Physics in Atlas

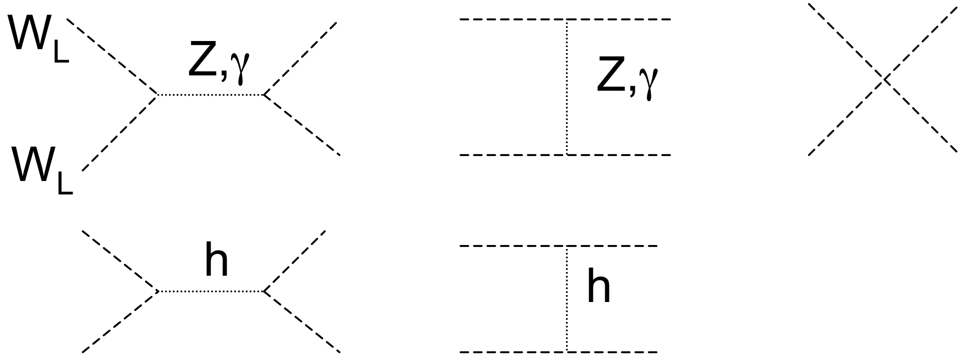
G.Unal (CERN)

Obviously, a non exhaustive talk…
~1000 pages of Physics TDR in 1999
Many notes since that time
Some emphasis on "early" data and their understanding (physics and detector)

Introduction

What the LHC should tell us:

- What is the mechanism responsible for the EW symmetry breaking ?
- The SM Higgs boson (only piece of SM not observed today) or something else ?
- The answer should be at E < ~ TeV

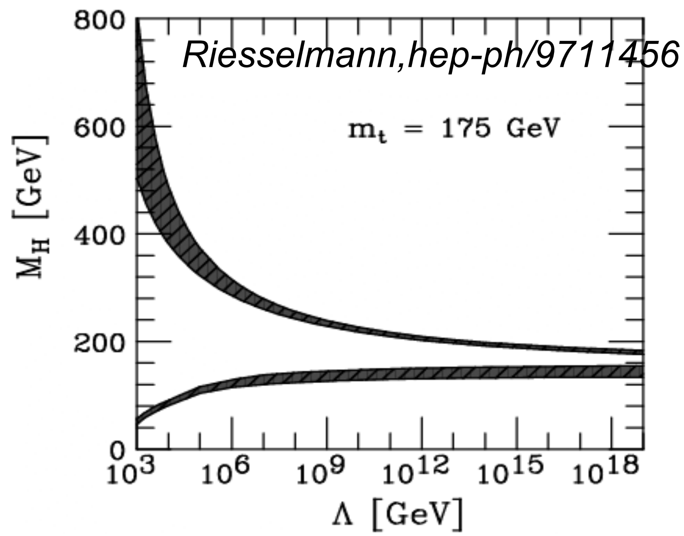


$\mathcal{M} \sim s/m_W^2$

$\mathcal{M} \sim s/m_W^2$

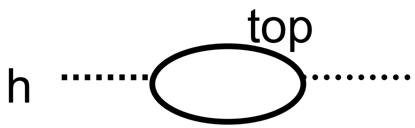
cancellation

What (we think) we know about M_H:
- Consistency of the theory
  - o Triviality
  - o Vacuum stability
- Indirect constraints (EW radiative corrections)
  - o M_H <186 GeV @ 95%CL (EW fit Moriond06)
- Direct limit (LEP): M_H>114.4 GeV



Beyond the Standard Model ?

- Radiative correction to Higgs Mass:



(+loops with W,Z and h)

- $\delta m_h^2 \sim - m_{top}^2/(4\pi^2 v^2)\ \Lambda^2$ (Λ=new physics scale)
- For Λ~ GUT or Planck scale, m_h ~100 GeV requires fine tuning between bare mass and radiative corrections
- « Traditional » Solution: Supersymmetry at the ~1 TeV scale: Cancellation between bosons and fermion loops
- Or a source of new physics such that $\Lambda << M_{planck}$
  - « Little Higgs »
  - Extra dimensions (several variants)
  - Models with alternative EWSB
  - Etc…
  - Energy Scale cannot be much more than ~ TeV
- Other « imperfections » in the Standard Model call for new physics (flavor sector, baryogenesis, ….) but the energy scale where these problems are solved is less obvious.

Experimental conditions

- Proton-Proton collisions @ 14 TeV
- Luminosity:
  - First run in 2007 at 900 GeV
  - First run @ 14 TeV in 2008, luminosity increasing to reach ~$10^{33}cm^{-2}s^{-1}$ "low luminosity" phase

    => ~ *30 fb^{-1} between 2008 and 2010/2011*
  - ~$10^{34}cm^{-2}s^{-1}$ "high luminosity" phase

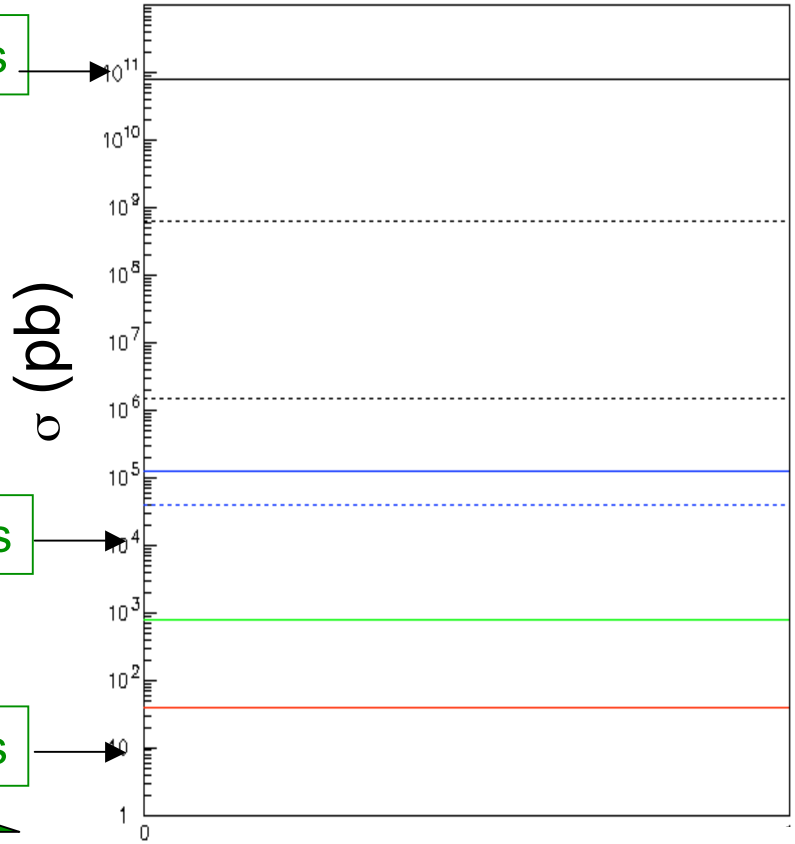
    => *~300 fb^{-1} by 2014/2015*
- Pile-up: ~ 2 (low luminosity) to 20 (high luminosity) pp interactions ("minimum bias") per bunch crossing (every 25 ns)
- Trigger to go from 40 MHz interaction rate to ~200Hz to disk for offline analysis

Order of magnitude of main processes

10^9/s

10^2/s

0.1/s



Event rate @ $10^{34} cm^{-2} s^{-1}$

σ(inelastic)

b quark production

QCD jet, Et>100 GeV

Quark and gluons in final state

W

Z

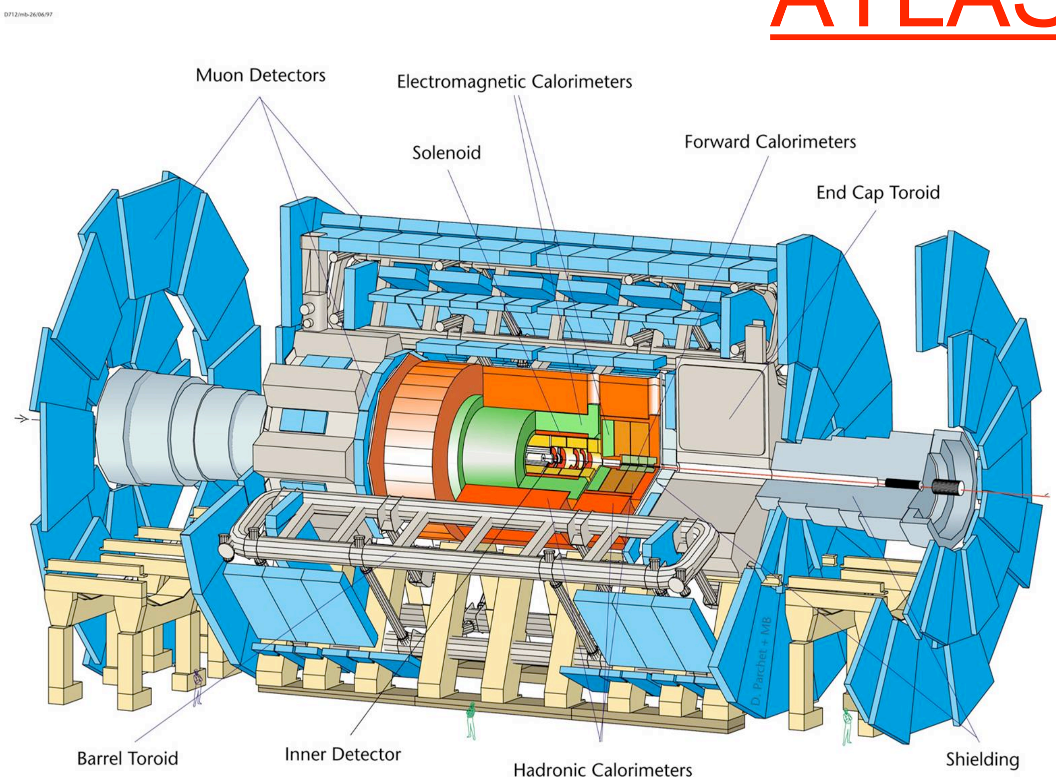
top

→high energy « isolated » e and μ

Higgs mass = 120 GeV

Note: Tevatron run 1
σ(top) ~ 5pb
σ(tot) ~ 60 mb

ATLAS

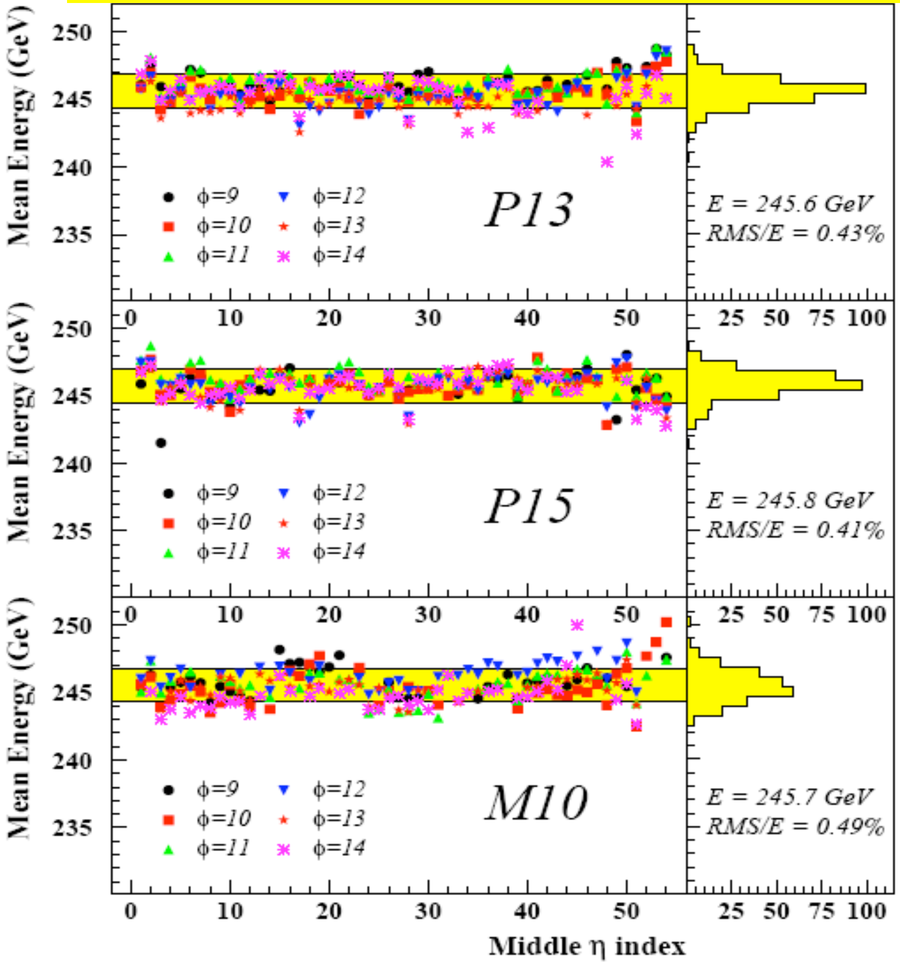


Length : ~45 m
Radius : ~12 m
Weight : ~ 7000 tons
(0.3 g/cm^3)
Electronic channels : ~ 10^8
~ 3000 km of cables

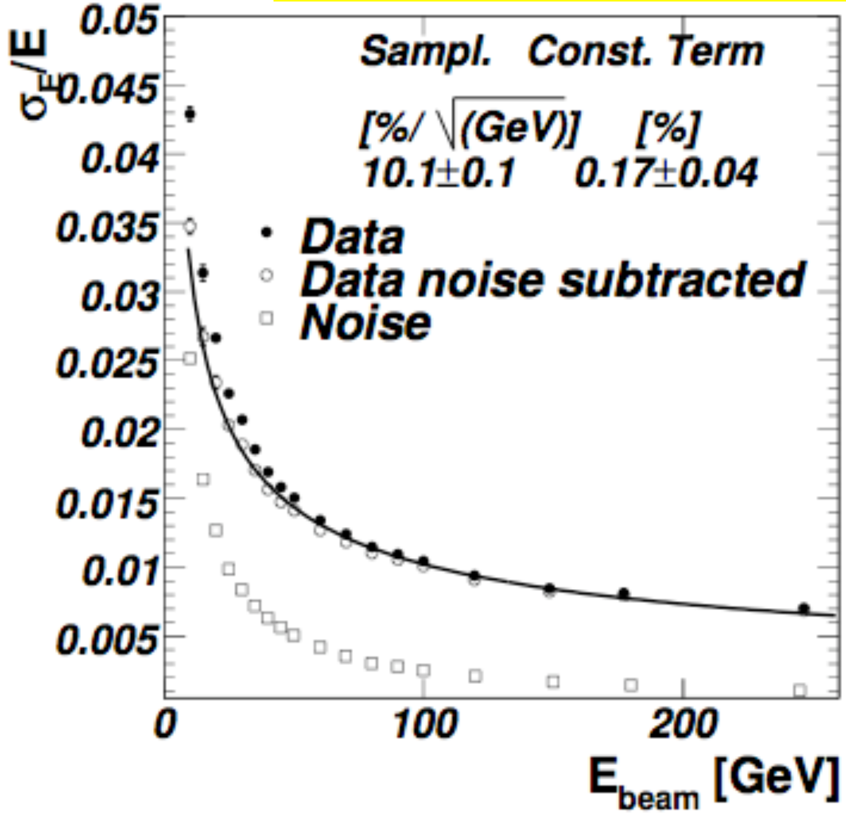
- Powerful e/photon/muon/tau/b-jet identification
  - Rjet ~few 10^3 for eff(photon) ~ 80%
  - Rjet ~10^5 for eff(elec) ~80%
  - R(light flavor jets) ~100 for eff(b-jet) ~60%
  - R(jet) ~few 10^2 for eff(tau$\rightarrow$hadrons) ~50 %
- Very good energy measurement of e/photon and muons
  - ~1 - 2 % for elec pt~25-100 GeV
- Jets and Transverse missing momentum

EM barrel calo performances from 2002 Test-Beam

Uniformity (~4% of all EM barrel tested)



Resolution on one impact cell

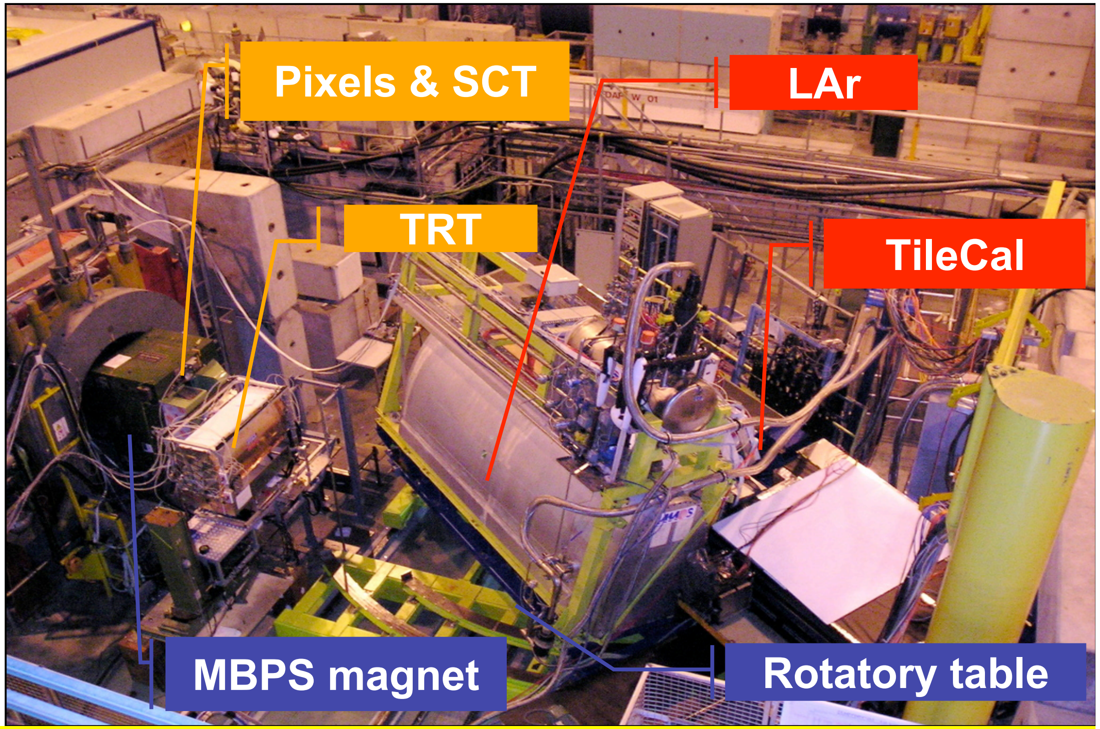


⇒Expect at day 0: ~1% (or better) intercalibration

few % on overall EM-scale

Detector Performance:Combined Test Beam 2004

22M events taken with the full ID/Calorimeter and validated by the offline monitoring;
- e^{+-}, π^{+-}, μ, γ
- E scan: 1 - 350 GeV
- B scan: 0 - 1.4 T
- Additional material ($\eta = 1.6$):
  - Pixel/SCT 12% X/X_0
  - SCT/TRT 24% X/X_0



CTB provides the means for studying detector performance.
Experience gained has had major impact on ATLAS-wide studies:

…besides the magnitude of the effort on the HW and SW integration…

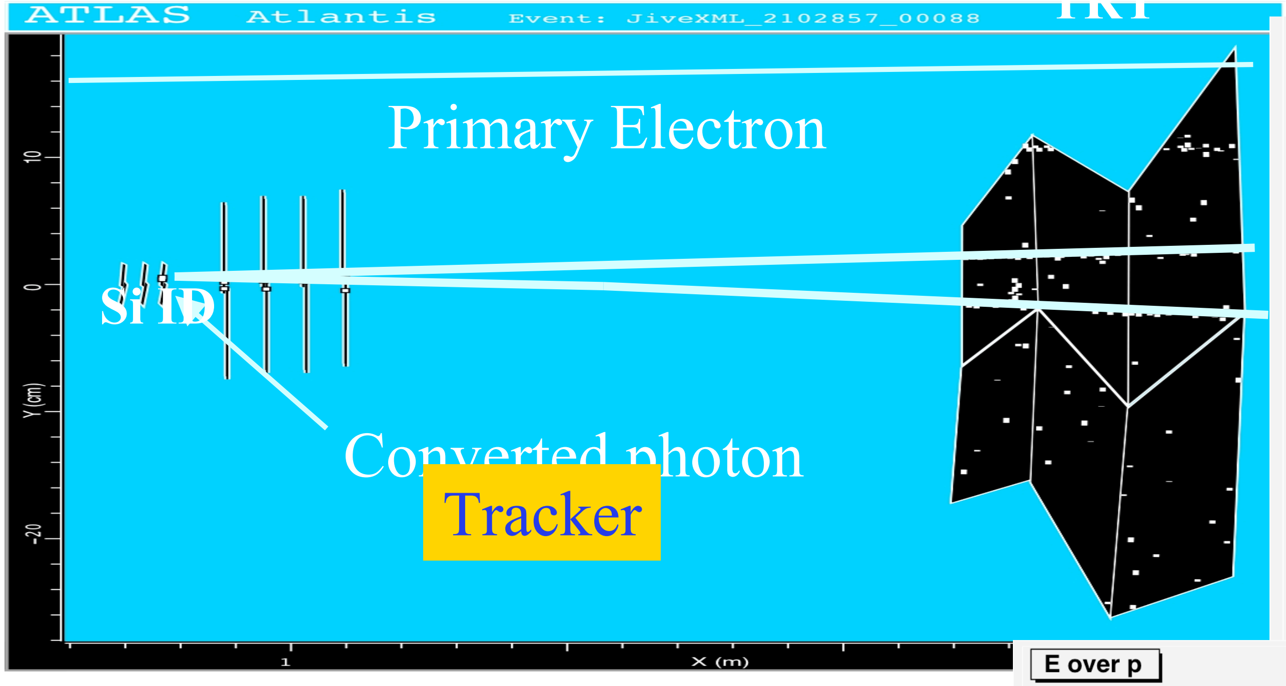
1. Development of reconstruction/alignment/calibration for real detector;
2. Study of individual detector performance (efficiency, resolutions, noise);
3. Improving the simulation/digitization;

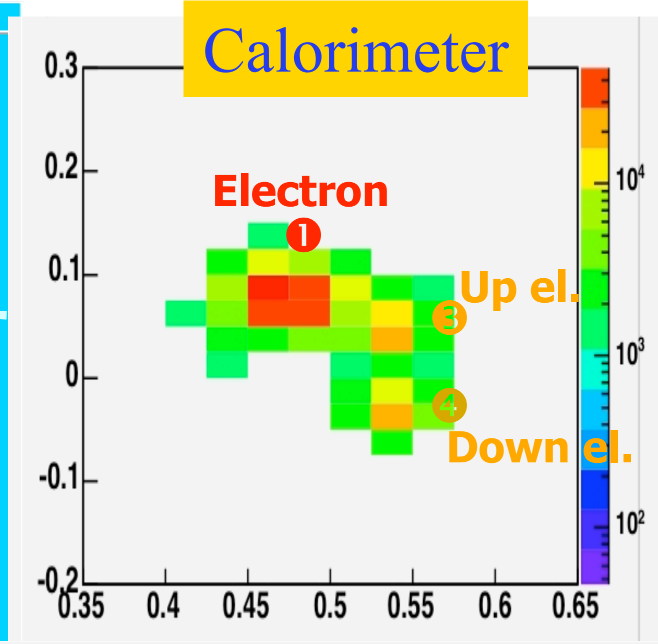
Good understanding of the above is necessary for moving towards…

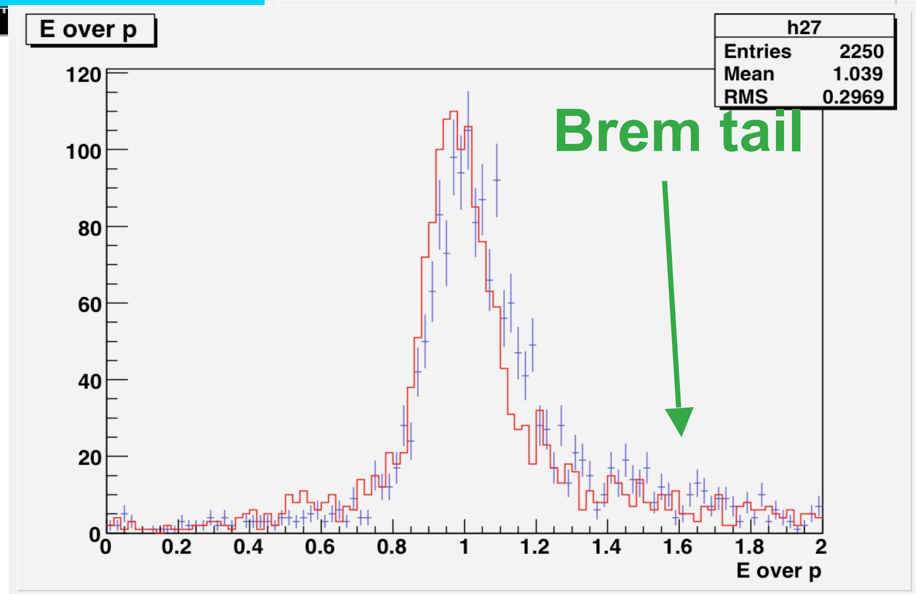
4. Combined performance (material effects, particle ID, photon conversions)

Photon Conversion Recovery in CTB-2004

(In Atlas ~30% of photons convert in the inner detector)







- **Topological clustering used to reconstruct 3 objects in EMC:**
  - primary e^-
  - e^+e^- pair from converted γ
- **Step 1: reconstruct conversion tracks in ID.**
- **Step 2: Combine to EM clusters, compute E/p.**

Physics menu

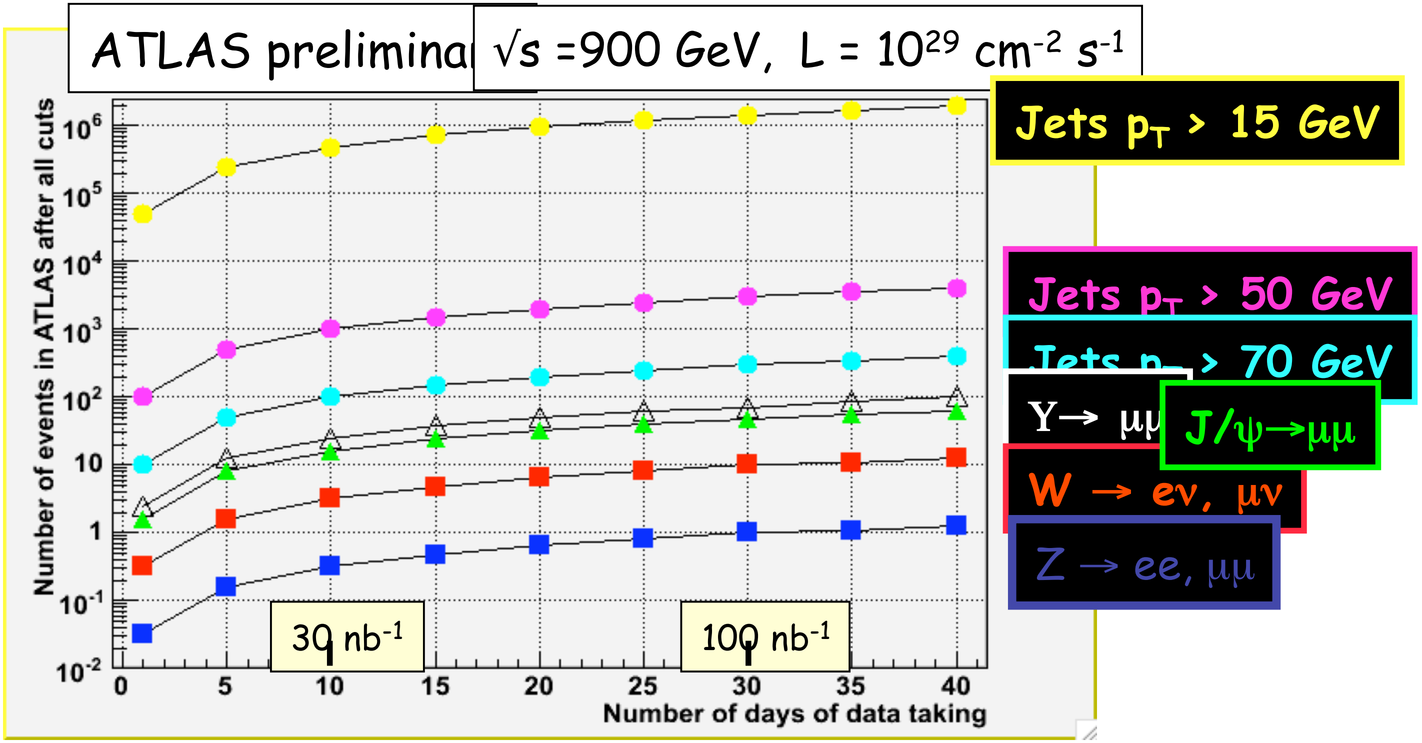
- *"amuse bouche":* 900 GeV (?), Jets, Minimum Bias
- *Appetizer:* Standard Model Physics (W,Z,top)
  - Precise top and W masses: more than just apperizers…
- *Main course:* Higgs physics
  - (see tomorrow morning for more details)
- *Dessert:* Supersymmetry

or "surprise du chef"

Will the data tell us to start with the dessert ?

not covered here: B physics, Heavy Ion physics

900 GeV data



Note: $30 nb^{-1}$ sample is less than the one of W,Z discovery

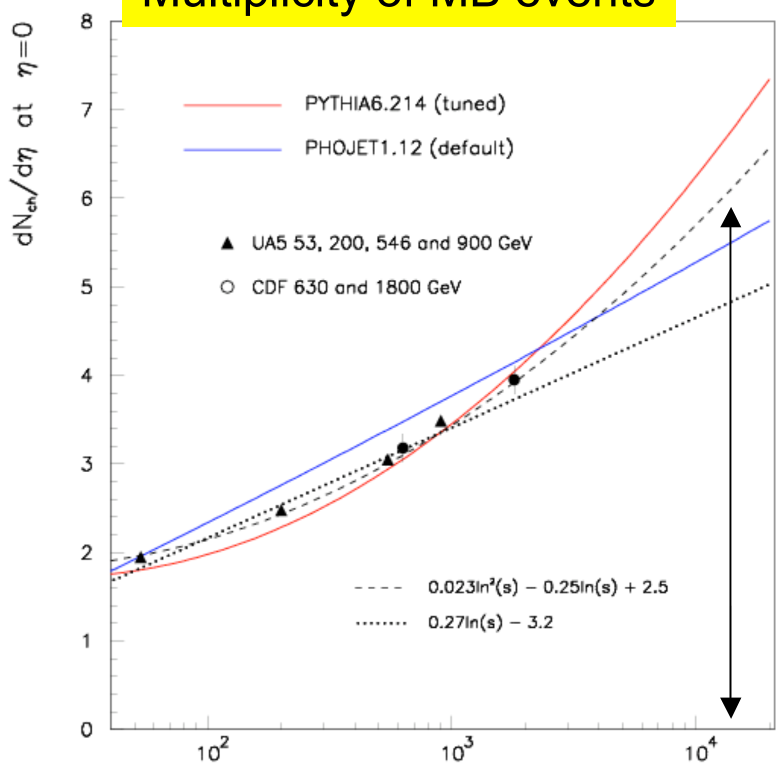
Enough MB and Jets to check problems

(also few direct photons)

But no "accurate" in-situ calibration possible

Minimum Bias

Multiplicity of MB events



√s (GeV)

Uncertainty in extrapolating to LHC energy

$O(10^4)$ events allow a first measurement

(reconstruct low pt tracks)

Similar studies required for underlying event

Can start from di-jet event

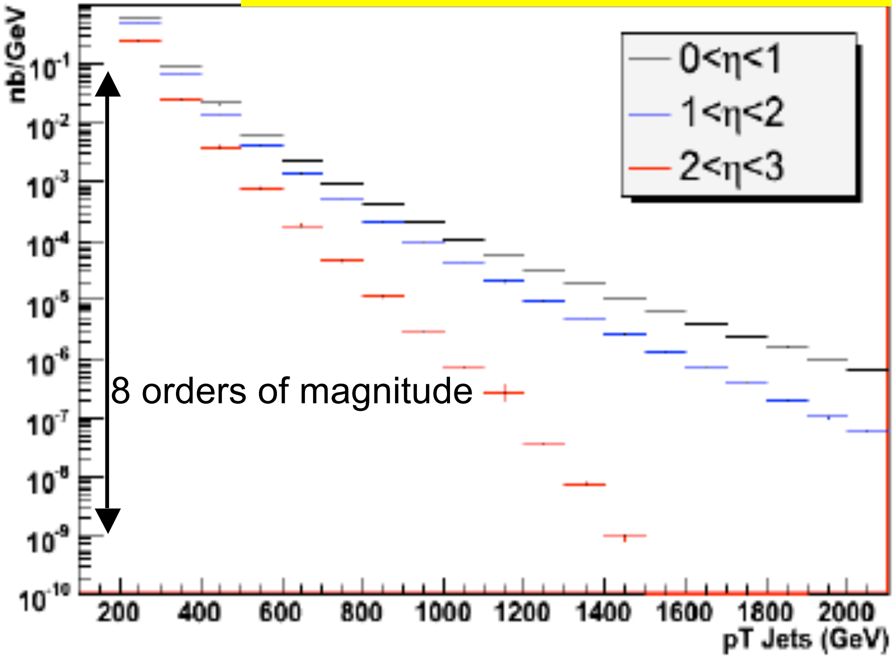
How universal is the underlying event tuning in the MC ?

Jets

Issues for cross-section:

- Stat error ~1% at Pt=1000 GeV for 1fb^{-1}
- Theory error ~15% (at 1TeV) from pdf, ~10% from higher order corrections
- Jet energy scale: 5% uncertainty => 30% error on cross-section. Should aim for 1-2% scale uncertainty !
- Jet algorithm issues (cone vs mid-point vs Kt)

NLO jet cross-section



Understanding jet reconstruction is a key issue in many channels

Standard Model Physics

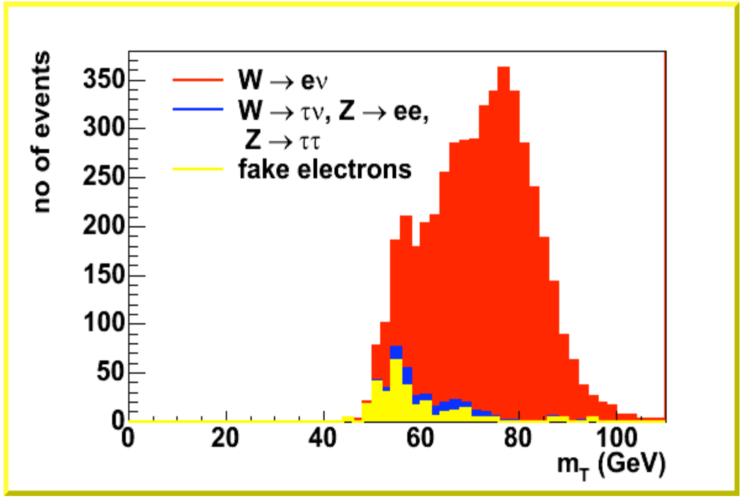
- W,Z production
- W,Z as probes of detector performances
- W mass measurement

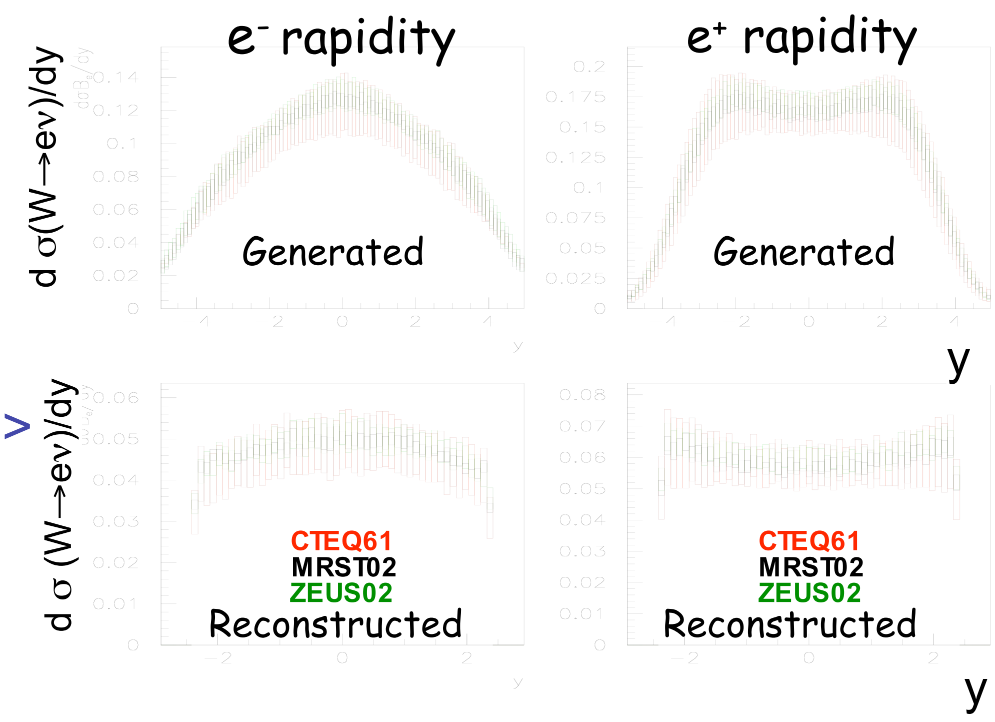
- Top production
- Top as probe of detector performances
- Top mass measurement

  (top properties, polarization, single top)

W,Z production

- Large production rates:
  - σ.BR(W→lν) ~15nb
  - σ.BR(Z→ll) ~ 1.5nb
- Selection relies on lepton identification (but Z→ee can be identified with calorimeter only)
- Measurement of cross-section:
  - Dominated by systematics
  - Few % from modelling of production
  - Few % from luminosity uncertainty
  - Can be used alternatively as luminosity probe
- Rapidity distribution of lepton sensitive to structure function => can help constraining pdf



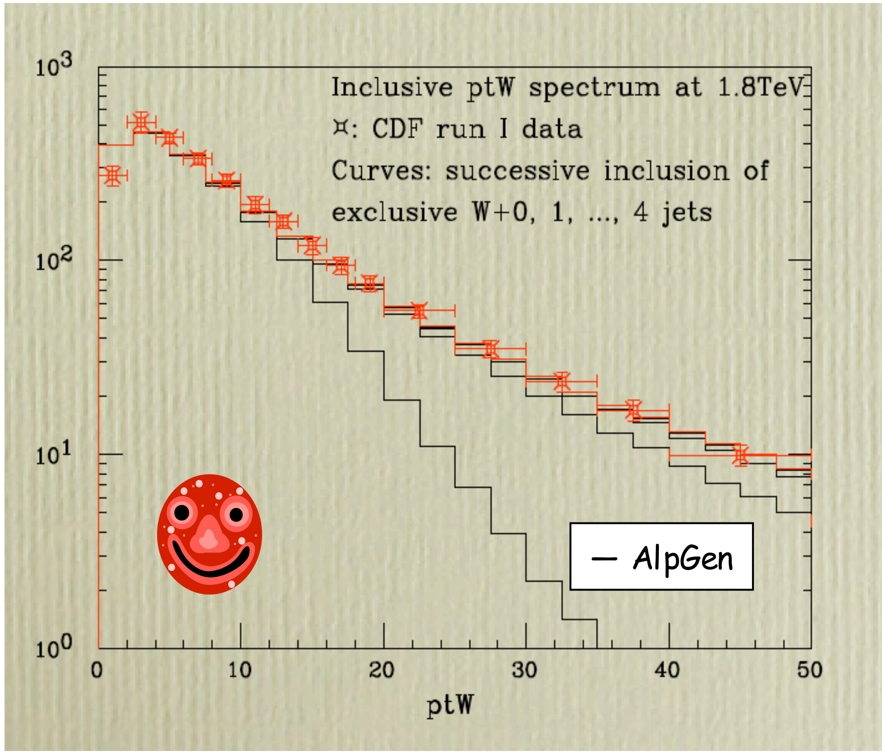


MC and SM understanding

- Many progress in recent years in MC tools for understanding SM processes (W,Z,top,jets,photons)
  - MC@NLO
  - Alpgen/Sherpa: matching between higher order tree diagrams and parton shower

  => Better description of Pt distribution, event shapes, …

(CDF data)



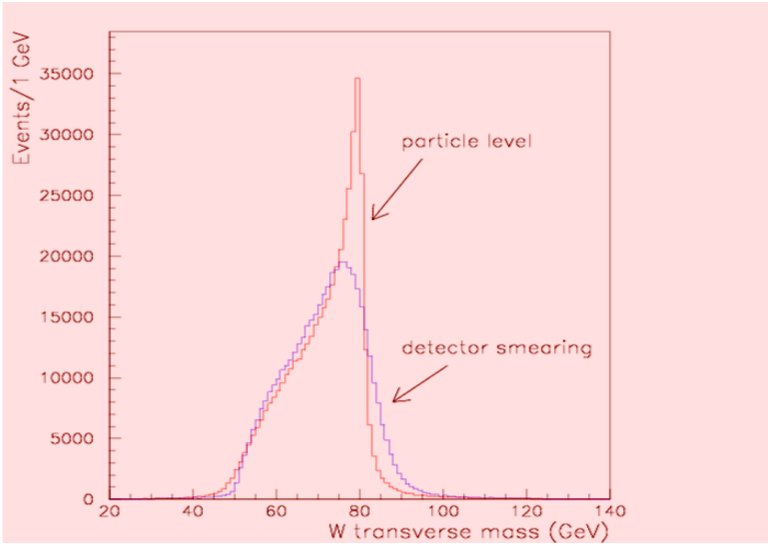
Intercalibration with Z

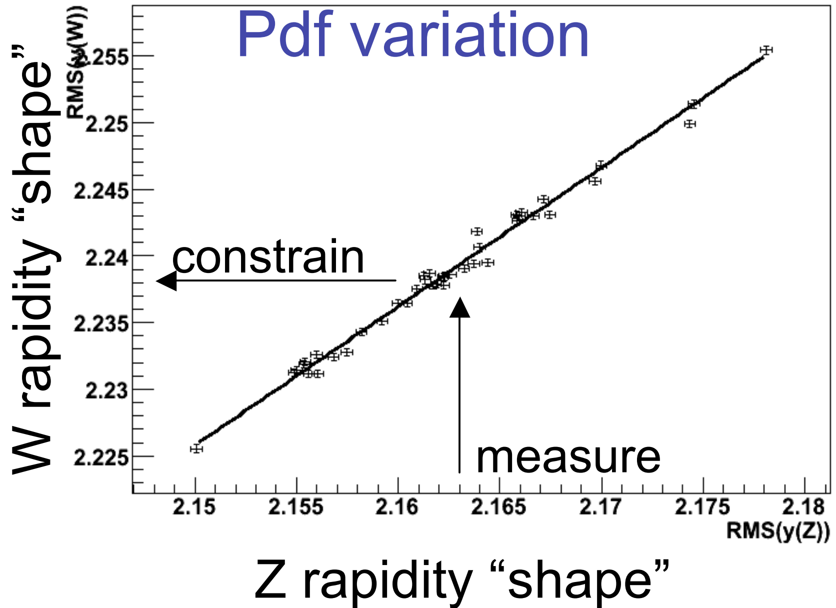
- Aim: Check/Improve intercalibration between regions of EM calorimeter
  - typical region size 0.2x0.4 in $\eta x \phi$
- Region i: $E \rightarrow E(1+\alpha_i)$ $M^2 \rightarrow M^2(1+\alpha_i+\alpha_j)$
- Use Z mass constraint to compute α_i
- With 100K Z statistical uncertainty is ~0.4%
  => good enough to improve intercalibration
- 100K Z <=> few days @$10^{33}cm^{-2}s^{-1}$
  few weeks @$10^{32}cm^{-2}s^{-1}$

Z events are also powerful to measure lepton identification efficiencies

W mass measurement

- W→lν: measure Pt(l) (or transverse mass)
- Stat. Uncertainty ~2MeV for 10fb^{-1}
- "Standard wisdom" for syst. uncertainty :20-25 MeV
  - 15 MeV from lepton energy scale
    - Scale is normalized with Z, so it is in fact the non linearity between M(Z) and M(W)
  - 10-15 MeV from modeling of W production
- Can this be improved by "better" use of Z events as a constraint on non-linearities, W/Z production model ?
  - 5 MeV from Z stat. feasible (?)
  - But should disentangle all the effects that will be mixed up together in the Z data
- Dedicated and difficult analysis…





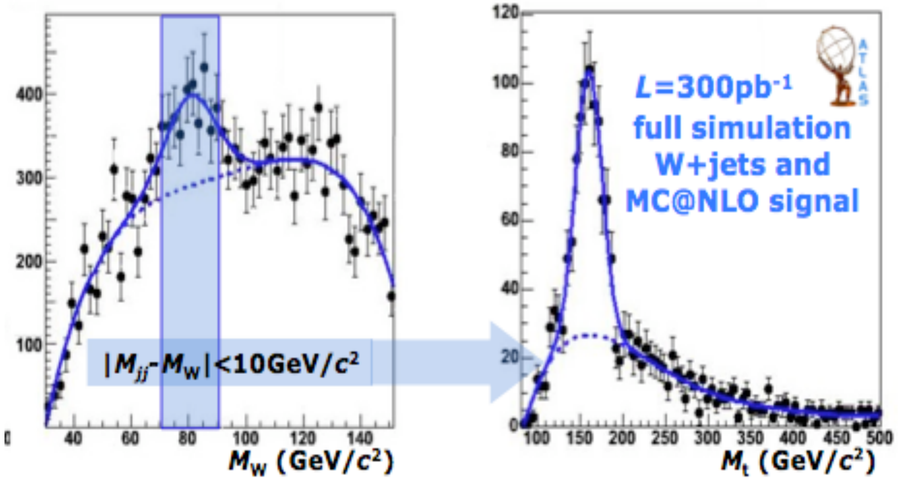
Cf M.Boonekamp @ Physics at LHC06

Top production

- QCD pair production
  - Dominated by gg fusion
  - 840 pb => LHC is a top factory (~1Hz@$10^{33}cm^{-2}s^{-1}$)
- Also EW single top production
  - 300 pb
  - Sensitive to Vtb
- Top decay before hadronisation
  - Polarisation studies possible, Spin correlations
- In SM: t→bW decay, final state driven by W decay

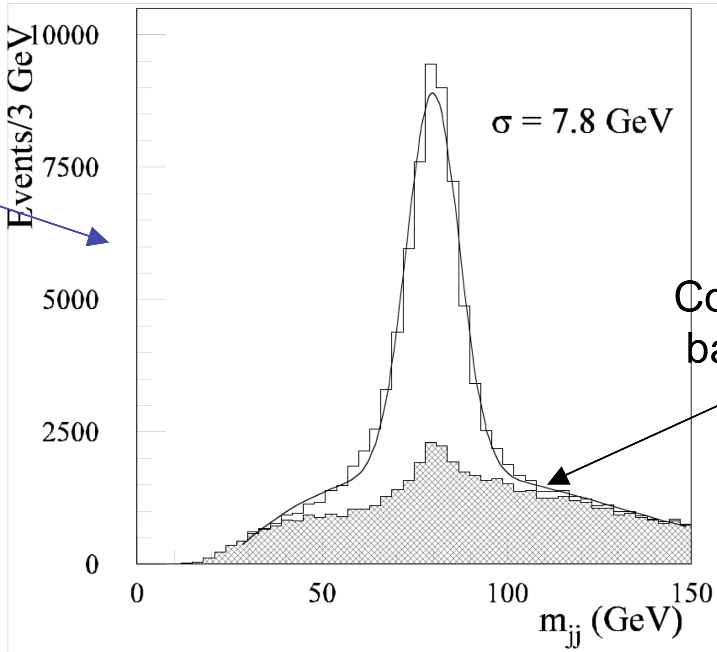
Chinese-french collaboration

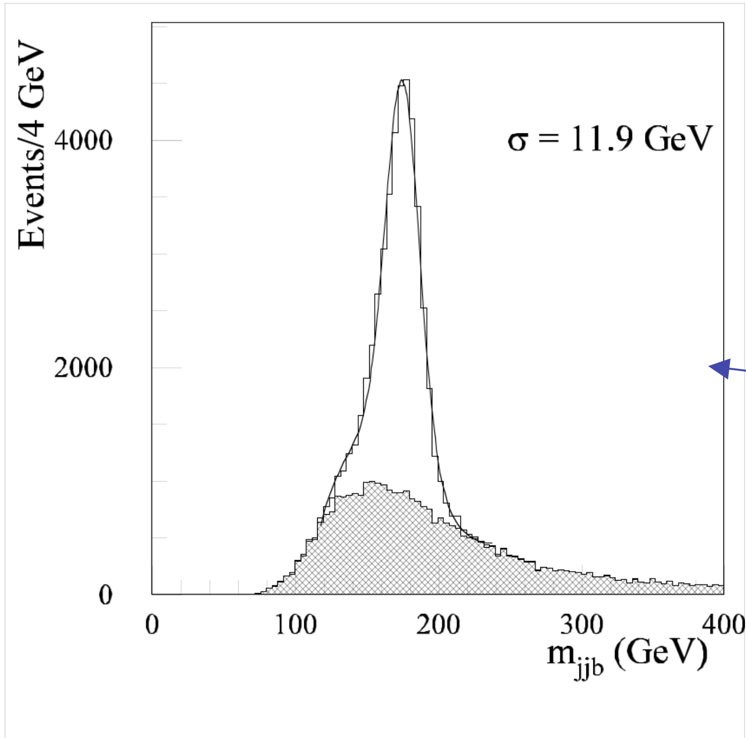
- "Benchmark" channel for top mass measurement: Lepton+Jets
  - One W to e/muon, one W to jets
  - Clean S/B possible with b-tagging
  - W → jet jet provides nice in-situ calibration for jet energy scale
- Top events can also be selected without b-tagging => measure b-tag efficiency with data



Top Mass measurement

W mass reconstruction: Adjust jet energy scale





Top mass reconstruction

Statistical uncertainty ~0.1 GeV for 10 fb^{-1}

Systematics:

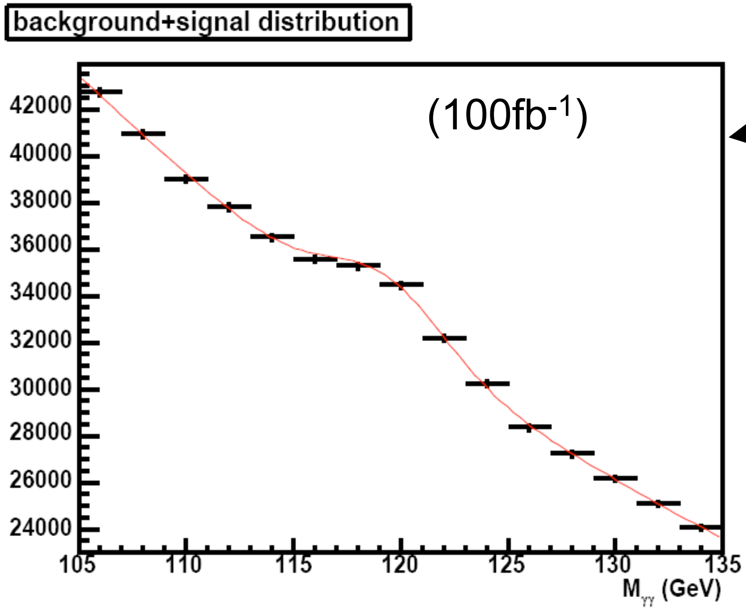
- Jet energy scale (b-jet vs light quark jet)
- Fragmentation (parton->hadrons)
- Hard gluon radiation

⇒**Uncertainty ~ 1 GeV for 10 fb^{-1}**

Will require some hard work

Higgs Physics

- "Easy" for ~200<M_H<600 GeV (gold-plated 4 lepton modes)
- Many channels to investigate to cover more interesting "low" mass range (115-200 GeV)
  - Higgs width is small in this range:
    - Mass resolution is limited by detector performances.
  - Benchmark channels (small BR)
    - $H \to \gamma\gamma$ (S/B ~5%, narrow peak)
    - $H \to$ 4 leptons (narrow peak, "good" S/B but low stat.)
  - Vector Boson Fusion production modes:
    - $H \to \tau\tau$
  - Several other modes

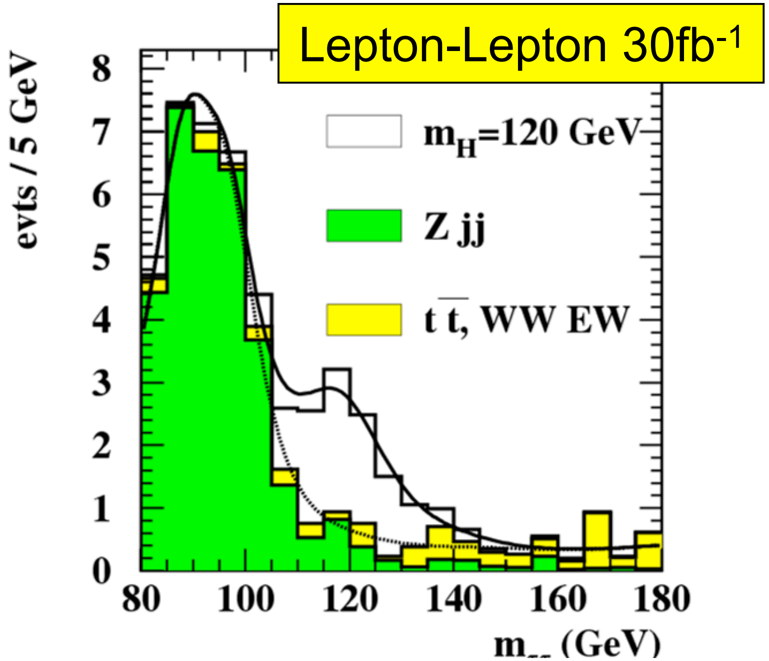


$H \to \gamma\gamma$:

- Energy resolution
- Photon angle measurement (+vertex from tracker)
- Jet background rejection (jet$\to\pi^0\to\gamma\gamma$)
- Handling of conversions

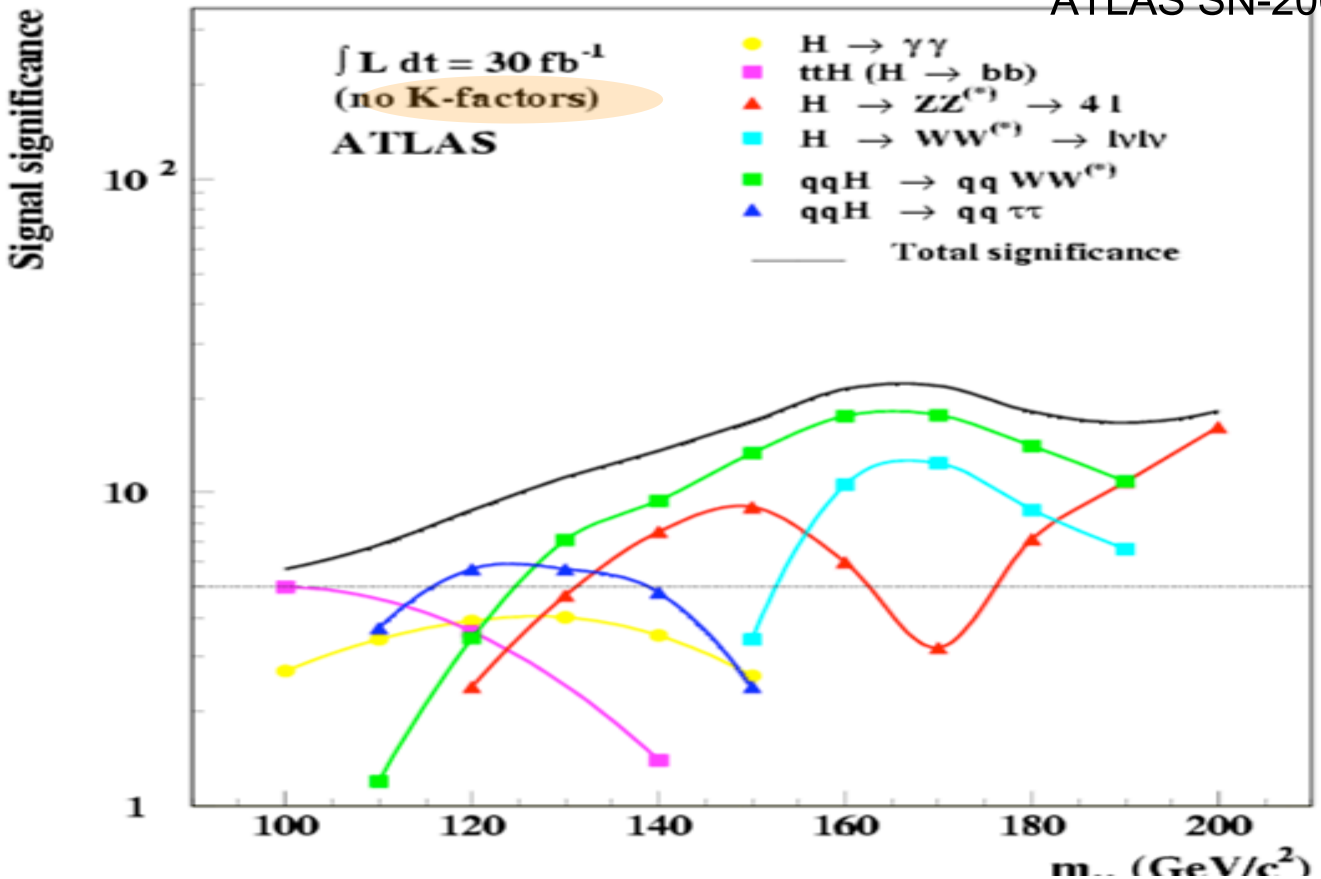
VBF production qqH, $H \to \tau\tau$:

- Hadronic and Leptonic tau decays
- Missing Et for mass reconstruction
- "Forward" jet tagging
- Central jet veto



SM Higgs Discovery potential

ATLAS SN-2003-24



-For M_H ~115 GeV, several channels can be combined

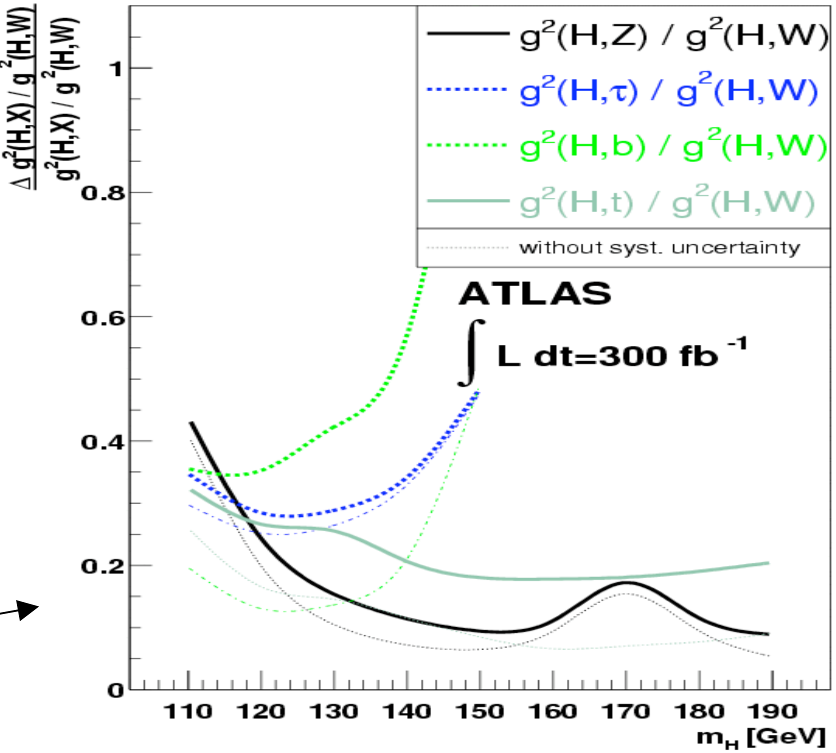
-Sensitivity better if NLO corrections to signal and background taken into account

-In principle, already good discovery potential with $10fb^{-1}$

Provided detector performances and background systematics are under control

- Higgs properties measurements
  - Mass: “easy”
  - Witdh: direct measurement for M_H>200 GeV
  - Spin,CP: Powerful 4 lepton channel above 200 GeV, more difficult below but several studies possible
  - Couplings to fermions and bosons: Measure as many (production)*(decay mode) channels as possible
    - ttH, WH with H→WW* for instance
    - ~5-20% accurary on ratio of couplings with 300 fb^{-1}

Chinese-french collaboration



- SUSY Higgs sector
  - 3 neutral, 2 charged states in MSSM
  - 2 parameters (+radiative corr.)
  - Apply SM searches
  - Dedicated channels: Tau’s are very important

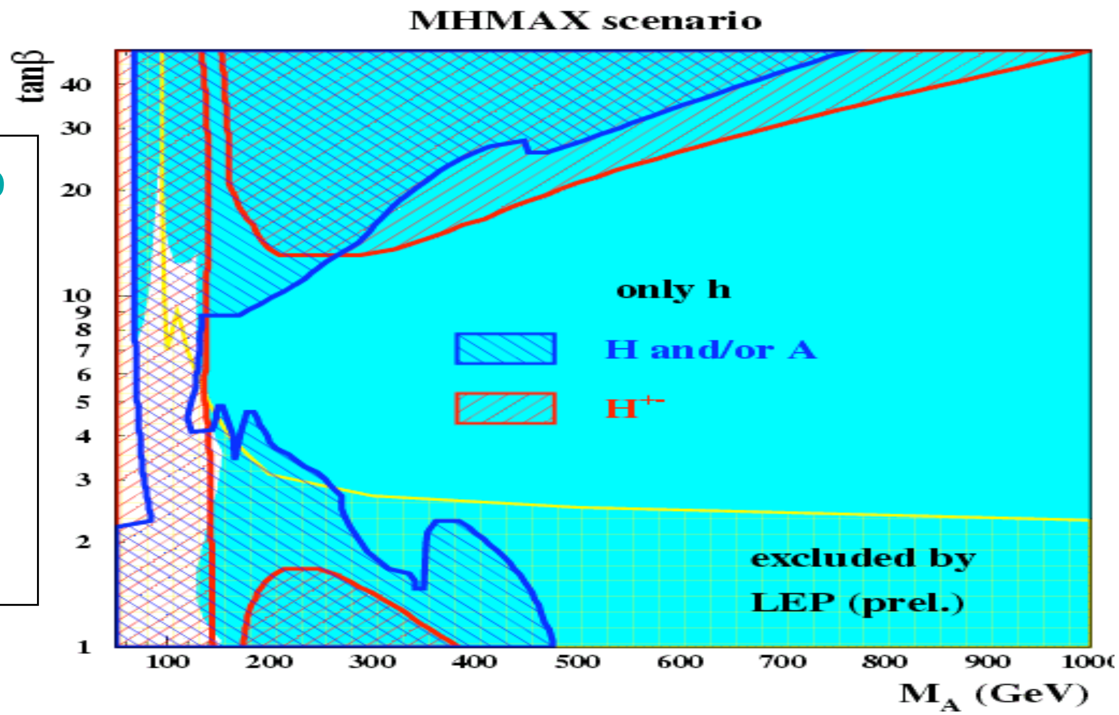
bb H/A(→ττ)
t b H+(→τν)

MSSM Summary for 300 fb^{-1} (ATLAS) no H->Susy

One particular scenario

Similar overall conclusions in other investigated scenarii

(no Higgs decay to SUSY)



At last one Higgs boson always found

But sometime only one Higgs boson found

SM or MSSM ?

Coupling measurement allows to distinguish up to M_A~300-400 GeV

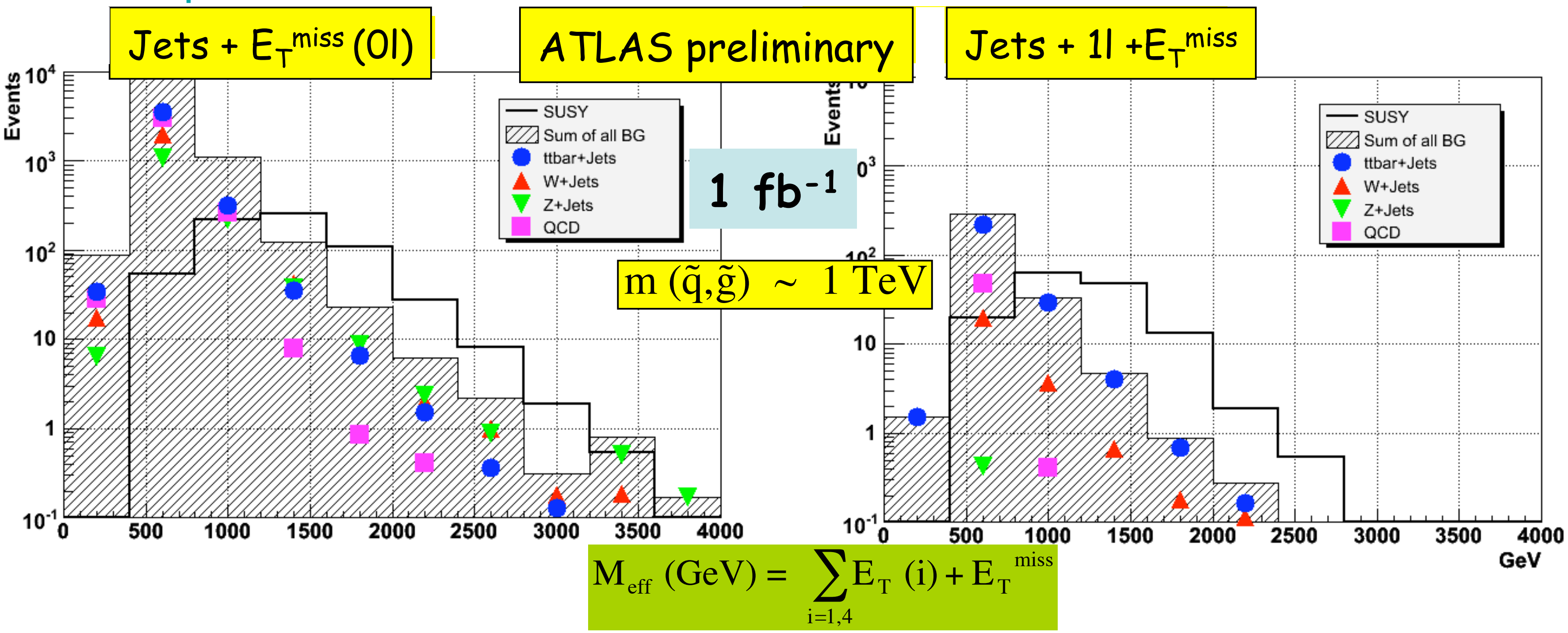
Higgs decay to SUSY and more complicated models (CP violation in Higgs sector, etc…) also under investigation

If no Higgs found ?

- Study $W_L W_L$ scattering at high mass
  - Requires probably large luminosity
  - Is there resonances ?
    - “Technicolor” like
  - Is the cross-section behaving like SM with light Higgs ?
    - Have we missed light Higgs because of unexpected decay ? (non minimal susy)
    - Interesting to measure also if a light Higgs is found
- Can we learn something from precision tests ? (W mass vs top mass)

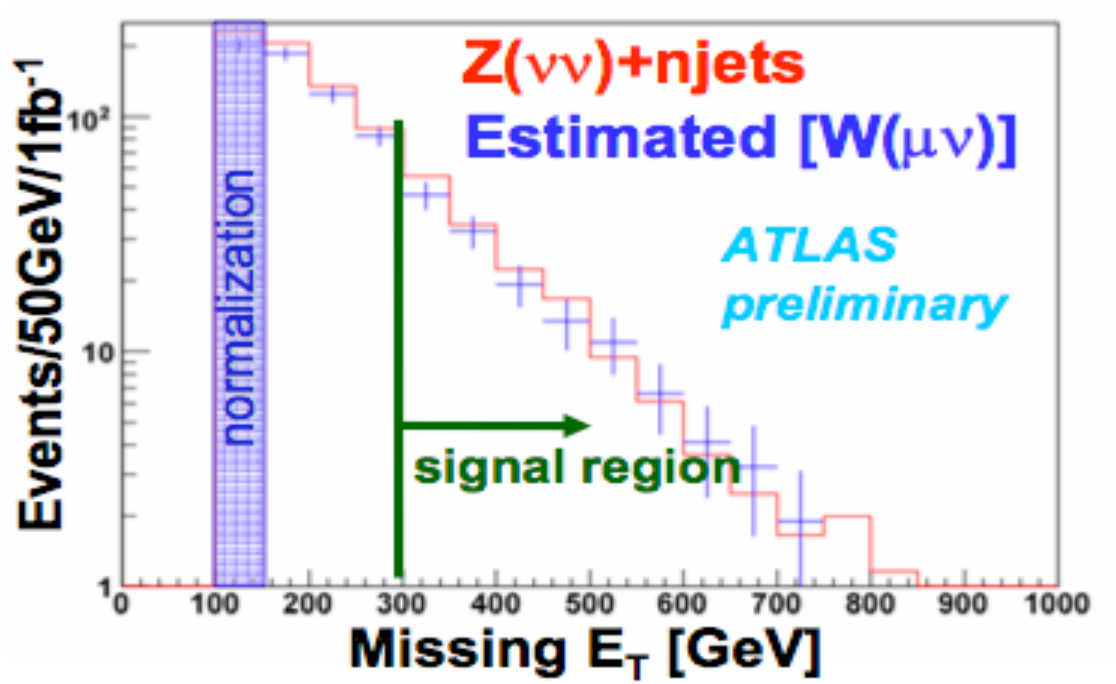
Supersymmetry

- Sparticles produced by pairs, and decay to LSP (if R parity conserved)
- Large production of squarks and gluinos by strong interaction
- Baseline signature: Jets + Etmiss
- Can also have lepton produced in SUSY cascade
- Proper modeling of SM background (events with many jet) important

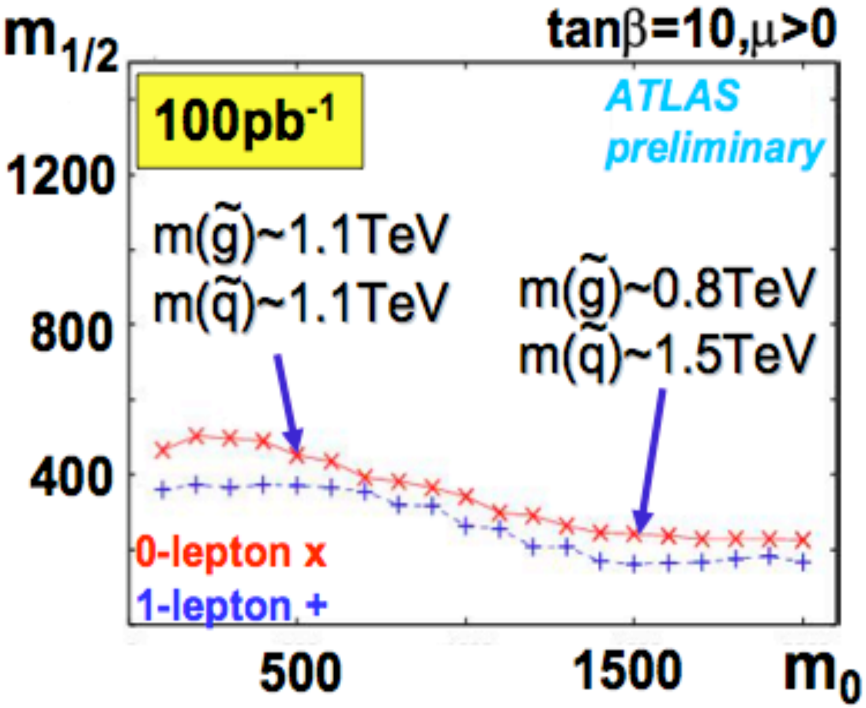


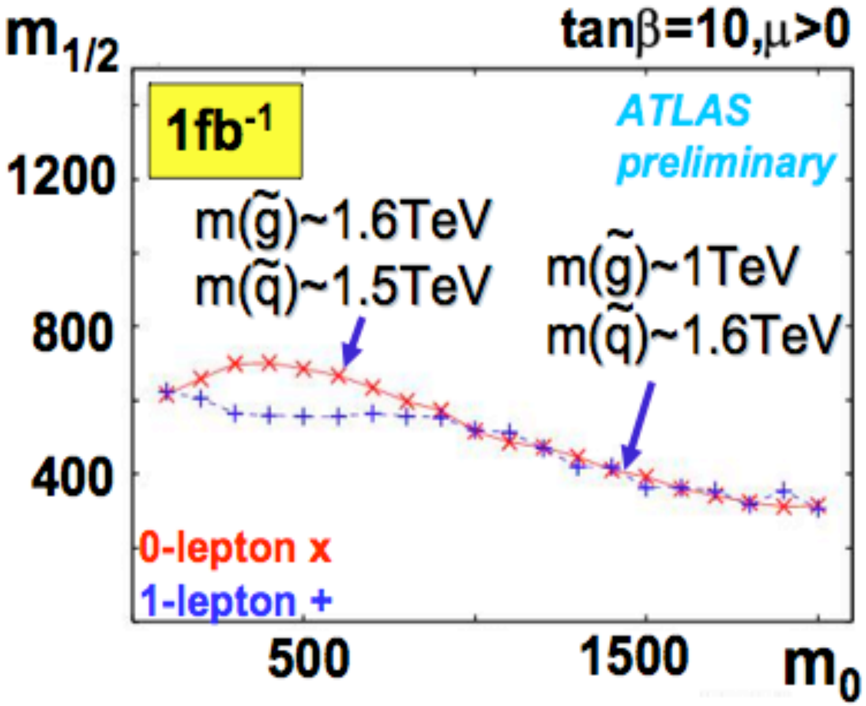
Understand Etmiss tails important

- Probably the limiting factor for early Susy discovery if squarks and gluino masses are < 1 TeV
- Many steps (noise, jet calibration,…)
- Instrumental part and Physics part
- Data driven approach:
  - o Example for physics background of Z(→νν)+jets: Use W(→μν)+jets as control sample



“Early” Susy discovery potential



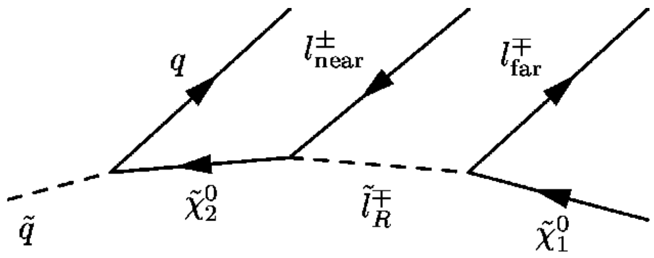


“Ultimate” reach with higher luminosity ~ 2.5 - 3 TeV

SUSY parameters measurement

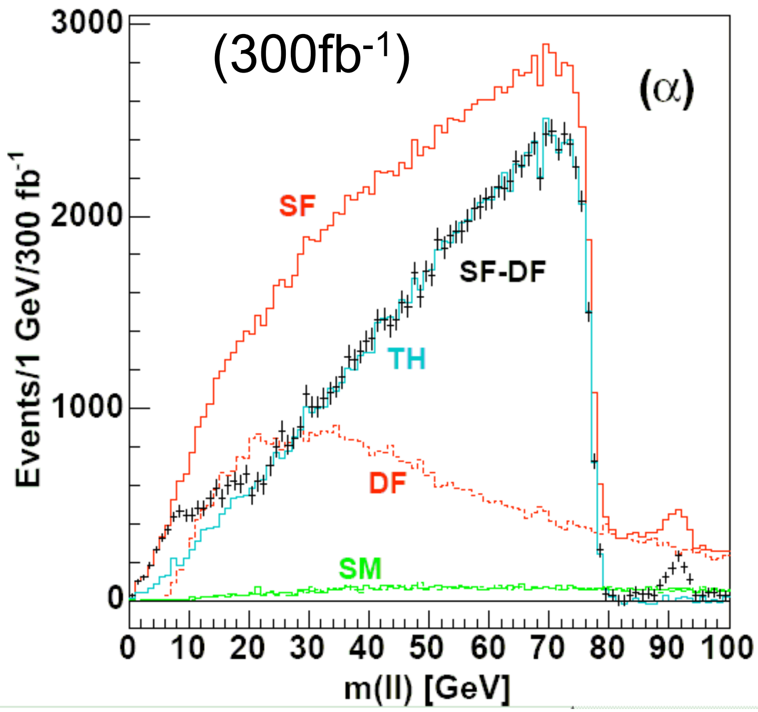
Example for one mSUGRA point:
Many kinematical edges in long decay chair

$$(m_{ll}^2)_{max} = \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{l}_R}^2}$$



(100fb^{-1})

	Nom	$\langle m \rangle$	σ
$m_{\tilde{\chi}_1^0}$	96.1	96.3	3.8
$m_{\tilde{l}_R}$	143.0	143.2	3.8
$m_{\tilde{\chi}_2^0}$	176.8	177.0	3.7
$m_{\tilde{q}_L}$	537.2	537.5	6.1
$m_{\tilde{b}_1}$	491.9	492.4	13.4
$m_{\tilde{l}_R} - m_{\tilde{\chi}_1^0}$	46.92	46.93	0.28
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	80.77	80.77	0.18
$m_{\tilde{q}_L} - m_{\tilde{\chi}_1^0}$	441.2	441.3	3.1
$m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0}$	395.9	396.2	12.0



Aim: go back to underlying mass parameters of mSUGRA

Some measurements could also be sensitive to SUSY particles spin

Other new physics

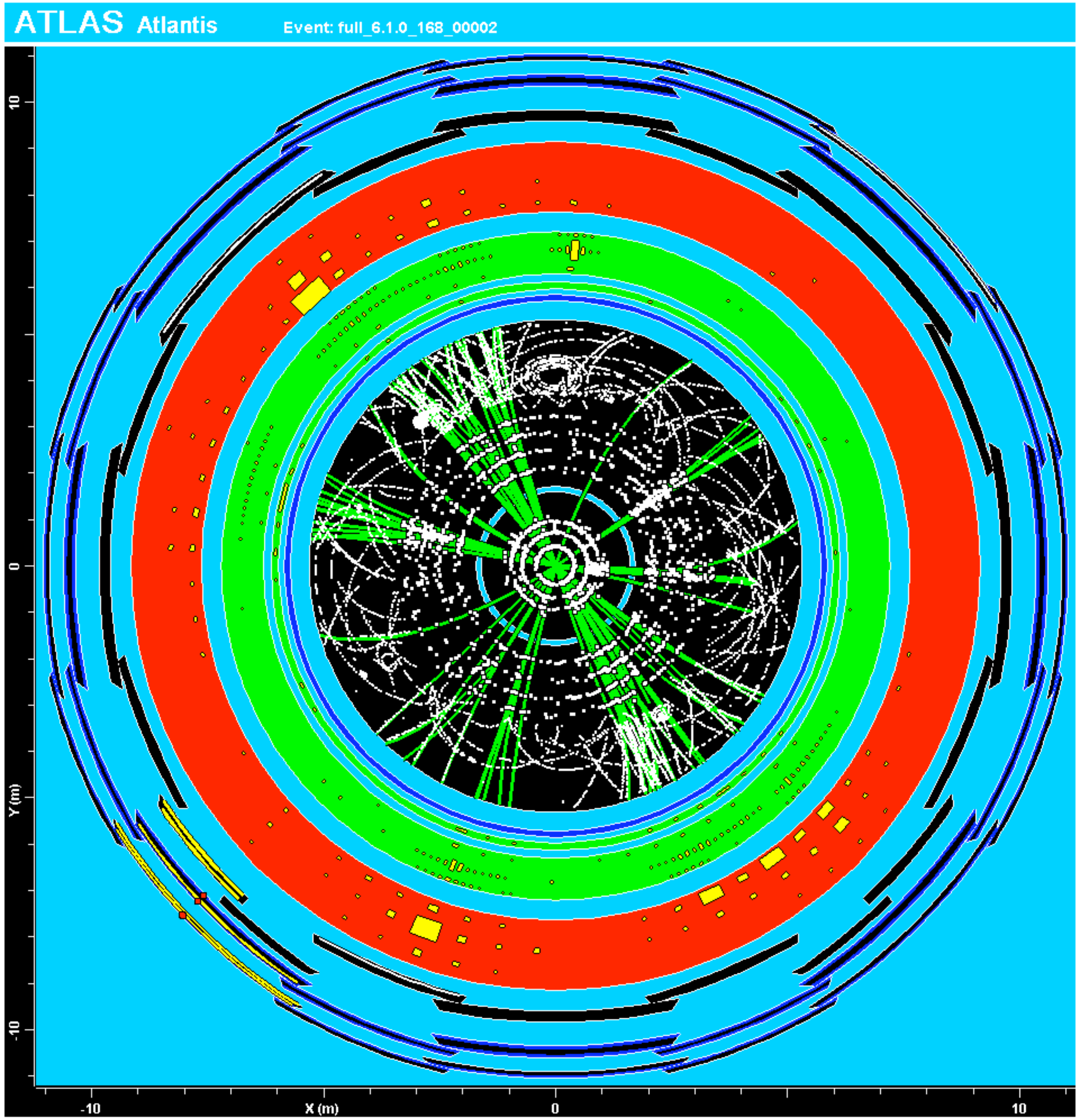
Many alternatives/complements to SUSY:

- – Little Higgs
- – Extra dimensions (large or warped or …)
- – Black Hole (quite spectacular signature…)
- – New gauge bosons
- – Compositness

- Heavy resonances (some extra dimensions model, Little Higgs, …)
- Deviations from Standard Model at high Et

- Many studies done or in progress

Black Hole event: High multiplicity event with several high energy jets, photon, muon,electron



Conclusions

- Wide physics program accessible in Atlas
- Expect to find answers on key questions related to EWSB
- Lot of work required to reach the final sensitivity
  - But expect already many interesting results in the first year(s): LHC opens a large new range of energy
- Understood detector and debugged software are crucial
  - Commissioning activities have already started
  - Ongoing CSC Physics studies to prepare data analysis of the first years
    - Establish procedures to get calibration, alignment, efficiencies, background from the data
    - Also a benchmark for computing on the grid