What to expect at LHC

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BERKELEY LAB

Outline

- Comments on LHC and detectors
- Early Physics I will give an indication of what might happen quickly
- A New Physics topic
  - Little Higgs Models
- Conclusions and Lessons.

LHC Status and Schedule

"Geneva, 17 December 2004. Speaking at the 131st session of CERN Council today, the Organization's Director General, Robert Aymar, confirmed that the top priority is to maintain the goal of starting up CERN's Large Hadron Collider (LHC) in 2007. ."

Status is updated monthly at

`http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.as`

LHC operation

- Single Beam operation – April 2007
- Collisions – June 2007
- Operation in "low luminosity mode" for 3 years 2×10^{33} cm^{-2} sec^{-1}
- 1 month per year of heavy ion running.
- Full luminosity in $\sim 10^{34}$ cm^{-2} sec^{-1}, 20 interactions per crossing cause some degradation in performance $e.g.$ b-tagging.
- Some detector elements have been staged and will not be available at turn-on. In the case of ATLAS: Middle layer of pixels, some muon chambers, little impact at low luminosity.
- Trigger/DAQ staging means less rate – impacts $b-$physics: Could be restored with extra funding.

Further ahead?

A further increase of a factor of 10 luminosity will occur eventually

Requires major changes to detectors ($e.g.$ tracking, DAQ)

Given lead times this must start now.

There have been physics studies

There has been discussion about upgrading the energy.

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I will focus on the next few years

Blank

Characteristic New physics signatures at LHC

Not all present in all models

Heavy objects decay into Standard Model particles with high energy

$\not\!\!E_T$ from ν or other new particles

High Multiplicity of large p_t jets

Many isolated leptons – from W, Z or directly produced

Copious b production – "democratic decays?"

Large Higgs production – this may be a standard model particle

Isolated Photons

Quasi-stable charged particles – like a heavy muon.

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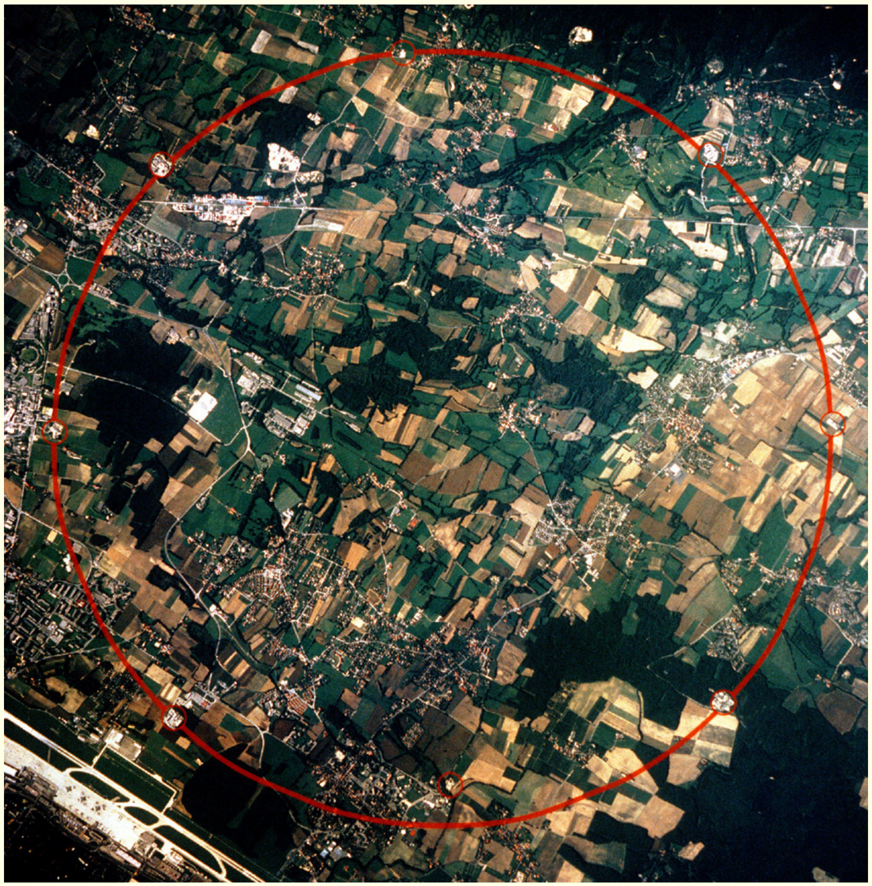
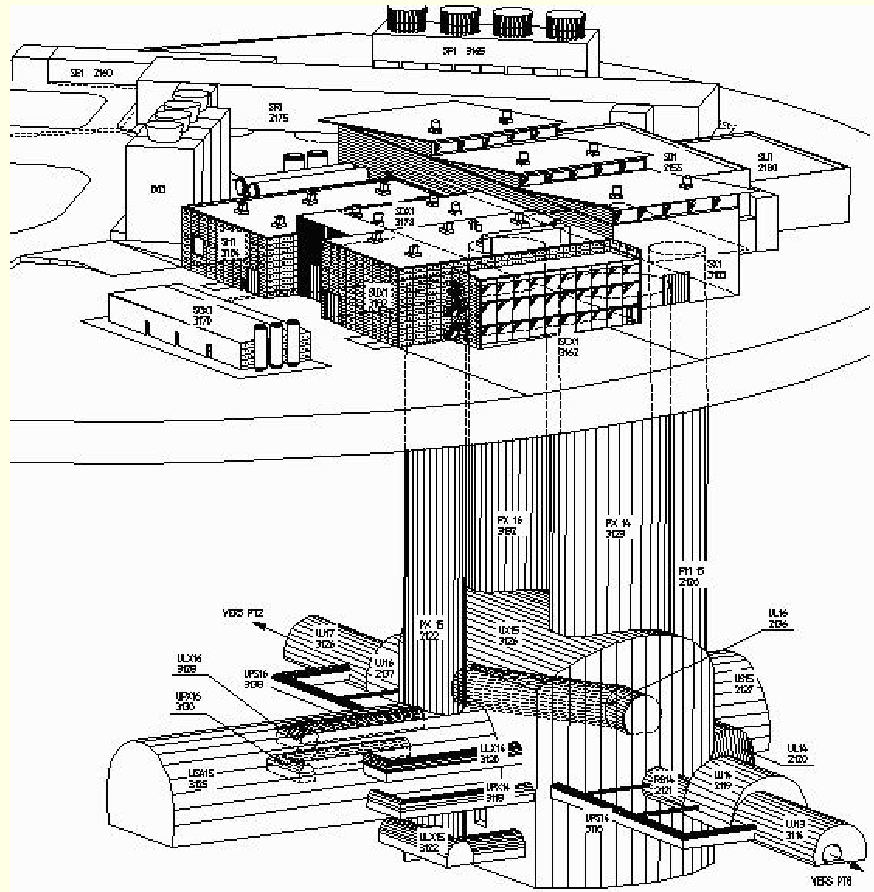
N.B.Production of heavy objects implies subset these signals

Important for triggering considerations

Atlas

Surface building – across street from CERN main gate





Above

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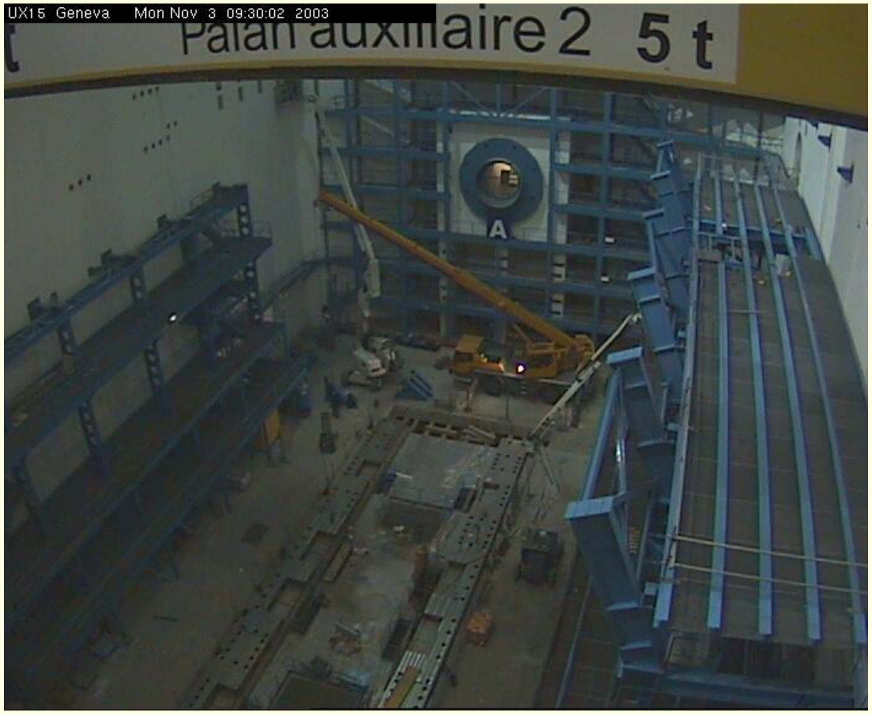
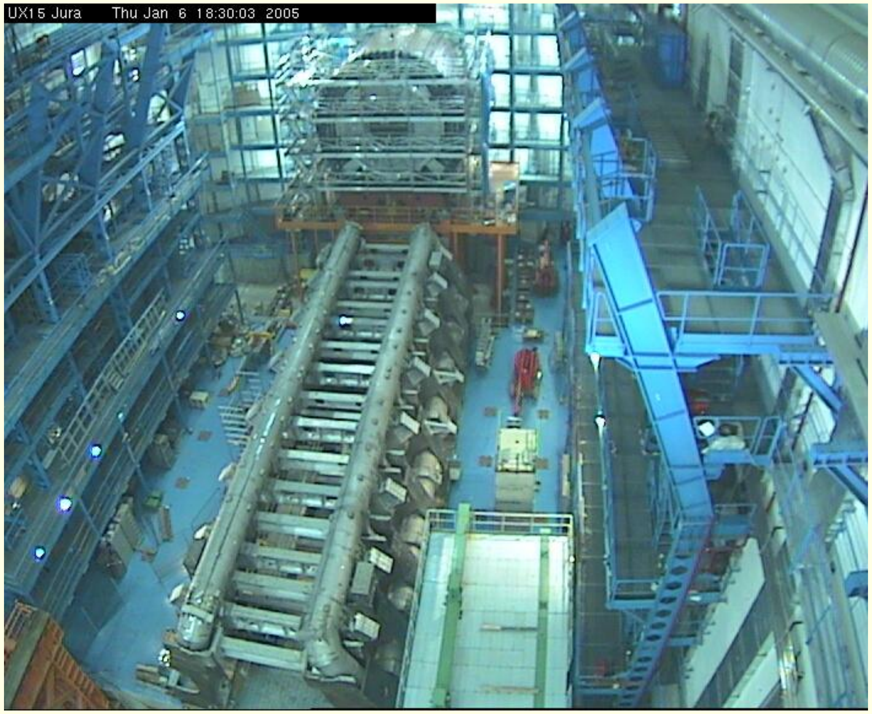


Last weeks photos

LHC Beam is at A and C

In the center is the support structure for the detector



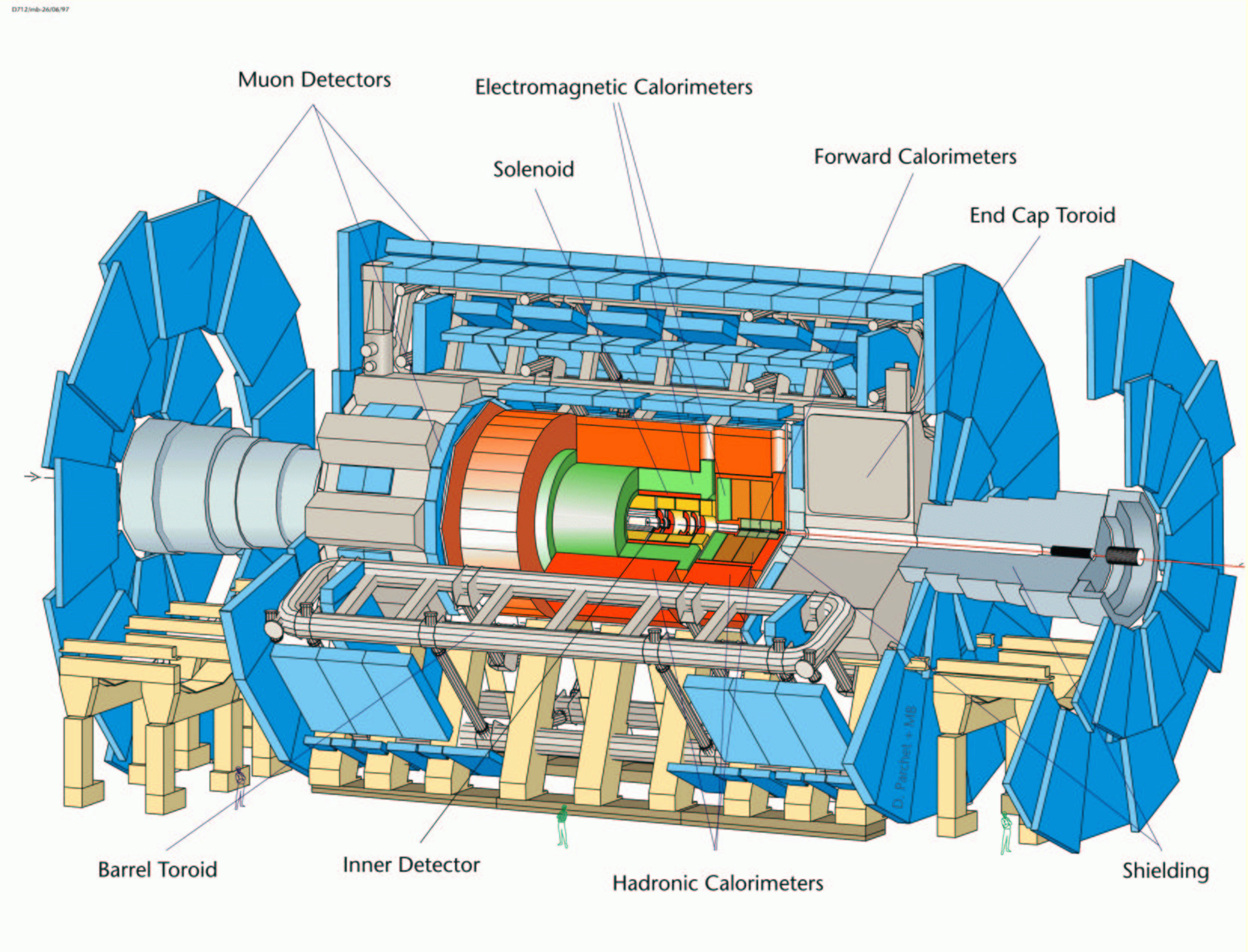
Comments on ATLAS and CMS

ATLAS and CMS are aimed at "new physics"

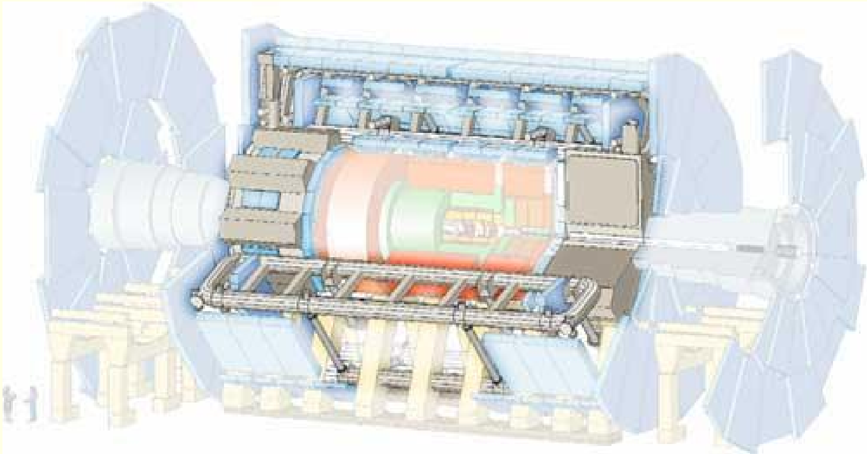
"Full acceptance" for physics objects, *i.e.* leptons and jets, missing E_T

Many detector choices driven by specific physics goals (*e.g.* LiAr Calorimeter) Equal response for e and μ

Physics performance is expected to be similar to CMS, technology choices are quite different


D712/mb-26/06/97
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

Magnet system

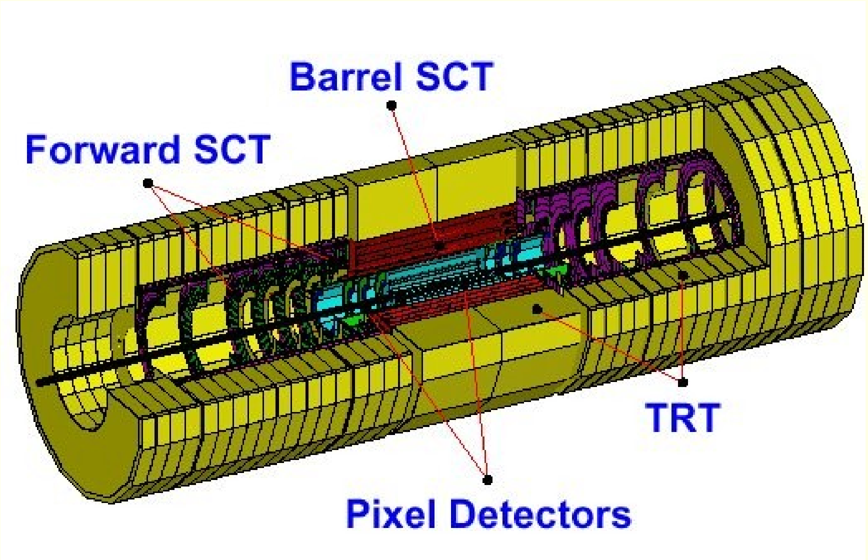


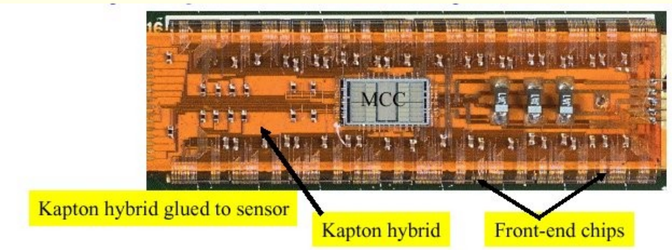
Solenoid – Central tracking

Muon endcap

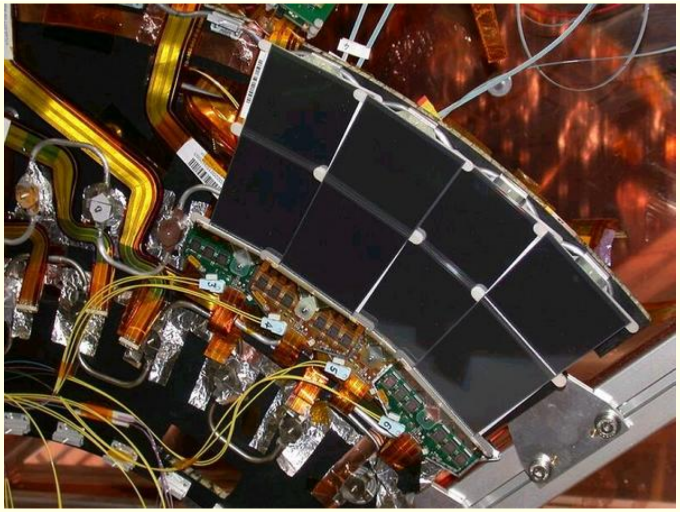
Central toroid under assembly

Inner Detector





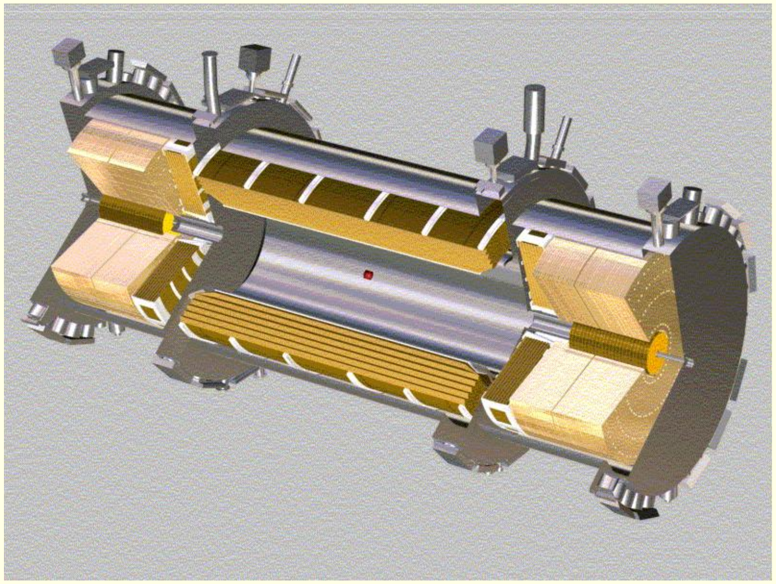
Pixel Hybrid



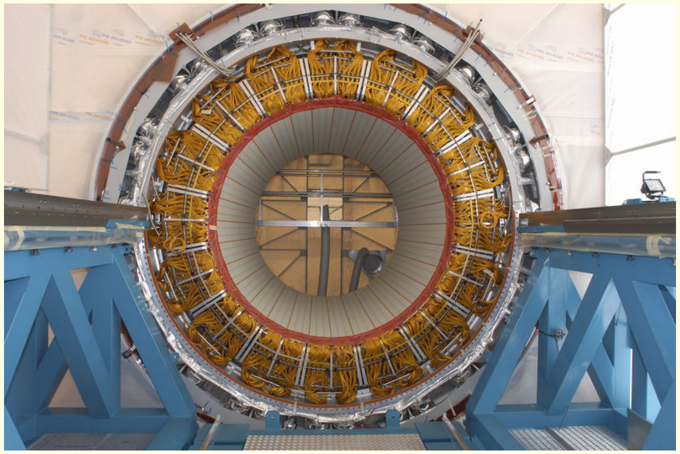
Forward Si Strip Module

Forward TRT wheel

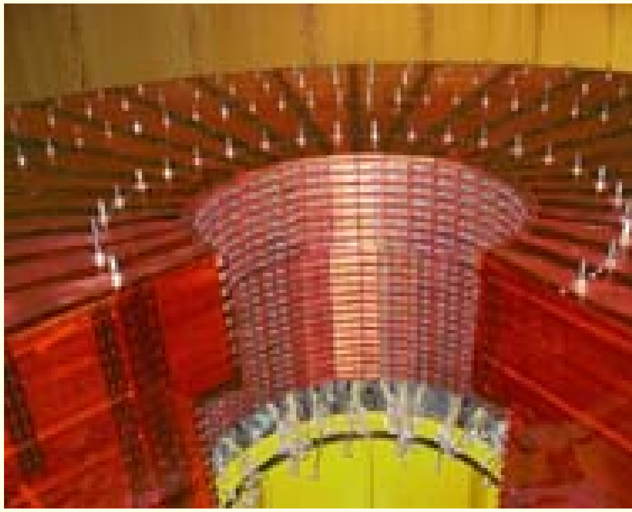
LiAr (EM) Calorimeter



Barrel EM

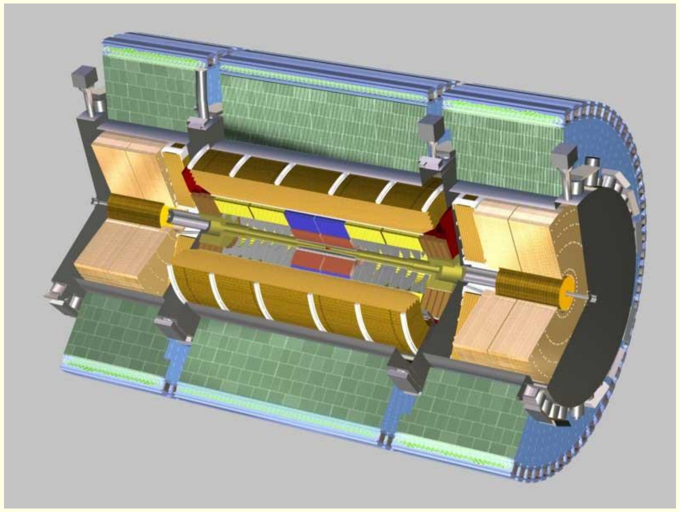


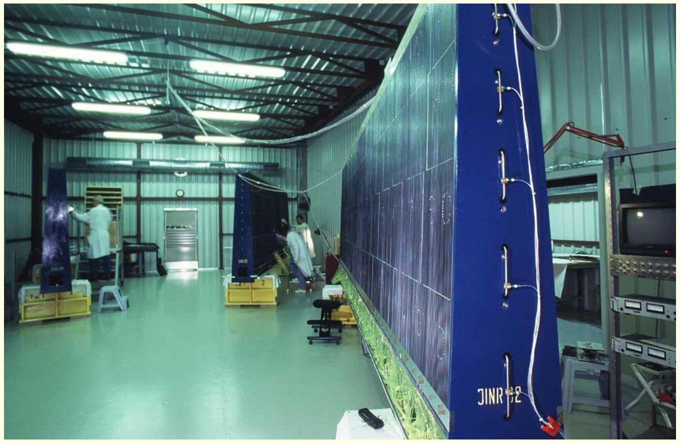
Barrel Cryostat



hadronic end cap

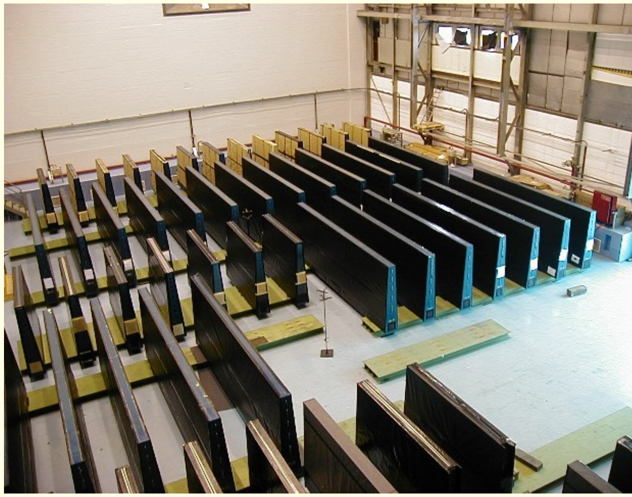
Tile (Hadronic) Calorimeter





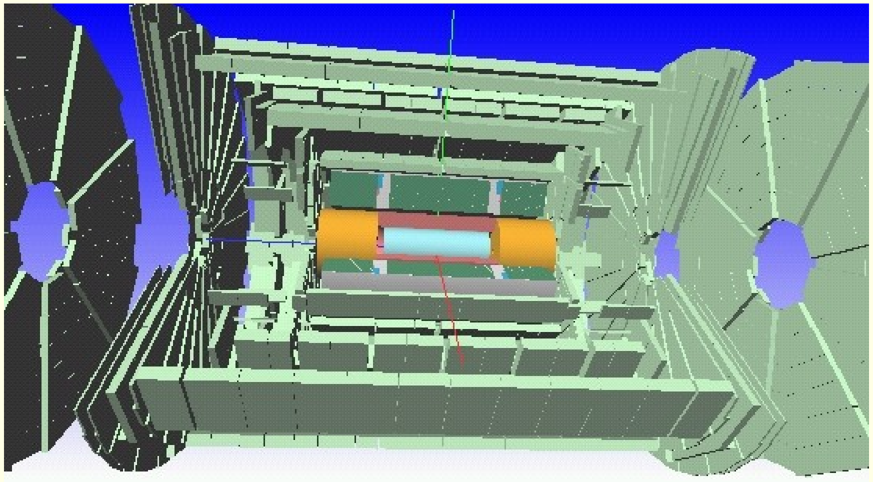
Single element

Barrel



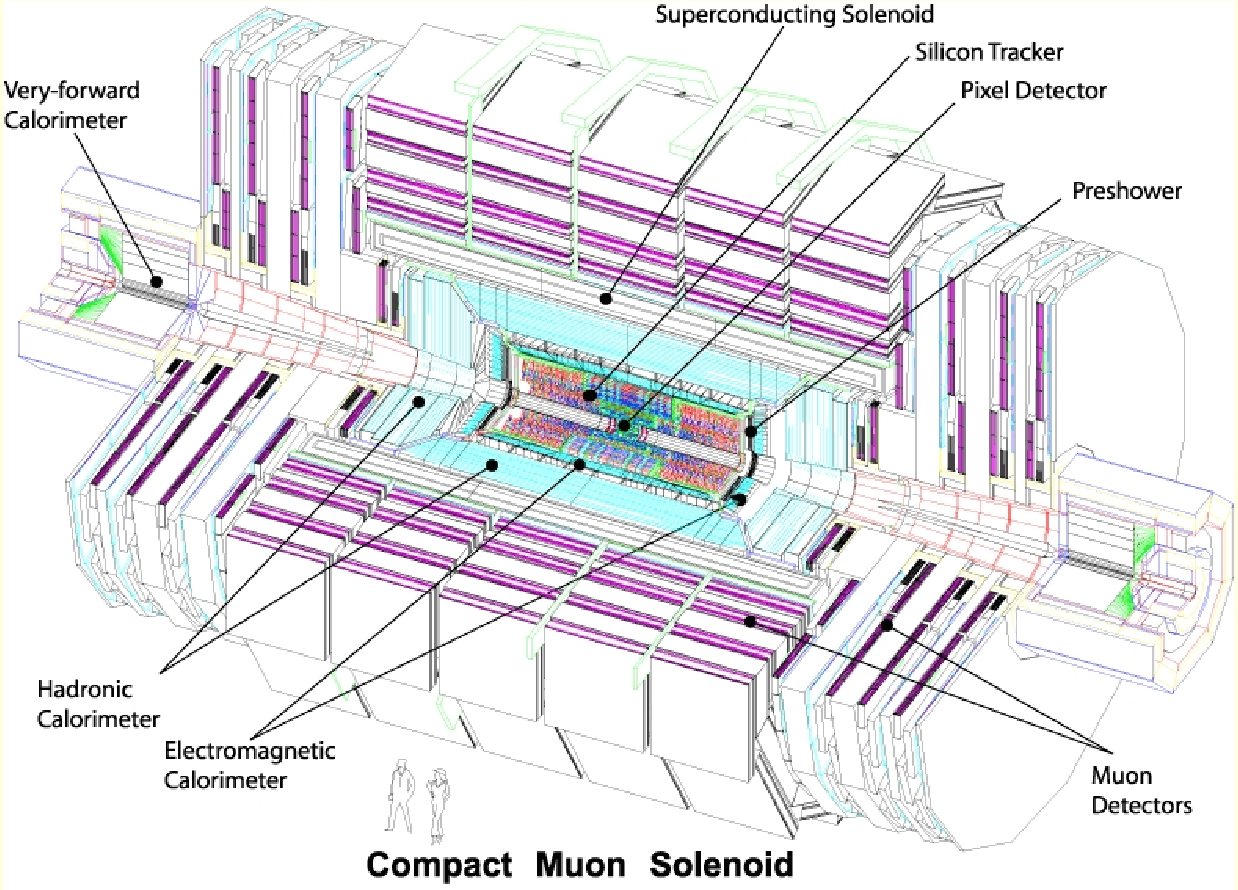
Sections in storage

Muons

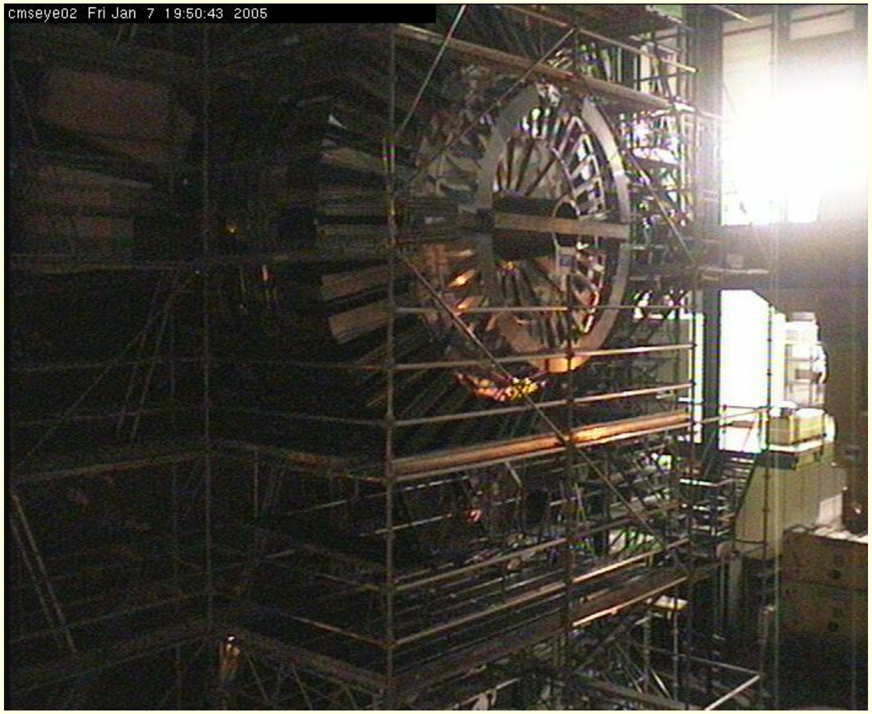


CMS

Much smaller than atlas, stronger solenoidal field, all Si tracker.

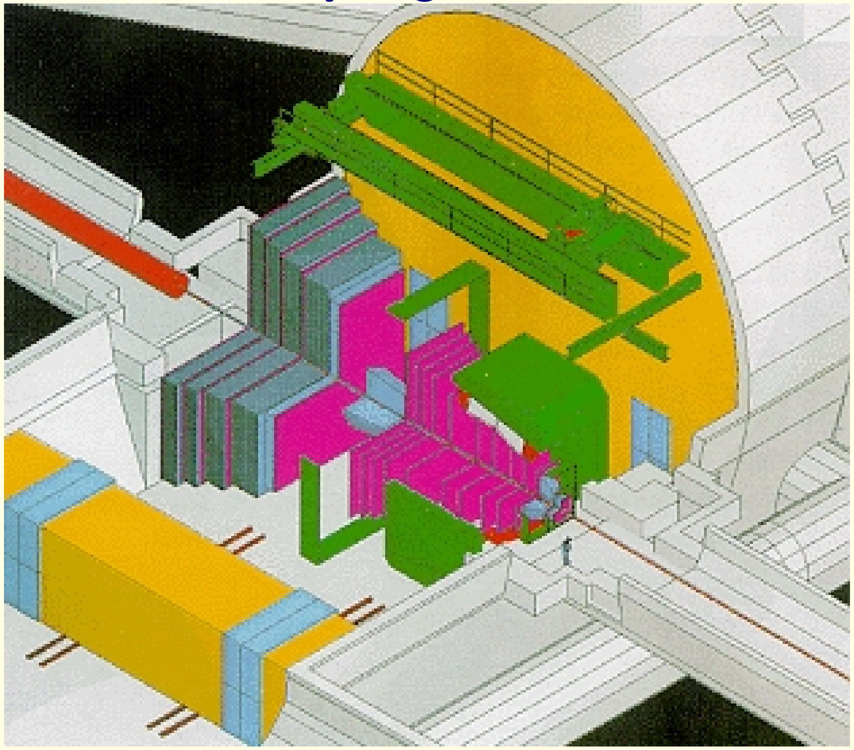


Surface building – in France



LHCb

Forward region: large acceptance for B's
Particle ID
Low luminosity region



ALICE

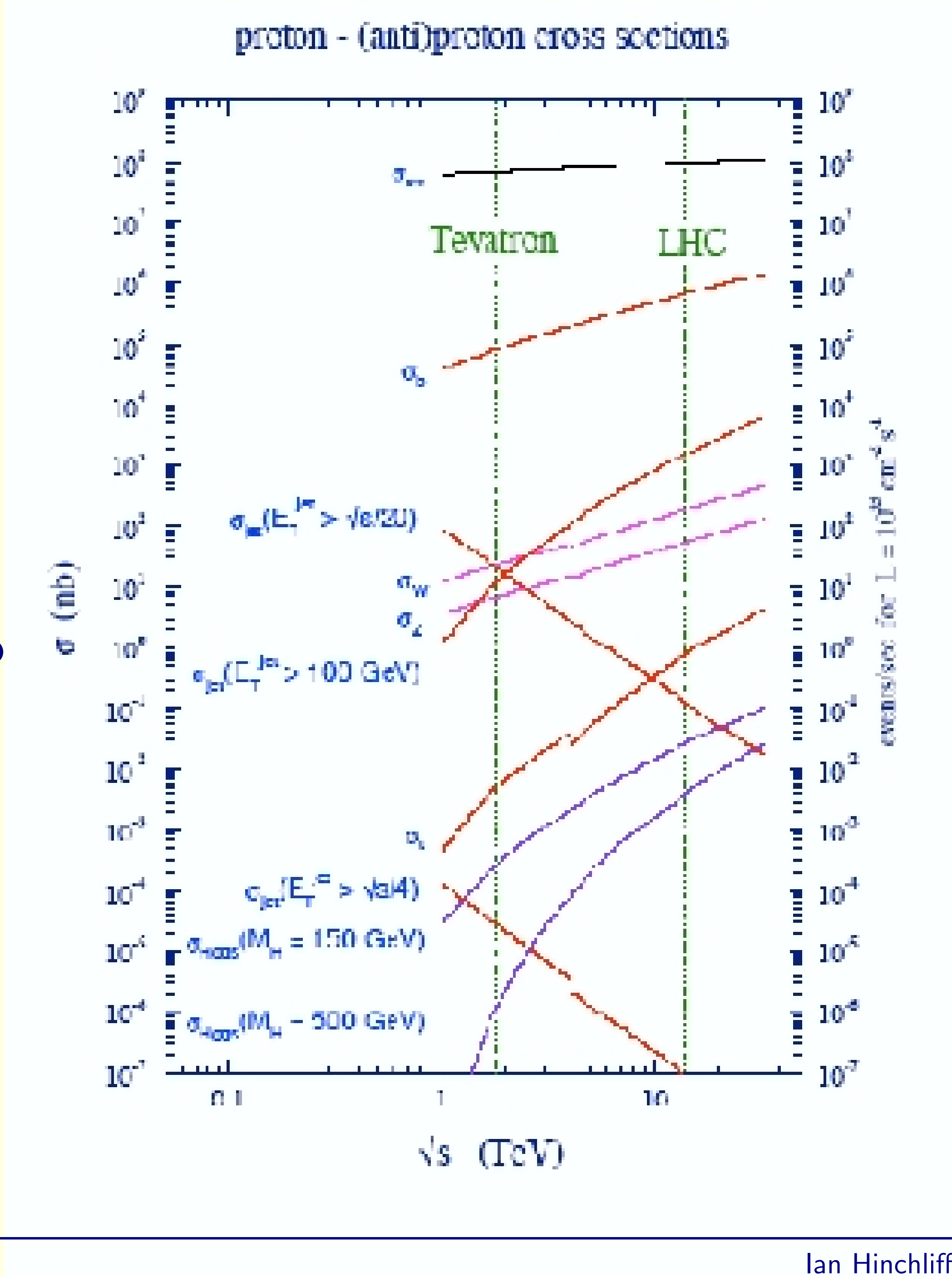
LHC will run one month per year with Pb-Pb collisions //

ATLAS and CMS may do some Heavy Ion physics (Jets and J/ψ production), but ALICE is a dedicated detector.

But... Start with what you think you know

Huge range of rates

How well do we expect to calculate them



Backgrounds – Measuring and Calculating

At present, we rely on MC for signal and background estimates

There are uncertainties in rates from PDF's, higher order QCD

Most of these do no matter at the moment, They will matter once data appears

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The MC/theory tools must match the experiments

Don't forget that the LHC will be a precision machine.

Some processes are not well understood: For these we need flexibility in the modelling

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My concern: underlying and min-bias events

Affects process that need forward jet tagging $e.g.$ $WW - scattering$ or central jet veto

Will be measured once data exists and MC will be tuned to agree... But

Speech

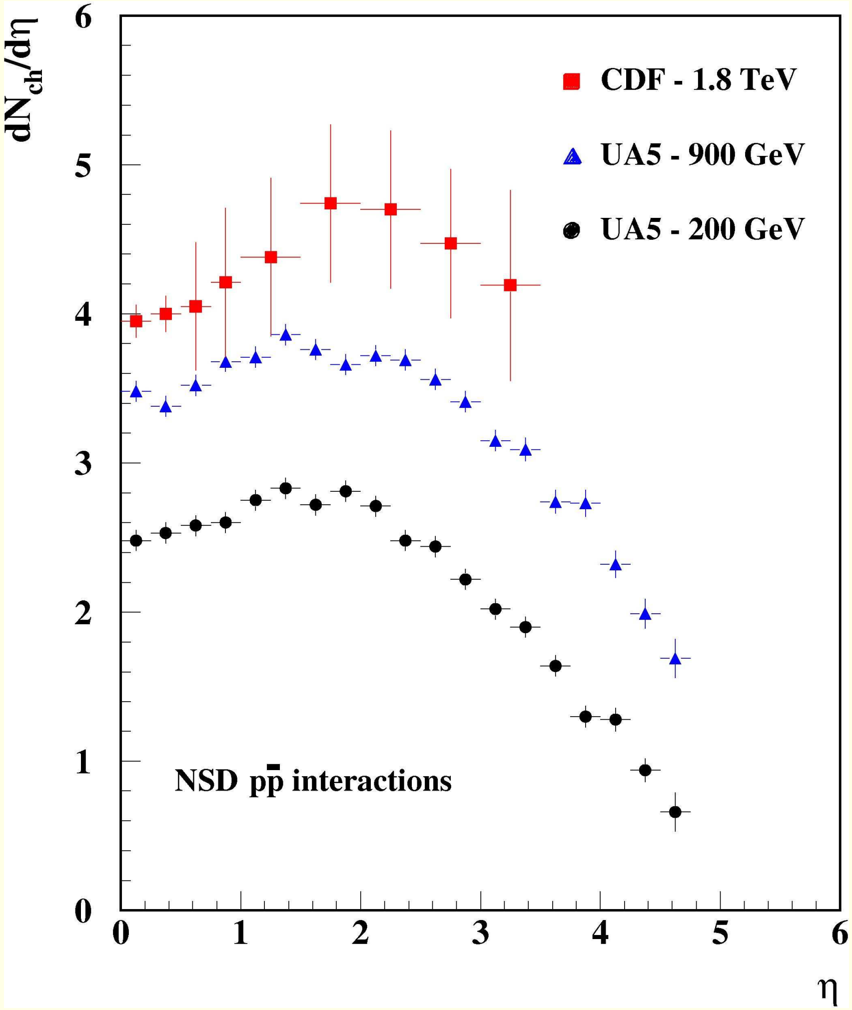
Getting Started: QCD

New energy regime so all data is important.

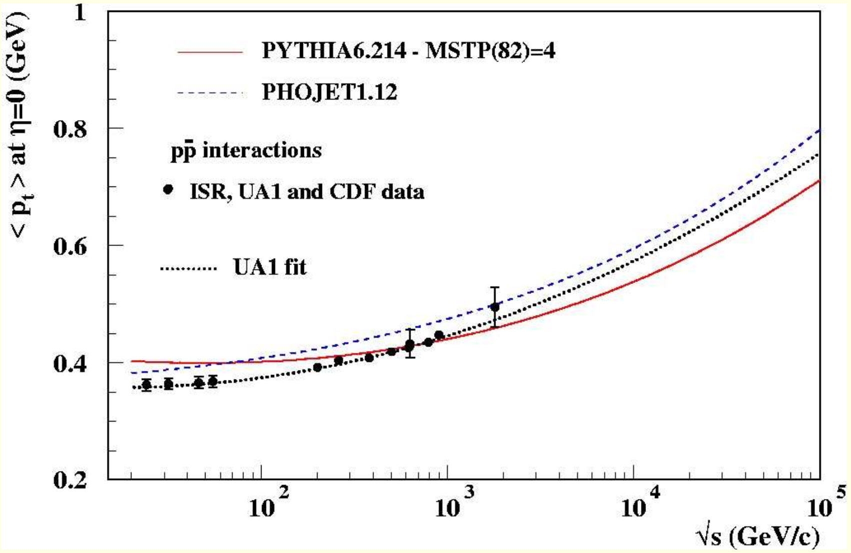
$1mb^{-1}$: Measure $dN/d\eta$ and dn/dp_T for min bias: Theory predictions now please

LHC line on here.

It needs working tracking or EM calorimeter: Precsion not needed

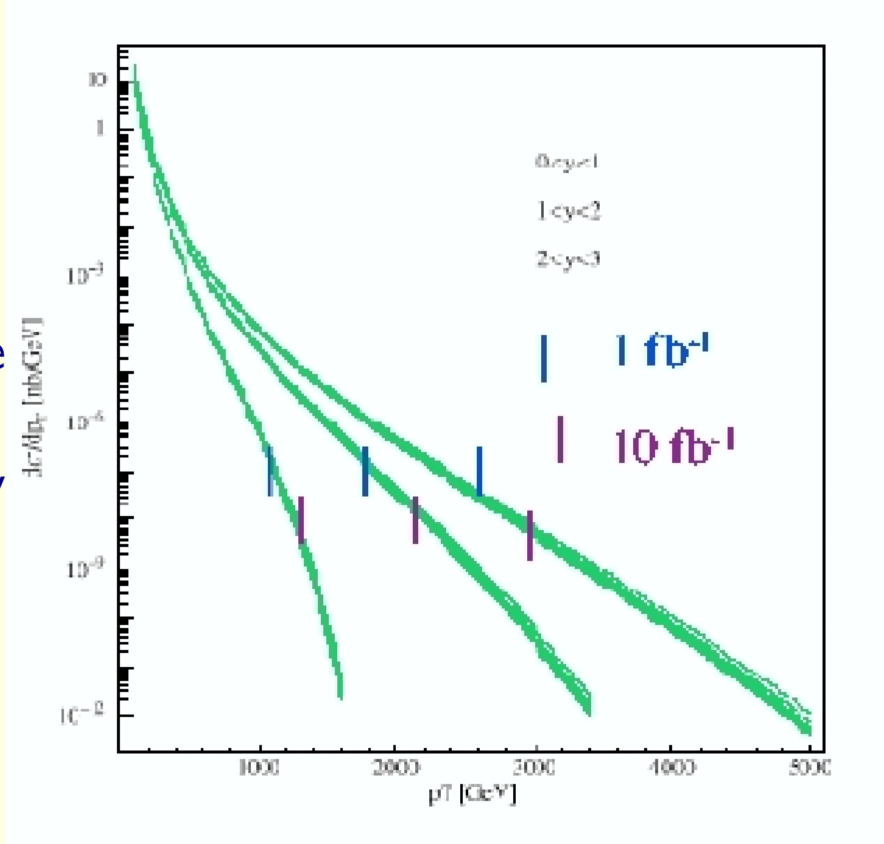


Cross section is much harder.
may never be done

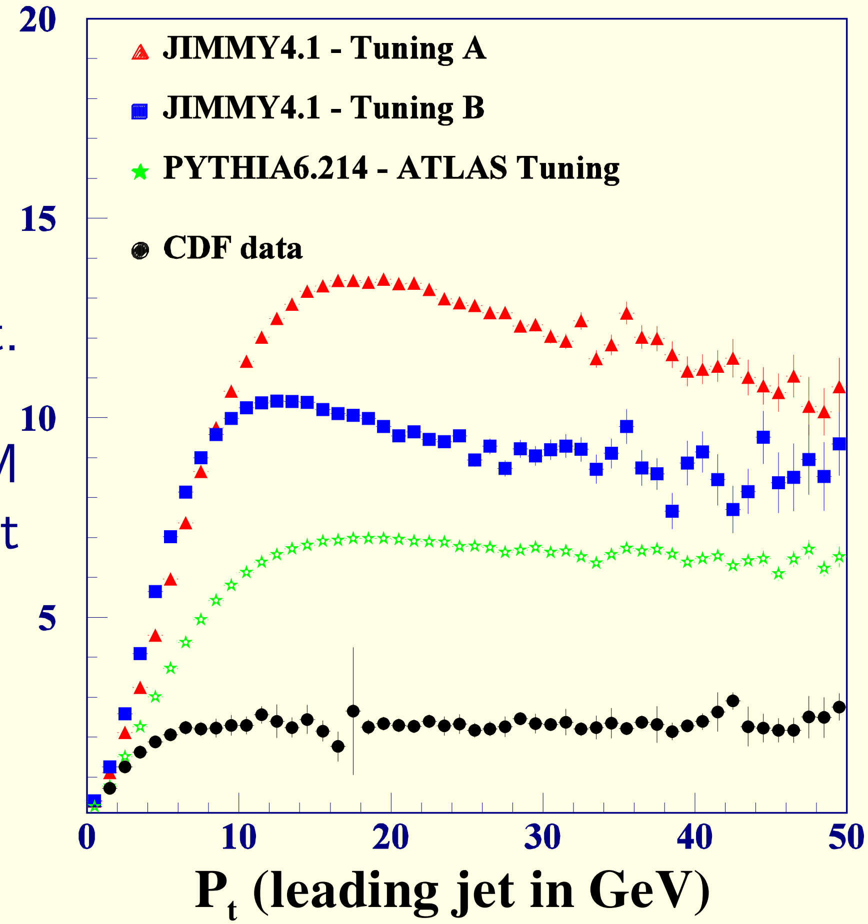


Next comes real QCD

This starts immediately and never ends
Don't expect any new physics at the bottom end
Biggest uncertainty comes from Jet energy scale (later)



$100 \mu b^{-1}$: Measure $dN/d\eta$ and dN/dp_T for low p_T jets:



Start QCD study of underlying event. Some predictions

It needs working tracking or EM calorimeter and jet finding: Precision not needed

These parts of QCD are least well understood: they are irrelevant in e^+e^-: Speech

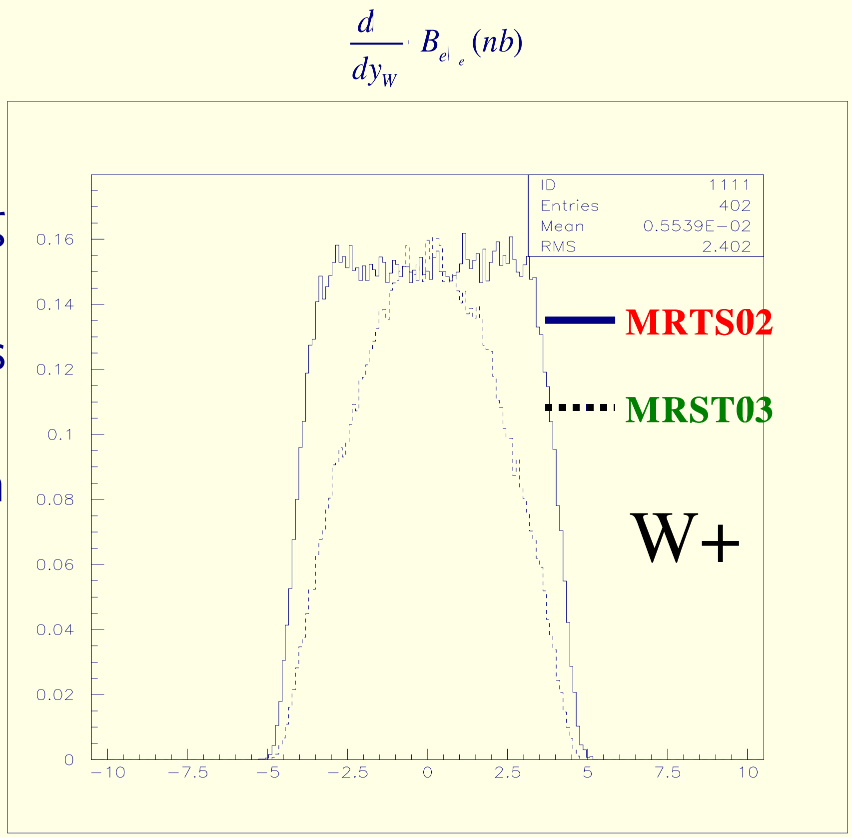
Now go and re-evaluate the jet tagging and vetoing, that you expect to use in Higgs searches

$10pb^{-1}$: 100 jets beyond the tevatron kinematic limit:

Electro-weak

$\sigma(W) \times BR(W \to e^+\nu) \sim 15nb$
High statistics starts with $1pb^{-1}$

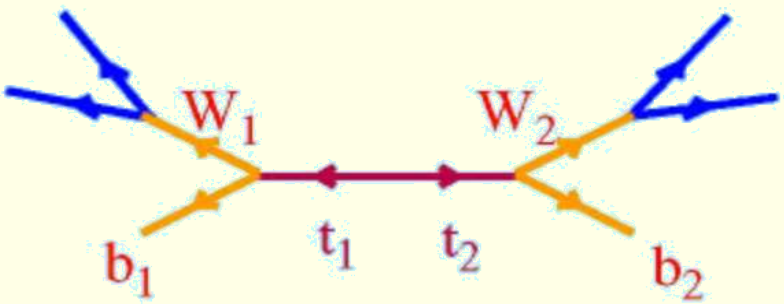
Used to calibrate EM calorimeters, missing E_T, understand e/μ behaviour
Physics measurements of cross-sections and structure functions
A long term goal will be precision measurement of W mass:
"I may be retired by then!"



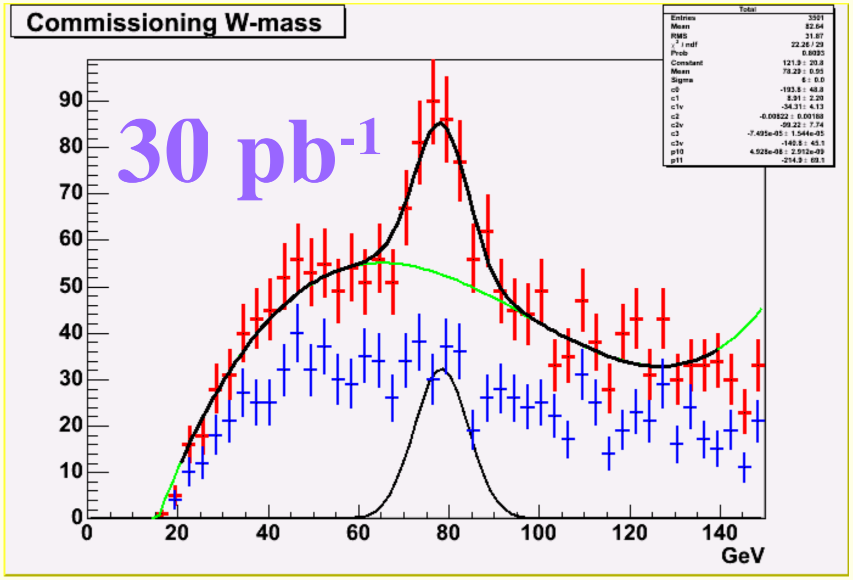
Top

- $10pb^{-1}$ (1 day at 1/100 of design luminosity) gives 8000 $t\bar{t}$
- S/B better than Tevatron
- Ultimate Gaol is precise measurement of top mass
- Intially, Calibrate the detector, measure cross-section

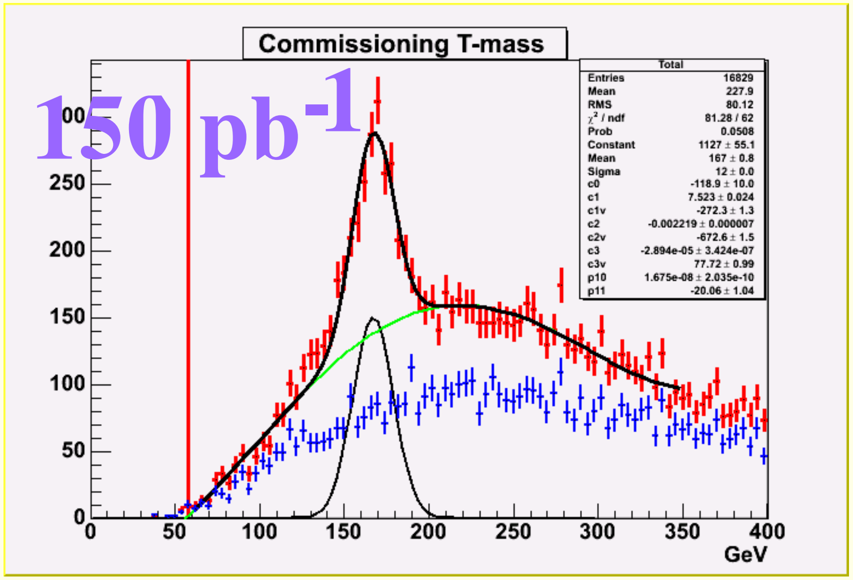
Use the semileptonic decay
Clean and plenty of rate
No b-tagging is needed It needs working tracking or EM calorimeter and jet finding



Use these to calibrate jets from W



assume b-jet scale is same (approx)
reconstruct top peak
measure cross section



Now have sample of events with two b's for measuring the b-tagging.

Many more

- B production rates
- Drell-Yan
- ψ and Υ
- WW, ZZ, $W\gamma$ at low p_T where SM should be OK

30 days with luminosity 10^{31} does most of this program:

Don't believe any claims of new physics until the above have been done

blank

New Physics

- I see a peak somewhere: Guaranteed to happen
- I see an excess which I cannot explain: Do you really believe the MonteCarlo?
- I'm looking for X and I found it: not surprised

New Physics: Past history

- I see a peak somewhere: OoopsLeon
- I see an excess which I cannot explain: Monojets (mainly $W \to \tau\nu$)
- I see an excess which I cannot explain: High p_t jets at Tevatron (mainly PDF's)
- I see an excess which I cannot explain: Neutrino anomaly (calorimeter not deep enough)
- I'm looking for X and I found it: M(top)=30, 70 GeV (statistics, background)

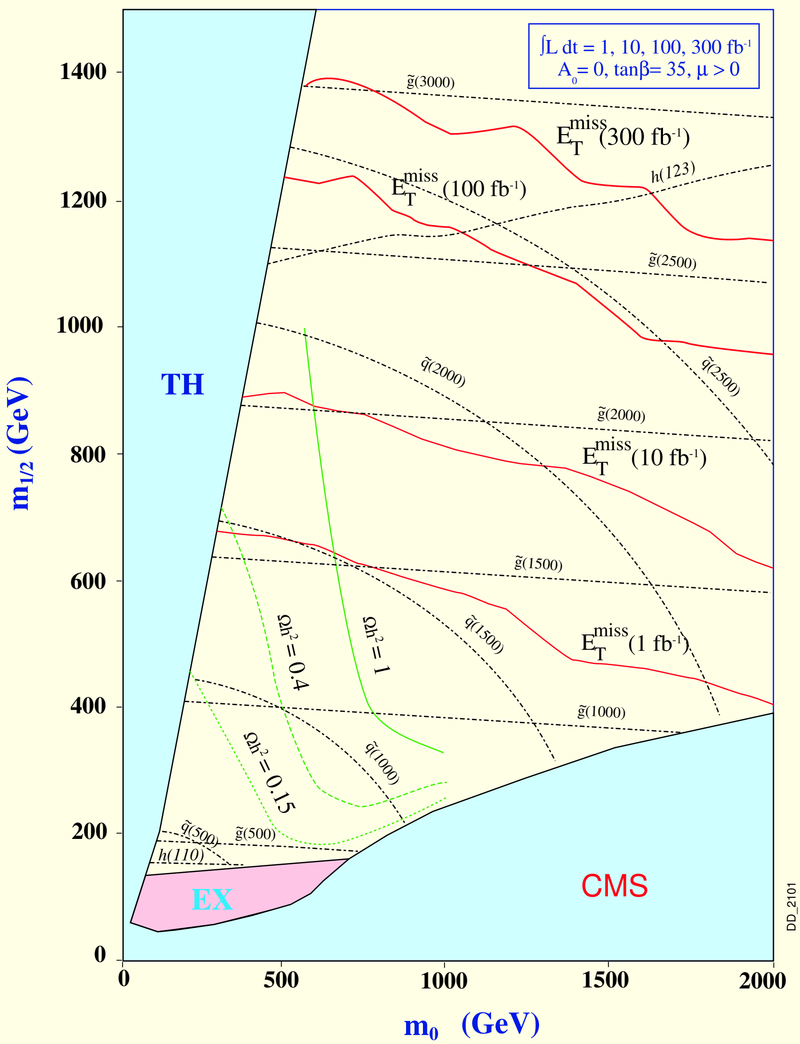
How long to wait before new physics??

- Must be be beyond exisiting limits
- rates must be less than something
- Single production of something $e.g.$ Z'
- Pair production of something

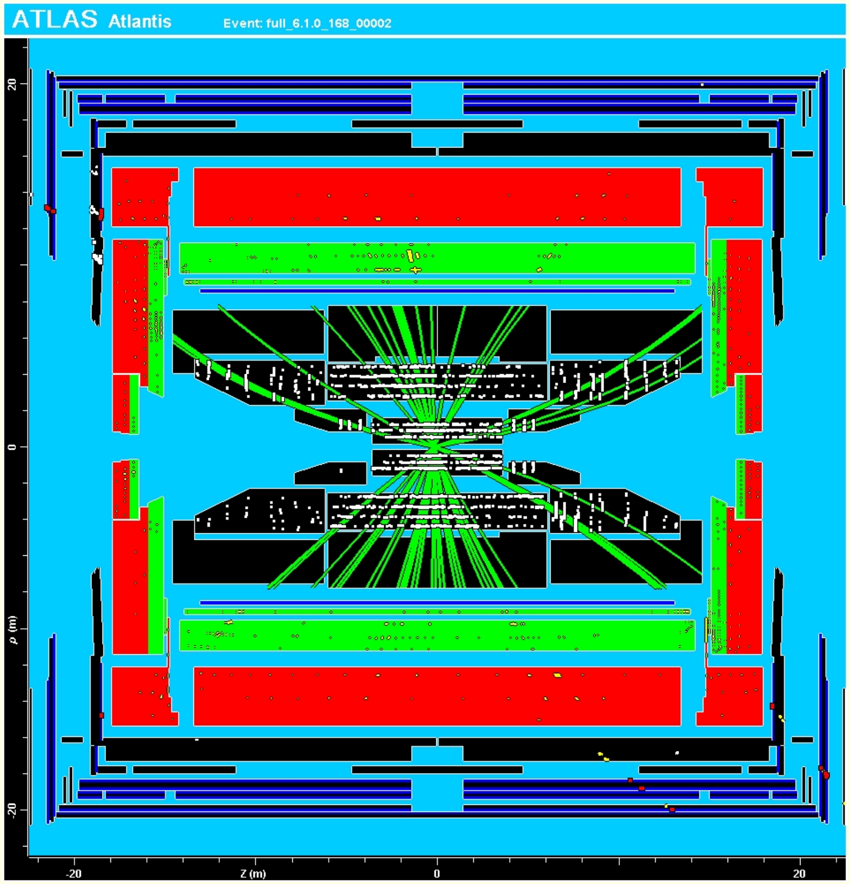
Things with QCD coupling will show up first

Best defined example is SUSY

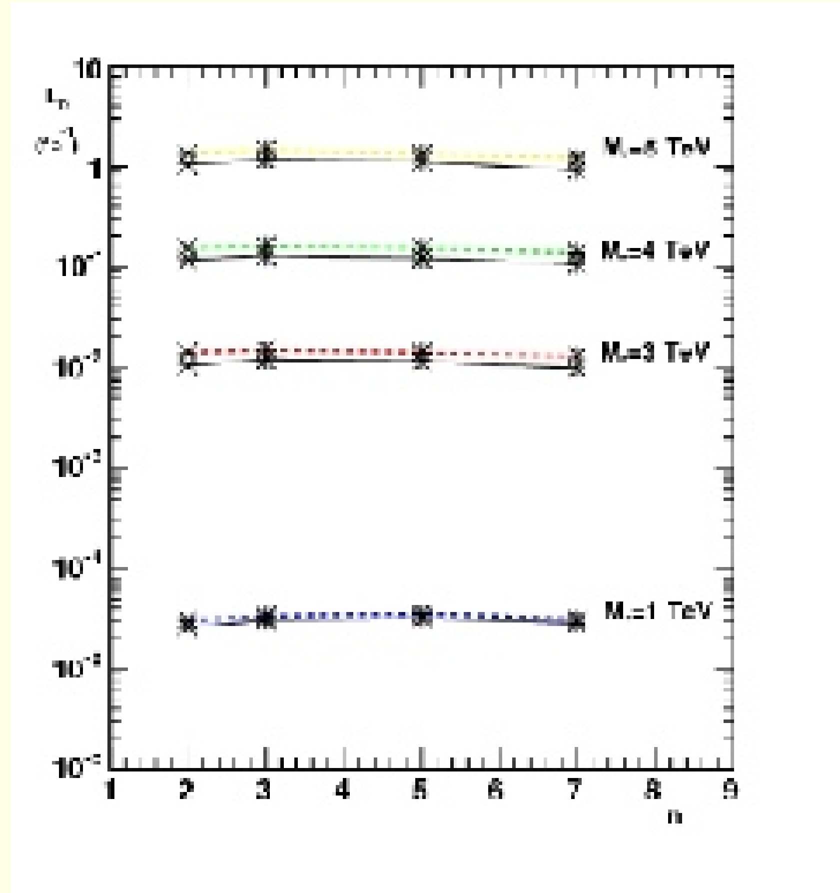
The CMS $\tilde{q},\tilde{g}$ mass reach in E_T^{miss} + jets inclusive channel for various integrated luminosities



Less well defined – Mini black holes



very clear signal
Boltzmann distributuion



Large rate (uncertain)
May not need much luminosity

Little Higgs Models

All data consistent with SM ($g - 2$???)

New particles of mass $\lesssim 10\mathrm{TeV}$ are constrained EW fits, FCNC limits etc

Calculate with a cut off $\Lambda = 10TeV$

top loop $\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim (2TeV)^2$

W/Z loops $\delta m_h^2 \sim \alpha_w\Lambda^2 \sim -(750GeV)^2$

Higgs loop $\delta m_h^2 \sim \frac{\lambda}{16\pi^2}\Lambda^2 \sim -(1.25m_h)^2$

$m_h^2 \sim (100GeV)^2$

Fine tuning of Higgs mass seems to require something else $\sim 1\mathrm{TeV}$

Most dangerous terms are top loop, Higgs loop, W/Z loops

Solve these and problem is $\gtrsim 10\mathrm{TeV}$ where we know nothing

SUSY solves it up to $\sim M_{Planck}$ by removing all quadratic divergences.

Can arrange ad-hoc cancellations by adding a few particles but need a symmetry

Little Higgs models (2)

- Models try to arrange new particles to cancel these effects
- Do this by extending the symmetries of the Standard Model so that the cancellations are forced by the new symmetries – SUSY is best example
- Need a theory with a broken global symmetry to get a massless Goldstone boson.
- Must break the symmetry "in a small way" so that this Goldstone Boson can have interactions and a VEV and play the role of the Higgs.
- Will solve the hierarchy problem; cancellations will appear as needed.
- The models are not simple (they may be "elegant") and not complete.

Arkani-Hamed, Georgi, Burdman, Schmalz, ...

LHC signals

What is the minimal stuff??

- Something to cancel the top loop.
  In the example this is T decays via $T \rightarrow Zt$, $T \rightarrow Wb$, $T \rightarrow ht$ with BR in the proportion $1:2:1$
  Ratio is test of model

- Something to deal with the W loop
  In the example this is the gauge bosons of the other $SU(2) \times U(1)$.
  Once the masses are specified their couplings have one free parameter (θ)

- Something to deal with the H loop
  In the example here this is the Higgs triplet ϕ which is produced via WW fusion

- Very small effects $< 5\%$ in $h \rightarrow gg$ and $h \rightarrow \gamma\gamma$

Masses and decays are model dependent. Higgs sector is most model dependent

Expected range of masses

- Fine tuning means that $f = \frac{\Lambda}{4\pi} < 1TeV(\frac{m_H}{200GeV})^2$
- $m_T < 2TeV(\frac{m_H}{200GeV})^2$
- $M_{W_H} < 6TeV(\frac{m_H}{200GeV})^2$
- $m_\phi < 10TeV$

New Quark

Properties determined by two parameters λ_1/λ_2 and mass.

Two production mechanisms $qb \to q'T$ and $gg \to T\overline{T}$: Former depends on $t-T$ mixing and therefore on λ_1/λ_2

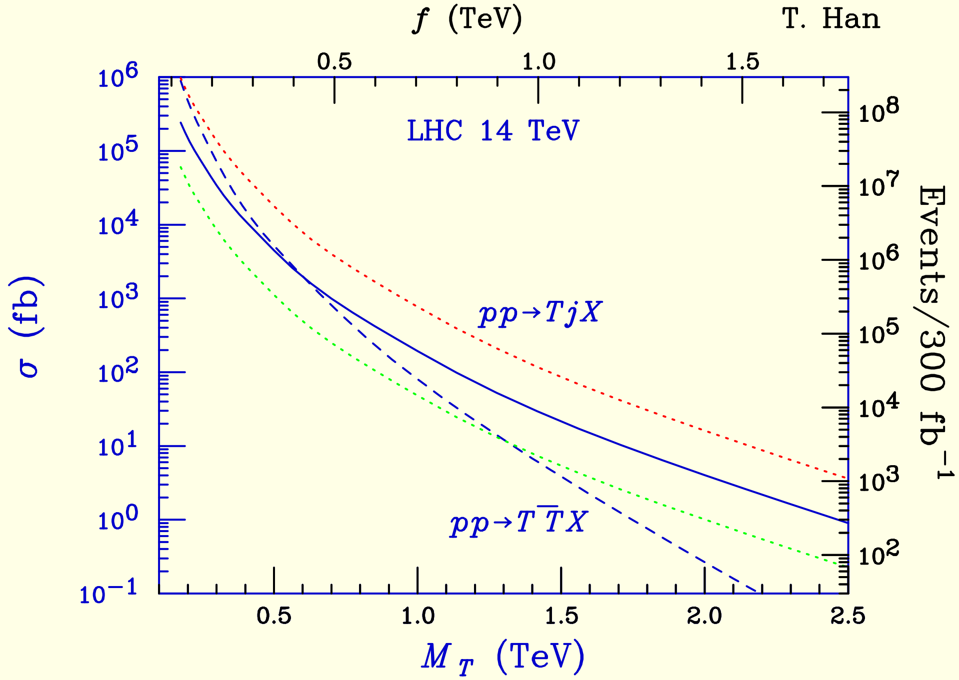


Figure from Han

Single production dominates at large masses

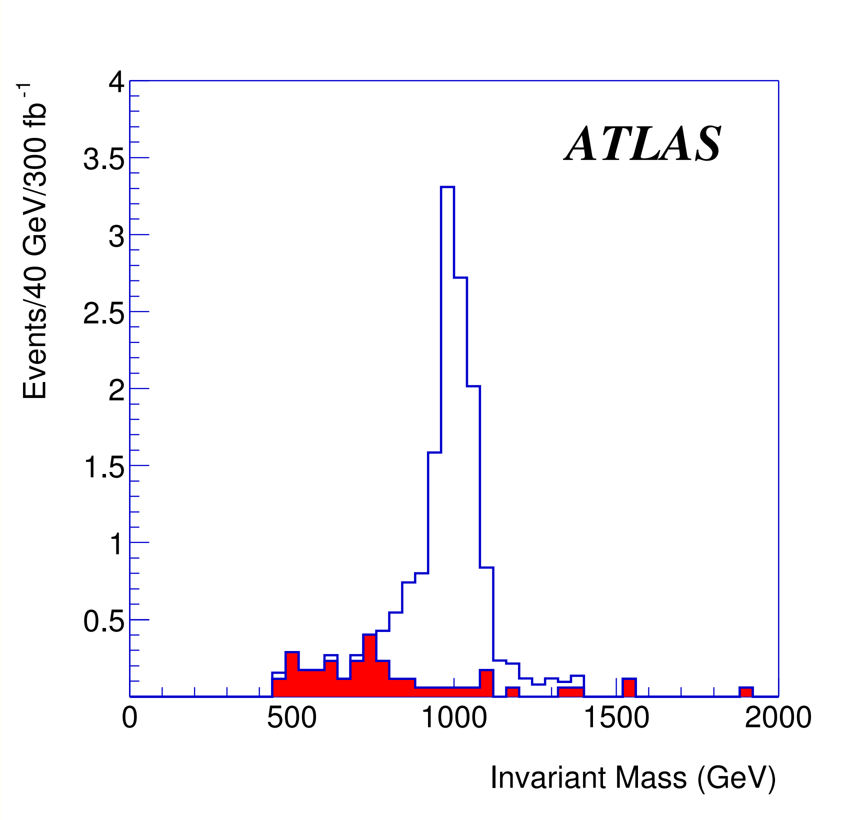
Three single production curves are for $\lambda_1/\lambda_2 = 2, 1, 0.5$

Width is small

Single Production is used in the following: note recoil jet.

$T \rightarrow Zt$

Reconstruct from $Z \rightarrow \ell^+\ell^-$ and $t \rightarrow b\ell\nu$

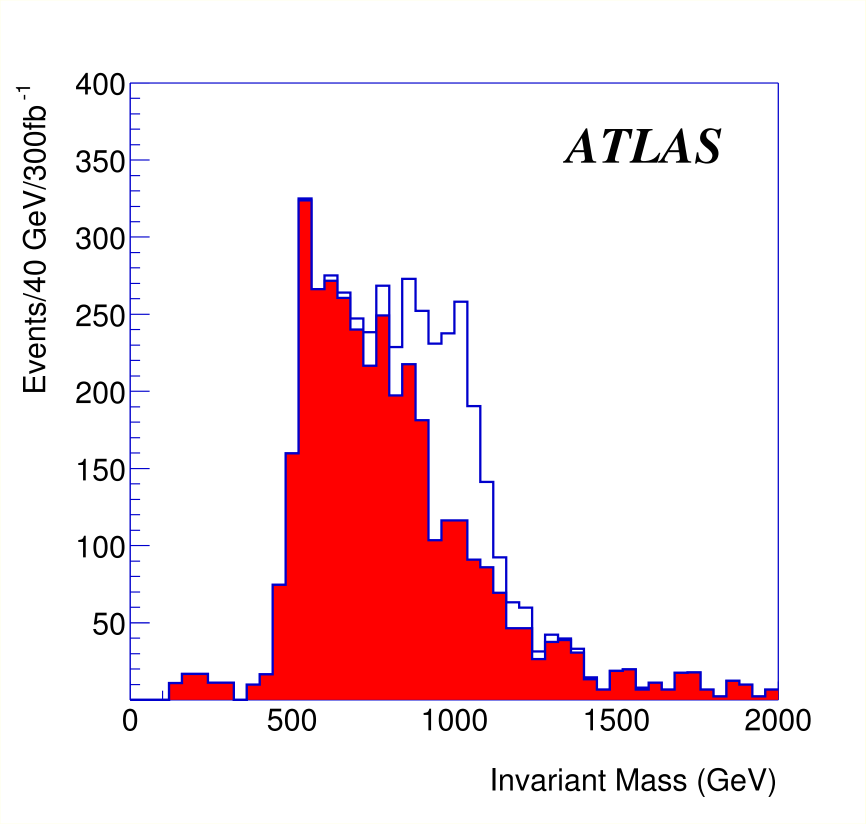


Three isolated leptons (either e or μ) with $p_T > 40$ GeV and $\mid \eta \mid < 2.5$ one of which has $p_T > 100$ GeV
No other leptons with $p_T > 15$ GeV
One pair of leptons within 10 GeV of Z mass.
$\not{E}_T > 100$ GeV
At least one tagged $b-$ jet with $p_T > 30$ GeV

Background is dominated by tbZ

$T \rightarrow Wb$

Reconstruct from $T \rightarrow b\ell\nu$



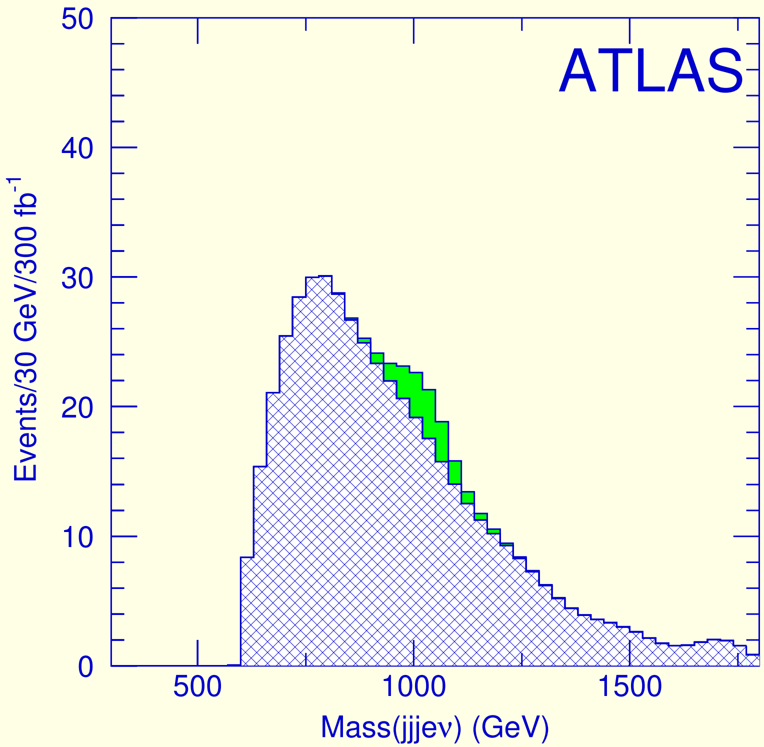
One isolated lepton (either e or μ) with p_T >100 GeV and $| \eta |< 2.5$
No other leptons with $p_T >$ 15 GeV No more than 2 jets with $p_T >$ 50 GeV and $M(j1, j2) > 200$ GeV
$\not{E}_T > 100$ GeV
at least one tagged $b-$ jet with $p_T >$ 200 GeV

Background is dominated by $t\bar{t}$

$T \to ht$

Reconstruct from $h \to b\bar{b}$ and $t \to b\ell\nu$

One isolated e or μ with $p_T > 100$ GeV and $\mid \eta \mid < 2.5$.
Three jets with $p_T > 130$ GeV.
Four jets with $p_T > 15$ GeV.
At least one jet tagged as a$b-$jet
Mass of dijet system within 20 GeV of Higgs mass (assumed to be 120 GeV)



Background dominated by $t\bar{t}$

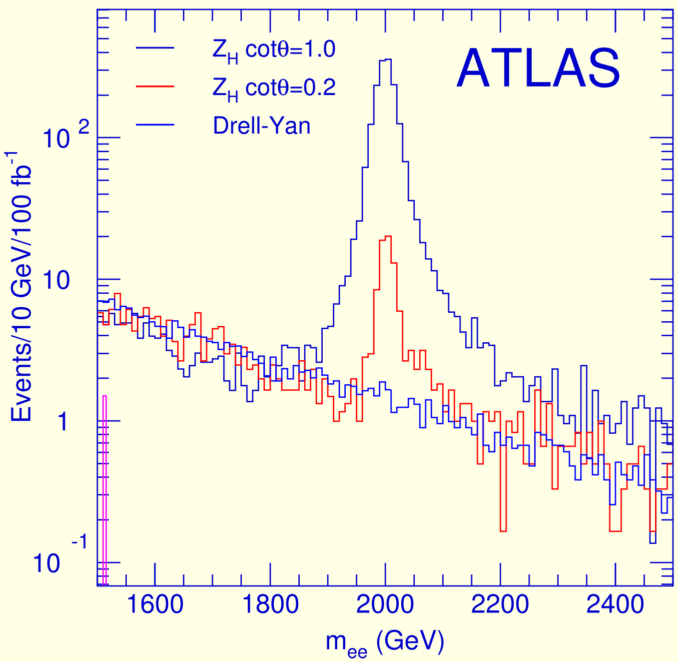
New Bosons

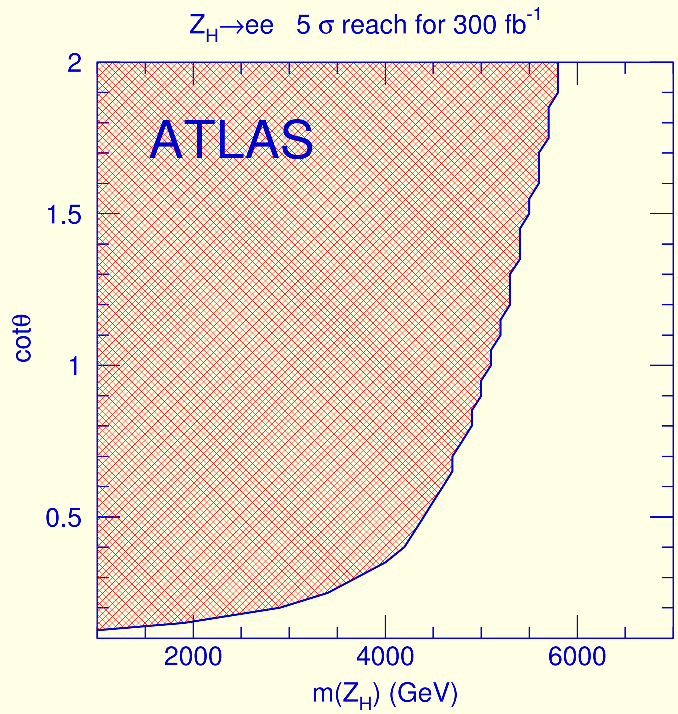
Expect two neutral and two charged: $Z_H, A_H, W_H^\pm$
Model has two additional couplings corresponding to the extra $SU(2) \times U(1)$,

Bosons will be discovered via leptonic decays **But critical test is cascades such as** $Z_H \to Zh$

New Bosons – Leptonic decays

Clear signal over Drell-Yan background. Plot shows 2 TeV mass for Z_H





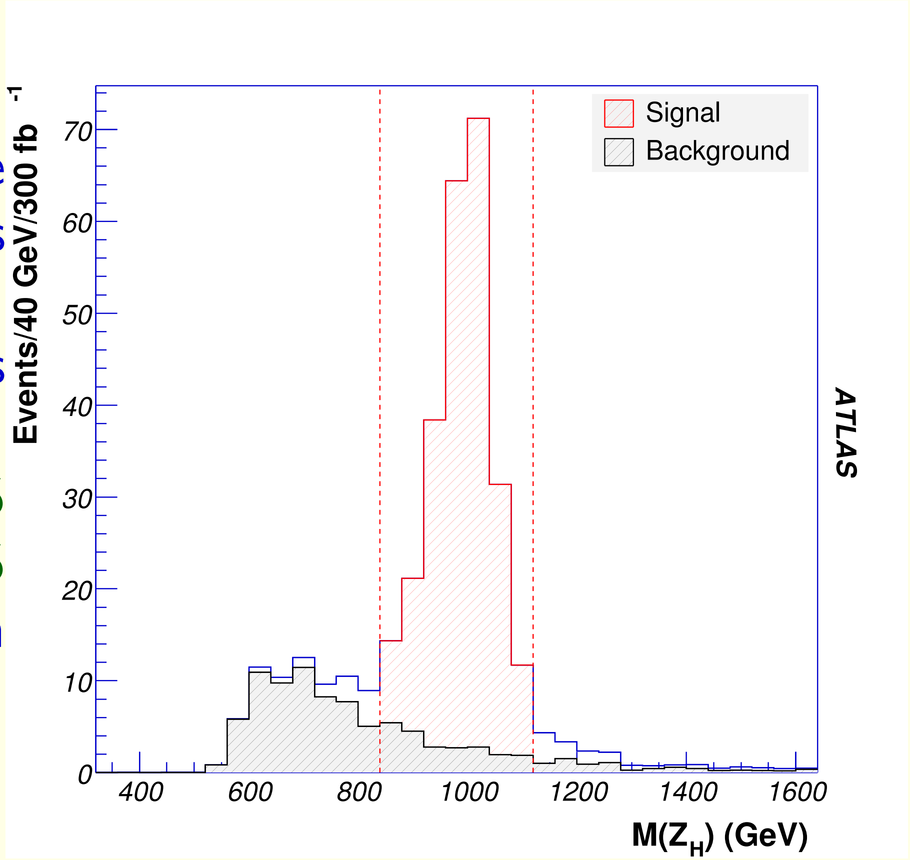
New Bosons – Cascade decay $Z_H \to Zh \to \ell^+\ell^- b\bar{b}$

Two leptons of opposite charge and same flavor with $p_T > 6(5)$ GeV for muons (electrons) and $|\eta| < 2.5$

The lepton pair should have a mass between 76 and 116 GeV

Two reconstructed $b-jets$ with $p_T > 25$ and $|\eta| < 2.5$, which are within $\Delta R < 1.5$

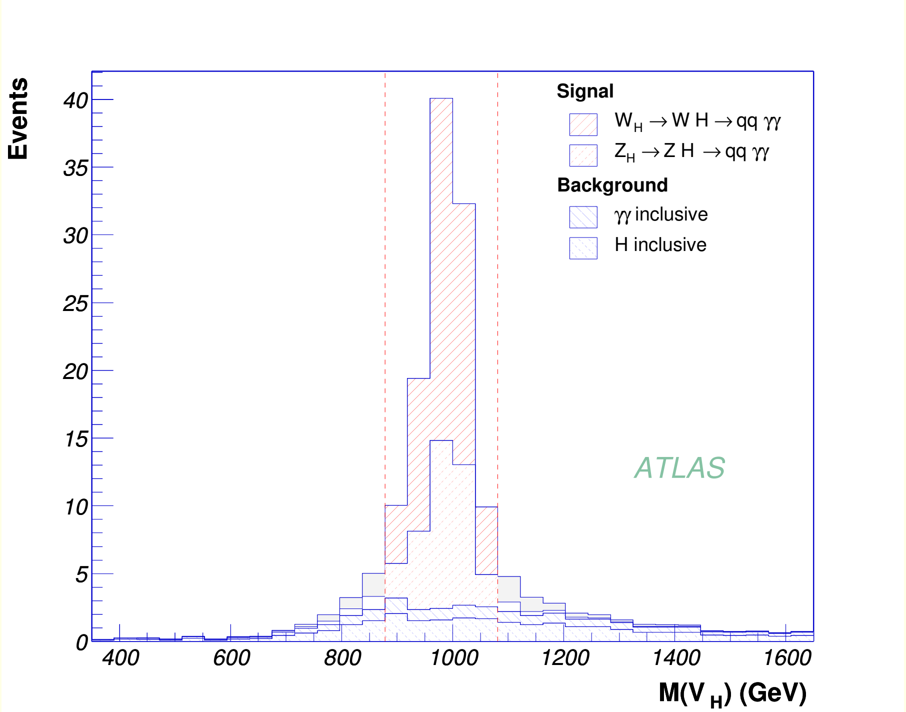
The $b-jet$ pair should have a mass between 60 and 180 GeV



$Z_H \to Zh$, $h \to \gamma\gamma$

Must use all hadronic mode of Z: Cannot distinguish W_H from Z_H

Two isolated photons one having $p_T(1) > 25$ GeV, $p_T(2) > 40$ GeV.
$M(\gamma\gamma) = m_h \pm 2\sigma$
The jet pair with invariant mass closest to M_W is selected.
Pair has a combined $p_T > 200$ GeV



Can also extract signal via Jacobian peak in the P_T dist of Higgs

Extra Higgs

ϕ^{++} produced by WW fusion: So must use the forward tagging jets

Two reconstructed positively charged isolated leptons (electrons or muons) with $| \eta |< 2.5$

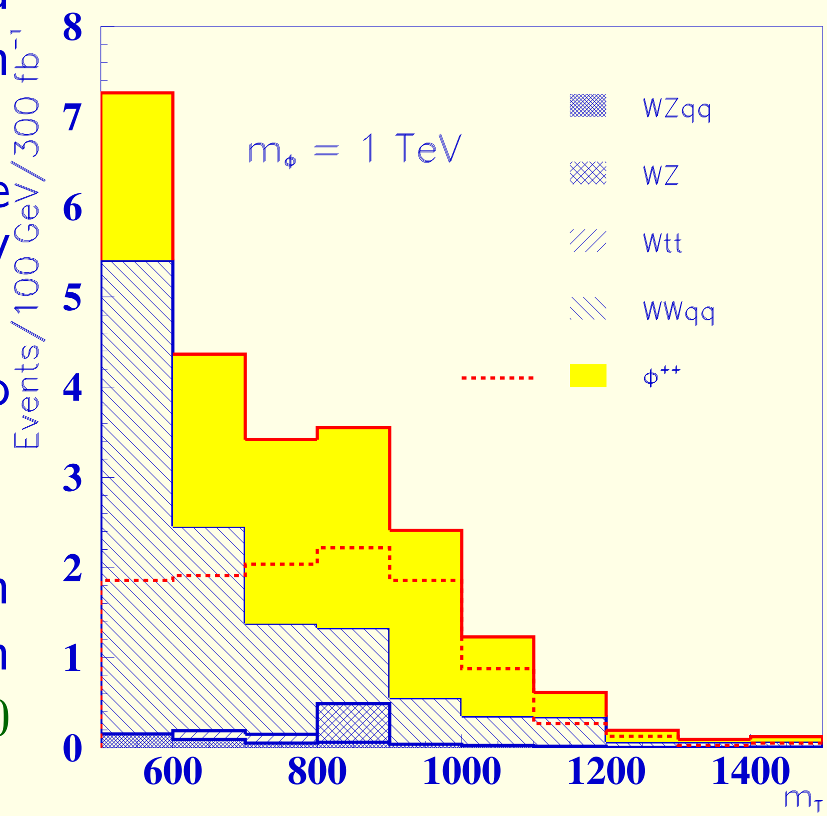
One of the leptons was required to have $p_T > 150$ GeV and the other $p_T > 20$ GeV

$|p_{T1} - p_{Ts}| > 200$ GeV

the difference in pseudorapidity of the two leptons $|\eta_1 - \eta_2| < 2.$

$\not{E}_T > 50$ GeV

Two jets each with $p_T > 15$ GeV, with rapidities of opposite sign, separated in rapidity $|\eta_1 - \eta_2| > 5$; one jet has $E > 200$ GeV and the other $E > 100$ GeV



Berkeley Lab

Summary of sensitivity

- T Observable in both $h(120)t$ (up to mass of 1.2 TeV) and Zt (up to mass 1.0 TeV): Wb is observable up to 1.3 TeV for $\lambda_1/\lambda_2 = 1$
- Z_H observable in e^+e^- to mass of 4.5 TeV for $\cot\theta = 0.5$
  $Z_H \rightarrow Zh(120) \rightarrow Zb\bar{b}$ observable for mass up to 2 TeV
  $Z_H \rightarrow Zh(120) \rightarrow Z\gamma\gamma$ observable for masses up to 1.1 TeV
- ϕ^{++} may be observable in W^+W^+ at 1.5 TeV
- More work needed for $m_h \gtrsim 150$ GeV

LHC finds it or motivation disappears

Personal comments

- The ψ, τ and Υ discovered while I was a graduate student
- Conservation of neutrino anomalies: one turned out to be right
- Triumph of standard Model
- Almost infinite number of "Beyond the SM" theoretical models:
  Best ones killed already, or will be by LHC
  One might be right.
  Large number cannot be tested in the foreseeable future
  No progress is possible without correct data
- Only Dark Matter and Dark energy have had comparable impact to ψ, τ and Υ.

Messages

- Everyone here: HEP is about to see first new energy regime since Tevatron started. You are fortunate
- Phenomenogists: Hadron colliders are where the action is.
- Everyone: Understand QCD:
- Experimenters: Try to avoid too many wrong results and "canine" actions.
- linear collider folks: No success at LHC may mean no linear collider