Aspen 2009: Experimental View on "Physics in the LHC Era"

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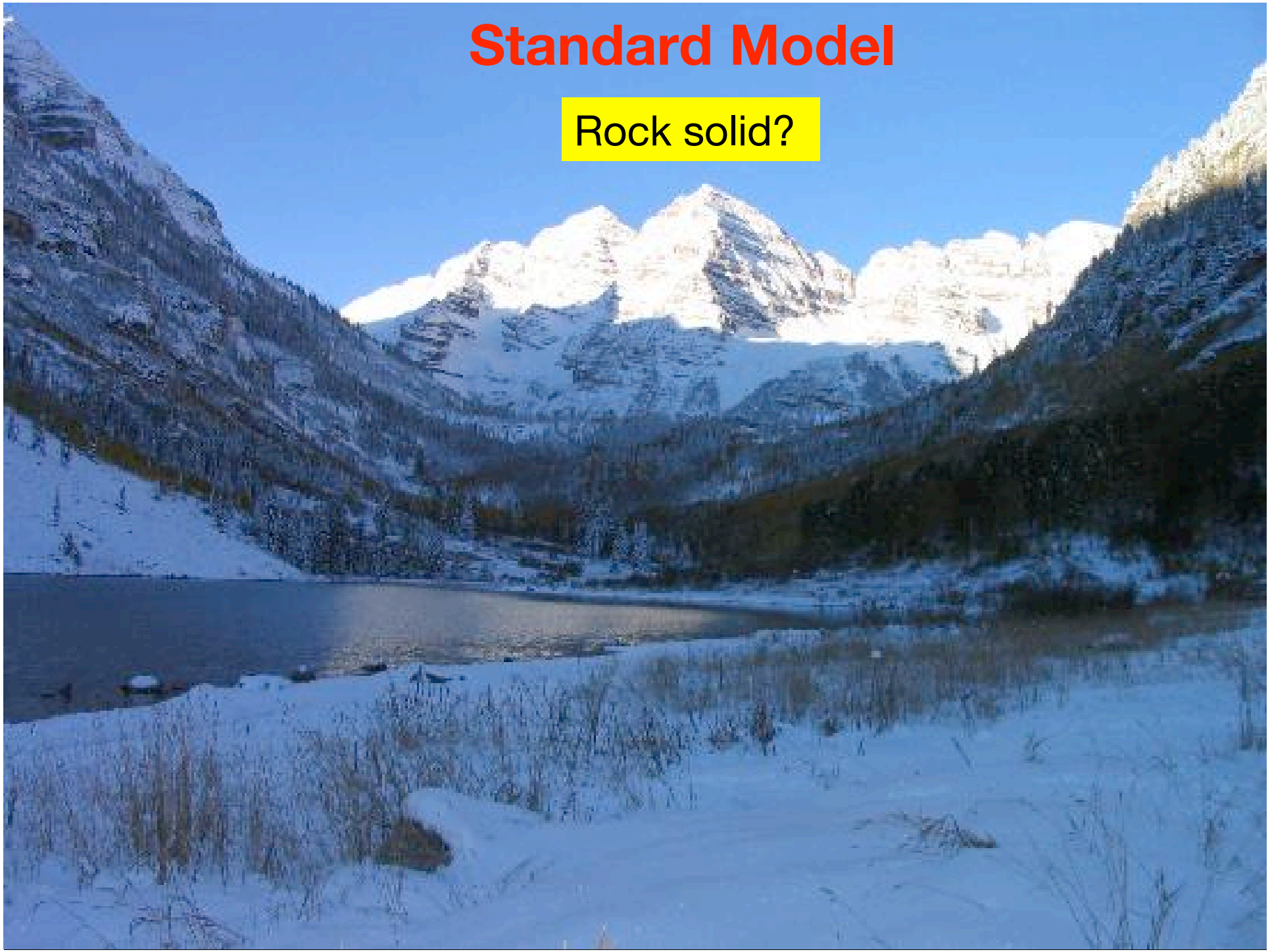
Aspen, February 14th 2009

Outline

- Experimental Status of the Standard Model
  - Strong Force
  - Flavor Sector
  - Electroweak Symmetry Breaking
  - Searches for the Unknown
- The beginning of the new Era
  - The Large Hadron Collider and it's Experiments

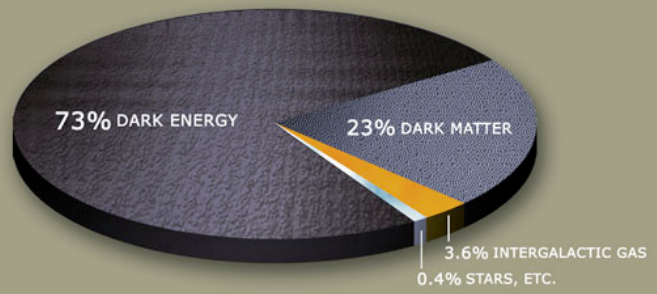
Standard Model



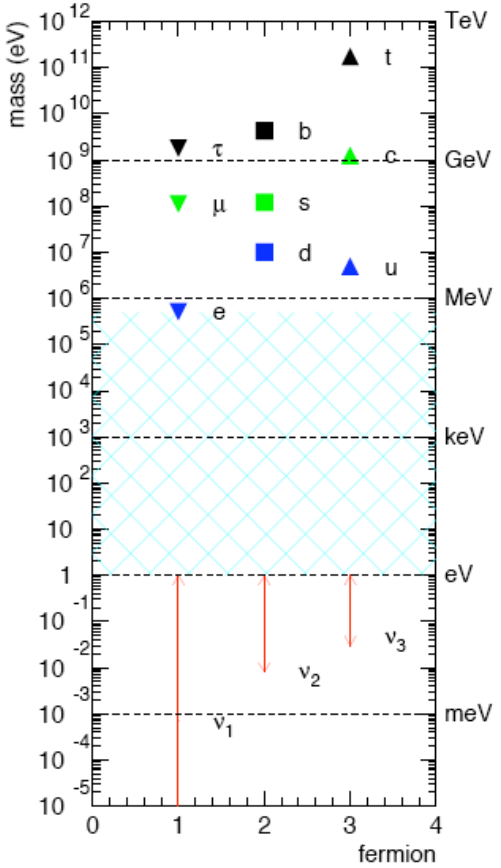
Standard Model

Not really!

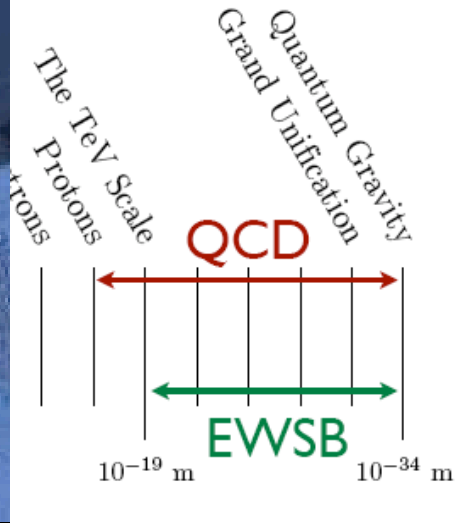
Dark Matter+Energy



Mass hierarchy

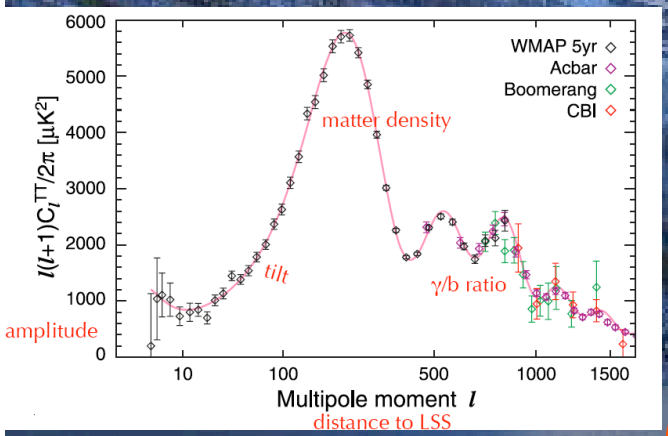


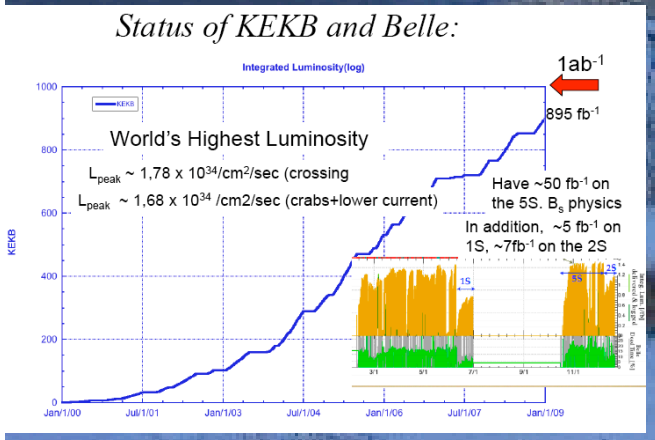
EWSB

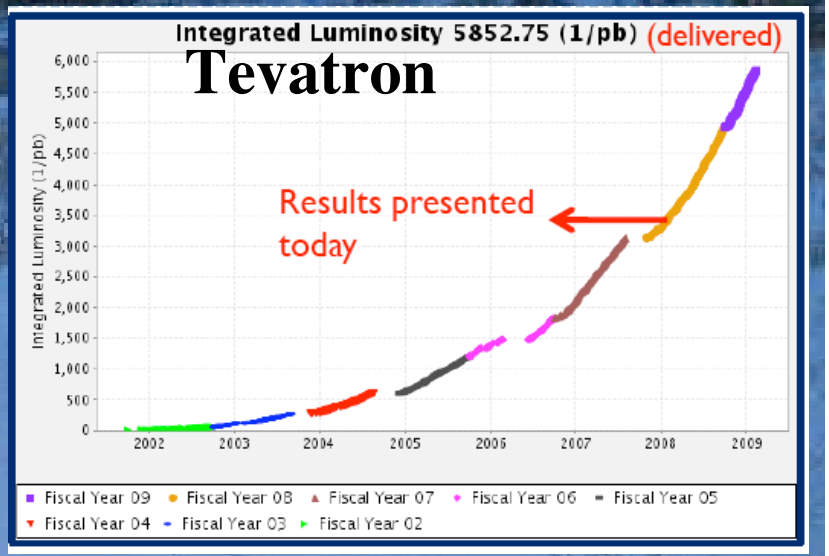


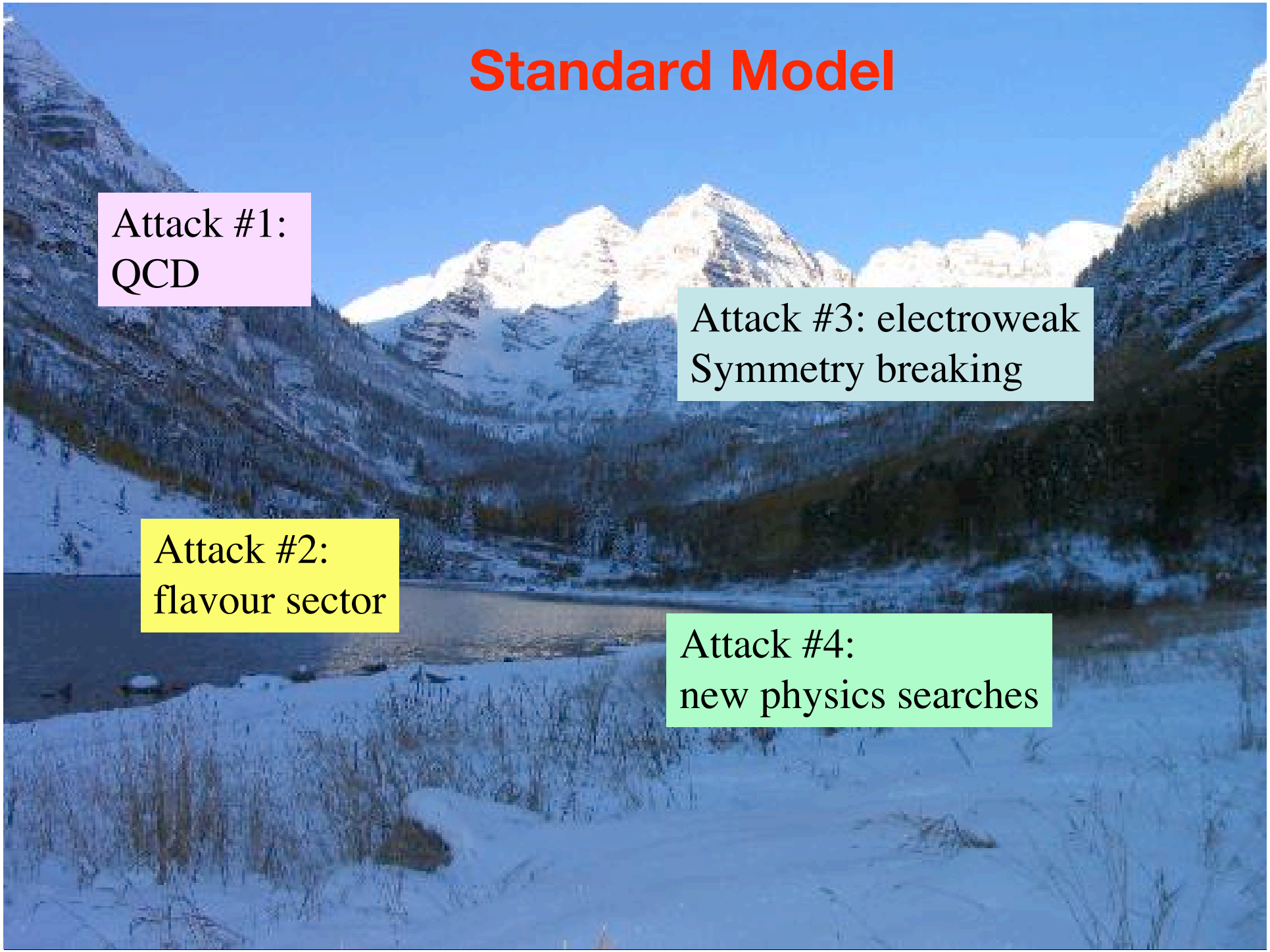

Pamela

ATTACK!!!


WMAP 5yr
Acbar
Boomerang
CBI
matter density
tilt
γ/b ratio
amplitude
distance to LSS
$l(l+1)C_l^{TT}/2\pi$ [μK²]
Multipole moment l


Status of KEKB and Belle:
Integrated Luminosity(log)
1ab-1
895 fb-1
World's Highest Luminosity
Lpeak ~ 1,78 x 10³⁴/cm²/sec (crossing
Lpeak ~ 1,68 x 10³⁴ /cm2/sec (crabs+lower current)
Have ~50 fb-1 on the 5S. Bs physics
In addition, ~5 fb-1 on 1S, ~7fb-1 on the 2S
KEKB

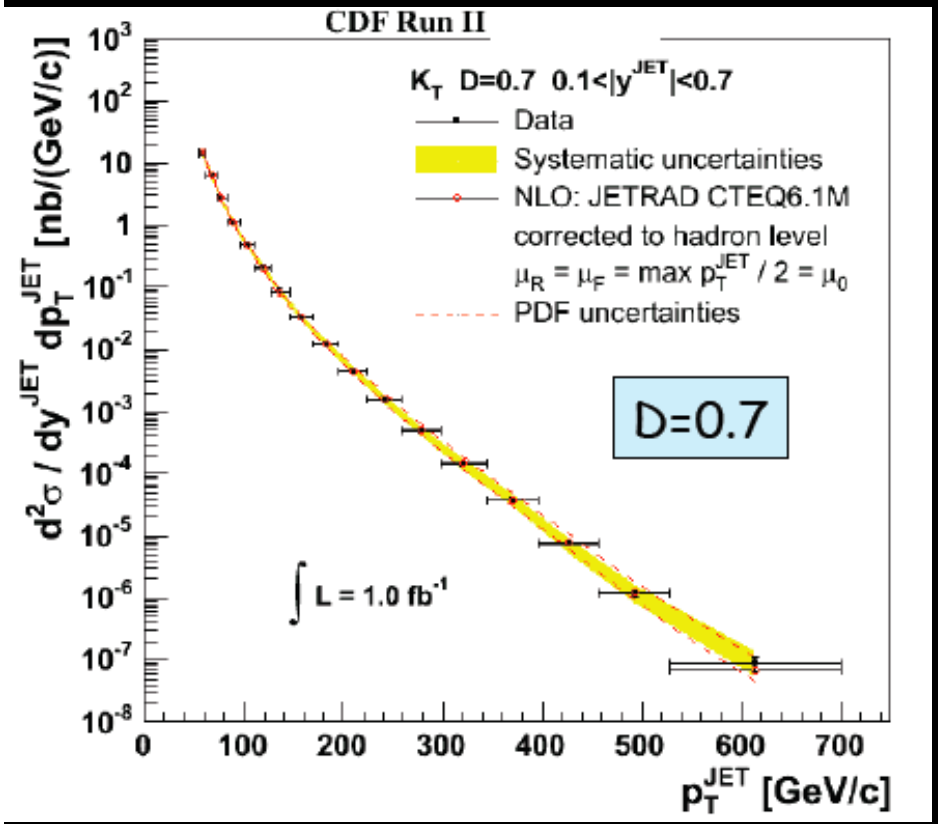

Integrated Luminosity 5852.75 (1/pb) (delivered)
Tevatron
Results presented today
Integrated Luminosity (1/pb)
Fiscal Year 09
Fiscal Year 08
Fiscal Year 07
Fiscal Year 06
Fiscal Year 05
Fiscal Year 04
Fiscal Year 03
Fiscal Year 02

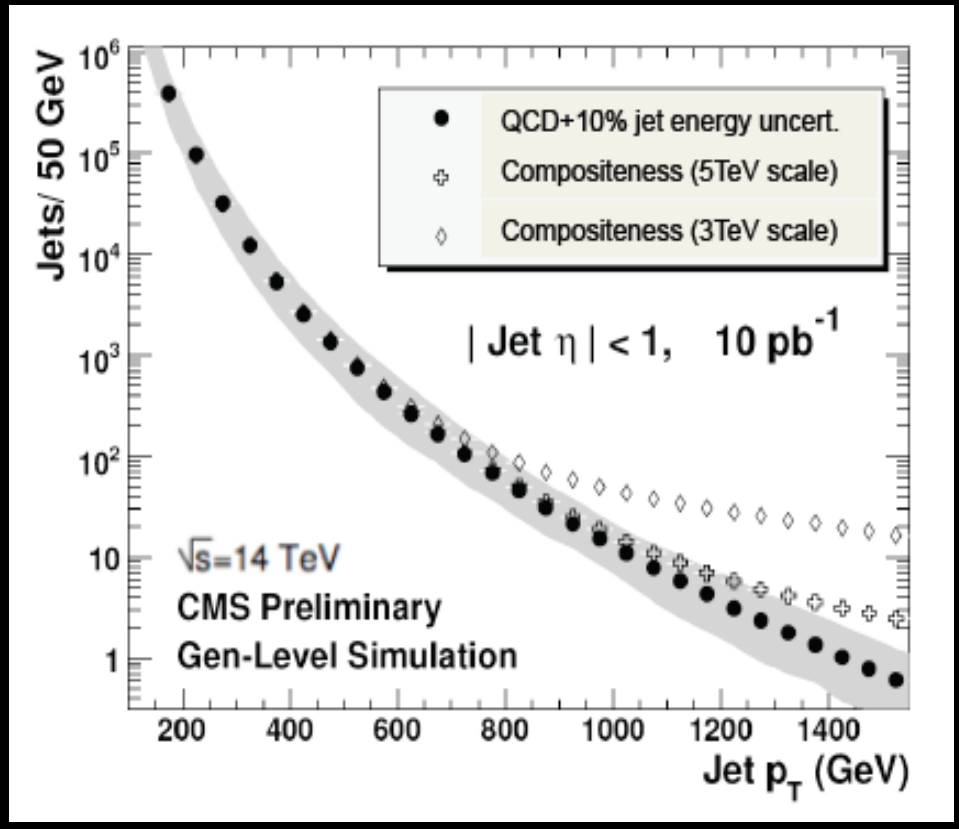

Standard Model
Attack #1:
QCD
Attack #3: electroweak
Symmetry breaking
Attack #2:
flavour sector
Attack #4:
new physics searches

The Strong Force

Jet Cross Section

M. Martinez
M. Dunford





- Impressive measurements at Tevatron
  - Data agree with NLO QCD over 8 order of magnitude
- Early physics opportunity at LHC
  - Already surpass Tevatron with 10 pb^{-1}!

Gluon Density

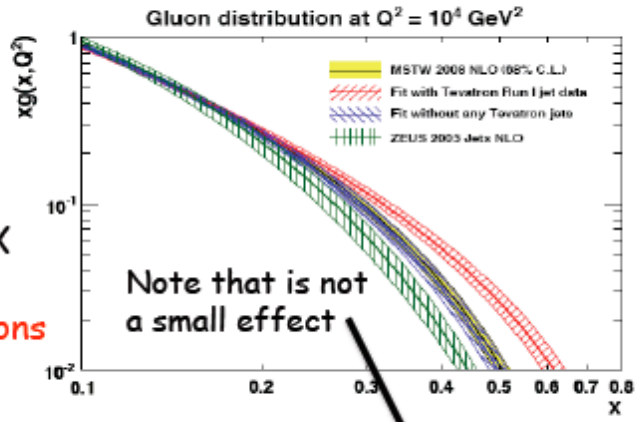
M. Martinez

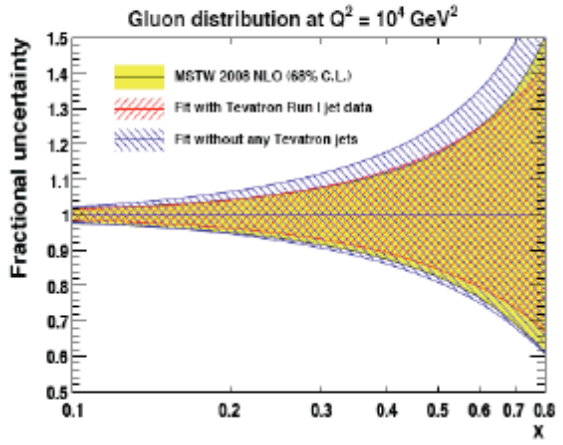
New Gluon (MSTW08) (hep-ph:09010002)

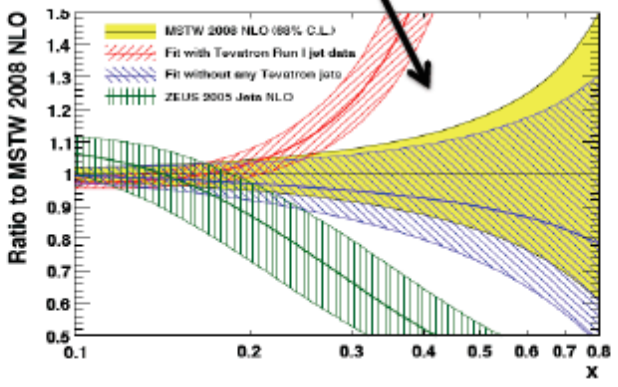
New MSTW analysis:

- Using CDF Kt and D0 Midpoint
- CDF and D0 data consistent

- Data dictate less gluons at high-X
- Reduced gluon PDF uncertainty
- Reduced gluon-driven cross sections



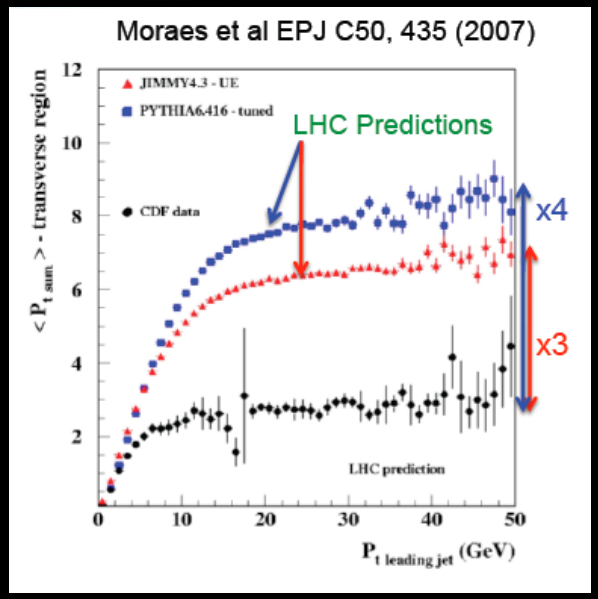


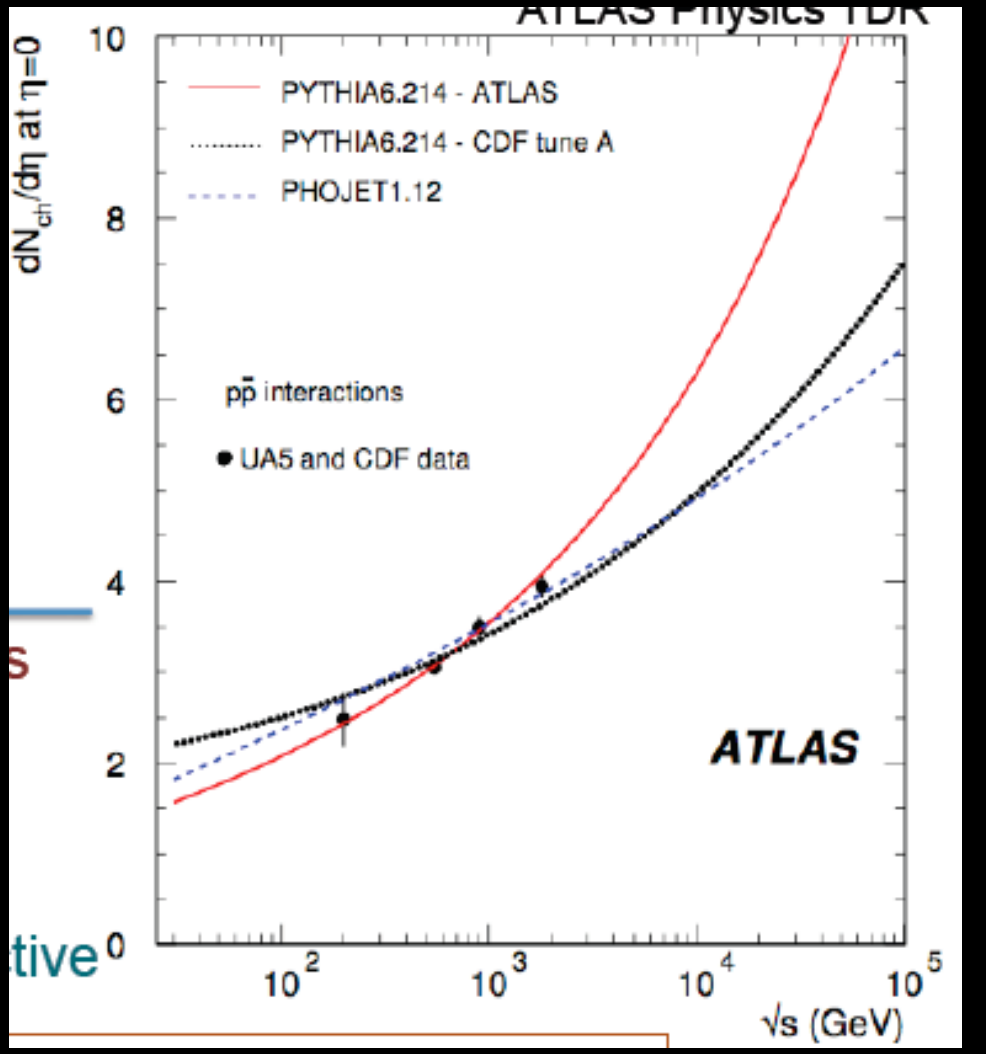


- New comprehensive analysis by Martin, Stirling, Thorne, Watt (MSTW): arXiv:0901.0002
  - Gluon reduced at high x due to Run2 Tevatron data
  - Reduces e.g. H->WW cross section at Tevatron by ~15%

Very early LHC Measurements

P. Skands
M. Dunford

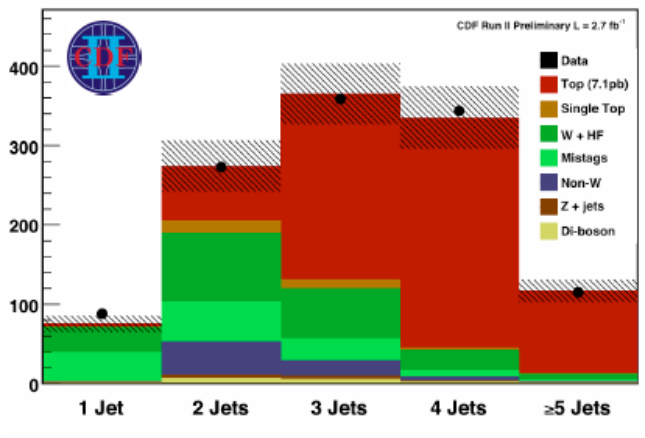




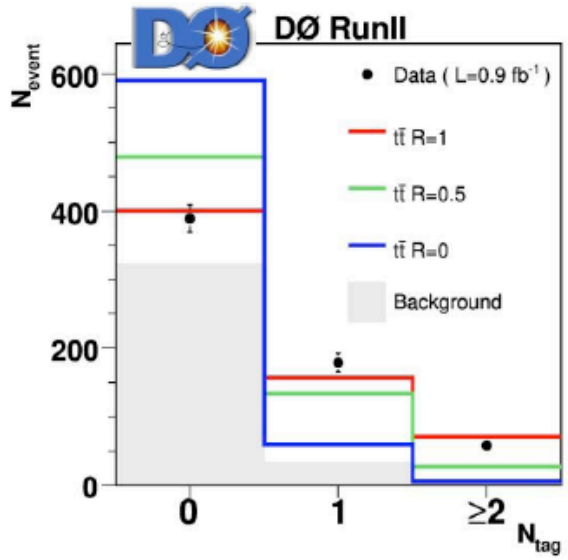
- Skands:
  - **LHC: N=12.5+/-1.5**
    - for p_T>0.5 and |eta|<2.5
  - **CDF: N=3.17+/- 0.31**
    - for p_T>0.5 and |eta|<1.0
- Critical for tuning MC
  - MinBias interactions
  - Underlying event

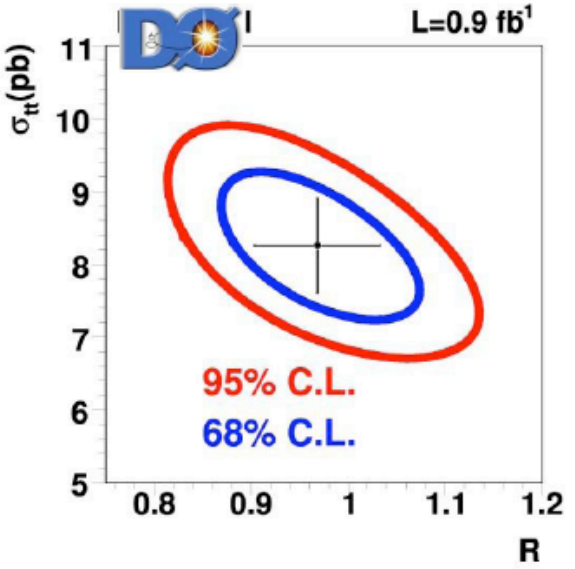
Top Production

Z. Ye

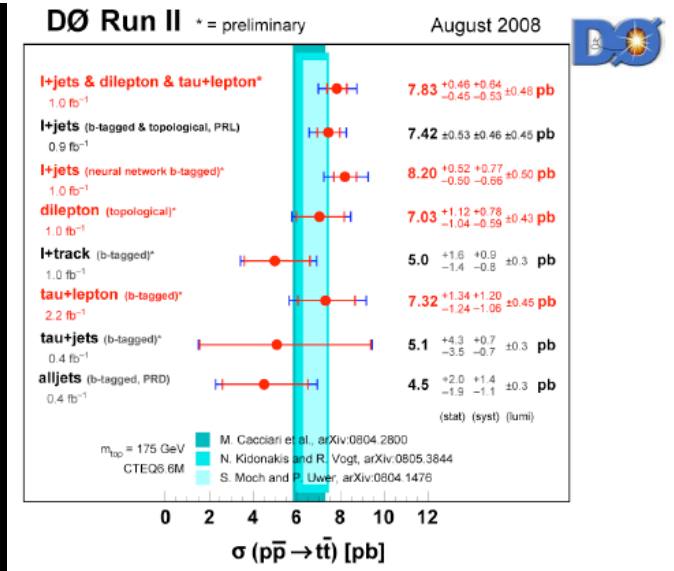


CDF btagged (2.8 fb^{-1}):
7.0±0.4(stat)±0.6(syst)±0.1(theo)pb





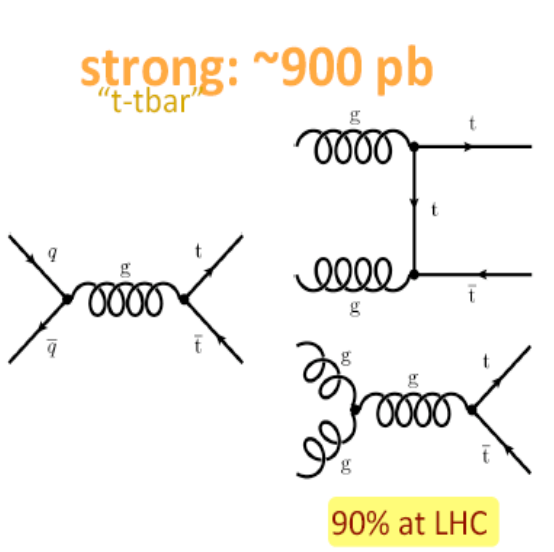
- Top production consistent with QCD calculations
  - Theoretical and experimental precision comparable

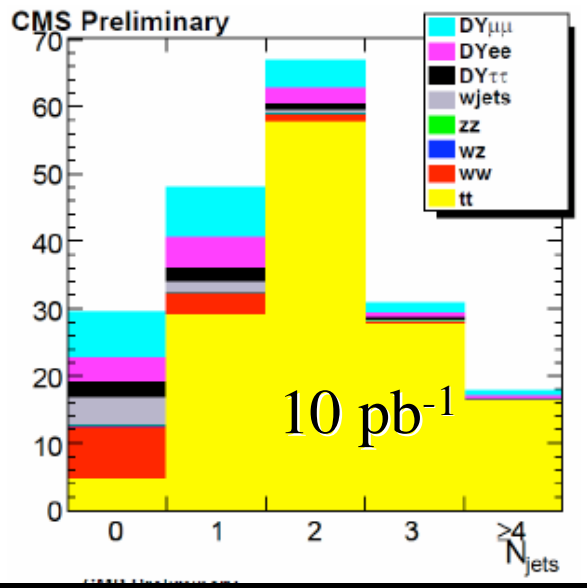


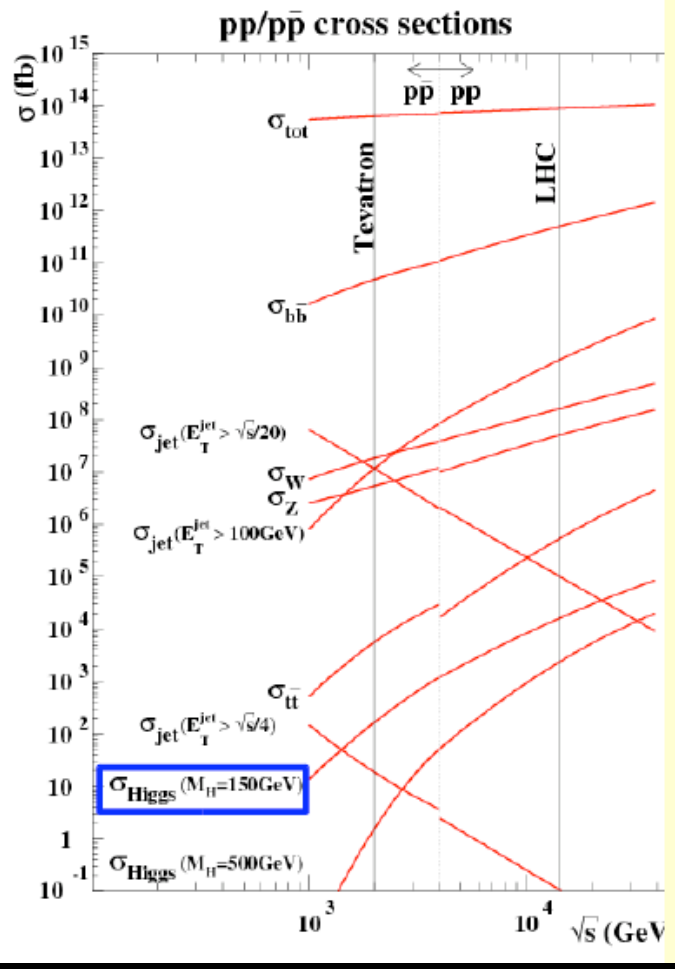
DØ combined (0.4-2.2 fb^{-1}):
7.8±0.5(stat)±0.6(syst)±0.5(lumi) pb

Top Production at LHC

A. Arce



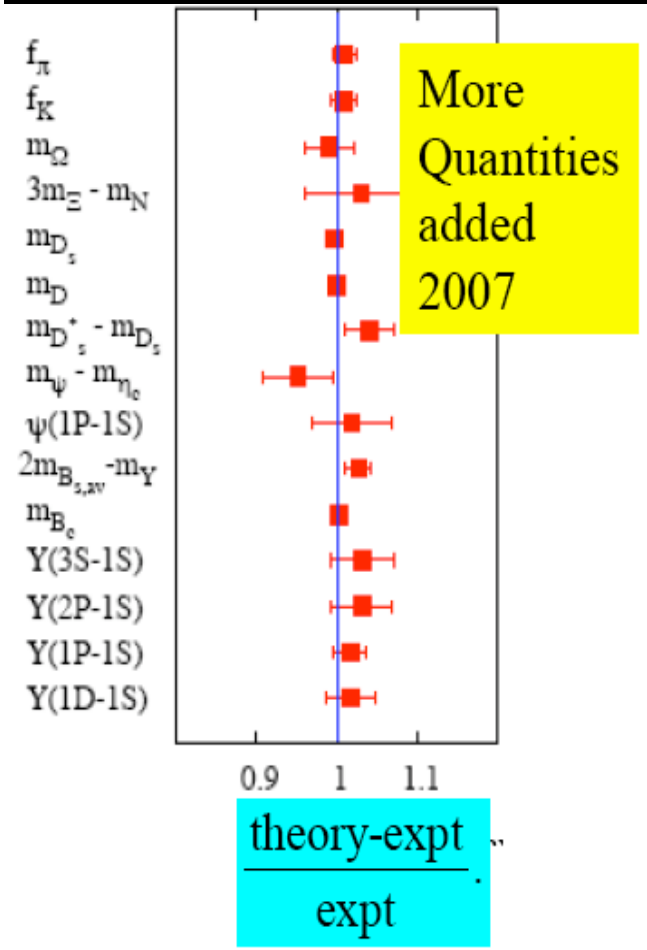




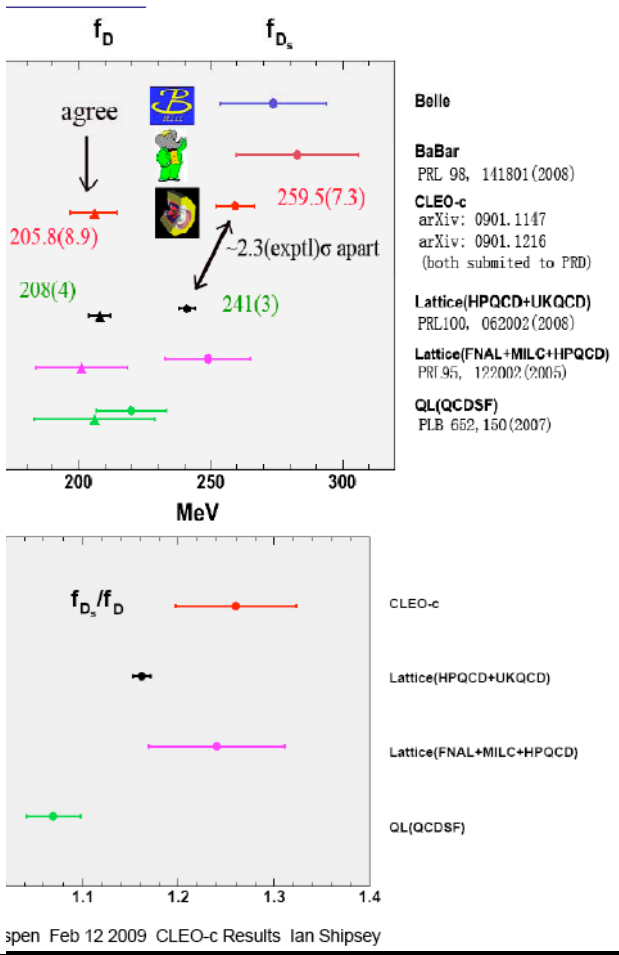
- Factor 100 increase in cross section
  - Backgrounds increase less: better S/B
- Establish top with 10-100 pb^{-1}
  - Important milestone on road to new physics discoveries

Tests of Lattice QCD

I. Shipsey



More Quantities added 2007



Comparison to LQCD

CLEO f_D consistent with calculations

CLEO f_{D_s} (and Belle & BABAR) higher than most theoretical expectations

CLEO f_{D_s} is ~2.3σ above the most recent & precise LQCD calculation (HPQCD+UKQCD).

Ds leptonic decay width could be modified by new physics ex: Dobrescu and Kronfeld arXiv:0803.0512

The difference between expt & HPQCD+UKQCD could be due to new physics, unlikely statistical fluctuations in experiment of lattice calculations or systematic uncertainties which are not understood in the lattice calculation or experiment. BES III measurements are eagerly awaited.

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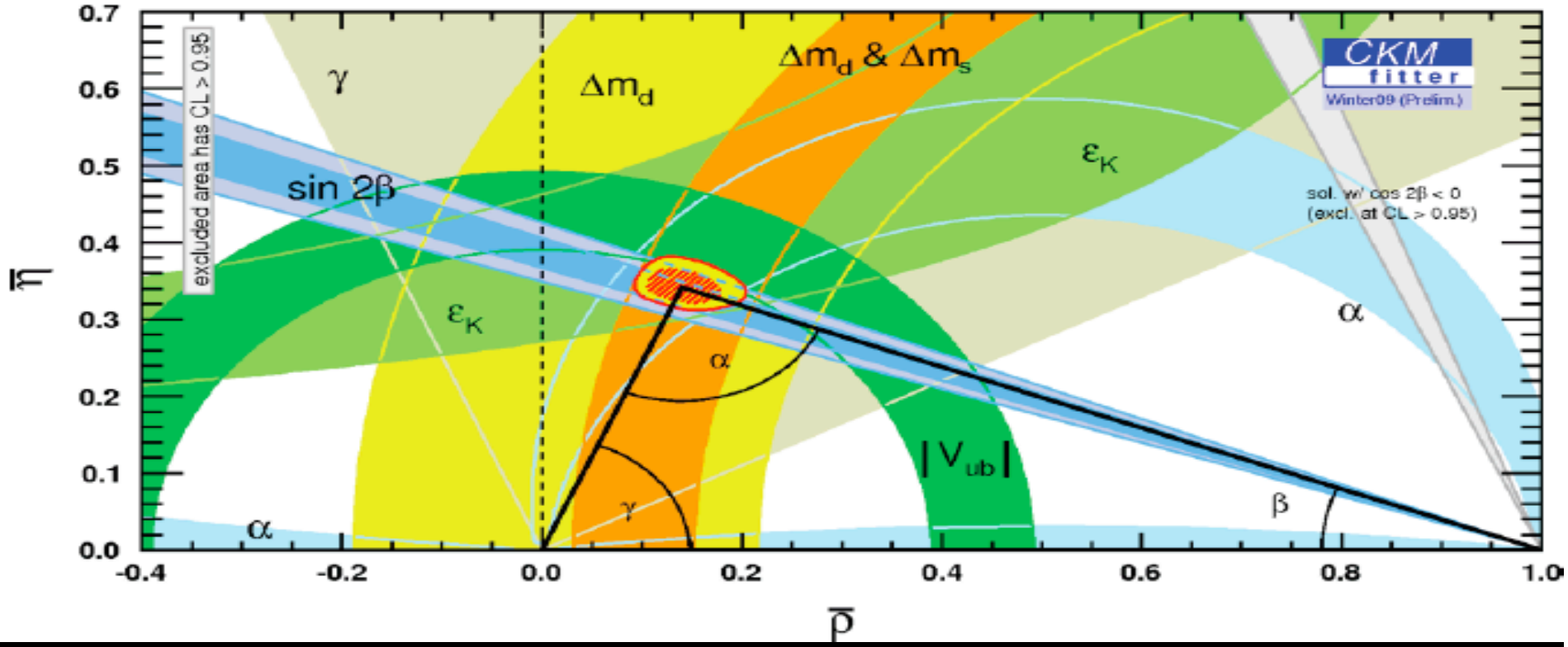
- Impressive precision: lattice tested to ~1% in many cases
- New measurements of f_D and f_{Ds} by CLEO-c

Flavor Physics

Unitarity Triangle

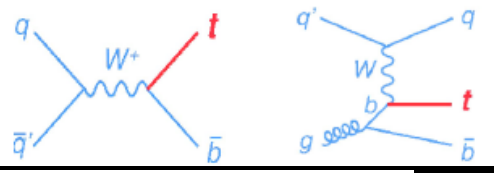
M. Graham

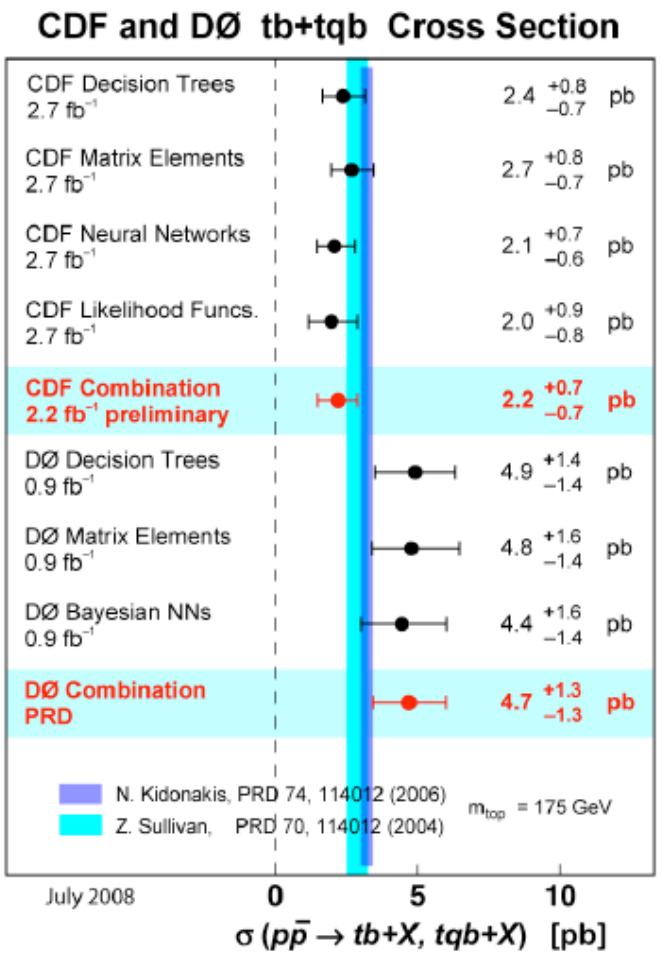


- New result by BaBar for angle α from $B^+ \rightarrow \rho^+ \rho^0$
  - $\alpha = 92.4^{+6.0}_{-6.5}$ degrees (7% precision!)
- New result by Belle for angle β from $J/\psi K^0_s$
  - $\sin 2\beta = 0.642 \pm 0.031$ (stat) ± 0.017 (syst)
    - Still statistically limited!
- The triangle closes perfectly!

Direct Measurement of V_{tb}

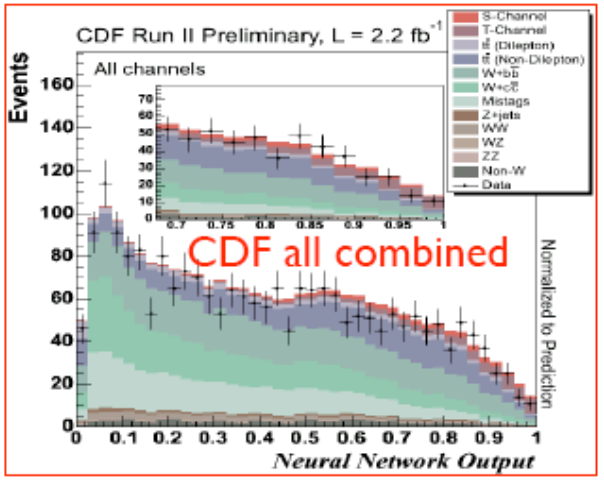
Z. Ye





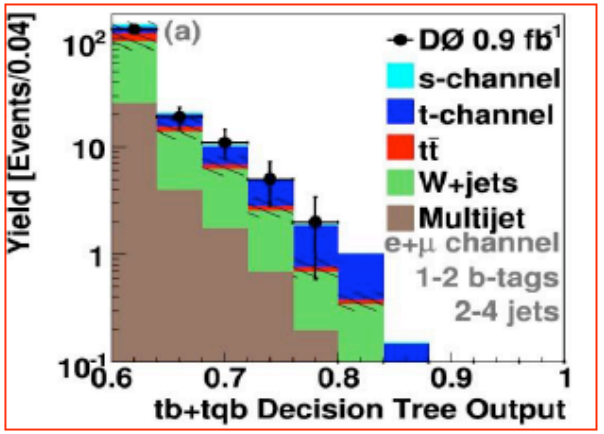
σ=2.2 ±0.7pb

5.1σ exp. significance
3.7σ obs. significance
$0.66<|V_{tb}|\leq 1$ at 95% C.L.



σ=4.7 ±1.3pb

2.3σ exp. significance
3.6σ obs. significance
$0.68<|V_{tb}|\leq 1$ at 95% C.L.



- Awaiting 5sigma discovery of single top production
  - V_{tb} consistent with 1.0
  - Similar precision expected from LHC with 1 fb^{-1}

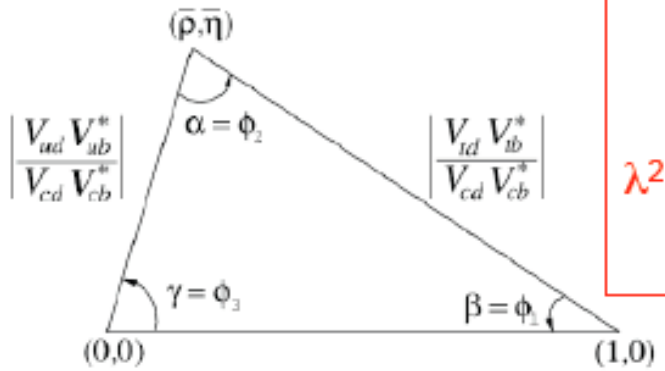
CP violation in B_s system

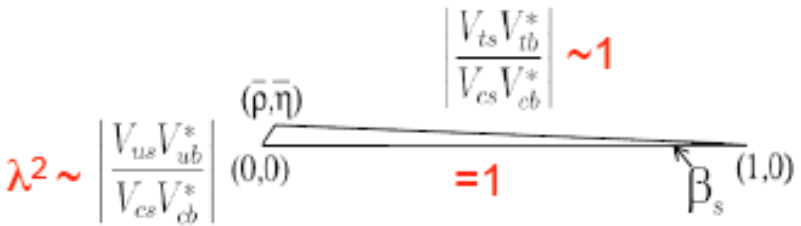
R.Jesik
M.N.Minard

unitarity relations: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$

unitarity triangles:



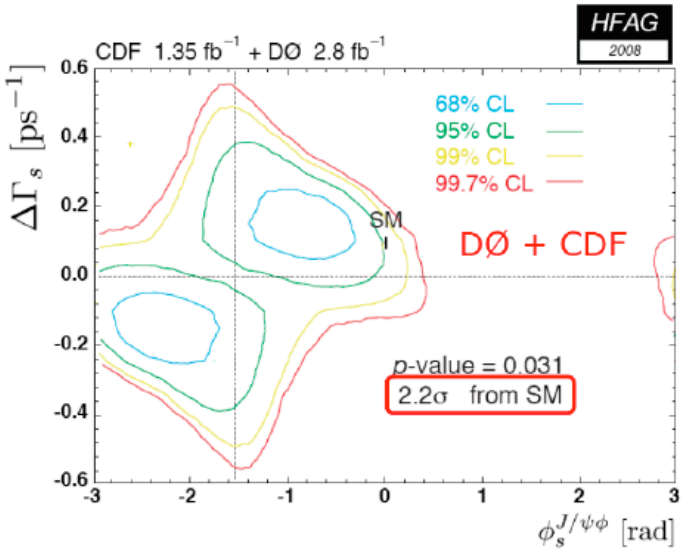


very small CPV phase β_s of order λ^2 accessible in B_s decays

R. Jesik, Aspen'09

27

- Predicted to be tiny in SM
  - CDF and D0 both see non-0 value at 2σ level in J/ψφ angular analysis
    - Combined: 2.7σ
    - Eagerly awaiting updates from both experiments
  - LHCb will measure SM angle with 10 fb^{-1} at 3σ from 0



arXiv:0808.1297v1

New CDF result not included in combination

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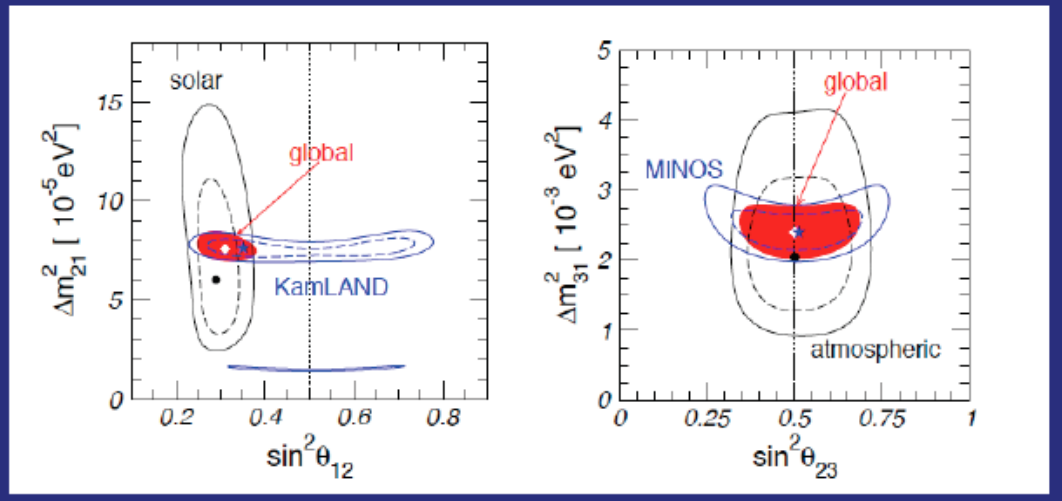
Neutrino Mixing

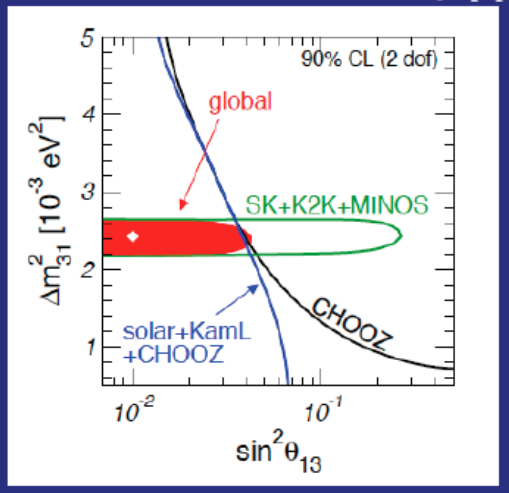
L. Winslow

$$U_{\alpha j} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\xi_1/2} & 0 & 0 \\ 0 & e^{i\xi_2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Maltoni and Schwetz arXiv:0812.3161 [hep-ph]



Maltoni and Schwetz arXiv:0812.3161 [hep-ph]



$\sin^2\theta_{13}<0.056$ at $3\sigma \rightarrow \sin^2 2\theta_{13}<0.21$

- Consistent picture of neutrino oscillations from solar, atmospheric, long baseline and reactor experiments
- New generation of experiments about to come online:
  - Long baseline: T2K (now) and NoVA (later)
  - Reactor: Double-Chooz, Daya Bay and Reno
- Sensitive to $\sin^2 2\theta_{13} \approx 0.01$
  - Order of magnitude better than current limits

Electroweak Symmetry Breaking

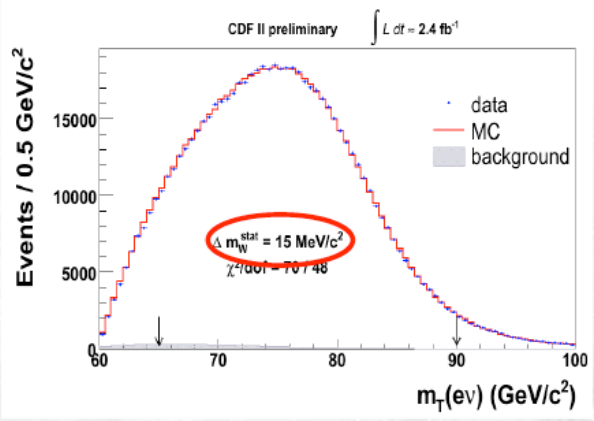
Tevatron W Mass Measurement

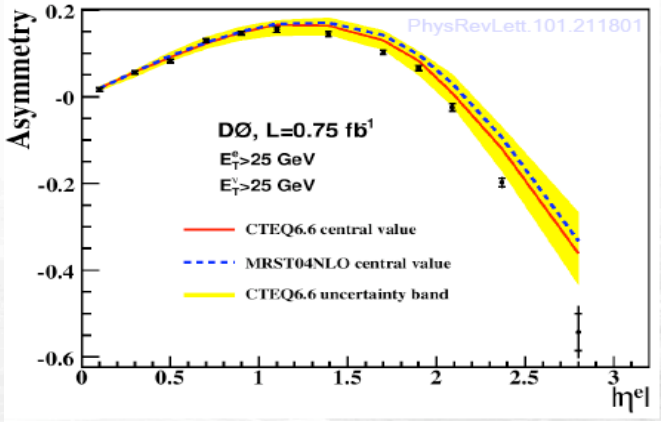
P. Murat
N. Neumeister

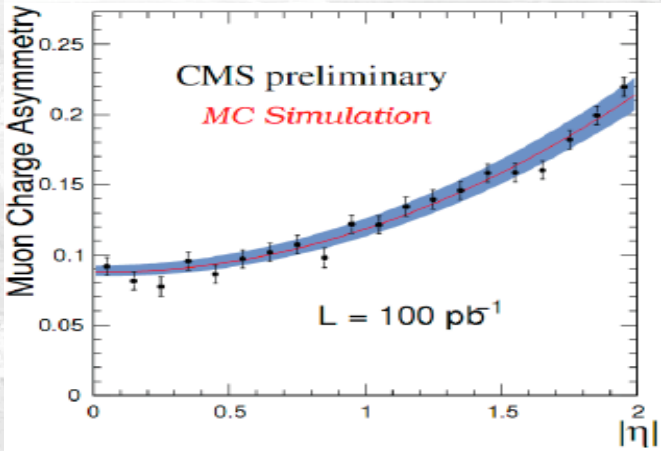
PDF's and uncertainties on the W mass measurement

Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton Scale	17	30	17
Lepton Resolution	3	9	0
Lepton Efficiency	1	3	0
Lepton Tower Removal	5	8	5
Recoil Energy Scale	9	9	9
Recoil Energy Resolution	7	7	7
Backgrounds	9	8	0
PDFs	11	11	11
W Boson p_T	3	3	3
Photon Radiation	12	11	11
Statistical	54	48	0
Total	60	62	26

CDF, 200 pb-1 (PRD 77, 112001)







- Expect most uncertainties to scale as 1/sqrt(L), studies in progress confirm this
- For 2 fb^{-1} statistical uncertainty ~ 11 MeV/c^2, same as current PDF contribution
- Improvement in PDF uncertainties will reduce total error on W mass

Fermilab

P. Murat, Aspen Winter Conference, 2009/02/09

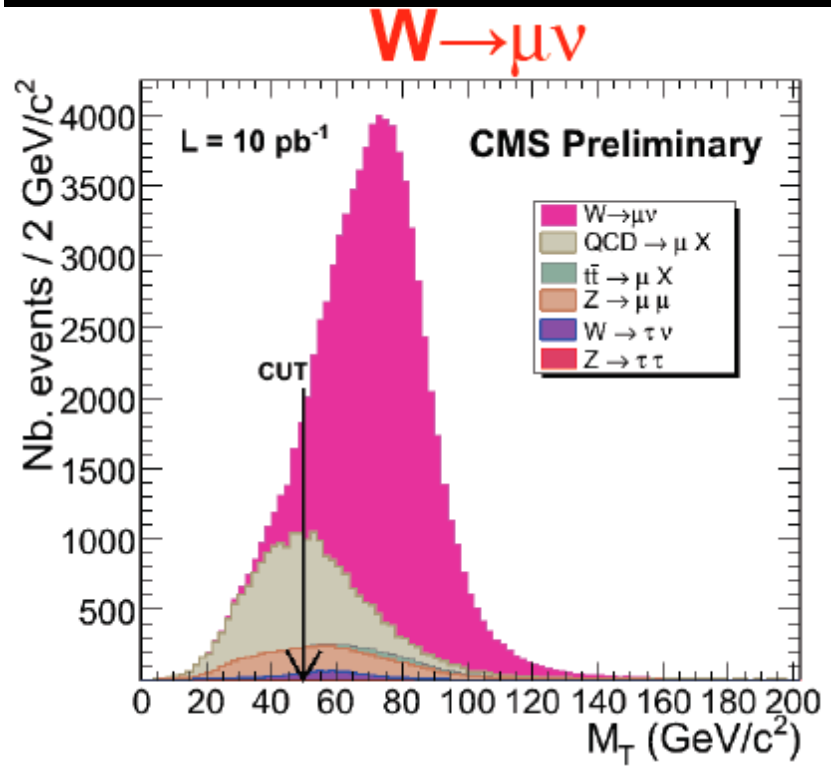
10

Norbert Neumeister, Purdue University

- Expected precision for Run 2: ~14 MeV (current world: 25 MeV)
  - Relies on reduction of e.g. PDF uncertainties
  - Important: W charge asymmetry measurements from CDF and D0
    - Can also be made at LHC with ~100 pb^{-1}

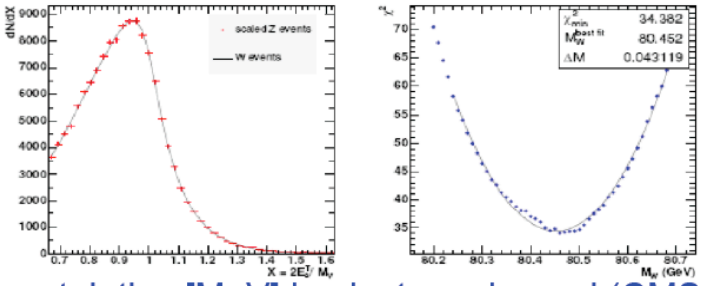
W's at the LHC

N. Neumeister



W Mass Measurement

- Rescaled distribution of electron p_T in CMS (1 fb^{-1}):



- Uncertainties [MeV] in electron channel (CMS):

	1 fb^{-1}	10 fb^{-1}
Statistical	40	15
Experimental	40	20
PDFs	20	10

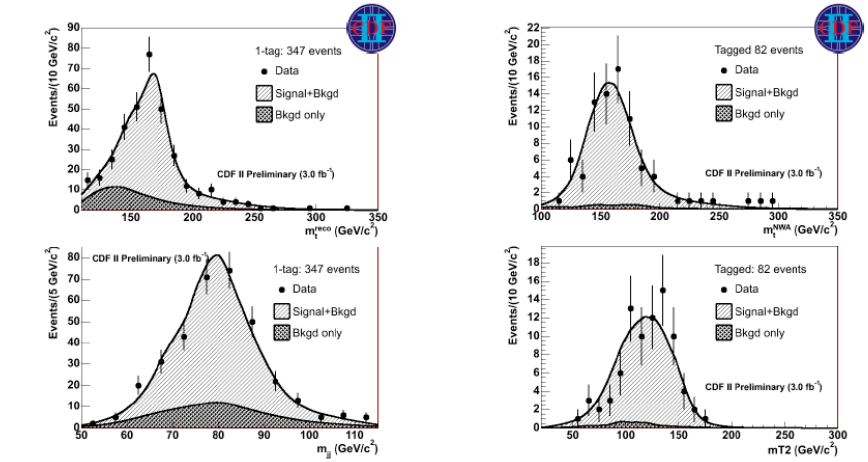
Improvement on the accuracy of current W mass measurements!

- Record ~6,000 W's/pb^{-1} per decay channel at 10 TeV
  - Early cross section measurement with ~5% precision
- W mass competitive with Tevatron with ~10 fb^{-1}

Top Quark Mass

Z. Ye
A. Arce

Top Quark Mass – Template Method

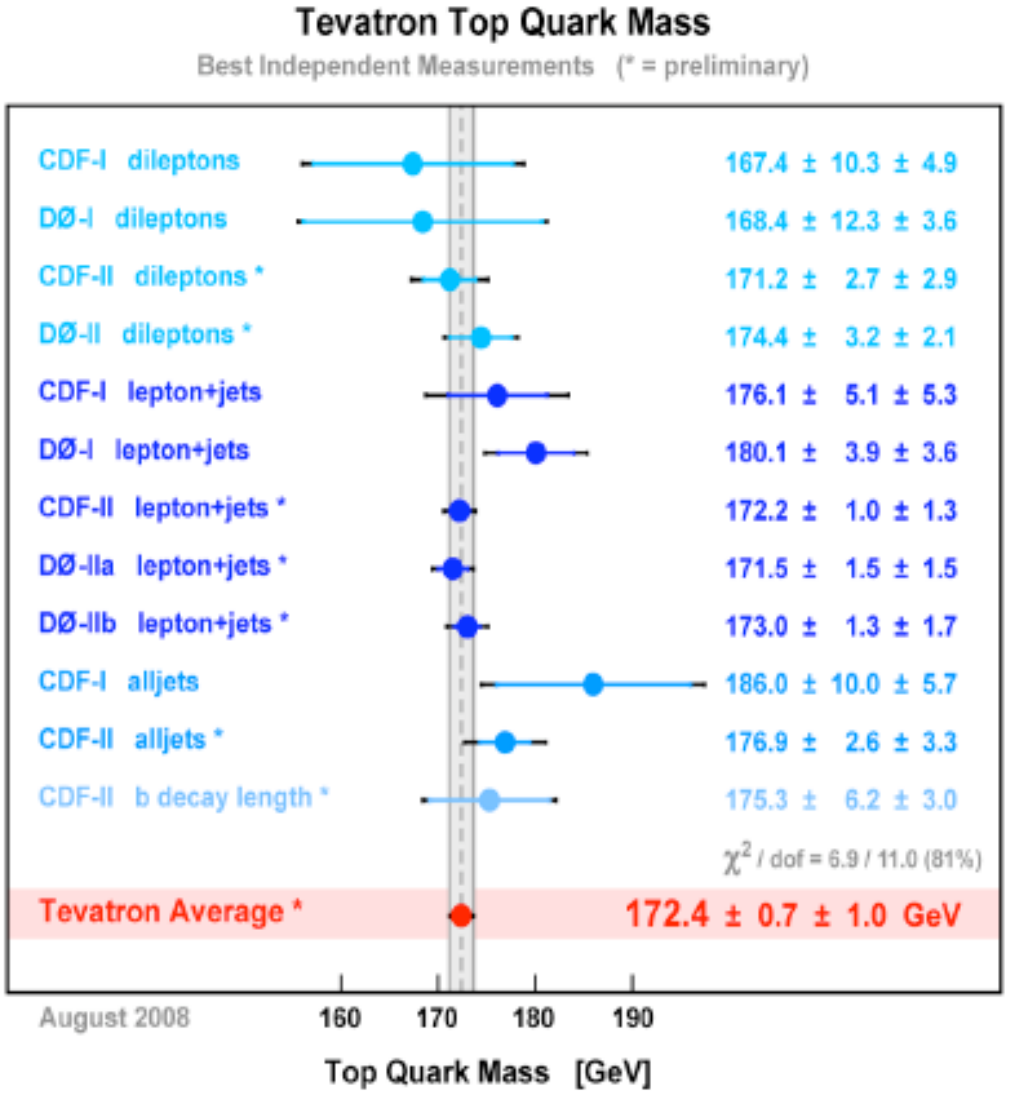


172.5 ±1.6 (stat.+JES) ± 1.1 (syst) GeV/c^2

169.0 ±2.7 (stat.) ± 3.2 (syst) GeV/c^2

Combined: 171.8 ± 1.5 (stat.+JES) ± 1.1 (syst) GeV/c^2

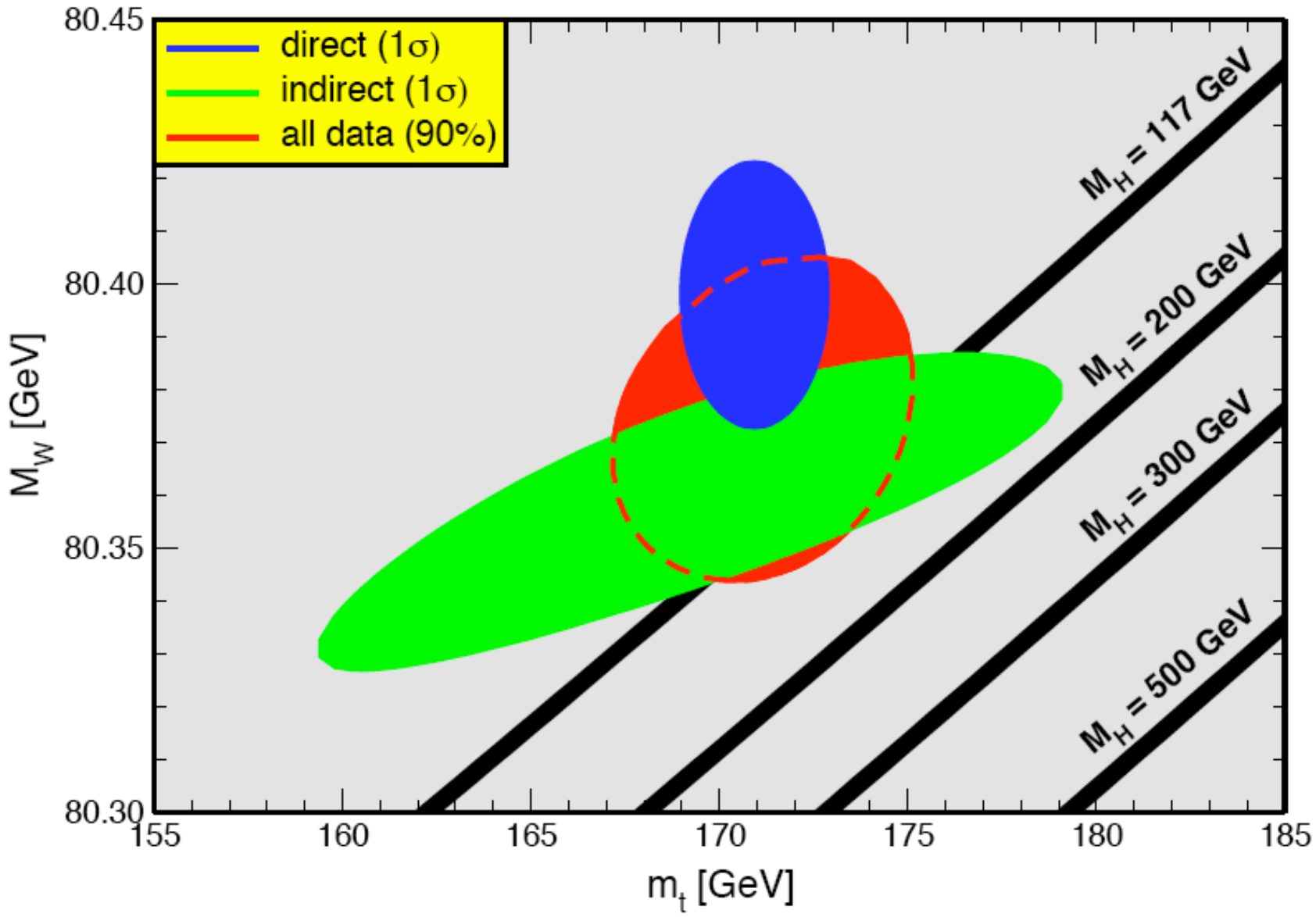
32 Z.Ye 2/10/2009



- New CDF measurement reported using template method
  - All measurements agree
- Uncertainty only 1.2 GeV
- LHC competitive with ~1 fb^{-1}

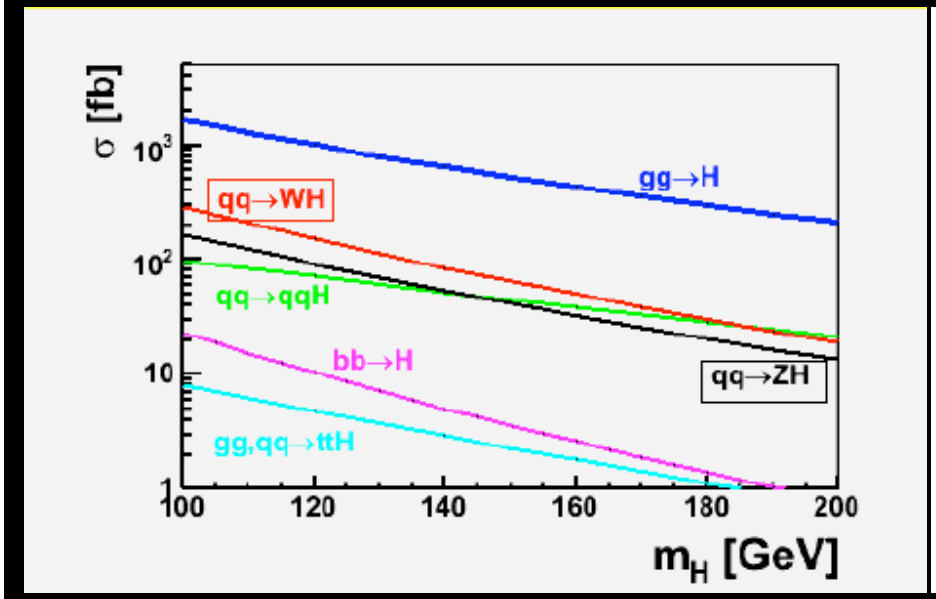
Electroweak Precision Data

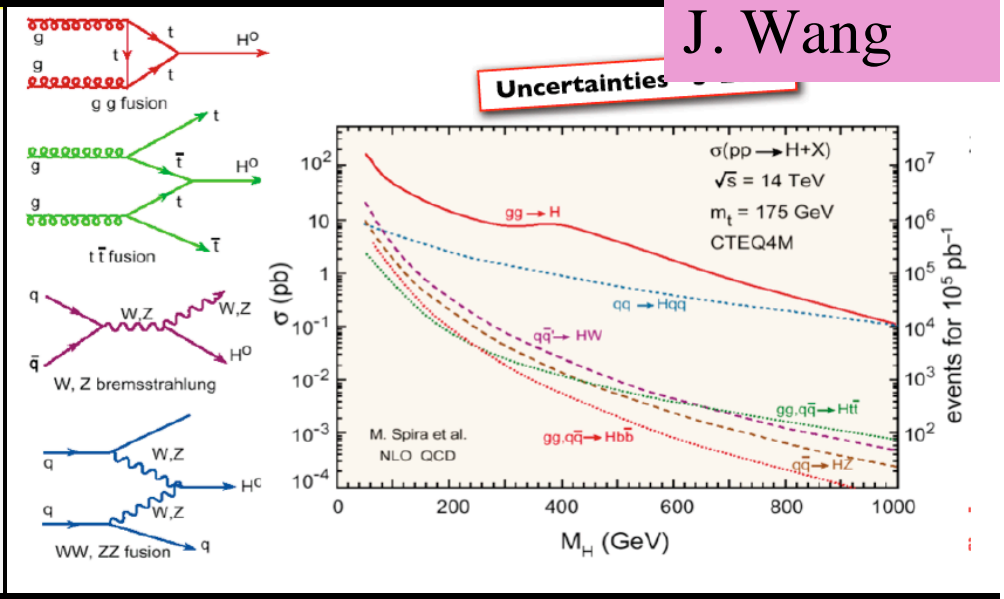
J. Erler



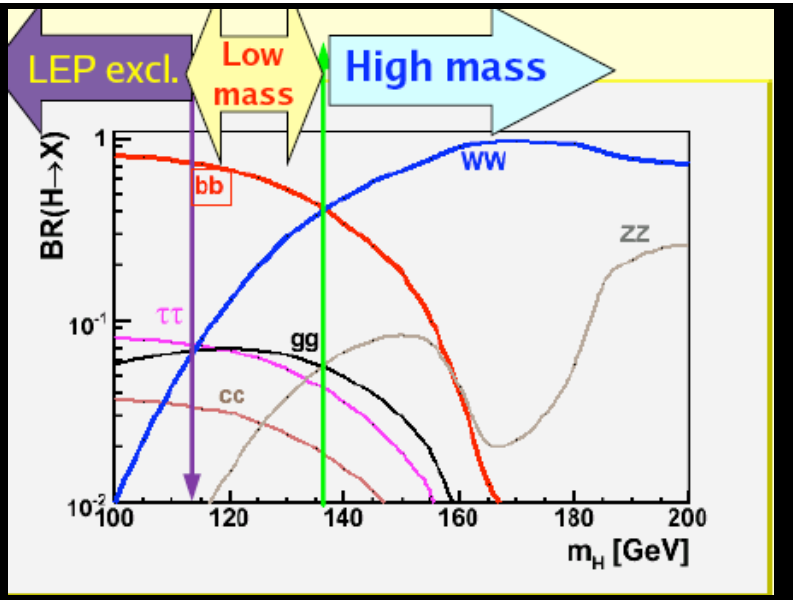
SM Higgs Searches

J. Pursley
L. Zivkovic
J. Wang





- Tevatron and LHC searches
  - Low mass:
    - Tevatron: W/Z+H(→bb)
    - LHC: gg→H→γγ , VBF H→ττ
  - High mass:
    - Tevatron H→WW*
    - LHC: H→WW*, H→ZZ*
- ♣ Complementary search channels



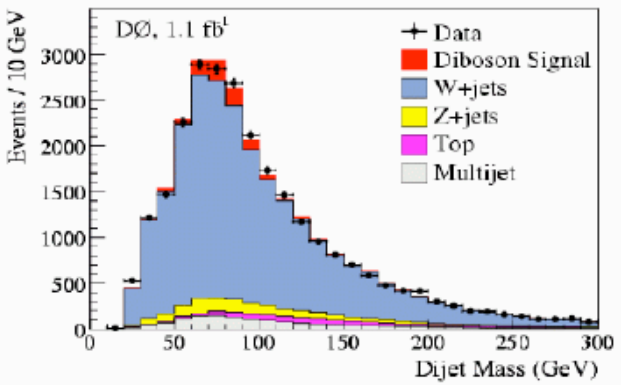
Evidence for WW/WZ ->lvjj

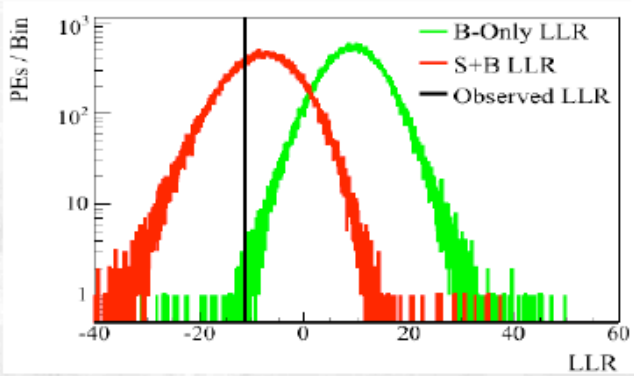
P. Murat

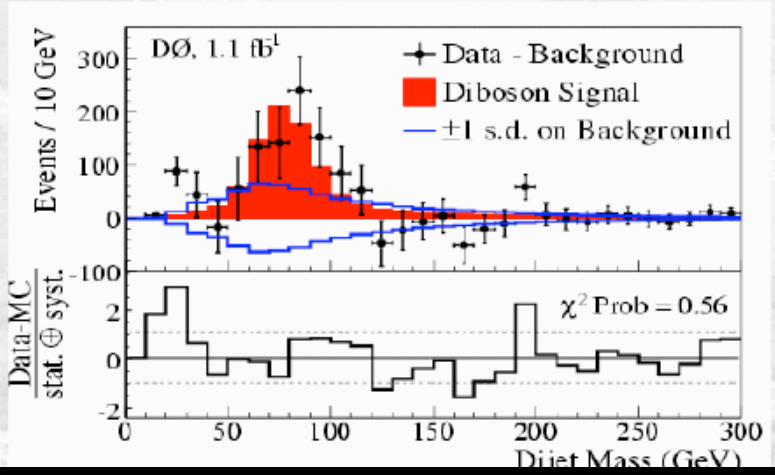
- Normalize all backgrounds except W+jets to NLO/NNLO cross sections,
  - let W+jets normalization float
- fit M(jj) spectrum with no signal hypothesis

  $1\text{-}CL_B$ = 2.5*10^-4 => 3.5σ (1-sided)
- Allow signal (WW/WZ) rate to float:

  σ(WW+WZ) = 18.5±2.8(stat)±4.9(sys)±1.1(lum)



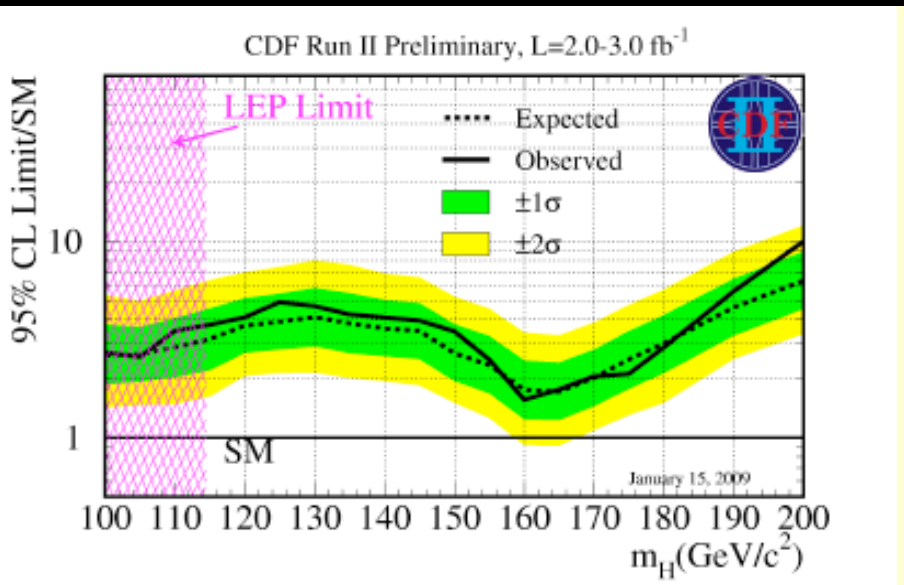


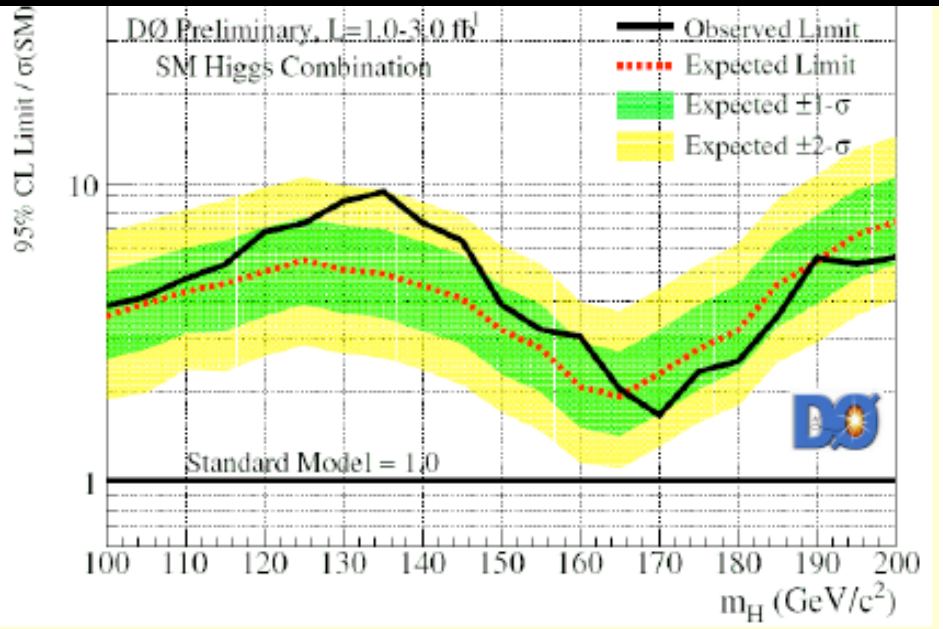


- Dijet resonance seen in W+2jets (4.6sigma)
  - Important milestone on the road to the Higgs

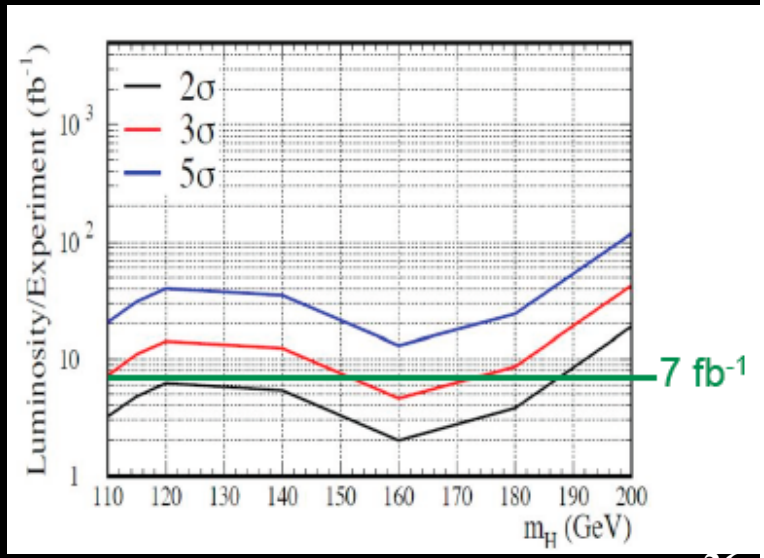
Tevatron Higgs Searches

L. Zivkovic





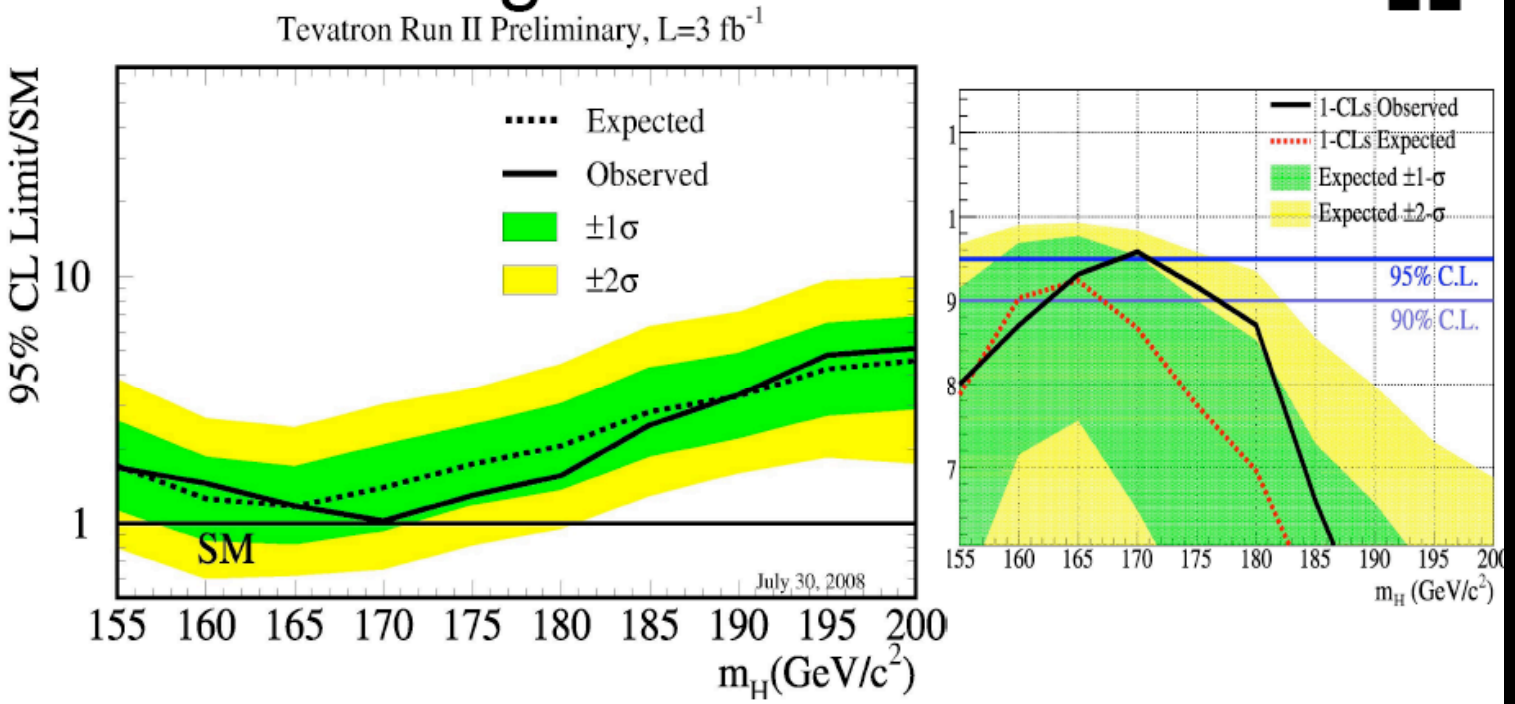
- Limits are factor 2-5 above SM cross section
- Future:
  - 95% exclusion up to 190 GeV
    - If it's not there
  - 3σ evidence at high mass possible
    - And with luck maybe at low mass
  - 5σ very very difficult



High Mass Higgs Boson

J. Pursley

Tevatron High Mass Combination



- Combine CDF and D0 results into an overall Tevatron Higgs limit
  - Calculate both Bayesian and CL_S limits

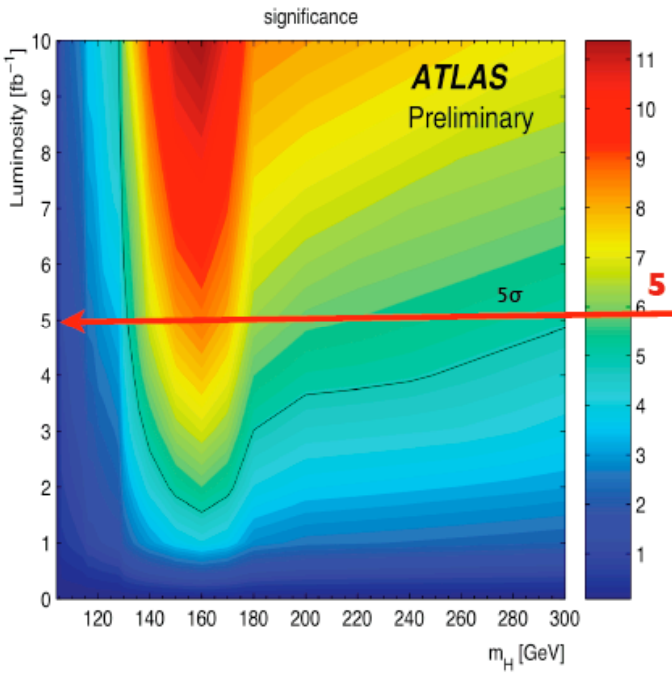
February 10, 2009 J. Pursley, Aspen 2009 19

Expect news for Moriond: more data and updated theory!

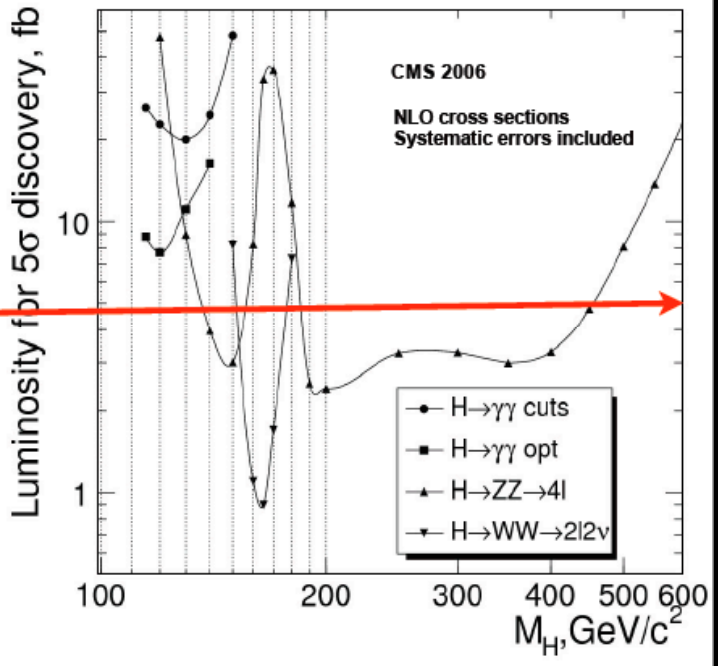
Higgs Search at LHC

J. Weng

Conclusion



5 fb⁻¹



=> With 10 fb⁻¹ (*normally* considered as one LHC year at low luminosity), 5σ discovery for $m_H \in [\sim 120, \sim 500]$ GeV

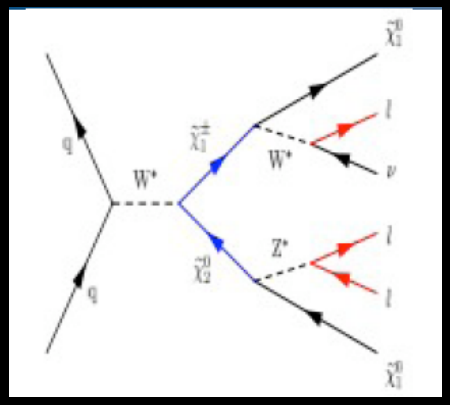
=> With 1-2 fb⁻¹ we can first say something the H-> WW channel

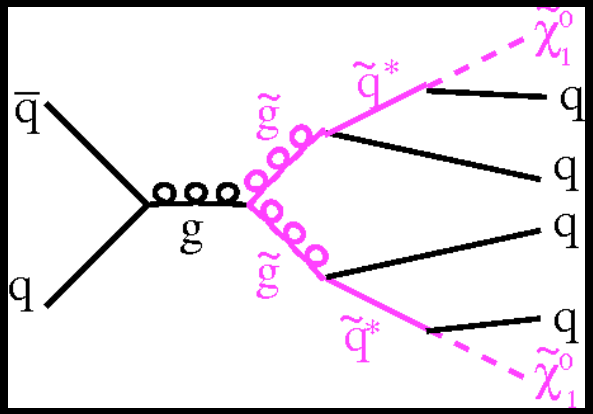
- Requires $\int Ldt$ = 1-30 fb^{-1} depending on mass for 5σ discovery
  - 2σ achieved over full mass range with 2-4 fb^{-1} (maybe 2012?)

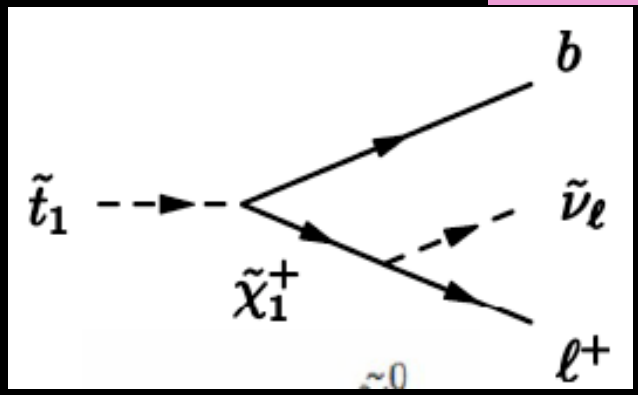
Searching for the Unknown

Supersymmetry

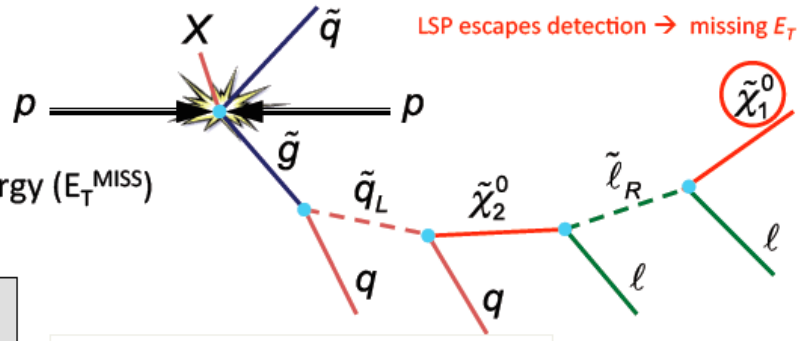
J. Boyd
M. Eads







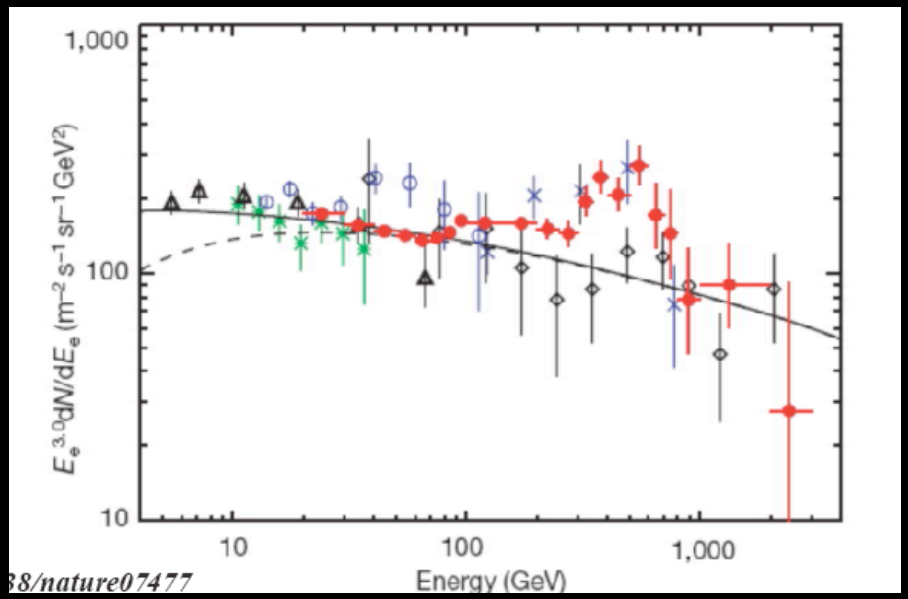
- SUSY signatures (model dependent)
  - Cascade decays
  - High P_T Jets
  - Isolated Lepton(s)
  - Missing Transverse Energy (E_T^{MISS})

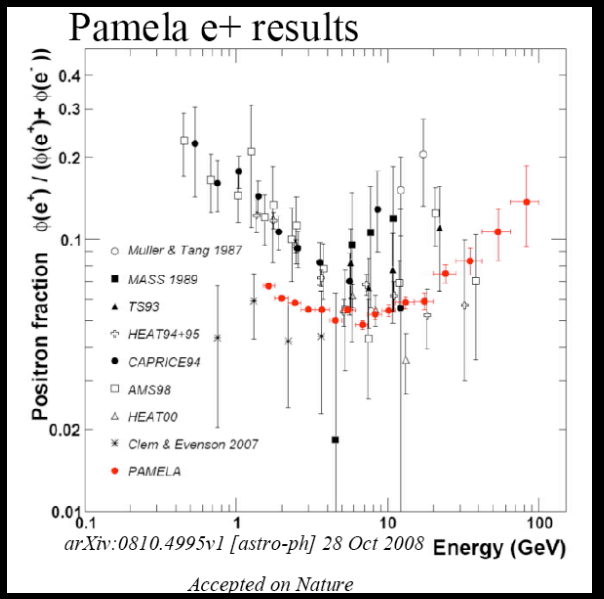


Look at transverse missing energy (and not overall missing energy) because hard scattering reaction usually has longitudinal boost

- Searches at Tevatron ongoing in many final states
- Vast discovery potential at LHC!

Latest Hints from Space

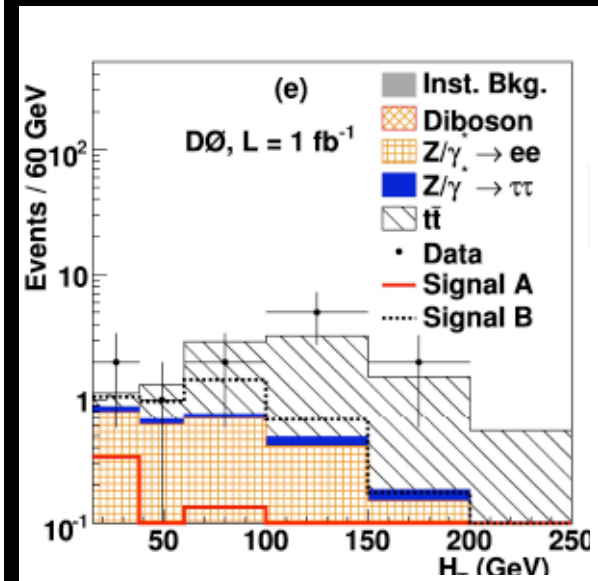


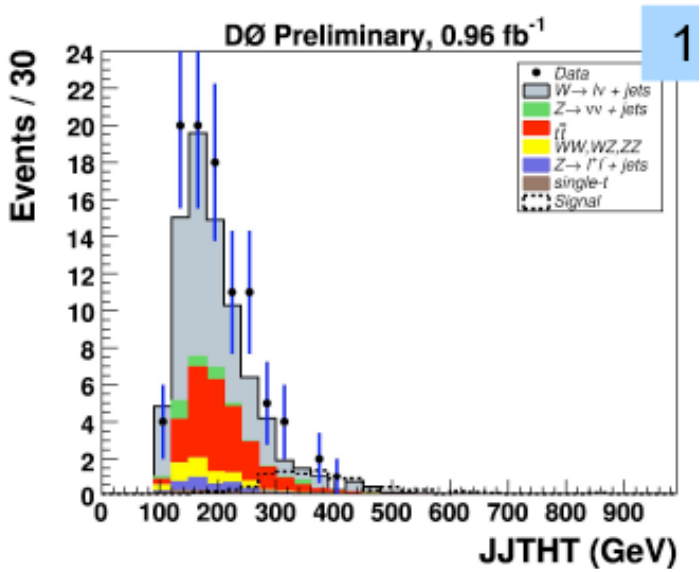


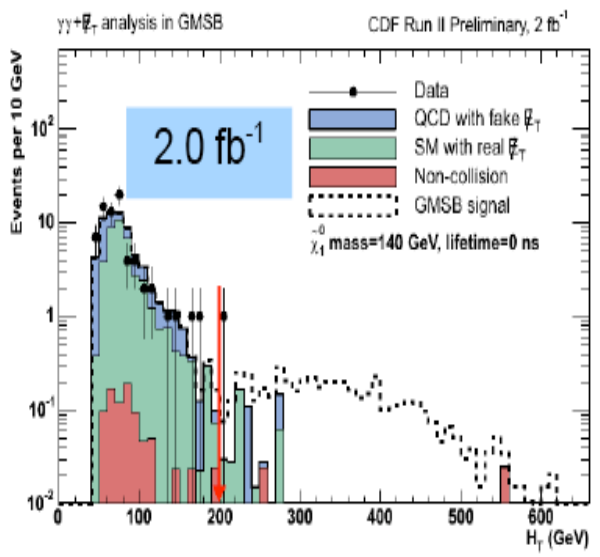
- Lot's of theoretical work on understanding if ATIC/Pamela are signal for dark matter
  - New experimental signatures at colliders proposed
    - Large cross section and clean signatures!
  - More data expected soon to clarify situation further

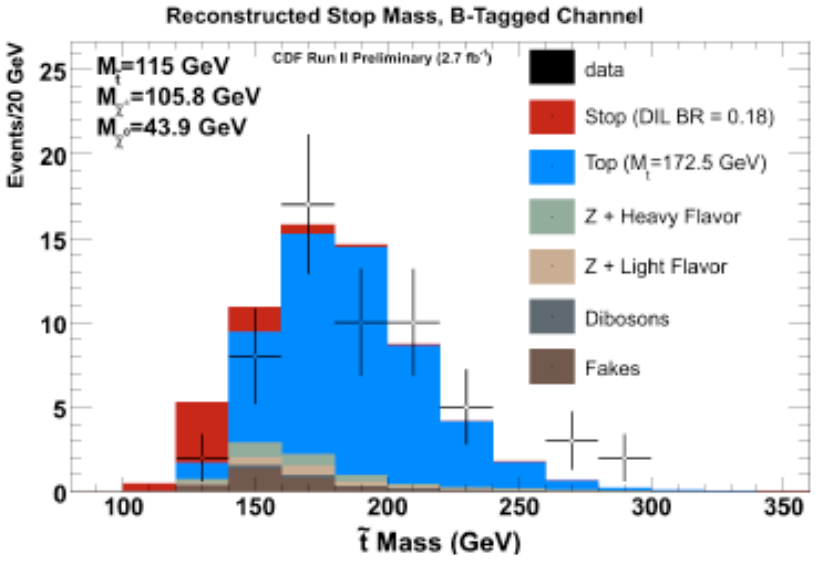
Tevatron SUSY Searches

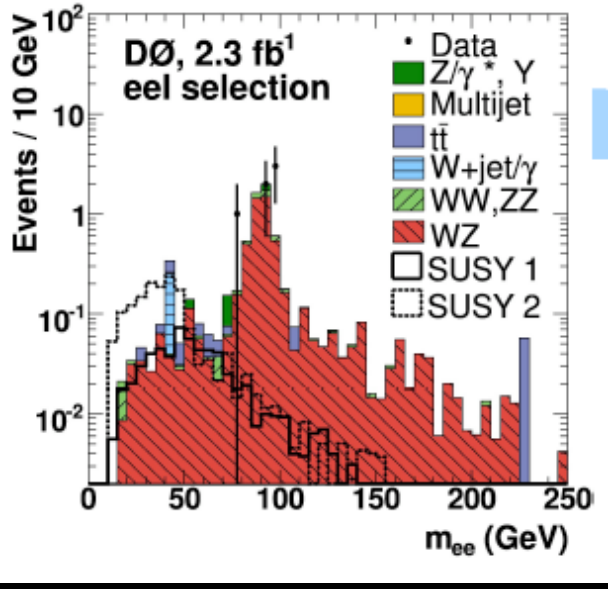
M. Eads







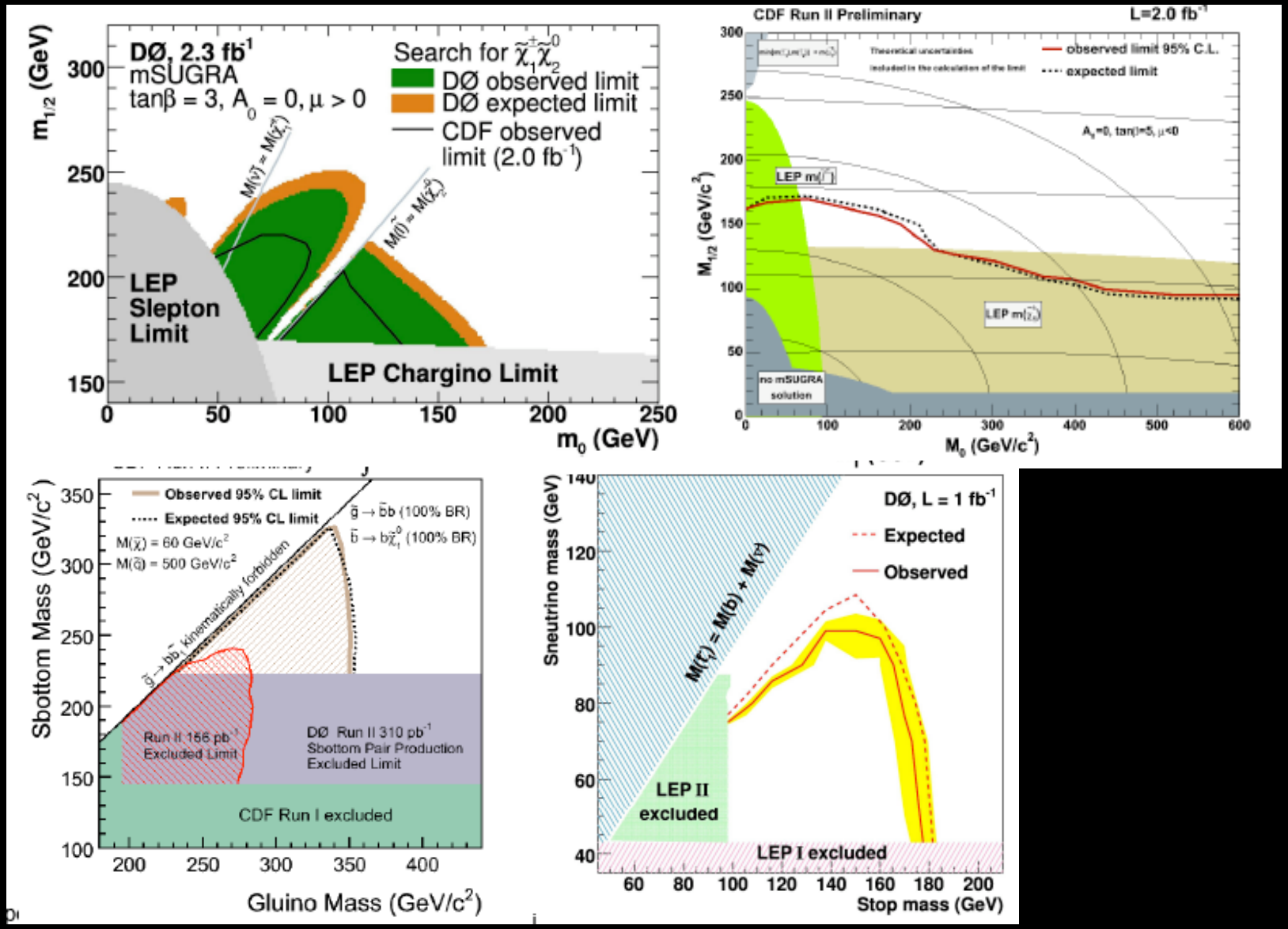




Nothing found yet

SUSY Limits

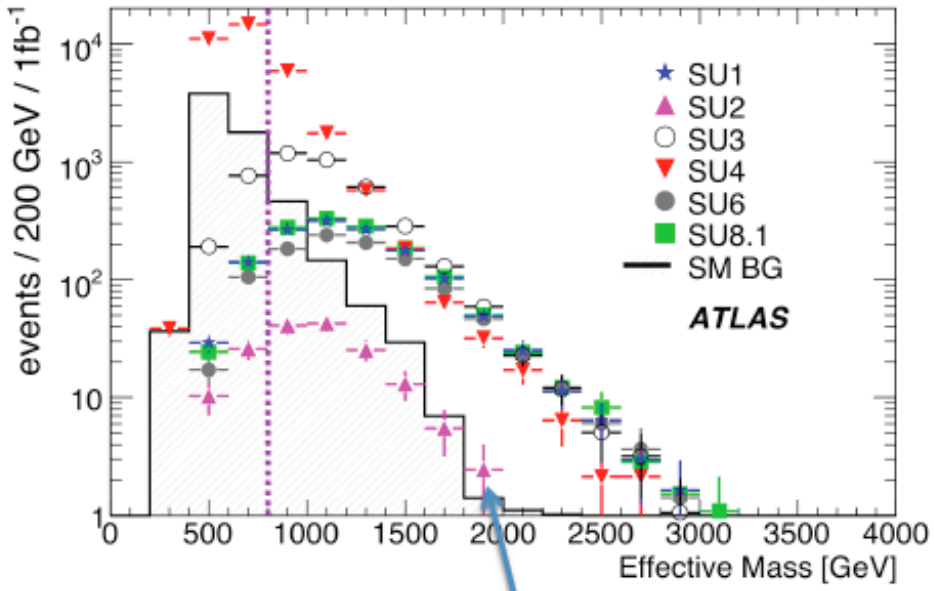
M. Eads



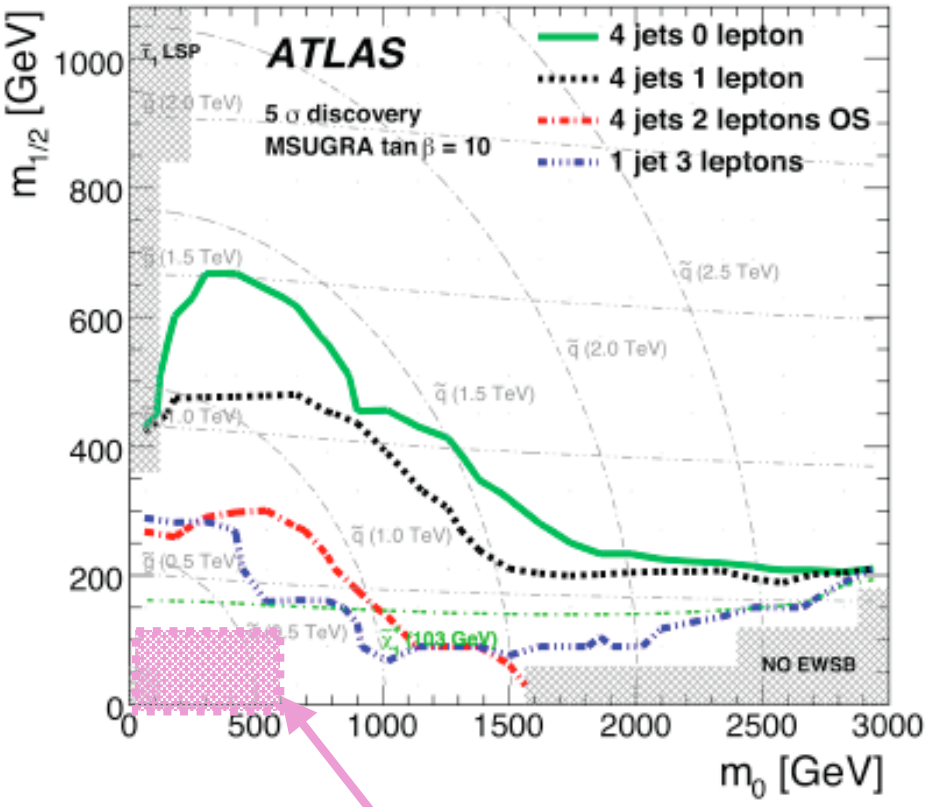
Limits set both in physical masses and in GUT scale parameters

LHC SUSY Discovery Potential

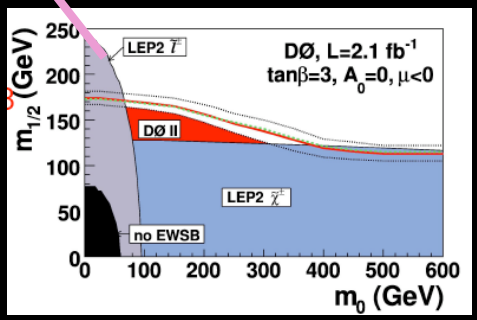
J. Boyd



Not all models found. SU2 has low cross-section and so not found with 1fb^{-1}



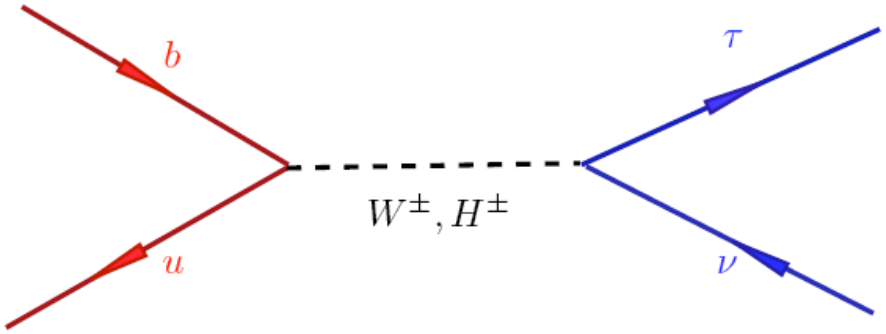
- Excellent discovery potential
  - Cross sections >1,000 times the Tevatron
  - Discovery could be fast (2010/11?)
    - Background understanding critical



Rare Decays: B→τν

T. Browder

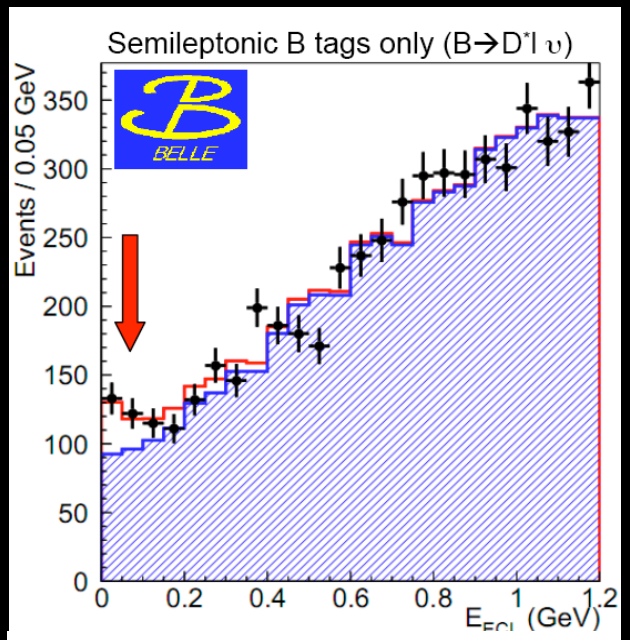
C. Wagner

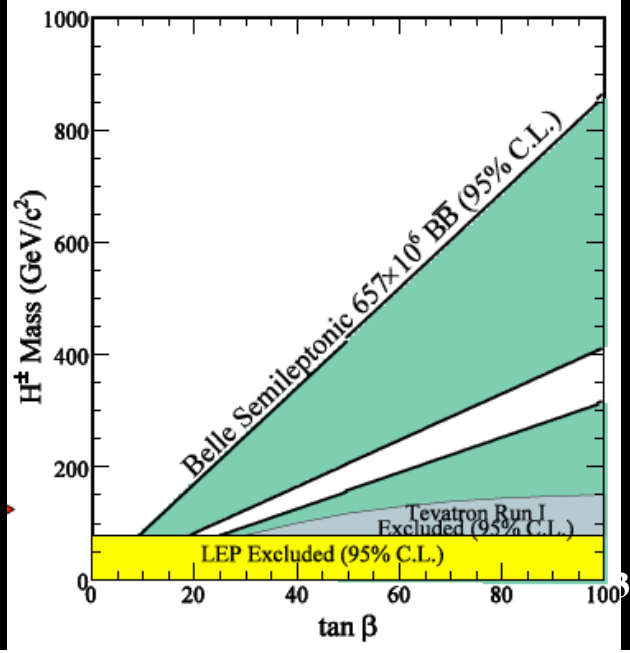


$$\frac{BR(B_u \to \tau\nu)^{\rm MSSM}}{BR(B_u \to \tau\nu)^{\rm SM}} = \left[1 - \left(\frac{m_B^2}{m_{H^\pm}^2}\right)\frac{\tan^2\beta}{(1+E_g\tan\beta)}\right]^2$$

$$\mathcal{BR}(B_u \to \tau\nu)^{\rm Exp} = (1.41 \pm 0.43) \times 10^{-4}. \quad \text{(Belle-Babar)}$$

$$\mathcal{BR}(B_u \to \tau\nu)^{\rm SM} = (1.09 \pm 0.40) \times 10^{-4}$$

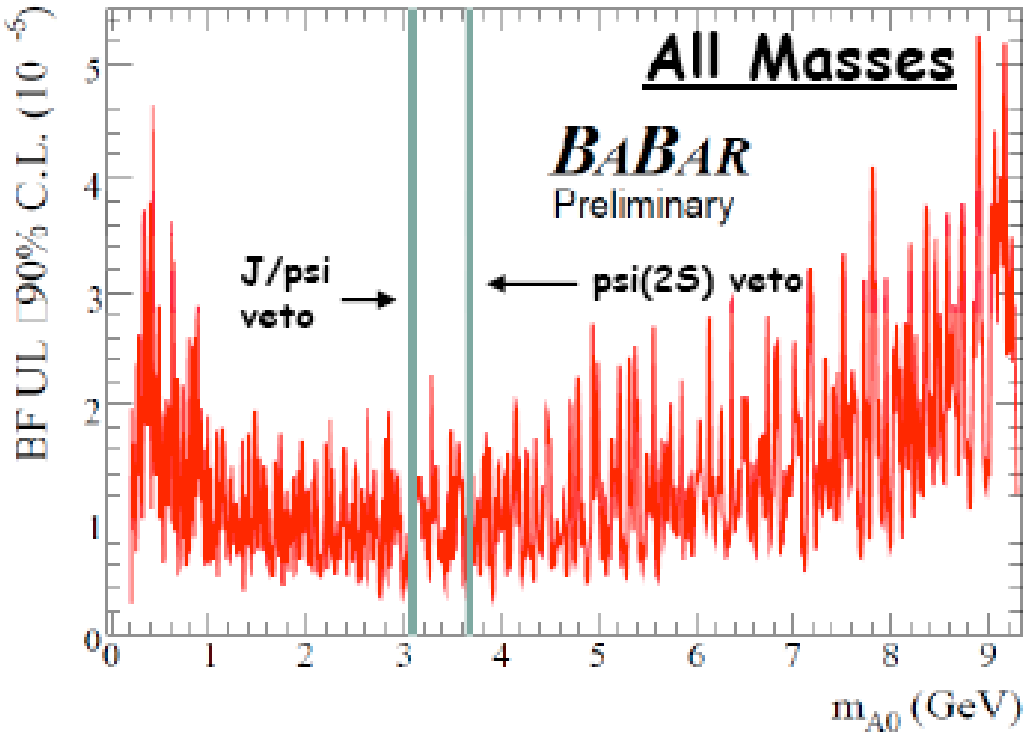


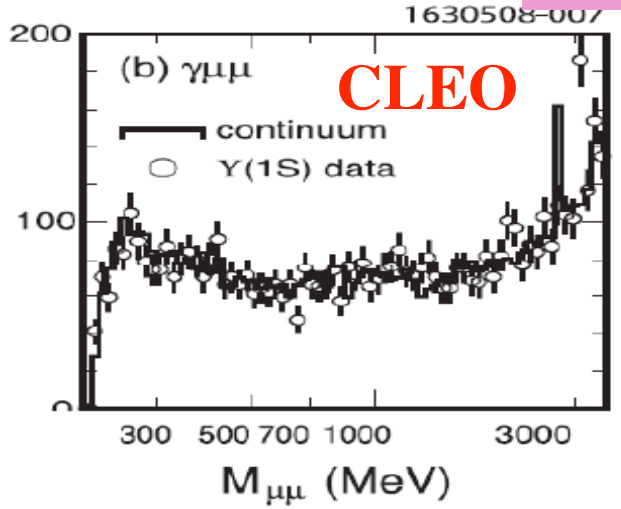


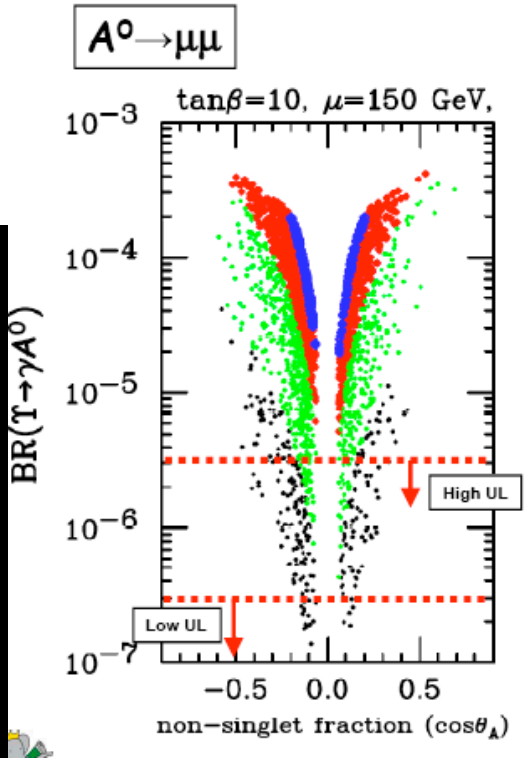
- New result from Belle: (1.65+0.52)x10^{-4}
  - About 1σ higher than SM
- Severely constrains mass of $H^{\pm}$ at high tanβ
  - Far beyond direct limits from Tevatron and LEP

A very light pseudo-scalar Higgs: a^0

K. Flood
I. Shipsey







- New searches by BaBar at Υ(3S) and Cleo at Υ(1S):
  - $\Upsilon \rightarrow a^0\gamma$
  - No signals found and severe constraints set

J. Gunion *et al.*

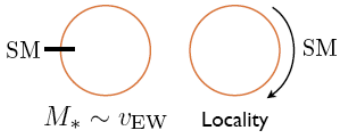
Beyond SUSY

Many Other Possibilities…

J. Thaler

Strong Dynamics/ Compositeness? $\langle\psi\psi^c\rangle \to v_{\rm EW}$ $\langle\psi\psi^c\rangle \to H \to v_{\rm EW}$

Higher Dimensional Structures?

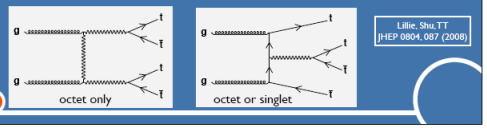


Supersymmetry?

T. Tait

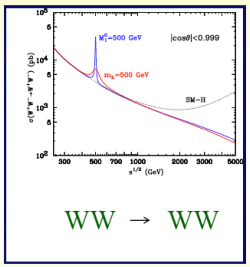
Four Tops at the LHC

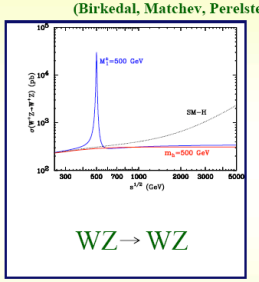
- The KK gluon is a perfect resonance decaying into top pairs. But it was produced by a light quark initial state. What happens when the coupling to light quarks is too small to use as a production mechanism?
- A possible signature has color octet (and/or singlet) vectors which couple strongly to top quarks, and perhaps negligibly weakly to light quarks.
- A color octet vector can be pair-produced purely by QCD. A color singlet needs to be "radiated" from a top quark.



C. Csaki

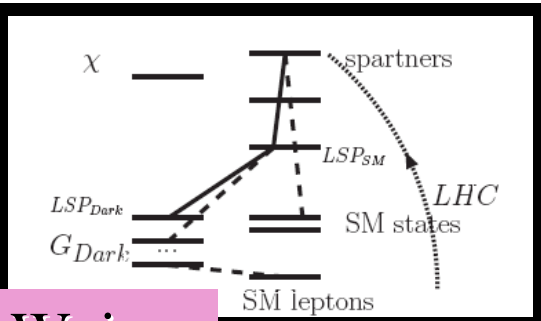
LHC predictions (Birkedal, Matchev, Perelstein)





- WW scattering not that different from SM
- WZ scattering is **very different** (new peak!)

N. Weiner



T. Plehn

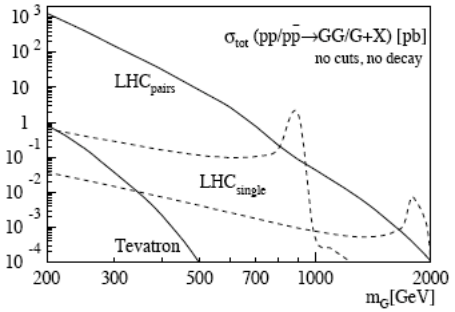
Sgluons at LHC

Production easy [TP & Tait, CDKKPZ]

- pair production via SUSY-QCD
- single production at one-loop

light-flavor quarks: $g_{Gqq} = 0$
heavy squarks: $g_{Ggg} \propto m_{\tilde{g}}/m^2_{\tilde{q}}$
left-right squarks: g_{Ggg} reduced

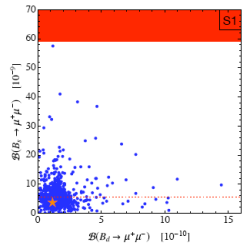
⇒ stop pairs with new color factor



M. Neubert

Rare B decays: Purely leptonic modes

- Factor ~10 enhancements possible in rare $B_{d,s} \to \mu^+\mu^-$ modes without violation of $Z \to b\bar{b}$ constraints. Effects largely uncorrelated with $|\varepsilon_K|$



★ SM: $\mathcal{B}(B_d \to \mu^+\mu^-) \approx 1.2 \cdot 10^{-10}$, $\mathcal{B}(B_s \to \mu^+\mu^-) \approx 3.9 \cdot 10^{-9}$

····· minimum of $5.5 \cdot 10^{-9}$ for 5σ discovery by LHCb, 2 fb^{-1}

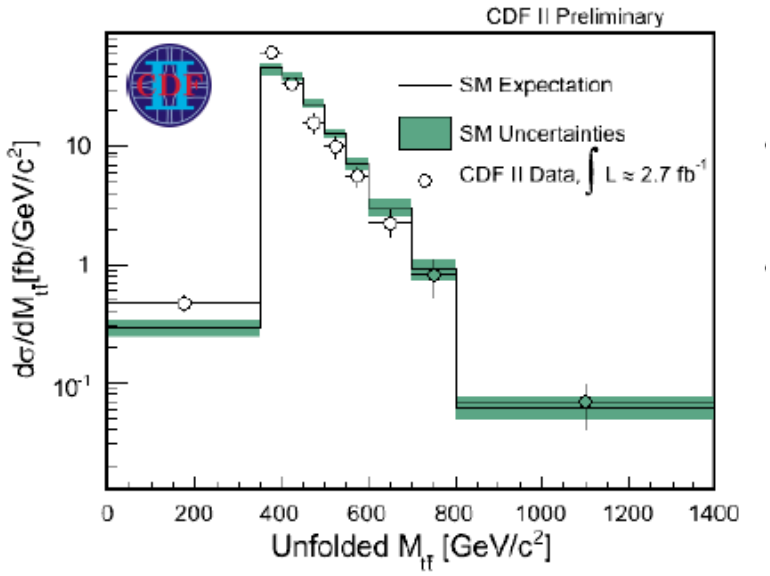
■ 95% CL upper limit from CDF $\mathcal{B}(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-8}$

• consistent with quark masses, CKM parameters, and 95% CL limit of $Z \to b\bar{b}$

*Bauer *et al.*, paper in preparation

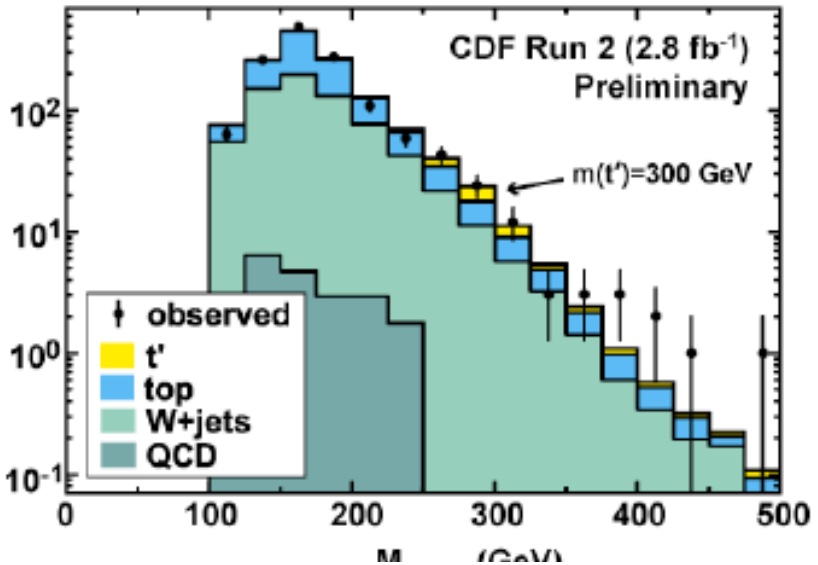
New Physics in Top?

Z. Ye
A. Arce



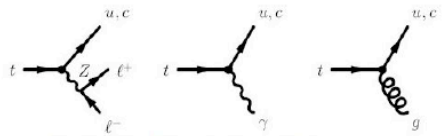
in Randull-Sandrum model

$\kappa/M^{Pl} > 0.16 @ 95\%\, CL$

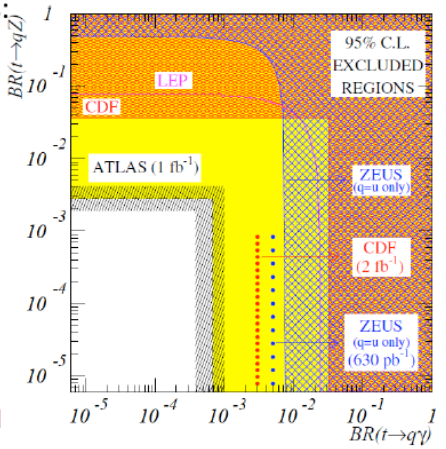


Rare top decays

- Flavor-changing neutral currents:
  - arise in many BSM models
  - usually, largest branching ratios around 10^{-4}



- ATLAS: look for top pairs with one rare decay
  - backgrounds are $t\bar{t}$, W/Z + jets
  - Select: ~ 130 events/fb^{-1} in cleanest (qZ) channel → refine using likelihood analysis

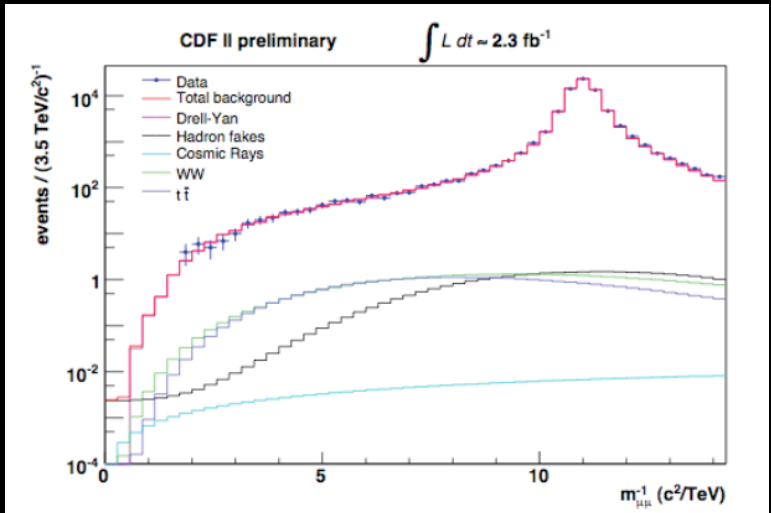


ATLAS : improve $q\gamma$ limit to 7 x 10^{-4} with 1 fb^{-1}

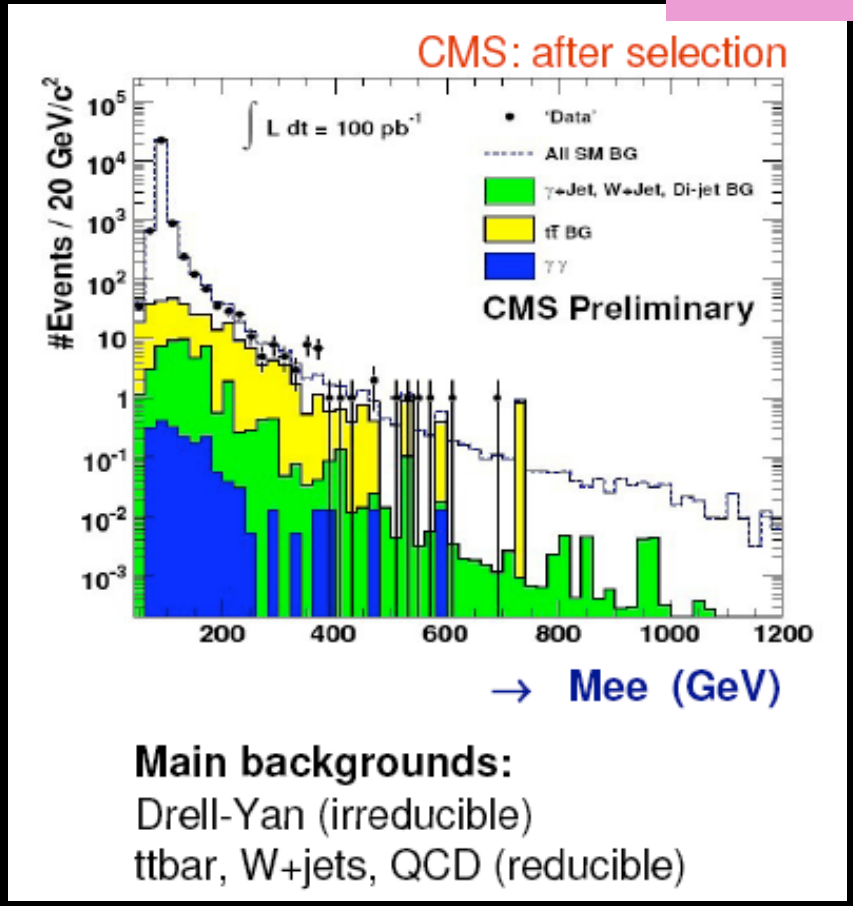
- Searches for
  - Resonances
  - Heavier partners (t')
  - Rare decays
- No evidence for BSM yet
  - LHC will probe with high precision

Dilepton Resonances

S. Pranko
B. Clerbaux



- **Results**
  - Data agree with SM predictions
  - 95% CL Limits on
    - Spin-0 Sneutrino
    - Spin-1 Z' Models
    - Spin-2 RS graviton



Main backgrounds:
Drell-Yan (irreducible)
ttbar, W+jets, QCD (reducible)

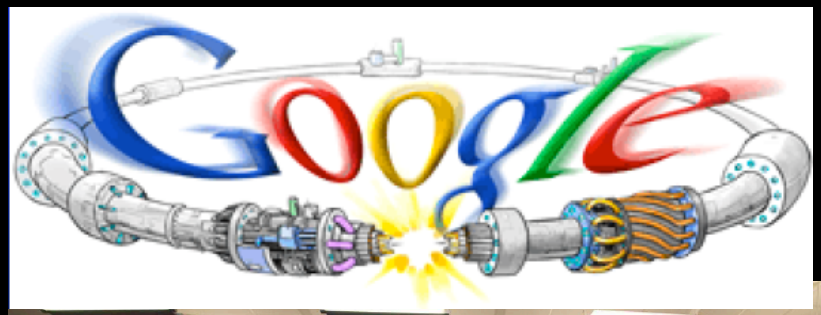
- Tevatron mass limits up to 1 TeV (for SSM Z')
  - Depending on couplings of course
- LHC will probe 1 TeV with ~50 pb^{-1}
  - 2 TeV with ~200 pb^{-1}
- Many other searches ongoing and planned

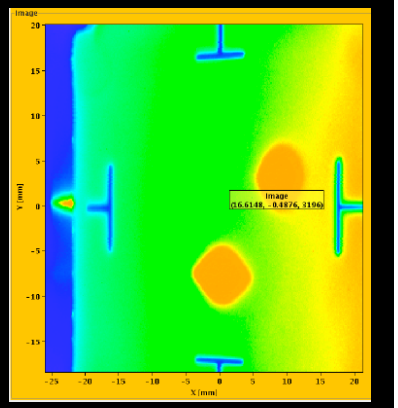

Some cracks in the Standard Model but
no smoking gun yet

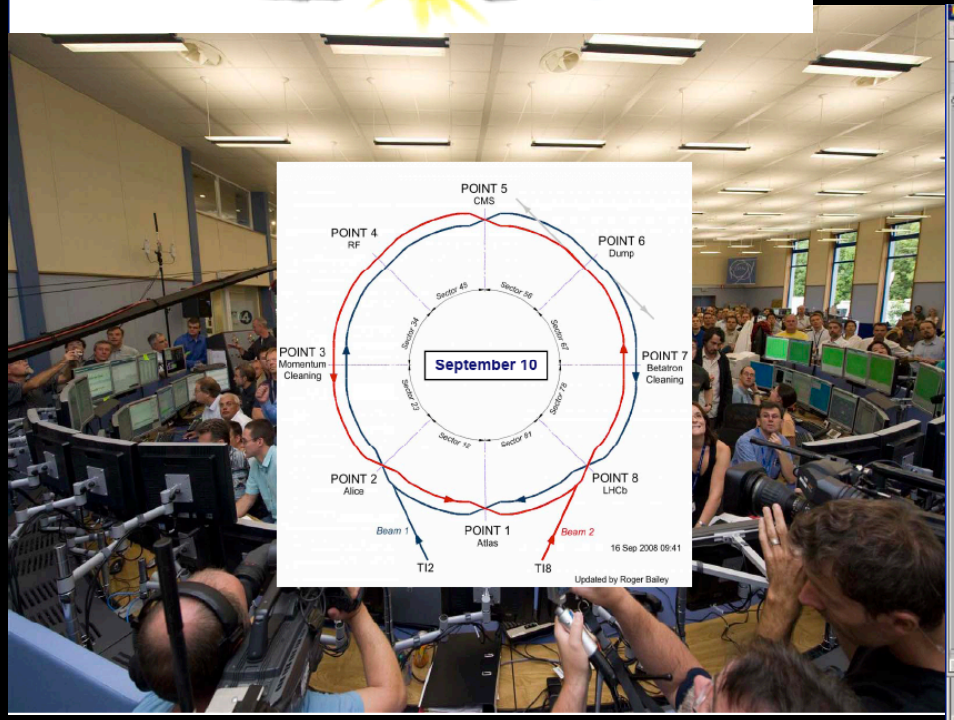
The Beginning of the Future: LHC startup in Sepember

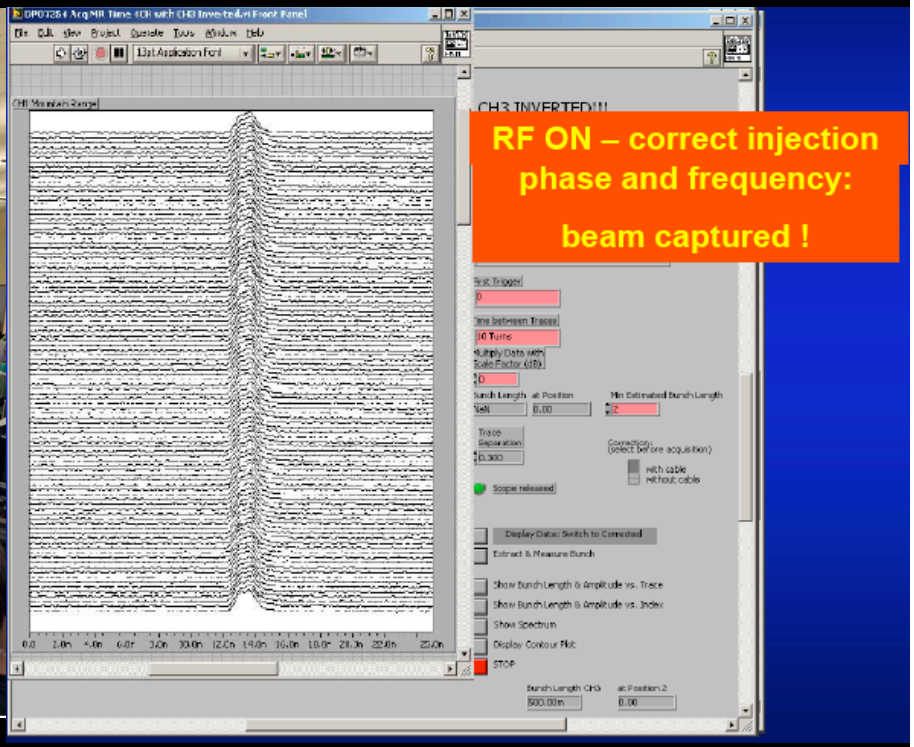
R. Bailey

September 10-12th 2008





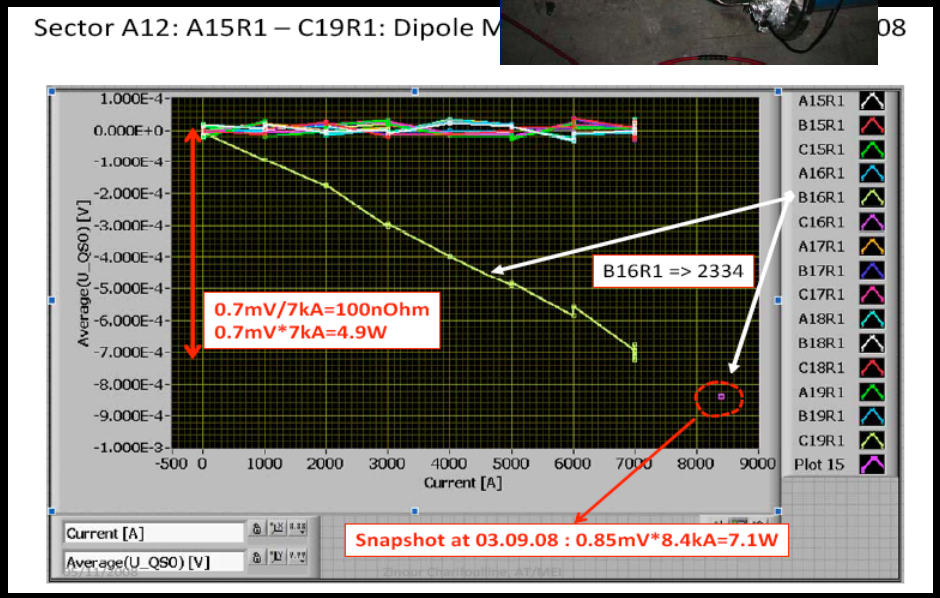


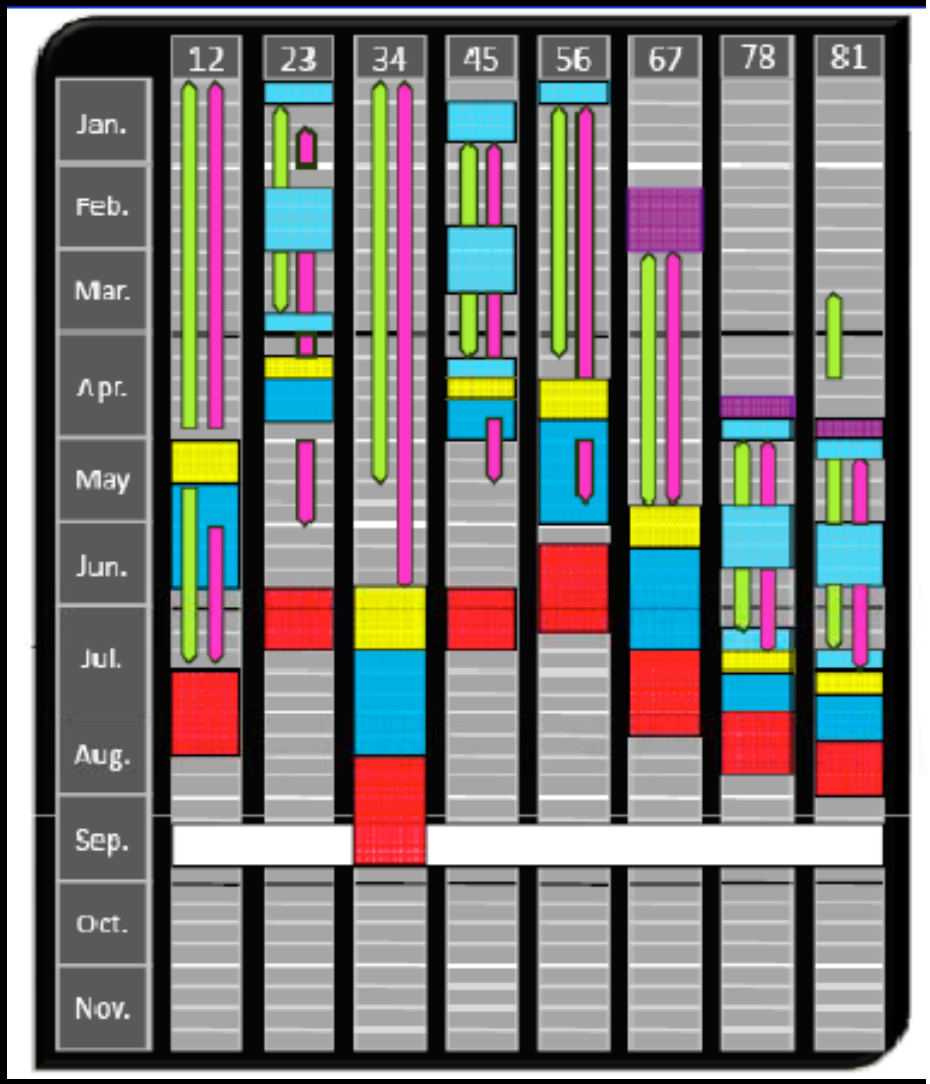


- First beam circulation broadcasted live on TV worldwide
- Worked very well: accomplished within <1h
  - Beam captured soon after

R. Bailey

LHC incident and plan

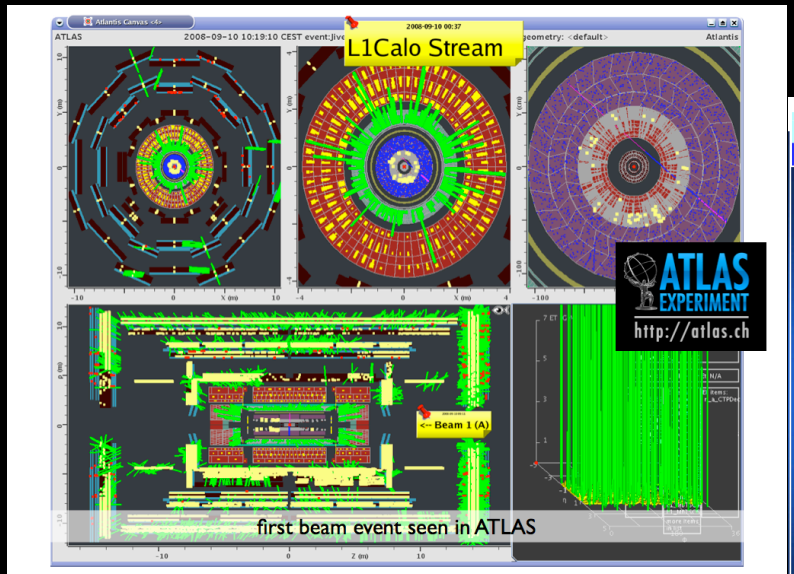


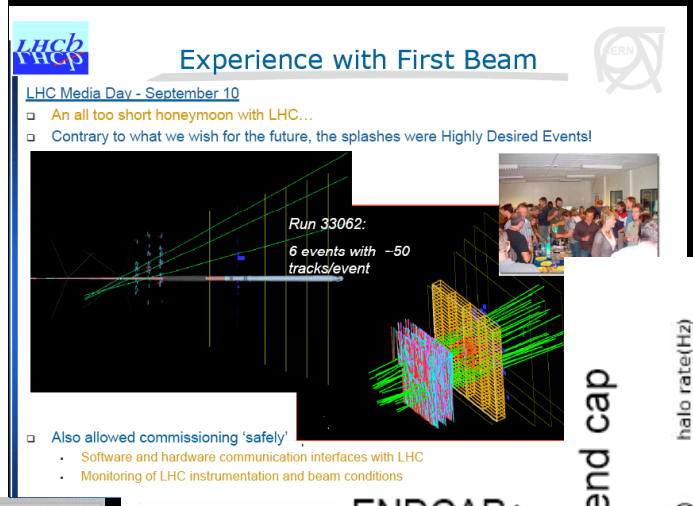


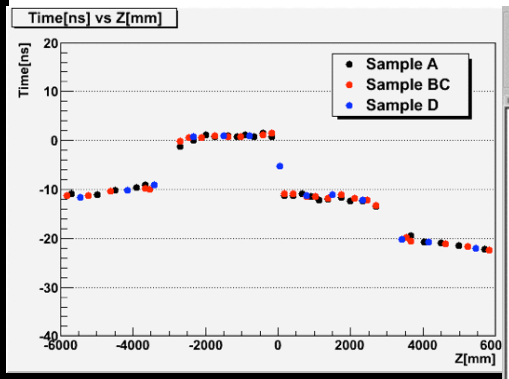
- LHC repair ongoing
- New schedule: run from Nov. 2009-Oct. 2010 at 10 TeV
  - Accumulate 200 pb^{-1} for experiments

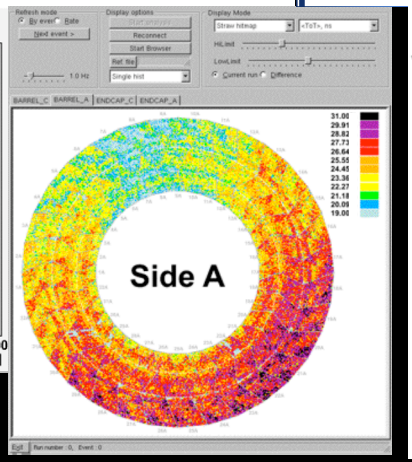
First Beams in Experiments

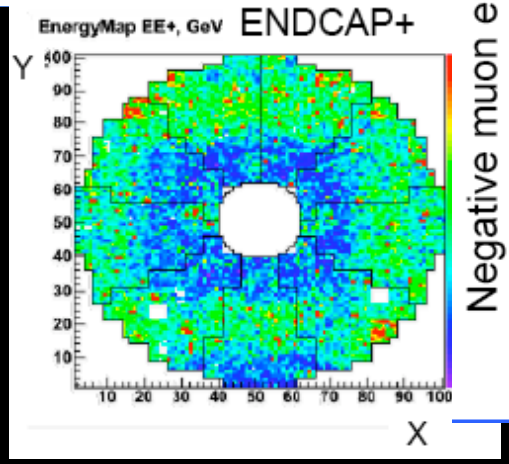
P. Krieger
M. Chamizo Llatas
R. Jacobsson

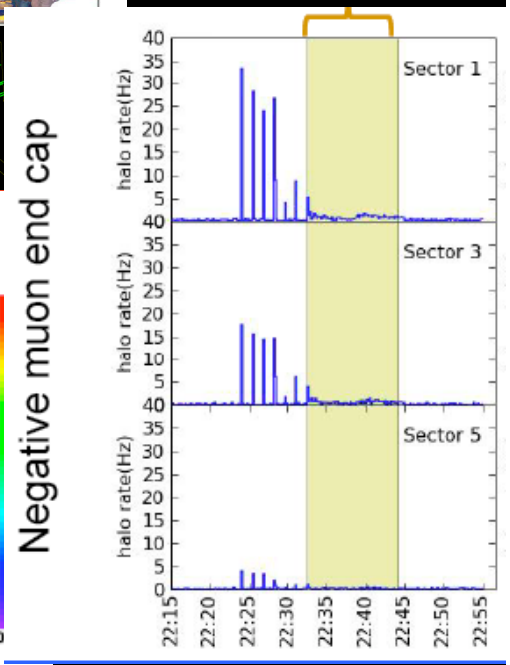








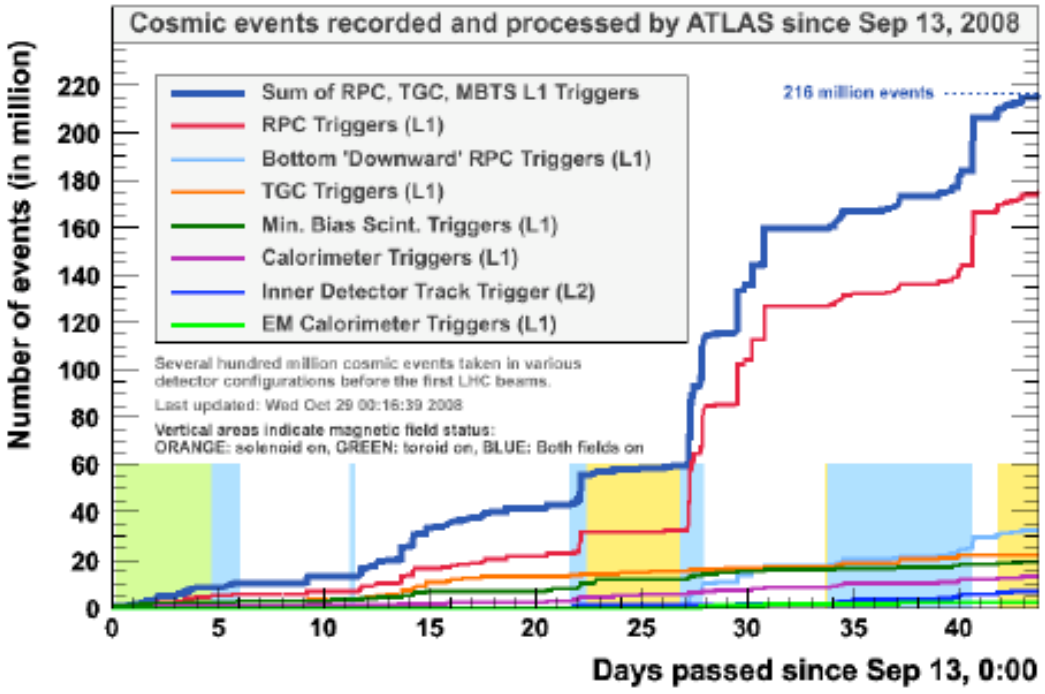


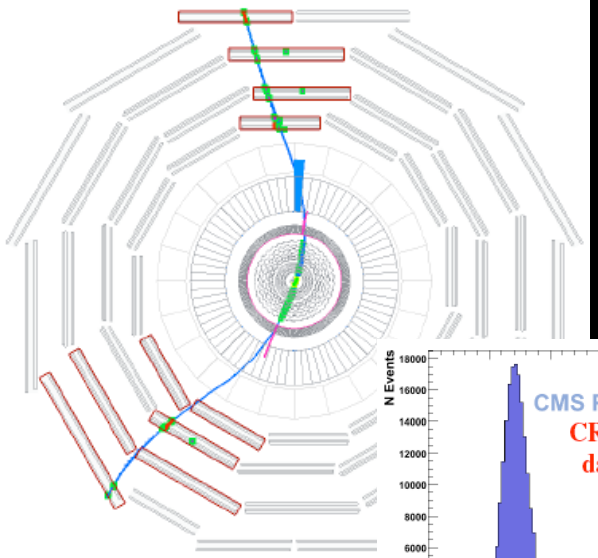


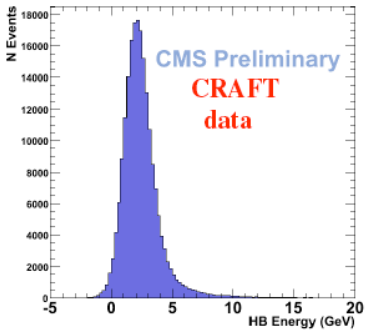
- Used by collaborations for calibration:
  - particularly for timing of subdetectors

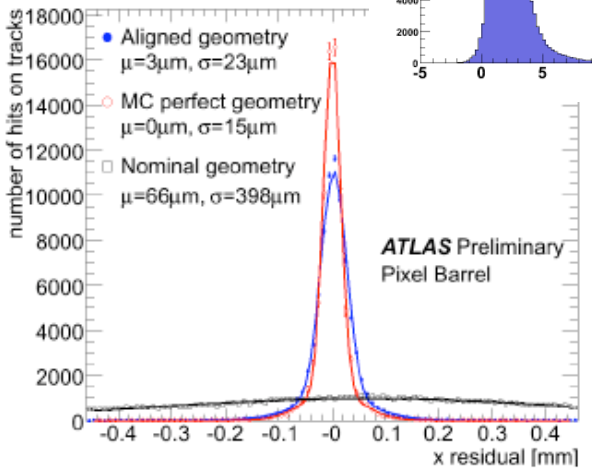
Cosmics in ATLAS and CMS

J. Dubbert
K. Maeshima









- After incident running cosmics
- Impressive performance achieved:
  - Much better prepared for LHC beam next time
  - Physics will come much faster!

Standard Model after next experimental attacks?

Final Words

- Experimentalists:
  - Good luck that
    - Your experiments will (or continue to) work
    - Your analyses converge quickly
- Theorists
  - We will need your help and inspiration
    - In understanding the backgrounds
    - In inventing and understanding the signals

Thanks!