EF02 Highlights
(BSM Higgs)
An Early Career Perspective

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Snowmass Day, September 24, 2021

The Higgs as a Portal to New Physics

Inextricably related with EF01!

Two (complementary) aspects:

- Learning about BSM physics from measuring the SM Higgs couplings
- Searching for new signals with additional Higgs bosons / new scalars

Important to consider these aspects together!

What *don't* we know about the SM Higgs?

Lots of room for more precision in all the Higgs couplings, but two gaping holes:

$$-\mu^2 H^\dagger H + \lambda\left(H^\dagger H\right)^2$$

Higgs potential (self-coupling)

Extended scalar sectors
EW phase transition
Baryogenesis
Hierarchy Problem
…
…

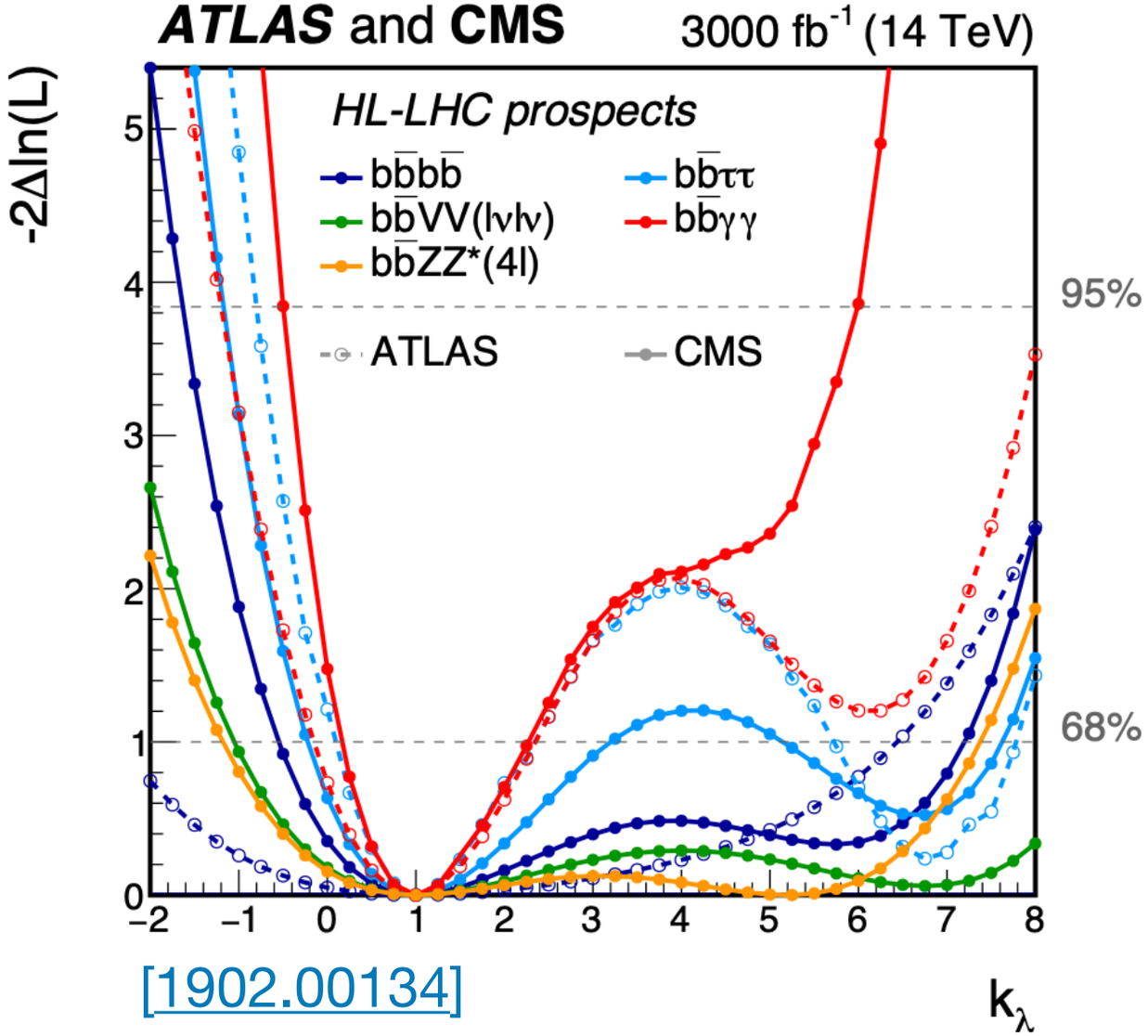
$$\lambda^u_{ij} Q_i H \bar{u}_j - \lambda^d_{ij} Q_i H^c \bar{d}_j$$

Light flavor Yukawas

Flavor Puzzle
Strong CP Problem
Baryogenesis
Extended scalar sectors
…
…

Di-Higgs Production — the Self-Coupling

HL-LHC prospects on λ_{hhh}:



[1902.00134]

(Note: ***huge*** improvement already compared to Snowmass 2013 projections!)

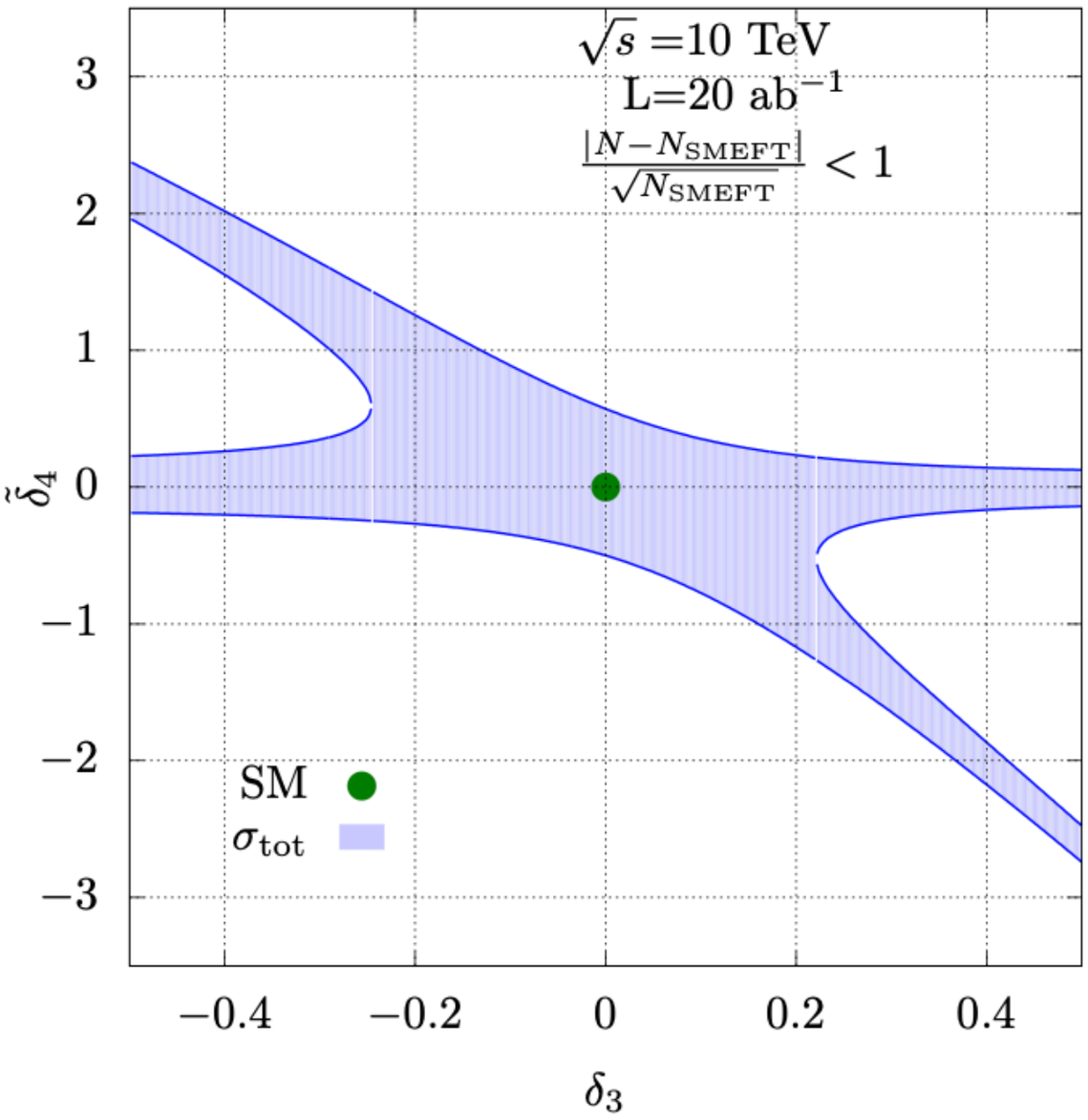
What is our BSM theory target?

- Can we exclude models with first-order EW phase transitions?
- Unitarity arguments connect deviations to scale of new physics
  (see e.g., Spencer Chang's EF02 talk)
- Large deviations typically involve models with ***new scalars***
  (see e.g., Sven Heinemeyer's EF02 talk)

Di-Higgs Production — the Self-Coupling

Future colliders needed!

Possibilities at a High-Energy Muon Collider?
(see e.g., Mauro Chiesa's EF02 talk)



[1910.00012]

collider	single-H	HH	combined
HL-LHC	100-200%	50%	50%
CEPC_{240}	49%	–	49%
ILC_{250}	49%	–	49%
ILC_{500}	38%	27%	22%
ILC_{1000}	36%	10%	10%
CLIC_{380}	50%	–	50%
CLIC_{1500}	49%	36%	29%
CLIC_{3000}	49%	9%	9%
FCC-ee	33%	–	33%
FCC-ee (4 IPs)	24%	–	24%
HE-LHC	-	15%	15%
FCC-hh	-	5%	5%

These values are combined with an independent determination of the self-coupling with uncertainty 50% from the HL-LHC.

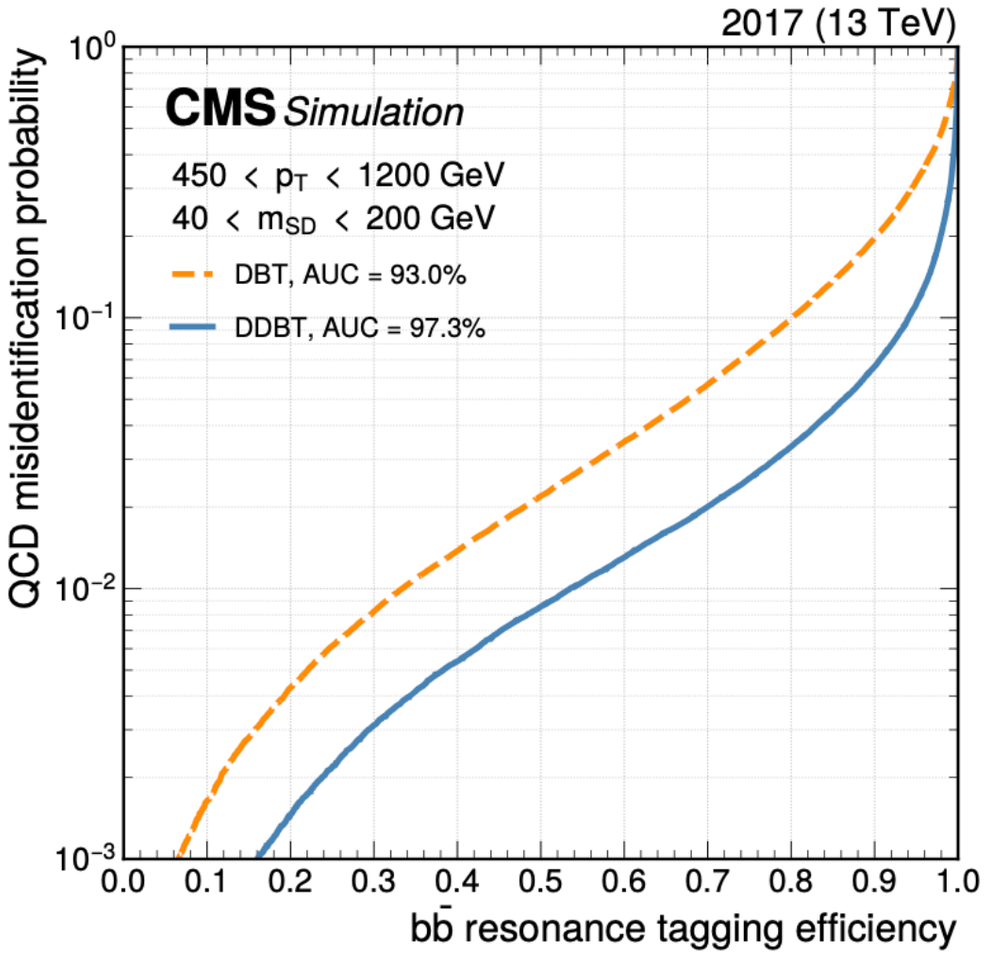
Di-Higgs Production — Experimental Improvements?

Still lots of room for improvement in boosted hadronic channels!

- Branching fractions for HH decays:
  - bbγγ : 0.26%
  - **bbbb** : 33.9%. 130× more signal than bbγγ
  - **bbWW** : 24.9% 98× more signal than bbγγ
  - **bbZZ** : 3.0% 12× more signal than bbγγ
  - **VVVV** : 5.8% 22× more signal than bbγγ
- After requiring both Higgs with $p_T > 400$ GeV
  - **bbbb** : 5.2× signal yield of bbγγ
  - **bbWW** : 4.3× signal yield of bbγγ
  - **VVVV** : 0.9× signal yield of bbγγ

See Javier Duarte's Talk from joint EF01/EF02 discussion last May + EF02 talk last Fall

New Higgs Tagging Approaches for boosted, large radius Higgs jets



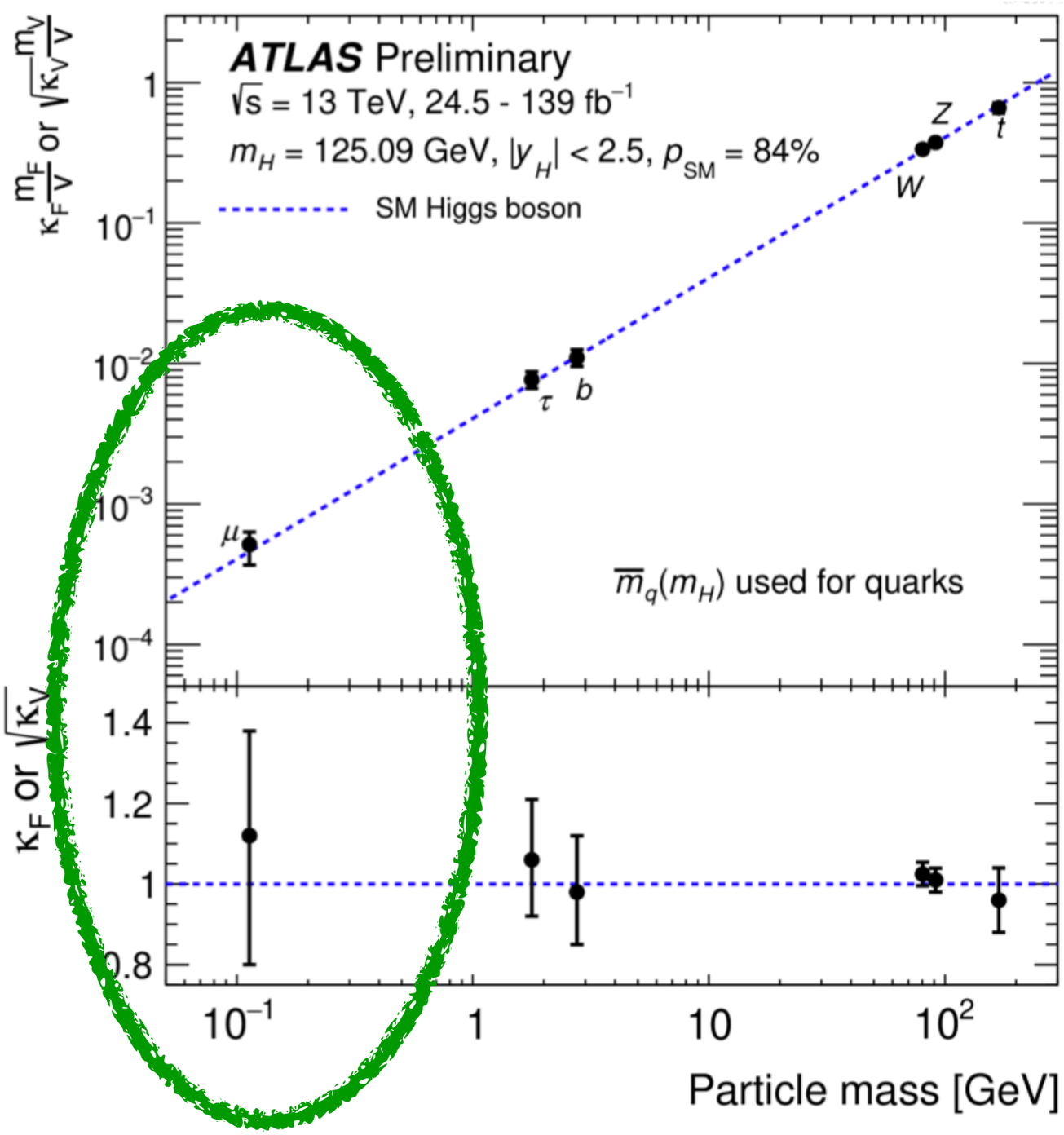
[2004.08262]

Higgs and Flavor

Higgs coupling-mass relationship well fit for the third generation

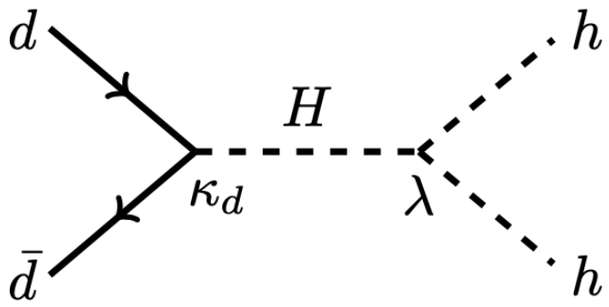
First and second generation quark Yukawas almost completely unconstrained!

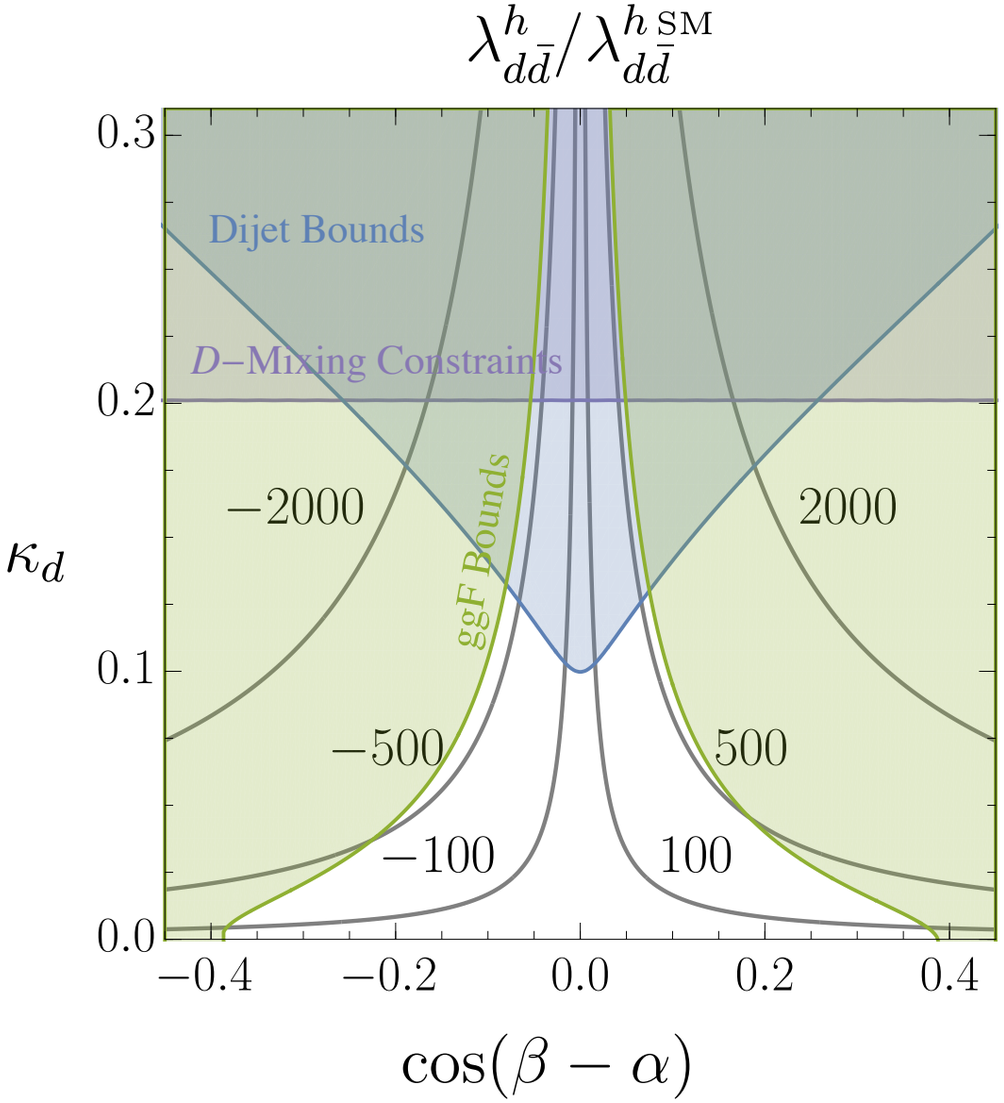
- What kind of theories predict large (observable?) enhancements?
- What about bounds on flavor-violating decays?
- How feasible are measurements of light flavor in the future?



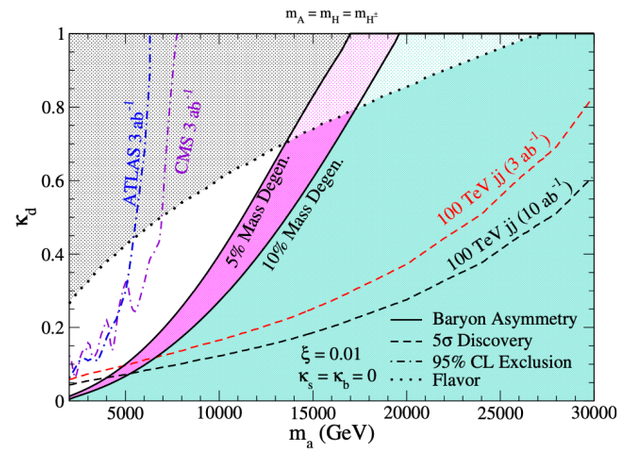
Higgs and Flavor — Theory Targets

New theory ideas: large enhancements of the Higgs Yukawas possible in models with *flavor alignment*
(D. Egaña, **SH**, P. Meade, 1908.11376, 2101.04119)





- Lead to interesting signatures from new states
- Straightforward extension to models of baryogenesis
  (see Davoudiasl et al., 2103.12089)
- $\mathcal{O}(30)$ enhancements to strange also possible!

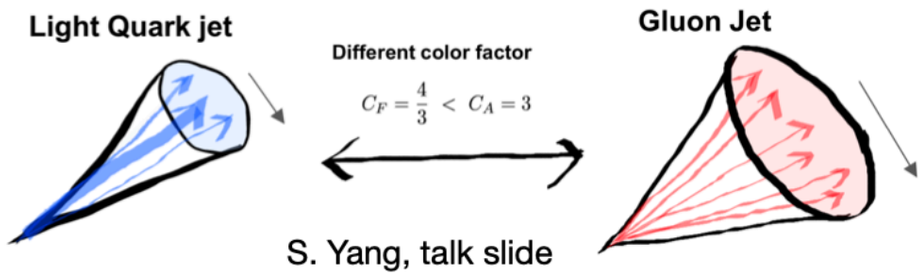


See also D. Tuckler's EF02 talk for ideas leading to flavor-violating Higgs decays

Higgs and Flavor — Tagging Prospects

Is is possible to tag all different flavor jets?

☑ Gluon



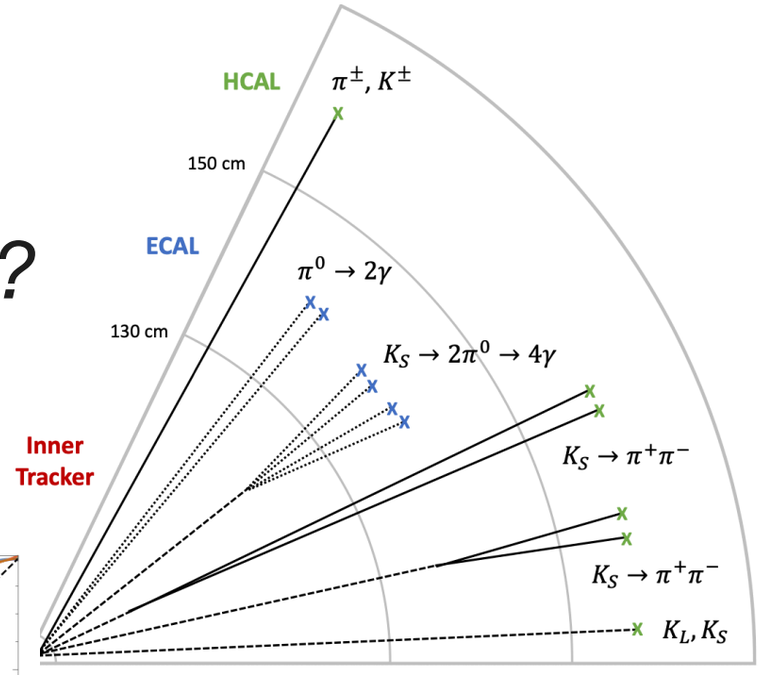
More constituents with more uniform energy fragmentation and wider.

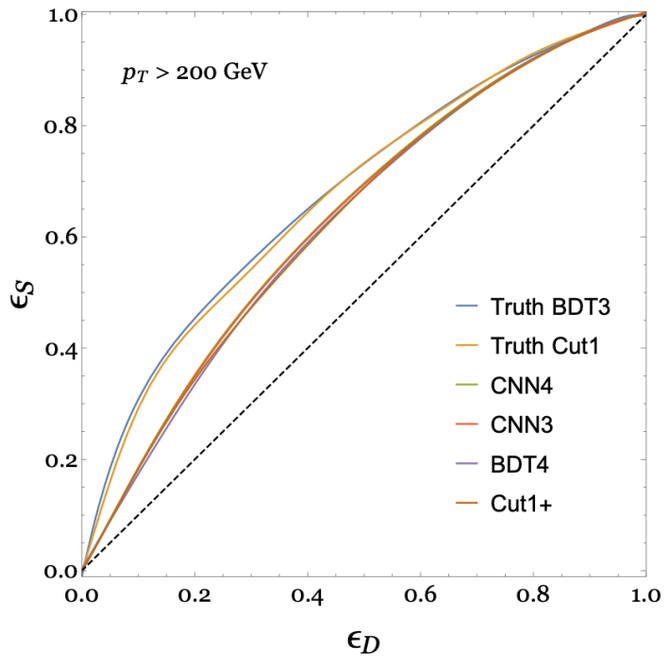
☑ Up-type vs Down-type

p_T-weighted jet charge

$$Q_\kappa^i = \frac{1}{(p_T^{\text{jet}})^\kappa} \sum_{j \in \text{jet}} Q_j (p_T^j)^\kappa$$

What about ***strange tagging?***





(Yuichiro Nakai, EF02 Meeting + [2003.09517])

See also Valentina Cairo's Talk in EF01 for prospects at ILC

Summary

Lots of other interesting studies and results that I don't have time to talk about!

A few takeaways:

- We still need to measure the self-coupling and light flavor to "complete" the SM
  - New ideas from theory on large Yukawas, di-Higgs production, and flavor-violating decays
  - Exciting improvements in prospects on light- and heavy-flavor tagging
- Ultimately need future colliders — lots of interesting options, each with strengths/weaknesses!
  - What are the ideas from BSM physics motivating our targets for Higgs precision?