ATLAS discovery prospects for few $100pb^{-1}$

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For the ATLAS collaboration

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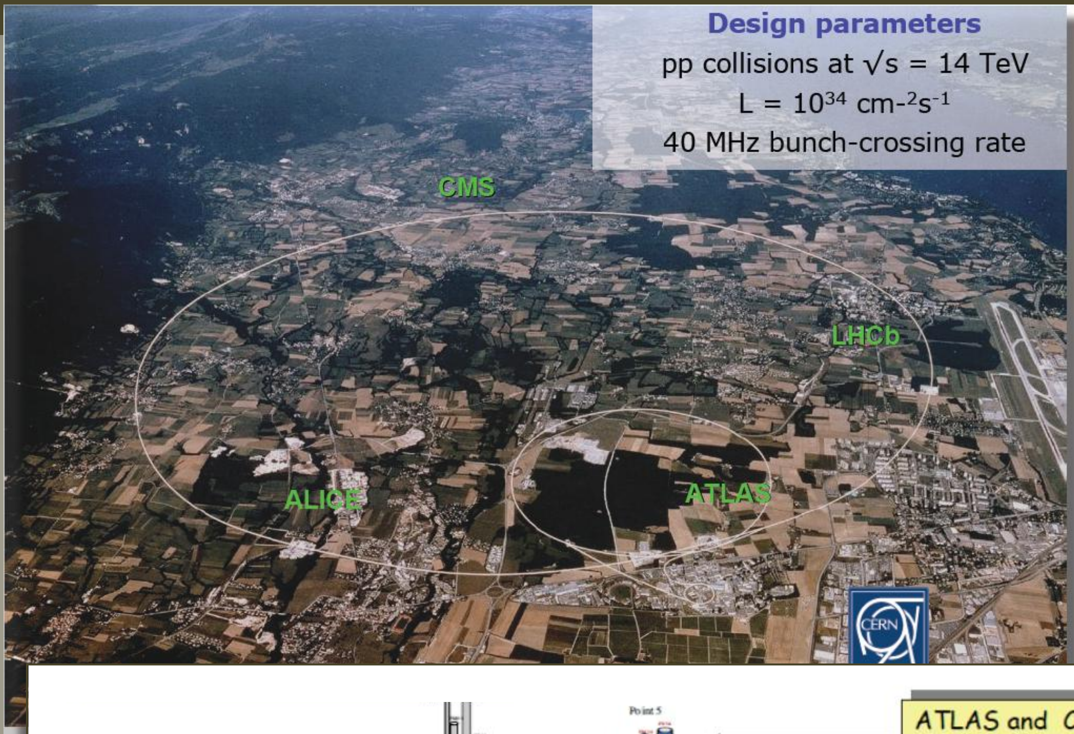
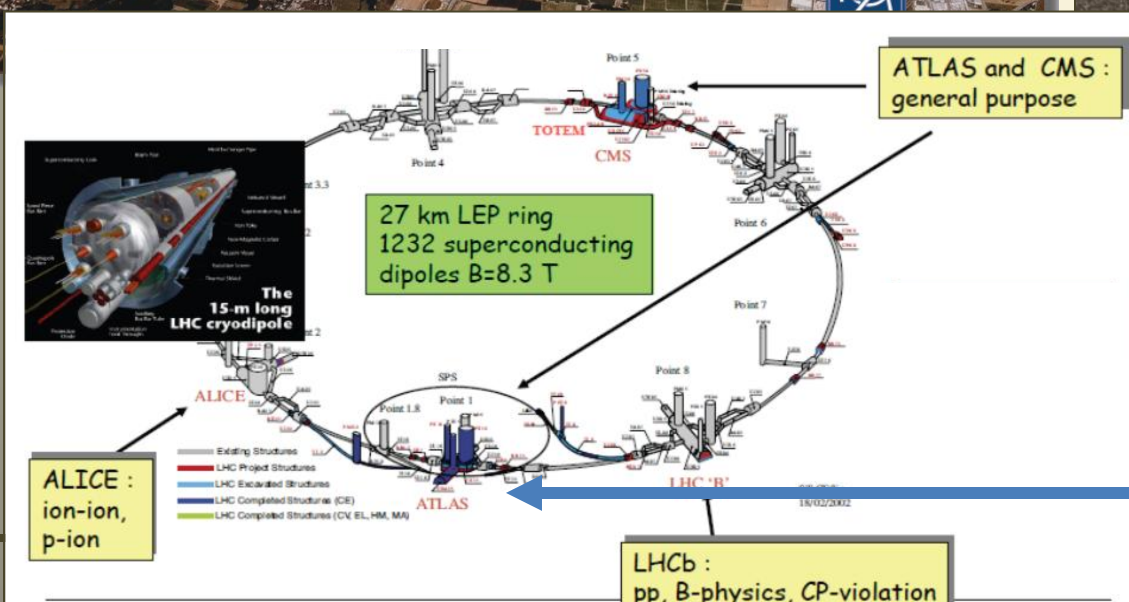
Beyond2010

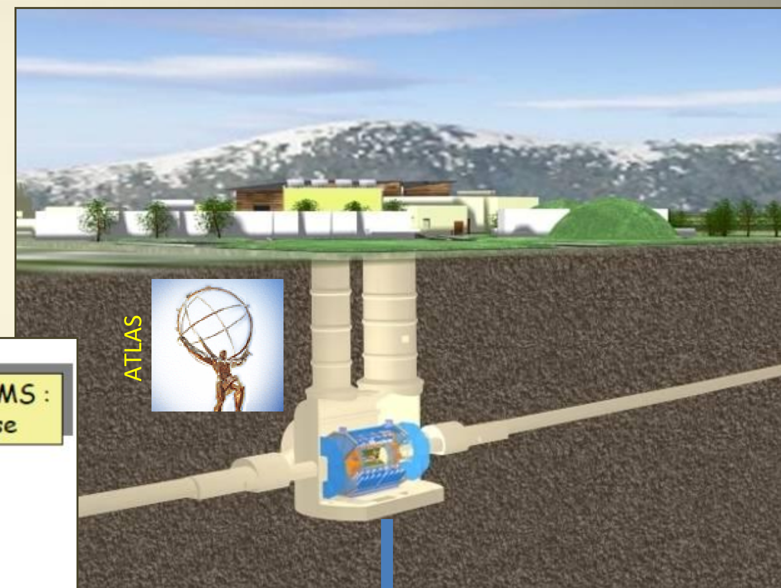
Fifth International Conference on
BEYOND THE STANDARD MODELS OF PARTICLE PHYSICS, COSMOLOGY AND ASTROPHYSICS

Cape Town, South Africa
1-6 February 2010

The LHC and its experiments







Expectations for 2010

- Startup scenario:
  - First Collisions at $\sqrt{s}$ = 0.9/2.3 TeV in Nov./Dec. 2009
  - Start collisions at 3.5 TeV per beam in Feb./Mar. 2010 aiming at a long run (9-10 months, possibly extending beyond 2010)

- Instantaneous luminosity of up to $1\text{-}2 * 10^{32}\ cm^{-2}\ s^{-1}$
  - No more than 2-3 proton collisions per bunch crossing (pile-up)

- Integrated luminosity (delivered by the LHC) up to 200-500 pb^{-1}

- CERN/LHC strategy for 2011 and later not fixed yet
  - Preliminary outcome from Chamonix LHC workshop, last week:
    - The LHC will run at 3.5+3.5 TeV in 2010 and 2011, until the experiments collect an integrated luminosity of ~ 1 fb^{-1}. Only a short technical stop is foreseen at the end of 2010-beginning of 2011. -- The 2010-2011 run will be followed by a long (~1 year) shut-down, to redo all splices and thus enable the machine to operate up to the design energy (7+7 TeV).
    - A firmer plan can only be made around June, after experience is gained with the machine operation and performance (e.g. in terms of luminosity) at 3.5+3.5 TeV .

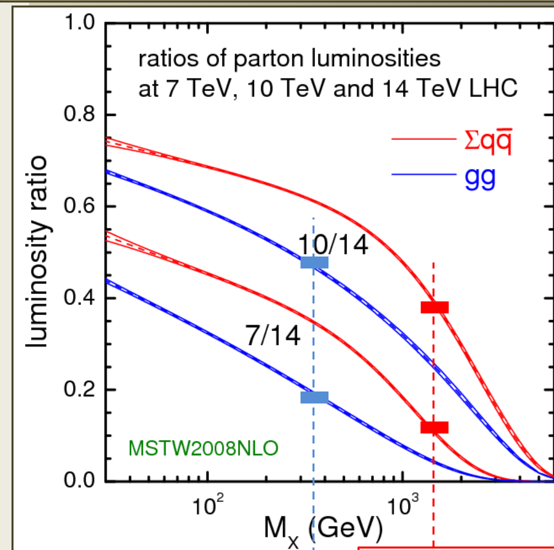
Impact of reduced beam energy

- Most physics simulation studies done so far with √s=14 TeV (some with 10 TeV).
- Impact of reduced center of mass energy on cross-sections compared to 14 TeV design:

Mass to be produced M_X	Ratio 10 TeV/ 14 TeV	Ratio 7 TeV/14 TeV
100 GeV	0.6 – 0.7	0.3 – 0.5
1 TeV	0.3 – 0.5	0.1 – 0.2

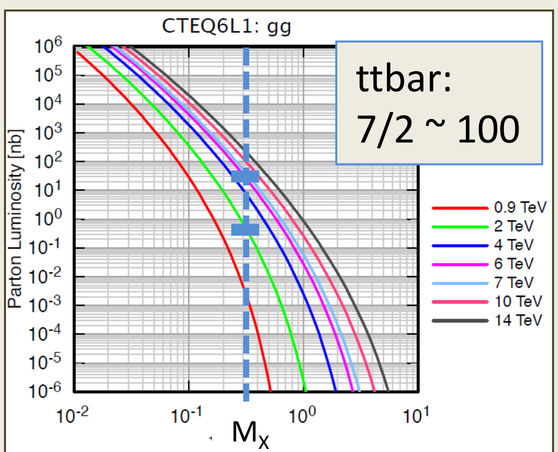
- Still a large gain w.r.t. Tevatron (√s=1.96 TeV):

J.Stirling
http://projects.hepforge.org/mstwpdf/plots/plots.html



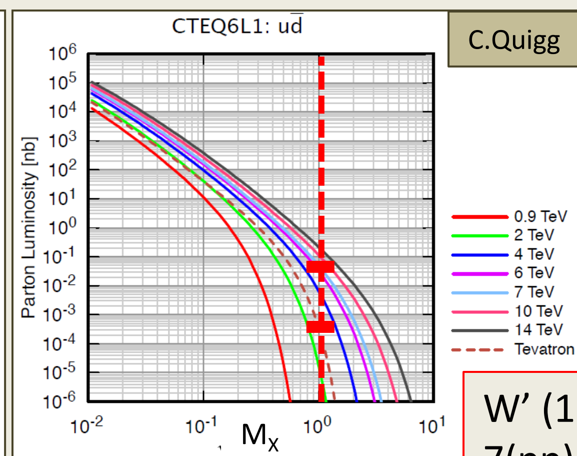
ttbar:
7/14 = 0.2
10/14 = 0.5

W' (1.5 TeV):
7/14 = 0.1
10/14 = 0.4



ttbar:
7/2 ~ 100

C.Quigg



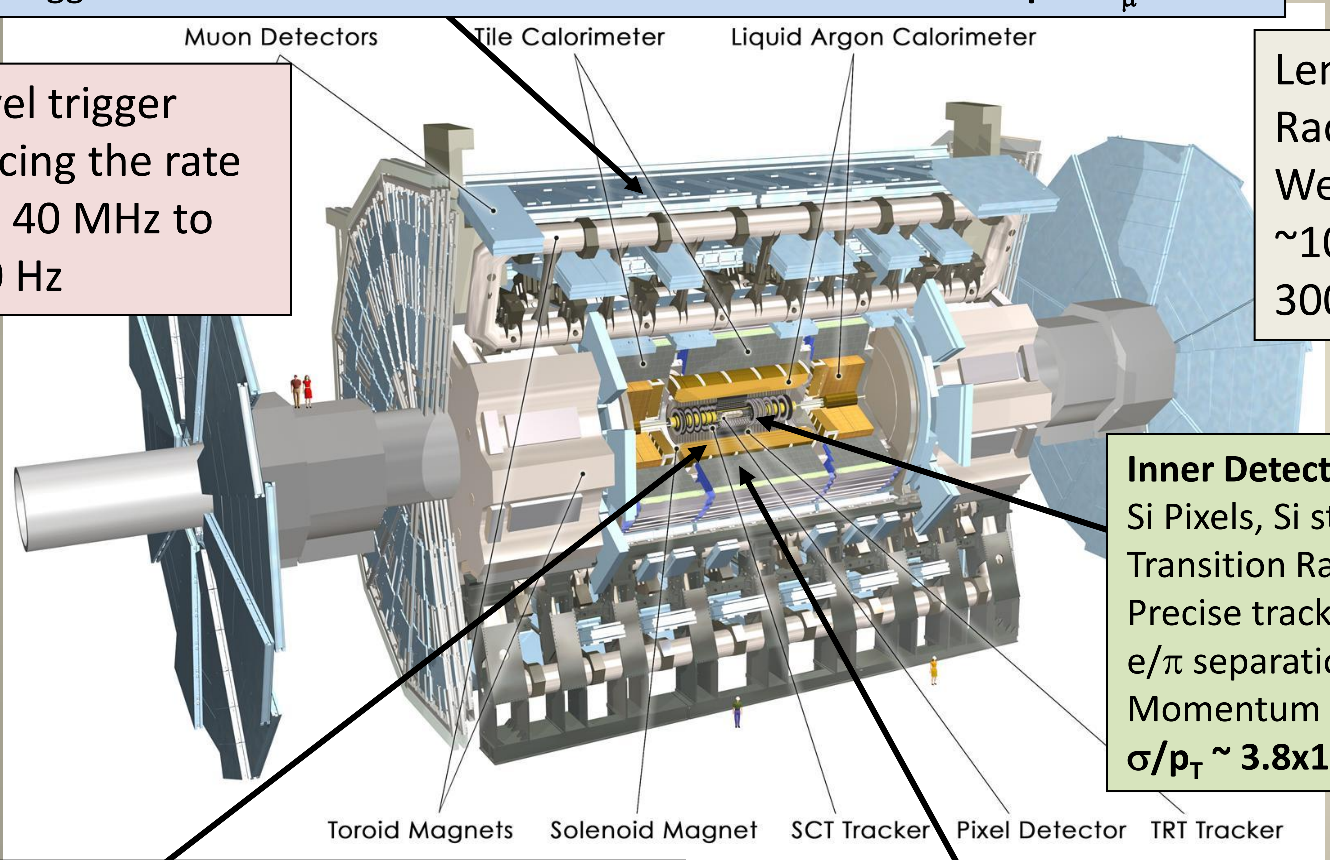
W' (1 TeV):
7(pp)/2(ppbar) ~ 150

The ATLAS detector

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with **momentum resolution < 10% up to E_μ ~ 1 TeV**

3-level trigger reducing the rate from 40 MHz to ~200 Hz

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

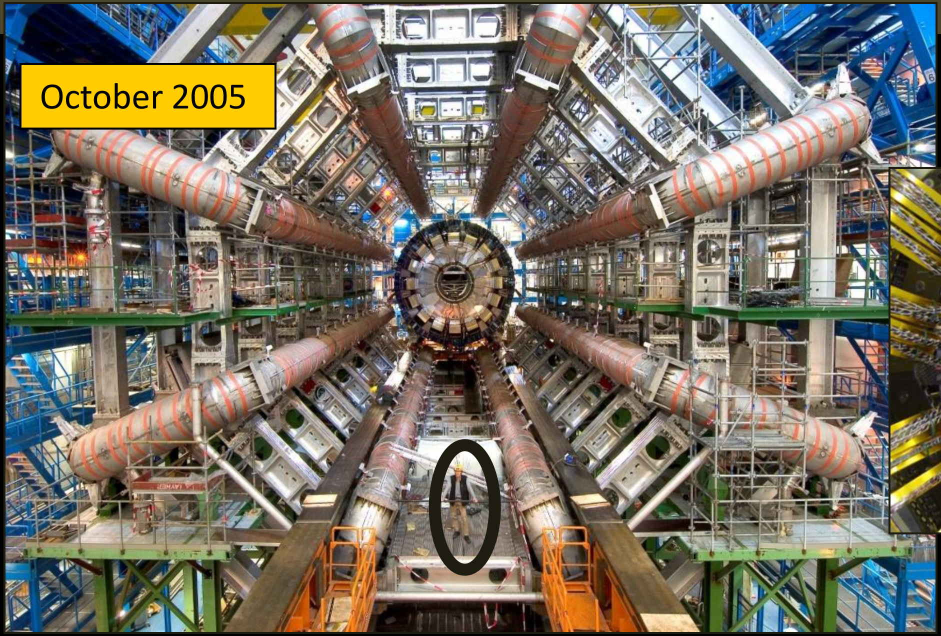


Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips,
Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\text{x}10^{-4}\, p_T\,(\text{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

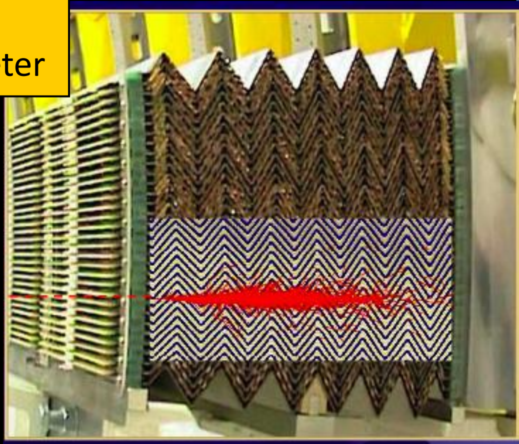
HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

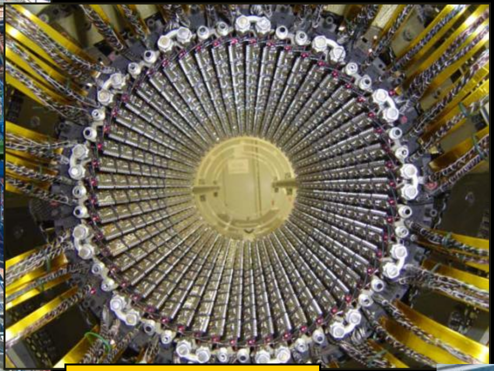
ATLAS in pictures...



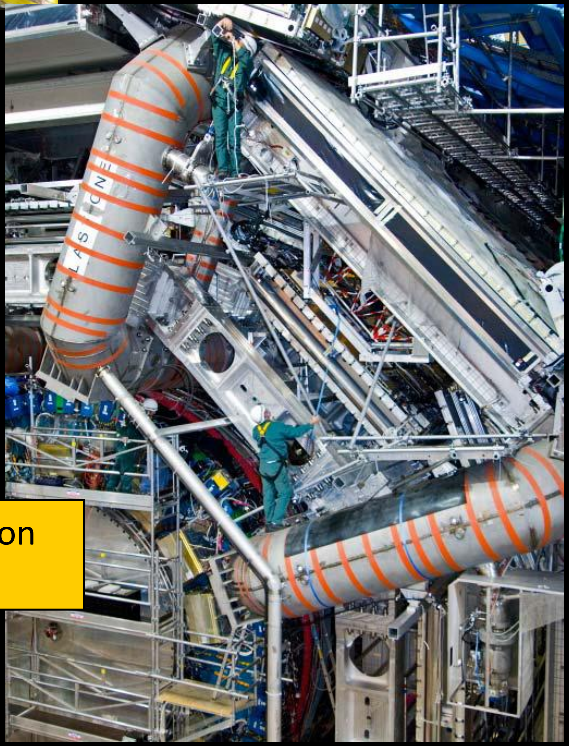
October 2005

Liquid Argon accordion calorimeter

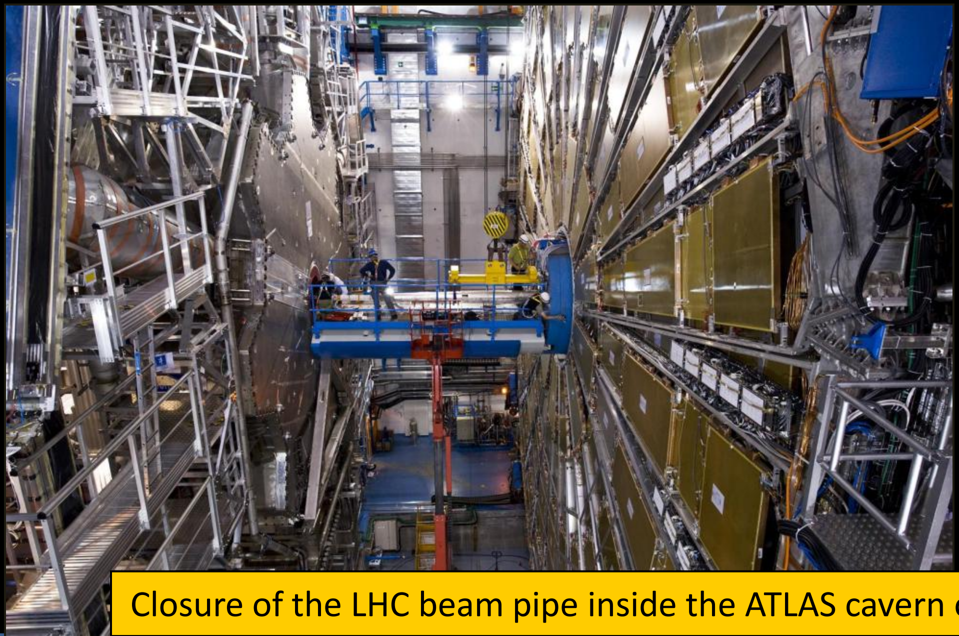




Pixel detector

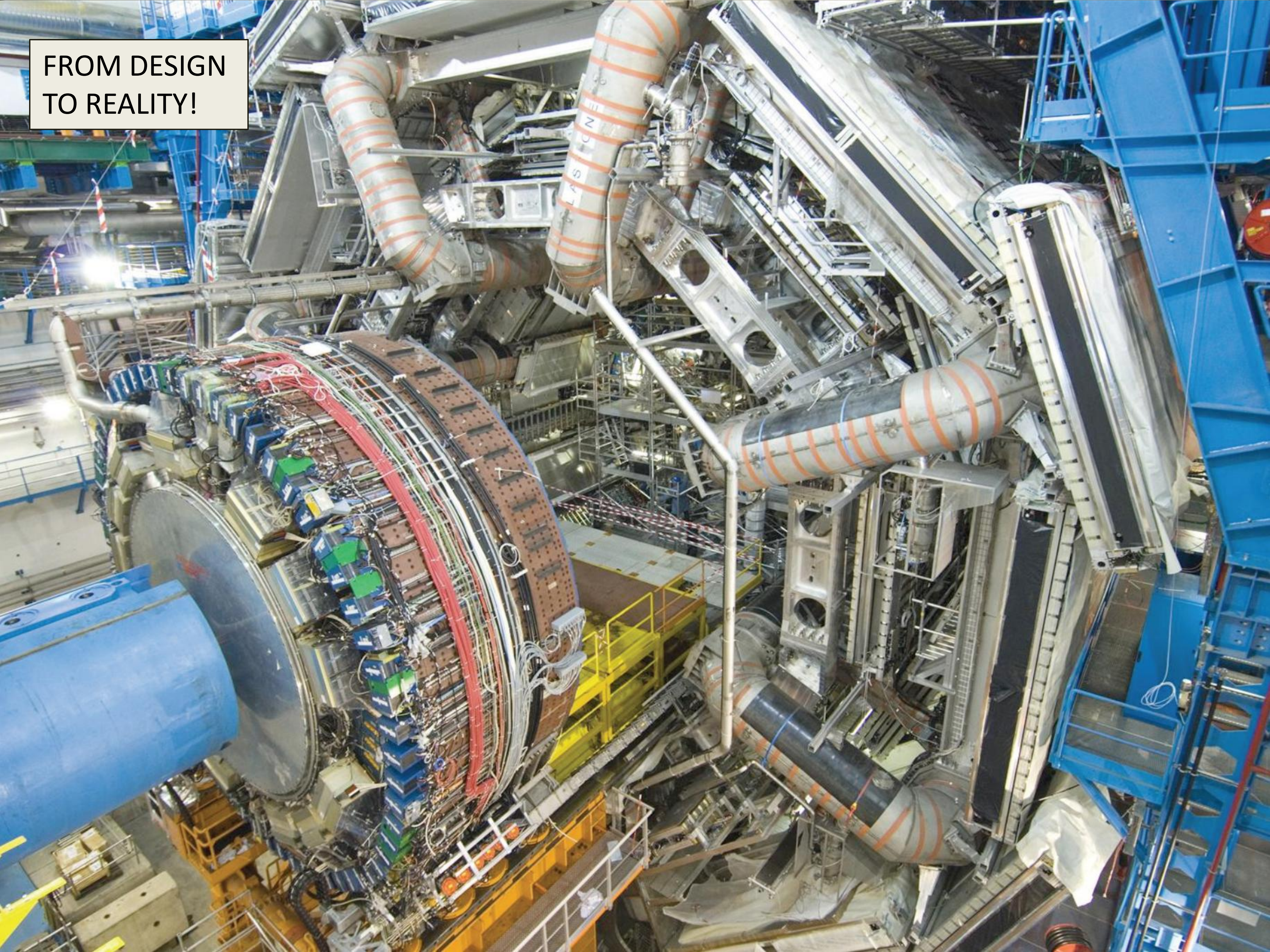


Barrel muon chambers



Closure of the LHC beam pipe inside the ATLAS cavern on 16 June 2008.

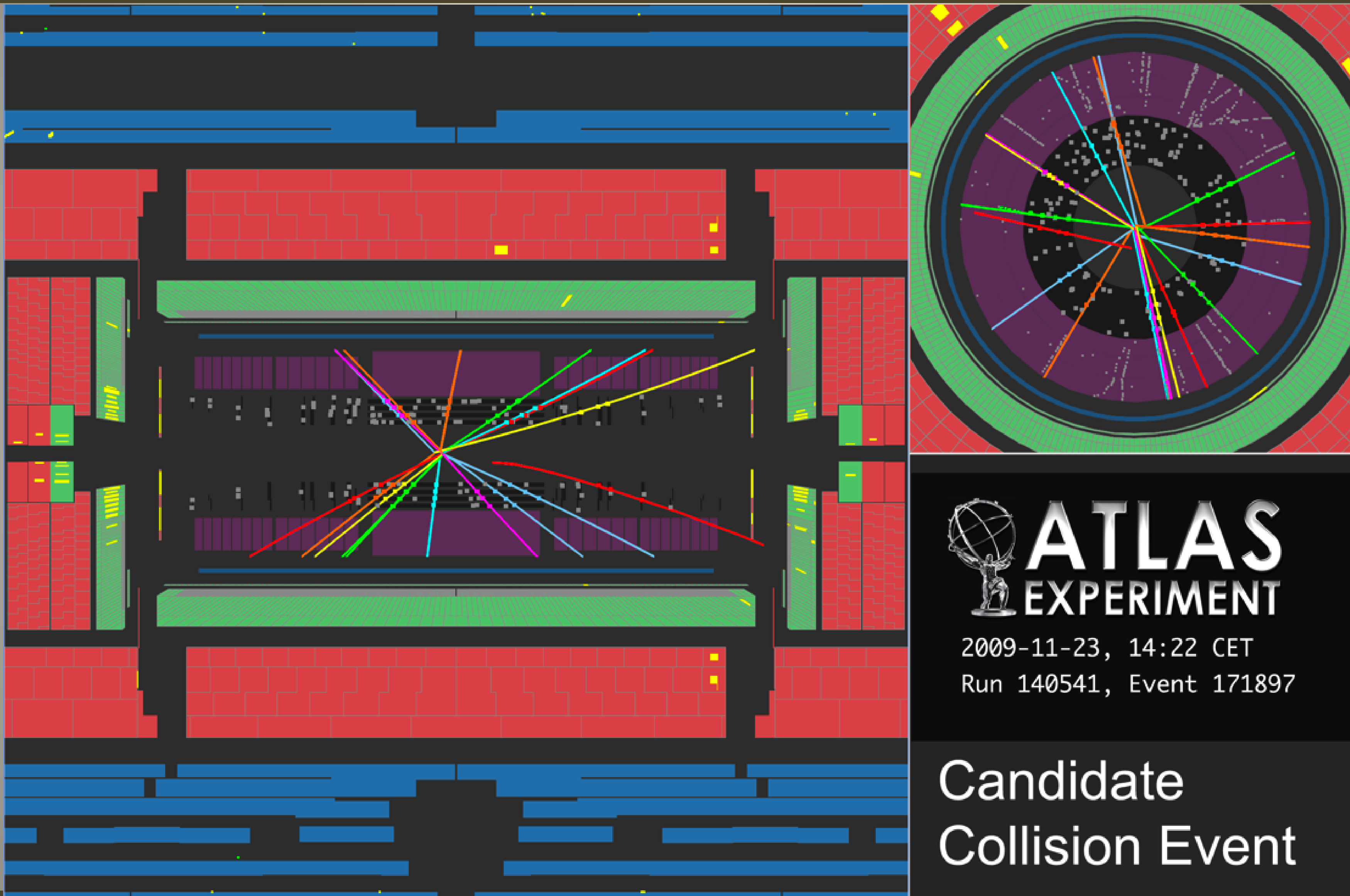
FROM DESIGN TO REALITY!



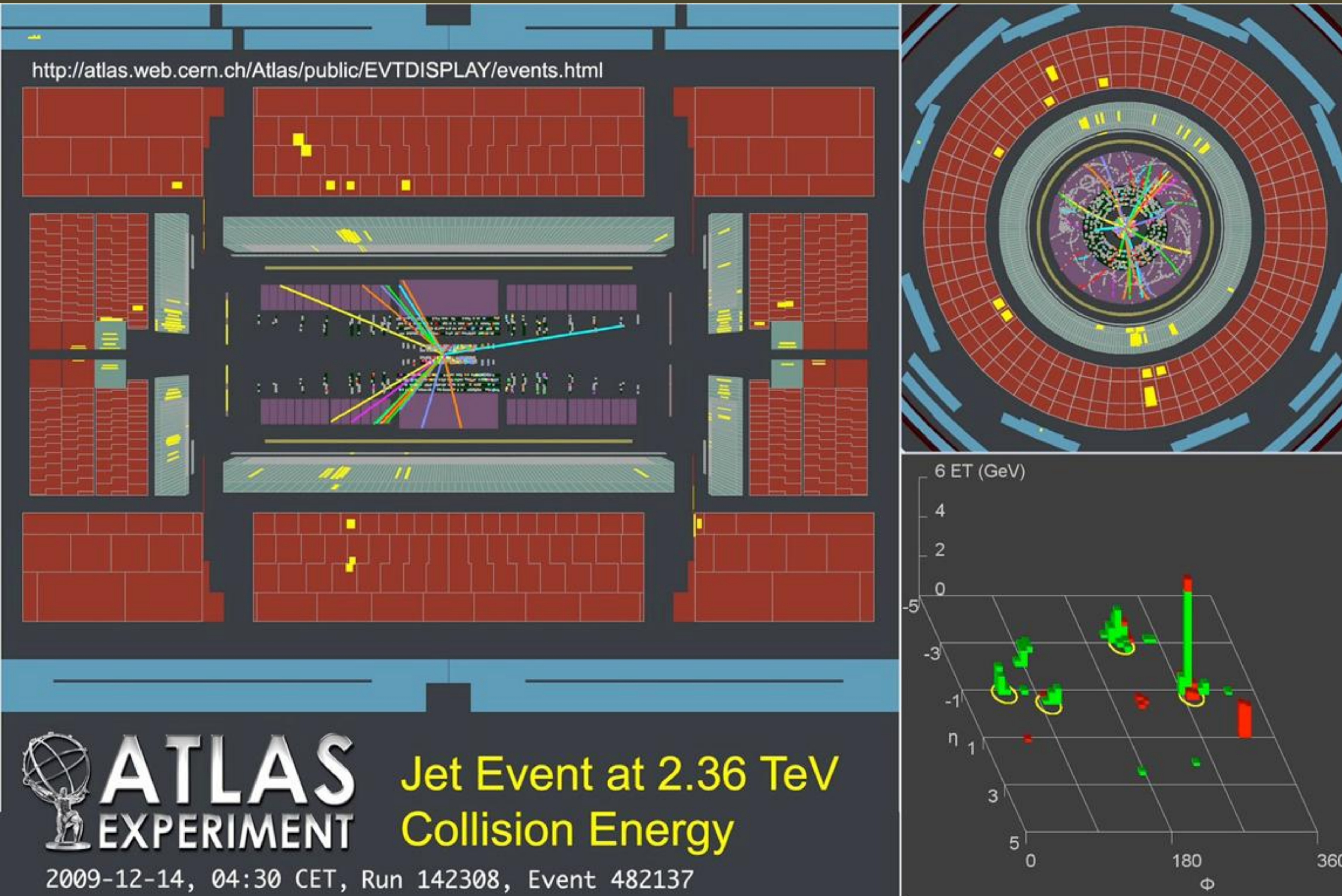
LHC is back !!!

☺We are all very excited about it ☺

First observed collision candidate at 900 GeV, November 23 2009



Note: Solenoid off and Si detectors off or at reduced voltage (no stable beam)


http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html
ATLAS
EXPERIMENT
Jet Event at 2.36 TeV
Collision Energy
2009-12-14, 04:30 CET, Run 142308, Event 482137
6 ET (GeV)
4
2
0
-5
-3
-1
η 1
3
5
0
180
360
Φ

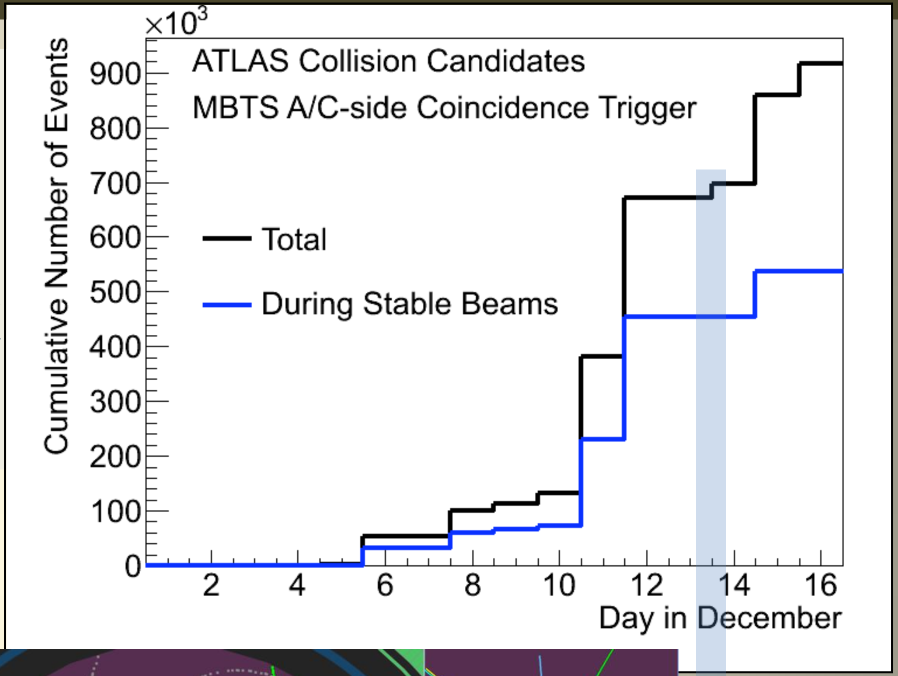
Detector Hardware Status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.8%
Tile calorimeter	9800	99.2%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Trigger	370 k	98.5%
TGC Endcap Muon Trigger	320 k	99.4%
LVL1 Calo trigger	7160	99.8%

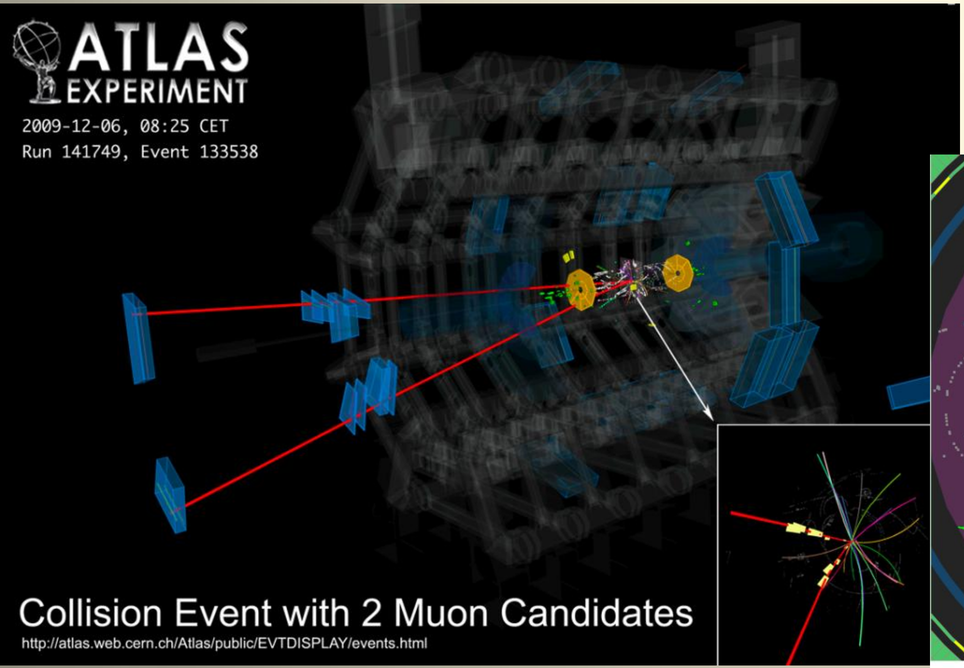
READY FOR PHYSICS!

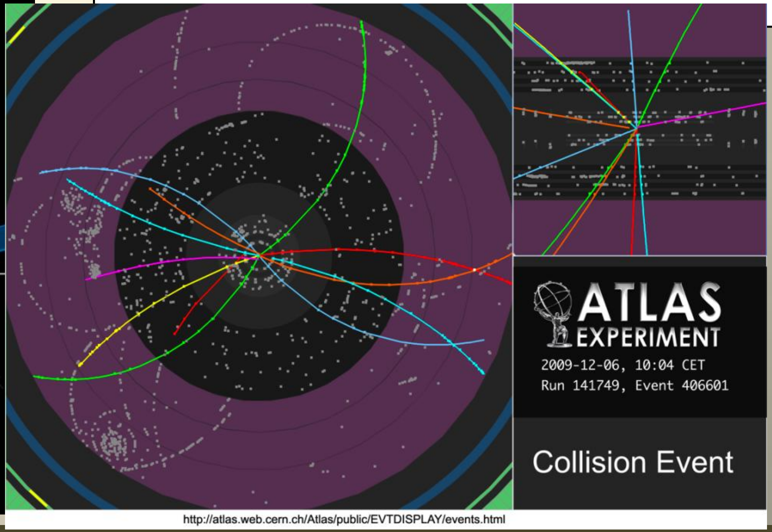
Collisions Data 2009 (mostly $\sqrt{s}$ = 900 GeV)

- Total number of collisions candidates: 917K
  - $\int L \sim 20\ \mu b^{-1}$ (~1 s of data taking at the expected luminosity in 2010)
- Collisions candidates @2.36TeV: 34 K
- Data taking efficiency ~ 90%



√s = 2.36 TeV





Start-up of LHC physics: Goals for 2010

Threefold approach (not fully sequentially):

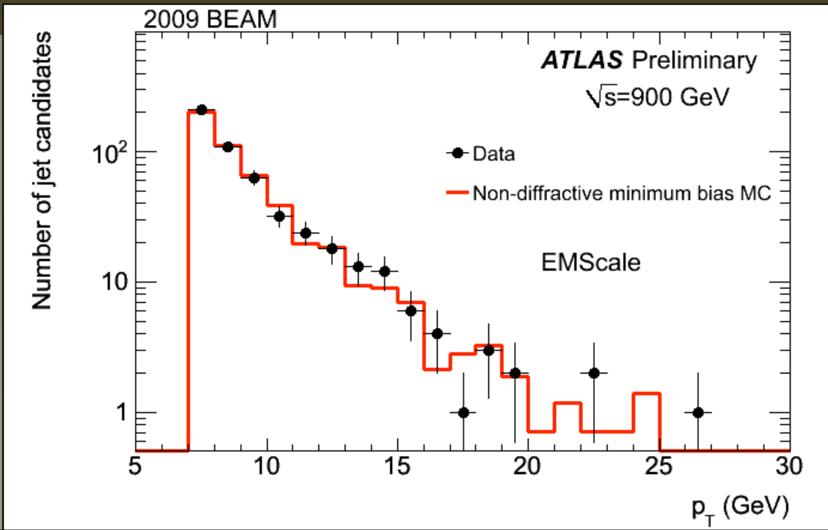
1. Detector and reconstruction understanding with collision data
   - Beyond extensive commissioning with cosmics
   - Using well-known physics samples
     - e.g. $Z \to ee$, $\mu\mu$: tracker, ECAL, Muon chamber calibration and alignment, etc.
     - $tt \to bl\nu\ bjj$: jet scale from $W \to jj$, b-tag performance, etc.

2. "Re-discovery" of Standard Model
   - Establish how pp collisions really look like at LHC
   - Followed later on by precision measurements

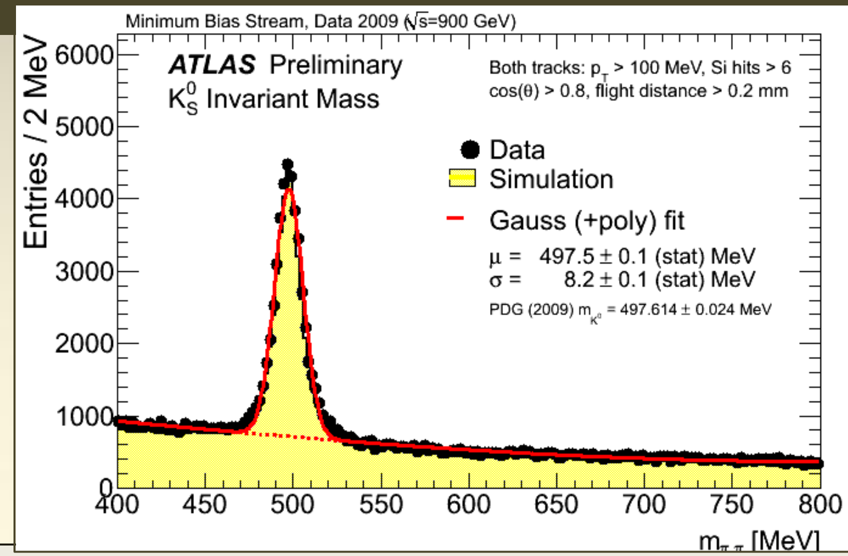
3. Search for new physics beyond the SM

Channels (examples ...)	Expected events in ATLAS after cuts $\sqrt{s}$= 10 TeV, 100 pb^{-1}
$J/\psi \to \mu\mu$	~ 10^6
$\Upsilon \to \mu\mu$	~ 5 10^4
$W \to \mu\nu$	~ 3 10^5
$Z \to \mu\mu$	~ 3 10^4
$tt \to W b W b \to \mu\nu + X$	~ 350
QCD jets p_T > 1 TeV	~ 500
$\tilde{g},\tilde{q}$ m ~ 1 TeV	~ 5

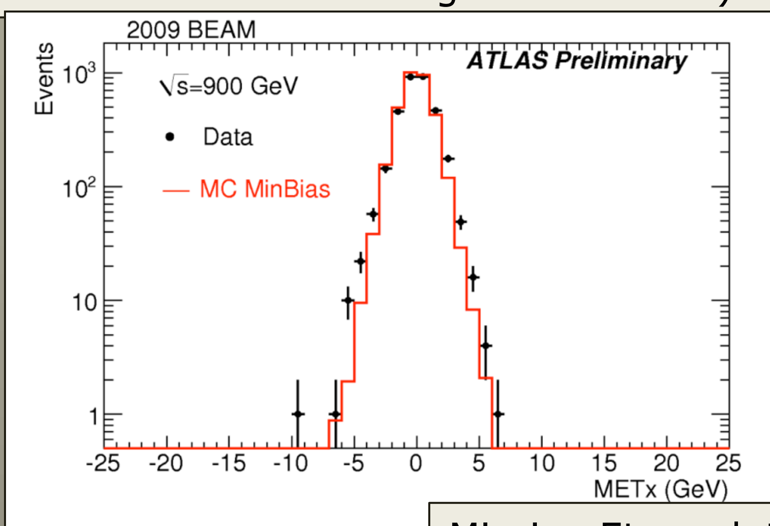
A selection of first results from 2009 runs

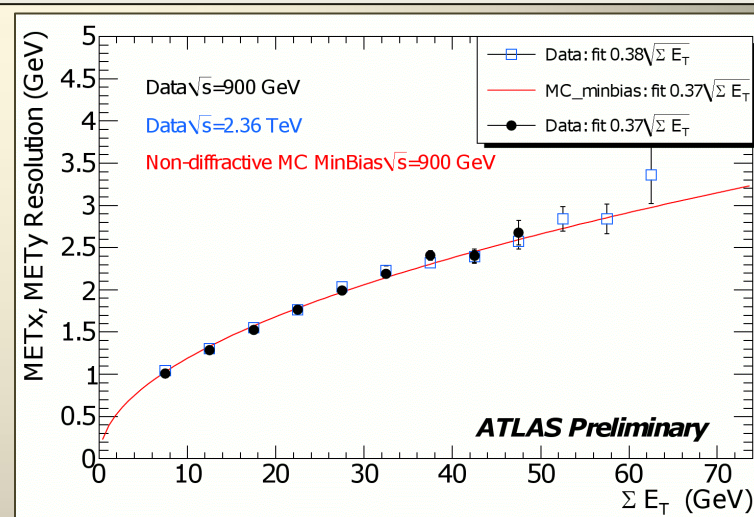


“uncorrected” (EM scale) Jet Et (Jets made from clusters with AntiKt algorithm D=0.4)



Invariant mass distribution of two track vertices.



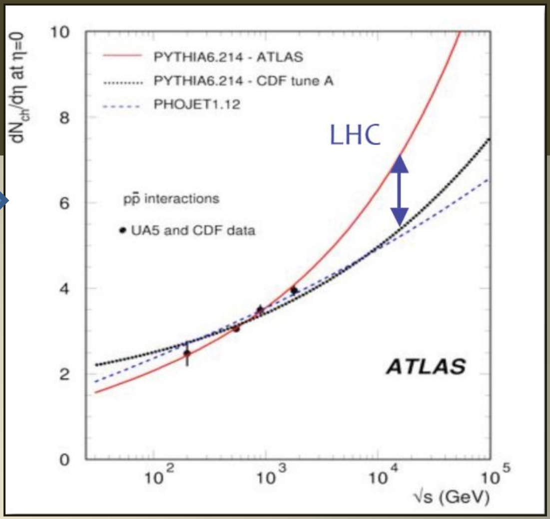


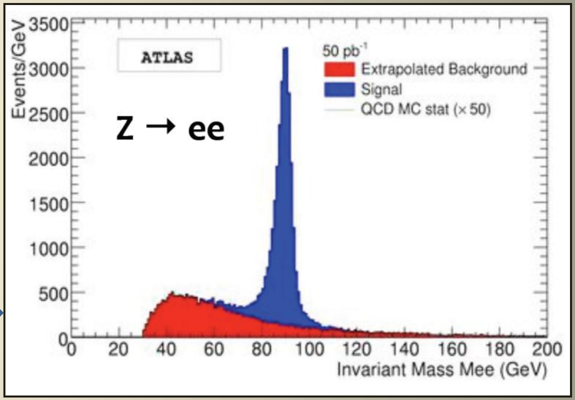
Missing Et resolution in collision events.
Use cells in calorimeter clusters (noise suppression)
EM scale to start, no specific hadronic calibration

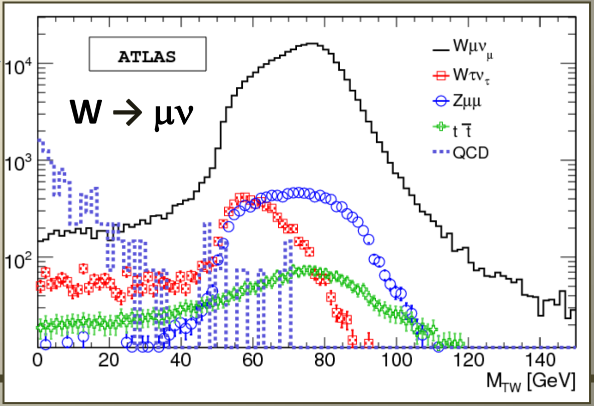
Standard Model "rediscovery"

- minimum bias properties
- underlying event structure
- jet production
  - cross-section
  - di-jet mass and angular distribution, shapes
  - Challenge is Jet energy scale determination
- direct photon production
- Drell-Yan lepton pair production
  - incl. low mass resonances (J/ψ, Y)
- W/Z production
  - $\mu^+\mu^-$ asymmetry distribution (-> u,d quark pdf)
  - W mass (σ ~150 MeV after ~ 200pb^{-1})
- di-boson production
  - gauge boson self coupling
- top quark production

Simulations

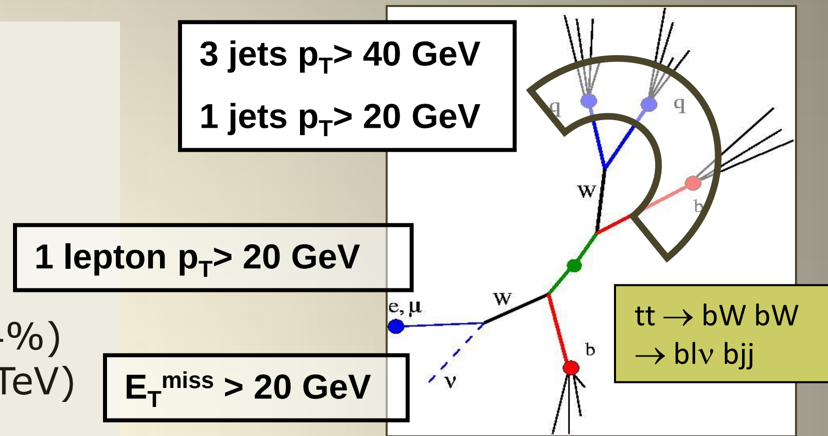




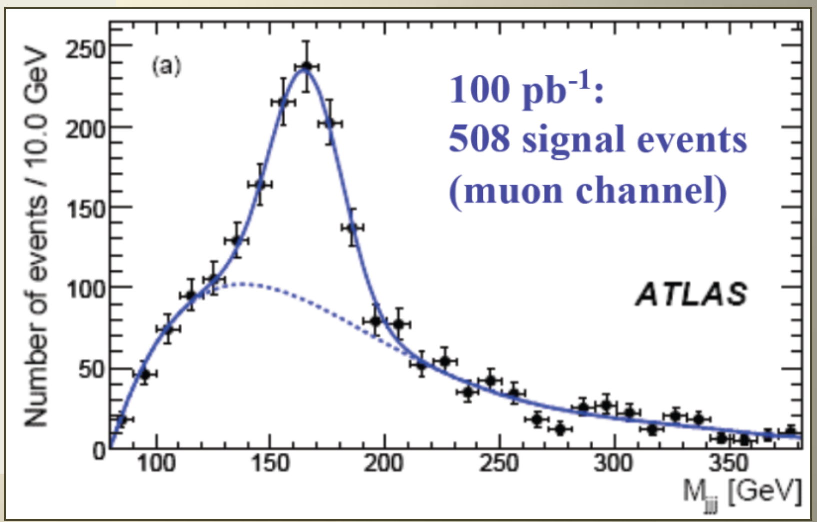


First top quarks in Europe

- Top signal observable in early days with no b-tagging and simple analysis.
  - For the golden-channel lepton-jets:
    tt →bW bW →blν bjj
    expect ~ 350 events in the m channel (eff~4%) with **100 pb^{-1}** at √s=10 TeV (**250 pb^{-1}** at 7 TeV) (~ Tevatron sample)



- Top quark events contain all relevant signatures: (e,μ, jet, Etmiss, b-jet)
  - Excellent sample for e.g.:
    - commissioning b-tagging,
    - set jet E-scale using the W → jj peak

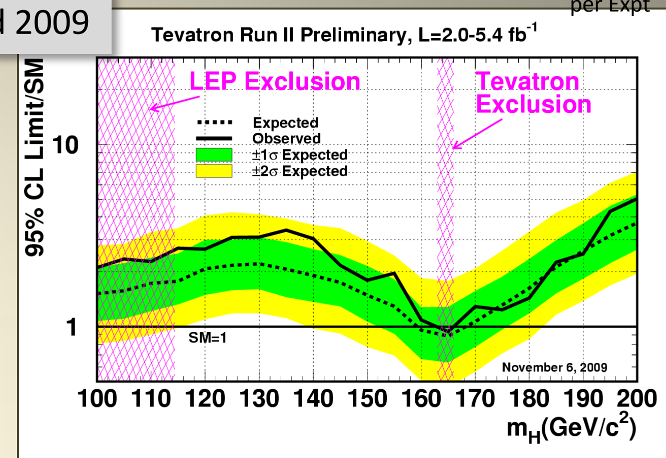


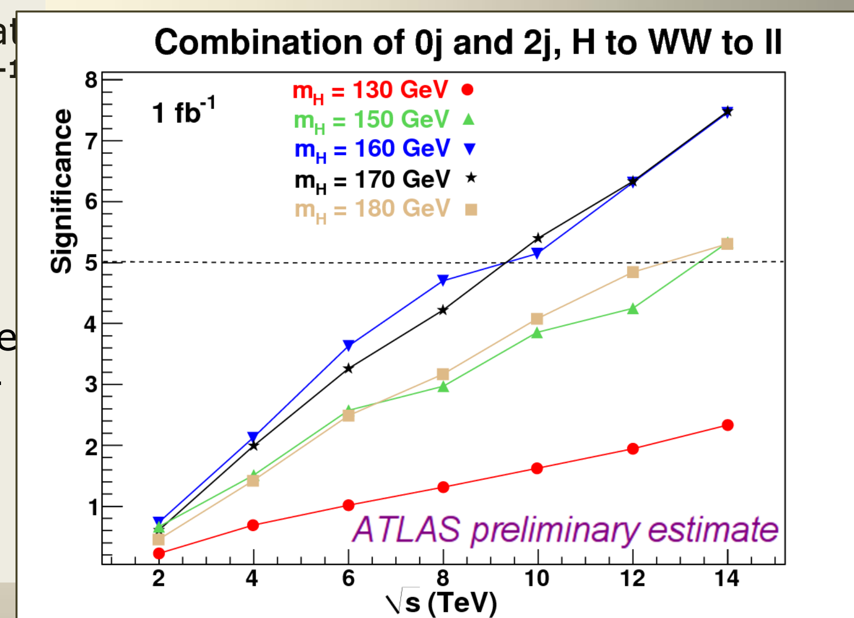
- Cross-section determination using dilepton channels

Higgs search

- Tevatron has excluded m_H~170 GeV with $3fb^{-1}$ per experiment
  - H → WW → lνlν most sensitive channel
  - Expect 8-9 fb^{-1} end of 2010
- ATLAS will profit from much larger cross section and better S/B
  - Factor~30 for gg→H for M_H=170GeV
  - Preliminary studies show that to reach Tevatron level at √**s = 7 TeV**, ATLAS needs at least ~**500 pb⁻¹** (per experiment) **(~200pb⁻¹ at 10 TeV)**
- Discovery significance vs c.o.m energy for $1fb^{-1}$:
  - At least 2 fb^{-1} (e.g. 1 fb^{-1} per experiment) are needed for a discovery in the M_H range [140-180 GeV] with √s = 10 TeV
  - Not for 2010

end 2009





New Physics Beyond the Standard Model?

WARNING:

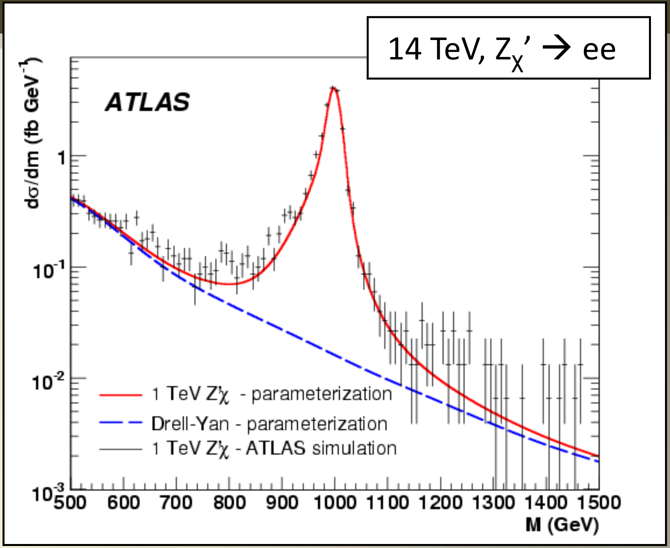
- Finding a deviation from SM predictions may be easy
- Proving that it is real new physics is much harder
- What we need to care about:
  - Detector response: Is it really understood?
    - efficiencies, fake rates, energy/momentum scales, non-Gaussian resolution, dead channels effects …
  - Is SM background under control?
    - cross-sections, kinematic distributions, underlying event, …
  - try to obtain as much information as possible from the data themselves

Examples of topics for the first few 100pb^{-1}:

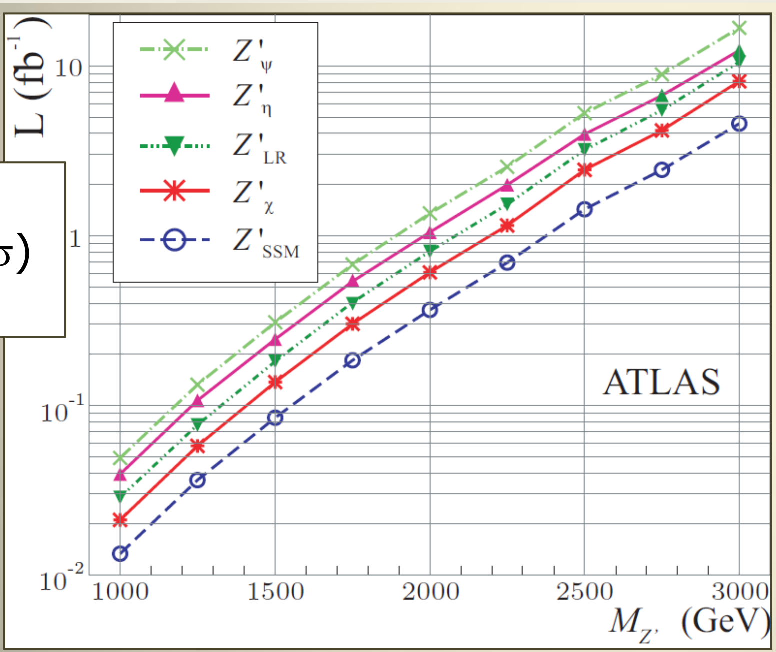
- Compositness (di-jets ET spectrum)
  - Not limited by statistics but requires a very good control of the jet energy scale
- Supersymmetry
- New gauge bosons and high mass resonances (dileptons, dijets, ttbar…)
- Extra dimensions, black hole search
- …

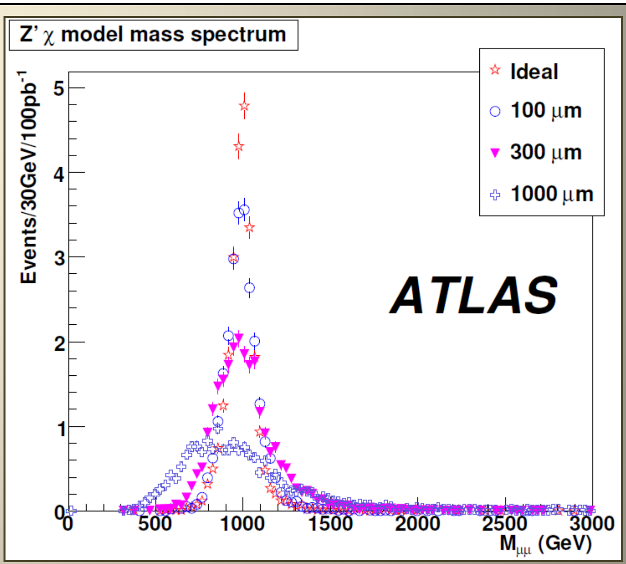
High Mass Dilepton Resonances

- A narrow Z′ resonance decaying in 2 leptons is predicted in many GUT extensions of the SM
- Such resonances also predicted in models with extra-dimension (e.g. KK excitation of vector bosons in Randall-Sundum models)



Z′ discovery potential (5σ) for √s = 14TeV

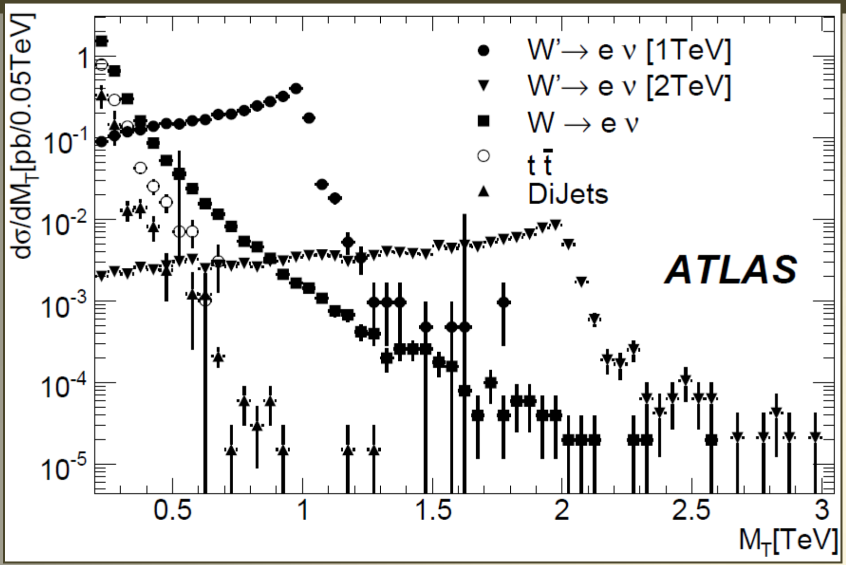


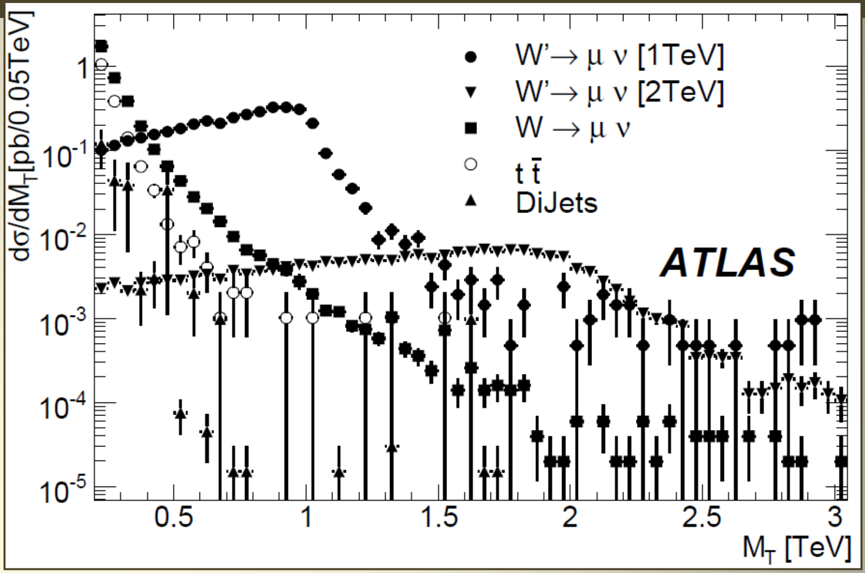


Invariant μμ mass distribution for several misalignment scenarios

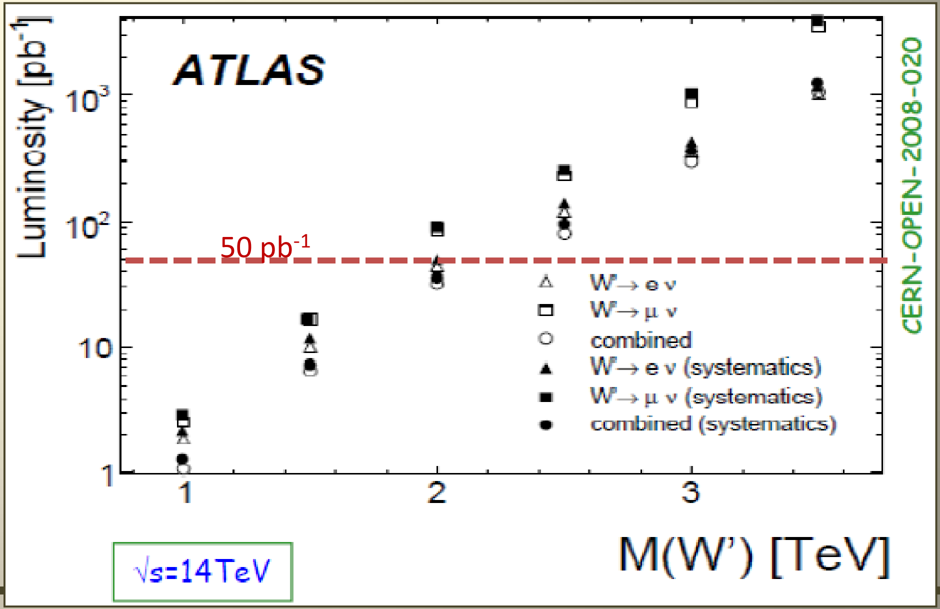
Even with √s = 10 TeV and 200 pb^{-1}, Dilepton resonances can be discovered up to a mass of 1.5 TeV (1 TeV and ~400 pb^{-1} with √s = 7 TeV) beyond Tevatron exclusion reach.

W’ discovery potential



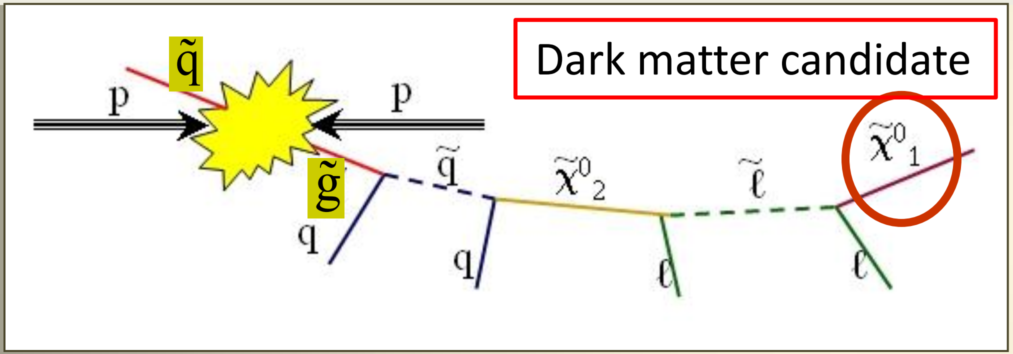


- 5σ discovery potential
  - Including systematics:
    - generator (higher orders, pdf)
    - Energy scale and resolution of lepton and jet
      - impact on missing ET
- Reduced reach for √s =10 or 7 TeV
  - e.g. ~1.5 TeV with 500 pb^{-1} at 7 TeV

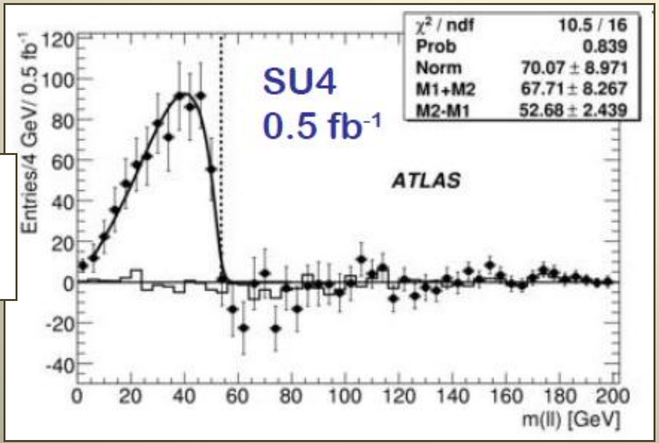


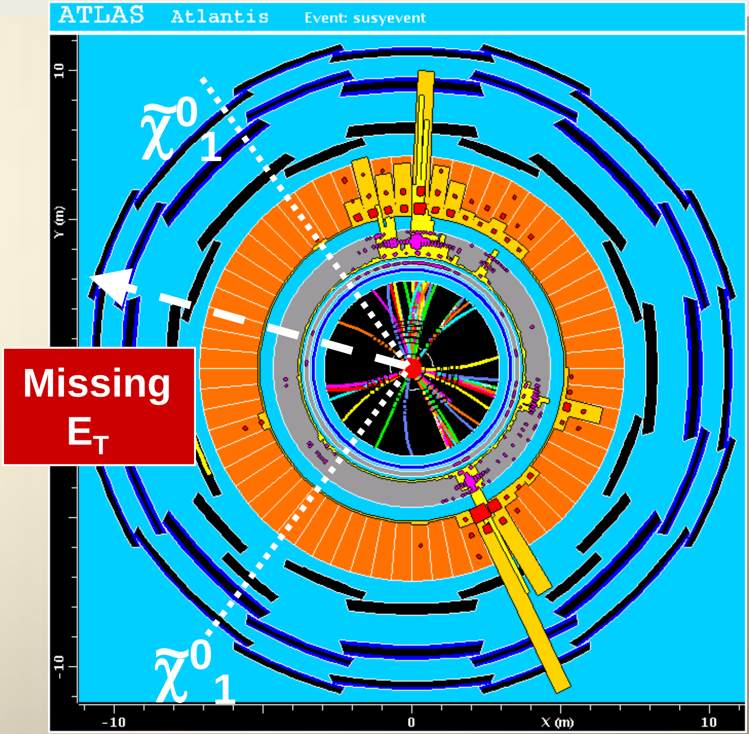
Supersymmetry

- R-parity conserving SUSY could be found rather quickly if it is actually at ~1TeV mass scale
  - Large cross-section for $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production
    - e.g. expect ~ 100 evts for 200 pb^{-1} ($\sqrt{s}$=10 TeV) in the spectacular golden dilepton channel (for benchmark SU3 SUGRA point)



$$m_{\ell\ell}^{\text{edge}} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$



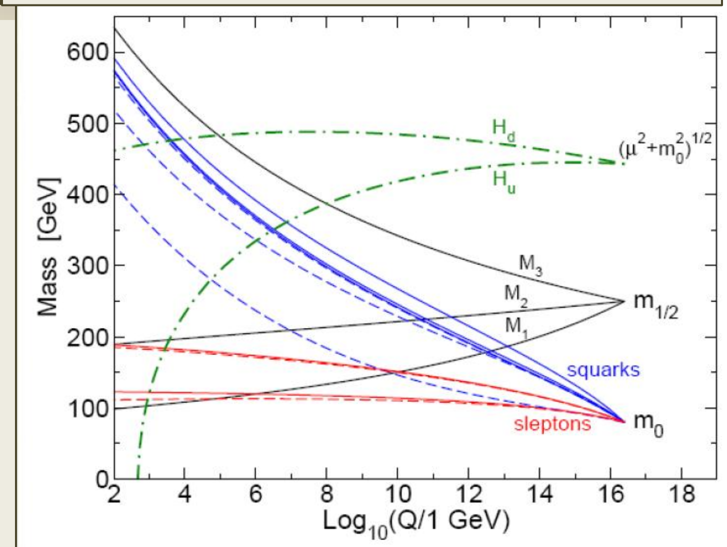


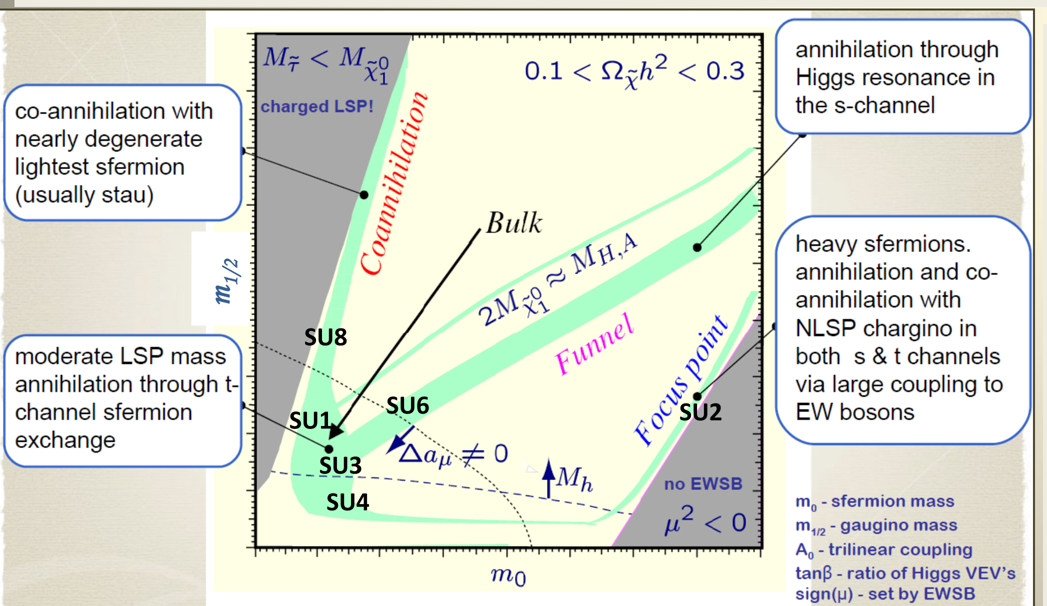
mSugra - generic searches in ATLAS

mSUGRA is merely a convenient framework to account for SUSY breaking (only 4 free parameters + 1 sign) for assessing the discovery potential for R-conserving SUSY with χ^0_1 as Lightest Super-symmetric Particle (LSP, Dark matter candidate).

The search strategy is largely motivated by the cosmological constraints on the DM relic density. Taking into account LEP and Tevatron results, define benchmark points in the (m_0,$m_{1/2}$ plane):

RG evolution of scalar and gaugino masses in a typical SUGRA



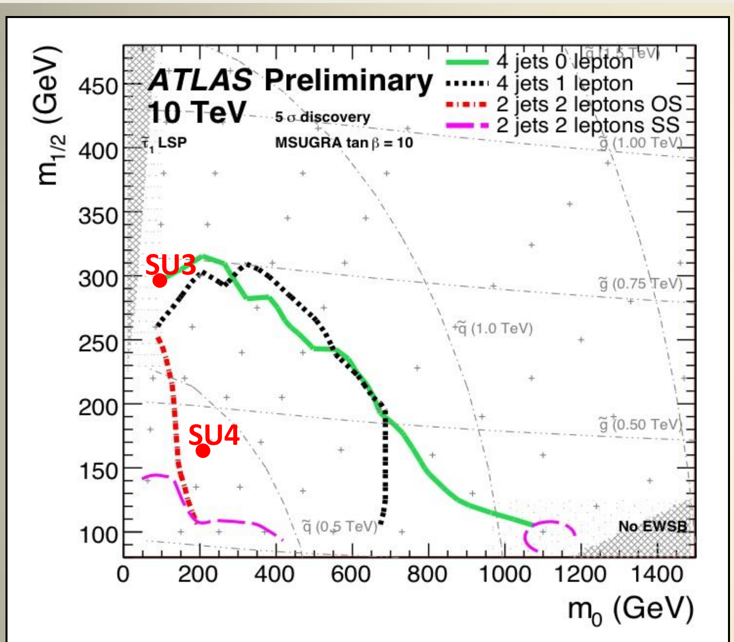


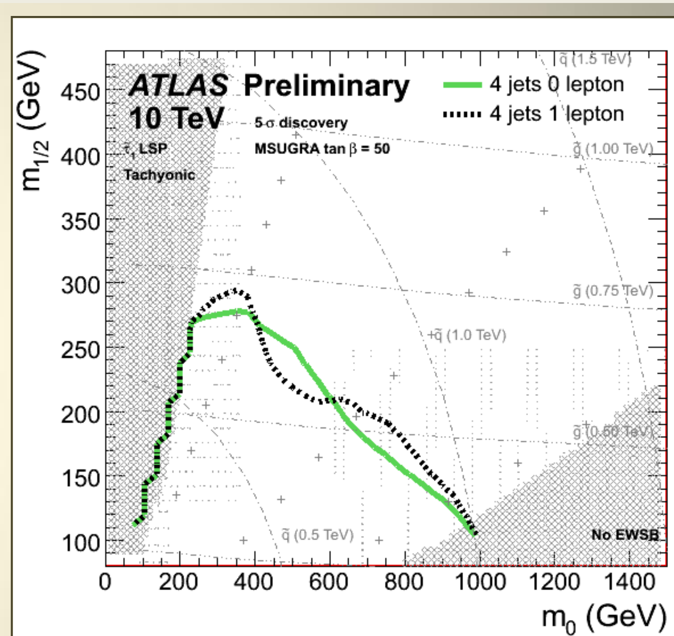
Other SUSY breaking scenarios lead to different EW-scale phenomenology, e.g. Gauge Mediated Susy Breaking:

- with gravitino LSP and χ^0_1 NLSP
- with gravitino LSP and meta-stable slepton NLSP
  - Heavy meta-stable particle with low velocity
  - Signature: penetrating tracks with high pT and low β
  - > c/f this morning talk on long-lived sparticle at LHC

What to expect in 2010? 200pb^{-1}@ 7 or 10 TeV ?

Many channels (n jets + m leptons) being investigated:
- Jets + E_T^{miss} channel: highest reach
- 1-lepton + jets + E_T^{miss} channel: more robust against Background uncertainties



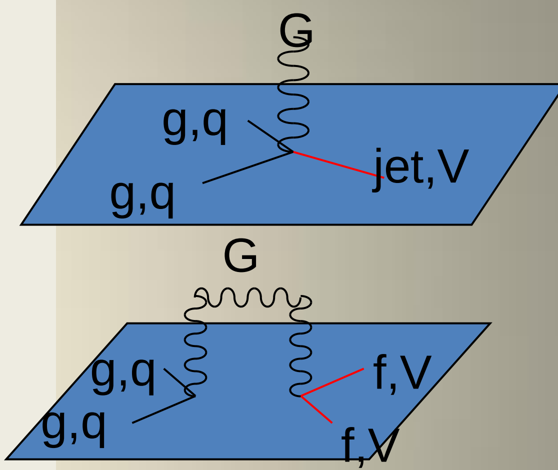


- Discovery up to m ~ 750 GeV
  - discovery reach beyond Tevatron expected exclusion (~400 GeV) for √s ≥ 7 TeV
- Requires very good understanding of backgrounds, in particular fake missing transverse energy coming from instrumental effects (noise, cracks, ..)
- Ultimate LHC reach: m ~ 3 TeV

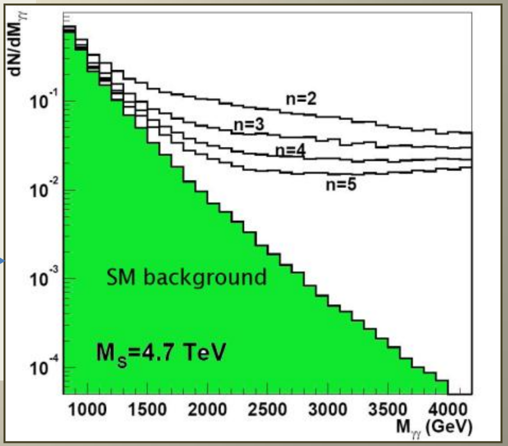
Large Extra Dimensions (ADD model)

- Large flat Extra-Dimensions (LED) in which gravity can propagate
  - could be as large as a few μm
  - SM particles restricted to 3D brane

- The fundamental scale is not planckian:
  - $M_S = M_{Pl(4+n)} \sim$ TeV
  - Present exp constraints => number of extra-dimension n>2
  - M_S > 1 TeV from Tevatron



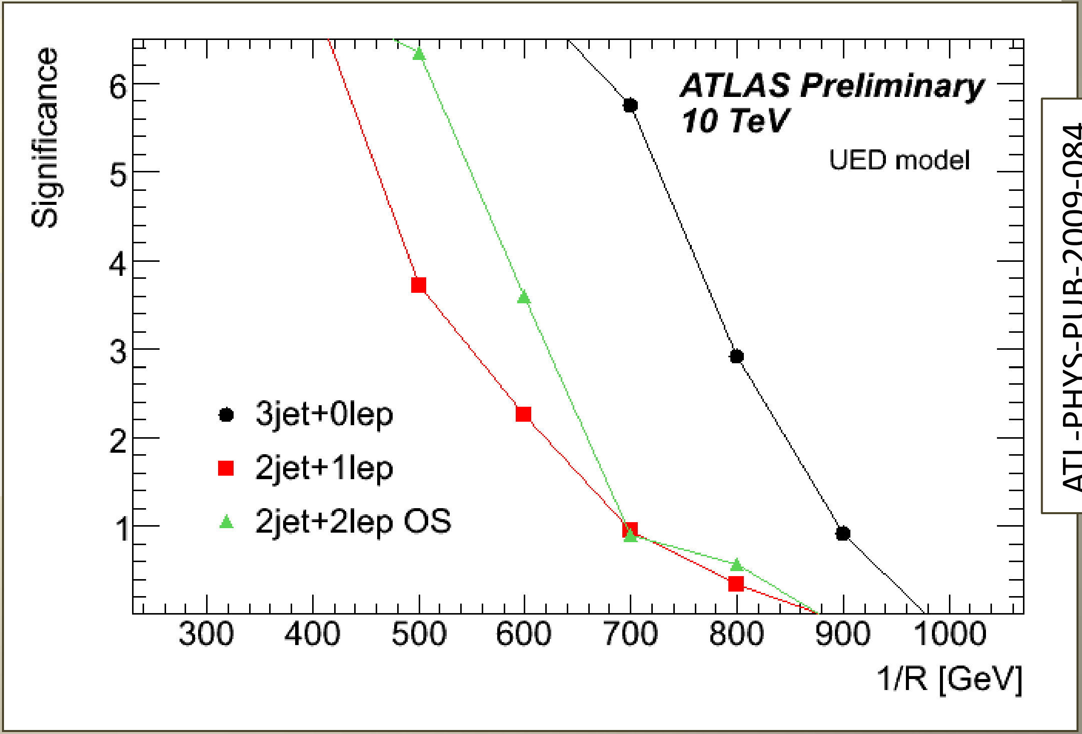
- Signatures:
  - Real graviton emission: in association with a vector-boson
    - (mono) jets + missing ET, V(e.g. g)+missing ET
    - Not for the first few 100 pb^{-1}
  - Deviations in virtual graviton exchange
    - e.g. Excess above di-photon or di-lepton continuum
    - **M_S discovery reach for 100 pb^{-1} at 14TeV: 3. - 4.3 TeV**



Universal Extra Dimensions

- In UED models the SM fields can propagate into 4 + δ dimensions, the extra dimensions being compactified at a scale 1/R >300 GeV.
- Similarly to SUSY each SM field has a Kaluza-Klein partner (but same spin).
- Momentum conservation in the universal dimensions implies the conservation of a KK quantum number (the KK parity) =>KK particles are also produced in pairs with a Lightest KK particle (LKP).

- Analysis similar to the R-parity conserved SUSY.
- In this analysis: δ=1.



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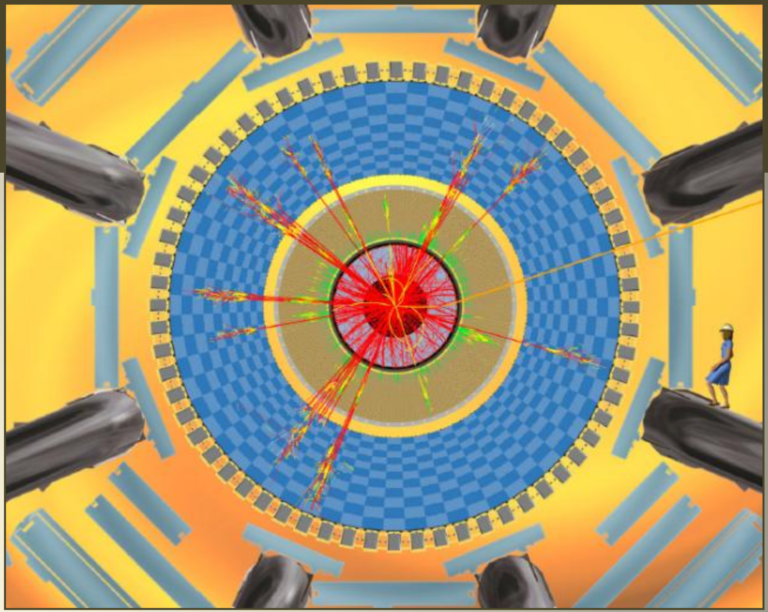
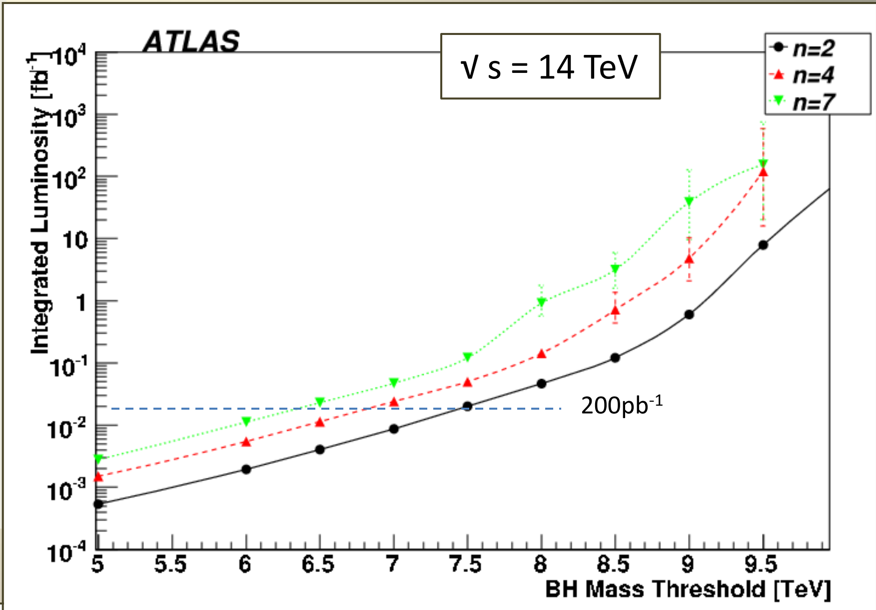
Micro Black Holes



- For Large Extra Dimensions or a strongly warped ED, the fundamental scale of gravity can be as low as the electroweak scale. If the Planck scale is low enough, black holes could be produced at the LHC leading to spectacular events very high multiplicity (challenging for high level trigger)

- Black holes decay democratically to all particles of the SM and are characterized by a large number of high energy and transverse momentum objects:
  - Selection: Σ|pT| > 2.5 TeV, 1 lepton with p >50 GeV
  - the primary SM backgrounds are states with high multiplicity or high energy jets



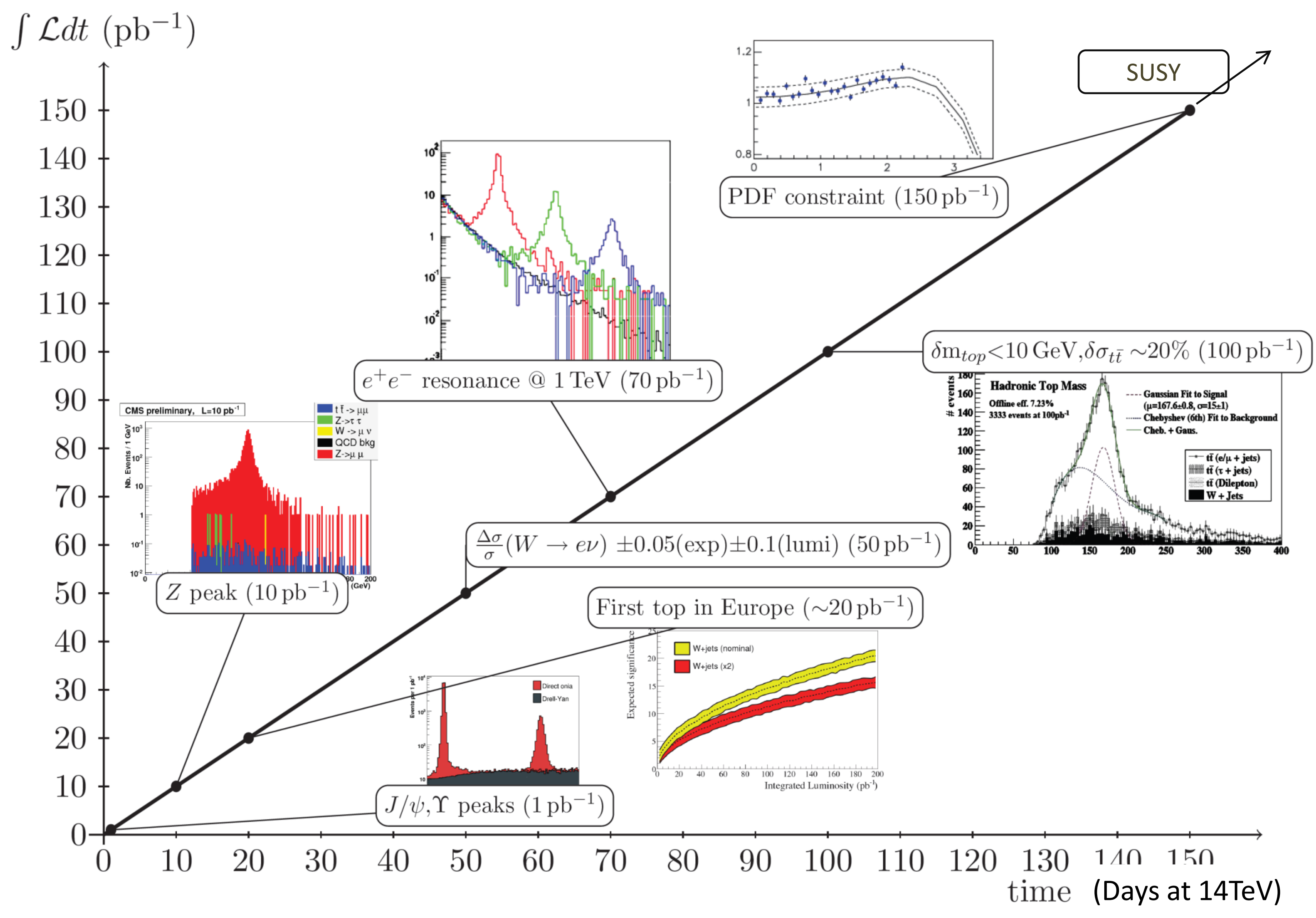
Accessible mass threshold largely reduced for √s = 7 - 10 TeV

Conclusions

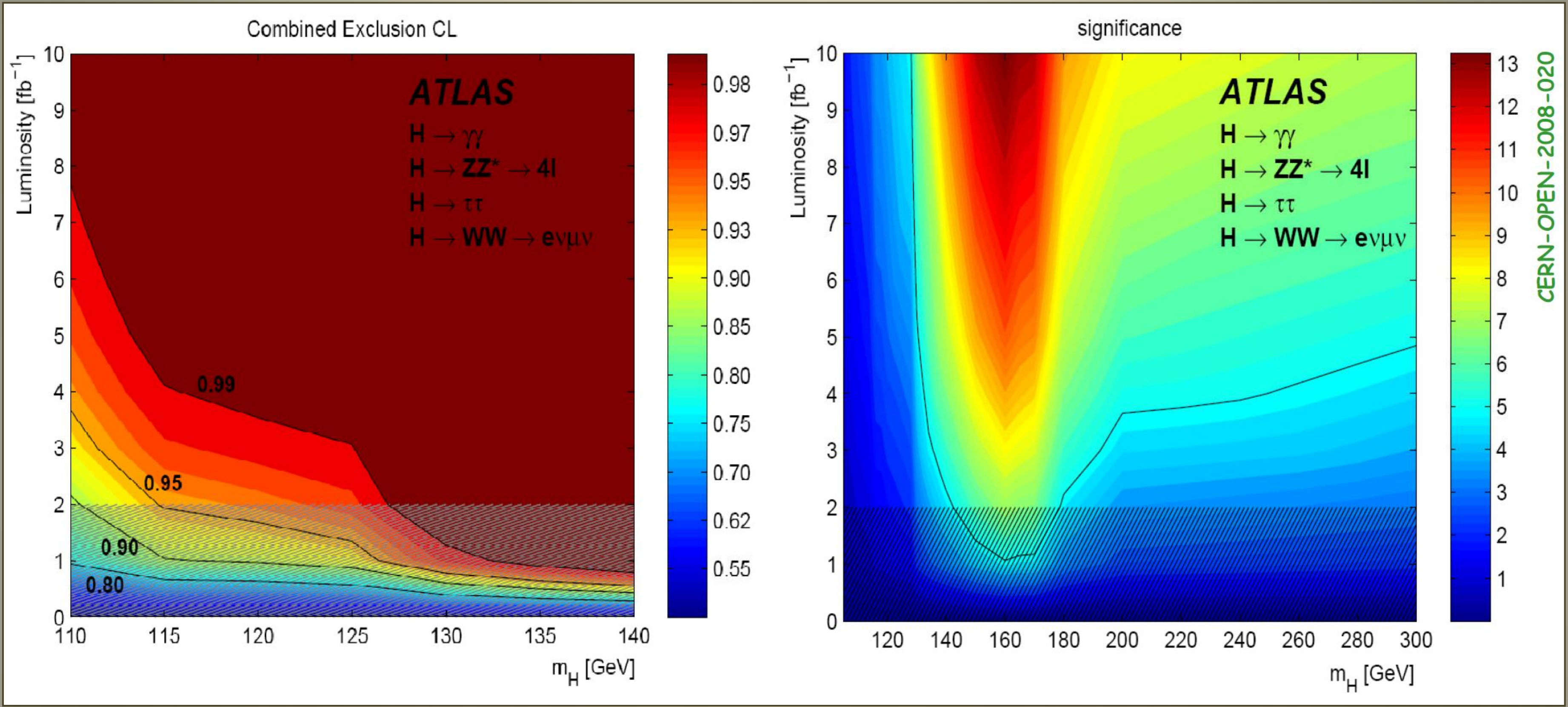
- First LHC physics run in 2010
  - $\sqrt{s}$ = 7 TeV (with possible upgrade to 8-10 TeV)
  - integrated luminosity of 200 – 500 pb^{-1}
- ATLAS is ready and well prepared to exploit these initial data
  - extensive commissioning (e.g. muons from cosmic rays)
- Threefold approach to initial data taking
  - refine detector understanding with collision data
    - Detector already in good shape for physics after extensive commissioning with cosmics
  - establish properties of pp collisions at 7 TeV and possibly beyond
    - ‘re-discovery’ of the Standard Model
  - search for new phenomena and surprises
    - first possibility to move beyond Tevatron sensitivity
    - If nature is kind with us and the LHC luminosity matches our hopes (e.g. 500pb^{-1} at $\sqrt{s}$ = 7 TeV), discoveries are possible beyond present Tevatron exclusion limits:
      - R-parity conserving SUSY
      - Dileptons resonances
      - Extra-dimensions and black holes.

Backup

A global view of early physics



Higgs discovery potential (prospects for 2011-2012?)



- For an integrated luminosity of 2 fb^{-1} ($\sqrt{s}$=14 TeV)
  - 5σ sensitivity for discovery: 143 GeV < M_H < 179 GeV
  - expected range of exclusion (95% C.L.)on M_H: 115 to 460 GeV

=> Not for the first few 100 pb^{-1} at $\sqrt{s}$ = 7 or 10 TeV

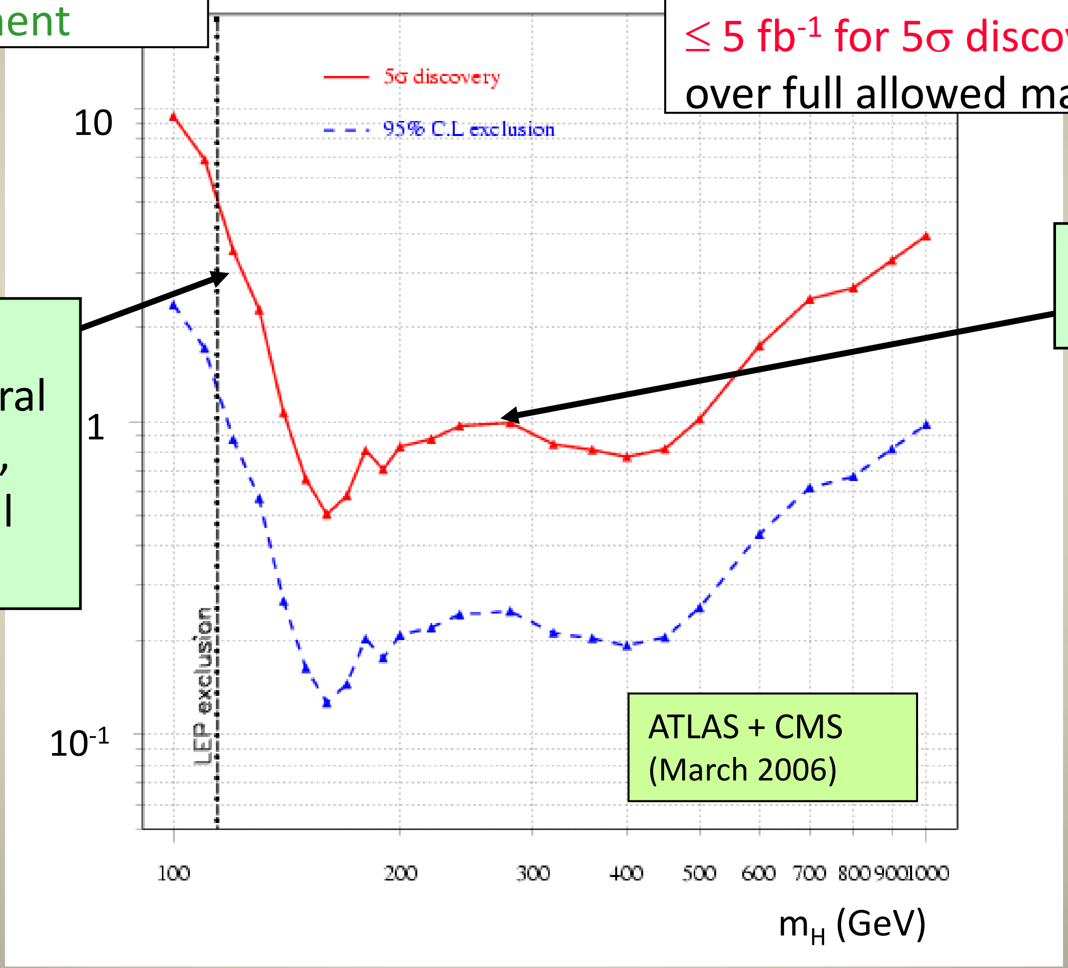
Summary of Higgs discovery potential at the LHC

Needed $\int L dt$ (fb^{-1}) of well-understood data per experiment

$\leq$ 1 fb^{-1} for 95% C.L. exclusion
$\leq$ 5 fb^{-1} for 5σ discovery
over full allowed mass range

Most difficult region: need to combine several channels (e.g. $H \to \gamma\gamma$, $qqH \to qq\tau\tau$) with small S/B or S

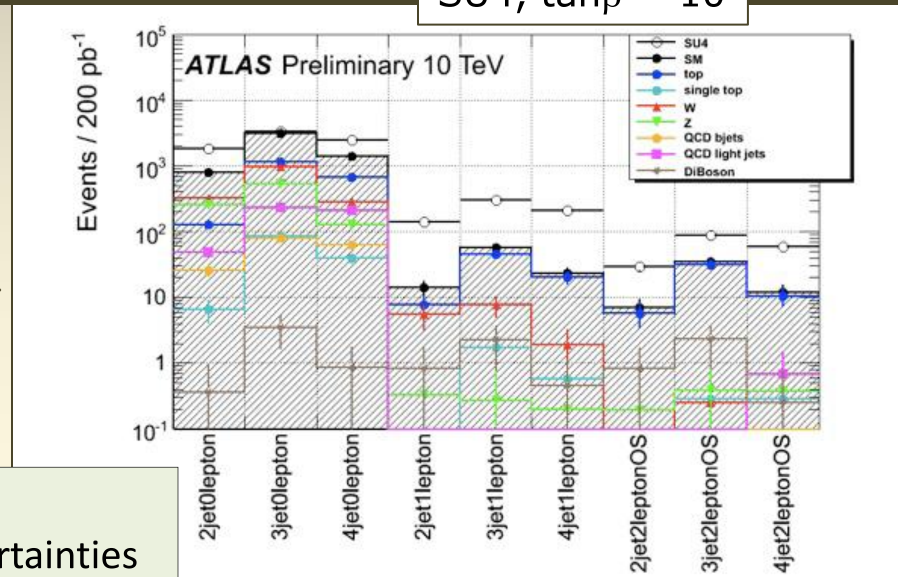
Easier region: $H \to 4l$



What to expect in 2010? 200pb^{-1}@ 7 or 10 TeV ?

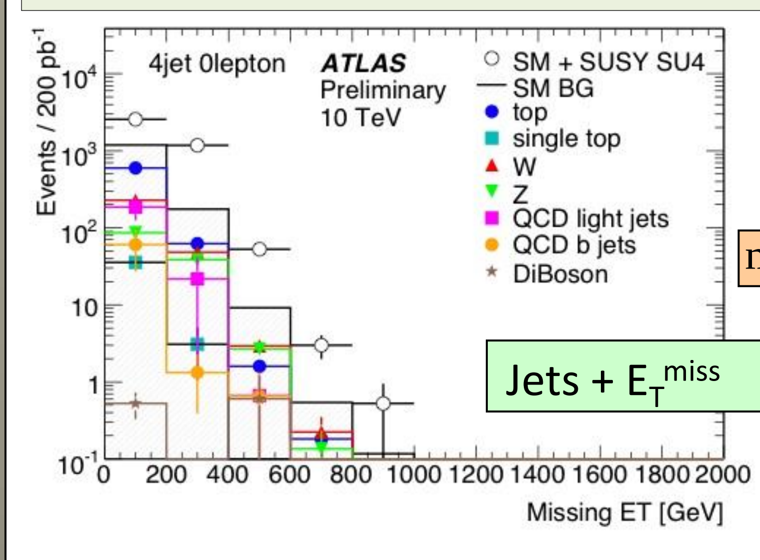
Many channels being investigated:
- 4 jets + 0 leptons
- 4 jets + 1 lepton
- 2 (or 3) jets + 0 leptons
- 2 (or 3) jets + 1 lepton
- 4 jets + 2 leptons (OS or SS)
- 3 leptons + jet
- 3 leptons + ET
- 4 jets + τ
- 4 jets + ≥2 b-tagged

SU4, tanβ = 10



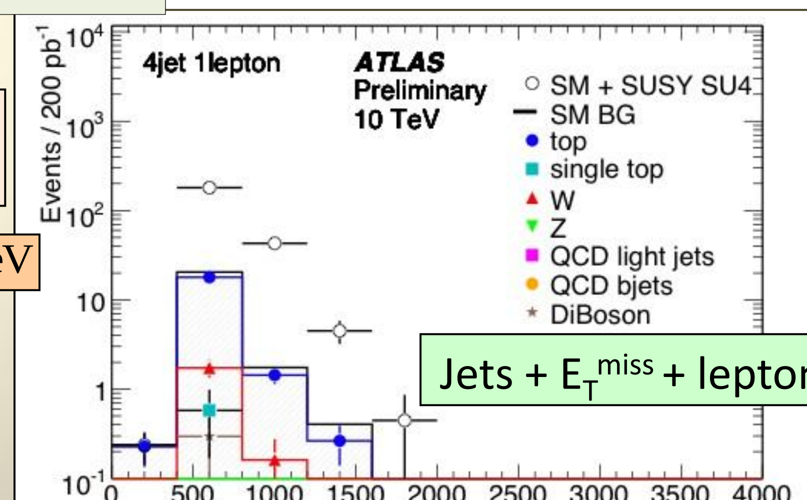
Jets + E_T^{miss} channel: highest reach

1-lepton channel: more robust against Background uncertainties



$\sqrt{s}$ = 10 TeV
200 pb^{-1}

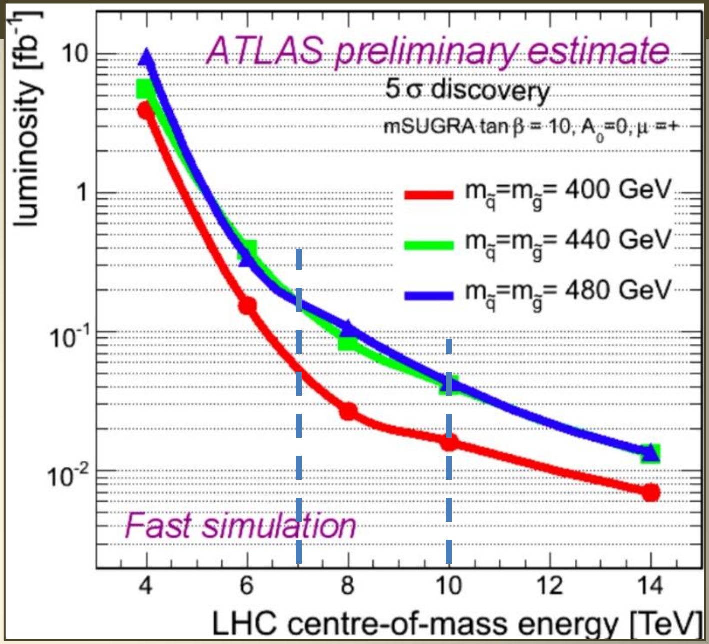
$m(\tilde{q},\tilde{g}) \sim 410\,\mathrm{GeV}$



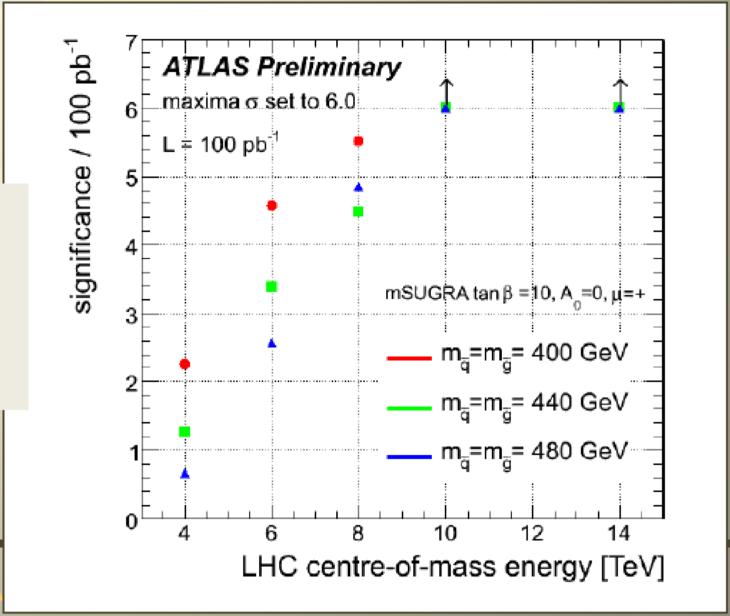
$$M_{\rm eff} \equiv \sum_{i=1}^{4} p_T^{{\rm jet},i} + \sum_{i=1} p_T^{{\rm lep},i} + E_T^{\rm miss}$$

Susy: discovery reach vs LHC c.o.m energy

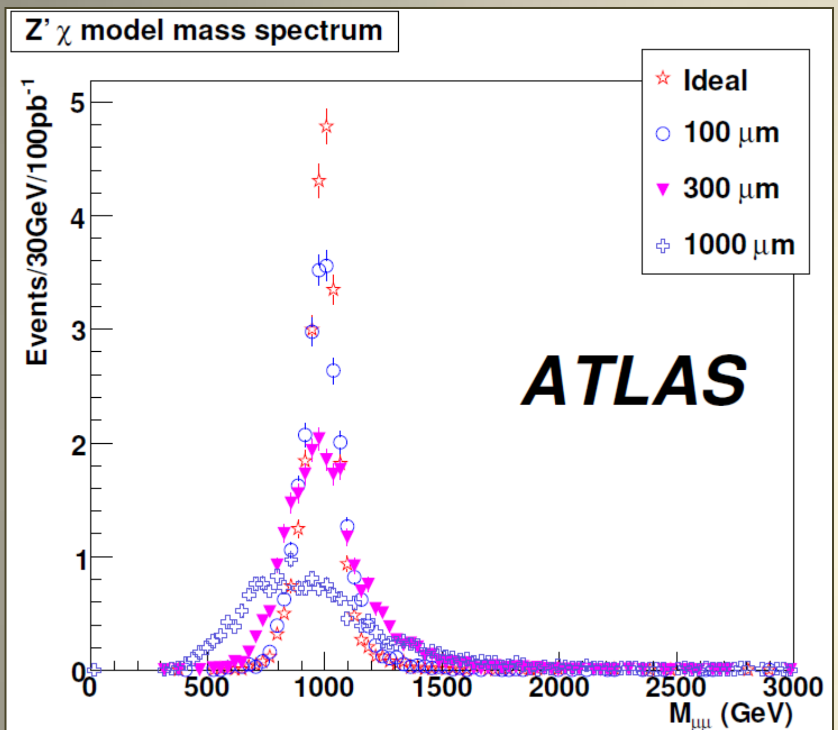
- ℓ+jets+missing-ET channel
  - ➢ Not the most sensitive, but will be usable before inclusive jets+missing-ET analysis
- Fast Simulation studies (all √s re-generated)
- Tevatron limit currently is 392 GeV (CDF preliminary) in this model ($m_{\tilde{q}} = m_{\tilde{g}}$)
- Study includes a 100% Systematic uncertainty on the background



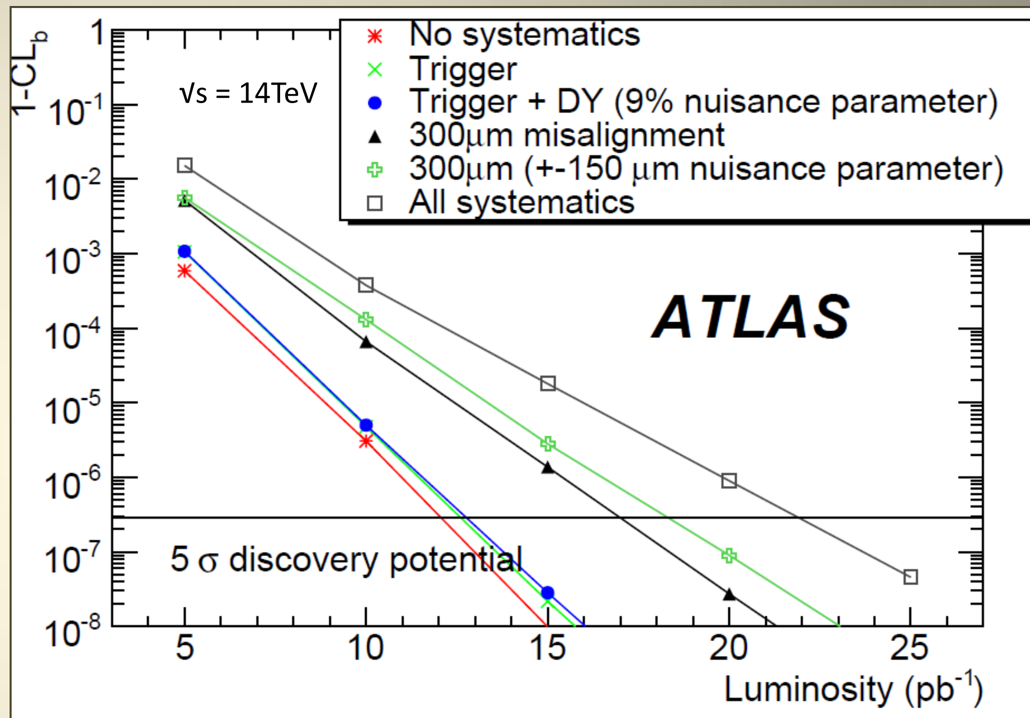
=>ATLAS has a large discovery potential with 200 pb^{-1} at √s=10 TeV
Significantly weakened for 7 TeV (need a factor 2.5-3 in integrated luminosity)



Misalignment and Z′ discovery potential



Invariant μμ mass distribution for several misalignment scenarios



$1\text{-}CL_b$ value vs. Integrated luminosity for Z'_χ model

Remark: muon spectrometer alignment already at the 100-150 μm level (from cosmic studies)