Can the Models of LHC Diphoton Excesses be Valid up to the Planck scale?

Koji TSUMURA (Kyoto U.)

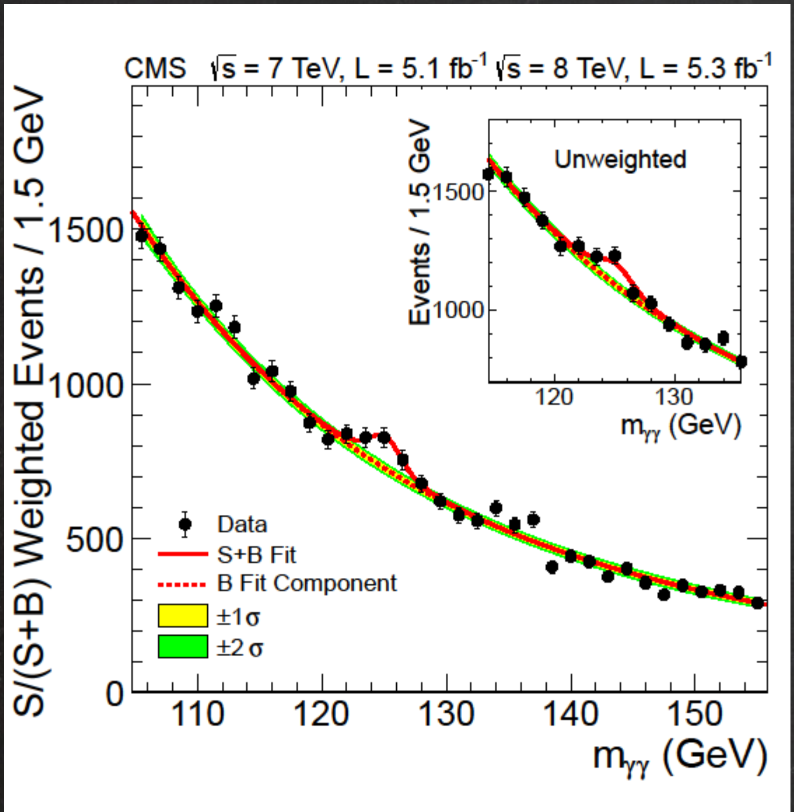
The 1st East Asia Joint Workshop on Fields and Strings

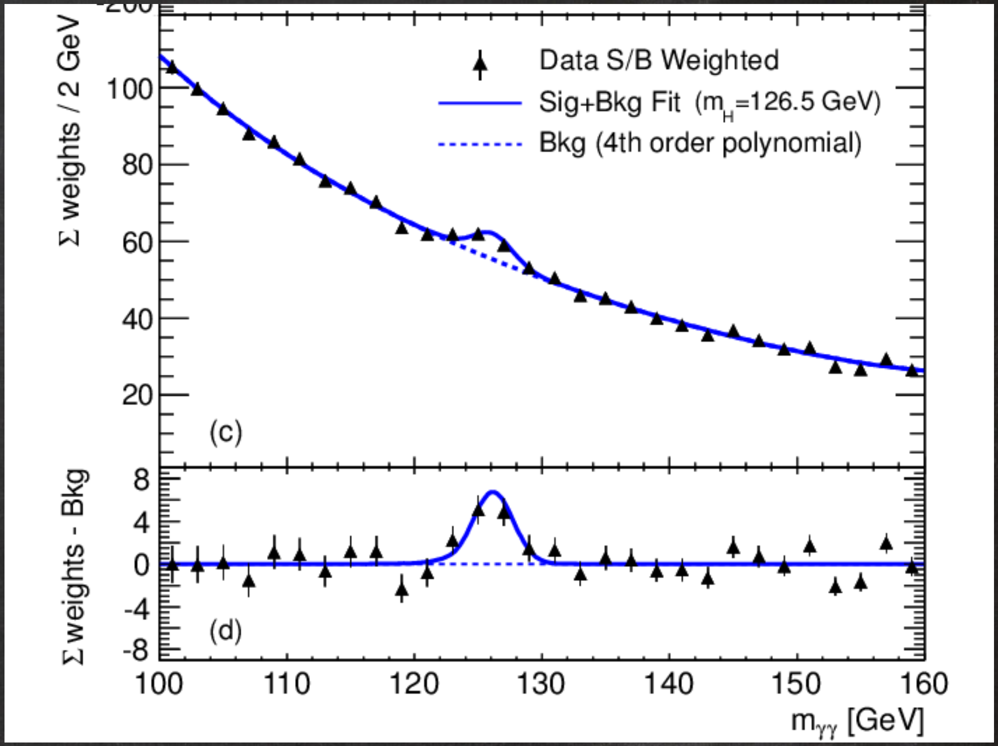
University of Science and Technology of China, May 27--Jun 2, 2016

Y. Hamada, H. Kawai, K. Kawana, KT, arXiv:1602.04170

Can the SM be valid up to M_{PL}?

July 4th, 2012





SM Completed

H^0 $J = 0$

Mass $m = 125.09 \pm 0.24$ GeV 0.2% precision measurement¥

H^0 Signal Strengths in Different Channels

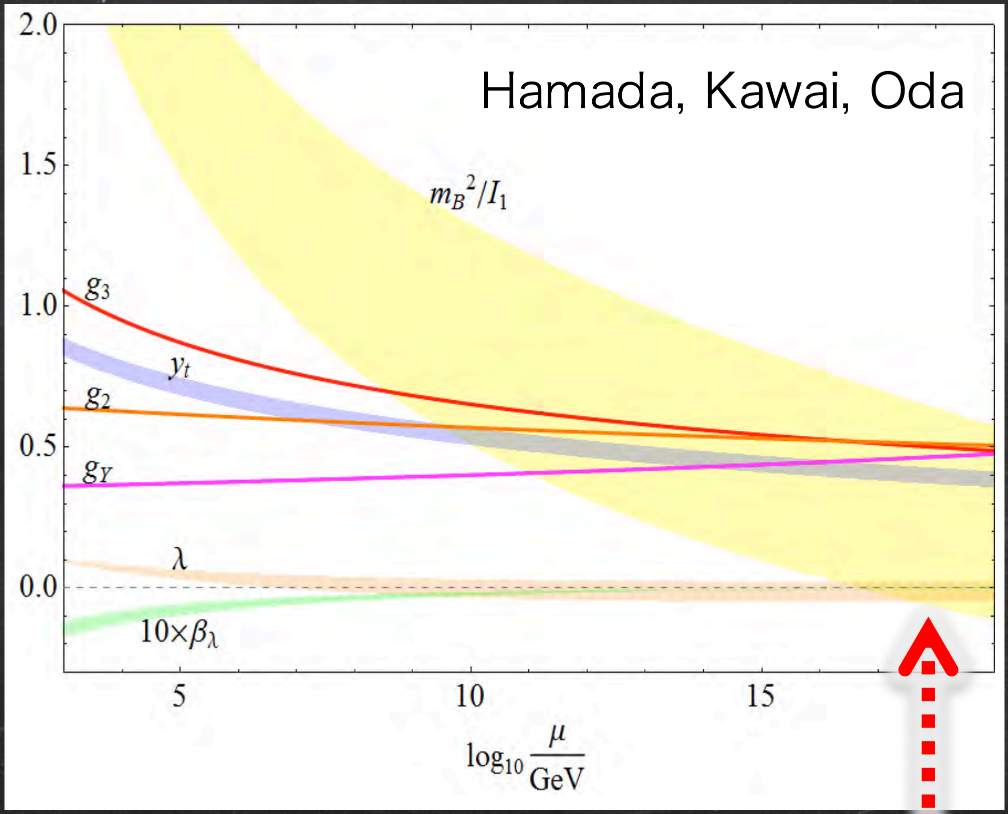
See Listings for the latest unpublished results.

Combined Final States $= 1.17 \pm 0.17$ (S = 1.2)
$WW^* = 0.81 \pm 0.16$
$ZZ^* = 1.15^{+0.27}_{-0.23}$ (S = 1.2)
$\gamma\gamma = 1.17^{+0.19}_{-0.17}$
$b\overline{b} = 0.85 \pm 0.29$
$\mu^+\mu^- < 7.0$, CL = 95%
$\tau^+\tau^- = 0.79 \pm 0.26$
$Z\gamma < 9.5$, CL = 95%
$t\overline{t}H^0$ Production $= 2.5^{+0.9}_{-0.8}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
invisible	<58 %	95%	–

New Paradigm ?

"M_h=125GeV" predicts …



Triple Coincidence @ M_{PL} : λ, β_λ, $m_B{}^2$

SM Criticality

New Paradigm ?

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SM Criticality Triple Coincidence @ M_{PL} : λ, β_λ, m_B^2

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SM Criticality

Triple Coincidence @ M_{PL} : λ, β_λ, m_B^2

- Boundary Conditions @ M_{PL} ?
  - → Classical Conformal Invariance (CCI)
  - → Hidden Duality
- New Principle @ M_{PL} ???
  - → Multiple Point Criticality Principle (MPP)
  - → Maximum Entropy Principle

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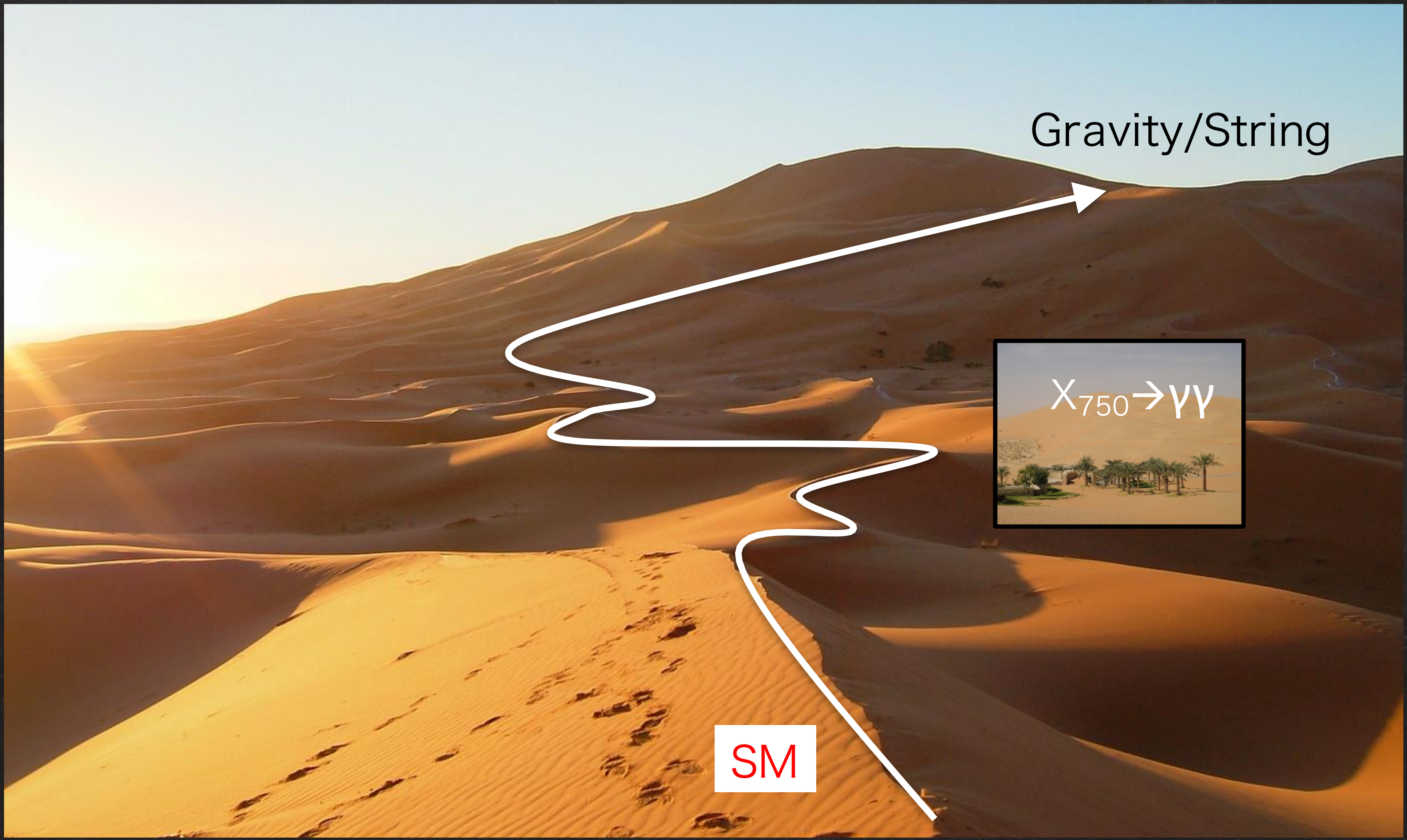
Good examples for making new paradigm from theoretical view point.

Grand Desert ?

Oasis



Towards New Paradigm

"M_X=750GeV" predicts ?

....

At least, this can be a first new physics beyond the SM,

Towards New Paradigm

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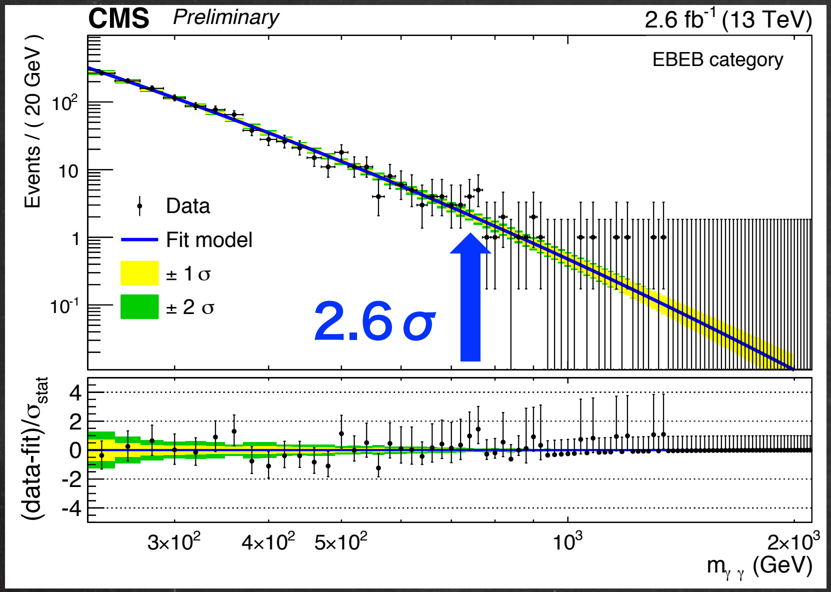
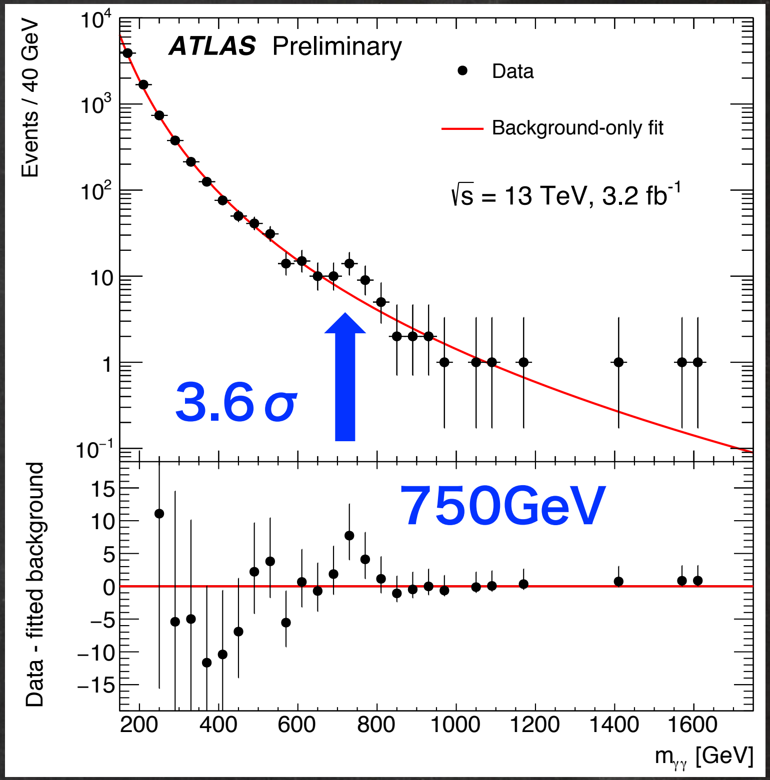
At least, this can be a first new physics beyond the SM,

Goal of This Talk : How exotic X_{750} is !!

Potential New Input !!

Dec 15th, 2015



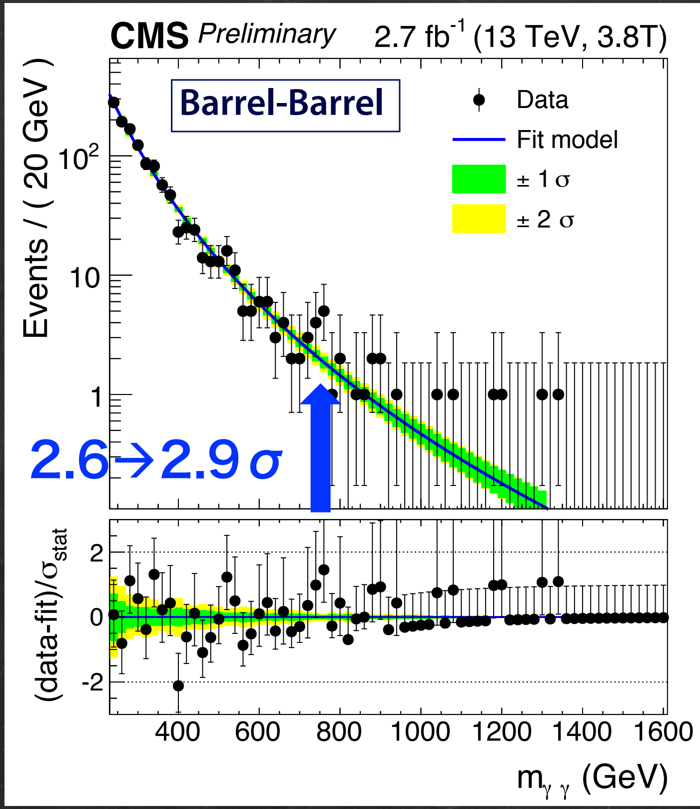


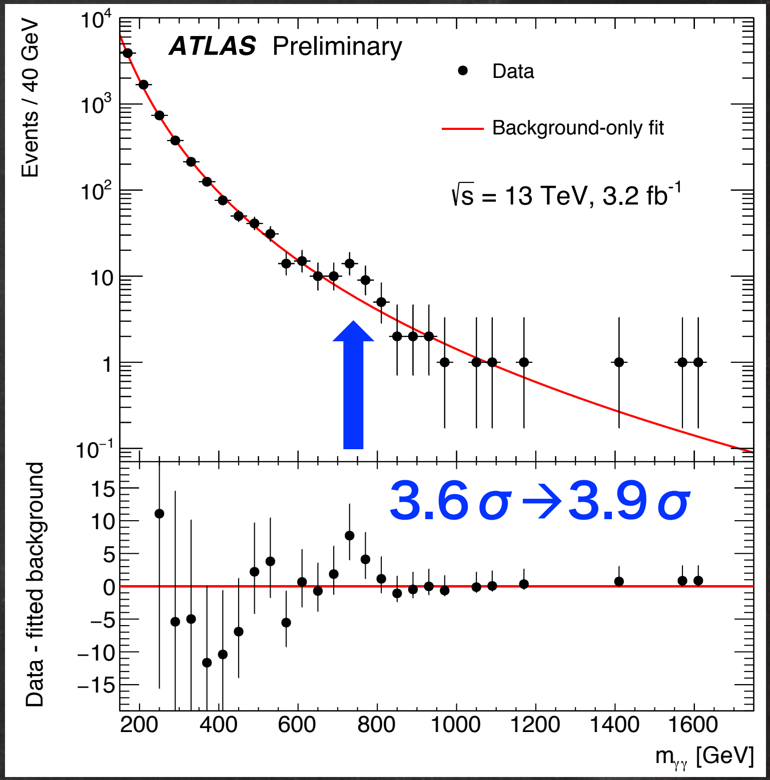
Diphoton Excess !!

Photos are for illustration purposes

Diphoton Updated

Combined w/ 8TeV : 3.4σ





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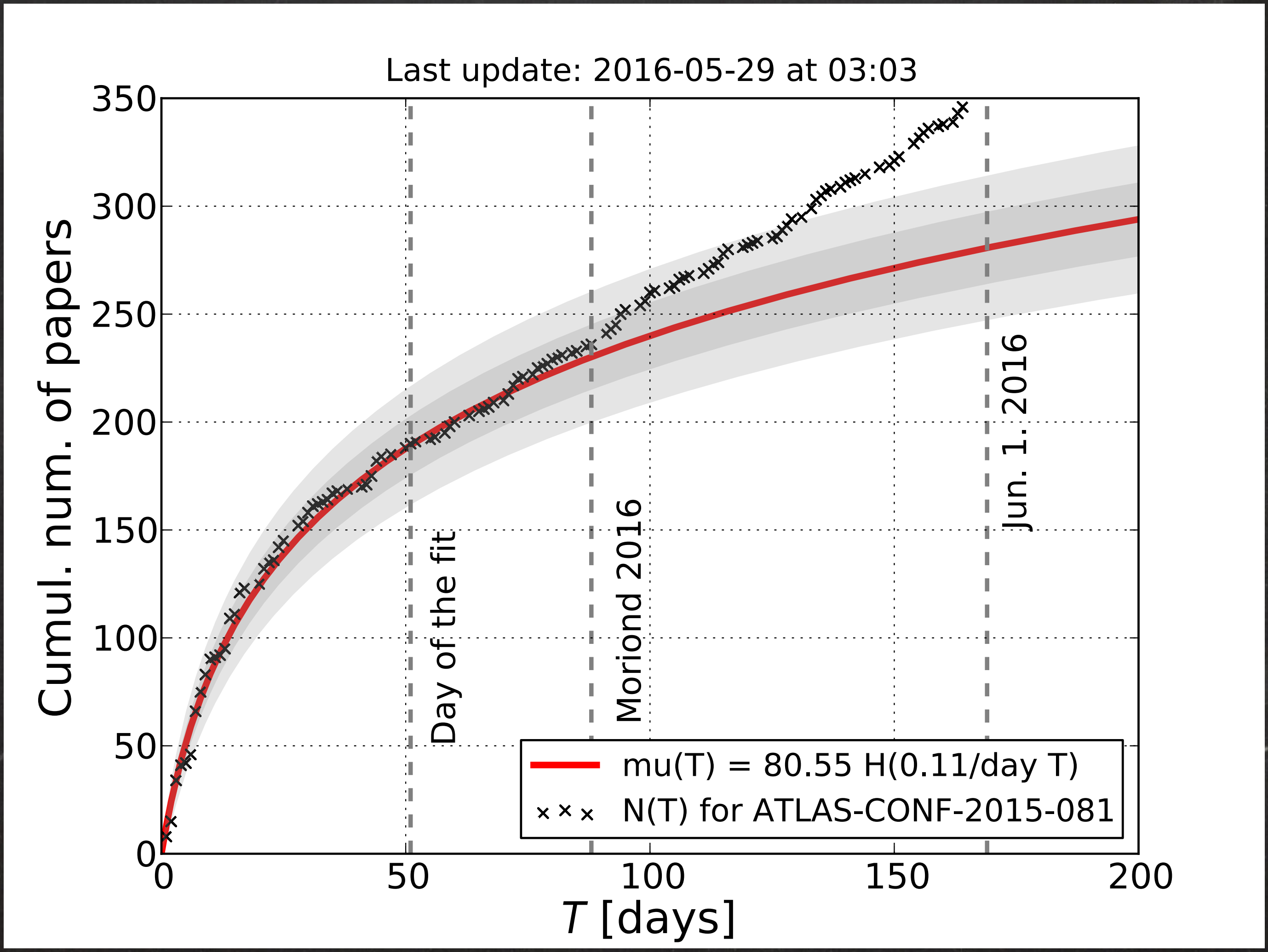
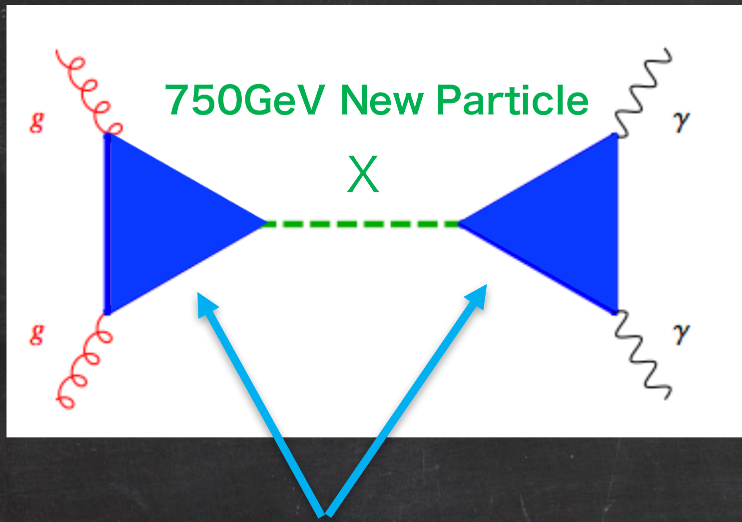
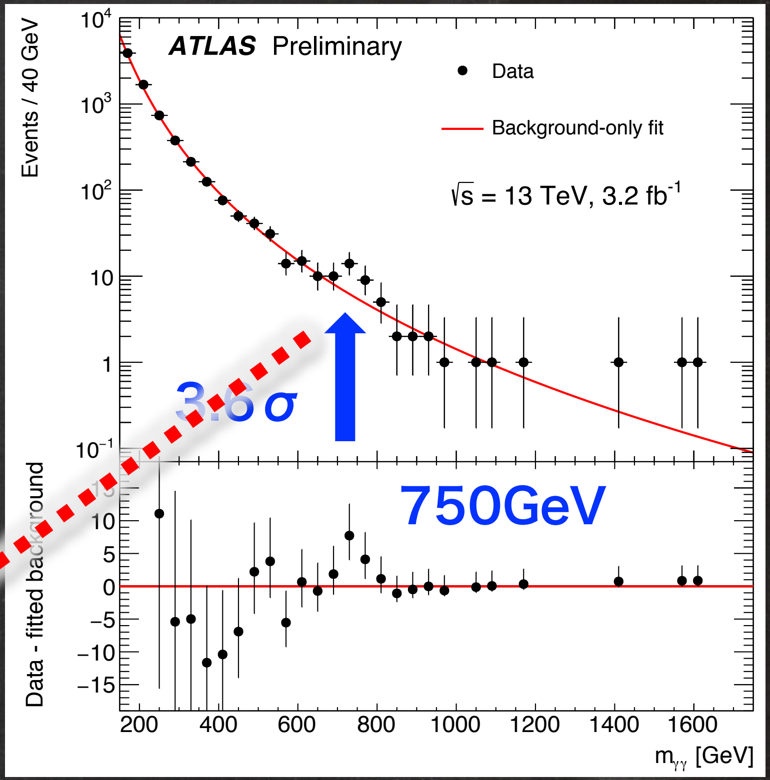
Ambulance Chasing



Everybody's Model

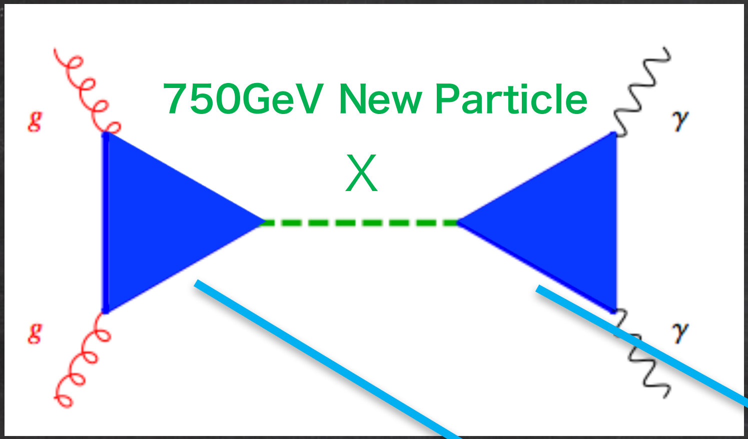




- Additional New Particle (Perturbative)
- Hidden Strong Dynamics (Non Perturbative)

$$\sigma(pp \to X) \times \mathrm{Br}(X \to \gamma\gamma) = 5\text{–}10\,\mathrm{fb}$$

Everybody's Model

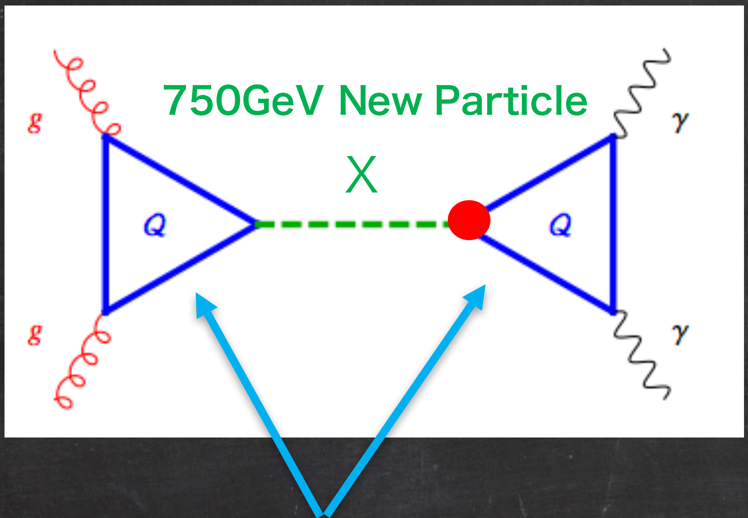


- Additional New Particle（Perturbative）
- Hidden Strong Dynamics（Non Perturbative）

$$\sigma(pp \to X) \times \mathrm{Br}(X \to \gamma\gamma) \simeq 6.6\,\mathrm{fb} \left[\underbrace{\frac{\Gamma(X \to gg)}{\Gamma(X \to \mathrm{All})}}\right] \left[\frac{\Gamma(X \to \gamma\gamma)}{1\mathrm{MeV}}\right]$$

Cancel if gg decay mode is dominate.

Everybody's Model



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Need Enhancement inside Loops

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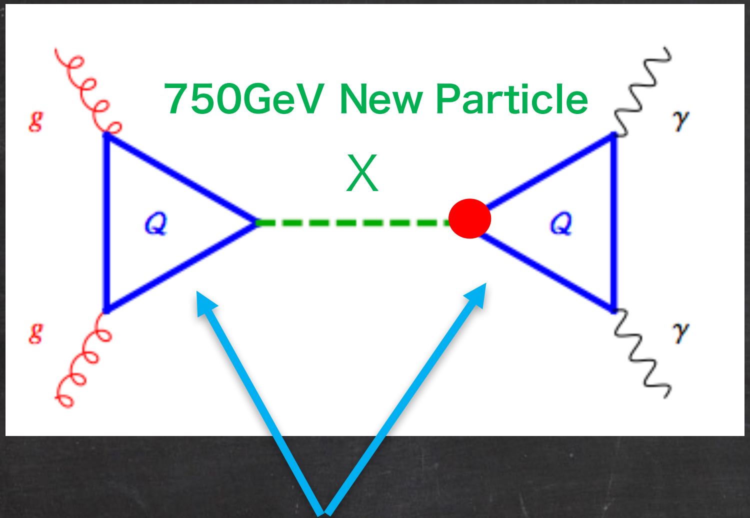

✓ a large charge, and/or

✓ a large multiplicity, and/or

✓ a large coupling

- **Additional New Particle (Perturbative)**
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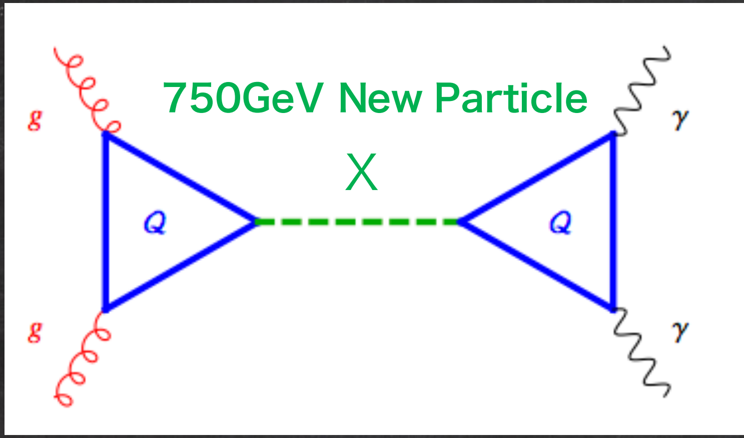
Need Enhancement inside Loops

Today's Question



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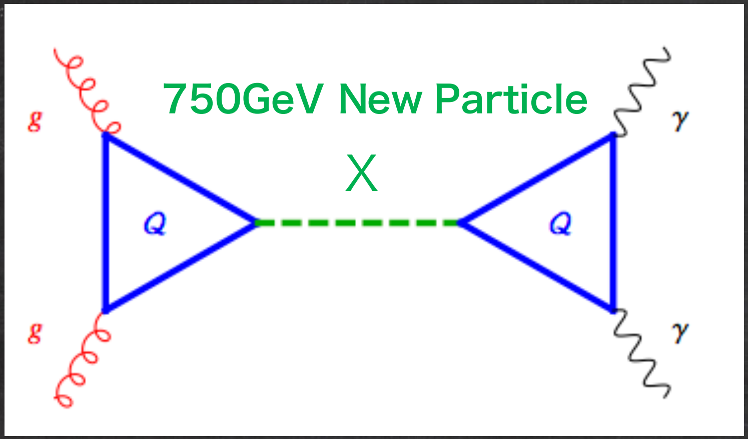
Can such a model remain perturbative up to M_{PL}?

Question



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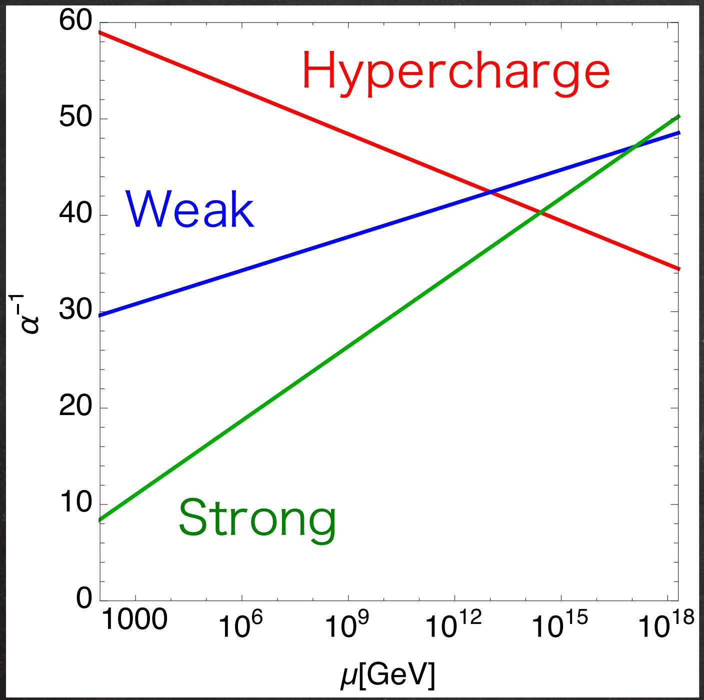
Can such a model remain perturbative up to M_{PL}?

$$\Gamma(X \to \gamma\gamma) \propto \left(\frac{\beta(\alpha_1)}{\alpha_1^2} + \frac{\beta(\alpha_2)}{\alpha_2^2}\right)^2$$

Running Coupling Constant

Running Gauge Coupling



SM

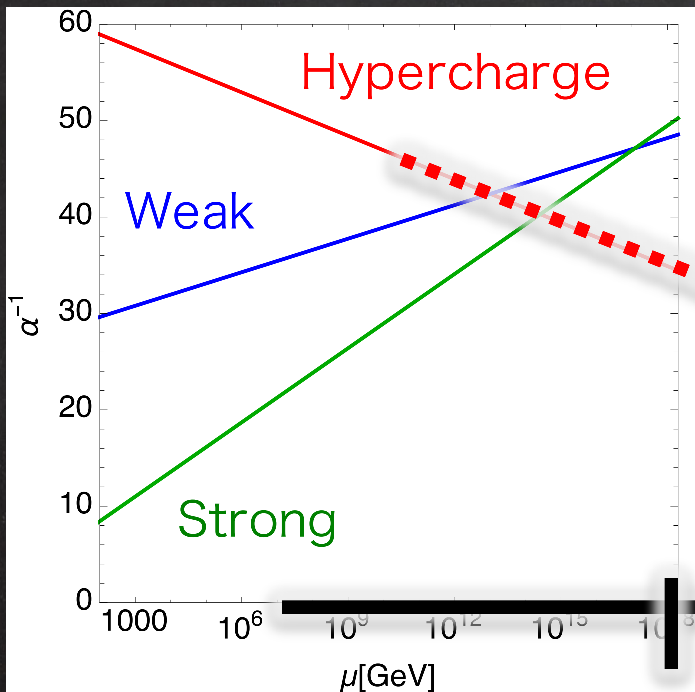
$$(4\pi)^2 \frac{dg_1}{dt} = +\frac{41}{10} g_1^3$$

$$(4\pi)^2 \frac{dg_2}{dt} = -\frac{19}{6} g_2^3$$

$$(4\pi)^2 \frac{dg_3}{dt} = -7 g_3^3$$

M_{PL}

Running Gauge Coupling



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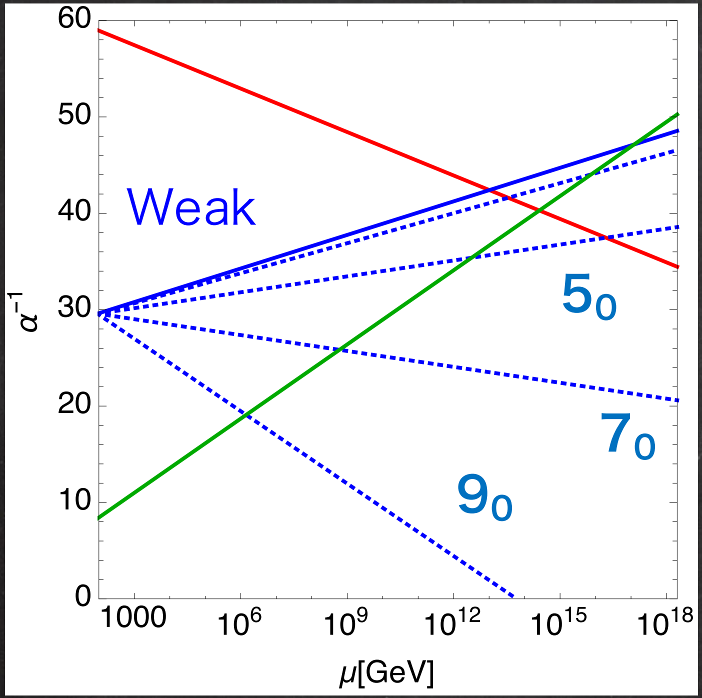
M_{PL}

Landau Pole

Running Gauge Coupling



SM + I_Y

$$(4\pi)^2 \frac{dg_1}{dt} = +\frac{3}{5}\Big\{ + \frac{41}{6} + \frac{1}{3} Y_\chi^2 (2T_\chi + 1) \Big\} g_1^3$$

$$(4\pi)^2 \frac{dg_2}{dt} = \Big\{ - \frac{19}{6} + \frac{1}{9} T_\chi (T_\chi + 1)(2T_\chi + 1) \Big\} g_2^3$$

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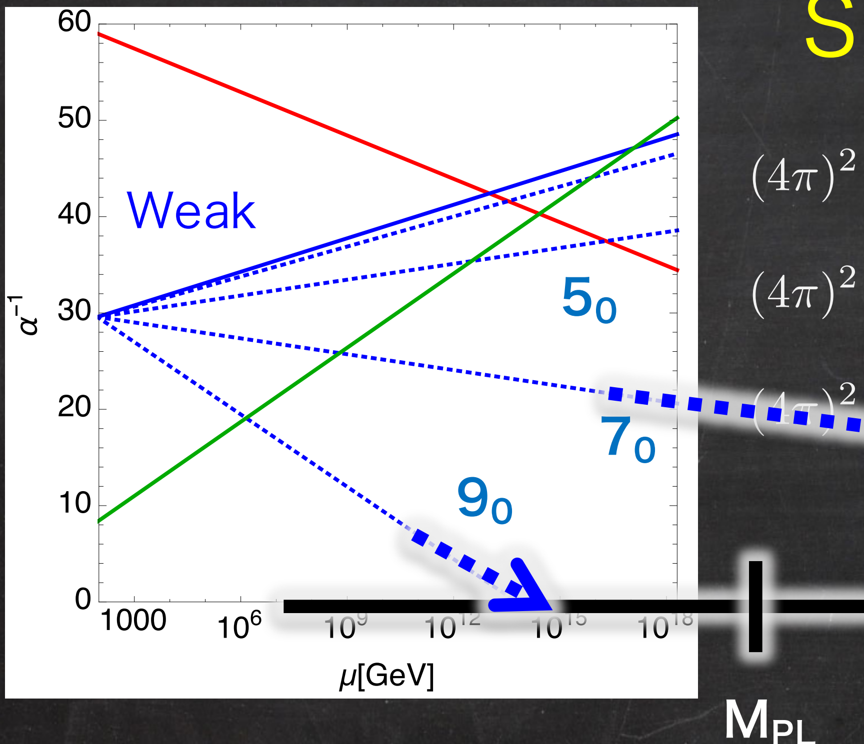
Running Gauge Coupling



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- $\geqq 7_{\text{plet}}$: Weak int. is no longer asymptotic free
- $\geqq 9_{\text{plet}}$: Perturbativity breakdown before M_{PL}

Landau Pole

(n_X, Y_X)	Λ_{g_Y} [GeV]	Λ_{g_2} [GeV]
(4, 1/2)	1.2×10^{41}	–
(4, 3/2)	3.1×10^{30}	–
(5, real)	9.6×10^{42}	–
(5, 1)	9.0×10^{34}	9.0×10^{488}
(5, 2)	5.7×10^{22}	9.0×10^{488}
(6, 1/2)	1.6×10^{40}	2.7×10^{32}
(6, 3/2)	5.2×10^{26}	2.7×10^{32}
(6, 5/2)	3.2×10^{16}	2.7×10^{32}
(7, real)	9.6×10^{42}	1.3×10^{56}
(7, 1)	3.6×10^{32}	1.4×10^{15}
(7, 2)	2.2×10^{19}	1.4×10^{15}
(7, 3)	1.2×10^{12}	1.4×10^{15}

$$n_\chi = 2T_\chi + 1$$

$$(4\pi)^2 \frac{dg_1}{dt} = +\frac{3}{5}\Big\{+\frac{41}{6} + \frac{1}{3}Y_\chi^2 n_\chi\Big\} g_1^3$$

$$(4\pi)^2 \frac{dg_2}{dt} = \Big\{-\frac{19}{6} + \frac{1}{72} n_\chi (n_\chi^2 - 1)\Big\} g_2^3$$

No Landau Pole up to M_{PL}

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No Landau Pole up to M_{PL}

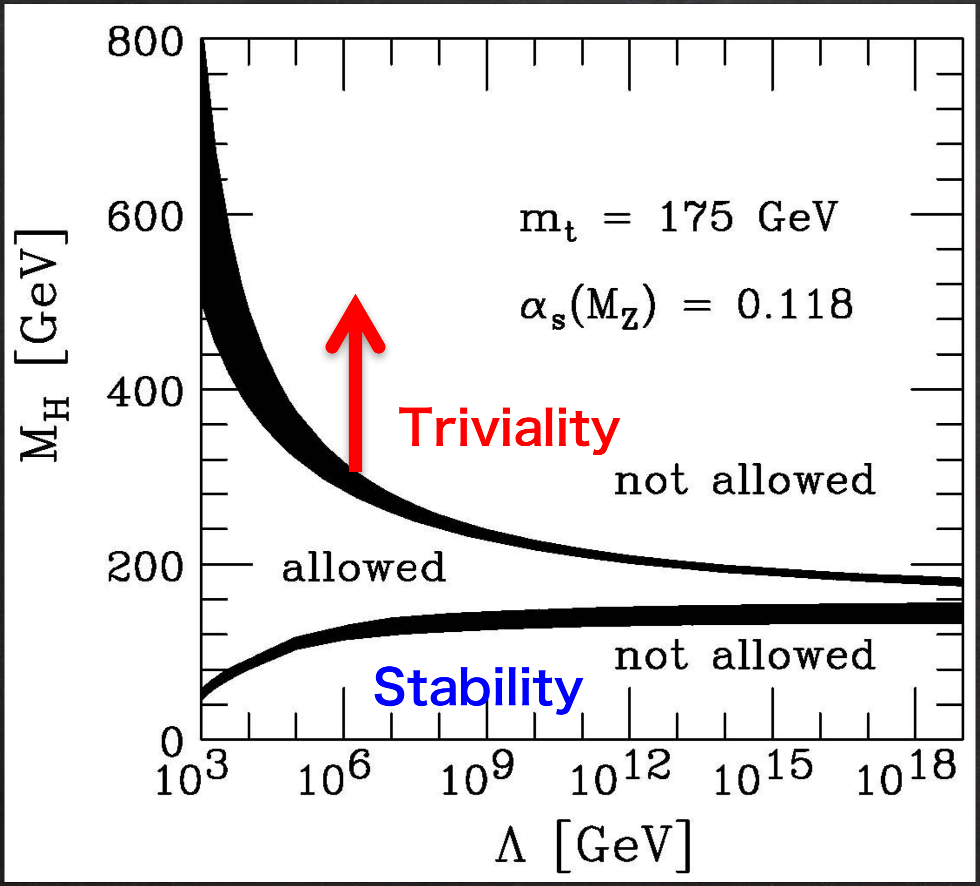
Other coupling constants ?

Quartic Coupling

Triviality (Lesson)

A bound for the SM Higgs Mass

$$(4\pi)^2 \frac{d}{d\log Q}\lambda = 24\lambda^2 - 6y_t^4 + \cdots$$



$$M_h^2 (= 2\lambda v^2) \lesssim \frac{4\pi^2 v^2}{3\log(\Lambda/v)}$$

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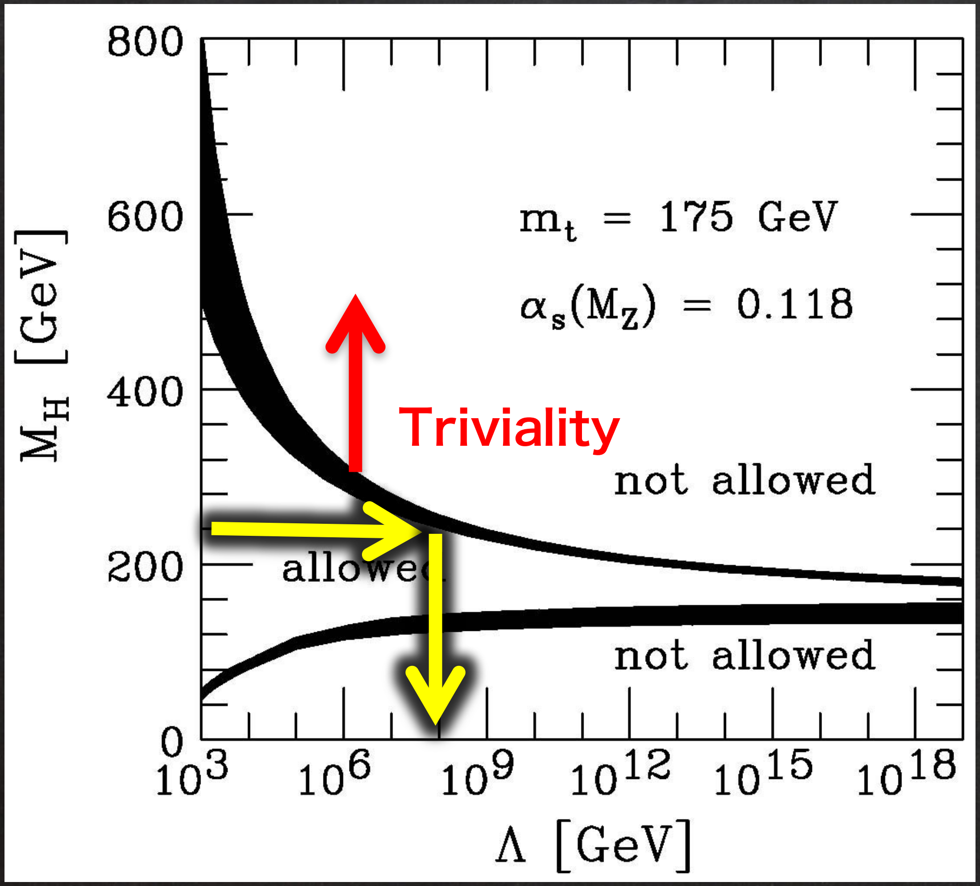


$$M_h^2 (= 2\lambda v^2) \lesssim \frac{4\pi^2 v^2}{3\log(\Lambda/v)}$$

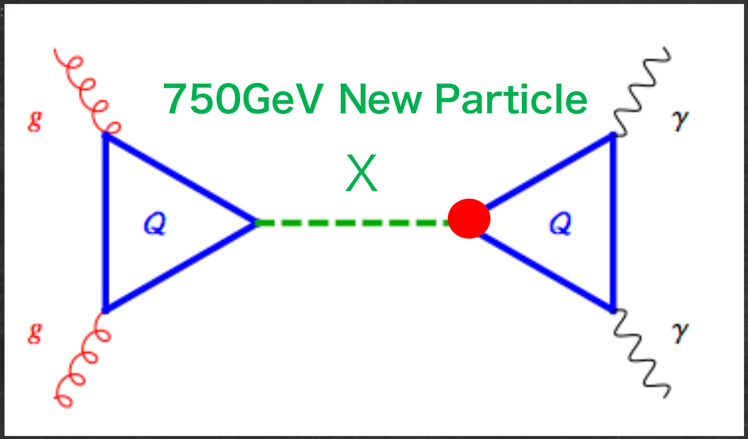
Large λ

⇕

Small Landau Pole

$$\Lambda_{\rm LP} = \mu_0 \exp\left(\frac{1}{24\lambda(\mu_0)/(4\pi)^2}\right)$$

Question



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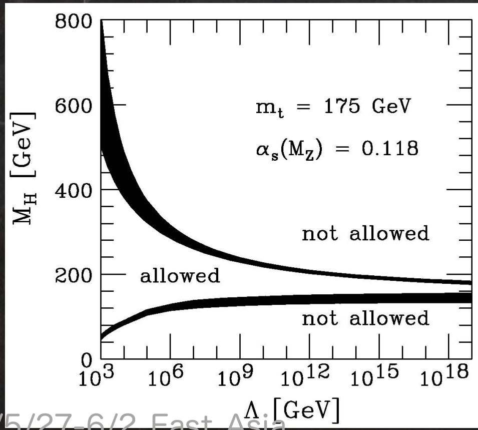

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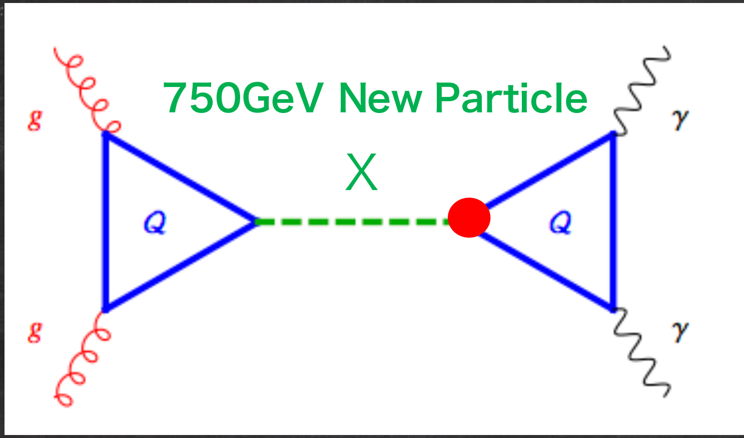

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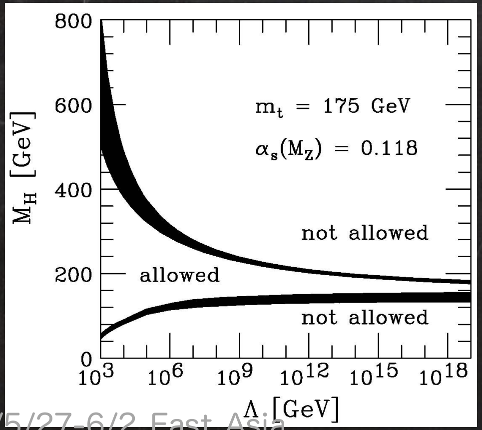
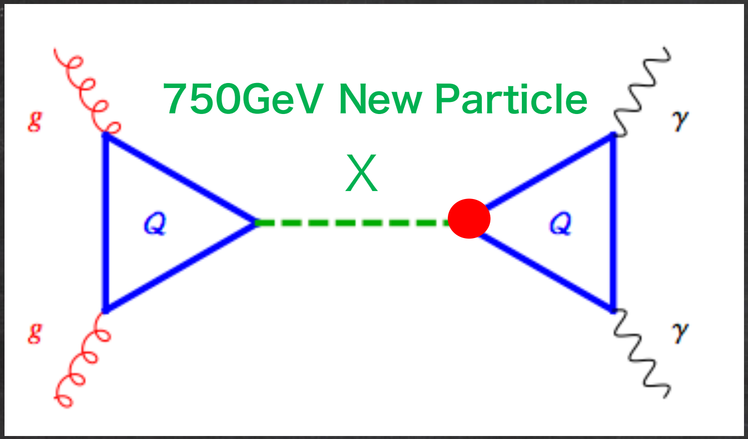


$$\Lambda_{\rm LP} = \mu_0 \exp\left(\frac{1}{24\lambda(\mu_0)/(4\pi)^2}\right)$$

"$X_{750}SS^*$" coupling is Not a Quartic Coupling.

→ Stability

Stability Condition



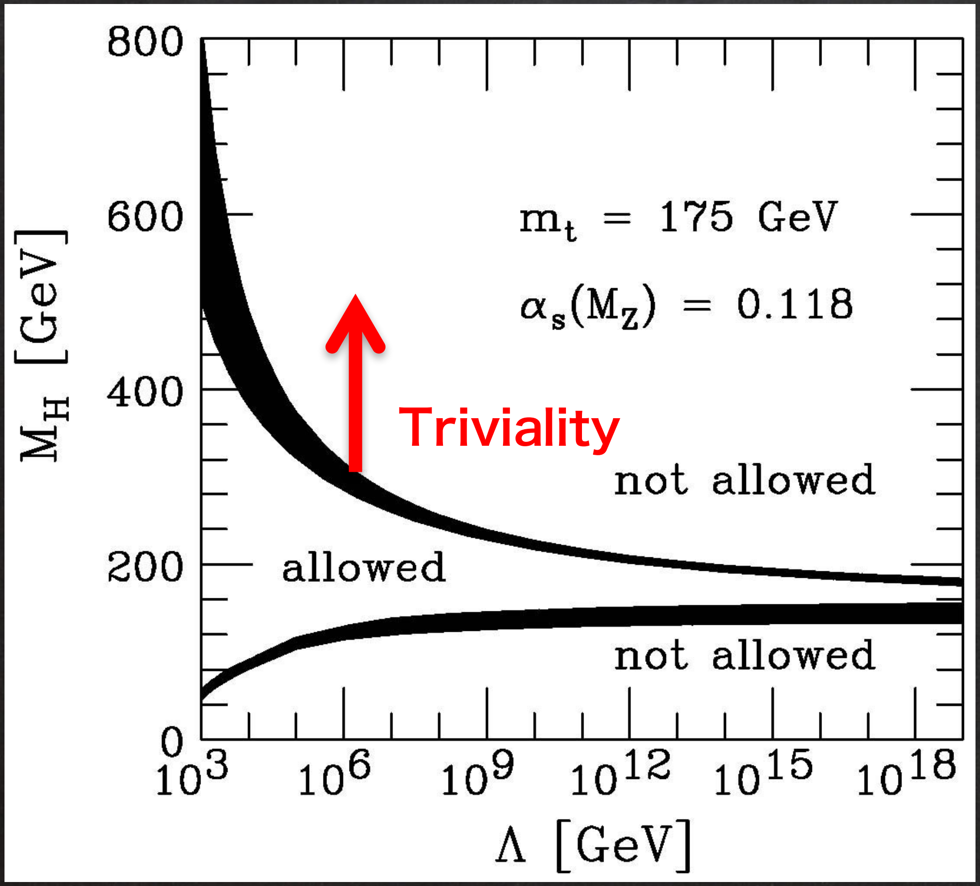
$$V = \frac{1}{2}M_X^2 X^2 + \mu(S^\dagger S)X + \lambda_S(S^\dagger S)^2$$
$$= \frac{1}{2}M_X^2\left(X + \frac{\mu}{M_X^2}(S^\dagger S)\right)^2 + \underline{\left(\lambda_S - \frac{\mu^2}{2M_X^2}\right)}(S^\dagger S)^2$$

$$\mu^2 < 2\lambda_S(750\mathrm{GeV})^2$$

Large Triple Coupling requires Large Quartic Coupling

Triviality for λ_χ

A bound for the SM Higgs Mass



$$V_\chi = \lambda_\chi (\chi^\dagger \chi)^2 \cdots$$

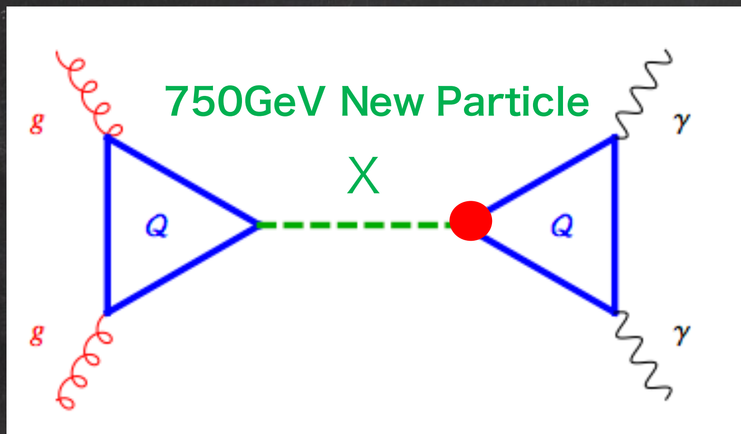
$$(4\pi)^2 \frac{d}{d\log Q} \lambda_\chi = c_i\, \lambda_\chi^2 + \cdots$$

Large λ_χ

Small Landau Pole

$$\Lambda_{\mathrm{LP}} = \mu_0 \exp\left(\frac{1}{c_i \lambda_\chi(\mu_0)/(4\pi)^2}\right)$$

λ_S^{Max}



$$f(x) := 8x\left(\arctan\frac{1}{\sqrt{4x-1}}\right)^2 - 2.$$

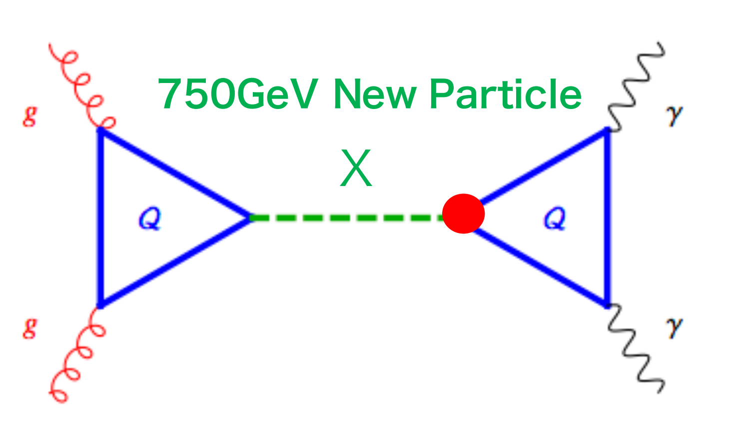
$$\sigma \times \mathcal{B}_{\gamma\gamma} = 46\text{pb} \times \lambda_S^{\text{Max}} \times \left(\frac{N_S\, \alpha \sum_S Q_S^2}{2\pi} f(M_S^2/M_X^2)\right)^2 \times \left(\frac{750\text{GeV}}{M_X}\right)^2$$

Converted by Stability Bound

λ_S^{Max} is calculated by RGE analysis when we specify the model

Something decaying to two quarks

Diquark (qq or qq^c) model



	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\rm Max}$	$(N_f^2\lambda_\phi)^{\rm Max}$
DQ_0^d	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$-1/3$	0.32 $(\times)$	$2.2\,\|_{N_f=6}$
DQ_0^y	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$-4/3$	0.34 $(\times)$	$1.2\,\|_{N_f=3}$
DQ_0^u	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$2/3$	0.33 $(\times)$	$2.2\,\|_{N_f=6}$
DQ_1	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{3}$	$-1/3$	0.13 $(\times)$	$0.13\,\|_{N_f=1}$
$DQ_{1/2}$	$\mathbf{1_H}$ $(\mathbf{8})$	$\mathbf{2}$	$1/2$	0.18 $(\times)$	$8.5\,\|_{N_f=20}$

assume tree level decays

Something decaying to two quarks

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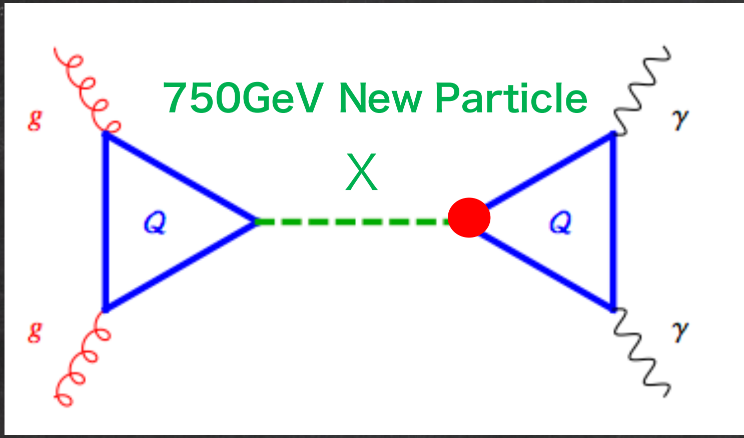

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assume tree level decays

Color $6_{\rm plet}$ & $8_{\rm plet}$ violate perturbativity of QCD before $M_{\rm PL}$

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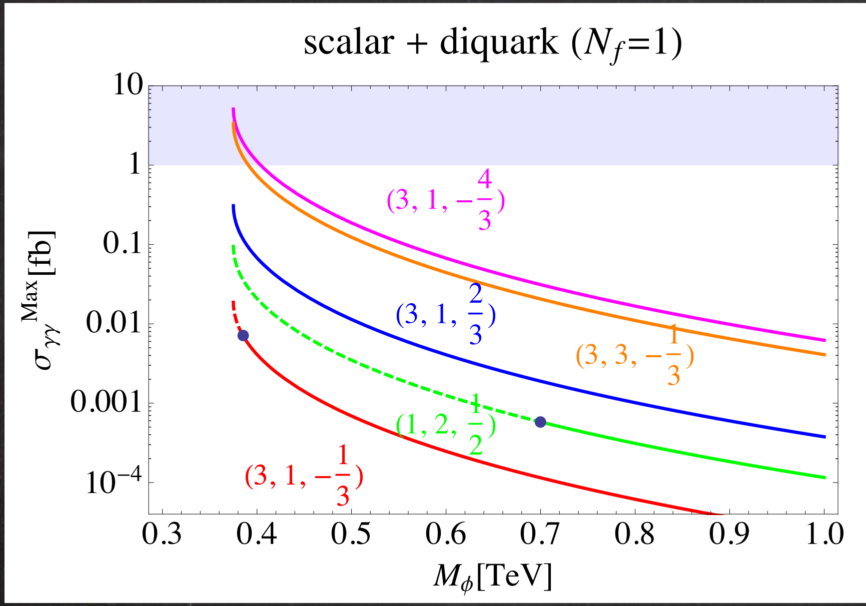

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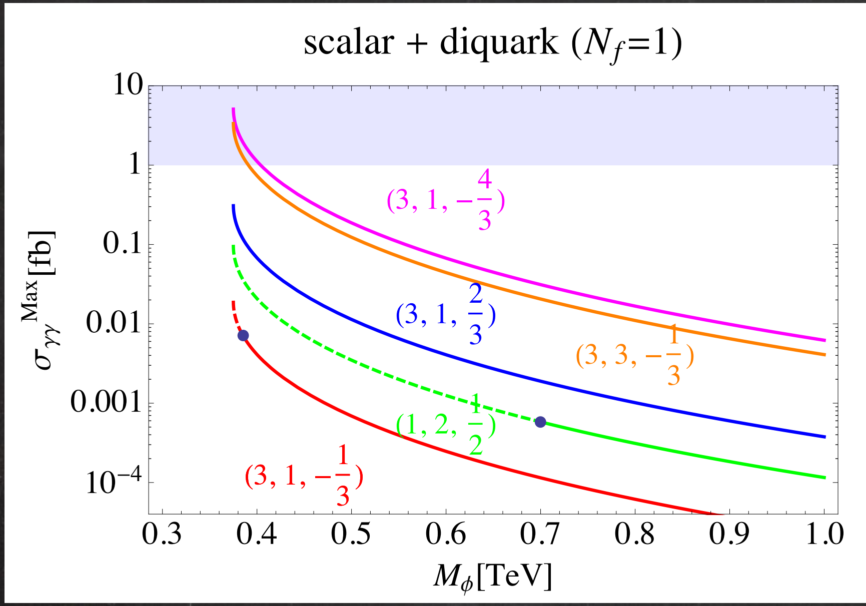
DQ_0^d	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-1/3$	0.32 ($\times$)	$2.2\,\lvert_{N_f=6}$
DQ_0^y	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-4/3$	0.34 ($\times$)	$1.2\,\lvert_{N_f=3}$
DQ_0^u	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$2/3$	0.33 ($\times$)	$2.2\,\lvert_{N_f=6}$
DQ_1	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{3}$	$-1/3$	0.13 ($\times$)	$0.13\,\lvert_{N_f=1}$
$DQ_{1/2}$	$\mathbf{1_H}$ ($\mathbf{8}$)	$\mathbf{2}$	$1/2$	0.18 ($\times$)	$8.5\,\lvert_{N_f=20}$

λ_S^{Max} for N_S=1

$$\sigma \times \mathcal{B}_{\gamma\gamma} = 46\mathrm{pb} \times \lambda_S^{\mathrm{Max}} \times \left(\frac{N_S\,\alpha\,\sum_S Q_S^2}{2\pi} f(M_S^2/M_X^2)\right)^2 \times \left(\frac{750\mathrm{GeV}}{M_X}\right)^2$$

Diquark (qq or qq^c) model



	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\rm Max}$	$(N_f^2\lambda_\phi)^{\rm Max}$
DQ_0^d	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-1/3$	0.32 ($\times$)	$2.2\,\|_{N_f=6}$
DQ_0^y	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-4/3$	0.34 ($\times$)	$1.2\,\|_{N_f=3}$
DQ_0^u	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$2/3$	0.33 ($\times$)	$2.2\,\|_{N_f=6}$
DQ_1	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{3}$	$-1/3$	0.13 ($\times$)	$0.13\,\|_{N_f=1}$
$DQ_{1/2}$	$\mathbf{1_H}$ ($\mathbf{8}$)	$\mathbf{2}$	$1/2$	0.18 ($\times$)	$8.5\,\|_{N_f=20}$

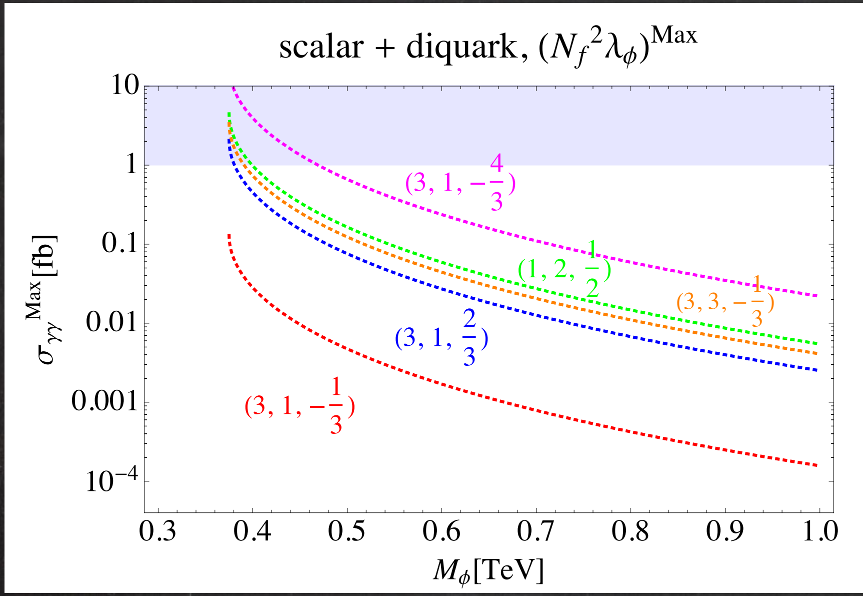
$\lambda_S^{\rm Max}$ for N_S=1

$$\sigma\times\mathcal{B}_{\gamma\gamma} = 46\text{pb}\times\lambda_S^{\rm Max}\times\left(\frac{N_S\,\alpha\,\sum_S Q_S^2}{2\pi}\,f(M_S^2/M_X^2)\right)^2\times\left(\frac{750\text{GeV}}{M_X}\right)^2$$

Only Two Models (N_S=1) are consistent with

LHC diphoton Excess & perturbativity up to M_{PL}

Diquark (qq or qq^c) model



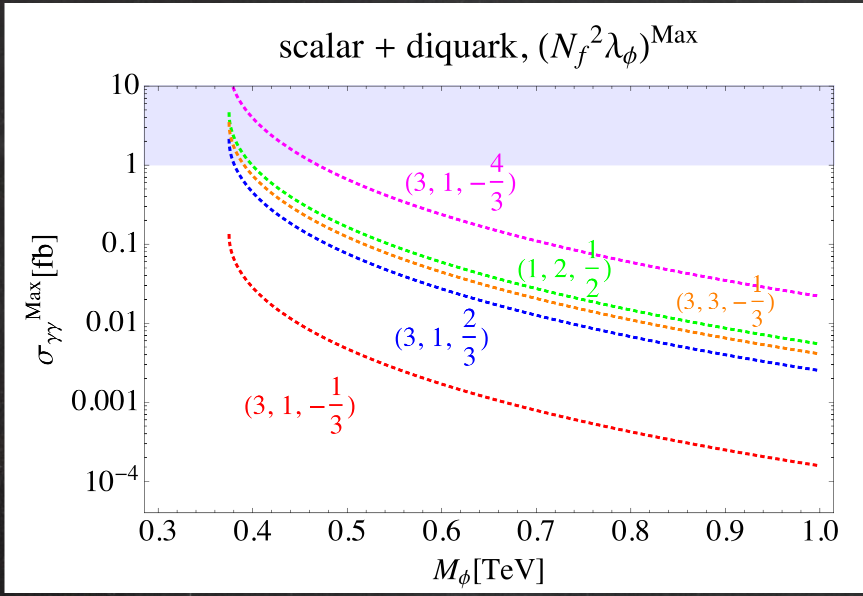
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\rm Max}$	$(N_f^2\lambda_\phi)^{\rm Max}$
DQ_0^d	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$-1/3$	0.32 $(\times)$	$2.2\,\vert_{N_f=6}$
DQ_0^y	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$-4/3$	0.34 $(\times)$	$1.2\,\vert_{N_f=3}$
DQ_0^u	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{1}$	$2/3$	0.33 $(\times)$	$2.2\,\vert_{N_f=6}$
DQ_1	$\mathbf{3}$ $(\mathbf{6}^*)$	$\mathbf{3}$	$-1/3$	0.13 $(\times)$	$0.13\,\vert_{N_f=1}$
$DQ_{1/2}$	$\mathbf{1_H}$ $(\mathbf{8})$	$\mathbf{2}$	$1/2$	0.18 $(\times)$	$8.5\,\vert_{N_f=20}$

Maximal Case

$$\sigma\times\mathcal{B}_{\gamma\gamma} = 46\text{pb}\times\lambda_S^{\rm Max}\times\left(\frac{N_S\,\alpha\,\sum_S Q_S^2}{2\pi}\,f(M_S^2/M_X^2)\right)^2\times\left(\frac{750\text{GeV}}{M_X}\right)^2$$

Most of diquark models survive if we increase multiplicity

Diquark (qq or qq^c) model



	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\mathrm{Max}}$	$(N_f^2\lambda_\phi)^{\mathrm{Max}}$
DQ_0^d	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-1/3$	0.32 (×)	$2.2\,\|_{N_f=6}$
DQ_0^y	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$-4/3$	0.34 (×)	$1.2\,\|_{N_f=3}$
DQ_0^u	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{1}$	$2/3$	0.33 (×)	$2.2\,\|_{N_f=6}$
DQ_1	$\mathbf{3}$ ($\mathbf{6}^*$)	$\mathbf{3}$	$-1/3$	0.13 (×)	$0.13\,\|_{N_f=1}$
$DQ_{1/2}$	$\mathbf{1_H}$ ($\mathbf{8}$)	$\mathbf{2}$	$1/2$	0.18 (×)	$8.5\,\|_{N_f=20}$

Maximal Case

$$\sigma \times \mathcal{B}_{\gamma\gamma} = 46\text{pb} \times \lambda_S^{\mathrm{Max}} \times \left(\frac{N_S\,\alpha\,\sum_S Q_S^2}{2\pi} f(M_S^2/M_X^2)\right)^2 \times \left(\frac{750\text{GeV}}{M_X}\right)^2$$

Most of diquark models survive if we increase multiplicity

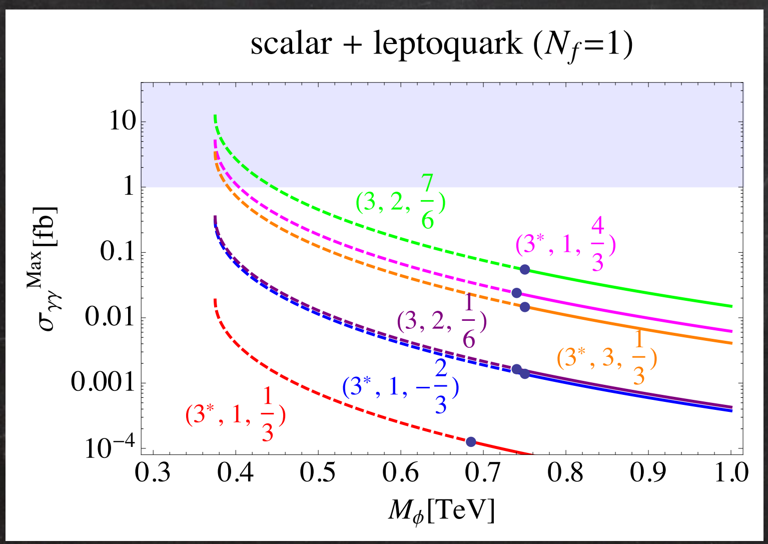
All the models can be test at the LHC!!

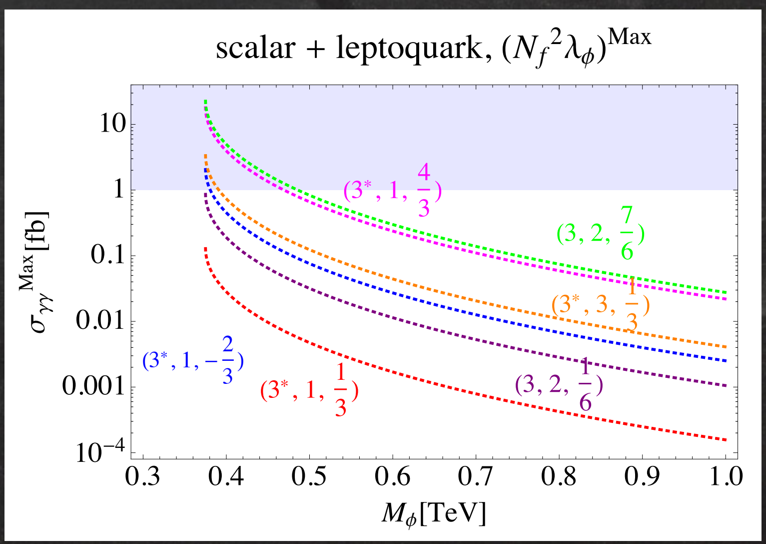
Something decaying to a lepton and a quark

Leptoquark (ql or ql^c) model

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\rm Max}$	$(N_f^2\lambda_\phi)^{\rm Max}$
S_0^{d*}	$\mathbf{3}^*$	$\mathbf{1}$	$1/3$	0.32	$2.2\,\|_{N_f=6}$
S_0^{y*}	$\mathbf{3}^*$	$\mathbf{1}$	$4/3$	0.34	$1.2\,\|_{N_f=3}$
S_1^*	$\mathbf{3}^*$	$\mathbf{3}$	$1/3$	0.13	$0.13\,\|_{N_f=1}$
$S_{1/2}$	$\mathbf{3}$	$\mathbf{2}$	$7/6$	0.25	$0.46\,\|_{N_f=2}$
$S_{1/2}^q$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	0.24	$0.59\,\|_{N_f=3}$
R_0^{u*}	$\mathbf{3}^*$	$\mathbf{1}$	$-2/3$	0.33	$2.2\,\|_{N_f=6}$
R_0^{d*}	$\mathbf{3}^*$	$\mathbf{1}$	$1/3$	0.32	$2.2\,\|_{N_f=6}$
$R_{1/2}^*$	$\mathbf{3}$	$\mathbf{2}$	$-1/6$	0.24	$0.59\,\|_{N_f=3}$

Exp. bounds are severe



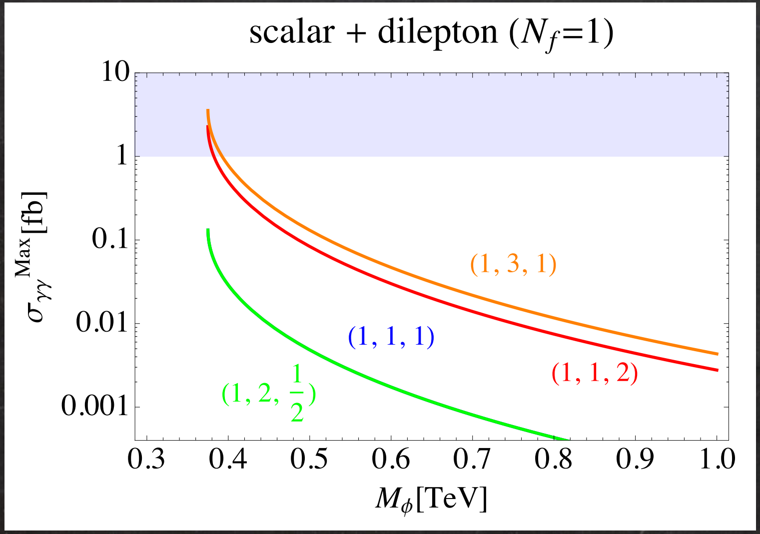


Something decaying to two leptons

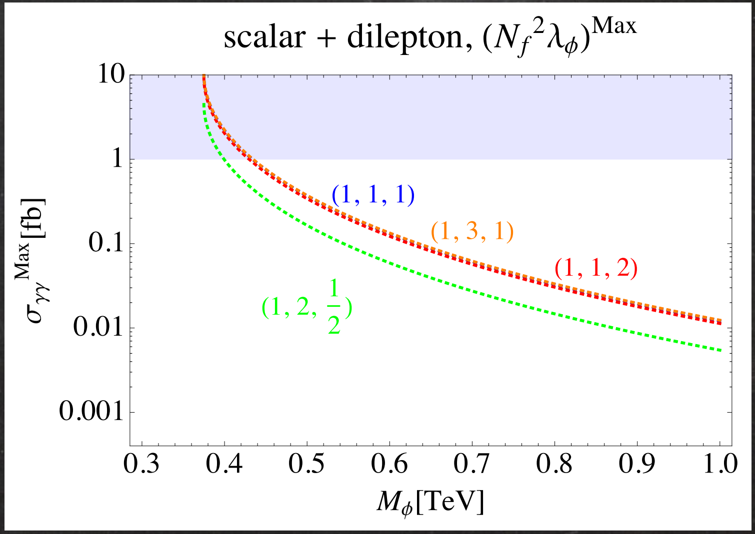
Dilepton (ll or ll^c) model

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\lambda_\phi^{\mathrm{Max}}$	$(N_f^2\lambda_\phi)^{\mathrm{Max}}$
h_0^+	$\mathbf{1}$	$\mathbf{1}$	1	0.25	$19\,\vert_{N_f=25}$
h_0^{++}	$\mathbf{1}$	$\mathbf{1}$	2	0.27	$1.1\,\vert_{N_f=3}$
Δ_1	$\mathbf{1}$	$\mathbf{3}$	1	0.27	$0.77\,\vert_{N_f=3}$
$\Phi_{1/2}$	$\mathbf{1_H}$	$\mathbf{2}$	1/2	0.25	$8.5\,\vert_{N_f=20}$
s_0	$\mathbf{1}$	$\mathbf{1}$	0	$\times$	$\times$

Exp. bounds are loose



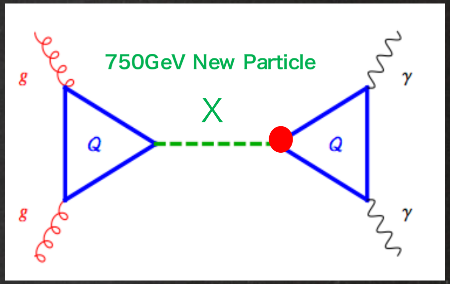
High multiplicity helps all the model



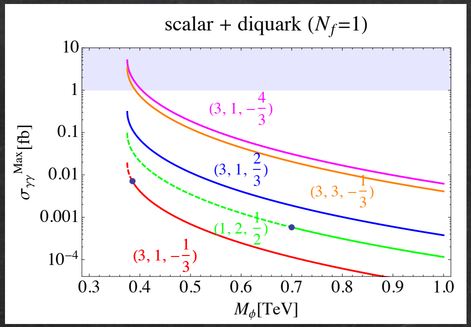
Summary

Summary

- Can the LHC diphoton excess be valid up to M_{Pl}?



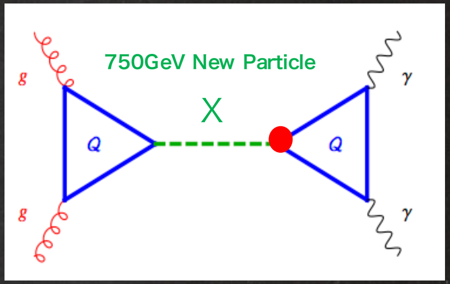
→ Yes, in a couple of models



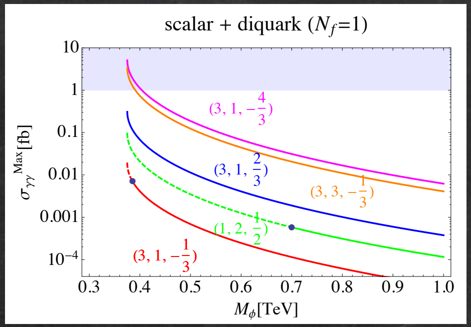
Fin

Summary

- Can the LHC diphoton excess be valid up to M_{Pl}?



→ Yes, in a couple of models

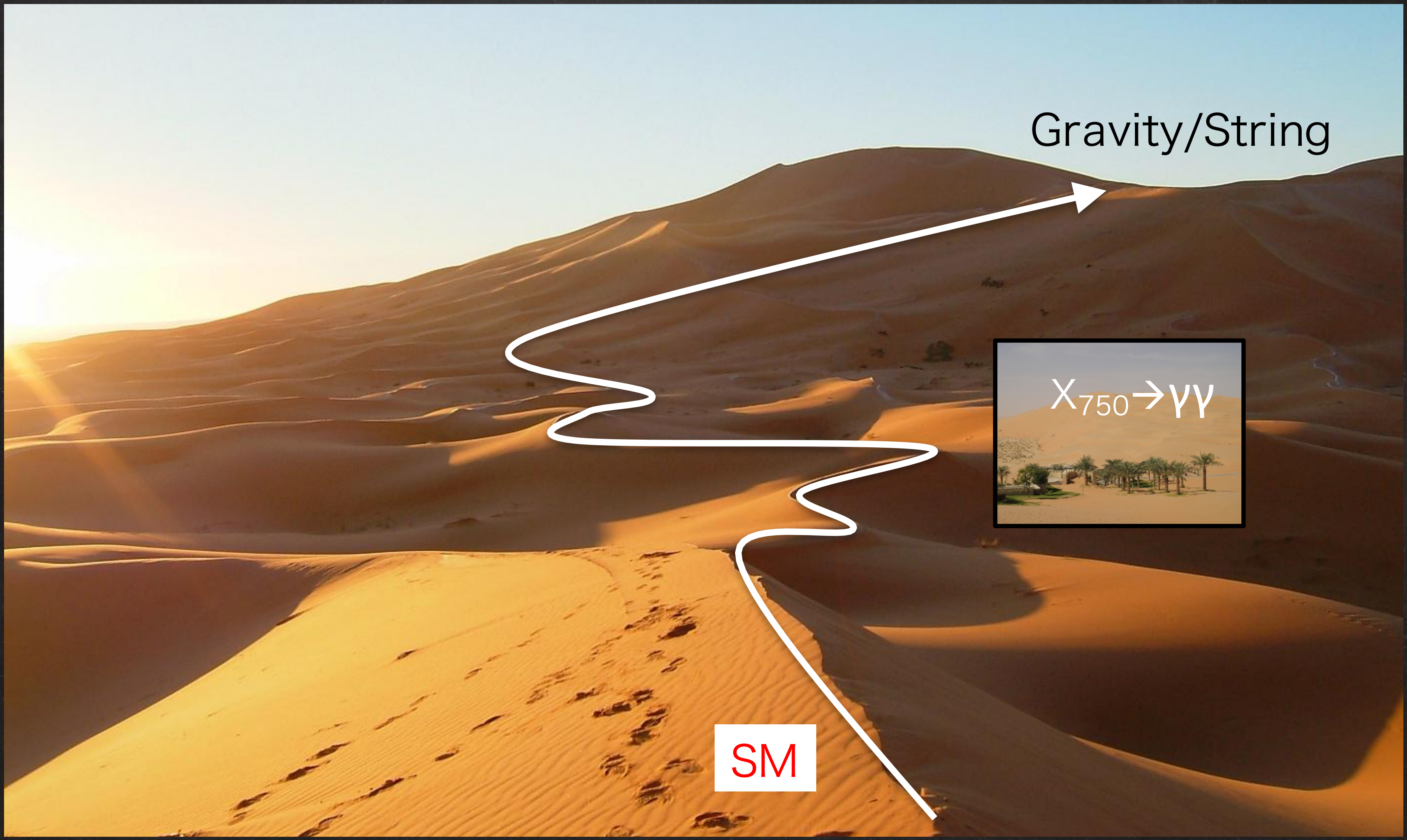


However, is looks very exotic, & may be excluded at future?

Important Date : August 3-10, ICHEP (Chicago)

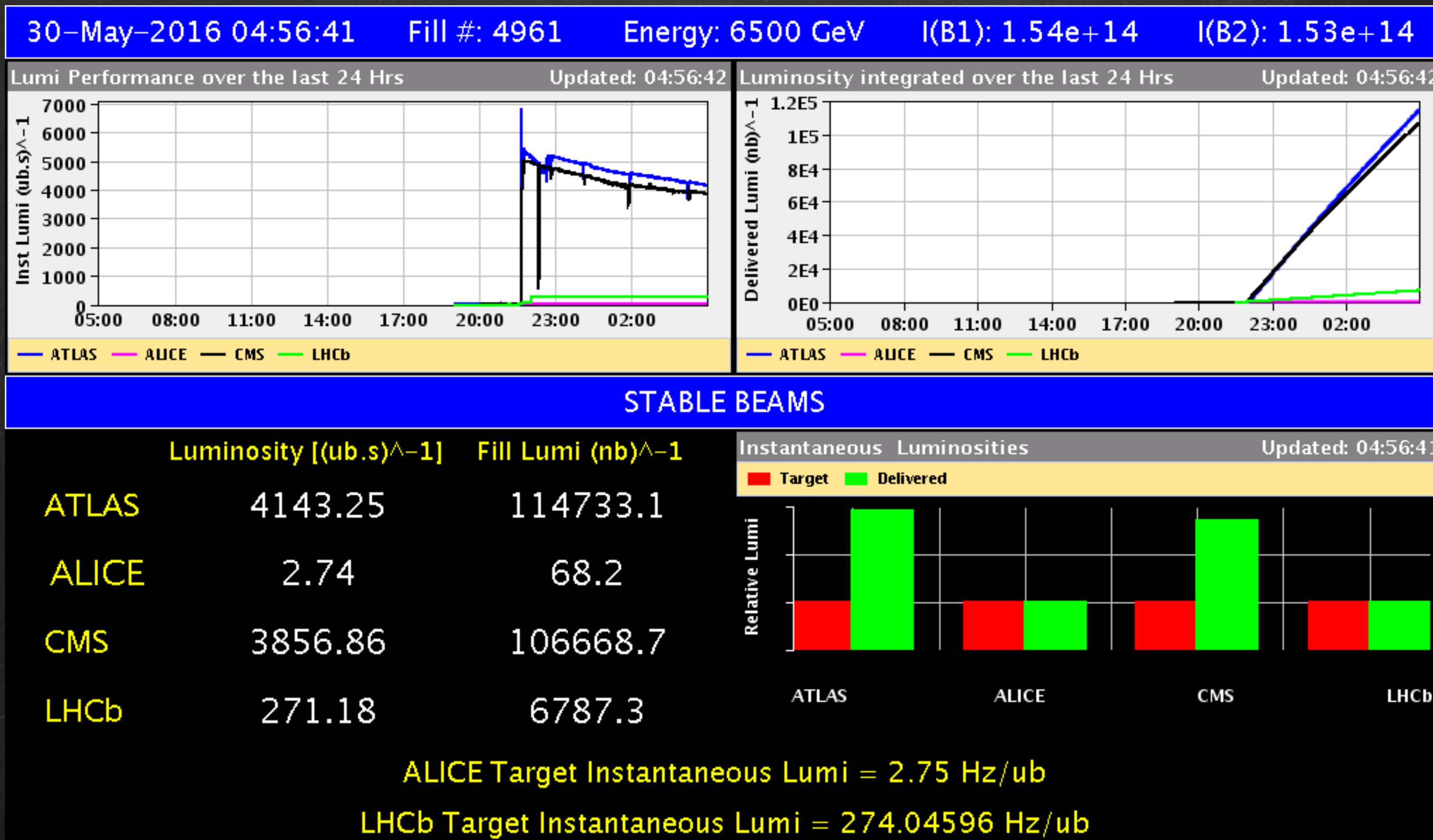
Fin

We Need a Big Picture

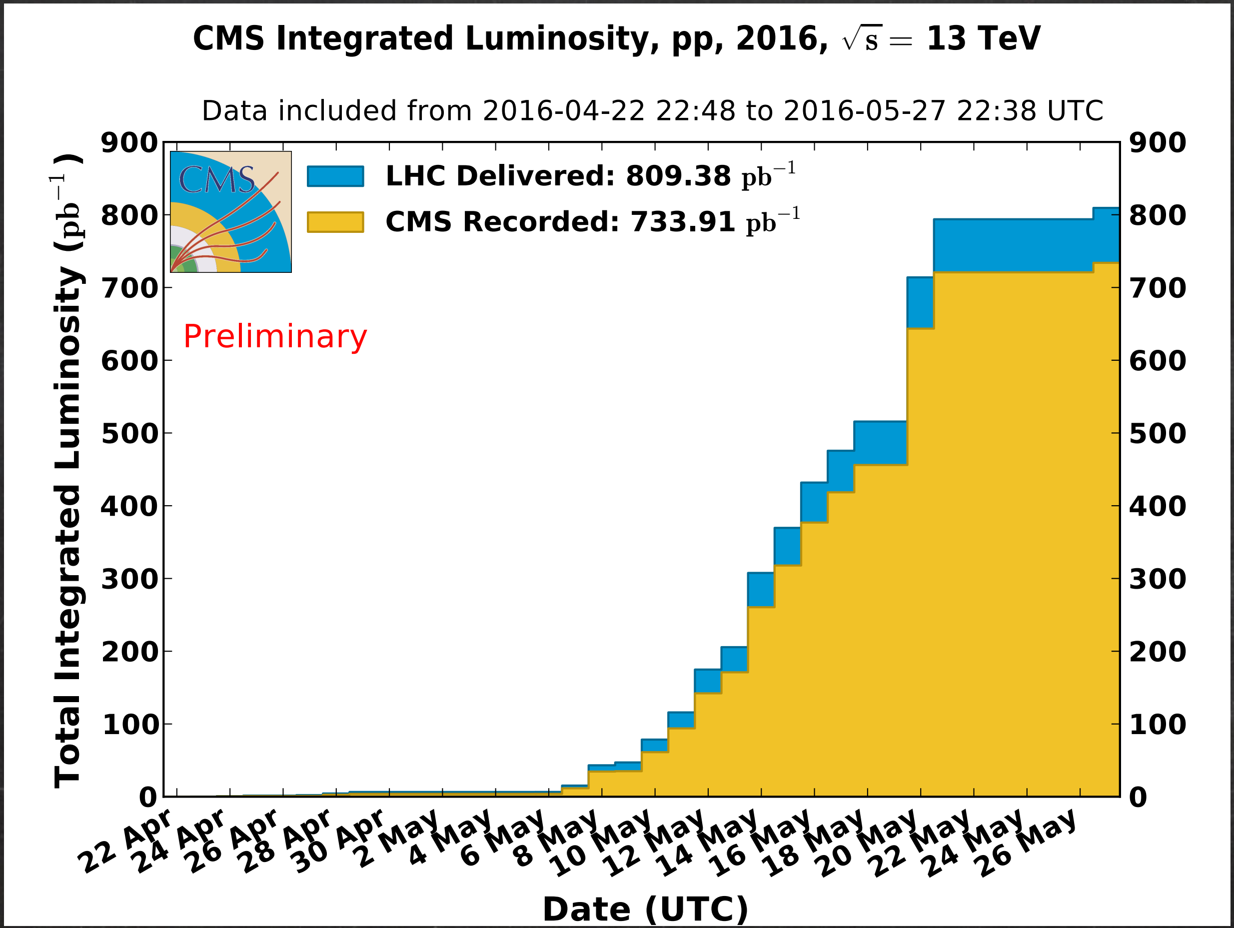


Backup Slides

LHC Status

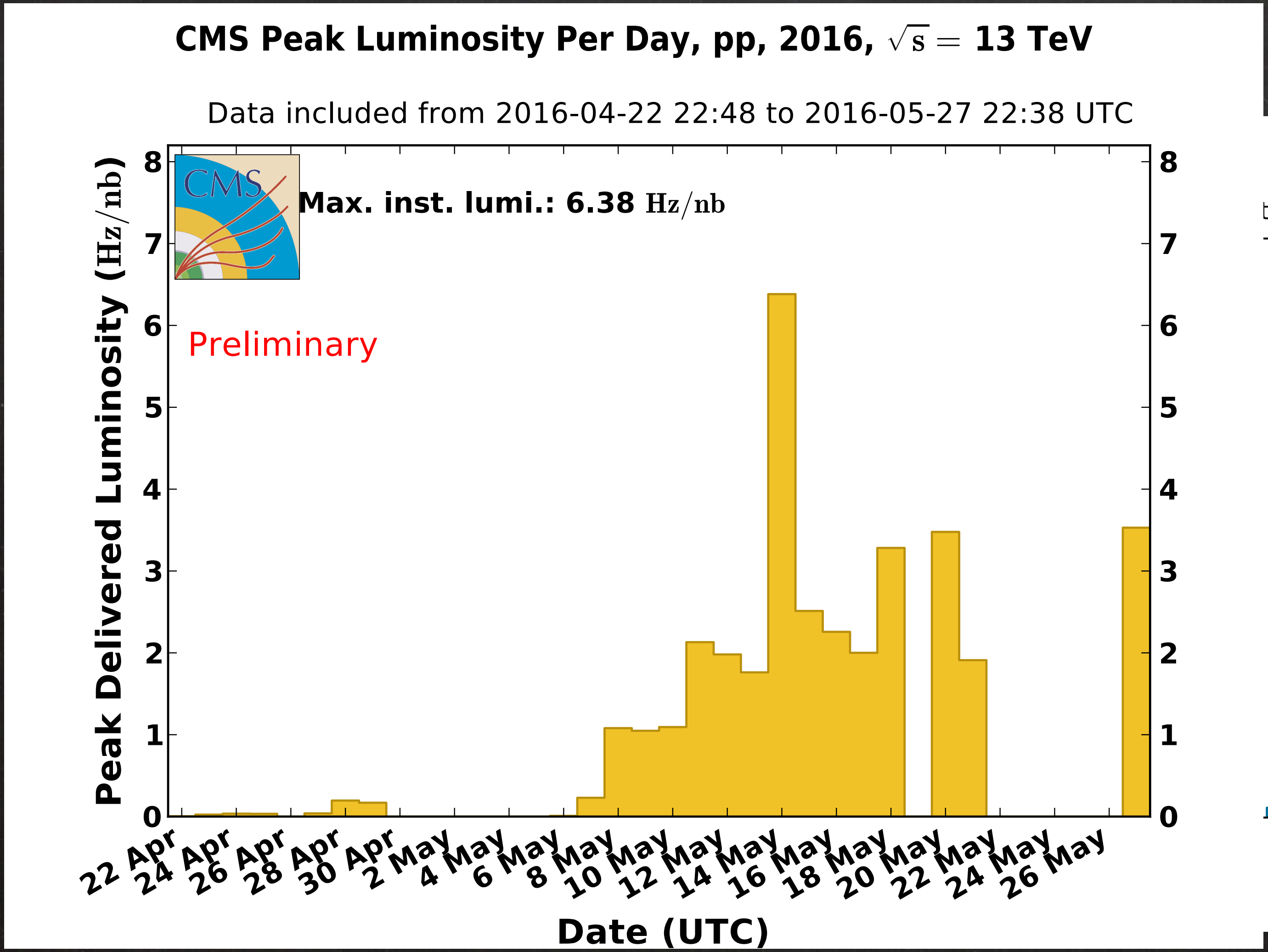

30-May-2016 04:56:41
Fill #: 4961
Energy: 6500 GeV
I(B1): 1.54e+14
I(B2): 1.53e+14
Lumi Performance over the last 24 Hrs
Updated: 04:56:42
Inst Lumi (ub.s)^-1
7000 6000 5000 4000 3000 2000 1000 0
05:00 08:00 11:00 14:00 17:00 20:00 23:00 02:00
ATLAS ALICE CMS LHCb
Luminosity integrated over the last 24 Hrs
Updated: 04:56:42
Delivered Lumi (nb)^-1
1.2E5 1E5 8E4 6E4 4E4 2E4 0E0
05:00 08:00 11:00 14:00 17:00 20:00 23:00 02:00
ATLAS ALICE CMS LHCb
STABLE BEAMS
Luminosity [(ub.s)^-1]
Fill Lumi (nb)^-1
ATLAS 4143.25 114733.1
ALICE 2.74 68.2
CMS 3856.86 106668.7
LHCb 271.18 6787.3
Instantaneous Luminosities
Updated: 04:56:41
Target
Delivered
Relative Lumi
ATLAS ALICE CMS LHCb
ALICE Target Instantaneous Lumi = 2.75 Hz/ub
LHCb Target Instantaneous Lumi = 274.04596 Hz/ub

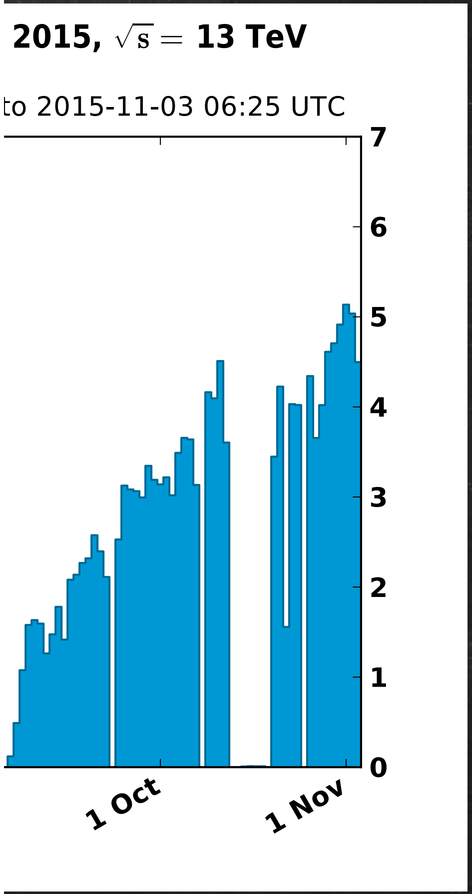
LHC Status



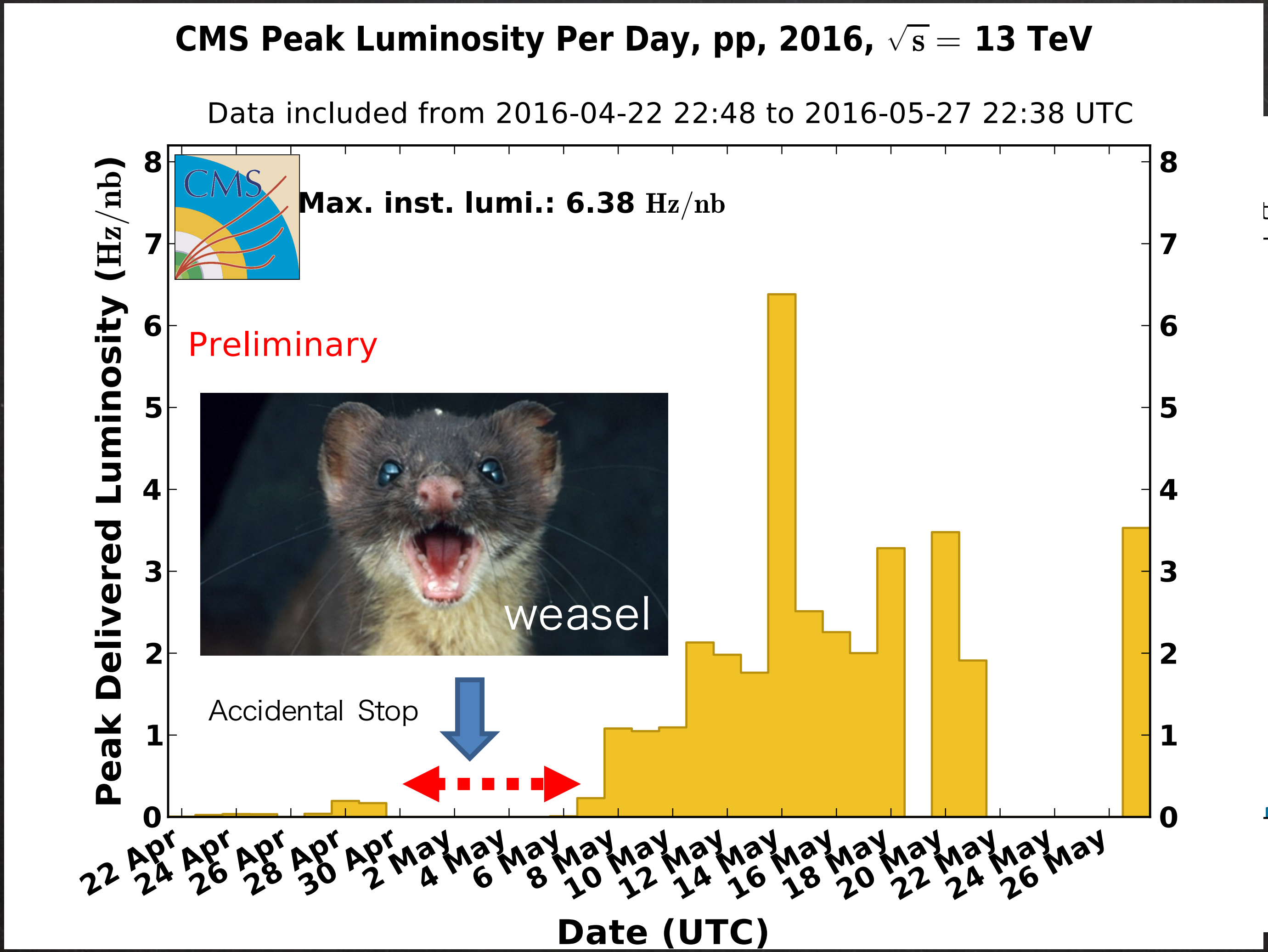
CMS Integrated Luminosity, pp, 2016, $\sqrt{s} = $ 13 TeV
Data included from 2016-04-22 22:48 to 2016-05-27 22:38 UTC
LHC Delivered: 809.38 pb^{-1}
CMS Recorded: 733.91 pb^{-1}
CMS
Preliminary
Total Integrated Luminosity (pb^{-1})
0
100
200
300
400
500
600
700
800
900
22 Apr
24 Apr
26 Apr
28 Apr
30 Apr
2 May
4 May
6 May
8 May
10 May
12 May
14 May
16 May
18 May
20 May
22 May
24 May
26 May
Date (UTC)

LHC Status

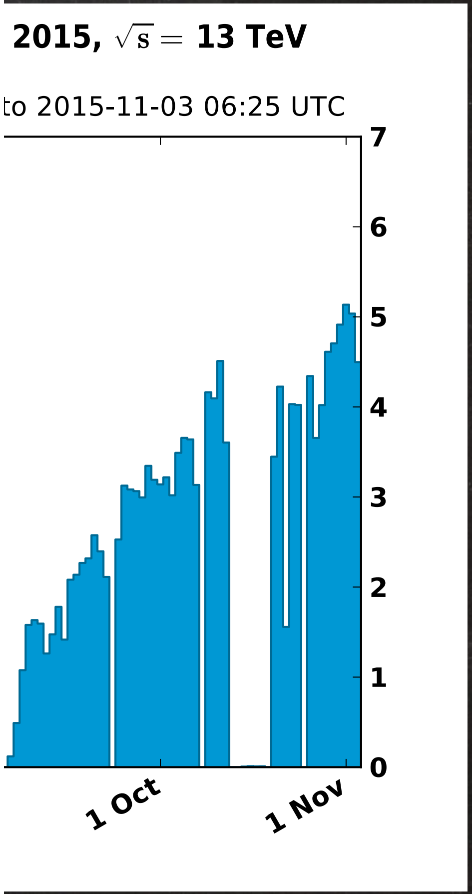

CMS Peak Luminosity Per Day, pp, 2016, $\sqrt{s} =$ 13 TeV
Data included from 2016-04-22 22:48 to 2016-05-27 22:38 UTC
Max. inst. lumi.: 6.38 Hz/nb
Preliminary
Peak Delivered Luminosity (Hz/nb)
Date (UTC)
22 Apr
24 Apr
26 Apr
28 Apr
30 Apr
2 May
4 May
6 May
8 May
10 May
12 May
14 May
16 May
18 May
20 May
22 May
24 May
26 May
0
1
2
3
4
5
6
7
8


2015, $\sqrt{s} =$ 13 TeV
to 2015-11-03 06:25 UTC
1 Oct
1 Nov
0
1
2
3
4
5
6
7

LHC Status



CMS Peak Luminosity Per Day, pp, 2016, $\sqrt{s} = $ 13 TeV
Data included from 2016-04-22 22:48 to 2016-05-27 22:38 UTC
Max. inst. lumi.: 6.38 Hz/nb
Preliminary
weasel
Accidental Stop
Peak Delivered Luminosity (Hz/nb)
Date (UTC)
22 Apr
24 Apr
26 Apr
28 Apr
30 Apr
2 May
4 May
6 May
8 May
10 May
12 May
14 May
16 May
18 May
20 May
22 May
24 May
26 May



2015, $\sqrt{s} = $ 13 TeV
to 2015-11-03 06:25 UTC
1 Oct
1 Nov