Rencontres de Moriond EWK

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Fermilab
20 March 2011

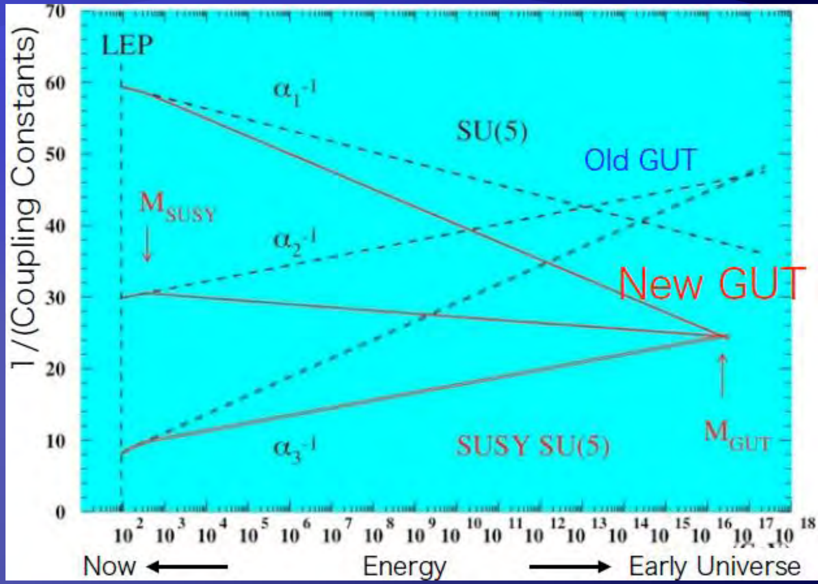
Speakers Caveats…

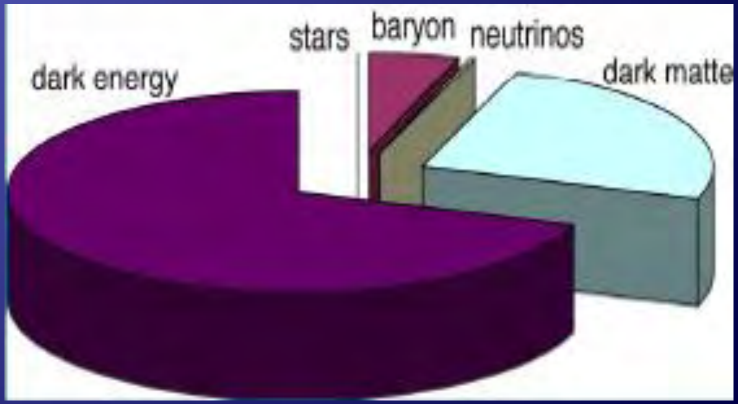
- This is my first conference summary talk – I hope it doesn't show…

- I didn't count how many talks – but there was a large number, each with an impressive array of results. Trying to do 1 page/talk seemed pointless
- I made choices to cover a sampling of topics
- I am sorry if I left yours out. For a better summary – look at the talks on-line. I can't do <u>any</u> of the talks or results justice

The Key Questions facing Particle Physics

- Origin of Mass and Matter
  - Origin of EWSB
- Unification of the Forces
- Fundamental Symmetry of Forces and Matter
- Unification of Quantum Physics and General Relativity
- # of space/time dimensions
- What is Dark Energy?
- What is Dark Matter?





Solutions???

In All proposed solutions, new particles should emerge at the TeV scale or much lower

- Supersymmetry – light Higgs, unification of forces, dark matter particle
  - Particles at TeV scale or below
- Technicolor – new strong interactions produce EWSB
  - Extension of SM gauge group (little Higgs, GUTS etc)
- Extra Dimensions (are introduced)
  - Mgravity ~ Mewk -> Hierarchy problem solved
  - New particles at TeV scale
- Anyone Inspired this week….?

2011-2013: Seminal Period for our Field

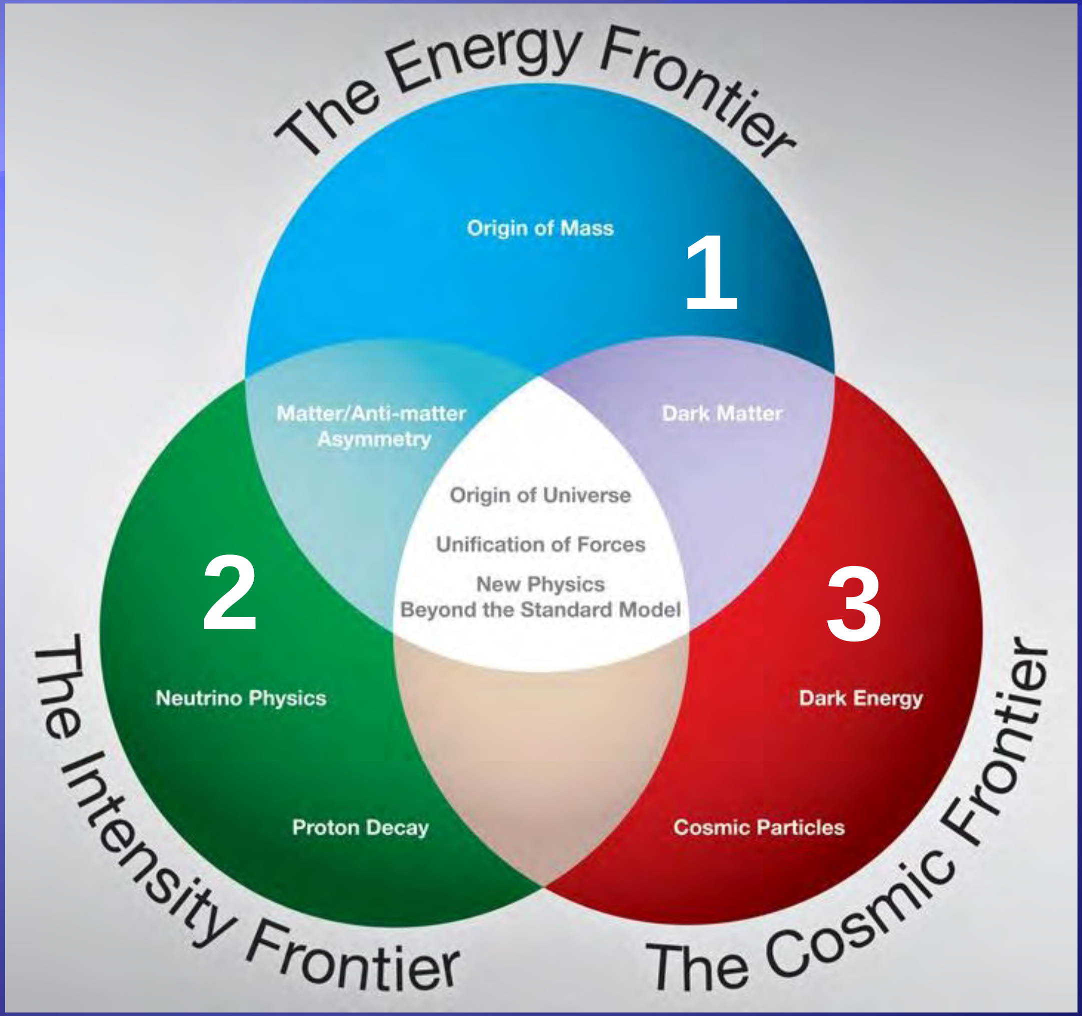
Our View of the world will change in the next few years – Todays experiments will drive the way we look at our Universe

- Tevatron will complete its analysis and LHC will have amazing reach with very substantial data sets
- θ_{13} will be measured (double Chooz, T2K, ..)
- Dark Matter Searches
- Turn-on of “Intensity Frontier” at Fermilab

Key Points

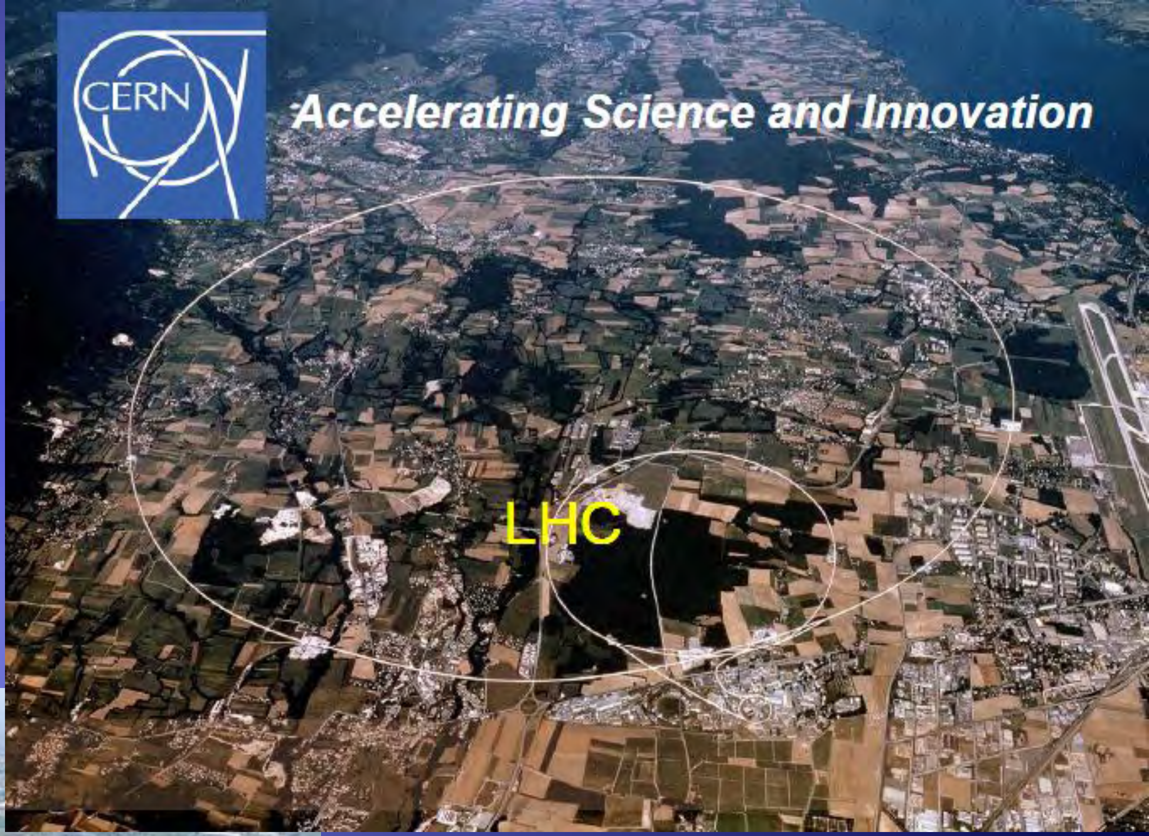
- LHC should remove "the fog" at the TeV scale in the coming few years
  - Is there a Higgs Mechanism?
  - Is Super Symmetry grounded in data?
  - What is dark matter
- These answers (available in a few short years or less) will determine the direction of our field
  - High Luminosity LHC upgrade?
  - Required LHC Energy Upgrade
  - CLIC vs ILC vs muon collider vs …
- Neutrino Sector in a similar situation with $\theta 13$

Outline



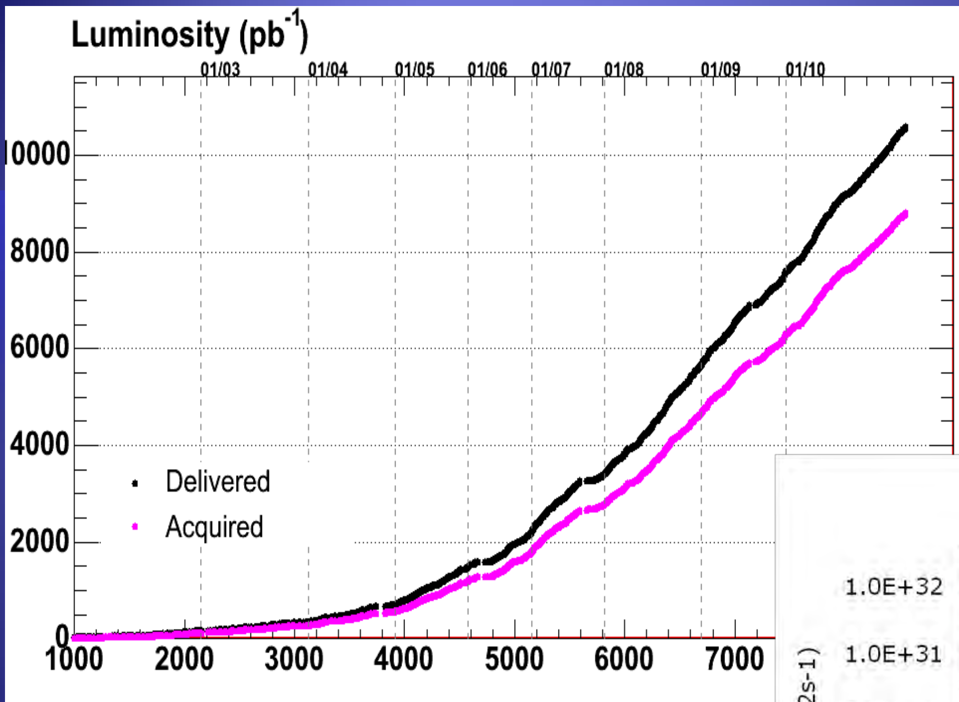
Using this graphic in the US to articulate the HEP strategy to funding agencies

Dream Machine is up and running – with every expectation for >5 fb-1 by end of 2012

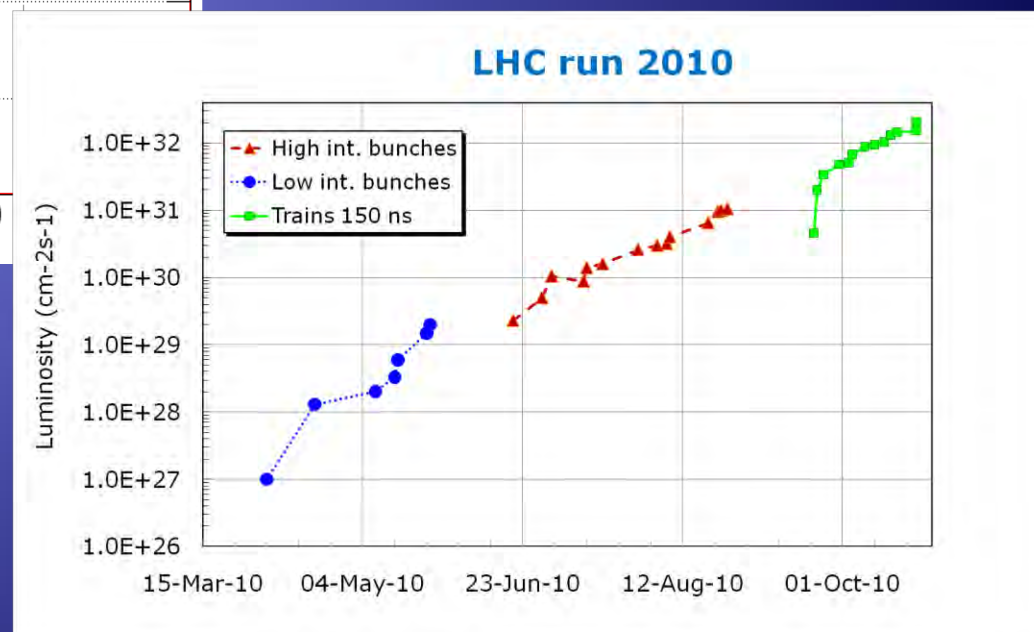


Old "workhorse" still colliding – with ~12 fb delivered by October 2011 – Lots of exploration in data still remain

Current Tools Working Well!!!



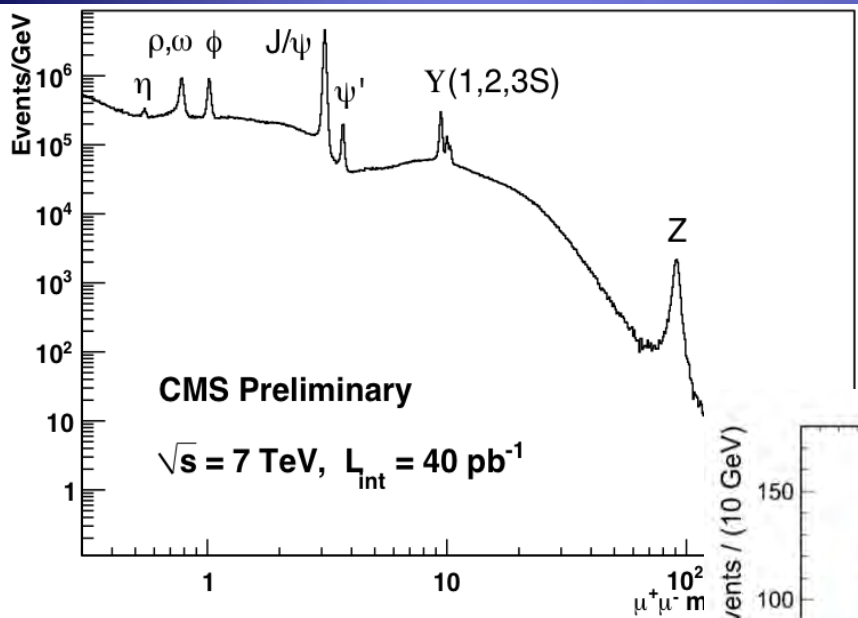
10.5 fb^{-1} delivered, ≈ 9 fb^{-1} acquired

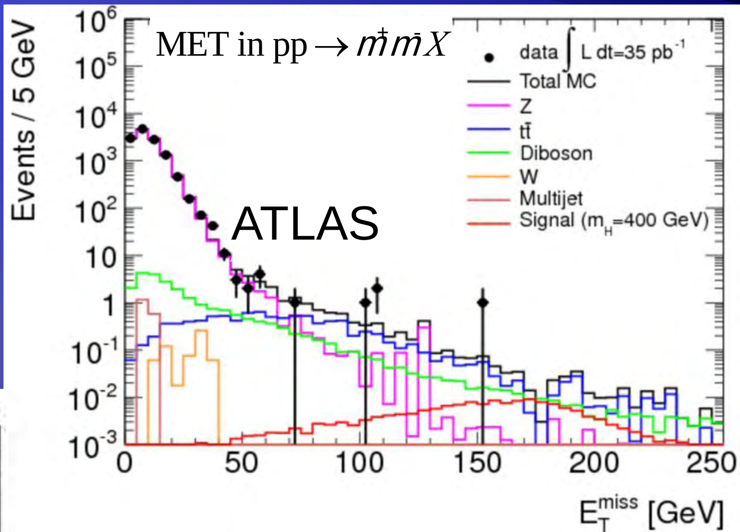


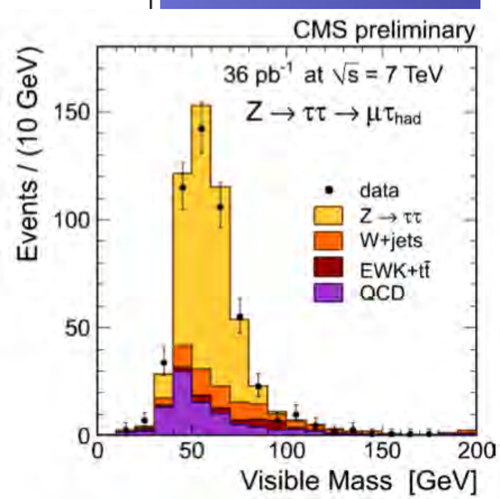
I expect LHC to exceed luminosity expectations in 2011 and 2012!!!

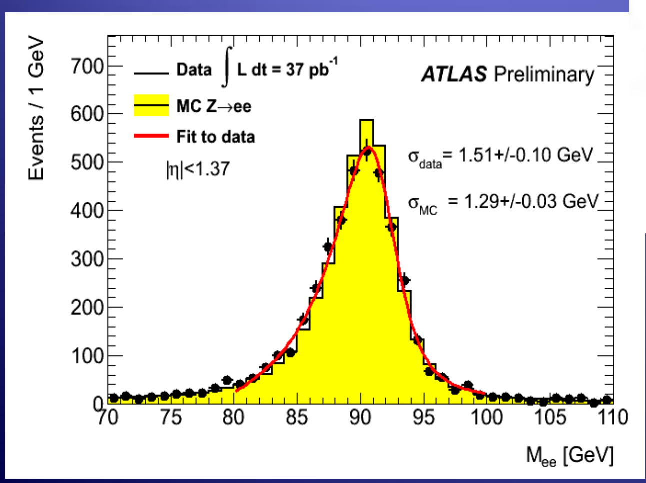
Integrated proton luminosity 2010 ~48 pb^{-1}

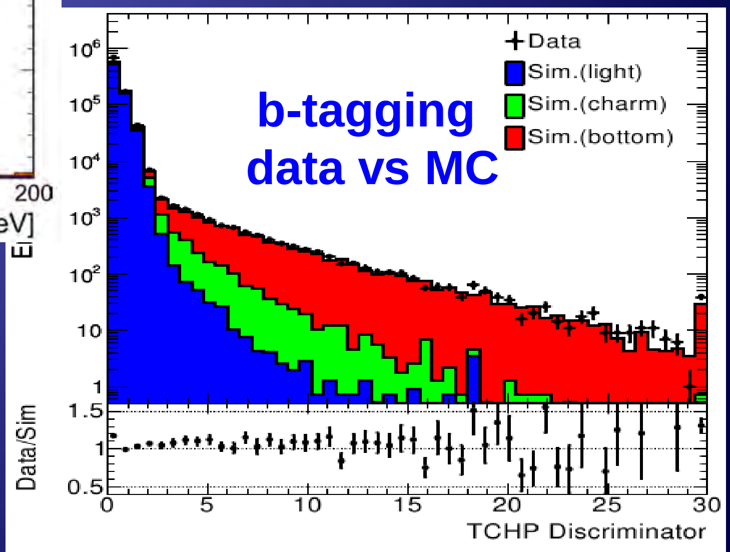
LHC - Amazing level of Maturity



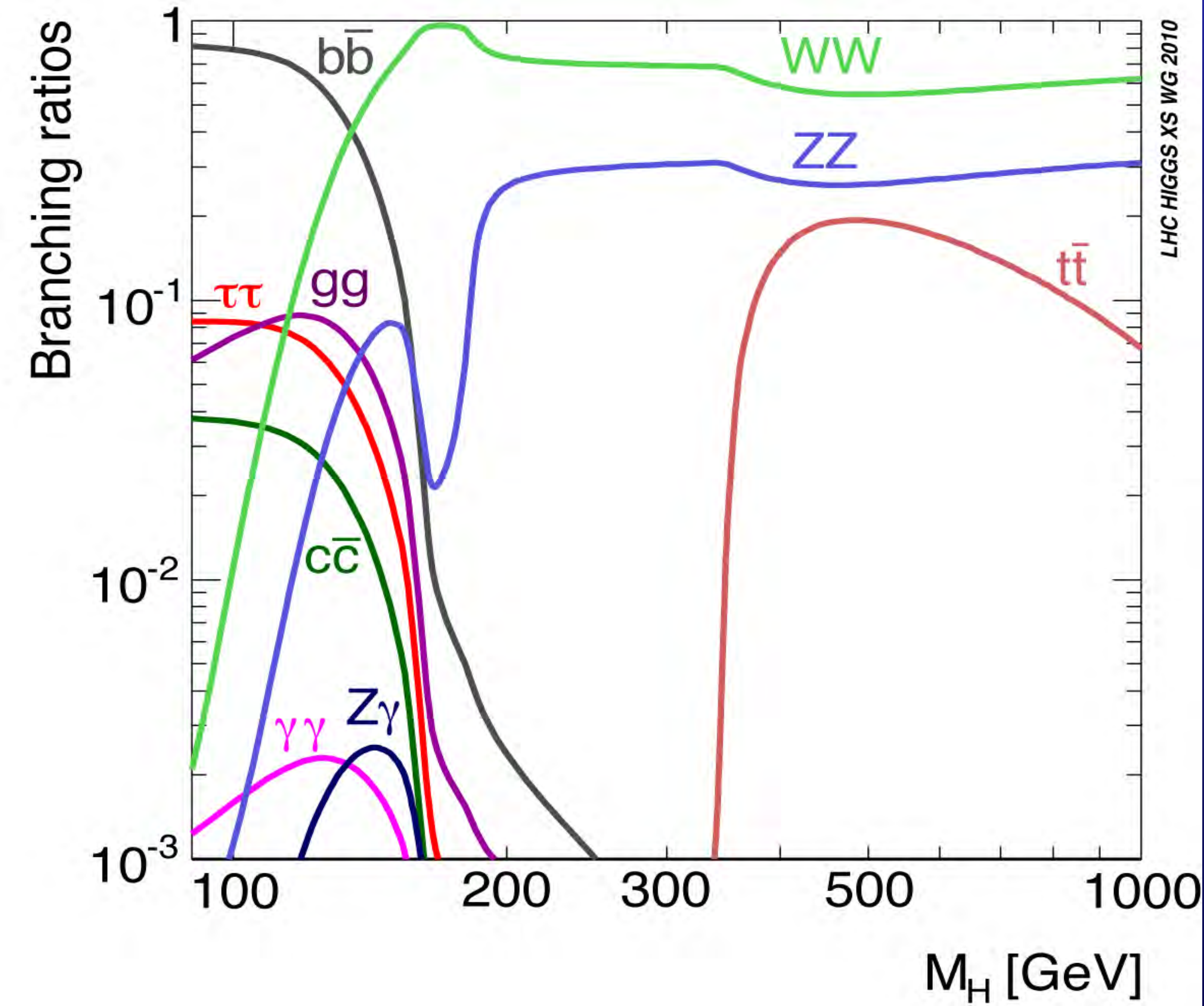








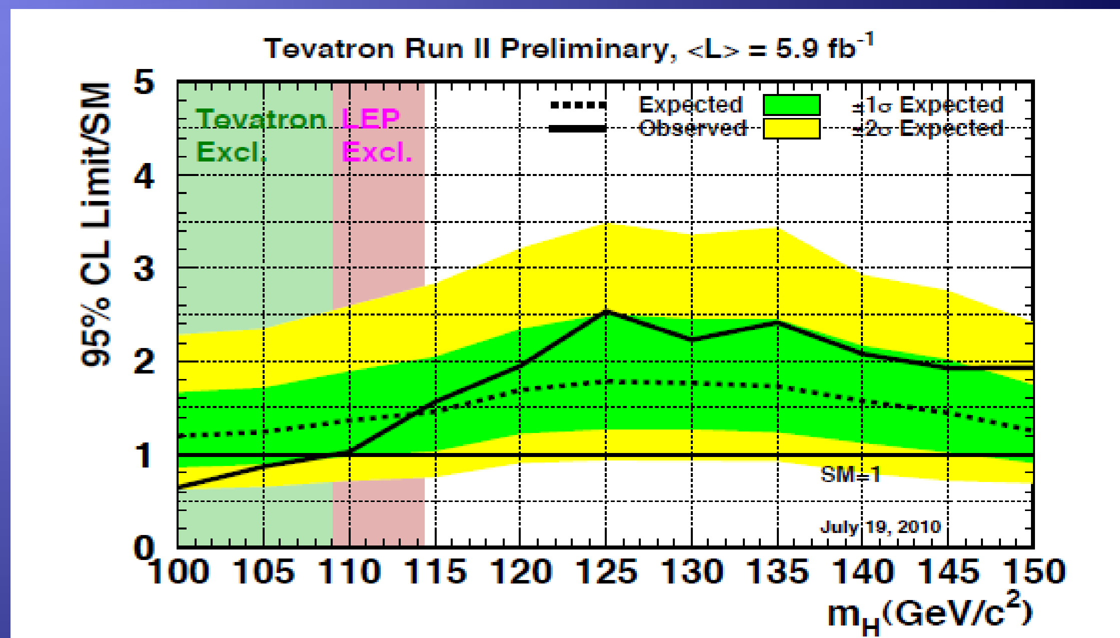
Higgs Decay modes vs Mass



Higgs Low Mass - Tevatron

- Higgs Searches can be divided up into 2 sections – low mass 114-135 – this is dominated by bbbar. The upper range (135-185) is dominated by WW. Higgs >185 is not accessible at the Tevatron
- For Low mass, the Tevatron relies on Associated production (WH, ZH(llbb) and ZH ($\nu\nu$bb)). Other channels do contribute at a lesser amount but are included to boost the sensitivity

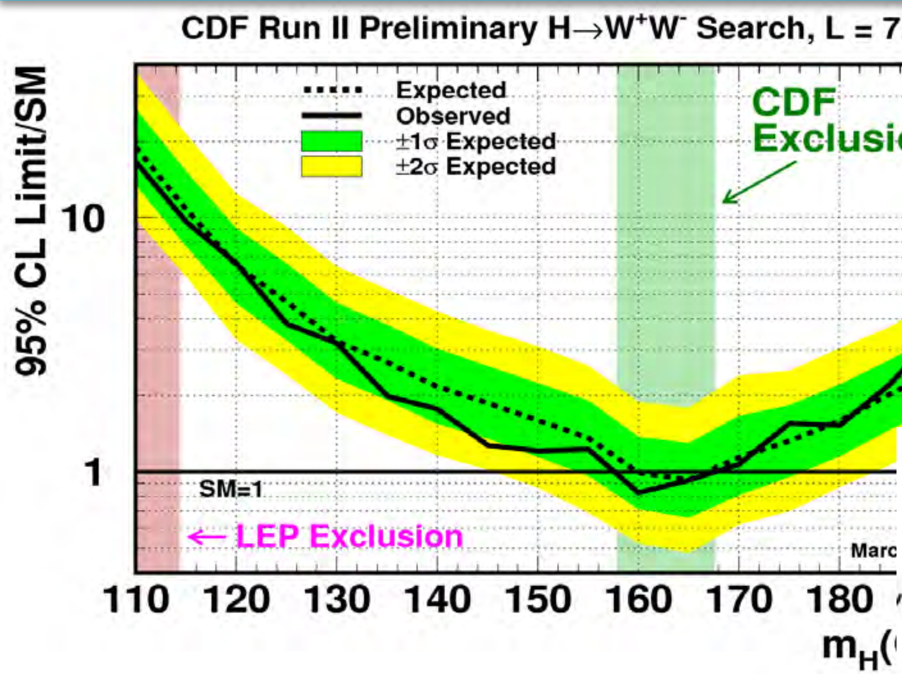
Summer 2010 Result – skipped Winter Conf. update in order to maximize improvements for EPS 2011



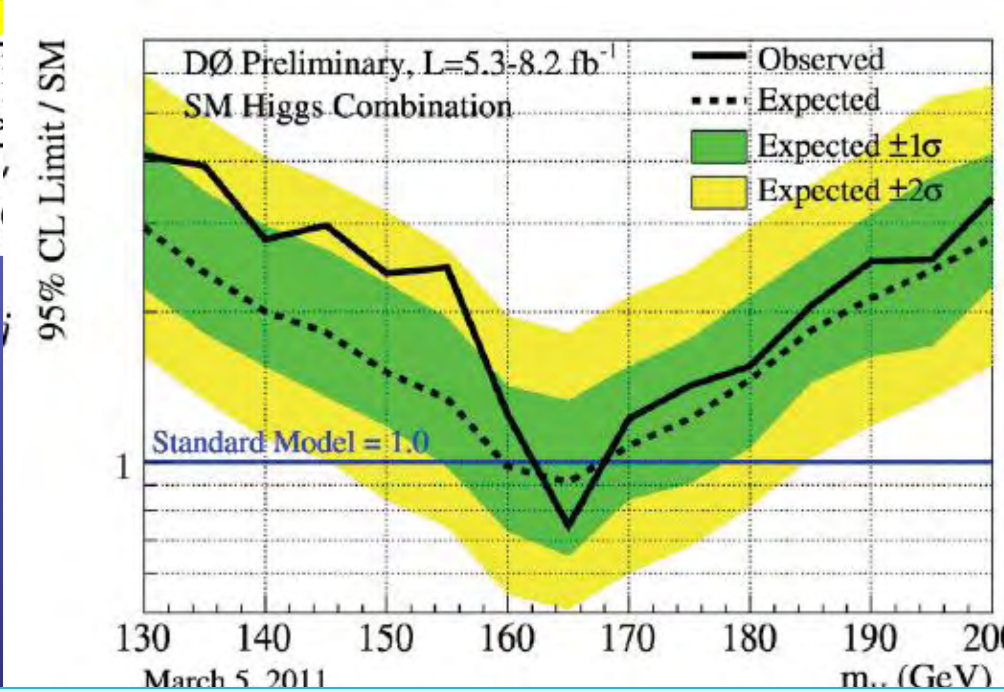
- Upper limit for m_H=115 GeV/c^2 of $1.56\times\sigma_{SM}$ @95% CL
- Tevatron-only exclusion at 95% CL of 100 < m_H < 109 GeV/c^2

Tevatron Individual High Mass Results

CDF excludes SM Higgs for $158<M_H<168$ GeV/c²

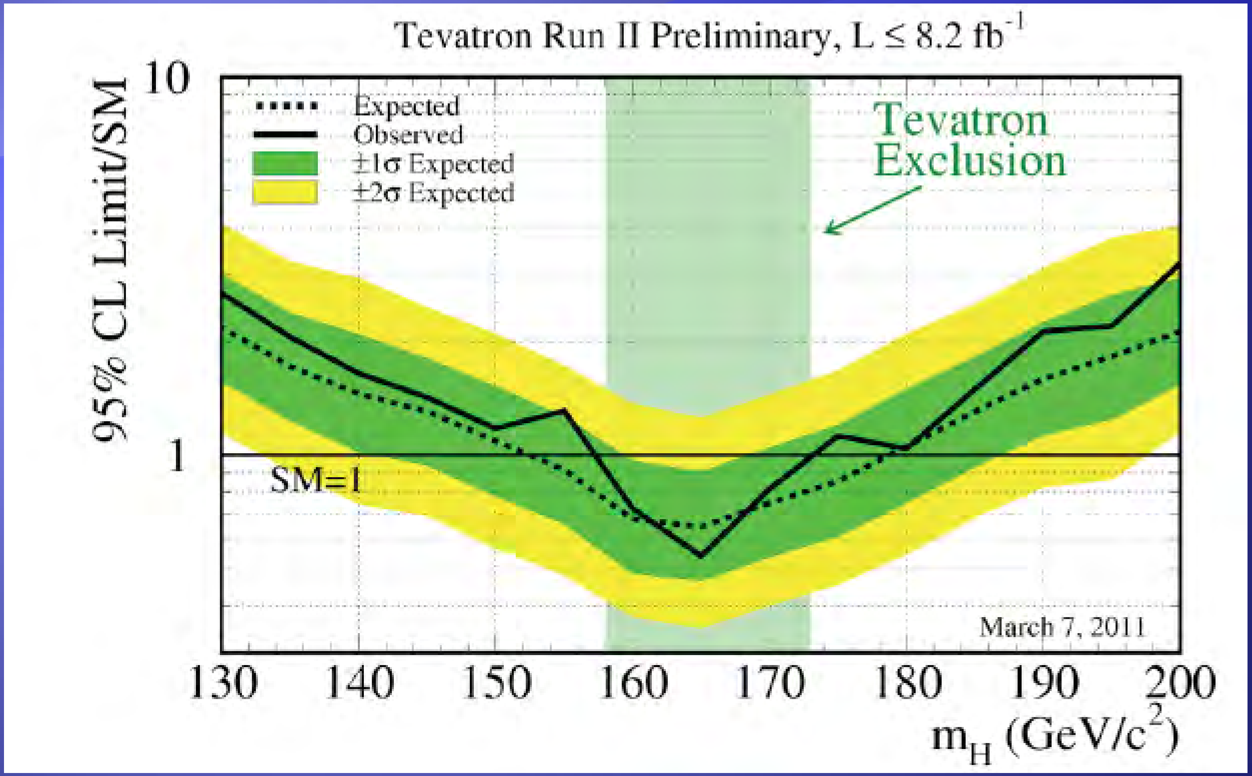


Single Experiment Exclusions



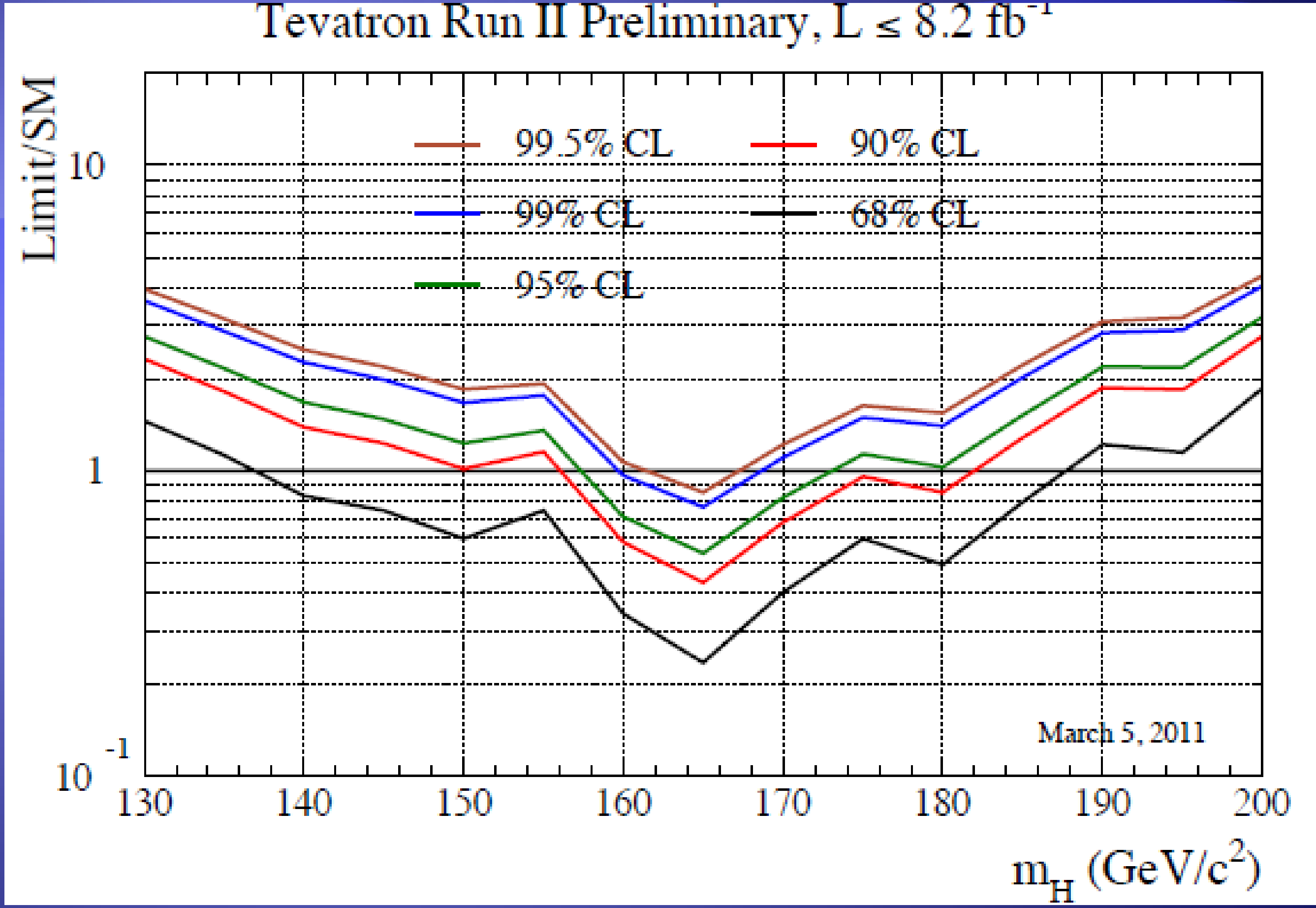
Do excludes SM Higgs for $163<M_H<168$ GeV/c²

Tevatron High Mass Combination



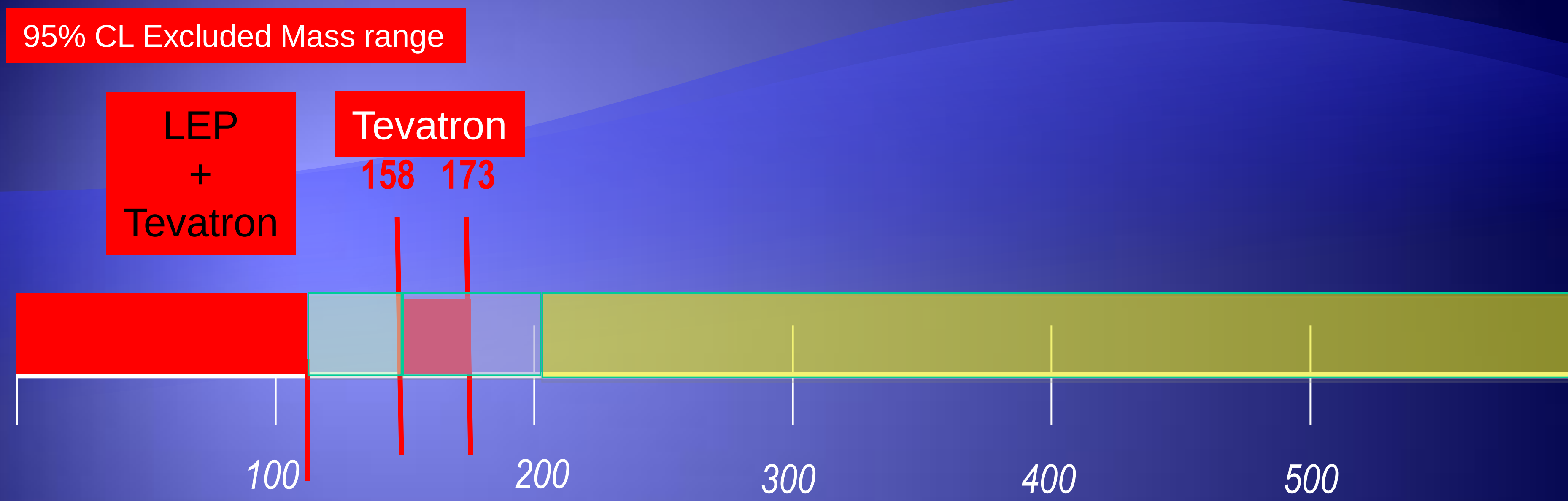
- SM Higgs boson **excluded** at 95% CL for **$158 < m_H < 173$ GeV**
- Expected exclusion at 95% CL for **$153 < m_H < 179$ GeV**
  - Compare to summer 2010 expected exclusion of $156 < m_H < 173$ GeV

Tevatron Combination



SM Higgs of 162 < m_H < 166 GeV excluded **@99.5% CL**

LHC Enters the Higgs Fray!!!



At masses between 114-135, there are a cocktail of final states that get combined. For 135 and up, its H->WW and H->ZZ

LHC owns the landscape above ~185

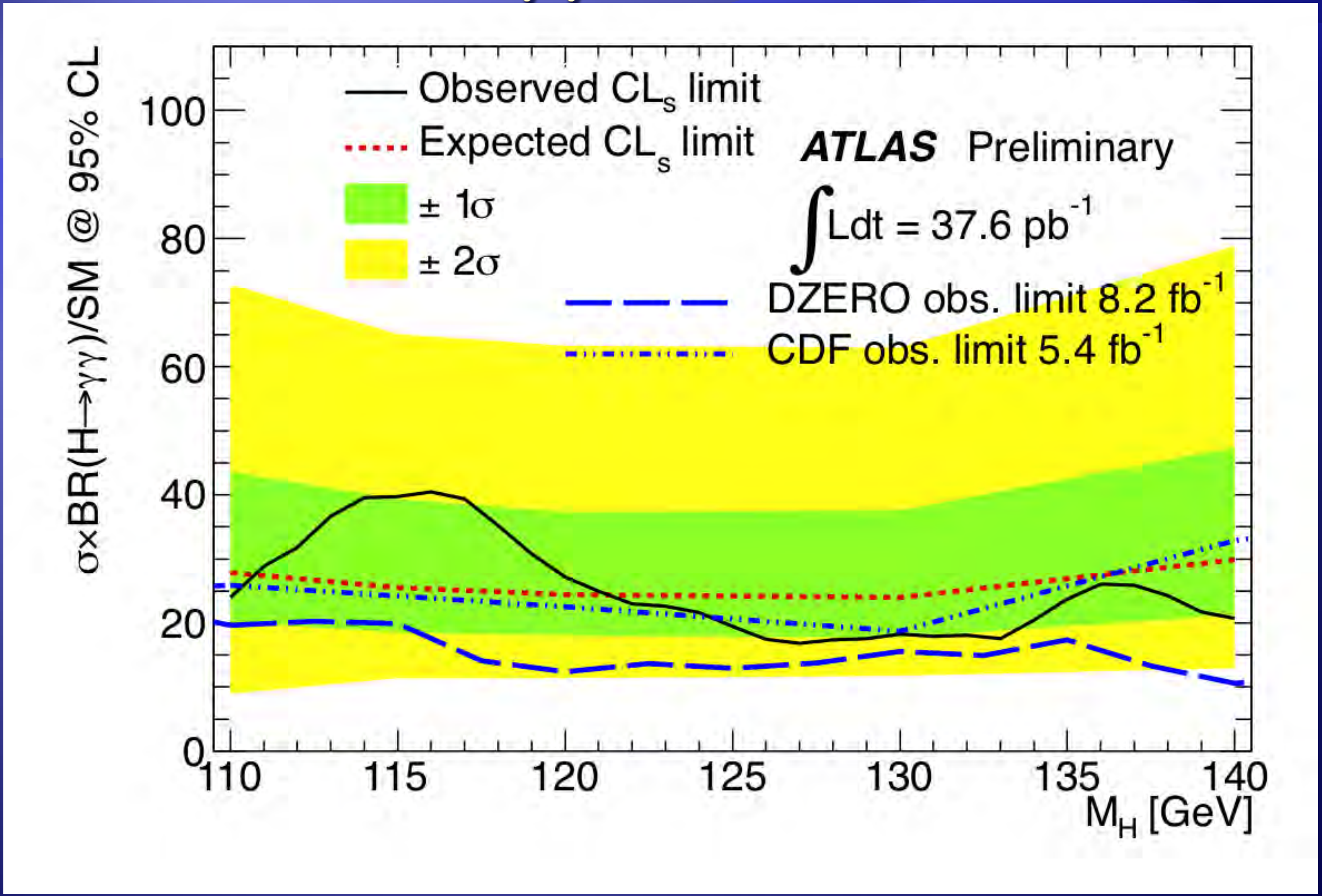
ATLAS

- $H \to W^+W^-$
- $H \to gg$
- $H \to t^+ \ t^-$
- $H \to ZZ$
- NMSSM Higgs

CMS

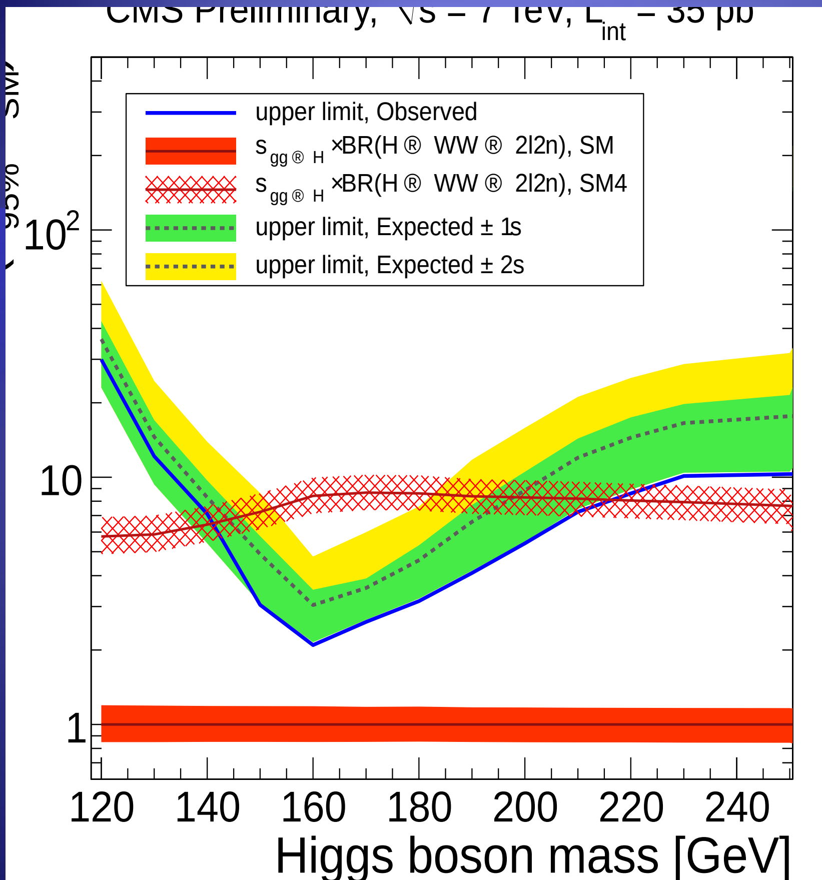
- $H \to W^+W^-$
- $H^+ \to t^+ n$
- $H \to t^+ \ t^-$
- $H^{++} \to \ell^+ \ell^+$

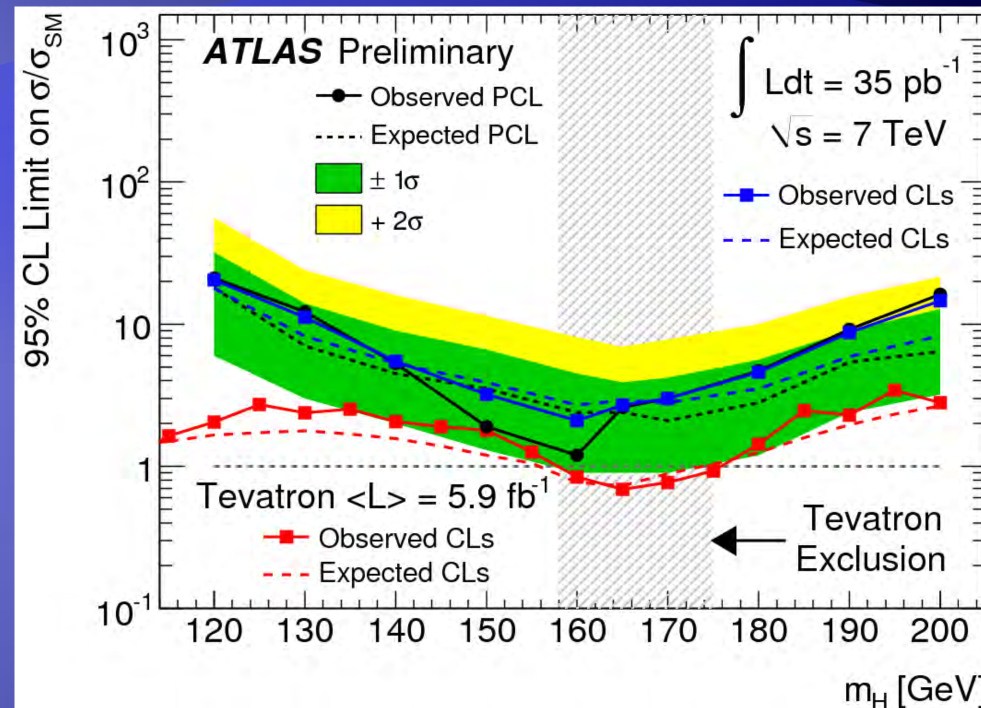
ATLAS $H \rightarrow \gamma\gamma$ Results



LHC already competitive with Tevatron

LHC Higgs -> WW Results

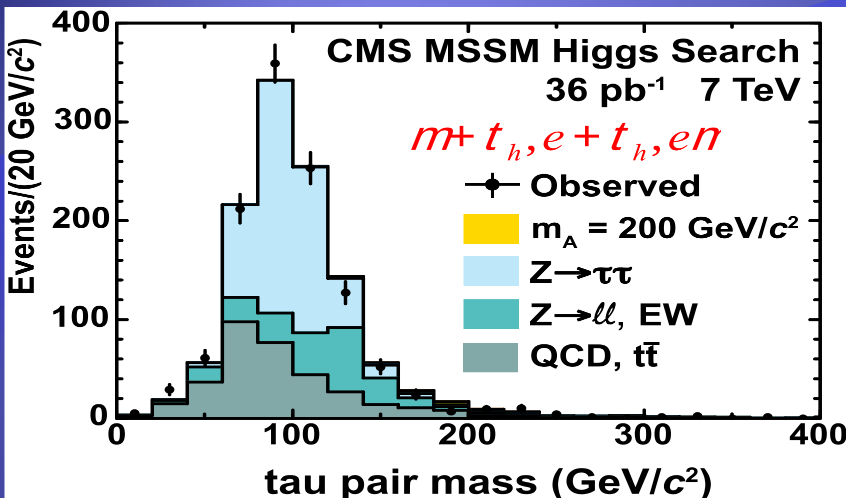


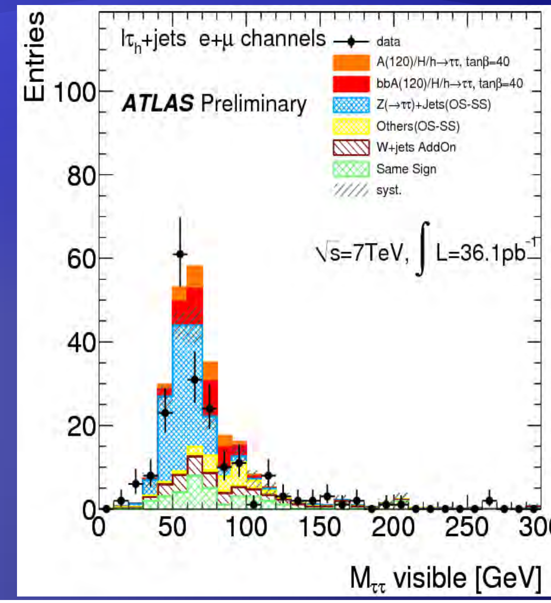


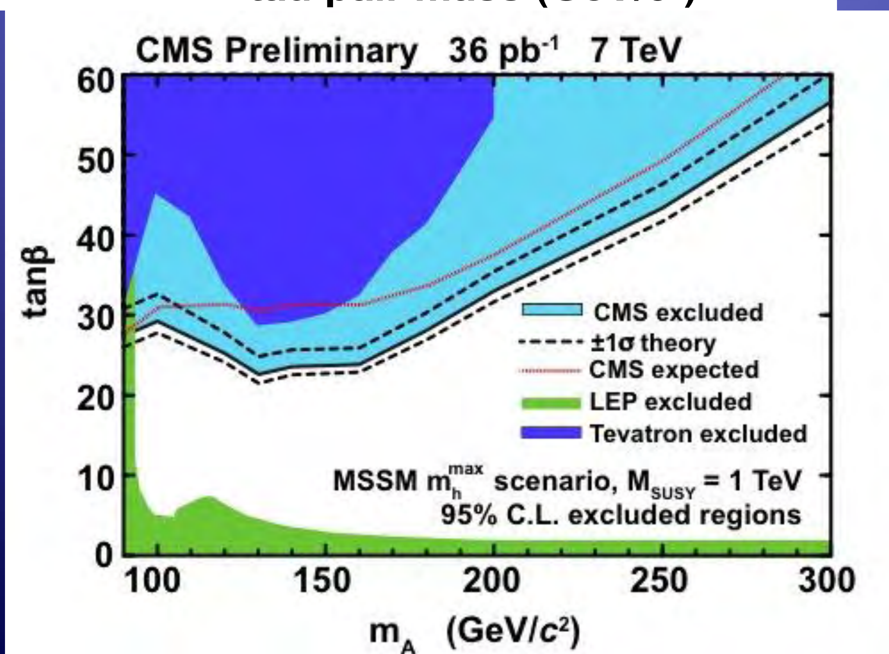
95 % CL Limit for M_H = 160 GeV	CMS (Bayesian)
Expected	3.0 x SM
Observed	2.1 x SM

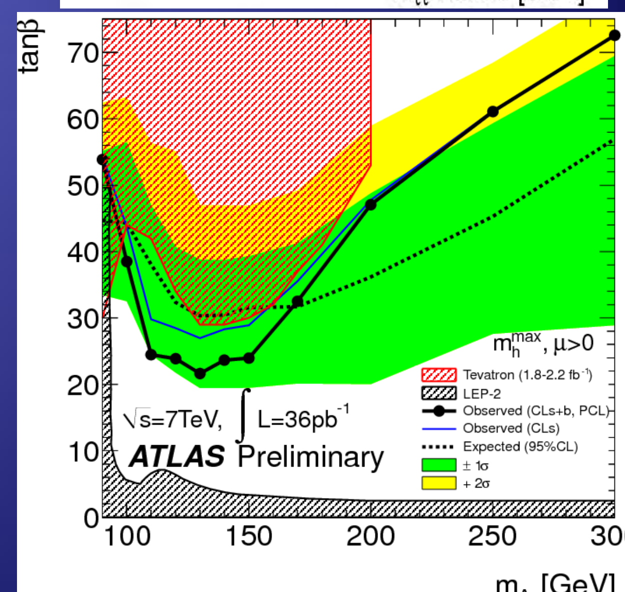
95 % CL Limit for M_H = 160GeV	ATLAS (CL_S)
Expected	2.7 x SM
Observed	2.1 x SM

MSSM H $\to\tau\tau$ at LHC









Gfitter Rules!!!

LEP + Tevatron (Fall 2010) :

- CL^{2s}_{s+b} central value $\pm 1\sigma$:

$$M_H = 120.2^{+17.9}_{-5.2}\ \text{GeV}$$

- 2σ interval:

$$-2\ln Q: \quad [115,152]\ \text{GeV}$$

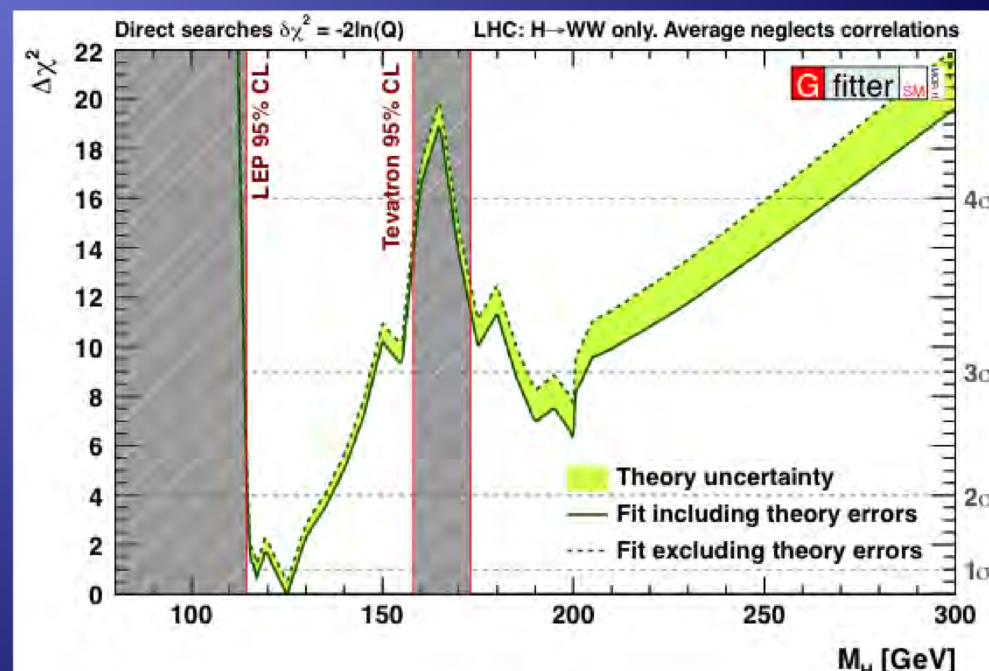
$$CL^{2-sided}_{s+b}: \quad [114,155]\ \text{GeV}$$

Fit with LEP + Tevatron + LHC (H➔WW) searches (Moriond 2011) :

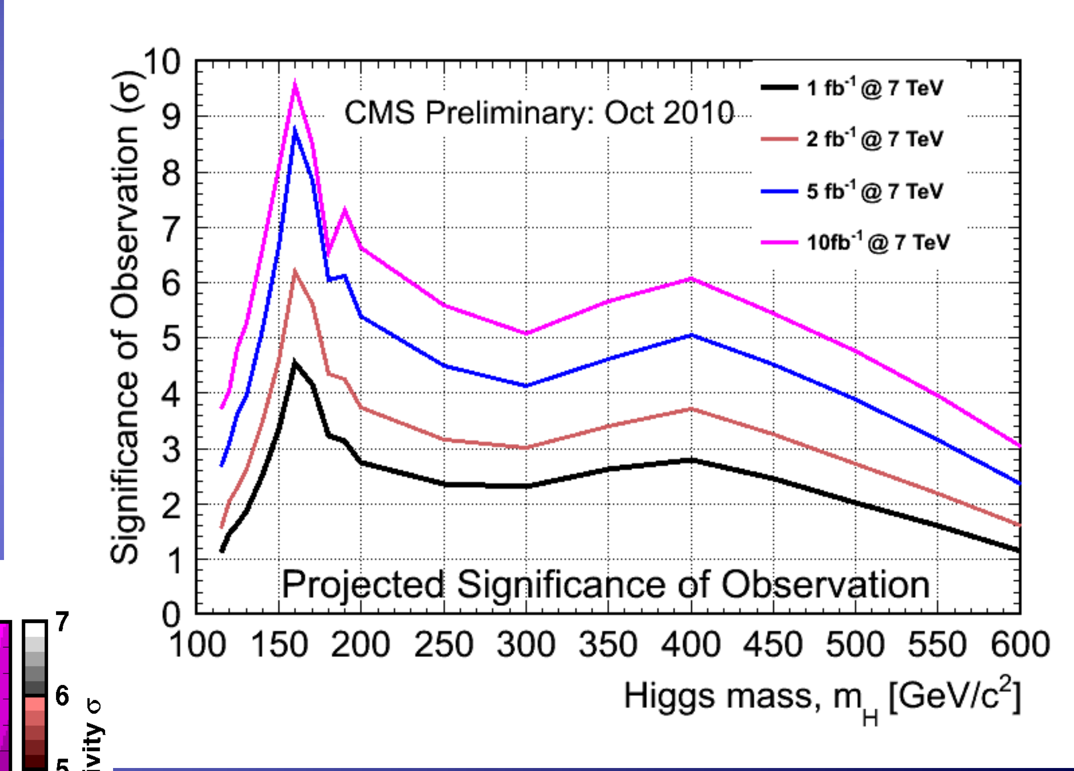
- Central value unchanged
- 2s interval:

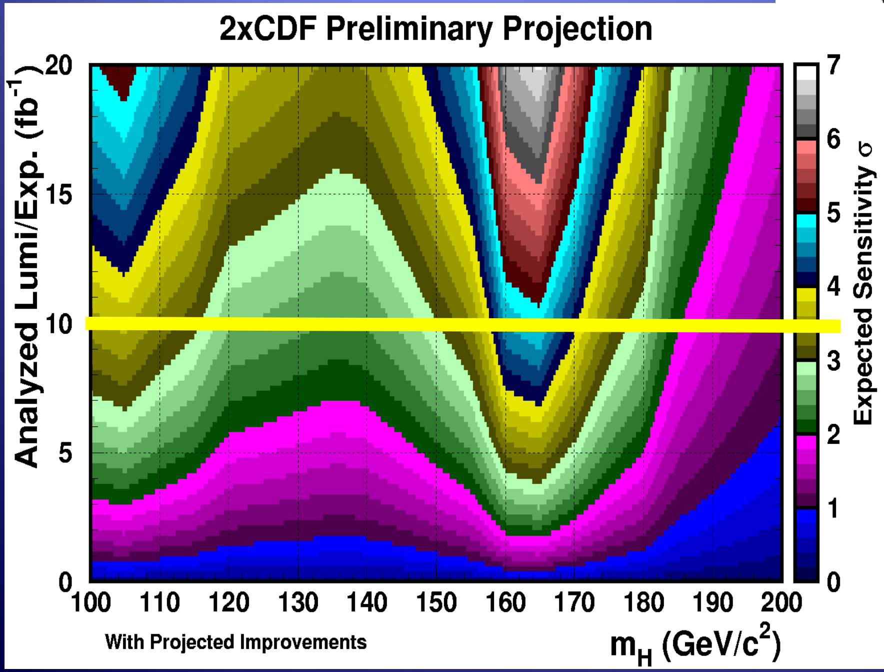
$$-2\ln Q: \quad [115,137]\ \text{GeV}$$

$$CL^{2-sided}_{s+b}: \quad [114,14?]\ \text{GeV}$$



What to look forward to…

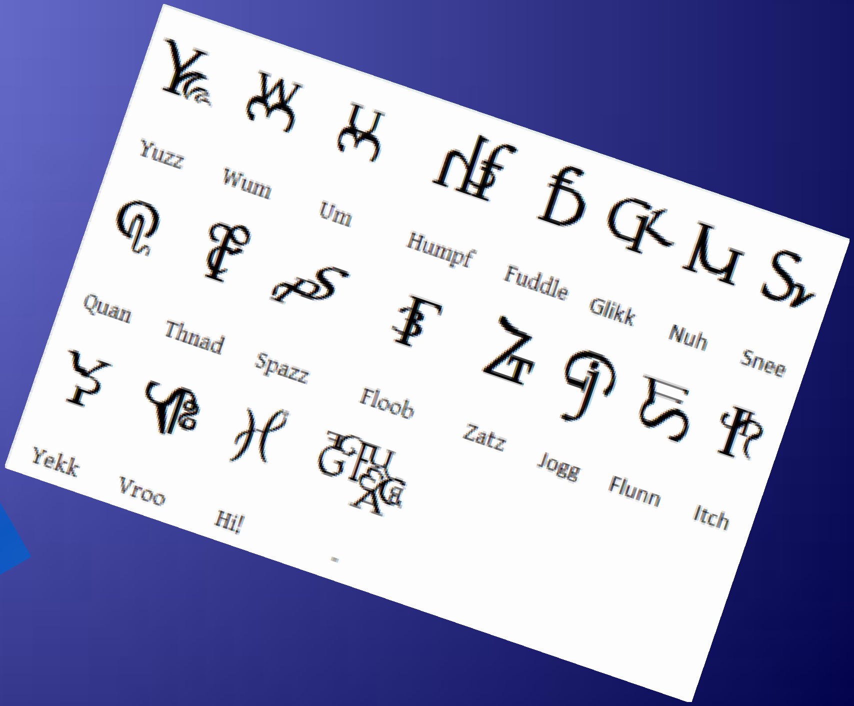




Atlas ≅ CMS

Above is single expt lum so divide by two when comparing to plot on left!

Searches Beyond the Standard Model



Search Results Shown…

CMS

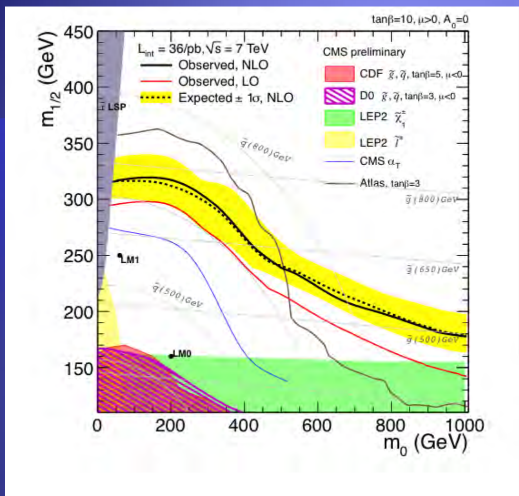
- 2-lepton searches
  - same sign + jets + "MET"
- 1-lepton search
  - e or mu + jets + "MET"
- 0-lepton search
  - jets + "MHT"
- Inclusive search
  - (e or mu) + jets, R & MR

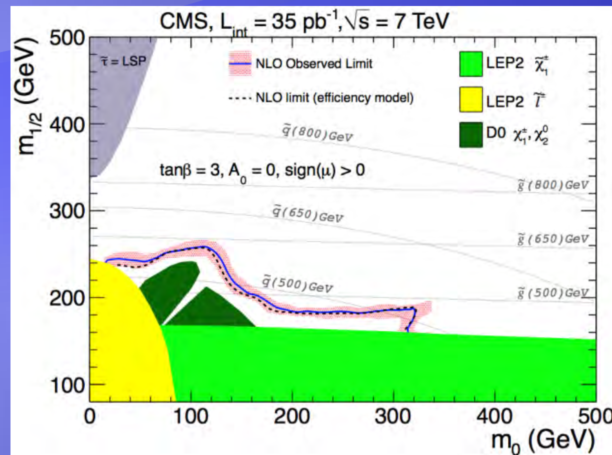
ATLAS

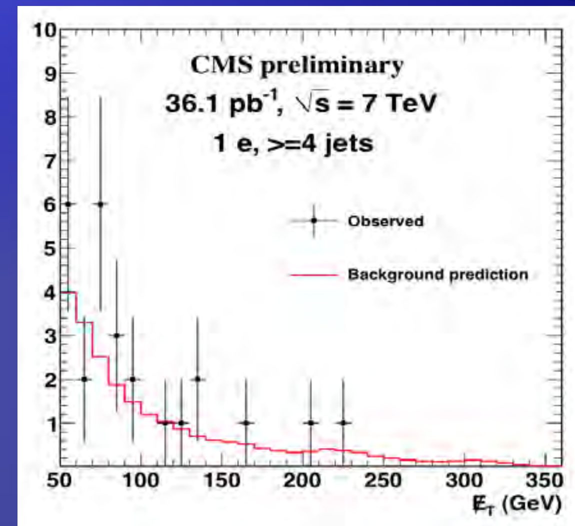
- **Jets + lepton +MET**
- **Jets +MET**
- **Jets + b-tag+MET**
- **Dilepton+ MET**
- Multileptons+ MET
- Photons + jets +MET
- **Slow Moving Particle**

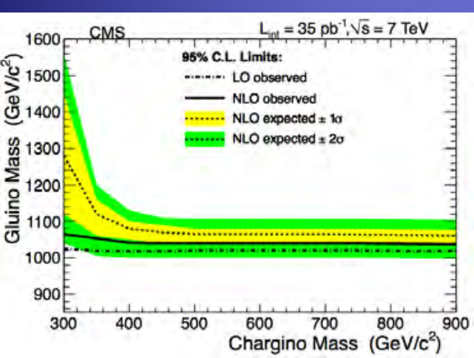
Small Subset of LHC Search knowledge!!!

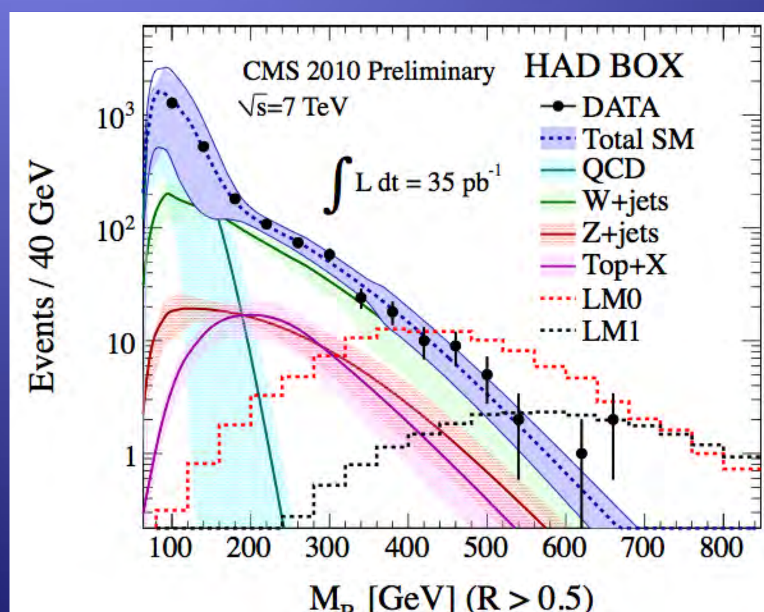
Searching For New Physics…CMS Style

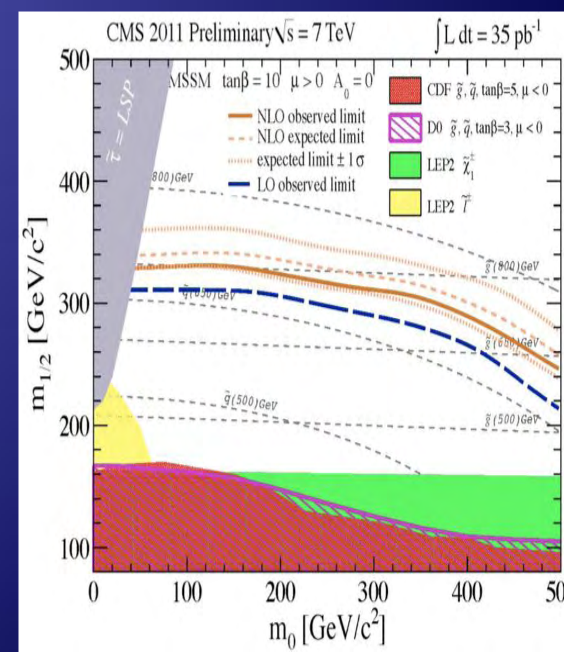




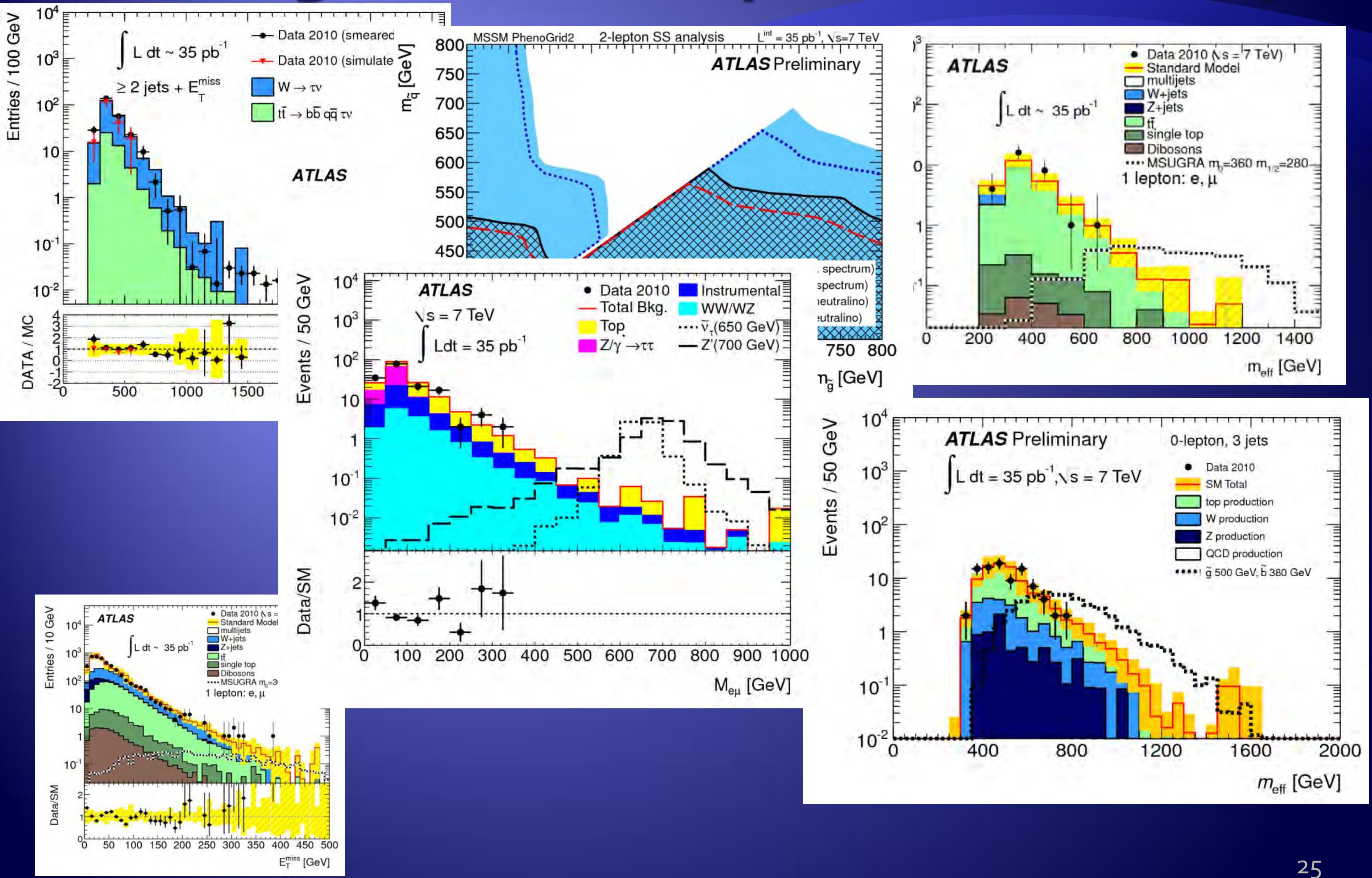




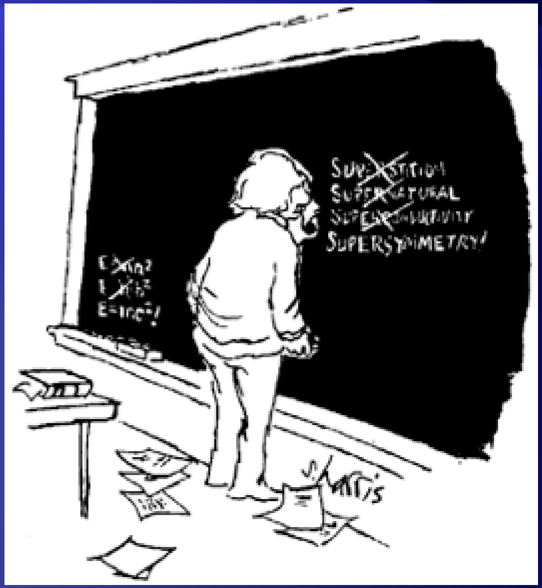




Searching For New Physics..ATLAS Style



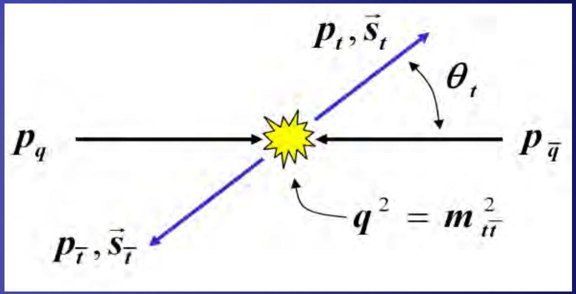
Is SUSY on its last legs…



- LHC experiments are really pushing into SUSY space already
- So far, SM is holding up well – no very “low hanging fruit”
- Most if not all of the interesting mass regions should be explored by LHC this year!
- SUSY better speak up soon if its there!

Top Production Asymmetry A_{FB}

- Recap:
  - Interference between diagrams (LO and NLO) gives small C violation
    - SM A_{FB}~5% (@NLO)
  - CDF +D0 both see a discrepancy



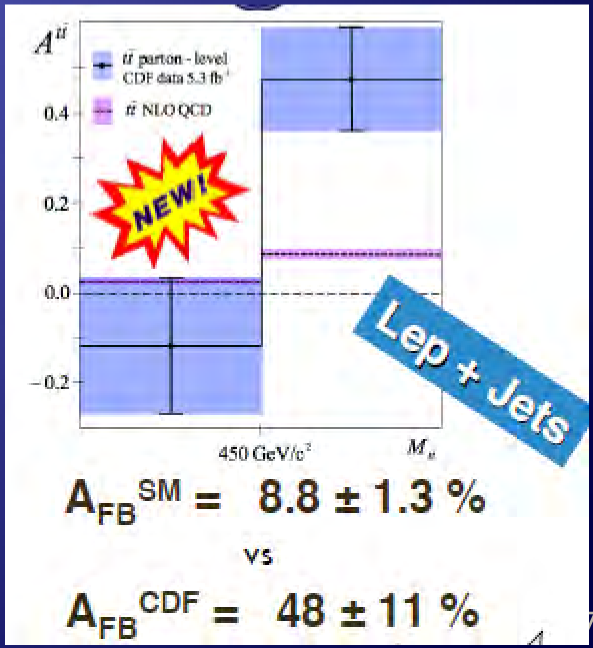
Experimental Results

D0 l+j Afb = 8 +- 4%, Afb(SM) = 1 +- 1.5% 2σ

CDF l+j Afb = 15 +- 5%, Afb(SM) = 5 +- 1.5% 2σ

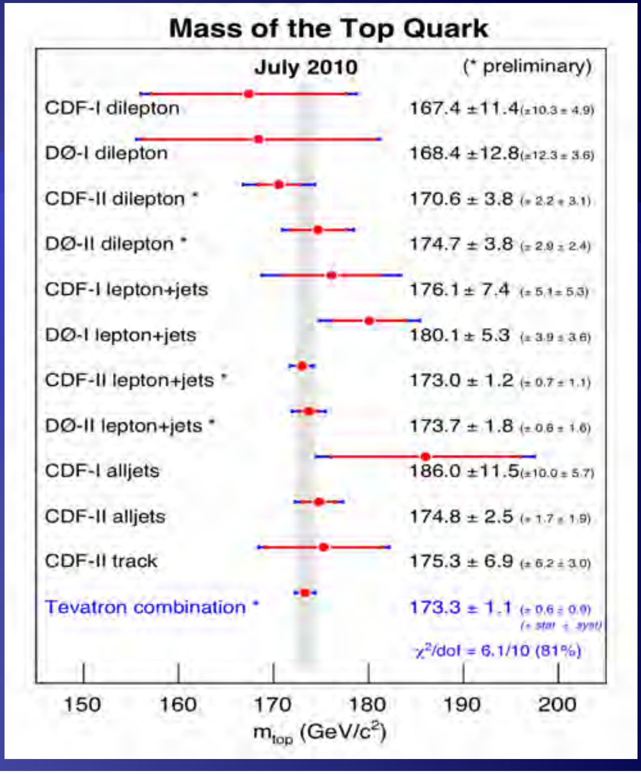
CDF dil Afb = 42 +- 16%, Afb(SM) = 5 +- 15% 2σ

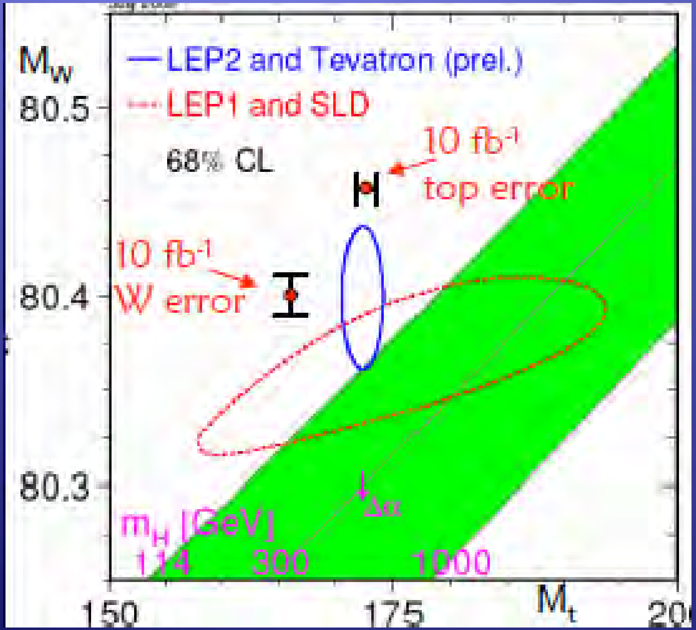
If CDF looks at Mttbar dependence; 3.2σ

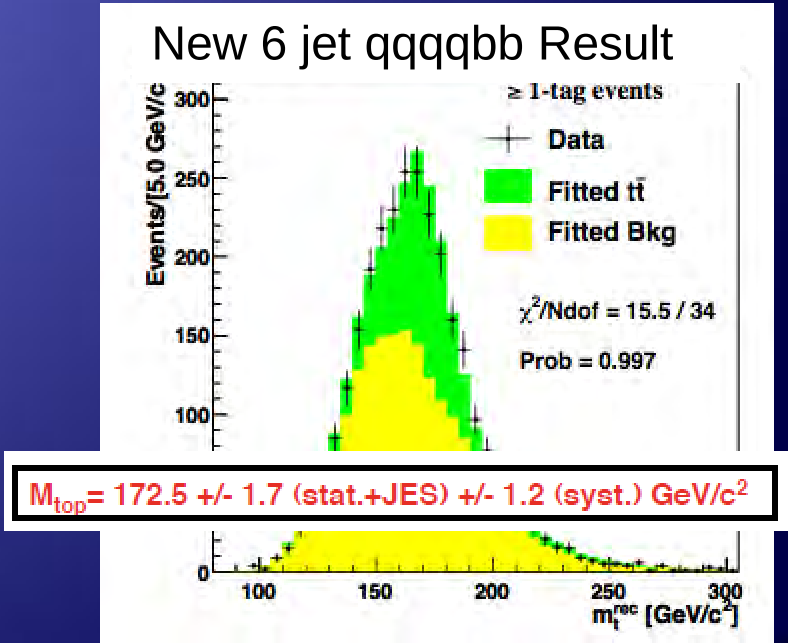


Top and EWSB

- Tevatron Top Mass is 173.3 +- 0.6 +- 0.9 GeV/c2
- CDF Combination now = Tevatron uncertainties
- Dominated by systematic uncertainties – people are working hard on them
- New TeV Top Mass in summer
  - It will take some time for LHC to reach this level of precision

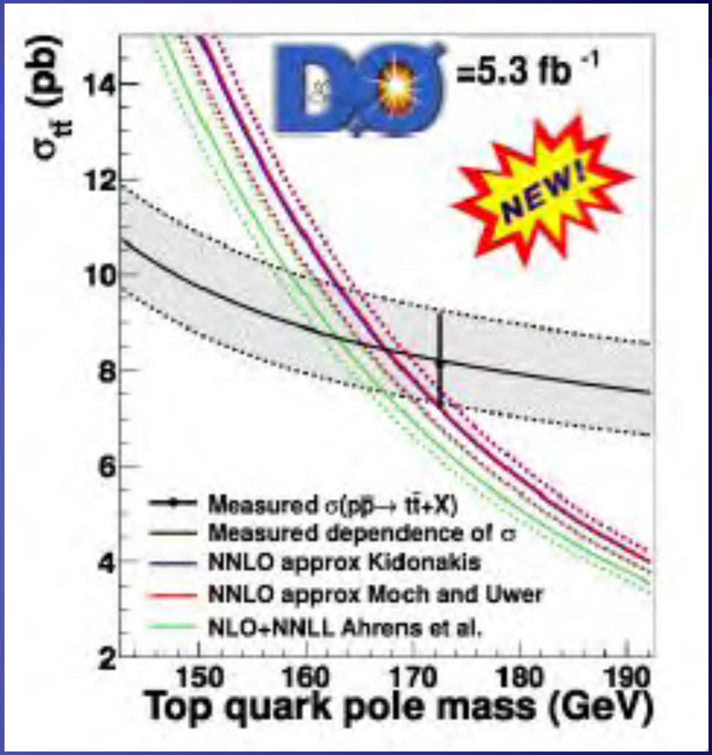






Top Mass is precise but what does it mean?

- Theorists tell us pole mass and running mass can differ by ~10 GeV
- Experiments measure something close to the pole mass
- Can we provide a translation?
- D0 Measures XS and its dependence on Mtop

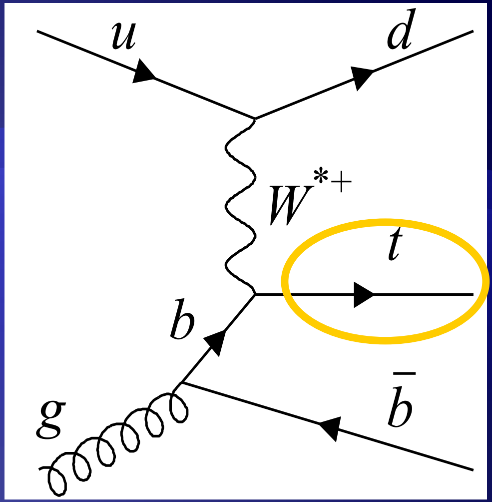


$M_{top}^{pole} = 167.5\,^{+5.4}_{-4.9}$ GeV/c^2 *

agreement (1 sigma) with Tevatron world average
$\overline{MS}$ interpretation disfavored

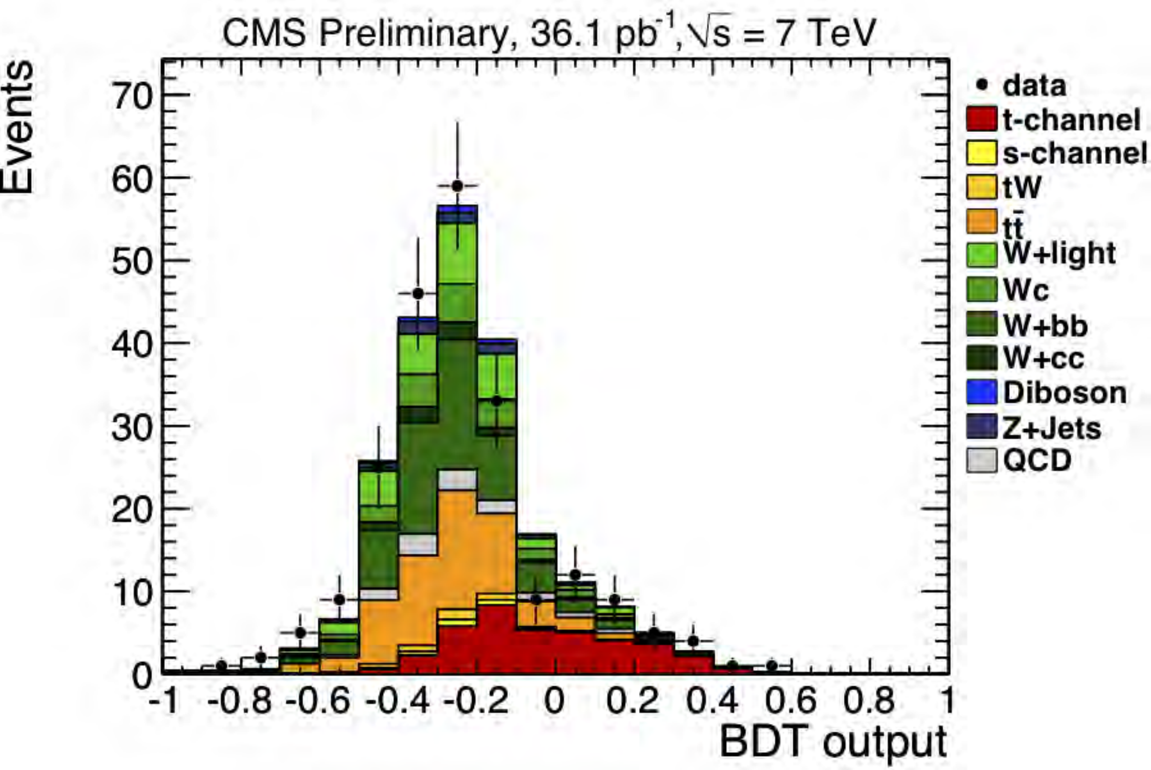
Single Top at LHC

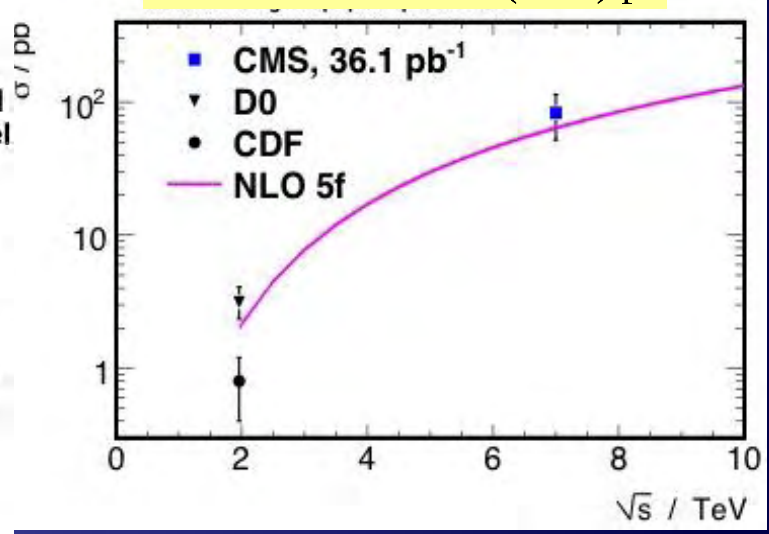
t channel
(σ ≈ 62 pb @ 7 TeV)



Cut based analysis using angular information!

s = 83.0±29.6±9.1(lumi) pb





NICE!

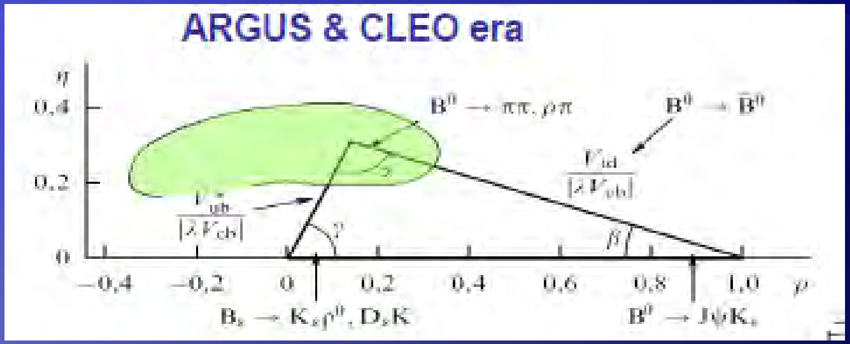
Some Personal Comments

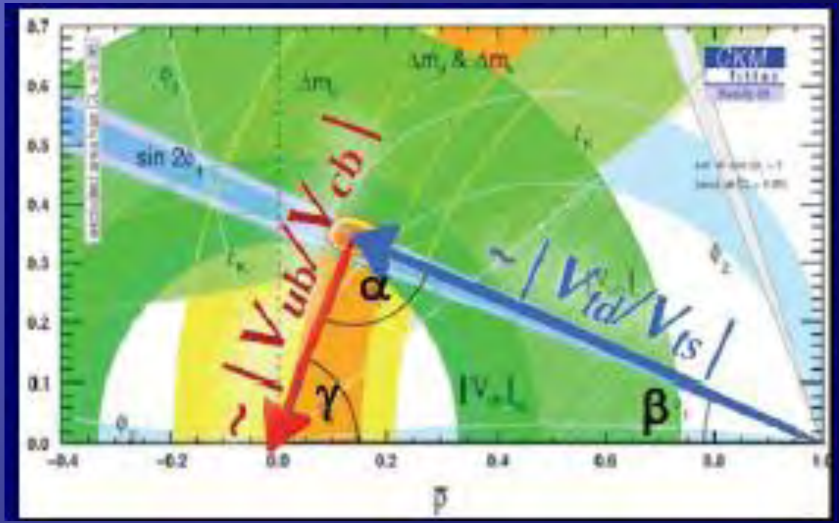
- Even when you do collider physics for a living, a conference forces you to step back and take stock in what we as a community have accomplished. Impressive!
- The Tevatron has taken us far in understanding the Standard Model but has sadly not been able to look beyond and peel back the next layer in the onion of understanding. Now it's the LHC's turn!
- The legacy of the Tevatron will be in its discovery of the top quark and defining its properties, W&Z physics and perhaps that one can do serious b physics in a hadron collider environment. It is also playing a critical role in the Higgs story.
- The Tevatron has laid the groundwork in terms of sophistication of its physics object algorithms and analysis techniques. The Tevatron has shown us to never give up. (single top, W mass precision, Oscillation frequency in B_s) just to name a few
- The LHC analyses being shown are remarkable. Learning from the Tevatron and then taking this sophistication to the next level already. The detectors are mind-boggling and performing extremely well. If NP is there to be found – LHC WILL!
- I believe that the slow LHC start has not hurt so much. The impressive performance of the detectors, algorithms and agreement to MC is remarkable – a year w/o that distracting data didn't hurt. ☺ A tribute to LHC physicists for staying focussed

Flavor Physics

Flavor: CKM Parameters

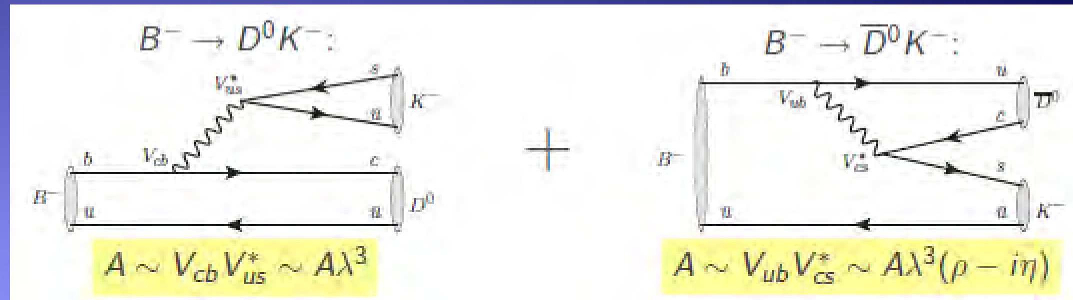
- B factories have been a remarkable success over the past decade – really refining our understanding of the Unitarity Triangle.
- The easy components are done and now making good progress on the harder triangle elements
- Super B Factories now approved in Japan and Italy have given new life to BaBar and Belle





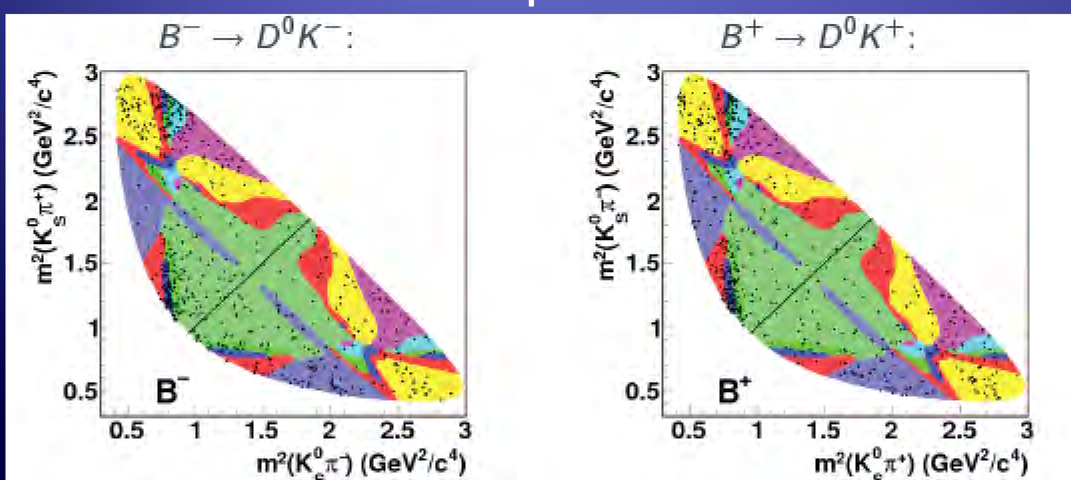
The overarching goal remains the same – to over-constrain the unitarity triangle in order to be sensitive to new physics in the loops.

BELLE

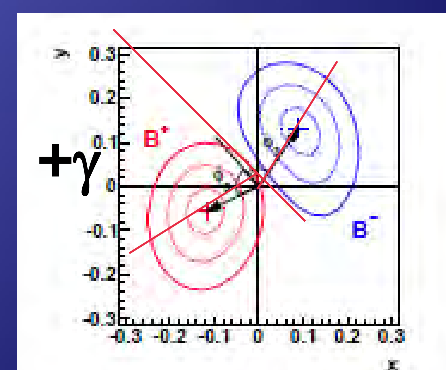


$B^{\pm} \to D K^{\pm}$

- The Angle γ has been very hard to measure!
- Belle (and BaBar) have nearly done the impossible
- The measurement of γ comes from the interference of two diagrams
- Use final states accessible from both D and D (Ksπ+π- and KsK+K-)
- 722M b-bbar pairs were considered!!! Measured the strong interaction and phase!
- Used binned dalitz plot and count events in each one

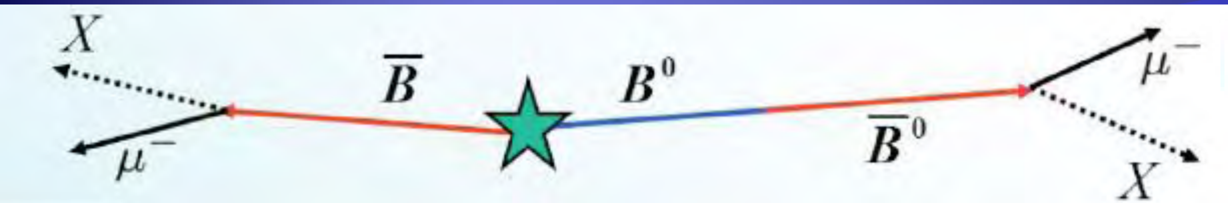


+γ



$$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.2 \pm 4.3)^\circ$$

Dimuon Charge Asymmetry



Decay of B tags its flavor

- Measure: $A_{sl}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$

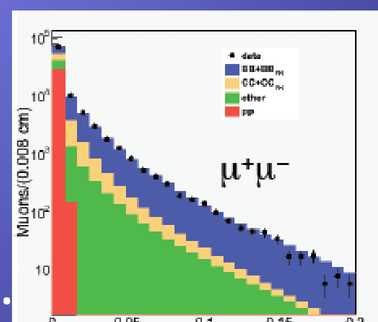
- D0 6.1 fb^{-1} analysis yields:

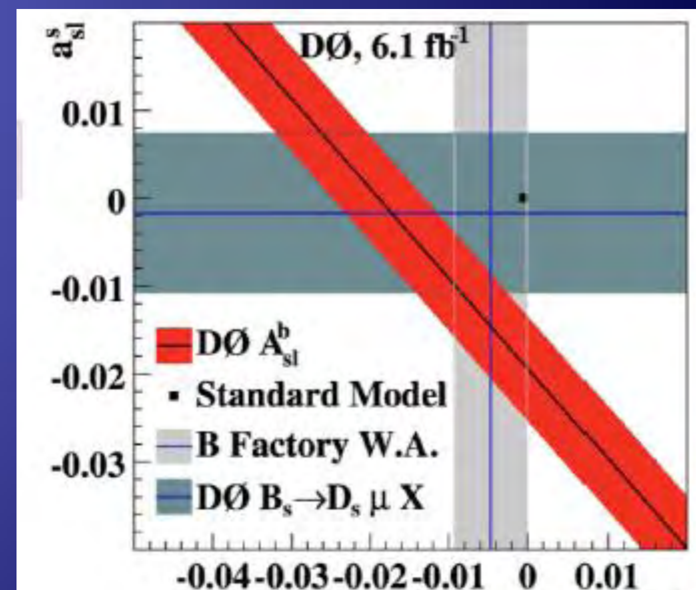
$$A_{sl}^b = (-0.957 \pm 0.251(stat) \pm 0.146(syst))\%$$

- SM prediction:

$$A_{sl}^b(SM) = (-0.023^{+0.005}_{-0.006})\%$$

using prediction of a_d and a_s from *A. Lenz, U. Nierste, hep-ph/0612167*





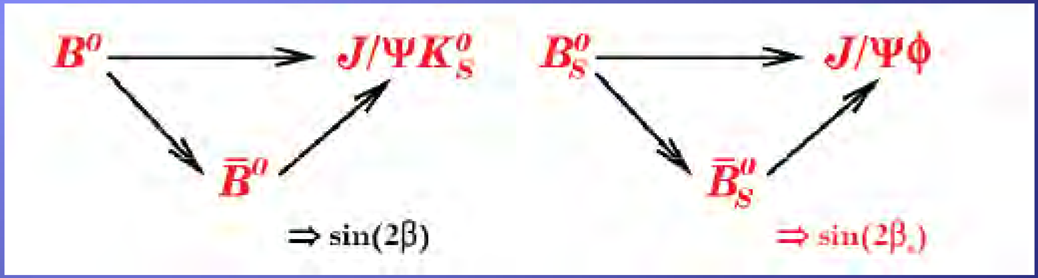
- CDF Walking before it runs…
- Measuring Chi-bar as first step

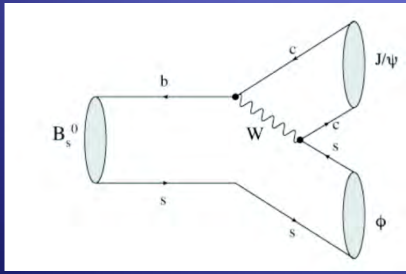
Defined as: $\overline{\chi} = \frac{\Gamma(B^0_{d,s} \to \overline{B}_{d,s} \to l^+ X)}{\Gamma(B_{all} \to l^{\pm} X)}$

- Result: $\overline{\chi}$ = 0.126±0.008 (LEP: 0.126± 0.004)

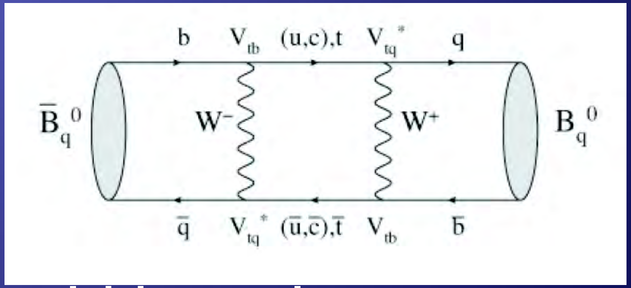
CP Violation -LHCb

- Analogous to neutral B0 system. CP violation in B_s system is accessible through interference of decays with and without mixing.





- penguin diagrams

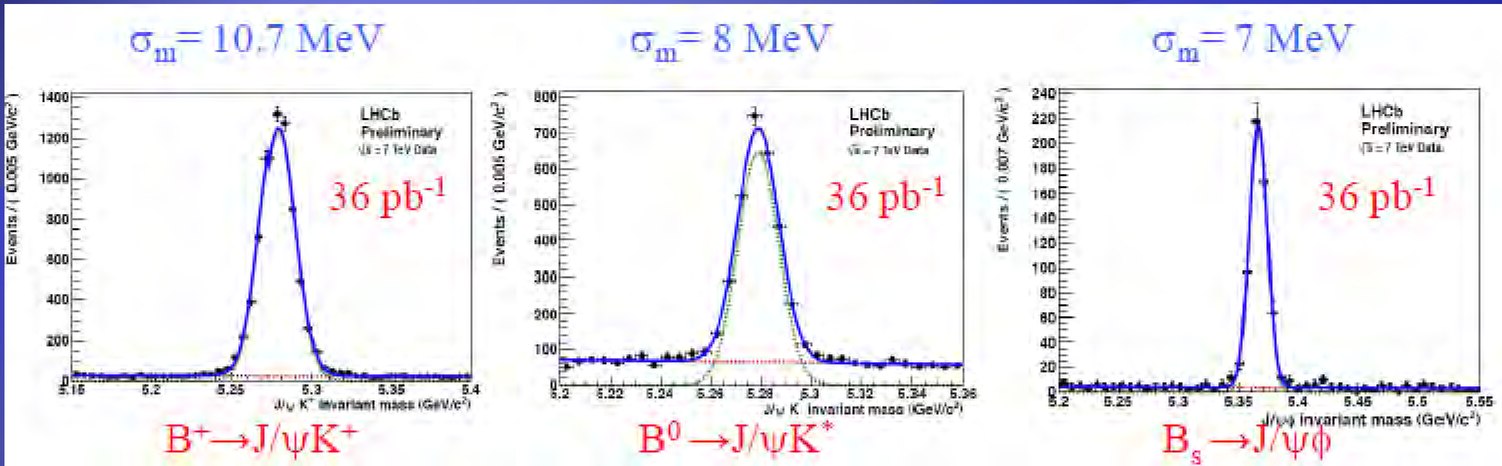


dominated by SM contribution could have large NP contribution

- *CP* violation phase β_s in SM is predicted to be very small, $O(\sin^2\theta_C)$
- New physics particles running in the mixing diagram may enhance β_s

CP Violation

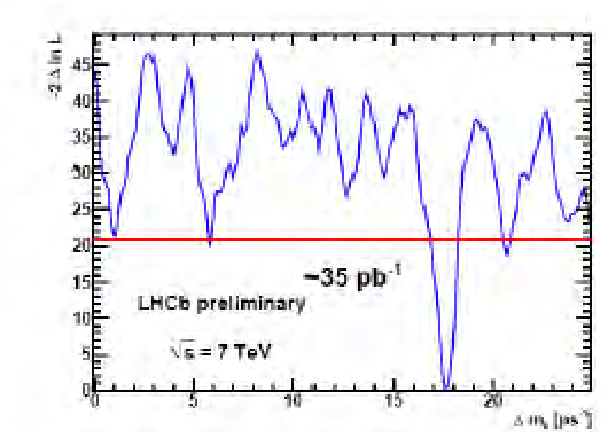
Basic Ingredients



Initial flavor of the B can be inferred

- **Opposite side tagging – products of the other B**
- **Same side tagging – fragmentation of particles from signal B**

LHCb: $\Delta m_s = 17.63 \pm 0.11 \pm 0.04\ ps^{-1}$
CDF: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ ps^{-1}$
(PRL 97, 242003)



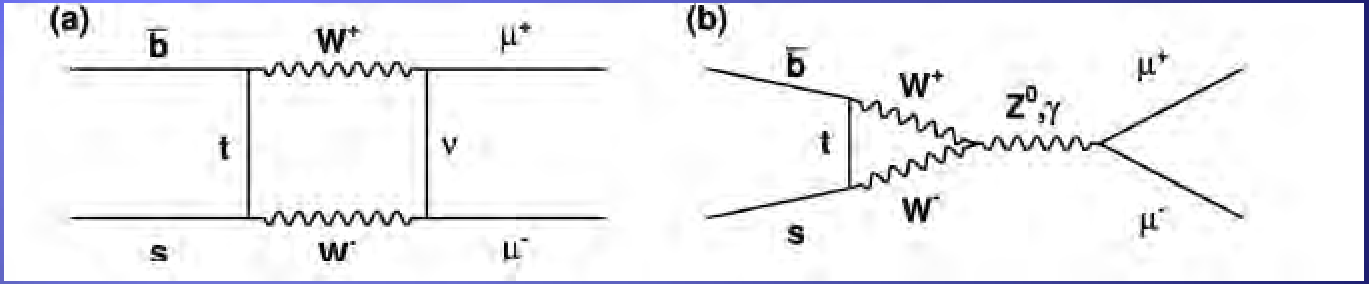
Redline: evaluated at infinite oscillation frequency

4.6 σ significance

Astonishing level of sophistication so soon after data taking! Speechless!

$B_s \to \mu\mu$

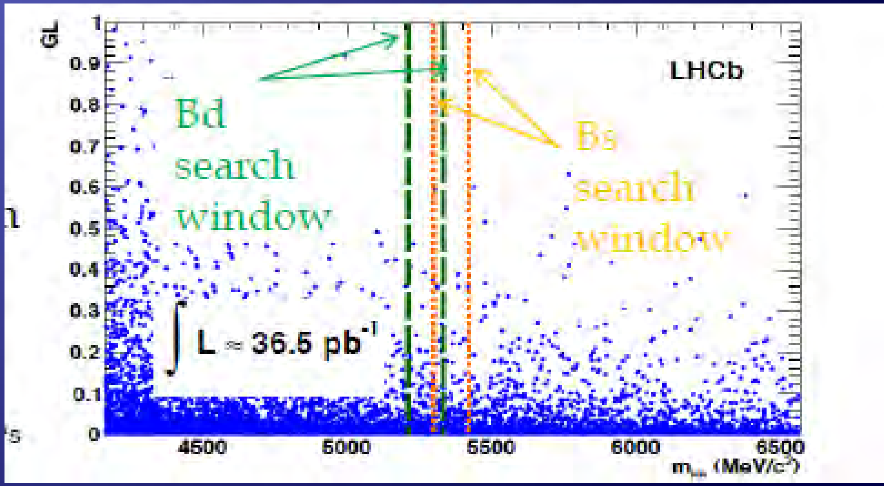
- $B_s \to \mu\mu$ is highly suppressed in the SM
- Some new physics models enhance the branching fraction significantly



Analysis Strategy is Classify B_s/d -> μμ in 2D bins

- Invariat mass of di-muon pair
- Multivariable discriminant that is flat for signal and pushes background to zero

$BR(B_s \to \mu\mu) < 4.3\ (5.6)\ \ 10^{-8}$ @ 90 (95% CL)
$BR(B_d \to \mu\mu) < 1.2\ (1.5)\ \ 10^{-8}$ @ 90 (95% CL)

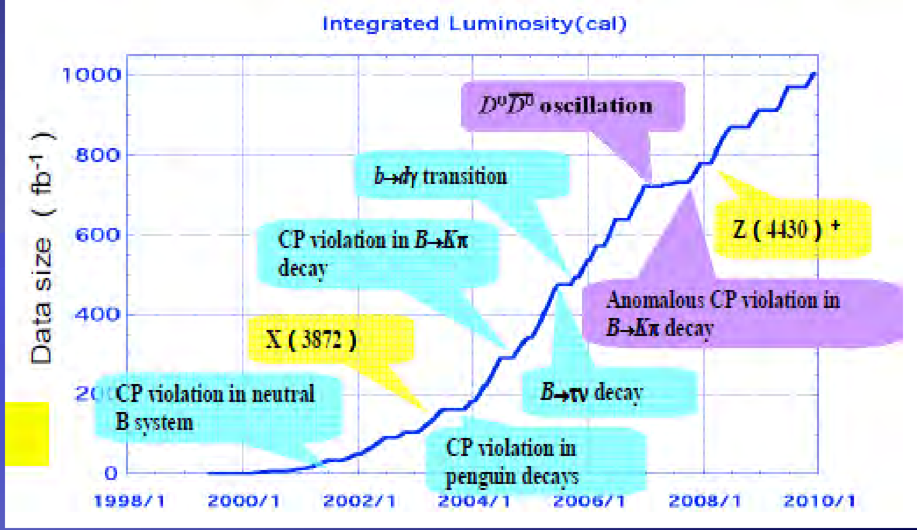


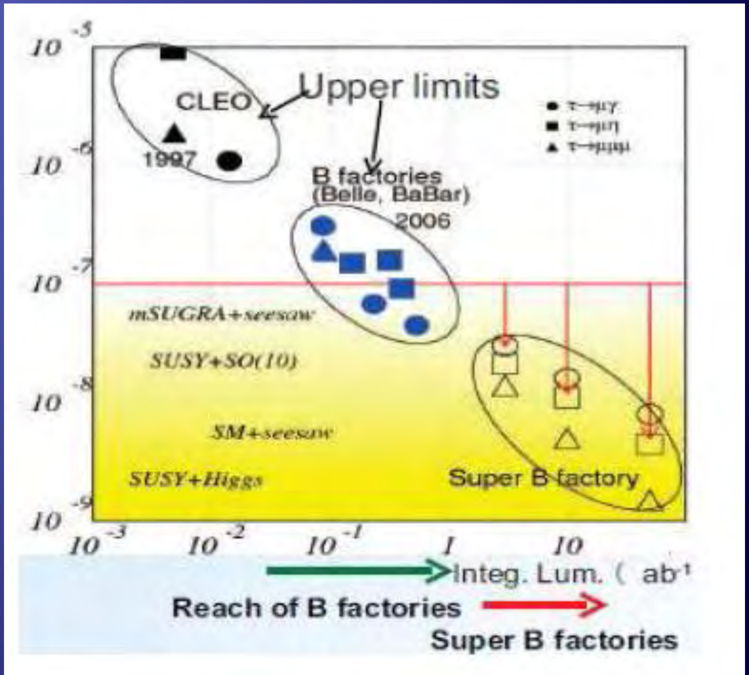
Already Comparable with Tevatron

Next B Factory

Examples of BELLE II Physics Goals

- Measure UT (angles & sides) *with much better precision*. If new phases contribute to any measurable → inconsistency of UT.
- CPV in $b \to sqq$ *vs* $b \to ccs$: Extra new phases in the penguin loop makes CPV parameters different. Typical accuracy in ΔS $\sigma \approx 0.02-0.03$ for $B \to K^0 \phi$ ($K^0 \eta'$) with $50ab^{-1}$
- search for CPV in radiative decays $B \to K^{*0}(K_S^0 \pi^0)\gamma$ is a test of right-handed current in the penguin loop (CPV ≠ 0).
- Rare decays $b \to sg(\gamma)$, $B \to \tau\nu$. Even Br's constrain mass of NP
- Electro-weak penguins $b \to s\mu\mu$, see, $s\nu\nu$: Br's, Q^2-distribution, FB asymmetry are sensitive to NP
- Rare tau decays
- Search for new particles, hadron spectroscopy
- Many more (see A.G. Akeroyd et al., arXiv:1002.5012)

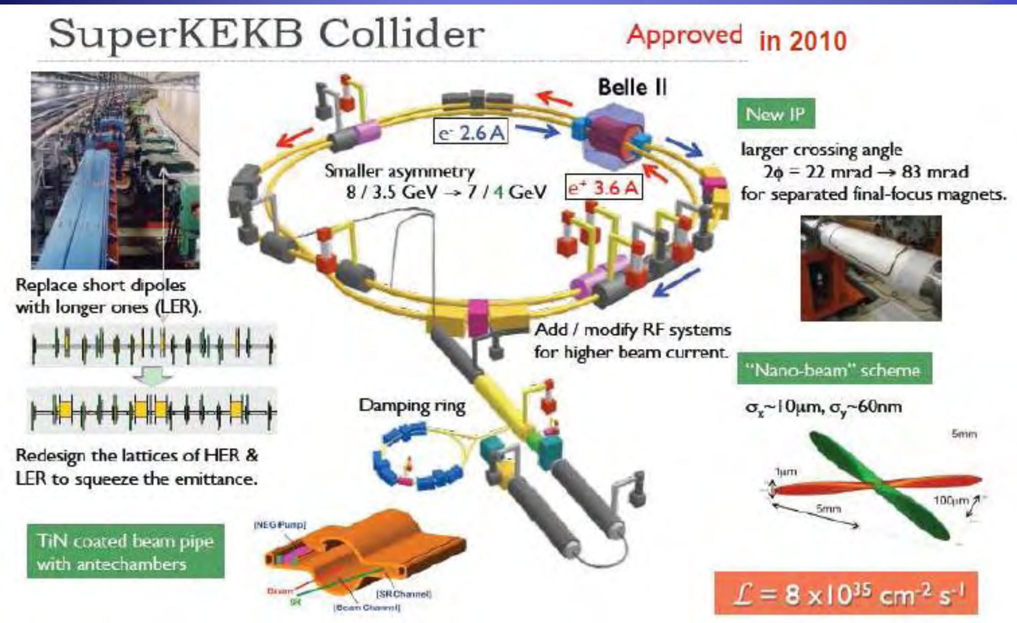




50ab^{-1} by 2022!!!
Initial Lum. of 8x10^{35} /cm^2/sec

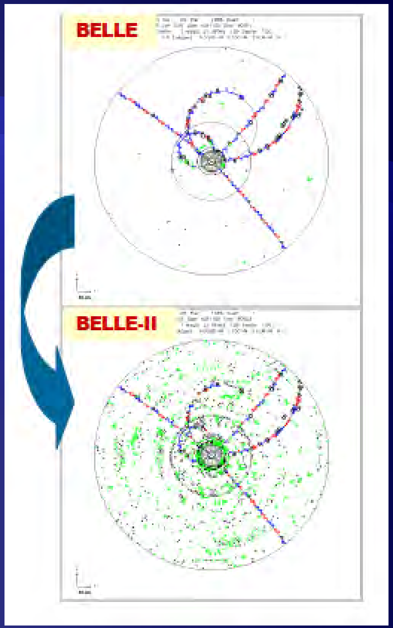
Mind-boggling!!!

Next B Factory

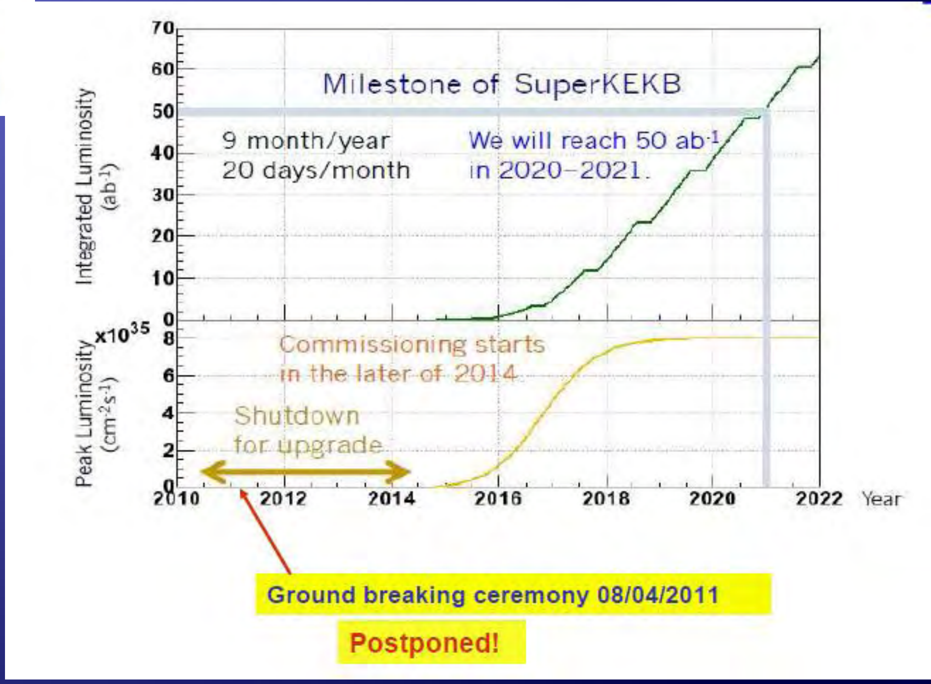


Detector upgrades

- Higher event rates
- Improved particle Id
- hermiticity
- Coping with radiation



1. Replace short dipoles with long ones
2. Redesign lattice to squeeze emittence
3. Provide for larger crossing angle
4. Nano beams 10's of microns wide

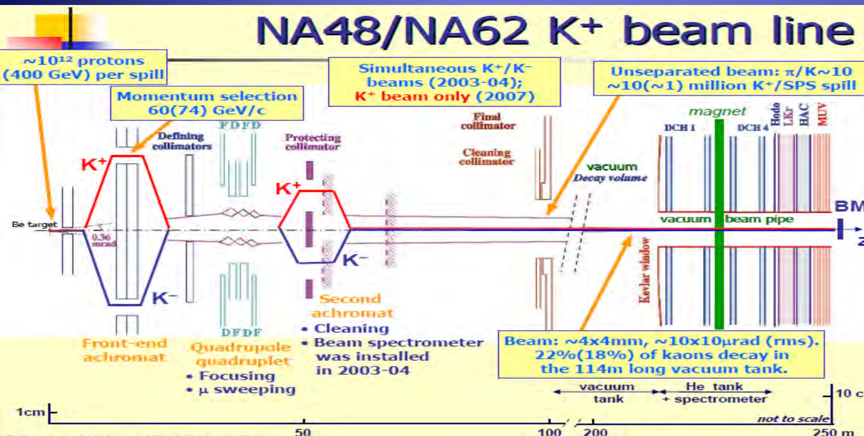


Perspective

- I have never worked in b-physics. I think if I started young – I would have liked it. I blame Professor Ferbel!!!
- I marvel at the precision of the measurements from the b-factories and what was once considered impossible is now routinely done. There is a wealth of knowledge out there!
- LHCb like ATLAS and CMS is remarkably advanced and already amploys quite sophisticated analysis techniques for such a young experiment.
- Looks to me like measurements in the last few years at the b-factories are getting incrementally better and the big gains have been in neglected channels
- Judging from my Tevatron experience in Run II, to make significant progress – is luminosity sufficient or do we need a step in energy?

Neutrino’s

Lepton Flavor



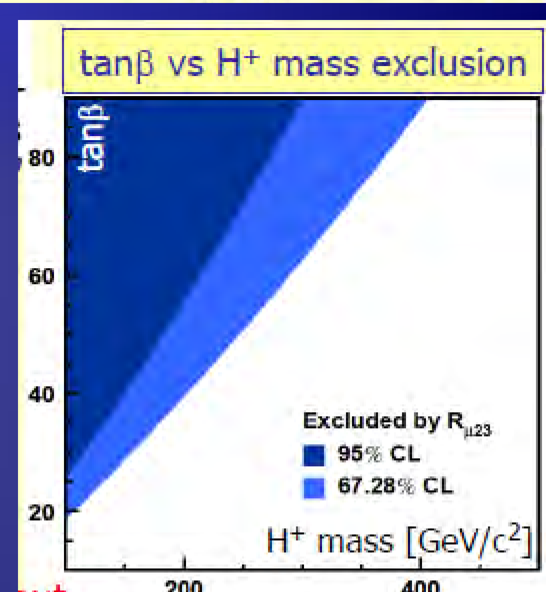
To reduce uncertainties of hadronic and EM corrections to $K_{\mu 2}$:

average from nuclear β decay PRC79 (2009) 055502

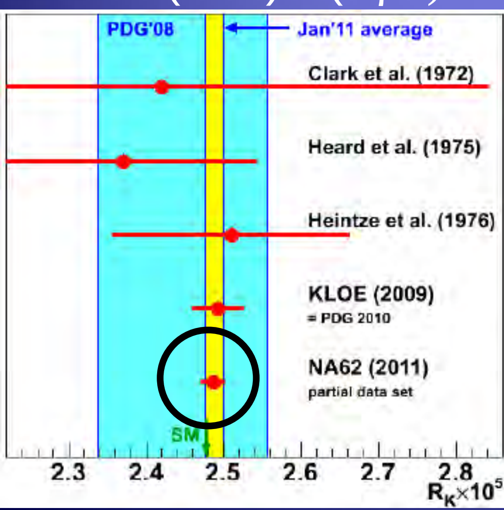
$$R_{\mu 23} = \left(\frac{f_K/f_\pi}{f_+(0)}\right)^{-1} \left(\left|\frac{V_{us}}{V_{ud}}\right| \frac{f_K}{f_\pi}\right)_{\mu 2} \frac{|V_{ud}|_{0^+\to 0^+}}{[|V_{us}| f_+(0)]_{\ell 3}}$$

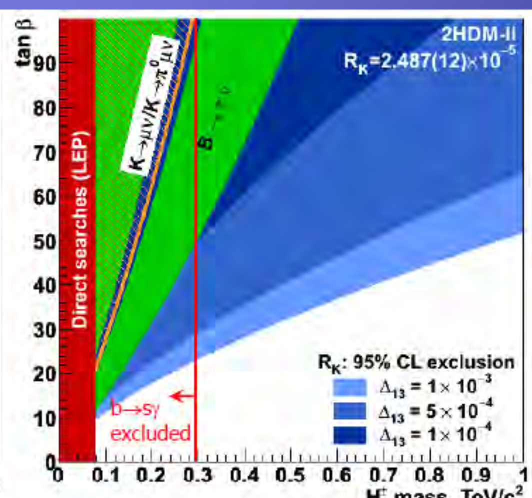
Lattice QCD input — Measured with $K_{\mu 2}/\pi_{\mu 2}$ — Measured with $K\to\pi\mu\nu$

Measured $R_{\mu 23}$ and setting very stringent bounds on charged Higgs



Final Measurment of Rk with 40% of the data.
Rk = B(Ke2)/B(Kμ2)



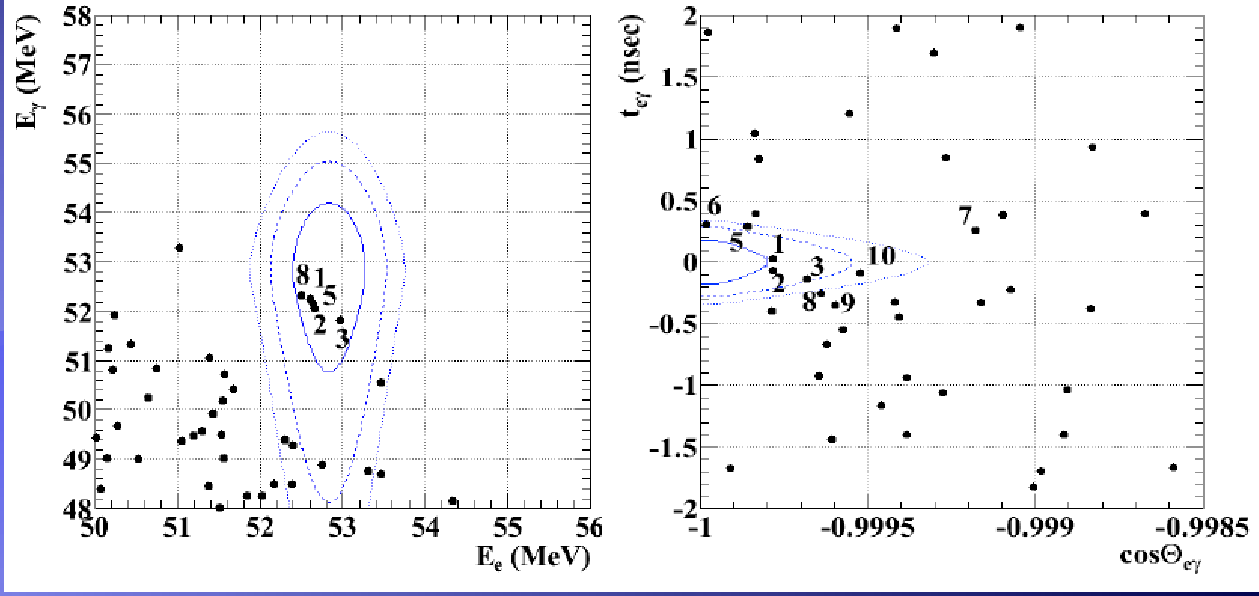


$R_K = (2.487 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$= (2.487 \pm 0.013) \times 10^{-5}$

In Excellent agreement with SM

Studies of lepton universality violations are setting world class limits on new physics beyond the SM.

Lepton Flavor (2)

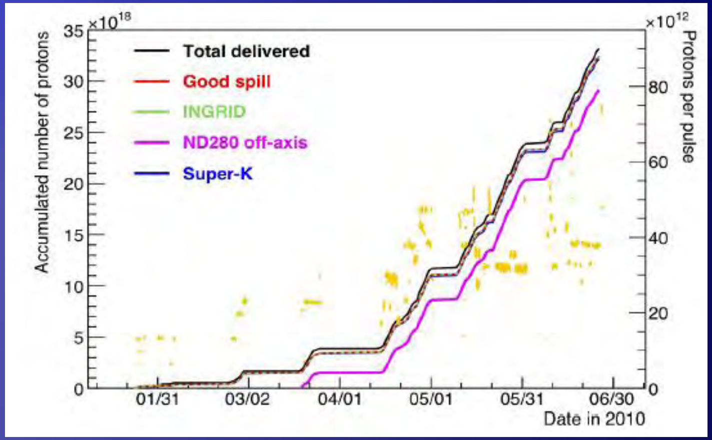


- MEG Experiment
  - Since neutrino's mix, so should charged leptons. SM predicts this to be small $<10^{-45}$
  - Looking for muon -> electron + gamma
  - If found, sure indication of new physics
  - Presented 2 months of 2009 data. Analysis of 3 mo 2010 data run very mature, ready this summer. Expected 09 sensitivity of a few $6*10^{-12}$ at 90% C.L.
  - Goal is $\sim10^{-13}$

BR < $1.5 * 10^{-11}$ @90% C.L. (preliminary)

Neutrino Parameters

- T2K – searching for a ν_e appearance in a ν_μ beam on a 295 km baseline
- Initial 6mo Run in 2010



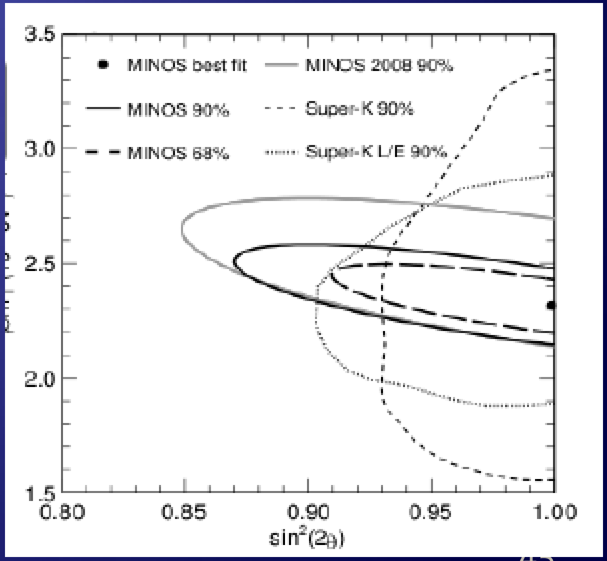
3.23×10^{19} POT = 15.5 kW$\times 10^7$ sec

• 90% C.L. sensitivity for $\sin^2(2\theta_{13}) \sim 0.35$

- 8 ν_μ observed at SK

exclude $\sin^2(2\theta_{13})$>0.5 (normal hierarchy) a

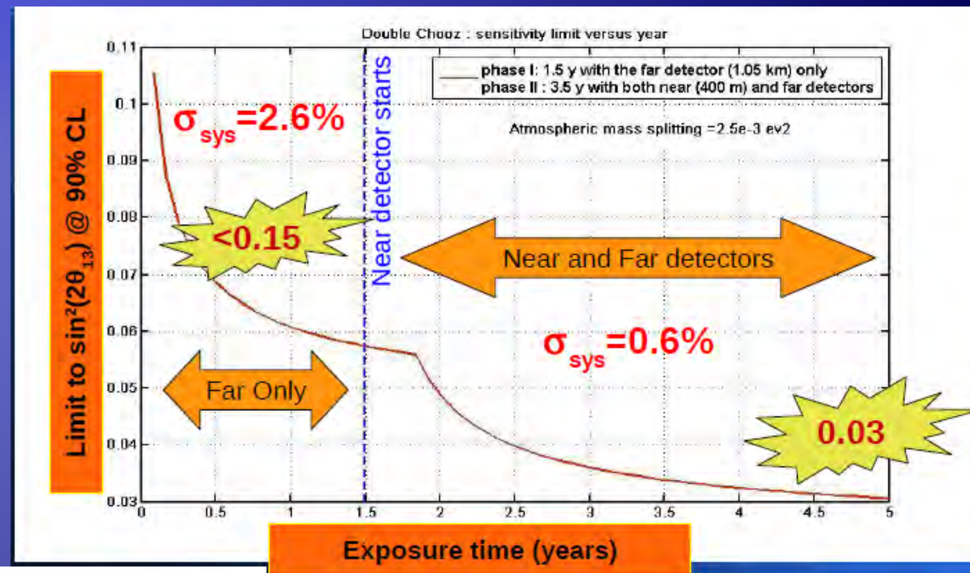
90% C.L.



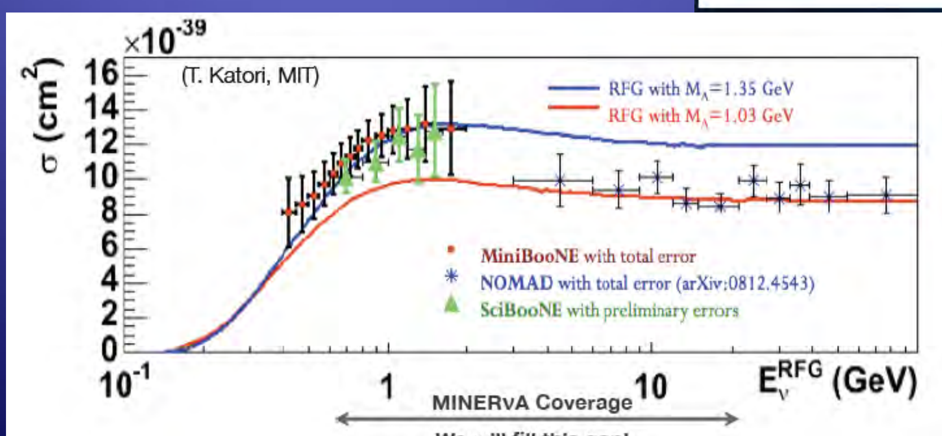
- Sciboone completed its data run to measure neutrino and anti neutrino cross sections. First results out.

Neutrino Parameters

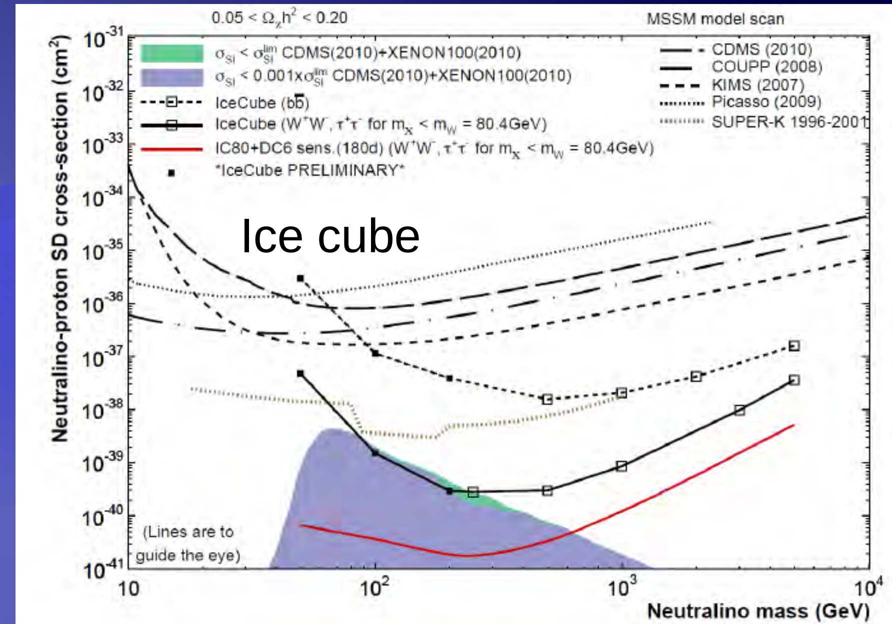
- Double Chooz – will search for $\sin^2(\theta_{13})$ down to 0.03.
- Just starting! Far detector built and filled, commissioned in early 2011.



- Detector yields look good and stable performance
- Near detector Ready in 2012
- Minerva – to measure nucleus neutrino XS. Starting up now at fnal



Neutrino Telescopes

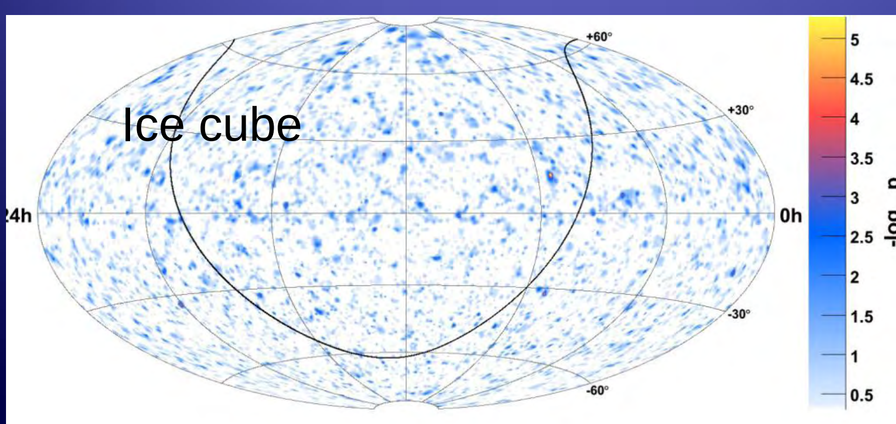


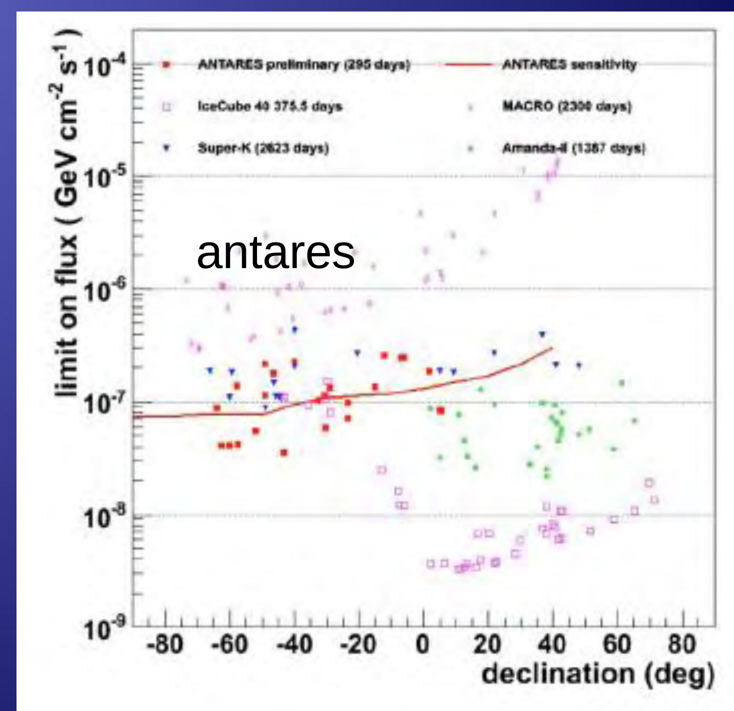
WIMPs can be trapped in the interior of the sun and ultimately will annihilate.
"Hard"= $\chi\chi \rightarrow$ WW or "soft"= $\chi\chi \rightarrow$bb

Neutrinos from W's and/or b's can be observed in deep detectors on earth like Ice Cube and Antares

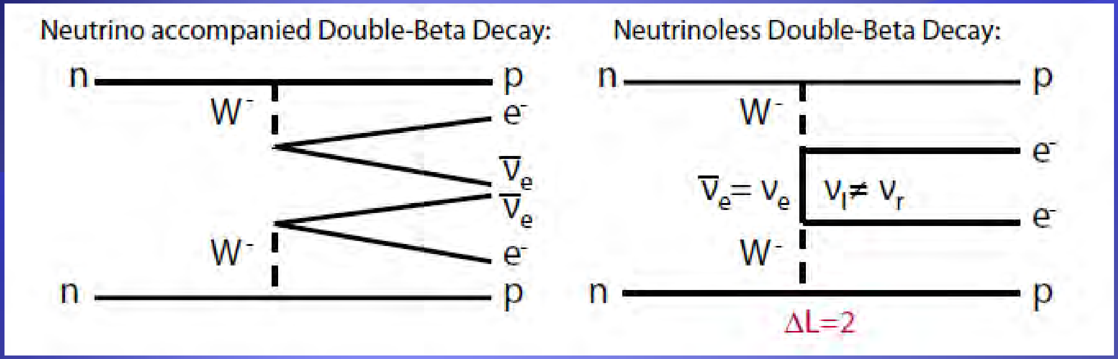
Both Ice Cube and Antares have performed searches for point like sources

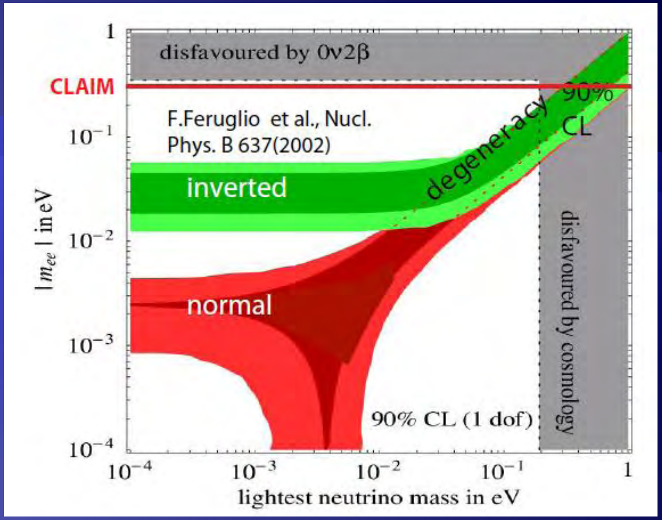
No Significant sources found!





Double β Decay





- IF observed, η is a majorana particle and we get information on absolute mass scale
- Next generation experiments (CUORE, SuperNEMO, EXO, GERDA) aim at mass limits in range 40 – 100 meV, thus getting into the range of the inverted mass pattern.

- GERDA came on line in June 2010 with first String
- Curently doing background runs
- Bckg at 0.055 cts/(keV kg y)
- Phase 1 to start soon
- Epected phase 1 sensitivity of 230-390 with a phase 2 goal of 90 mev

Personal Thoughts

- Entering the era of Intensity Frontier – neutrino facilities are ramping up all over the world
- The Major Issues facing us are
  - What are the masses of the neutrino’s
  - Are neutrinos majorana or dirac?
  - Discovering CP violation in this sector
  - What is the value of θ_{13}
- Future expts and facilities are on hold until we know θ_{13}
- Precision neutrino physics is here and will only get better. Neurtrino’s will play an important role along with the LHC and potentially lepton collider in understanding our world

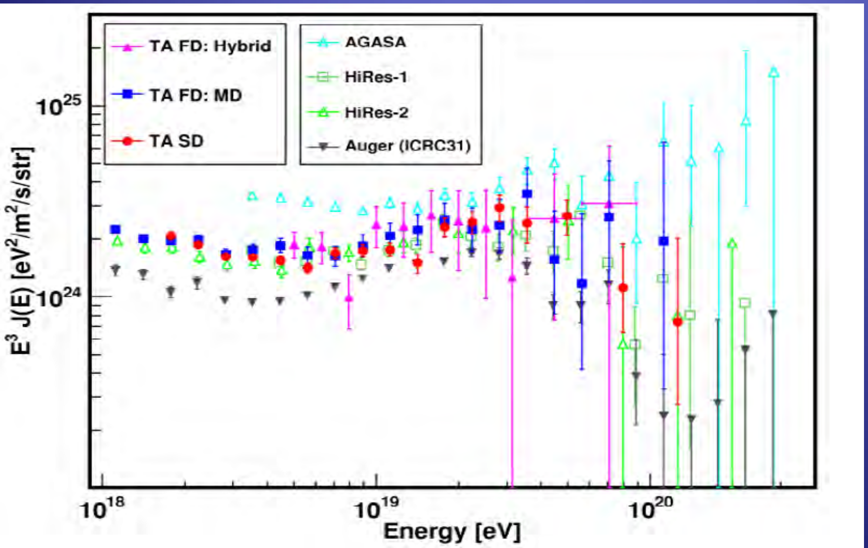
Cosmic Frontier

Large Array Detectors

Large Array Detectors like Telescope Array Experiment and Pierre Auger are Seeking to characterize ultra high energy cosmic ray

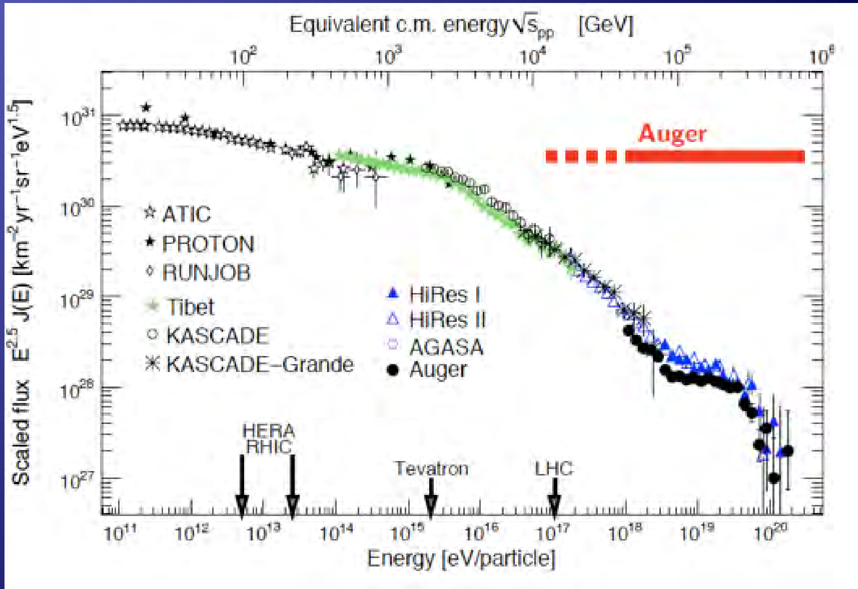
Telescope array experiment

- Operational in 08 with trigger upgrades in 08 and 10.
- Hybrid spectrum consistent with HiRES



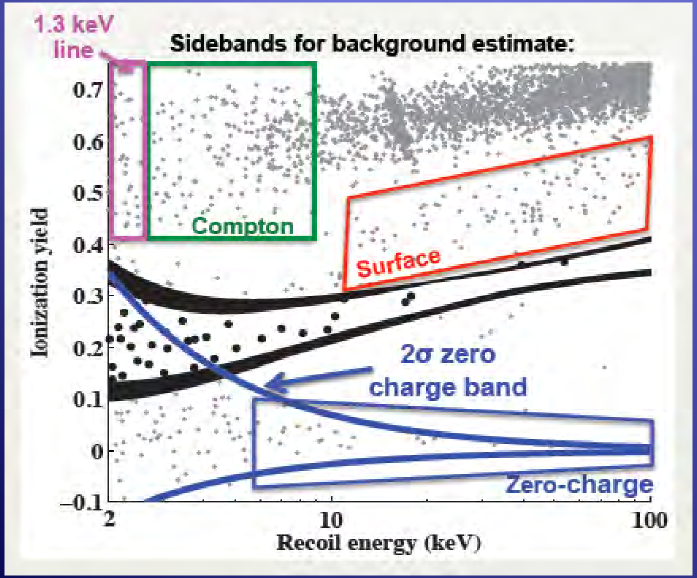
Pierre Auger

- Much improved energy spectrum
- Sharp ankle at 4ev, supression of flux above 50Eev
- Consistent with GZK Supression

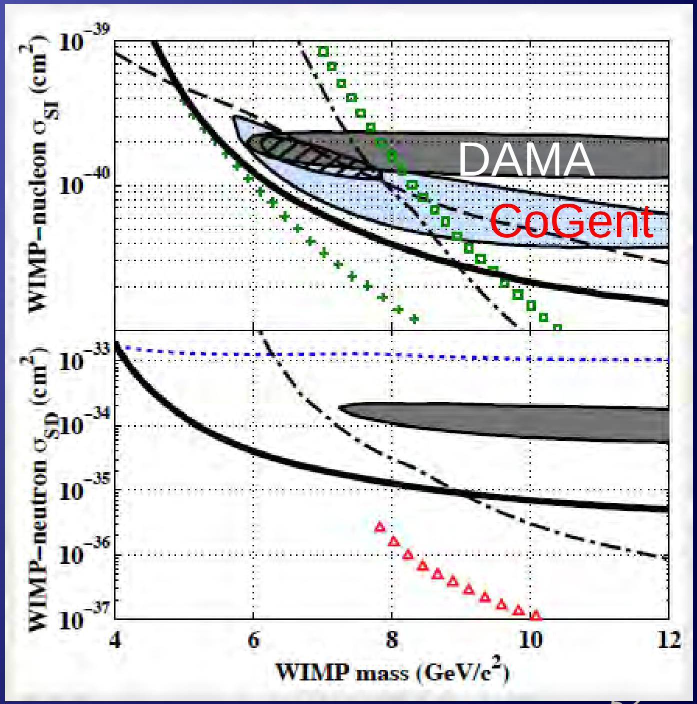


Dark Matter Searches

- We have learned from cosmological observations that DM is “cold” do to heavy particles
- CDMS showed an exposure with 241 kg days taken between 2006 and 2008 in Soudan
- Cuts maximize sensitivity to nuclear recoil while minimizing bckg.
- Conservative (very) analysis approach where known events were NOT subtracted



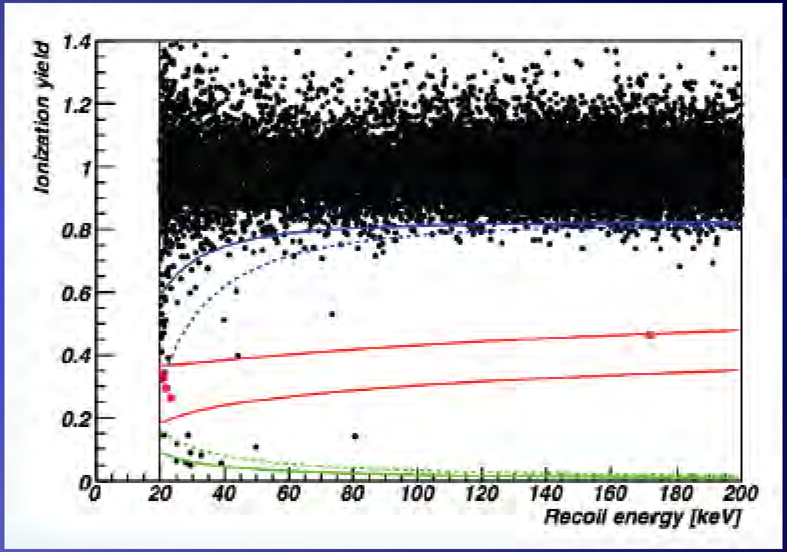
Wimp Nucleon 90% Exclusion



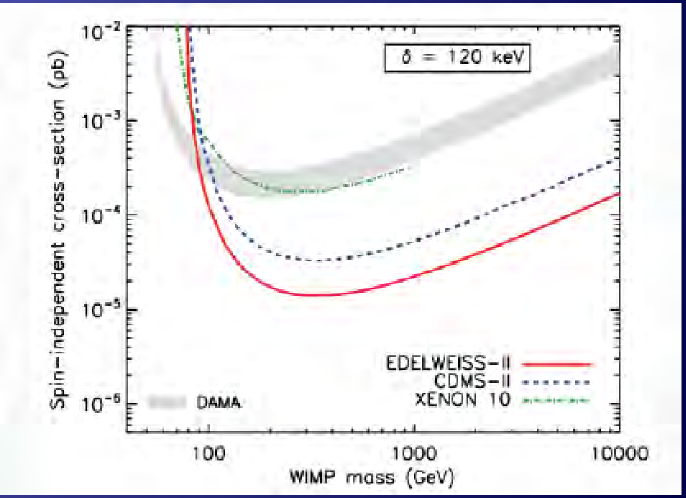
Signal in CoGent not seen in CDMS

Dark Matter (2)

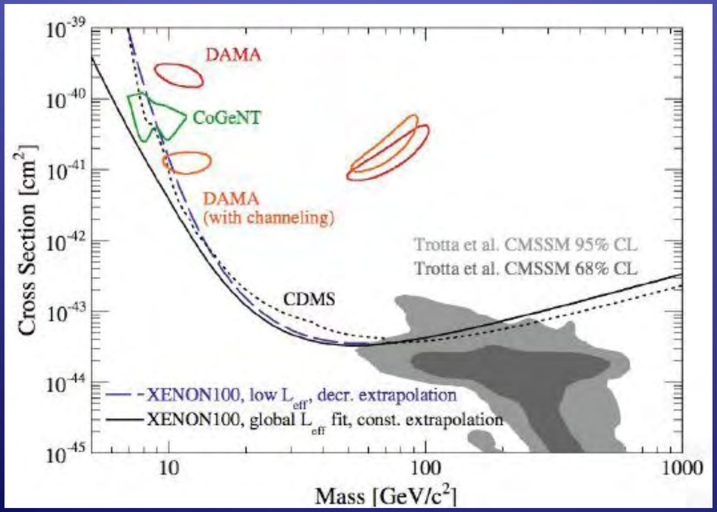
- Edeleweiss presented a 384 kg/d result
  - 5 events in WIMP band: 20.8, 21.1, 21.8, 23.2, 172 keV
  - Expected background: < 2.9 evt



DAMA allowed region excluded for $M\chi$ > 90 GeV (90%CL)



- Nobel liquids in part due to their ease in scalability and background rejection are at the forefront of sensitivity

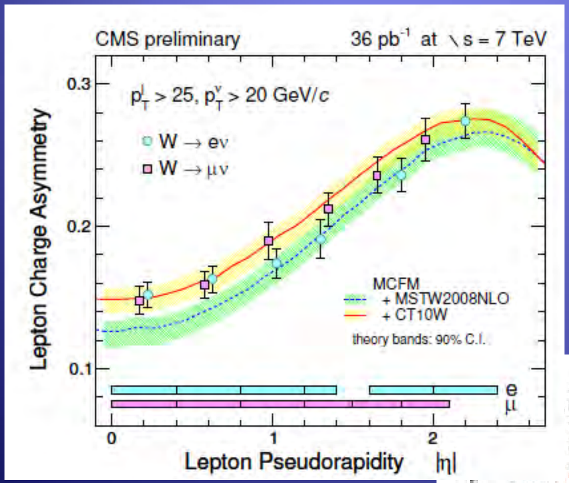


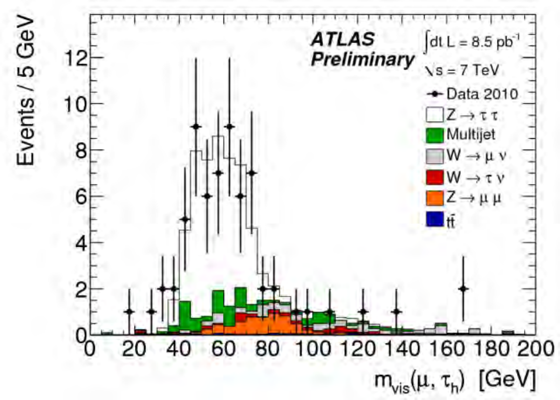
Personal thoughts

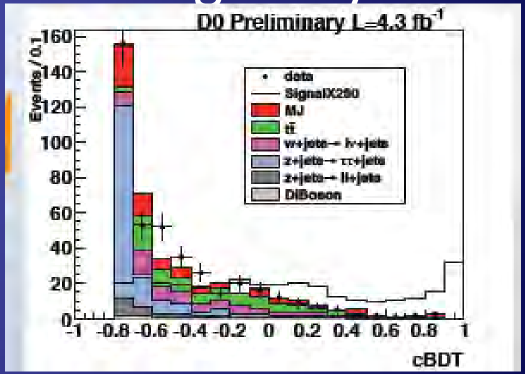
- Investigation of dark matter is a joint effort between astrophysical and particle physics experiments
- Masses from accelerators will provide important interpretation of DM measurements.
- Dark Matter Check list!
  - Observe a positive signal in 2+ detectors
  - Deduce velocity dependence of DM candidates in local environment
  - Determine how many types of DM is out there
- We are due for a break here!!!

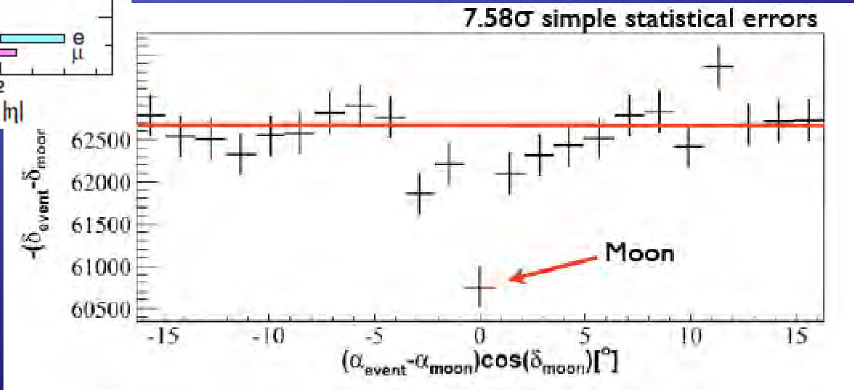
Young Scientist Forum

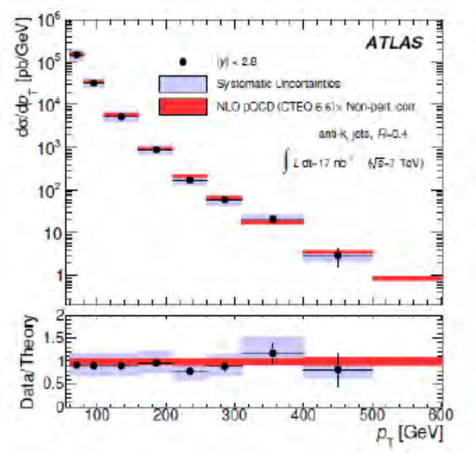
- I very much enjoyed the YSM talks. They were very well presented and very informative. Its amazing how sophisticated you all are compared to when I was in your shoes… I learned something -- and I hope you did in putting these presentations together. Some plots that caught my attention.











What a Difference a Year Makes
and "will" make!!!

Conclusions.

- In this meeting, we have taken a few important steps in answering the big questions ahead of us
- We have also demonstrated that the tools are working well to get those answers in the next few years
- I would like you all to join me in thanking the organizers for a very productive, stimulating and enjoyable meeting
- And a big thank you to all the speakers for a wonderful set of very clear presentations

Private Plea…

- Particle Physics has in the past has one of the spearheads for growth
- Many new technologies have come out of what we do that has been of great benefit to society
  - Not to mention a better understanding of the world we live in
- We can continue to be that spearhead into the future
- PLEASE don’t take our funding for granted – we are not entitled – lobby for it! These are tough times

Moriond EWK

- Not sure who gets more out of this conference – attendee's , speakers, or tevatron spokespeople…
- We use this conference as an important target to produce updated results – we start our planning for it back in September.
- Thank you – people want to come here – and we try hard to put on a good show!