CMS Physics Overview

Günther Dissertori
ETH Zürich

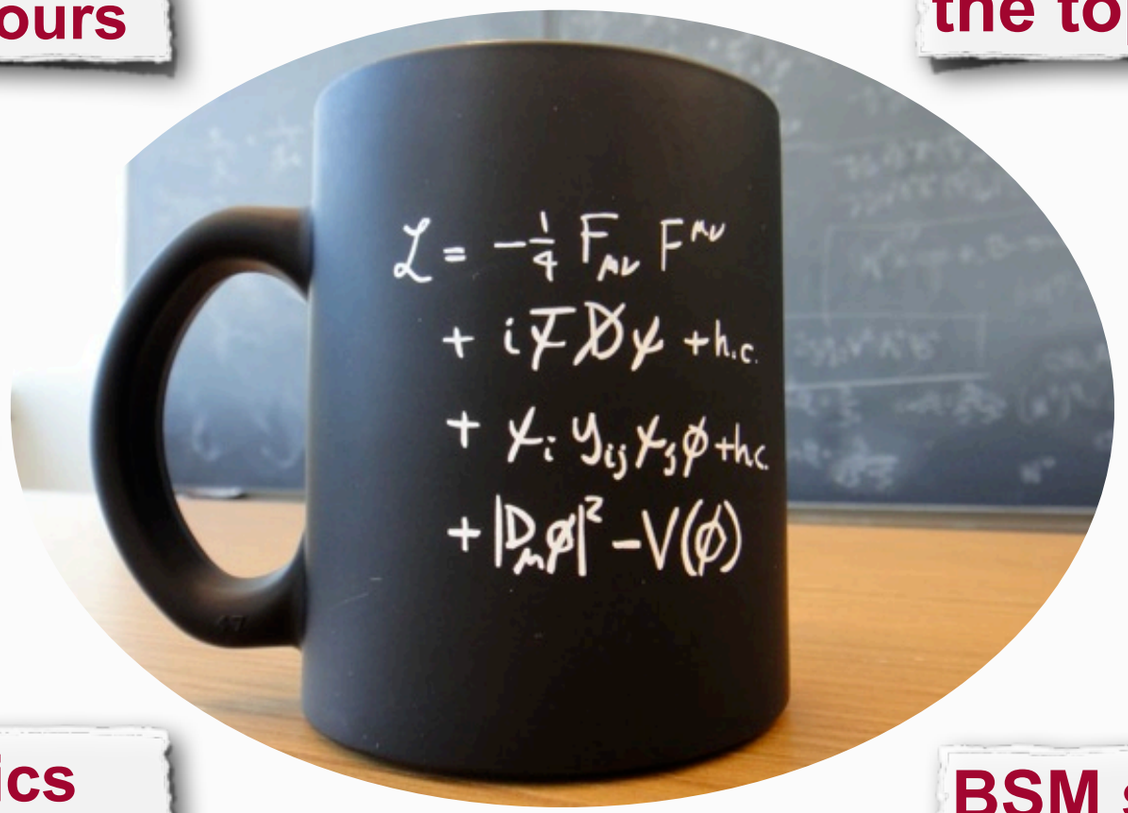
on behalf of the CMS collaboration

Outline

ETH Institute for Particle Physics

Heavy Flavours

the top



probing QCD

Higgs searches

EWK physics

BSM searches

Remarks:
- a selection only, with focus on most recent results
- will focus on pp physics only
- see all the specialized talks at this conference for much more details
- e.g. see M. Chamizo's talk about the detector's performance

A 3-year long sprint....

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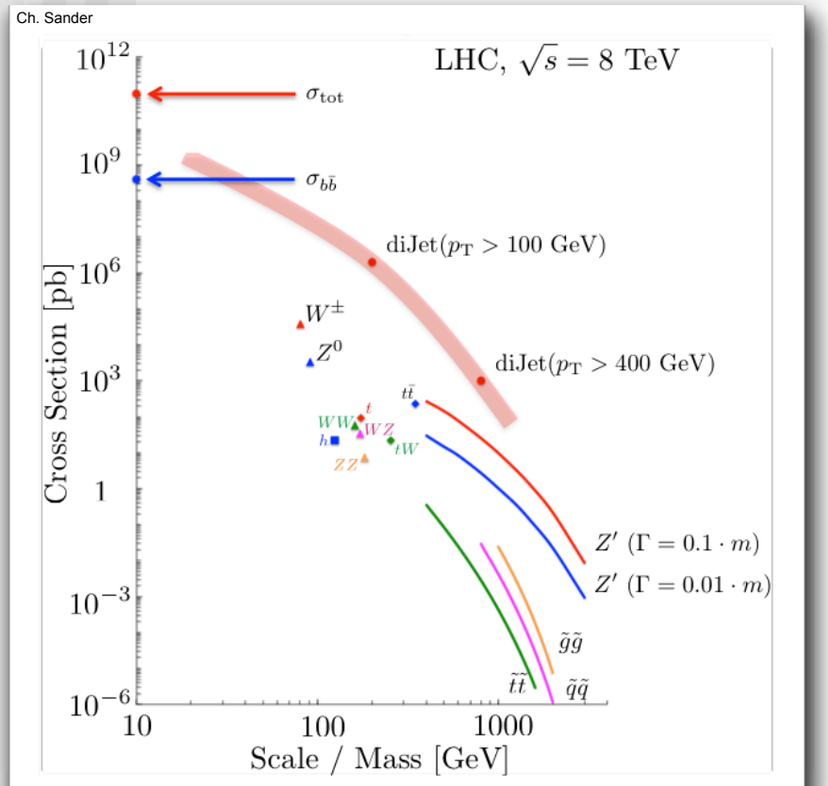

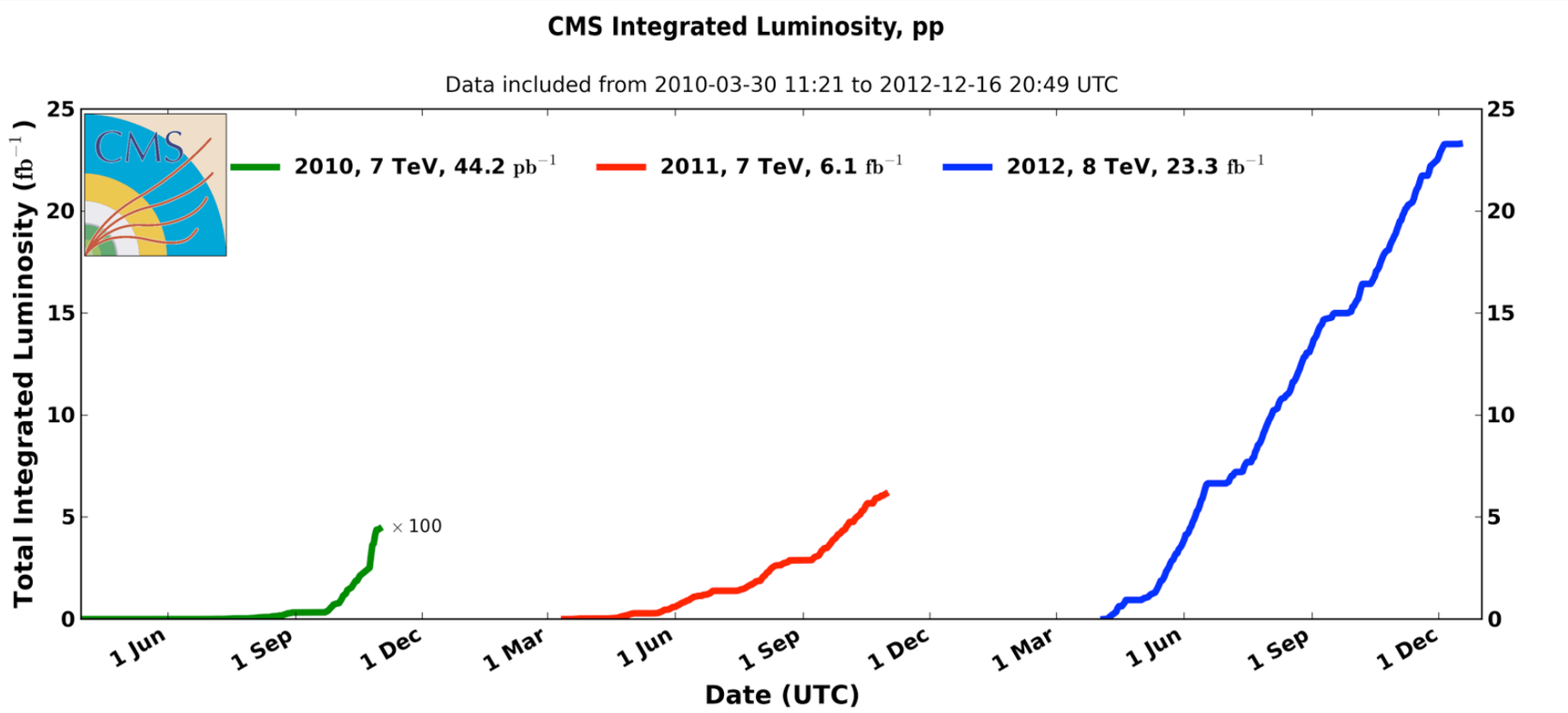

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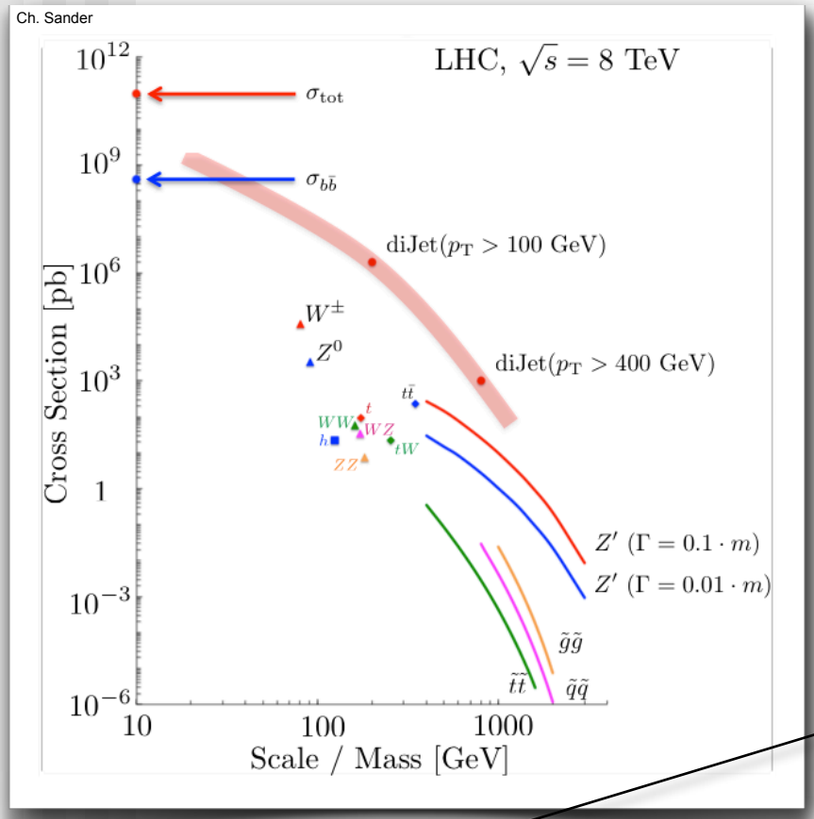

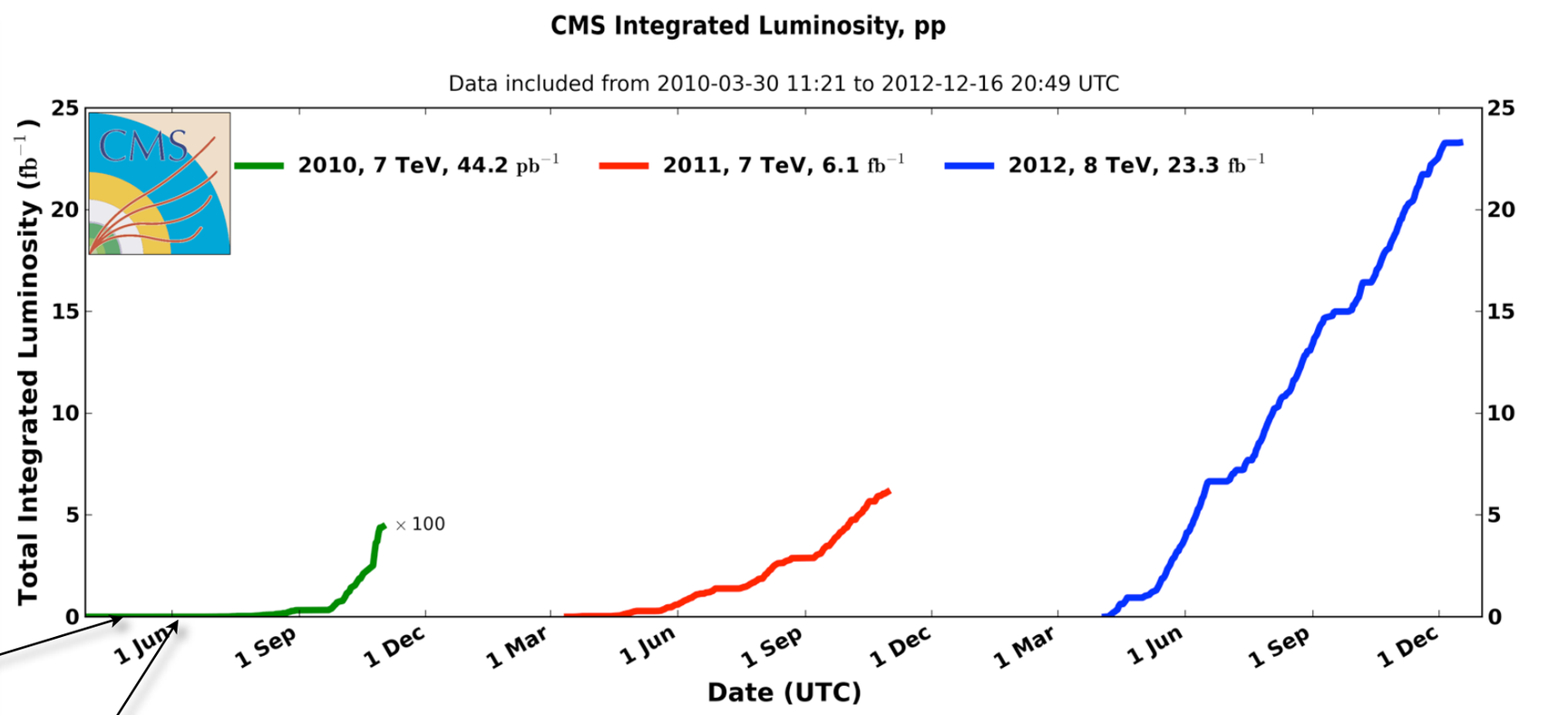

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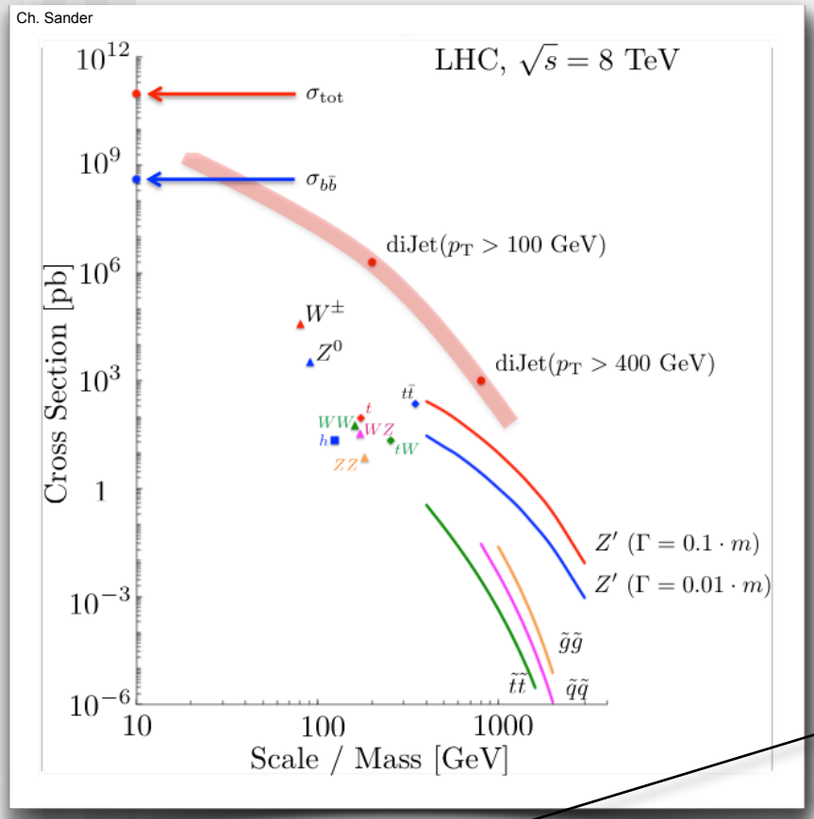

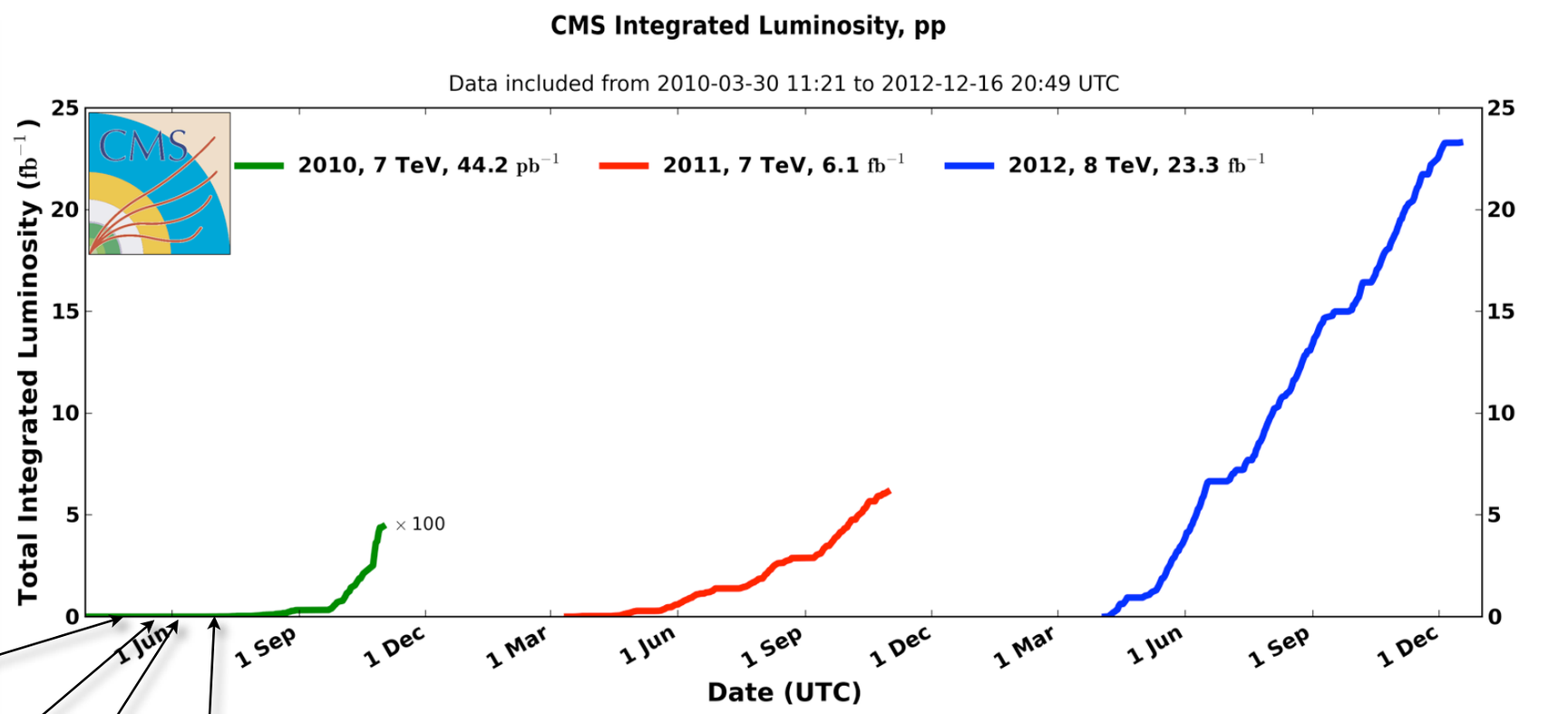

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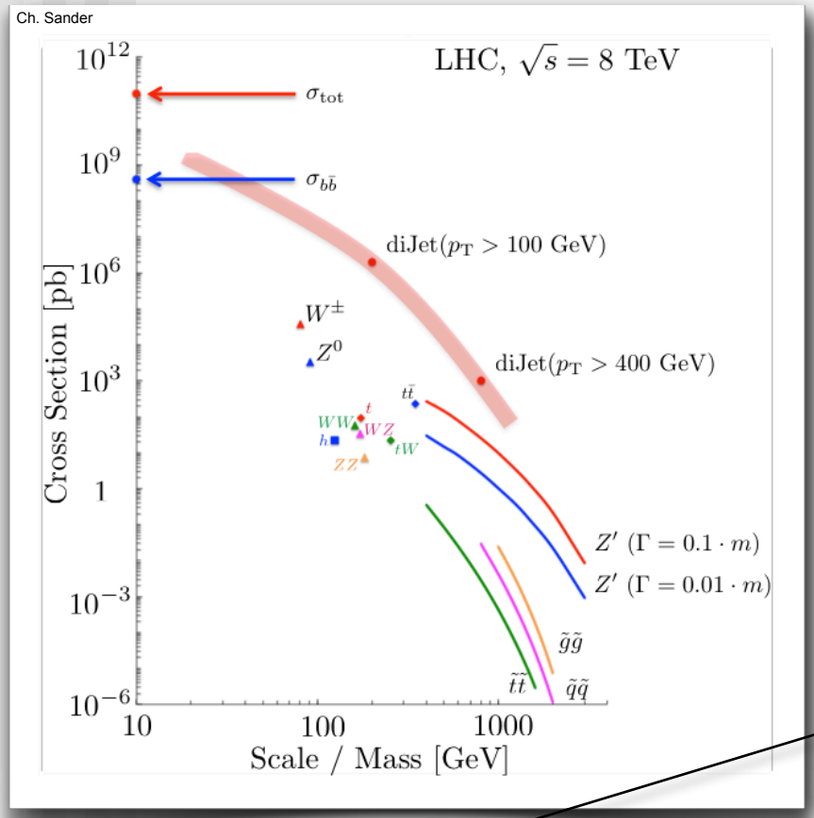

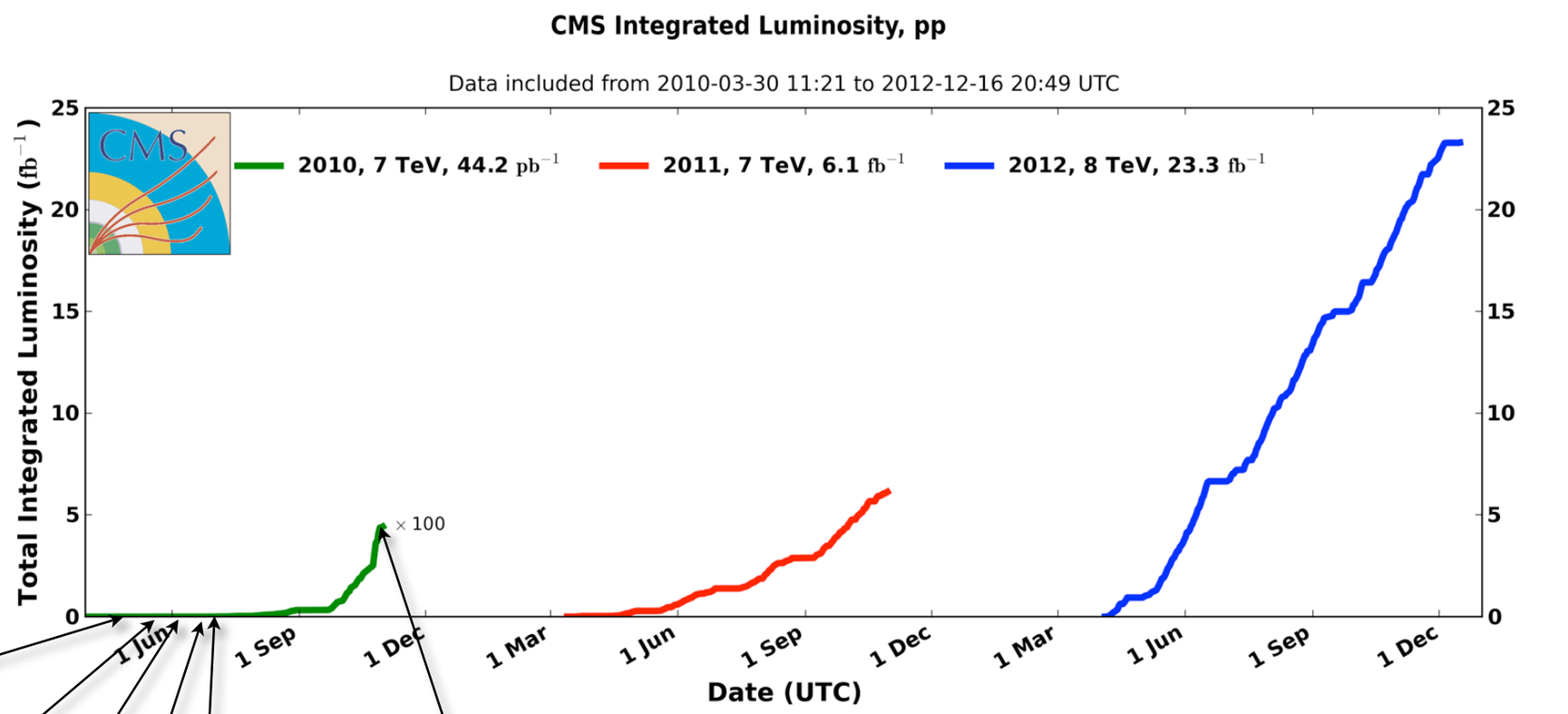

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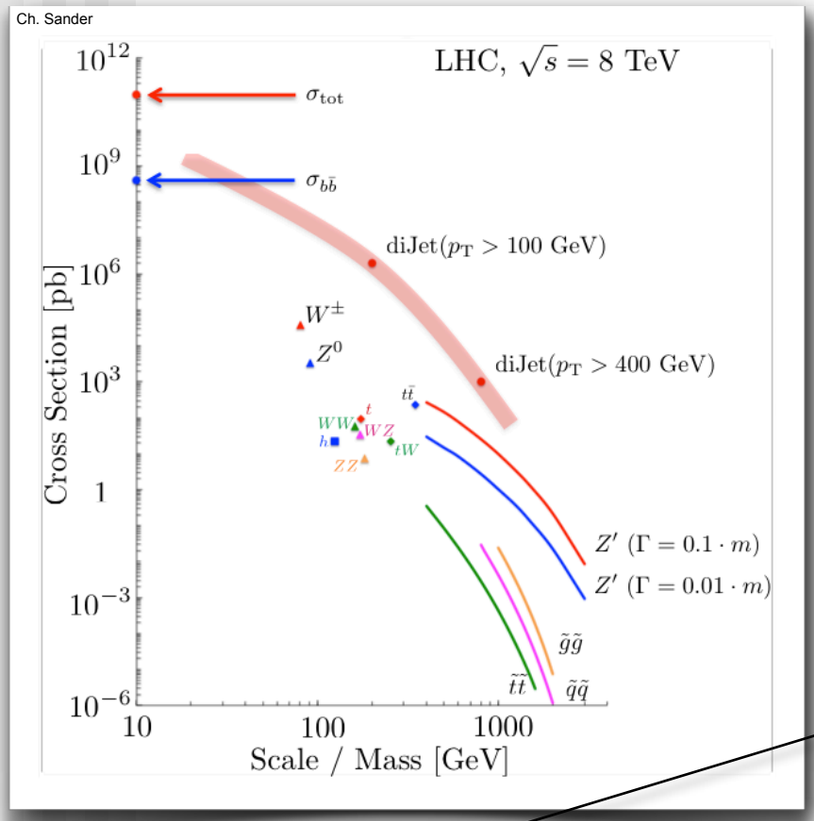

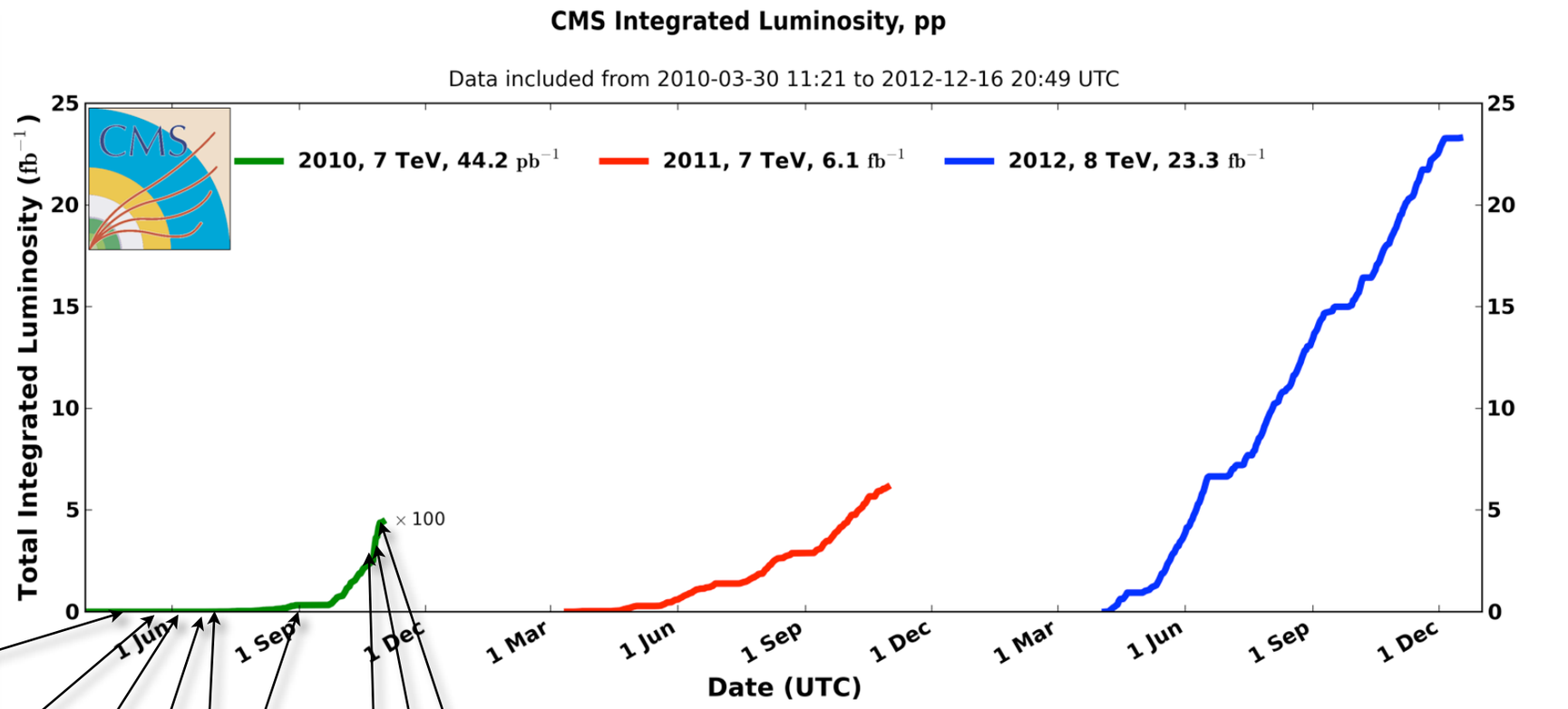

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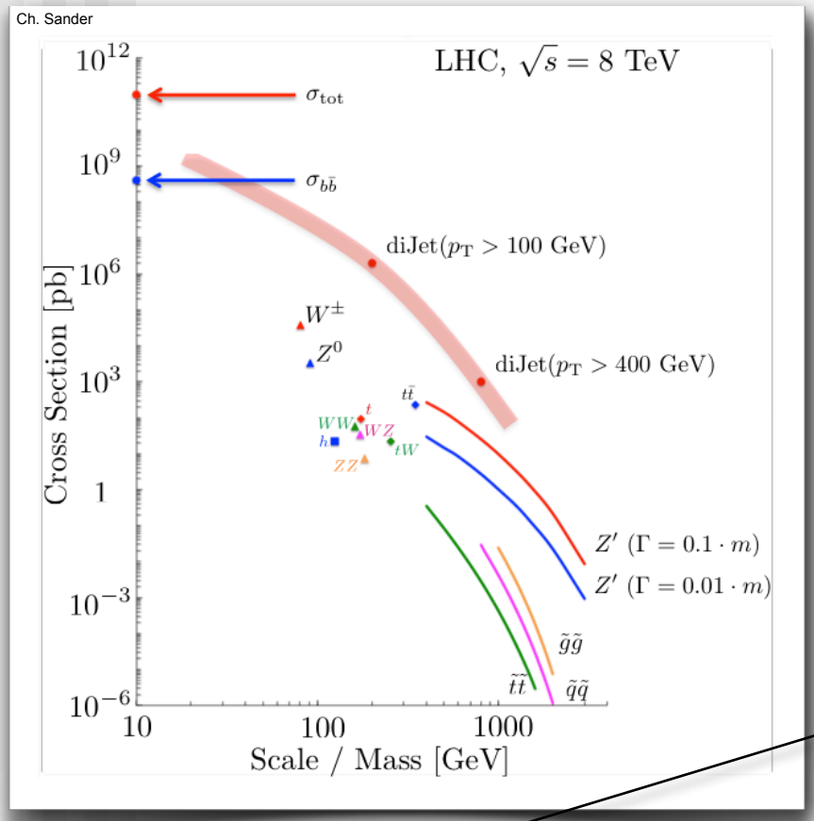

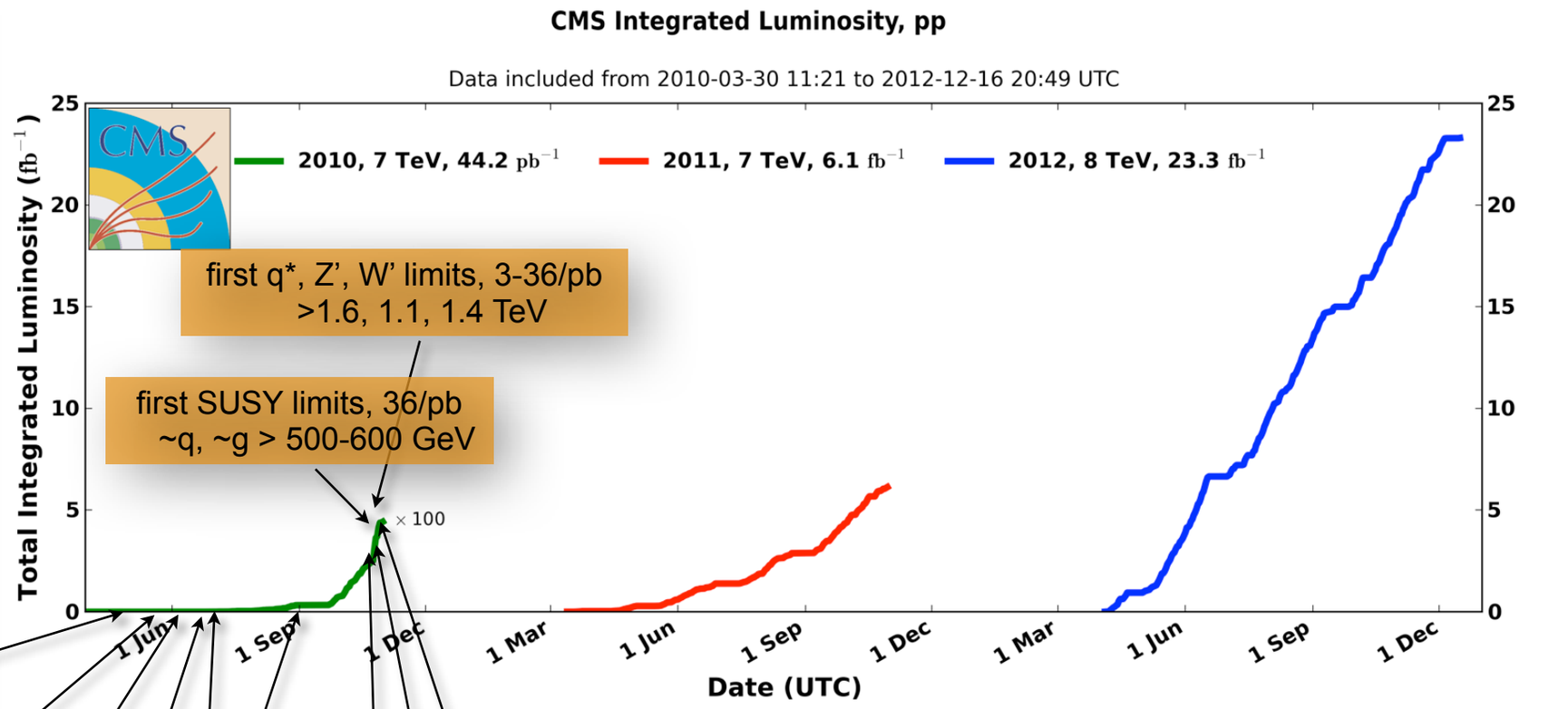

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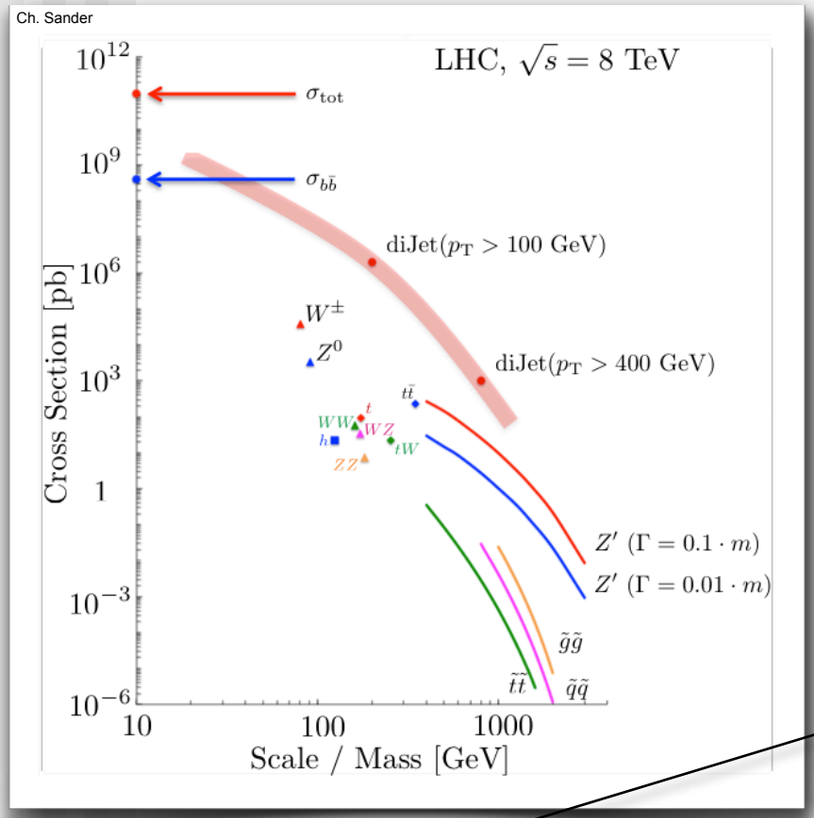

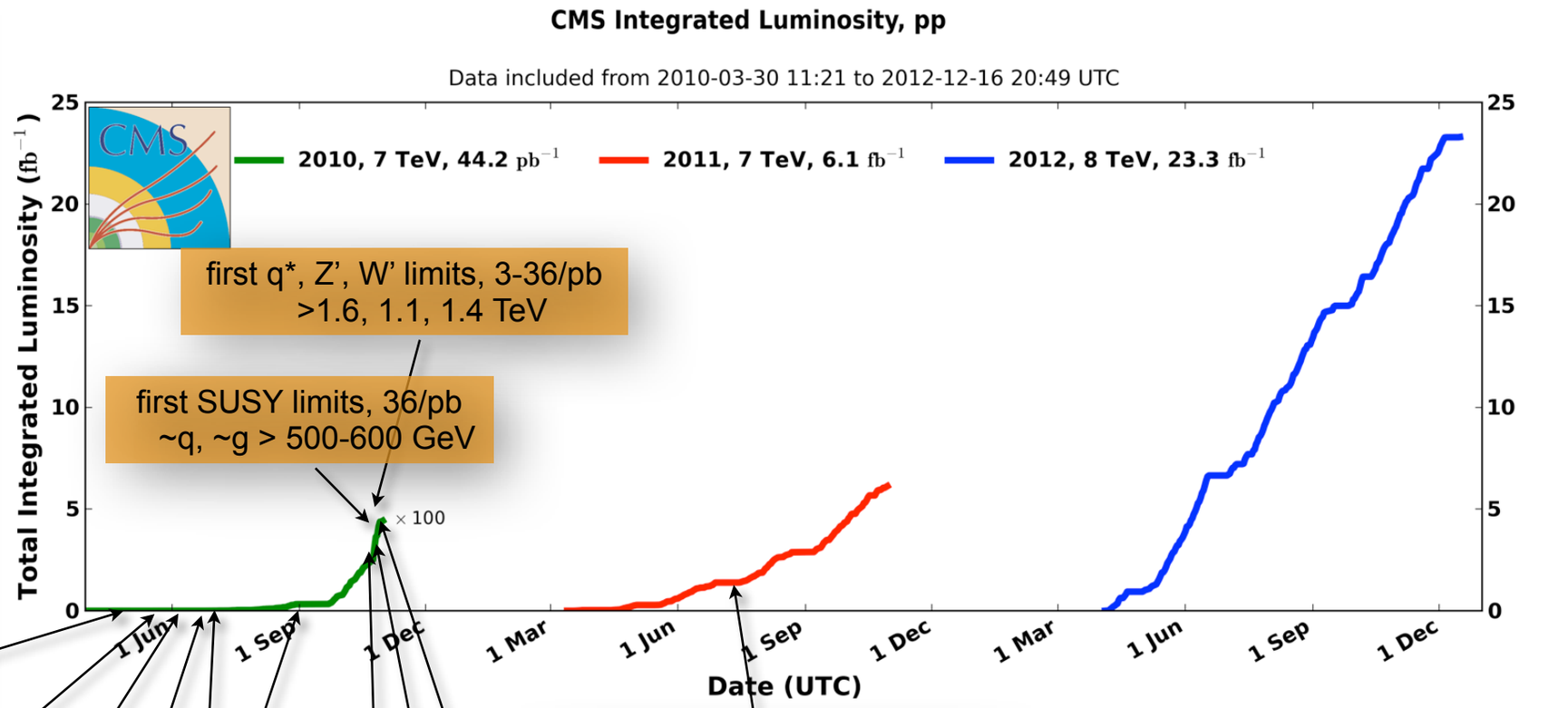

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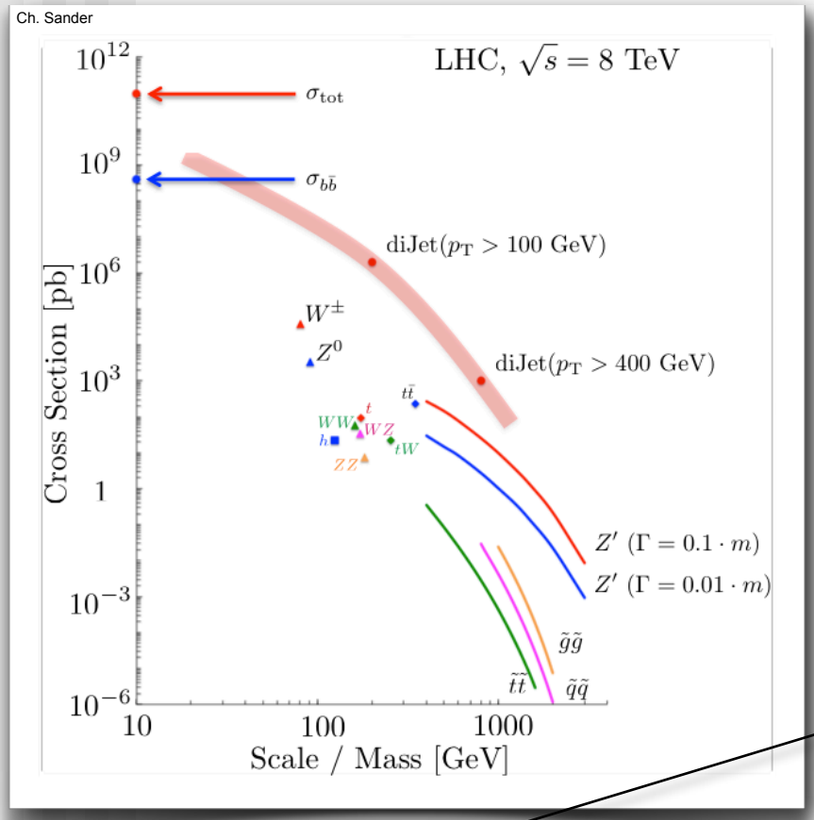

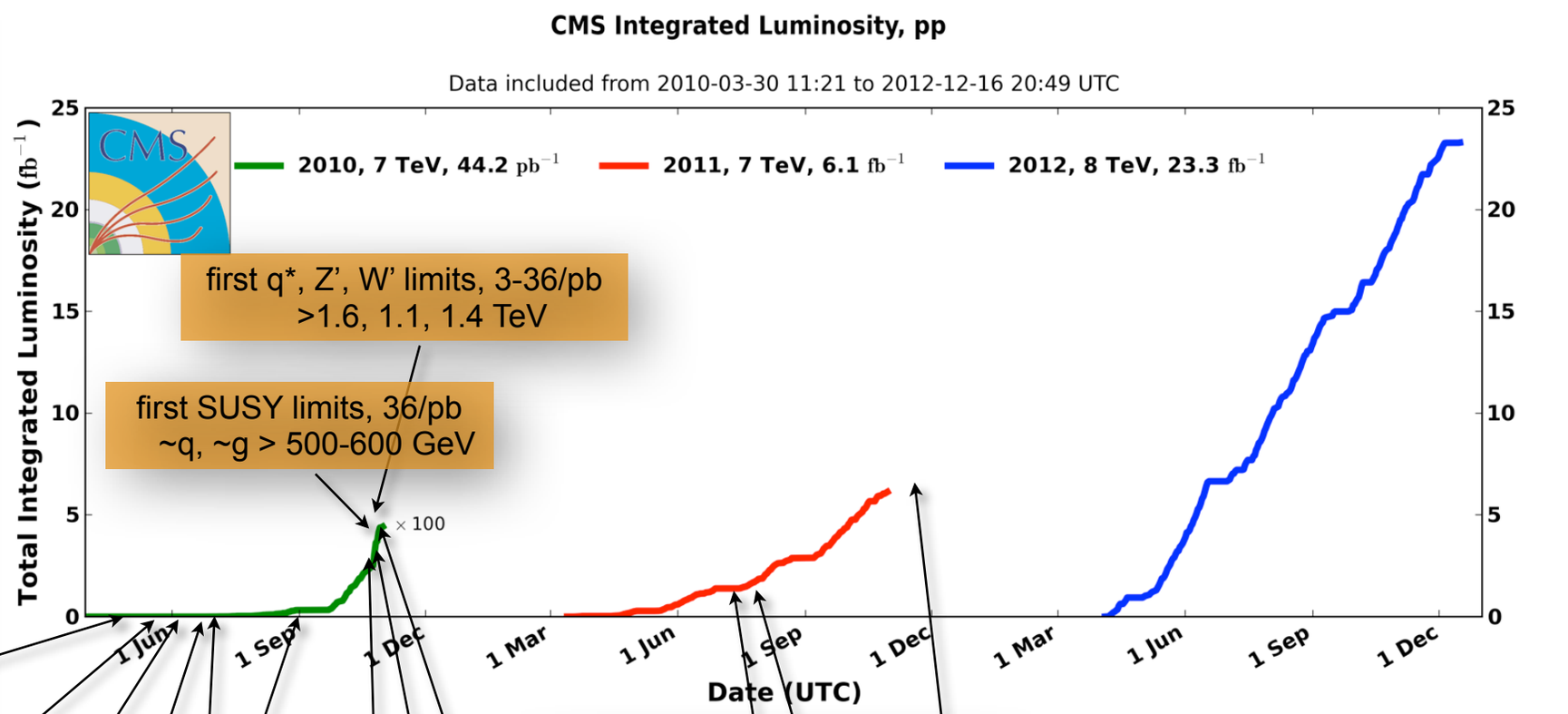

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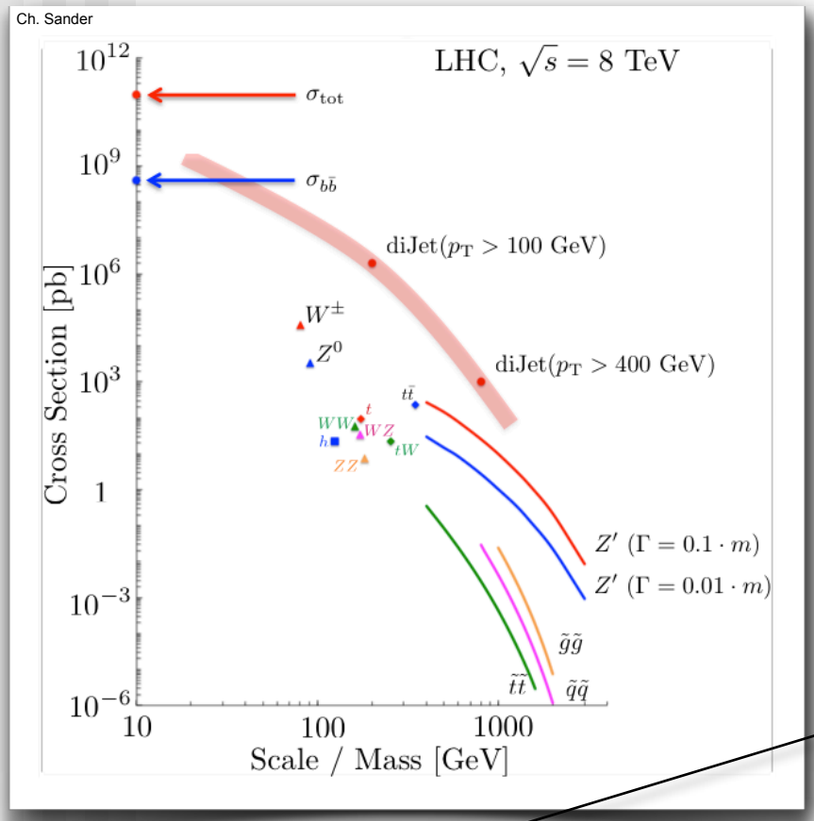

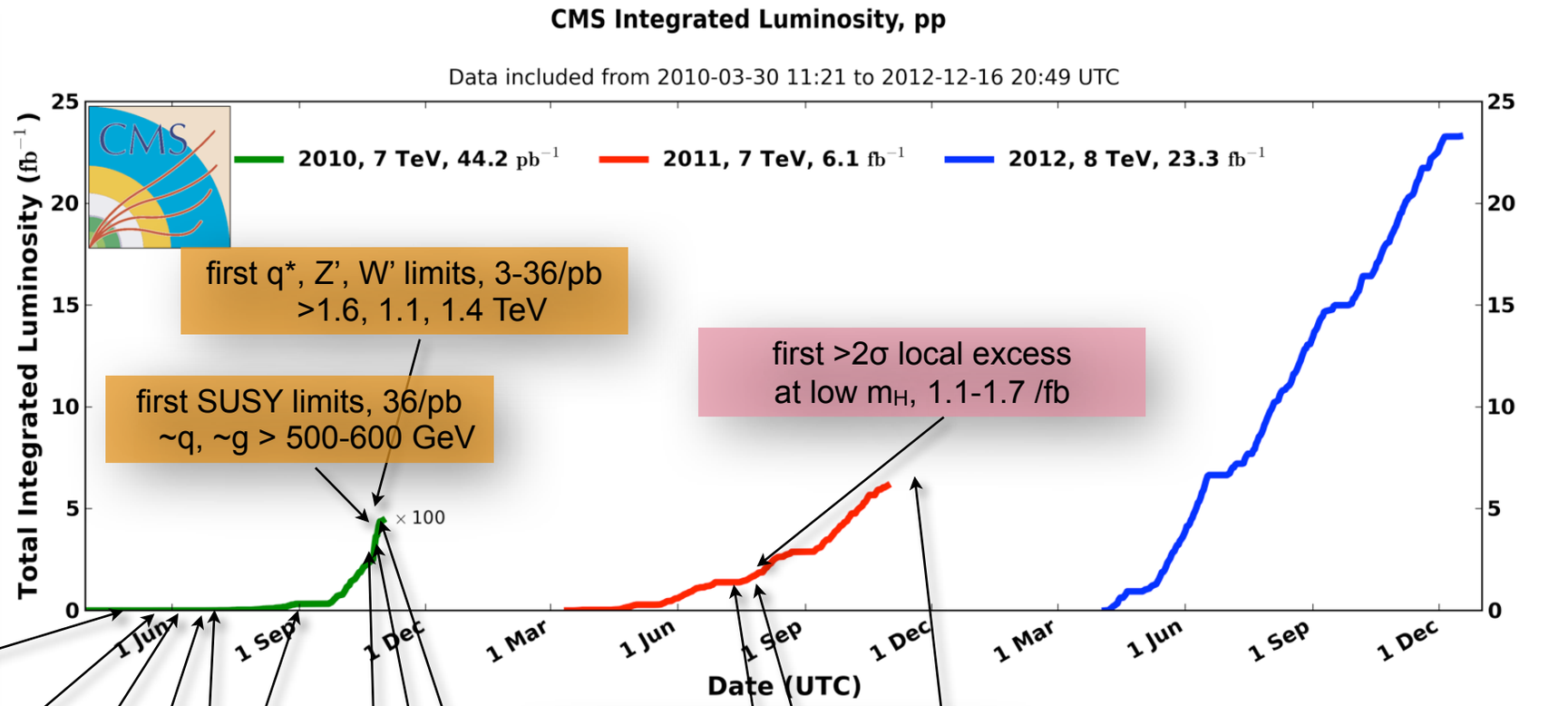

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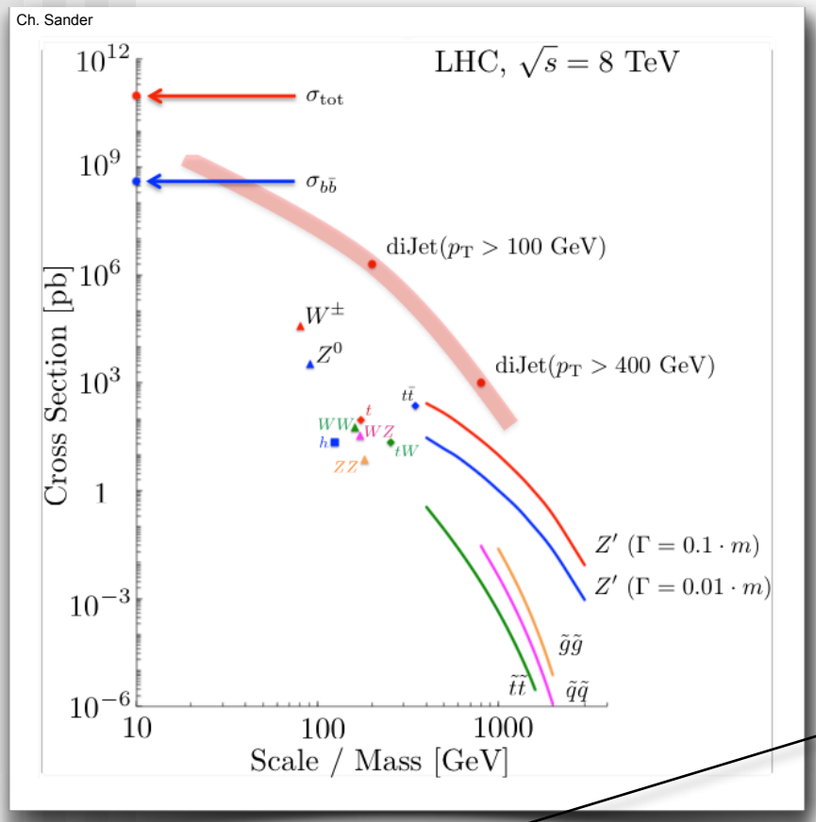

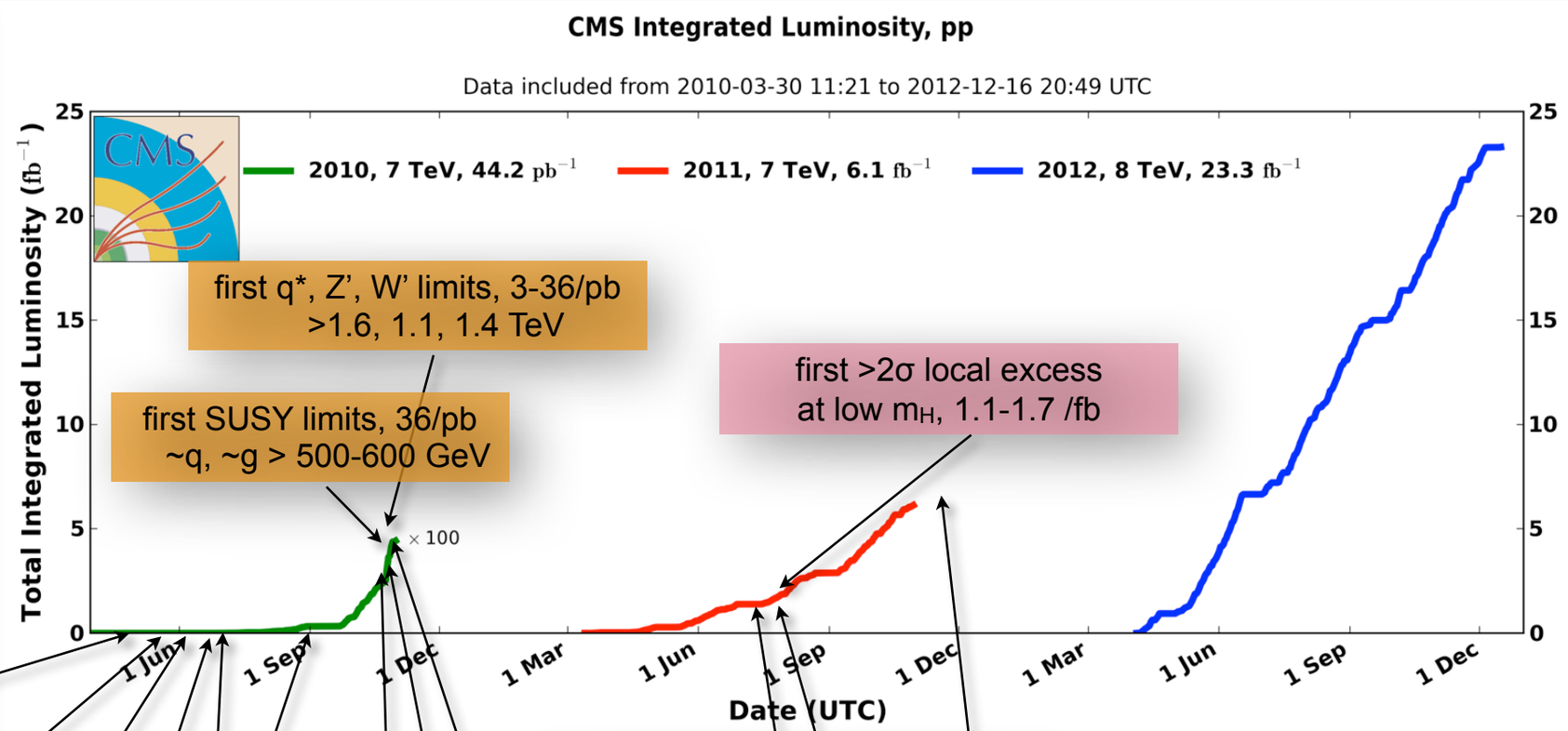

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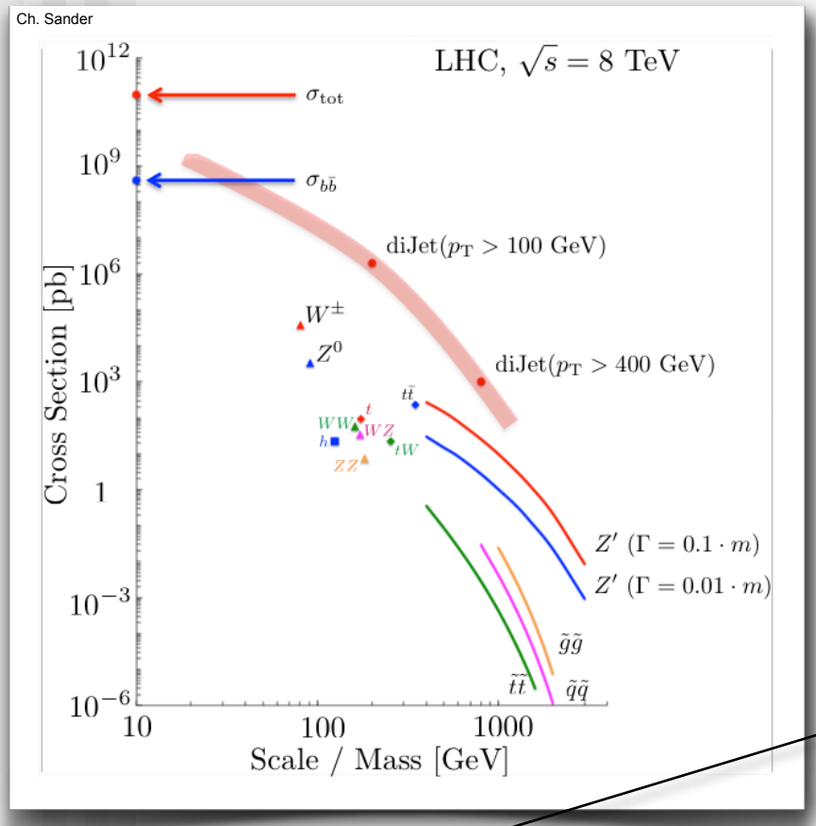

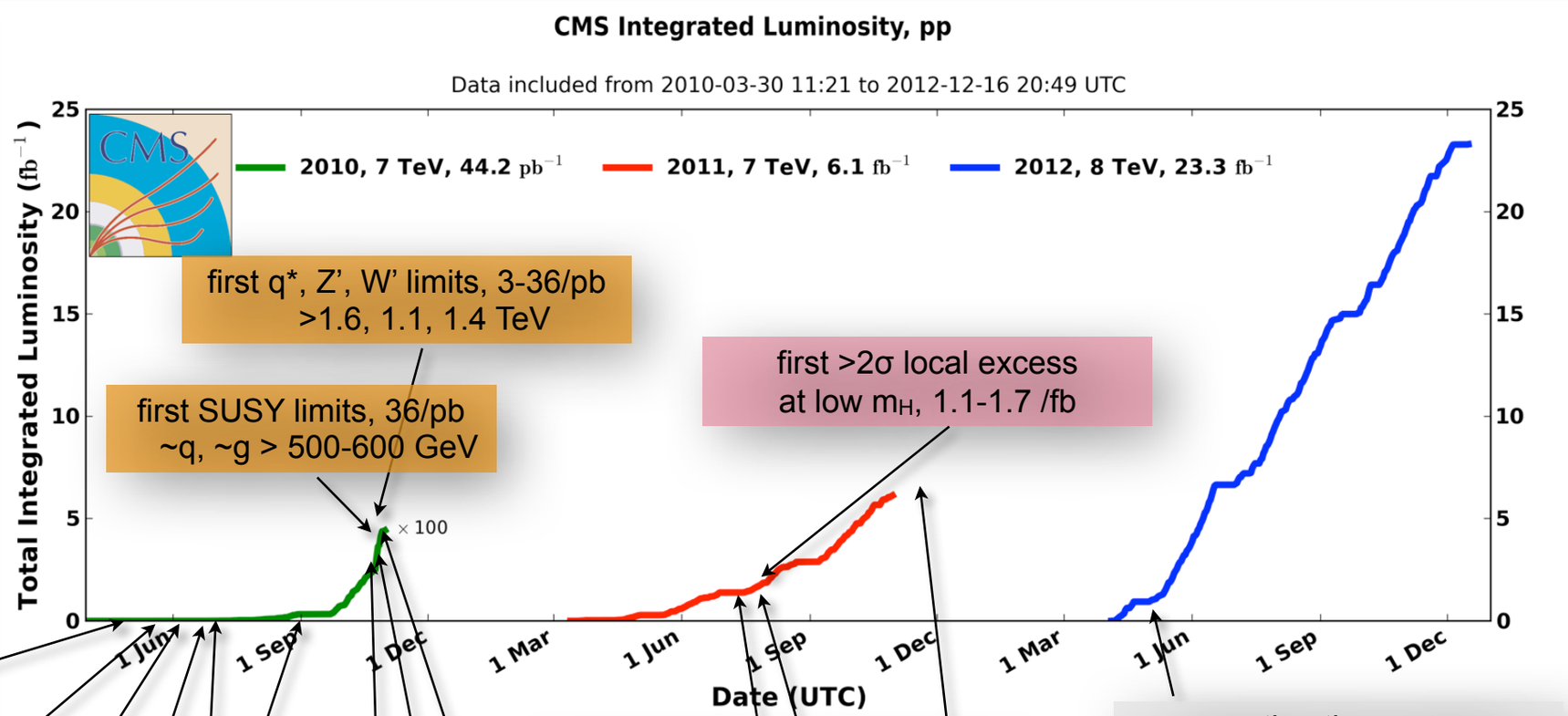

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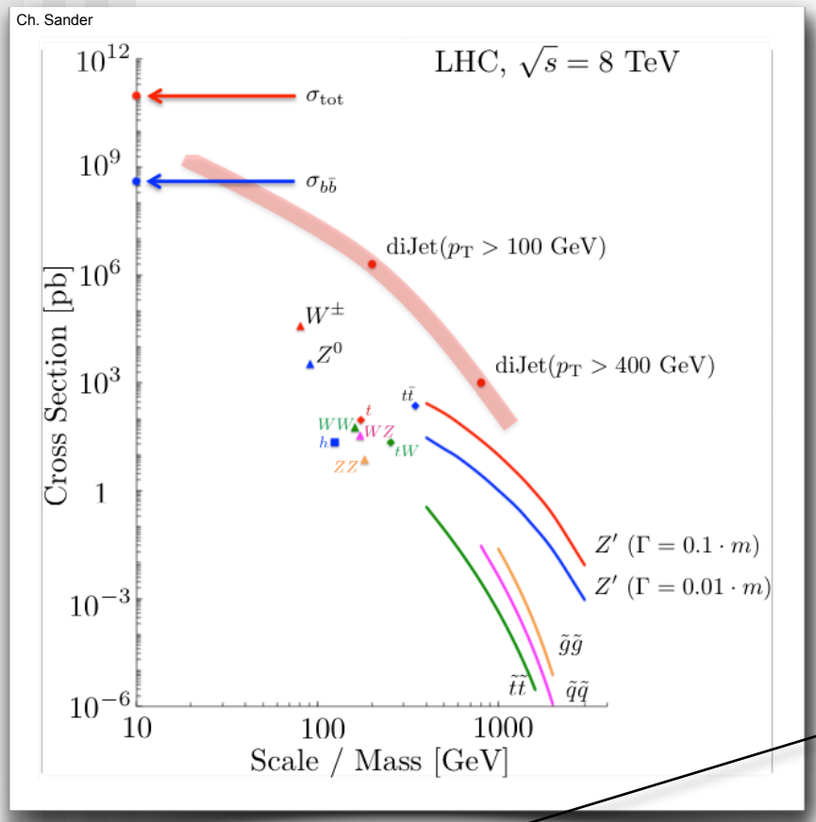

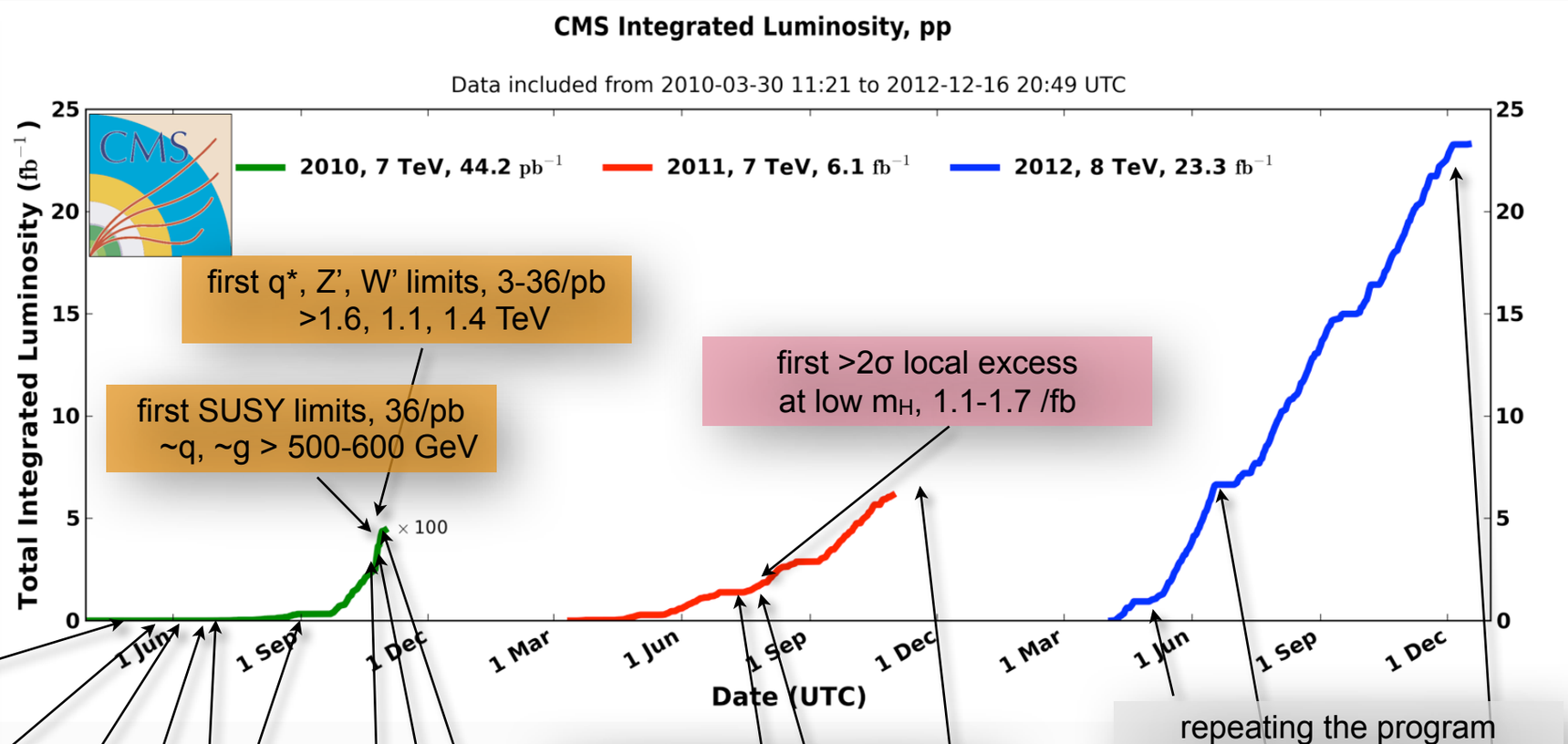

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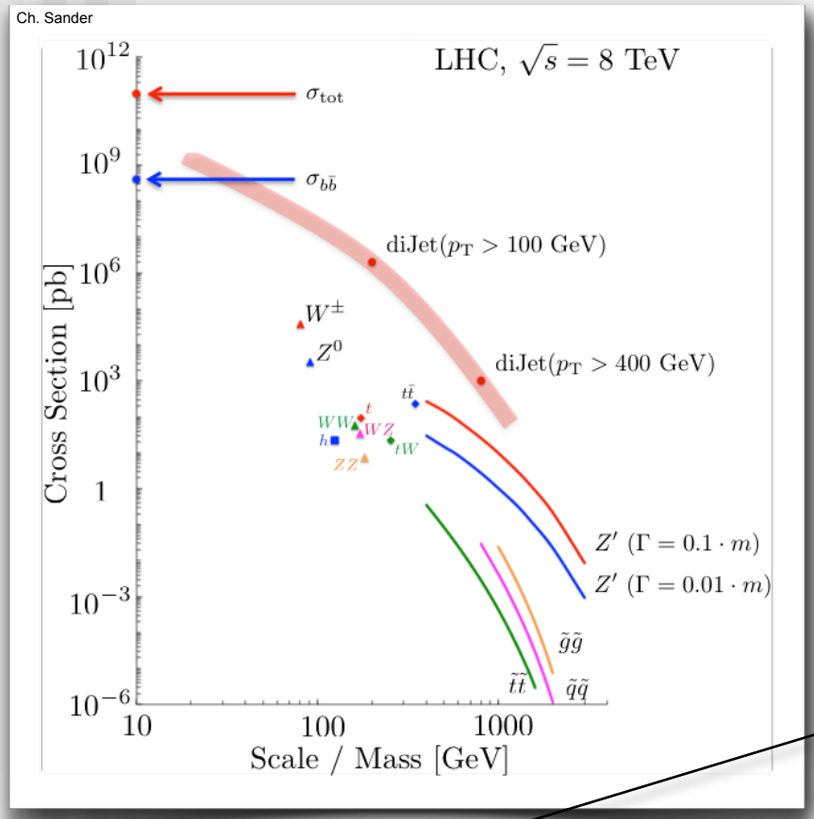

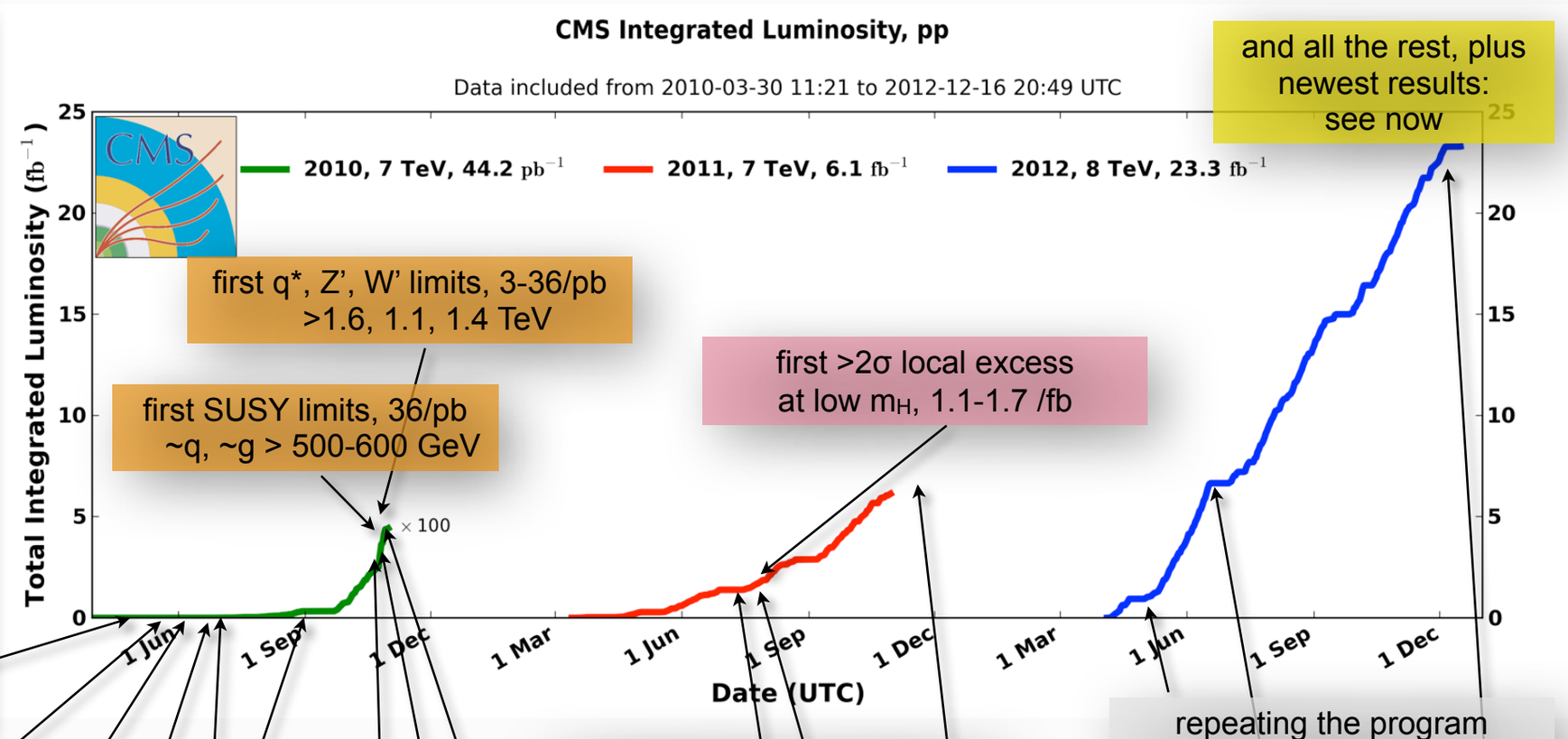

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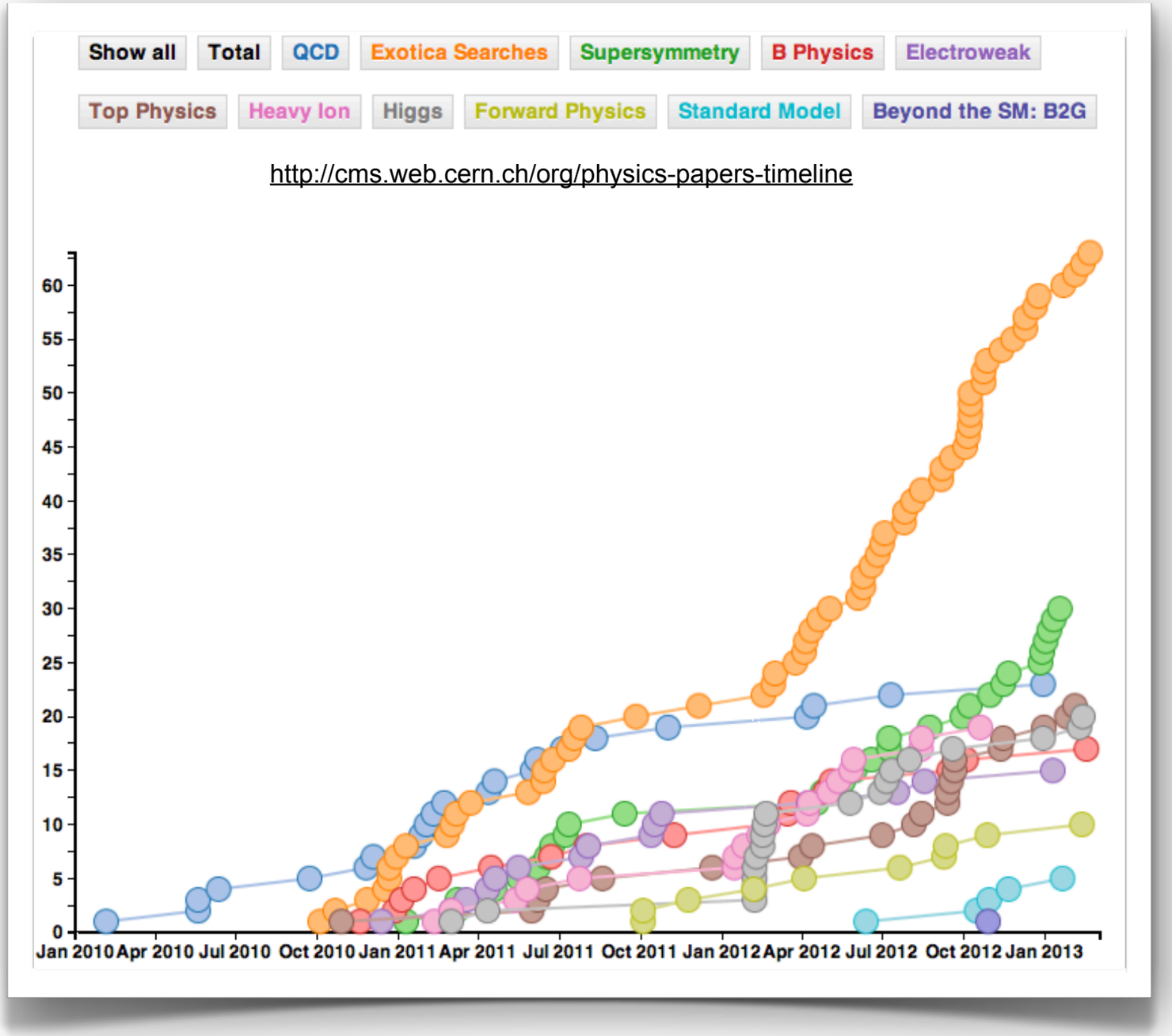
a new boson is announced, 5 /fb

first spin parity analysis of the boson, 17 /fb

The consequence: a lot of reading material



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

- on CDS, 3.3.13 :
  229 papers submitted or published on collision data

- **254** CMS papers in total

- 362 Physics Analysis Summaries in total

- still much more to come

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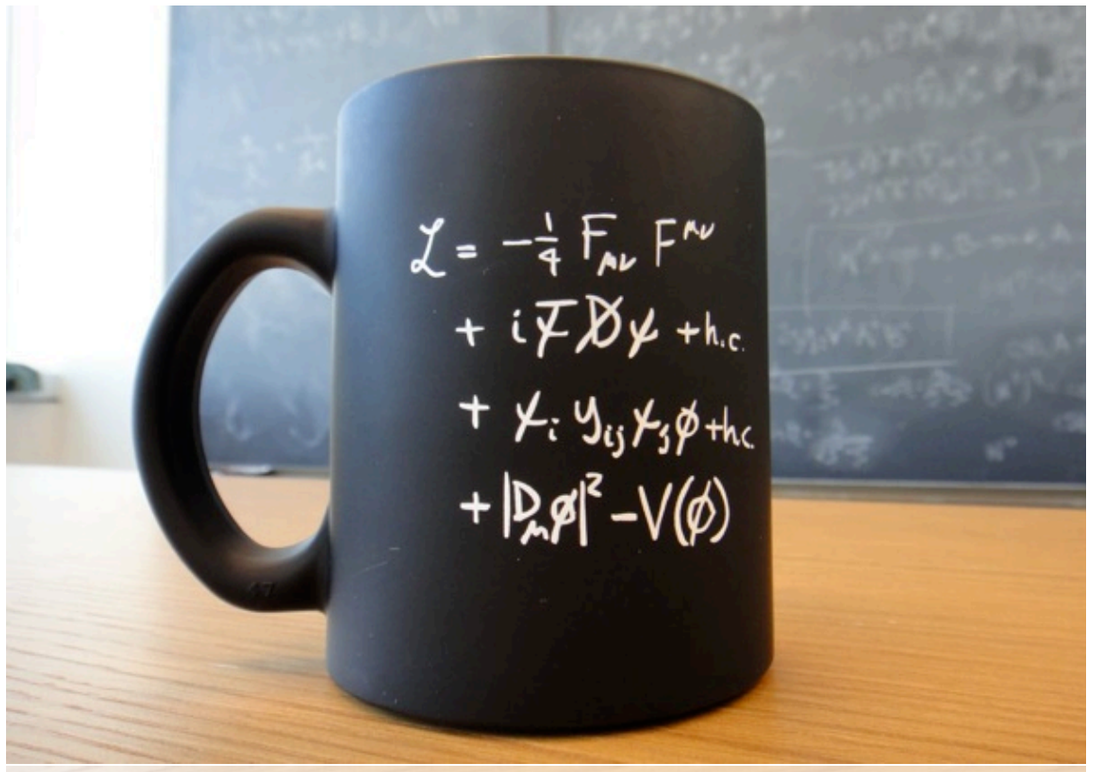
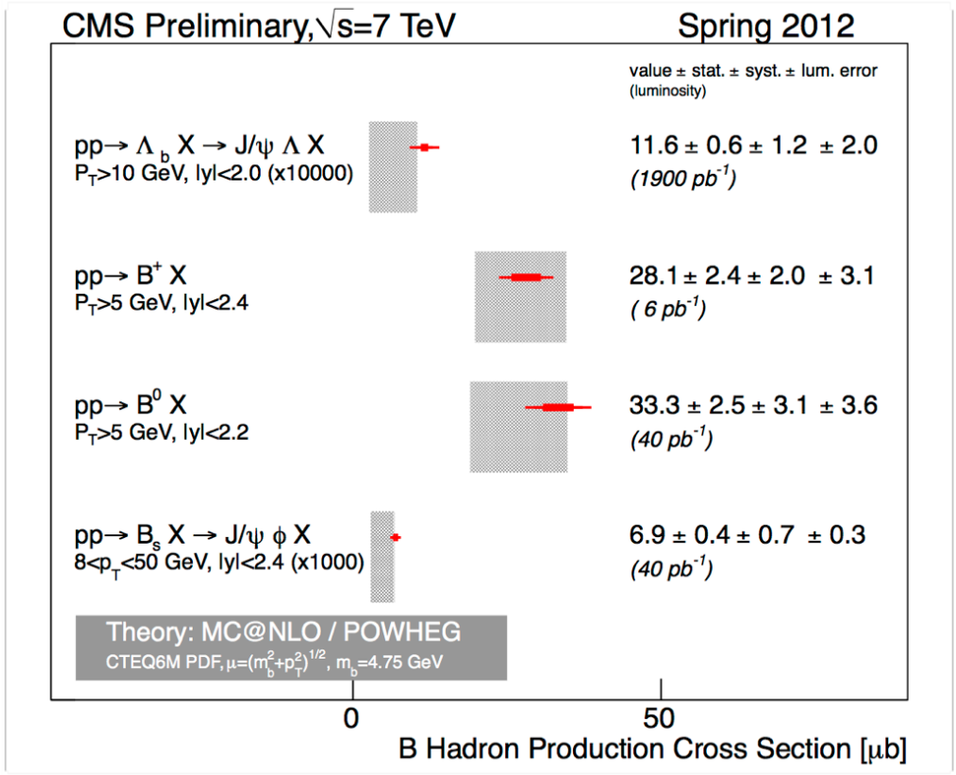
Heavy Flavour Physics

recent highlights



Heavy Quark and Quarkonia production



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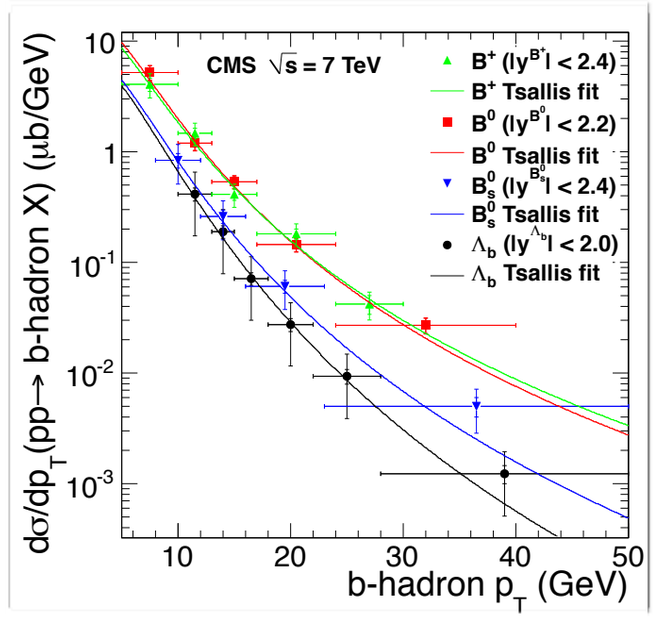

Overall, for open b, B hadron and b-jet production:

- pQCD (and/or MC models) in reasonable agreement, but some discrepancies seen (in p_T and/or eta); ~10% precision
- bb angular correlations studied, low-angle region not well modeled
- Λ_b : steeper spectrum than B mesons

Some recent highlights :

- measurement of X(3872) production xsec
- measurement of Λ_b lifetime
- observation of $B^+_c \to J/\psi\ \pi^+$ and $B^+_c \to J/\psi\ \pi^+\ \pi^-$
- observation of structures in $B^+ \to J/\psi\ \varphi\ K^+$

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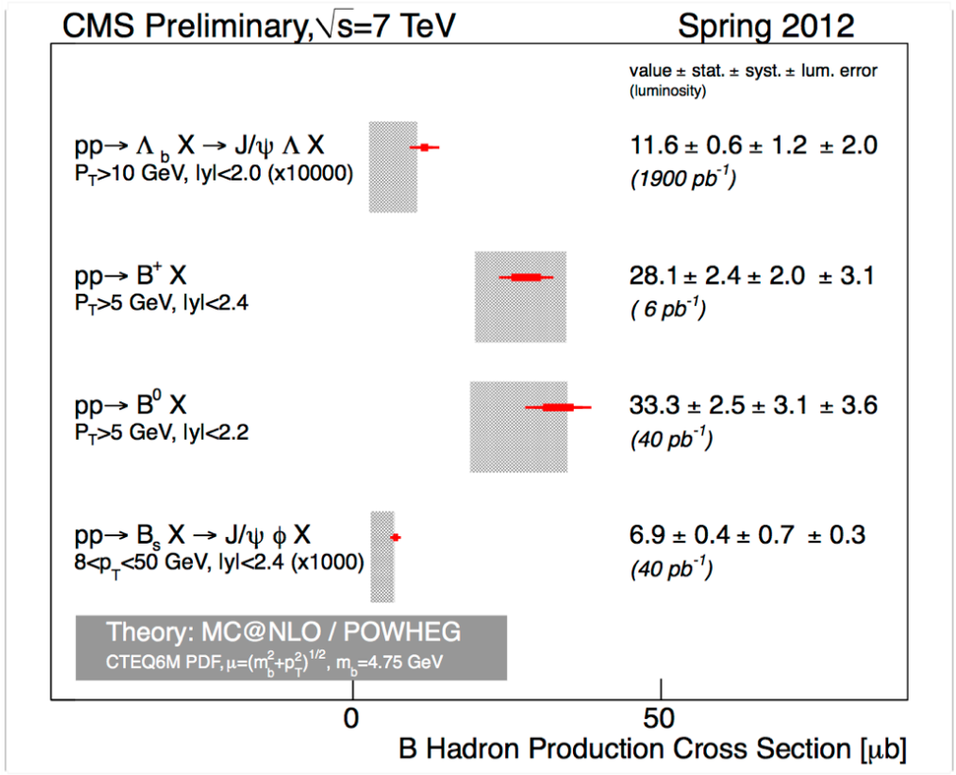

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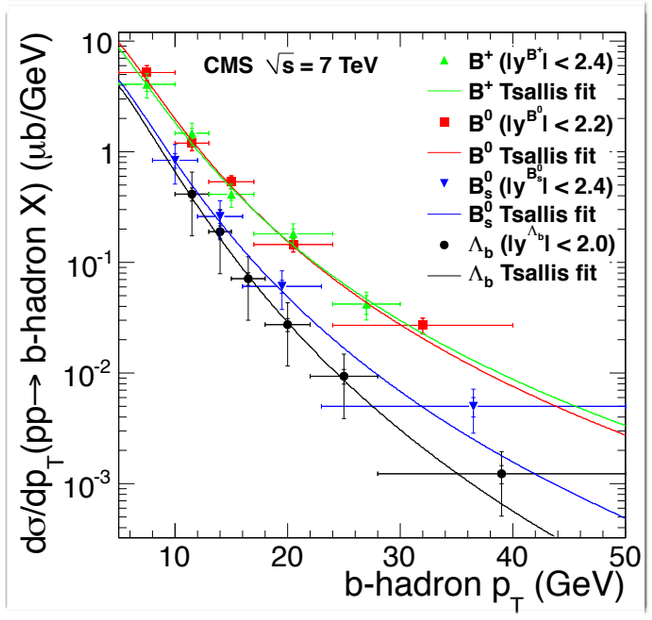


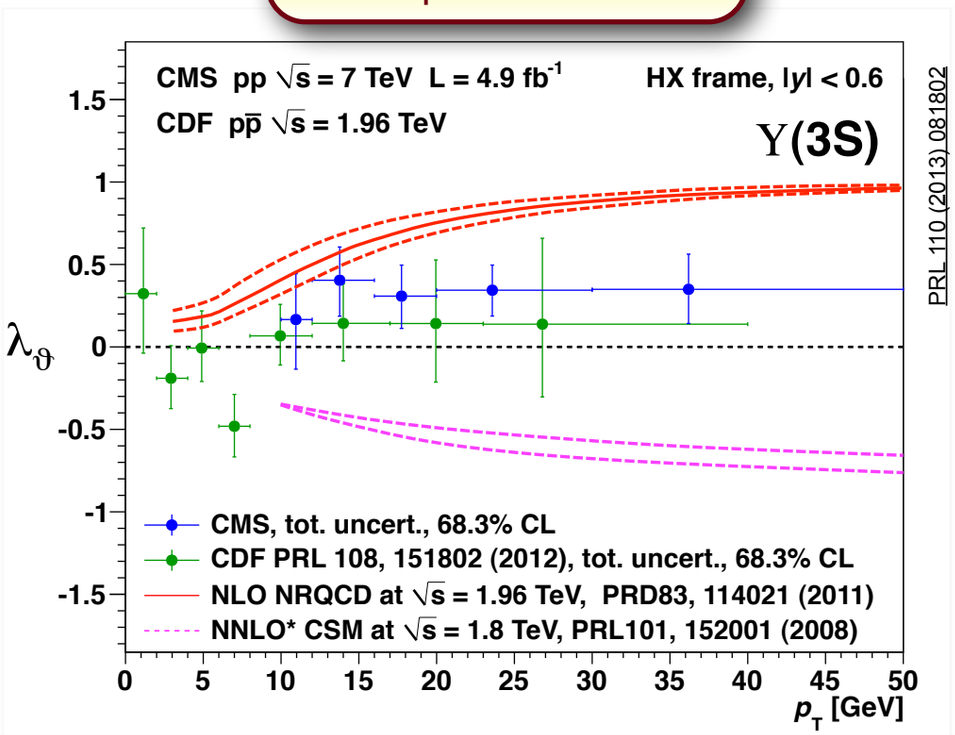
Overall, for open b, B hadron and b-jet production:

- pQCD (and/or MC models) in reasonable agreement, but some discrepancies seen (in p_T and/or eta); ~10% precision
- bb angular correlations studied, low-angle region not well modeled
- Λ_b : steeper spectrum than B mesons

Some recent highlights :

- measurement of X(3872) production xsec
- measurement of Λ_b lifetime
- observation of $B^+_c \to J/\psi\, \pi^+$ and $B^+_c \to J/\psi\, \pi^+\, \pi^-$
- observation of structures in $B^+ \to J/\psi\, \varphi\, K^+$

Y polarization

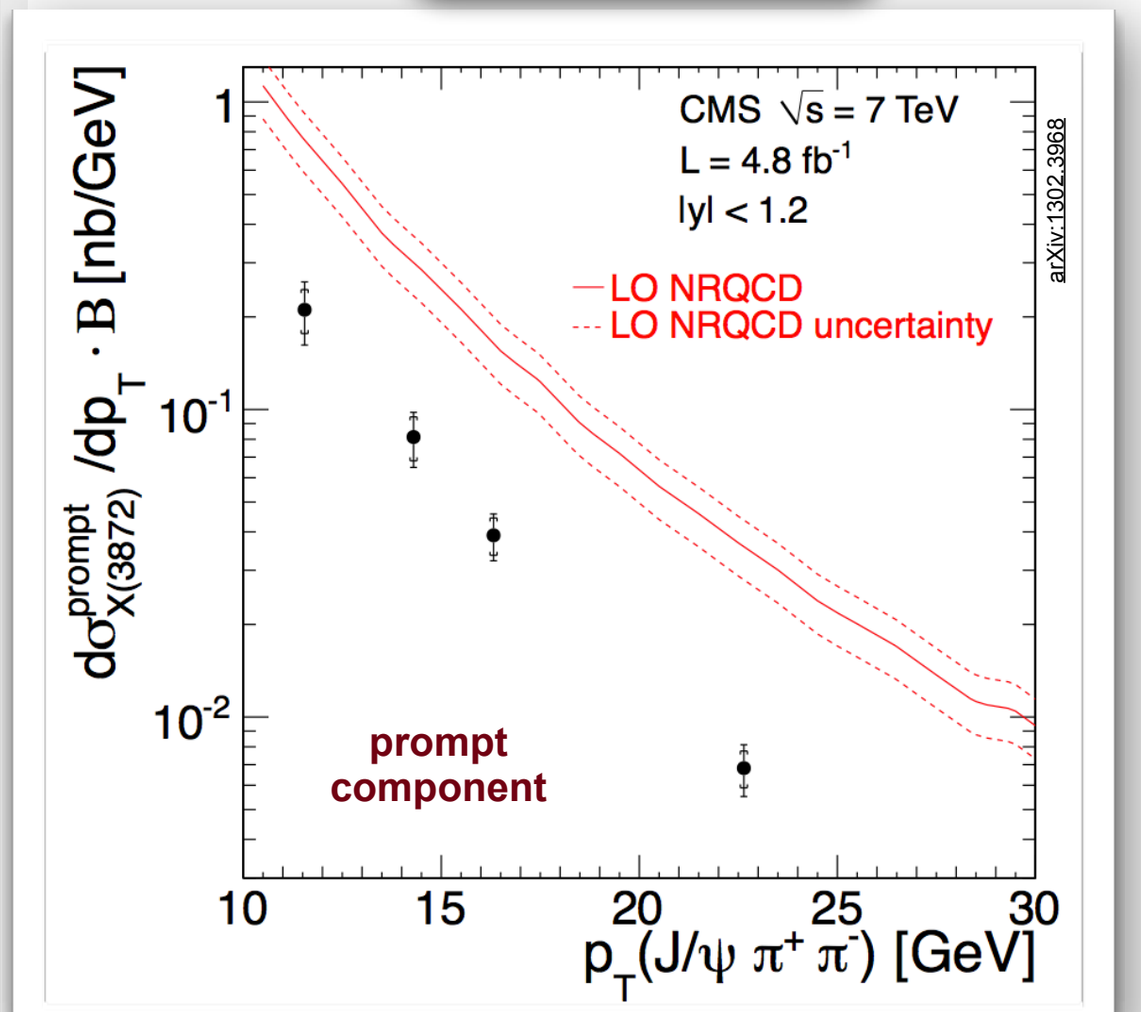


- First LHC measurement of Y(1S), Y(2S), Y(3S) polarization. **No evidence for significant polarization!**

Two recent observations

ETH Institute for Particle Physics

X(3872) production



- From ratio of X(3872) to ψ(2s) production, and measured ψ(2s) cross section
- First p_T differential cross-section measurement at LHC

Two recent observations

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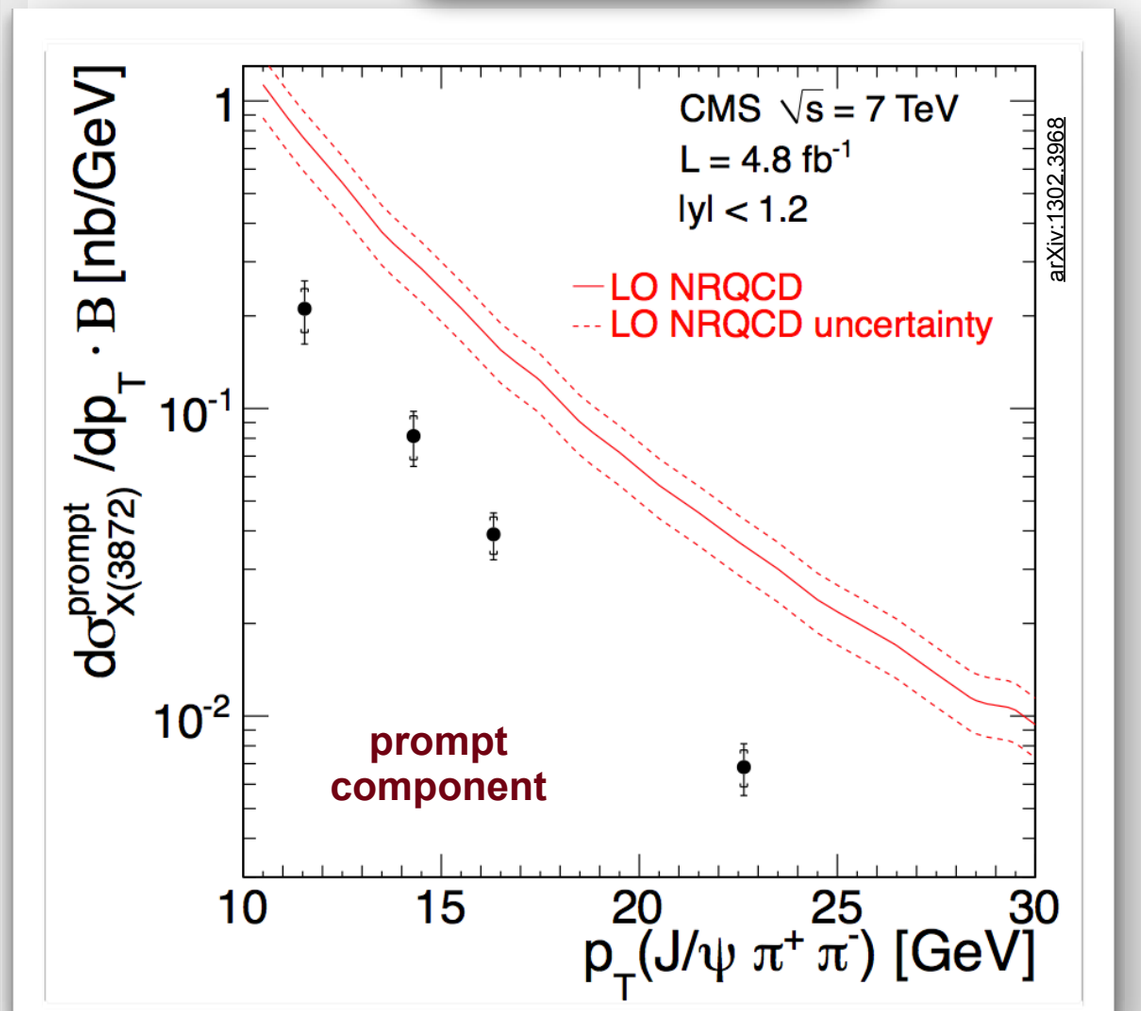

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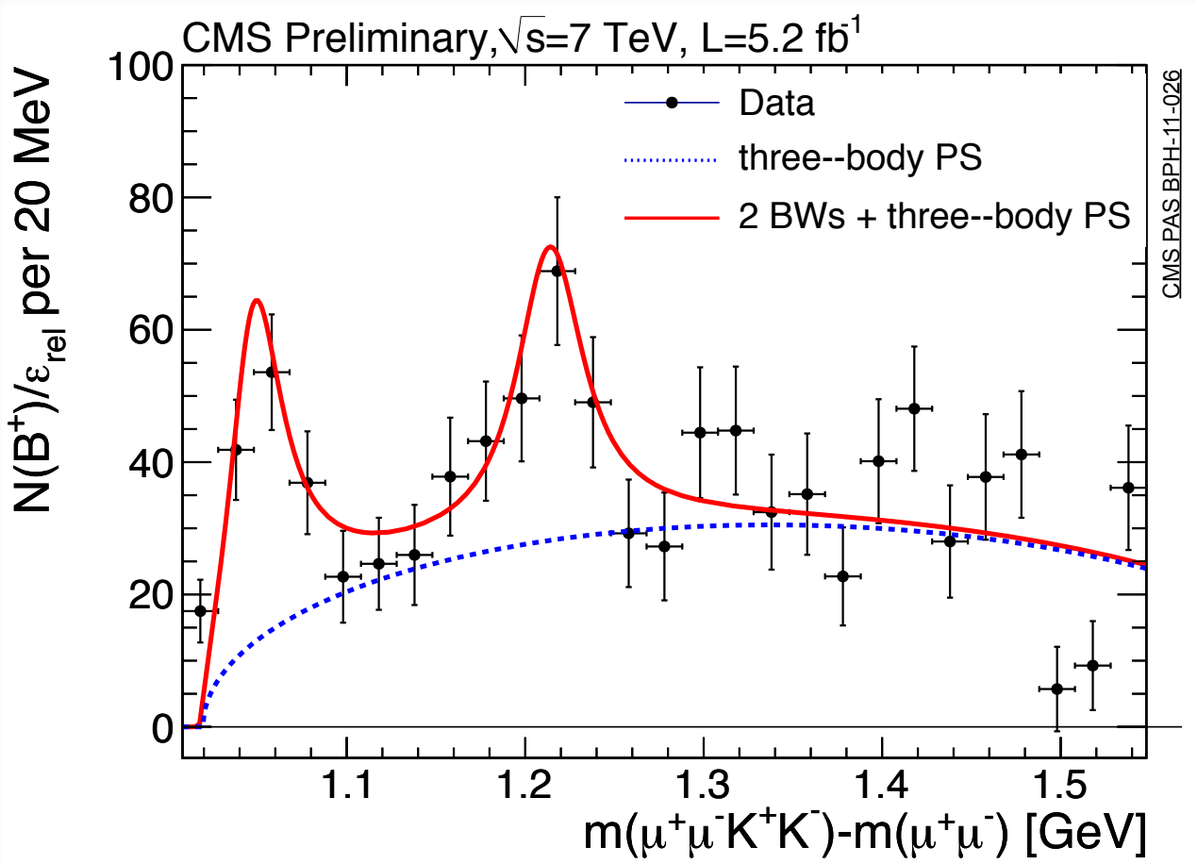
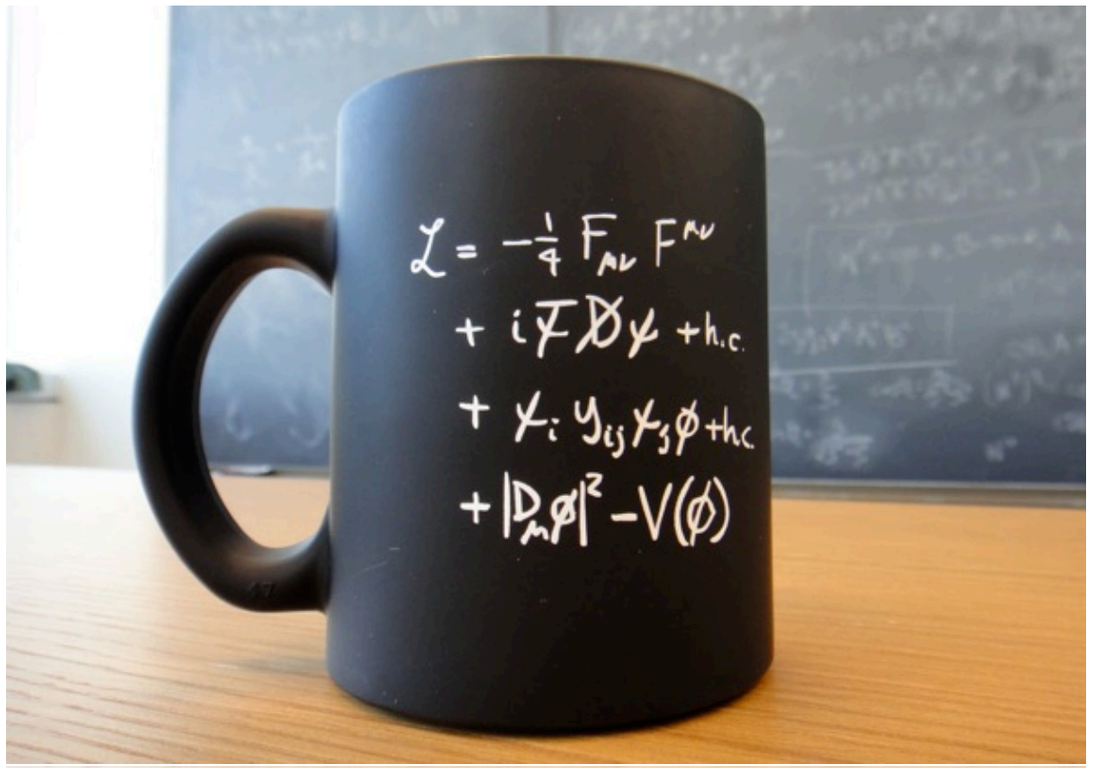
Structures in J/ψ φ spectrum from B+ → J/ψ φ K+



- structure 1 (4148 MeV) : confirms CDF result with > 5σ
- evidence for a 2nd structure at 4316 MeV : interpretation complicated by possible reflections from φK resonances
- angular analysis needed for further understanding

probing QCD



see also talk by

N. Neumeister ....

Soft QCD : two recent results

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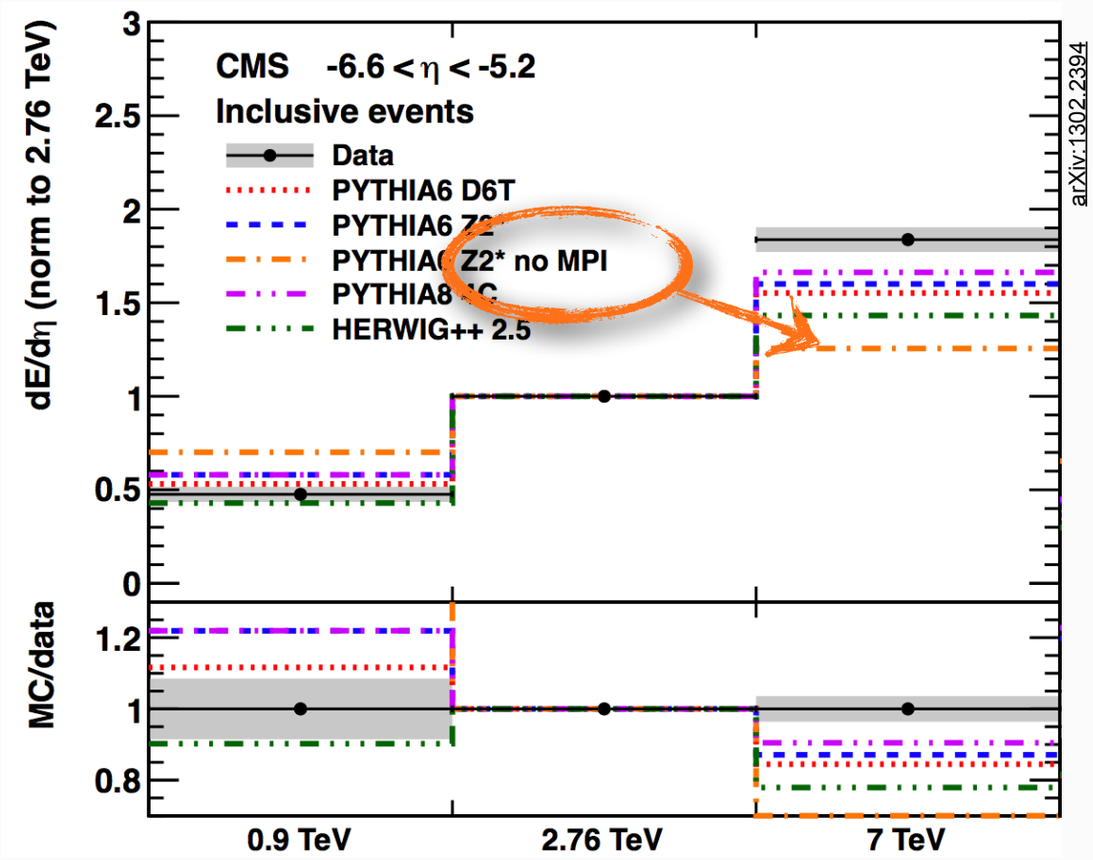
Very forward energy flow



- Analysis exploiting CASTOR acceptance !
- FWD energy flow both inclusive, and with central jet
- importance of MPI effects shown, much stronger when requesting central jet
- also models relevant for cosmic rays tested

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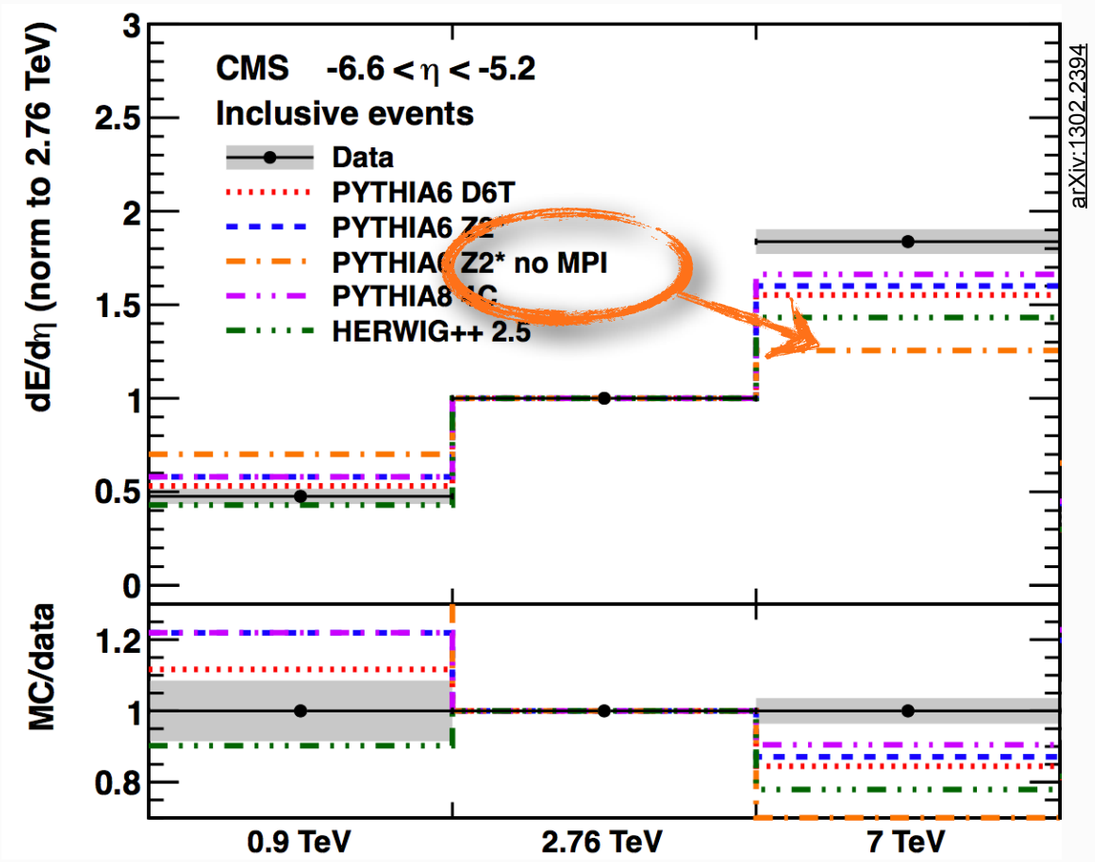

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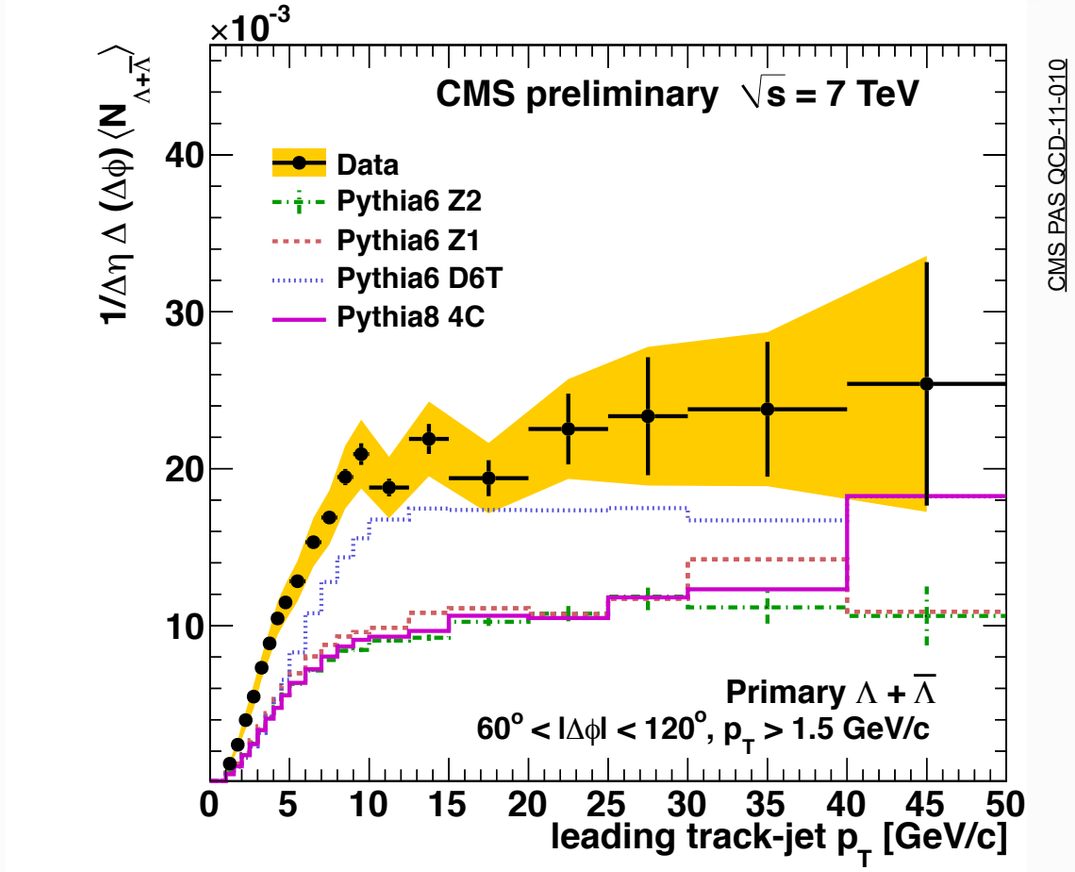
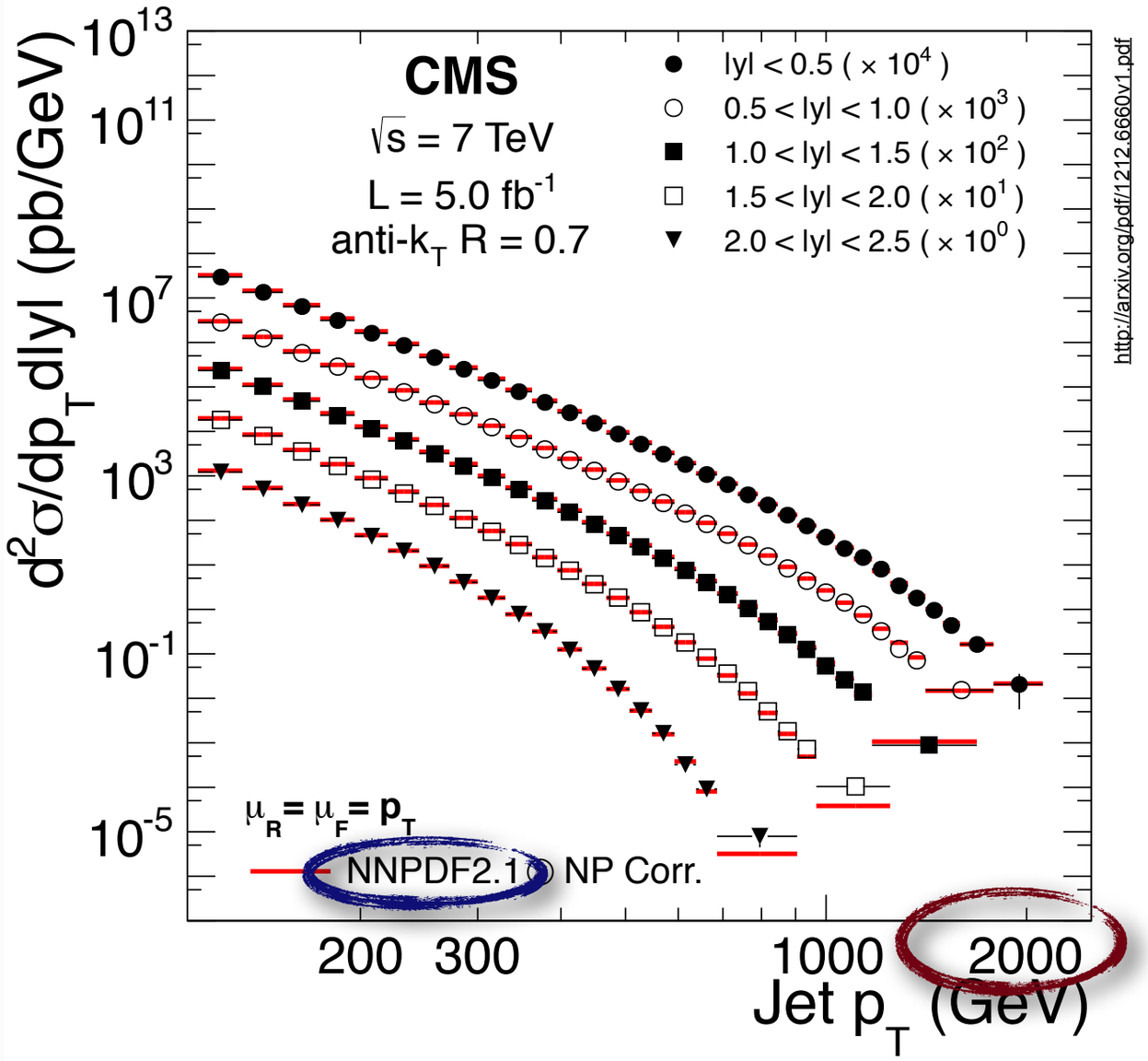
Strangeness production in the underlying event



- Monte Carlo models underestimate strange particle production in the underlying event
- 15-30% for K^0_S, 50% for Λ !
- confirms earlier observations in min bias studies

Inclusive Jet Production



- NLO QCD describes data over ~9 orders of magnitude!
- excellent exp. progress: jet energy scale uncertainties at the **1-2%** level
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- inclusive jet data : start to be important tool for constraining PDFs

Inclusive Jet Production

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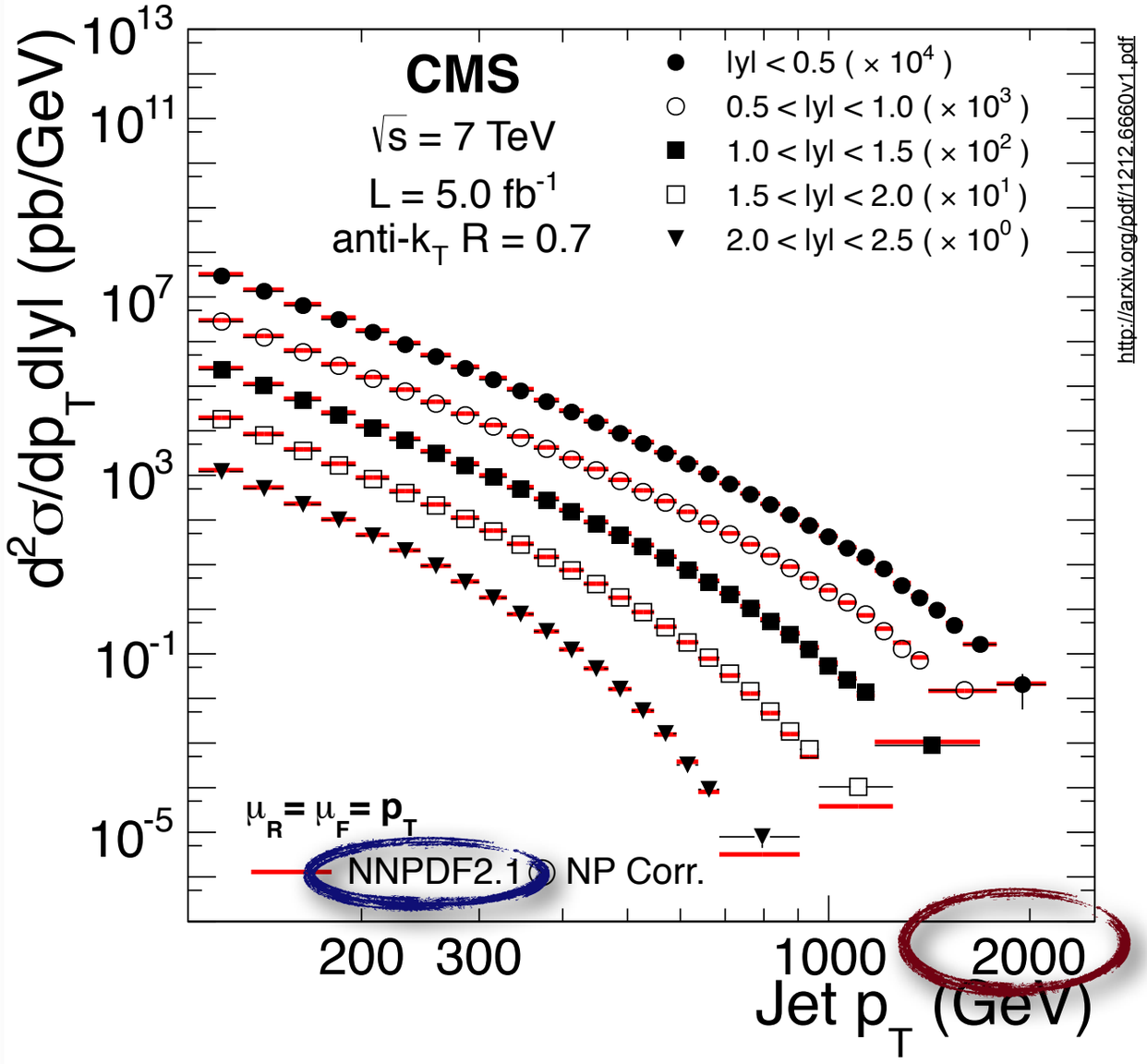

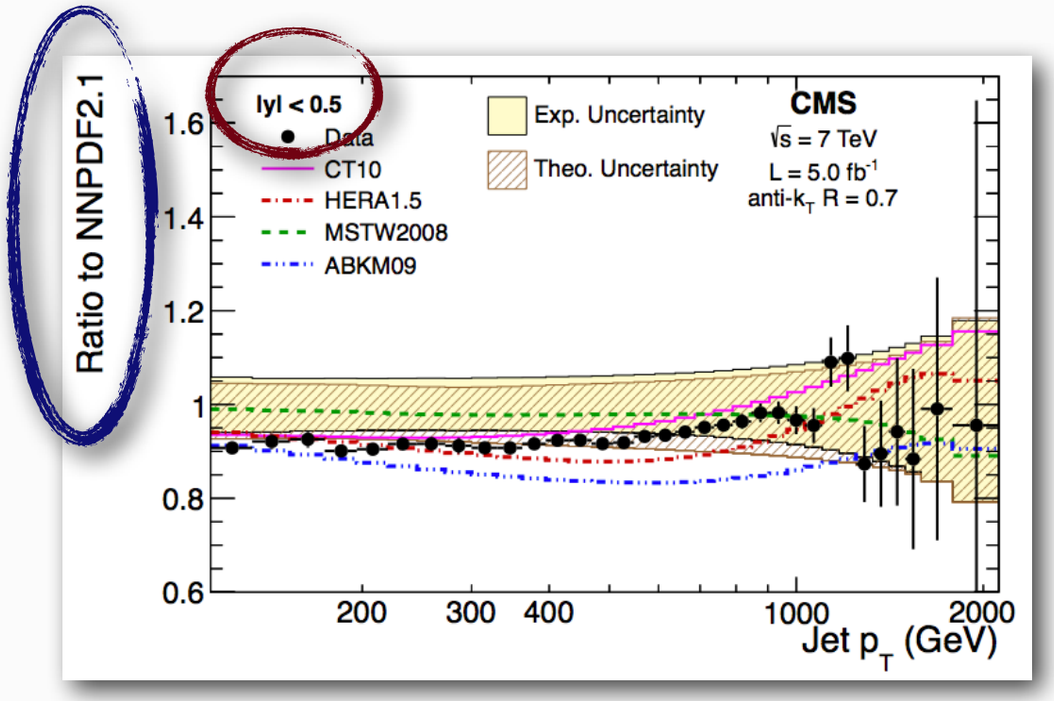

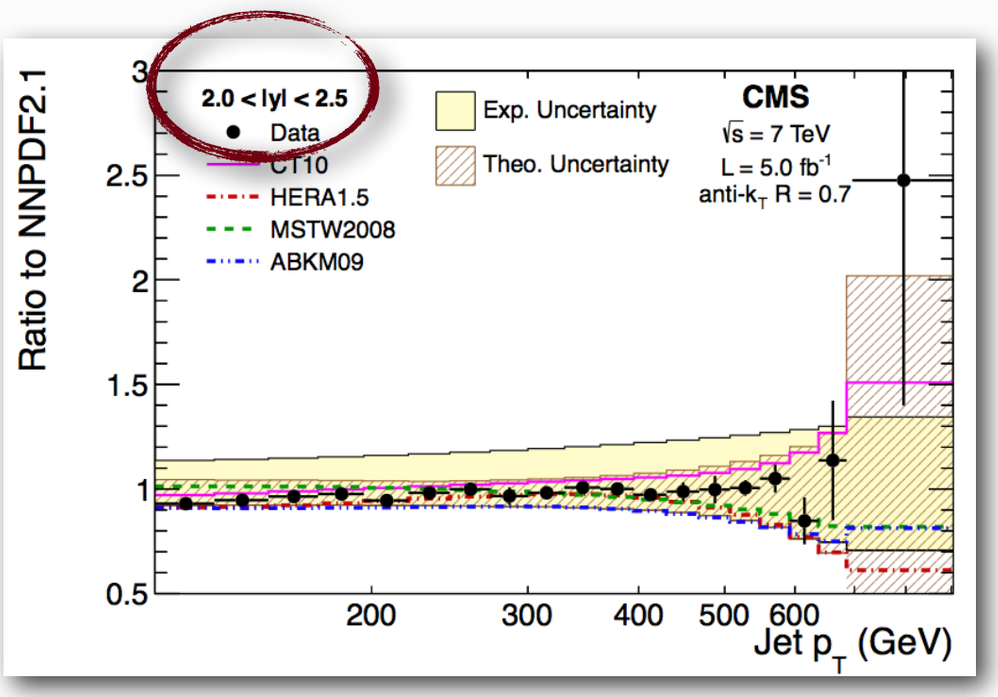

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Further recent results on jets

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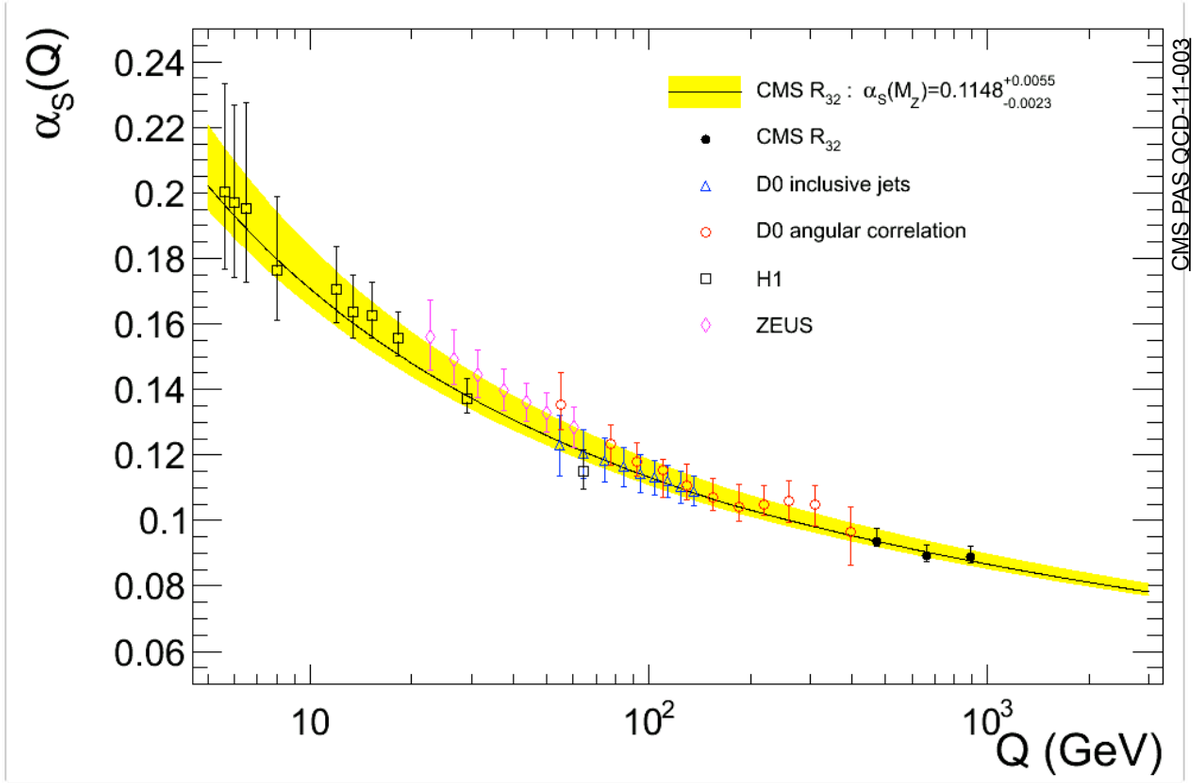
3-to-2 jet cross section ratio



$\alpha_S(M_Z) = 0.1148 \pm 0.0014$ (exp.) ± 0.0018 (PDF) $^{+0.0050}_{-0.0000}$ (scale)

- R_{32} (in the 400-1400 GeV range) is used to measure α_s
- First derivation of $\alpha_S(M_Z)$ from momentum scales > 0.4TeV
- also very recent: **first $\alpha_S(M_Z)$ extraction from top x-section** (TOP-12-022)

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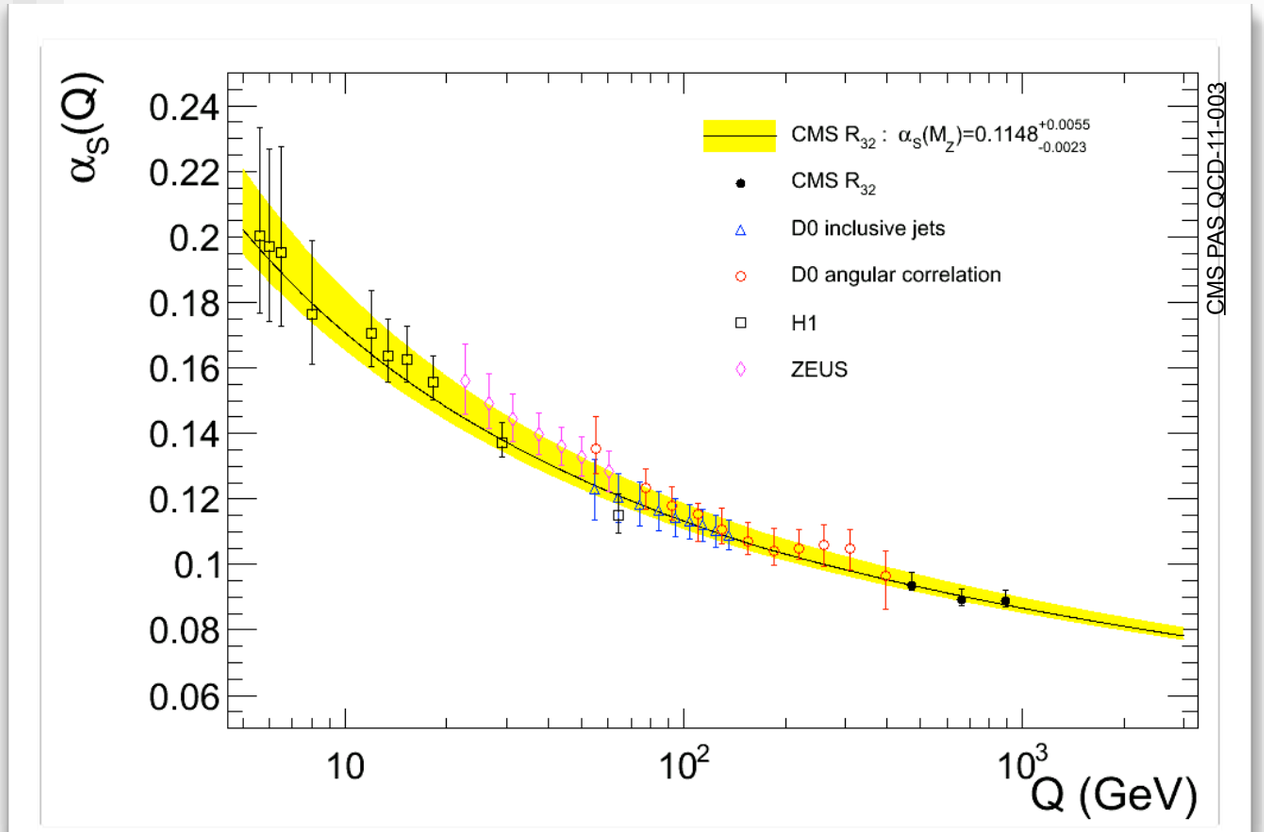

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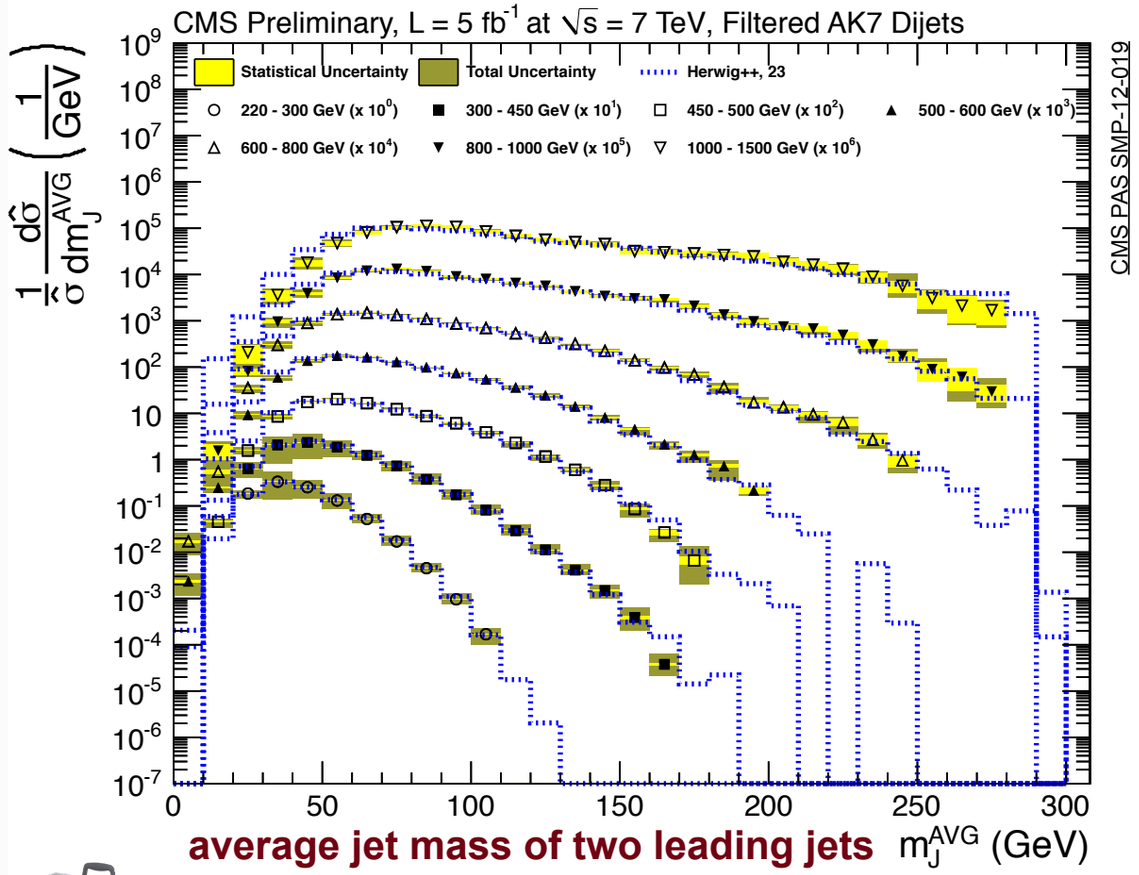
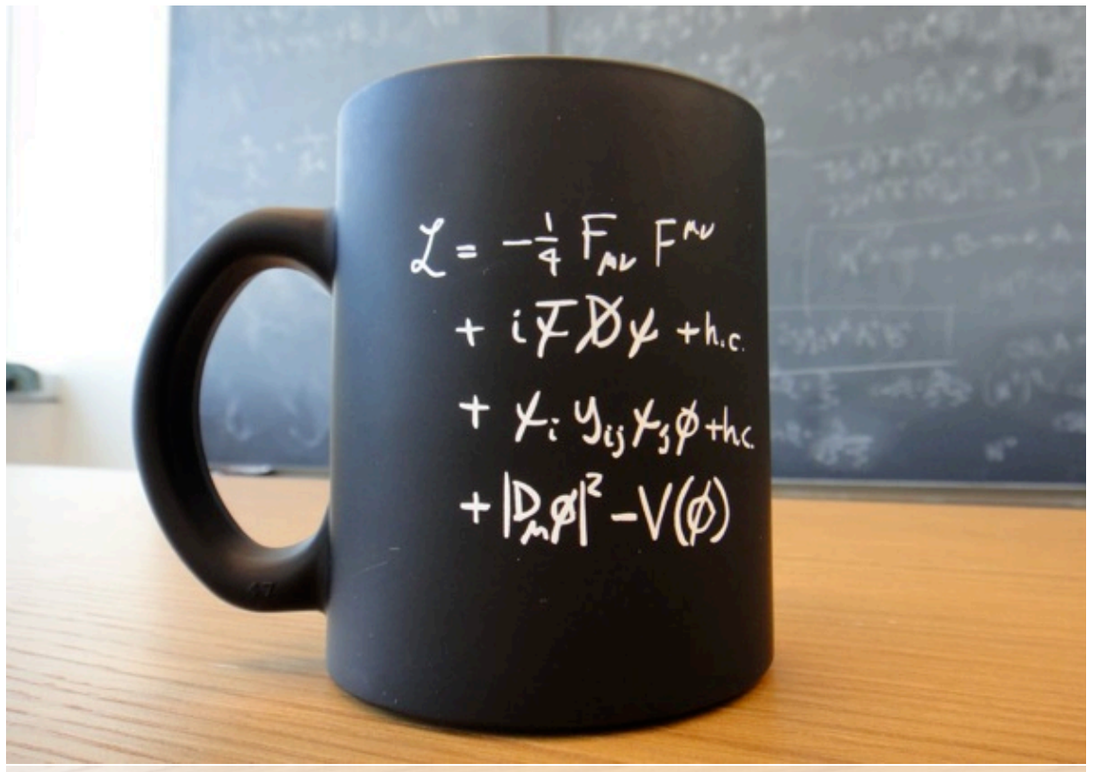
First systematic study of jet grooming techniques, in dijets and V+jet events



- Filtering, trimming and pruning tested
- for different hard scales in the event
- in general, good description by LO+PS Monte Carlos
- Herwig++ somewhat better for “aggressive” grooming
- slightly better description of V+jets (more quark jets)

- Also **new**: triple-differential γ+jet cross sections (QCD-11-005)

EWK physics



see also talk by

N. Neumeister ....

Incl. W/Z Production at 8 TeV

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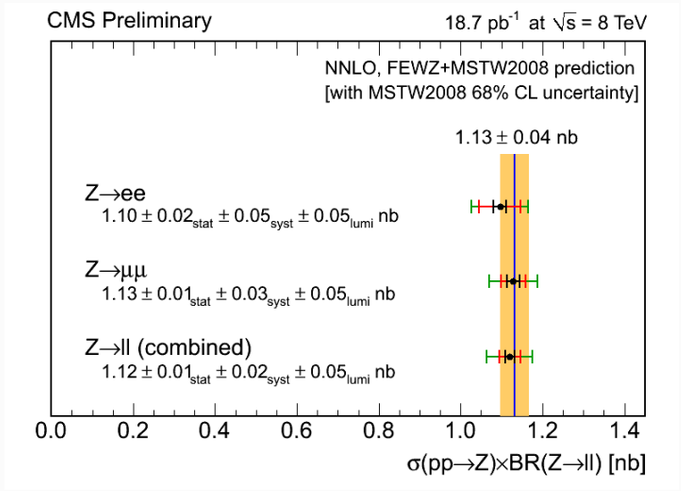
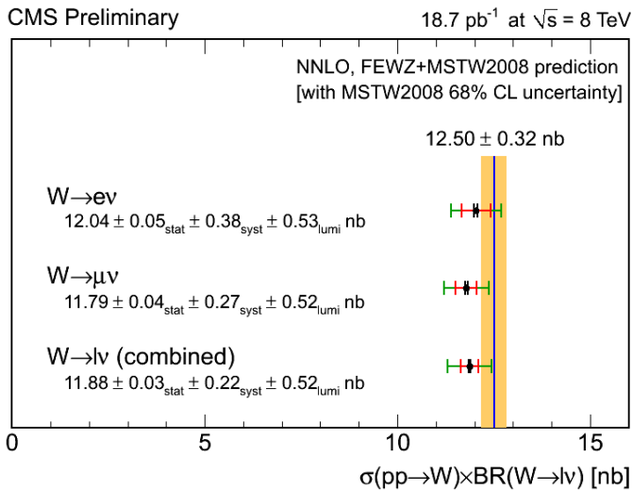
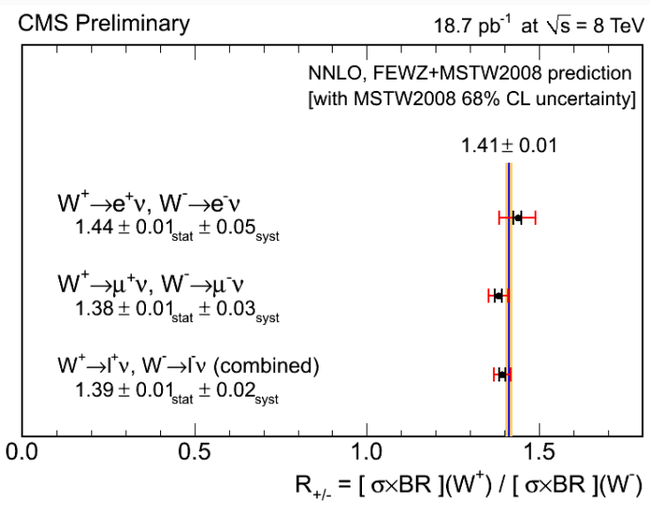
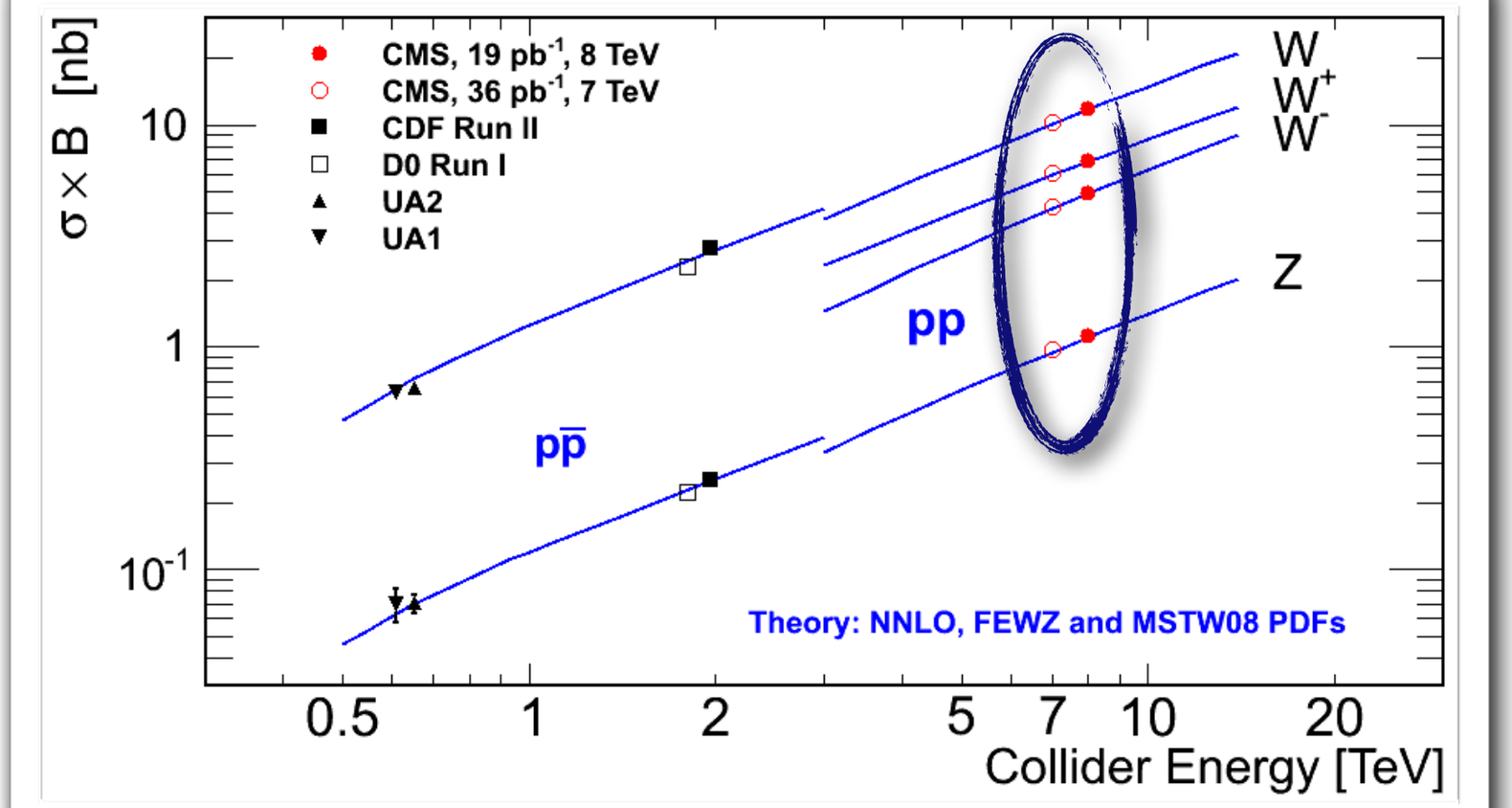




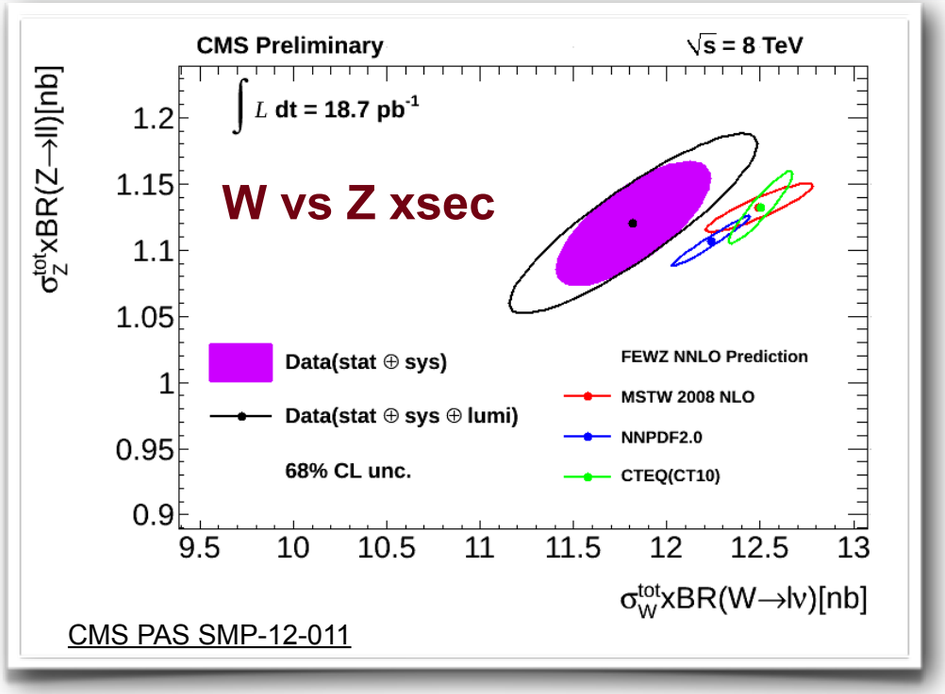


CMS PAS SMP-12-011



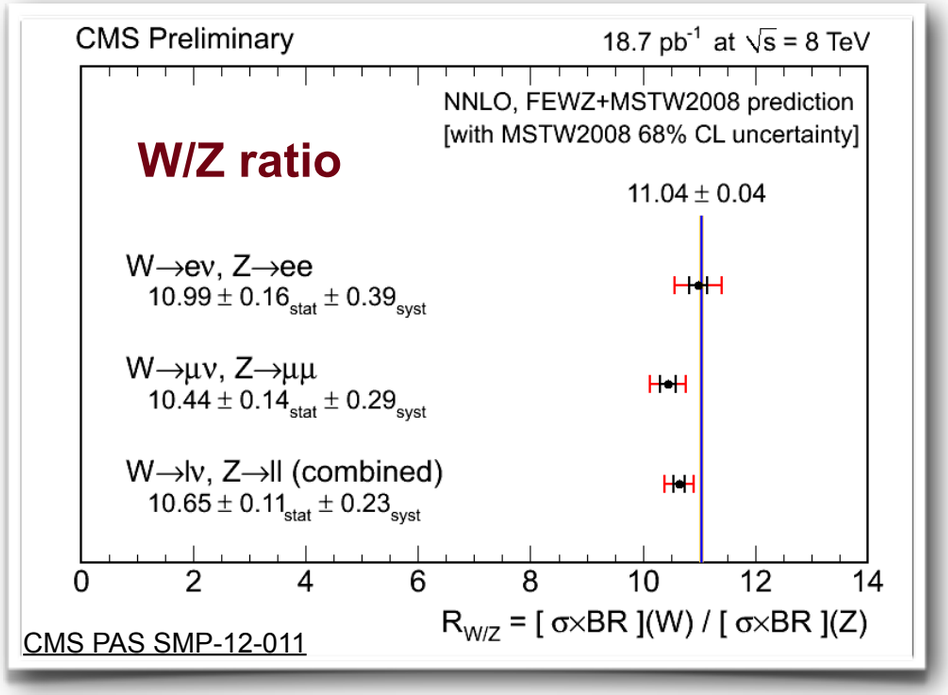
- **incl. cross sections:**
- at 7 TeV (36/pb): experimental precision had reached the **1% level**, especially for ratio-observables
- **new 8 TeV results from dedicated low-pile up run early in 2012**
- total uncert. 2-5 % (4.4 % lumi, 2-3% acceptance, 1.1-1.7% exp)
- good agreement with NNLO QCD, both at 7 and 8 TeV
- measurements about to be published, also for fiducial region only

Improving the PDF knowledge



CMS PAS SMP-12-011

- data start to put interesting constraints
- **W/Z ratio** at 8 TeV: 1.5 sigma difference with MSTW08
- MSTW08 too low for the **lepton asymmetry** at 7 TeV
- low-mass **Drell-Yan** gives interesting PDF sensitivity



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Improving the PDF knowledge

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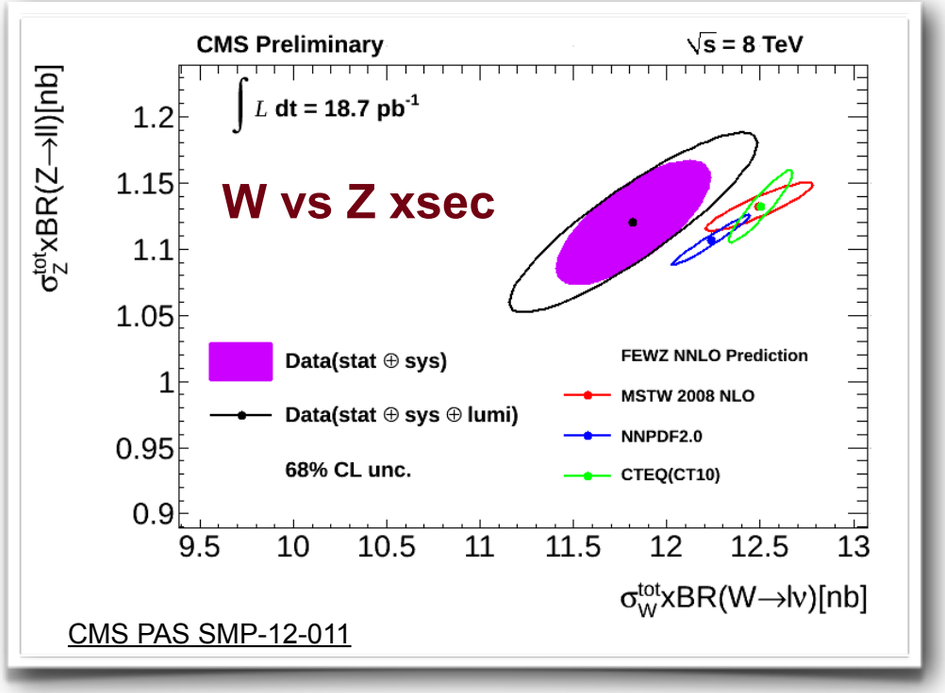

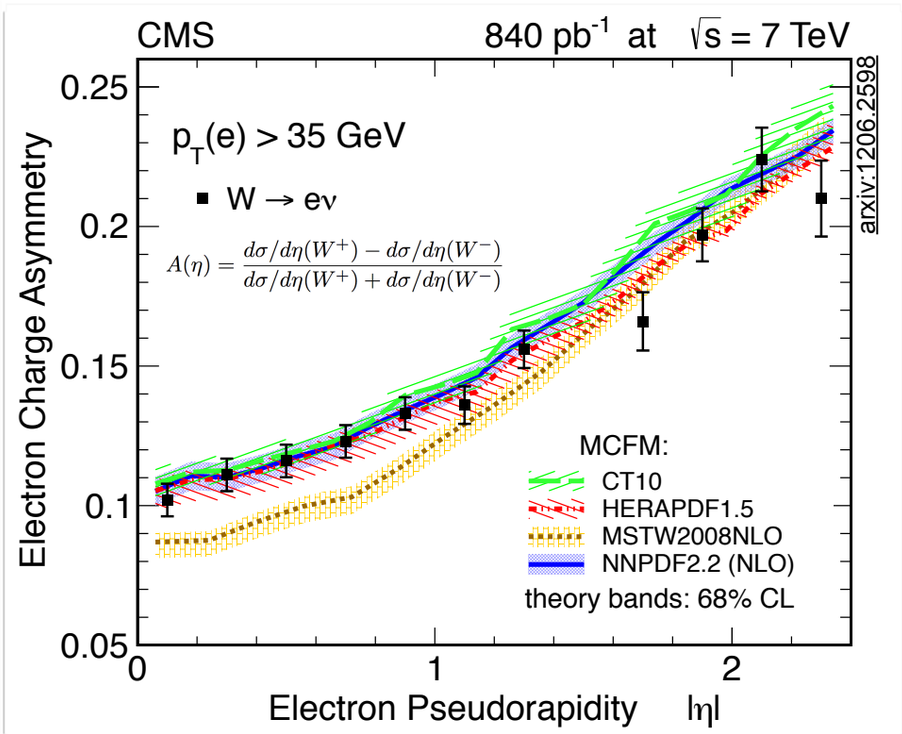

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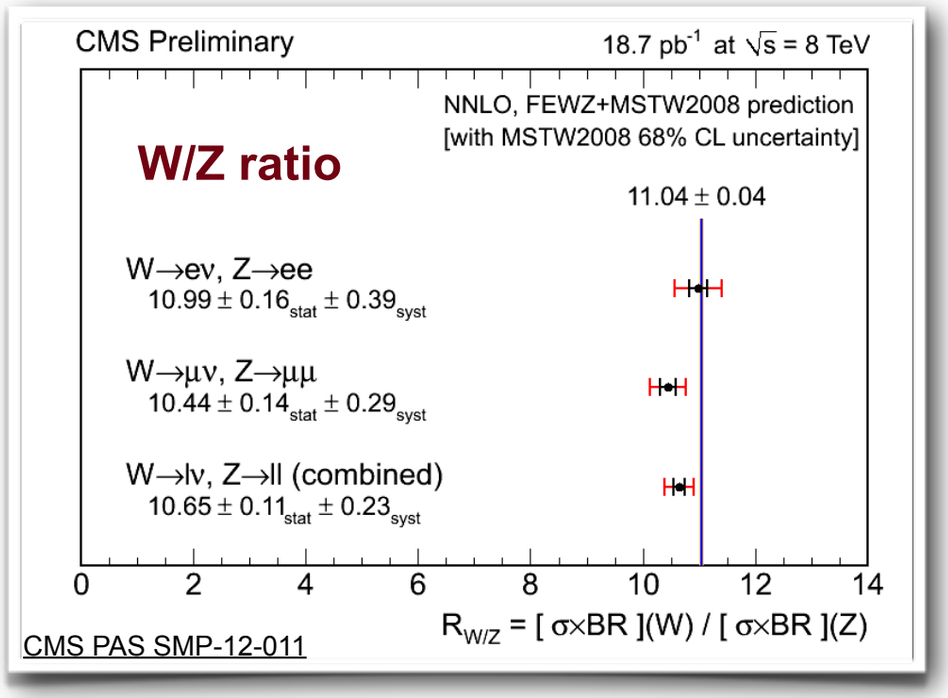

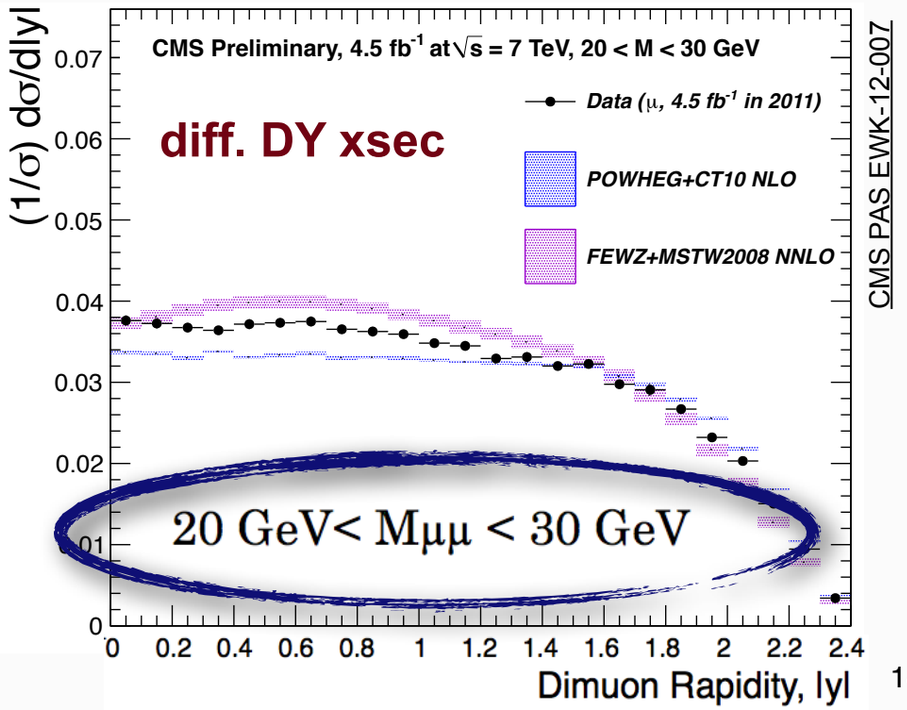

New results on Z+jet production

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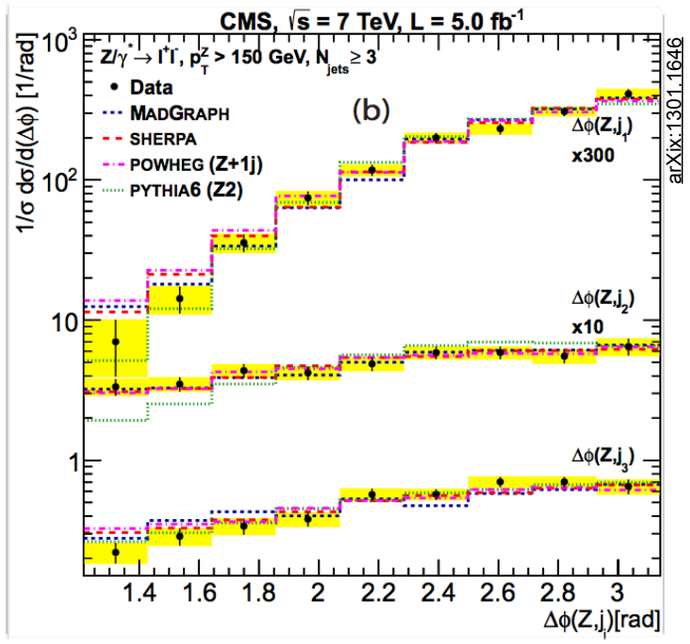

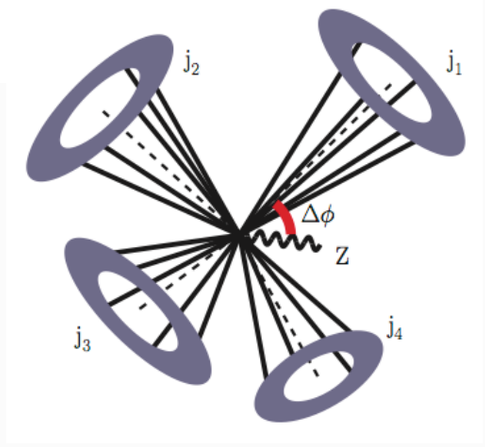

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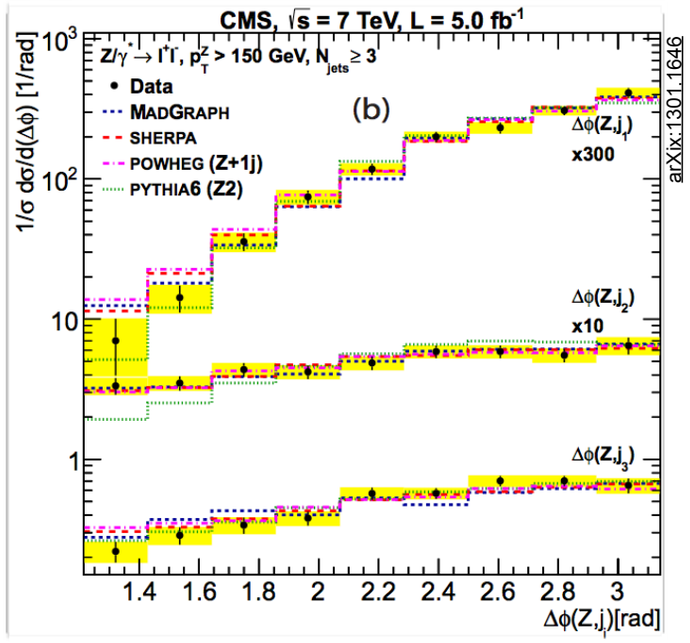

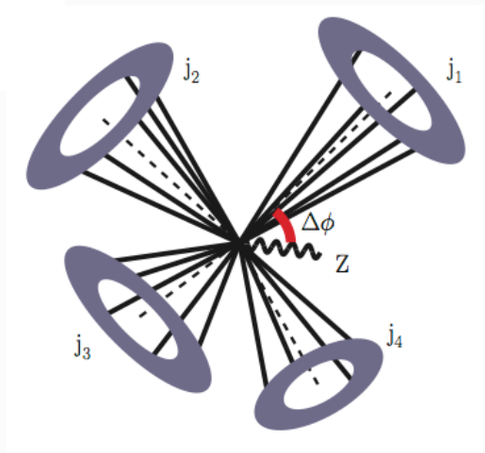

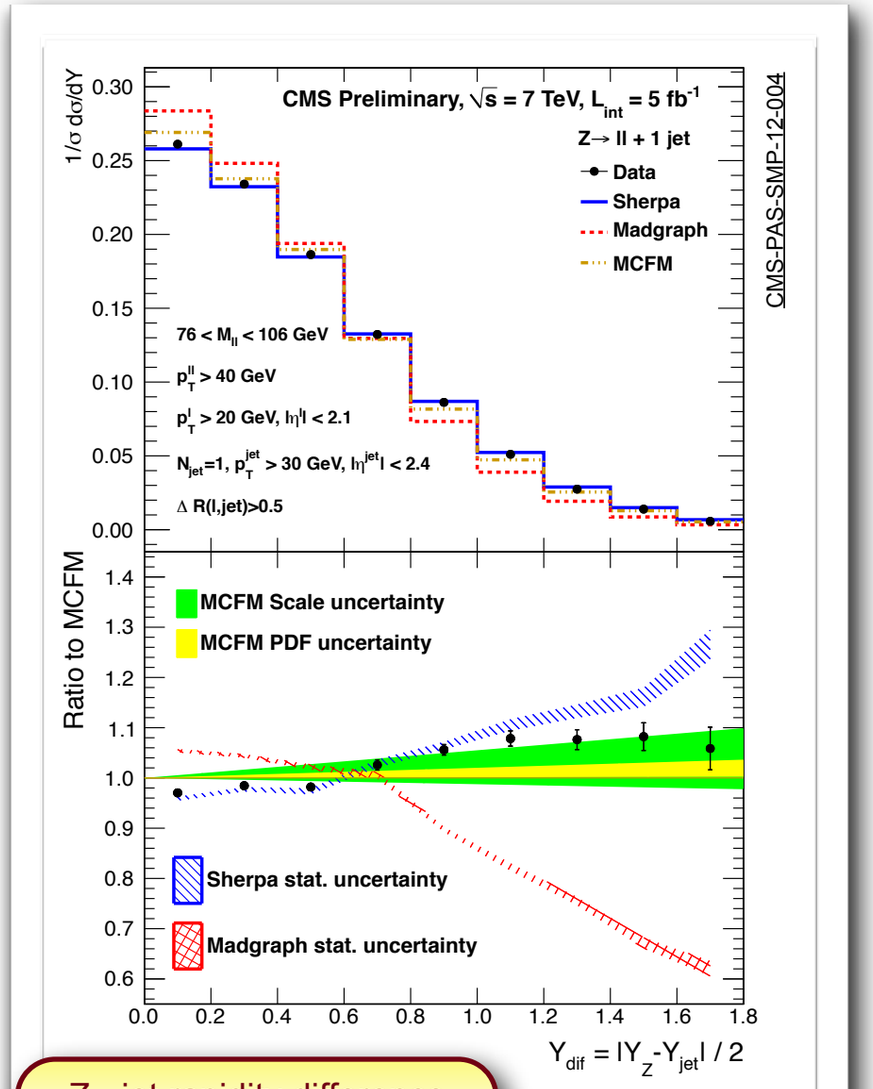

Z - jet rapidity difference

- **V+jets:** see also N. Neumeister's talk
  - after jet rates, now also probing further the phase space:
  - angular correlations (incl. and for large Z p_T), rapidity distributions
- **V+heavy flavours**: Z+b(b), W+bb, W+c : see N. Neumeister's talk

New results on Z+jet production

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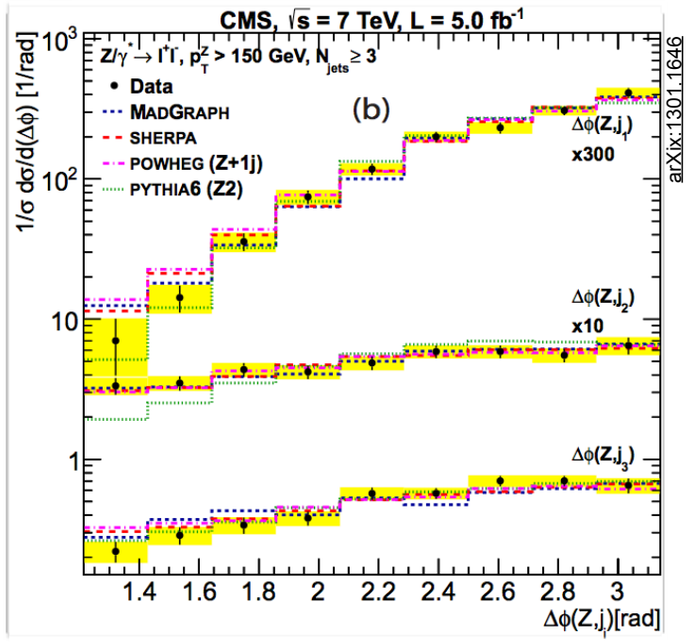
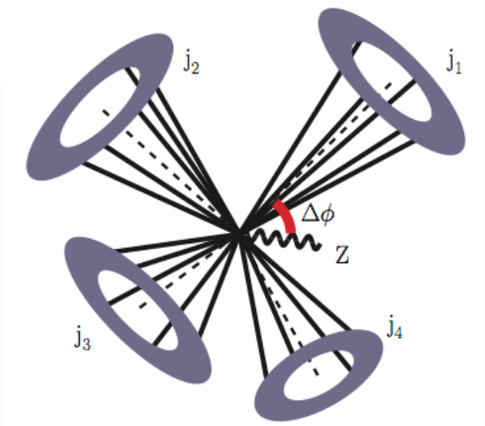
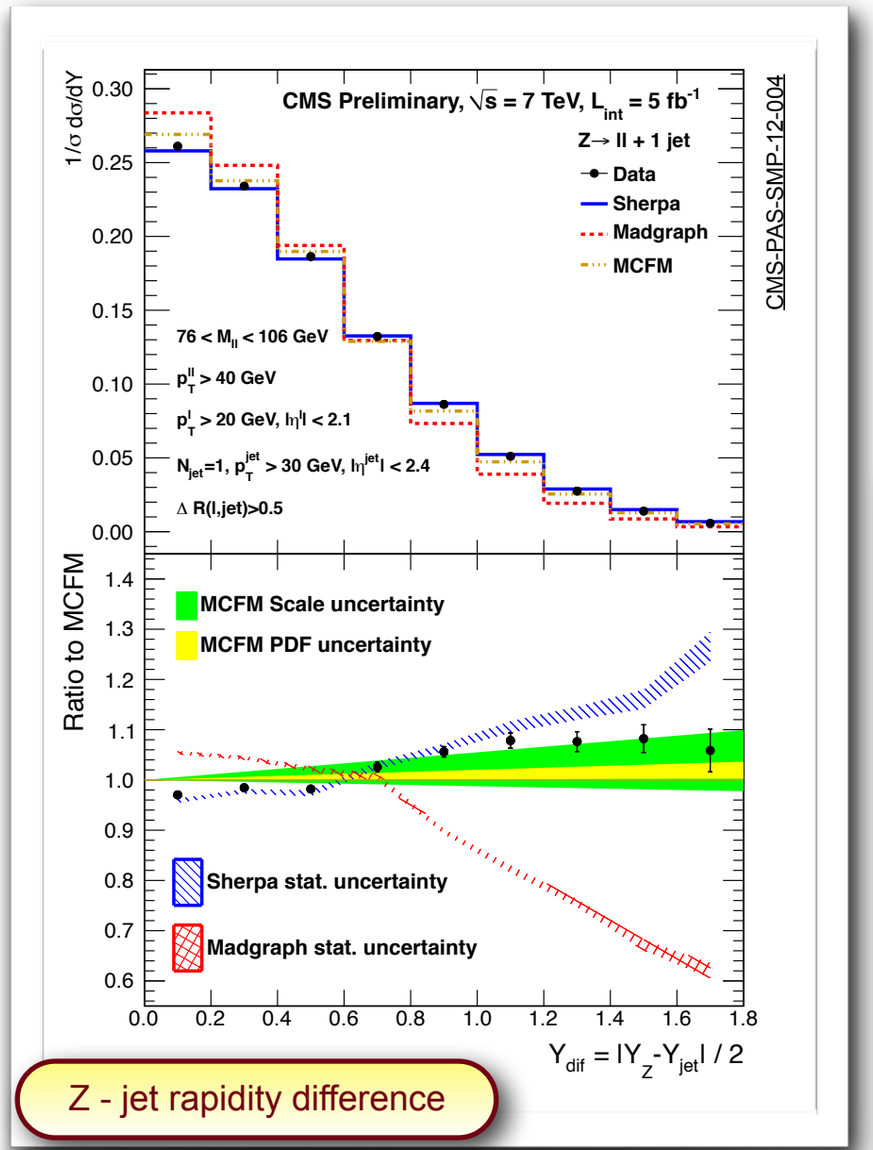
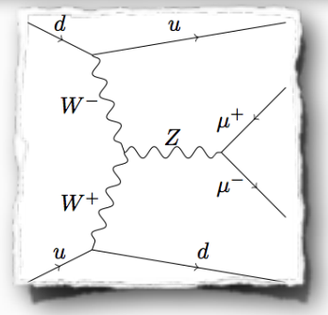


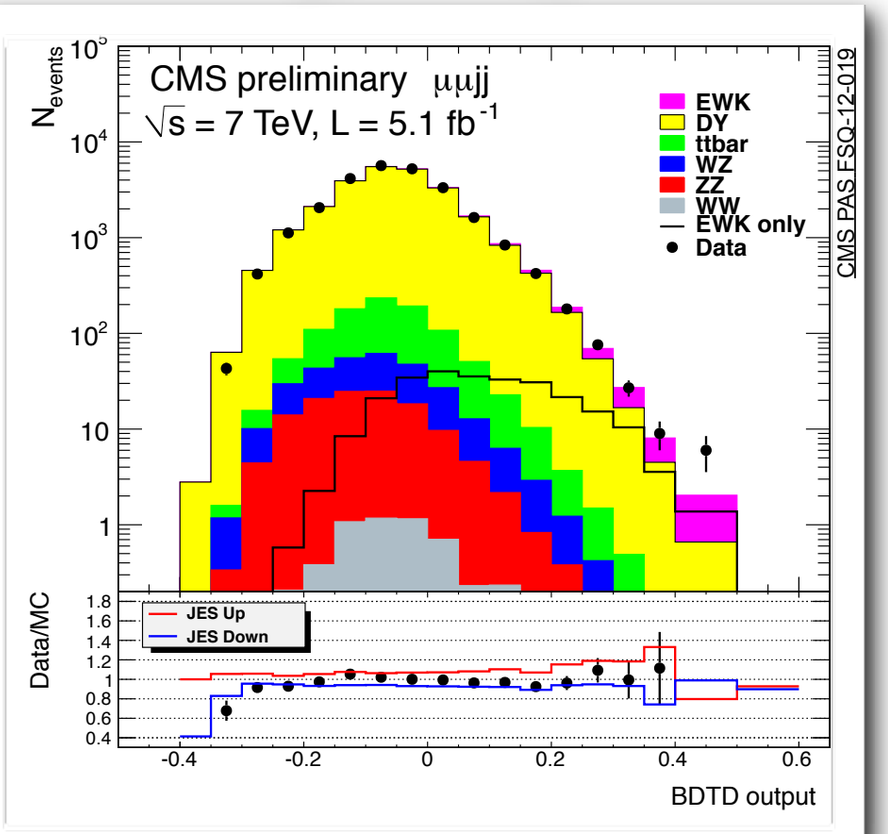




Z - jet rapidity difference

first evidence (~3 sigma) for electroweak Z+jets production





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- measured cross section in agreement with NLO prediction

Di-Boson production

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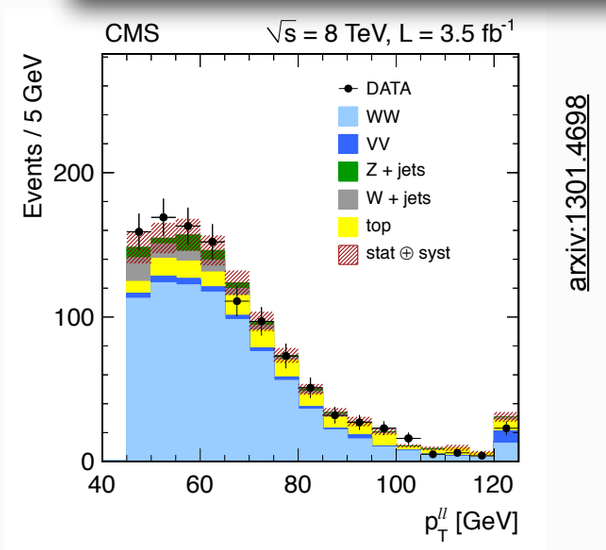
Duric, La Thuile 2013	*Int. luminosity*		*Cross section measurement phase space*	
	@ 7TeV	*@ 8TeV*		
ZZ→2l2l' (l = e/μ;l' = e/μ/τ)	5.0 fb^{-1}	5.3 fb^{-1}	60<M($Z_{1,2}$)<120 GeV	pp→ZZ
Wγ→lνγ	5.0 fb^{-1}	-	E_T^{γ}>15/60/90 GeV & ΔR(l,γ)>0.7	pp→Wγ→lνγ
Zγ→llγ	5.0 fb^{-1}	-	E_T^{γ}>15/60/90GeV & ΔR(l,γ)>0.7 & M^{ll}>50GeV	pp→Zγ→llγ
Zγ→ννγ	5.0 fb^{-1}	-	E_T^{γ}>145 GeV & $\|\eta^{\gamma}\|$<1.4	pp→Zγ→ννγ
W^+W^-→lνlν	4.9 fb^{-1}	3.5 fb^{-1}	full	pp→W^+W^-
W^+W^-+WZ→lνjj	5.0 fb^{-1}	-	full	pp→WW+WZ
WZ→lνll	1.0 fb^{-1}	-	full	pp→WZ
Exclusive γγ→W^+W^-	5.0 fb^{-1}	-	full P_T(μ,e)>20GeV & |η(μ,e)|<2.4 & P_T(μe)>100GeV	pp→$p^{(*)}W^+W^-p^{(*)}$ →$p^{(*)}$eμ$p^{(*)}$

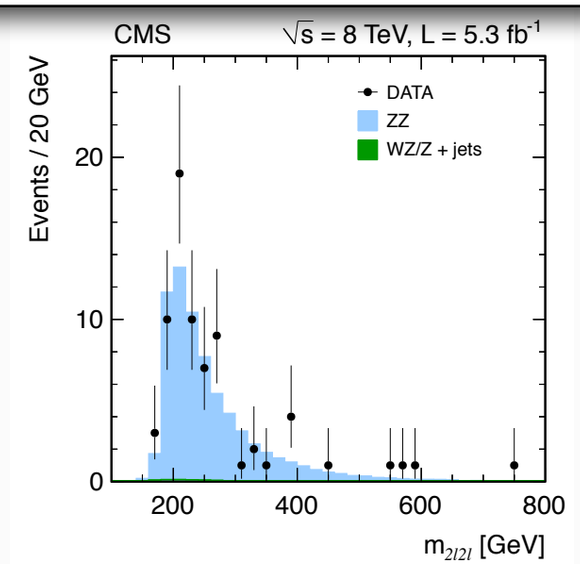
new 8 TeV results:

$$\sigma(pp \to ZZ) = 8.4 \pm 1.0\,(stat.) \pm 0.7\,(syst.) \pm 0.4\,(lum.)\,pb$$

MCFM+MSTW, NLO: $7.7 \pm 0.4\,pb$



arxiv:1301.4698



$$\sigma(pp \to W^+W^-) = 69.9 \pm 2.8\,(stat.) \pm 5.6\,(syst.) \pm 3.1\,(lum.)\,pb$$

MCFM+MSTW, NLO: $57.3^{+2.4}_{-1.6}\,pb$

- **WW** consistently above NLO pred. (by 10-20%)

Di-Boson production

ETH Institute for Particle Physics

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W^+W^-→lνlν	**4.9 fb^{-1}**	**3.5 fb^{-1}**	full	pp→W^+W^-
W^+W^-+WZ→lνjj	**5.0 fb^{-1}**	-	full	pp→WW+WZ
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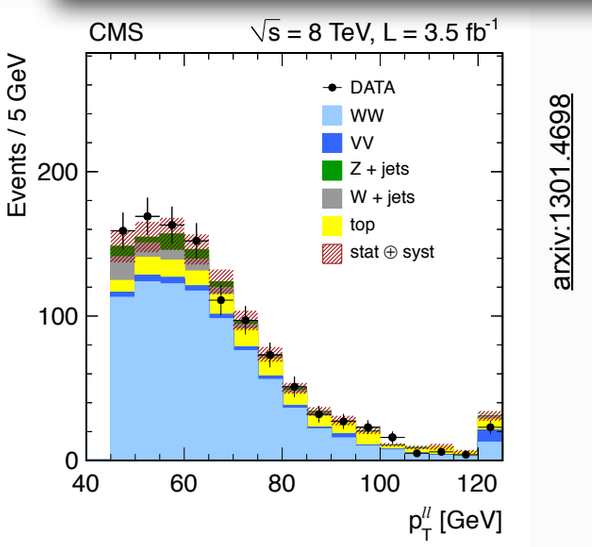

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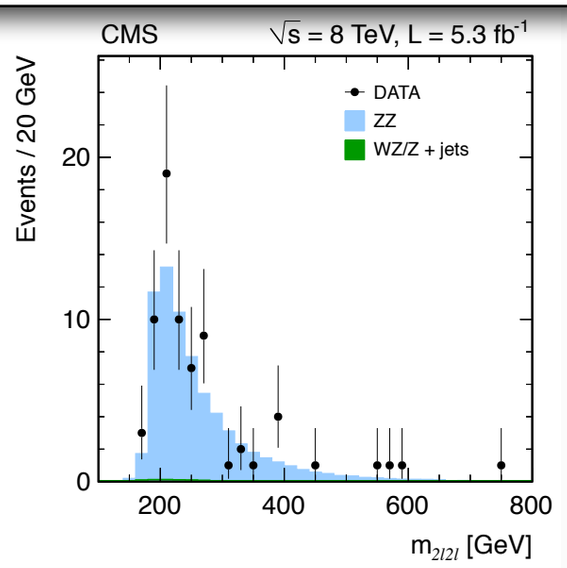
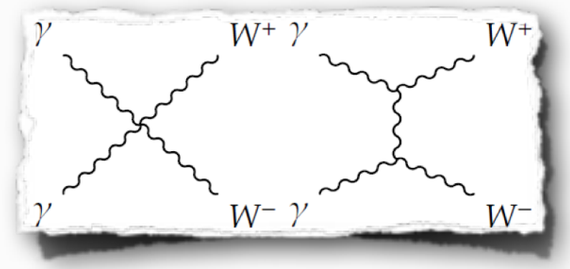
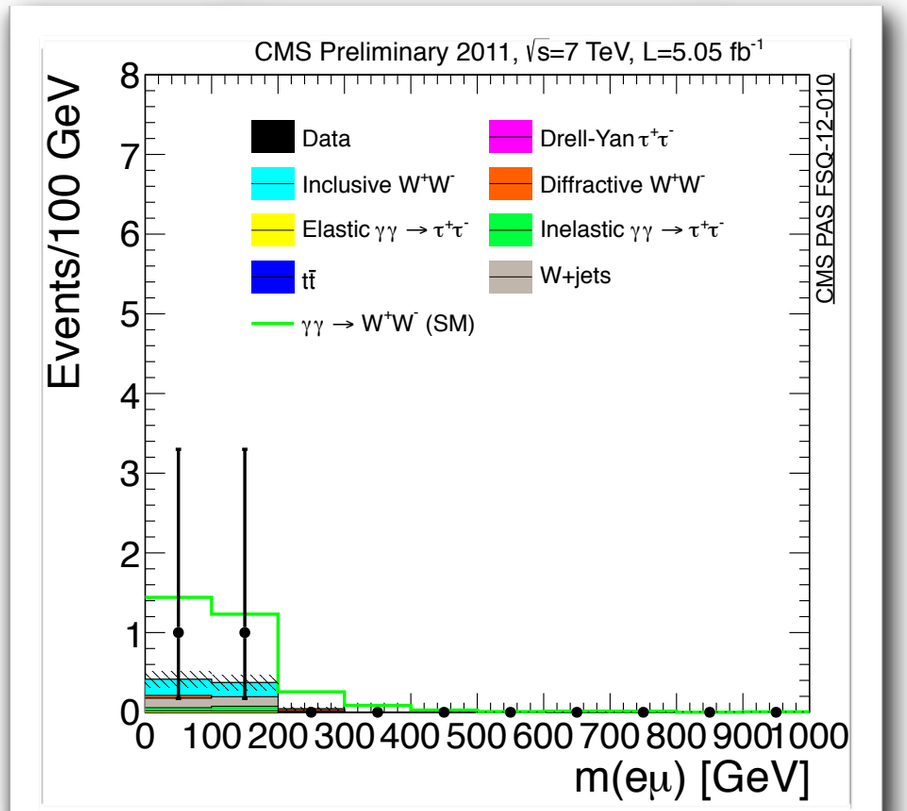


$$\sigma(pp \to W^+W^-) = 69.9 \pm 2.8\,(stat.) \pm 5.6\,(syst.) \pm 3.1\,(lum.)\ pb$$

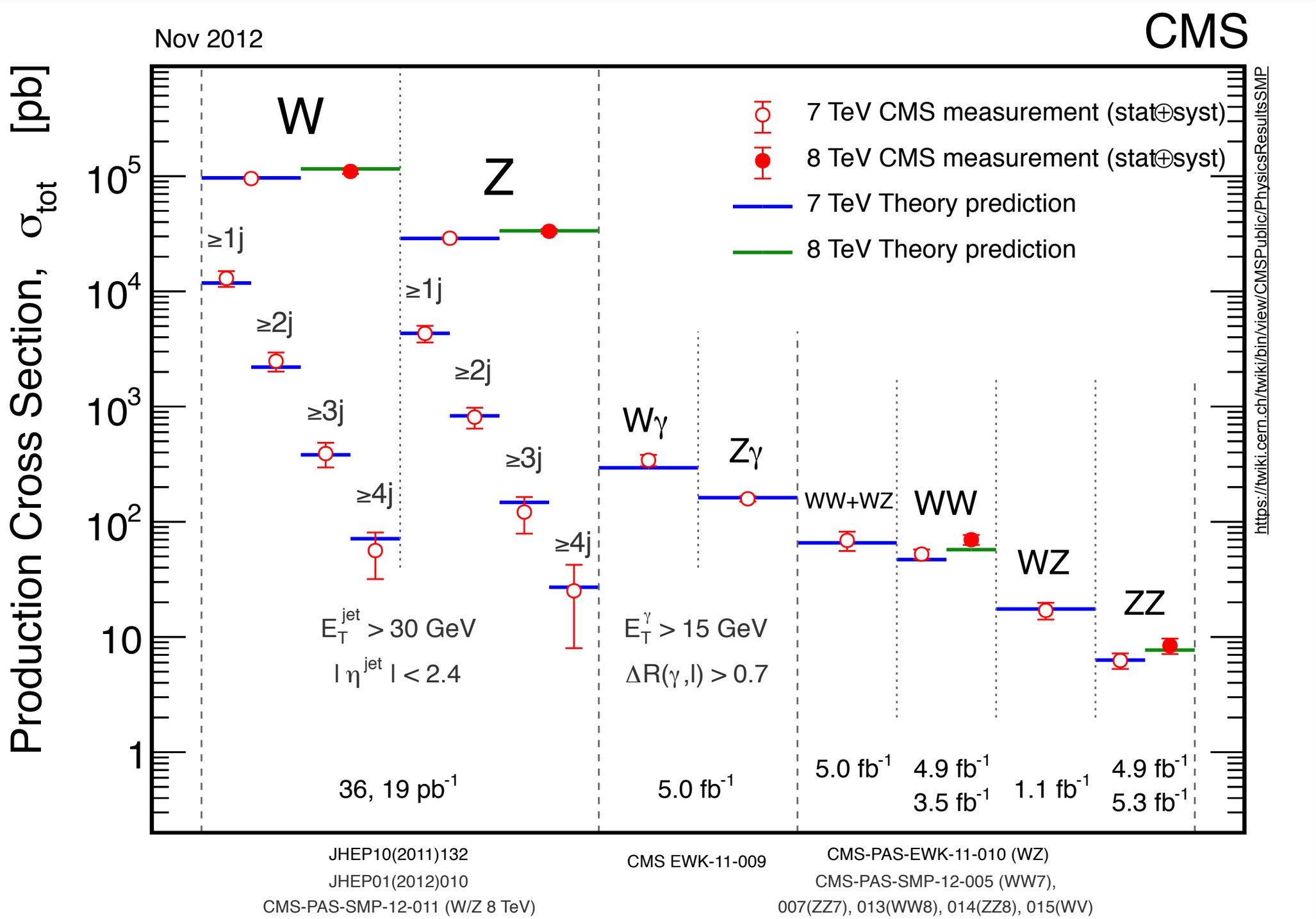
MCFM+MSTW, NLO: $57.3\,^{+2.4}_{-1.6}\,pb$





- **WW** consistently above NLO pred. (by 10-20%)
- **excl. WW production**: first upper limit on xsec, interesting limits on QGC, sensitivity exceeding LEP

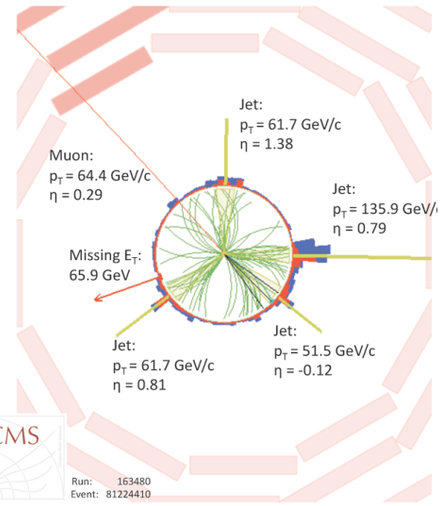
The big picture

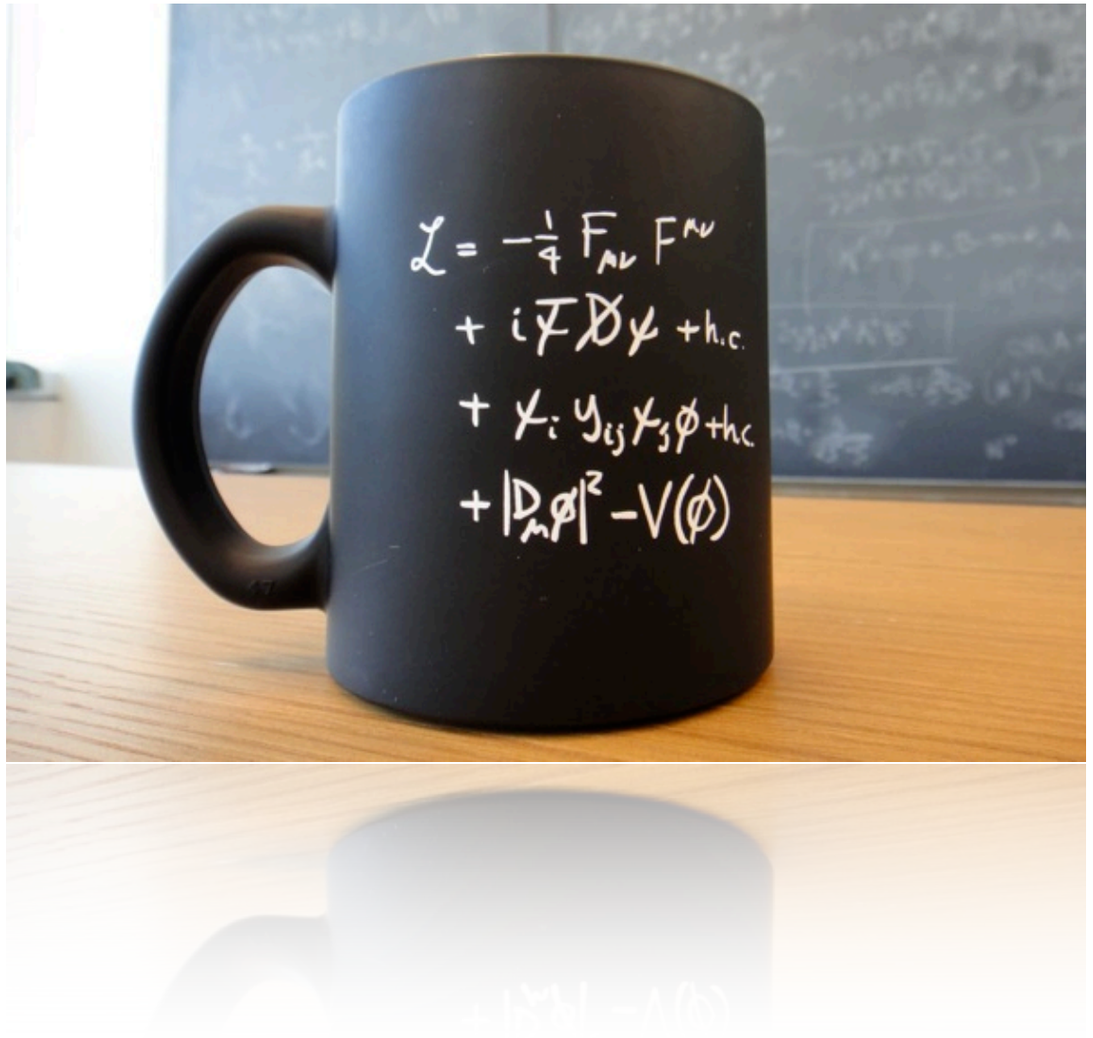


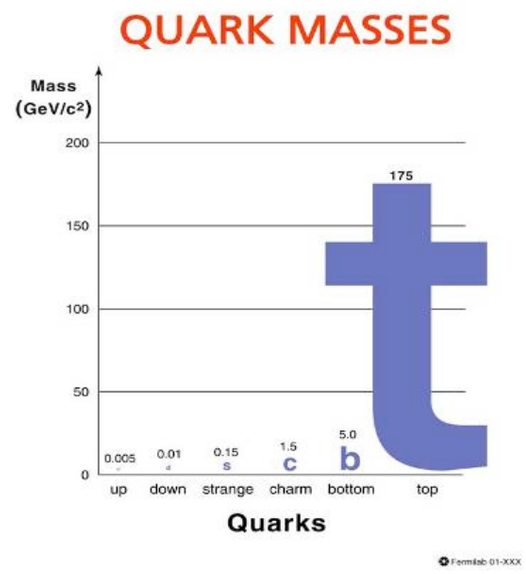
overall, the SM works at 7 and 8 TeV centre-of-mass energy...

the top

some recent highlights







TOP pair prod. @ 7 and 8 TeV

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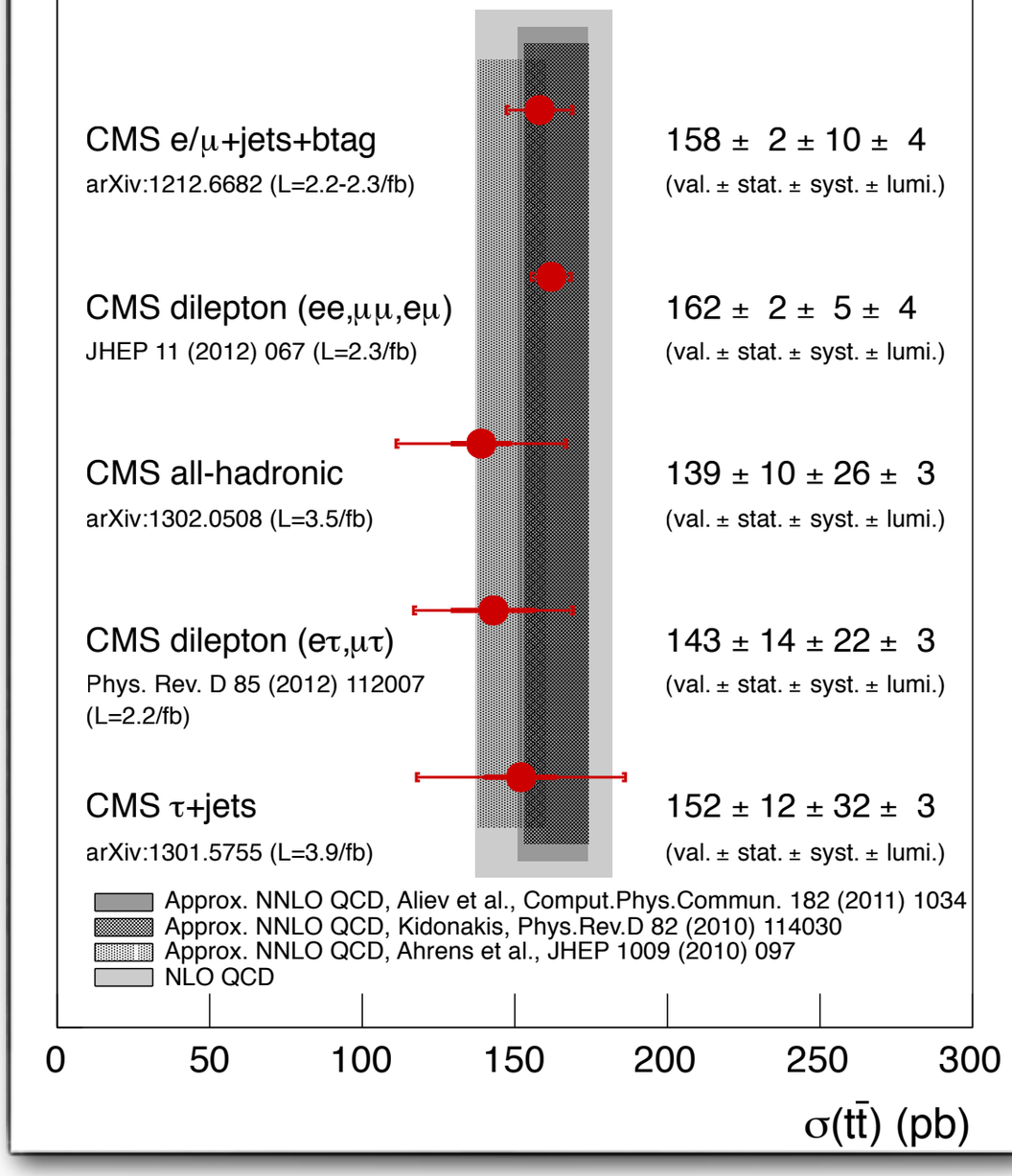

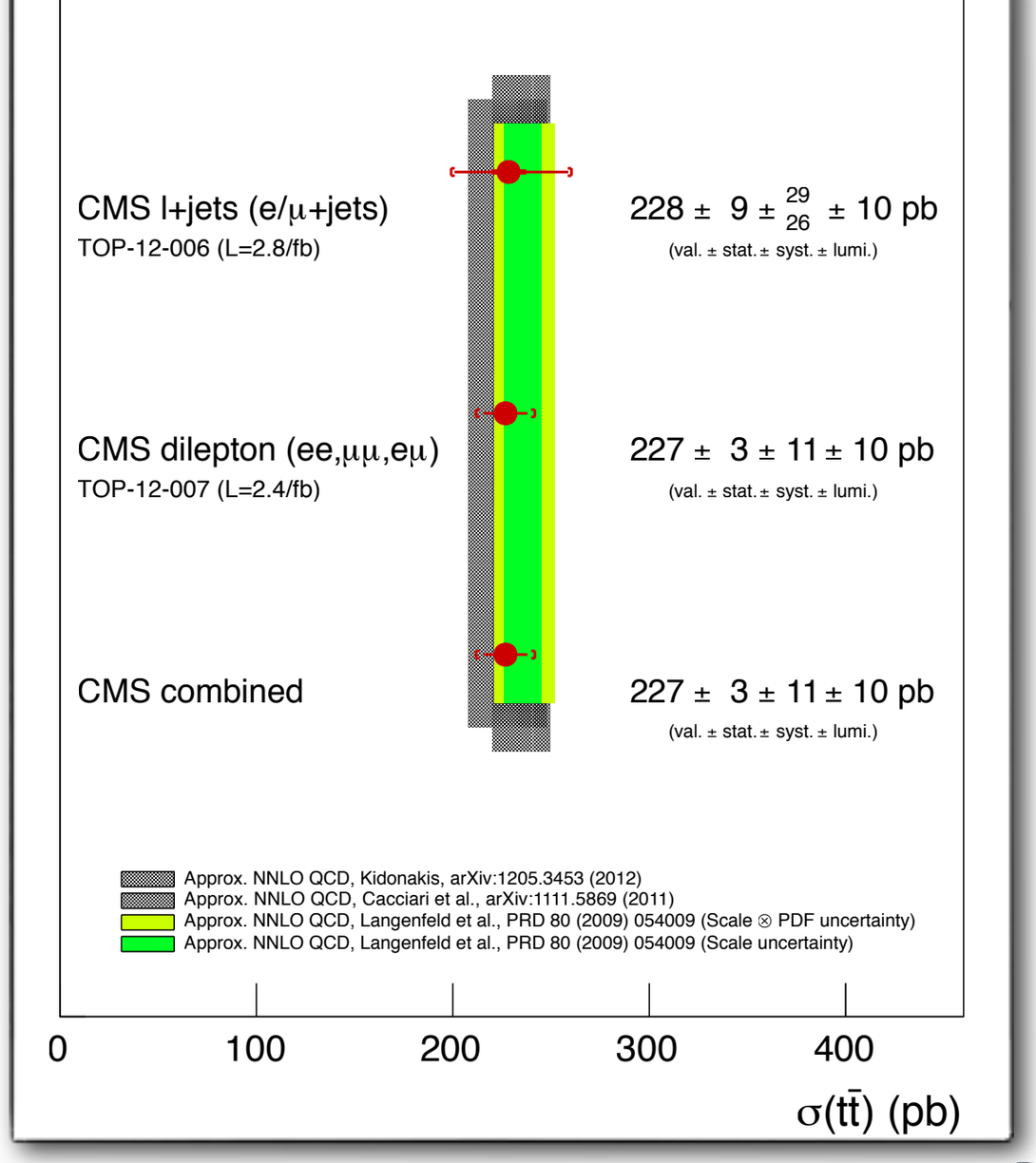

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOPSummaryPlots

- **Consistency across all channels, experimental uncertainty < 5% - 15 % !**
- similar to theoretical uncertainty (scales + PDF), compatible with approx. NNLO predictions
- significant theoretical improvement (full NNLO) very recently, then making top production a gluon pdf tester?

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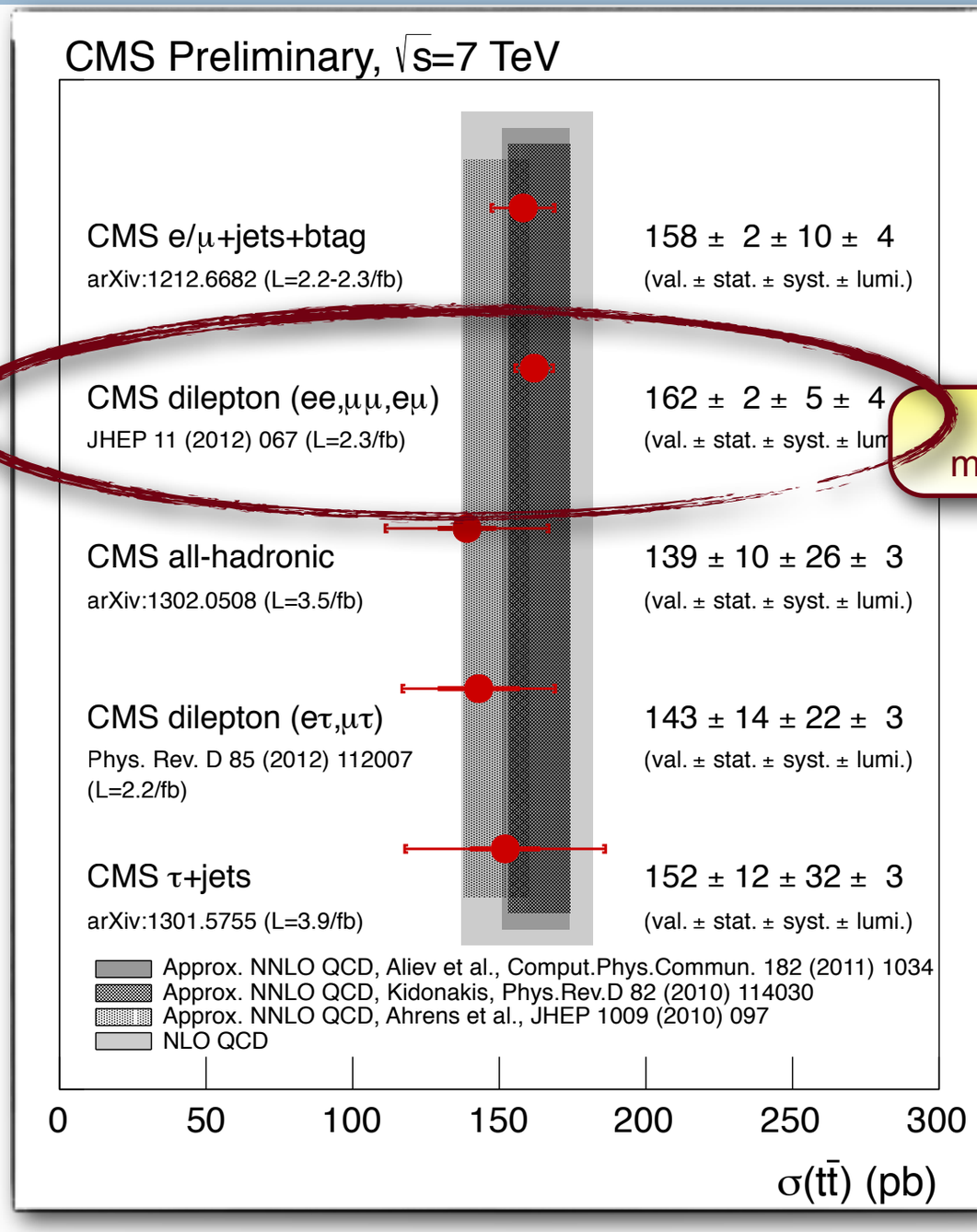
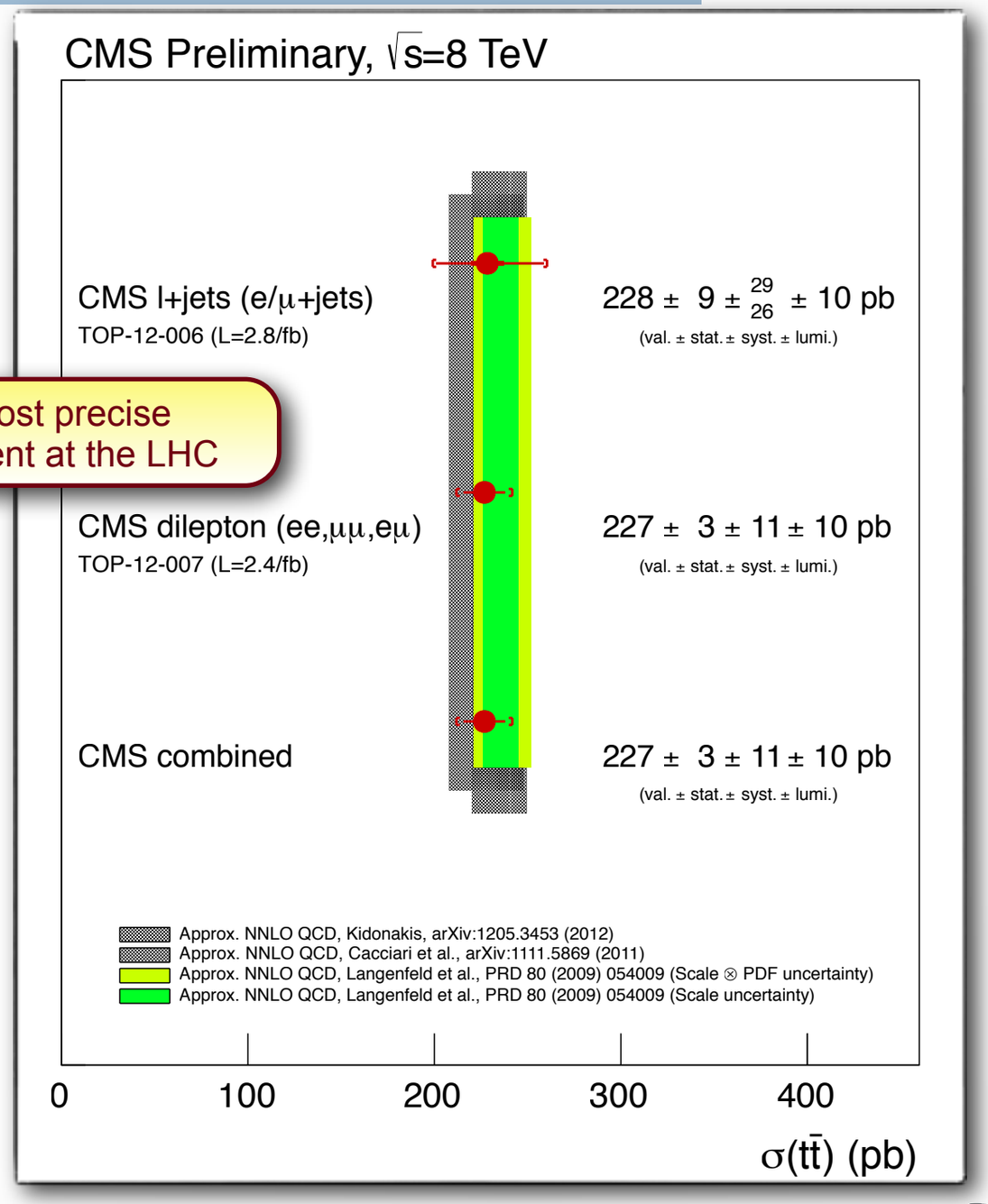


single most precise measurement at the LHC



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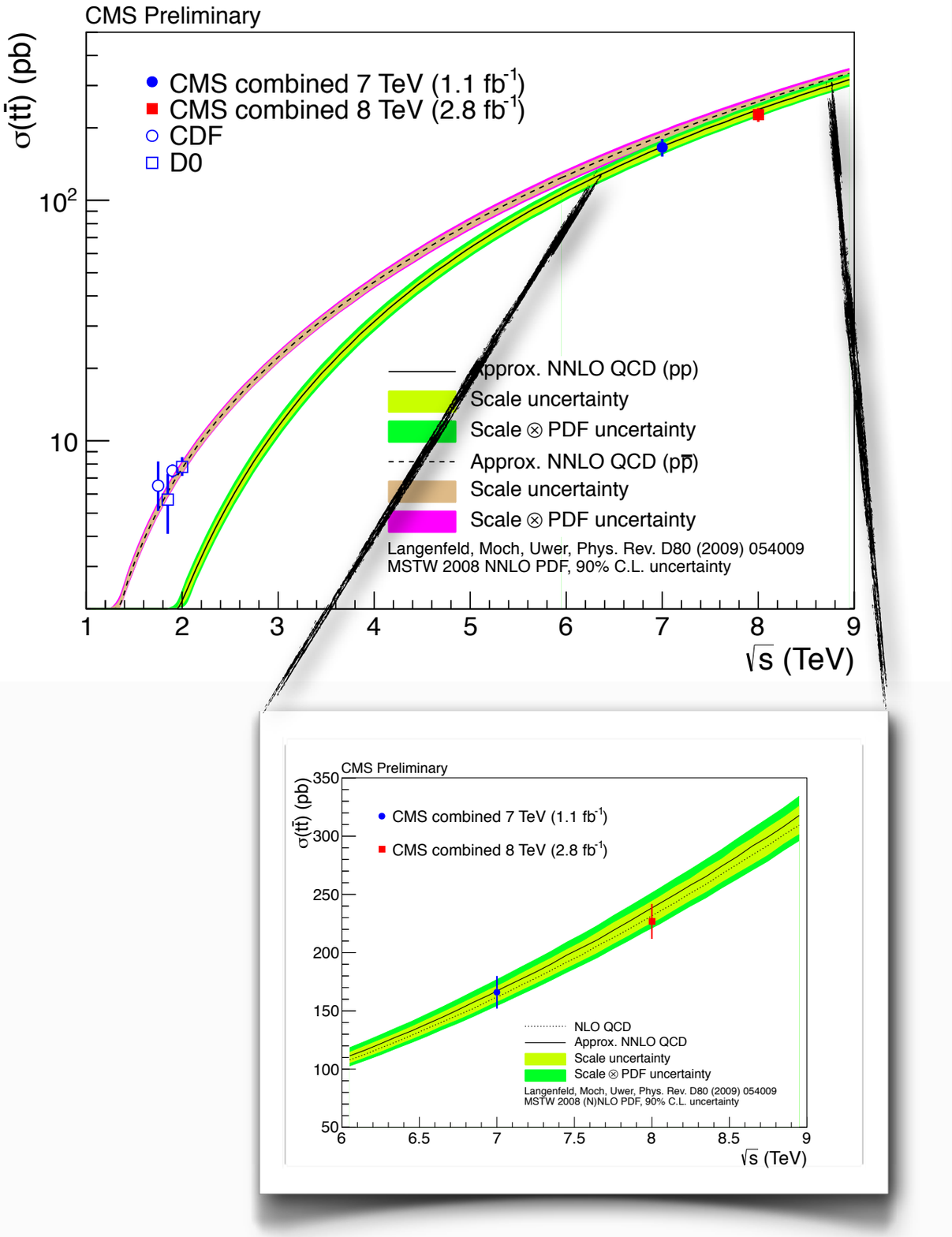

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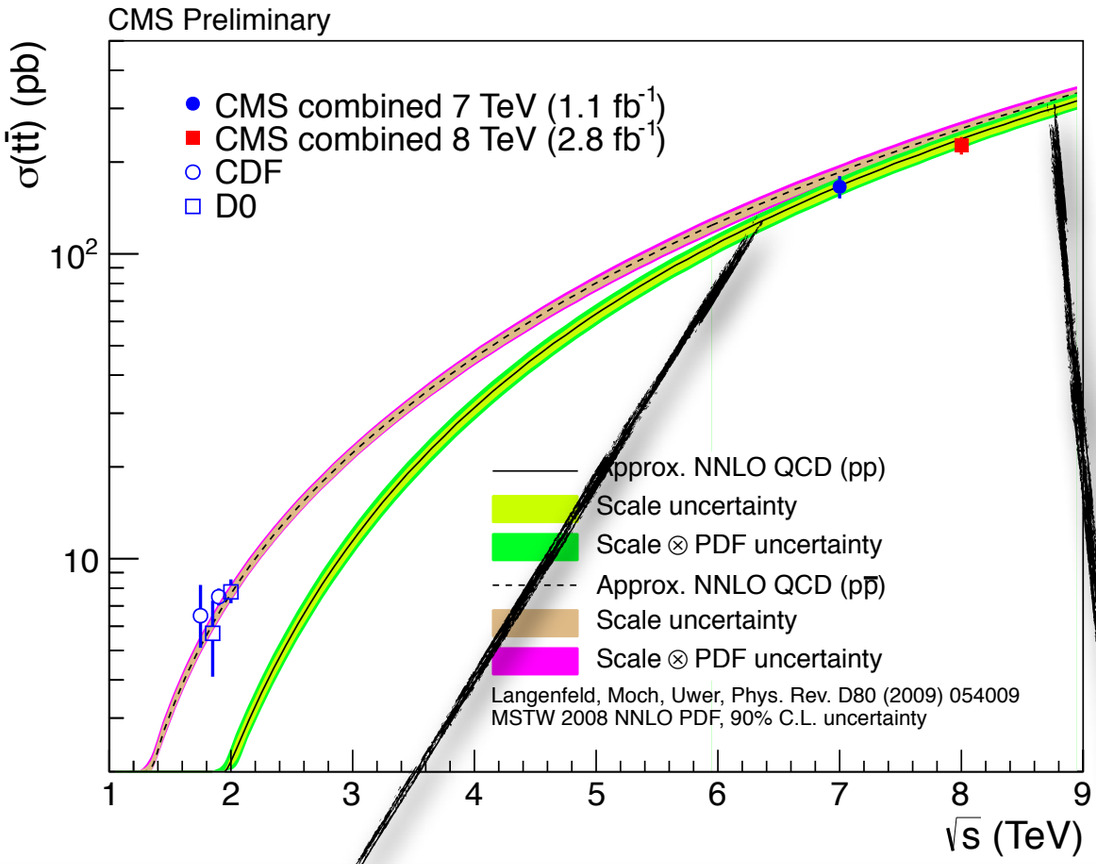

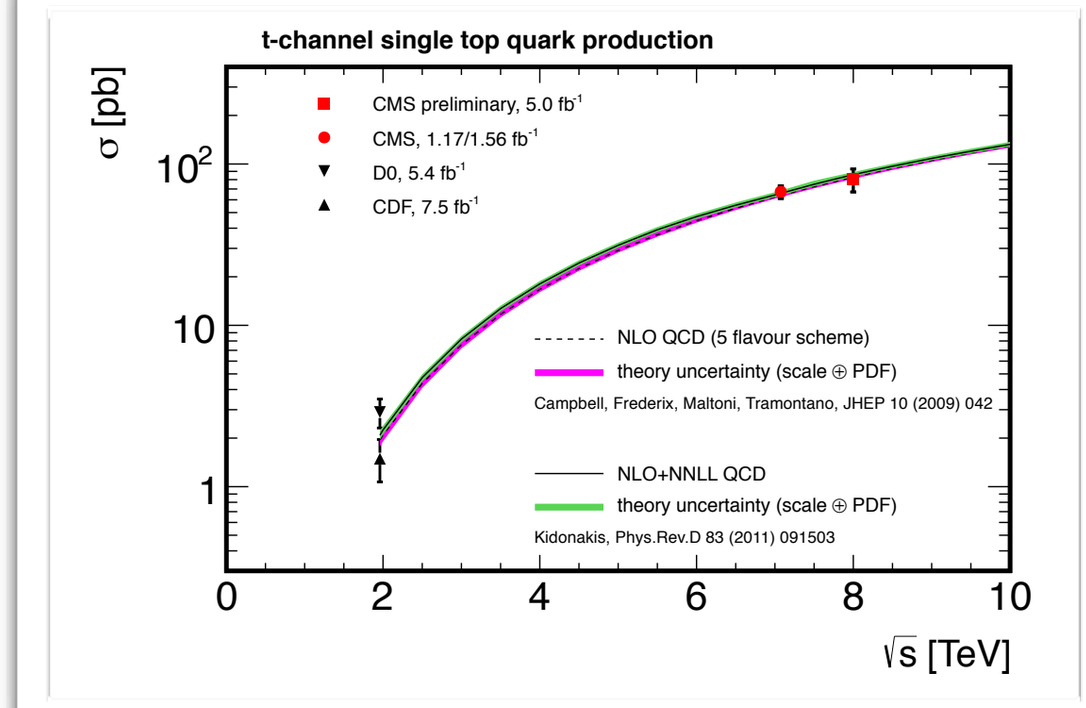

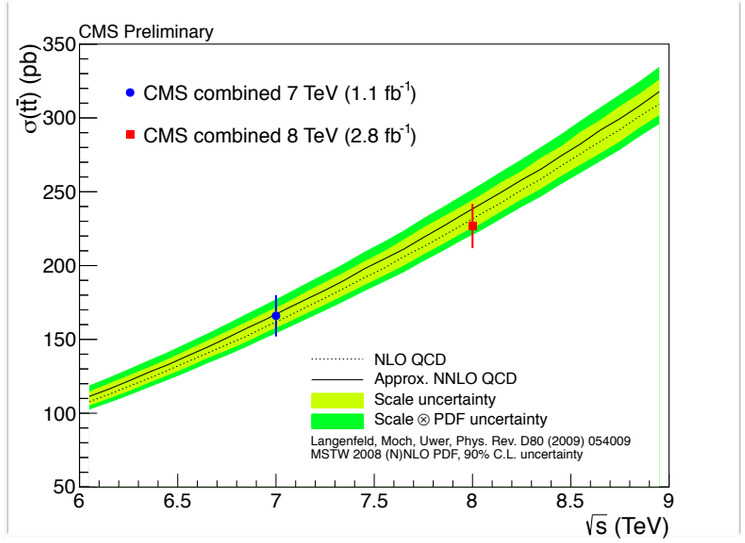

- **Top pair prod:**
  - evolution 7 to 8 TeV as expected
  - uncertainties at 8 TeV 7 - 13 % so far
- **Singe Top prod:**
  - new measurement of t-channel prod. at 8 TeV (16% uncert)
  - also : ratio t vs anti-top production tested
    - see CMS PAS TOP-12-011 and CMS PAS TOP-12-038

Probing the TOP: going differential

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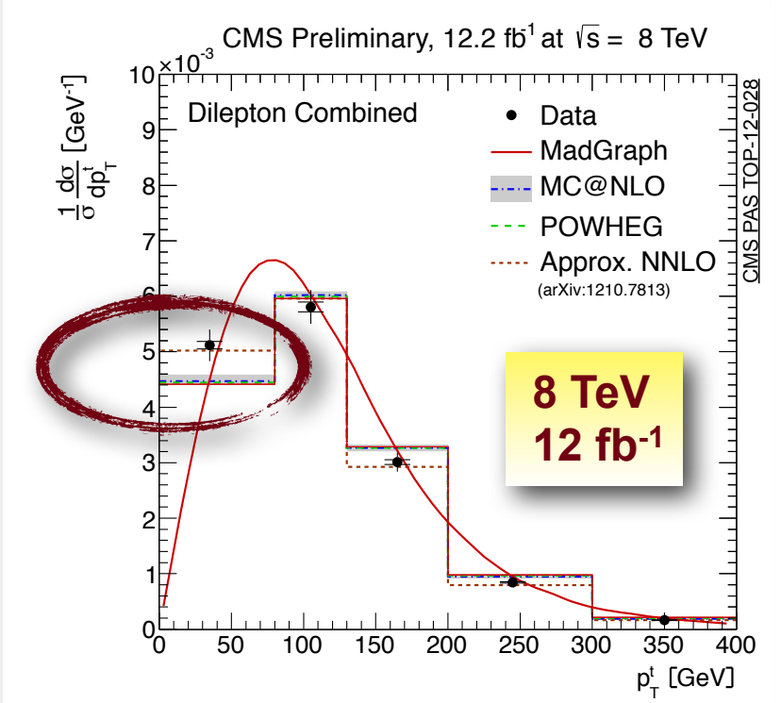
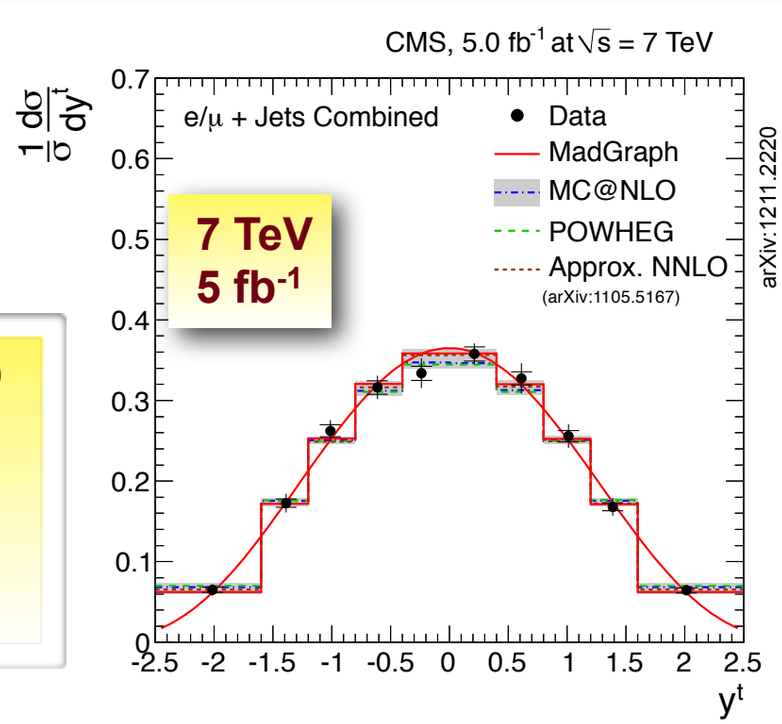


differential cross sections: top p_T and rapidity

- unfolded results (dilepton, lepton+jets channels)
- kinematic properties (p_T, y, m) of leading (and sub-leading) leptons, lepton pair, b-jets, top quarks, top quark pairs
- good description by MCs and approx. NNLO



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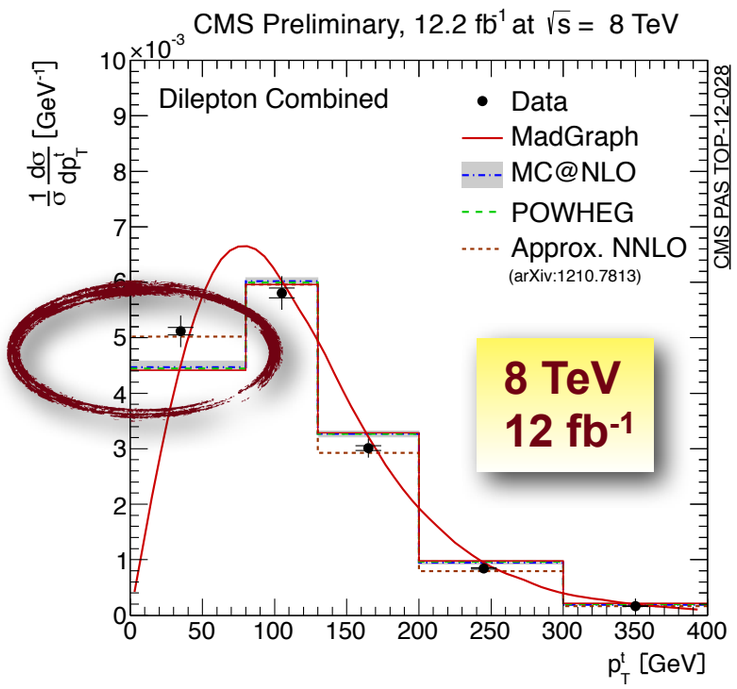

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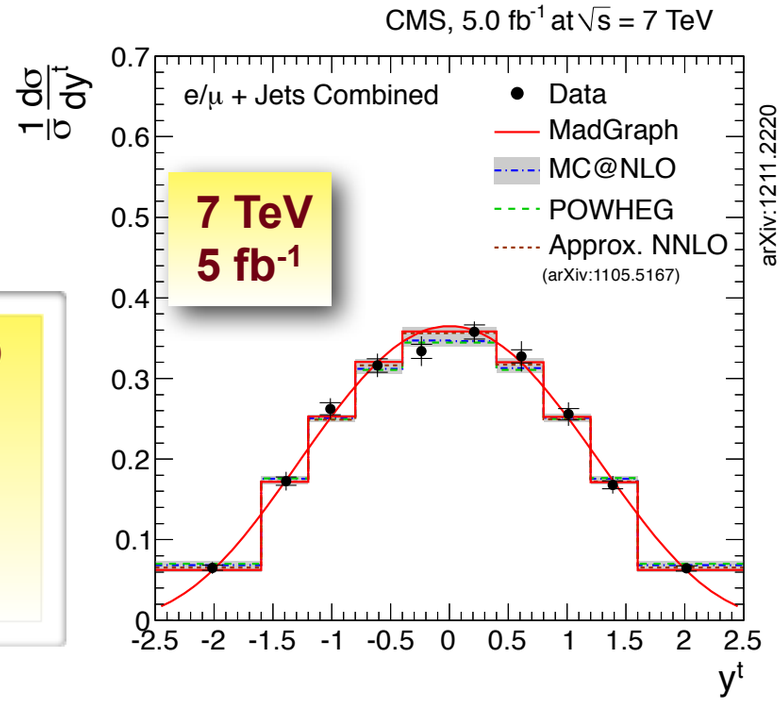
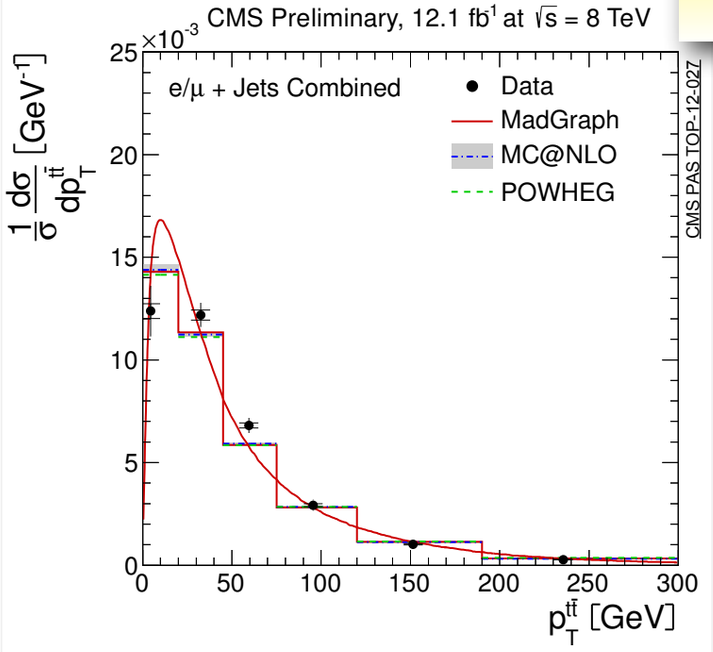
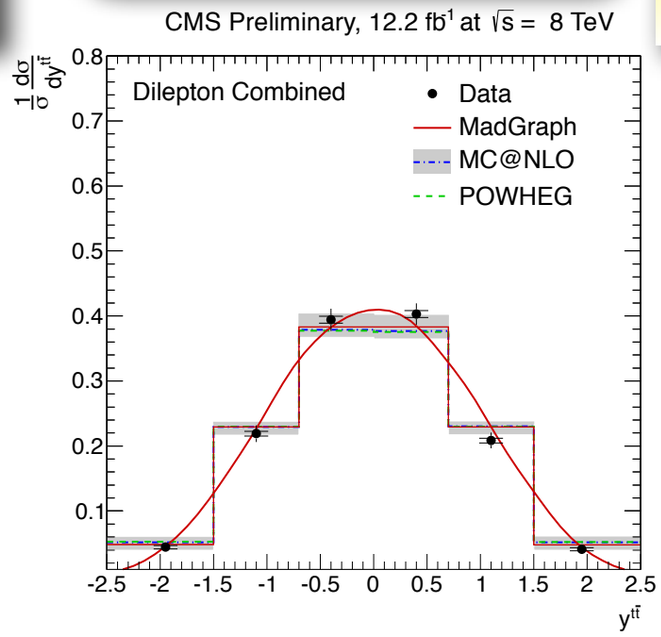


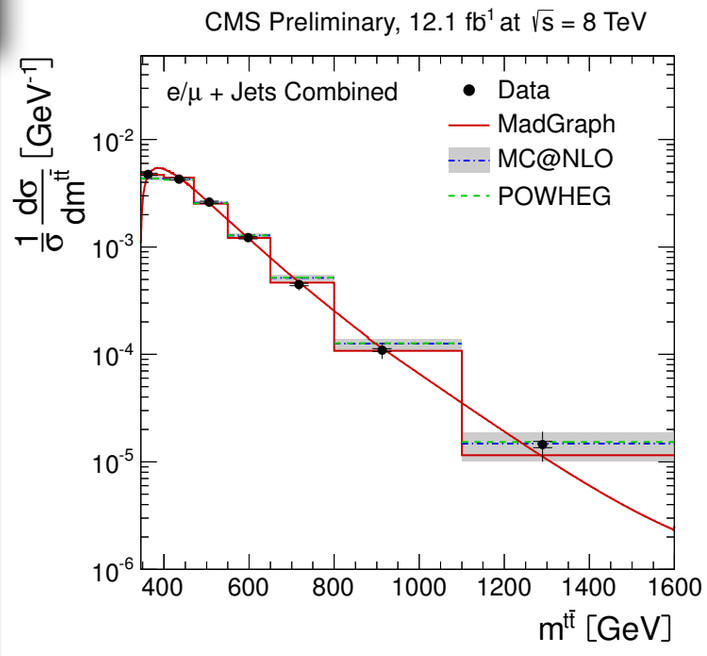
differential cross sections: top-pair system

8 TeV 12 fb-1



8 TeV 12 fb-1





Probing the TOP: top + X (@ 7 TeV)

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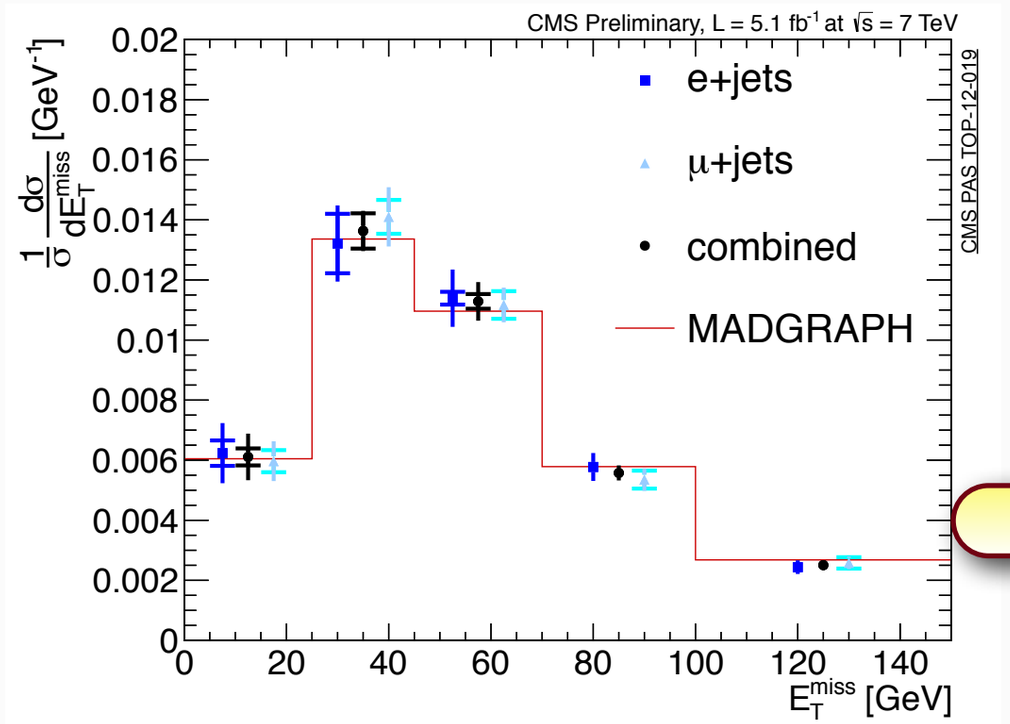
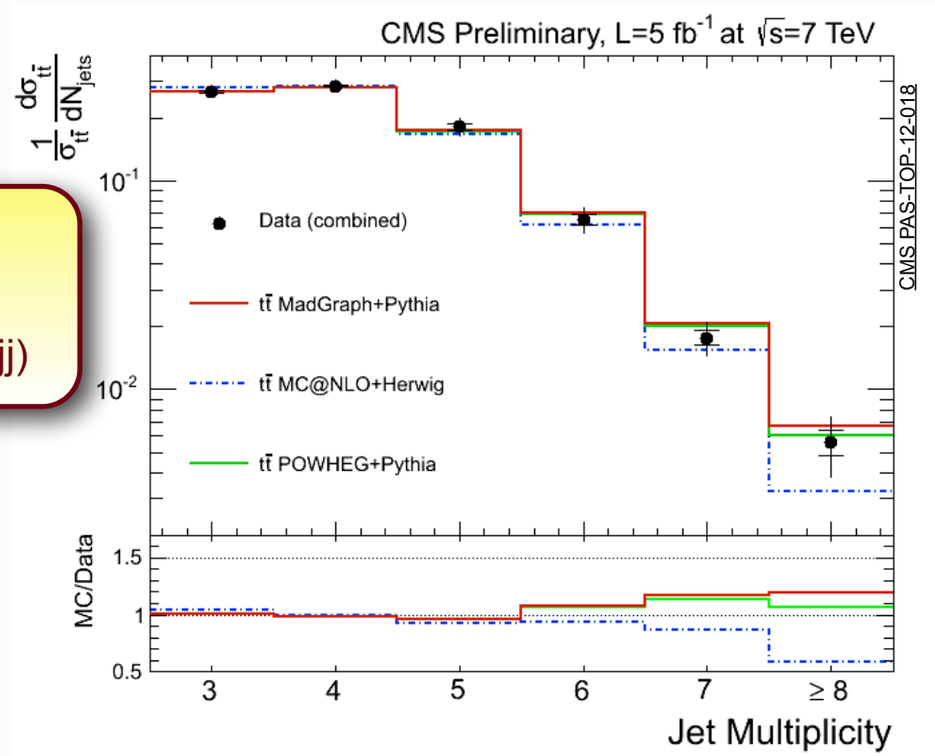


tT+MET

tT+jets

also:
(tT+bb)/(tT+jj)



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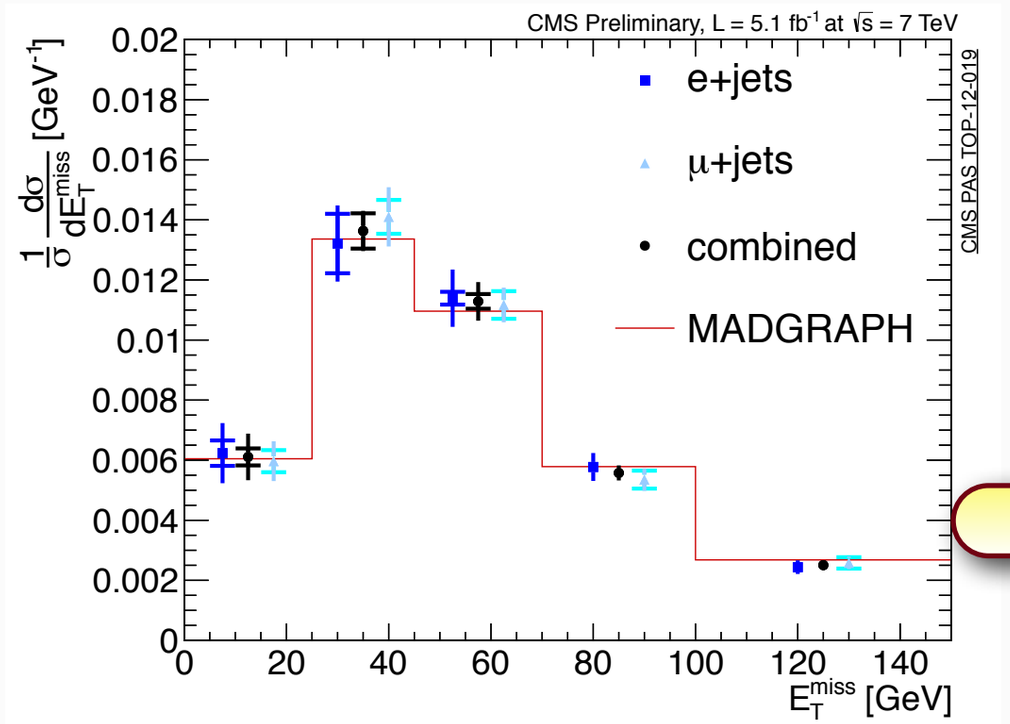

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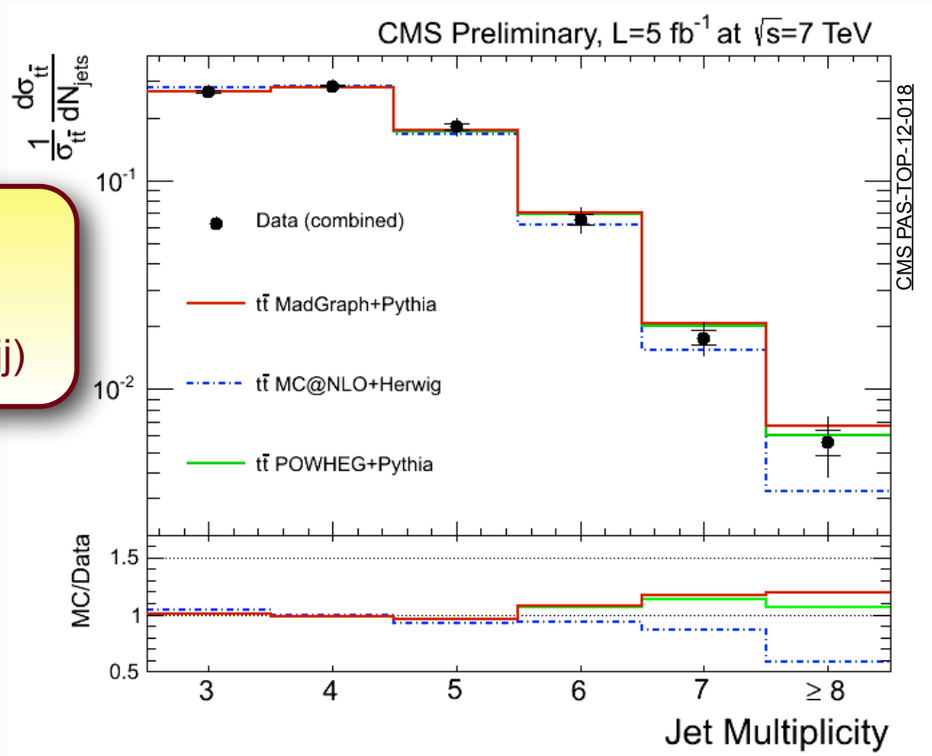
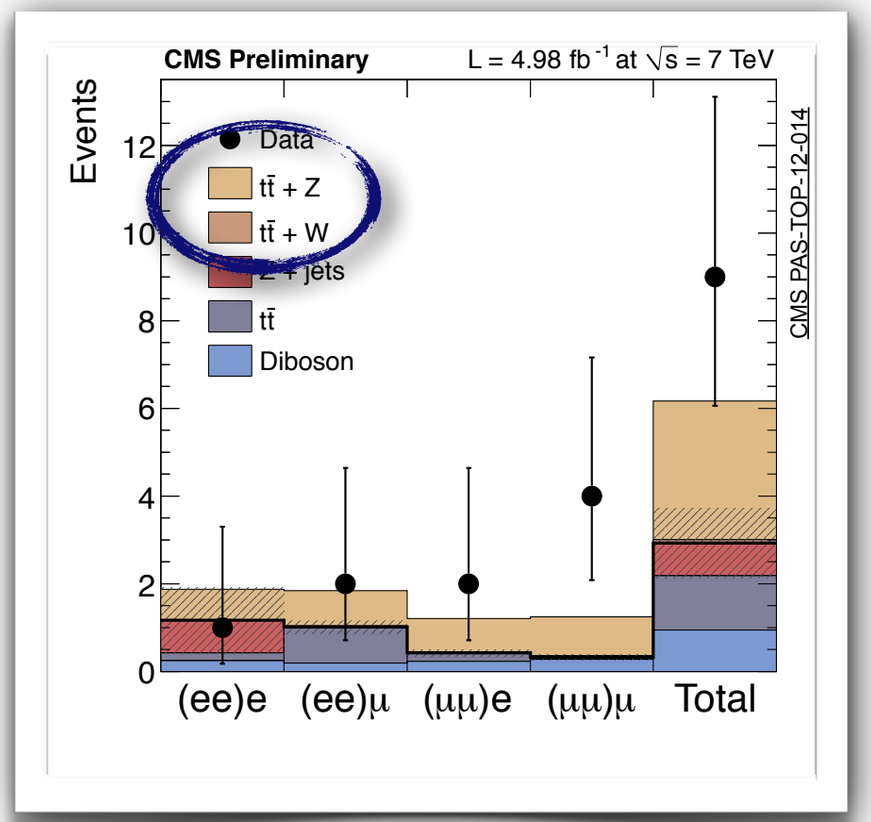
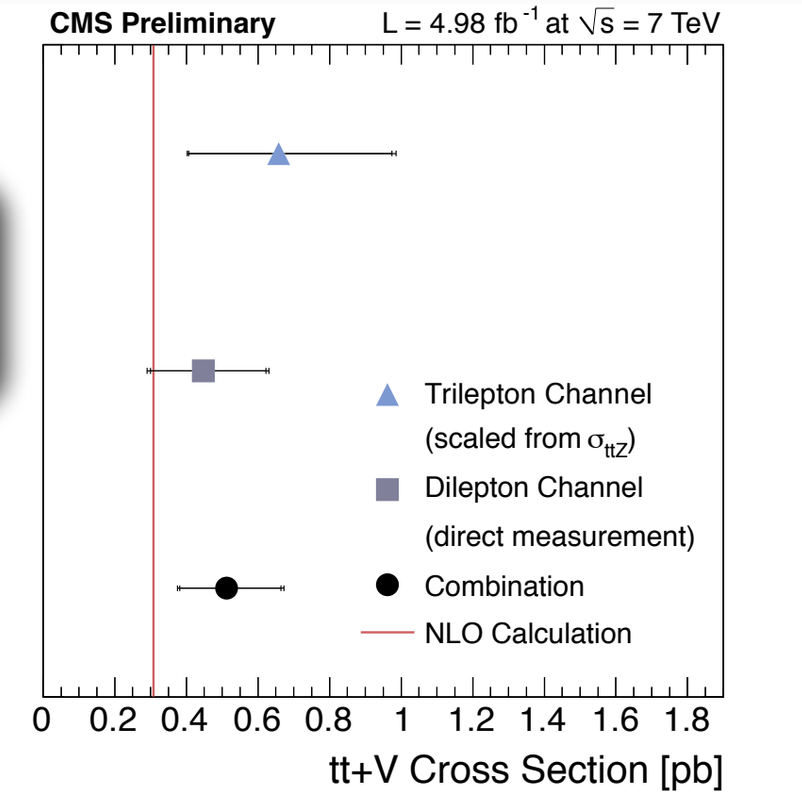


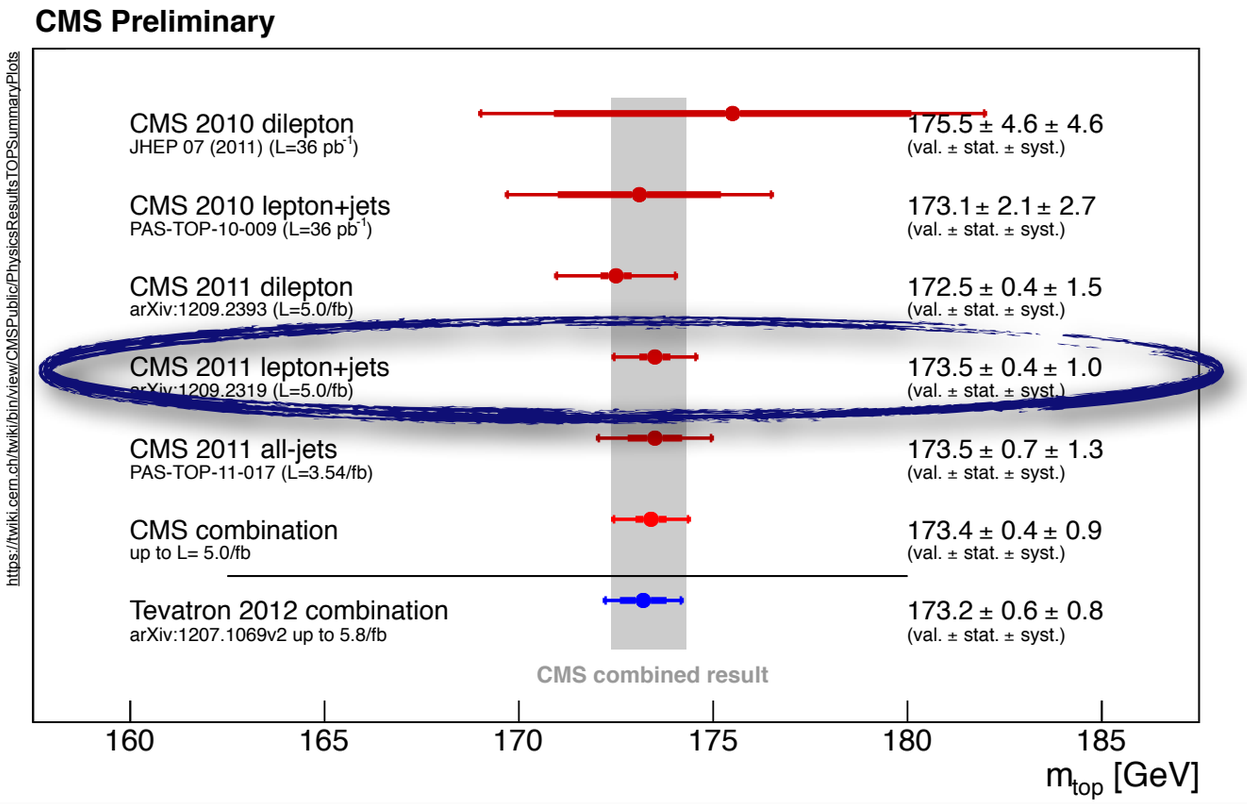


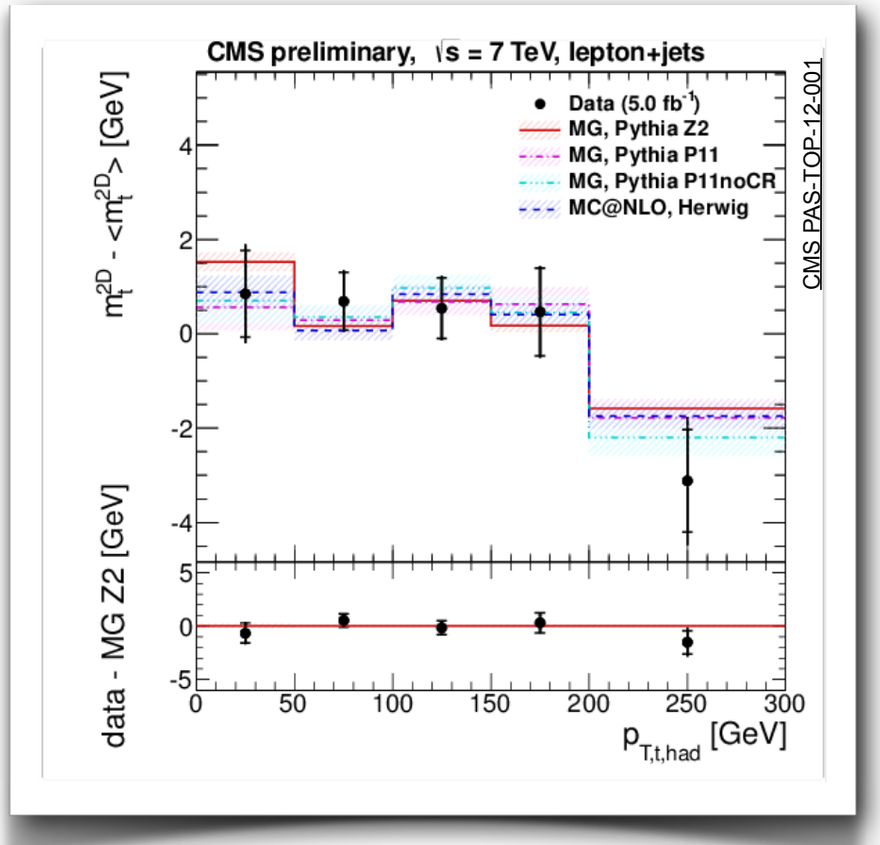
first
evidence for

tT+V (W, Z)



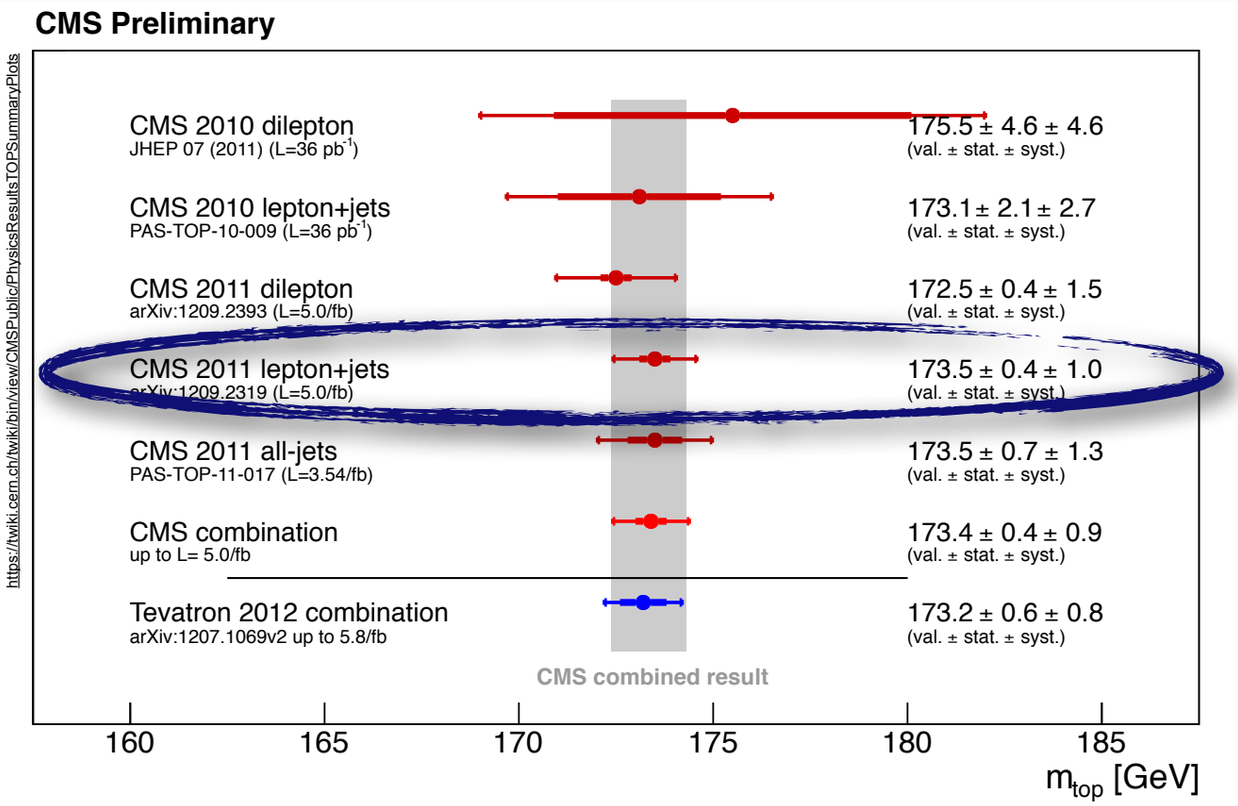
TOP properties



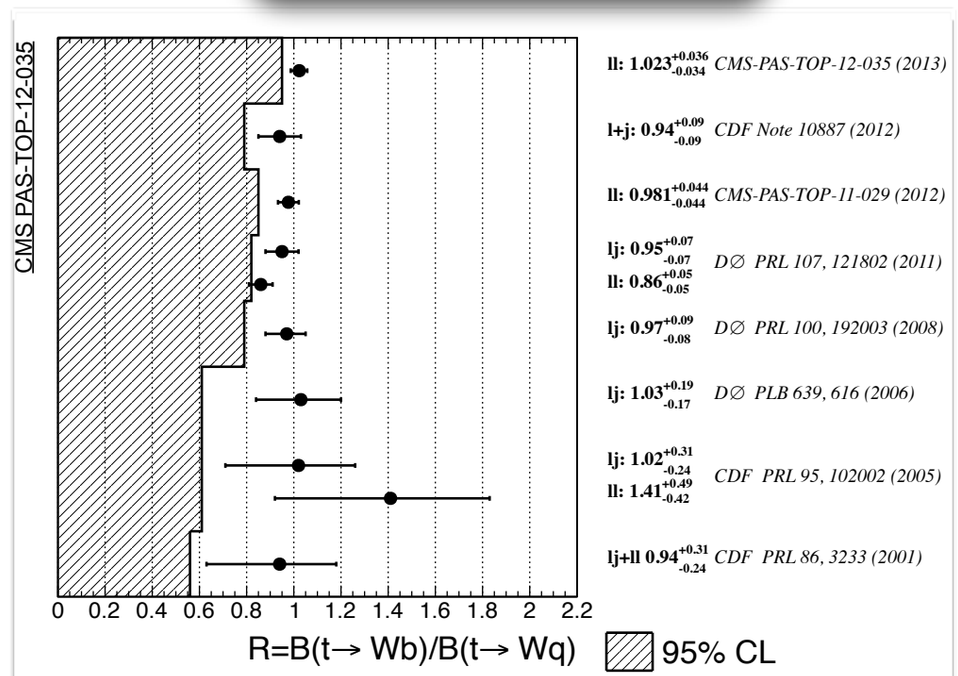


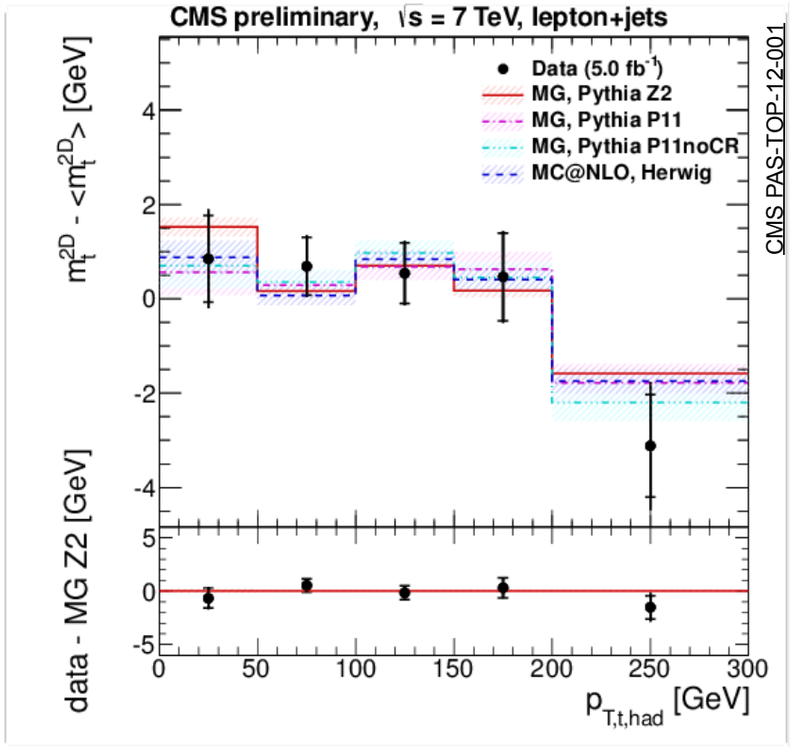
- **Top mass:**
  - Best measurements in all channels!
  - combination has syst. uncert. < 1 GeV, same precision as Tevatron comb.
  - **New**: detailed study of top mass dependence on event kinematics (test for colour reconnection, ISR, FSR, b-quark kin.) - excellent stability observed!
  - **New** : top-antitop mass diff: $\Delta m_t = -272 \pm 196$ (stat.) $\pm$ 122 (syst.) **MeV**

TOP properties



R=B(t→ Wb)/B(t→ Wq)





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  - **New** : top-antitop mass diff: $\Delta m_t = -272 \pm 196$ (stat.) $\pm$ 122 (syst.) **MeV**
- **Other properties:**
  - **New**: world's best measurement of b-content in top decays, extracting R=B(t→ Wb)/B(t→ Wq) --> |Vtb| > 0.972 @ 95% CL
  - **New**: W helicity measurement in dilepton channel and single-top topologies!

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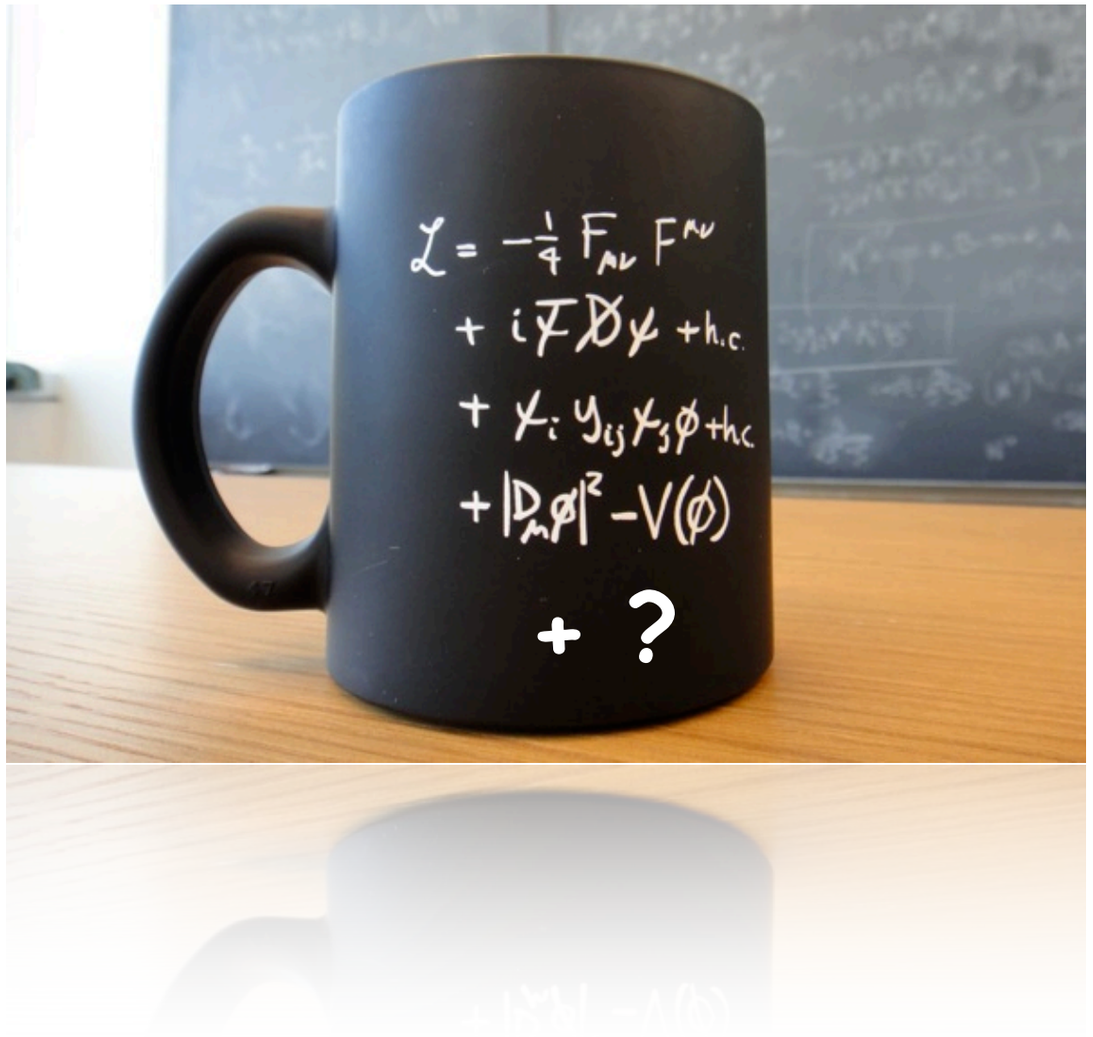
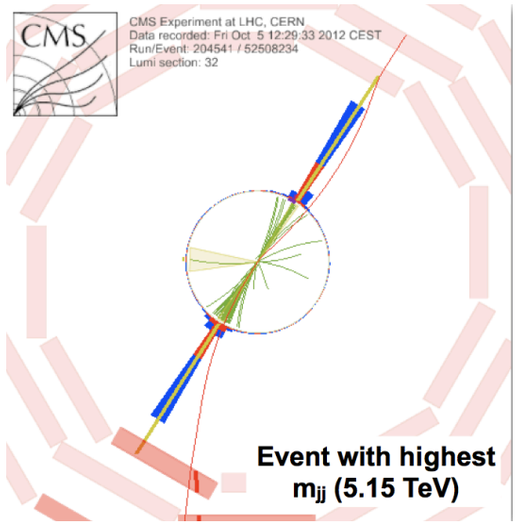
what about BSM physics?

see talks by

M. Stoye (SUSY)

S.W. Lee (Exotics)





SUSY: The strategy

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

Large SM backgrounds **Low**

sensitivity to strongly produced SUSY

particularly sensitive to gauge-mediated SUSY

focus on topologies, generic signatures, with different observables, data-driven bkg estimations

SUSY: The strategy

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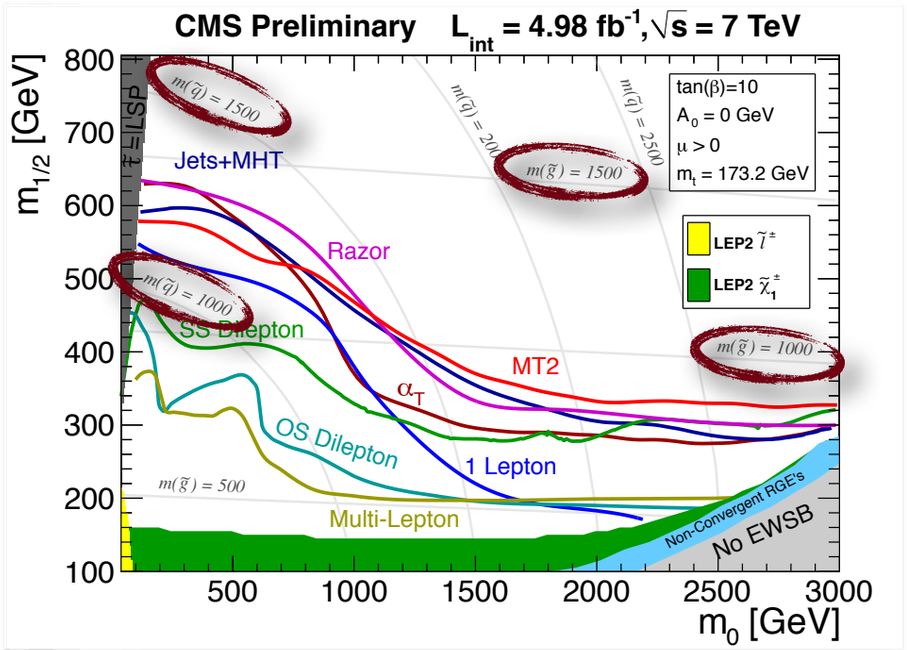
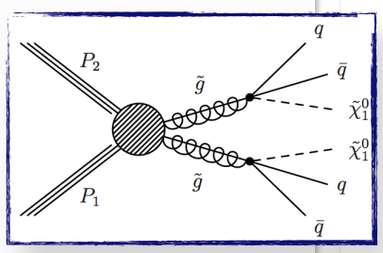
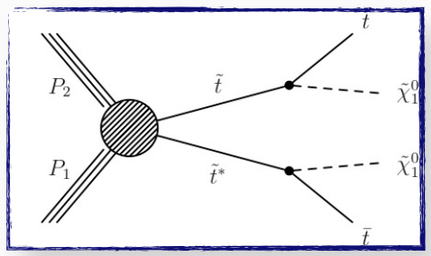
Interpretations:

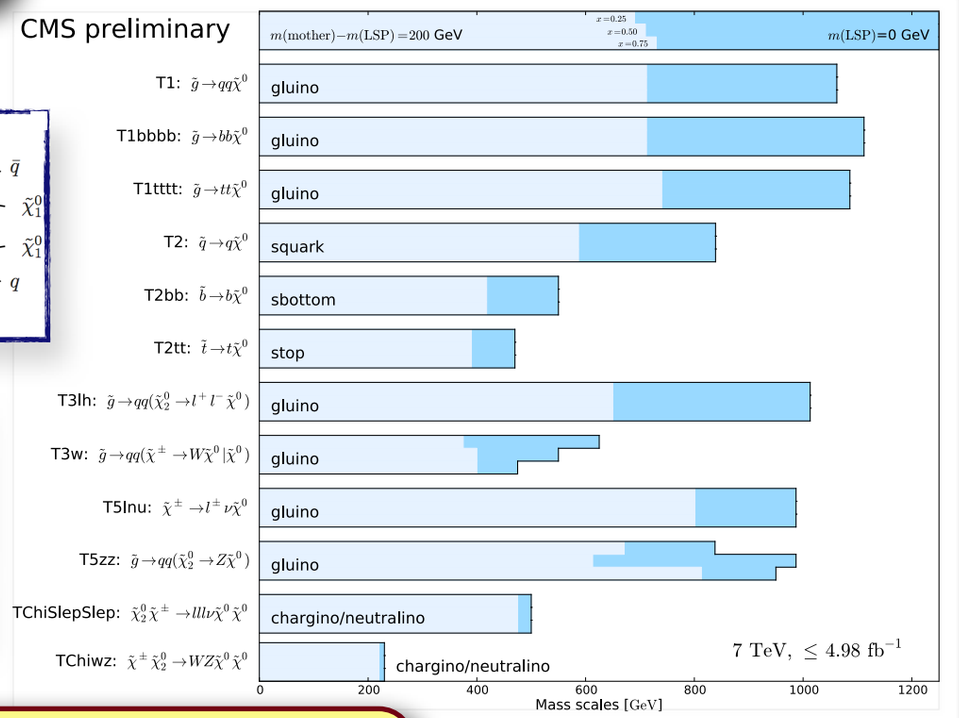
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS



in the context of a concrete model, e.g. cMSSM







in the context of a simplified models

Focusing on the 3rd generation

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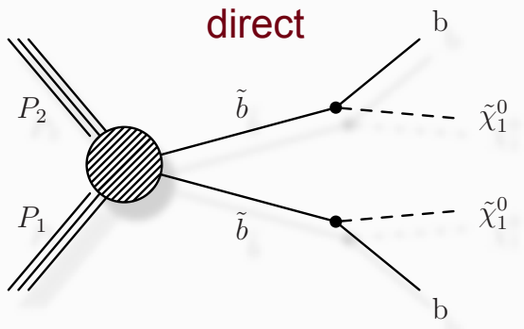
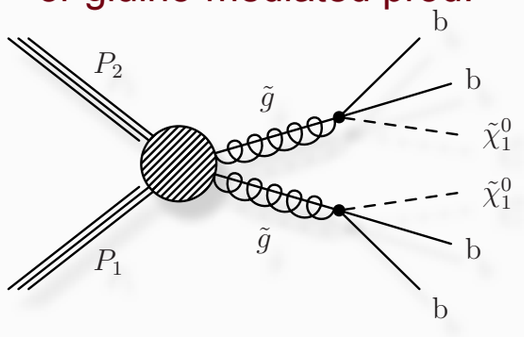
direct



or gluino-mediated prod.



- now a lot of focus **"natural" SUSY scenarios, with "light" sbottom/stop**
  - and other squarks very heavy
- targeting direct or gluino-mediated sbottom/stop production
- eg. extending generic searches by adding b-tags, or "ttbar+MET" searches
- as well as direct production of "EWKinos" (charginos, neutralinos)

- also in the pipeline: targeting more compressed spectra, with special triggers - "parked data"

Focusing on the 3rd generation

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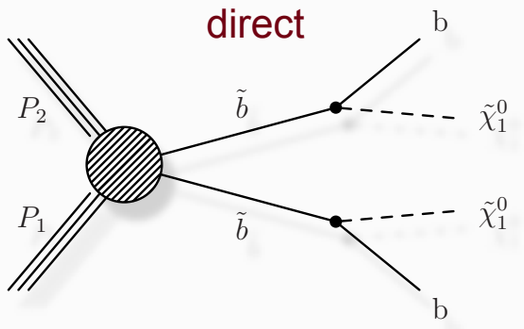

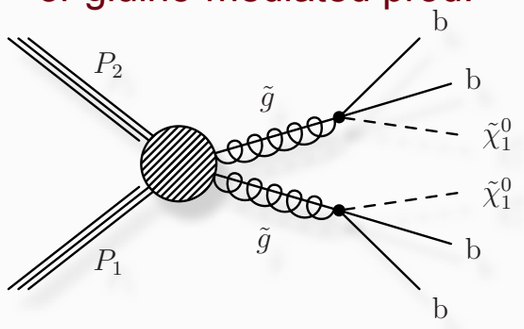

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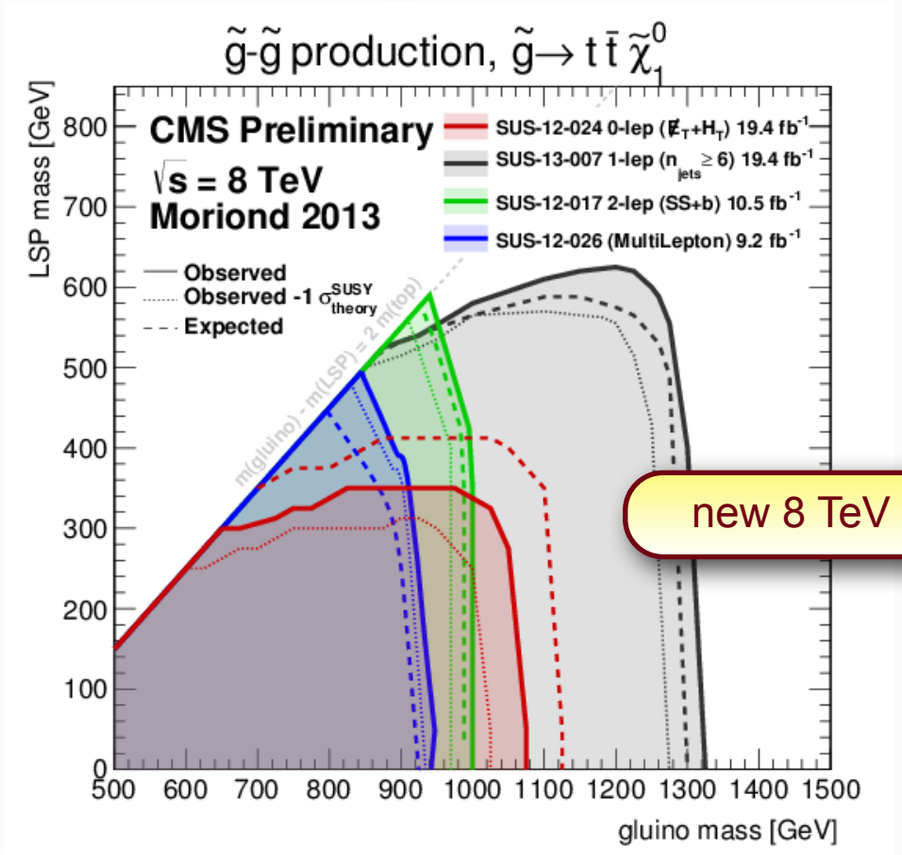
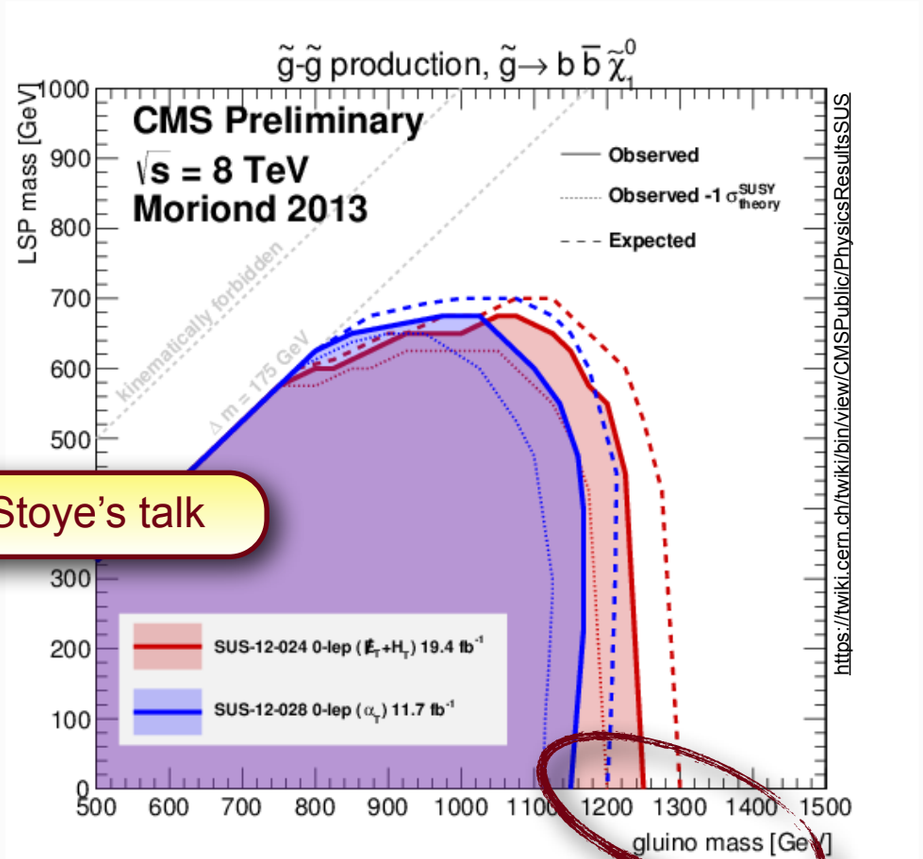
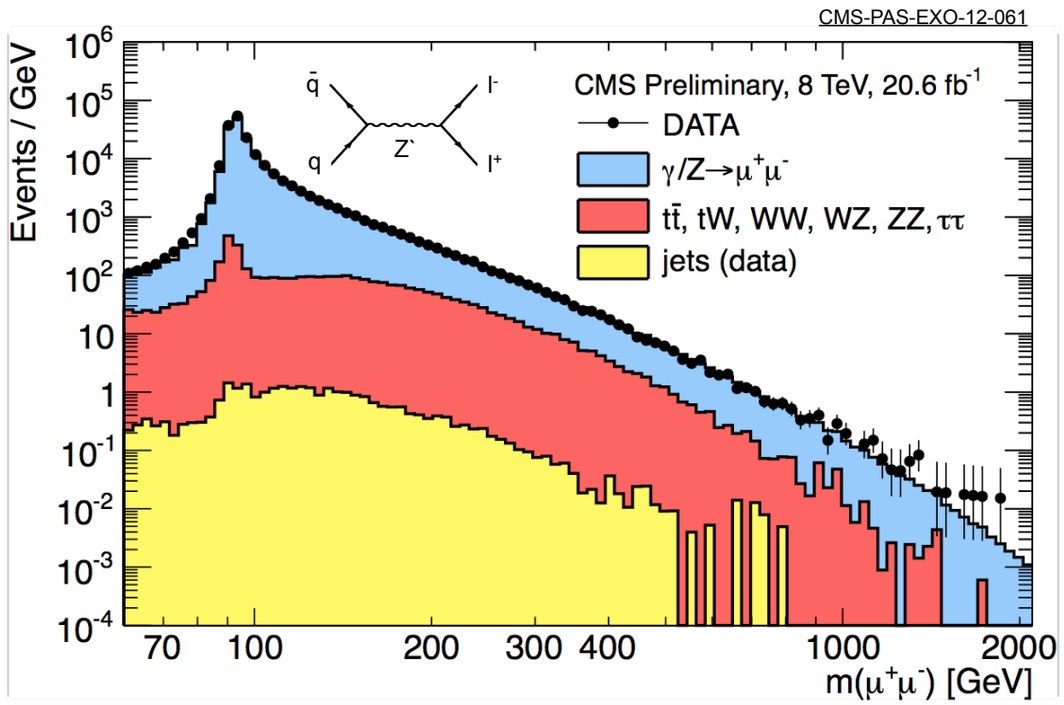


new 8 TeV results! see M. Stoye's talk



Exotica : nothing so far...

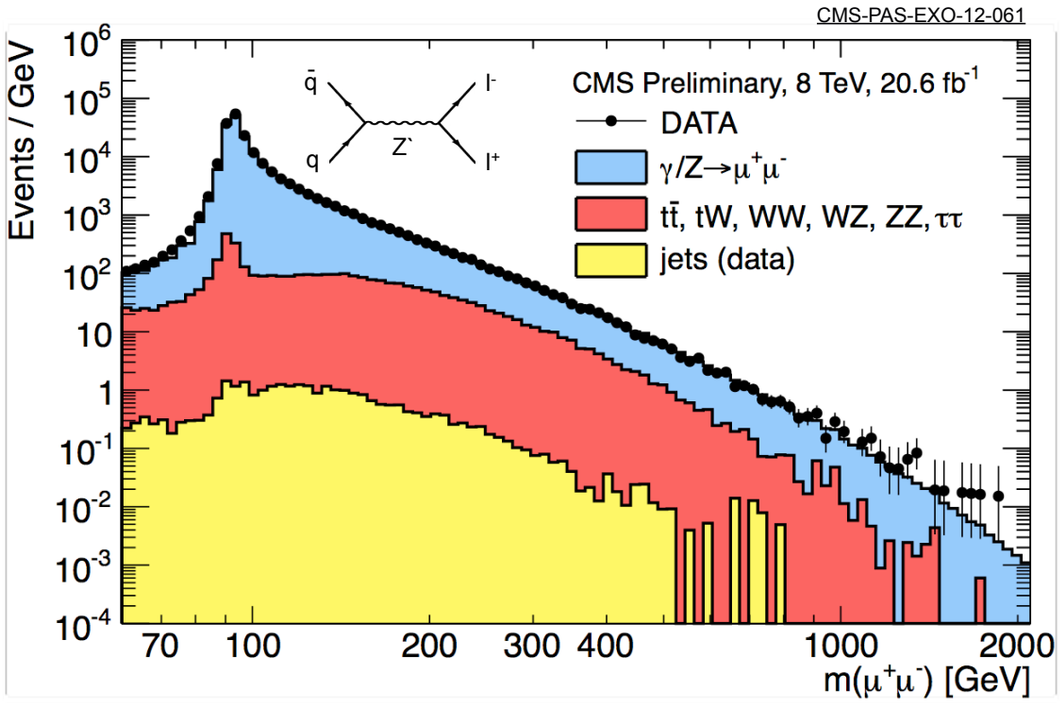
- the philosophy: leave no stone unturned...
- two highlights:



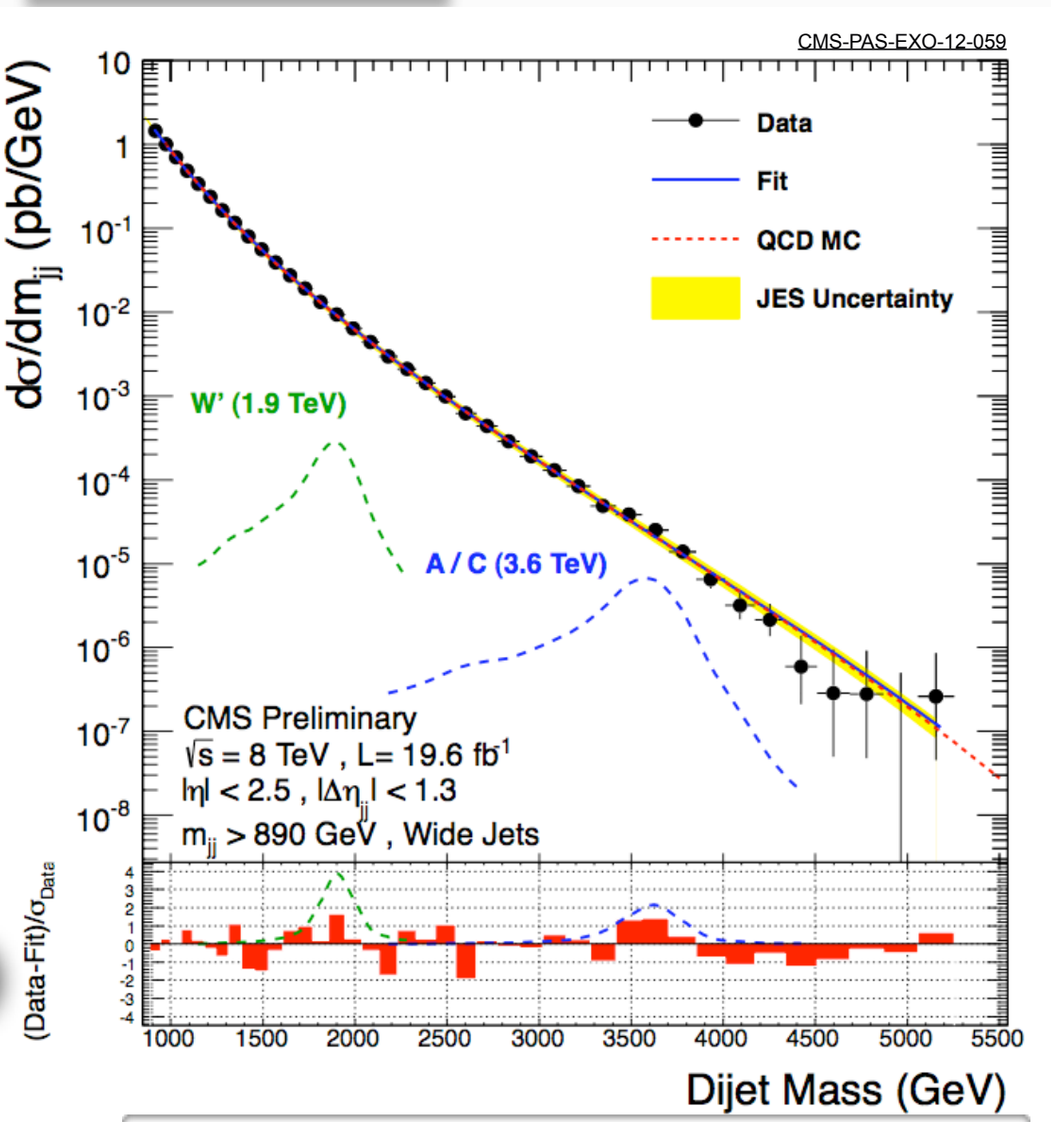
Z' with SM-like couplings > 2.96 TeV

Exotica : nothing so far...

- the philosophy: leave no stone unturned...
- two highlights:



- **Z' with SM-like couplings > 2.96 TeV**



- **q* excluded for [1.2, 3.5] TeV**
- **string resonance for [1.2, 5.08] TeV**
- plus a number of other interpretations

see also S.W. Lee's talk

Also, new on full statistics, 8 TeV:

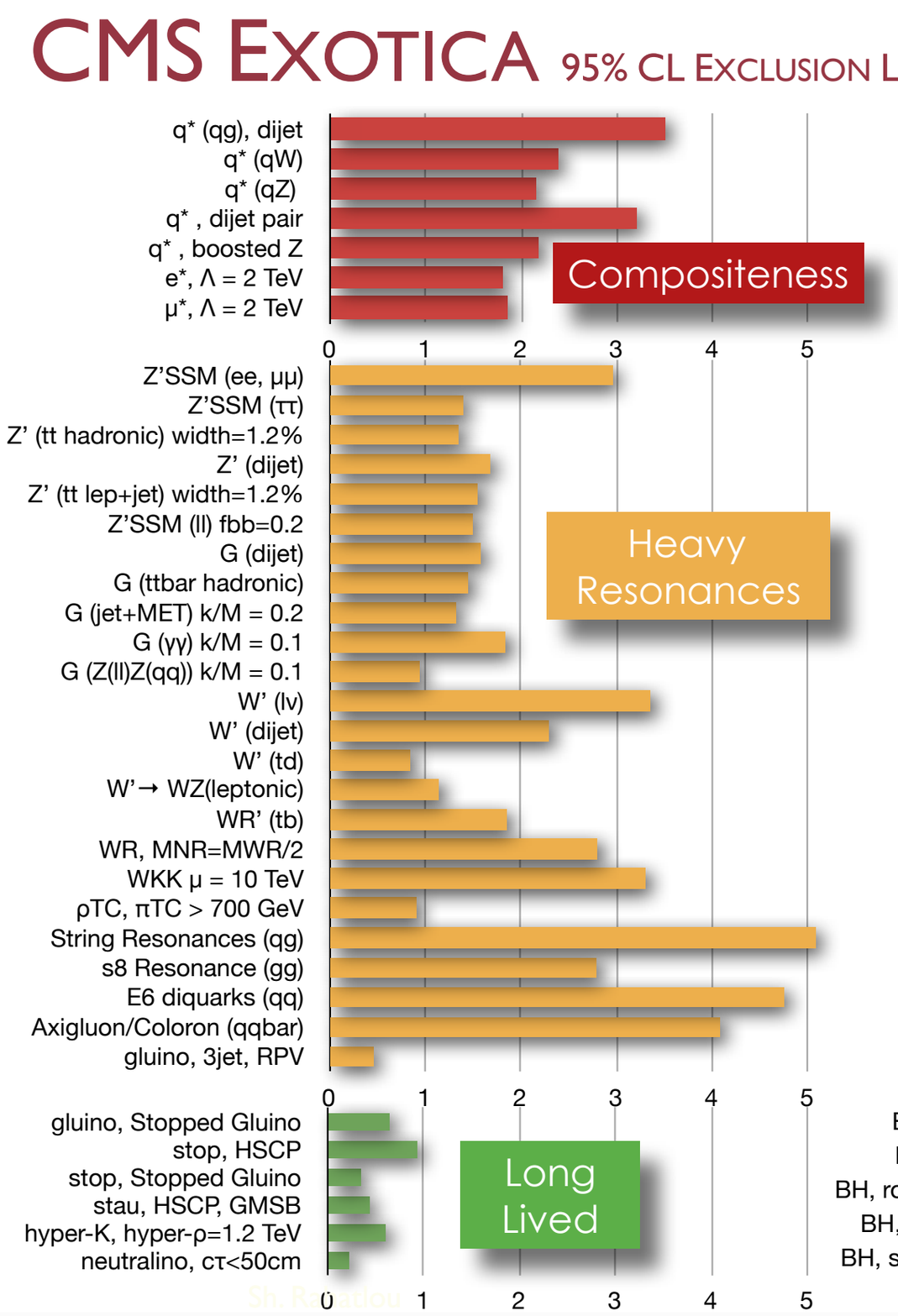
- W' with SM-like couplings > 3.35 TeV
- Update on long-lived particles (HSCP), best current limits
- Top partners, T5/3, exclude [550-770] GeV
- Limits on large extra dimensions from dielectron, dimuon evts

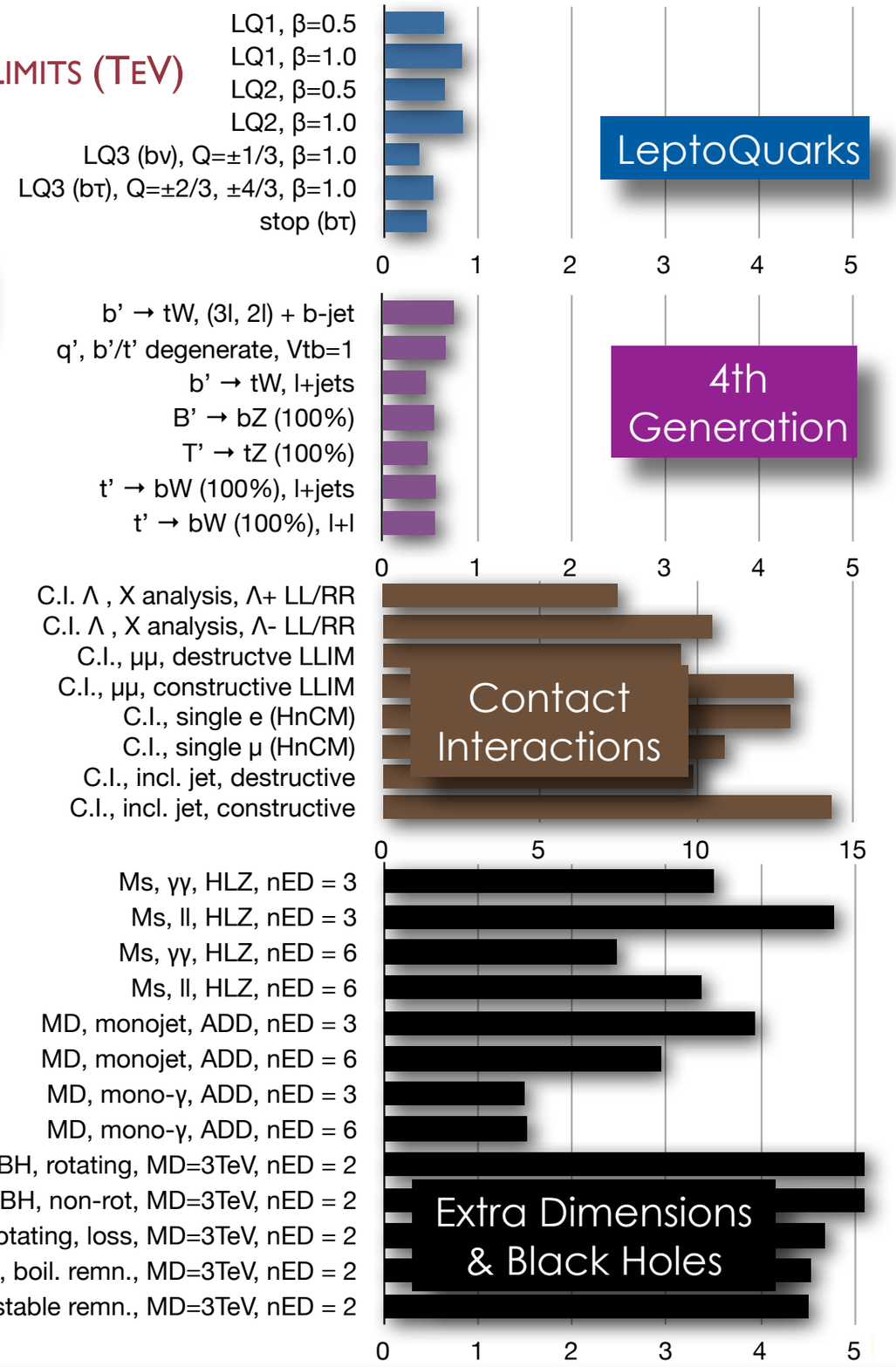
Exotica: Executive summary

ETH Institute for Particle Physics

https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/CMS-EXO-Moriond2013.pdf

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)





Higgs - quo vadis?

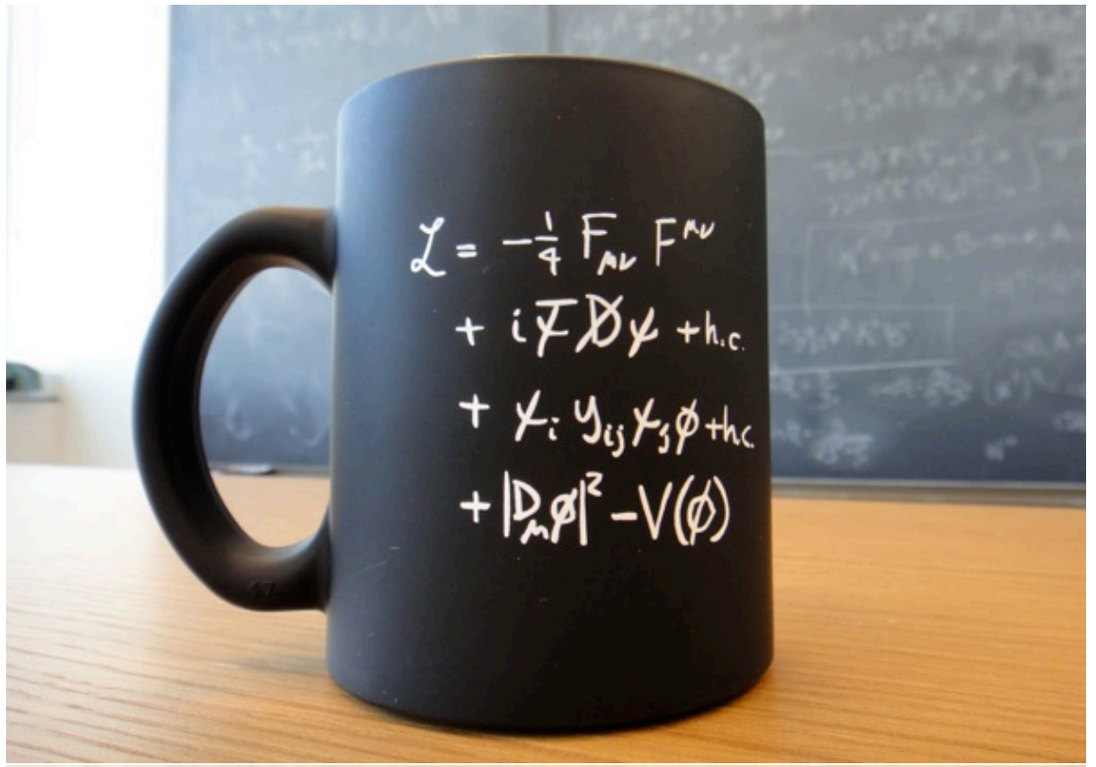
for all the details, see talks by

R. Volpe (Hγγ, HZγ)

M. Takahashi (HWW)

S. Xie (HZZ)

A. Rizzi (Hbb)



P.C. Harris (H $\tau\tau$)

M. Tosi (2HDM)

M. Gallinaro (heavy and BSM H)

J. Groth-Jensen (rare decays)

N. Wardle (H couplings)

At a glance...

ETH Institute for Particle Physics

@ 125GeV	signature	S/B	Mass Resol.	N events in 20fb^{-1}	Good For
H→bb	two b-jets, Z or W, bb inv. mass	low O(0.1)	10%	~10^5 ~50 (sel)	couplings to fermions
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H→γγ	two photons peak in inv. mass	low O(0.1)	2%	800 ~400 (sel)	H mass, couplings $K_V K_F$, discovery
H→ZZ	four leptons with right charge peaks in inv. mass (Z_1 and Higgs)	high >1	1-2%	40 ~12 (sel)	H mass, discovery

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not yet updated since HCP12

stay tuned

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2.9 (2.6) σ obs (exp), @125 GeV
μ = 1.1 ± 0.4

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Not updated since ICHEP, stay tuned

New result, full stat!
6.7 (7.2) σ obs (exp), @125.8 GeV
$\mu = 0.91\ ^{+0.3}\ _{-0.24}$

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μ = 0.91 $^{+0.3}_{-0.24}$

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Also new (based on full statistics):
H→Zγ
WH→WWW→3l3ν
H →ZZ→2l2τ (high mass)

Recent publications on 7 TeV data:
ttH→bb arXiv:1303.0763
MSSM b(b)H→bb arXiv:1302.2892

Highlights: 7+8 TeV, full stat.

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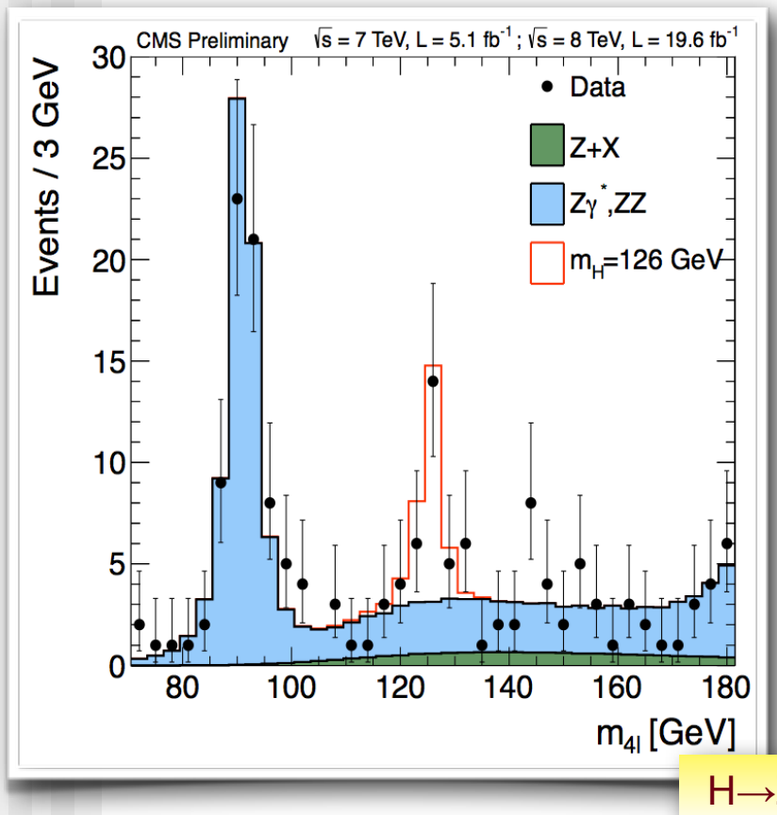
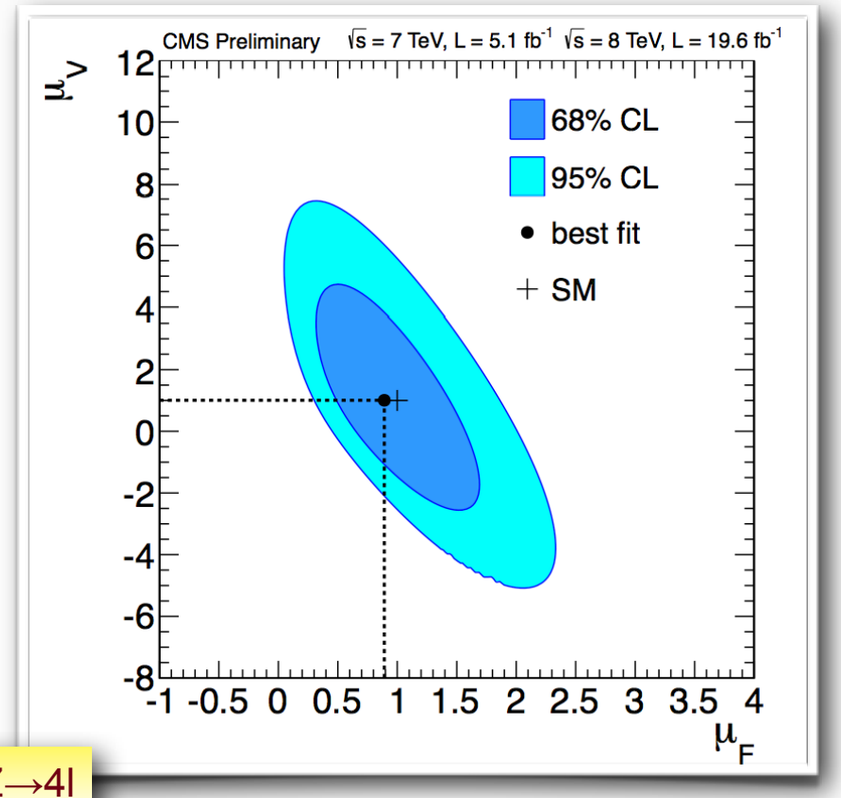
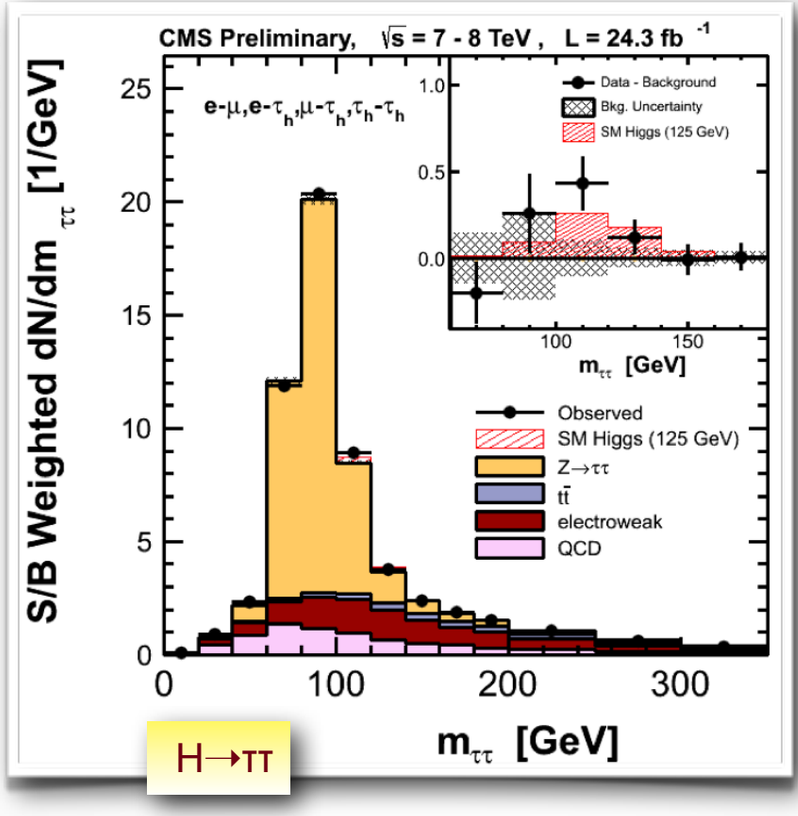


CMS-PAS-HIG-13-002



H→ZZ→4l

CMS-PAS-HIG-13-004



H→ττ

Highlights: 7+8 TeV, full stat.

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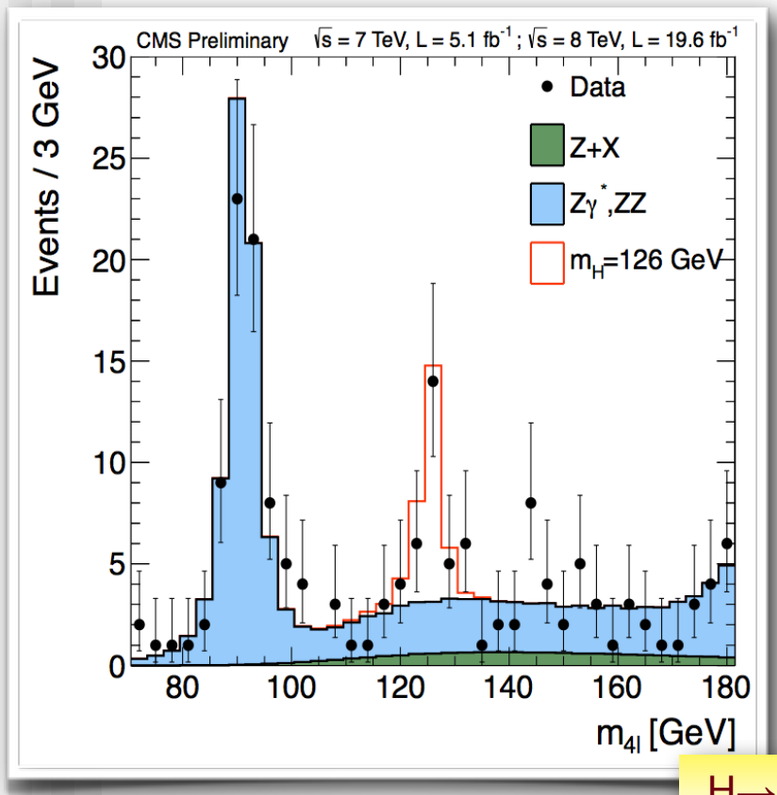
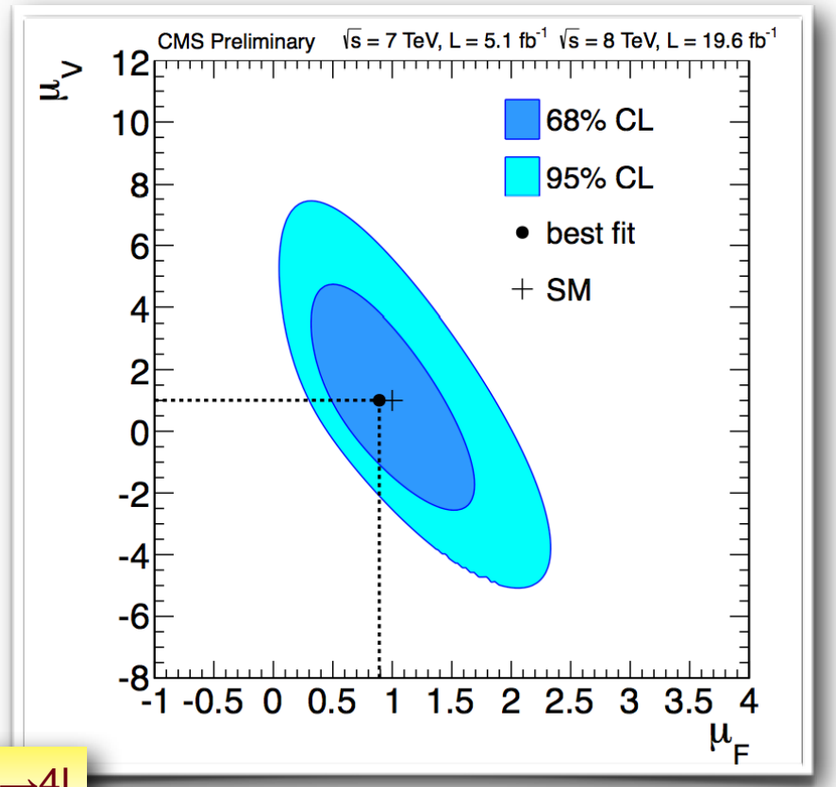


H→ZZ→4l

CMS-PAS-HIG-13-002



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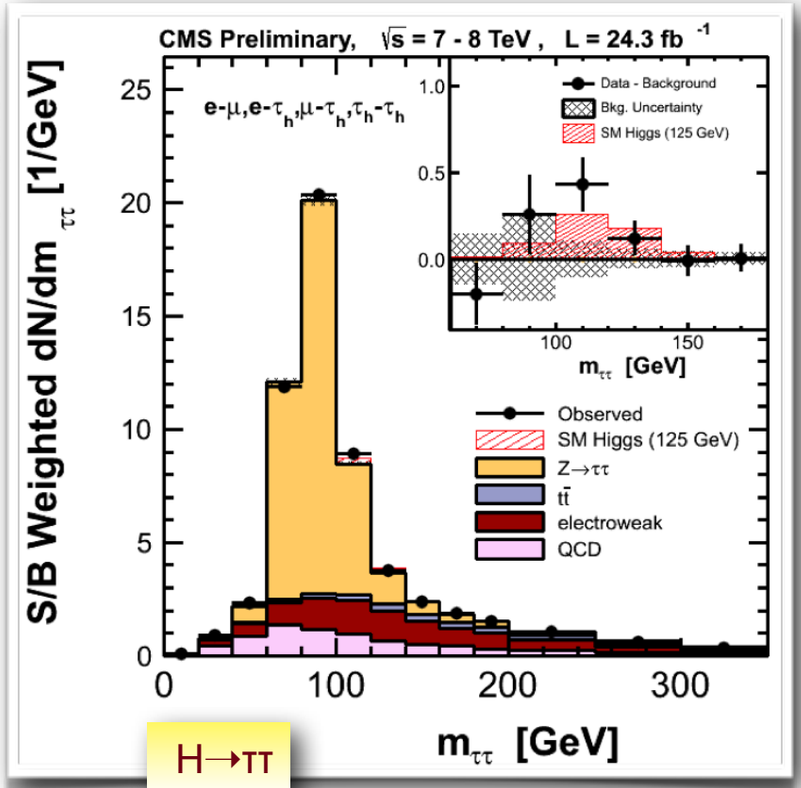
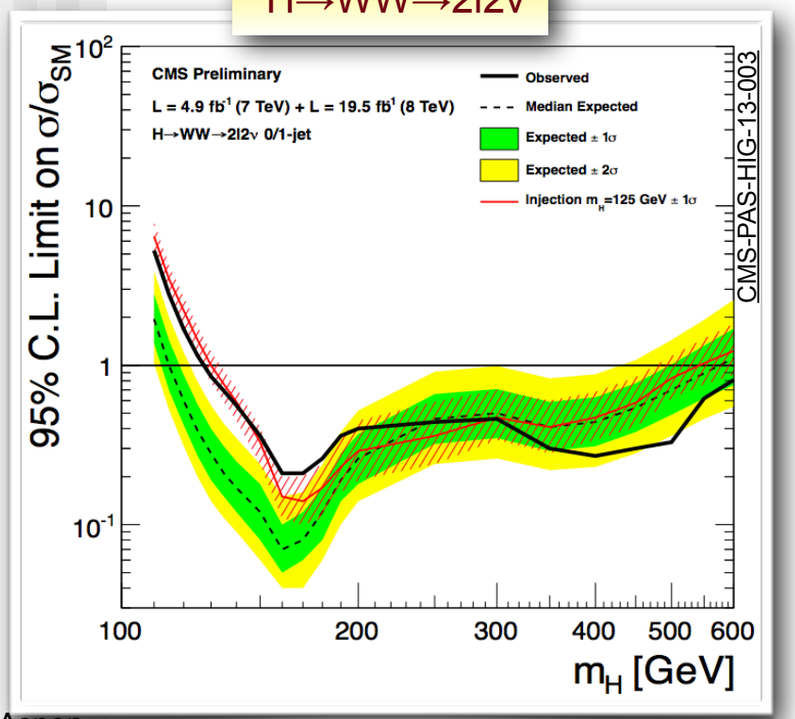


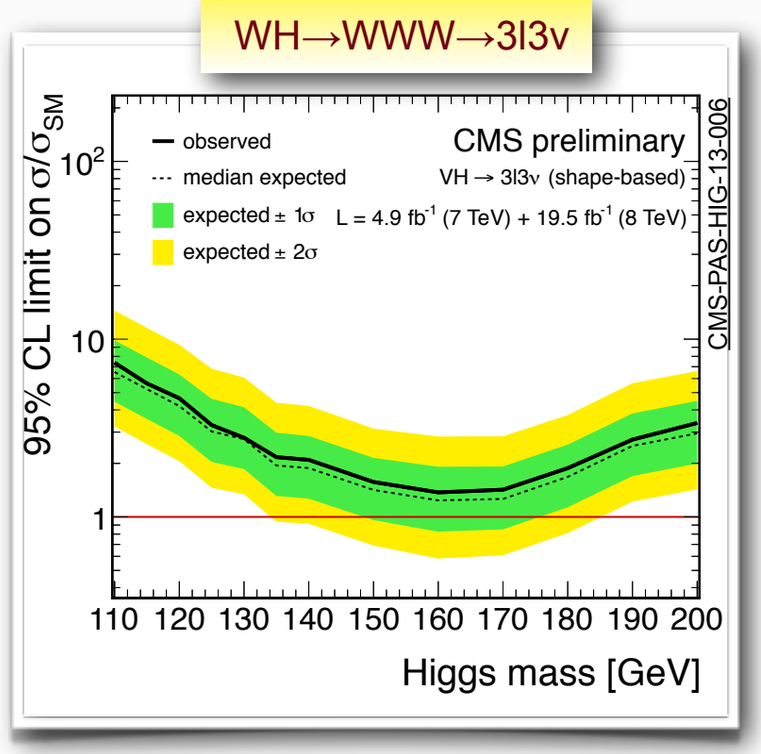
H→ττ

H→WW→2l2ν



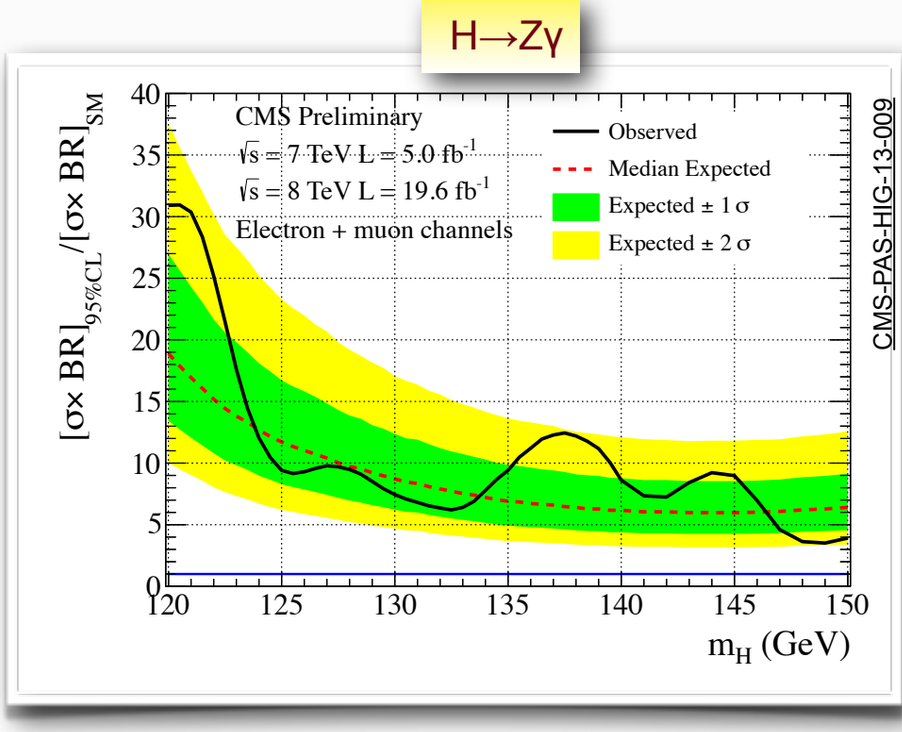
CMS-PAS-HIG-13-003

WH→WWW→3l3ν



CMS-PAS-HIG-13-006

H→Zγ



CMS-PAS-HIG-13-009

Questionnaire

Question	Done?	How
Statistically significant?	yes	Estimate p-value on combination
Is it a boson?	yes	It decays in γγ
Mass?	yes (improving)	Use γγ and ZZ channels
Spin?	yes (improving)	Use kinematics of decay products
Parity?	yes (improving)	Use kinematics of decay products
Is it "the" Higgs boson?	progressing	Measure BRs and couplings
Is it "a" Higgs boson?	checking	Measure couplings and look at different mass regions

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Questionnaire

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new results from HZZ and HWW

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Evolution

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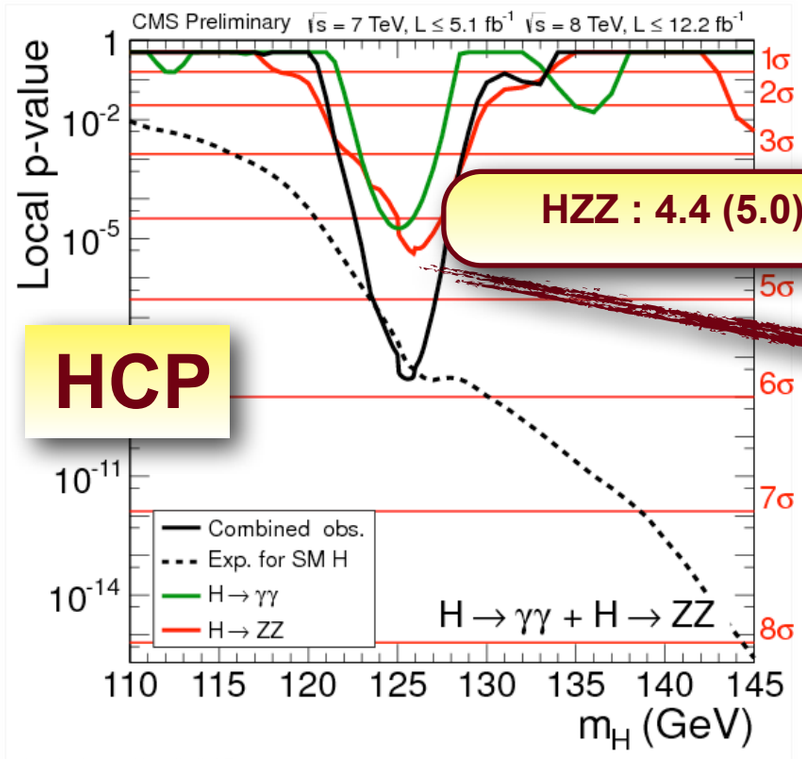
p-value

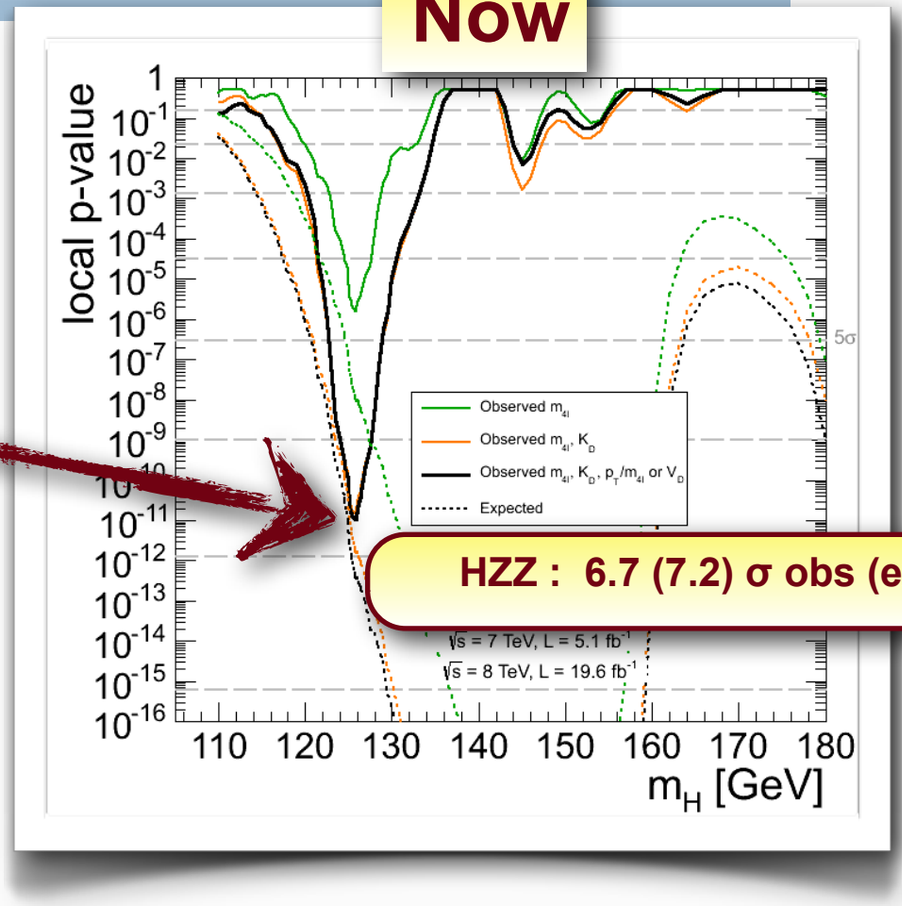
HCP



CMS-PAS-HIG-12-045

HZZ : 4.4 (5.0) σ obs (exp)

Now



HZZ : 6.7 (7.2) σ obs (exp)

Evolution

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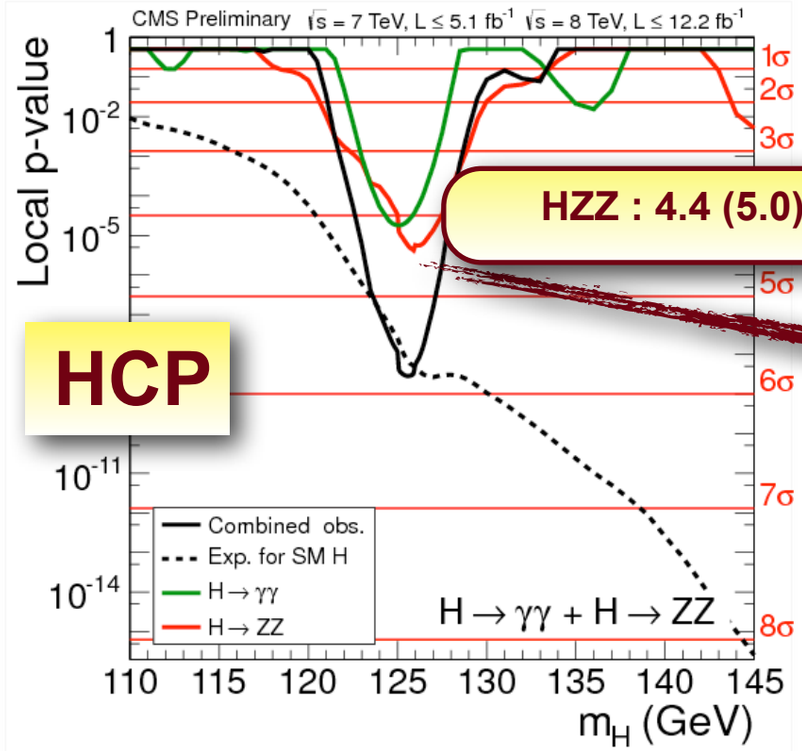
p-value

HCP



CMS-PAS-HIG-12-045

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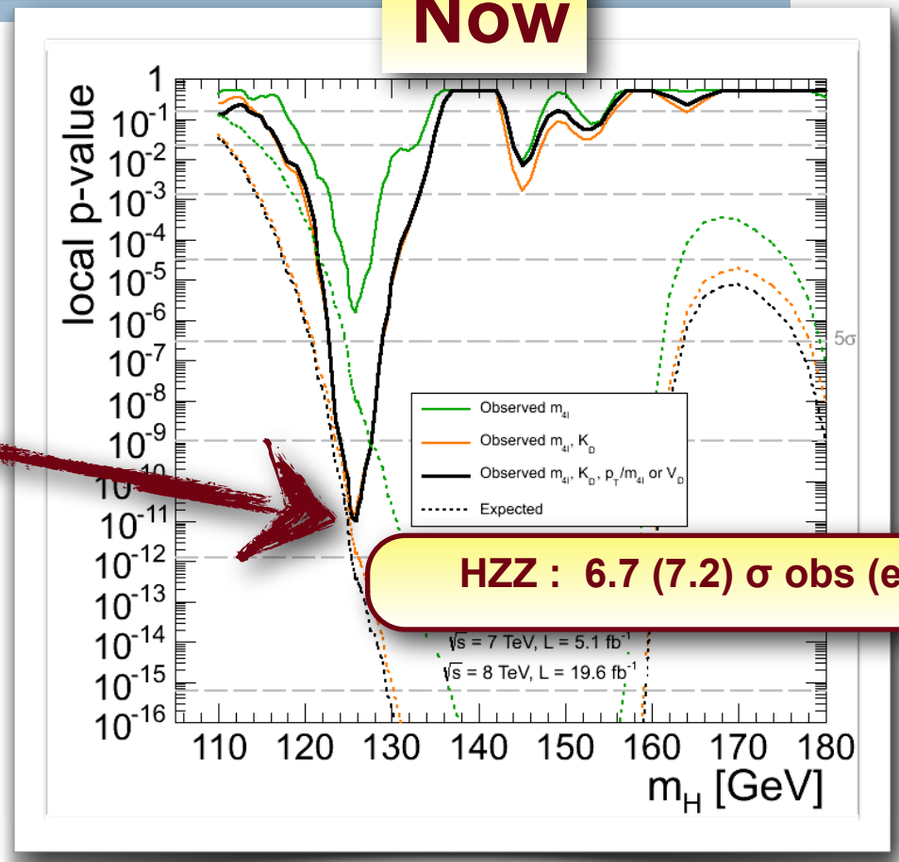

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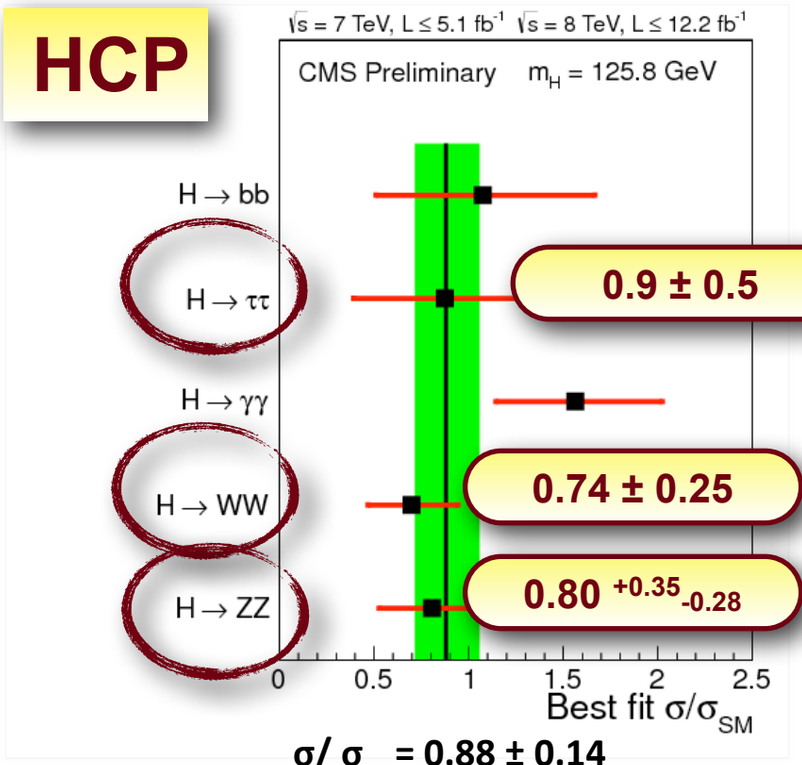
signal strength

HCP

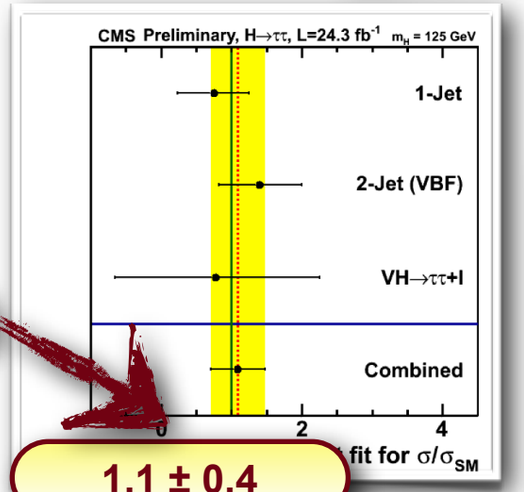


σ/ σ_SM = 0.88 ± 0.14

0.9 ± 0.5

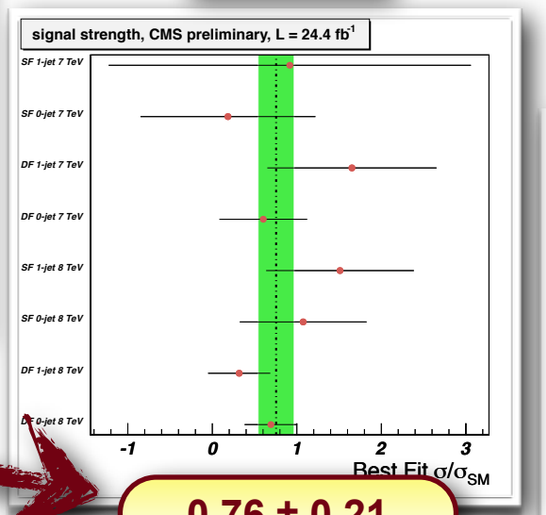
0.74 ± 0.25

0.80 +0.35 -0.28



1.1 ± 0.4

Now



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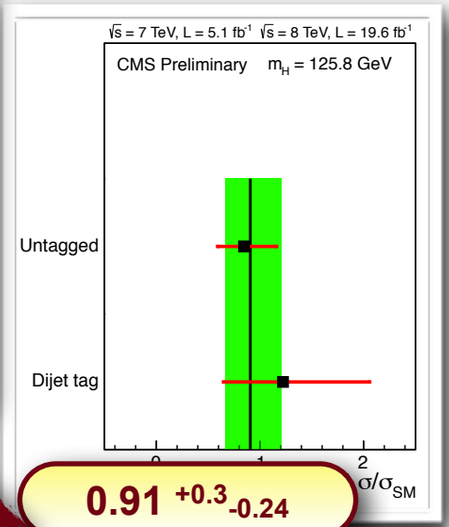

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Evolution

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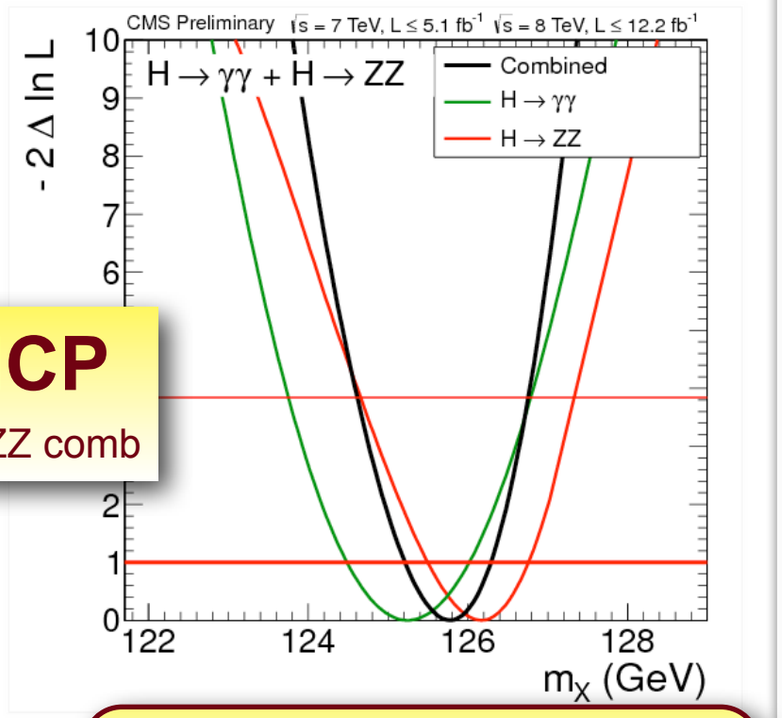
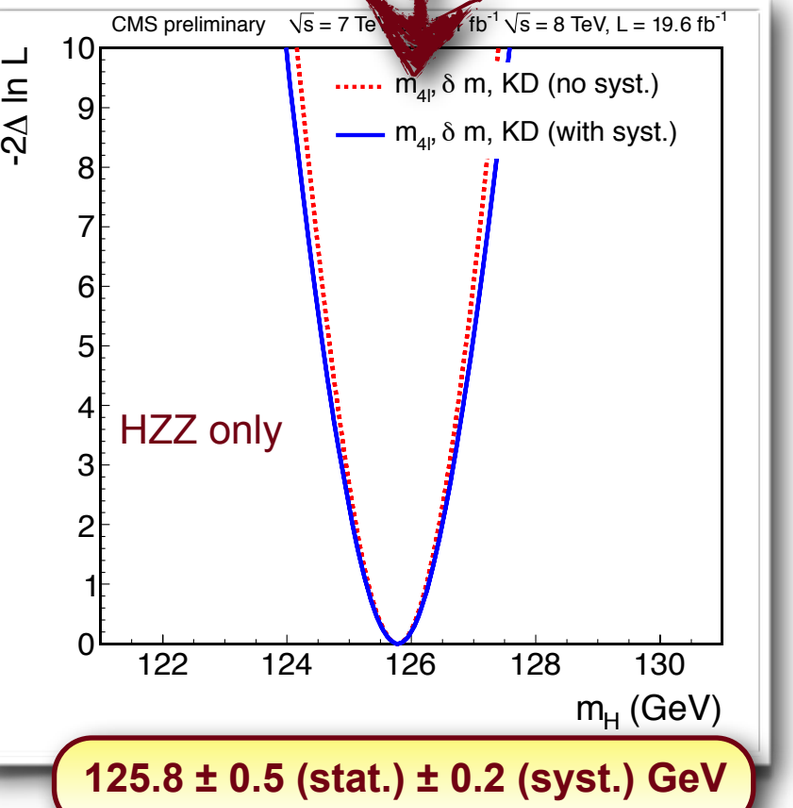


HCP

γγ+ZZ comb

125.8 ± 0.4 (stat) ± 0.4 (syst) GeV



125.8 ± 0.5 (stat.) ± 0.2 (syst.) GeV

Evolution

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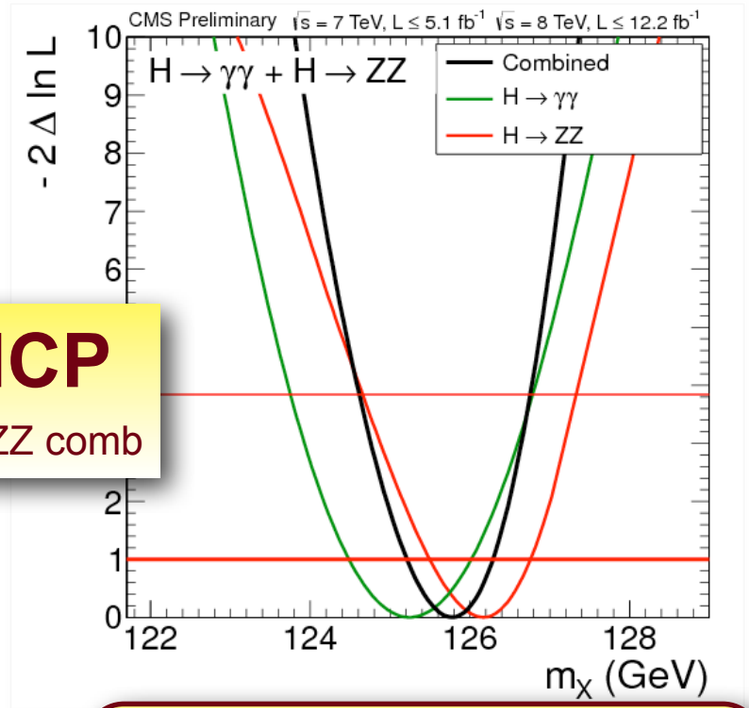
HCP
γγ+ZZ comb



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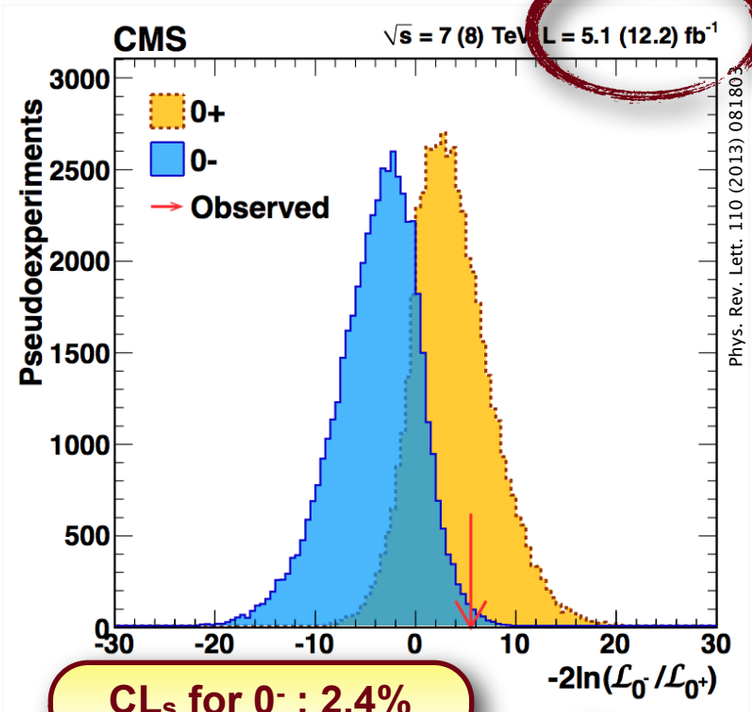
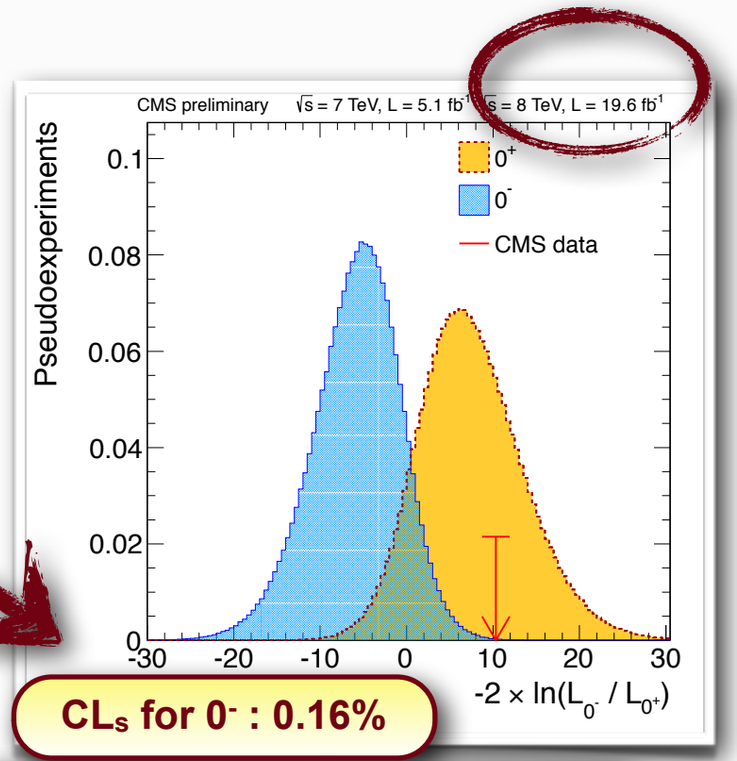
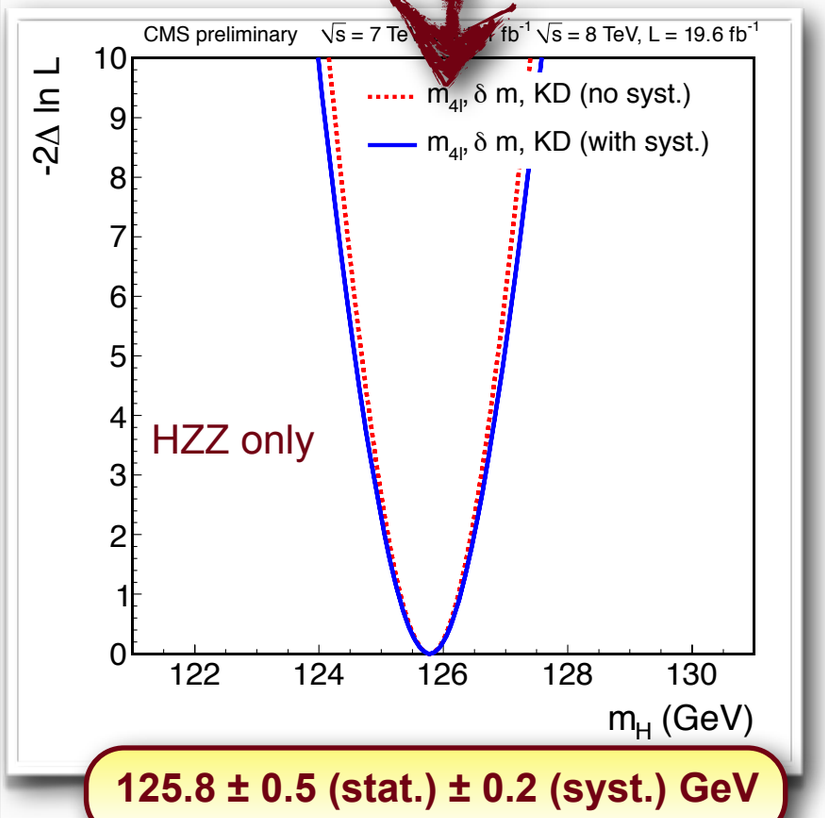


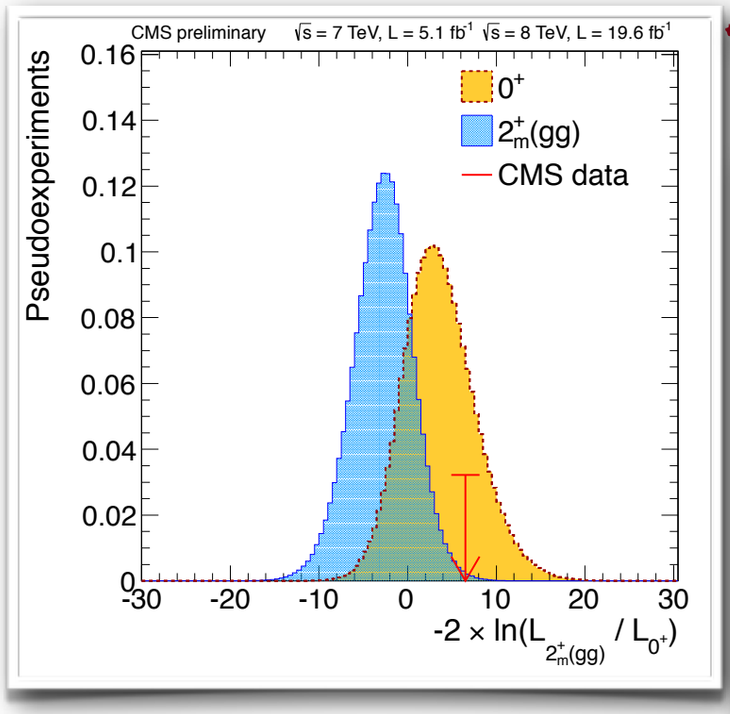
CLs for 0⁻ : 2.4%

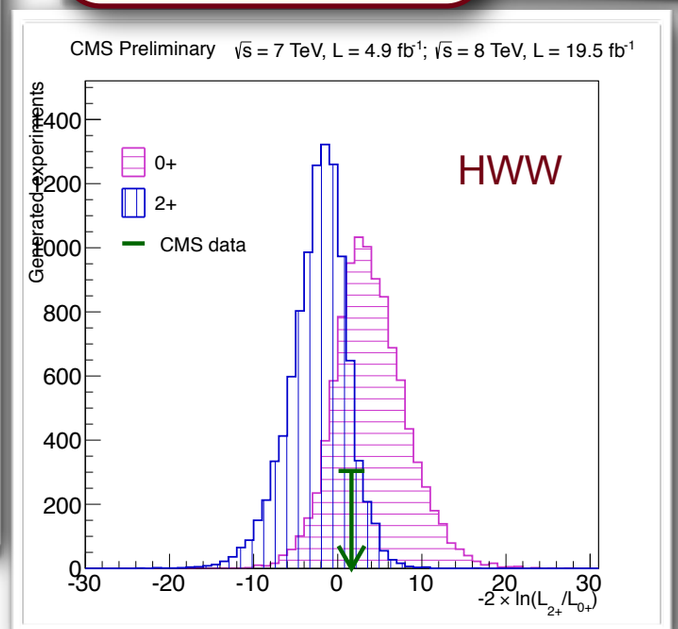


CLs for 0⁻ : 0.16%



125.8 ± 0.5 (stat.) ± 0.2 (syst.) GeV





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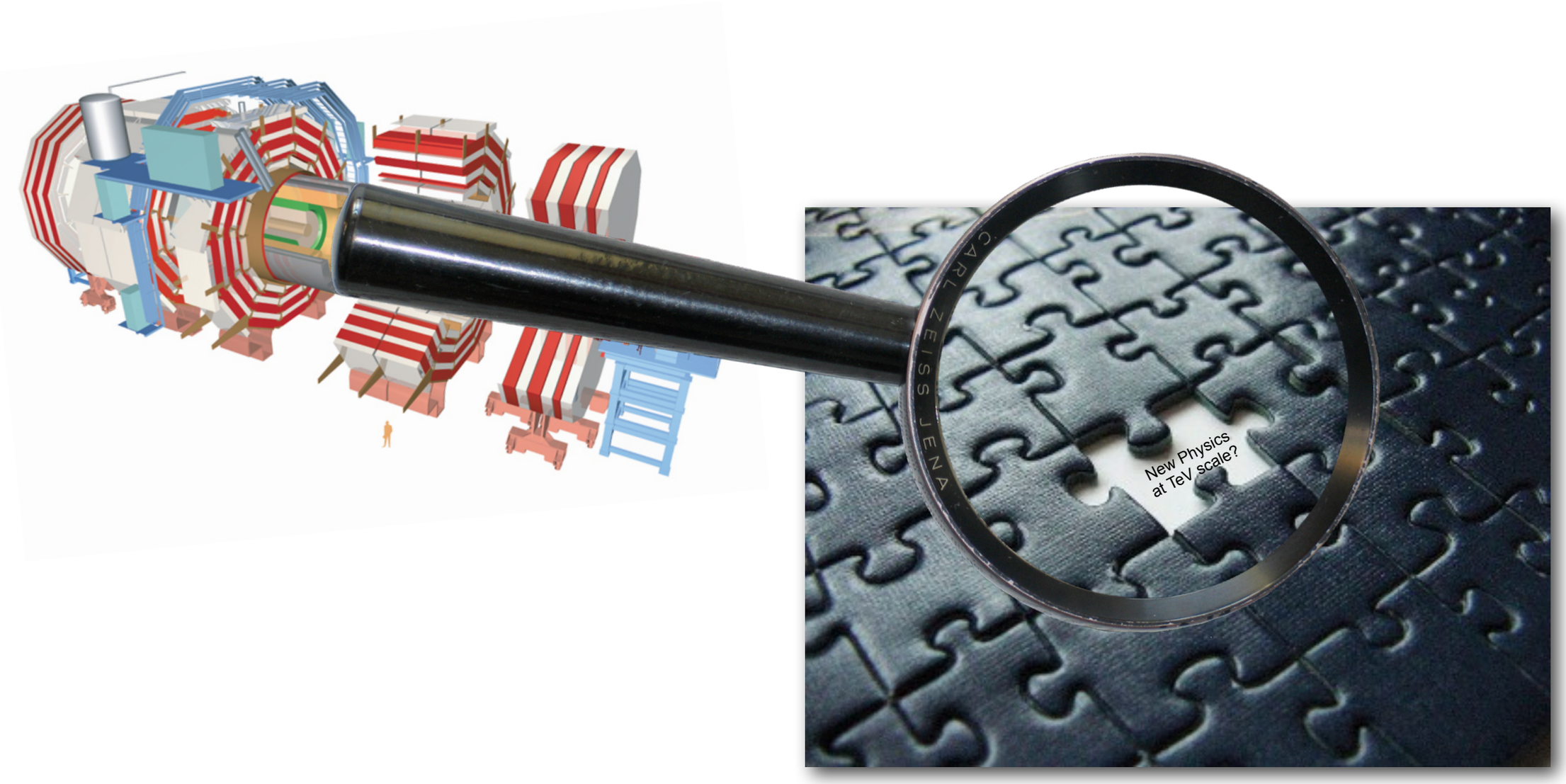
Summary



Summary

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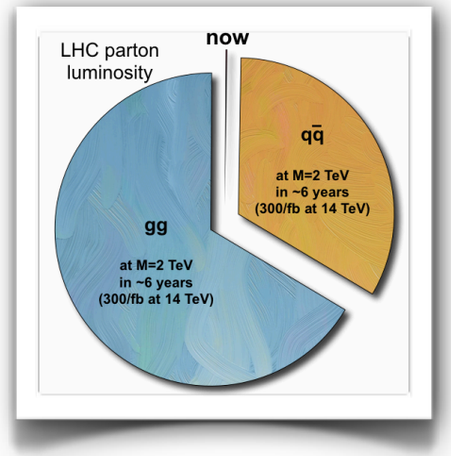
- CMS has contributed in a significant manner to probing nature at the TeV scale
- CMS have given extensive proof of being able to deliver, at high quality and over short time scales
  - this promises well also for the coming years



- These years have been exciting, rewarding, tough,...
- **The adventure in the TeV energy regime has just begun!**

Big thanks to all colleagues who helped preparing this talk!