Towards an (un)Natural Weak Scale

Josh Ruderman
UC Berkeley & LBNL
Bay Area Seminar, 10/4

Michal Czakon, Alexander Mitov, Michele Papucci, JTR, Andreas Weiler, *to appear.*

Lawrence Hall, David Pinner, JTR, *to appear.*

$$m_h \approx 125 \text{ GeV}$$

+ no obvious BSM below ~1 TeV

natural

fine-tuned

missing top partner?

multiverse?
(landscape?)

this talk:

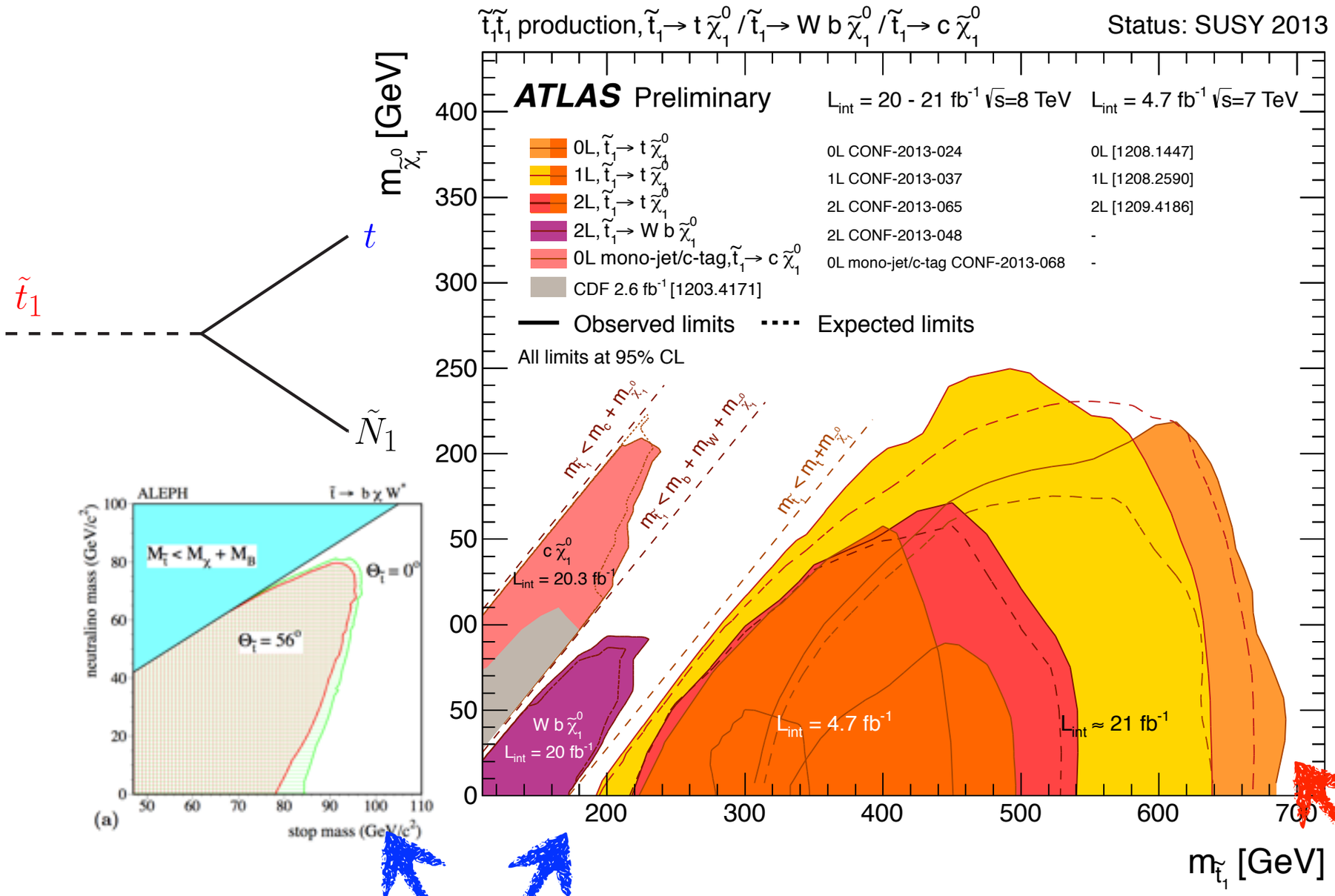
part I: closing the light stop window (stealth stop)

part II: the weak scale from BBN

1. killing the stealth stop

Michal Czakon, Alexander Mitov, Michele Papucci, JTR,
Andreas Weiler, *to appear.*

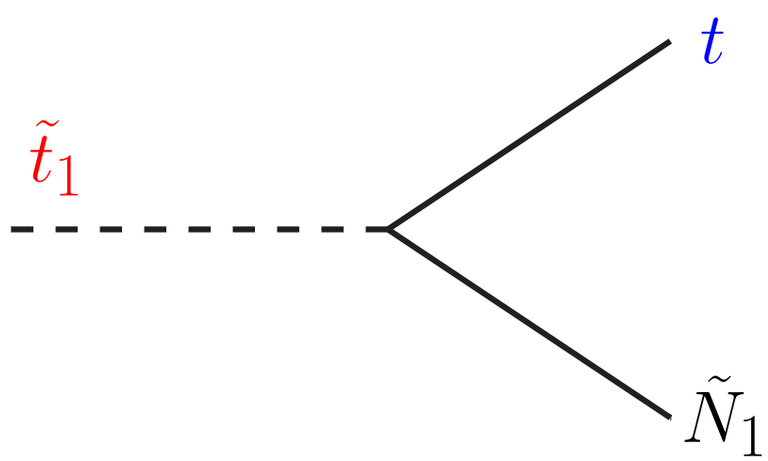
state of stops



interesting gaps

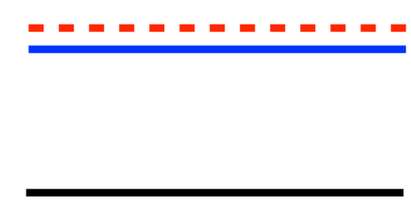
~10% tuning

stealth stop

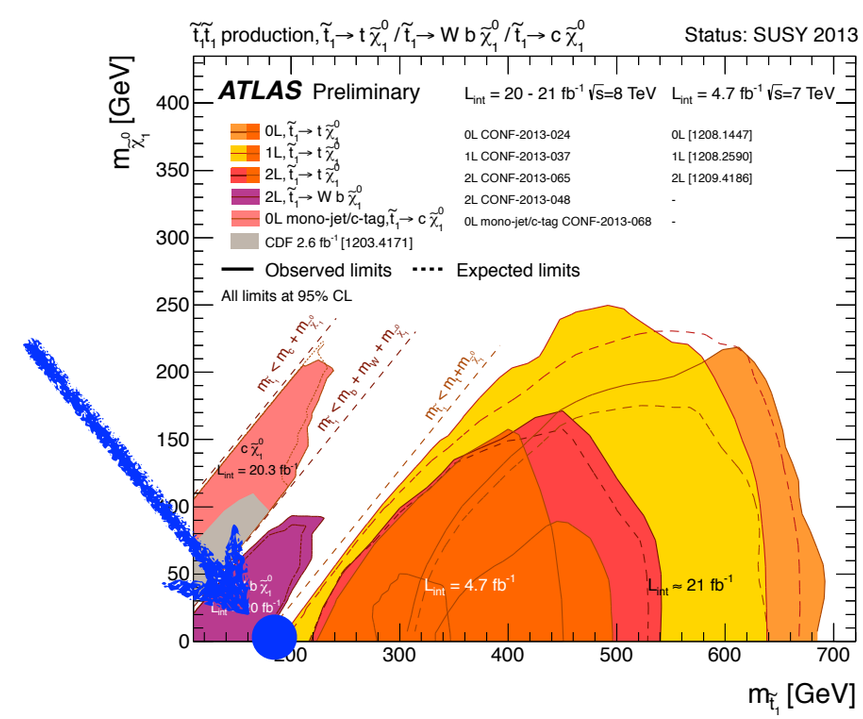


$$m_{\tilde{t}_R} \approx m_t$$

$$m_{LSP} \approx 0$$



$$\frac{\sigma_{\tilde{t}\tilde{t}^*}}{\sigma_{t\bar{t}}}(m_{\tilde{t}} = m_t) \approx 0.15$$

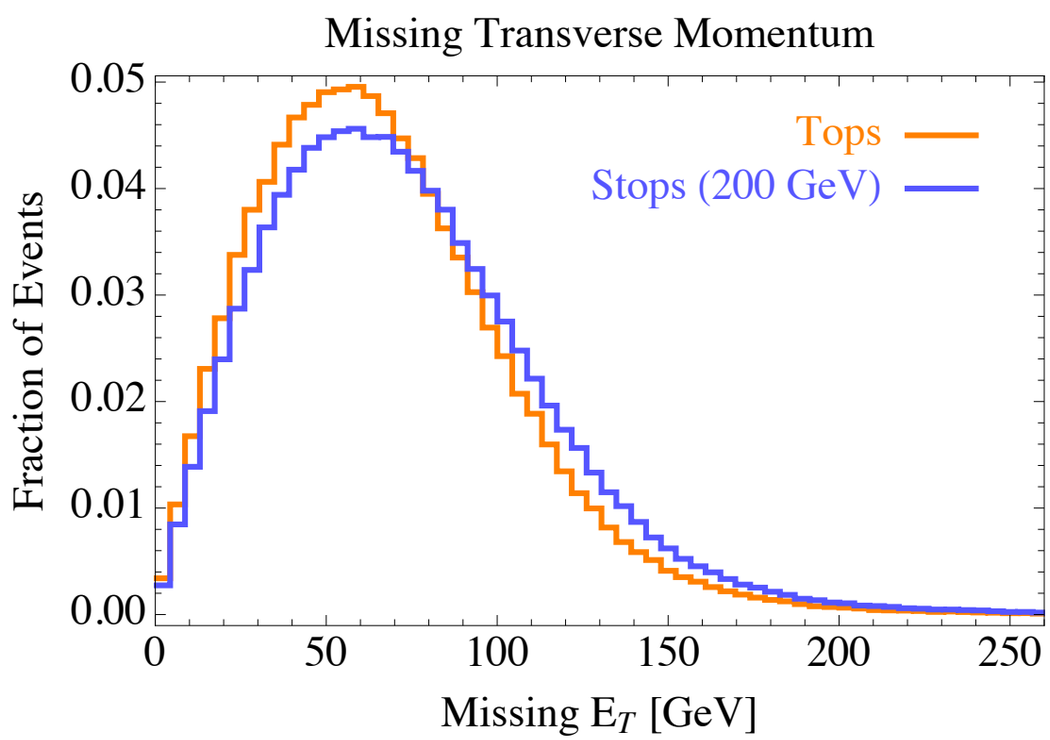


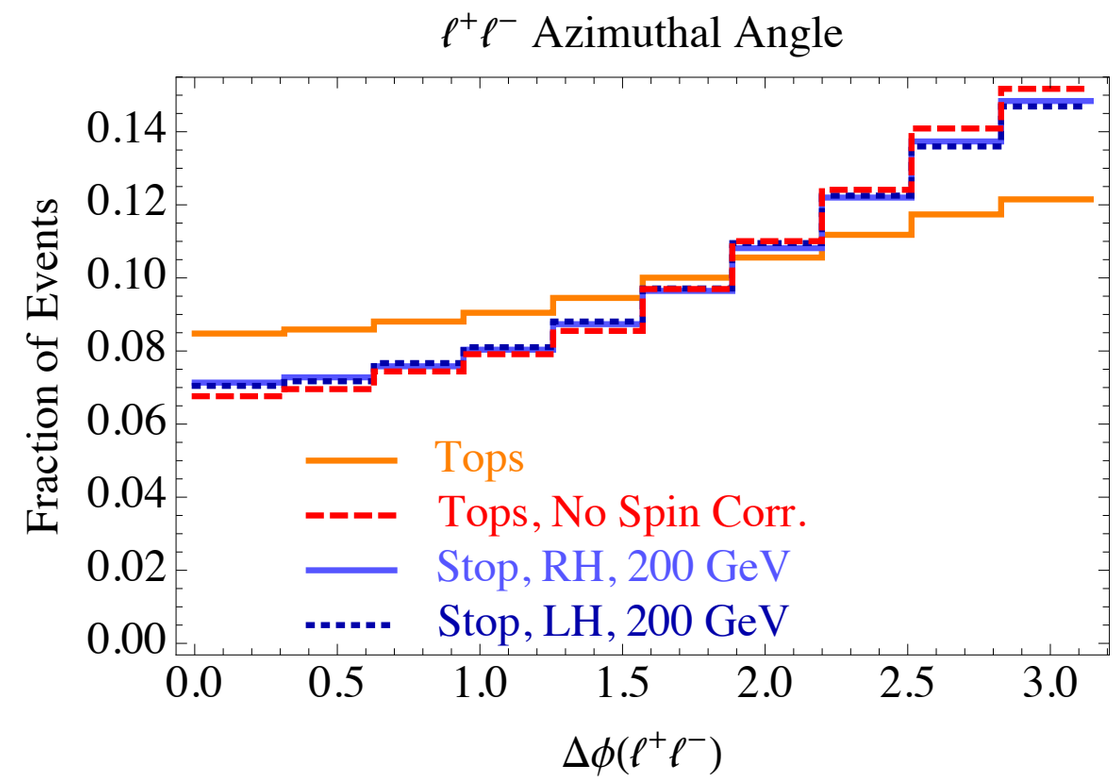
JiJi Fan, Matt Reece, JTR, 1105.5135

stealth stop

$m_{\tilde{t}_R} \approx m_t$

$m_{LSP} \approx 0$





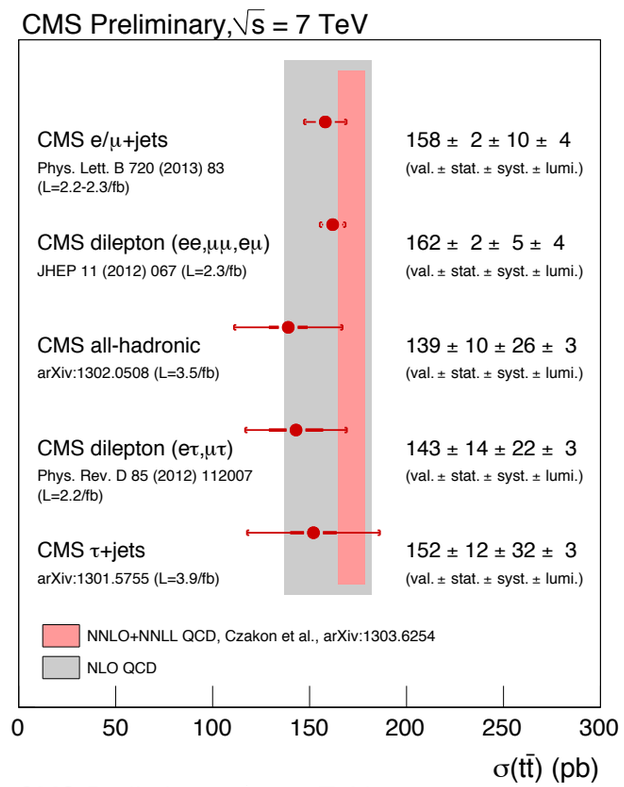
Han, Katz, Krohn, Reece 1205.5808

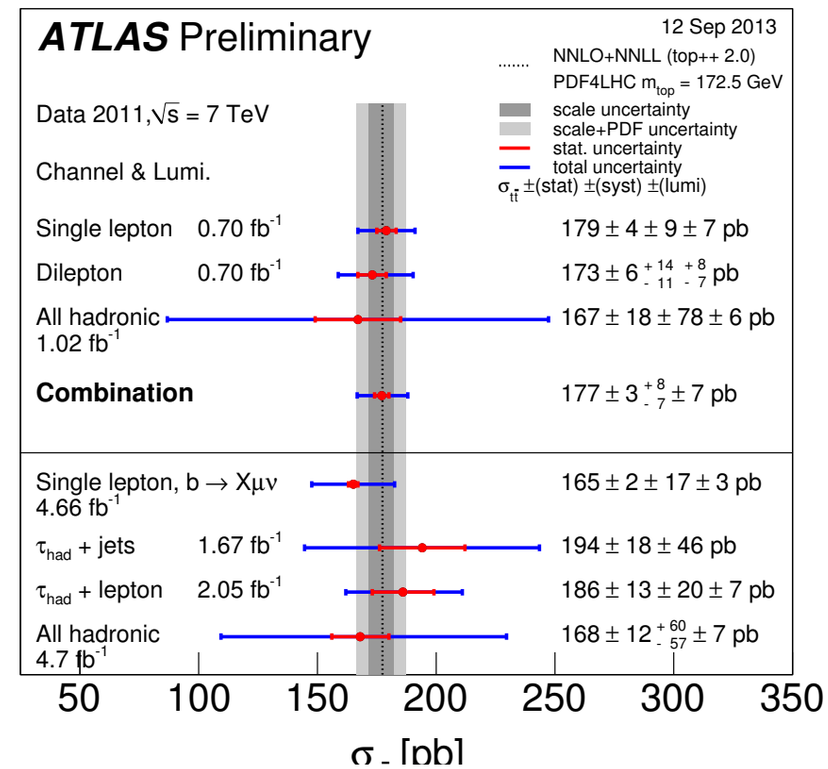
where is SUSY?

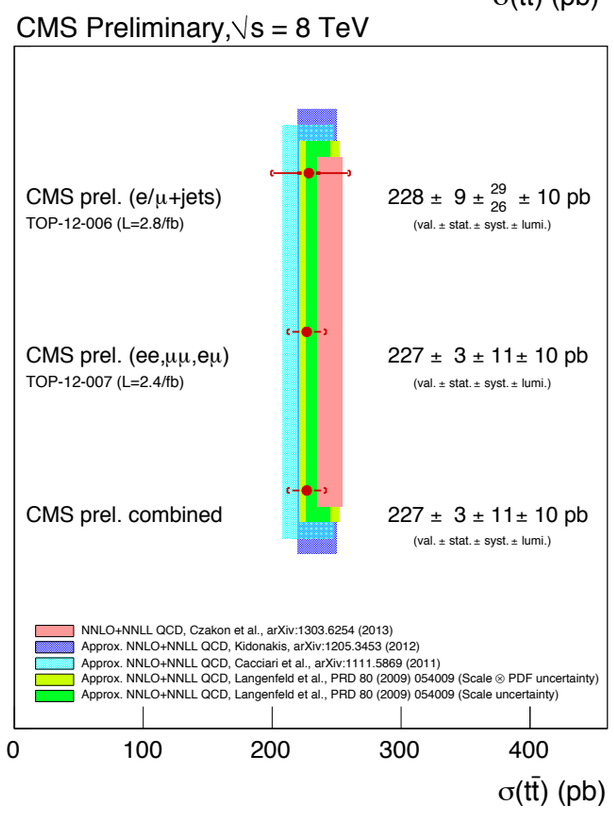
- we usually look for SUSY by separating signal from background (MET/H_T tails, ...)

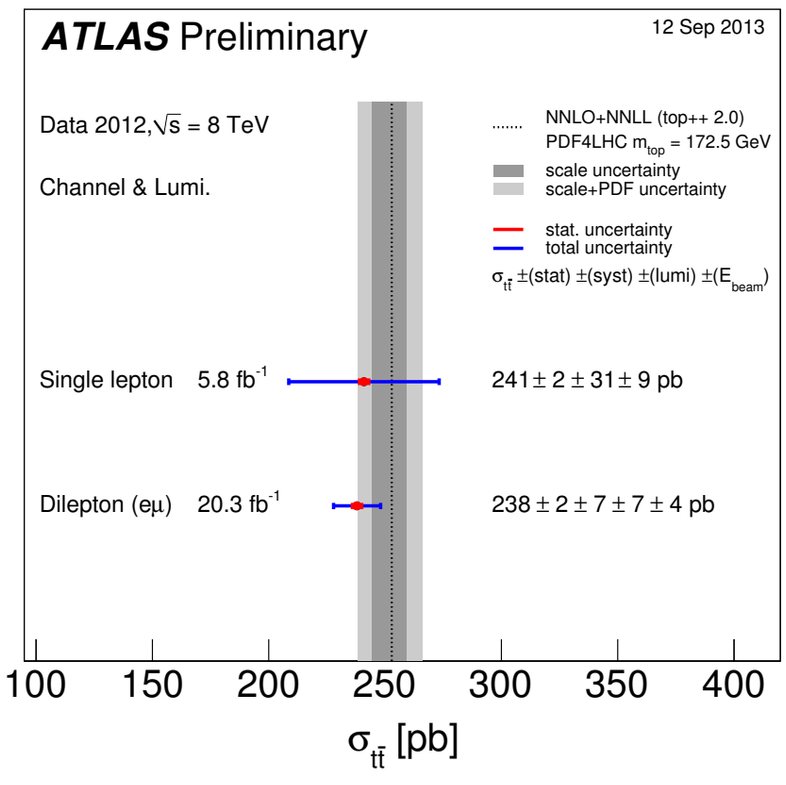
- instead, what about using precision SM measurements?

top σ


CMS Preliminary, √s = 7 TeV
CMS e/μ+jets
Phys. Lett. B 720 (2013) 83
(L=2.2-2.3/fb)
158 ± 2 ± 10 ± 4
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (ee,μμ,eμ)
JHEP 11 (2012) 067 (L=2.3/fb)
162 ± 2 ± 5 ± 4
(val. ± stat. ± syst. ± lumi.)
CMS all-hadronic
arXiv:1302.0508 (L=3.5/fb)
139 ± 10 ± 26 ± 3
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (eτ,μτ)
Phys. Rev. D 85 (2012) 112007
(L=2.2/fb)
143 ± 14 ± 22 ± 3
(val. ± stat. ± syst. ± lumi.)
CMS τ+jets
arXiv:1301.5755 (L=3.9/fb)
152 ± 12 ± 32 ± 3
(val. ± stat. ± syst. ± lumi.)
NNLO+NNLL QCD, Czakon et al., arXiv:1303.6254
NLO QCD
0 50 100 150 200 250 300
σ(tt̄) (pb)


ATLAS Preliminary
12 Sep 2013
NNLO+NNLL (top++ 2.0)
PDF4LHC m_top = 172.5 GeV
scale uncertainty
scale+PDF uncertainty
stat. uncertainty
total uncertainty
σ_tt̄ ±(stat) ±(syst) ±(lumi)
Data 2011, √s = 7 TeV
Channel & Lumi.
Single lepton 0.70 fb⁻¹ 179 ± 4 ± 9 ± 7 pb
Dilepton 0.70 fb⁻¹ 173 ± 6 +14 -11 +8 -7 pb
All hadronic 1.02 fb⁻¹ 167 ± 18 ± 78 ± 6 pb
Combination 177 ± 3 +8 -7 ± 7 pb
Single lepton, b → Xμν 4.66 fb⁻¹ 165 ± 2 ± 17 ± 3 pb
τ_had + jets 1.67 fb⁻¹ 194 ± 18 ± 46 pb
τ_had + lepton 2.05 fb⁻¹ 186 ± 13 ± 20 ± 7 pb
All hadronic 4.7 fb⁻¹ 168 ± 12 +60 -57 ± 7 pb
50 100 150 200 250 300 350
σ_tt̄ [pb]


CMS Preliminary, √s = 8 TeV
CMS prel. (e/μ+jets)
TOP-12-006 (L=2.8/fb)
228 ± 9 ± 29 26 ± 10 pb
(val. ± stat. ± syst. ± lumi.)
CMS prel. (ee,μμ,eμ)
TOP-12-007 (L=2.4/fb)
227 ± 3 ± 11 ± 10 pb
(val. ± stat. ± syst. ± lumi.)
CMS prel. combined
227 ± 3 ± 11 ± 10 pb
(val. ± stat. ± syst. ± lumi.)
NNLO+NNLL QCD, Czakon et al., arXiv:1303.6254 (2013)
Approx. NNLO+NNLL QCD, Kidonakis, arXiv:1205.3453 (2012)
Approx. NNLO+NNLL QCD, Cacciari et al., arXiv:1111.5869 (2011)
Approx. NNLO+NNLL QCD, Langenfeld et al., PRD 80 (2009) 054009 (Scale ⊗ PDF uncertainty)
Approx. NNLO+NNLL QCD, Langenfeld et al., PRD 80 (2009) 054009 (Scale uncertainty)
0 100 200 300 400
σ(tt̄) (pb)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scale uncertainty
scale+PDF uncertainty
stat. uncertainty
total uncertainty
σ_tt̄ ±(stat) ±(syst) ±(lumi) ±(E_beam)
Data 2012, √s = 8 TeV
Channel & Lumi.
Single lepton 5.8 fb⁻¹ 241 ± 2 ± 31 ± 9 pb
Dilepton (eμ) 20.3 fb⁻¹ 238 ± 2 ± 7 ± 7 ± 4 pb
100 150 200 250 300 350 400
σ_tt̄ [pb]

top σ

7 TeV

σ

$$\sigma_{t\bar{t}} \approx 172 \text{ pb} \qquad \sigma_{\tilde{t}\tilde{t}^*}(m_{\tilde{t}} = m_t) \approx 26 \text{ pb}$$

theory error

NLO:

$$\delta\sigma_{\text{th}} \approx 20 \text{ pb}$$

experimental error

$$\delta\sigma_{\text{exp}} \approx 7 \text{ pb}$$

top σ

7 TeV

σ **The total top quark pair production cross-section at hadron colliders through $\mathcal{O}(\alpha_S^4)$**

$\sigma_{t\bar{t}} \approx 172$ pb $\sigma_{tt^*}(m_{t^*} = m_t) \approx 26$ pb

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Alexander Mitov
Theory Division, CERN, CH-1211 Geneva 23, Switzerland
(Dated: March 26, 2013)

theory error

NLO:

$\delta\sigma_{\rm th} \approx 20$ pb

NNLO+NNLL

$$\sigma_{t\bar{t}} = 172^{+4.4}_{-5.8}(\text{scale})^{+4.7}_{-4.8}(\text{pdf})\ \text{pb}$$

experimental error

$\delta\sigma_{\rm exp} \approx 7$ pb

top σ

7 TeV

σ

$$\sigma_{t\bar{t}} \approx 172 \text{ pb}$$

$$\sigma_{\tilde{t}\tilde{t}^*}(m_{\tilde{t}} = m_t) \approx 26 \text{ pb}$$

theory error

NLO:

$$\delta\sigma_{\text{th}} \approx 20 \text{ pb}$$

NNLO:

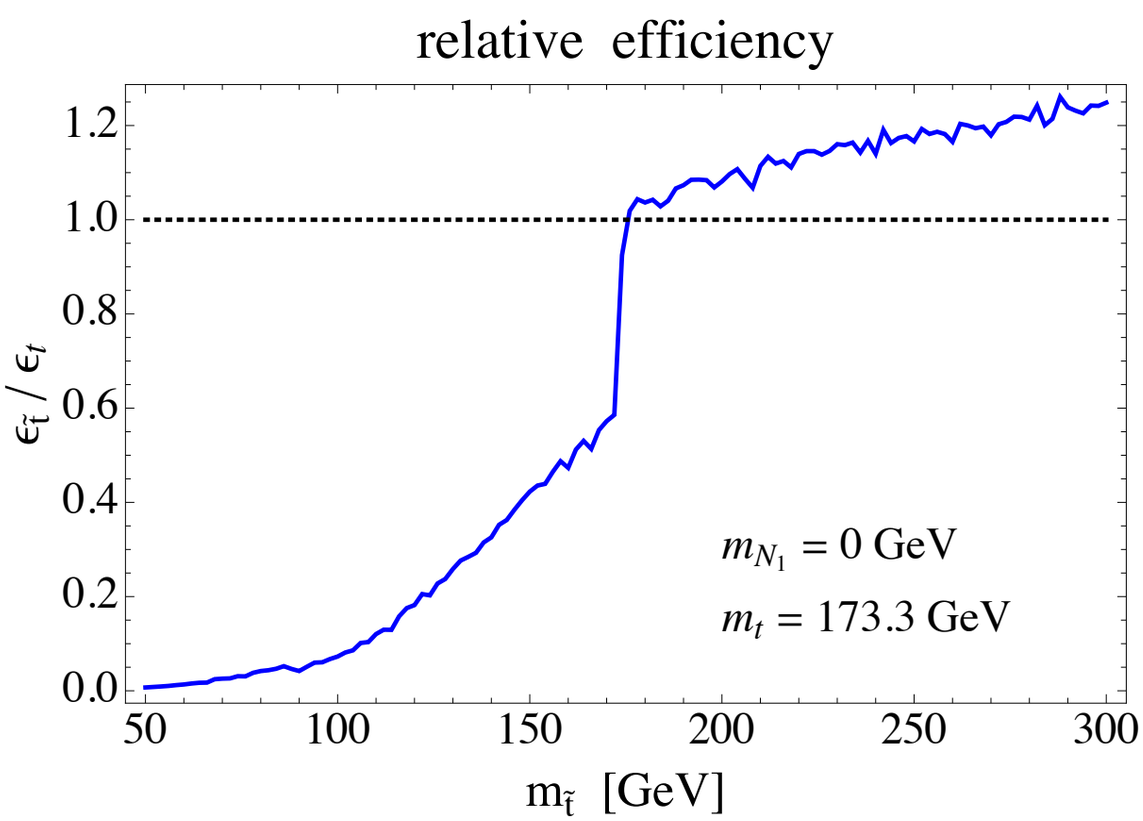
$$\delta\sigma_{\text{th}} \approx 8 \text{ pb}$$

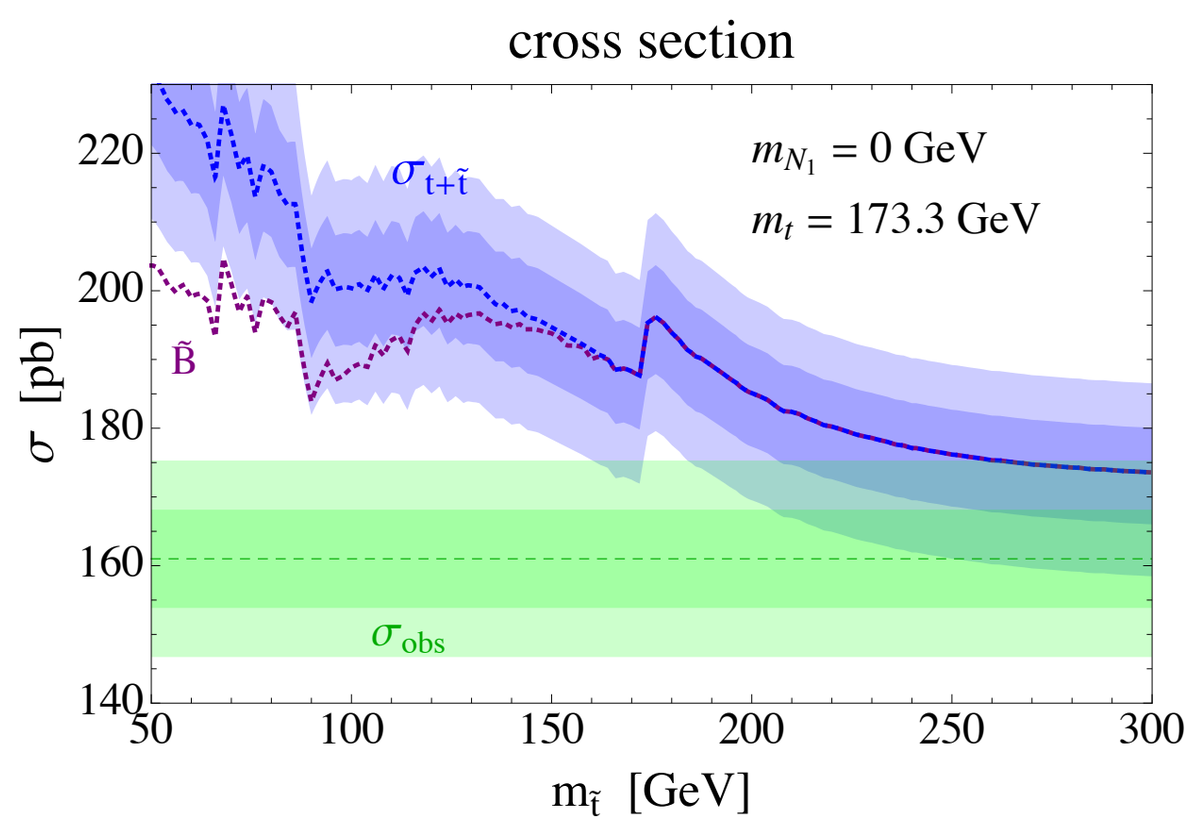
experimental error

$$\delta\sigma_{\text{exp}} \approx 7 \text{ pb}$$

stop + top

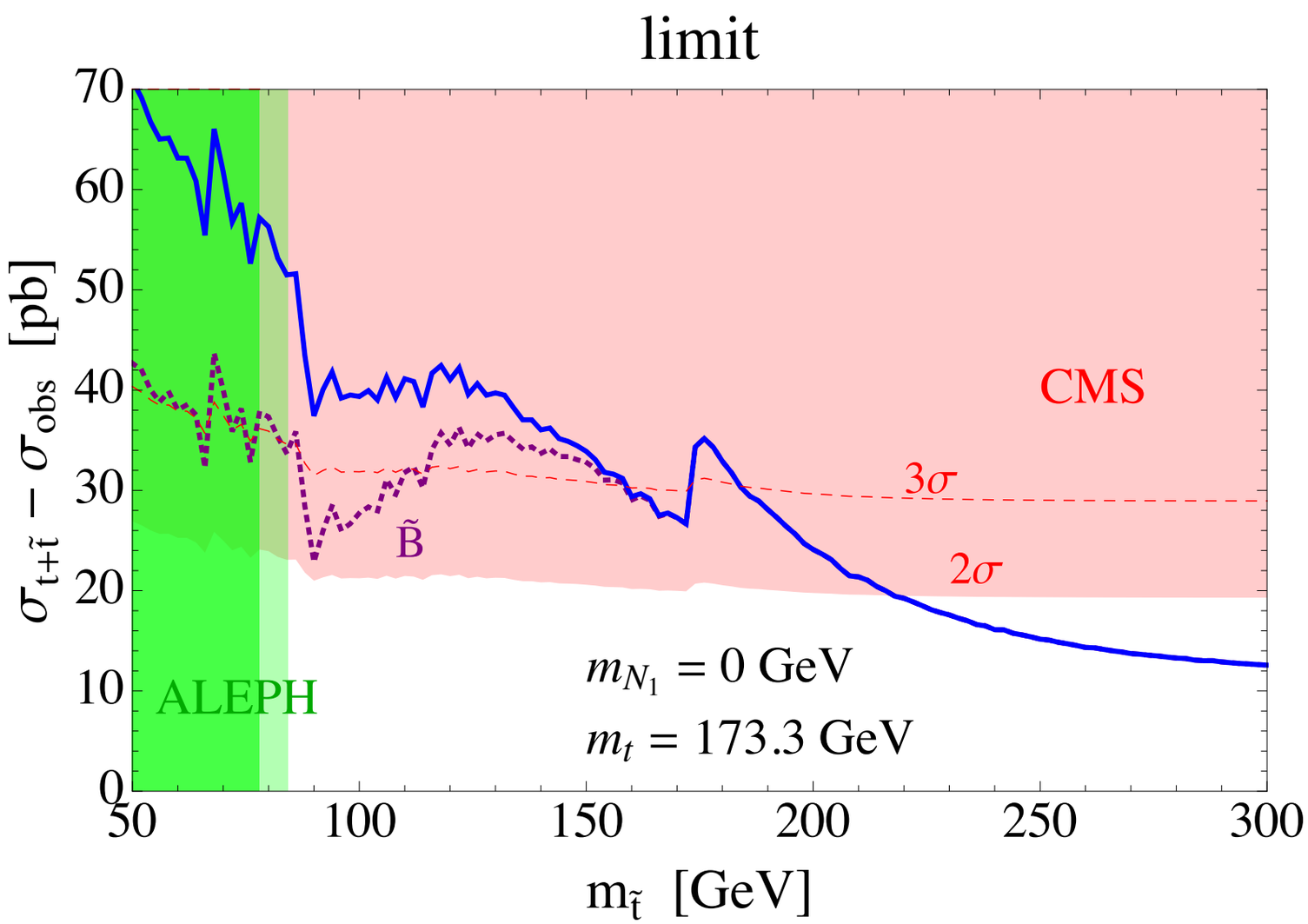
CMS dilepton @7TeV:





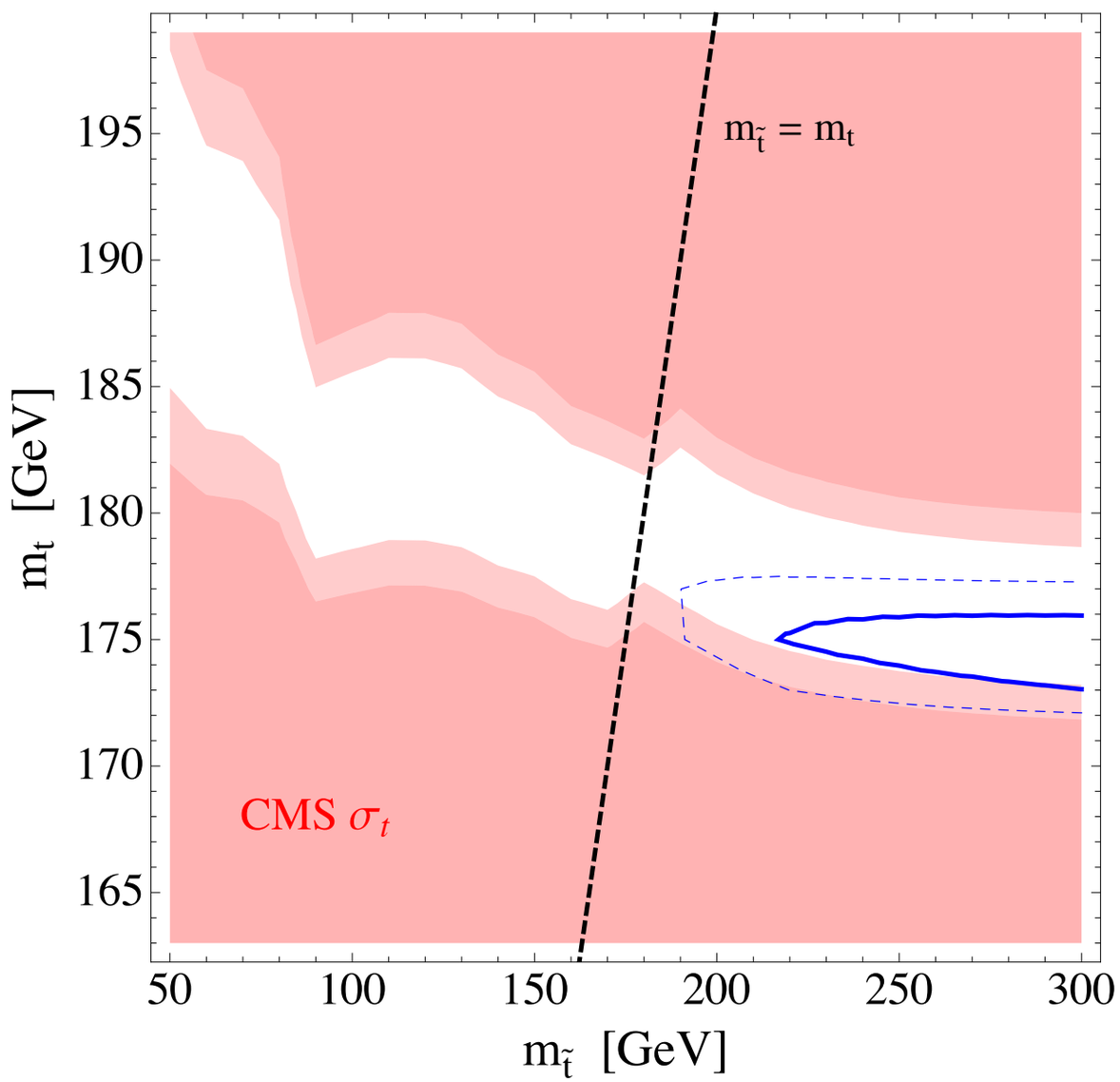
stop + top

CMS dilepton @7TeV:



stop + top

varying the top mass:



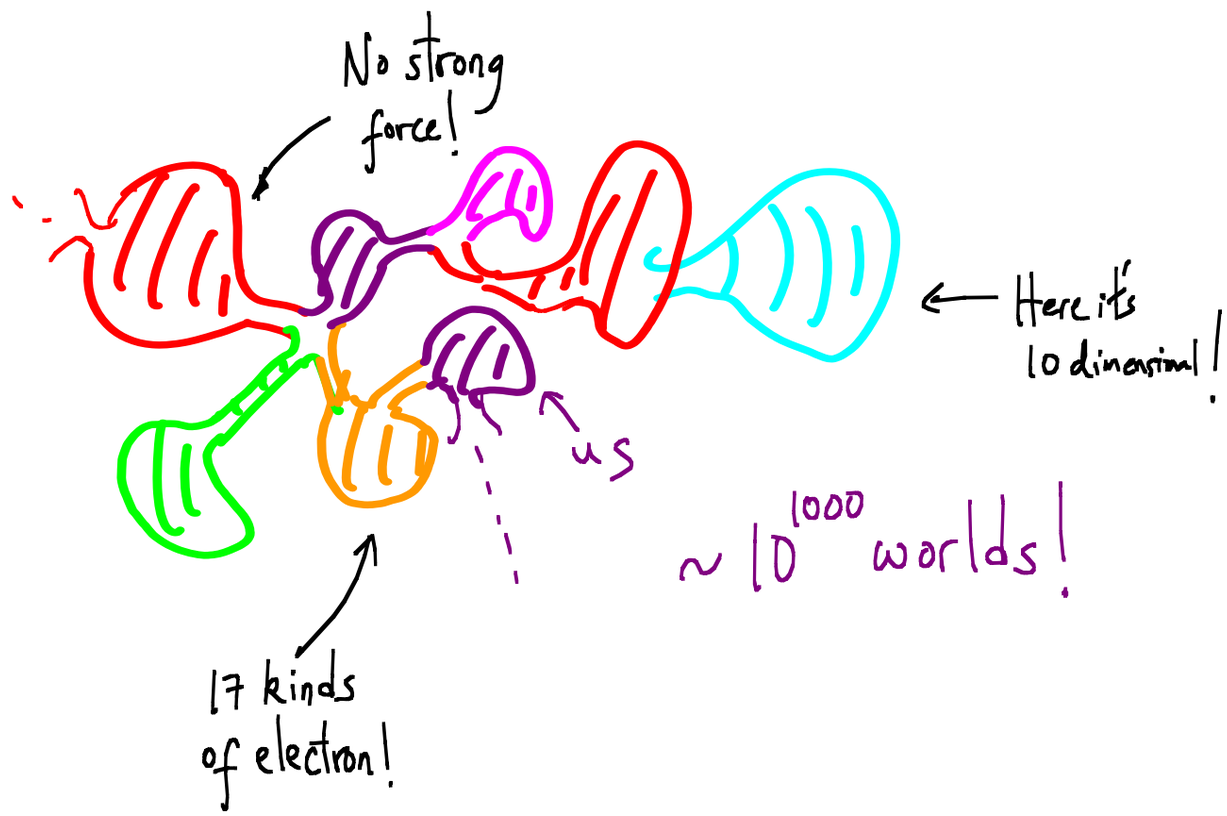
LHC top mass
(5/fb)

$173.3 \pm 0.5 \pm 1.3$ GeV

what is m_t in the presence of stop contamination?

and now for something completely different...

2. the weak scale from BBN

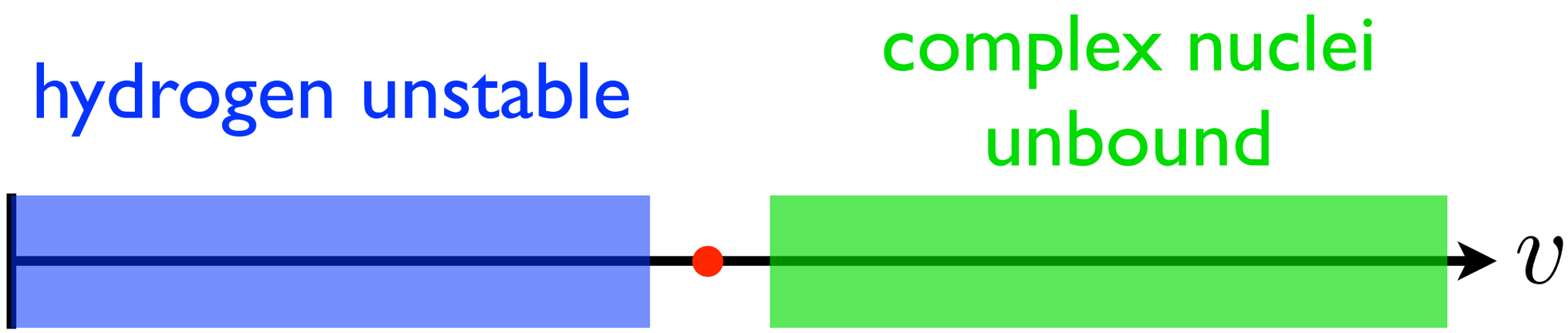


Lawrence Hall, David Pinner, JTR, *to appear.*

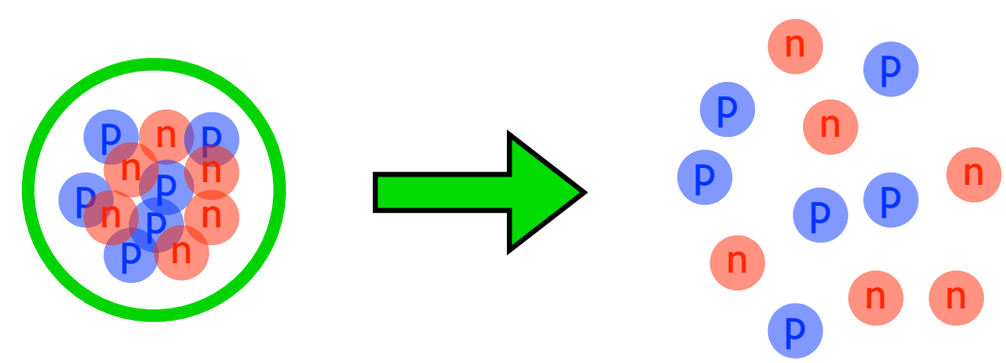
dangers of a variable weak scale

$$m_u = y_u\, v$$

$$m_d = y_d\, v$$



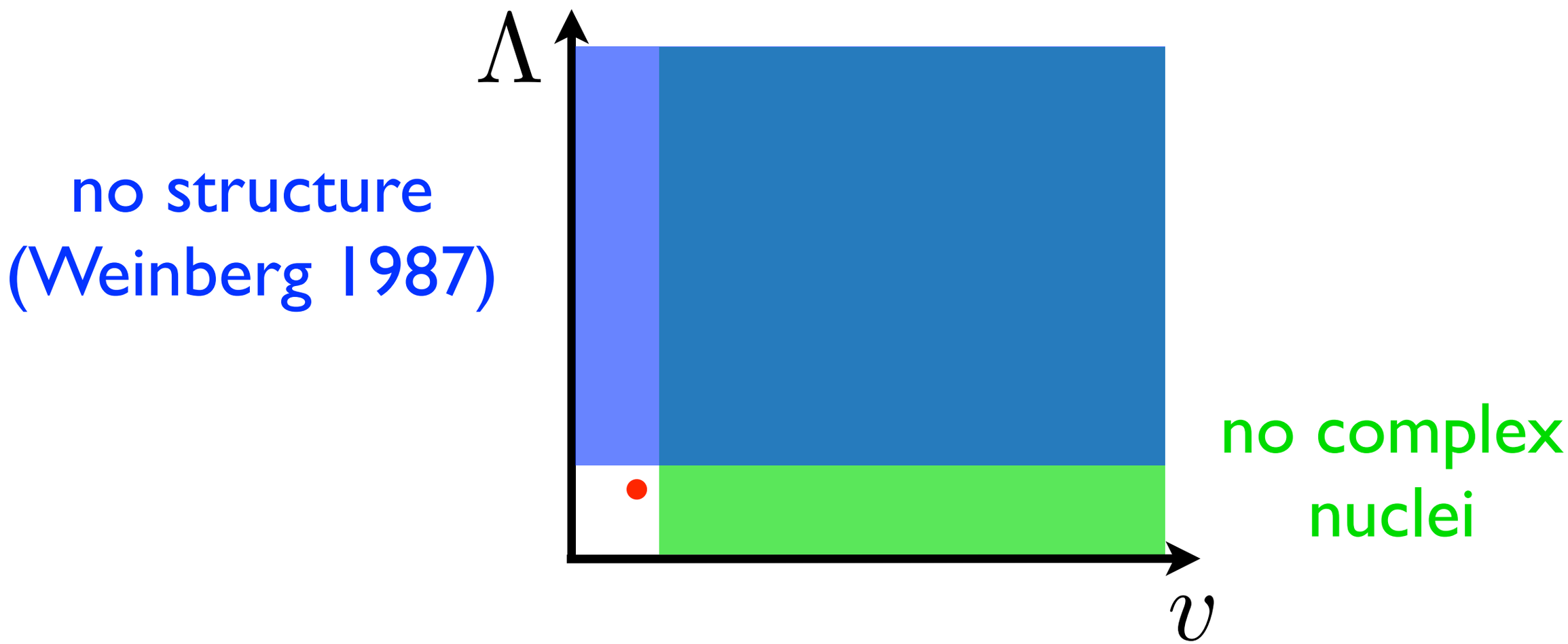
$$p + e^- \to n + \nu_e$$



- Agrawal, Barr, Donoghue, Seckel 9707380
- Damour, Donoghue 0712.2968

minimal landscape

assume only dimensionful parameters scan:

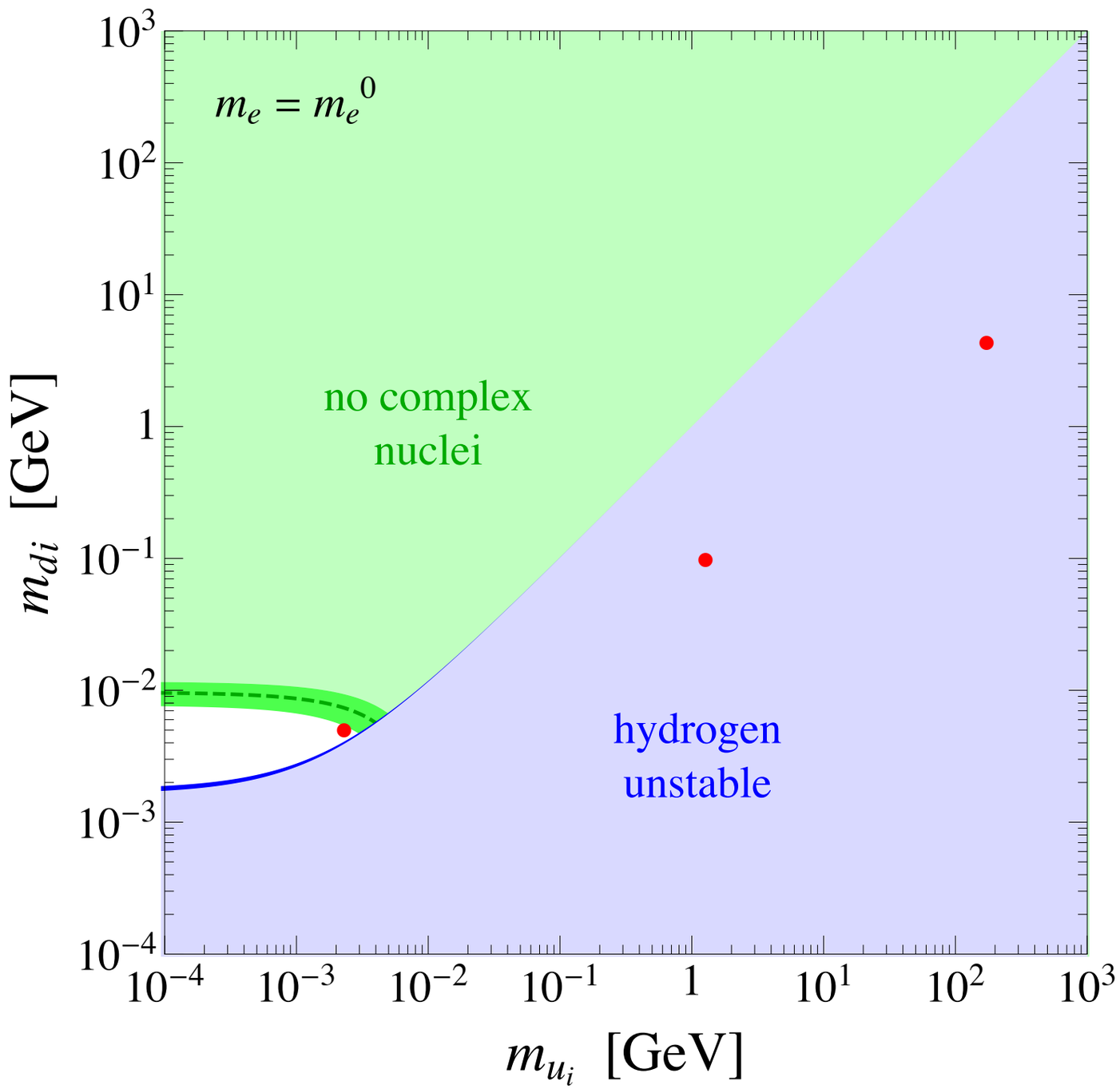


Arkani-Hamed, Dimopoulos, Kachru 0501082

general landscape

scan:

(y_u, y_d, v)



runaway to large v?

scan:
(y_u, y_d, v)

- nuclear physics depends on the quark masses

- runaway: increase v, fixing quark masses,

$$y_{u,d} \to \frac{m_{u,d}}{v}$$

"Weakless Universe," Harnik, Kribs, Perez 0604027

weak-scale physics in our Universe

1. BBN

$$p + \bar{\nu}_e \to n + e^+$$

2. pp chain in stars

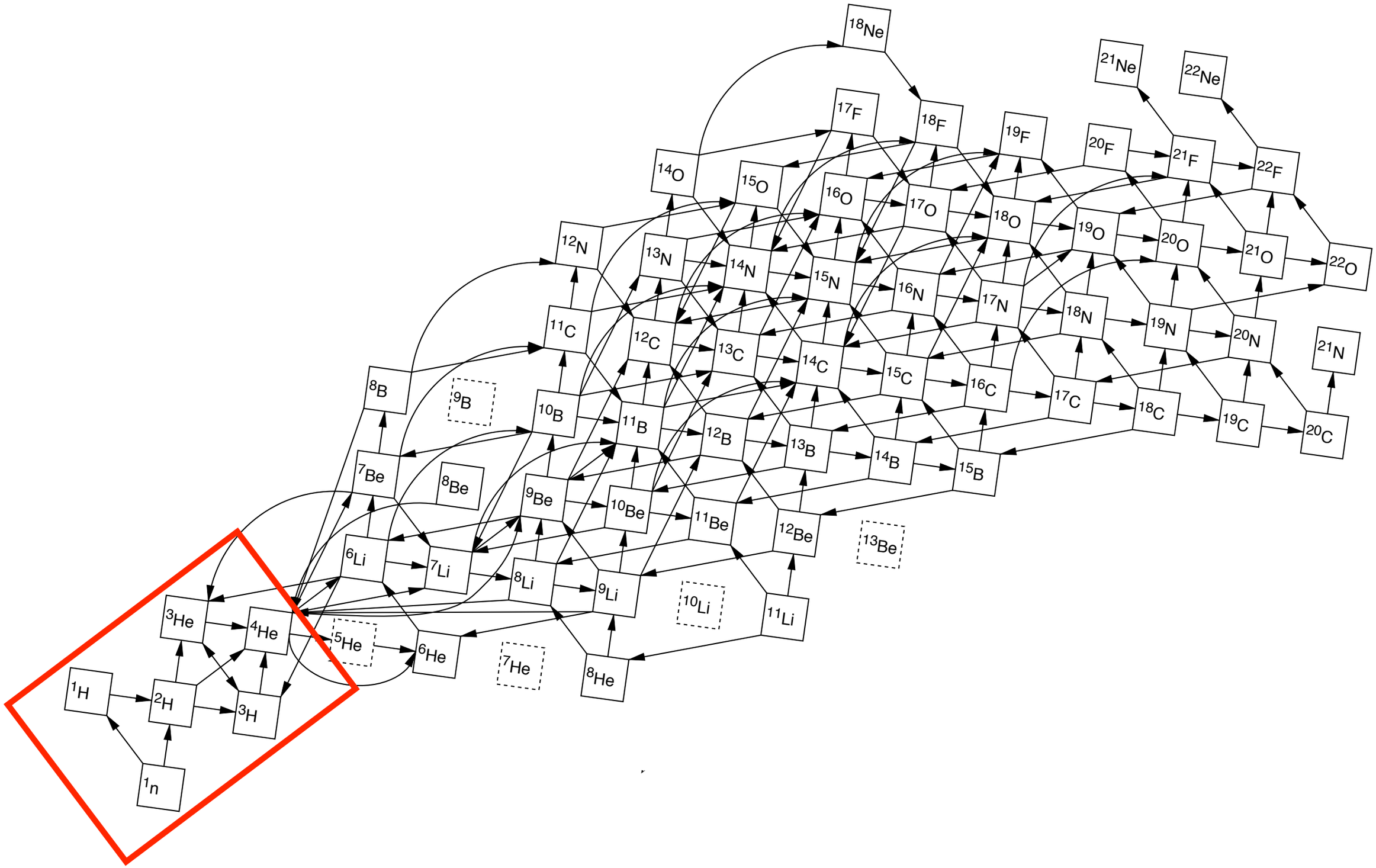
$$p + p \to d + e^+ + \nu_e$$

3. supernovae

$$e^- + e^+ \to \nu + \bar{\nu}$$

$$\bar{\nu} + p \to n + e^+$$

BBN


18Ne
21Ne
22Ne
17F
18F
19F
20F
21F
22F
14O
15O
16O
17O
18O
19O
20O
21O
22O
12N
13N
14N
15N
16N
17N
18N
19N
20N
21N
11C
12C
13C
14C
15C
16C
17C
18C
19C
20C
8B
9B
10B
11B
12B
13B
14B
15B
7Be
8Be
9Be
10Be
11Be
12Be
13Be
6Li
7Li
8Li
9Li
10Li
11Li
3He
4He
5He
6He
7He
8He
1H
2H
3H
1n

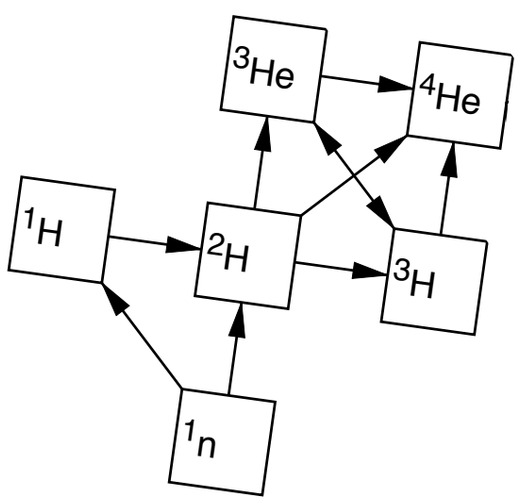
BBN and He4

$$p + \bar{\nu}_e \longleftrightarrow n + e^+$$

decouples: $$T_{\rm fr} \sim \frac{v^{4/3}}{M_p^{1/3}} \approx 1 \text{ MeV}$$

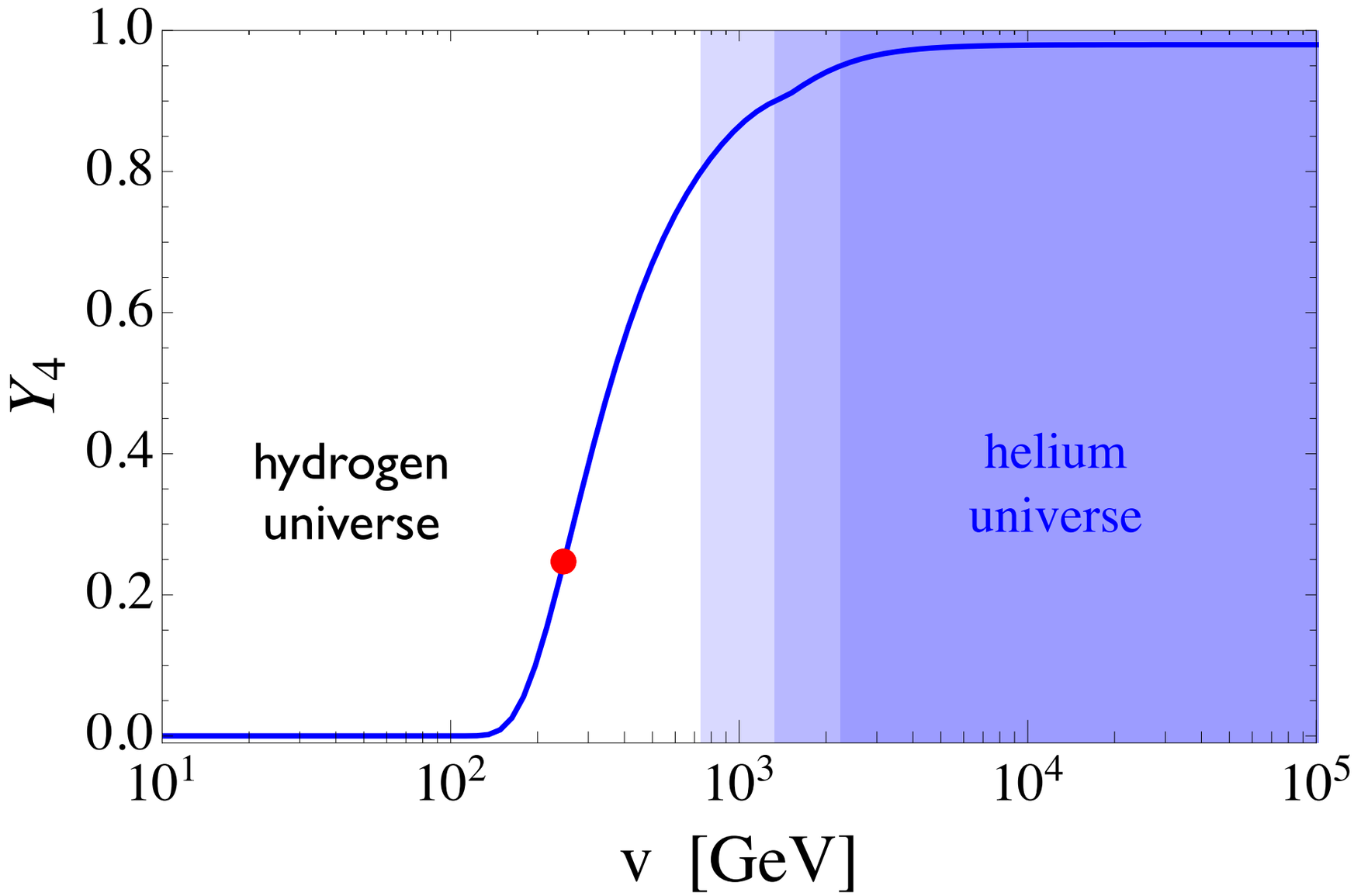
$$\frac{n}{p} = e^{-(m_N - m_P)/T_{\rm fr}}$$

$$m_N - m_P \approx 1.3 \text{ MeV}$$



$$Y_4 \approx \frac{2(n/p)}{1 + n/p} \approx 0.25$$

BBN and He4



$$(m_N - m_P)^3 M_p \sim v^4$$

dangers of a helium universe

primordial hydrogen is important for:

- galactic halo cooling
- stars powered by pp chain
- water

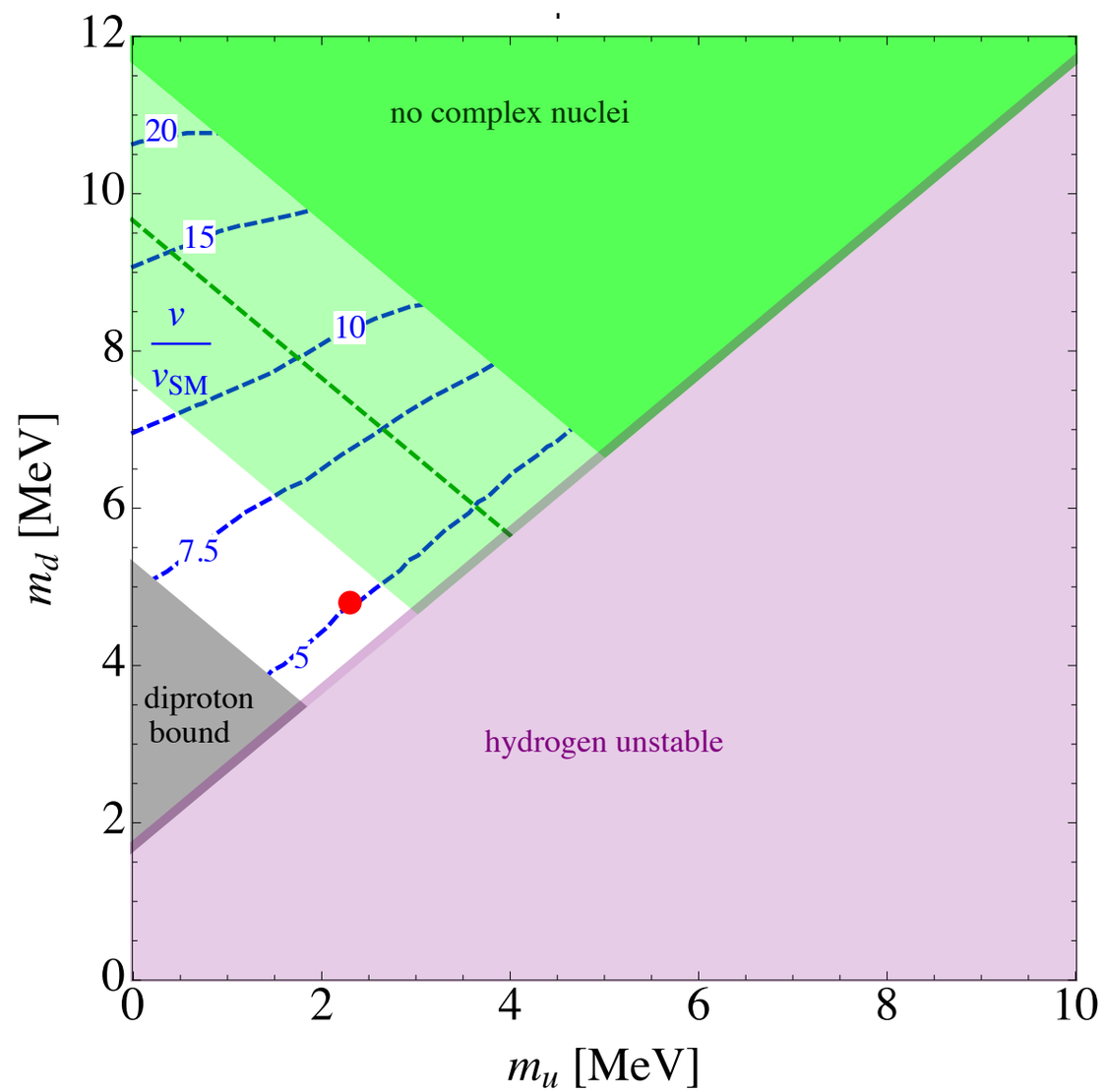
quantifying how much hydrogen is needed for observers we leave for future work...

BBN and the weak scale

scan:

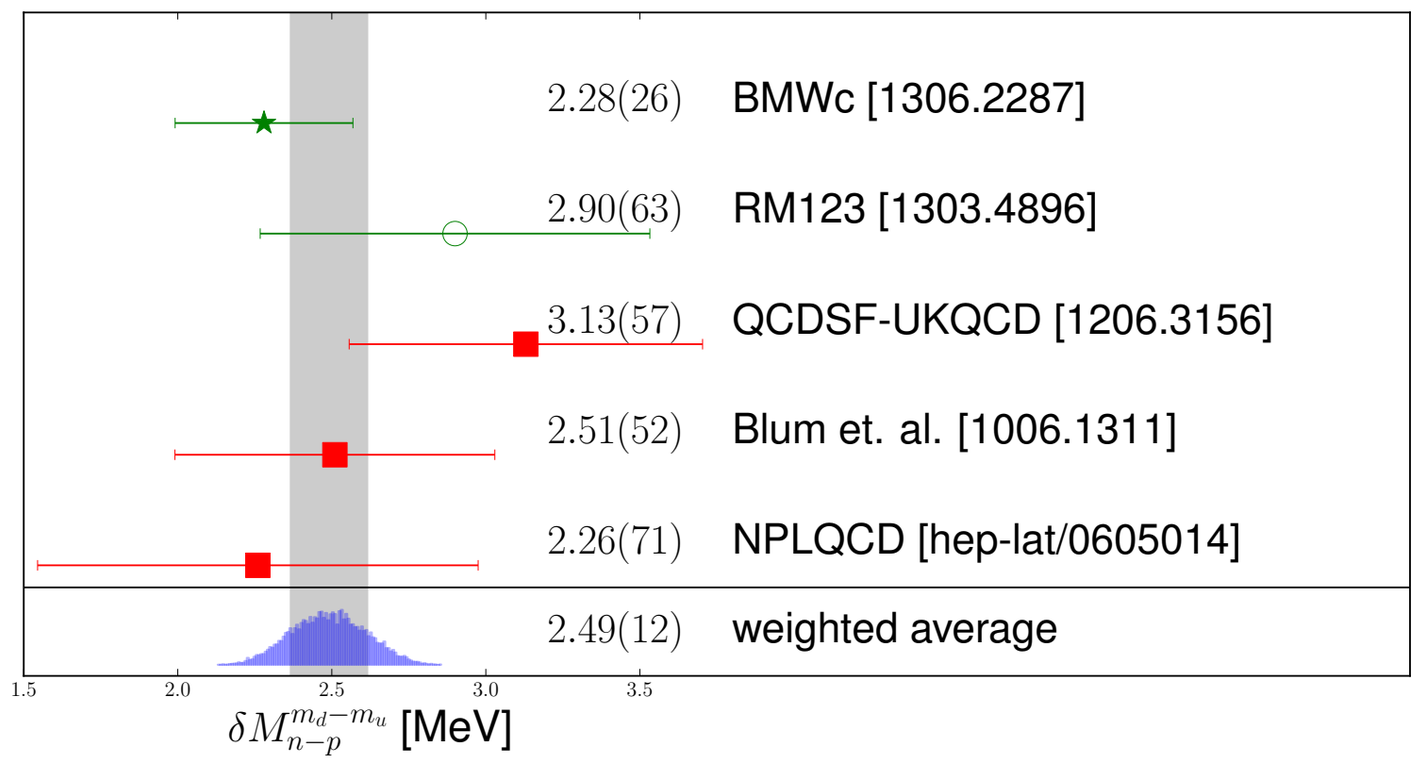
(y_u, y_d, v)

$Y_4 < 0.9$



(technical aside)

- $\delta M_{n-p}^{m_d - m_u} = 2.49(12)$ MeV



$$\delta M_{p-n}^{\gamma} = M_p - M_n - \delta M_{p-n}^{m_d - m_u} = 1.20(12) \text{ MeV}$$

[AWL, C.Carlson, G.Miller PRL 108 (2012) $1.40(03)(47)$ MeV]

from Andre Walker-Loud, *Lattice 2013*

- in a multiverse where (y_u, y_d, v) scan, all three parameters are bounded by requiring stable Hydrogen, complex nuclei, and not too much Helium from BBN

- but what if other parameters scan too?

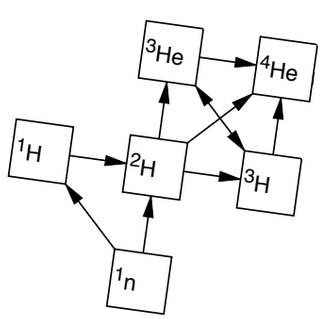
varying the baryon density

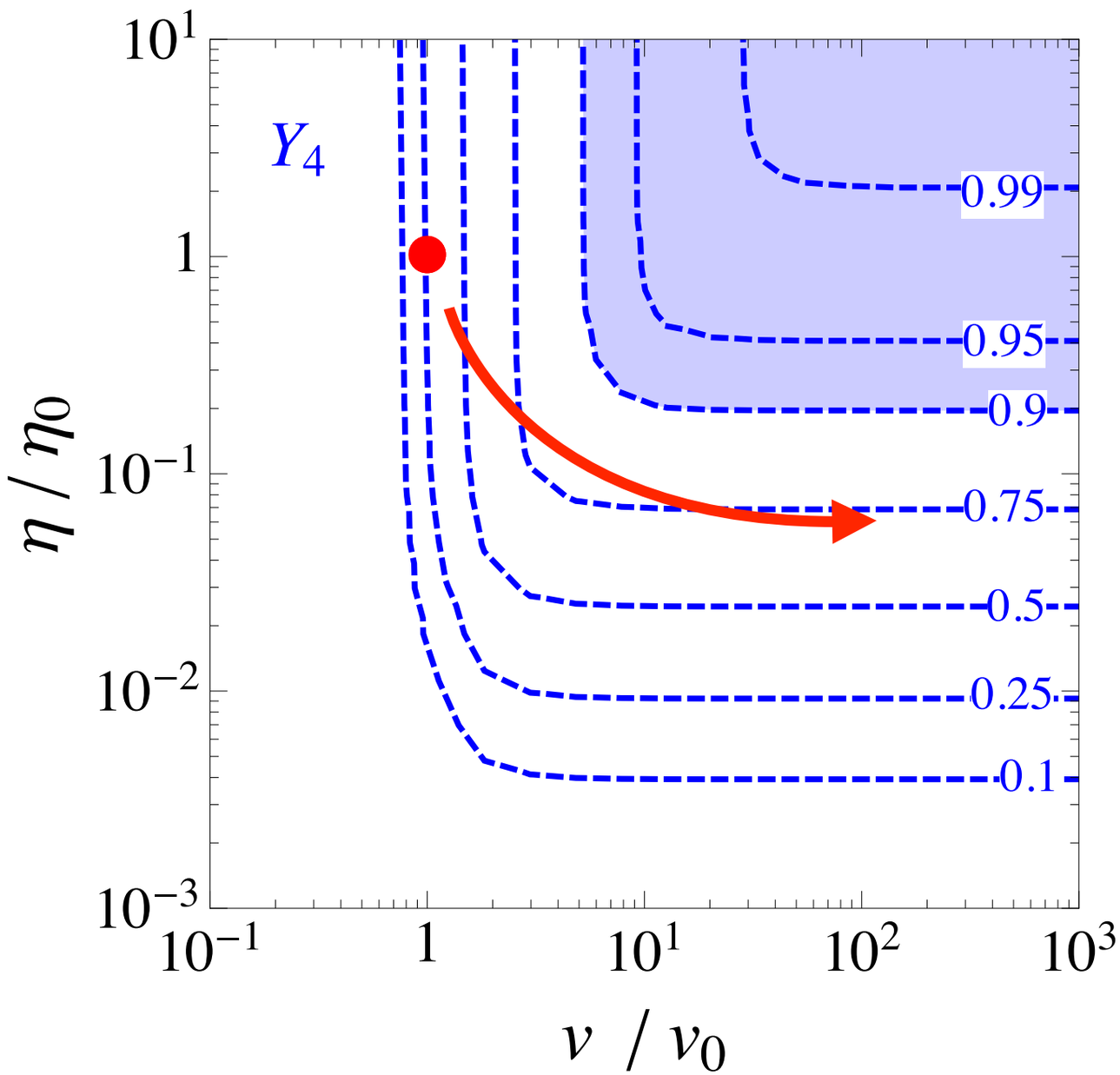
scan:

(v, η)

$p + n \to d + \gamma$

freezes out



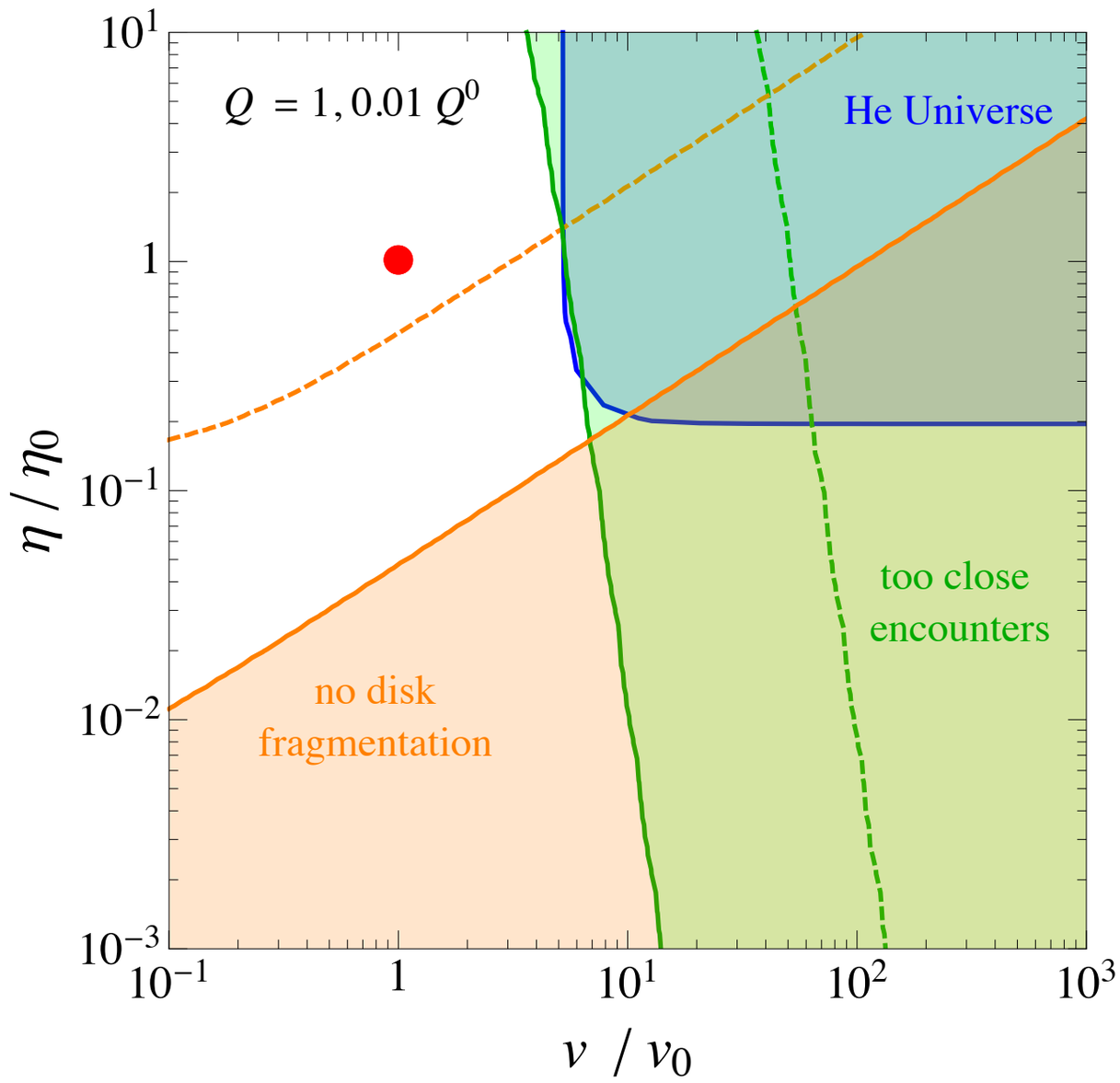


runaway to large v?

varying the baryon density

if DM is a WIMP,

$$\sigma \propto \frac{1}{v^2}$$

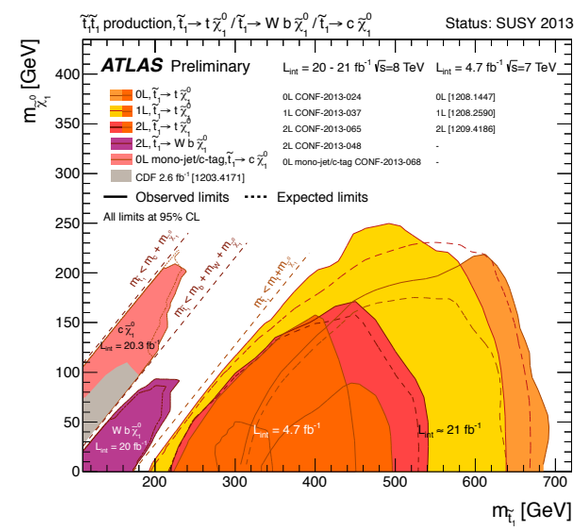


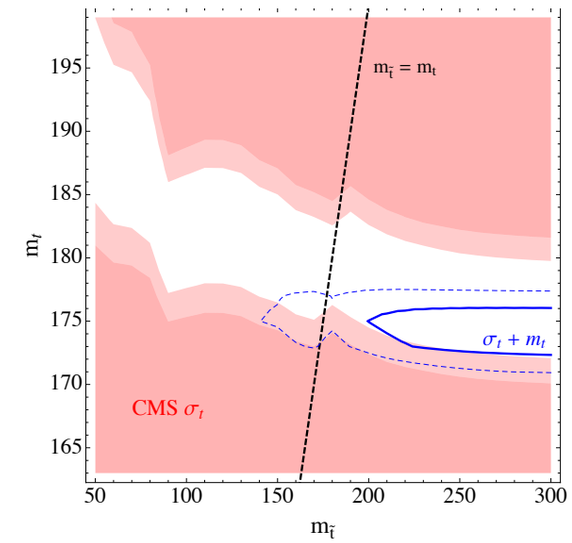
close encounters and disk fragmentation:

Tegmark, Aguirre, Rees, Wilczek 0511774

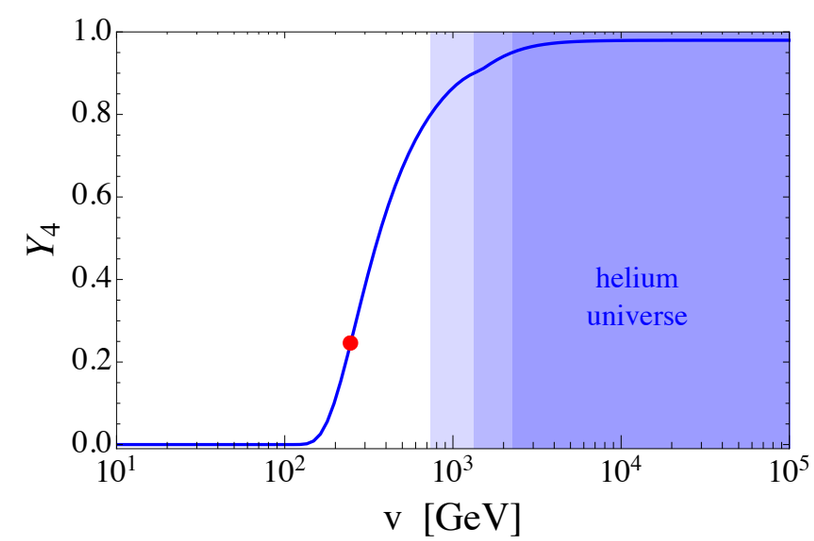
take away

1. the stealth stop window can be probed using the top σ and mass





2. BBN may determine the weak-scale in the multiverse



natural or tuned? 13 TeV awaits!