The CP Violating pMSSM

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Based on 1510.Sunday
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TRIUMF, Dawn of the LHC Run-2
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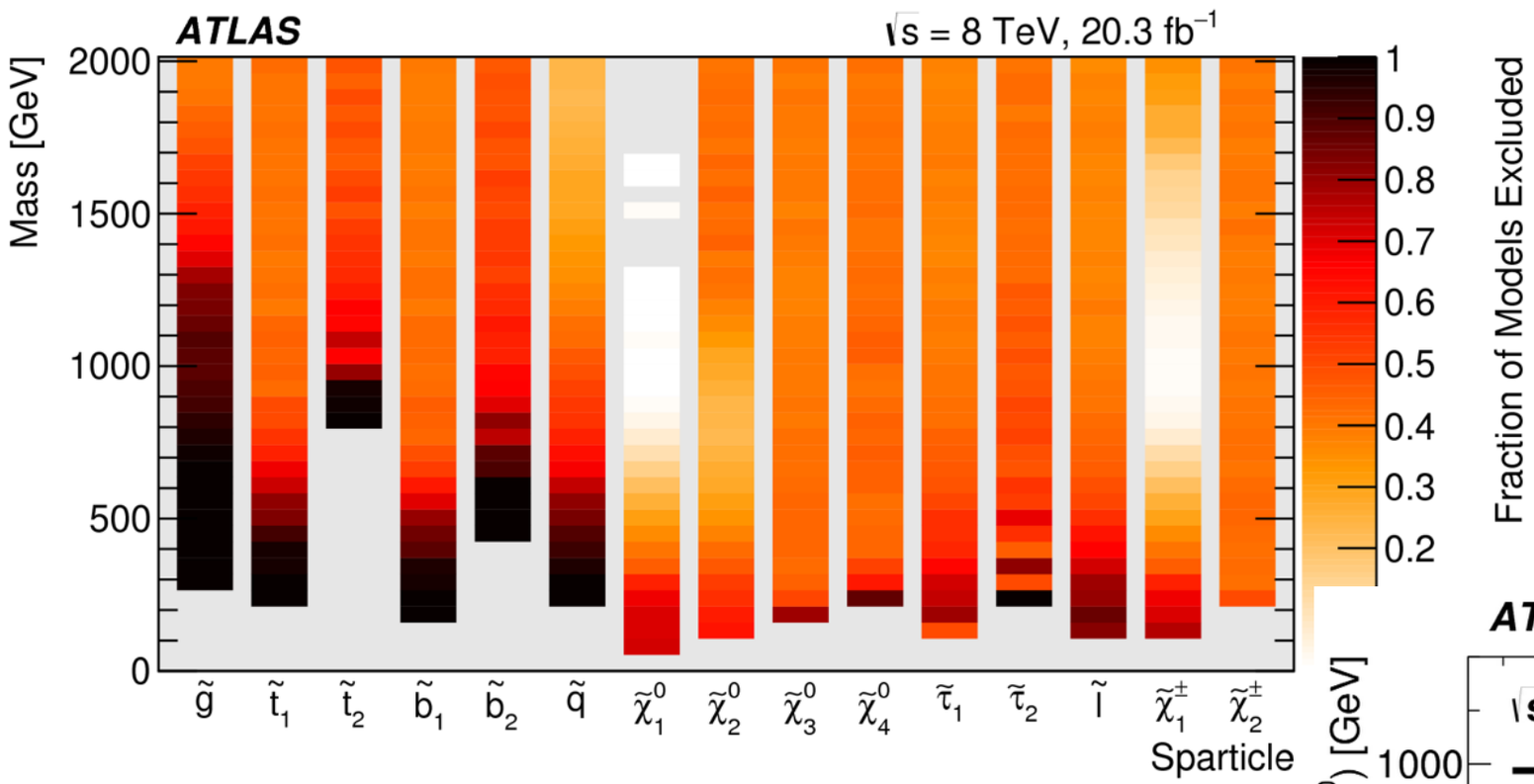
Why the pMSSM?

- For tuning specific searches, we have simplified models
- But what about the big picture?
- And what else are we missing?
- pMSSM: An MSSM subspace that can be studied given current computing, but also covers the vast majority of conceivable LHC phenomenology of the MSSM

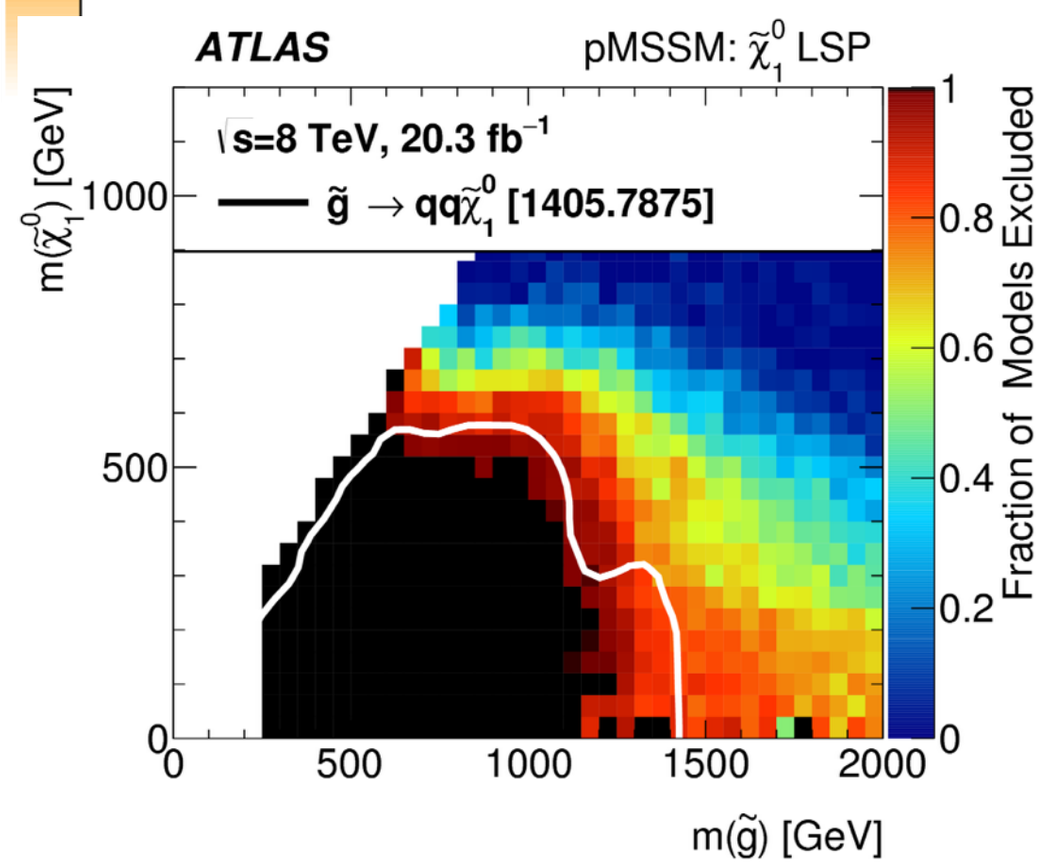
Reducing the MSSM

- The MSSM is hardly minimal: 105 new parameters
- Most of these parameters are irrelevant to LHC pheno
- Most are highly restricted by flavor and CP measurements
- Reduce to 19 new parameters that dominantly affect the spectrum and Higgs properties, while being mostly safe from flavor and CP (to be checked, of course)

Constraining the pMSSM

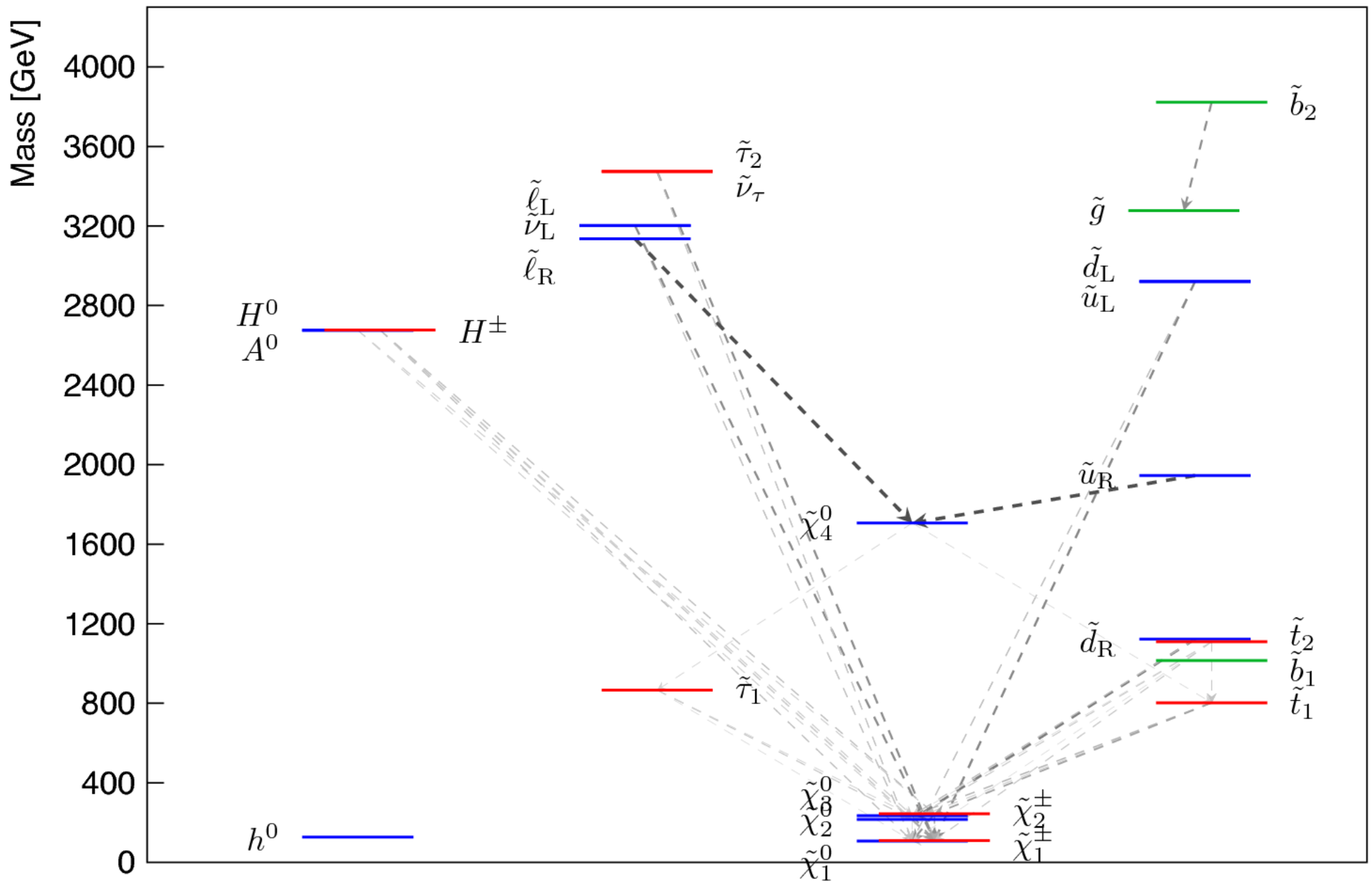


ATLAS: 1508.06608



Coverage quite strong…
but some gaps

Typical Surviving Model: Many Nearby States



ATLAS: 1508.06608

Any Other Handles?

- Models are designed to have minimal additional flavor- and CP-violation (MFV)
- This assumption is ad hoc, but common
- Can flavor- and CP-violating observables cut a complementary swath out of parameter space?
- This talk: focus on CP, adding back all the pMSSM phases set to 0

Two Classes of Phases

- The 3 independent -ino phases of $\mu B^* M_i$ and $M_i M_j^*$
- Choose a basis with physical phases of M_1, M_2, and μ
- Denoted: ϕ_1, ϕ_2, ϕ_μ

- The 3 independent 3rd gen A-term phases of $A_i \mu^*$
- Choose a basis with physical phases of A_i
- Denoted: ϕ_t, ϕ_b, ϕ_τ

The Roster of Models

- Start with over 200k pMSSM models passing a set of current collider, precision, DM, and theoretical constraints
- Choose 1000 of these to which we add phases
- Half predicted to be detectable at LHC-14 with 300 fb^{-1}
- Half would evade detection at LHC-14 with 3000 fb^{-1}
- Choose 1000 sets of phases for each: 10^6 models total

Cahill-Rowley et. al. 1206.4321

A Phenomenological Approach to Parameters

- Mass scales above LEP/Tevatron bound (0 to 400 GeV), but below limit of LHC sensitivity (4 TeV)
- Phases chosen on from logarithmic distribution to maximize coverage
- All chosen from 10^{-6} $\pi/2$ to $\pi/2$

Intensity Observables

- $|d_e|$, $|d_\mu|$, $|d_n|$ (95 % limits)
- a_e (a_μ special… see upcoming slide)
- $Br(K \to \pi\nu\nu)$
- $Br(B \to \mu\mu)$
- $Br(B \to \tau\nu)$, $Br(B \to X_s\gamma)$
- ΔM_H
- ε_K, $\sin 2\beta$

The deal with a_μ

- 3.4σ discrepancy between latest measurement and SM theory prediction
- Not entirely without controversy on both experimental and theoretical sides…
- We do not lump a_μ constraints with other constraints, but instead consider this observable separately

Calculating the Observables

- Numerous tools exist to calculate certain flavor observables in the MSSM
- Many restrict parameter space or number of observables
- All-purpose tool available at the time: SUSY_FLAVOR
- For consistency: SM predictions calculated in SUSY_FLAVOR as well

Theory Uncertainties

- Current uncertainties taken from latest SM studies
- Several observables (for e.g. $\Delta M_{d,s}$) “theory” uncertainties will improve significantly
- Improvements will be dominated by improved measurement of 1-3 CKM matrix elements and phase
- Estimate this effect using:

$$\sigma_i(O) = \frac{\partial O}{\partial \alpha_i}\sigma(\alpha_i), \qquad \sigma^2(O) = \sigma^2_{\rm th}(O) + \sum_i \sigma_i^2(O)$$

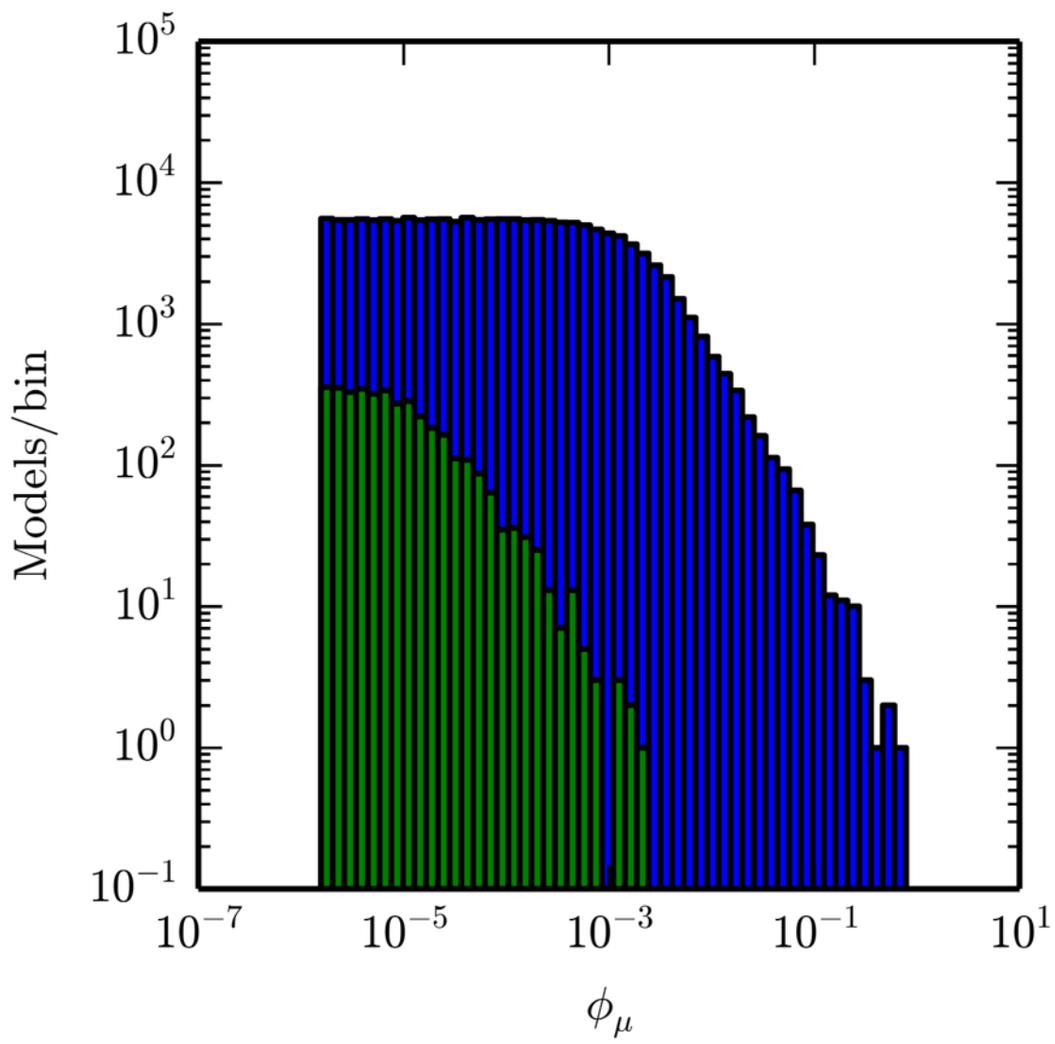
Experimental Uncertainties

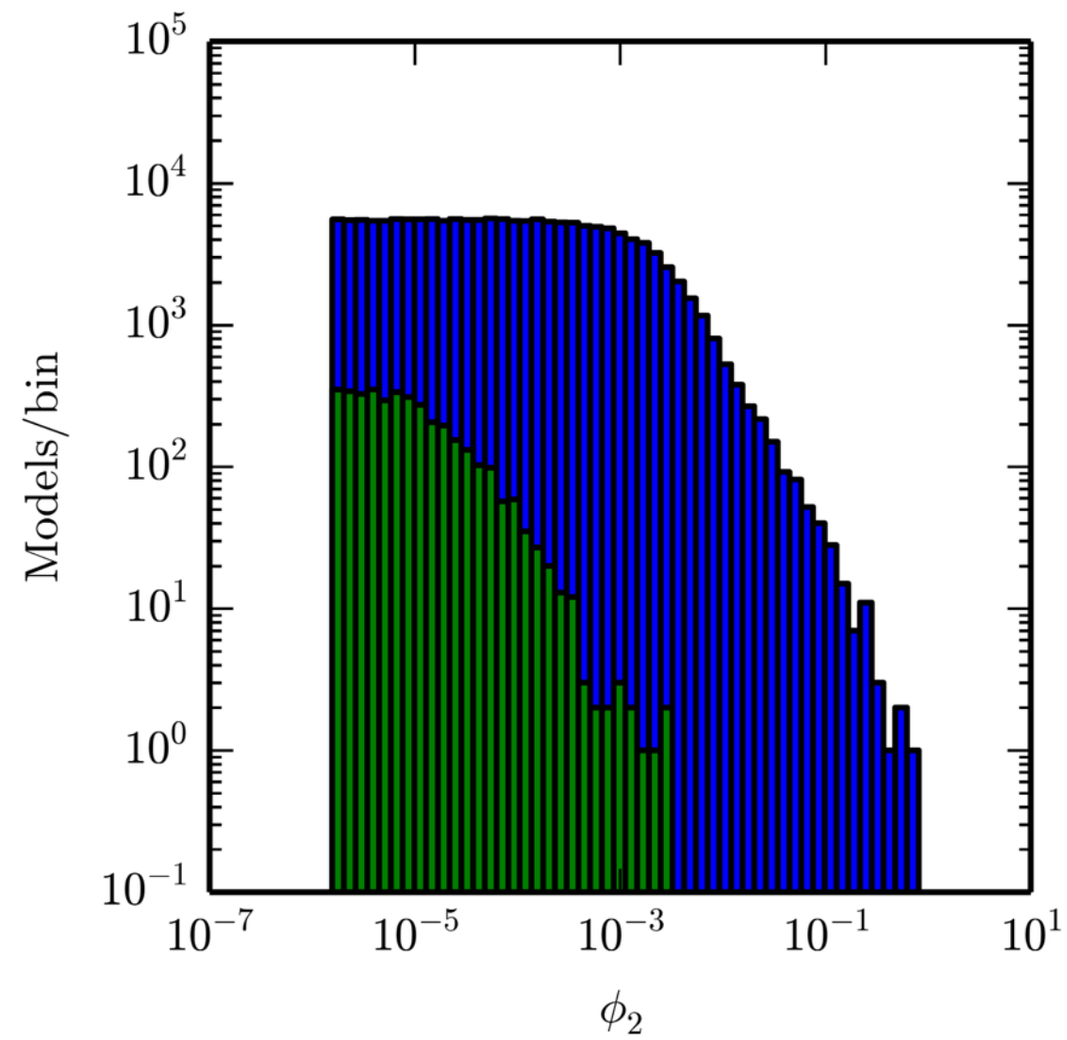
- Again, a question of what to take for future uncertainties
- Improvements studied systematically in “Fundamental physics at the intensity frontier” workshop report
- Predicted sensitivity is plausible, but take with a grain of salt as always

Model Labels

Set Name	# of models	Description
A	1000	Full pMSSM, no phases
A1	500	A with LHC-14 sensitivity
A2	500	A that evade LHC-14
B	10	A extended with phases
B1	5 x 10	A1 with phases
B2	5 x 10	A2 with phases
C	155,474	B allowed by current flavor & CP
C1	75,216	B1 allowed by current flavor & CP
C2	80,258	B2 allowed by current flavor & CP
D	3708	B evading future flavor & CP
D1	1714	B1 evading future flavor & CP
D2	1994	B2 evading future flavor & CP

Phase sensitivity, pt. 1

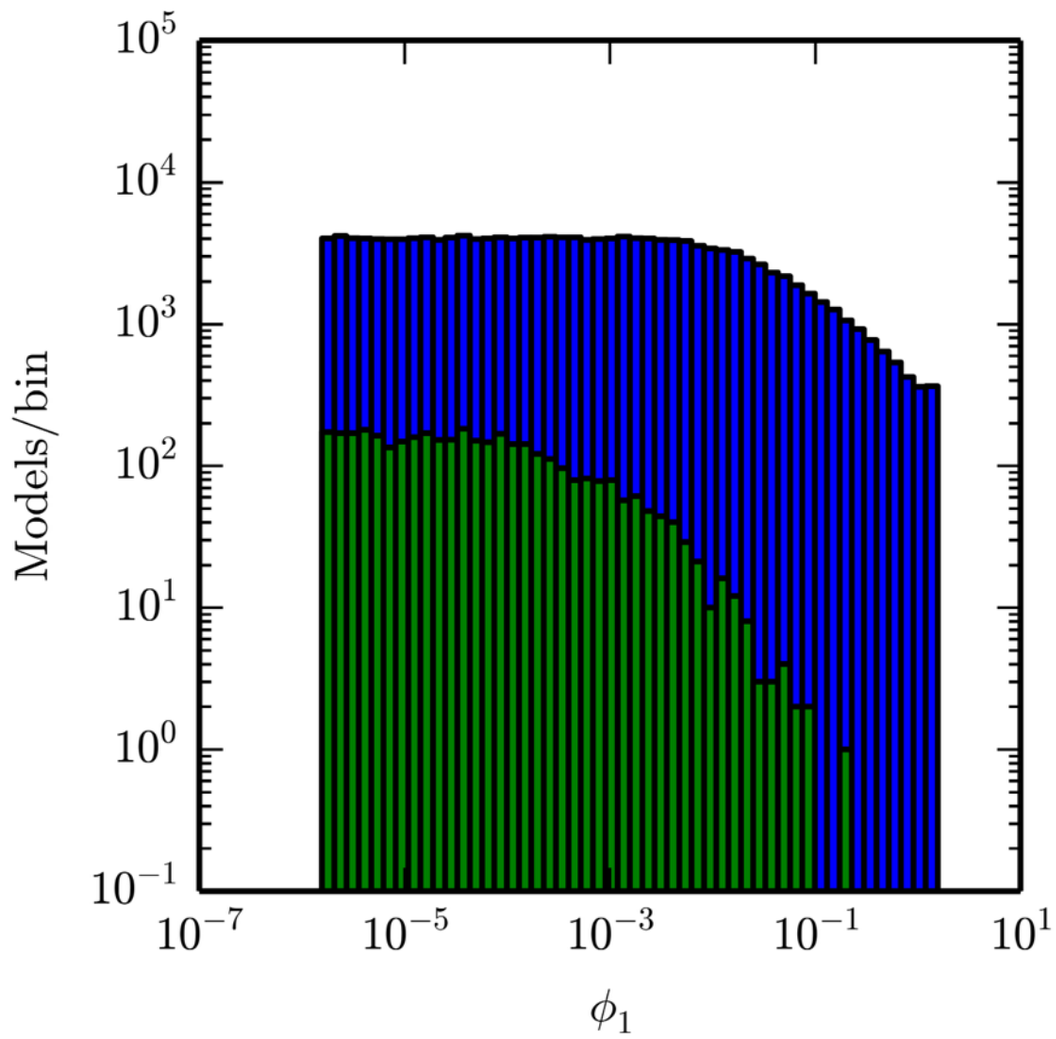


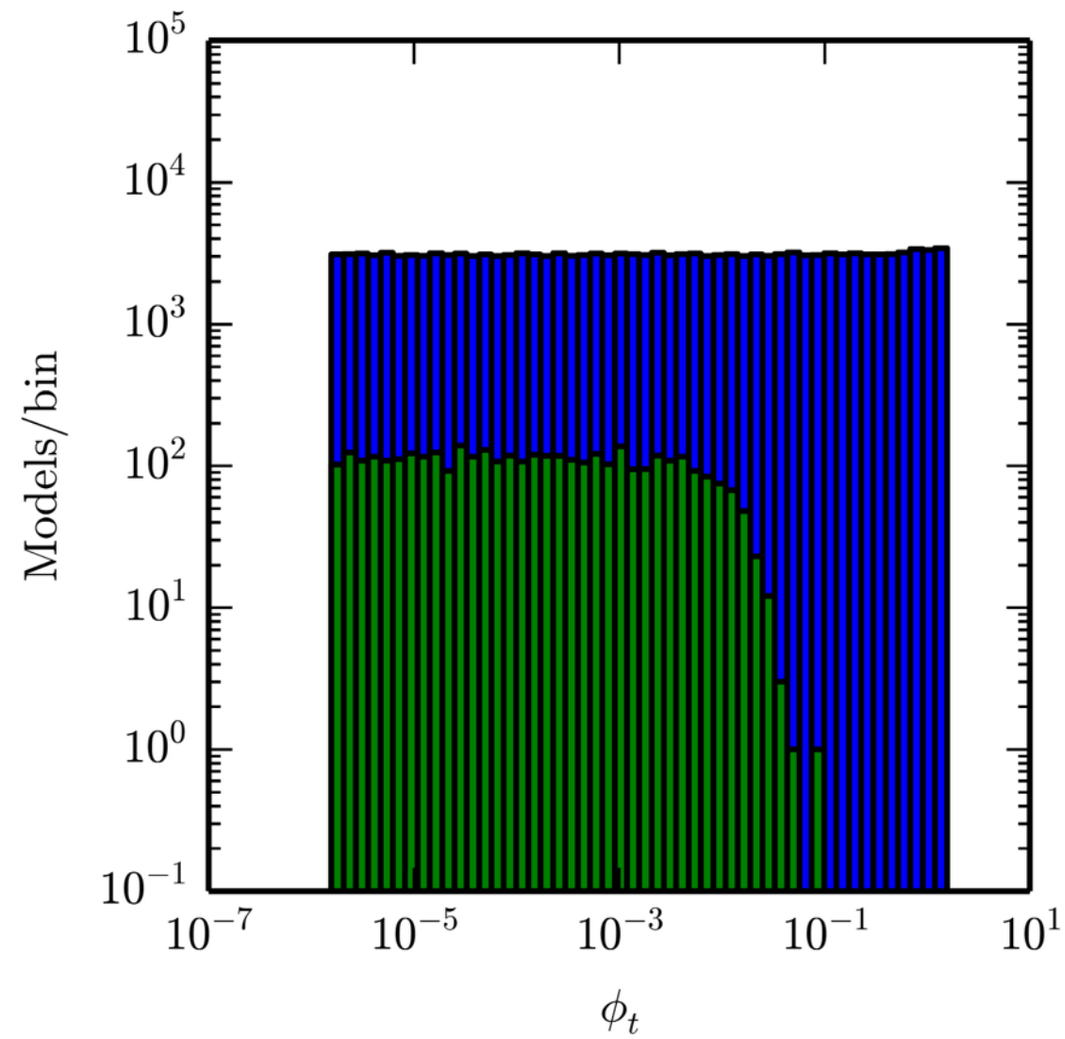


Currently Viable

Viable After Future Null Result

Phase sensitivity, pt. 2

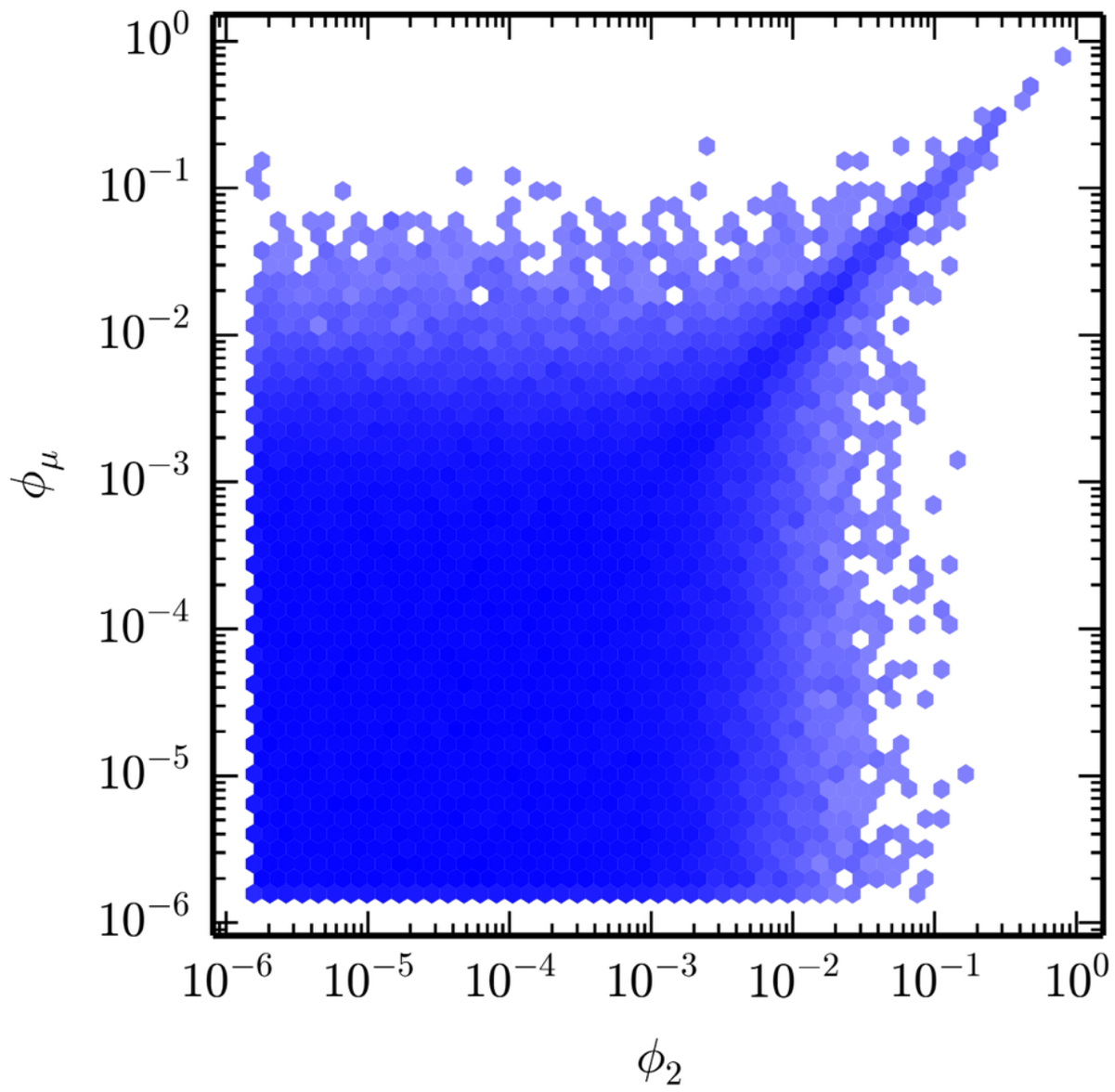




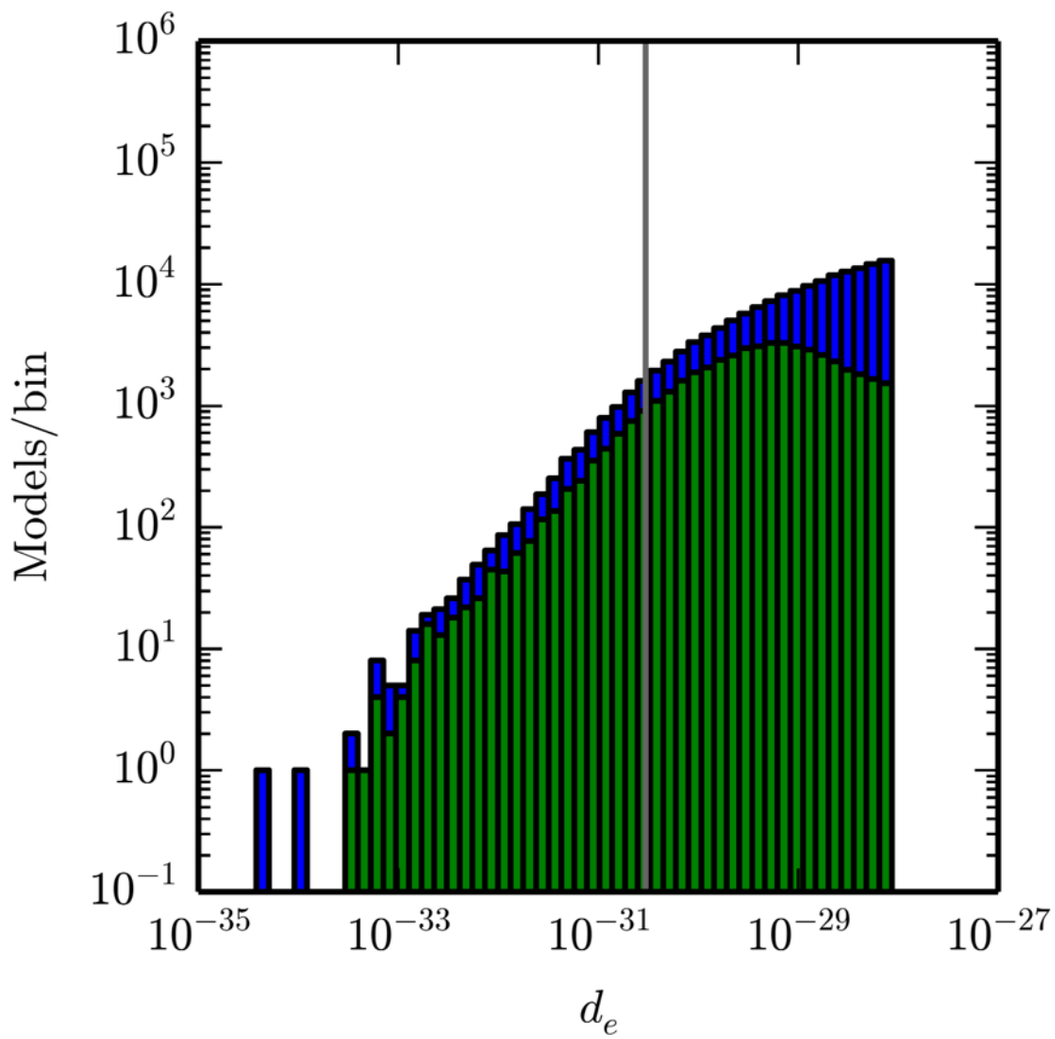
Currently Viable

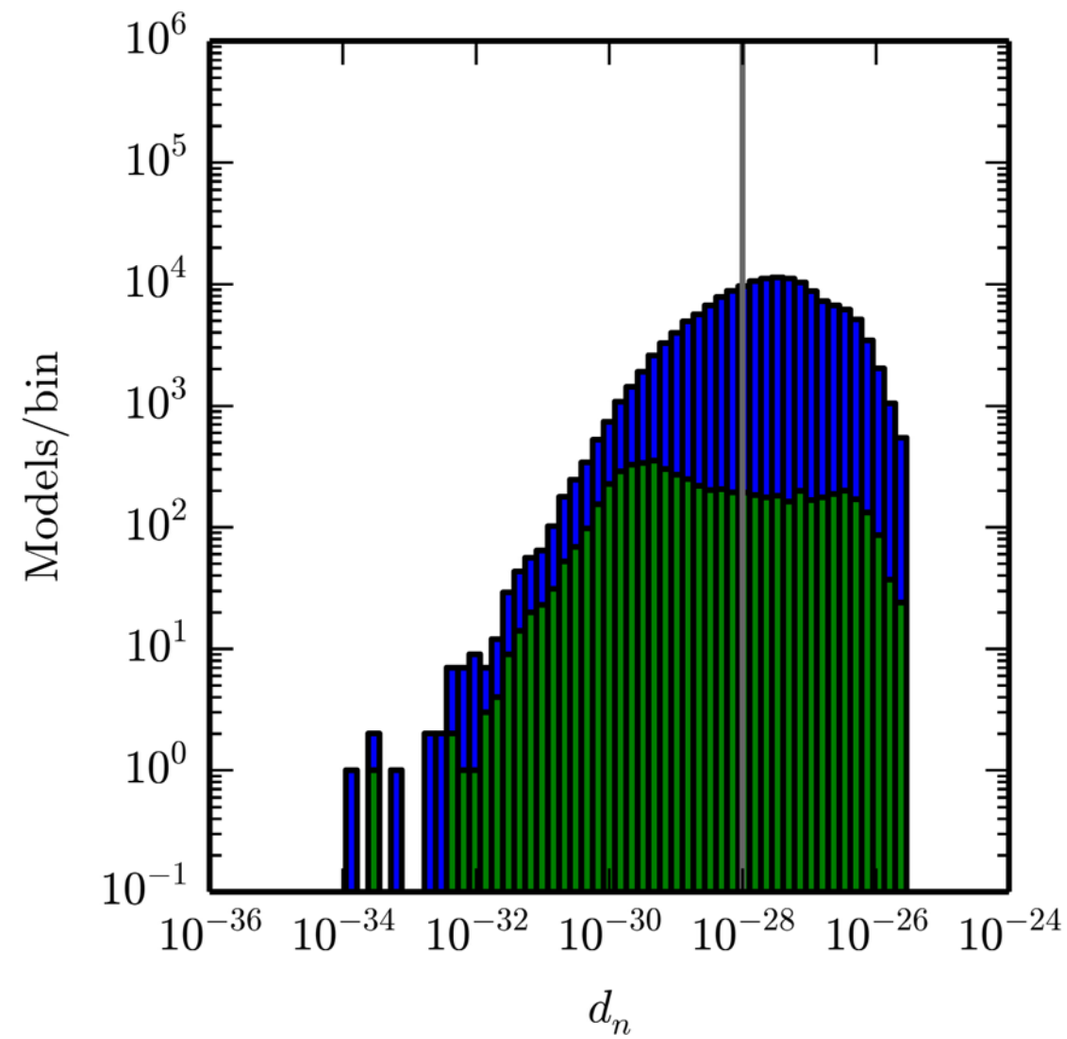
Viable After Future Null Result

Comparison Plot



Constraints from EDMs



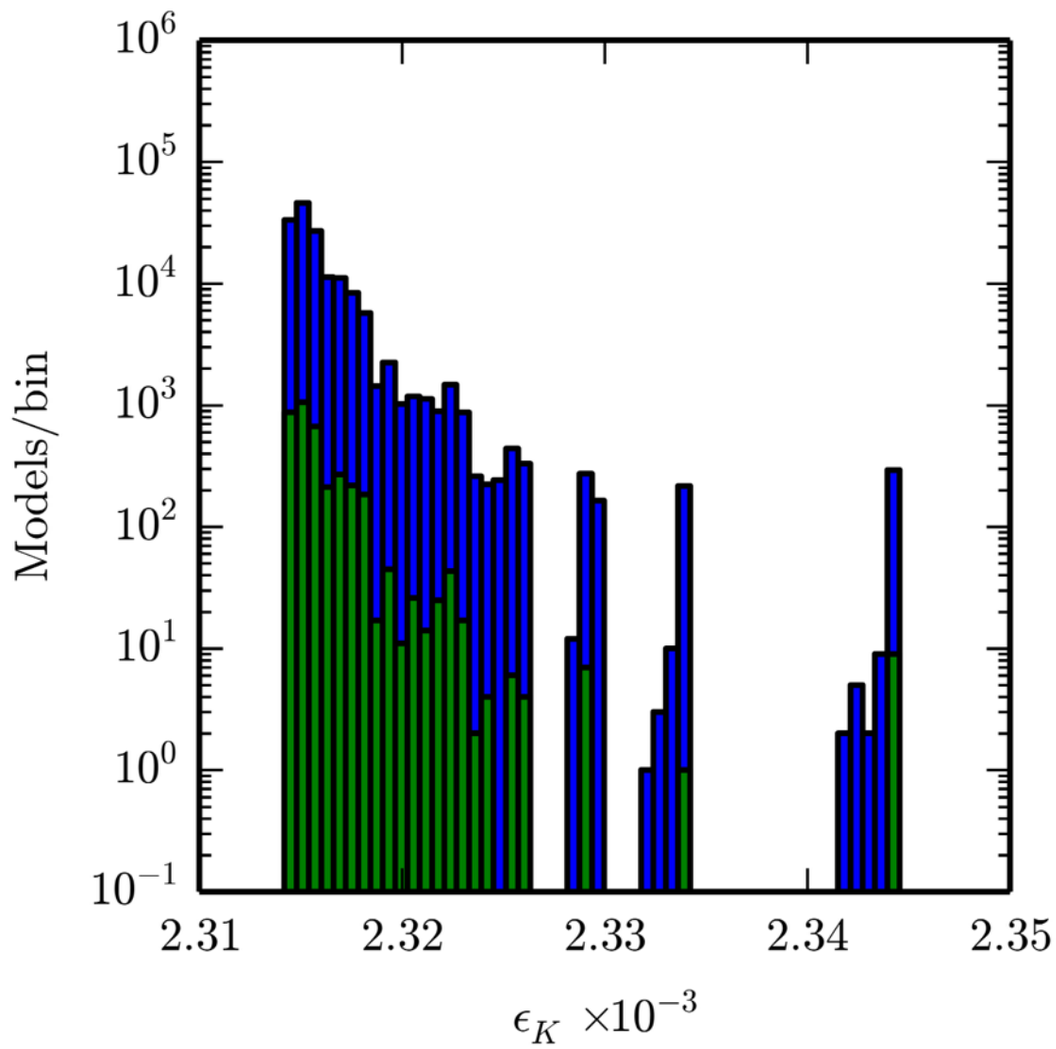


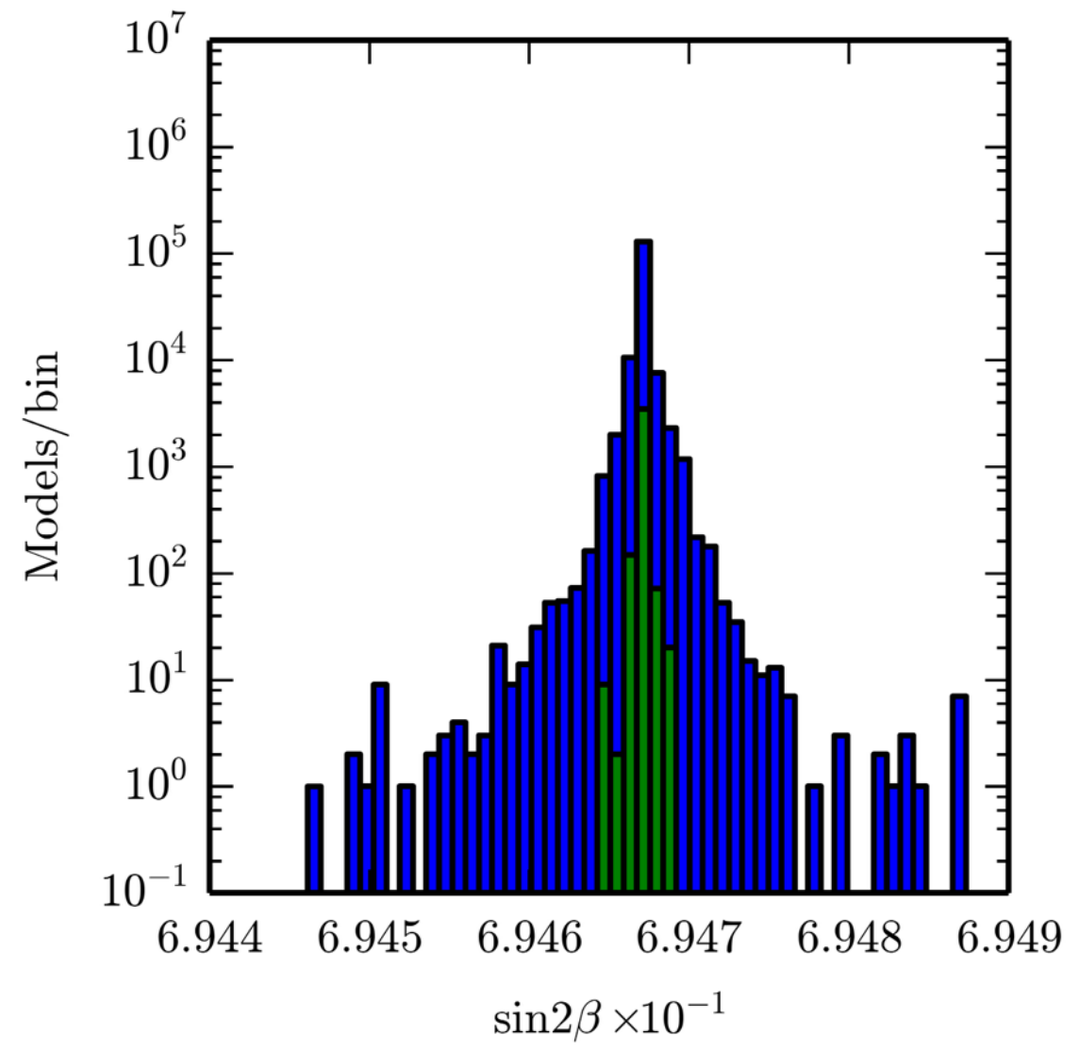
Currently Viable

Future Null Result (minus plotted observable)

Future Sensitivity

Other Observables



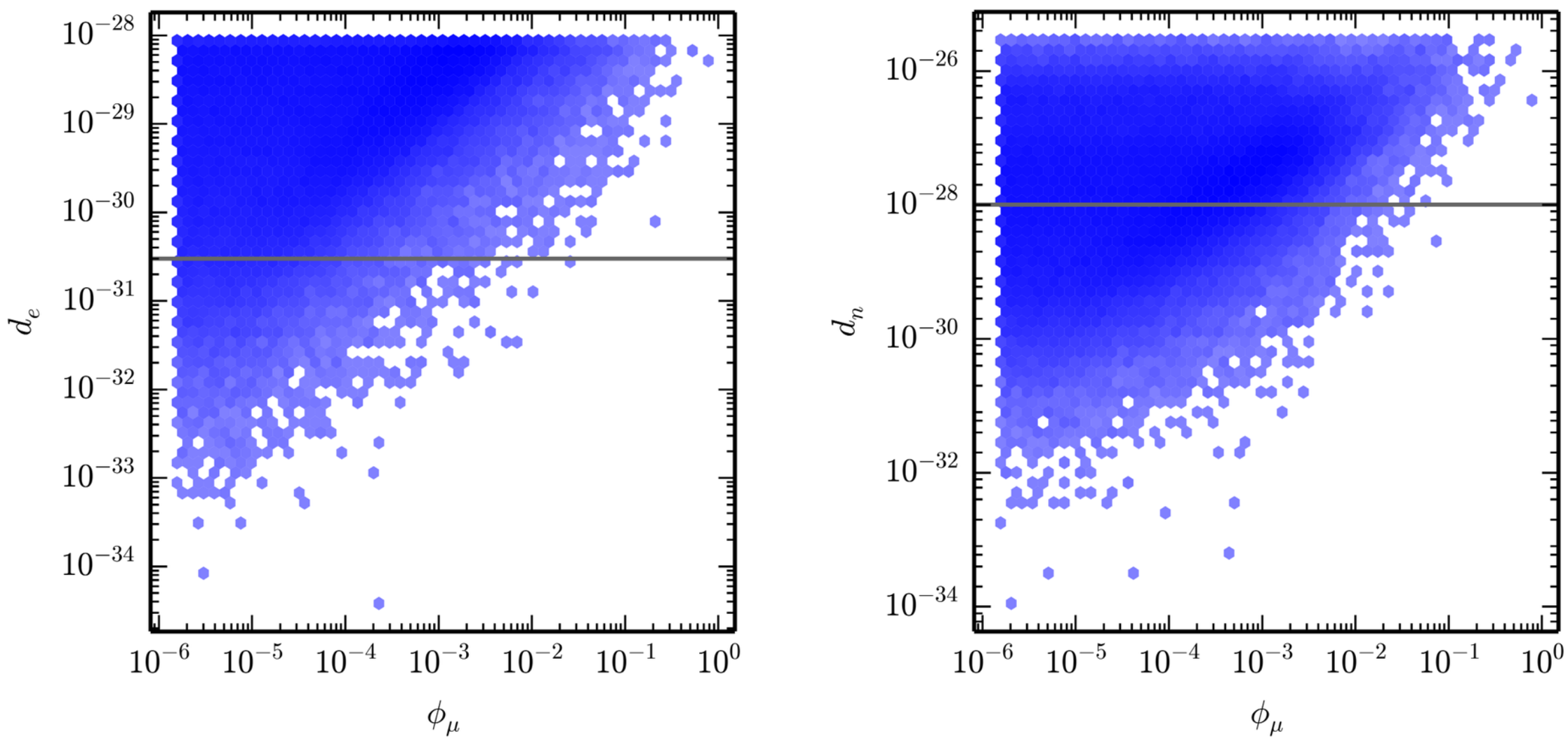


Currently Viable

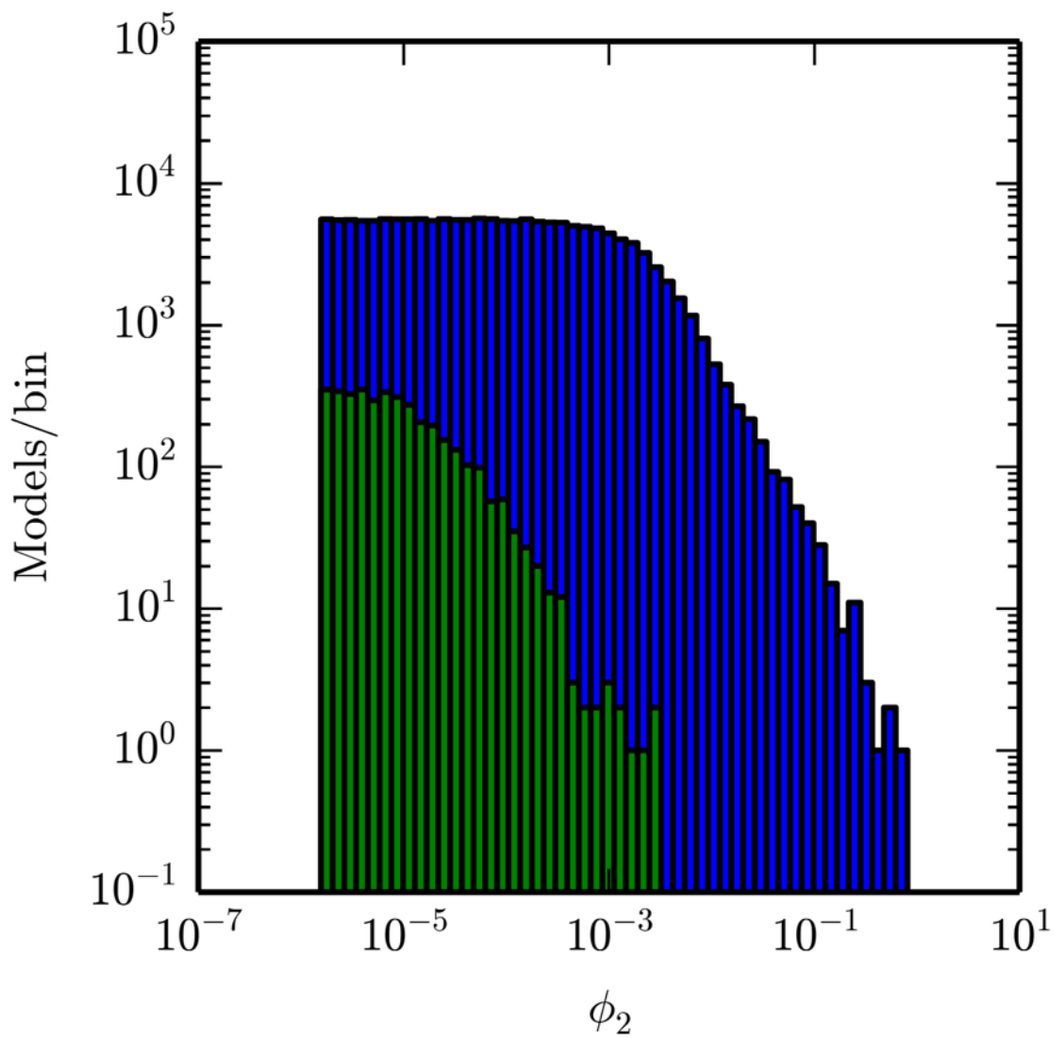
Future Null Result (minus plotted observable)

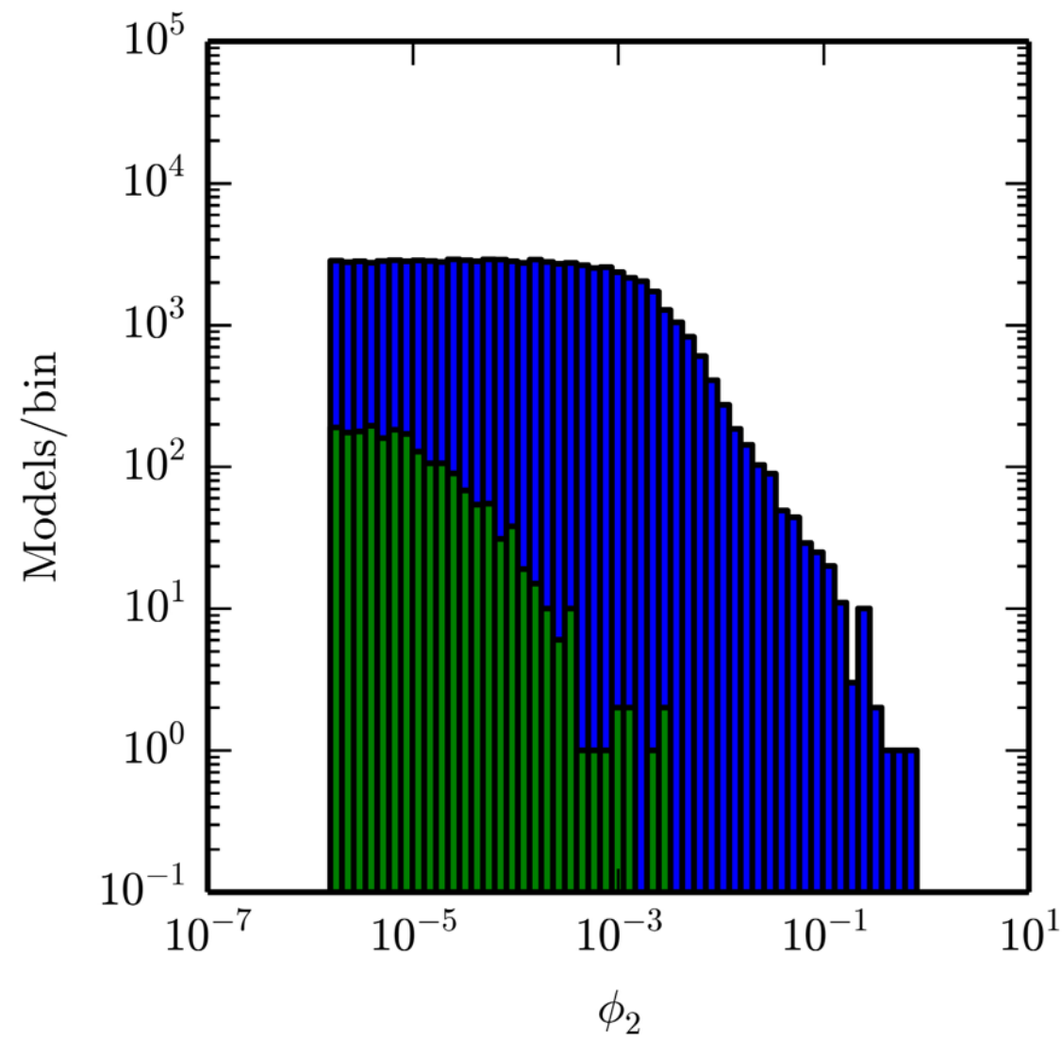
Future Sensitivity

Strong Correlation Between Observable and Phase

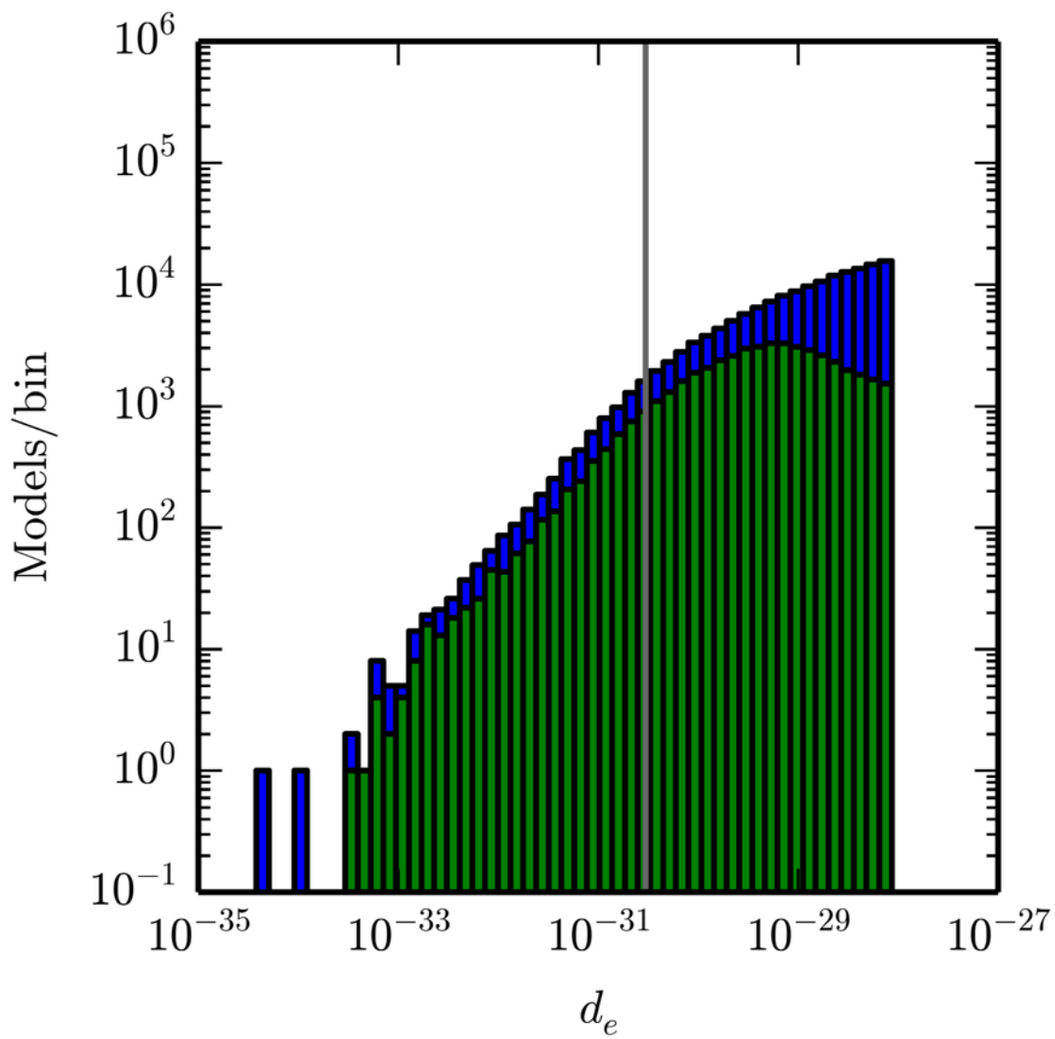


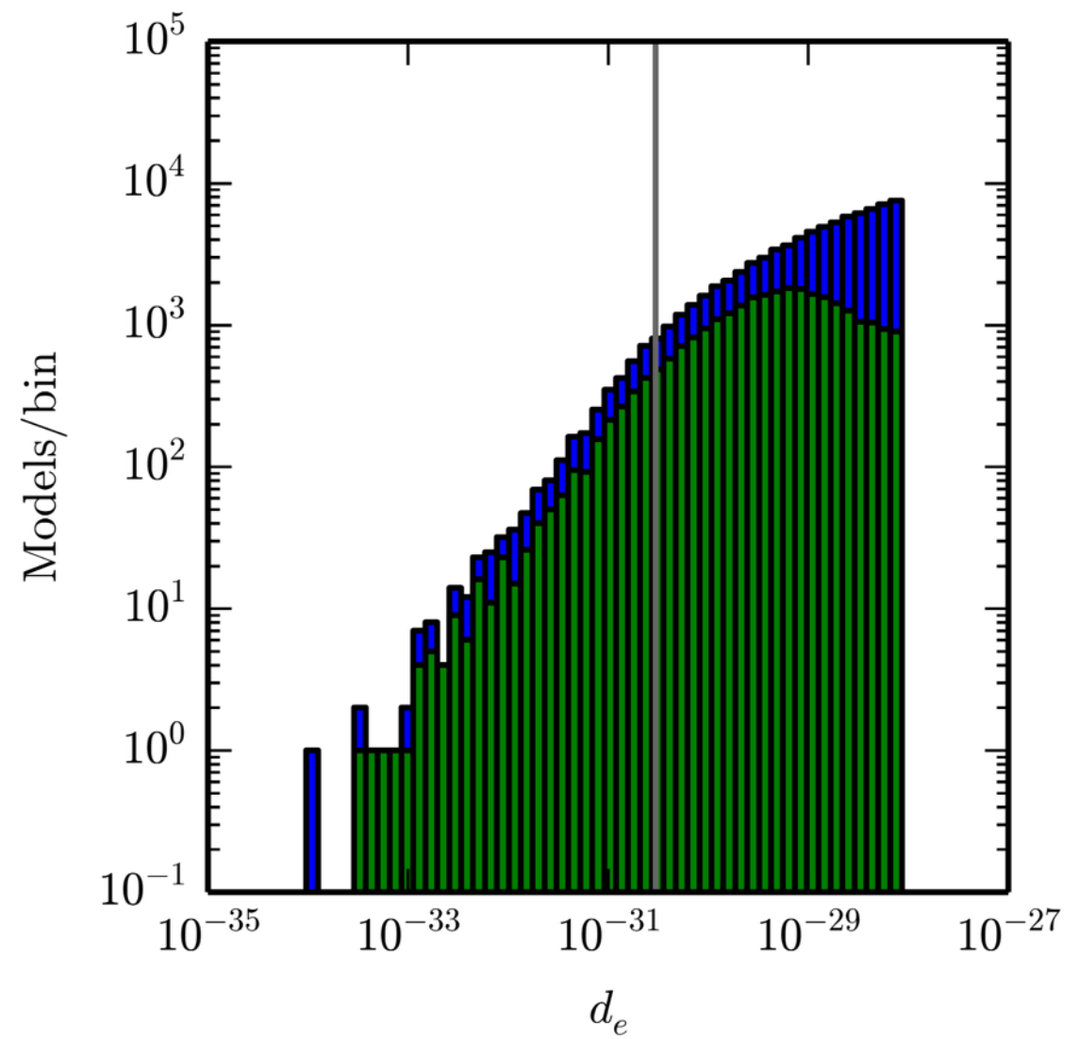
LHC vs. CPV


Models/bin
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^1
ϕ_2

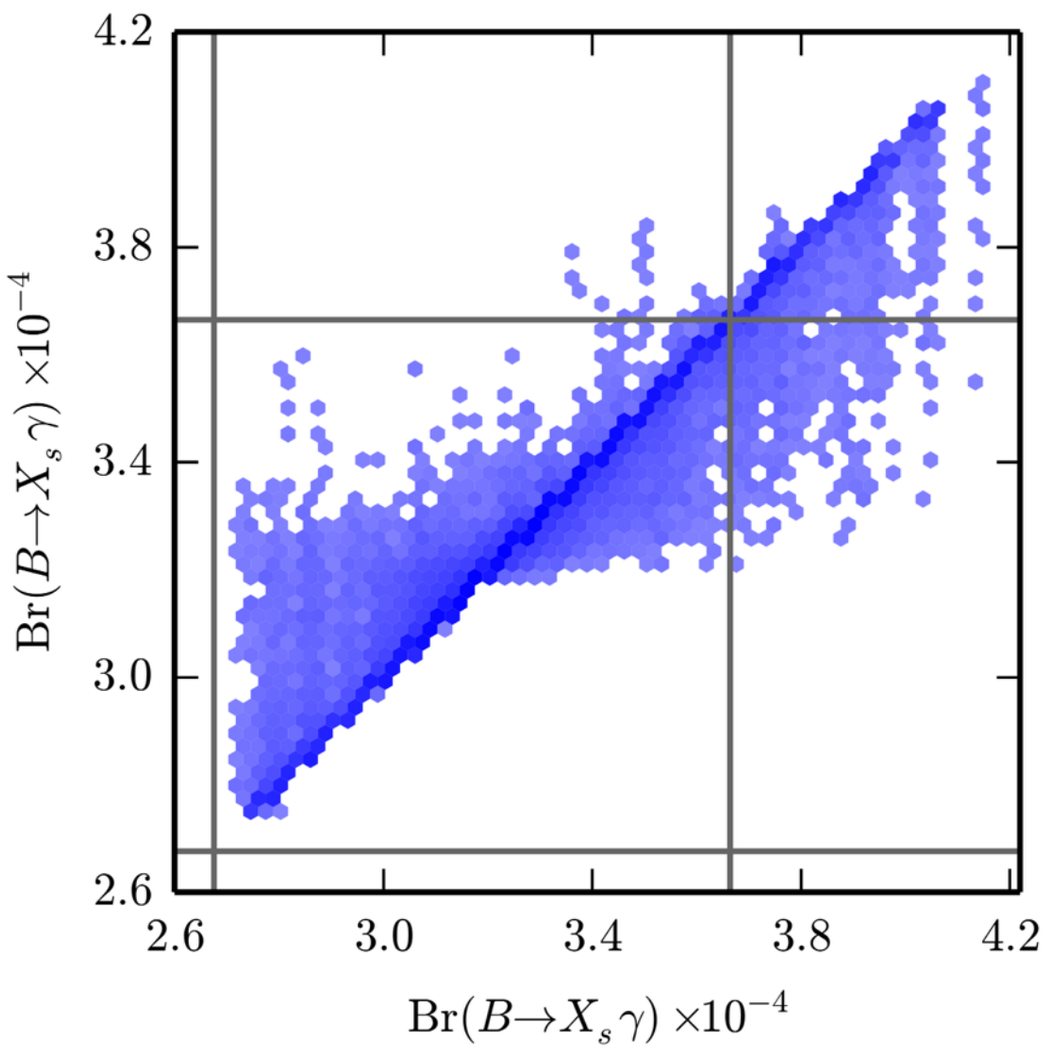

Models/bin
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^1
ϕ_2

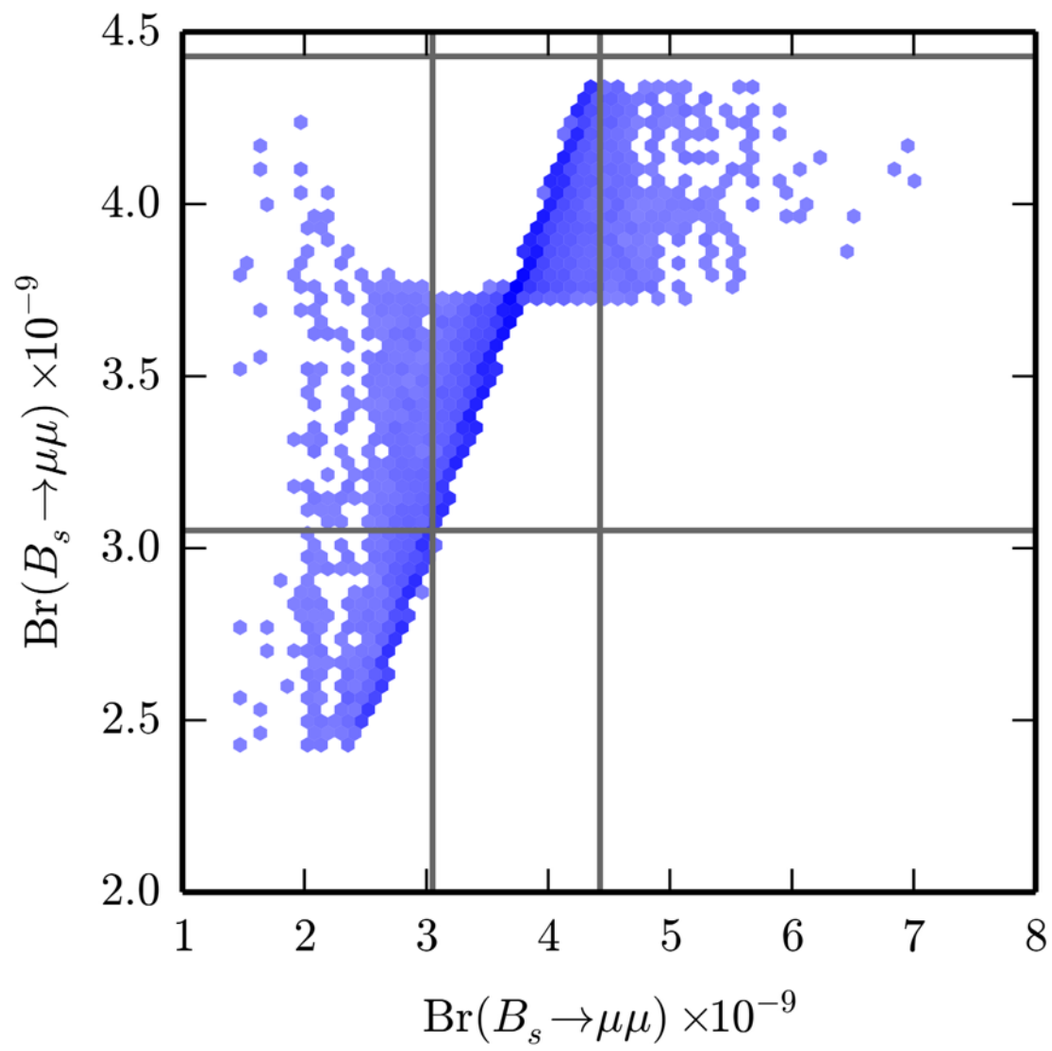
LHC vs CPV, pt. 2



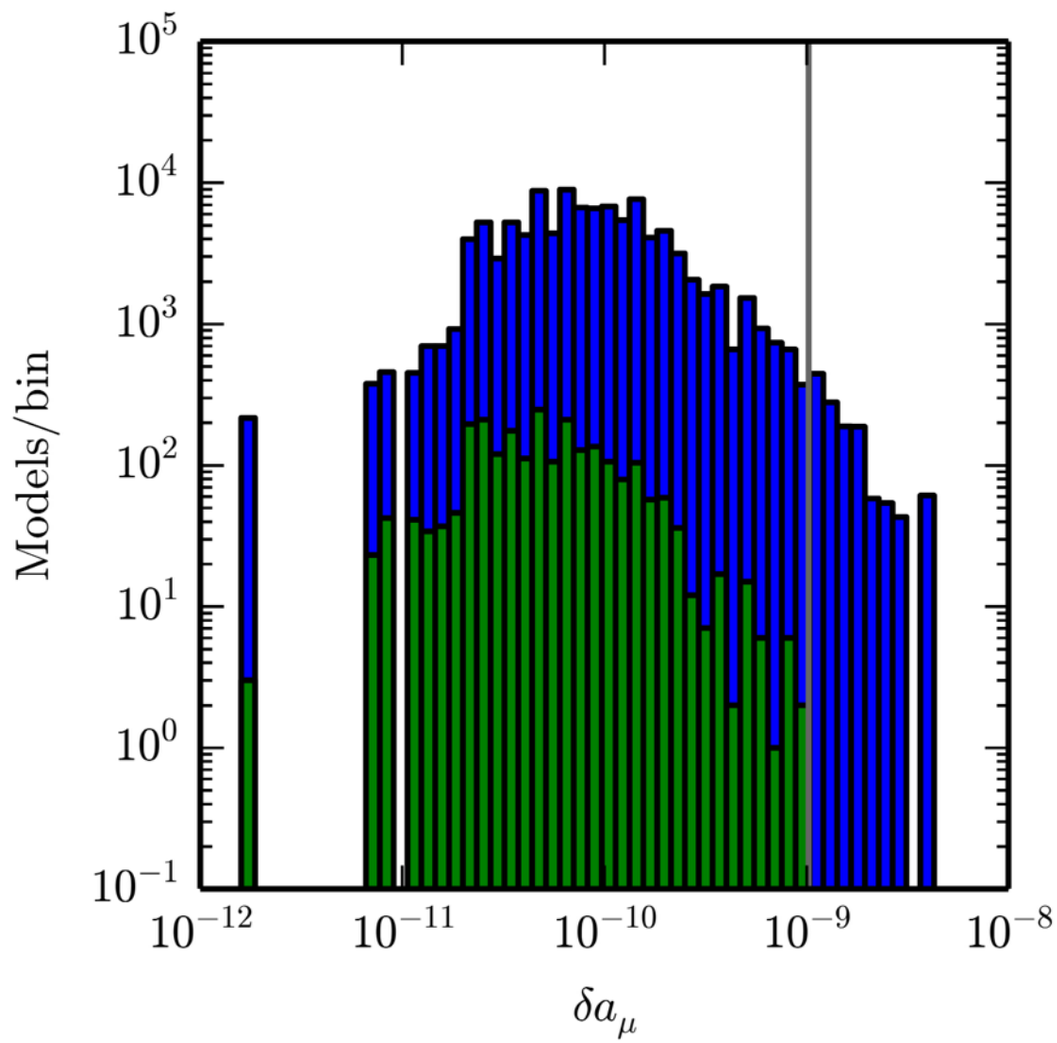


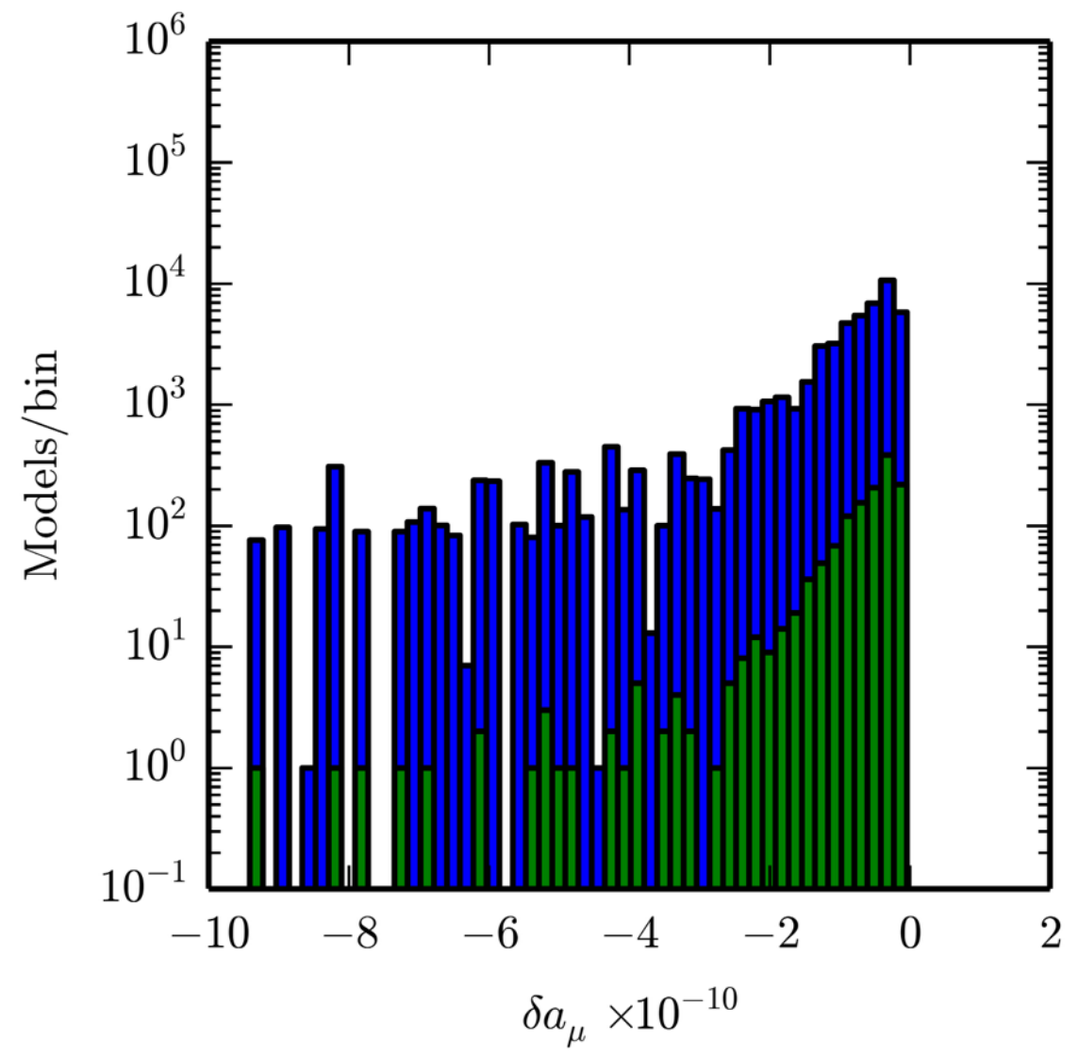
Flavor Observables





Muon g-2


Models/bin
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
δa_μ


Models/bin
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
-10
-8
-6
-4
-2
0
2
$\delta a_\mu \times 10^{-10}$

The Most Sensitive Observables

Observable	Fraction of B Models	Fraction of A Models
d	0.00645	0.746
d	0.0539	0.764
Br(B	0.144	0.877
Br(B	0.148	0.888
a	0.000366	0.009
All future (except a	0.00371	0.587

Conclusions

- The pMSSM is an excellent tool for studying the MSSM with a phenomenological bias only
- Flavor and CP constraints form a complementary probe of phenomenologically accessible MSSM models
- Lots to look forward to at Run 2 in the CPV, flavor AND direct search realms