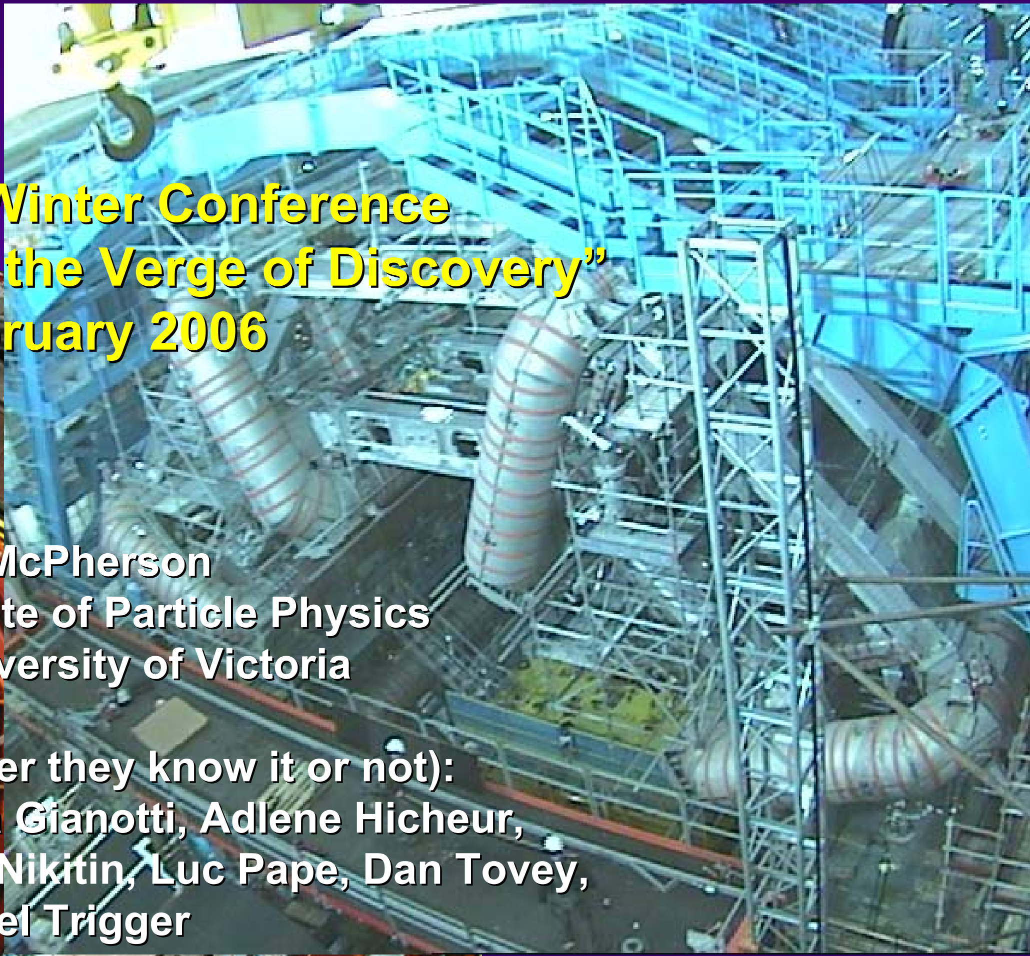
LHC: Physics with 1 fb^{-1}



2006 Aspen Winter Conference
"Particle Physics at the Verge of Discovery"
15 February 2006

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Canadian Institute of Particle Physics
and the University of Victoria

Thanks to (whether they know it or not):
Fares Djama, Fabiola Gianotti, Adlene Hicheur,
Joachim Mnich, Nikolai Nikitin, Luc Pape, Dan Tovey,
Isabel Trigger

The Stage for this talk

- Assume detectors installed
  - Some components incomplete for pilot run
    - ATLAS: 1/3 pixel layer, high η TRT (straw-tube tracker)
    - CMS: high η RPC, some EC μ chambers, EC ECAL, pixels
    - Both: deferred high-level trigger (~ 2x reduction in LVL1 rate)
- (long) History of simulation studies, beam tests, commissioning at low and (very) high rates with
  - electronics (pulser) systems
  - cosmic rays
  - single beams (beam gas collisions / beam halo muons)
- Day 0: first collisions (2^{nd} ½ of 2007 ?)
  - Detector shake-down, first analyses
- Day 1: first physics run (2008?)
  - pessimist: 100 pb^{-1} / experiment
  - optimist: 10 fb^{-1} / experiment

I'm always optimistic ...

... will talk about days 0-1

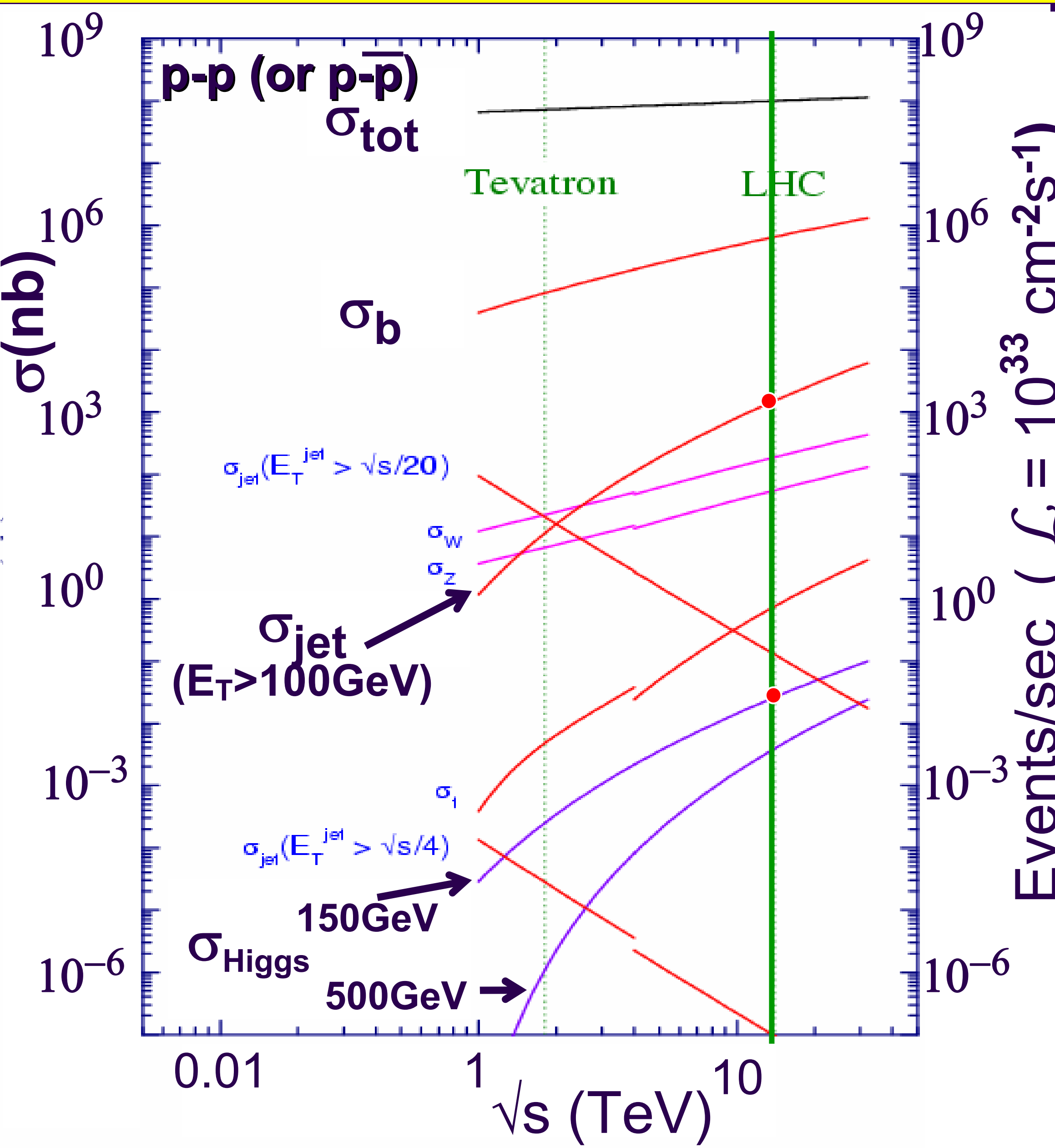
Detector Performance

	Expected Day 0	Goals for Physics
ECAL uniformity	~ 1% ATLAS ~ 4% CMS	< 1%
Lepton energy scale	0.5—2%	0.1%
HCAL uniformity	2—3%	< 1%
Jet energy scale	<10%	1%
Tracker alignment	20—200 μm in Rϕ	$\mathcal{O}$(10 μm)

Timeline from Day 0

- Complete detector calibrations
  - Fine tracking alignment + alignment with other systems
  - EM energy scale, muon momentum scale, hadronic energy scale
  - b-tagging
  - Constant monitoring of detector conditions/problems with data
- First Standard Model physics measurements
  - Underlying event at $\sqrt{s}$ = 14 TeV: absolutely critical
  - Demonstrate ability to measure critical Standard Model processes, especially in regions “near” new-physics
- First searches for BSM physics
  - Initially: high cross-section, low (understood) background
  - But ready in all channels from very beginning

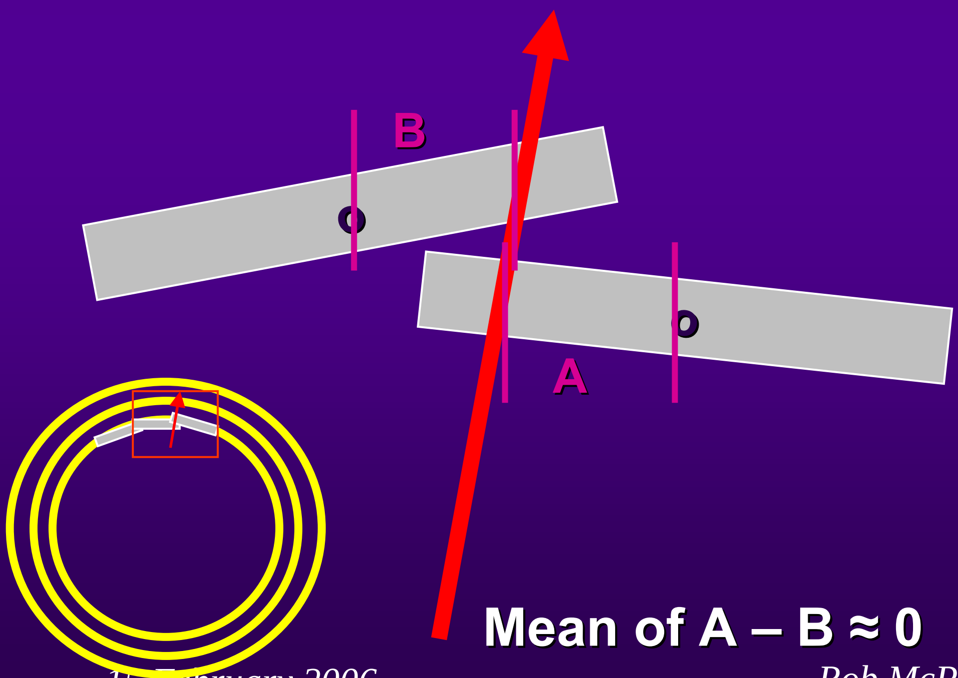
The environment: cross-sections



Channel	Recorded [1 fb^{-1}]
$W \rightarrow \mu\nu$	7×10^6
$Z \rightarrow \mu\mu$	1×10^6
$tt \rightarrow \mu + X$	0.1×10^6
Jets p_T>150GeV (if 10% bandwidth)	~10^6
Min Bias (10% bandwidth)	~10^6 (can be larger)
$\tilde{g}\tilde{g}$ (M~1 TeV)	10^2-10^3

Tracker alignment

- Will have already started with hardware systems, cosmic ray muons, etc.
- Large min-bias samples can be used for inner detectors
- Also need muons for alignment of muon system
  - Also provided low multiple scattering samples for inner trackers
- Global χ^2 techniques will be used eventually, but simpler local overlap methods will probably provide initial alignment
  - Eg: Overlap residual = inner hit residual – outer hit residual

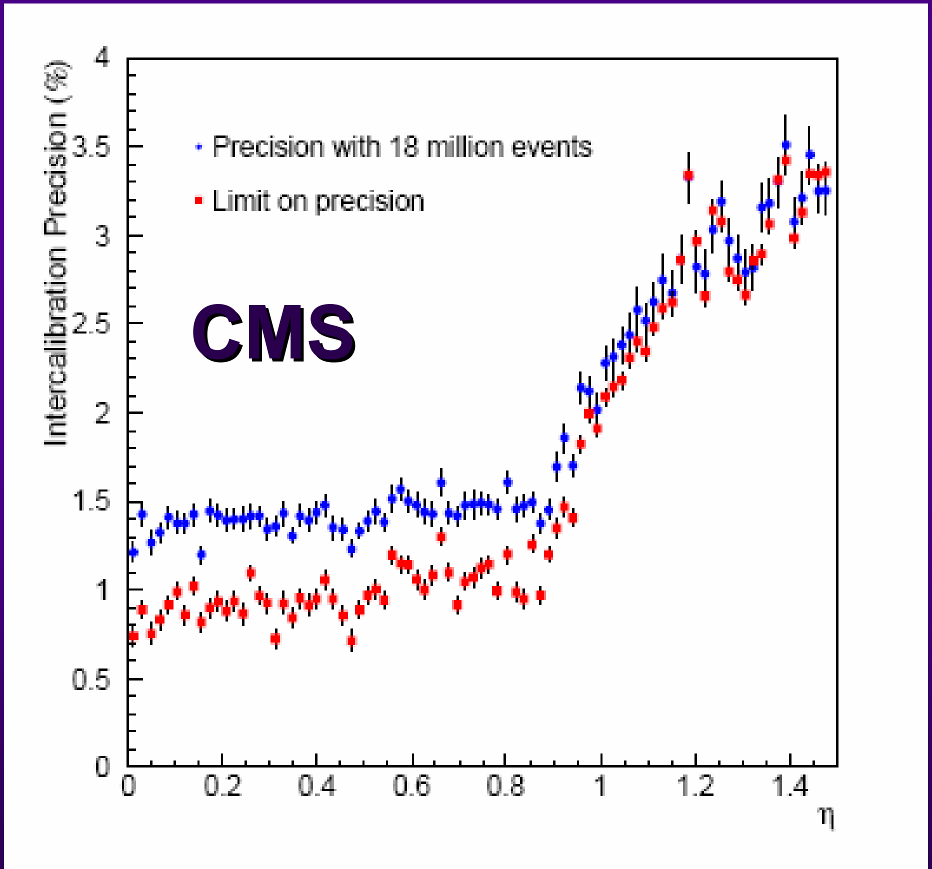


Mean of A – B ≈ 0

- Can achieve desired statistical precision with relatively small data samples
- Dead material understanding will take longer
- Will clearly be a goal of the first 10's of pb^{-1}
- Critical to have tools in place ahead of time ...

ECAL uniformity: min bias

- Can also use minimum bias events for early ECAL uniformity calibrations (before large $Z \rightarrow ee$ statistics available)
- Eg of CMS study with a few days of data-taking at $10^{33}\ cm^{-2}s^{-1}$



- Quickly approach the 1% level in barrel

$Z \to ee, \mu\mu$: e/μ scales

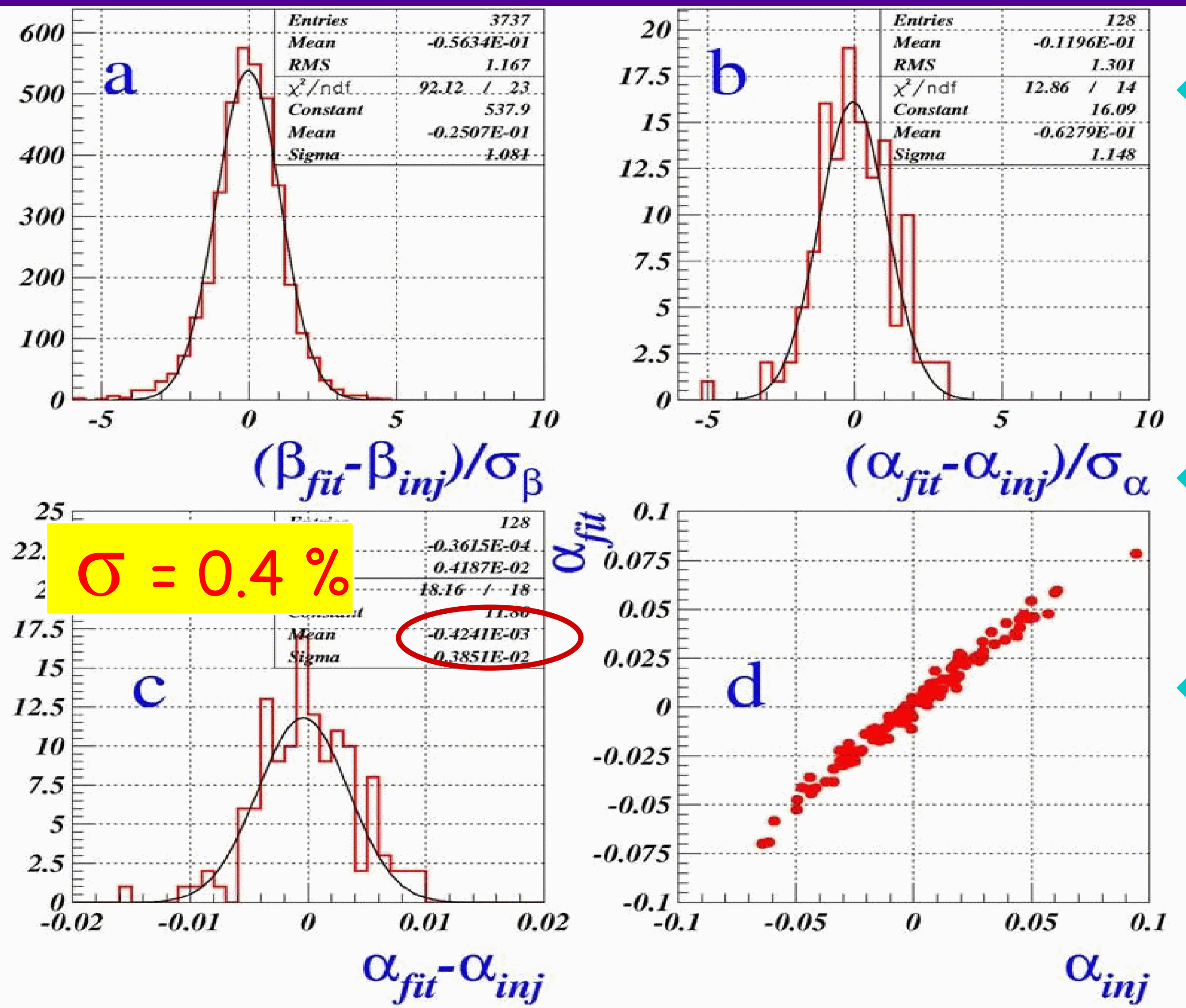
- $Z \to \ell\ell$: clean calibration channel for leptons
  - High rate (eg, 0.5 – 1 Hz @$10^{33}cm^{-2}s^{-1}$, depending on trigger)
  - Nearly uniform η/ϕ coverage
  - Absolute mass scale near M_Z
  - $Z \to \ell\ell\gamma$ will also be used for photon scale
- $Z \to ee$: example of a simple method
  - Split calorimeter in 2D (η/ϕ) "towers" around electronics
  - Assume each "tower" needs scale correction α_i
  - Solve for "pairs" (can be overlapping) of α_i with MZ constraint

$$E_i^{new} = E_i^{true} * (1+\alpha_i)$$

$$M_{ij} = M_{ij}^{true} * (1+\frac{\alpha_i+\alpha_j}{2}) = M_{ij}^{true} * (1+\frac{\beta_{ij}}{2})$$

Z→ee: Example using mis-calibrated MC

ATLAS |η|⟨0.8



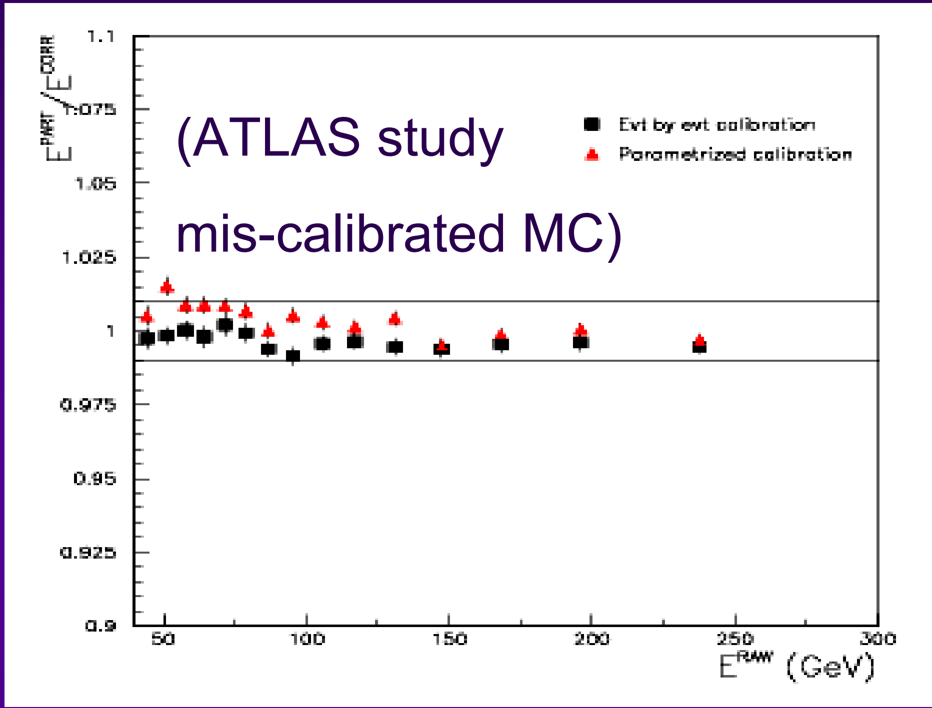
- **Uses 170k Z→ee events**
  - About 2-3 days running at $10^{33}cm^{-2}s^{-1}$ (1-200 pb^{-1})
- **448 η–φ regions to η=2.5**
  - $\Delta\eta\times\Delta\Phi = 0.2 \times 0.4$
- **Adjust "tower" size with increasing data**

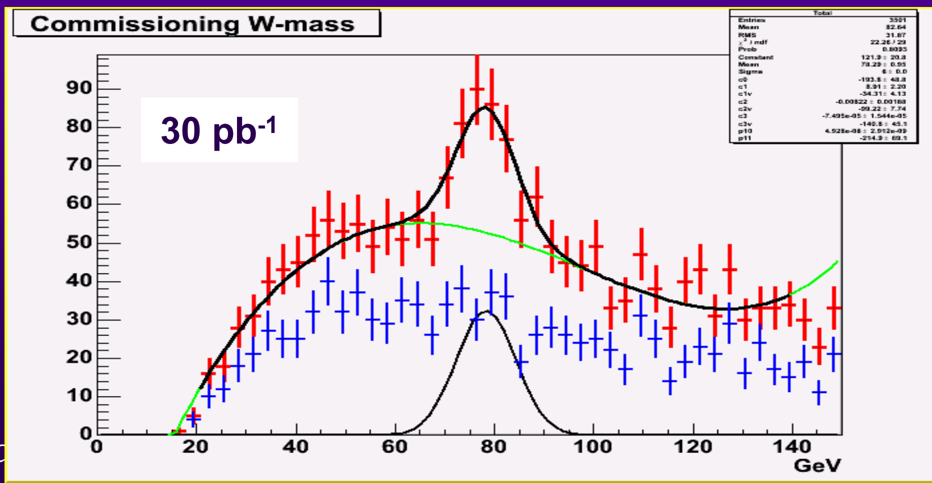
W → jet jet: Jet Energy Scale

- **Use the mass constraint of the W in ttbar events, to set the JES / rescale jet to parton energy**
  $\alpha = E_{parton} / E_{jet}$

$$Mjj = \sqrt{2Ej1Ej2(1-\cos\theta j1j2)} = MW$$

  - **Take into account E, η and ϕ in the minimization procedure and corrected energies and angles.**
  - **E of parton and jet agree within ~ 1% over the range 50-250 GeV**
  - **<u>Pros</u>: Good statistics, easily triggerable, small physics backgrounds.**
  - **<u>Cons</u>: Only light q jets, limitations in E and η reach.**

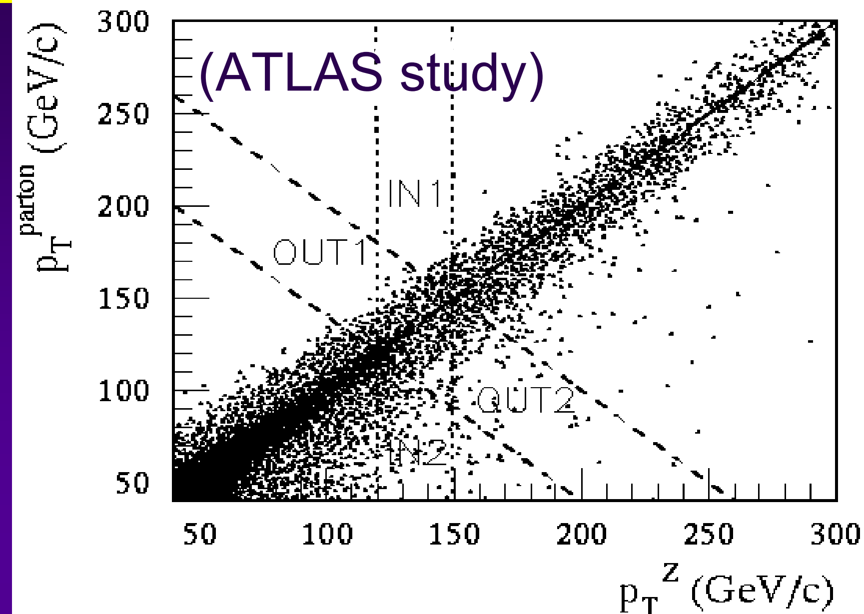




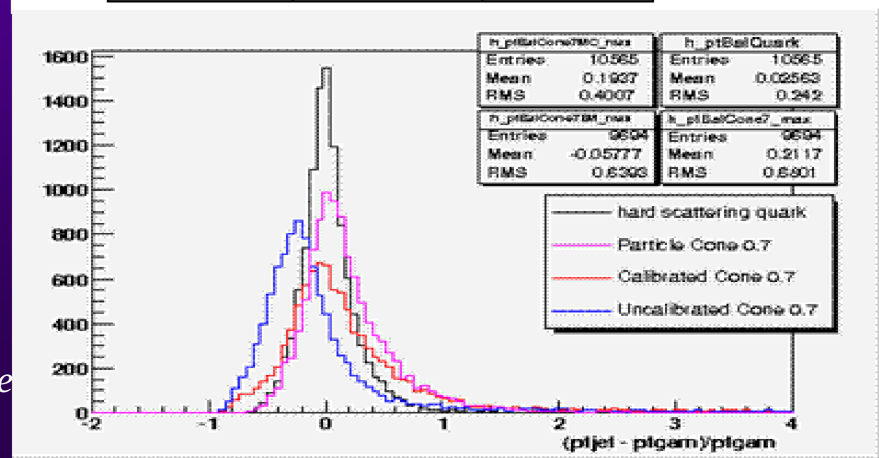
Z/γ + jet: Jet Energy Scale

- @ 10^{33}cm^{-2}s^{-1} for p_T > 50 GeV
  - γ+jet: ~ 2 Hz
  - Z+jet: ~ 1/10 Hz
- Use the p_T balance between Z /γ and highest p_T jet
  - Jet p_T rescaled to balance Z p_T.
- Distribution syst. skewed by ISR

  Pros:
  - Enlarged E and η reach wrt W→jj,
  - includes 6% of b-jets,
  - large stats: γ+jet with p_T>20 GeV: ~10K events/min. (not incl. eff. & trigger)
- Cons:
  - Easy to introduce biases via selection,
  - sensitivity to ISR modeling, esp at low p_T,
  - background to γ or Z^0 can add additional bias
  - p_T range covered with good statistics limited.
  - Needs prescaled trigger
- Also use Z^0 + b-jet to calibrate b-JES

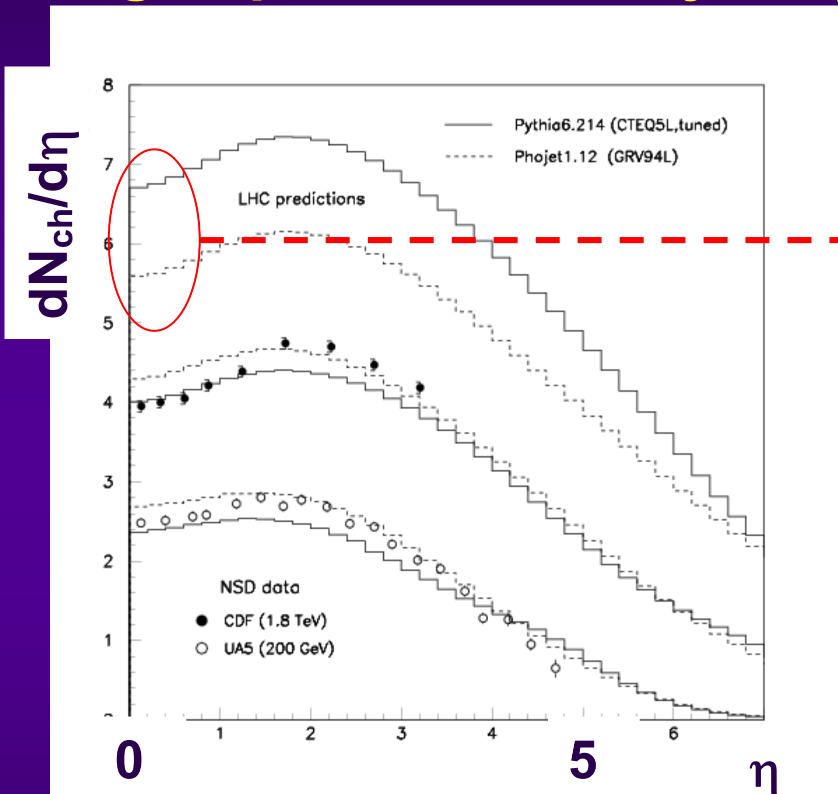


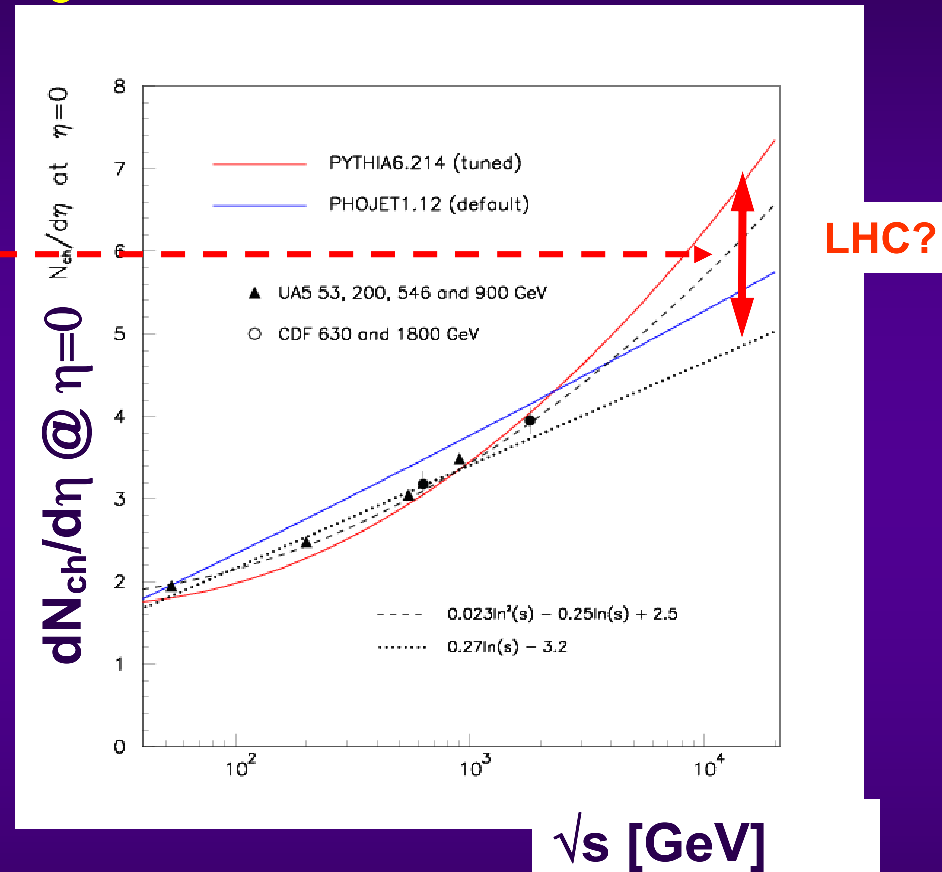
20-60 GeV	60-120 GeV	>120 GeV
0.049	0.015	0.004



Min-bias : underlying event

Charged particle density at η = 0





- Energy dependence of dN/dη ?
- Vital for tuning underlying event model
- Only requires only a few days of data (in principle)

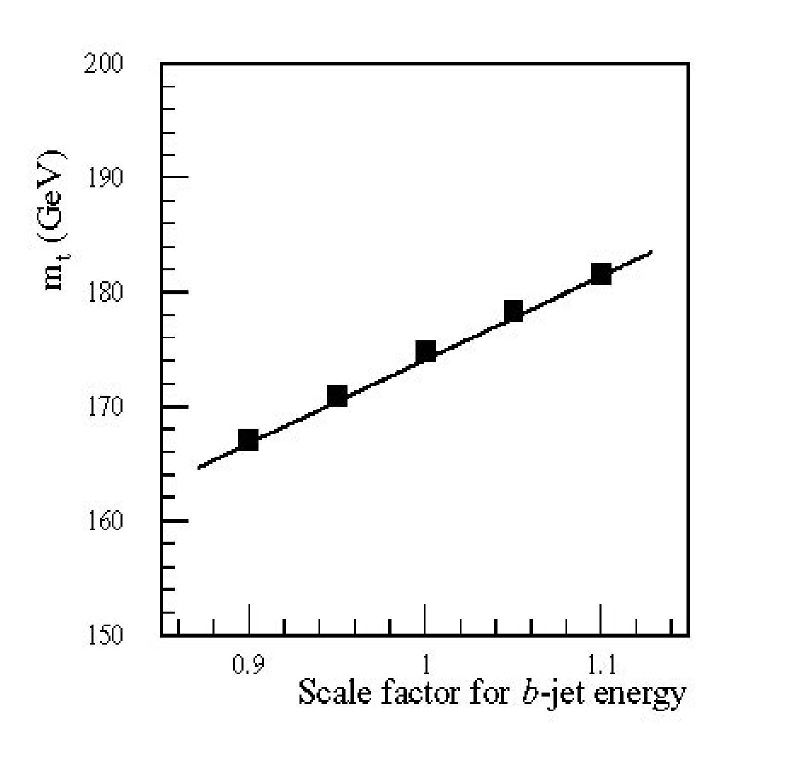
• PYTHIA models favour $\ln^2(s)$;
• PHOJET suggests a ln(s) dependence.

Top Mass

- **Initially low luminosity and imperfect detector**
  - **Worry about**
    - Early b-tagging
    - jet energy scale
    - detector problems
- **Initially uncertainty on b-jet energy scale dominant:**

b-jet scale uncertainty	δM_{top}
1%	0.7 GeV
5%	3.5 GeV
10%	7 GeV

(10% on q-jet scale → 3 GeV on M_{top})

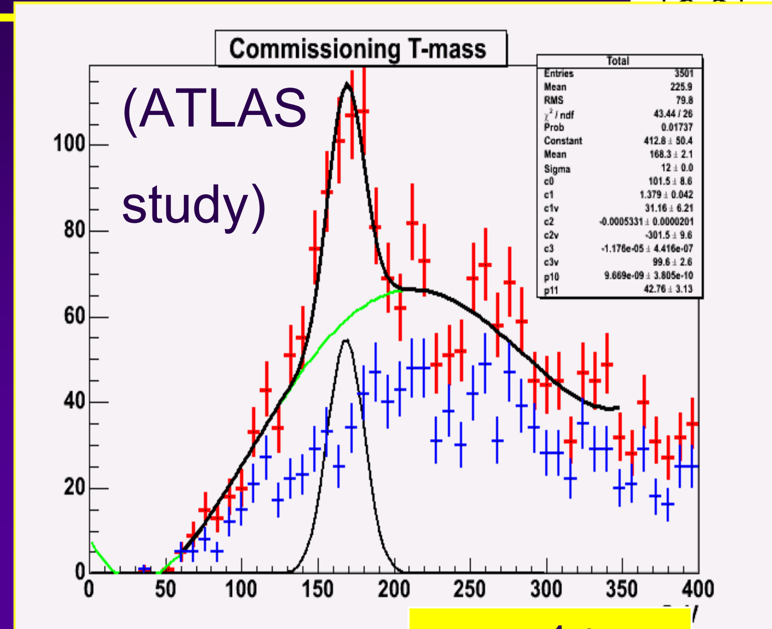


- **Important to understand UE**
  - **→ can have a large effect (as large as 5 GeV on m_t)**

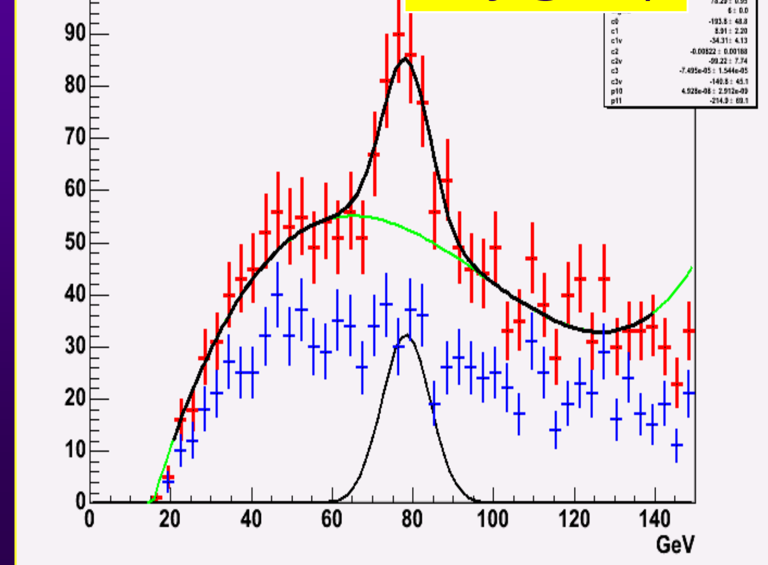
Top Mass : without b-tag

- Most important background for top: W+4 jets
  - Leptonic decay of W, with 4 extra 'light' jets
- Selection:
  - Isolated lepton with P_T>20 GeV
  - Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
- Reconstruction:
  - Select 3 jets with maximal resulting P_T
- Identify W peak (also useful for JES calibration)
- Select highest p_T 2 jet combination
  - W peak visible in signal
  - No peak in background
- W and Top peaks visible with 30 pb^{-1}

30 pb^{-1}	σ(stat)
Mtop	3.2 GeV



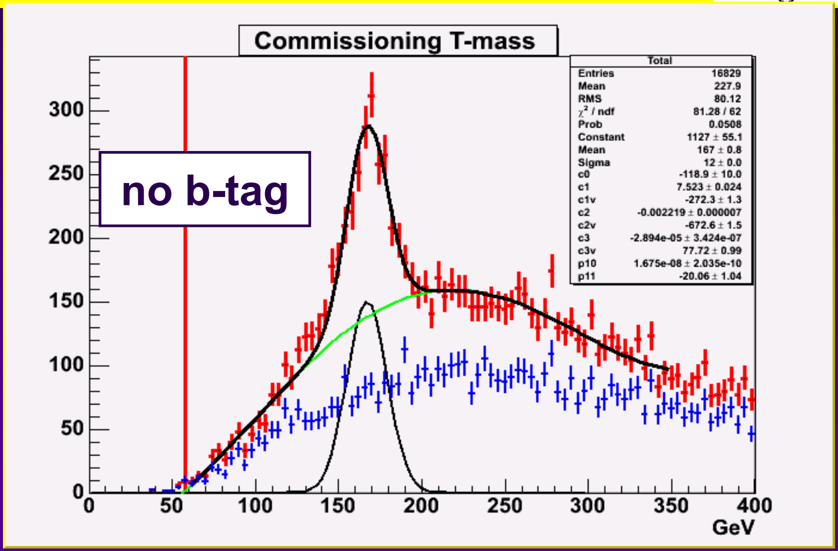
30 pb^{-1} (<1 day @10^{33})

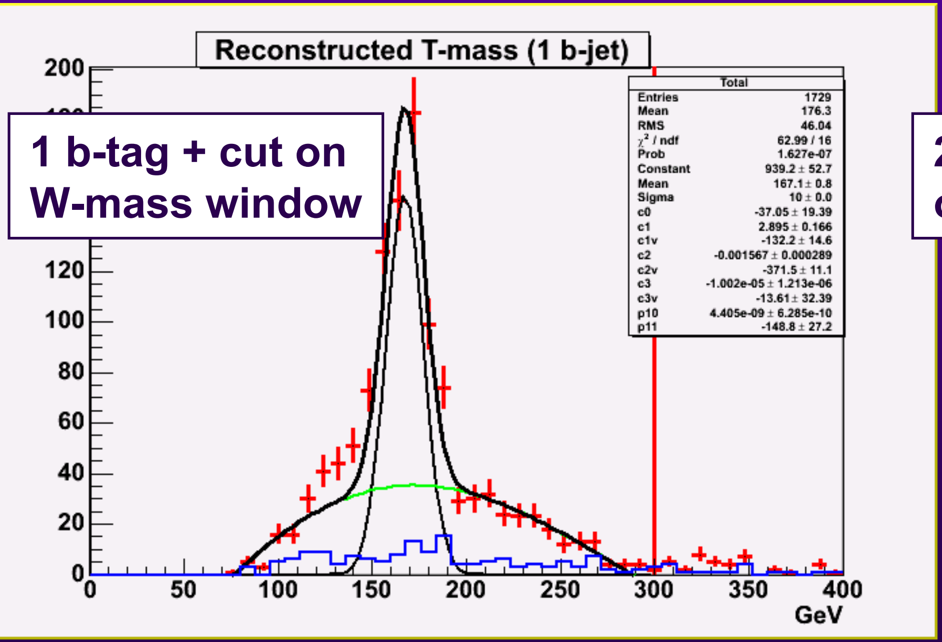


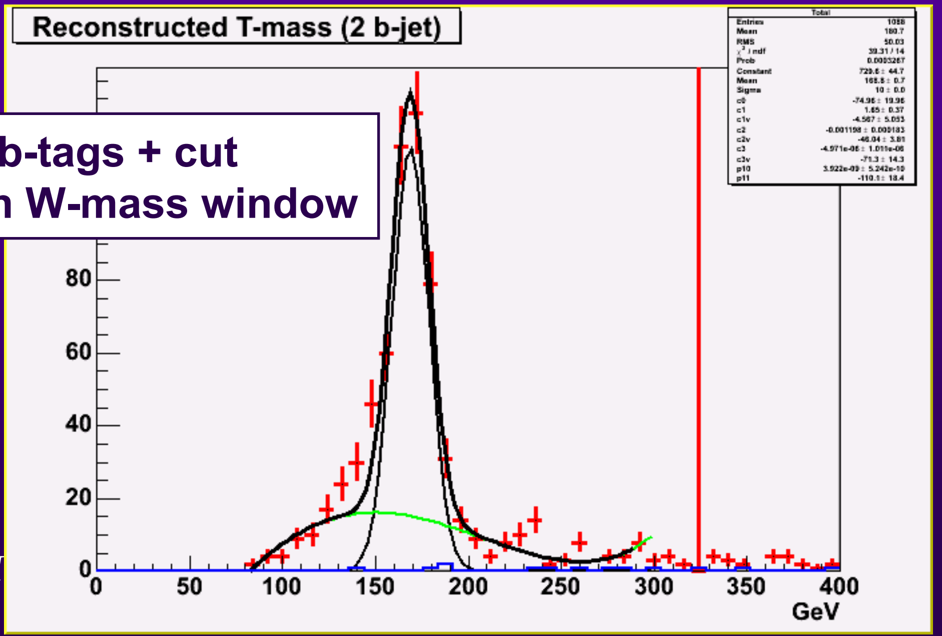
A bit more data ..

150 pb^{-1}	σ(stat)
Mtop	0.8 GeV

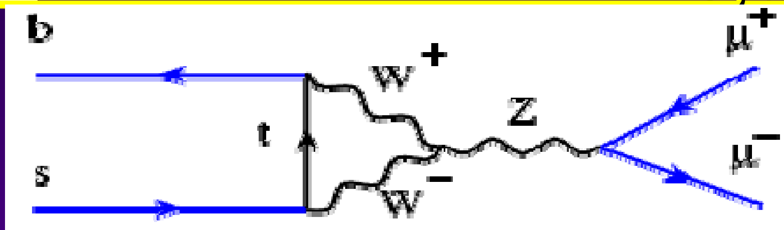
- Quickly hit systematics limit
- Will move to b-tag analyses when possible
  - Background composition changes: jet combinatorics from top becomes more and more important

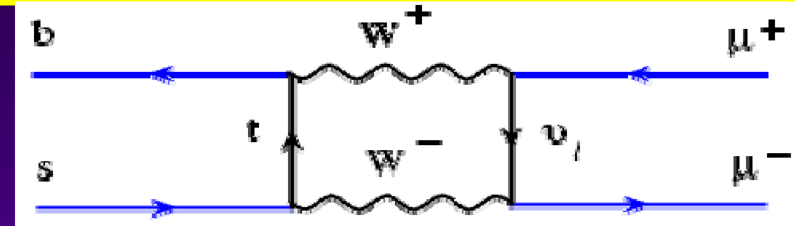






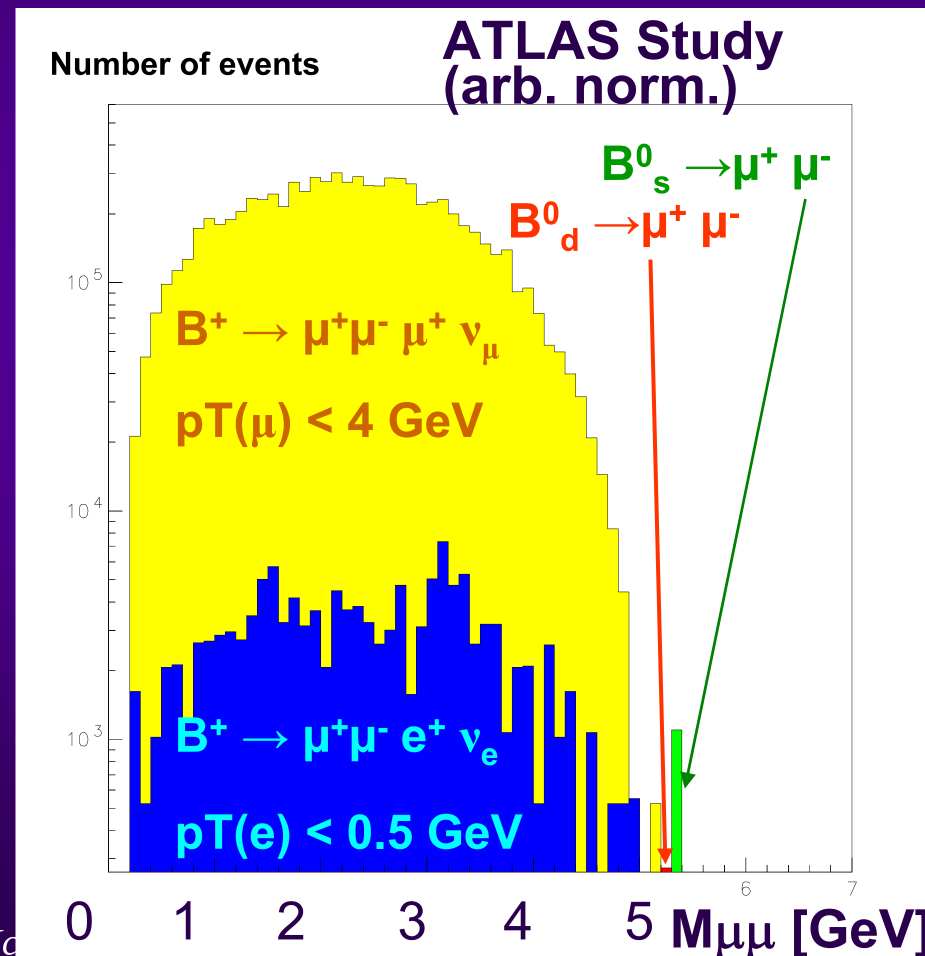
$B_{s,d} \to \mu\mu$





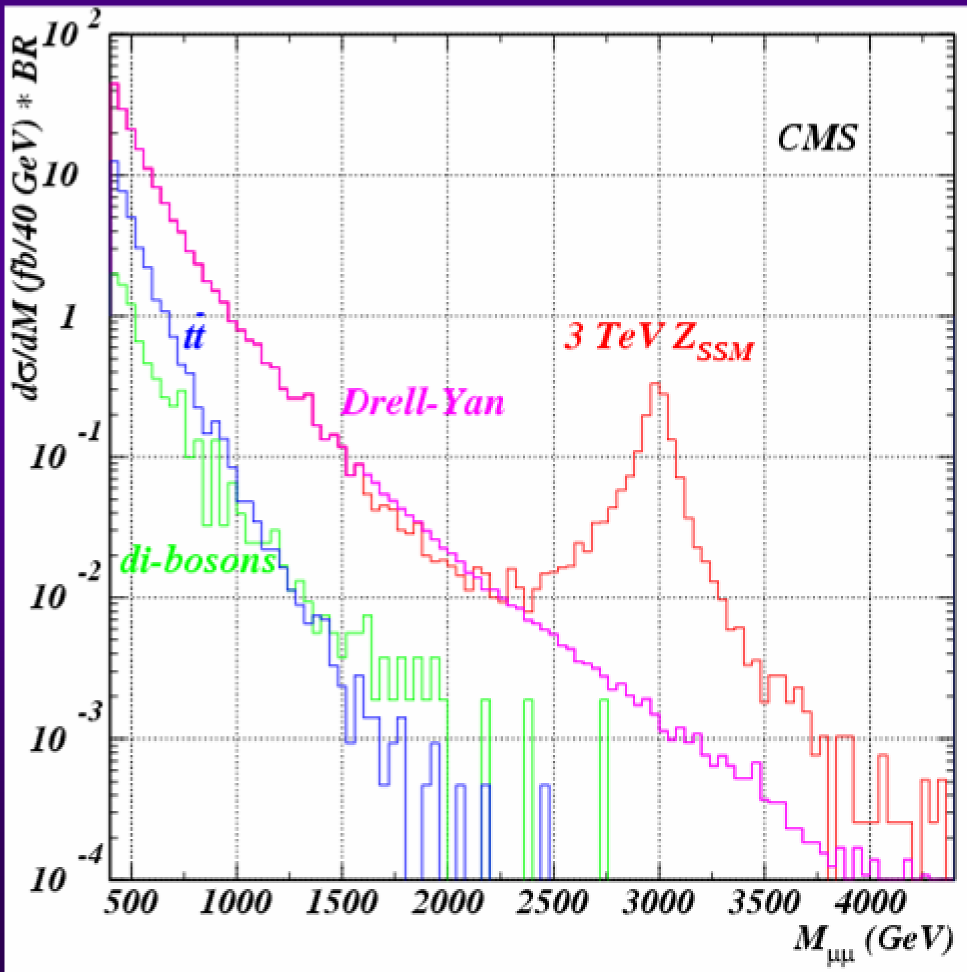
- **Standard Model**
  - **$Br(B^0_s \to \mu^+ \mu^-) \approx 3.5 \times 10^{-9}$**
  - **$Br(B^0_d \to \mu^+ \mu^-) \approx 10^{-10}$**
- ***Eg:*** **ATLAS (yes, "staged" ATLAS for early running)**
  - **Trigger: $P_T(\mu) > 6$ GeV for $|\eta(\mu)|<2.5$**
  - **Analysis optimized for $S/\sqrt{B}$**
  - **$\sigma(B\to\mu\mu) \approx 80$ MeV**

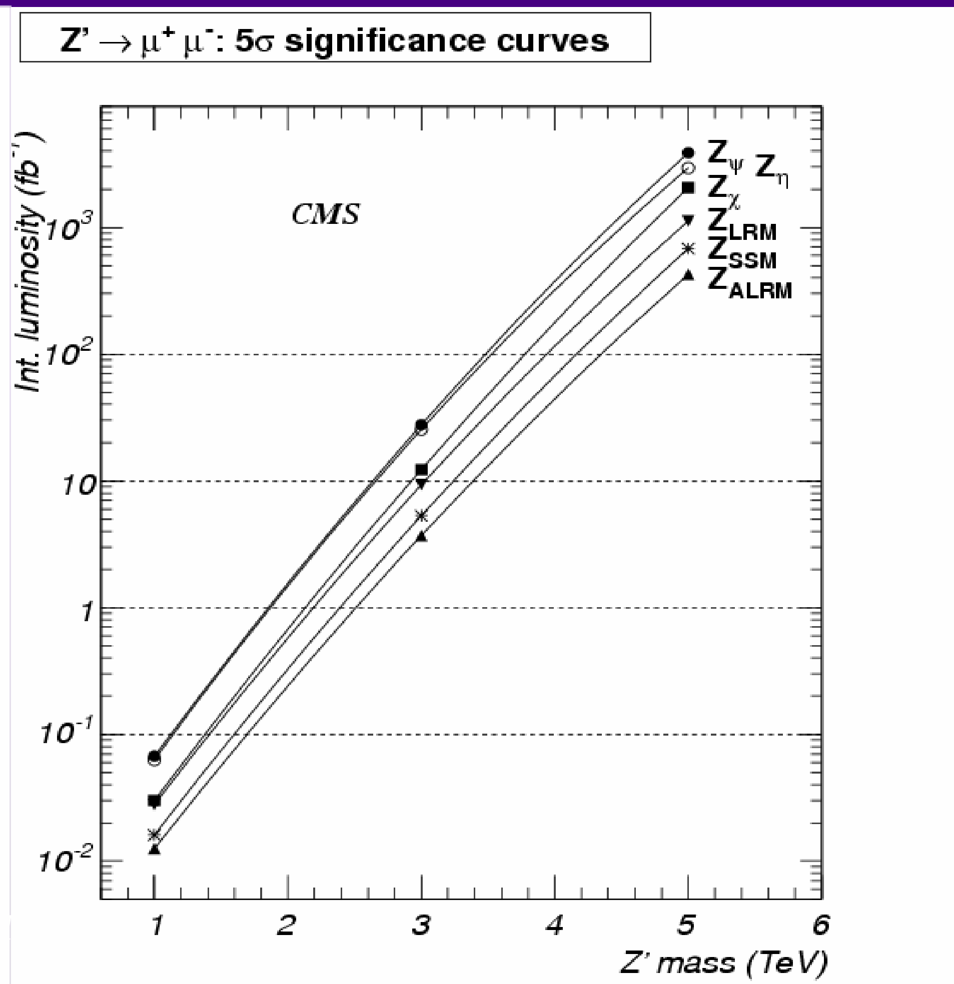
Integral LHC Luminosity	ATLAS upper limit at 90% CL
100 pb^{-1}	$< 1.0\times10^{-7}$
1 fb^{-1}	$< 1.5\times10^{-8}$
10 fb^{-1}	$< 5.5\times10^{-9}$



$Z' \rightarrow ee/\mu\mu$: early golden search

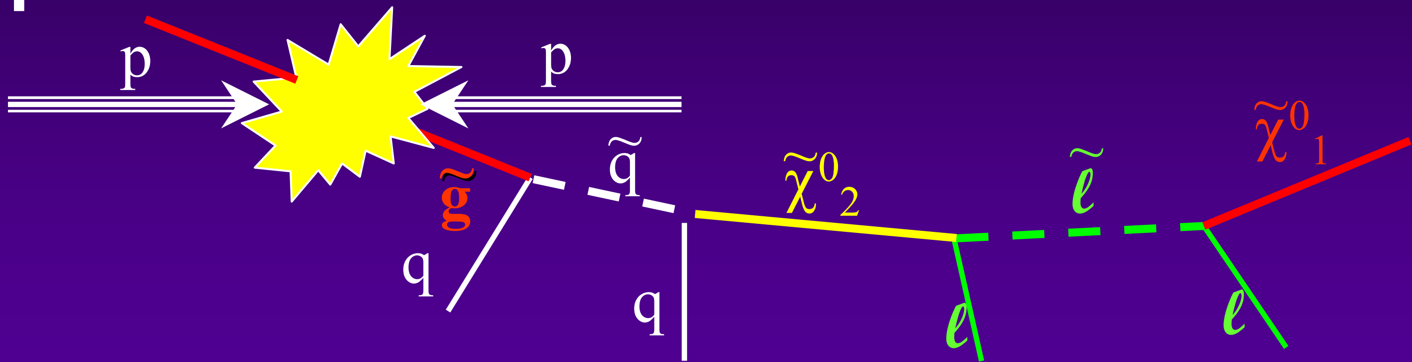
- Search for high mass Z' resonance decaying to ee or $\mu\mu$
- Mass peak well separated from background





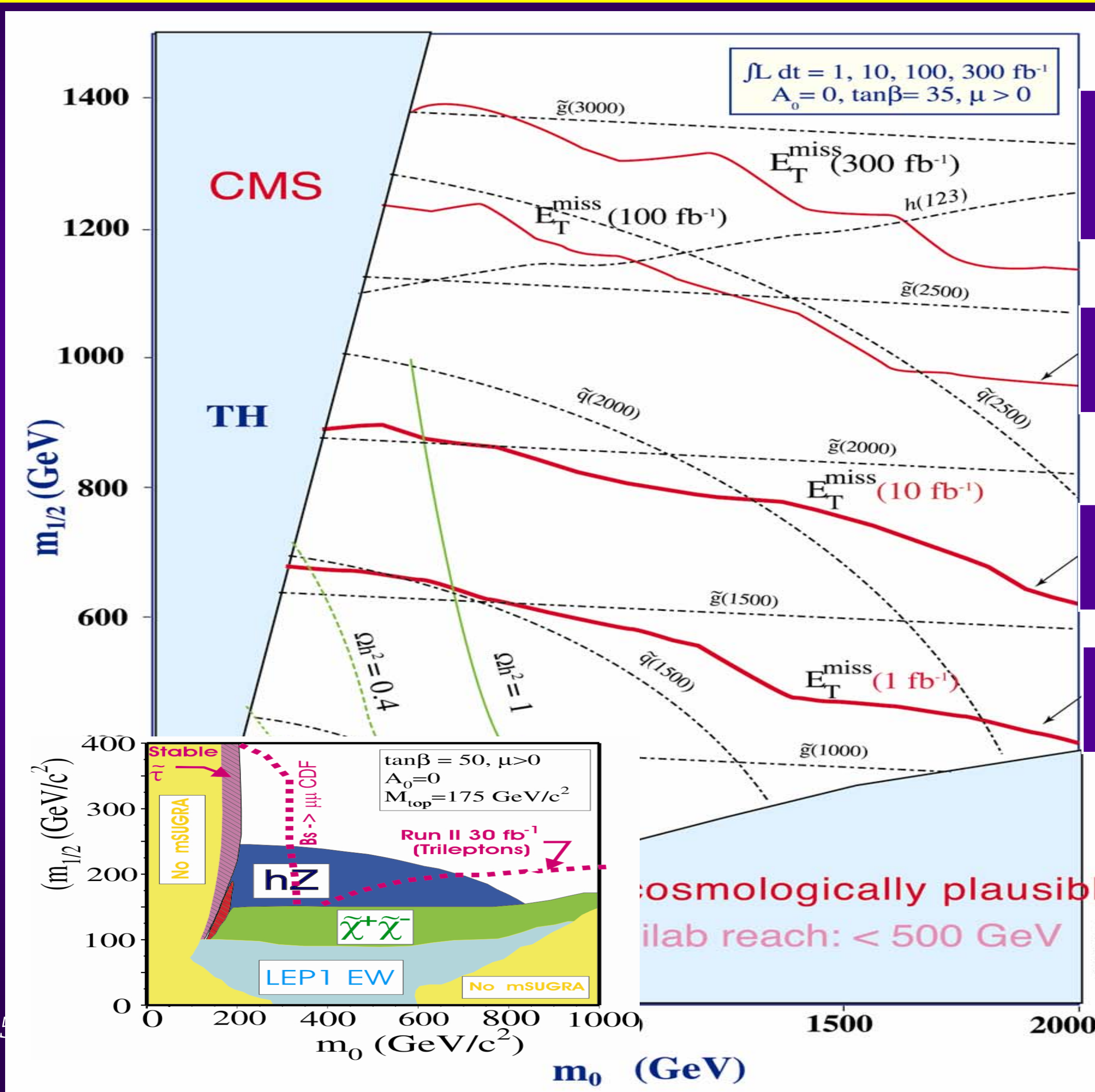
SUSY Searches

- **Typical SUSY event at LHC:**



  - **Strongly interacting sparticles (squarks, gluinos) dominate production**
    - **Can have high cross-sections ⇒ good candidate for early discovery**
  - **sleptons, gauginos etc. $\tilde{g}$ cascade decays to LSP.**
  - **Long decay chains and large mass differences between SUSY states**
    - **Many high pT objects observed (leptons, jets, b-jets).**
  - **If R-Parity conserved LSP stable and sparticles pair produced.**
    - **Large ETmiss signature**
  - **Closest equivalent SM signature t → Wb with W → $\ell\,\nu$**

CMS SUSY Reach: 5σ discovery curves



Inclusive search STATISTICAL reach only!

~ one year at 10^{34}: up to 2.8 TeV

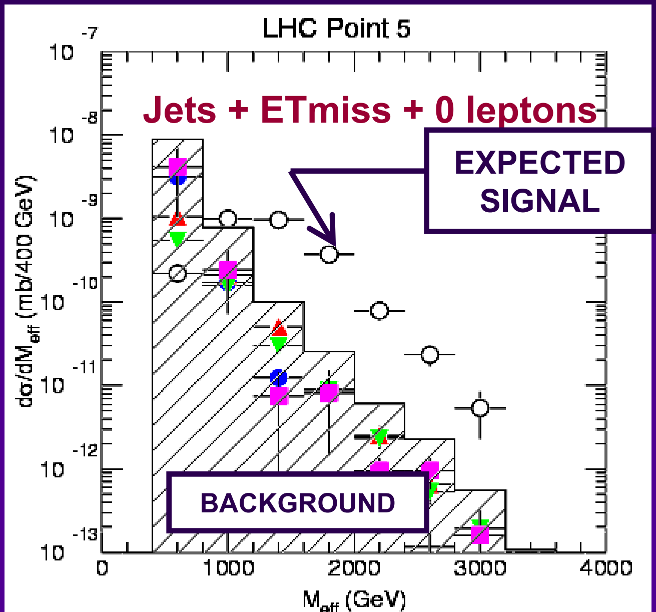
~ one year at 10^{33} : up to 2.3 TeV

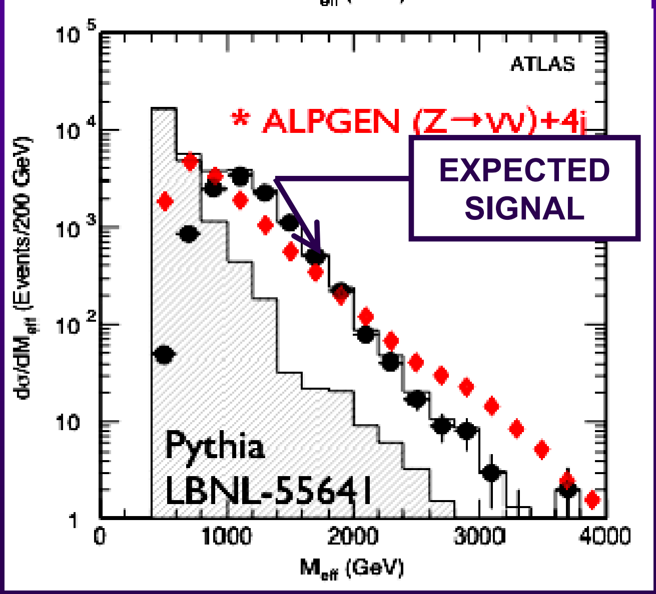
~ one month at 10^{33} : up to 2 TeV

Inclusive SUSY: Background Estimation

- Inclusive signature: jets + n leptons + E_T^{miss}
- Main backgrounds:
  - Z + n jets
  - W + n jets
  - ttbar
  - QCD
- Greatest discrimination power from E_T^{miss} (R-Parity conserving models)
- Generic approach to background estimation:
  - Select low E_T^{miss} background calibration samples;
  - Extrapolate into high E_T^{miss} signal region.
- Extrapolation is non-trivial.
  - Must find variables uncorrelated with E_T^{miss}
- We have learned a lot from Run II but one big difference:
  - no previous measurements at similar $\sqrt{s}$
- ATLAS Example: ~ 1 TeV SUSY scale, look at

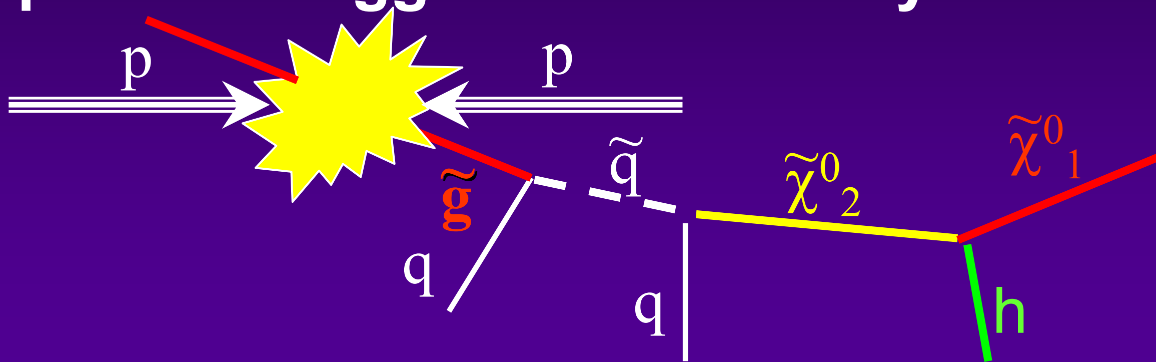
$$M_{eff}=\Sigma|p_T^i| + E_T^{miss}$$



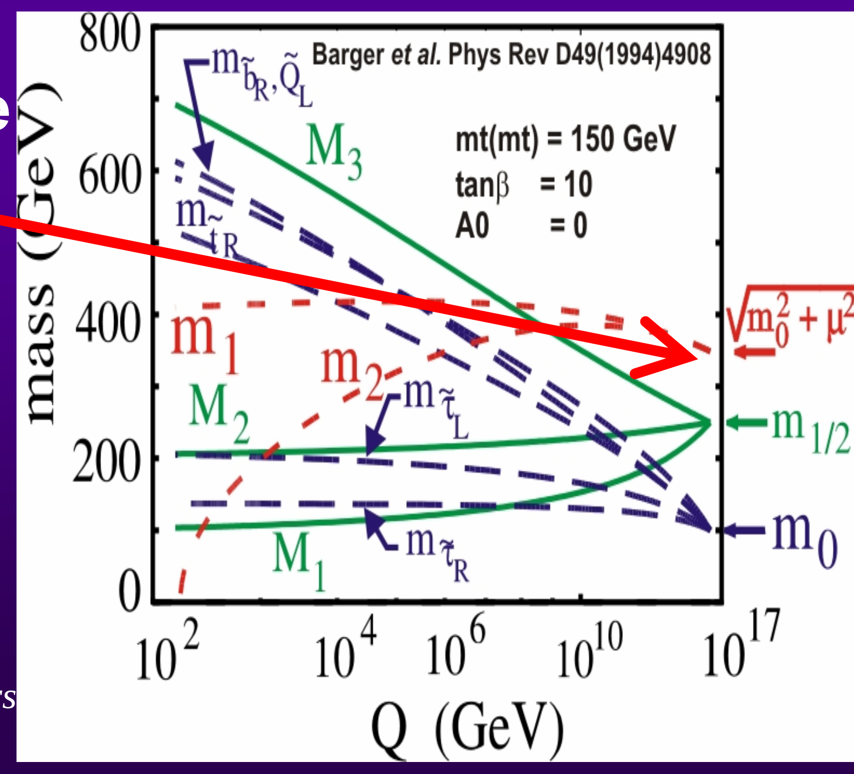


Higgs in SUSY events (I)

- Can produce Higgs in SUSY decay chains

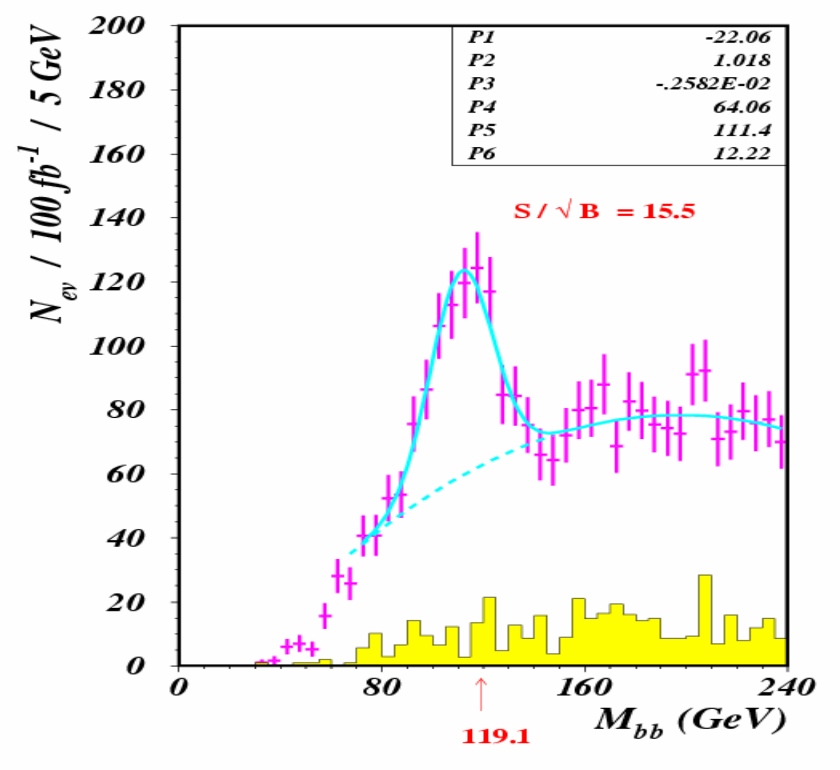


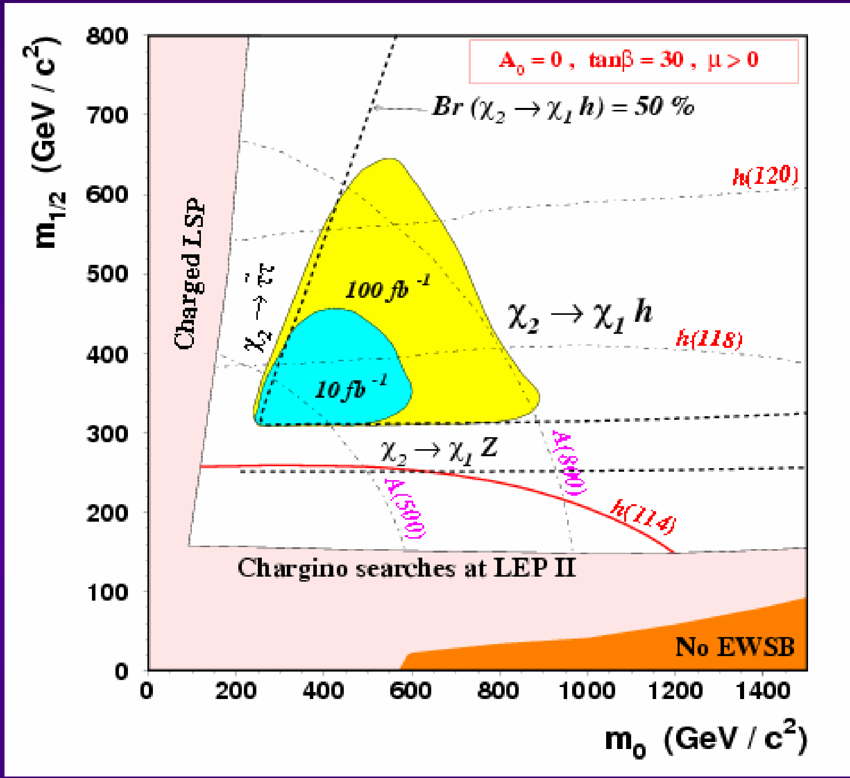
- Can happen in MSUGRA, but even more allowed space if we don't assume h ↔ sfermion unification
- Good candidate for higgs discovery if SUSY true
- Initial CMS study:
  - 2 b-jets + E_T^{miss}



Higgs in SUSY events (II)

CMS MSUGRA

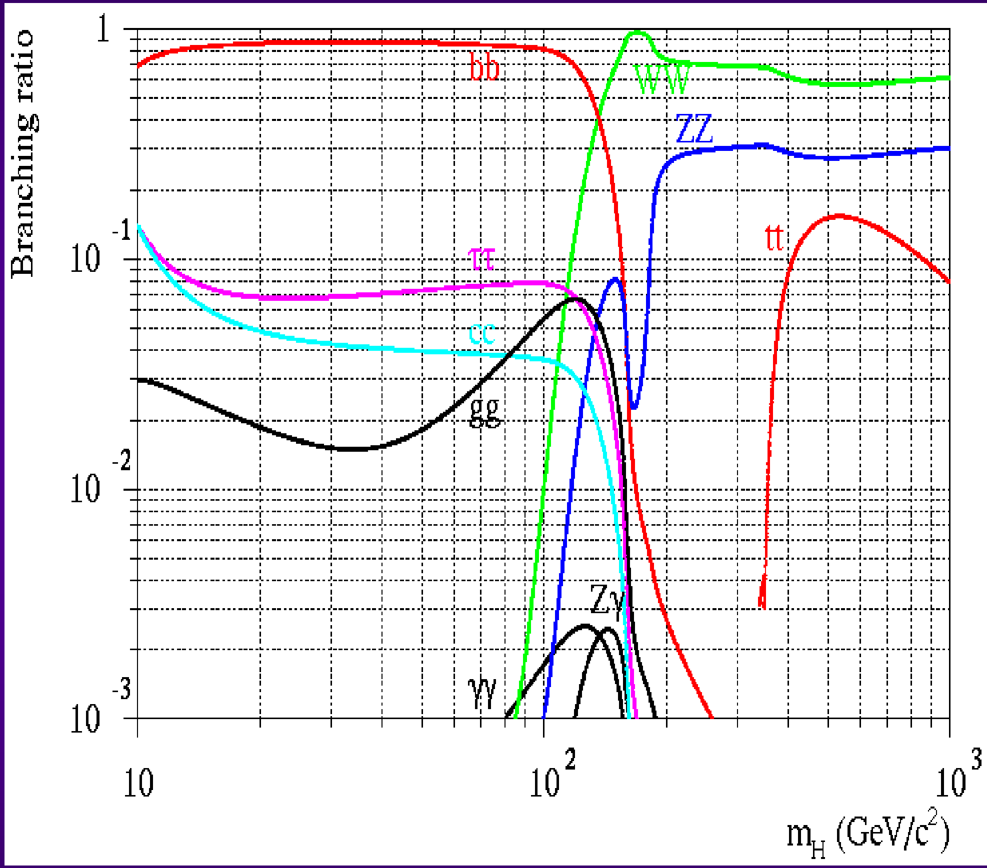




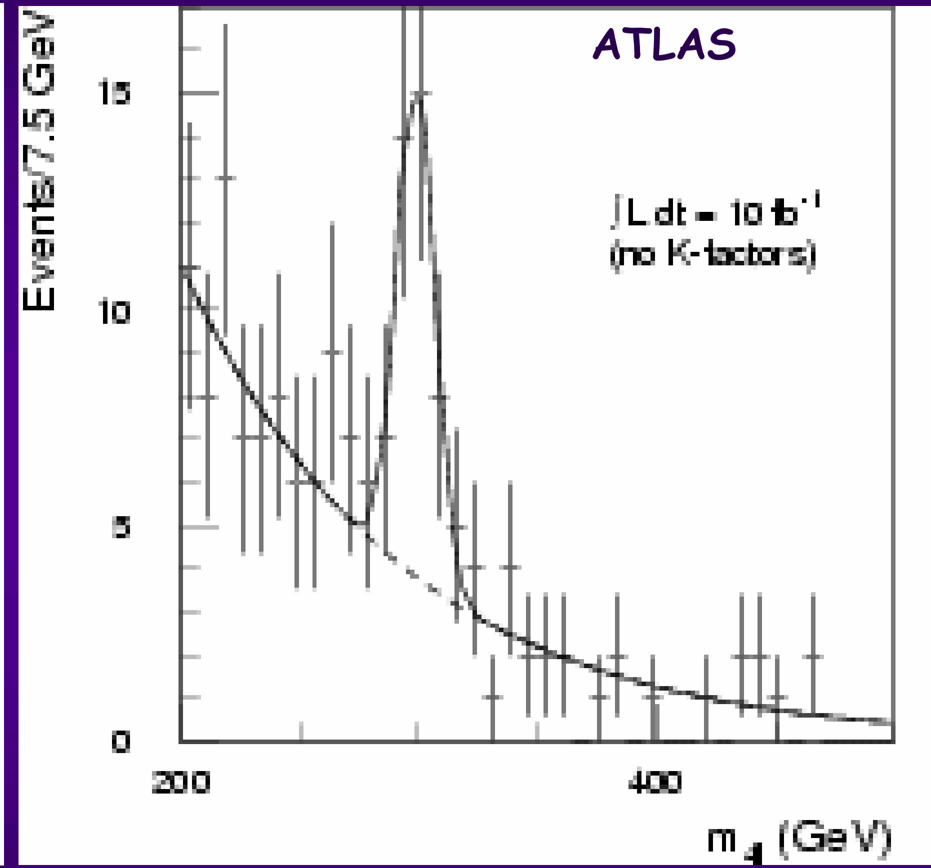
- Need to optimize non b-tag analyses for early data

Direct SM Higgs Search: depends on mass

SM Higgs: branching fractions



High mass search: $H \to ZZ(^*) \to 4\,\ell$

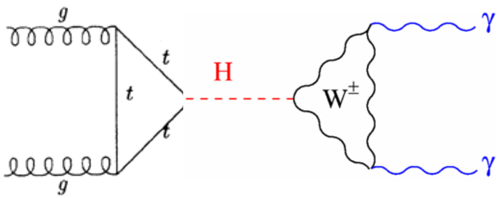


- Electron / muon reconstruction probably OK with early data
  - ⇒ Higher mass Higgs is possible

Lower mass Higgs Harder

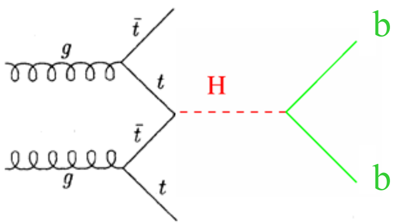
3 channels contribute ~ 2σ with 10 fb^{-1}

$H \rightarrow \gamma\gamma$



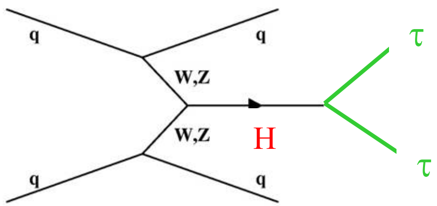
- EM resolution
- EM uniformity
- $\gamma\gamma$ mass:
  - $\sigma/m < 1\%$

$ttH \rightarrow tt\ bb \rightarrow b\ell\nu\ bjj\ bb$



- Good b-tagging
- Reduce QCD background:
  - 4 b-tags
- Hadronic transverse mass resolution

$qqH \rightarrow qq\tau\tau$



- Forward jet tag
- Good central jet veto
  - $\Rightarrow \tau$ ID

- b-tagging, final EM resolution/uniformity, forward jet reco ...
  - $\Rightarrow$ Lower mass Higgs (eg: < 130 GeV) will take significant detector/data understanding
    - (Not just a luminosity question ...)

Summary

- The first priority of early LHC collision will be to push detector understanding
  - Calibrations
  - Dead/hot channel characteristics/understanding
  - Dead material understanding ...
- Basic Standard Model measurements critical
  - Underlying event, parton distribution functions, ...
  - SM processes “near” possible new physics
  - Top/W masses will be systematics dominated from early-on
  - Many other SM opportunities (eg, $B^0_s \rightarrow \mu^+ \mu^-$)
- First searches for clean processes with high cross-sections next
  - High mass Z’, SUSY are strong candidates
- Don’t expect early SM light higgs results
  - But that’s not really what we want to discover in any case ...