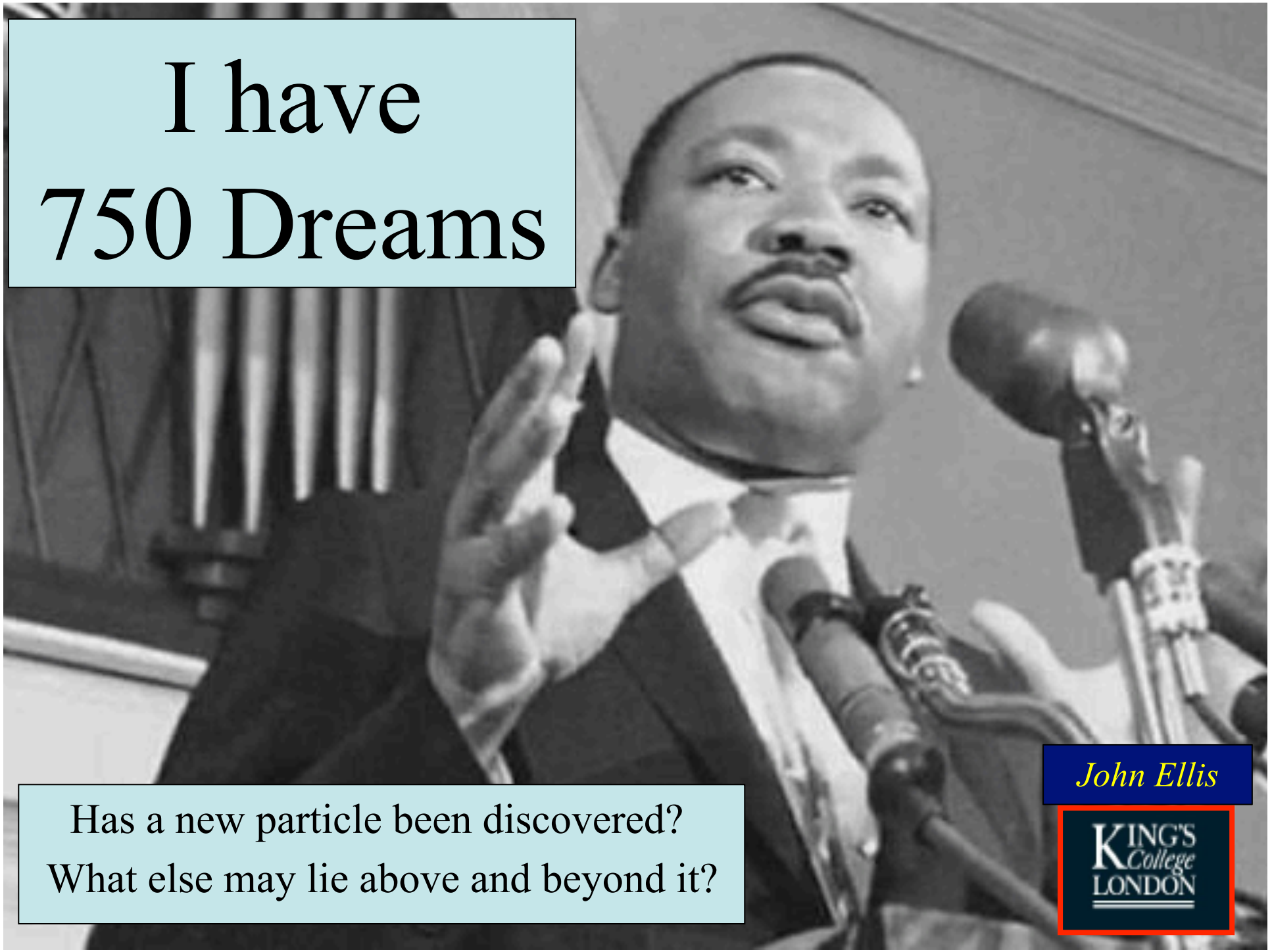
I have 750 Dreams



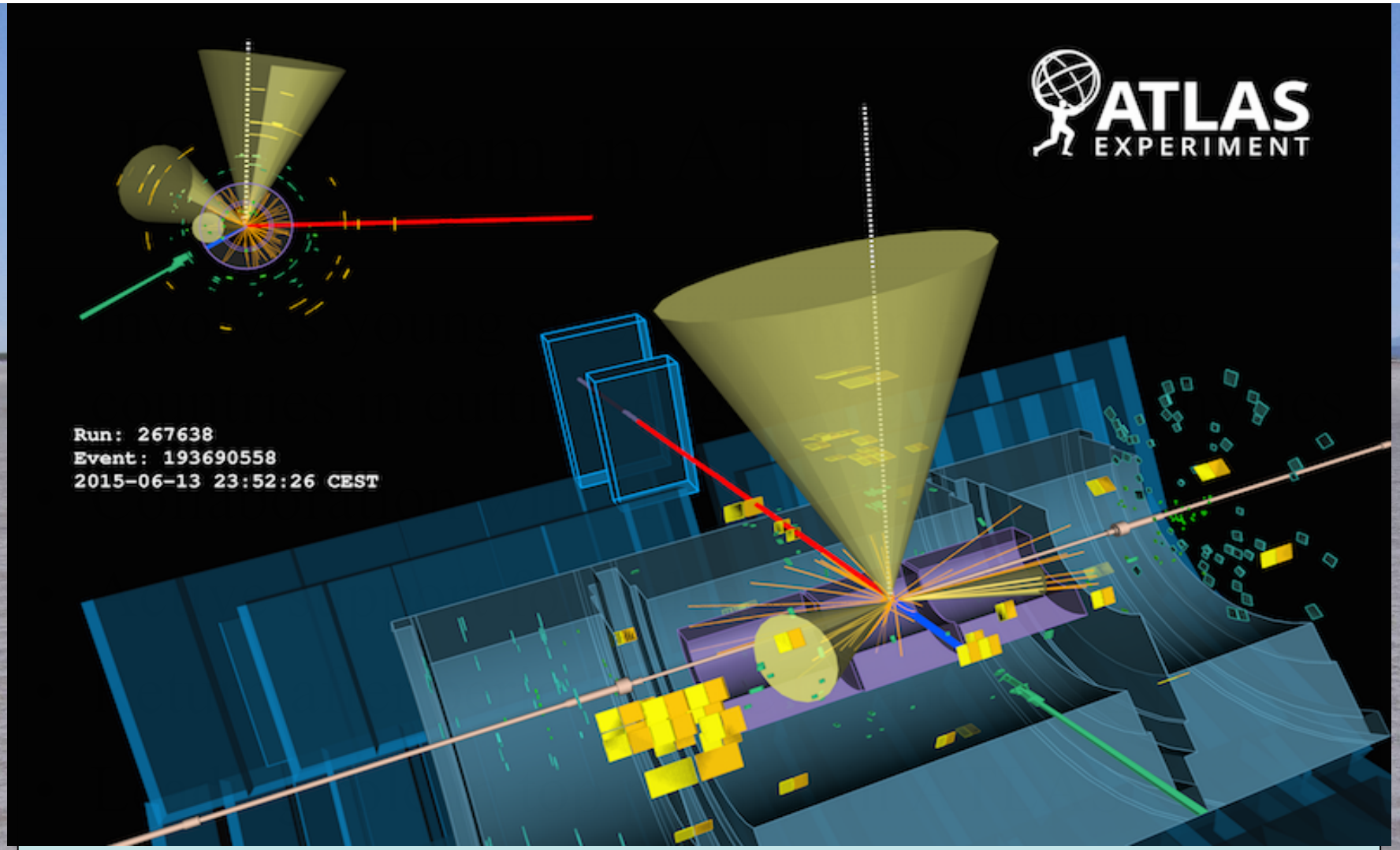
Has a new particle been discovered?
What else may lie above and beyond it?

John Ellis
KING'S College LONDON

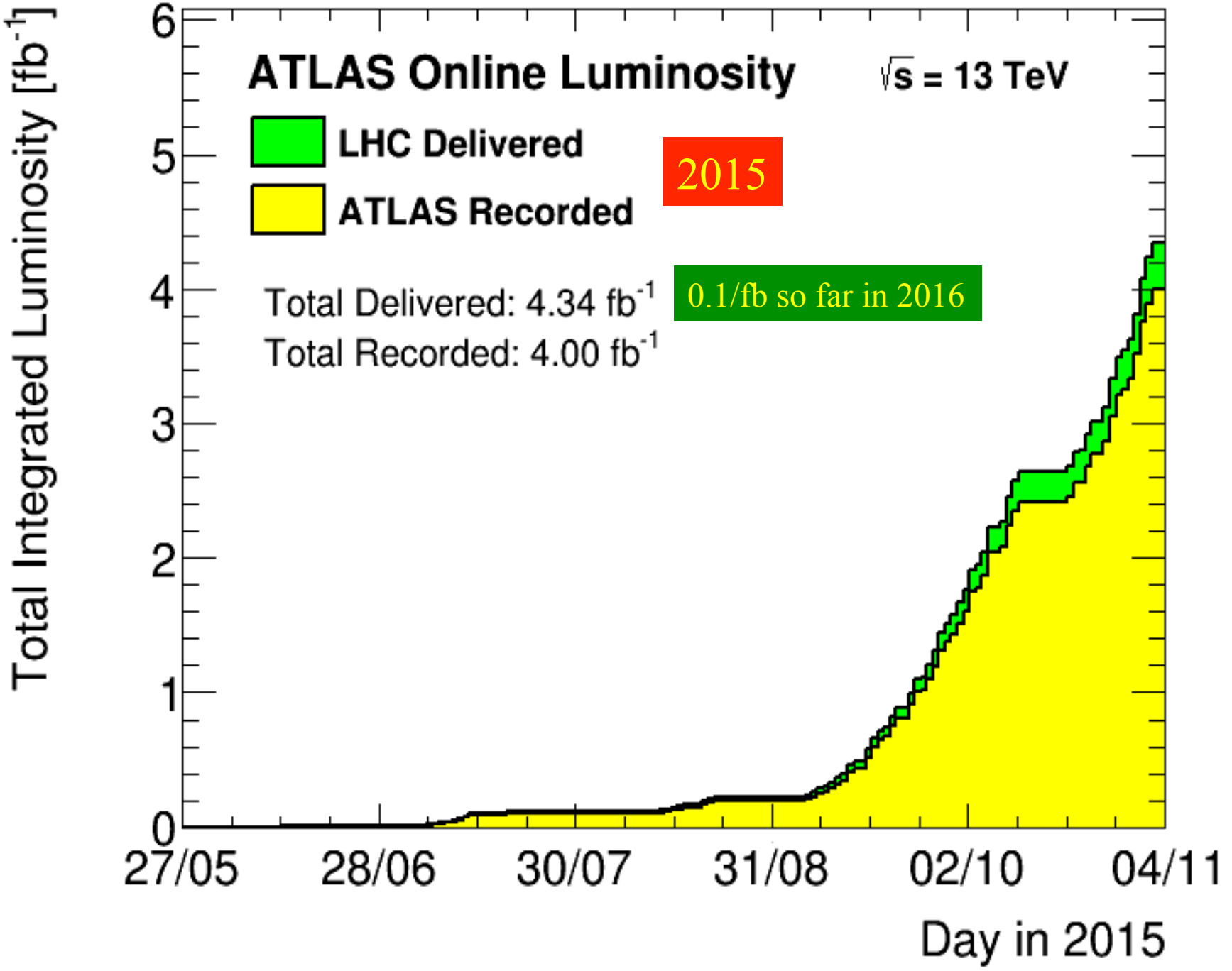
Papers with Fernando

- **Supersymmetry parameter analysis: SPA convention and project**
- Juan Antonio Aguilar-Saavedra (Lisbon, IST) *et al.. Nov 2005.*
- **Eur.Phys.J. C46 (2006) 43-60**
- e-Print: **hep-ph/0511344 | PDF**
- Cited by 324 records

- **The Hunt for New Physics at the Large Hadron Collider**
- Pran Nath (Northeastern U.) *et al.. Jan 2010.*
- **Nucl.Phys.Proc.Suppl. 200-202 (2010) 185-417**
- e-Print: **arXiv:1001.2693 [hep-ph] | PDF**
- Cited by 125 records

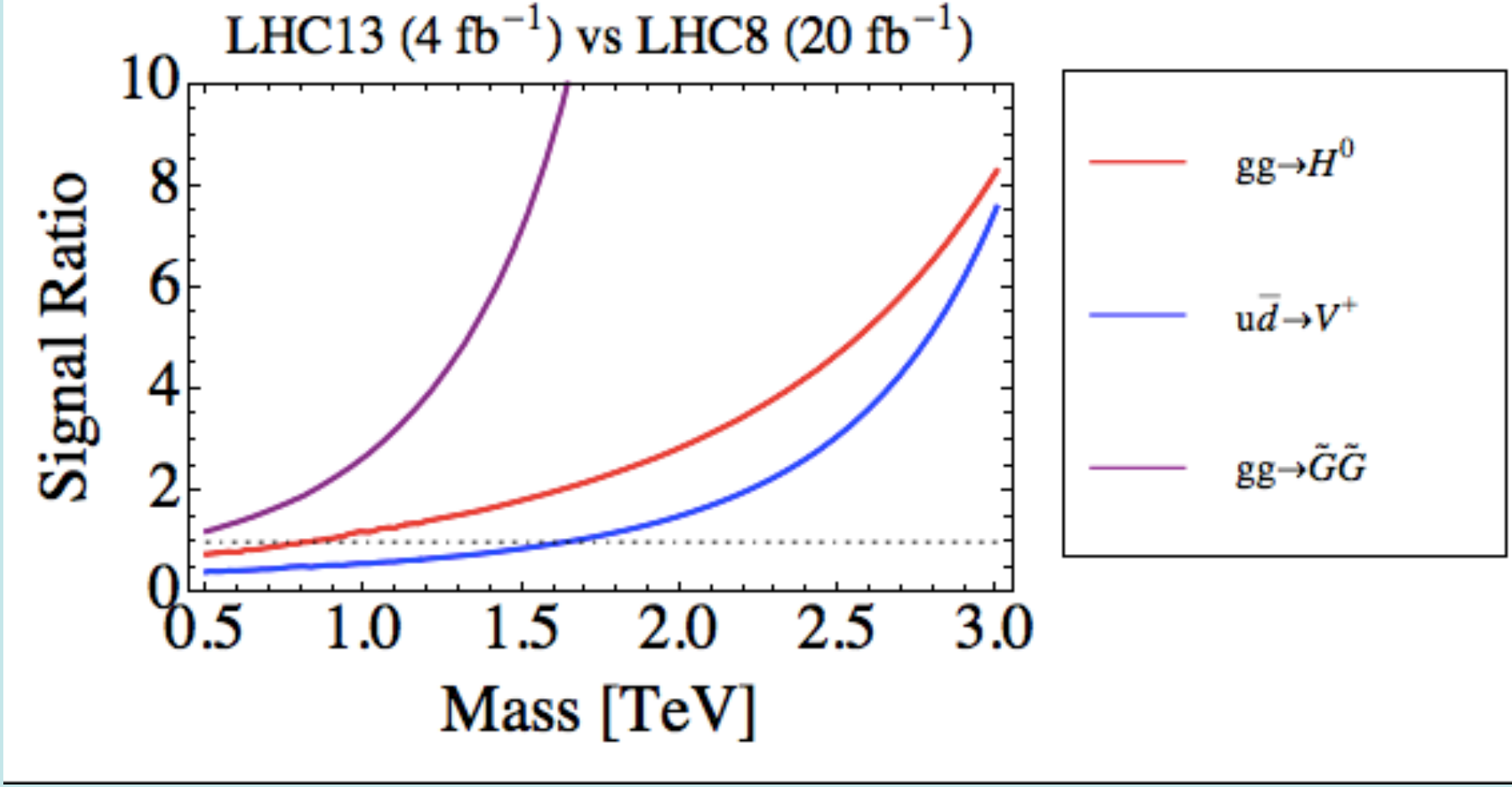


- Top production, mass, H $t\bar{t}$ production
- Possible connection to X(750)


ATLAS Online Luminosity
√s = 13 TeV
LHC Delivered
ATLAS Recorded
2015
Total Delivered: 4.34 fb-1
Total Recorded: 4.00 fb-1
0.1/fb so far in 2016
Total Integrated Luminosity [fb-1]
0
1
2
3
4
5
6
27/05
28/06
30/07
31/08
02/10
04/11
Day in 2015

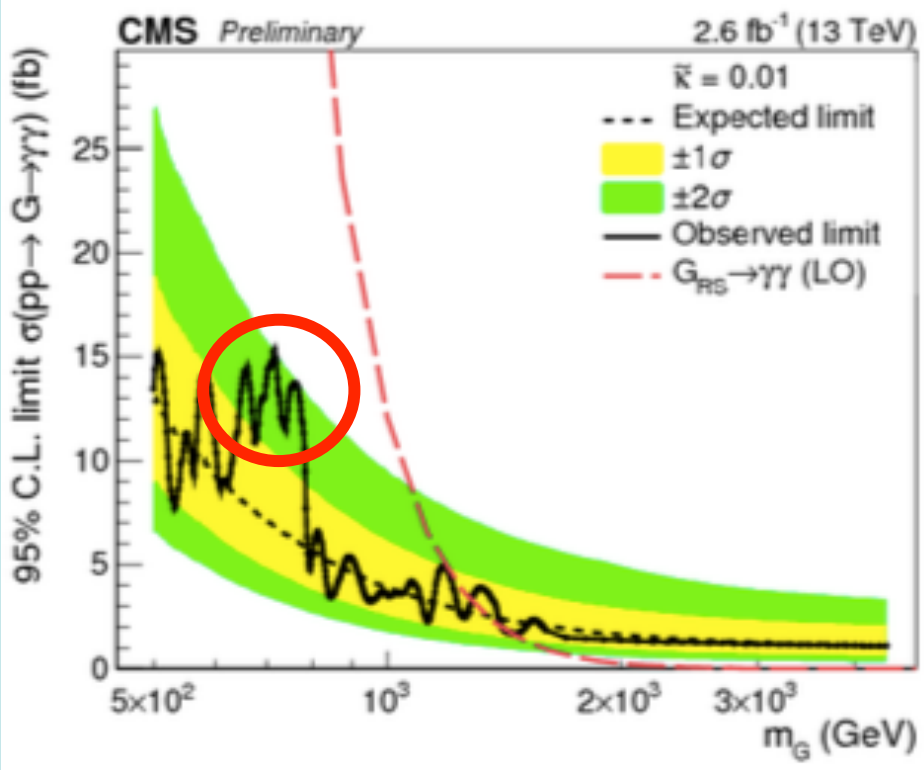
Why we are so excited by Run 2

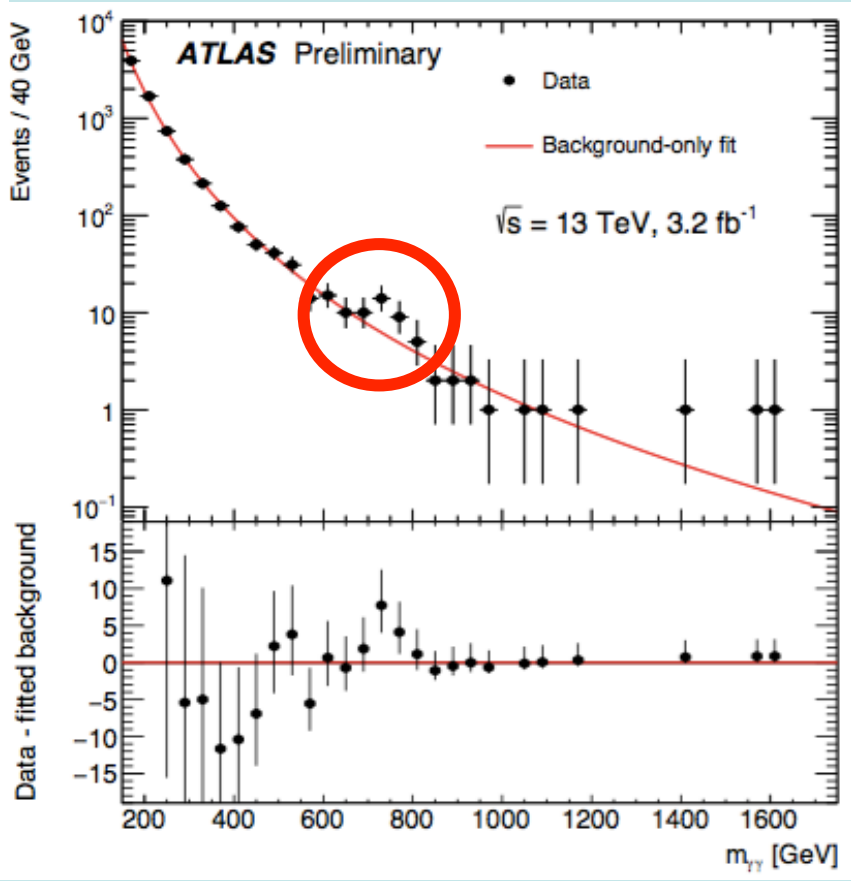
- 2015 luminosity already explores new physics



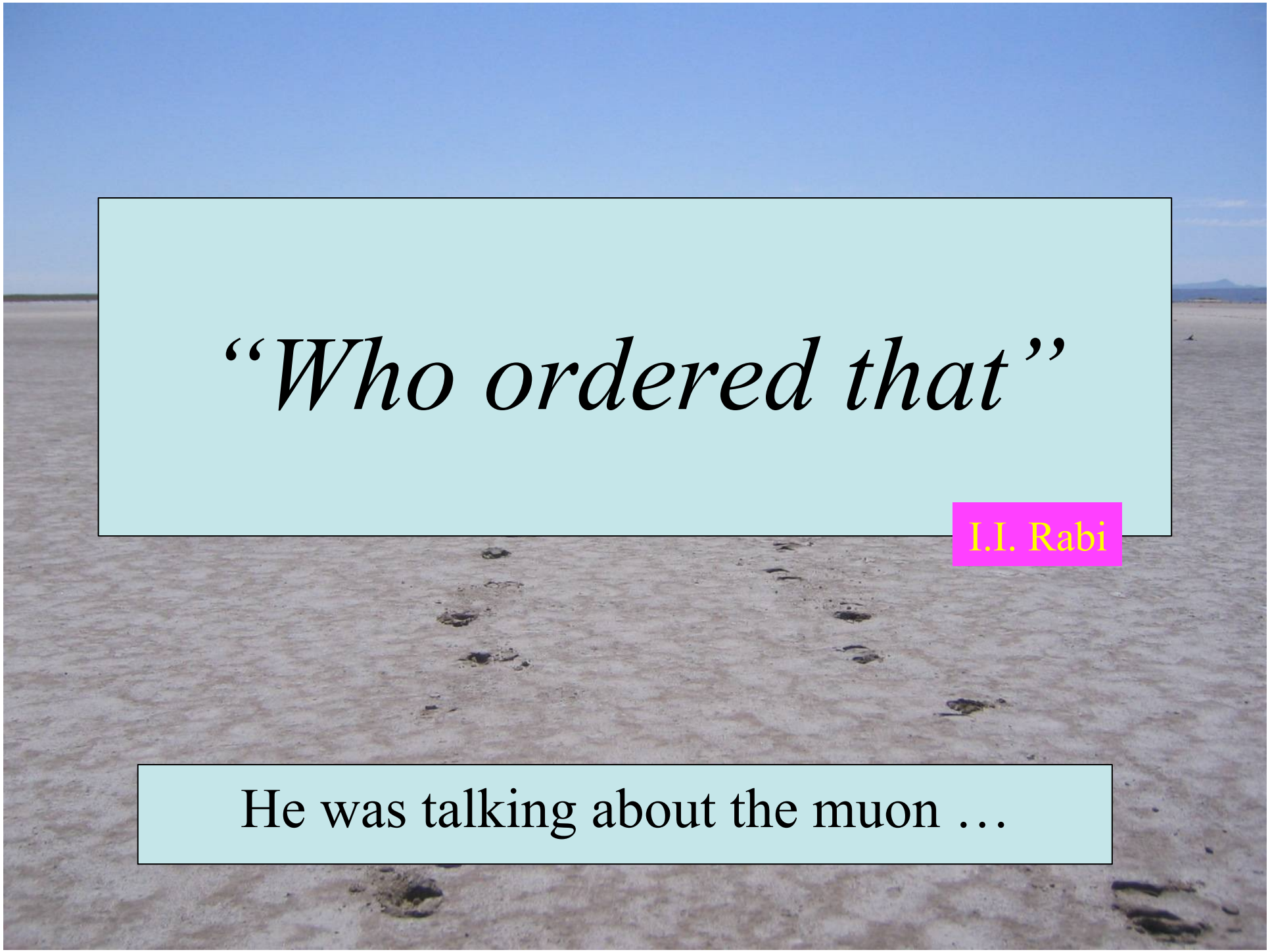
Reported on Tuesday, Dec. 15

- **Peaks in γγ invariant mass distributions**



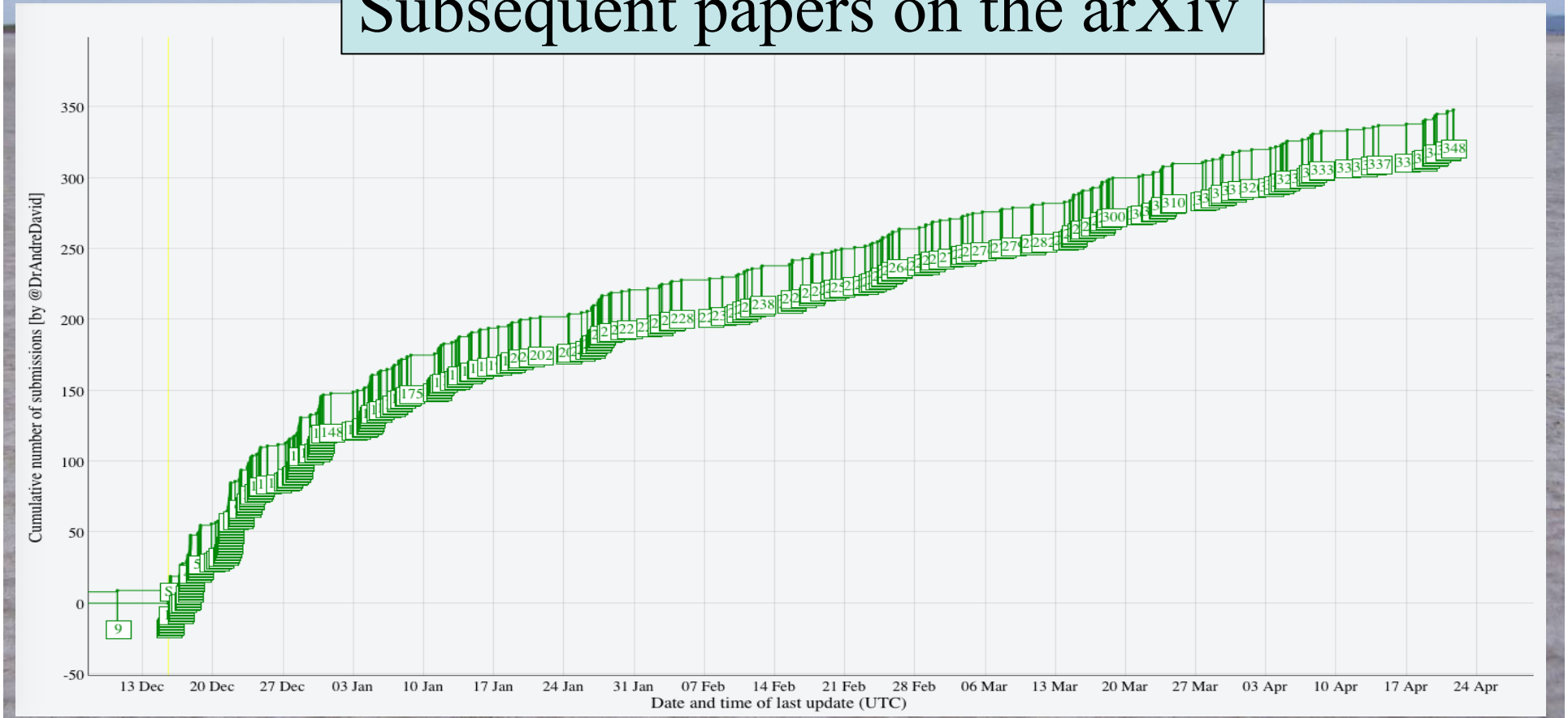


- Possible new particle X with mass ~ 750 GeV decaying into 2 photons


"Who ordered that"
I.I. Rabi
He was talking about the muon …

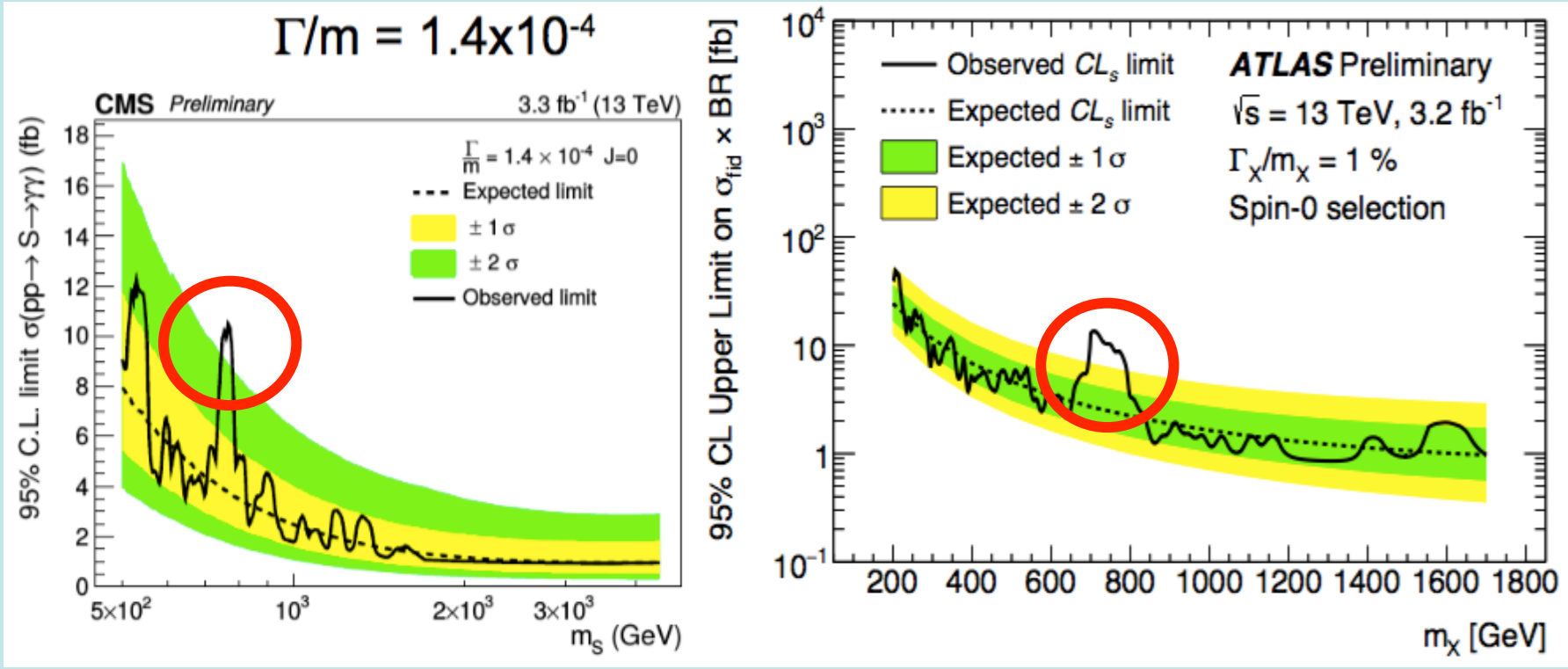
A Much-Chased Ambulance

Subsequent papers on the arXiv

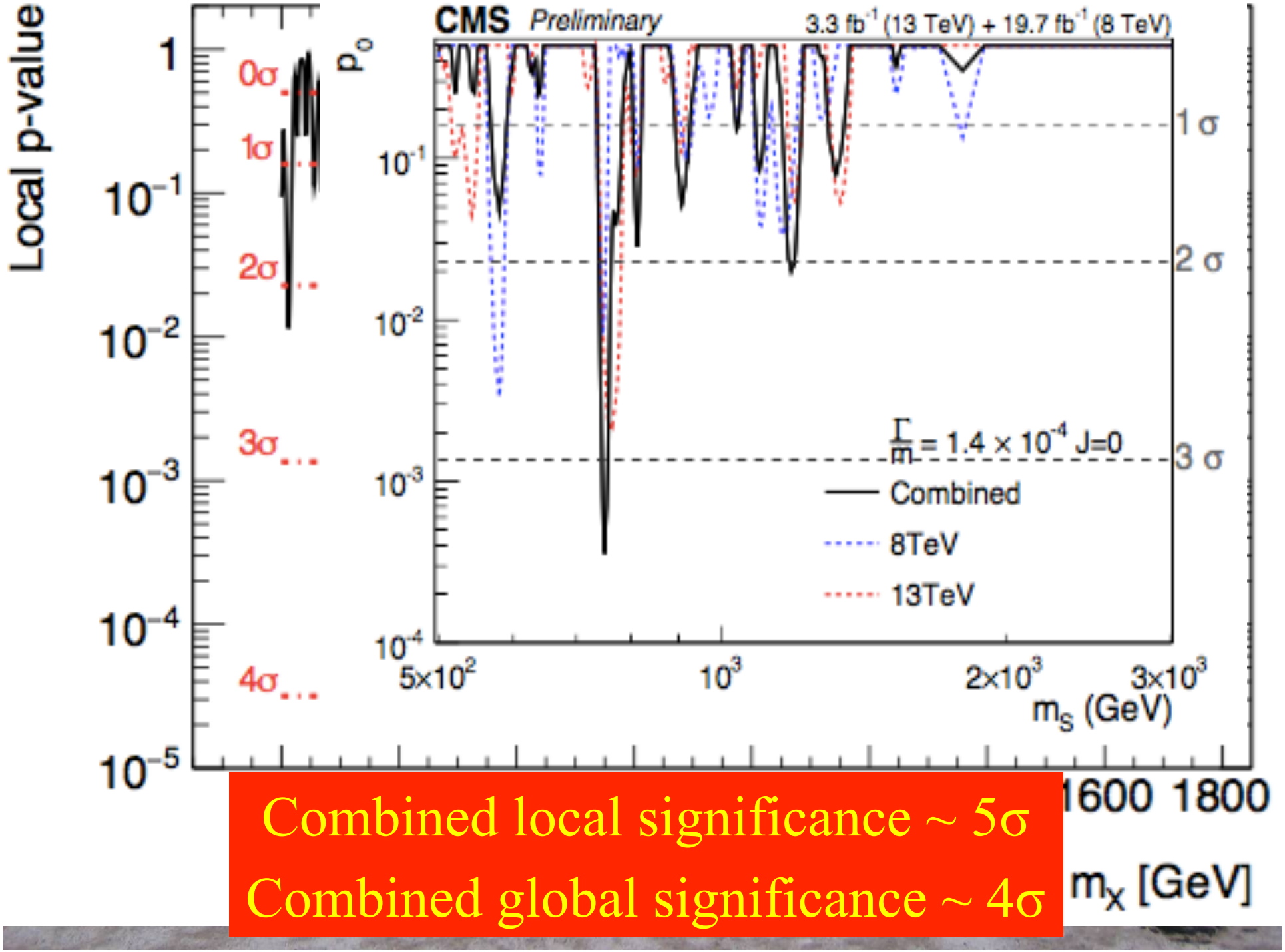


Update on Thursday, March 17

- **Peaks in γγ invariant mass distributions**

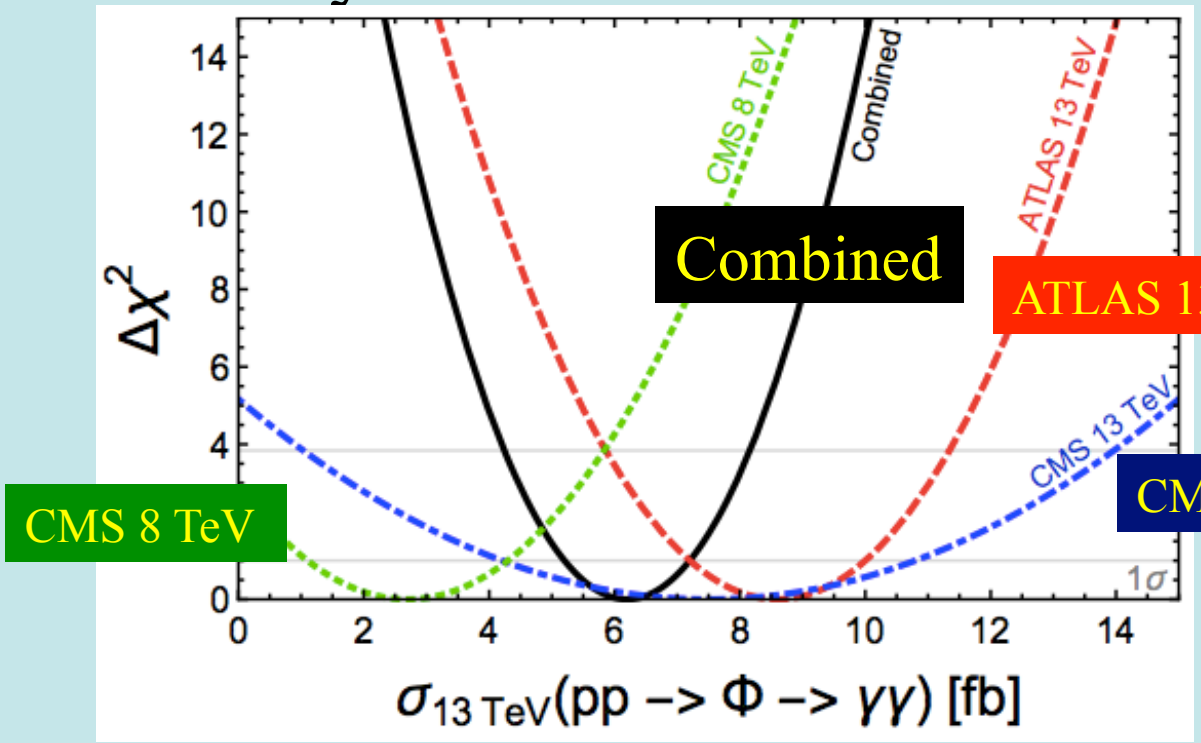


- Hint of new X(750) particle has not gone away
- **Wait and see!**


CMS Preliminary
3.3 fb^{-1} (13 TeV) + 19.7 fb^{-1} (8 TeV)
Local p-value
p_0
$\frac{\Gamma}{m}$ = 1.4 × 10^{-4} J=0
Combined
8TeV
13TeV
m_S (GeV)
m_X [GeV]
0σ
1σ
2σ
3σ
4σ
1 σ
2 σ
3 σ
Combined local significance ~ 5σ
Combined global significance ~ 4σ

Global Analysis of X Signal

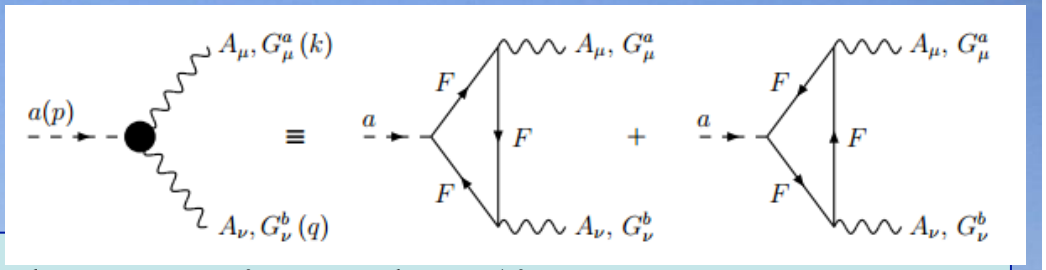
- Assume scalar/pseudoscalar (angular distribution?)
- Combined analysis of CMS and ATLAS data



- Some tension between data fom Run 1 and Run 2?

JE, S.Ellis, Quevillon, Sanz & You, arXiv:1512.05327

X Decays?

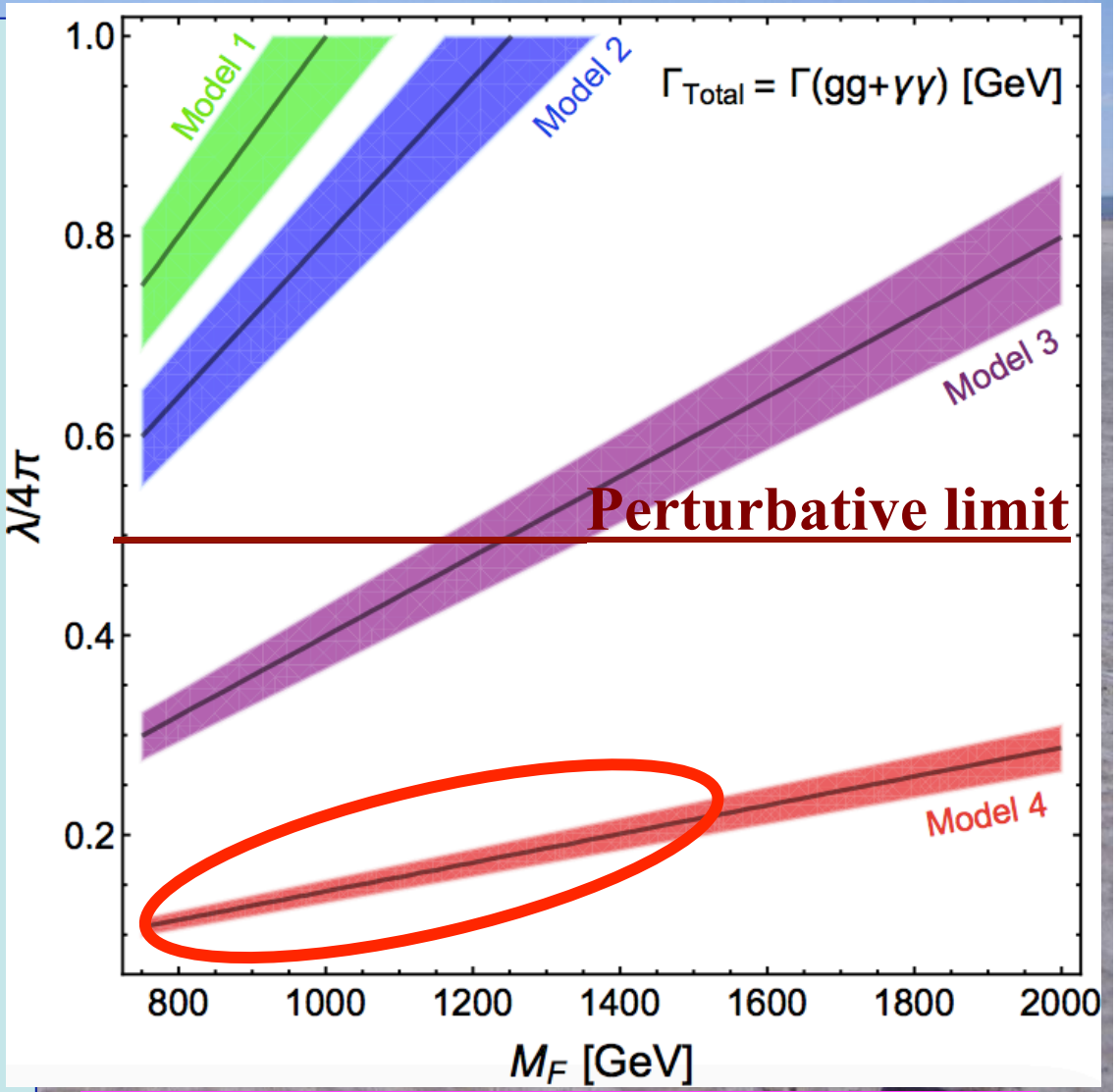


- Decay to γγ via anomalous triangle diagrams
- Probably also production via gluon fusion
- **Loops need heavy particles, m > 350 GeV**
- **Can't be 4th generation/minimal supersymmetry**
- Single vector-like quark enough, could be more
  - 1: Single VL quark, cf, t_R
  - 2: Doublet of VL quarks, cf, q_L
  - 3: Doublet + 2 singlets, cf, q_L, t_R, b_R
  - 4: Complete VL generation, including leptons
- **Assume *gg* decays dominant**

JE, S.Ellis, Quevillon, Sanz & You, arXiv:1512.05327

Scalar/Pseudoscalar Models for X

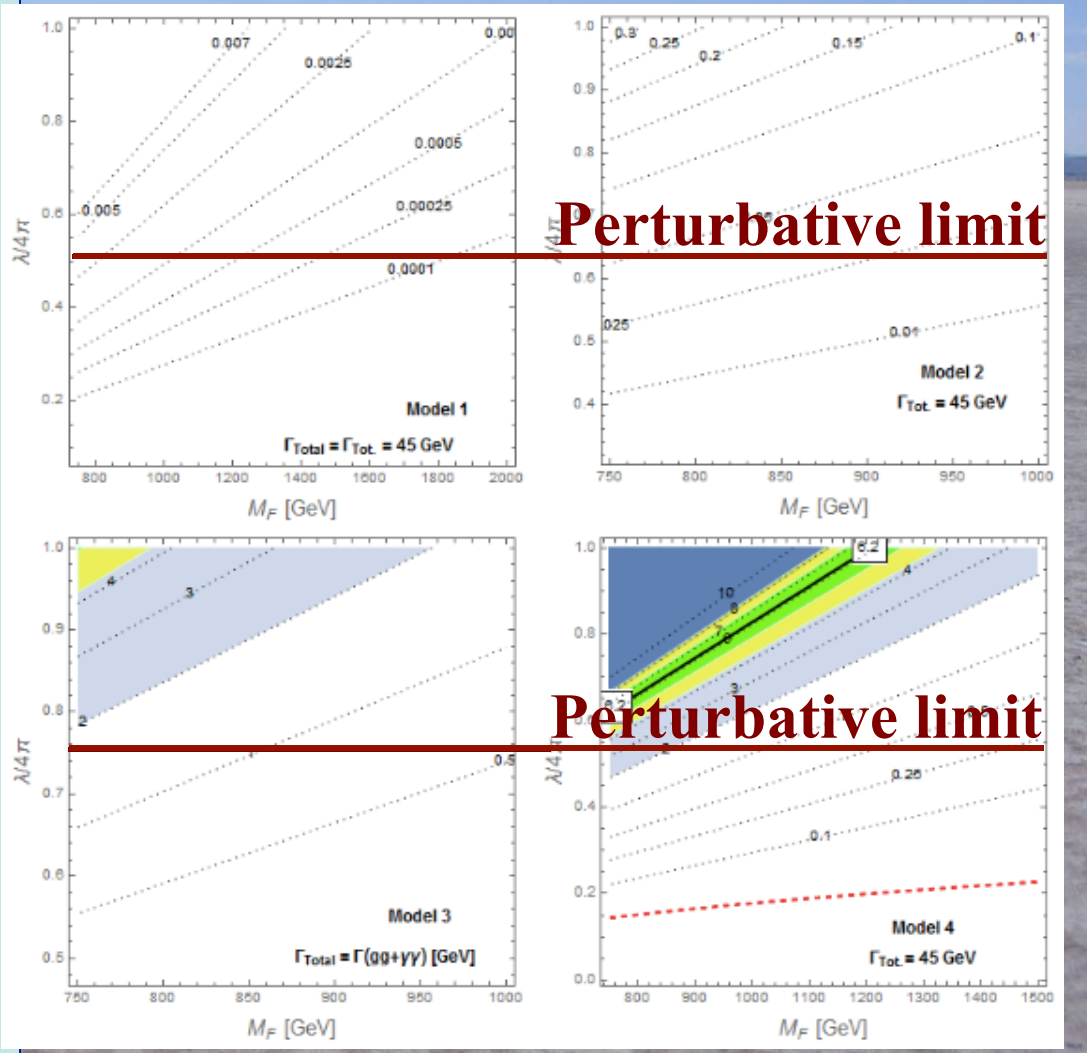
- Required X couplings λ to heavy fermions in different models
- Black line = best fit
- **Band = 1 σ**
- **Perturbative limit**
- **Neutral fermion could be dark matter**



JE, S.Ellis, Quevillon, Sanz & You, arXiv:1512.05327

Scalar/Pseudoscalar Models for X

- What if Γ_X=45 GeV?
- Required X couplings λ to heavy fermions in different models
- Black line = best fit
- **Green band = 1 σ**
- **Perturbative limit**
- **More fermions in loops?**



JE, S.Ellis, Quevillon, Sanz & You, arXiv:1512.05327

How to Probe Possible Models?

- Other possible decay modes

Model	$Tr[Y^2]$	$Tr[D(r)^2]$	$\frac{\mathrm{BR}(X\to gg)}{\mathrm{BR}(X\to\gamma\gamma)}$	$\frac{\mathrm{BR}(X\to Z\gamma)}{\mathrm{BR}(X\to\gamma\gamma)}$	$\frac{\mathrm{BR}(X\to ZZ)}{\mathrm{BR}(X\to\gamma\gamma)}$	$\frac{\mathrm{BR}(X\to W^{\pm}W^{\mp})}{\mathrm{BR}(X\to\gamma\gamma)}$
1	8/3	0	180	1.2	0.090	0
2	1/3	3	460	10	9.1	61
3	11/3	3	460	1.1	2.8	15
4	20/3	4	180	0.46	2.1	11
Current limit			$\sim 2\times 10^4$	7	13	46

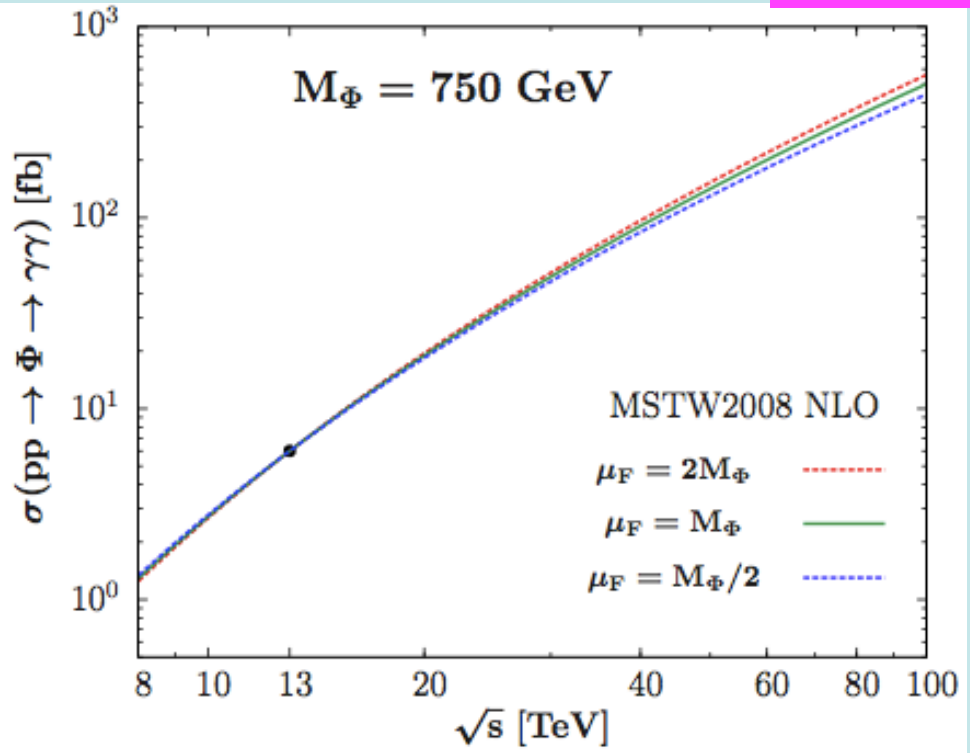
- Predictions ≤ experimental limits
- Potentially accessible to experiment
- Also look for heavy fermions!
- **Work for a generation – if X particle exists!**
- **Will know in 2016**

JE, S.Ellis, Quevillon, Sanz & You, arXiv:1512.05327

Possible Future X Signal

- Assuming production by gluon-gluon fusion
- Normalized to $\sigma B(\gamma\gamma) = 6$ fb

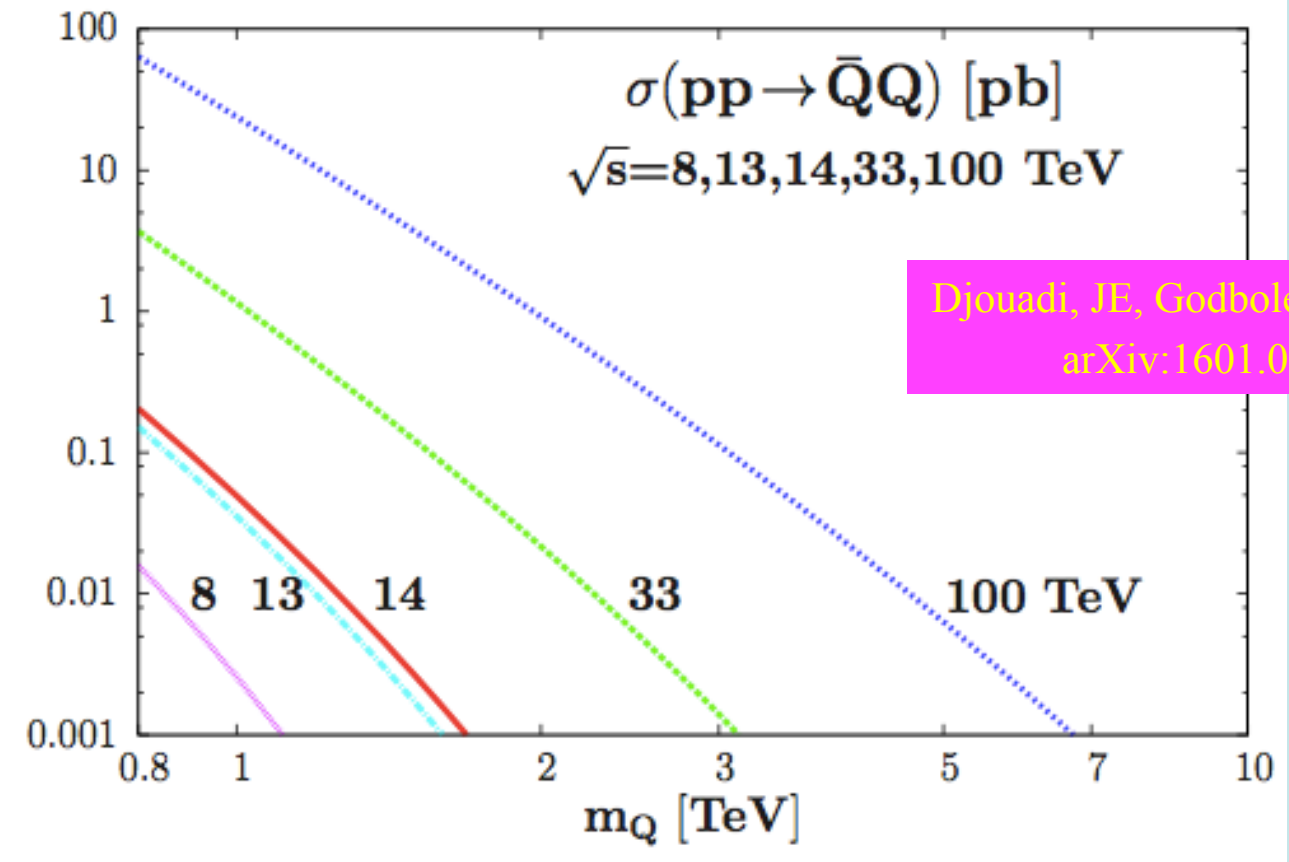
Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696



- PDF, ren'n scale uncertainties @ 100 TeV ~ 30%

Cross Sections for Vector-Like Q

- Pair-production at LHC, future circular colliders

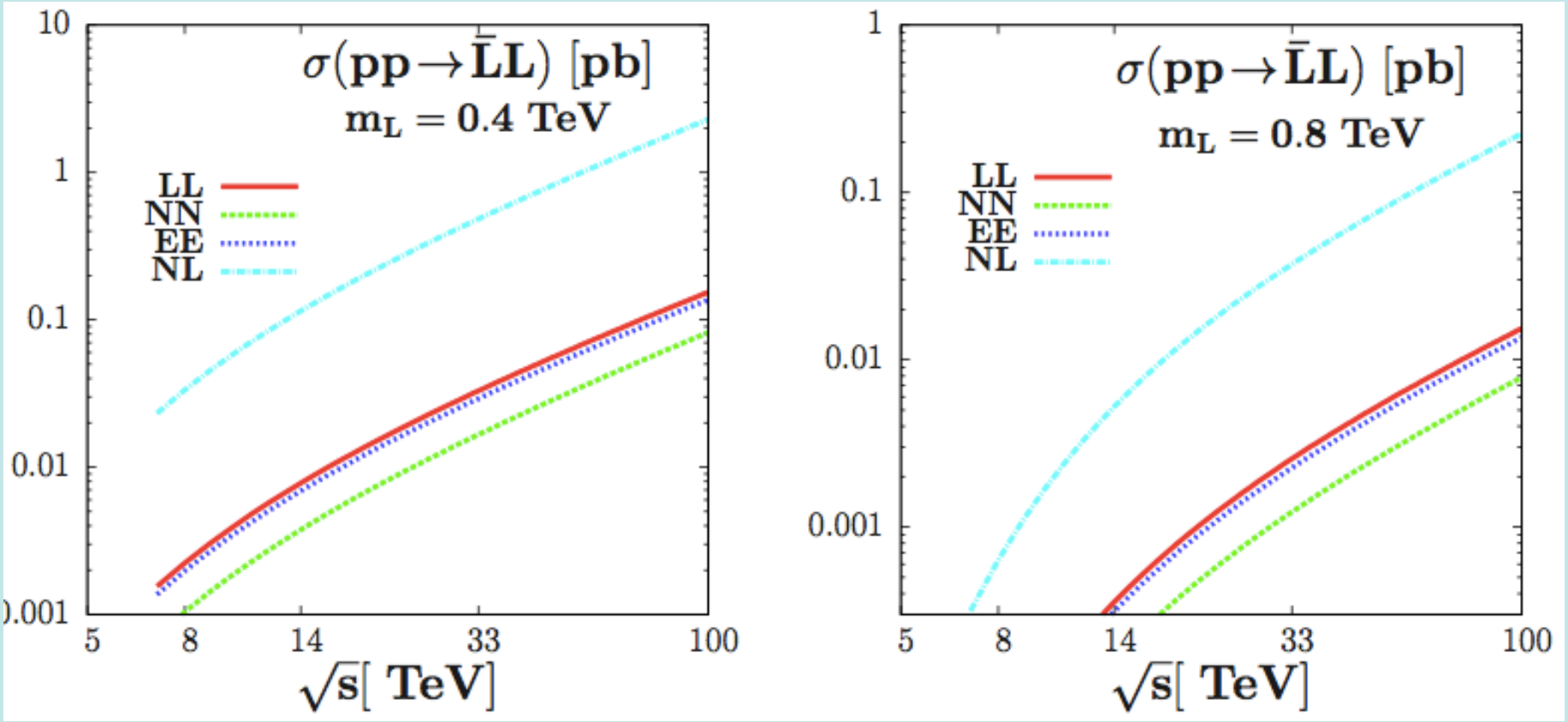


Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

- Present lower mass limit ~ 800 GeV

Cross Sections for Vector-Like L

- Pair-production at LHC, future circular colliders



- Present mass limit < 400 GeV

Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Sensitivity to Vector-Like Q, L

model	Vector-like quark mass sensitivity				Vector-like lepton mass sensitivity			
	$100fb^{-1}$ 13 TeV	$300fb^{-1}$ 14 TeV	$300fb^{-1}$ 33 TeV	$20ab^{-1}$ 100 TeV	$100fb^{-1}$ 13 TeV	$300fb^{-1}$ 14 TeV	$300fb^{-1}$ 33 TeV	$20ab^{-1}$ 100 TeV
1	1.4	1.7	3.1	11.7	-			
2	1.5	1.8	3.4	12.7	-			
3	1.6	2.0	3.7	13.7	-			
4	1.6	2.0	3.7	13.7	0.56	0.73	1.7	5.3

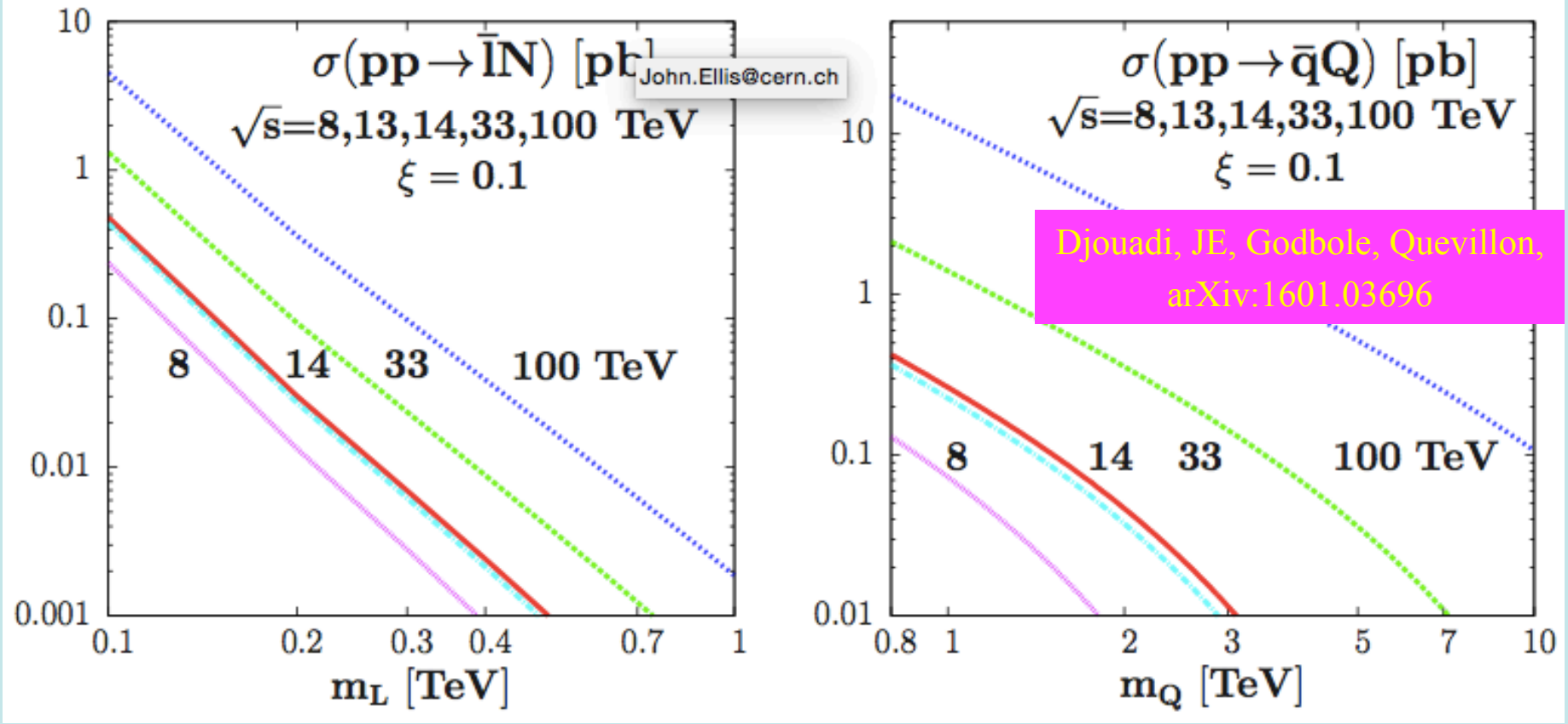
- Model 1: Single VL quark, cf, t_R
  - Non-perturbative coupling required
- Model 2: Doublet of VL quarks, cf, q_L
  - Non-perturbative coupling favoured
- Model 3: Doublet + 2 singlets, cf, q_L, t_R, b_R
  - Perturbative range covered by LHC
- Model 4: Complete VL generation, including leptons
  - Covering perturbative range needs higher energy

Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

How do they mix with conventional q, l?

Single Vector-Like Q, L Production

- Single production at LHC, future circular colliders



- Assuming mixing angle with light fermions $\xi = 0.1$

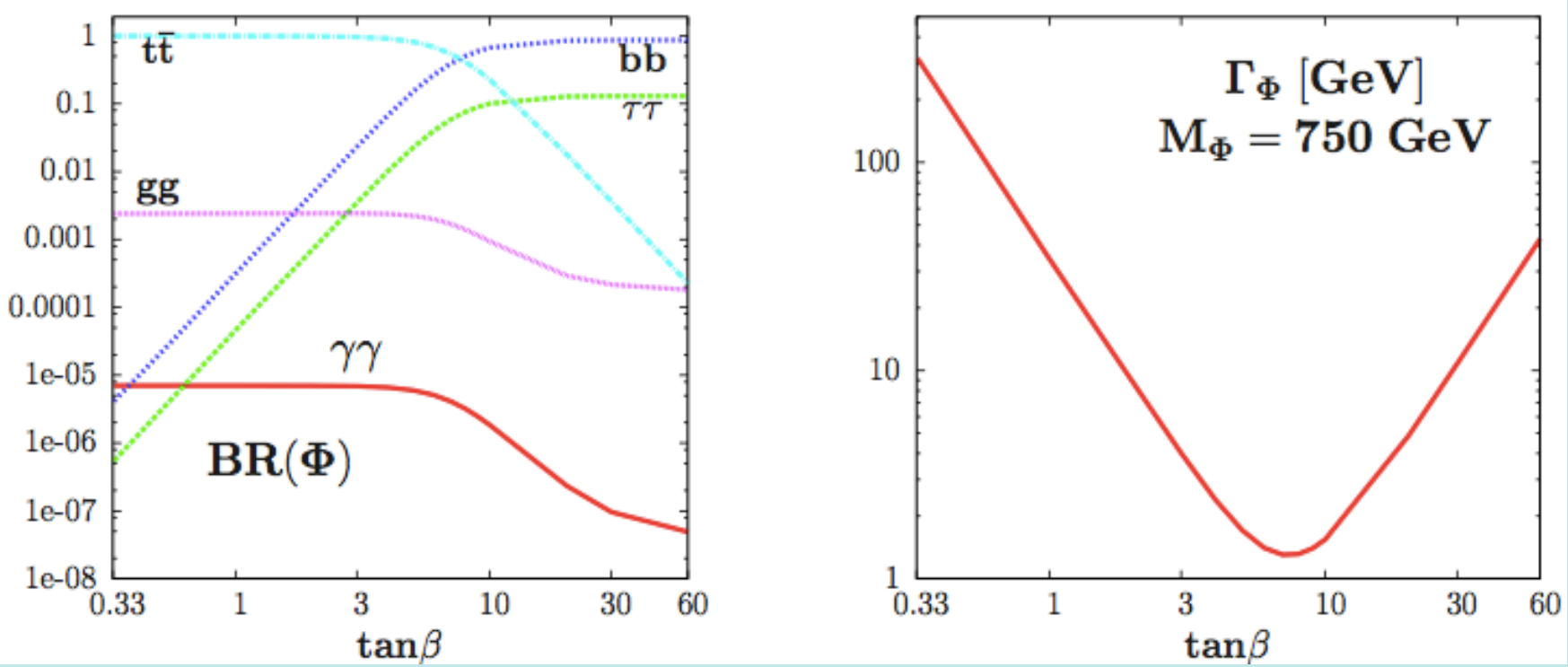
Alternative Higgs Doublet Scenario

- After singlet, doublet?
- Heavy Higgses in 2 Higgs doublet model: $\Phi = H, A$
- Nearly degenerate in many versions, e.g., SUSY
- Expect t tbar decays to dominate
- Can accommodate $\Gamma_\Phi \sim 45$ GeV (ATLAS)
- Need larger enhancement of loops compared to singlet model
- **Rich bosonic phenomenology**

Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Φ = H, A Decays in Doublet Model

- Dependences on tan β of branching ratios, Γ_Φ

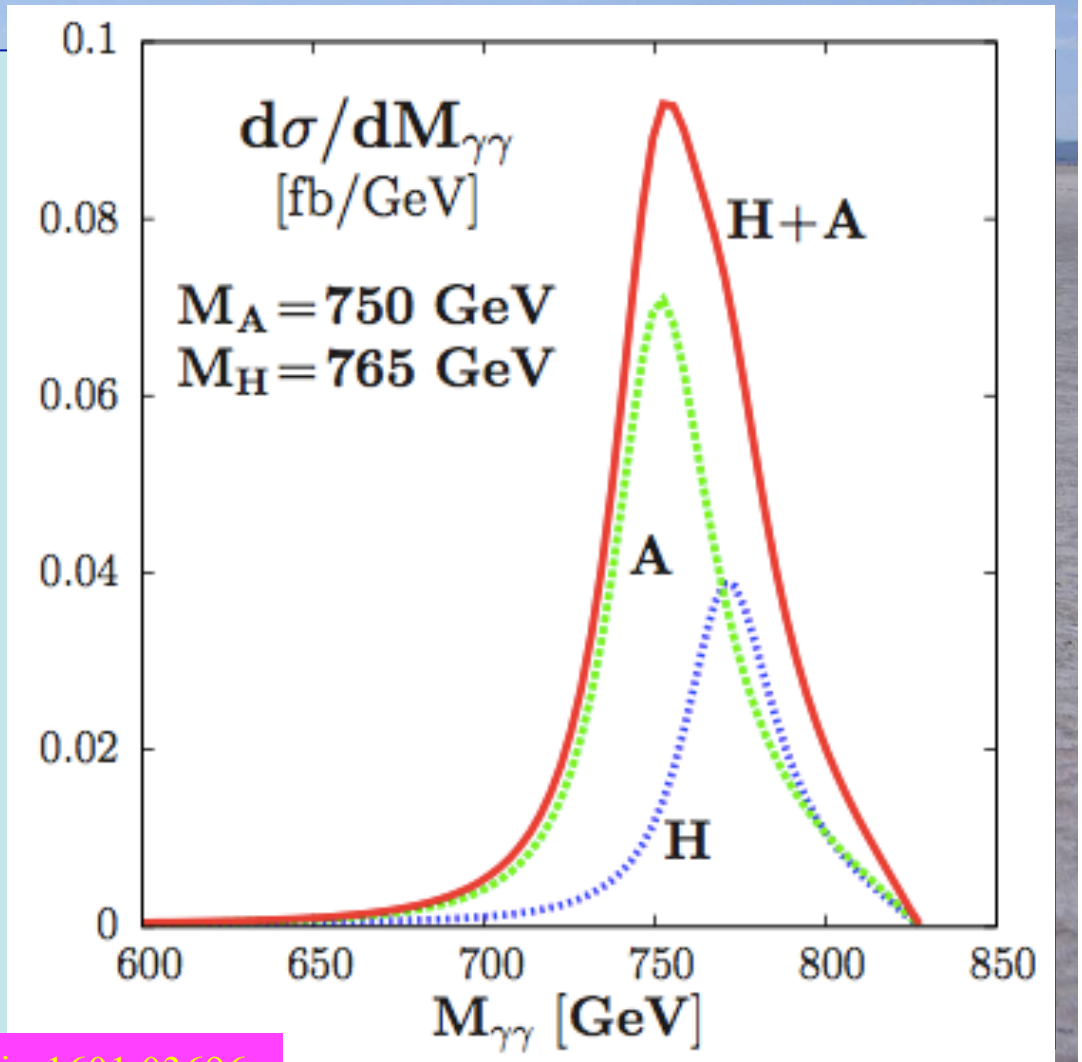


- Prefer tan β ~ 1
- Dominant Φ decays to t tbar

Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Lineshape in *pp* Collisions

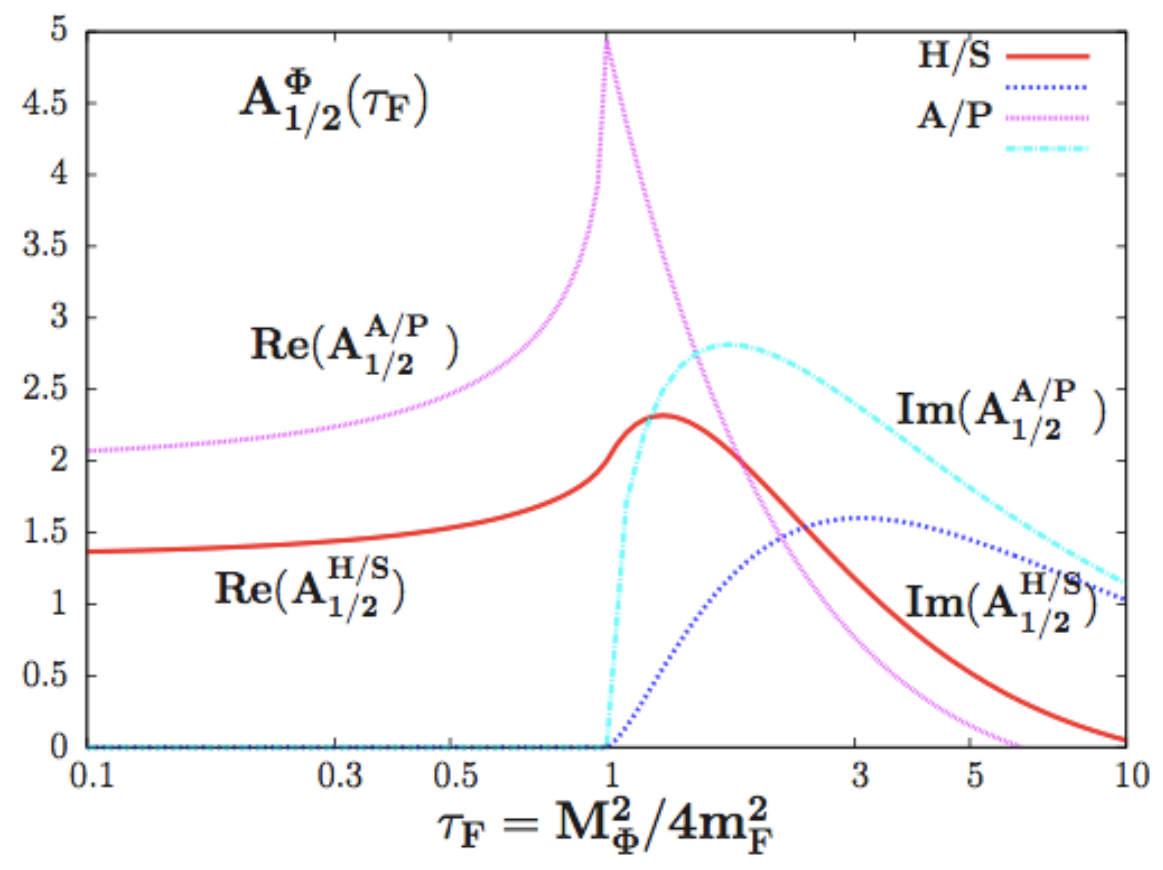
- +MSSM: $\tan\beta = 1$
- $M_H - M_A \sim 15$ GeV
- $\Gamma_H, \Gamma_A \sim 33, 36$ GeV
- $\sigma B(A \rightarrow \gamma\gamma) =$
  $2 \times \sigma B(H \rightarrow \gamma\gamma)$
- Asymmetric
  'Breit-Wigner'
- **Resolvable?**



Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Fermion Loop Form Factors

- Triangle diagrams suppressed for small M_F

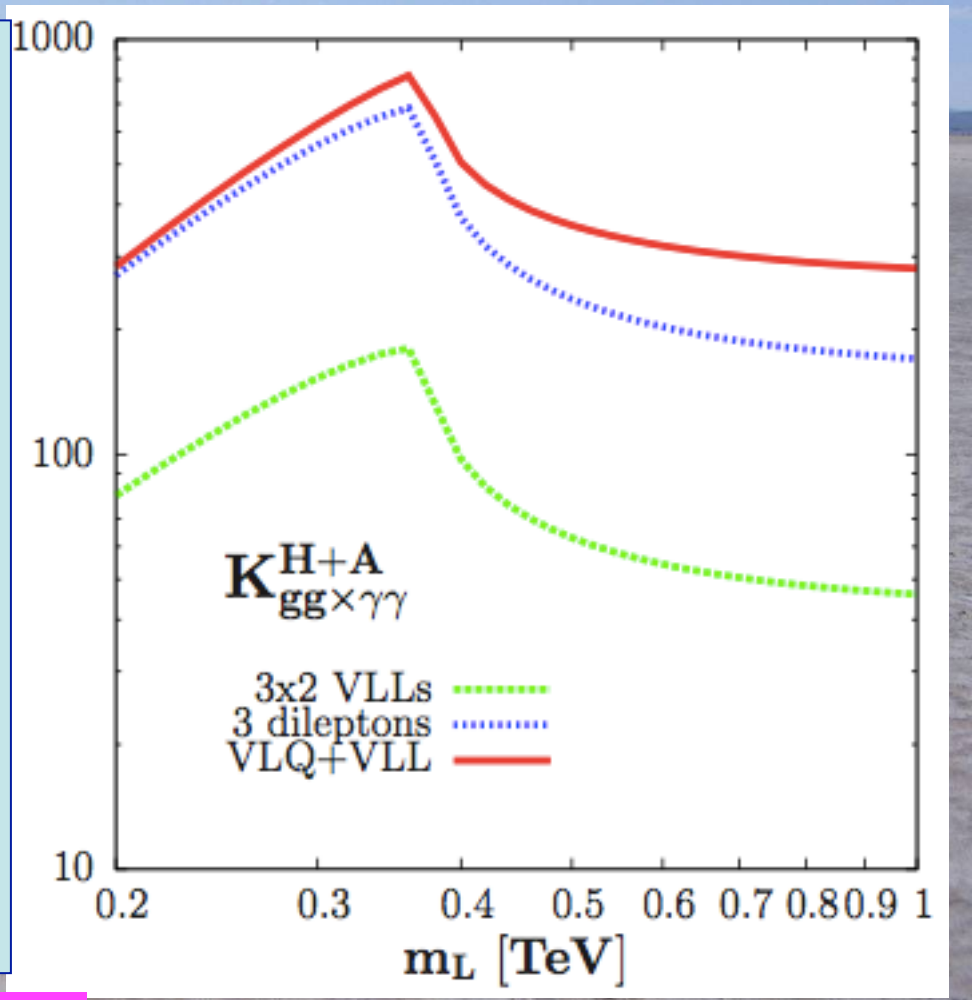


- Enhanced if $m_F \sim M_\Phi/2$

Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Obtaining Loop Enhancement

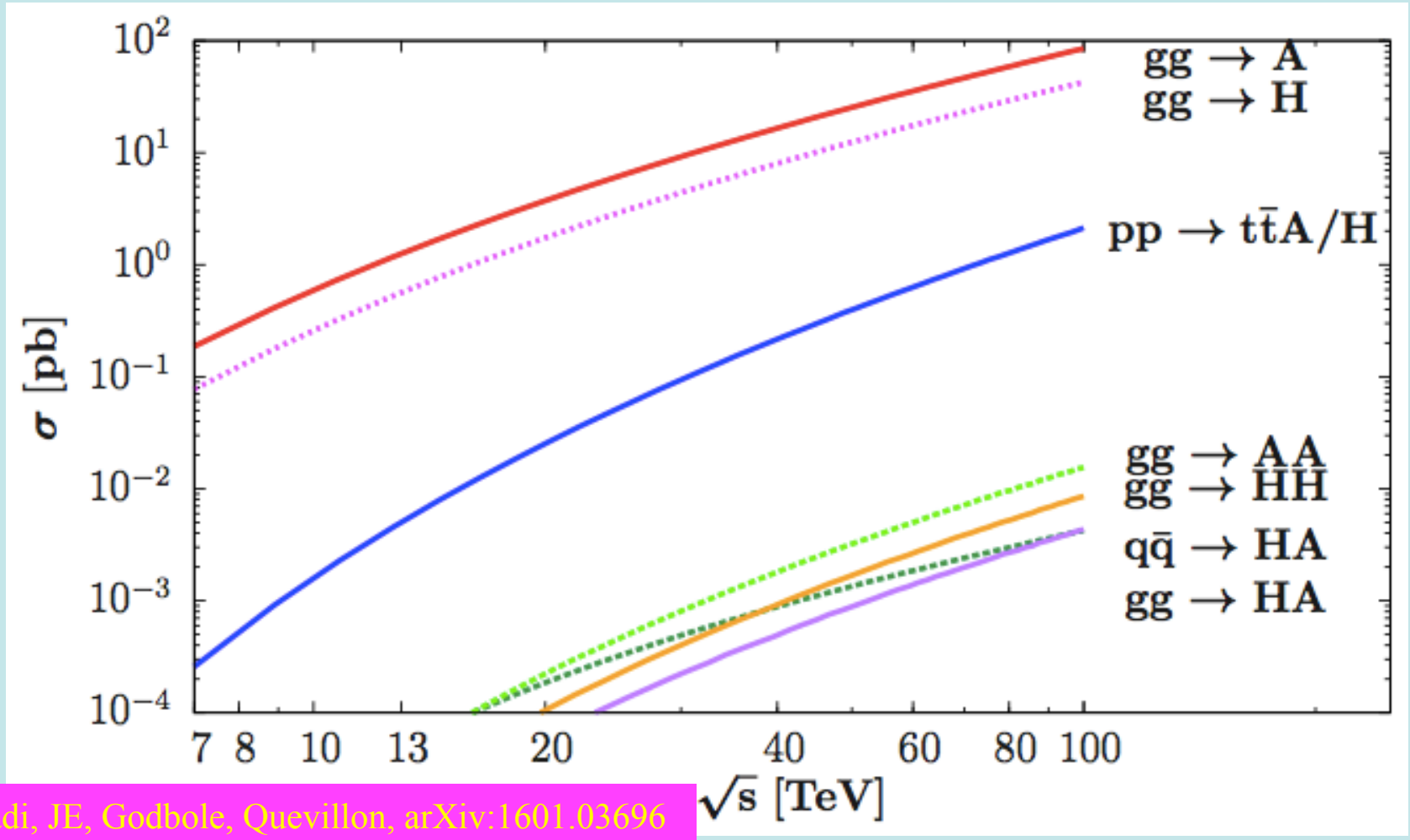
- Need loop enhancement ~ 500 if $\Gamma \sim 45$ GeV
- **Vector-like generation of quarks and leptons**
- **3 doubly-charged leptons**
- **3 pairs of vector-like leptons**



Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Possible Φ = H,A Signals

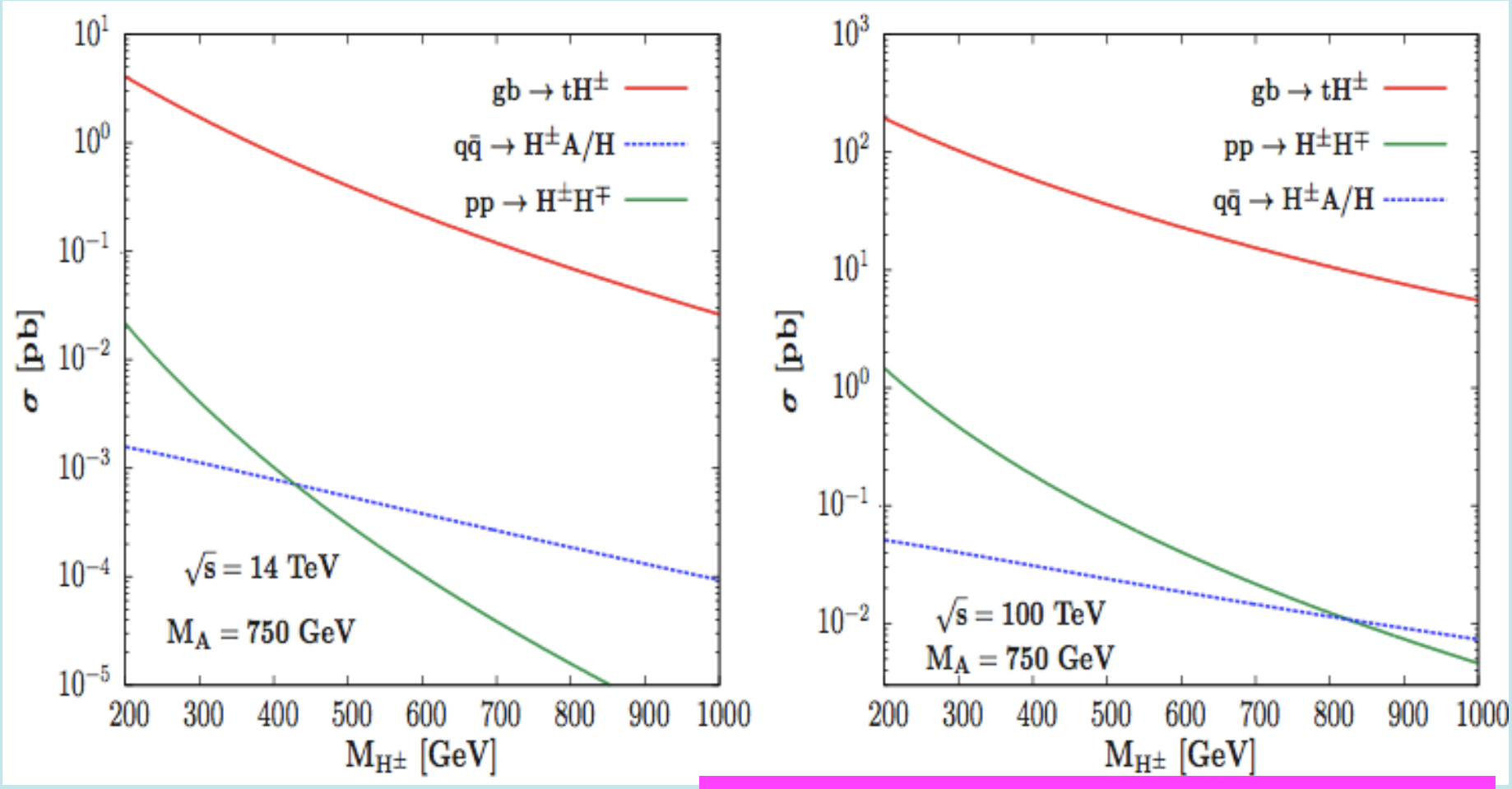
- Normalized to σB(γγ) = 6 fb @ 13 TeV



Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

Possible $H^{\pm}$ Signals

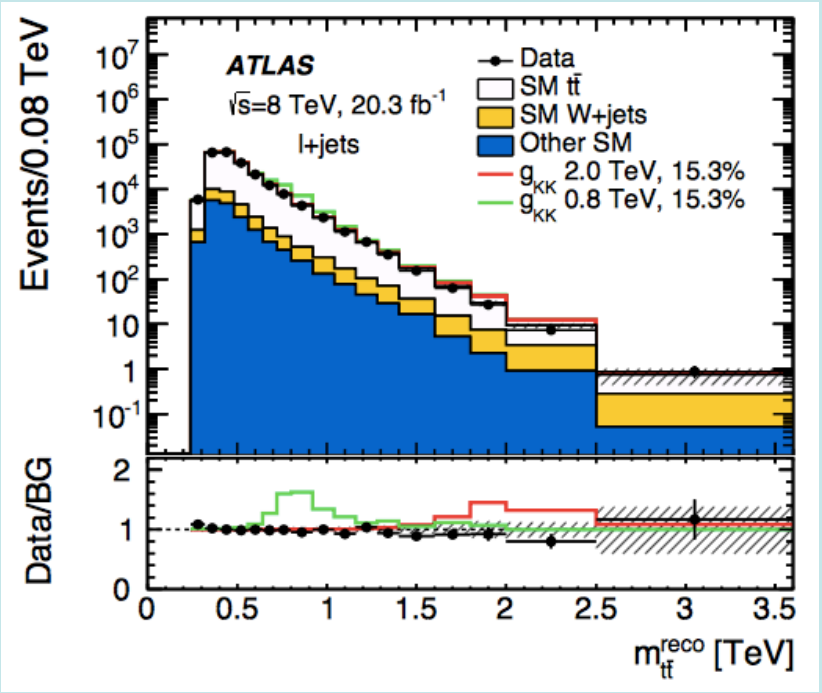
- @ 14, 100 TeV for varying $M_{H\pm} \neq M_{\Phi}$ in general

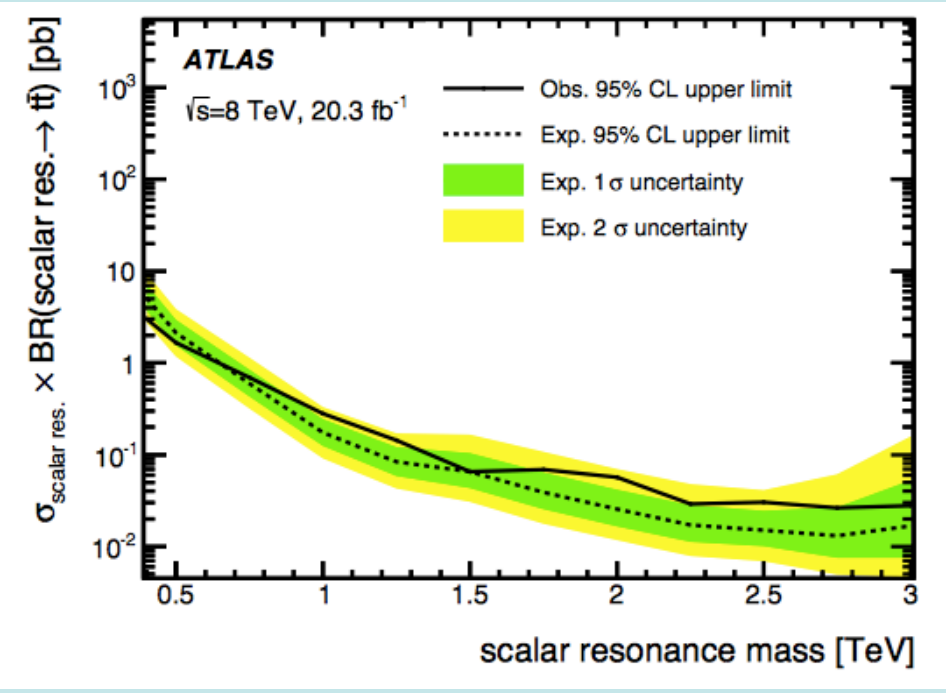


Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

ATLAS Search for Scalar ➔ $t\bar{t}$

- No sign of any feature in the $t\bar{t}$ mass spectrum





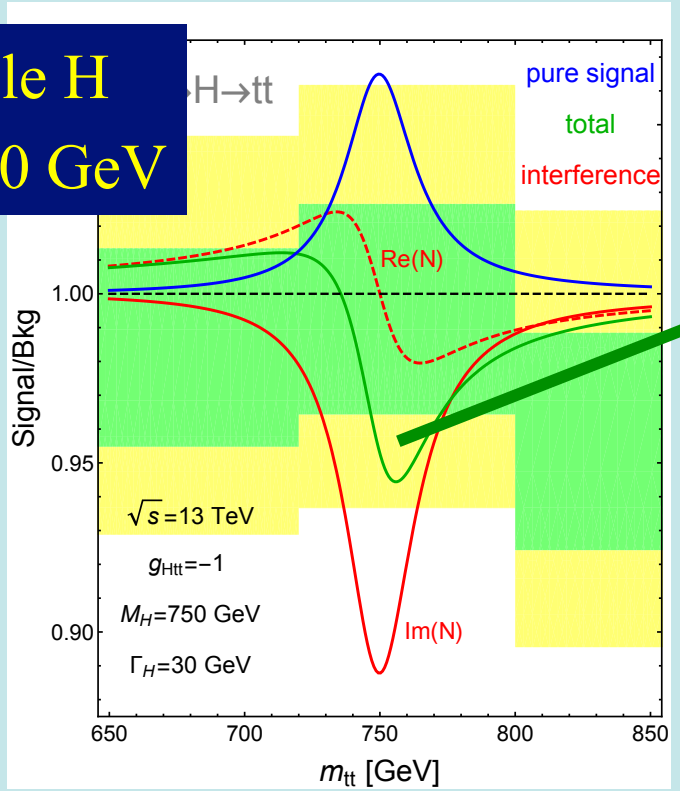
- Absence of peak interpreted as upper limit on resonance production
- **BUT interference effects could give a DIP!**

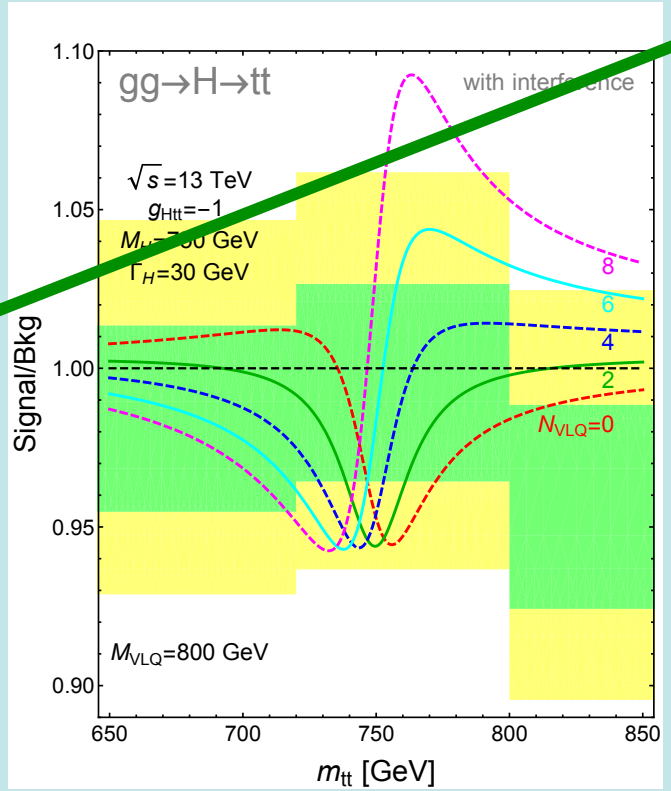
Djouadi, JE & Quevillon: arXiv:1605.00542

Interference Effects in Scalar → $t\bar{t}$

- Interference with gg→$t\bar{t}$ background can give **dip**

Single H
Γ_H = 30 GeV





Top loop alone vs. + vector-like quarks

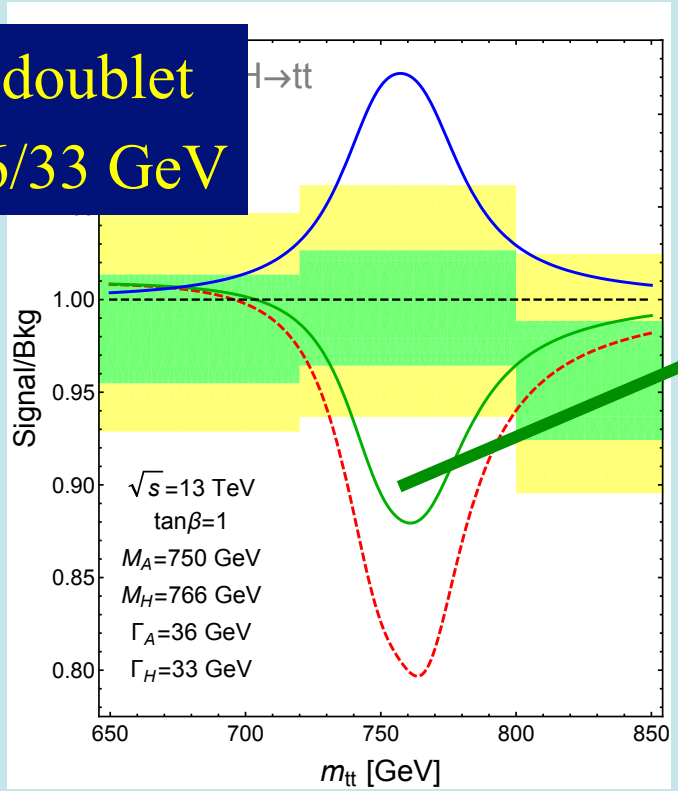
- Brazil bands from ATLAS 8 TeV data

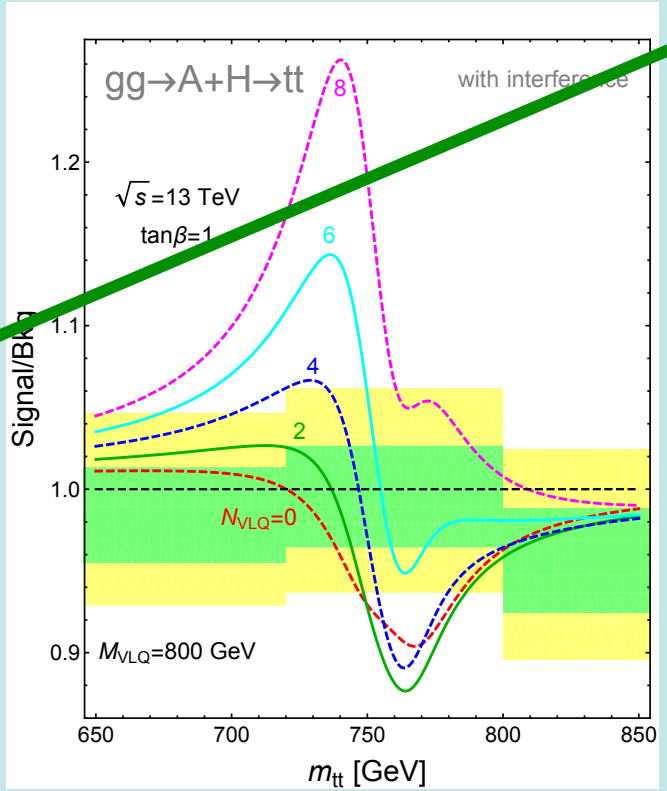
Djouadi, JE & Quevillon: arXiv:1605.00542

Interference Effects in Doublet ➔ $t\bar{t}$

- Interference with $gg \rightarrow t\bar{t}$ background can give **dip**

A/H doublet
Γ = 36/33 GeV





Top loop alone vs. + vector-like quarks

- Brazil bands from ATLAS 8 TeV data

Djouadi, JE & Quevillon: arXiv:1605.00542

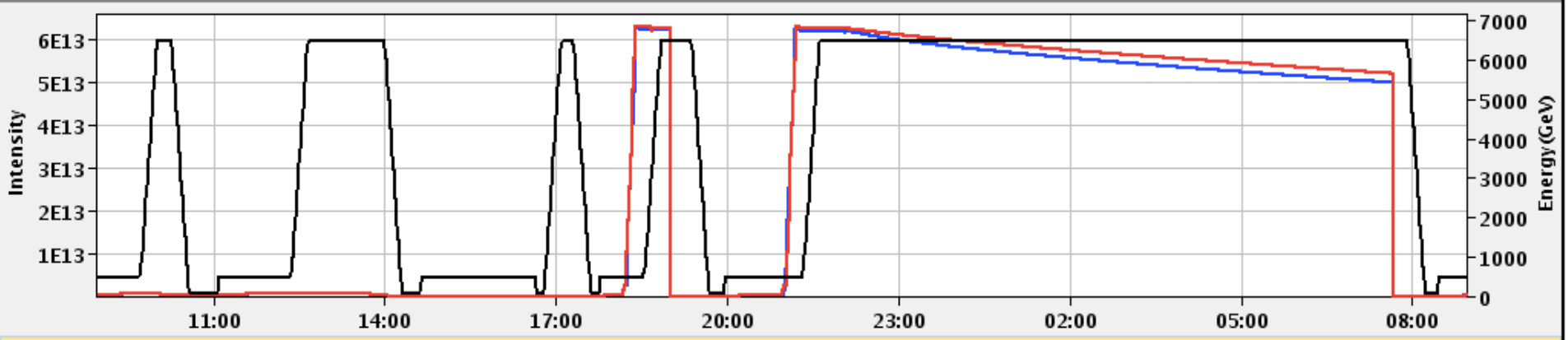

"Plus un fait est extraordinaire, plus il a besoin d'être appuyé de fortes preuves"
Laplace, 1812
"The more extraordinary a claim, the stronger the proof required to support it."

12-May-2016 08:56:21 | Fill #: 4916 | Energy: 450 GeV | I(B1): 7.77e+09 | I(B2): 7.70e+09

	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	STANDBY	STANDBY	STANDBY
Instantaneous Lumi [(ub.s)^-1]	0.000	0.000	0.000	0.000
BRAN Luminosity [(ub.s)^-1]	0.0	0.0	0.0	0.0
Fill Luminosity (nb)^-1	58867.137	0.000	0.000	3343.732
Beam 1 BKGD	0.000	0.000	0.000	0.000
Beam 2 BKGD	0.000	0.000	0.000	0.000

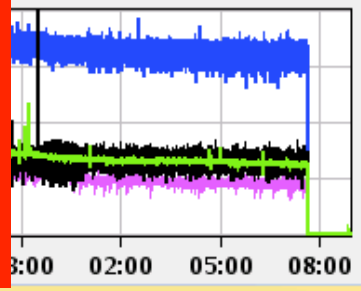
LHCb VELO Position: OUT | Gap: 58.0 mm | INJECTION PROBE BEAM | TOTEM: STANDBY

Performance over the last 24 Hrs — Updated: 08:56:20



Collisions at 13 TeV have started again!

Updated: 08:56:20



ATLAS ALICE CMS LHCb

ATLAS ALICE CMS LHCb

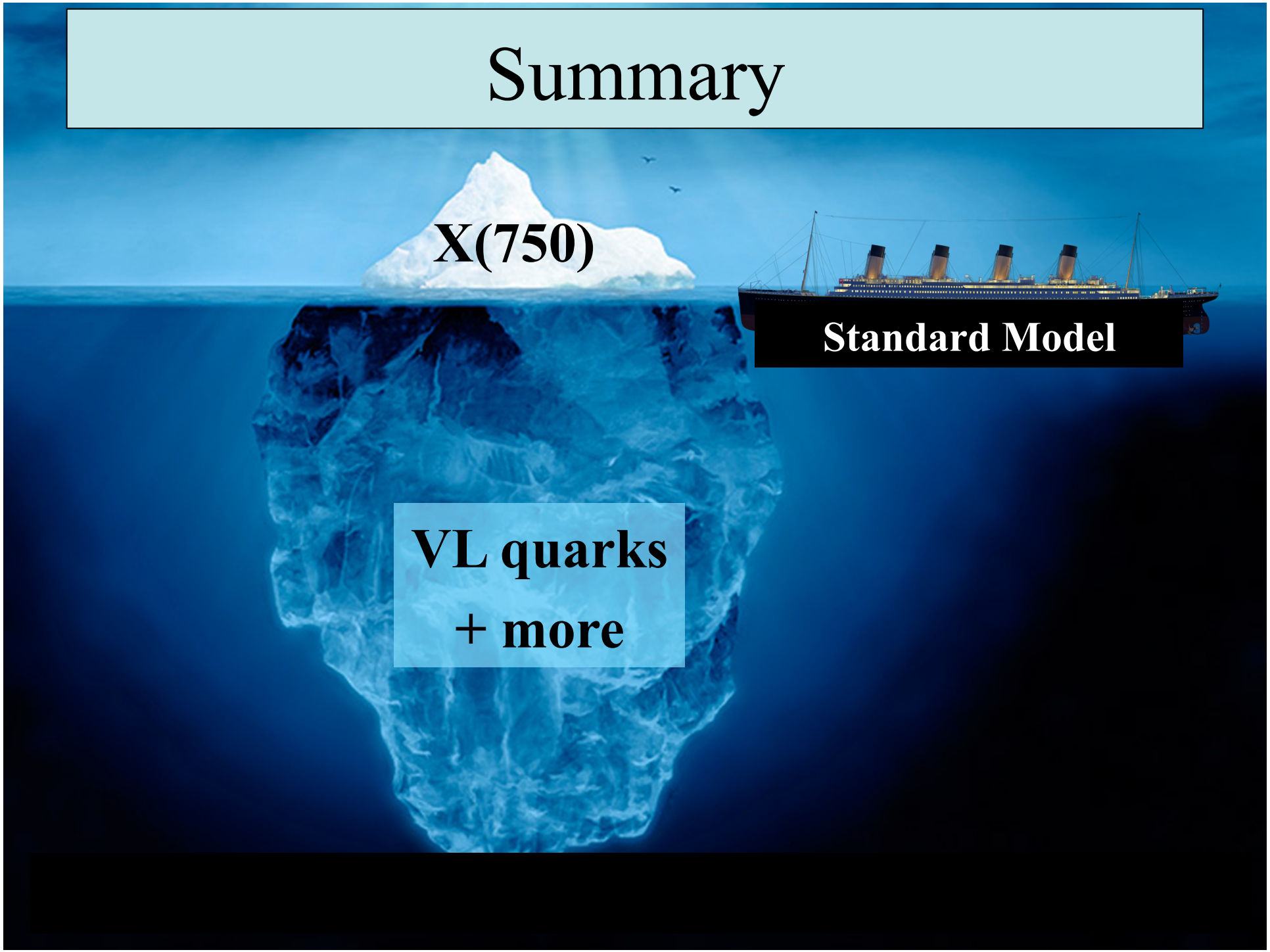
Higgs champagne in Singapore

July 4th 2012

The discovery of a new particle

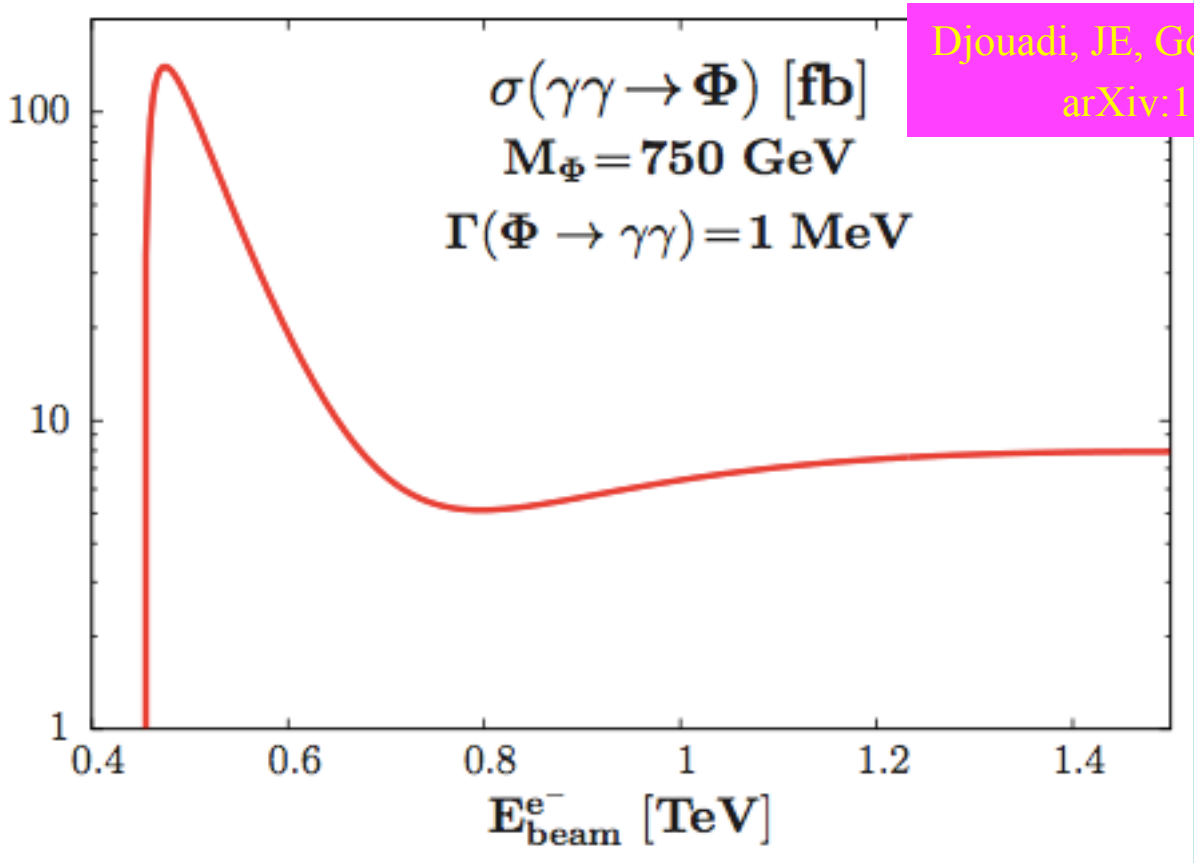

July 4th 2016
The discovery of a new particle?

Summary



$\gamma\gamma \rightarrow X$ Signal at e^+e^- Collider

- For $\sigma B(\gamma\gamma) = 6$ fb, assuming $X \rightarrow gg$ dominant

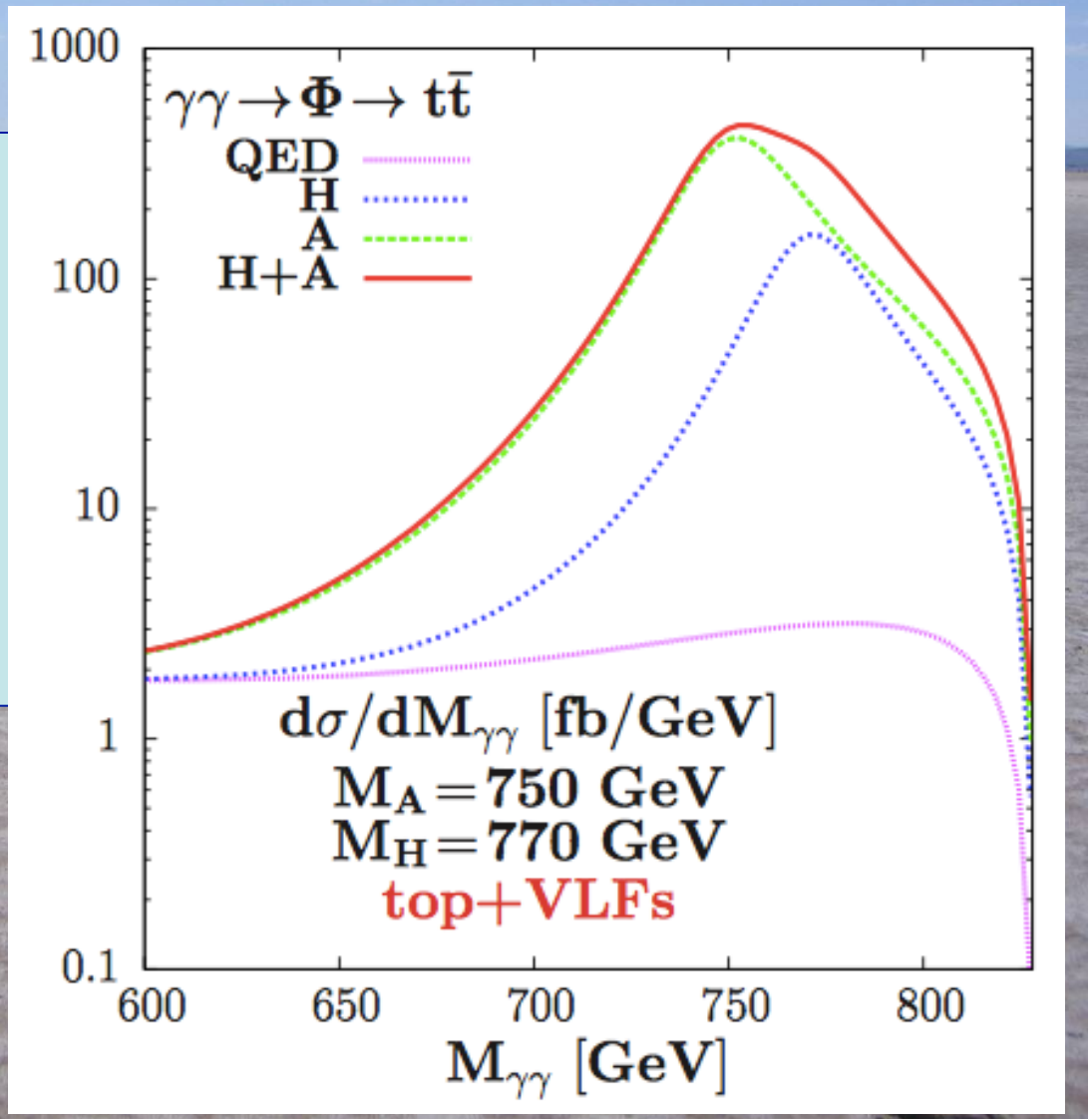


Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696

- Centre-of-mass energy ~ 1 TeV preferred!

$\gamma\gamma \rightarrow \Phi$ Signal at e^+e^- Collider

- For $\sigma B(\gamma\gamma) = 6$ fb, assuming $\Gamma(\Phi=H,A) = 45$ GeV
- e^+e^- centre-of-mass energy ~ 1 TeV



Djouadi, JE, Godbole, Quevillon, arXiv:1601.03696