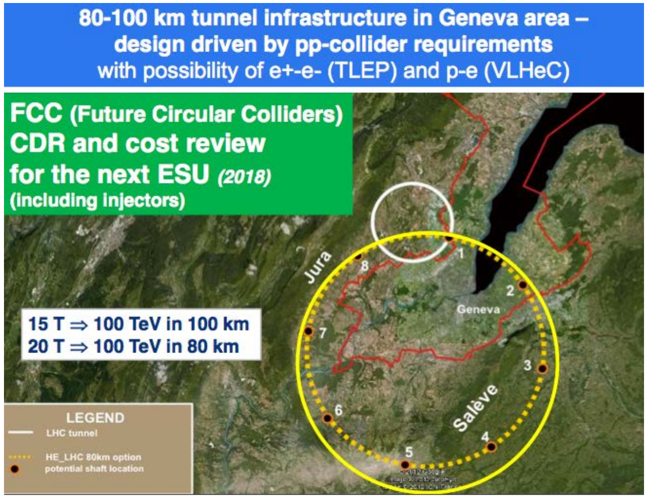
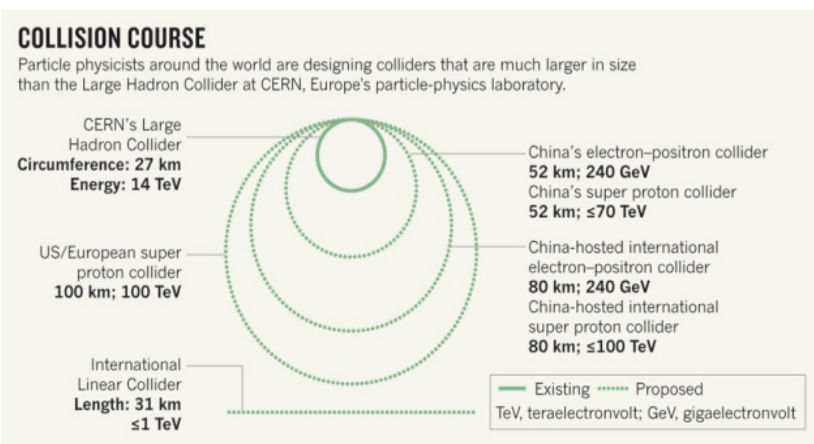
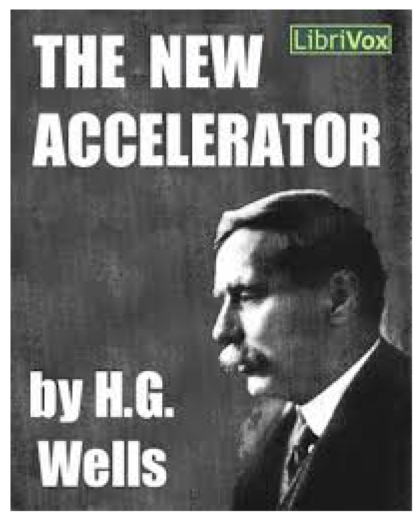
Luminosity Scaling Laws For Future Hadron Colliders







T.G. Rizzo 1501.05583 (EPJC) 5/4/15

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Some Obvious But Important Questions

- Should we have specific luminosity goals in mind for a future ~100 TeV hadron collider ?
- What criteria should we use to determine these goals ?
- What benchmark processes should we use to make this argument?
- Can we reconcile lumi requirements with accelerator & detector technology?

A balance is required: searches for high background, weakly coupled, ‘low-mass’ phenomena vs. searches for new heavy states will require different luminosities.

- B. Richter (1409.1196) has suggested maintaining the same scaled mass reach, $M_{NP}/\sqrt{s}$, as the LHC for new heavy states. In the scaling limit this means we need the lumi to scale as L ~ s ! ..which implies a factor of ~ 50(!) increase in lumi 'above that of LHC-14' for a 100 TeV collider.

→ What luminosities does this criterion actually require? (There are scaling violations in the real world.)

→ What is the search reach 'cost' if these (quite lofty) goals are not met ? How do the various search reaches scale with lumi?

→ One can ask what exactly does 'above that of LHC-14' mean? 300 fb^{-1} ? 1 ab^{-1} ? 3 ab^{-1} ? Where are we starting from ?

$$300\ fb^{-1} \rightarrow \sim 15\ ab^{-1}$$

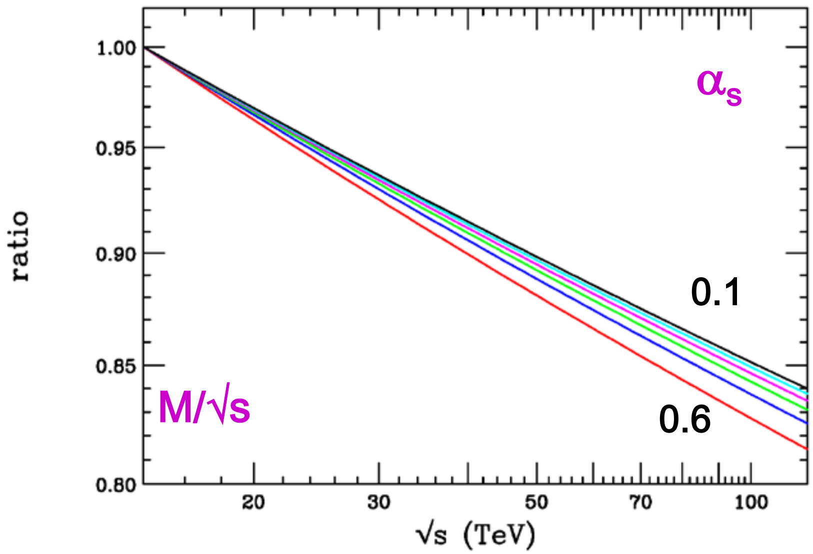
Burt (daily) suggested that I examine these questions…so..

The analysis presented here is very simple & is mostly based only on the event counts. A detailed analysis should leave the results qualitatively unchanged.

Recall: Scaling violations (SV) result from both the running of the couplings (mostly α_s) & the Q^2 -dependence of the PDFs & so will differ from process to process .. but in all cases they lead to reduced σ's compared to the scaling limit.

$\rightarrow$ NNLO MMHT2014
1412.3989

- A given production process depends upon various products of the PDFs & powers of α_s . Showing how much the SV in these individual products reduce σ (for $M_{NP}/\sqrt{s}$ held fixed) as $\sqrt{s}$ increases is interesting...

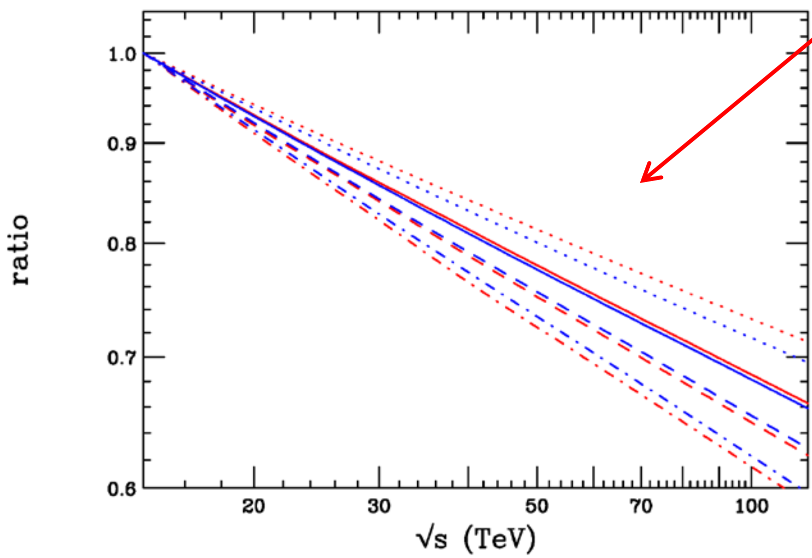


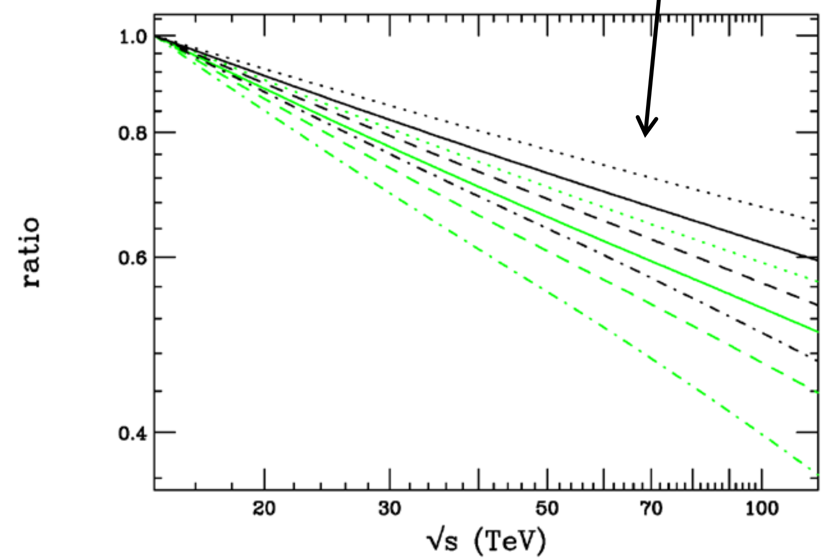
← Running of α_s for fixed $M\sqrt{s}$

Below we see ratios of the PDF luminosities in comparison to their scaling values as functions of $\sqrt{s}$ for fixed $M\sqrt{s}$.

red = uu-bar
blue = dd-bar

green = gg
black = gq





$M/\sqrt{s}$ = 0.3, 0.4, 0.5, 0.6 correspond to dotted, solid, dash, dash-dot curves

Supercollider physics

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Eichten *et al.* summarize the motivation for exploring the 1-TeV ($=10^{12}$ eV) energy scale in elementary particle interactions and explore the capabilities of proton-(anti)proton colliders with beam energies between 1 and 50 TeV. The authors calculate the production rates and characteristics for a number of conventional processes, and discuss their intrinsic physics interest as well as their role as backgrounds to more exotic phenomena. The authors review the theoretical motivation and expected signatures for several new phenomena which may occur on the 1-TeV scale. Their results provide a reference point for the choice of machine parameters and for experiment design.

CONTENTS

I. INTRODUCTION

The physics of elementary particles has undergone a remarkable development during the past decade. A host of new experimental results made accessible by a new generation of particle accelerators and the accompanying rapid convergence of theoretical ideas have brought to the subject a new coherence. Our current outlook has been shaped by the identification of quarks and leptons as fundamental constituents of matter and by the gauge theory synthesis of the fundamental interactions.[1] These developments represent an important simplification of

[1]For expositions of the current paradigm, see the textbooks by Okun (1981), Perkins (1982), Aitchison and Hey (1982), Leader and Predazzi (1982), Quigg (1983), and Halzen and Martin (1984) and the summer school proceedings edited by Gaillard and Stora (1983).

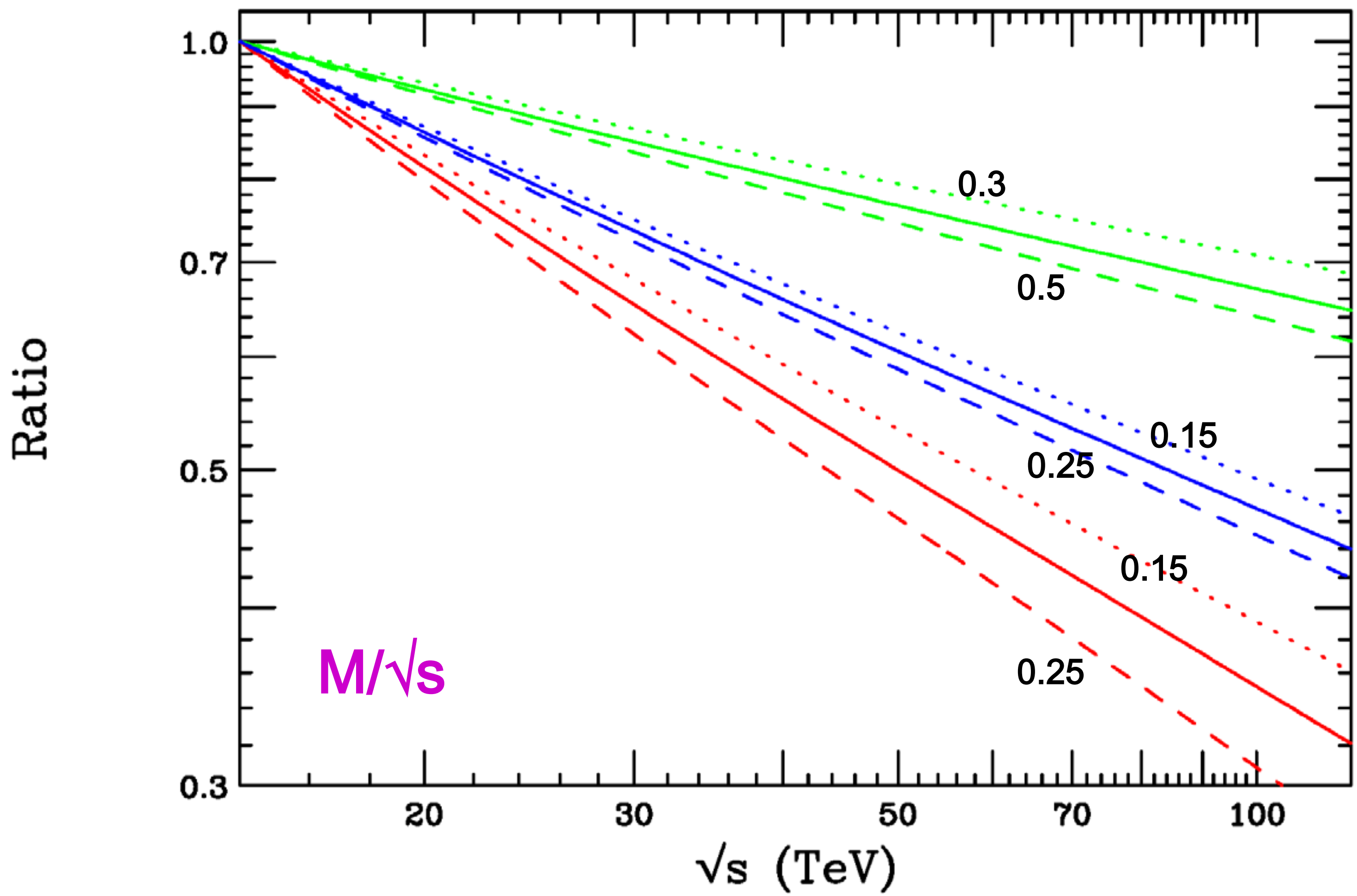
We follow the traditional method of selecting an array of BSM models, each with its own luminosity scaling law & then make some comparisons*

Except for the W' case, 100 evts will be assumed as the required lumi target for NP. (The W' case was examined in detail in 1403.5465)

→ Even larger lumis are needed to maintain the same $M_{NP}/\sqrt{s}$ than what are obtained from the scaling argument above

* For a recent detailed discussion of the lumi requirements at 100 TeV, see Hinchliffe et al. in 1504.06108. These authors advocate a luminosity in the 10-20 ab^{-1} range.

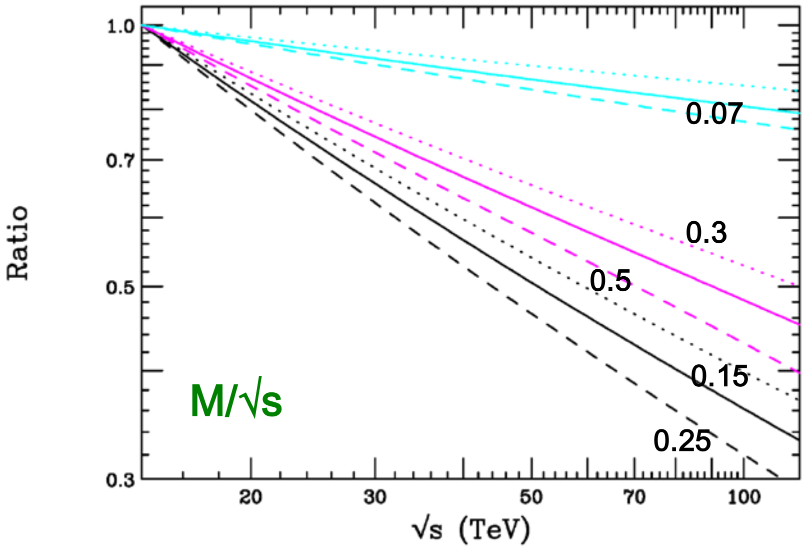
To quantify this, fix $M/\sqrt{s}$ & then determine $\sigma/\sigma_{Scaling}$, e.g.



Green= qq-bar → W±' →lν
Blue = qq-bar → QQ-bar
Red = gg → QQ-bar

Note the decrease as $M/\sqrt{s}$ increases.
These are substantial reductions..
but they are hardly unique.

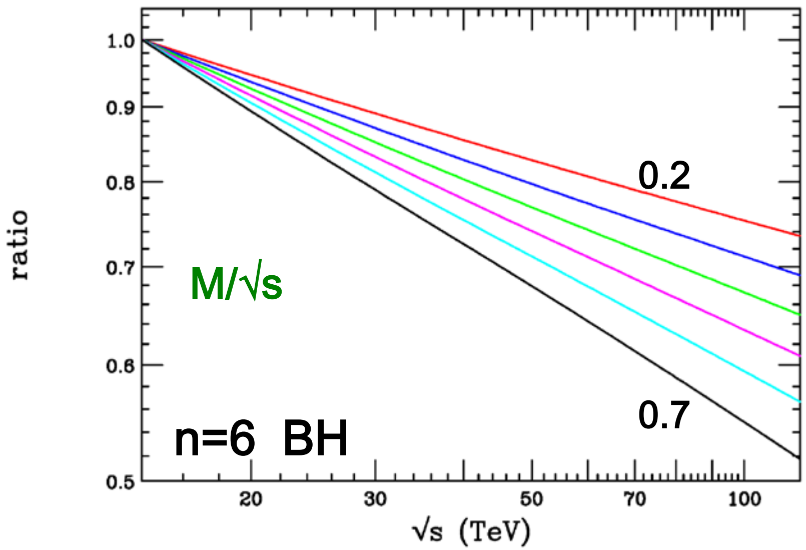
$\sigma/\sigma_{Scaling}$



qq-bar → L+L-

gq → q* → dijets $|\eta_j| < 0.5$

gg+qq-bar → LQ LQ-bar (triplet scalar)



The magnitude of the cross section reductions from SV are found to be process dependent but they occur in all BSM scenarios

Note that they are almost linear In log-log over the mass & energy ranges of interest

So the answer to Burt's question: "What luminosities are needed at 100 TeV to preserve the scaled mass reaches of the 14 TeV LHC ?"

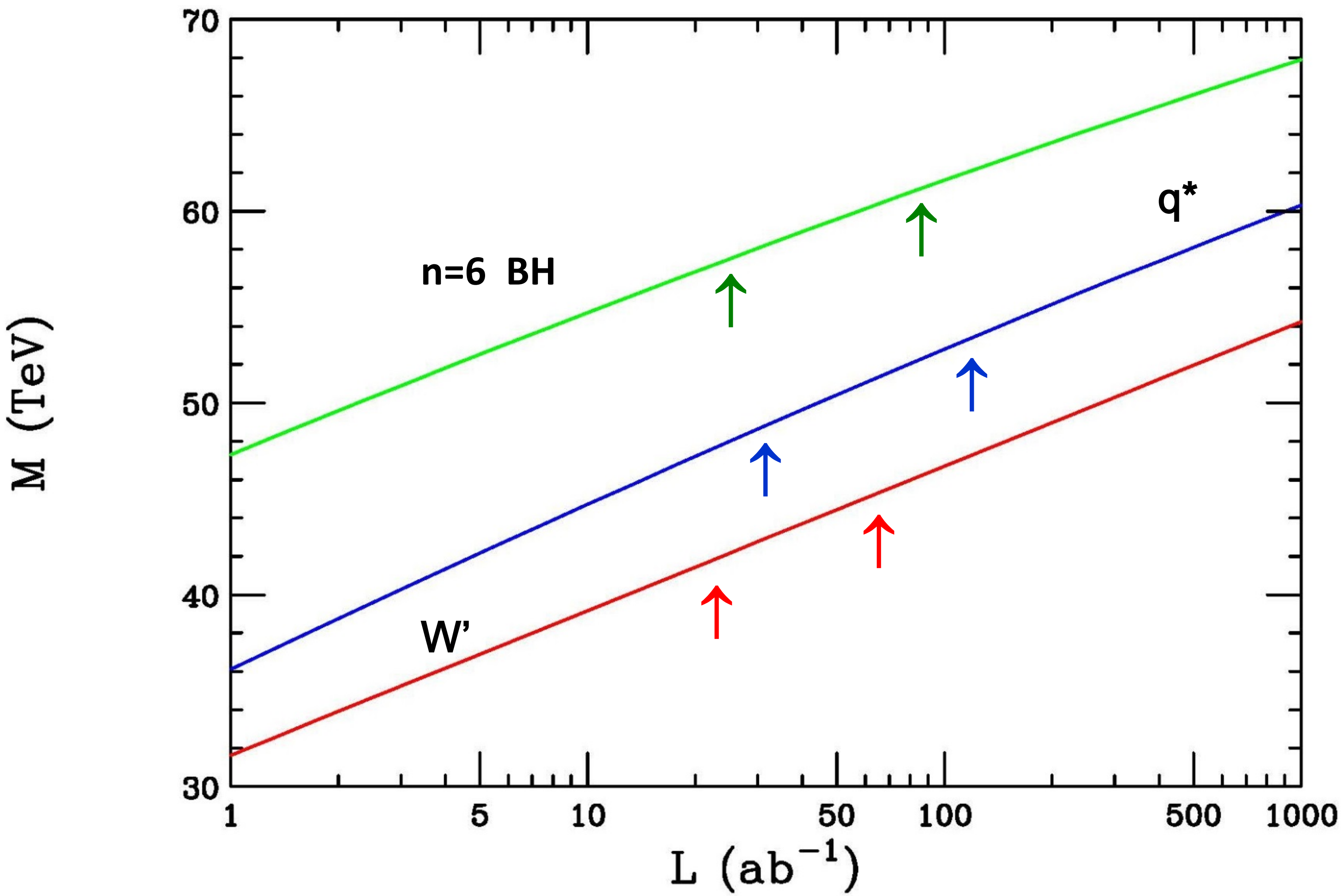
Particle	$M/\sqrt{s}$	L(100)/L(14)
W'	0.30	74.3
W'	0.50	79.6
Q($q\bar{q}$)	0.15	103.6
Q($q\bar{q}$)	0.25	113.5
Q(gg)	0.15	130.5
Q(gg)	0.25	165.2
L	0.03	59.9
L	0.07	65.9
LQ	0.15	127.9
LQ	0.25	159.4
q^*	0.40	96.5
q^*	0.60	118.8
BH6	0.20	67.8
BH6	0.70	93.0

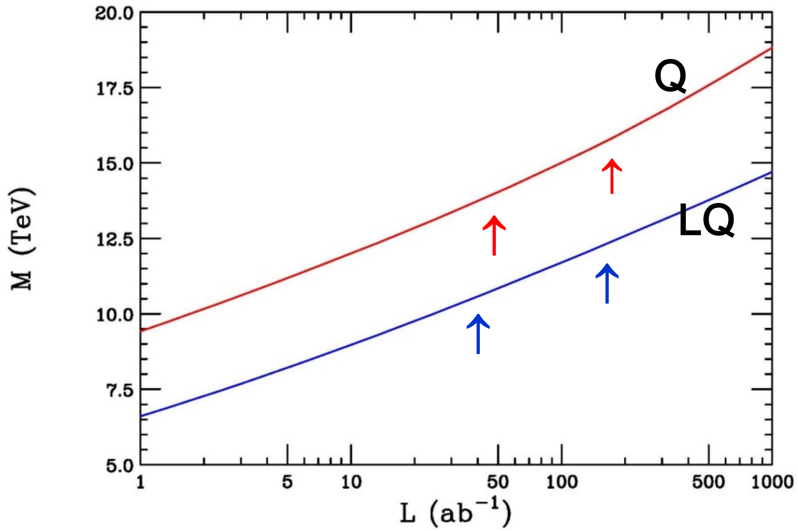
← These lie in the ~60 -165 range vs the scaling expectation of ~50.

- EWK qq-bar processes show the smallest increases due to SV
- O(α_s^2) gg-dominated processes show the largest increases due to SV

Next question: if we fail to attain these lumis how are the reaches affected?

Search reaches grow slowly with increases luminosity ~ log L

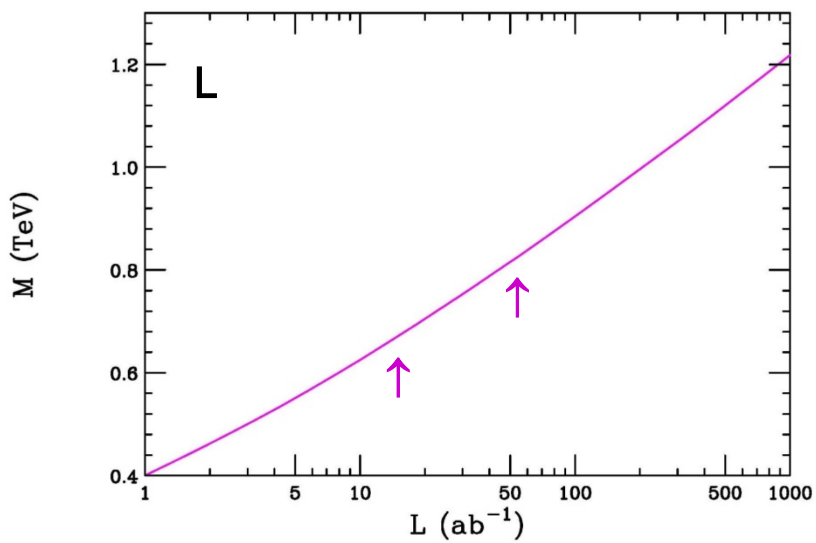




Scaling from 300 fb^{-1} @ 14 TeV puts us in the 15 – 55 ab $^{-1}$ lumi range at 100 TeV for most BSM scenarios

However an order of magnitude change in the luminosity in either direction from 10 ab^{-1} only modifies these search reaches by ~20-30%

→ Very high lumis don't add too much to search reaches



Particle	1 ab^{-1}	100 ab^{-1}	10 ab^{-1}
W'	31.6	46.7	39.1
Q	9.42	15.57	12.40
L	0.40	0.90	0.625
LQ	6.60	11.70	8.97
q^*	36.1	46.7	44.7
BH6	47.3	67.9	54.7

Summary & Conclusions

- If we require maintaining the same scaled mass reach, M/√s, as √s increases then the luminosity required at a 100 TeV collider compared to LHC-14 must be ~55-165x larger.. This depends on the process. This is larger than the factor of ~50 obtained by assuming scaling
- The luminosity dependence of BSM mass reaches roughly scales as ~ log L
- Changes in lumi by an order of magnitude modify the search reaches for BSM by only ~20-30%at most
- More sophisticated studies with signal and backgrounds details need to be performed

Backups