ATLAS, early physics reach

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Where do we stand in 2007

Commissioning
- Inner detector
- Calorimeter
- Muon detector
- staging of detector

Physics results
- Structure functions
- Discoveries:
  -- Higgs
  -- SUSY

Physics in 2007

Results on most important variables will stem from Tevatron, HERA, Belle, BaBar, LEP

Expected precision:

W mass	**20 –30 MeV**	**LEP + Tevatron**
Top mass	**2 GeV**	**Tevatron**
Structure functions:	**Few percent up to $Q^2 = 10^4$ GeV^2**	**HERA**
Higgs	**possible exclusion up to 175 GeV discovery unlikely, but hint may be there**	**Tevatron**

What can ATLAS achieve in the first year?

Event rates at ATLAS

Early results: 1 year of operation at low luminosity
integrated luminosity 10 fb^{-1}

All results and plots correspond to this luminosity

Luminosity L = 2 $\times 10^{33}$ cm^{-2} s^{-1}

Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by 2007
$W \to e\nu$	30	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	3	10^7	10^7 LEP
$t\bar{t}$	2	10^7	10^4 Tevatron
$b\bar{b}$	10^6	10^{12} – 10^{13}	10^9 Belle/BaBar ?
H m=130 GeV	0.04	10^5	?
$\tilde{g}\tilde{g}$ m= 1 TeV	0.002	10^4	---

Commissioning

Several steps:

• Test beams
• Mapping of detector material and magnetic field
• Alignment
• Electronic calibration
• Cosmic running
• One proton beam
• Proton proton collisions

Precision of detector understanding is given by desired precision of physics results

Equal error on Higgs mass from W- and top mass measurement:

$$\Delta m_W \approx 0.7 \times 10^{-2} \Delta m_{top}$$

Error on top mass: 2 GeV
Error on W mass: 15 MeV
this puts severe constraints on detector understanding

Inner detector

Alignment:

Degrading of track parameters by misalignment less than 20%

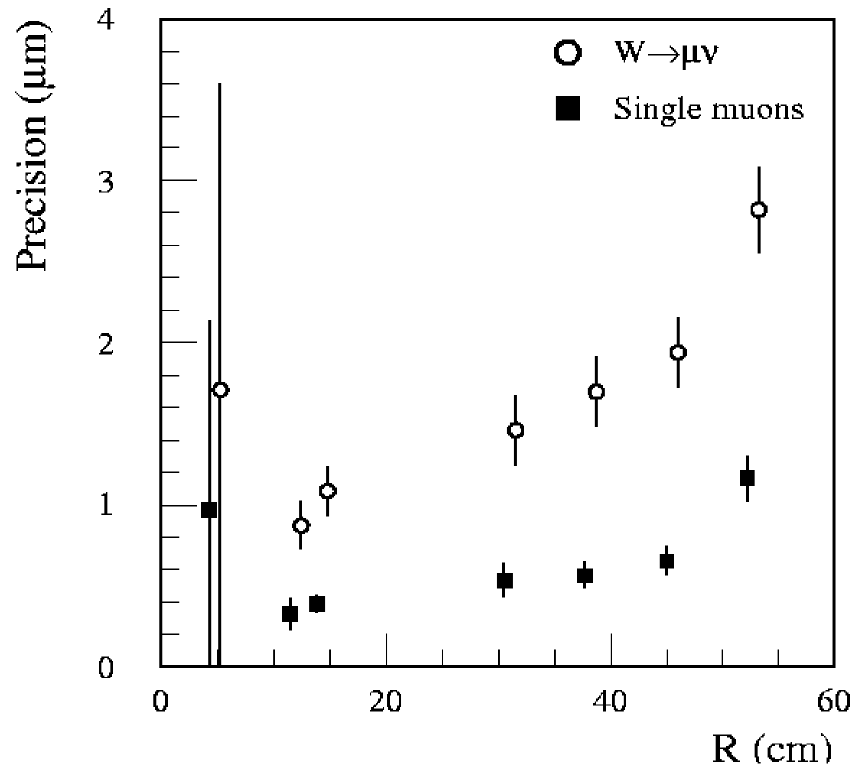
→Pixel Rf alignment 7 mm

→ SCT Rf alignment 12 mm

Use single muons from W (rate 3 Hz) or B decays (rate 50 Hz for p_T > 6 GeV)

Already after one day of running track fits result in

	residual	precision
Pixel	20 mm	1 mm
SCT	40 mm	2 mm



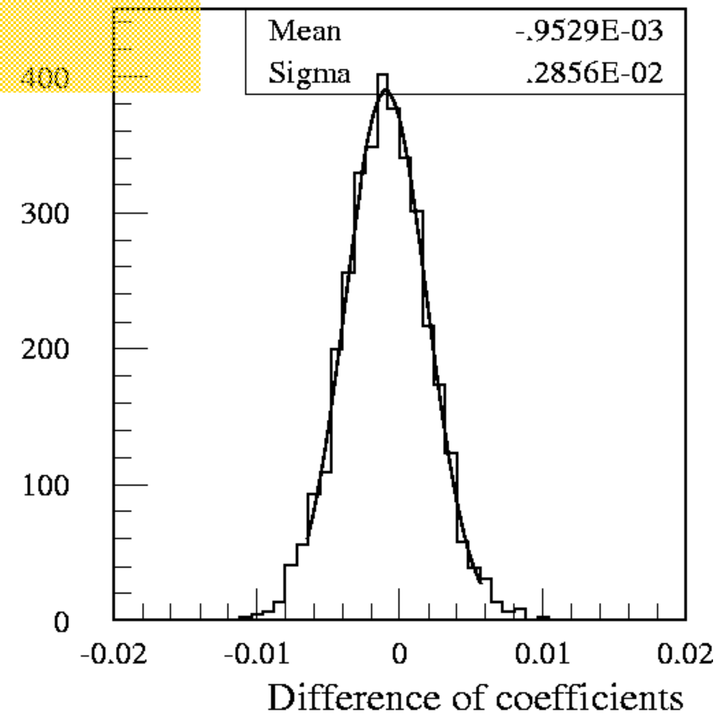
Error bars indicate spread for different modules

Measurement of W mass to 20 MeV:

→ Knowledge of momentum scale to 0.02%

Electromagnetic Calorimeter

- By construction, local calorimeter constant term of 0.5% over a region Dh Df = 0.2 x 0.4
- There are 400 such regions for |h| < 2.5
- Use Z → e^+e^- events to intercalibrate all ~400 regions
- Standalone calibration imposing Z mass constraint
- Almost background free channel
- large rate (~1Hz) yields >30 k events in one day
- close to mass of W and light Higgs



Energy reconstructed using calibration coefficients for each cell

Energy scale known to 1-2% from test beam

Using Z mass constraint a 1.5% rms miscalibration could be reduced to 0.3% using 50 k Z events

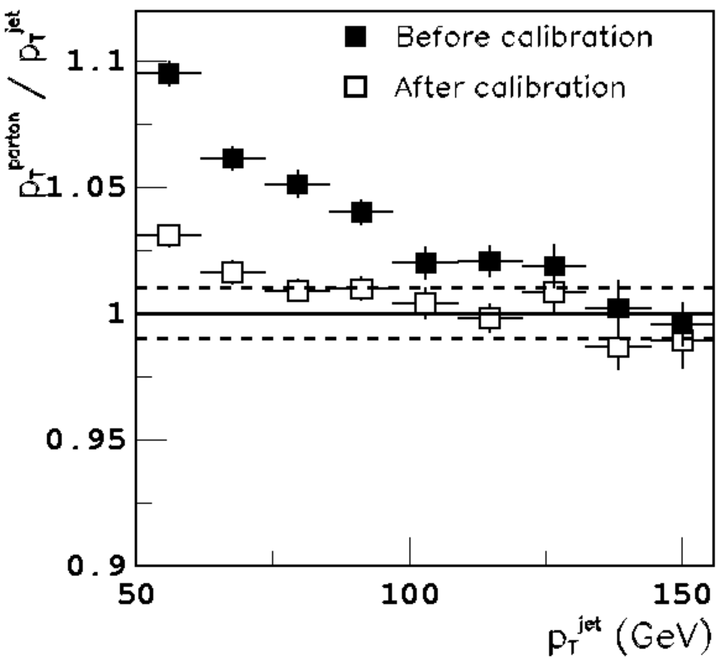
local calorimeter constant term : 0.5%

→ Total constant term 0.6 %
(less than goal of 0.7 %)

Hadronic calorimeter

Absolute energy scale for hadronic jets known to 5 – 10 % from test beam and MC studies
In situ calibration with W → jj and Z + jet events
Non-linearity in energy scale causes problems for jet energies and masses far from W mass

New studies taking into account angles give even better results



Calibration using
tt → Wb Wb → lnjjbb

Clean sample of 45 k events in first year
Calibrating jet jet mass to W mass results in 1% resolution for p_T of 50 – 250 GeV

Muon system

Momentum resolution and absolute calibration depend on:
- **alignment of precision chambers**
- **knowledge of magnetic field**
- **knowledge of muon energy loss in calorimeters**

Calibration procedures:

Alignment: **special runs with toroidal magnetic field off and solenoid field on**
→ straight tracks with known momentum from inner detector
barrel region precision of sagitta correction < 30μm within 1 hour
(well below intrinsic chamber error of 50 μm)

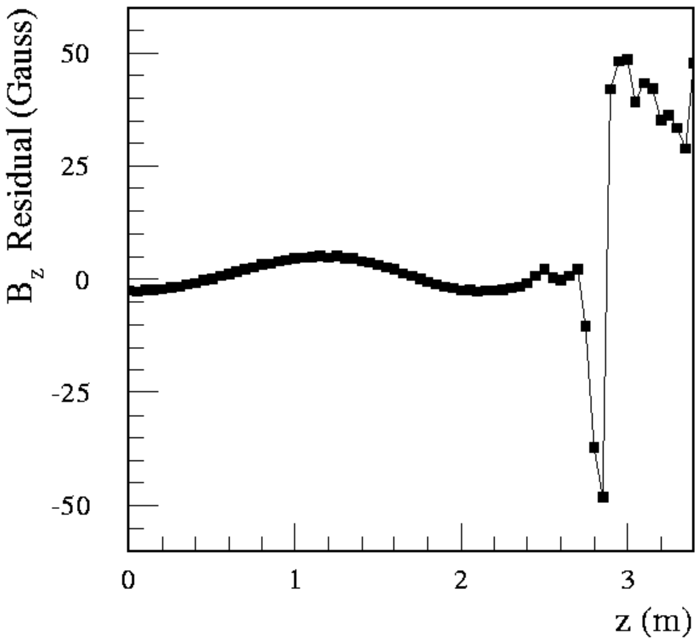
Magnetic field: **measured with 5000 Hall probes with relative precision of 0.1%**

Z → μμ: **30k events per day, fit to Z peak**
Difficulty: energy loss inside calorimeter ~4 GeV,
depends on momentum of muon
fit magnetic field and average energy loss simultaneously

Final uncertainty of 0.02 % difficult to reach in first year

General track resolution

mapping of magnetic field with Hall probes (due to non-uniform field) with precision 0.05 % before installation of ID (inner detector)
Determine magnetic field in ID using tracks
Using fit magnetic field can be reconstructed with precision of 4 Gauss, i.e. 0.02 %



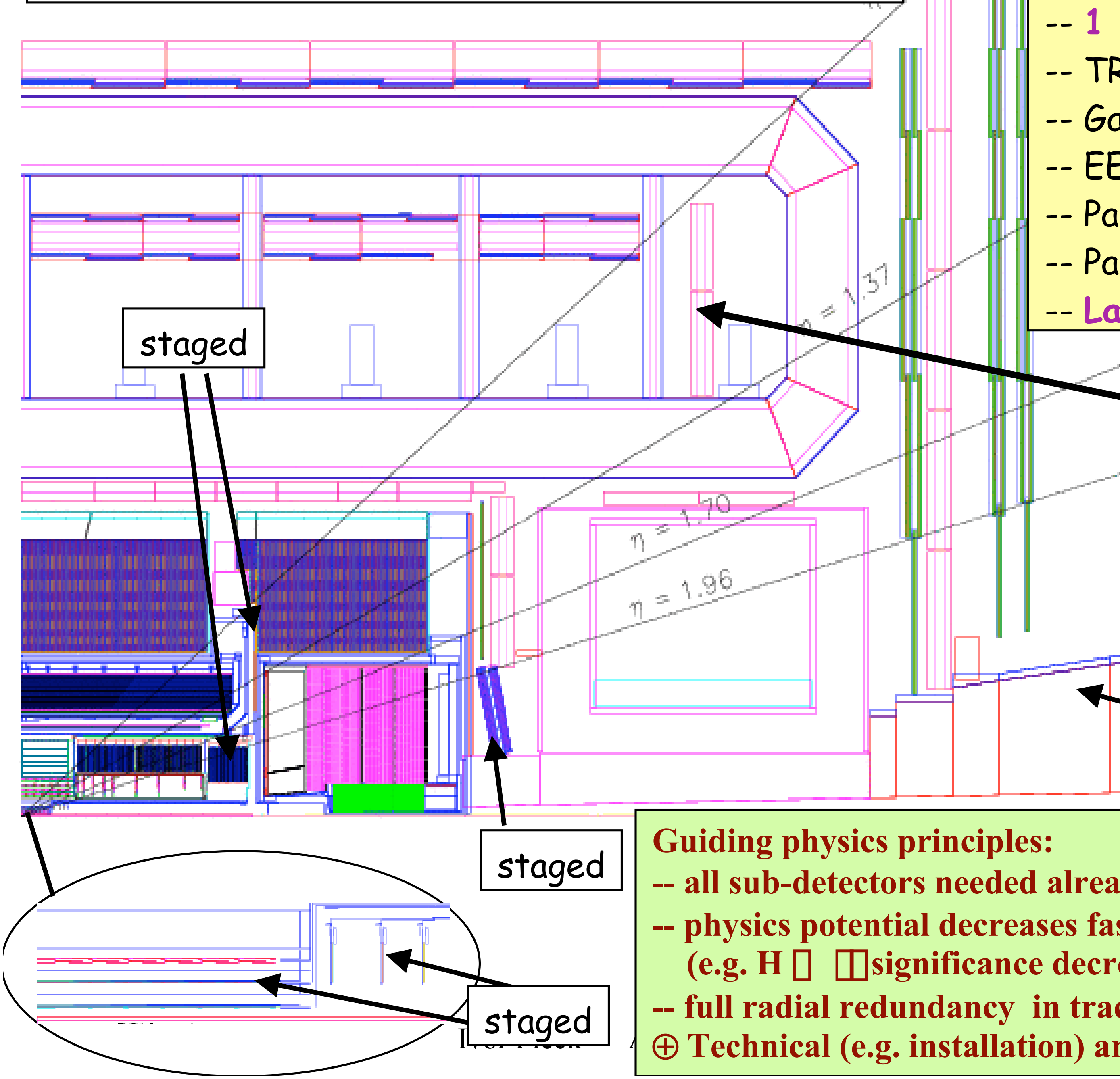
Solenoid coil ends at 2.65 m

Understanding of material of ID

- **W→ en decays to measure E/p from calorimeter (EM) and ID**
- **E/p distribution very sensitive to amount of material at different radii**
- **Final accuracy of 0.02% needs understanding of ID material distribution of 1%**
- **Within a few weeks of data taking this precision will be reached**

Momentum uncertainty of 0.02 % will be reached within first year for ID and EM

Staged components during initial physics run



Staged detector components:

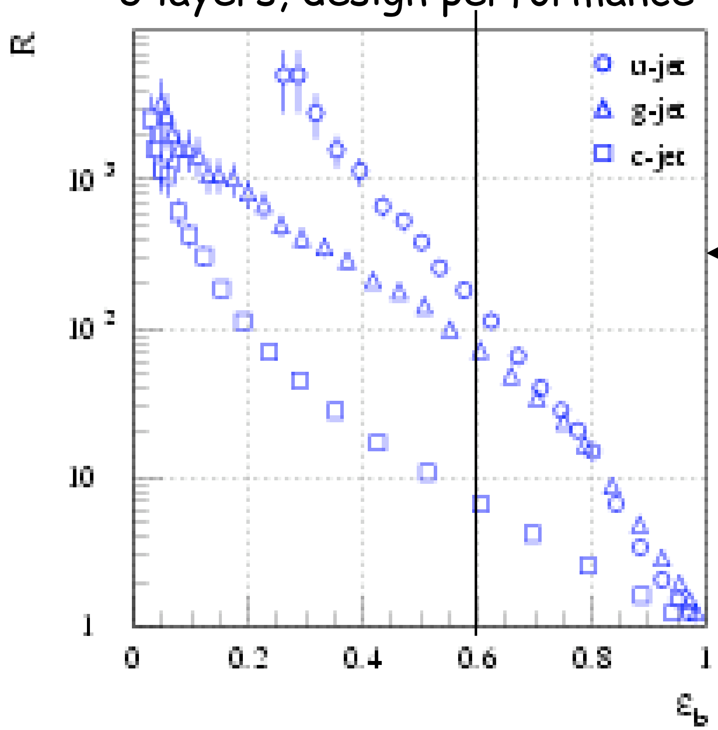
-- 1 pixel layer
-- TRT outer end-cap
-- Gap scintillator
-- EEL/EES MDT and half CSC
-- Part of forward shielding
-- Part of LAr ROD
-- Large part of HLT/DAQ

Guiding physics principles:

-- all sub-detectors needed already in 1st year
-- physics potential decreases fast with decreasing η coverage
(e.g. H → γγ significance decreases linearly)
-- full radial redundancy in tracking less crucial at ~ 10^{33}
⊕ Technical (e.g. installation) and schedule constraints

Missing pixel layer

3 layers, design performance



From full simulation of
WH → ℓν bb
"WH" → ℓν uu, ℓν gg, ℓν cc
m_H= 100 GeV

2D vertexing algorithm
3% pixel inefficiency included

For ε_b ~ 60% :
R_u (u-quark rejection) degraded by ~ 30% with 2 pixel layers

Significance of ttH → ttbb (most sensitive/important channel in first year) is reduced by ≈ 8%

⇒ need ~ 15% more integrated luminosity to reach same S/√B as with 3 layers

Trigger

Approach: **mostly inclusive selections, with relatively low pT thresholds for fundamental objects (e.g. leptons)**

-- keep safety margin against big (>2) uncertainties (e.g. from QCD cross-sections)
-- reserve enough bandwidth for “control triggers” (calibration, pre-scaled, …)

HLT trigger system is scalable,
Output bandwidth for level 1 triggers reduced from 75 kHz to 25 kHz

→ Trigger levels have to be raised
→ No dedicated B-physics trigger
→ high p_T triggers have no safety margin

ttH □ □□ bb + X m_H= 120 GeV

Thresholds (GeV)	Normalised S/ B
p_T (e) > 20, p_T (□) > 20	1
p_T (e) > 25, p_T (□) > 20	0.98
p_T (e) > 30, p_T (□) > 20	0.96
p_T (e) > 30, p_T (□) > 30	0.92
p_T (e) > 35, p_T (□) > 25	0.92

Note : ~ 8% loss from pixel staging not included

Physics impact of staging

Staged items	Main impact during first run on	Effect
1 pixel layer	ttH □ ttbb	~8% loss in significance
Gap scintillator	H □ 4e	~8% loss in significance
Muon detector (MDT)	A/H □ 2□	~5% loss in significance for m~ 300 GeV
HLT /DAQ	B-physics → High-p_T physics →	program jeopardised no safety margin (e.g. for EM triggers)

Requires 10-15% more integrated luminosity to compensate.

Complete detector needed at high luminosity

QCD

- QCD processes represent major background to most analyses
- Production cross-sections for most processes are controlled by QCD

Need detailed understanding of QCD before any other analyses

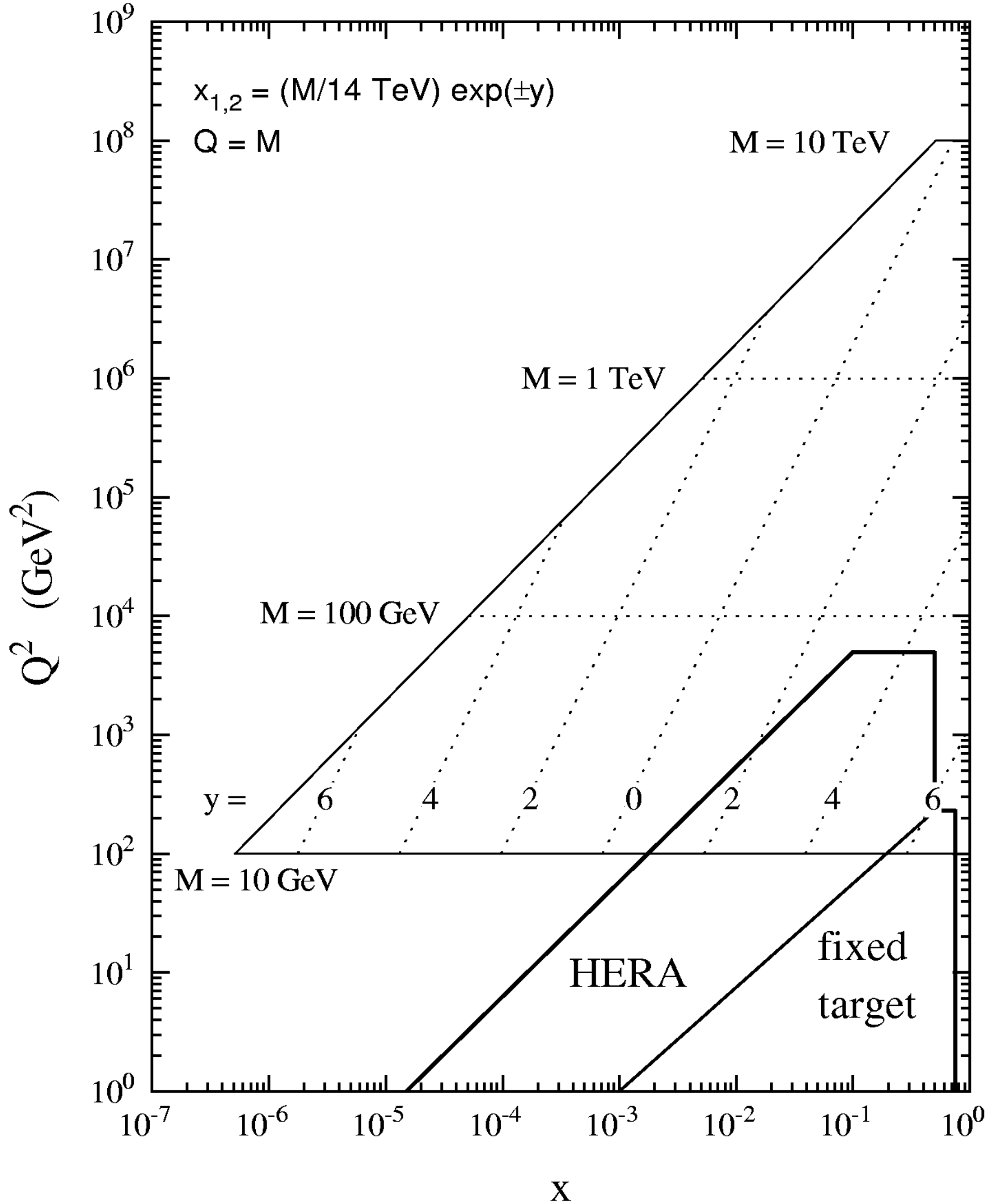
Parton distribution functions need to be known (from HERA and Tevatron) with great precision

Evolution in Q^2 with DGLAP equations, but uncertainties in F_2 (several %) from uncertainty in α_s

measurement of pdf at LHC via Drell-Yan (for quark distribution)
and direct photon and jet production (gluon distribution)
→check agreement with previous measurements

Most important at LHC is gluon distribution
Global fits needed for final check

Structure functions



- Overlap region with HERA is excellent test for pdf measurements
- Overlap with Tevatron up to $Q^2 = 10^6$ GeV^2
- Large new region will be explored

Higgs

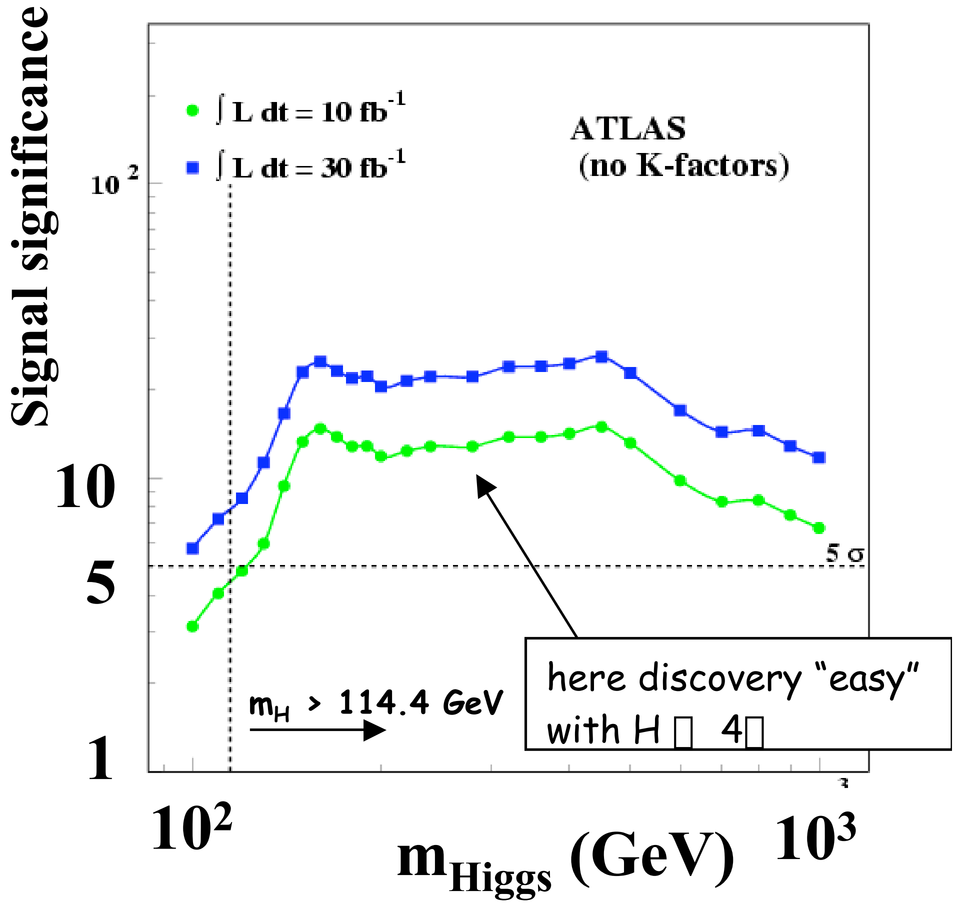
Most wanted particle in Standard model

One or several Higgs bosons may exist

Theoretical limits:
M(Higgs) < 1 TeV

Experimental limits:
M(Higgs) > 114.4 GeV

Indirect constraints:
M(Higgs) < 211 GeV



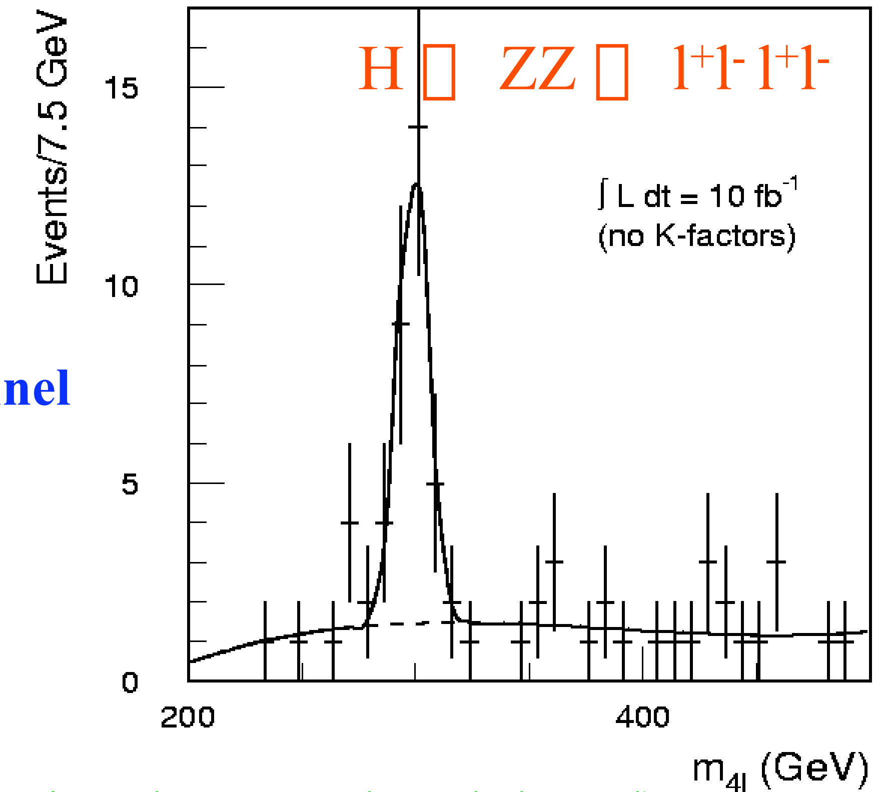
Large mass region

200 GeV < m(Higgs) < 600 GeV:

- discovery in $H \rightarrow ZZ \rightarrow l^+l^- l^+l^-$

background smaller than signal,
Higgs natural width larger than
experimental resolution (m_{Higgs} > 300 GeV)

- confirmation in $H \rightarrow ZZ \rightarrow l^+l^-$ jj channel



m(Higgs) > 600 GeV:

4 lepton channel statistically limited

$H \rightarrow ZZ \rightarrow l^+l^-$ nn

$H \rightarrow ZZ \rightarrow l^+l^-$ jj , $H \rightarrow WW \rightarrow$ ln jj (150 times larger BR than 4l channel)

Event signature: high p_T lepton, two high p_T jets

Combination of analyses allows Higgs discovery in full mass range

Low mass Higgs

M(Higgs) ~ 115 GeV, favored from LEP

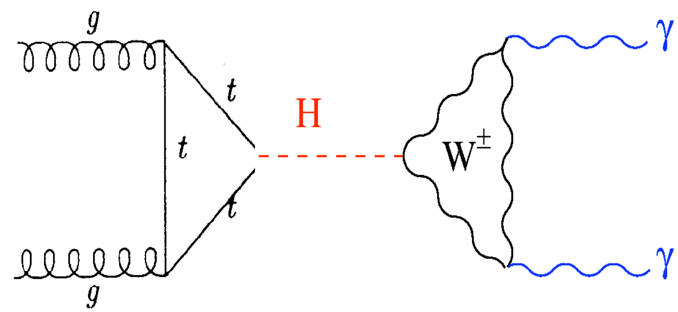
Several channels give ~ 2 s significance
□ observation of all channels important to extract convincing signal in first year

H □ □□relies only on electromagnetic calorimeter, constant term < 0.7 % needed for observation

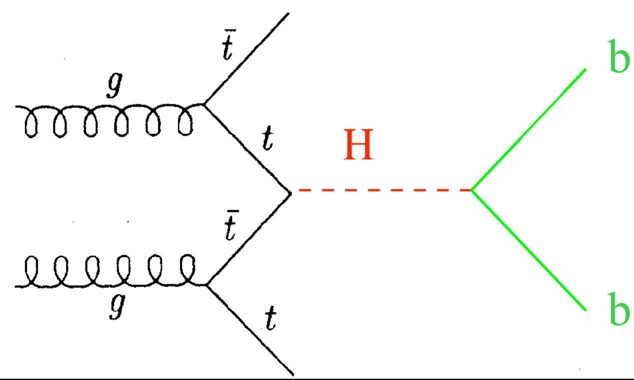
	H □ □□	ttH □ ttbb	qqH □ qq□□ (□□ + □-had)
S	130	15	~ 10
B	4300	45	~ 10
S/ B	2.0	2.2	~ 2.7

K□factor ≡ $\frac{ó_{NLO}}{ó_{LO}}$ □2 not included

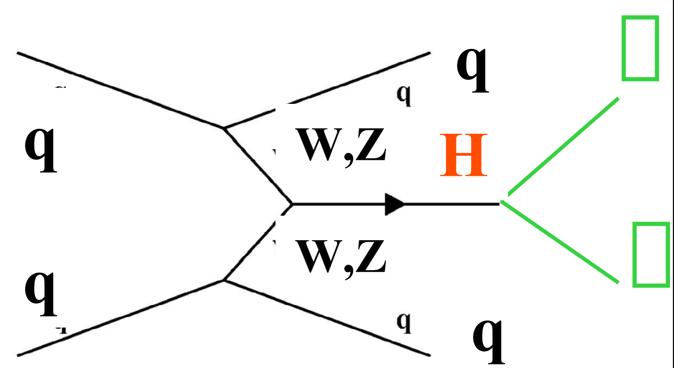
H □ □□



ttH □ tt bb □ b□□ bjj bb



qqH □ qq□□



Vector Boson Fusion

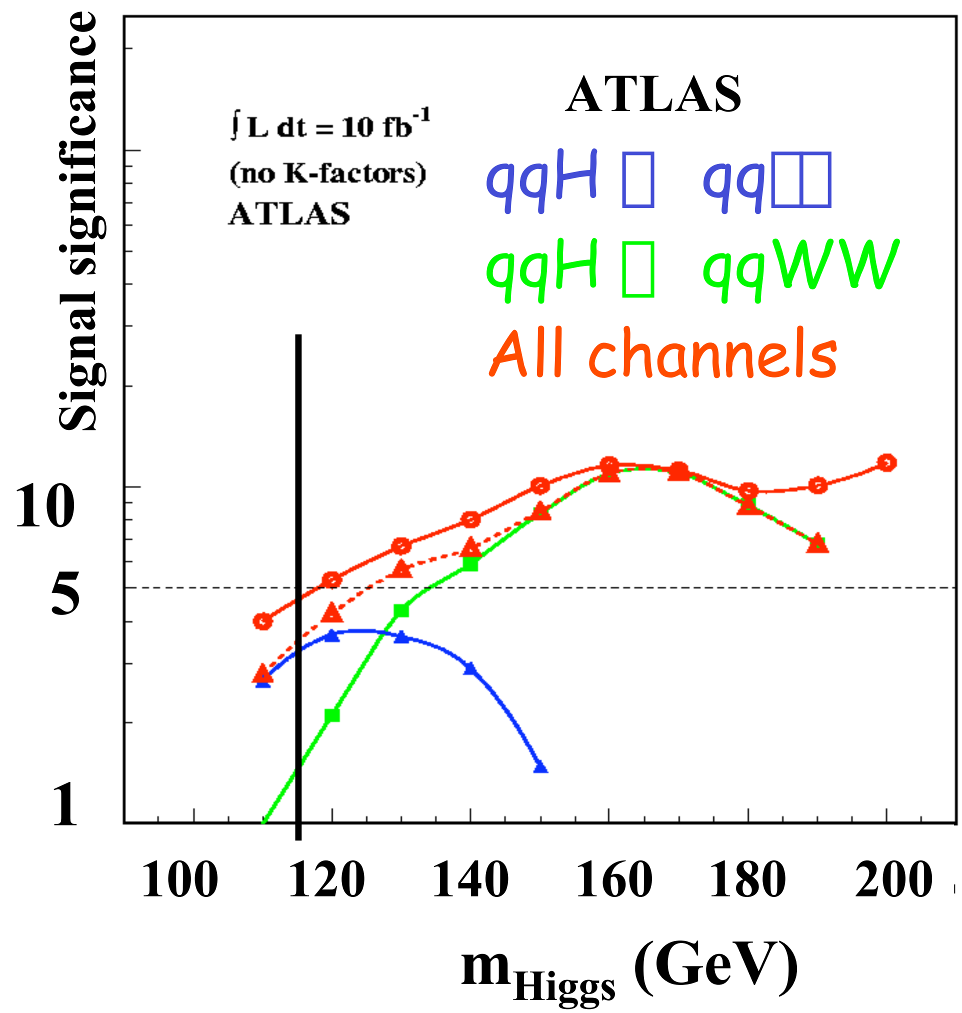
Recent studies demonstrate that vector boson fusion channels may be accessible in the low mass region already in the first year.

Several studies to improve performance

For m(Higgs) = 115 GeV combined significance ~ 5s

Results are conservative:

- K-factor not included
- very simple analyses used



Low mass remarks

The 3 channels are complementary $\Rightarrow$ robustness:

- different production and decay modes
- different backgrounds
- different detector/performance

requirements:

-- ECAL crucial for $H \rightarrow \gamma\gamma$
(in particular response uniformity) :
$\sigma/m \sim 1\%$ needed

-- b-tagging crucial for ttH :
4 b-tagged jets needed to reduce combinatorics

-- efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \rightarrow qq\tau\tau$:
forward jet tag and central jet veto needed against background

Note :
all require "low" trigger thresholds.
e.g. ttH analysis cuts :
$p_T(\ell) > 20$ GeV,
$p_T(\text{jets}) > 15\text{-}30$ GeV

MSSM Higgs

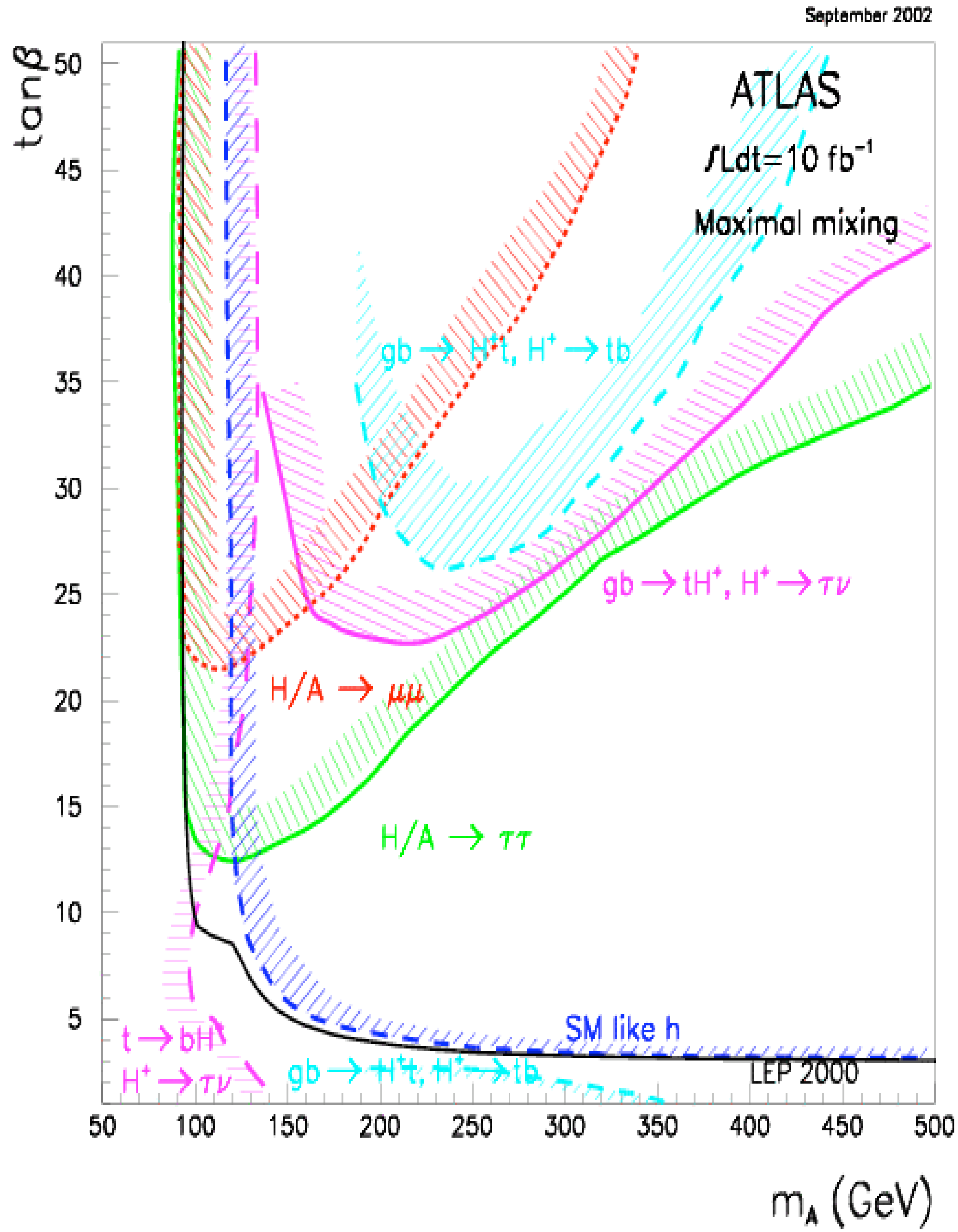
Supersymmetry 5 Higgs: h, H, A, H±
Theory prediction: m(h) < 135 GeV

Many more decay modes
Branching ratios depending on MSSM parameters

Most of parameter space can be probed by SM Higgs analyses for h

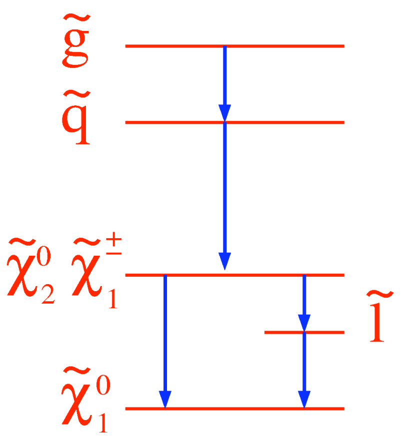
New decay channel H/A mm covers large part of region not excluded by LEP
Muon spectrometer crucial

H/A tt important for medium tan b



SUSY

Large cross-section for squark and gluino production



(high p_T) jets

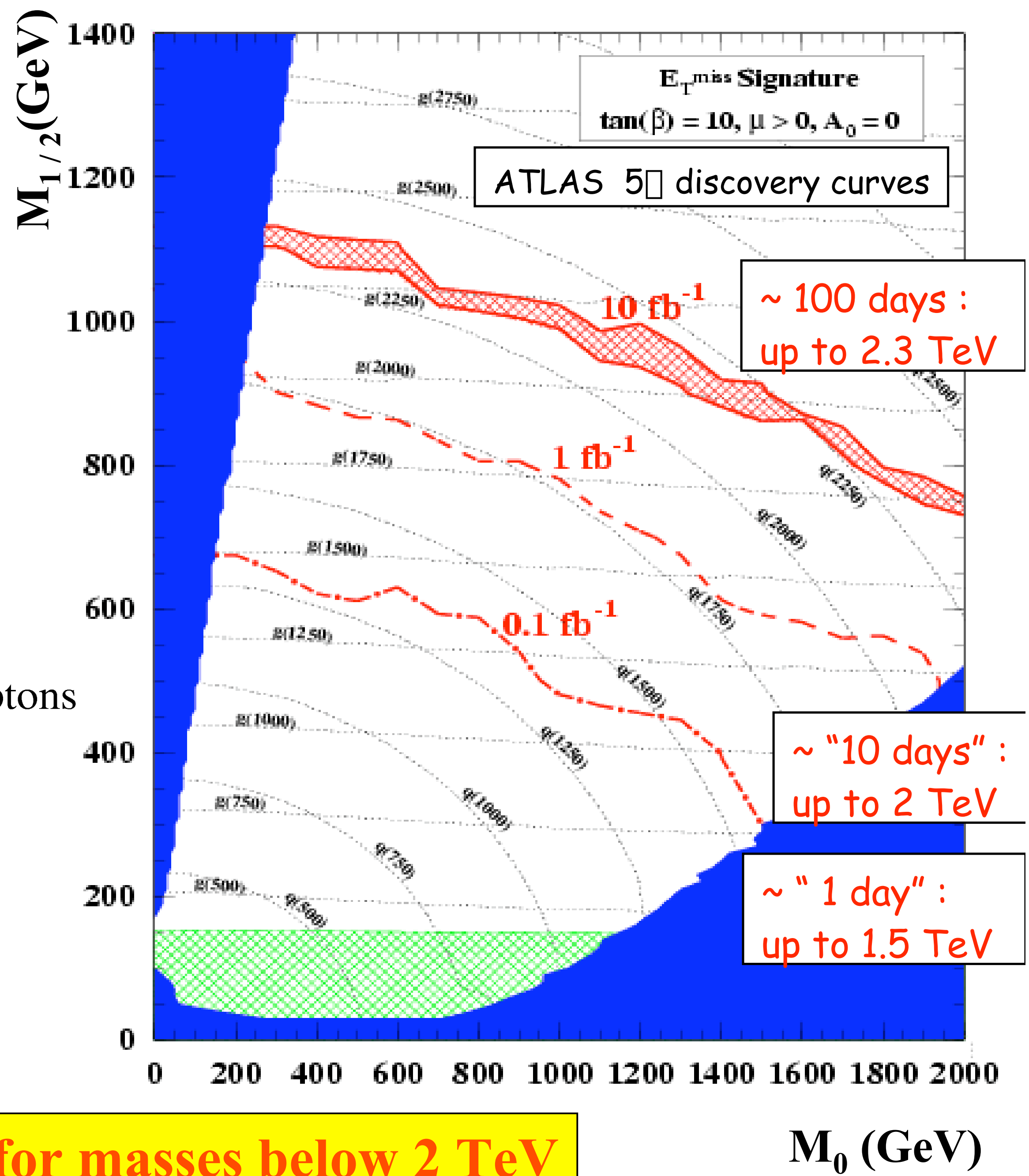
high p_T jets

jets and/or leptons

missing E_T

Decay chain leads to

- **high p_T jets**
- **large missing E_T**
- **isolated leptons**



Discovery of SUSY is easy for masses below 2 TeV

SUSY parameters

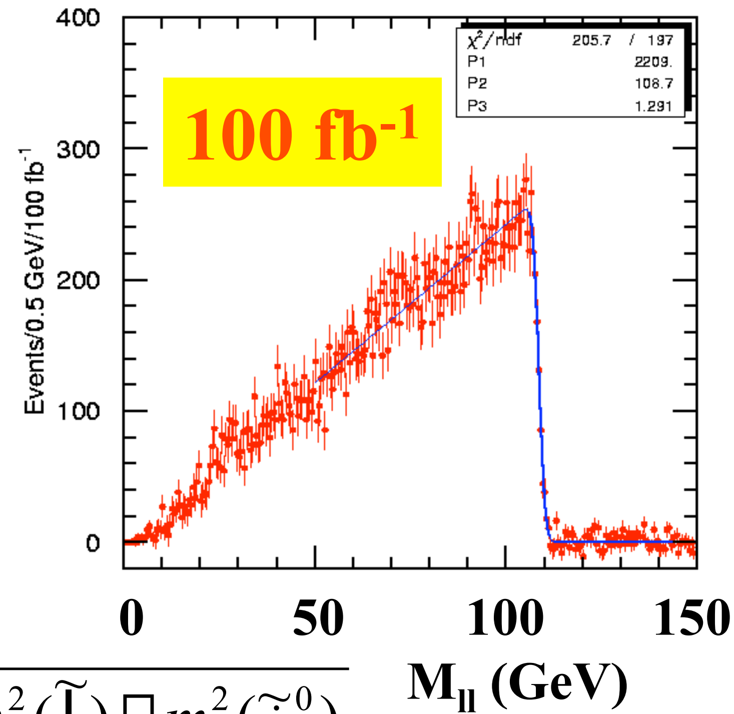
Two body decay chain

$$\tilde{\chi}^0_2 \rightarrow \tilde{l}^{\pm} l^{\mp} \rightarrow l^+ l^- \tilde{\chi}^0_1$$

Invariant mass of both leptons shows steep edge

Edge in m_{ll} distribution depends on

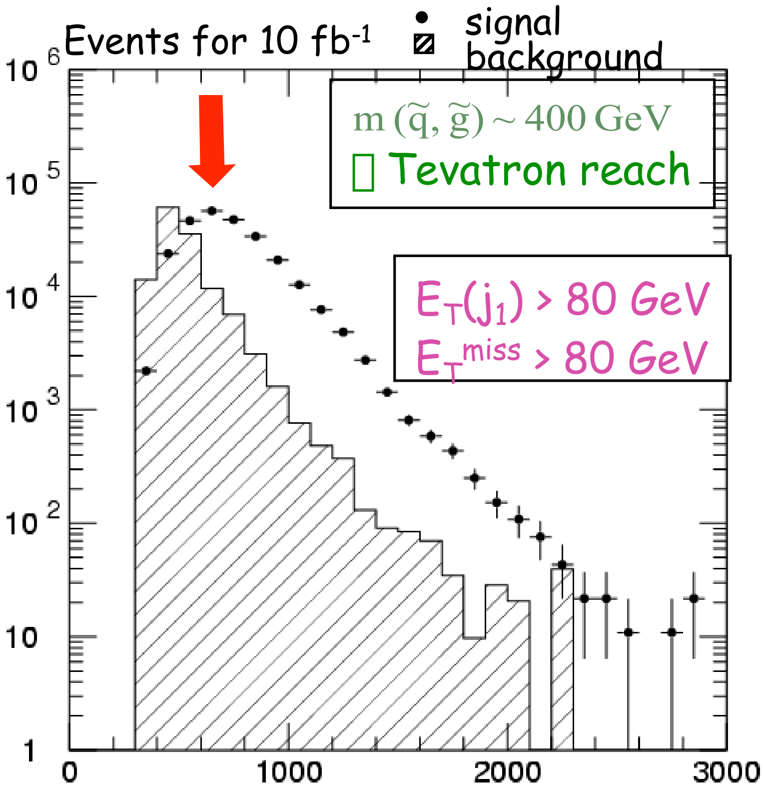
$$m(\tilde{\chi}^0_2) \quad m(\tilde{l}) \quad m(\tilde{\chi}^0_1)$$



$$\max(m(l^+l^-)) = m(\tilde{\chi}^0_2)\sqrt{\frac{m^2(\tilde{\chi}^0_2) - m^2(\tilde{l})}{m^2(\tilde{\chi}^0_2)}}\sqrt{\frac{m^2(\tilde{l}) - m^2(\tilde{\chi}^0_1)}{m^2(\tilde{l})}}$$

Resolution of edge is few GeV for 10 fb^{-1}

Lower SUSY masses



$$M_{eff} = E_T^{miss} + \sum_{i=1}^{4} p_T\,(jet_i) \quad (GeV)$$

Position of peak correlated to SUSY mass scale

$$M_{SUSY} \equiv \min\,(m\,(\tilde{q}), m\,(\tilde{g}))$$

Measurement of SUSY mass scale ≈ 20% (mSUGRA) with 10 fb^{-1}

Low trigger thresholds necessary to measure mass scale in overlap region with Tevatron (400 GeV)

Calorimeter must have good hermeticity up to |η|=5

Conclusions

- **Commissioning of detector challenging**
- **procedures are being developed now**
- **within first days:**
  - **Alignment of central detector using muon tracks to < 2 mm**
  - **Calibration of EM using $Z \rightarrow ee$ to 0.6 %**
- **Impact of staging: Need ~ 10 - 15 % more integrated luminosity**

Physics results within first year:

- **Higgs boson may be discovered over full mass range (low mass region very challenging)**
- **MSSM Higgs likely to be seen**
- **LHC is factory for SUSY particles, discovery immediately first year reach is squark masses up to 2 TeV**

Looking forward to many interesting physics analyses

All channel plot