Oxford
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Seeking Evidence for the Multiverse in Particle Physics

Lawrence Hall
University of California, Berkeley

Two Types of Evidence

Theories

Mathematical
construct
+
physical
interpretation

Lots of assumptions!
Can't look inside the box!

Evidence

I) Quantitative

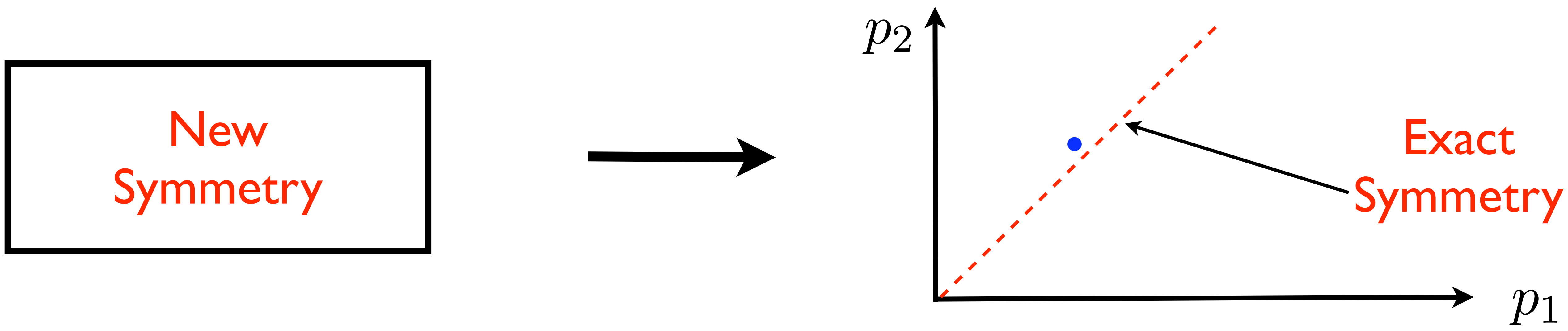
$m_e = 0.51099$ MeV

II) Structural

Why three gauge forces?

Judge theories by evaluating
these two types of prediction

Quantitative Evidence

- Standard Model: $p_1, p_2, \ldots$
- Invent theory to relate the free parameters
- 

$$\frac{p_2}{p_1} = 1 + \epsilon$$

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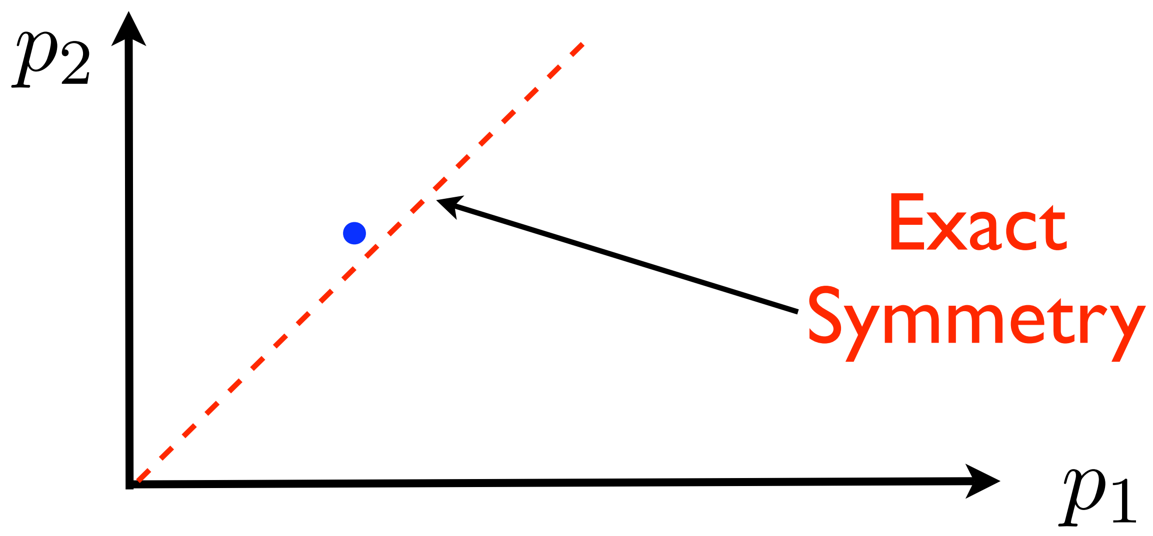
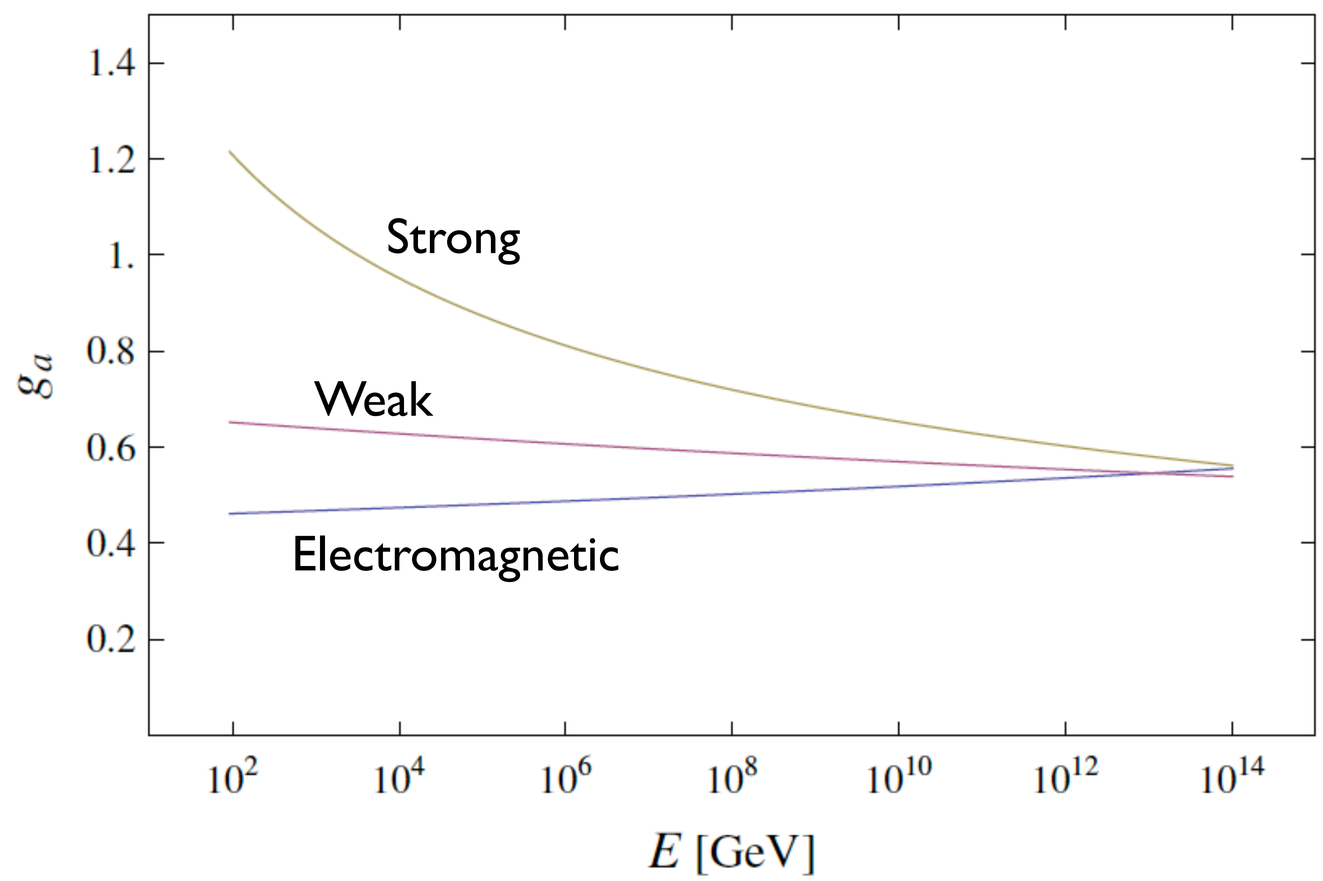
- Invent theory to relate the free parameters
- New Symmetry $\longrightarrow$



$$\frac{p_2}{p_1} = 1 + \epsilon$$

eg

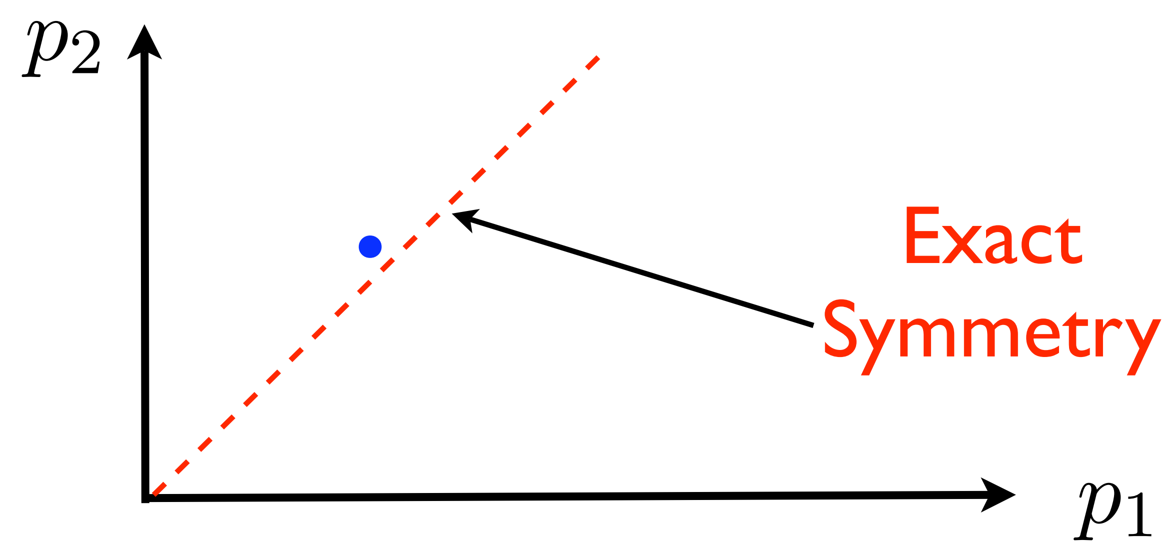
- Unified Symmetry "SU(5)" $\longrightarrow$



or More Universes?

- **New Symmetry**

Assumptions: Symmetry,
Symmetry breaking



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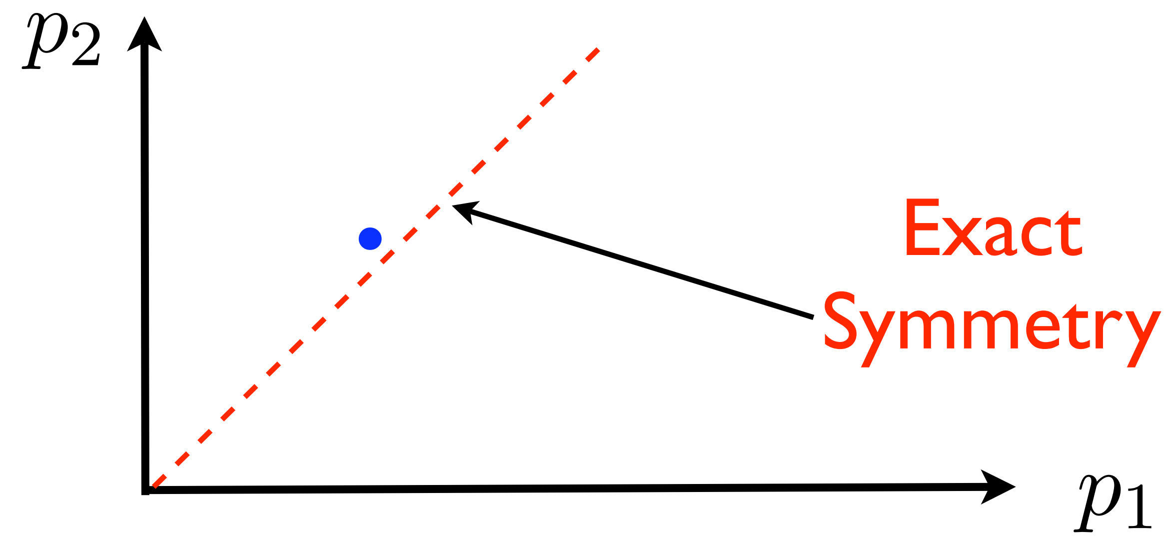
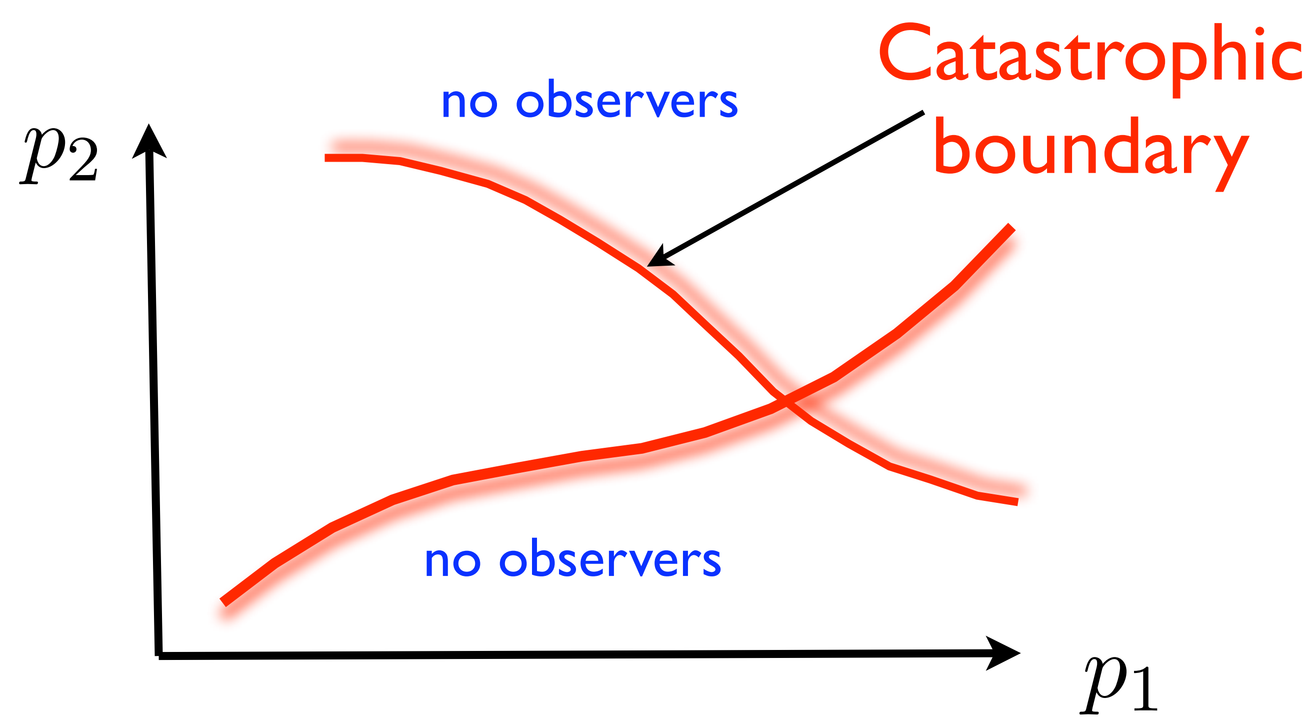


✻ **Multiverse**

Assumptions: Catastrophic boundary
Distribution f



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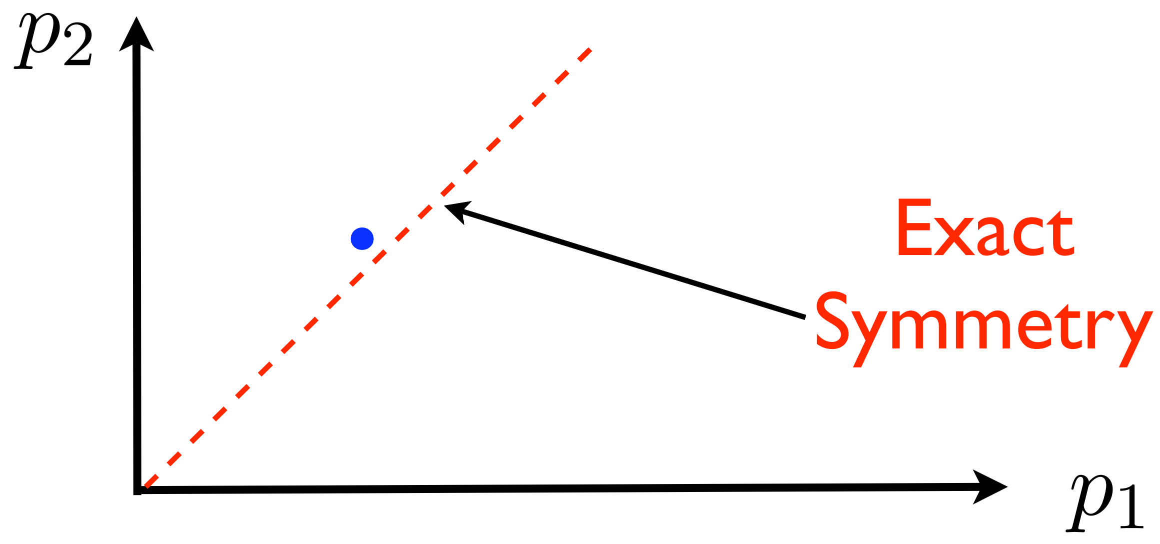

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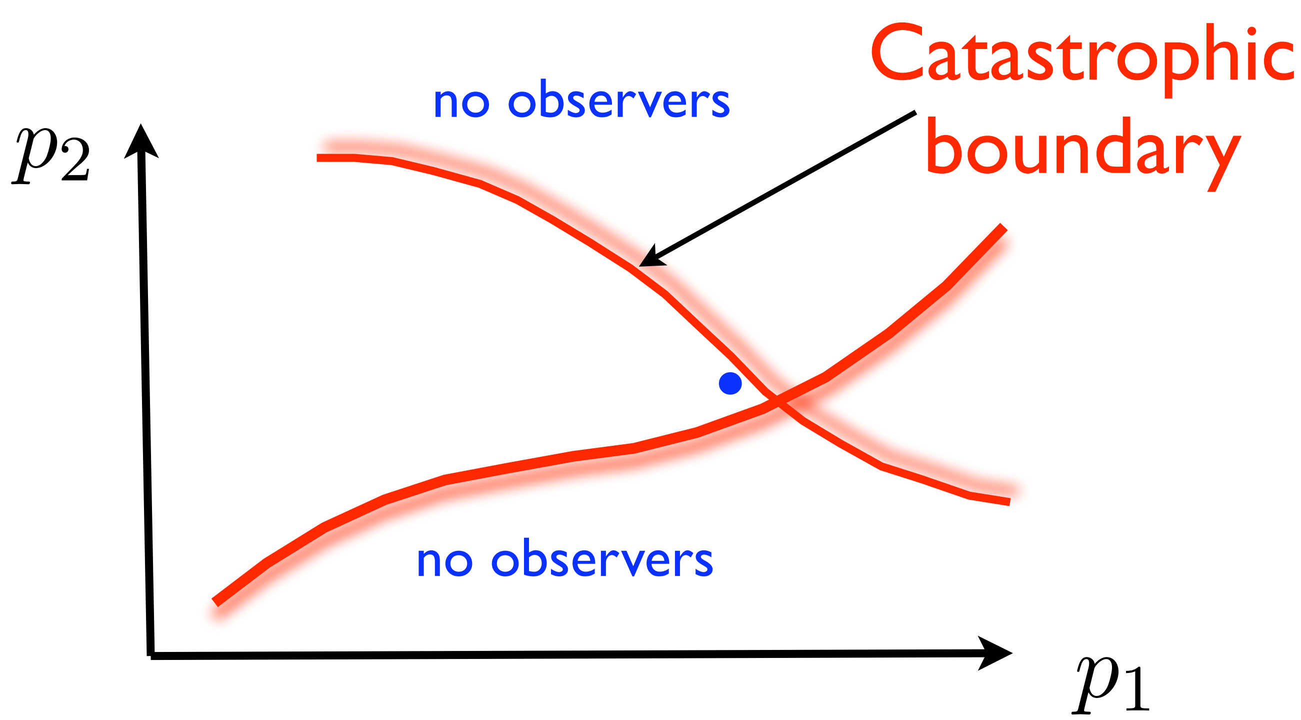

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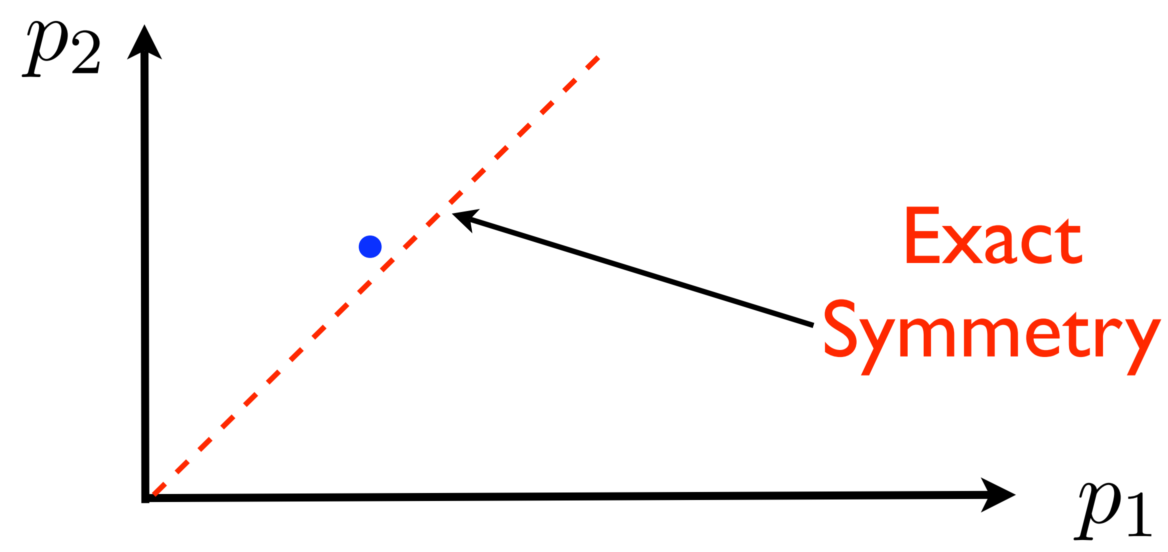
- New Symmetry → 

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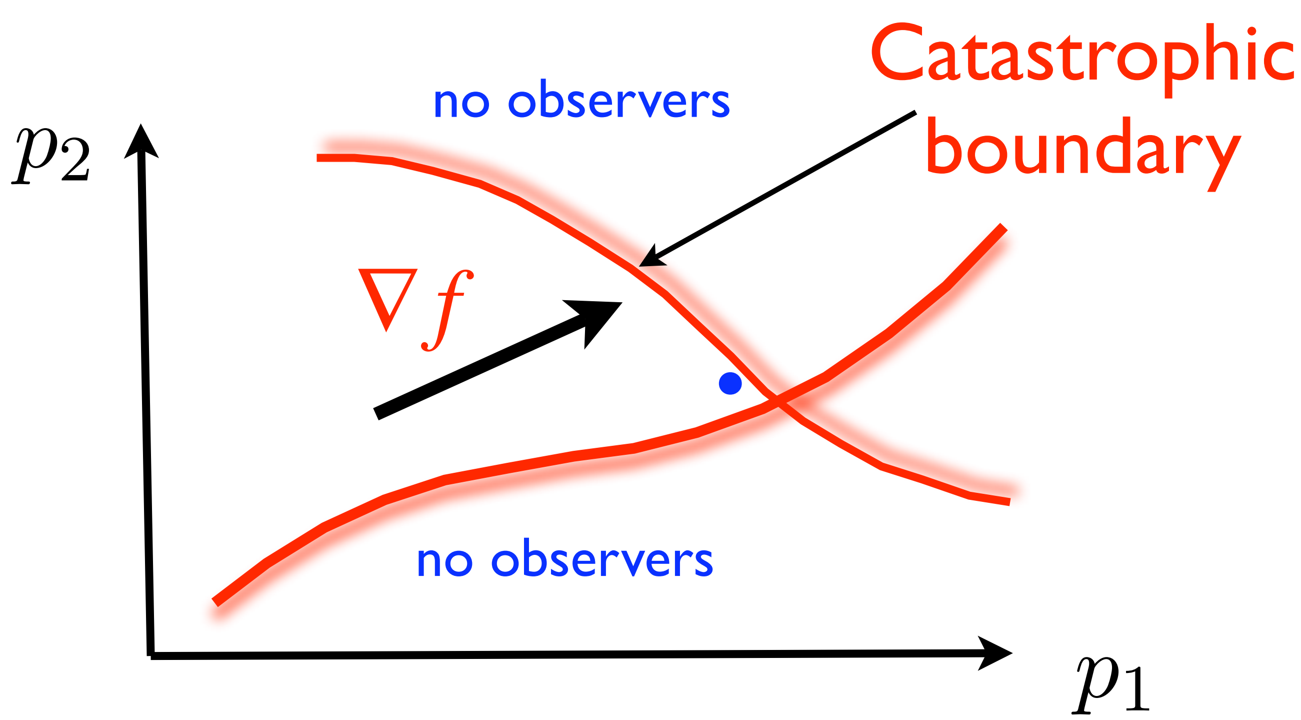
- Multiverse → 

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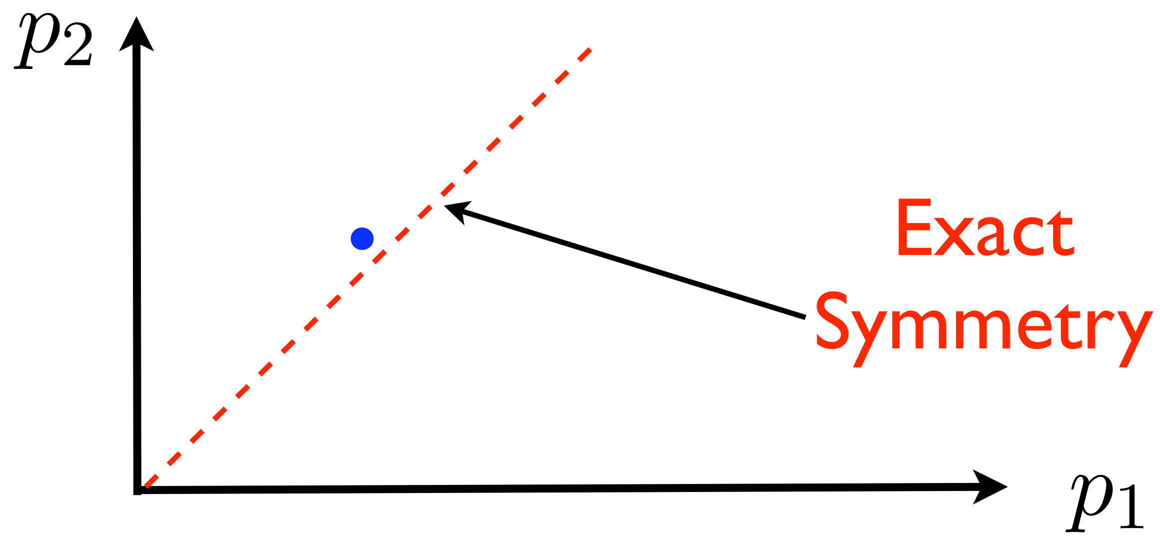

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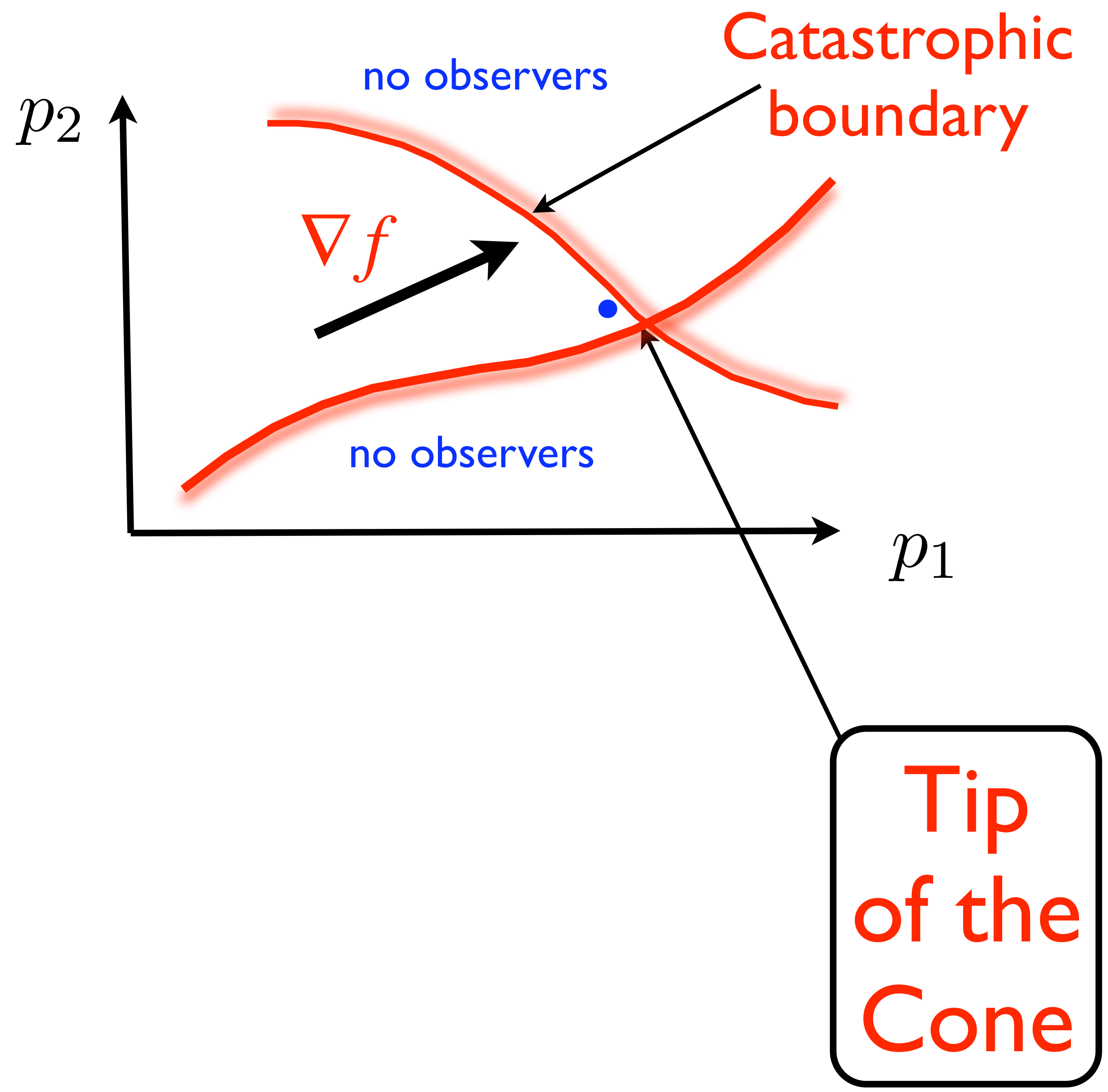

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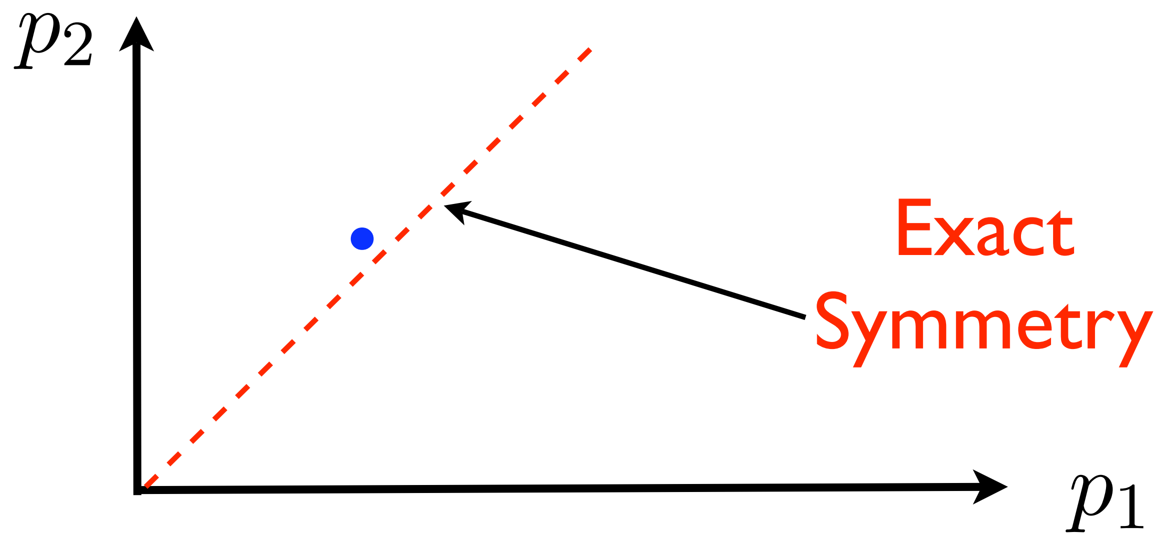

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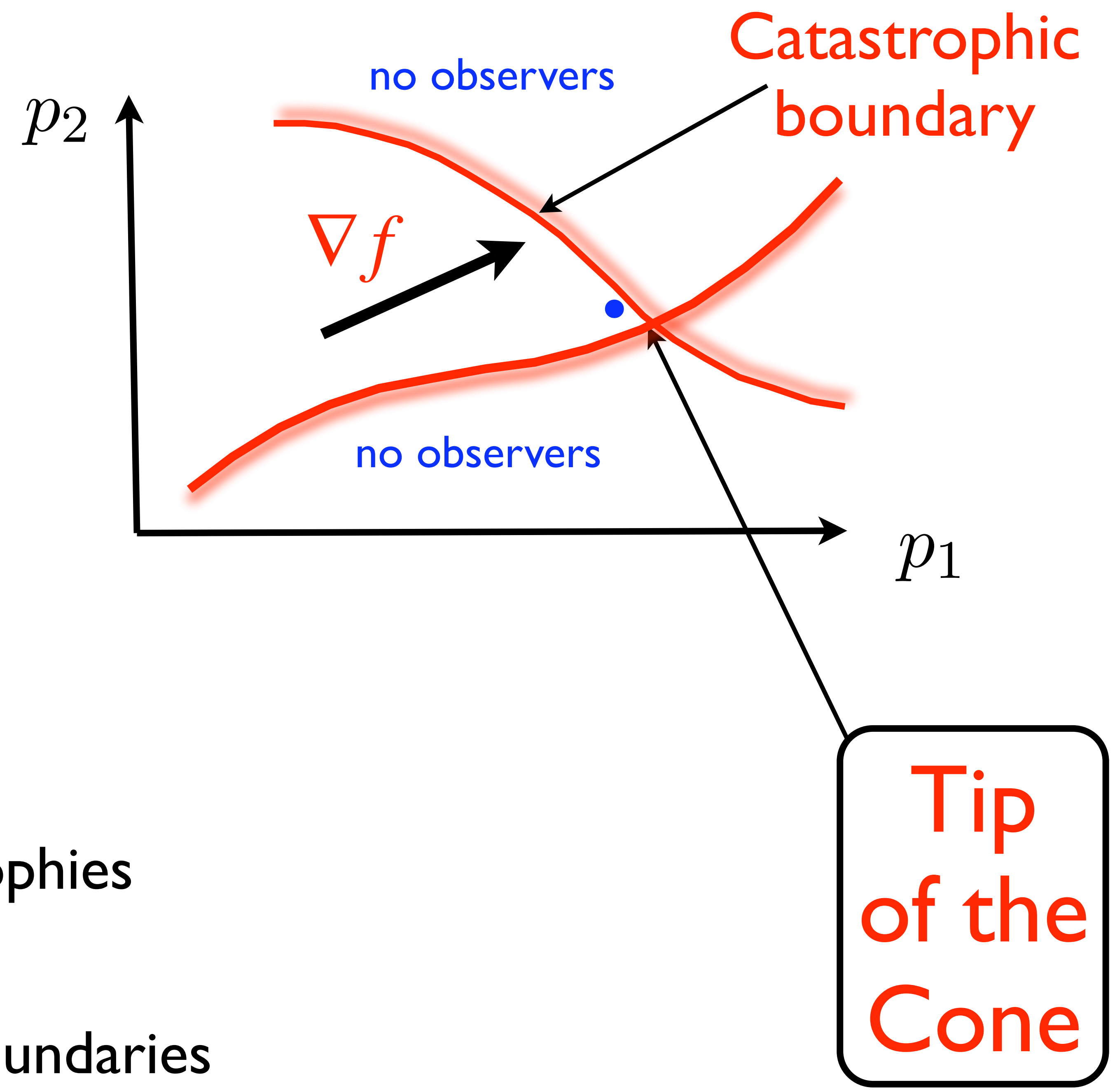


Assumptions: Catastrophic boundary, Distribution f

❊ **Program:**

1. Identify possible catastrophies
2. Compute boundaries
3. Evaluate closeness to boundaries (fine-tuning)

Structural Evidence

Phenomena:

1. $F_{Coul} \propto \frac{1}{r^2}$ ...
2. Hadron spectrum, ...
3. Short range of weak interactions, ...
4. Q(3,2,1/6), L(1,2,-1/2), ...
5. Mass hierarchy $M_W \ll M_{Pl}$

Puzzling array of phenomena

Theory

QED

QCD

Higgs boson

Unified theory, SU(5)

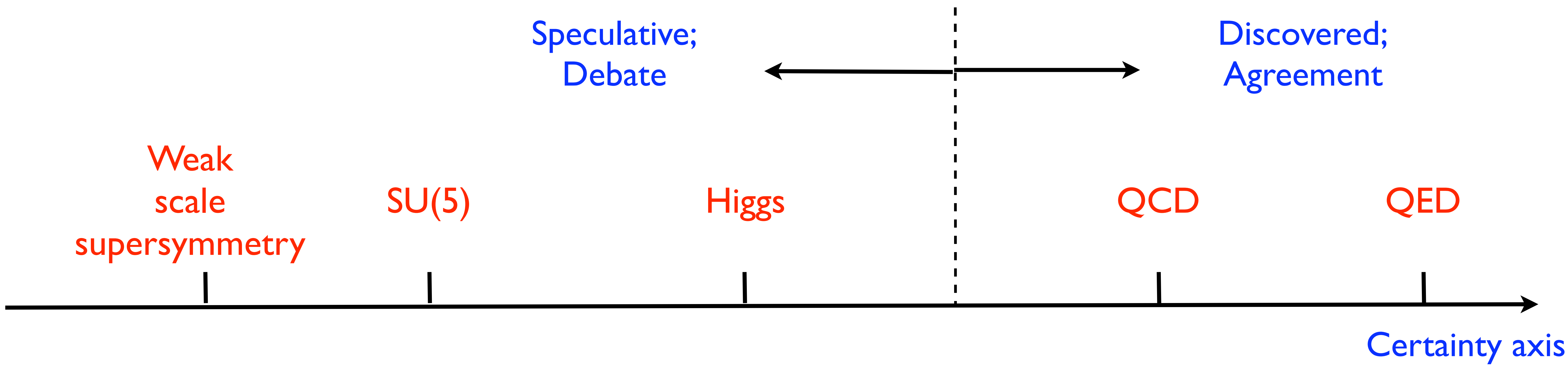
Weak scale supersymmetry

Order and simplicity

Quantitative Evidence

Theory	Predicts
1. QED	g-2 = 1159.6521...
2. QCD	several at 5%
3. Higgs boson	?? (problems with alternatives)
4. Unified theory, SU(5)	coupling unification at 5%
5. Weak scale supersymmetry	coupling unification at 1%

Order and simplicity



The Structural Problem of the Standard Model

- Why is the weak scale so small $M_W \ll M_{Pl}$?

- Must arrange for 32 orders of magnitude cancellation

$$M_W^2 = M_1^2 - M_2^2$$

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2. Supersymmetry is at the weak scale
3. The weak scale varies in the multiverse

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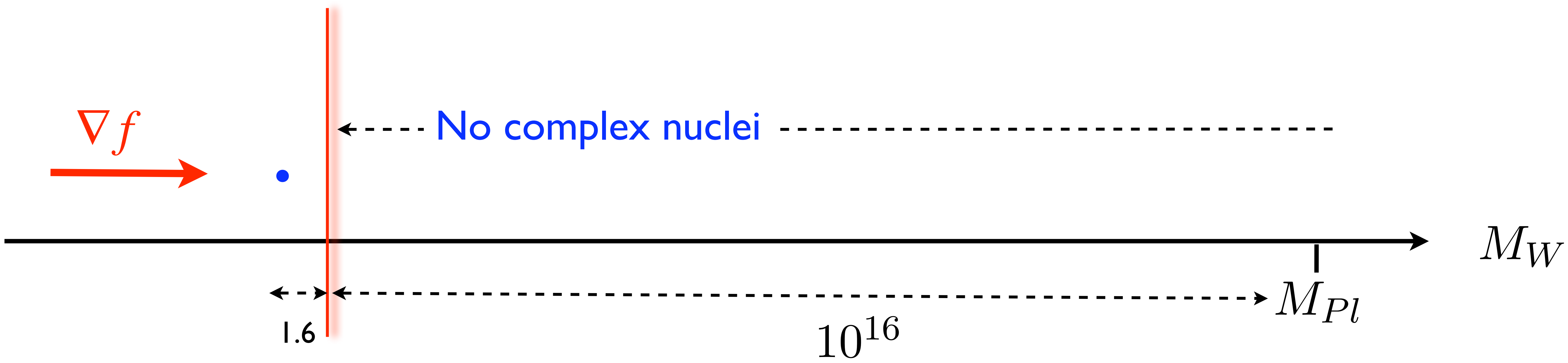
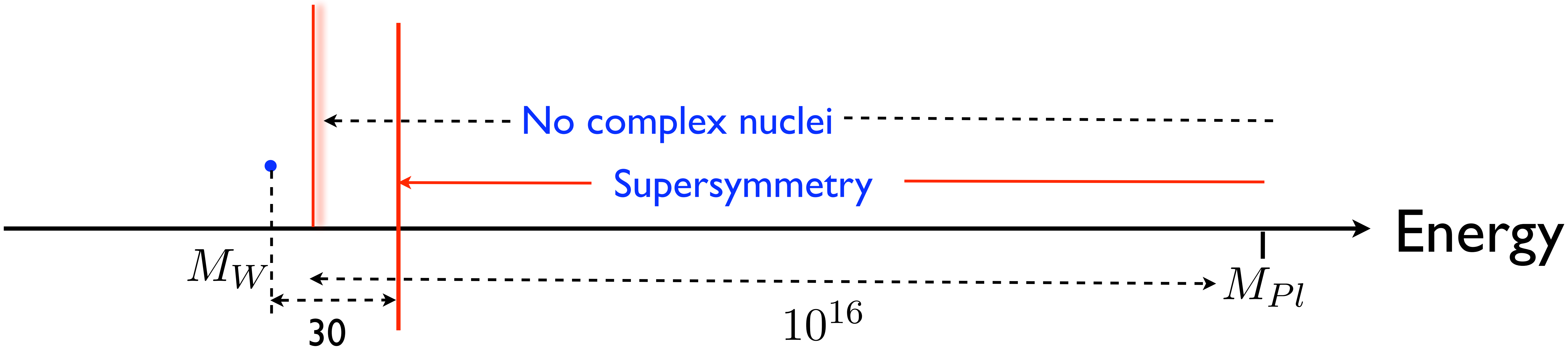


Can We Really Get Evidence For For 10^32 Fine Tune?

- Even with supersymmetry beyond the reach of LHC, the fine tuning may be "only" 1 in 1000



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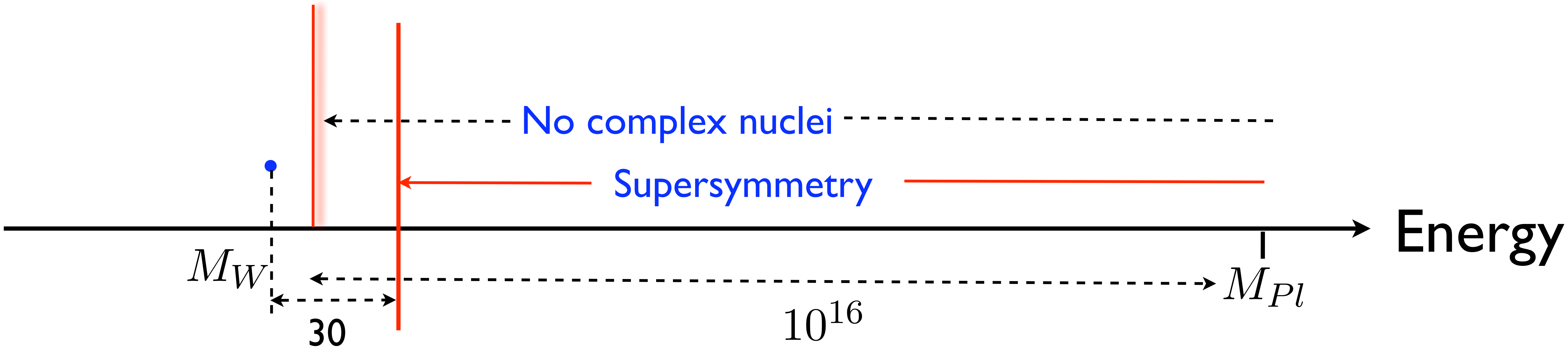
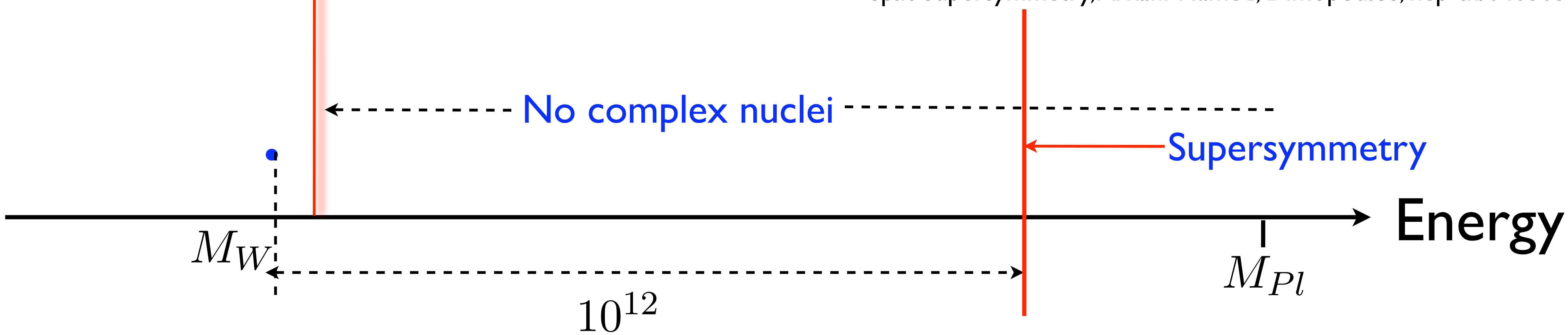


- It may be that the measured mass and couplings of the Higgs accurately reflect a boundary condition from supersymmetry at very high scales

Split Supersymmetry, Arkani-Hamed, Dimopoulos, hep-th/0405159



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Brian Feldstein, LJH, Taizan Watari;
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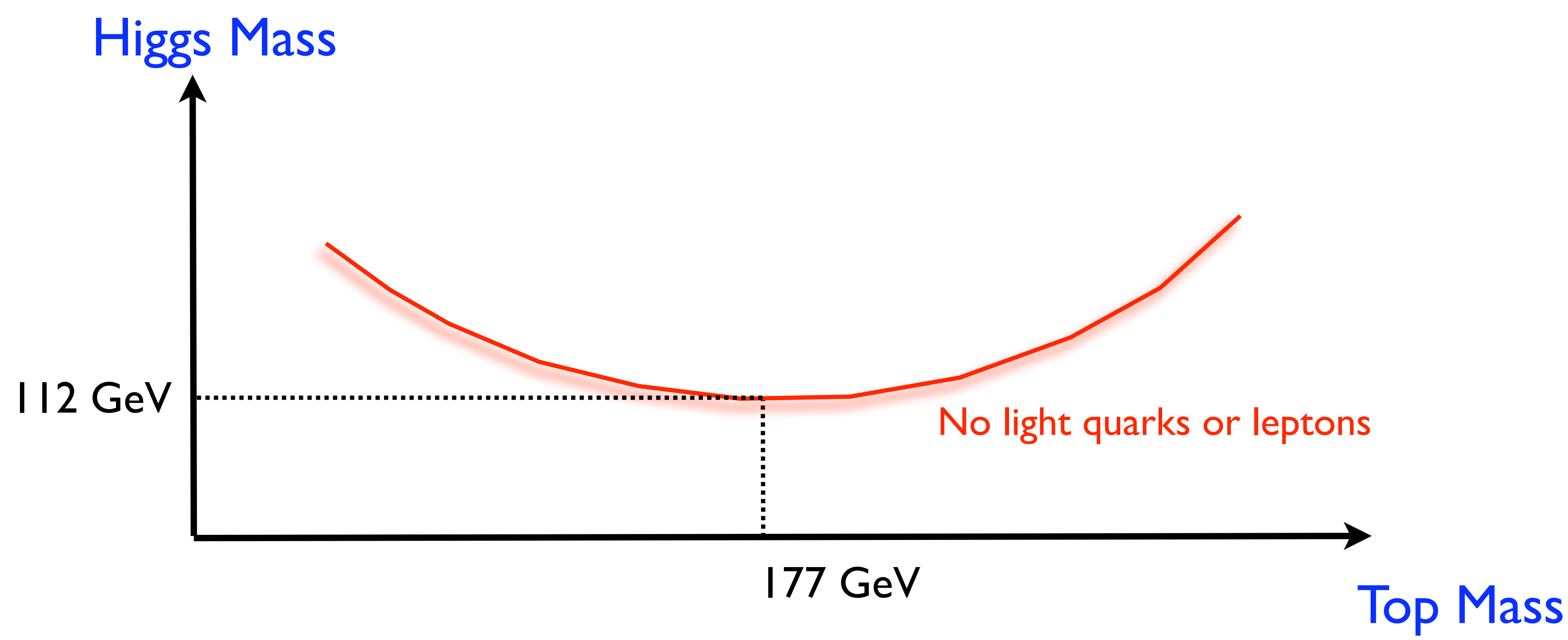

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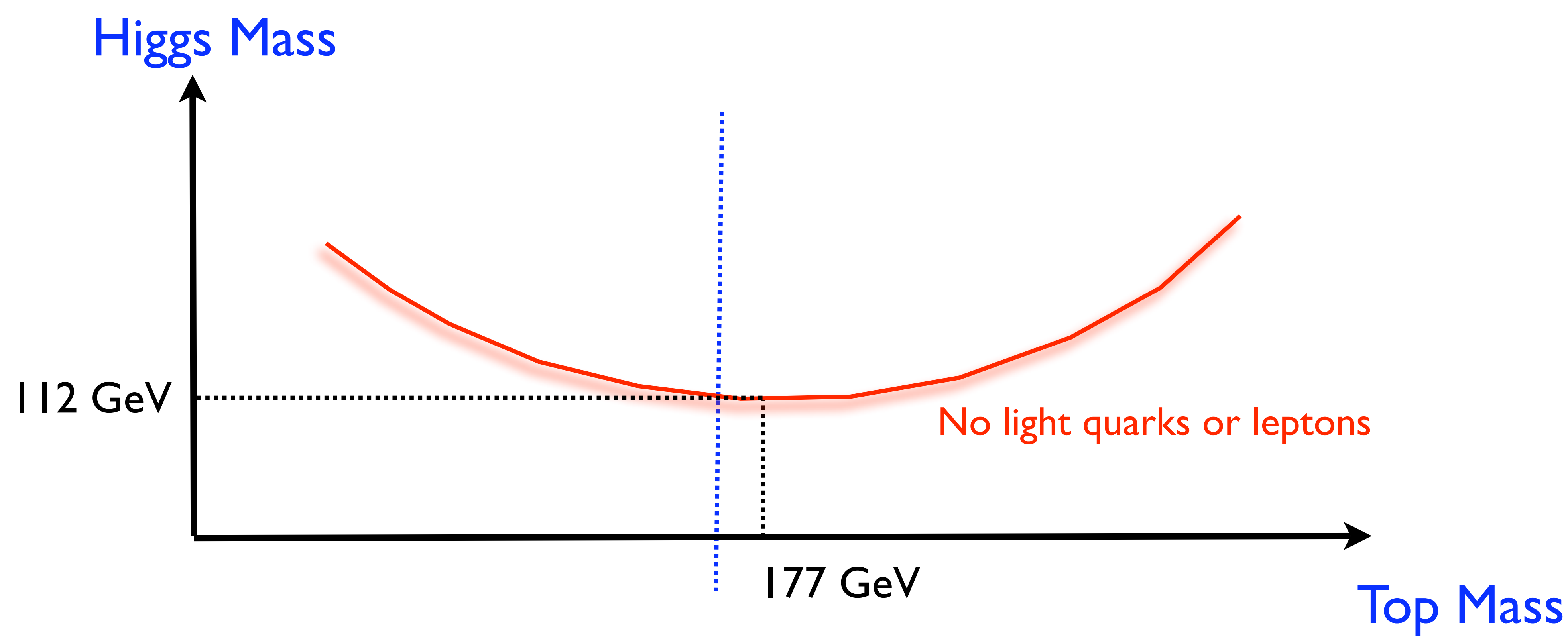

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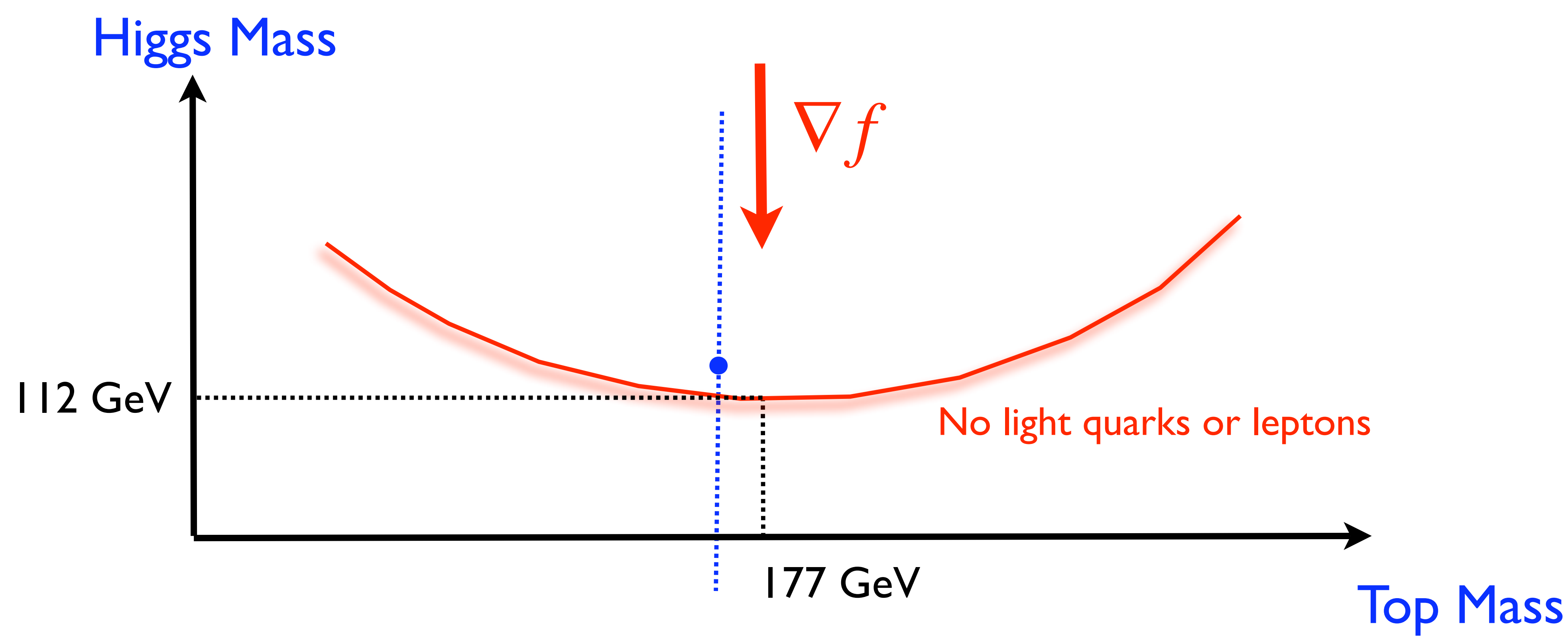

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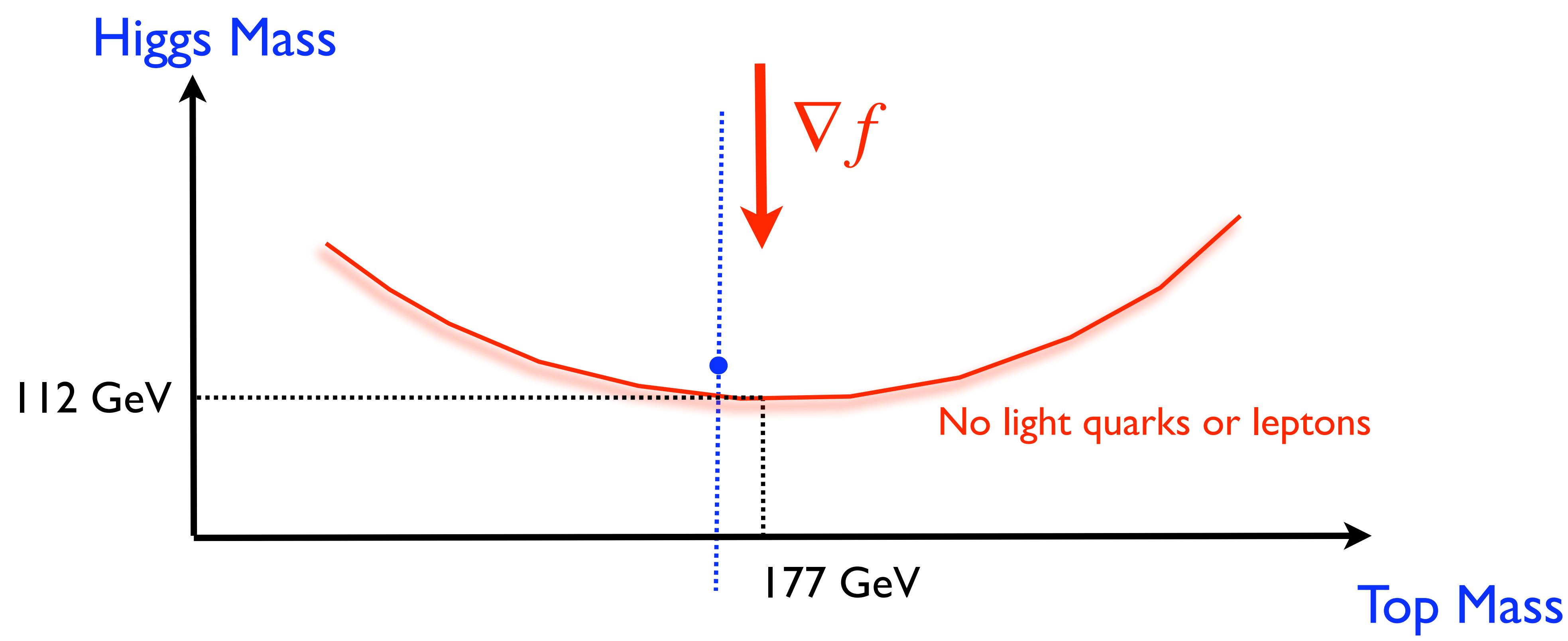

- If Higgs discovered close to boundary:

  - A quantitative prediction of Higgs/top masses at 5% level

  - Evidence that multiverse solved structural fine tuning problem

    (The other two known solutions are excluded)

Symmetries v Multiverse

	SU(5)	Multiverse
Huge extrapolation	Energy	Distance
Features that will never be tested	$pp \to XX$	$\alpha', m'_e, \ldots$
Structural evidence	$q(3,2,1/6), \ldots$	$M_W \ll M_{Pl}$
Primary quantitative evidence	$g_1 = g_2 = g_3$	$M_W \quad (\Lambda)$
Further quantitative evidence	m_b/m_τ	m_H ⁇
New experiments needed	proton decay, ⁇ weak scale supersymmetry ⁇	precision m_t, g_3

Conclusions

Criticisms of the multiverse:

1. Many aspects of the theory cannot be tested

True

The same is true for SU(5), inflation, baryogenesis, axions, quark masses, ...

For any new theory the question is the same:
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No "fundamental" calculation of $\alpha, m_e, \ldots$

True if by "fundamental" you mean "symmetries" ... but little success in 35 years

Multiverse offers an alternative way to calculate

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Multiverse offers an alternative way to calculate

⇒ An exciting advance! Shouldn’t we give it a try?

Higgs and Top Mass Predictions

$$m_H = \left[106 + 6\left(\frac{m_t - 171\,\mathrm{GeV}}{2\,\mathrm{GeV}}\right) - 2.6\left(\frac{\alpha_s - 0.1176}{0.002}\right) \pm 6\right]\mathrm{GeV} \quad + \frac{25\,\mathrm{GeV}}{p}$$

2 loop running

Top and QCD contributions to running

running to pole

$$m_t = \left[176.7 + 2.2\log_{10}\left(\frac{\Lambda_{SM}}{10^{18}\,\mathrm{GeV}}\right) \pm 3\right]\mathrm{GeV} \quad - \frac{35\,\mathrm{GeV}}{\sqrt{p}}$$

relatively insensitive to SM cutoff

p sufficiently large for a tight Higgs mass prediction

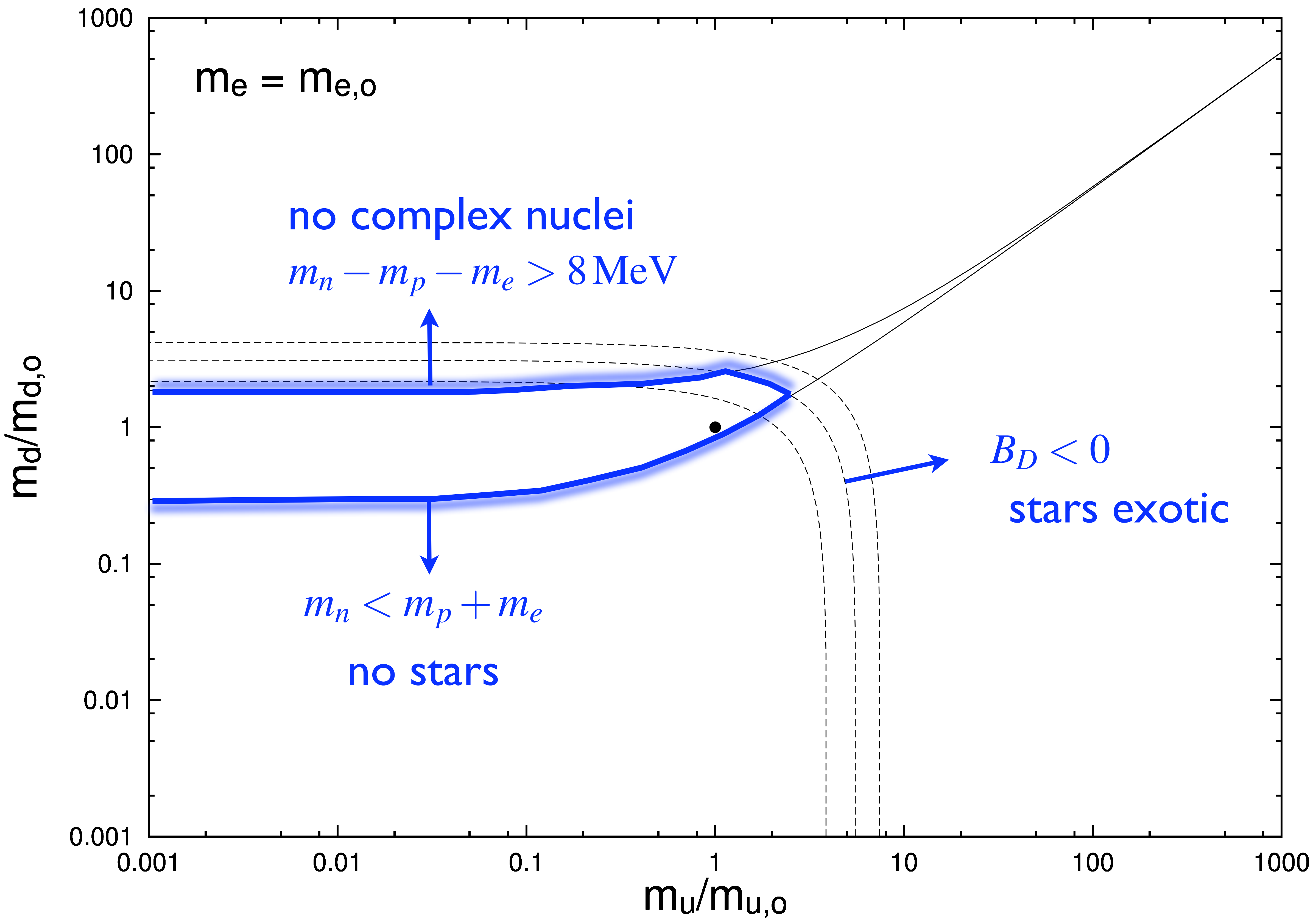
What is the future of the field?

Nuclear Boundaries

Relevant parameters $\left(\alpha, \frac{m_e}{m_p}, \frac{m_u}{m_p}, \frac{m_d}{m_p}\right)$

Yasunori Nomura,
LJH
arXiv:0712.2454

2d slice



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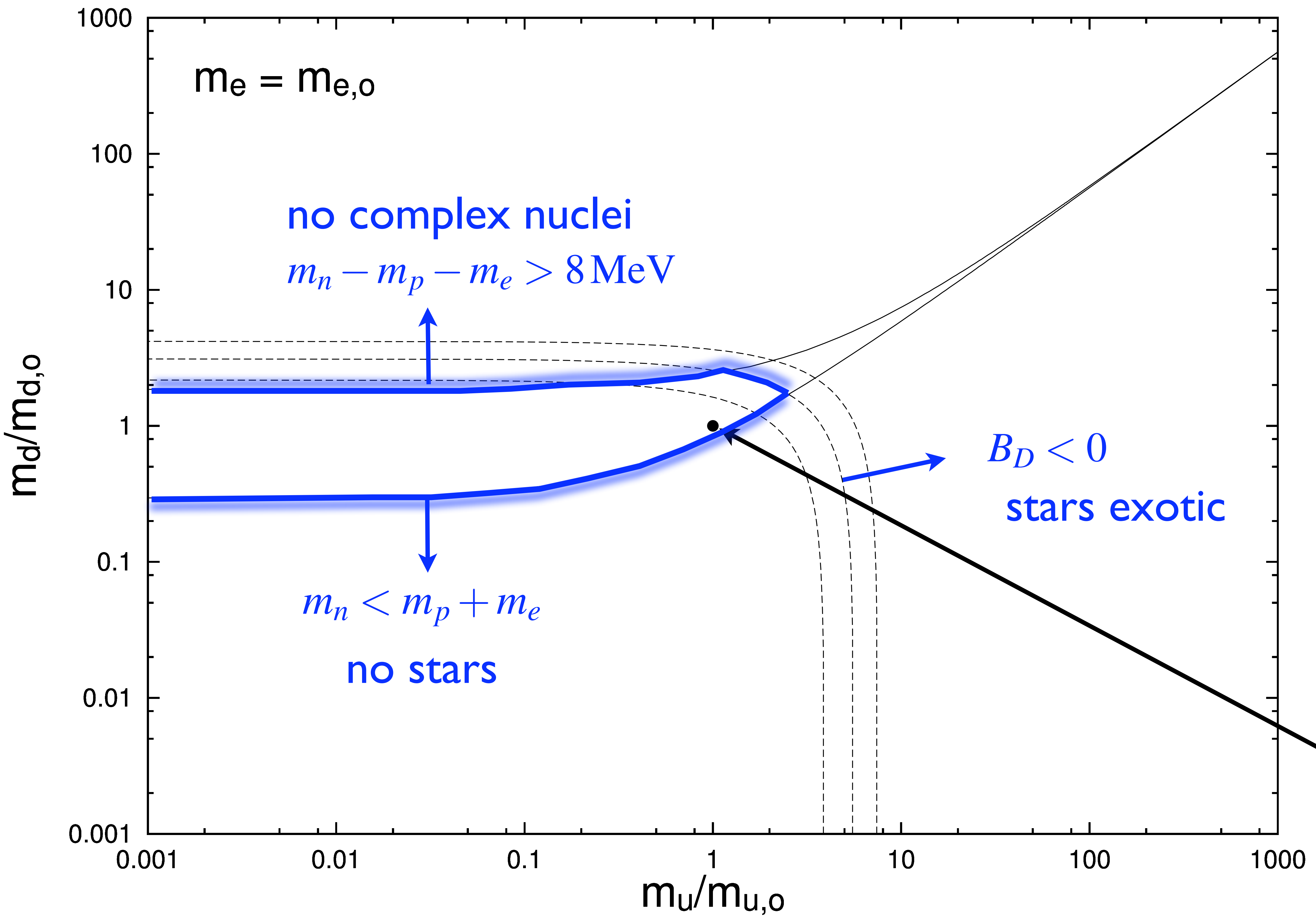

Closeness to
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(10 - 30)%

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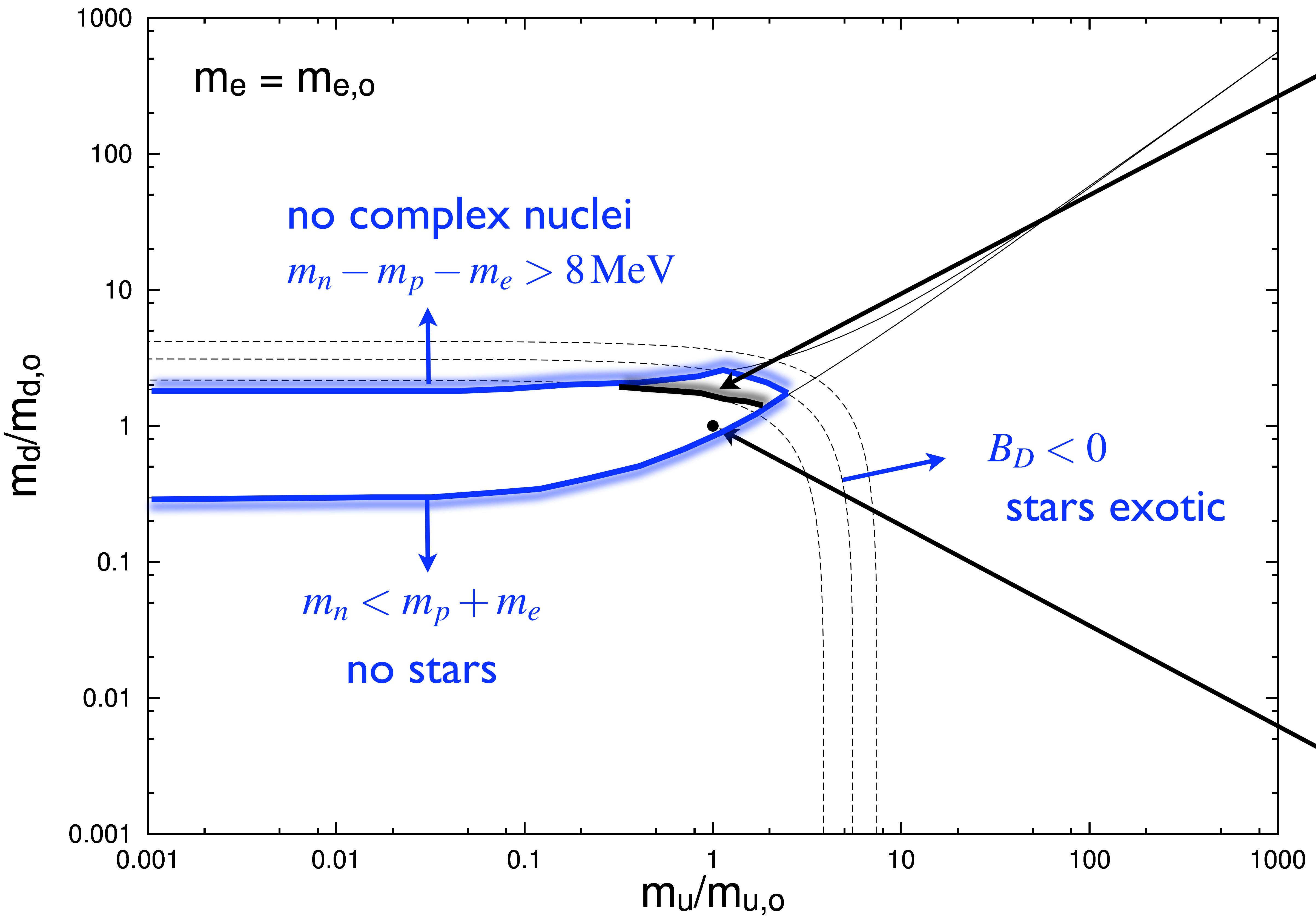

Damour Donoghue arXiv:0712.2968

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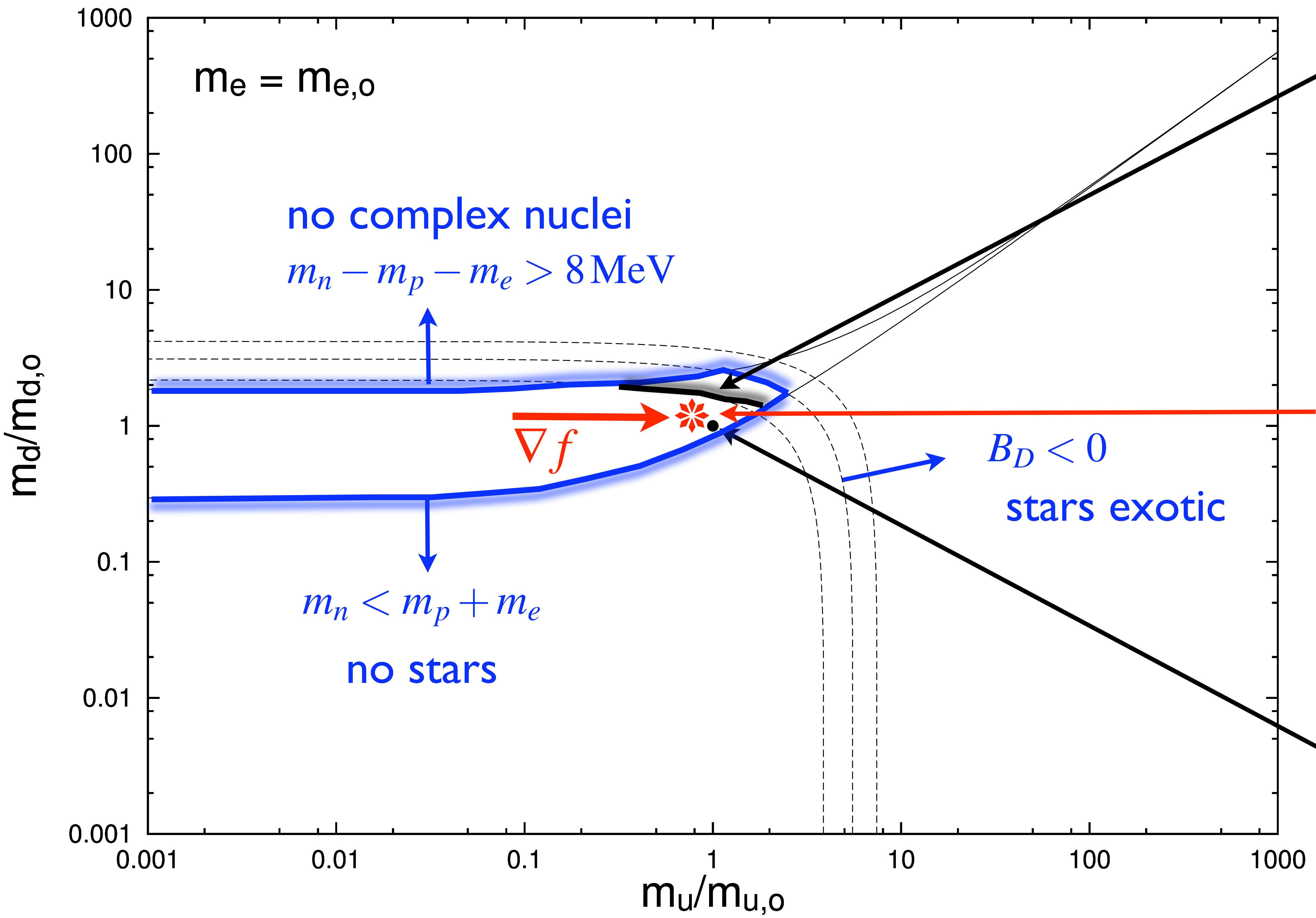

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Tip of theCone!

$m_{u,d,e}$
determined by nuclear physics of boundaries

Closeness to n boundary

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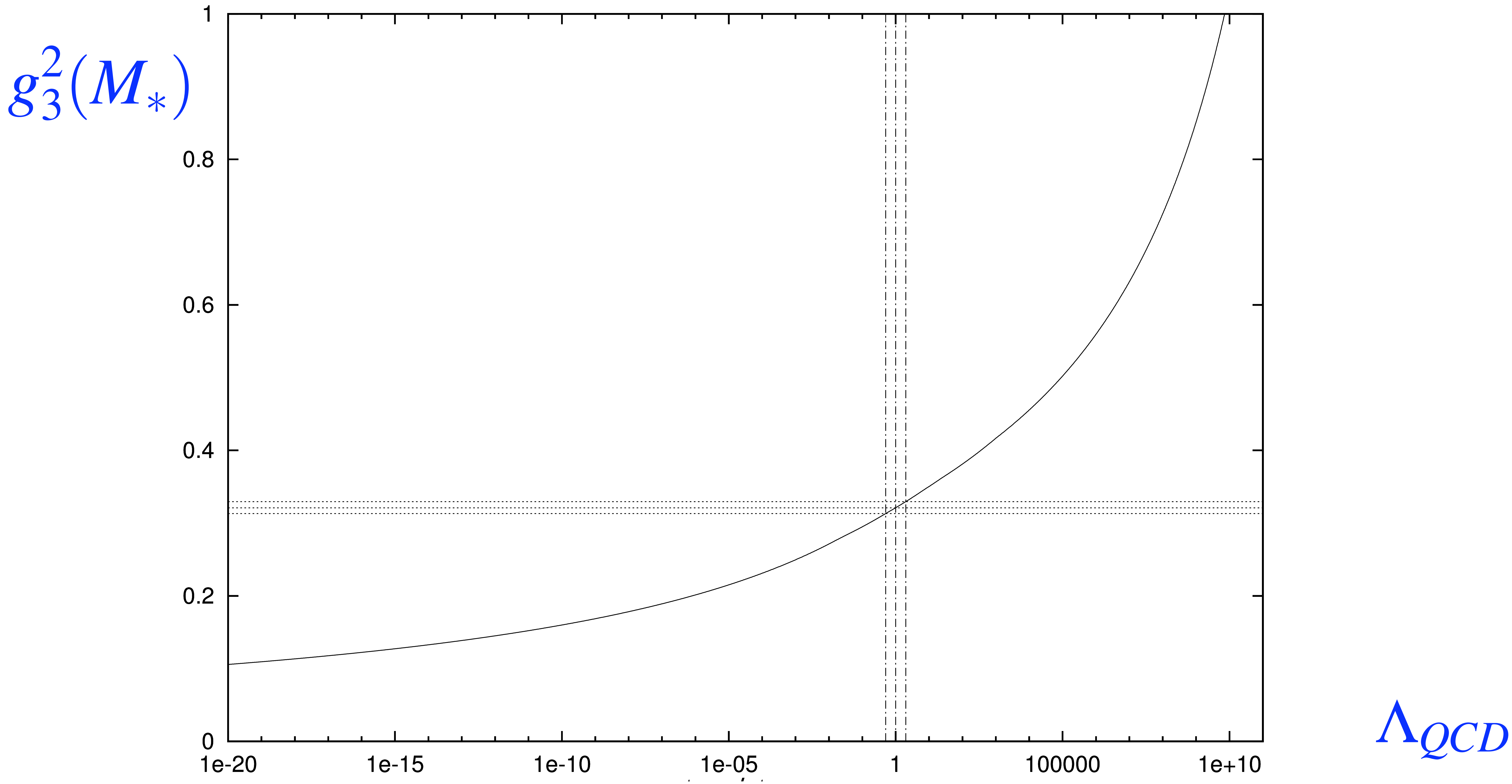
Even with Symmetries that precisely predict $y_{u,d,e}$ and v

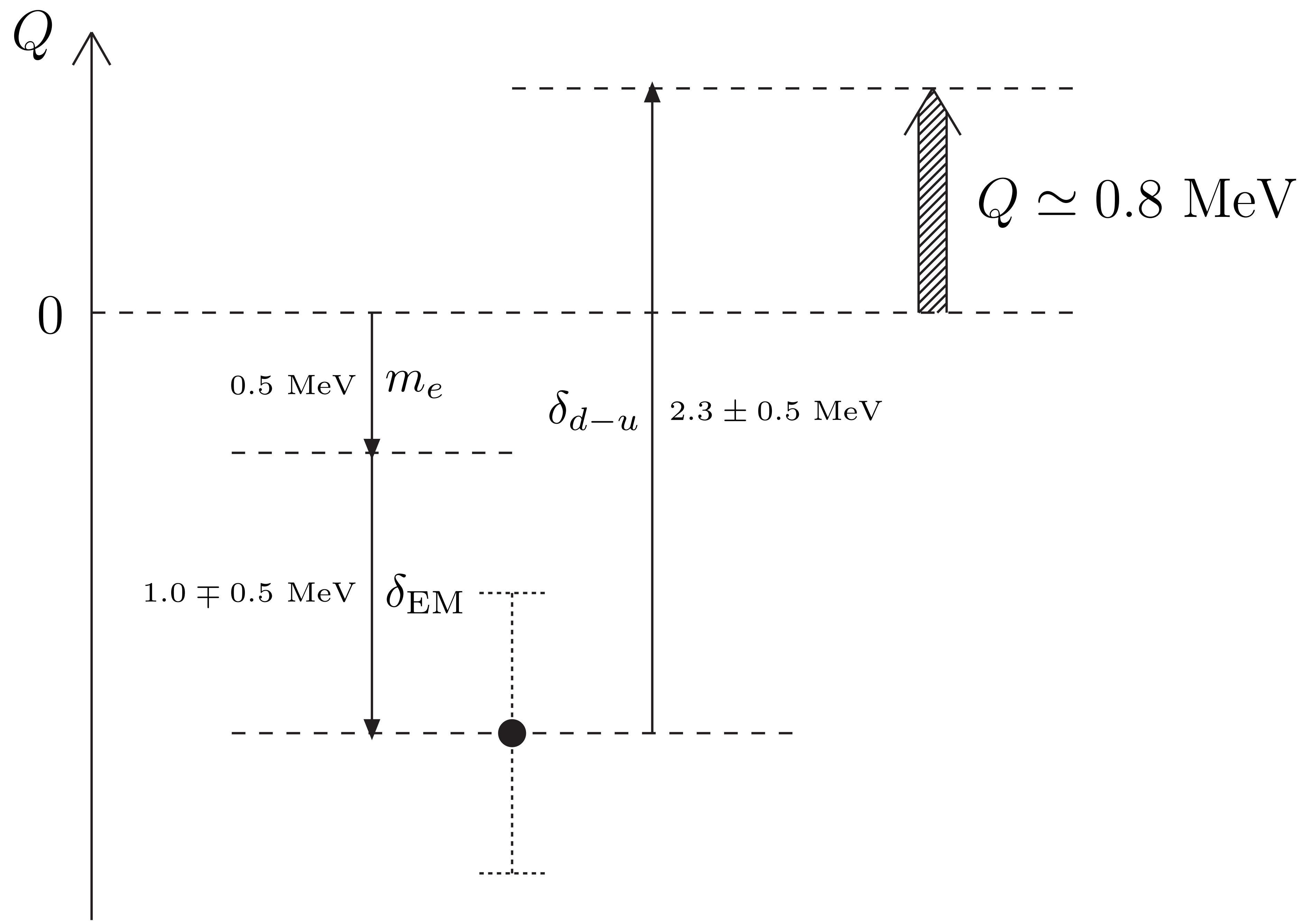


flat $f(g_3^2)$ $\Rightarrow$ $P_{\Lambda_{QCD}} \sim \frac{1}{30} - \frac{1}{100}$

Understanding Coincidences

- Why are the three contributions to $Q(n \to pe\nu)$ comparable?

- m_e, m_u, m_d are determined by the physics of the boundary comparable?



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- Simple distributions give

  - $m_e \simeq \delta_{EM}$

  - $m_{u,d} \simeq \frac{B}{N}, B_D$