



Physics at the LHC

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Presentation to the WLCG Workshop

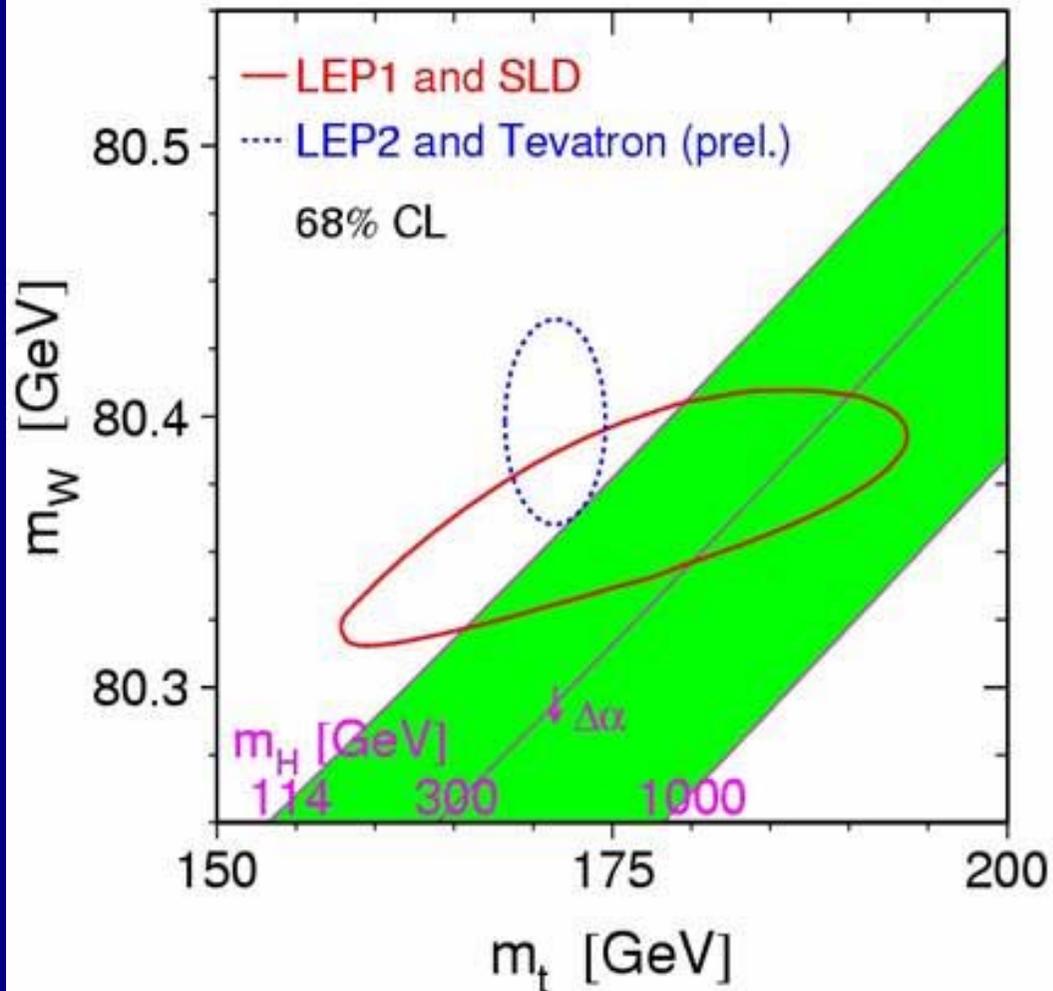
January 22, 2007

to remind us all of the exciting opportunities to be seized at the LHC, where we are very likely going to find a new, fundamental energy scale and cross the threshold giving access to new physics

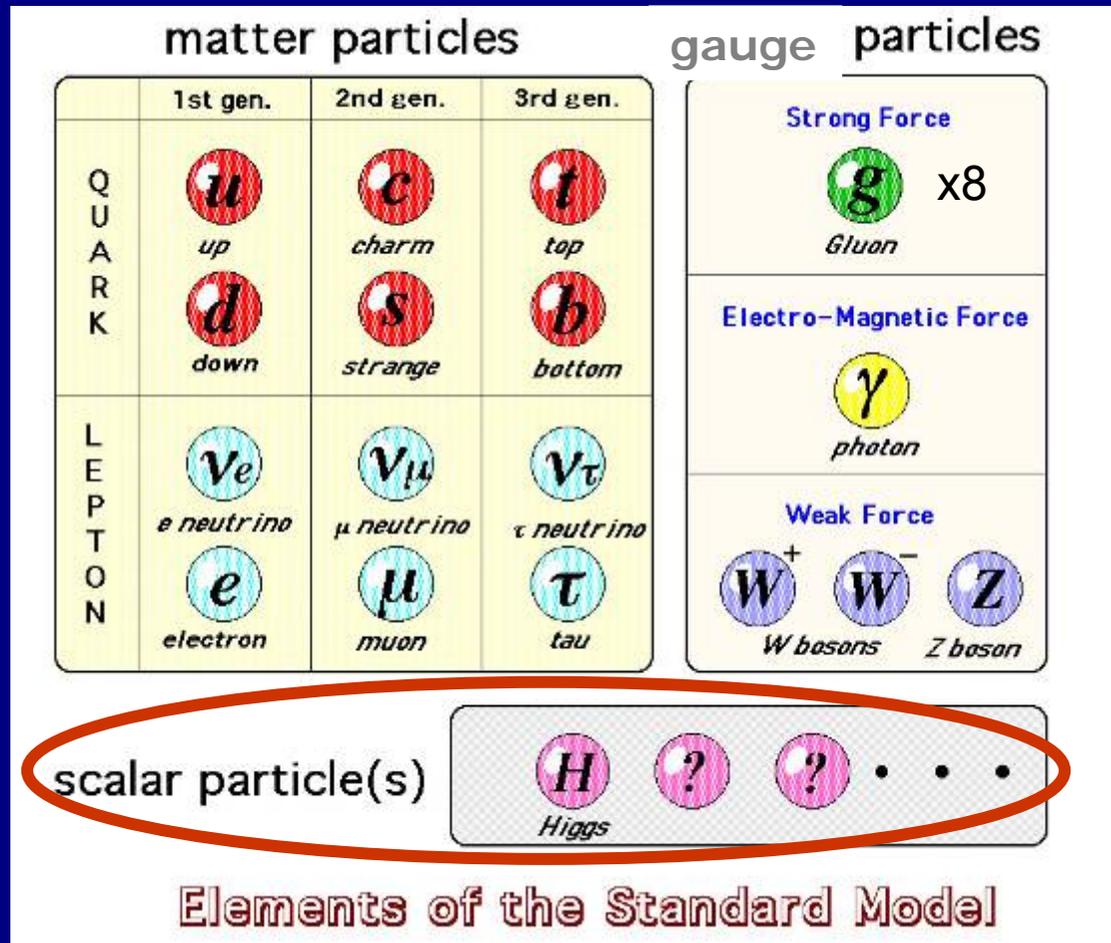
Thanks: Fabiola Gianotti, Peter Jenni, Jim Virdee, Michel Della Negra, Wouter Verkerke, Tatsuya Nakada, Juergen Schukraft, Karsten Eggert and others



Before we start, the Standard Model Higgs boson mass limits:



CDF
precision measurement
of W mass very recently
added (January 2007)





A formula

The full GSW Lagrangian, including the Higgs sector

$$L_{\text{GSW}} = L_0 + L_H + \sum_l \left\{ \frac{g}{2} \bar{L}_l \gamma_\mu \vec{\tau} L_l \vec{A}^\mu + g' \left[\bar{R}_l \gamma_\mu R_l + \frac{1}{2} \bar{L}_l \gamma_\mu L_l \right] B^\mu \right\} +$$

$$+ \frac{g}{2} \sum_q \bar{L}_q \gamma_\mu \vec{\tau} L_q \vec{A}^\mu +$$

$$+ g' \left\{ \frac{1}{6} \sum_q [\bar{L}_q \gamma_\mu L_q + 4 \bar{R}_q \gamma_\mu R_q] + \frac{1}{3} \sum_{q'} \bar{R}_{q'} \gamma_\mu R_{q'} \right\} B^\mu$$

SU(2)xU(1)

$$L_H = \frac{1}{2} (\partial_\mu H)^2 - m_H^2 H^2 - h \lambda H^3 - \frac{h}{4} H^4 +$$

$$+ \frac{g^2}{4} (W_\mu^+ W^\mu + \frac{1}{2 \cos^2 \theta_W} Z_\mu Z^\mu) (\lambda^2 + 2 \lambda H + H^2) +$$

$$+ \sum_{l, q, q'} \left(\frac{m_l}{\lambda} \bar{l} l + \frac{m_q}{\lambda} \bar{q} q + \frac{m_{q'}}{\lambda} \bar{q}' q' \right) H$$

Makes theory gauge invariant (renormalizable)

Also preserves unitarity

Mass terms !



Precision Measurement from LEP

The standard Model is a beautiful and one of the most precisely tested theories

Why then do we need to probe further ?

Quantity	Value	Standard Model	Pull
m_t [GeV]	$172.7 \pm 2.9 \pm 0.6$	172.7 ± 2.8	0.0
M_W [GeV]	80.450 ± 0.058	80.376 ± 0.017	1.3
	80.392 ± 0.039		0.4
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0011	-0.7
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.65 ± 0.11	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.996 ± 0.021	—
σ_{had} [nb]	41.541 ± 0.037	41.467 ± 0.009	2.0
R_e	20.804 ± 0.050	20.756 ± 0.011	1.0
R_μ	20.785 ± 0.033	20.756 ± 0.011	0.9
R_τ	20.764 ± 0.045	20.801 ± 0.011	-0.8
R_b	0.21629 ± 0.00066	0.21578 ± 0.00010	0.8
R_c	0.1721 ± 0.0030	0.17230 ± 0.00004	-0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01622 ± 0.00025	-0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1031 ± 0.0008	-2.4
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0737 ± 0.0006	-0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1032 ± 0.0008	-0.5
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23152 ± 0.00014	0.7
	0.2238 ± 0.0050		-1.5
A_e	0.15138 ± 0.00216	0.1471 ± 0.0011	2.0
	0.1544 ± 0.0060		1.2
	0.1498 ± 0.0049		0.6
A_μ	0.142 ± 0.015		-0.3
A_τ	0.136 ± 0.015		-0.7
	0.1439 ± 0.0043		-0.7
A_b	0.923 ± 0.020	0.9347 ± 0.0001	-0.6
A_c	0.670 ± 0.027	0.6678 ± 0.0005	0.1
A_s	0.895 ± 0.091	0.9356 ± 0.0001	-0.4
g_L^2	0.30005 ± 0.00137	0.30378 ± 0.00021	-2.7
g_R^2	0.03076 ± 0.00110	0.03006 ± 0.00003	0.6
$g_V^{e\bar{e}}$	-0.040 ± 0.015	-0.0396 ± 0.0003	0.0
$g_A^{e\bar{e}}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0
A_{PV}	-1.31 ± 0.17	-1.53 ± 0.02	1.3
$Q_W(\text{Cs})$	-72.62 ± 0.46	-73.17 ± 0.03	1.2
$Q_W(\text{Tl})$	-116.6 ± 3.7	-116.78 ± 0.05	0.1
$\frac{\Gamma(b \rightarrow s\gamma)}{\Gamma(b \rightarrow X e \nu)}$	$3.35^{+0.50}_{-0.44} \times 10^{-3}$	$(3.22 \pm 0.09) \times 10^{-3}$	0.3
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	4511.07 ± 0.82	4509.82 ± 0.10	1.5
τ_τ [fs]	290.89 ± 0.58	291.87 ± 1.76	-0.4



What is Wrong with the Standard Model?

SM contains too many apparently arbitrary features

SM has an unproven element – not some minor detail but a central element – namely the mechanism to generate observed masses of known particles

A solution is to invoke the Higgs mechanism

SM gives problems at high energies

At centre of mass energies > 1000 GeV the probability of $W_L W_L$ scattering becomes greater than 1 !!

A solution is to introduce a Higgs boson exchange to cancel the bad high energy behaviour

SM is logically incomplete – does not incorporate gravity – build a Unified Theory

Is superstring theory the Unified Theory ?

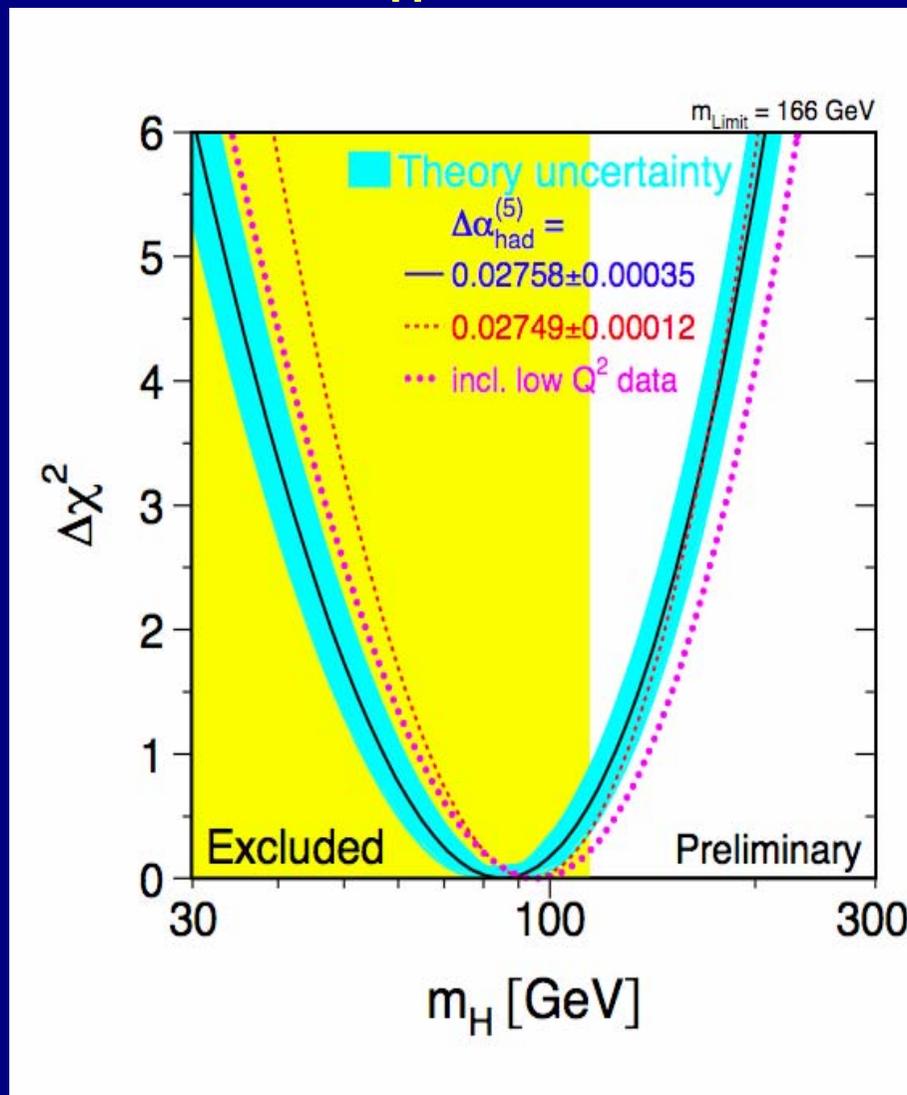
Are there extra dimensions ?

Experimentally: New particles/new symmetries/new forces? Higgs boson(s), Supersymmetry, Extra dimensions etc. ?



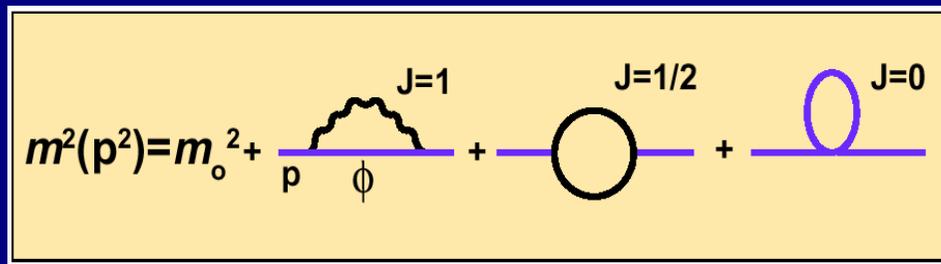
Experimental Limits on Mass of SM Higgs Boson

114.4 GeV < m_H < 194 GeV (95% CL)



What happens if extend validity of SM to scales $\Lambda \gg 1 / \sqrt{G_F}$?

Radiative corrections to the Higgs boson mass



$$m^2(p^2) = m_0^2 + \text{[diagram with wavy line, } J=1 \text{]} + \text{[diagram with circle, } J=1/2 \text{]} + \text{[diagram with loop, } J=0 \text{]}$$

$$M_H^2 \rightarrow M_H^2 \text{ (bare)} + c \Lambda^2$$

Λ is the scale of the underlying theory (could be $M_{\text{GUT}} \sim 10^{15}$ GeV !)

Requires incredibly unnatural fine tuning to keep M_H small !!

What can be done ?

L_{SSB} does not contain an elementary Higgs boson

OR

Cancel quadratic divergences

Invoke additional symmetry (e.g. Supersymmetry) to cancel divergences

bosons have fermion superpartners
fermions have boson superpartners

SUSY is obviously broken

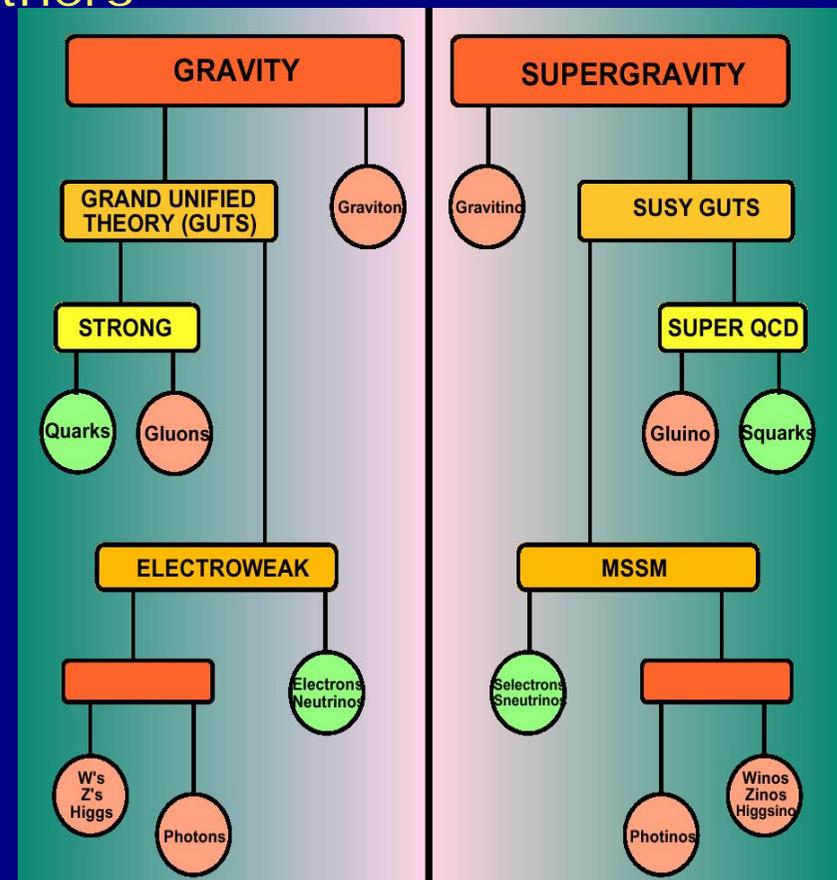
But if require SUSY to solve naturalness $|M^2_{\text{spart}} - M^2_{\text{part}}| < O(1 \text{ TeV}^2)$

Minimal SUSY Model

Gluginos, squarks, sleptons
4 neutralinos, 2 charginos
Higgs sector: h^0, H^0, A^0, H^\pm

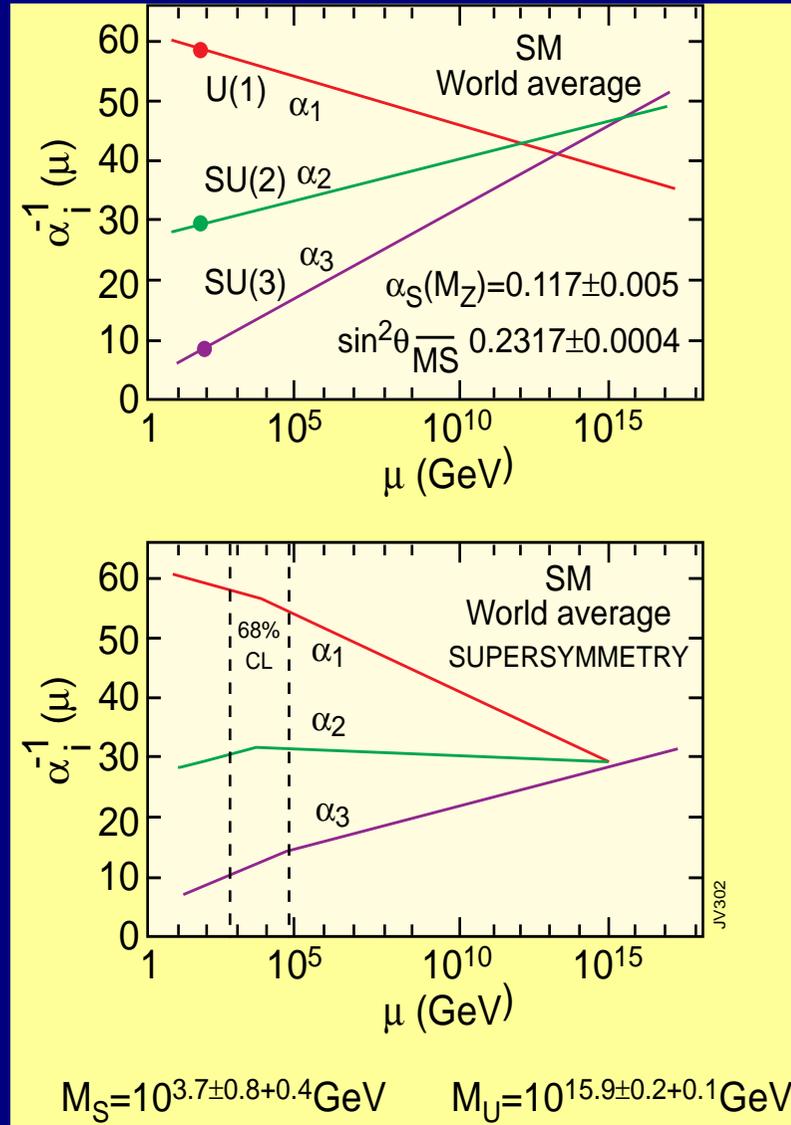
R-parity conservation

Pair production of sparticles
LSP: stable and weakly interacting



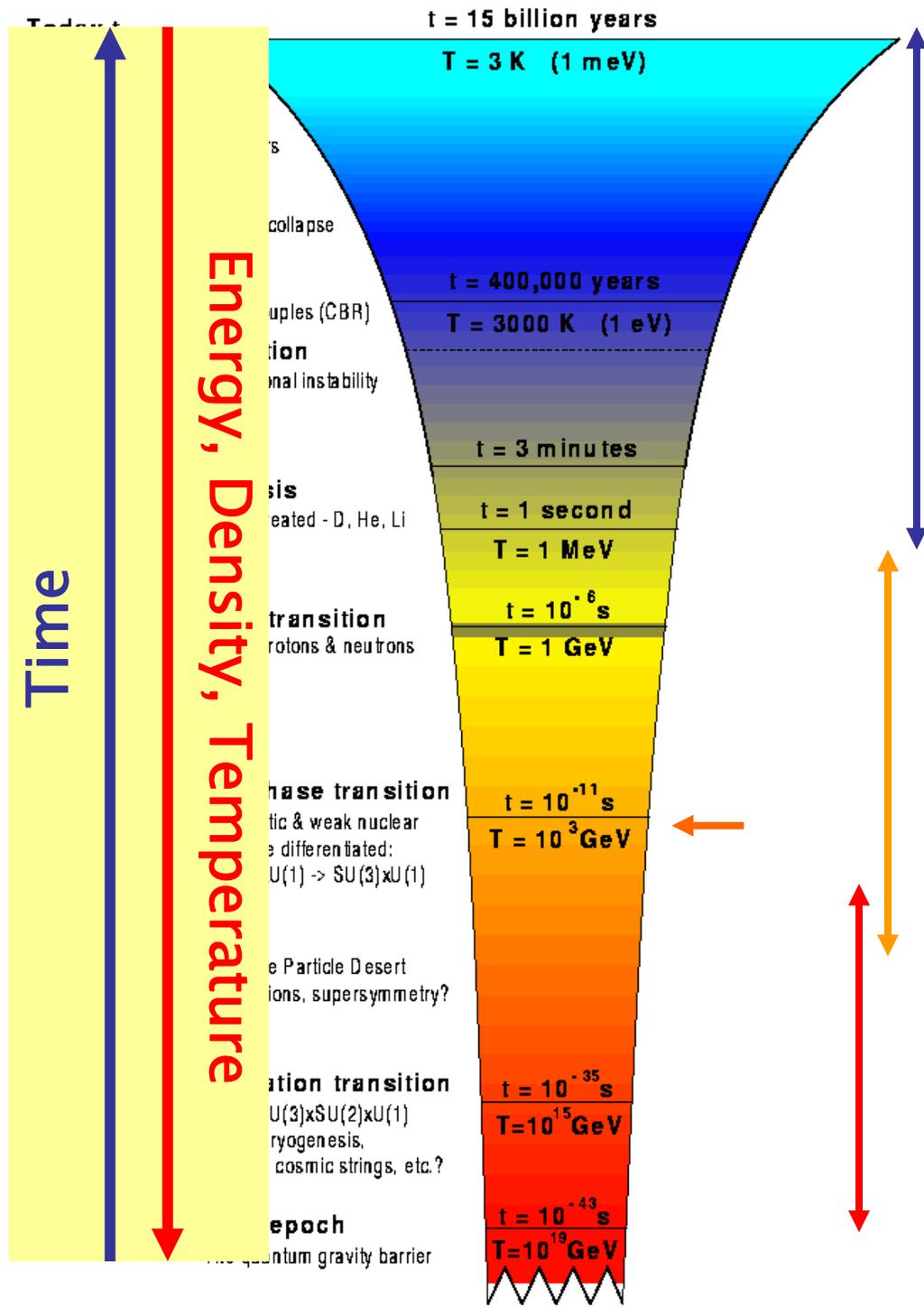


Features of Supersymmetry



Supersymmetry apparently plays an important role in:

- Naturalness problem i.e why is the Higgs mass so low ?
- Grand unification (strong + EW forces)
- Proton decay
- Lightest neutral sparticle - candidate for dark matter
- String theory requires supersymmetry (reconcile gravity and QM)
- No SUSY particle yet observed! presumably massive -
- Low energy SUSY will certainly be found at LHC



Standard Cosmology

Good model from 0.01 sec after Big Bang

Supported by considerable observational evidence

Elementary Particle Physics

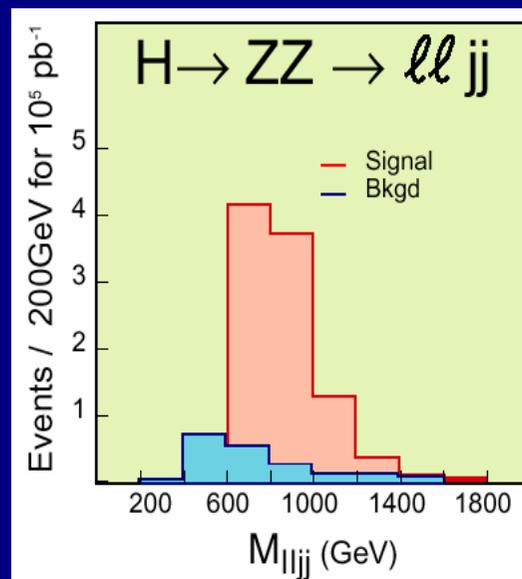
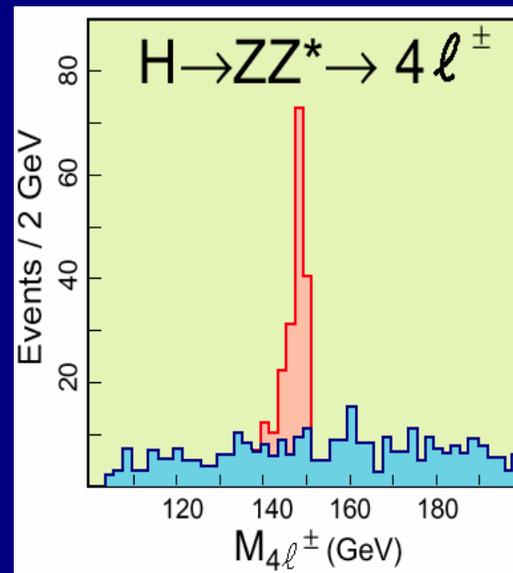
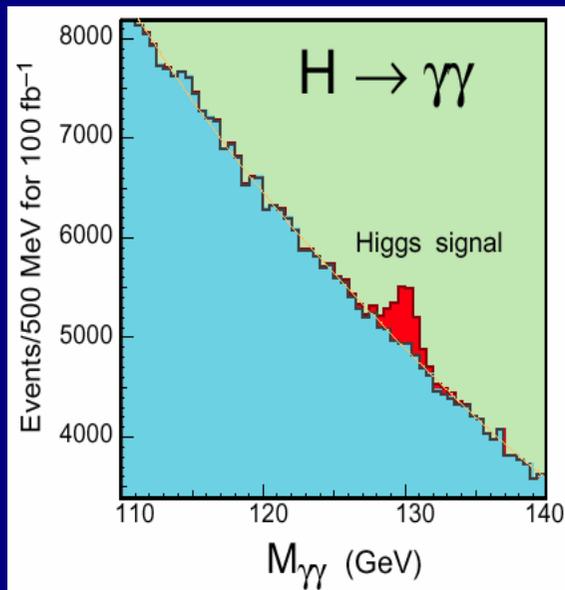
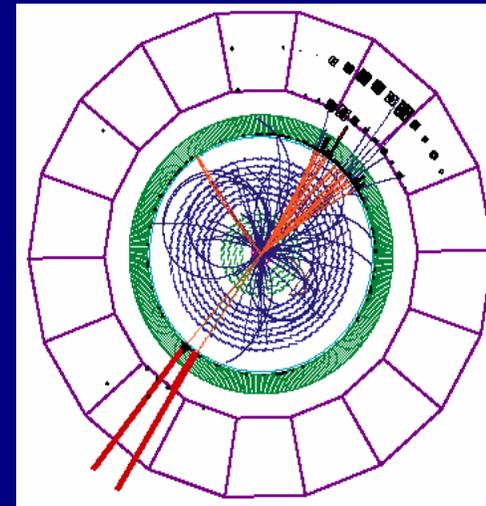
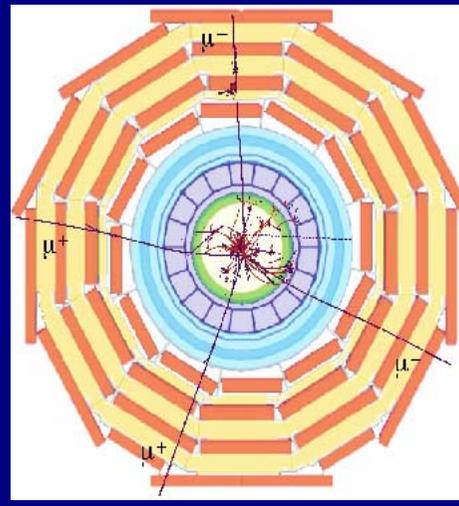
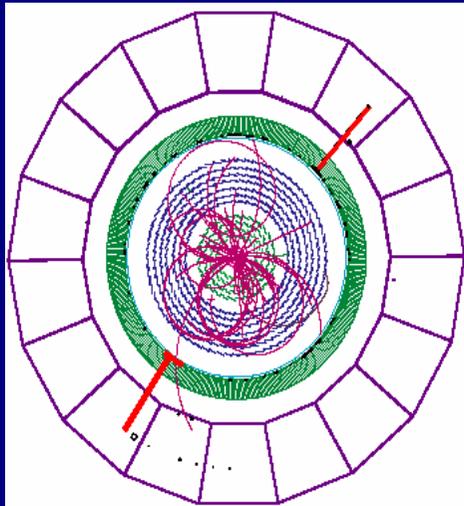
From the Standard Model into the unknown: towards energies of 1 TeV and beyond: the **Terascale**

Towards Quantum Gravity

From the unknown into the unknown...



- LEP, SLC and the Tevatron: established that we really understand the physics at energies up to ~ 100 GeV
 - And any new particles have masses above 200–300 GeV – and in some cases TeV
- The Higgs itself can have a mass up to ~ 700 –800 GeV; if it's not there, something must be added by ~ 1.2 TeV, or WW scattering exceeds unitarity
- Even if the Higgs exists, all is not 100% well with the Standard Model alone: next question is “why is the (Higgs) mass so low”?
 - The same mechanism that gives all masses would drive the Higgs mass to the Planck scale. If SUSY is the answer, it must show up at $O(\text{TeV})$
 - Recent: extra dimensions. Again, something must happen in the $O(1$ – $10)$ TeV scale if the above issues are to be addressed
- **Conclusion: we need to study the TeV region**

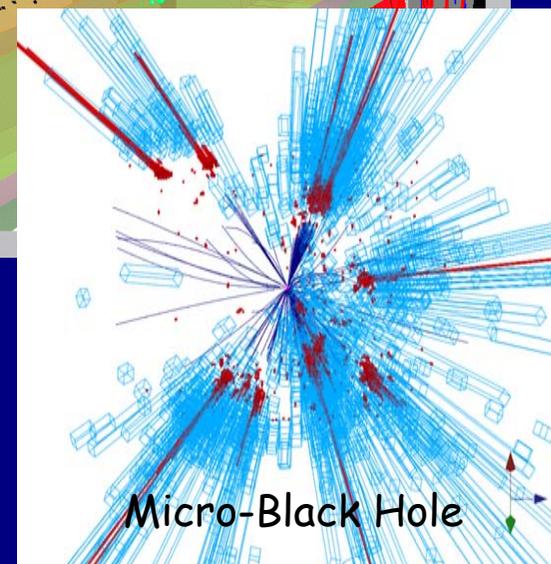
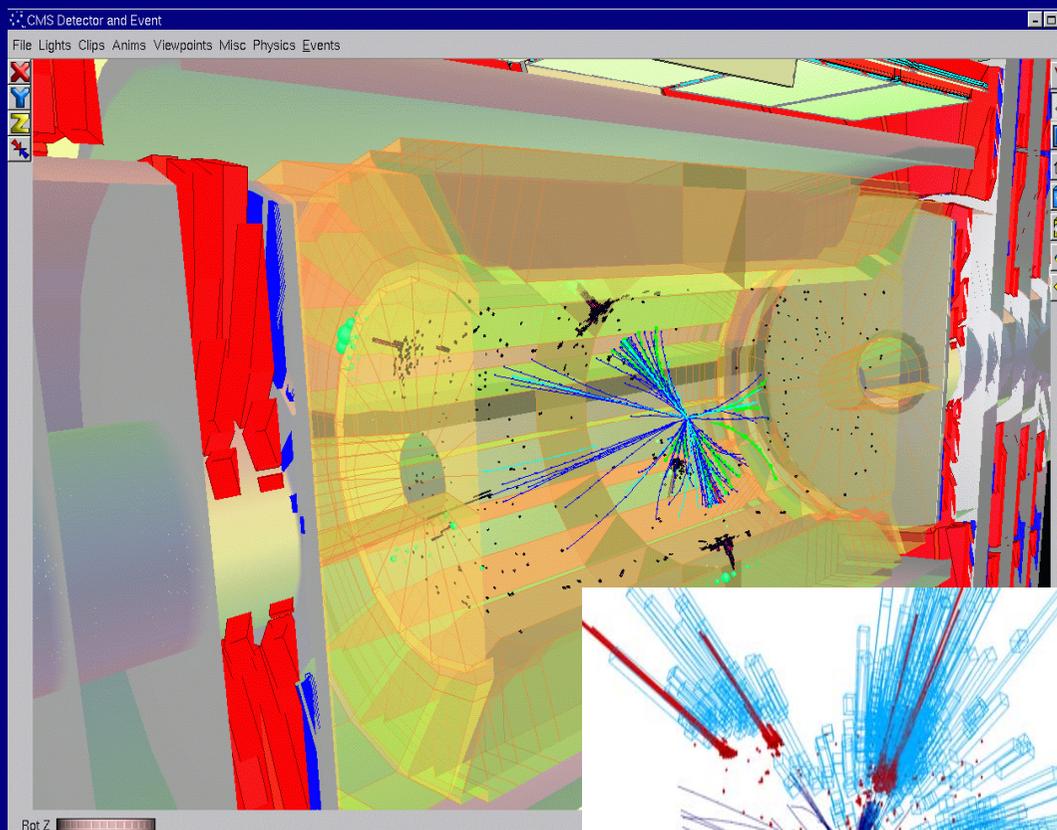


In extra dimensions

Semi-classical argument:
two partons approaching
with impact parameter $<$
Schwarzschild radius, R_S
 \rightarrow black hole

Spectacular decays –
democracy of SM
particles – high
multiplicity incl lots of
charged leptons and
photons at high p_T

Can determine Hawking
Temperature, M_{BH} , n – no.
of dimensions !



Cross sections for various physics processes vary over many orders of magnitude

Inelastic: 10^9 Hz

$W \rightarrow l \nu$: 10^2 Hz

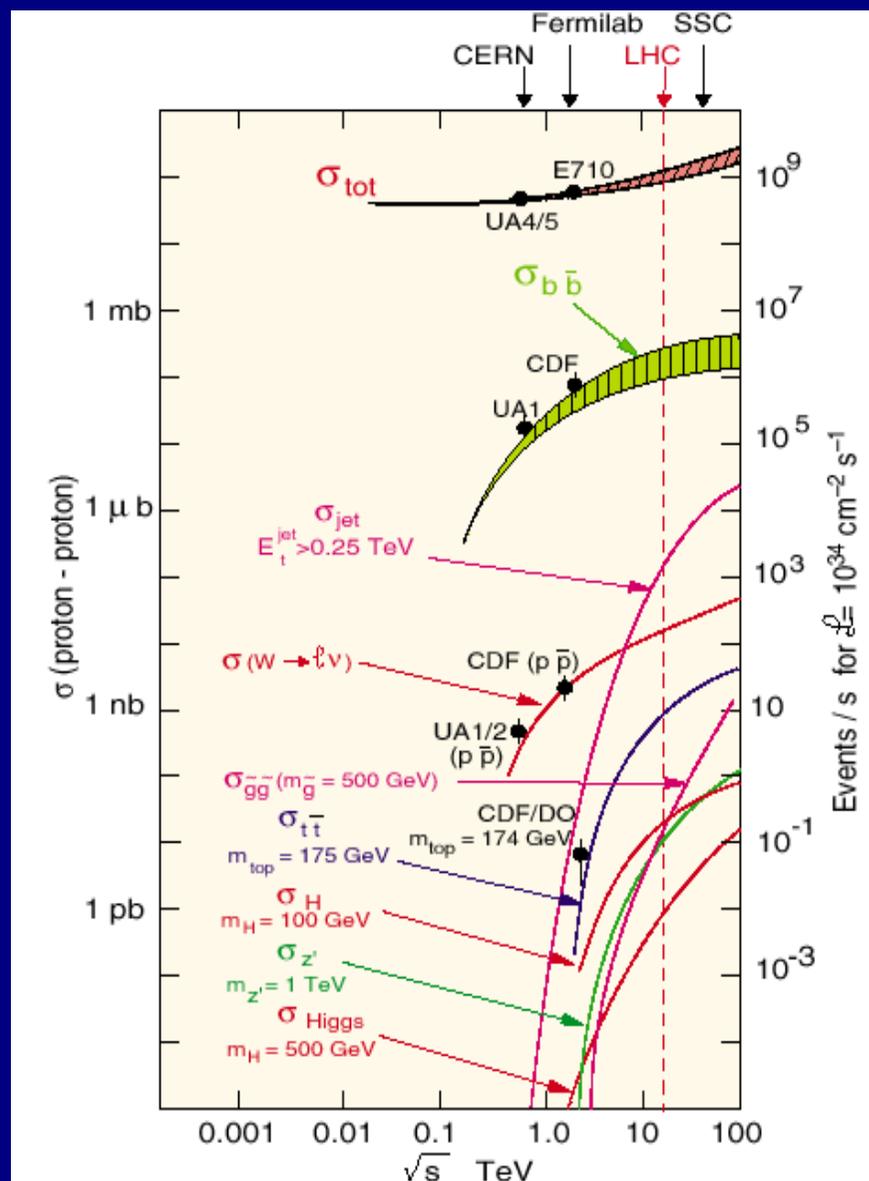
$t \bar{t}$ production: 10 Hz

Higgs ($100 \text{ GeV}/c^2$): 0.1 Hz

Higgs ($600 \text{ GeV}/c^2$): 10^{-2} Hz

Selection needed: $1:10^{10-11}$

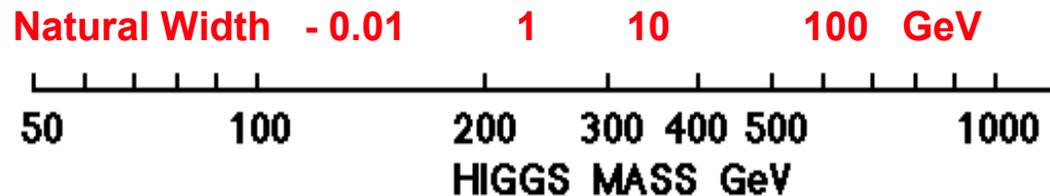
Before branching fractions...





Physics Requirements

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector



Lep 190 ← **LEP200(>), $M_H > 114.4$ GeV**

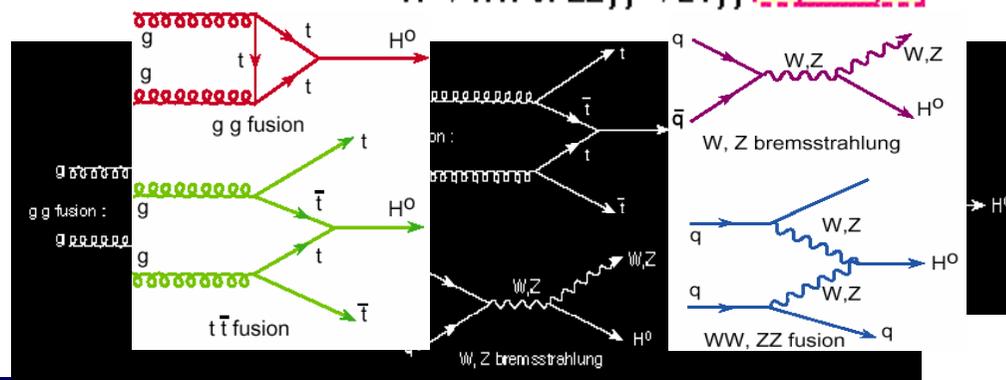
$H \rightarrow \gamma\gamma$ ($WH \rightarrow \gamma\gamma l$) ($t\bar{t}H \rightarrow \gamma\gamma l$)

$H \rightarrow ZZ^* \rightarrow 4l$

$H \rightarrow ZZ \rightarrow 4l$

$H \rightarrow ZZ \rightarrow 2\nu + 2\mu$ or $2e$

$H \rightarrow WW$ or $ZZjj \rightarrow 2ljj$





Physics Requirements

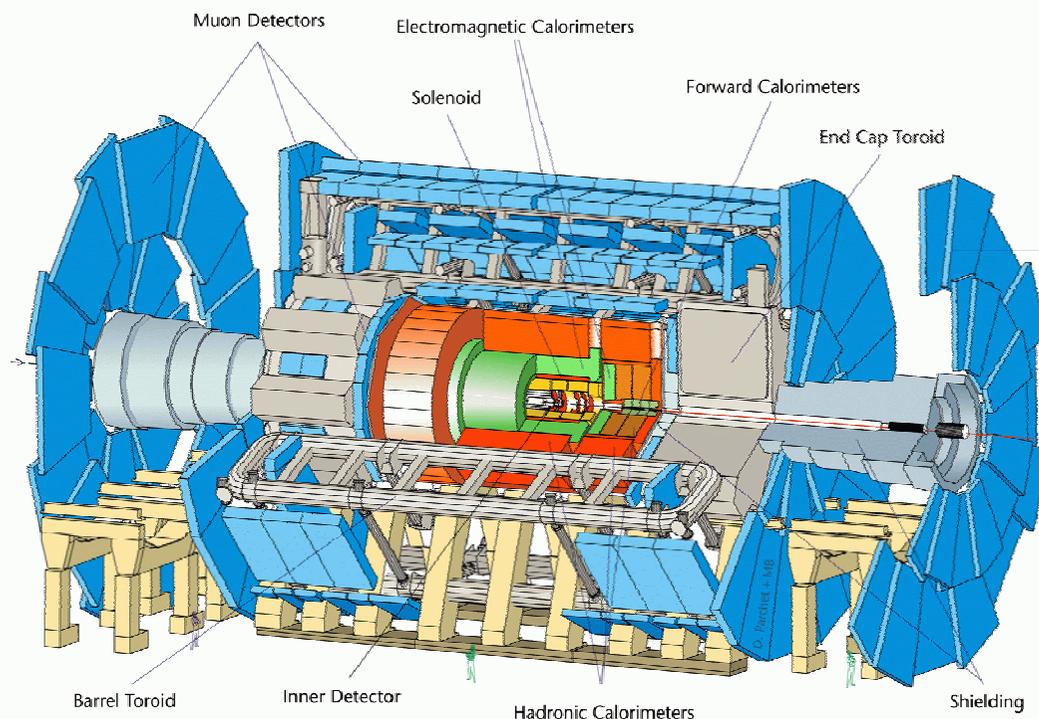
Very good muon identification and momentum measurement
trigger efficiently and measure sign of a few TeV muons

High energy resolution electromagnetic calorimetry
~ 0.5% @ $E_T \sim 50$ GeV

Powerful inner tracking systems
factor 10 better momentum resolution than at LEP

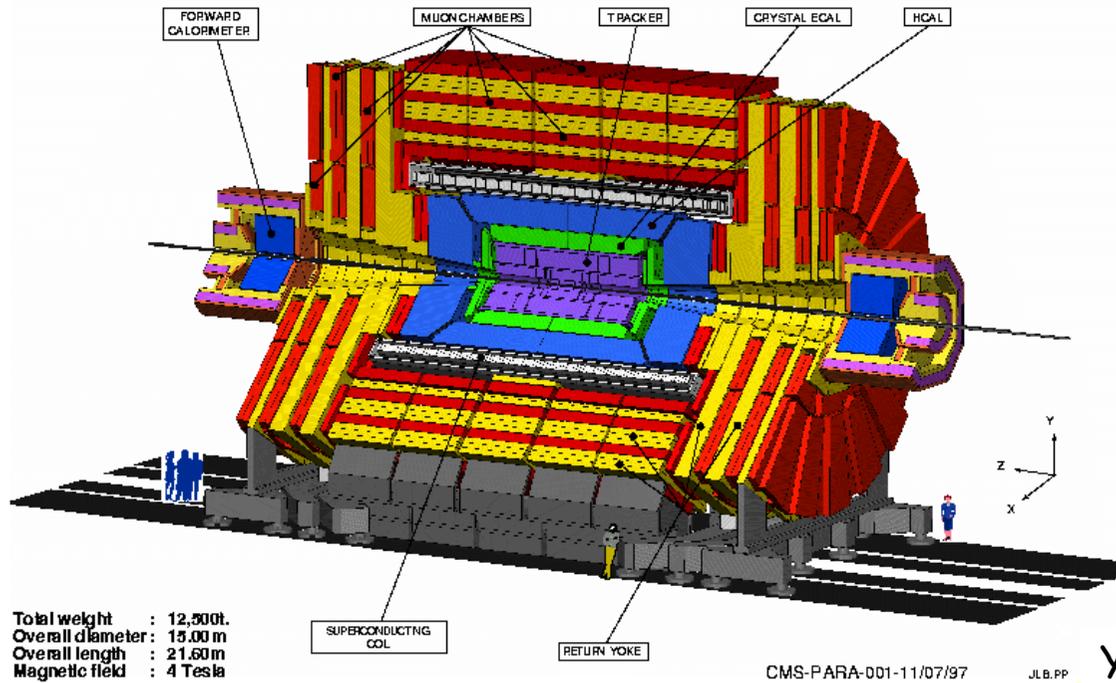
Hermetic calorimetry
good missing E_T resolution

(Affordable detector)



Length : ~45 m
 Radius : ~12 m
 Weight : ~ 7000 tons
 Electronic channels : ~ 10^8
 ~ 3000 km of cables

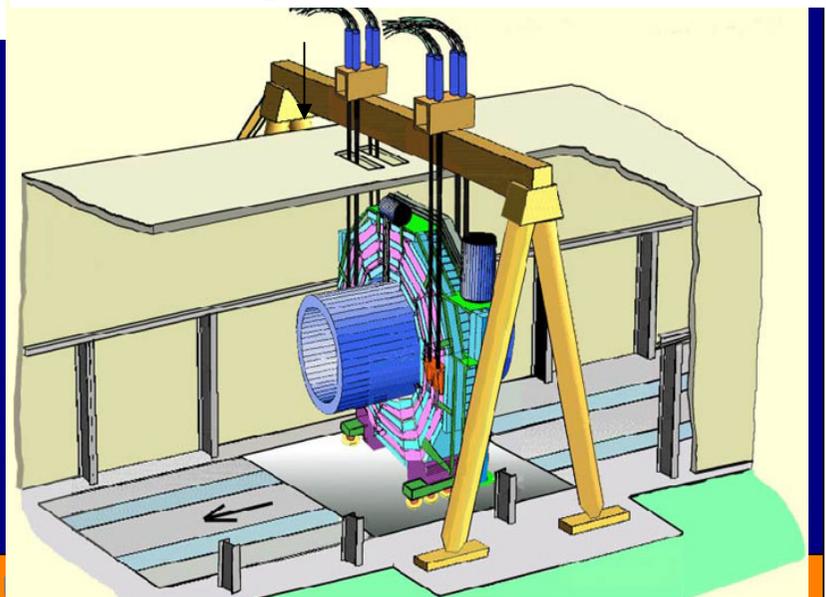
- **Tracking ($|\eta| < 2.5$, $B=2T$) :**
 - Si pixels and strips
 - Transition Radiation Detector (e/π separation)
- **Calorimetry ($|\eta| < 5$) :**
 - EM : Pb-LAr with Accordion shape
 - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- **Muon Spectrometer ($|\eta| < 2.7$) :**
air-core toroids with muon chambers



Length : ~22 m
 Radius : ~7 m
 Weight : ~ 12500 tons

Compact and modular:
 assembled at the surface
 and lowered in the cavern
 piece by piece

YBO lowering (2000t)



- Tracking ($|\eta| < 2.5, B=4T$) : Si pixels and strips
- Calorimetry ($|\eta| < 5$) :
 - EM : $PbWO_4$ crystals
 - HAD: brass/scintillator (central+ end-cap), Fe/Quartz (fwd)
- Muon Spectrometer ($|\eta| < 2.5$) : return yoke of solenoid instrumented with muon chambers

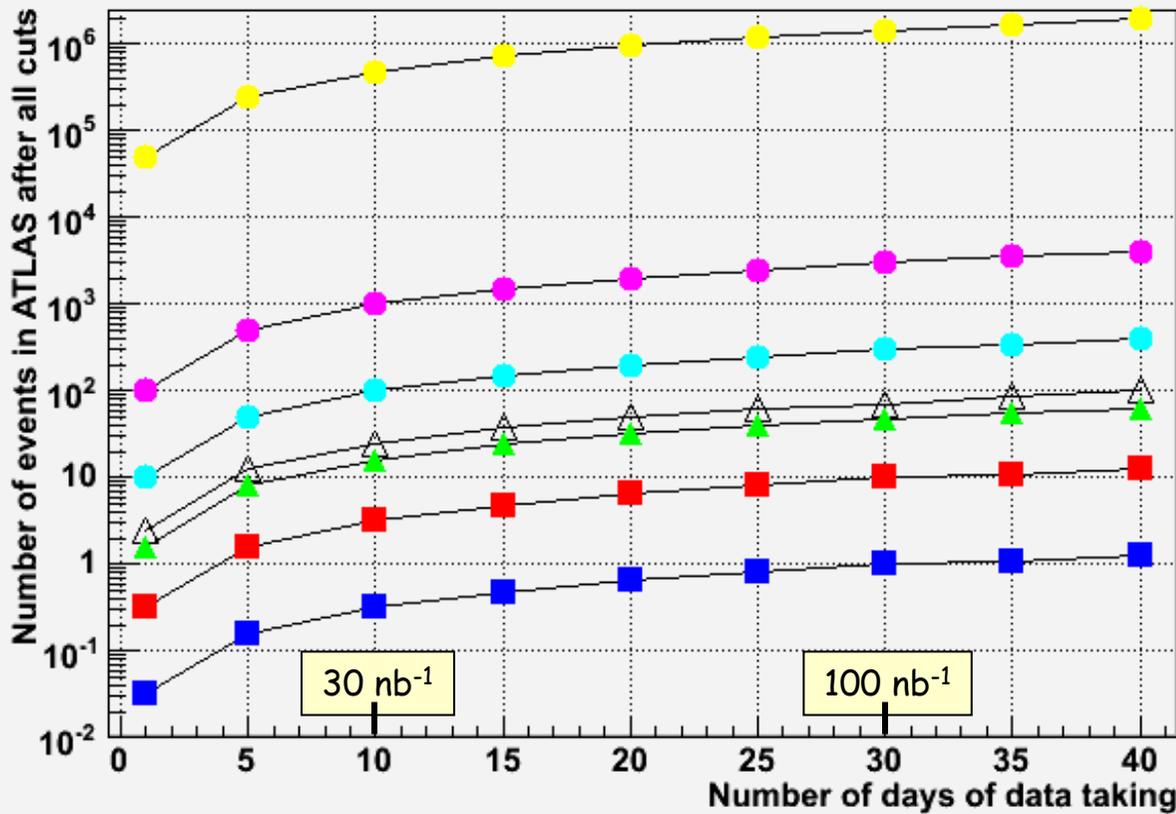


What data samples in 2007 ?

30% data taking efficiency included (machine plus detector)
Trigger and analysis efficiencies included

ATLAS preliminary

$\sqrt{s} = 900 \text{ GeV}$, $L = 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$



Jets $p_T > 15 \text{ GeV}$

(b-jets: ~1.5%)

Jets $p_T > 50 \text{ GeV}$

Jets $p_T > 70 \text{ GeV}$

$Y \rightarrow \mu\mu$

$J/\psi \rightarrow \mu\mu$

$W \rightarrow e\nu, \mu\nu$

$Z \rightarrow ee, \mu\mu$

+ 1 million minimum-bias/day

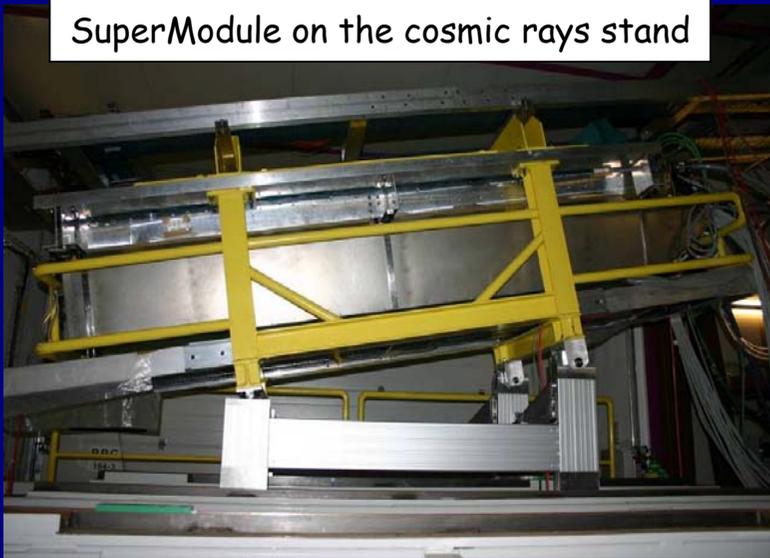
- Start to commission triggers and detectors with collision data (minimum bias, jets, ..) in real LHC environment
- Maybe first physics measurements (minimum-bias, underlying event, QCD jets, ...)?
- Observe a few $W \rightarrow l\nu$, $Y \rightarrow \mu\mu$, $J/\psi \rightarrow \mu\mu$?



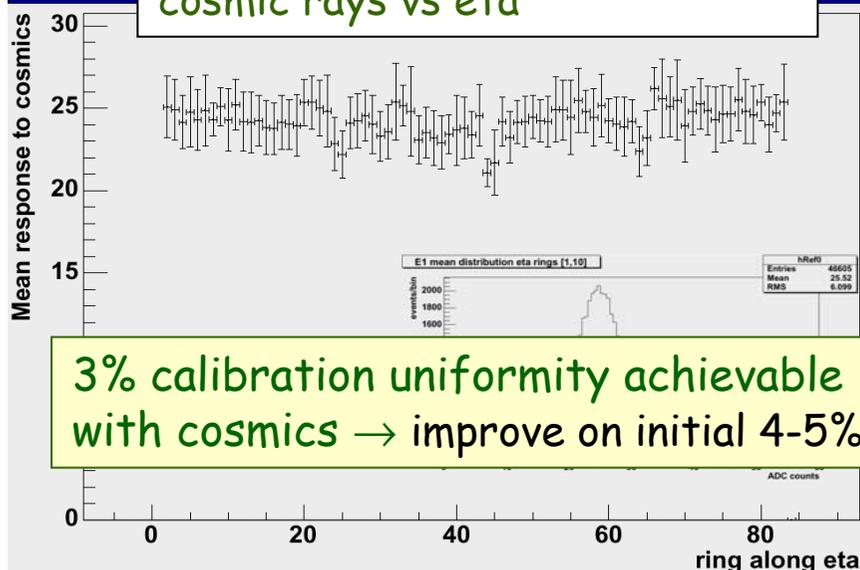
Example 1: CMS ECAL calibration

only ~ 6 SM will be tested with test beams → most/all SM will be calibrated with cosmic rays

SuperModule on the cosmic rays stand

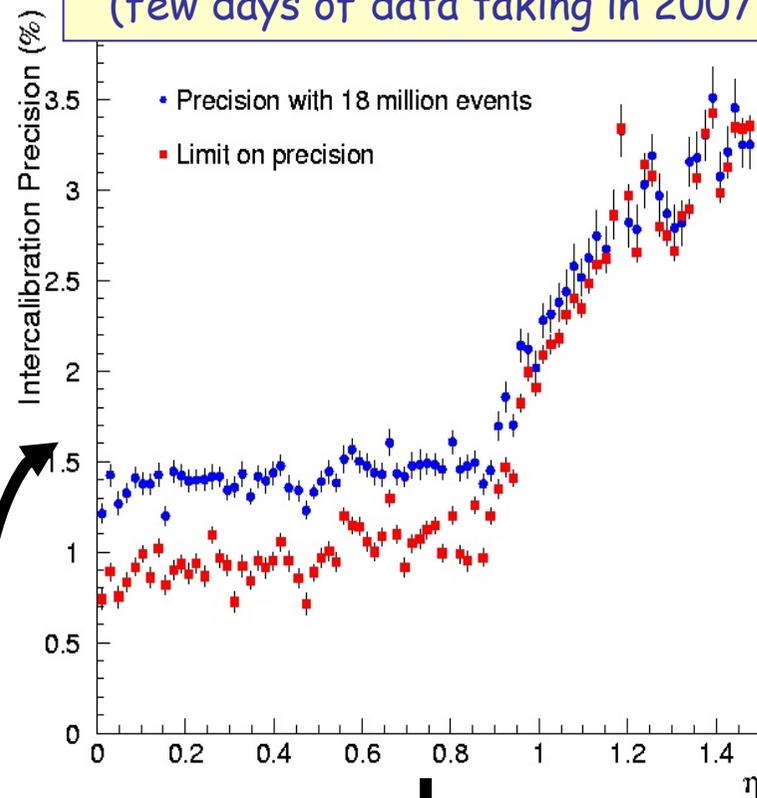


Energy deposition of traversing cosmic rays vs eta



3% calibration uniformity achievable with cosmic → improve on initial 4-5%

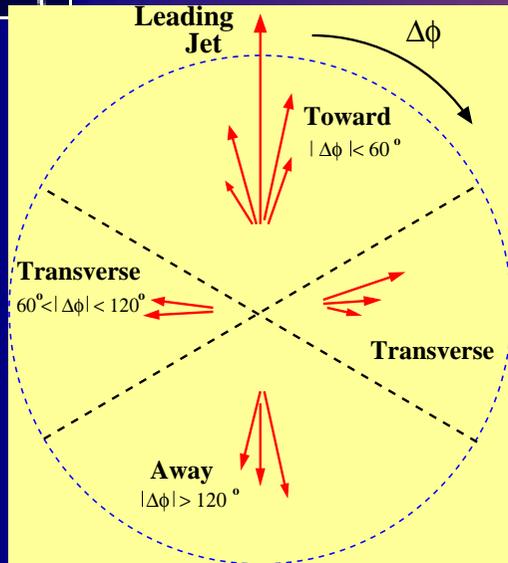
~ 1.5% calibration uniformity achievable in central barrel with 18 million minimum-bias (few days of data taking in 2007)



Further step toward the ~ 0.5% needed to observe a $H \rightarrow \gamma\gamma$ signal



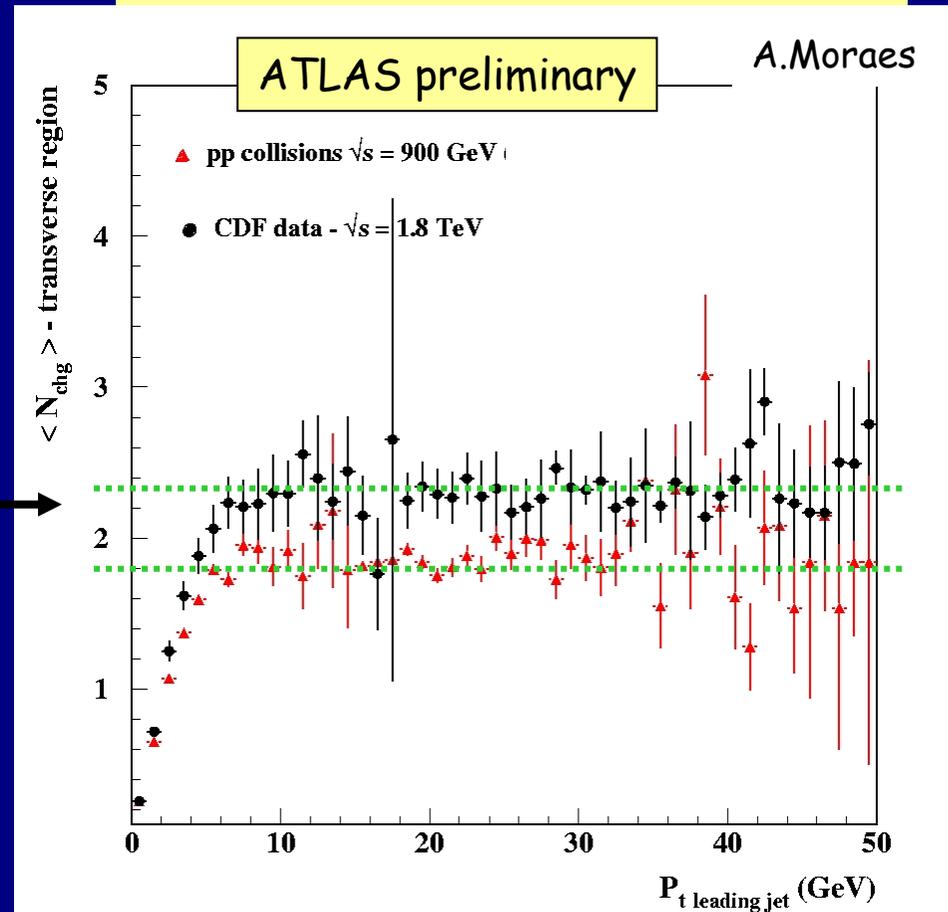
Example 2: Measurement of the underlying event in di-jet production



Multiplicity of charged particles with $p_T > 0.5 \text{ GeV}$ and $|\eta| < 1$ in region transverse to leading jet

Particle multiplicity of underlying event obtained from the region transverse to the leading jet.

Comparison of plateau's between LHC and Tevatron will tell if detector performance, reconstruction tools and physics are under control



~ 15 days of data taking in 2007 enough to cover up to $p_T(\text{leading jet}) \sim 40 \text{ GeV}$



LHC is a factory for b, W,Z, top

1 fb⁻¹ (100 pb⁻¹) ≡ 6 months at L= 10³² cm⁻²s⁻¹ with 50% data-taking efficiency

Channels (<u>examples</u> ...)	Events to tape for 100 pb ⁻¹ (per expt: ATLAS, CMS)	Total statistics from previous Colliders
W → μ ν	~ 10 ⁶	~ 10 ⁴ LEP, ~ 10 ⁶ Tevatron
Z → μ μ	10 ⁵	~ 10 ⁶ LEP, ~ 10 ⁵ Tevatron
tt → W b W b → μ ν+X	~ 10 ⁴	~ 10 ⁴ Tevatron
QCD jets p _T > 1 TeV	> 10 ³	---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50	---

With these data:

- Understand and calibrate detectors in situ using well-known physics samples
 e.g. - Z → ee, μμ tracker, ECAL, Muon chambers calibration and alignment, etc.
 - tt → blν bjj jet scale from W → jj, b-tag performance, etc.
- Measure SM physics at √s = 14 TeV : W, Z, tt, QCD jets ...
 (also because omnipresent backgrounds to New Physics)



Example of initial measurement: understanding detector and physics with top events

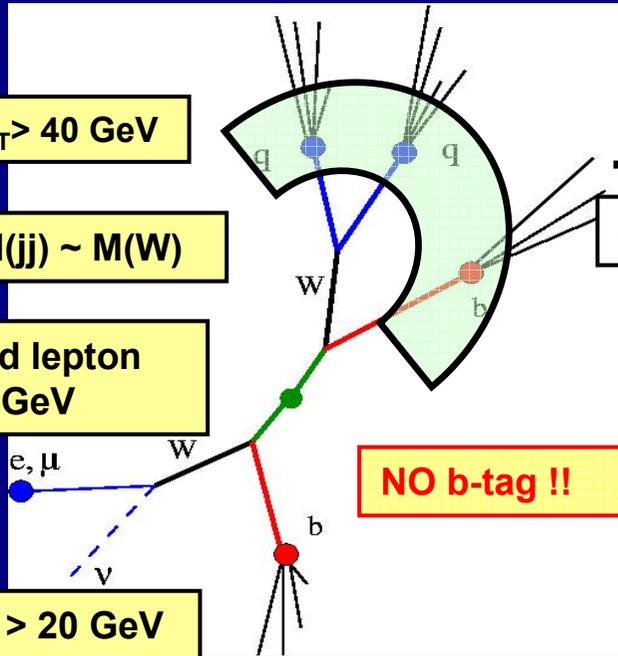
$\sigma_{tt} \approx 250 \text{ pb}$ for $tt \rightarrow bW bW \rightarrow blv bjj$

4 jets $p_T > 40 \text{ GeV}$

2 jets $M(jj) \sim M(W)$

Isolated lepton
 $p_T > 20 \text{ GeV}$

$E_{T, \text{miss}} > 20 \text{ GeV}$

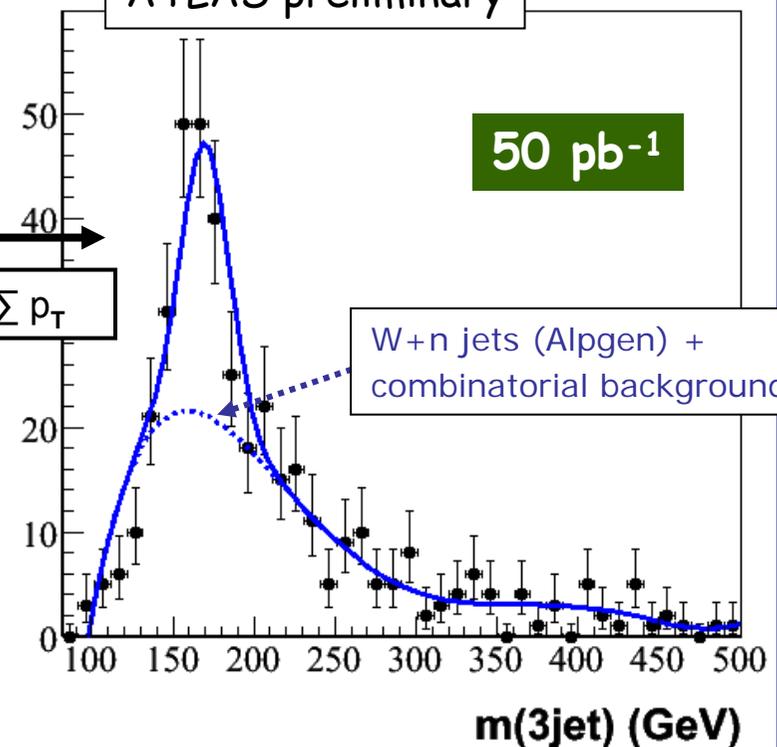


NO b-tag !!

3 jets with largest $\sum p_T$

ATLAS preliminary

W.Verkerke



50 pb⁻¹

W+n jets (Alpgen) +
combinatorial background

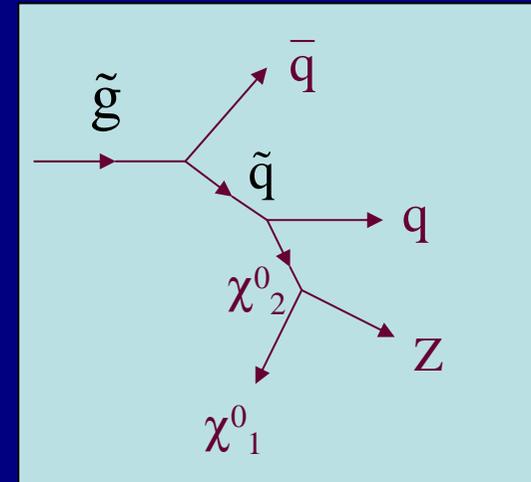
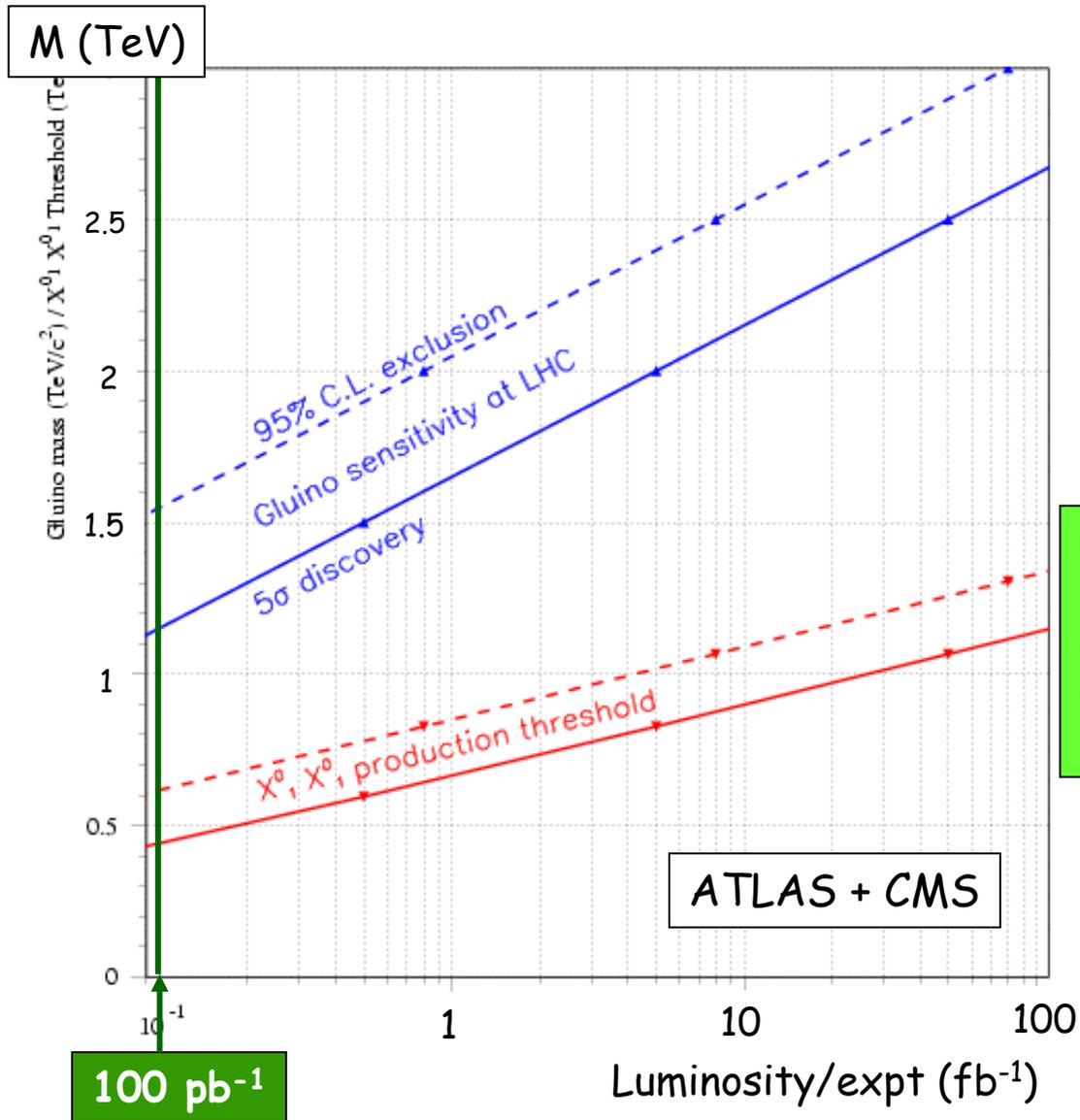
Top signal observable in early days with no b-tagging and simple analysis (100 ± 20 evts for 50 pb⁻¹) → measure σ_{tt} to 20%, m to 10 GeV with ~100 pb⁻¹ ?

In addition, excellent sample to:

- commission b-tagging, set jet E-scale using $W \rightarrow jj$ peak
- understand detector performance for e, μ , jets, b-jets, missing E_T , ...
- understand / constrain theory and MC generators using e.g. p_T spectra



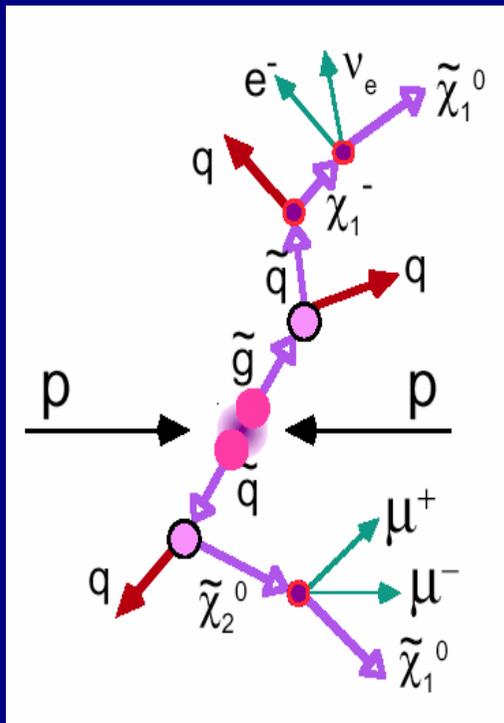
Example of "early" discovery: Supersymmetry ?



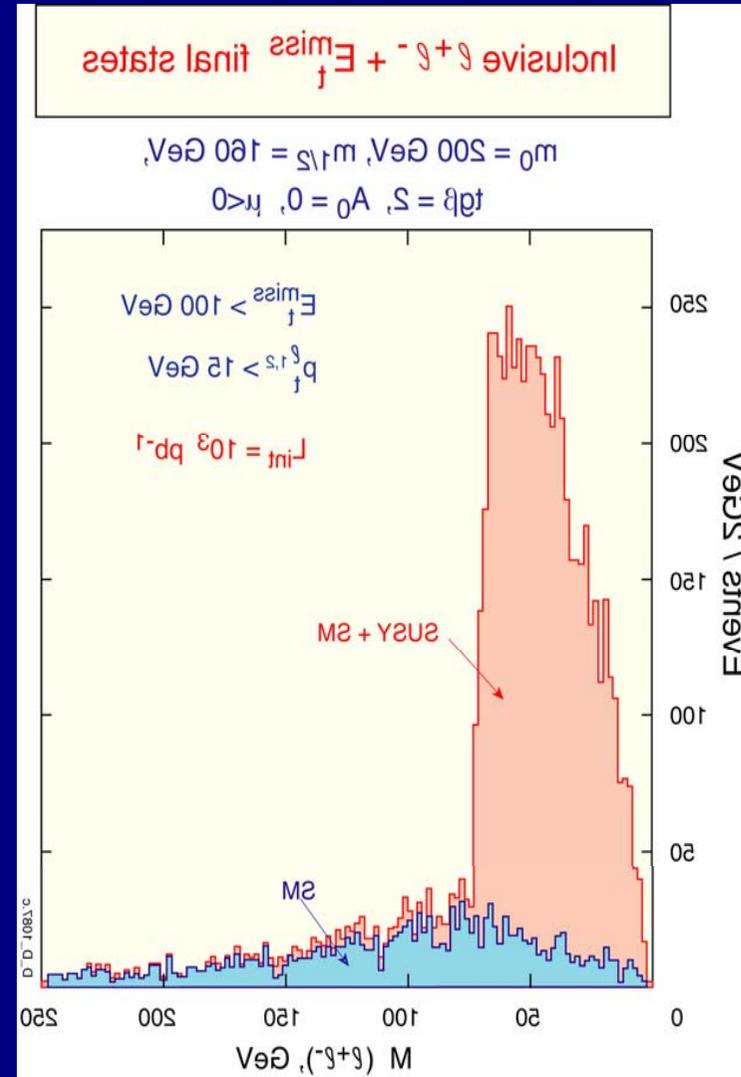
Our field, and planning for future facilities, will benefit a lot from quick determination of scale of New Physics. E.g. with 100 (good) pb^{-1} LHC could say if SUSY accessible to a ≤ 1 TeV ILC

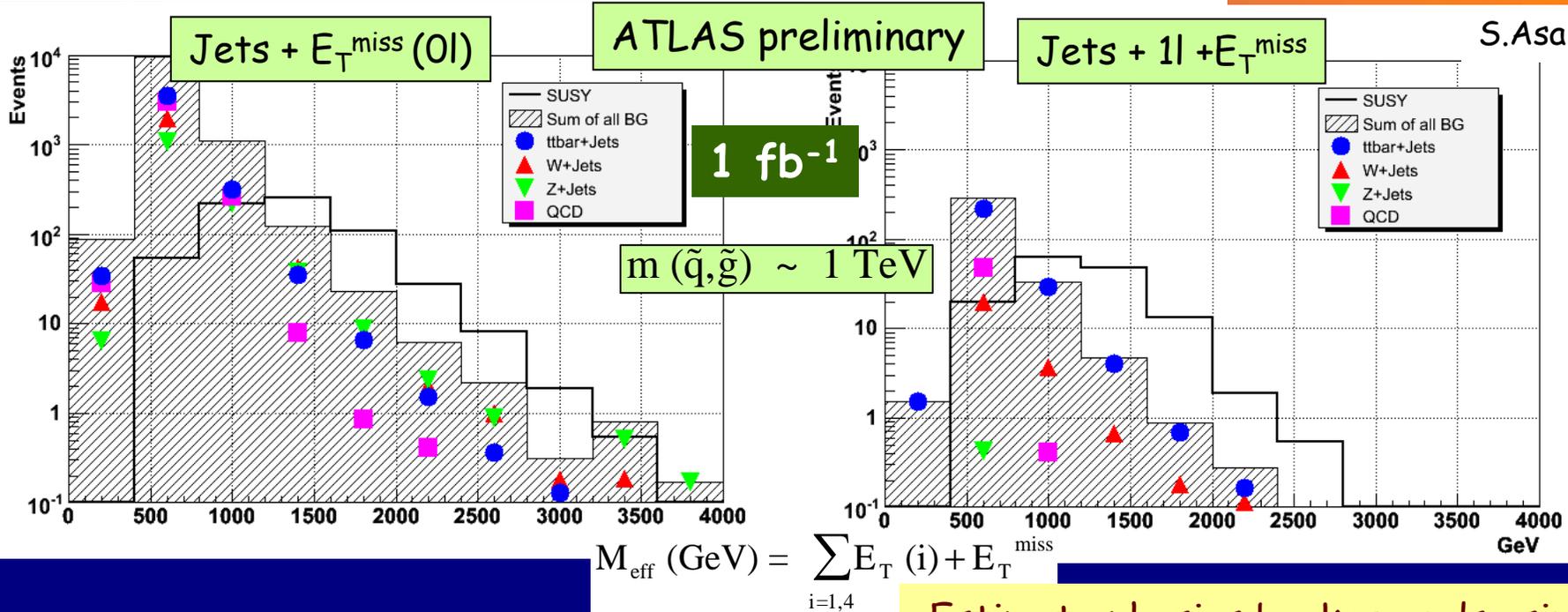
BUT: understanding $E_{\text{T}}^{\text{miss}}$ spectrum (and tails from instrumental effects) is one of the most crucial and difficult experimental issue for SUSY searches at hadron colliders.

Squarks & gluinos

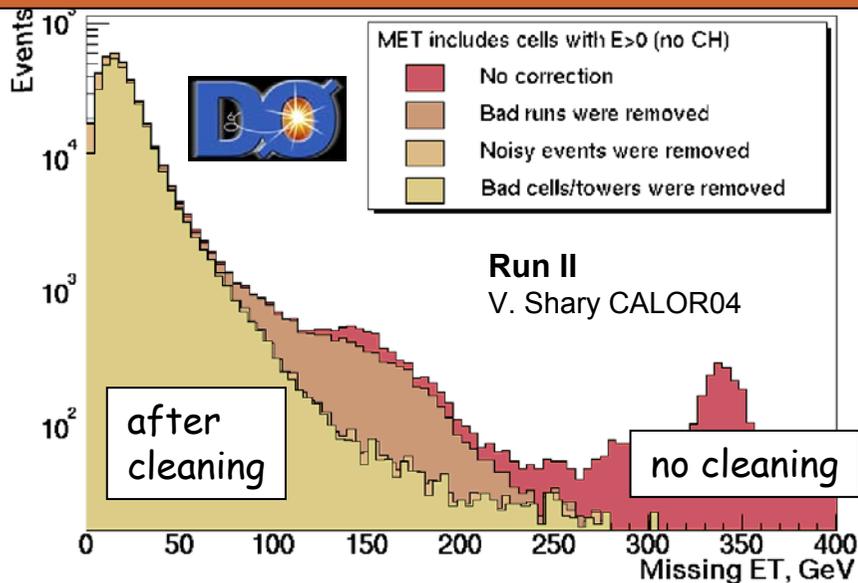


Low energy SUSY will be found quickly

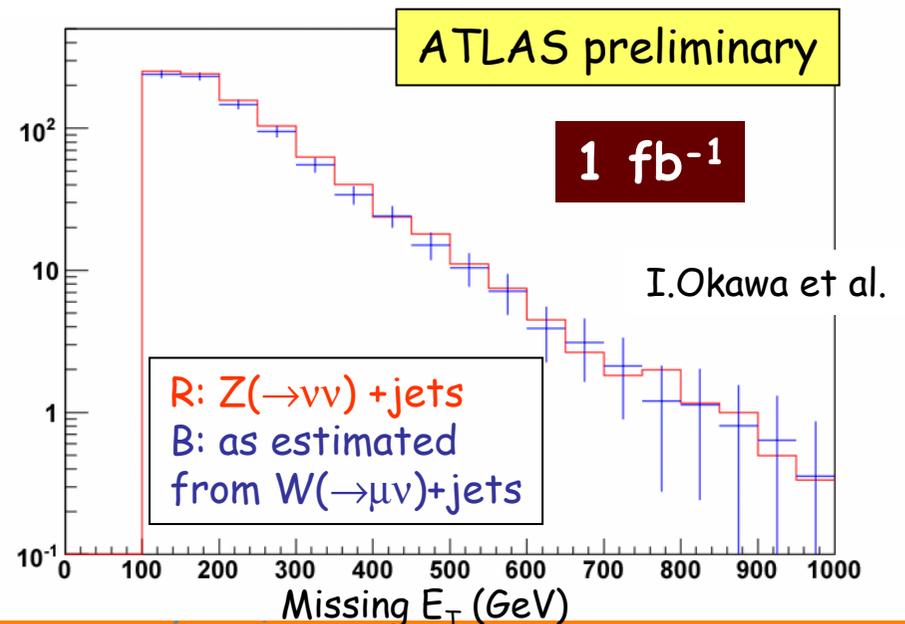




E_T^{miss} spectrum contaminated by cosmics, beam-halo, machine/detector problems, etc.

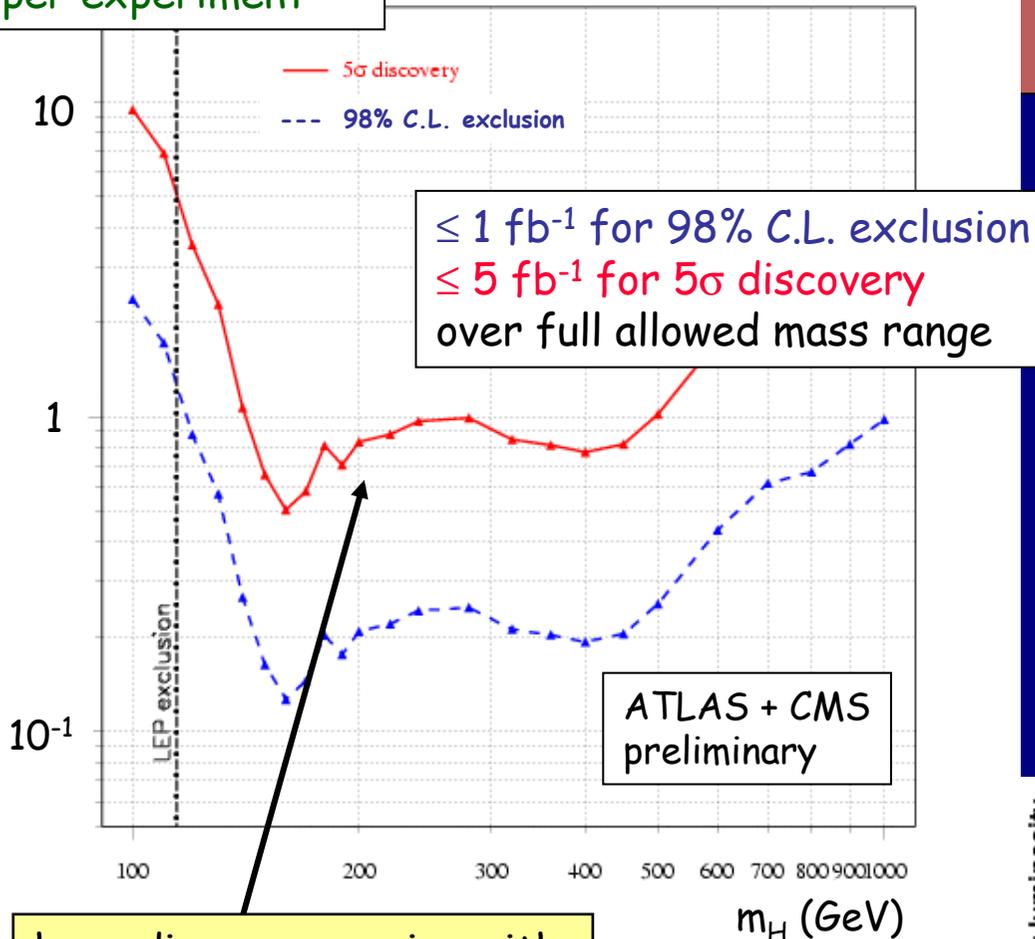


Estimate physics backgrounds using data (control samples)



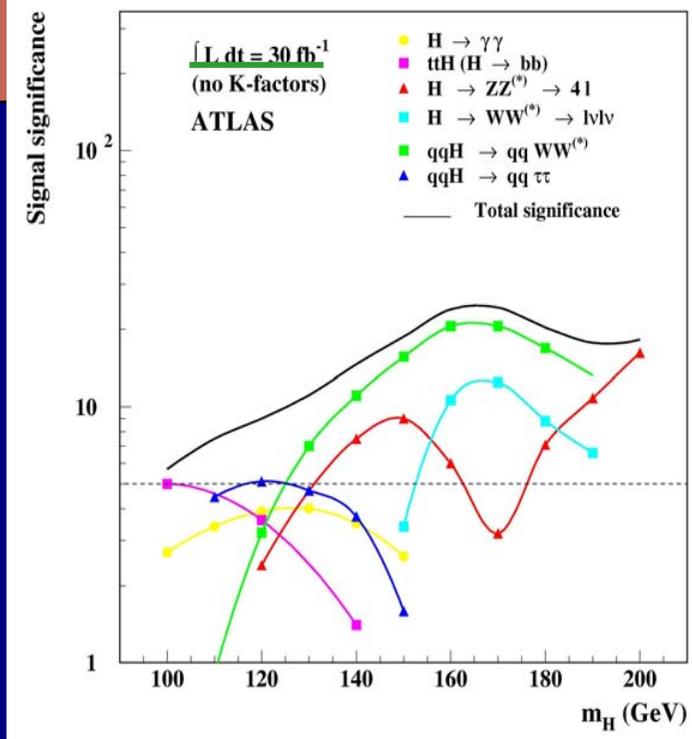
What about the SM Higgs boson ?

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

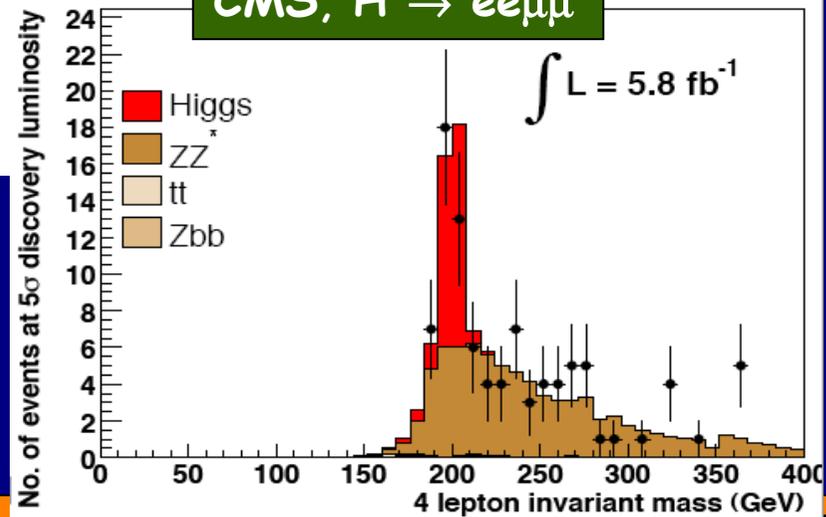


here discovery easier with gold-plated $H \rightarrow ZZ \rightarrow 4l$
 \rightarrow by end 2008 ?

$H \rightarrow 4l$: narrow mass peak, small background
 $H \rightarrow WW \rightarrow l\nu l\nu$ (dominant at the Tevatron): counting channel (no mass peak)

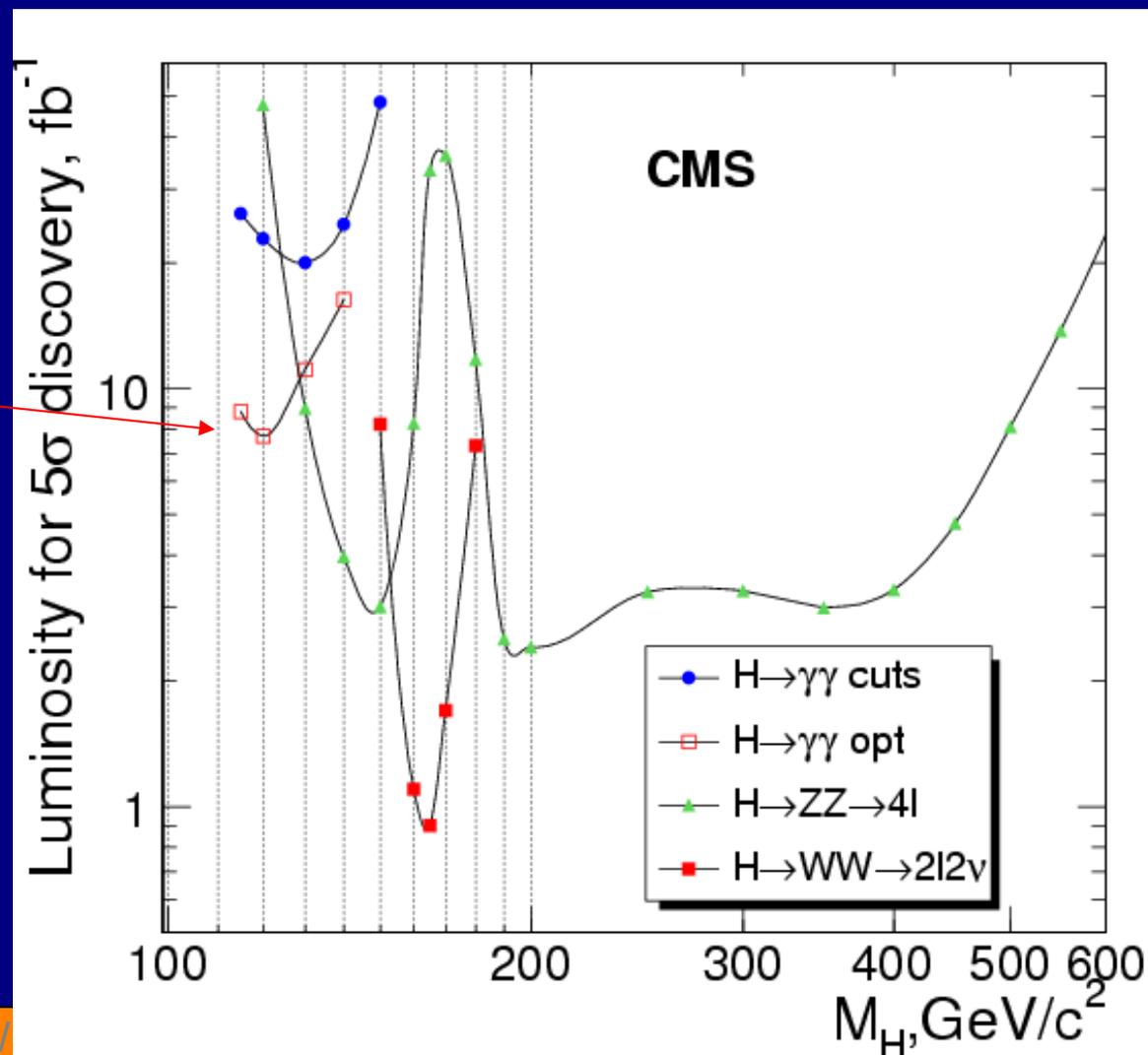


CMS, $H \rightarrow ee\mu\mu$



The Physics Reach of CMS has been re-evaluated in 2006

The low mass Higgs in the two photon mode can be discovered in CMS alone with 10 fb^{-1}

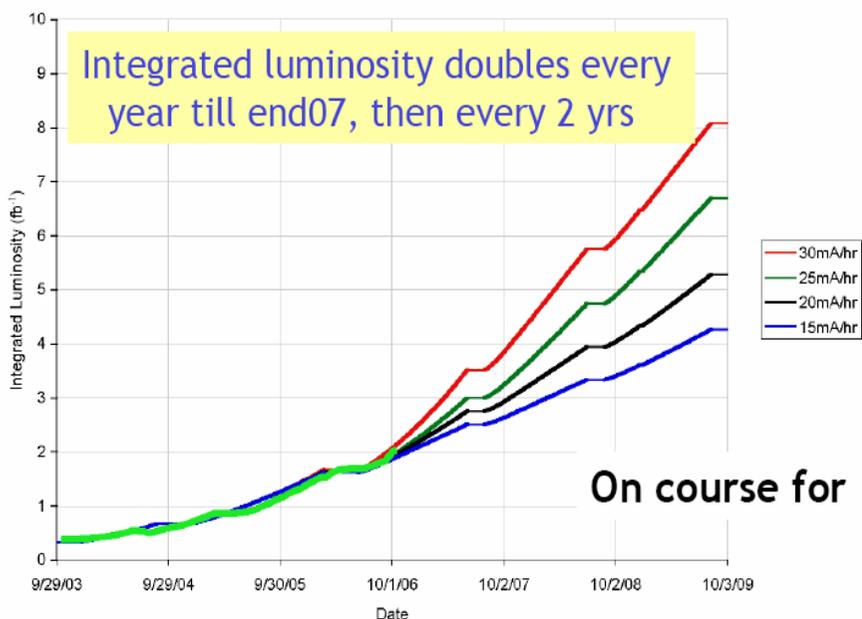
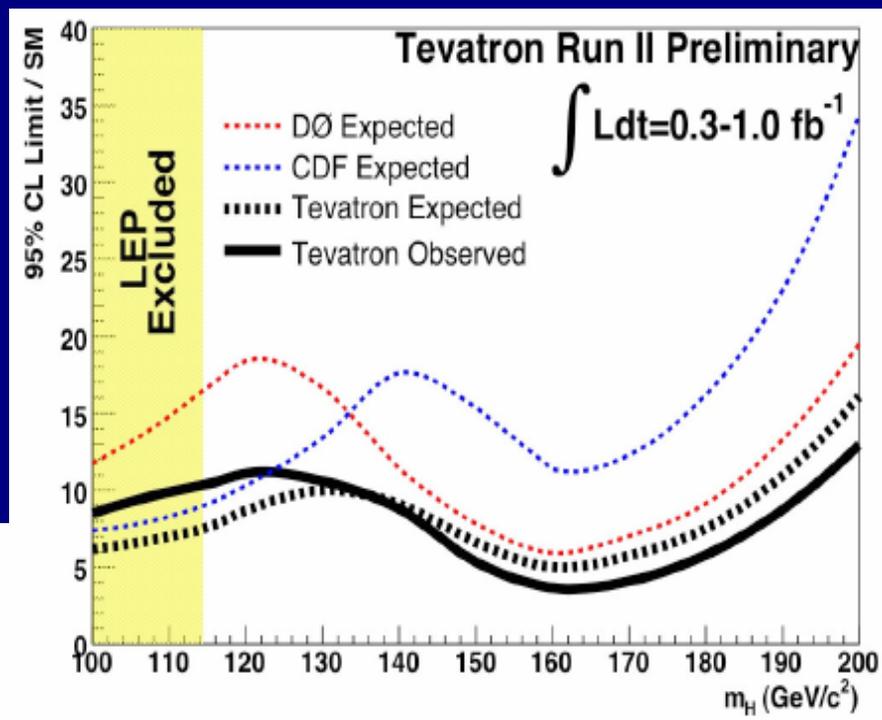




Meanwhile across the Ocean ...

SM Higgs Boson at FNAL

Current Limits: 5–10 times SM cross-section
Anticipation: reach SM sensitivities





Light Higgs : more difficult ...

$m_H \sim 115 \text{ GeV}$ 10 fb^{-1} : $S/\sqrt{B} \approx 4$ ATLAS

K-factors $\equiv \sigma(\text{NLO})/\sigma(\text{LO}) \approx 2$
for $H \rightarrow \gamma\gamma$ NOT included (conservative)

3 (complementary) channels with similar (small) significances:

$H \rightarrow \gamma\gamma$

$S=130, B=4300, S/\sqrt{B}=2$

$t\bar{t}H \rightarrow t\bar{t}b\bar{b} \rightarrow b\bar{b}b\bar{b}j\bar{j}b\bar{b}$

$S=15, B=45, S/\sqrt{B}=2.2$

$q\bar{q}H \rightarrow q\bar{q}\tau\tau$

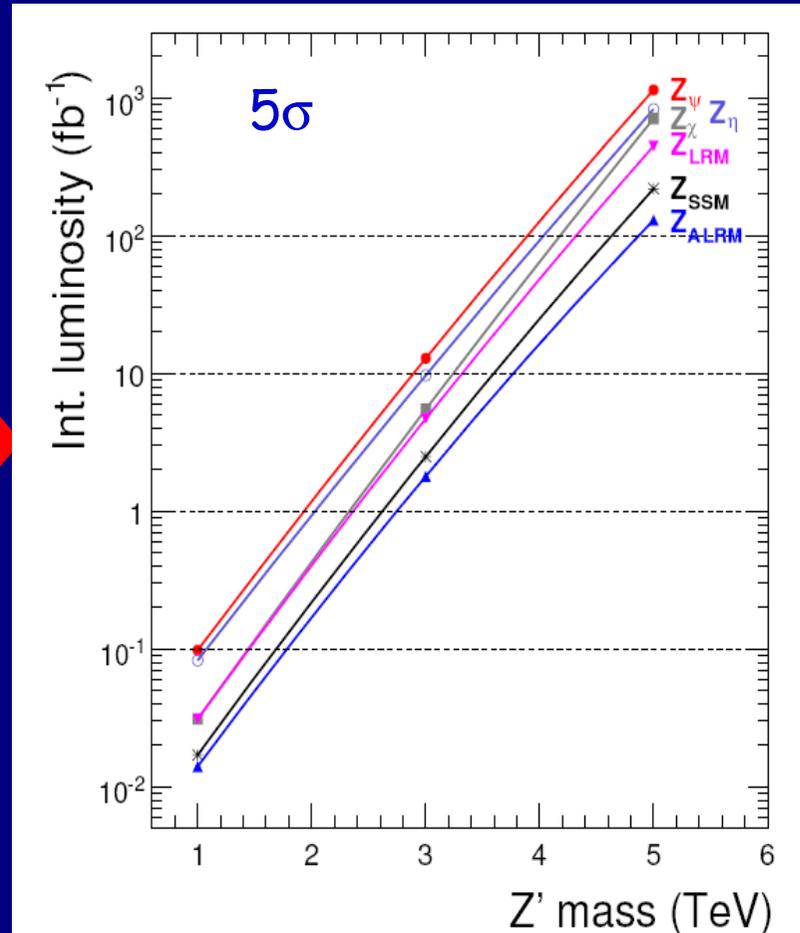
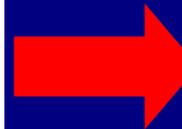
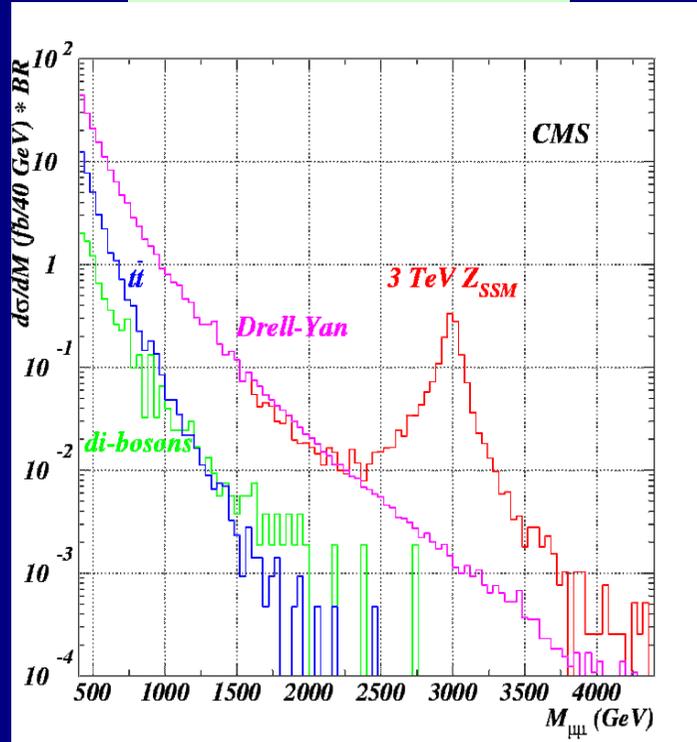
$S=10, B=10, S/\sqrt{B}=2.7$

- 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 $t\bar{t}H$: 4 b-tagged jets needed to reduce combinatorics
 - efficient jet reconstruction over $|\eta| < 5$ crucial for $q\bar{q}H \rightarrow q\bar{q}\tau\tau$: forward jet tag and central jet veto needed against background

All three channels require very good understanding of detector performance and background control to 1-10% \rightarrow convincing evidence likely to come later than 2008 ...

Note: $WH \rightarrow l\nu b\bar{b}$ (dominant at the Tevatron) provides less sensitivity than $t\bar{t}H$ at LHC

$Z' \rightarrow \mu\mu$ production



Low lumi 0.1 fb^{-1} : discovery of 1-1.6 TeV possible, beyond Tevatron II
 High lumi 100 fb^{-1} : extend range to 3.4-4.3 TeV

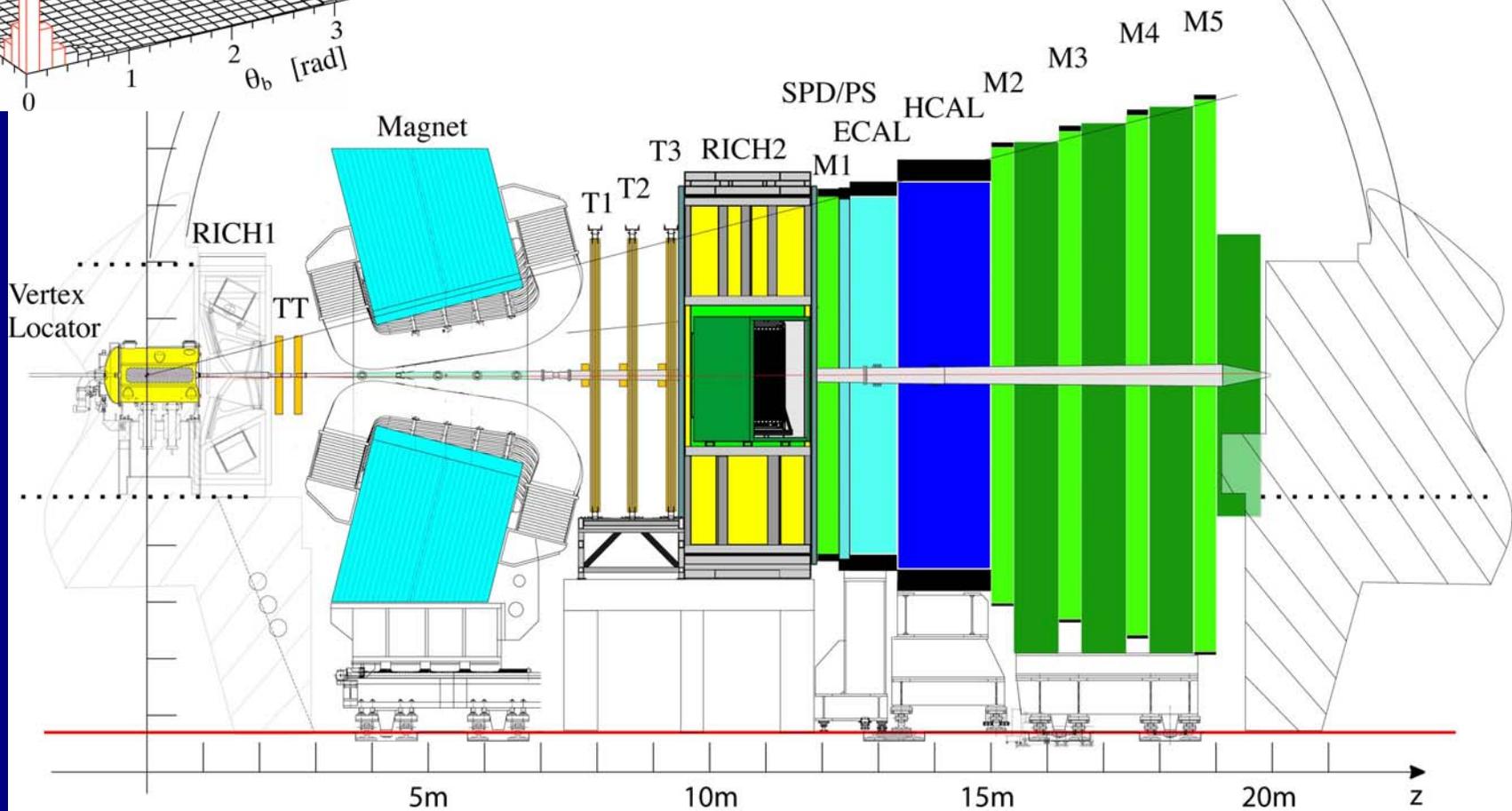
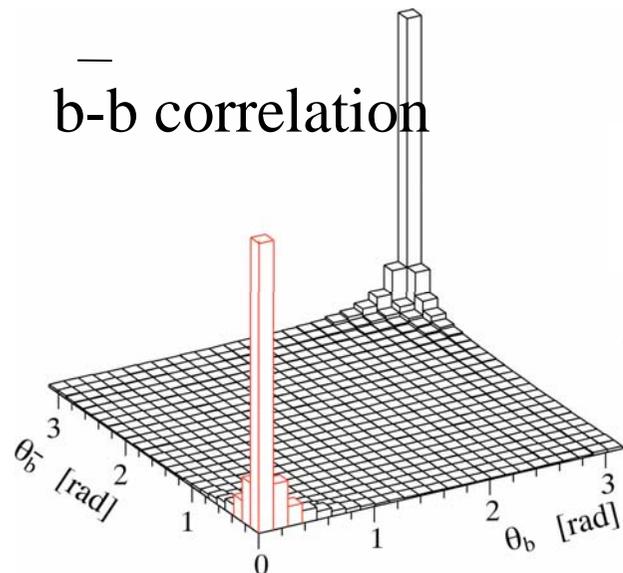


‘Dedicated’ experiments:

ALICE, LHCb, TOTEM, (LHCf)

LHCb detector at IP8

b-b correlation





Let us assume 0.5 fb^{-1} of physics data with LHCb
1/4 of the “nominal” year with $\langle L \rangle = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
= less than 10% of a calendar year

With this data, first check some established results,
e.g.

$\sigma_{\Delta m_S} = 0.014 \text{ ps}^{-1}$ cf. 0.10 ps^{-1} by CDF now
 $\sigma_{\sin 2\beta} = 0.04$ cf. 0.03 current world average
lifetimes

⇒ understanding of trigger, momentum scale,
 σ_τ , tagging performance, detector acceptance etc.



Then proceed to exclude (or discover!) not yet excluded (relatively) large New Physics effects

e.g.

CP violation in B_s , $B_s \rightarrow J/\psi \phi$ measuring $\phi_s = -2 \arg V_{ts}$

ϕ_s : B_s - B_s oscillation phase (respect to that of V_{cb})

$\sigma_{\phi_s} = 0.04$ rad, SM prediction $\phi_s \approx -0.04$ rad

cf. current D0 result: $\sigma_{\phi_s} = -0.56(+0.44-0.41)$ rad @1 fb⁻¹

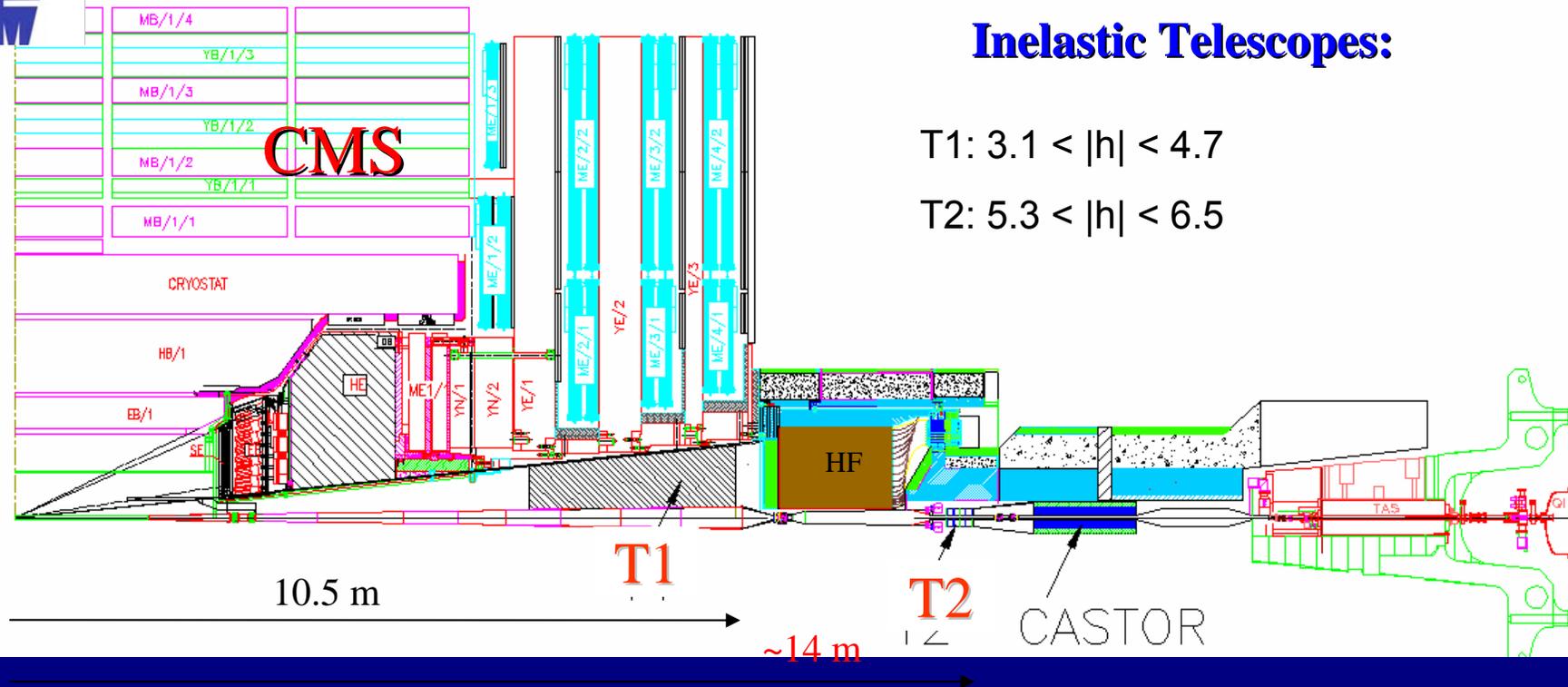
Search for very rare $B_s \rightarrow \mu^+ \mu^-$ decays

$\text{Br}(B_s \rightarrow \mu^+ \mu^-) < \text{SM-Br}$ (90% CL) $\text{SM-Br} \sim 3 \times 10^{-9}$

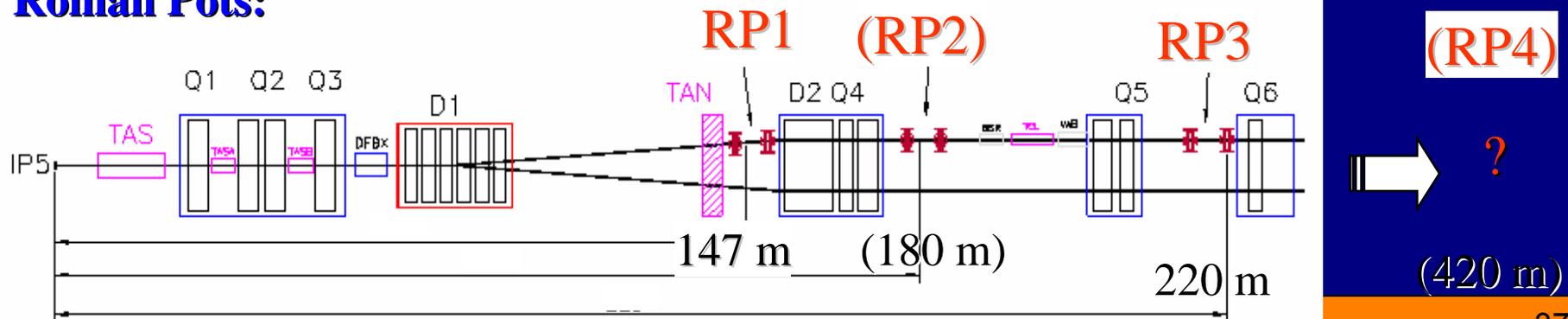
cf current CDF result $< 0.8 \times 10^{-7}$ (90% CL) @780 pb⁻¹

cf current D0 results $< 1.9 \times 10^{-7}$ (90% CL) @700 pb⁻¹

i.e. With 2008 LHCb data, we should be able to reach the Standard Model level of sensitivities



Roman Pots:



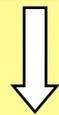


TOTEM Physics: Total p-p Cross-Section

- Current models predict for 14 TeV:
90 – 130 mb
- Aim of TOTEM: ~ 1% accuracy
- **Luminosity independent method:**

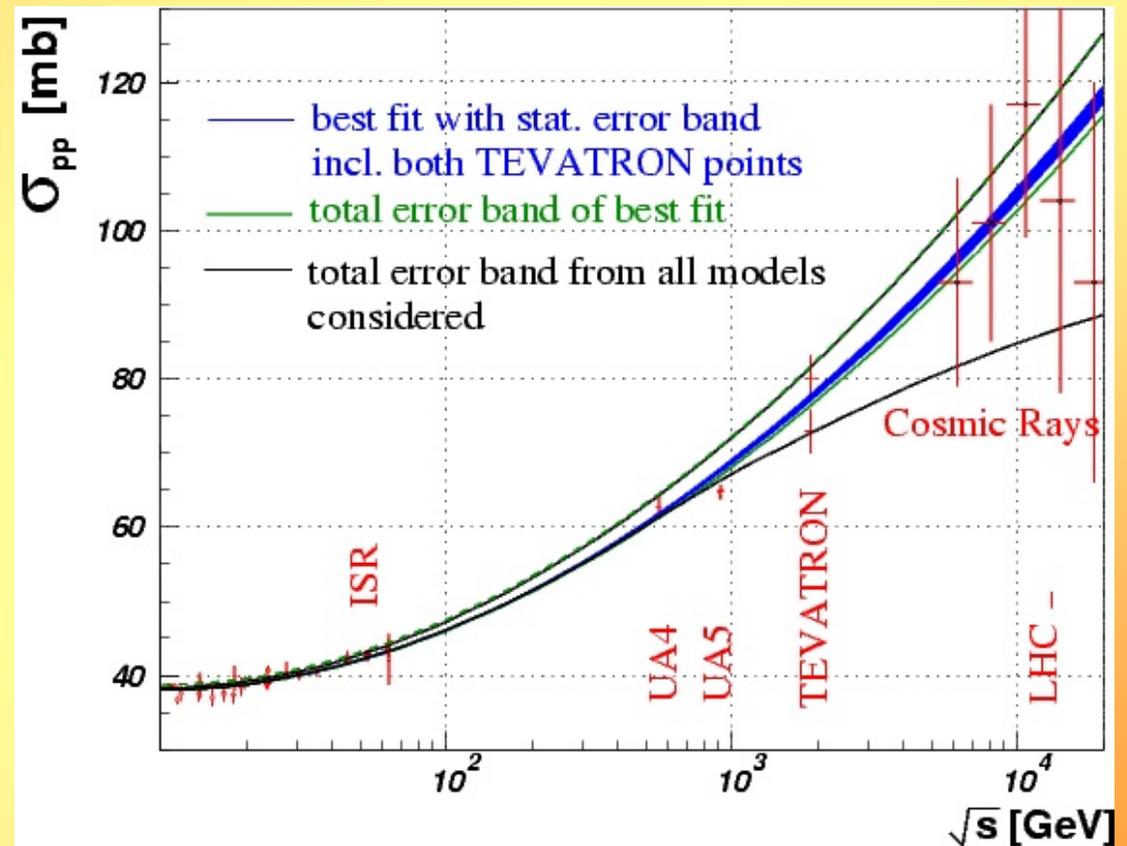
Optical Theorem
$$L \sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \frac{dN}{dt} \Big|_{t=0}$$

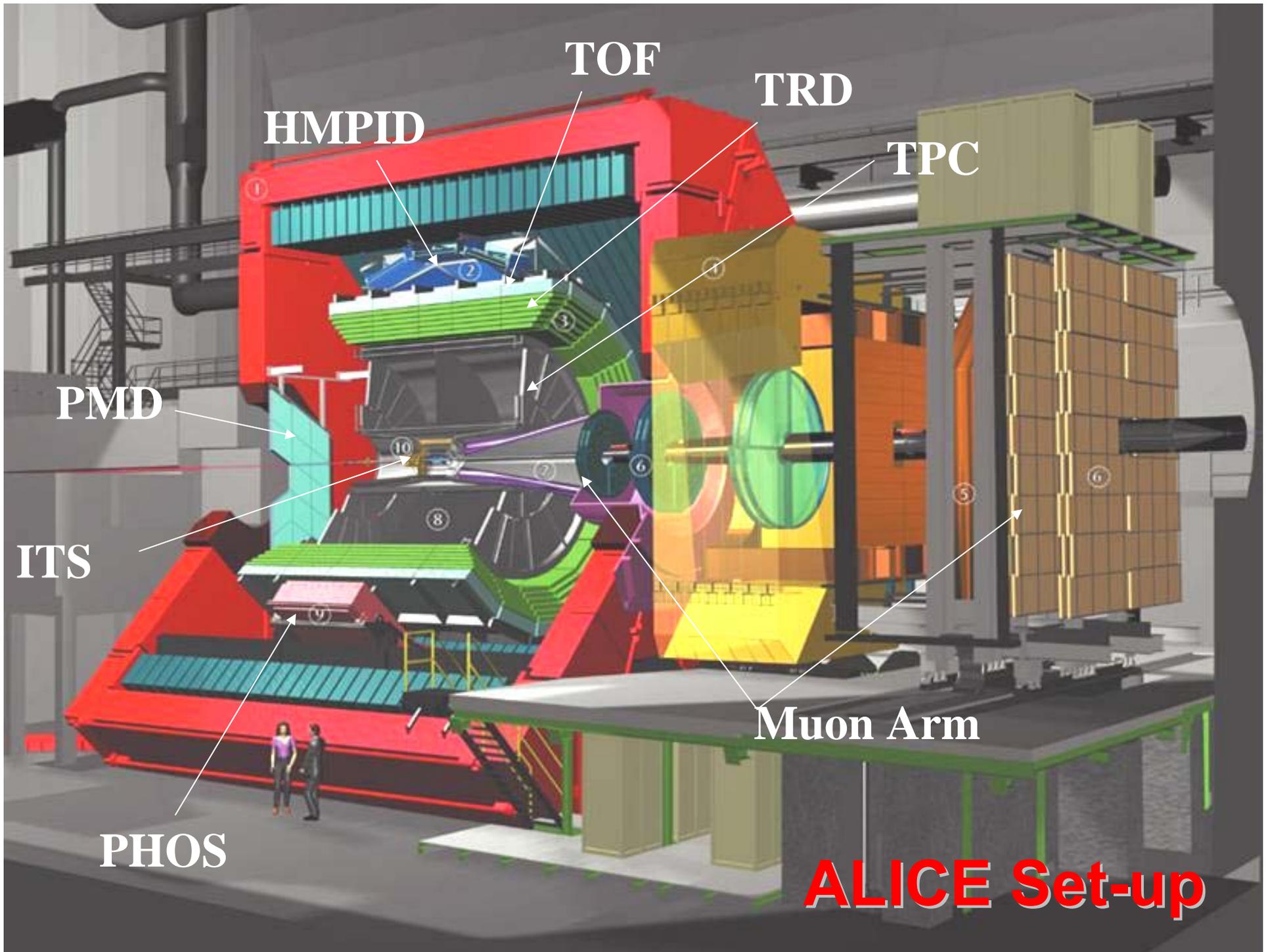
$$L \sigma_{tot} = N_{elastic} + N_{inelastic}$$



$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN/dt) \Big|_{t=0}}{N_{el} + N_{inel}}$$

COMPETE Collaboration:







Hard Processes at the LHC

Main novelty of the LHC: large hard cross section

~2% at SPS

$$\sigma^{hard}(p_T > 2\text{GeV}; y = 0) / \sigma^{tot} \sim 50\% \text{ at RHIC}$$

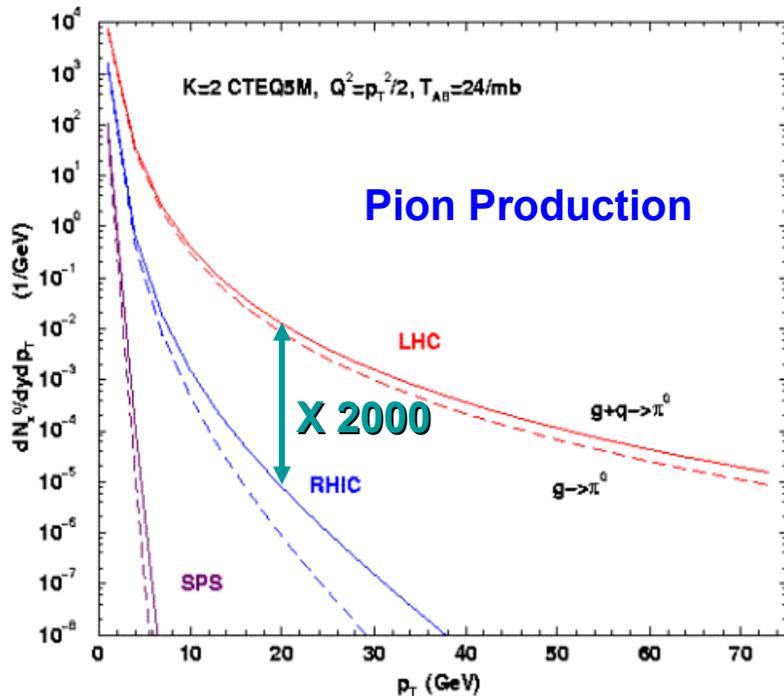
~98% at LHC

Hard processes are extremely useful tools

- *probe matter at very early times (QGP) !!!*
- *hard processes can be calculated by pQCD -> precision measurements*

Reasonable jet rates up to $E_T > 200$ GeV

Au+Au ($b < 3$) $\rightarrow \pi^0$ $\sqrt{s} = 20, 200, 5500$ AGeV



Pb Pb jet rates $|\eta| < 0.5$:

$p_T \text{ jet} >$ (GeV/c)	jets/event (10% central)	jets/0.5 nb ⁻¹
5	>200	
20	2	$2 \cdot 10^9$
50	$5 \cdot 10^{-2}$	$5 \cdot 10^5$
100	$2.5 \cdot 10^{-3}$	$2.5 \cdot 10^6$
200	10^{-4}	10^5



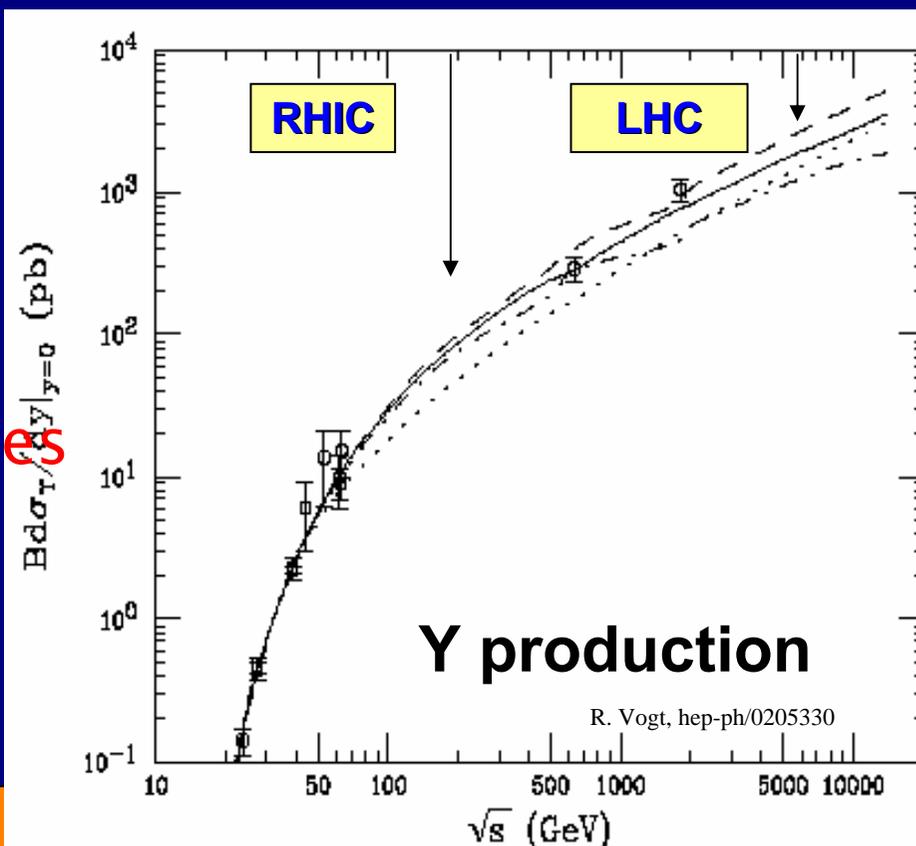
Heavy Quarks & Quarkonia

copious heavy quark production

- charm @ LHC ~ strange @ SPS
 - statistical hadronization picture?
 - jet-quenching with heavy quarks

N(qq̄) per central AA (b=0)			
	SPS	RHIC	LHC
charm	0.2	10	200
bottom	---	0.05	6

- Y_{ds}/dy LHC ~ 20 x RHIC
- full set of quarkonia states
 - J/Y, Y', Y, Y', Y''

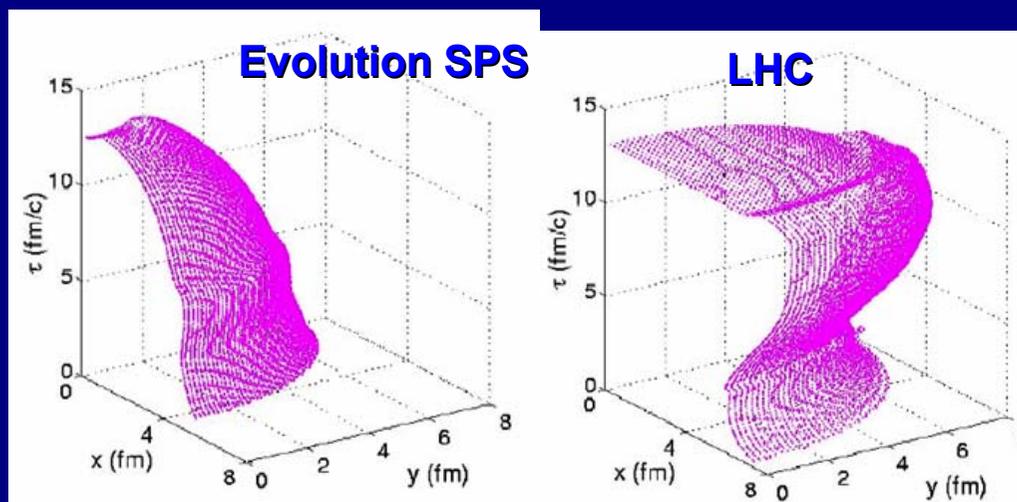




Soft Physics

Important changes compared to lower energies are expected

- very different evolution with time
much larger volume & longer lifetime
- Is the QGP a 'perfect liquid' ?
 - large flow (v_2) discovered at RHIC
 - theory predicts it will saturate with energy
 - extrapolation of data suggests continued rise ?





With the first collision data ($1-100 \text{ pb}^{-1}$) at 14 TeV

Understand detector performance in situ in the LHC environment, and perform first physics measurements:

- Measure particle multiplicity in minimum bias (a few hours of data taking ...)
- Measure QCD jet cross-section to $\sim 30\%$?
(Expect $> 10^3$ events with $E_T(j) > 1 \text{ TeV}$ with 100 pb^{-1})
- Measure W, Z cross-sections to 10% with 100 pb^{-1} ?
- Observe a top signal with $\sim 30 \text{ pb}^{-1}$
- Measure tt cross-section to 20% and $m(\text{top})$ to 7–10 GeV with 100 pb^{-1} ?
- Improve knowledge of PDF (low-x gluons !) with W/Z with $O(100) \text{ pb}^{-1}$?
- First tuning of MC (minimum-bias, underlying event, tt, W/Z+jets, QCD jets,...)

And, more ambitiously:

- Discover SUSY up to gluino masses of $\sim 1.3 \text{ TeV}$?
- Discover a Z' up to masses of $\sim 1.3 \text{ TeV}$?
- Surprises ?



Conclusions

And, later on

- The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to $m \approx 5-6$ TeV
- if New Physics is there, the LHC will find it
- it will say the final word about the SM Higgs mechanism and many TeV-scale predictions
- it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology
- most importantly: it will likely tell us which are the right questions to ask, and how to go on

