quantum Einstein gravity meets ATLAS & CMS

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based on collaborations with
J Brinckmann, P Dabruck, M Demmel, K Falls, E Gerwick,
F Hautmann, G Hiller, K Nikolakopoulos, R Old, T Plehn,
C Rahmede, J Schroeder, H Sedello & M Zenglein

Rencontres de Moriond
Electroweak Interactions & Unified Theories
19 Mar 2014

the standard model

University of Sussex

local QFT for fundamental interactions

strong nuclear force
weak force
electromagnetic force

degrees of freedom

spin 0 (the Higgs has finally arrived)
spin 1/2 (quite a few)
spin 1

perturbatively renormalisable & predictive

how does gravity fit in ?

dynamics of space-time

spin 2

dimensionful Newton coupling

perturbatively non-renormalisable

how does gravity fit in ?

dynamics of space-time

spin 2

dimensionful Newton coupling
perturbatively non-renormalisable

conjecture

asymptotic safety

gravity non-perturbatively renormalisable
and predictive

asymptotic freedom

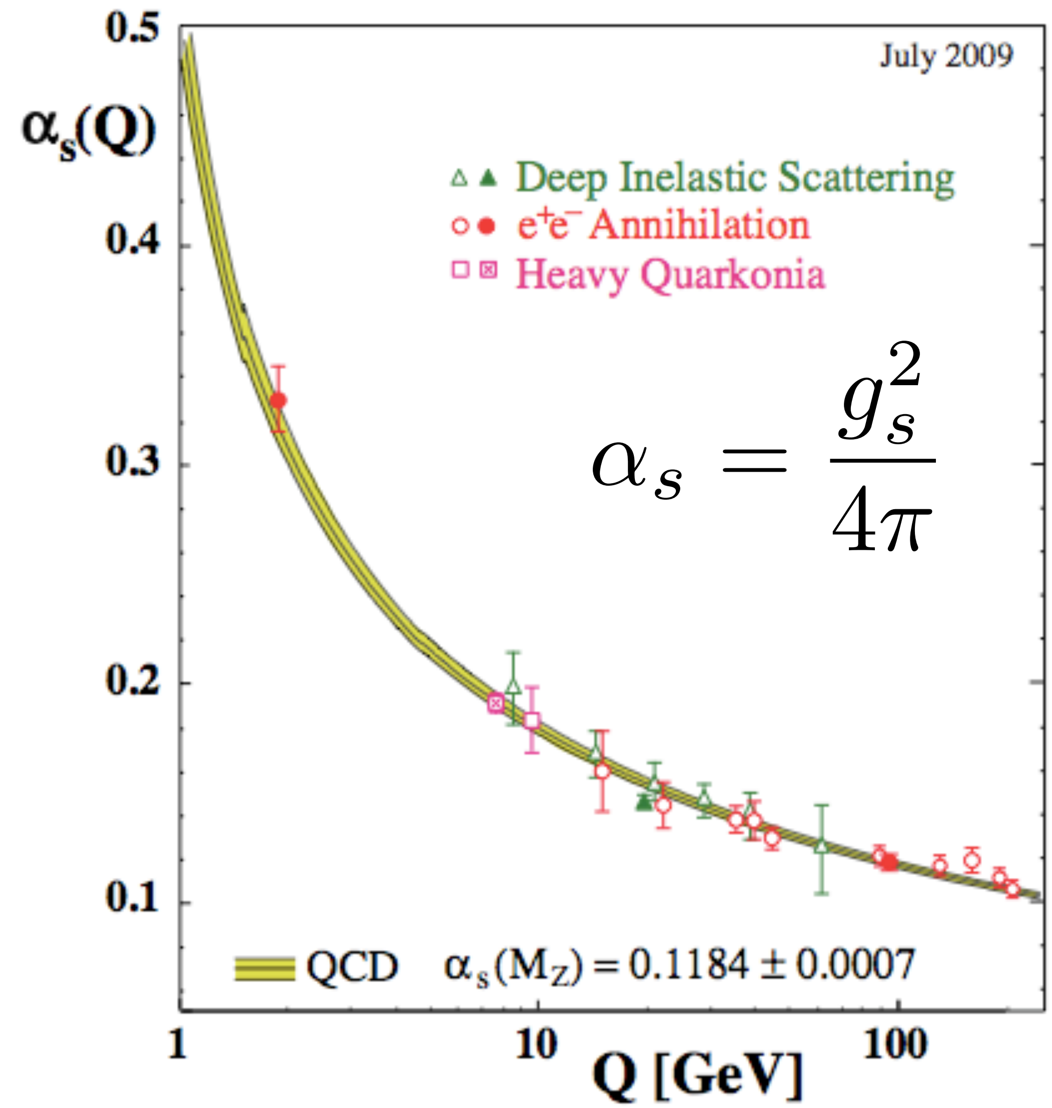
running couplings

quantum fluctuations modify interactions

couplings depend on eg. energy or distance

asymptotic freedom of the strong force

(taken from PDG)



asymptotic freedom

running couplings

quantum fluctuations modify interactions

couplings depend on eg. energy or distance

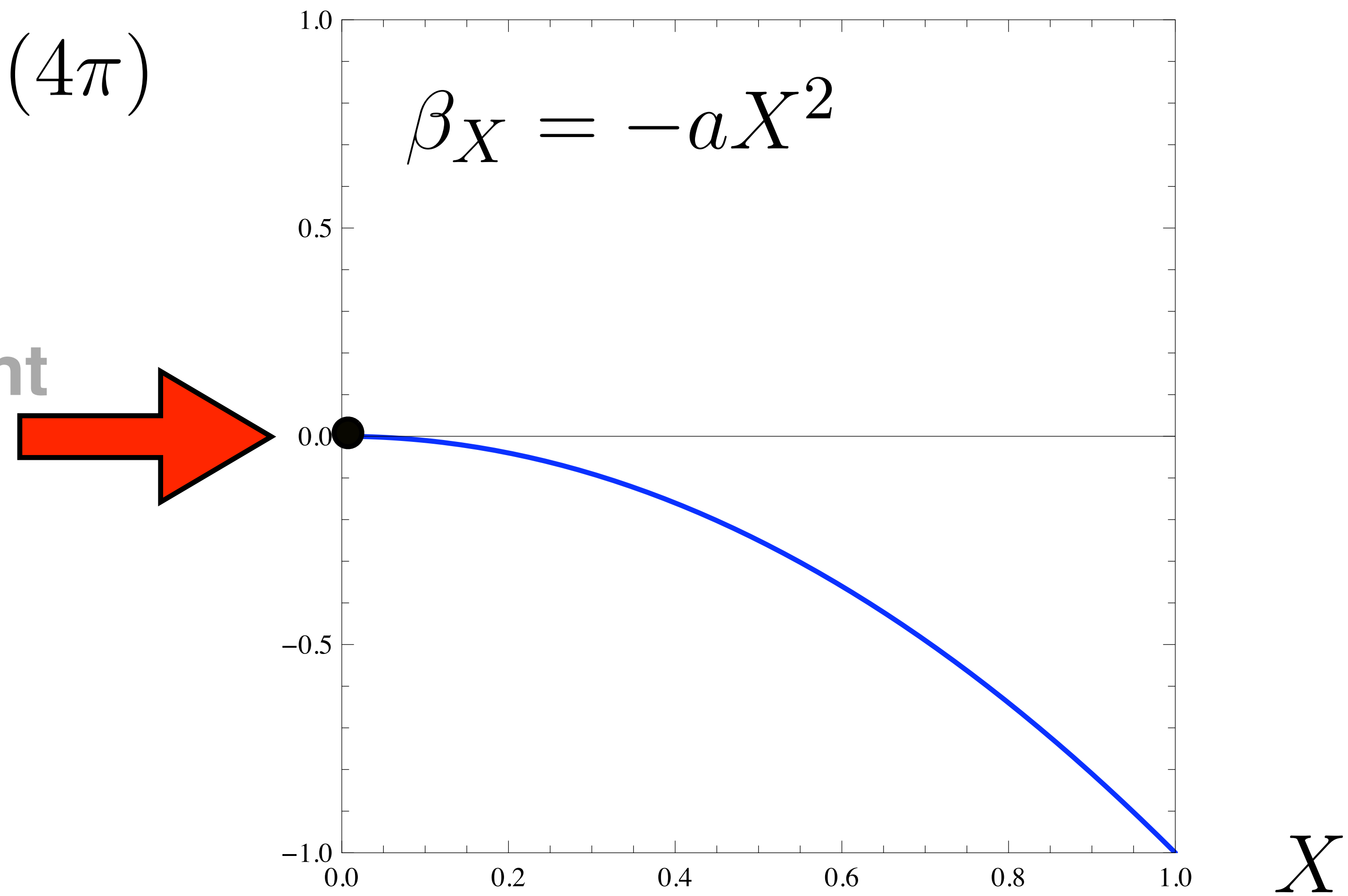
asymptotic freedom of the strong force

coupling $X = g_s^2/(4\pi)$

$$\beta_X \equiv \frac{dX}{d\ln\mu}$$

trivial UV fixed point

$$X_* = 0$$



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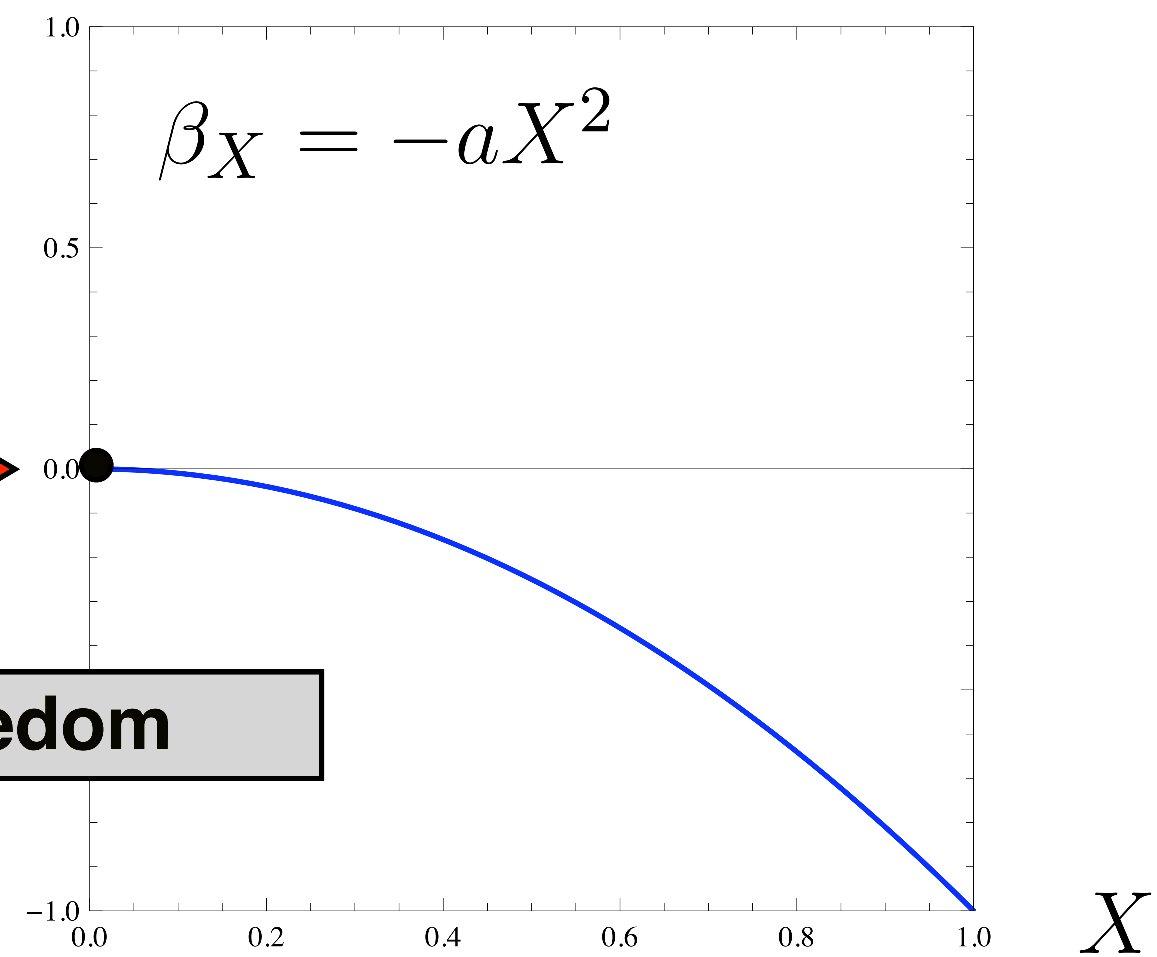

asymptotic freedom

asymptotic safety

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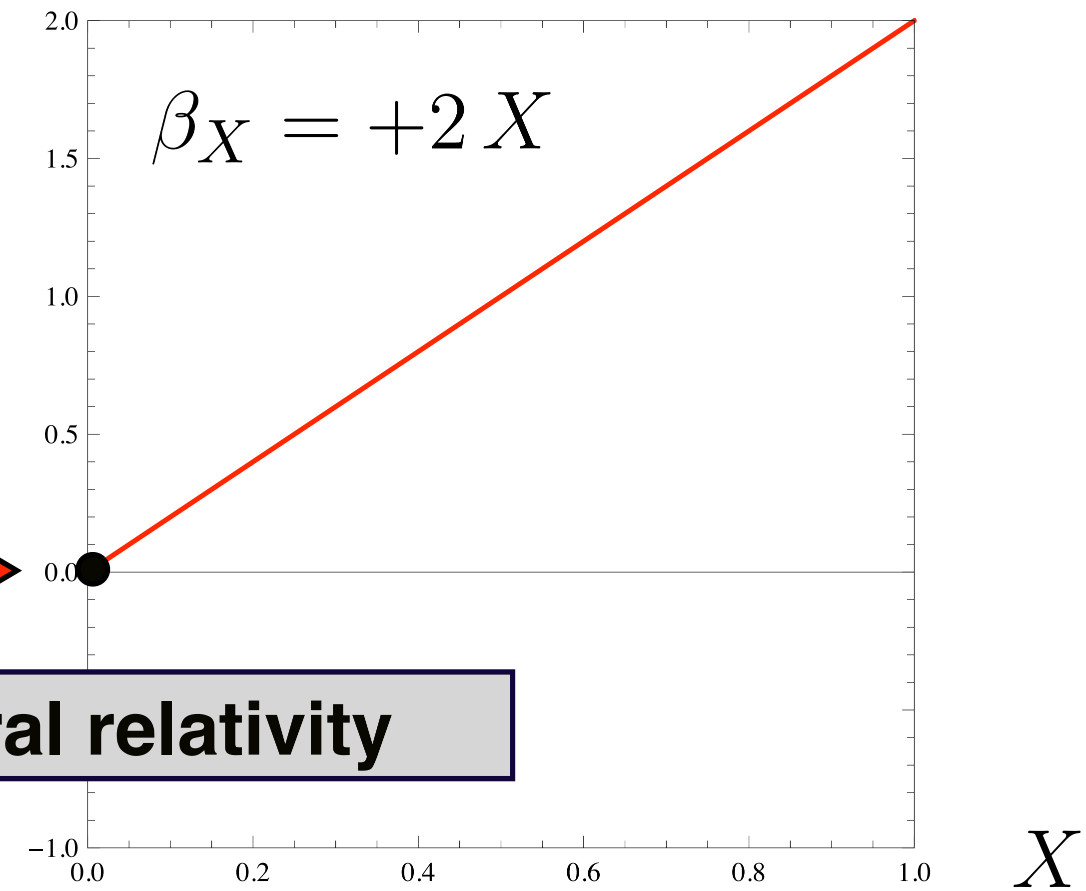
gravitation



coupling $X = G_N\,\mu^2$

$$\beta_X \equiv \frac{dX}{d\ln\mu}$$

trivial IR fixed point

classical general relativity

quantum Einstein gravity

running couplings

quantum fluctuations modify interactions

couplings depend on eg. energy or distance

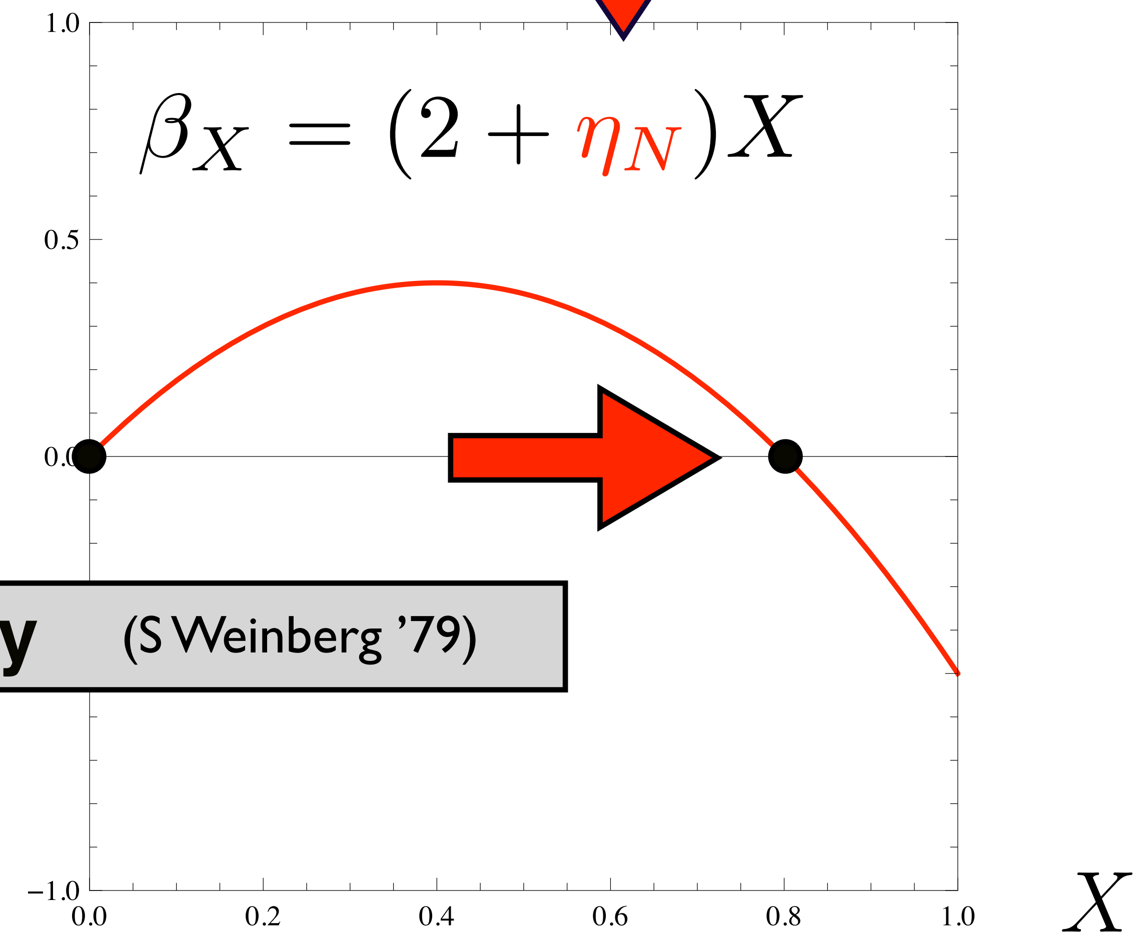
gravitation

coupling $X = G(\mu)\,\mu^2$

$$\beta_X \equiv \frac{dX}{d\ln\mu}$$

non-trivial UV fixed point

$$\beta_X = (2 + \eta_N)X$$



asymptotic safety (S Weinberg '79)

evidence for asymptotic safety

overviews: DL **0810.3675** and **1102.4624**

gravitation

Einstein-Hilbert (Souma '99, Reuter, Lauscher '01, DL '03)

higher dimensions, dimensional reduction (DL '03, Fischer, DL '05)

f(R), polynomials in R (Lauscher, Reuter, '02, Codello, Percacci, Rahmede '08, Machado, Saueressig '09 Benedetti,Caravelli'12, Dietz, Morris'12, Falls, DL, Nikolakopoulos, Rahmede '13)

local potential approximation (Benedetti,Caravelli'12, Dietz, Morris, '12, Demmel, Saueressig, Zanusso '12, Falls, DL, Nikolakopoulos, Rahmede '13, Benedetti '13, Benedetti, Guarnieri '13)

higher-derivative gravity (Codello, Percacci '05) (Benedetti, Saueressig, Machado '09, Niedermaier '09) (DL, Rahmede, in prep.)

conformally reduced gravity (Reuter, Weyer '09, Machado, Percacci '10)

Holst action + Immirzi parameter (Daum, Reuter '10, Benedetti, Speciale '11)

signature effects (Manrique, Rechenberger, Saueressig '11)

gravitation + matter

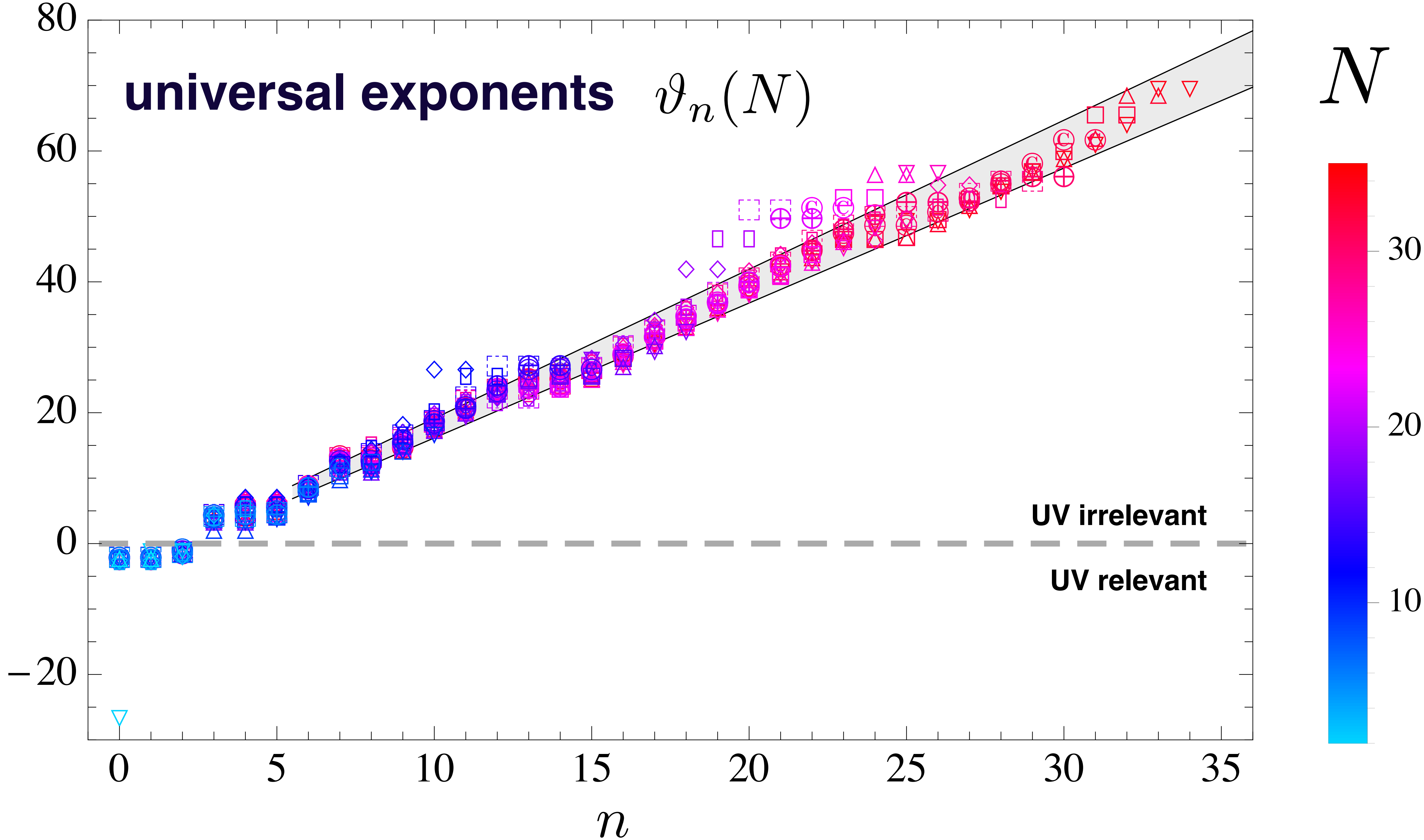
matter (Percacci '05, Perini, Percacci '05, Narain, Percacci '09, Narain, Rahmede '09, Codello '11)

Yang-Mills gravity

1-loop: (Robinson, Wilczek '05, Pietrokowski, '06, Toms '07, Ebett, Plefka, Rodigast '08)

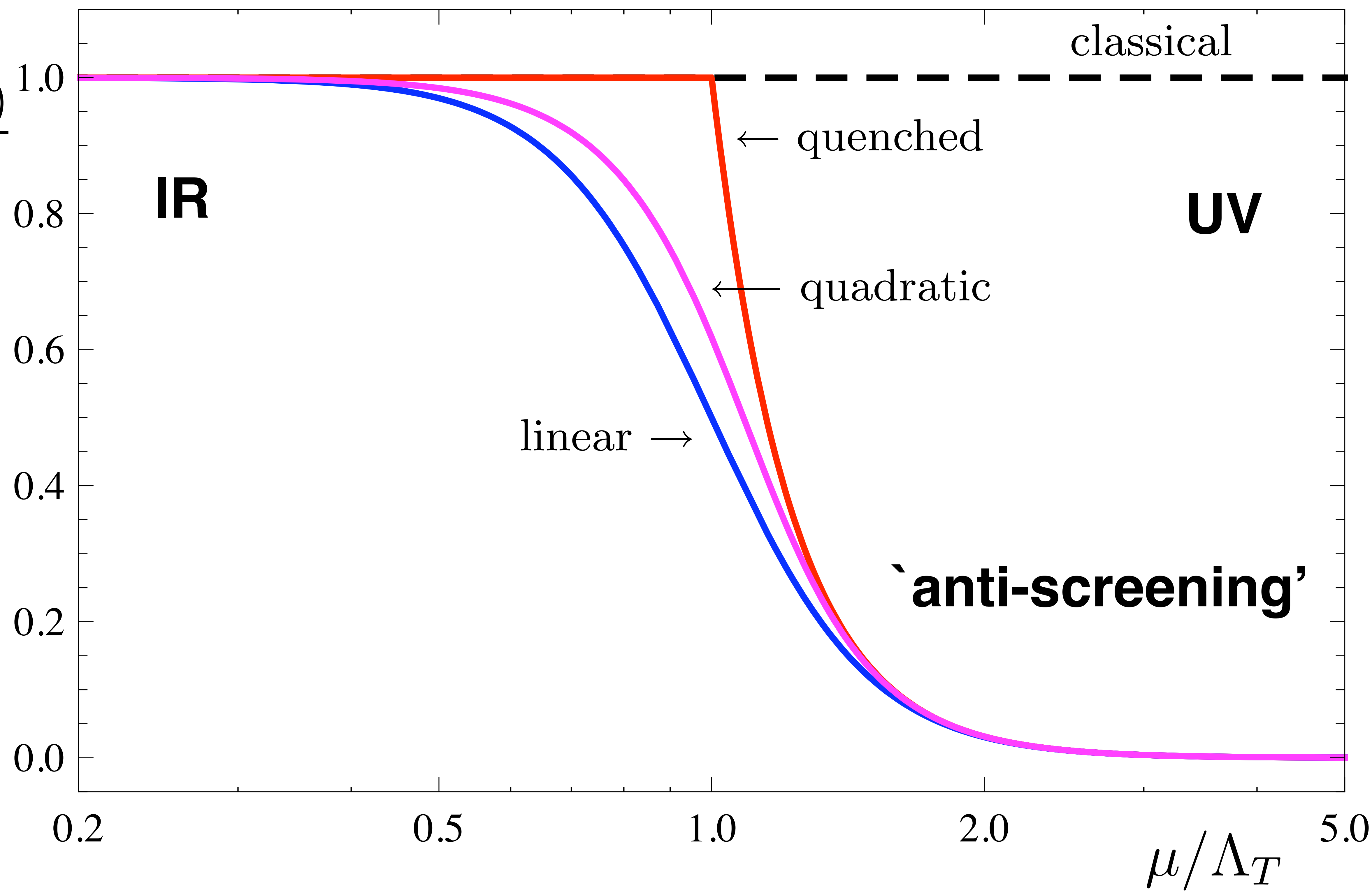
beyond: (Manrique, Reuter, Saueressig '09, Folkerts, DL, Pawlowski, 11, Harst, Reuter '11)

$$S = \int d^4x \sqrt{\det g_{\mu\nu}}\, \frac{1}{16\pi G}\, [-R + 2\Lambda] \;+ \sum_{n=2}^{N-1} \lambda_n R^n$$



(Falls, DL, Nikolakopoulos, Rahmede, 1301.4191)

cross-over scale Λ_T



(DL '03)

low-scale quantum gravity

- **theory**
  fundamental parameters $M_D \quad \Lambda_T \quad g_*$

  predictions for LHC experiments

- **experiment**
  data to fix or constrain theory parameters

unitarity

Higgs-Higgs-type scattering $\Phi\Phi \longrightarrow \Phi\Phi$

effective theory

unitarity provides bounds on M_D & s/M_D^2 (He '99)

asymptotic safety

quantum gravity corrections

bounds on M_D relaxed

$$a_0(s) = \frac{1}{16\pi\, s}\int_{-s}^{0} dt\, \mathcal{M}(s,t)$$

$$|a_0(s)| \leq 1$$

(Brinckmann, Hiller, DL, Schroeder, to appear)

unitarity bounds

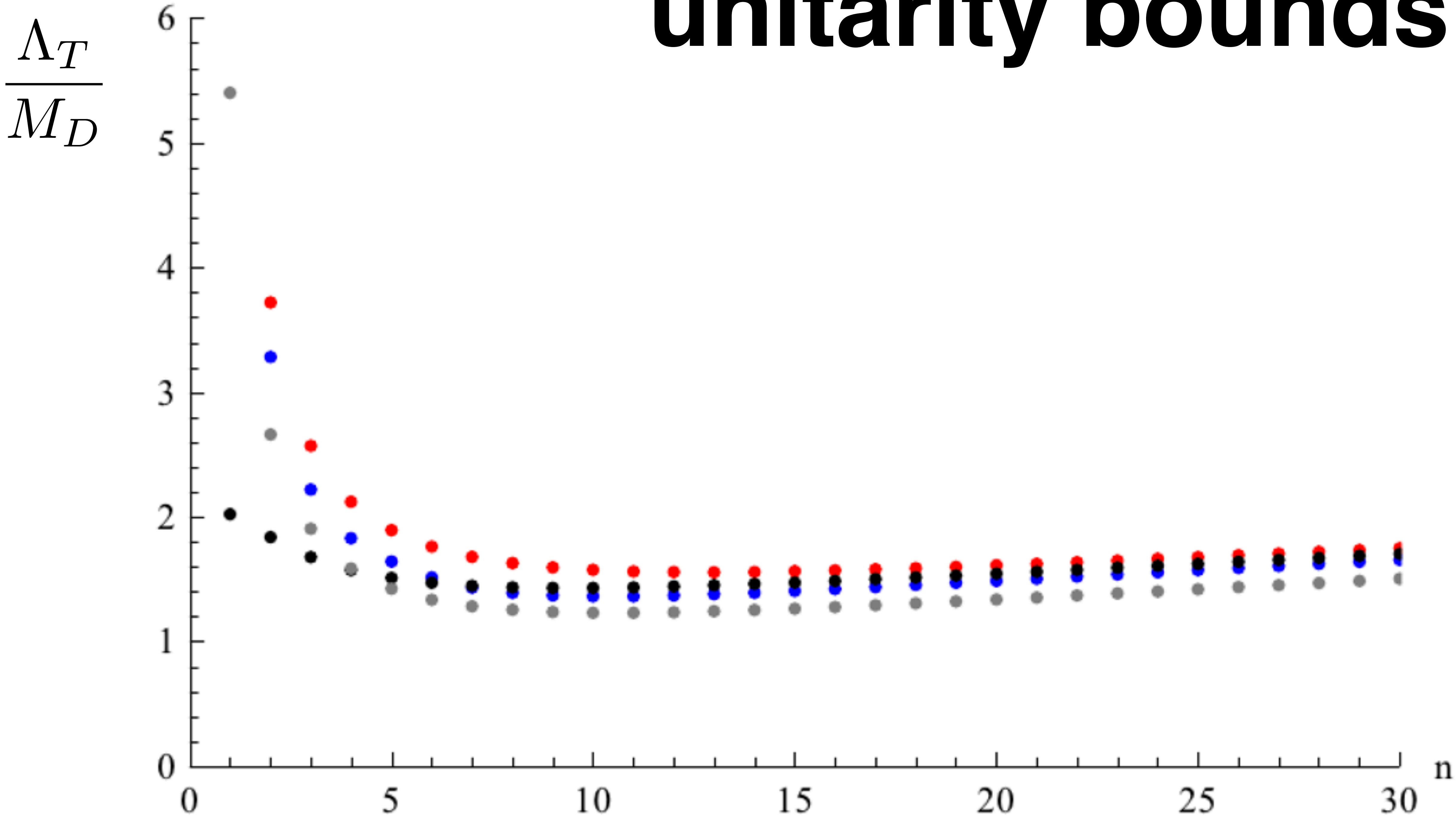
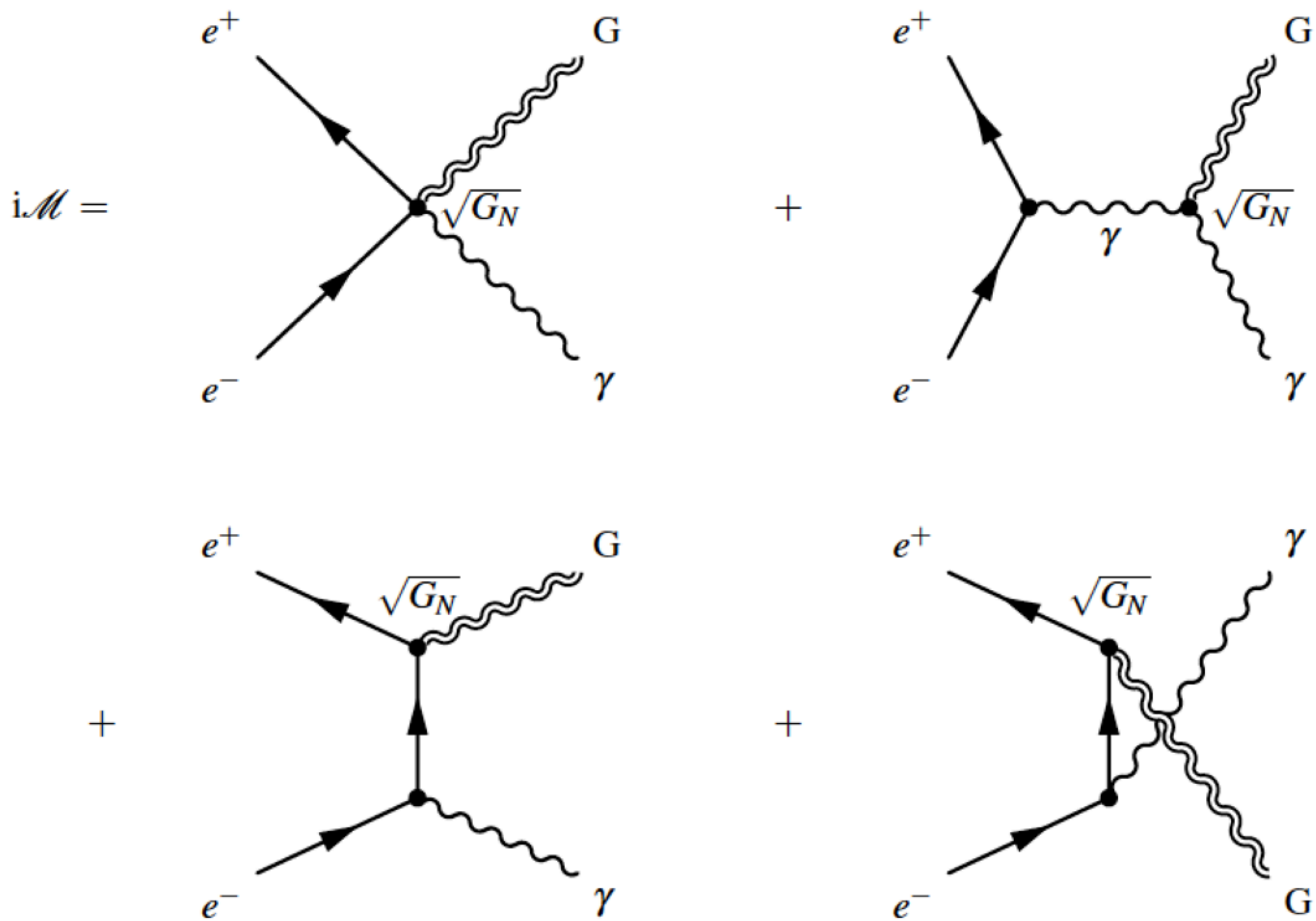


FIG. 1: Unitarity bounds on the crossover scale Λ_T versus n. The points in red, blue and black correspond to results from analytic continuation Eq. (18), a direct $s > 0$ calculation Eq. (19) and the $t + u$ channel constraint Eq. (24), respectively. The strong coupling limit from NDA Eq. (25) is shown in grey.

(Brinckmann, Hiller, DL, Schroeder, to appear)

1) missing ET: real gravitons



+ quantum gravity corrections of vertices

real gravitons+jet

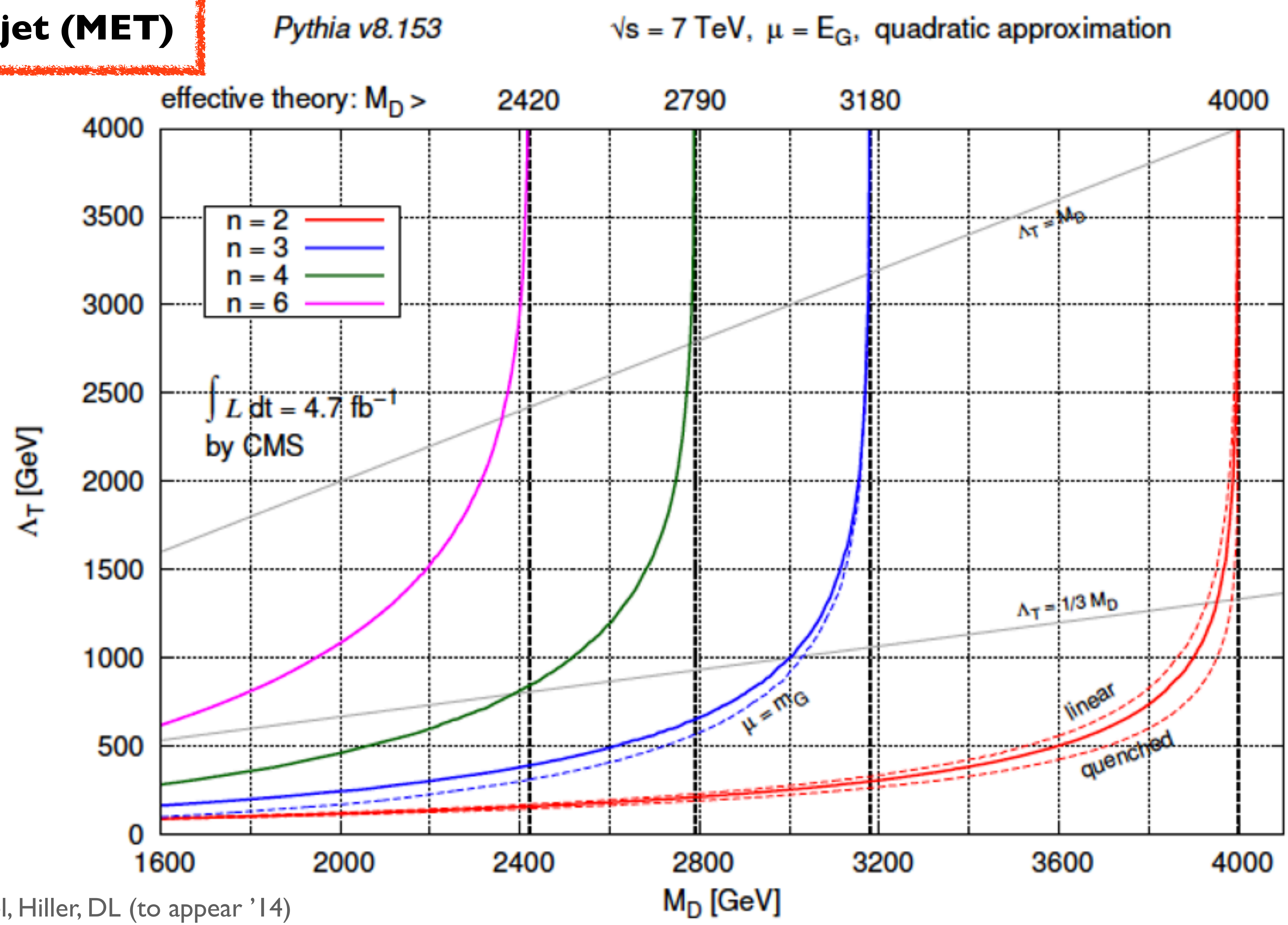
bounds from effective theory

			n	2	3	4	5	6	
LEP	$0.65\,\mathrm{fb}^{-1}$	$e^+e^- \to \gamma + \not{E}$		1.60	1.20	0.94	0.77	0.66	[27]
CDF	$1.1\,\mathrm{fb}^{-1}$	$p\bar{p} \to \mathrm{jet} + \not{E}$		1.31	1.08	0.98	0.91	0.88	[28]
CMS	$36\,\mathrm{pb}^{-1}$	$pp \to \mathrm{jet} + \not{E}$		2.29	1.92	1.74	1.65	1.59	[29]
ATLAS	$33\,\mathrm{pb}^{-1}$	$pp \to \mathrm{jet} + \not{E}$		2.30	2.00	1.80	n/a	n/a	[30]
ATLAS	$1.0\,\mathrm{fb}^{-1}$	$pp \to \mathrm{jet} + \not{E}$		3.16	2.56	2.27	2.10	1.99	[31]
CMS	$1.1\,\mathrm{fb}^{-1}$	$pp \to \mathrm{jet} + \not{E}$		3.67	2.96	2.66	2.41	2.25	[32]
CMS	$4.7\,\mathrm{fb}^{-1}$	$pp \to \mathrm{jet} + \not{E}$		4.00	3.18	2.78	2.52	2.37	[33]

Table 4.1.: The 95% CL lower limits on M_D in effective theory for $n = 2, \ldots, 6$ extra dimensions and different datasets collected by LEP, CDF, ATLAS and CMS. Values are given in TeV.

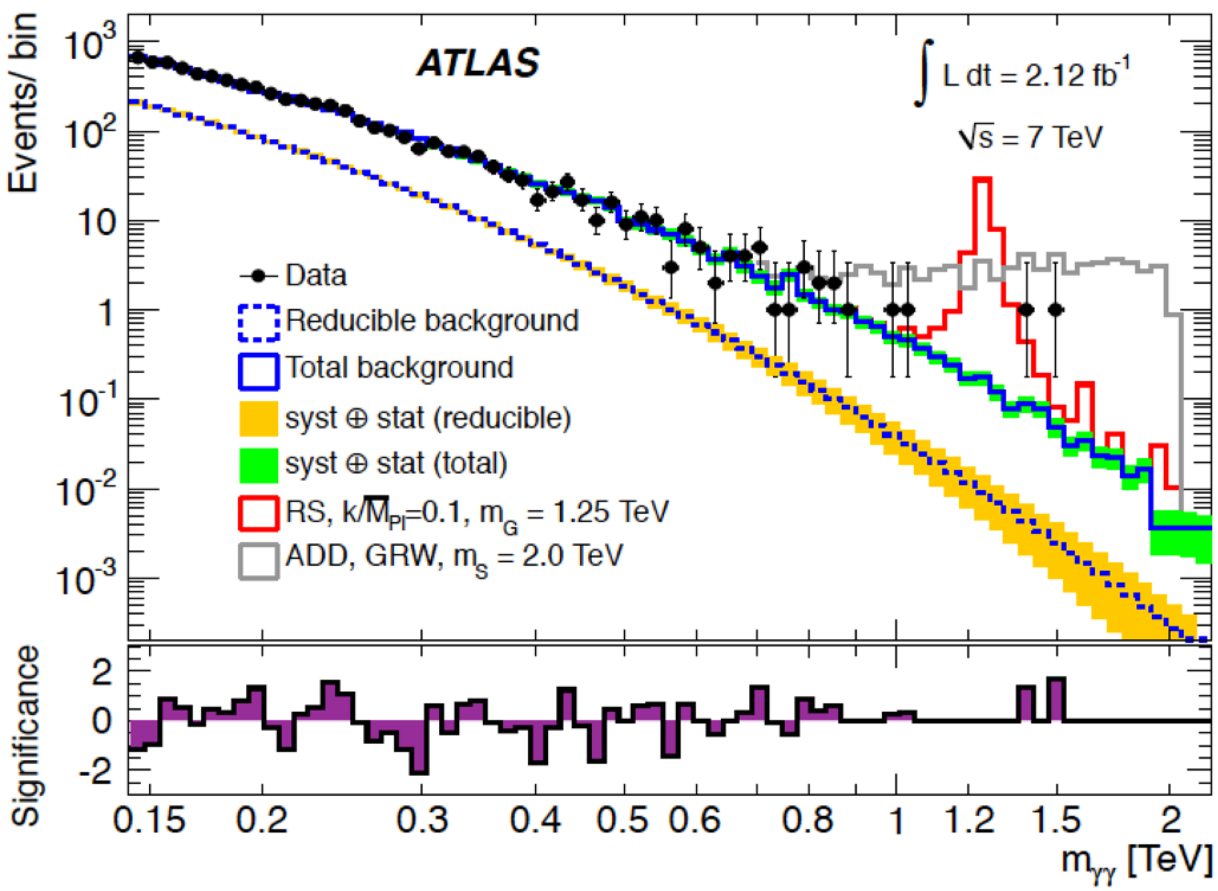
interpreting LHC data

graviton+jet (MET)

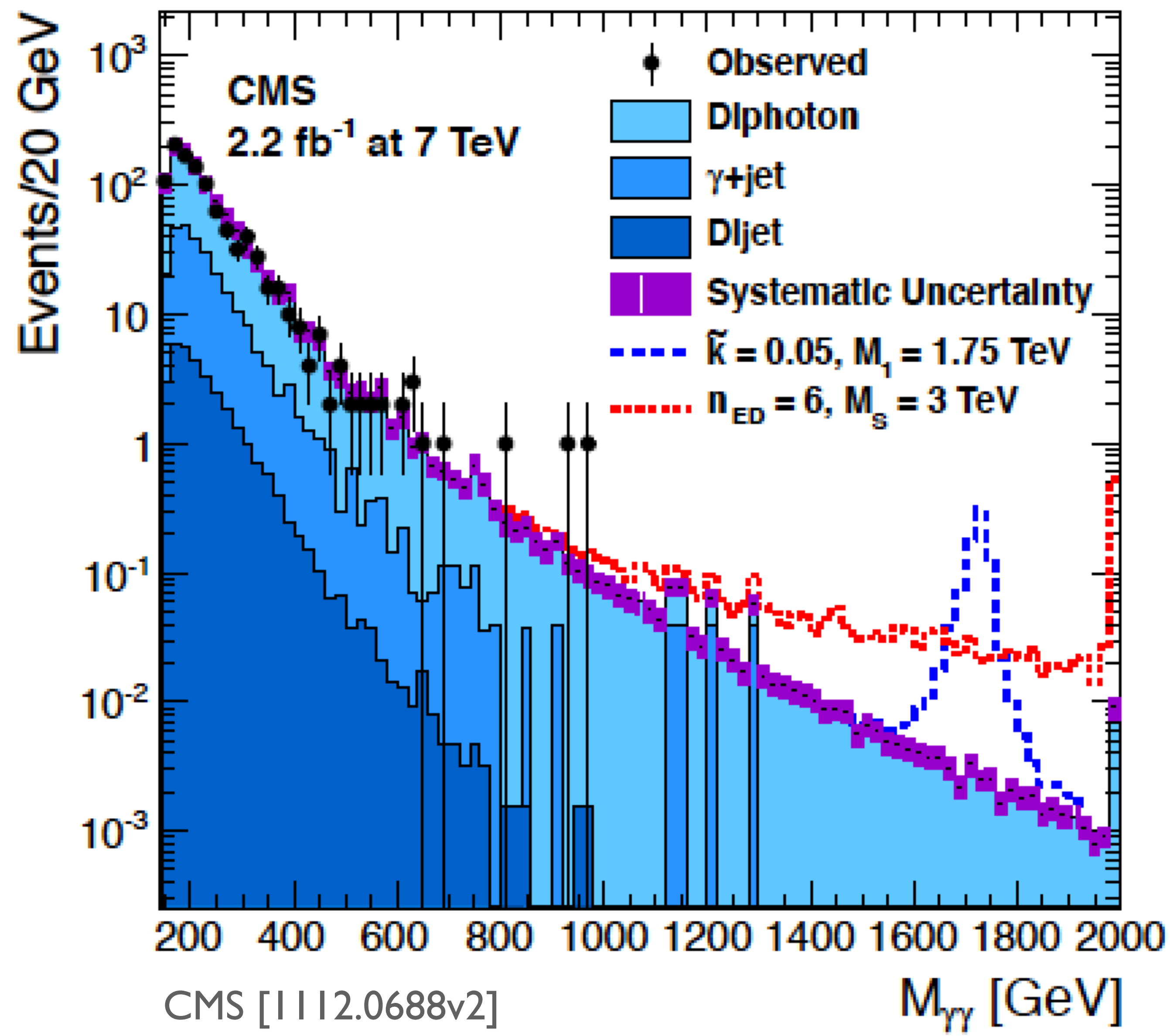


Dabruck, Demmel, Hiller, DL (to appear '14)

2) virtual gravitons + diphotons



ATLAS [1112.2194v2]



CMS [1112.0688v2]

No signifcant excess → 95% confidence level lower limits

k	$\Lambda_{\text{eff. Th.}}$
1	3.05 TeV
1.7	3.29 TeV

ATLAS (Oct 2012)

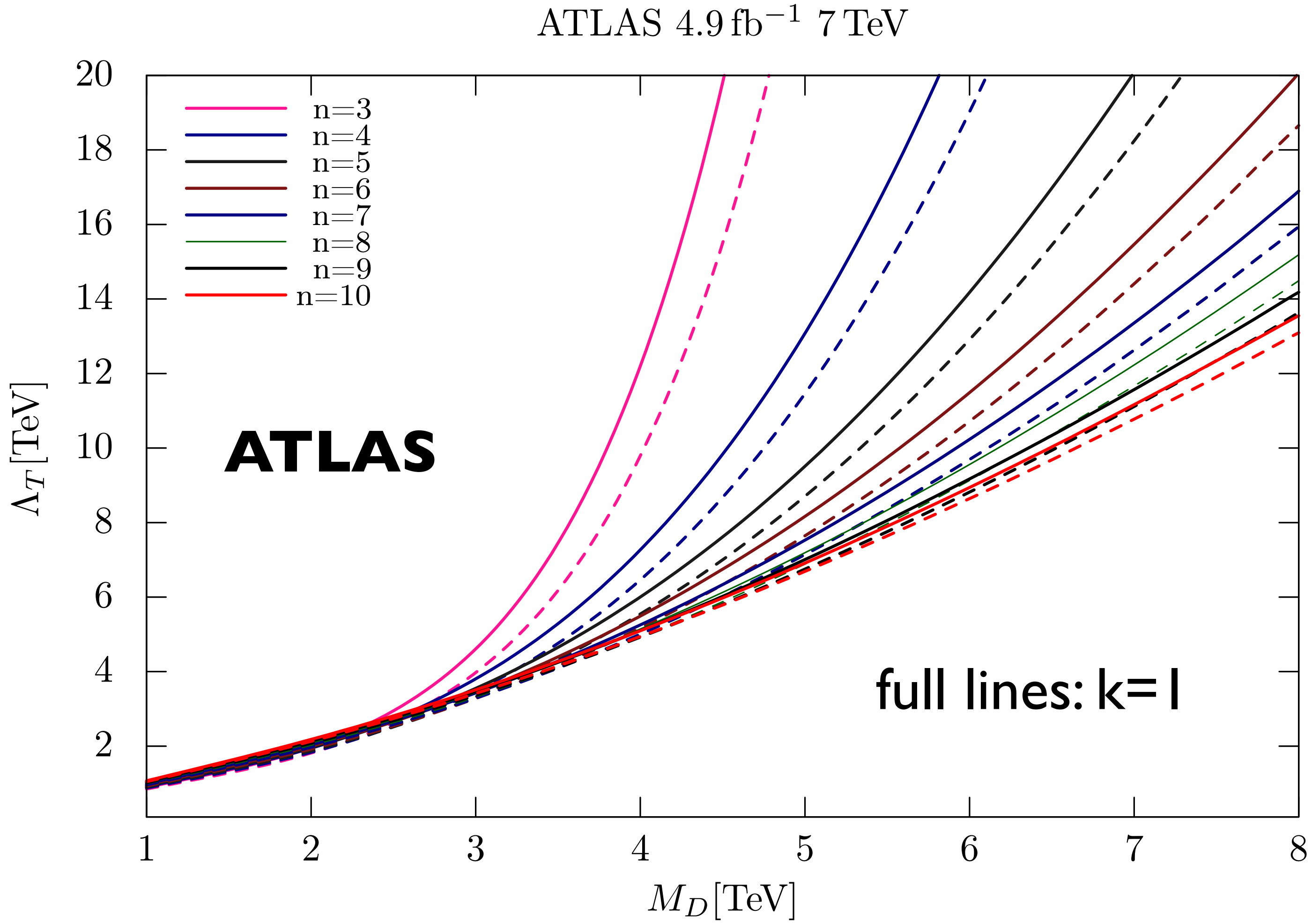
k	$\Lambda_{\text{eff. Th.}}$
1	2.94 TeV
1.6	3.18 TeV

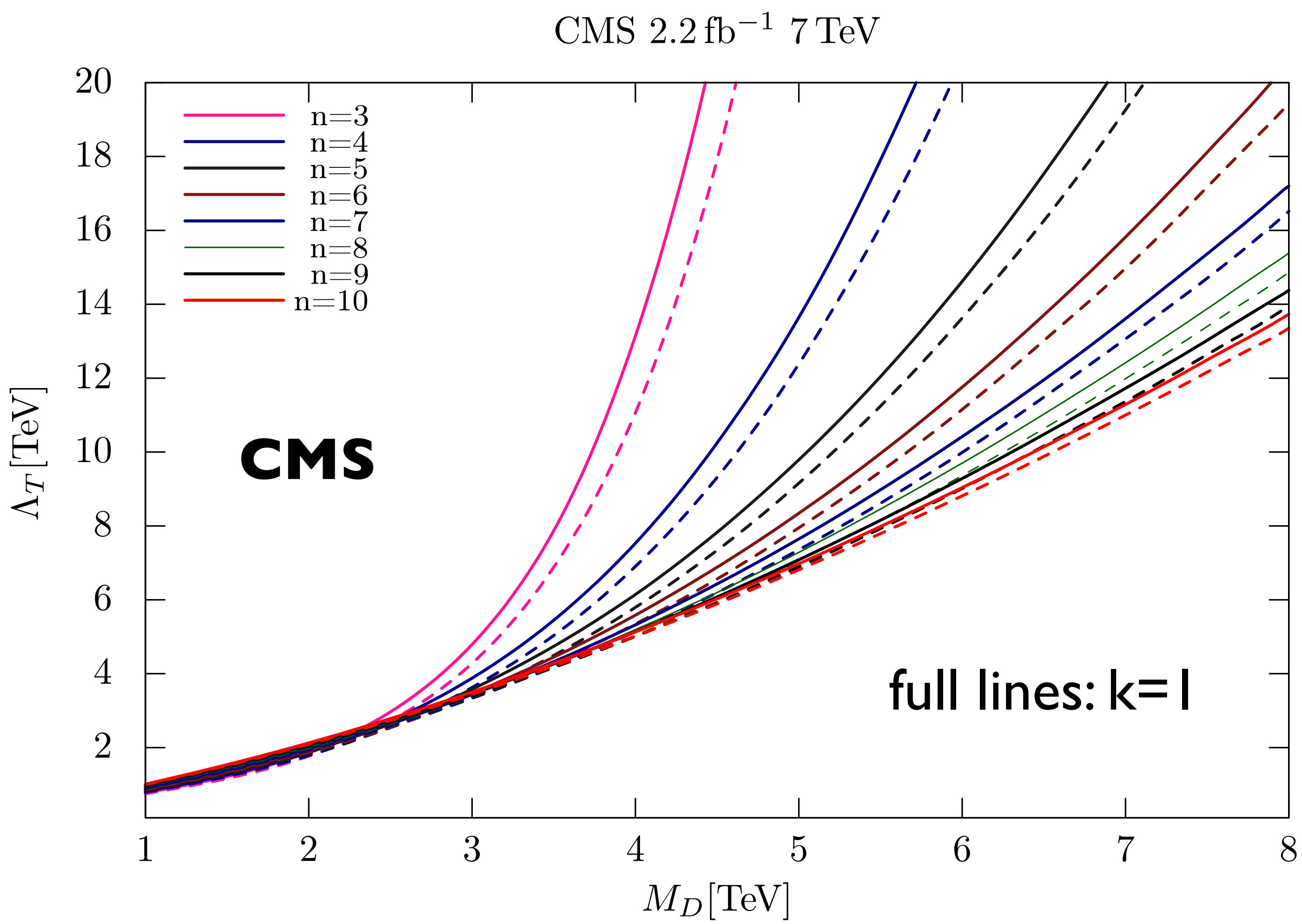
CMS (Dec 2011)

interpreting LHC data

virtual gravitons+ diphotons

implementation in Pythia8
weak PDF dependence
weak RG scheme dependence





(Hiller, DL, Zenglein)

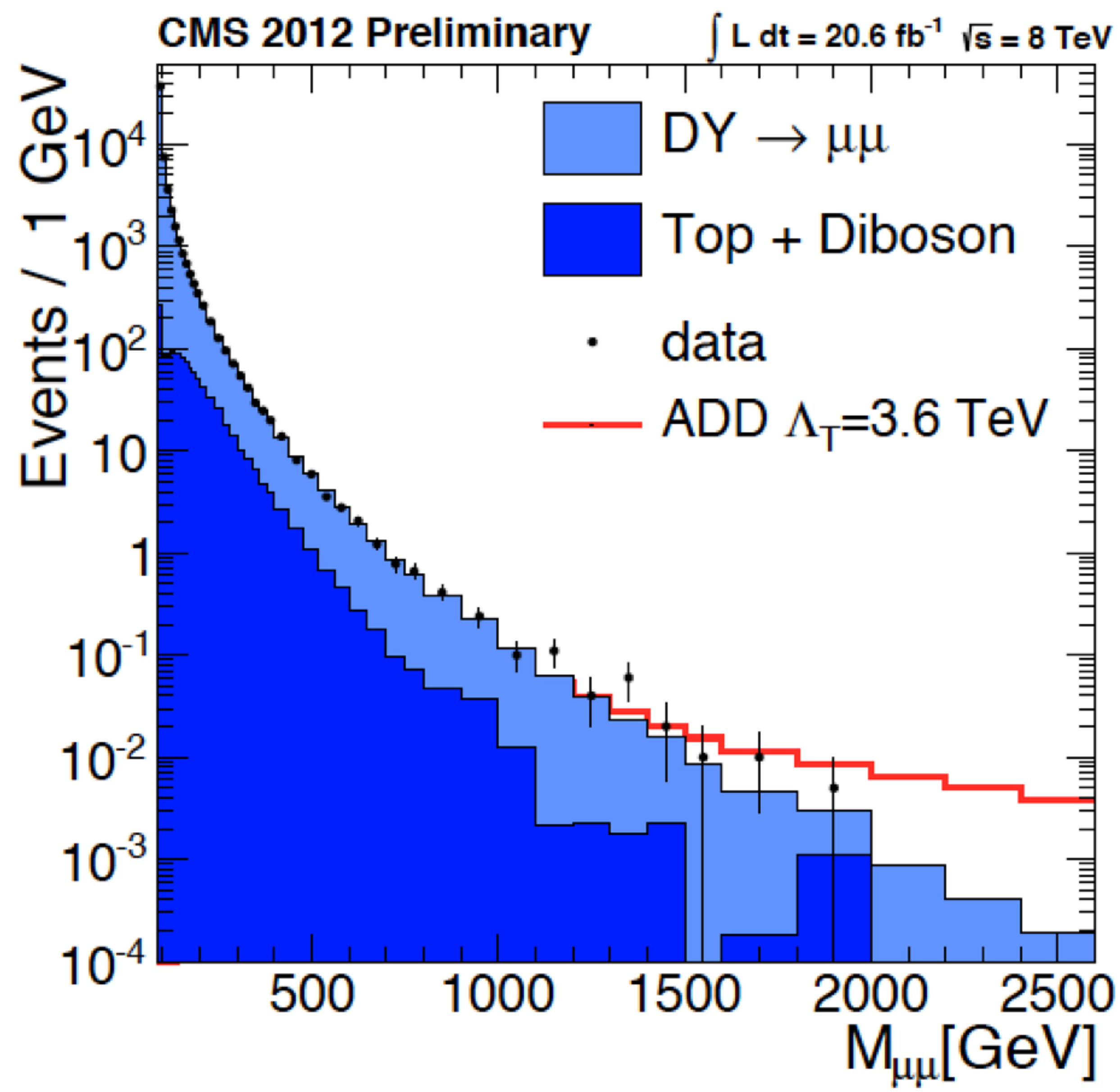
3) virtual gravitons + dileptons

$$\mathcal{S}_{\text{eff}} = -\frac{4\pi}{\Lambda_{\text{eff}}^4}$$

combined 95% CL

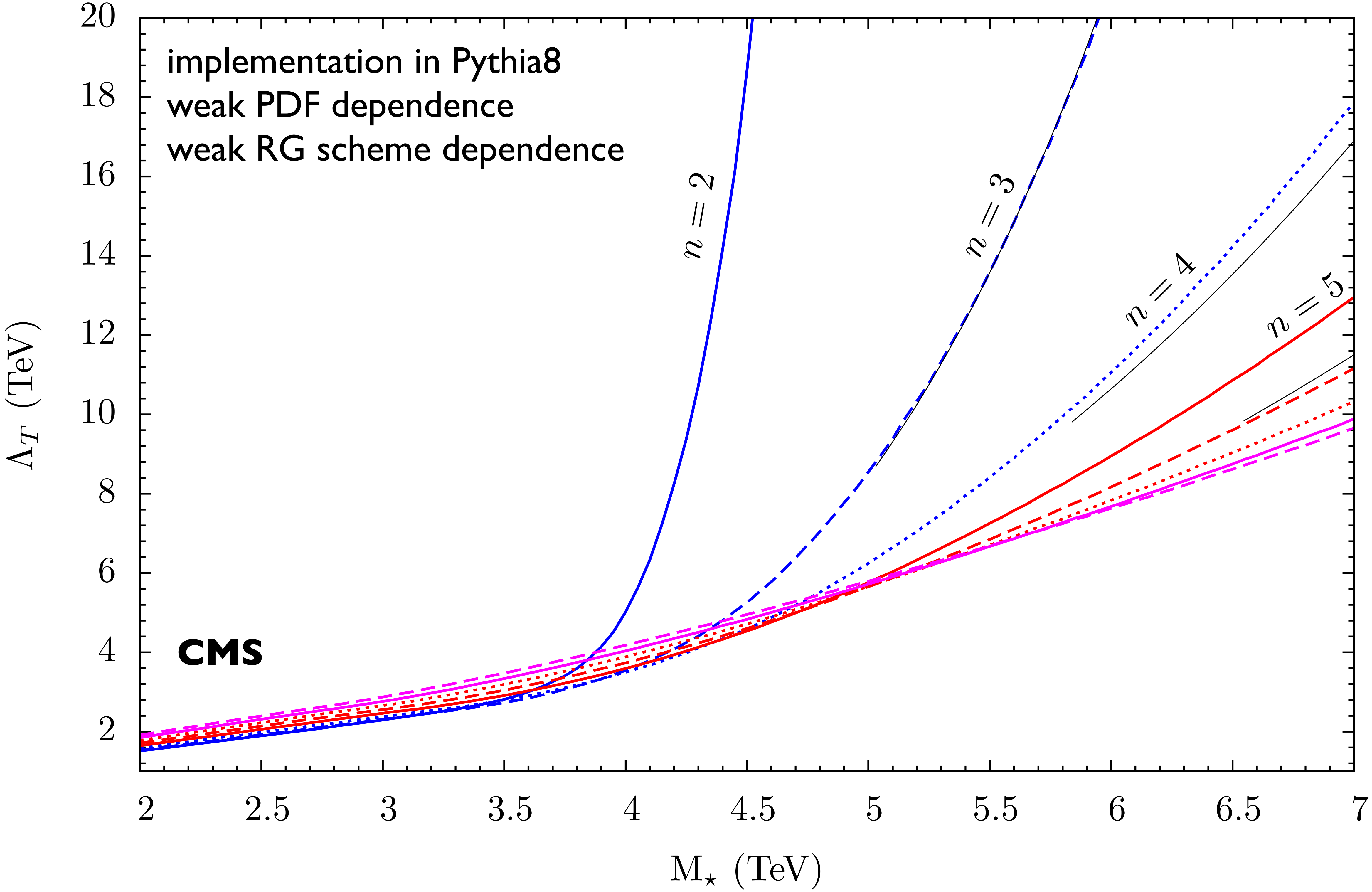
$$\Lambda_{\text{eff}} > 4.15 \text{ TeV}$$

based on 20.6 fb^{-1}



CMS [EXO-12-027]

3) virtual gravitons + dileptons



(Hiller, DL, Sedello '14)

conclusions

- asymptotic safety offers QFT-based description of gravity even at high energies

    - framework for SM & BSM particle physics
      predictive at the LHC and beyond
      no UV cutoff

        - LHC sensitive to theory parameters
          DY, MET+jet, photons, BHs
          re-interpretation of LHC bounds