



Universität Hamburg
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WG3 Summary

Higgs and BSM Physics

Chris Hays¹, Roman Kogler², Eleni Vryonidou³

¹ Oxford, ² Hamburg, ³ NIKHEF

DIS 2017

Birmingham, 3-7 April, 2017

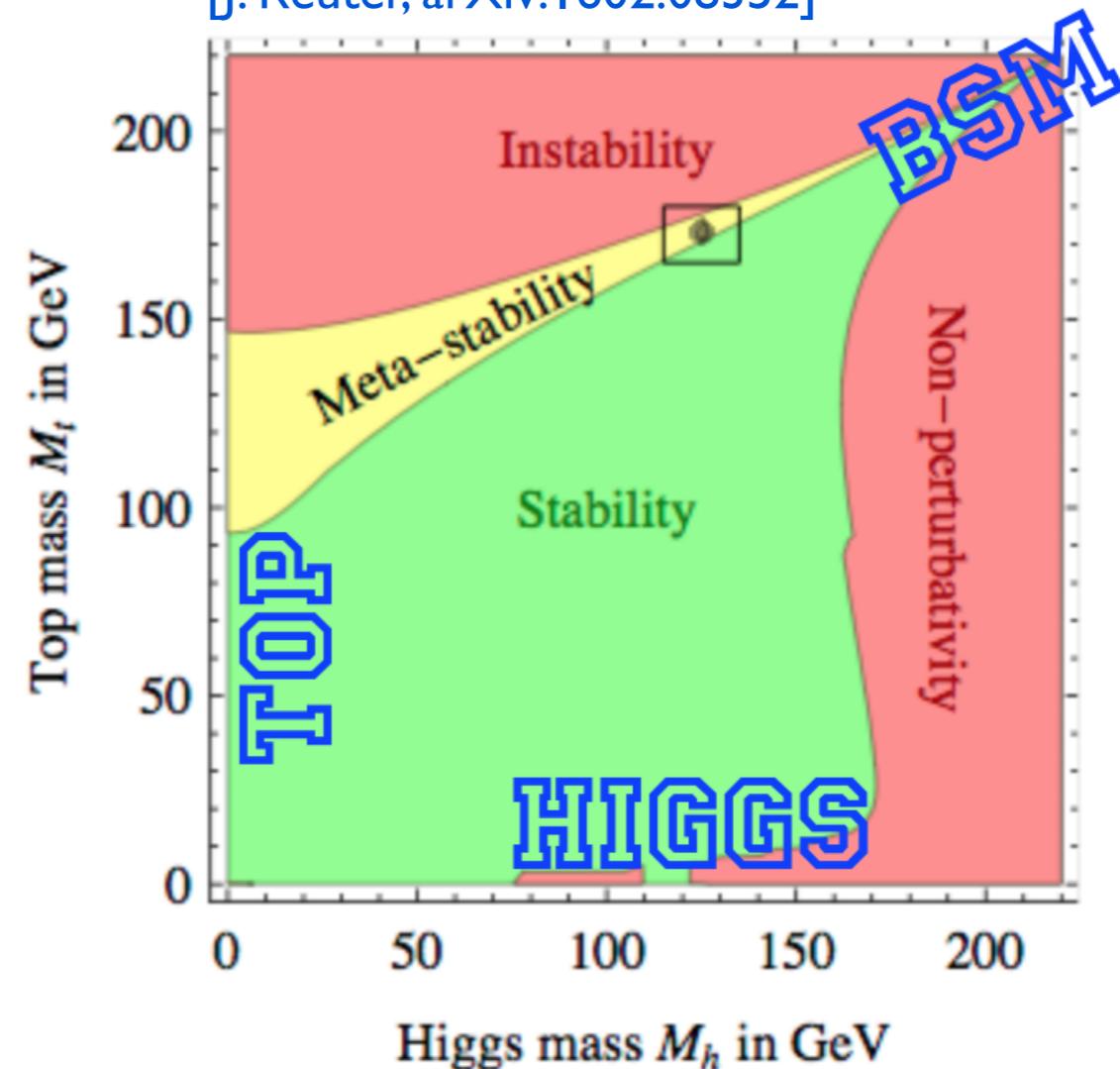
Overview

- ▶ 42 excellent talks with many new results!
- ▶ 1. Higgs Physics
- ▶ 2. Higgs as a Probe of BSM
- ▶ 3. New Particles and Forces
- ▶ 4. Dark Matter
- ▶ 5. SUSY

Disclaimer:

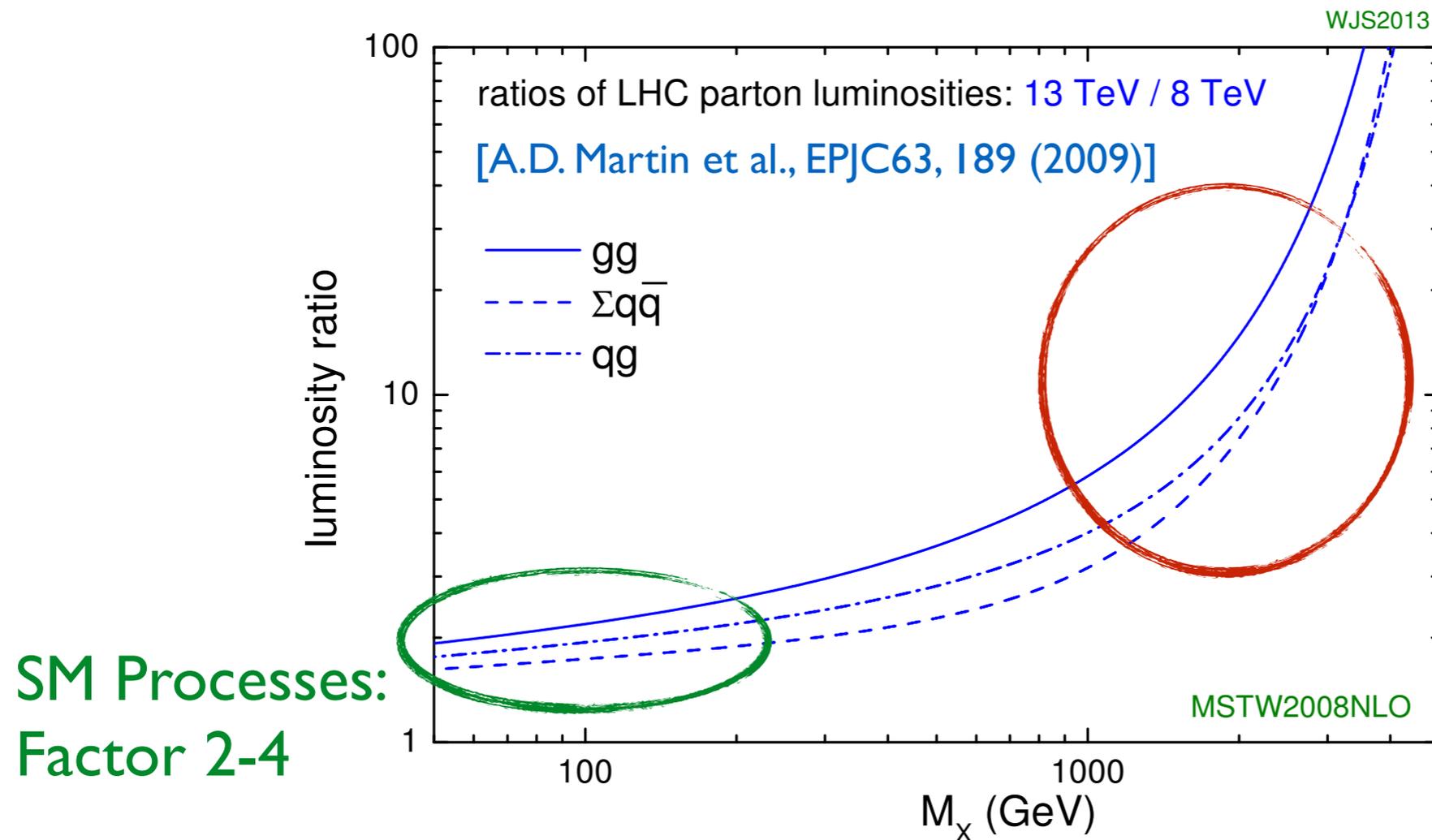
Huge number of brand new results from experiments and theory - personal selection shown here!

[J. Reuter, arXiv:1602.08352]



The LHC at 13 TeV

Transition from Run 1 to Run 2



SM Processes:
Factor 2-4

New physics:
Factor $10-10^3$

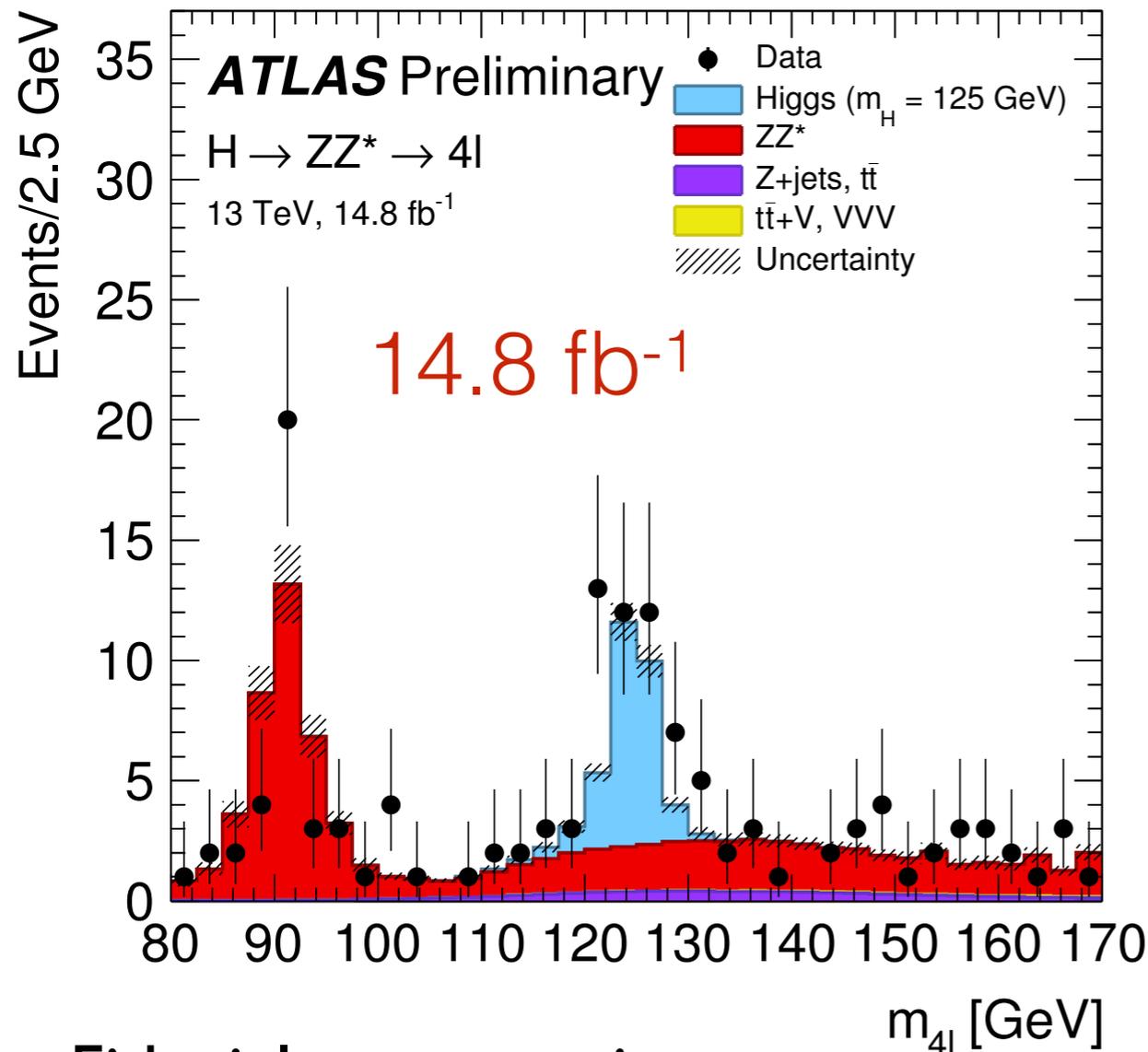
Luminosity:
8 TeV: 20 fb^{-1}
13 TeV: 40 fb^{-1}

- ▶ Largest increase in \sqrt{s} since the start of the LHC
- ▶ Luminosity doubling will need some time

News from the Higgs

1. Measurements (diboson couplings)
2. Searches (fermion couplings)

Higgs $\rightarrow ZZ^* \rightarrow 4l$

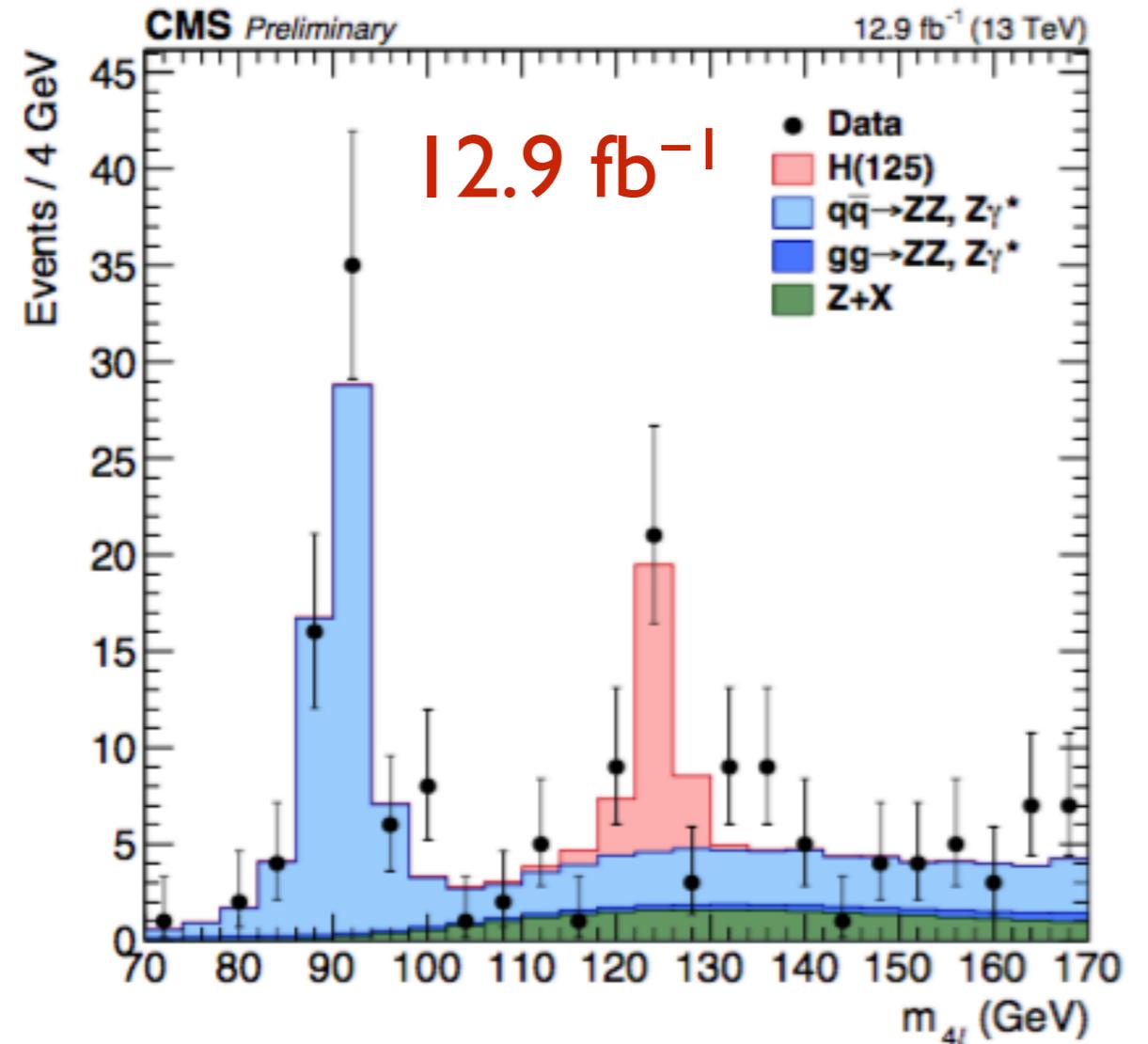


Fiducial cross section

$$\sigma_{\text{tot}} = 81^{+18}_{-16} \text{ pb}$$

$$\sigma_{\text{tot,SM}} = 55.5^{+3.8}_{-4.4} \text{ pb}$$

Compatible with SM at 1.6 σ



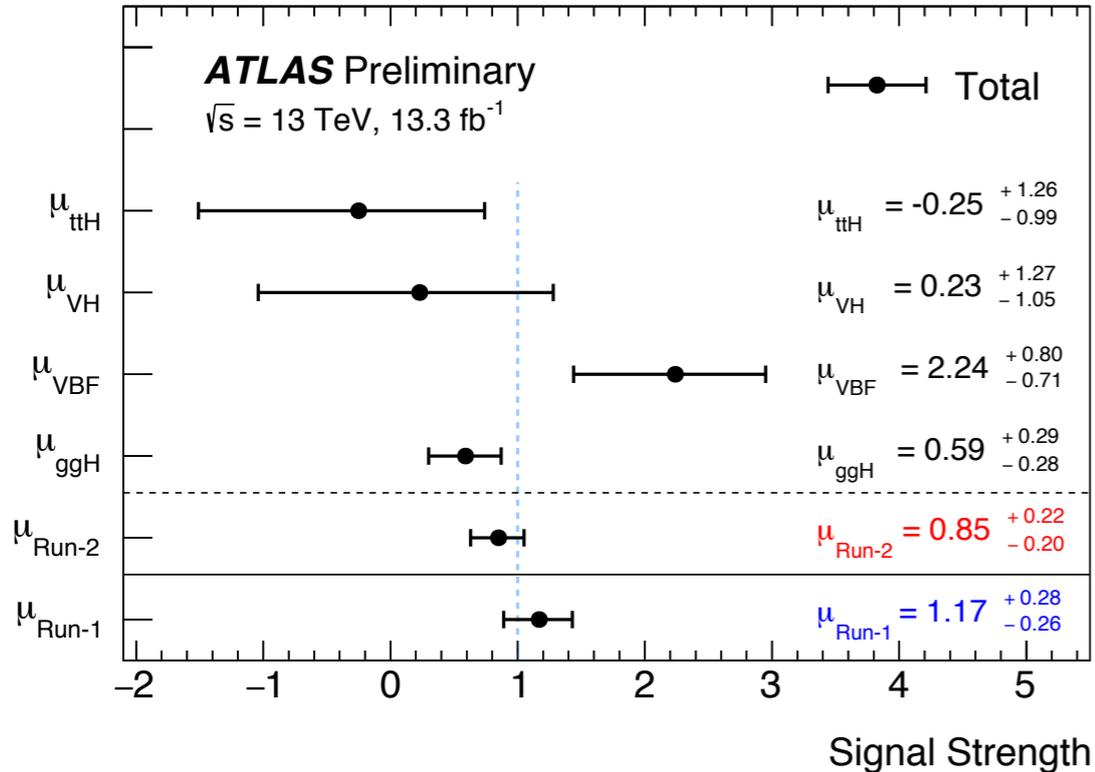
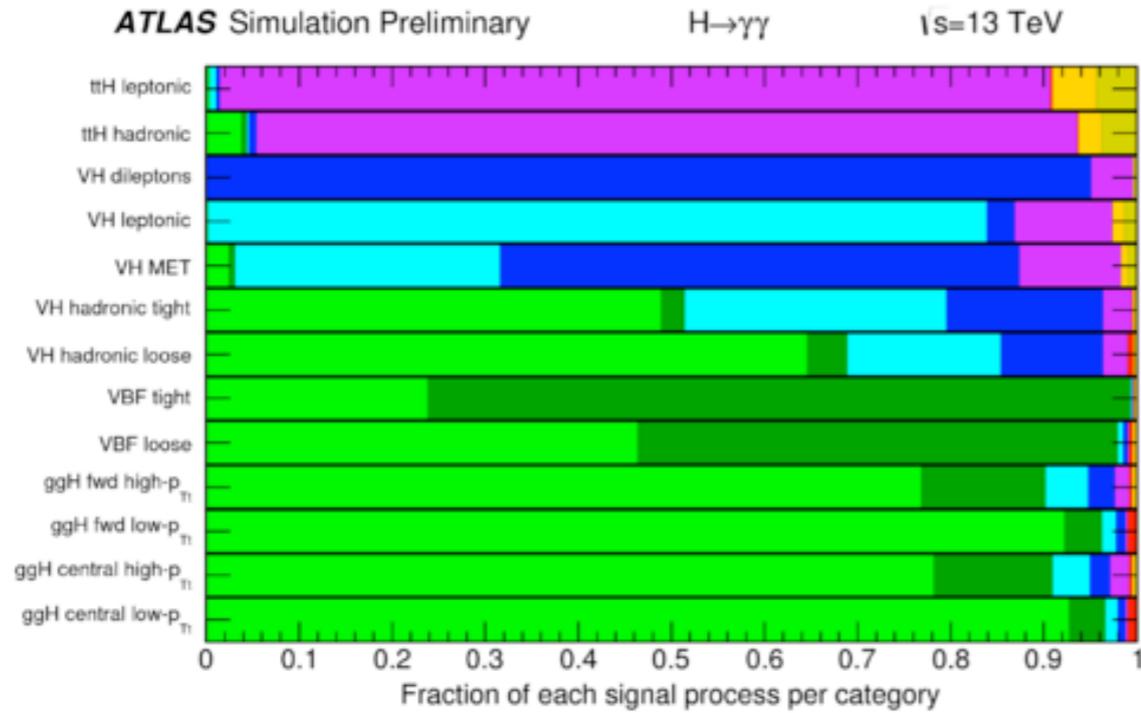
Higgs width

On-shell only: $\Gamma_H < 3.9$ GeV
 On- and off-shell: $\Gamma_H < 41$ MeV

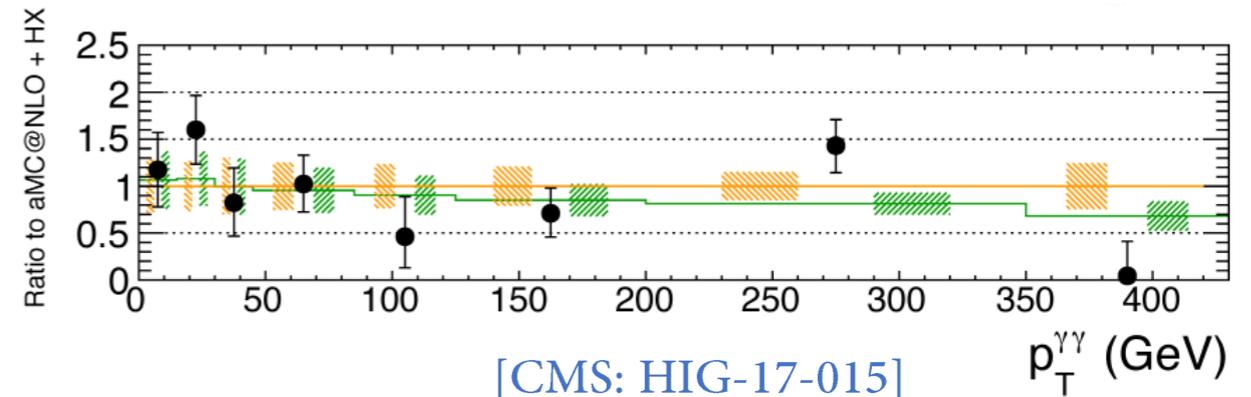
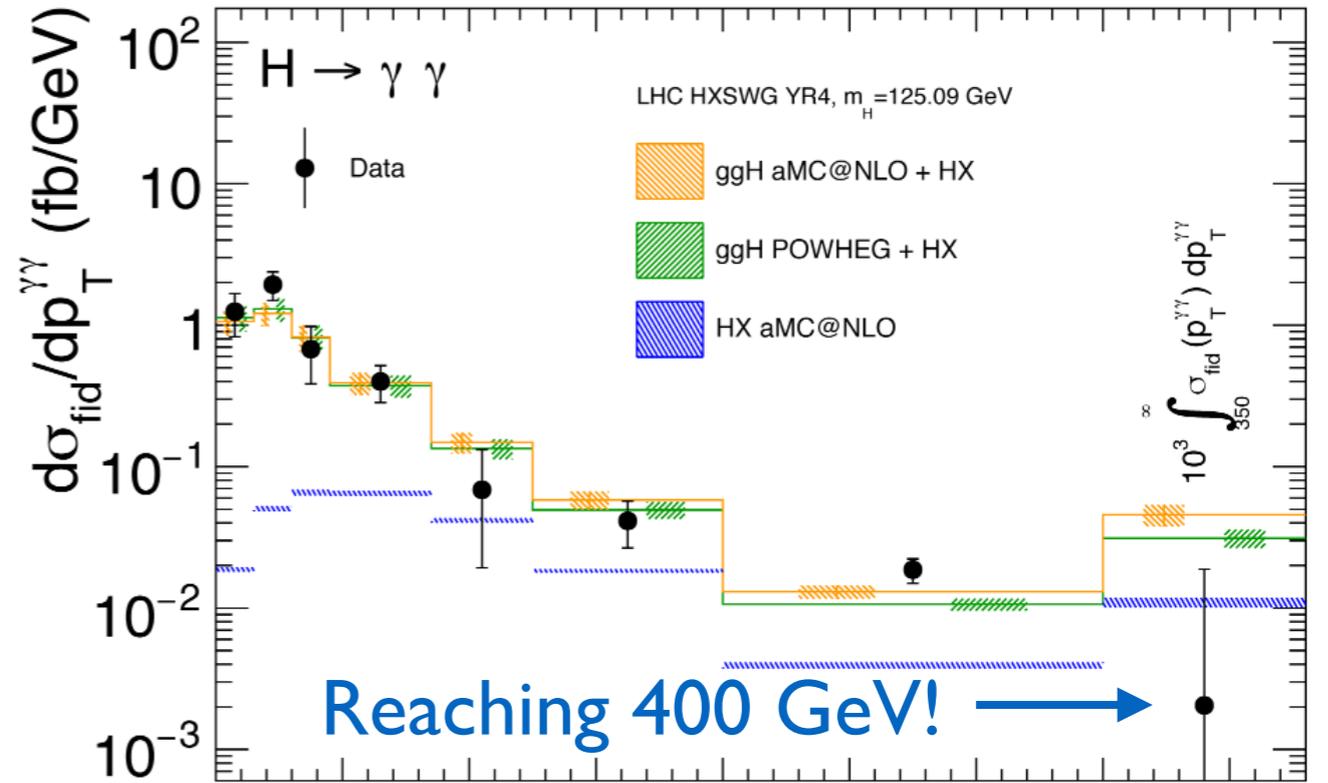
Assumes SM cross sections and no SM particles in loops

Higgs $\rightarrow \gamma\gamma$

ggH VBF WH ZH ttH bbH tHjb tWH



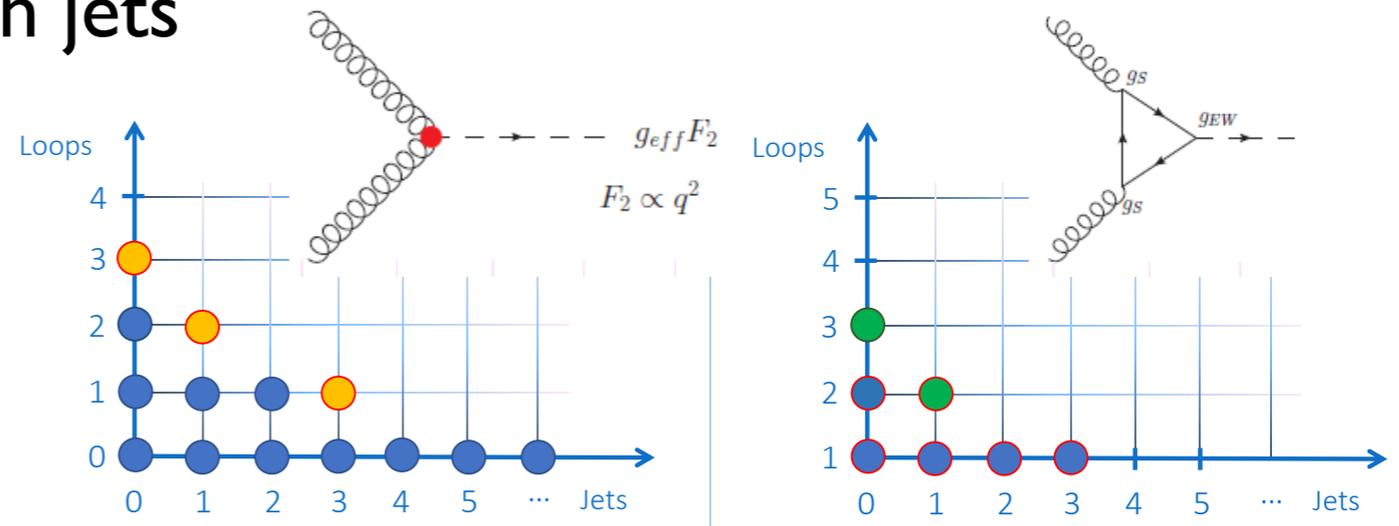
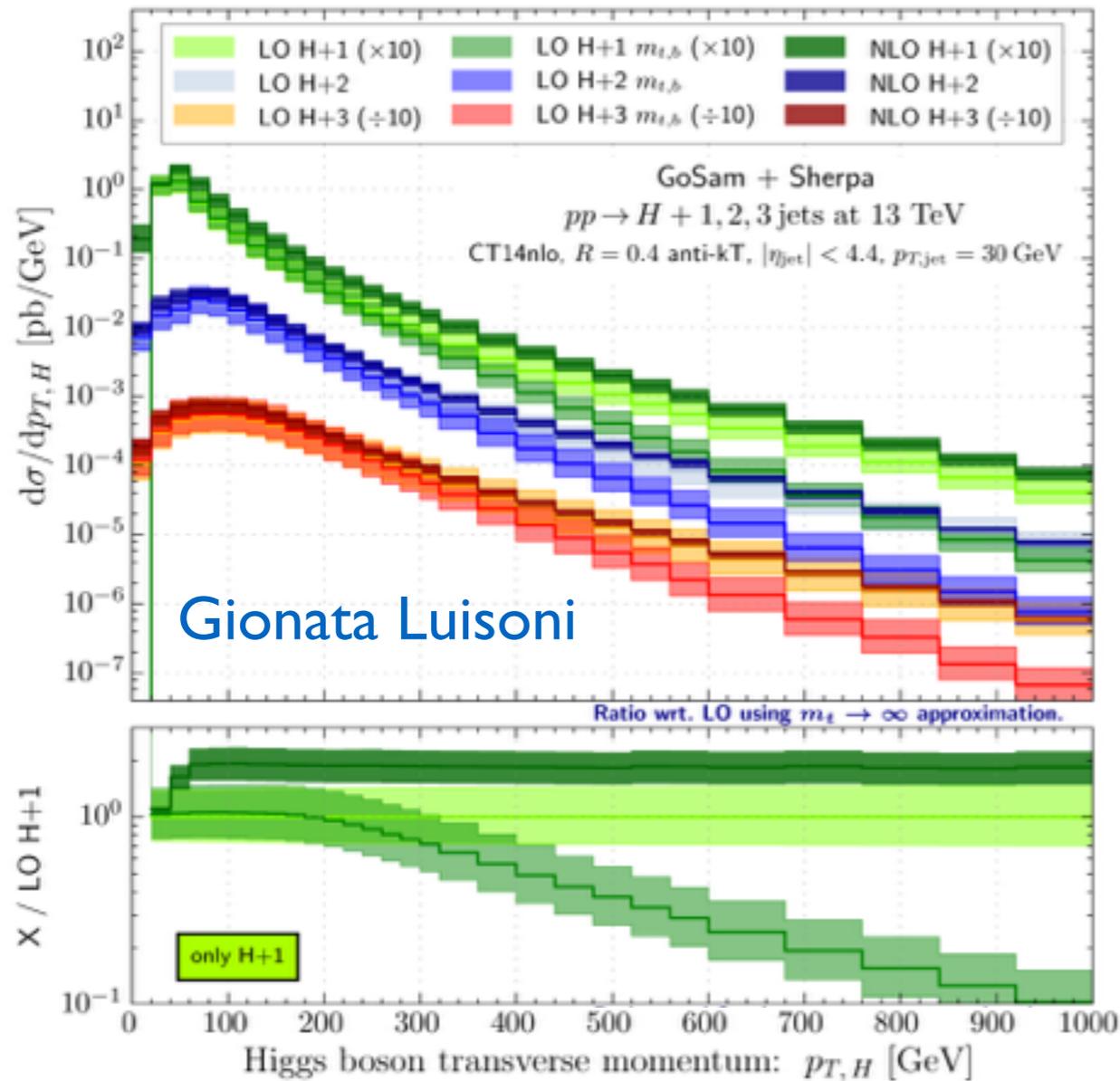
CMS Preliminary 35.9 fb^{-1} (13TeV)



Run-2: similar precision achieved as in Run-1!

Precision for SM Higgs Production

Higgs production in association with jets



Hadronic Higgs decays

α_s^4 contributions to $\Gamma(H \rightarrow \bar{b}b, gg)$

Born $\xrightarrow{1\text{-loop}}$ 20.3% $\xrightarrow{2\text{-loop}}$ 3.50% $\xrightarrow{3\text{-loop}}$ 0.361% $\xrightarrow{4\text{-loop}}$ 0.0567%

Joshua Davies

- Numerically small
- QCD series is well converging

H+jets: Large impact of finite top quark mass effects at large p_T

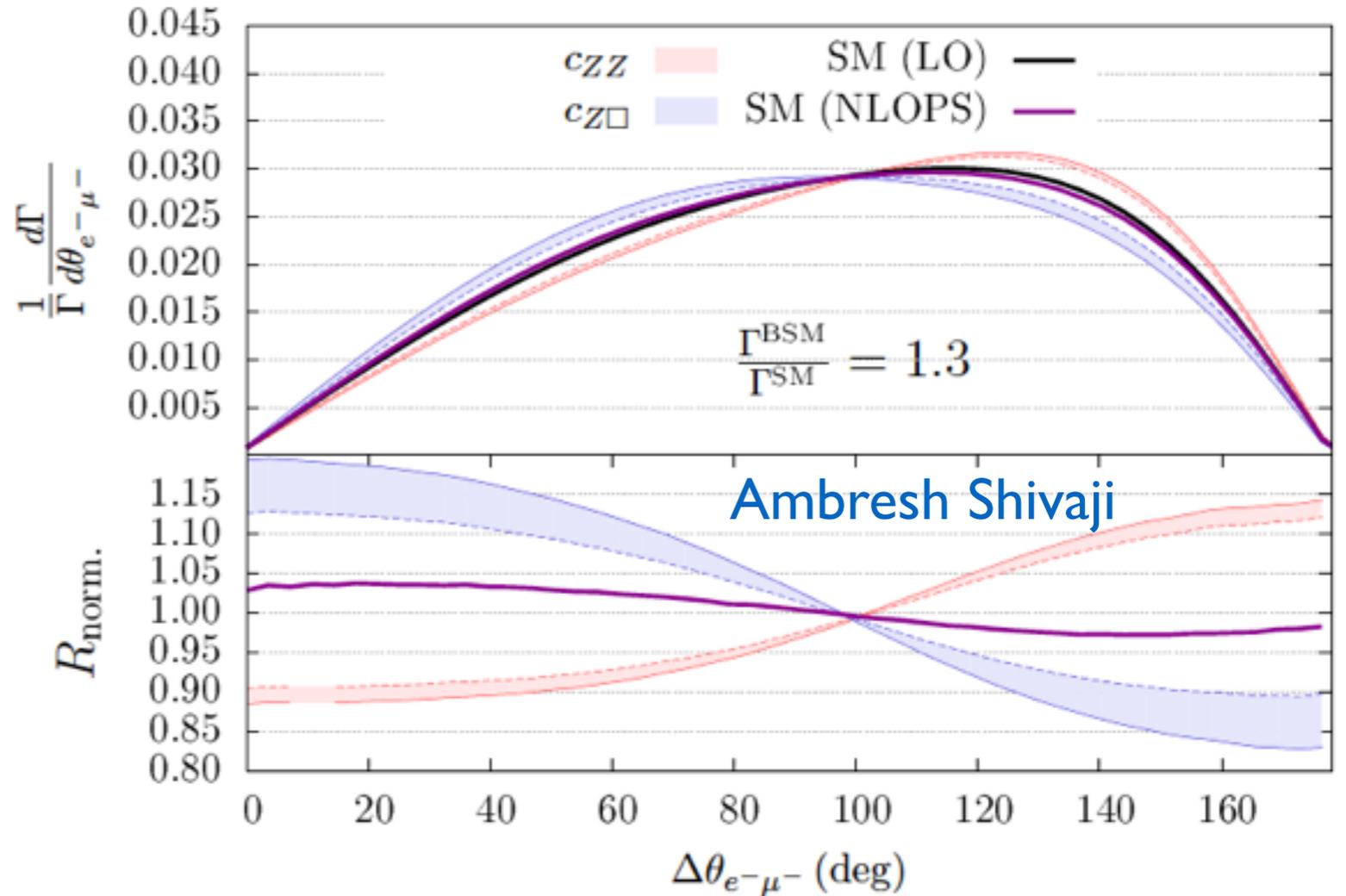
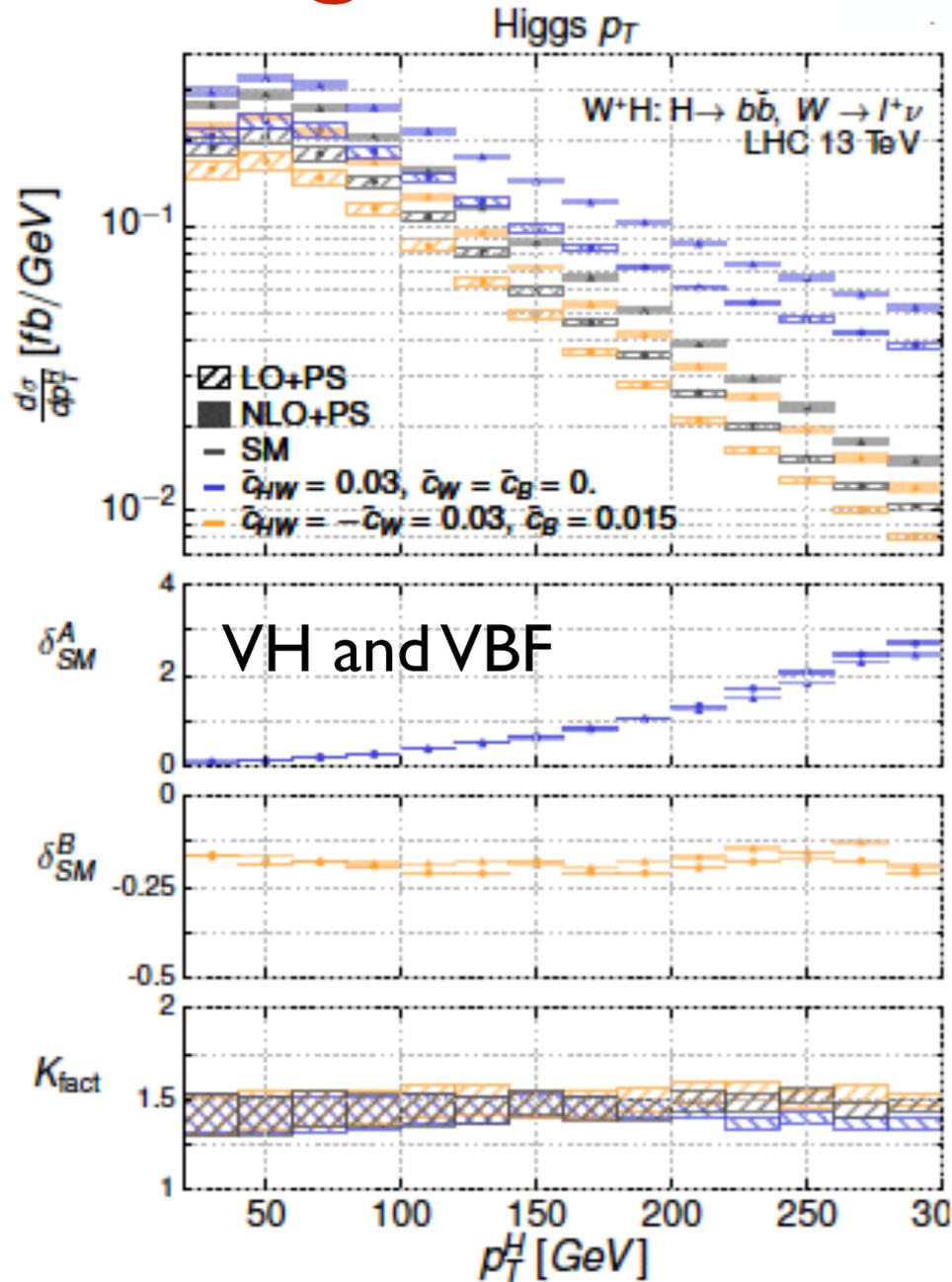
EFT for Higgs Physics

No light new particles:

$$\mathcal{L}_{\text{eff}} = \sum_i \frac{c_i \mathcal{O}_i^D}{\Lambda^{D-4}}$$

EFT@NLO in QCD

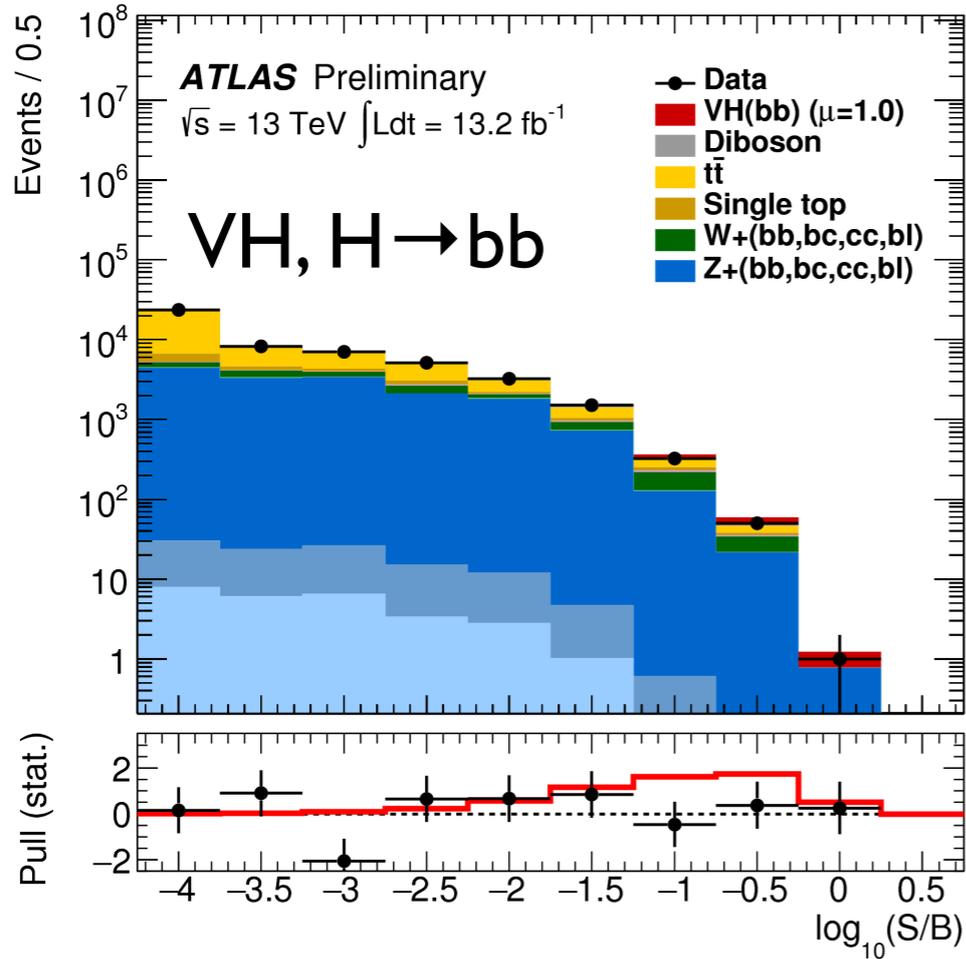
$$\begin{aligned} \mathcal{L}_{D6} = & \frac{1}{\Lambda^2} \left[\frac{g'^2}{4} \bar{c}_{BB} \Phi^\dagger \Phi B^{\mu\nu} B_{\mu\nu} + \frac{ig}{2} \bar{c}_W [\Phi^\dagger T_{2k} \overleftrightarrow{D}^\mu \Phi] D^\nu W_{\mu\nu}^k + \frac{ig'}{2} \bar{c}_B [\Phi^\dagger \overleftrightarrow{D}^\mu \Phi] \partial^\nu B_{\mu\nu} \right. \\ & + ig \bar{c}_{HW} [D^\mu \Phi^\dagger T_{2k} D^\nu \Phi] W_{\mu\nu}^k + ig' \bar{c}_{HB} [D^\mu \Phi^\dagger D^\nu \Phi] B_{\mu\nu} \\ & \left. + \frac{g'^2}{4} \tilde{c}_{BB} \Phi^\dagger \Phi B^{\mu\nu} \tilde{B}_{\mu\nu} + ig \tilde{c}_{HW} [D^\mu \Phi^\dagger T_{2k} D^\nu \Phi] \tilde{W}_{\mu\nu}^k + ig' \tilde{c}_{HB} [D^\mu \Phi^\dagger D^\nu \Phi] \tilde{B}_{\mu\nu} \right] \end{aligned}$$



H→4l implementation of H decays in the EFT

H → bb, μμ

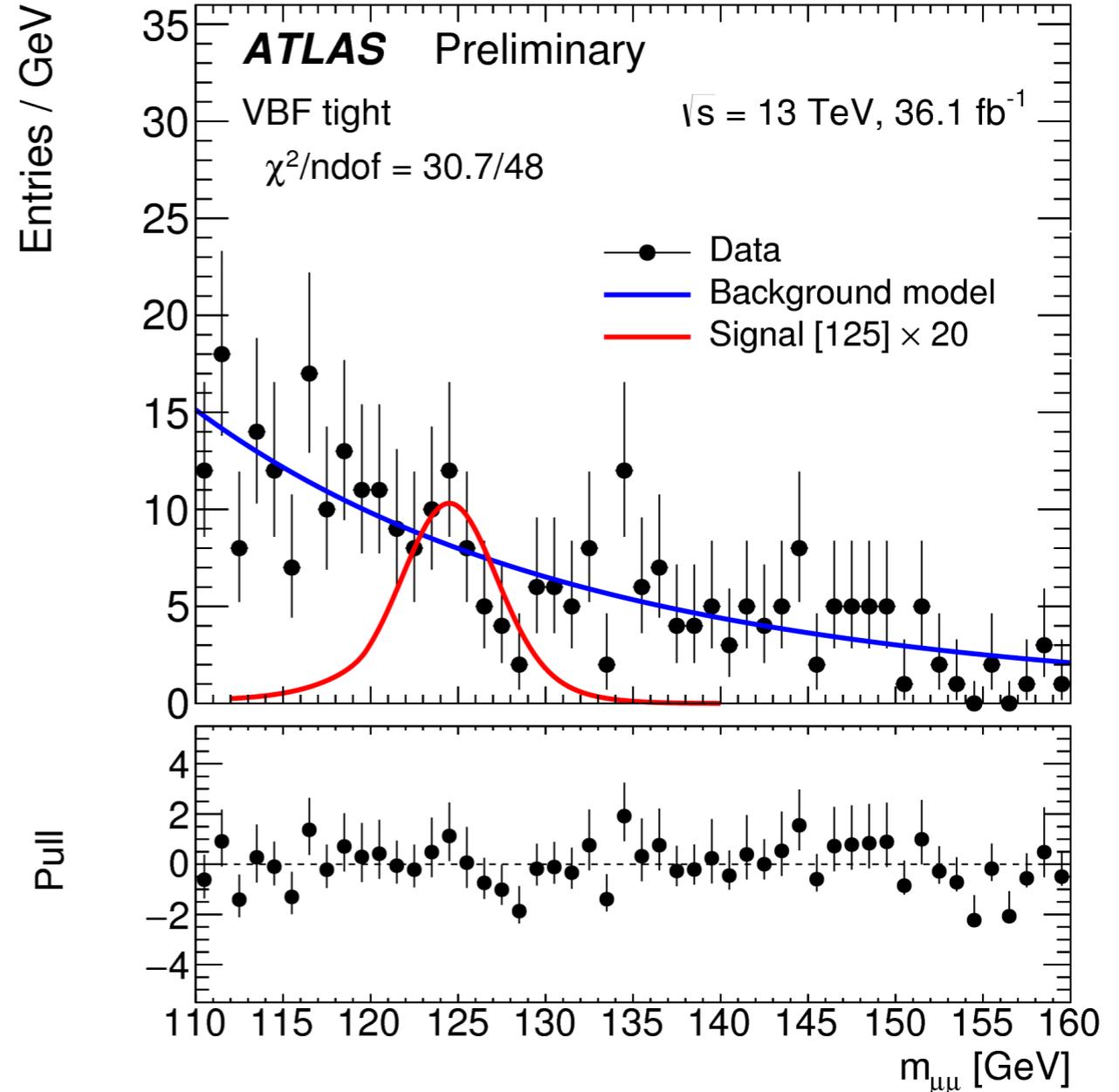
Full 13 TeV dataset!



All discriminant bins combined

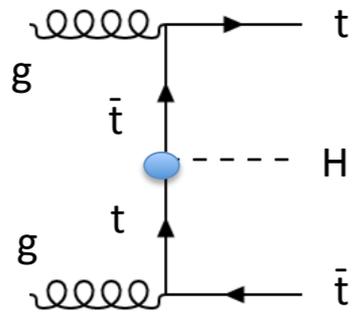
$$\mu = 0.21_{-0.35}^{+0.36} (\text{stat.}) \pm 0.36 (\text{syst.})$$

with significance of 0.42σ (exp. 1.94σ)
 and $\mu < 1.2$ (exp. 1.0) @95%CL

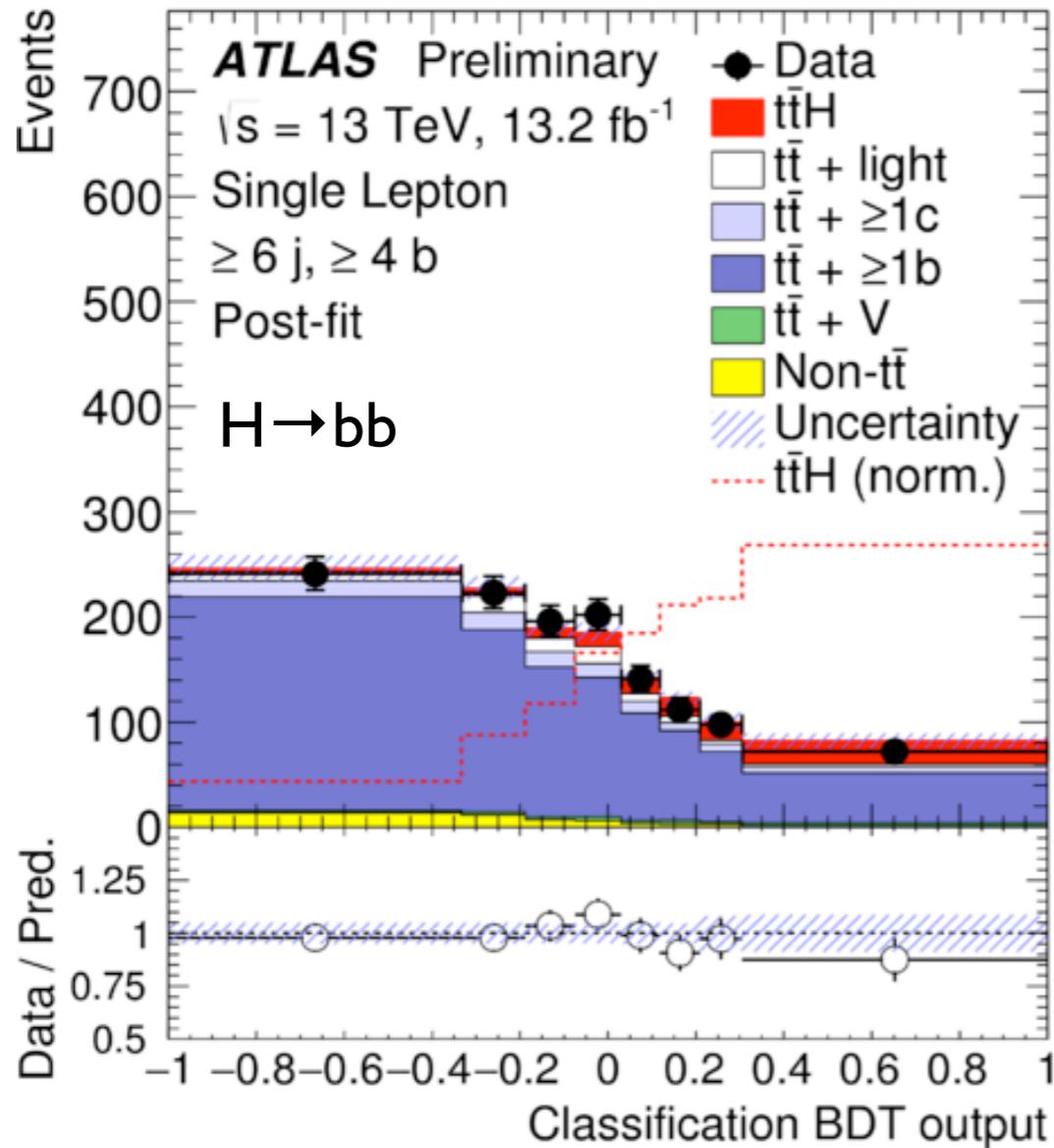


New for Run-2: VBF selection

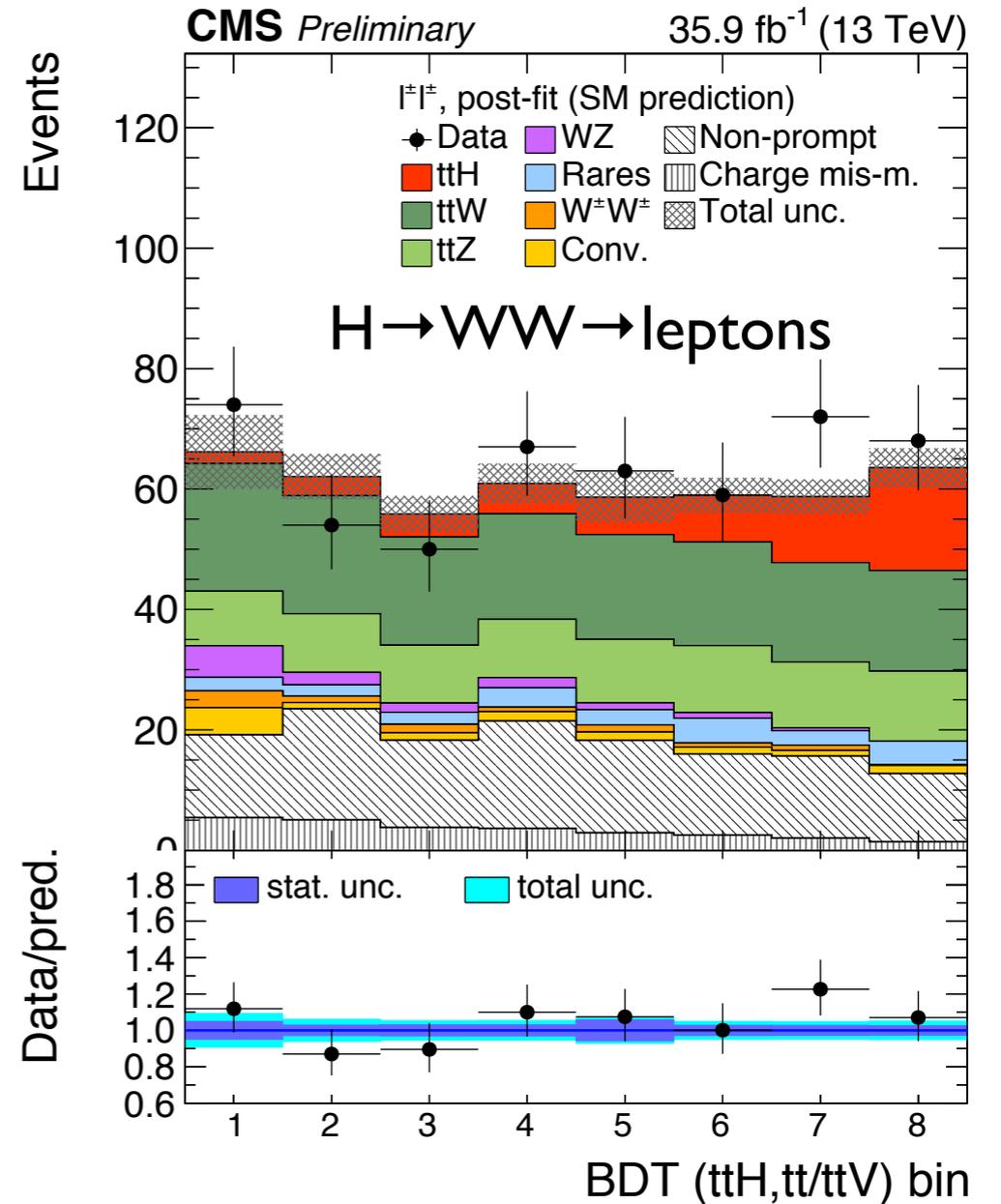
$$\mu = -0.07 \pm 1.5 \text{ with } \mu < 3.0 \text{ (3.1)}$$



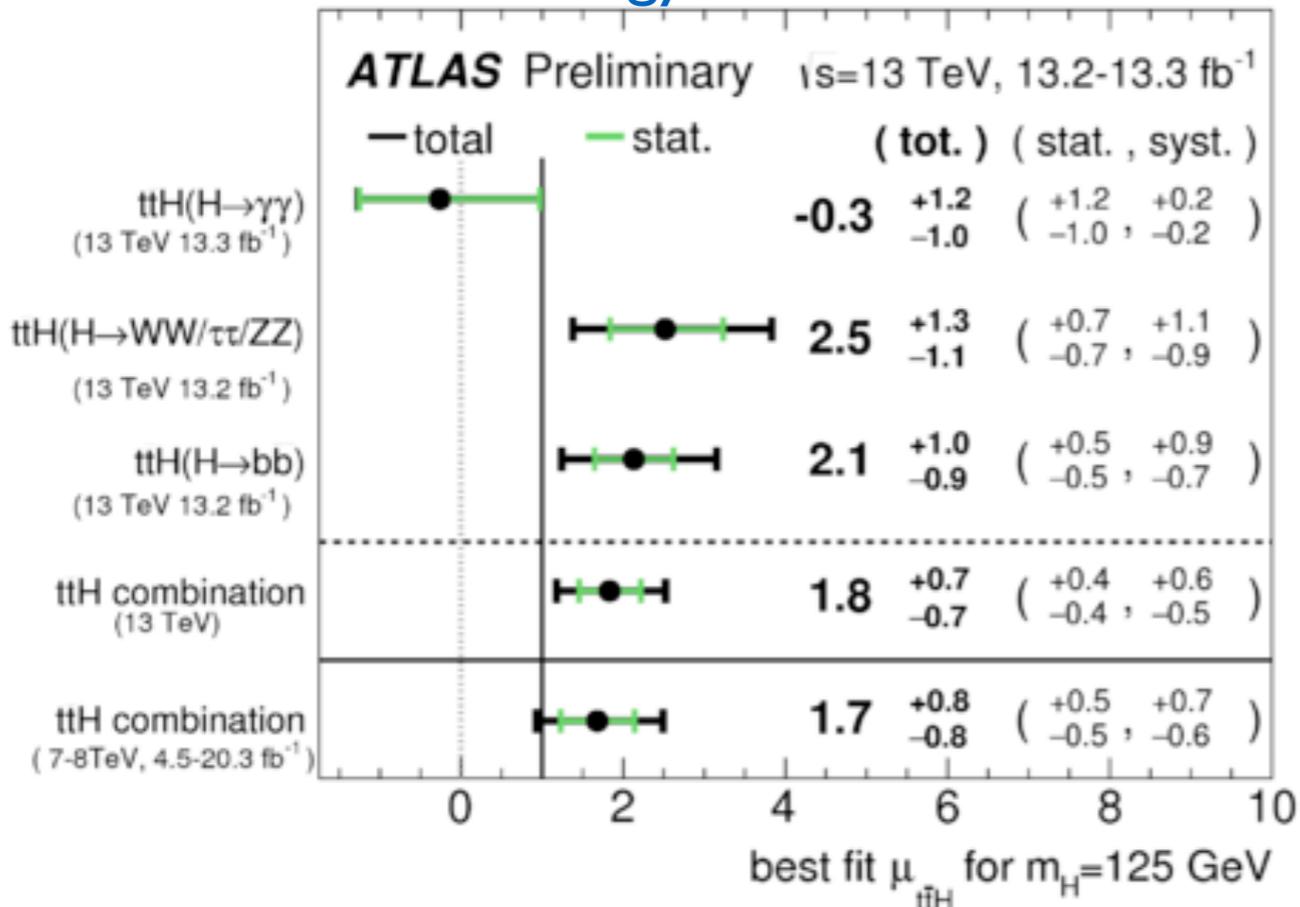
ttH



Full 13 TeV dataset!



MVA methods for suppression of irreducible backgrounds
 (tt+bb, tt+cc, ttV)

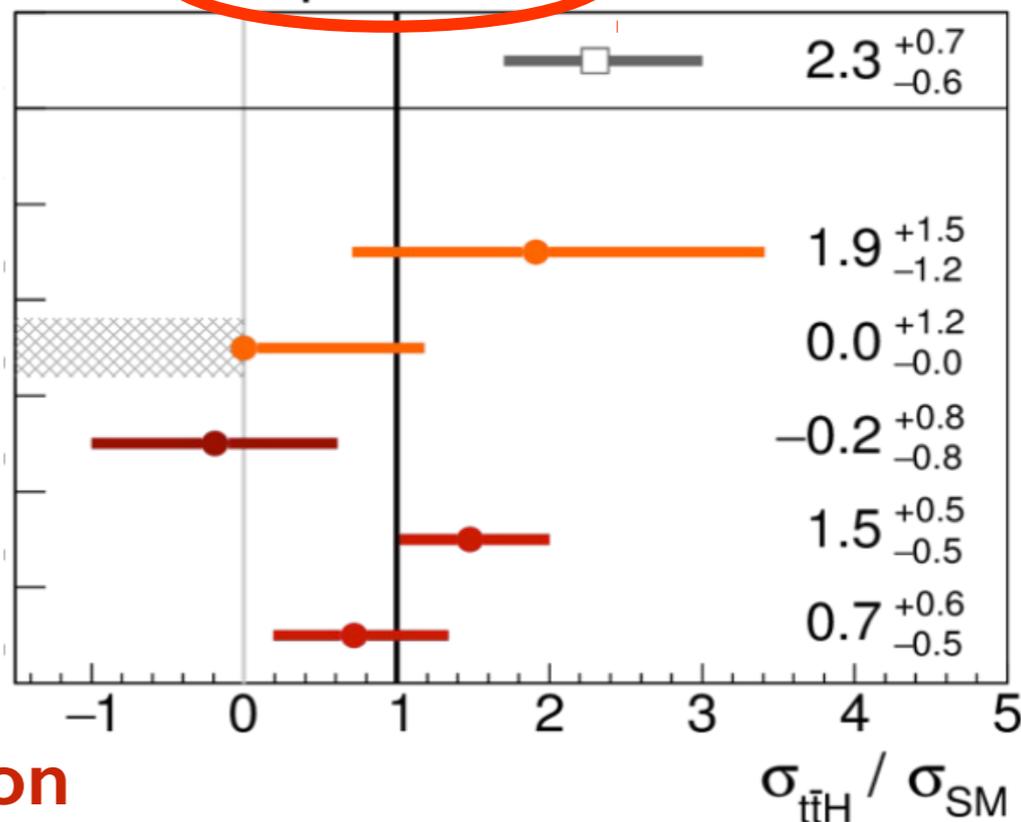


Similar sensitivity between Run-1 and Run-2 (half the data)

Full 13 TeV dataset!

- YY
- ZZ → 4l
- bb
- WW/ZZ/ττ
- ττ

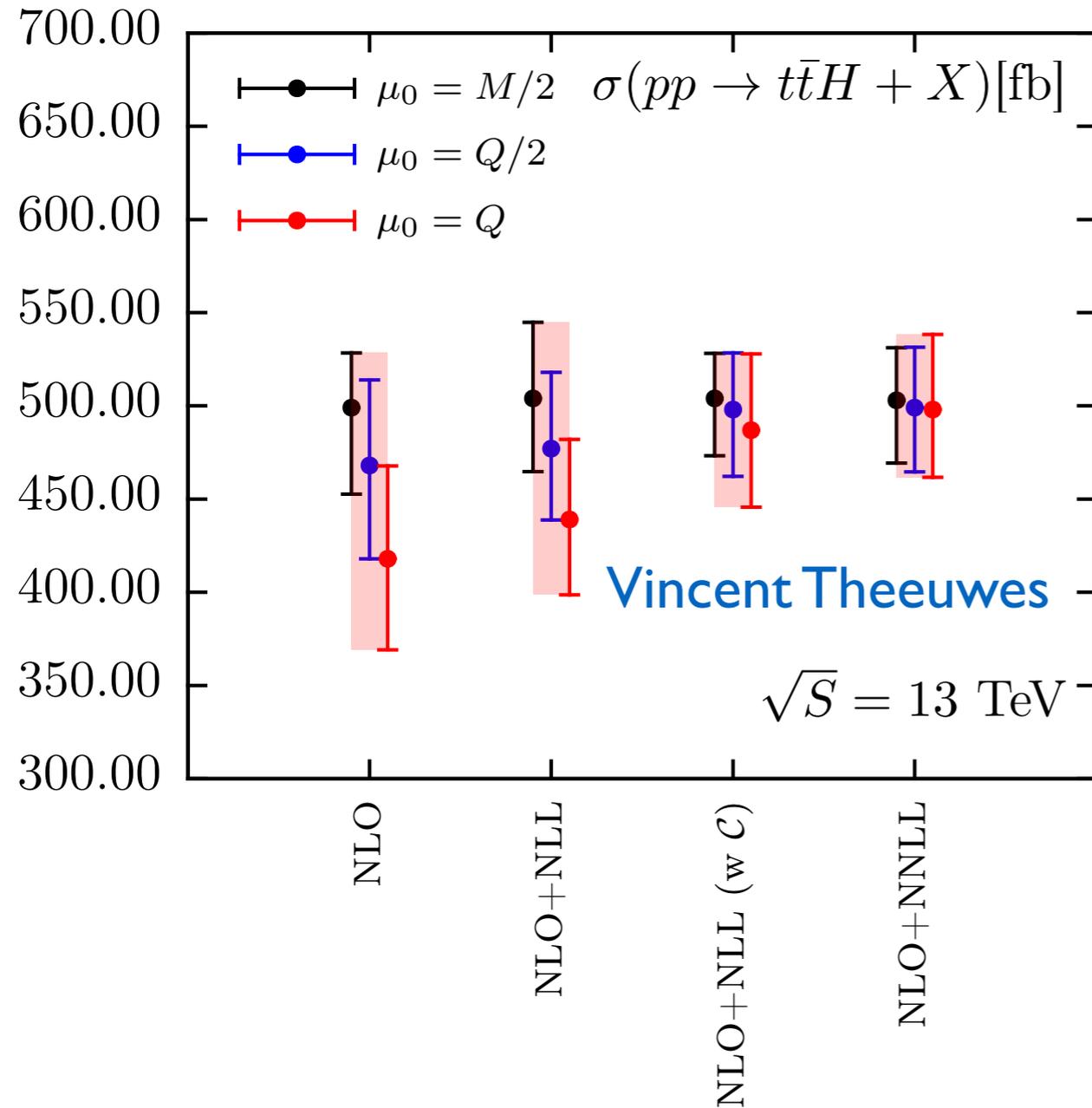
CMS $t\bar{t}H$ production Georgios Krintiras



3.3σ (2.5σ expected) for ttH production

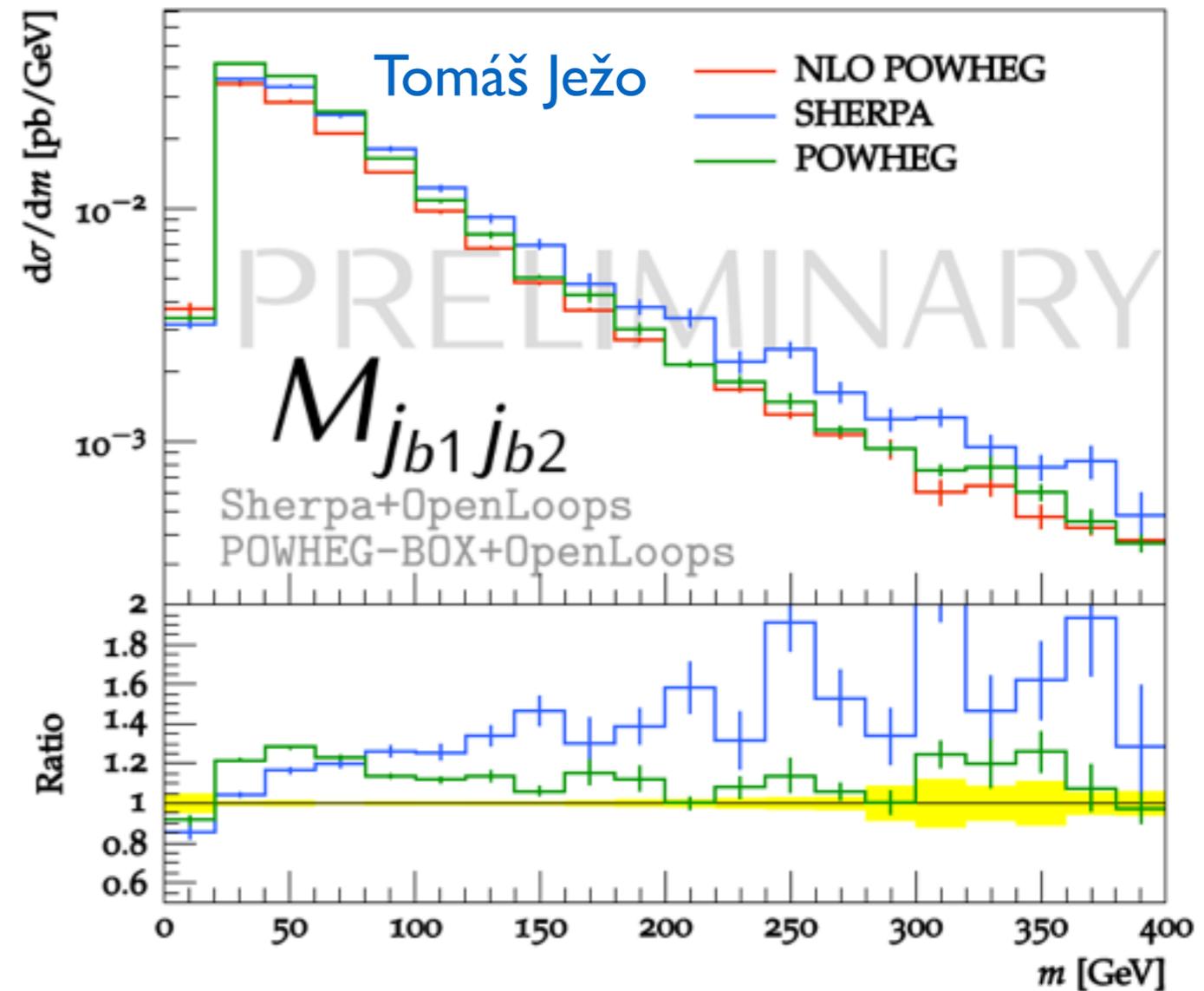
Precision ttH Modelling

Soft Gluon Resummation for ttH



Dependence on scale choice reduced through resummation

NLO+PS matching for ttbb with massive b's (irreducible background to ttH)



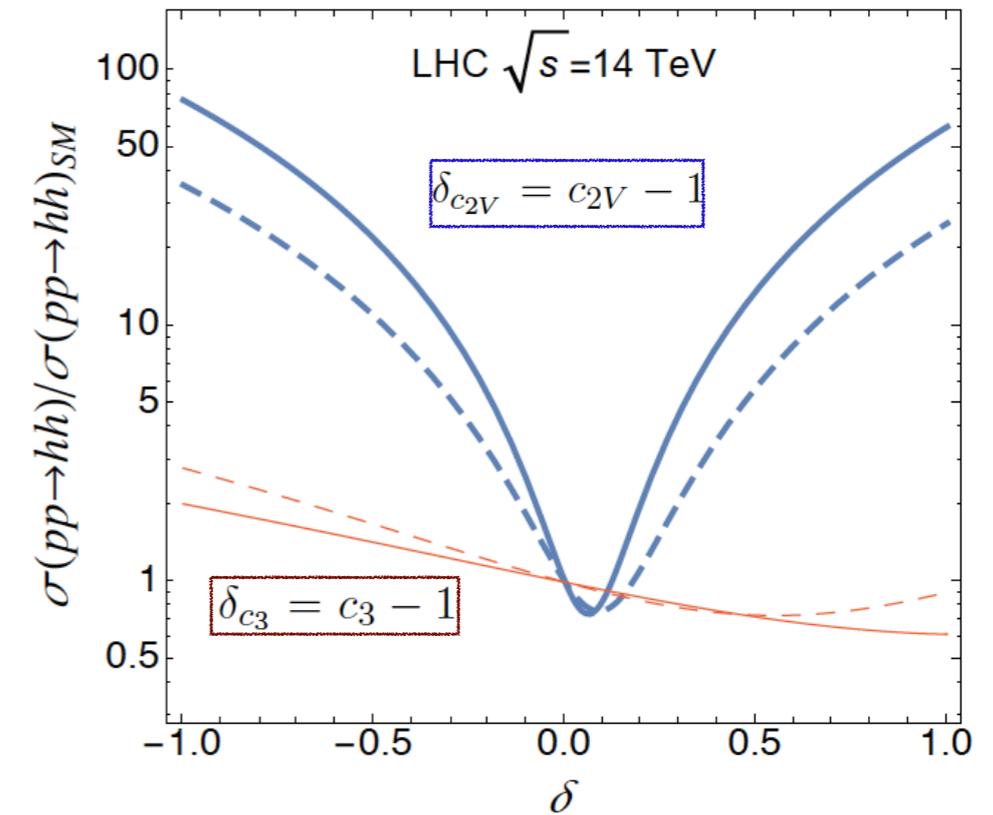
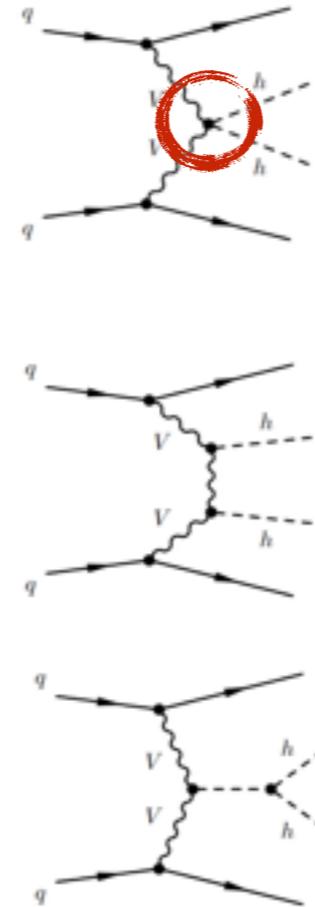
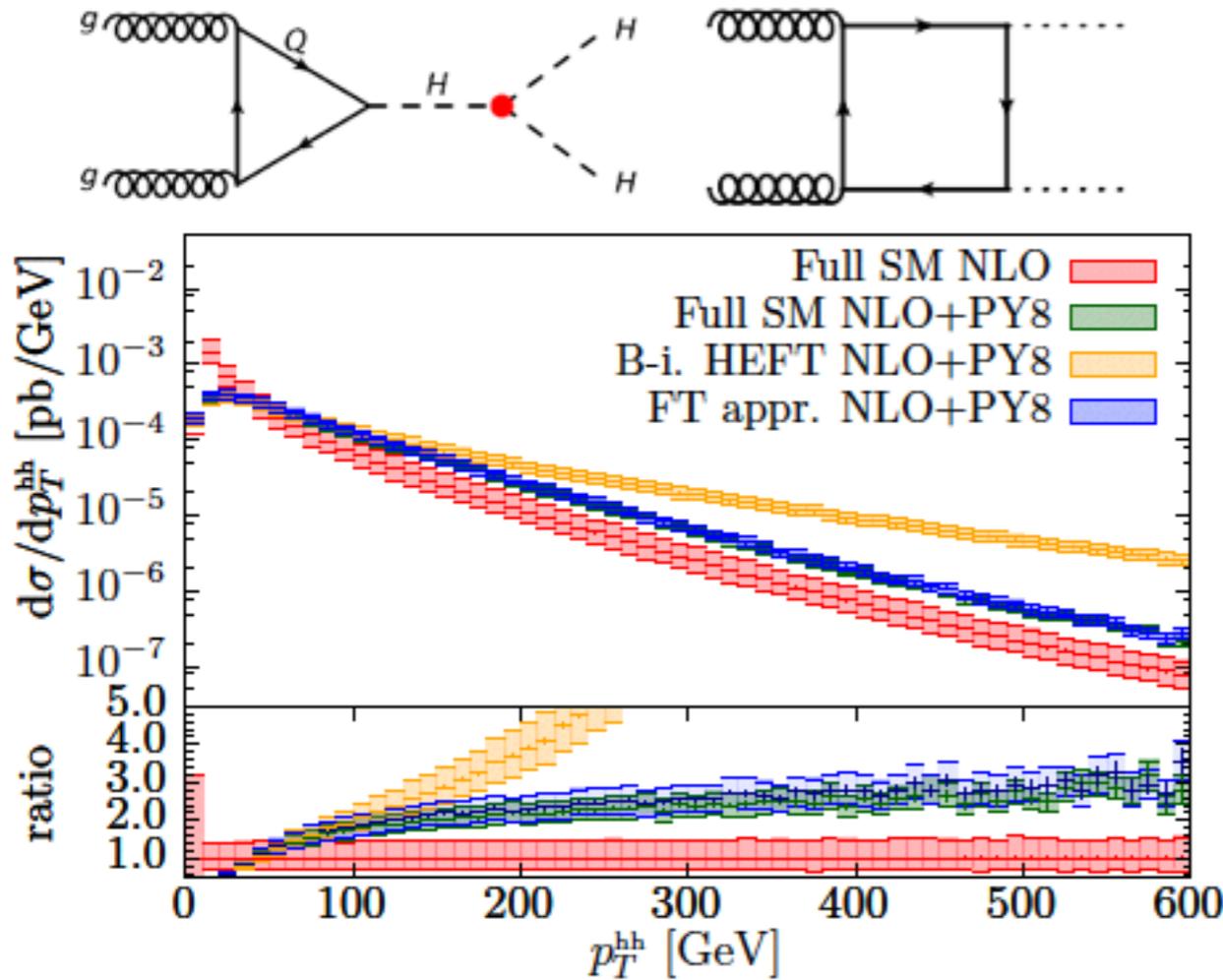
Shower corrections less significant

Higgs as a Probe of New Physics

Higgs Pair Production

Juan Rojo

Matthias Kerner



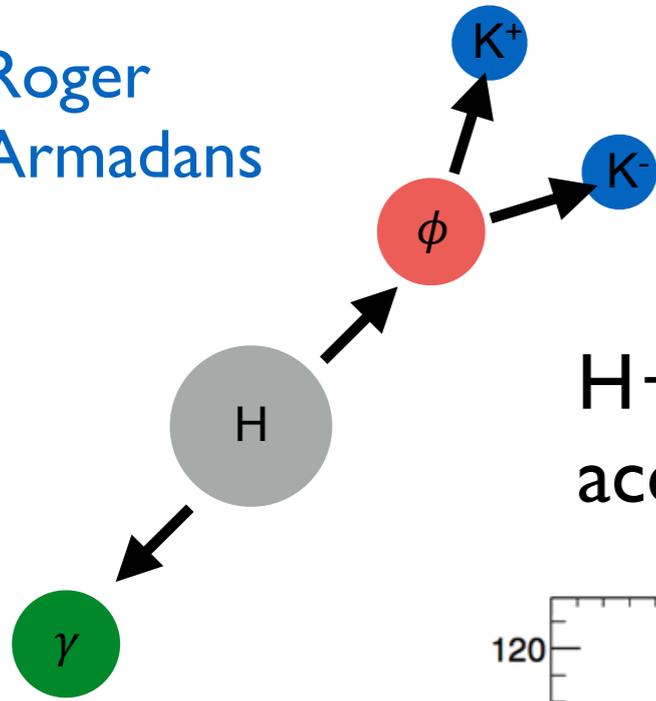
Full top-quark dependence for HH at NLO+PS

Prospects for HHV coupling

	68% probability interval on $\delta_{c_{2V}}$	
	$1 \times \sigma_{\text{bkg}}$	$3 \times \sigma_{\text{bkg}}$
LHC ₁₄	[-0.37, 0.45]	[-0.43, 0.48]
HL-LHC	[-0.15, 0.19]	[-0.18, 0.20]
FCC ₁₀₀	[0, 0.01]	[-0.01, 0.01]

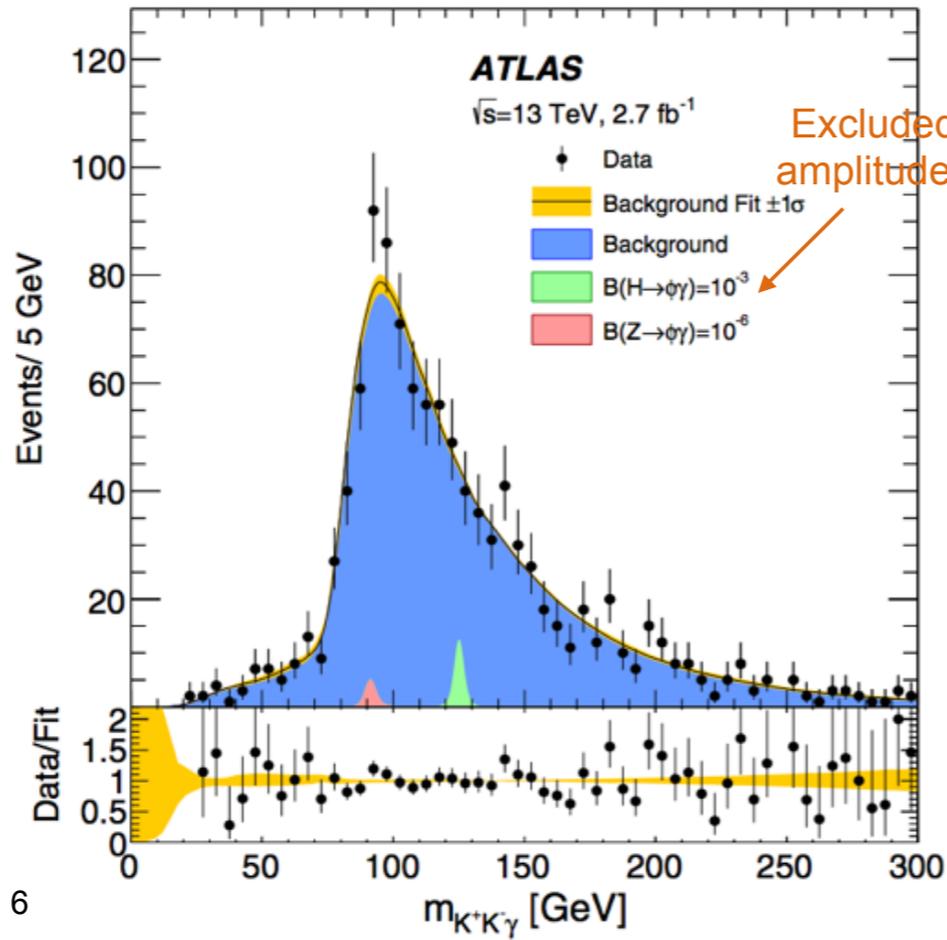
Idealized study in 4b channel

Rare Higgs Decays



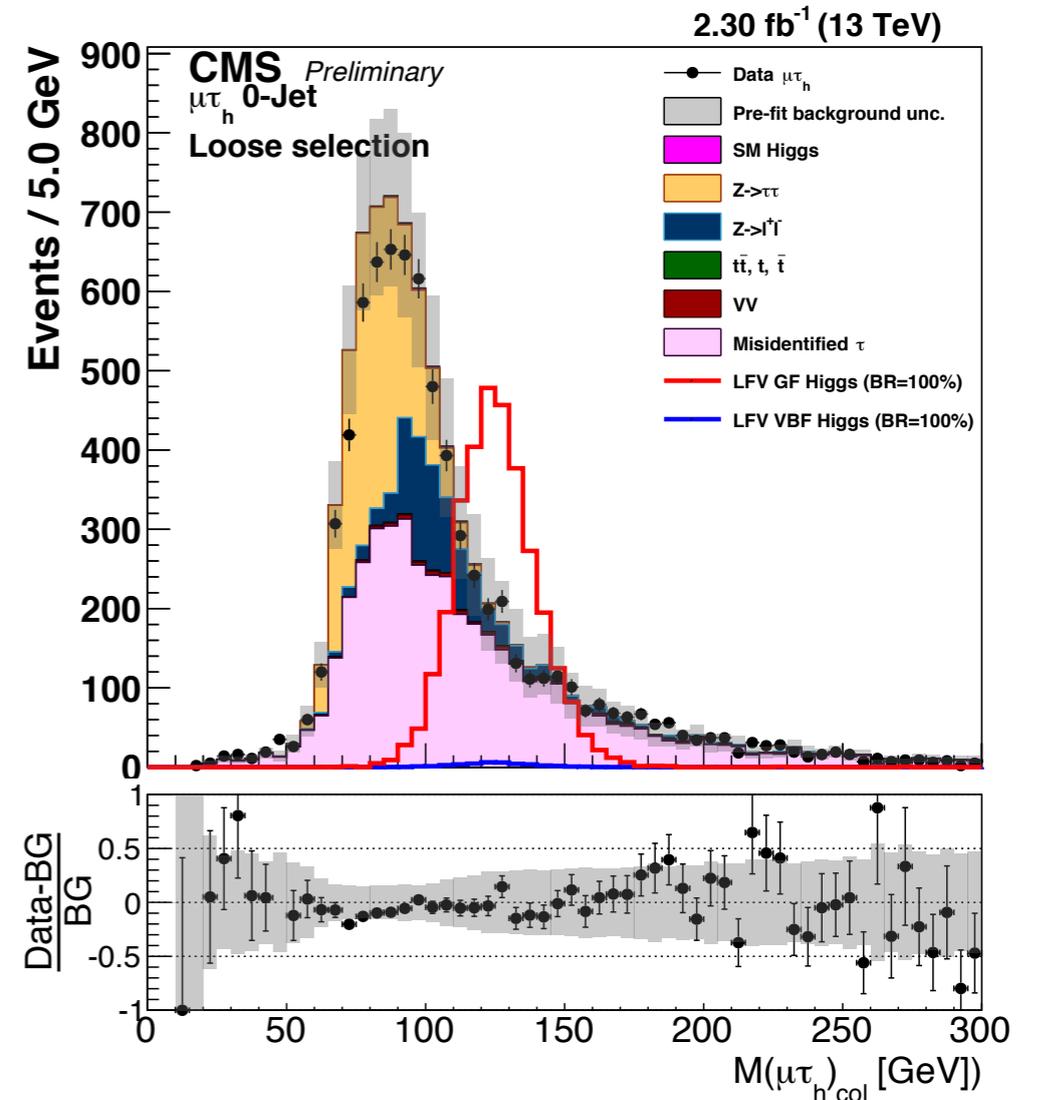
$H \rightarrow \phi\gamma$, $BR \sim 10^{-6}$
access s quark coupling

First measurement!



Branching fraction limit (95% C.L.)	Expected	Observed
$B(H \rightarrow \phi\gamma)[10^{-3}]$	$1.5^{+0.7}_{-0.4}$	1.4
$B(Z \rightarrow \phi\gamma)[10^{-6}]$	$4.4^{+2.0}_{-1.2}$	8.3

LFV Higgs decays
 $H \rightarrow e\mu, e\tau, \mu\tau$

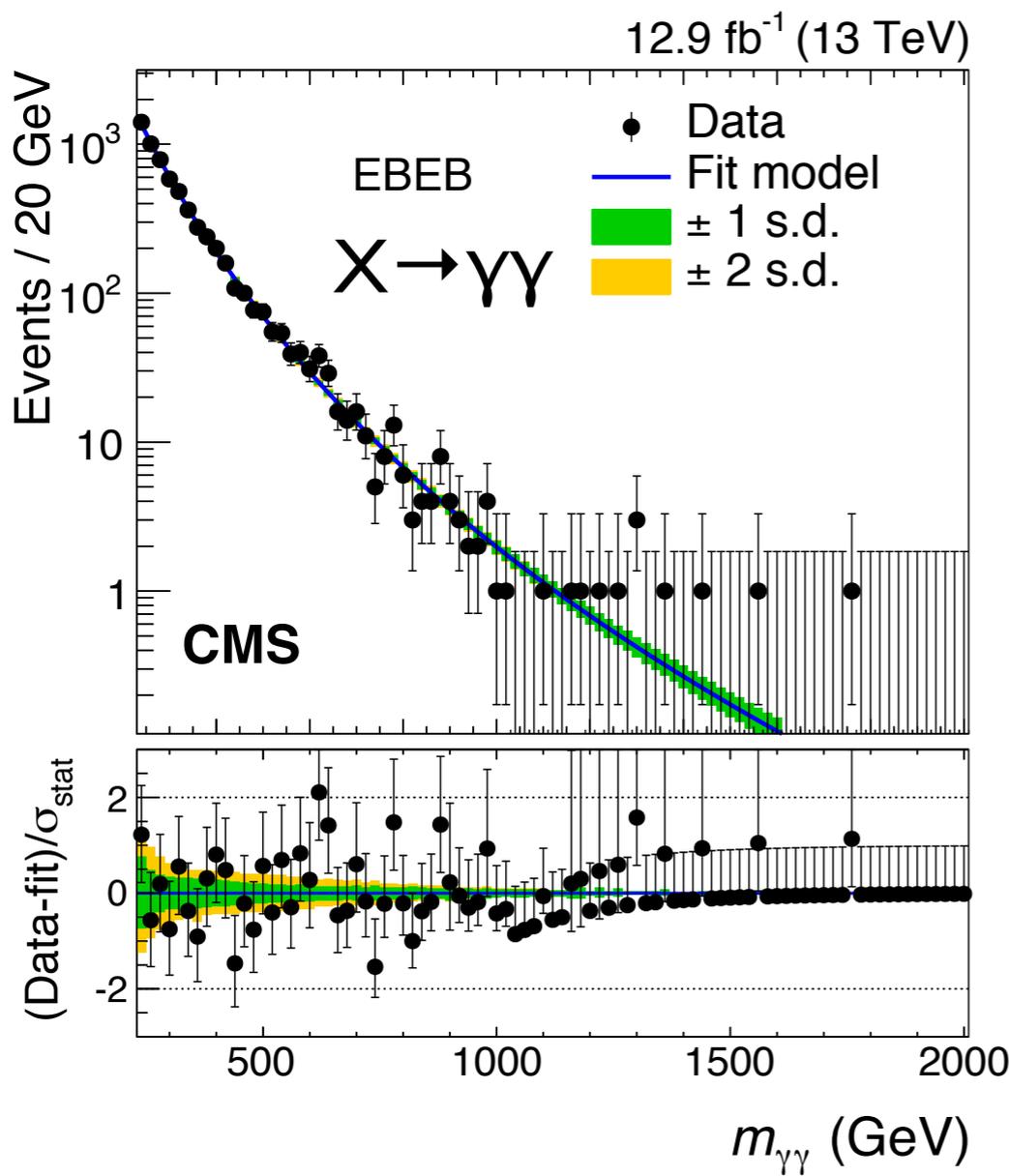


$Br(h \rightarrow \mu\tau) < 1.20\%$
(1.62% expected)

(2.4σ at 8 TeV from $h \rightarrow \mu\tau$ not confirmed, comparable sensitivity)

Additional Scalars

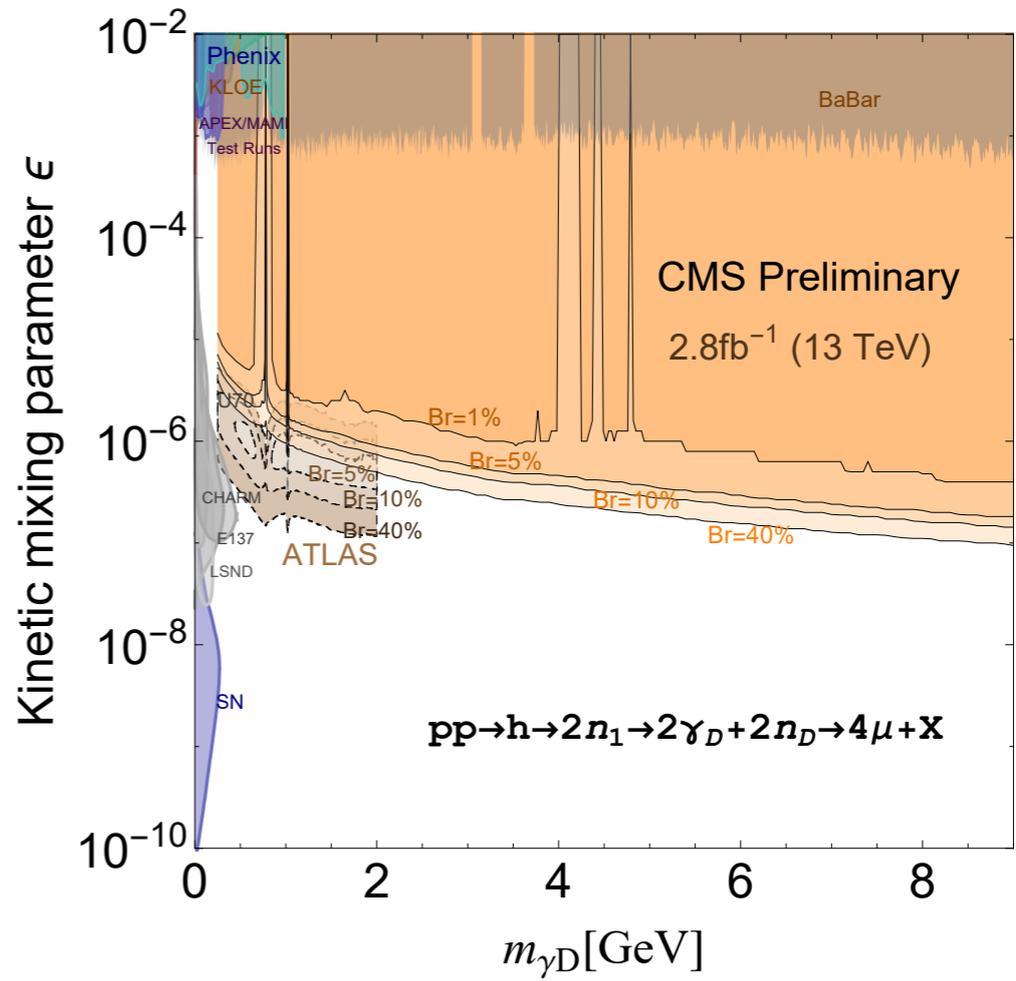
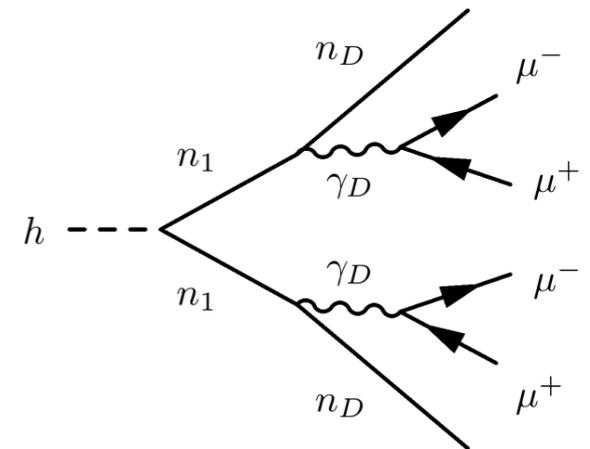
High Mass Searches

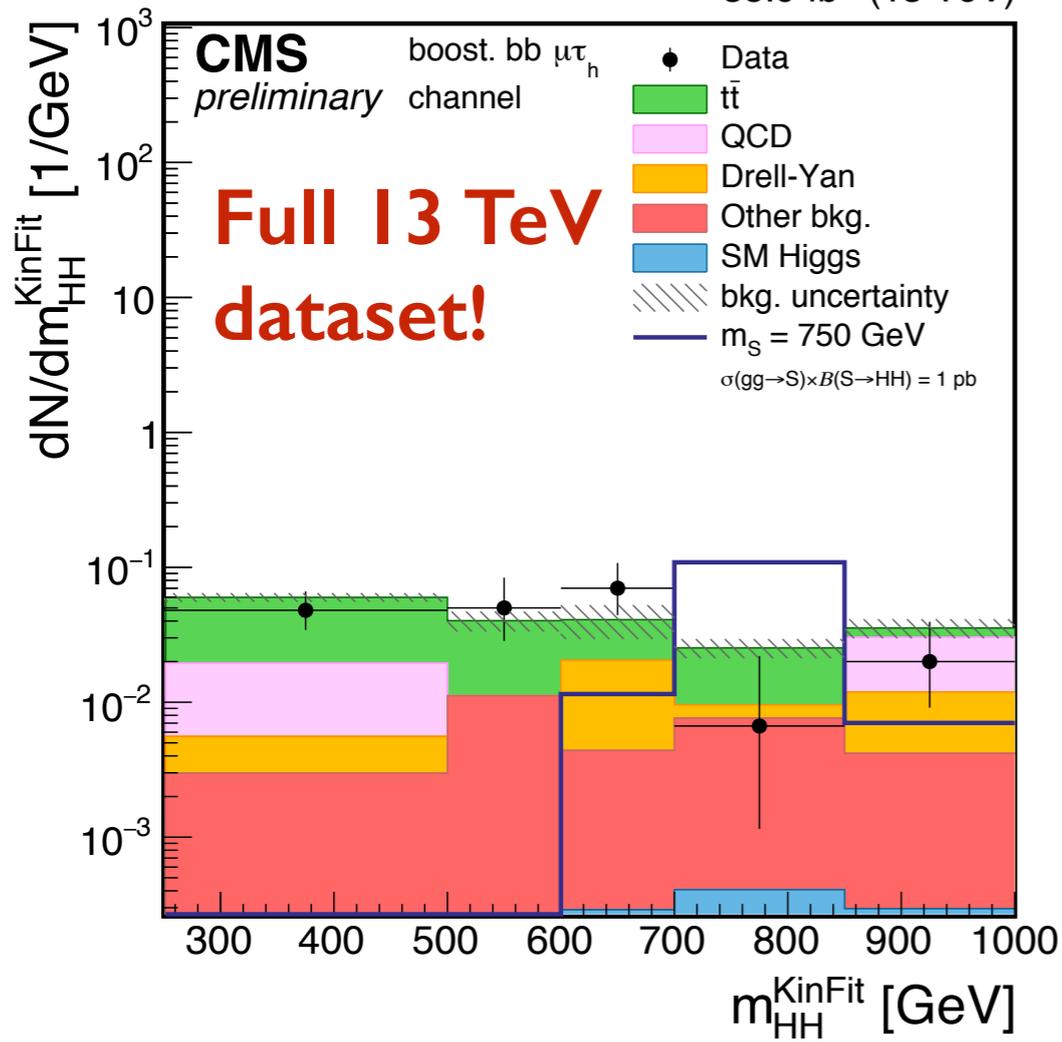
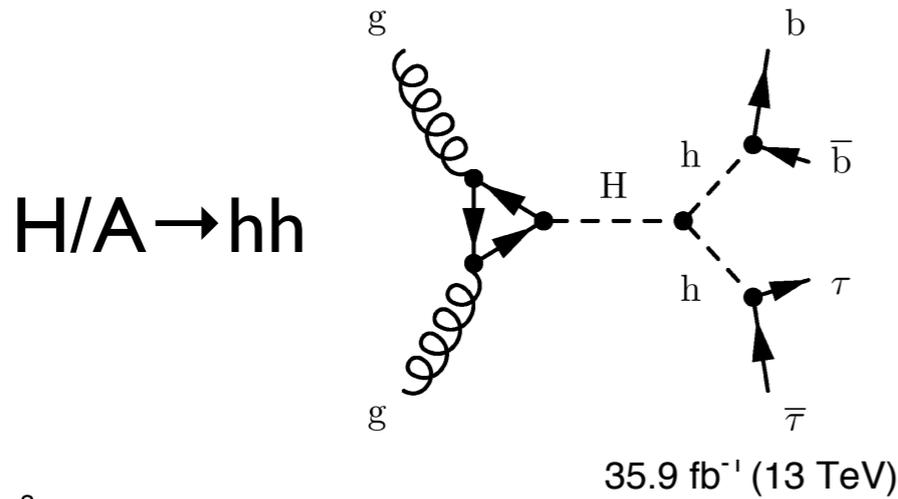


Upper cross section limits: fb region
Also: $X \rightarrow Z\gamma$ searches

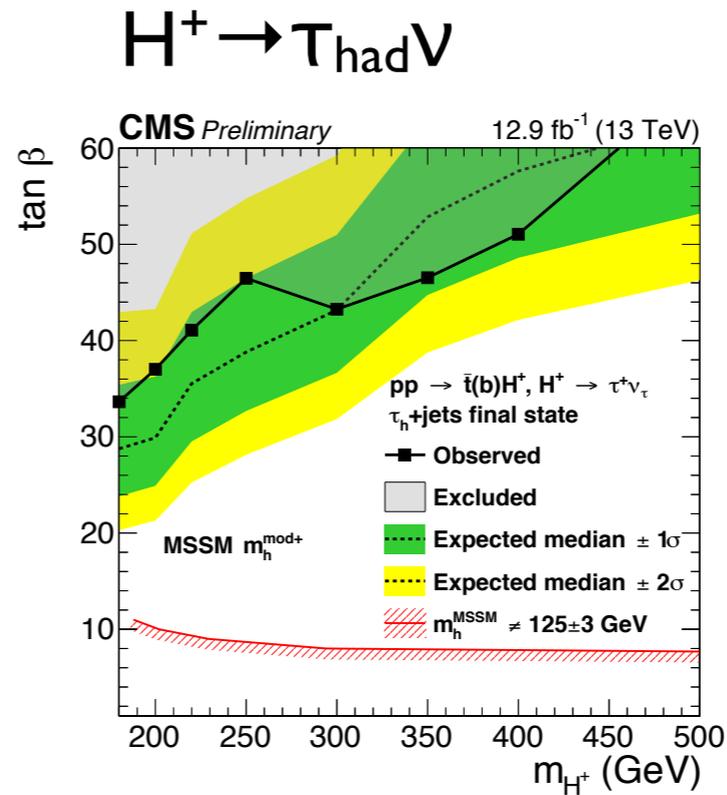
Low Mass Searches $H \rightarrow aa \rightarrow 4\mu$

Dark photon interpretation

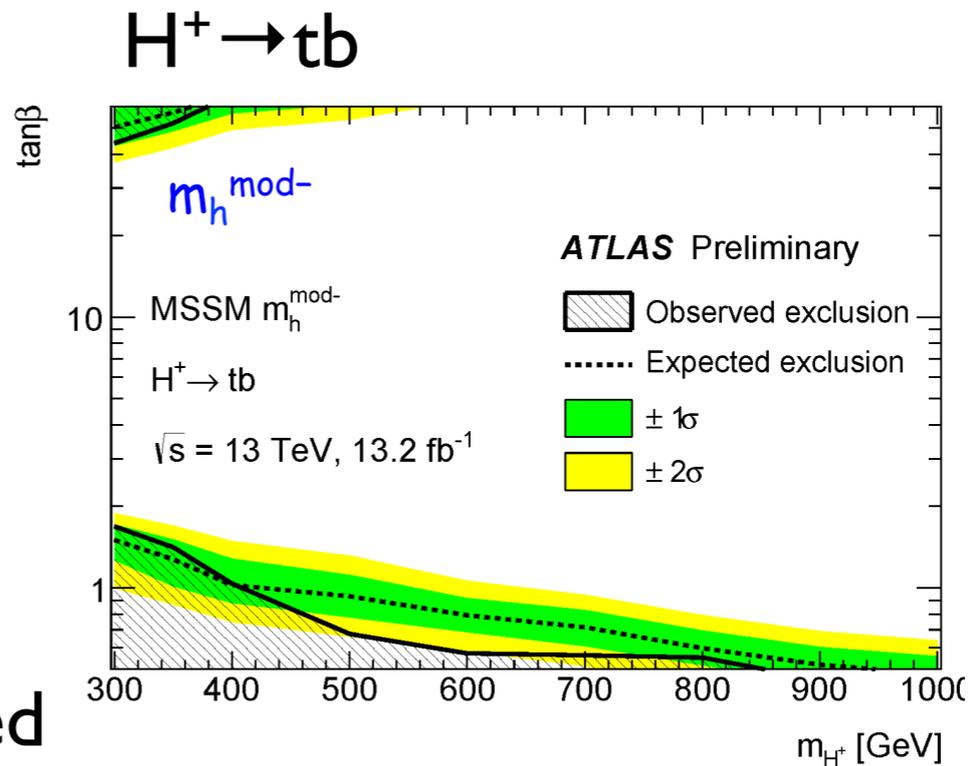




$M_A \sim 300$ GeV for small $\tan\beta$ excluded



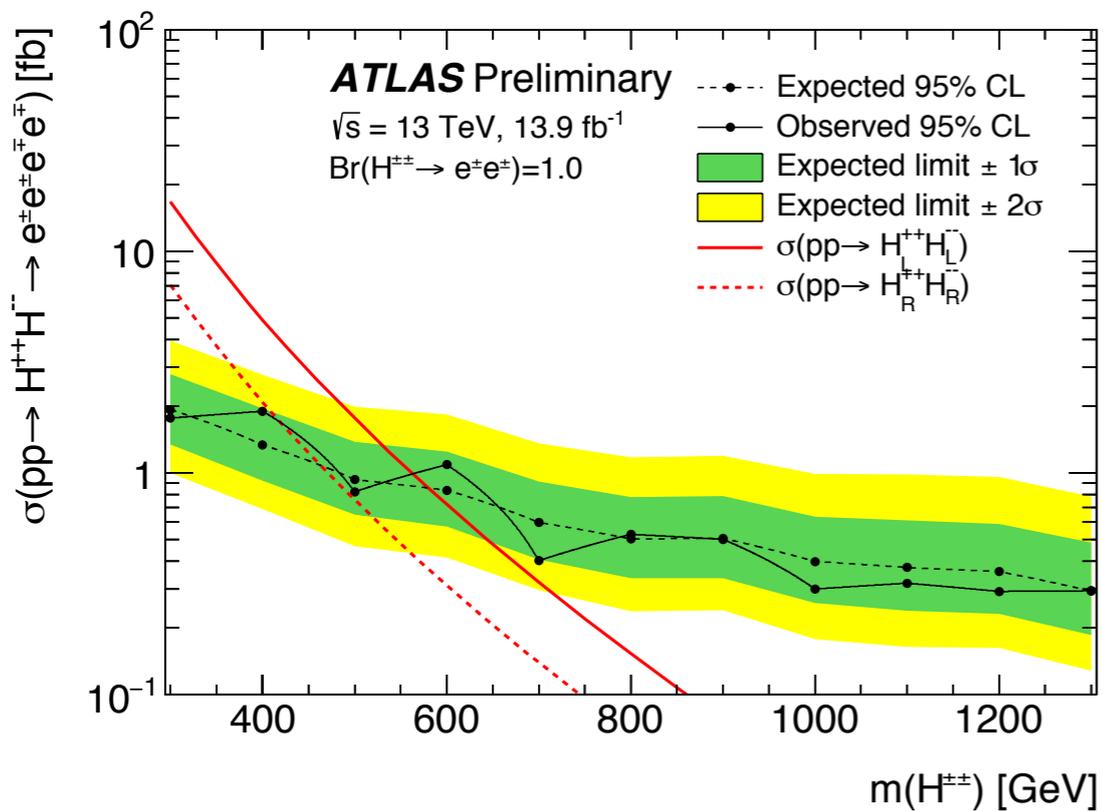
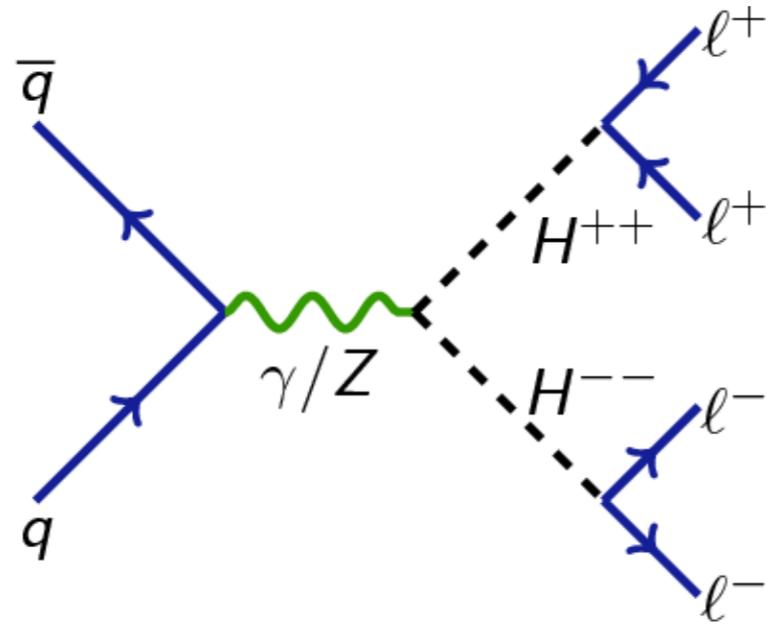
Starting to cover the $\tan\beta / M_{H^+}$ plane with 13 TeV



Doubly-Charged Higgs

Imma Riu

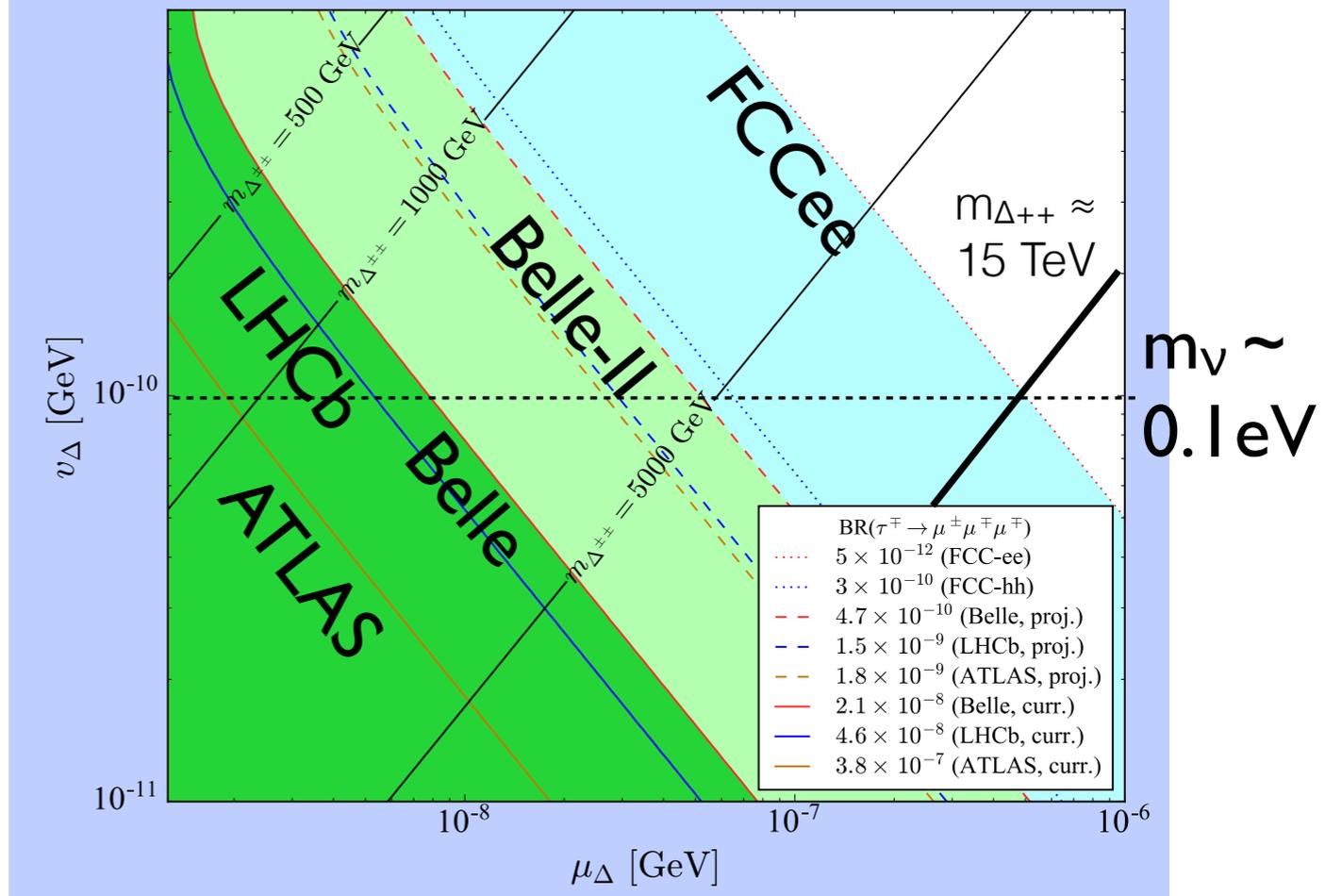
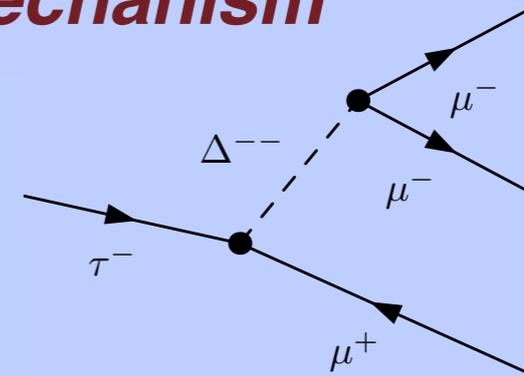
Direct production



Indirect constraints, $\tau \rightarrow 3\mu$

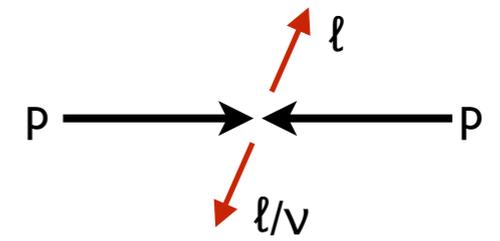
Chris Hays

See-saw mechanism



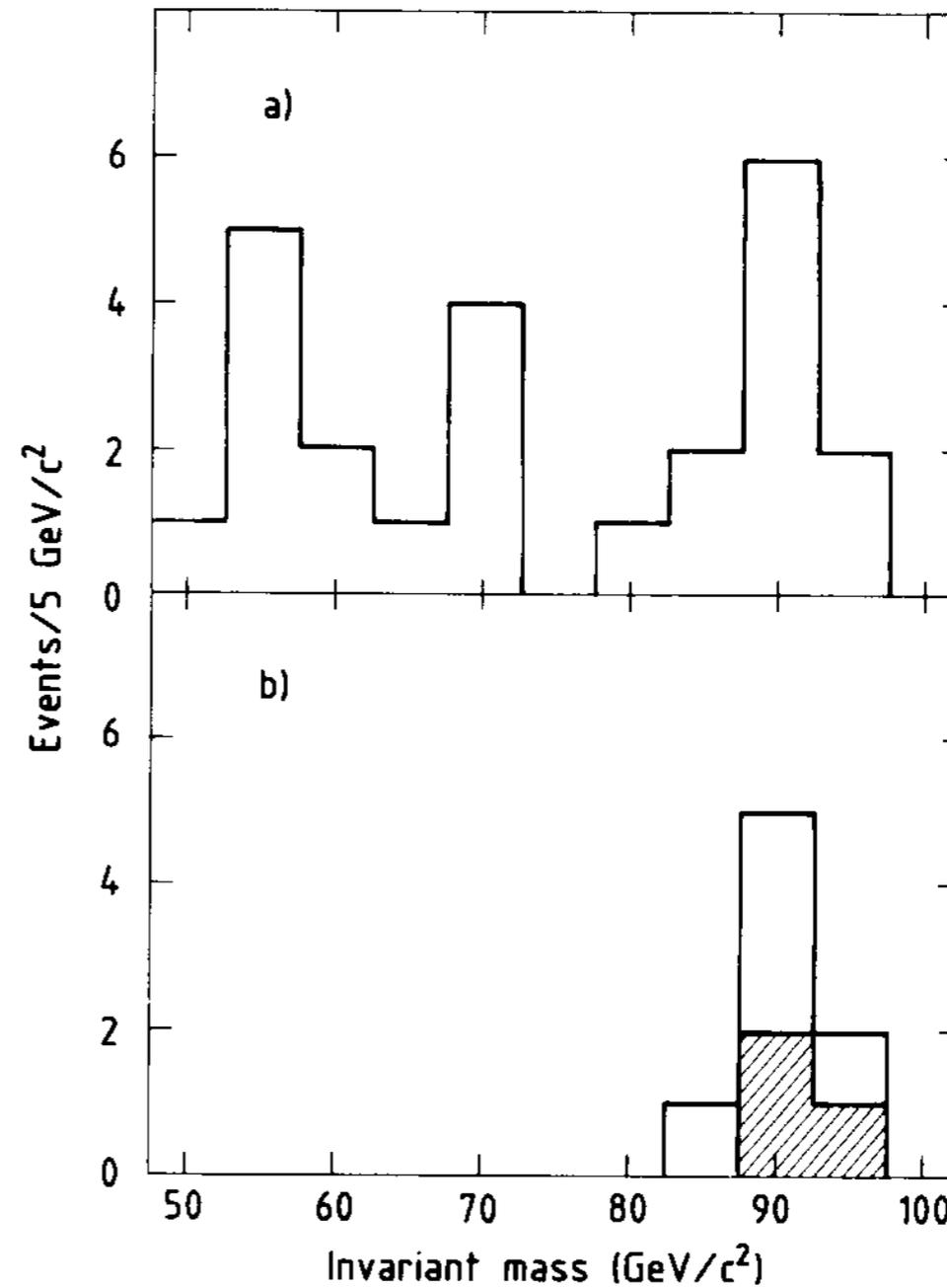
New Particles and Forces

$l\bar{l}/l\nu$ Resonances

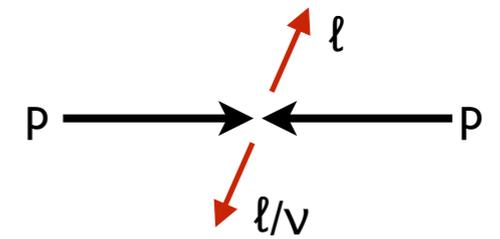


- ▶ Historic example:
Discovery of W/Z bosons
at UA1 & UA2

[UA1, PLB126, 398 (1983)
UA2, PLB129, 130 (1983)]

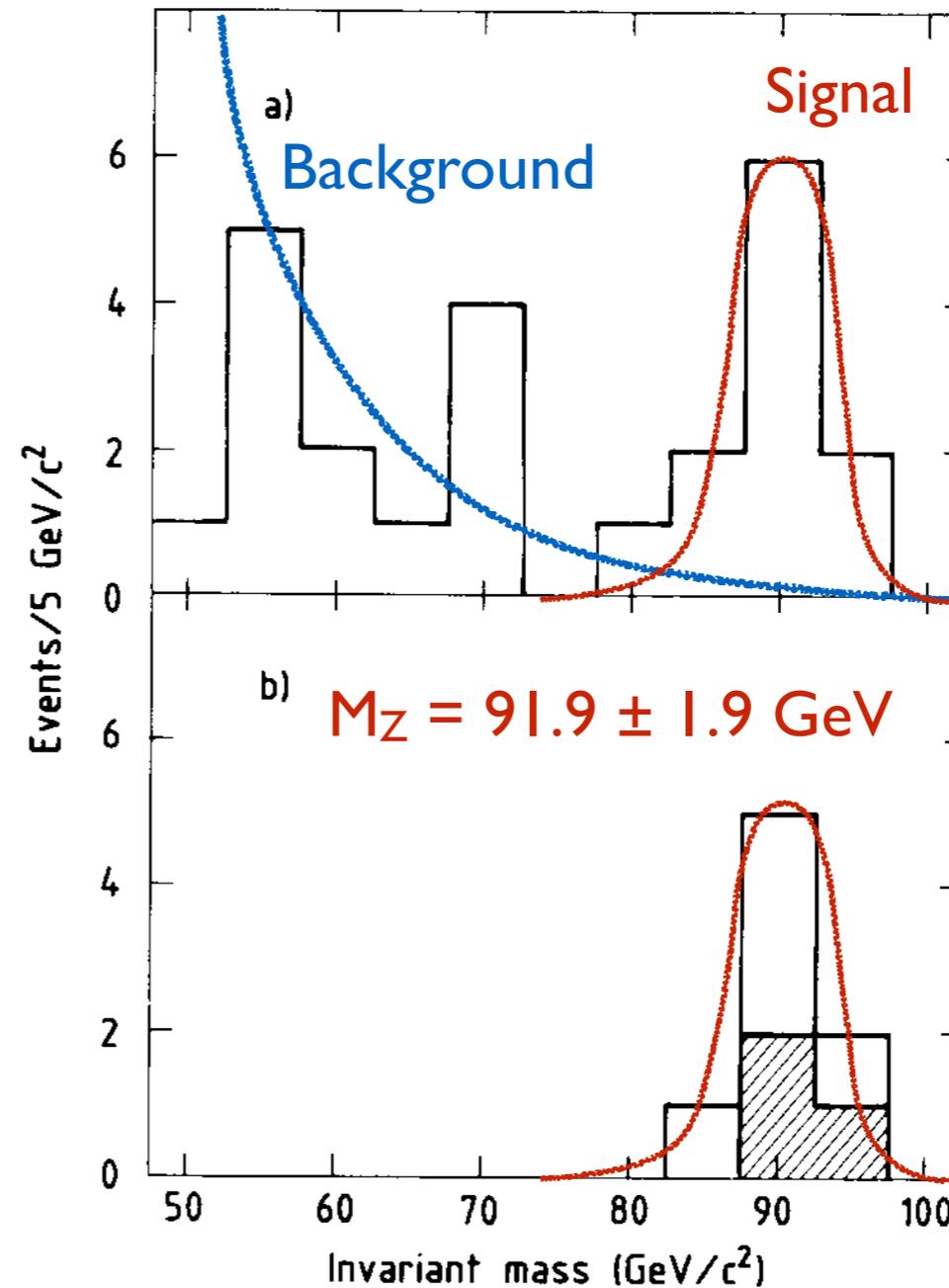


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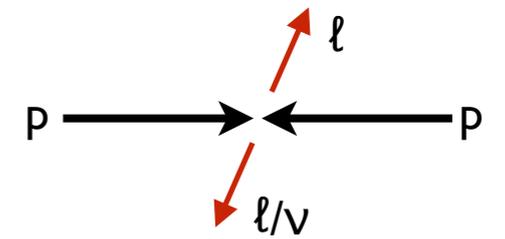


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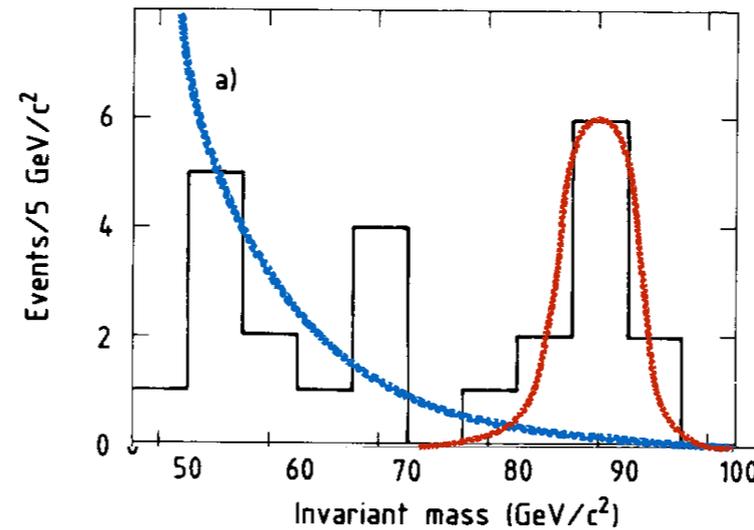


$ll/\ell\nu$ Resonances



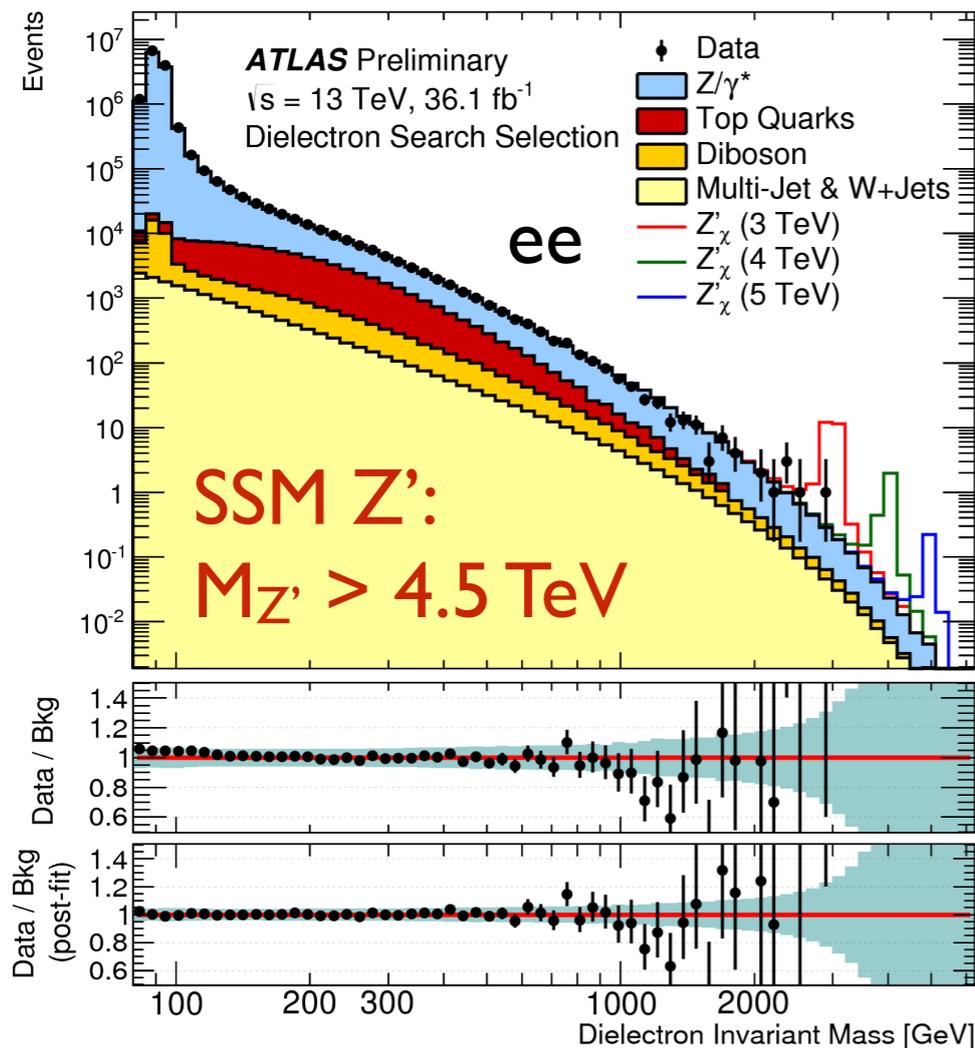
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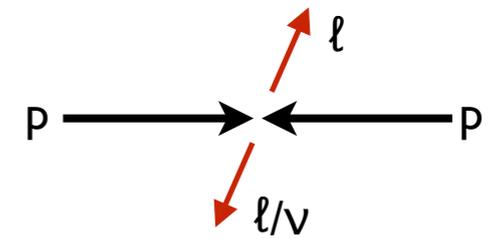


$Z' \rightarrow \tau\tau$ Halil Saka
higher backgrounds
from multijet prod.

Yanlin Liu

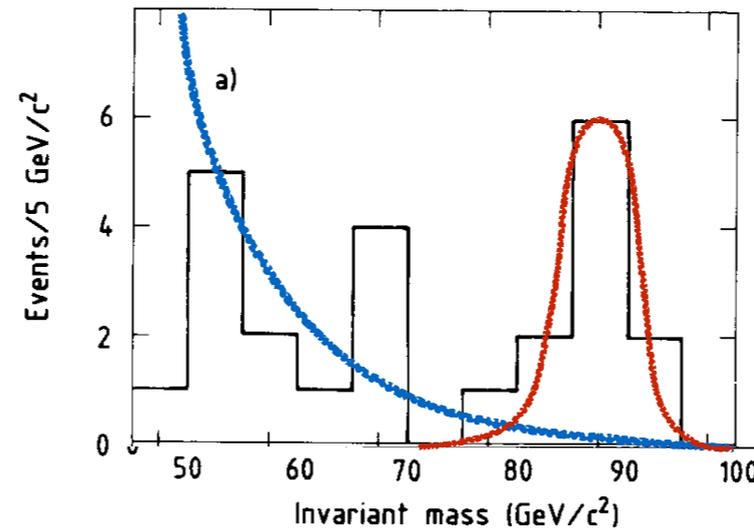


$ll/\ell\nu$ Resonances

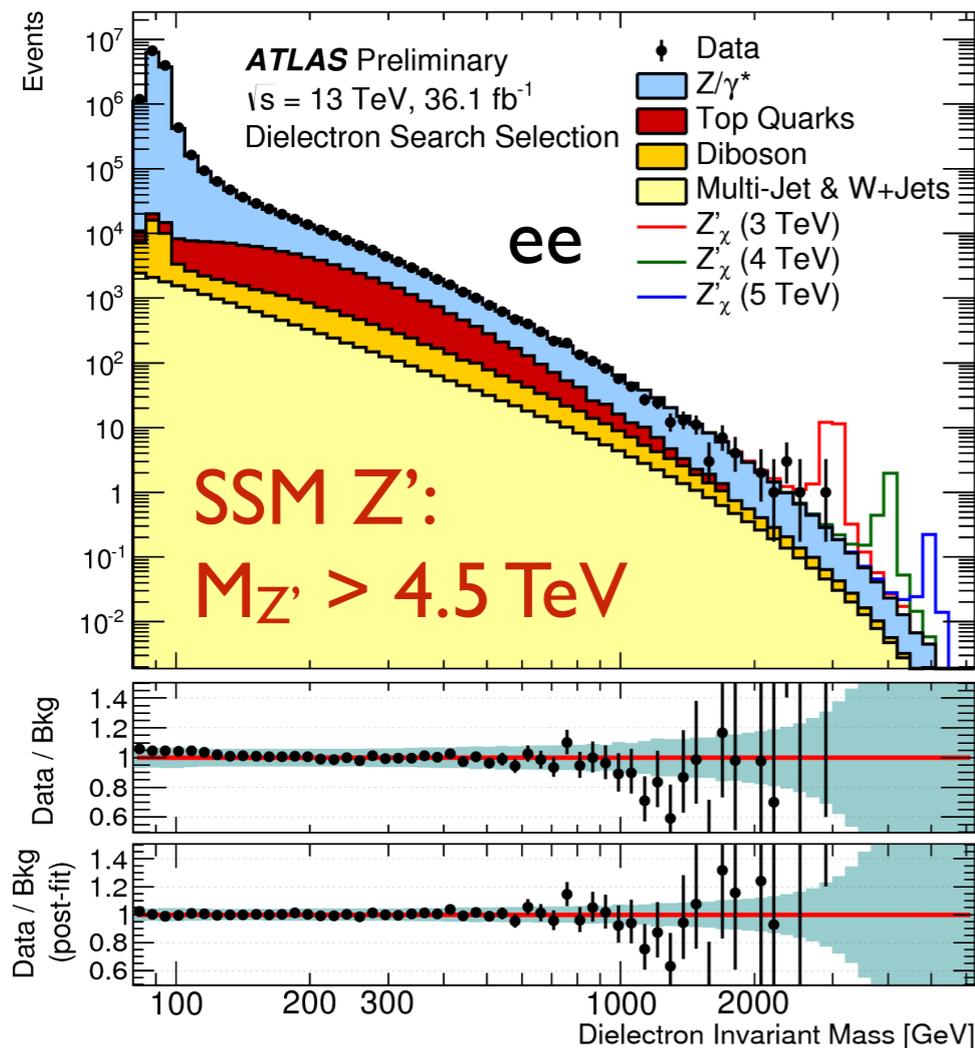


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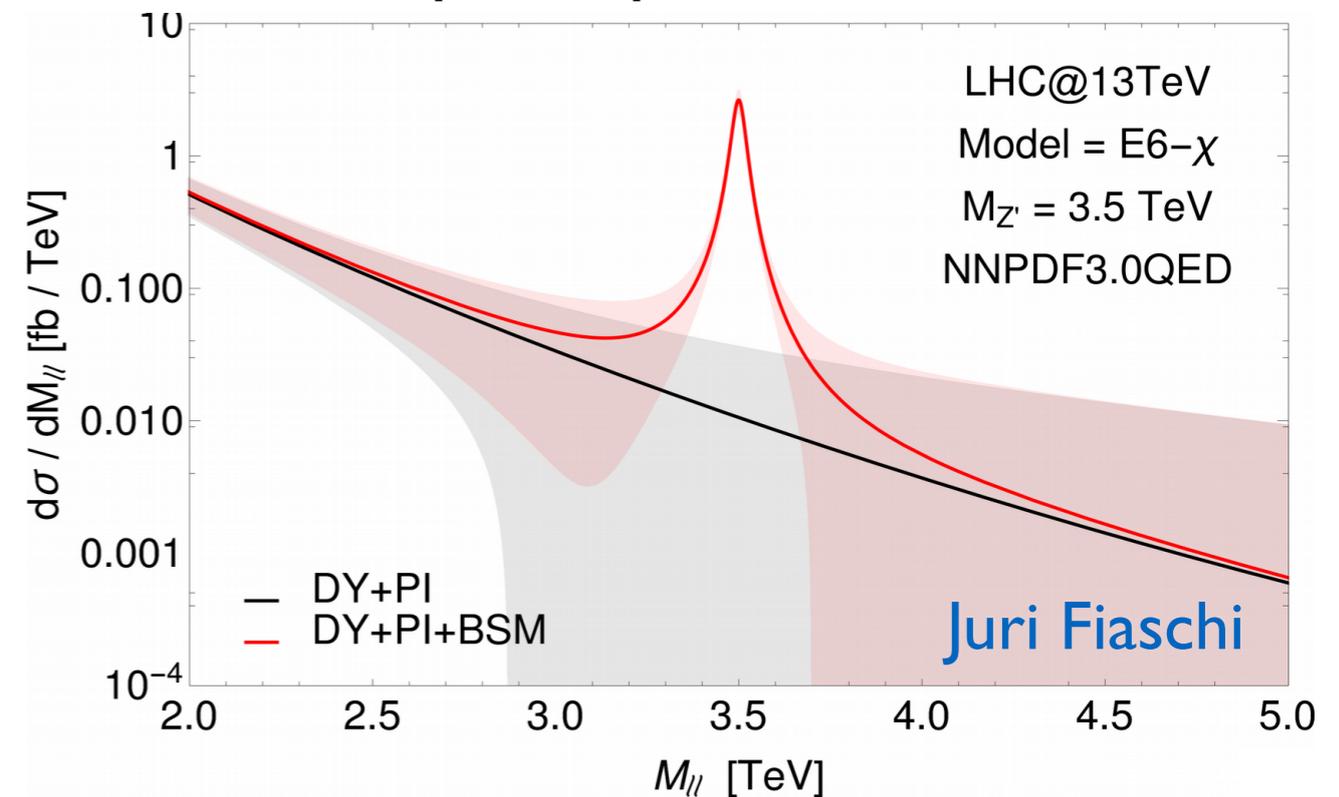


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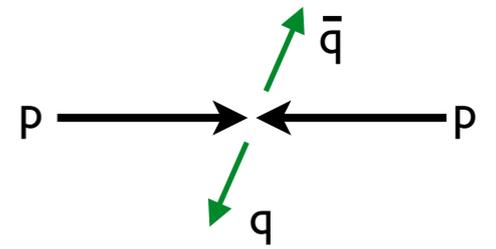


Yanlin Liu

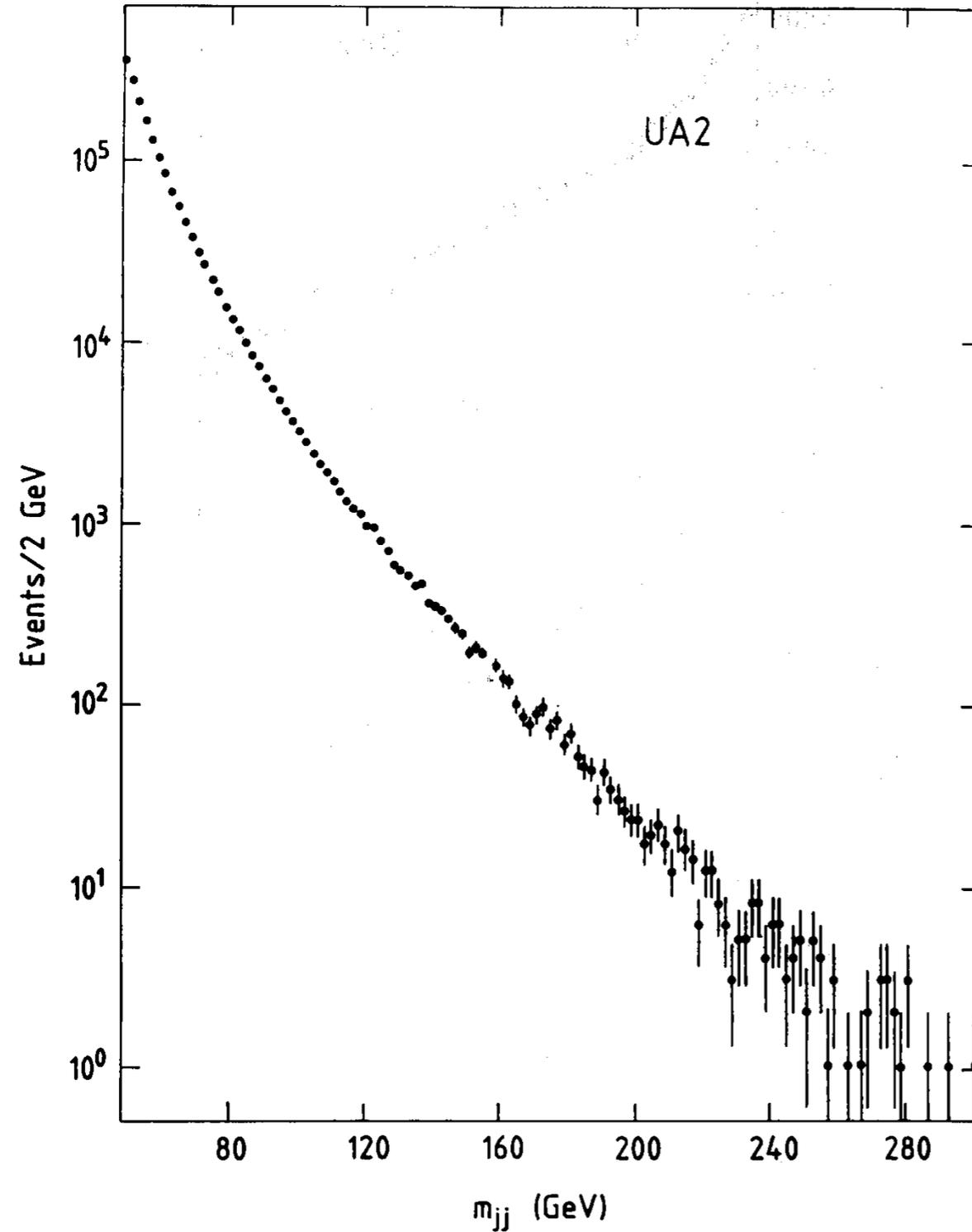
Photon induced contribution to the dilepton spectrum



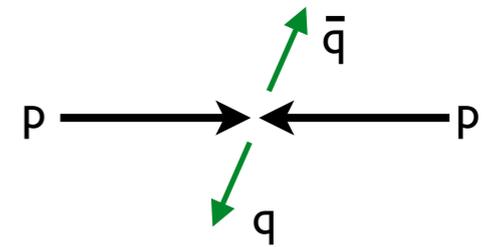
qq/gg Resonances



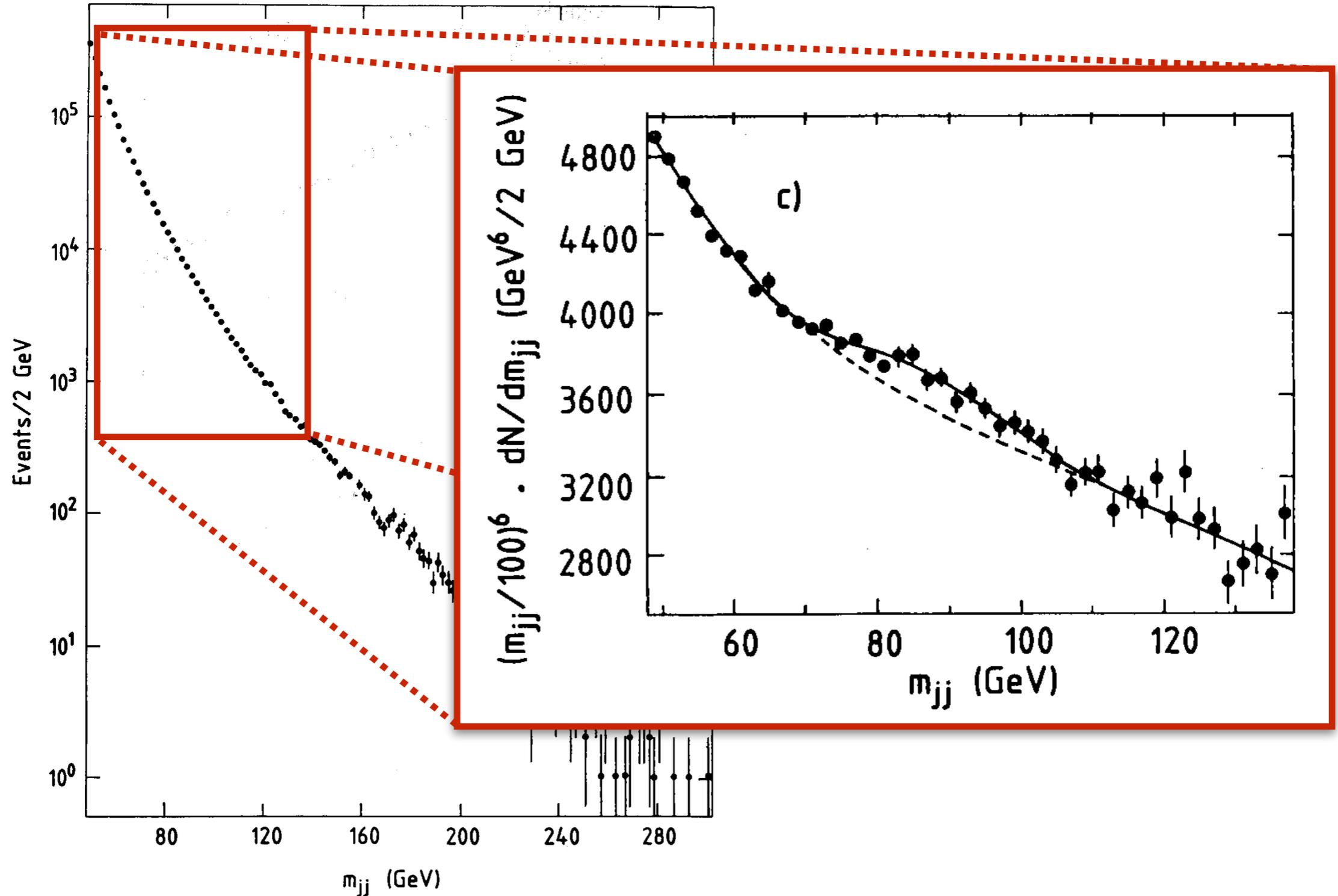
[UA2, Z. Phys. C 49, 17 (1991)]



qq/gg Resonances



[UA2, Z. Phys. C 49, 17 (1991)]



$M_{jj} = 8,12 \text{ TeV}$



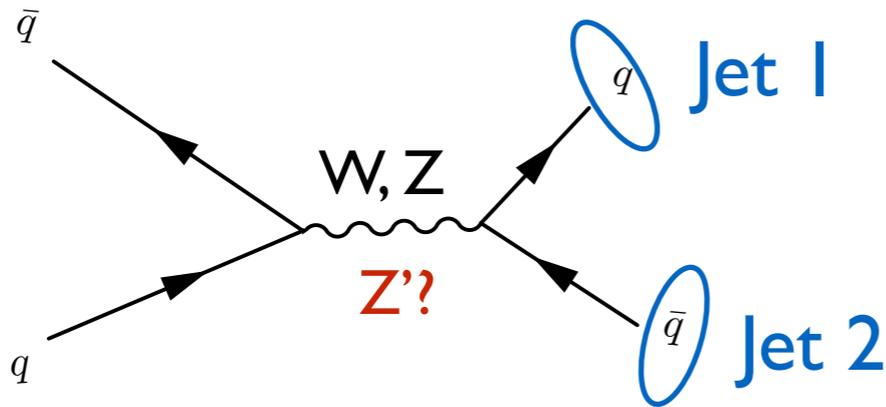
ATLAS
EXPERIMENT

Run: 305777

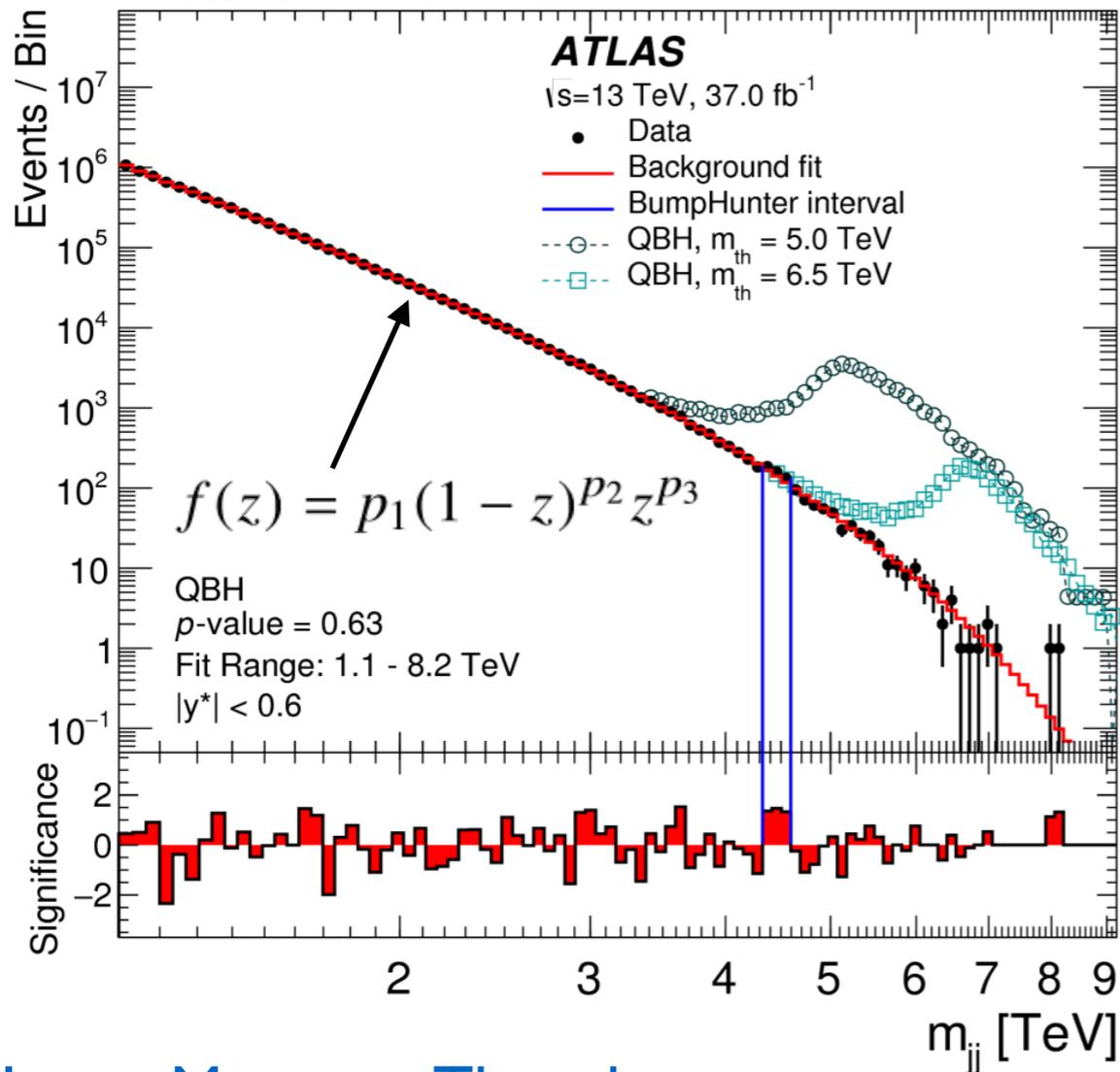
Event: 4144227629

2016-08-08 08:51:15 CEST

qq/gg Resonances

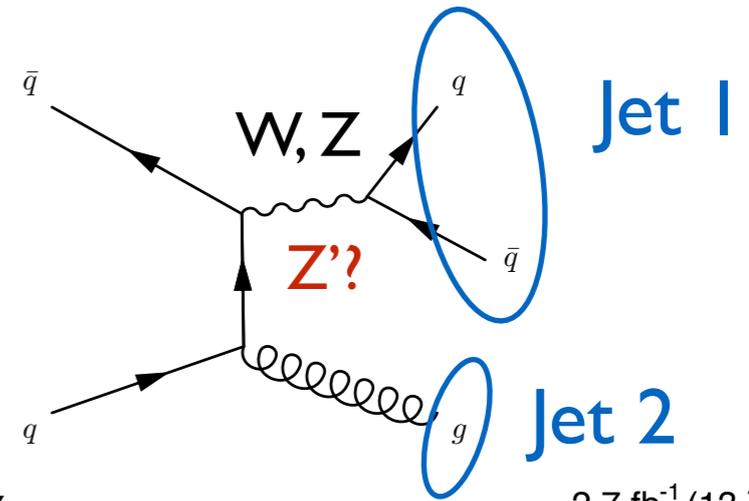
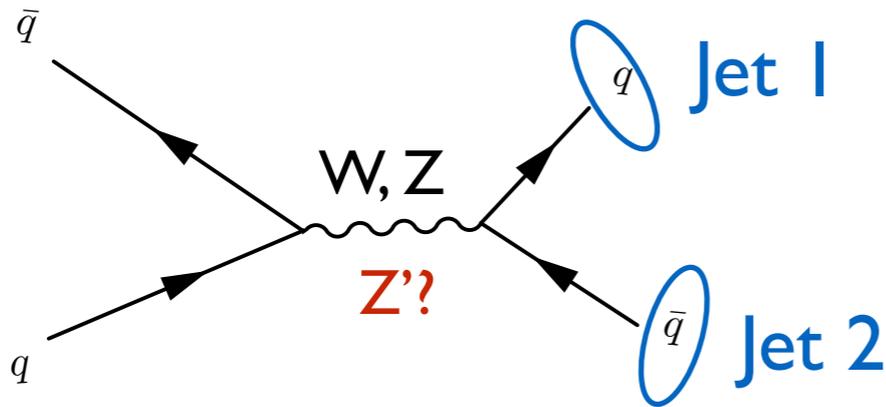


Full 13 TeV dataset!

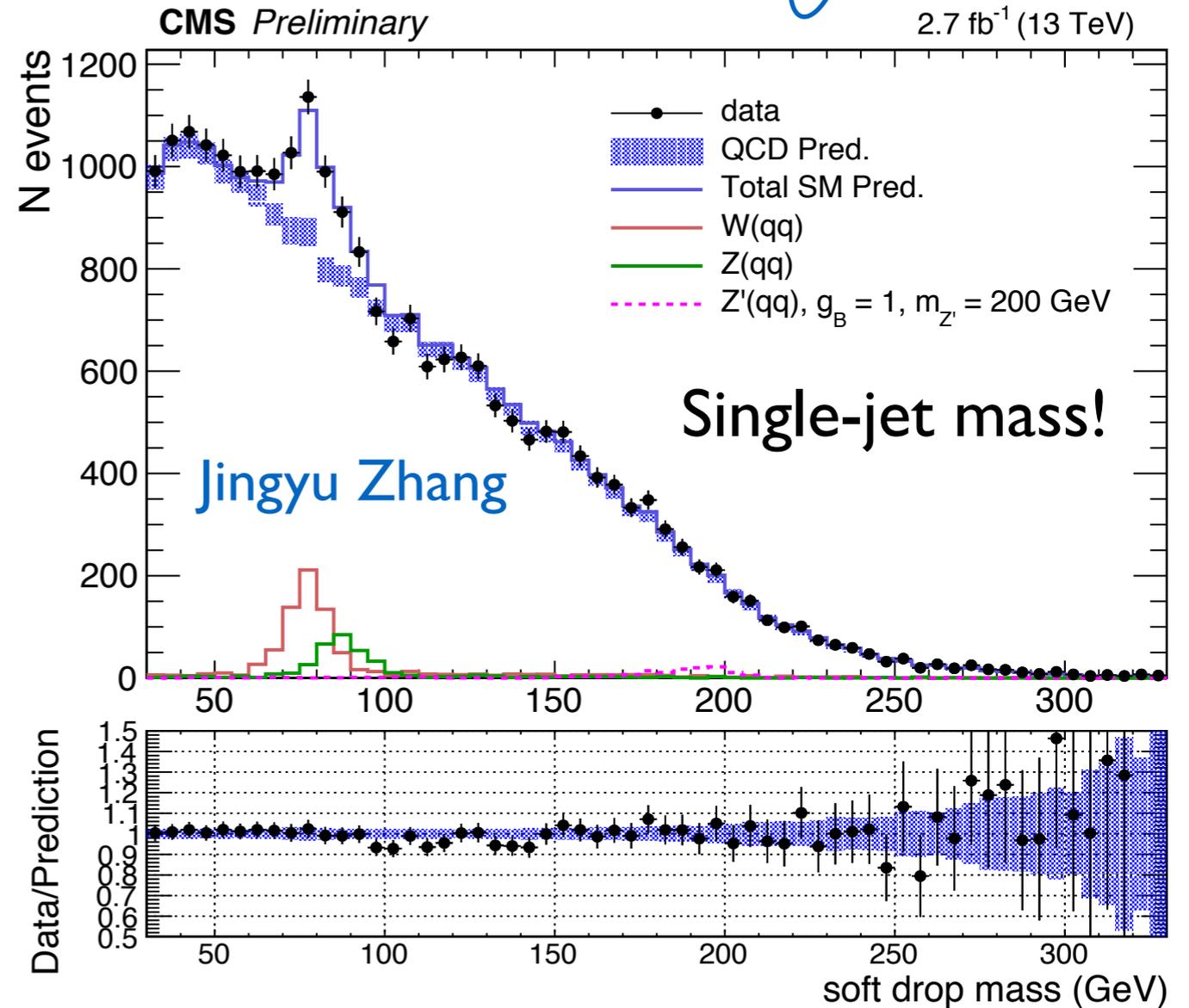
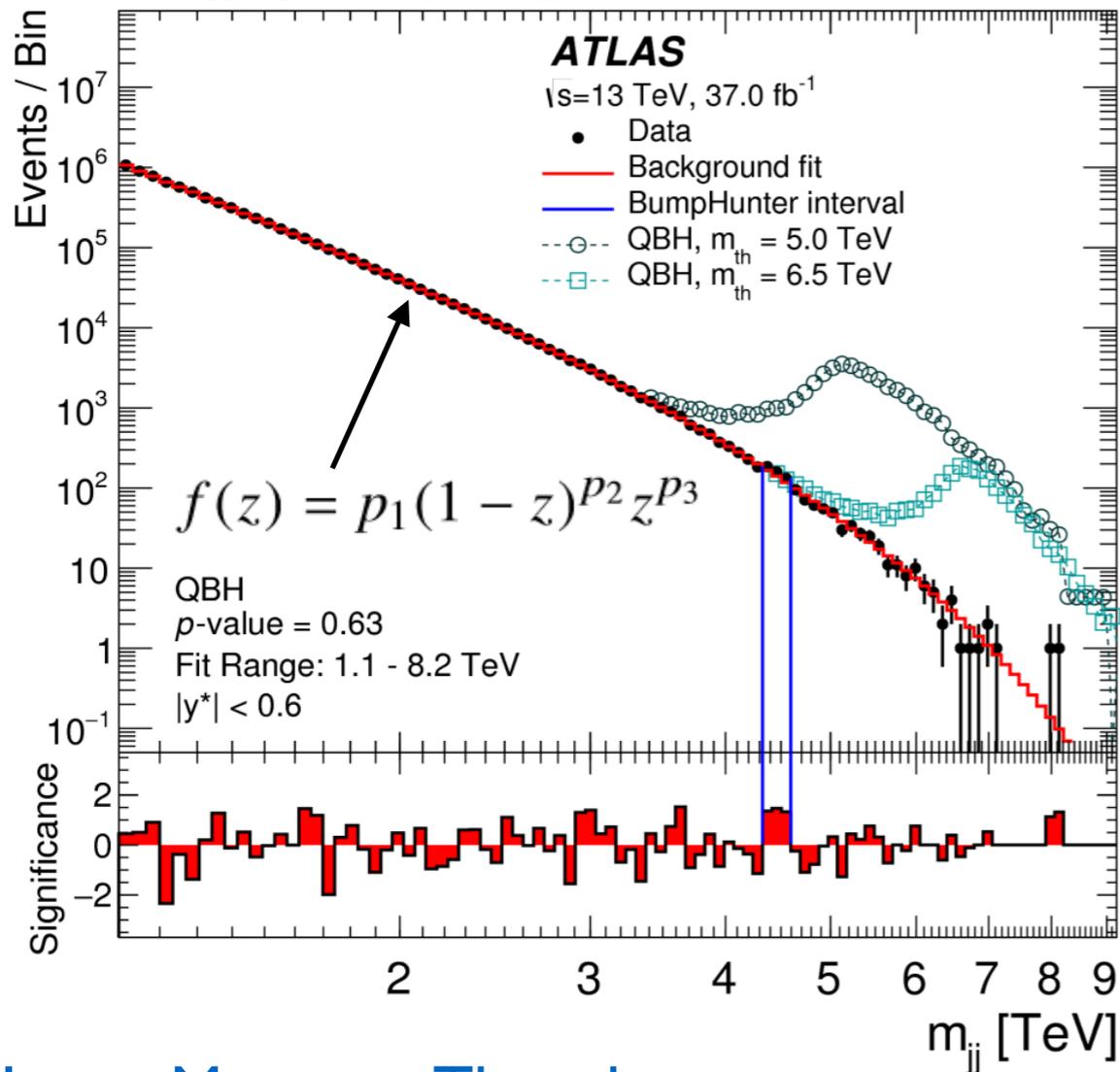


Hanno Meyer zu Theenhausen

qq/gg Resonances



Full 13 TeV dataset!

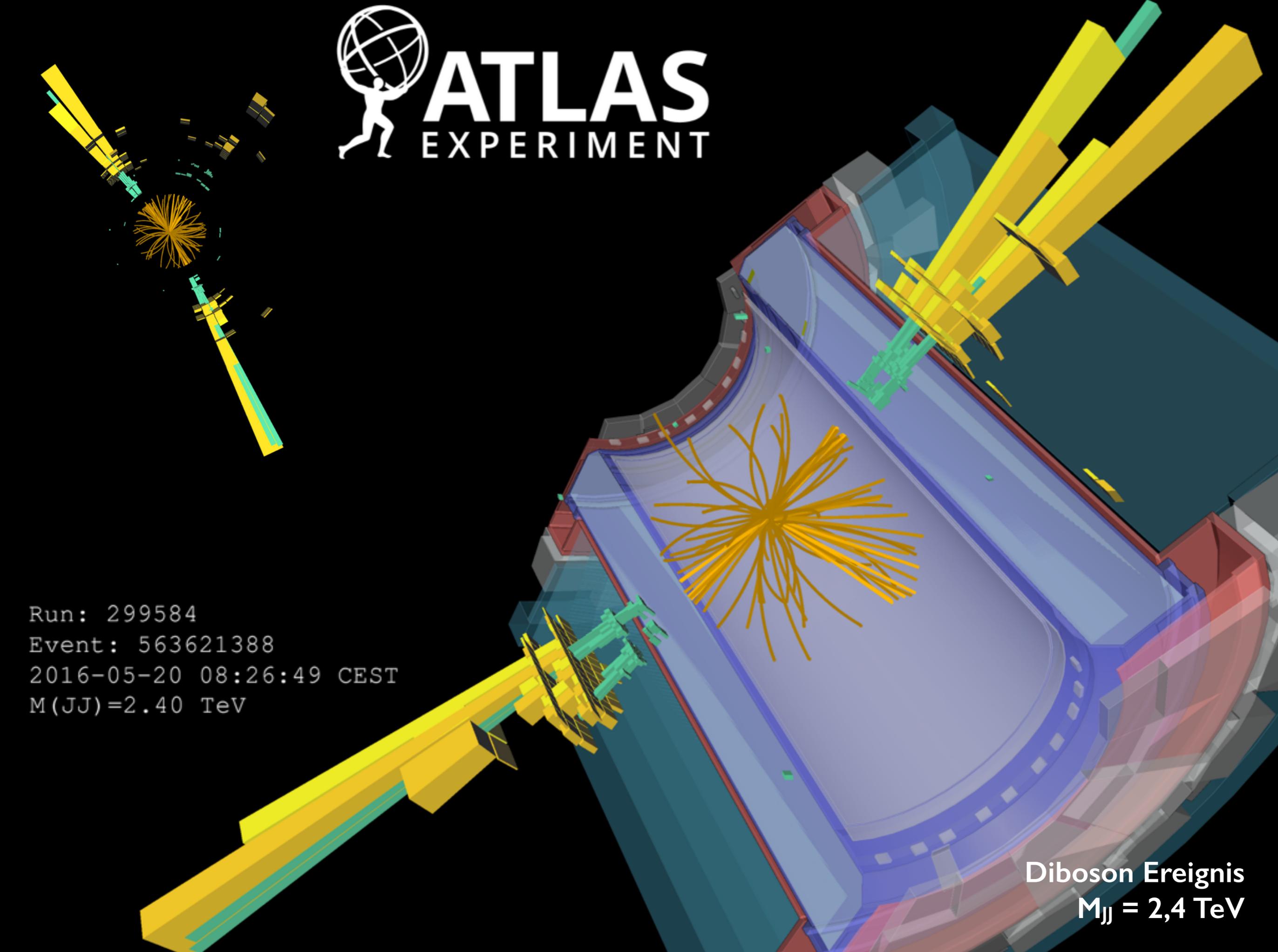


Hanno Meyer zu Theenhausen



ATLAS

EXPERIMENT

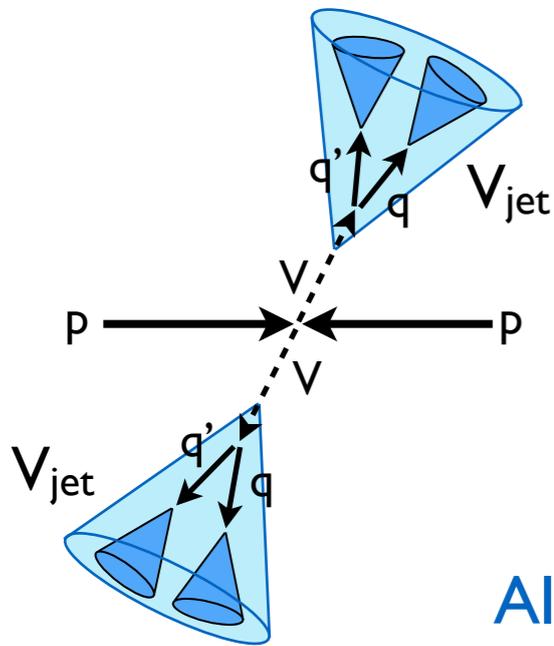


Run: 299584
Event: 563621388
2016-05-20 08:26:49 CEST
M(JJ)=2.40 TeV

Diboson Ereignis
 $M_{JJ} = 2,4 \text{ TeV}$

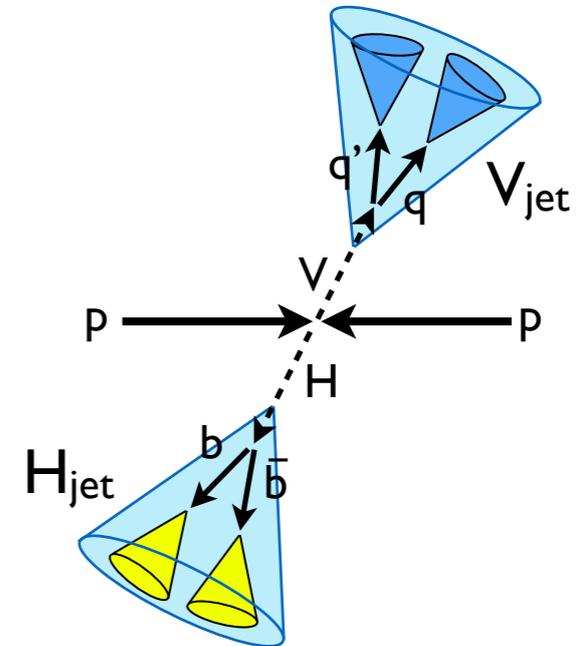
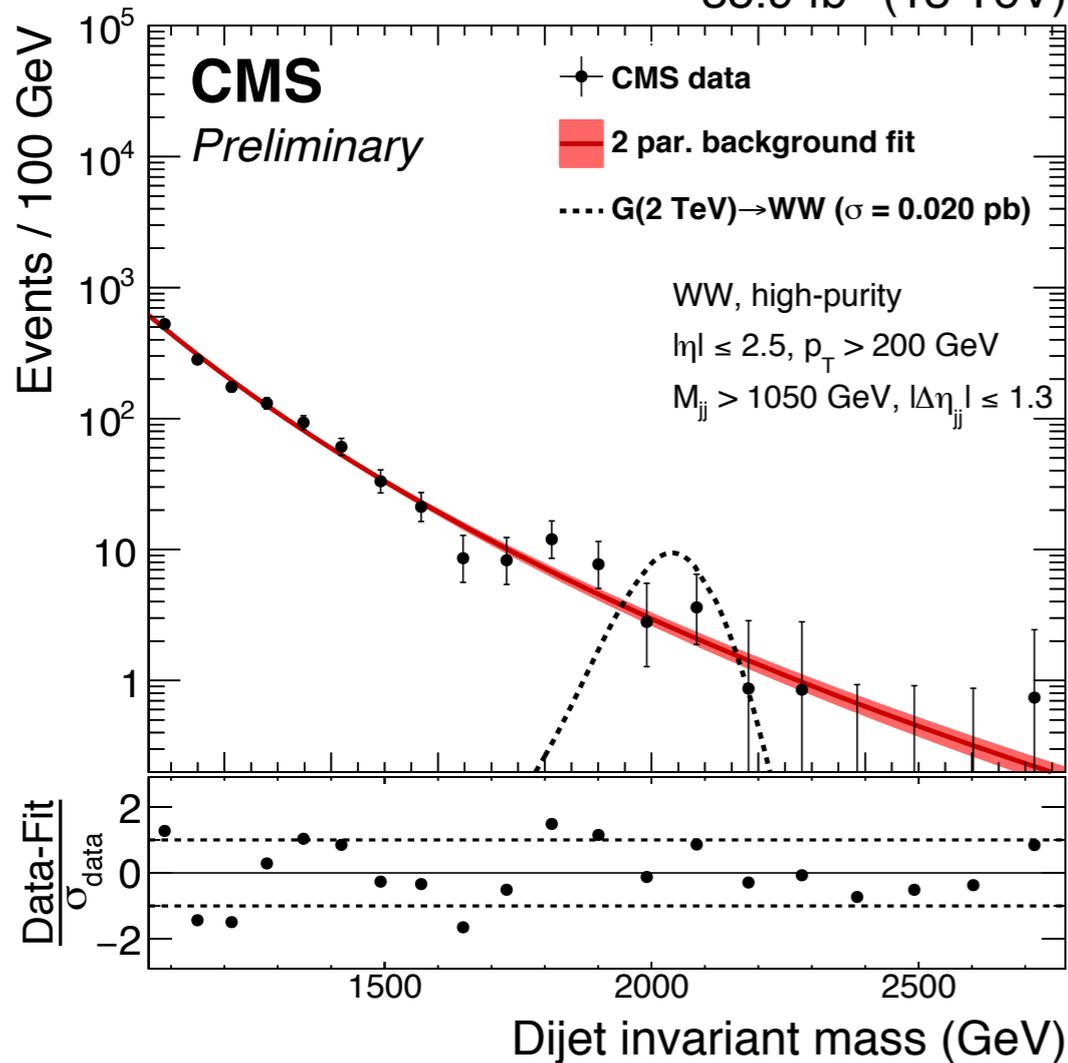
VV/VH Resonances

Full 13 TeV dataset!

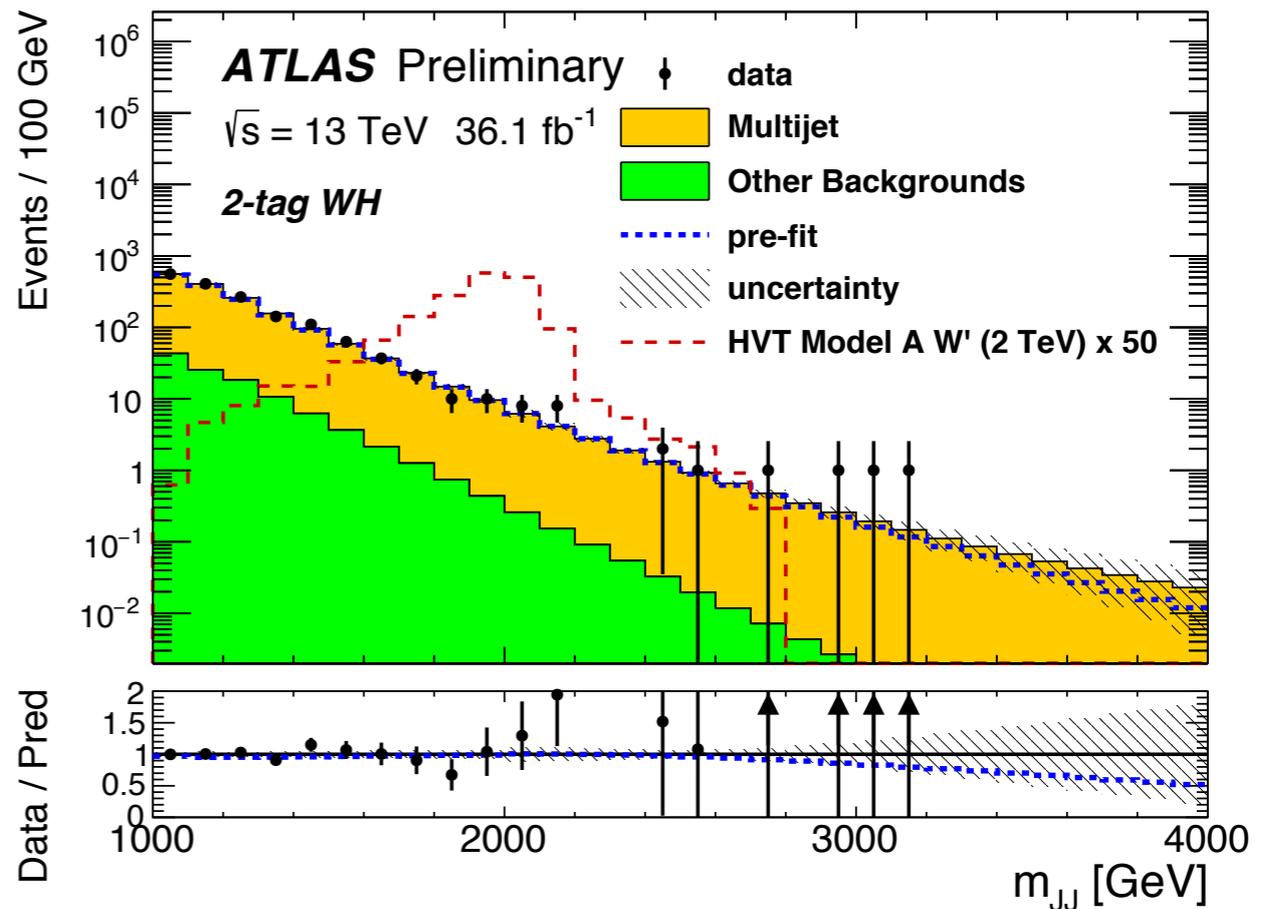


Alberto Zucchetta

35.9 fb⁻¹ (13 TeV)

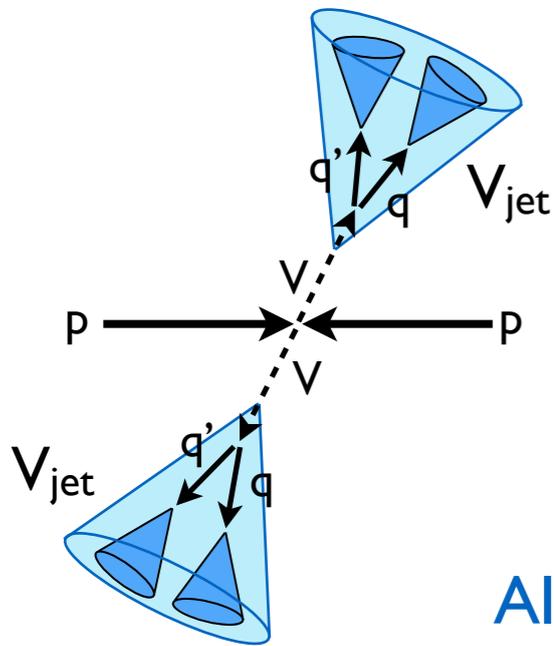


Nicolò Vladi Biesuz



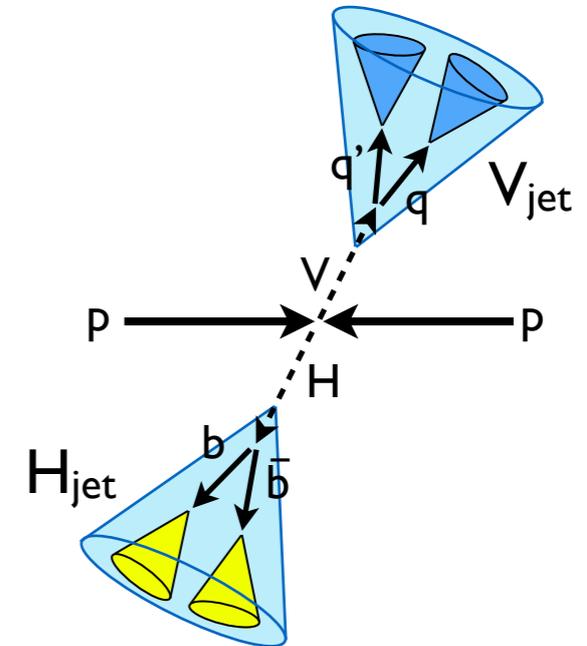
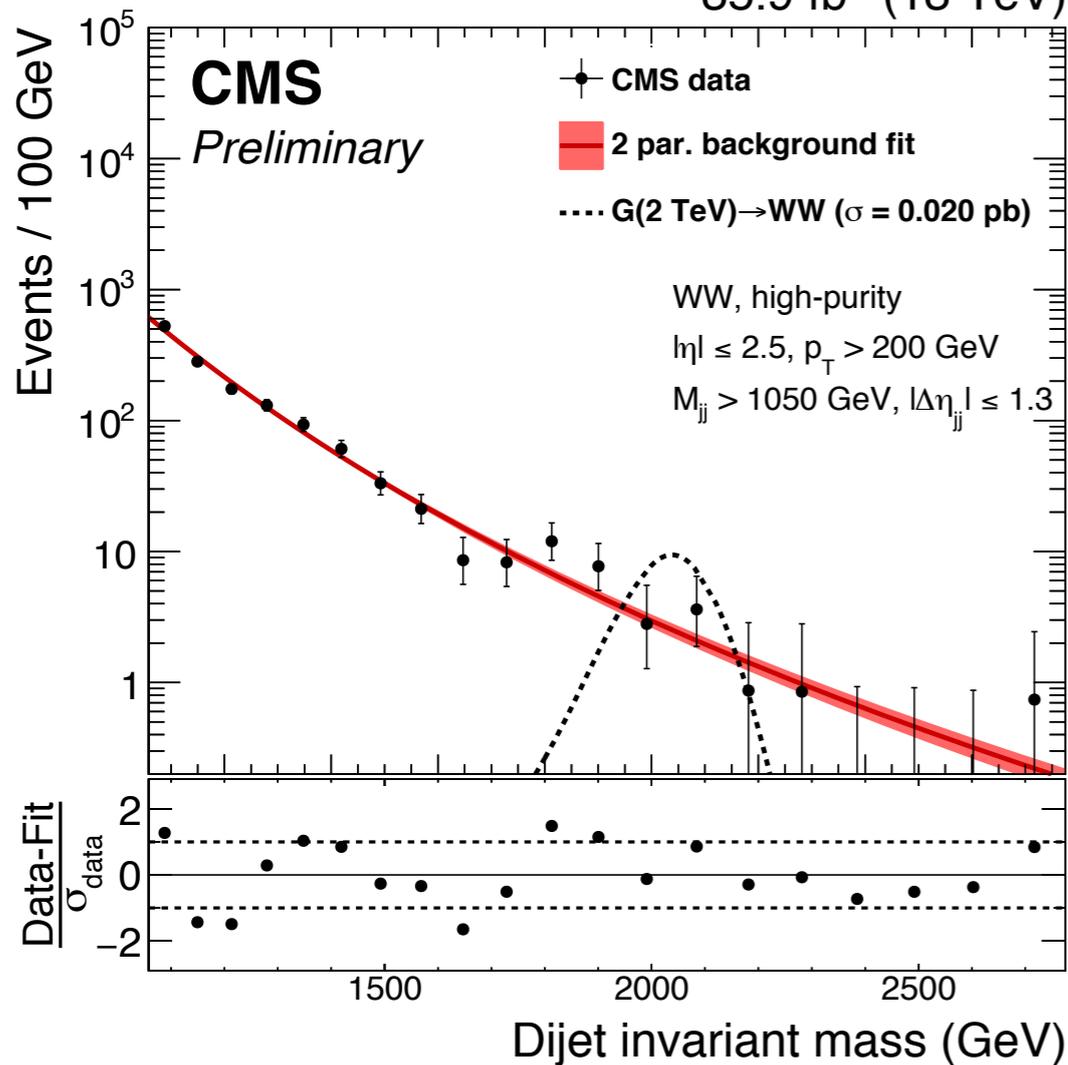
VV/VH Resonances

Full 13 TeV dataset!

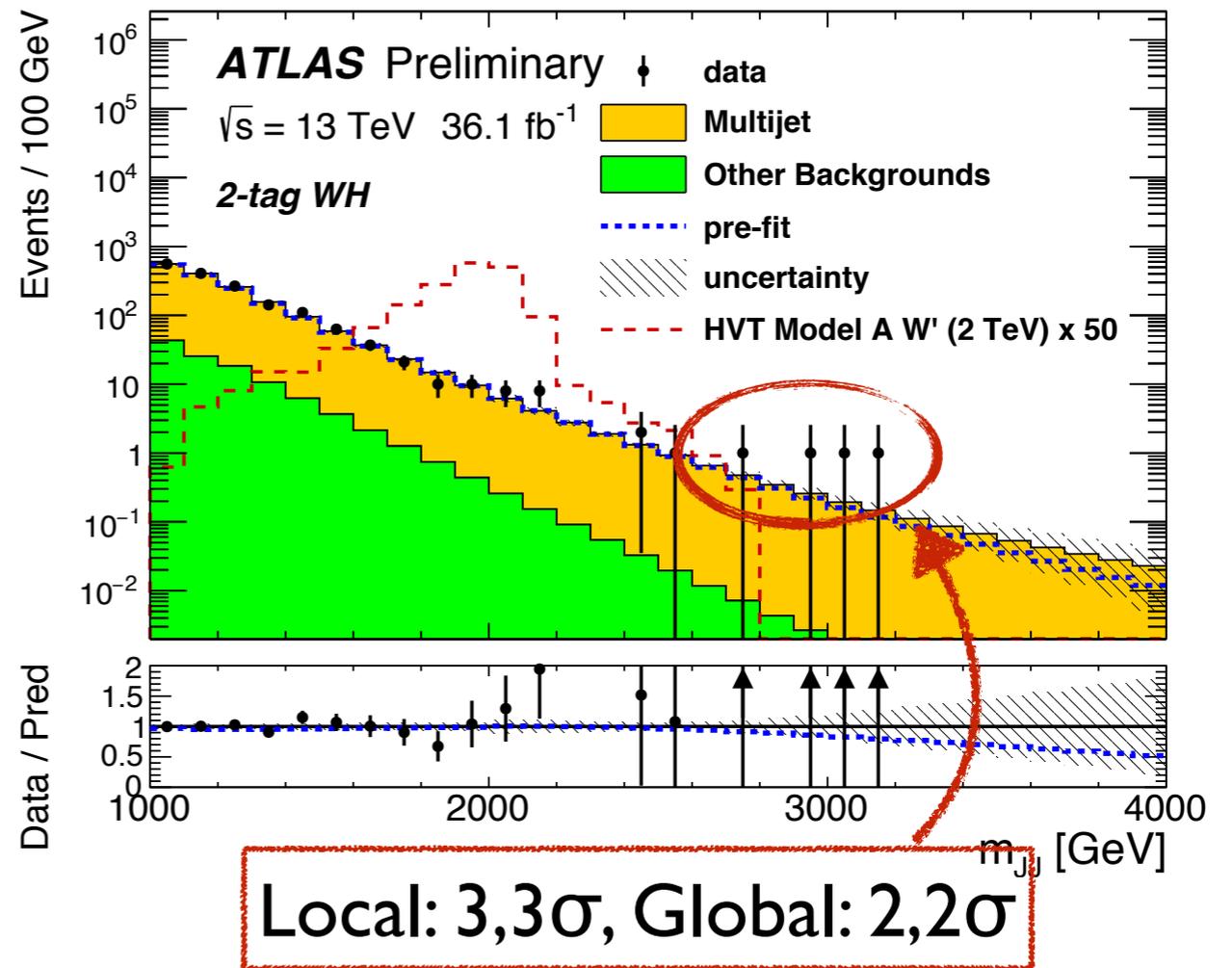


Alberto Zucchetta

35.9 fb⁻¹ (13 TeV)

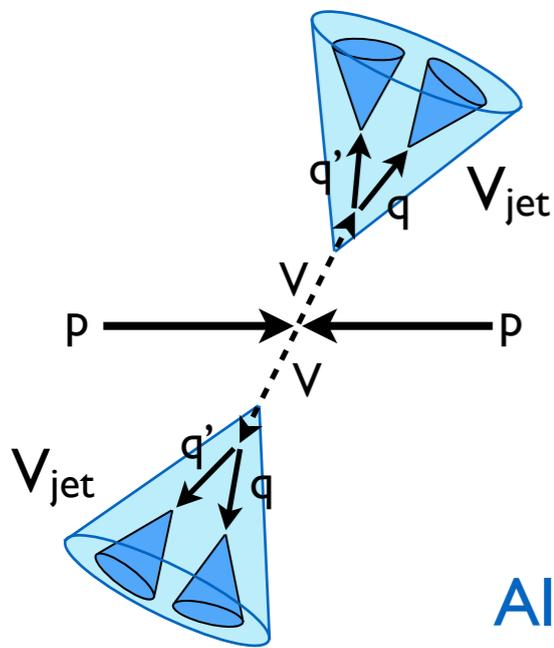


Nicolò Vladi Biesuz



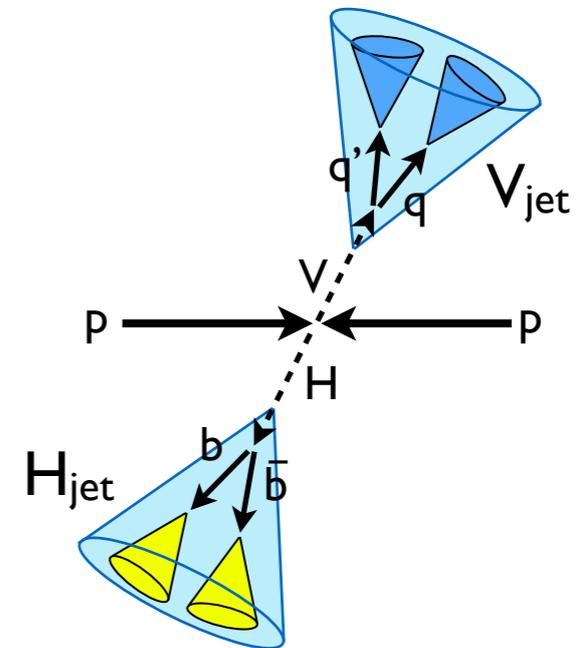
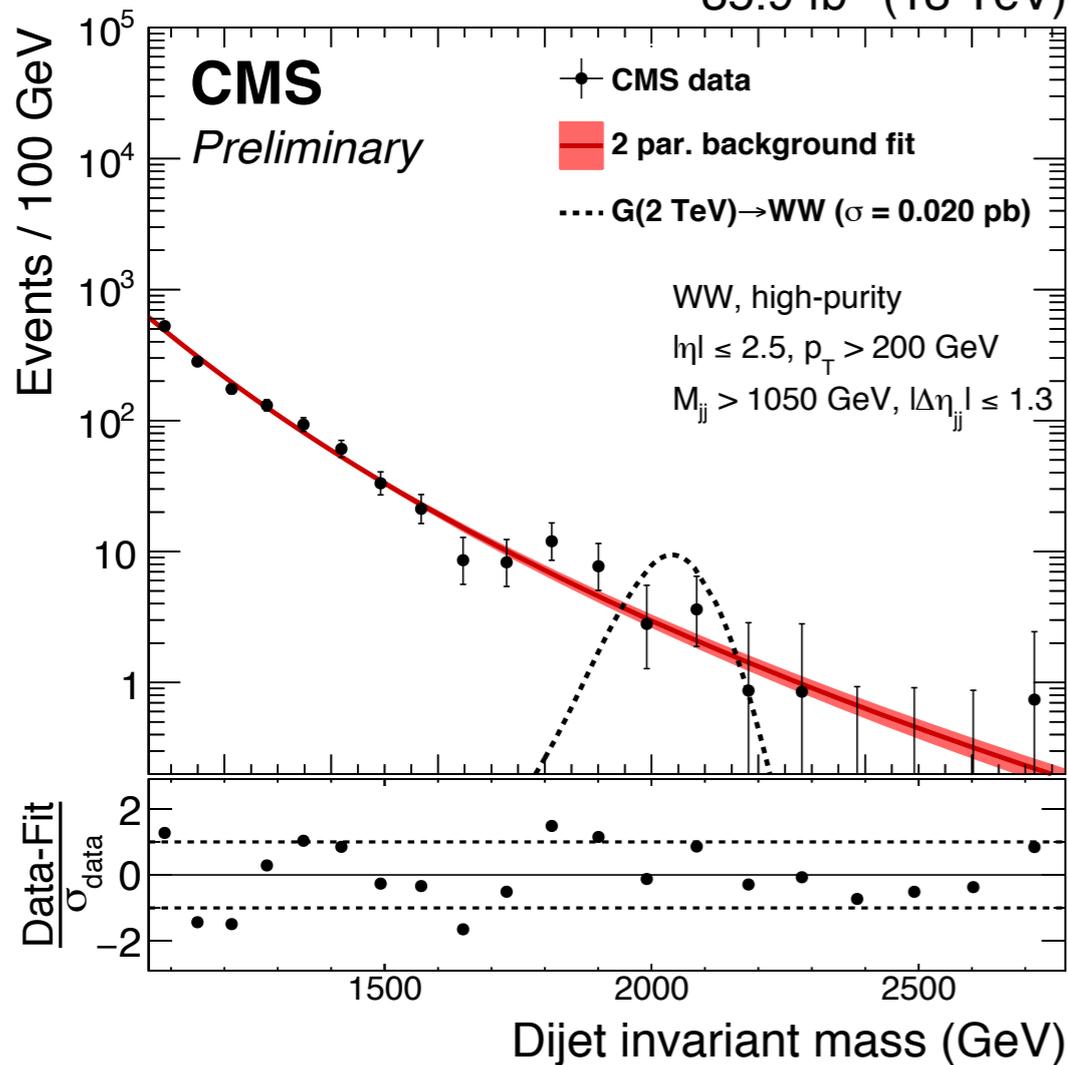
VV/VH Resonances

Full 13 TeV dataset!

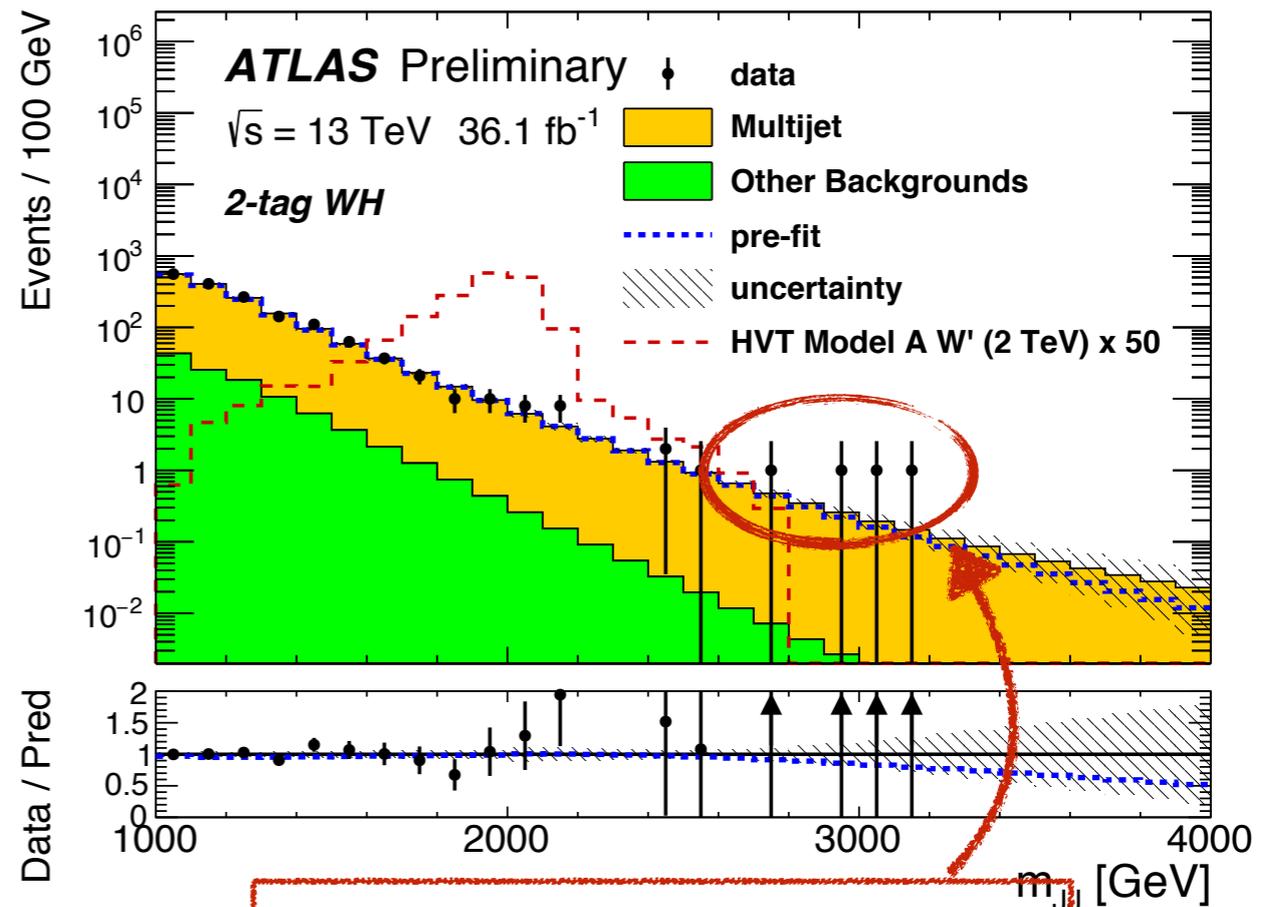


Alberto Zucchetta

35.9 fb⁻¹ (13 TeV)



Nicolò Vladi Biesuz

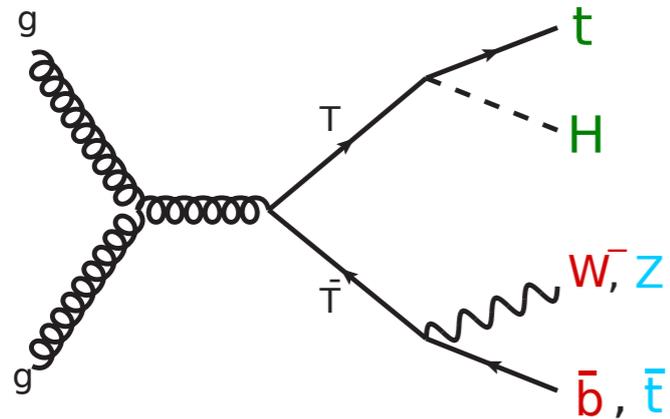


Local: 3,3 σ , Global: 2,2 σ

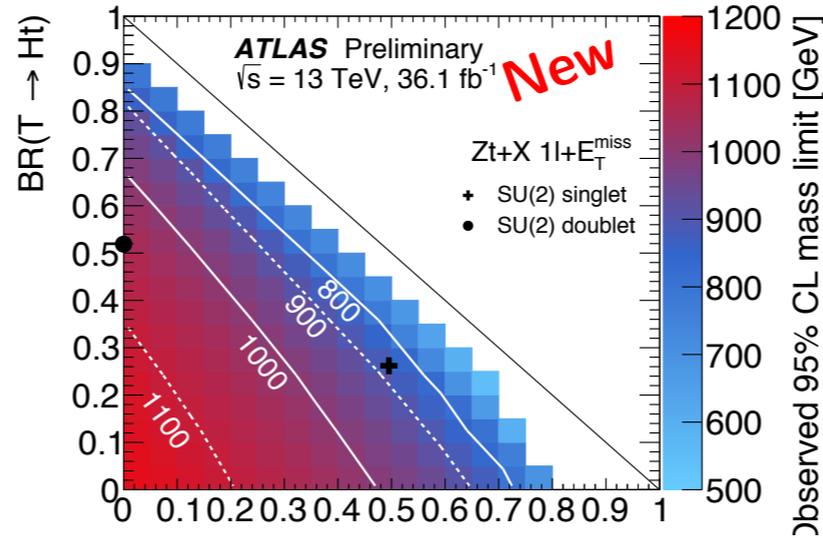
Not confirmed by CMS

Vector Like Quarks

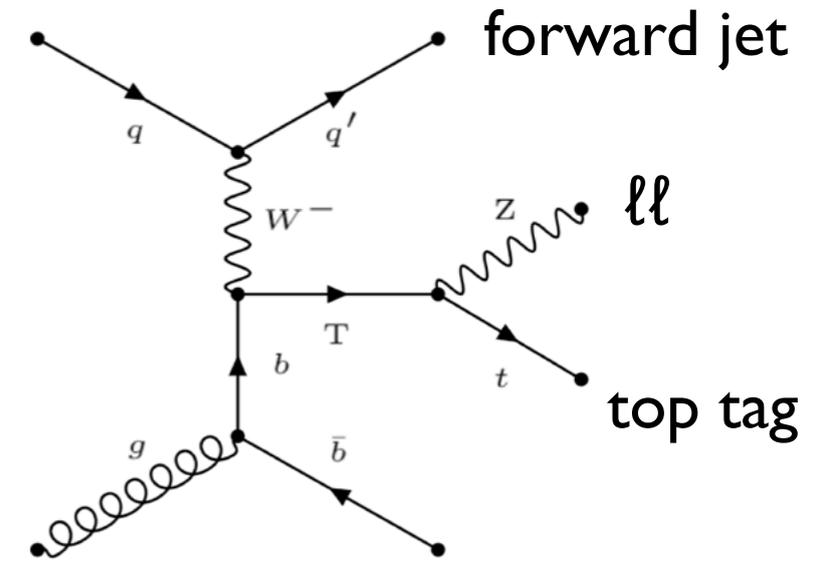
Pair production



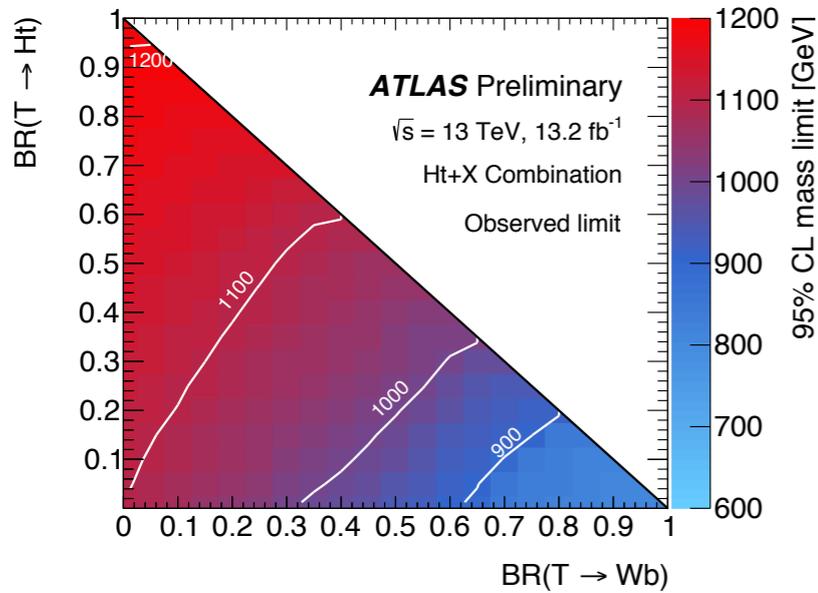
Zt+X



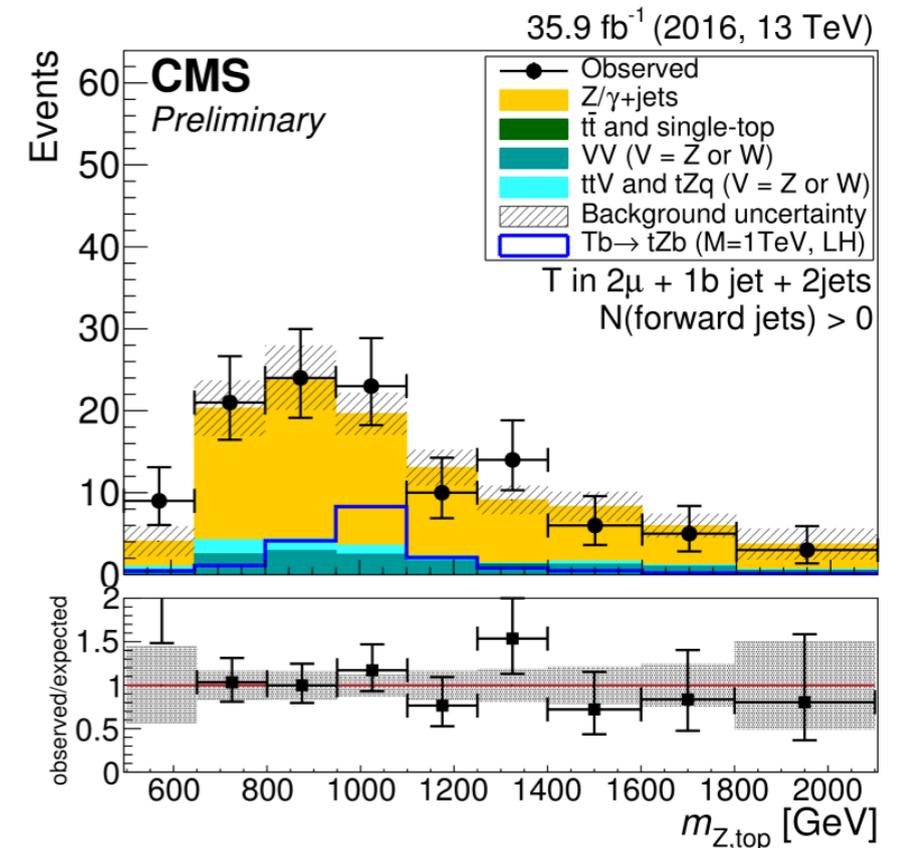
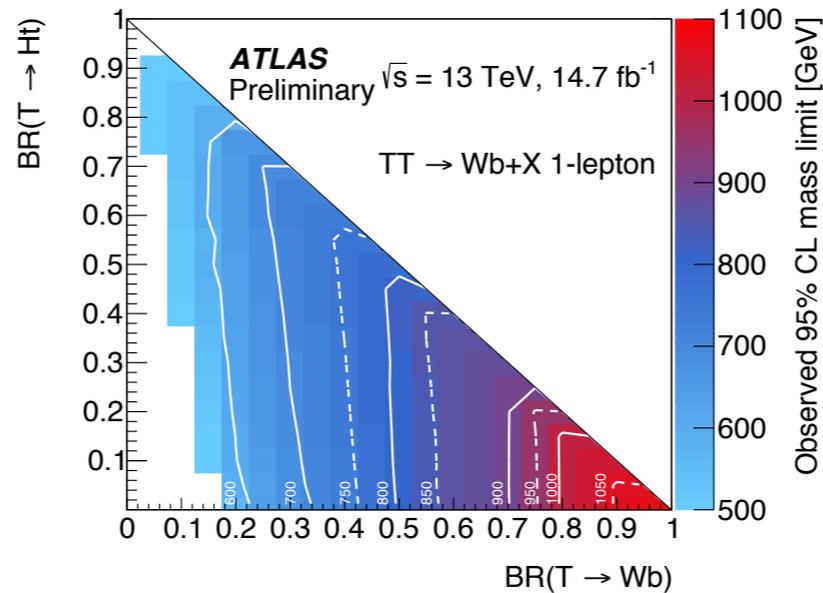
Single production



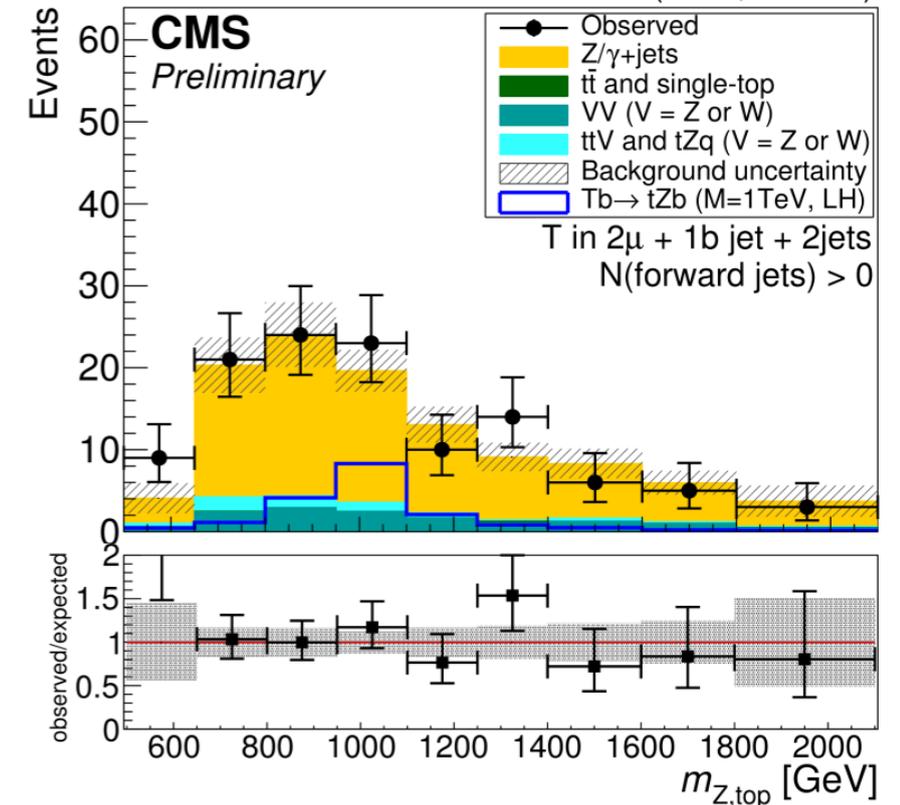
Ht+X



Wb+X



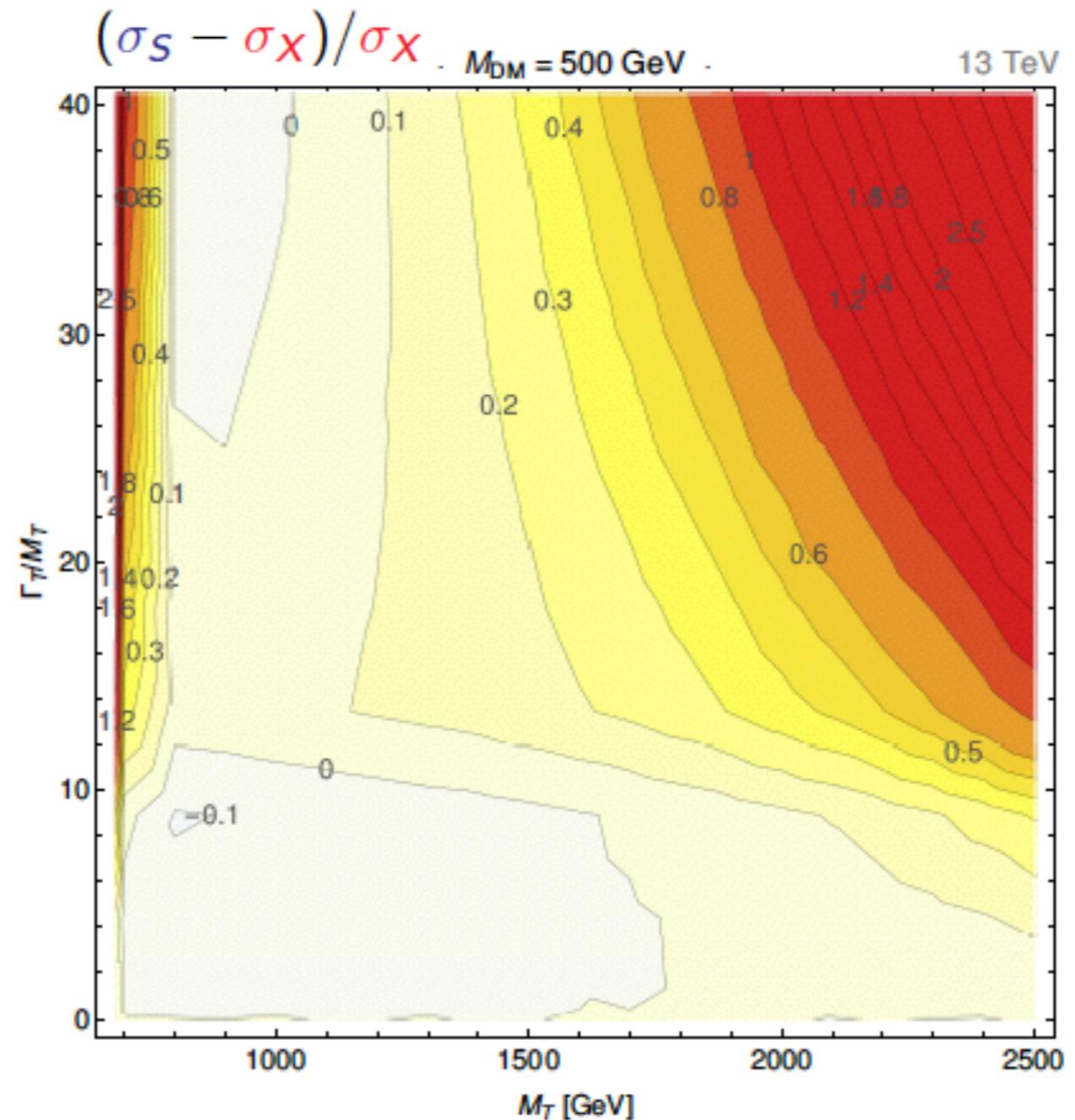
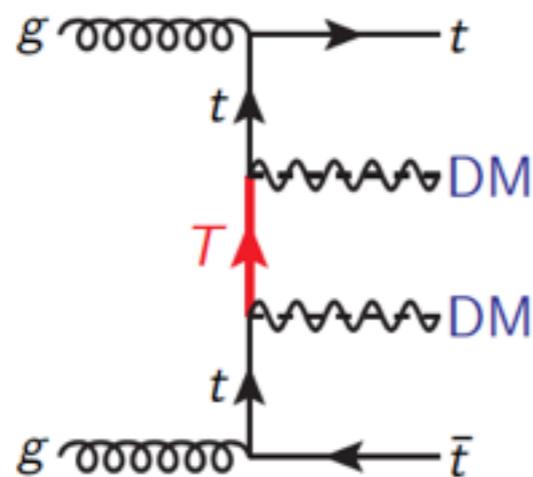
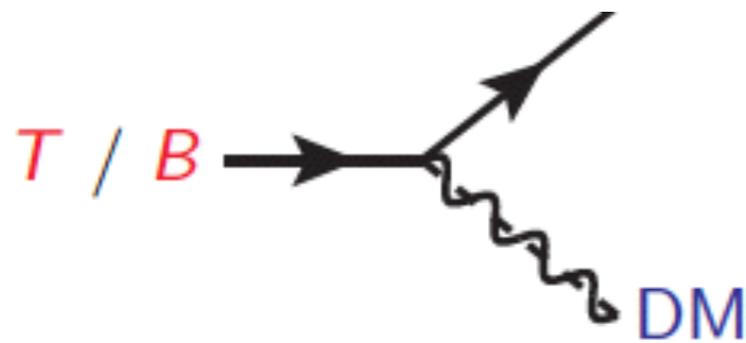
Mass limits above 1 TeV for each analysis at 100% BR!



Vector Like Quarks, Width Effects

Hugo Prager

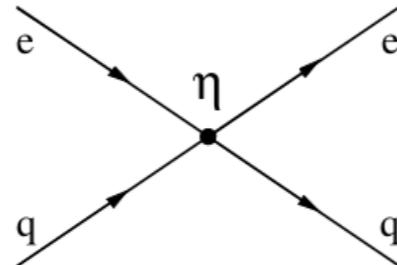
Heavy quark decays to DM
beyond the NWA



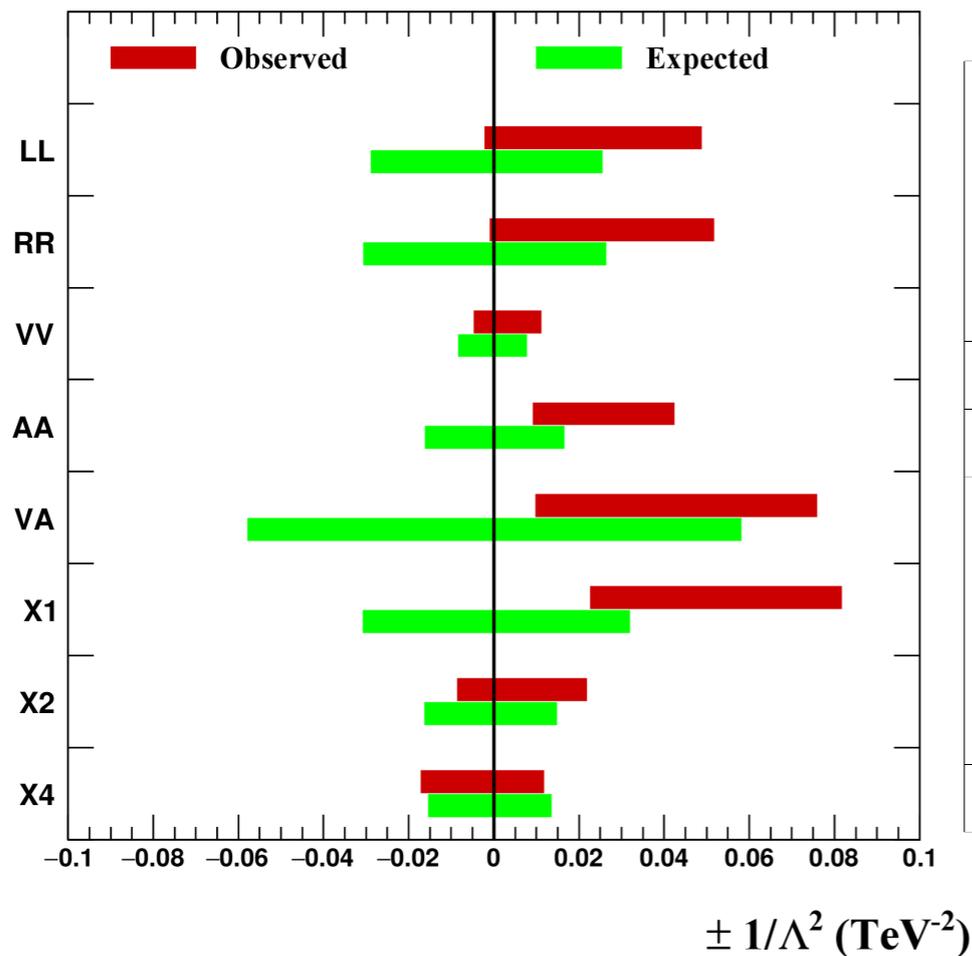
Width impact on total cross-section and mass exclusion

HERA and NA62

Limits on quark radius R_q and eq contact interactions



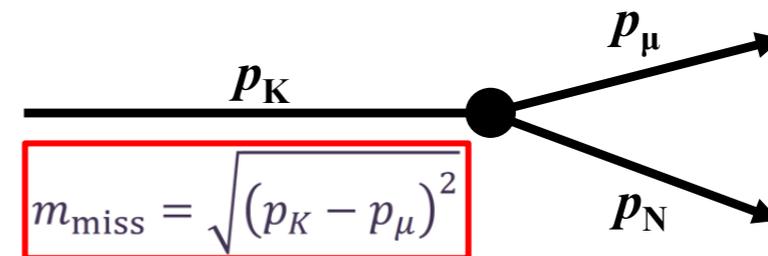
HERA $e^\pm p$ 1994-2007 95% C.L.



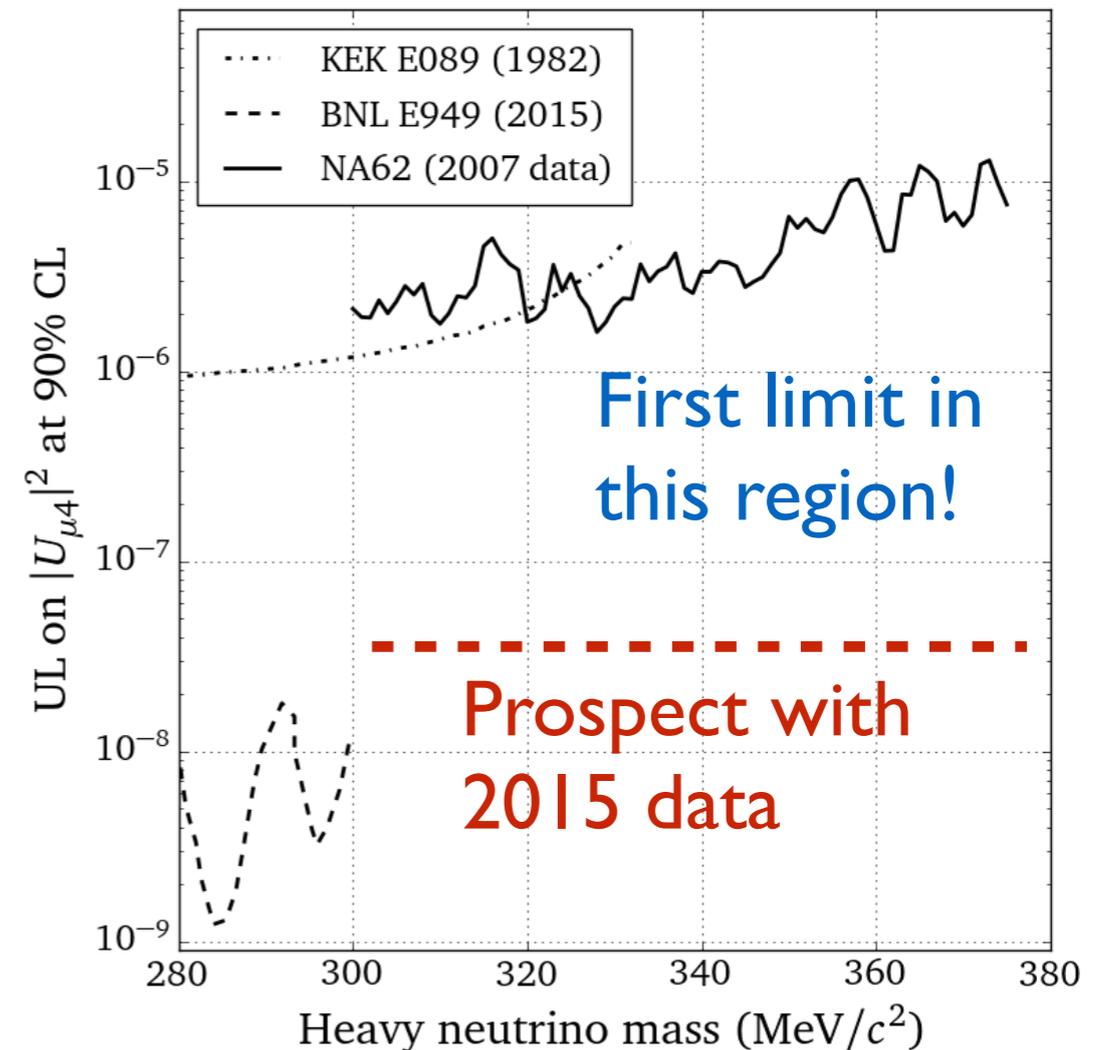
Full HERA-2 combined data

$$R_q < 0.43 \cdot 10^{-18} \text{ m}$$

Heavy neutrinos in kaon-decay



Chris Parkinson

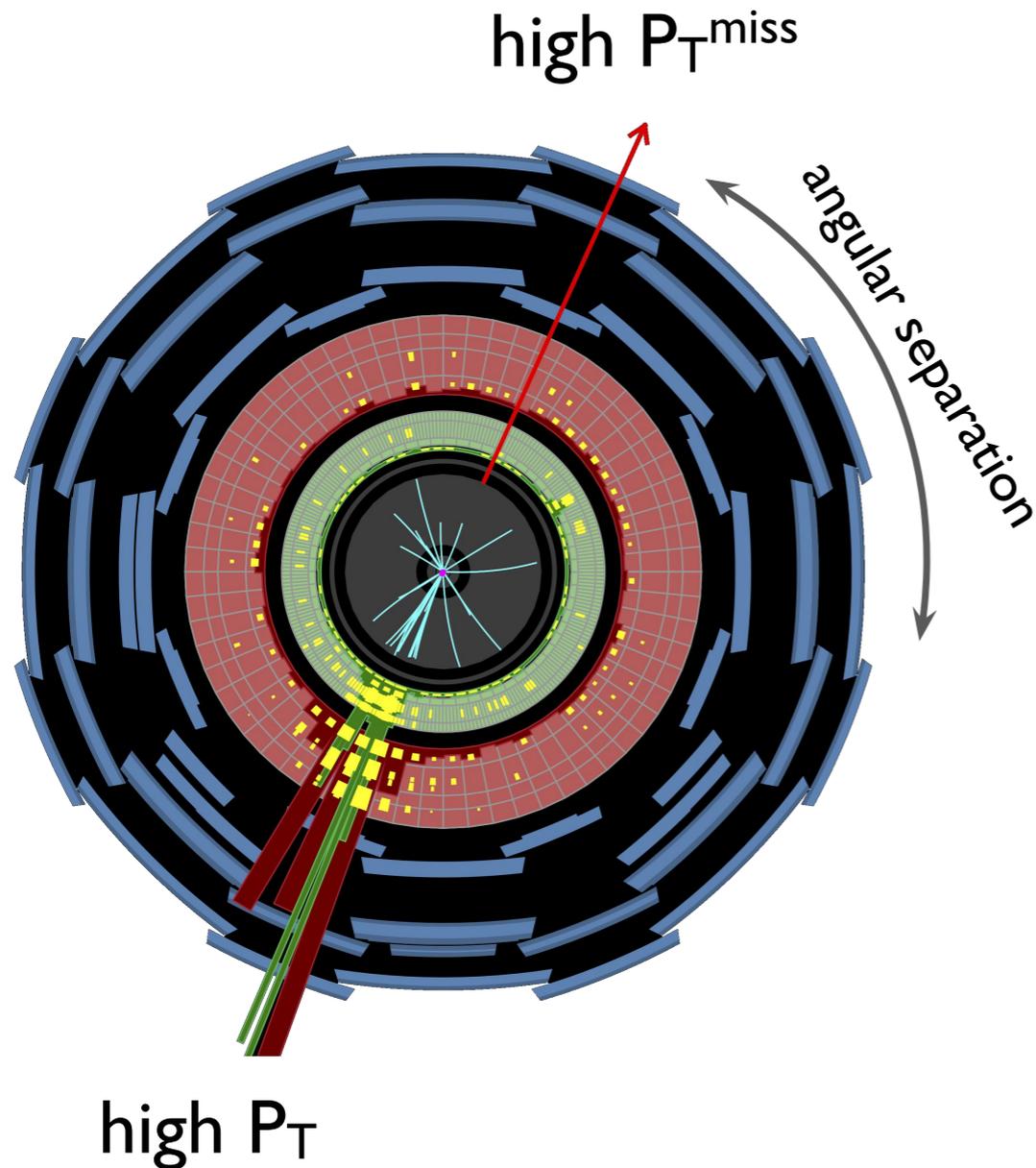
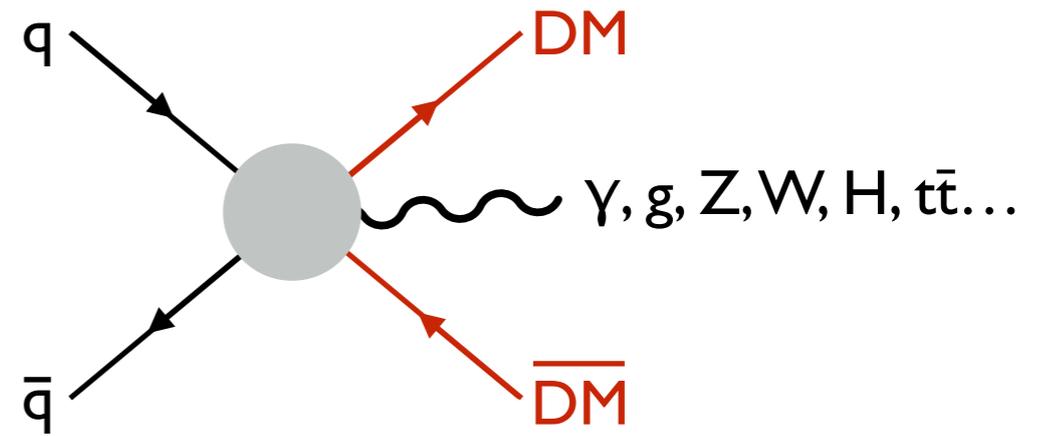


Dark Matter

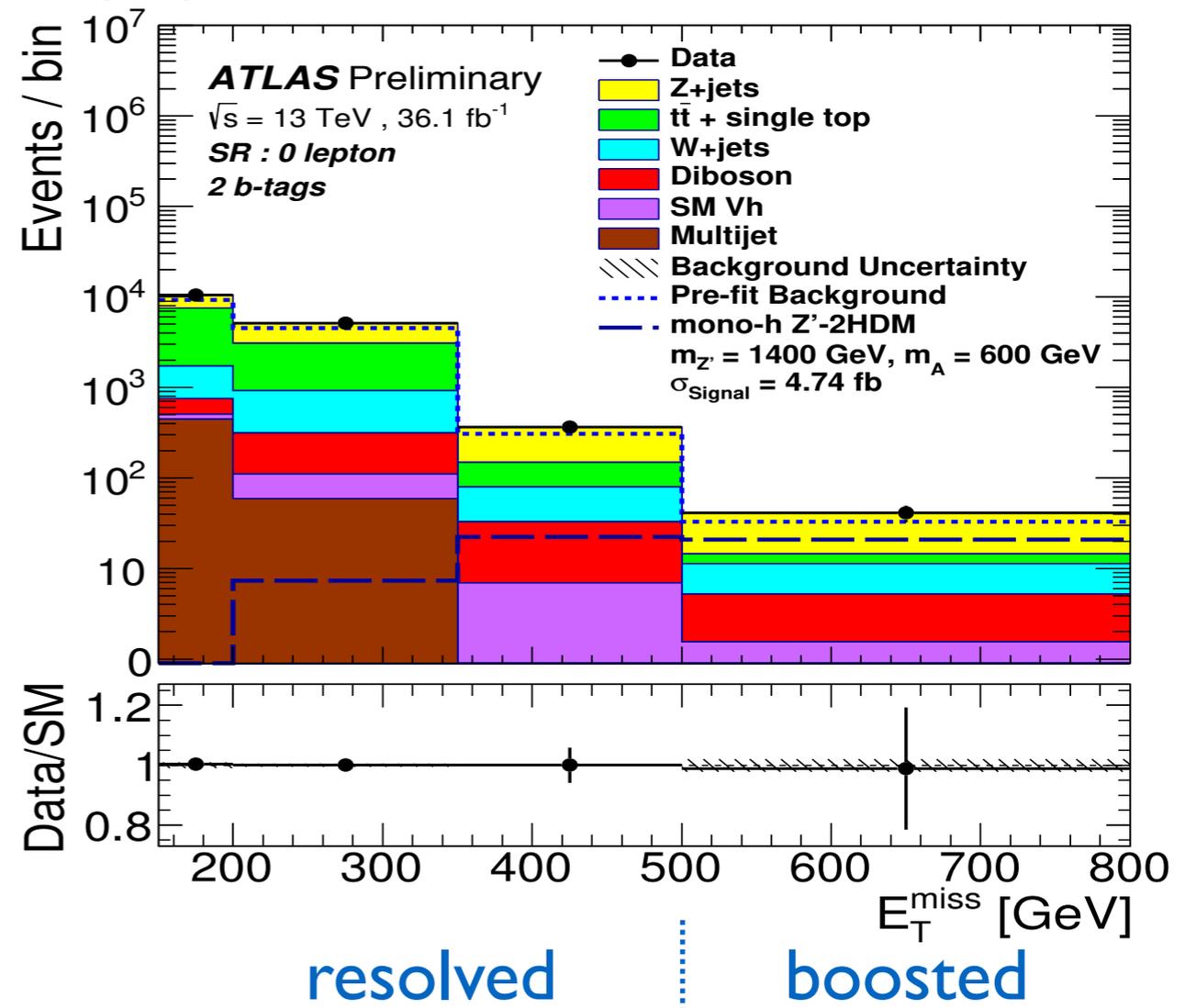
Dark Matter Production

Mono-X Searches

- ▶ Recoil of SM particle against DM system

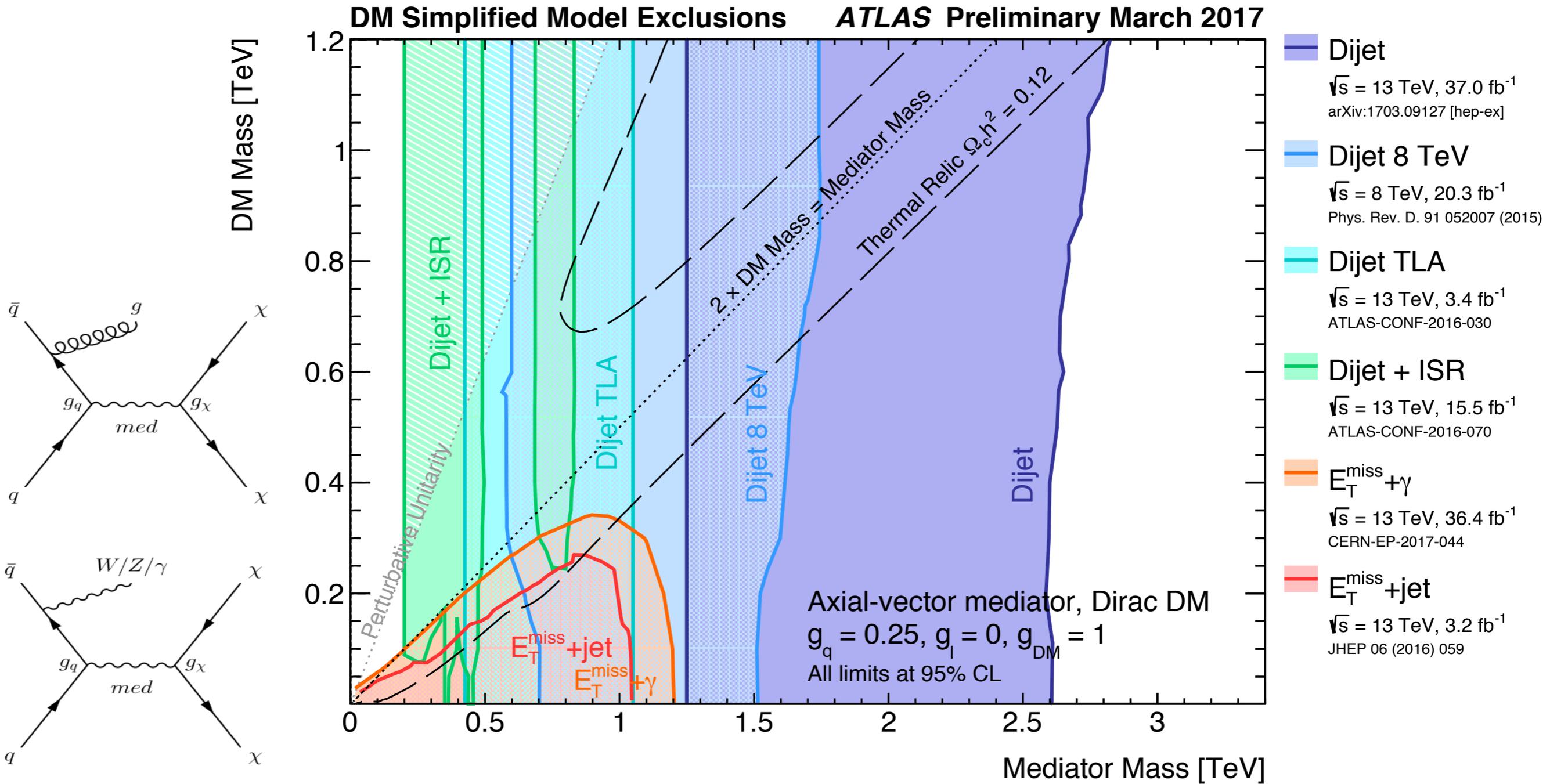


H(bb) + P_T^{miss} Full 13 TeV dataset!



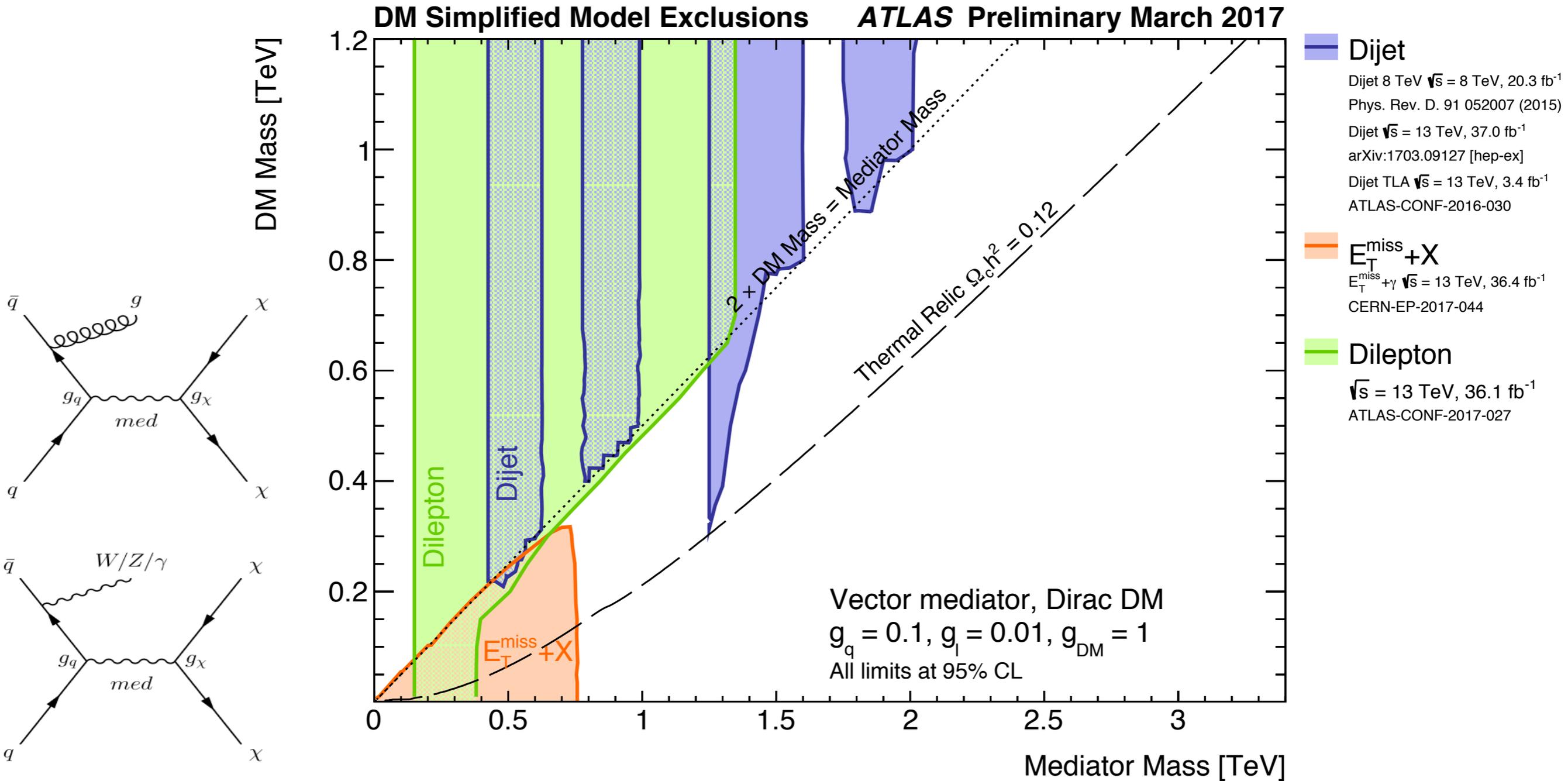
Interpretation in Simplified Models

Cora Fischer

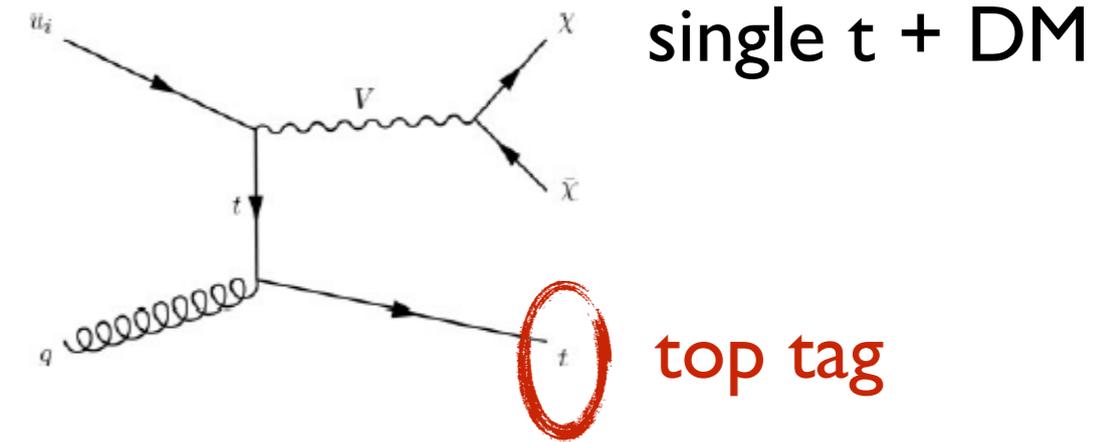
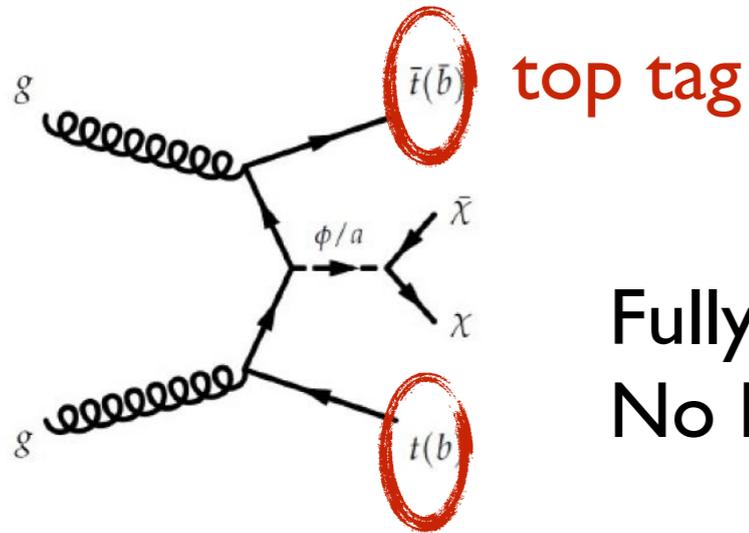


Interpretation in Simplified Models

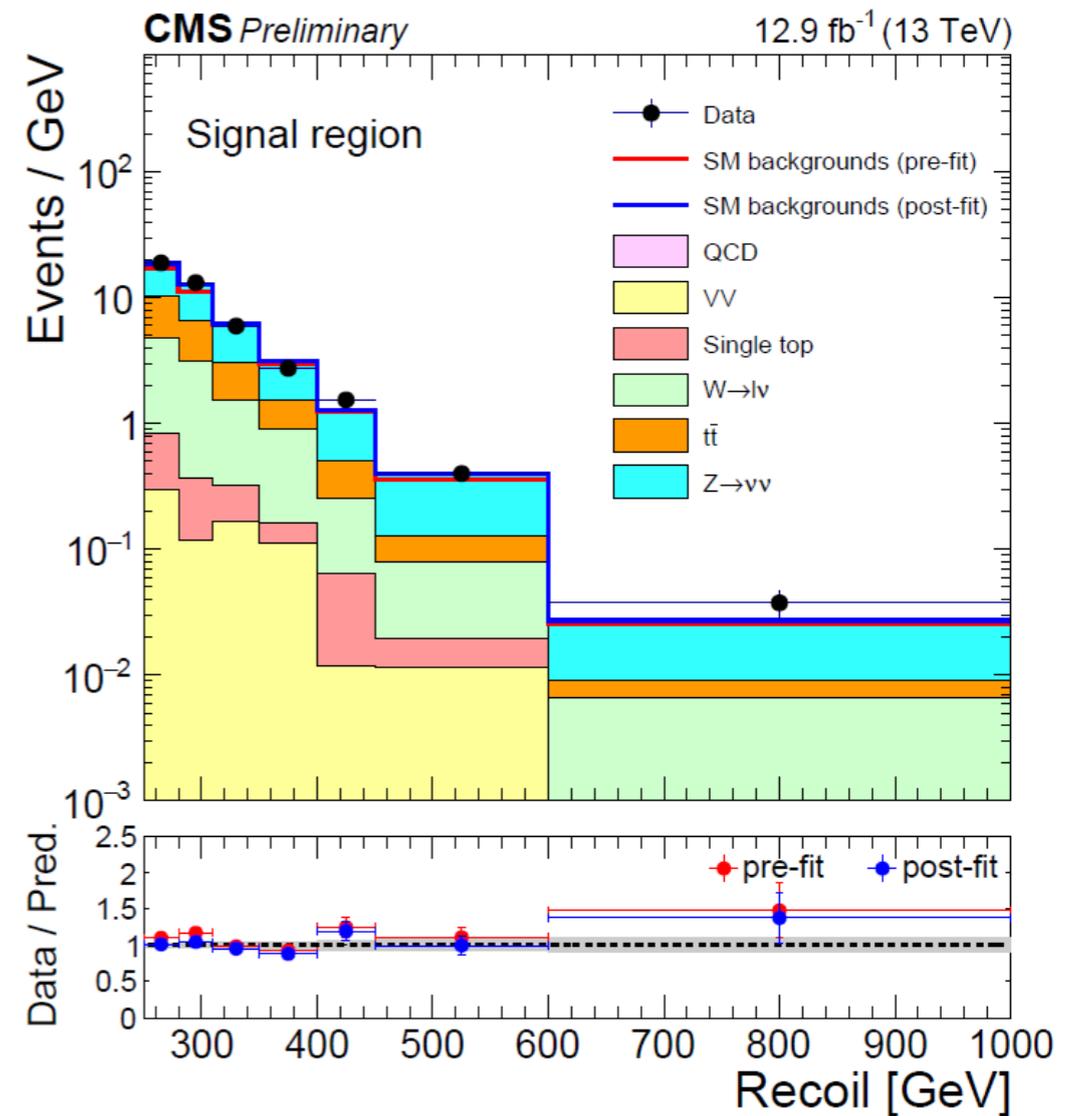
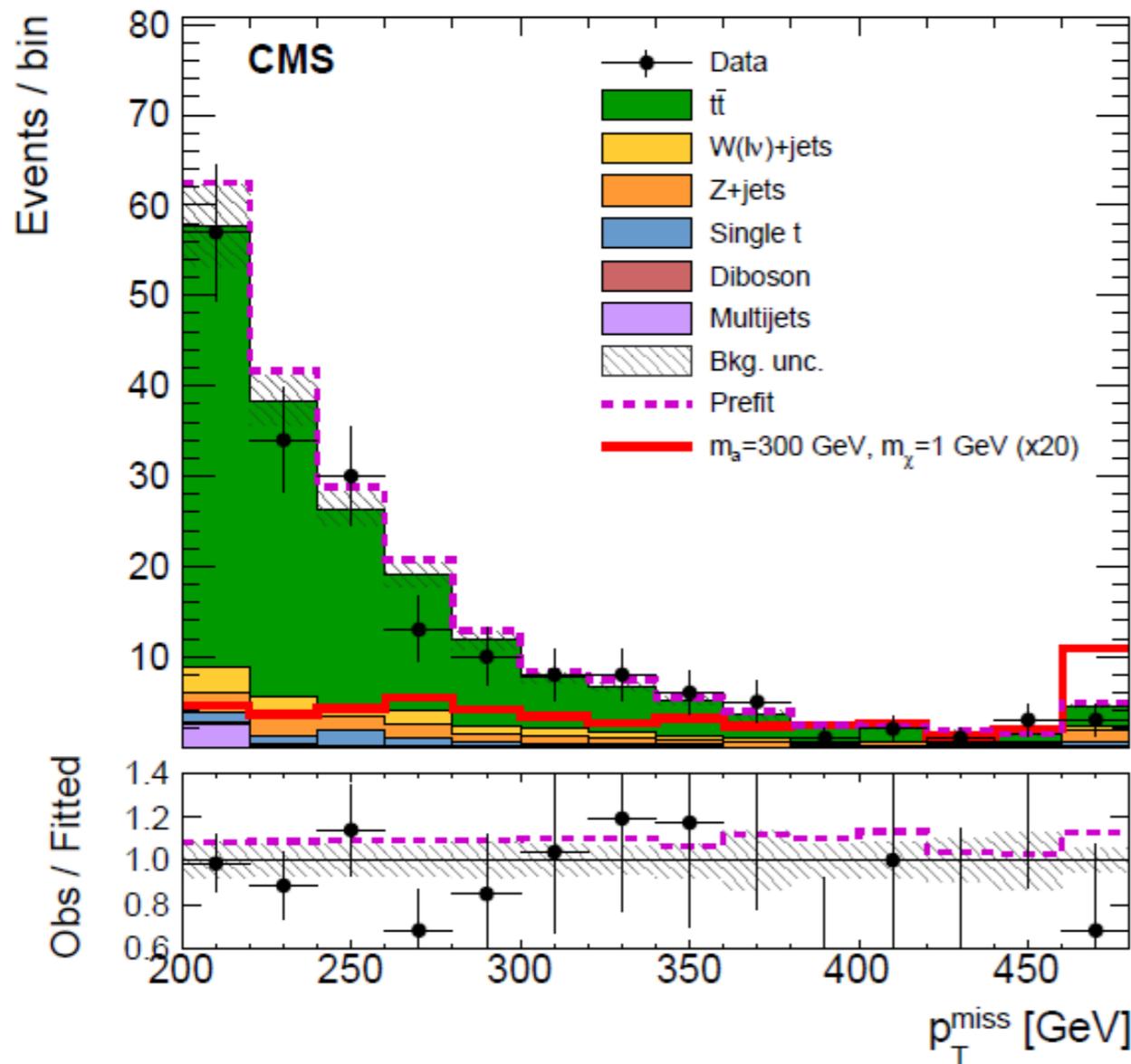
Cora Fischer



DM+bb/tt



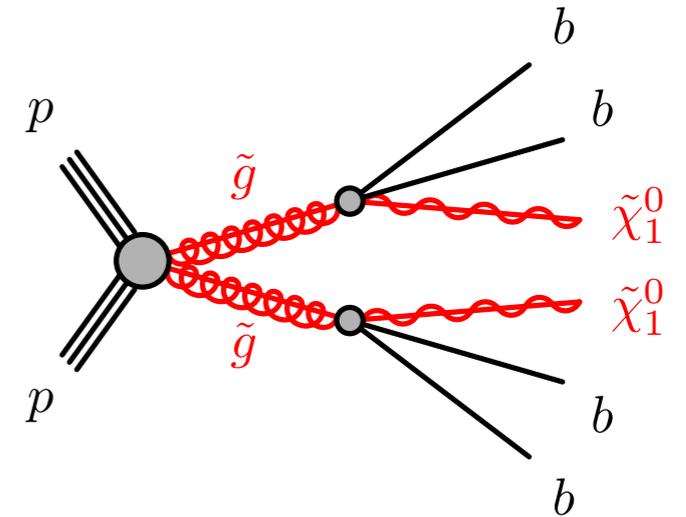
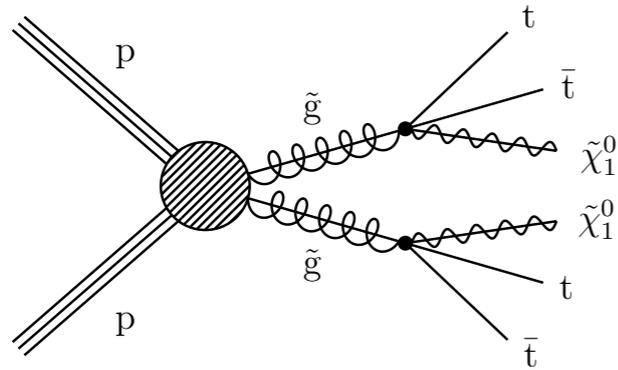
2.2 fb⁻¹ (13 TeV)



SUSY

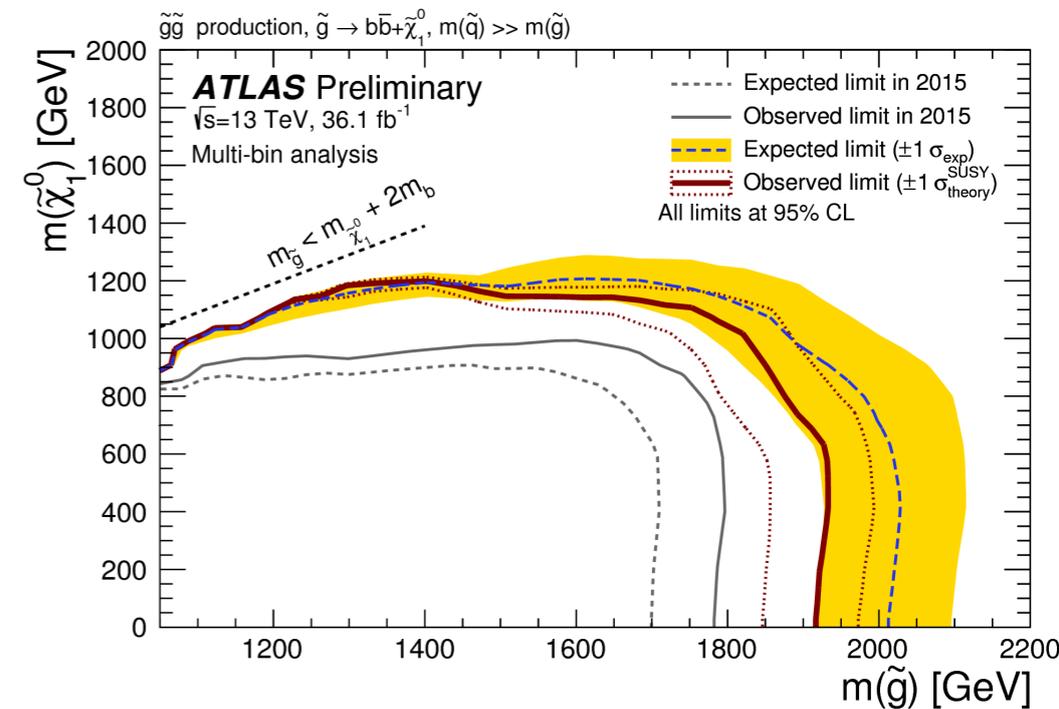
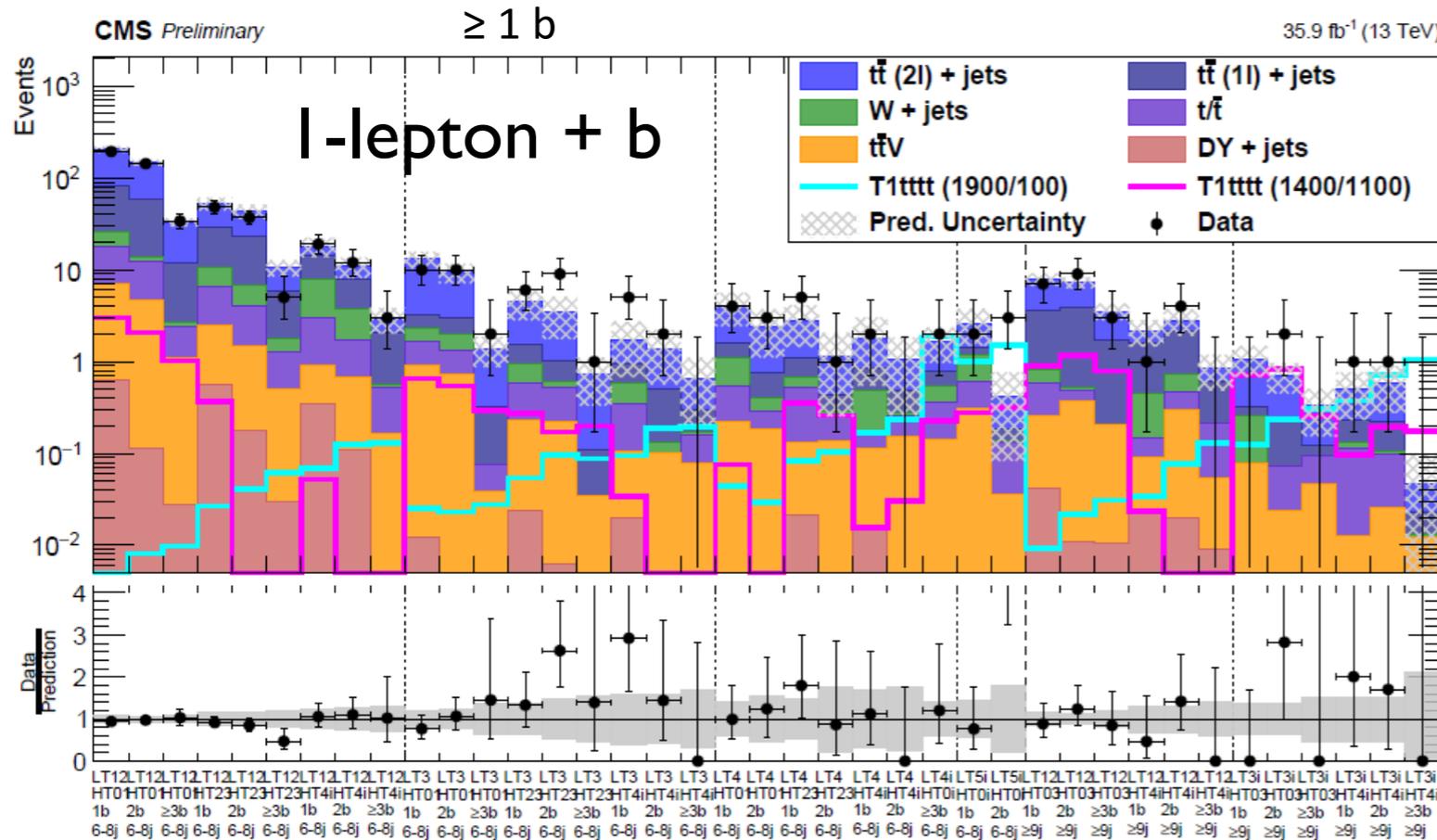
Strong production

Full 13 TeV dataset!



- ▶ 0, 1, 2, multi-leptons
- ▶ Categorize in N_{jet} , N_{b-jet} , H_T , P_T^{miss} ...

- ▶ 0/1 lepton, multiple b-jets, P_T^{miss}

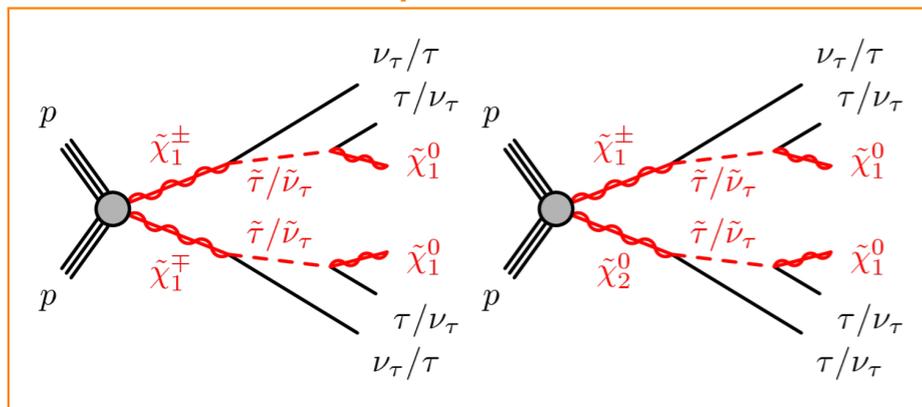


Simplified Model:
 $m_{\tilde{g}} > 1800 \text{ GeV}$

Chargino/Neutralino Production

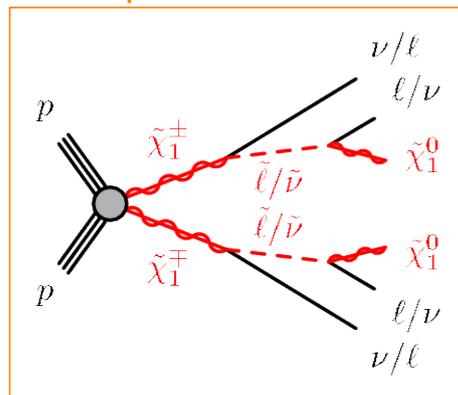
- ▶ Electroweak production \rightarrow smaller cross sections
- ▶ Multitude of final states

C1C1 & C1N2 production

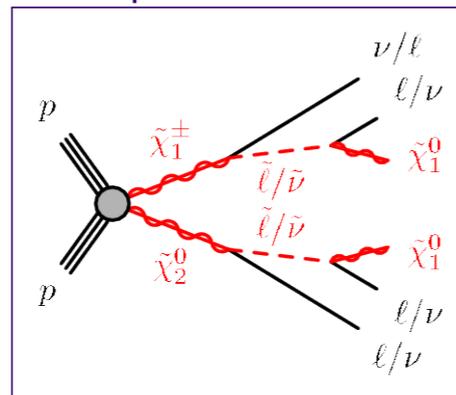


τ final states

C1C1 production



C1N2 production



light leptons

Nicky Santoyo Castillo

Chargino/Neutralino Production

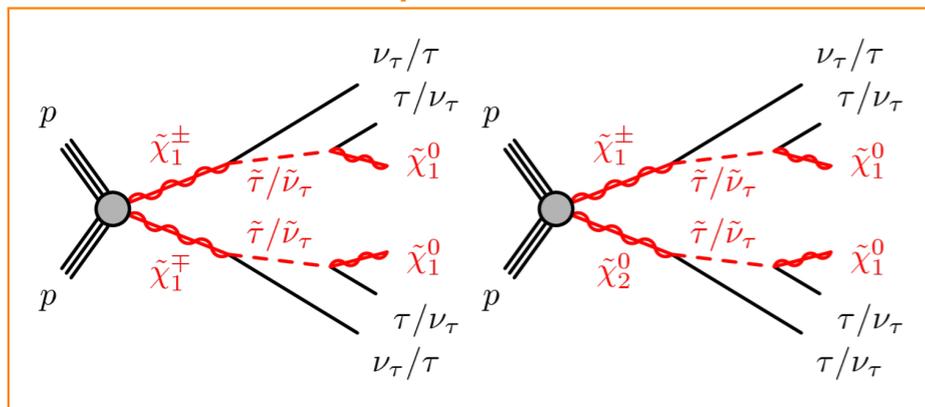
- ▶ Electroweak production → smaller cross sections **Full 13 TeV dataset!**
- ▶ Multitude of final states

Ece Aşilar

Moriond 2017

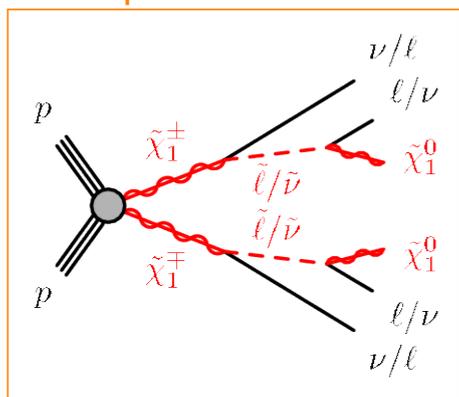
$$pp \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$$

C1C1 & C1N2 production

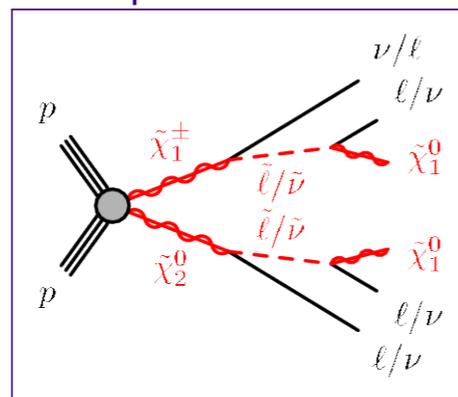


τ final states

C1C1 production

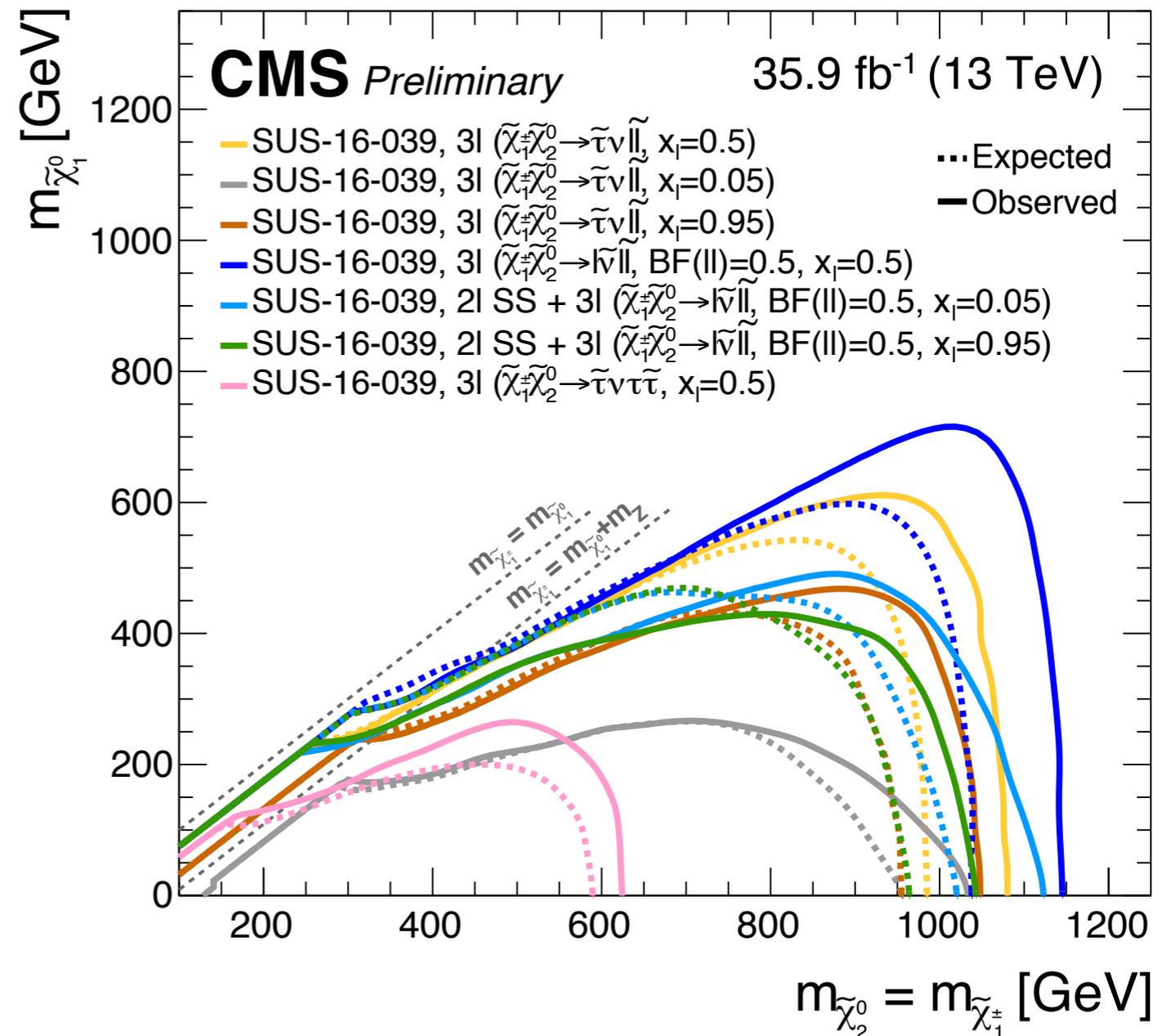


C1N2 production



light leptons

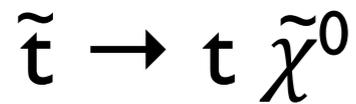
Nicky Santoyo Castillo



Natural SUSY, $\tilde{t}\tilde{t}$ production

John Anders

Markéta Jansová



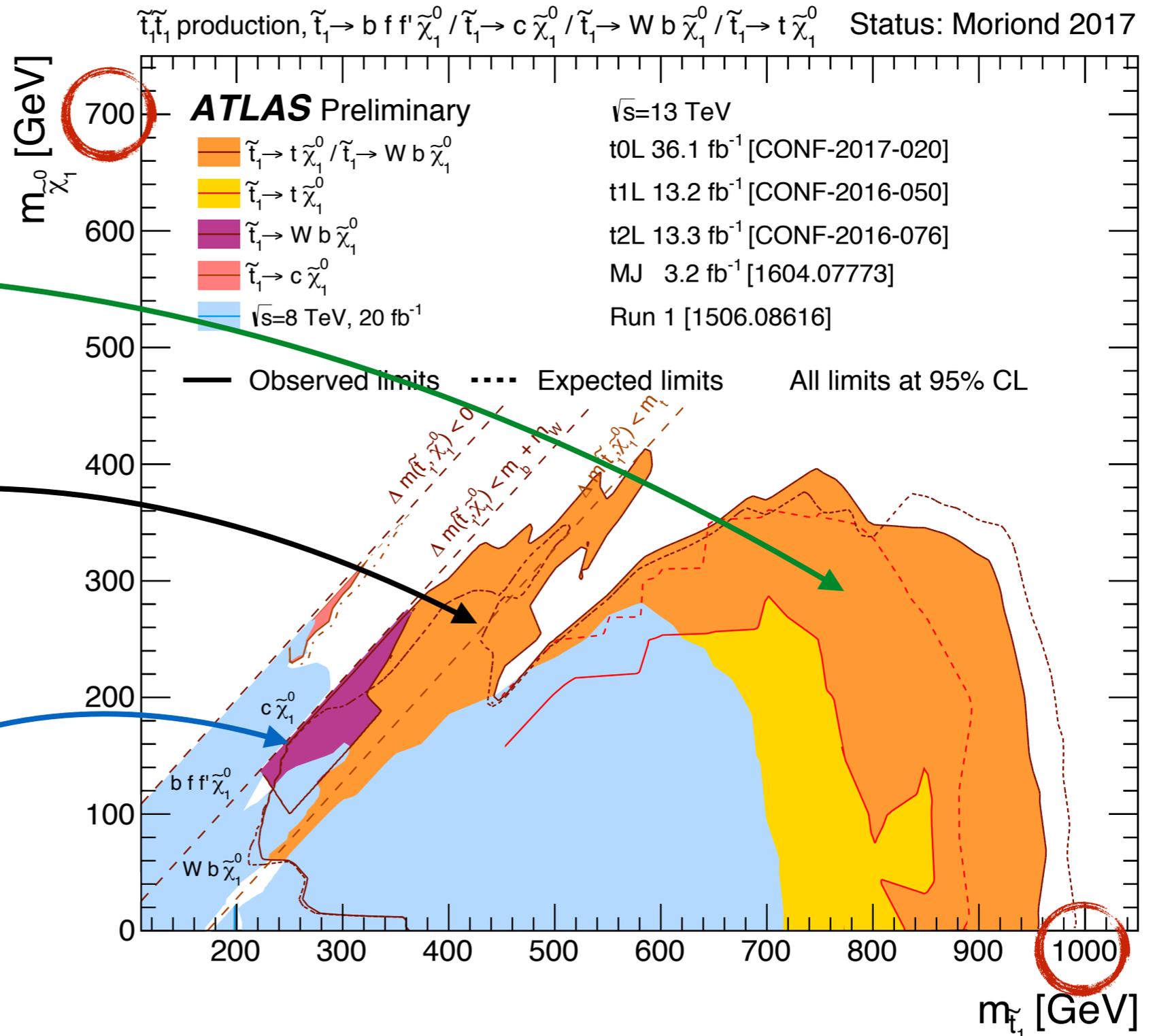
Jet-Substructure



ISR Jet



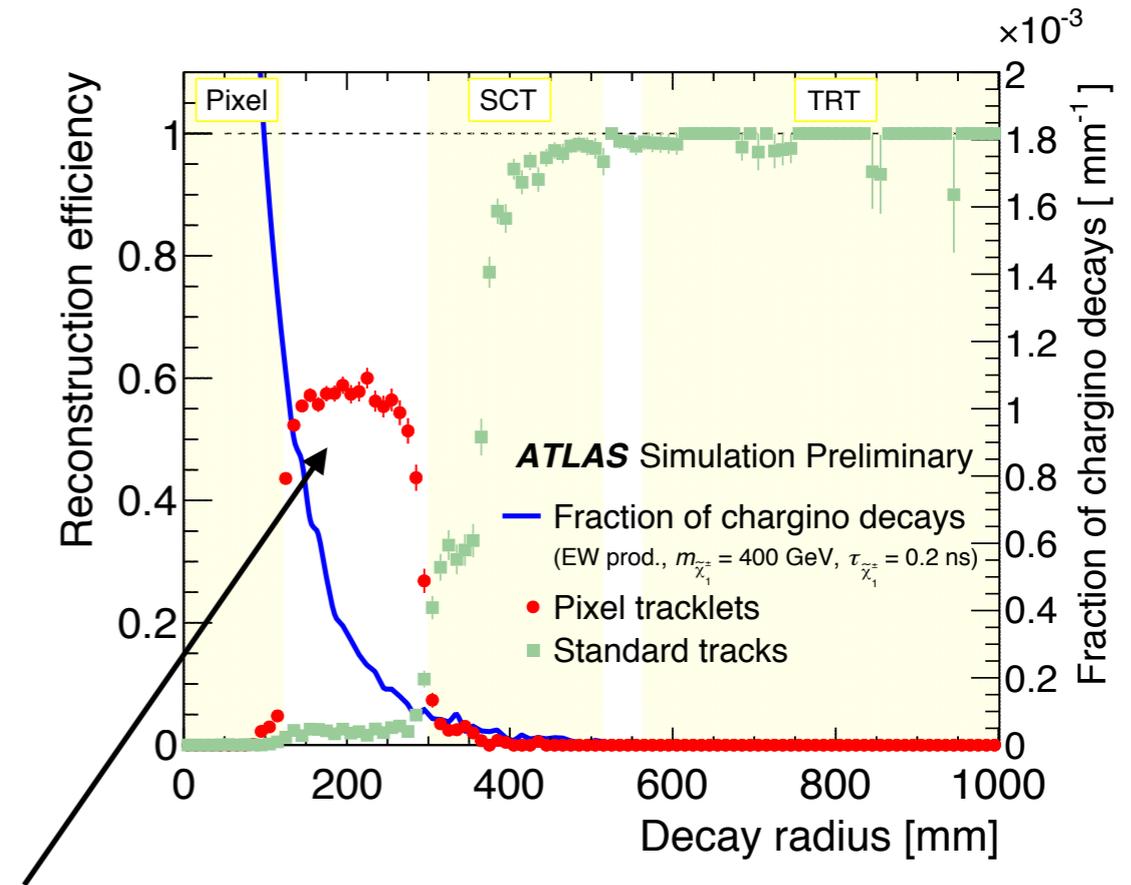
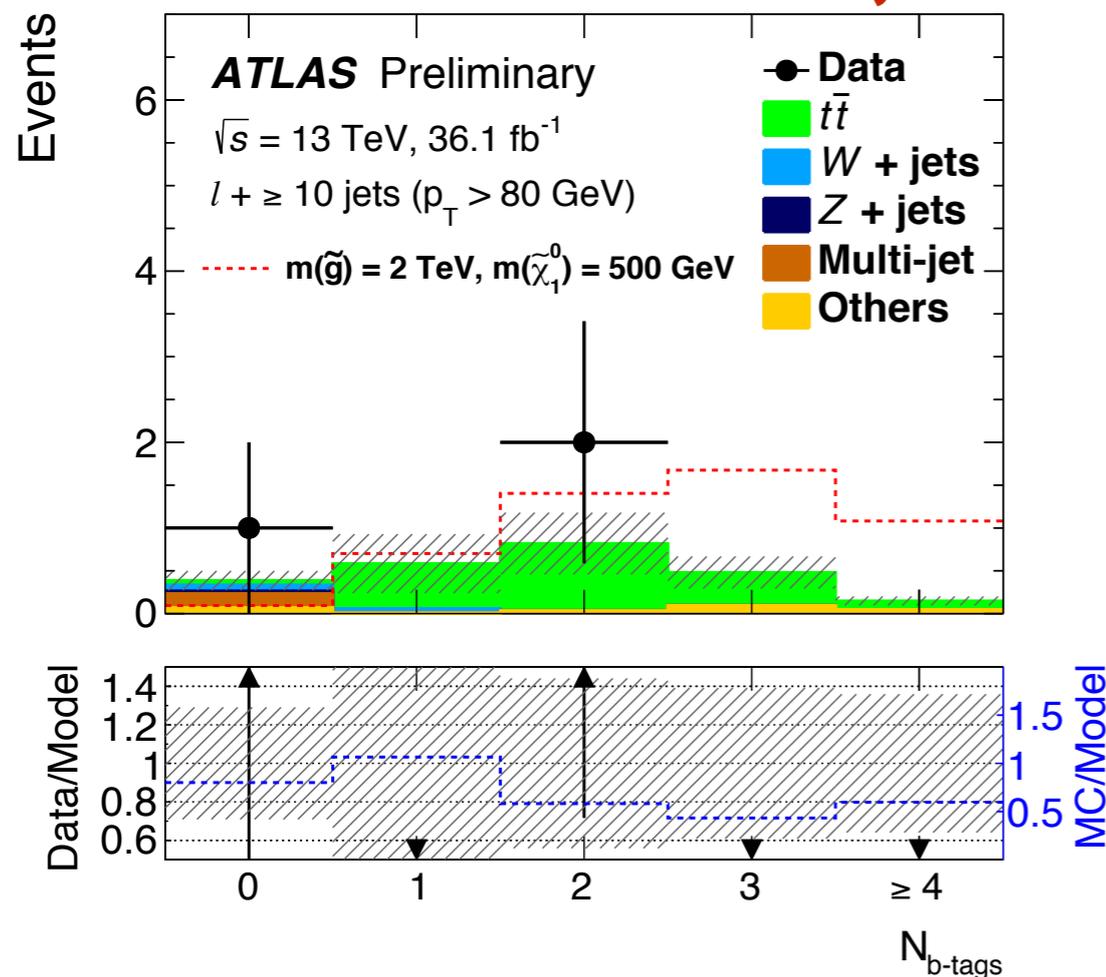
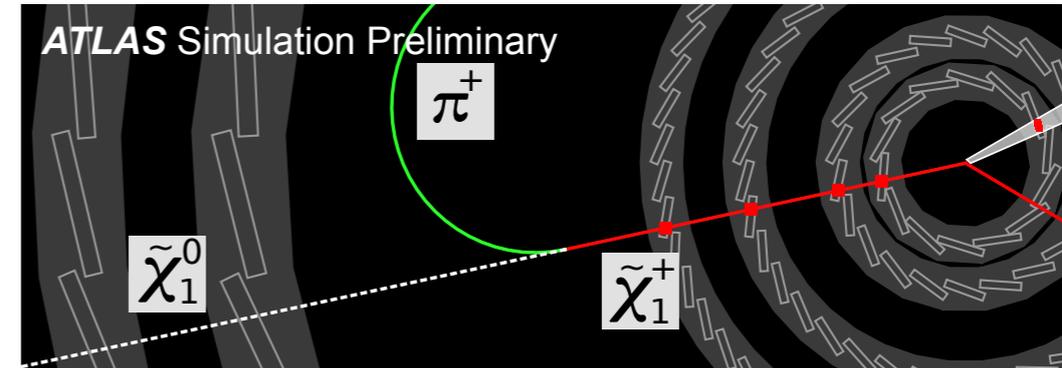
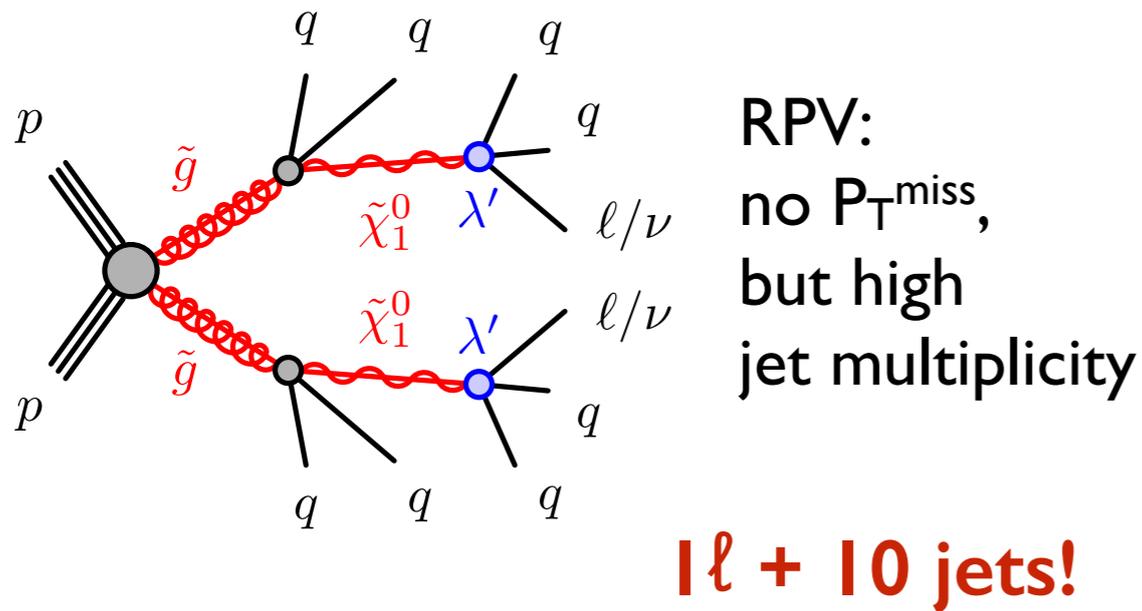
soft b-tagging,
charm tagging



RPV SUSY and Long-lived Particles

Nathan Bernard

Disappearing tracks from long-lived particles



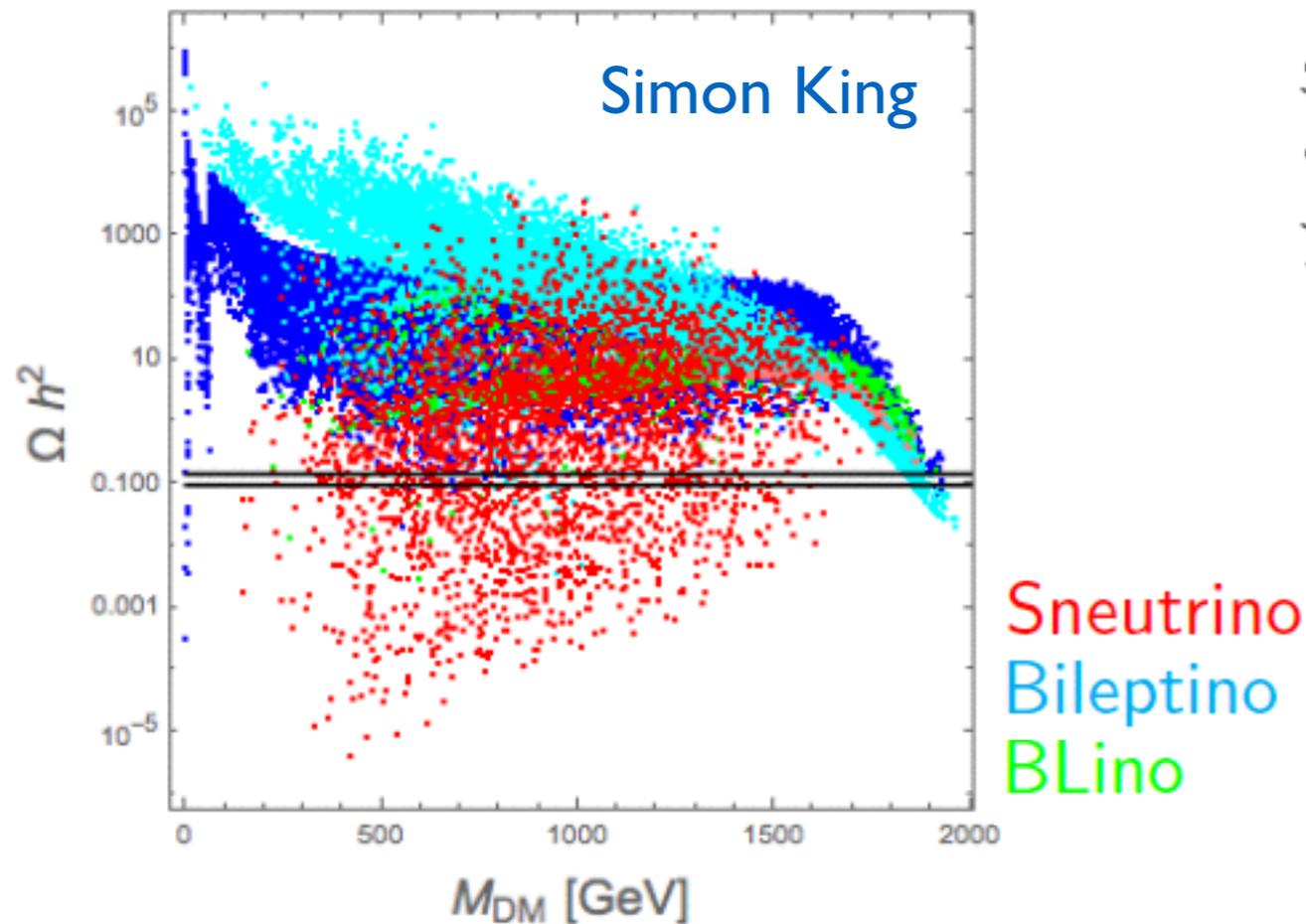
Improved efficiency through IBL

SUSY Extensions

BLSSM: Extended Gauge group

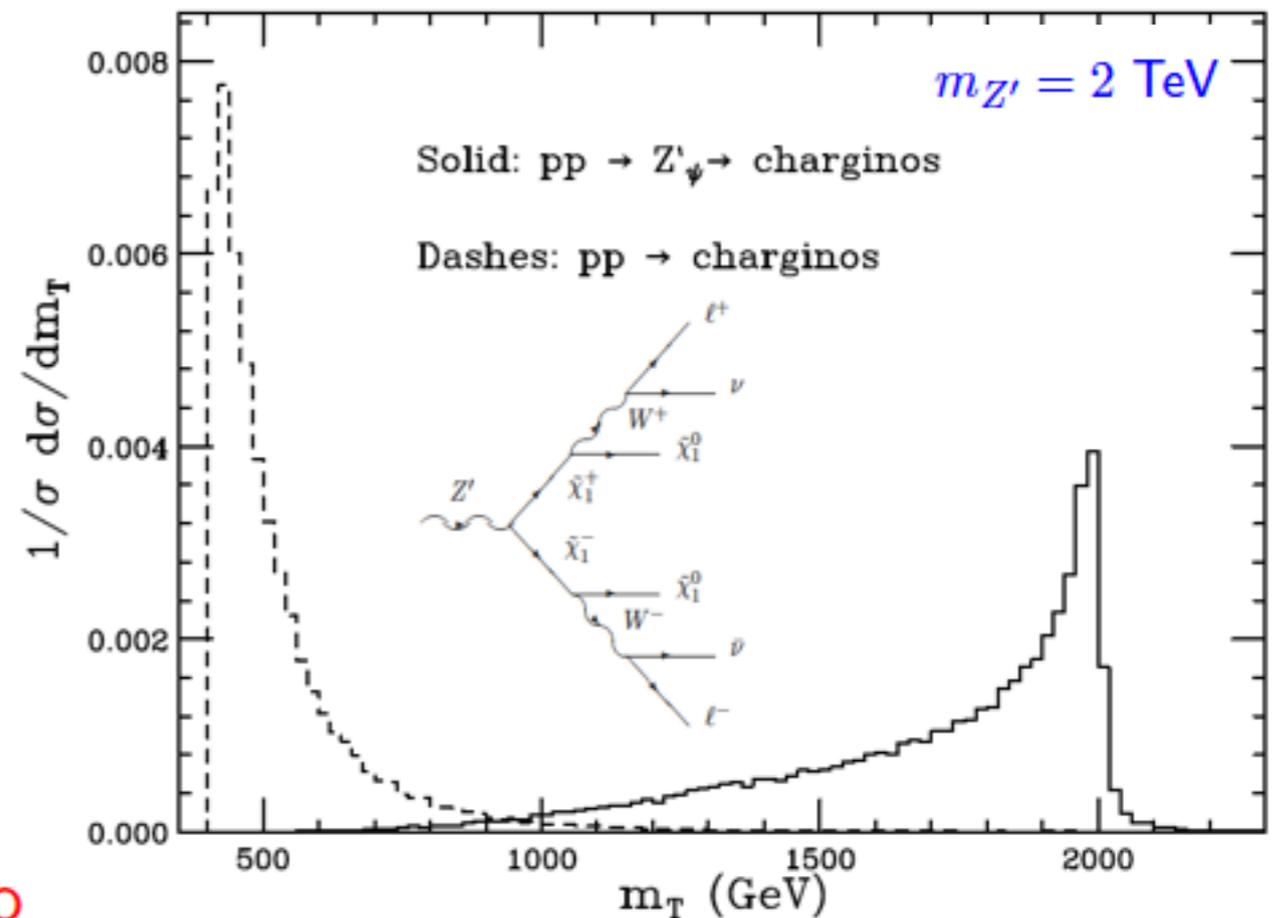
$$G_{B-L} = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

- Solution to Hierarchy problem
- Similar fine-tuning as MSSM
- Right-handed neutrinos
- Dark Matter candidates



MSSM and $U(1)'$: UMSSM

Z' decays to charginos, neutralinos and SM particles



Z' phenomenology in supersymmetry at the LHC

Gennaro Corcella

On the verge of discovering direct
Hbb and Htt couplings

Keep looking for the unexpected!

Thanks to all speakers and to the
organisers for a very stimulating
DIS2017!

