Supersymmetry: Preparation for Early LHC Running

R. Cavanaugh
University of Florida

- *Restaurant*
- *Entrée*
- *Main Course*
- *Dessert*

23 June, Institute for Physics and Mathematics of the Universe, Tokyo, Japan

Brief History of Supersymmetry

- Introduced in Early 70's
  - as a part of an extension to special relativity
    - Golfand, Likhtman, Volkov, Akulov, Wess, Zumino
  - in context of String Theory
    - Ramond, Schwarz, Neveu
- Early 80's
  - First Realistic version of Supersymmetry: MSSM
    - Georgi, Dimopoulos
- Many breaking variations:
  - CMSSM, GMSB, AMSB, ...
- Intensely sought since then to present day
  - LEP (CERN)
  - Tevatron (Fermilab)
- Result:
  - No irrefutable evidence!


Vith the Arts
ınd Entertainment

Science Times

The New York Times

315 Physicists Report Failure In Search for Supersymmetry

The negative result illustrates the risks of Big Science, and its often sparse pickings.

By MALCOLM W. BROWNE

THREE HUNDRED AND FIFTEEN physicists worked on the experiment.

Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets.

But despite this arsenal of brains and technological brawn assembled at the Fermilab accelerator laboratory, the participants have failed to find their quarry, a disagreeable reminder that as science gets harder, even Herculean efforts do not guarantee success.

In trying to ferret out ever deeper layers of nature's secrets, scientists are being forced to accept a markedly slower pace of discovery in many fields of research, and the consequent rising cost of experiments has prompted public and political criticism.

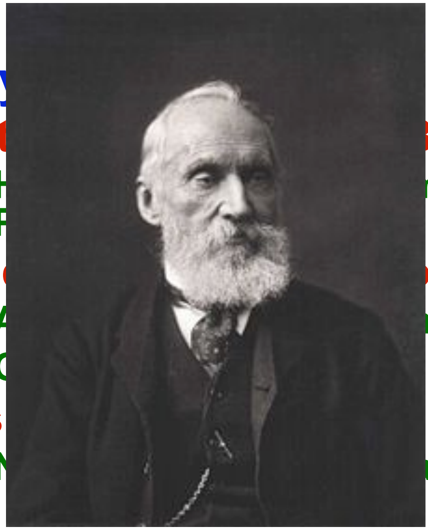
To some, the elaborate trappings and null result of the latest Fermilab experiment seem to typify both the lofty goals and the staggering difficulties of "Big Science," a term coined in 1961 by Dr. Alvin M. Weinberg of Oak Ridge National Laboratory. Some regard such fail-

From Fly to Man, Cells Ob

Why ~~Should~~ Shouldn't there be Anything Beyond the SM?

Phys. Lett. B, 657/87-94 (200 CMSSM

- After many years,
  - No unambiguous evidence of new physics!
  - SM is remarkably robust!
- Deep my
  - Elect ... Breaking?
    - H ... n? Hierarchy P
  - Stan ... rk?
    - A ... mmetries?
    - C
  - Miss
    - N ... at is it?



"There is nothing new to be discovered in physics now, All that remains is more and more precise measurement."

Lord Kelvin (1824 – 1907)

...and then came Quantum Mechanics, Relativity, and a revolution in Physics and Society

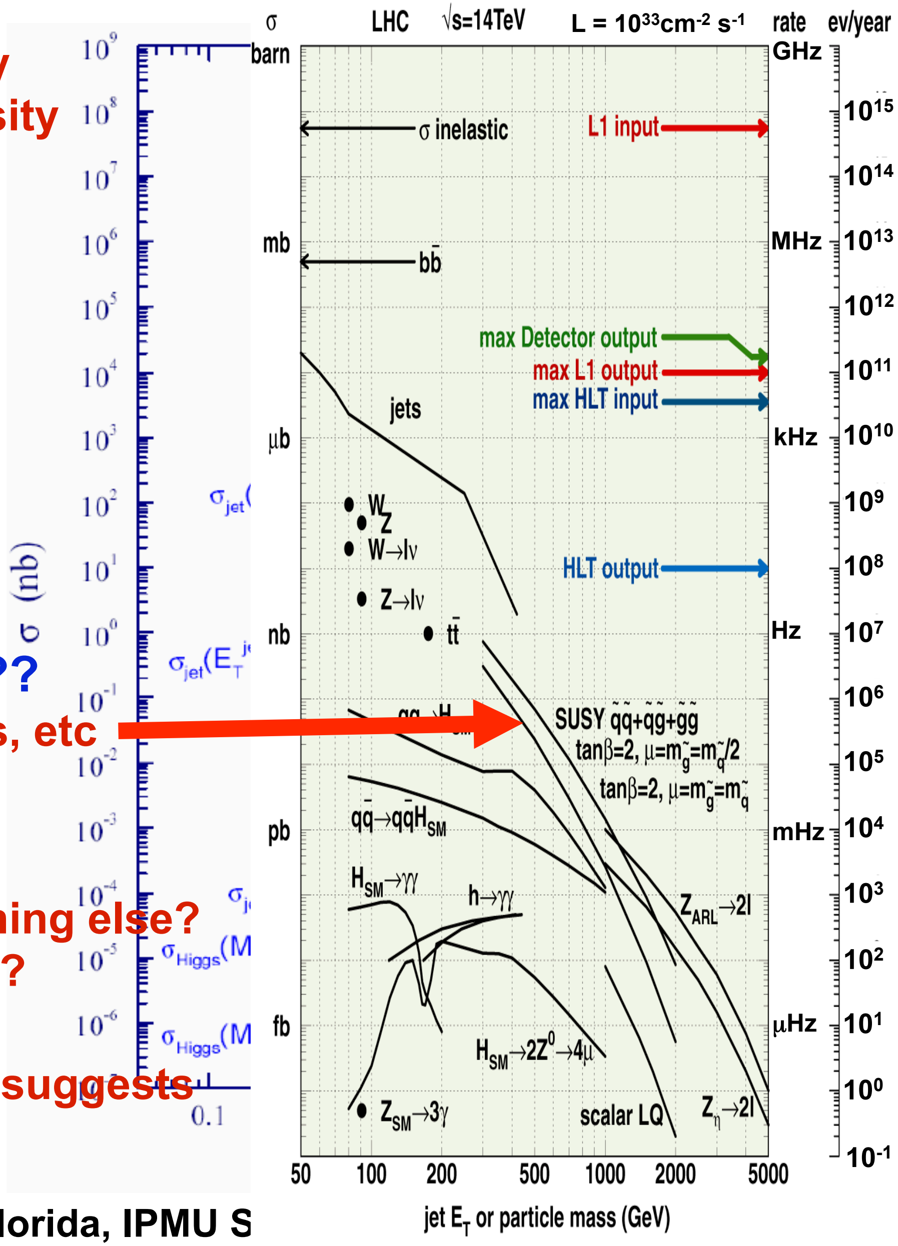
- Actually...
  - SM not only model which describes the data well...
  - CMSSM also accommodates all existing data!
    - Dark Matter included (but not batteries)!
    - Other Models can do this too!

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$ (0 1 2 3)
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ_{had}^0 [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037	
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

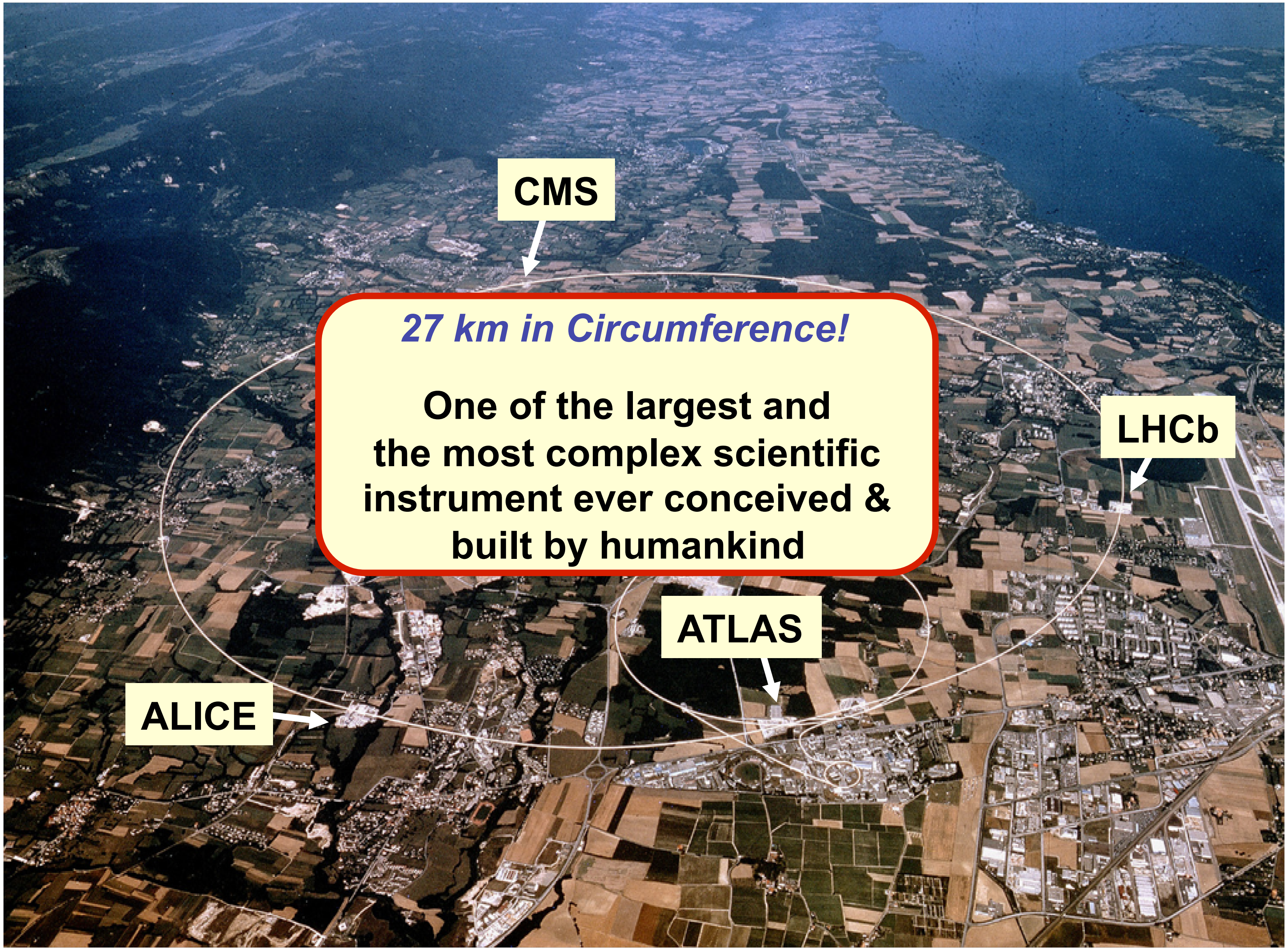
x^2/ndof = 17.0/13 (20% probability)

Physics *Menu* at the LHC

- ***Restaurant*: Chez LHC**
  - **~order of magnitude higher beam energy**
  - **~1-2 orders of magnitude higher luminosity**
- ***Entrée*: Standard Model:**
  - **QCD (pT > 100 GeV)**
    - **100x higher than any previous collider**
  - **Electroweak**
    - **10x higher than any previous collider**
  - **Top**
    - **100x higher than any previous collider**
  - **Use to commission & calibrate detectors**
- ***Main Course*: New Phenomena Factory??**
  - **Low Mass SUSY, Z', Contact Interactions, etc**
  - **Could appear almost immediately!**
- ***Dessert*: Discovery Interpretation**
  - **Is it SUSY? Extra Dimensions? Something else?**
  - **Can we disentangle the new phenomena?**
- **We Live in Exciting Times!**
  - **Huge increase in CM energy! → History suggests that we should see <u>something</u> new!**
  - **CMS working hard to be ready**

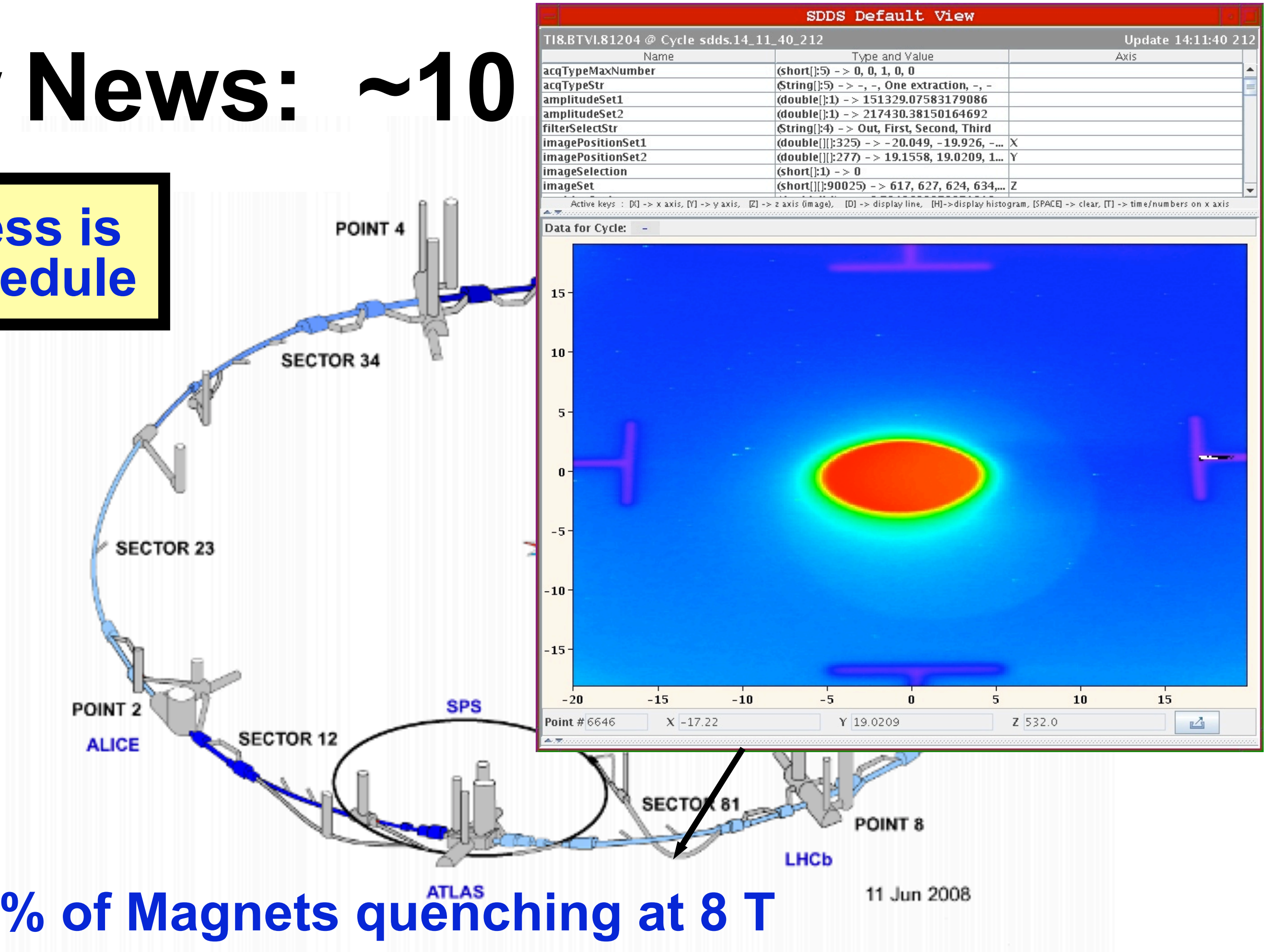


Restaurant : The Large Hadron Collider



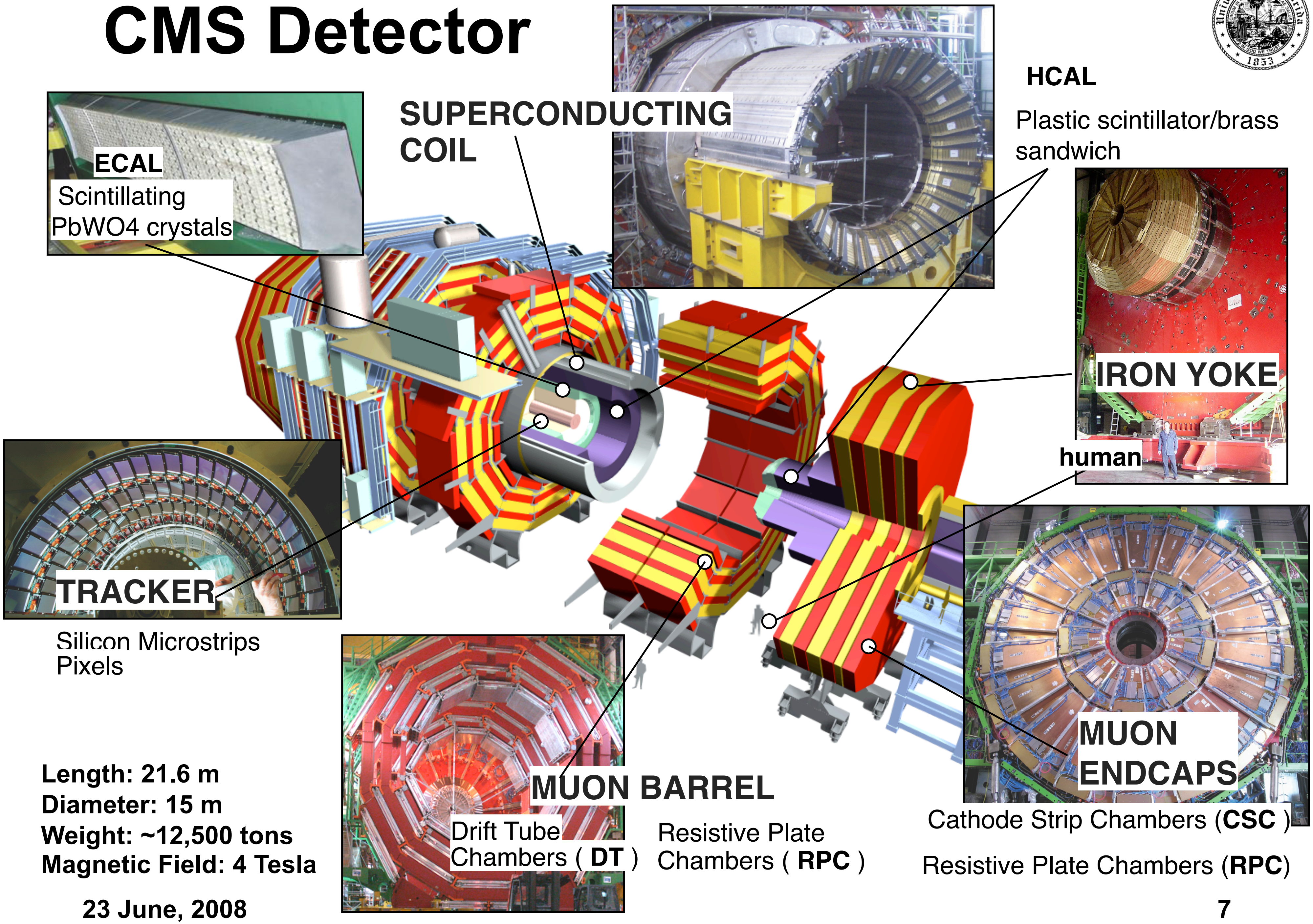
New News: ~10

- **Cool Down Progress is essentially on schedule**



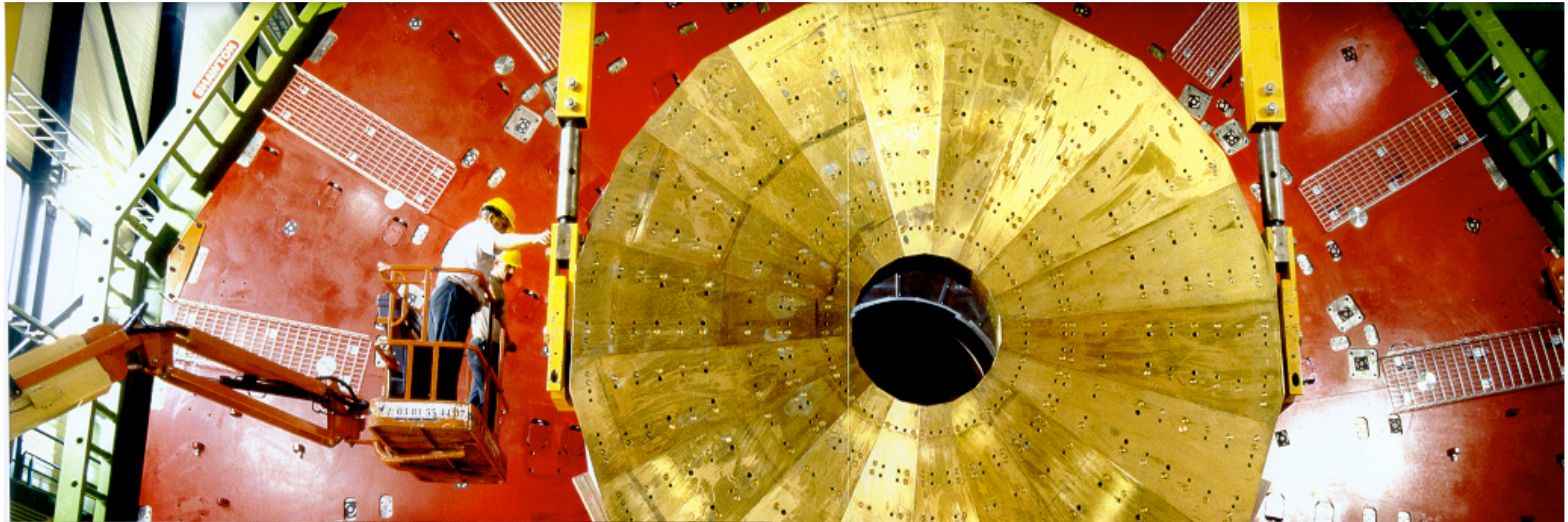
- **But unacceptable % of Magnets quenching at 8 T**
  - **Solution is simple: Must re-train magnets during winter shut-down**
- **Fall back to 5.7 T in 2008 : 10 TeV Center of Mass Energy**
- **Goto 8 T 2009 and beyond: 14 TeV Center of Mass Energy**
- **Still studying the impact -- cross-sections drop by O(50%), etc**
  - **The rest of this talk will assume 14 TeV**
- **LHC Beam scheduled for August!**

CMS Detector



Length: 21.6 m
Diameter: 15 m
Weight: ~12,500 tons
Magnetic Field: 4 Tesla

Hadronic Calorimeter: Swords to Ploughshares



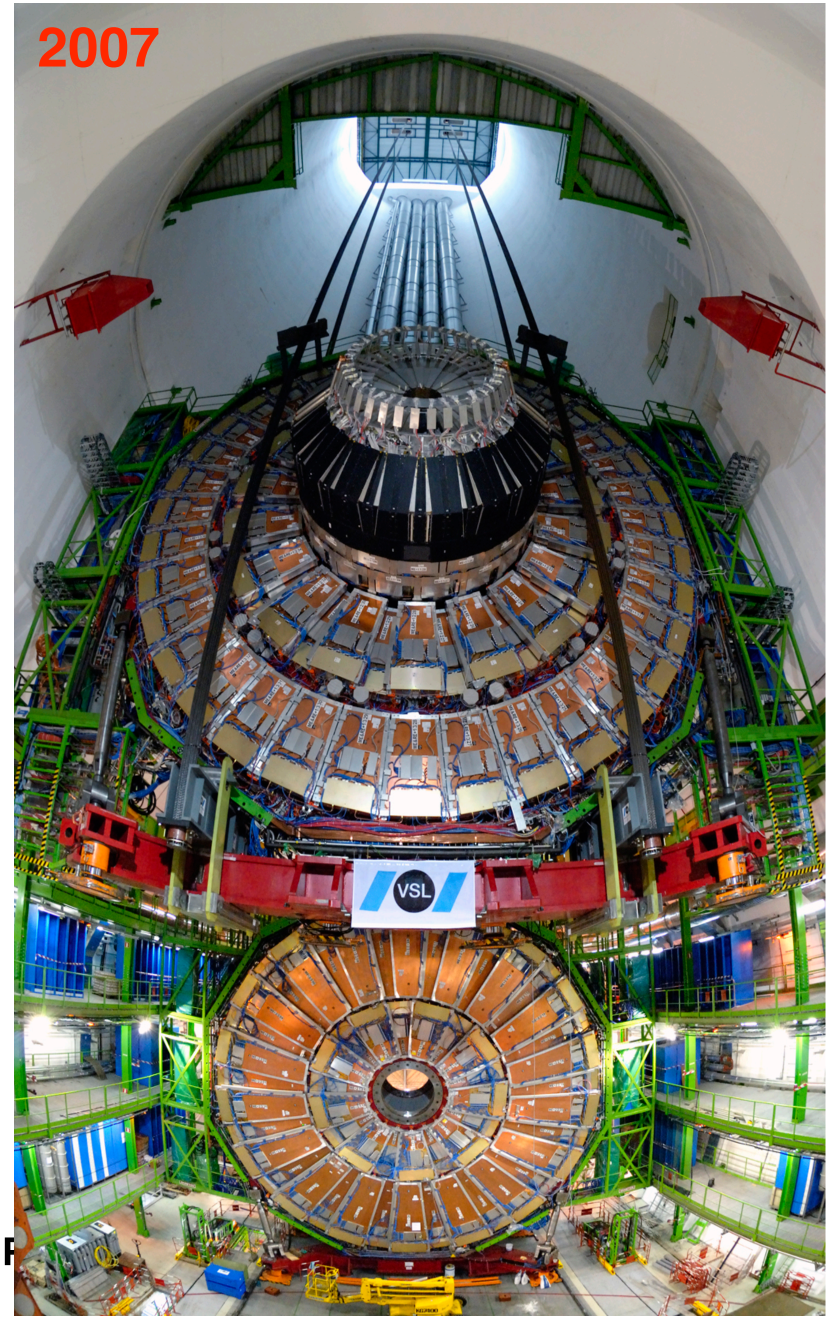
CMS Assembled & Tested on Surface...

...then Lowered Underground

Started end 2006; Finished beginning 2008

...then Lowered Underground

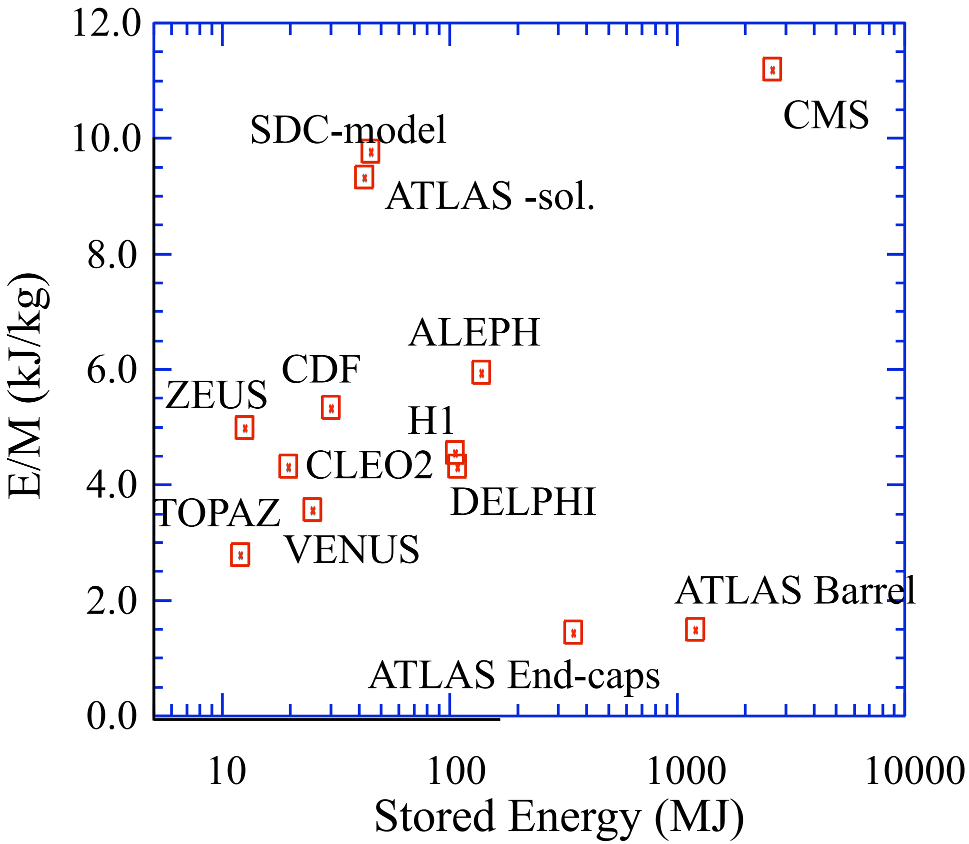
Started end 2006; Finished beginning 2008

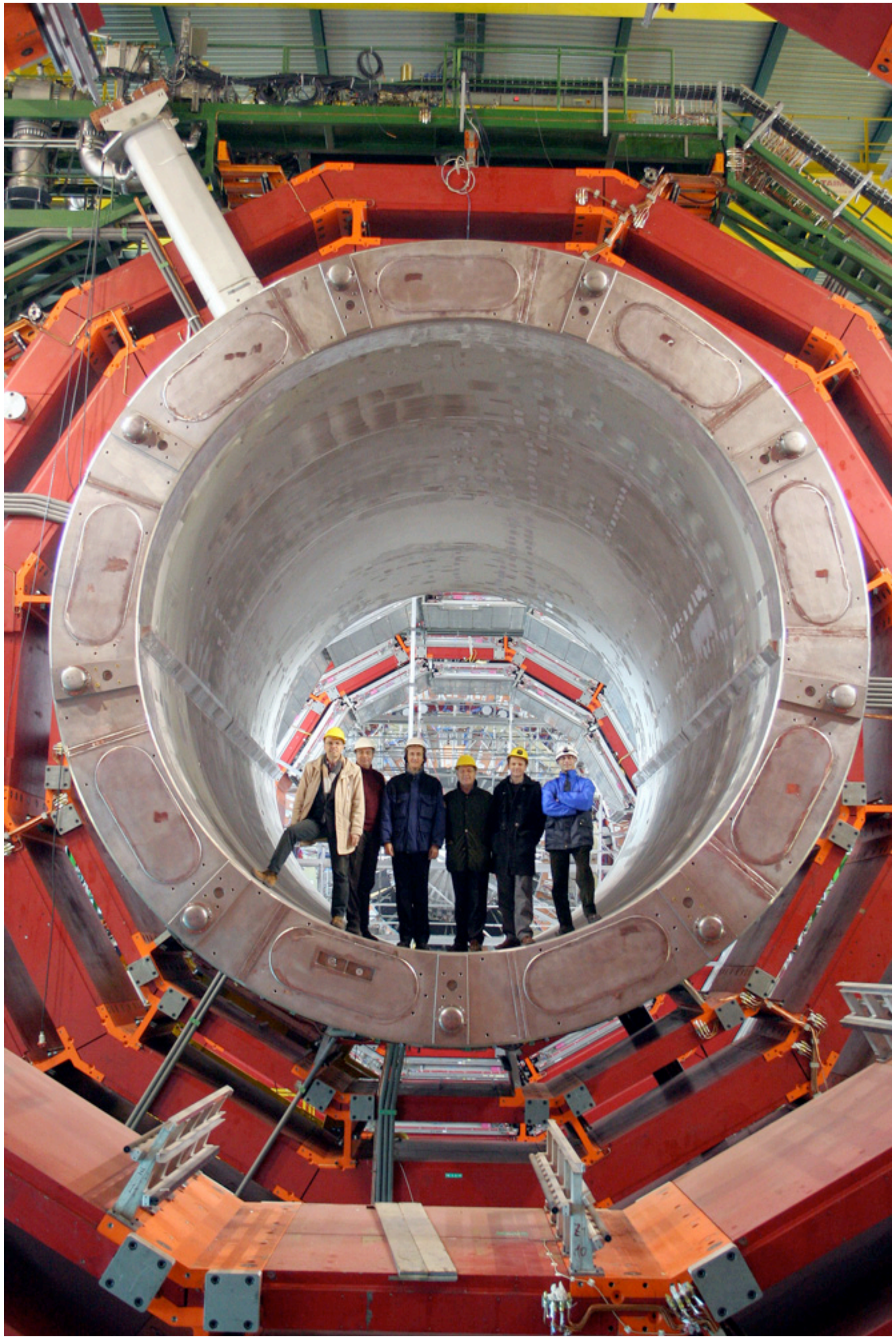


, Florida, IF

Largest Superconducting Magnet in the World

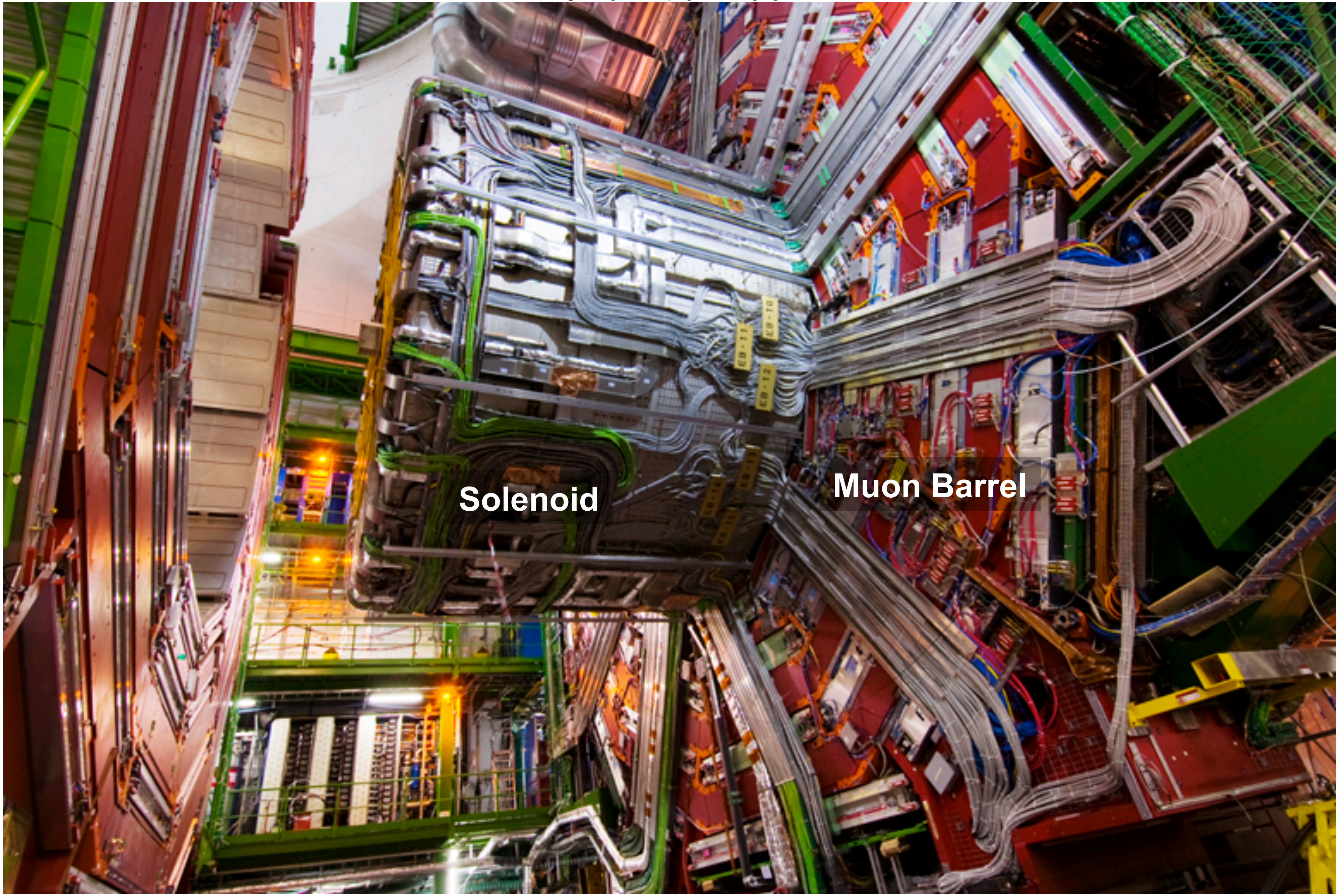
- **4 Tesla Field**
- **6 Meter diameter Bore**
- **2.66 Giga-Joules of Stored Energy**
  - **half-a-tonne of TNT!!**



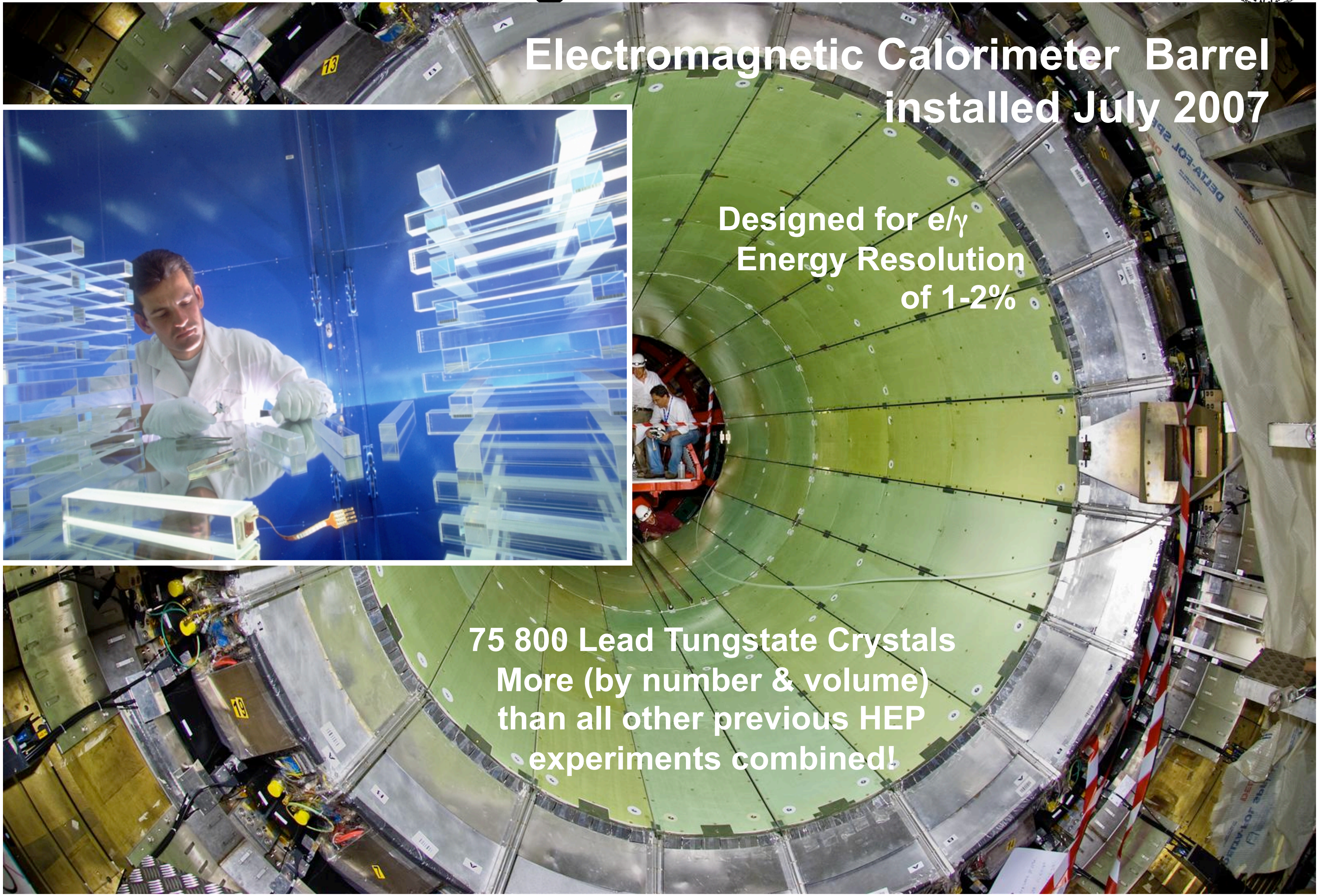


Installed Services on Solenoid

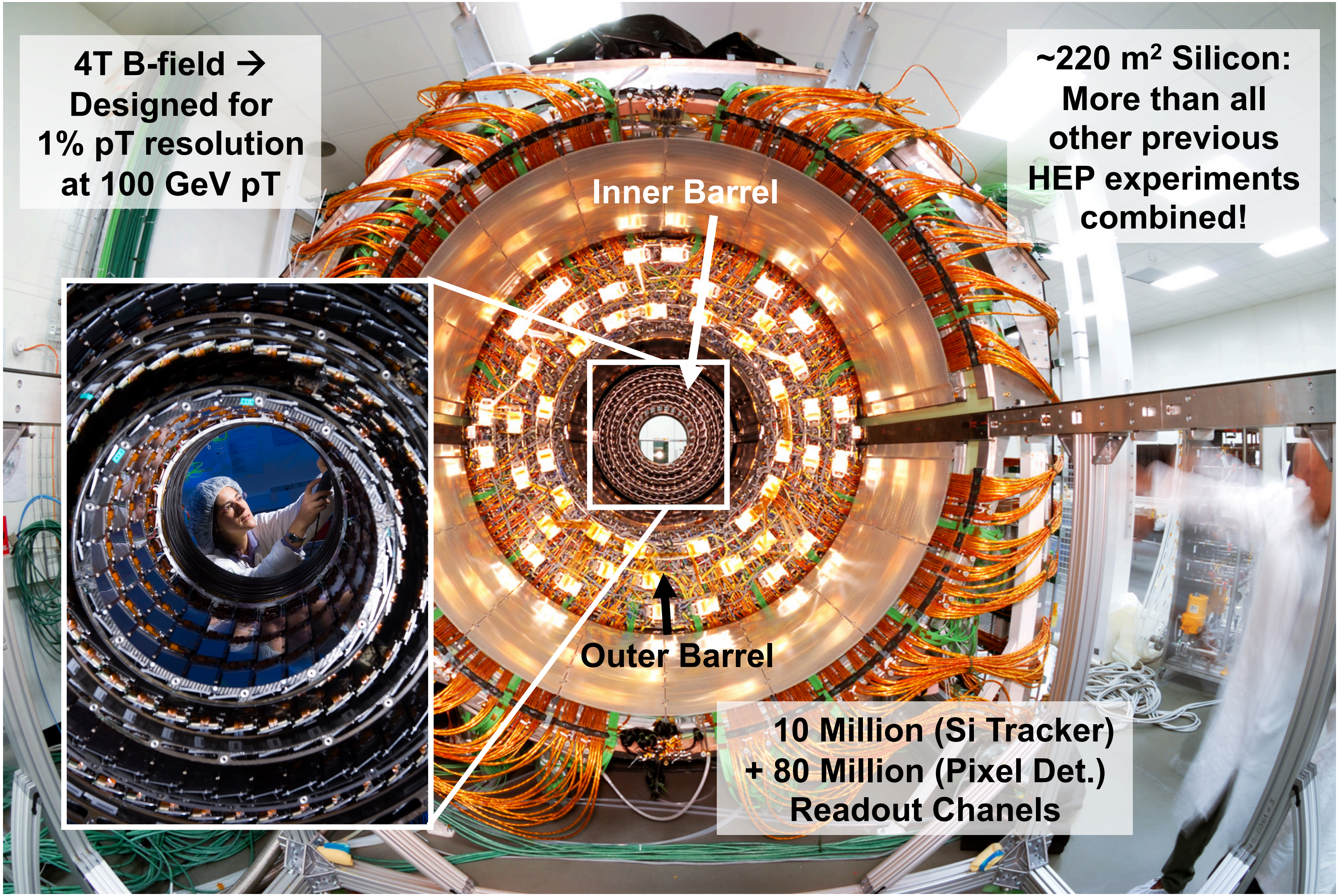
November 2007

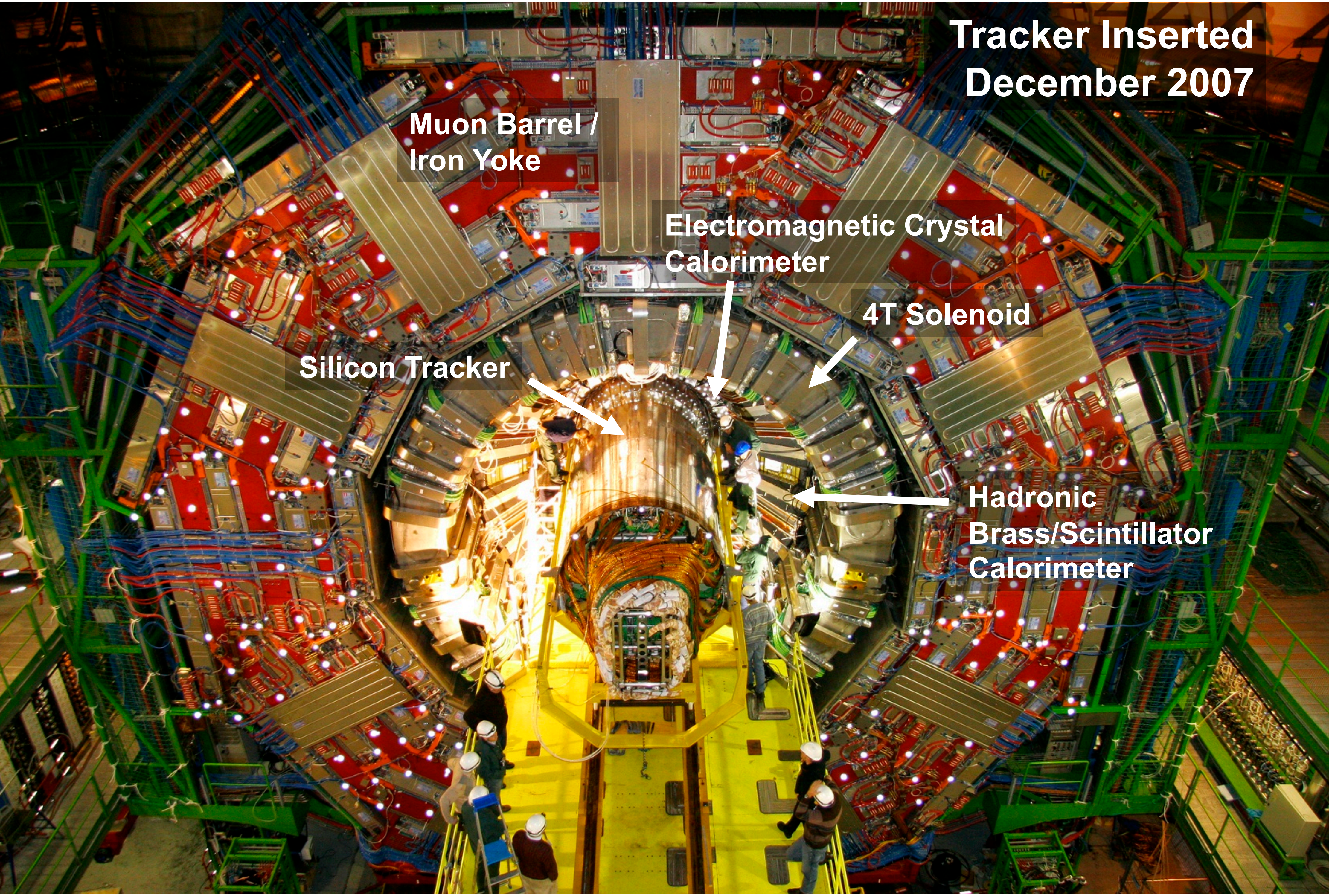


Electromagnetic Calorimeter



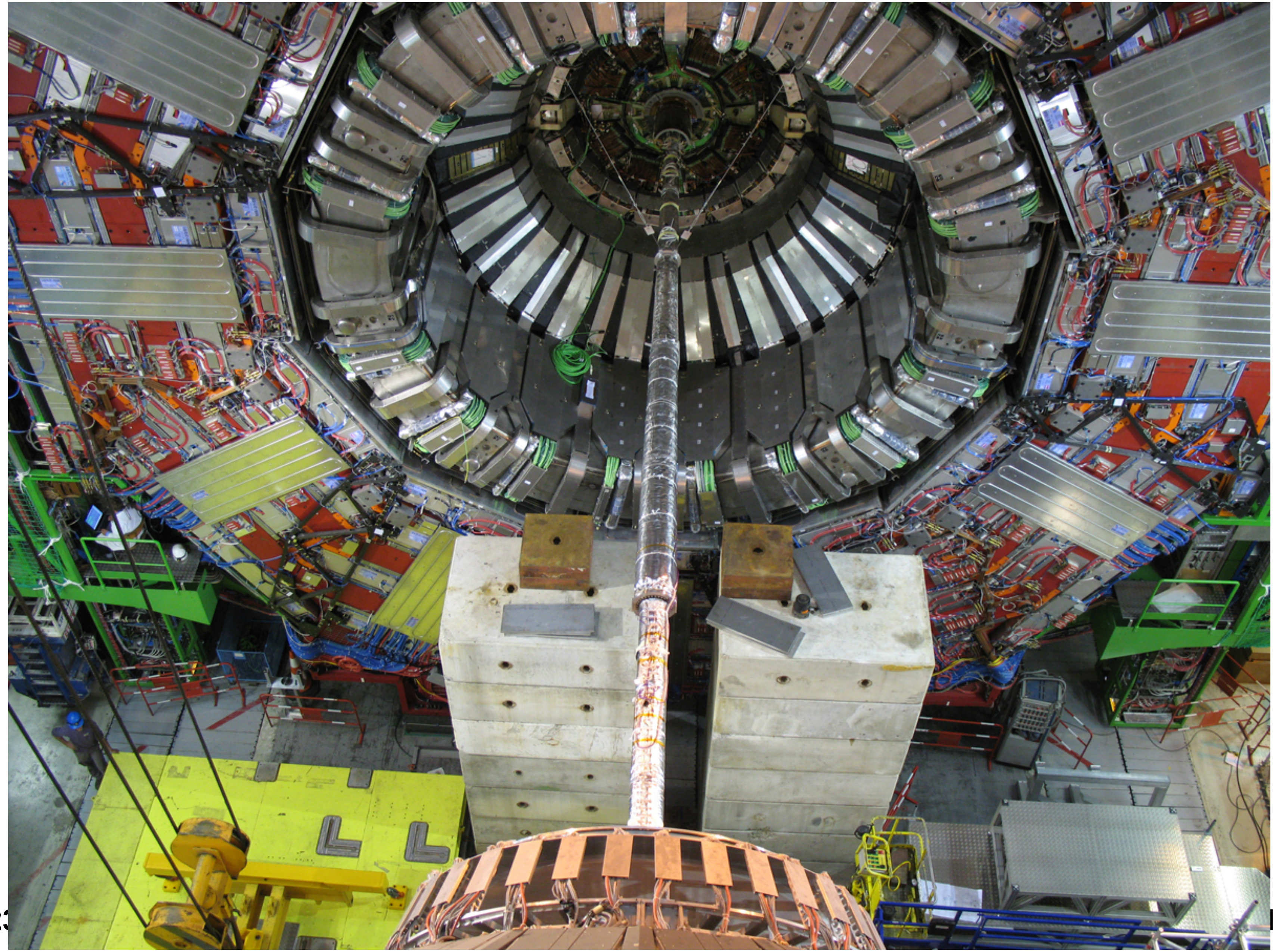
All Silicon Tracker



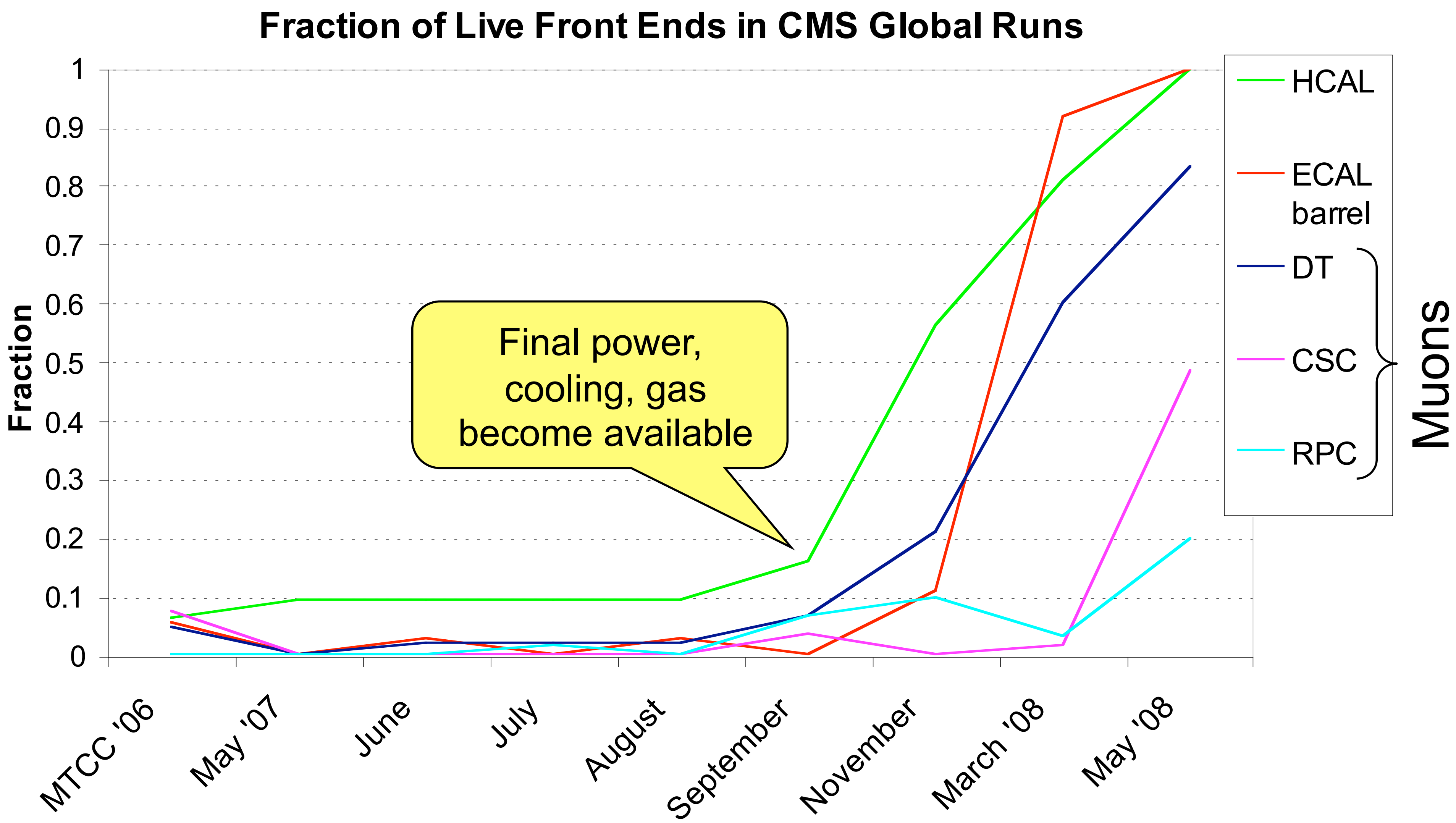

Tracker Inserted
December 2007
Muon Barrel /
Iron Yoke
Electromagnetic Crystal
Calorimeter
4T Solenoid
Silicon Tracker
Hadronic
Brass/Scintillator
Calorimeter

Beam Pipe Installation on "-" Side

("+" Side now installed too)



Getting Ready: Scale of Global Operations



CMS Commissioning Plans

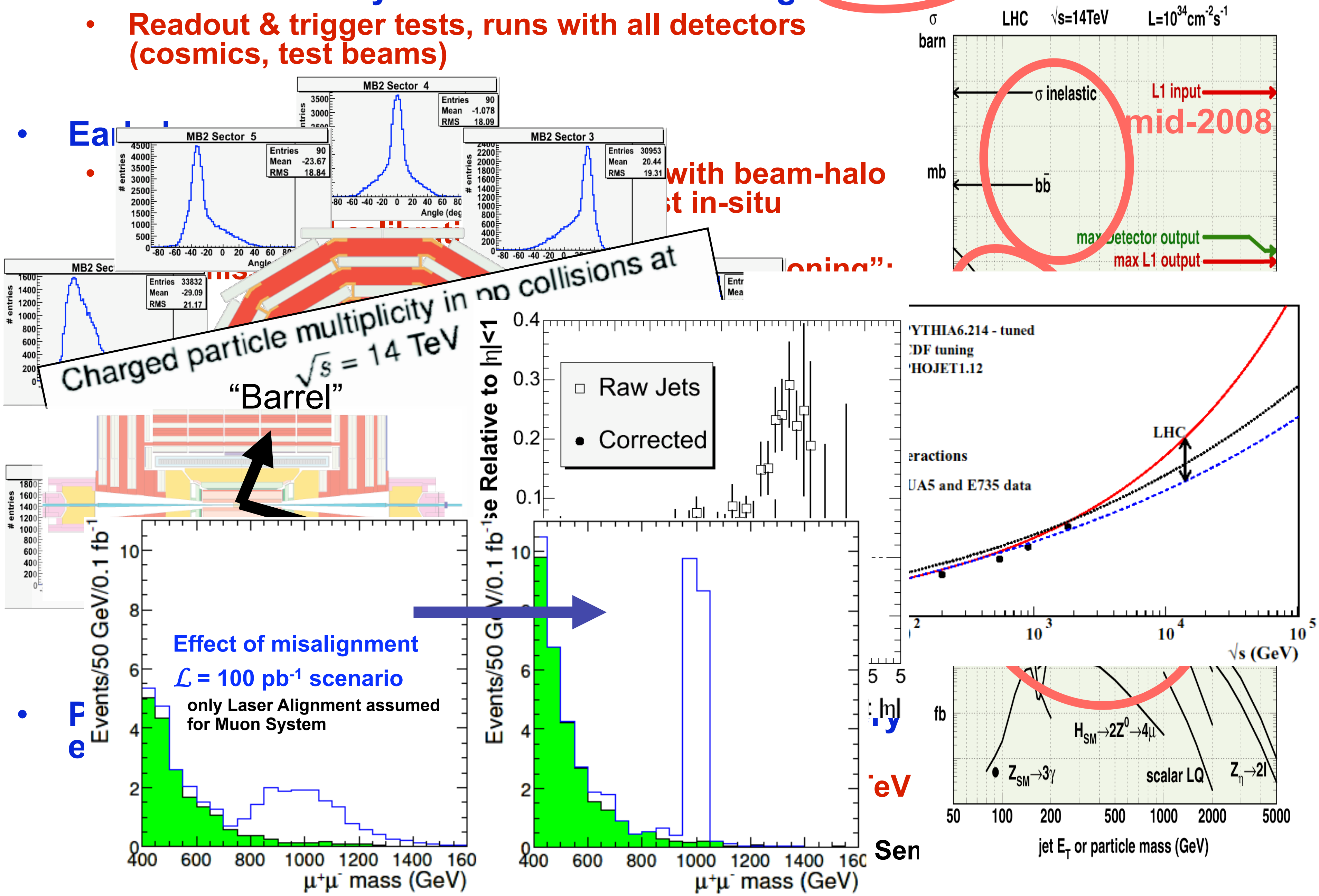
Construction started in 1998!

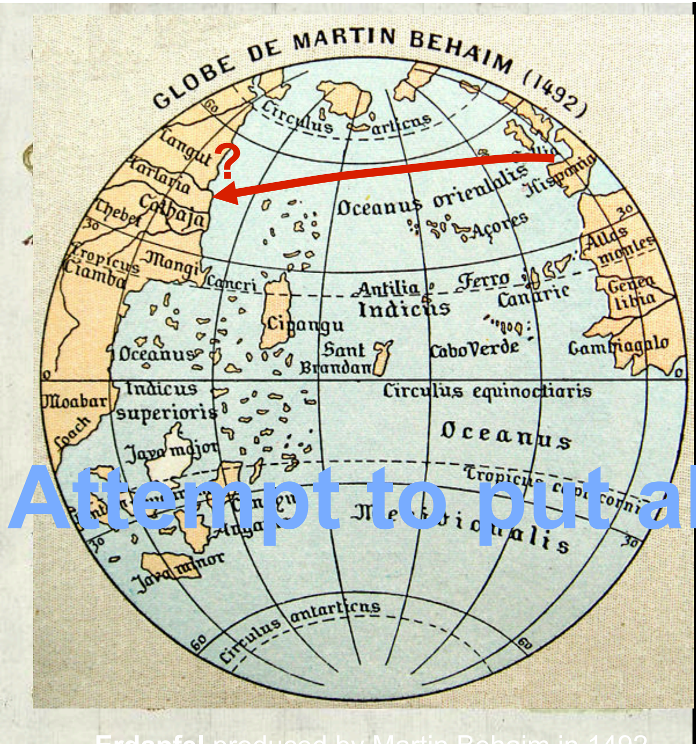
Month	Plans
Apr	
May	Cosmic Run with 0T Magnetic Field Computing Readiness Challenge Pixels installed
Jun	Cosmic Run with 0T Magnetic Field Beam-pipe Closed and Baked-out 1st ECAL Endcap (Dees) Installed
Jul	2nd ECAL Endcap (Dees) Ready for Installation end July CMS Closed end July Cosmic Run with 4T Magnetic Field
Aug	First LHC Collisions?
Sep	

CMS Expects to be Ready for Physics at 10 TeV!

Entrée : Preparation for Physics Plan

- **Prior to beam: early detector commissioning** 2007-8
  - **Readout & trigger tests, runs with all detectors (cosmics, test beams)**
- **Ea**
  - **with beam-halo**
  - **t in-situ**
- **F**
  e





Erdapfel produced by Martin Behaim in 1492
(theoretical extrapolation / prediction!)

World turned out to be much larger & interesting than predicted!

New World (America) discovered by Columbus October 12, 1492.
(initially interpreted incorrectly!)

Attempt to put all this into perspective...

$\sqrt{s}$ = 10 TeV

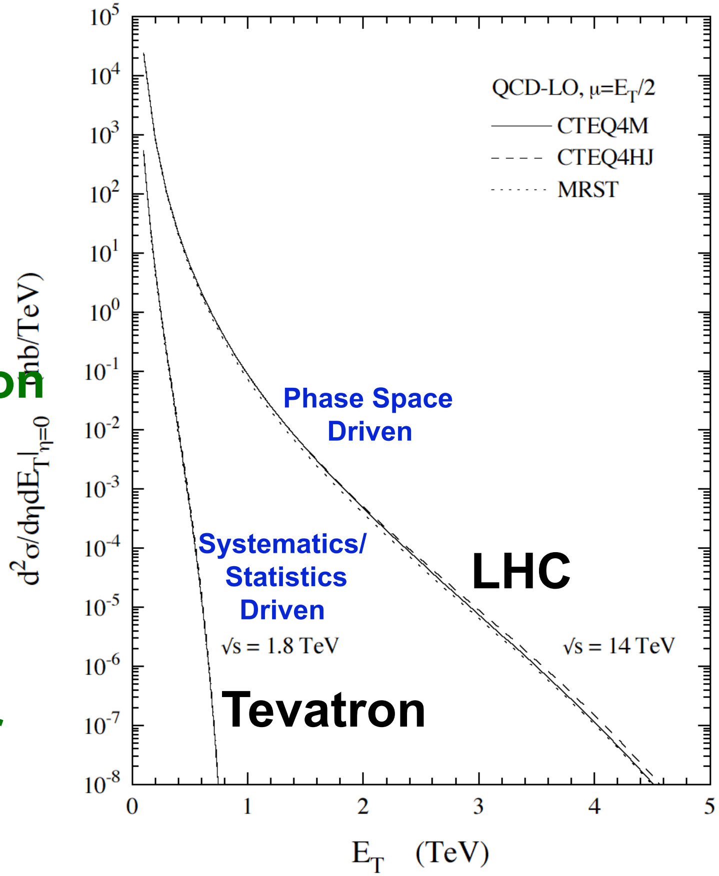
$\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$

We've never been there before!

Main Course : LHC Different from Tevatron

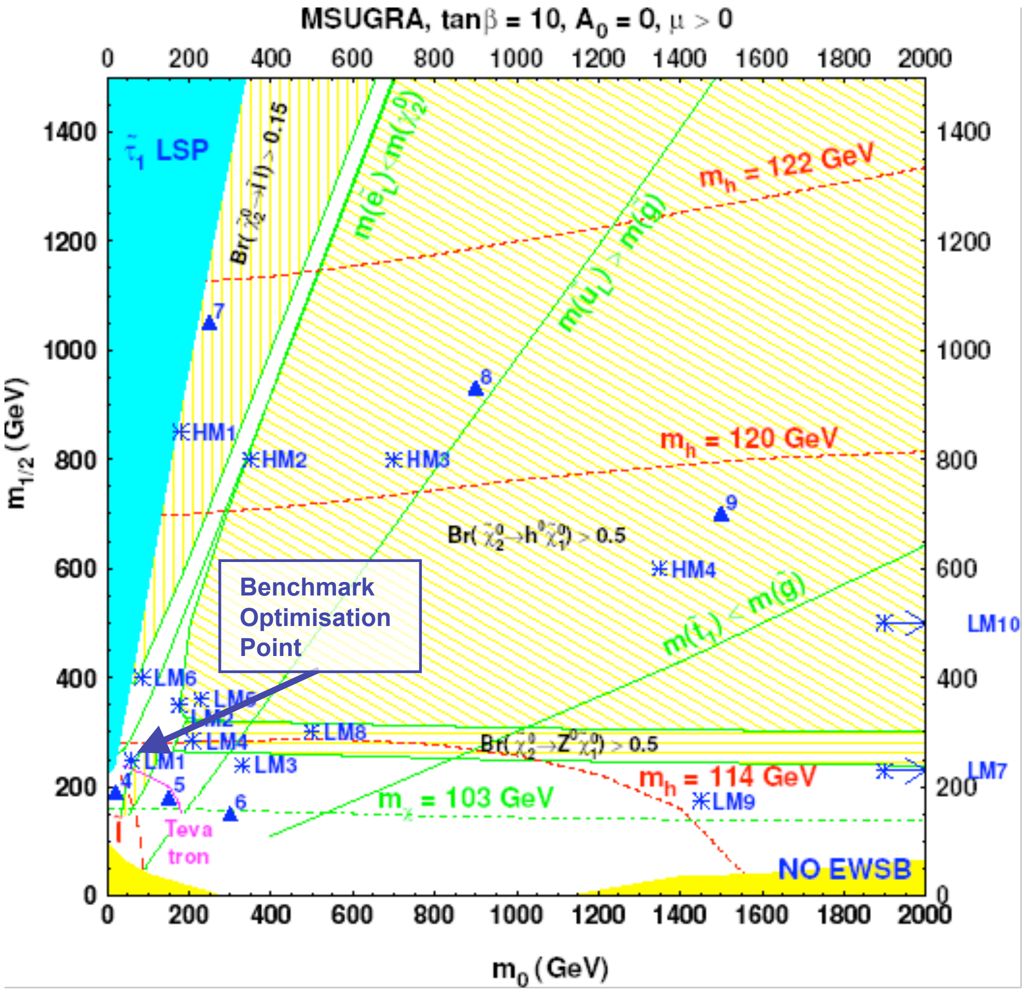
Explores the Frontier of a Whole New World!

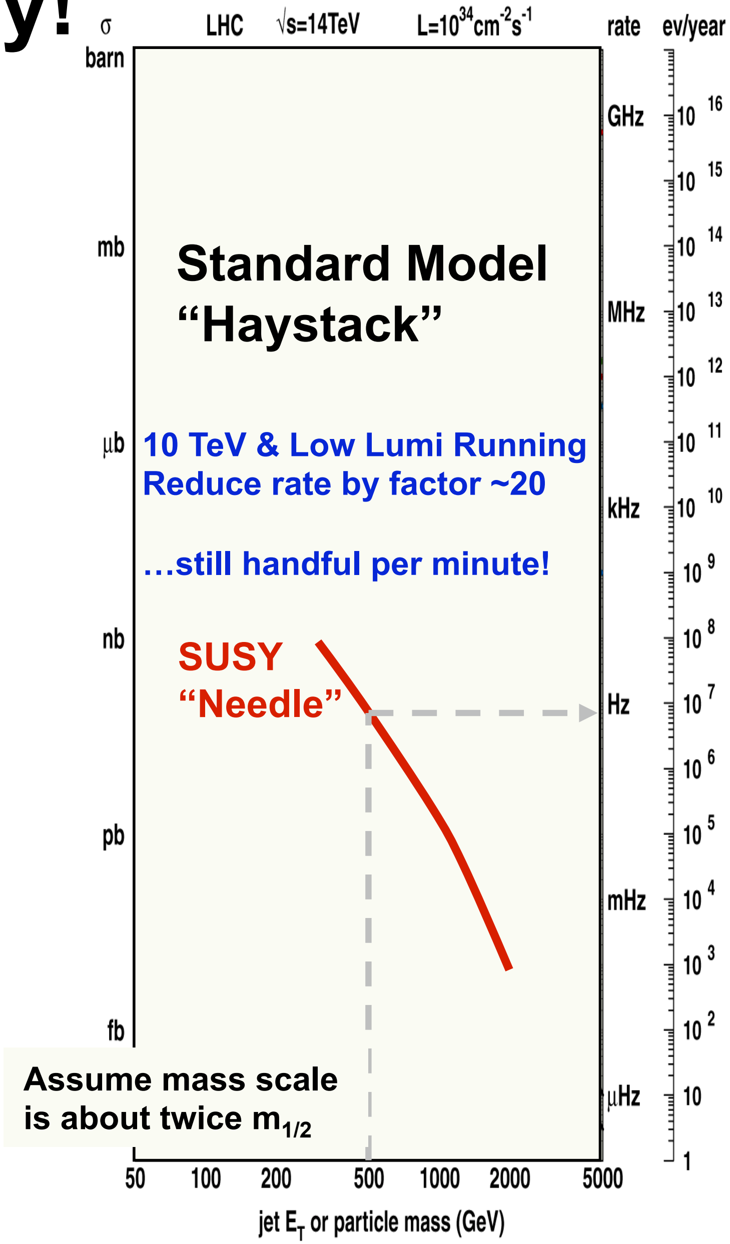
- **Precision vs discovery physics**
  - **Only need to understand Detector and Backgrounds <u>well enough</u>, not more!**
    - **TeV dijets → 10% jet energy scale OK**
    - **TeV dileptons → 10% PT resolution OK**
    - **0.5 TeV MET → 10% HT resolution OK**
  - **Improve systematic understanding as we need it**
    - **Discovery interpretation, Model parameter estimation, Subtle Signatures, etc**



- **Must not blind ourselves to gross features of new world!**
  - **(well motivated) obsession to understand Detector & Backgrounds**
  - **Be ready to <u>robustly</u> explore with <u>imperfect</u> knowledge!**
    - **....very quickly!**
    - **Calibrate to Data...use ratios & shapes, where possible!**

Low Mass SUSY could be Visible Early! Must Be Ready!

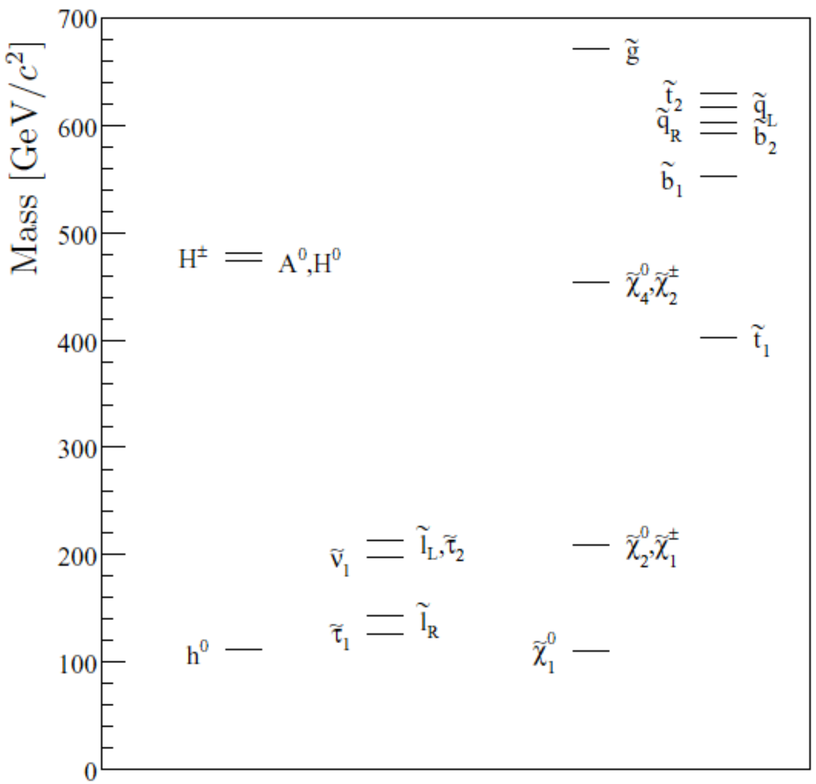


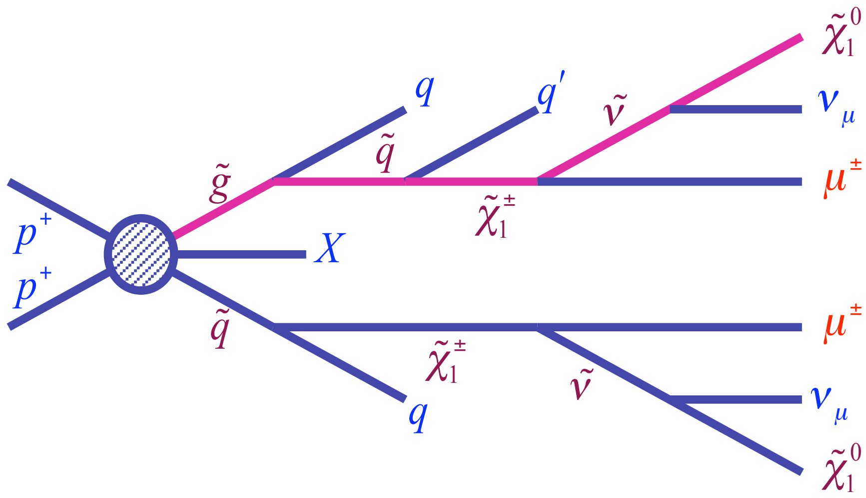


- Low mass points for early LHC running but outside Tevatron reach
- High mass points for ultimate LHC reach

Example CMSSM Parameters

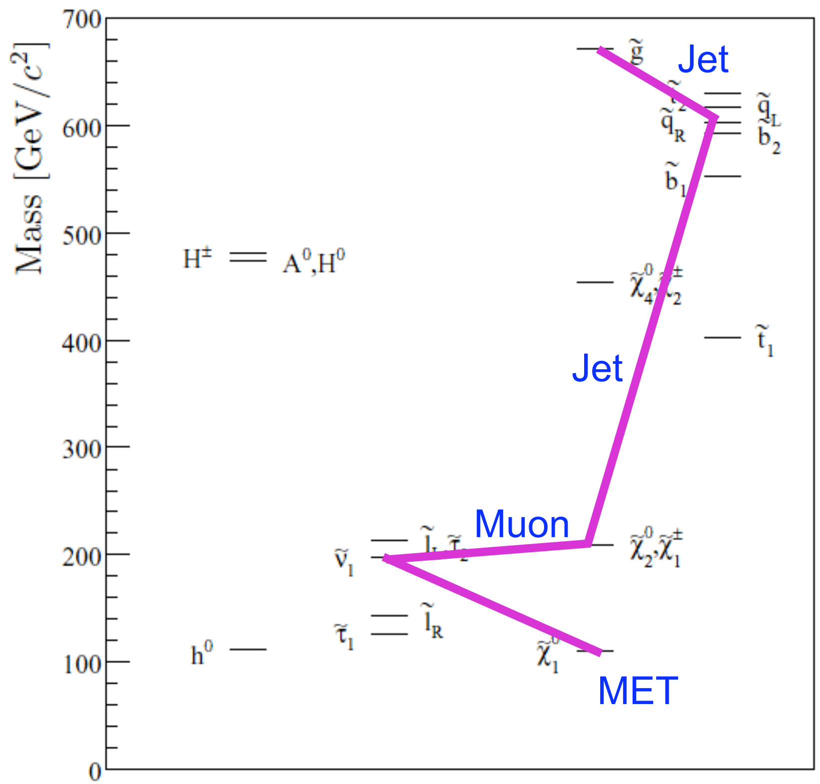
- Sparticles ➔ complex decays chains
  - Jets (q, g),
    - Several with some high pT
  - Leptons (χ, l, W, Z)
    - Possibly many, but isolated and low pT
  - MET (LSP)
    - Can be large

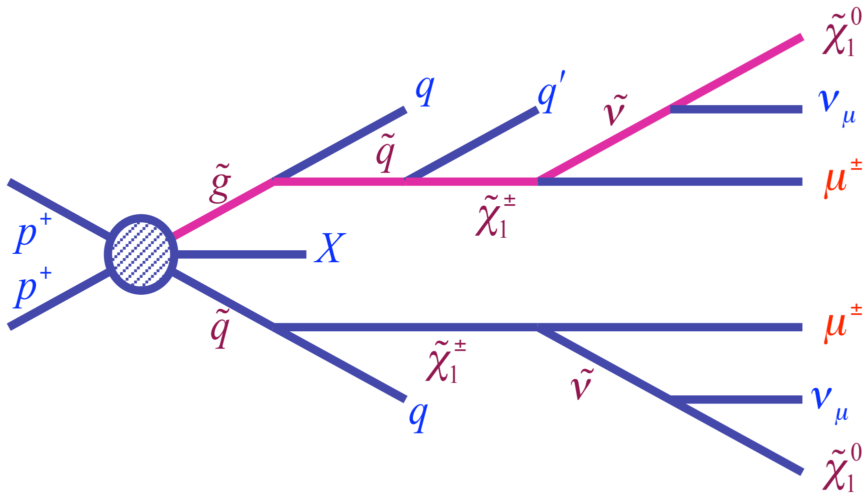




Example CMSSM Parameters

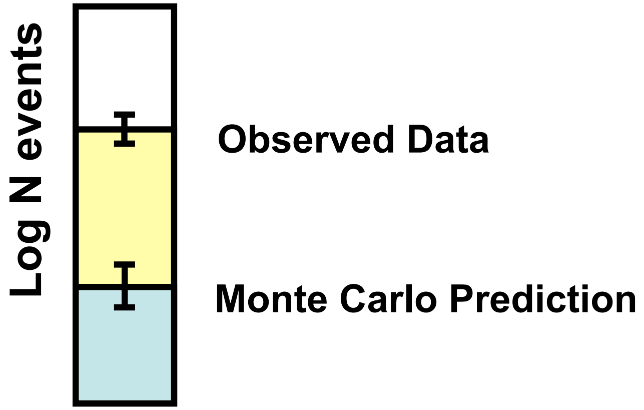
- **Sparticles ➔ complex decays chains**
  - **Jets (q, g),**
    - **Several with some high pT**
  - **Leptons (χ, l, W, Z)**
    - **Possibly many, but isolated and low pT**
  - **MET (LSP)**
    - **Can be large**



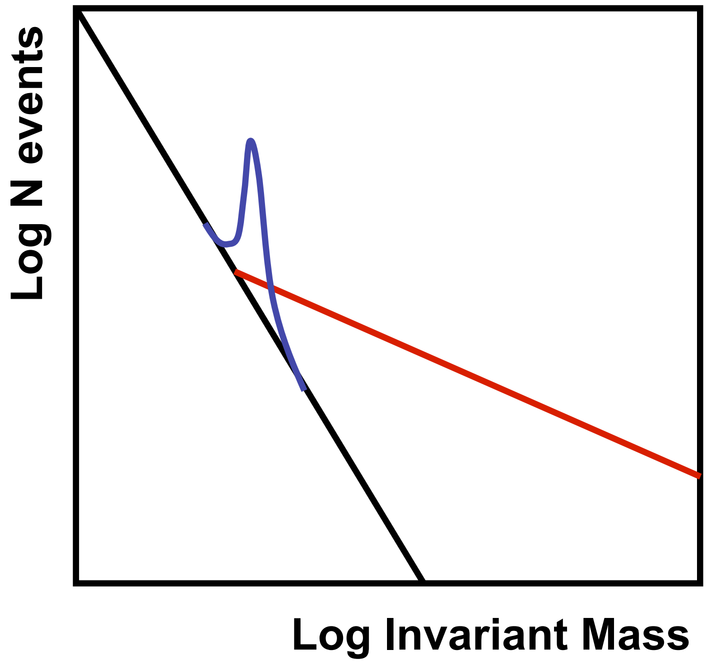


Early New Physics at High pT

- **Counting Experiments**
  - **Absolute Cross-sections**
  - **Challenging → Just a number!**



- **Continuum Modification**
  - **New Interactions, etc**
  - **less difficult → Use Ratios**



- **Multi-object Mass Resonances/Endpoints**
  - **New Particles**
  - **"Easier" → Use Shapes/Ratios**

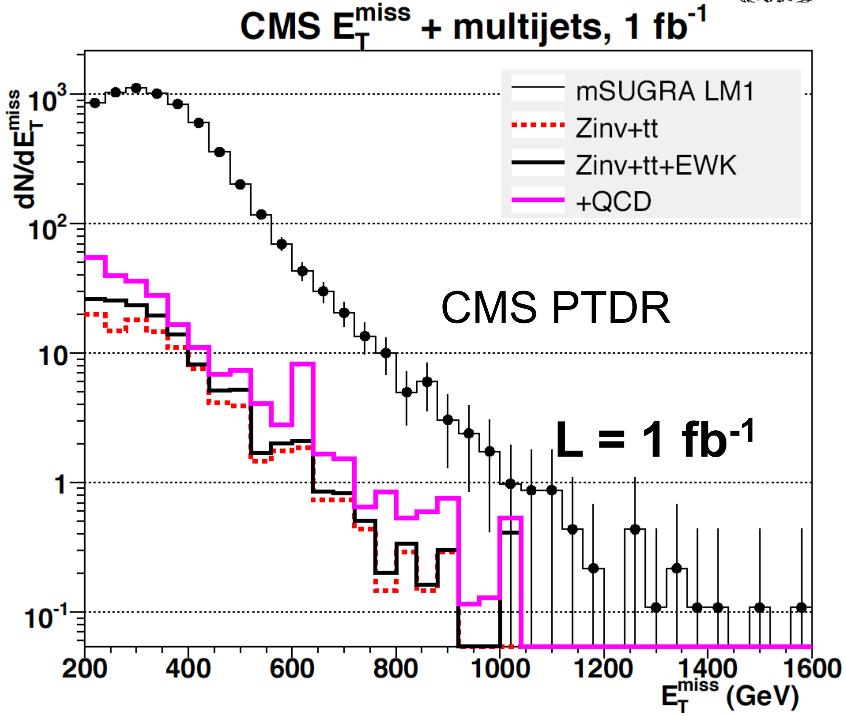
Different Jets + MET Signatures

0 leptons	-	-	-
1 lepton	μ	e	τ
2 OSSF leptons	μμ	ee	ττ
2 OSOF leptons	eμ	μτ	τe
2 SSSF leptons	μμ	ee	ττ
2 SSOF leptons	eμ	μτ	τe
3 leptons	…		

- Each Signature can shed light on the underlying model
  - Dilepton mass edges, rate of positive same sign to negative same sign, etc
- Note that increased lepton multiplicity improves background rejection, but
  - Decreases production cross-section
  - Decreases efficiency for finding isolated leptons (overlap with jet)

Inclusive MET + Jets + 0 Leptons

- **Example Selection Criteria**
  - **Very Large MET**
    - **Typically > 200 GeV (+ Cleanup)**
  - **≥ 3 jets:**
    - **Hard leading and next-to-leading jets**
  - **lepton veto**
  - **Cuts on $\Delta\phi$ between jets and MET**
  - **Very Large M_{eff}**
    - **Typically > 500 GeV**



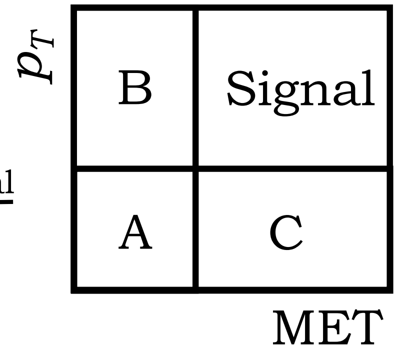
- **Example Expected Results:**
  - **LM1 efficiency is 13%, S/B ~ 26 :**
    Expected number of events for 1 fb^{-1}

Signal	$t\bar{t}$	single t	$Z(\to \nu\bar{\nu})$+ jets	$(W/Z, WW/ZZ/ZW)$ + jets	QCD
6319	53.9	2.6	48	33	107

  - **~6 pb^{-1} for 5σ discovery**

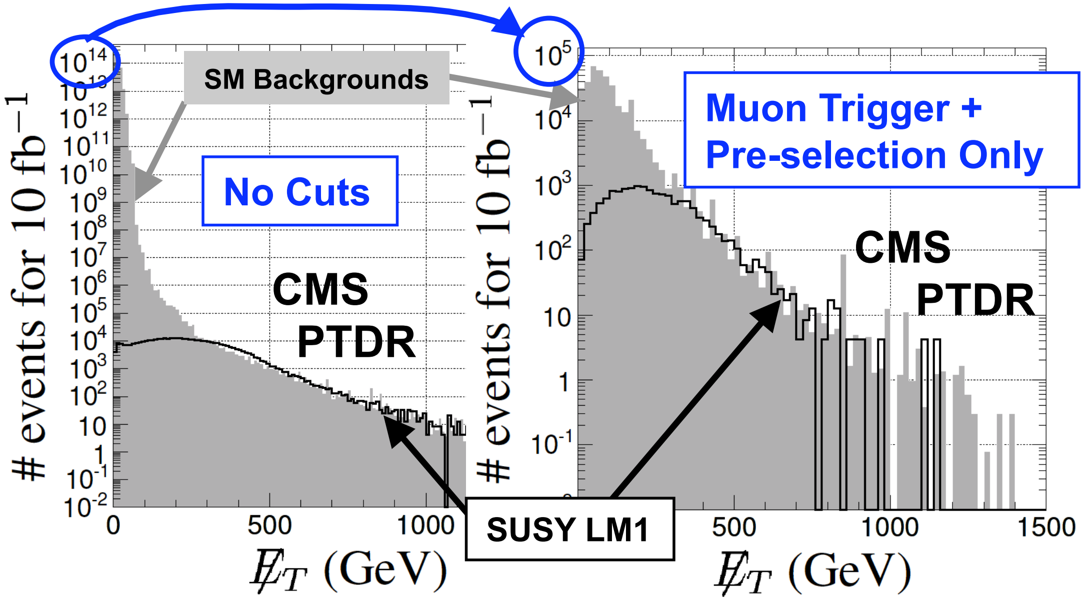
- **Lower jet multiplicity requirement reduces sensitivity to higher-order QCD corrections**
- **New studies on-going to estimate QCD Background using ratios from control regions**
  - **Similar techniques successfully used at Tevatron**

$$\frac{N_A}{N_B} \text{ “=” } \frac{N_{Signal}}{N_C}$$



Inclusive MET + Jets + 1 lepton

- Add lepton ⇒ clean trigger
  - Important during early running!
- Typical Characteristics:
  - Single Isolated lepton
    - Low pT ~ 20-30 GeV
  - ≥ 3 or ≥ 4 jets:
    - Hard leading (& NL) Jets
  - Large MET
    - Typically > 100 GeV
  - Cuts on Δϕ(jets, MET)
  - Large M_{eff}



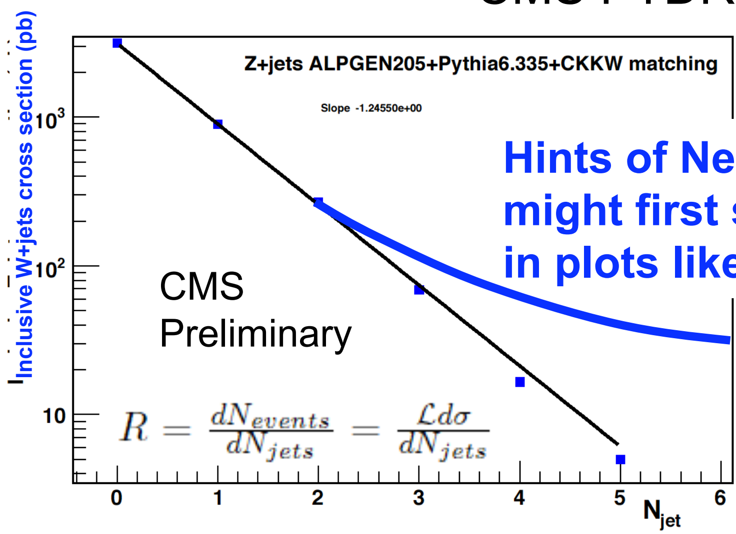
Lepton provides powerful handle to control QCD backgrounds

- Still depends on Jets + MET cuts, though
- Still basically just a counting experiment

- Main remaining backgrounds
  - ttbar : high jet mult. helps, but still hard to fully estimate from data
  - W/Z+n-Jets : SM Standard Candles →

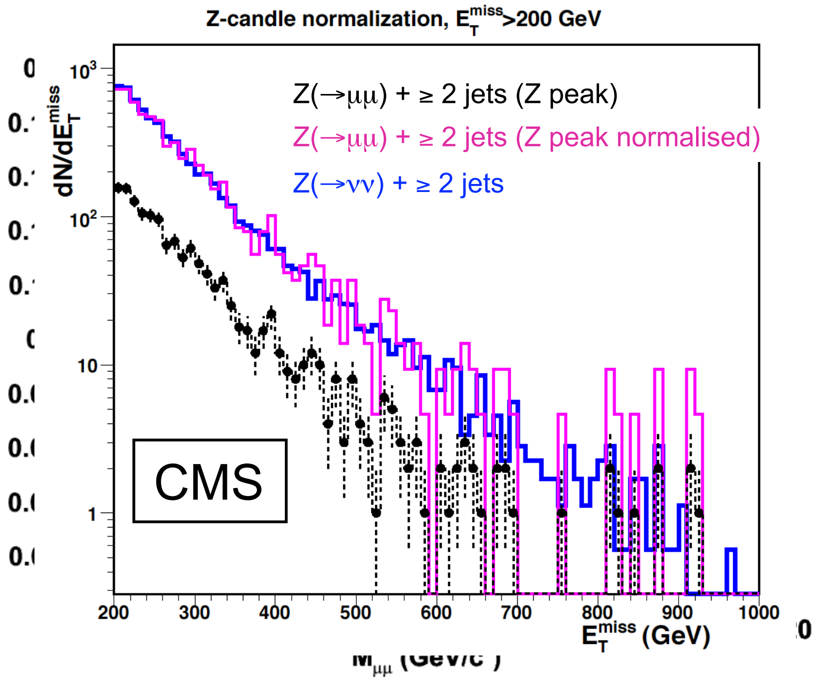
Electroweak Multijet Backgrounds:
Z→μμ Standard Candle

CMS PTDR



Hints of New Physics might first show up in plots like this...

- MET & Jets expected from
  - Z(→νν) + n jets
  - W(→lν) + n jets
- Study with Z →μμ Events
  - Easy to tag
  - Sufficient statistics at LHC



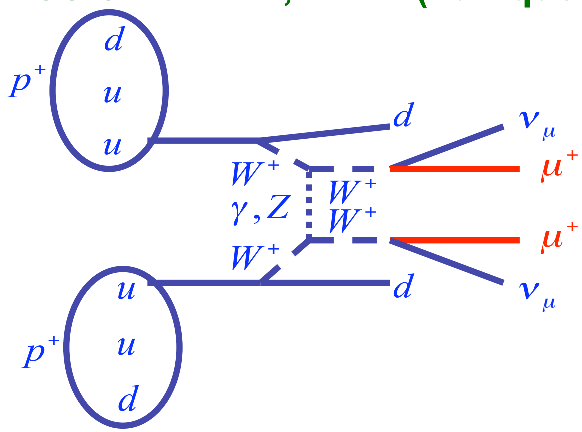
- Z + n-Jets x-sect ∝ α_s^N
- Normalise MC to Data
  - Assume lepton universality
  - For W + n-jets, use

$$\rho \equiv \frac{\sigma(pp \to W(\to \mu\nu)+jets)}{\sigma(pp \to Z(\to \mu^+\mu^-)+jets)}$$

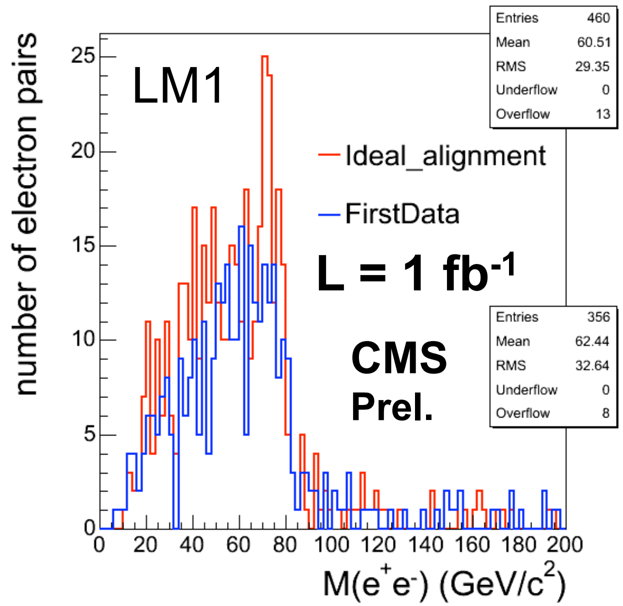
- Expectation
  - 5% precision with 1.5 fb-1
  - Approx. same precision for lumi. est.

Inclusive MET + Jets + 2 leptons

- Add another Same Flavour Lepton
  - Even cleaner; little to no QCD
  - 2 OSSF : benefits from shape analysis
  - 2 SSSF : benefits from even less Bkgs
- Typical Selection Strategy
  - Several, high pT Jets
  - Large MET
  - Strong lepton isolation cuts
- Main remaining backgrounds
  - ttbar : subtract using OSOF leptons
  - Double boson
    - 2 OS SF : W^+W^-, WZ, ZZ
    - 2 SS SF : W^+W^+, W^-W^- (~unique to LHC)



  - Double parton (not yet considered)
    - W "+" W, W "+" Z, Z "+" Z

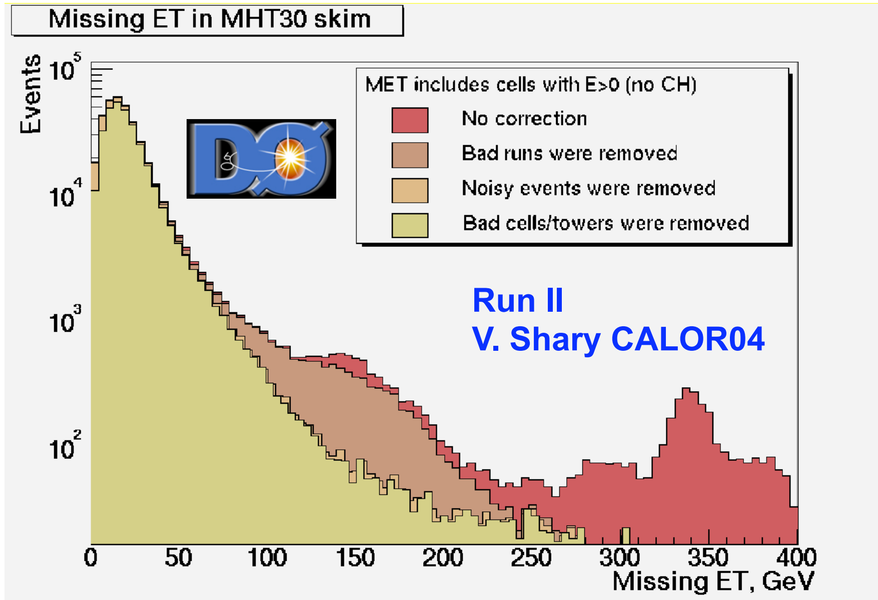


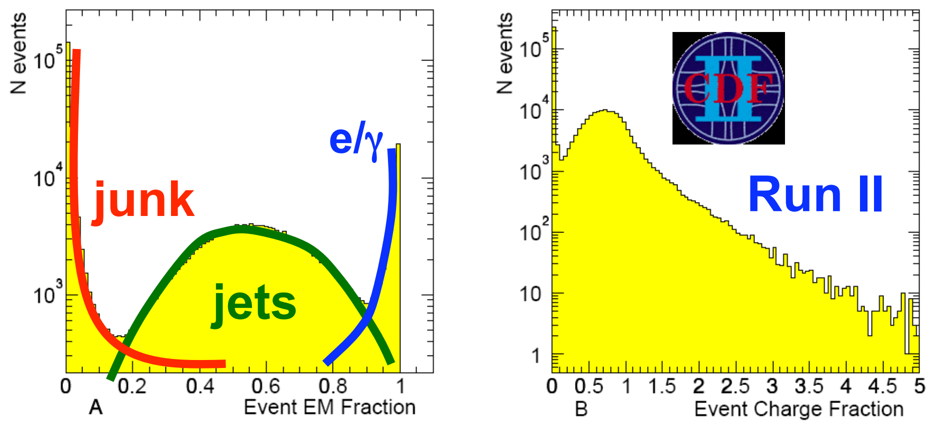
Can use MADGraph or CompHEP to simulate…but how to estimate 2 SSSF Bkg using Data Driven Methods during early running?

(SM cross section simply too low)

Environmental Challenges

- **MET is very powerful discriminator for New Physics**
  - **Difficult part is to convince yourself that there is a real excess!**
- **Tevatron teaches us**
  - **MET is not easily understood!**
- **Collisional backgrounds**
  - **Pile-up**
  - **Underlying Event**
- **Non-collisional backgrounds**
  - **Beam halo**
  - **Cosmic muons**
- **Detector Effects**
  - **Instrumental Noise**
  - **Hot/dead channels (DQM)**
  - **Inter-module calibration**





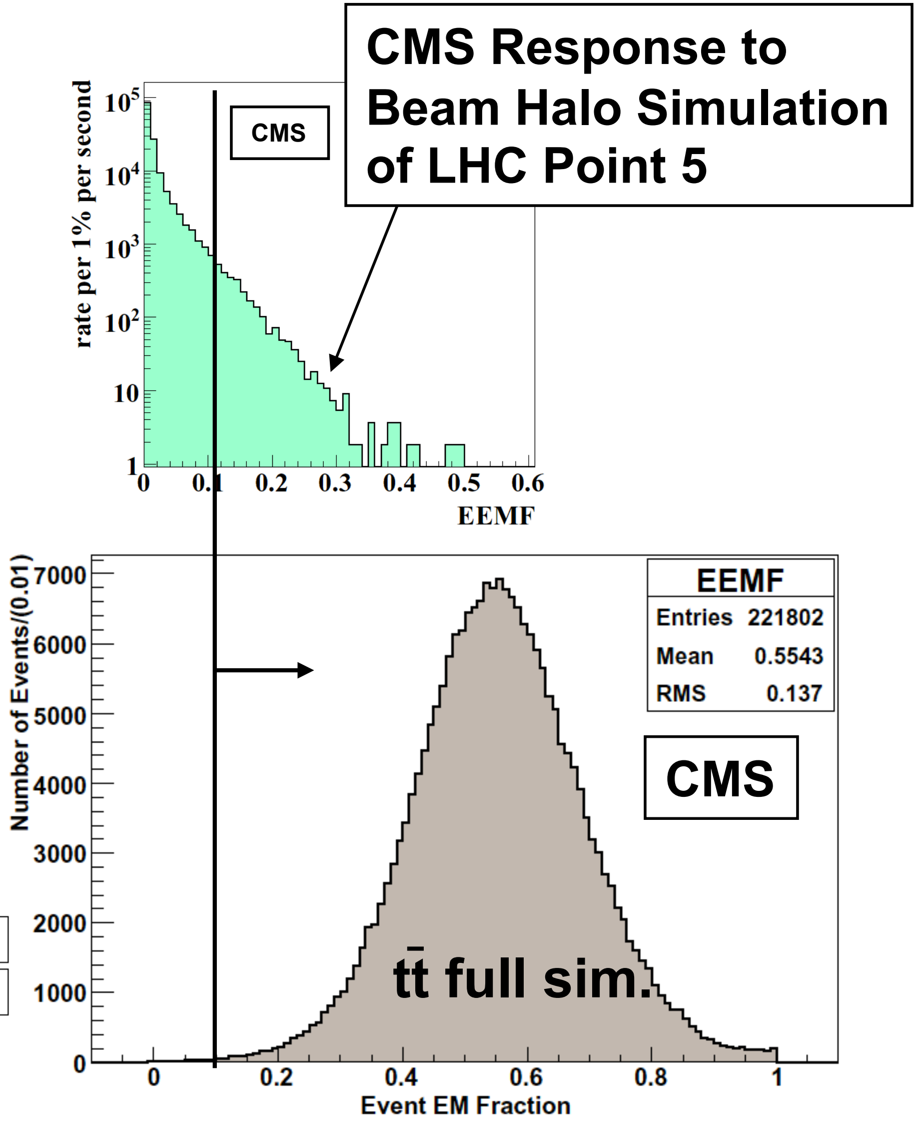
D. Tsybychev, Fermilab-thesis-2004-58

Early Study of MET Cleaning in CMS

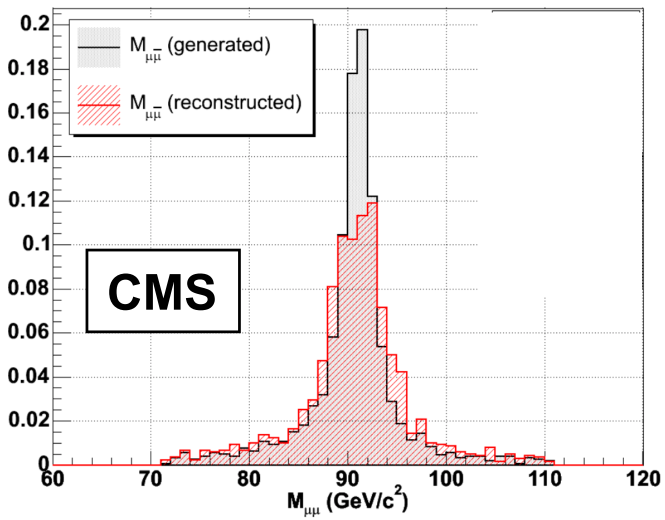
(of course, Real Data will be different!)

- **Apply clean up cuts to remove fake high MET events (inspired by CDF & D0)**
  - ≥ 1 central jet (|η|<1.7) with ≥ 4 tracks
  - ≥ 1 vertex
  - F_{em} > 0.1 (Event Electromagnetic Frac.)
  - F_{ch} > 0.175 (Event Charged Fraction)
- **Effect on SUSY Signal**

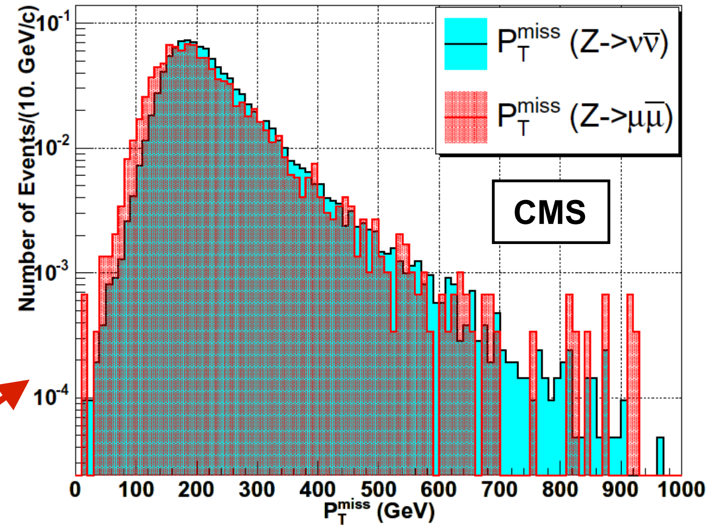
Sample/Requirement	$F_{em} > 0.1$	$F_{ch} > 0.175$	Both(%)
LM1	99.88%	91.32%	91.24%

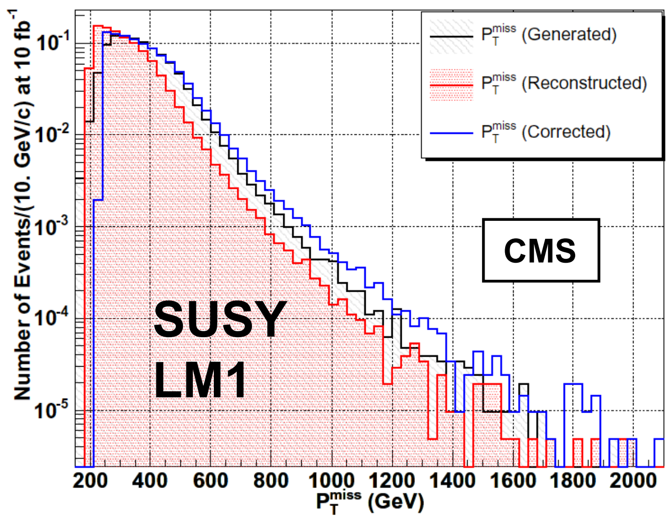


Use Track and Muon System to Calibrate Calorimeter (MET)



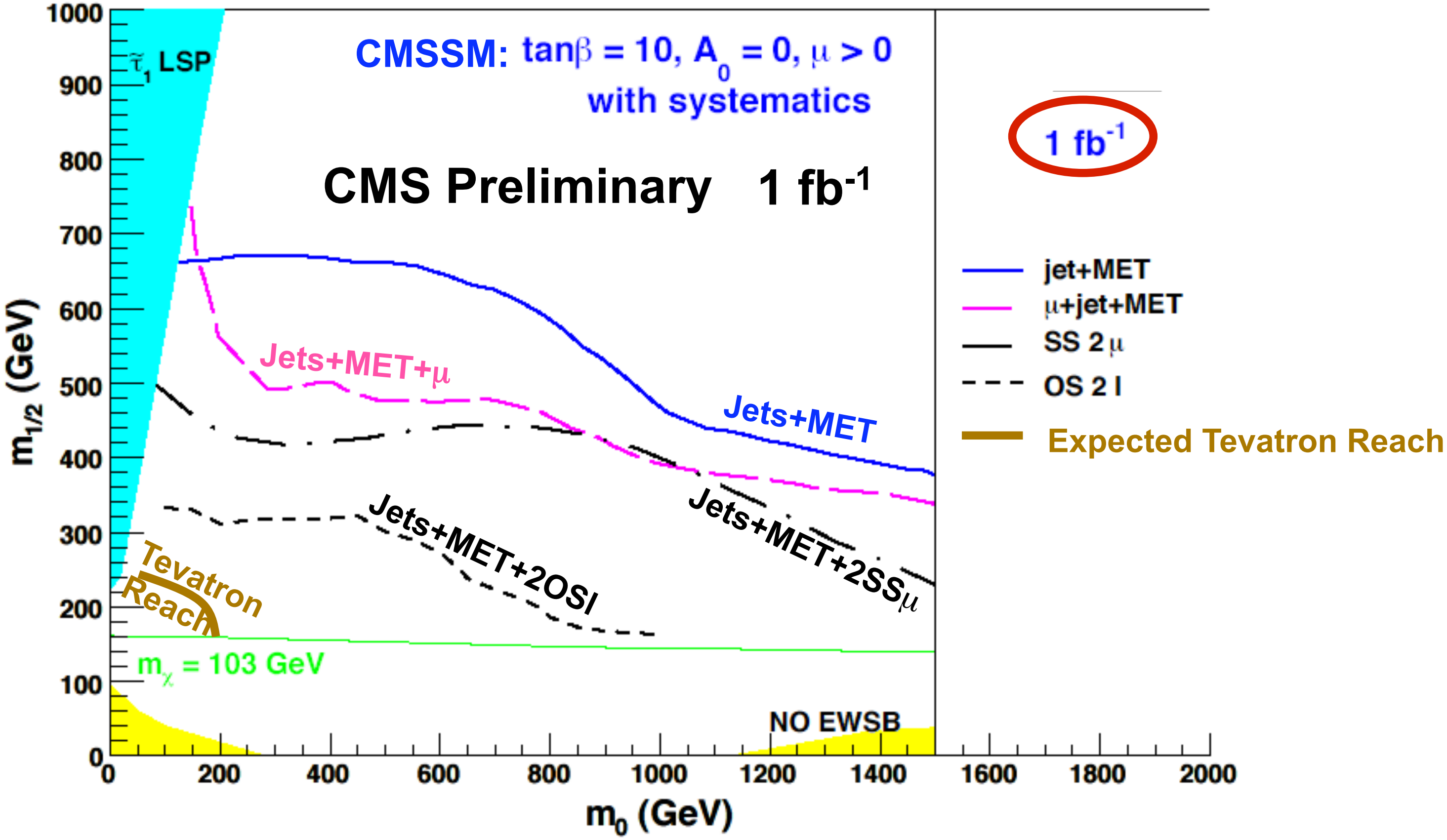
CMS
PTDR





- **Use Z→μμ Candle**
  - **Derive calorimeter MET corrections from di-muon system**
  - **Apply to SUSY Sample (to test)**
- **Some fine tuning required**
  - **But basically works**
- **Probably will use MHT for day-1**
  - **MET calculated from hard pT objects only**

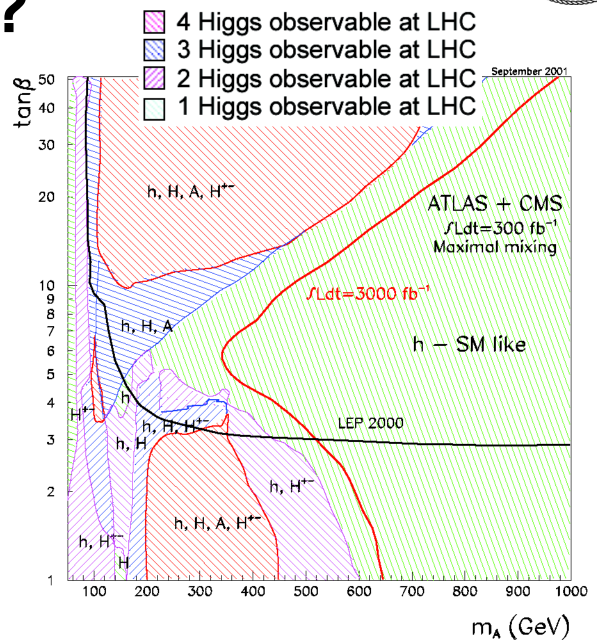
Expected CMSSM Discovery Reach at 14 TeV

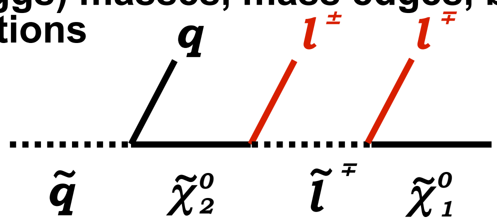


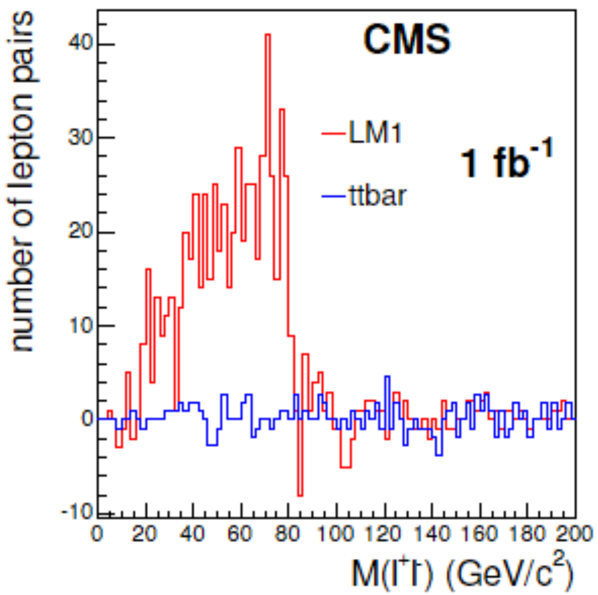
Dessert : After Discovery, what then?

Is it Asia? Or, America?

- **Distinguish Between Models**
  - **In general difficult to do : Inverse Problem**
    - **SUSY Models vs Extra Dimensions Models**
      - **Typically requires spin measurements**
  - **MSSM vs "something else"**
    - **Heavy Light-higgs rules out MSSM!**
- **Constrain Model Parameters**
  - **Directly**
    - **Difficult with a hadron collider**
    - **Not always possible in all regions of p-space!**
    - **Reconstruct exclusive decay chains**
      - **measure (higgs) masses, mass edges, branching ratios, x-sections**







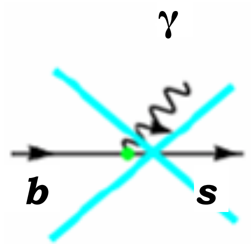
- **Indirectly**
  - **Apply global fits with constraints from**
    - **Low energy Electroweak & Heavy Flavour data**
    - **High energy data from LHC**
    - **Cosmology**
  - **Demand Consistency with all Experimental Data**

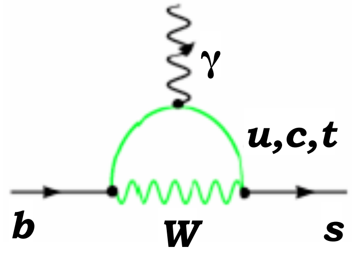
Indirect Sensitivity to Higher Scales via Loop Calculations

Observable	Constraint
$\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z)$	0.02758 ± 0.00035
m_Z [GeV/c^2]	91.1875 ± 0.0021
Γ_Z [GeV/c^2]	2.4952 ± 0.0023
σ^0_{had} [nb]	41.540 ± 0.037
R_l	20.767 ± 0.025
$A_{\mathrm{fb}}(\ell)$	0.01714 ± 0.00095
$A_\ell(P_\tau)$	0.1465 ± 0.0032
R_{b}	0.21629 ± 0.00066
R_{c}	0.1721 ± 0.003
$A_{\mathrm{fb}}(\mathrm{b})$	0.0992 ± 0.0016
$A_{\mathrm{fb}}(\mathrm{c})$	0.0707 ± 0.0035
A_{b}	0.923 ± 0.020
A_{c}	0.670 ± 0.027
$A_\ell(\mathrm{SLD})$	0.1513 ± 0.0021
$\sin^2\theta^\ell_{\mathrm{w}}(Q_{\mathrm{fb}})$	0.2324 ± 0.0012
m_W [GeV/c^2]	80.398 ± 0.025
m_t [GeV/c^2]	170.9 ± 1.8
$BR^{\mathrm{SUSY}}_{\mathrm{b}\to s\gamma}/BR^{\mathrm{SM}}_{\mathrm{b}\to s\gamma}$	1.13 ± 0.12
$BR_{\mathrm{B_s}\to\mu^+\mu^-}$	$< 8.0 \times 10^{-8}$
$a^{\mathrm{SUSY}}_\mu - a^{\mathrm{SM}}_\mu$	$(29.5 \pm 8.7) \times 10^{-10}$
Ωh^2	0.113 ± 0.009

Flavour changing neutral current processes like $b \to s\gamma$ or $b \to sl^+l^-$

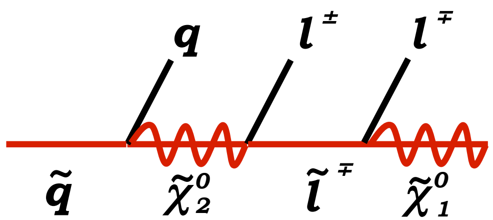
- directly probe the SM at the one-loop level



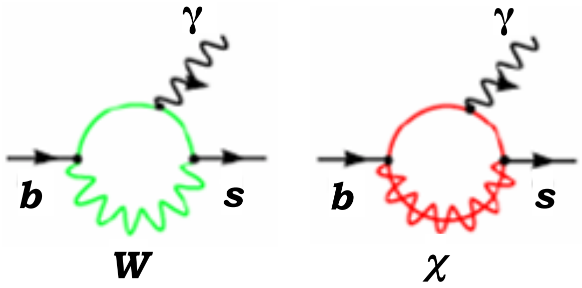


Indirect search for new degrees of freedom beyond the SM

Direct:



Indirect:



High sensitivity for 'New Physics'

- Electroweak precision data at 0.1% level
- New Physics loop effects can contribute at 10% level

Slide adapted from Tobias Hurth

Progress in Calculating Flavour, Higgs, Cosmology, and EWK Observables

Low energy observables

$BR(b \to s\gamma)$	MicrOMEGAs	Isidori & Paradisi
$BR(b \to sll)$		Isidori & Paradisi
$BR(B_s \to \mu\mu)$	MicrOMEGAs	Isidori & Paradisi
$BR(B \to \tau\nu)$		Isidori & Paradisi
$BR(D \to \tau\nu)$		Isidori & Paradisi
$BR(K \to \tau\nu)$		Isidori & Paradisi
$BR(K \to \pi\nu\nu)$		Isidori & Paradisi
Δm_s		Isidori & Paradisi
Δm_d		Isidori & Paradisi
Δm_K		Isidori & Paradisi
$g-2$	FeynHiggs	

Higgs sector observables

m_h^{light}	FeynHiggs

Cosmology observable

Ωh^2	MicrOMEGAs	DarkSUSY

High energy EW observables

R_l	A. Weber *et al.*
R_b	A. Weber *et al.*
R_c	A. Weber *et al.*
$A_{fb}(b)$	A. Weber *et al.*
$A_{fb}(c)$	A. Weber *et al.*
A_b	A. Weber *et al.*
A_c	A. Weber *et al.*
$A_l(SLD)$	A. Weber *et al.*
$\sin^2\theta_{eff}$	A. Weber *et al.*
m_W	A. Weber *et al.*
Γ_Z	A. Weber *et al.*

Many calculations (MSSM Higgs, etc) now available at the two-loop level.
Care required to consistently use different observables across different codes!

Discovery Guide: "Global Fits"

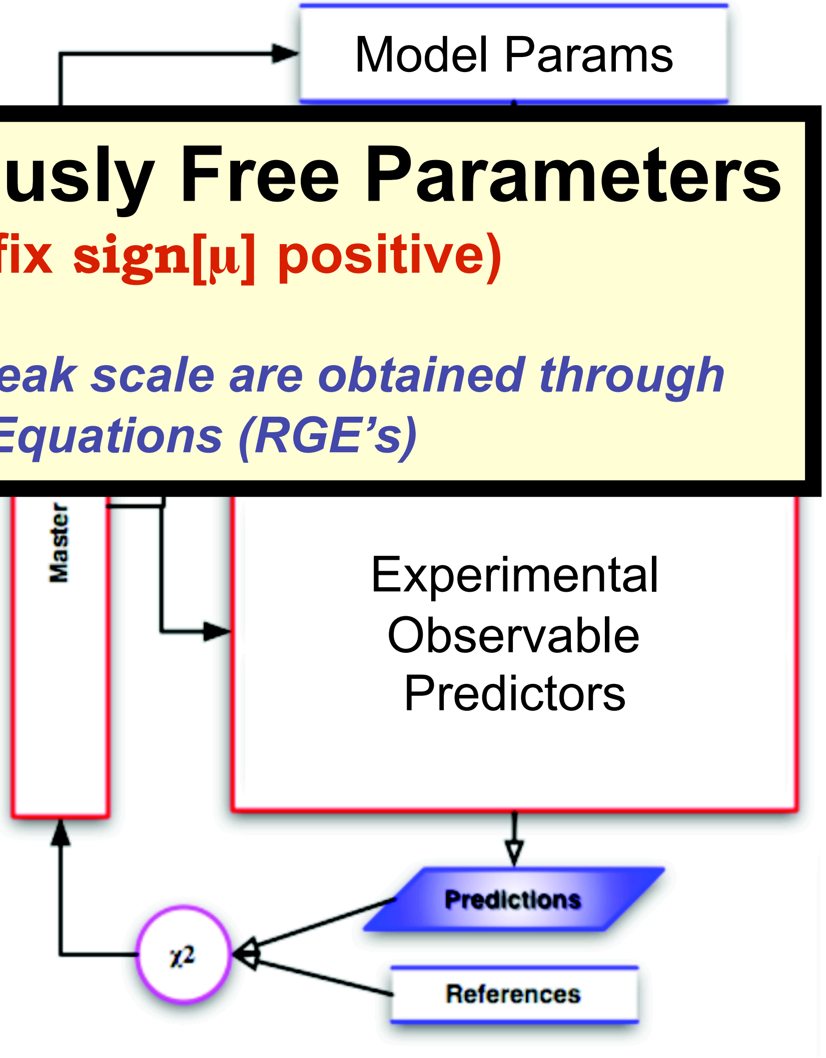
- **Consistently combine all observables in single code**
- **Collaboration between:**
  - **Experimentalists**

Full χ^2 Fit to 4 Simultaneously Free Parameters

m_0, $m_{1/2}$, A_0, $\tan\beta$; (fix sign[μ] positive)

All SUSY predications at the electroweak scale are obtained through Renormalization Group Equations (RGE's)

  - **Sven Heinemeyer (Santander)**
  - **Gino Isidori (INFN Frascati)**
  - **Keith Olive (Minnesota)**
  - **Paride Paradisi (Valencia)**
  - **Arne Weber (MPI Munich)**



Example of similar analyses:
- Allanach, Lester, Weber - hep-ph/0705.0487
- Trotta, Austri, Roszkowski - hep-ph/0609126
- … there are more!

Constraining Model Parameters using Observed Data

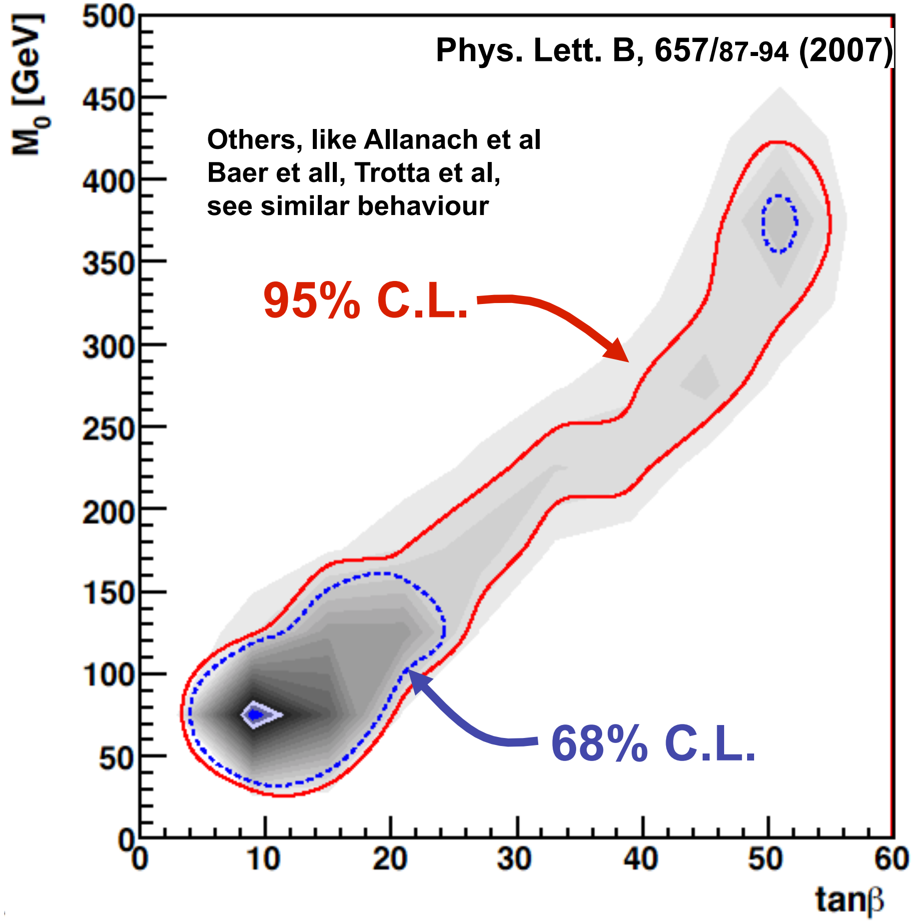
Phys. Lett. B, 657/87-94 (2007)

CMSSM

Variable	Measurement	Fit	$\lvert O^{meas} - O^{fit} \rvert / \sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b \to s\gamma)$	1.13 ± 0.12	1.12	
$B_s \to \mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

x^2/ndof = 17.0/13 (20% probability)

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f^{obs}_{SM_i} - f^{fit}_{SM_i})^2}{\sigma(f_{SM_i})^2}$$

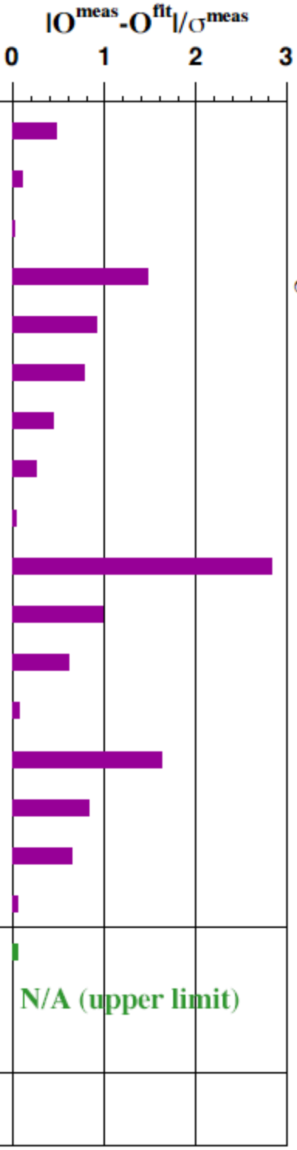


Constraining Model Parameters using Observed Data

Phys. Lett. B, 657/1-3 (2007)

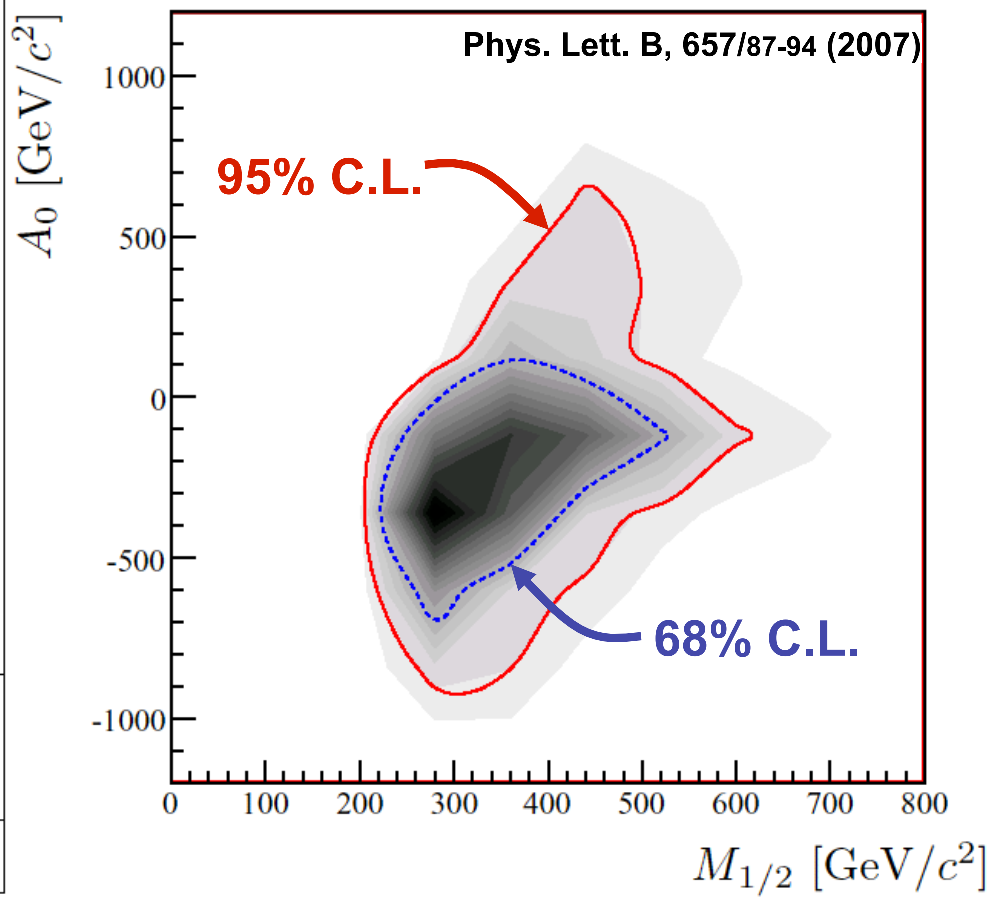
CMSSM

Variable	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02774
m_Z [GeV]	91.1875 ± 0.0021	91.1873
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952
σ_{had}^0 [nb]	41.540 ± 0.037	41.486
R_l	20.767 ± 0.025	20.744
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01641
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479
R_b	0.21629 ± 0.00066	0.21613
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0741
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1479
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.382
m_t [GeV]	170.9 ± 1.8	170.8
$R(b\to s\gamma)$	1.13 ± 0.12	1.12
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113



x^2/ndof = 17.0/13 (20% probability)

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f_{\mathrm{SM}_i}^{\mathrm{obs}} - f_{\mathrm{SM}_i}^{\mathrm{fit}})^2}{\sigma(f_{\mathrm{SM}_i})^2}$$

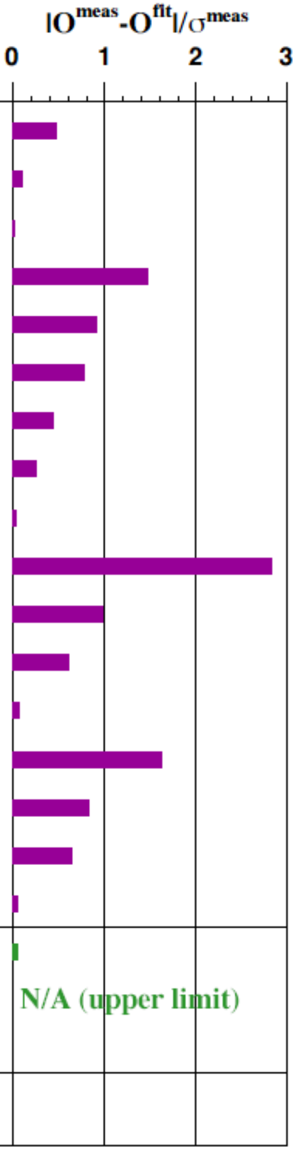


Constraining Model Parameters using Observed Data

Phys. Lett. B, 657/87-94 (2007)

CMSSM

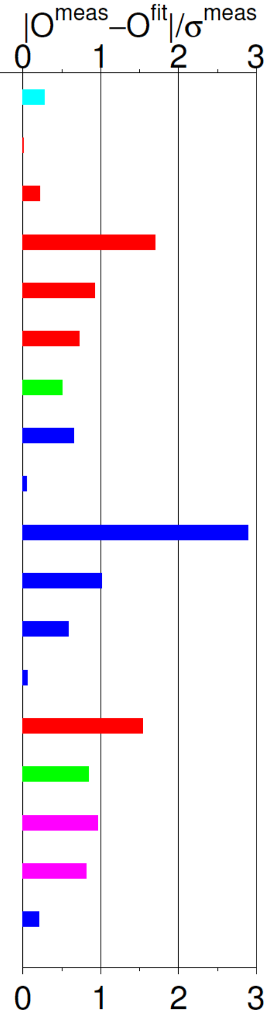
Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774
m_Z [GeV]	91.1875 ± 0.0021	91.1873
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952
σ^0_{had} [nb]	41.540 ± 0.037	41.486
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479
R_b	0.21629 ± 0.00066	0.21613
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1479
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.382
m_t [GeV]	170.9 ± 1.8	170.8
$R(b\to s\gamma)$	1.13 ± 0.12	1.12
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113



χ^2/ndof = 17.0/13 (20% probability)

Standard Model

$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3



LEP Electroweak Working Group

(courtesy M. Gruenewald)

χ^2/ndof = 18.2/13 (15% probability)

Constraining Model Parameters using Observed Data

Phys. Lett. B, 657/87-94 (2007)

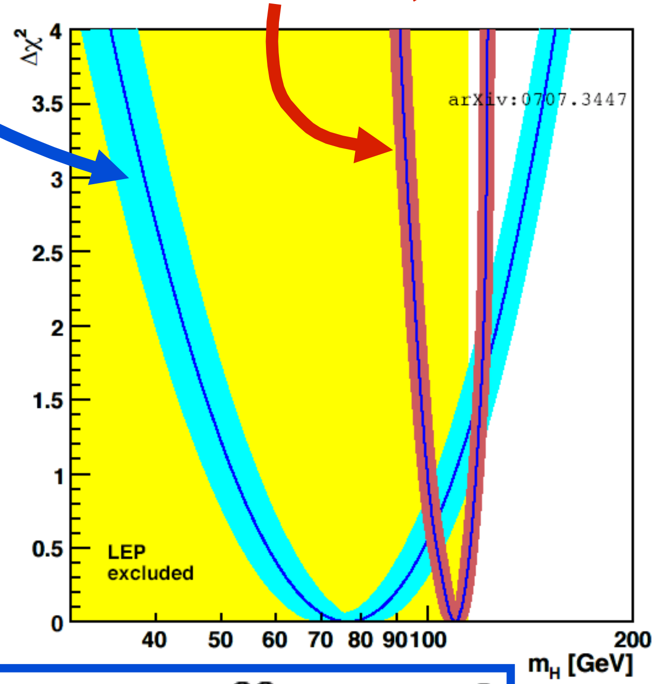
CMSSM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

χ^2/ndof = 17.0/13 (20% probability)

LEP Electroweak Working Group
(courtesy M. Gruenewald)

Fit Results from PLB, 657/87-94 (2007)

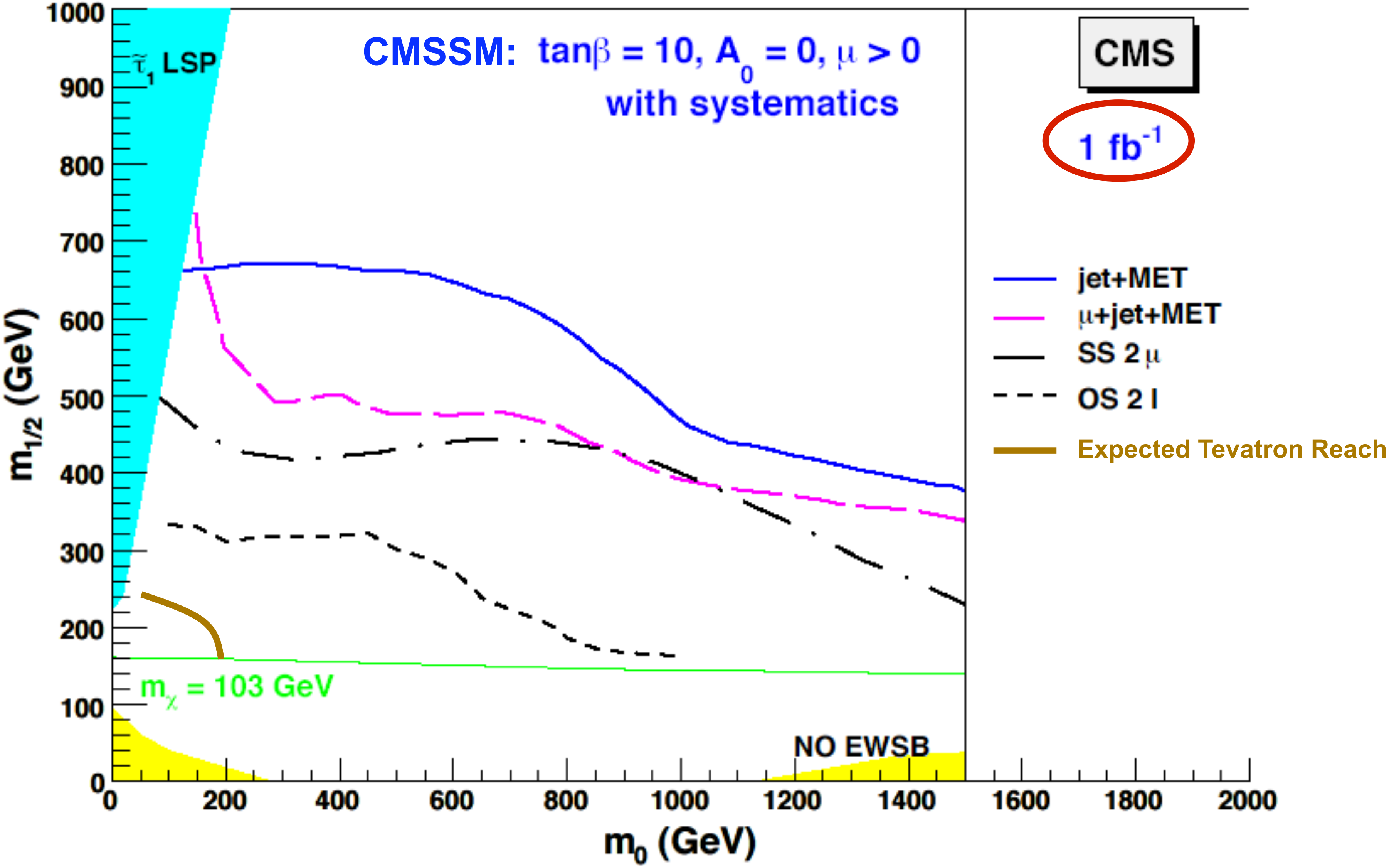


$$m_H = 76^{+33}_{-24}\ \mathrm{GeV}/c^2$$

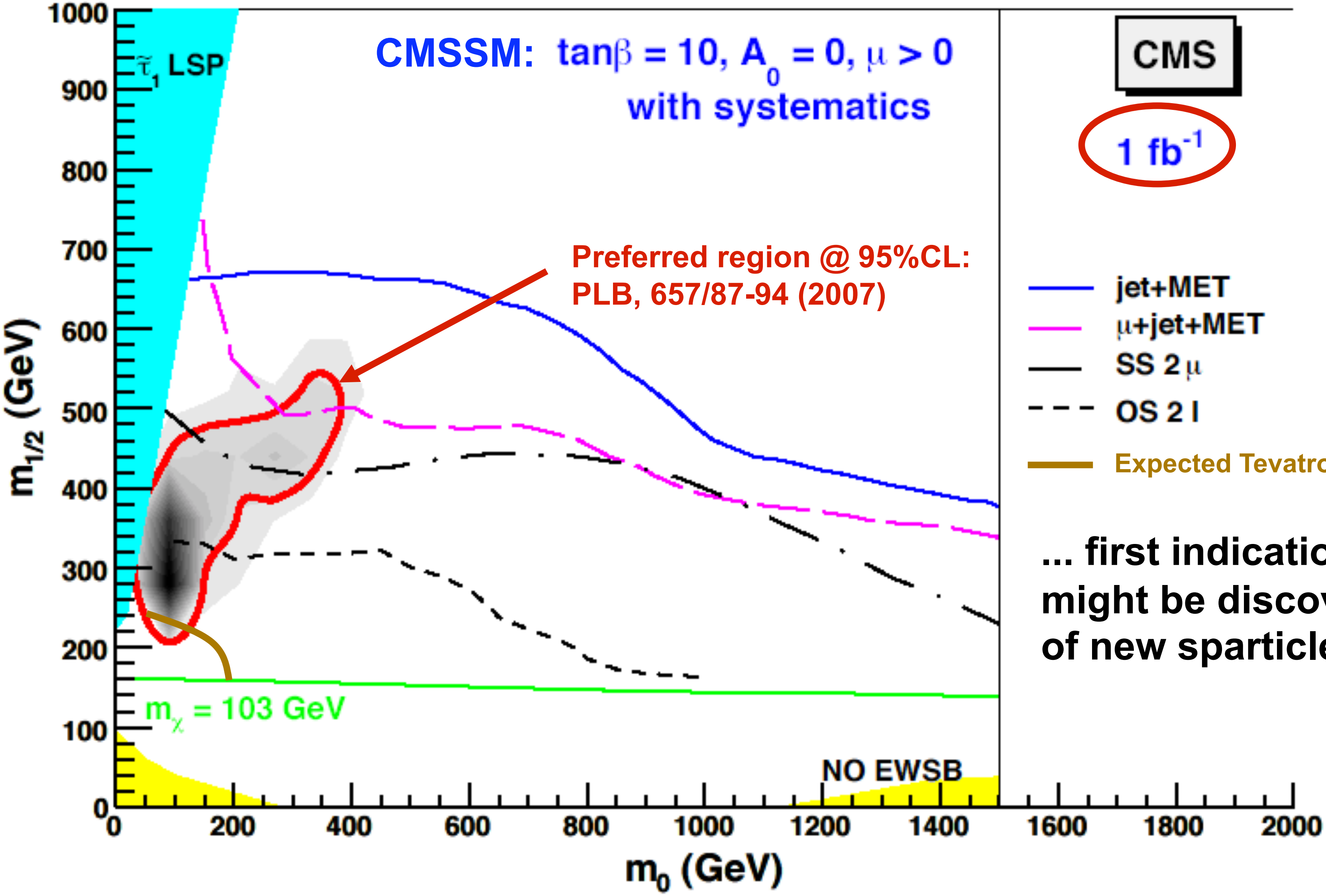
$$m_h = 110^{+8}_{-10} \pm 3\ \mathrm{GeV}/c^2$$

Compared to SM, CMSSM prefers a higher Higgs ; this is remarkable...

Expected Reach for 1 fb^{-1}



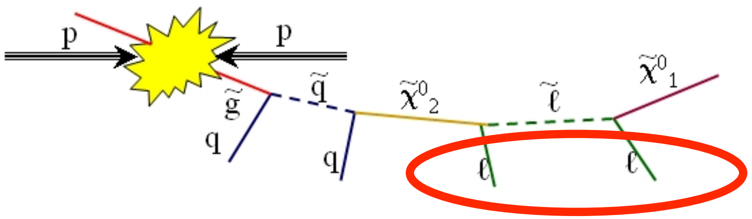
Expected Reach for 1 fb^{-1}

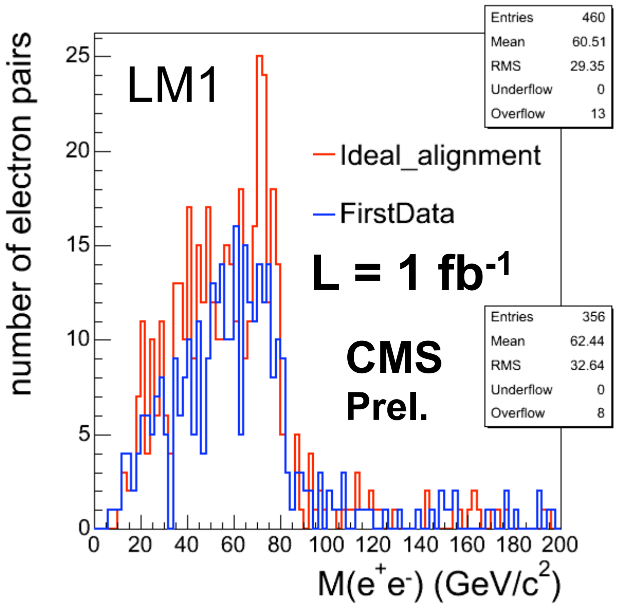


... first indication might be discovery of new sparticles!

Discovery Scenario

- **CMSSM TODAY:**
  - **Use of indirect constraints only**
- **CMSSM 2009:**
  - **Use of indirect & direct constraints**
    - **assume kinematic edge measurements from LHC:**





$$\left(m_{ll}^2\right)^{\text{edge}} = \frac{\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2\right)\left(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2\right)}{m_{\tilde{l}_R}^2}$$

Assume 5% measurement of the edge with leptons only

$$\left(m_{qll}^2\right)^{\text{edge}} = \frac{\left(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2\right)\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2\right)}{m_{\tilde{\chi}_2^0}^2}$$

$$\left(m_{ql}^2\right)^{\text{edge}}_{\text{min}} = \frac{\left(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2\right)\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2\right)}{m_{\tilde{\chi}_2^0}^2}$$

$$\left(m_{ql}^2\right)^{\text{edge}}_{\text{max}} = \frac{\left(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2\right)\left(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2\right)}{m_{\tilde{l}_R}^2}$$

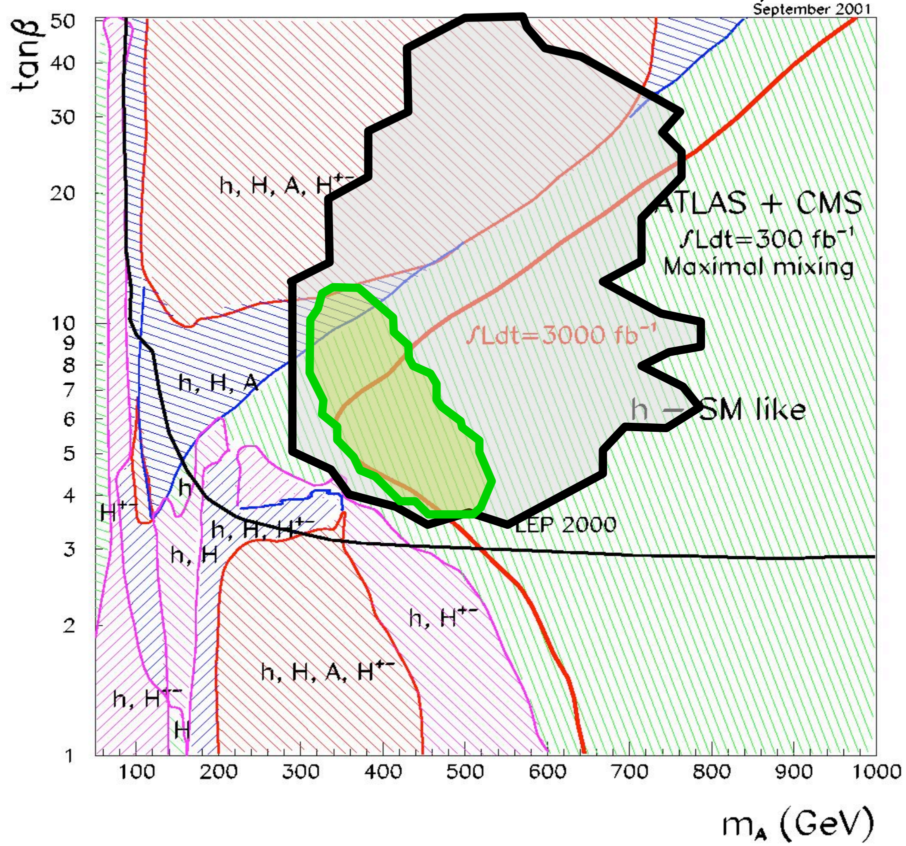
Assume 10% measurements of the kinematic Quantities involving jets

[Conservative uncertainty estimates]

CMSSM Higgs 95% CL

- **CMSSM Today (95% CL)**
  - **No LHC Data**
- **CMSSM 2009 (95% CL)**
  - **Assume Discovery**
  - **Assume measurement of mass edges**
- **Relatively small positive signal**
  - ***dramatically reduces allowed p-space***

Buchmueller, et al



Demanding consistency with all experimental data :
Interpretation within CMSSM context vastly improved

Summary

- *Restaurant*: **LHC & CMS**
- *Entree*: **Turn on**
  - **Detector Calibration**
  - **Monte Carlo Simulation tuning**
  - **Standard Model rediscovery**
- *Main Course*: **Emphasize Quick Discovery Mode**
  - **SM Candles (+NSM Candles?): Z→μμ to get Z→vv and MET**
  - **Searches with bold signatures: High pT**
    - **isolated jets, MET, isolated leptons**
  - **Low mass Supersymmetry could be visible quickly**
- *Dessert*: **Tools for Fast Interpretation**
  - **Global Fits,**
  - **Hypothesis testing**
  - **Existing data accomodates Low mass Supersymmetry well**

Later this Year...

Theoretical & Experimental Speculation may finally give way to Observation (yea or nea)

At a resolution of 10^{-24} metres, isolated clumps of Strange Matter pop briefly out of the quantum foam to debate the possible existence of Particle Physicists.

...Stay Tuned!!

Backup Sides

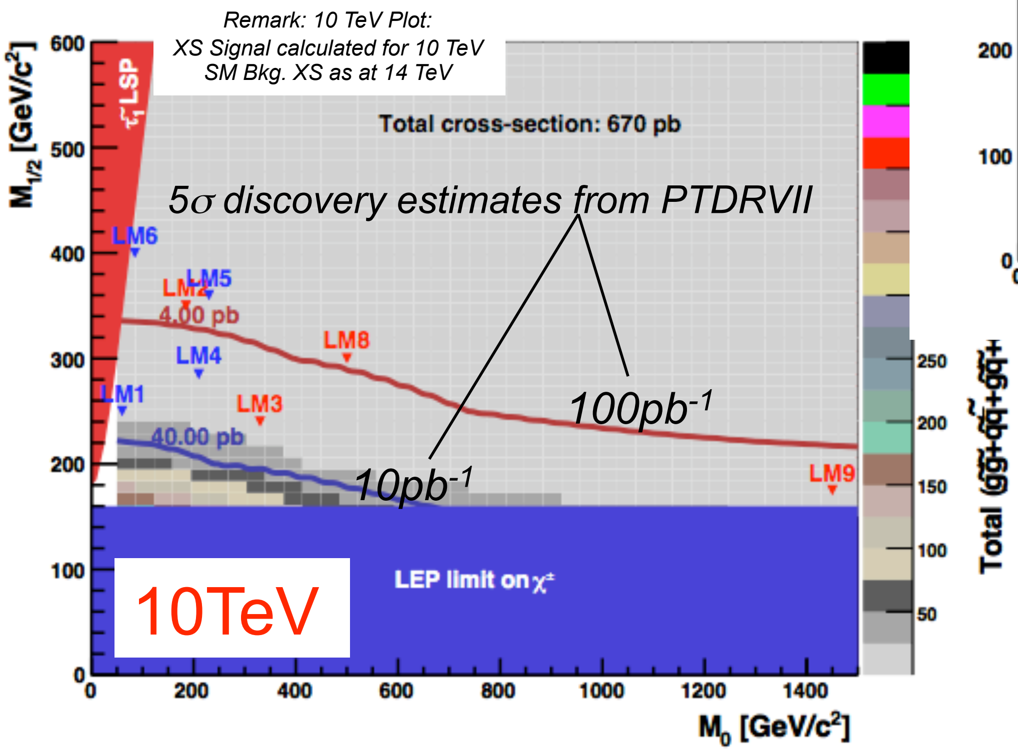
SUSY (CMSSM) Reach: 14TeV vs. 10TeV

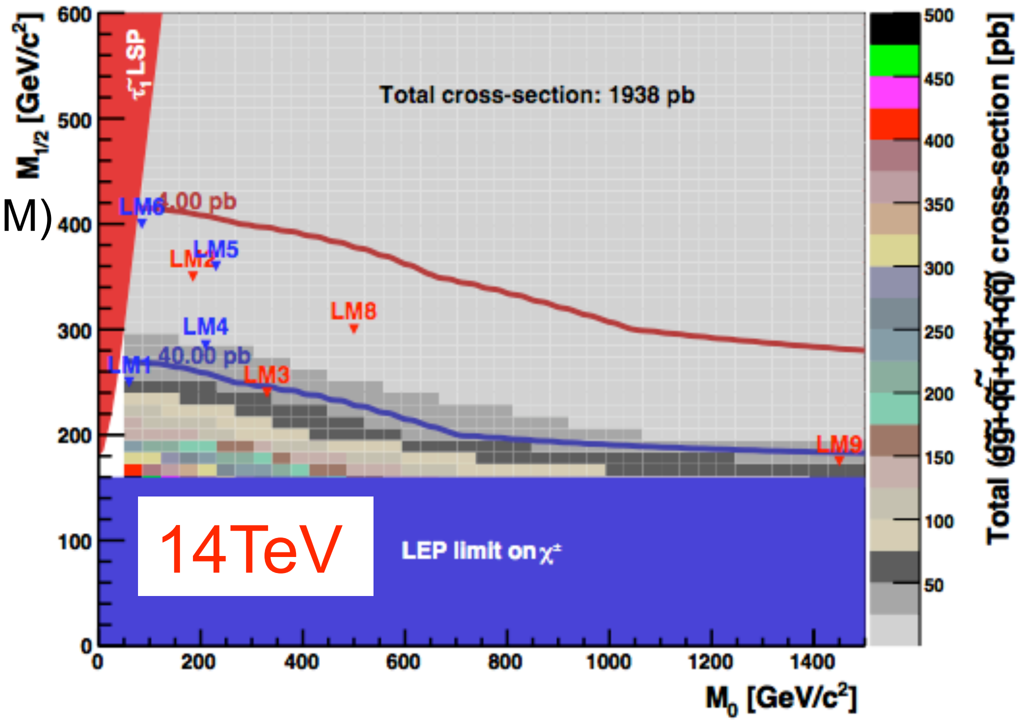
Comparison of SUSY production XS for 14TeV and 10TeV.

For 10TeV the reach is reduced but:

- 10 to 100pb^{-1} start to cover our low mass (LM) SUSY points (i.e. interesting phase space)

[assumes reasonably well understood data - of course]



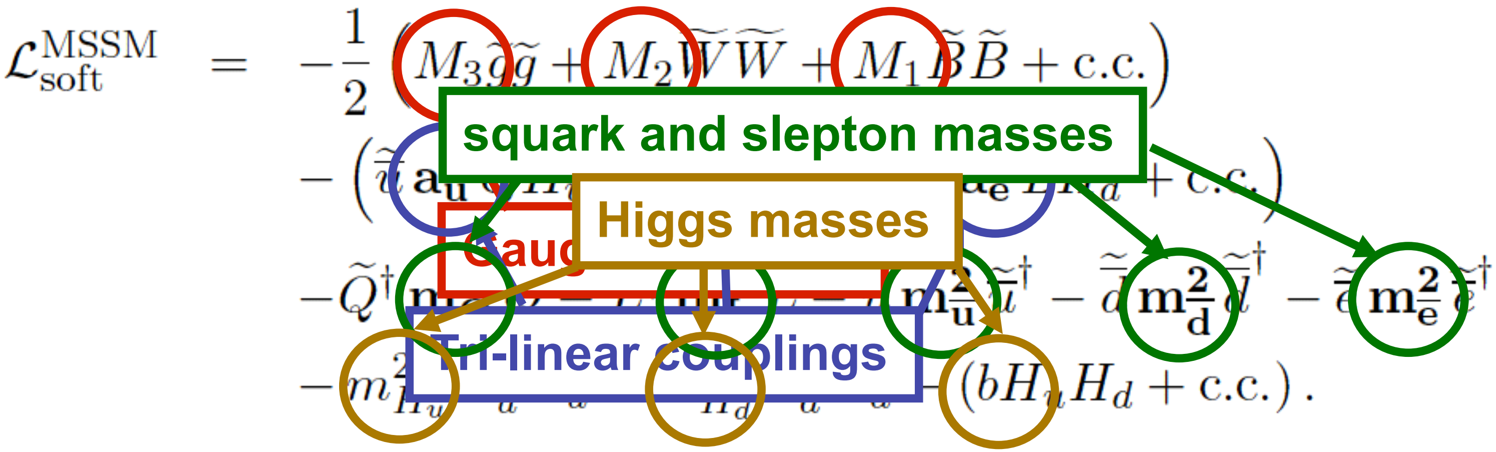


10pb^{-1}(blue) and 100pb^{-1}(red) 5σ discovery lines are based on PTDRVII studies (simple scaling!).

For illustration only!

Supersymmetry Phenomenology

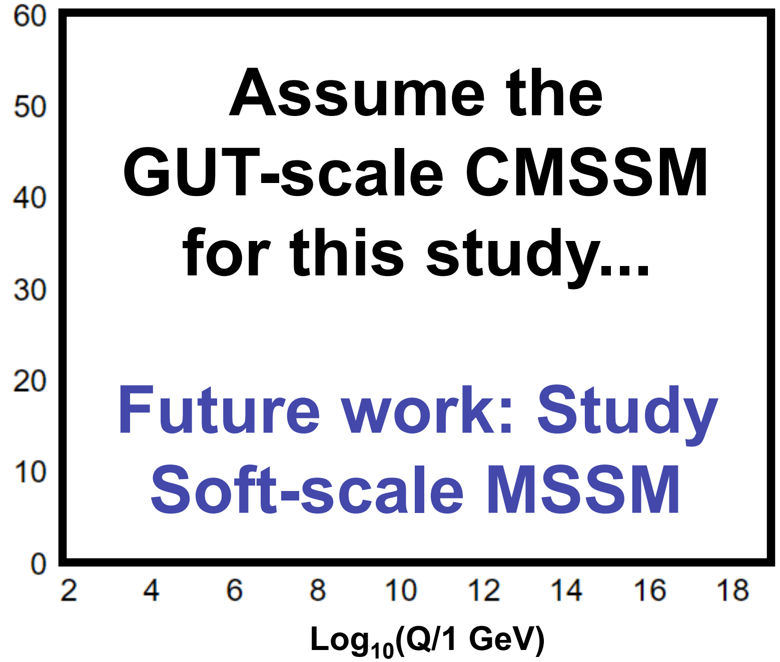
- **Supersymmetric particles not observed experimentally**
  - **SUSY must be broken (softly)!**



- **Mechanism is unknown ⇒ many new free parameters**
  - **MSSM: > 100 additional parameters**
  - **Pheno. Viable: < 20 additional parameters**
    - **3 gaugino masses, 5 squark and slepton masses, 3 tri-linear couplings, 4 higgs masses**
    - **Defined at the Soft Scale!!**
  - **CMSSM: 4 additional parameters (gravity inspired)**
    - **m_0, $m_{1/2}$, A_0, tan β, Sign(μ)**
    - **Defined at the GUT Scale!!**
  - **Others!**
- **Generally assume Lightest SUSY particle is stable (R-parity)**

The Constrained MSSM: Gravity inspired, GUT scale unification

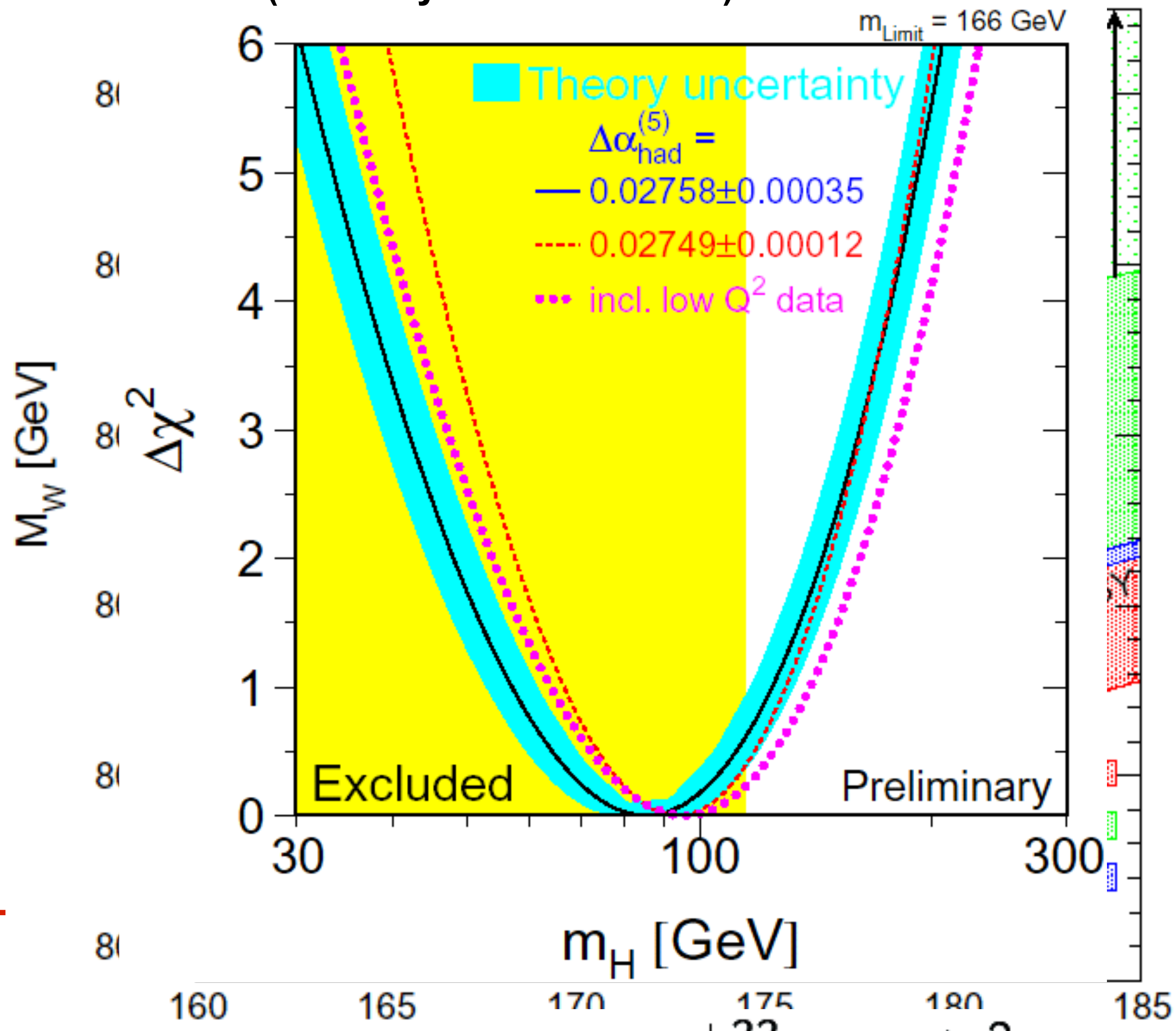
- Universal trilinear couplings
  - $A_0\delta_{ij}$ $= a^u_{ij}(M_{GUT}) = a^d_{ij}(M_{GUT}) = a^l_{ij}(M_{GUT})$
- Ratio of Higgs vacuum expectation values
  - $\tan\beta$ $= \langle H_u \rangle / \langle H_d \rangle$
- Higgs mixing parameter
  - $\mathrm{sign}(\mu)$ (typical to fix positive)
- Unification of the gaugino (bino, wino, gluino) masses
  - $m_{1/2}$ $= M_1(M_{GUT}) = M_2(M_{GUT}) = M_3(M_{GUT})$
- Universal scalar (squark, slepton and Higgs boson) masses
  - m_0 $= m_{Qi}(M_{GUT}) = m_{uRi}(M_{GUT}) = m_{dRi}(M_{GUT}) = m_{Li}(M_{GUT}) = m_{lRi}(M_{GUT}) = m_{Hu}(M_{GUT}) = m_{Hd}(M_{GUT})$



The Current Situation

- **Higgs most sensitive to top-mass**
  - **Tevatron: 171.4 ± 2.1**
  - **But W-mass more precisely measured...**
- **Best W-mass measurement up to 2007:**
  - **ALEPH: 80.440 ± 0.051 (published our final result in 2006)**
- **Best W-mass measurement (as of January '07):**
  - **CDF: 80.413 ± 0.048**
- **Current Exp. Lower Limit:**
  - **SM: 114 < M(h)**
- **Theory bound on Higgs mass**
  - **SM fits:**
    64 < M(H) < 116 (68% CL
  - **MSSM excluded if:**
    ~135 < M(h)

LEP Electroweak Working Group
(courtesy M. Gruenewald)

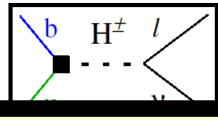


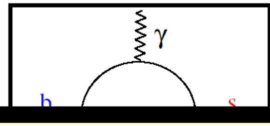
$$m_{\rm H} = 76^{+33}_{-24}\ \mathrm{GeV}/c^2$$

Constraining Model Parameters using Observed Data

- **Multi Parameter Fit to Electro-weak and Low-Energy Observables**

Observable	Constraint
$\sin^2\theta^\ell(Q_{fb})$	0.2324 ± 0.0012
:	:



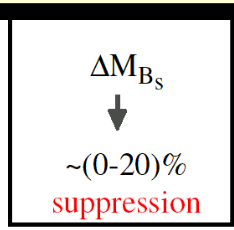


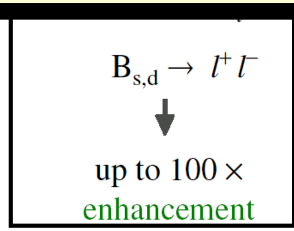
Full χ^2 Fit to 4 Simultaneously Free Parameters

m_0, $m_{1/2}$, A_0, $\tan\beta$; (fix sign[μ] positive)

All SUSY predications at the electroweak scale are obtained through Renormalization Group Equations (RGE's)

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f^{\rm obs}_{{\rm SM}_i} - f^{\rm fit}_{{\rm SM}_i})^2}{\sigma(f_{{\rm SM}_i})^2}$$





  - **Results published in Phys. Lett. B (arXiv:0707.3447)**
- **Others (Allanach et al, Baer et al, Trotta et al, etc) are applying similar strategies**
  - **Partial χ^2s, Bayesian Priors, Monte Carlo Markov Chains, etc**

MSSM Higgs and Loop Corrections

- **Unlike SM Higgs, MSSM lightest higgs boson is determined at tree level → sharper dependence**

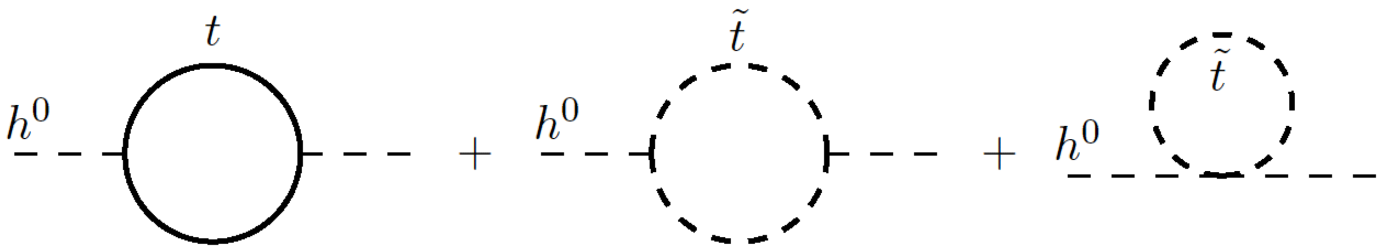
$$m^2_{h^0,H^0} = \frac{1}{2}\left(m^2_{A^0} + m^2_Z \mp \sqrt{(m^2_{A^0} - m^2_Z)^2 + 4m^2_Z m^2_{A^0}\sin^2(2\beta)}\right)$$

- **Naively the MSSM demands a very light Higgs:**

$$m_{h^0} < m_Z|\cos(2\beta)| < 91\ \mathrm{GeV}$$

- **However, the MSSM higgs "feels" all other (s)particles and thus gets large radiative loop corrections**

$$\Delta(m^2_{h^0}) =$$



- **It is only through these loop corrections, that the MSSM higgs can gain a higher mass, above the *Z⁰***

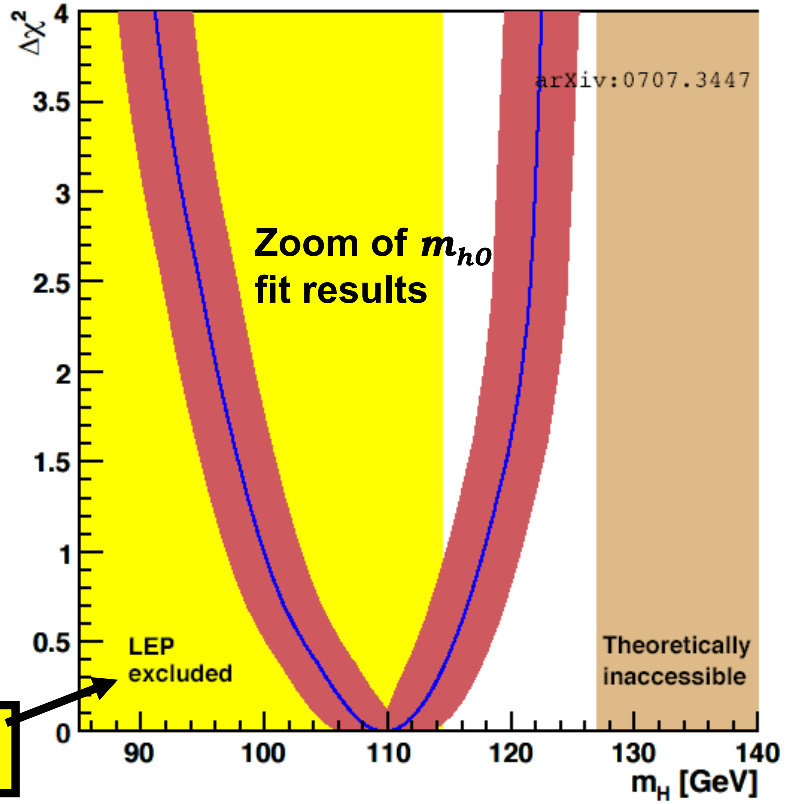
But, Lightest MSSM Higgs Must Stay "Light"

- At one loop order, MSSM Lightest Higgs boson has an upper bound

$$m^2_{h^0} = m^2_Z \cos^2(2\beta) + \frac{3}{4\pi^2} \sin^2\beta \, y^2_t \Big[m^2_t \ln\left(m_{\tilde{t}_1} m_{\tilde{t}_2}/m^2_t\right) + c^2_{\tilde{t}} s^2_{\tilde{t}} (m^2_{\tilde{t}_2} - m^2_{\tilde{t}_1}) \ln(m^2_{\tilde{t}_2}/m^2_{\tilde{t}_1}) + c^4_{\tilde{t}} s^4_{\tilde{t}} \Big\{ (m^2_{\tilde{t}_2} - m^2_{\tilde{t}_1})^2 - \frac{1}{2}(m^4_{\tilde{t}_2} - m^4_{\tilde{t}_1}) \ln(m^2_{\tilde{t}_2}/m^2_{\tilde{t}_1}) \Big\} / m^2_t \Big].$$

plus assume sparticle masses < few TeV and other important considerations

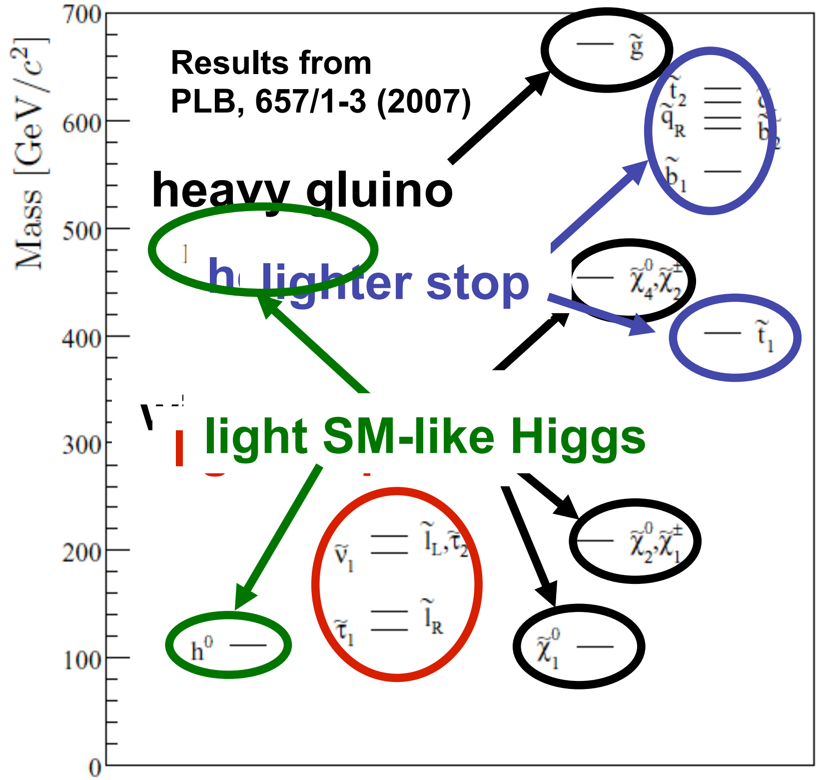
$$m_{h^0} \lesssim 135 \text{ GeV}$$



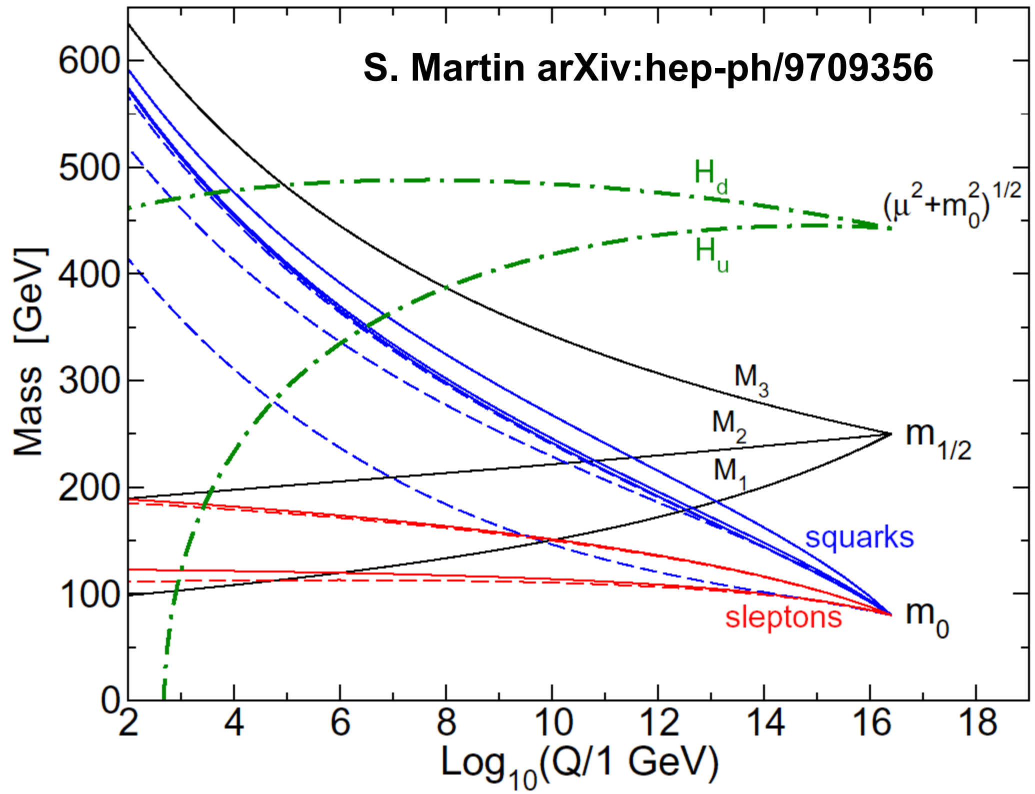
LEP limit not applied in fit!!

Preferred CMSSM Parameters

CMSSM parameter	Preferred value
M_0	(85^{+40}_{-25}) GeV$/c^2$
$M_{1/2}$	(280^{+140}_{-30}) GeV$/c^2$
A_0	(-360^{+300}_{-140}) GeV$/c^2$
$\tan\beta$	10^{+9}_{-4}
sgn(μ)	+1 (fixed)



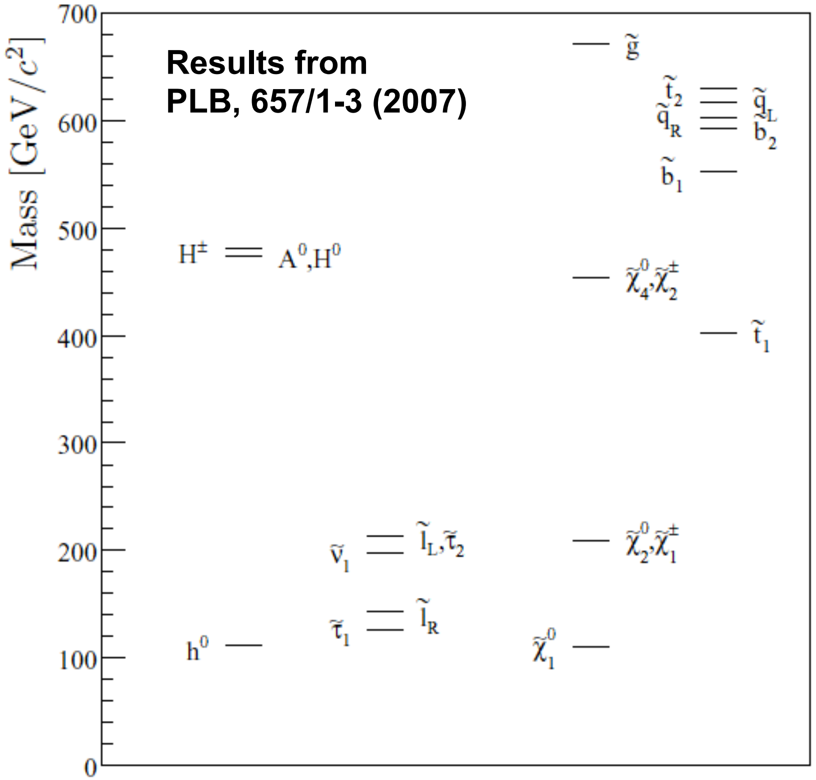
- **Surprisingly similar to**
  - **SPS1a benchmark point (ATLAS)**
  - **LM1 benchmark point (CMS)**



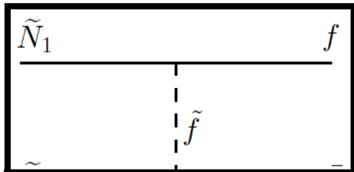
Traditional Regions of Interest

DM relic density can not be too large!

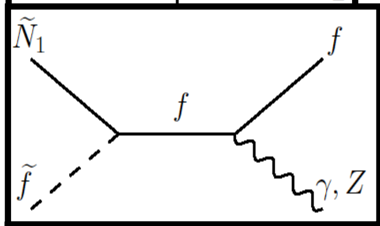
CMSSM parameter	Preferred value
M_0	(85^{+40}_{-25}) GeV/c^2
$M_{1/2}$	(280^{+140}_{-30}) GeV/c^2
A_0	(-360^{+300}_{-140}) GeV/c^2
$\tan\beta$	10^{+9}_{-4}
sgn(μ)	+1 (fixed)

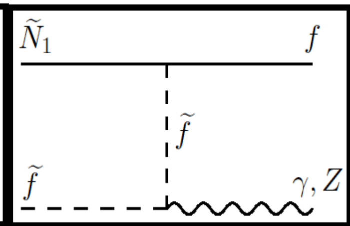


- "Bulk" Region:
  - Traditional before $\Omega_{DM}h^2$ known (WMAP)
  - bino-like LSP
    - t-channel annihilation (sfermion exchange)
  - "SPS1a" or "LM1"
    - Consistent with preferred CMSSM parameters

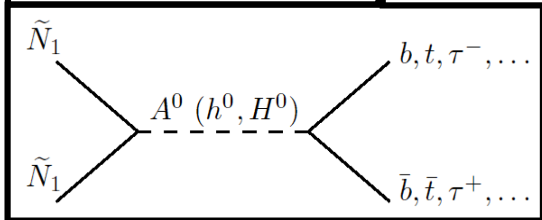


- ino Co-annihilation" Region
  - only slightly heavier than LSP
    - annel annihilation via taus & staus

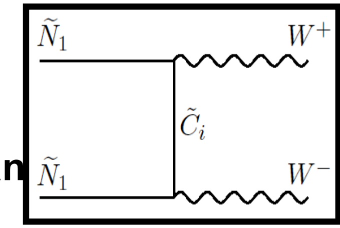


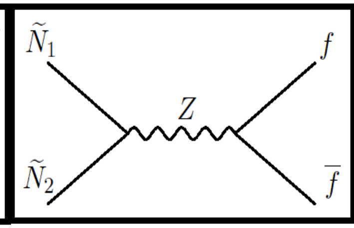


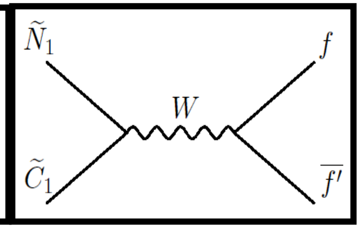
- , or h
  - s resonance)
  - s



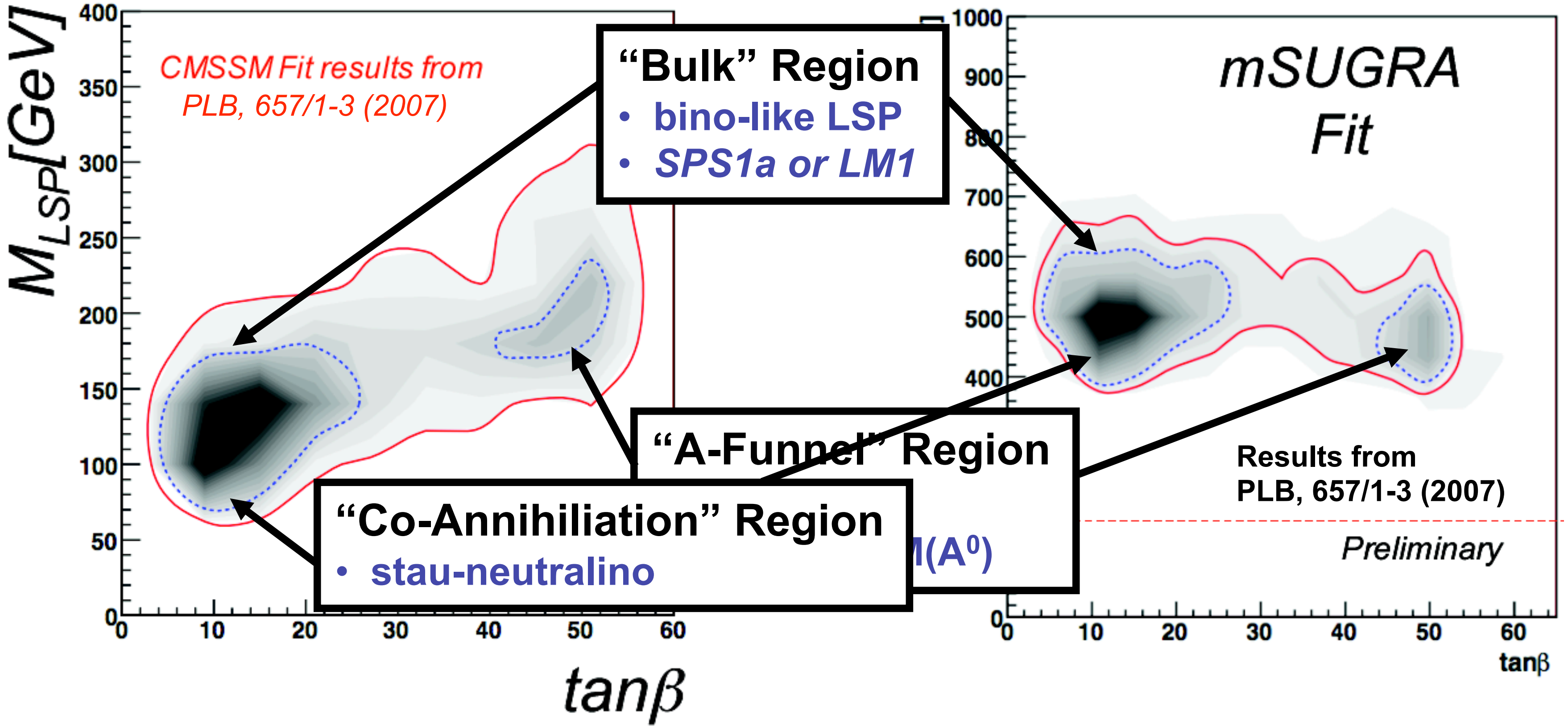
- :
  - " properties of RGEs
  - sino and wino admixture
    - t- & s-channel annihilation via gauginos, W, Zs
  - typically very heavy squarks and sleptons







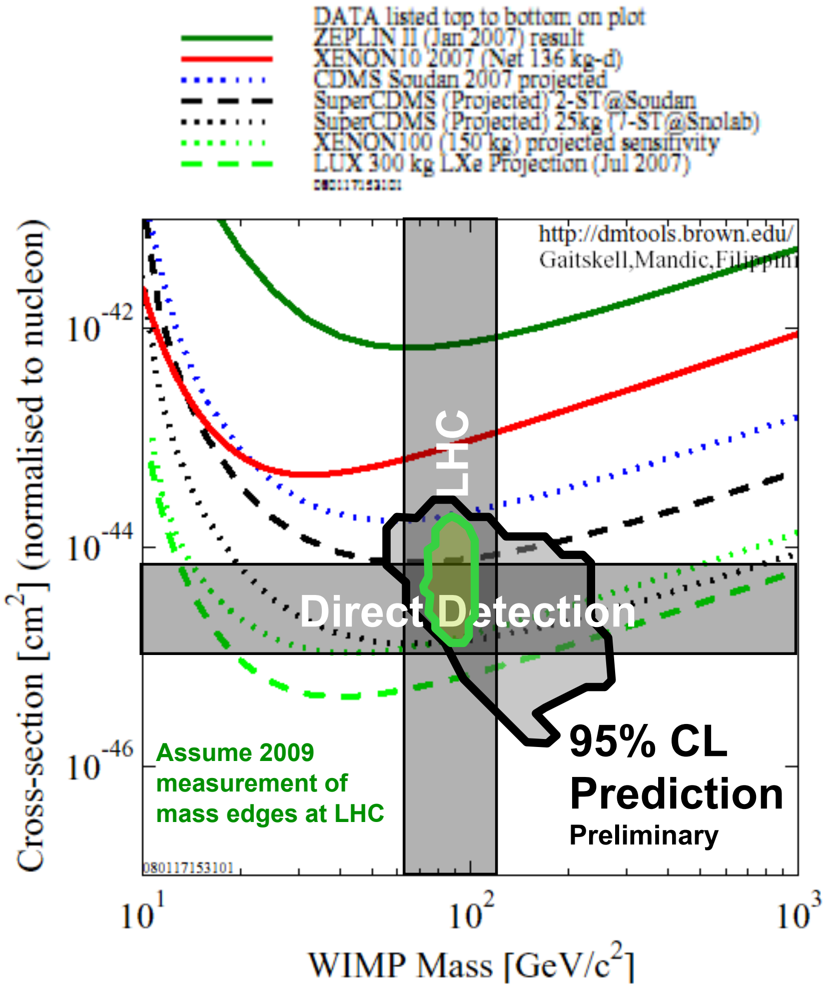
Future Directions...



- Already provide interesting glimpse!
- Suggests interesting follow-up work
  - Study effect of Relic Density constraint!
    - Entire relic density need not solely be due to the LSP!
  - Study effect of g-2 constraint (artificially increase errors)
    - Focus Point Region currently disfavoured
- Errors are large, but, can be significantly reduced with LHC discoveries!

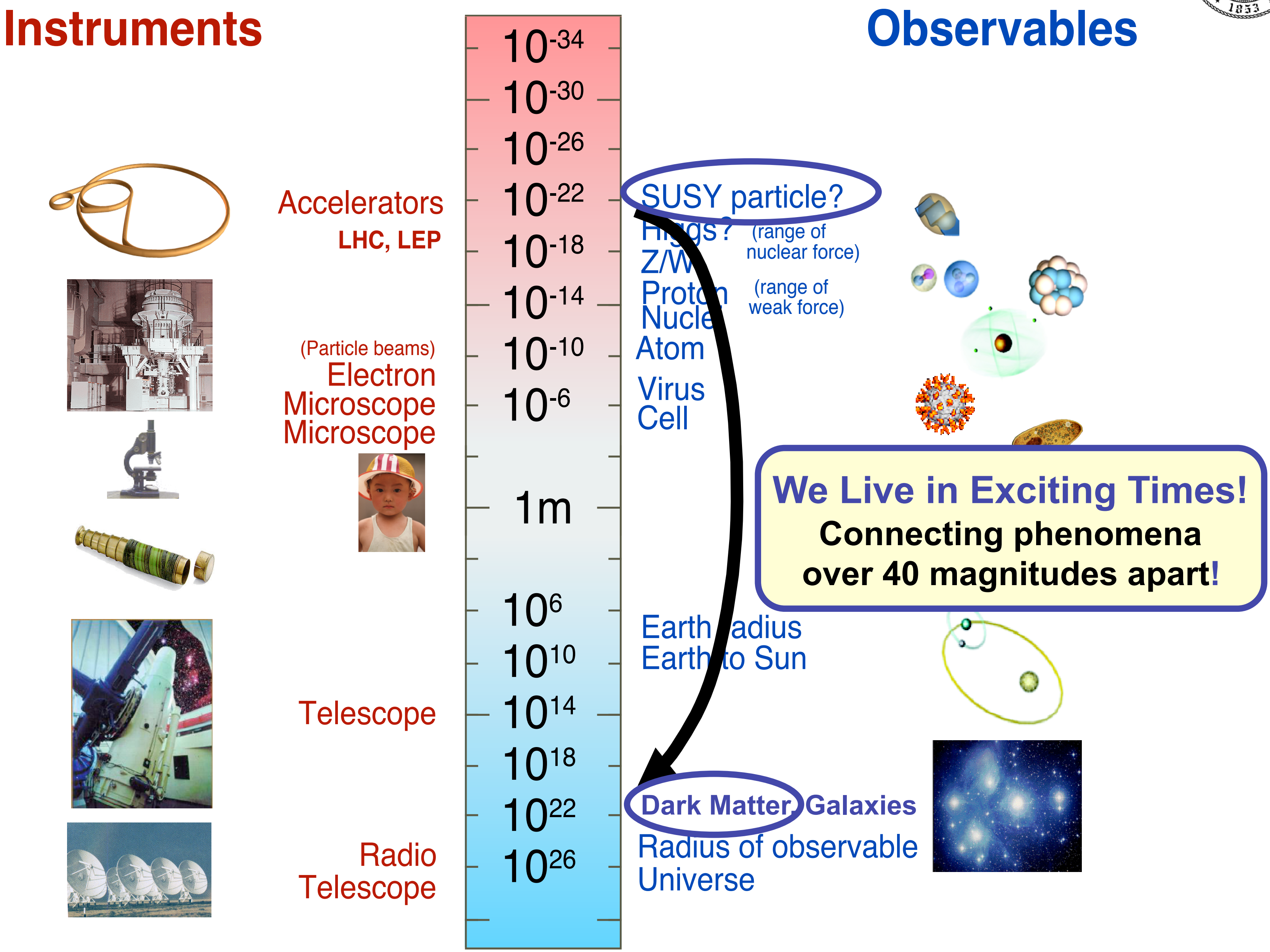
Making Dark Matter in the Lab!

- **Study properties of a newly discovered WIMP at LHC**
  - **Measure it's mass, production rate, etc**
  - **Likely will depend on theoretical models**
- **Compare properties with**
  - **direct observation experiments (scattering off nuclei)**
  - **indirect observation experiments (satellites)**
- **If we all agree,**
  - **Good chance we made Dark Matter in the lab!**
  - **Requires strong cross disciplinary collaboration!**



Warning: Ellis, Olive → Elastic SI cross section uncertain to factor 10!!

Microscopes vs Telescopes



The **Fast Physics** LHC Discovery *Menu*

Integrated luminosity (fb^{-1})

Model	Mass reach	Luminosity (fb^{-1})	Early Systematic Challenges
Contact Interaction	Λ < 2.8 TeV	0.01	Jet Eff., Energy Scale
Z' ALRM SSM LRM E6, SO(10)	 M ~ 1 TeV M ~ 1 TeV M ~ 1 TeV M ~ 1 TeV	 0.01 0.02 0.03 0.03 – 0.1	Alignment
Excited Quark	M ~0.7 – 3.6 TeV	0.1	Jet Energy Scale
Axigluon or Colouron	M ~0.7 – 3.5 TeV	0.1	Jet Energy Scale
E6 diquarks	M ~0.7 – 4.0 TeV	0.1	Jet Energy Scale
Technirho	M ~0.7 – 2.4 TeV	0.1	Jet Energy Scale
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6 M_D~ 5 - 4 TeV, n = 3-6	0.1 1	Alignment
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	0.1	MET, Jet/photon Scale
SUSY Jet+MET+0 lepton Jet+MET+1 lepton Jet+MET+2 leptons	M ~1.5 – 1.8 TeV M ~0.5 TeV M ~0.5 TeV M ~0.5 TeV	1 0.01 0.1 0.1	MET, Jet Energy Scale, Multi-Jet backgrounds, Standard Model backgrounds
mUED	M ~0.3 TeV M ~ 0.6 TeV	0.01 1	ibid
TeV^{-1} ($Z_{KK}^{(1)}$)	M_{z1} < 5 TeV	1	
RS1 di-je di-m	 c=0.1 M_{G1}~0.8- 2.3 TeV, c=0.01-0.1	 0.1 1	

Early LHC Runs: 0.1 to 1 fb^{-1}

Not an exhaustive list!!

LHC: Worlds Largest Cryogenic System

- 1,000 8-Tesla superconducting dipole magnets
  - 8,000 total superconducting magnets (dipoles, quadrupoles, etc)
- 40,000 tonnes of cold mass spread over 27 km
- 10,000 tonnes of Liquid Nitrogen (300 K to 4.5 K)
  - 500 Trucks needed to deliver
- 120 tonnes of Liquid Helium (cools ring to final 1.9 K)
  - O(1%) of worlds annual production
  - Higher Helium prices affecting LHC costs

chicagotribune.com
Chicago Tribune Web Edition
January 20, 2008

Search Go

chicagotribune.com Web enhanced by Google

RIZZA LUXURY CARS

Classified
Cars
Jobs
Real estate
Apartments
Local stores & deals
Dating
Pets
Items for sale
Place an ad

Shopping

Home > Business

Consumers feeling the helium squeeze

The gas that floats balloons also powers industrial and scientific projects. And it's disappearing fast.

By Bob Secter | Tribune staff reporter
November 5, 2007

Helium is the talk of the party balloon industry these days, and it is not a discussion being carried out in high-pitched giggles.

The second most plentiful element in the universe is suddenly in short supply on this planet, and that means soaring prices for a lot of things, balloons included.

"Some customers have told me they're just not going to sell balloons anymore because they can't get helium," said Chicago party wholesaler Lee Kaufman. "Everybody's scrambling."

Article tools
E-mail
Share
Print
Reprints
Post comment
Text size:

Magnetic Energy Stored in LHC Ring

8 T Magnetic Field, two 2 cm bores, 27 kilometers →

10 Giga-Joules

Beam Energy Stored in LHC Ring

2808 bunches, 10^{11} protons per bunch, 7 TeV per proton →

What is Supersymmetry?

- **Supersymmetry is a symmetry between fermions and bosons**
  - **Q(SUSY) | fermion > = | boson >**
  - **Q(SUSY) | boson > = | fermion >**
- **Implies (more than) doubling of Standard Model particles**

SM Particles	SUSY Particles			
quarks: q	q	squarks: $\tilde{q}$		
leptons: l	l	sleptons: $\tilde{l}$		
gluons: g	g	gluino: $\tilde{g}$		
charged weak boson: $W^{\pm}$	$W^{\pm}$	Wino: $\widetilde{W}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$	chargino
Higgs: H^0	$H^{\pm}$	charged higgsino: $\widetilde{H}^{\pm}$		
	h^0, A^0, H^0	neutral higgsino: $\tilde{h}^0, \tilde{A}^0$,	$\widetilde{H}^0$	higgsino
neutral weak boson: Z^0	Z^0	Zino: $\widetilde{Z}^0$	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
photon: γ	γ	photino: $\tilde{\gamma}$		

- **Exact Supersymmetry implies**
  - **Each SUSY particle same mass, quantum #'s, etc as SM partner**
    - **Except each SUSY partner differs by ½ unit of spin from SM partner**
  - **Almost no new parameters...but many new particles!**