Highlights of Experimental Results at Moriond-QCD

Arun Nayak
(DESY-CMS Group)

LHC-Discussion
04th May 2015

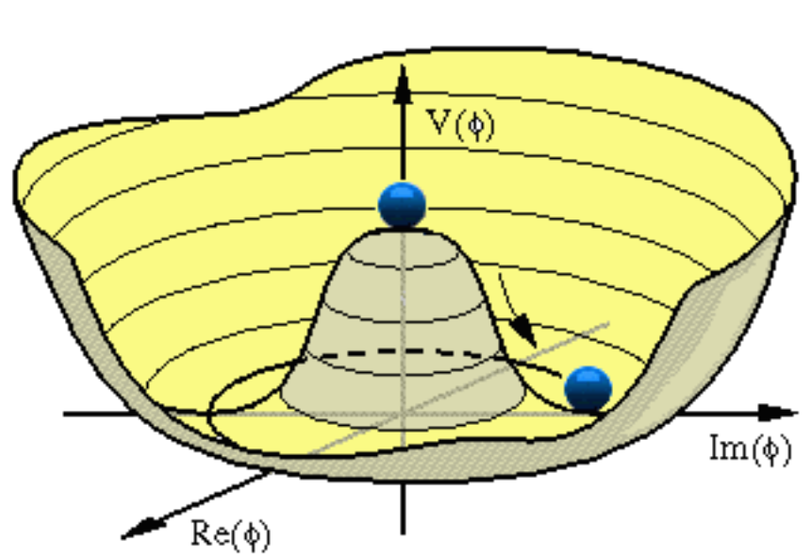
Overview

- Goal of this talk:
  - As the strategy of the conference, more time was devoted to topics other than electroweak and Higgs
  - Will try to highlight some important results from each session
    - I may have excluded some important results/topics due to my ignorance
- Disclaimer:
  - I will not discuss any results from heavy ion and Onia
  - Some slides are taken from summary talk of T LeCompte

Higgs Results

Speakers:

- Christos Anastopoulos
- Tatsuya Masubuchi
- Andrew Mehta
- Aruna Nayak
- Roko Plestina
- Si Xie

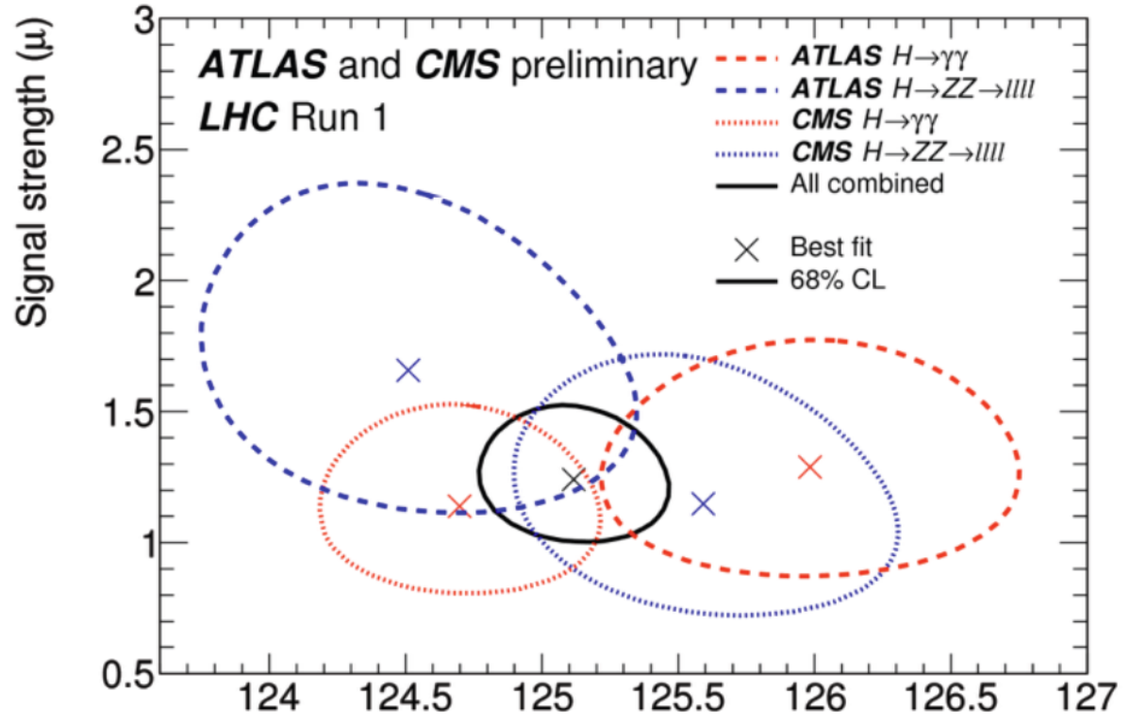


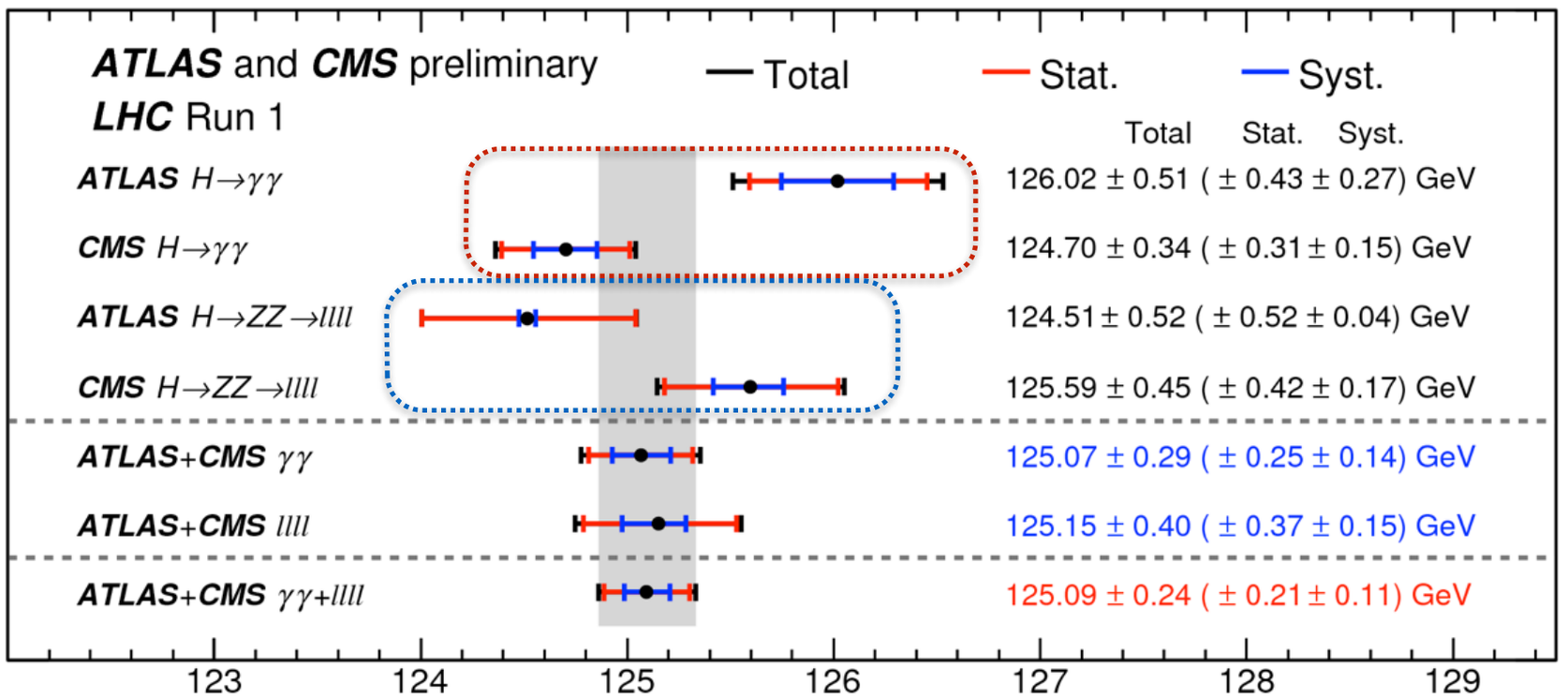
Higgs Mass

$m_H = 125.09 \pm 0.24$ (± 0.21 (stat) ± 0.11 (syst)) GeV

Consistent with one Higgs boson, as opposed to two

The measurement is still statistically limited



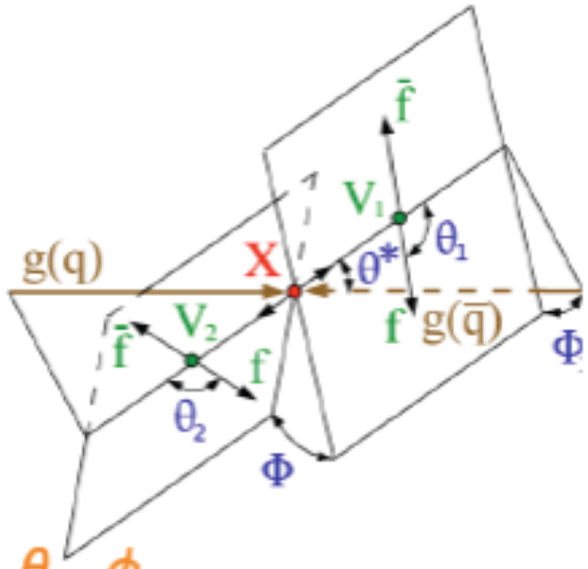


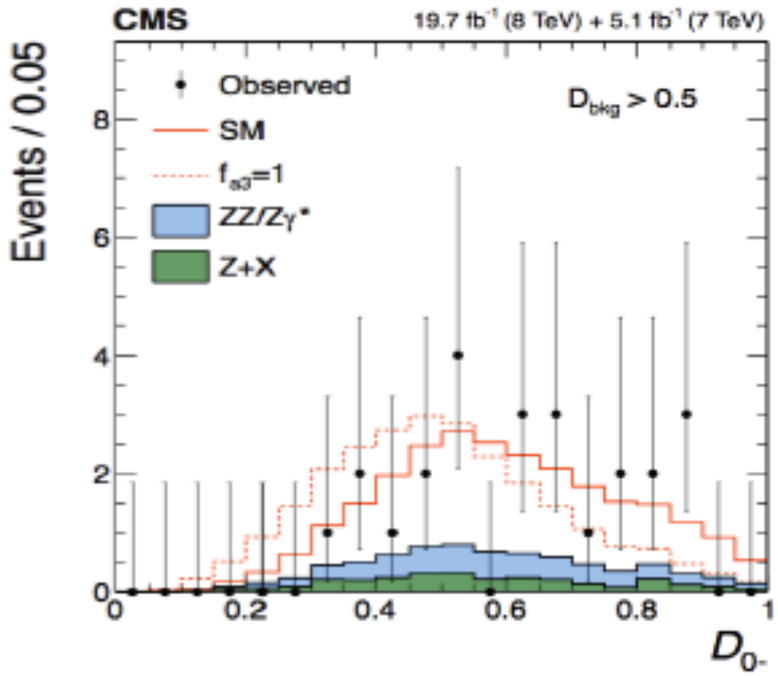
Spin & Parity

- **H→ZZ→4l :**
  - **ME based discriminant with angle and mass variables**

$$D_{J^P} = \left[1 + \frac{P^{kin}_{J^P}(m_1, m_2, \vec{\Omega} \mid m_{4l})}{P^{kin}_{SM}(m_1, m_2, \vec{\Omega} \mid m_{4l})} \right]^{-1}$$

$\theta^*, \phi_1, \theta_1, \theta_2, \phi$

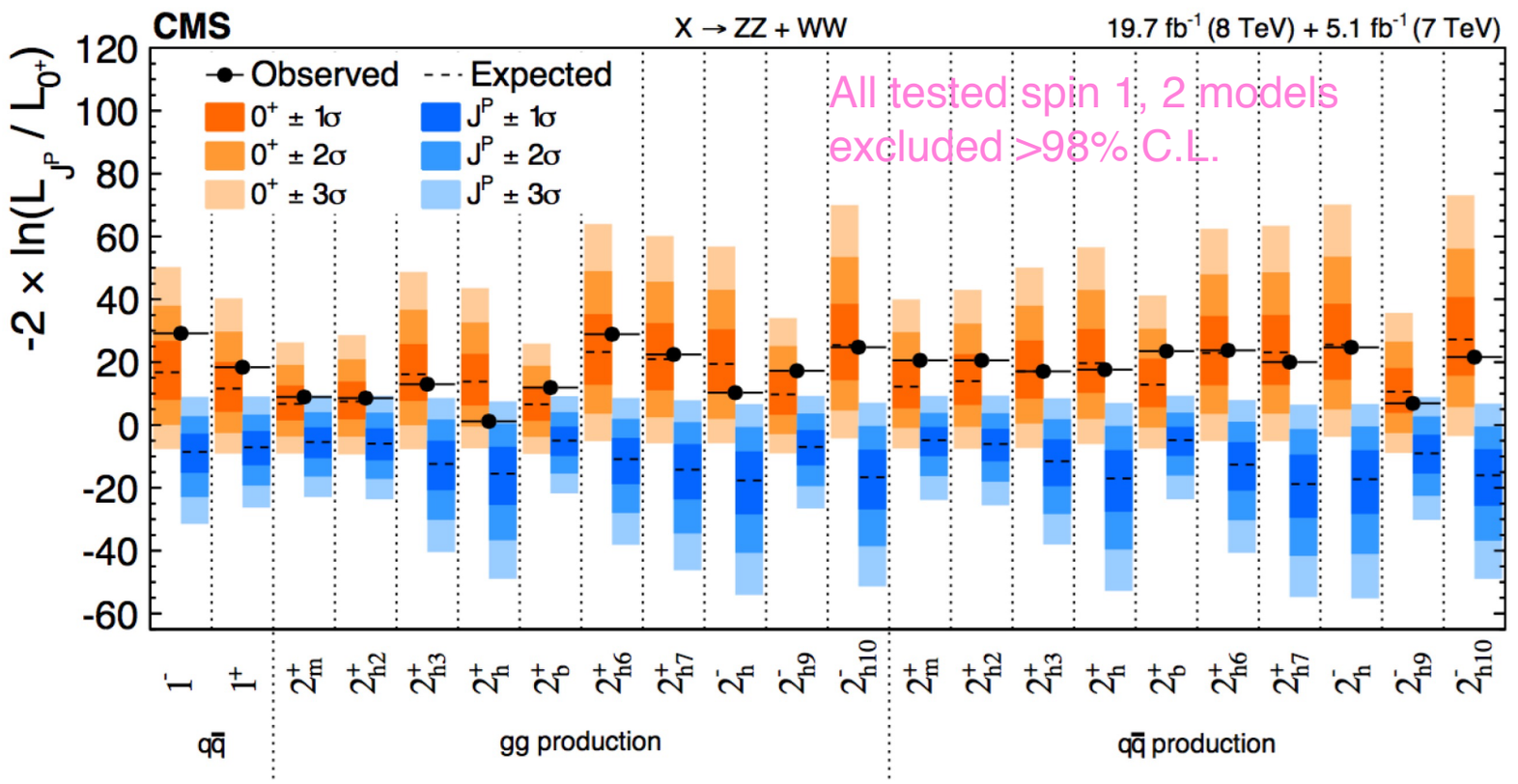




- **H→WW→2l :**
  - **ATLAS : BDT with Spin/CP sensitive variables($\Delta\phi_{ll}$, p_T^{ll}, m_{ll}...)**
  - **CMS : m_{ll}-m_T 2D fitting**
- **H→ $\gamma\gamma$:**

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma})^2}} \frac{2p_T^{\gamma 1} p_T^{\gamma 2}}{m_{\gamma\gamma}^2}$$

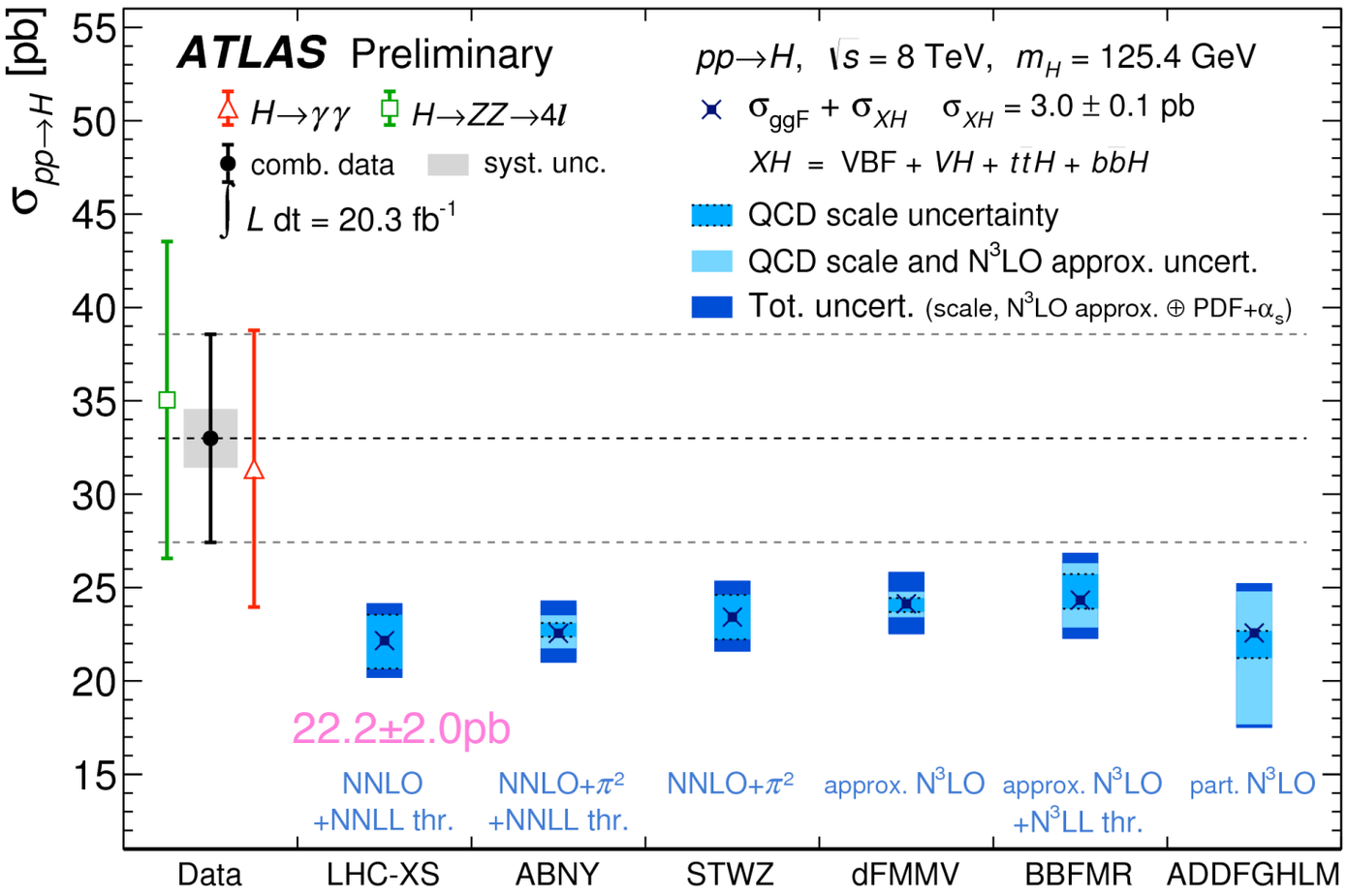
(in Collins-Soper frame)

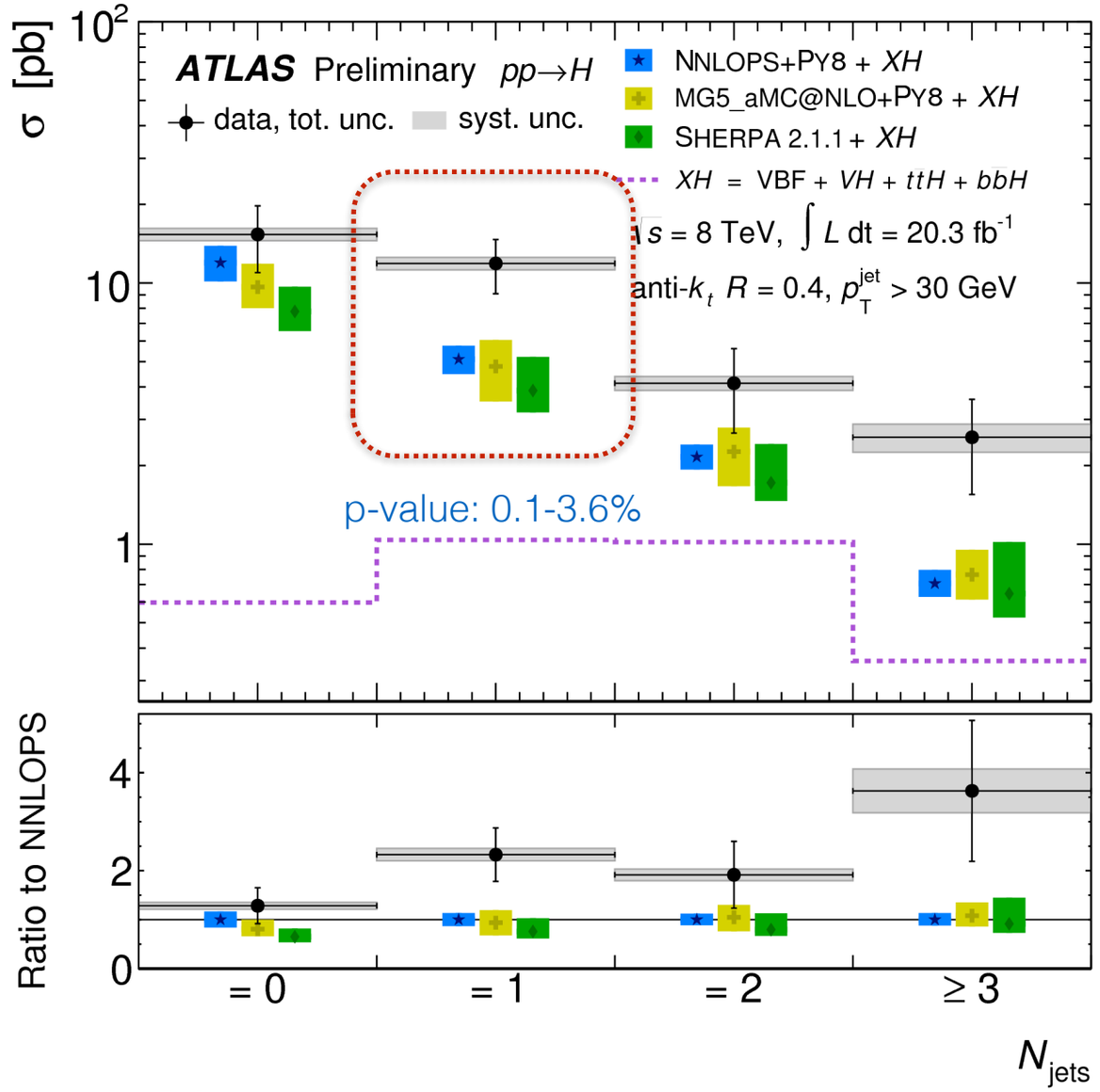


Cross section Measurements

- **Total cross section combined H→ZZ→4l and H→ $\gamma\ \gamma$**

$$\sigma = \frac{\sigma_{fid}}{\alpha}$$ ← Acceptance factor (fid.→incl.)



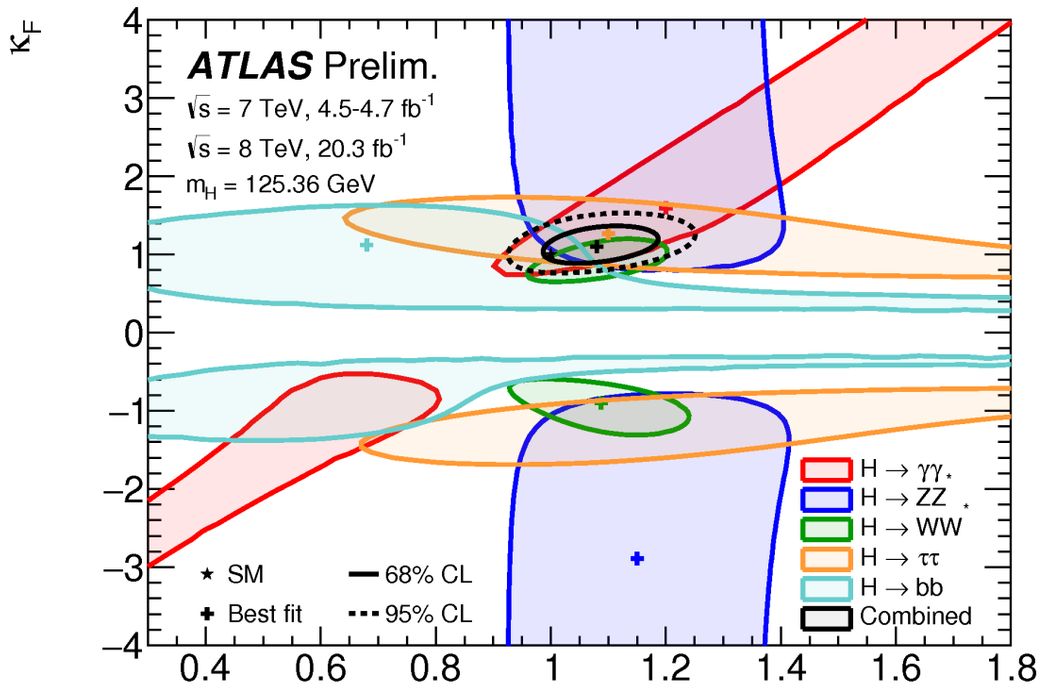


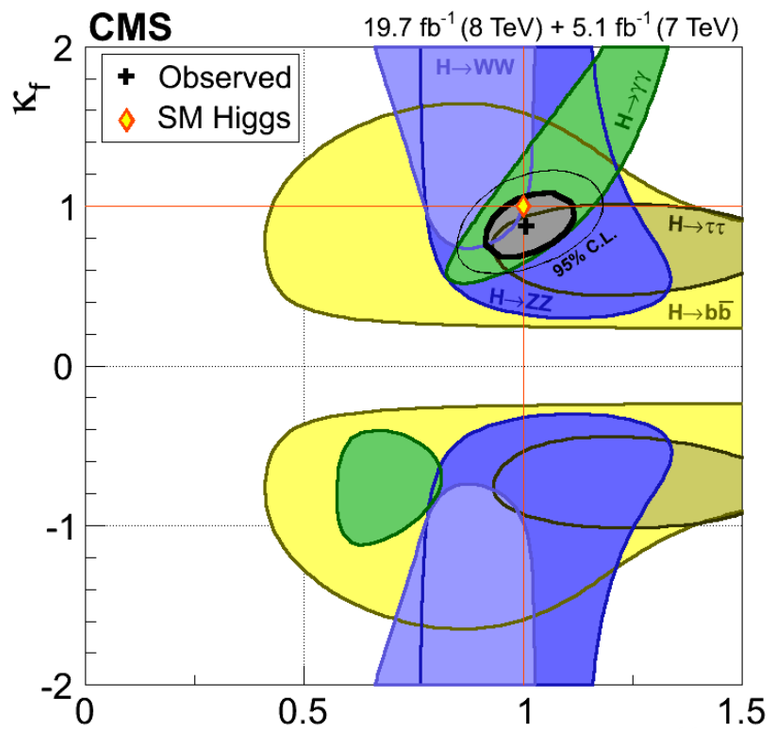
$\sigma_{pp\to H}$ = 33.0±5.3(stat)±1.6(sys)pb

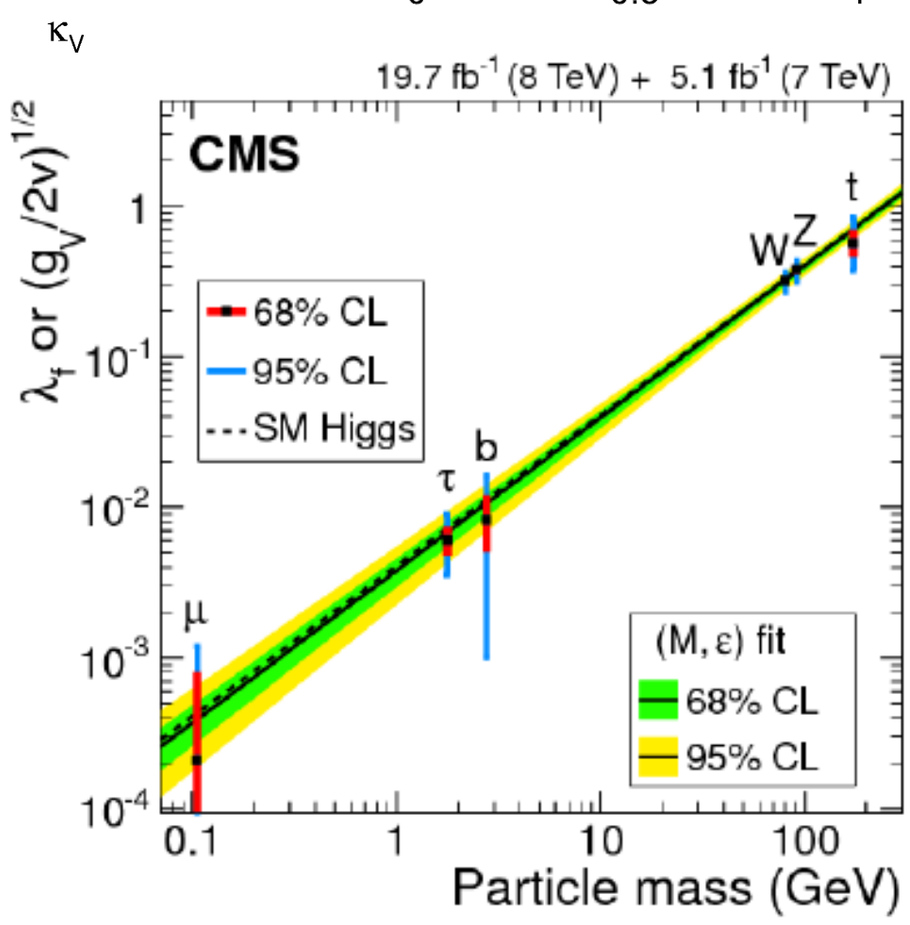
Slightly higher than theory calculation (lowest p-value 5.5% at LHC-XS)

Couplings

- Searches for a 2nd Higgs have come up negative
- Couplings look as predicted, to within the experiment's ability to measure
  - Note that the top coupling comes from the production, not from ttH







$$\lambda = \kappa_f \frac{m_f}{vev}$$

$$\left(\frac{g_V}{2vev}\right)^{1/2} = \kappa_V^{1/2}\frac{m_V}{vev}$$

Higgs to Fermions

	VH, H→bb Obs. (Exp.)	H→$\tau\tau$ Obs. (Exp.)	H→fermions Obs. (Exp.)
ATLAS	**1.4** (2.6)σ	**4.5** (3.4)σ	**4.5** σ (obs.)
CMS	**2.0** (2.5)σ	**3.2** (3.7)σ	**3.8** (4.4)σ

- Close to 5 sigma evidence for Higgs decays to fermions (If CMS and ATLAS results are combined)
- Higgs to tau decay is the most significant
- The best evidence for Higgs to b decays is still from Tevatron

ttH

95% CL upper limit on σ/σ_{sm}

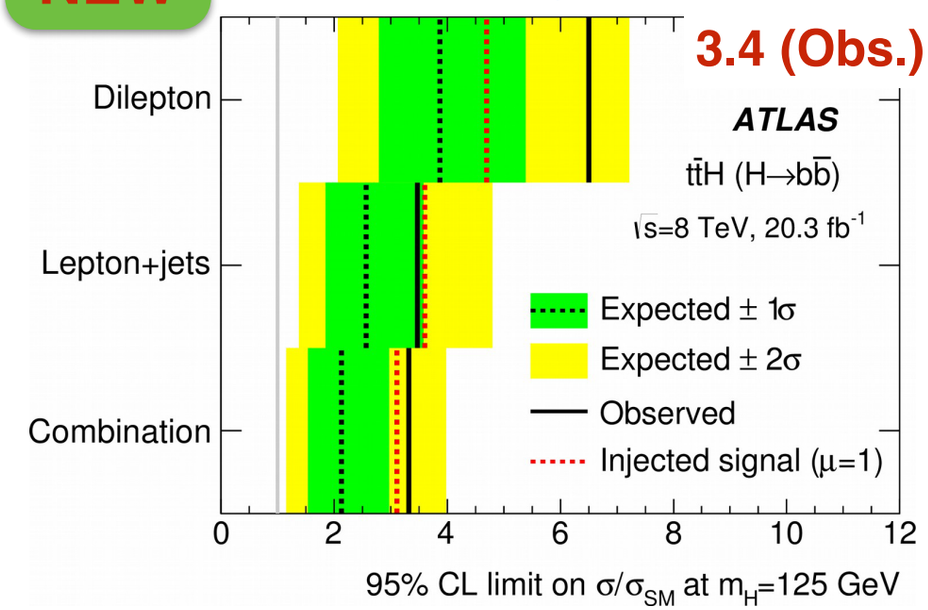
ATLAS: arXiv:1503.05066

CMS-HIG-13-029

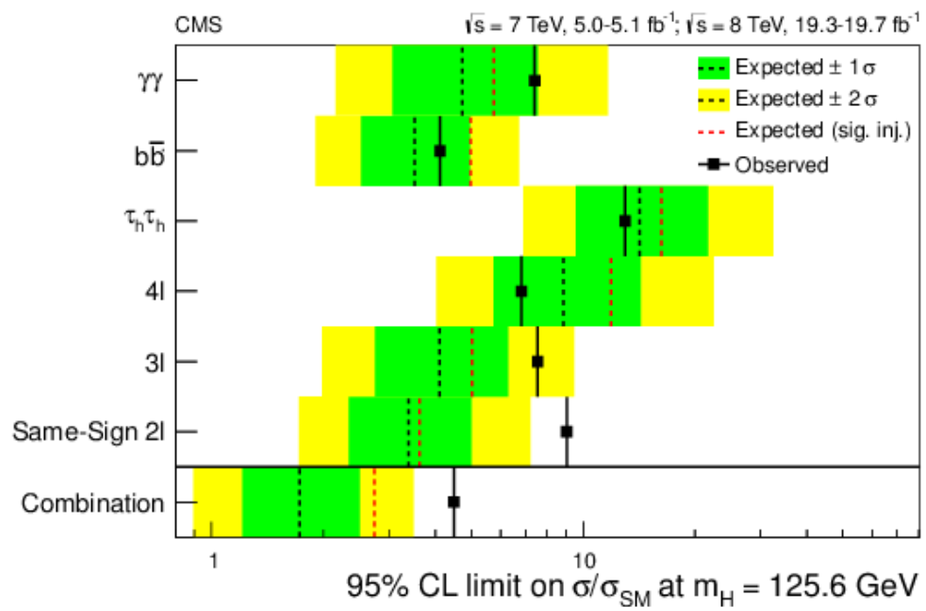
NEW

ATLAS ttH, H→bb

3.4 (Obs.) / 2.2 (Exp.)

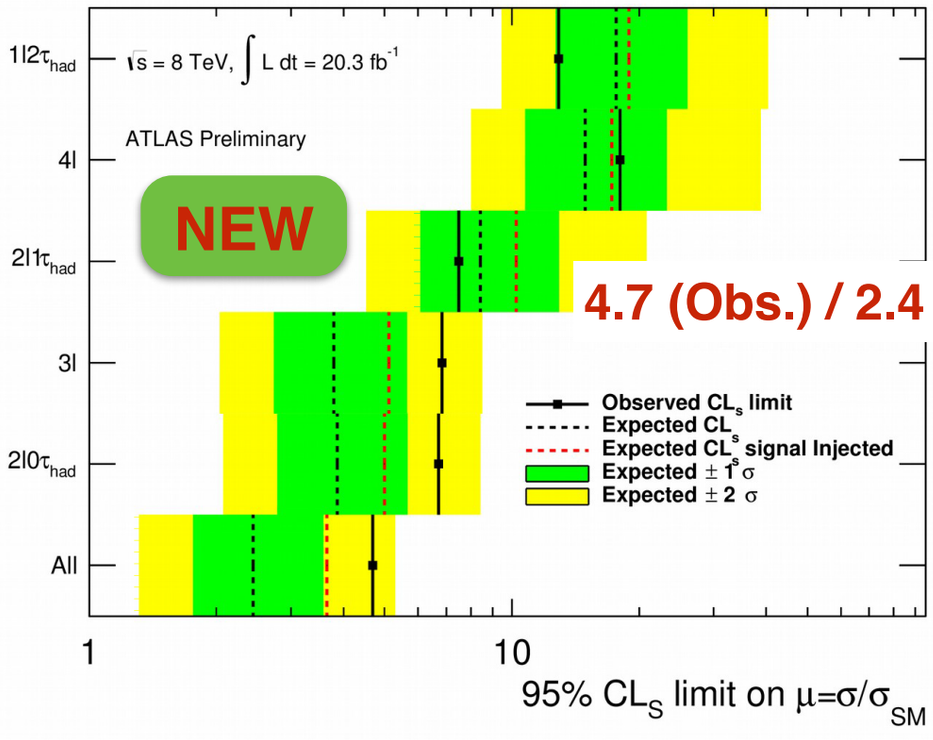


CMS ttH combination

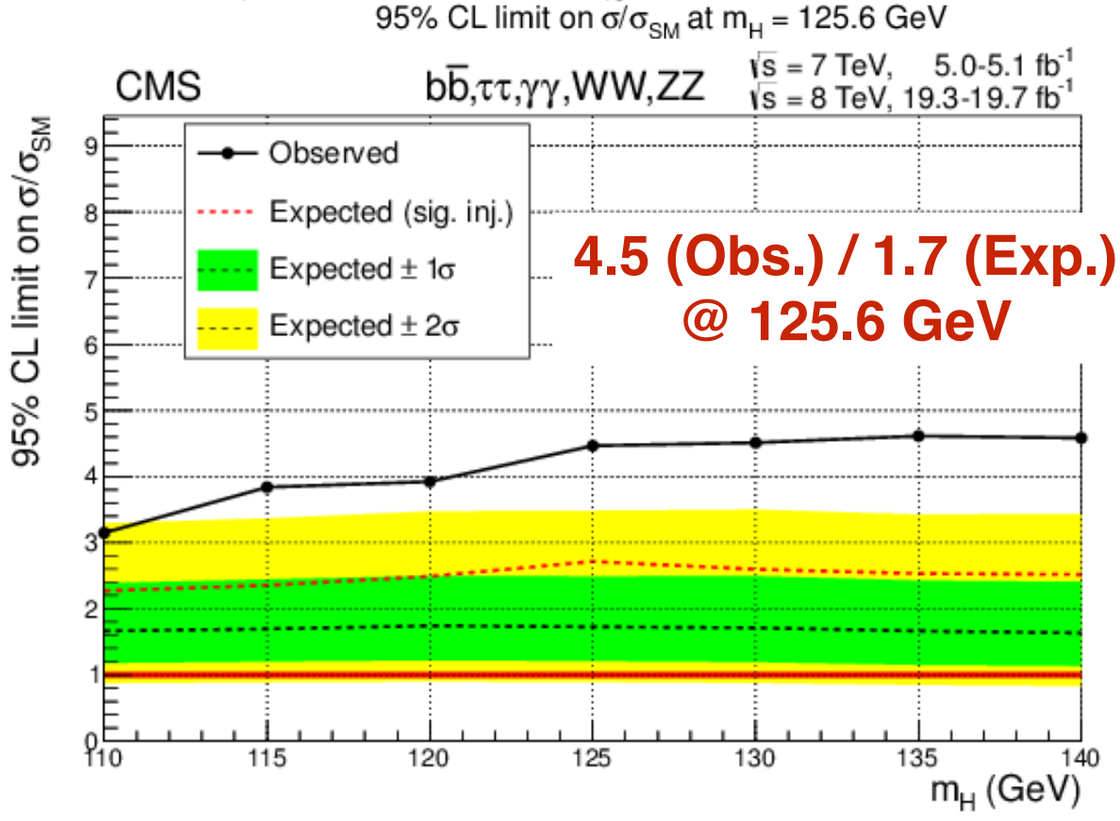


ATLAS-CONF-2015-006

ATLAS ttH, H→WW/$\tau\tau$

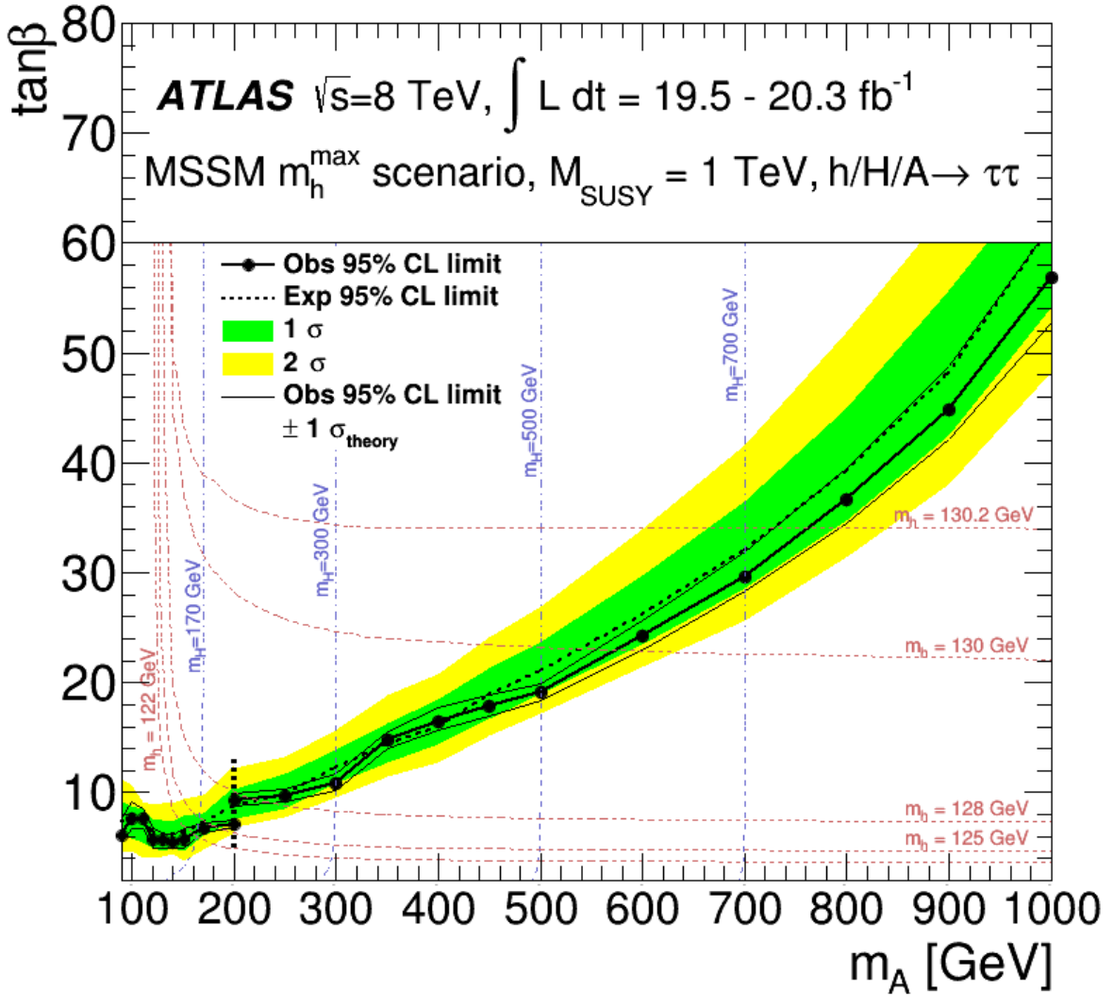


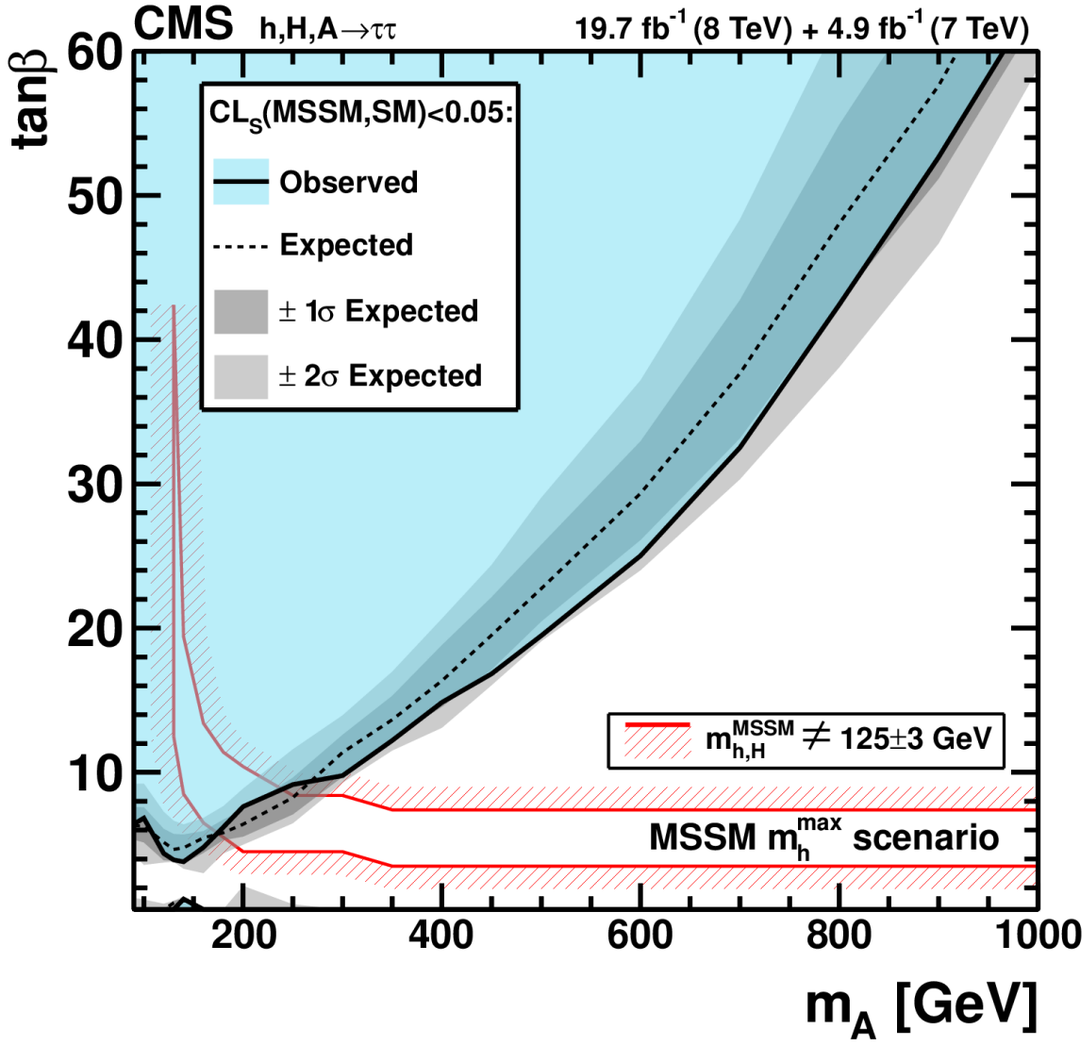
4.7 (Obs.) / 2.4 (Exp.)



4.5 (Obs.) / 1.7 (Exp.) @ 125.6 GeV

BSM Higgs





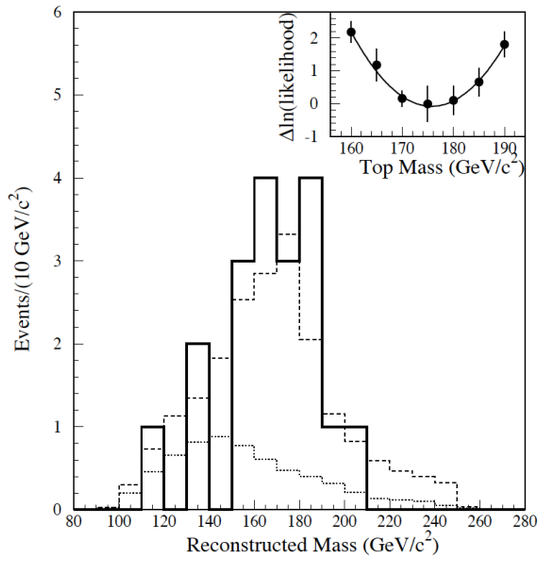
- Analysed in MSSM (type II) models
- Best exclusion at high tan β up to large masses

- **Also results at low tanβ: H→hh, A→Zh**
- **Charged Higgs searches: pp→tt~, t→bH⁺ ($m_H < m_t$) & pp→tH⁺/tbH⁺ ($m_H > m_t$)**

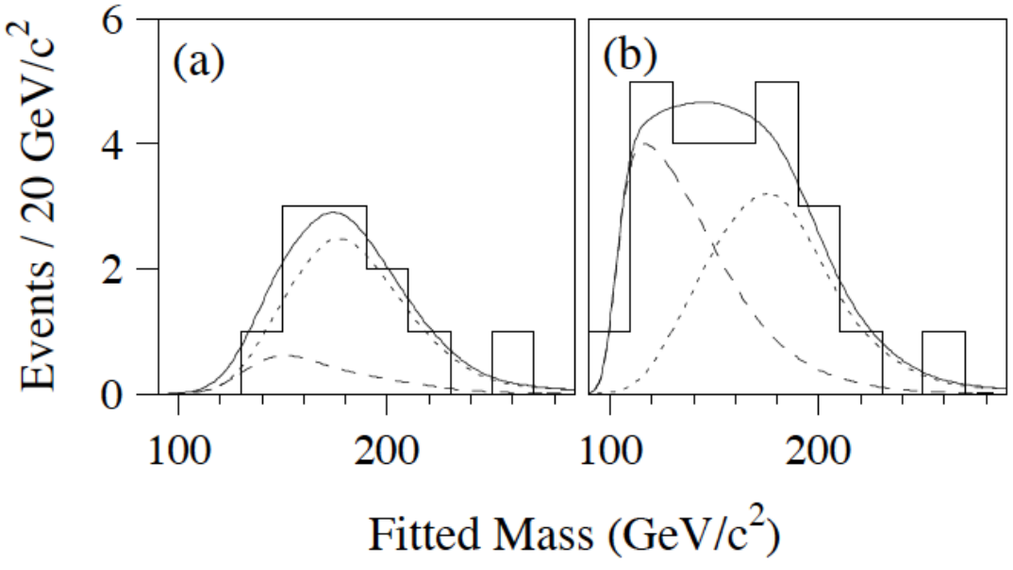
Top Quark

Speakers:

- Fabrice Balli
- Gabriele Benelli
- Oleg Brandt
- Yuan Chao
- Matteo Cremonesi
- Carlos Escobar



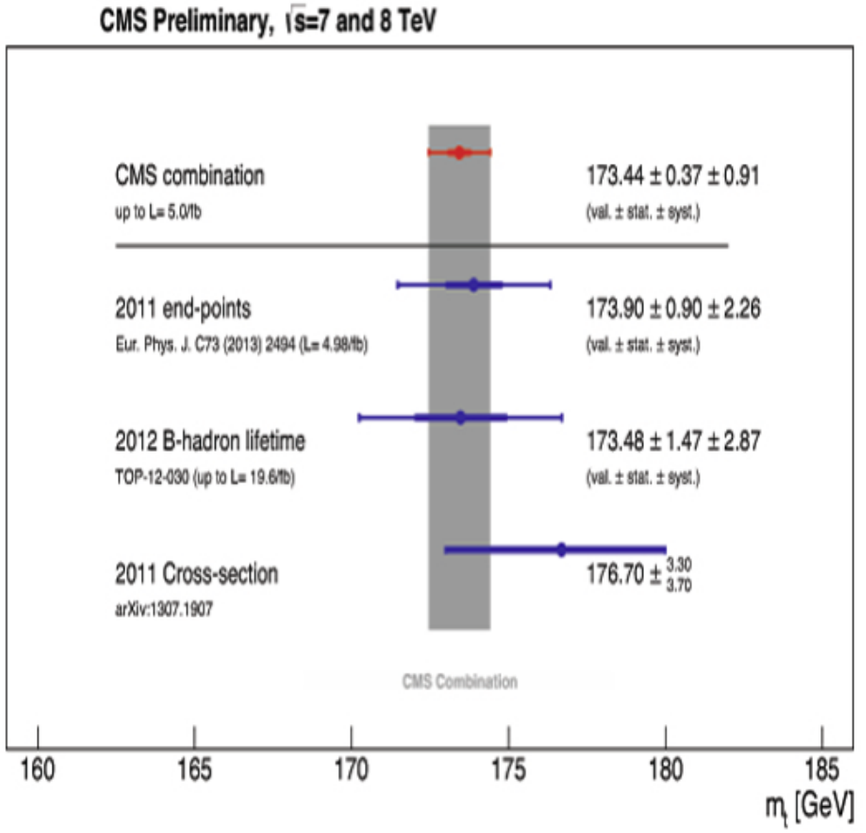
CDF: Phys.Rev.Lett.74:2626 (1995)

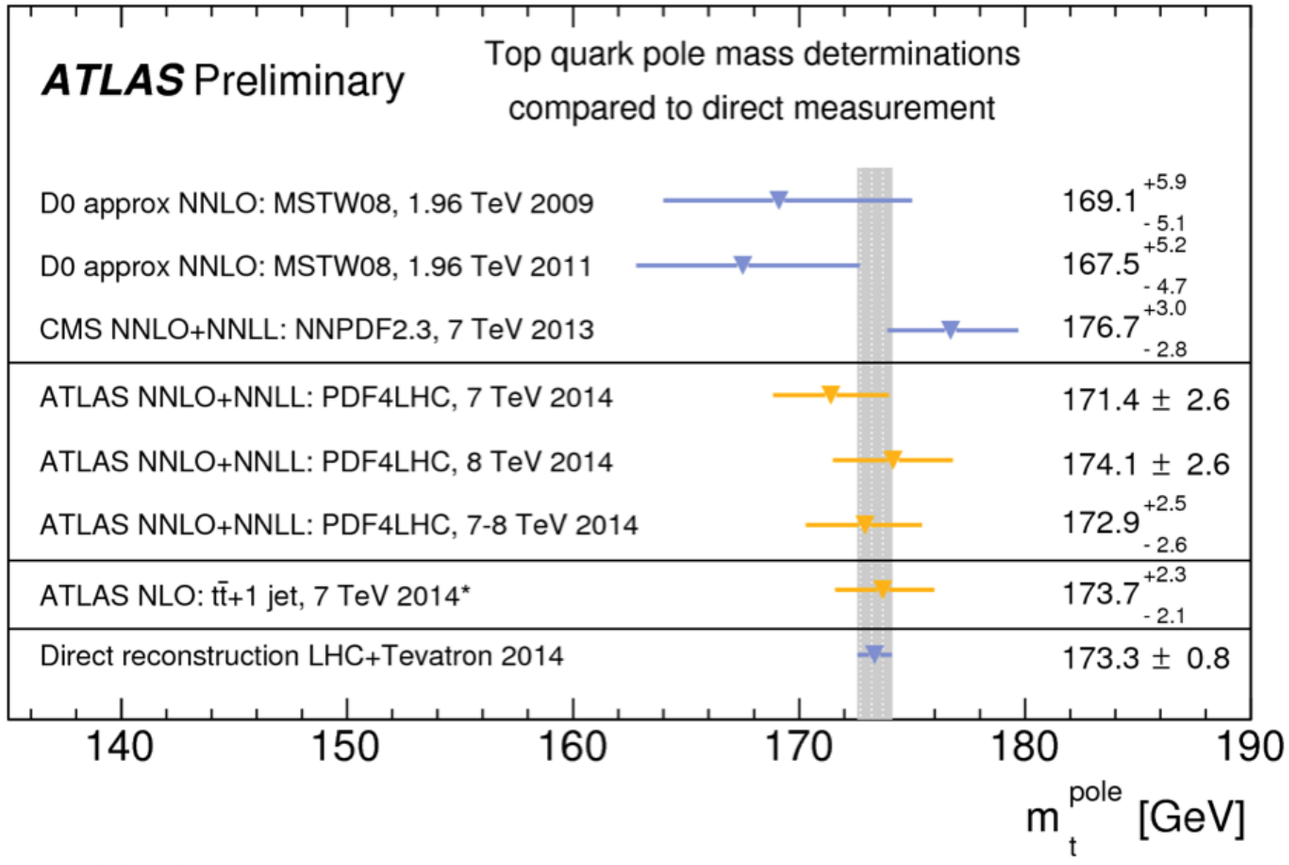


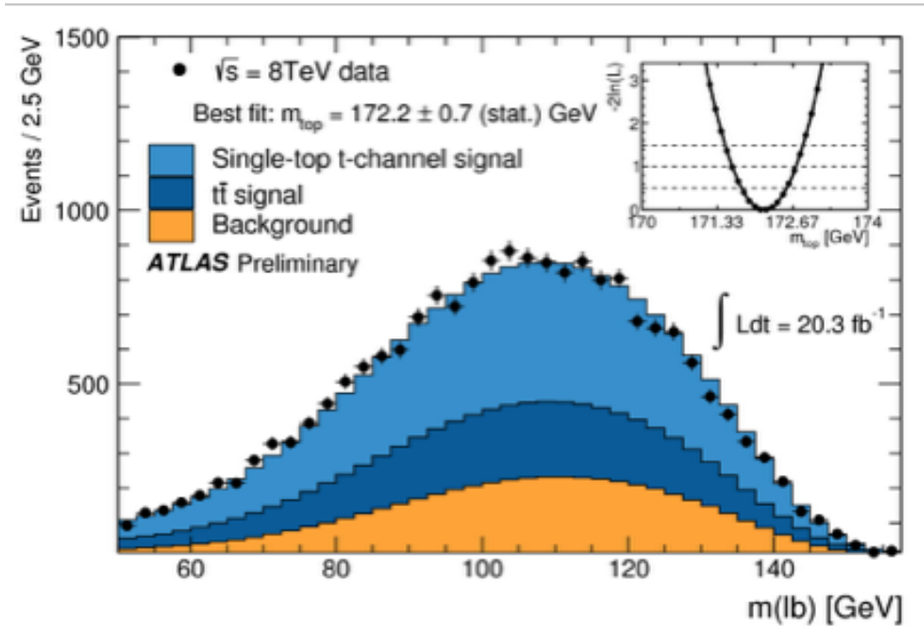
D0: Phys.Rev.Lett.74:2632-2637,1995

Top mass

- In-situ JES calibration
- Top mass measurements also from single top events
- Determination of poll mass from cross section measurements

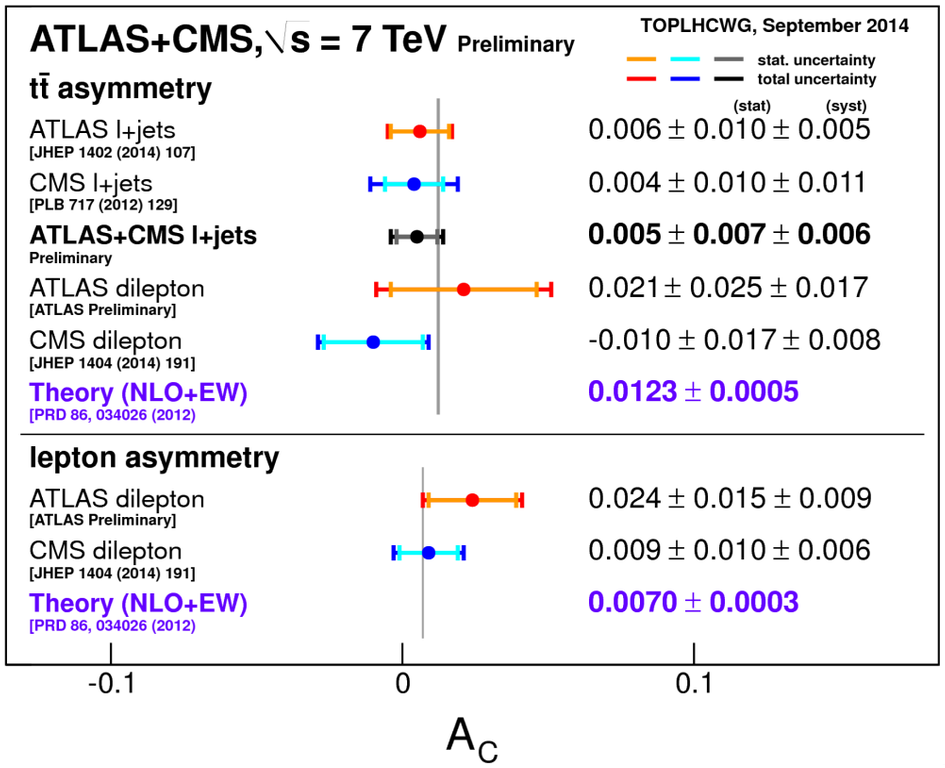


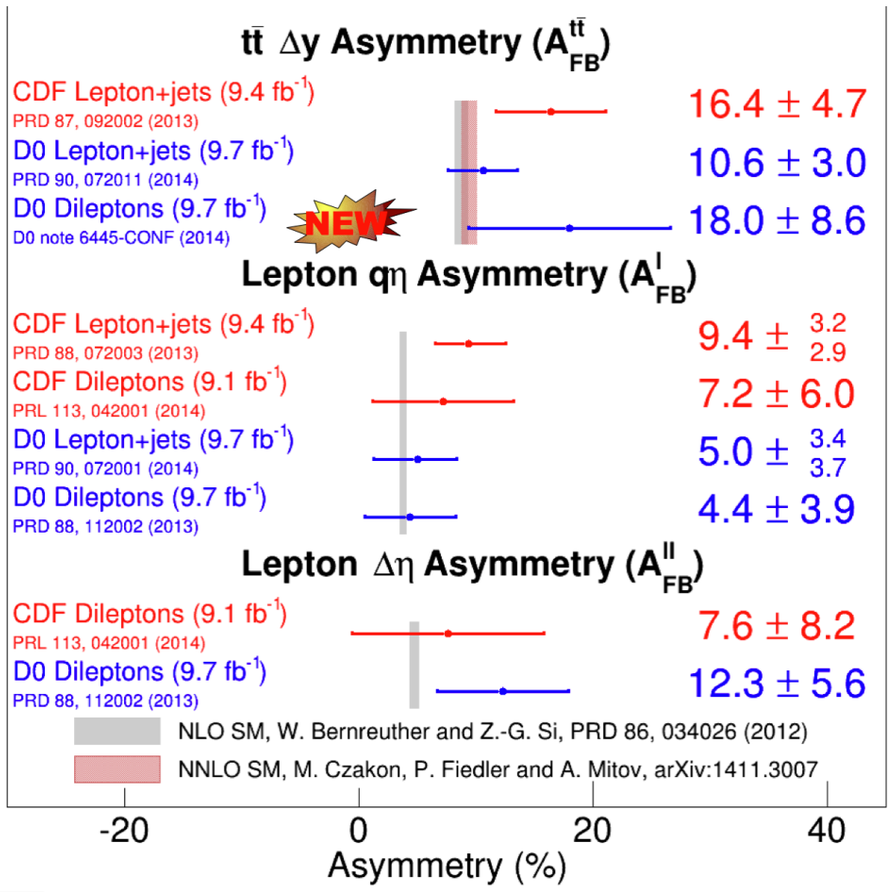


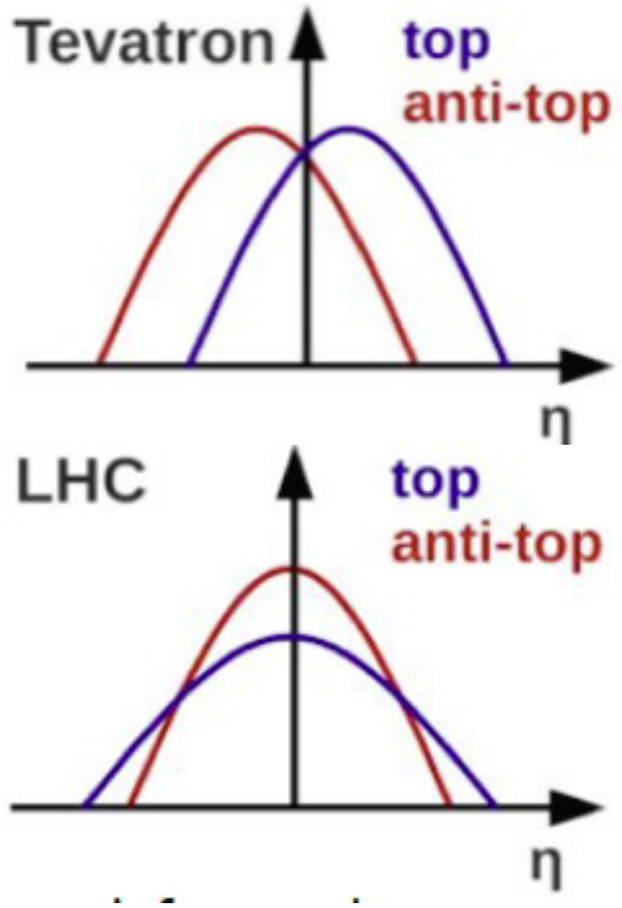


Top Asymmetry

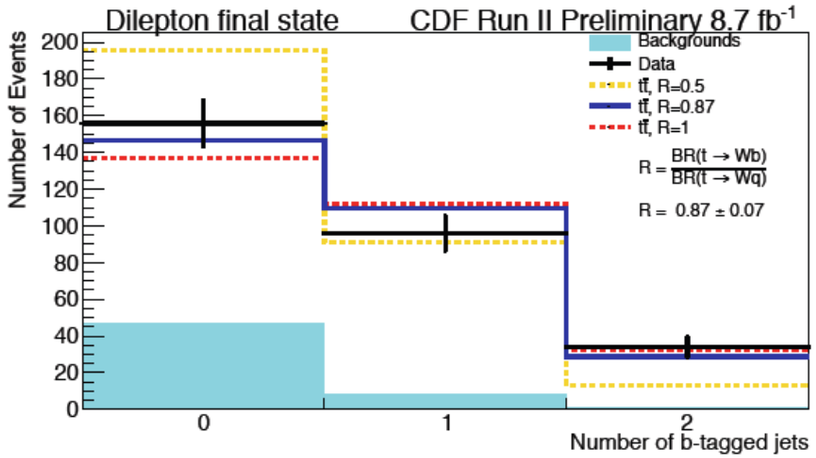
- New Results from D0 and LHC
- Consistent with theory predictions
  - The LHC asymmetry changes from forward-backward to narrow-wide







V_{tb} Measurement



Single top production allows direct measurement of V_{tb}: $\sigma \sim |V_{tb}|^2$

R = 0.87 ± 0.07 (stat.+syst)

$|V_{tb}|$ = 0.93 ± 0.04 (stat.+syst)

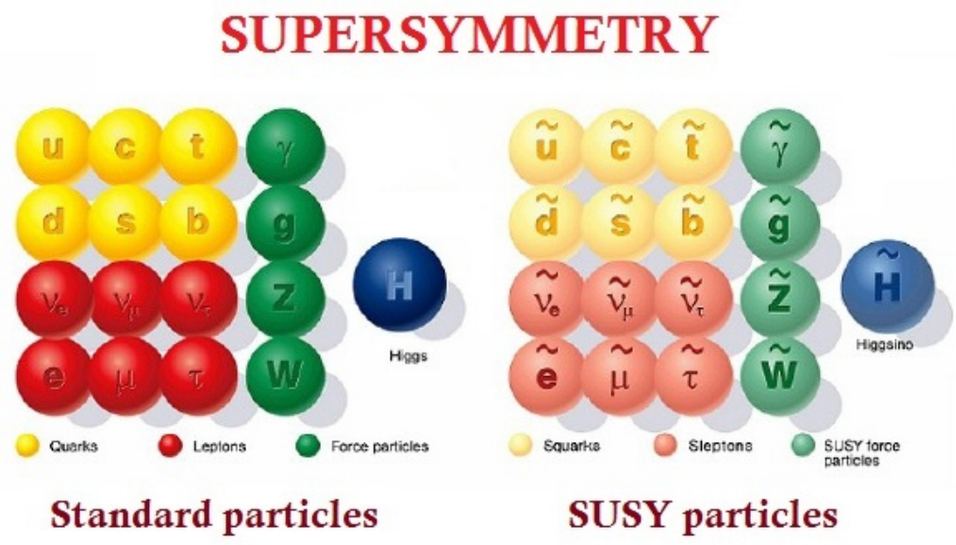
PRL 112 221801

• *Wt*-channel (7 TeV, 4.9 fb^{-1}) PRL110 (2013) 022003	$\|V_{tb}\| = 1.010^{+0.163}_{-0.196}$ (16%)	$\|V_{tb}\| > 0.79$ @ 90 C.L.
• *Wt*-channel (8 TeV, 12.2 fb^{-1}) PRL 112 (2014) 231802	$\|V_{tb}\| = 1.030 \pm 0.127$ (12%)	$\|V_{tb}\| > 0.78$ @ 95 C.L.
• *t*-channel (7 TeV, 1.17/1.56 fb^{-1}) JHEP12 (2012) 035	$\|V_{tb}\| = 1.029 \pm 0.049$ (5%)	$\|V_{tb}\| > 0.92$ @ 95 C.L.
• *t*-channel (8 TeV, 19,7 fb-1) JHEP06 (2014) 090	$\|V_{tb}\| = 0.979 \pm 0.048$ (5%)	-
• *t*-channel (7 and 8 TeV combined) JHEP06 (2014) 090	$\|V_{tb}\| = 0.998 \pm 0.041$ (4%)	$\|V_{tb}\| > 0.92$ @ 95 C.L.
• *t*-channel (7 TeV, 4.6 fb^{-1}) PRD 90 112006 (2014)	$\|V_{tb}\| = 1.02 \pm 0.07$ (7%)	$\|V_{tb}\| > 0.88$ @ 95 C.L.
• *t*-channel (8 TeV, 20.3 fb^{-1}) ATLAS-CONF-2014-007	$\|V_{tb}\| = 0.97^{+0.09}_{-0.10}$ (10%)	$\|V_{tb}\| > 0.78$ @ 95 C.L.
• *Wt*-channel (8 TeV, 20.3 fb^{-1}) ATLAS-CONF-2013-100	$\|V_{tb}\| = 1.10 \pm 0.12$ (11%)	$\|V_{tb}\| > 0.72$ @ 95 C.L.
• *Wt*-channel (8 TeV) ATLAS-CONF-2014-052 CMS-PAS-TOP-14-009	$\|V_{tb}\| = 1.06 \pm 0.11$ (10%)	$\|V_{tb}\| > 0.79$ @ 95 C.L.

BSM Searches

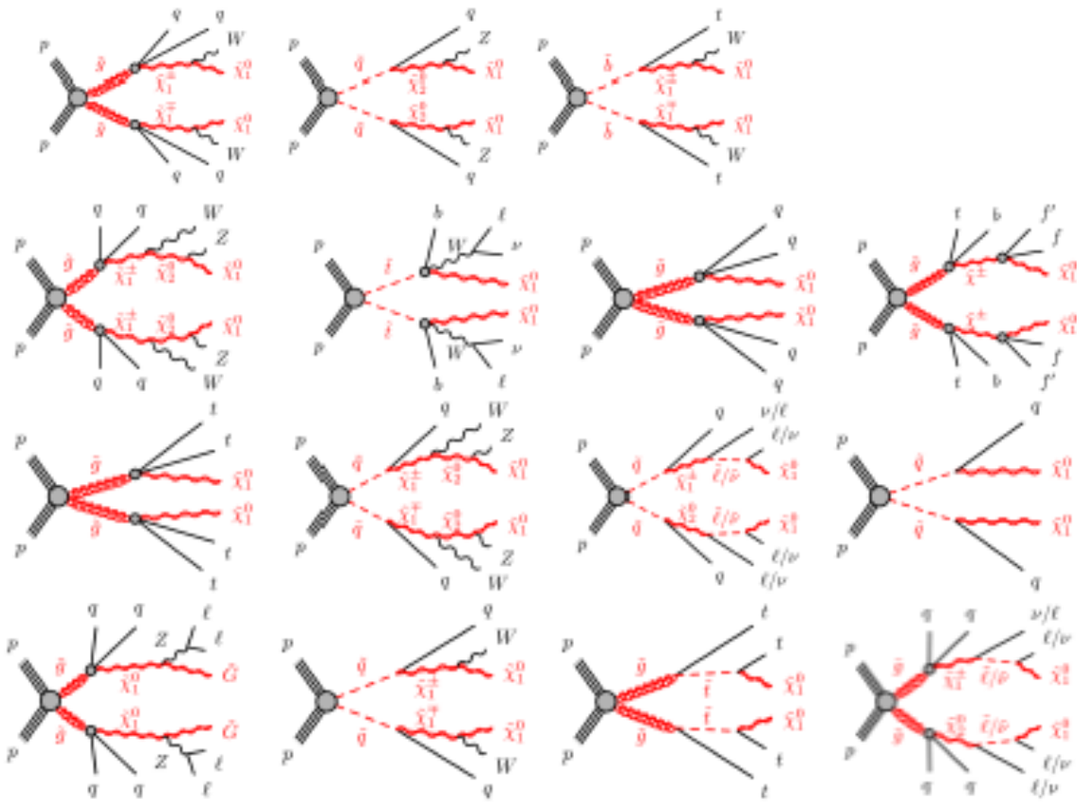
Speakers:

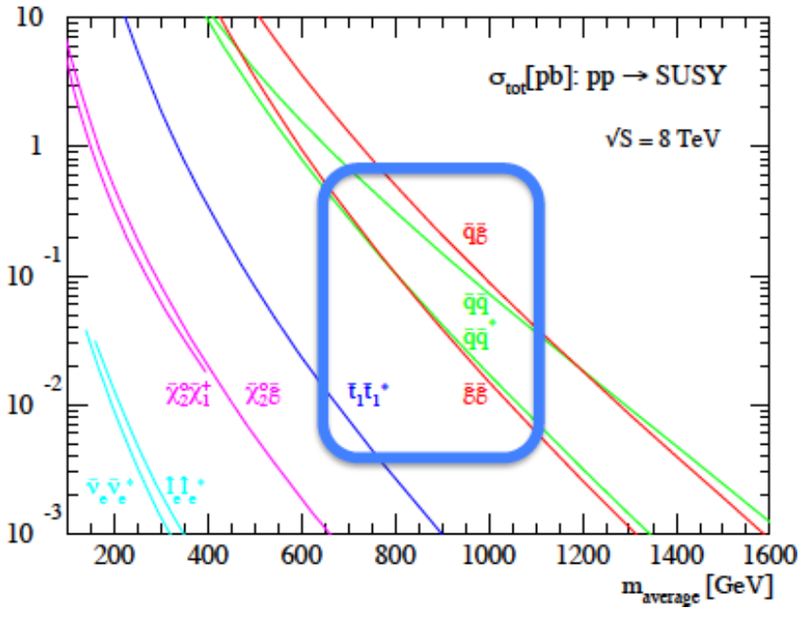
- Zach Marshall
- Santiago Folgueras
- H. Wells Wulsin
- Enrique Kajomovitz
- Oleg Ruchayskiy
- Zeynep Demiragli
- Greg Landsberg
- Jim Hirschauer



SUSY - I

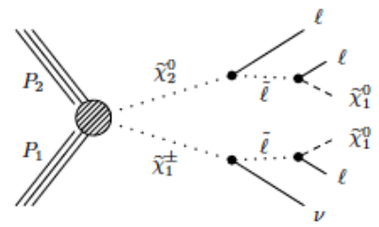
Strong SUSY production @LHC



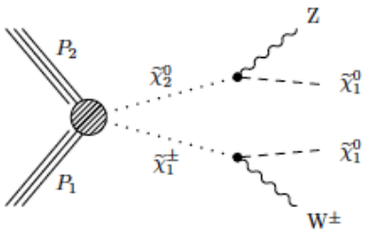


Electroweak SUSY production @LHC

Chargino-neutralino



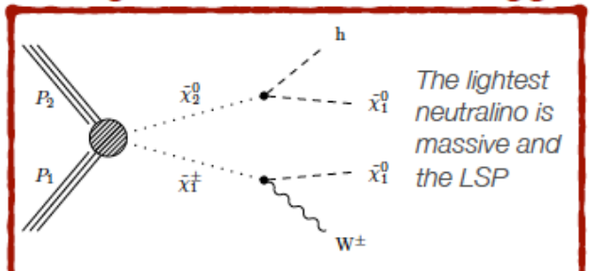
light sleptons and sneutrinos.



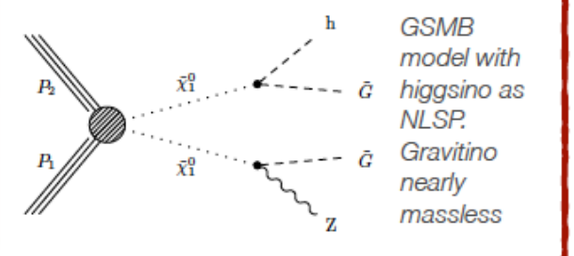
heavy sleptons, decay to W/Z. More difficult due to leptonic BF

3L, 4L search
2L (OS/SS) search
2τ_h search

Chargino-neutralino with higgs



The lightest neutralino is massive and the LSP



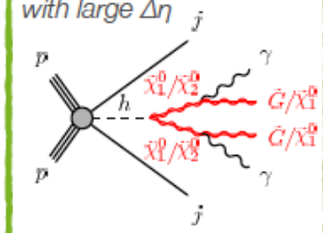
GSMB model with higgsino as NLSP. Gravitino nearly massless

Decay to h → bb, ττ, WW, ZZ and γγ

4b's
2γ + 2(b)jets
1 lepton + γγ
1 lepton + bb
2L (SS)
3L search

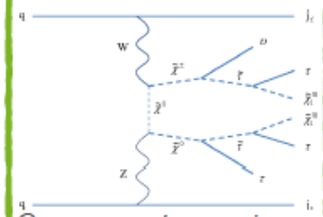
VBF production

VBF topology: 2 jets with large Δη



Intepretations in GMSB and NMSSM.

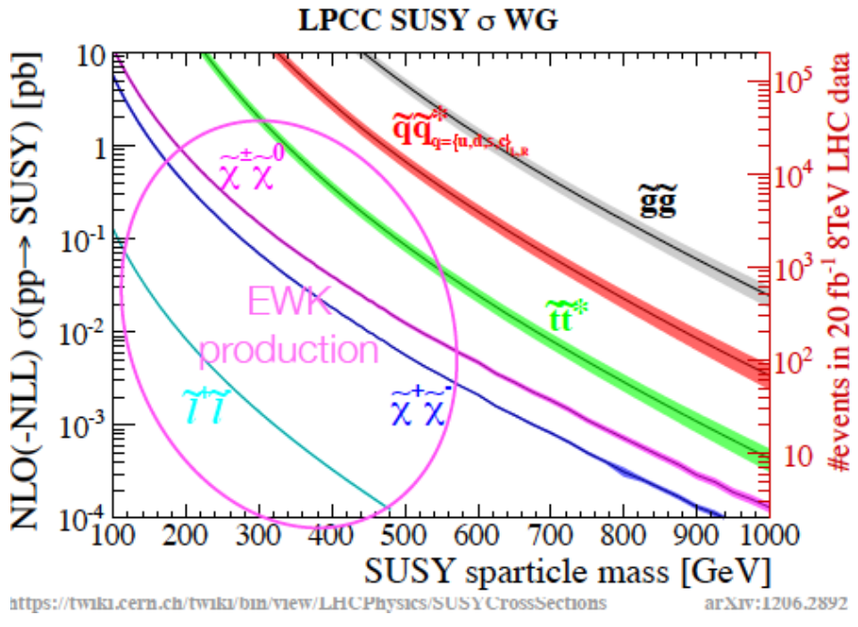
γ(γ) + MET



Compressed scenario. Stau as the NLSP.

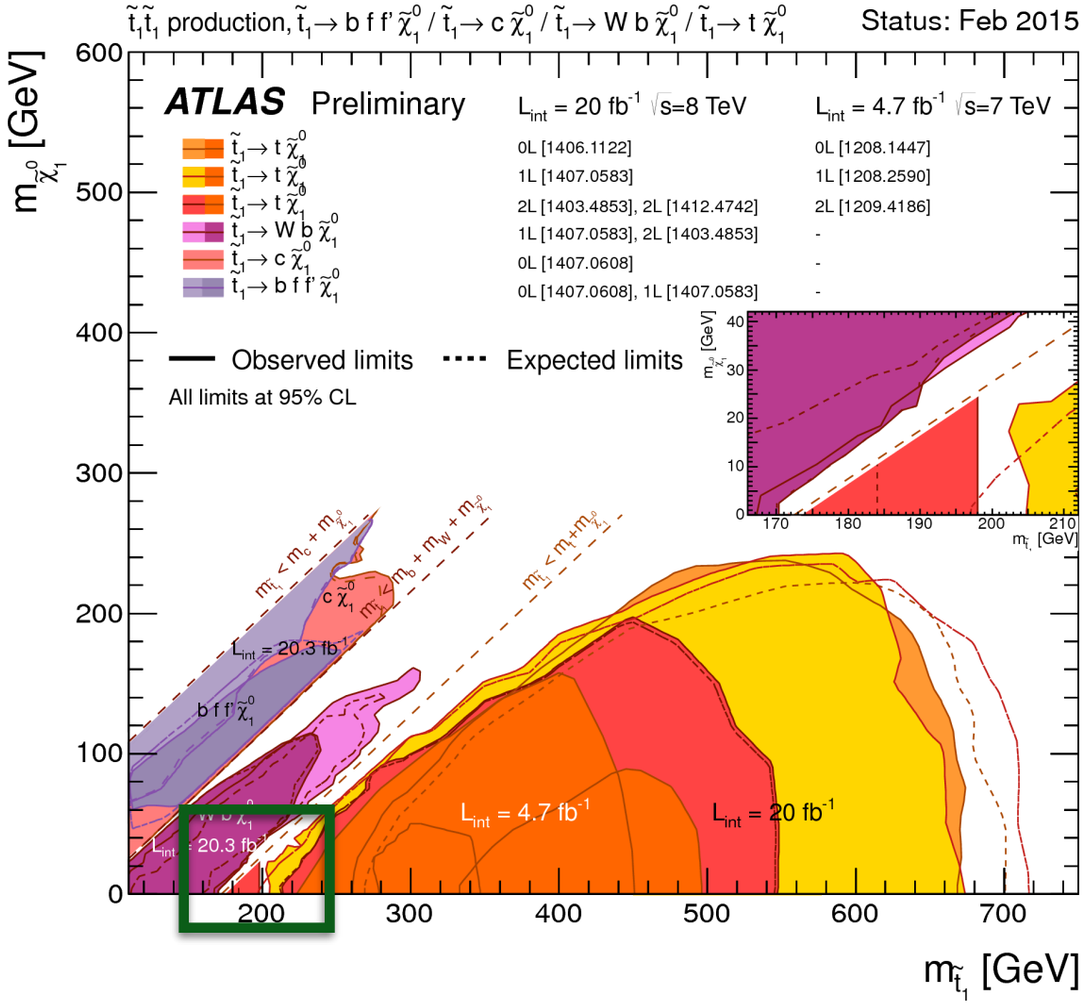
2L + MET

3

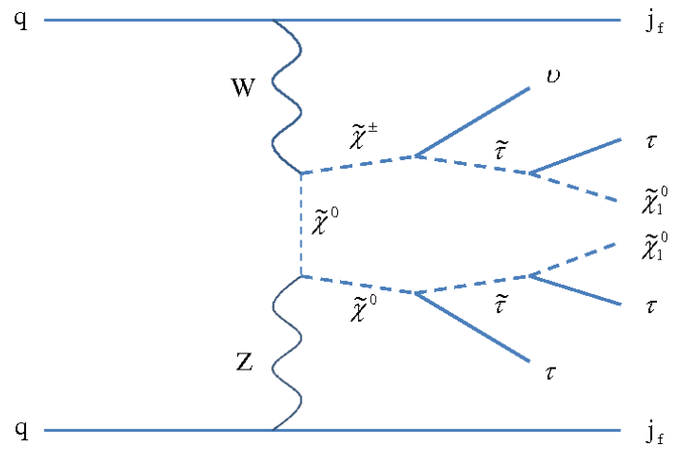


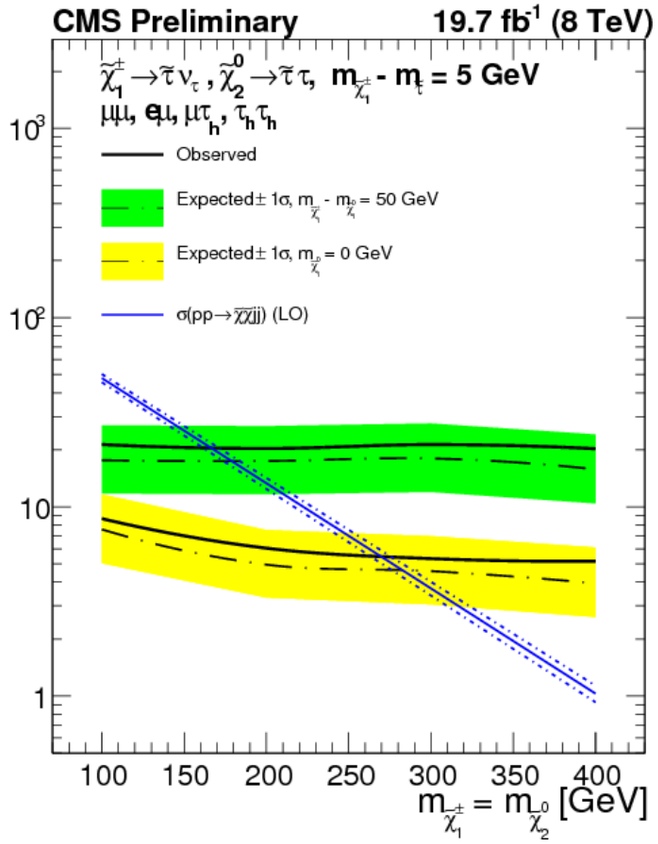
SUSY-II

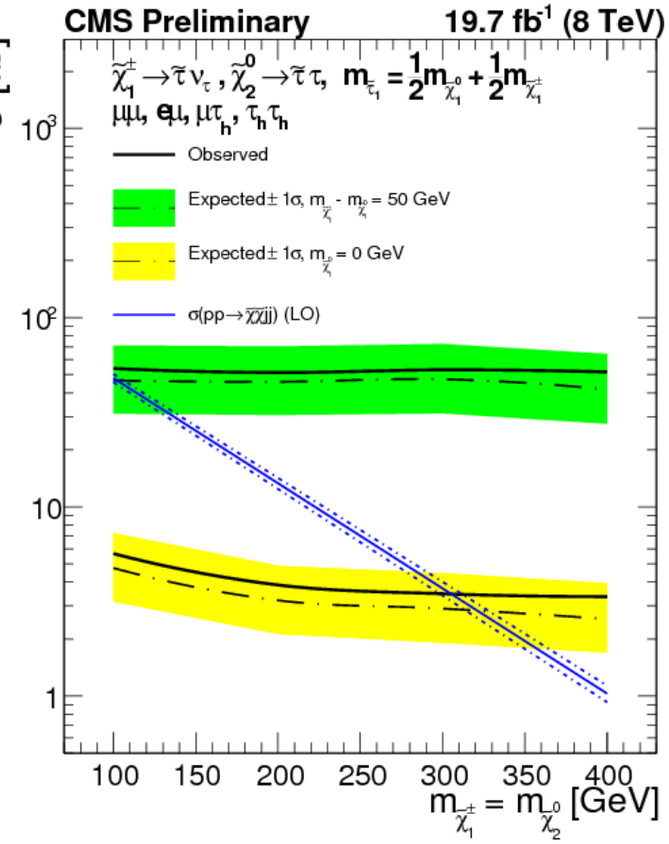
Stop searches



Not much room left for a light stop





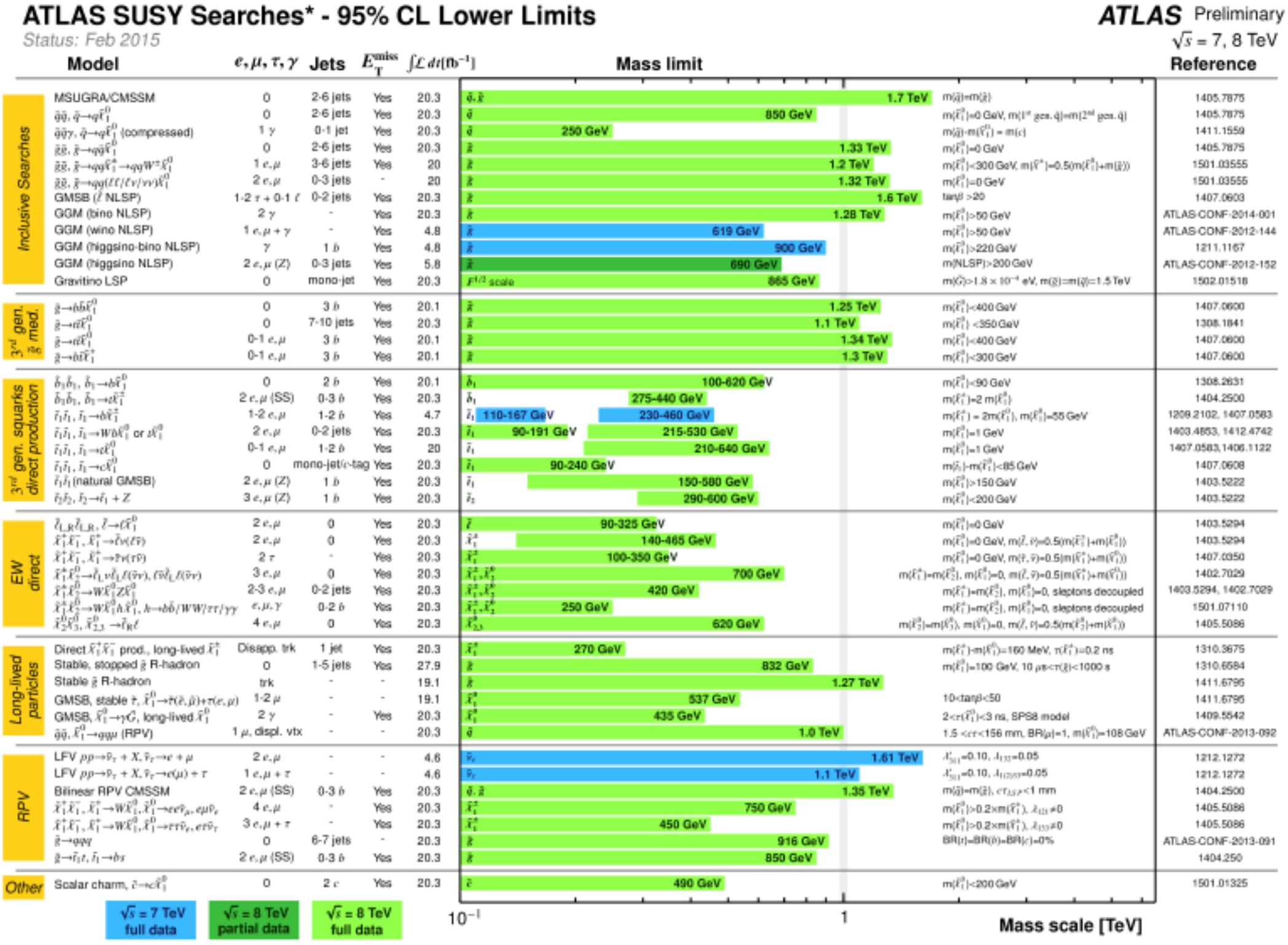


Searches in VBF topology

Techniques developed originally in Higgs studies

SUSY Summary

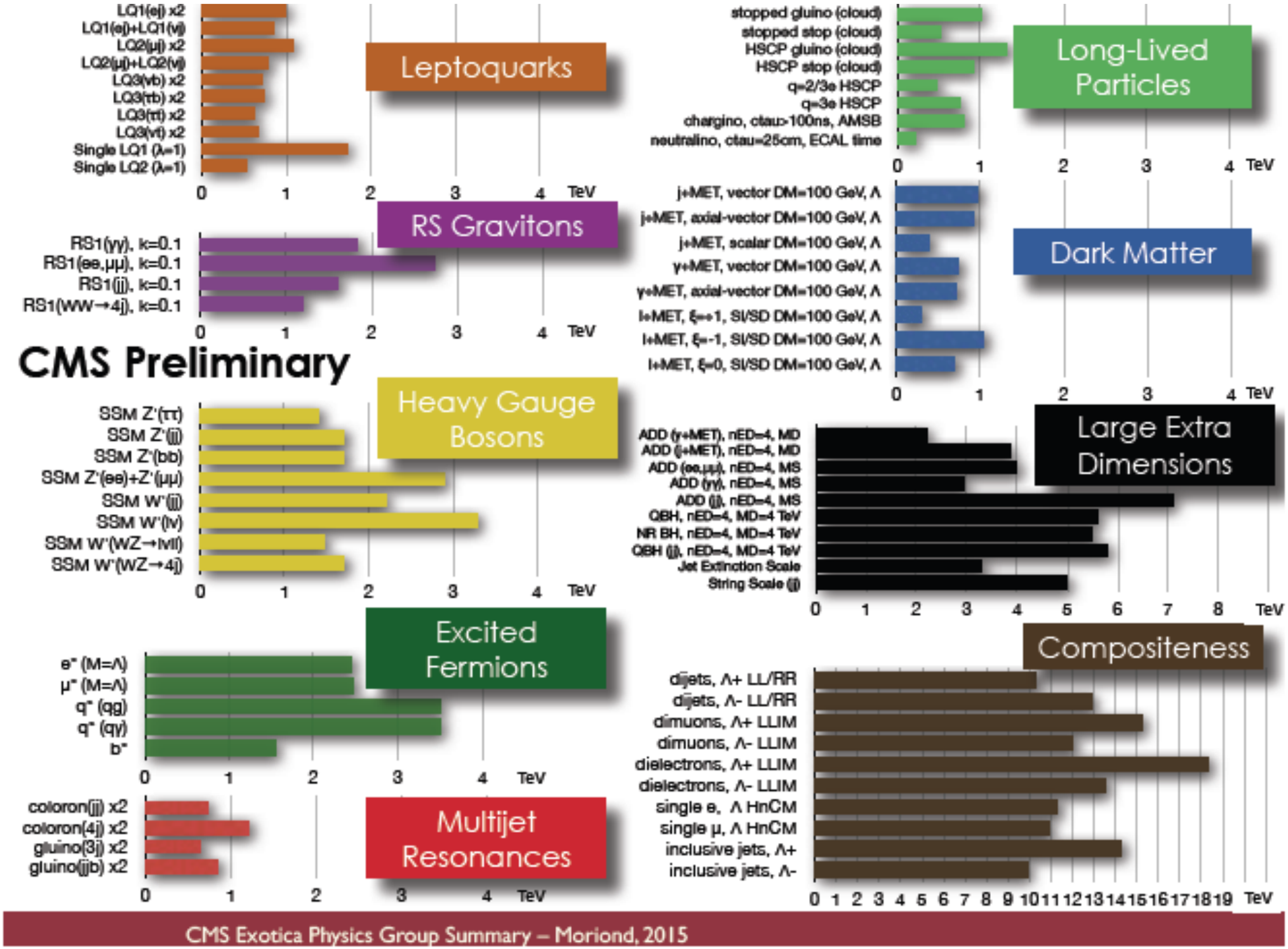
Large Number of analyses with many different final states



And similar results from CMS….

Exotics

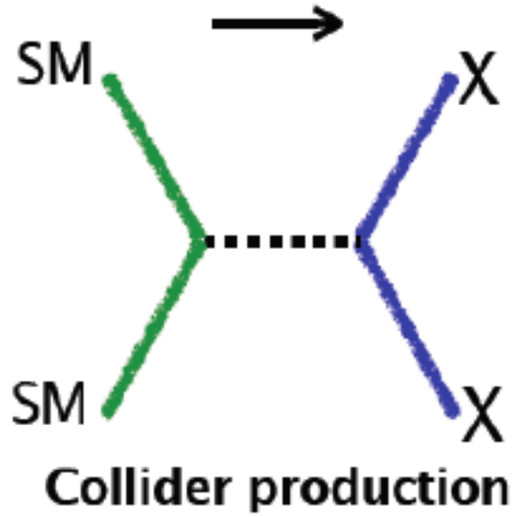
Again many searches for high mass exotic particles…



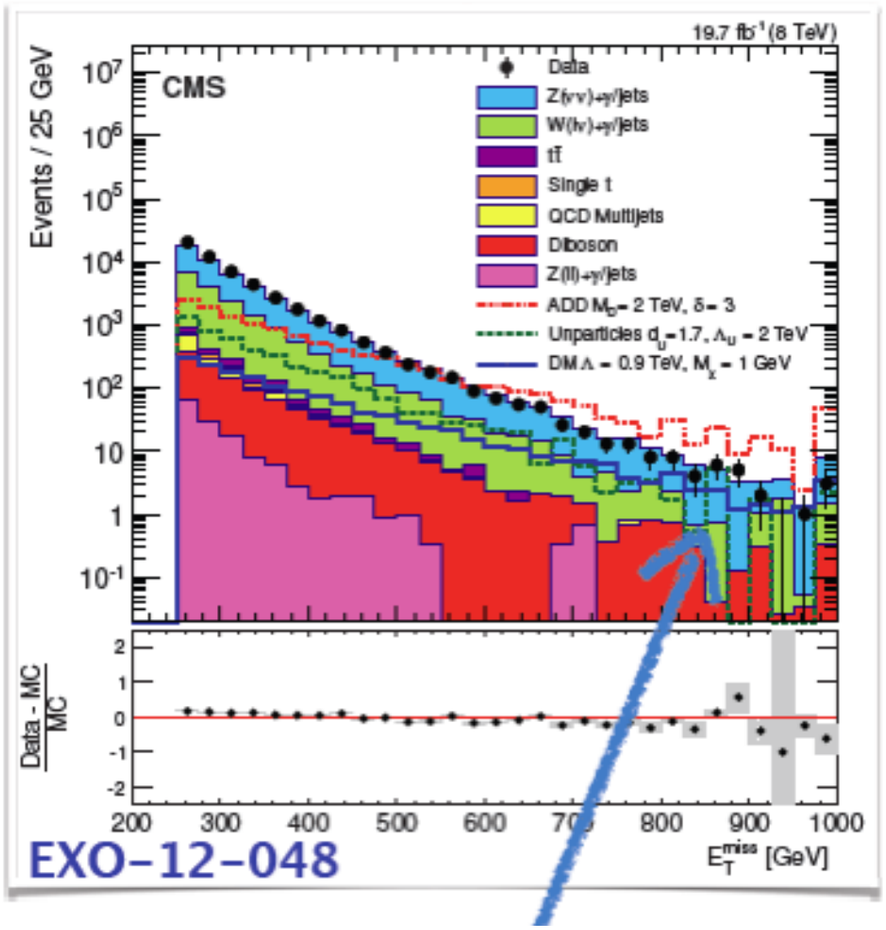
And similar results from ATLAS

Dark Matter

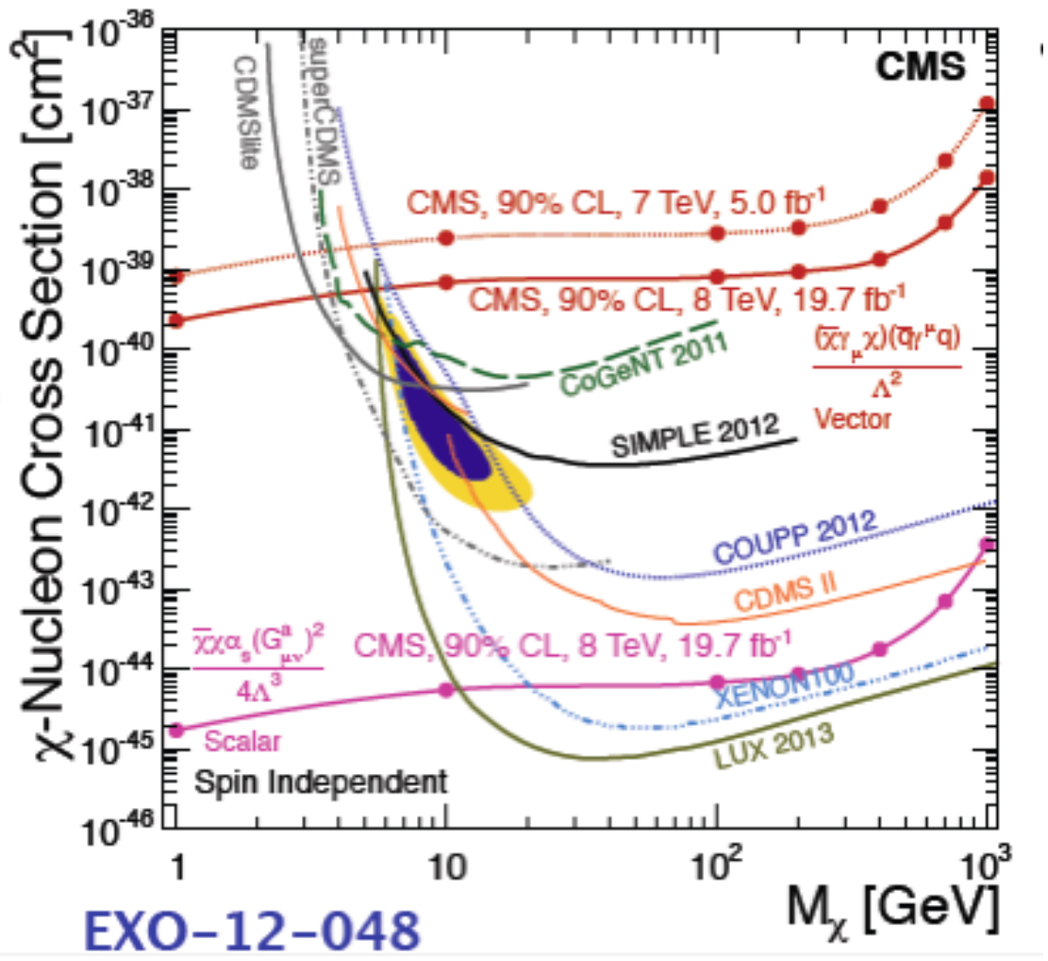
- Use same objects as other searches (leptons, jets, MET)
- No significant excess have been observed so far



Collider production

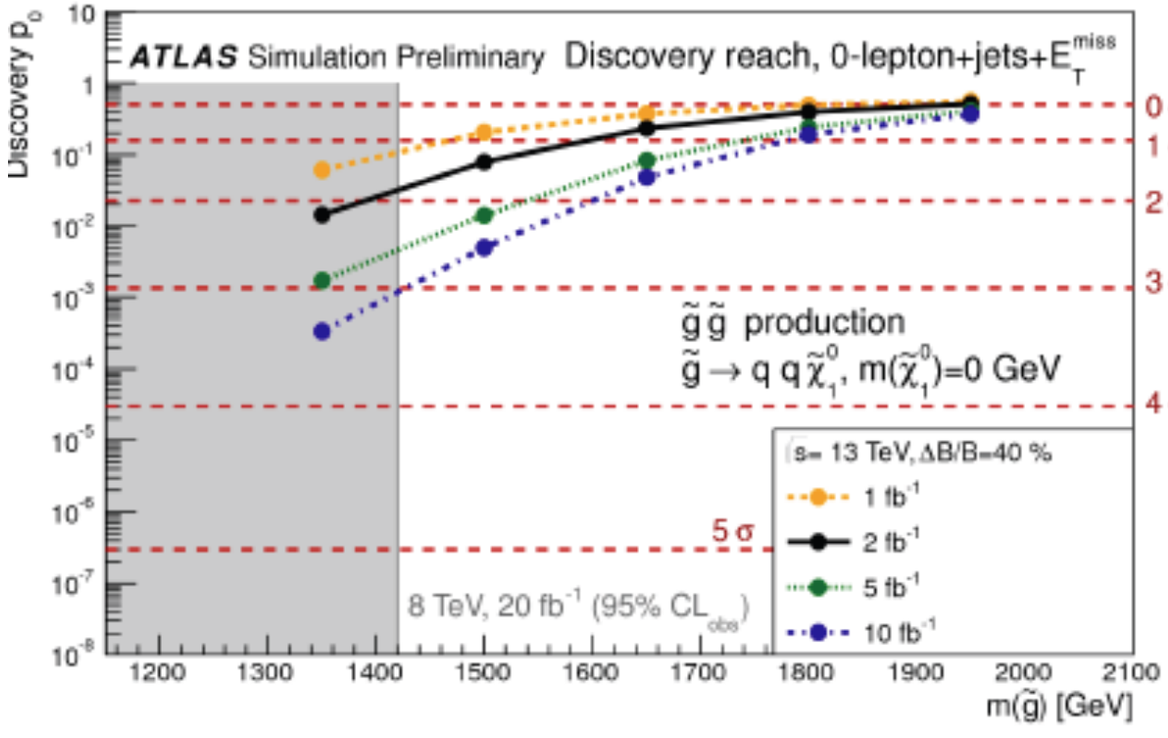


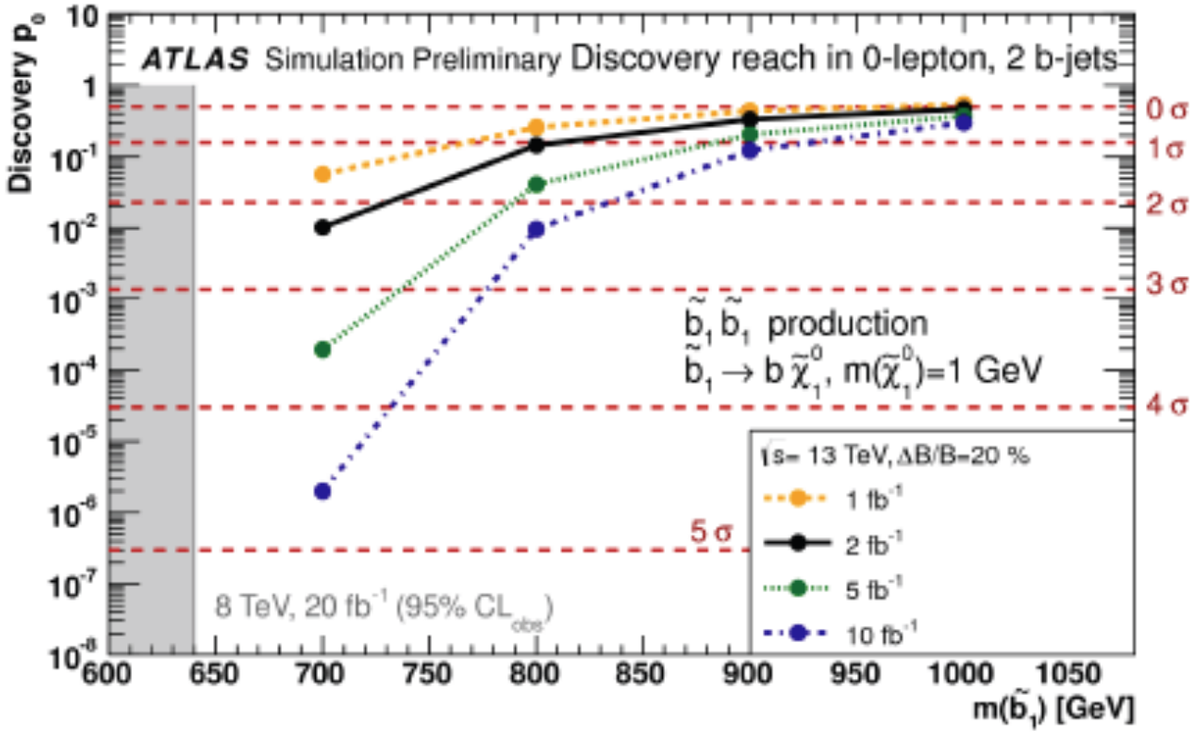
?



Summary of BSM searches

- No evidence of any new Physics yet
- Looking forward to Run-2

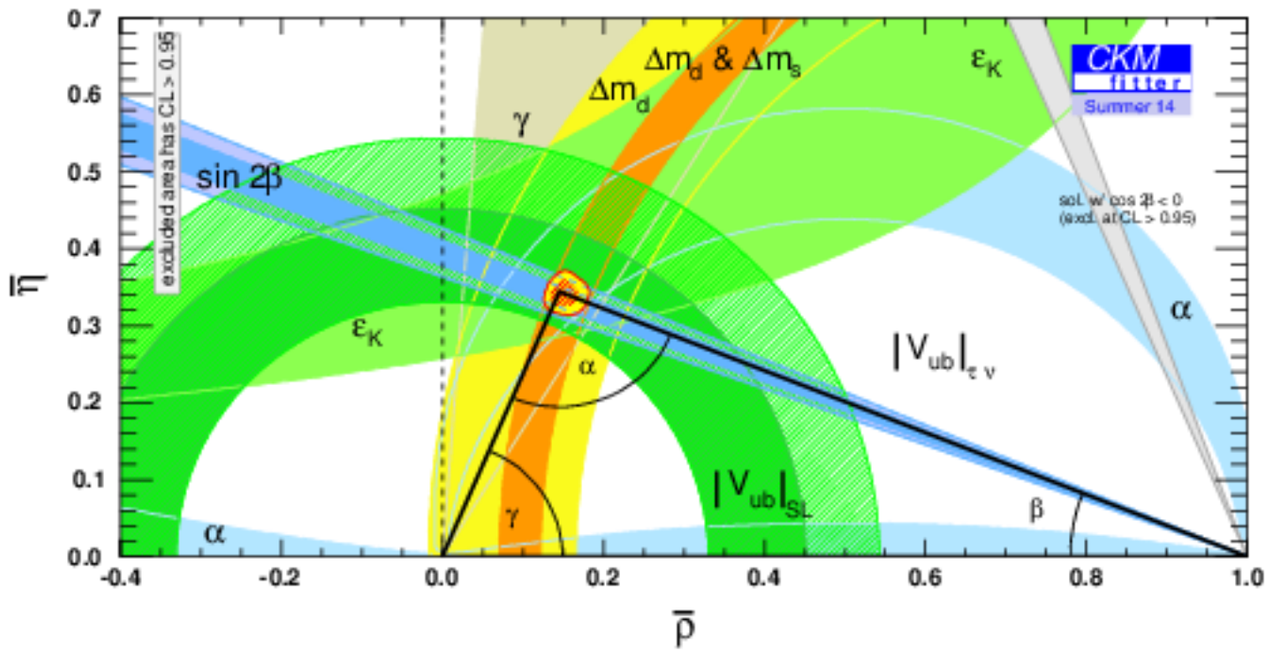




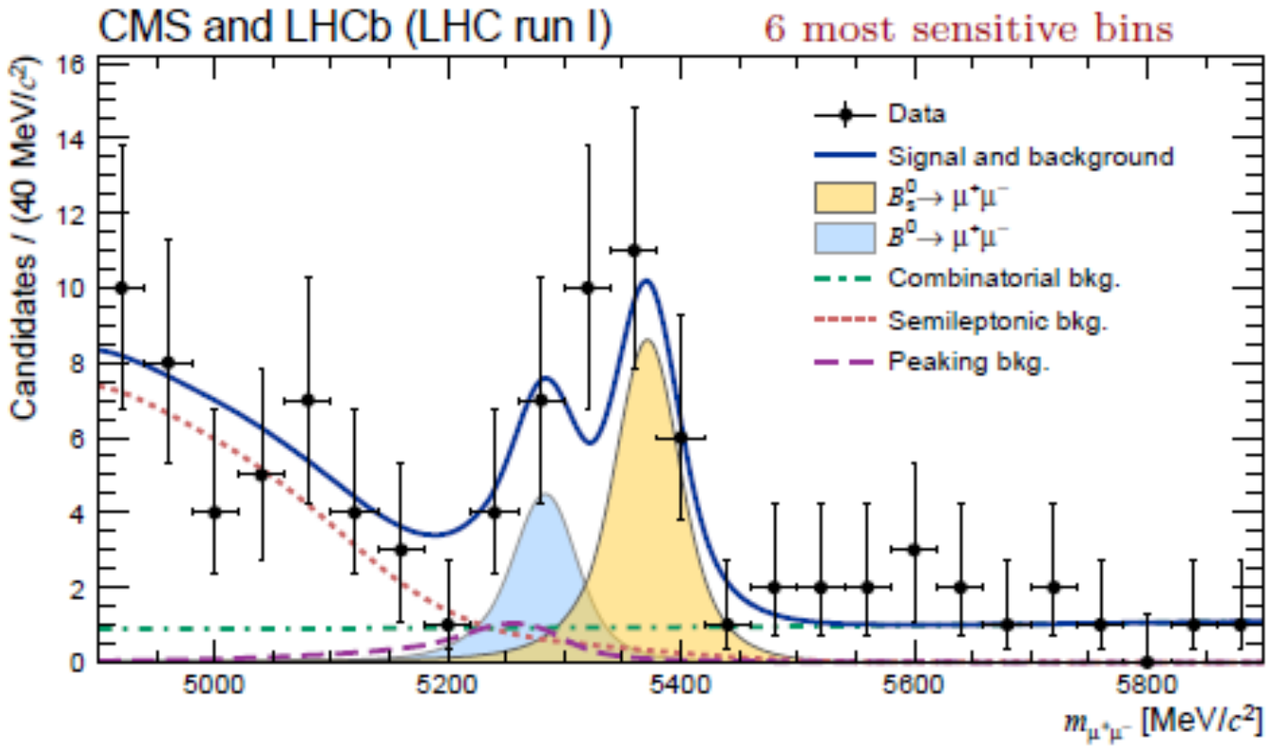
B-Physics

Speakers:

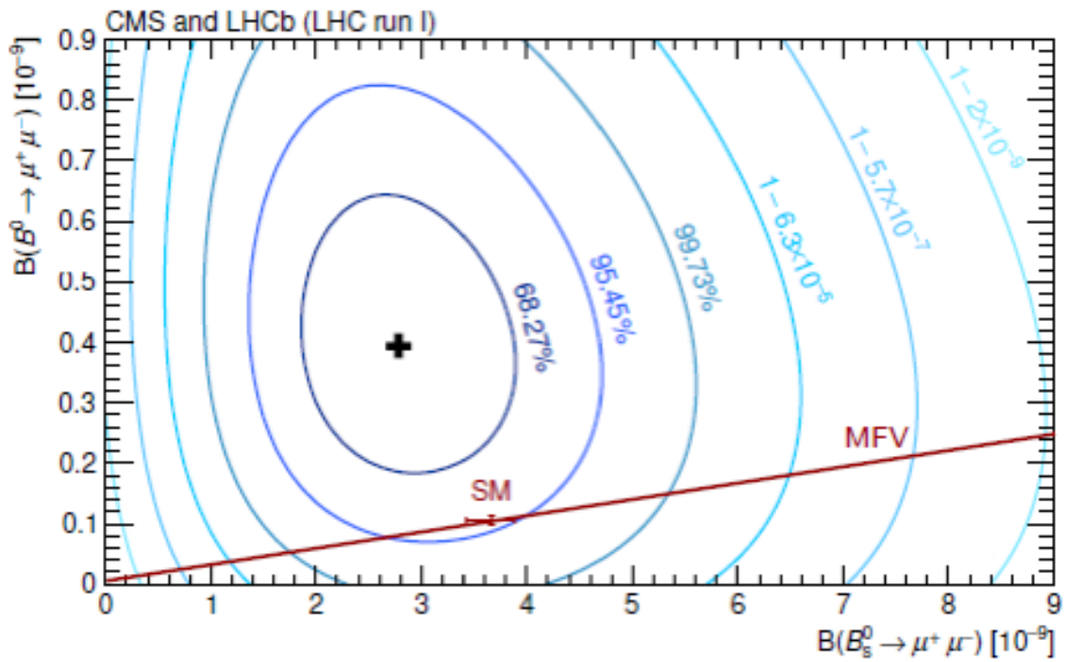
- Angelo Carbone
- Andreas Crivellin
- Francesco Dettori
- Leonid Gladilin
- Nazim Hussain
- Cai-Dian Lu
- Donatalla Lucchesi
- Derek Strom



Rare Decays



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9} \quad (6.2\sigma \text{ significance})$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10} \quad (3.0\sigma \text{ significance}^*)$$



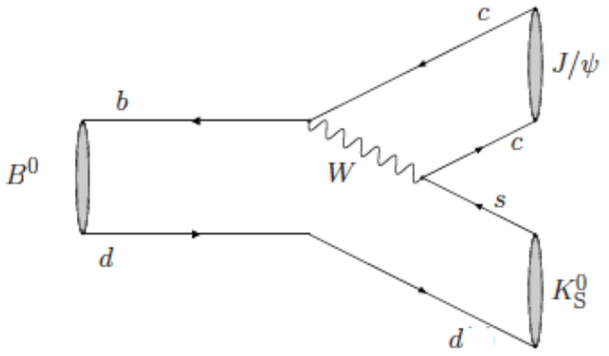
First observation of the $B_s^0 \to \mu^+\mu^-$ decay
and a first evidence for the $B^0 \to \mu^+\mu^-$ decay

Measurement of the ratio:

$$\mathcal{R} = 0.14^{+0.08}_{-0.06}$$

compatible with the SM prediction
$\mathcal{R} = 0.0295^{+0.0028}_{-0.0025}$ at the 2.3σ level

Measurement of sin(2β) at LHCb



J/ψ→μ⁺μ⁻

K⁰s→π⁺π⁻

Exhibits a time dependent CP asymmetry

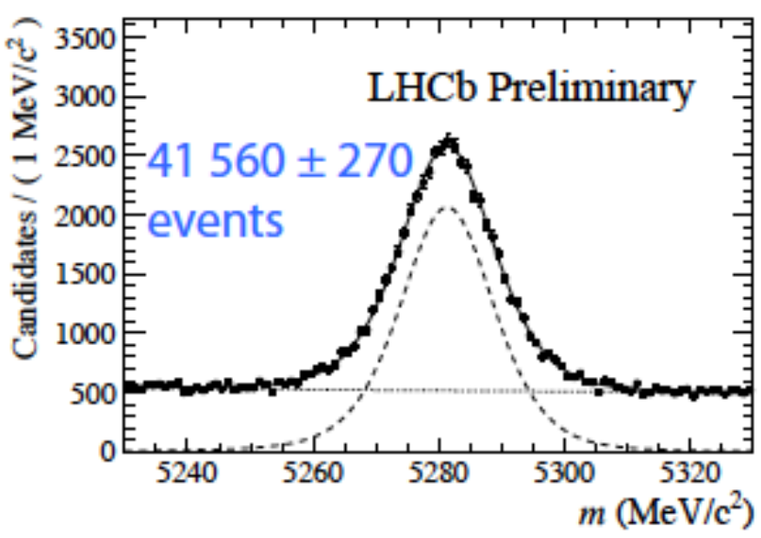
$$\mathcal{A}(t) \equiv \frac{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) - \Gamma(B^0(t) \to J/\psi K^0_S)}{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) + \Gamma(B^0(t) \to J/\psi K^0_S)} = \frac{S \sin(\Delta m\, t) - C \cos(\Delta m\, t)}{\cosh(\frac{\Delta\Gamma t}{2}) + A_{\Delta\Gamma} \sinh(\frac{\Delta\Gamma t}{2})}$$

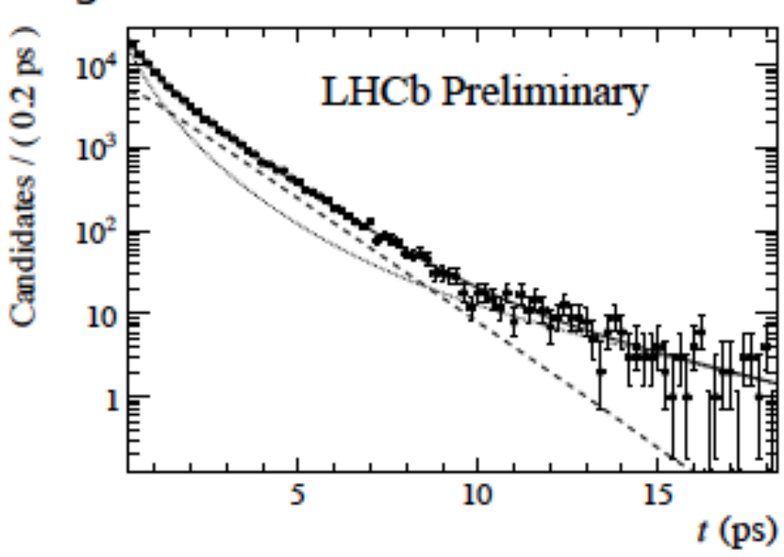
ΔΓ≈0 for B^0 mesons,

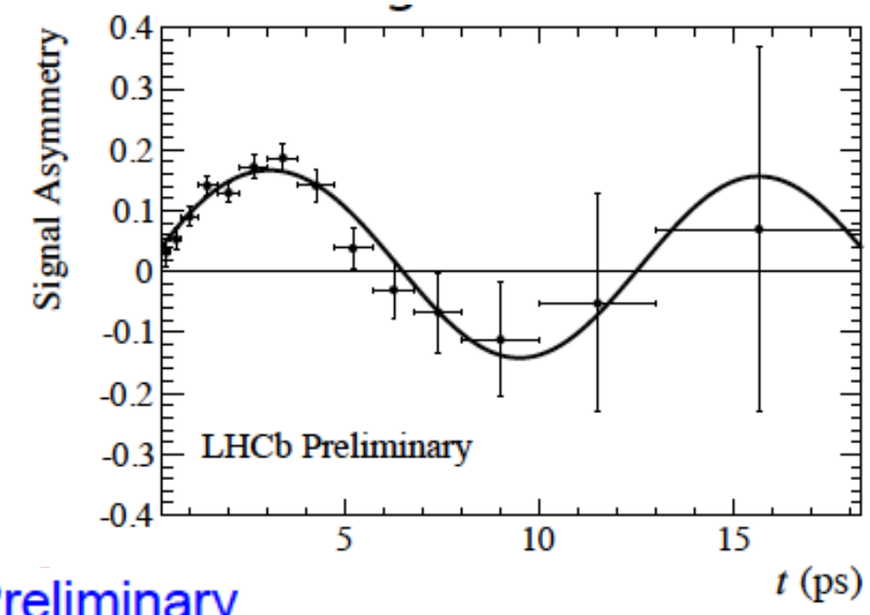
$$\mathcal{A}(t) = S \sin(\Delta m\, t) - C \cos(\Delta m\, t)$$

S and C are CP observables and **S ≈ sin(2β)**

LHCb-PAPER-2015-004







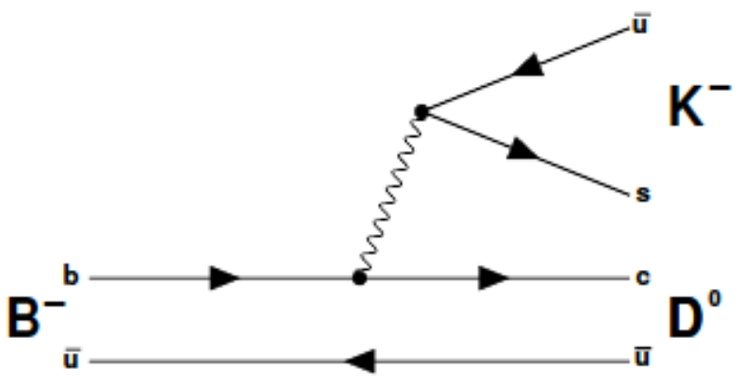
S Belle: 0.667±0.023±0.012†
S BaBar: 0.687±0.028±0.012‡

LHCb Preliminary

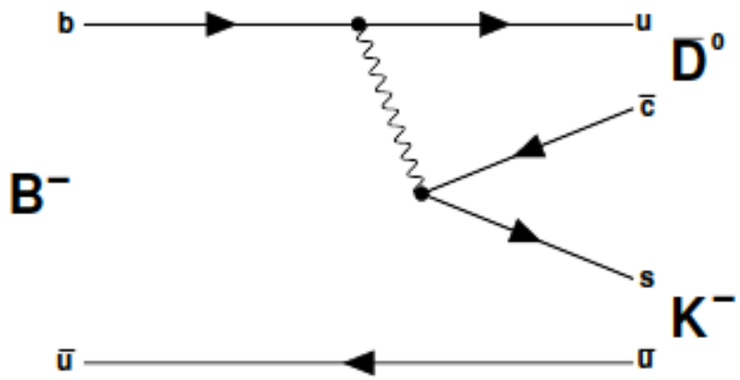
S = 0.731±0.035±0.020
C = −0.032±0.032±0.05

LHCb result competitive to that of B-factories

Measurement of γ at LHCb



Colour Favoured



Colour Suppressed

Parameters of interest

$$r_B = \left| \frac{A(\mathrm{SUP})}{A(\mathrm{FAV})} \right|$$

$$\delta_B = \phi_{\mathrm{FAV}} - \phi_{\mathrm{SUP}}$$

$$\Gamma(B^- \to (hh)_D K^-) \propto 1 + r_B^2 + 2\, r_B \cos(\delta_B - \gamma)$$

Channel	Data Set (fb^{-1})
$B^\pm \to [hh]_D h^\pm$	1
$B^\pm \to [K\pi\pi\pi]_D h^\pm$	1
$B^\pm \to [K^0_S hh]_D K^\pm$	3
$B^\pm \to [K^0_S K\pi]_D K^\pm$	3
$B^0 \to [hh]_D K^{*0}$	3
$B^0_s \to D_s^\mp K^\pm$	1

LHCb Preliminary

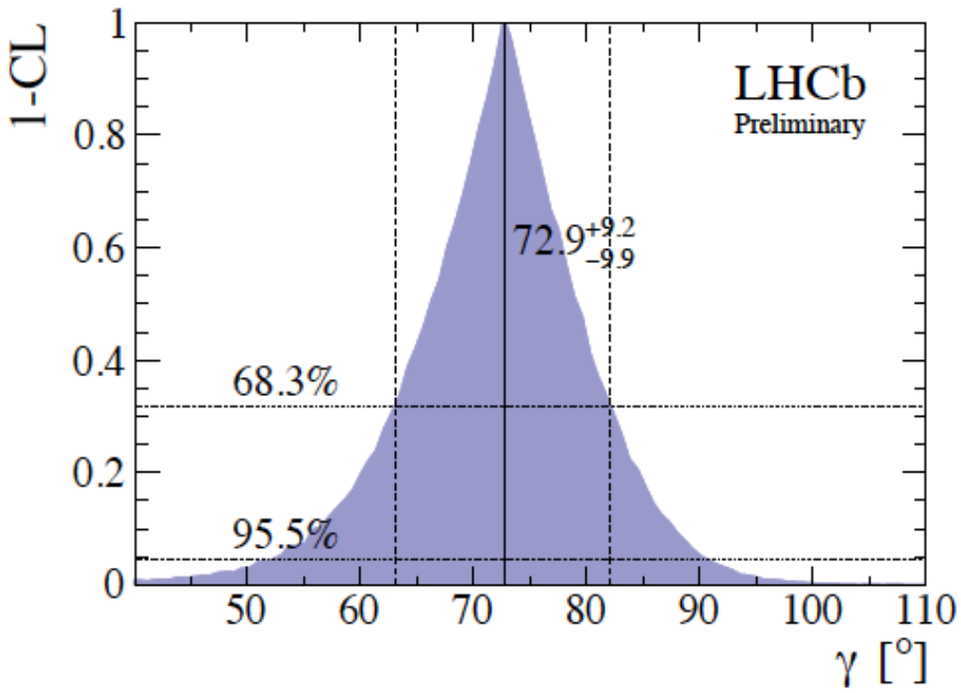
DK only (68% CL)

$$\gamma = (73^{+9}_{-10})^\circ$$

$$r_B = 0.091^{+0.008}_{-0.009}$$

$$\delta_B = (127^{+10}_{-12})^\circ$$

LHCb-CONF-2014-004

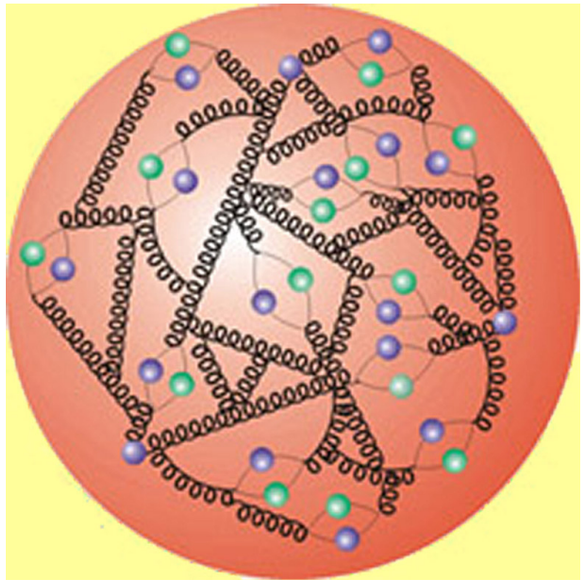


Better than the B-factories

EWK & QCD

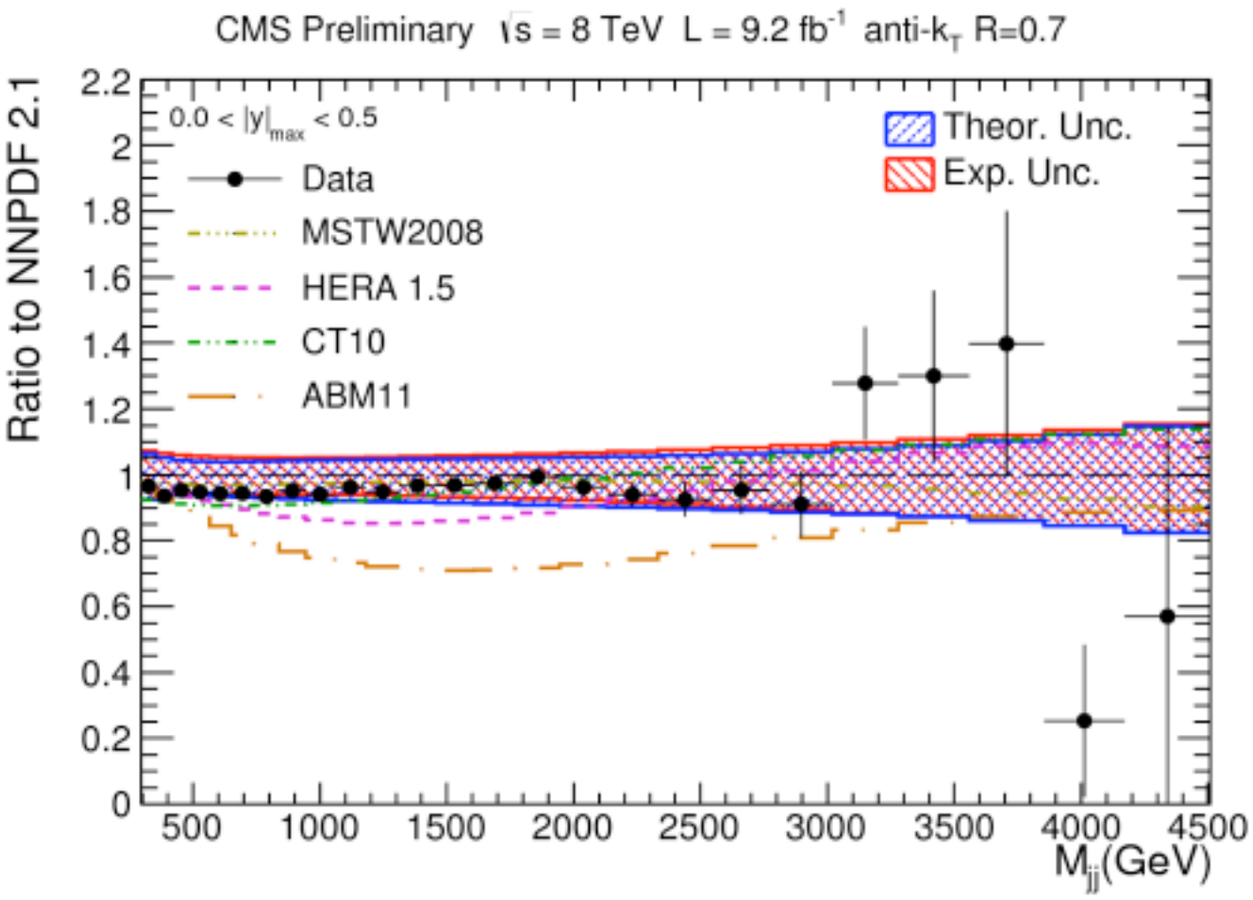
Speakers:

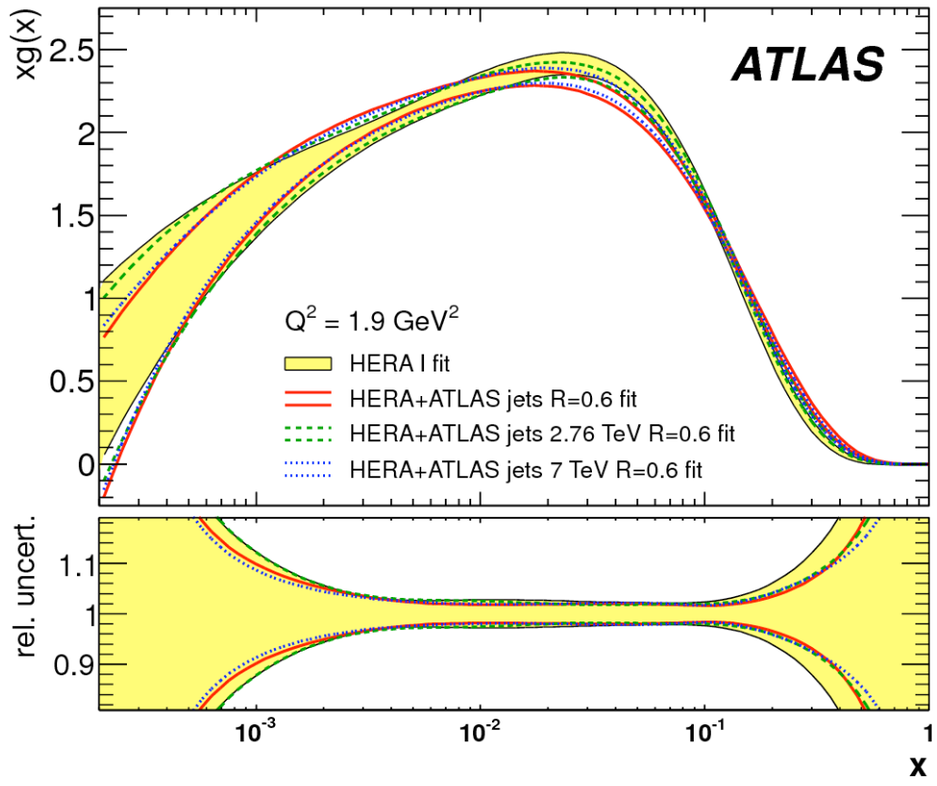
- Sabine Lammers
- Daniel Johnson
- Daniel Britzger
- Stefano Carmada
- Andreas Hafner
- Milena Misheva
- Peter Svoisky
- Georgios Mavromanolakis
- Brian Lindquist

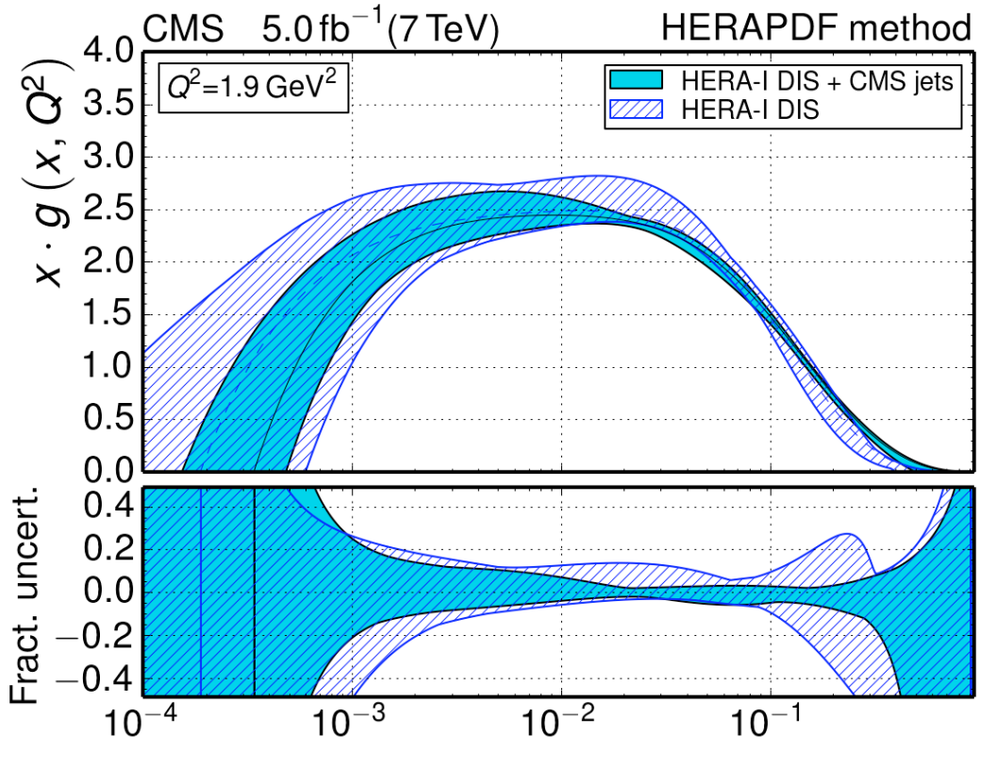


Jet cross sections & PDF

$$\frac{d^2\sigma}{dp_T d|y|} = \frac{C_{unfold}}{\varepsilon \cdot L} \cdot \frac{N_{jets}}{\Delta p_T \Delta |y|}$$







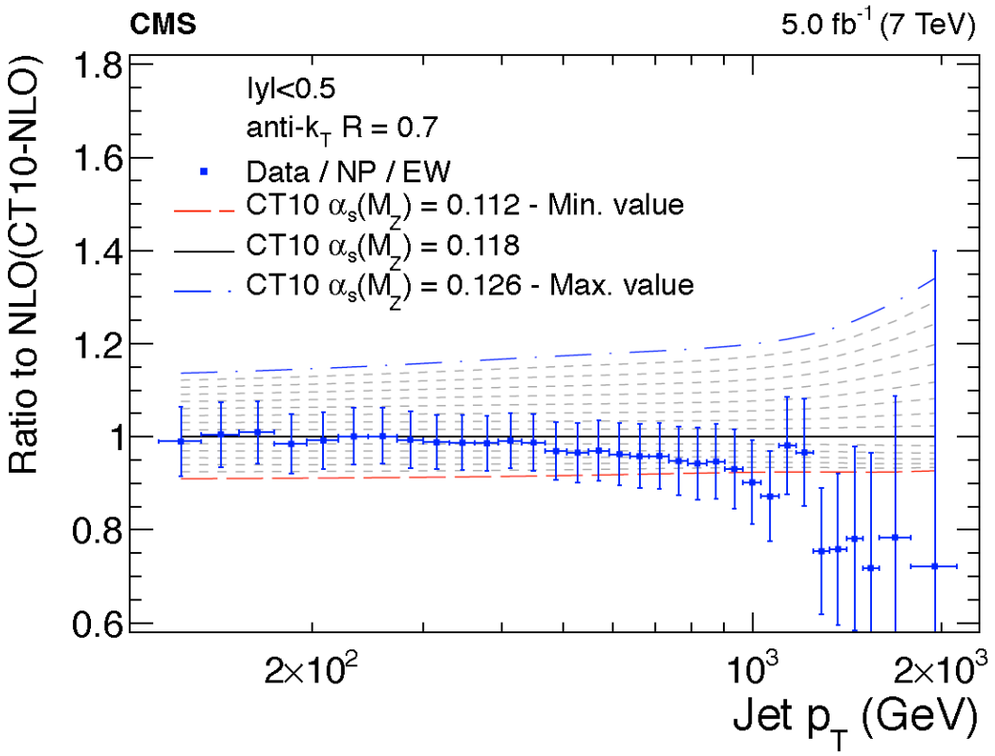
Experimental uncertainties comparable to the theoretical ones

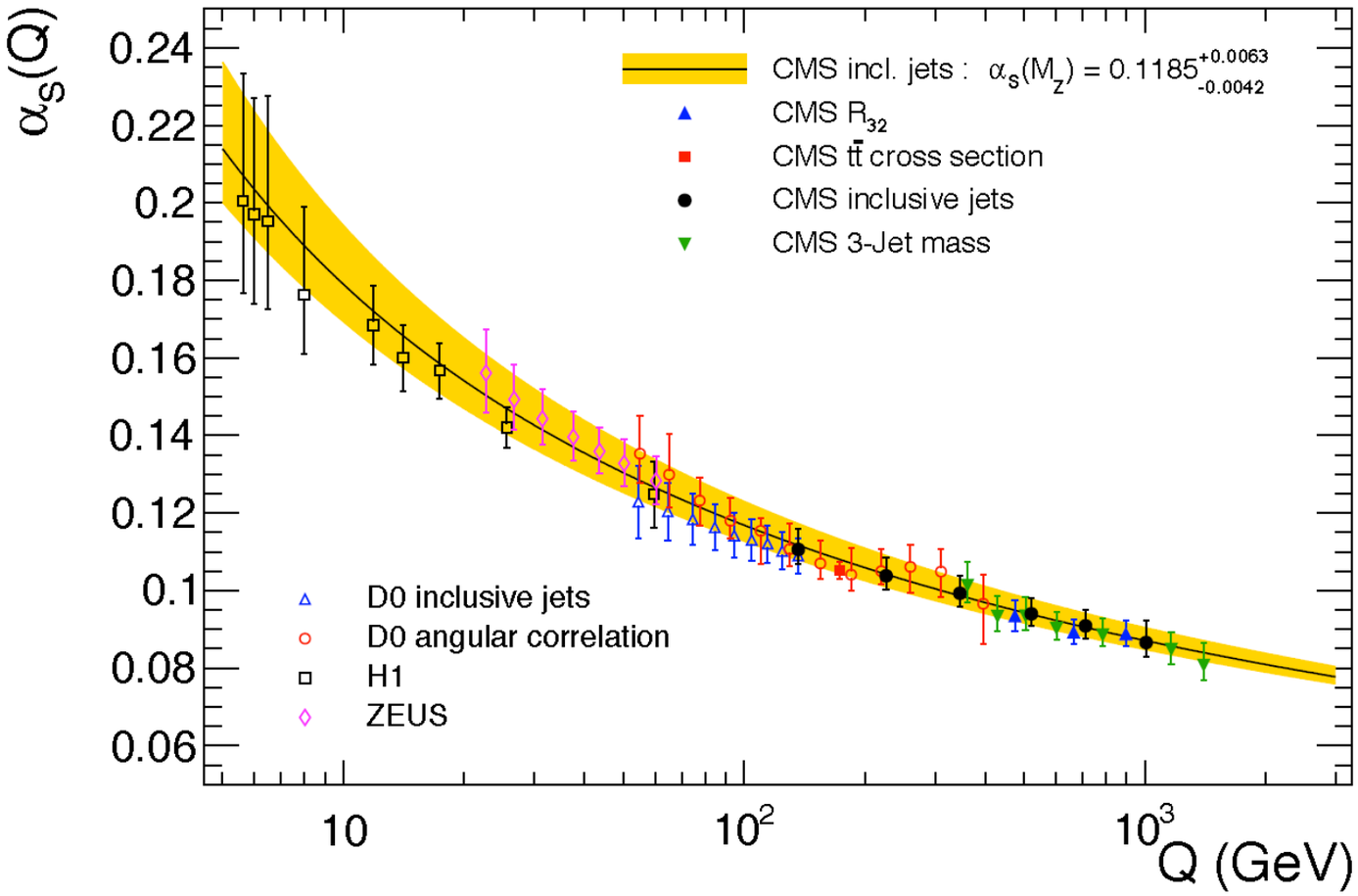
Some PDFs describe the data better than others

These measurements are useful for tuning and constraining PDFs

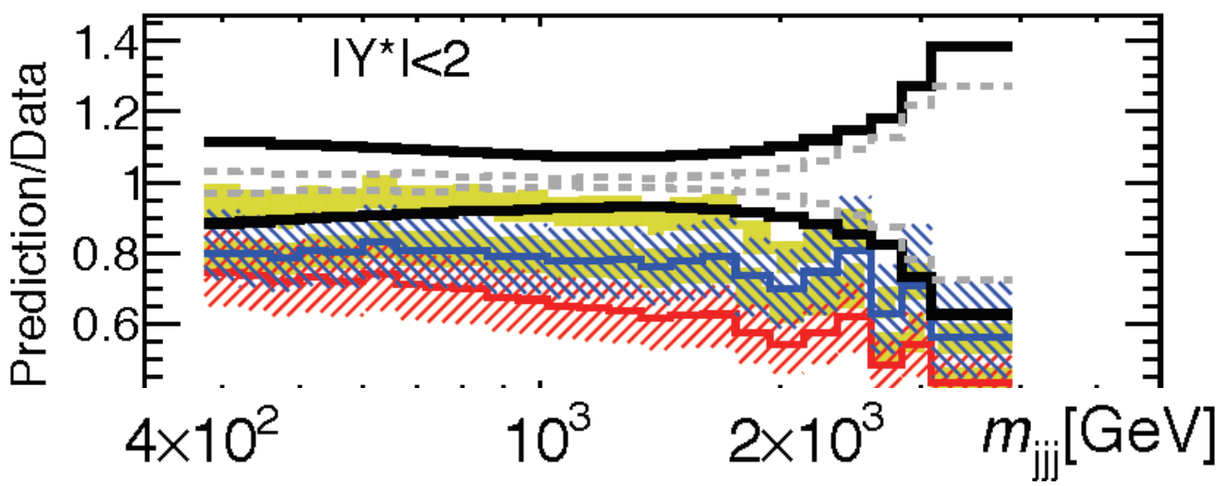
α_S measurements

Inclusive jet cross sections





three jet mass

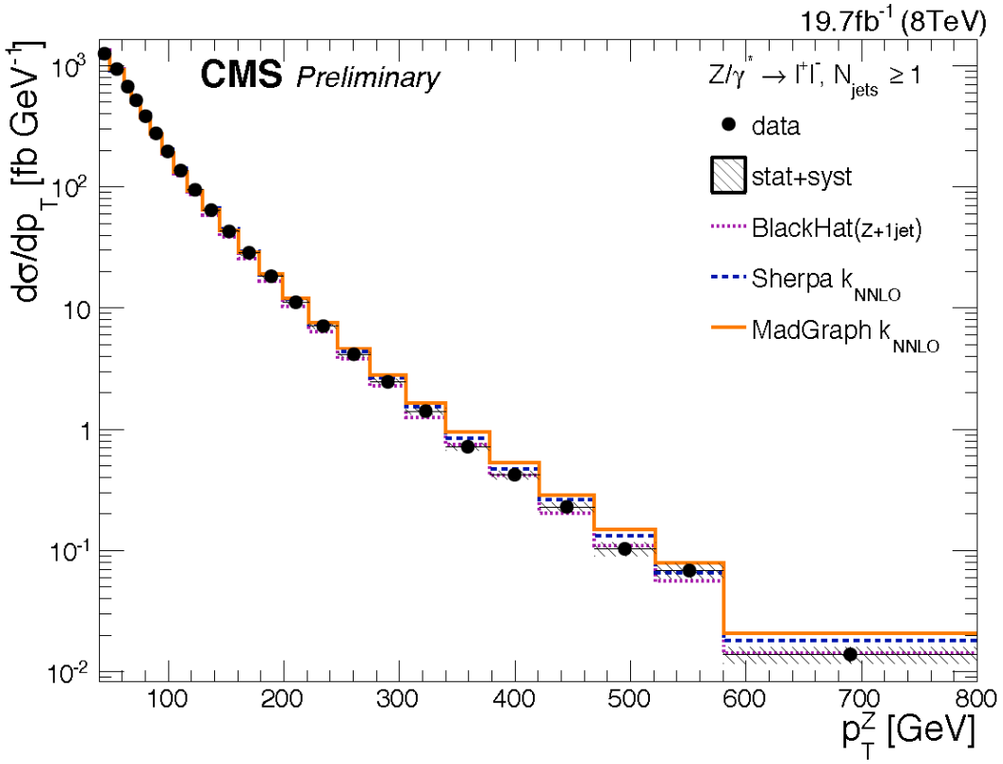


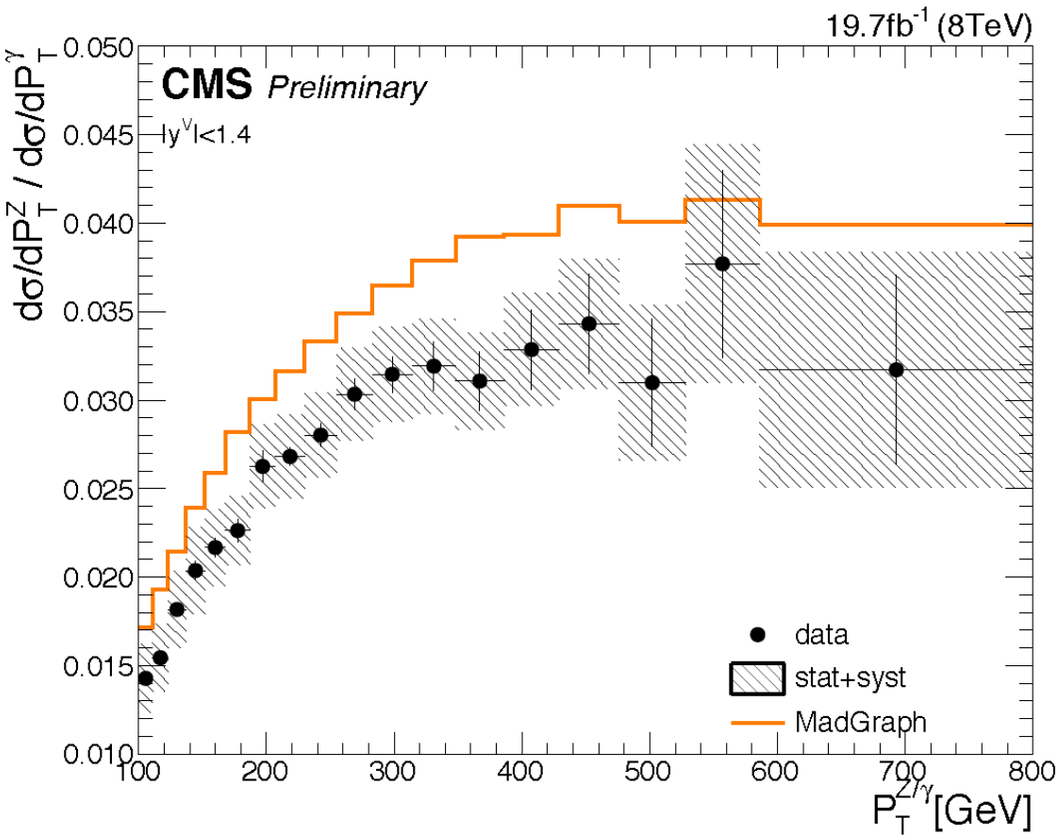
$\alpha_S(M_Z) = 0.1185 \pm 0.0019$ (exp.) $\pm$ 0.0028 (PDF) $\pm$ 0.0004 (NP) -/+ (0.0024, , 0.0053) (scale)

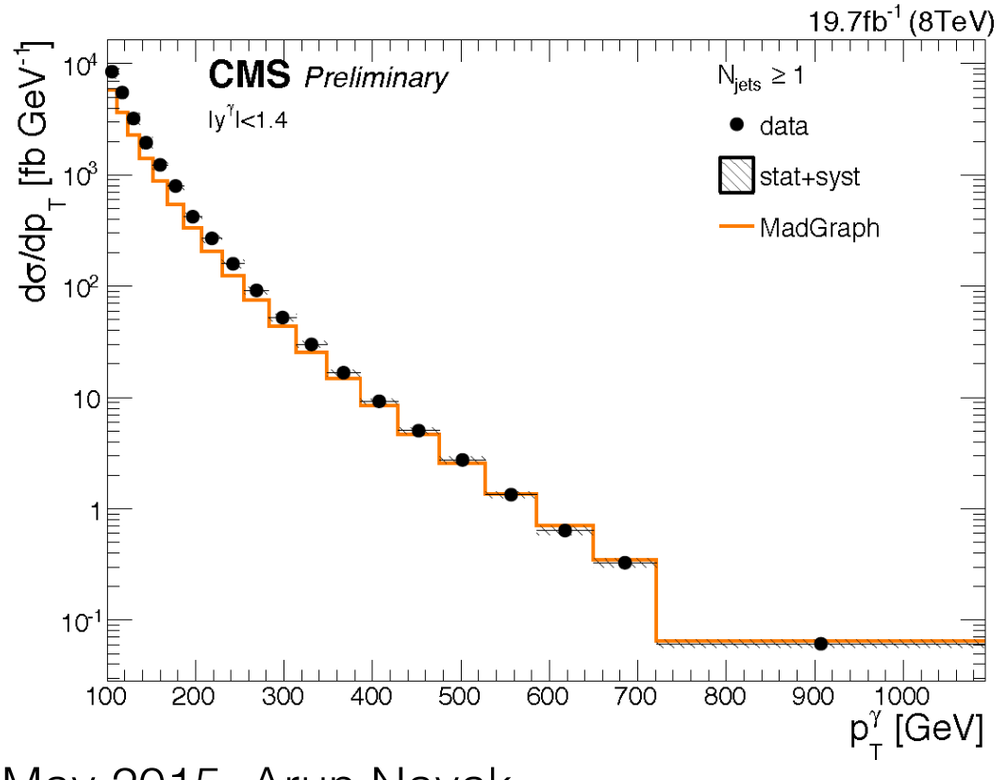
First Measurements at 1.4 TeV

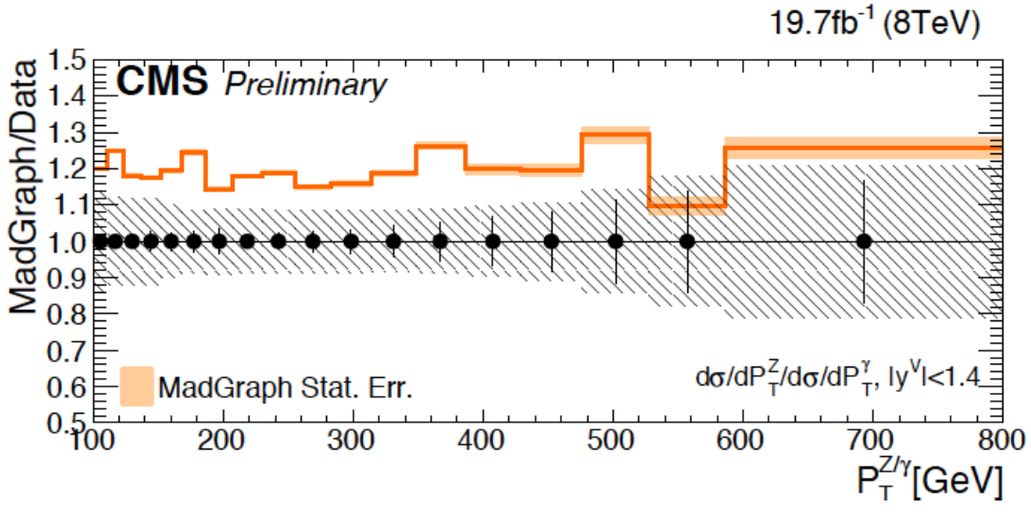
Also results from H1 with most precise measurements from multi-jet cross sections

Z+jets & γ+jets



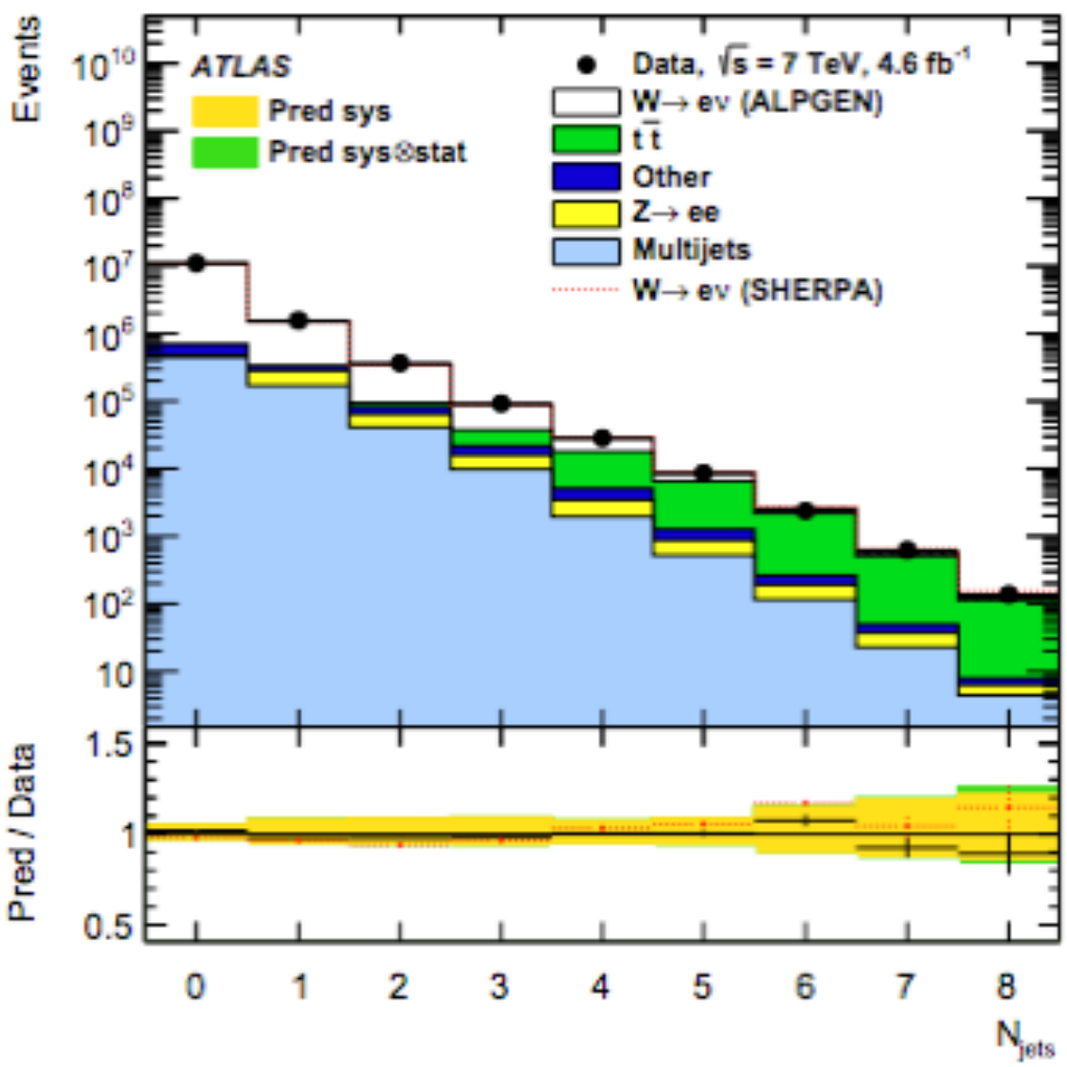


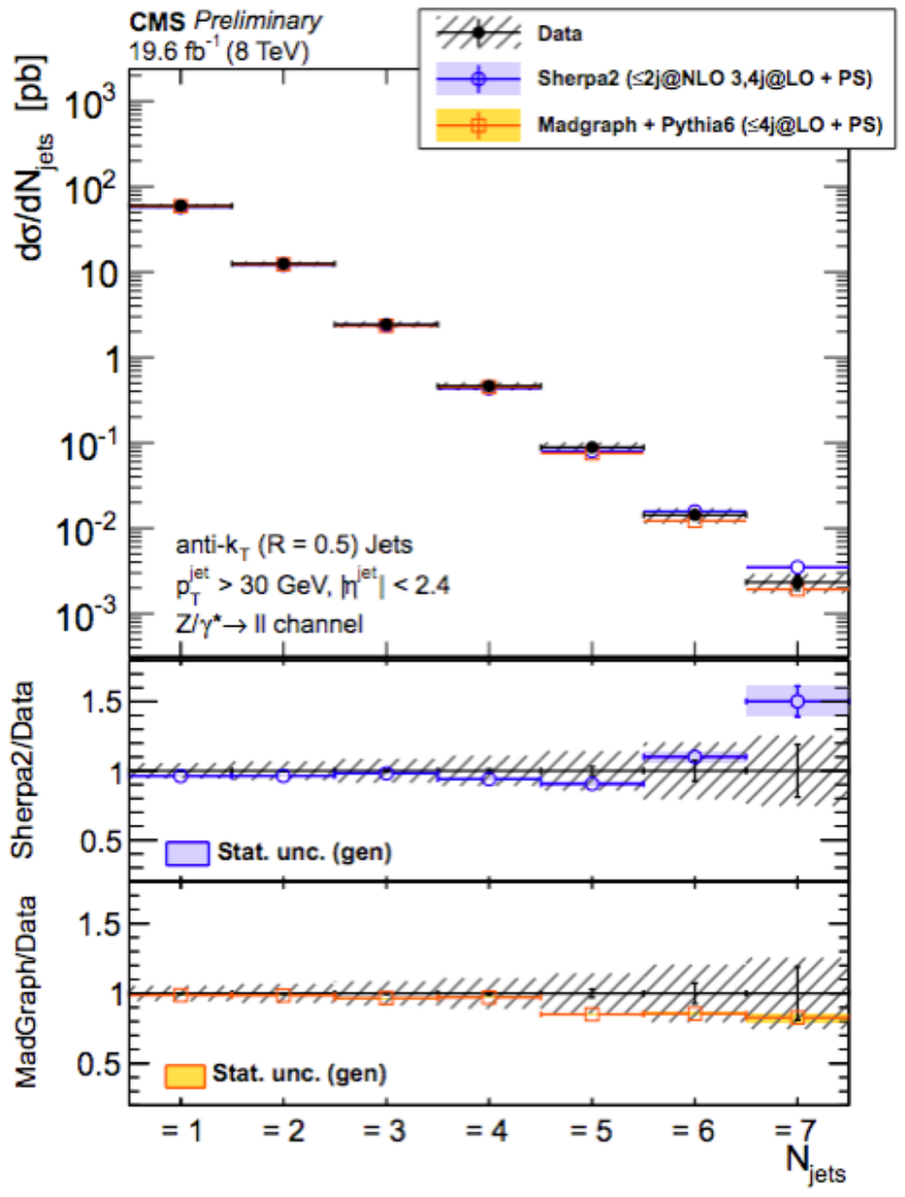




MadGraph describes the shape of the ratio, but predicts 20% normalization difference

V+N-Jets





- Major backgrounds to many searches
- Measurements up to >= 8 jets
- Overall good agreement with the prediction

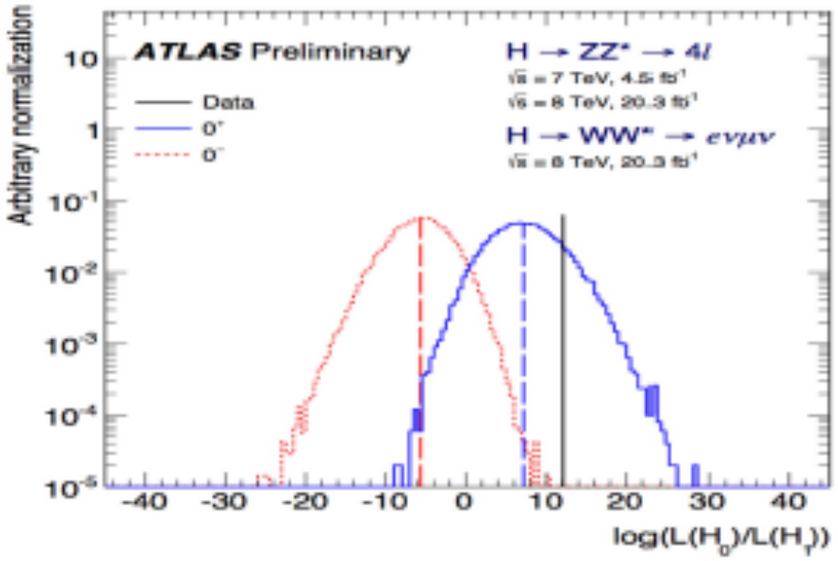
Summary

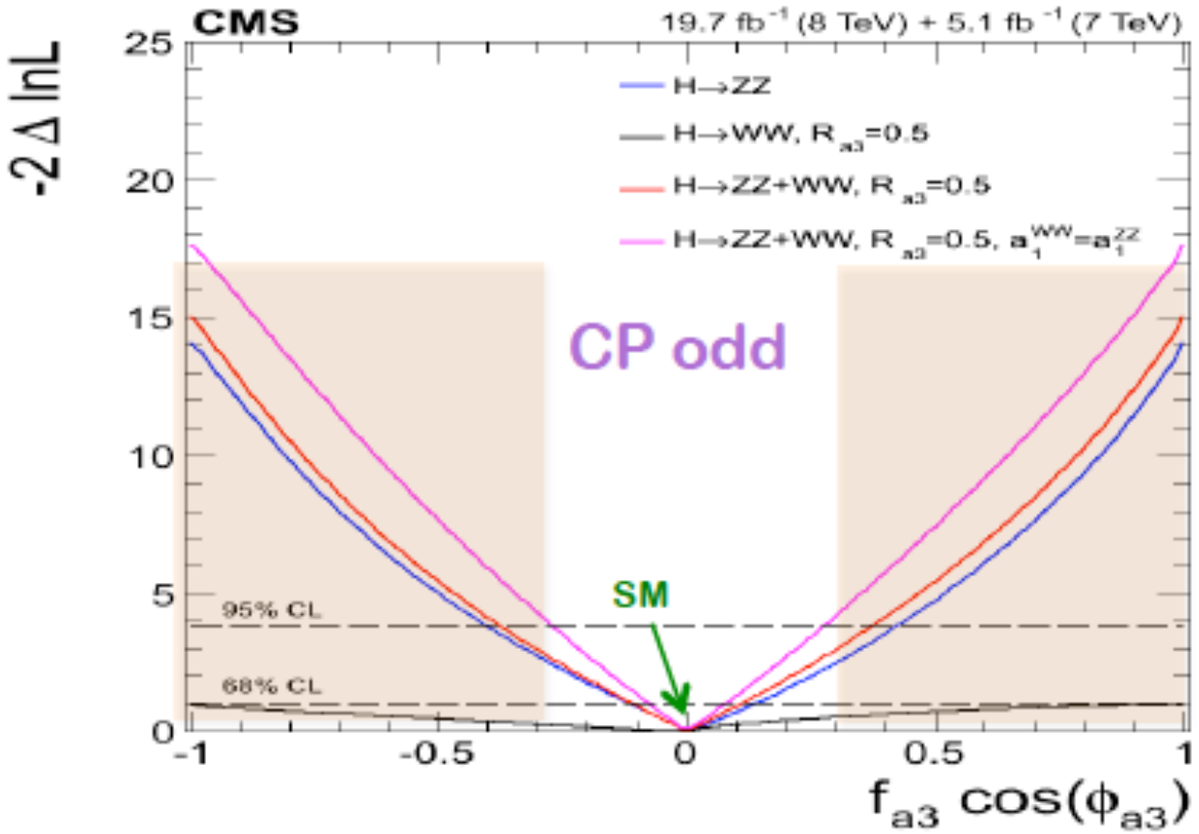
- Many interesting results were presented at 2015 Moriond-QCD
- This shows the hard work of the experimental community in trying to extract maximum possible information from available data
- However, no-signs of new physics yet
- The coming years will be much more exciting with LHC Run-II

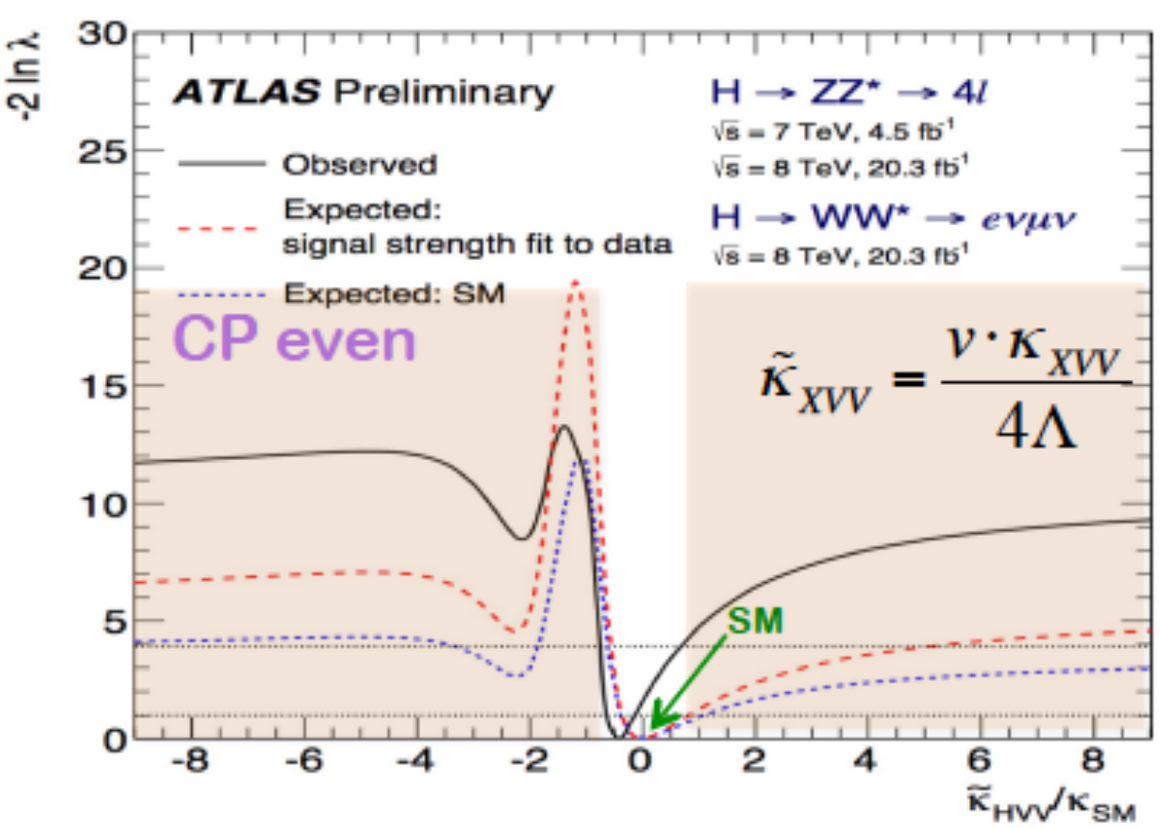
backup

CP Mixing

- **Spin 0 and CP-mixing studies**
  - **Pure BSM CP-odd (0^-) scenario excluded > 97.4% C.L.**
  - **Set limit on BSM coupling and mixing angle in CP even (or odd) mixing scenarios**







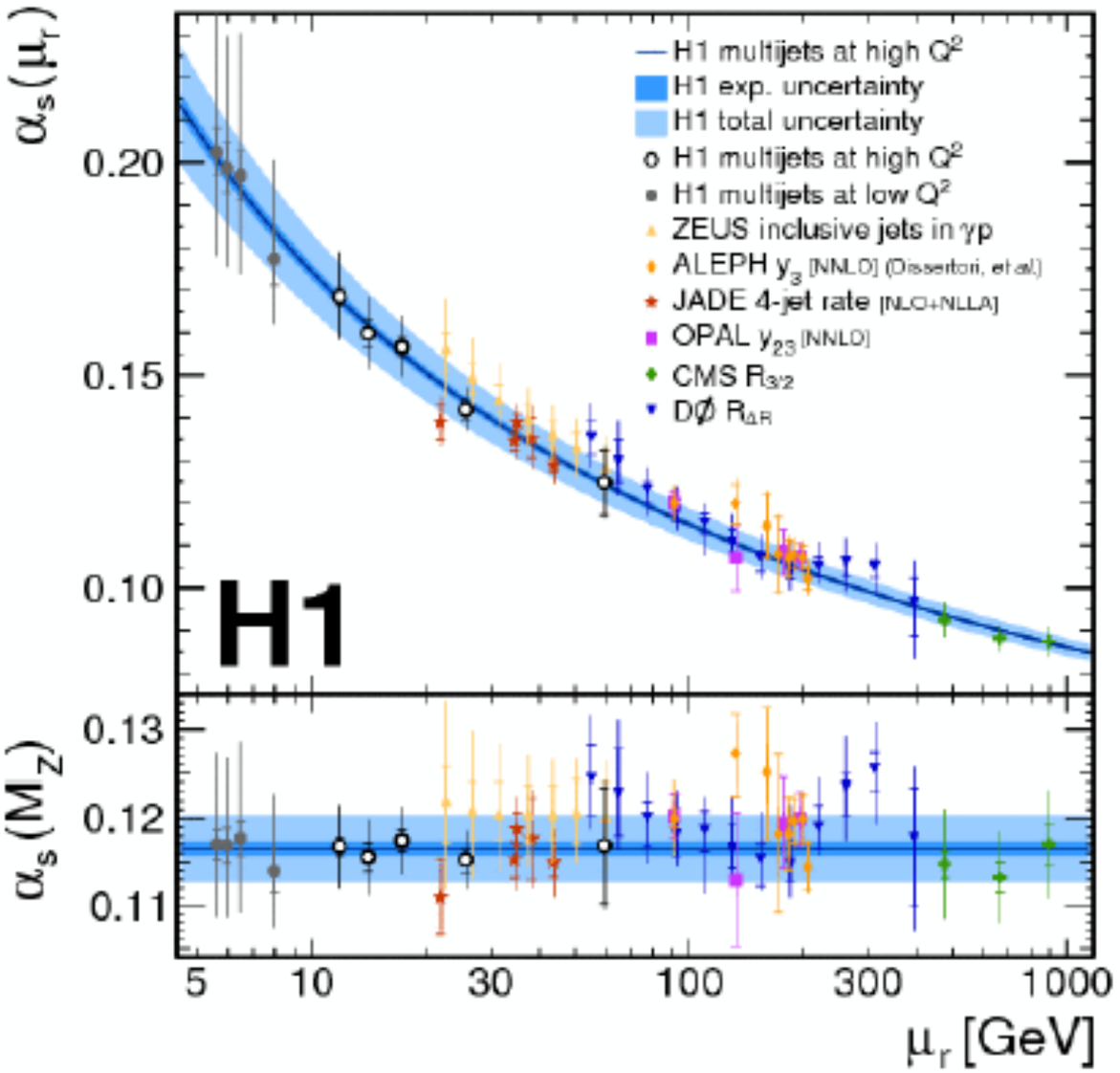
$$\tilde{\kappa}_{XVV} = \frac{v \cdot \kappa_{XVV}}{4\Lambda}$$

No large CP violation in Higgs sector is observed

Eur.Phys.J. C75 (2015) 65

Extraction of strong coupling constant α_s

Simultaneous χ^2-fit to normalised inclusive jet, dijet and trijet cross section



Determination of $\alpha_s(M_Z)$ at various scales

- H1 Multijet cross sections with superior experimental precision
- Consistency with other jet data
- Confirmation of prediction by SU(3) over more than two orders of magnitude

Extraction from all measurements

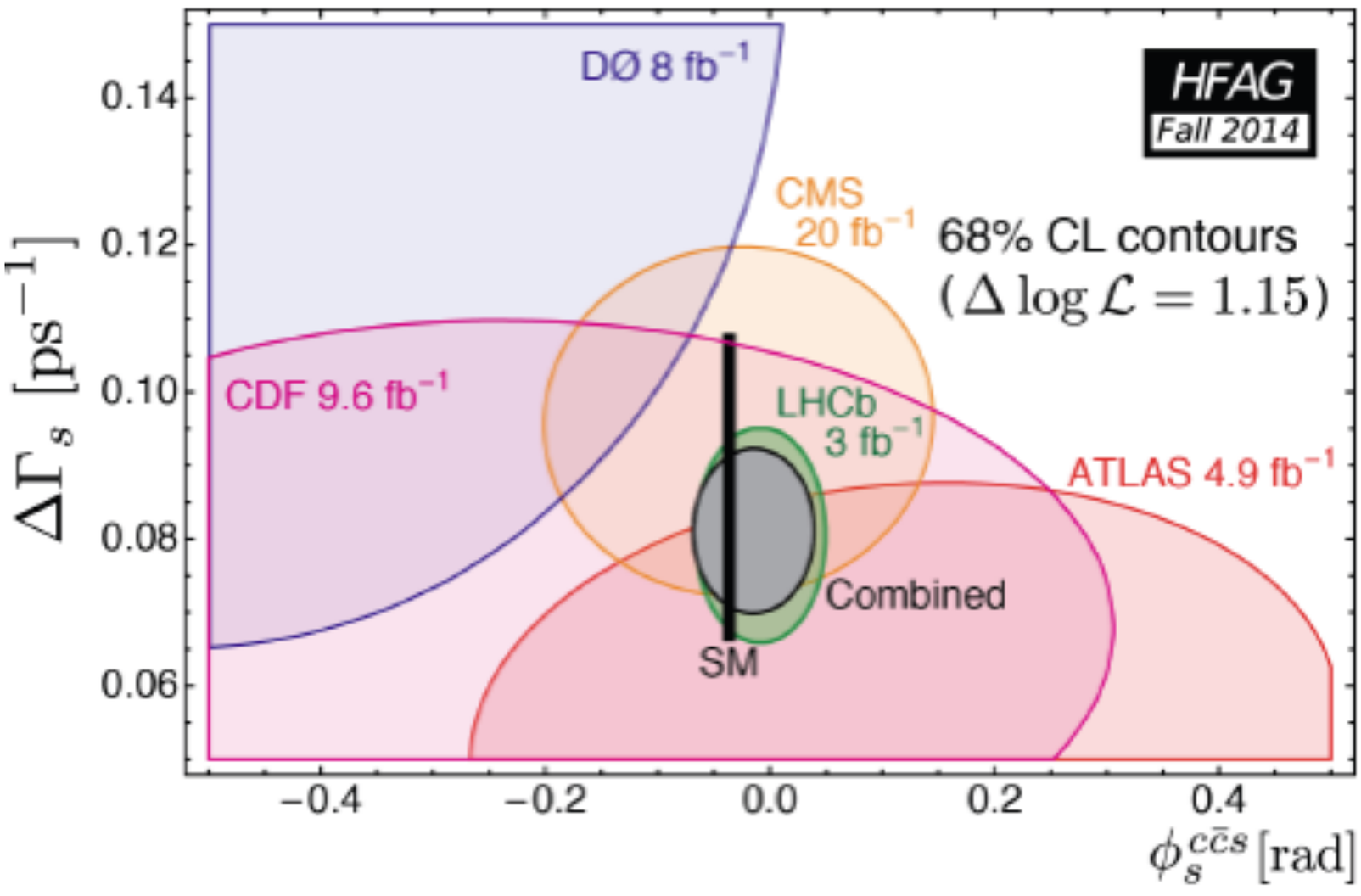
- Experimental uncertainty significantly smaller than theoretical one
- Value consistent with other extractions

Most precise value of $\alpha_s(M_Z)$ from jet cross sections

$$\alpha_s(M_Z)|_{k_T} = 0.1165\ (8)_{\text{exp}}\ (5)_{\text{PDF}}\ (7)_{\text{PDFset}}\ (3)_{\text{PDF}(\alpha_s)}\ (8)_{\text{had}}\ (36)_{\mu_r}\ (5)_{\mu_f}$$
$$= 0.1165\ (8)_{\text{exp}}\ (38)_{\text{pdf,theo}}\ .$$

6

Bs → J/ψ + ϕ



No extra CP violation in bottom physics?