alpha_s beyond the Standard Model

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CP³ Origins
Cosmology & Particle Physics

Beyond the asymptotic freedom paradigm

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The Standard Model ado

The Standard Model ado

Fields:

Gauge fields + fermions + scalars

The Standard Model ado

Fields:

Gauge fields + fermions + scalars

Interactions:

Gauge: SU(3) x SU(2) x U(1) at EW scale

The Standard Model ado

Fields:

Gauge fields + fermions + scalars

Interactions:

Gauge: SU(3) x SU(2) x U(1) at EW scale

Yukawa: Fermion masses/Flavour

Culprit: Higgs

Scalar self-interaction

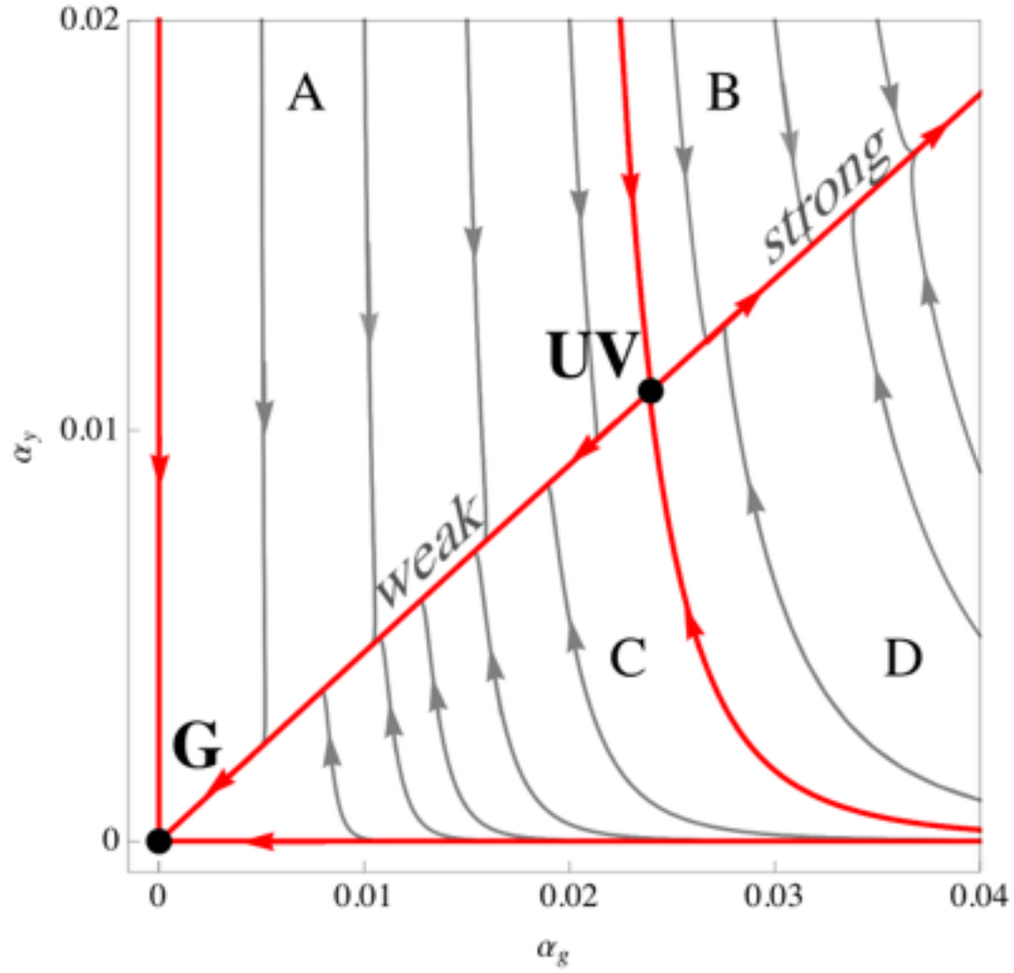
Fundamental theory

Fundamental theory

Wilson: A fundamental theory has an UV fixed point

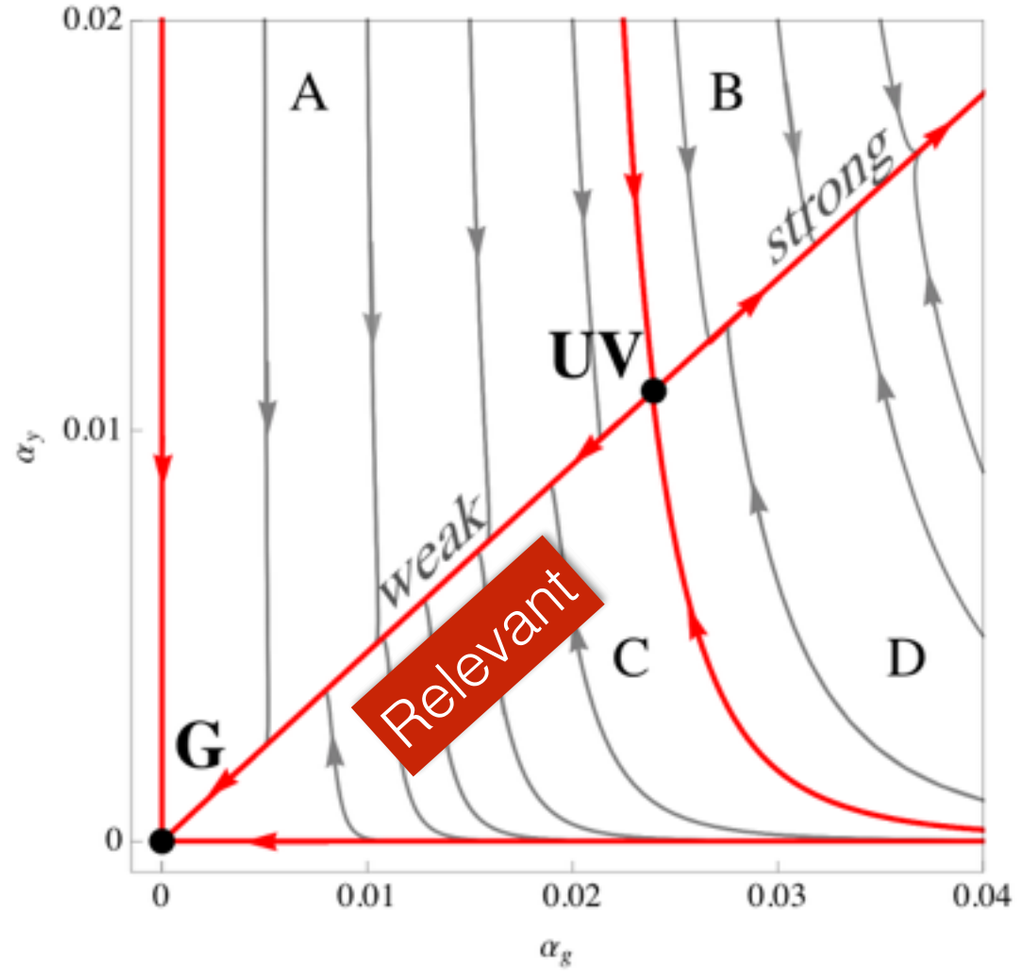
Fundamental theory

Wilson: A fundamental theory has an UV fixed point



Fundamental theory

Wilson: A fundamental theory has an UV fixed point



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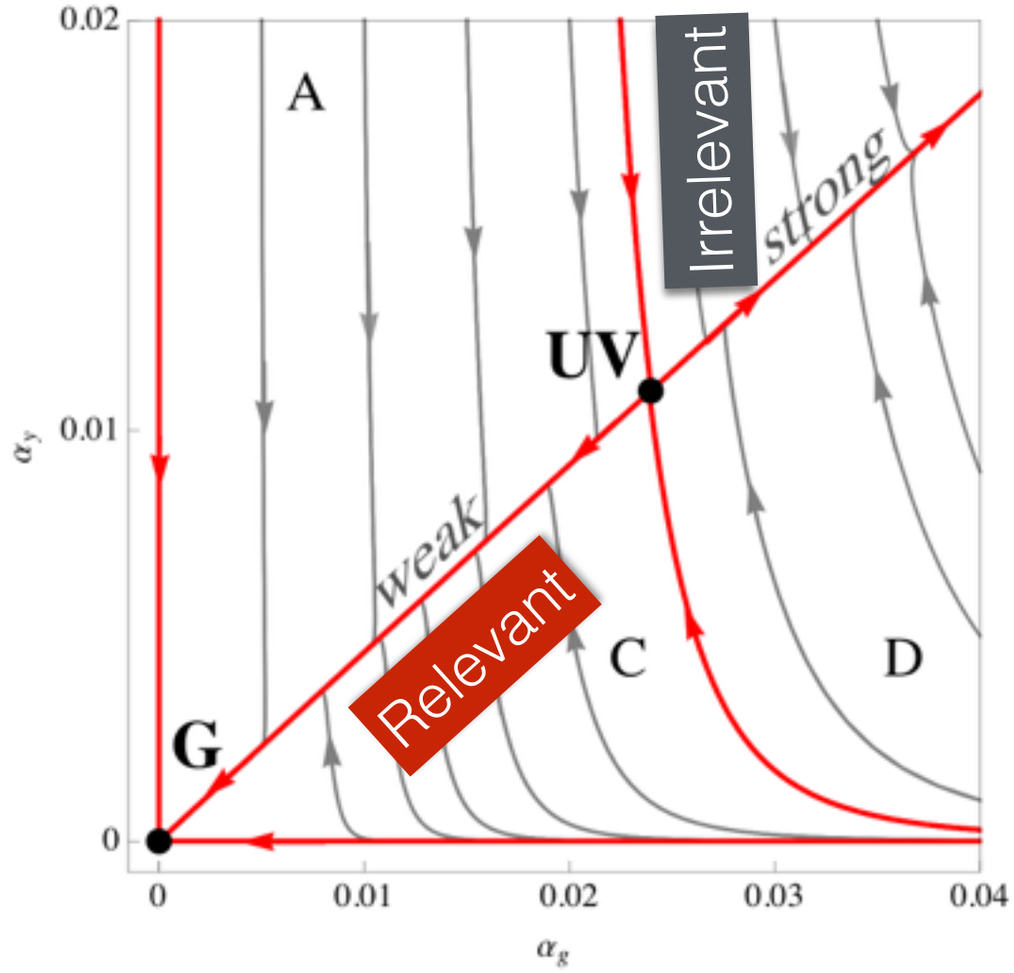
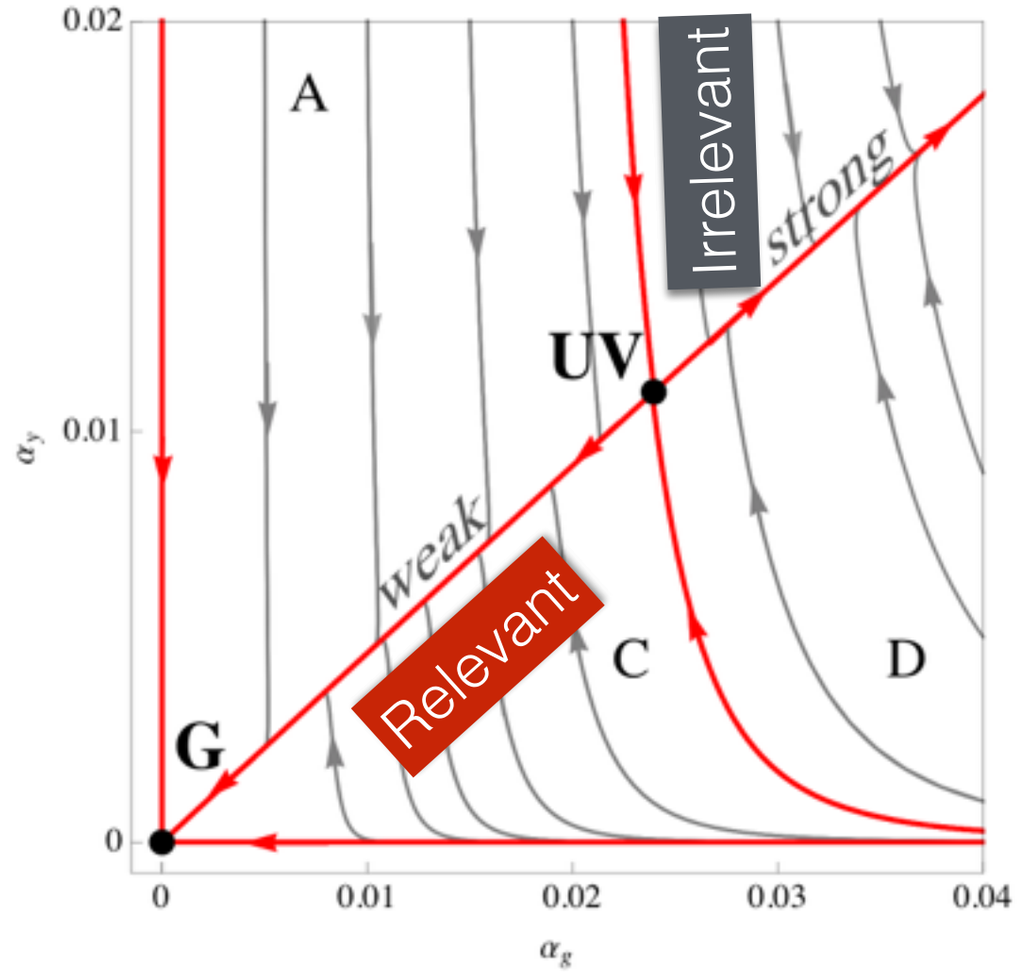


Fundamental theory

Wilson: A fundamental theory has an UV fixed point

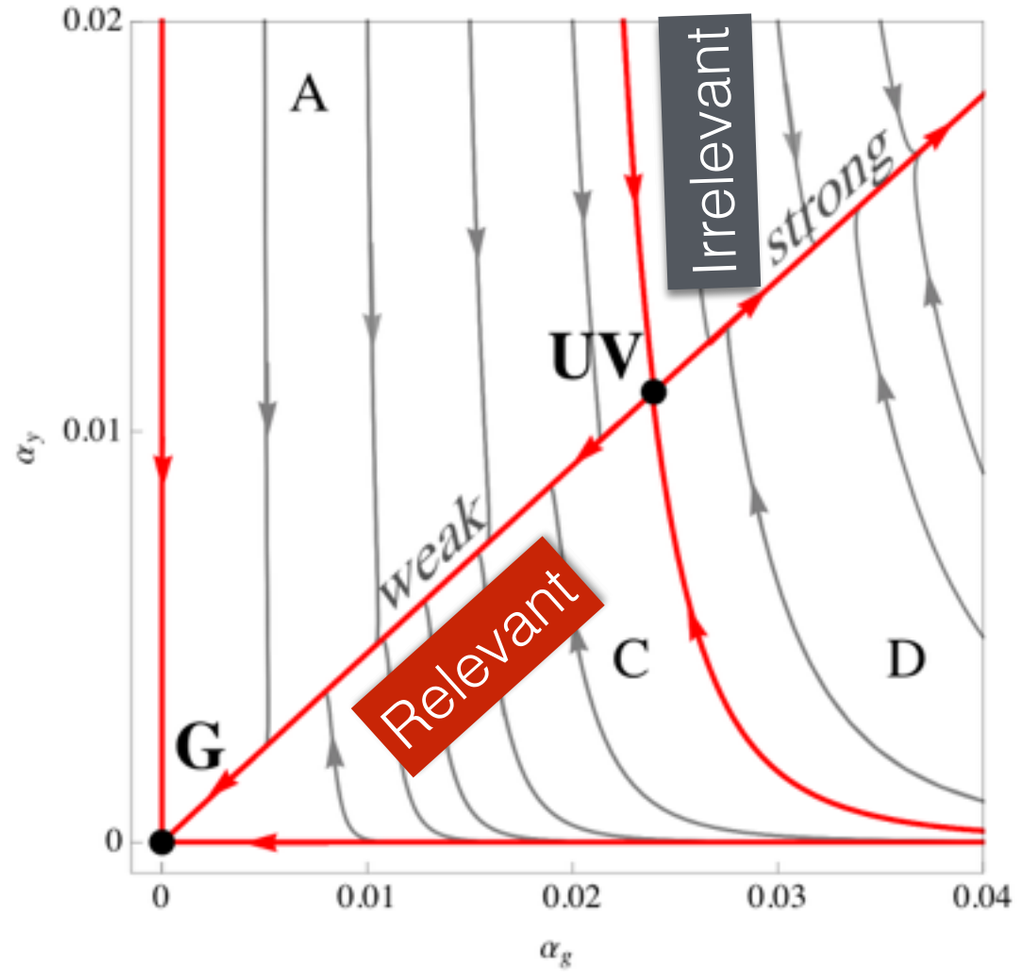
- Short distance conformality



Fundamental theory

Wilson: A fundamental theory has an UV fixed point

- Short distance conformality
- Continuum limit well defined



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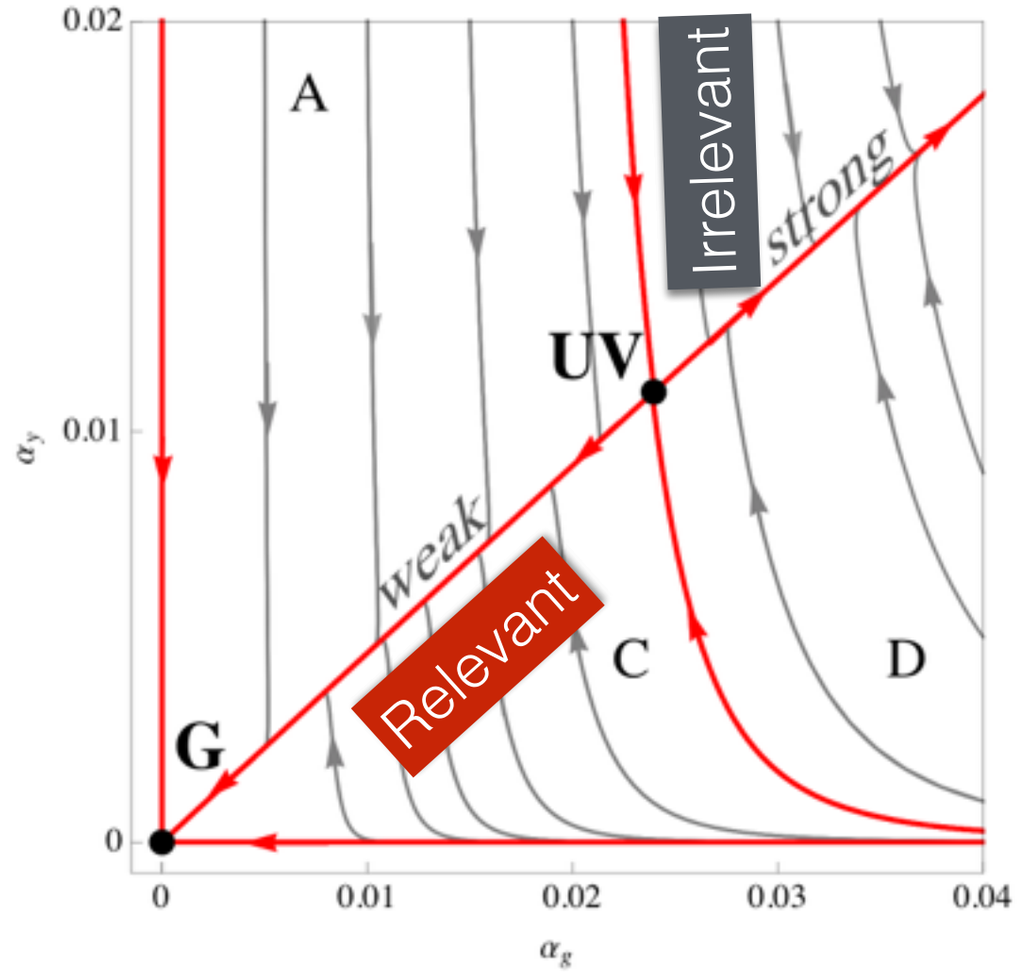

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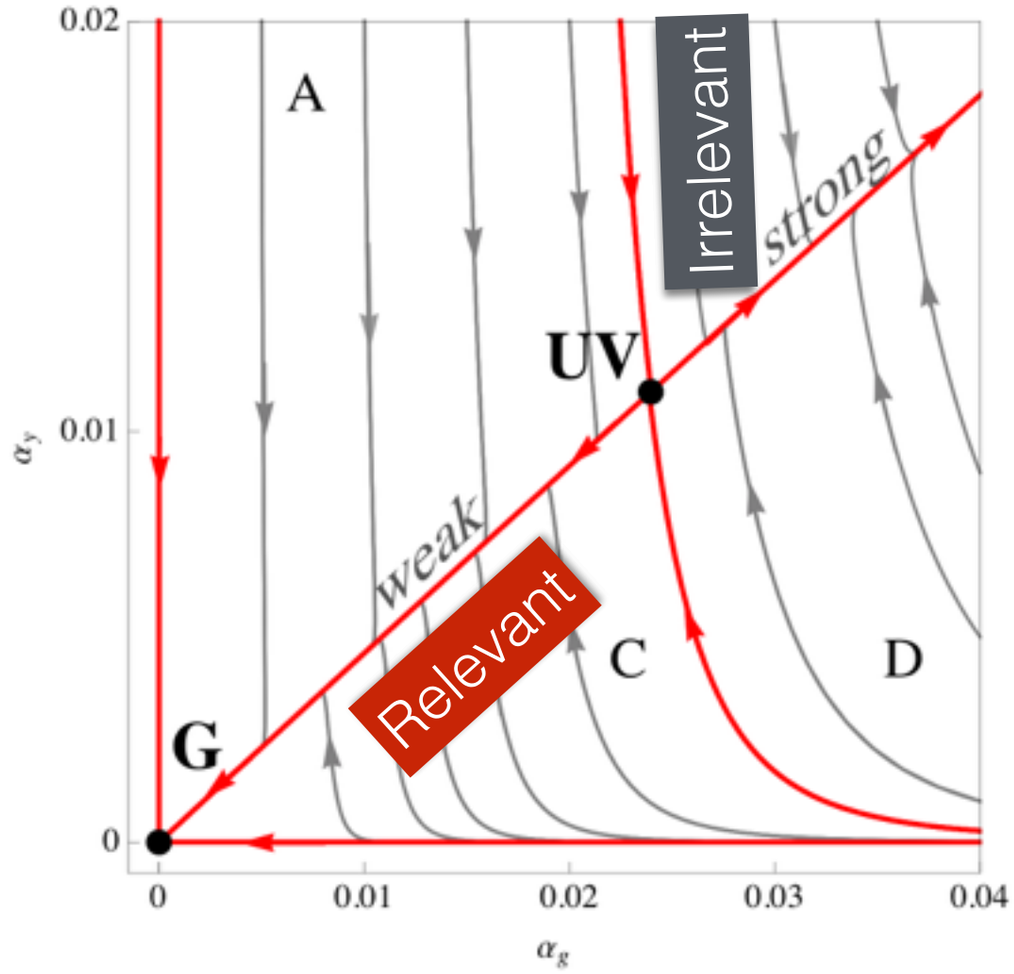
Wilson: A fundamental theory has an UV fixed point

- Short distance conformality
- Continuum limit well defined
- Complete UV fixed point
- Smaller critical surface dim. = more IR predictiveness



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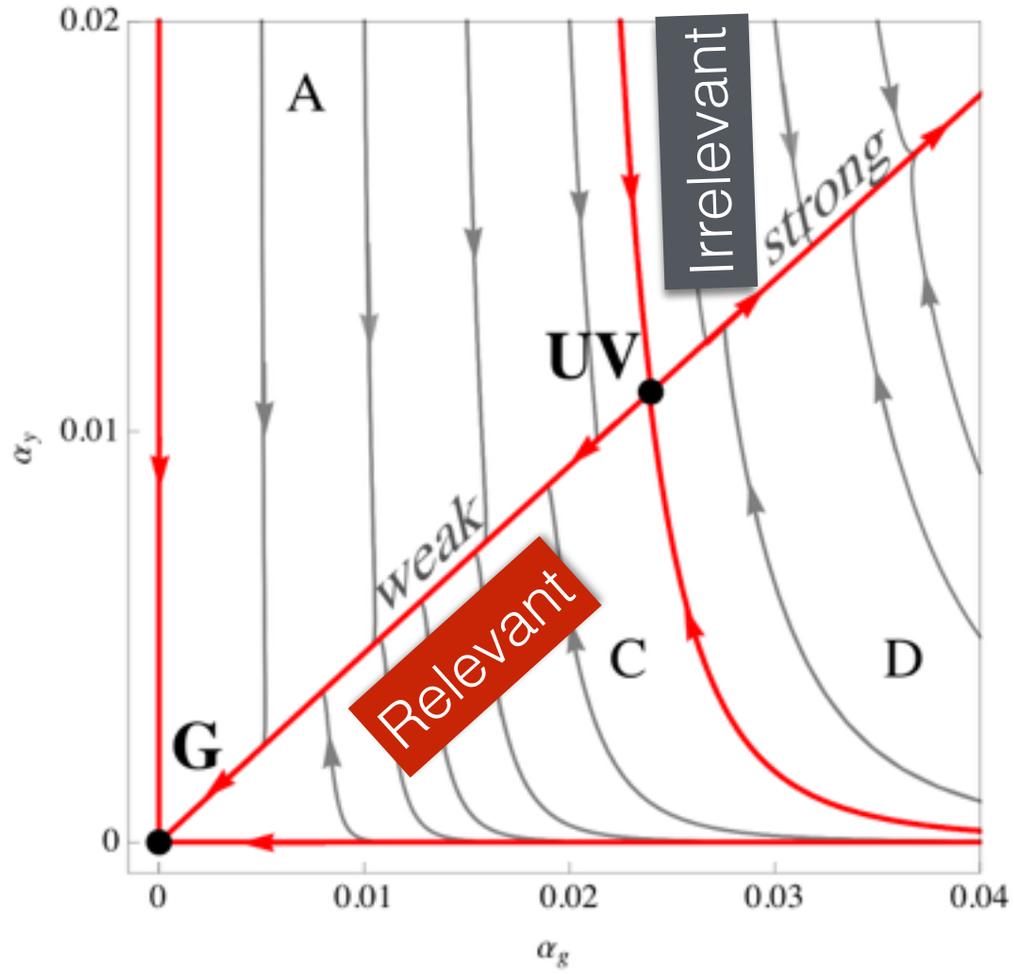

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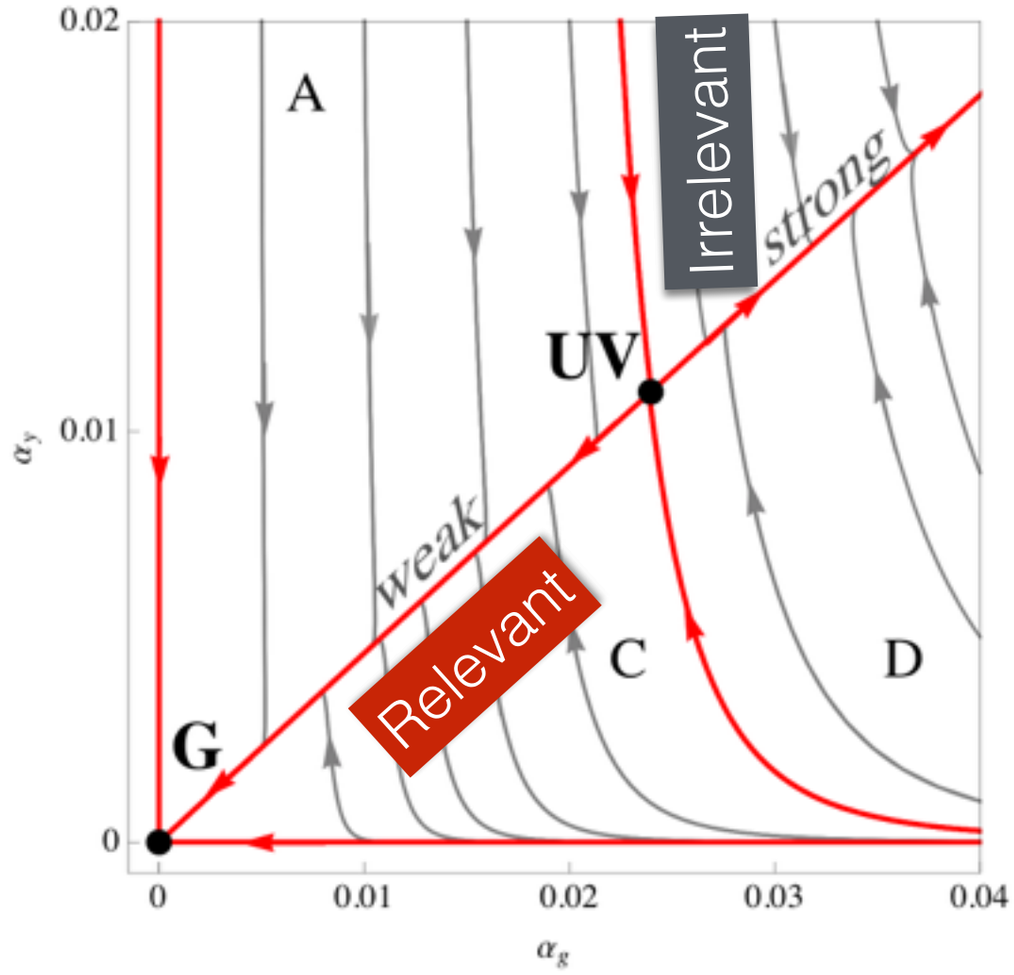


The Standard Model is not a fundamental theory

Asymptotic Freedom

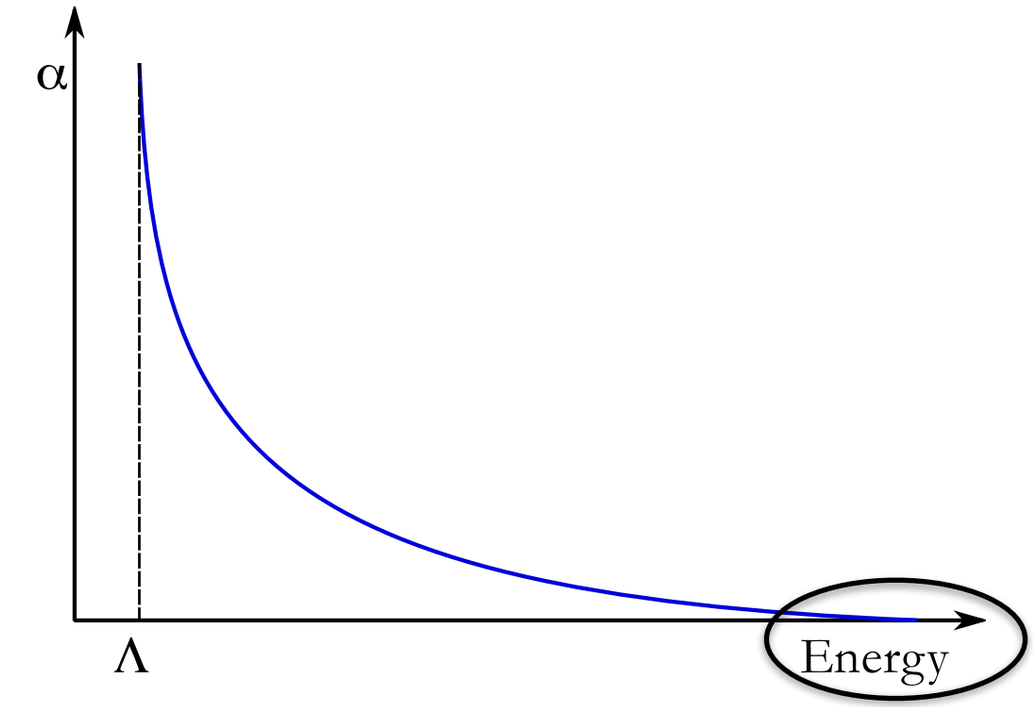
Asymptotic Freedom

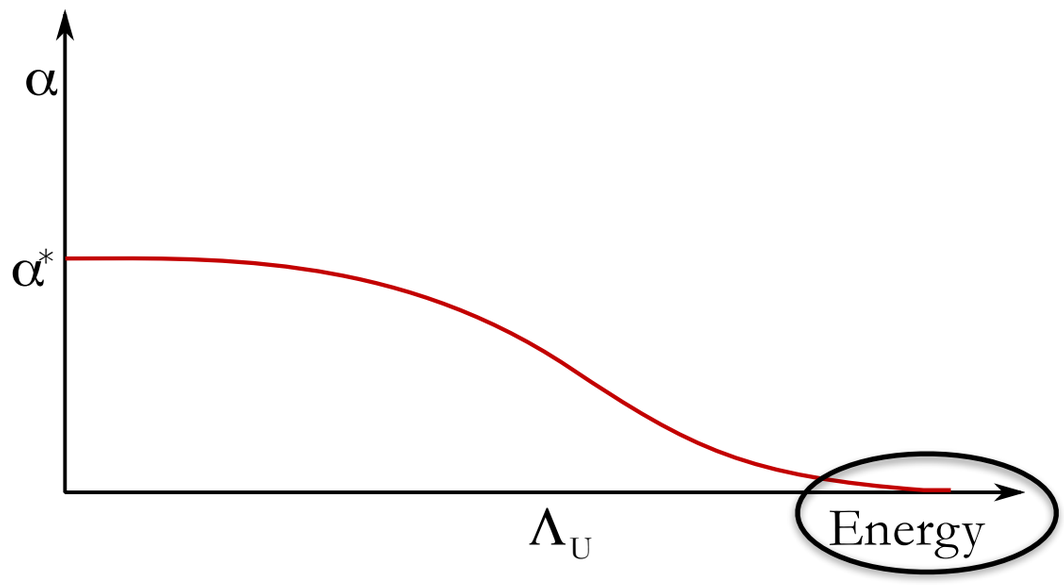
Trivial UV fixed point

Asymptotic Freedom

Trivial UV fixed point

- Non-interacting in the UV

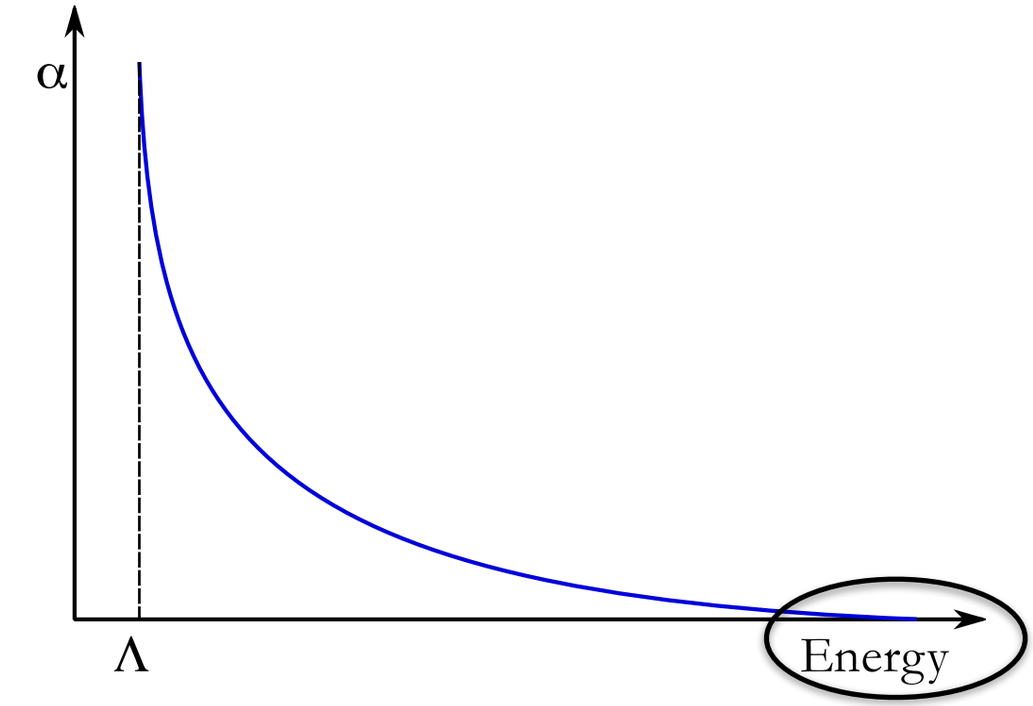


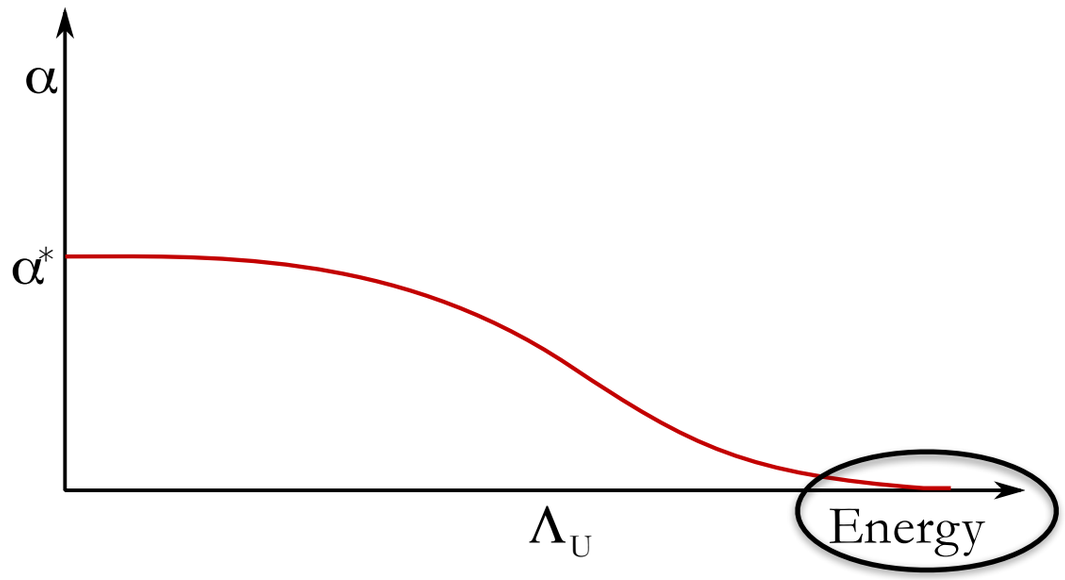


Asymptotic Freedom

Trivial UV fixed point

- Non-interacting in the UV
- UV logarithmic approach





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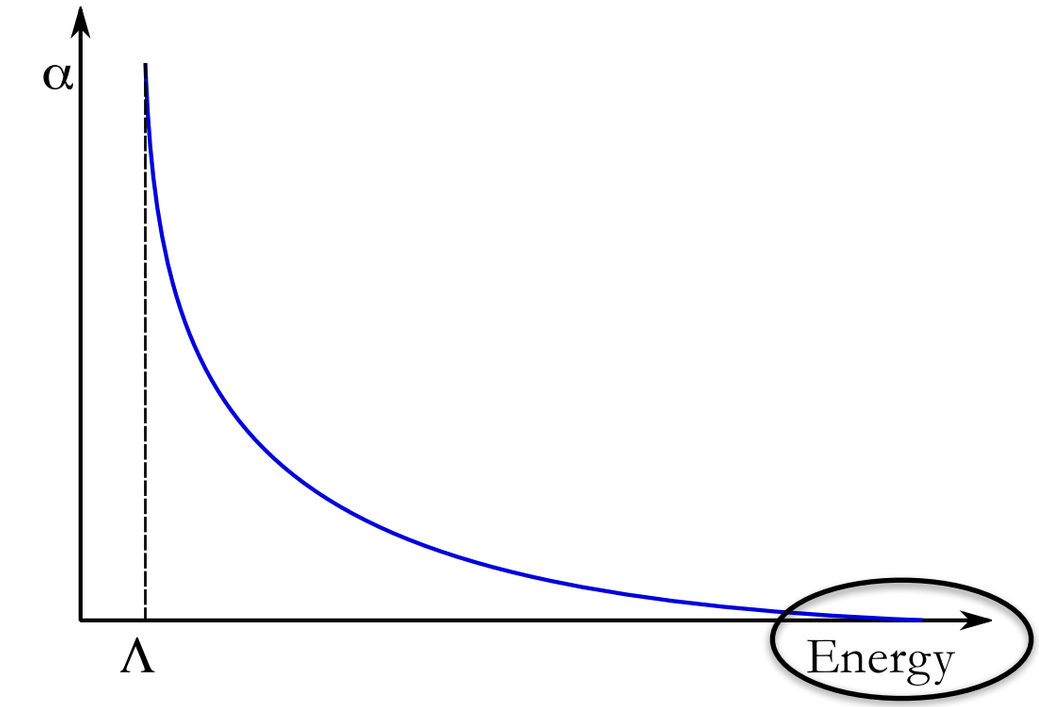
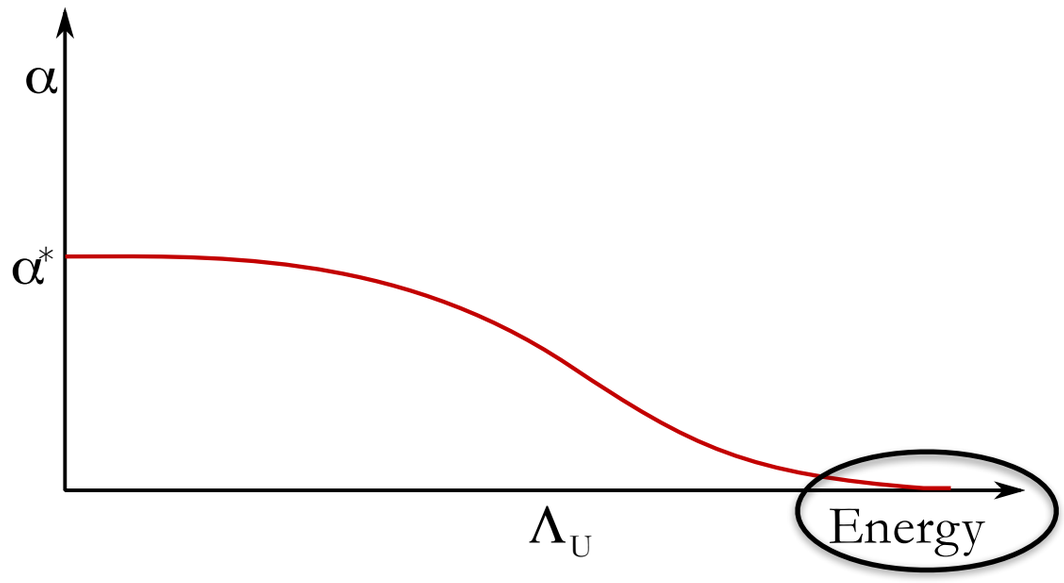
- Perturbation theory in UV

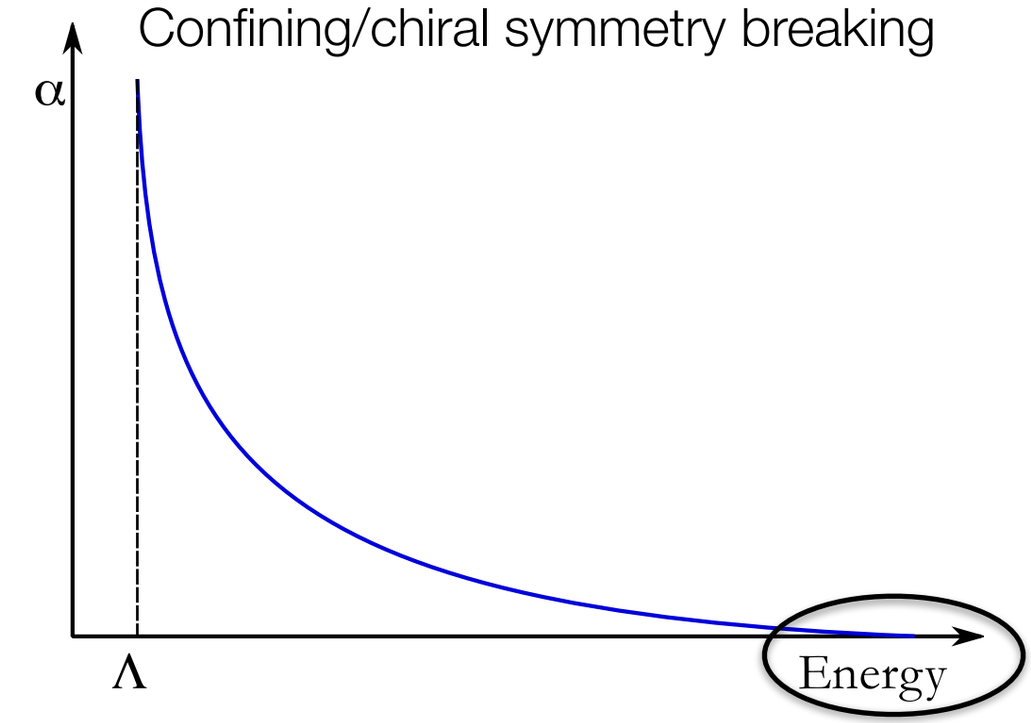


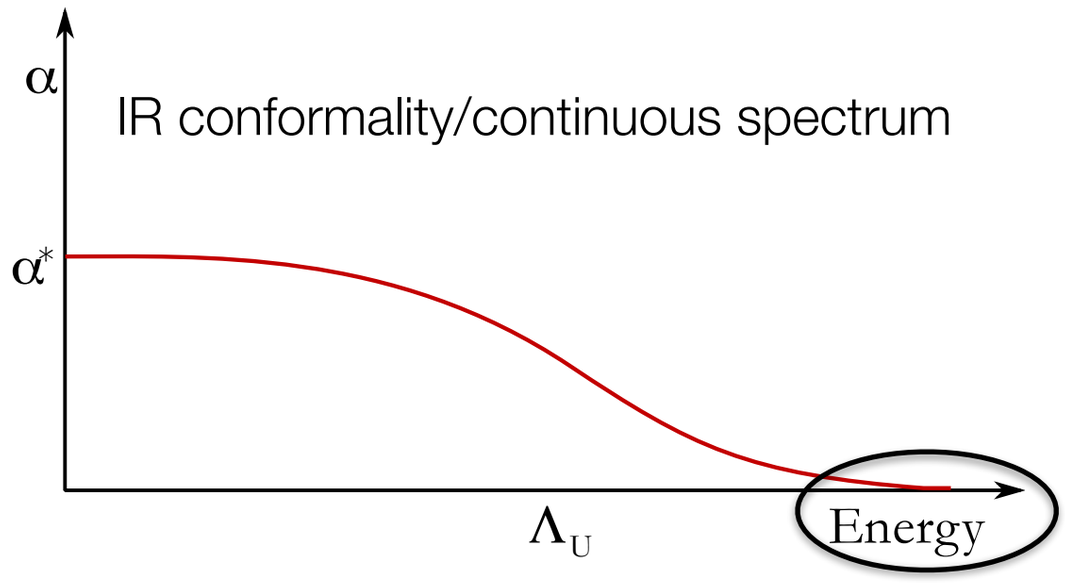


Asymptotic Freedom

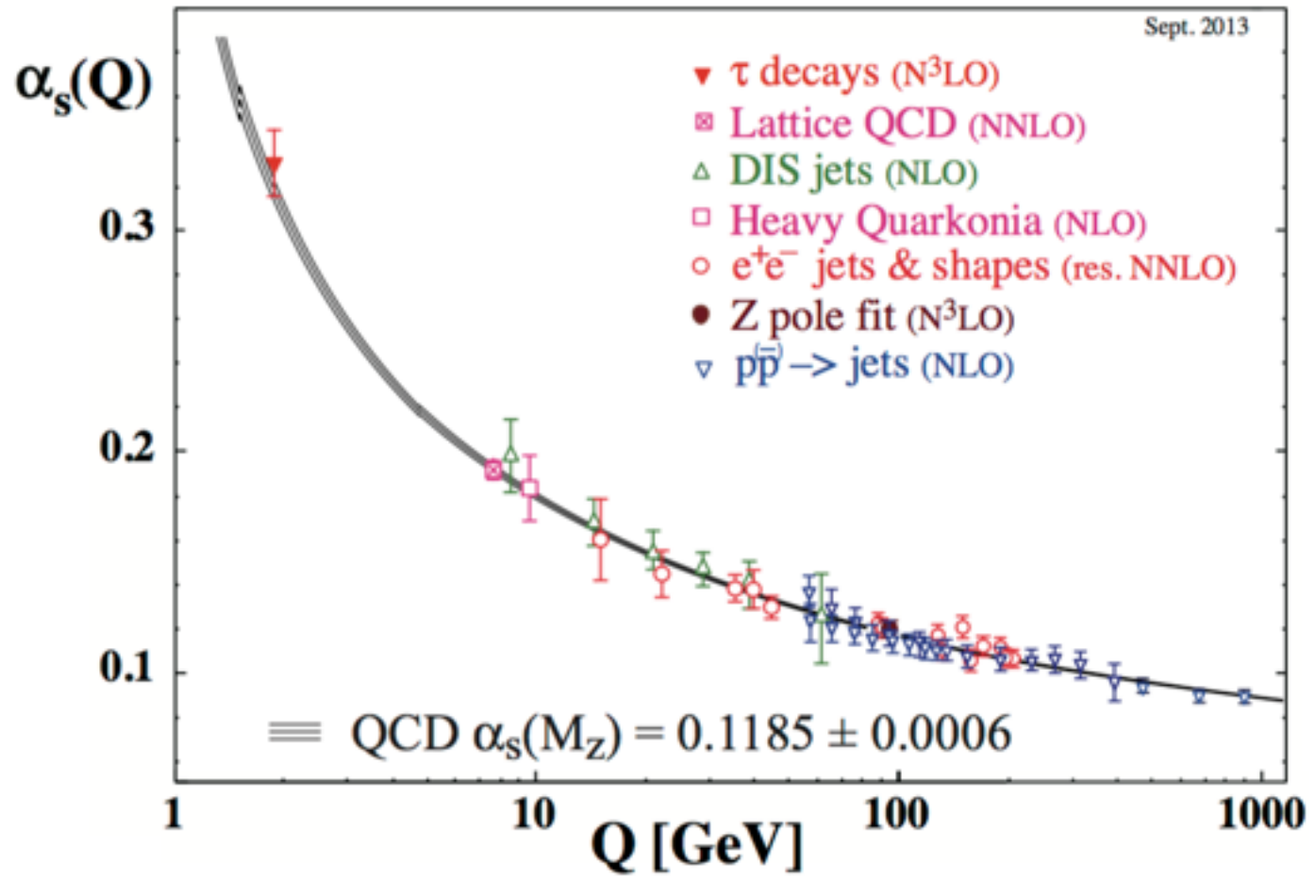
Trivial UV fixed point

- Non-interacting in the UV
- UV logarithmic approach
- Perturbation theory in UV
- IR conformal or dyn. scale



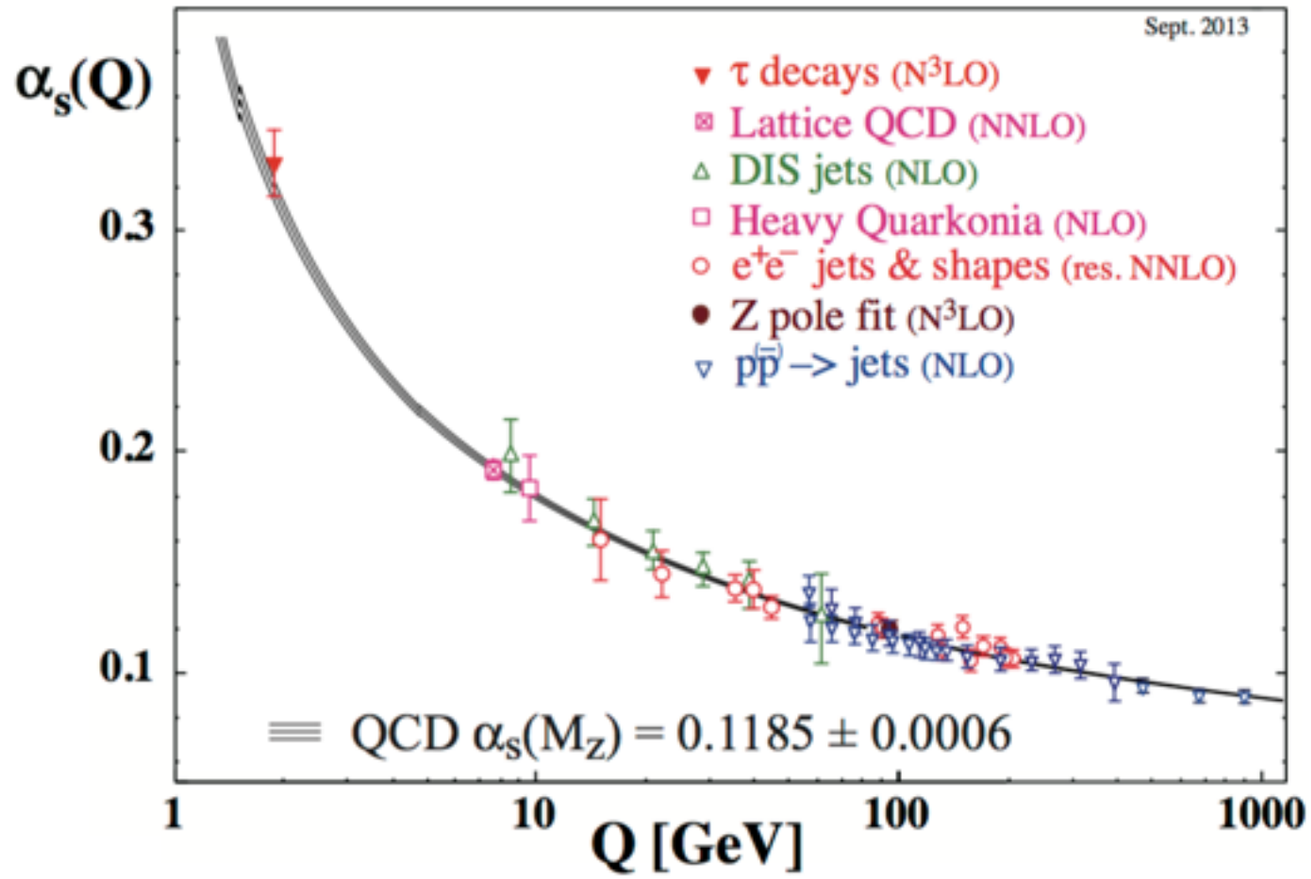


QCD


Sept. 2013
$\alpha_s(Q)$
0.3
0.2
0.1
τ decays (N³LO)
Lattice QCD (NNLO)
DIS jets (NLO)
Heavy Quarkonia (NLO)
e⁺e⁻ jets & shapes (res. NNLO)
Z pole fit (N³LO)
$p\bar{p}$ –> jets (NLO)
QCD $\alpha_s(M_Z) = 0.1185 \pm 0.0006$
1
10
100
1000
Q [GeV]

QCD

QCD is not IR conformal because



QCD

QCD is not IR conformal because

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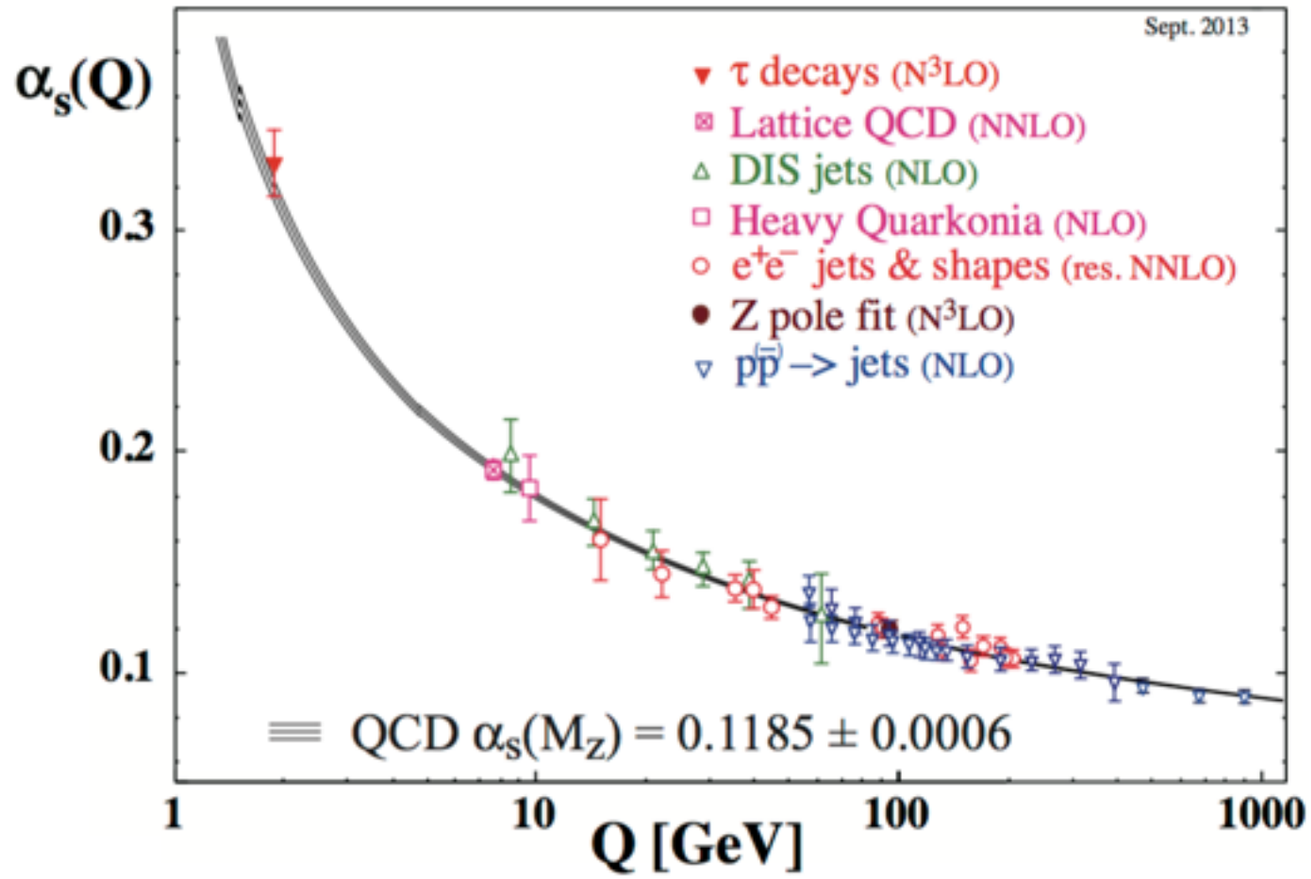

QCD

QCD is not IR conformal because

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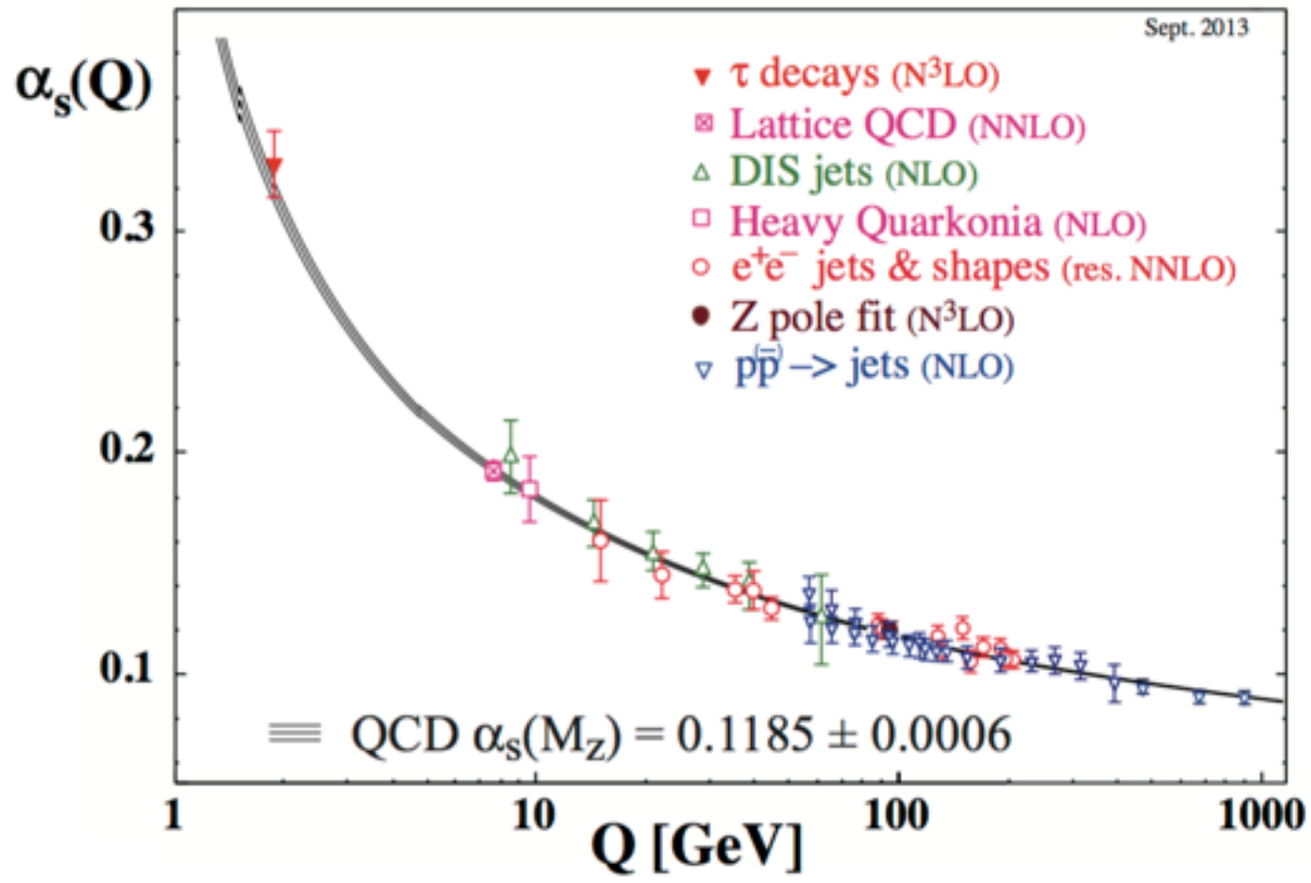
- Pions <-> Spont. ChSB



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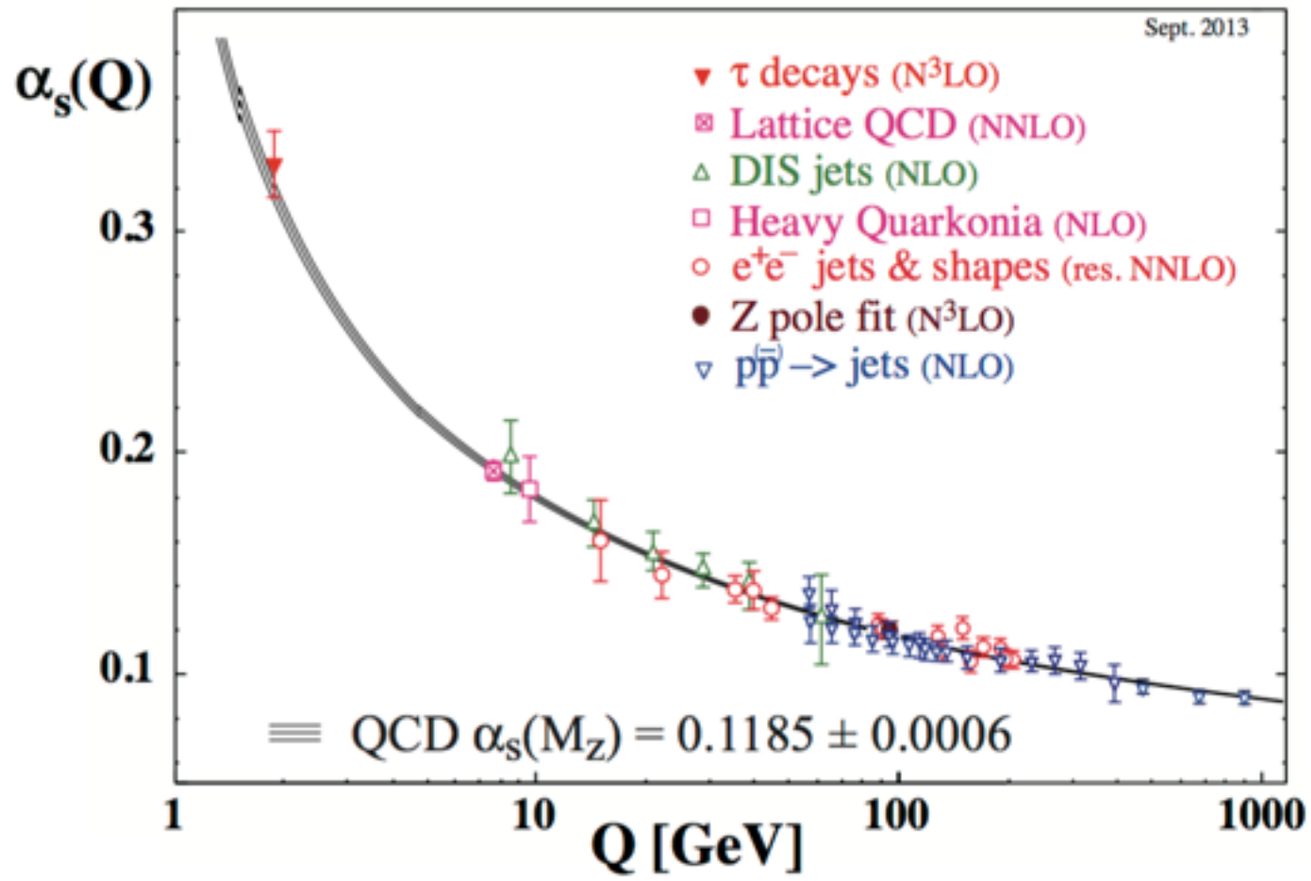

Asymptotic freedom verified < TeV

QCD

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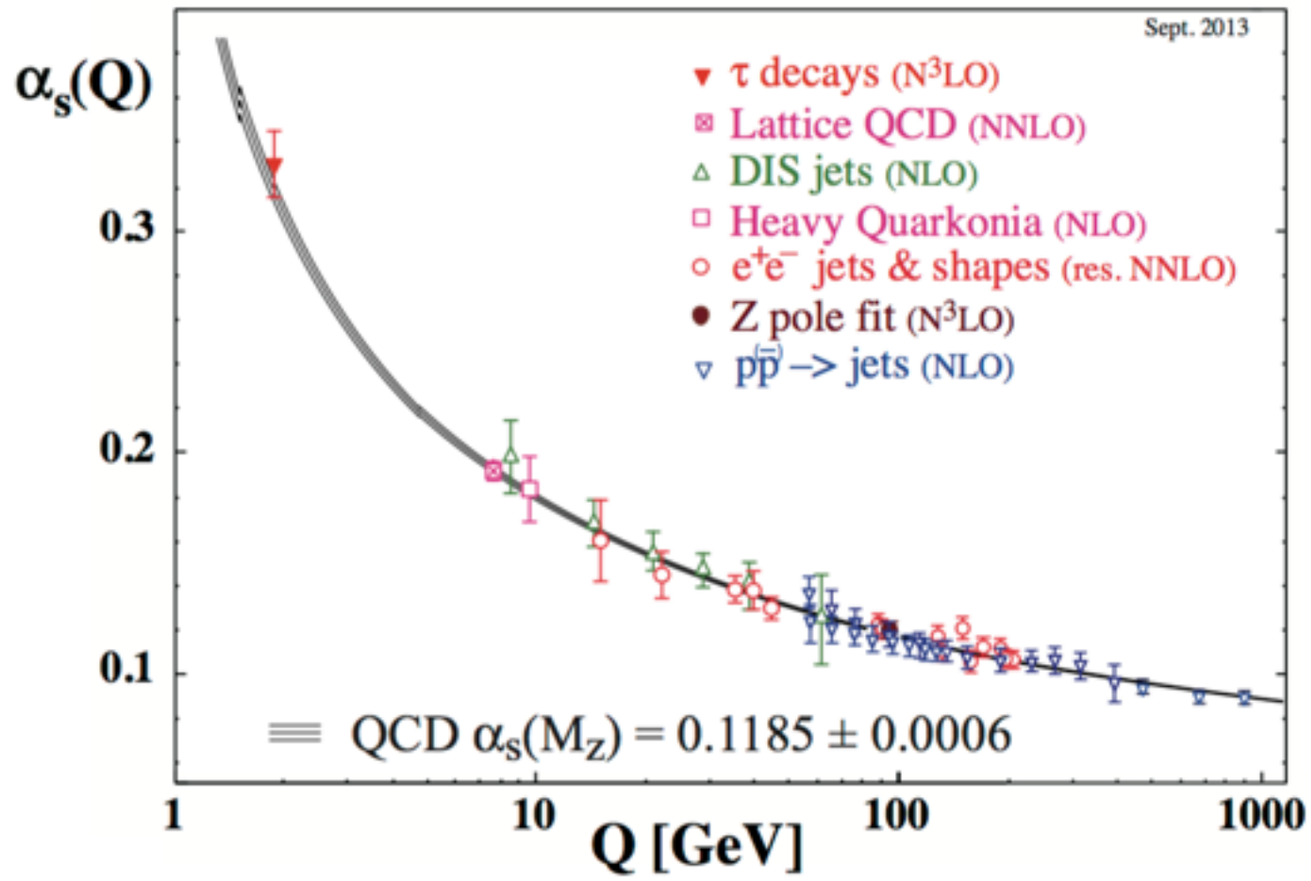


Asymptotic freedom verified < TeV

If above TeV asymptotic freedom is lost, then what?

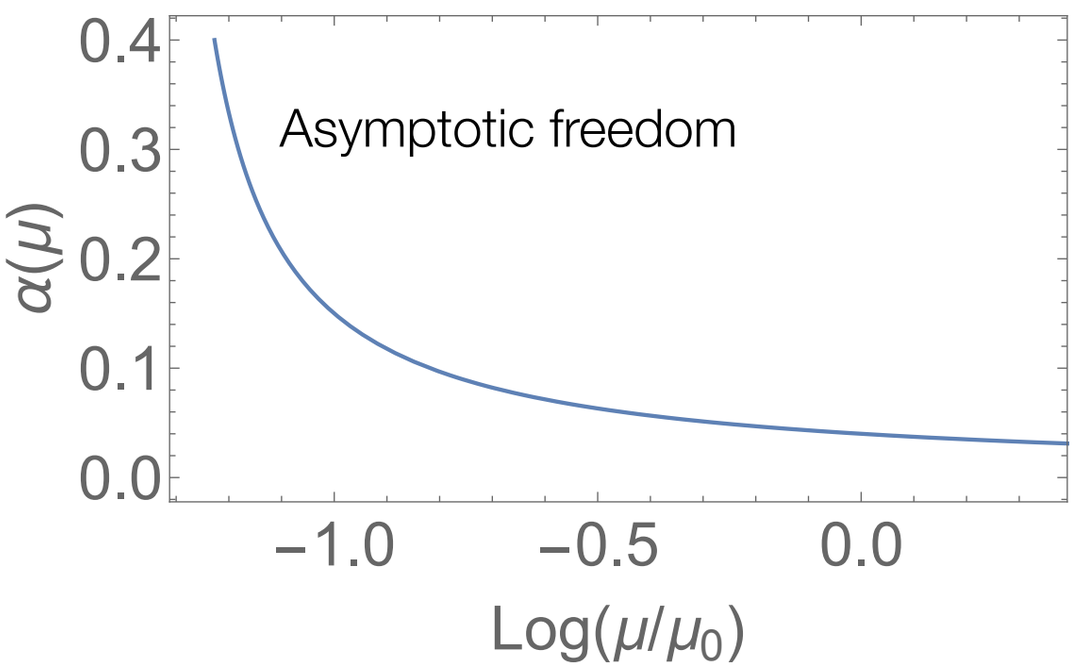
Beyond asymptotic freedom

Asymptotic Safety

Wilson: A fundamental theory has an UV fixed point

Trivial fixed point

- Non-interacting in the UV
- Logarithmic scale depend.



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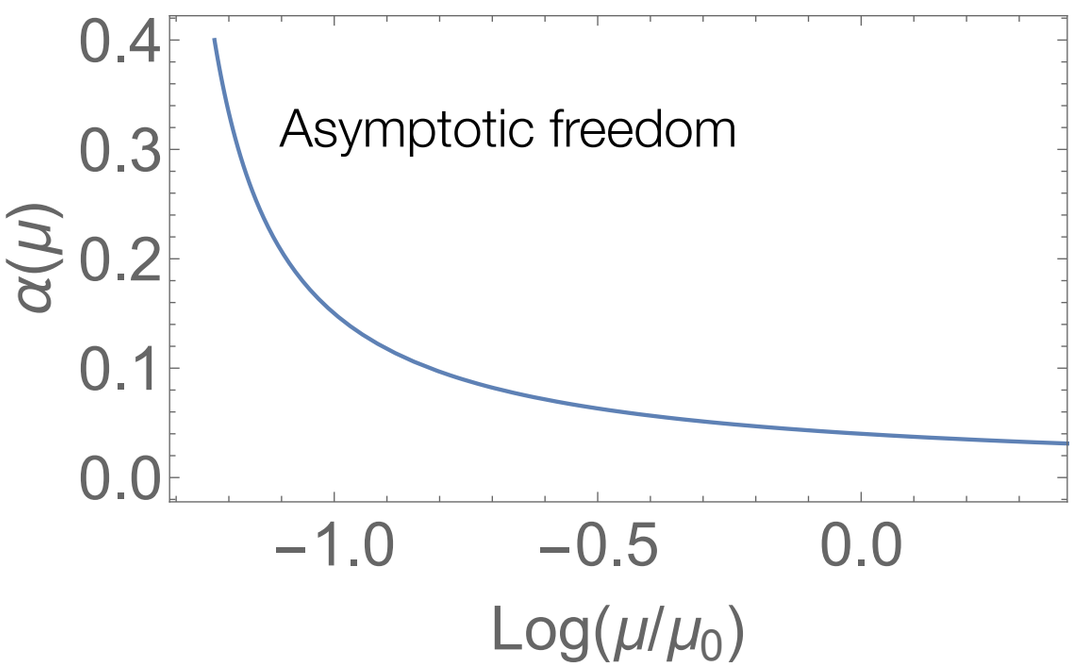

Interacting fixed point

Asymptotic Safety

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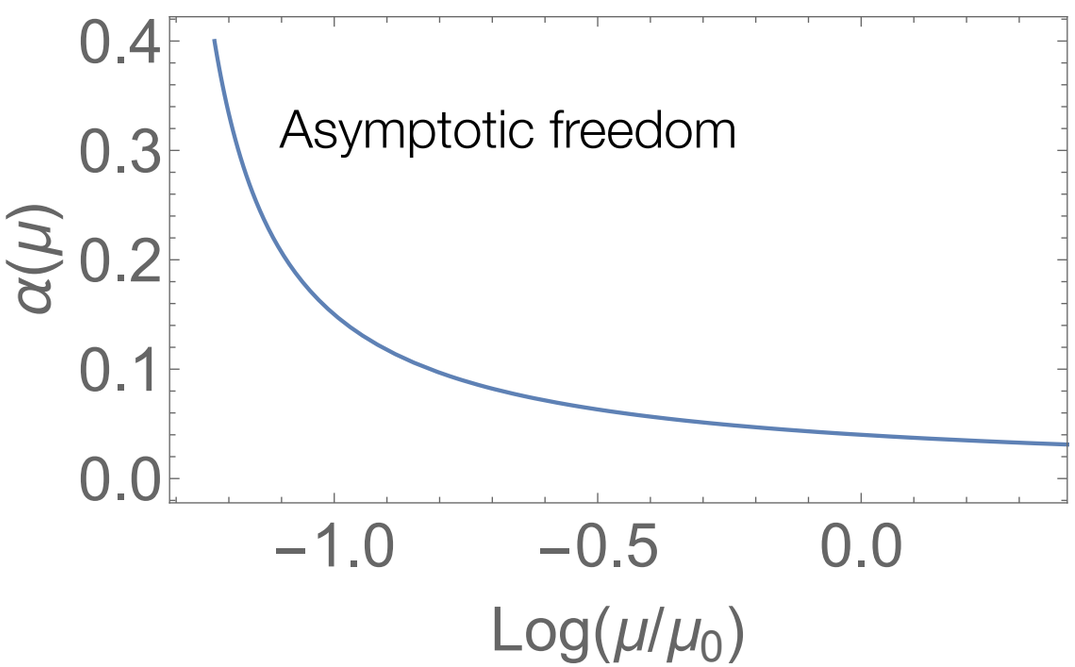
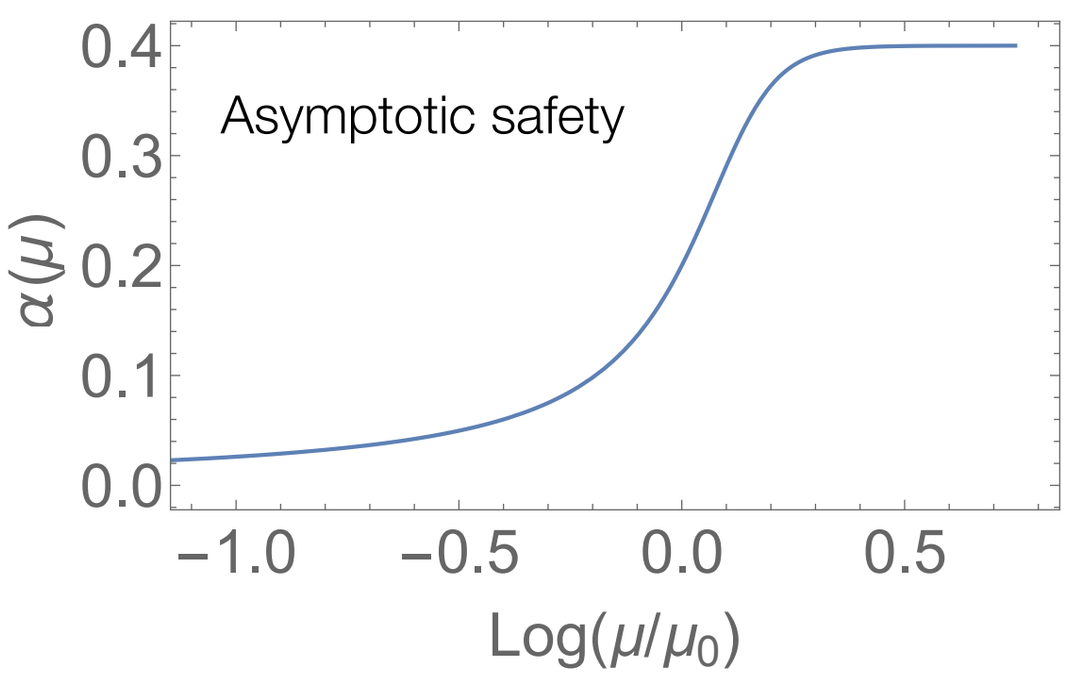
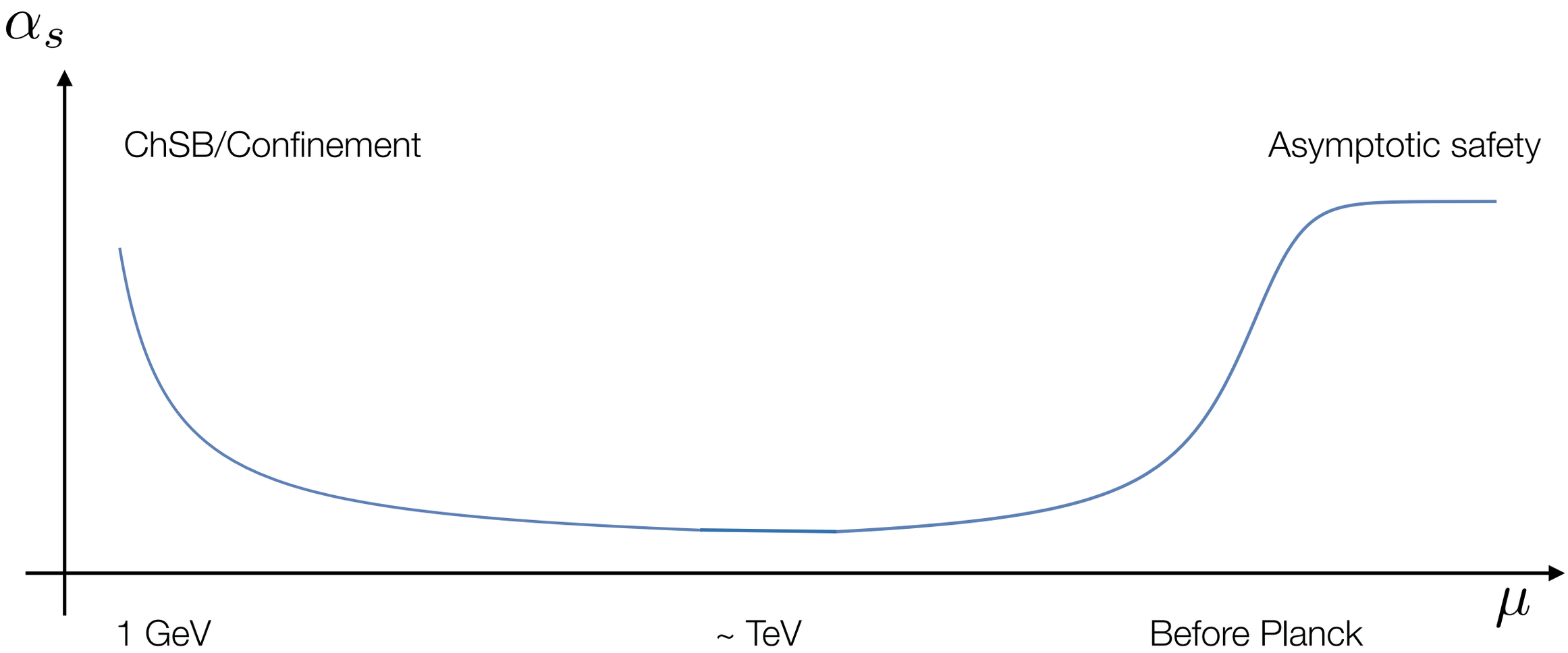


Interacting fixed point

- Integrating in the UV
- Power law

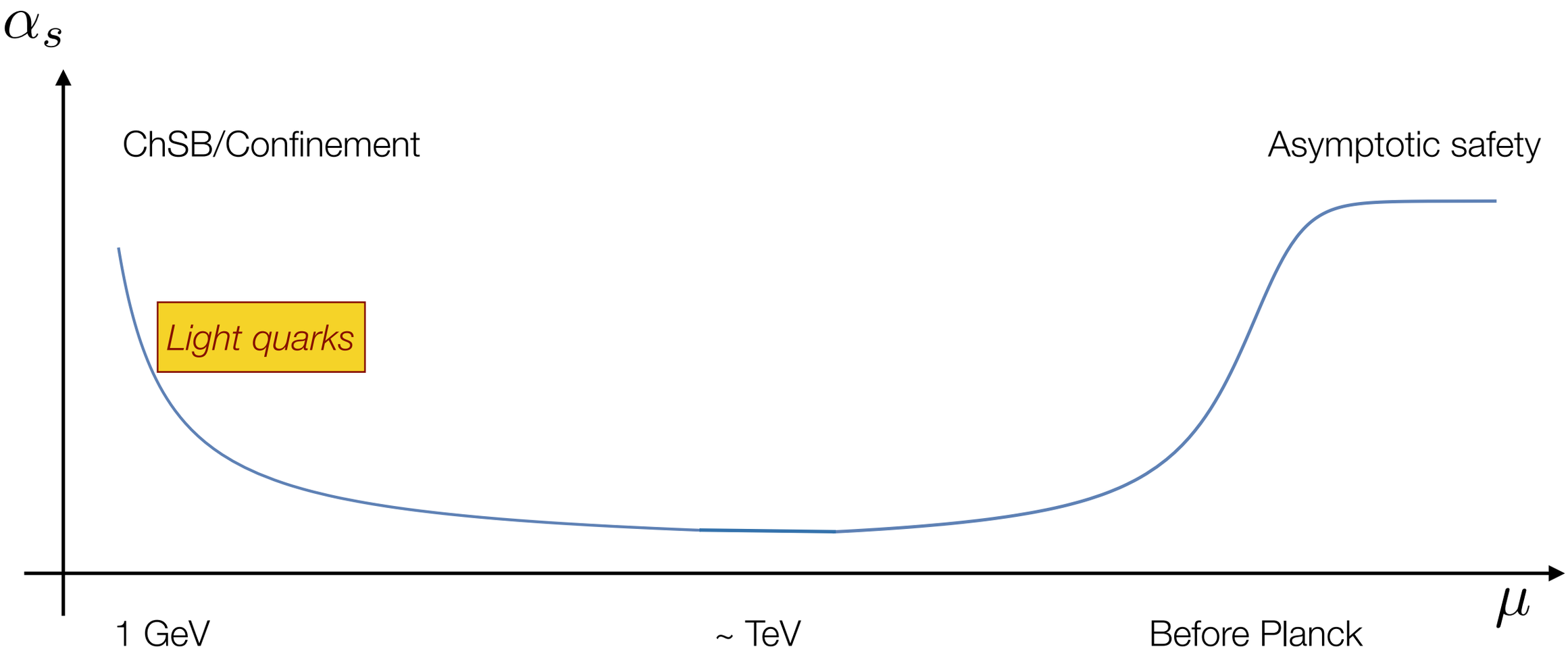


Safe QCD scenario



Sannino, 15

Safe QCD scenario



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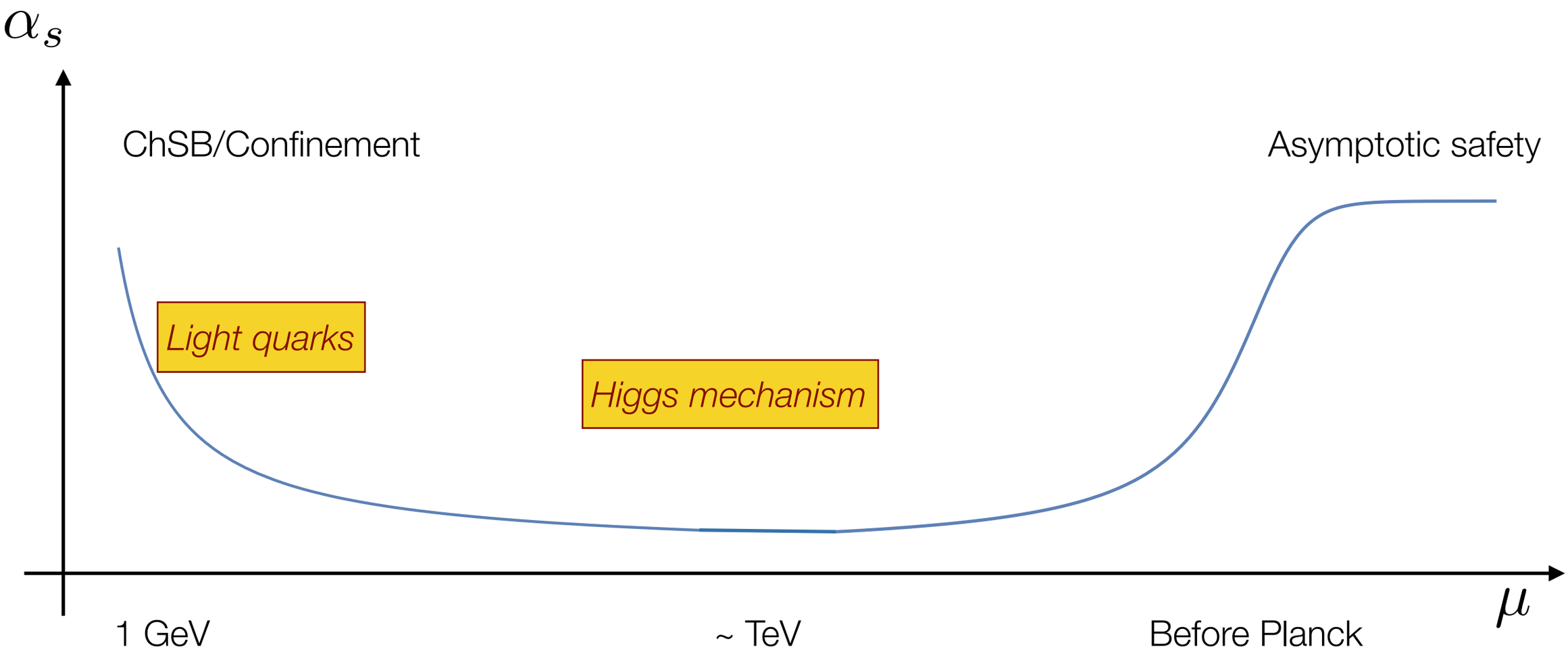

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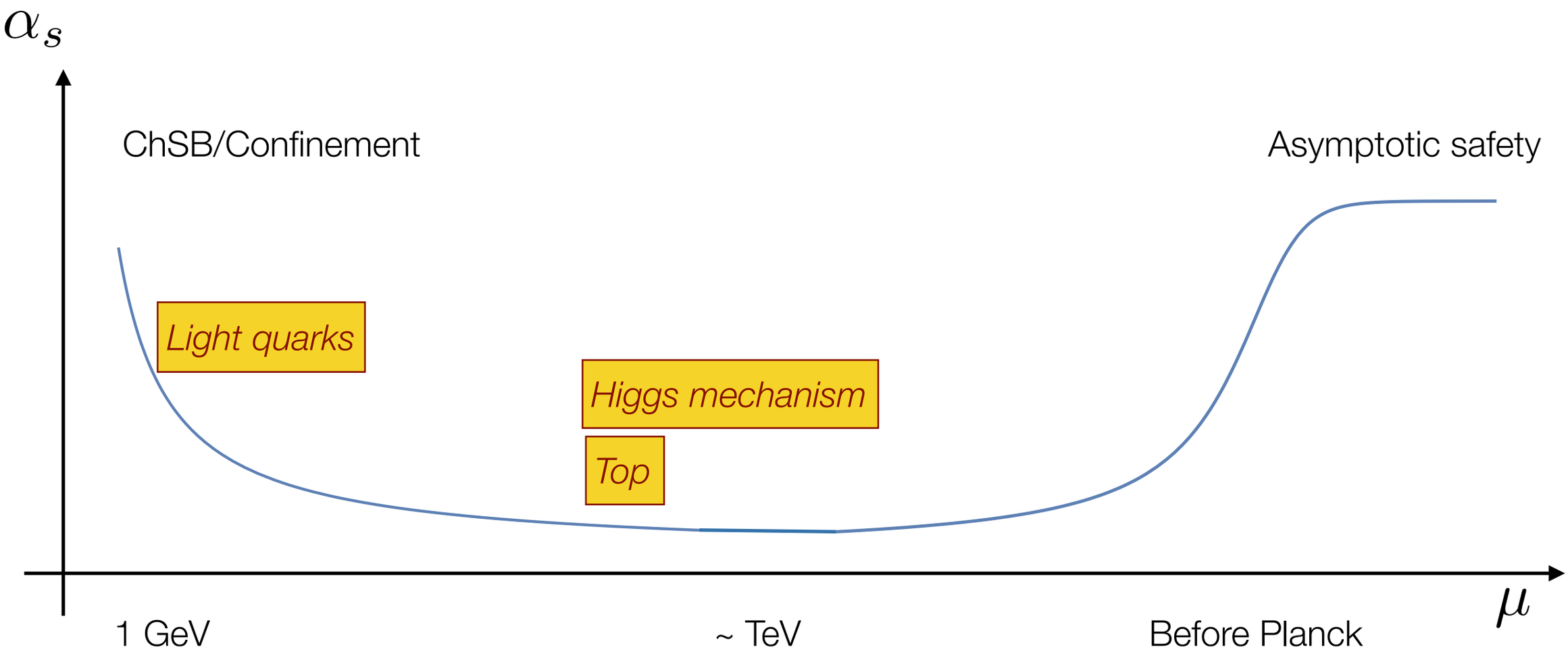

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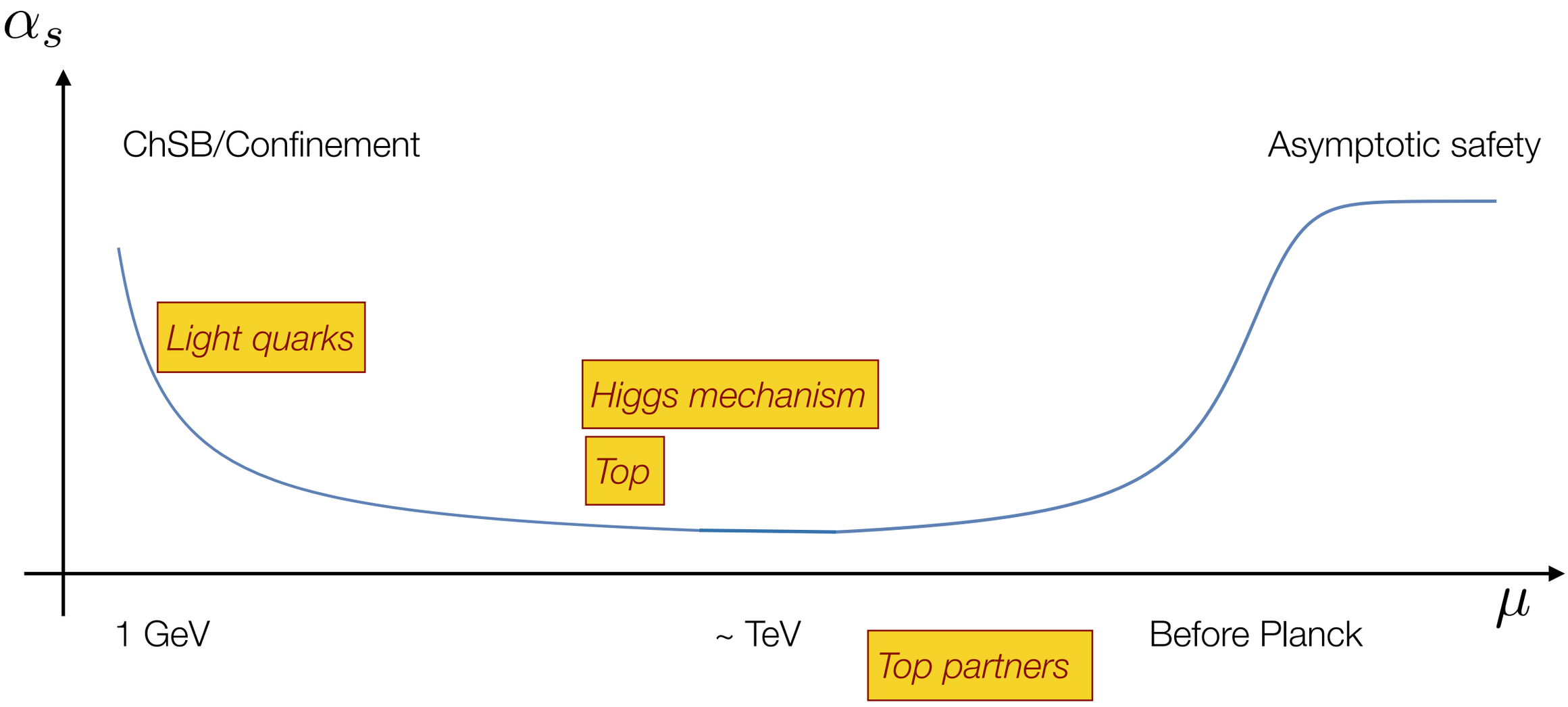

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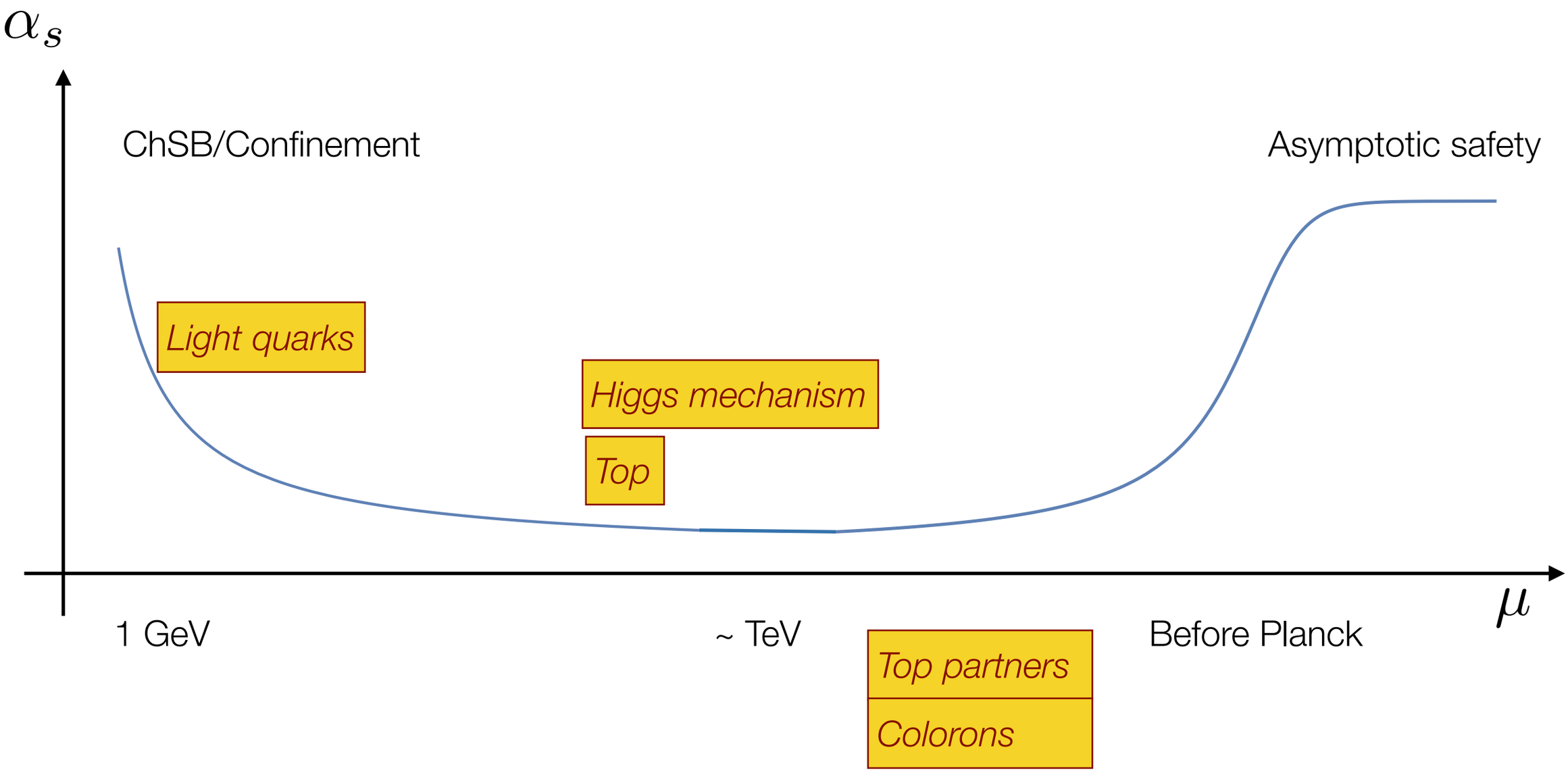

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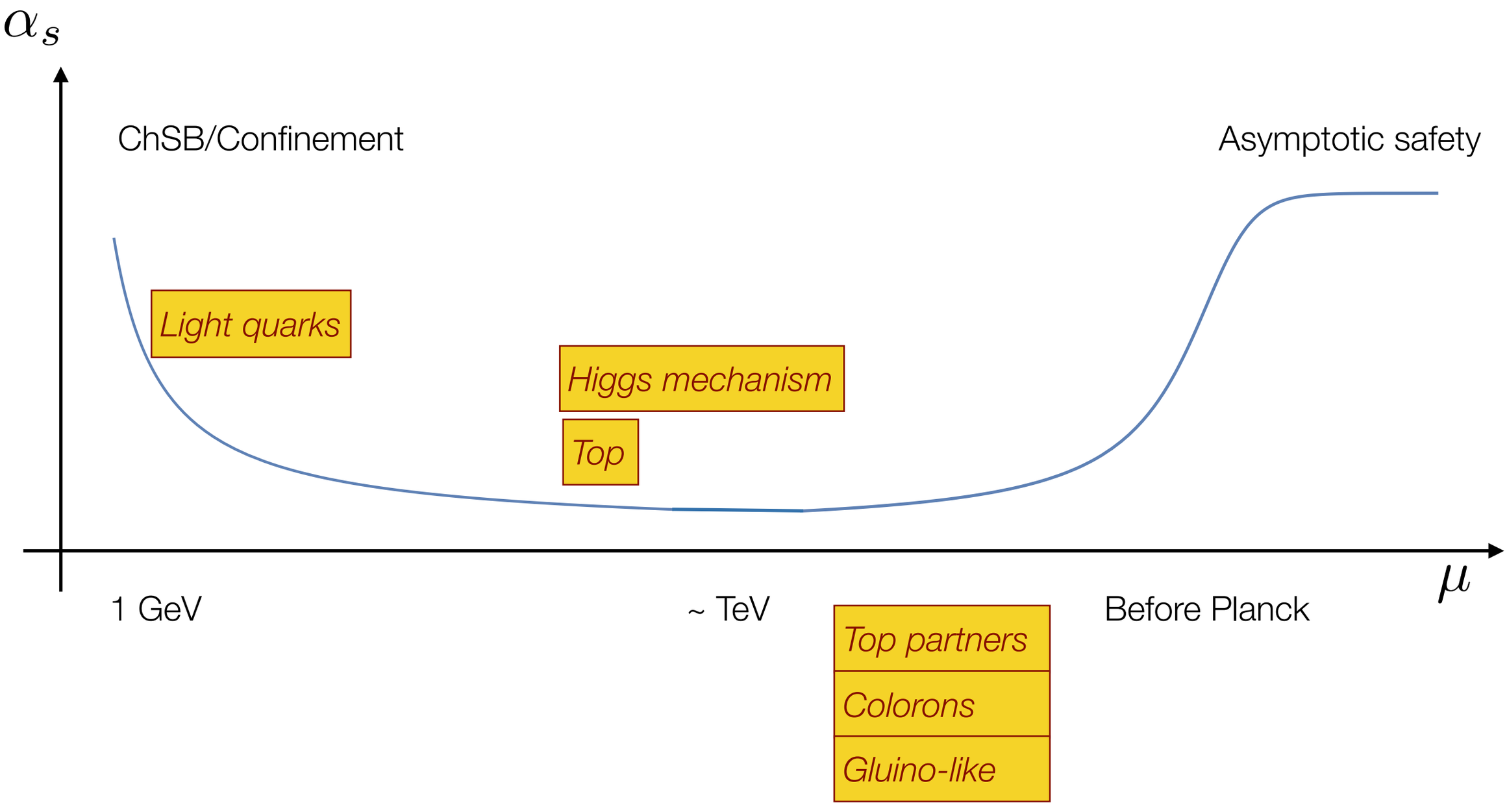

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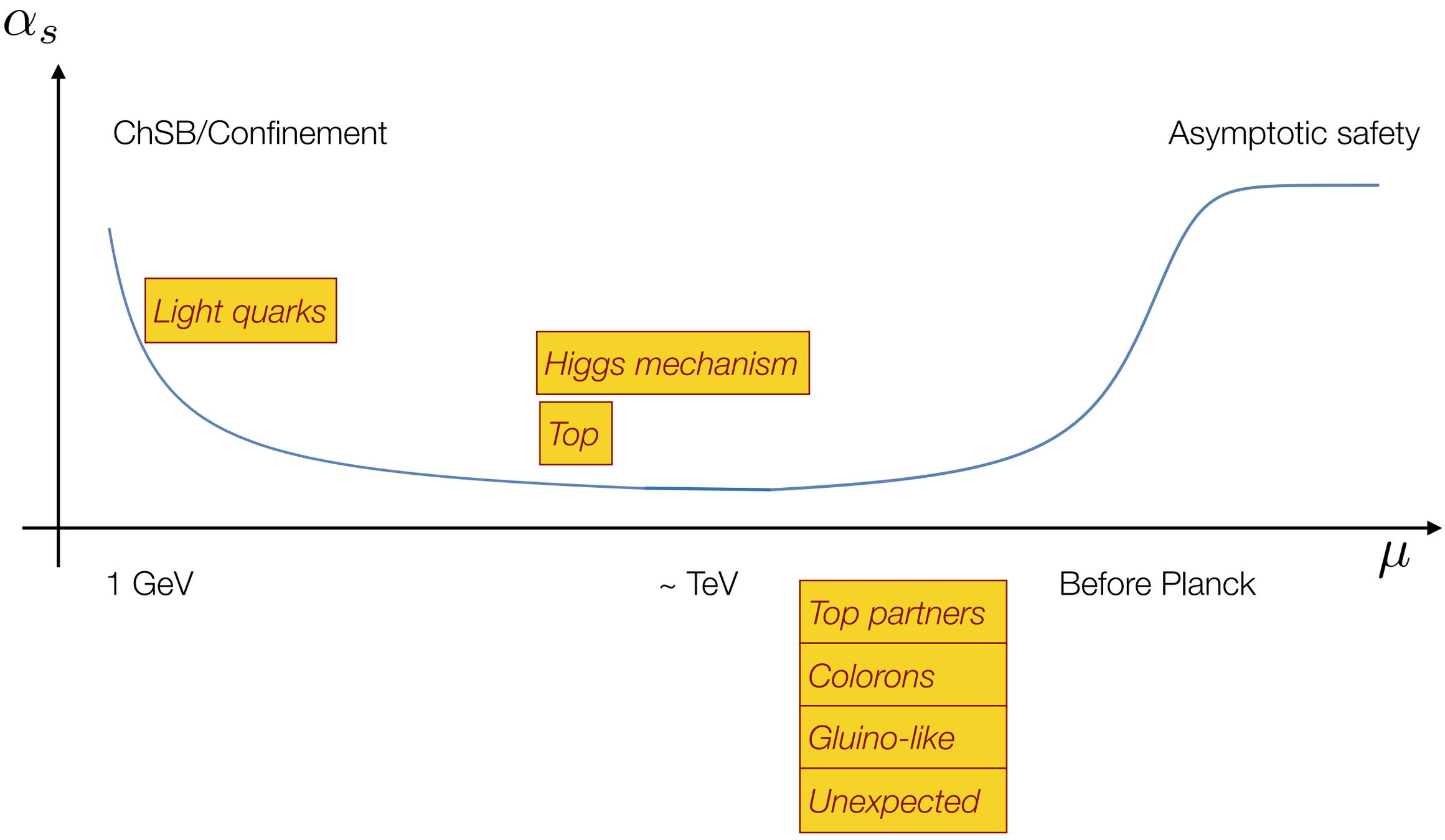

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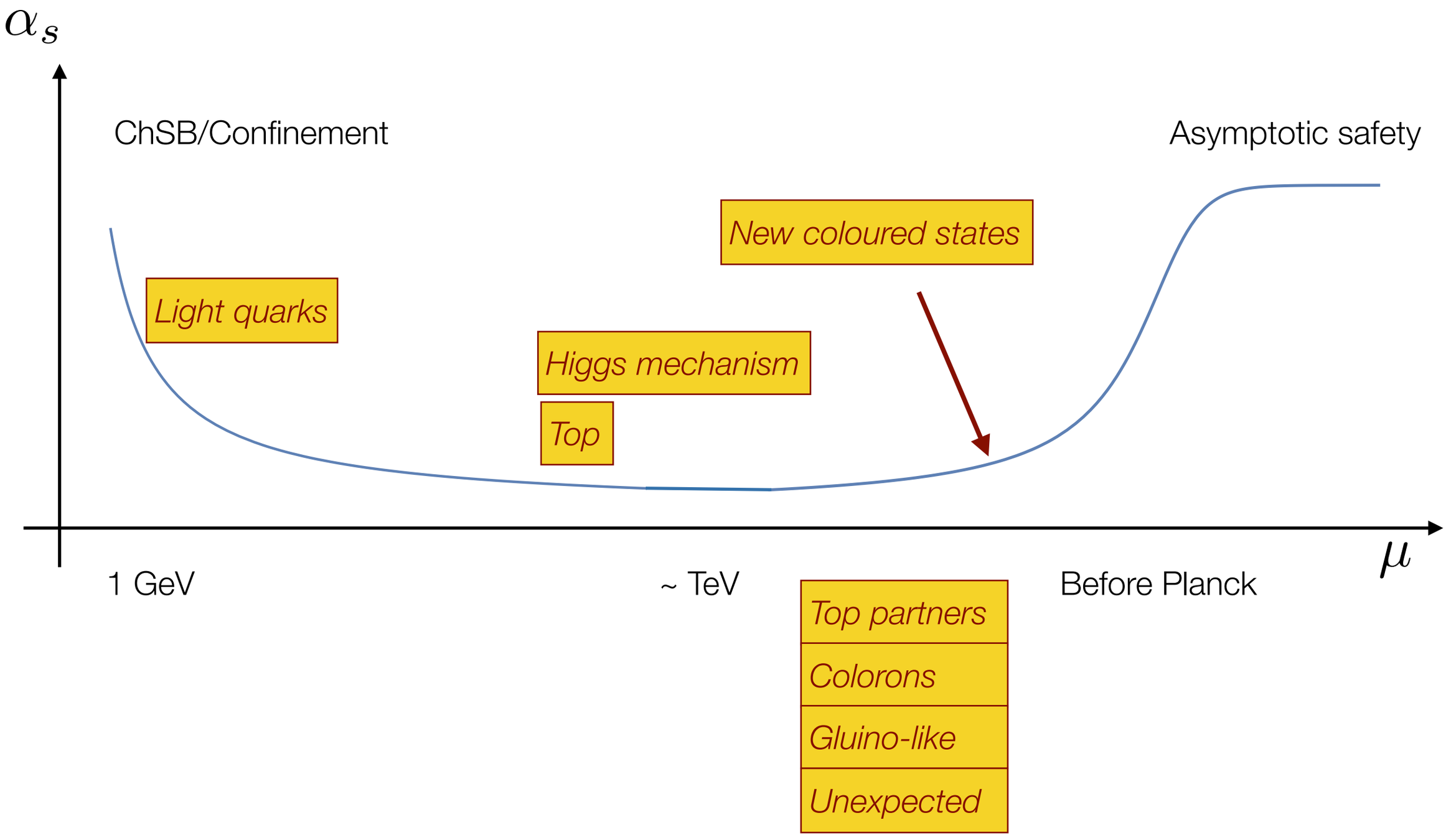

Sannino, 15

Does a theory like this exists?

Exact 4D Interacting UV Fixed Point

Litim and Sannino, 1406.2337, JHEP

Exact 4D Interacting UV Fixed Point

Litim and Sannino, 1406.2337, JHEP

Fields	$[SU(N_c)]$	$SU_L(N_f)$	$SU_R(N_f)$	$U_V(1)$
G_μ	Adj	1	1	0
Q_L	$\square$	$\overline{\square}$	1	1
Q_R^c	$\overline{\square}$	1	$\square$	-1
H	1	$\square$	$\overline{\square}$	0

$$L = -F^2 + i\overline{Q}\gamma \cdot DQ + y(\overline{Q}_L H Q_R + \text{h.c.}) +$$

$$\text{Tr}\left[\partial \text{H}^\dagger \partial \text{H}\right] - \text{uTr}\left[(\text{H}^\dagger \text{H})^2\right] - \text{vTr}\left[(\text{H}^\dagger \text{H})\right]^2$$

Exact 4D Interacting UV Fixed Point

Litim and Sannino, 1406.2337, JHEP

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$$\alpha_g = \frac{g^2\, N_C}{(4\pi)^2}\,, \quad \alpha_y = \frac{y^2\, N_C}{(4\pi)^2}\,, \quad \alpha_h = \frac{u\, N_F}{(4\pi)^2}\,, \quad \alpha_v = \frac{v\, N_F^2}{(4\pi)^2}$$

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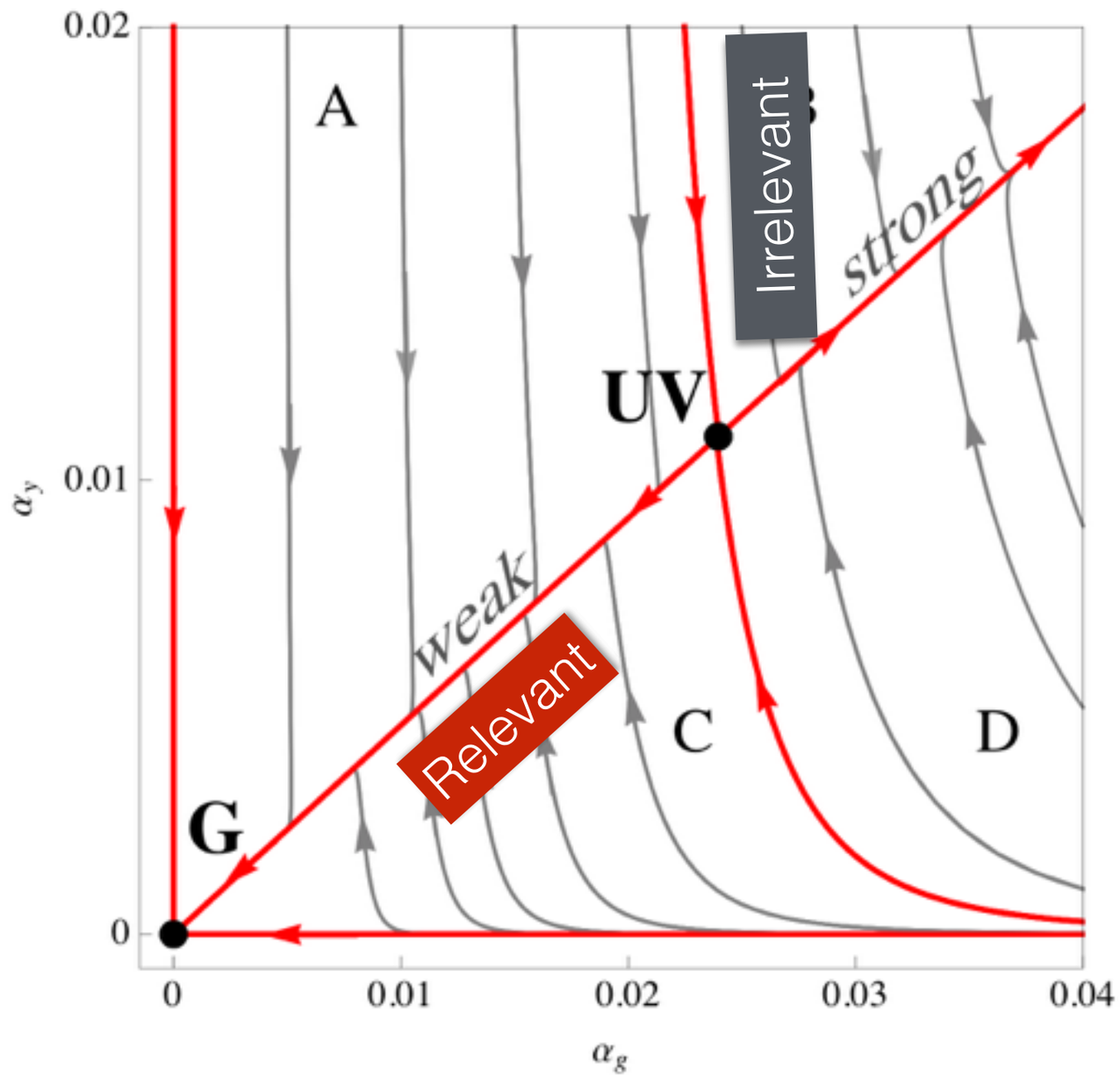
$$\epsilon = \frac{N_F}{N_C} - \frac{11}{2} \qquad\qquad 0 \leq \epsilon \ll 1$$

Phase Diagram



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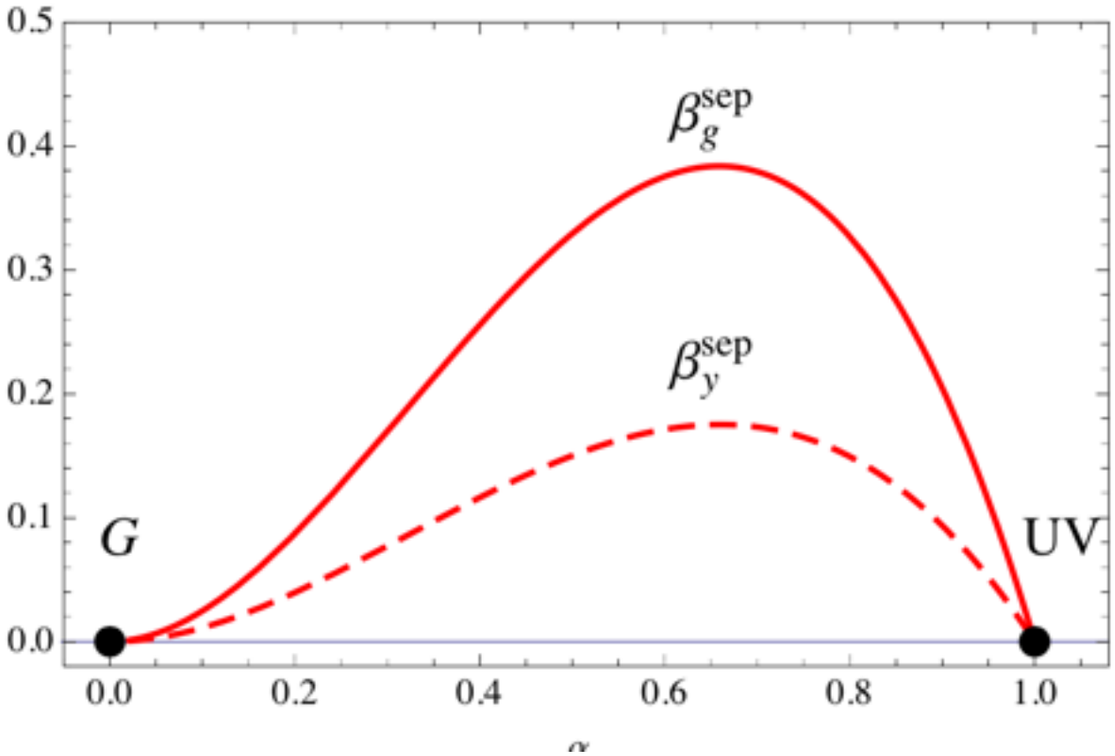
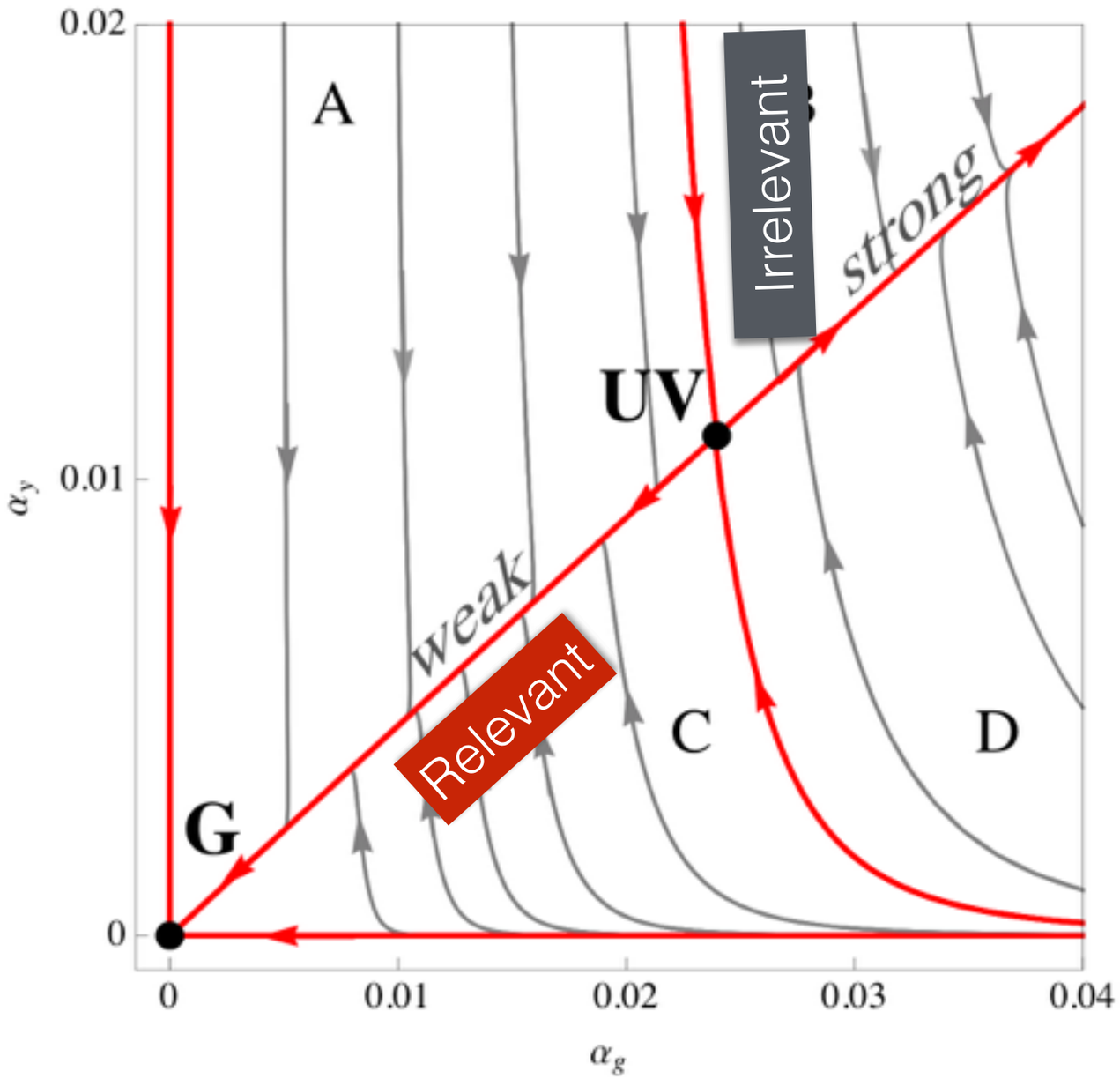
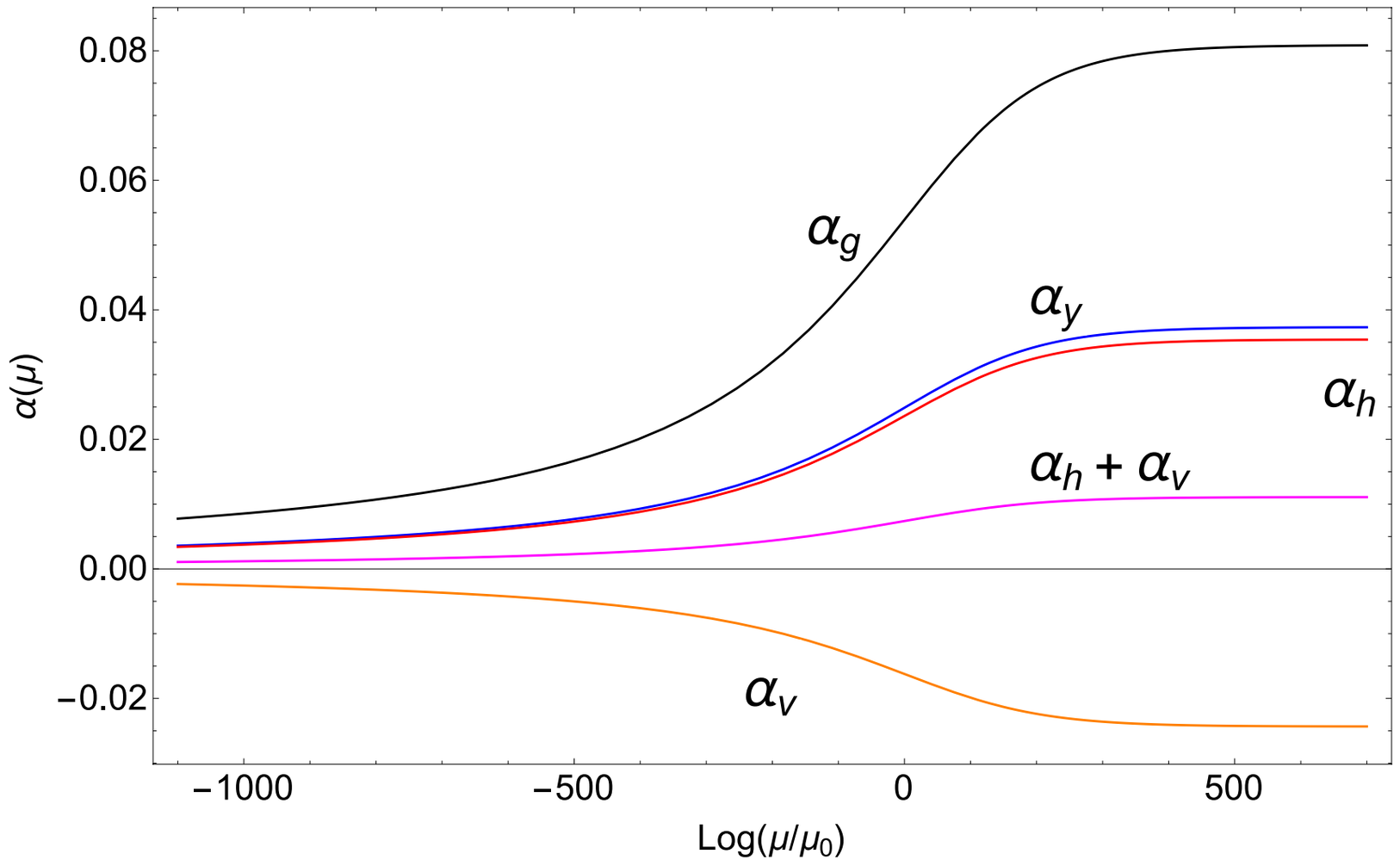




Complete asymptotic safety

Litim and Sannino, 1406.2337, JHEP

Gauge + fermion + scalars theories can be fund. at any energy scale



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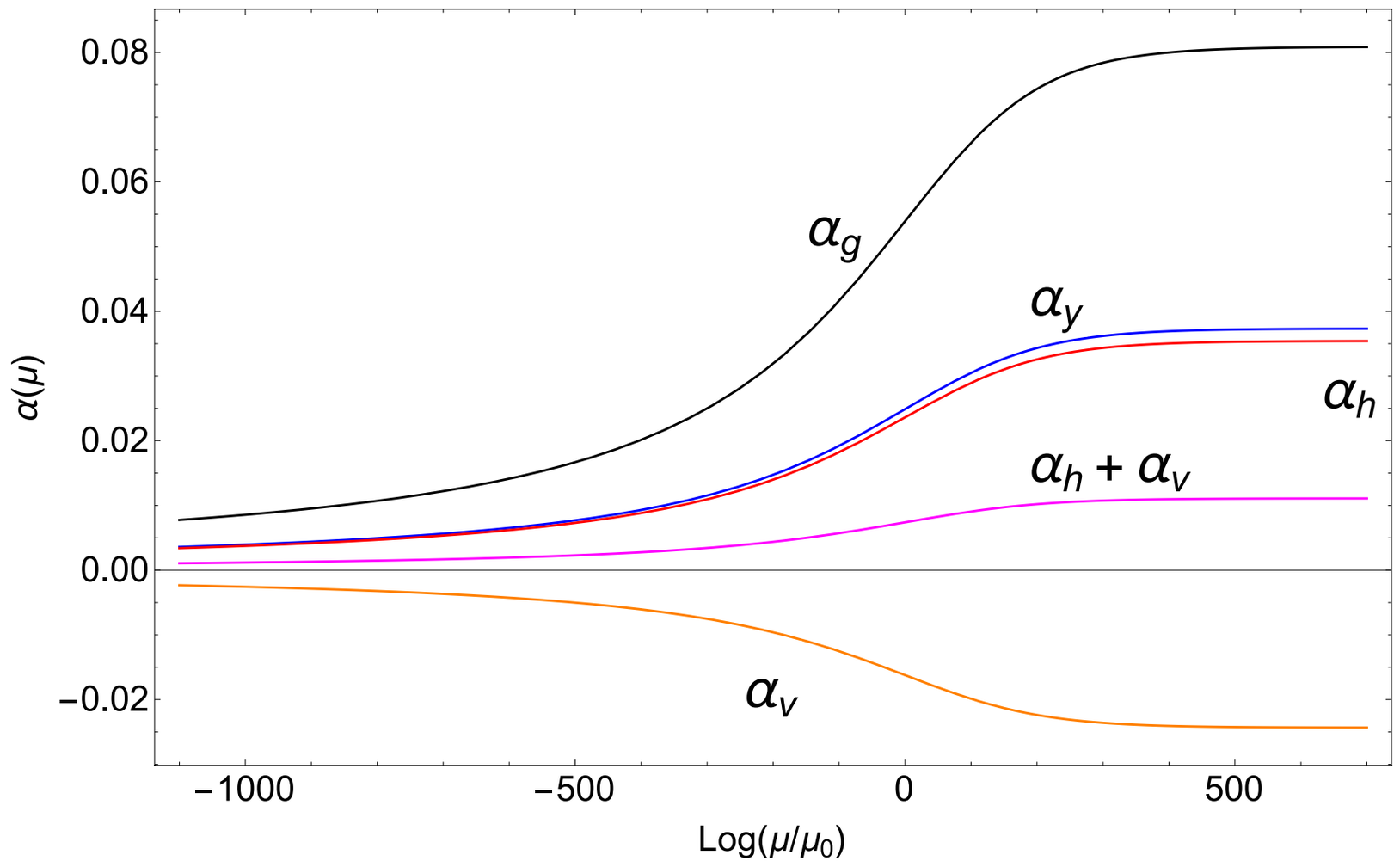

Scalars are needed to make the theory fundamental

Constraining new colored matter

Becciolini, Gillioz, Nardecchia, Sannino, Spannowsky 1403.7411, PRD

Sannino and Vignaroli, in preparation

Constraining new colored matter

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Sannino and Vignaroli, in preparation

Testing asymptotic freedom/alpha_s running

Constraining new colored matter

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Sannino and Vignaroli, in preparation

Testing asymptotic freedom/alpha_s running

- Probe QCD at harder scales
- Determine observables at LHC
- Model indep. bound of new colored states

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Caveats

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Becciolini, Gillioz, Nardecchia, Sannino, Spannowsky 1403.7411, PRD

Sannino and Vignaroli, in preparation

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Caveats

- Exp. alpha_s interpretations?
- Parton distributions functions
- …

Constraining new colored matter

Becciolini, Gillioz, Nardecchia, Sannino, Spannowsky 1403.7411, PRD

Sannino and Vignaroli, in preparation

Testing asymptotic freedom/alpha_s running

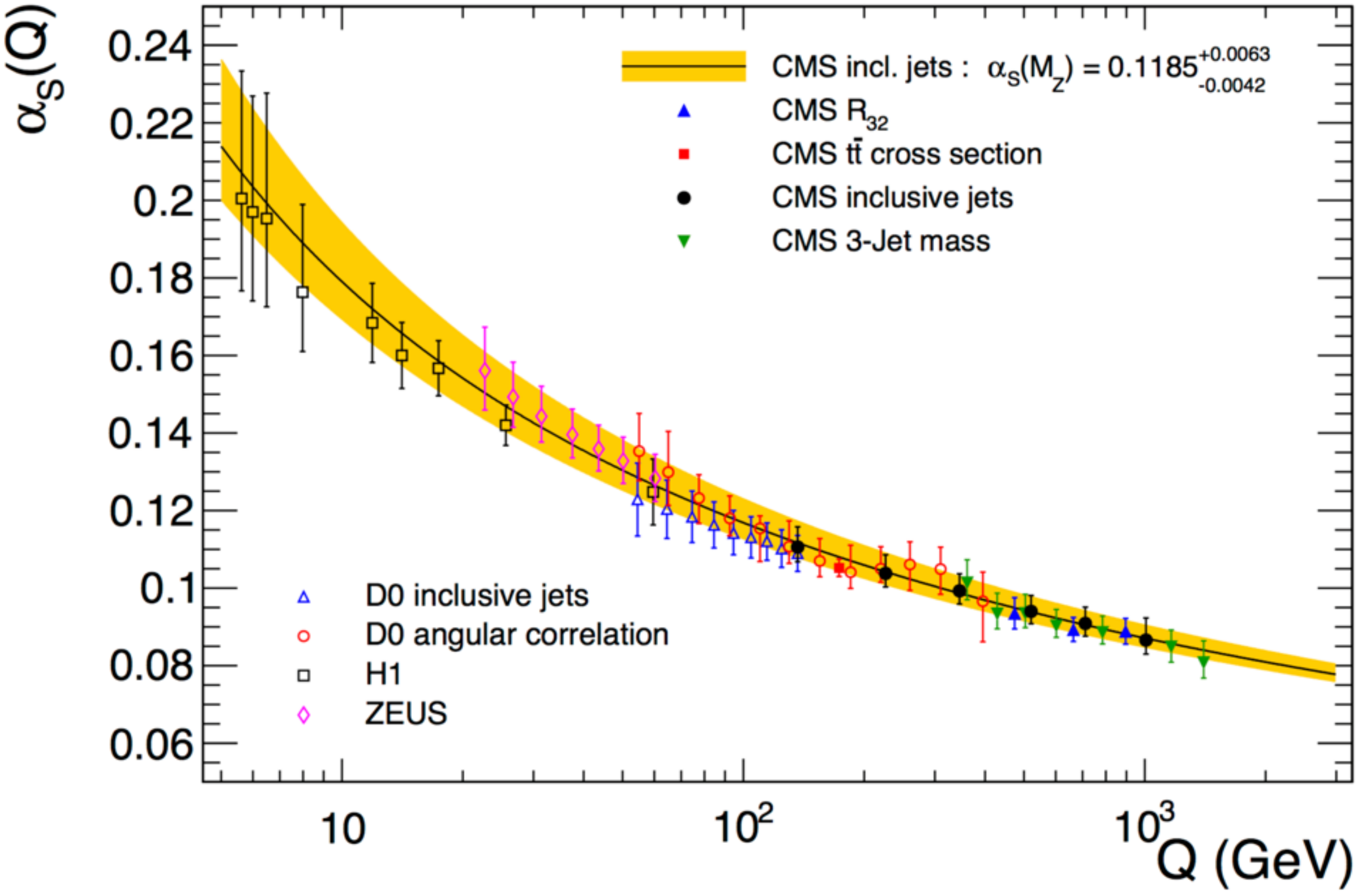
- Probe QCD at harder scales
- Determine observables at LHC
- Model indep. bound of new colored states

Caveats

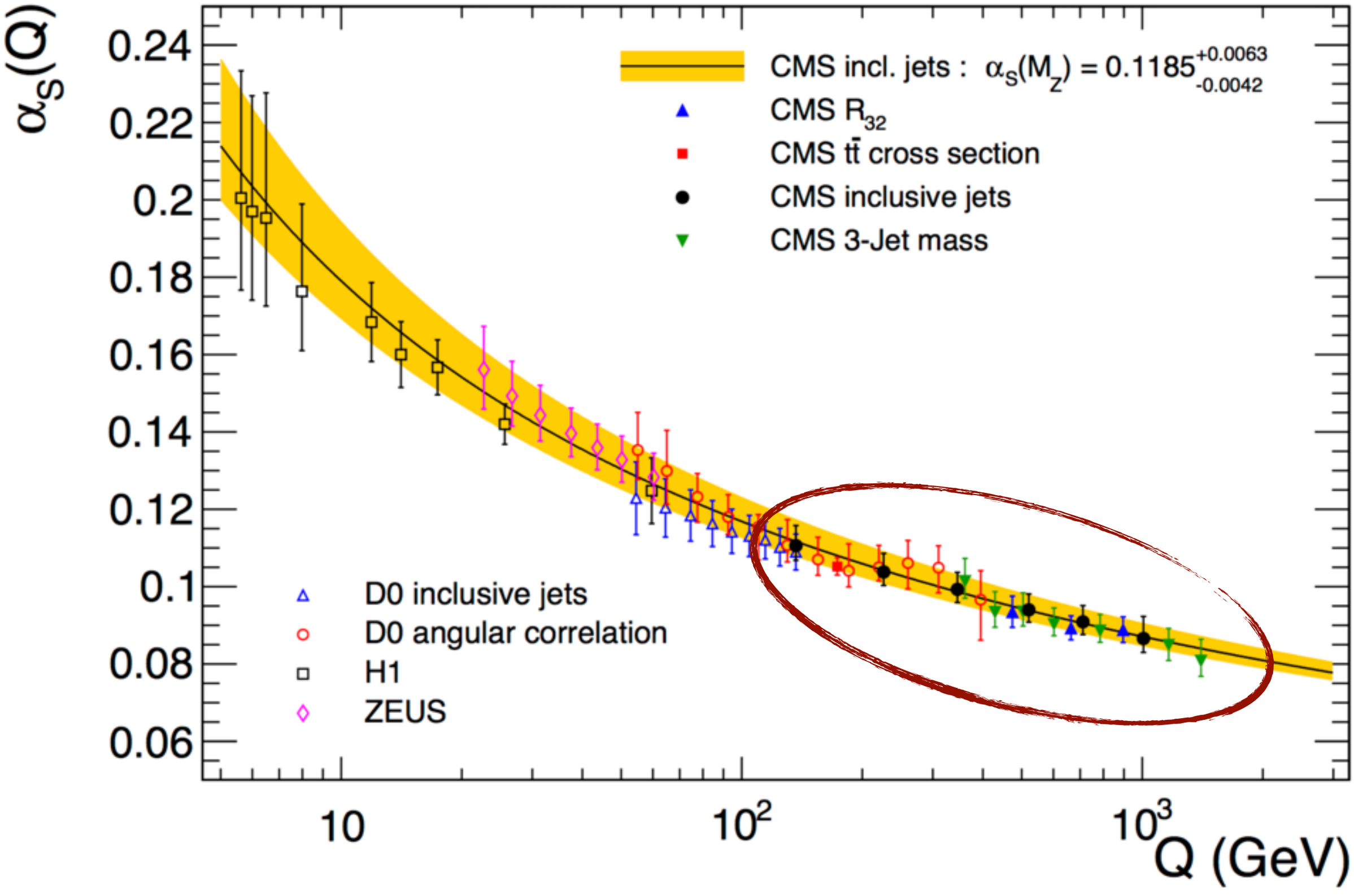
- Exp. alpha_s interpretations?
- Parton distributions functions
- …

Berger et al. 1010.4315, hadronic constraints

Kaplan and Schwartz 0804.2477, event shapes



ATLAS and CMS 1509.04380



ATLAS and CMS 1509.04380

R_{32} Observable

Chatrchyan et al. (CMS) 1304.7498

$$R_{32}\left(\langle p_{T1,2}\rangle\right) \equiv \frac{\mathrm{d}\sigma^{n_j\geq 3}/\mathrm{d}\left\langle p_{T1,2}\right\rangle}{\mathrm{d}\sigma^{n_j\geq 2}/\mathrm{d}\left\langle p_{T1,2}\right\rangle}$$

NLO in alpha_s and _w

NLO QCD via NLOJ$_{ET++}$

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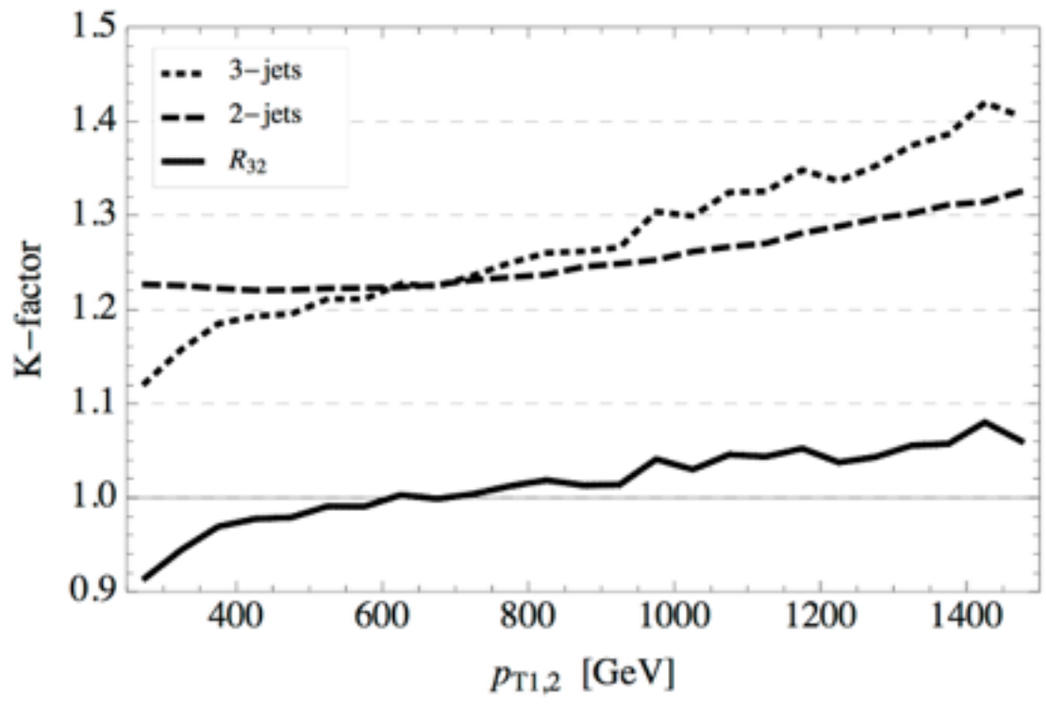
- 5-10%: RG/factorisation/resummation scales, tuning of showering
- R_{32} less sensitive to higher order corrections



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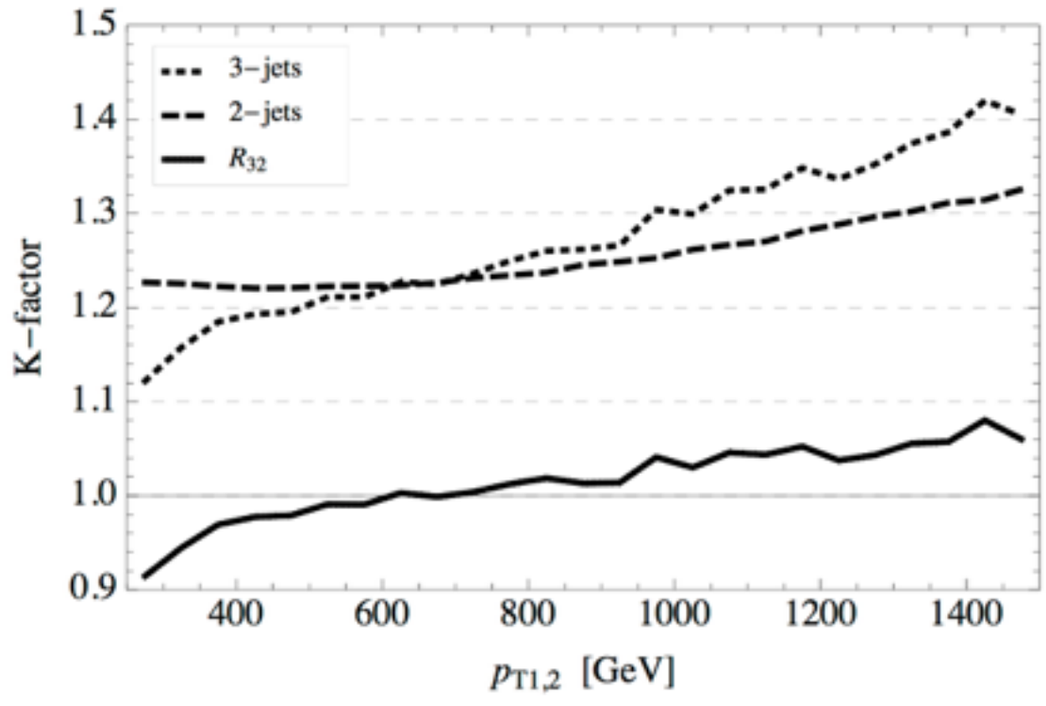

main issue

* 3-jet events involve multiple scales. Too naive identification.

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Running

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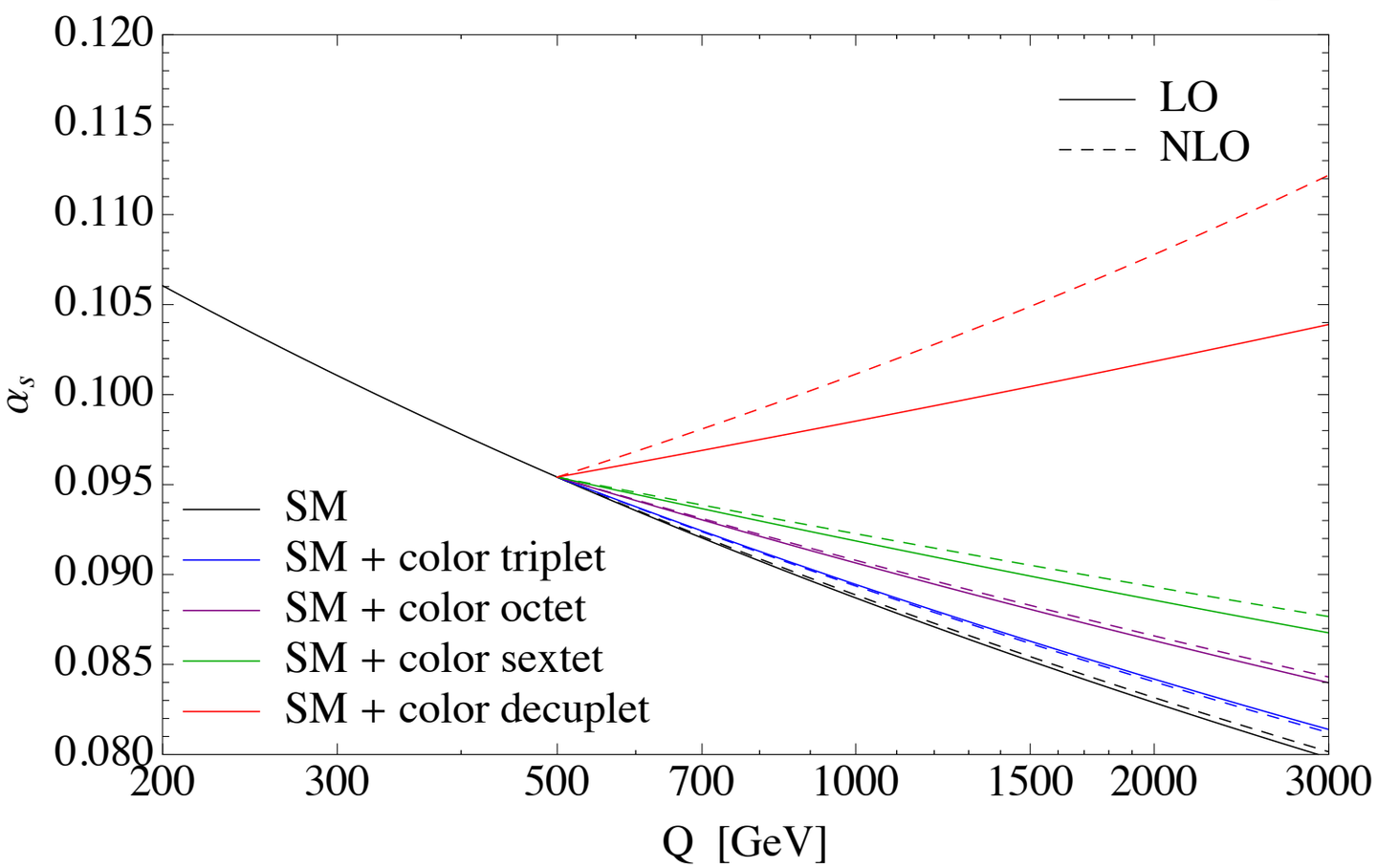

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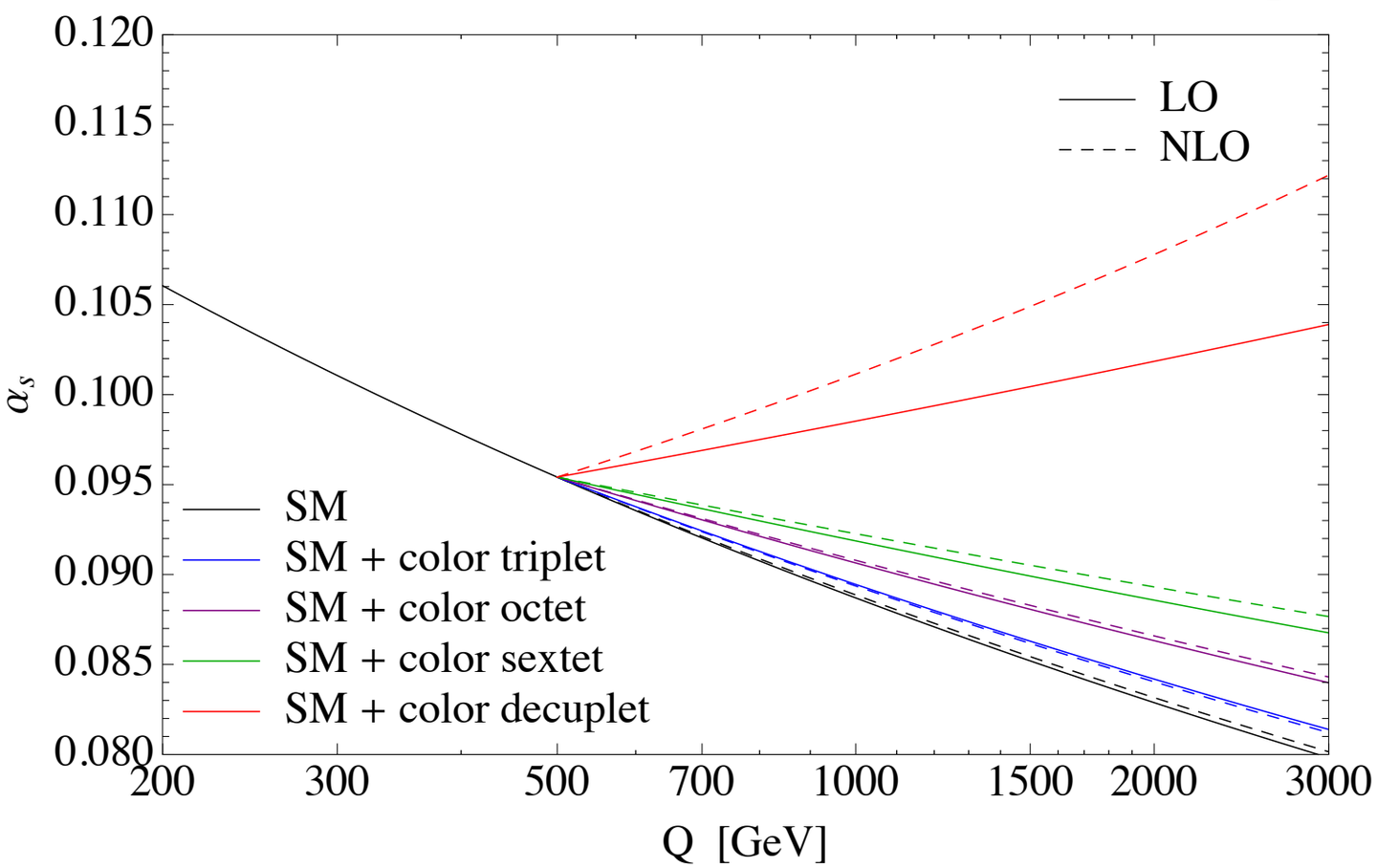

$$n_{\text{eff}}(MSSM) = 6$$

1 Gluino + 12 complex scalars

(1 Dirac = 4 Complex S)

Bounds

Chatrchyan et al. (CMS) 1304.7498

R_{32} CMS data

Q [GeV]	$\alpha_s^{exp}(Q) \pm \sigma(Q)$
474	0.0936 ± 0.0041
664	0.0894 ± 0.0031
896	0.0889 ± 0.0034

$$\alpha_s(M_Z) = 0.1185 \pm 0.0006$$

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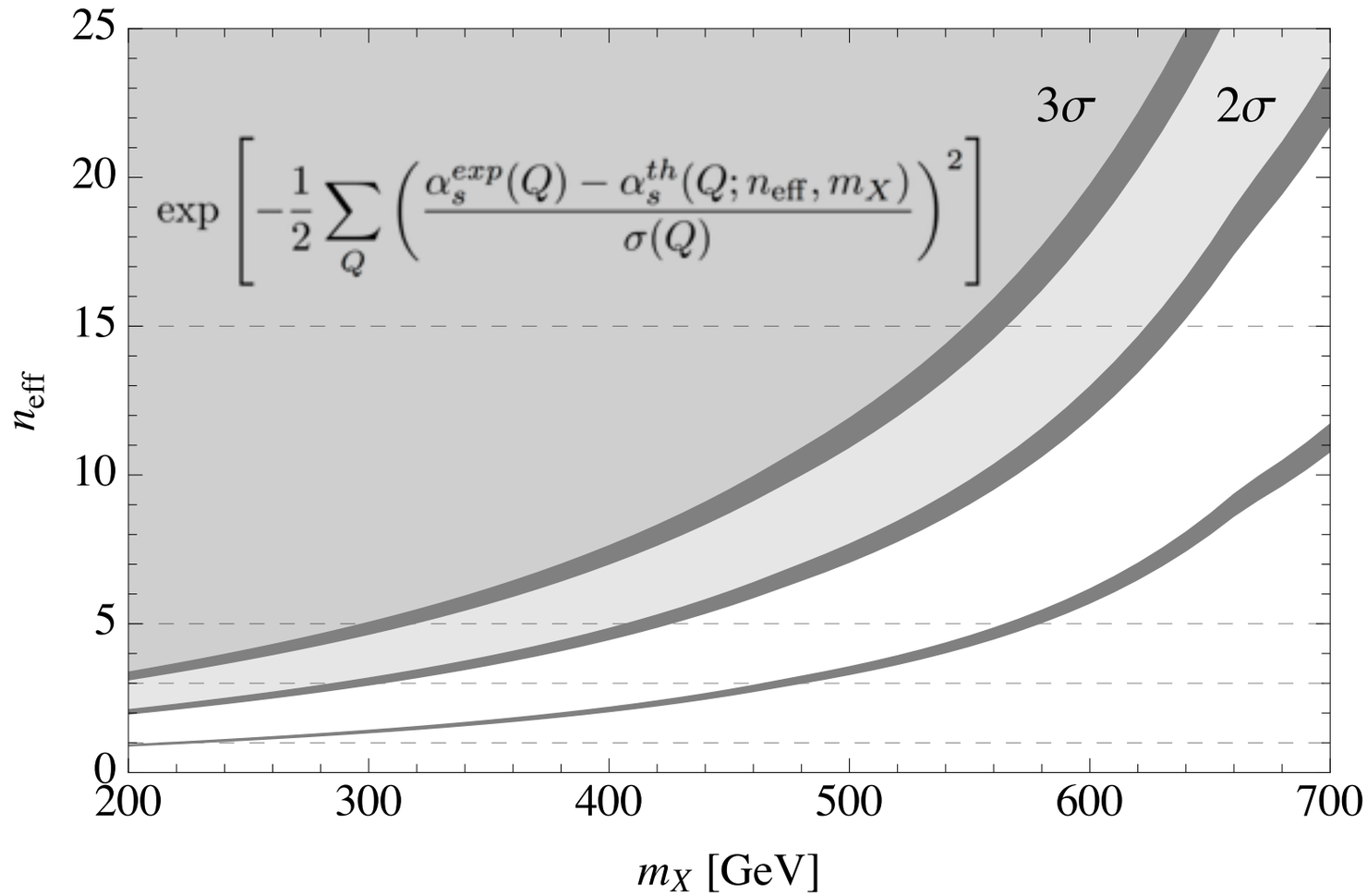

2-loop alpha_s varying C_X *w.r.t. fund. (small effect)*

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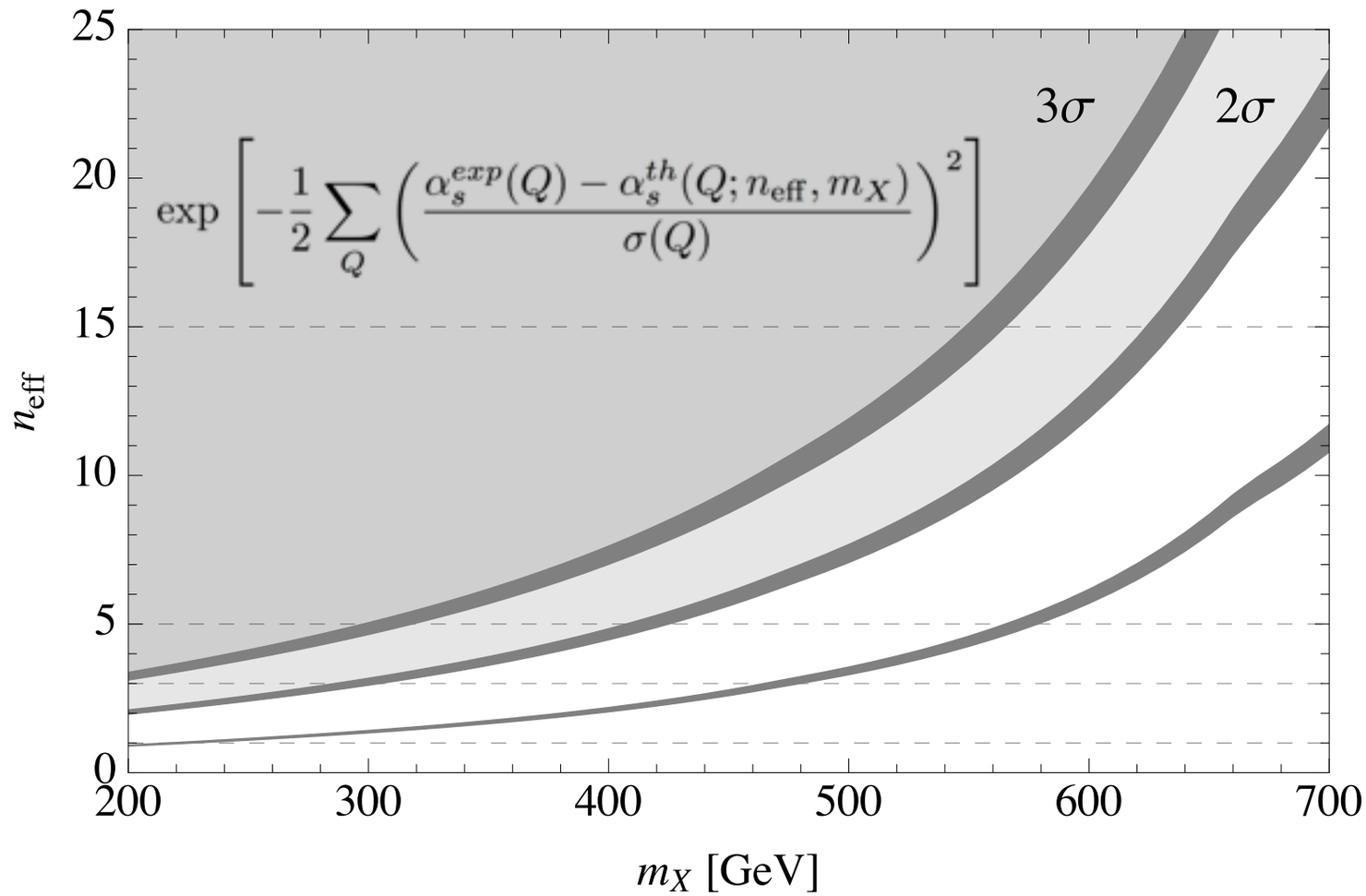

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95% CL mass exclusions bounds

color content	$n_{\rm eff}$	m_X in GeV
Gluino	3	280
Dirac sextet	5	410
MSSM	6	450
Dirac decuplet	15	620

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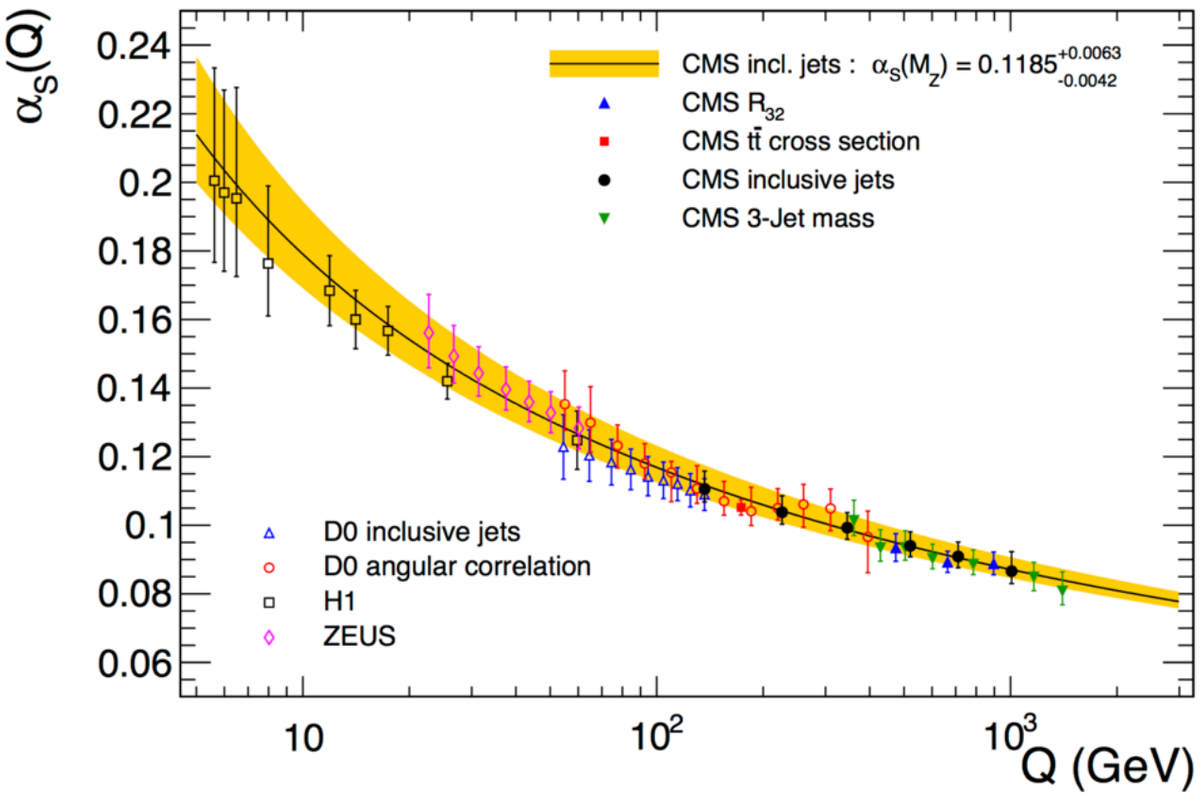
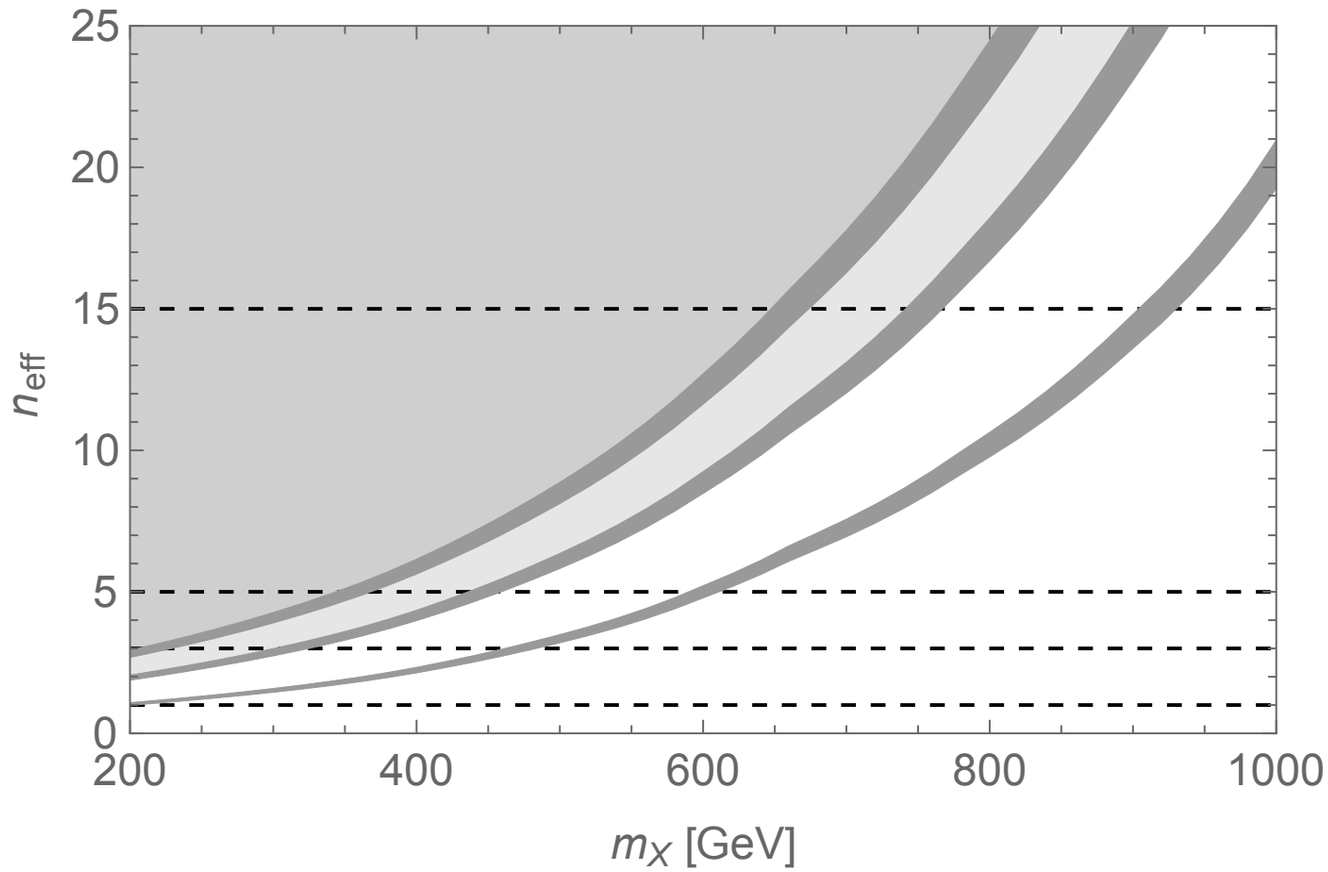
Updated Bounds

Sannino and Vignaroli (preliminary)





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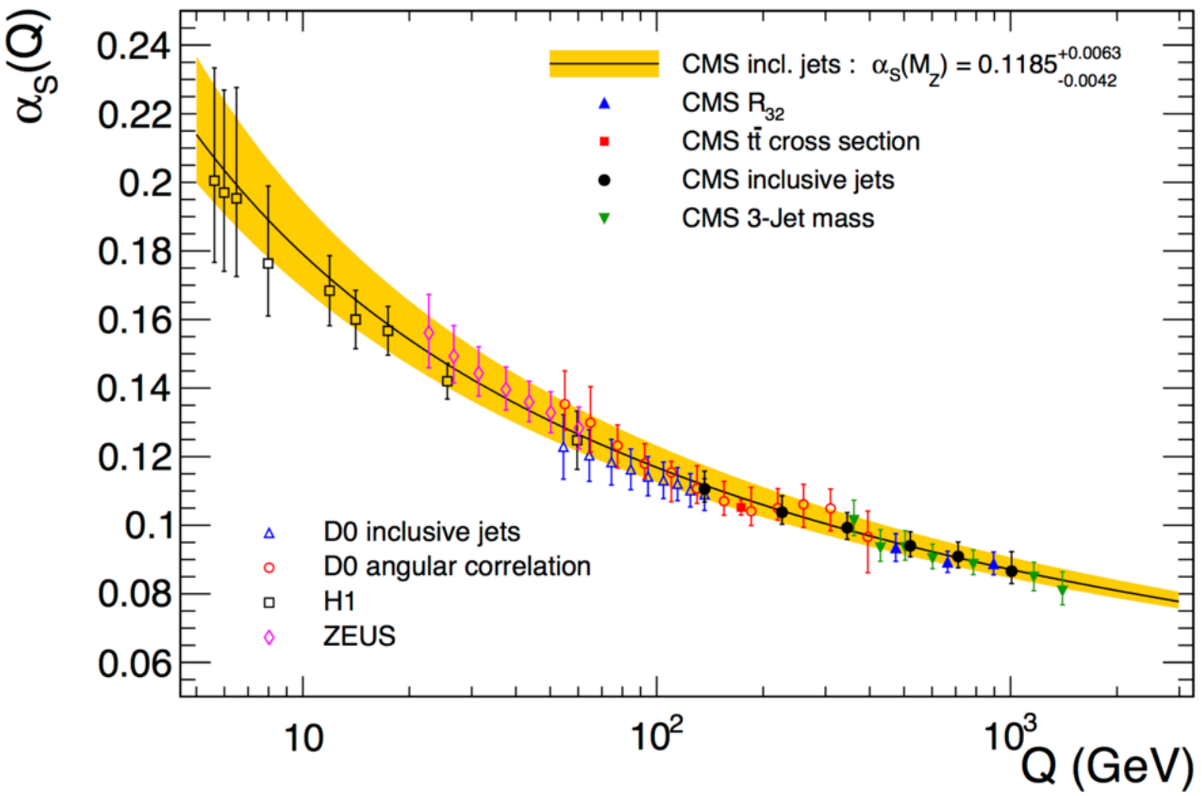

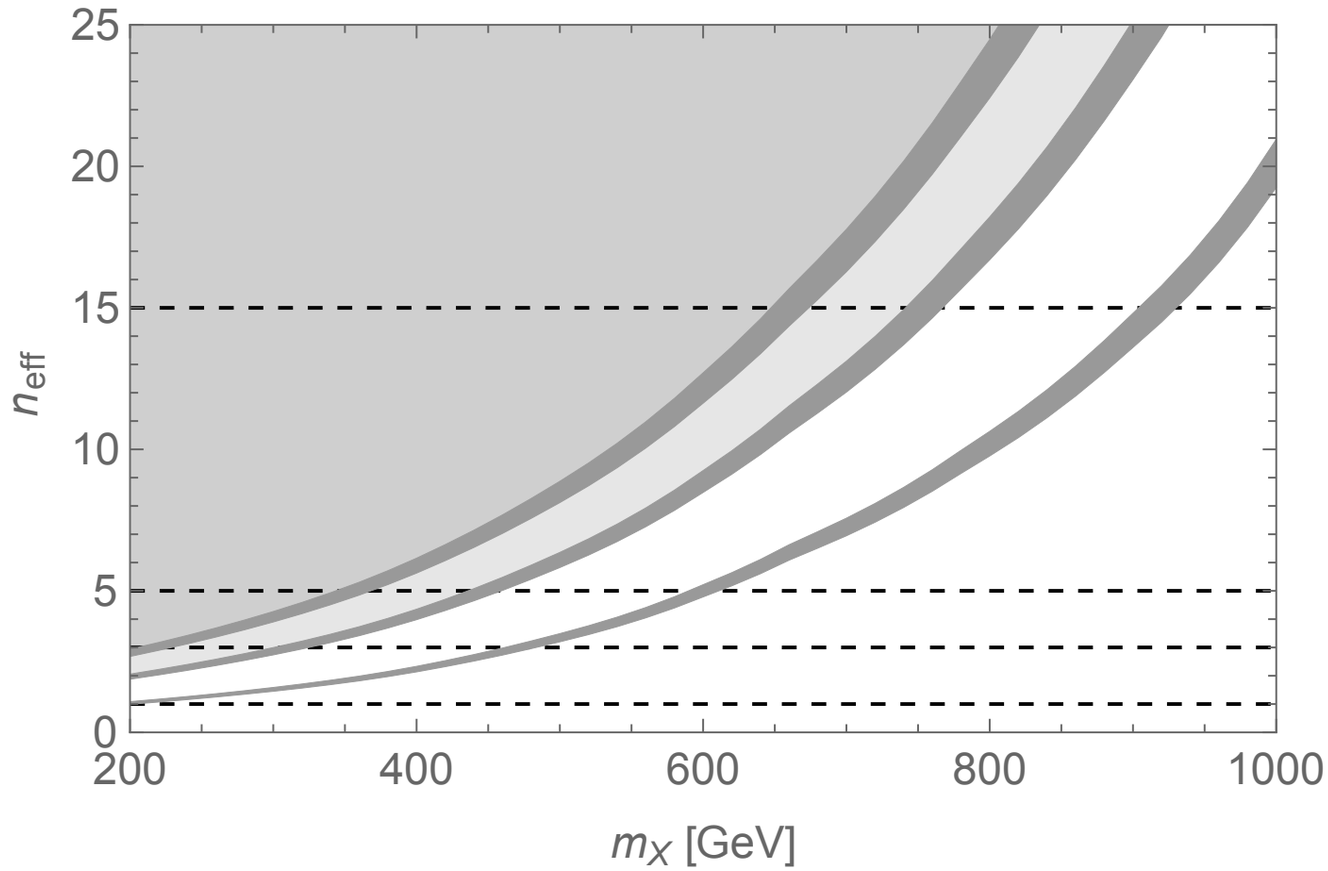

95% CL bounds increase roughly by 50 -100 GeV

Outlook

Asymptotic freedom to be tested

Novel safe paradigm requires new colored states

Extra colored states predicted from many SM extensions

General bounds on new colored states via pp collisions

Needs and challenges: identify better observables, effects on PDFs, (RG) scale setting and identification, ….