Experimental Summary Moriond EWK 2014

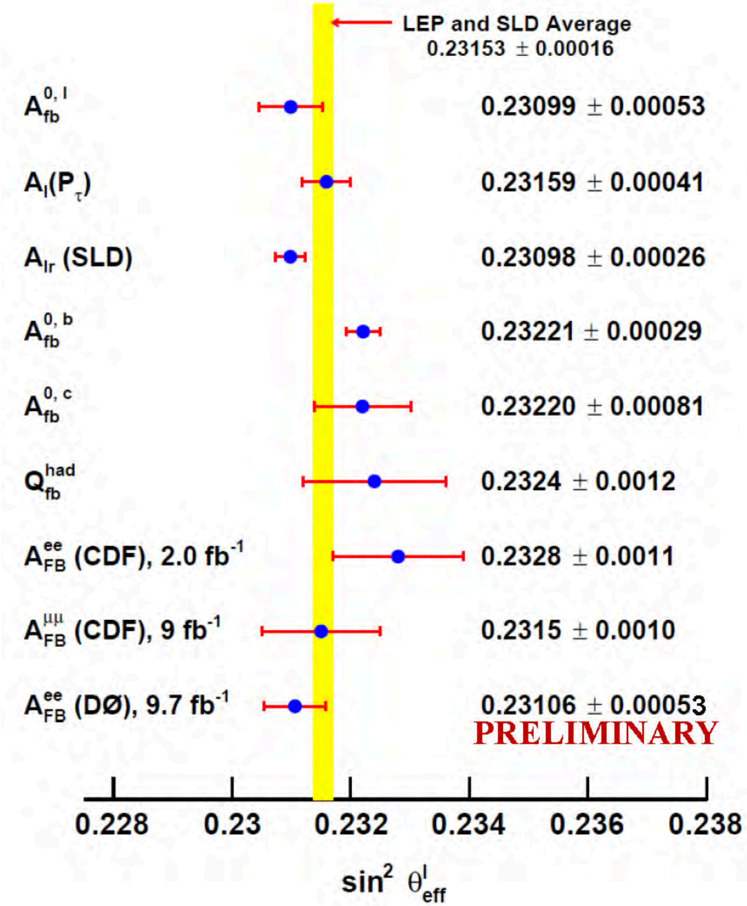
- Impossible task to summarize 82 (25) outstanding talks…
- Provide highlights and trends, starting from SM and moving in widening spirals outwards…

- Standard Model Physics:
  - Electroweak and QCD
  - Very Heavy Flavor (t)
  - Heavy Flavor (c, b)
- Neutrino Physics
- Particle Astro/Dark Matter/Cosmology
- Physics of Scalar Boson
  - Now an unusual mix of SM and BSM analyses
- Searches for New Physics
  - SUSY and Exotica

Disclaimer: all selections and mistakes are entirely the property of the speaker !

SM W/Z Physics: Z A_{fb}

- CDF and D0 have updated their measurements of Z A_{fb} using full Tevatron statistics (9.2/9.7 fb^{-1}) (*Quinn*).



CDF uses di-muons only, |y|<1

D0 uses di-electrons only, |η|<3.2

Both expect to provide second channel soon, and to perform combination. Potential to approach individual LEP/SLD precision?

Dilution effects much smaller at ppbar collider than LHC !

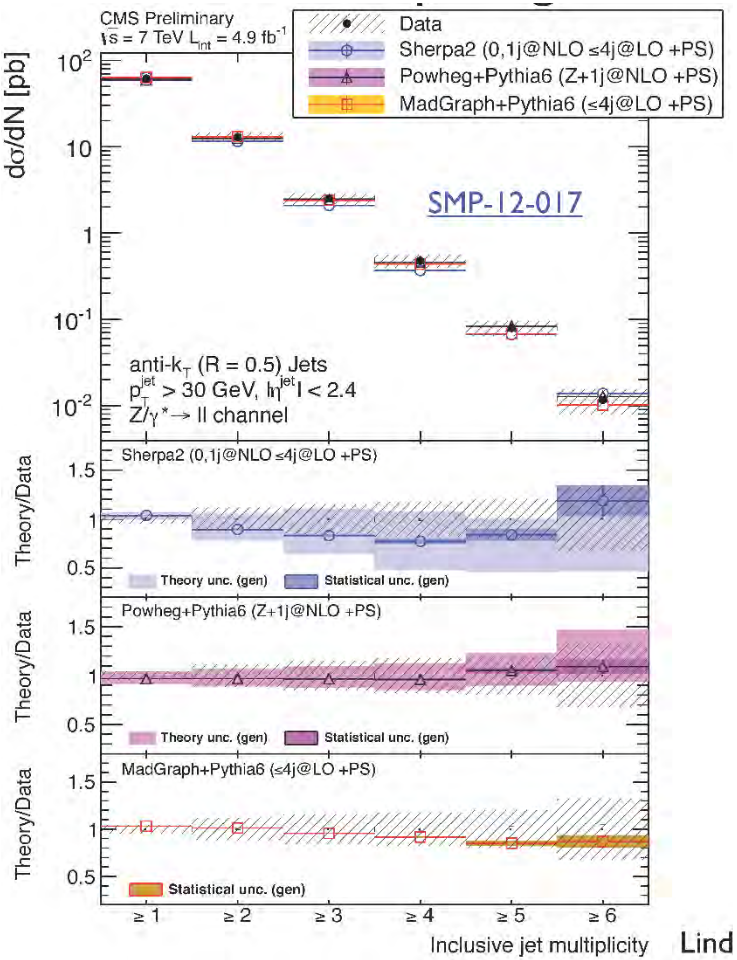
D0 result is now best from a hadron collider (was ATLAS 0.2297 +/- 0.0010).

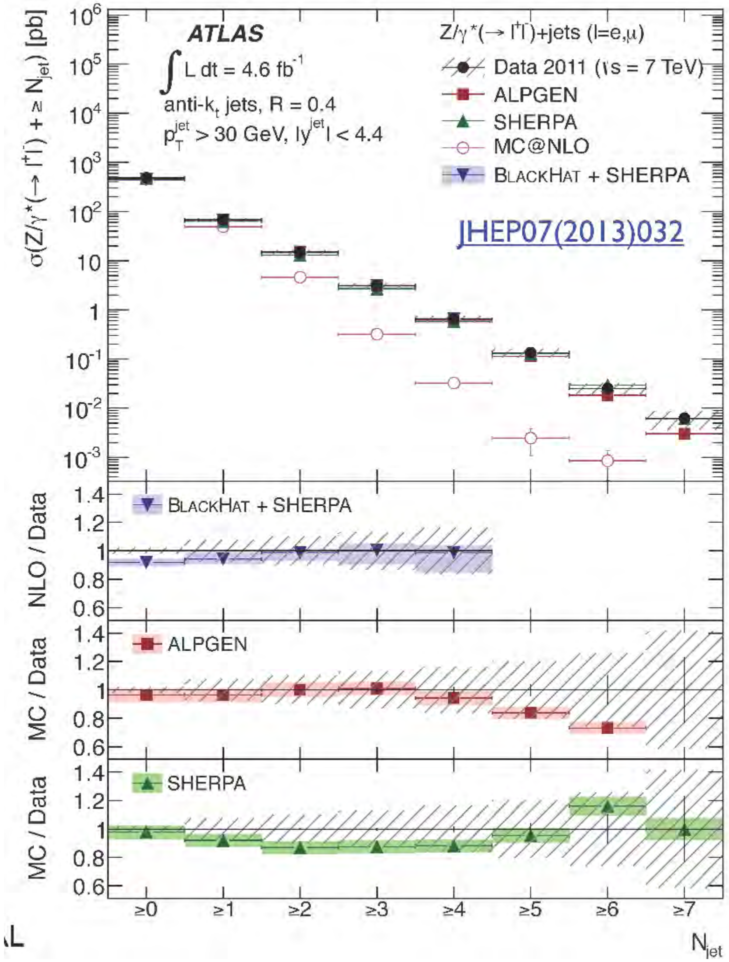
SM W/Z Physics: Boson+jets, Diboson

- **ATLAS and CMS have wide range of new W/Z measurements (*Gray*), including:**
  - W+jets: detailed QCD/Generator comparisons
  - W+charm: sensitive to PDFs (s density)
  - Z+Jets: detailed QCD/Generator comparisons (see next)
  - Z+b(b): cross-sections for Z+HF
  - Di-boson (VZ; Z -> bb and ZZ -> 2l2ν): cross-section, couplings
  - Anomalous couplings (aTGC, aQGC) for dibosons
- **Fundamental studies provide precision QCD tests, allow generator cross-checks and tuning, form basis for understanding SM backgrounds for BSM searches.**
- **Anomalous coupling measurements probe EWK sector and EFTs, complement studies now underway in Higgs sector. Major LHC measurement goal !**

SM W/Z Physics: Boson+jets, Diboson

- **Example: comparisons of ATLAS+CMS Z+jets:**

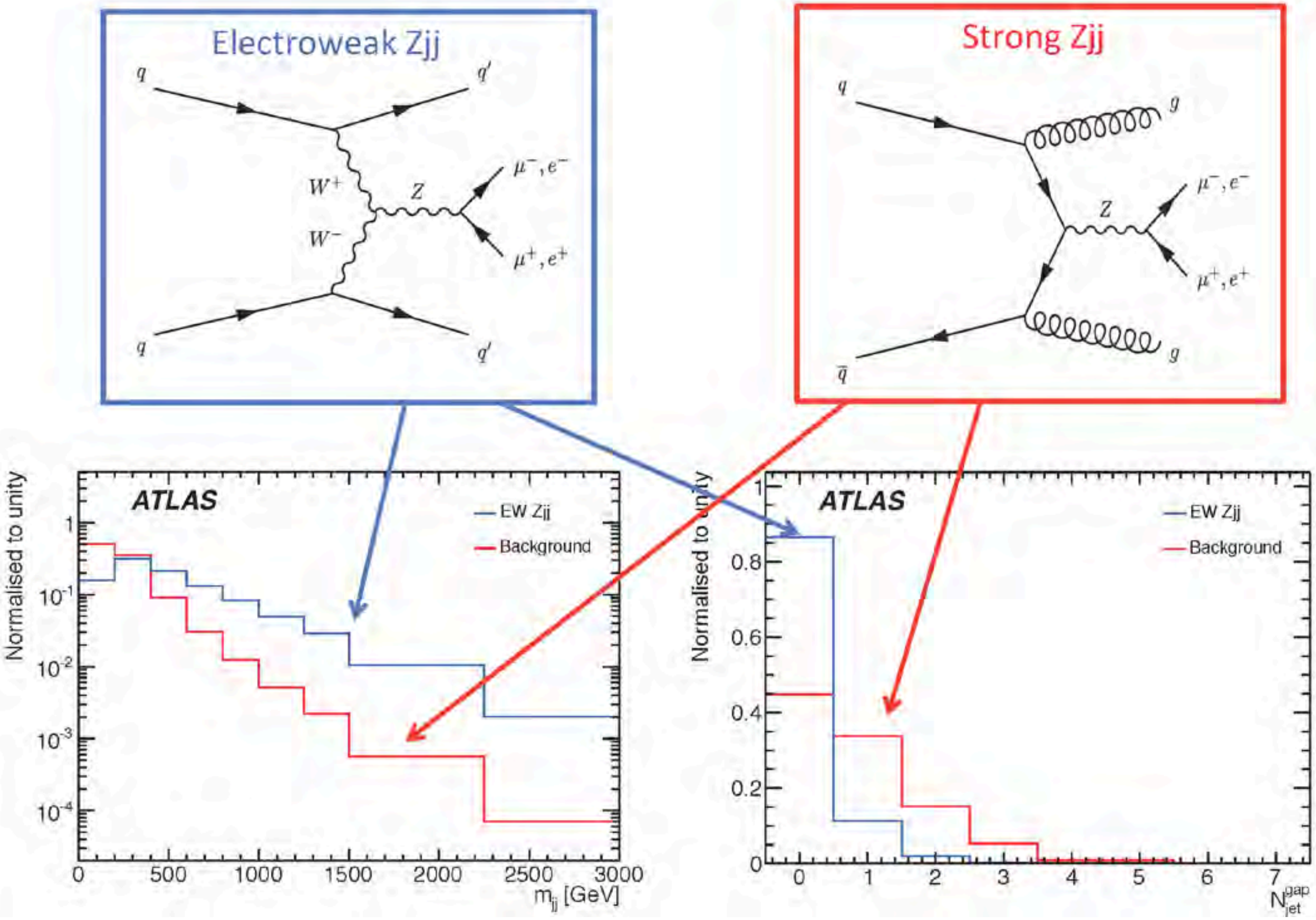




Generator comparisons (Sherpa2, Powheg, MG5, Blackhat/Sherpa, Alpgen)

SM W/Z Physics: EWK Z Production

- **New result from ATLAS on observation (>5σ) of EWK Z+jj production (Higgs VBF process) (*Pilkington*):**



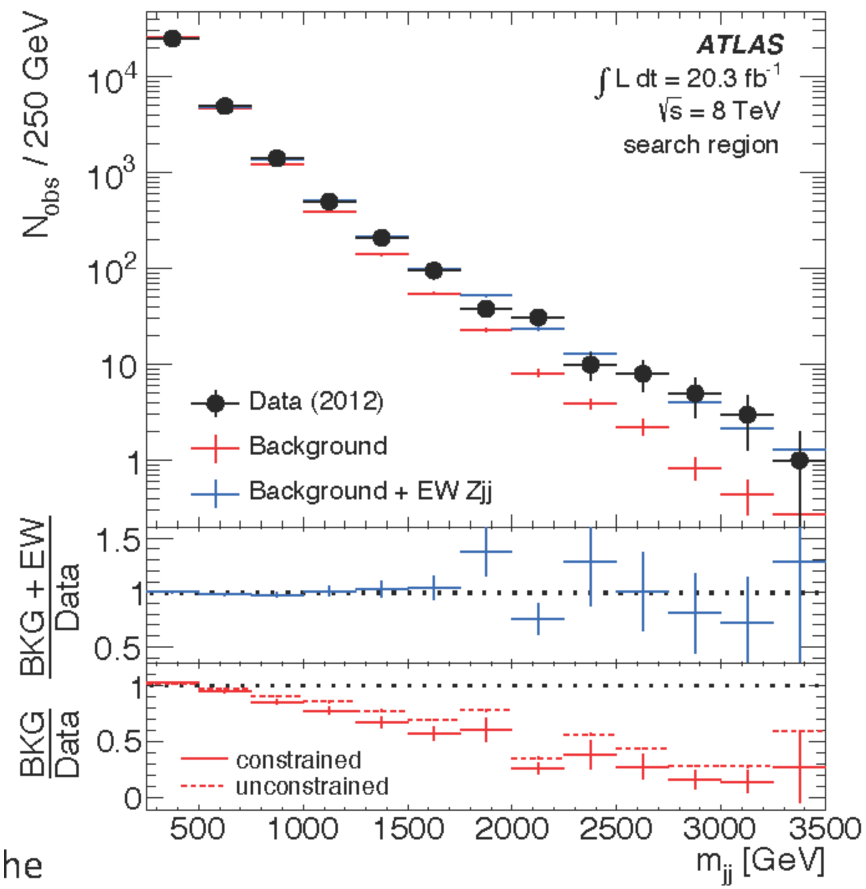
Two key variables for selection of EWK process:

M(jj) – large due to large $\Delta\eta$

N_{jet}(gap) – jets in gap between forward quarks

SM W/Z Physics: EWK Z Production

- **Measure σ in 5 fiducial regions with different sensitivity to EWK Z+jj**



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Kinematic regions near search region

Control region inverting "jet in gap" veto

Use data-driven approach to correct data/MC differences in control region, extrapolate to search region. Many cross-checks.

Very clear evidence for EWK component in m(jj) plot !

SM Top Physics: Mass

- **Top Mass Combination (Tevatron *Brigliadori*, LHC *Castro*):**

LHC/Tevatron NOTE

ATLAS-CONF-2014-008
CDF Note 11071
CMS PAS TOP-13-014
D0 Note 6416

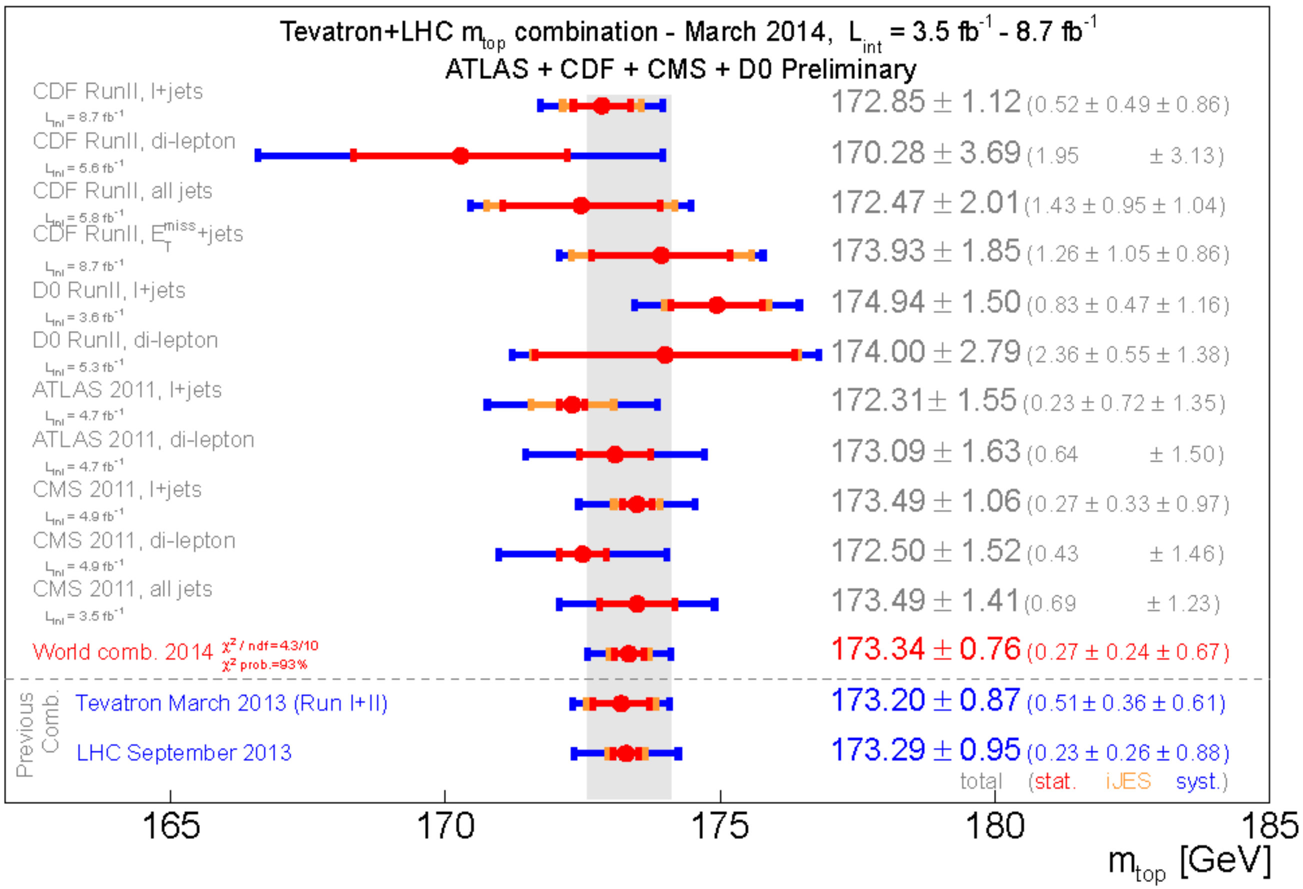
March 17, 2014

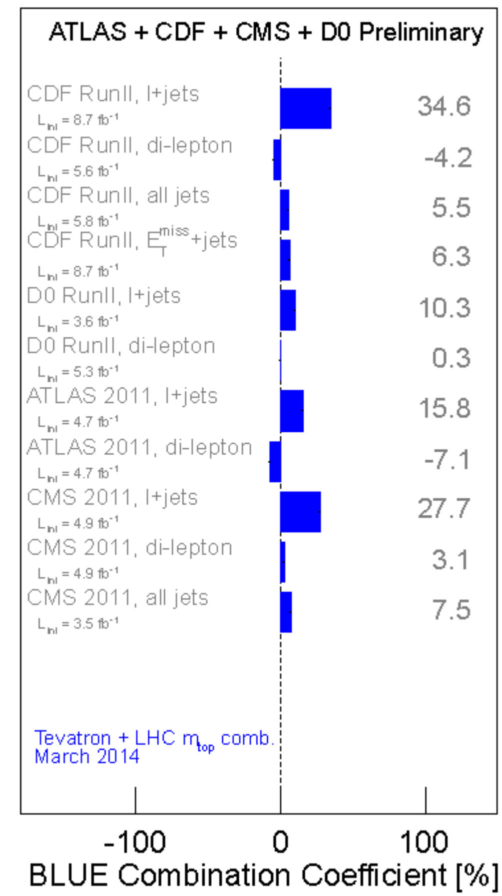
CERN/FNAL Press Release:

A total of more than six thousand scientists from more than 50 countries participate in the four experimental collaborations. The CDF and DZero experiments discovered the top quark in 1995, and the Tevatron produced about 300,000 top quark events during its 25-year lifetime, completed in 2011. Since it started collider physics operations in 2009, the LHC has produced close to 18 million events with top quarks, making it the world's leading top quark factory.

SM Top Physics: Mass

- **Top level results of the LHC/Tevatron combination: 173.34 +/- 0.76 GeV (Tevatron +/- 0.87, LHC +/- 0.95)**





SM Top Physics: Mass

- **Cloud over Top Mass measurements: what are we measuring (see Mangano, Top 2013) ?**
  - **Theoretically useful quantities are pole or Msbar mass.**
  - **Relationship well-known (to 3-loops, dating from 2000): m(pole) = 1.060 m(MSbar) – last term is 0.003m – small !**
  - **Useful to look at 4-loop, revisit "renormalon" ambiguity…**
  - **Suggests that MC parameter which is fit in the experimental measurements is m(pole) with an ambiguity of 250-500 MeV**
- **Given huge effort on the experimental side, certainly worth greater effort on theory side. Of course it is a mixture of "soft" and "hard" physics => difficult !**
- **Alternative: make the measurement in e^+e^- collider, where ambiguities are tiny…**

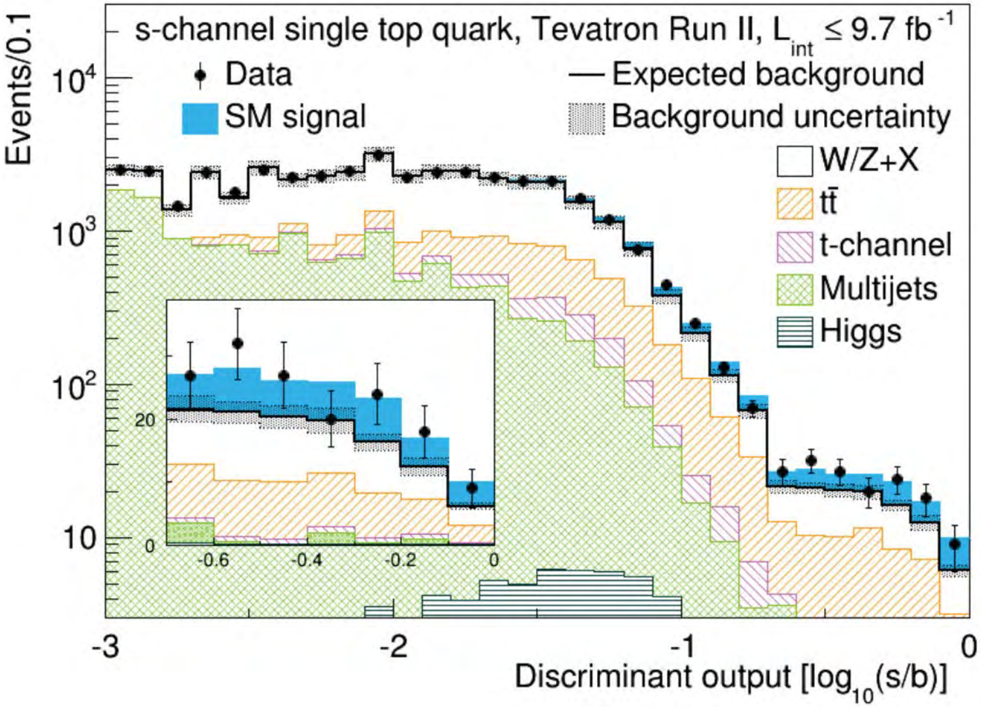
SM Top Physics: Tevatron

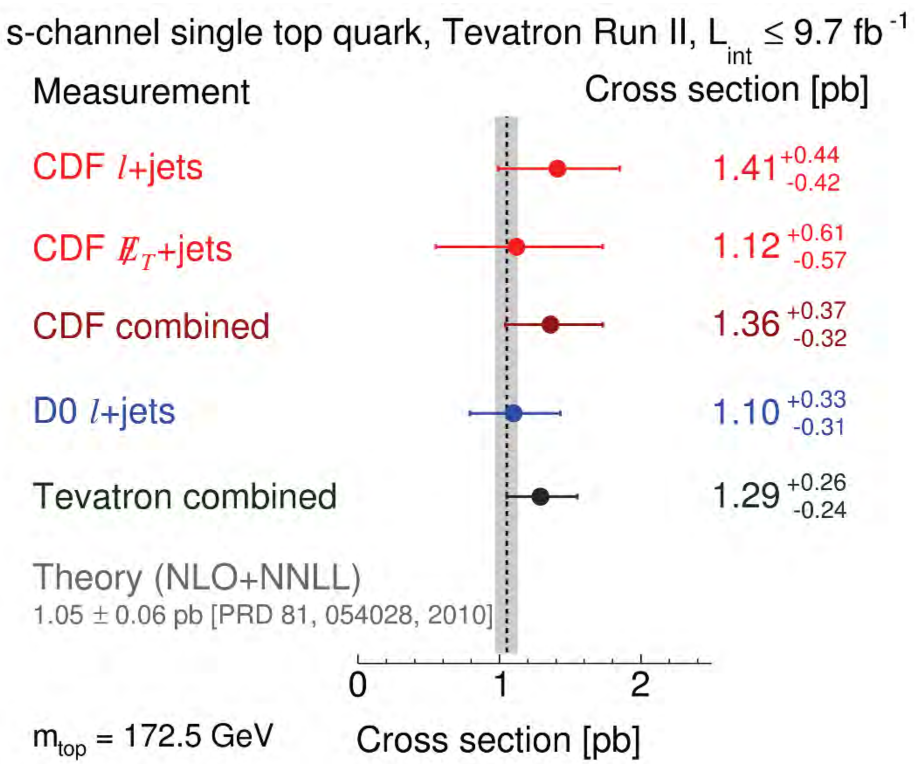
- **ttbar asymmetry (*Harel*):**
  - In 2011, >3σ anomalies in both CDF and D0. Now have almost final update on all channels
  - Much careful work. Measurements include A^{l}_{FB} in l+jets and dileptons, A_{FB} inclusive and vs m(ttbar).
  - Results fairly consistent with each other (CDF still a bit high) and with SM. Finalize and combine. Anomaly not confirmed…
- **Observation of s-channel single-top (*Schwienhorst*):**
  - Channel very difficult at LHC, background even larger at 13 TeV than 8 TeV - Tevatron observation unique for some time !
  - Individual measurements from both CDF and D0.
  - D0 sees signal in l+jets with 3.7σ, CDF sees signal in l+jets and MET+jets with 4.2σ significance.
  - Perform combination at the level of the discriminant.

SM Top Physics: Tevatron

- **Combined discriminant for CDF+D0, and combined result for cross-section, result 6.3σ !**

  $$\sigma = 1.29 + 0.26 - 0.24\ \text{pb}^{-1}$$

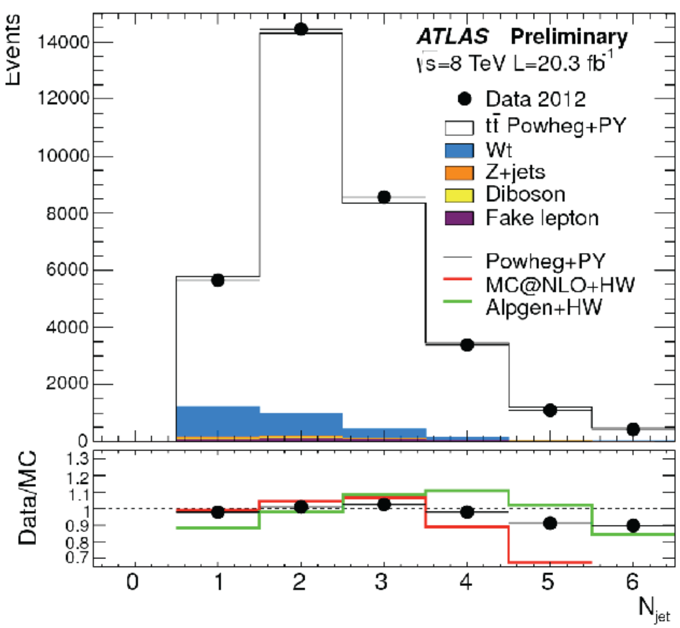




SM Top Physics: LHC Production

- **Single-top results: single-top cross-sections, differential distributions, polarization, Vtb (*Lista*).**
- **Results for ttbar: precision cross-sections, differential distributions, ttbar+HF, ttbar+γ/W/Z.**

$\sigma_{t\bar{t}}$ = 237.7 ± 1.7 (stat) ± 7.4 (syst) ± 7.4 (lumi) ± 4.0 (beam energy) pb



World's most precise ttbar cross-section: total uncert = 4.8%

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\sigma_{t\bar{t}}$ (pb)
Data statistics	0.72	1.7
$t\bar{t}$ modelling	1.52	3.6
Initial/final state radiation	1.23	2.9
Parton density functions	1.09	2.6
QCD scale choices	0.30	0.7
Single-top modelling	0.38	0.9
Single-top/$t\bar{t}$ interference	0.15	0.4
Single-top Wt cross-section	0.70	1.7
Diboson modelling	0.42	1.0
Diboson cross-sections	0.03	0.1
Z+jets extrapolation	0.05	0.1
Electron energy scale/resolution	0.48	1.1
Electron identification/isolation	1.42	3.4
Muon momentum scale/resolution	0.05	0.1
Muon identification/isolation	0.52	1.2
Lepton trigger	0.16	0.4
Jet energy scale	0.49	1.2
Jet energy resolution	0.59	1.4
Jet reconstruction/vertex fraction	0.04	0.1
b-tagging	0.42	1.0
Pileup modelling	0.28	0.7
Misidentified leptons	0.38	0.9
Total systematic	3.12	7.4
Integrated luminosity	3.11	7.4
LHC beam energy	1.70	4.0
Total uncertainty	4.77	11.3

Heavy Flavor: Belle/Babar/CDF/D0

- Belle (*Ritter*) and Babar (*Ben-Heim*) continue to produce interesting and complex results.
- Despite 0.8 and 0.5 ab^{-1} respectively, many results remain stat limited – eagerly await Belle2 in 2016, promising 50 ab^{-1}.
- Tevatron legacy of HF results demonstrated power of hadron colliders to carry out precise measurements (*Donati*) on lifetimes, decays, and asymmetries.
- Unique capabilities such as SVT trigger in CDF, and first extensive use of silicon vertexing in hadron colliders => baton is now passing to LHCb, ATLAS, and CMS…

Heavy Flavor: D0

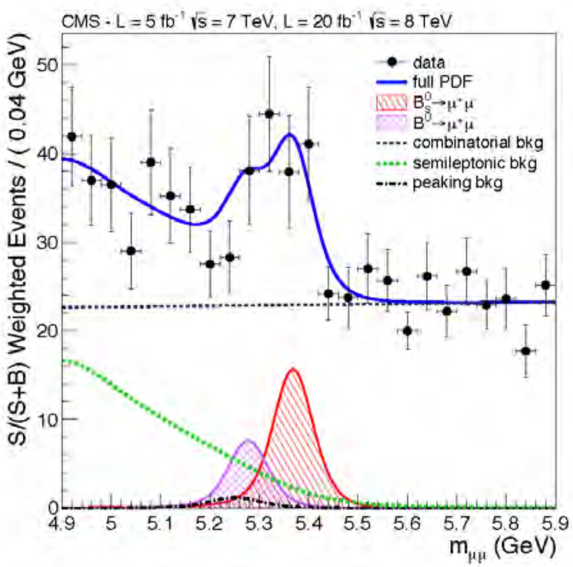
- **D0 inclusive like-sign di-muon asymmetry – the only anomaly left standing from the Tevatron (*Hoeneisen*) ?**
  - Detailed study of muon asymmetries:
    single muon charge asymmetry (n_+ - n_-)
    like-sign di-muon asymmetry (n_{++} - n_{--})
  - Measured single muon asymmetry is consistently zero.
  - Measured like-sign di-muon is consistently negative. Final value now determined -0.235 +/- 0.064 +/- 0.055, 3.6σ effect.
  - Measurement only possible in D0 (ppbar, hermetic and deep detector with little punch-through, individually reversed solenoid and toroid fields to control systematics).
  - Done in 54 bins: 9 bins (PT, η), 6 bins (IP1,IP2) for muons.
  - Need to correct for A_{CP} and $\Delta\Gamma$ contributions – issues ?
  - Inclusive measurements very powerful because they integrate all small (known and unknown) effects – "Altarelli cocktail" ?

Heavy Flavor: ATLAS+CMS+LHCb

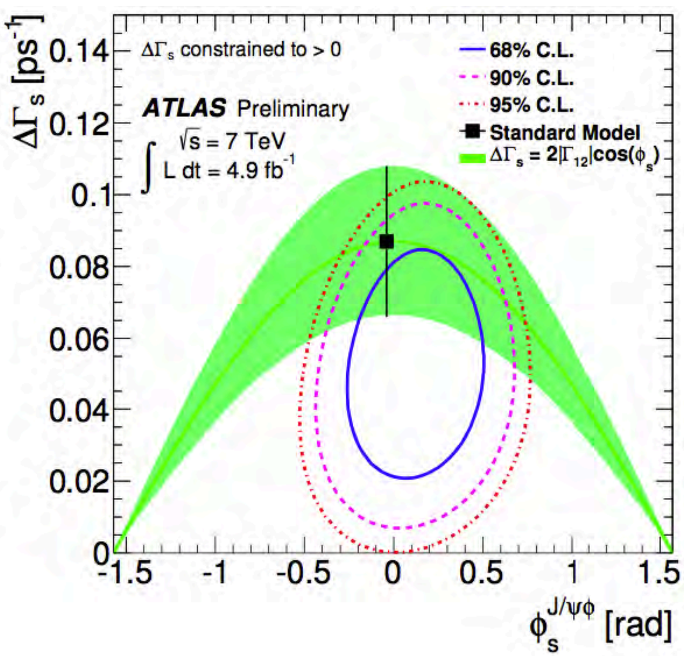
- **For a few high profile measurements, including: $B_s \to \mu\mu$, $B \to K^*\mu\mu$, and $B \to J/\psi\phi$, ATLAS and CMS contribute too (*Patel, Argiro*):**
- **Announcement of 5σ combined $B_s \to \mu\mu$ from LHCb and CMS was a high point of 2013.**

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}, \quad > 5\sigma$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(3.6\,^{+1.6}_{-1.4}\right) \times 10^{-10}, \quad < 3\sigma$$



B -> J/ψφ



Heavy Flavor: LHCb Results

- **Cannot do justice to huge list of results in CKM γ/ϕ_3, charm mixing/CPV, and CPV in B_s (*Carson, di Canto, Dordei*) – most results are 2011 data only !**
- **Multiple new results on CKM angle γ 67 +/- 12 degrees. Already equal to precision of previous world average.**
- **Wide range of results on charm mixing and CPV, leading to best mixing measurements and best bounds on CPV in charm.**
- **Even more wide ranging results on CPV in neutral B's, including direct CPV in B -> ϕK^* and time-dependent CPV in B_s -> K^+K^- and $\pi^+\pi^-$.**
- **As a non-expert, fail to begin to absorb and digest this beautiful work, but look forward to full Run1 results !**

Heavy Flavor: Future

- Overall, HF physics continues to be area where new physics could appear with scales far beyond those directly accessible at LHC – unique window !
- Extraordinarily consistent with SM, with exception of "modest" B->K*$\mu\mu$ anomaly – 8 TeV analyses awaited !
- Theory for B_s->$\mu\mu$ impressively under control: 7% uncertainty in BR, dominated by CKM (expt) and f_{Bs} (lattice calculations). Now in hands of experiments !
- LHCb has shown astonishing capabilities in all areas, and has taken the lead in B and D physics. Producing staggering number of results of high quality.

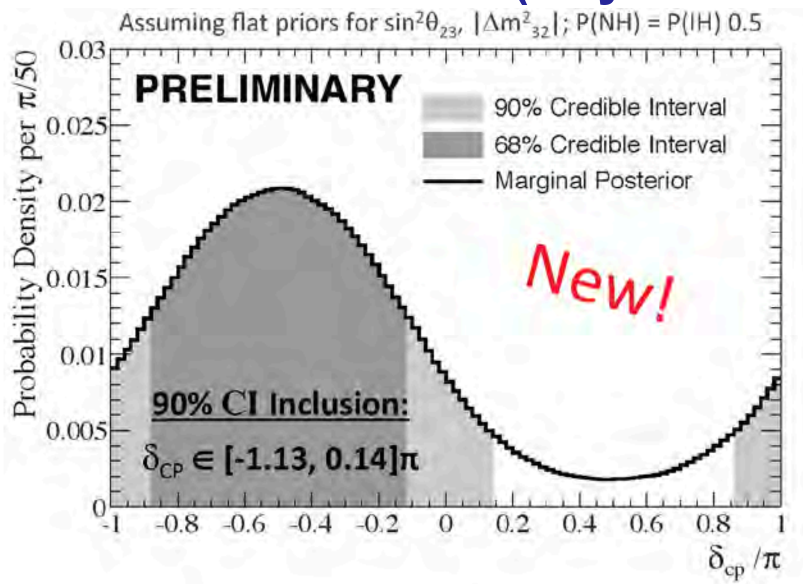
Neutrinos: Big Questions

- Mixing angles and Δm^2 fairly well known – O(10%).
- Neutrino masses: absolute values and hierarchy ?
- CP violation in lepton sector (δ non-zero on horizon ?)
- Is N_ν=3, or are there more (sterile or ?) neutrinos ?
- Are neutrinos Marjorana – if yes, observation of $0\nu\beta\beta$ is critical, L is violated.

- *Altarelli*: preferred scenario Majorana neutrinos – explains large mixing and small ν_L masses. Then ν_R are (very) heavy ? Many views on ν_R masses/roles !
- Can provide baryogenesis via leptogenesis near GUT scale – attractive…

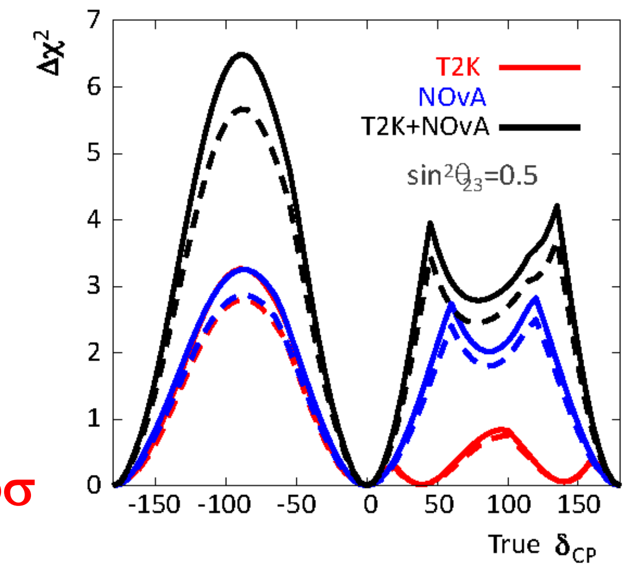
Neutrinos: Update on Oscillations

- **Opera result on $\nu_\mu \to \nu_\tau$ appearance (2/3 of data analyzed): 3.4σ based on 3 events seen (*Jollet*).**
- **T2K has several beautiful results (*de Perio*):**
  - **ν_μ disappearance, most precise $\sin^2\theta_{23}$ = 0.514 (0.511) with normal (inverted) hierarchy and 11% uncertainty.**
  - **ν_e appearance with 7σ. Joint $\nu_e+\nu_\mu$ fit gives indication for δ_{CP} about $-\pi/2$ (Bayesian fit, marginalized over hierarchy):**



Ultimate pot of 8×10^{21} (x12)

Result with Nova about 3.5σ



Neutrinos: Update on Oscillations

- **Double Chooz has used both n-Gd and n-H capture to cross-check their result. Derived combined result:**
  $\sin^2 2\theta_{13} = 0.109 +/- 0.035$
- **Expect to start operation of ND+FD configuration this Summer, with the goal of 10% precision (*Novella*).**

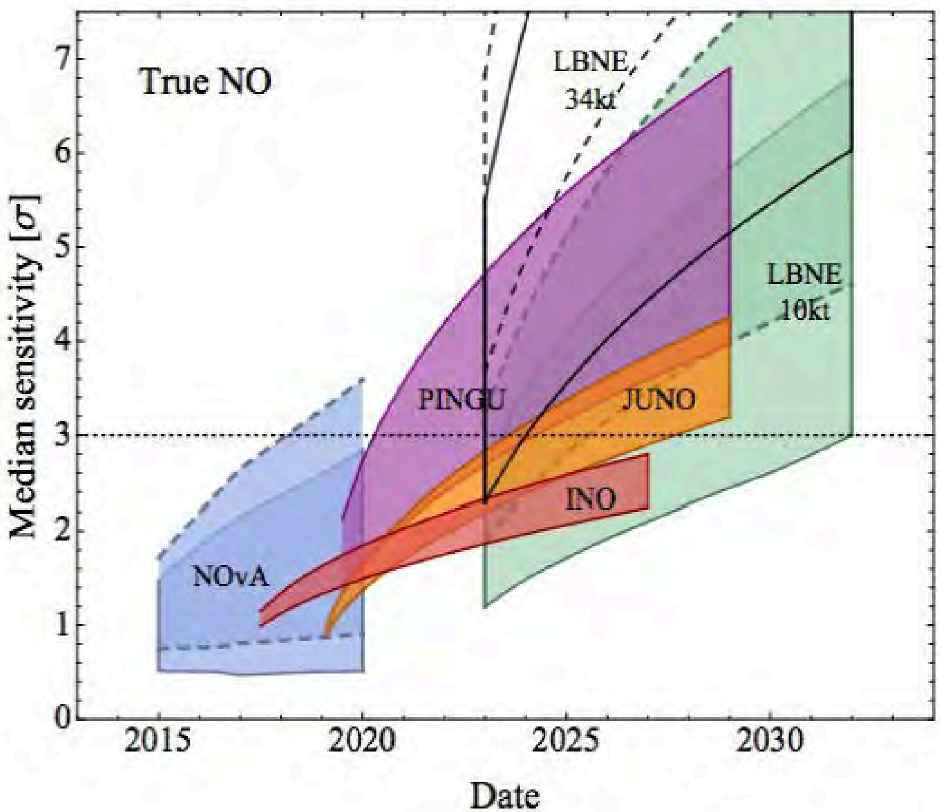
- **Daya Bay has also performed n-H capture analysis (*Wang*), with result of:**
  $\sin^2 2\theta_{13} = 0.082 +/- 0.018$,
- **This leads to a new combined (most precise 8.5%) result:**
  $\sin^2 2\theta_{13} = 0.089 + 0.007 - 0.008$

Neutrinos: Mass Heirarchy ?

- **Talk of *Coloma* (Blennow, Coloma, Huber and Schwetz, 1311.1822 [hep-ph]) consistent assessment of determination of mass hierarchy from oscillations:**

Sensitivity to reject inverted hierarchy (rejecting the normal hierarchy is more difficult, and really requires LBNE). Bands include variations in δ, etc.

Unlikely to have solid (> 3σ) result for another 8-10 years…



Neutrinos: $0\nu\beta\beta$ and Mass

- **New results at this meeting from many experiments:**
  - **GERDA (*Lehnert*):**
    - **Uses ^{76}Ge in LAr (cooling, shielding, and veto).**
    - **Phase I: 2012/2013 22 kg-yr, achieved 2.1×10^{25} yr (3.0×10^{25} when combined with other Ge detectors HdM and IGEX).**
    - **Phase II: start in 2014, aim for 100 kg-yr, E resolution improvements, 10x lower background, target 10^{26} yr !**
  - **KAMLAND-ZEN (*Yoshida*):**
    - **Uses 300 kg ^{136}Xe gas dissolved in liquid scintillator.**
    - **DS-1 + DS-2 combined to 90 kg-yr, achieved 1.9×10^{25} yr despite ^{110}Ag contamination. Combined with EXO200 (2012), reach 3.4×10^{25} yr.**
    - **During purification process to remove ^{110}Ag contamination, fire in Kamioka mine caused major set-backs. Lost one year, now back in operation since Dec 2013.**
    - **Phase-2: 600-800 kg ^{136}Xe. Hope to cross 100 meV within year…**

Neutrinos: $0\nu\beta\beta$ and Mass

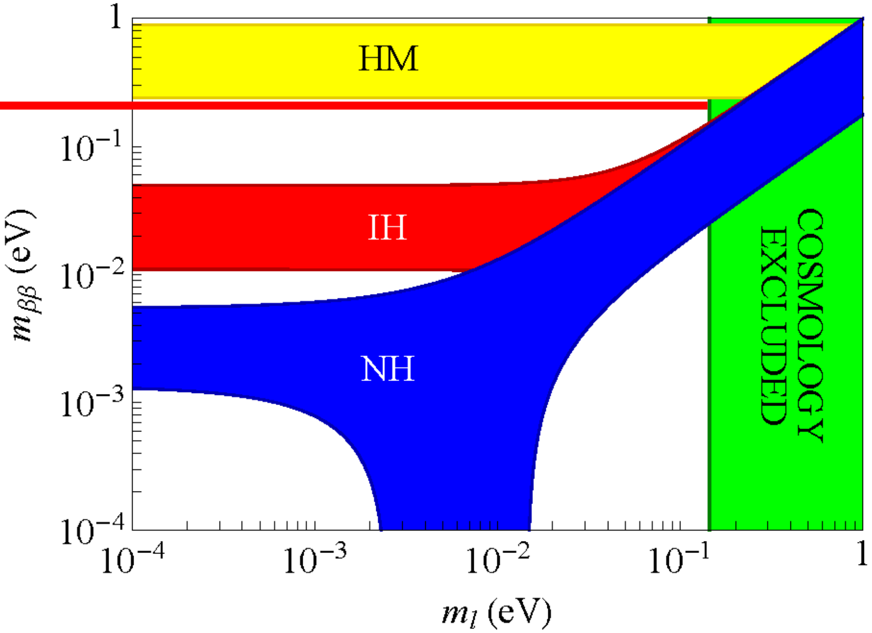
- CUORE (*Bellini*):
  - Uses ^{130}Te. Started with Cuoricino (20 kg-yr). After many improvements, starting with first module of CUORE (CUORE-0) to confirm improvements – started data-taking.
  - Full scale will be x20 (206 kg ^{130}Te). Over 5 years of operation, expect to reach 10^{26} yr limit (m < 50-130 meV).
- NEMO (*Torre*):
  - NEMO-3 uses ^{100}Mo (7 kg) primarily (but also ^{82}Se, and others at low level). Have 35 kg-yr for ^{100}Mo, m < 0.3-0.9 eV.
  - Uses tracker and magnet for spectrometer, scintillator for calorimeter, surrounding “source” foils (full reconstruction).
- **Best combined results (individually for ^{76}Ge and ^{136}Xe) about $3x10^{25}$ yrs. Both should cross the 100 meV threshold in next few years.**

Neutrinos: 0νββ and Mass

- Current limits are slowly approaching expected range for inverted mass hierarchy.
- If oscillations tell us that we have an inverted hierarchy, but the 0νββ limits extend down to 10 meV, probably the Majorana hypothesis would be in trouble.

Best limits from ^{76}Ge or ^{136}Xe combinations…

Still a <u>long</u> way to go to confirm Majorana hypothesis, unless we are lucky…



Neutrinos: Many small Anomalies ?

- **Results not "perfectly coherent" with N_ν=3 :**
  - **SAGE and GALLEX**
  - **LSND and MiniBoone**
  - **ν_μ -> ν_e appearance**
  - **ν_μ -> ν_μ disappearance**
- **Minerνa: multi-hadron effects in CCQE; impact on LSND/MiniBoone ?**
- **Some results => 3+1 or 3+n sterile neutrino scenario ? No scenario consistent with all results (*Maltoni*)…**

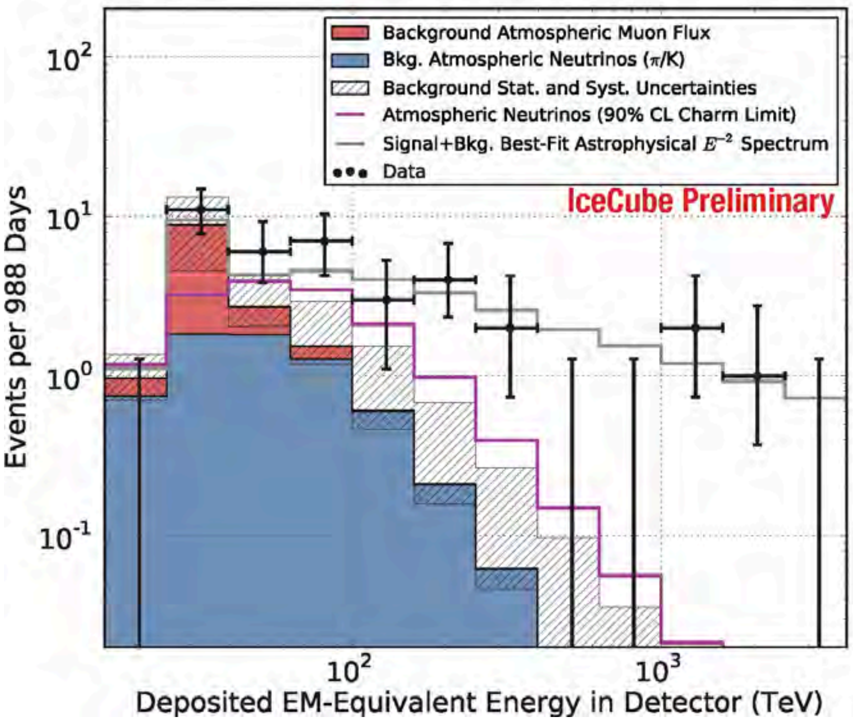
Requirement	(3+0)	(2+2)	(3+1)	(3+2)	(1+3+1)
Ordinary neutrino oscillation data	OK	NO	OK	OK	OK
$\bar{\nu}_e \to \bar{\nu}_e$: SBL reactor & gallium data	NO	OK	OK	OK	OK
$\bar{\nu}_\mu \to \bar{\nu}_e$: LSND & MB $\bar{\nu}$ data	NO	OK	OK	OK	OK
$\nu_\mu \to \nu_e$: MB high-energy ν data	OK	POOR	POOR	OK	OK
$\bar{\nu}_\mu \to \bar{\nu}_e$: MB low-energy excess	NO	POOR	POOR	OK	OK
$\bar{\nu}_\mu \to \bar{\nu}_\mu$: disappearance data	OK	OK	NO	NO	NO
Constraints from cosmology	OK	NO	OK	NO	NO

Neutrinos: Astrophysical

- **Sources of Astrophysical neutrinos:**
  - **<u>AGNs and GRBs</u>: p in relativistic "jets" scatter inelastically, producing hadrons, decaying to ν.**
  - **<u>Cosmic Rays (GZK)</u>: p interact with CMB/IRB photons, producing hadrons, decaying to ν.**
  - **<u>Atmospheric</u>: p interact in atmosphere, producing hadrons, decaying to ν.**
  - **CR are mostly p, also Fe or other nuclei…**
  - **Very high energy neutrinos (PeV) expected to be produced mostly by CR protons interacting with IRB photons.**

Neutrinos: Astrophysical - IceCube

- **Recent results from UHE tail (*Kopper*). Last year, reported 2 events above 1 PeV, now a new 2 PeV event.**
- **Performed fiducial search (full mass 400 MTons !):**
  - **Criteria very efficient above about 100 TeV. In 3 yr (988 days) search, new results are 34+3 events.**



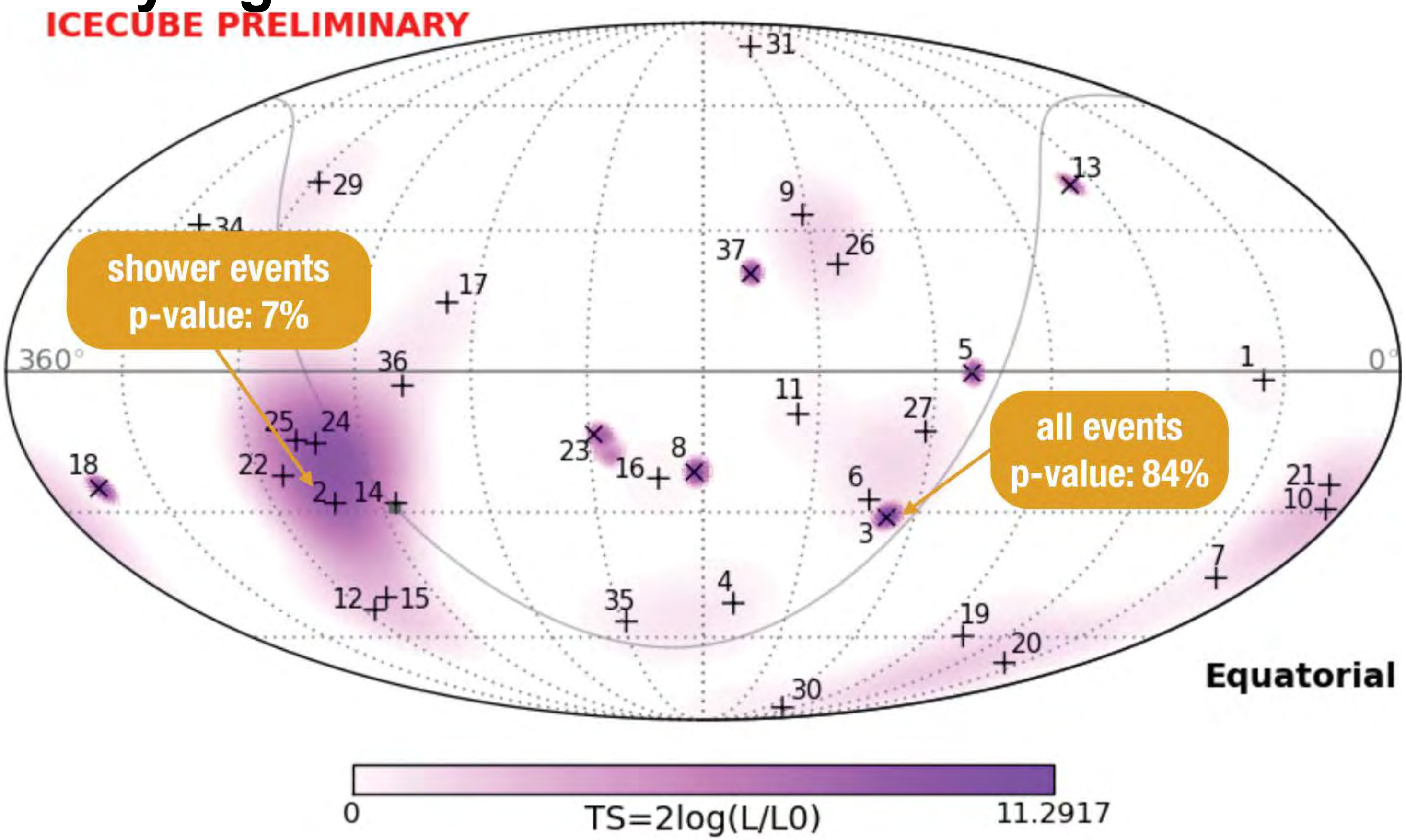
Below about 100 TeV, atmospheric muons and neutrinos dominate.

Best fit E^{-2} spectrum describes data well. Significant excess above atmospheric contributions (5.7σ) !

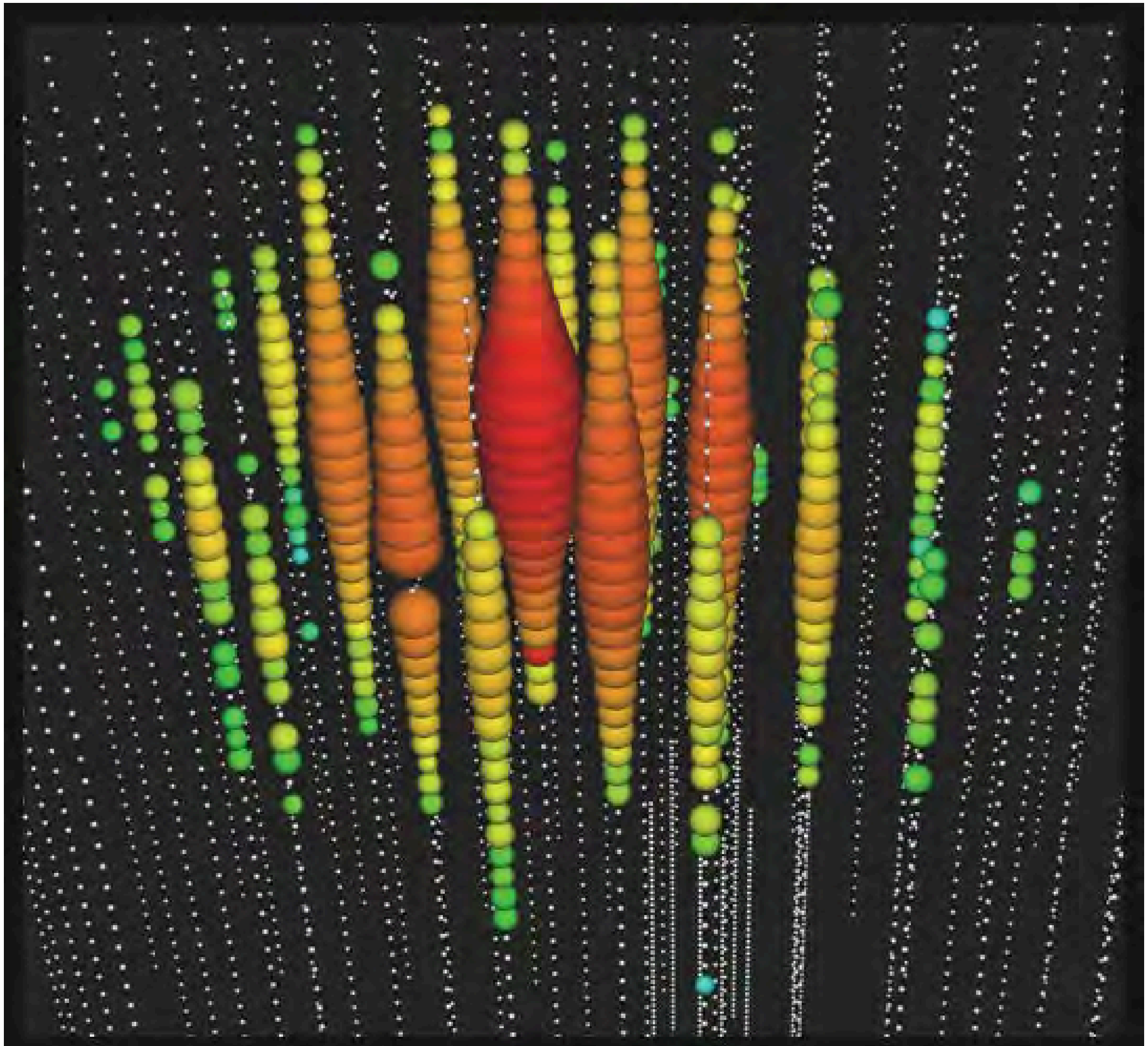
Maximum "cosmogenic" contribution predicted to be about factor 10 less. Other sources fill in this gap, or ?

Neutrinos: Astrophysical - IceCube

- Look at “skymap” of 37 events.
- Most significant excess is near galactic center, but is not very significant:



Neutrinos: Astrophysical - IceCube



2 PeV event - "Big Bird"

Dark Matter

- **Dark Matter searches across a very wide spectrum were reported at this meeting:**
  - Latest (first !) results from LUX (Xe)
  - Optimized results from CDMS for light WIMPs (Ge)
  - Update from COGENT (Ge)
  - News from PICO (PICASSO + COUPP)
  - Latest results from IceCube
  - Update from AMS
  - Dark Matter searches at LHC

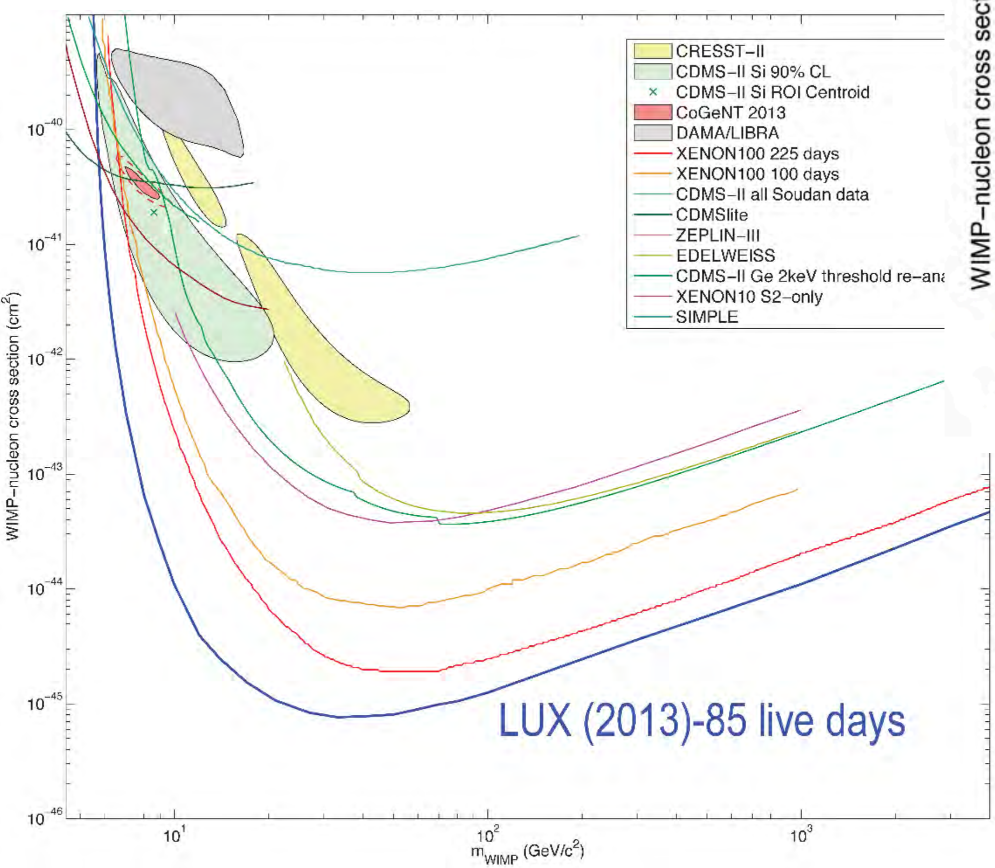
- **Broad-based search effort essential given how little we know about DM – want a multi-dimensional view.**
  - Make sure mature approaches get necessary support !

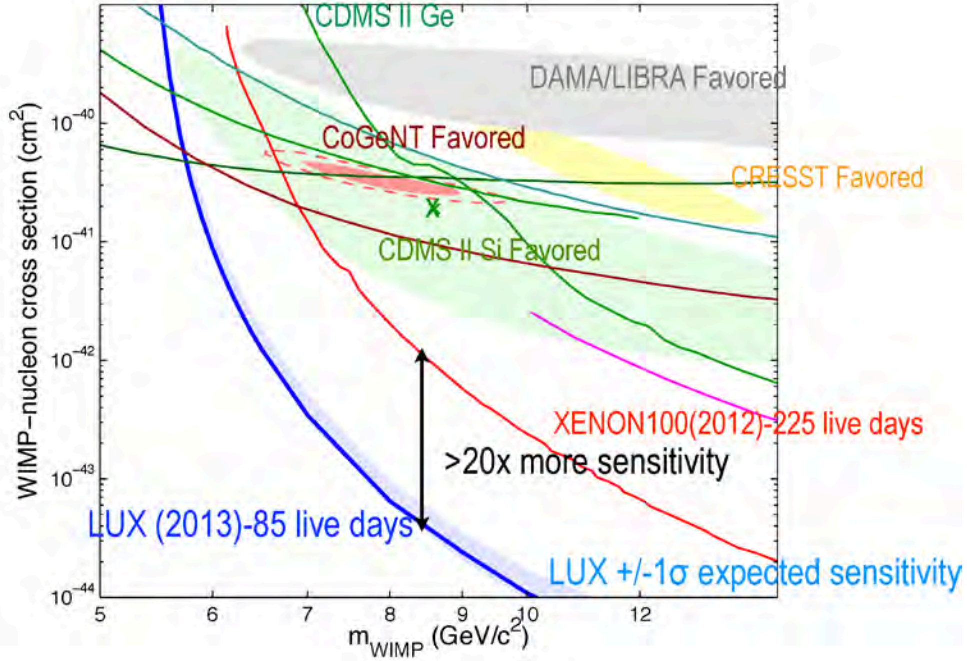
Dark Matter: LUX

- LUX uses 370 (118 fiducial) kg of Xe viewed by 122 ultra-low background PMTs in PTFE cylinder with high VUV reflectivity (*Silva*)
- Surrounded by 8m water shield, at more than 4000m water-eq in SURF lab.
- Two-phase TPC, coincidence between primary and secondary (drift) signals, determines position.
- Use relative pulse-height to discriminate e/γ from WIMPs
- LUX had their first physics run in 2013, 85 live days, calibrated with neutron generator, ^{241}Am and ^{252}Cf.

Dark Matter: LUX

- **Results from first run:**



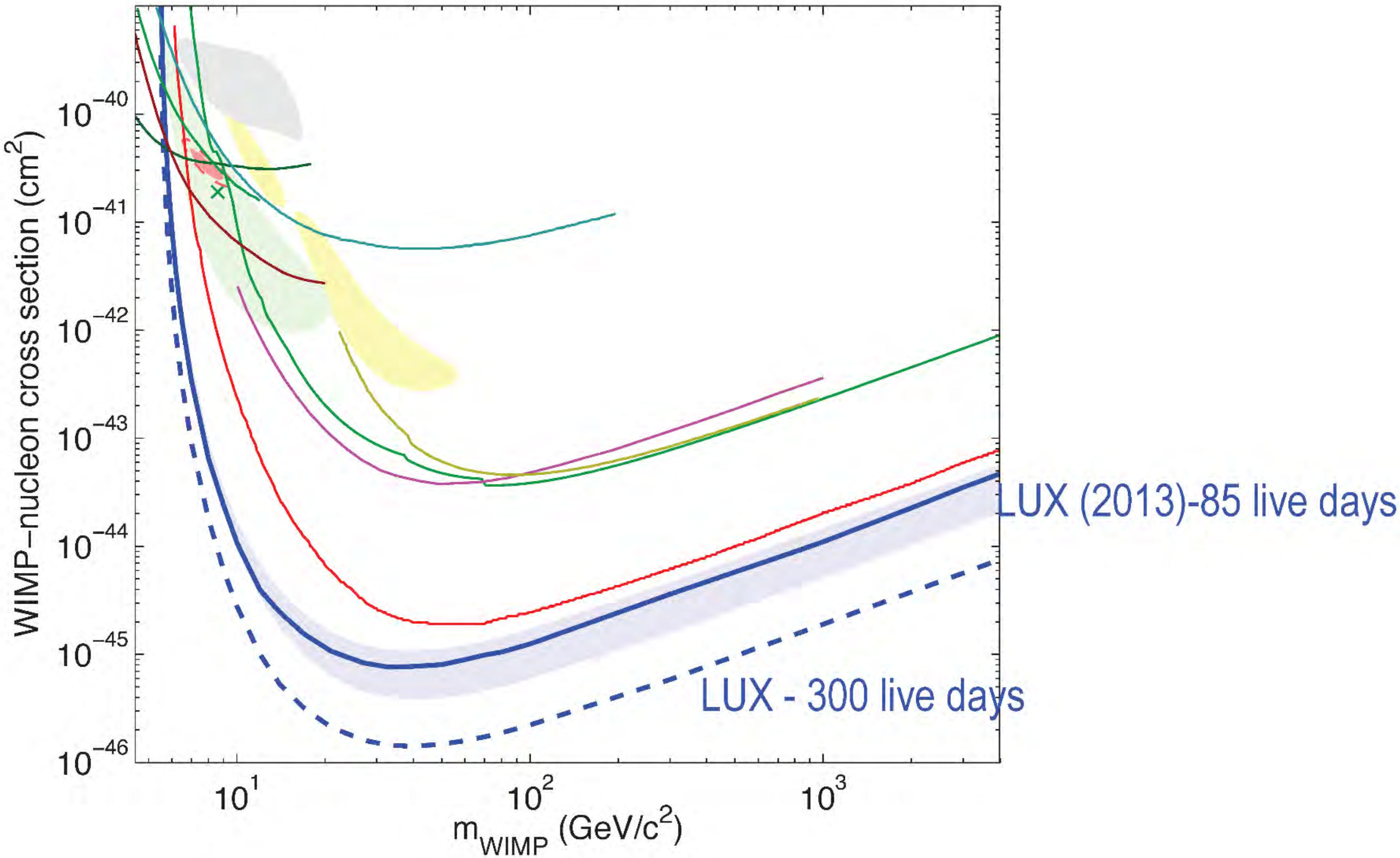


Extremely low background at low energy => sensitivity at low mass.

First run delivered the best Spin-Independent limits so far !

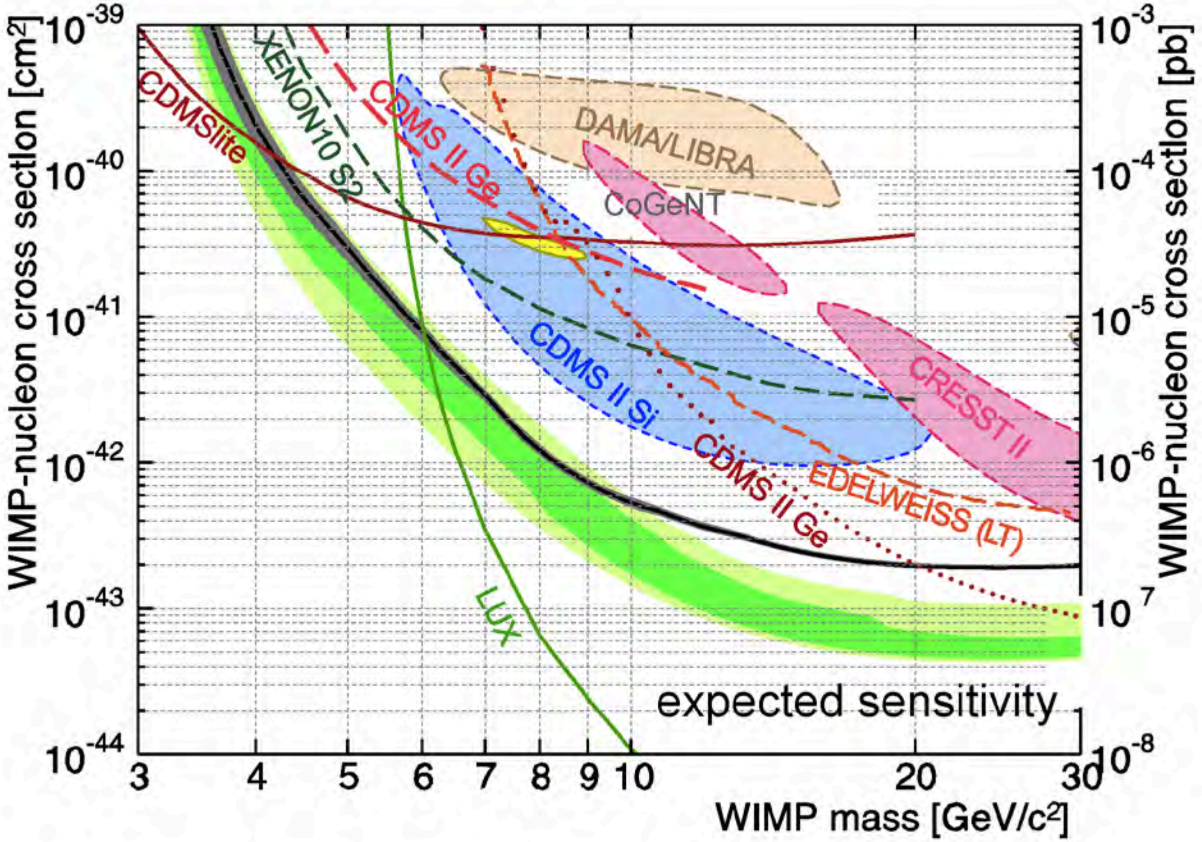
Dark Matter: LUX

- **Plan a 300-day run in 2014/2015, with at least a factor 5 improvement in sensitivity (XENON1T soon as well):**



Dark Matter: SuperCDMS

- **SuperCDMS uses new detectors with integrated phonon and ionization detection (*Anderson*). Low threshold dataset with subset of detectors:**



Strong disagreement with COGENT and other hints of signals in 10 GeV region, using Ge detectors.

First experience with new detectors good !

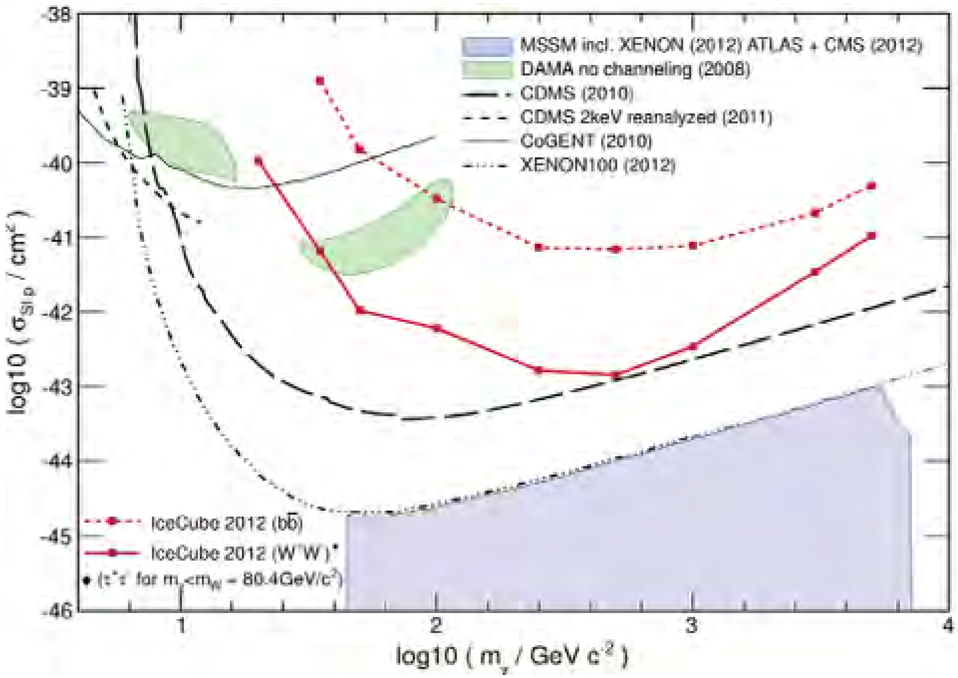
Scale up to 100 kg SNOLAB.

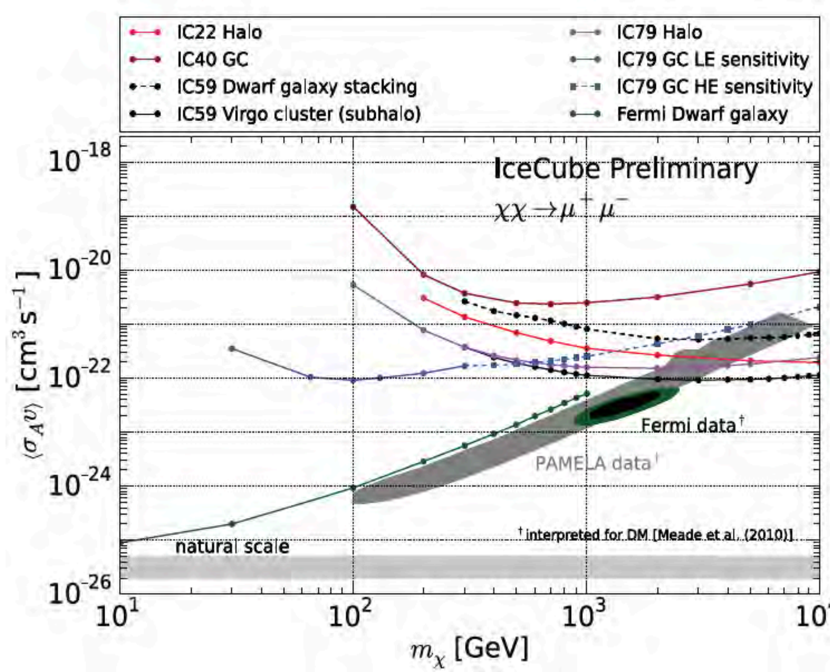
Dark Matter: COGENT + PICO

- COGENT (*Kos*):
  - Focus on deeper understanding of background sources, and push towards lower mass searches.
  - Expect new C4 detectors will allow going down to below 0.5 keVee. Competing with CDMS for this region.
- PICO (PICASSO+COUPP next generation) (*Noble*):
  - Unusual bubble-based techniques with acoustic detection => make detector blind to e/γ backgrounds, distinguish α from nuclear recoils (spatial extent of E deposition).
  - Focusing on PICO-2L using C_3F_8, and going very deep (SNOLAB). Scale up to 250 kg, target best Spin-Dependent limits.
- ***Wide-ranging DM program promises significant extensions in sensitivity in all areas in near future !***

Dark Matter: IceCube

- IceCube has searched for DM in Sun, galactic center or halo, galaxy clusters, dwarf spheroids, looking for neutrinos from WIMP self-annihilation (*Kopper*).
- Use DeepCore section of IceCube to achieve neutrino thresholds in 10 GeV range, use rest for muon veto.

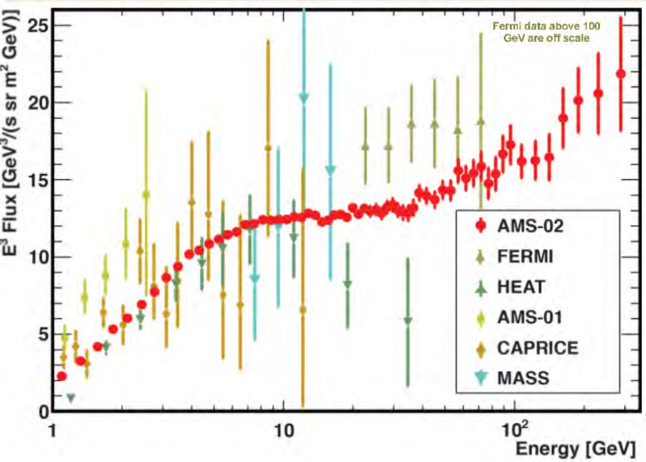




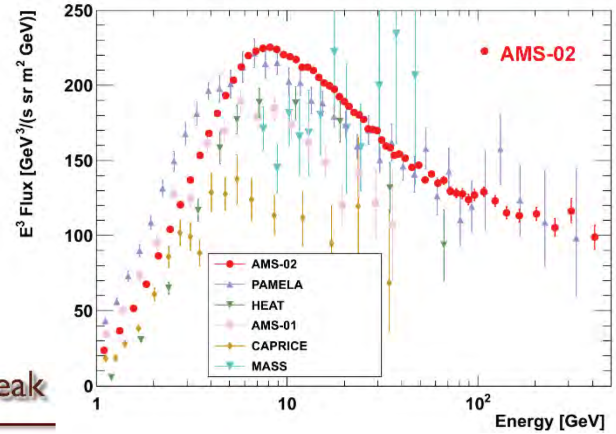
Dark Matter: AMS

- New e^+, e^-, and p flux measurements from 70% of current data. Impressive precision (*Duranti*) !

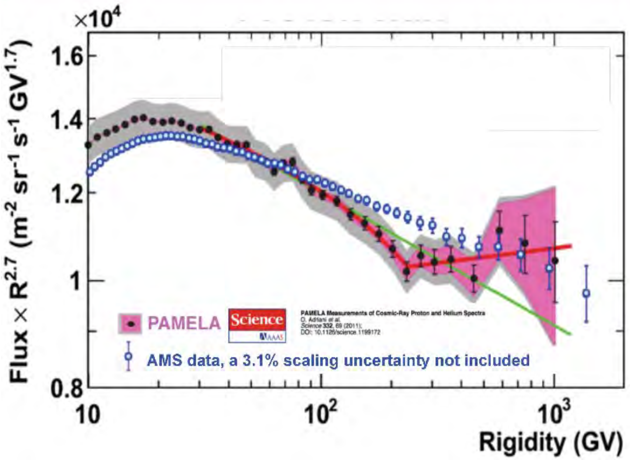
Positron (e^+) flux



Electron (e^-) flux



AMS-02 proton flux and the Pamela's break

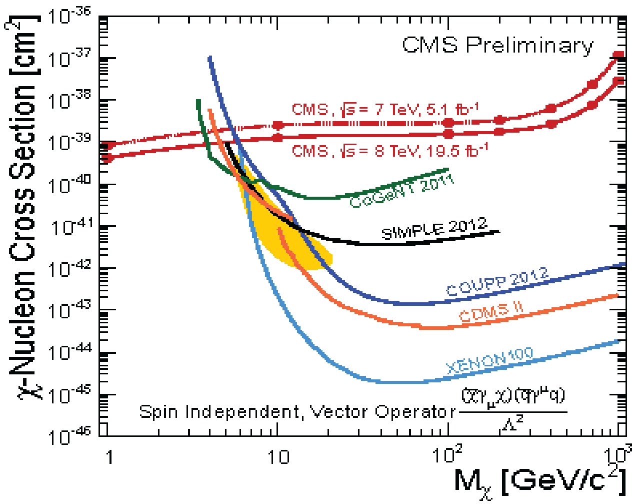


Eagerly awaiting further results !

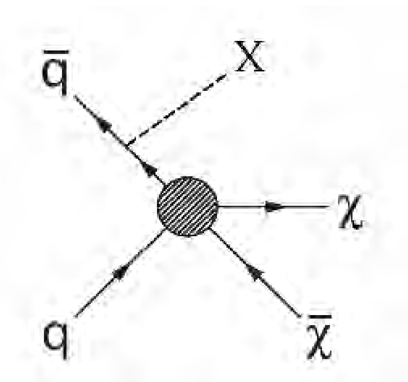
Dark Matter: ATLAS + CMS

- Assume DM is pair-produced, but invisible. Then trigger/reconstruct using ISR hard emission (*Calfayan*).
- Refer to this as "mono-X", where X = jet, γ, W/Z, Top.
- If mediator is heavy, interpret using EFT ("contact int")
- Alternatively: use simplified models (no validity issue).

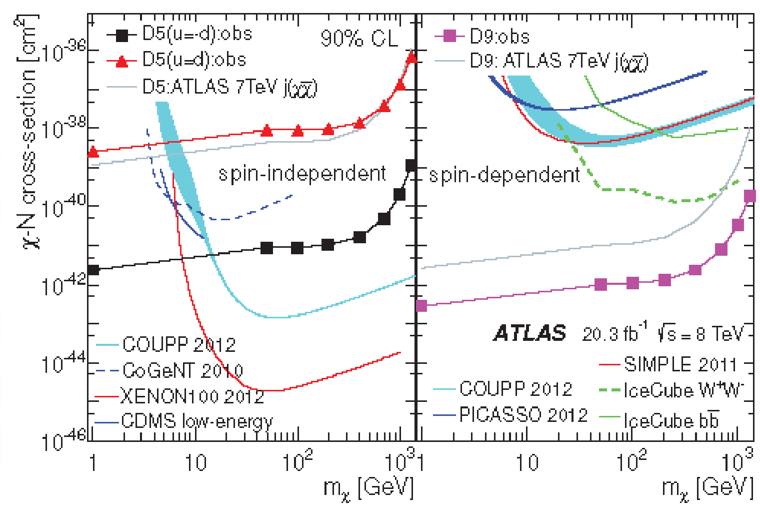
CMS Mono-jet



Production Diagram

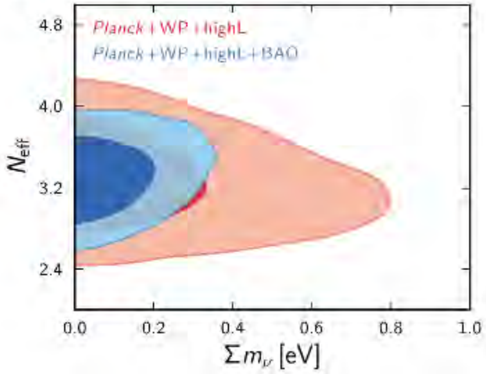


ATLAS Mono-W/Z(qq)



Cosmology: Planck + Bicep2

- **Update on Planck results (note, full dataset and polarization release targeted for Oct 2014):**
  - The 6 parameter ΛCDM is a good fit !
  - lower H_0 , larger Ω_m
  - Flat universe : $100\Omega_K = -0.1 \pm 0.6$ (95% c.l.)
  - $N_{eff} = 3.30 \pm 0.54$ (95% c.l.) ; $\Sigma m_\nu < 0.23$ (95% c.l.)
  - dark energy : $w = -1.13 \pm 0.24$ (95% c.l.)
  - good agreement with BBN
  - no evidence for primordial non gaussianities
  - large angular scale $\sim 2\sigma$ "anomaly"
  - $n_s = 0.96$ at more than 5σ, no evidence for running, limit on tensor modes



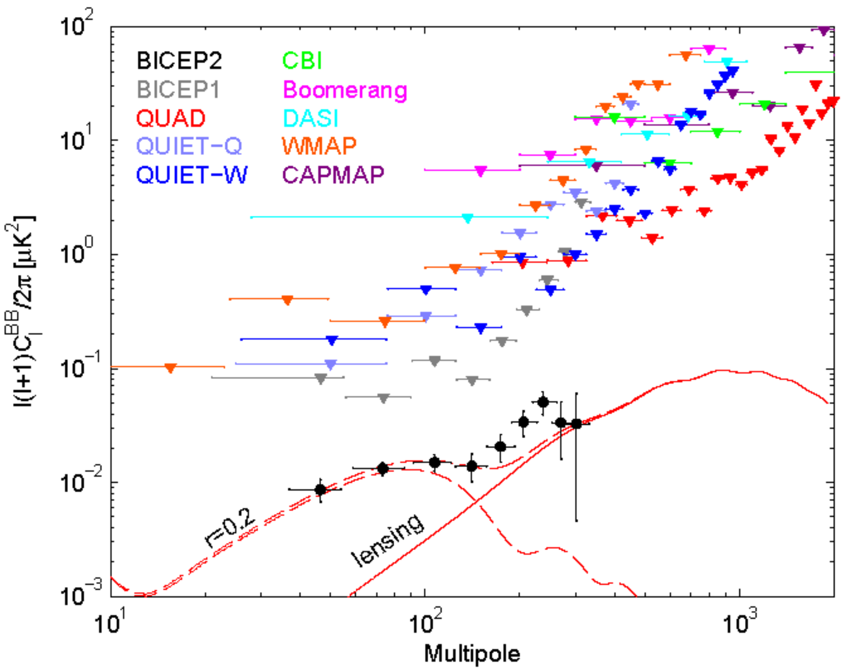
Neff is the number of "effective" neutrinos, here indicating that there is barely room for 1 additional sterile neutrino…

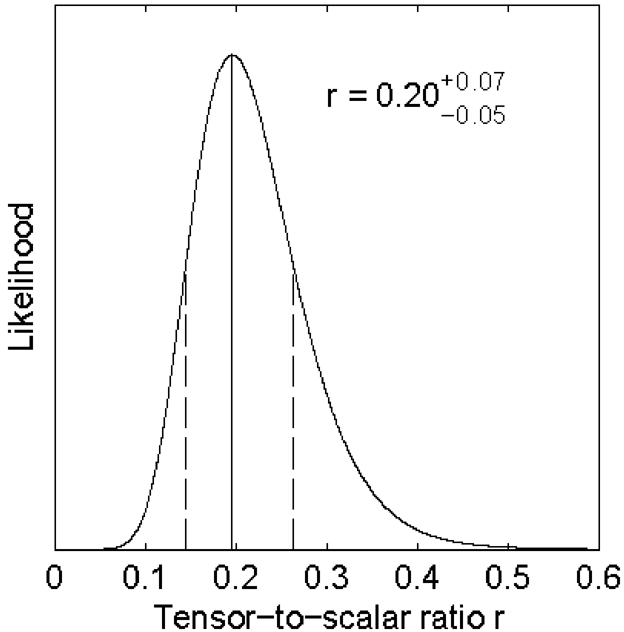
Overall, excellent agreement with "concordance" ΛCDM model…

Thanks to *O. Perdereau* for Planck and Bicep insights.

Cosmology: Planck + Bicep2

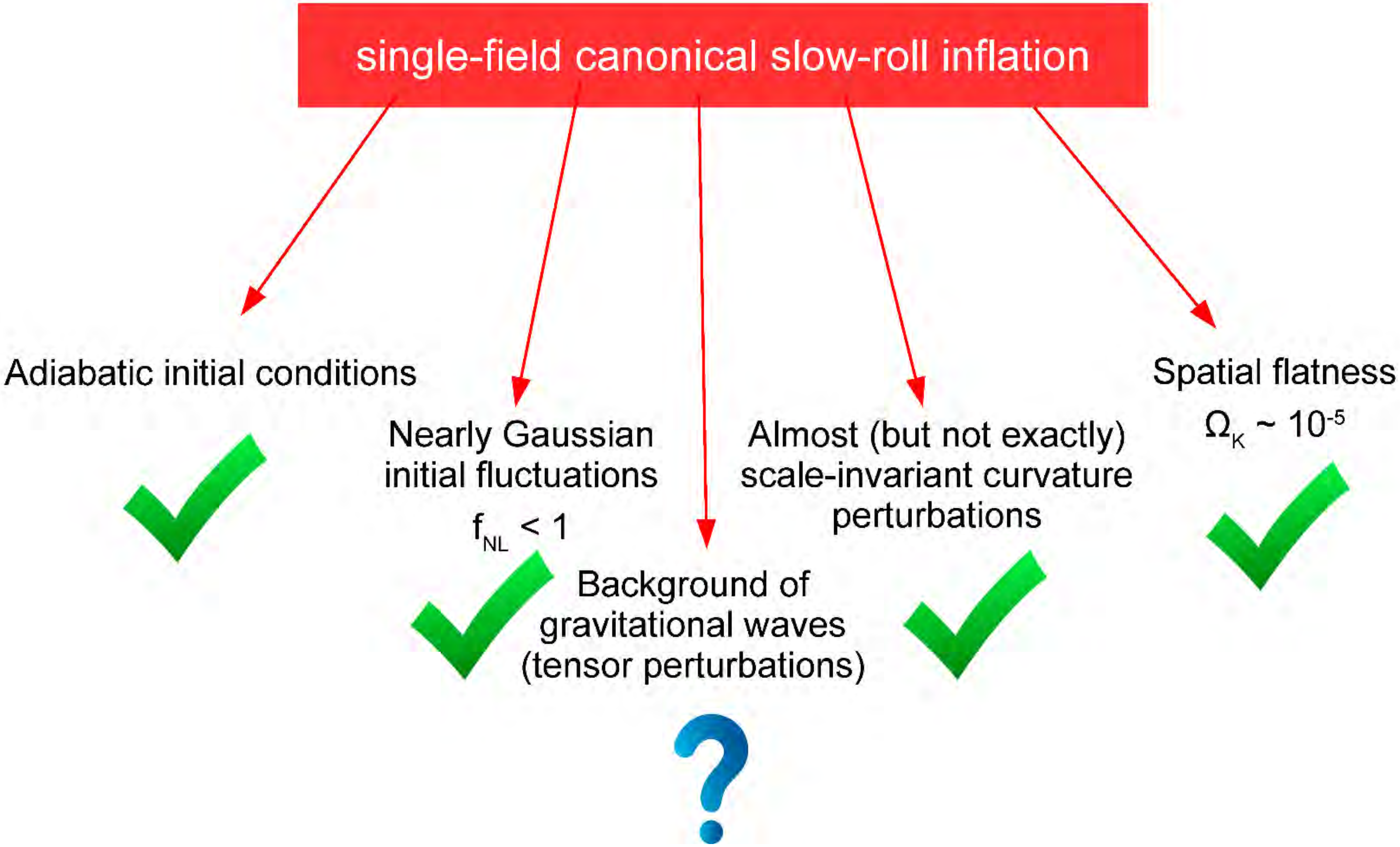
- **New Bicep2 result (astro-ph 1403.3985):**
  "Detection of B-mode Polarization…"
- **Observed B-mode polarization near *l*=80 with significance > 5σ, as expected for primordial gravitational waves from inflation. Also observed tensor/scalar ratio r=0.20 with r=0 disfavored at 7σ.**





Cosmology: Planck + Bicep2

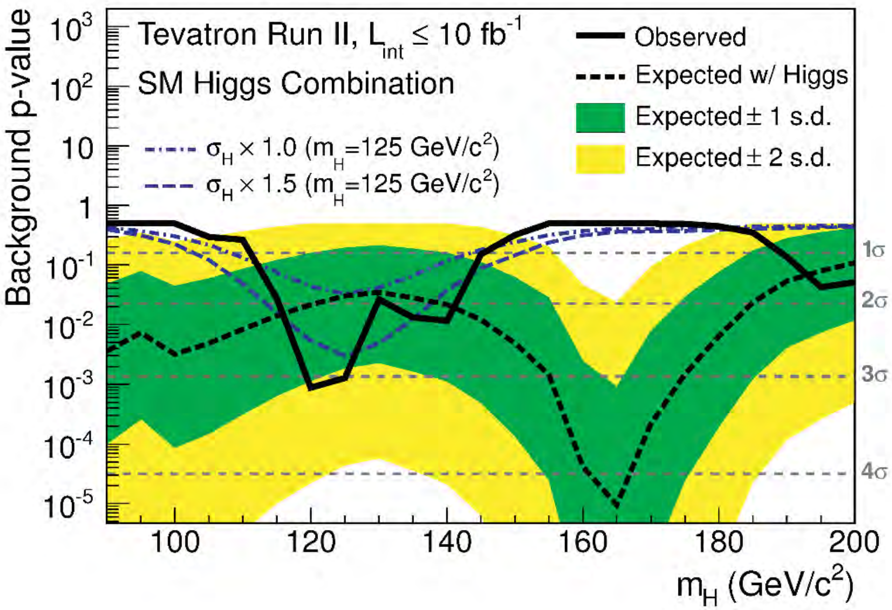
- **Predictions of basic inflation models (*Hamann*):**

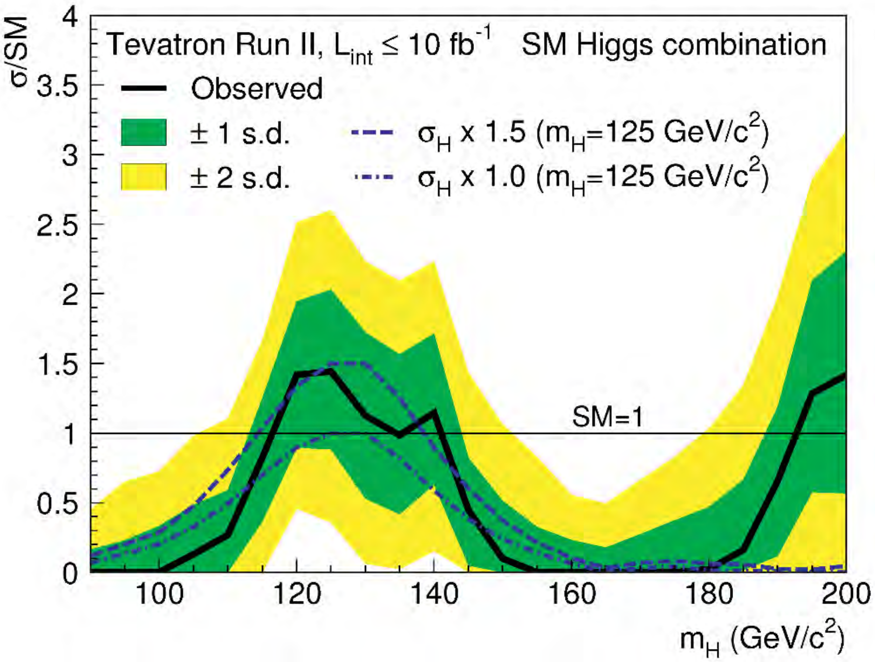


Planck results demonstrate four green checks, Bicep2 appears to have resolved the question mark !

Scalar Boson: Final Tevatron Results

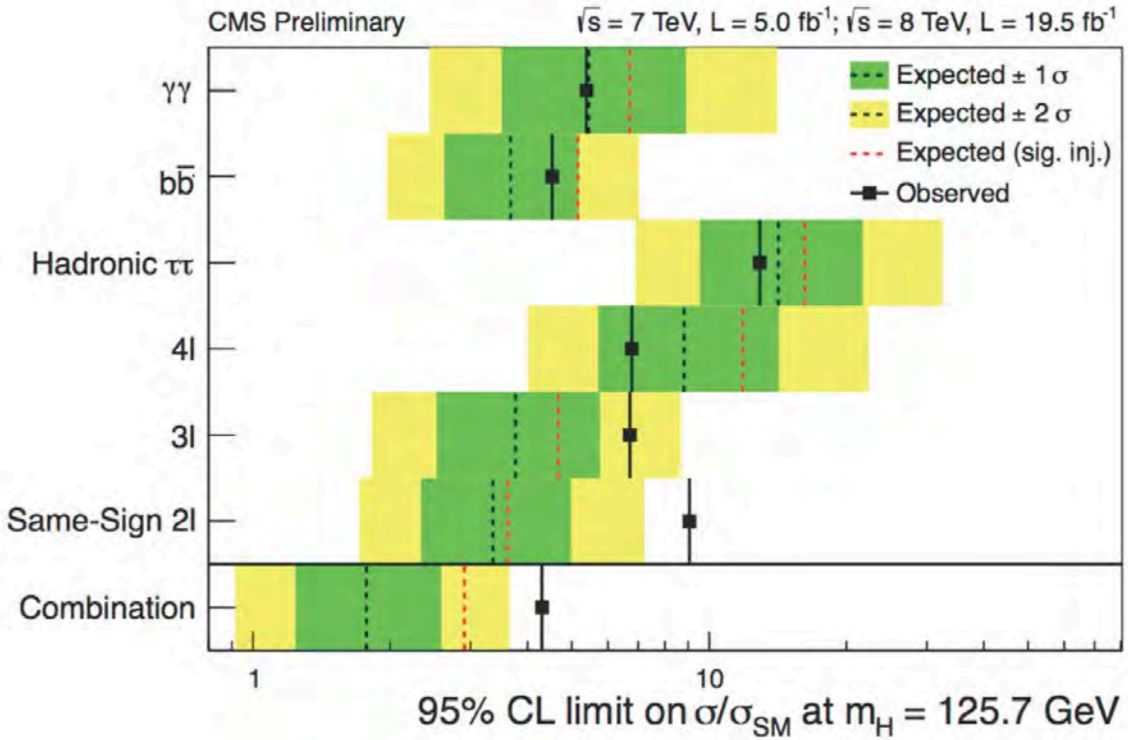
- **Tevatron has now released their final Higgs combination, based on H -> bb, WW, $\gamma\gamma$, and $\tau\tau$ (*Sforza*).**
- **P-value = 3.0σ (1.9 expected) at m_H = 125 GeV.**
- **Fitted μ = 1.49 + 0.59 - 0.56.**





Scalar Boson: New ttbarH Results

- CMS has performed a search in ttbar+H; H -> $\gamma\gamma$, bb, $\tau_h\tau_h$, leptonic (2l SS, 3l, 4l), and combined (*Botta*).
- Result is limit of μ = 4.3 (expected 2.9) 95% CL. Best fit value is μ = 2.5 + 1.1 – 1.0 (excess all in 2l SS).



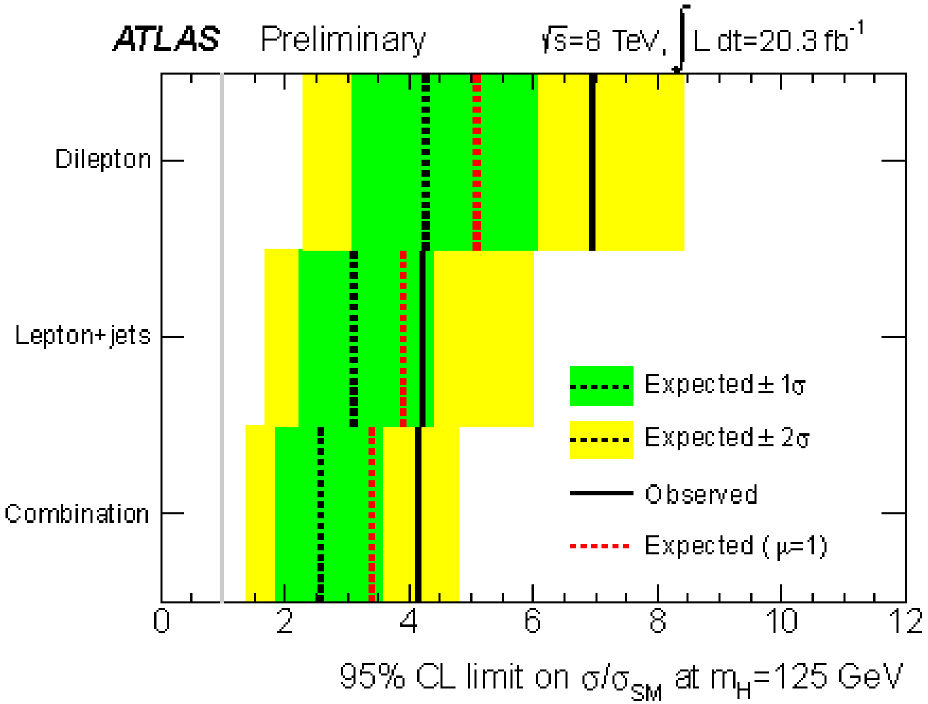
Internal consistency for common value is 22%.

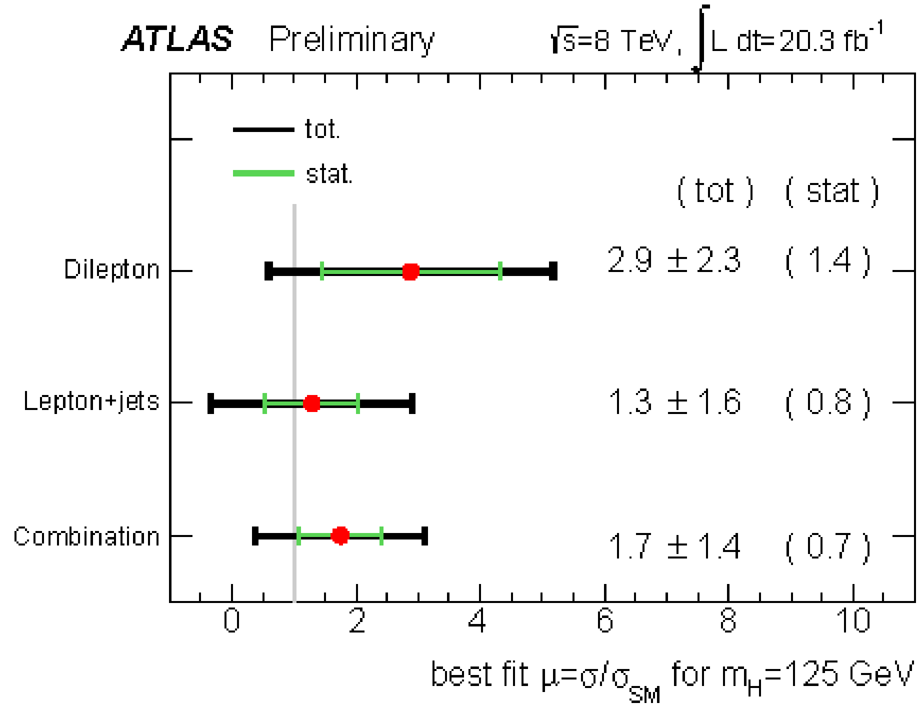
P-value for μ = 1 is 1.6σ

Note: ttbarH increases by almost 5 for Run2 @ 13 TeV

Scalar Boson: New ttbarH Results

- ATLAS has performed a search in ttbar+H; H -> γγ. Observed limit of μ = 4.7 (5.4 expected). Leptonic (2l, 3l, 4l, ττ) modes in progress (*Le Menedeu*).
- New analysis in ttbar+H; H -> bb. Result is limit of μ = 4.1 (expected 2.6) 95% CL. Best fit value is μ = 1.7 +/- 1.4





Scalar Boson: Higgs Interferometry

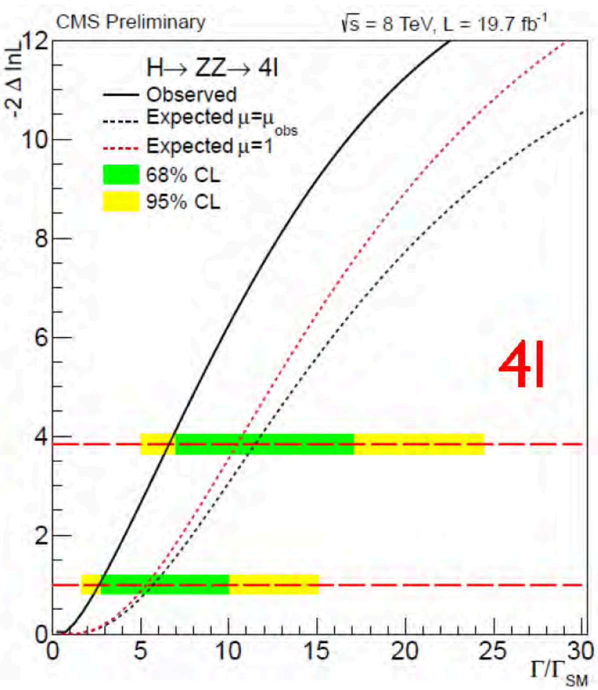
- Until recently, seemed unlikely that LHC could contribute to knowledge of Γ_H. For this reason, coupling analyses use ratios of couplings (κ).
- In 2012, Kauer and Passarino (hep-ph 1206.4803) noted that despite the 4 MeV Γ_H in the SM, the zero-width approximation is not accurate for H->ZZ far from the H pole.
- In fact 7.6% of the cross-section is above ZZ threshold (180 GeV). This off-shell contribution is independent of Γ_H, so a ratio of on-shell and off-shell cross-sections can provide information on Γ_H.
- Li and Dixon analyzed the $\gamma\gamma$ case, while Caola and Melnikov (hep-ph 1307.4935) plus Campbell, Ellis, and Williams (hep-ph 1311.3589) analyzed the ZZ case.

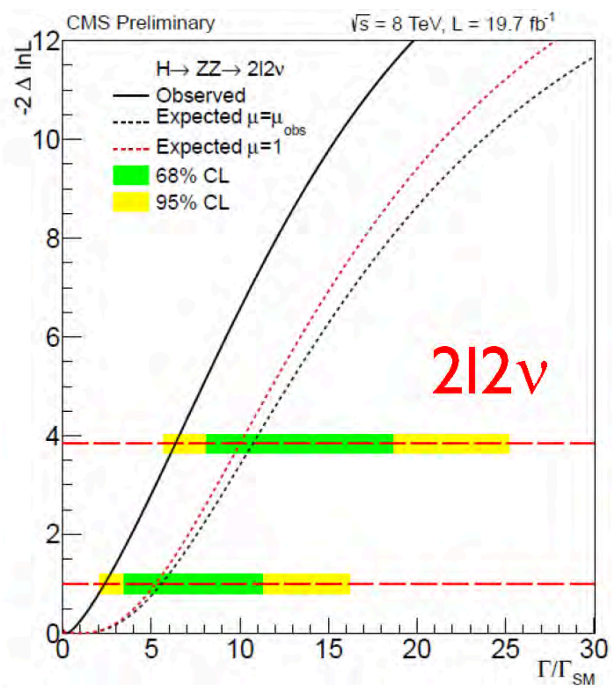
Scalar Boson: Higgs Interferometry

- At Moriond, CMS released first measurement of $r=\Gamma/\Gamma_{SM}$, using H -> ZZ decaying into 4l and 2l2ν (PAS HIG-14-002) (*Covarelli*).
- They use their published H -> ZZ on-shell cross-section value μ=0.93+0.26-0.24, and also compare with μ=1.0 for reference.
- They use a kinematic discriminant, similar to that of Campbell et al. to reduce the qq -> ZZ continuum relative to the gg signal.

At 95% CL:

Expected
r < 11.5
Observed
r < 6.6



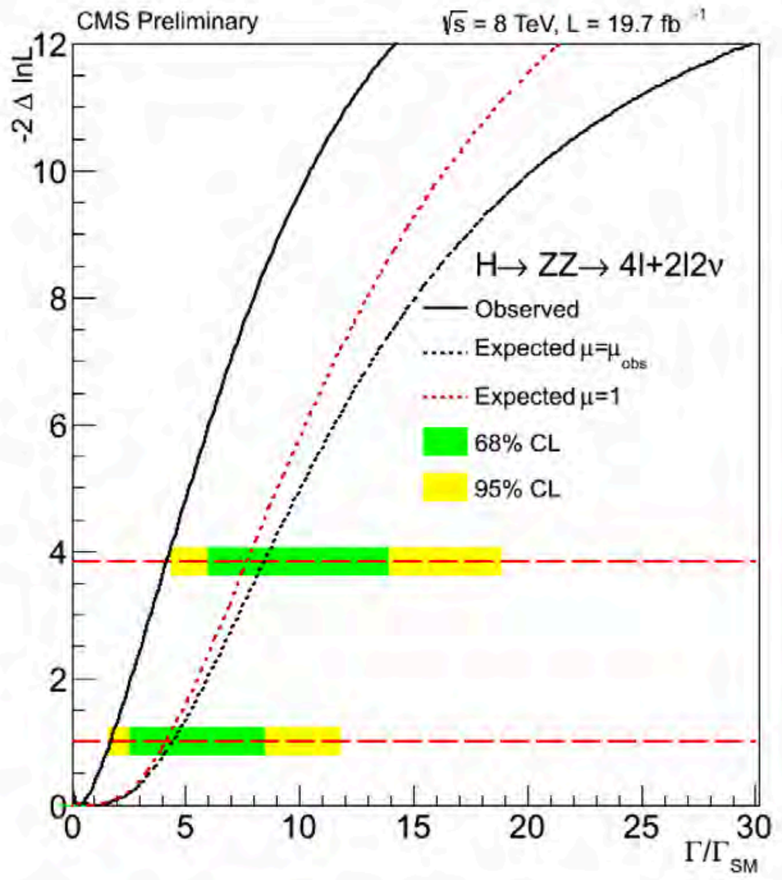


At 95% CL:

Expected
r < 10.7
Observed
r < 6.4

Scalar Boson: Higgs Interferometry

- **Combination of two channels gives:**

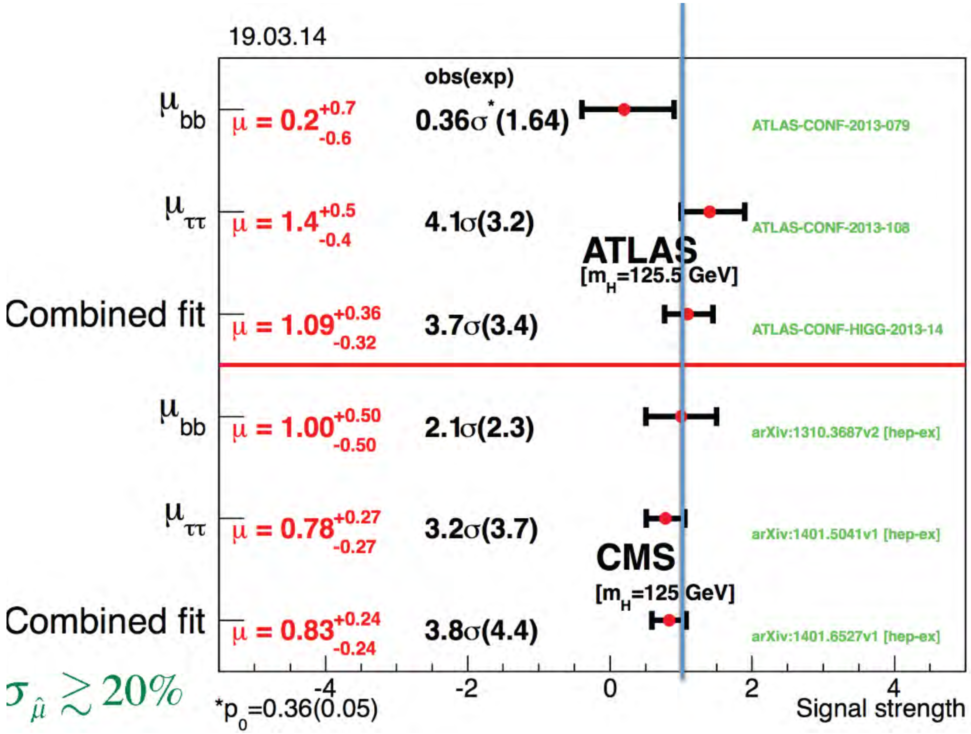


- Combined observed (expected) values
  - $r = \Gamma/\Gamma_{SM} < 4.2$ (8.5) @ 95% CL
    (p-value = 0.02)
  - $r = \Gamma/\Gamma_{SM} = 0.3^{+1.5}_{-0.3}$
- equivalent to:
  - $\Gamma < 17.4$ (35.3) MeV @ 95% CL
  - $\Gamma = (1.4^{+6.1}_{-1.4})$ MeV

Very important result ! Observed limit is half of expected – data deficits in both channels ? Theory systs (LO+K_f) under control ?

Scalar Boson: Coupling Results

- Beautiful talk covering everything we know today about the 125 GeV scalar boson couplings (*Gross*).
- Many results (ATLAS) or some results (CMS) still missing, so nothing here is final for Run1 yet.
- Status of knowledge about H -> fermion pairs:



$\sigma_{\hat{\mu}} \gtrsim 20\%$

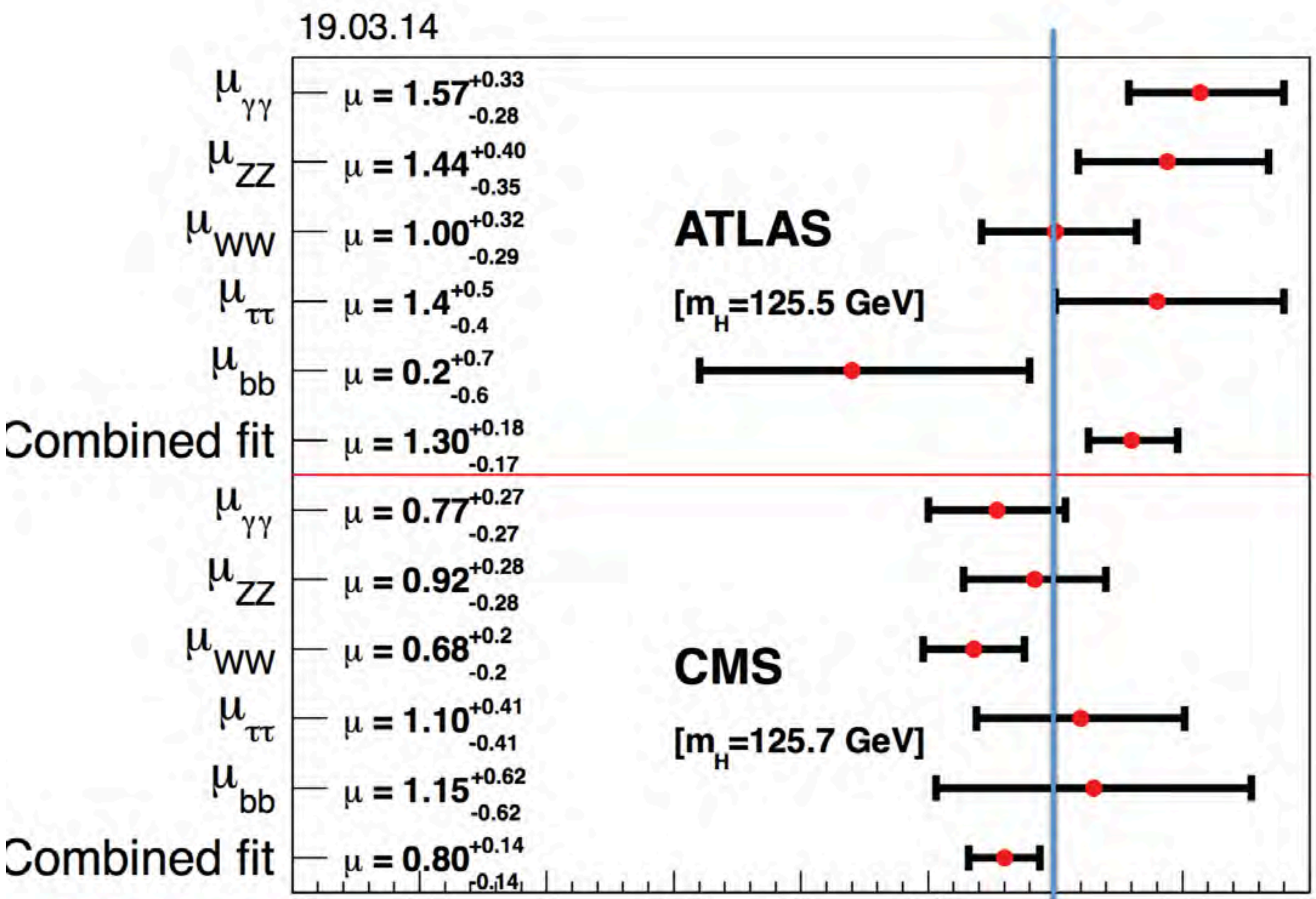
Very significant results for H->ττ (5σ combined ?)

H->bb is more difficult, waiting for final ATLAS result (3σ combined ?)

μ slightly below 1, about 20% uncertainty…

Scalar Boson: Coupling Results

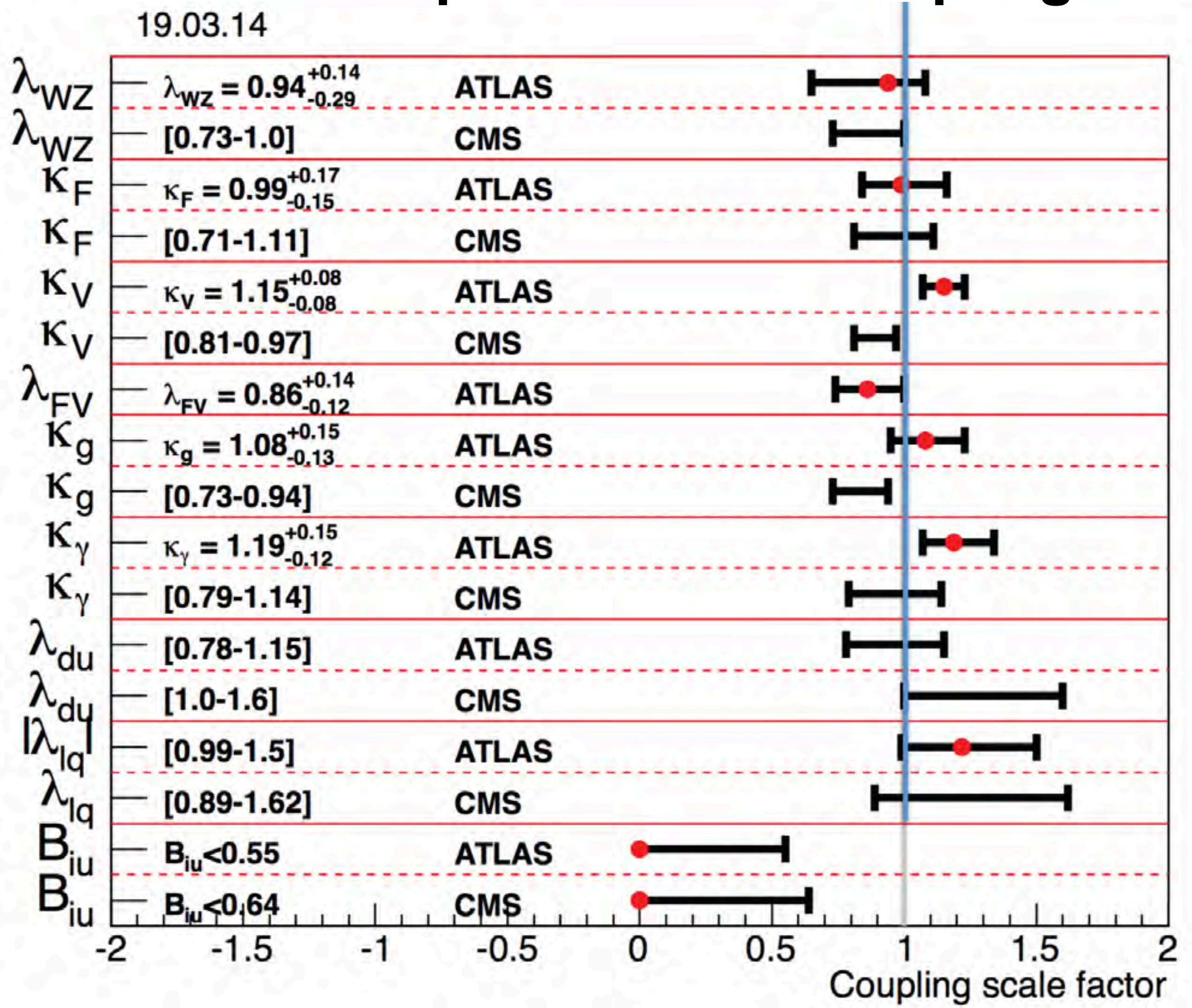
- **Overall comparison of all individual μ values:**



$\sim 1.0, \sigma_{\hat{\mu}} \gtrsim 12\%$

Scalar Boson: Coupling Results

- **Overall comparison of all coupling values:**



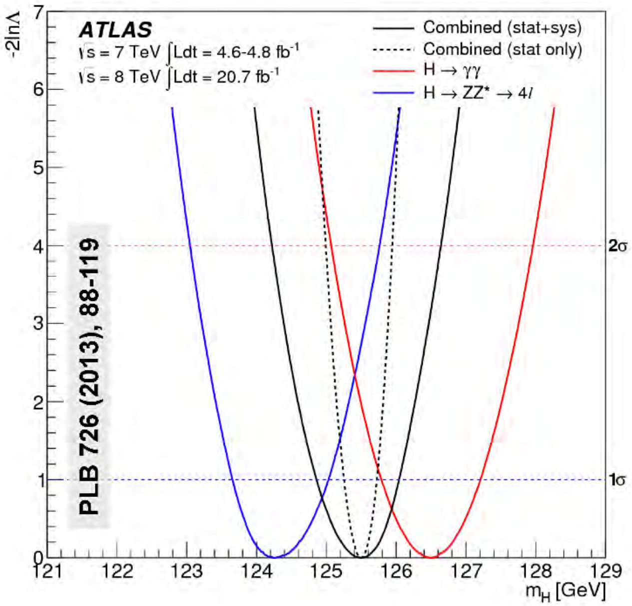
No sign of anything beyond the SM Higgs expectations !!!

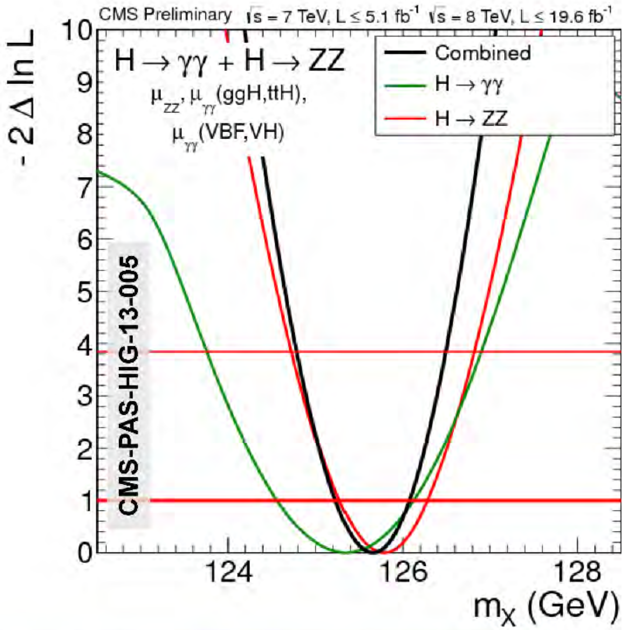
Extraordinary amount of information extracted on the scalar boson from Run1 data !

Still more to come

Scalar Boson: Properties

- **Many properties measured (mass, J^P hypothesis tests for 0^+, 0^-, 2^+), but no new results (*Musella*).**
- **Show mass today, although both experiments should produce final results on a "Summer" timescale:**





ATLAS	CMS (new ZZ(4l) not used)
125.5 +-0.2 (stat) $^{+0.5}_{-0.6}$(syst) GeV	125.7 +- 0.3(stat) +- 0.3(syst) GeV

Scalar Boson: BSM Higgs

- **Two different approaches: "indirect" using coupling results, "direct" using targeted searches (*Thompson*).**
- **Limits from recent ATLAS couplings analysis:**
  - **Minimal Composite Higgs (MCHM)**
  - **Additional EW singlet**
  - **2HDM**
  - **Simplified MSSM**
  - **Higgs Portal**

No sign of BSM Higgs (yet) !

- **Limits from direct Searches:**
  - **H -> hh, A -> Zh (CMS)**
  - **2HDM limits (CMS)**
  - **t -> cH (CMS) and t -> qH (ATLAS)**
  - **MSSM H -> $\tau\tau$ (CMS)**
  - **Charged Higgs (ATLAS)**

SUSY Limits: ATLAS

Squarks/gluinos are > O(1 TeV), Stop/sbottom > O(300-600 GeV)

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$		Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	$\tan\beta$ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	1209.0753
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	$m(\tilde{H})$>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	$m(\tilde{g})>10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2013-061
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	$m(\tilde{\chi}_1^{\pm})=2\ m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)<<m(\tilde{\chi}_1^{\pm})$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	$m(\tilde{t}_1)=m(\tilde{\chi}_1^0)$+180 GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$	125-450 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^{\pm}$	180-330 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$	600 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$	315 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$	285 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$	270 GeV	$m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<$\tan\beta$<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\rightarrow\tilde{\nu}_{\tau} + X, \tilde{\nu}_{\tau}\rightarrow e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_{\tau}$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\rightarrow\tilde{\nu}_{\tau} + X, \tilde{\nu}_{\tau}\rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_{\tau}$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\tilde{\nu}_{\mu}, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^{\pm}$	760 GeV	$m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_{\tau}$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^{\pm}$	350 GeV	$m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\rightarrow qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\rightarrow\tilde{t}_1 t, \tilde{t}_1\rightarrow bs$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\rightarrow q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\rightarrow t\bar{t}$	2 e, μ (SS)	1 b	Yes	14.3	sgluon	800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

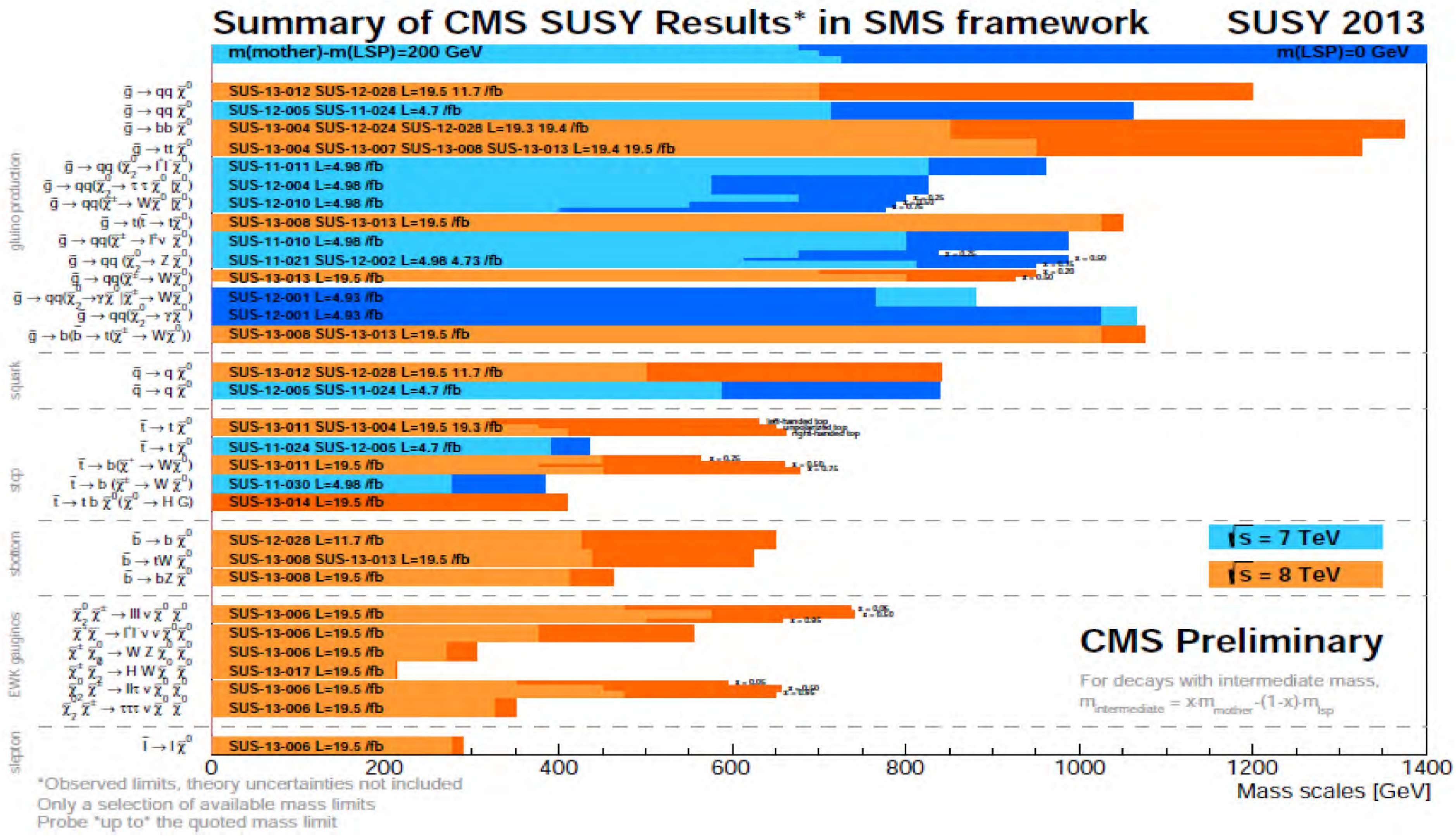
10^{-1} 1 **Mass scale [TeV]**

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

SUSY Limits: CMS

(*Bargassa, Flowerdew*)



Exotics Searches

- **Wide range of searches reported at this meeting (*Tomei Fernandez*) – no evidence for BSM…**
- **Hundreds of searches – highlighted some of the "off the beaten path" examples – limited by physicists…**
  - **Two general searches ("general phenomena", 697 classes where >0.1 event expected in SM, plus multilepton 94 classes)**
  - **Resonant X -> HH -> 4b's**
  - **Excited fermions**
  - **Lepto-quarks**
  - **Vector-like quarks (general area of "Top partners")**

- ***Leaving few (but surely some !) stones un-turned.***
- ***Run2 @ 13 TeV will rapidly open new opportunities !!!***

Summary of Summary

- **Huge range of new results since Moriond 2013 – we live in data-driven times ! Final LHC Run1 results still to come (2012 data) – mostly “consolidation”, or ???**
- **Properties of new scalar boson continue to look more and more like THE SM Higgs boson, though very large phase space remains for BSM Higgs (or other !) models.**
- **Many impressive neutrino results, but νSM still very far from clear - major open questions will take time…**
- **Much improved DM limits – SUSY WIMPs squeezed ?**
- ***MAJOR* cosmology result with indirect observation of gravity waves from inflationary period !!!**
- **No signs of SUSY or Exotica, though hints of anomalies in heavy flavor and neutrino sectors**
- **Naturalness is looking decidedly less natural…**