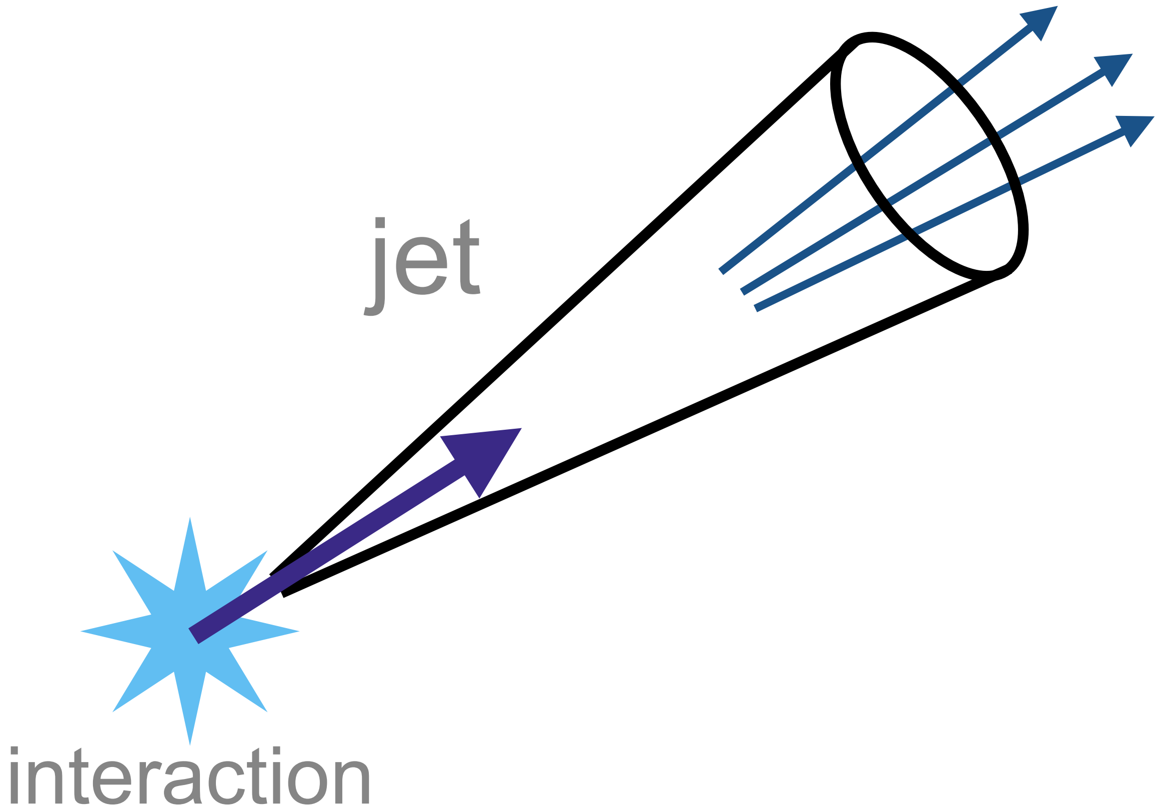
flavor tagging for enhancing sensitivity for new physics

Yotam Soreq

LHCP-2021, June 10, 2021

flavor tagging



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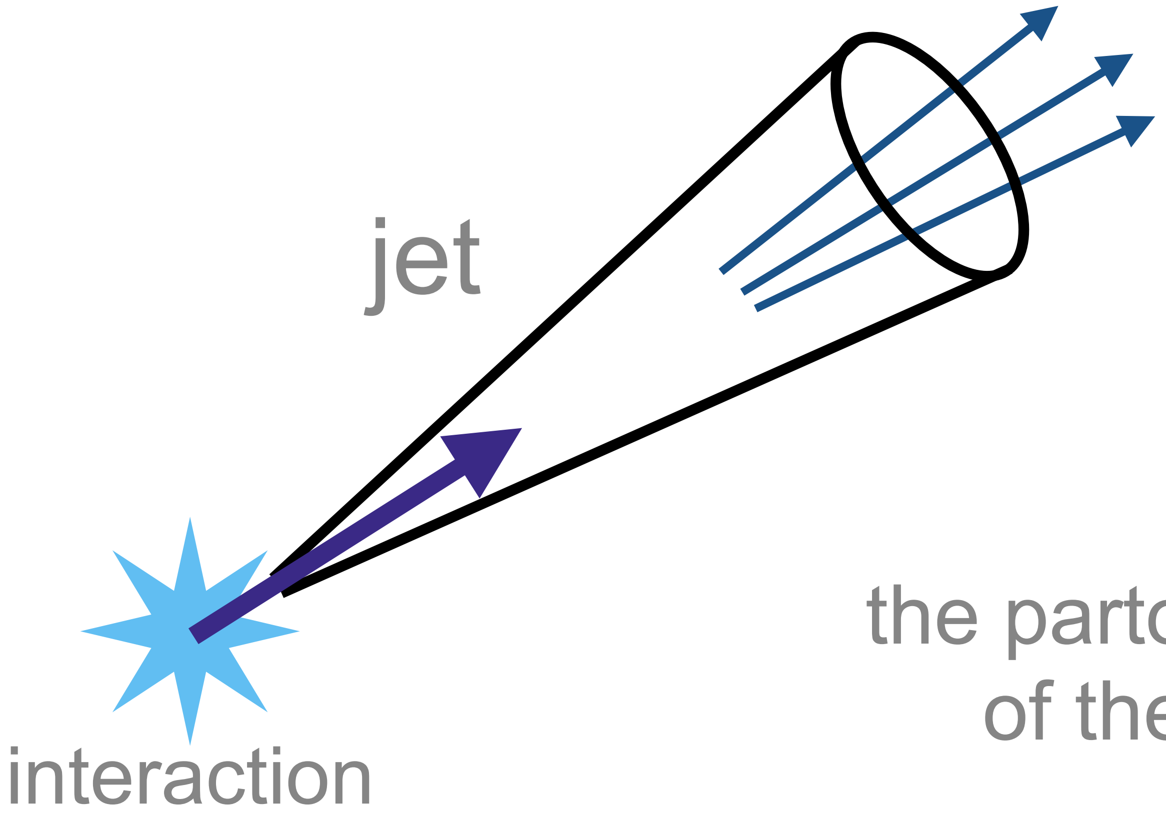
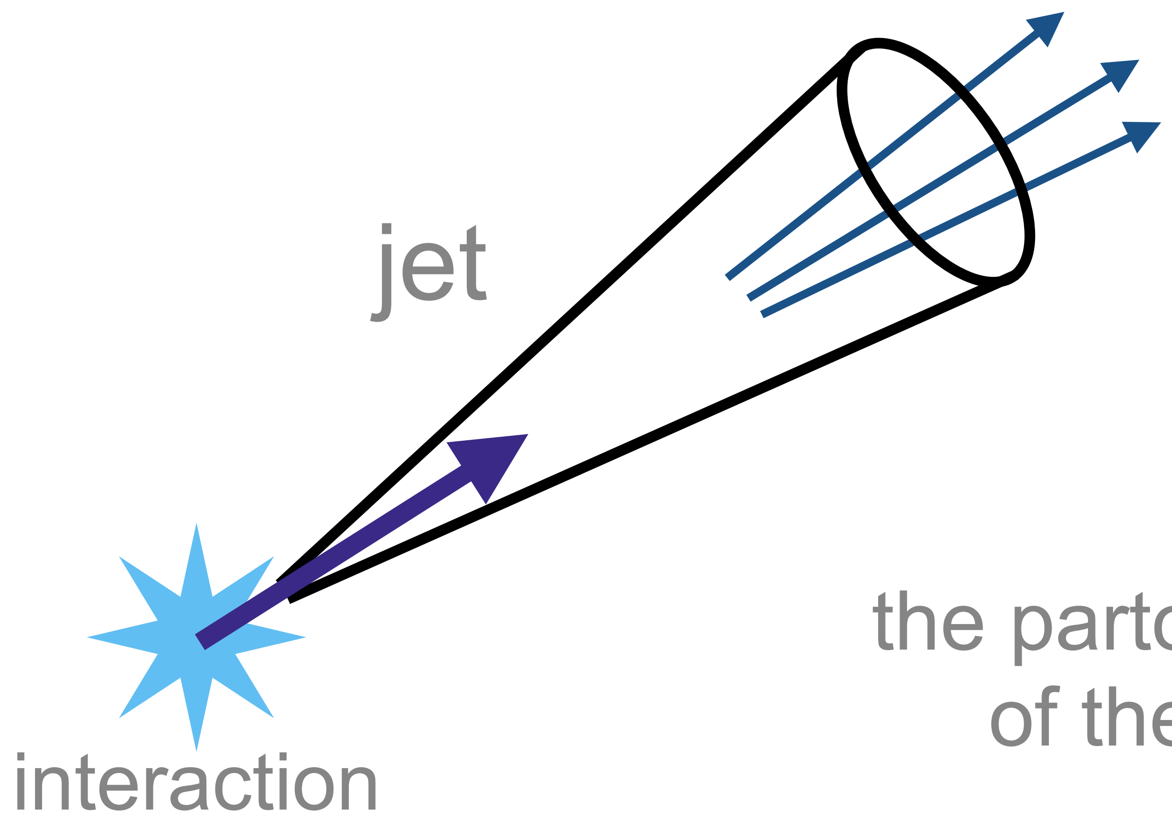


the parton origin of the jet?

g, u, d, s, c, b, t ?

flavor tagging



the parton origin of the jet?

g, u, d, s, c, b, t ?

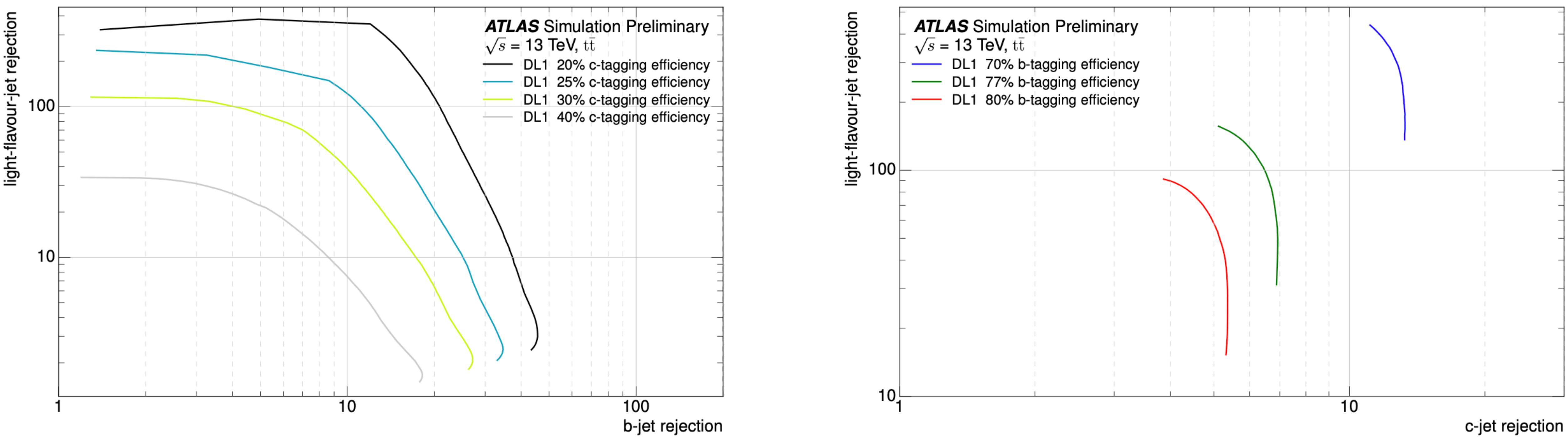
$l = g, u, d$ (light)

s (in many cases considered as light)

c

b

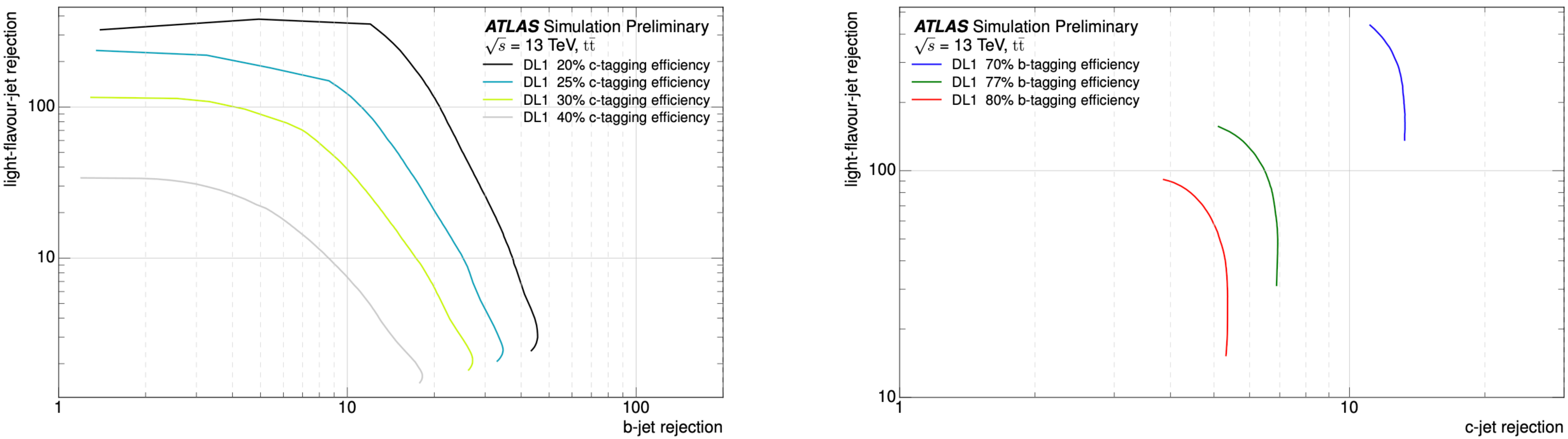
flavor tagging



(a) (b)

ATLAS - ATL-PHYS-PUB-2017-013,1907.05120, 2106.03584
CMS - 1712.07158

flavor tagging



(a) (b)

ATLAS - ATL-PHYS-PUB-2017-013,1907.05120, 2106.03584
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tags combinations of flavors $(b/c/l)$
measure linear combinations of tagged jet

for neural network parameterization see Di Bello et al 2004.02665

importance of flavor tagging

where do we expect to gain?

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$\Delta F \neq 0$: strong bound from precision flavor

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$\Delta F = 0$ + high energy processes

SM: tests of flavor universality (e.g. Z -pole, Higgs)

BSM: models with flavor diagonal effects and suppressed flavor violation (e.g. alignment models, MFV)

tests of SM

Z-Pole observables

gauge universality?

Z-Pole observables

gauge universality?

LEP: b/c - tagging

SLD: $+s$ - tagging

Observable	Experimental value	Ref.	SM prediction	Definition
R_b	0.21629 ± 0.00066	[47]	0.21578	$\frac{\Gamma(Z\to b\bar{b})}{\sum_q \Gamma(Z\to q\bar{q})}$
R_c	0.1721 ± 0.0030	[47]	0.17226	$\frac{\Gamma(Z\to c\bar{c})}{\sum_q \Gamma(Z\to q\bar{q})}$
$A_b^{\rm FB}$	0.0992 ± 0.0016	[47]	0.1032	$\frac{3}{4}A_e A_b$
$A_c^{\rm FB}$	0.0707 ± 0.0035	[47]	0.0738	$\frac{3}{4}A_e A_c$
A_b	0.923 ± 0.020	[47]	0.935	$\frac{\Gamma(Z\to b_L\bar{b}_L)-\Gamma(Z\to b_R\bar{b}_R)}{\Gamma(Z\to b\bar{b})}$
A_c	0.670 ± 0.027	[47]	0.668	$\frac{\Gamma(Z\to c_L\bar{c}_L)-\Gamma(Z\to c_R\bar{c}_R)}{\Gamma(Z\to c\bar{c})}$
A_s	0.895 ± 0.091	[48]	0.935	$\frac{\Gamma(Z\to s_L\bar{s}_L)-\Gamma(Z\to s_R\bar{s}_R)}{\Gamma(Z\to s\bar{s})}$
R_{uc}	0.166 ± 0.009	[45]	0.1724	$\frac{\Gamma(Z\to u\bar{u})+\Gamma(Z\to c\bar{c})}{2\sum_q \Gamma(Z\to q\bar{q})}$

Efrati, Falkowski, YS - 1503.0787

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flavorful probes of Z couplings and dim-6 operators

Efrati, Falkowski, YS - 1503.0787

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flavorful probes of Z couplings and dim-6 operators

$$[\delta g_L^{Zu}]_{ii} = \begin{pmatrix} -0.8 \pm 3.1 \\ -0.16 \pm 0.36 \\ -0.28 \pm 3.8 \end{pmatrix} \times 10^{-2}, \quad [\delta g_R^{Zu}]_{ii} = \begin{pmatrix} 1.3 \pm 5.1 \\ -0.38 \pm 0.51 \\ \times \end{pmatrix} \times 10^{-2},$$

$$[\delta g_L^{Zd}]_{ii} = \begin{pmatrix} -1.0 \pm 4.4 \\ 0.9 \pm 2.8 \\ 0.33 \pm 0.16 \end{pmatrix} \times 10^{-2}, \quad [\delta g_R^{Zd}]_{ii} = \begin{pmatrix} 2.9 \pm 16 \\ 3.5 \pm 5.0 \\ 2.30 \pm 0.82 \end{pmatrix} \times 10^{-2}.$$

$$\mathscr{L}_{\rm EFT} = \sum_i \frac{c_i}{\Lambda^2} \mathscr{O}_6$$

typically $c_i \sim \delta g_i$: $\Lambda_i \gtrsim 2.4 \sqrt{\frac{10^{-2}}{g_i}} \mathrm{TeV}$

Efrati, Falkowski, YS - 1503.0787

top Vcb

the CKM elements are determined via hadron decays

flavor tagging allows to **directly** determine V_{cb} at the weak scale

Harrison, Vladimirov - 1810.09424

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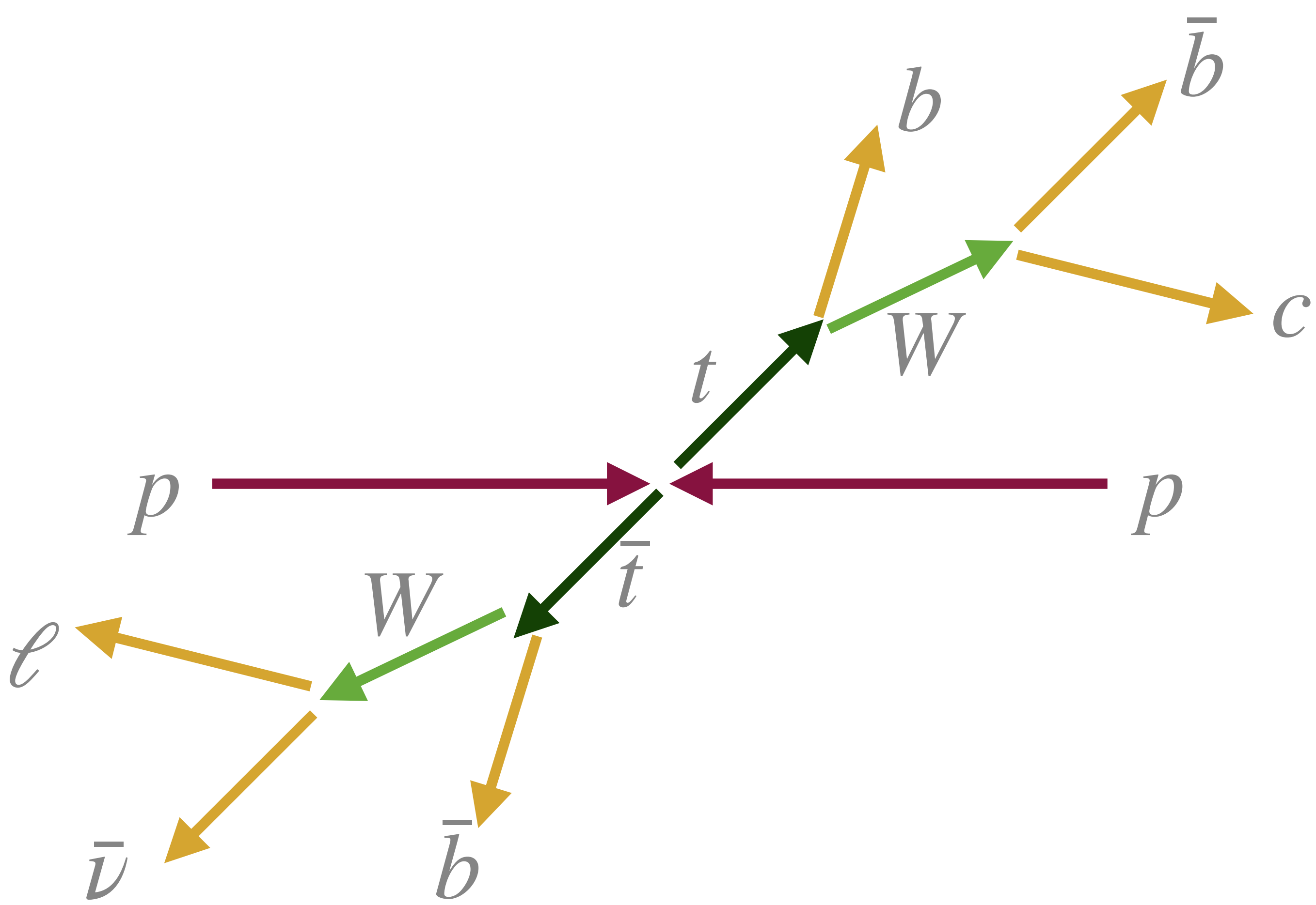

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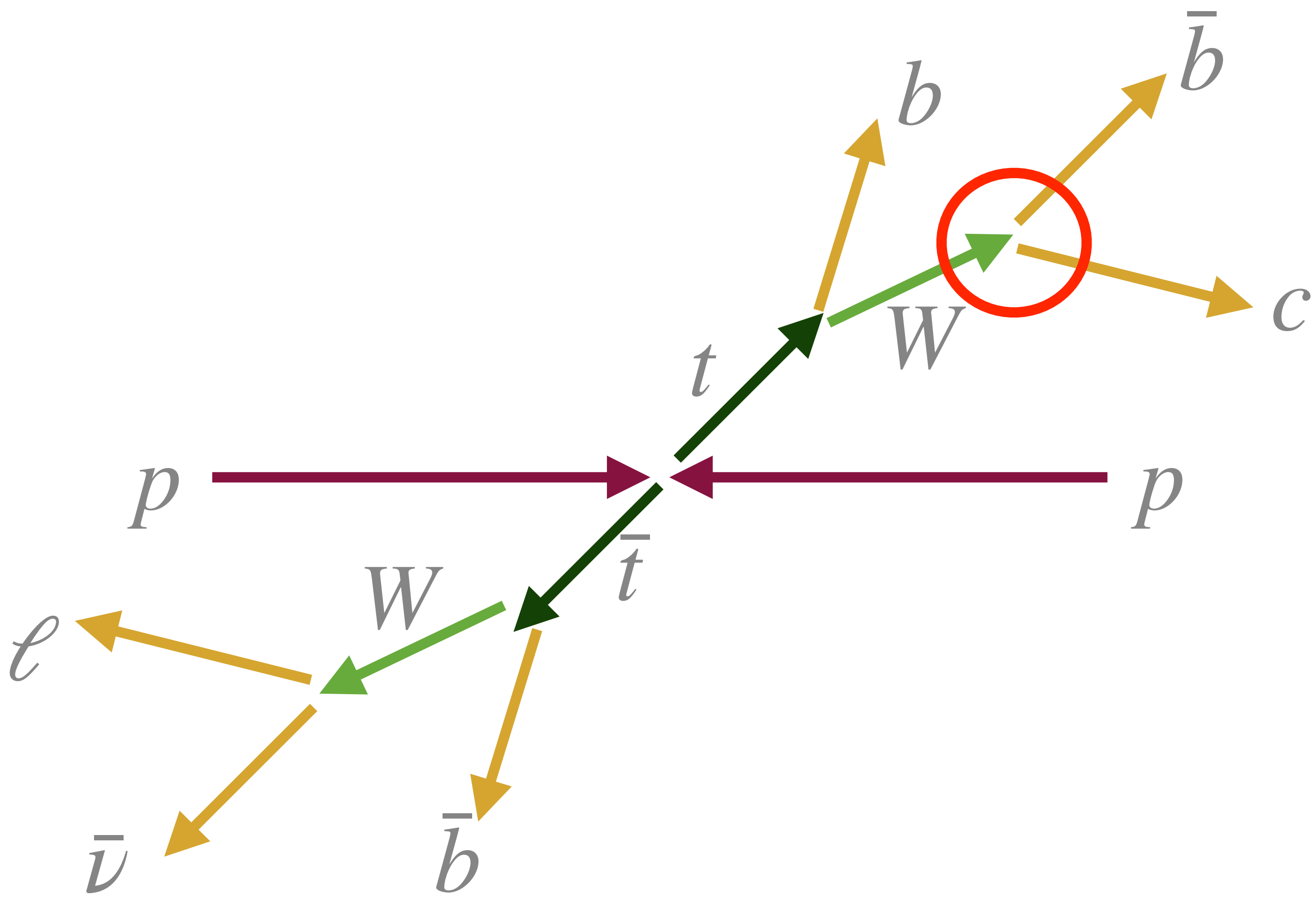

140/fb: $\delta V_{cb}/V_{cb} \sim 7\,\%$

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from flavor physics $\sim 2\,\%$

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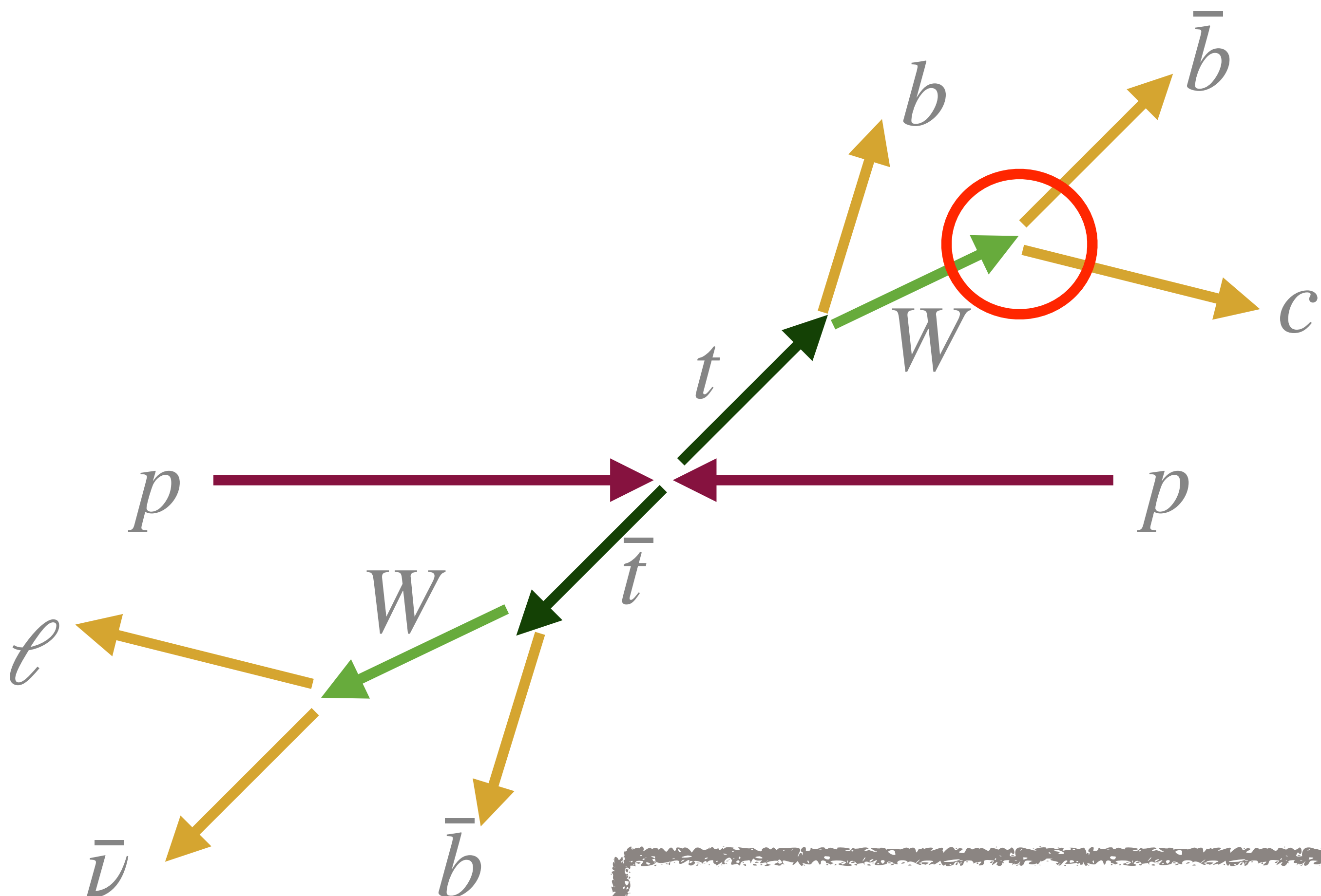

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also important in $t \to ch, cZ$

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the source of the charged fermions mass?

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LHC (ATLAS/CMS/LHCb): b/c - tagging

future e^+e^-: $+s$ - tagging

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$$pp \to Vh,\, h \to \bar{c}c, \bar{b}b$$

$$V = W, Z$$

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effective Lagrangian

$$y_f \tilde{H} \bar{f}_L f_R + \frac{c_f}{\Lambda^2} \tilde{H} \bar{f}_L f_R (H^\dagger H)$$

$$\Lambda_f \equiv \frac{\Lambda}{\sqrt{c_f}} = 4\,\mathrm{TeV} \sqrt{\frac{y_c^{\mathrm{SM}}/y_f^{\mathrm{SM}}}{\left|\kappa_f - 1\right|}}$$

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ATLAS, CMS

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ATLAS, CMS

$$\mu_{b\bar{b}} = 1.1 \pm 0.3$$

$$\mu_{c\bar{c}} < 26\,,\ (y_c/y_c^{\rm SM} < 8.5)$$

recent ATLAS

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⇒ $\Lambda_b \gtrsim 3.6\,\text{TeV}$

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ATLAS, CMS
Delaunay et al 1310.7029,
Perez et al 1505.06689, 1503.00290
Brivio et al 1507.02916

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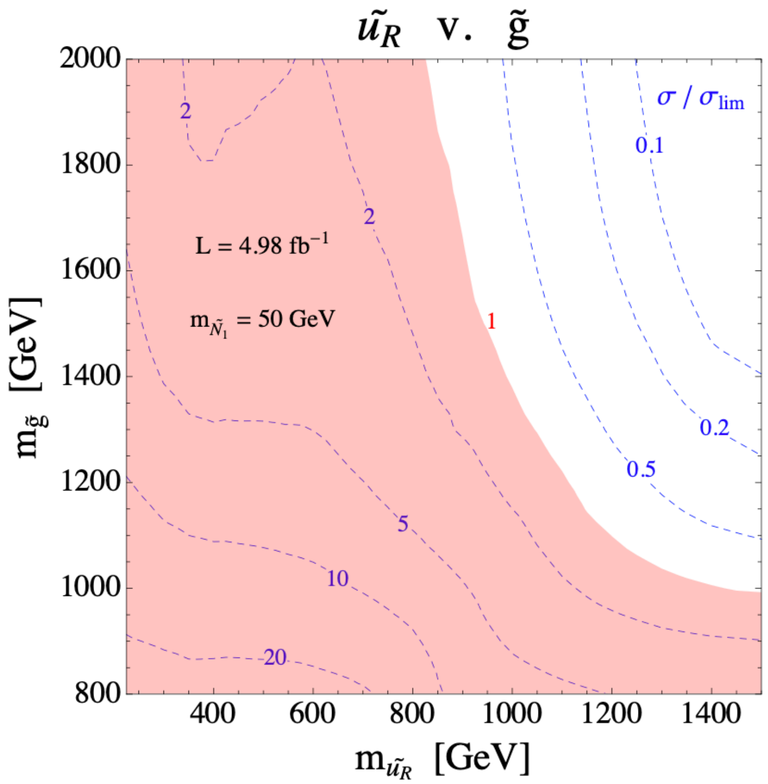
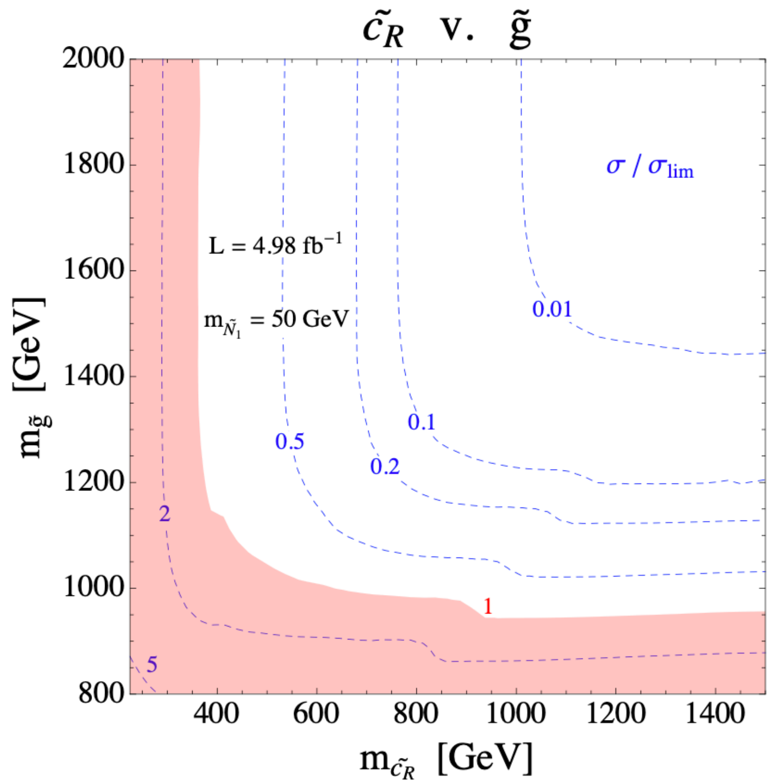
s-tagging possible at e^+e^-collider
projected $\mu_{ss} < 14\,(7)$ with $5\,(20)\,\mathrm{ab}^{-1}$

Duarte-Campderros et at 1811.09636

BSM

flavorful SUSY/composite search





Mahbubani, Papucci, Perez, Ruderman, Weiler 1212.3328
Blanke, Giudice, Paradis, Perez, Zupan - 1302.7232
Da Rold, Delaunay, Grojean, Perez - 1208.1499
Delaunay, Flacke, Gonzalez-Fraile, Lee, Panico - 1311.2072
Galon, Perez, Shadmi - 1306.6631

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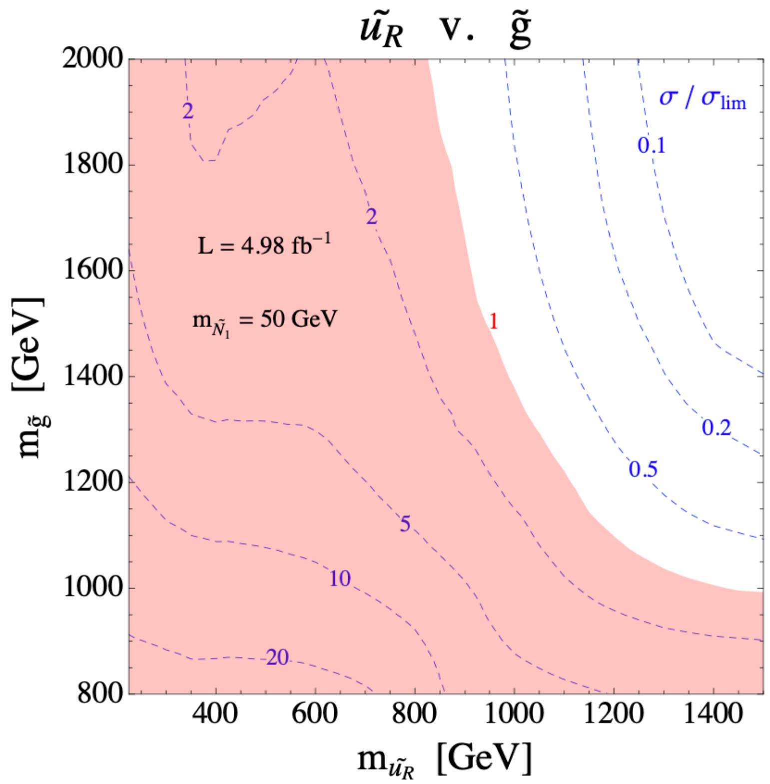

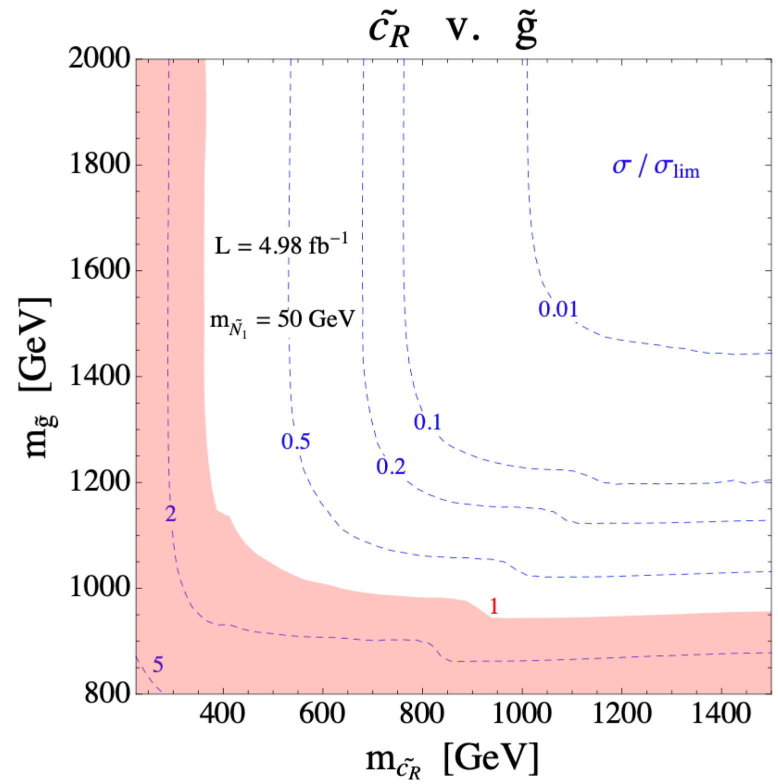

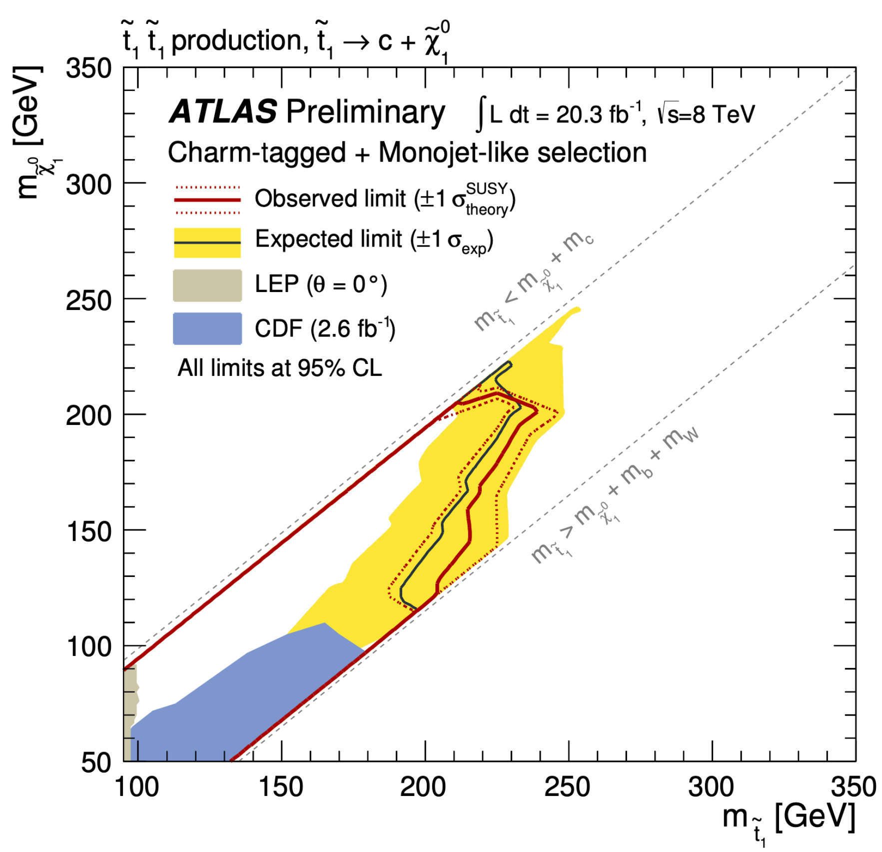

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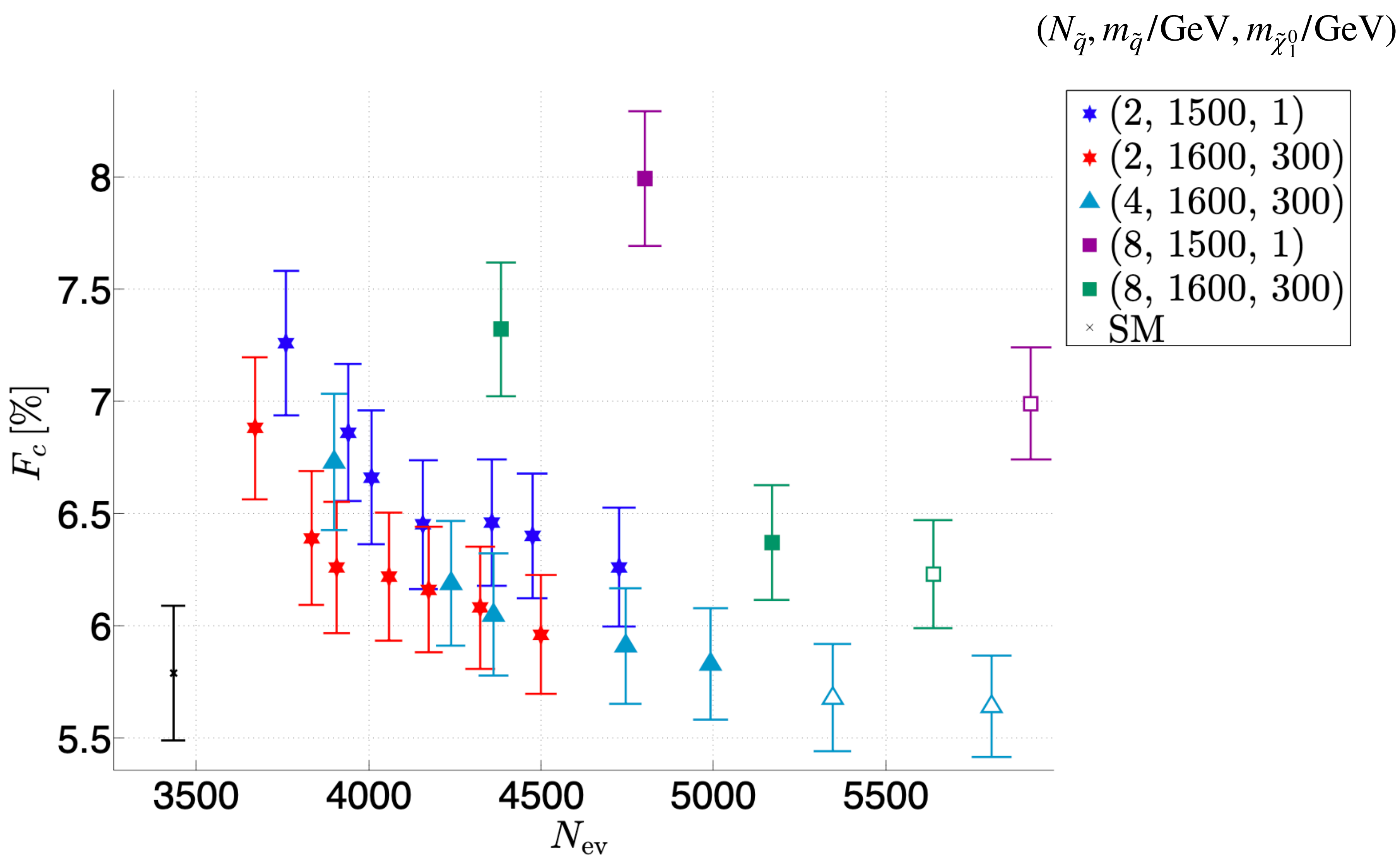
ATLAS-CONF-2013-068

flavorful SUSY search

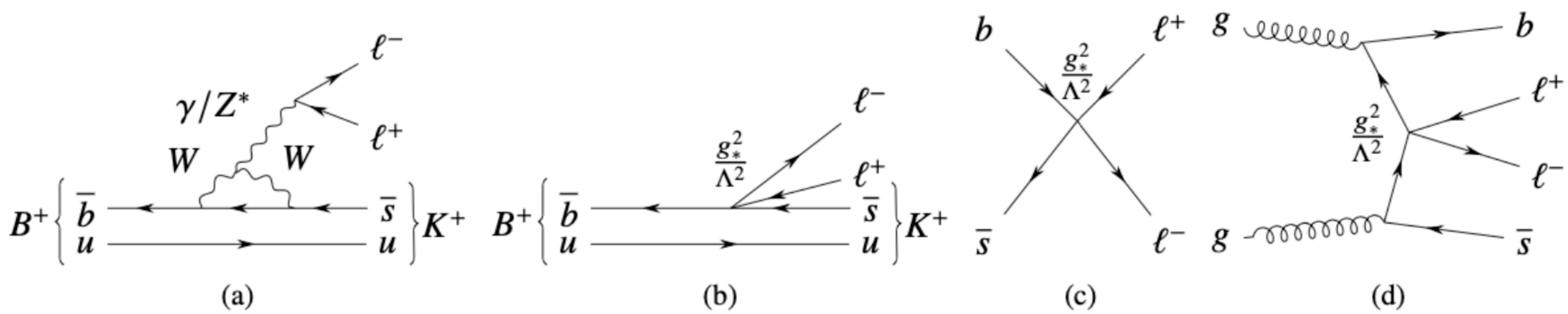
charm fraction: $F_c = \dfrac{\#(c\text{-tagged jet in the sample})}{\#(\text{total number of events in signal region})}$

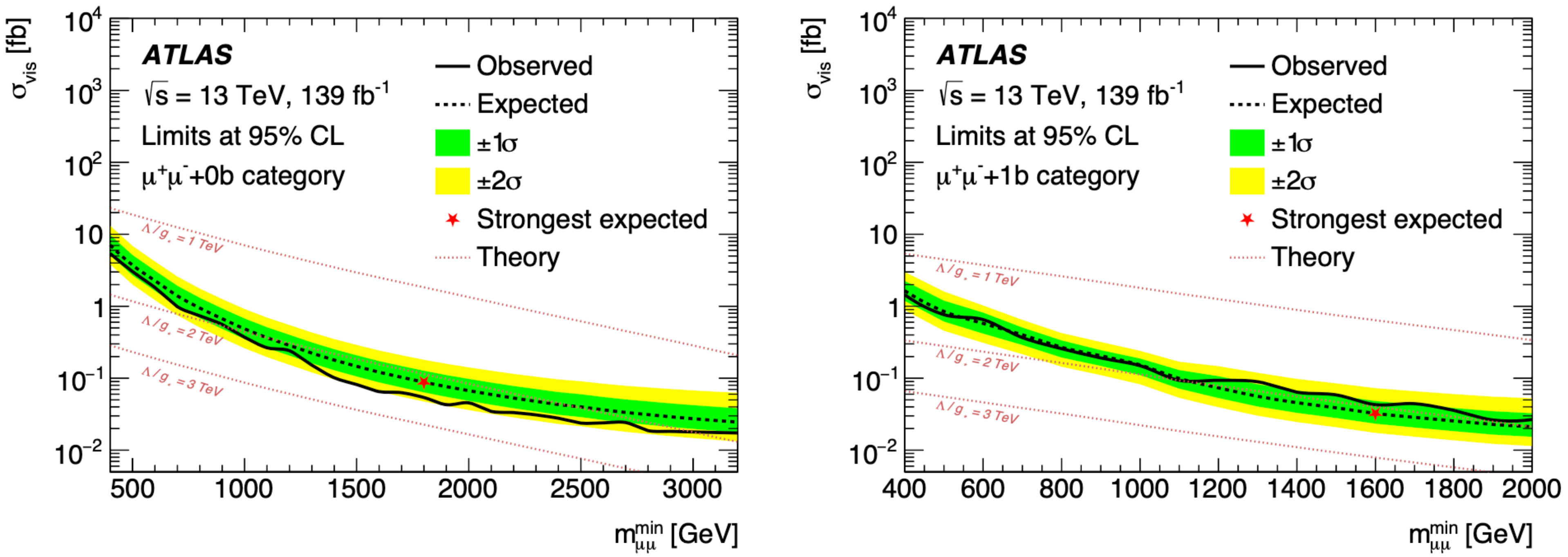


working point: $\epsilon_c = 0.5,\ \epsilon_b = 0.2,\ \epsilon_l = 0.005$

Iwamoto, Lee, Shadmi, Weiss - 1703.05748

EFT: b-tag ATLAS analysis





ATALS b-tag bound: $\Lambda \gtrsim 2\,\mathrm{TeV}$

B rare decays: $\Lambda \gtrsim 35\,\mathrm{TeV}$

ATLAS - 2105.13847

summary

* flavor tagging is very powerful tool, both for SM tests and for BSM searches
* expect to gain the flavor conserving observables, related to high energy process (Z, Higgs)
* useful in $t \to ch, cZ$, mostly distinguish between light and charm flavor
* the SM test (Z-pole, Higgs) tightly related to BSM searches and bound multi TeV scale new physics
* flavor tagging is also useful in other BSM search (e.g. SUSY)

Backups

EFT: charm operators

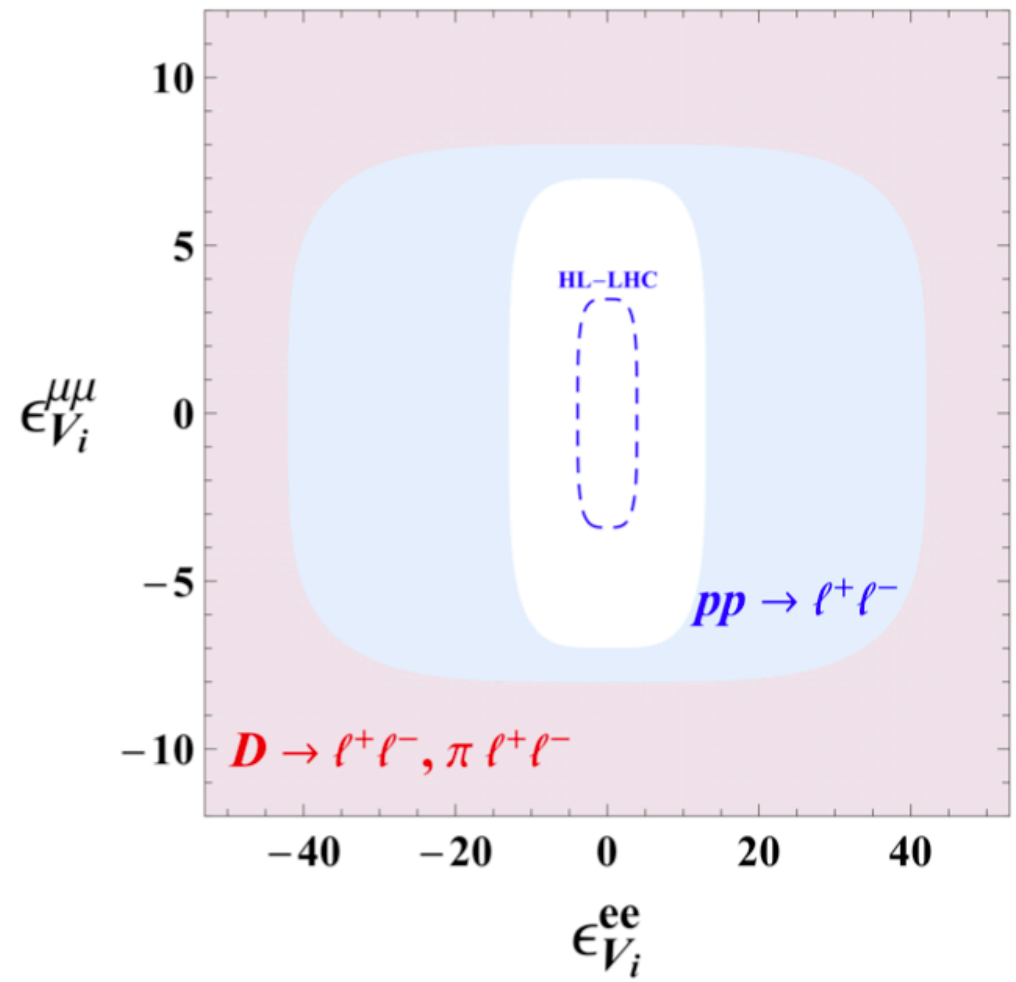


Figure 4. Exclusion limits at 95% CL on $c \to u\ell^+\ell^-$ transitions in the $(\epsilon_{V_i}^{ee}, \epsilon_{V_i}^{\mu\mu})$ plane, where $i = LL, RR, LR, RL$. The region outside the red contour is excluded by D meson decays, while the region outside the blue contour is excluded by high-p_T LHC.

Fuentes-Martin, Greljo, Martin Camalich, Ruiz-Alvarez - 2003.12421