Experimental Summary Talk – LHCP 2016

K. Einsweiler, LBL

- Attempt to summarize intense 5.5 days of LHCP in ~30 mins with selected highlights…

- Almost entirely a summary of Plenary sessions (already 42 talks !)

- Apologies to all of those whom I overlooked – all omissions and misunderstandings are the property of the speaker.

Many thanks to the organizers (especially the local ones !) for a wonderfully organized conference in a superb location !

Overview: the Lull before the Storm…

- This conference has focused on Run 1 results (many interesting and beautiful results continue to emerge !) and 2015 13 TeV analyses.
- The boost in energy from 8 → 13 TeV has a tremendous impact on searches at high mass – 2-3 fb^{-1} was enough to obliterate most limits above 1 TeV from Run 1. Suite of improved measurements at 13 TeV slowly emerging.
- The LHC has now reached "luminosity production" mode => initial luminosity reached 0.94 x 10^{34}, record fill with 517 pb^{-1} and almost 2 fb^{-1} delivered, this week ! Expectation of ~2 fb-1/week in coming weeks (~5 fb^{-1} so far in 2016).

- Two major threads in LHC physics prominently on display at LHCP 2016:

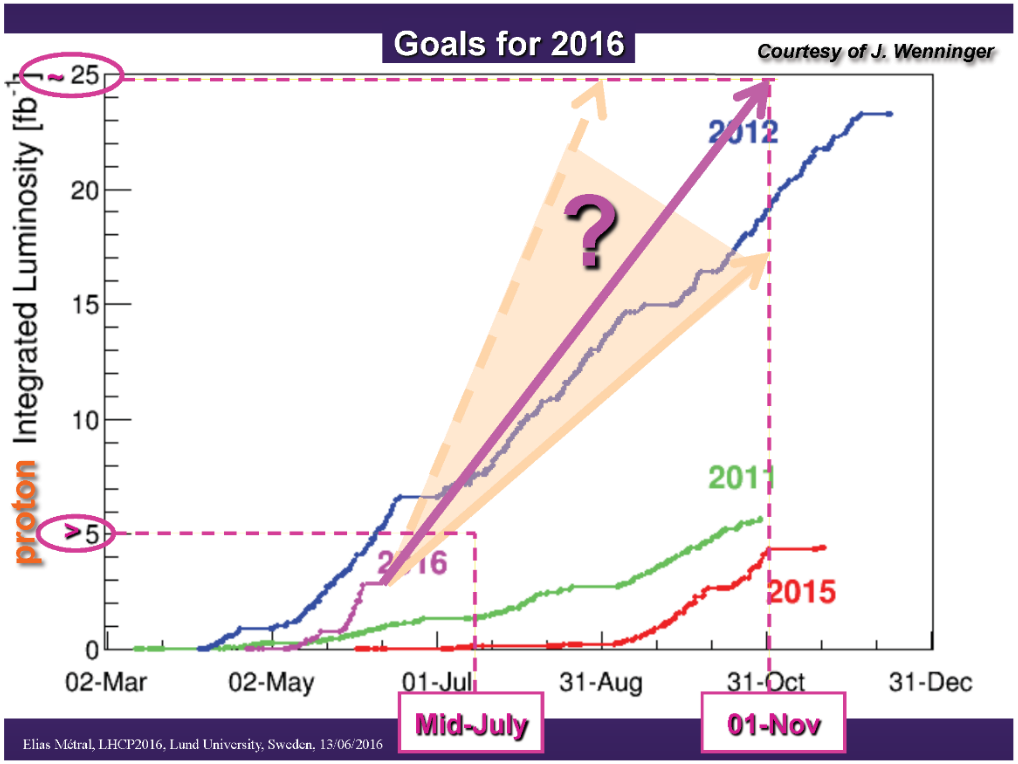
"Precision Frontier": extraordinary progress in precision of predictions for LHC physics (calculations, generators) combined with outstanding detector performance (simulation, reconstruction, physics) => powerful physics results verifying SM Lagrangian + limits on deviations (aTGC, aQGC, EFT).

"Search Frontier": confront all available final states with a vast cornucopia of models, searching for cracks in SM armor, and any traces of new physics. Probe both high-mass and low-coupling axes => leave no stone unturned !

Elias Metral

LHC Status and Outlook

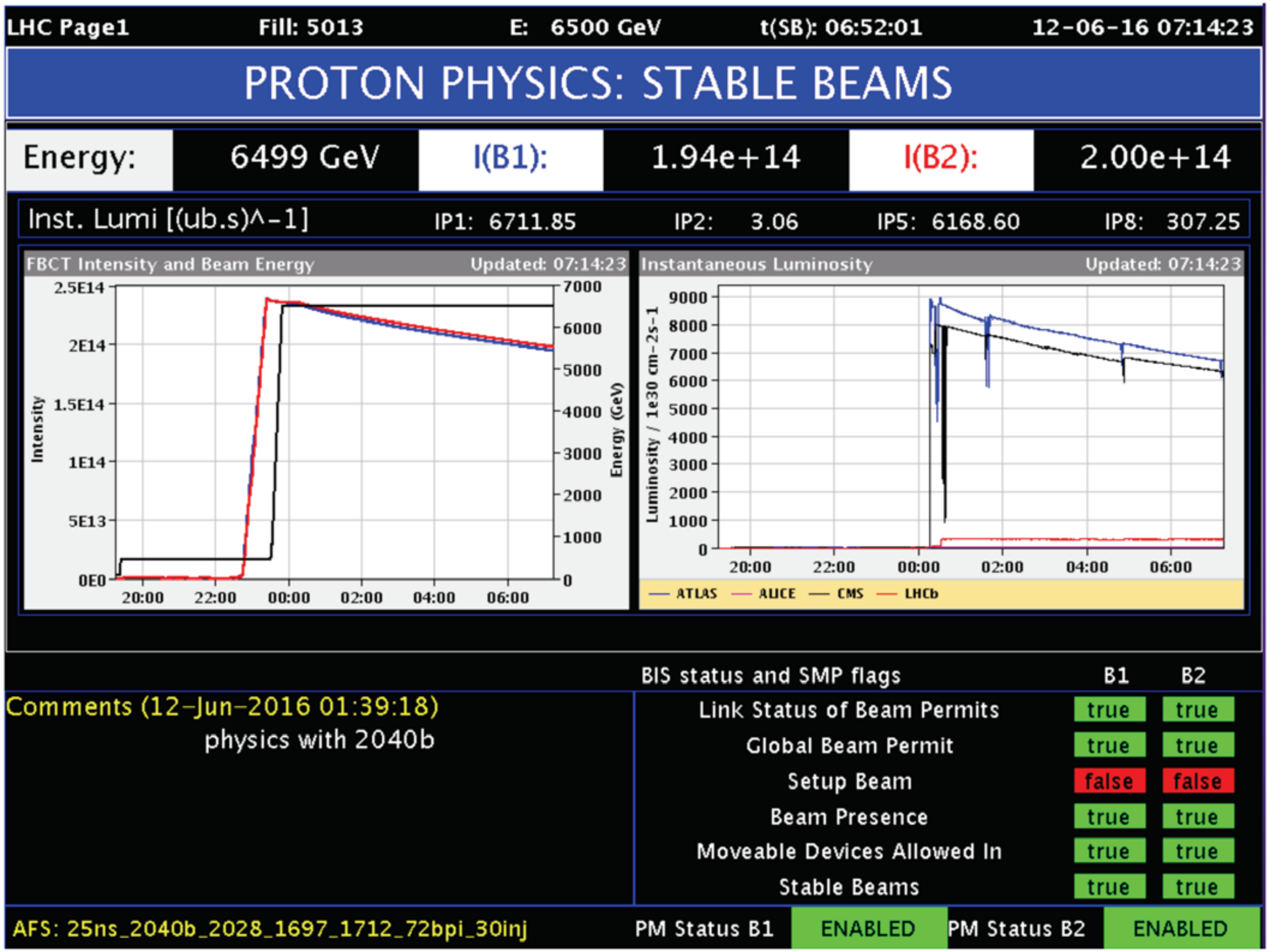
- Without outstanding performance of LHC, there would be little to discuss at this conference ! Detailed technical overview from Elias Metral:
- Based on performance to date, and plausible extrapolations, may exceed design luminosity by ~20% despite limitations of SPS beam dump (TIDVG) !
- Delivery of 25 fb^{-1} in 2016 seems within reach, and even more is possible…



Parameter	Nominal	2016 (done)	2016 (possible?)
Energy [TeV]	7	6.5	
Bunch spacing [ns]	25	25	
Bunch population [10^{11}]	1.15	1.15	1.25 (?)
Bunches / LHC injection	288	72	SPS dump limit?
Total number of bunches	2748 (2808 in DR)	2040	
Collisions in IP1&5	2736 (2808 in DR)	2028	↗ (?)
Transv. emittance [μm]	3.75	3.4	3.5 (?) ↘ (BCMS?)
Brightness [10^{11} / μm]	0.31	0.34	
β* in IP1&5 [cm]	55	40	
X-angle in IP1&5 [μrad]	142.5	185	↘ (?)
Rms bunch length [cm]	7.55	9.4	7.55 (?)
Peak lumi [10^{34} $cm^{-2}s^{-1}$]	**~ 0.99** (1)	**~ 0.77**	**1 => 1+**

LHC Status and Outlook

- Record performance achieved at start of conference (already obsolete): 8.8×10^{33} peak lumi, 459 pb^{-1} integrated lumi, with stable beams…



Torbjorn Sjostrand

Overview of Event Generators

- Having worked at hadron colliders since 1984 (SppS, Tevatron, SSC, LHC), long ago accepted that when we talk about comparing theory and experiment at a hadron collider, the Lund string model and all that has followed from it is the foundation on which we stand…
- Thanks to Torbjorn for the masterful tour from beginnings of the technology for parton shower generators through to todays “legs and loops” overview !

Lund contributions

Physics:

- string fragmentation (& colour coherence)
- dipole showers
- backwards evolution (for ISR)
- multiparton interactions (MPI)
- colour reconnection (CR)
- matching (POWHEG style) & merging (CKKW-L, . . .)
- small-x evolution (CCFM, . . .)
- interleaved evolution
- heavy-ion collisions
- QCD effects for BSM

Generators:

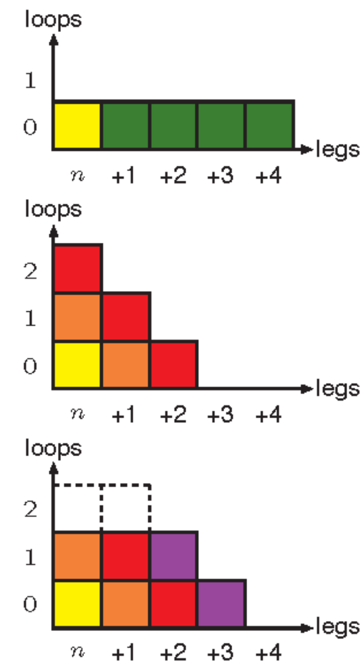
JETSET
PYTHIA
Fritiof
Ariadne
LDC
DIPSY

Lepto
VINCIA
DIRE

RapGap
HIJING
. . .
GEANT

Match and merge strategies

Input from:
Madgraph5_aMC@NLO
POWHEG BOX
ALPGEN
COMIX/Sherpa
NLOJET++
JETRAD
HJETS++
BlackHat
GoSam
Helac
OpenLoops
VBFNLO
CalpHEP/CompHEP
. . .



CKKW
CKKW-L
MLM
UMEPS
MC@NLO
POWHEG
MENLOPS
MEPS@NLO
NL^3
UNLOPS
FxFx
NNLOPS
MiNLO
UN^2LOPS
MIN^2LOPS

Intense activity, no “final word”.

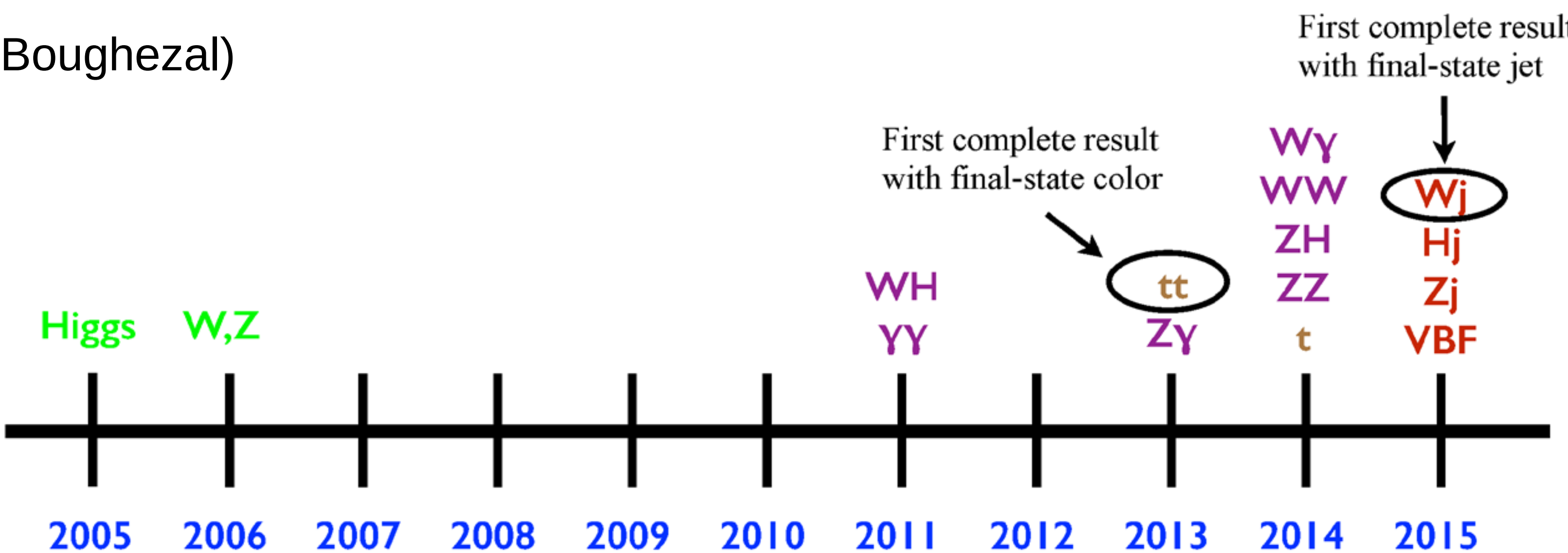
State of the Art: Precision SM Physics

- Extraordinary advances in QCD calculational technology since the LHC startup have brought us (just a few recent personal favorites !):
  - Inclusive Higgs : N3LO+NLO finite-m_t effects + EWK 1602.00695
  - VBF Higgs : N3LO assuming no color exchange 1606.00840
  - Inclusive W^+W^- : N3LL+NNLO + resummed jet-veto 1606.01034
  - Differential W^+W^- : NNLO differential with off-shell 1605.02716
  - Inclusive WZ : NNLO with off-shell decays/cuts 1604.08576
  - Two-loop corrections to interference $gg \rightarrow ZZ$ (key ingredient for off-shell $H \rightarrow ZZ$ analysis) 1605.01380

Will bring Higgs and EWK physics to the next level !

- Complete NNLO hadron-collider cross sections with control over kinematics:

(R. Boughezal)



State of the Art: Precision SM Physics

- Critical experimental ingredient is precision luminosity measurement !
- Very impressive survey of "state-of-the-art" => ATLAS/CMS ~ 2-2.5%

$\mathcal{L}$ performance summary *(new since 2014)*

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	LHCb	ATLAS	CMS	LHCb	ALICE	ATLAS	CMS	LHCb
Running period	2011 pp	2012 pp	2012 pp	2012 pp	2015 pp	2015 pp	2015 pp	2015 pp
$\sqrt{s}$ [TeV]	7	8	8	8	13	13	13	13
$\sigma_{\mathcal{L}}/\mathcal{L}$ [%]	1.7	1.9	2.5	1.2	3.4 Prelim.	2.1	2.7 Prelim.	3.9 Prelim.

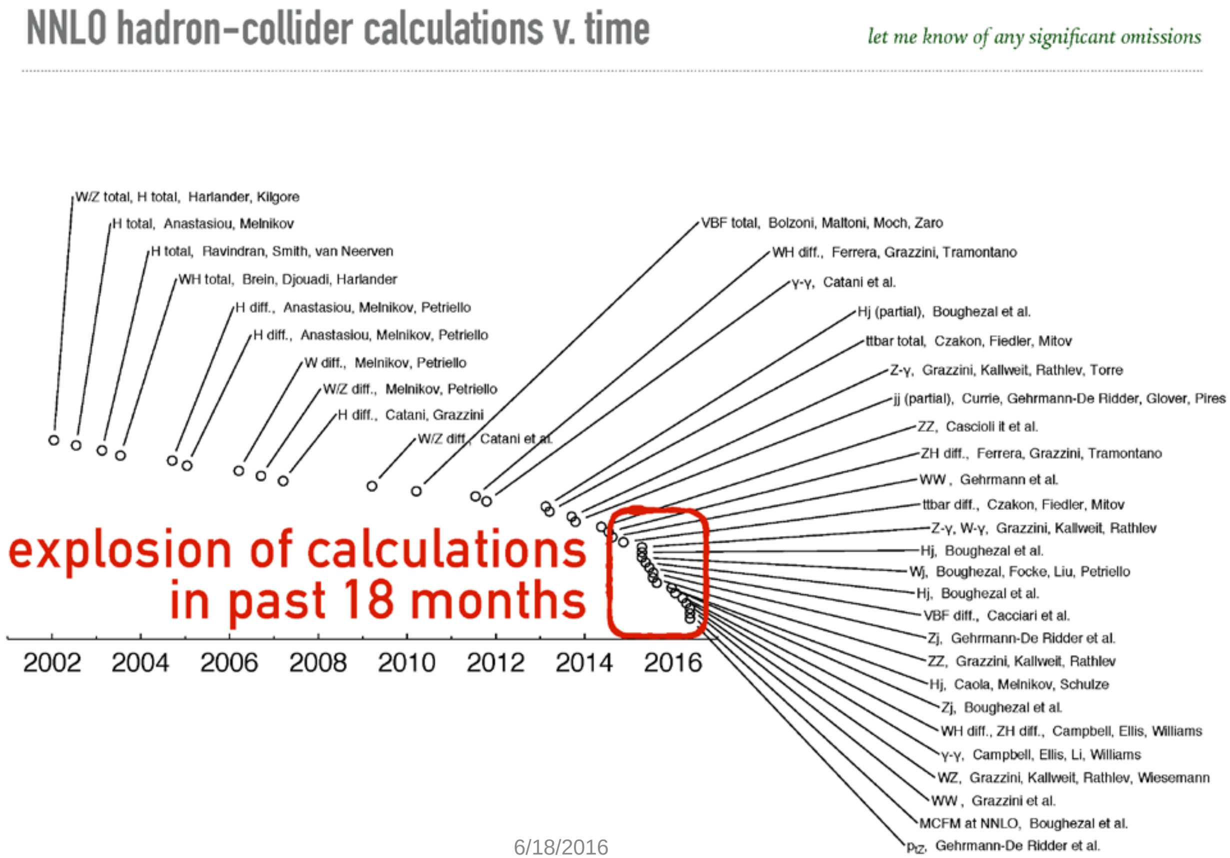
	ALICE	ALICE	ATLAS	CMS	LHCb	ATLAS	CMS	LHCb
Running period	2010/ 2011 PbPb	2013 p-Pb / Pb-p	2013 p-Pb / Pb-p	2013 p-Pb / Pb-p	2013 p-Pb / Pb-p	2013 pp	2013 pp	2013 pp
$\sqrt{s_{NN}}$ [TeV]	5	5	5	5	5	2.76	2.76	2.76
$\sigma_{\mathcal{L}}/\mathcal{L}$ [%]	5.8/4.2	3.7/3.4	2.7	3.6/3.4	2.3/2.5	3.1	3.7	2.2

W. Kozanecki 13 June 2016

Gavin Salam

QCD Updates: Theory Progresses !

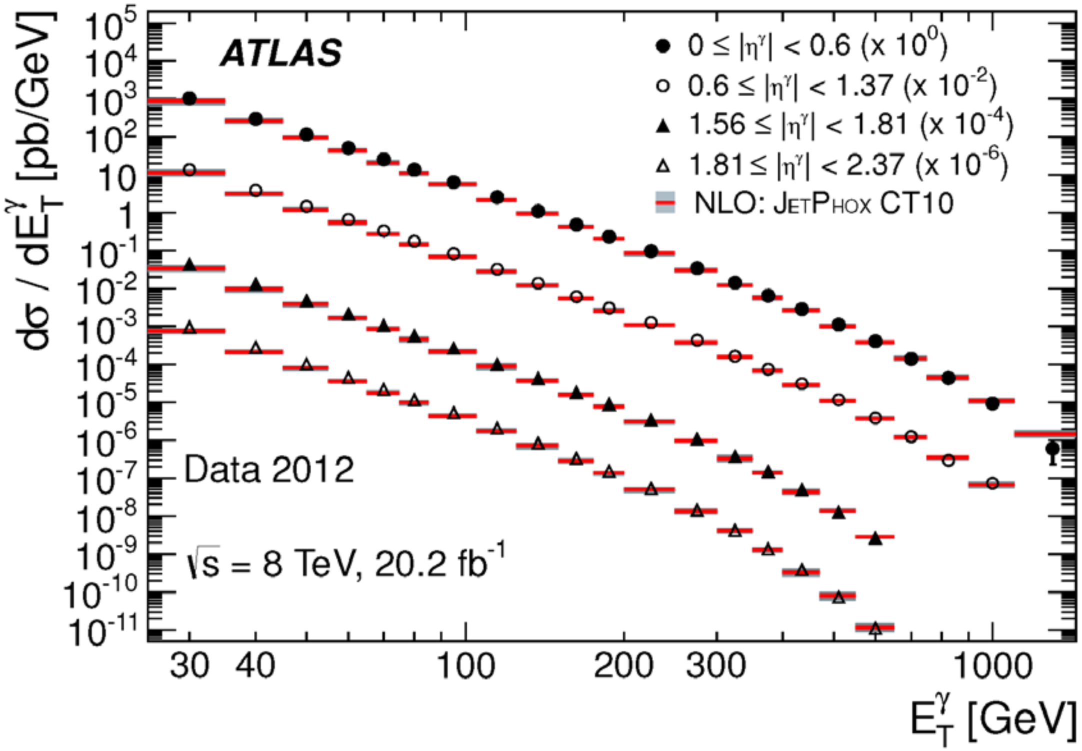
- Excellent overview of upcoming challenges in calculations.
- First N3LO calculations indicate control of scales – need for N3LO PDFs ? Extending N3LO beyond 2 → 1 processes such as H or D-Y will take time !
- Critical to have control over kinematics (fiducial cross-sections, differential distributions) and to include EWK corrections (mixed QCD/EWK needed ?)
- The "precision revolution":

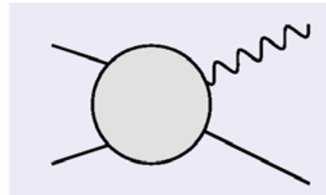


Vitaliano Ciulli

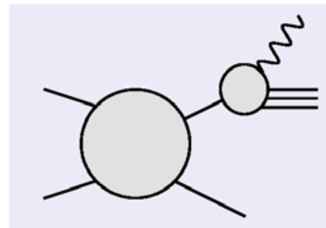
QCD Updates: Precision at 8 and 13 TeV

- Very precise inclusive photon analysis at 8 TeV from ATLAS (NLO+N3LL):
  - **New ATLAS paper arXiv:1605.03495**
    - results unfolded using bin-by-bin, cross-checked with iterative method
    - cross-section given in the fiducial region
    - might constraint the PDF global fit
    - very small experimental uncertainties of a few % (better than theory uncert.)





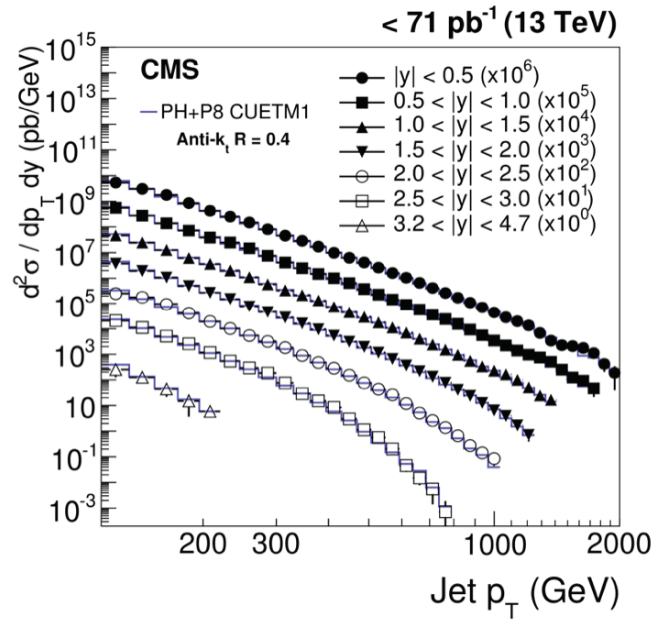
direct (fixed order)

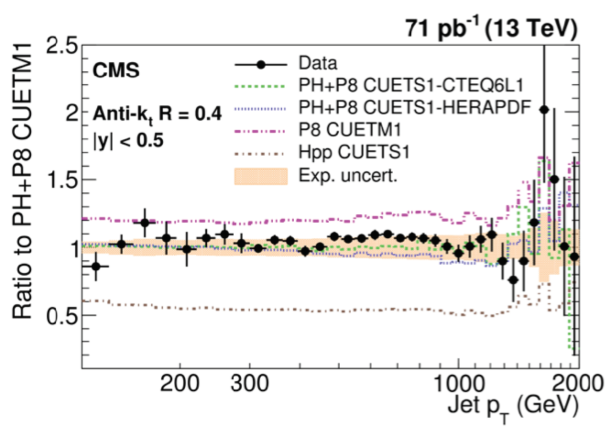


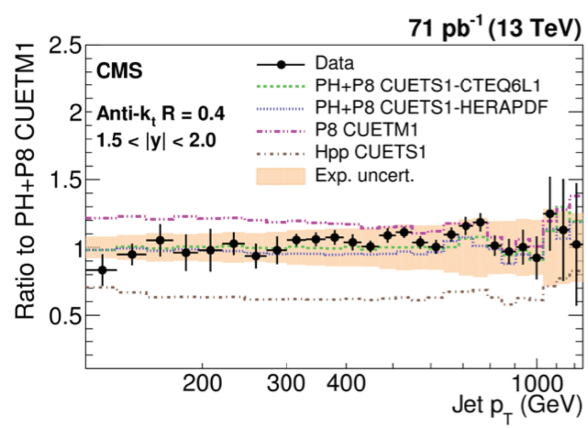
fragmentation (resummed)

QCD Updates: Precision at 8 and 13 TeV

- First jet cross-sections at 13 TeV from CMS:
  - **New CMS paper arXiv:1605.04436**
  - Double-differential inclusive: $\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon \mathcal{L}} \frac{N_j}{\Delta p_T \Delta y}$
  - L = 71 pb^{-1} at 50 ns bx, ~19 pile-up
  - Results for ΔR = 0.7 and 0.4 up to $|y|$ = 4.7
  - Excellent agreement with Powheg+Pythia8
    - p_T shape ok in Herwig++
    - softer p_T in Pythia8 for larger |y|
  - Same results for both ΔR's







John Campbell

EWK Updates: Improved Diboson Calculations

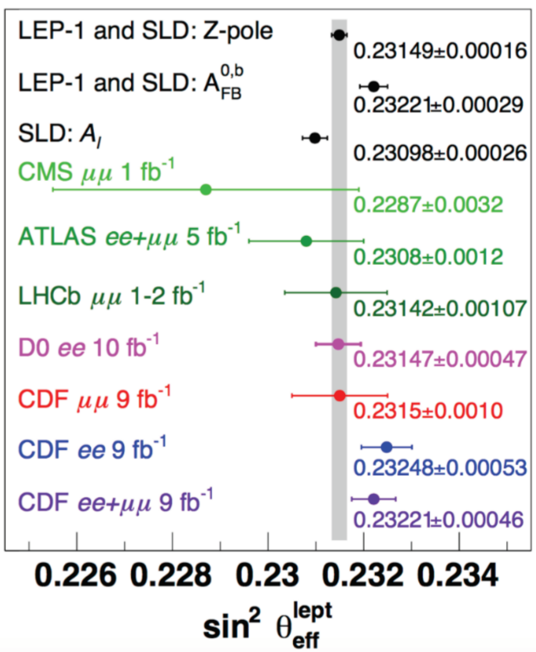
- Freshly-minted NNLO QCD and NLO EW for diboson processes complete the set, together with improvements to pioneering calculations of the last few years.

	LHCP 2015 status	new developments	comments
γγ	NNLO QCD: Catani et al, arXiv: 1110.2375	NNLO(+) QCD: Ellis, Li, Williams, JMC, arXiv: 1603.02663	independent calculation, improved treatment of gg contribution
Vγ	NNLO QCD: Grazzini, Kallweit, Rathlev, arXiv: 1504.01330 NLO EW (Wγ): Denner, Dittmaier, Hecht, Pasold, arXiv:1412.7421	NLO EW (Zγ): Denner, Dittmaier, Hecht, Pasold, arXiv:1510.08742	includes off-shell effects, radiation from leptons in decay
WW	NNLO QCD: Gehrmann, Grazzini, Kallweit, Maierhofer, von Manteuffel, Pozzorini, Rathlev, Tancredi, arXiv: 1408.5243 (approx) NLO EW	NNLO QCD: Grazzini, Kallweit, Pozzorini, Rathlev, Wiesemann, arXiv: 1605.02716 beyond NNLO QCD: Caola, Melnikov, Rontsch, Tancredi, arXiv:1511.08617 NLO EW: Biedermann, Biloni, Denner, Dittmaier, Hofer, Jager, Salfelder, arXiv: 1605.03419	single-resonant diagrams, same-flavor lepton ZZ contributions; higher-order gg loops; exact EW corrections
WZ	NLO QCD (on-shell) NLO EW	NNLO QCD: Grazzini, Kallweit, Rathlev, Wiesemann, arXiv: 1604.08576	off-shell effects, single-resonant diagrams
ZZ	NNLO QCD: Grazzini, Kallweit, Rathlev, arXiv: 1507.06257 (approx) NLO EW: Gieseke, Kasprzik, Kuhn, arXiv: 1401.3964	beyond NNLO QCD: Caola, Melnikov, Rontsch, Tancredi, arXiv:1509.06734 NLO EW: Biedermann, Dittmaier, Hofer, Jager, arXiv: 1601.07787	higher-order gg loops; exact EW corrections

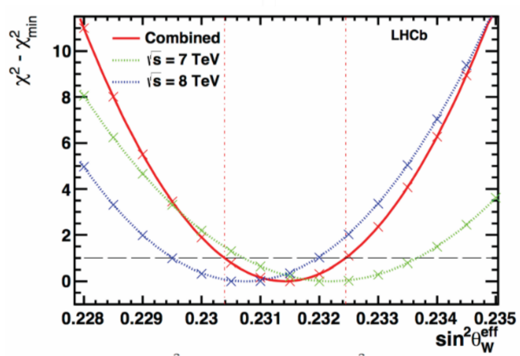
Matthias Schott

EWK Updates: Measurement of $\sin^2\theta_{eff}$

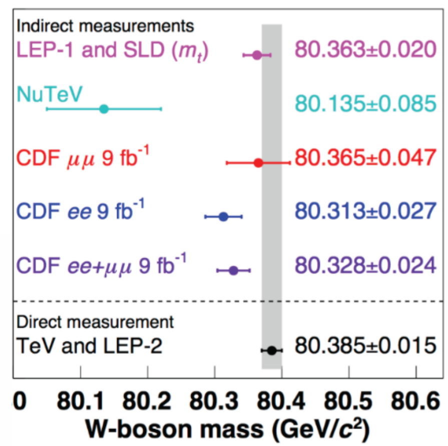
- Measurement at Tevatron is hard, at LHC is much harder ! Can LHC compete ?
- Lack of valence anti-quarks => difficult to define Collins-Soper angle, leads to substantial dilution of information at LHC (large η leptons have best information).
- Final Tevatron results approach power of LEP/SLD – Run 1 LHC can match this ?
  - Dominating uncertainties **due to PDFs**
  - LEP and SLD measurement still most precise measurement
    - new CDF measurement gets close to solve discrepancy
    - **Profiling during $\sin^2\theta_W$ fit** might be able to improve PDF uncertainties



Uncertainty source	CC electrons $[10^{-4}]$	CF electrons $[10^{-4}]$	Muons $[10^{-4}]$	Combine $[10^{-4}]$
PDF	10	10	9	9
MC statistics	5	2	5	2
Electron energy scale	4	6	–	3
Electron energy resolution	4	5	–	2
Muon energy scale	–	–	5	2
Higher-order corrections	3	1	3	2
Other sources	1	1	2	2



[LHCb arXiv1509.07645]



[CDF arXiv:1605.02719]

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

EWK Updates: Measurement of W Mass

- EWK fits are presently limited by W mass => should aim for ±5 MeV.
- Present Tevatron combination (from 2012) gives 80.387 ± 0.016 GeV (1204.0042). World average gives ± 0.015 GeV. Using all available Tevatron data, could optimistically reach ± 0.010 GeV.
- Many areas need development (LHC measurement is more difficult):
  - Mastering impact of pile-up on hadronic recoil.
  - Precision modeling of vector boson P_T: measure $P_T(Z)$ precisely and use physics to transfer to $P_T(W)$ with uncertainties.
  - PDF effects, particularly the different heavy-flavor dependence of W and Z production coupling to P_T of W and Z and different behavior of W^+ and W^-.
  - Polarization effects on both W and Z production.
- Requires a large associated measurement program to control systematic uncertainties. Several reported at this conference.
- CMS has performed a “W-like” measurement of m_Z as a “proof-of-principle” exercise. Progress, but still some ways to go to compete with Tevatron !
- For further information: see talk of Nenad Vranjes in EWK parallel session…

Matthias Schott

EWK Updates: Measurement of W Mass

- Recent progress through detailed measurements of Z polarization by both ATLAS and CMS (ATLAS 1606.00689) – not well-modelled !

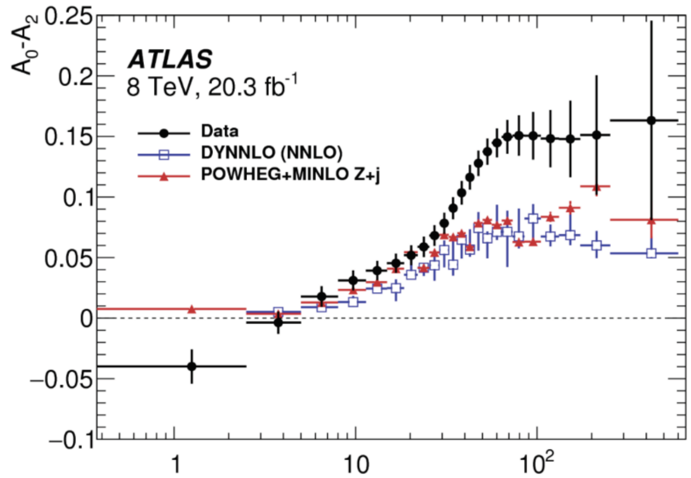
- The fully differential DY cross section can be reorganised by **factorising the dynamic of the boson** production, and the kinematic of the decay (CS-Frame)

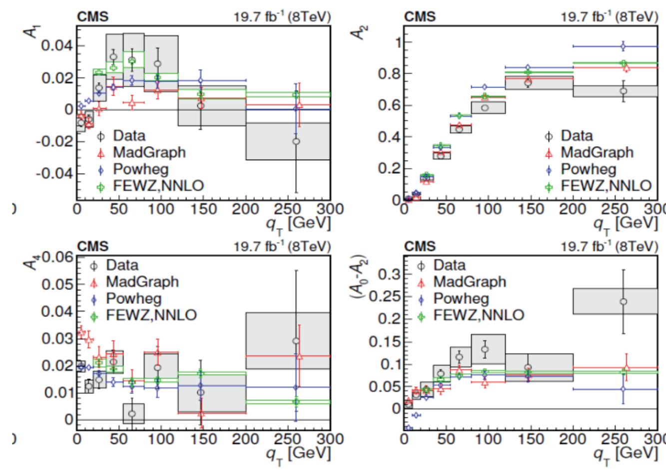
$$\frac{d\sigma}{dp_T^2 dy dM d\cos\theta d\phi} = \frac{3}{16\pi}\frac{d\sigma}{dp_T^2 dy dM} \times [(1+\cos^2\theta) + A_0\frac{1}{2}(1-3\cos^2\theta) + A_1 \sin 2\theta\cos\phi + A_2\frac{1}{2}\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta + A_5\sin^2\theta\sin 2\phi + A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi]$$

- Uncertainties in A_i will **affect decay kinematics** of leptons

- CMS and ATLAS Results:
  - Significant **differences** to predictions
  - A_2 shows sensitivity to parton shower implementation

[ATLAS-STDM-2014-10]



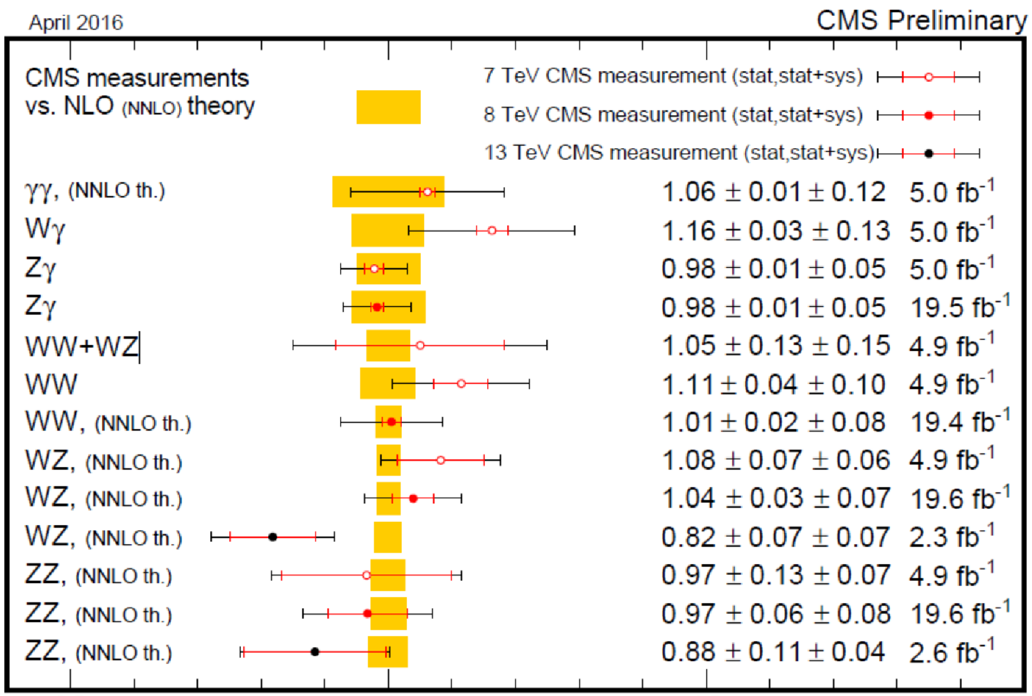


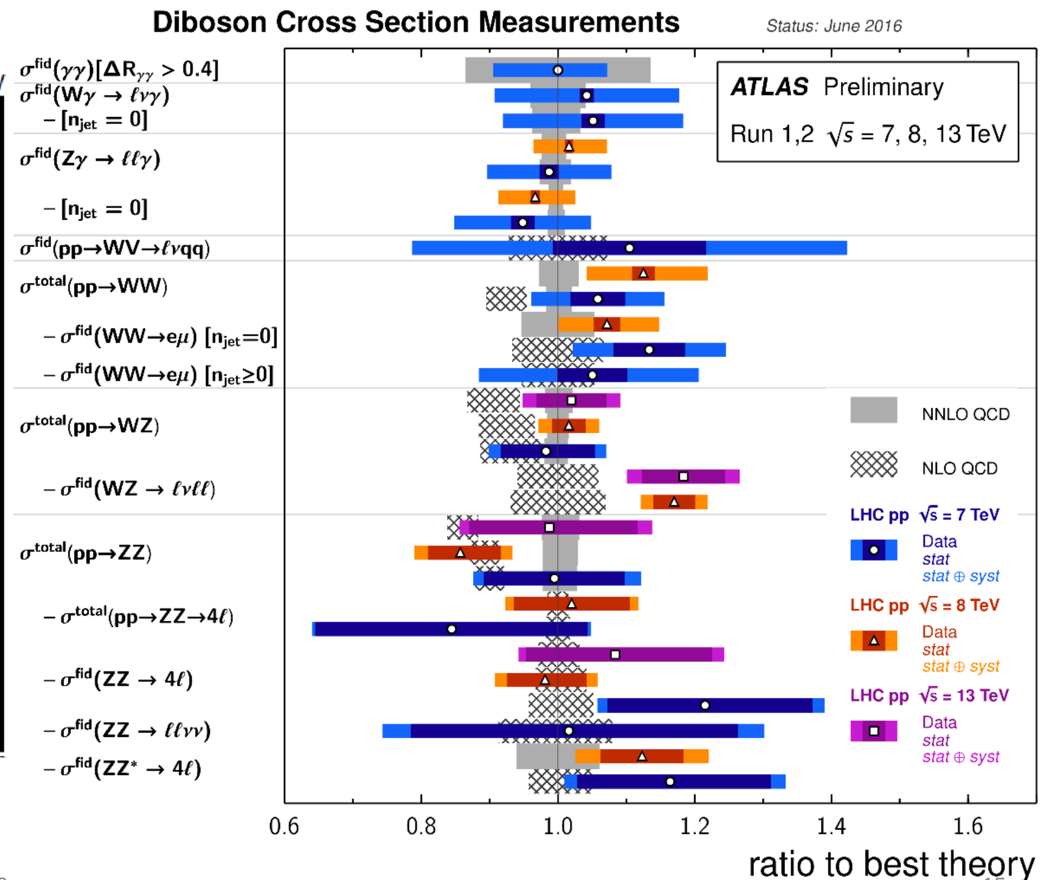
[PLB 750 (2015) 154]

Lara Lloret Iglesias

EWK Updates: Diboson Measurements

- Huge number of measurements available at 7, 8, and even 13 TeV.
- Mostly QCD, but contain EWK vertices => look for anomalies ! Limits on aTGC now similar to or better than LEP
- When NNLO calculations are available, agreement is generally good (many fiducial cross-section calculations are not yet there at NNLO).





EWK Updates: VBF, VBS, Multi-bosons

	Fiducial dijet cuts	EWK cross section [fb]	
		Data	Theory
ATLAS Zjj	p_T>55,45 GeV,|y|<4.4; m_{jj} >250 GeV; jet veto; $p_T^{balance}$<0.15	54.7 ± 4.6 (stat)$^{+9.8}_{-10.4}$ (syst) ± 1.5 (lumi)	46.1 ± 1.0 [Powheg+Py]
CMS Zjj	p_T>25 GeV, |η|<5; m_{jj} > 120 GeV;	174 ± 15 (stat) ± 40 (syst)	208 ±18 [LO MG+Py]
CMS Wjj	p_T>60,50 GeV,|η|<4.7; m_{jj} > 1 TeV	420 ± 40 (stat) ± 90 (syst)	500 ± 30 [LO MG+Py]

	Fiducial dijet cuts	Fiducial cross section [fb]		Significance	
		Data	Theory	Obs.	Exp'd
CMS incl. W±W±jj	p_T > 20 GeV, |η|<5; m_{jj}> 300 GeV,|$\Delta\eta_{jj}$| > 2.5	4.0 $^{+2.4}_{-2.0}$ (stat) $^{1.1}_{-1.0}$ (syst)	5.8 ±1.2 [VBFNLO]	2.0 σ	3.1 σ
ATLAS incl. W±W±jj	p_T > 30 GeV, |η|<4.5; m_{jj}> 500 GeV	2.1 ± 0.5 (stat) ± 0.3 (syst)	1.52 ± 0.11 [Powheg+Py8]	4.5 σ	3.4 σ
ATLAS EWK W±W±jj	as above + |Δy_{jj}| > 2.4	1.3 ± 0.4 (stat) ± 0.2 (syst)	0.95 ± 0.06 [Powheg+Py8]	3.6 σ	2.8 σ

	Fiducial dijet cuts	Data σ [fb]	Exp'd σ [fb]	Theory σ [fb] [VBFNLO]
ATLAS EWK WZjj	p_T >30 GeV, |η|<4.5; m_{jj}>500 GeV	< 0.63 @ 95% CL	< 0.45	0.13 ± 0.01
CMS incl. WZjj	p_T >20 GeV, |η|<5; m_{jj}>300 GeV,|$\Delta\eta_{jj}$| >2.5	10.8 ± 4.0(stat) ±1.3(syst)	N/A	14.4 ± 4.0

	Fiducial dijet/photon cuts	Fiducial cross section [fb]		Significance	
		Data	Theory [MG+Py] +NLO/LO kfactor	Obs.	Exp'd
EWK Zγjj	Jets: p_T > 30 GeV, |η|<4.7; Photon: p_T > 20 GeV, |η|<1.4; m_{jj}> 400 GeV, |$\Delta\eta_{jj}$| > 2.5	1.86 $^{+0.89}_{-0.75}$ (stat) $^{0.41}_{-0.27}$ (syst) ± 0.05 (lumi)	1.26 ±0.12	3.0 σ	2.1 σ
incl. Zγjj	as above + m_{jj} > 800 GeV	1.00 ± 0.43 (stat) ± 0.26 (syst) ± 0.03 (lumi)	0.78 ± 0.09	4.5 σ	4.3 σ
EWK Wγjj	Jets: p_T > 30 GeV, |η|<4.7; Photon: p_T > 20 GeV, |η|<1.4; m_{jj}>700 GeV, |$\Delta\eta_{jj}$| > 2.4;	10.8 ± 4.1 (stat) ± 3.4 (syst) ± 0.3 (lumi)	6.1 ± 1.2	2.7 σ	1.5 σ
incl. Wγjj	as above	23.2 ± 4.3 (stat) ± 1.7 (syst) ± 0.6 (lumi)	23.5 ± 6.6	7.7 σ	7.5 σ

Run 1 shows great progress !

Observation of VBF (EWK production of single W or Z). The Z channel will be "golden" mode for detailed study of VBF features.

Evidence for VBS (EWK scattering of VV pairs) in ssWW and Zγ. WZ and Wγ channels more challenging. Will develop substantially during Run 2

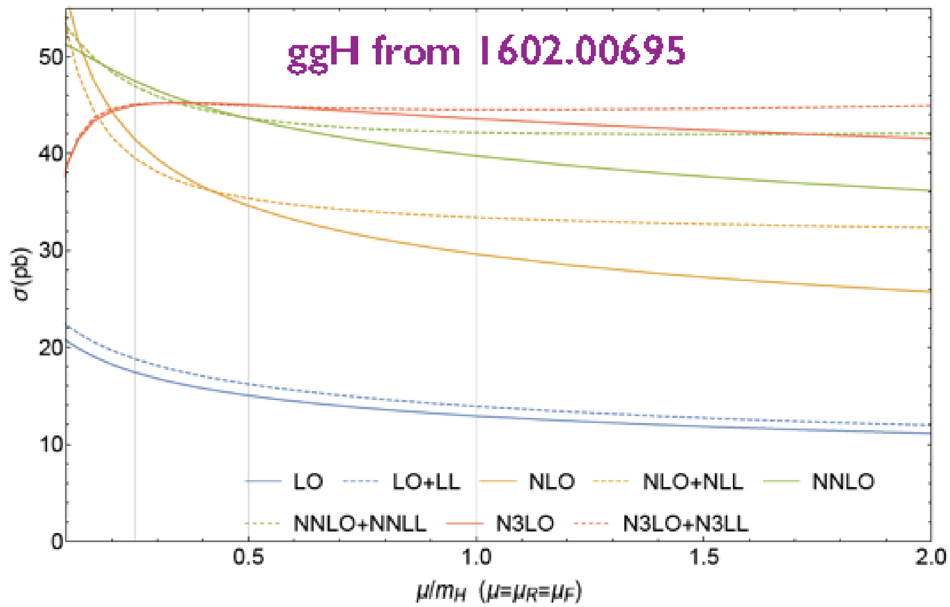
Tri-boson production with observation of Zγγ and evidence for Wγγ just beginning. Run 2 luminosity will be critical addition.

Frank Petriello

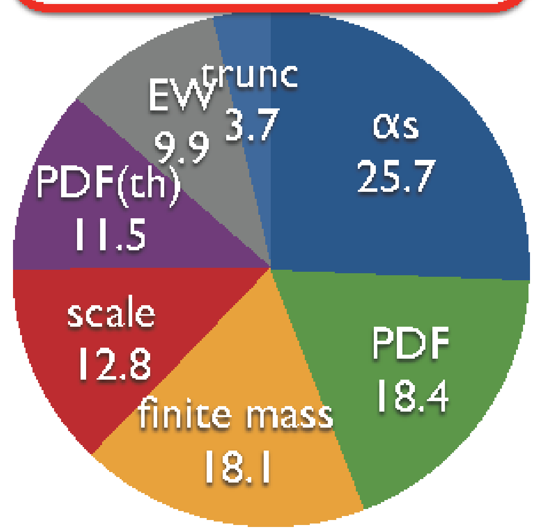
Higgs Updates: Theory Improvements

After years of investment, N3LO revolution has arrived – essential for precision Higgs physics (couplings !) to keep up with future experimental uncertainties !

- Inclusive gluon-fusion Higgs production known at N^3LO! Important part of all coupling analyses (Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Lazopoulos, Mistlberger 1602.00695)
- VBF production known at N^2LO differentially, and N^3LO inclusively (Cacciari, Dreyer, Karlberg, Salam, Zanderighi 1506.02660; Dreyer, Karlberg 1606.00840)



Approximate error budget (percentage of total error):



13 TeV:

$$\sigma = 48.58\,\text{pb}^{+2.22\,\text{pb}\,(+4.56\%)}_{-3.27\,\text{pb}\,(-6.72\%)}\,(\text{theory}) \pm 1.56\,\text{pb}\,(3.20\%)\,(\text{PDF}+\alpha_s)\,.$$

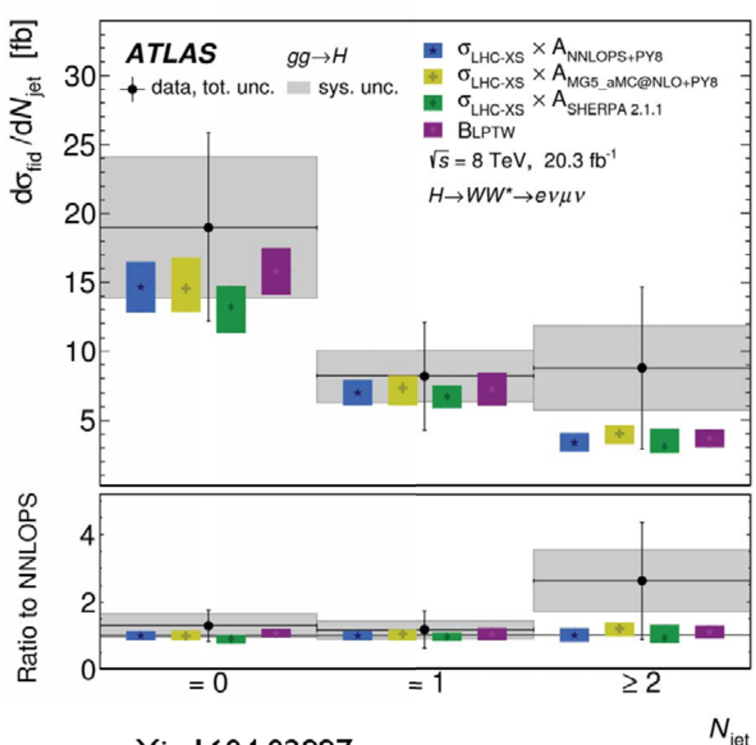
Precision ~ 6%

Jonas Strandberg

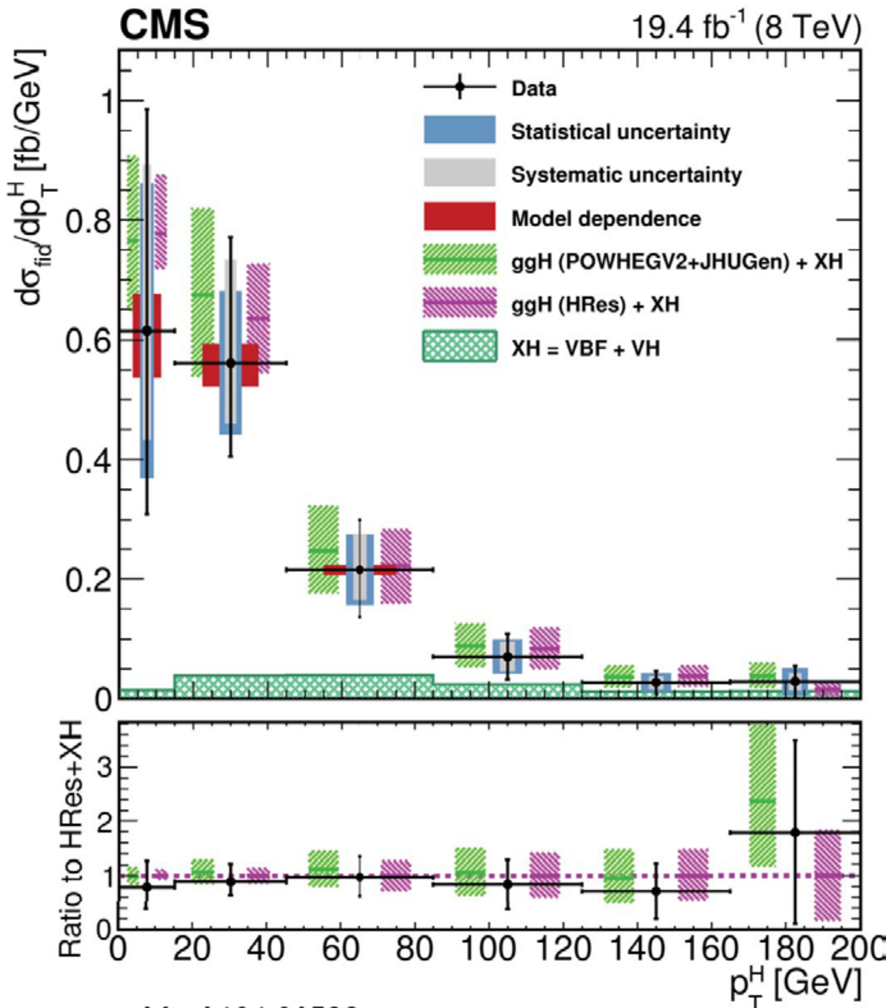
Higgs Updates: New Differential Results

Extend existing results in $\gamma\gamma$ and ZZ channels to very challenging WW channel
=> more powerful checks of production dynamics - check latest MC modeling !

- ATLAS and CMS recently released the first differential measurements in the $H \to WW$ channel.



arXiv:1604.02997



arXiv:1606.01522

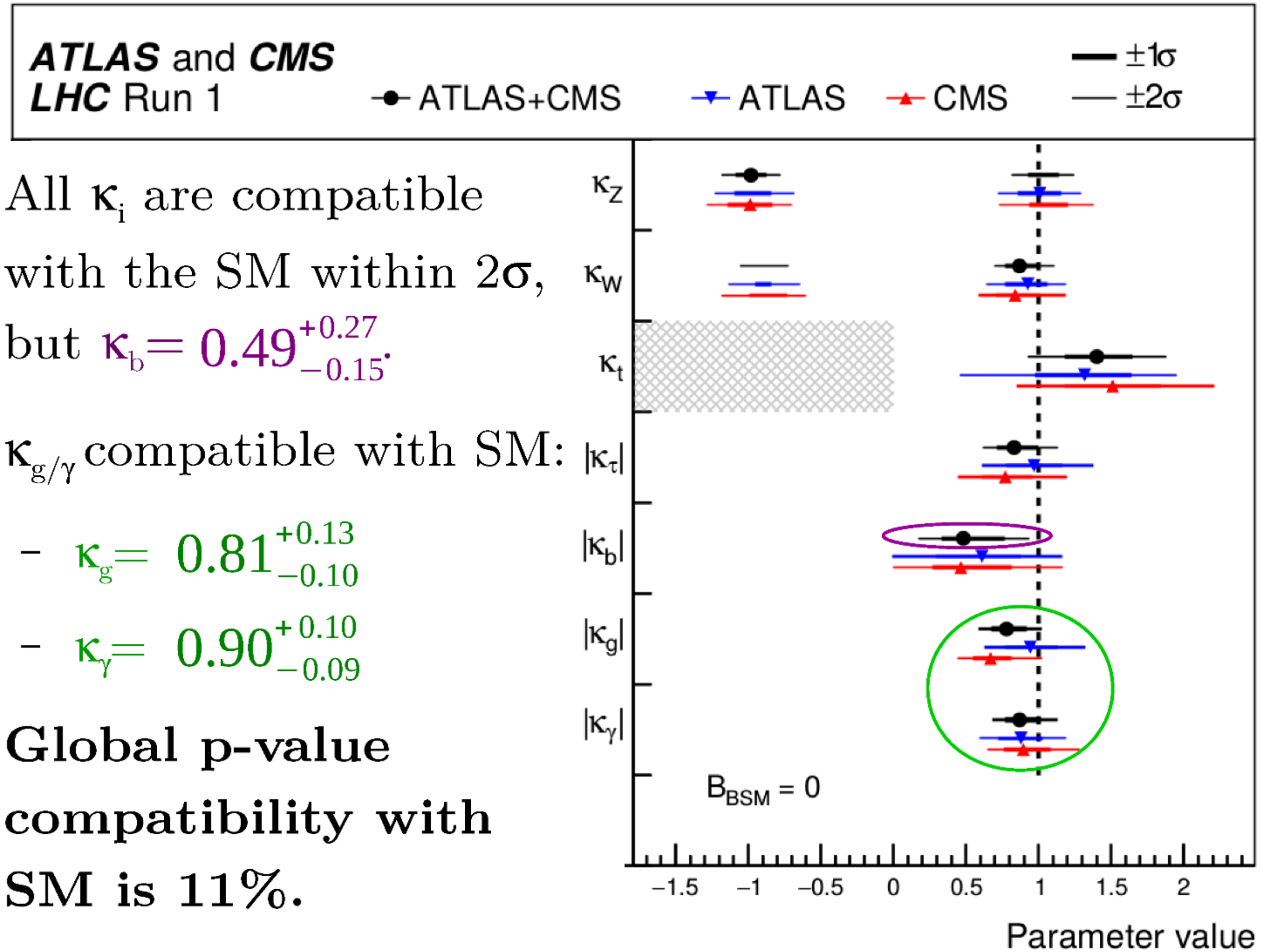
Silvio Donato

Higgs Updates: ATLAS+CMS Couplings

- Monumental (71 pages) combined couplings paper is out (1606.02266) !
- Production signal strengths as expected (ttH somewhat high, but difficult !)

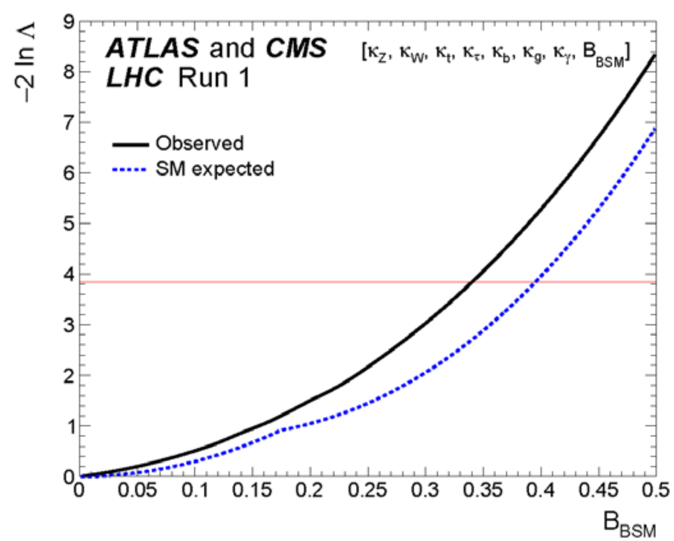
$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\text{ (stat) }^{+0.04}_{-0.04}\text{ (expt) }^{+0.03}_{-0.03}\text{ (thbgd)}^{+0.07}_{-0.06}\text{ (thsig)}$$

- All κ_i are compatible with the SM within 2σ, but $\kappa_b = 0.49^{+0.27}_{-0.15}$.
- $\kappa_{g/\gamma}$ compatible with SM:
  - $\kappa_g = 0.81^{+0.13}_{-0.10}$
  - $\kappa_\gamma = 0.90^{+0.10}_{-0.09}$
- **Global p-value compatibility with SM is 11%.**



Higgs Couplings assuming no BSM (left) or allowing BSM contributions (below)

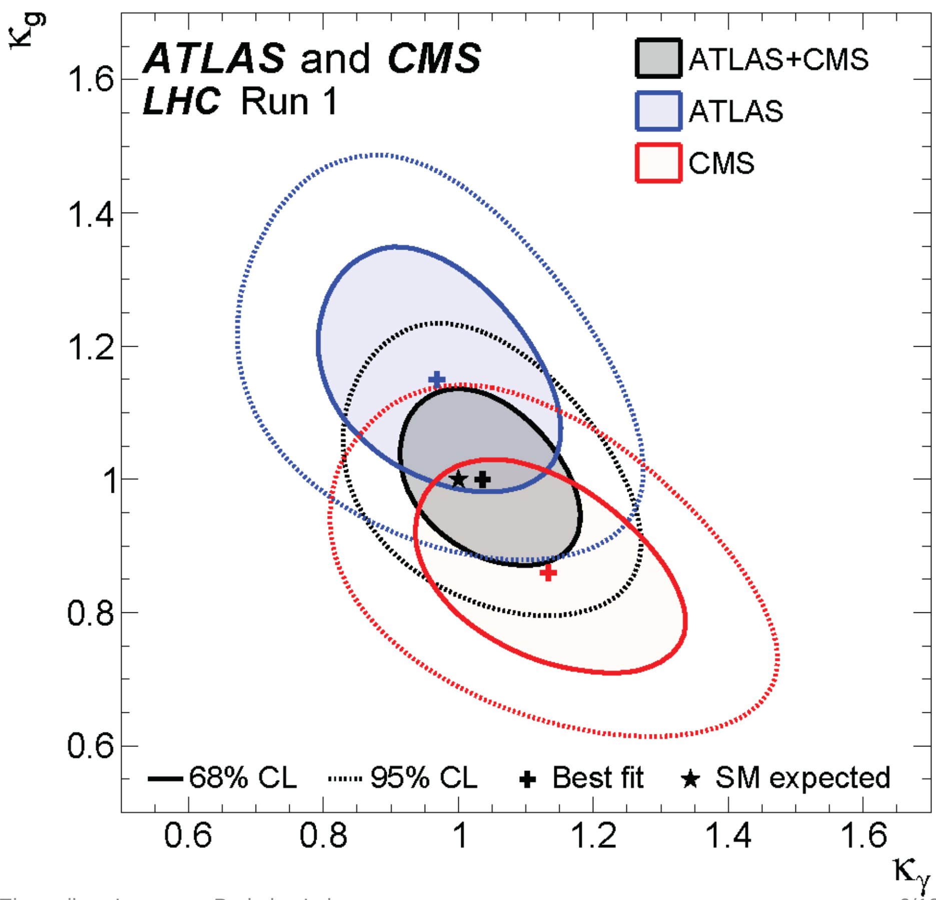
BSM < 0.34 (0.39 exp) 95% CL

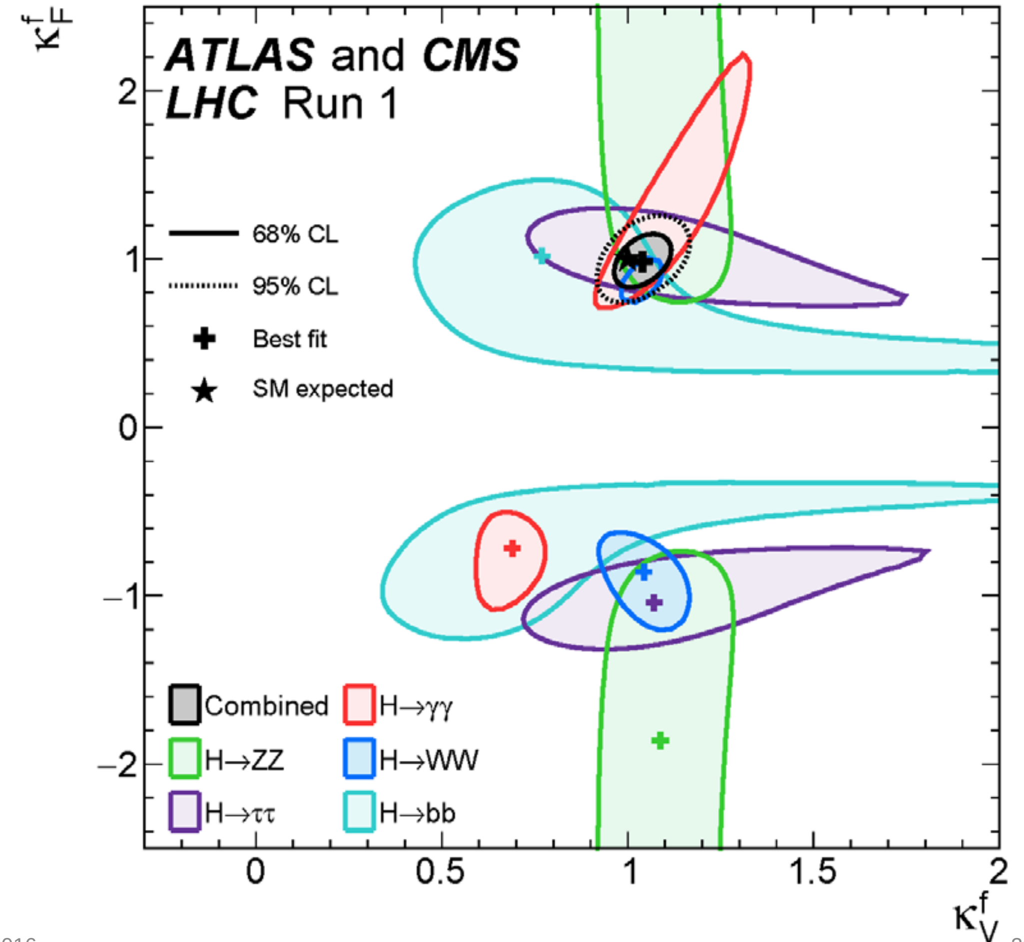


Silvio Donato

Higgs Updates: ATLAS+CMS Couplings

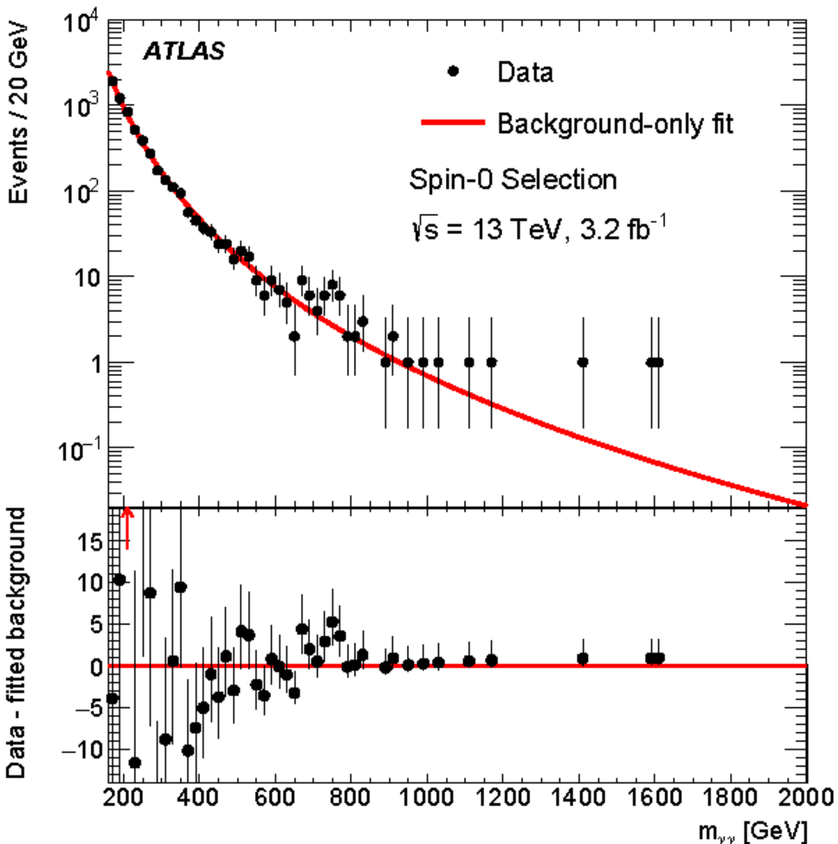
- Allowing additional BSM contributions in loop couplings (only κ_γ and κ_g are varied) gives results on lower left. Very consistent with SM…
- Collapse couplings into fermionic ($\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_\mu$) and bosonic ($\kappa_V = \kappa_Z = \kappa_W$), perform 2D fit to each mode separately = compatible with SM.

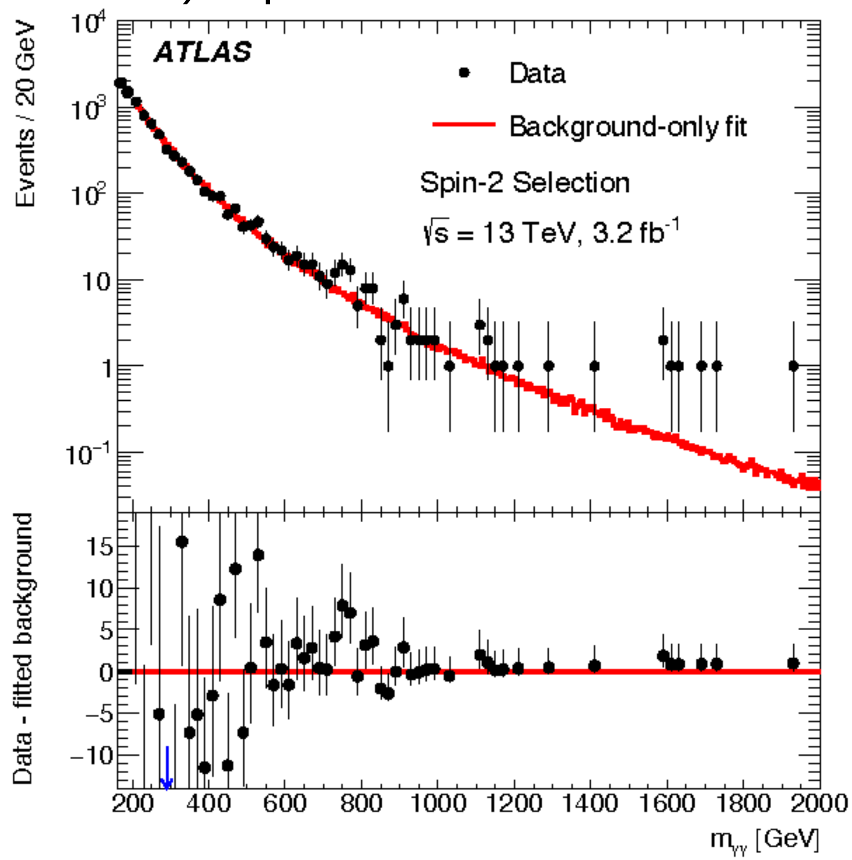




Higgs Updates: Diphoton Resonances

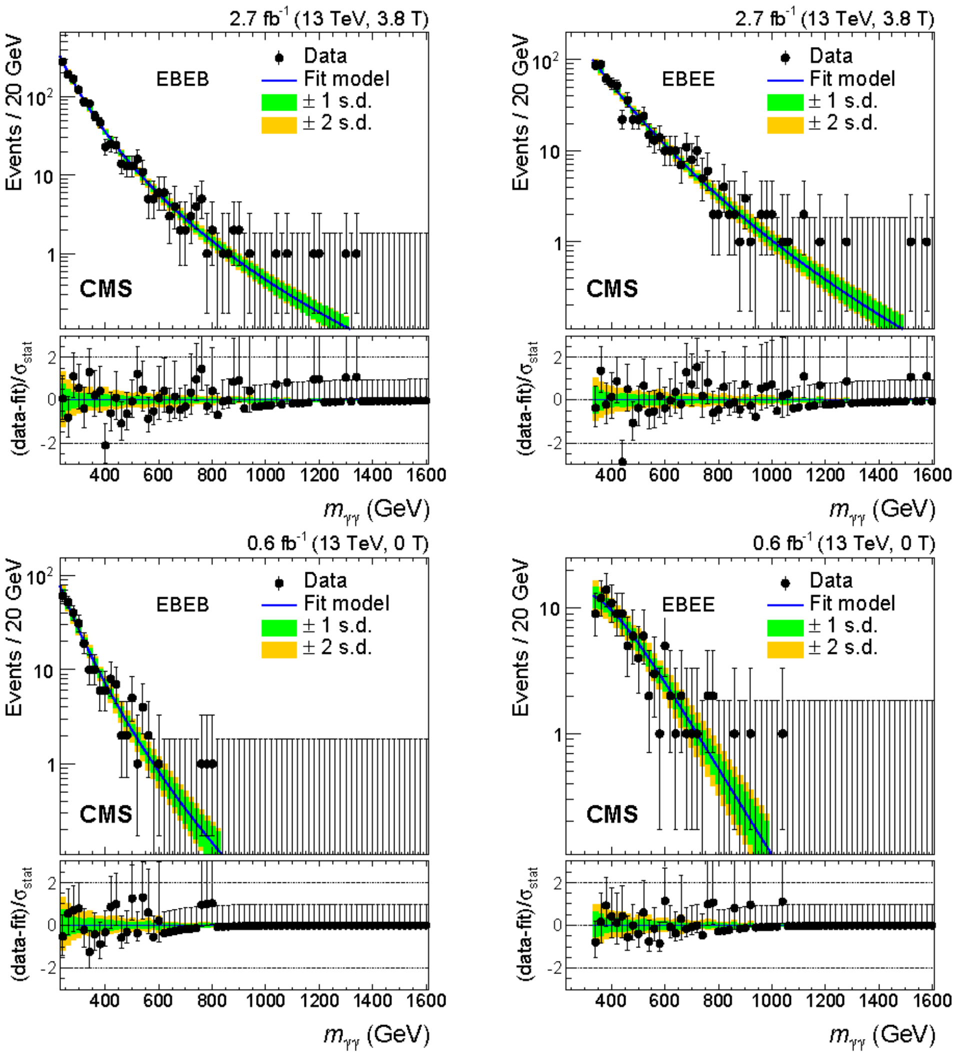
- The ATLAS paper appeared on arXiv on Tues: 1606.03833. Below: 13 TeV.
- Spin-0 hypothesis analysis (left): $E_{T1} > 0.4m_{\gamma\gamma}$, $E_{T2} > 0.3m_{\gamma\gamma}$, m~750 GeV, significance: local 3.9σ, global 2.1σ
- Spin-2 hypothesis analysis (left): $E_{T1} > 55$ GeV, $E_{T2} > 55$ GeV, m~750 GeV, significance: local 3.8σ, global 2.1σ
- More data (~10 fb^{-1} ? have recorded ~5 fb^{-1} in 2016) expected for ICHEP.





Higgs Updates: Diphoton Resonances

- The CMS paper appeared on arXiv on Tues: 1606.04093.



- B=3.8T data sample (top) and B=0 sample (bottom): E_{T1} > 75 GeV, E_{T2} > 75 GeV, m~750 GeV.
- Combined 8 and 13 TeV significance: local 3.4σ, global 1.6σ.
- More data (up to ~10 fb^{-1} ?) expected for ICHEP update…

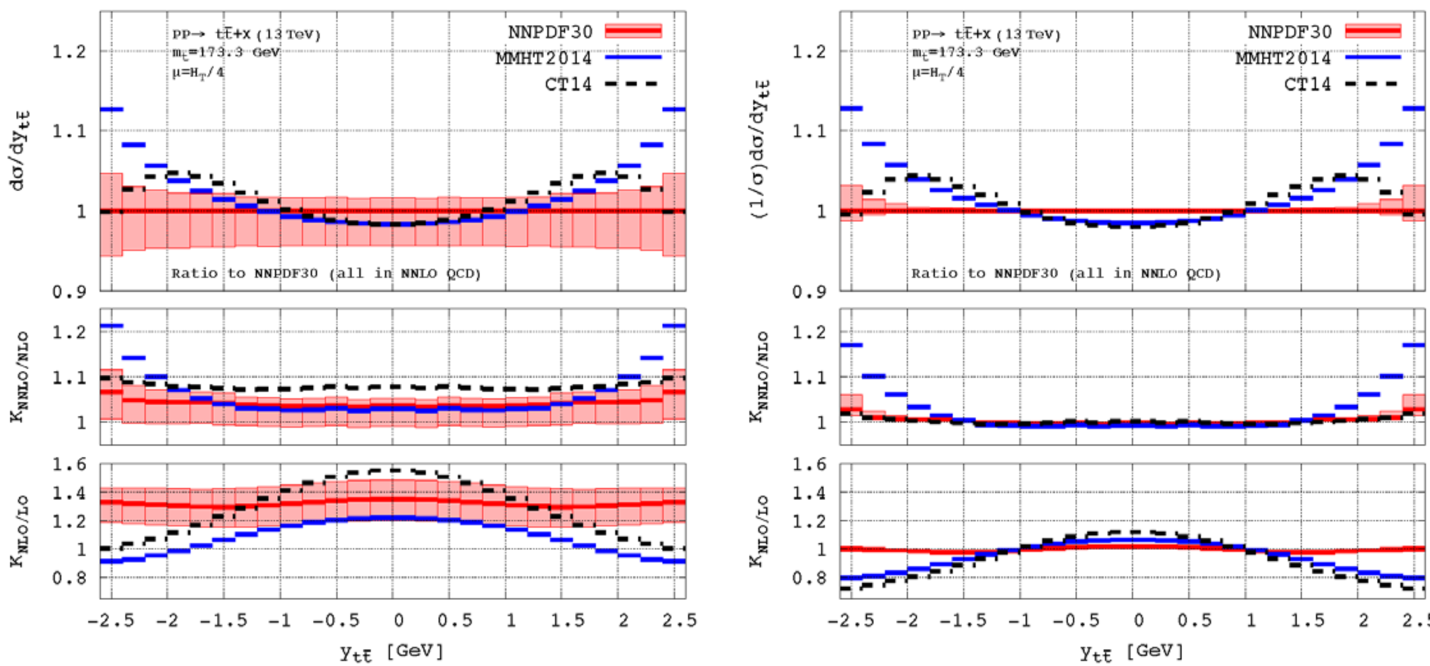
Alexander Mitov

Top Updates: Theoretical Predictions

- For NNLO, better understanding of “optimal scale” (there is one) and PDF sensitivity (significant => need highest-quality PDFs for precision predictions):

◆ A scale that ensures fastest perturbative convergence (and agreement with data at low P_T, where lots of data is available and well understood)

$$\mu_0 = \begin{cases} \frac{m_T}{2} & \text{for :} \quad p_{T,t},\ p_{T,\bar{t}} \text{ and } p_{T,t/\bar{t}}\,, \\ \frac{H_T}{4} & \text{for :} \quad \text{all other distributions}\,. \end{cases}$$

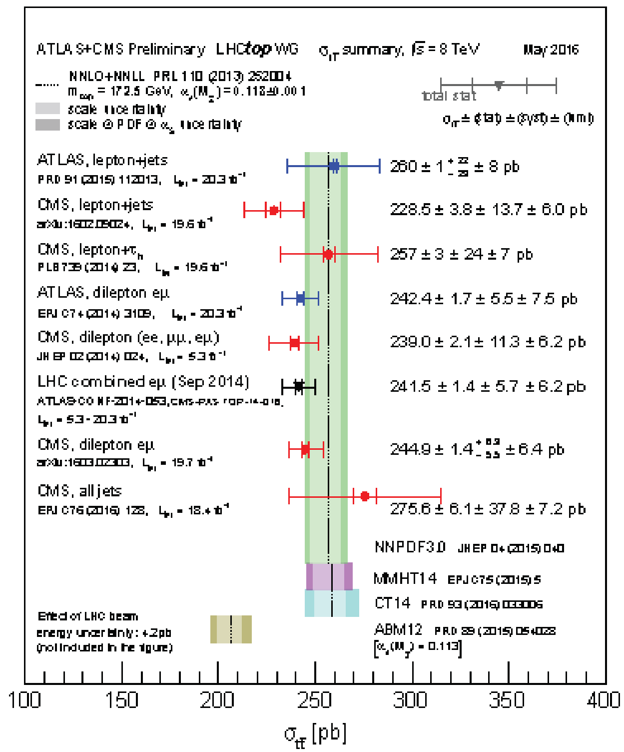


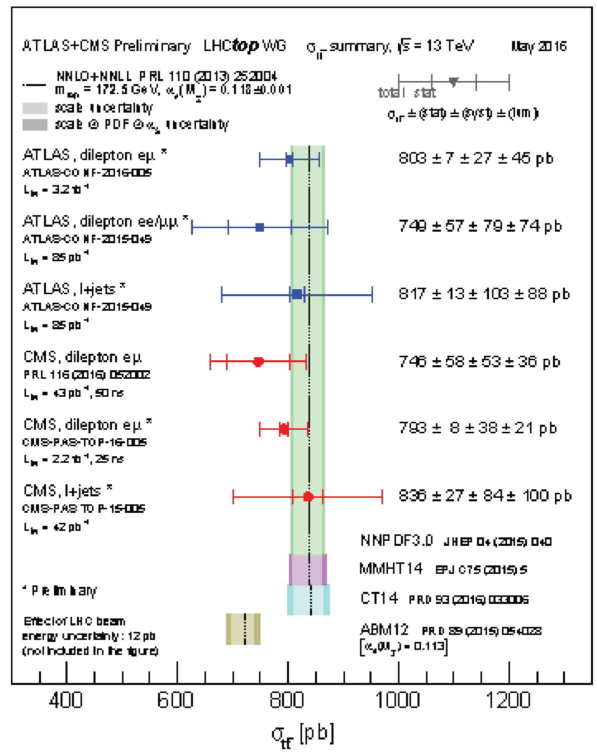
arXiv:1606.03350

Andrea Knue

Top Updates: Top Production Results

- Many high-precision inclusive results. Good ATLAS/CMS agreement, and good agreement with NNLO predictions.
- Many unfolded differential measurements appearing (resolved and boosted) – agreement with different generators not always great…



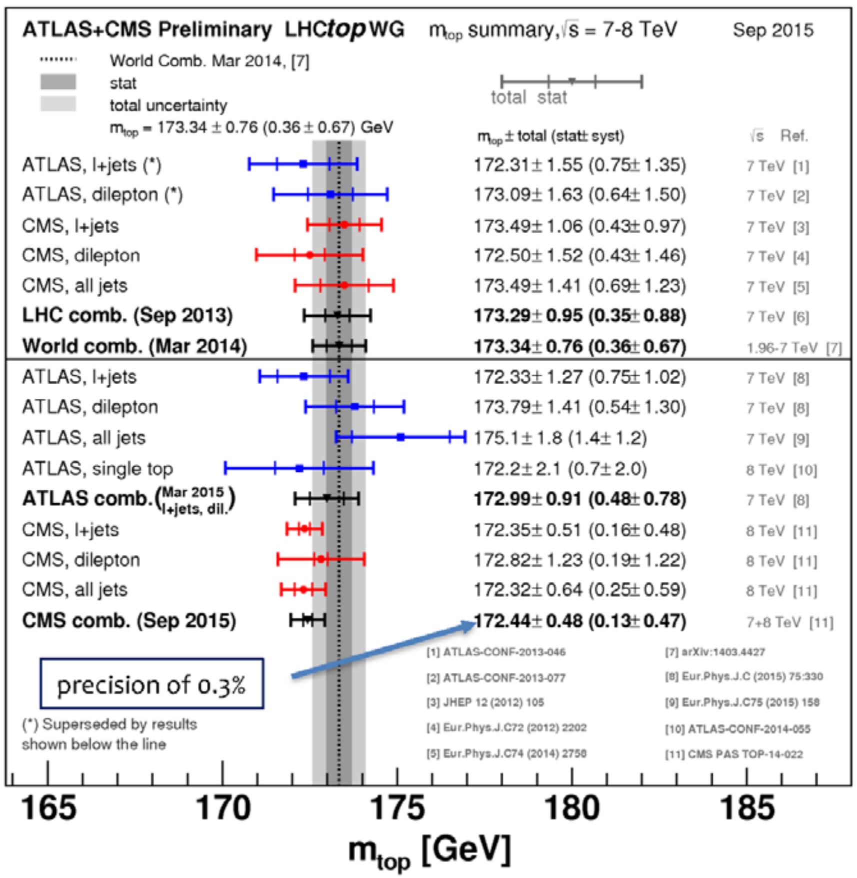


➔ 8 TeV: combined LHC $e\mu$ result: 3.5% precision
➔ 13 TeV: most precise result from ATLAS $e\mu$ channel: 4.4%

Top Updates: Top Properties Results

- Very broad-based program to measure Top properties, including spin and polarization, charge asymmetry, plus looking for CP violation or FCNC decays.
- Multi-faceted effort to measure Top mass (directly or indirectly) in different final states => substantial advances in progress. No signs of anything BSM !

LHCTOPWG



Analysis combined using BLUE, accounts for correlations between all uncertainties.

CMS combination :

m_{top} = 172.44 ± 0.48 GeV

ATLAS combination :

(OLD) m_{top} = 172.99 ± 0.91 GeV

(NEW) m_{top} = 172.84 ± 0.70 GeV

(not in the combination plot)

World combination:

m_{top} = 174.34 ± 0.76 GeV

Total uncertainty is now well below 1 GeV

Heavy Flavor: Theory

- Summary of challenges in LHC Heavy Flavor physics:

Conclusions

Unexpected smallness of NP challenge for theory + experiment!

Unprecedented control over hadronic uncertainties required

➥ challenge met by e.g.

- impressive improvements in LQCD
- symmetry analyses including breaking effects
- improved analyses of production fractions

Exciting anomalies in flavour processes!

$\gtrsim 4\sigma$ in $b \to c\tau\nu$ and $b \to s\ell\ell$ processes

- NP models constrained by complex global analyses
- could indicate e.g. presence of a Z' or leptoquarks

Scale-hierarchies allow for model-independent EFT analyses:

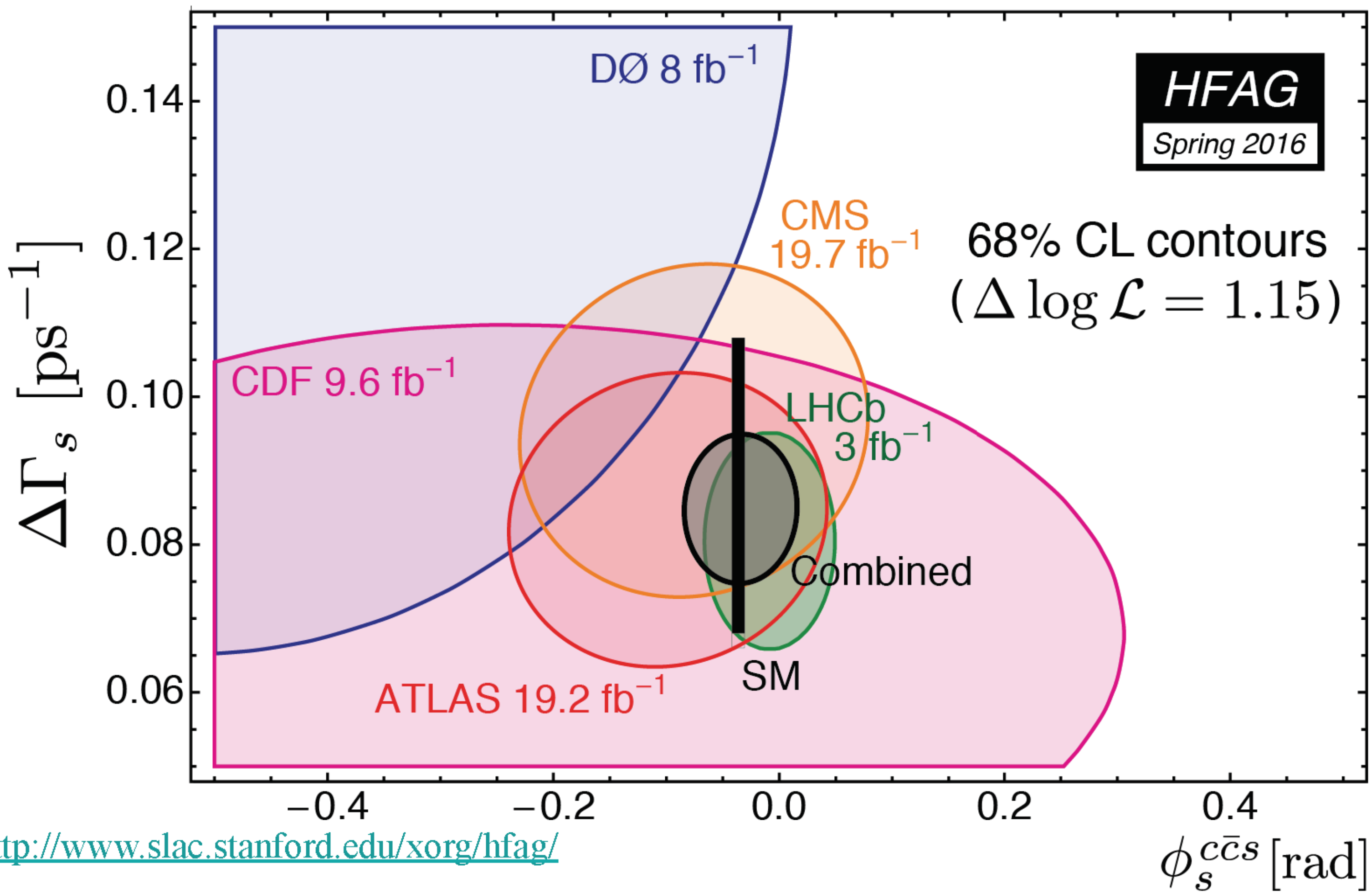
- Meson mixing seems SM like → strong constrains on NP
- SMEFT yields relations between flavour-coefficients
  - ➥ allows to distinguish between Higgs-realizations!

Exciting times ahead!

Matthew Needham

Heavy Flavor: B_s Mixing Phase

- ATLAS, CMS, and LHCb have all completed their Run 1 analyses:



http://www.slac.stanford.edu/xorg/hfag/

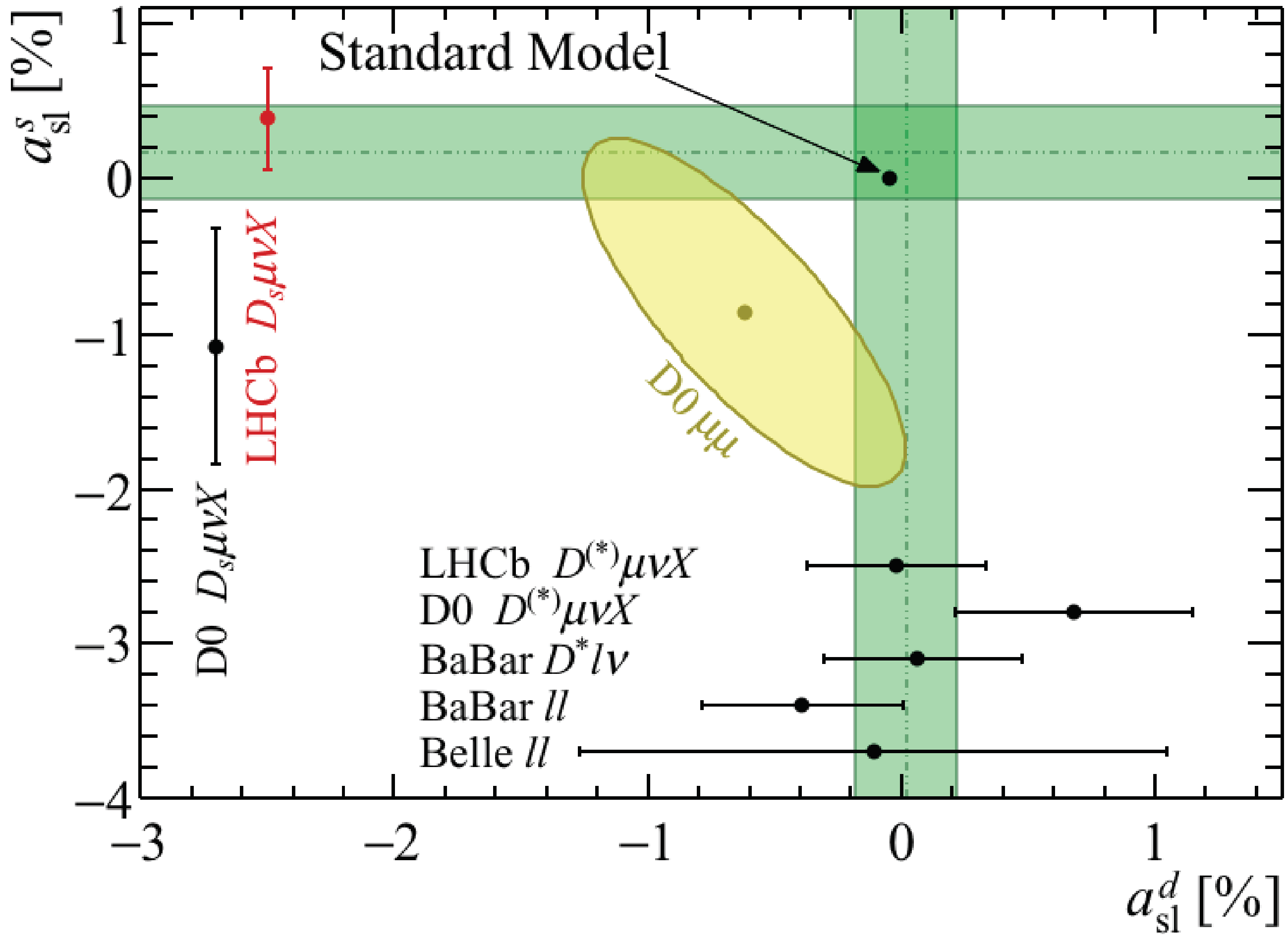
Results consistent with Standard Model

Matthew Needham

Heavy Flavor: CP Violation in B_s Mixing

- LHCb has updated their analysis for the full Run 1 statistics. Increased tension with D0 $\mu\mu$, but no signs of significant CPV – good agreement with SM:

LHCb-PAPER-2016-013



$$a^s_{sl} = (0.39 \pm 0.26 \pm 0.20)\%$$

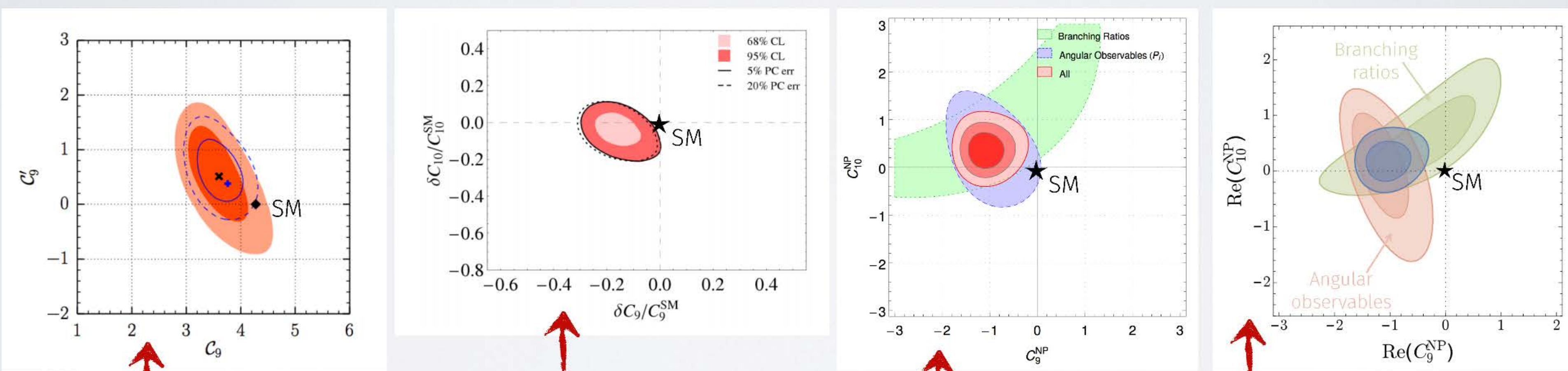
Matthew Needham

Heavy Flavor: Rare Decays

- New results on angular analyses such as $B \to K^*\mu\mu$, $B_s \to \phi\mu\mu$, $B \to K^*ee$ continue to show modest anomalies.
- Global fits required to look for patterns, assess whether New Physics is indicated. Typically see tensions at few sigma level – better hadronic modeling needed ?

Global fits to the Wilson coefficients are the best way to assess if NP is needed to explain measurements

- Take into account ~80 observables from 6 experiments including $b \to \mu^+\mu^-$, $b \to s\ell^+\ell^-$ and $b \to s\gamma$ transitions

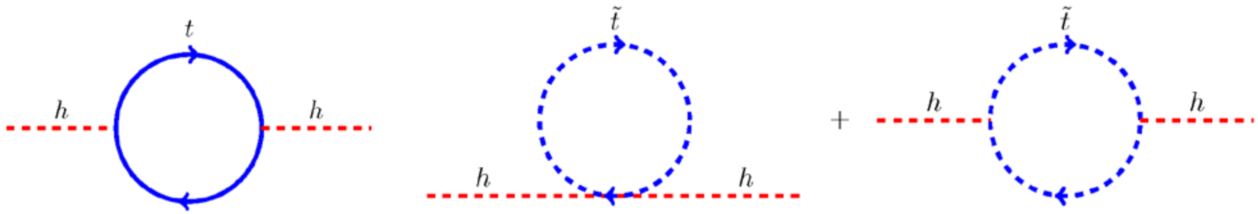


[Beaujean *et al*, EPJC 74 (2014) 2897]
[Hurth *et al*, arXiv:1603.00865]
[Descotes-Genon *et al*, arXiv:1510.04239]
[Altmannshofer+Straub, arXiv:1503.06199]

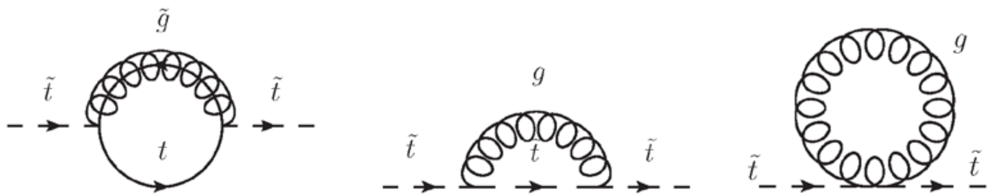
SUSY: Theory

- Status/meaning of present SUSY searches, "naturalness" and 125 GeV Higgs:

The desired cancelations from SUSY aren't happening. Rather than corrections being **much smaller** than initial value, corrections are **canceling** to a part in ~20.



Stops above 800 GeV: ~ factor of 20 tuning.



Gluinos above 1.8 TeV: ~ factor of 30 tuning. (Less if **Dirac**)

- Missed super-partners ? Compressed SUSY, Stealth SUSY, peculiar corner of pMSSM space, Split SUSY could be the reason… Still have many holes to fill in !

SUSY: Squarks and Gluinos

- Impressive overview of search variables and suite of analyses – conclusions:

Mass (TeV)/ Search	Squark	Gluino	Stau
Zero Lepton	1.2 (0.61 for small Δm)	1.7 (Gqq), 1.4 (1-Step Gqq), 1.8 (Gbb)	N/A
One Lepton	N/A	1.6 (Gqq), 1.75 (Gtt)	N/A
Long Lived	1 (Stop), 0.935 (sbottom)	1.6	0.48

A lot more data still to come in 2016!

Jan-Frederik Schulte

SUSY: Lepton and Photon Final States

- Broad overview of searches with di/tri-leptons, taus, and photons – conclusions:

Summary

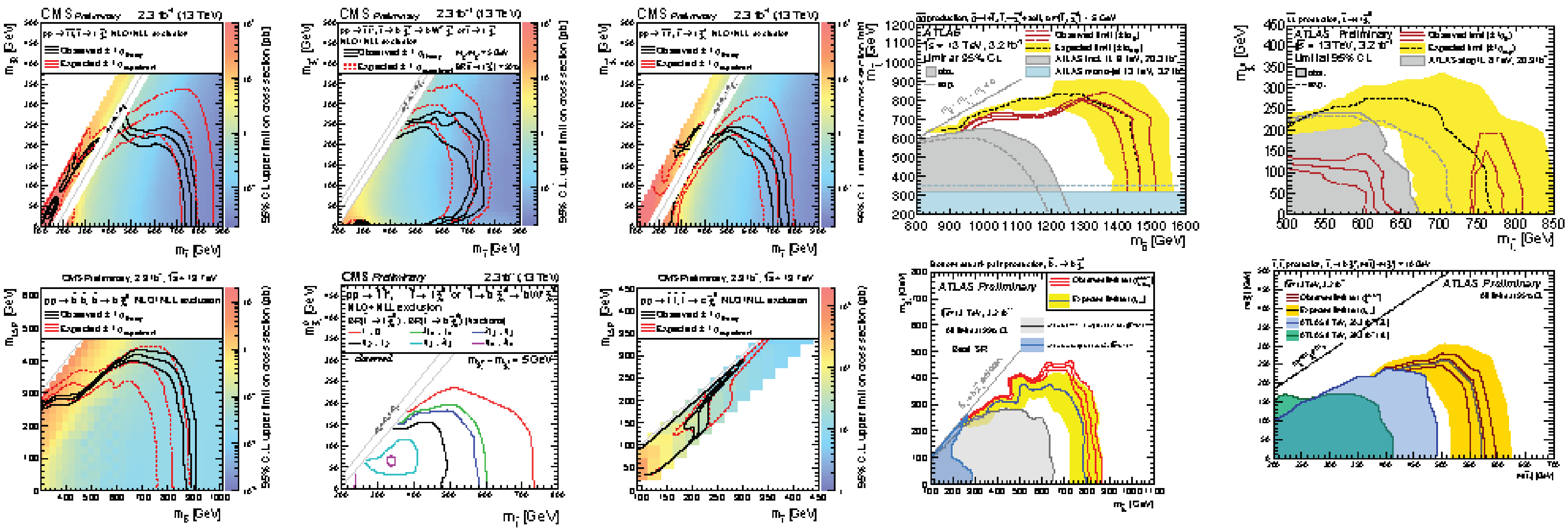
- The search for Supersymmetry exploiting final states with leptons and photons is a vital part of our search programs
- 8 TeV data left us with excesses in the 2L OS searches
- First 13 TeV results give puzzling picture in the on-Z search $\rightarrow$ remains exciting topic
- Searches give limits on $m_{\tilde{g}}$ in the range of 1.1-1.3 TeV in a multitude of simplified models
- Reach over 2 TeV in the context of GMSB
- $m_{\tilde{b}}$ limits range from 540 to 680 GeV, depending on model and search
- Expected large increase in available luminosity will improve the sensitivity further, so these final states remain a topic to be watched

Walter Hopkins

SUSY: Third Generation Searches

- Detailed overview of searches for stop (+ RPV) and sbottom – conclusions:

  - Many results from ATLAS and CMS for 3G searches
  - Based on 2015 data (2.3 fb^{-1} for CMS, 3.2 fb^{-1} for ATLAS)
  - No significant excesses this time around…
    - New constraints on 3G SUSY parameter space
  - More results based on 2016 data are coming soon
    - Maybe we'll have to do more than set limits…



Alex Pomarol

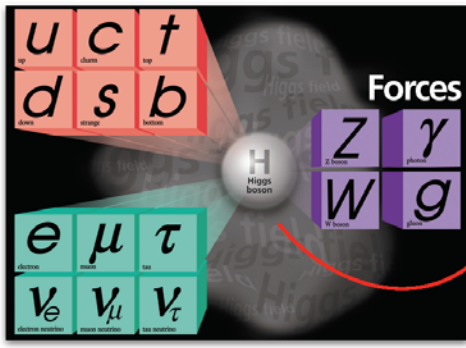
Exotics/Dark Matter: Theory

- Proceeded to give us guidance (and inspiration !) for new physics searches:

Making progress from *null* results:

If we assume that **the only scale** is $\langle H \rangle \sim 246$ ***GeV*** (as in the SM),

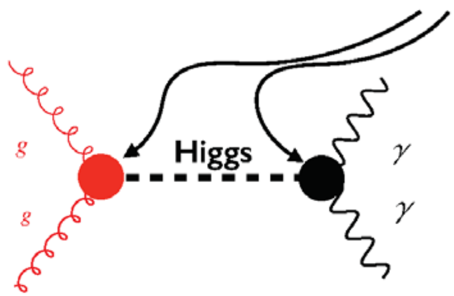
we have excluded **experimentally** any new physics!

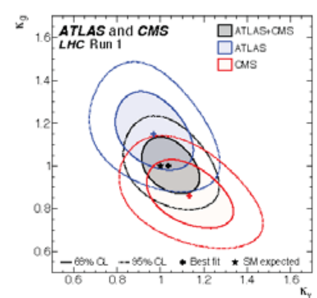


No extra fermions, gauge bosons,… getting their mass from H

We know this thanks to the interplay between direct & indirect searches:

- **If light:** should have been seen in detectors
- **If heavy:** should have been seen indirectly





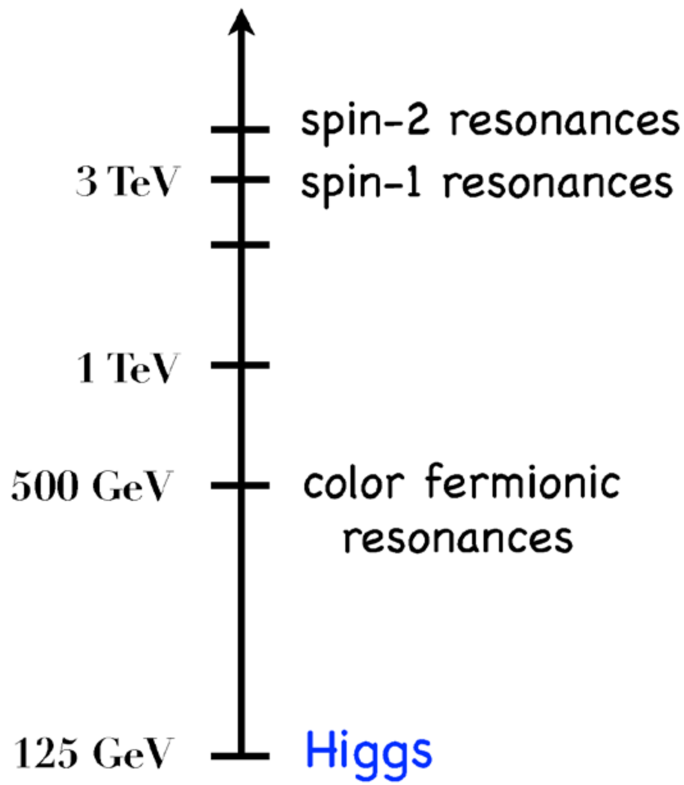
crucial piece of information!

Alex Pomarol

Exotics/Dark Matter: Theory

- Assume there is a new scale Λ ~ TeV => plausible template for new physics:

Expected spectrum of the TeV Composite Sector



Good BSM prototype for many searches

By the AdS/CFT correspondence:

Physics of Composite Sector ↔ Physics of Extra dimension

Michele Redi

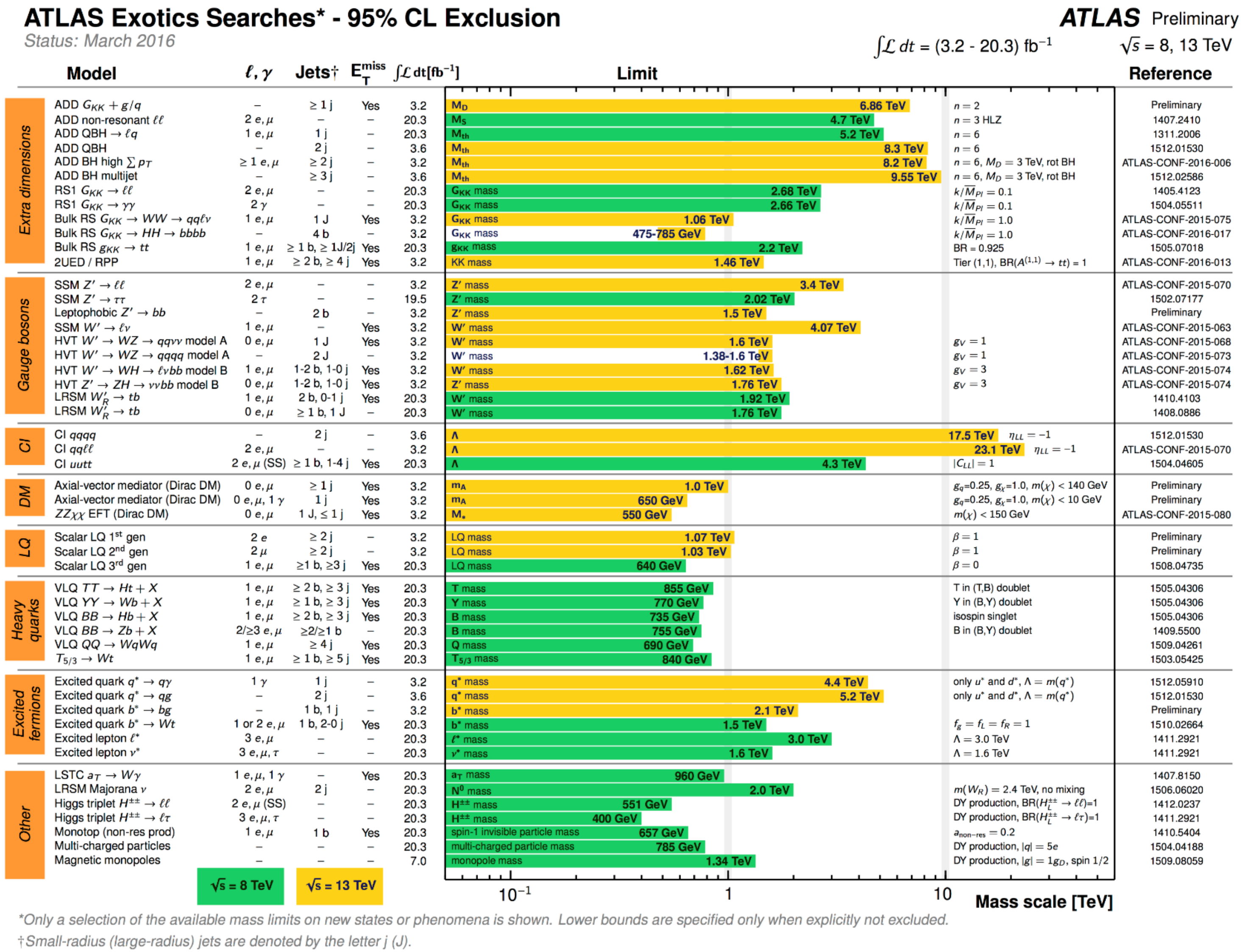
Exotics/Dark Matter: Diphoton Resonances

- Exploration of models/explanations for an X(750) decaying to diphotons:
  - If the excess is confirmed it will be revolutionary. It is the dream nobody in our field anymore had.
  - Many models can explain the di-photon excess. They predict effects visible in many different channels. Nearly all models prefer a narrow width. With more data we might be able to pin down the right theory.
  - The di-photon resonance is plausible but very unexpected. Is it elementary or composite? Is it related to EWSB or dark matter? Hopefully the fun is just starting...

Alexander Schmidt

Exotics/Dark Matter: Fermionic Final States

- Covers tt resonances, tb resonances, vector-like quarks, dilepton and dijet resonances, low-mass (low coupling) dijet resonances, etc…



Exotics/Dark Matter: Fermionic Final States

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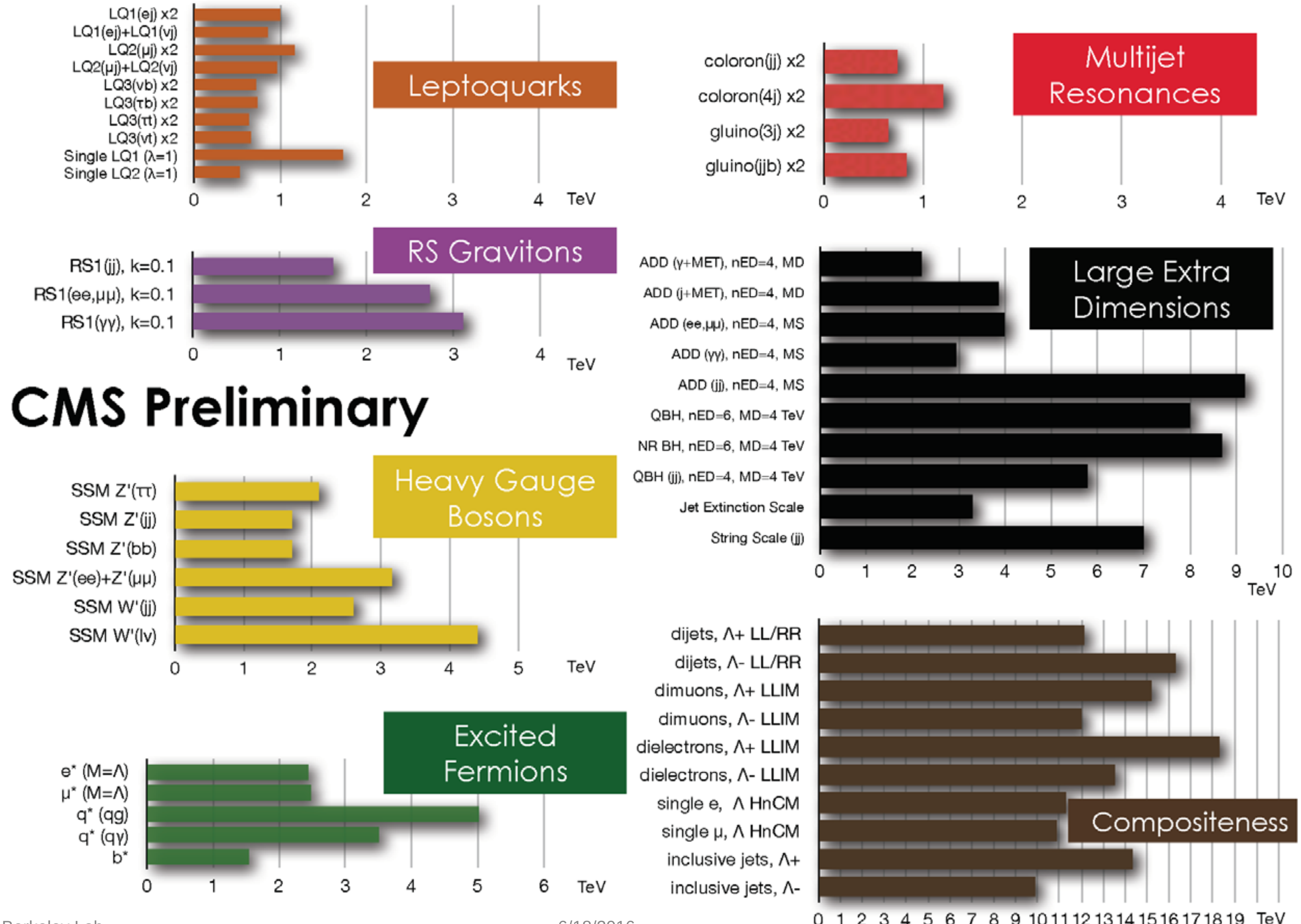
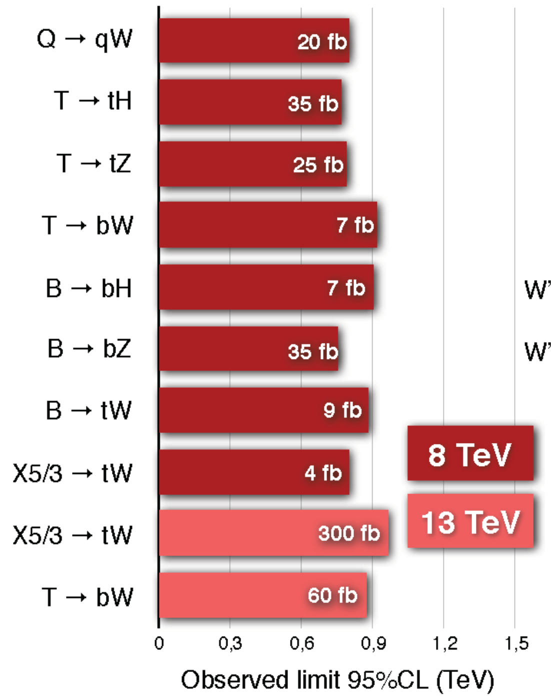


Alexander Schmidt

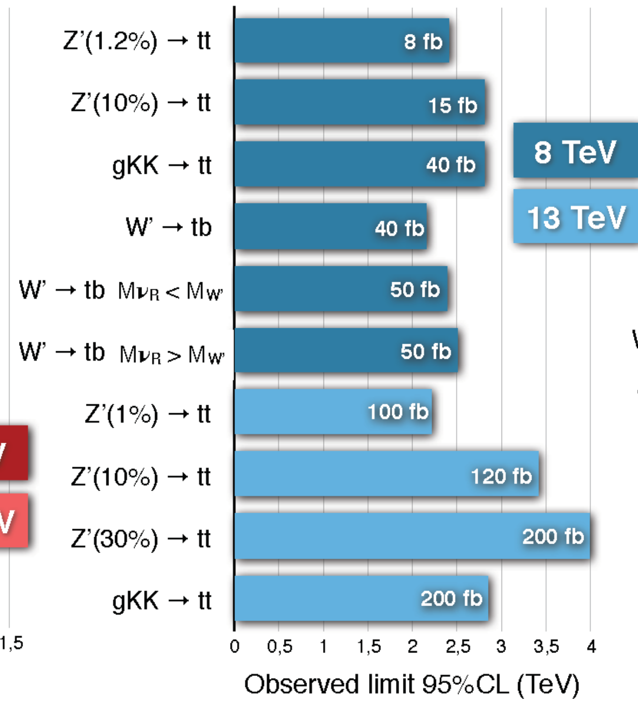
Exotics/Dark Matter: Fermionic Final States

- Covers tt resonances, tb resonances, vector-like quarks, dilepton and dijet resonances, low-mass (low coupling) dijet resonances, etc…

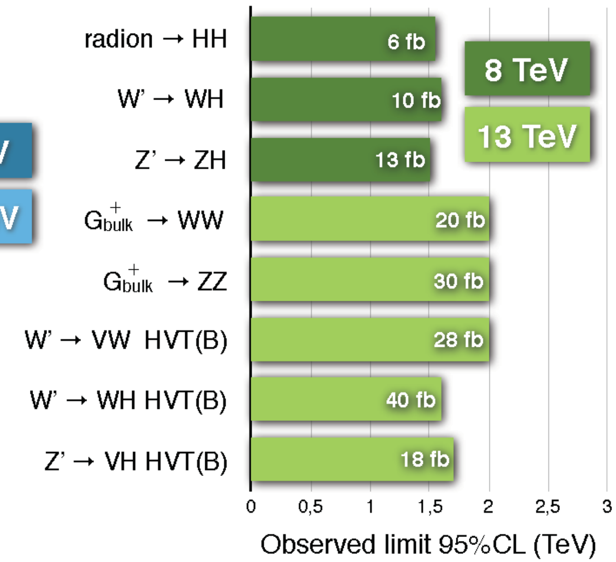
Vector-like quark pair production



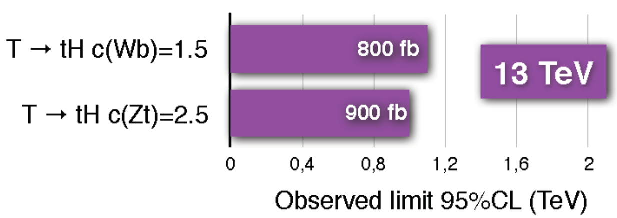
Resonances to heavy quarks



Resonances to dibosons

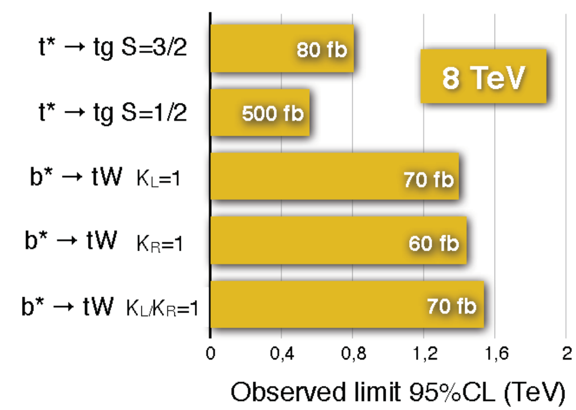


Vector-like quark single production



B2G: new physics searches with heavy SM particles

Excited quarks



Exotics/Dark Matter: Bosonic Final States

- Covers diboson (VV) resonances, diphoton resonances, VH resonances, HH resonances, low-mass (< 5 GeV) boson → μμ resonances (LHCb), etc…

- Combining 8 and 13 TeV data, conclude a solid "maybe" on 750 GeV
  - LHC already delivered another 4/fb of data in 2016
    → better understanding soon!

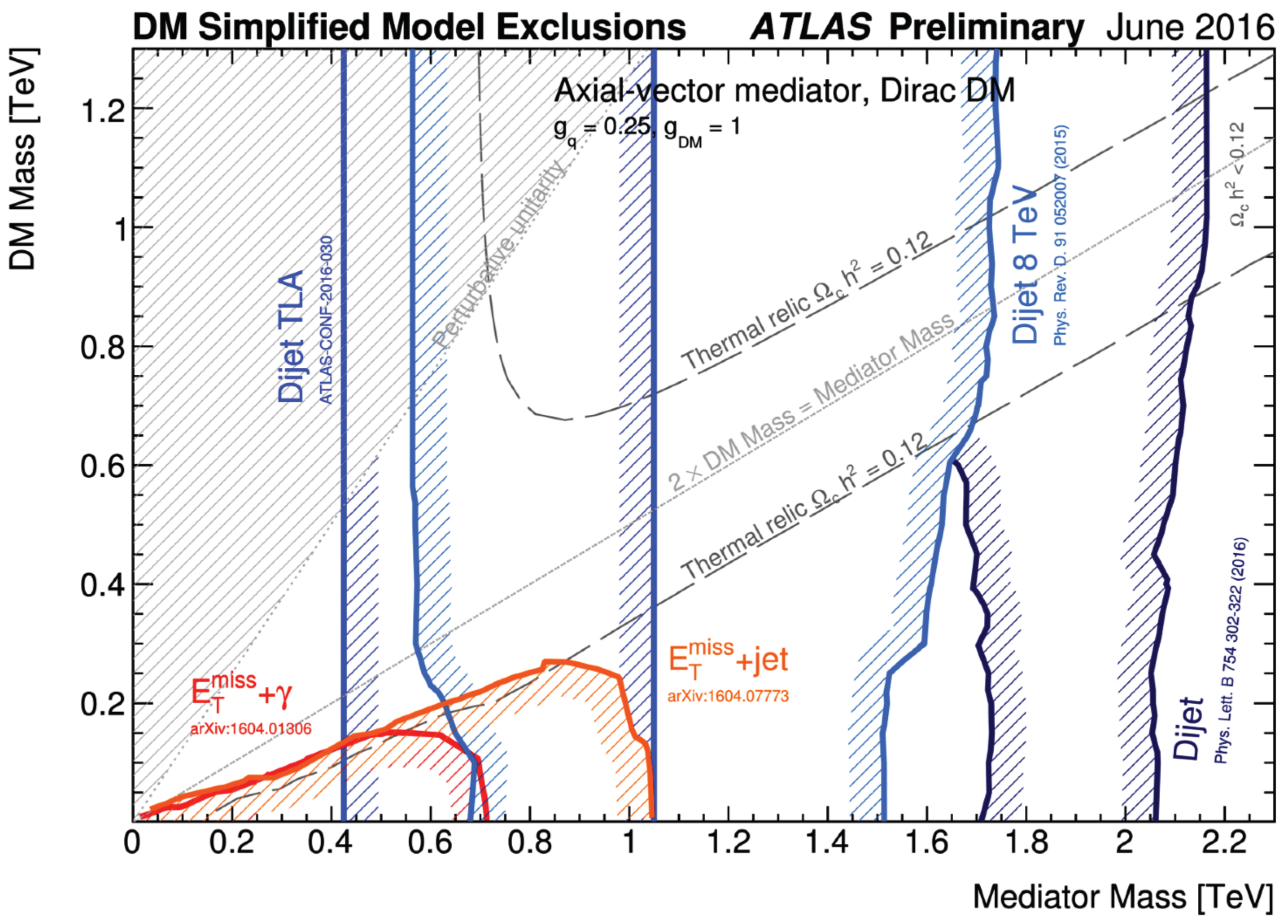
- Di-boson resonance masses >TeV explored in all important final states
  - Interpretations in spin-0, spin-1 (HVT), spin-2 (RSG) scenarios

- Analyses with 13 TeV data supersede 8 TeV searches at >TeV masses
  - Most stringent mass limits on W'/Z'/G* resonances

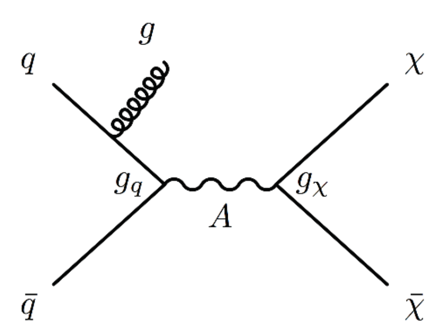
- Combination of 8+13 TeV VV+VH searches disfavors bump at 2 TeV
  - Final confirmation with 2016 data

Exotics/Dark Matter: DM Searches

- Use simplified models (DM mass, mediator mass, SM/DM couplings), search for WIMP DM plus mediator(s) in X + MET and dijet channels.
- Includes MET + monojet, γ/W/Z/H, Q. Also look for mediator in dijet channels.



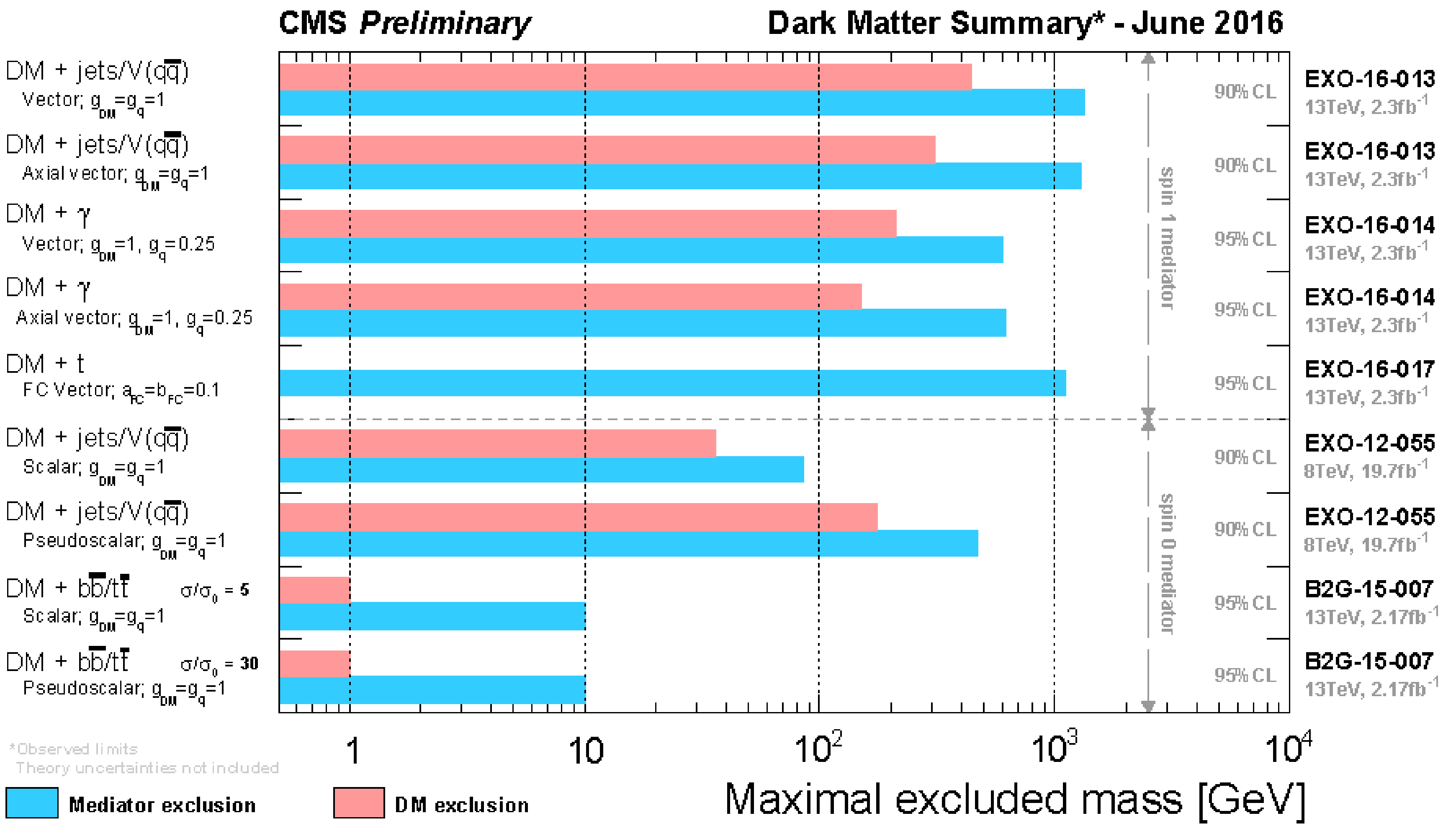
- Relative exclusion power depends on the relative model couplings, g_q and $g_{DM} = g_\chi$.



James Frost

Exotics/Dark Matter: DM Searches

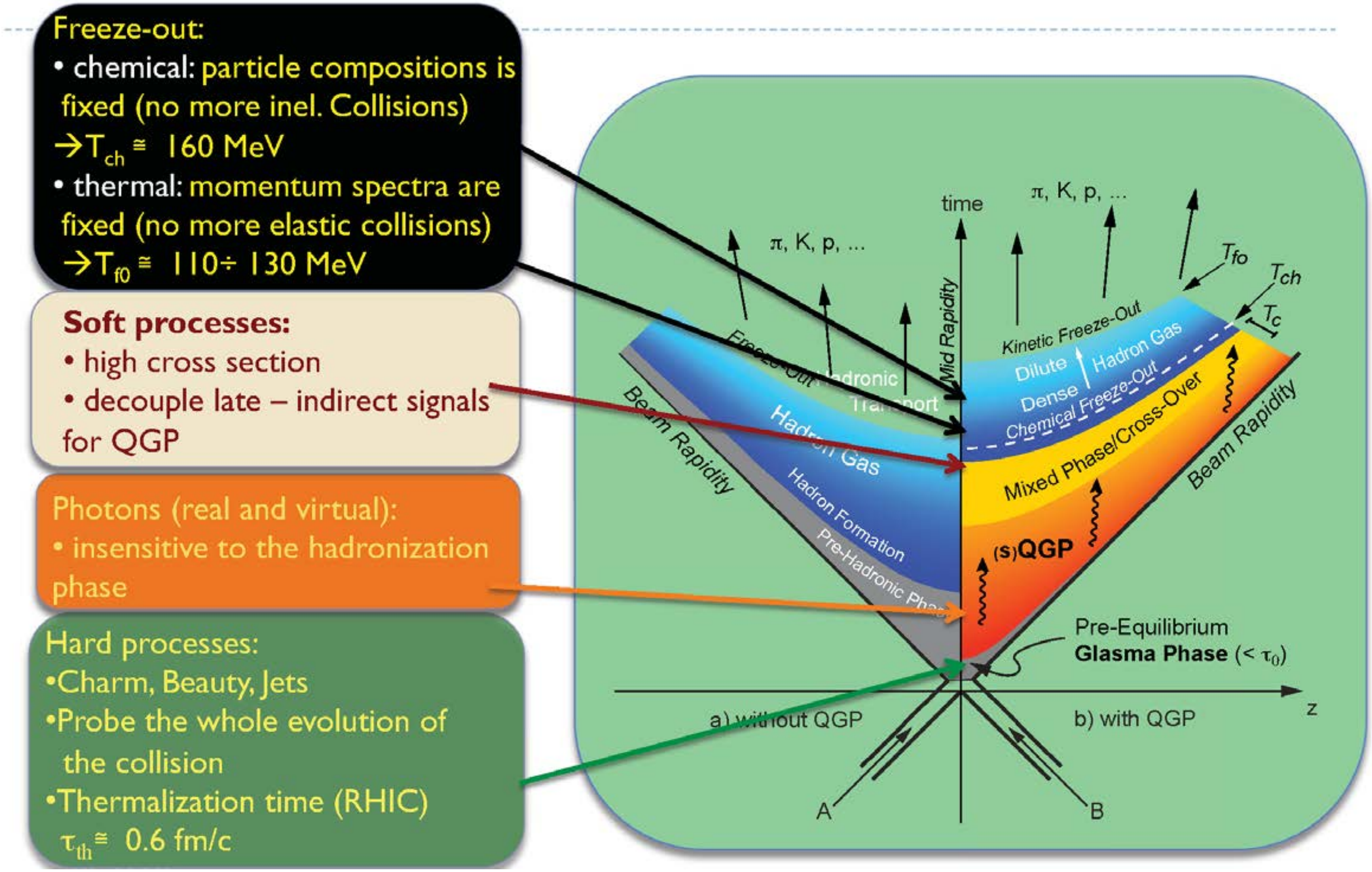
- Use simplified models (DM mass, mediator mass, SM/DM couplings), search for WIMP DM plus mediator(s) in X + MET channels.
- Includes MET + monojet, γ/W/Z/H, Q. Also look for mediator in dijet channels.



Stefania Bufalino

Heavy Ion Updates: Theory

- Why are Heavy Ion collisions so interesting ?

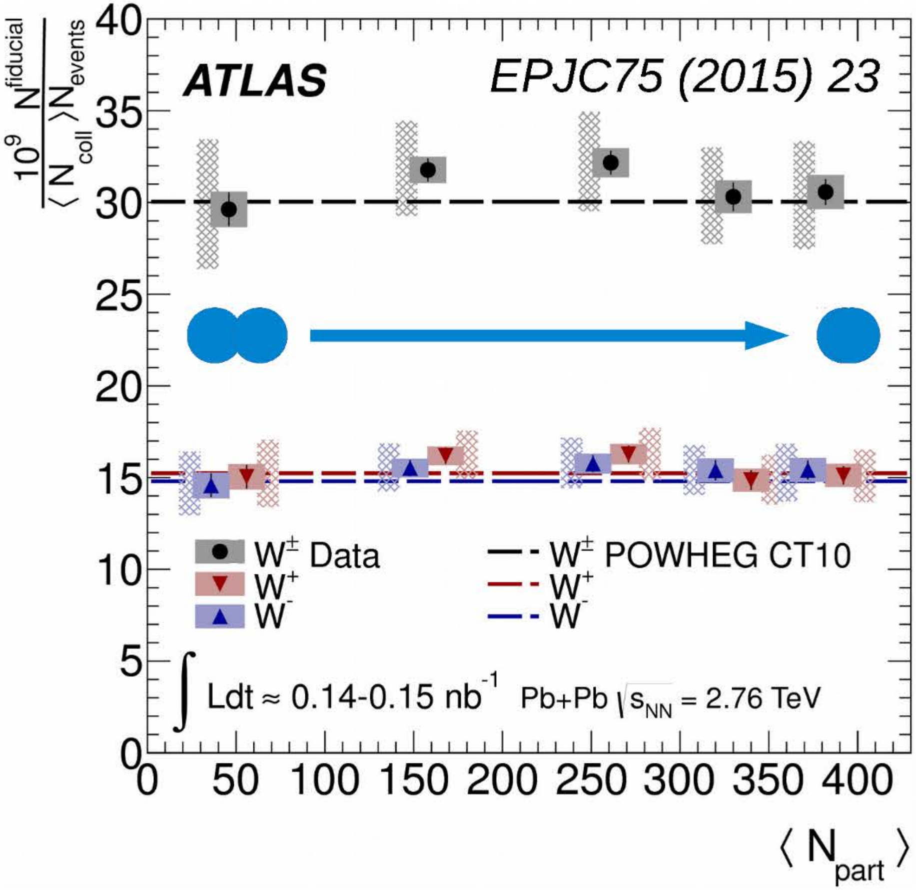


- Key areas: **Soft Probes** (global features, bulk properties), **Small Systems** (collective “multi-particle” effects observed in pp, pPb, and PbPb), and **Hard Probes** (production of “high P_T” physics objects: photons, W/Z, jets, b/c quarkonia, heavy-flavor jets…)

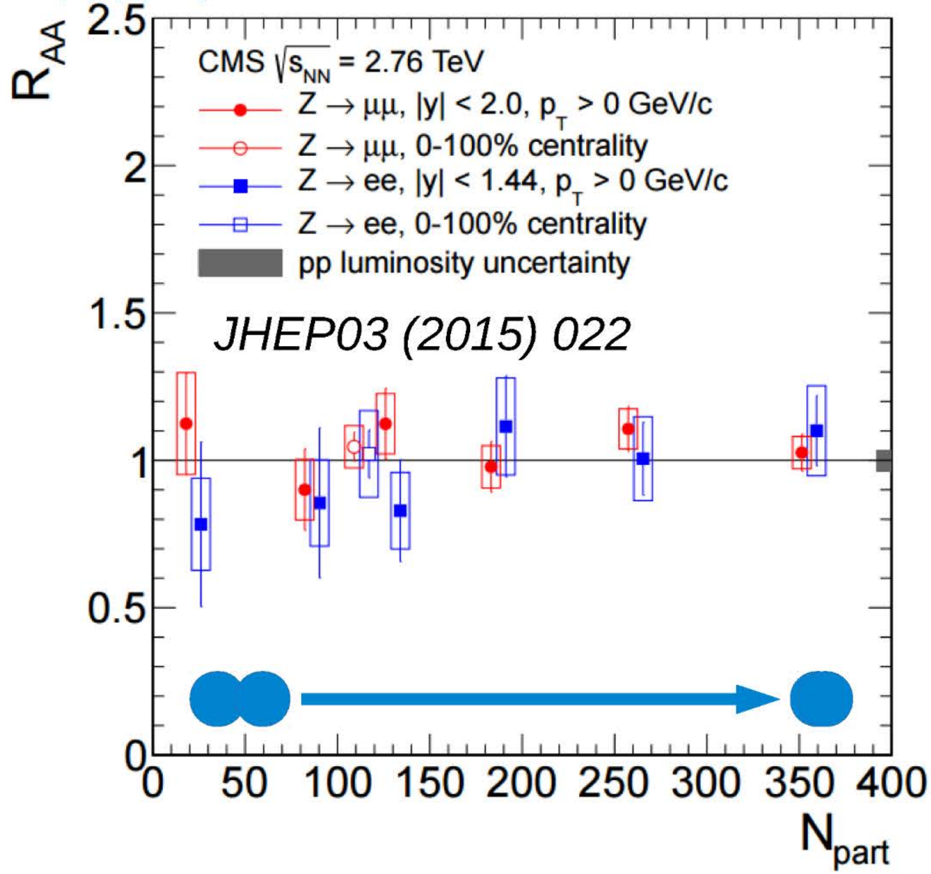
Heavy Ion Updates: Hard Probes

- Examine behavior of EWK (γ/W/Z) objects in PbPb collisions as a function of centrality => overlap between colliding nuclei => number of individual collisions.
- Naively, not expected to feel influence of QGP or whatever happens between initial "pre-equilibrium" phase and final "freeze out" when temperature → 0. Confirmed for non-colored hard probes in detail…

W bosons:



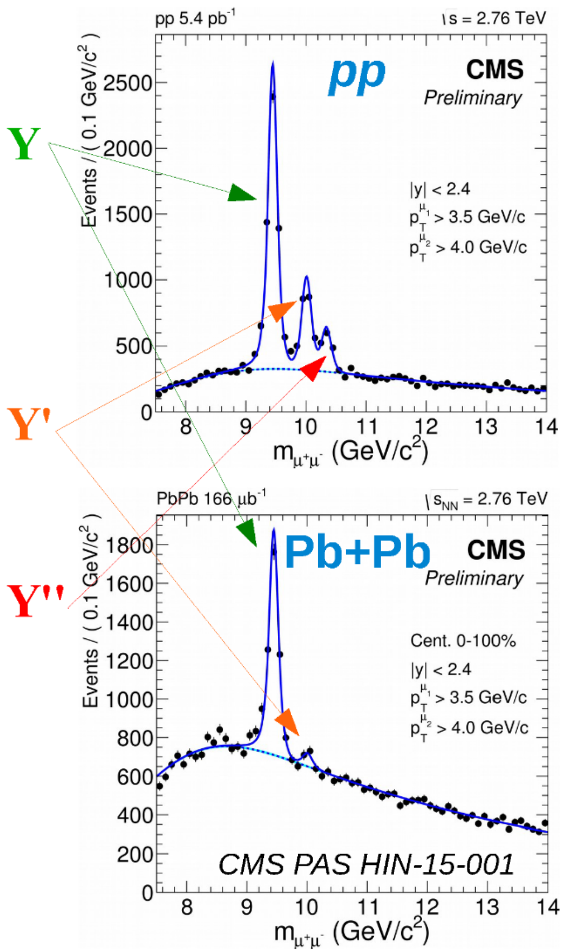
Z bosons:



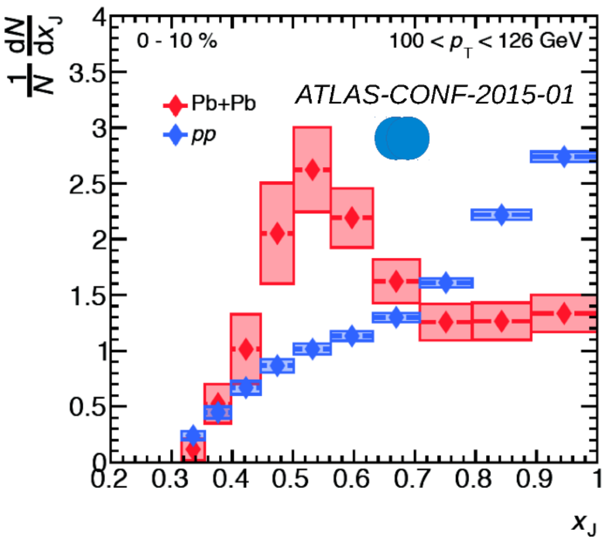
Martin Rybar

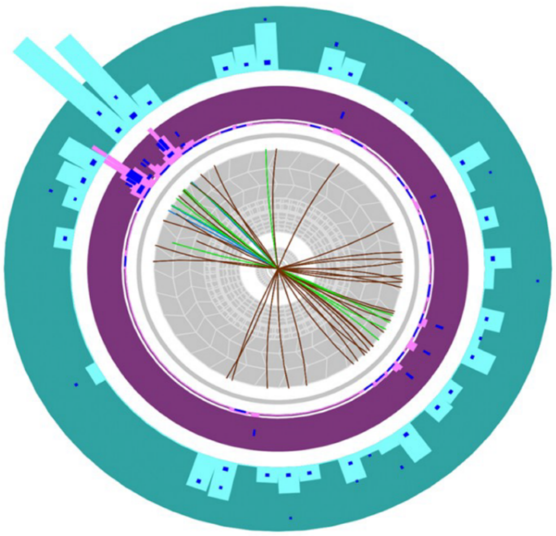
Heavy Ion Updates: Hard Probes

- Examine behavior of colored objects: quarkonia (upsilon states) and jets.
- For quarkonia, observe “melting” of bound state as qqbar potential is changed.
- For jets, observe “asymmetry” as high P_T partons lose energy to medium, which is transported to large angles and lower energies relative to nominal jet axis.



- ATLAS fully unfolded di-jet asymmetry distributions $x_J \equiv p_{T_2}/p_{T_1}$

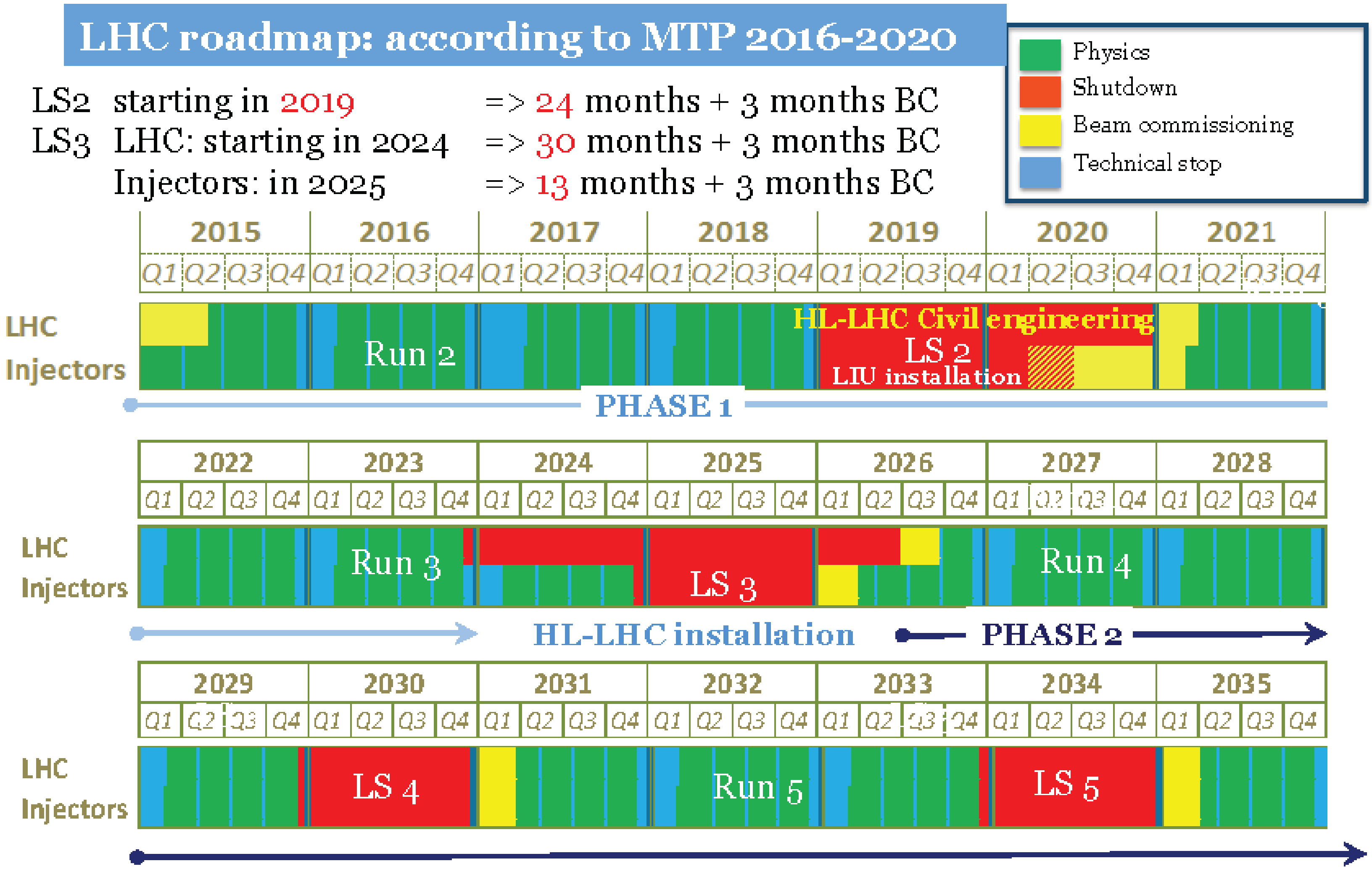




- Significant shift toward large di-jet asymmetry in central HI collisions w.r.t. *pp* reference.

Upgrades at LHC: Overview

- Future LHC/HL-LHC Plan: LS2: ~100 fb^{-1}, LS3: ~300 fb^{-1}, 20xx: ~3000 fb^{-1}



Lumi-level @ 5x10^{34} => 250 fb^{-1}/yr, @ 7.5x10^{34} => 300 fb^{-1}/yr, HL-LHC is 12-15 year program !

Upgrades at LHC: Overview

Phase-1 Upgrade programs (ready for installation in LS2 => 2019):

- All four LHC experiments have embarked on very substantial phase-1 upgrades, with only about 2.5 years to go before installation.
- The scope of ALICE+LHCb is similar to ATLAS+CMS, with a CORE value of around 200M in total => these are very substantial upgrades.
- For ALICE and LHCb, these upgrades provide major new capabilities to extend their ability to digest more data and make more precise measurements (note neither experiment operates at full LHC luminosity).
- For ATLAS and CMS, these upgrades are largely “anticipating” their larger phase-2 programs, enhancing the performance of the detectors for maximum physics up to LS3 (2024), while reducing phase-2 work in LS3.
- Run 3 will benefit from the injector upgrade (LIU), and this could allow β^* luminosity leveling to double the integrated luminosity. Expect L ~ 2×10^{34}.

Phase-2 Upgrade programs (ready for installation in LS3 => 2024):

- Major upgrades for ATLAS and CMS, with total tracker replacements, and combined total cost of around 500M.
- Designed to allow operation up to ultimate luminosity of HL-LHC of 7.5×10^{34} (μ = 200). Brings LHC to the limits of a 25ns machine, as at ultimate luminosity, beam lifetime limited by “burn-off” from pp inelastic cross-section.

Upgrades at LHC: Comments

- Starting already during Run 2, all four LHC collaborations are running a “three ring circus” of Operations, Physics, and Upgrade.

This creates major conflicts for resources (people !):

  - Intense pressure to produce rapid physics results keeps a large fraction of the community in “physics production” mode as luminosity pours in and analyses are constantly updated and improved.
  - Operational challenges in a constantly upgraded operational configuration (more luminosity per unit time !) requiring high efficiency and reliability for the detectors. Detectors, and the people who know them, are constantly aging !
  - Upgrades require substantial investments of both instrumentation and performance/physics expertise to design, optimize, construct, and commission. This clashes very substantially with previous two critical activities.

- Collaborations are constantly working to improve efficiency in all areas, but at some point we exceed our capacity !

- If we are truly committed to the phase-1 and phase-2 upgrades, we will need to significantly improve the way we produce physics. Otherwise we (at least for ATLAS and CMS with phase-1/2 !) will not succeed with our goals !
- Think more carefully about timescales and numbers of updates required for any given analysis during Run 2/3. Higher thresholds for “re-doing” analyses will not reduce our science output very much, but will free many people for operations and upgrade, and reduce the barriers between these activities !

Summary of Summaries…

- Run 2 at the LHC is finally up to speed, with potential for data to arrive at roughly 2 fb^{-1}/week => 2015 data sample every ~10 days !
- Run 2 promises to deliver O(100) fb^{-1} by the end of 2018 => typically a factor 10 in statistical power over Run 1 for measurements (will not see this again until early 2030's !!!), and even more for searches !
- Extraordinary progress in theoretical and experimental precision will bring a new round of stringent tests on the "precision frontier" by the end of Run 2.
- The arrival of 13 TeV data in large quantities should make 2016 the best year for the "search frontier" so far.
- New analyses for ICHEP should deliver clarity on the X(750) saga !
- No other significant anomalies visible at this conference (sigh…)

Can look forward to an even more exciting LHCP 2017 !!!