LHC Begins…

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ATLAS

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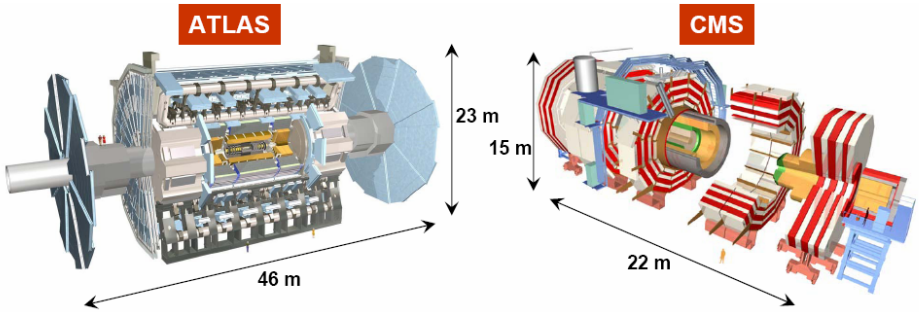
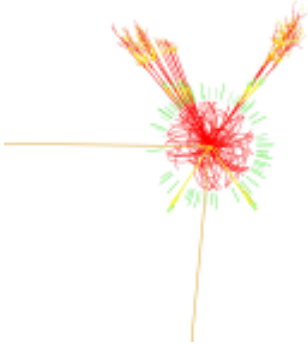
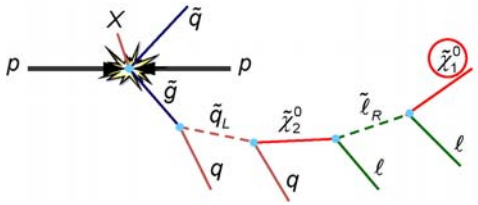
Outline

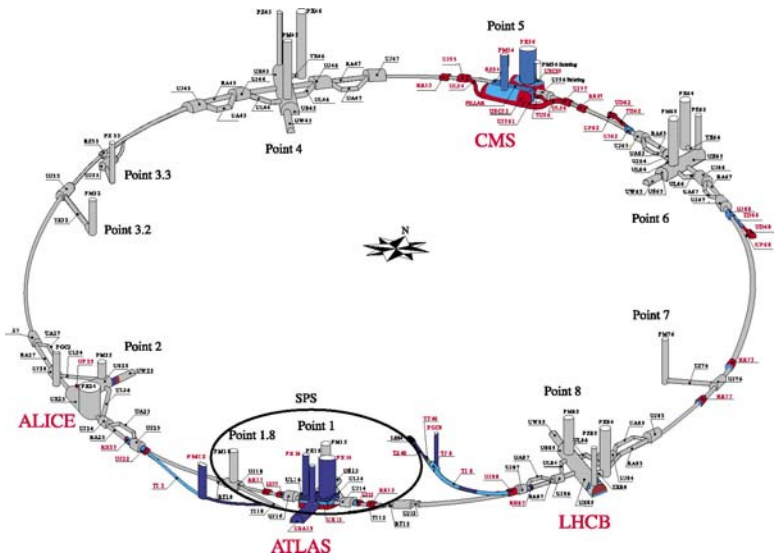
- Brief look at the Large Hadron Collider (LHC)
  - Design features
  - Machine commissioning and early beams
- Detectors
  - ATLAS and CMS mostly
- Expectations for first physics
  - Commissioning for physics
  - Early Standard Model measurements
  - Early discoveries?
- Outlook



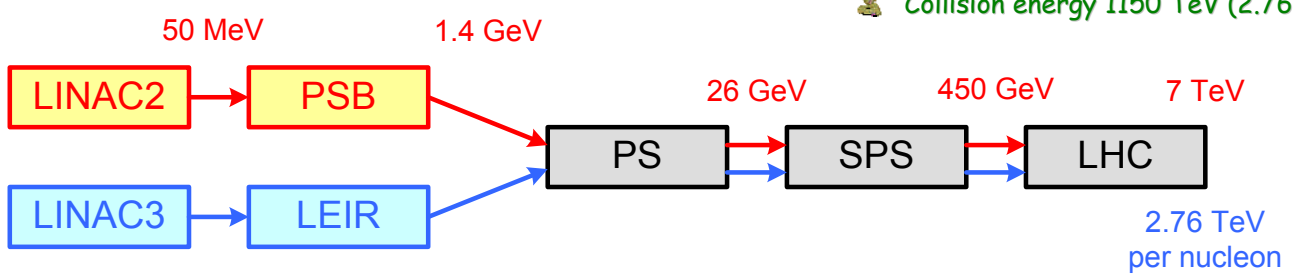




The Large Hadron Collider (LHC)



- **Machine**
  - Occupies old LEP tunnel at CERN, Geneva, Switzerland & France
  - About 27 km long
  - 50-100m underground
  - 1232 bending magnets
  - 392 focusing magnets
  - All superconducting
    - ~96 tons of He for ~1600 magnets
- **Beams (design)**
  - pp collider
    - 7 TeV on 7 TeV (14 TeV collision energy)
    - Luminosity 10^{34} $cm^{-2}s^{-1}$
    - 2808 x 2808 bunches
    - Bunch crossing time 25 ns (40 MHz)
    - ~20 pp collisions/bunch crossing
  - Heavy ion collider (Pb)
    - Collision energy 1150 TeV (2.76 TeV/nucleon)



Proton acceleration chain:

LINAC→Proton Synchrotron Booster (PSB)→Proton Synchrotron (PS)→Super Proton Synchrotron (SPS)→LHC

Pb ion acceleration chain:

LINAC→Low Energy Ion Injector Ring (LEIR)→Proton Synchrotron (PS)→Super Proton Synchrotron (SPS)→LHC

Initial LHC Running Conditions

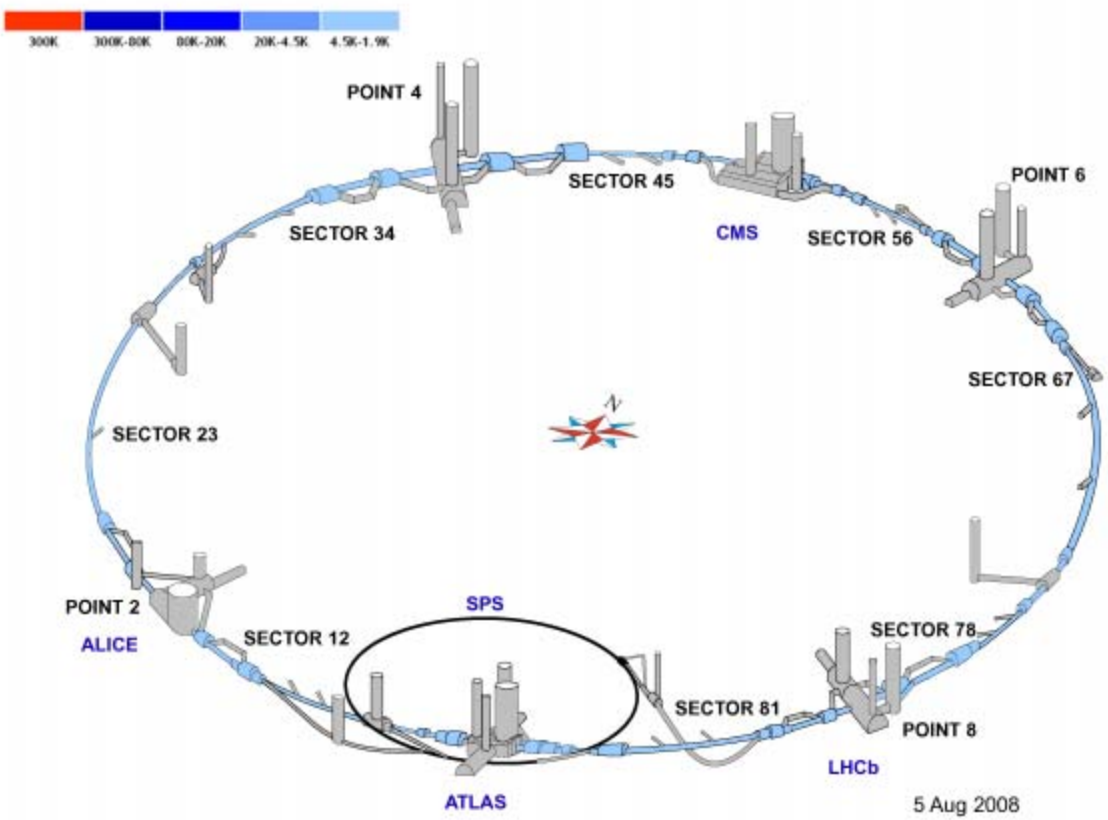
- **Stage A (5 TeV/beam):**
  - LHC commissioning
    - Single beam
  - Pilot physics running
    - First collisions
  - Starts 09/2008 for about 2 months
    - 10-15% of nominal current
    - ~3 pb^{-1} possible?
- **Stage B (5 TeV/beam):**
  - 75 ns commissioning
    - 12-23% of nominal current
  - End of 2008 run year?
- **Stage C (7 TeV/beam):**
  - Move to 25 ns bunch spacing
    - 35-52% of nominal current
  - Early 2009?
- **Stage D (7 TeV/beam):**
  - 70-100% of nominal current
    - Requires phase 2 collimators to be installed

	# bunches	β* [μ]	Intensity $\times 10^{10}$	Lumi [$cm^{-2}s^{-1}$]	Coll. rate	X-ing
A	1×1	11	1	1.6×10^{27}	~0	70 ms
	43×43	2	4	6.1×10^{29}	0.76	1.6 ms
	156×156	2	9	1.1×10^{32}	3.9	450 ns
B	936×936	10	4	2.3×10^{31}	0.13	75 ns
	936×936	1	6	5×10^{32}	2.8	75 ns
C	2808×2808	4	4	1.7×10^{32}	0.32	25 ns
	2808×2808	0.55	6	2.8×10^{32}	5.2	25 ns
D	2808×2808	2	8	1.4×10^{32}	2.6	25 ns
	2808×2808	0.55	11	1.0×10^{34}	19.3	25 ns

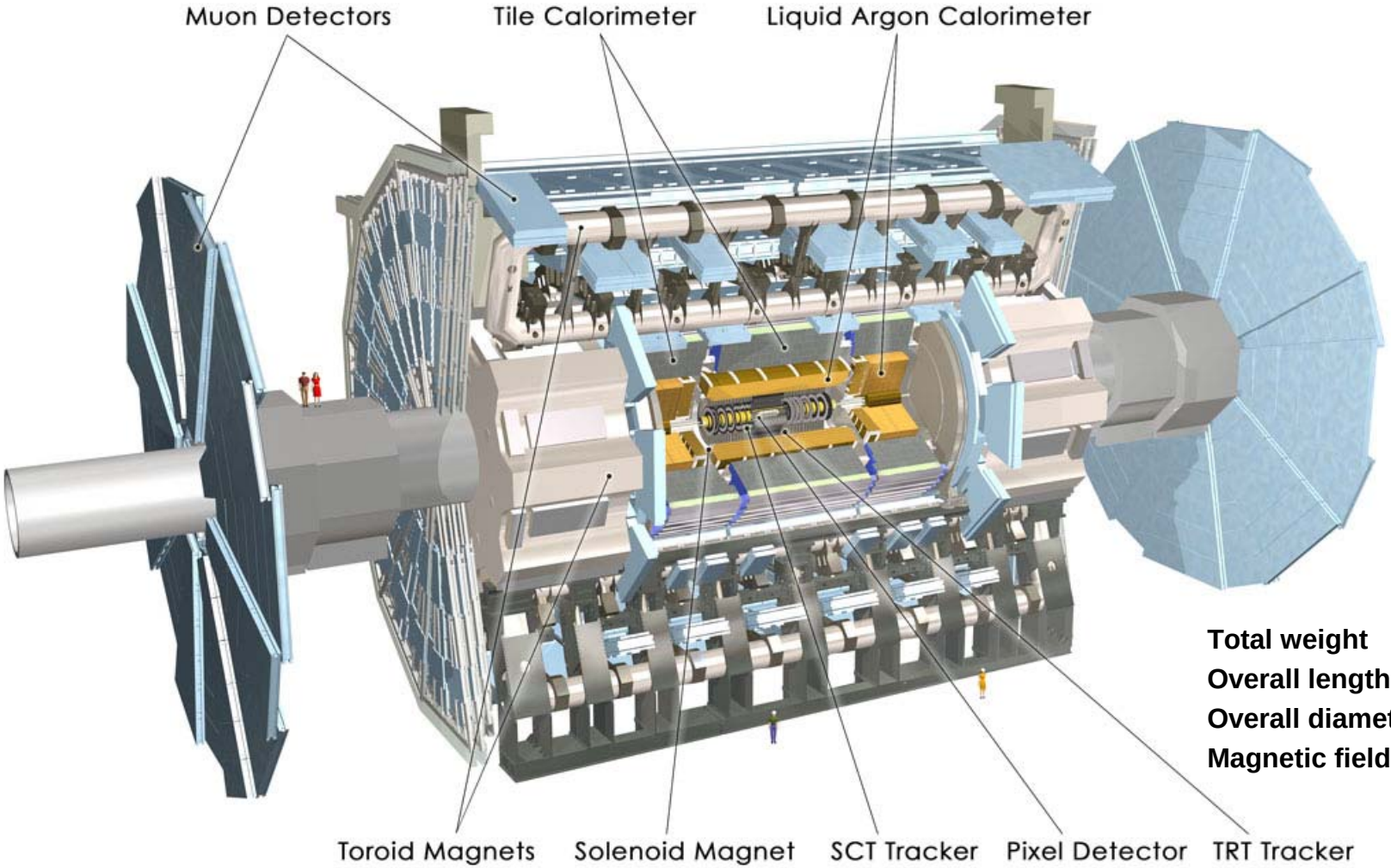
Very preliminary! See http://lhc-commissioning.web.cern.ch for current status!

LHC Status

- All segments are cold!

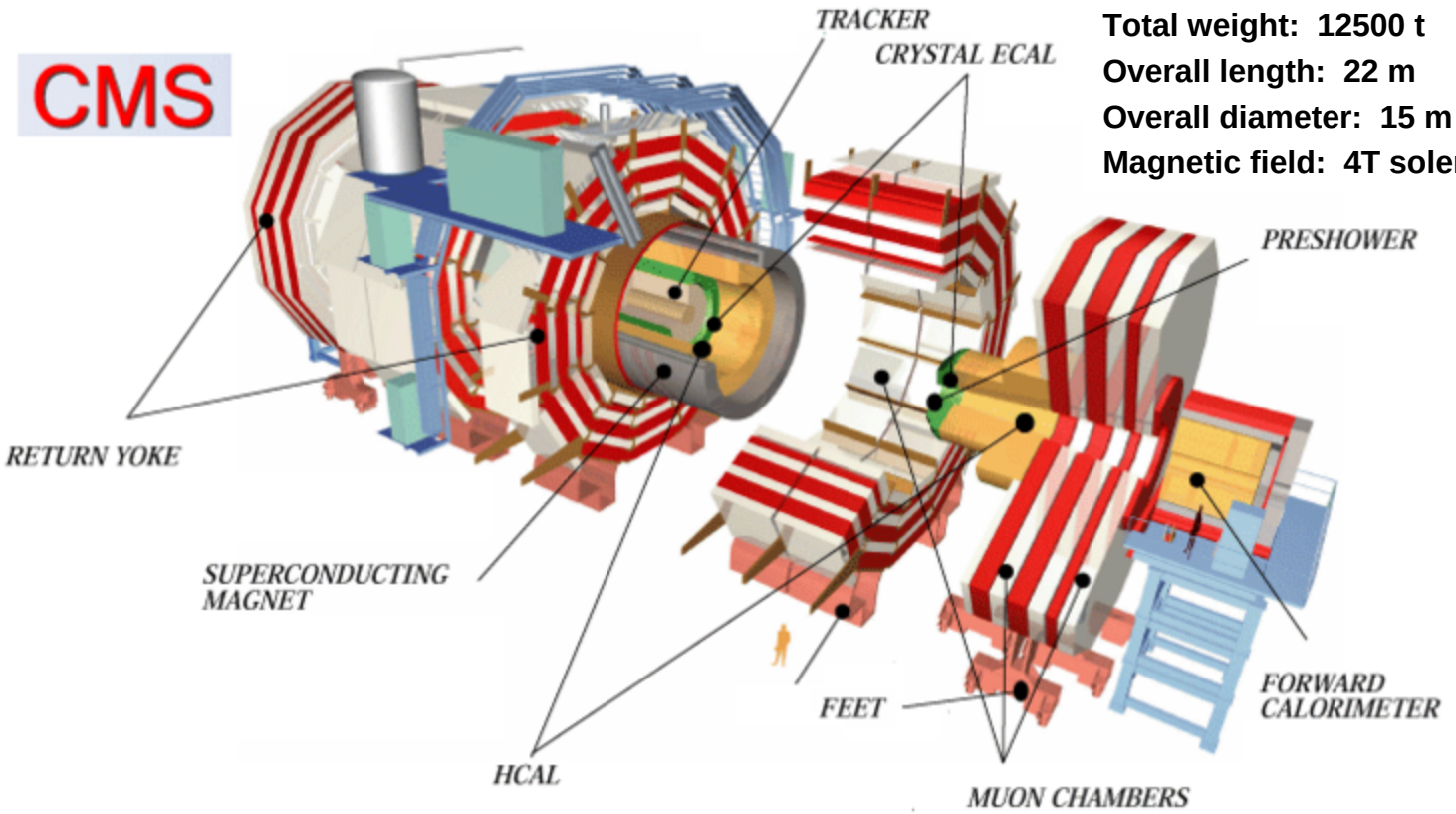


ATLAS: A General Purpose Detector For LHC



Total weight : 7000 t
Overall length: 46 m
Overall diameter: 23 m
Magnetic field: 2T solenoid + toroid

CMS: A General Purpose Detector For LHC



Total weight: 12500 t
Overall length: 22 m
Overall diameter: 15 m
Magnetic field: 4T solenoid

Typical Detector Features

- **Hermetic coverage over a wide angular range**
  - Efficient missing transverse energy reconstruction due to large coverage in pseudo-rapidity

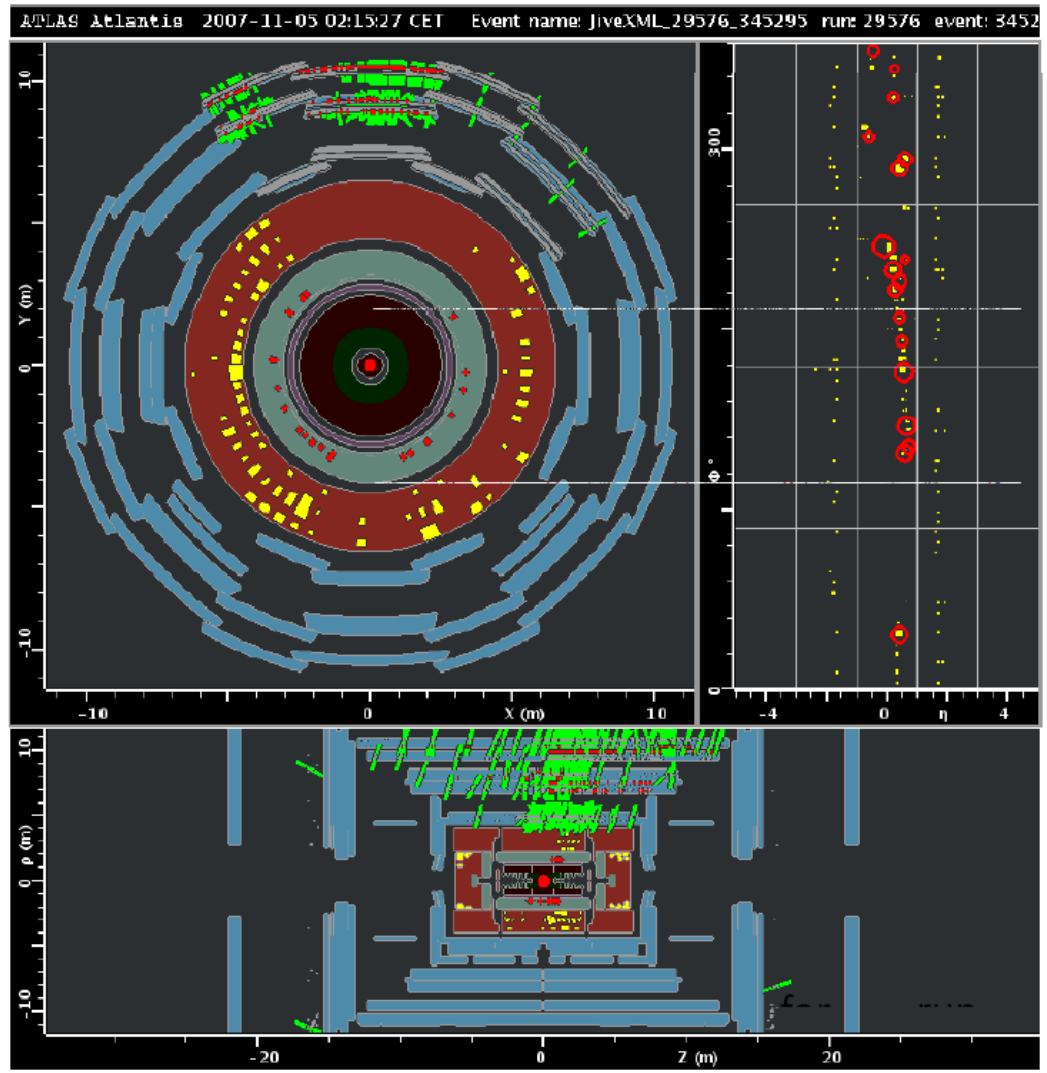
$$|\eta| = \left|\frac{1}{2}\ln\left(\frac{p+p_z}{p-p_z}\right)\right| = \left|\ln\left(\tan\frac{\theta}{2}\right)\right| \leq 5$$

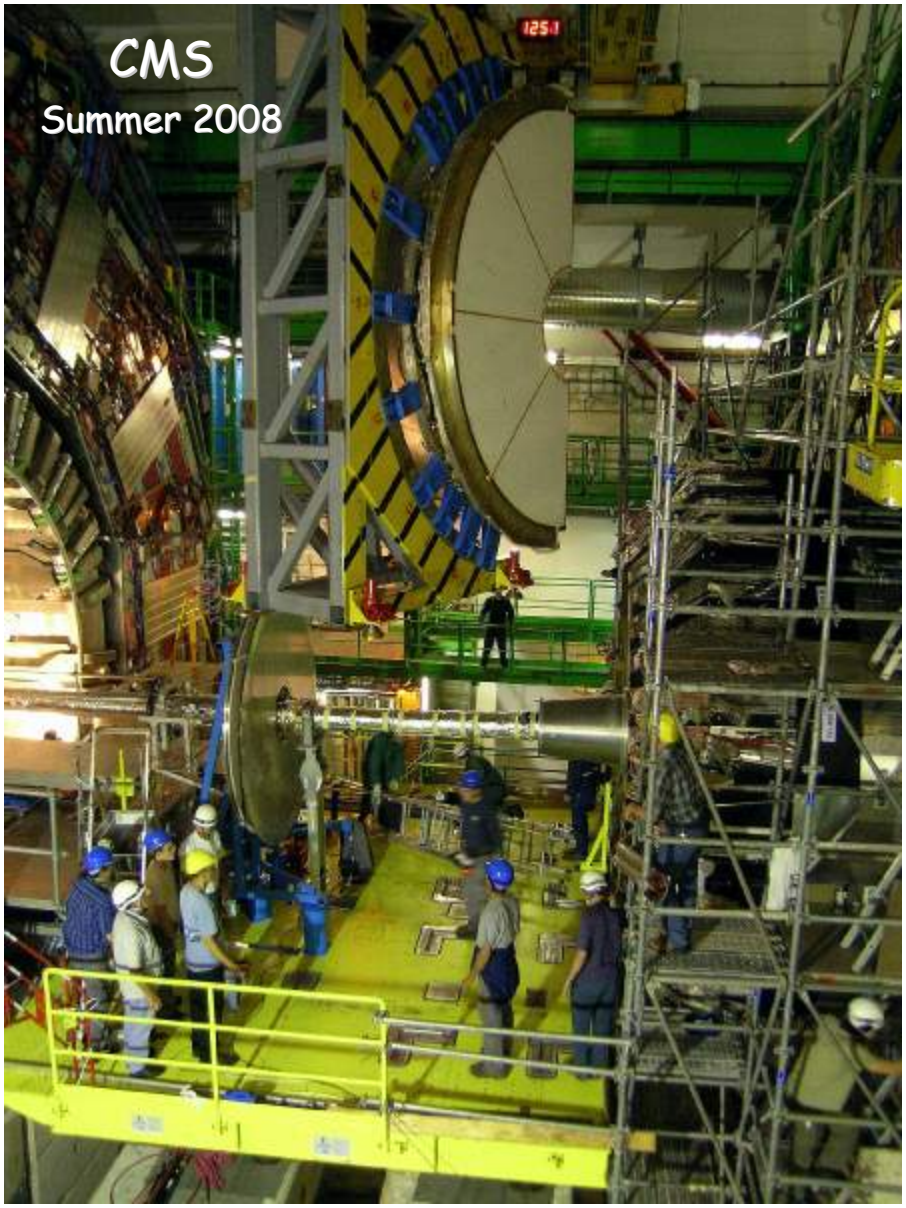
  - Very forward detection of particles and jets produced in pp collisions
- **High particle reconstruction efficiency**
  - Important for final state reconstruction and classification
- **Relative energy resolution for electrons, photons and muons is 2-4%**

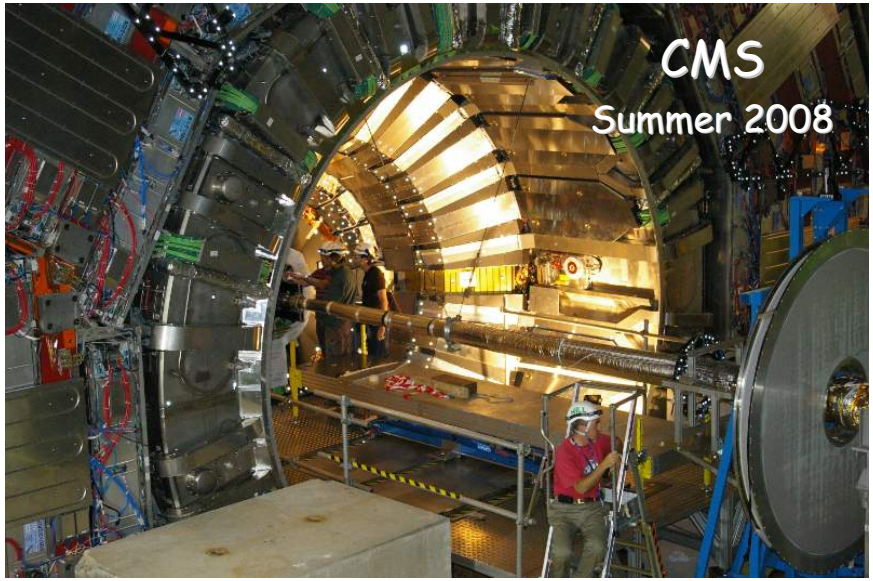
Particles	Efficiency	Jet Rejection
muon	~90%	10^5
$e^{\pm}$	~80%	10^5
photon	~80%	10^3
b-jet	~60%	100
tau	~50%	100

Detector Status

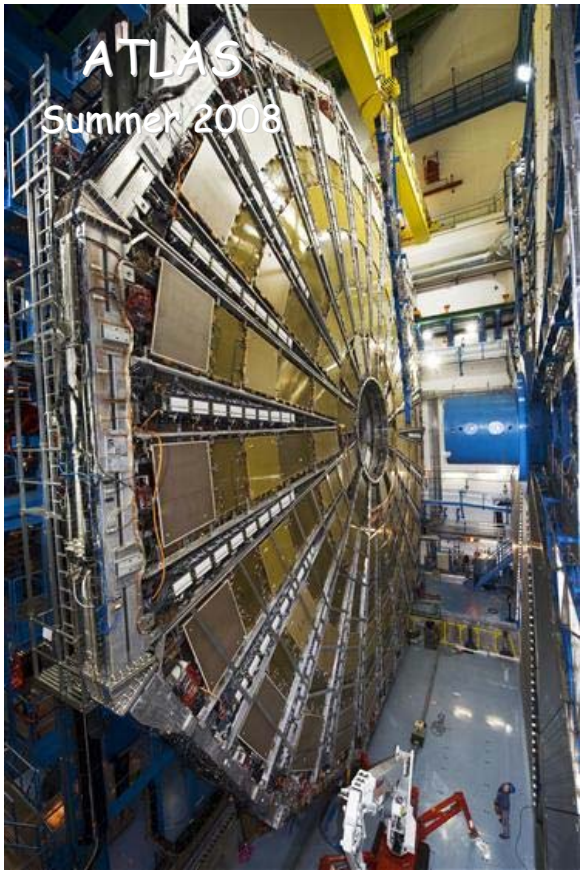
- Both ATLAS and CMS are or will be sufficiently complete for physics
  - Detector integration and commissioning ongoing since several months
  - So far calibration (pulses), noise studies ("empty" readings) and cosmic data
- Some repairs and completions needed
  - Scheduled for first break winter 2008/2009

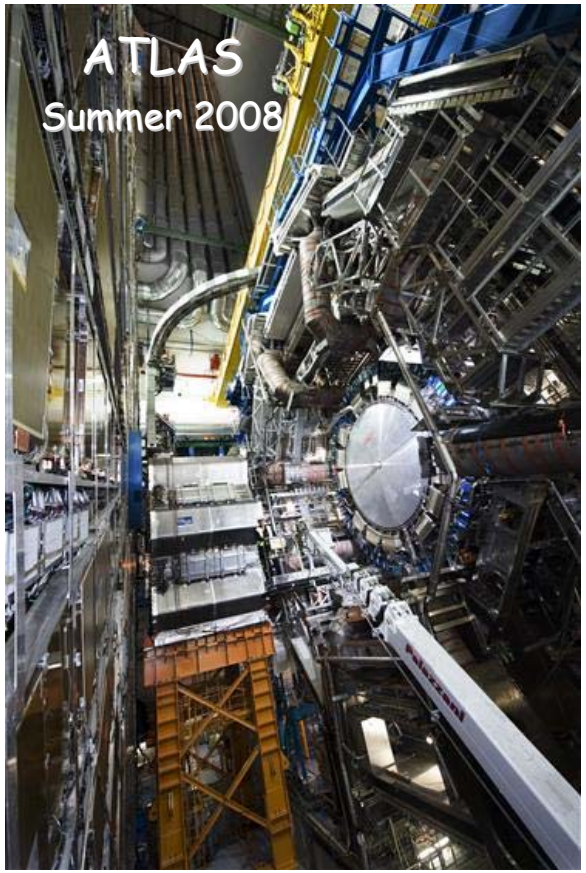



CMS
Summer 2008


CMS
Summer 2008


CMS
Summer 2008


ATLAS
Summer 2008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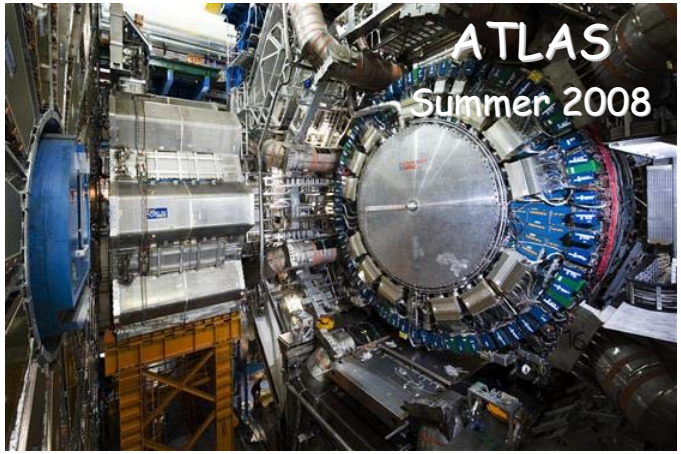
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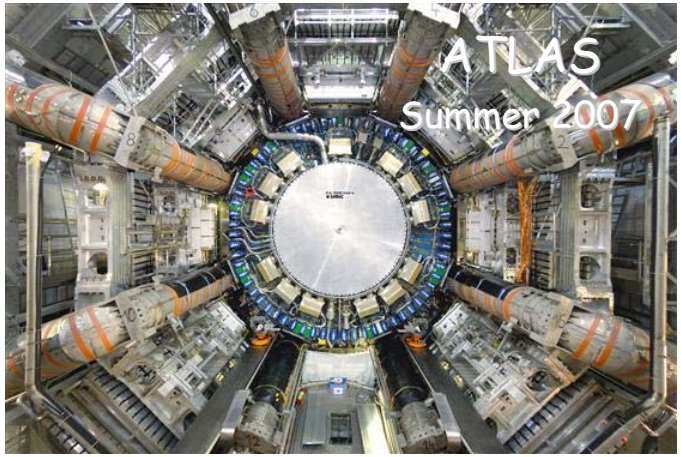
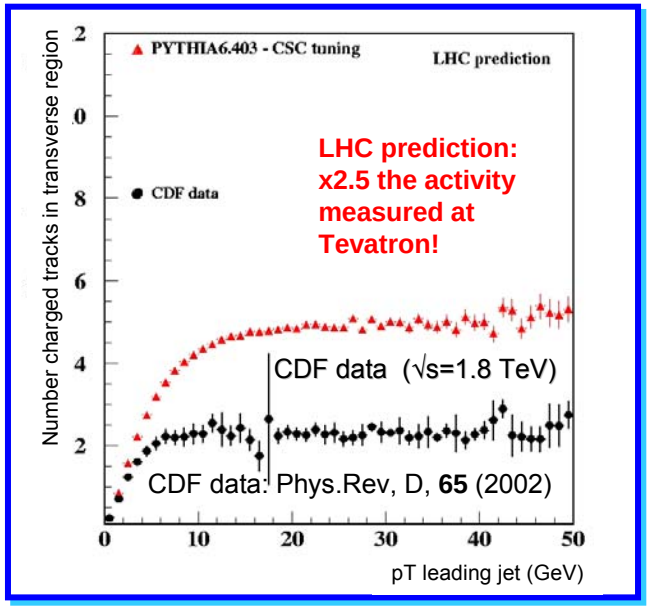

ATLAS
Summer 2007

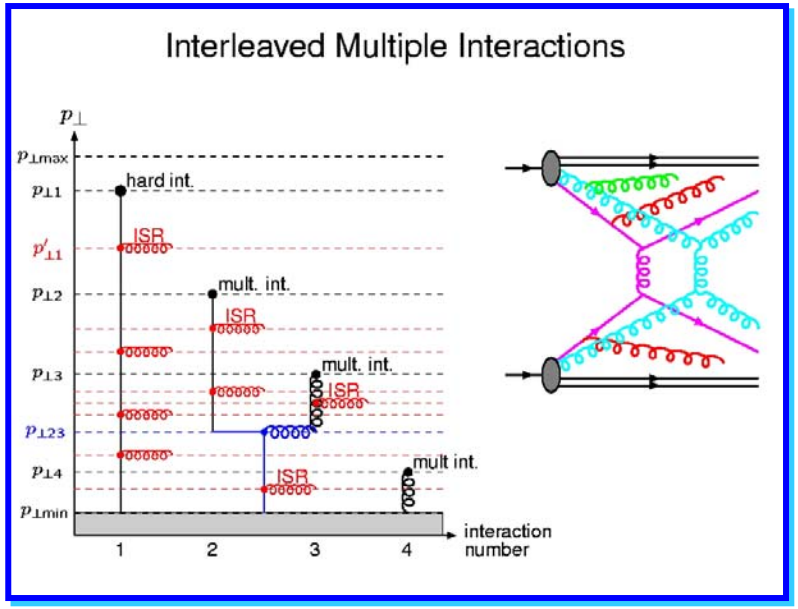
Challenges To Physics Reconstruction

Underlying event in proton-proton collisions

- Collisions of other partons (quarks and gluons) in the same two protons generating the (high transverse momentum) interaction of interest
  - Cannot easily be suppressed
  - Has been extensively studied at Tevatron
- Large phase space at LHC
  - Activity is correlated with hard scattering

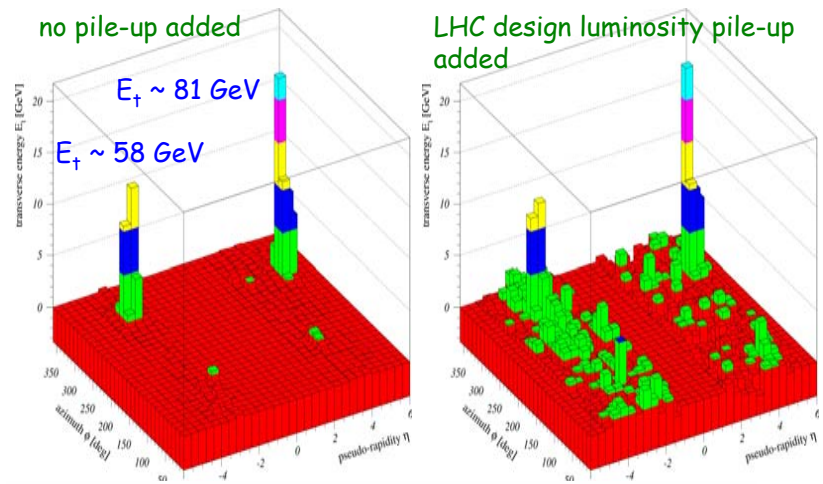


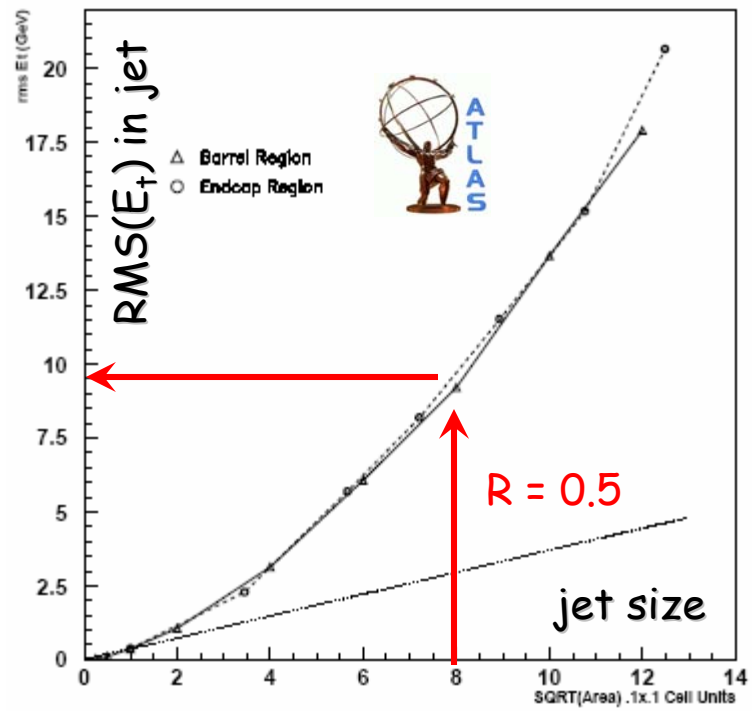
A.Moraes, HERA-LHC Workshop, DESY, March 2007



Pile-Up Events

- **Multiple collisions of other protons in bunch crossings**
  - Effect of high luminosity at LHC
  - Independent of (triggered) hard scattering process
  - Generates additional particles and particle jets
- **Generates additional noise in detectors**
  - High bunch crossing rate creates signal history from pile-up in detectors
    - Sensitivity up to 25 bunch crossings for "slow" detectors (calorimeters)
  - Average contribution cancels due to chosen signal shaping
- **Pile-up noise is not gaussian**
  - Coherent effects due to physics source





P. Savard et al., ATLAS-CAL-NO 084/1996

Reconstruction Challenges

Complex but common signal objects final states in LHC collisions: particle jets

longitudinal energy leakage

detector signal inefficiencies (dead channels, HV…)

pile-up noise from (off- and in-time) bunch crossings

electronic noise

calo signal definition (clustering, noise suppression ,…)

dead material losses (front, cracks, transitions…)

detector response characteristics (e/h ≠ 1)

jet reconstruction algorithm efficiency

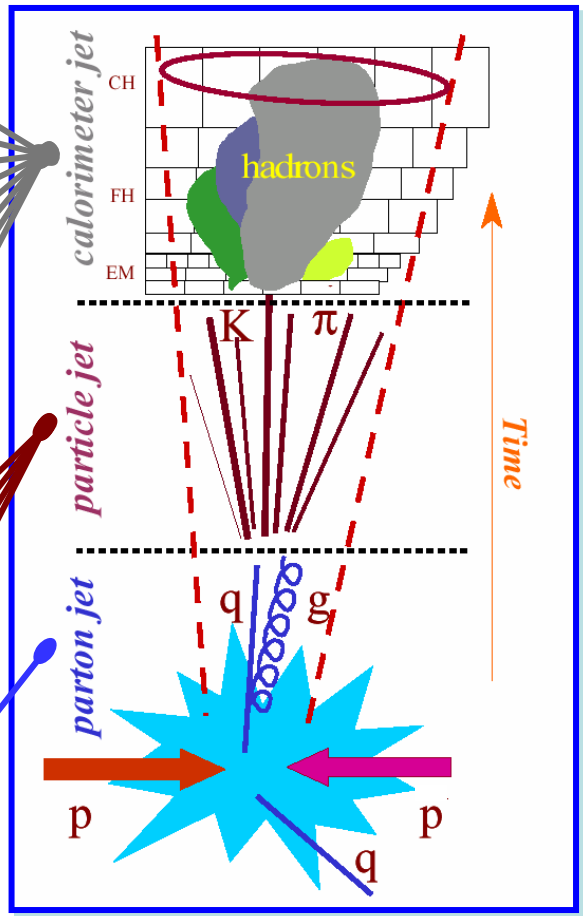
jet reconstruction algorithm efficiency

added tracks from in-time (same trigger) pile-up event

added tracks from underlying event

lost soft tracks due to magnetic field

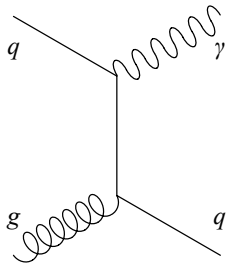
physics reaction of interest (interaction or parton level)



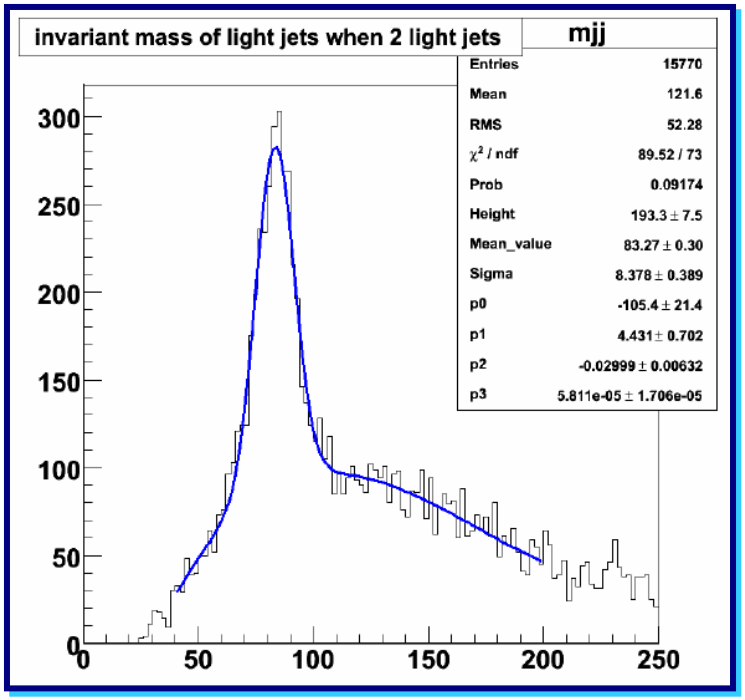
Tasks For First Collisions

- **Calorimeter calibration**
  - Validate simulation and test beam based hadronic calibration functions
  - In-situ calibration with collision physics
    - Z→ee for electromagnetic signals
    - Prompt photons, Z+jets, W→jj for hadrons
- **Response to low transverse momentum physics**
  - Particle flow in "minimum" bias physics
    - Understand modeling for LHC!
  - Needed to correct for underlying event and pile-up
- **Measure Standard Model Physics**
  - Inclusive jet cross-section
    - Hard to believe discoveries if standard physics is not seen!
  - Particle density functions of the proton
    - Needed for all cross-section analysis

Transverse momentum balance in direct photon production

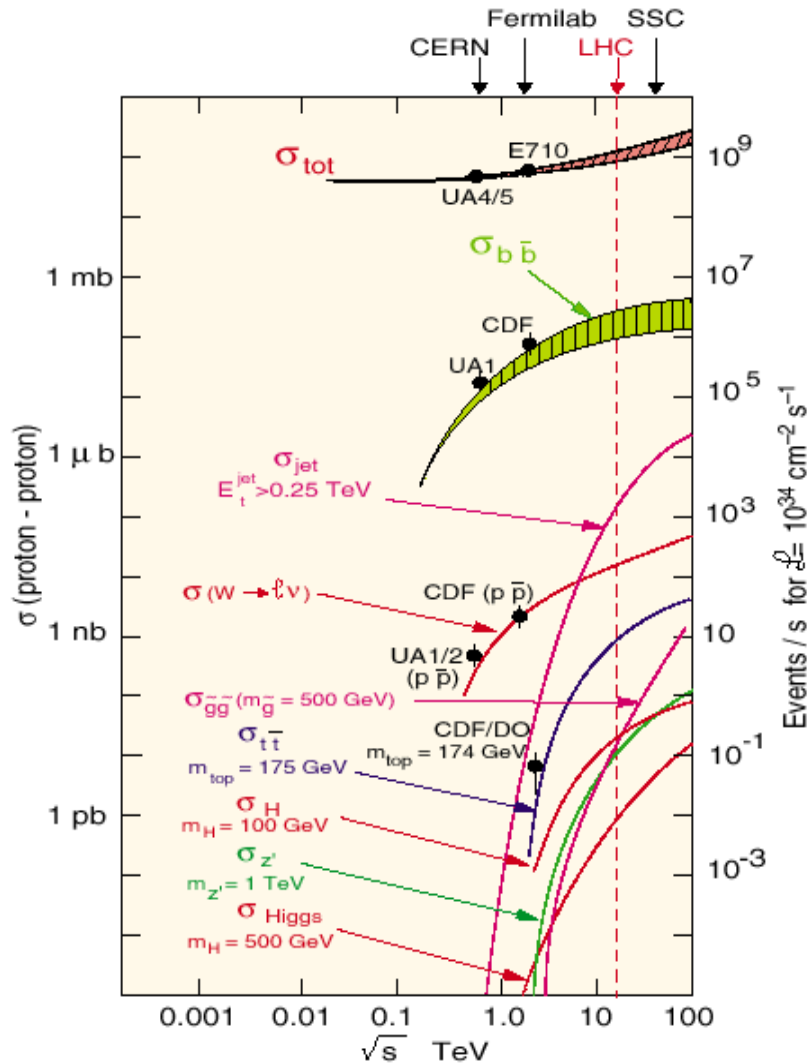


$W \rightarrow jj$



pp Collisions @ LHC

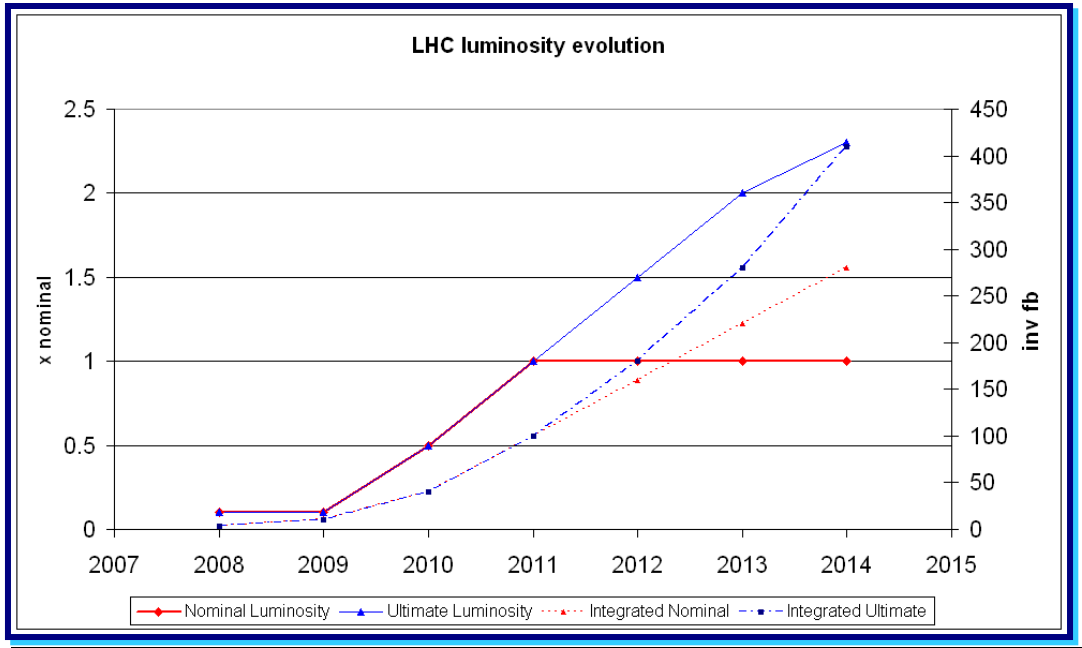
- **Increased reach on various final states**
  - ~100 times more top-anti-top pairs than Tevatron
  - Higgs cross-section several orders of magnitude larger
    - Discovery potential!
  - Enormous increase of inclusive jet cross-section
- **Potentially small signal-to-background ratios for discoveries**
  - Background is Standard Model
    - E.g. top pairs for Higgs!
    - Needs to be well understood
  - Large statistics may afford hard cuts on event topologies to increase signal significance

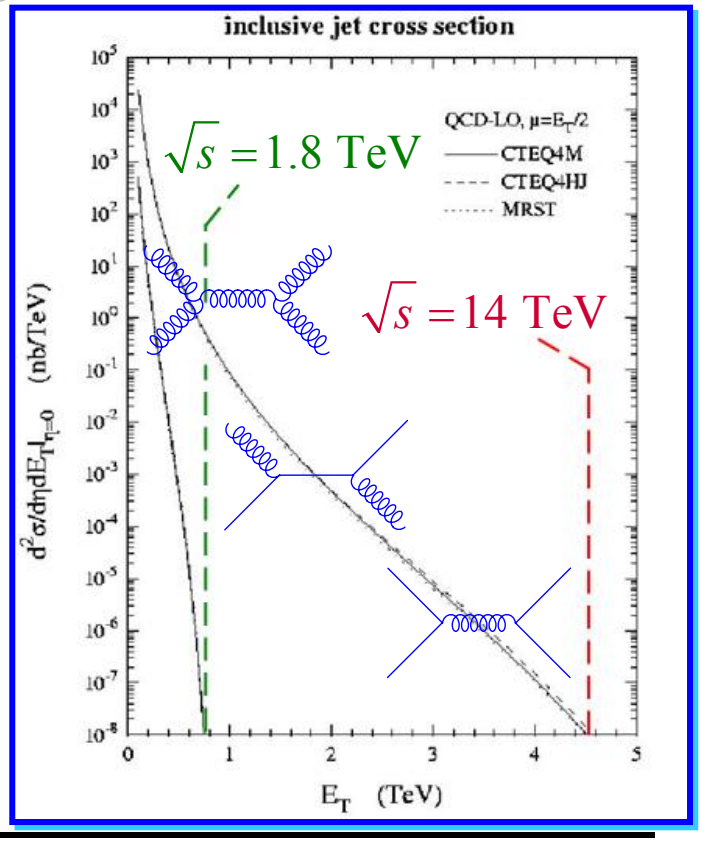


Standard Model @ LHC

Jet physics

- High transverse momentum jets quickly accessible!
  - 100,000 jets with pT > 1 TeV at 1 fb^{-1}
- First attempt at cross-section as early as 2009?

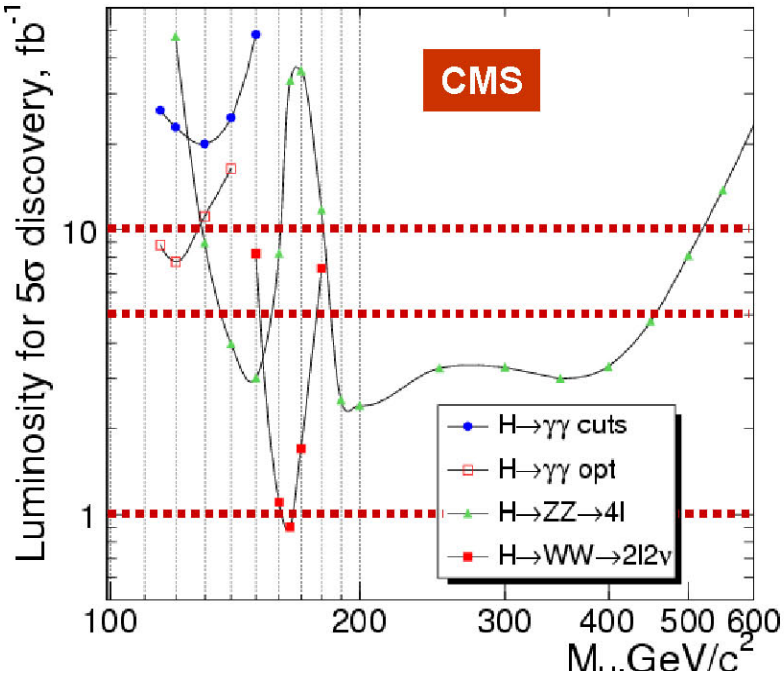


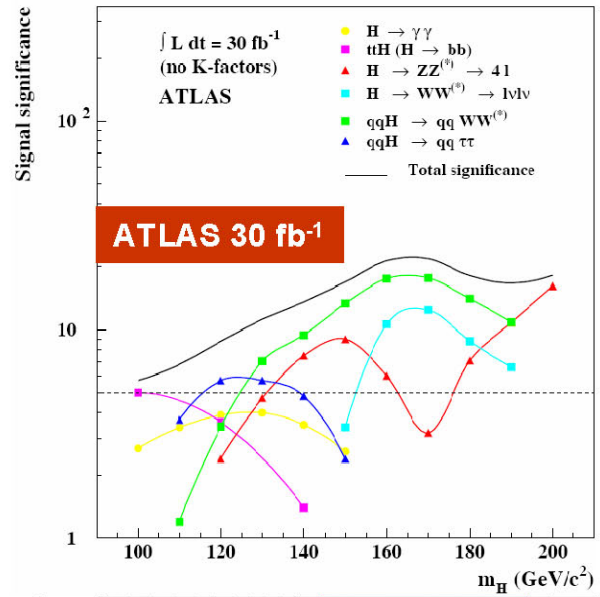


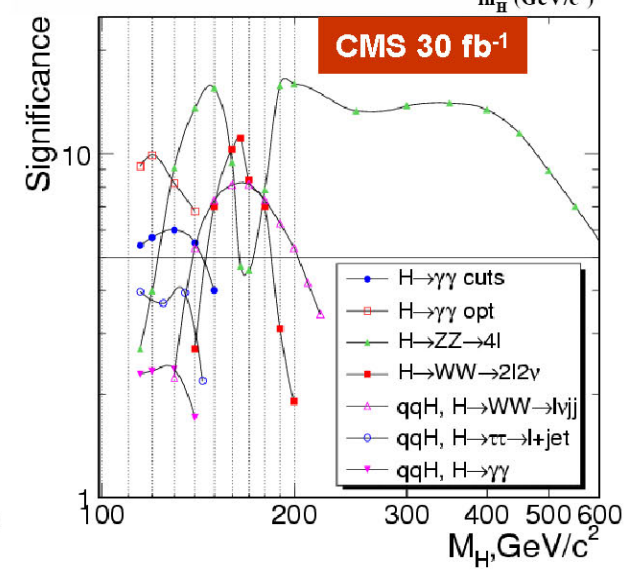
Discovery Physics: Higgs

- **Main goal of LHC: find the Higgs particle!**
  - Search will start day 1
    - Expected mass range 115-160 GeV/c^2
  - But significant statistics needed for full discovery
    - few 100 pb^{-1}: some final state exclusions
    - ~1 fb^{-1}: discovery if 160-180 GeV/c2
    - ~10 fb^{-1}: full mass range covered
- **Unlikely in the first two years**

Collected from T.Vickey's talk at Moriond 2008!

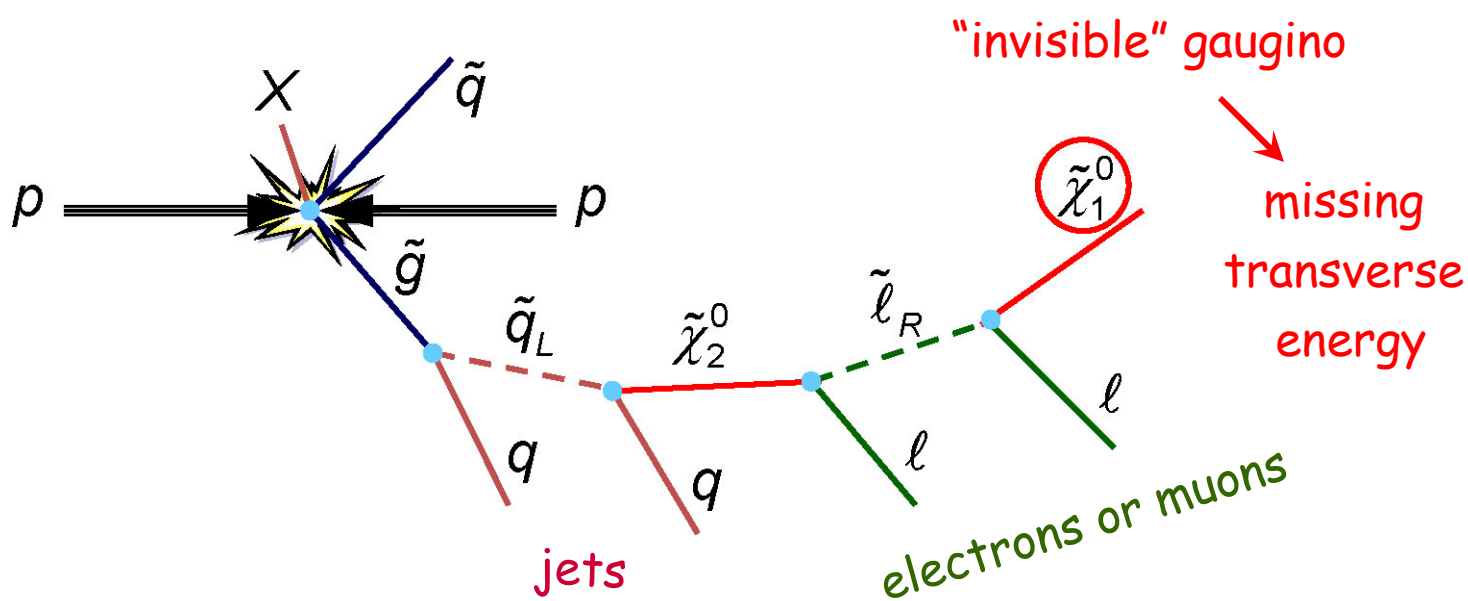






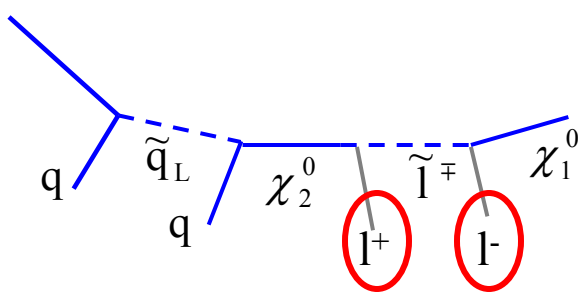
New Physics: SUSY

- Focus on (minimal) Super Symmetry
  - Some signatures can be quickly detected
  - Typical "busy" final state from long decay chains with several leptons, jets, and significant missing transverse momentum

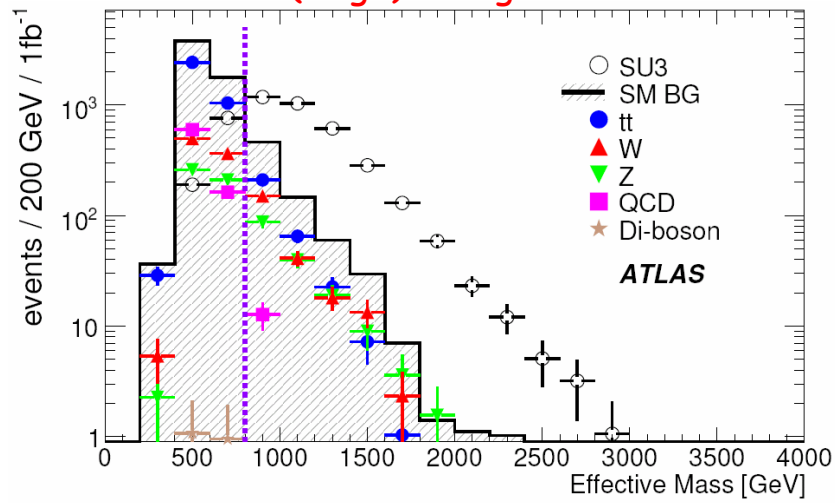


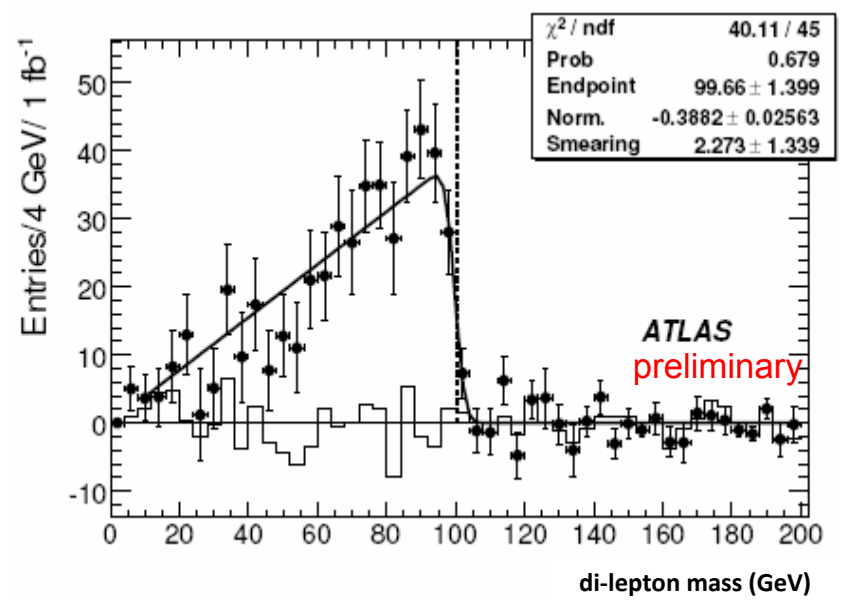
SUSY Searches

- **Inclusive effective mass spectrum**
  - $M_{eff} = \sum |p_{T,i}| + E_{T,miss}$
- **Exclusive search**
  - Ask for same flavour, opposite charged leptons in decay chain
  - Look at lepton invariant mass
    - Characteristic kinematic endpoint
  - Small background
    - Early discovery possible?



Note top-anti-top pair production is (large) background!





Outlook

- **The LHC experiments are getting ready for data**
  - Important early data to understand backgrounds from multiple interactions and underlying event
    - Analysis strategies for soft physics triggers lined up, but extraction of input for models challenging due to detector acceptance and resolution limitations
  - Initial physics analysis is prepared and tested for Standard Model physics
    - Electroweak and QCD
    - Recent and ongoing important tests of worldwide computing infrastructure due to large amount of data
- **Early discoveries possible**
  - Higgs discovery faces large background
    - Unlikely very fast
  - Some new physics indications early on
    - SUSY candidates
    - But good understanding of detector required
- **We all hope for first collisions this year!**
  - At least useful data for commissioning of the detectors for physics