

Collider reach β

Estimating the reach of (hadron) colliders
using parton luminosities

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Wine & cheese seminar, about work in progress,
Princeton University, February 28, 2014

It's common to want to estimate the ability of a given collider to search for new particle/phenomenon "X".

E.g.

How soon will LHC@13TeV beat 8TeV searches?

What can high-luminosity LHC (3000fb^{-1}) find/exclude and how does that compare to LHC as originally planned (300fb^{-1})?

How large is the gain from a future
33/50/100/150 TeV collider?

The proper way of doing it:

Generate Monte Carlo events for signal and background,
process them through a detector simulation,
design and carry out an optimal analysis,
work out discovery/exclusion reach.

**This is very time consuming (months of work!),
and not always easy to do optimally.**

**Can we find an alternative that's
easy, quick and adequately good?**

(and in the process maybe learn some general lessons?)

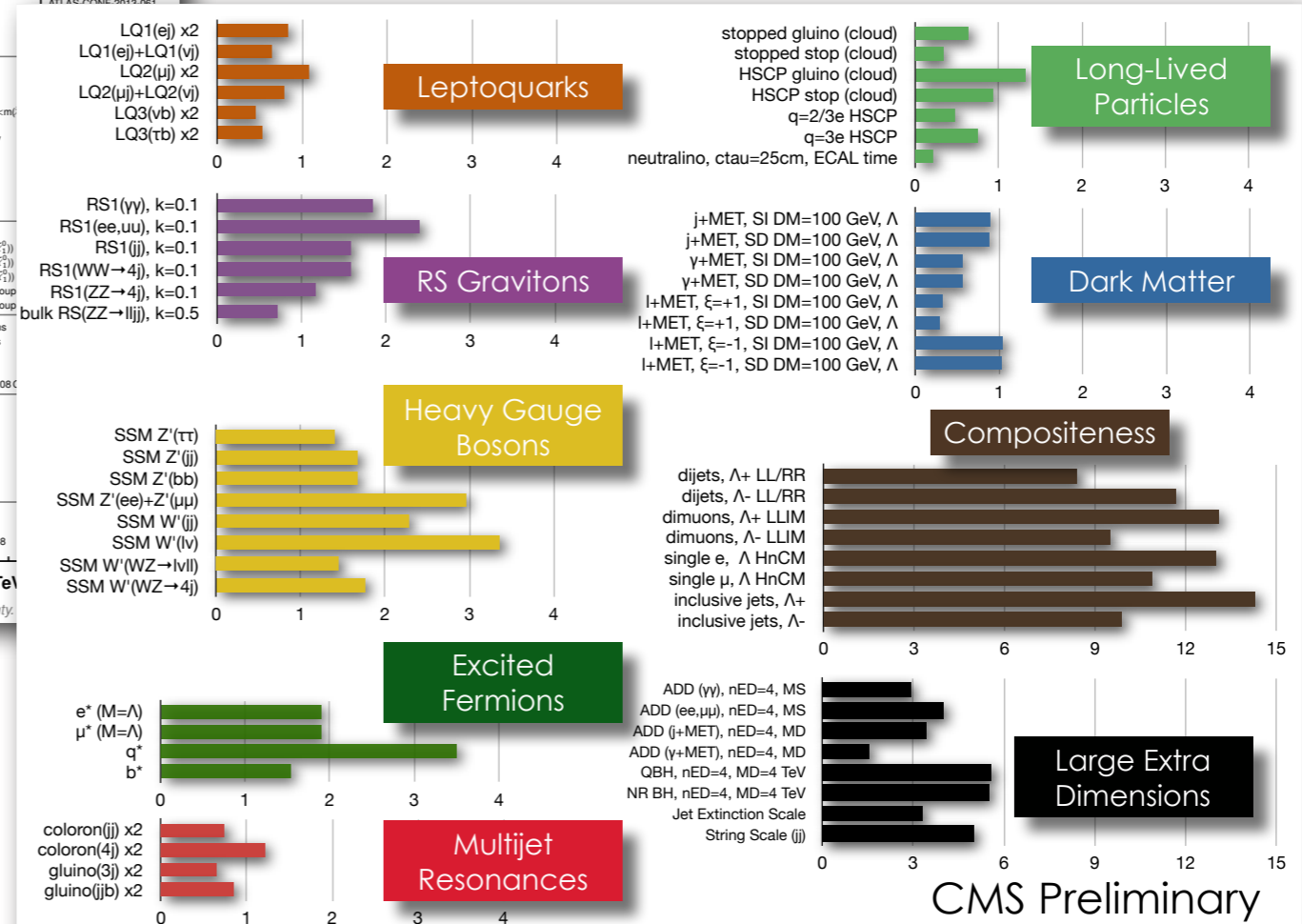
There are already many well-designed searches

ATLAS SUSY Searches* - 95% CL Lower Limits
 Status: SUSY 2013 ATLAS Preliminary
 $\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$

Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference		
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	\tilde{g}, \tilde{g} 1.7 TeV	ATLAS-CONF-2013-047	
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.2 TeV	ATLAS-CONF-2013-062	
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	\tilde{g} 1.1 TeV	1308.1841	
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{q}\tilde{q}_1^0$	0	2-6 jets	Yes	20.3	\tilde{q} 740 GeV	ATLAS-CONF-2013-047	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{q}_1^0$	0	2-6 jets	Yes	20.3	\tilde{g} 1.3 TeV	ATLAS-CONF-2013-047	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{q}_1^0 + qqW^{\pm}\tilde{q}_1^0$	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.18 TeV	ATLAS-CONF-2013-062	
	GMSB (\tilde{L} NLSP)	2 e, μ	0-3 jets	-	20.3	\tilde{g} 1.12 TeV	ATLAS-CONF-2013-089	
	GMSB (\tilde{L} NLSP)	2 e, μ	2-4 jets	Yes	4.7	\tilde{g} 1.24 TeV	1208.4688	
	GGM (bino NLSP)	1-2 τ	0-2 jets	Yes	20.7	\tilde{g} 1.4 TeV	ATLAS-CONF-2013-026	
	GGM (wino NLSP)	2 γ	-	Yes	4.8	\tilde{g} 1.07 TeV	1209.0753	
3 rd gen. squarks & gluons	$\tilde{g} \rightarrow b\tilde{b}^0$	0	3 b	Yes	20.1	\tilde{g} 1.2 TeV	$m(\tilde{g}) < 600 \text{ GeV}$	
	$\tilde{g} \rightarrow t\tilde{t}^0$	0	7-10 jets	Yes	20.3	\tilde{g} 1.1 TeV	$m(\tilde{g}) < 350 \text{ GeV}$	
	$\tilde{g} \rightarrow \tau\tilde{\tau}^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.34 TeV	$m(\tilde{g}) < 400 \text{ GeV}$	
	$\tilde{g} \rightarrow b\tilde{t}_1^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.3 TeV	$m(\tilde{g}) < 300 \text{ GeV}$	
	3 rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{t}_1^0$	2 e, μ (SS)	2 b	Yes	20.1	\tilde{b}_1 100-620 GeV	$m(\tilde{b}_1) < 90 \text{ GeV}$
		$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow t\tilde{t}_1^0$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{b}_1 275-430 GeV	$m(\tilde{b}_1) = 2 m(\tilde{t}_1^0)$
		$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\tilde{t}_1^0$	1-2 e, μ	1-2 b	Yes	4.7	\tilde{t}_1 110-167 GeV	$m(\tilde{t}_1) = 55 \text{ GeV}$
		$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow Wb\tilde{t}_1^0$	2 e, μ	0-2 jets	Yes	20.3	\tilde{t}_1 130-220 GeV	$m(\tilde{t}_1) = m(\tilde{t}_1) - m(W) - 50 \text{ GeV}, m(\tilde{t}_1) < m(\tilde{g})$
		$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow t\tilde{t}_1^0$	2 e, μ	2 jets	Yes	20.3	\tilde{t}_1 225-525 GeV	$m(\tilde{t}_1) = 0 \text{ GeV}$
		$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow b\tilde{t}_1^0$	1 e, μ	2 b	Yes	20.1	\tilde{t}_1 150-580 GeV	$m(\tilde{t}_1) < 200 \text{ GeV}, m(\tilde{t}_1) - m(\tilde{t}_1^0) = 5 \text{ GeV}$
$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{t}_1^0$		0	2 b	Yes	20.7	\tilde{t}_1 200-610 GeV	$m(\tilde{t}_1) = 0 \text{ GeV}$	
$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{t}_1^0$		0	2 b	Yes	20.5	\tilde{t}_1 320-660 GeV	$m(\tilde{t}_1) = 0 \text{ GeV}$	
$\tilde{t}_1\tilde{t}_1$ (natural GMSB)		2 e, μ (Z)	1 b	Yes	20.7	\tilde{t}_1 500 GeV	$m(\tilde{t}_1) - m(\tilde{t}_1^0) < 85 \text{ GeV}$	
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$		3 e, μ (Z)	1 b	Yes	20.7	\tilde{t}_2 271-520 GeV	$m(\tilde{t}_2) > 150 \text{ GeV}$	
EW direct	$\tilde{L}_L\tilde{L}_L, \tilde{L} \rightarrow \tilde{L}^0$	2 e, μ	0	Yes	20.3	\tilde{L} 85-315 GeV	$m(\tilde{L}) = 0 \text{ GeV}$	
	$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow \tilde{L}^0(\tilde{\nu})$	2 e, μ	0	Yes	20.3	\tilde{L}_1 125-450 GeV	$m(\tilde{L}_1) = 0 \text{ GeV}, m(\tilde{L}_1) = 0.5(m(\tilde{L}_1) + m(\tilde{L}_1^0))$	
	$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow \tilde{L}^0(\tilde{\nu})$	2 τ	-	Yes	20.7	\tilde{L}_1 180-330 GeV	$m(\tilde{L}_1) = 0 \text{ GeV}, m(\tilde{L}_1) = 0.5(m(\tilde{L}_1) + m(\tilde{L}_1^0))$	
	$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow \tilde{L}^0(\tilde{\nu})$	3 e, μ	0	Yes	20.7	\tilde{L}_1 315 GeV	$m(\tilde{L}_1) = m(\tilde{L}_1^0), m(\tilde{L}_1^0) = 0, \text{ sleptons decouple}$	
	$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow W\tilde{L}_1^0$	3 e, μ	0	Yes	20.7	\tilde{L}_1 285 GeV	$m(\tilde{L}_1) = m(\tilde{L}_1^0), m(\tilde{L}_1^0) = 0, \text{ sleptons decouple}$	
	$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow W\tilde{L}_1^0$	1 e, μ	2 b	Yes	20.3	\tilde{L}_1 270 GeV	$m(\tilde{L}_1) - m(\tilde{L}_1^0) = 160 \text{ MeV}, \tau(\tilde{L}_1^0) = 0.2 \text{ ns}$	
	Long-lived particles	Direct $\tilde{L}_1\tilde{L}_1$ prod., long-lived \tilde{L}_1^0	Disapp. trk	1 jet	Yes	20.3	\tilde{L}_1 475 GeV	$m(\tilde{L}_1) = 100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{L}_1^0) < 1000 \text{ s}$
		Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	22.9	\tilde{g} 832 GeV	$10^{-4} < \tau(\tilde{g}) < 50$
		GMSB, stable $\tilde{L}_1 \rightarrow \tilde{L}_1^0 + \tau(e, \mu)$	1-2 μ	-	-	15.9	\tilde{L}_1 230 GeV	$0.4 < \tau(\tilde{L}_1^0) < 2 \text{ ns}$
		GMSB, $\tilde{L}_1 \rightarrow \tilde{L}_1^0 + G$, long-lived \tilde{L}_1^0	2 γ	-	-	4.7	\tilde{L}_1 475 GeV	$1.5 < \tau < 156 \text{ mm}, \text{BR}(\mu) = 1, m(\tilde{L}_1^0) = 108 \text{ GeV}$
$\tilde{q}\tilde{q}, \tilde{L}_1 \rightarrow q\tilde{q}\mu$ (RPV)		1 μ , displ. vtx	-	-	20.3	\tilde{q} 1.0 TeV		
RPV		LFV $pp \rightarrow \tilde{\nu}_e + X, \tilde{\nu}_e \rightarrow e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_e$ 1.61 TeV	$A_{131} = 0.10, A_{132} = 0.05$
		LFV $pp \rightarrow \tilde{\nu}_e + X, \tilde{\nu}_e \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_e$ 1.1 TeV	$A_{131} = 0.10, A_{12133} = 0.05$
		Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	\tilde{g}, \tilde{g} 1.2 TeV	$m(\tilde{g}) = m(\tilde{g}), c\tau_{\tilde{LSP}} < 1 \text{ mm}$
		$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow W\tilde{L}_1^0, \tilde{L}_1 \rightarrow ee\tilde{\nu}_e, e\mu\tilde{\nu}_e$	4 e, μ	-	-	20.7	\tilde{L}_1 760 GeV	$m(\tilde{L}_1) > 300 \text{ GeV}, A_{121} > 0$
		$\tilde{L}_1\tilde{L}_1, \tilde{L}_1 \rightarrow W\tilde{L}_1^0, \tilde{L}_1 \rightarrow \tau\tilde{\nu}_e, e\tau\tilde{\nu}_e$	3 $e, \mu + \tau$	-	-	20.7	\tilde{L}_1 350 GeV	$m(\tilde{L}_1) > 80 \text{ GeV}, A_{131} > 0$
	$\tilde{g} \rightarrow q\tilde{q}$	0	6-7 jets	-	20.3	\tilde{g} 916 GeV	$\text{BR}(\tau) = \text{BR}(\mu) = \text{BR}(e) = 0\%$	
	$\tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow b\tilde{t}_1^0$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{g} 880 GeV		
	Other	Scalar gluon pair, sgluon $\rightarrow q\tilde{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693
		Scalar gluon pair, sgluon $\rightarrow t\tilde{t}$	2 e, μ (SS)	1 b	Yes	14.3	sgluon 800 GeV	
		WIMP interaction (DS, Dirac χ)	0	mono-jet	Yes	10.5	\tilde{L}^* scale 704 GeV	$m(\chi) < 80 \text{ GeV}$, limit of $\sim 687 \text{ GeV}$ for D8

Legend: $\sqrt{s} = 7 \text{ TeV}$ full data (blue), $\sqrt{s} = 8 \text{ TeV}$ partial data (green), $\sqrt{s} = 8 \text{ TeV}$ full data (red)

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.



CMS Exotica Physics Group Summary – January, 2014

Can we leverage that experience to guesstimate future reaches?

A rough way of doing it

Suppose ATLAS/CMS are currently sensitive to gluinos of 1250 GeV (95% CL_s , 8 TeV, 20 fb⁻¹)



Work out how many signal events that corresponds to



Find out for what gluino mass you would get the same number of signal events at 14 TeV with 300 fb⁻¹ (assume # of background events scales same way)

This is too simplistic

Backgrounds may not scale in the same way as signal

New irreducible backgrounds may appear at higher scales

Reconstruction efficiencies may depend on mass scale

Detector effects (e.g. granularity), and run conditions (pileup) vary enormously across energy scales and luminosities



It can't possibly work!

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Calculating mass for constant # of signal events is pretty straightforward

But it still requires some work and setup

E.g. you need to equip yourself with different cross section calculators for each new physics process (Prospino/Pythia/...), run them for a range of masses, etc.



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can we get an iPhone app?

What we're discussing is solution of the following equation for M_{high}

$$\frac{N_{\text{signal-events}}(M_{\text{high}}^2, 14 \text{ TeV}, \text{Lumi})}{N_{\text{signal-events}}(M_{\text{low}}^2, 8 \text{ TeV}, 19 \text{ fb}^{-1})} = 1$$

Many complications (e.g. coupling constants & other prefactors) mostly cancel in the ratio.

Dependence on M and on \sqrt{s} mostly comes about through parton distribution functions (PDFs) & simple dimensions.

Consider a resonance of mass M . Cross section \propto **partonic luminosity** and a **$1/M^2$ factor for dimensions**

Coefficient for ij scattering channel (e.g. $q\bar{q}$, gg)

$$N(M, s) \sim \frac{1}{M^2} \sum_{ij} C_{ij} \mathcal{L}_{ij}(M^2, s)$$

Parton luminosity for ij scattering channel

$$\mathcal{L}_{ij}(M^2, s) = \int_{\tau}^1 \frac{dx}{x} x f_i(x, M^2) \frac{\tau}{x} f_j\left(\frac{\tau}{x}, M^2\right) \quad \tau \equiv \frac{M^2}{s}$$

i & j parton densities

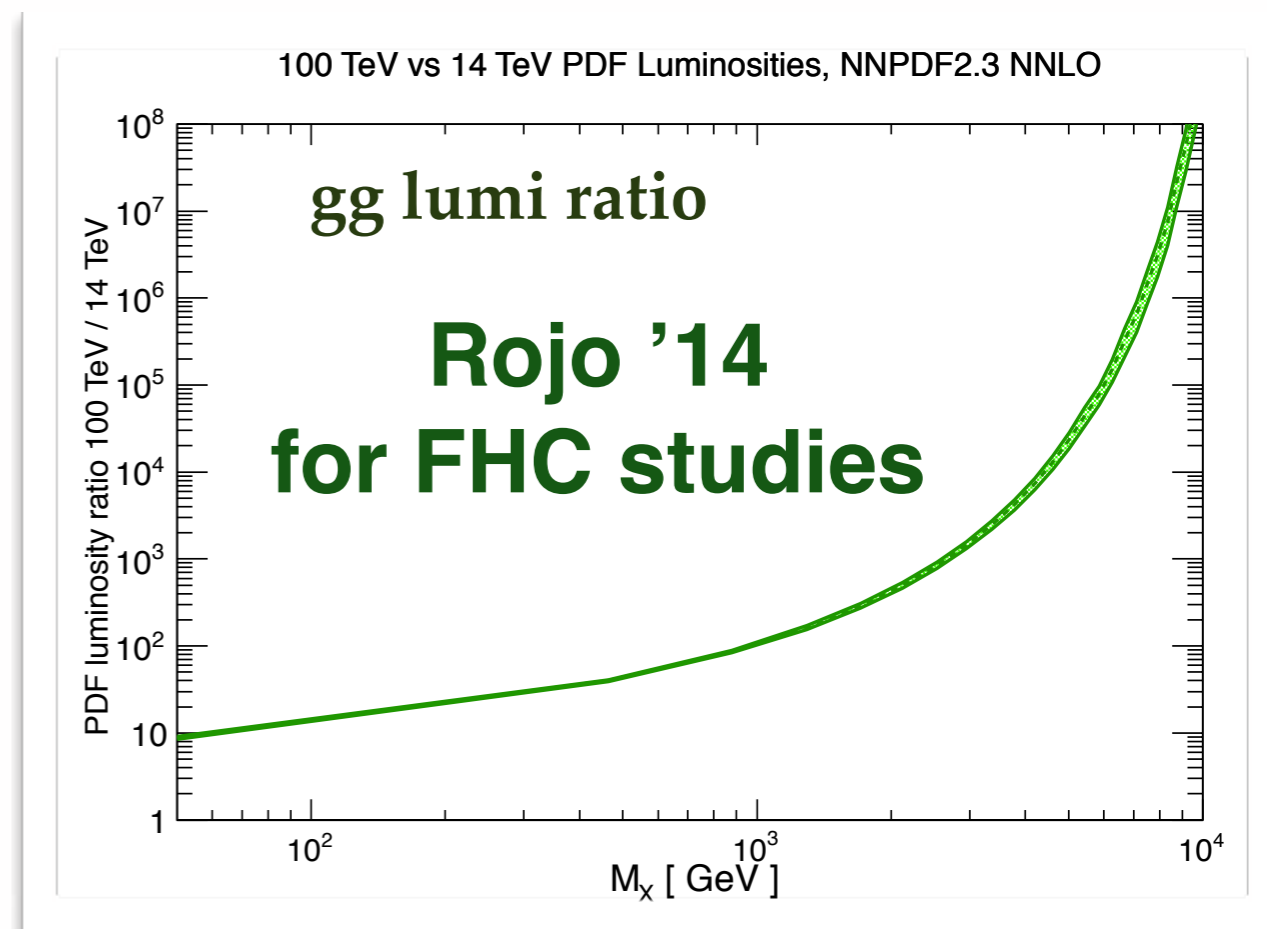
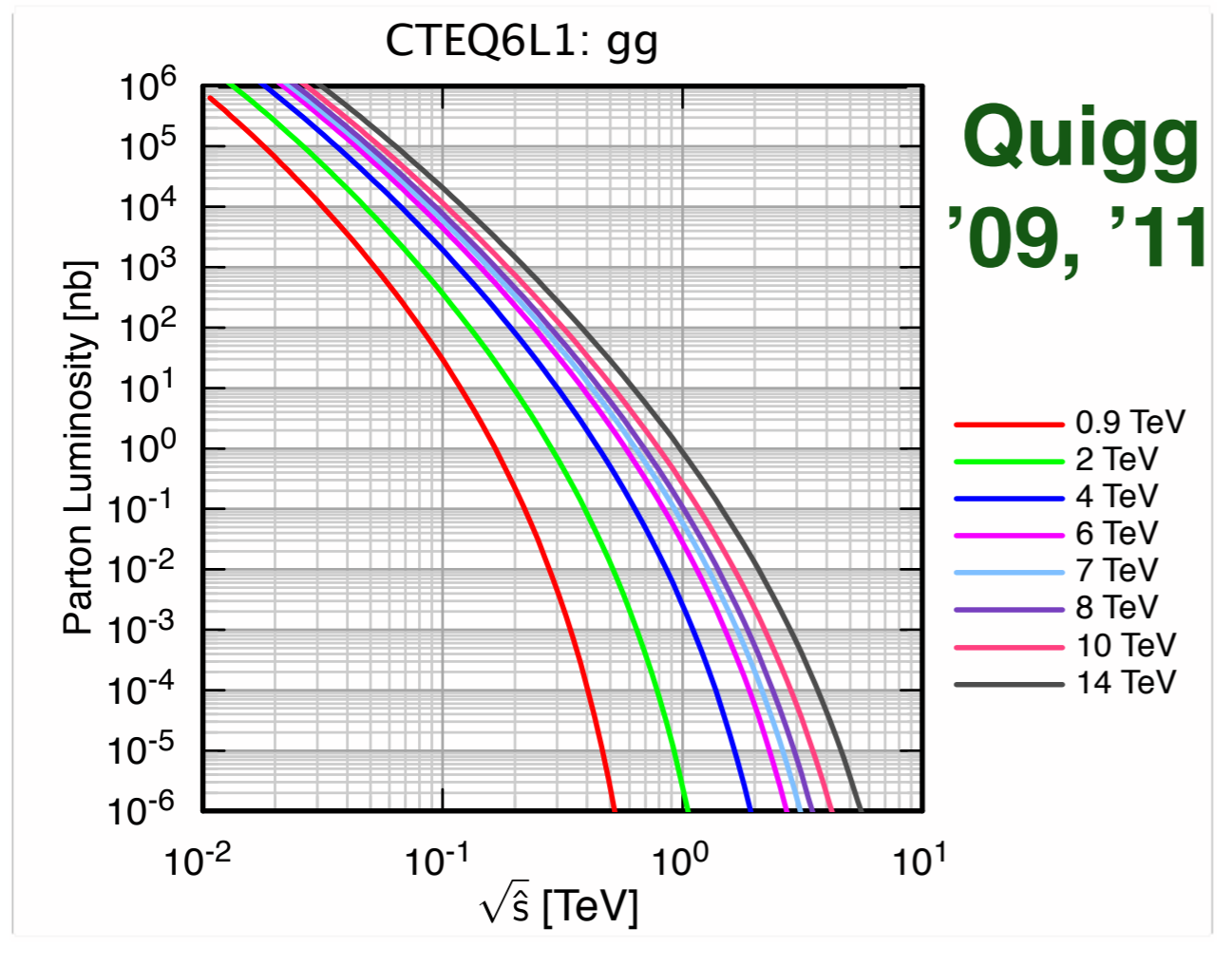
Assume dominance of a single partonic scattering channel, ij (you have to know enough physics to figure out which is most appropriate).

Equation we solve to find M_{high} is then

$$\frac{\mathcal{L}_{ij}(M_{\text{high}}^2, s_{\text{high}})}{\mathcal{L}_{ij}(M_{\text{low}}^2, s_{\text{low}})} \times \frac{\text{lumi}_{\text{high}}}{\text{lumi}_{\text{low}}} = \frac{M_{\text{high}}^2}{M_{\text{low}}^2}$$

The tools we use for this are
LHAPDF and HOPPET
most plots with MSTW2008 NNLO PDFs

A side remark: Studying partonic luminosities is a standard technique



How do we differ?

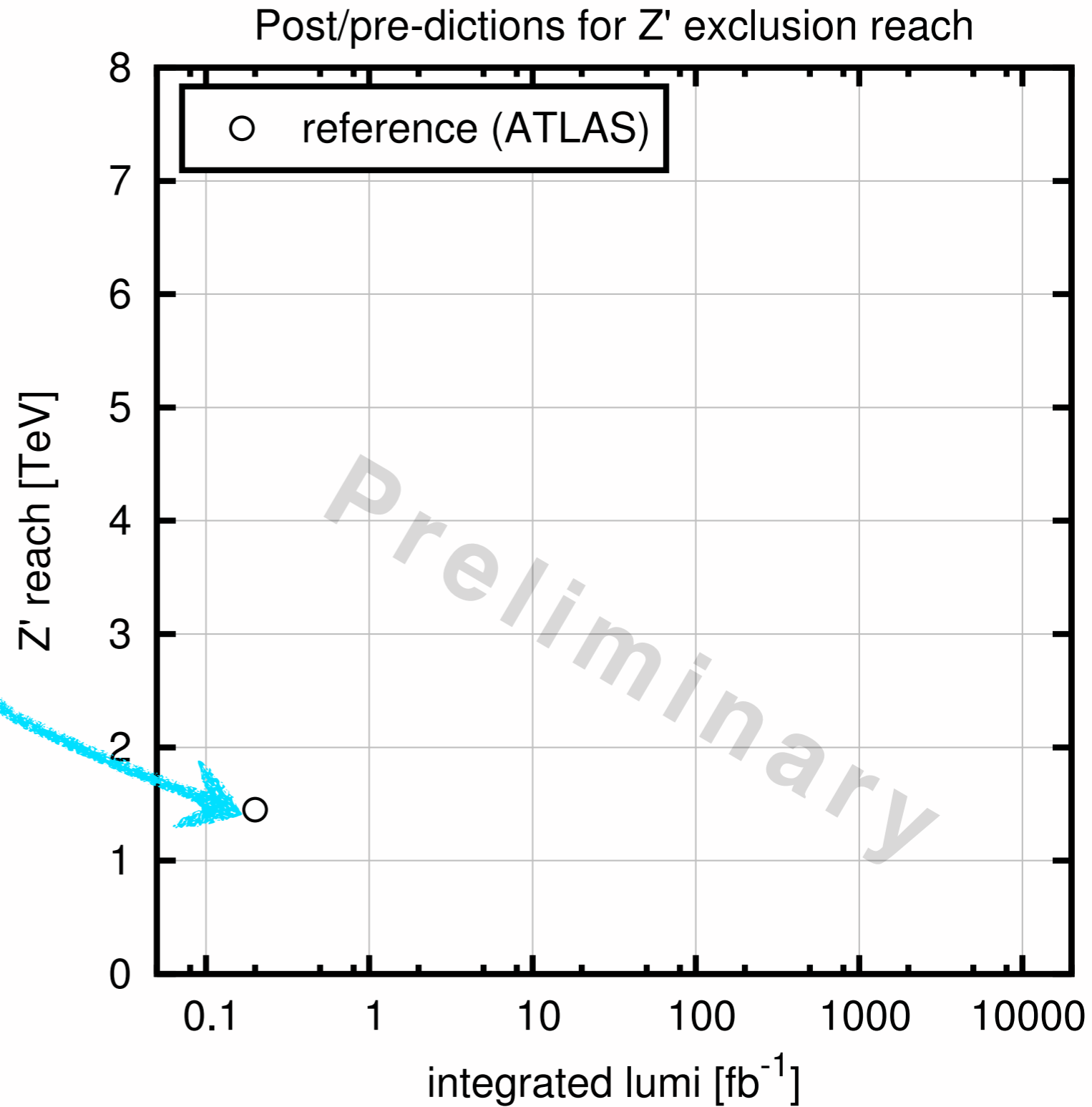
Study one key question:
relate reaches [TeV] of
different colliders

Validate the approach
by postdicting LHC and
Tevatron results

Does it work?

Try a Z' search. Take a baseline analysis:

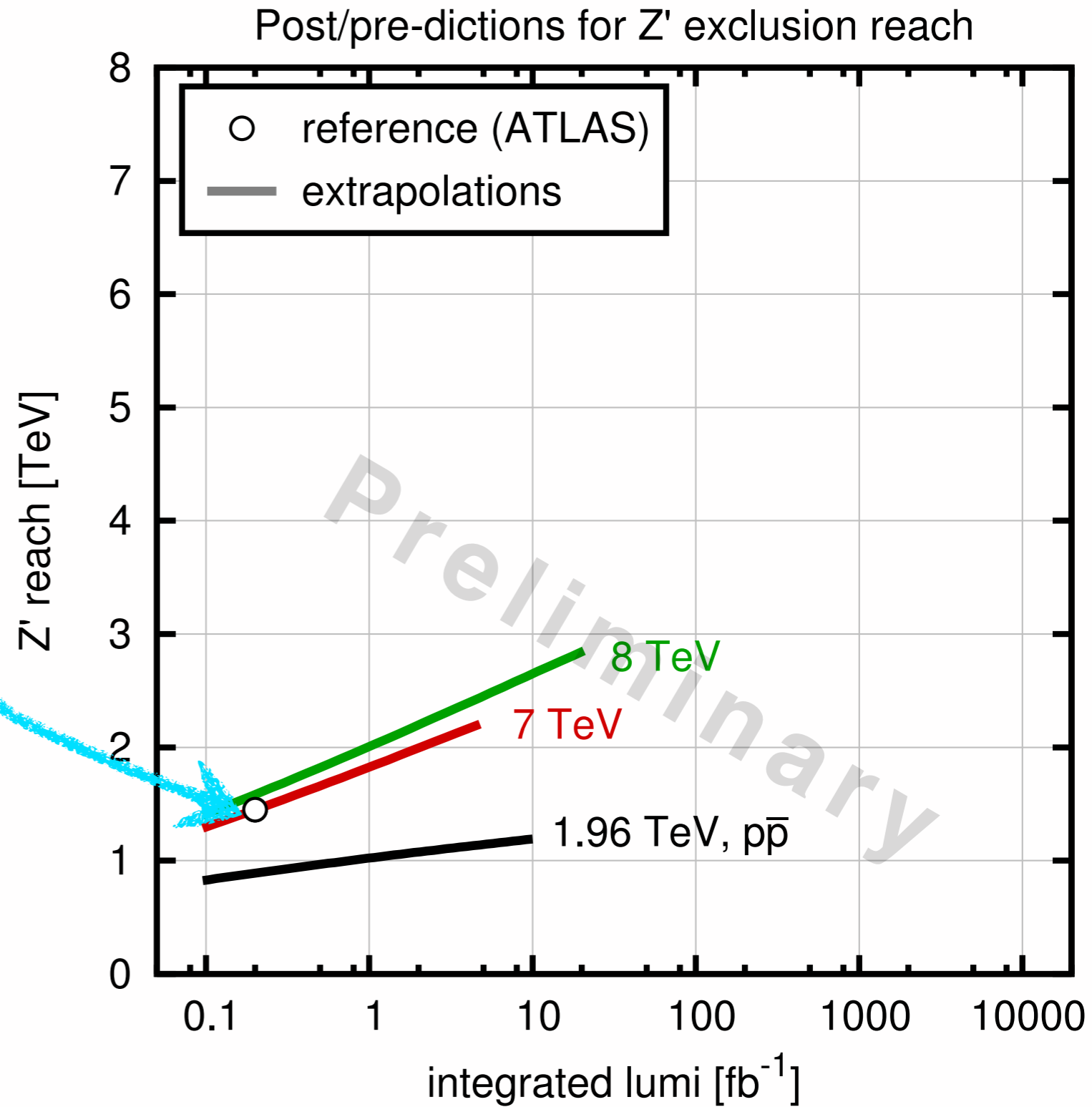
ATLAS,
0.2 fb⁻¹ @ 7 TeV
excludes M < 1450 GeV



Try a Z' search. Take a baseline analysis:

ATLAS,
 0.2 fb^{-1} @ 7 TeV
excludes $M < 1450 \text{ GeV}$

“Predict” exclusions
at other lumis &
energies (assume $q\bar{q}$)

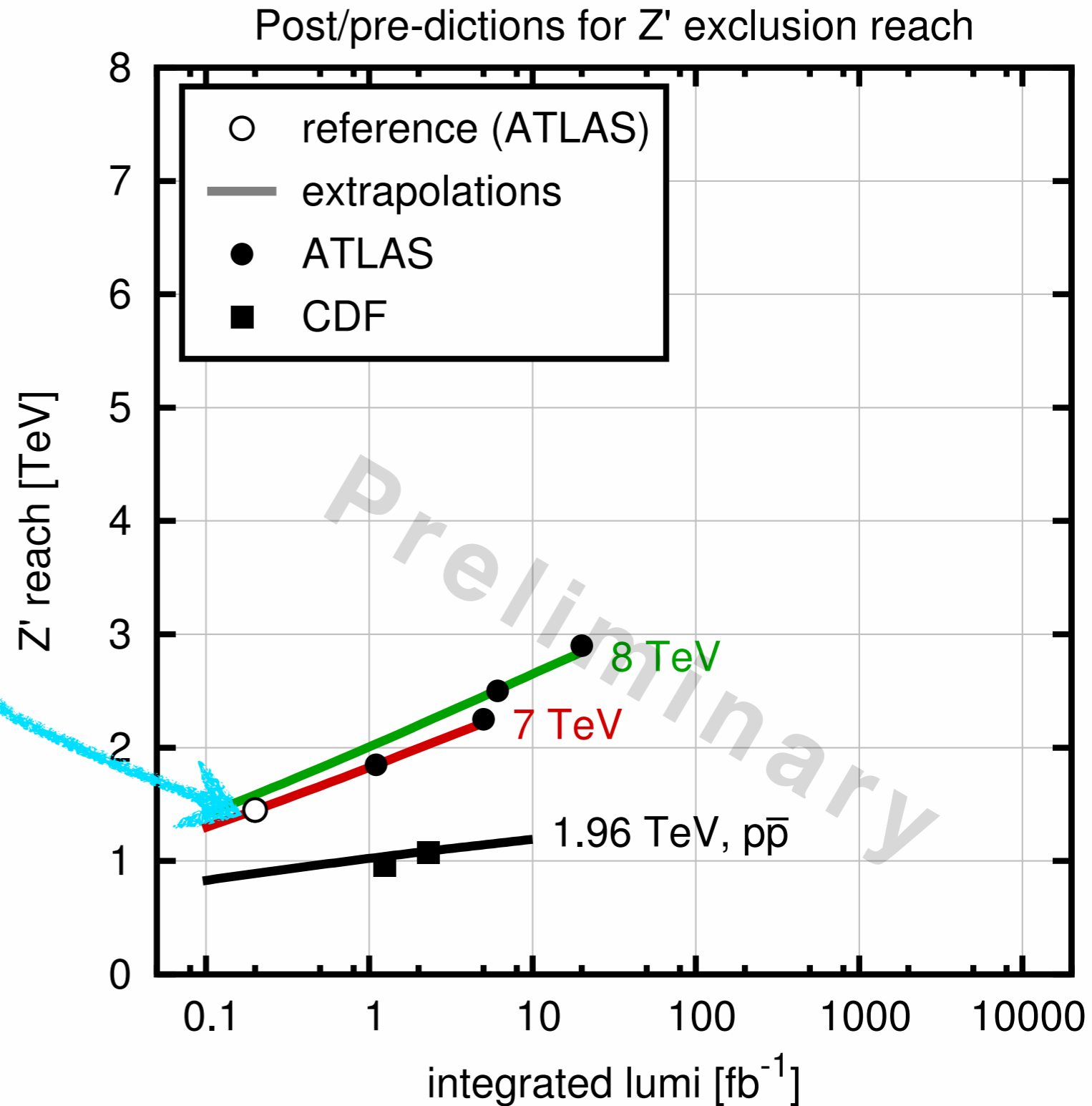


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Compare to actual
exclusions

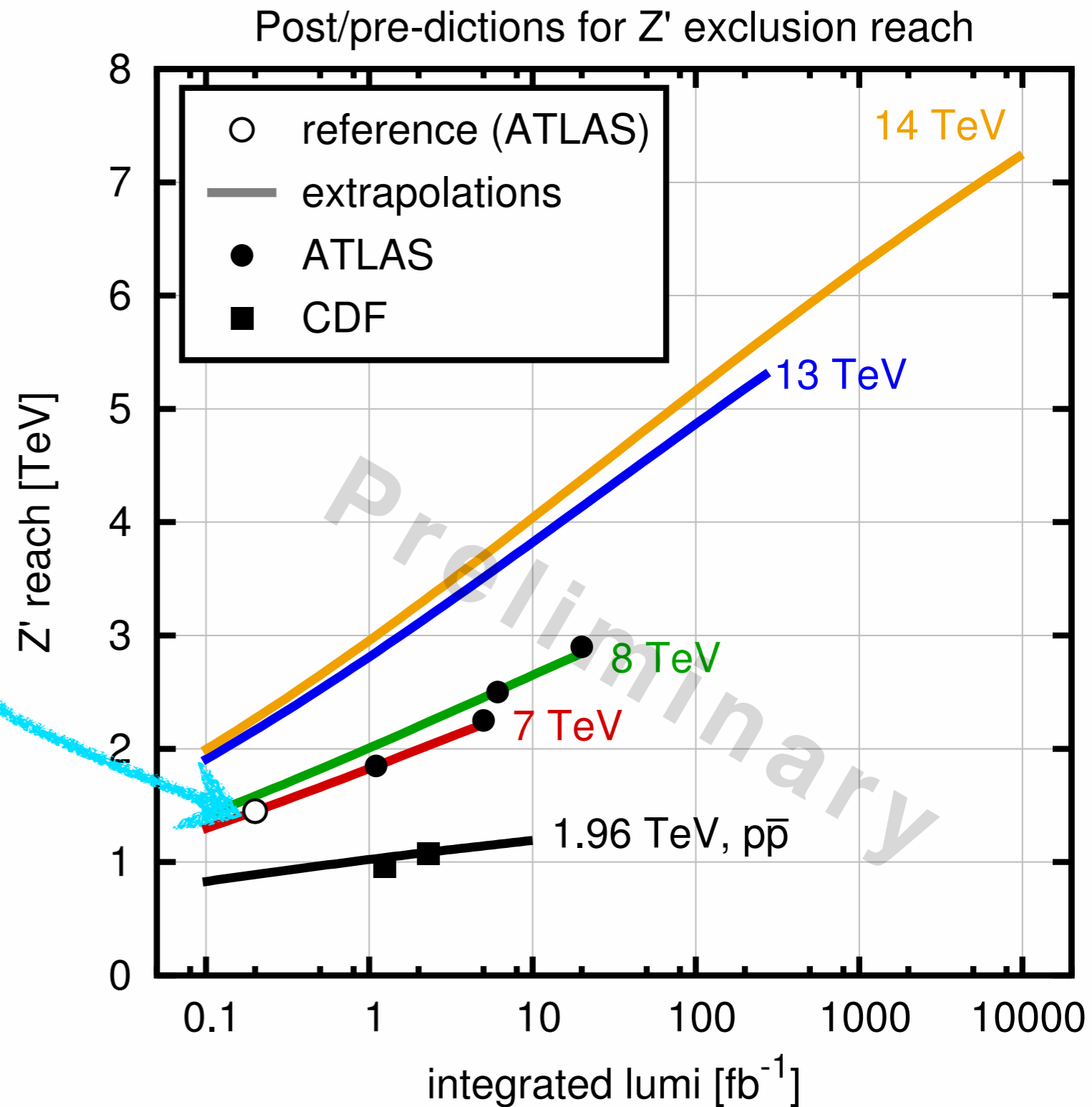


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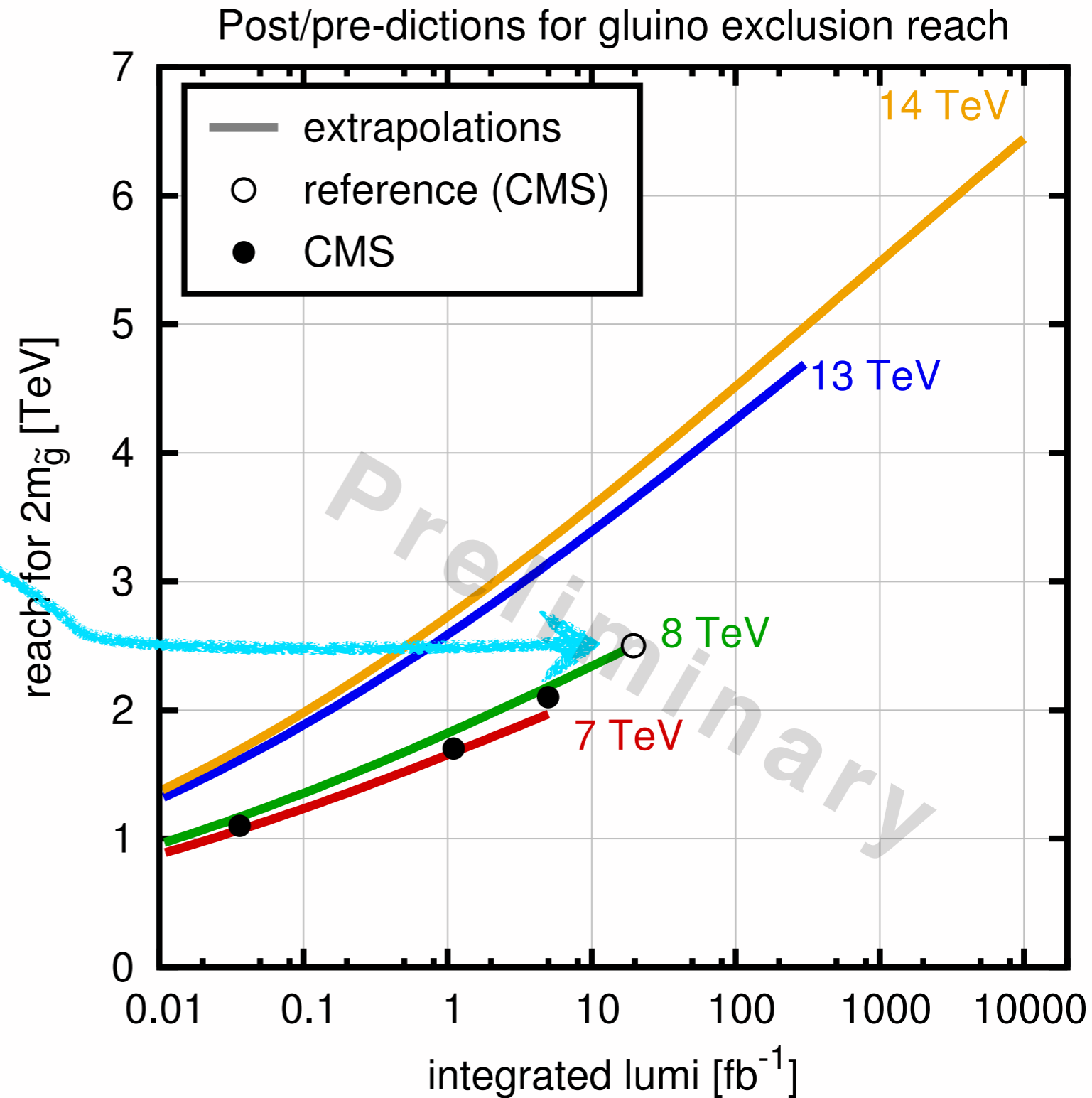
Maybe it only works so well because it's a simple search?
(Signal & Bkgd are both $q\bar{q}$ driven)

Try a SUSY example,
gluinos. Baseline:

CMS, 20 fb⁻¹ @ 8 TeV
excludes $M_{\tilde{g}} < 1250$ GeV
i.e. $2M_{\tilde{g}} < 2.5$ TeV

“Predict” exclusions
at other lumis &
energies (assume gg)

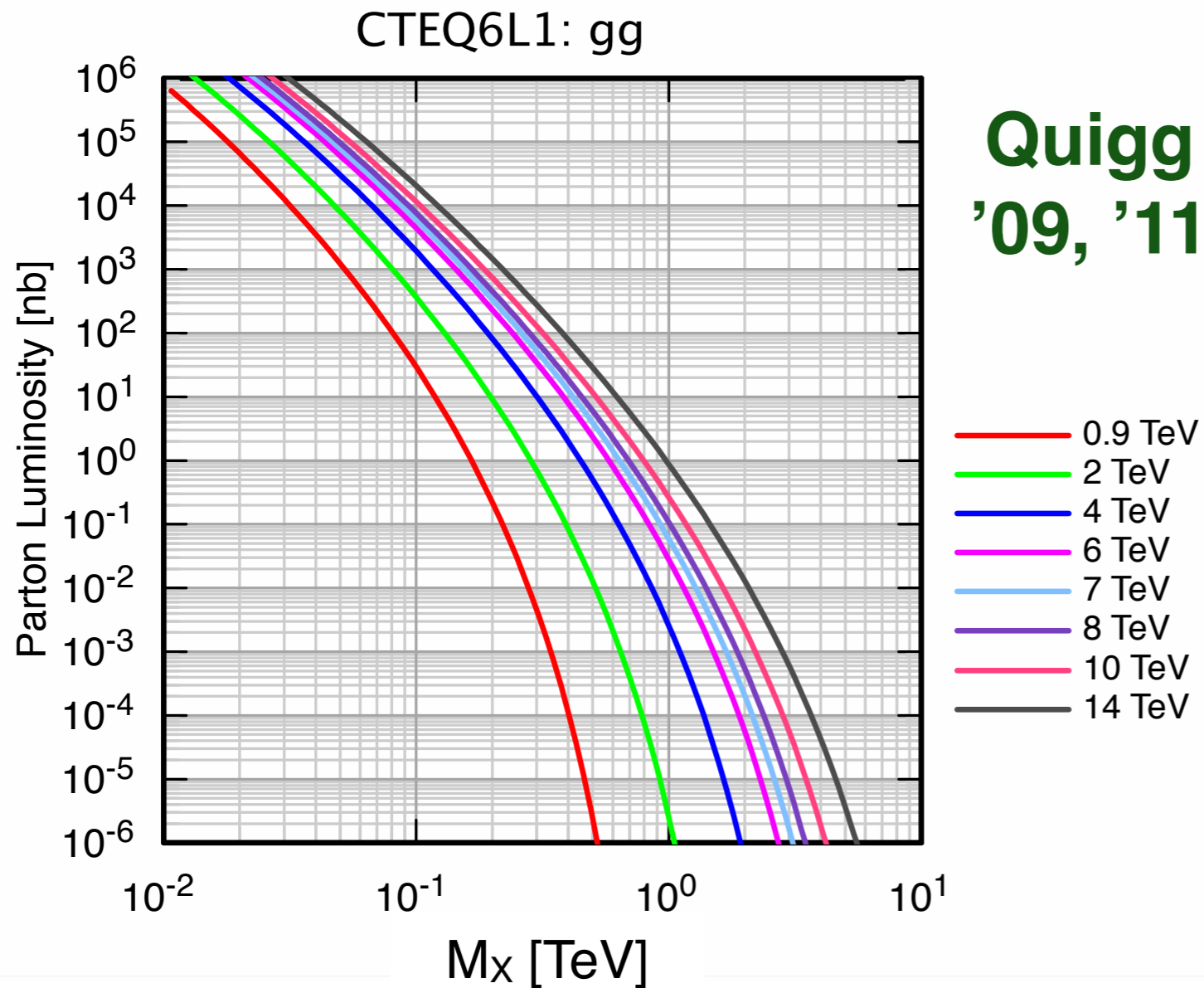
Compare to actual
exclusions



Still works OK, despite (poor) assumption of same
signal and background channels [see also later]

ATLAS						
Search	Signal	Bgd	$E_{\text{CM}}[\text{TeV}]$	$\mathcal{L}_{\text{int}}[\text{fb}^{-1}]$	Expected [GeV]	collider-reach [GeV]
Sequential Z'	$\sum \bar{q}_i q_i$	$\sum \bar{q}_i q_i$	7	0.2	1450 [?]	(base-line)
			7	1.1	1850 [?]	1849
			7	5	2200 [?]	2219
			8	6.1	2550 [?]	2510
			8	20	2900 [?]	2844
Stop ($m_{\text{LSP}} = 0 \text{ GeV}$)	gg	gg	7	4.7	500 [?]	(base-line)
			8	20.5	650 [?]	675
Excited quark	gq	gg	7	$315 \cdot 10^{-6}$	1010 [?]	(base-line)
			7	$36 \cdot 10^{-3}$	2040 [?]	2026 (gq)
			7	$163 \cdot 10^{-3}$	2490 [?]	2395 (gq)
			7	0.81	2910 [?]	2790 (gq)
			7	4.8	3090 [?]	3220 (gq)
			8	13	3840 [?]	3865 (gq)
CMS						
Search	Signal	Bgd	$E_{\text{CM}}[\text{TeV}]$	$\mathcal{L}_{\text{int}}[\text{fb}^{-1}]$	Expected [GeV]	collider-reach [GeV]
gluinos ($m_{\text{LSP}} = 100 \text{ GeV}$)	gg	$gg/gq/qq$	7	0.036	550 [?]	(base-line)
			7	1.1	850 [?]	855
			7	4.98	1050 [?]	1005
			8	19.5	1250 [?]	1275
squarks ($m_{\text{LSP}} = 100 \text{ GeV}$)	gg	$gg/gq/qq$	7	0.036	400 [?]	(base-line)
			7	1.1	650 [?]	663
			7	4.98	725 [?]	801
			8	19.5	910 [?]	1033
T-quarks ($\text{Br}(T \rightarrow tZ) = 1$)	gg	$gg/gq/qq$	7	1.14	510 [?]	(base-line)
			7	5	550 [?]	629
			8	19.6	813 [?]	827

Why does it work?

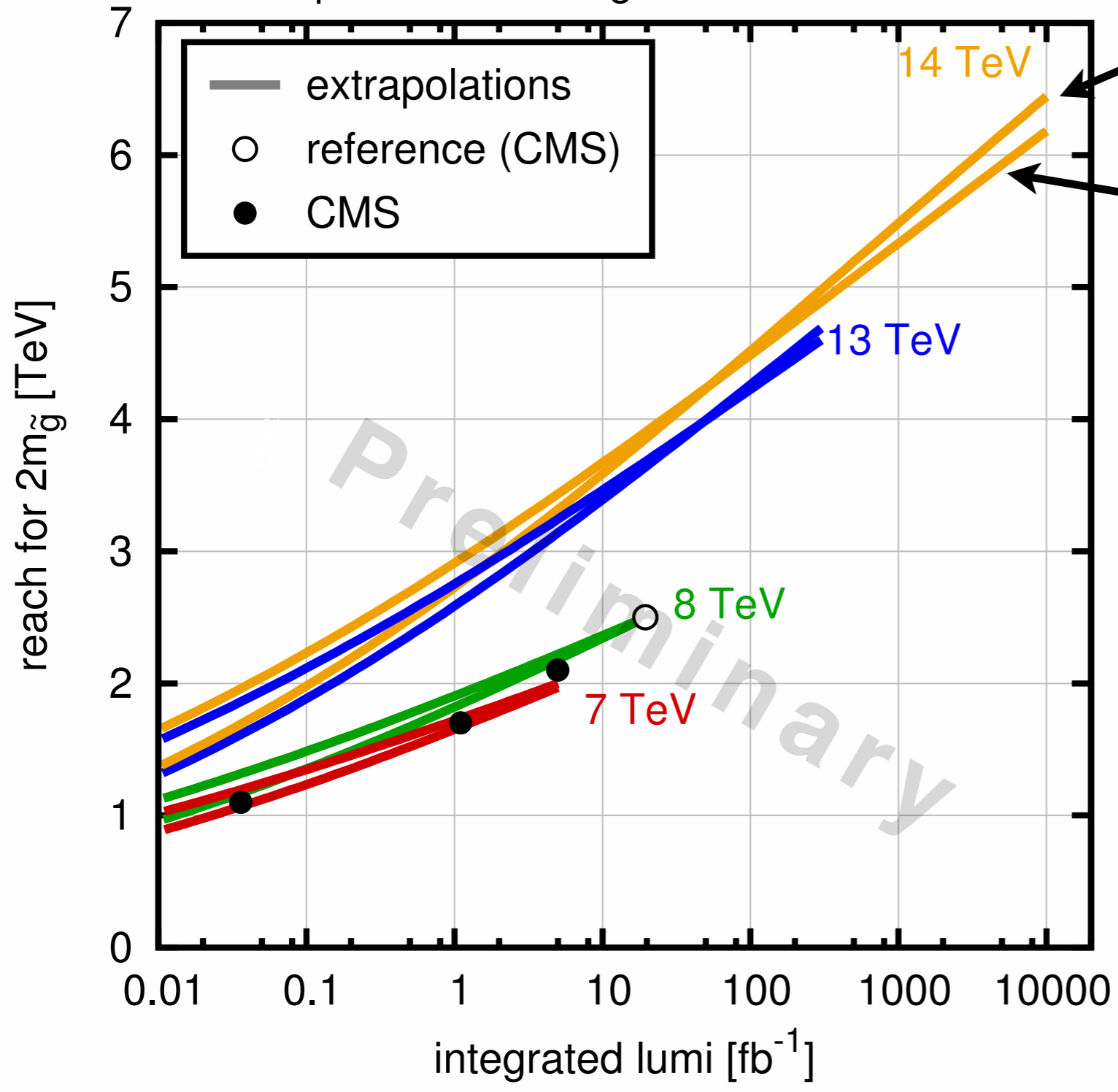


Parton luminosities fall off very fast with increasing M_X

Even when you make a mistake (e.g. wrong partonic channel) the impact on estimated M_X reach is modest

x2 in lumi \sim 10% in M_X

Post/pre-dictions for gluino exclusion reach



Signal gg ; bkgd: gg

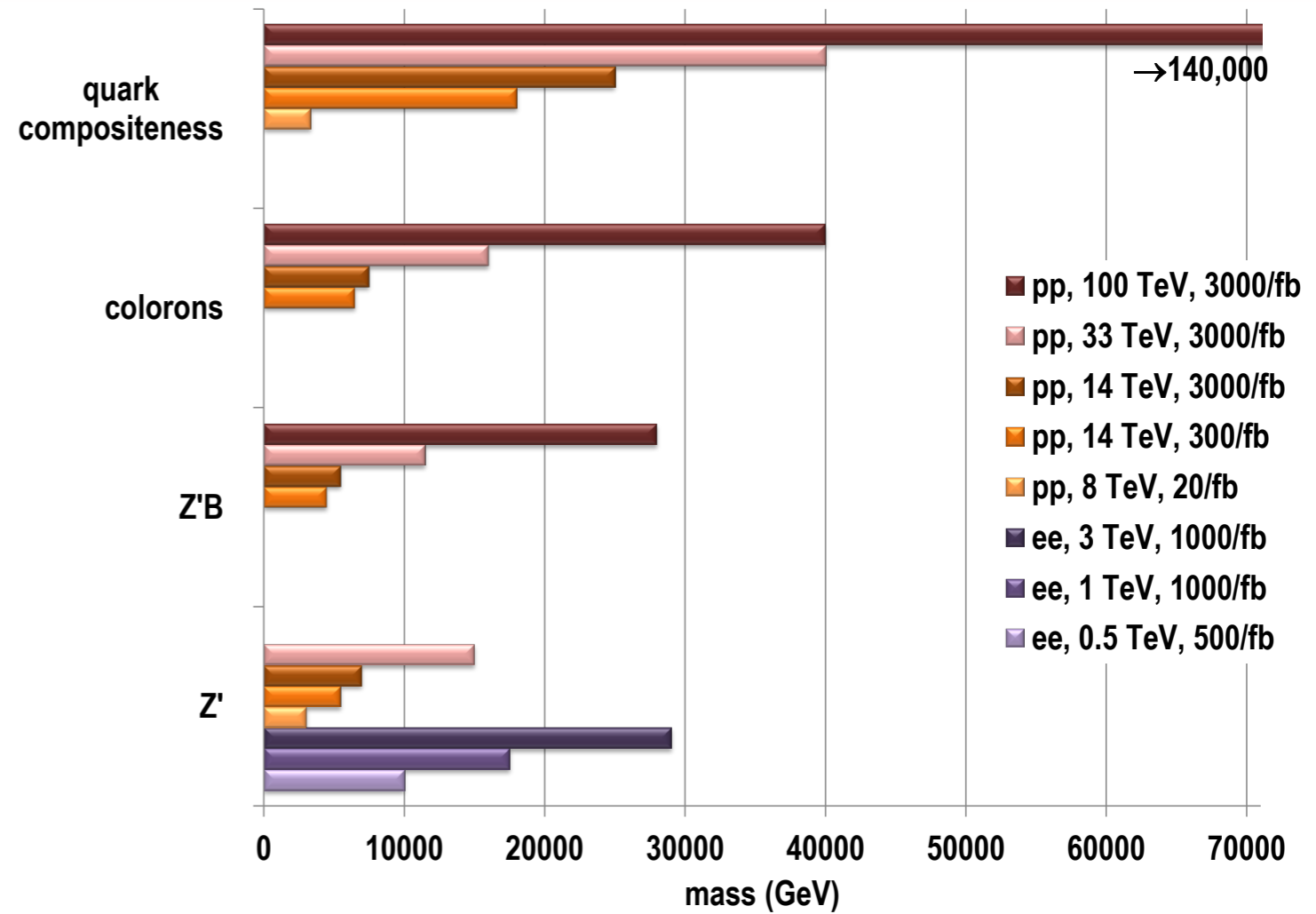
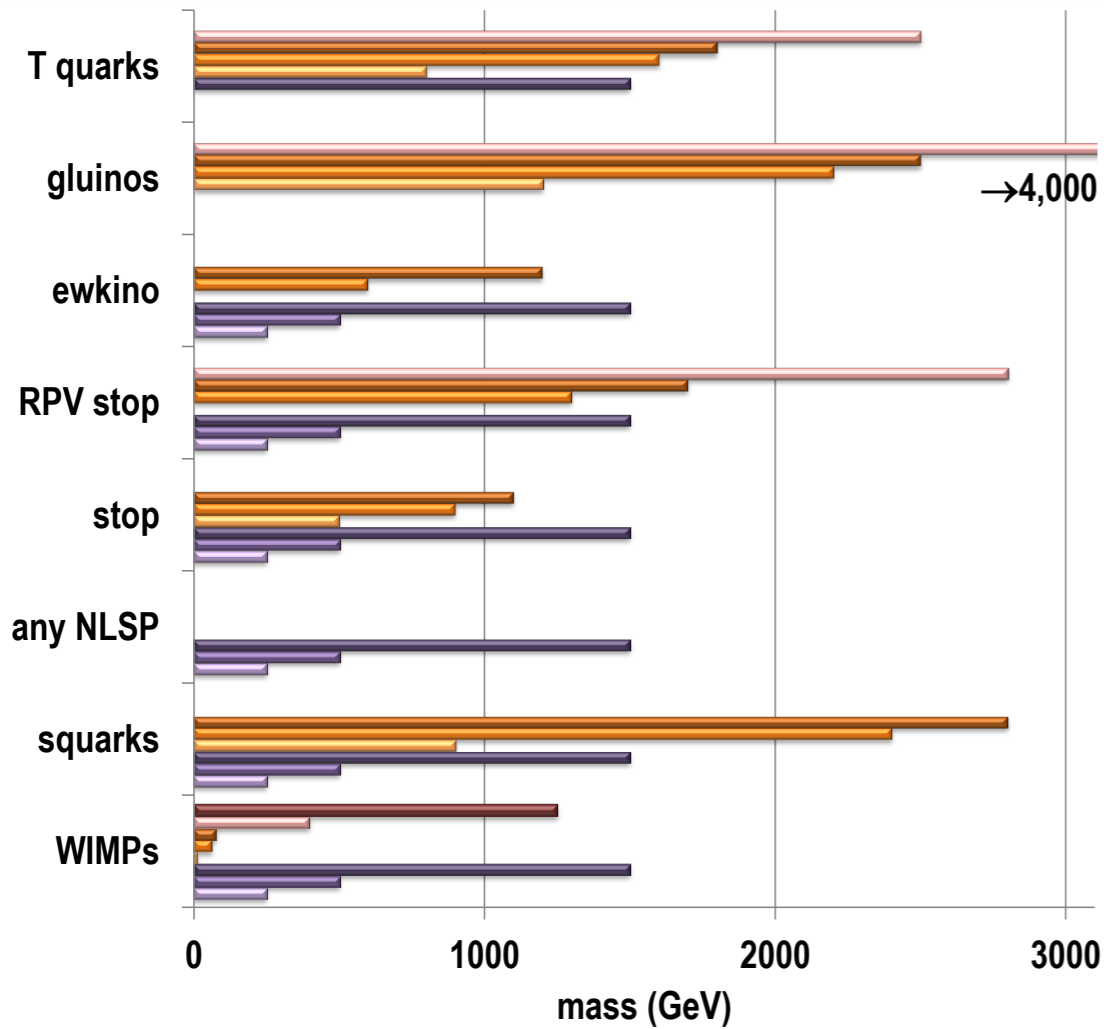
Signal gg ; bkgd: qg

Scattering channel matters, but not too much

Future colliders

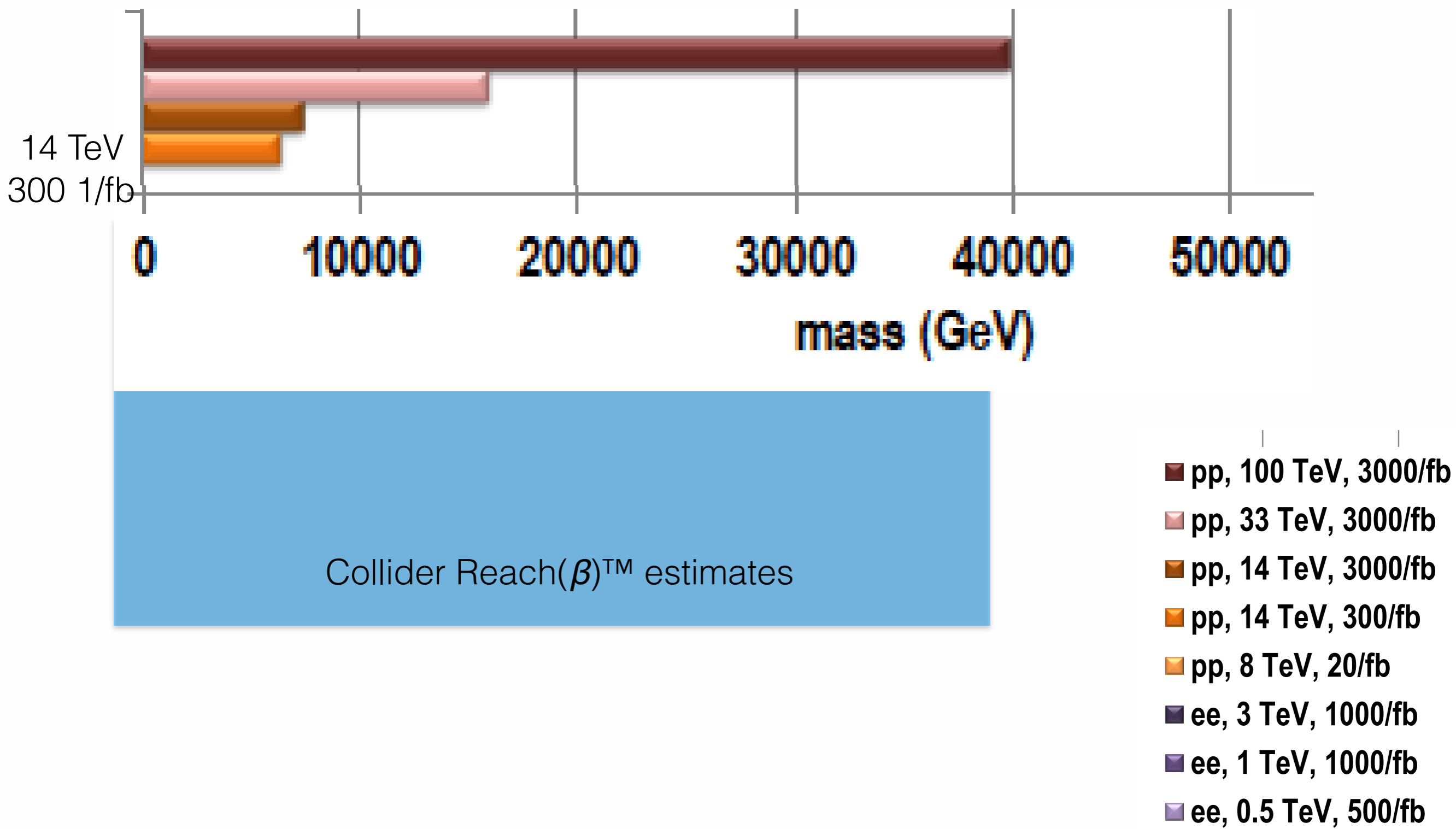
- We're ignoring all subtleties, just going for a baseline check
- If our estimate differs a lot from sophisticated simulations, something interesting has happened:
 - brick-wall (new irreducible backgrounds, granularity of assumed detectors, ...)
 - overly conservative or non-optimal estimates

Future colliders comparison

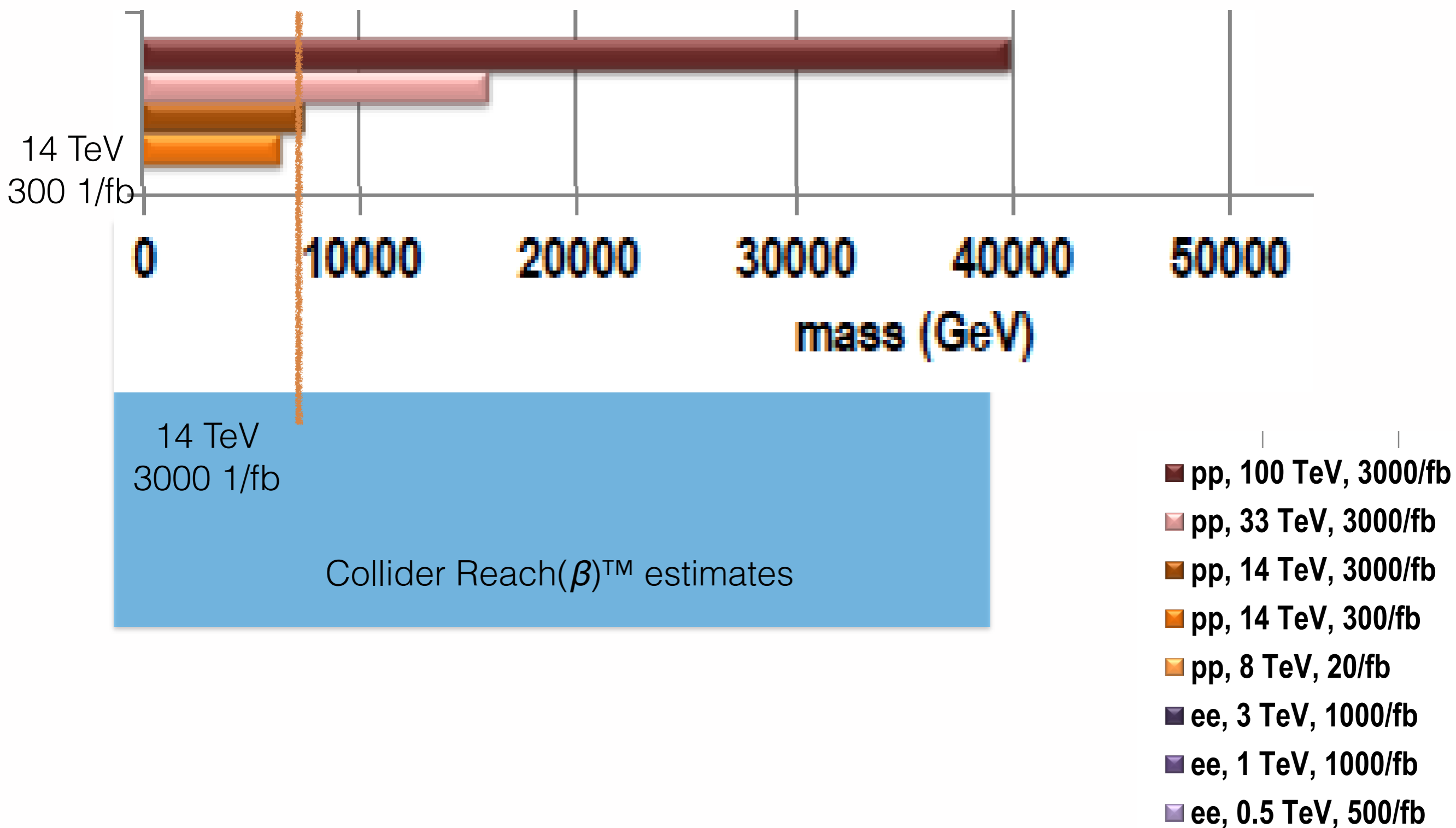


Energy Frontier Snowmass study ([1311.0299](https://arxiv.org/abs/1311.0299))

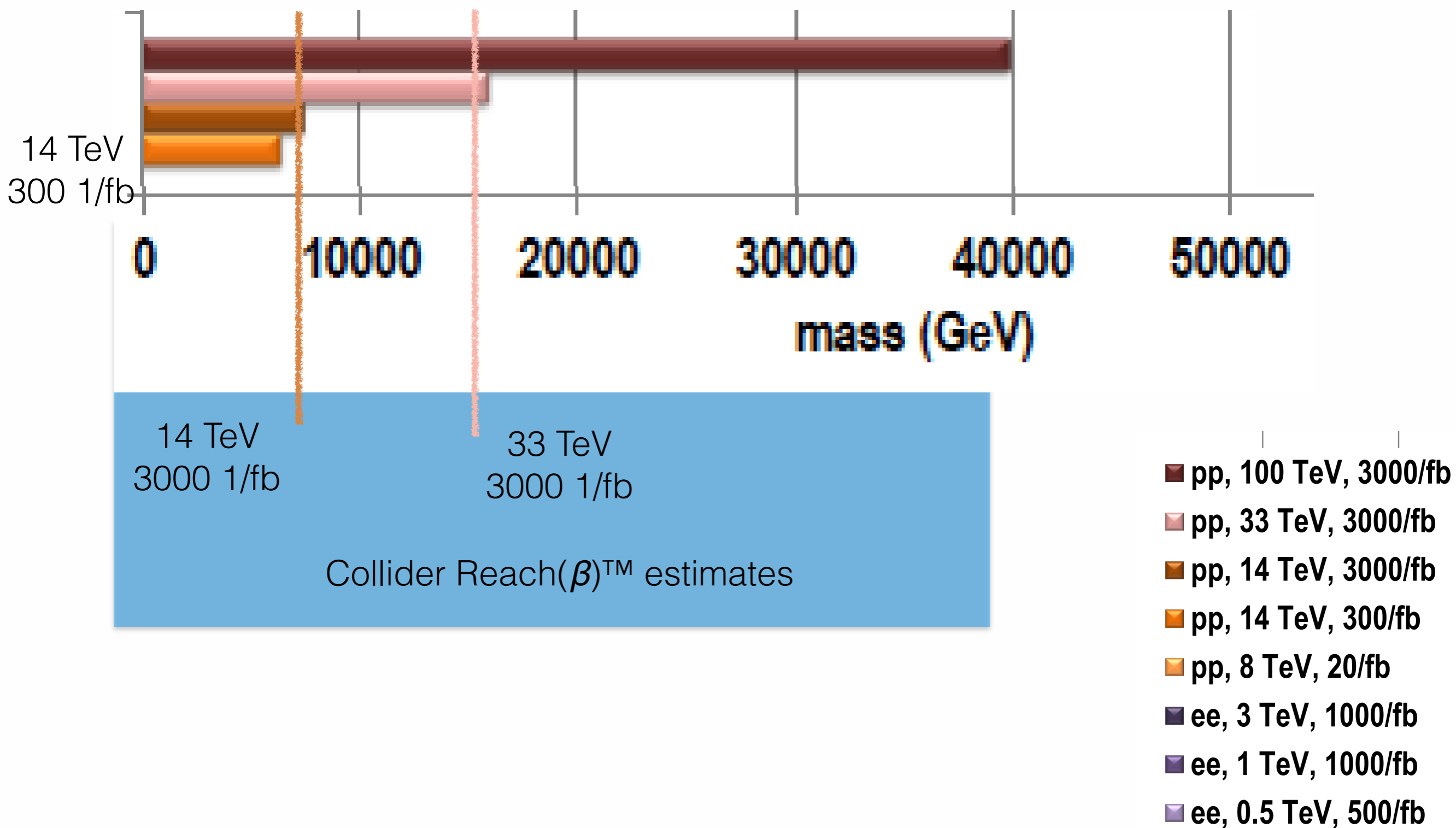
Colorons



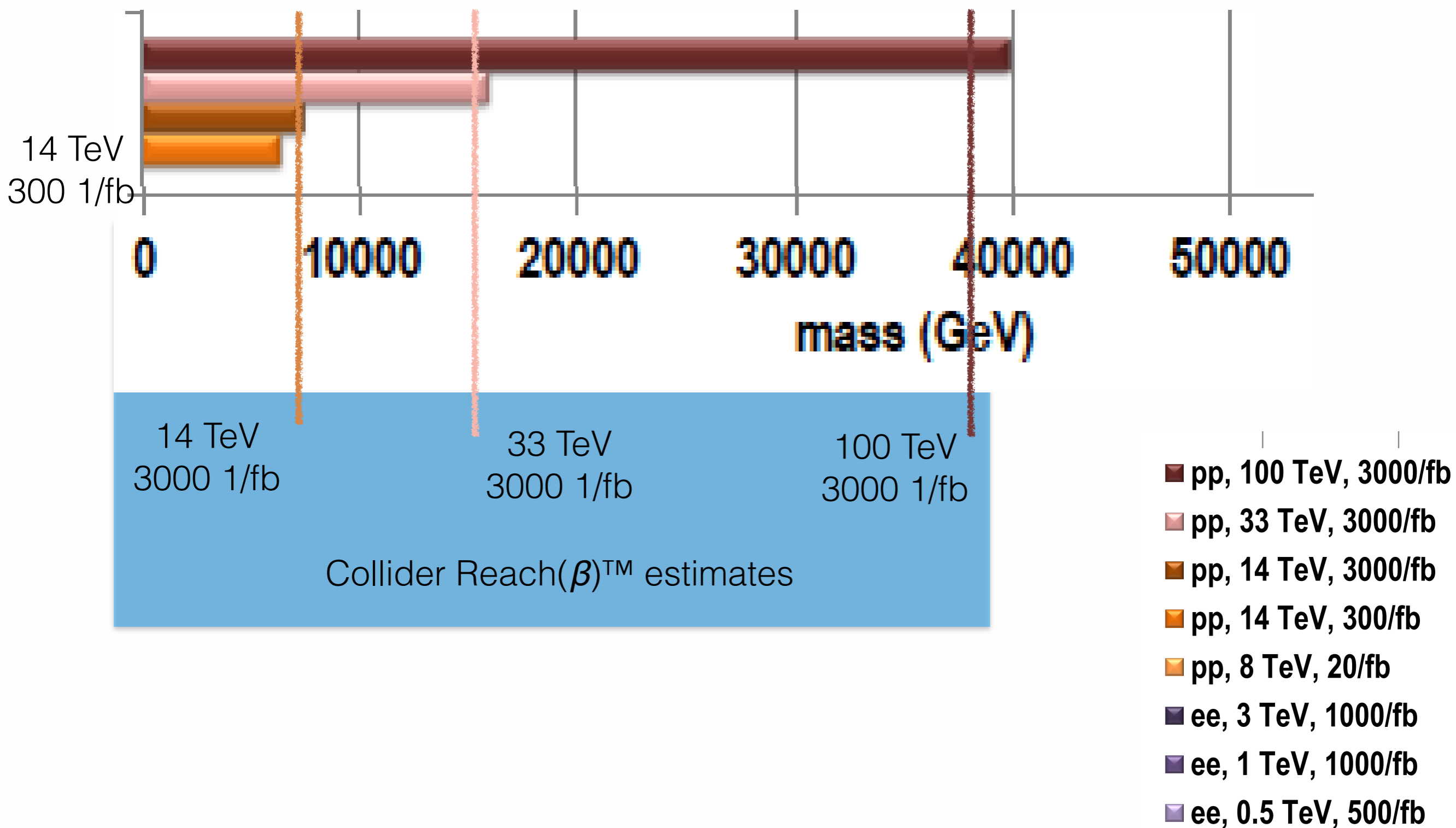
Colorons



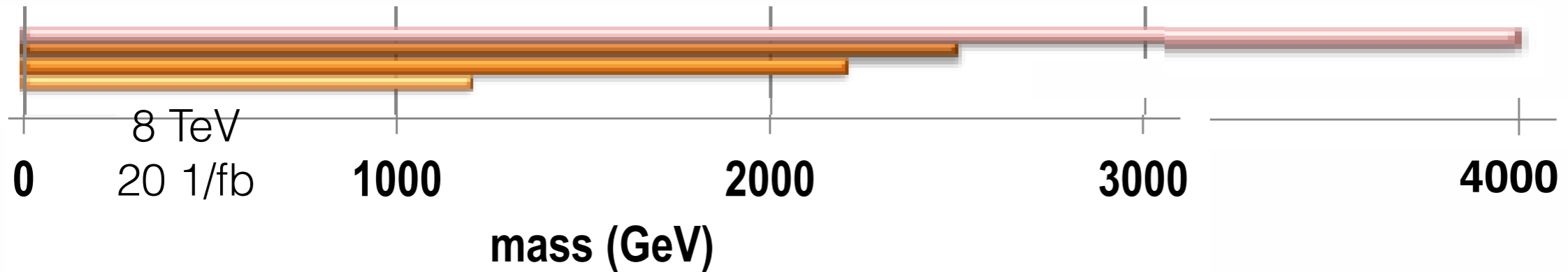
Colorons



Colorons



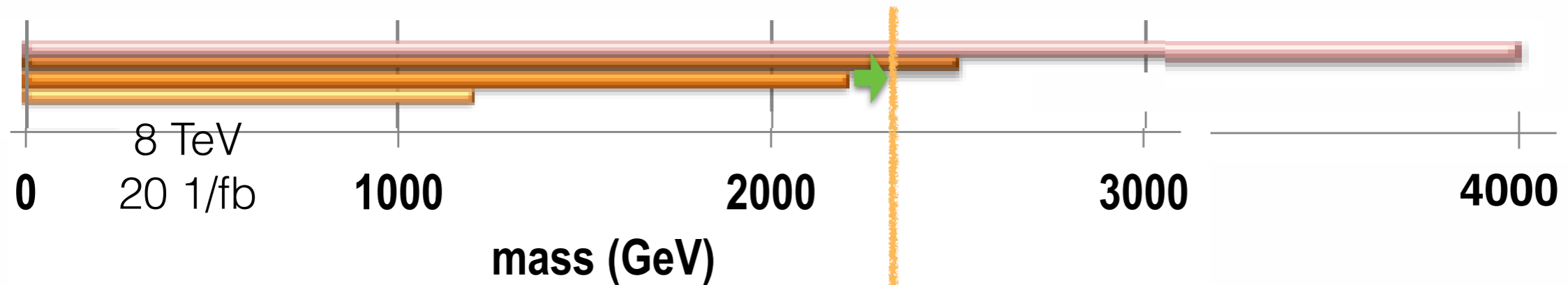
Gluinos



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

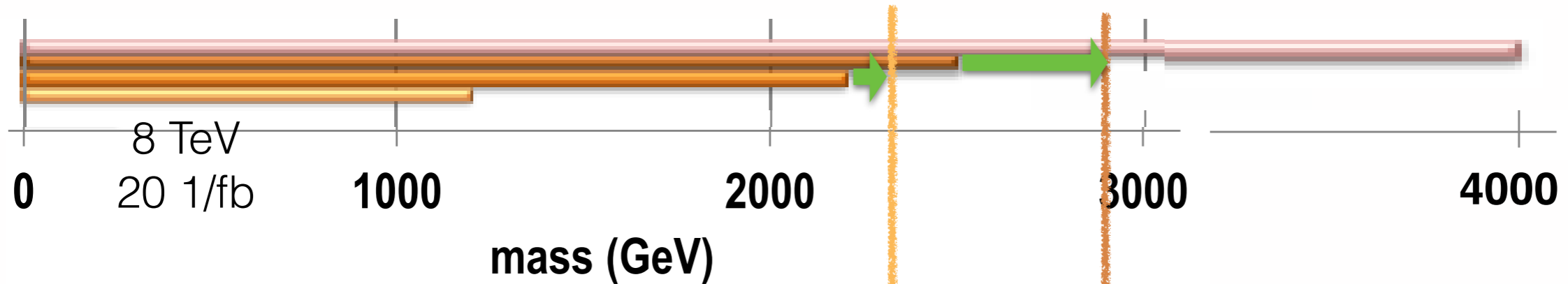
Collider Reach(β)TM estimates

Gluinos



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

Gluinos



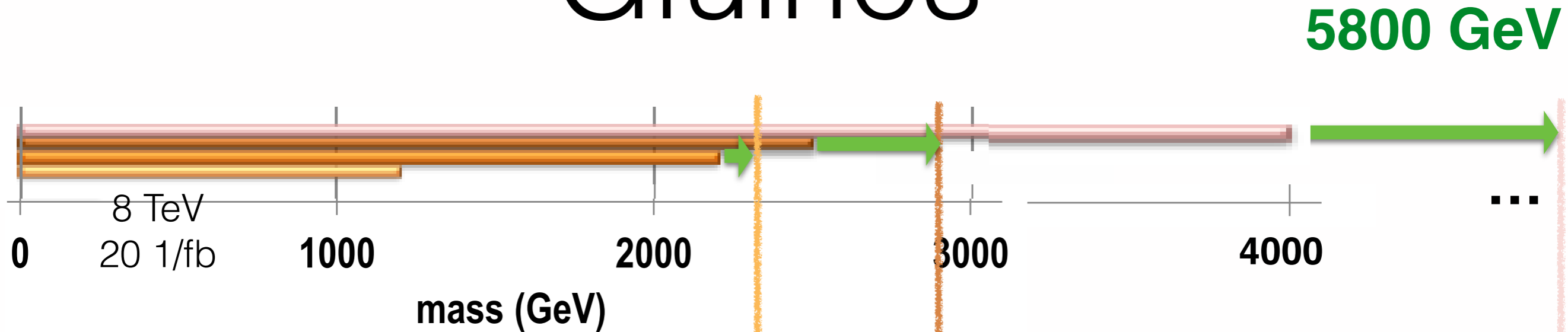
14 TeV
300 1/fb

14 TeV
3000 1/fb

Collider Reach(β)TM estimates

- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

Gluinos



14 TeV
300 1/fb

14 TeV
3000 1/fb

33 TeV
3000 1/fb

■ pp, 100 TeV, 3000/fb

■ pp, 33 TeV, 3000/fb

■ pp, 14 TeV, 3000/fb

■ pp, 14 TeV, 300/fb

■ pp, 8 TeV, 20/fb

■ ee, 3 TeV, 1000/fb

■ ee, 1 TeV, 1000/fb

■ ee, 0.5 TeV, 500/fb

Collider Reach(β)™ estimates

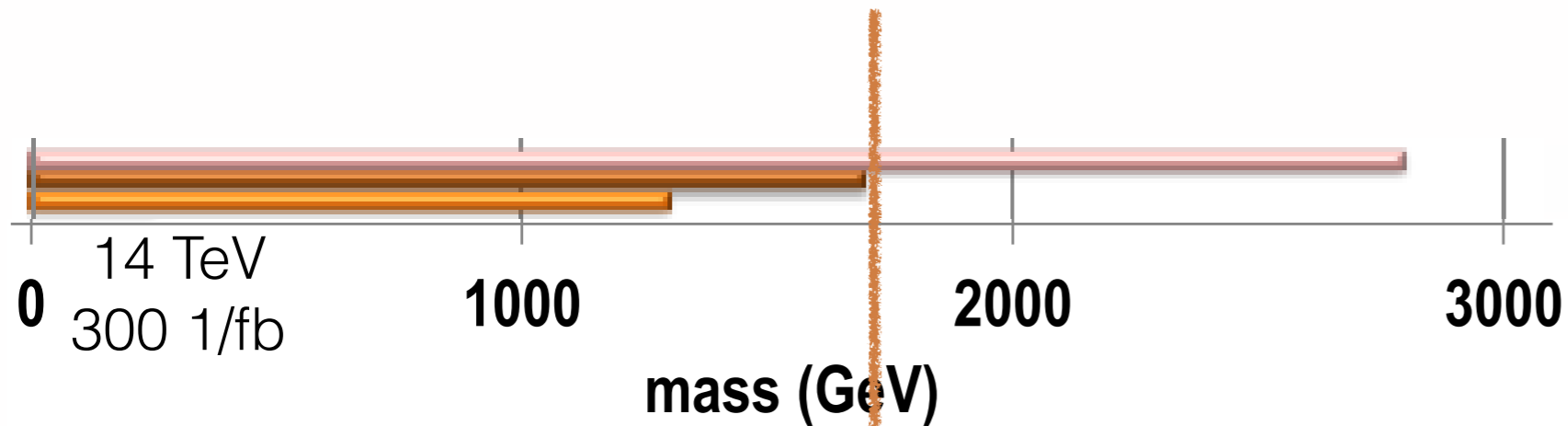
RPV stops



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

Collider Reach(β)TM estimates

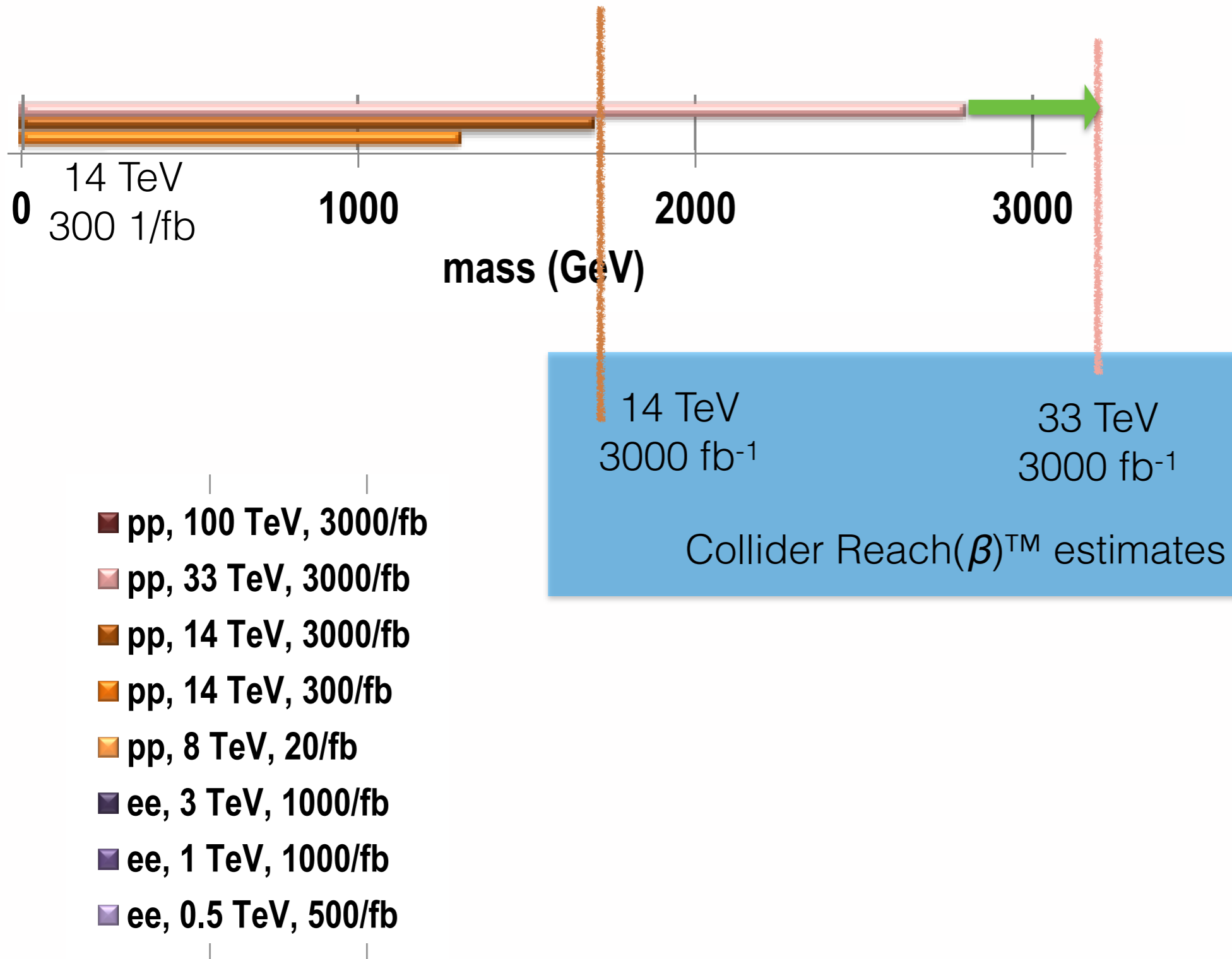
RPV stops



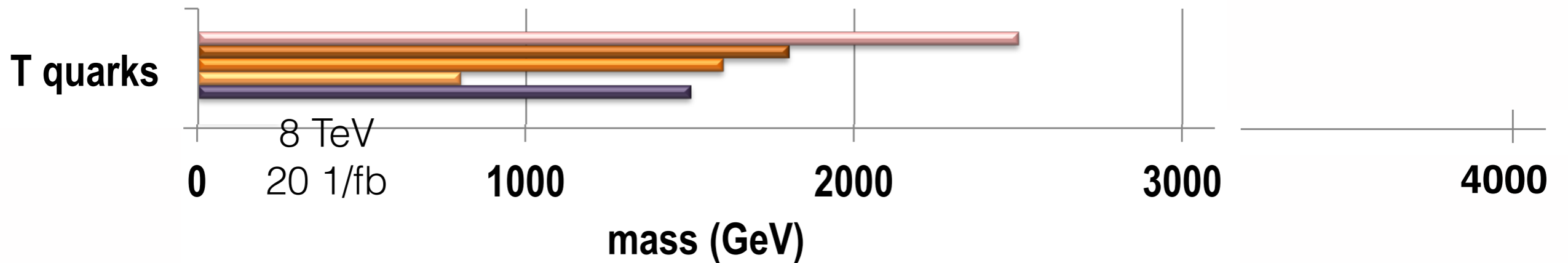
14 TeV
3000 fb⁻¹
Collider Reach(β)TM estimates

- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

RPV stops



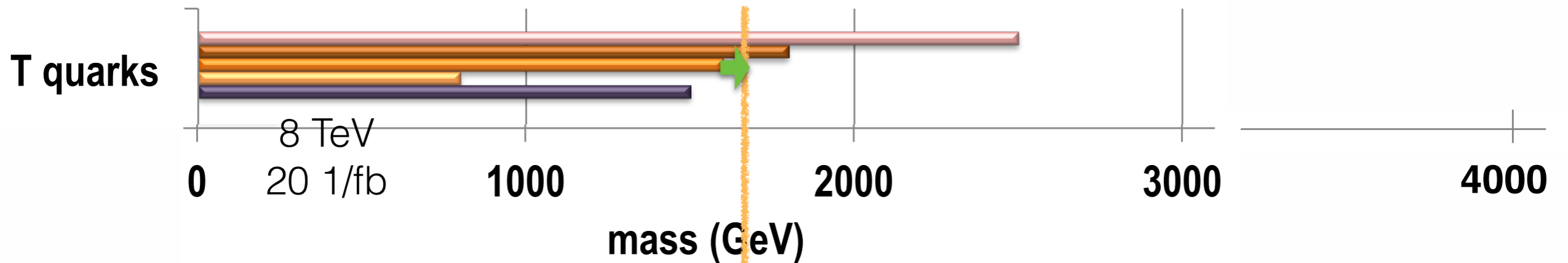
T Quarks



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

Collider Reach(β)TM estimates

T Quarks

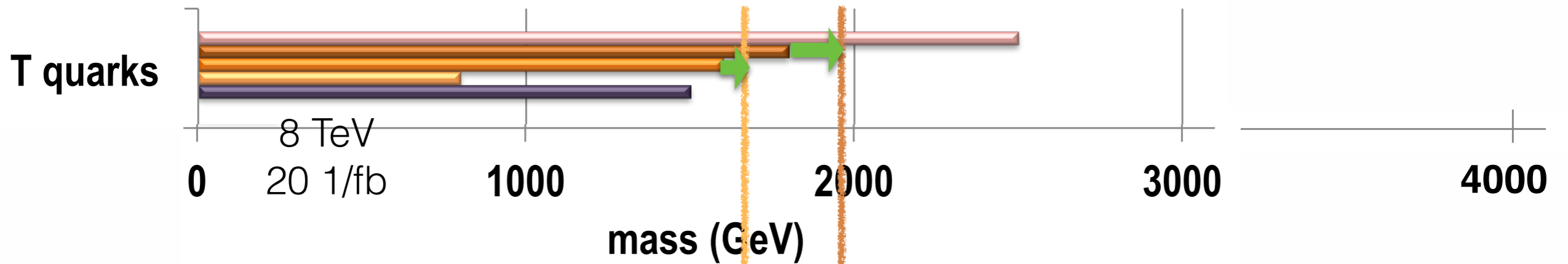


- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

14 TeV
300 1/fb

Collider Reach(β)TM estimates

T Quarks



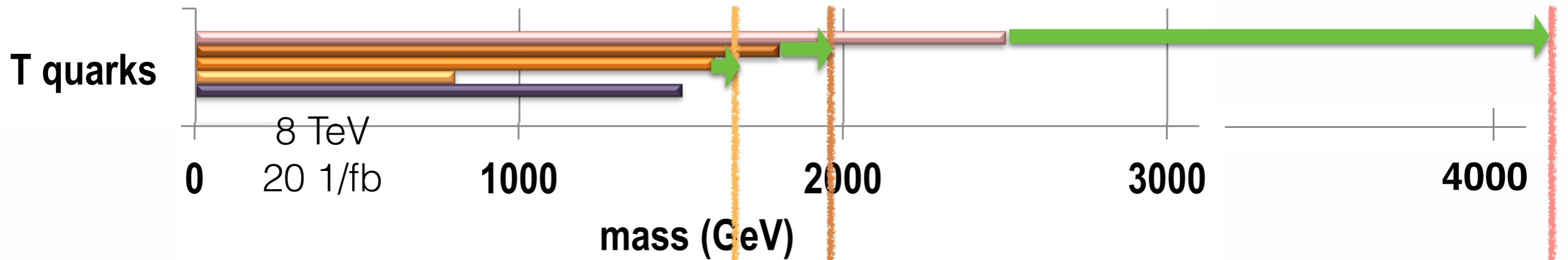
- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

14 TeV
300 1/fb

14 TeV
3000 1/fb

Collider Reach(β)™ estimates

T Quarks



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

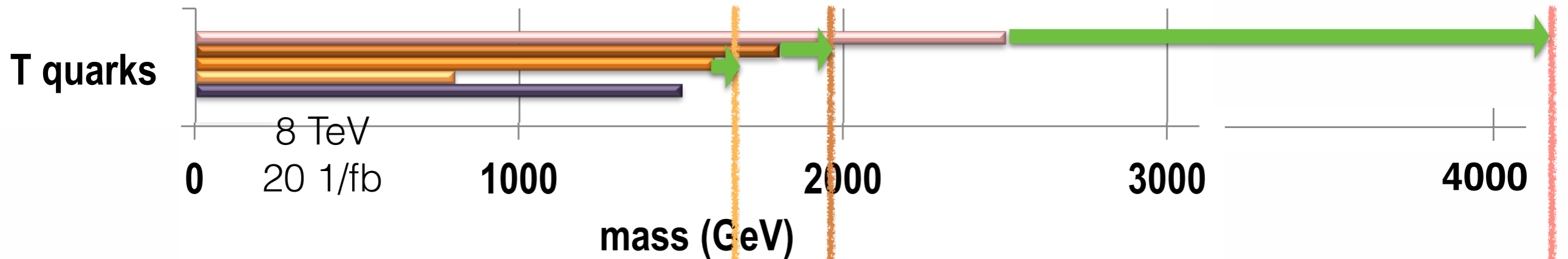
14 TeV
300 1/fb

14 TeV
3000 1/fb

33 TeV
3000 1/fb

Collider Reach(β)TM estimates

T Quarks



- pp, 100 TeV, 3000/fb
- pp, 33 TeV, 3000/fb
- pp, 14 TeV, 3000/fb
- pp, 14 TeV, 300/fb
- pp, 8 TeV, 20/fb
- ee, 3 TeV, 1000/fb
- ee, 1 TeV, 1000/fb
- ee, 0.5 TeV, 500/fb

14 TeV
300 1/fb

14 TeV
3000 1/fb

33 TeV
3000 1/fb

Collider Reach(β)™ estimates



From your iPhone
(or a generic browser)
cern.ch/collider-reach

Collider 1: CoM energy

8

TeV, integrated luminosity

20

fb^{-1}

Collider 2: CoM energy

14

TeV, integrated luminosity

300

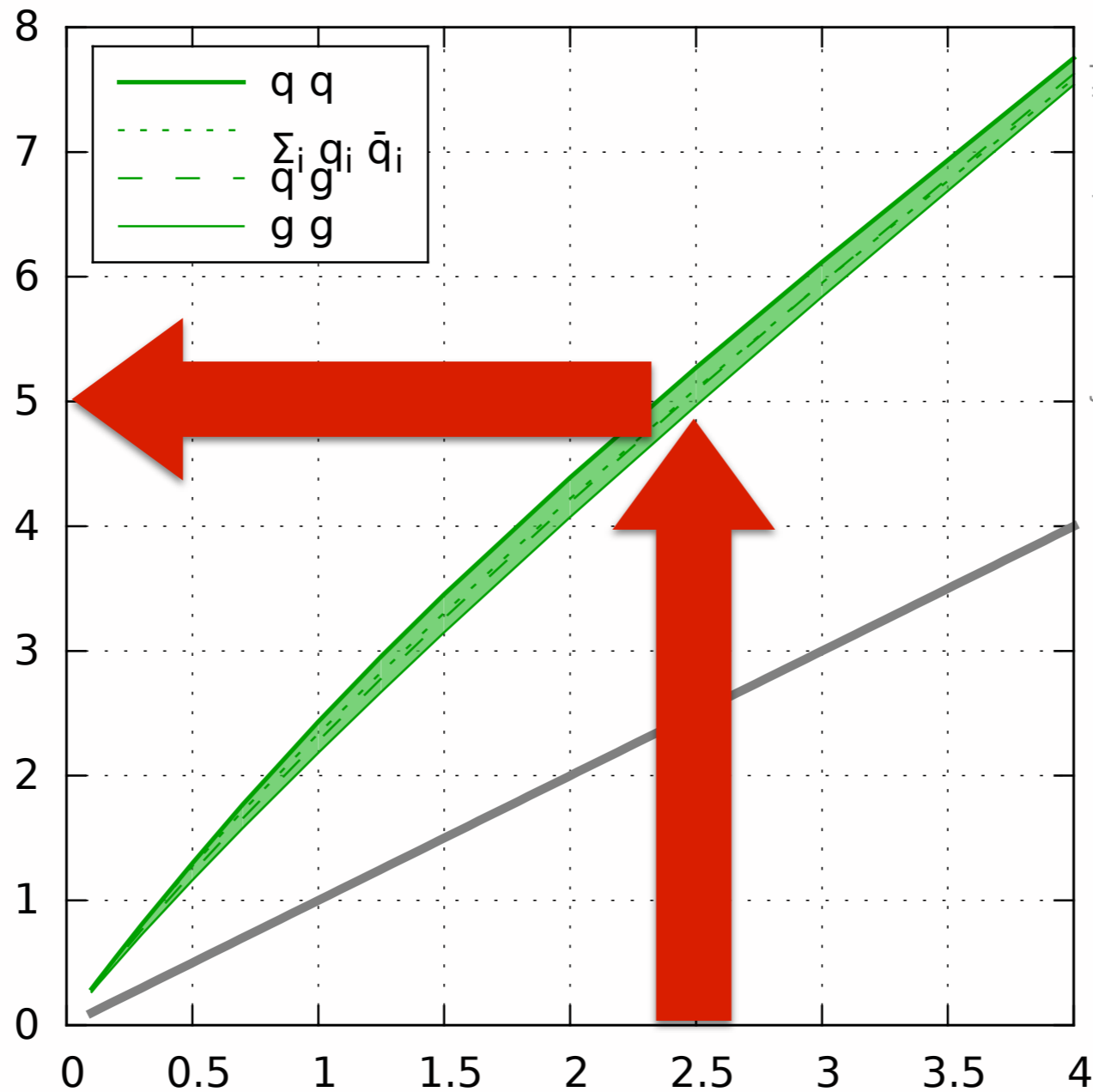
fb^{-1}

PDF:

MSTW2008nnlo68cl



Mass [TeV] at
collider #2



Mass [TeV] at collider #1

Collider 1: CoM energy

8

TeV, integrated luminosity

20

fb^{-1}

Collider 2: CoM energy

14

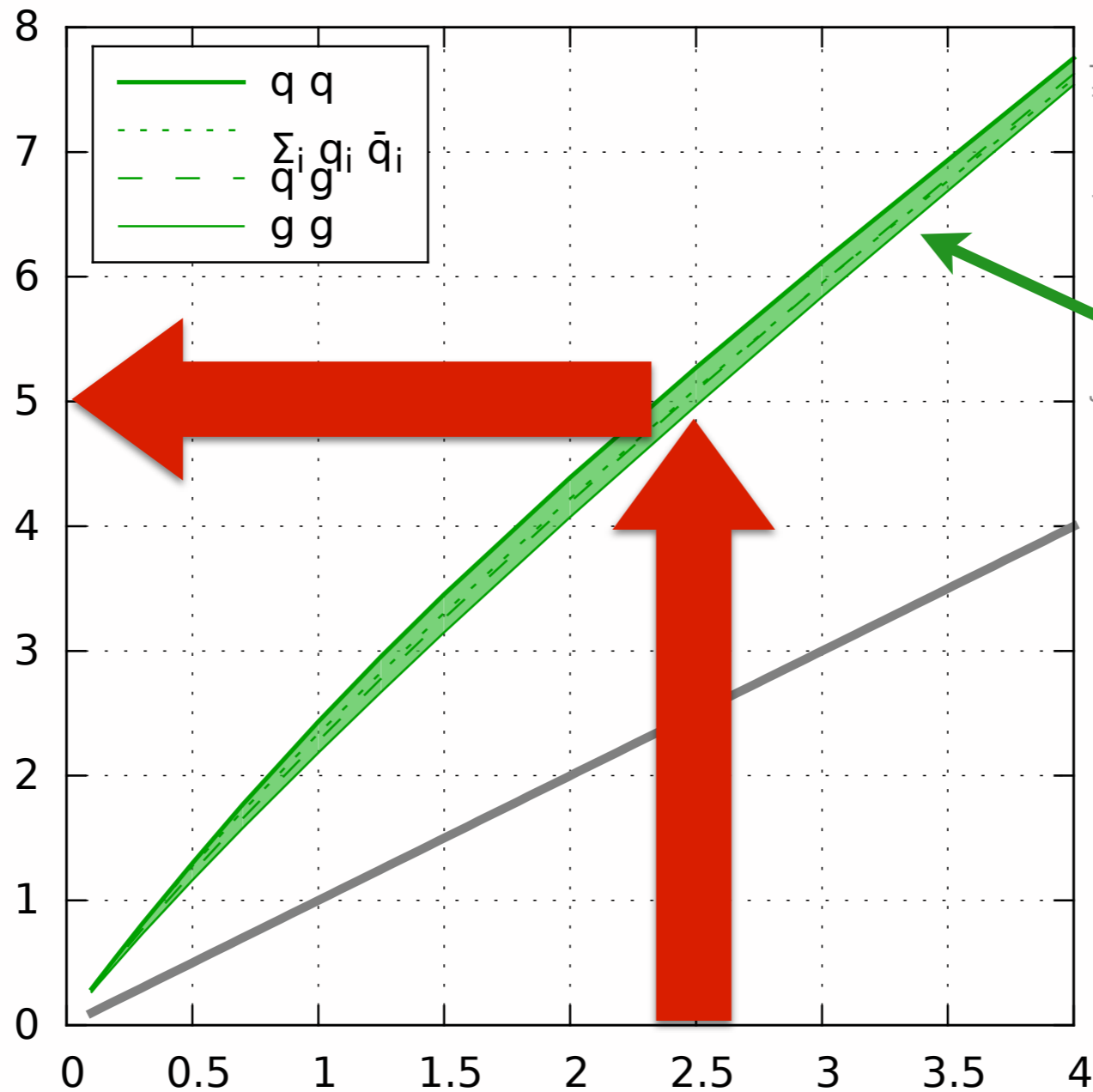
TeV, integrated luminosity

300

fb^{-1}

PDF:

MSTW2008nnlo68cl



Mass [TeV] at
collider #2

Spread of
partonic
channels
(assume same
channel for
S & B)

Mass [TeV] at collider #1

The Collider Reach tool gives you a quick (and dirty) estimate of the relation between the mass reaches of different proton-proton collider setups.

Collider 1: CoM energy TeV, integrated luminosity fb⁻¹

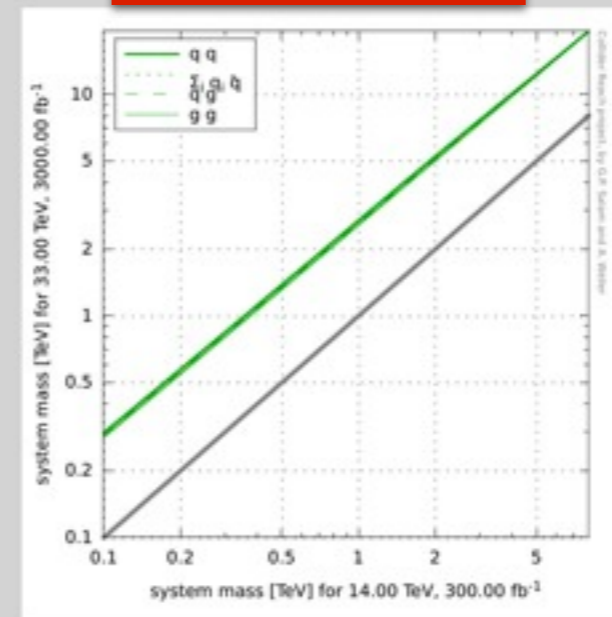
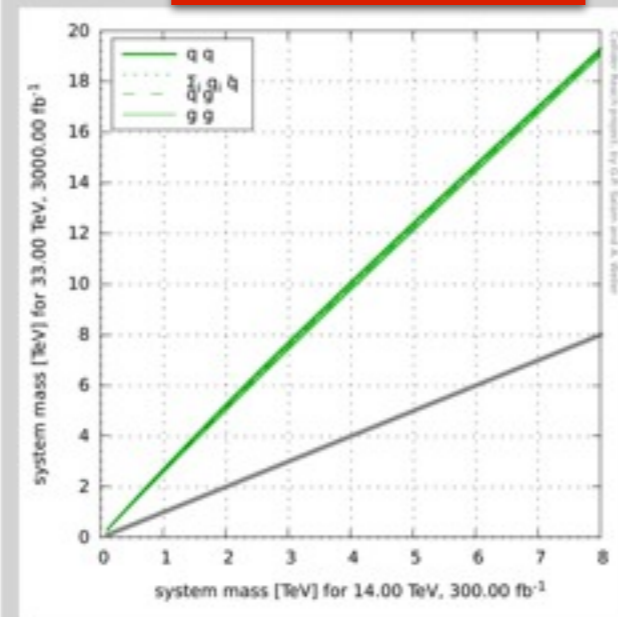
Collider 2: CoM energy TeV, integrated luminosity fb⁻¹

PDF:

linear plot

log-log plot

Plots

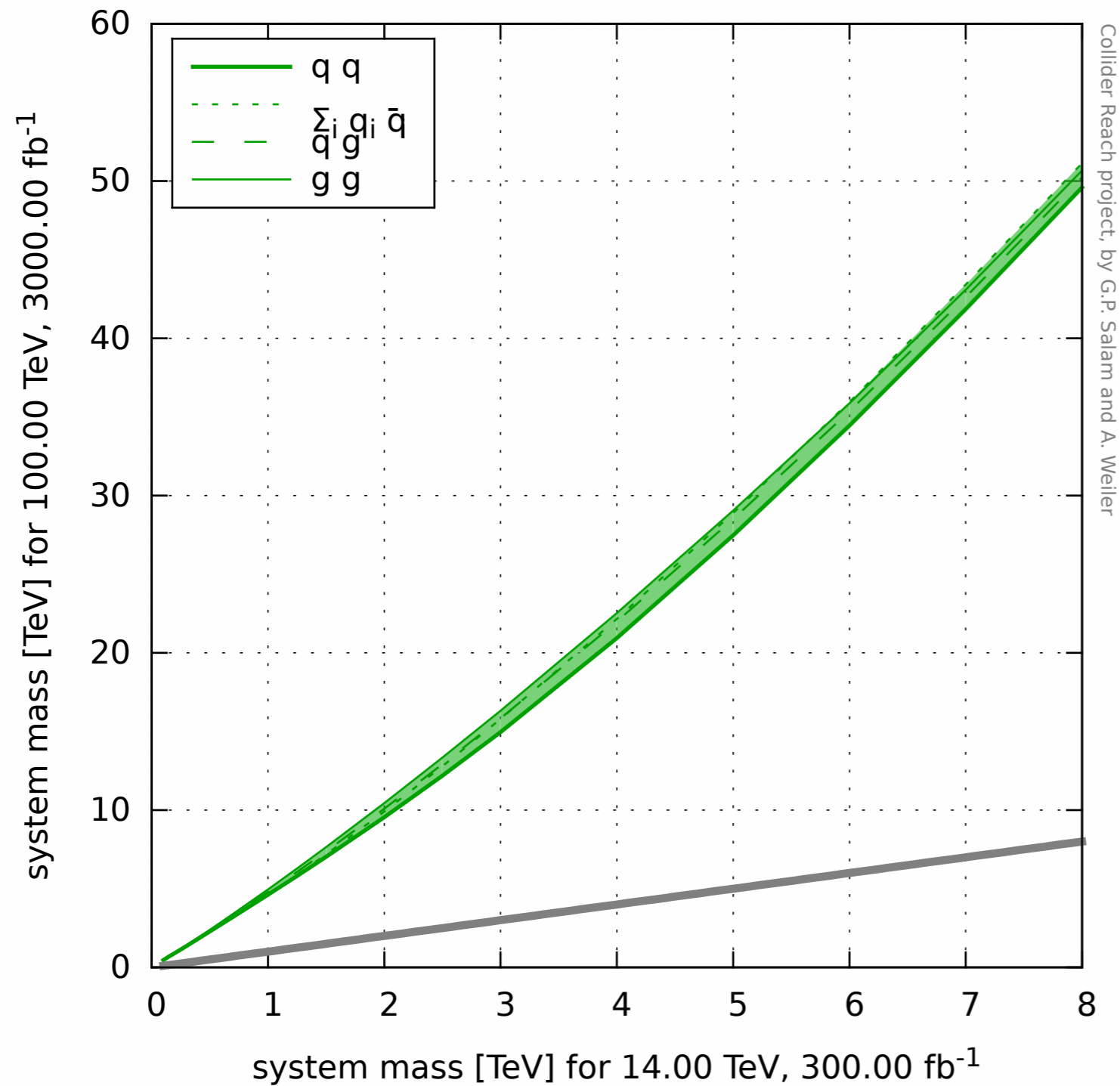


Download: [collider.pdf](#), [colliderloglog.pdf](#), plot generation [log file](#)

The PDF choice was CT10nlo.LHgrid

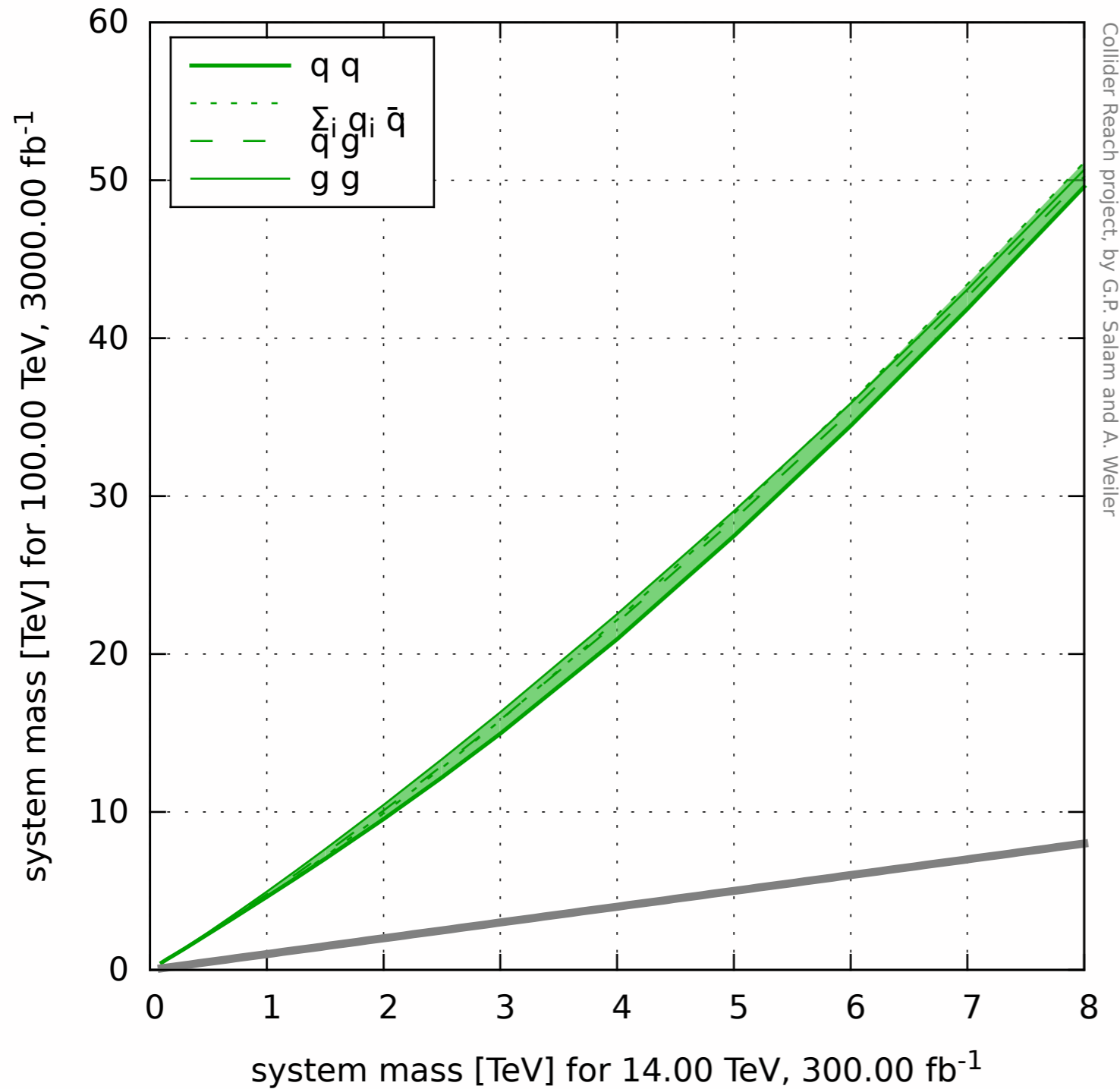
Original mass	gg	qg	allqq	qqbar
100.	283.	291.	298.	297.
125.	350.	359.	368.	367.
150.	416.	427.	438.	437.
200.	547.	562.	576.	575.
300.	806.	827.	848.	847.
500.	1317.	1350.	1386.	1382.
700.	1822.	1866.	1916.	1907.
1000.	2570.	2628.	2702.	2680.
1250.	3188.	3256.	3349.	3314.
1500.	3802.	3879.	3990.	3939.
2000.	5018.	5110.	5251.	5169.
2500.	6223.	6327.	6488.	6380.
3000.	7417.	7530.	7703.	7578.
4000.	9782.	9904.	10082.	9945.
5000.	12120.	12246.	12417.	12284.
6000.	14439.	14565.	14726.	14601.
7000.	16748.	16871.	17021.	16905.
8000.	19053.	19169.	19310.	19206.

14 TeV_{300 fb⁻¹} → 100 TeV_{3 ab⁻¹}



Collider Reach project, by G.P. Salam and A. Weiler

14 TeV_{300 fb⁻¹} → 100 TeV_{3 ab⁻¹}



The PDF choice was CT10nlo.LHgrid

Original mass	gg	qg	allqq	qqbar
100.	469.	465.	462.	457.
125.	585.	579.	575.	568.
150.	702.	693.	687.	679.
200.	937.	923.	912.	902.
300.	1414.	1386.	1365.	1350.
500.	2394.	2332.	2279.	2261.
700.	3401.	3300.	3206.	3194.
1000.	4956.	4793.	4619.	4640.
1250.	6287.	6072.	5818.	5892.
1500.	7647.	7382.	7038.	7187.
2000.	10444.	10090.	9552.	9905.
2500.	13337.	12908.	12185.	12781.
3000.	16319.	15833.	14954.	15795.
4000.	22531.	21986.	20933.	22162.
5000.	29050.	28508.	27467.	28894.
6000.	35863.	35366.	34451.	35960.
7000.	43079.	42620.	41854.	43411.
8000.	50671.	50230.	49590.	51132.

When you've lost your iPhone

Rule of Thumb #1

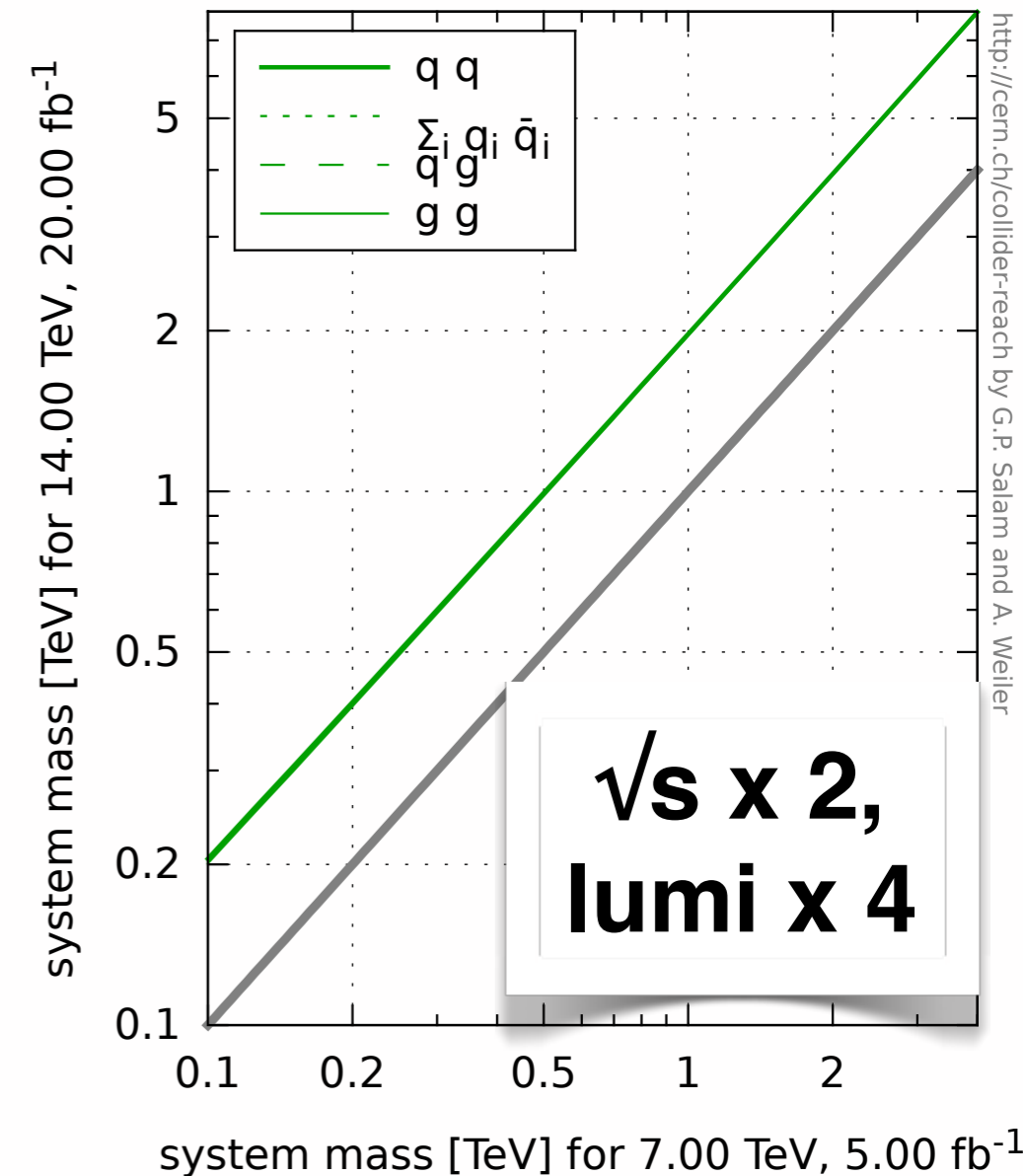
(well known among practitioners)

Increase collider energy by factor X
& increase luminosity by a factor X^2

→ **reach goes up by a factor X**

[Because you keep same Bjorken- x &
luminosity increase compensates for
 $1/\text{mass}^2$ scaling of cross sections]

PDF scaling variations are small effect



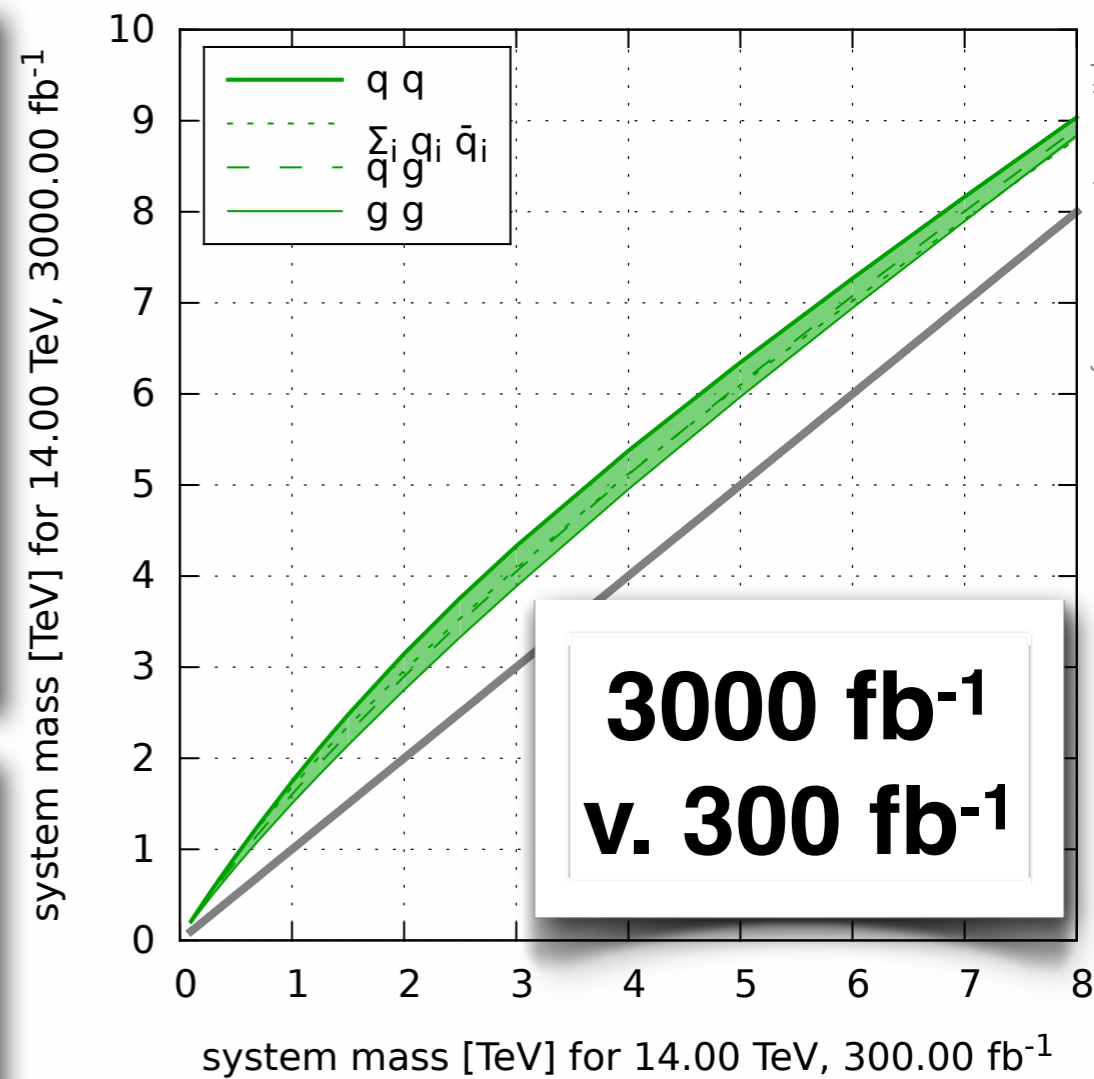
Rule of Thumb #2

(apparently not widely known previously)

Increase luminosity by factor 10
→ **reach increases by constant**
 $\Delta m = 0.07\sqrt{s}$

i.e. for $\sqrt{s}=14$ TeV, reach goes by up
1 TeV

No deep reason — a somewhat
random characteristic of large-x PDFs.
Only holds for $0.15 \lesssim M/\sqrt{s} \lesssim 0.6$



Consequence of rule #2

(may be a bit fragile & only for $S \approx B$)

Exclusion is $2\text{-}\sigma$

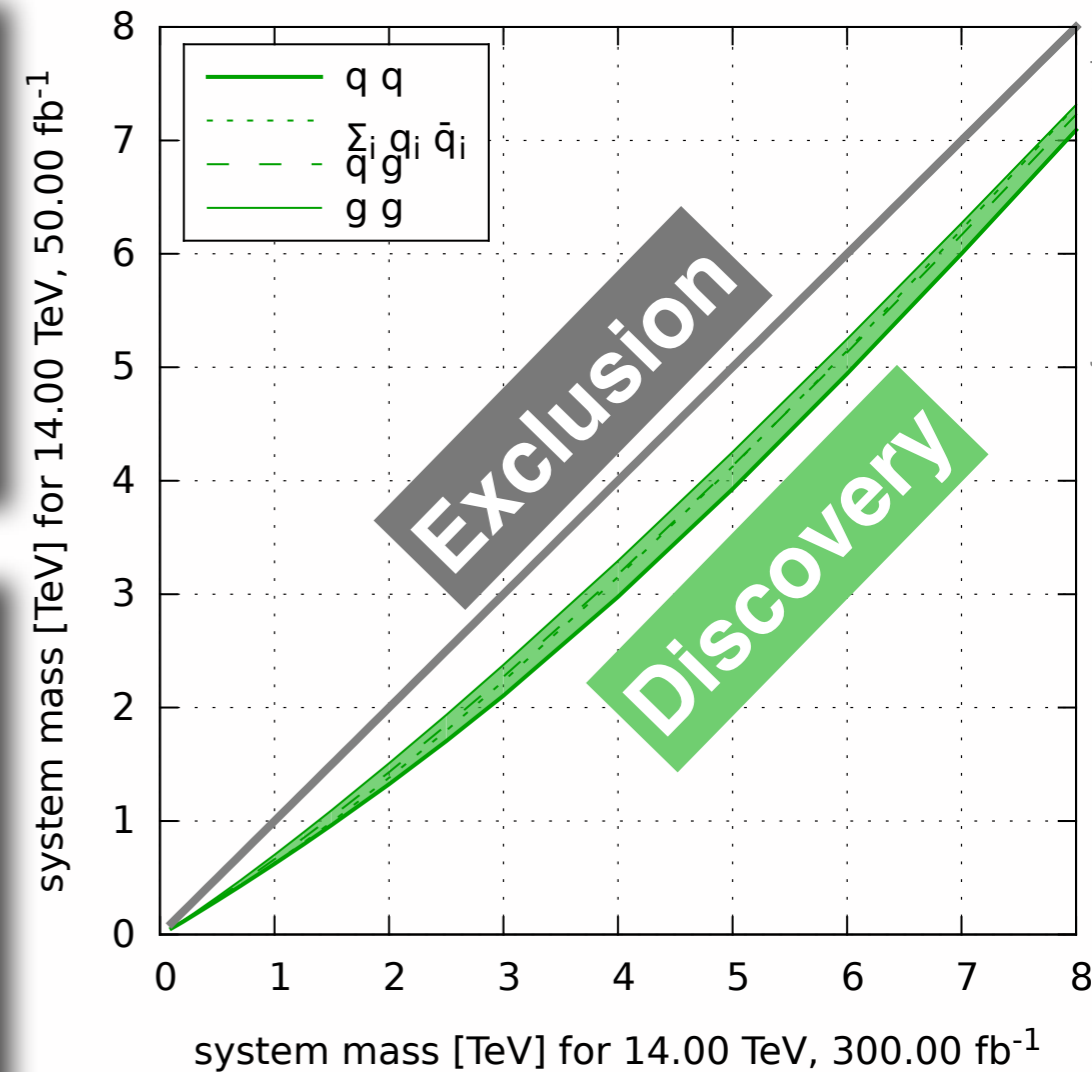
Discovery is $5\text{-}\sigma$

Need $(5/2)^2 = 6.25$ increase in lumi to go from one to the other.

Using rule #2:

discovery reach is about $0.05\sqrt{s}$
below exclusion reach

~ 0.8 TeV at 14 TeV



Conclusions

cern.ch/collider-reach

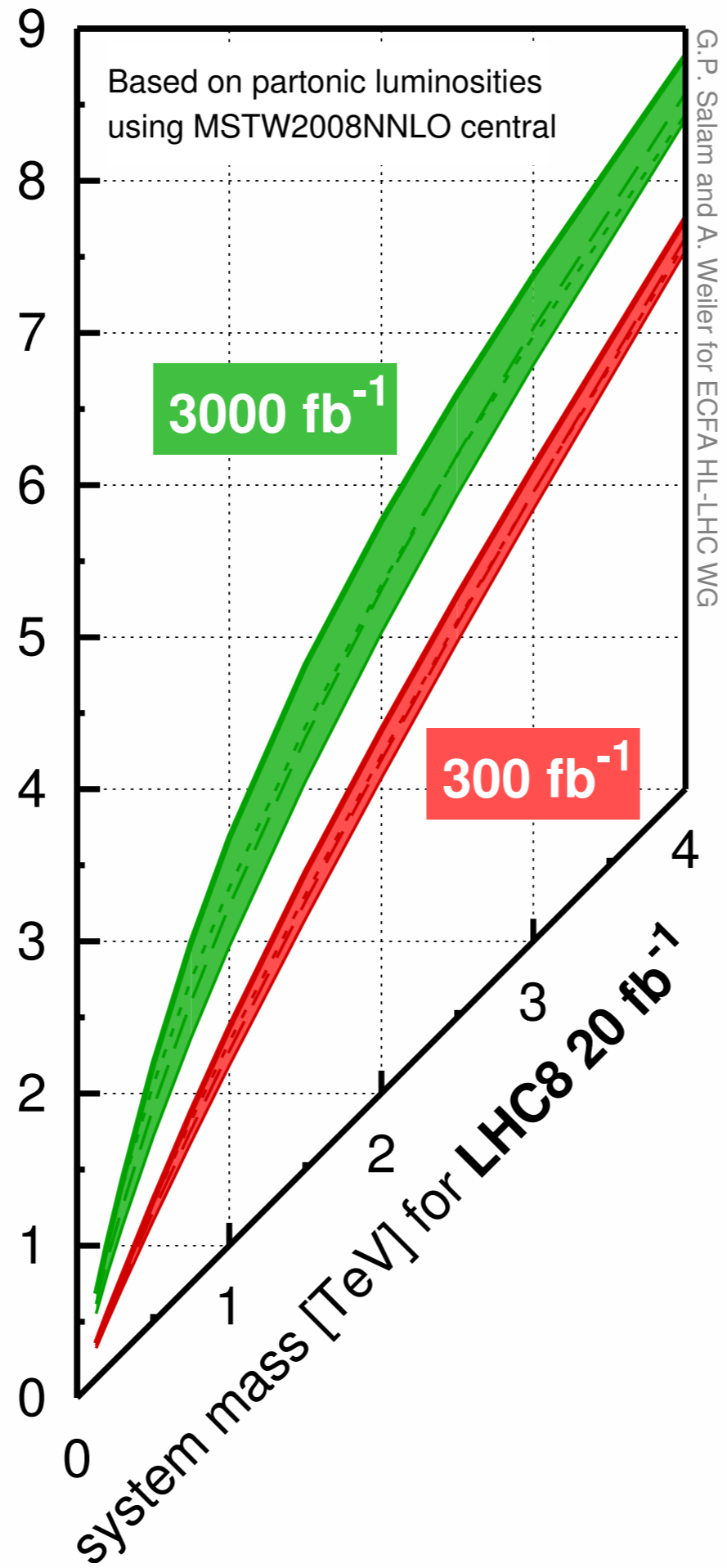
Based on LHAPDF, HOPPET and a PDF of your choice

BACKUP SLIDES

Assumptions

- We don't need to worry about scaling of background vs. signal
- Reconstruction efficiencies, background rejection, etc all stay reasonably constant

system mass [TeV] for LHC14



- $\Sigma\Sigma$
- - Σg
- ⋯ $\Sigma_i q_i \bar{q}_i$
- gg

LHC comparison

1208.1447
ATLAS-CONF-2013-024

gg

stop limits	[expected]	(lsp = 0gev)
7TeV, 4.7 ifb	500 gev	
8TeV, 20.5 ifb	650 gev	----> 675 GeV

qqbar

ATLAS EXOT-2011-06
ATLAS-CONF-2012-129
ATLAS-CONF-2013-017

sequential z-prime	[expected]	
7TeV, 1.1 ifb	1800 gev	
8TeV, 6 ifb,	2550 gev	----> 2450 GeV
8TeV, 20 ifb	2800 gee	----> 2790 GeV

qg

EXOT-2011-07
ATLAS-CONF-2012-088
ATLAS-CONF-2012-148

excited quark q*	[expected]	(NB, sig \neq bgd scaling)
7 TeV, 1 ifb	2900 gev	
8 TeV, 5.8 ifb	3500 gev	----> 3700 GeV
8 TeV, 13 ifb	3700 gev	----> 3900 GeV

LHC comparison

1208.1447
ATLAS-CONF-2013-024

gg
stop limits [expected] (lsp = 0gev) Baseline

7TeV, 4.7 ifb	500 gev	←	
8TeV, 20.5 ifb	650 gev	----	→ 675 GeV

qqbar
ATLAS EXOT-2011-06
ATLAS-CONF-2012-129
ATLAS-CONF-2013-017

sequential z-prime [expected]

7TeV, 1.1 ifb	1800 gev	←	
8TeV, 6 ifb,	2550 gev	----	→ 2450 GeV
8TeV, 20 ifb	2800 gee	----	→ 2790 GeV

qq
EXOT-2011-07
ATLAS-CONF-2012-088
ATLAS-CONF-2012-148

excited quark q* [expected] (NB, sig ≠ bgd scaling)

7 TeV, 1 ifb	2900 gev	←	
8 TeV, 5.8 ifb	3500 gev	----	→ 3700 GeV
8 TeV, 13 ifb	3700 gev	----	→ 3900 GeV

LHC comparison

1208.1447
ATLAS-CONF-2013-024

gg
stop limits [expected] (lsp = 0gev) Baseline

7TeV, 4.7 ifb	500 gev	←
8TeV, 20.5 ifb	650 gev	----> 675 GeV

qqbar Lumi method

ATLAS EXOT-2011-06
ATLAS-CONF-2012-129
ATLAS-CONF-2013-017

sequential z-prime [expected]

7TeV, 1.1 ifb	1800 gev	←
8TeV, 6 ifb,	2550 gev	----> 2450 GeV
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EXOT-2011-07
ATLAS-CONF-2012-088
ATLAS-CONF-2012-148

qq

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