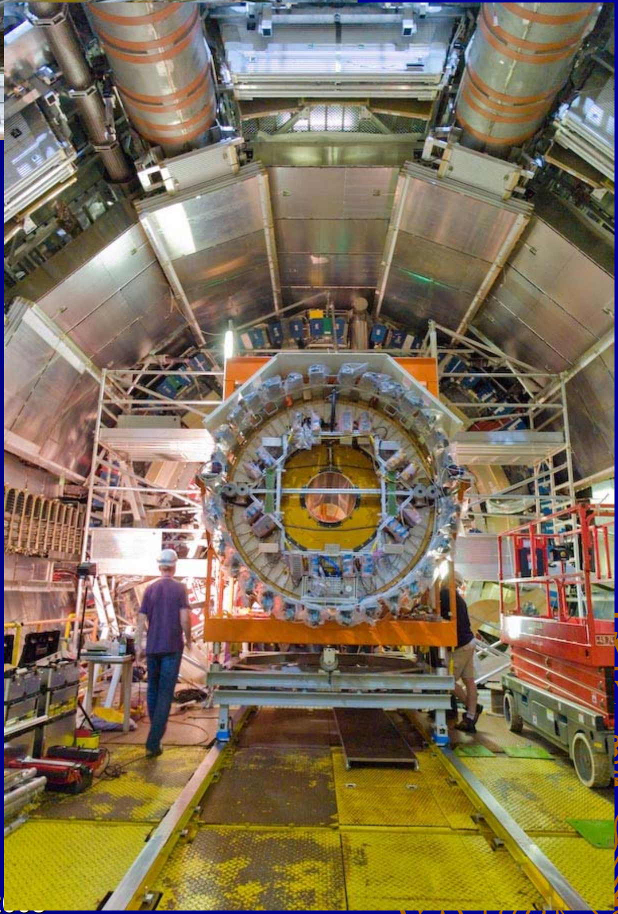




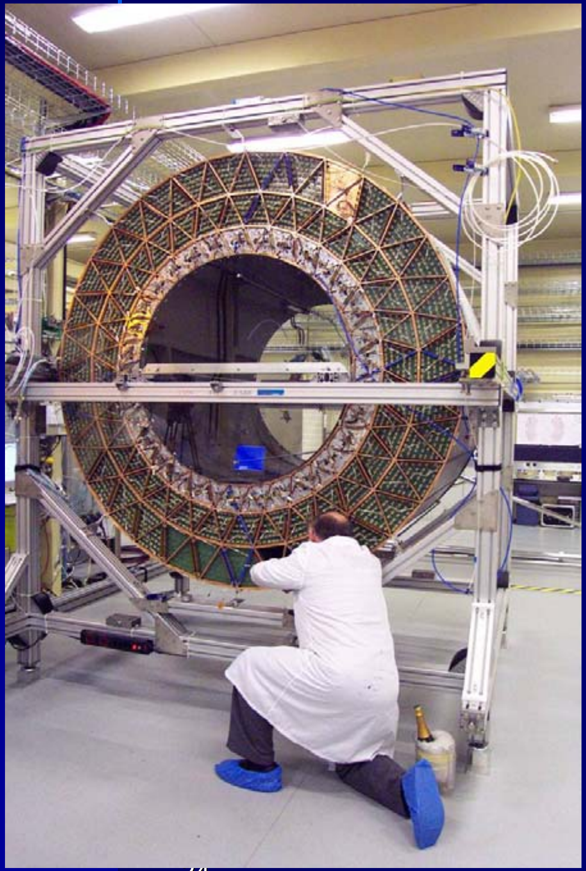
Inner Detector Barrel, August 2006







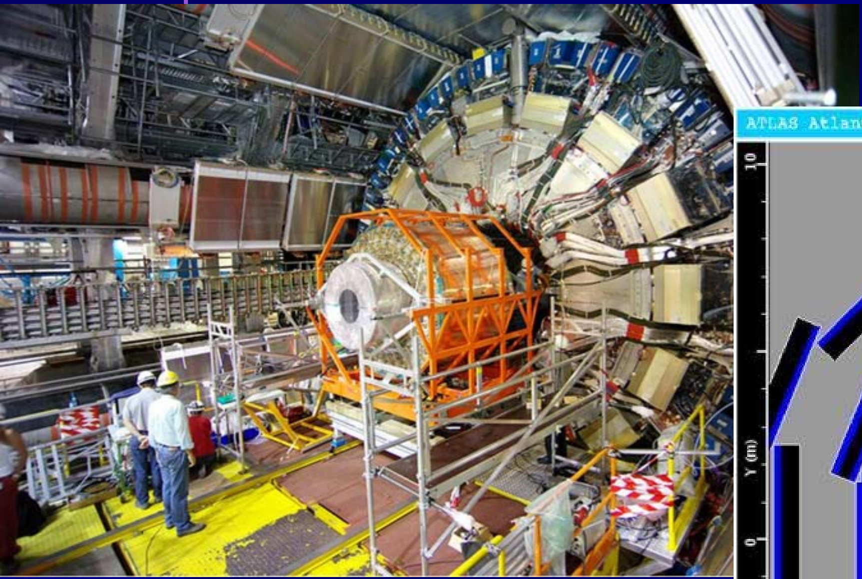
Inner Detector end-cap, 24 May 2007

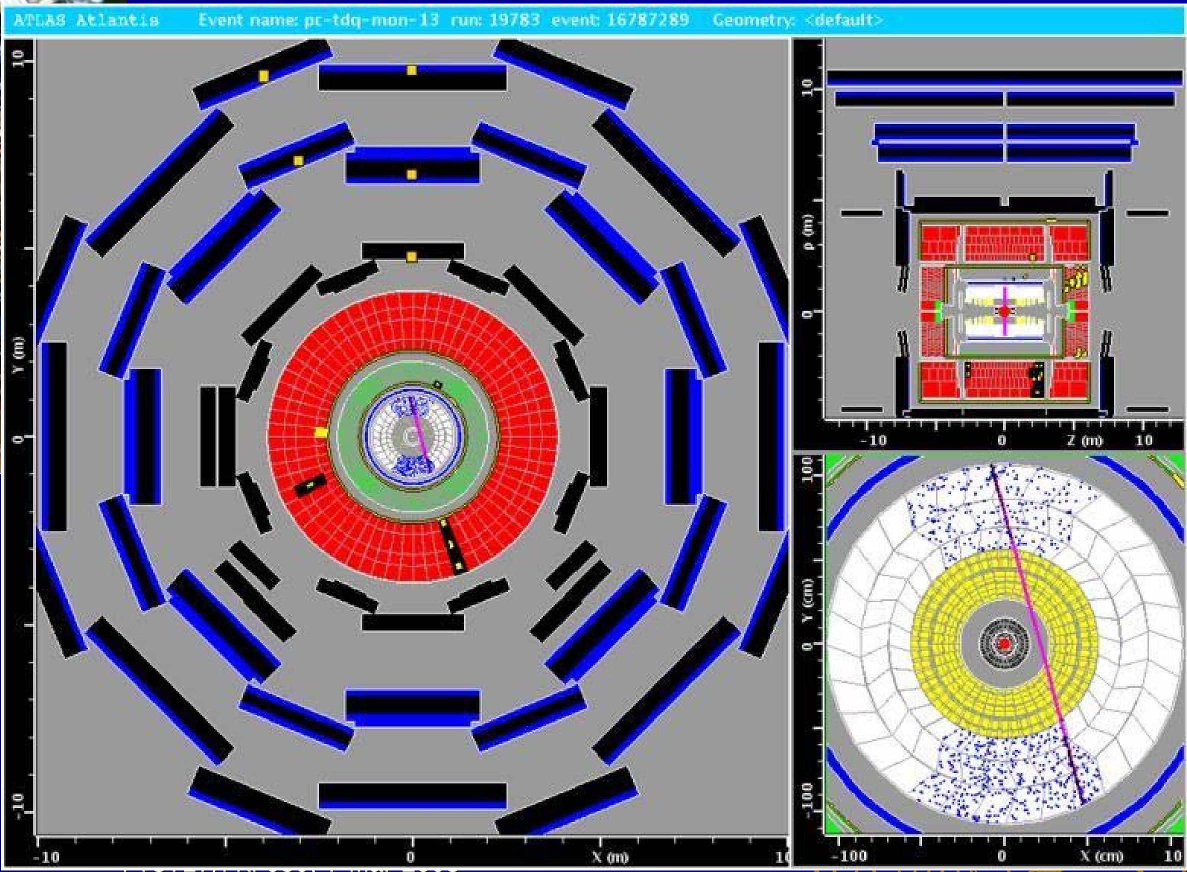


ATLAS Transition Radiation Tracker (TRT), electronics and design partly in Lund

Cosmic muon recorded in ATLAS

Commissioning and data-taking: start with cosmic muons





Our research in Lund-ATLAS and student possibilities

- ATLAS/Grid-group has currently 5 physicists, 4 PhD students, and 2 engineers.
- Analysis of B-hadrons, for example B_c
  - CP violation, precision measurements,…
- Black holes, extra dimensions and other exotic signals
  - …and many other possibilities?
- Scattering at small angles
  - QCD, hadron dynamics, Higgs?,…
- Express stream
  - Special data stream for calibration and for fast alerts
- TRT calibration and data analys
- Roman pots – LUCID detector for luminosity measurement
  - Installation and data-analys
- *Possibilities for diploma works - contact us!* We give also the necessary training in computing etc.
- Paula.eerola [at] hep.lu.se, 046-222 7695, or anybody else in the division of Experimental High Energy Physics

Studies and summer courses

- Master's programme in subatomic physics: see Fysicum homepage for education
- CERN Summer Student programme: see http://public.web.cern.ch/Public/
  - 3 months summer course at CERN, including research and lectures. Full salary, travels are reimbursed!
  - Over 100 students from CERN member states and some other countries – typically 4-6 from Sweden every year.
  - Requirements: 3 years of studies of physics, engineering or computing
  - Next deadline: end of January 2009
- More info: contact us!

Thanks!