LHC Physics, the first 1-2 years

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- Physics opportunities at the beginning
- Machine start-up scenario
- Which detectors, triggers and performance at the beginning ?
    - Construction → test beam → cosmics → first collisions
- How well will we know the physics and the Monte Carlo generators at the beginning ?
- Physics goals and potential with the first 0.1-1 - 10 fb^{-1} (a few examples …)
- Conclusions

What can we expect at the beginning?

Some history:

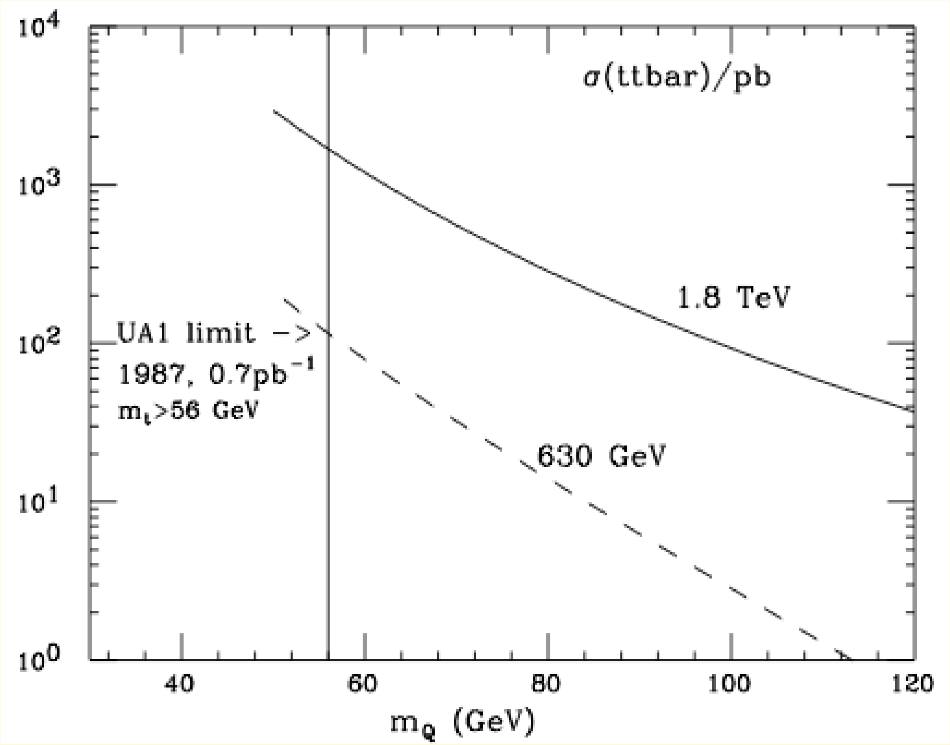
- **Fall 1982:** first physics run for UA1 and UA2 at the SppbarS
  - $L_{max} = 5x10^{28} cm^{-2}s^{-1} \approx 1\%$ asymptotic L
  - $L_{int} = 20 nb^{-1}$ in 30 days

outcome: W/Z discovery, as expected
ingredients: plenty of kinematical phase-space (ISR was sub-threhsold!), clear signature, and good hands-on control of backgrounds

- **Summer 1987:** first physics run for CDF at the Tevatron
  - $L_{max} = 5x10^{28} cm^{-2}s^{-1} \approx 1\%$ nominal L
  - $L_{int} = 20 nb^{-1}$ in 30 days

  outcome: nothing exciting, as expected
  why: not enough phase-space, given the strong constraints on new physics already set by UA1/UA2!

In the region of the UA1 limit the production cross-section at the Tevatron was only a factor of 10-20 larger



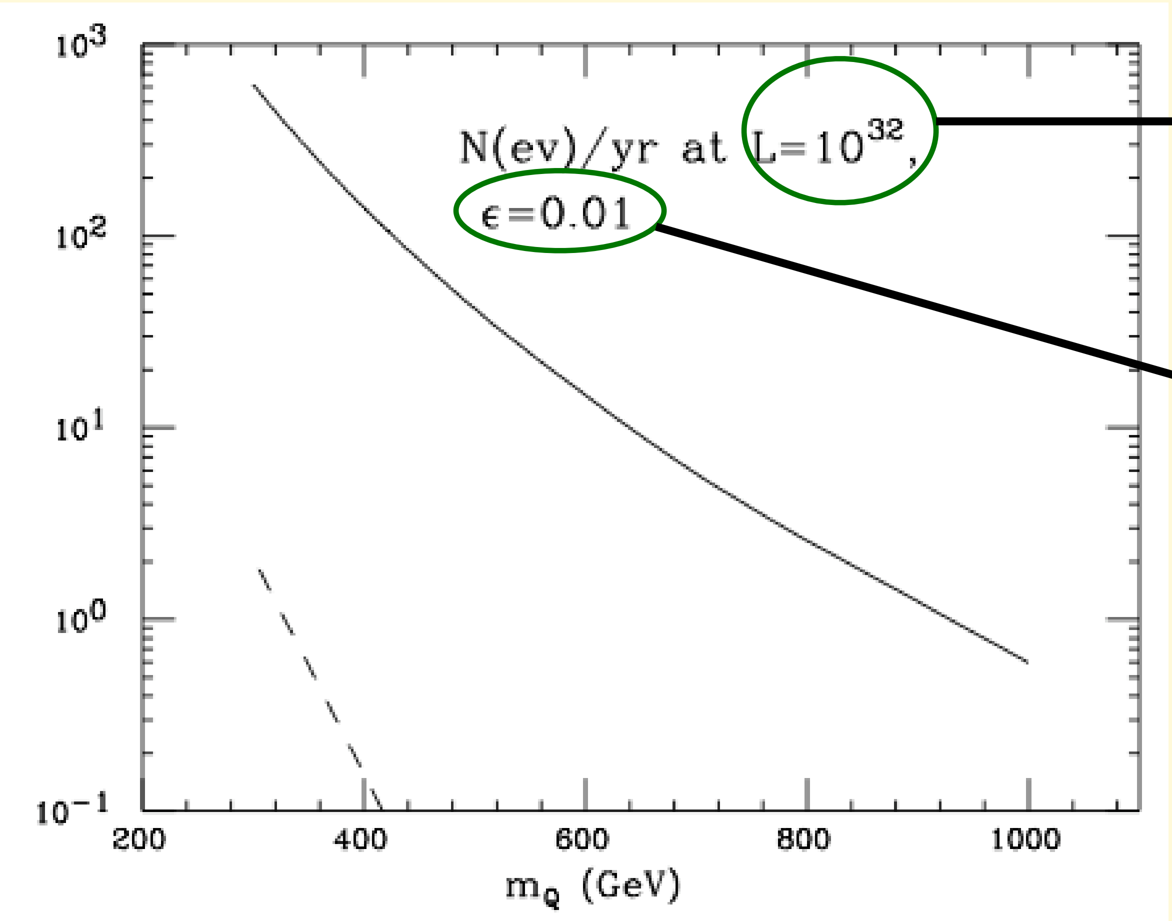
By the time of CDF startup, the SppS had already logged enough luminosity to rule out a possible observation at the Tevatron within the first $100nb^{-1}$

It took 2 more years (and $4pb^{-1}$) for CDF to improve (m_{top}>77 GeV) the UA1 limits (in spite of the fact that by '89, and with $5pb^{-1}$, it had only improved to 60 GeV - UA2 eventually went up to 69 GeV). This is the consequence of much higher bg's at the Tevatron, and of the steep learning curve for such a complex analysis

At the start of LHC, the situation will resemble much more that at the beginning of UA1/ UA2:

The phase-space for the Tevatron will have totally saturated the search boundary for most phenomena, at a level well below the LHC initial reach: seen from the LHC, the Tevatron will look like the ISR as seen from the SppS!

Rates 10^3 times larger in the region of asymptotic Tevatron reach

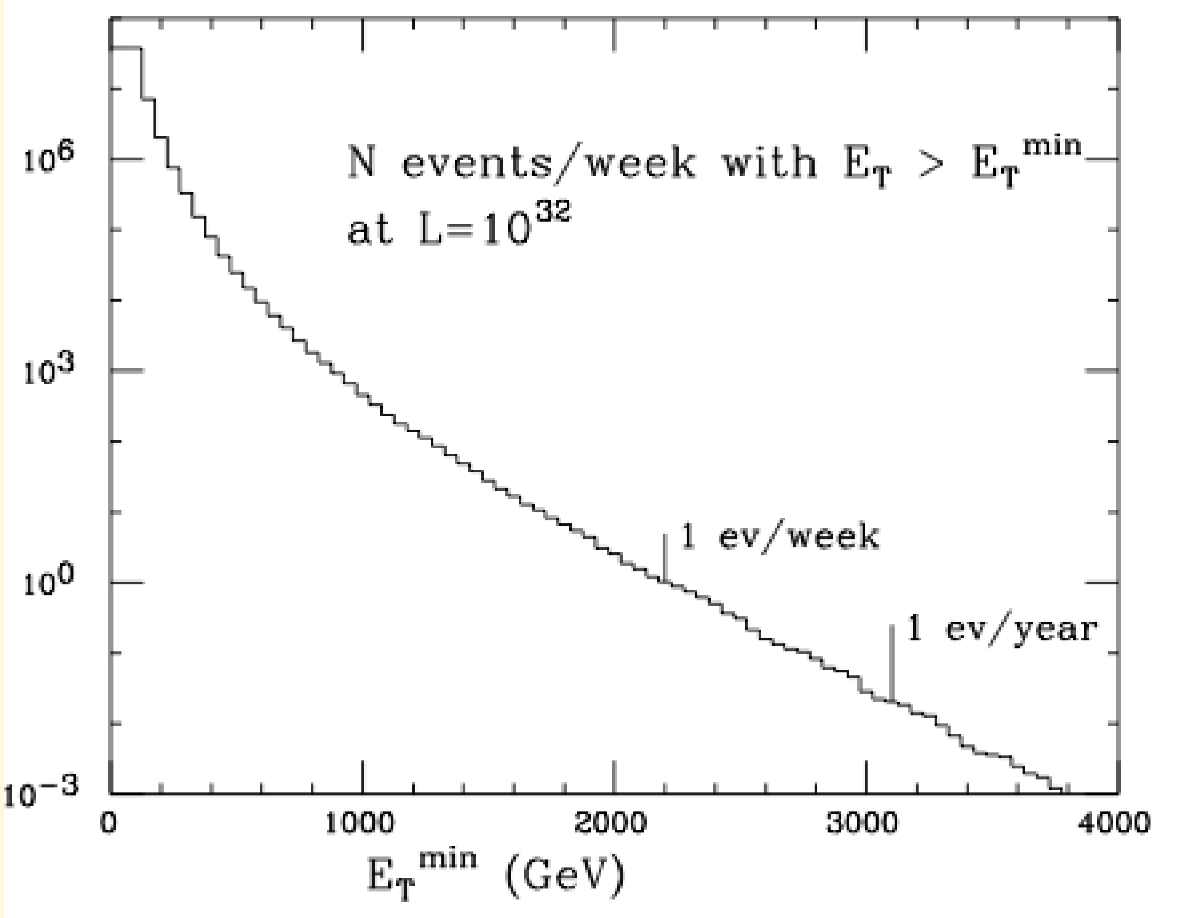


1% of L_{max} for the LHC, (as in SppS and Tevatron early runs), close to L_{max} for Tevatron

(assume a 1% signal efficiency)

N.B.: rates for gluino production are roughly a factor of 10 larger than for HQs

Similar considerations hold for jets, where few days of data will probe quarks at scales beyond the overall Tevatron CM energy!



Fine, we have phase-space, we have rates. But should we truly expect something to show up at scales reachable early on?

LEP's heritage is a strong confirmation of the SM, and at the same time an apparent paradox:

On one side m(H)=98+52-36; on the other, SM radiative corrections give

$$\delta m_H^2 = \frac{6G_F}{\sqrt{2}\pi^2}\left(m_t^2 - \frac{1}{2}m_W^2 - \frac{1}{4}m_Z^2 - \frac{1}{4}m_H^2\right)\Lambda^2 \sim (115\mathrm{GeV})^2 \left(\frac{\Lambda}{400\mathrm{GeV}}\right)^2$$

How can counterterms artificially conspire to ensure a cancellation of their contribution to the Higgs mass?

The existence of new phenomena at a scale not much larger than 400 GeV appears necessary to enforce such a cancellation in a natural way!

On the other hand, the accuracy of the EW precision tests at LEP sets the scale for "generic new physics" (parameterized in terms of dim-5 and dim-6 effective operators) at the level of few-to-several TeV.

This puts very strong constraints on the nature of this possible new physics: to leave unaffected the SM EW predictions, and at the same time to play a major role in the Higgs sector.

Supersymmetry, among others, offers one such possible solution

In Supersymmetry the radiative corrections to the Higgs mass are not quadratic in the cutoff, but logarithmic in the size of SUSY breaking (in this case M_{stop}/M_{top}):

$$m_h^2 < m_Z^2 + \frac{3G_F}{\sqrt{2}\pi^2} m_t^4 \left[\ln\left(\frac{M_S^2}{m_t^2}\right) + x_t^2 \left(1 - \frac{x_t^2}{12}\right) \right]$$

with

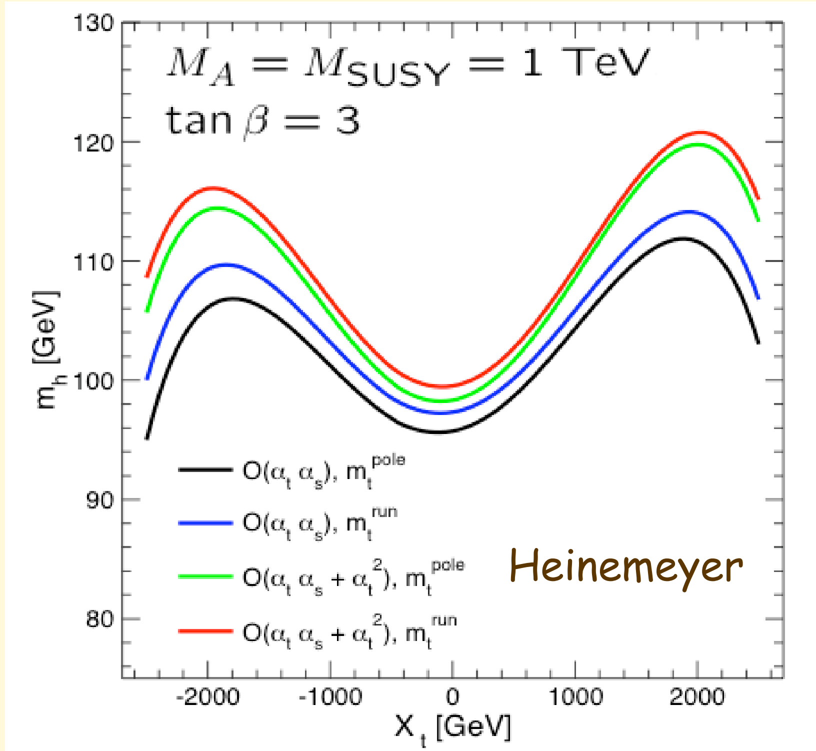
$$M_S^2 \equiv \frac{1}{2}(M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2) \qquad X_t \equiv A_t - \mu \cot\beta$$

$$x_t \equiv X_t / M_S$$

For $M_{susy} < 2$TeV

$$m_h^{max} \simeq 122 \text{ GeV}, \quad \text{if top-squark mixing is minimal,}$$

$$m_h^{max} \simeq 135 \text{ GeV}, \quad \text{if top-squark mixing is maximal}$$



The current limits on m_H point to M(lightest stop) > 600 GeV. Pushing the SUSY scale towards the TeV, however, forces fine tuning in the EW sector, reducing the appeal of SUSY as a solution to the Higgs mass naturalness:

$$\delta m_Z^2 \sim (90GeV)^2 \left(\frac{M_S}{230GeV}\right)^2 \ln\frac{\Lambda_{UV}}{M_S}$$

In other words, the large value of m_H shows that room is getting very tight now for SUSY, at least in its “minimal” manifestations.

This makes the case for an early observation of SUSY at the LHC quite compelling, and worth investing into!

The search for Supersymmetry is in my view the single most important task facing the LHC experiments in the early days. In several of its manifestations, SUSY provides very clean final states, with large rates and potentially small bg's.

Jets + miss ET
(squarks/gluinos)

Same-sign dileptons + MET
(gluinos)

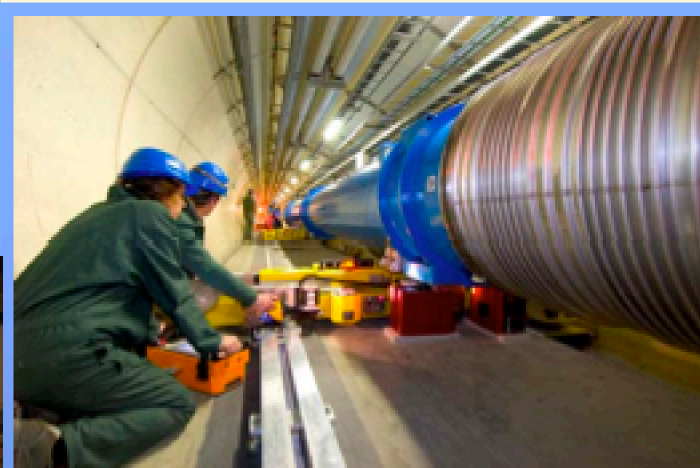
$B_s \to \mu^+\mu^-$

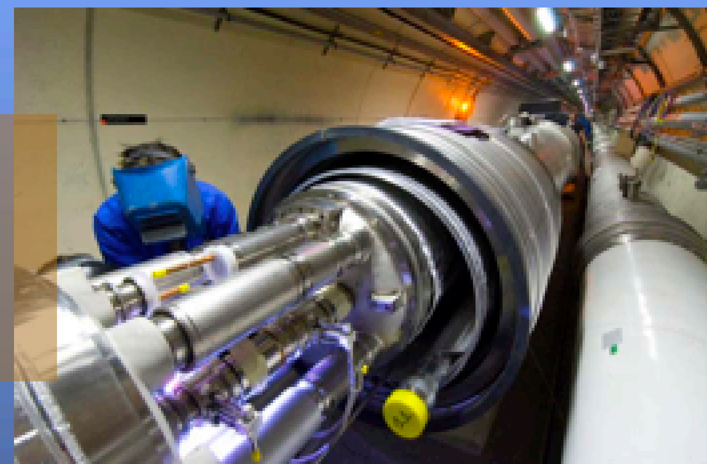
t tbar+ MET
(stop production)

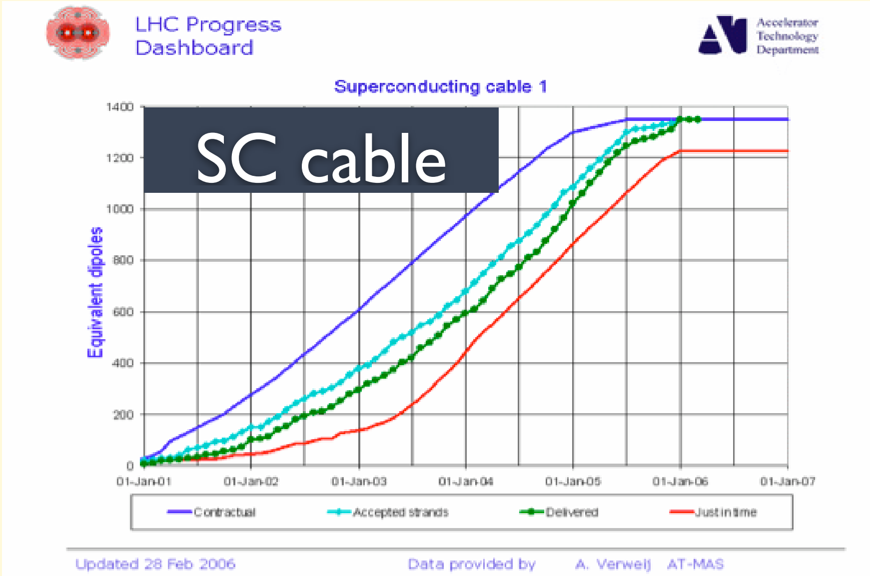
photons+MET
(gauge mediated ~~SUSY~~)

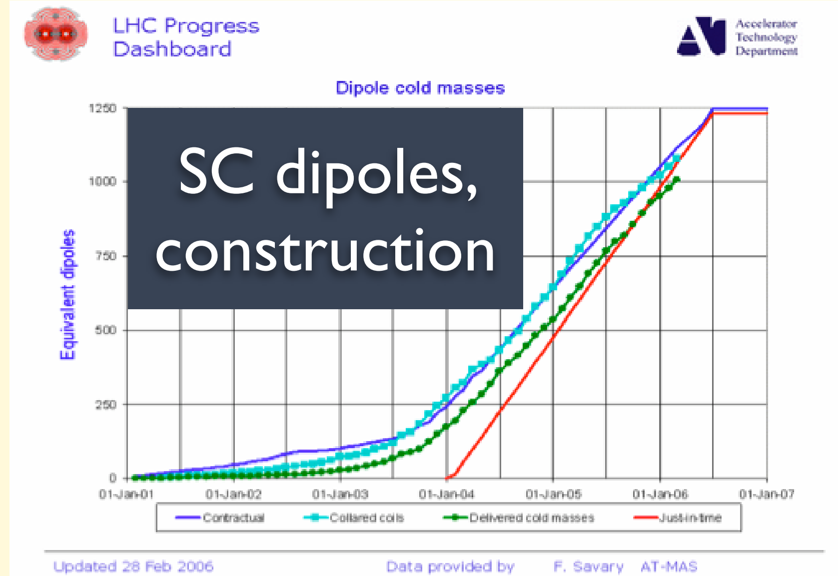
Given the big difficulty and the low rates characteristic of Higgs searches in the critical domain $m_H<135$ GeV, the detector and physics commissioning should be optimized towards the needs of SUSY searches rather than light-Higgs (I implicitly assume that for $m_H>140$ Higgs searches will be almost staightforward and will require proper understanding of only a limited fraction of the detector components -- e.g. muons)

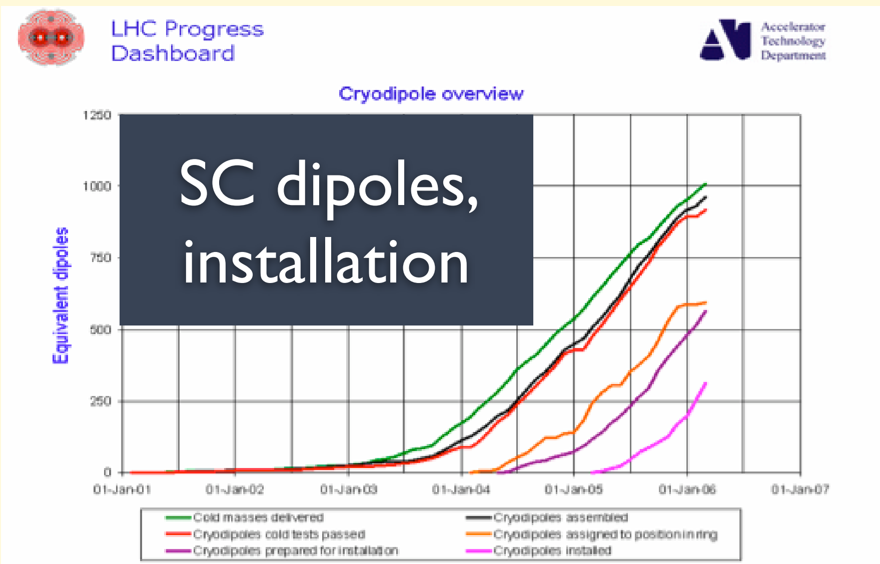
LHC, machine status

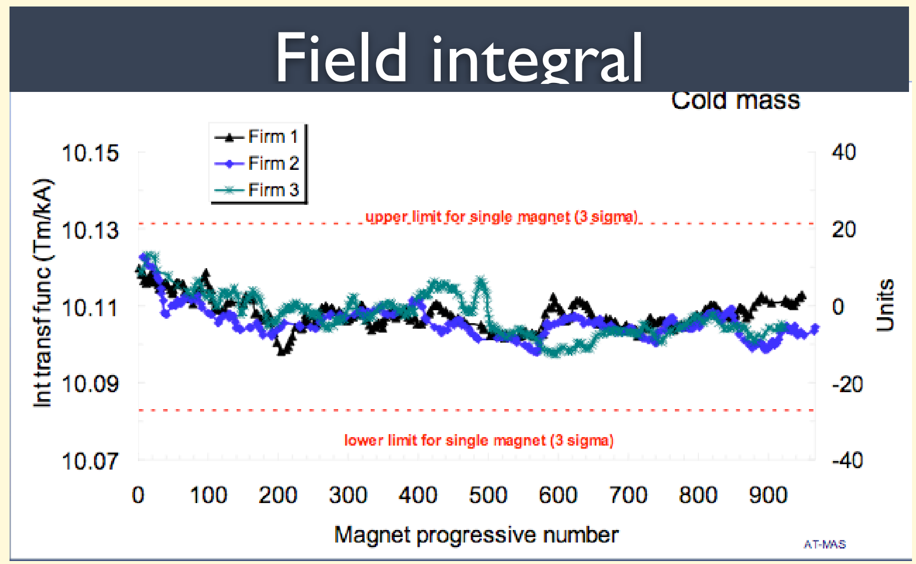






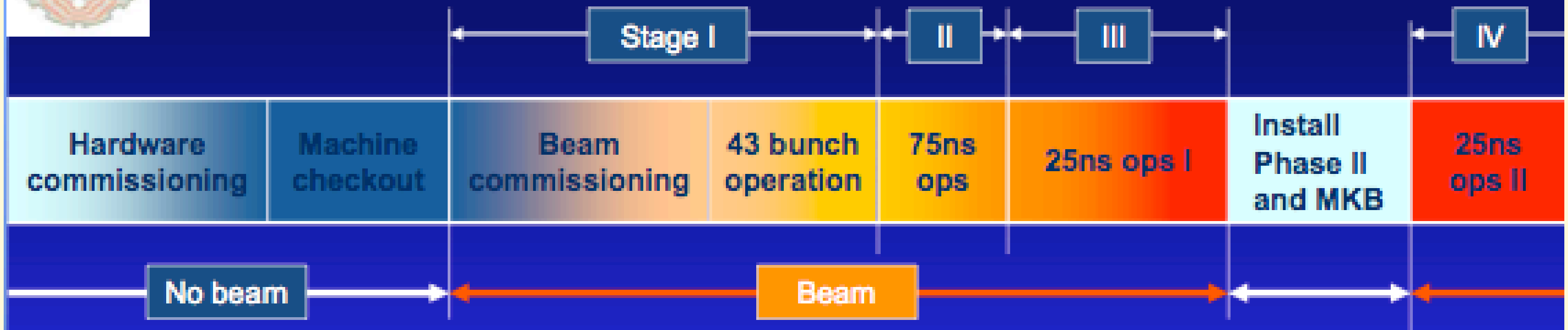






Installation complete by March 07

Staged commissioning plan for protons



I. **Pilot physics run**
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

II. **75ns operation**
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. **25ns operation I**
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. **25ns operation II**
- Push towards nominal performance

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Stage I physics run

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate/Cross = \frac{L\sigma_{TOT}}{k_b f}$$

- Start as simple as possible
- Change 1 parameter (k_b, N, $\beta^*_{1,5}$) at a time
- All values for
  - nominal emittance
  - 7TeV
  - 10m β^* in point 2 (luminosity looks fine)

Protons/beam ? 10^{13}
(LEP beam currents)

Stored energy/beam ? 10MJ
(SPS fixed target beam)

Parameters			Beam levels		Rates in 1 and 5		Rates in 2	
k_b	N	β^* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1	10^{10}	18	$1\ 10^{10}$	10^{-2}	10^{27}	<< 1	$1.8\ 10^{27}$	<< 1
43	10^{10}	18	$4.3\ 10^{11}$	0.5	$4.2\ 10^{28}$	<< 1	$7.7\ 10^{28}$	<< 1
43	$4\ 10^{10}$	18	$1.7\ 10^{12}$	2	$6.8\ 10^{29}$	<< 1	$1.2\ 10^{30}$	0.15
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76	$1.2\ 10^{30}$	0.15
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76	$4.4\ 10^{30}$	0.15
156	$9\ 10^{10}$	2	$1.4\ 10^{13}$	16	$1.1\ 10^{32}$	3.9	$2.2\ 10^{31}$	0.77

1month ~ 10^6s
@ 10^{32} =>
~100 pb^{-1}

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Stage II physics run

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$F = 1/\sqrt{1+\left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

- Relaxed crossing angle (250 μrad)
- Start un-squeezed
- Then go to where we were in stage I
- All values for
  - nominal emittance
  - 7TeV
  - 10m β* in points 2 and 8

Protons/beam ? few 10^{13}

Stored energy/beam ? 100MJ

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
936	$4\ 10^{10}$	18	$3.7\ 10^{13}$	42	$1.5\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
936	$4\ 10^{10}$	1	$3.7\ 10^{13}$	42	$2.5\ 10^{32}$	1.4	$2.6\ 10^{31}$	0.15
936	$9\ 10^{10}$	1	$8.4\ 10^{13}$	94	$1.2\ 10^{33}$	7	$1.3\ 10^{32}$	0.76

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Stage III physics run

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$F = 1 / \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

$$Eventrate / Cross = \frac{L \sigma_{TOT}}{k_b f}$$

- Nominal crossing angle (285 μrad)
- Start un-squeezed
- Then go to where we were in stage II
- All values for
  - nominal emittance
  - 7TeV
  - 10m β* in points 2 and 8

Protons/beam ? 10^{14}

Stored energy/beam = 100MJ

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
2808	$4\ 10^{10}$	18	$1.1\ 10^{14}$	126	$4.4\ 10^{31}$	<< 1	$7.9\ 10^{31}$	0.15
2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
2808	$5\ 10^{10}$	2	$1.4\ 10^{14}$	157	$5.9\ 10^{32}$	1.1	$1.2\ 10^{32}$	0.24
2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24
2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6	$1.2\ 10^{32}$	0.24
Nominal			$3.2\ 10^{14}$	362	10^{34}	19	$6.5\ 10^{32}$	1.2

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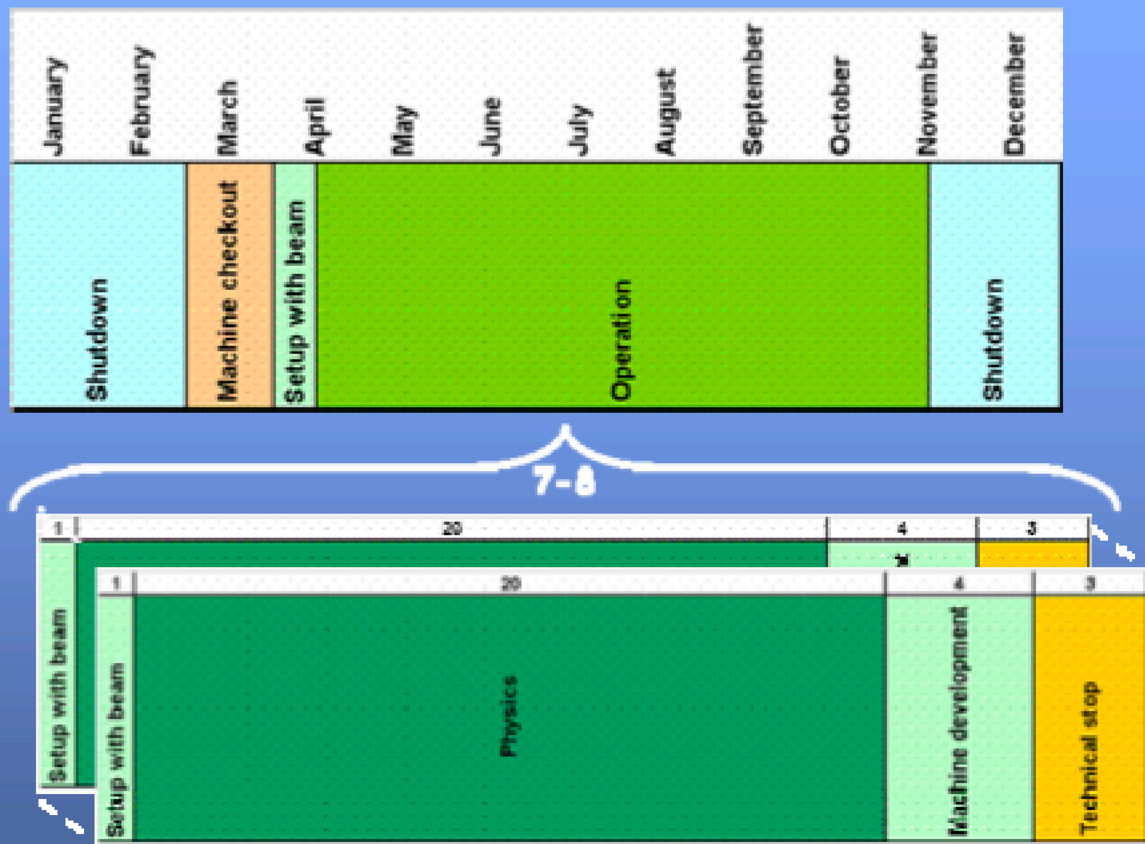
Breakdown of a normal year



~ 140-160 days for physics per year
Not forgetting ion and TOTEM operation
Leaves ~ 100-120 days for proton luminosity running
? Efficiency for physics 50% ?
~ 1200 h or ~ 4 10^6 s of proton luminosity running / year

L.R. Evans – EDMS Document No. 712870

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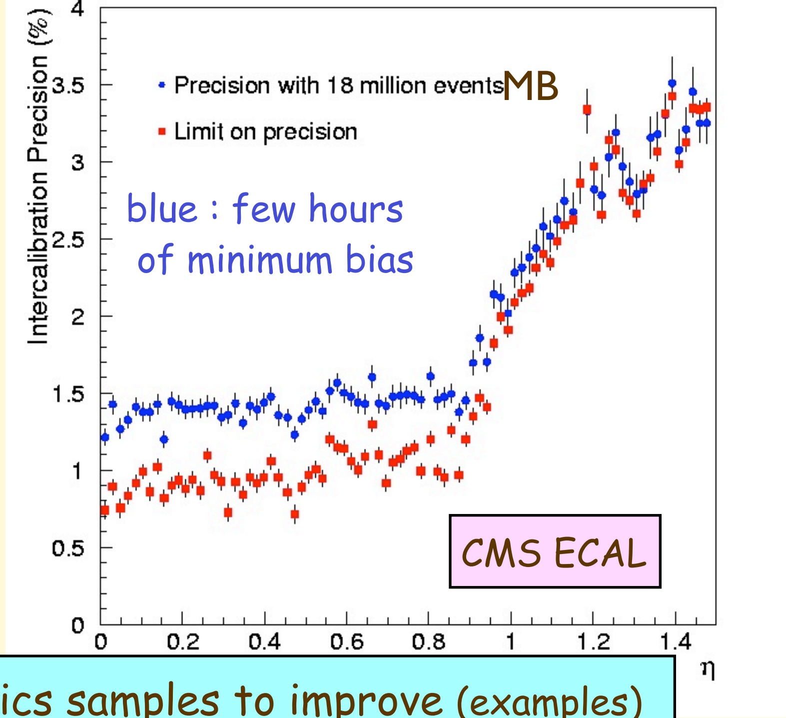
Which detector performance at day one ?

A few examples and educated guesses
based on test-beam results and simulation studies

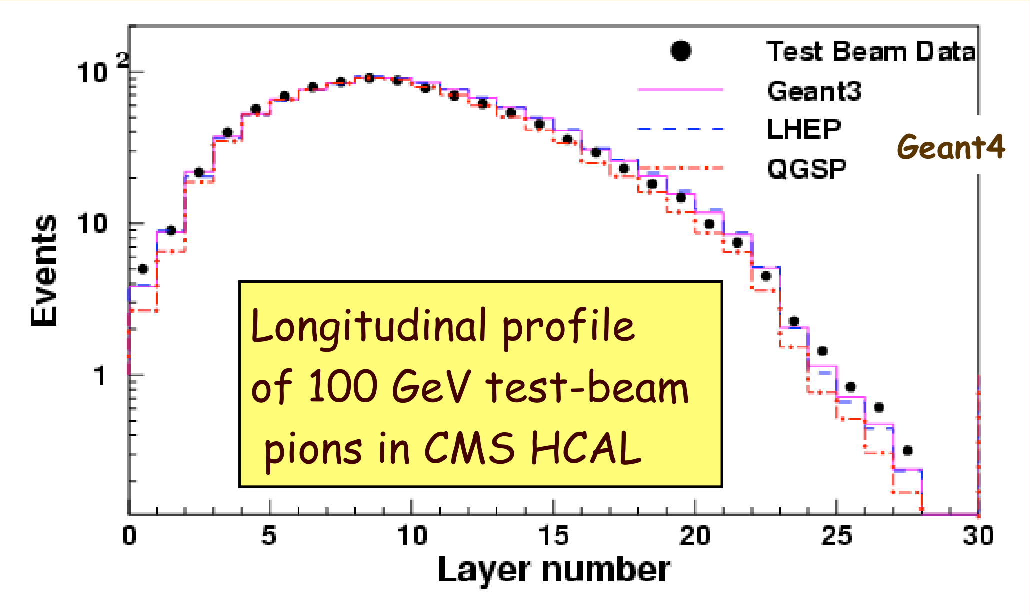


	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, $Z \to ee$ $Z \to ee$
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets $Z (\to ll)$ +1j, $W \to jj$ in tt events
Tracking alignment	20-500 μm in Rϕ ?	Generic tracks, isolated μ , $Z \to \mu\mu$

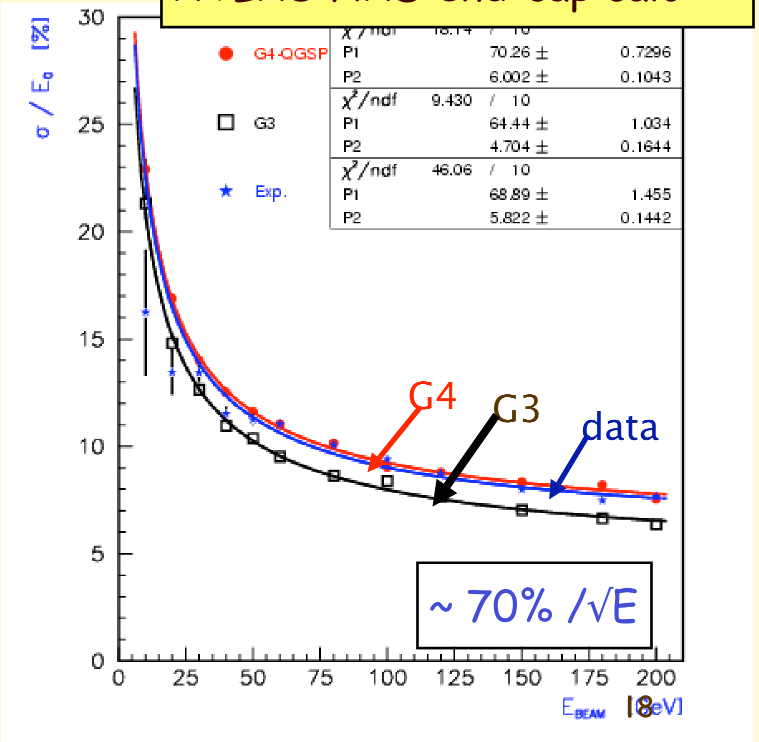
Ultimate statistical precision achievable after few days of operation. Then face systematics ....
E.g. : tracker alignment : 100 μm (1 month) → 20μm (4 months) → 5 μm (1 year) ?

Steps to achieve the detector goal performance

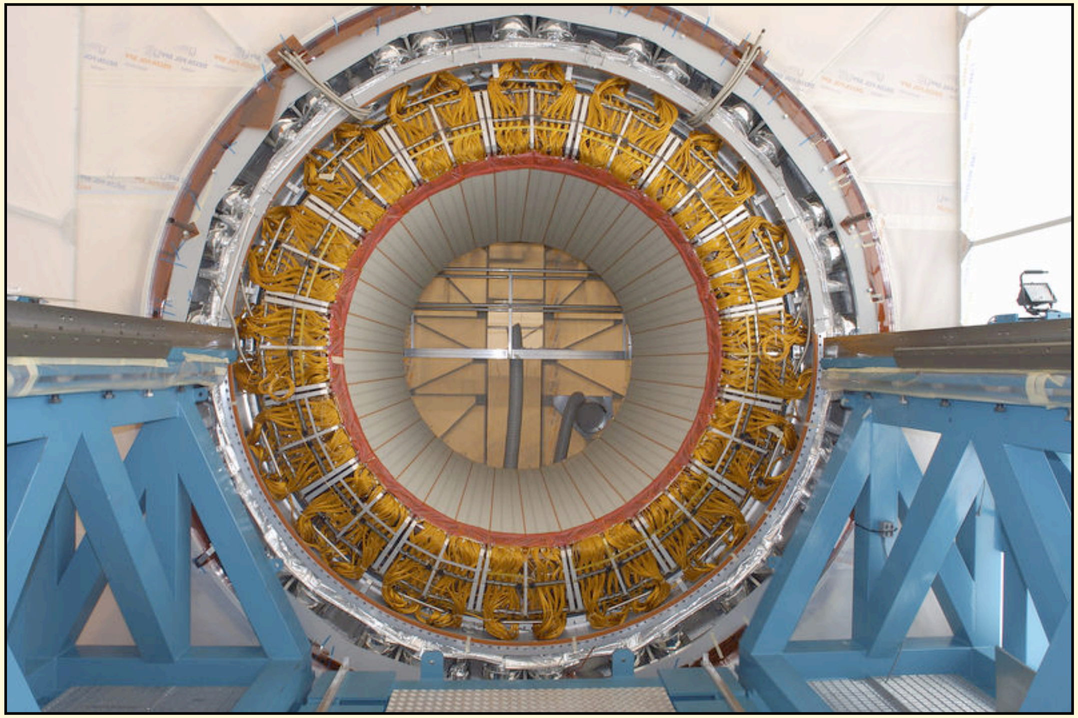
- Stringent construction requirements and quality controls (piece by piece …)
- Equipped with redundant calibration/alignment hardware systems
- Prototypes and part of final modules extensively tested with test beams (allows also validation of Geant4 simulation)
- In situ calibration at the collider (accounts for material, global detector, B-field, long-range mis-calibrations and mis-alignments) includes :
  - -- cosmic runs : end 2006-mid 2007 during machine cool-down
  - -- beam-gas events, beam-halo muons during single-beam period
  - -- calibration with physics samples (e.g. $Z \rightarrow ll$, tt, etc.)



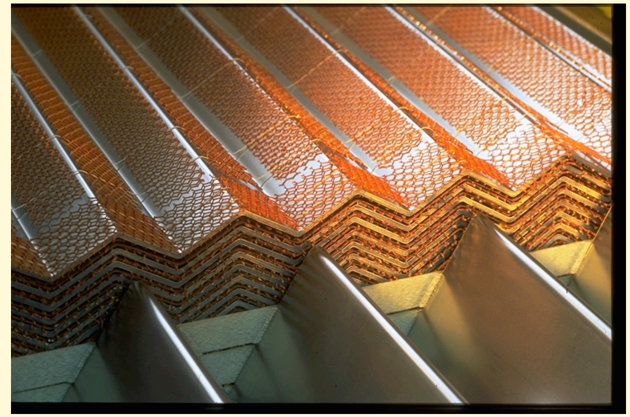
Test-beam π E- resolution
ATLAS HAD end-cap calo



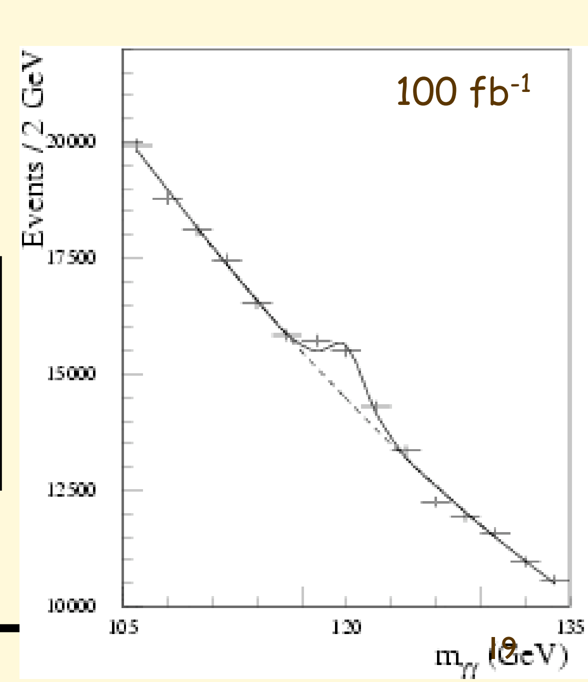
Example of this procedure : ATLAS electromagnetic calorimeter



Pb-liquid argon sampling calorimeter with Accordion shape, covering $|\eta| < 2.5$

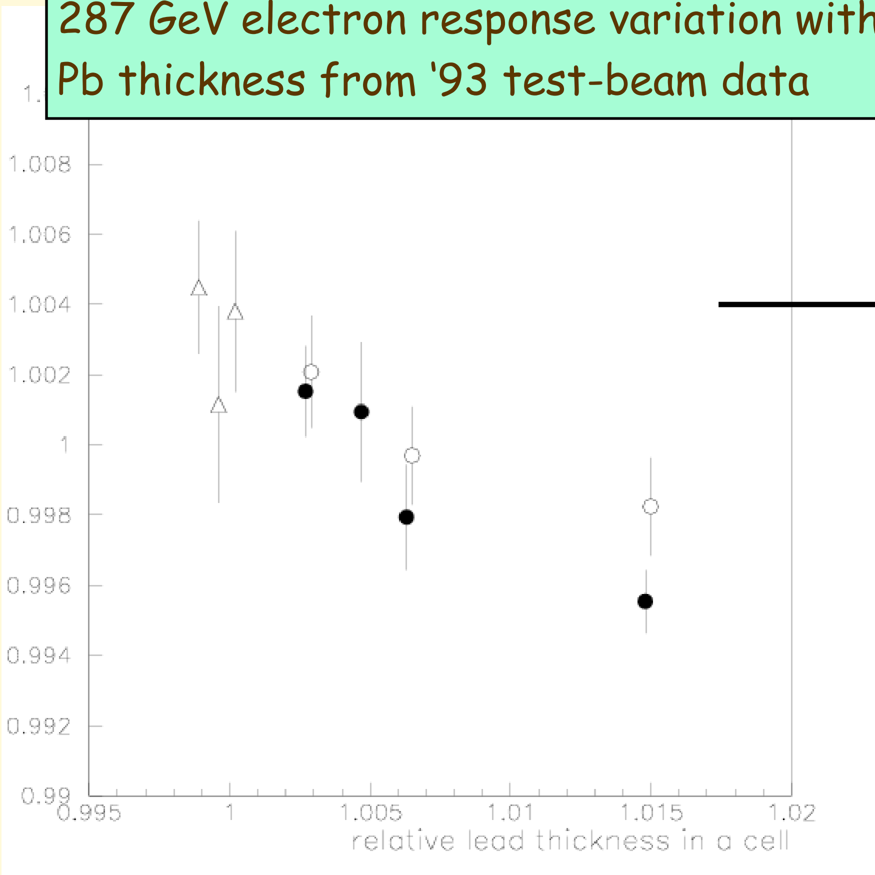


$H \to \gamma\gamma$: to observe signal peak on top of huge $\gamma\gamma$ background need mass resolution of ~ 1% → response uniformity (i.e. total constant term of energy resolution) $\leq 0.7\%$ over $|\eta| < 2.5$



① Construction phase (e.g. mechanical tolerances):

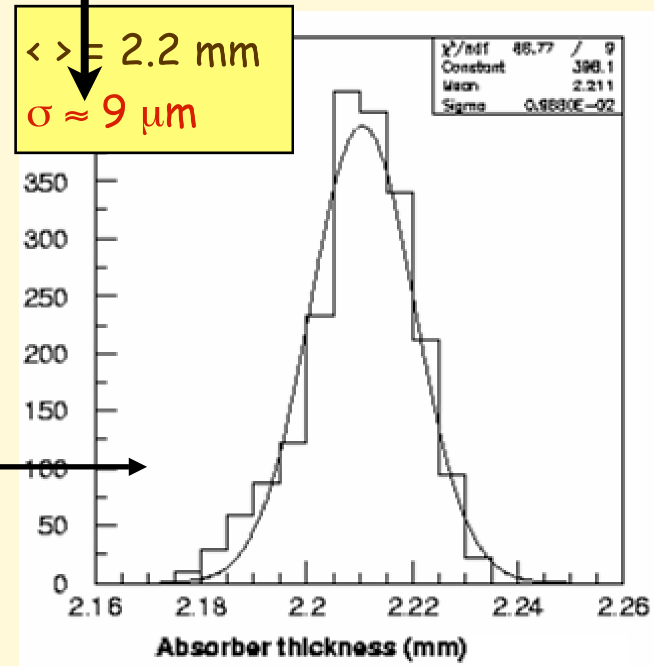
287 GeV electron response variation with Pb thickness from '93 test-beam data



1% more lead in a cell → 0.7% response drop
→ to keep response uniform to 0.2-0.3%, thickness of **Pb plates must be uniform to 0.5% (~ 10 μm)**

OK!

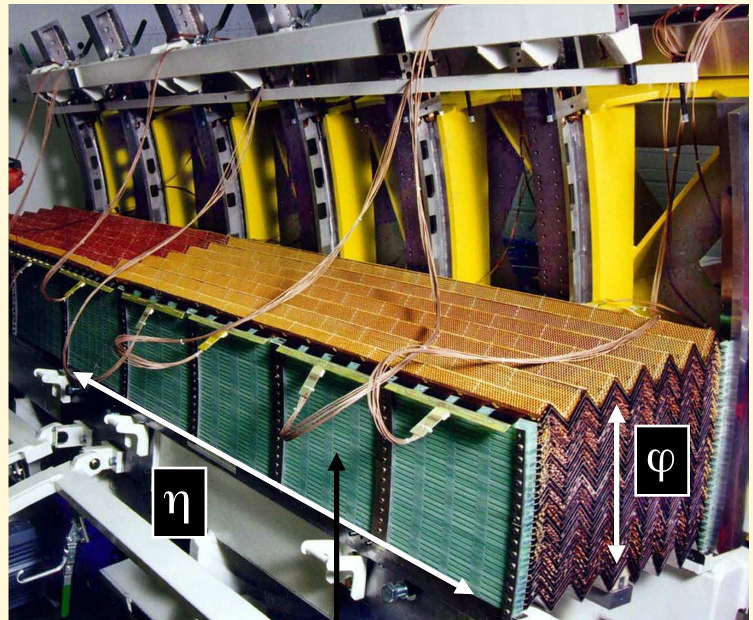
⟨ ⟩ = 2.2 mm
σ ≈ 9 μm



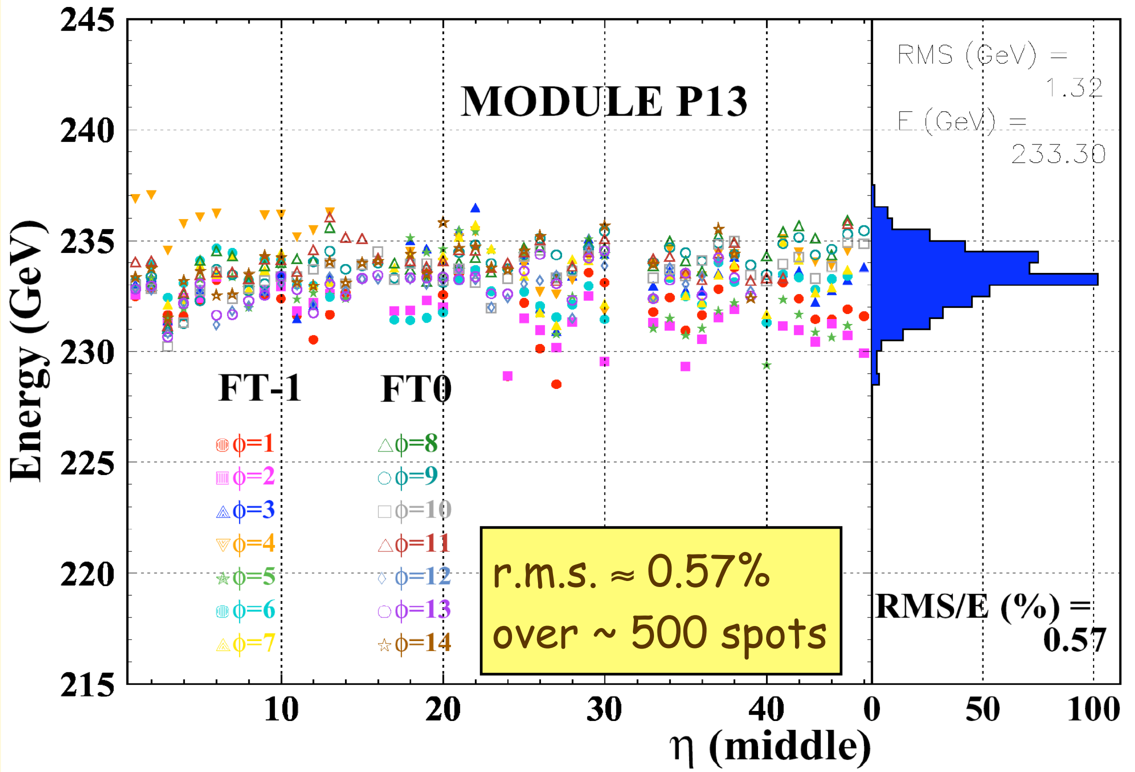
Thickness of all 1536 absorber plates
(1.5m long, 0.5m wide) for Atlas barrel EM calorimeter
measured with ultrasounds during construction

② Beam tests of 4 (out of 32) barrel modules and 3 (out of 16) end-cap modules:

1 barrel module:
$\Delta\eta \times \Delta\varphi$ = 1.4 x 0.4
≡~ 3000 channels

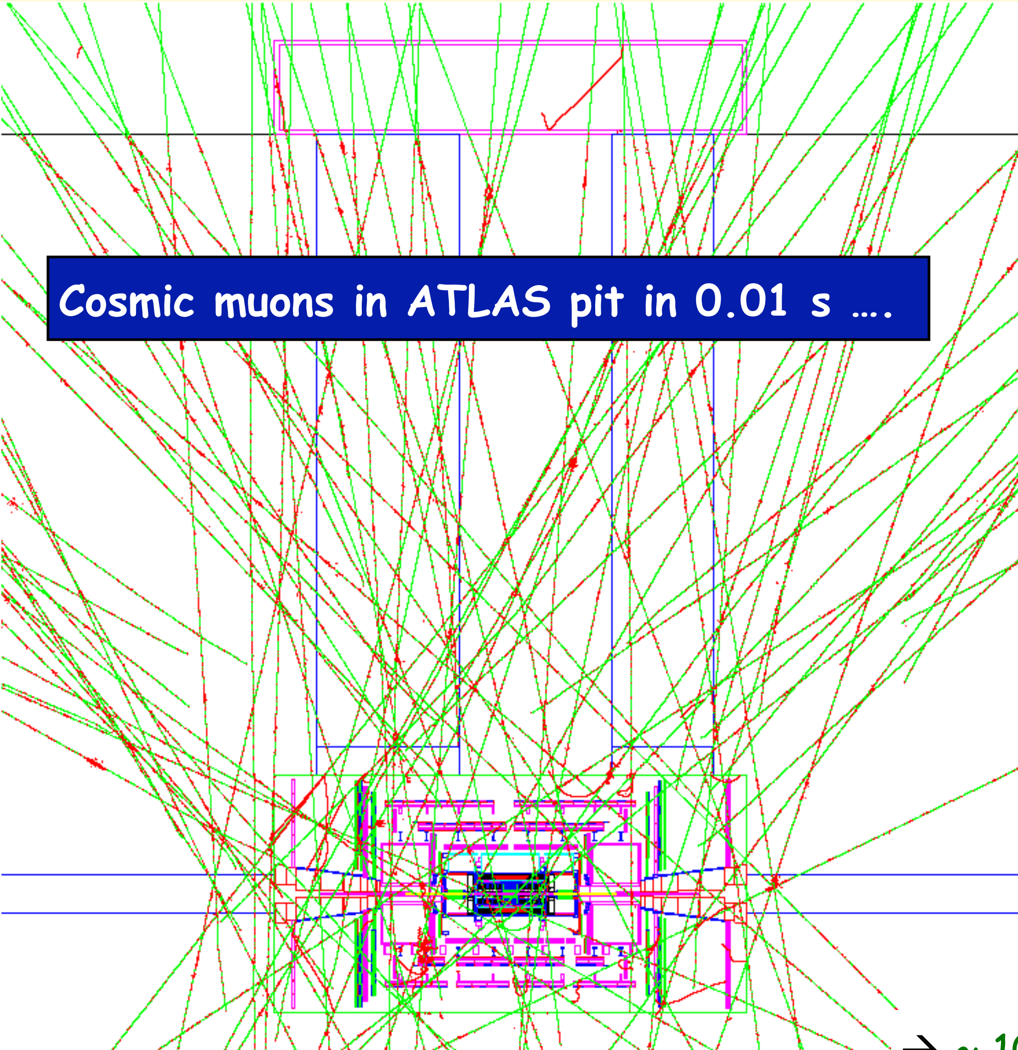


Scan of a barrel module with 245 GeV e^-



Uniformity over "units" of size
$\Delta\eta \times \Delta\varphi$ = 0.2 x 0.4 : ~ 0.5%
400 such units over the full ECAL

③ Check calibration with cosmic muons:



From full simulation of ATLAS (including cavern, overburden, surface buildings) + measurements with scintillators in the cavern:

Through-going muons (hits in ID + top and bottom muon chambers)	~ 25 Hz
Pass by origin (|z| < 60 cm, R < 20 cm, hits in ID)	~ 0.5 Hz
Useful for ECAL calibration (|z| < 30 cm, E_{cell} > 100 MeV, ~ 90^0)	~ 0.5 Hz

→ ~ 10^6 events in ~ 3 months of data taking

→ enough for initial detector shake-down

(catalog problems, gain operation experience, some alignment/calibration, detector synchronization, …)

First collisions : calibration with $Z \rightarrow ee$ events

$c_{tot} = c_L \oplus c_{LR}$

$c_L \approx 0.5\%$ demonstrated at the test-beam over units $\Delta\eta \times \Delta\varphi = 0.2 \times 0.4$

$c_{LR} \equiv$ long-range response non-uniformities from unit to unit (400 total) (module-to-module variations, different upstream material, temperature effects, etc.)

Use $Z \rightarrow ee$ events and Z-mass constraint to correct long-range non-uniformities.

From full simulation : ~ 250 $e^\pm$ / unit needed to achieve $c_{LR} \leq 0.4\%$ → $c_{tot} = 0.5\% \oplus 0.4\% \leq 0.7\%$

~ 10^5 $Z \rightarrow ee$ events (few days of data taking at 10^{33})

Nevertheless, let's consider the worst (unrealistic ?) scenario : no corrections applied

- c_L = 1.3 % measured "on-line" non-uniformity of individual modules → $c_{tot} \approx 2\%$
- c_{LR} = 1.5 % no calibration with $Z \rightarrow ee$

conservative : implies very poor knowledge of upstream material (to factor ~2)

$H \rightarrow \gamma\gamma$ significance m_H ~ 115 GeV degraded by ~ 30%

→ need 70% more L for discovery

How well will we know LHC physics on day one (before data taking starts) ?

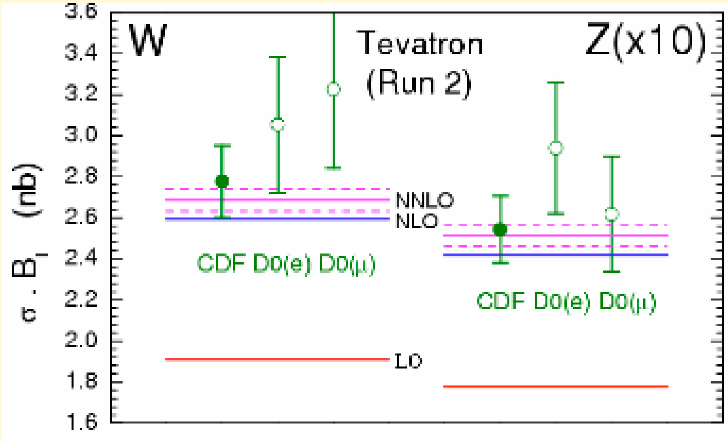
* DY processes

* top X-sections

* bottom X-sections

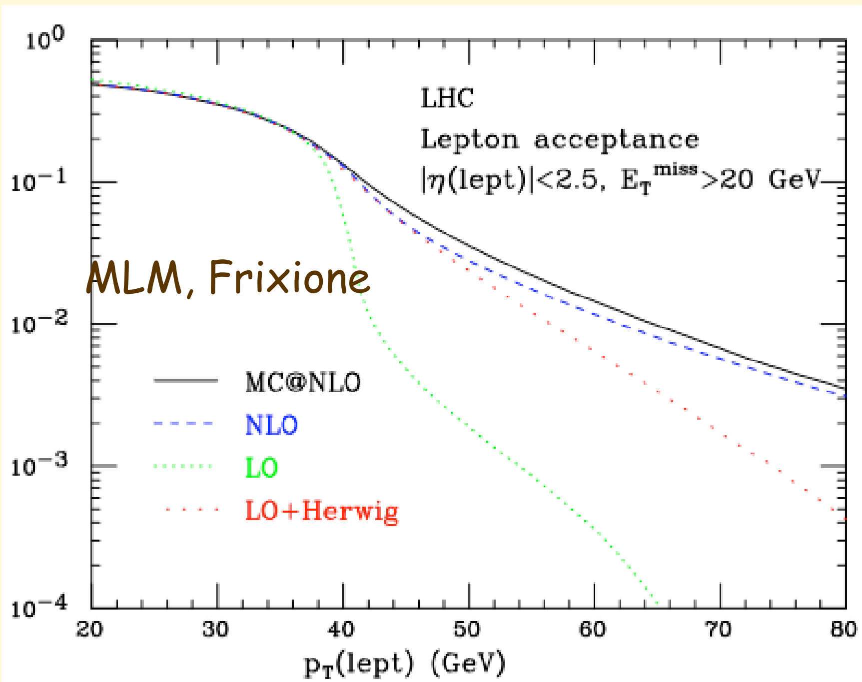
* jet X-sections

W/Z cross-sections



- Test of QCD to NNLO: potential accuracy ~ 2% on σ_{tot}
- Luminosity monitor
- Probe of PDF's

=> In view of incomplete detector coverage, need to ensure that the potential NNLO accuracy is reflected in the calculation of acceptancies. The realization of a QCD NNLO event generator, however, will still take few years. Is it required?



Cuts A → $|\eta^{(e)}| < 2.5$, $p_T^{(e)} > 20$ GeV, $p_T^{(\nu)} > 20$ GeV

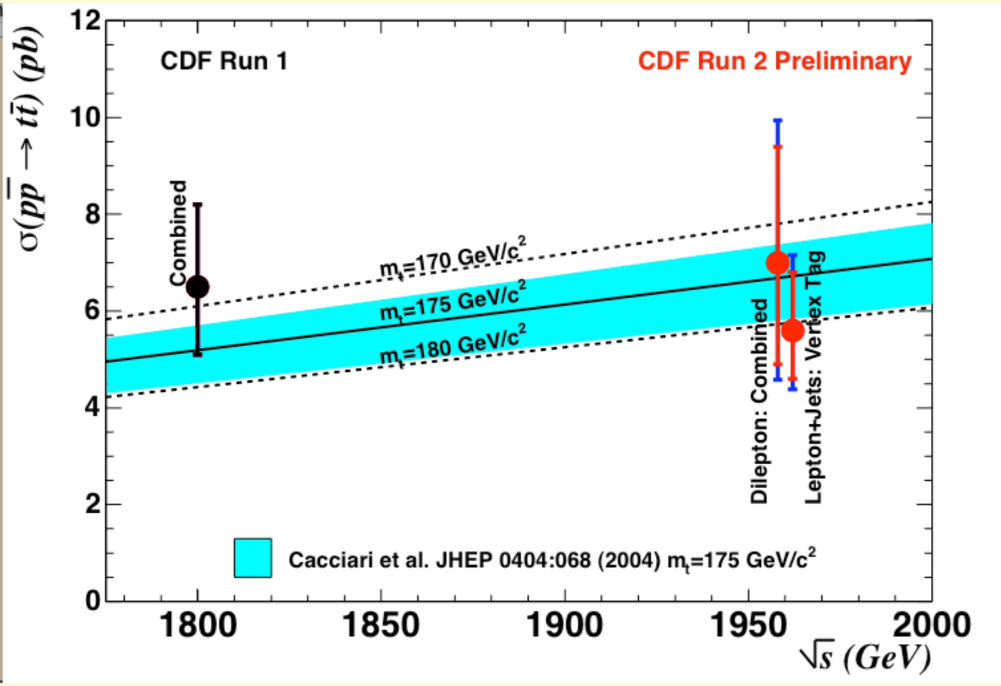
Cuts B → $|\eta^{(e)}| < 2.5$, $p_T^{(e)} > 40$ GeV, $p_T^{(\nu)} > 20$ GeV

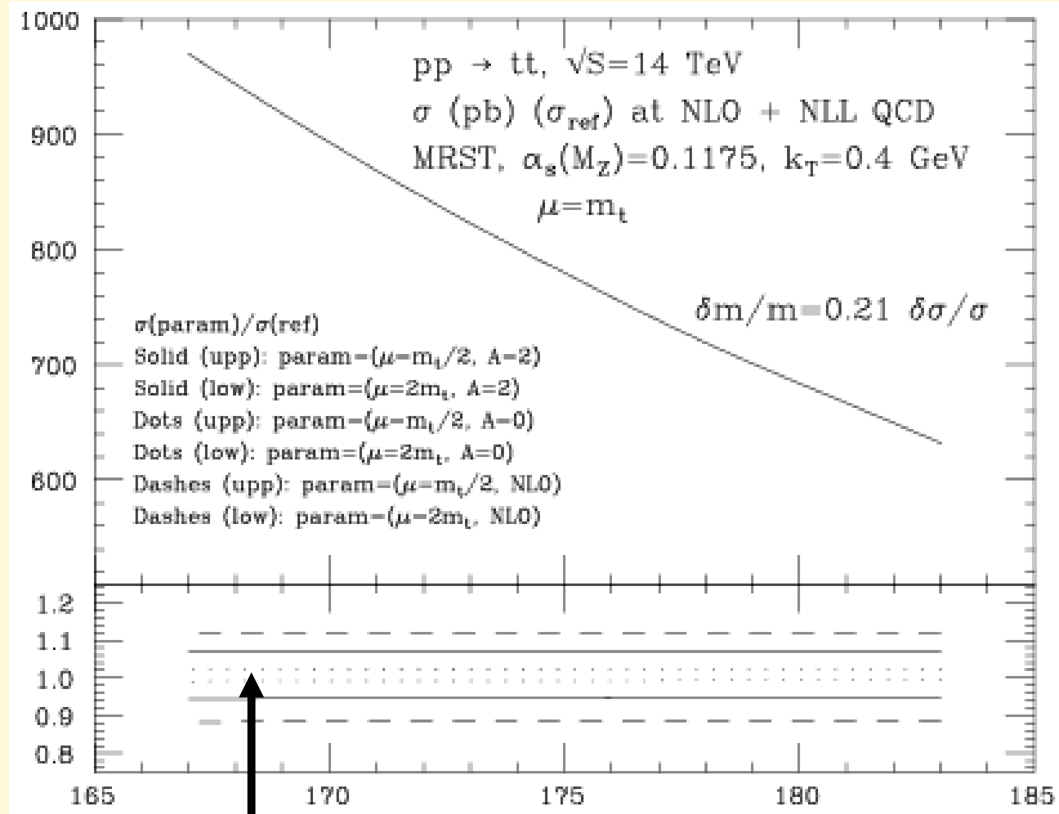
	LO		LO+HW	NLO		MC@NLO
Cuts A	0.5249	−7.7% →	0.4843	0.4771	+1.5% →	0.4845
	↓5.4%			↓7.0%		↓6.3%
Cuts A, no spin	0.5535			0.5104		0.5151
Cuts B	0.0585	+208% →	0.1218	0.1292	+2.9% →	0.1329
	↓29%			↓16%		↓18%
Cuts B, no spin	0.0752			0.1504		0.1570

Theory OK to 2% + 2%(PDF)

Similar accuracy for high-mass DY (bg, as well as signal, for massive Z'/W')

tt cross-section





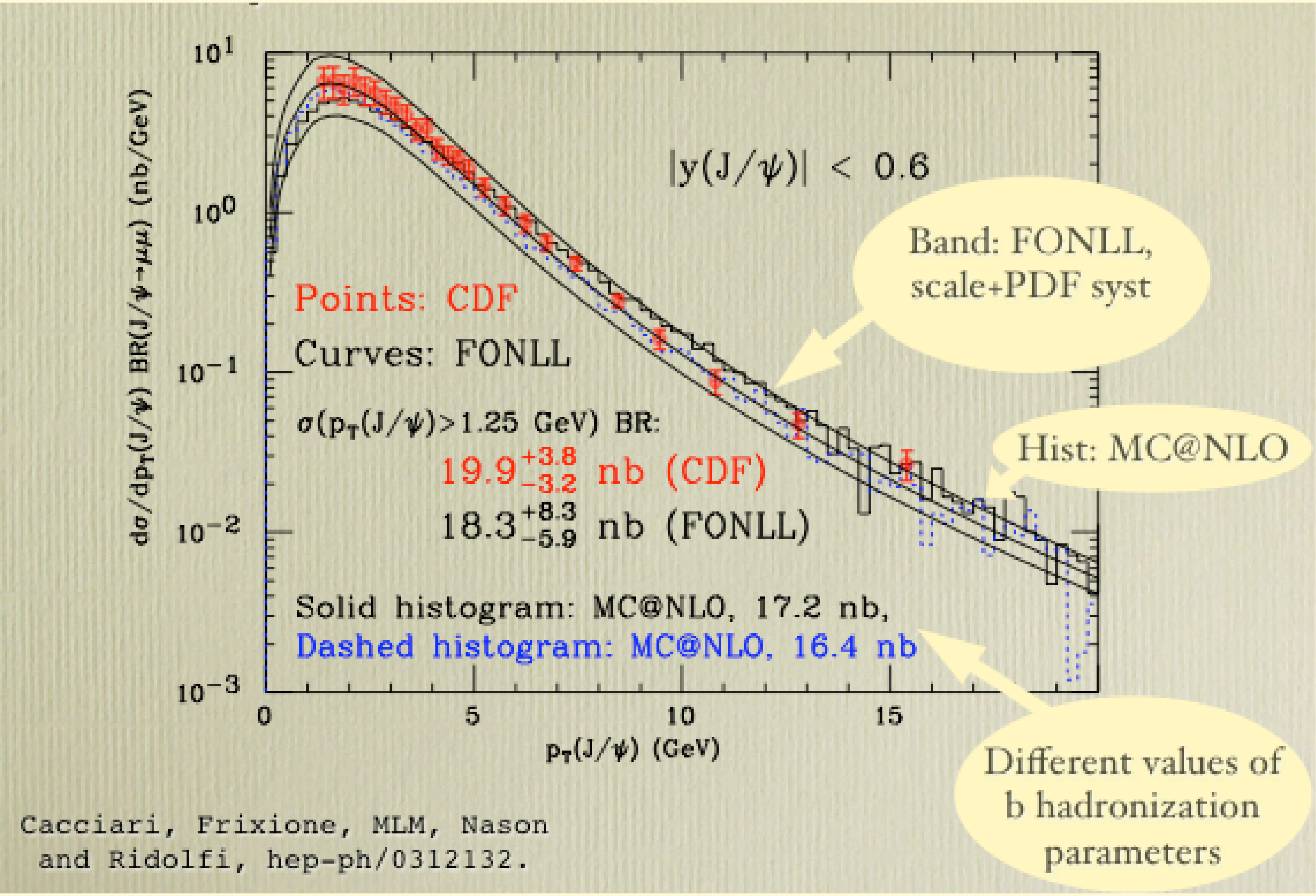
Scale unc: ± $12\%_{NLO}$ => ± $5\%_{NLO+NLL}$)

$\sigma_{tt}^{FNAL} = 6.5\text{pb}\ (1 \pm 5\%_{scale} \pm 7\%_{PDF})$

$\sigma_{tt}^{LHC} = 840\text{pb}\ (1 \pm 5\%_{scale} \pm 3\%_{PDF})$

$\Delta\sigma = \pm 6\%$ => $\Delta m = \pm 2$ GeV

bb cross-sections



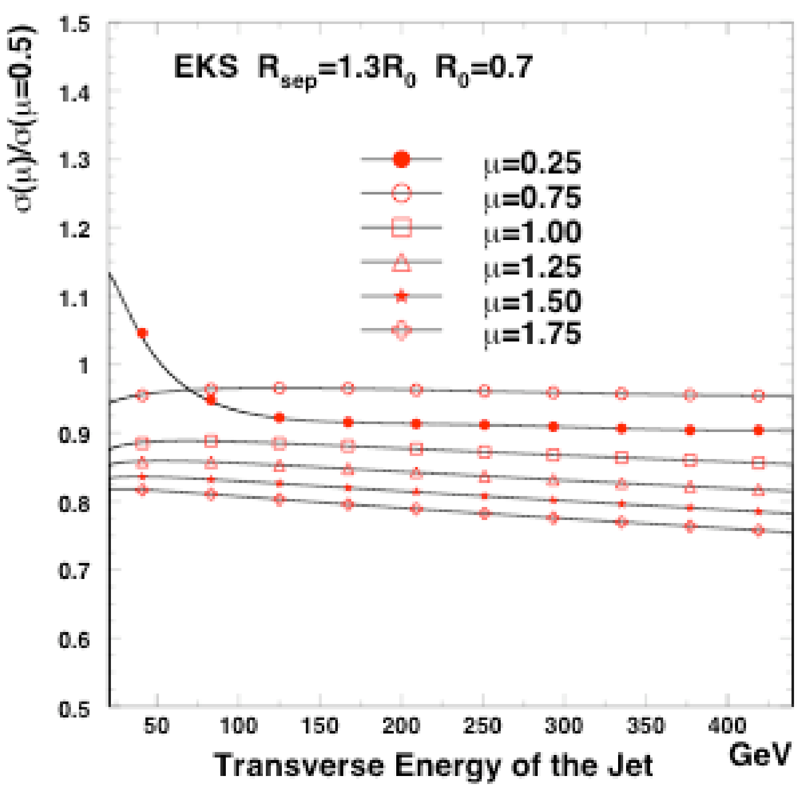
OK, but theoretical systematics still large:

+-35% at low pt
+-20% for pt>>mb

In view of the recent run II results from CDF, more validation required.

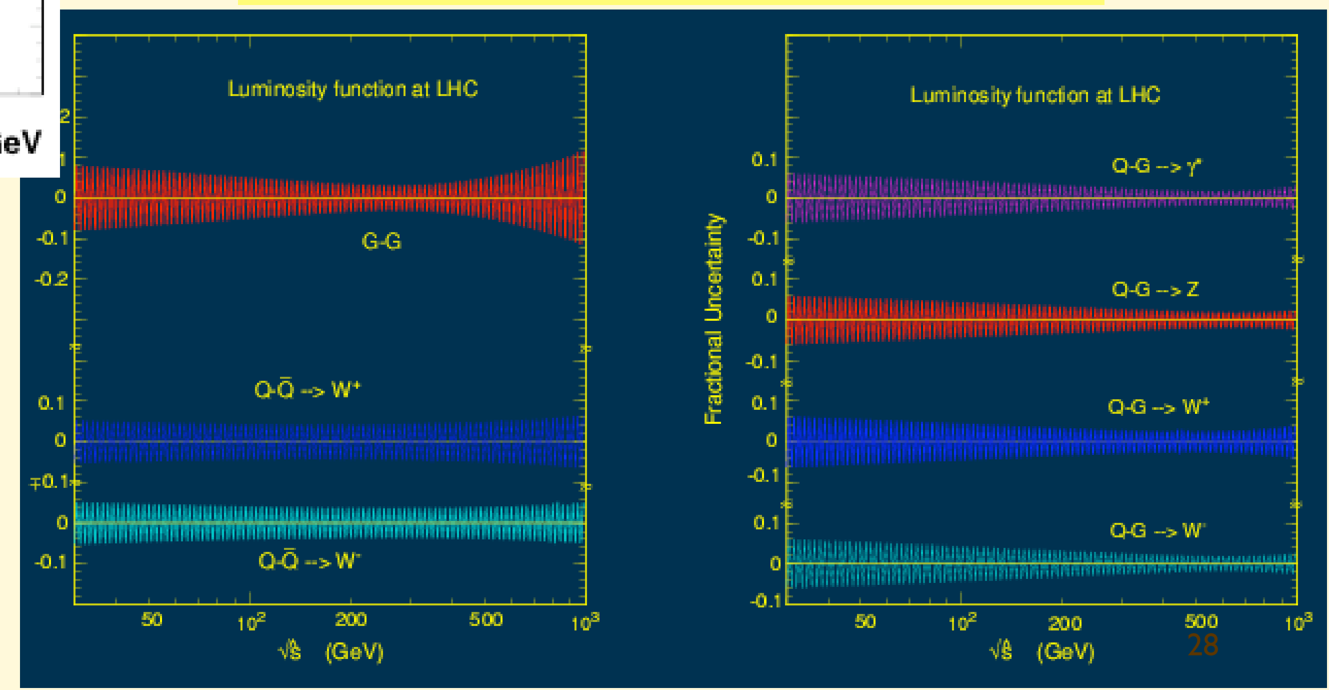
To verify the better predictivity at large pt, need to perform measurements in the region 30-80 geV, and above (also useful to study properties of high-Et b jets, useful for other physics studies)

Jet cross-sections



Theoretical syst uncertainty at NLO ~ +-20%

PDF uncert (mostly g(x)) growing at large x



Main sources of syst uncertainties (CDF, run I)

At high E_T the syst is dominated by the response to high p_T hadrons (beyond the test beam p_T range) and fragmentation uncertanties

Out to which E_T will the systematics allow precise cross-section measurements at the LHC?

Out to which E_T can we probe the jet structure (multiplicity, fragm function)?

NB: stat for Z+jet or gamma+jet runs out before ET~500 GeV

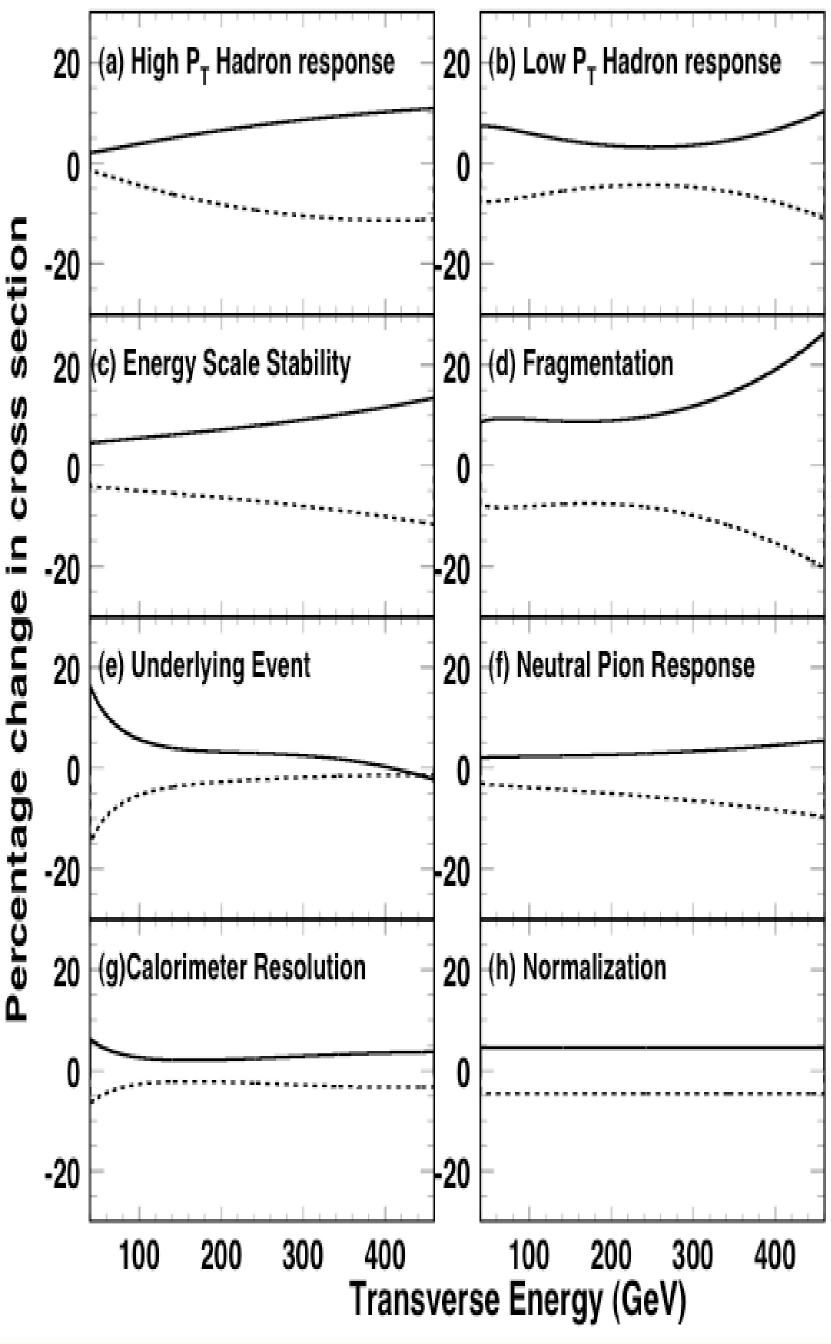


Table 8: Rates for $L_{int} = 10\,fb^{-1}$ for different intervals of P_t^Z and η^Z ($P_{tCUT}^{clust} = 10\,GeV/c$, $P_{tCUT}^{out} = 10\,GeV/c$ and $\Delta\phi \leq 15°$).

Z+jet

P_t^Z (GeV/c)	$\lvert\Delta\eta^Z\rvert$ intervals 0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-5.0	all $\lvert\eta^Z\rvert$ 0.0-5.0
40 – 50	4594	5425	6673	7267	6732	4796	35486
50 – 60	3128	3509	4297	4570	3976	2000	21471
60 – 70	2253	2443	2855	2934	2229	851	13567
70 – 80	1580	1734	1948	1786	1307	341	8692
80 – 90	1152	1148	1267	1236	824	170	5790
90 –100	741	859	812	808	523	59	3802
100 –110	582	590	594	546	305	36	2657
110 –120	384	428	451	412	226	8	1905
120 –140	523	582	562	531	293	12	2503
140 –170	392	380	368	341	190	4	1675
170 –200	170	186	162	170	63	2	756
200 –240	111	103	99	91	40	0	444
240 –300	71	51	44	48	20	0	238

s ($P_{tCUT}^{clust} = 5\,GeV/c$ and $\Delta\phi \leq 15°$).

gamma+jet

P_t^γ (GeV/c)	η^γ intervals 0.0-0.4	0.4-0.7	0.7-1.1	1.1-1.5	1.5-1.9	1.9-2.2	2.2-2.6	all η^γ 0.0-2.6
40 – 50	102656	107148	100668	103903	103499	116674	126546	761027
50 – 60	43905	41729	41074	45085	42974	47640	50310	312697
60 – 70	18153	18326	19190	20435	20816	19432	23650	140005
70 – 80	9848	10211	9963	10166	9951	11397	10447	71984
80 – 90	5287	5921	5104	5823	5385	6067	5923	39509
90 – 100	2899	3033	3033	3326	3119	3265	3558	22234
100 – 120	2908	3091	2995	3305	3133	3282	3429	22143
120 – 140	1336	1359	1189	1346	1326	1499	1471	9525
140 – 160	624	643	626	674	706	614	668	4555
160 – 200	561	469	557	555	519	555	557	3774
200 – 240	187	176	186	192	187	185	151	1264
240 – 300	103	98	98	98	100	92	74	665
300 – 360	34	34	33	32	31	27	20	212
40 – 360	188517	192274	184734	194957	191761	210742	226819	1389484

Physics goals and potential in the first year
(a few examples ....)

Channels (examples ...)	Events to tape for 1 fb^{-1}
$W \rightarrow \mu\nu$	7×10^6
$Z \rightarrow \mu\mu$	1.1×10^6
$tt \rightarrow WbWb \rightarrow \mu\nu + X$	8×10^4
QCD jets $p_T>150$	$\sim 10^6$
Minimum bias	$\sim 10^6$
$\tilde{g}\tilde{g}$ m = 1 TeV	$10^2 - 10^3$

~ few PB of data per year per experiment → challenging for software and computing (esp. at the beginning ...)

assuming 1% of trigger bandwidth

➡ Already in first year, large statistics expected from:
- -- known SM processes → understand detector and physics at $\sqrt{s}$ = 14 TeV
- -- several New Physics scenarios

Note: overall event statistics limited by ~ 100 Hz rate-to-storage
~ 10^7 events to tape every 3 days assuming 30% data taking efficiency

Goal # 1

Understand and calibrate detector and trigger <u>in situ using well-known physics samples</u>

e.g. - $Z \rightarrow ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.

- $tt \rightarrow bl\nu\ bjj$ 10^3 evts/day after cuts → jet scale from W→jj, b-tag perf., etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV → first checks of Monte Carlos (hopefully well understood at Tevatron and HERA)

e.g. - measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~ 10-20 %), look at basic event features, first constraints of PDFs, etc.

- measure top mass (to 5-7 GeV) → give feedback on detector performance

Note : statistical error negligible after few weeks run

Goal # 2

Prepare the road to discovery:

-- measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent …)

-- look at specific "control samples" for the individual channels:

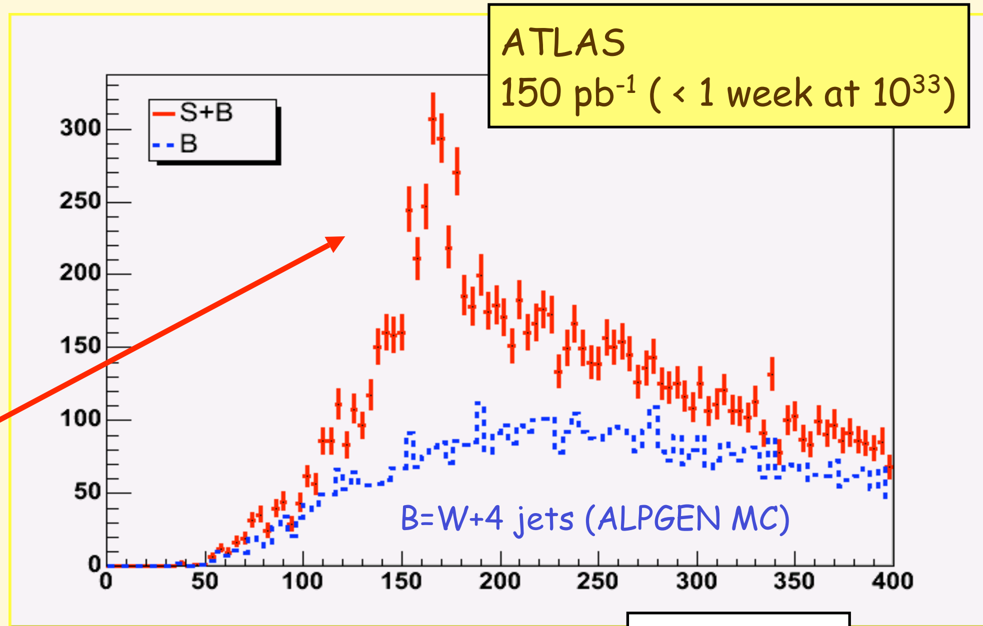
e.g. ttjj with $j \neq b$ "calibrates" ttbb irreducible background to ttH → ttbb

Goal # 3

Look for New Physics potentially accessible in first year (e.g. Z', SUSY, some Higgs ? …)

Example of initial measurement : top signal and top mass

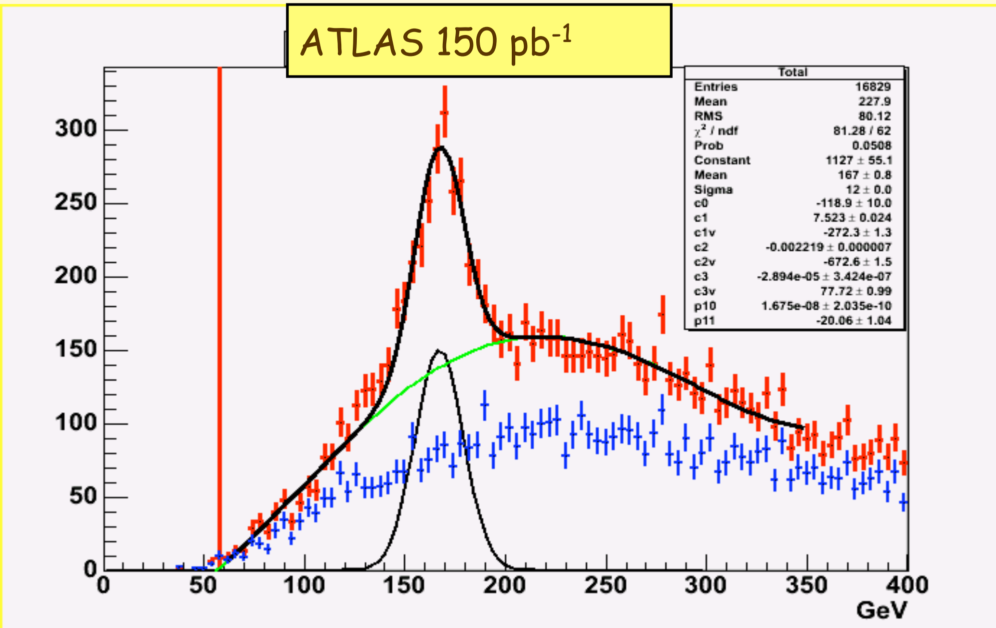
- Use gold-plated tt → bW bW → blν bjj channel
- Very simple selection:
  - -- isolated lepton (e, μ) p_T > 20 GeV
  - -- exactly 4 jets p_T > 40 GeV
  - -- no kinematic fit
  - -- no b-tagging required (pessimistic, assumes trackers not yet understood)
- Plot invariant mass of 3 jets with highest p_T

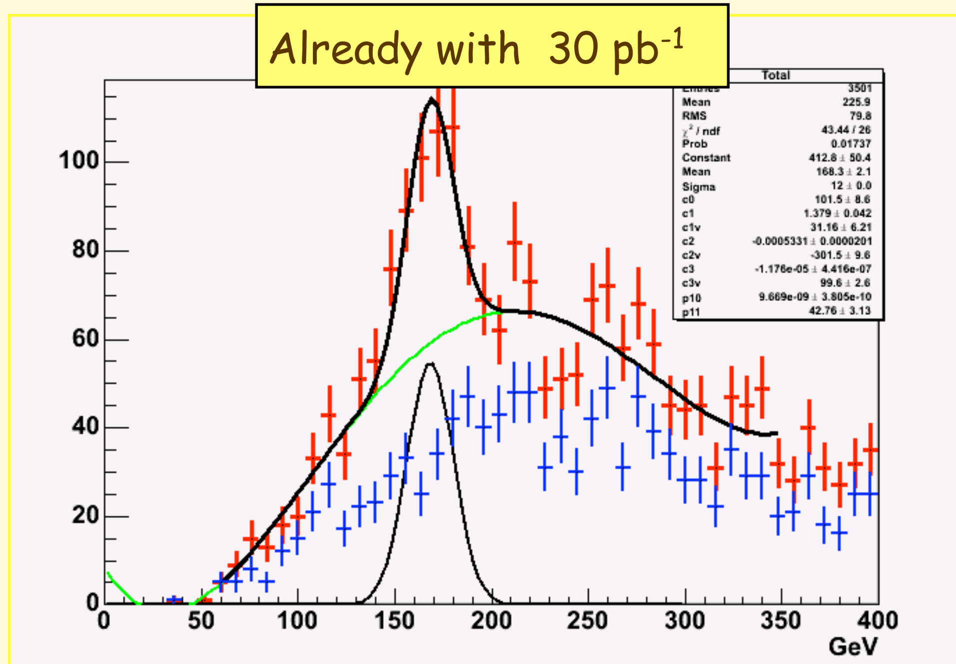


Time	Events at 10^{33}	Stat. error δM_{top} (GeV)	$[\delta\sigma/\sigma]$stat
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%

- top signal visible in few days also with simple selections and no b-tagging
- cross-section to ~ 20% (10% from luminosity)
- top mass to ~7 GeV (assuming b-jet scale to 10%)
- get feedback on detector performance :
  - -- m_{top} wrong → jet scale ?
  - -- gold-plated sample to commission b-tagging

Fit signal and background (top width fixed to 12 GeV) → extract cross-section and mass



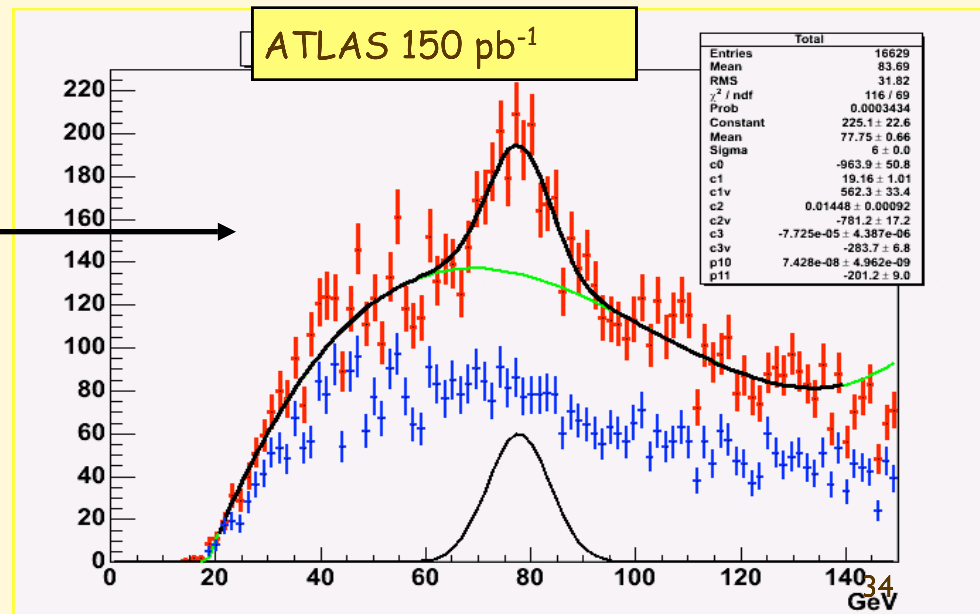


Can we see a W → jj peak ?

Select the 2 jets with highest p_T

(better ideas well possible …)

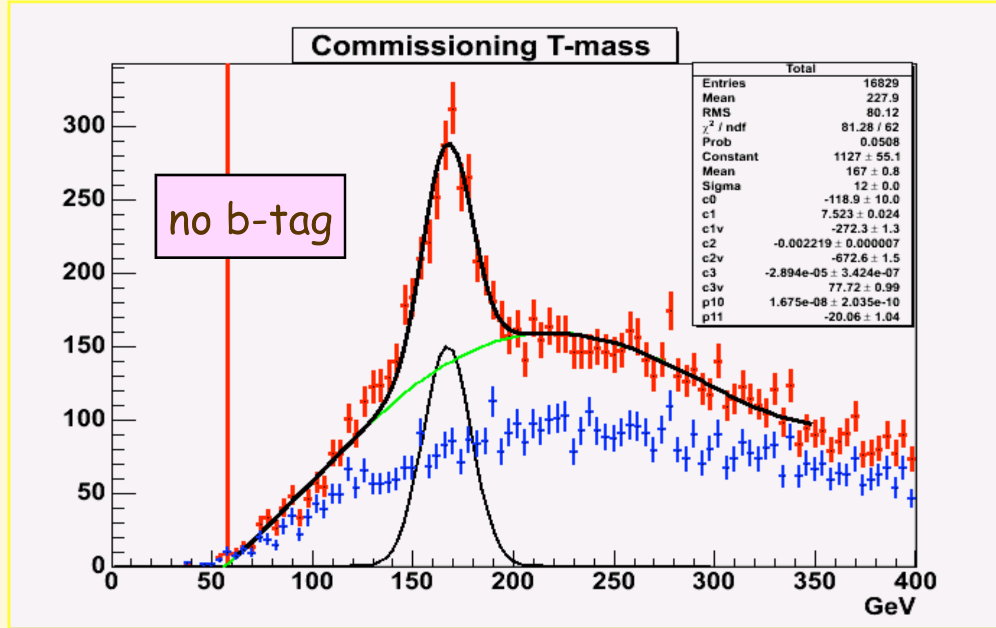
W peak visible in signal, no peak in background

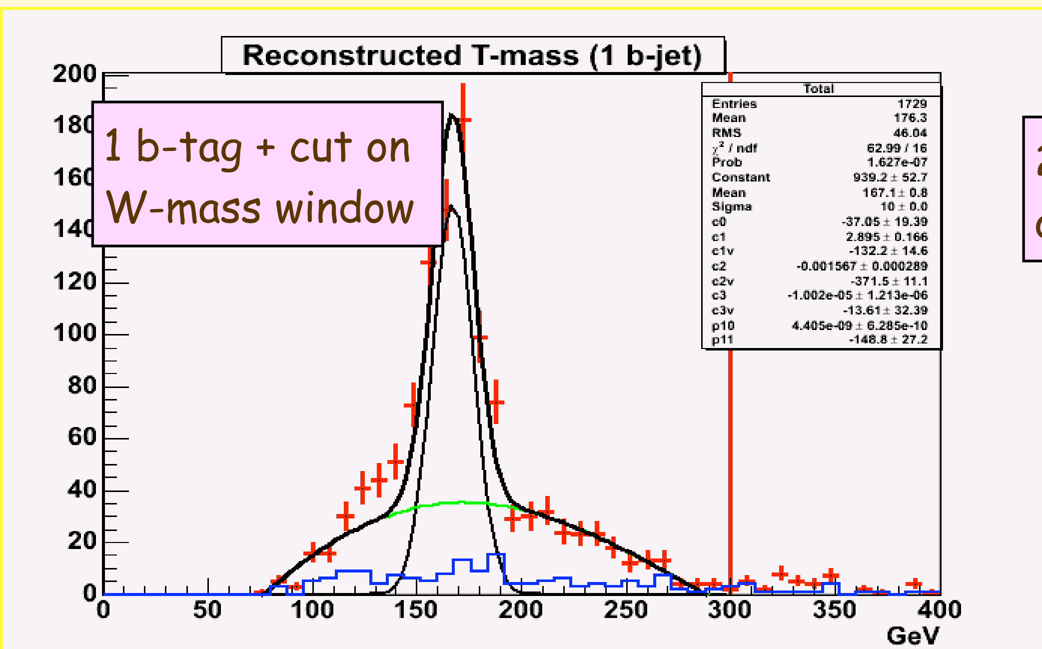


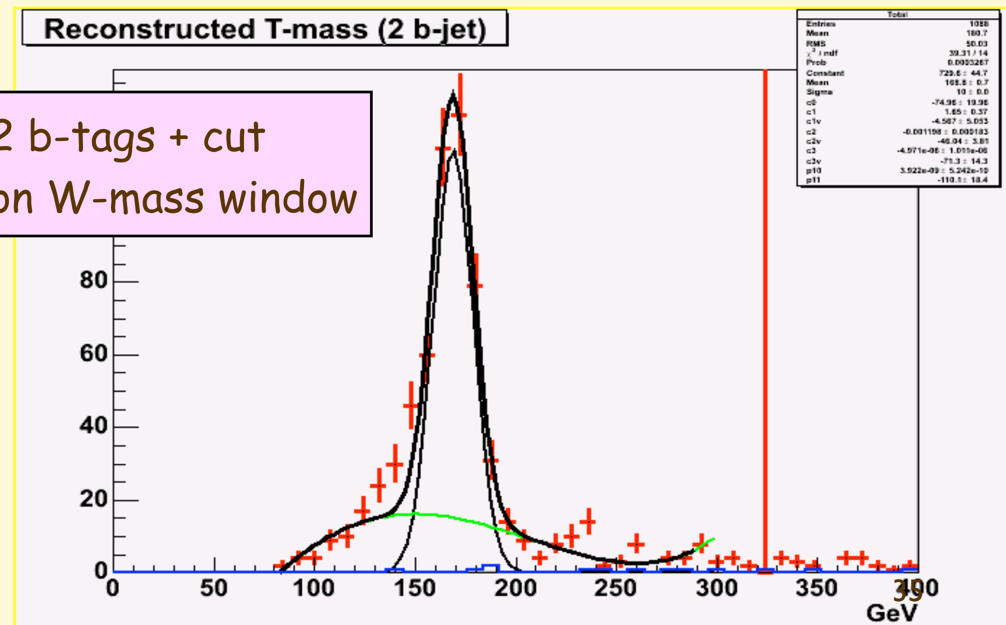
Introduce b-tagging ….

ATLAS 150 pb^{-1}

Bkgd composition changes: combinatorial from top itself becomes more and more important







Examples of possible early discoveries

- An easy case : a new resonance decaying into e+e-, e.g. a Z ' → ee of mass 1-2 TeV
- An intermediate case : SUSY
- A more difficult case : a light Higgs (m ~ 115 GeV)

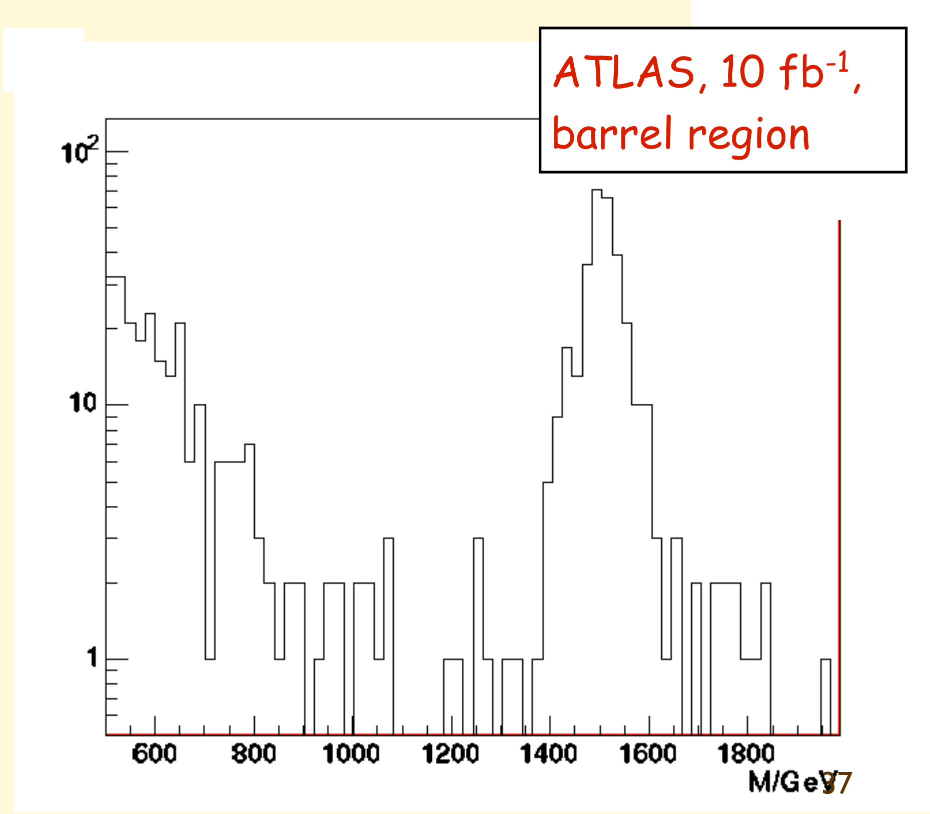
An "easy case" : Z' of mass 1-2 TeV with SM-like couplings

$Z' \to ee$, SSM

Mass	Expected events for 10 fb^{-1} (after all cuts)	$\int L\,dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 1600	~ 70 pb^{-1}
1.5 TeV	~ 300	~ 300 pb^{-1}
2 TeV	~ 70	~ 1.5 fb^{-1}

- signal rate with $\int L\,dt \sim$ 0.1-1 fb^{-1} large enough up to $m \approx$ 2 TeV if "reasonable" Z'ee couplings
- dominant Drell-Yan background small (< 15 events in the region 1400-1600 GeV, 10 fb^{-1})
- signal as <u>mass peak</u> on top of background

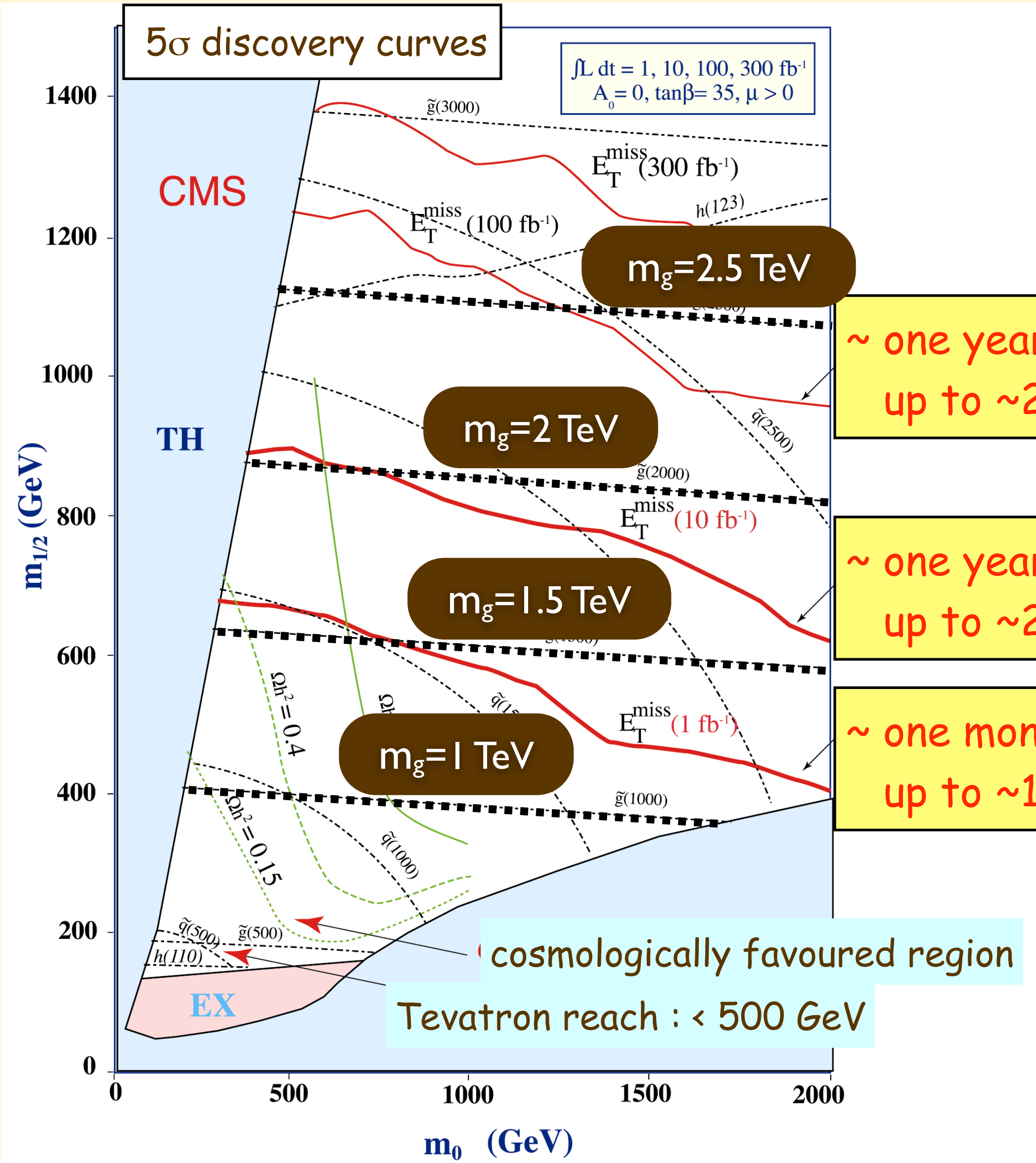
Z → ll +jet samples and DY needed for E-calibration and determination of lepton efficiency



An intermediate case : SUPERSYMMETRY

Large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section → ≈ 100 events/day at 10^{33} for $m(\tilde{q}, \tilde{g}) \sim 1$ TeV

Spectacular signatures → SUSY could be found quickly

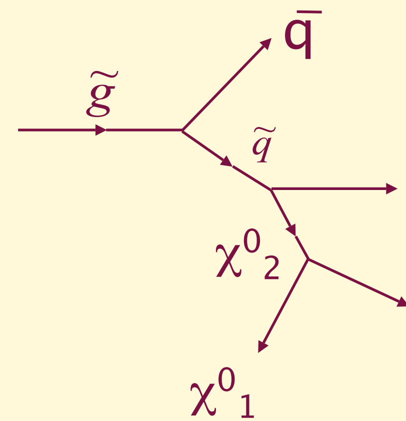


~ one year at 10^{34}: up to ~2.5 TeV

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

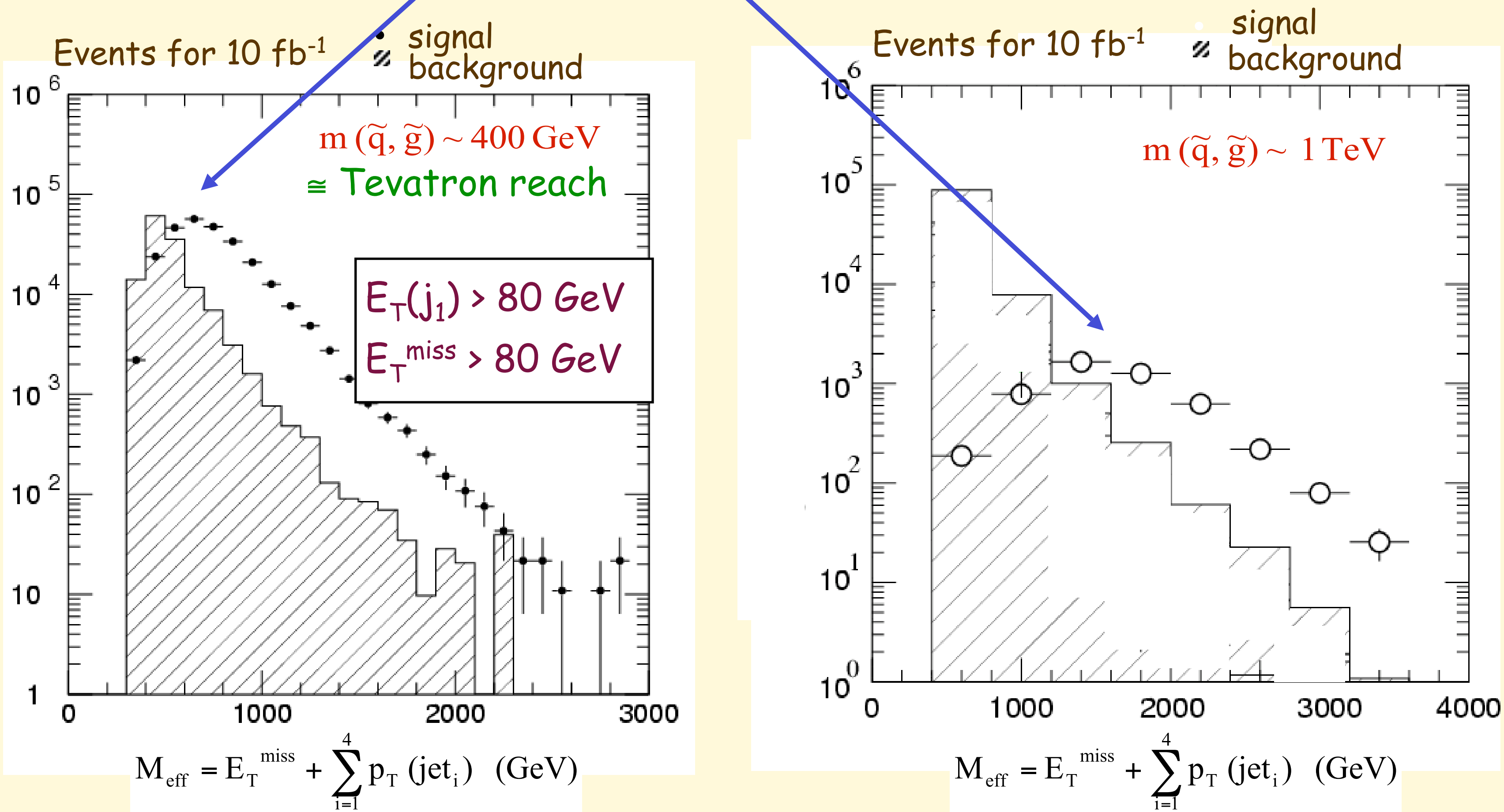
~ one month at 10^{33} : up to ~1.5 TeV

Using multijet + E_T^{miss} (most powerful and model-independent signature if R-parity conserved)



Measurement of sparticle masses likely requires > $10fb^{-1}$ year. However …

Peak position correlated to M_{SUSY} ≡ $\min(m(\tilde{q}), m(\tilde{g}))$



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

ATLAS

From M_{eff} peak → first/fast measurement of SUSY mass scale to ≈ 20% (10 fb^{-1}, mSUGRA)

Detector/performance requirements:

-- quality of E_T^{miss} measurement (calorimeter inter-calibration/linearity, cracks)

→ apply hard cuts against fake MET and use control samples (e.g. Z → ll +jets)

-- "low" Jet / E_T^{miss} trigger thresholds for low masses at overlap with Tevatron region (~400 GeV)

Backgrounds will be estimated using data (control samples) and Monte Carlo:

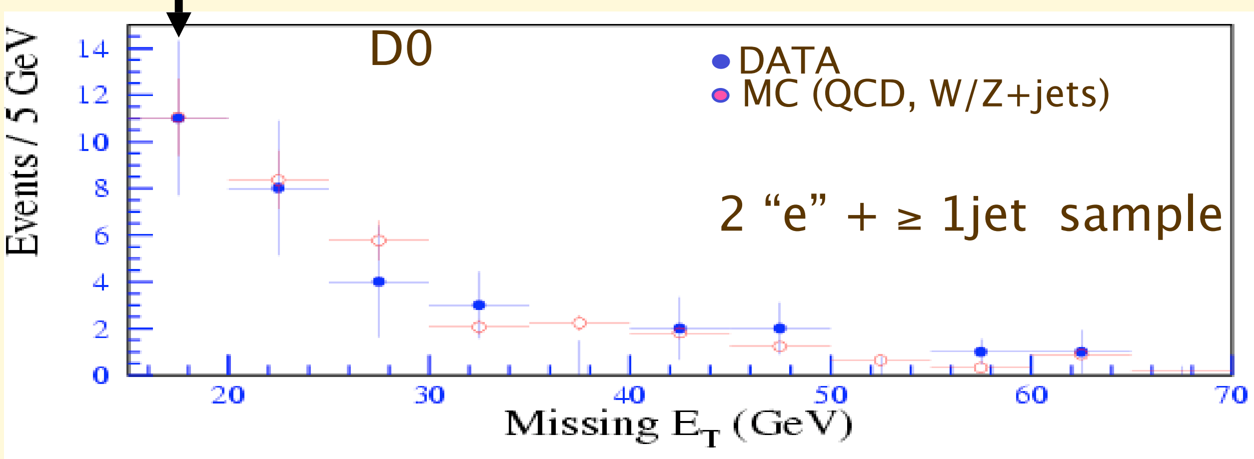
Background process (examples ….)	Control samples (examples ….)
Z (→ νν) + jets	Z (→ ee, μμ) + jets
W (→ τν) + jets	W (→ eν, μν) + jets
tt→ blνbjj	tt→ blν blν
QCD multijets	lower E_T sample

Can estimate background levels also varying selection cuts (e.g. ask 0,1,2,3 leptons …)

A lot of data will most likely be needed !

normalization point

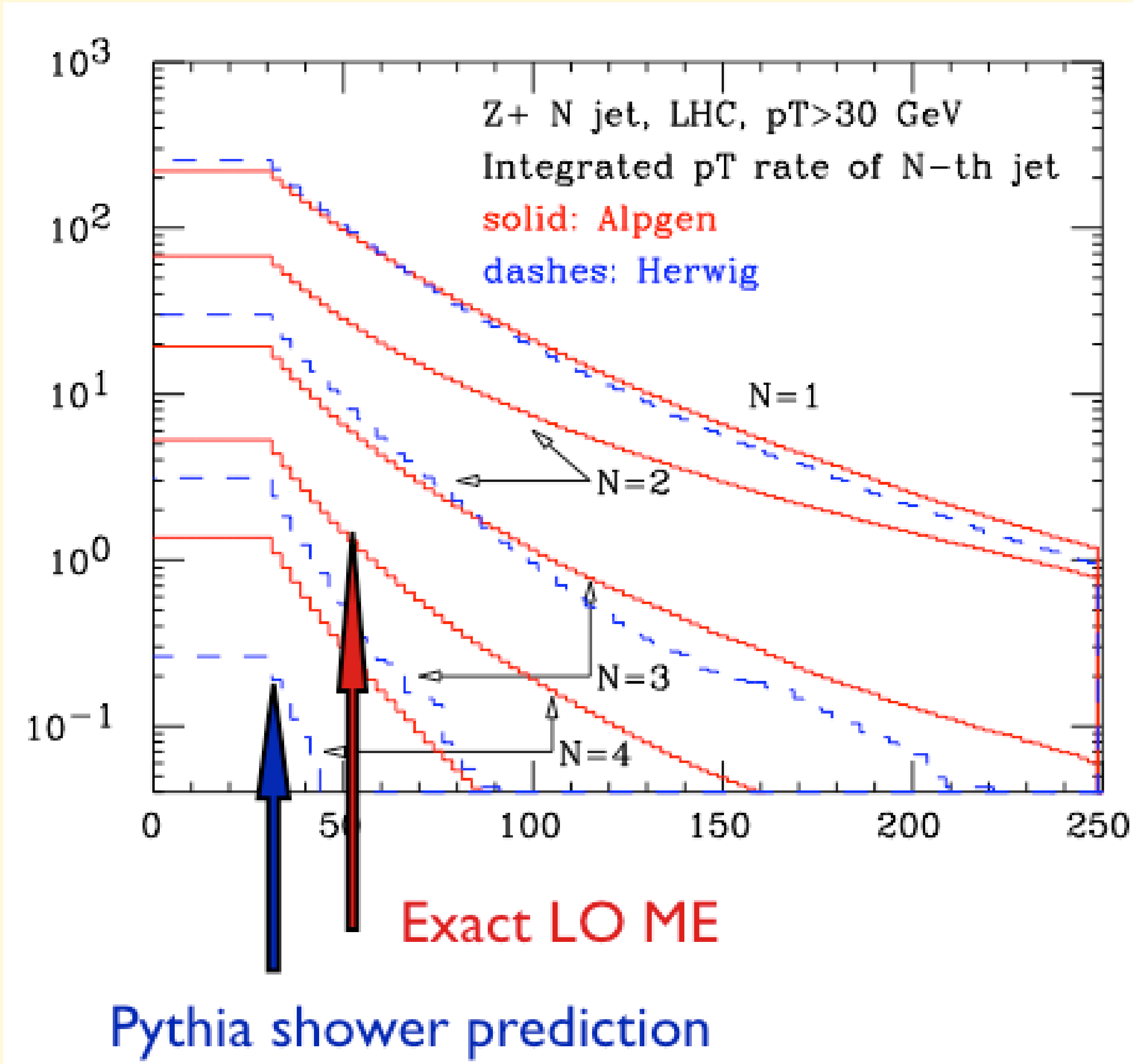
normalise MC to data at low E_T^{miss} and use it to predict background at high E_T^{miss} in "signal" region

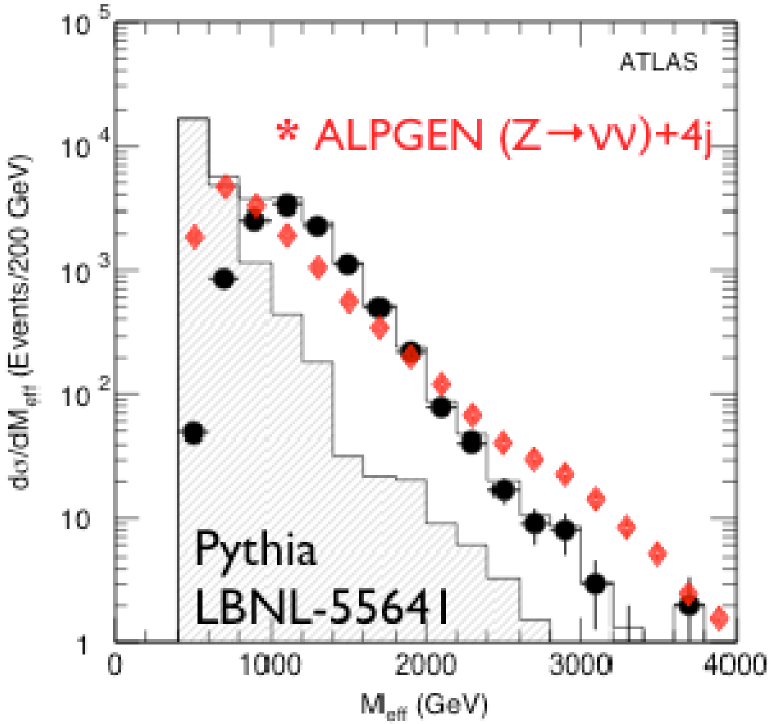


Hard cuts against fake E_T^{miss} :

- reject beam-gas, beam-halo, cosmics
- primary vertex in central region
- reject event with E_T^{miss} vector along a jet or opposite to a jet
- reject events with jets in cracks
- etc. etc.

Can we trust the current estimates of bg rates?





Njet≥4

$E_{T(1,2)}$>100 GeV

$E_{T(3,4)}$>50 GeV

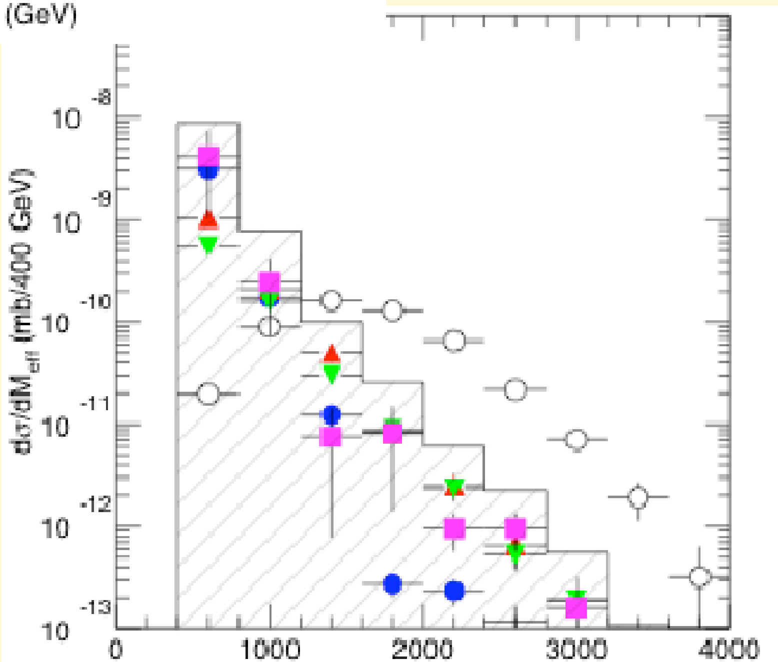
MET>max(100,M_{eff}/4)

M_{eff}=MET+$\sum E_{Tj}$

"Correct" bg shape indistinguishable from signal shape!

Bg breakdown:

- QCD jets
- tt
- Z→νν
- W→lν



Indeed the Z →νν bg appears to be understimated by a factor 10–50! It will dominate the highMET tail, and could be measured in Z→ee+jets

Use Z->ee + multijets, apply same cuts as MET analysis but replace MET with ET(e^+e^-)

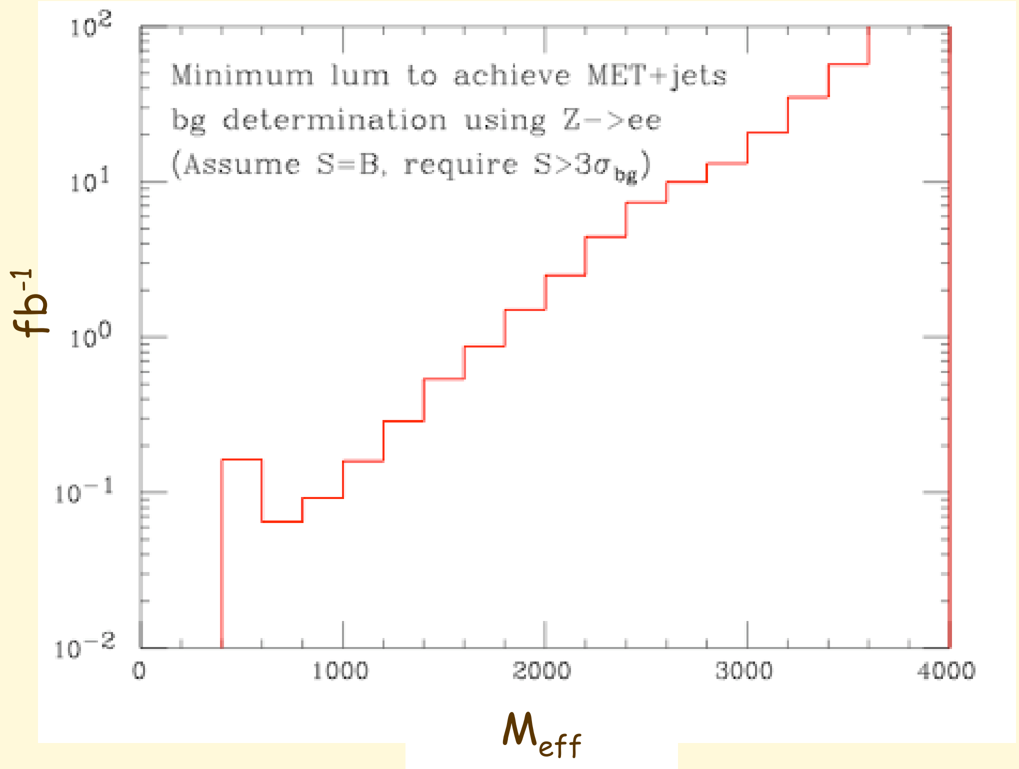
Extract Z->nunu bg using, bin-by-bin:
(Z->nunu) = (Z->ee) B(Z->nunu)/B(Z->ee)

Assume that the SUSY signal is of the same size as the bg, and evaluate the luminosity required to determine the Z->nunu bg with an accuracy such that:

N_{susy} > 3 sigma

where

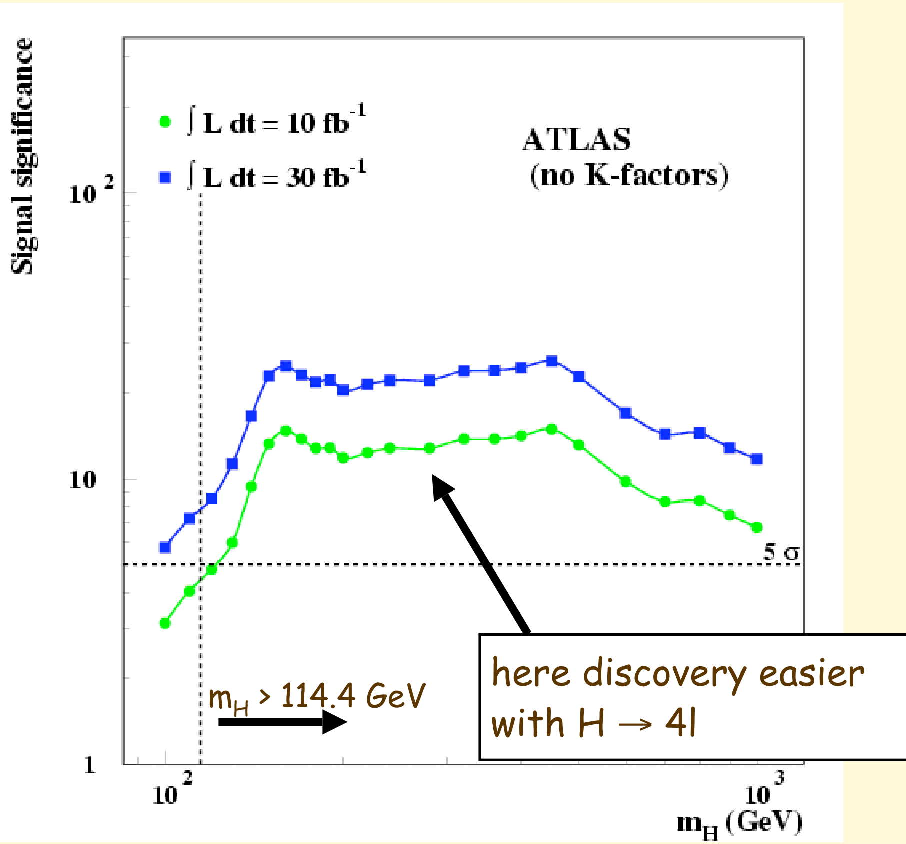
sigma=sqrt[N(Z->ee)] * B(Z->nunu)/B(Z->ee)

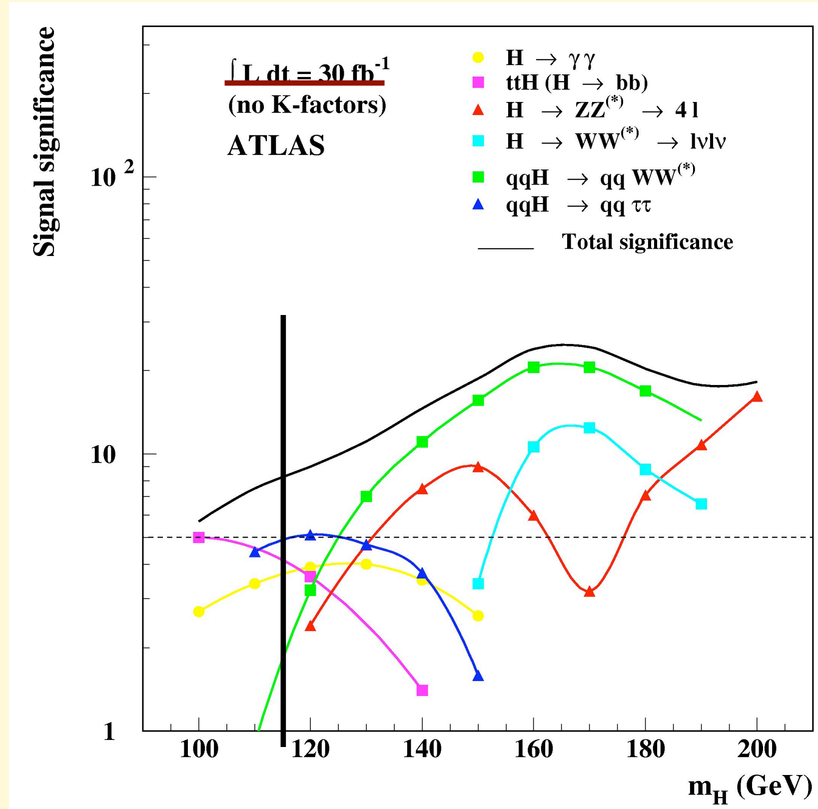


=> several hundred pb^{-1} are required. They are sufficient if we believe in the MC shape (and only need to fix the overall normalization). Much ore is needed if we want to keep the search completely MC independent

How to validate the estimate of the MET from resolution tails in multijet events??

A difficult case: a light Higgs m_H ~ 115 GeV





m_H ~ 115 GeV 10 fb^{-1}

total $S/\sqrt{B} \approx 4^{+2.2}_{-1.3}$

ATLAS	$H \to \gamma\gamma$	$ttH \to ttbb$	$qqH \to qq\tau\tau$ (ll + l-had)
S	130	15	~ 10
B	4300	45	~ 10
$S/\sqrt{B}$	2.0	2.2	~ 2.7

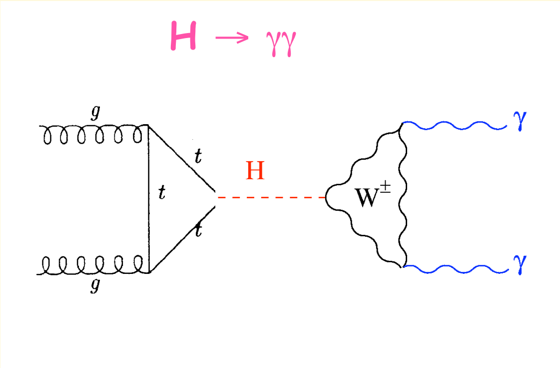
K-factors ≡ σ(NLO)/σ(LO) ≈ 2 not included

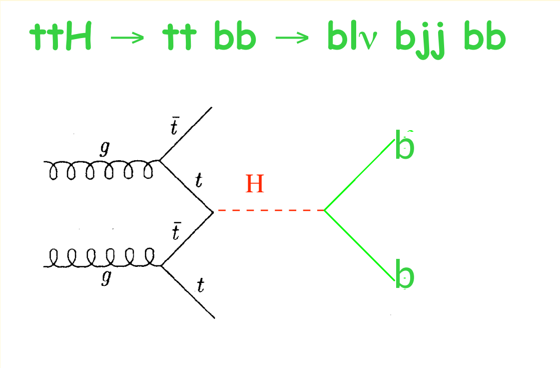
Full GEANT simulation, simple cut-based analyses

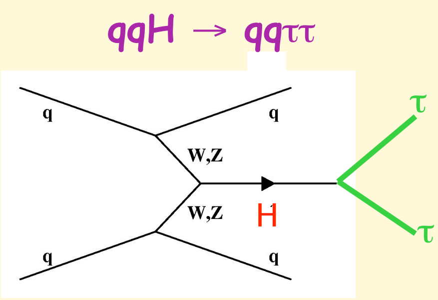
Remarks:

Each channel contributes ~ 2σ to total significance → observation of all channels important to extract convincing signal in first year(s)

The 3 channels are complementary → robustness:







- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for H → γγ (in particular response uniformity) : σ/m ~ 1% needed
  - -- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics
  - -- efficient jet reconstruction over |η| < 5 crucial for qqH → qqττ : forward jet tag and central jet veto needed against background

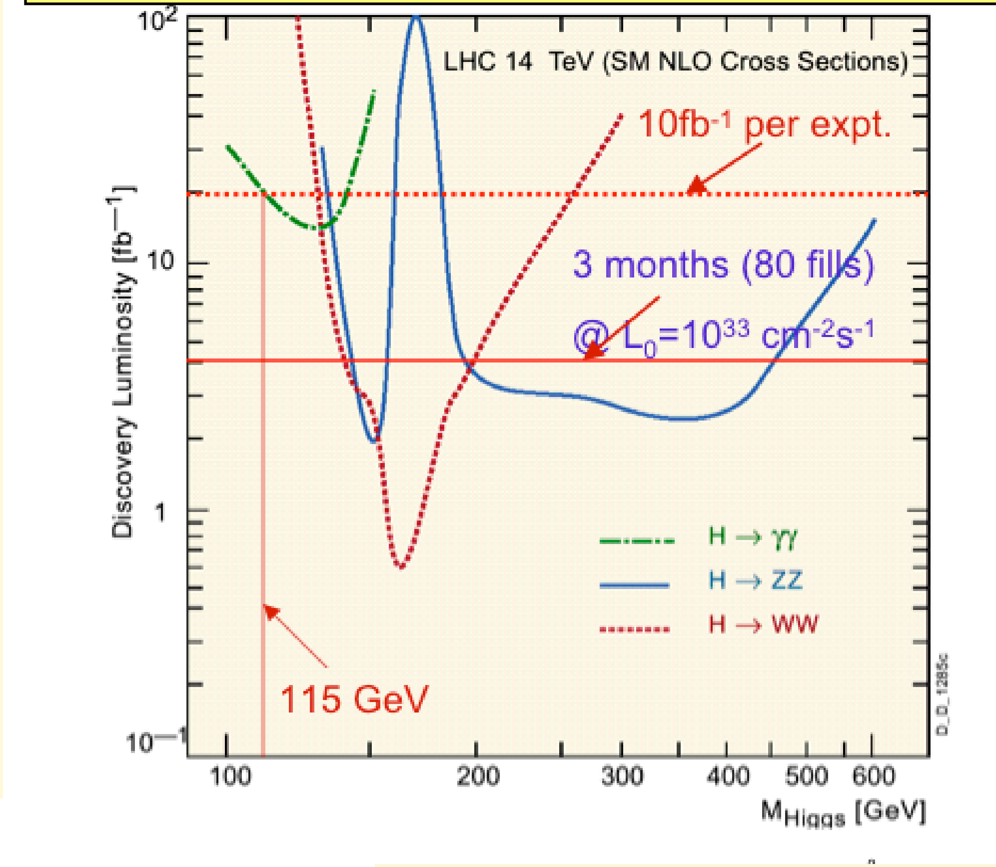
Note : -- all require "low" trigger thresholds

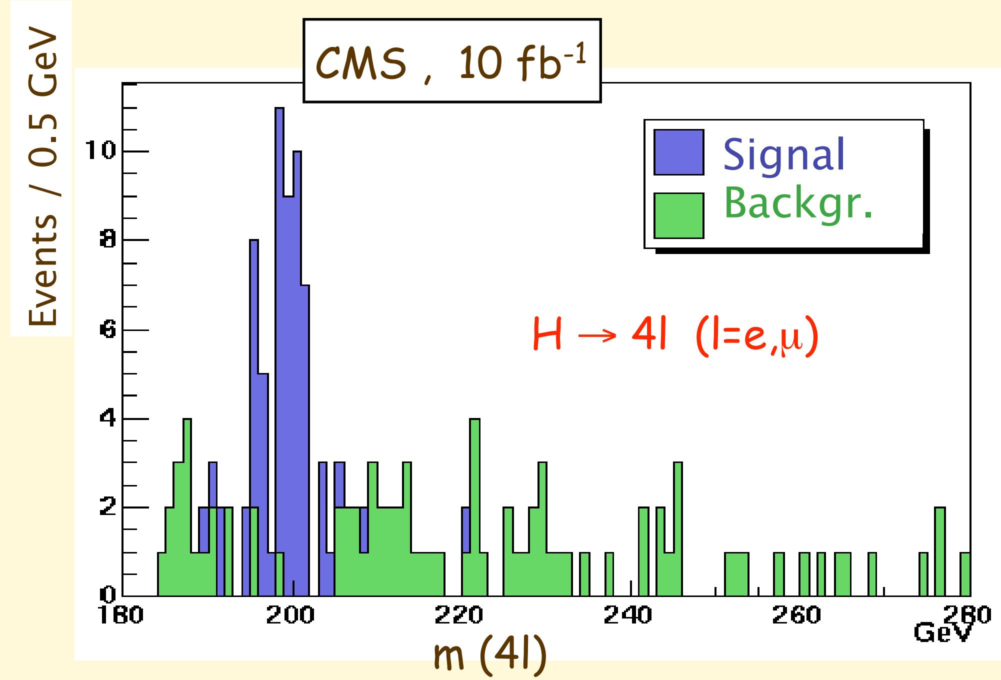
E.g. ttH analysis cuts : p_T (l) > 20 GeV, p_T (jets) > 15-30 GeV

-- all require very good understanding (1-10%) of backgrounds

If m_H > 180 GeV : early discovery may be easier with $H \to 4l$ channel

Luminosity needed for 5σ discovery (ATLAS+CMS)



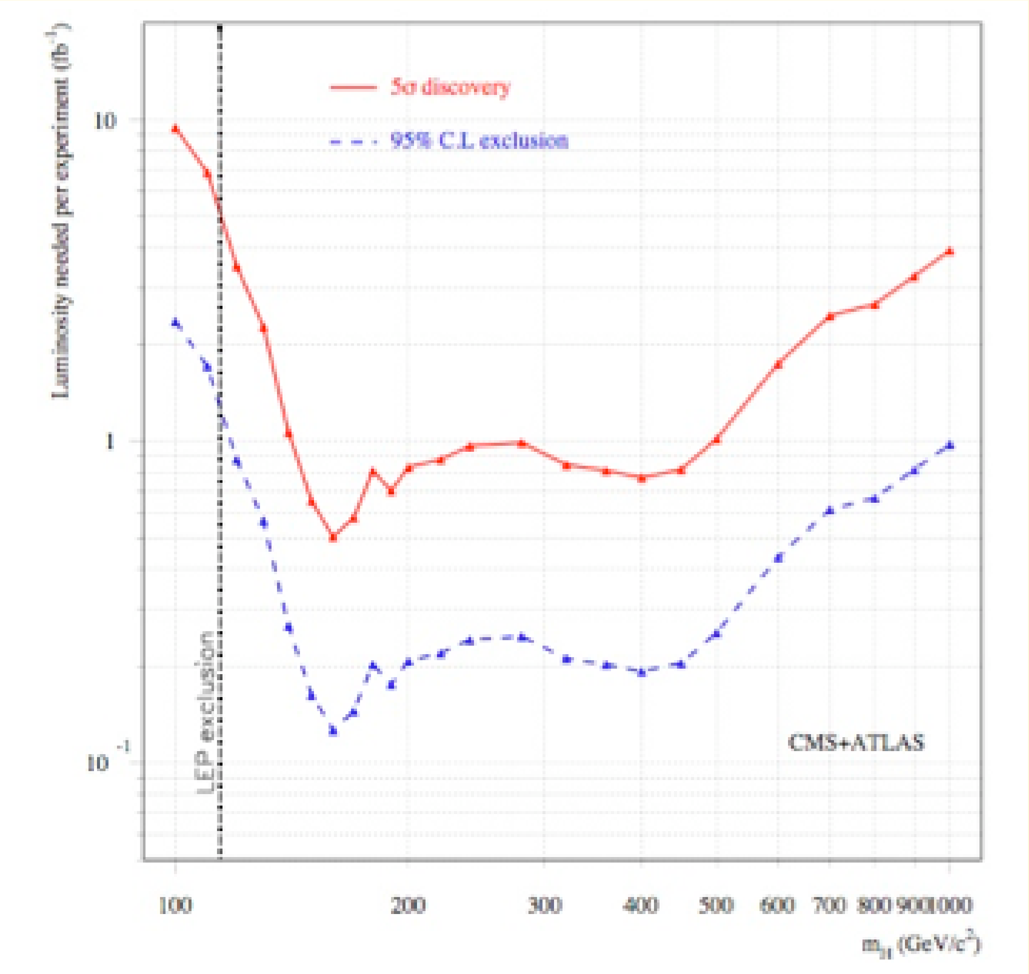


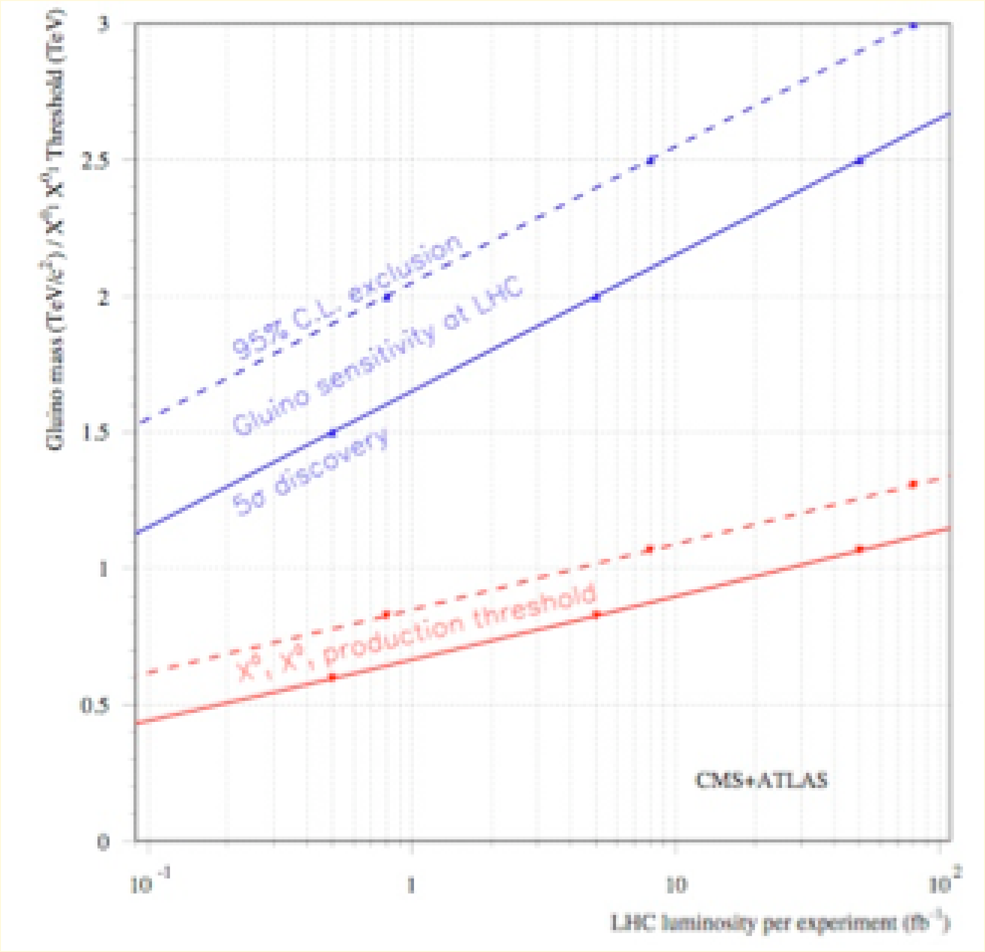
- $H \to WW \to l\nu\, l\nu$: high rate (~ 100 evts/expt) but no mass peak → not ideal for early discovery …
- $H \to 4l$: low-rate but very clean : narrow mass peak, small background

Requires: -- ~ 90% e, μ efficiency at low p_T (analysis cuts : $p_T^{1,2,3,4}$ > 20, 20, 7, 7, GeV)

-- σ/m ~ 1%, tails < 10% → good quality of E, p measurements in ECAL and tracker

Summary of discovery potential for Higgs and SUSY with < 10 fb-1





By 2010 we should already have a good picture of TeV-scale physics!

The LHC will be our first, and for a long time only, direct probe of the TeV scale

Rates for new phenomena will be 10^3 times larger in the region of asymptotic Tevatron read, and the exploration will extend to regions as yet totally unchartered

The immense rates, and striking signatures, will make it possible to extract signals of BSM physics early on

The detectors, after yrs of carefully monitored development and construction, and extensive test beam and pre-run debugging and validation, promise to be ready for the challenge!

LHC discoveries will not settle once and forever all the questions in HEP, but we expect they will firmly define the framework within which to phrase and address them

A truly exciting future is ahead of us!