TECHNICOLOR @ LHC: fundamental partial compositeness in the perturbative limit

ROBERTA CALABRESE

IN COLLABORATION WITH:

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OUTLINE

- Introduction on fundamental partial compositeness
- Production and signatures at LHC
  - Comparison with SuperSymmetry
  - Collider constraints on our model
- Anomalies
- W mass anomaly
- Conclusions

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F. Sannino et al, JHEP 2016
A. Arbey et al, PRD 2017
G. Cacciapaglia et al, PRD 2018
G. Cacciapaglia et al, Phys. Rept. 2020

INTRODUCTION

Composite Dynamics → **TechniColor**

Fundamental partial compositeness: Extensions of the SM featuring a composite Higgs sector made by a new fundamental technistrong theory that besides featuring TechniFermions ($\mathcal{F}$) also features TechniScalars ($\mathcal{S}$).

Standard Model masses

(Standard model fermion) X (TechniColor fermion) X (TechniColor Scalar)

TechniBarions

Fundamental partial compositeness

$$-\mathcal{L}_{NP} = y_Q^{ij}\, Q'^i \mathcal{F}_L (\mathcal{S}_D^j)^* + y_U^{ij}\, (U'^i)^c \mathcal{F}_E^c \mathcal{S}_D^j + y_D^{ij} (D'^i)^c \mathcal{F}_N^c\, \mathcal{S}_D^j +$$
$$y_L^{ij}\, L^i \mathcal{F}_L (\mathcal{S}_E^j)^* + y_E^{ij} (E^i)^c \mathcal{F}_N^c \mathcal{S}_E^j + y_N^{ij} (N^i)^c \mathcal{F}_E^c \mathcal{S}_E^j +$$
$$\sqrt{2}\, k (\mathcal{F}_L \mathcal{F}_N^c + \mathcal{F}_E \mathcal{F}_L^c) \Phi_H + h.c.$$

$G_{TC} = SU(N_{TC})$

We consider the case $Y = 1/2$

		G_{TC}	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
New fermions	$F_L = \begin{pmatrix} F_L^\uparrow \\ F_L^\downarrow \end{pmatrix}$	F	1	2	Y
	F_N^c	$\overline{F}$	1	1	$-Y-1/2$
	F_E^c	$\overline{F}$	1	1	$-Y+1/2$
New scalars	S_E	F	1	1	$Y-1/2$
	S_D	F	3	1	$Y+1/6$

F. Sannino et al, JHEP 2016
G. Cacciapaglia et al, PLB 2022
G. Cacciapaglia et al, PR 2020
F. Sannino, Acta Phys.Polon.B 2009
A. Martin, Subnucl.Ser. 2011
S. Weinberg, PRD 1976
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FUNDAMENTAL PARTIAL COMPOSITENESS

$$
\begin{aligned}
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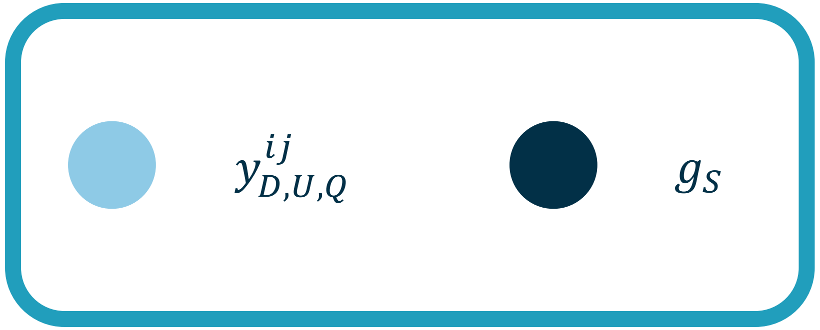
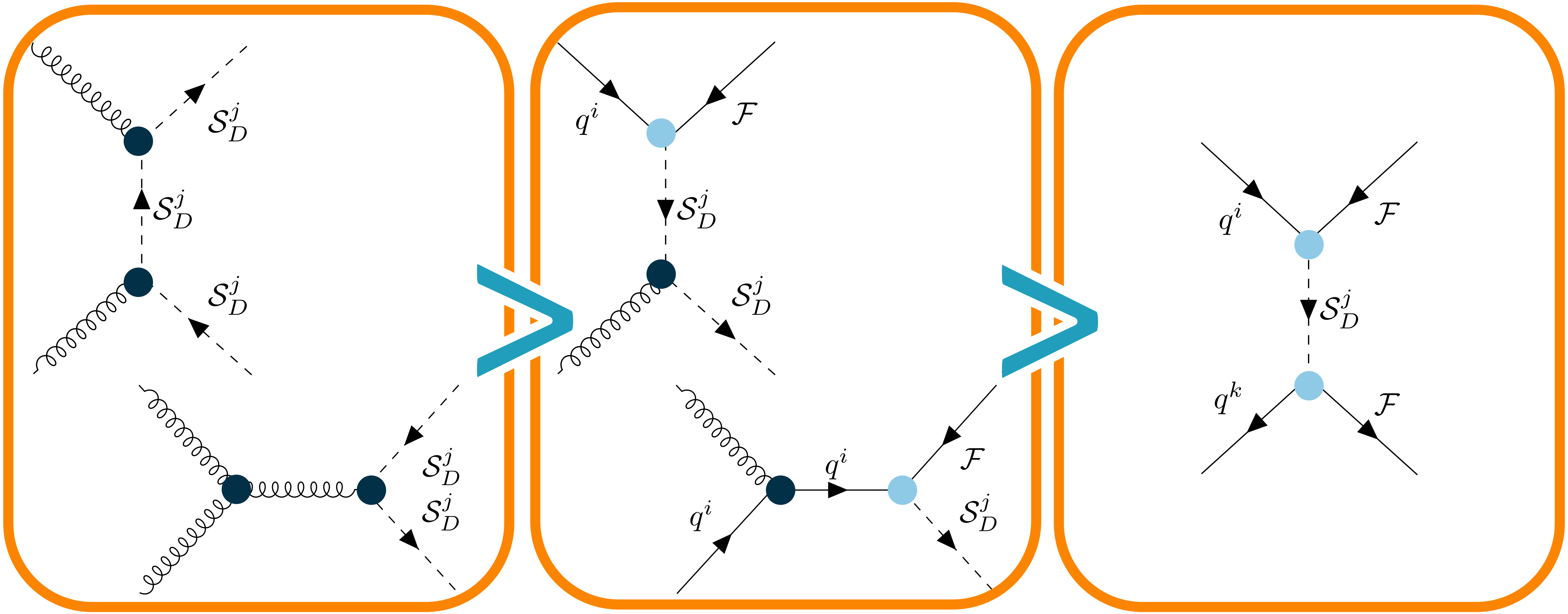
PRODUCTION IN PP COLLISION





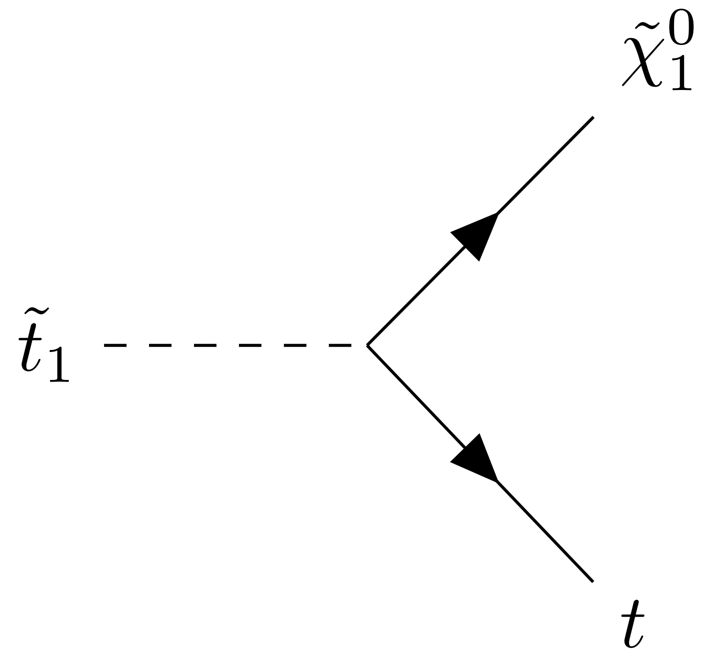
J. Alwall et al, PRD 2009
LHC new physics group, JPG 2012

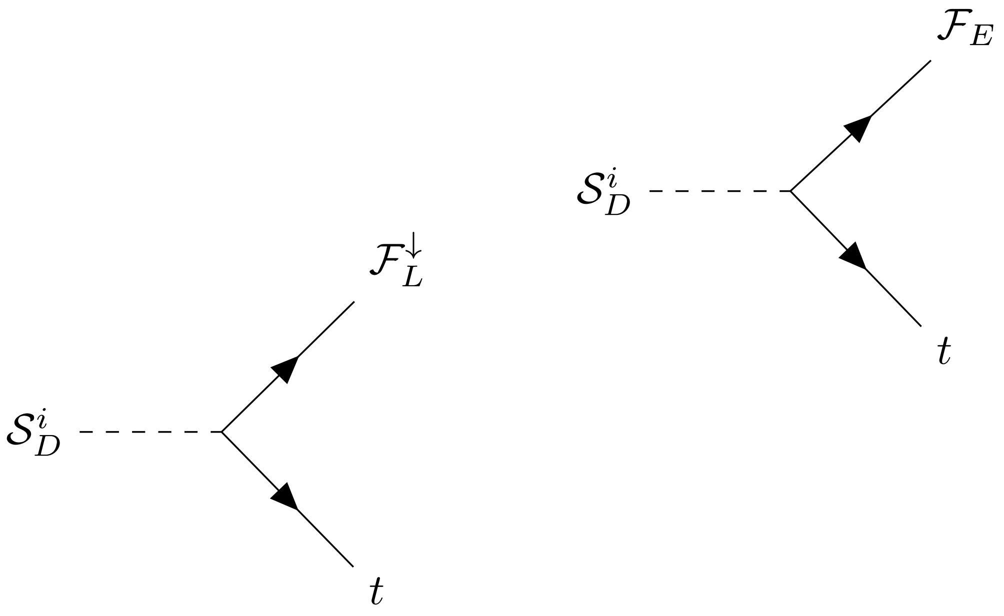
COMPARISON WITH SUSY

It is interesting to notice that the fundamental partial compositeness model and SuperSymmetry can produce similar signatures at LHC.

$\tilde{t}_1$ is produced in the same way as $\mathcal{S}_D$

TOP + MISSING TRANSVERSE ENERGY





COMPARISON WITH SUSY

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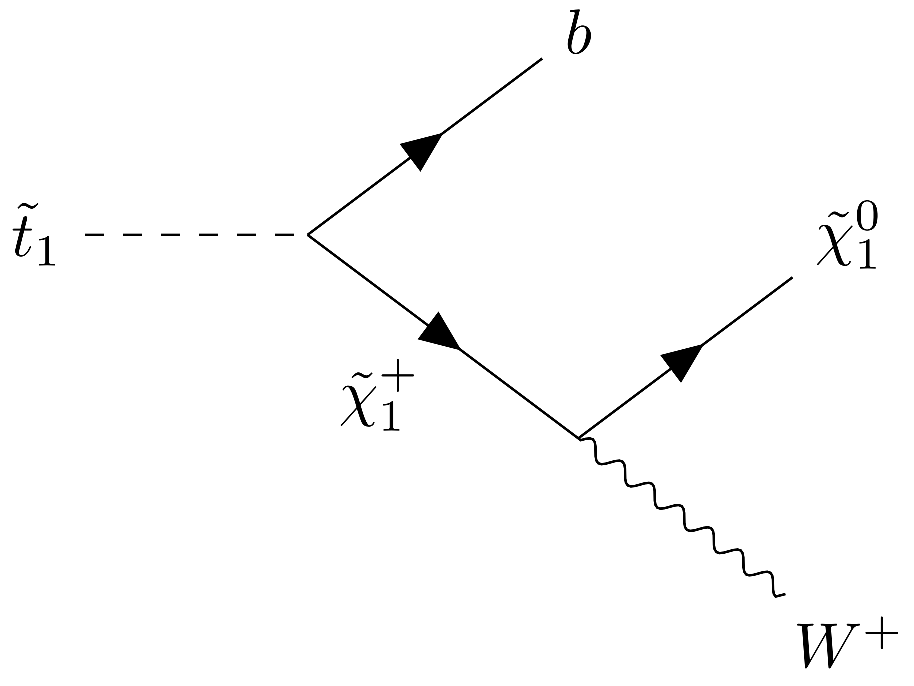
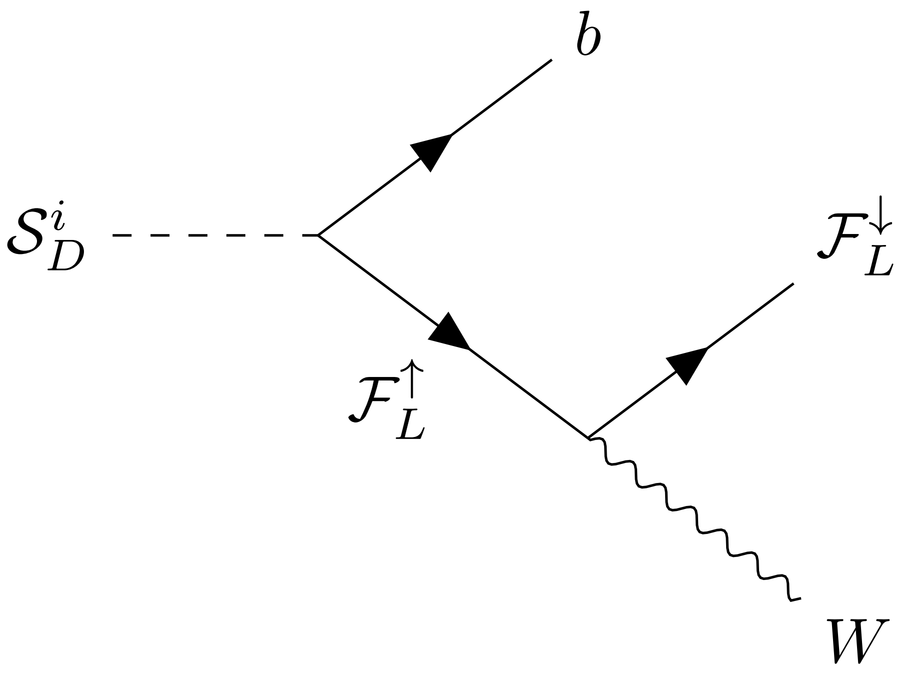
BOTTOM + W + MISSING TRANSVERSE ENERGY



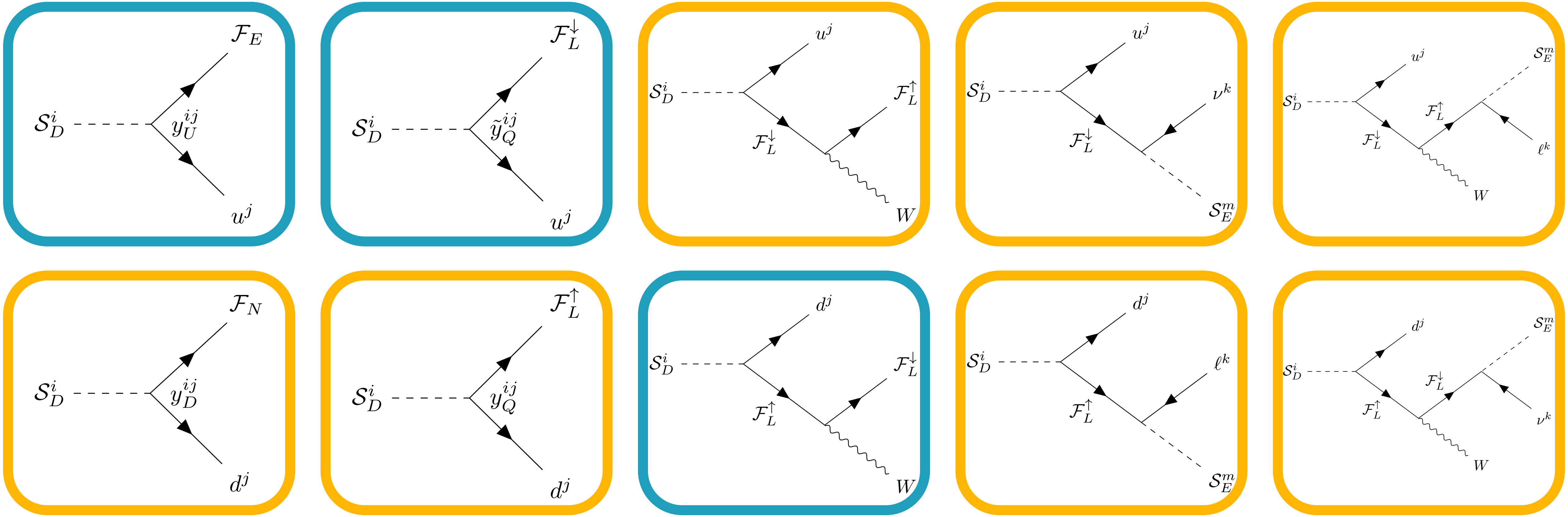


$\mathcal{S}_D$ Decay channels

Additional decay channel

Decay channel in common with susy

The decay width of such processes depends on the masses of $\mathcal{F}, \mathcal{S}_D, \mathcal{S}_E$

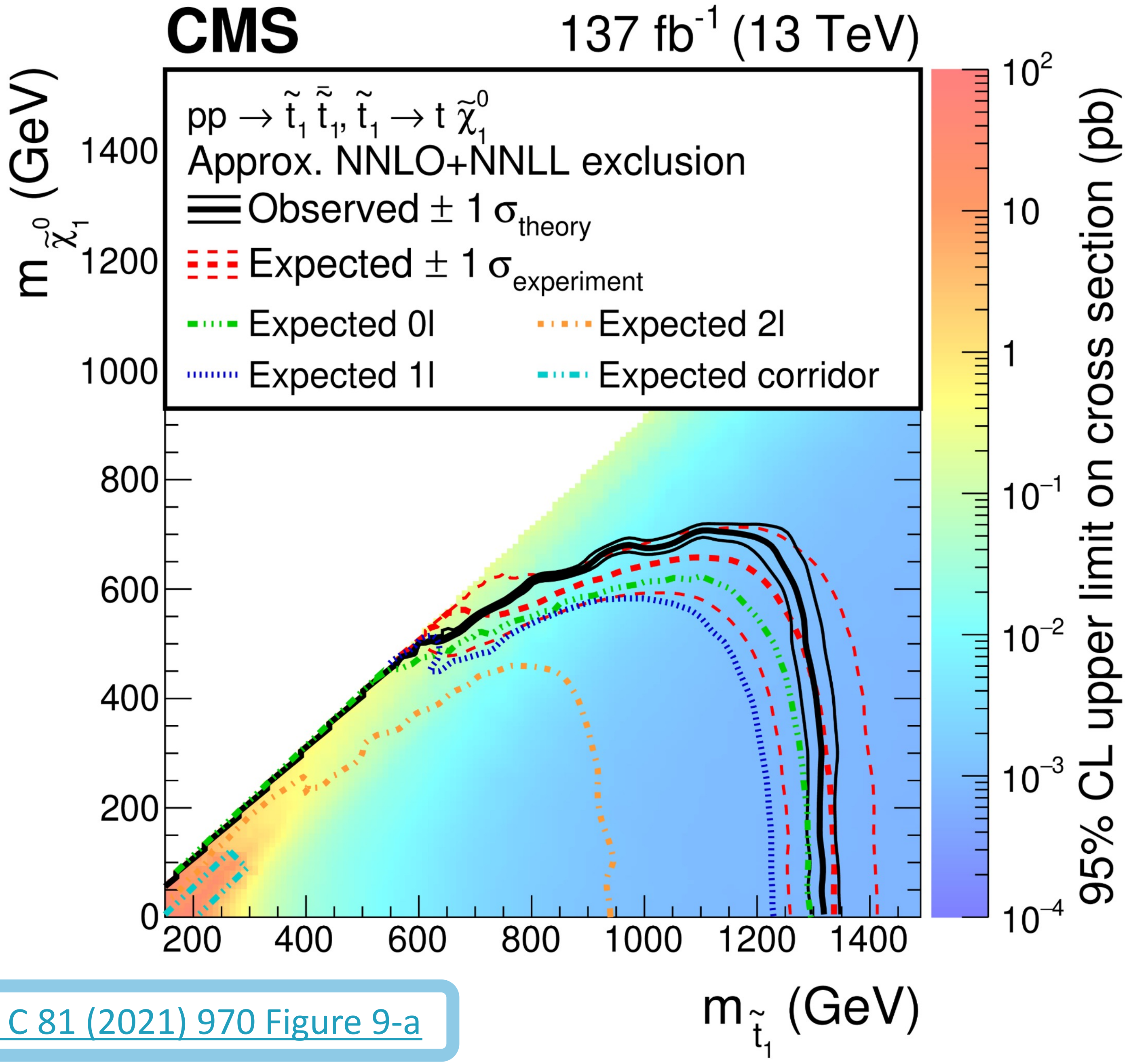


SUPERSYMMETRY @LHC

We focus on t + Missing transverse Energy

We need to take into account of the different branching ratio

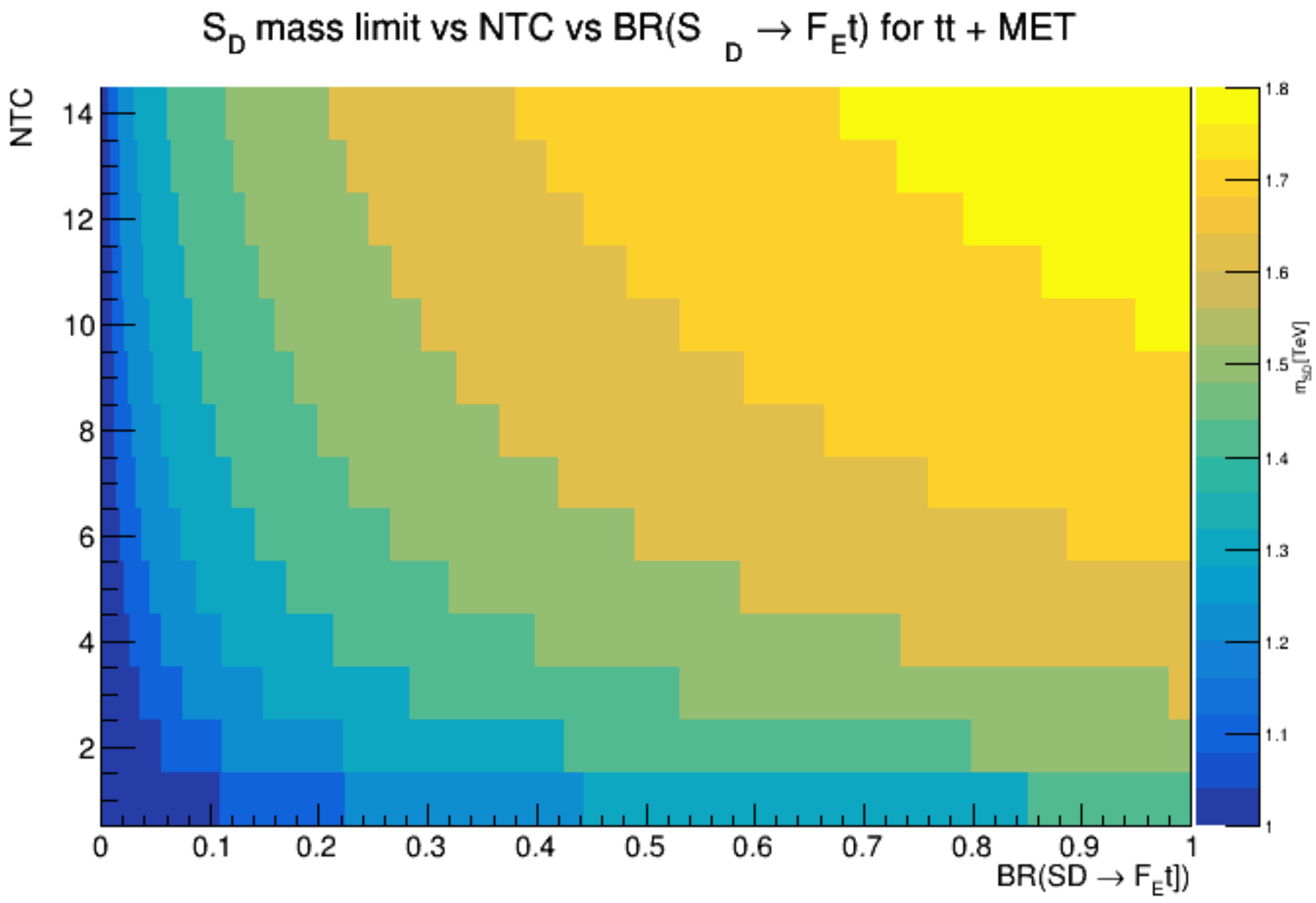
Valid for $m_{\tilde{t}_1} < 1400\ GeV$



J. Alwall et al, PRD 2009
LHC new physics group, JPG 2012

Eur. Phys. J. C 81 (2021) 970 Figure 9-a

FUNDAMENTAL PARTIAL COMPOSITENESS @LHC



The color bar represents the masses excluded considering the analysis shown before and it is valid for $m_{\mathcal{F}_E} \ll m_{\mathcal{S}_D}$.

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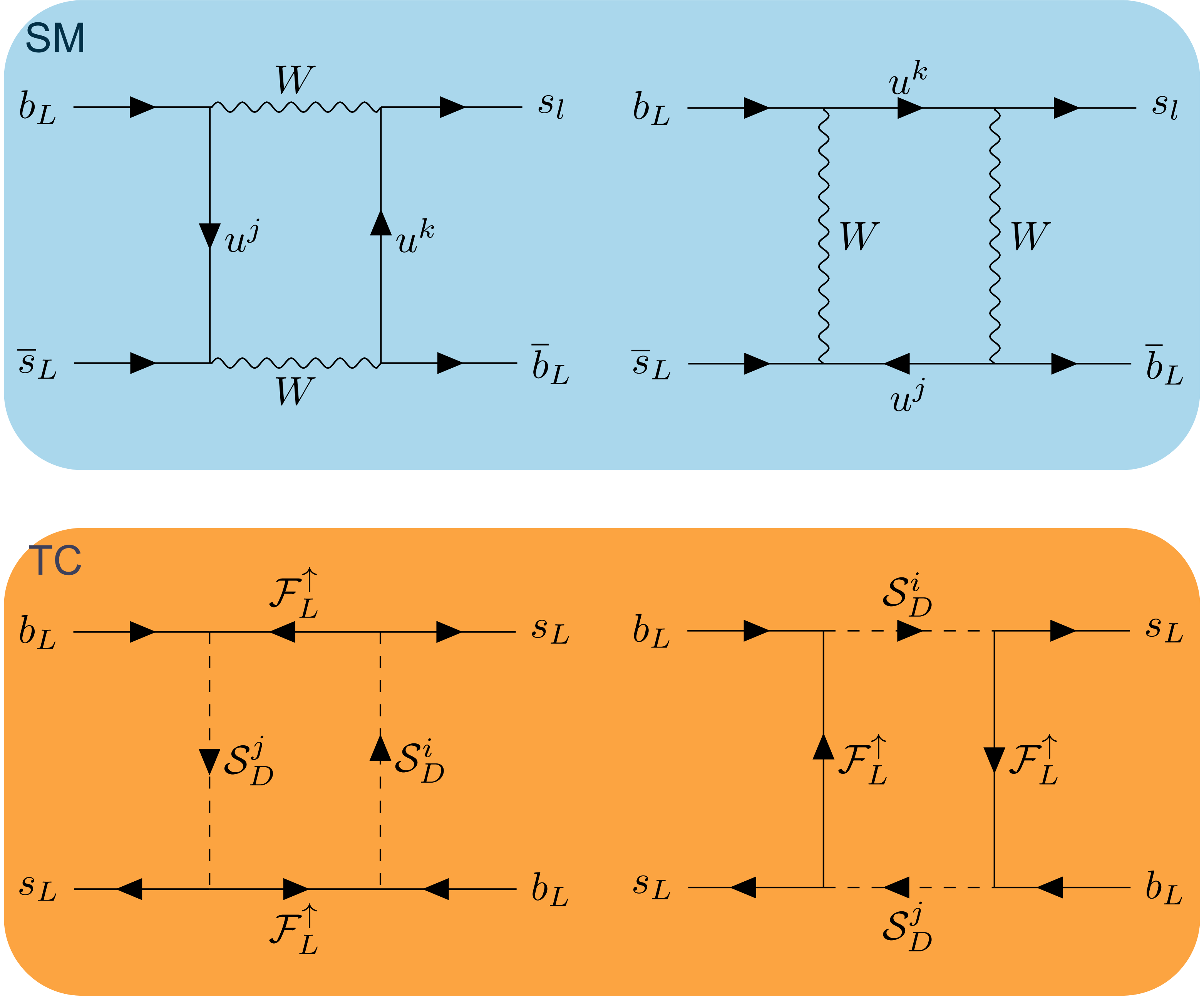
$B - \overline{B}$ Mixing

$$H_{eff} = C_{B\overline{B}}(\overline{s_\alpha}\gamma^\mu P_L b_\alpha)(\overline{s_\beta}\gamma^\mu P_L b_\beta)$$

$$R_{\Delta B_s} = \frac{\Delta M_{B_s}^{\exp}}{\Delta M_{B_S}^{SM}} - 1 = \frac{C_{B\overline{B}}(2m_W)}{C_{B\overline{B}}^{SM}(2m_W)}$$

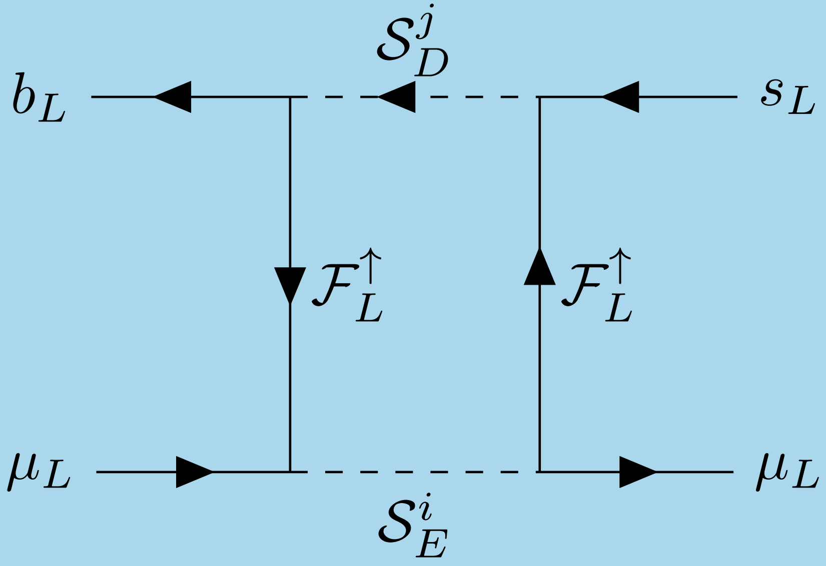
$$C_{B\overline{B}}^{SM}(2m_W) = 8.2 \times 10^{-5} TeV^{-2}$$

$$R_{\Delta B_s} = 0.09 \pm 0.08$$

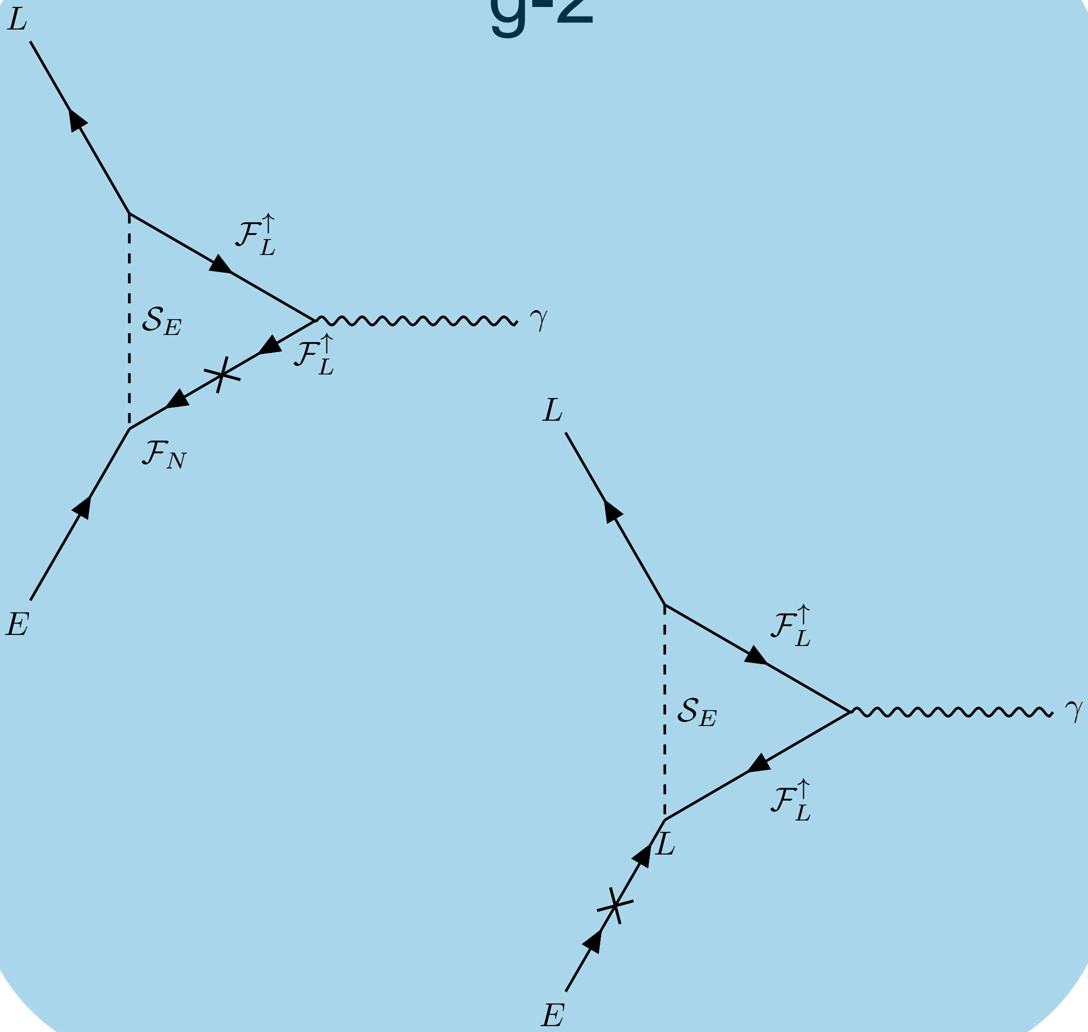


ANOMALIES

R_k Anomaly



g-2



A. D'Alise et al, arXiv: 2204.03686
G. D'Amico et al, JHEP 2017
B. Abi et al, PRL 2021

ANOMALIES

Free parameters: $(y_Q y_Q^\dagger)_{bs}$, $(y_L y_L^\dagger)_{\mu\mu}$, $(y_L y_E^\dagger)_{\mu\mu}$, k, $M_{\mathcal{S}_D}$, $M_{\mathcal{S}_E}$, $M_{\mathcal{F}}$

		PREDICTION	EXPERIMENTAL VALUE
R_K	$c_{b_l\mu_l}$	$N_{TC}\frac{(y_L y_L^\dagger)_{\mu\mu}(y_Q y_Q^\dagger)_{bs}}{(4\pi)^2 M_{\mathcal{F}}^2}\frac{1}{4}F(x,y)$	$\frac{0.09 \pm 0.08}{(110\, TeV)^2}$
$B\overline{B}$	$c_{b_l b_l}$	$N_{TC}\frac{(y_Q y_Q^\dagger)_{bs}^2}{(4\pi)^2 M_{\mathcal{F}}^2}\frac{1}{8}F(x,x)$	$\frac{0.72 \pm 0.14}{(36\, TeV)^2}$
$g-2$	Δa_μ	$N_{TC}\frac{m_\mu (y_L y_E^\dagger)_{\mu\mu} k v_{SM}}{(4\pi)^2 M_{\mathcal{F}}^2}\, 2\, q_{\mathcal{F}} G_{LR}(y) +$ $N_{TC}\frac{m_\mu^2 (y_L y_L^\dagger)_{\mu\mu}}{(4\pi)^2 M_{\mathcal{F}}^2}\, 2\, q_{\mathcal{F}}\, \tilde{F}_7(y)$	$(251 \pm 59)10^{-11}$

$$x = \left(M_{\mathcal{S}_D}/M_{\mathcal{F}}\right)^2 ,\; y = \left(M_{\mathcal{S}_E}/M_{\mathcal{F}}\right)^2$$

A. D'Alise et al, arXiv: 2204.03686
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Free parameters: $\left(y_Q y_Q^\dagger\right)_{bs}, \left(y_L y_L^\dagger\right)_{\mu\mu}, \left(y_L y_E^\dagger\right)_{\mu\mu}, k$ $M_{\mathcal{S}_D}, M_{\mathcal{S}_E}, M_{\mathcal{F}}$

		PREDICTION	EXPERIMENTAL VALUE
R_K	$c_{b_l\mu_l}$	$N_{TC}\dfrac{\left(y_L y_L^\dagger\right)_{\mu\mu}\left(y_Q y_Q^\dagger\right)_{bs}}{(4\pi)^2 M_{\mathcal{F}}^2}\dfrac{1}{4}F(x,y)$	$\dfrac{0.09 \pm 0.08}{(110\,TeV)^2}$
$B\overline{B}$	$c_{b_l b_l}$	$N_{TC}\dfrac{\left(y_Q y_Q^\dagger\right)_{bs}^2}{(4\pi)^2 M_{\mathcal{F}}^2}\dfrac{1}{8}F(x,x)$	$\dfrac{0.72 \pm 0.14}{(36\,TeV)^2}$
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$$x = \left(M_{\mathcal{S}_D}/M_{\mathcal{F}}\right)^2,\ y = \left(M_{\mathcal{S}_E}/M_{\mathcal{F}}\right)^2$$

ANOMALIES: THEORETICAL PARAMETER SPACE ALLOWED

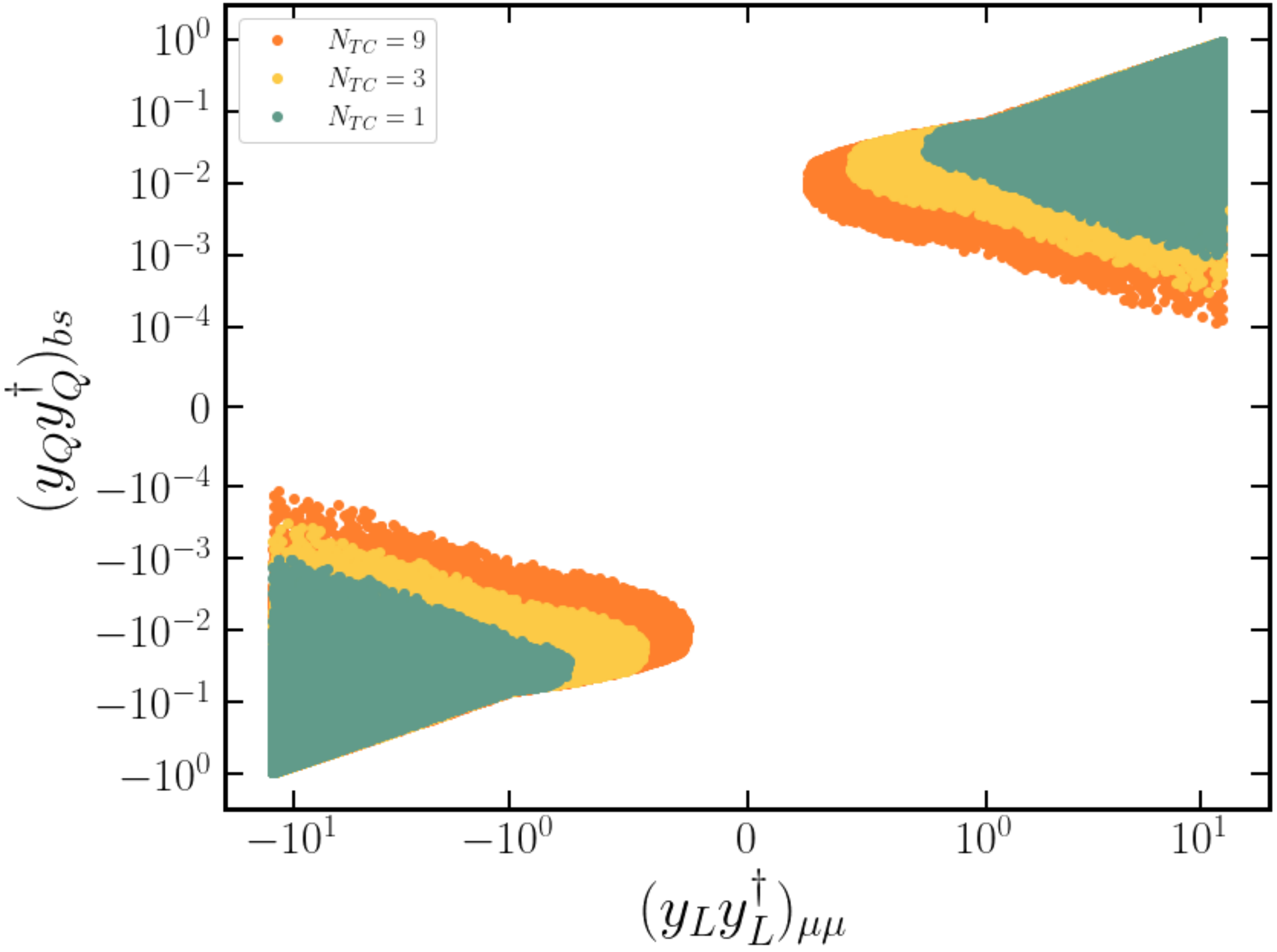
MASS RANGE CONSIDERED:

$m_{\mathcal{F}_L^\uparrow}, m_{\mathcal{S}_D}, m_{\mathcal{S}_E} \in [0.1 - 5]TeV$

ASSUMPTION:

$m_{\mathcal{F}_L}^\uparrow < m_{\mathcal{S}_D}$

Unitarity



ANOMALIES: THEORETICAL PARAMETER SPACE ALLOWED + LHC CONSTRAINTS

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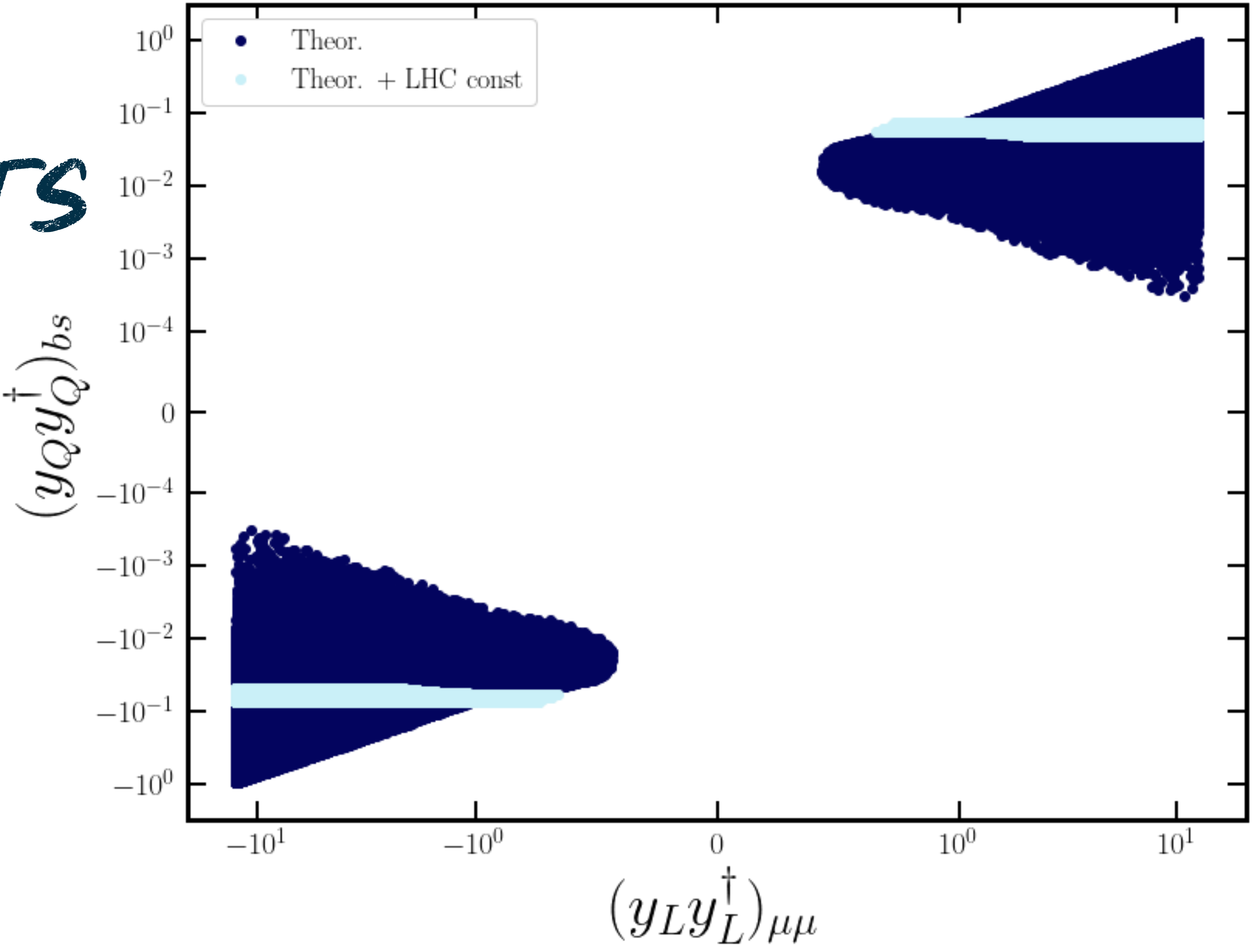
Unitarity

$N_{TC} = 3$



ANOMALIES: THEORETICAL PARAMETER SPACE ALLOWED + LHC CONSTRAINTS

ASSUMPTIONS:

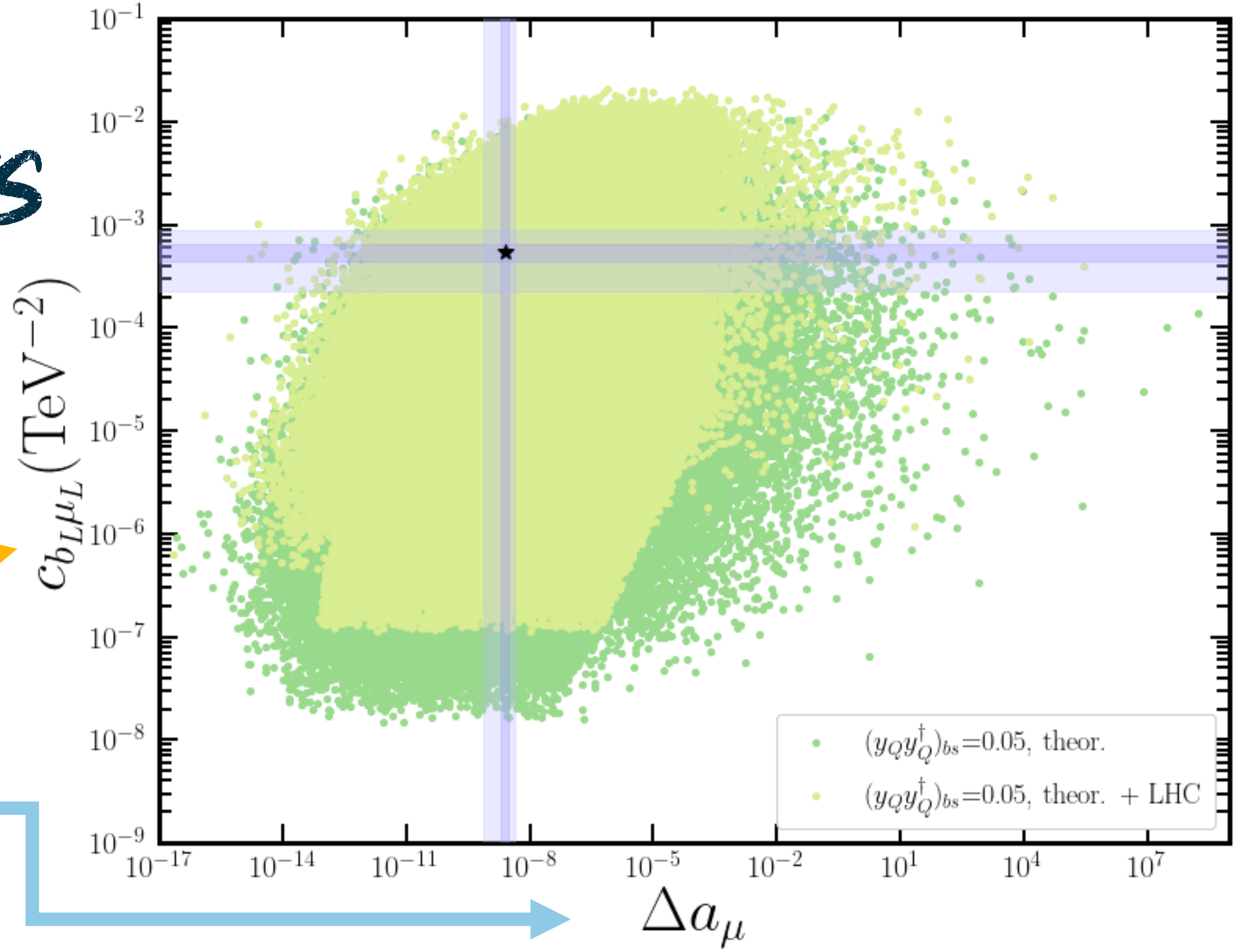
Unitarity

$m_{\mathcal{F}_L}^{\uparrow} < m_{S_D}$

$B - \overline{B}$ mixing

R(K)

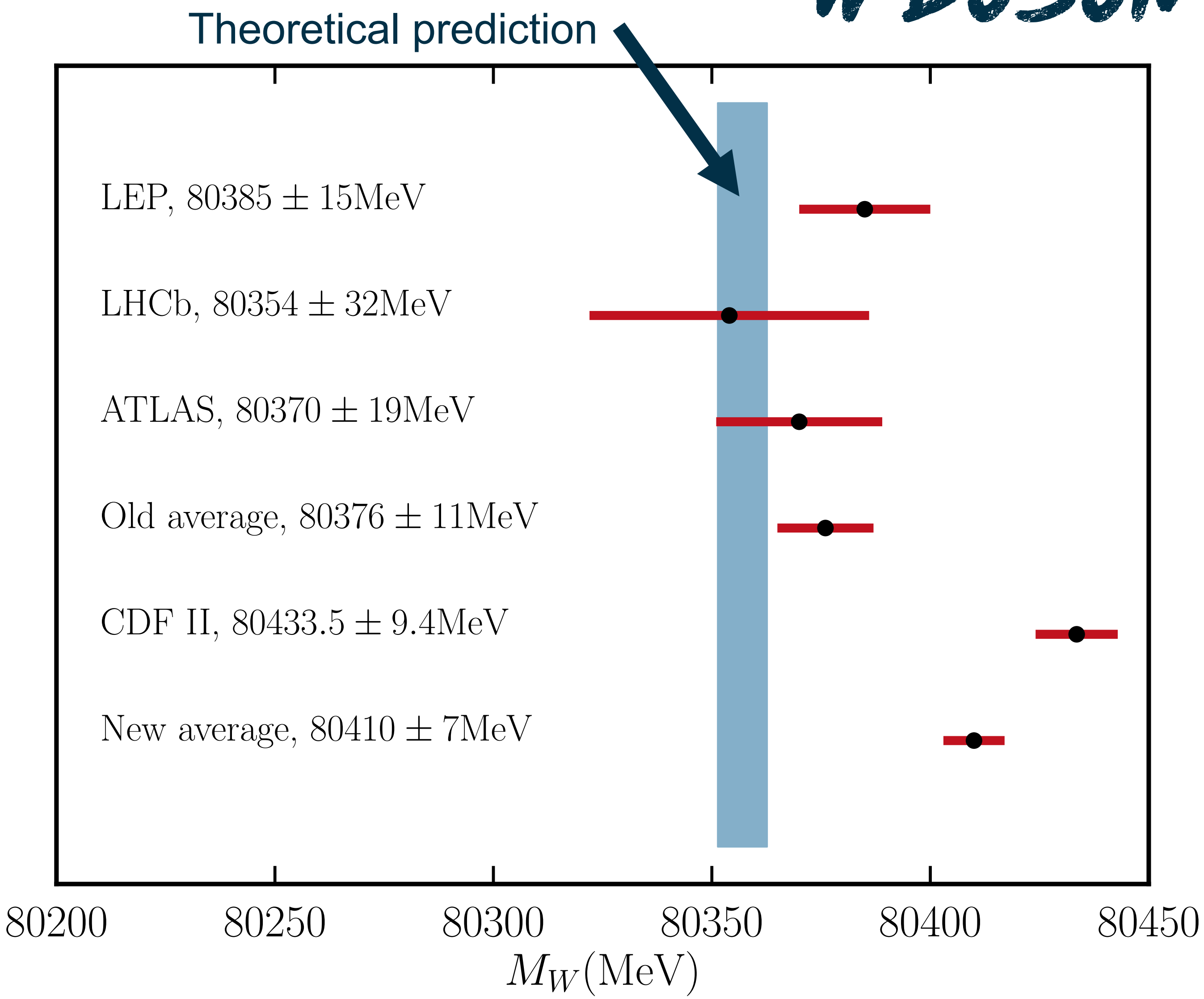
$g - 2$



OUTLINE

- Introduction on fundamental partial compositeness
- Production and signatures at LHC
  - Comparison with SuperSymmetry
  - Collider constraints on our model
- Anomalies
- **W mass anomaly**
- Conclusions

W BOSON MASS



Correction to the W mass due to new physics

$$\Delta M_W \approx 300\ MeV\ (1.43\ T\ - 0.86\ S)$$

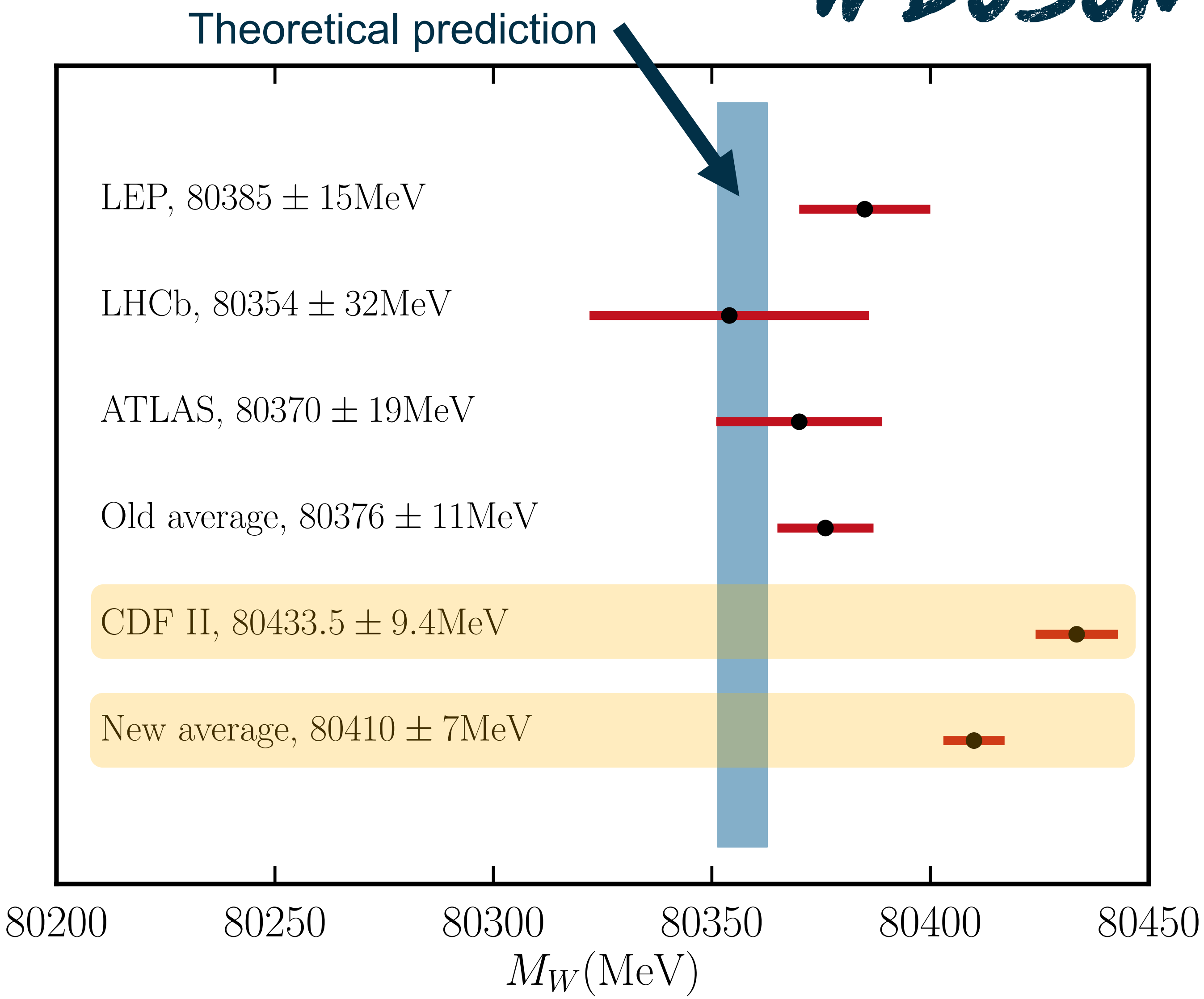
Where T and S are the oblique parameters

$$S = -16\pi \frac{\Pi_{3Y}(M_Z^2) - \Pi_{3Y}(0)}{M_Z^2},$$

$$T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 M_Z^2}.$$

M. E. Peskin and T. Takeuchi, PRD 1992 and PRL 1990
D. C. Kennedy and P. Langacker, PRL 1990
P. A. Zyla et al, PTEP 2020
T. Aaltonen er al, Science 2022
R. Aaij et al, JEHP 2022
M. Aaboud et al, EPJC 2018
Arxiv: 1012.2367
G. Altarelli et al, PLB 1995
H.-J. He et al, PRD 2001

W BOSON MASS



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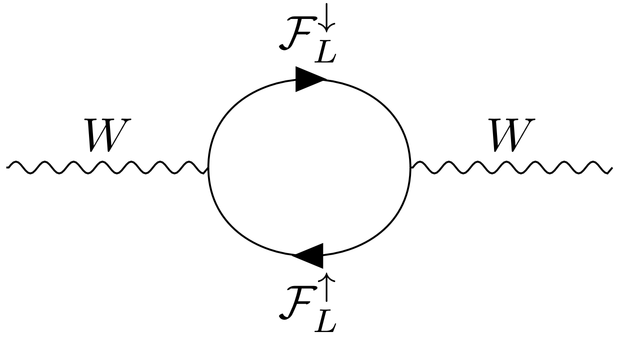
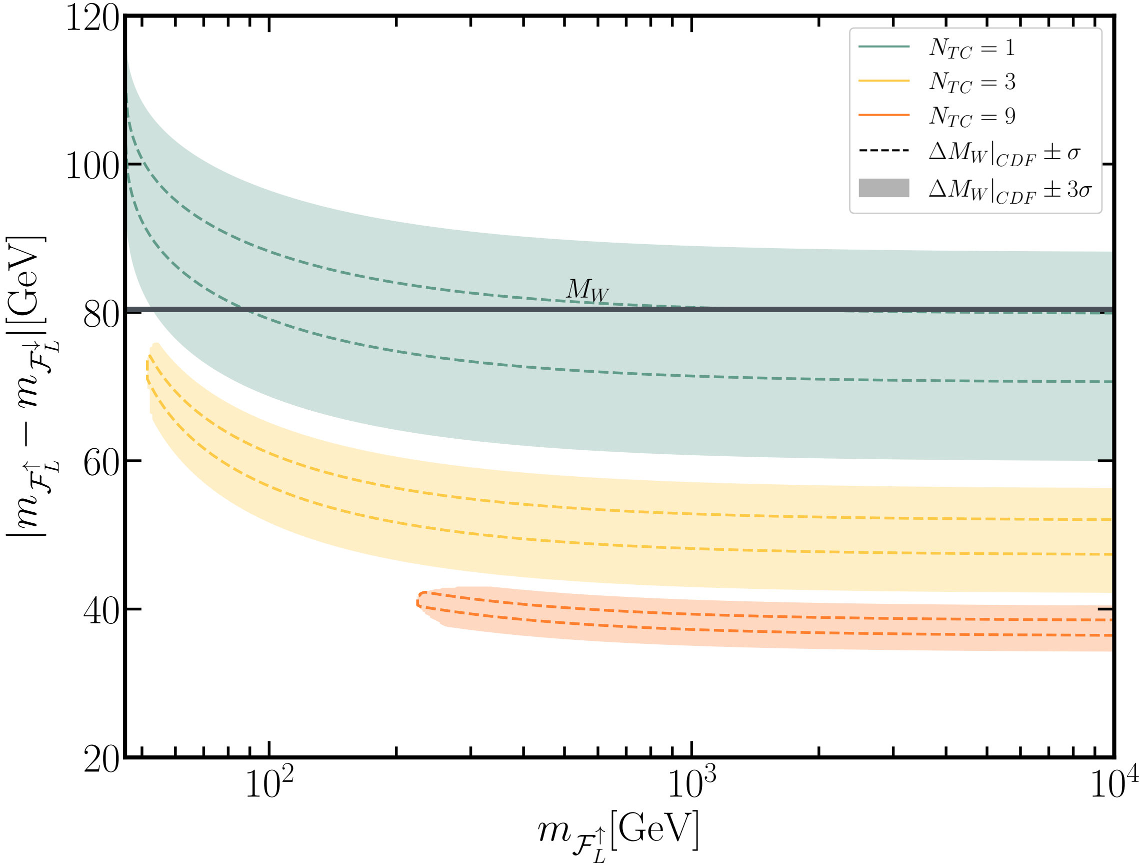
Arxiv: 1012.2367
G. Altarelli et al, PLB 1995
H.-J. He et al, PRD 2001

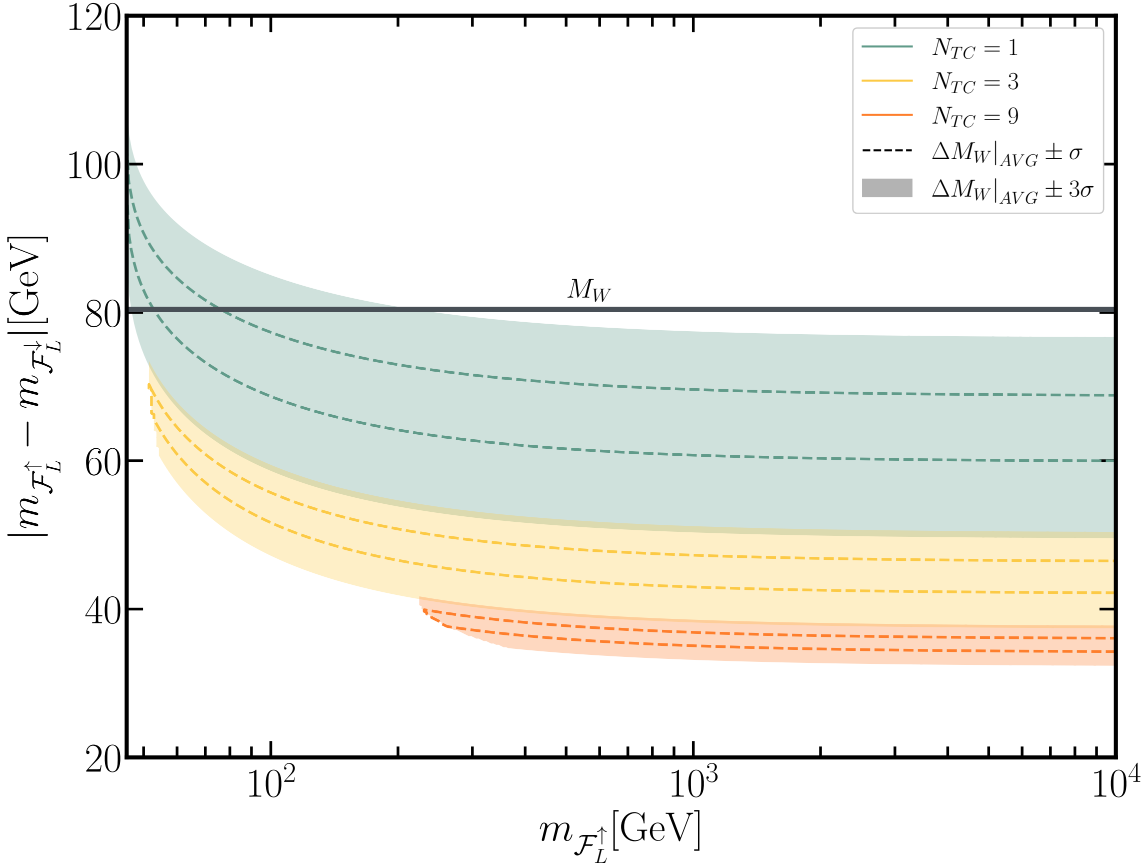
W BOSON MASS: ALLOWED PARAMETER SPACE



CDF II

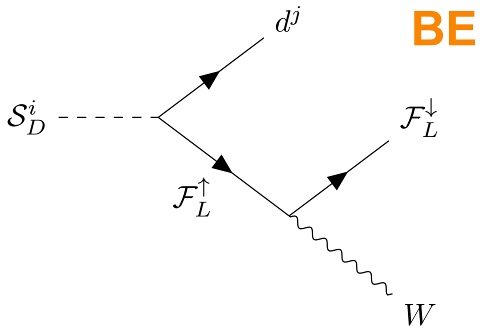


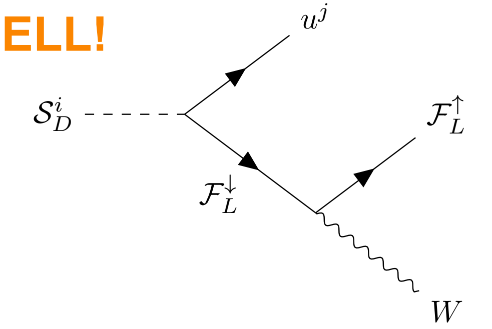
NEW AVERAGE



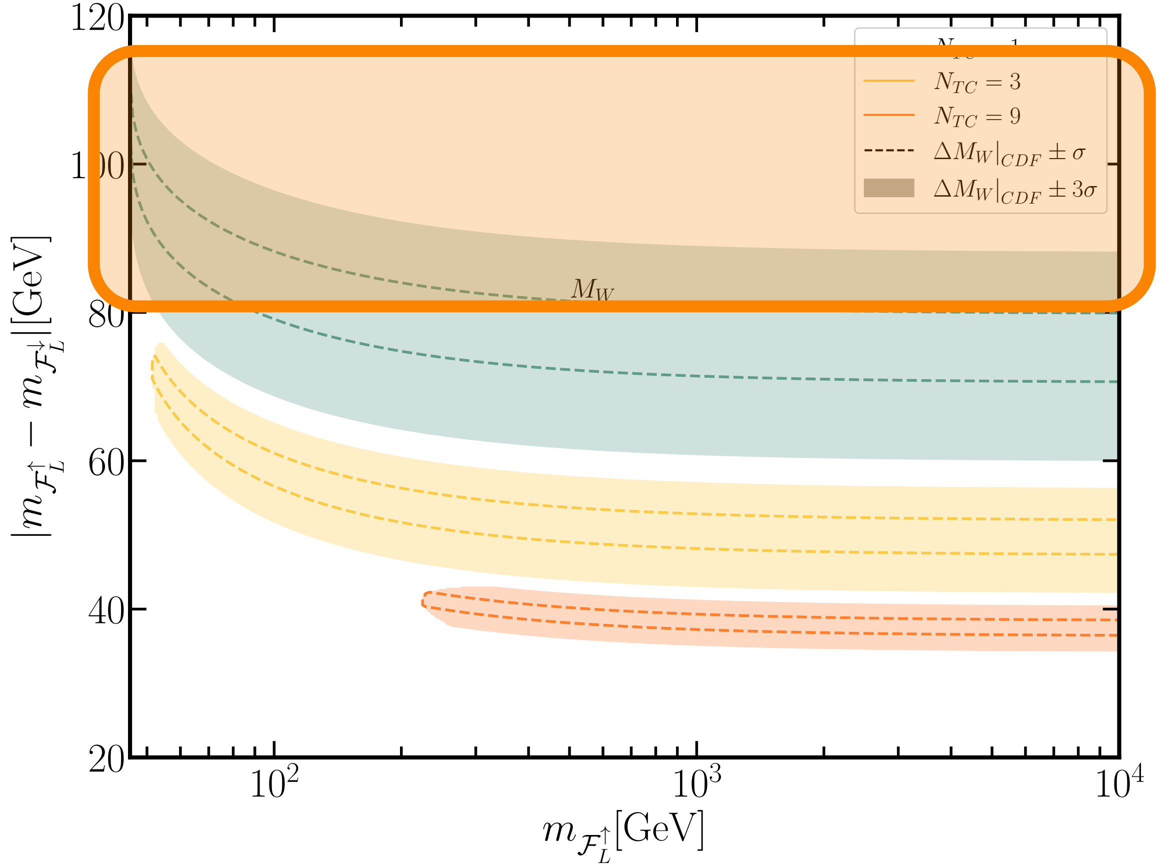
THE W BOSON MASS

ONE OF THEM CAN BE ON SHELL!

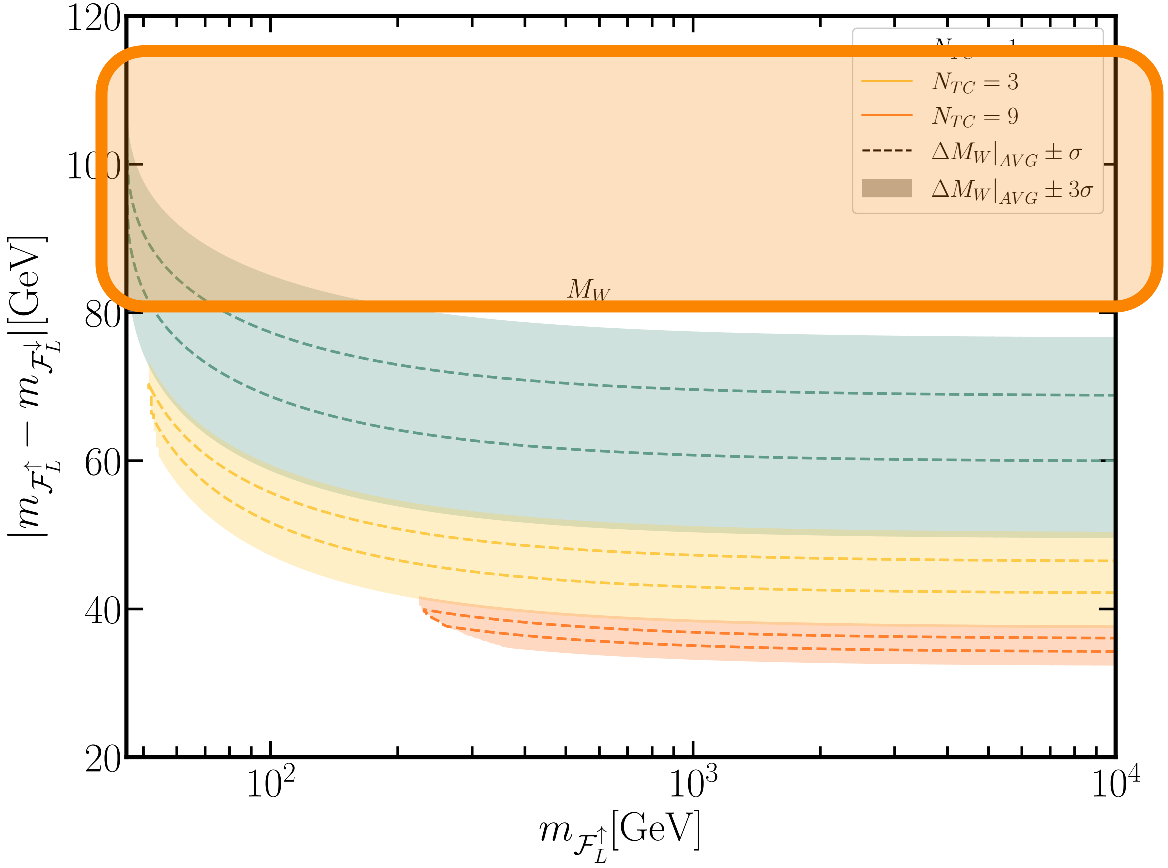




CDF II



NEW AVERAGE



Conclusions

- ★ We studied the signatures that the fundamental partial composites model would produce at LHC
  - ★ We compared fundamental partial composites signatures with Supersymmetry signatures
  - ★ We obtained Constraints on the fundamental partial composites model

- ★ We studied the parameter space allowed assuming that the fundamental partial composites can explain the anomalies
- ★ We connected anomalies and LHC searches in this context
- ★ We studied which masses are required for $\mathcal{F}_L$ to explain the W boson anomaly measured

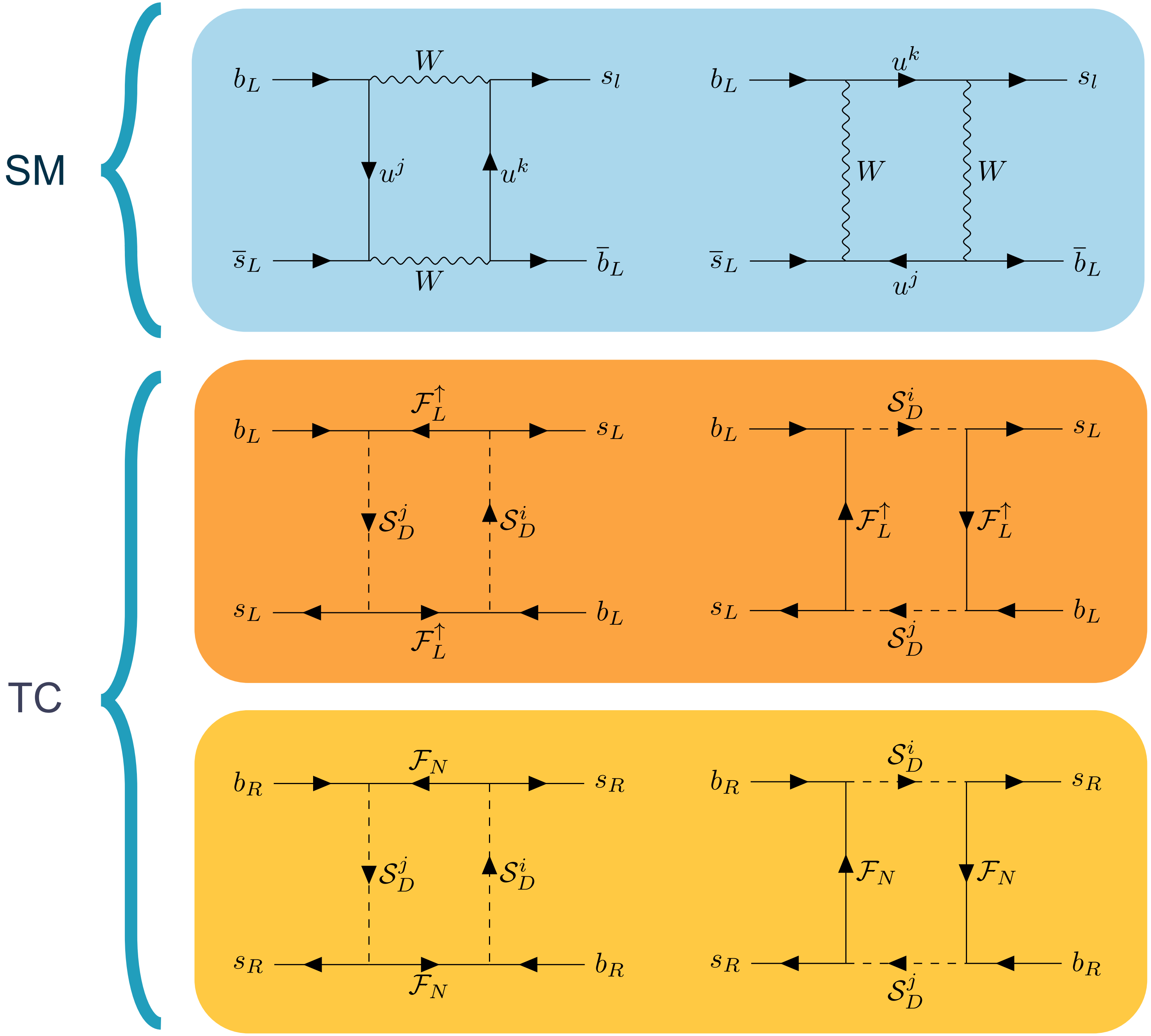
THANK YOU FOR THE ATTENTION

$B - \overline{B}$ Mixing

Cyan: Standard Model contribution at tree level

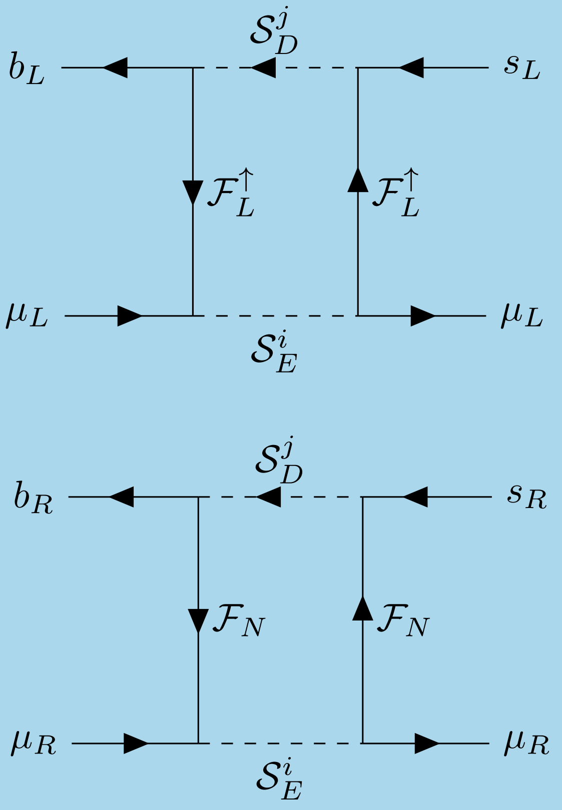
Orange: fundamental partial compositeness contribution at tree level with left-handed quarks

Yellow: : fundamental partial compositeness contribution at tree level with right-handed quarks.

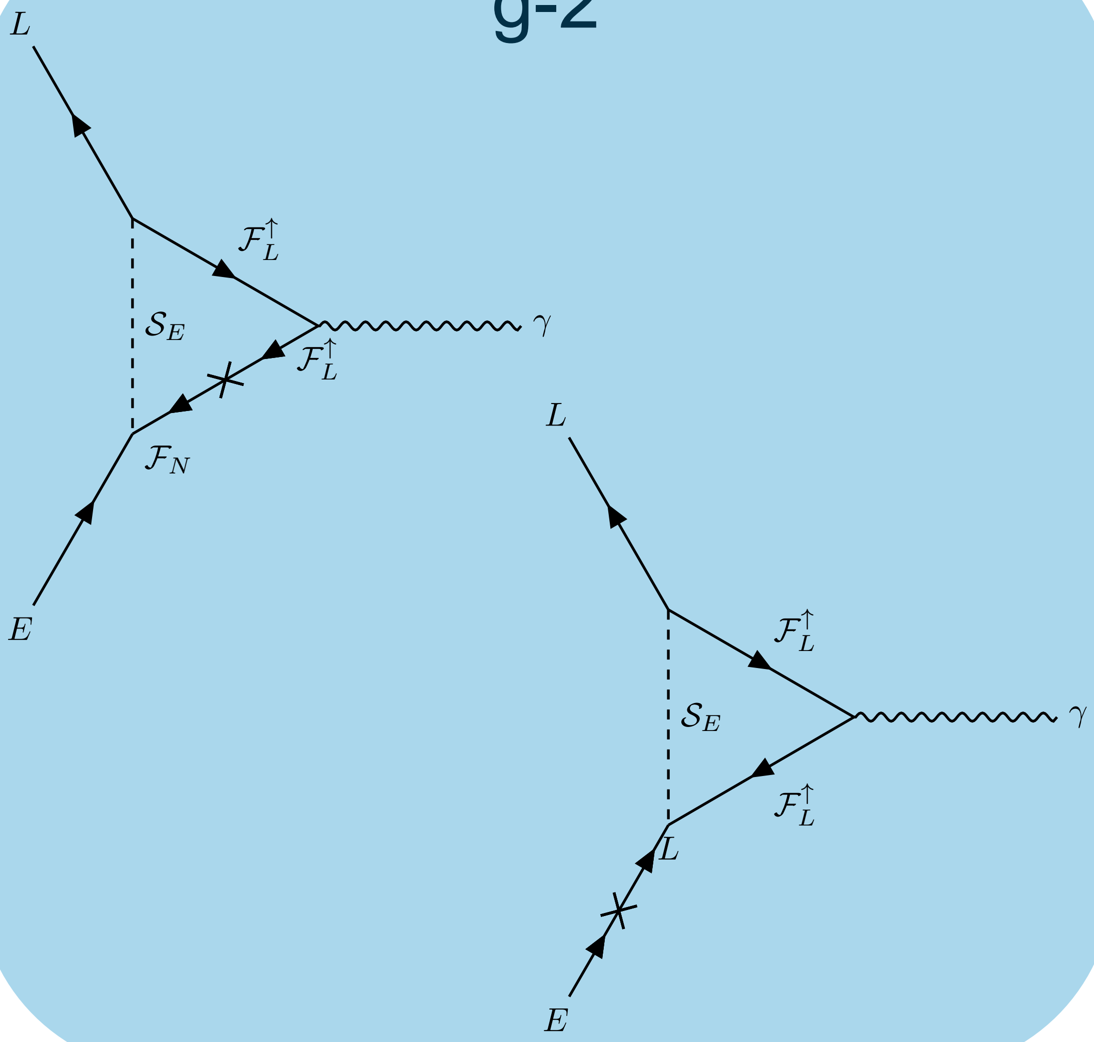


FLAVOR ANOMALIES

R_k Anomaly

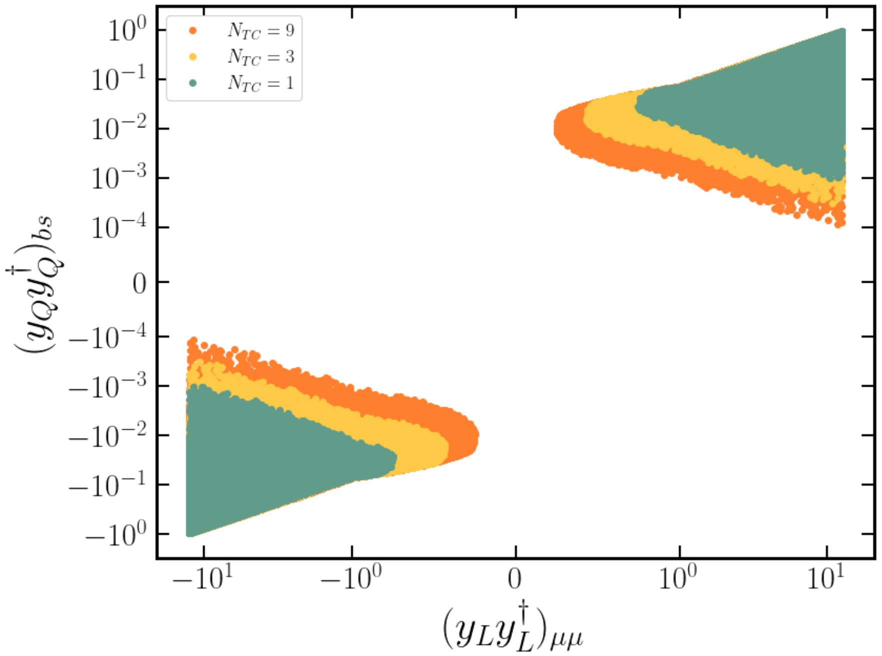


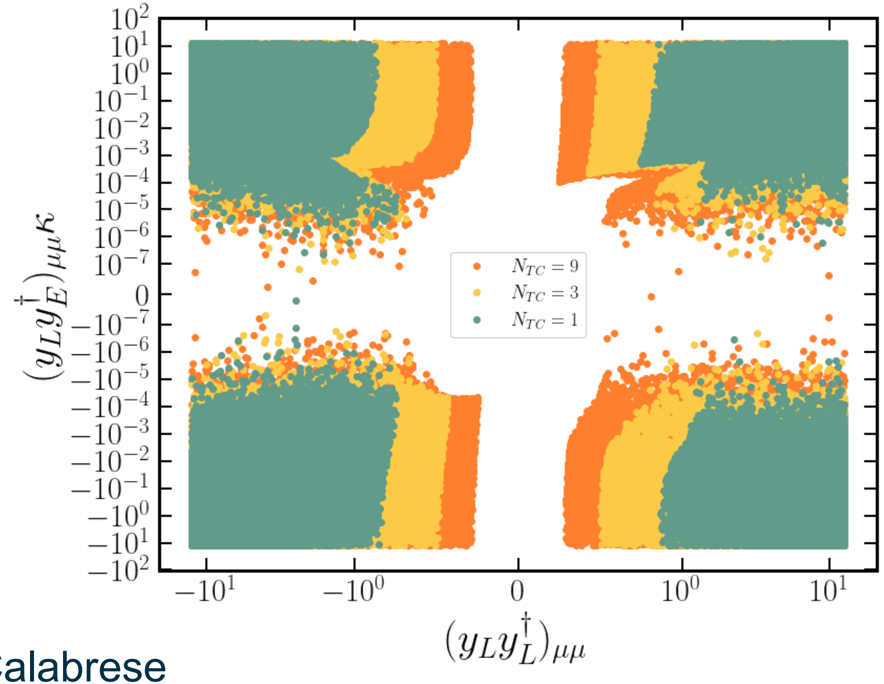
g-2

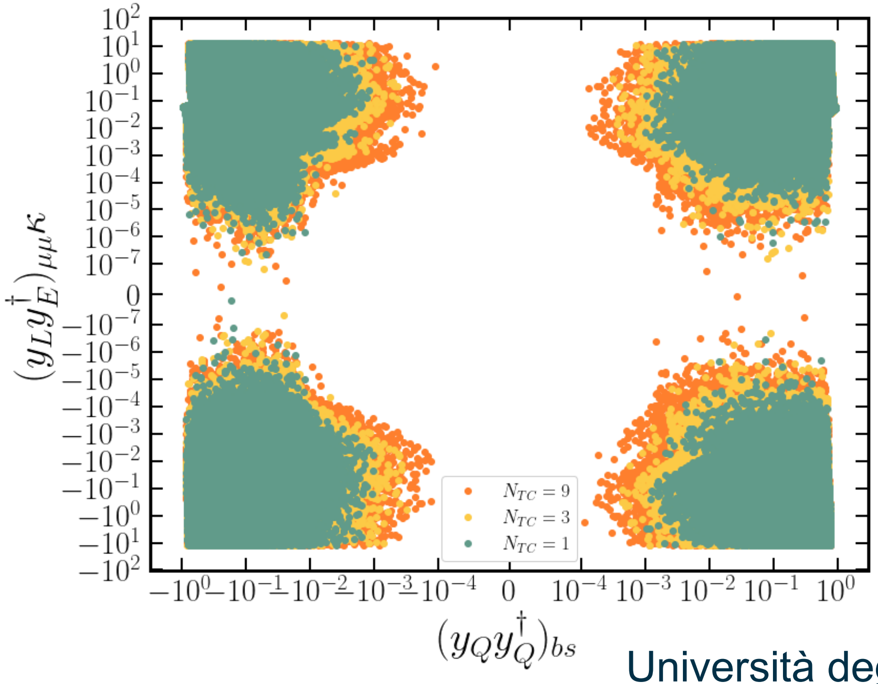


MASS RANGE CONSIDERED: $m_{\mathcal{F}_L^\uparrow}, m_{\mathcal{S}_D}, m_{\mathcal{S}_E} \in [0.1 - 5]TeV$

ASSUMPTION: $m_{\mathcal{F}_L}^\uparrow < m_{\mathcal{S}_D}$

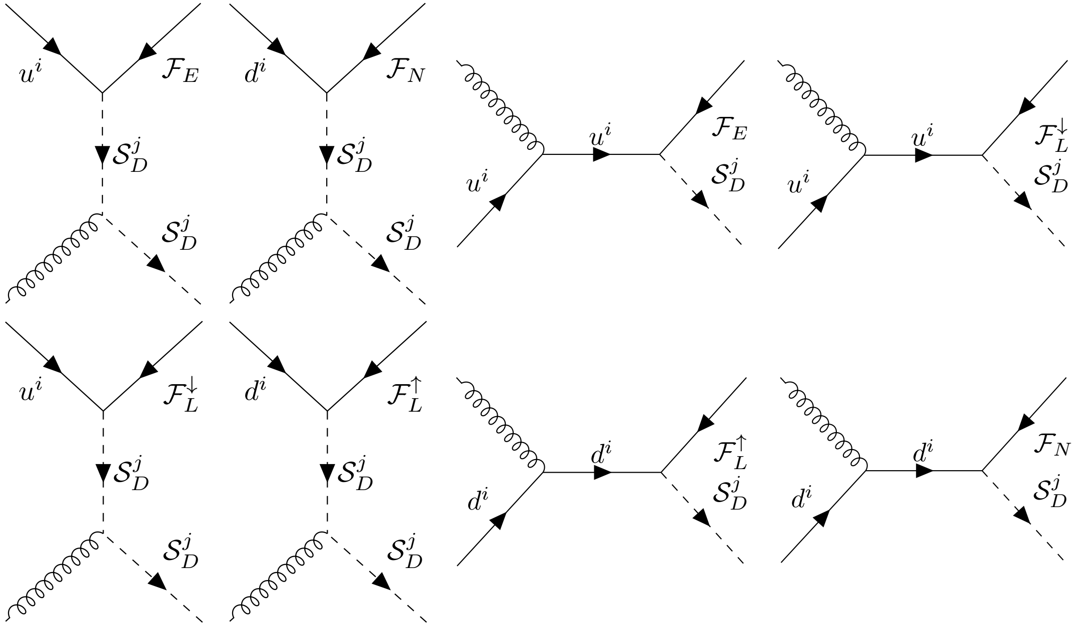




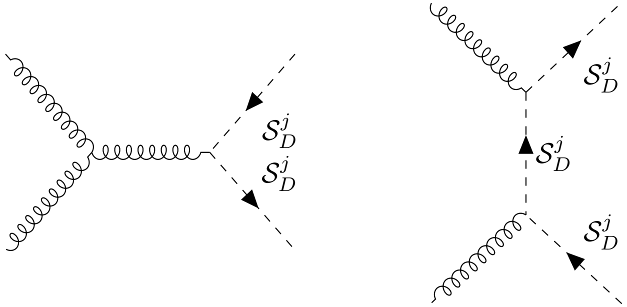


ALL THE PRODUCTION DIAGRAMS FROM PP COLLISIONS

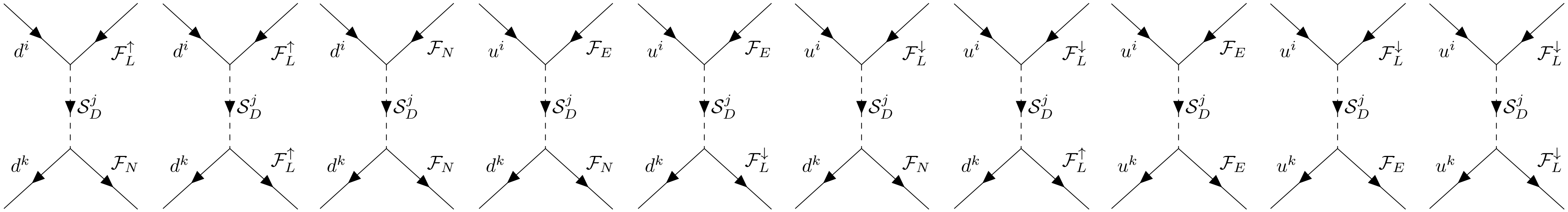
One $\mathcal{S}_D$ and one F



Two $\mathcal{S}_D$



Two $\mathcal{F}$



Roberta Calabrese
Università degli studi di Napoli “Federico II”

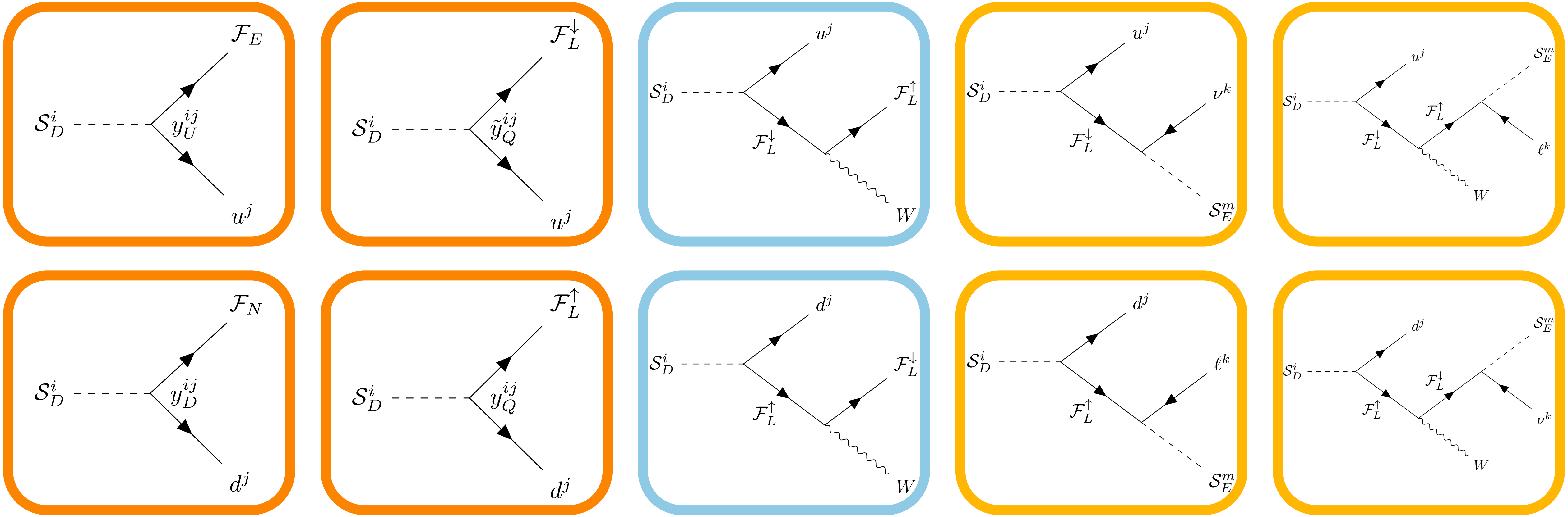
$\mathcal{S}_D$ DECAY CHANNELS

CASE 1: $M_{\mathcal{F}} < M_{\mathcal{S}}$

The new fermions can not decay into any new scalar

Diagrams in yellow can not happen on shell

At most only one of the diagrams in cyan can be on shell depending on $|m_{\mathcal{F}_L^\uparrow} - m_{\mathcal{F}_L^\downarrow}| \lessgtr m_W$

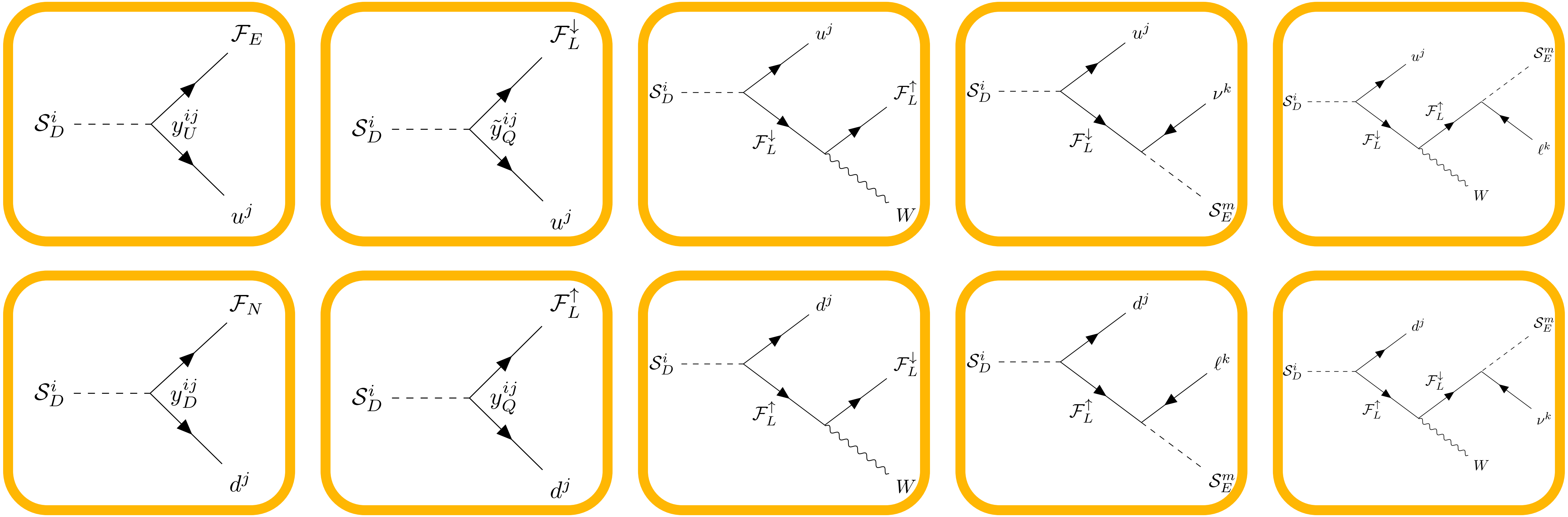


$\mathcal{S}_D$ DECAY CHANNELS

CASE 2: $M_{\mathcal{S}_D} < M_{\mathcal{F}} < M_{\mathcal{S}_E}$

The new fermions can decay into $\mathcal{S}_D$

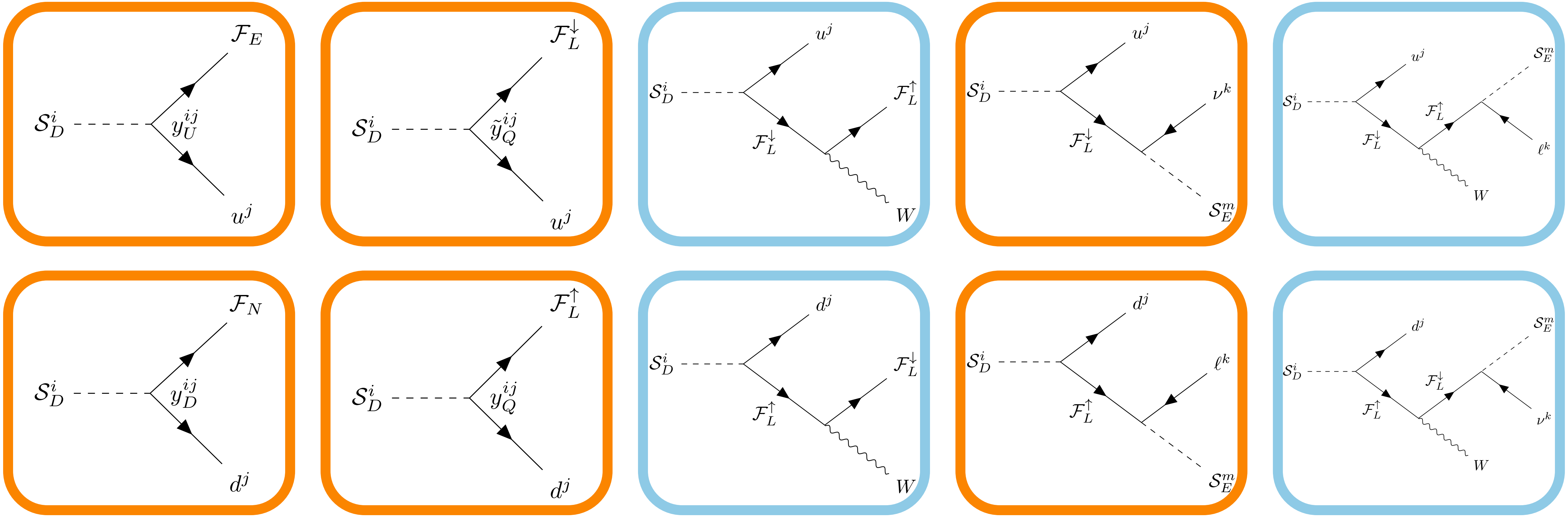
None of the processes can happen on shell



$\mathcal{S}_D$ DECAY CHANNELS

CASE 3:: $M_{\mathcal{S}_E} < M_{\mathcal{F}} < M_{\mathcal{S}_D}$

The diagram in cyan can be on shell depending on $|m_{\mathcal{F}_L^\uparrow} - m_{\mathcal{F}_L^\downarrow}| \lesseqgtr m_W$ (at most one per column)



P. Arnan et al, JEHP 2017
L. Calibbi et al, JHEP 2018

LOOP FUNCTIONS

$$F_{LR}(y) = \frac{1 - y^2 + 2y\ln y}{2(1-y)^3}$$

$$F_{LR}(1) = \frac{1}{6}$$

$$G_{LR}(y) = \frac{1 - 4y + 3y^2 - 2y^2\ln y}{2(1-y)^3}$$

$$G_{LR}(1) = \frac{1}{3}$$

$$F(x,y) = \frac{1}{(1-x)(1-y)} + \frac{x^2\ln x}{(1-x)^2(x-y)} + \frac{y^2\ln y}{(1-y)^2(y-x)}$$

$$F(1,x) = F(x,1) = \frac{-1 + 4x - 3x^2 + 2x^2\ln x}{2(-1+x)^3}$$

$$F(x,x)\ \frac{1 - x^2 + x\ln x}{(1-x)^3}$$

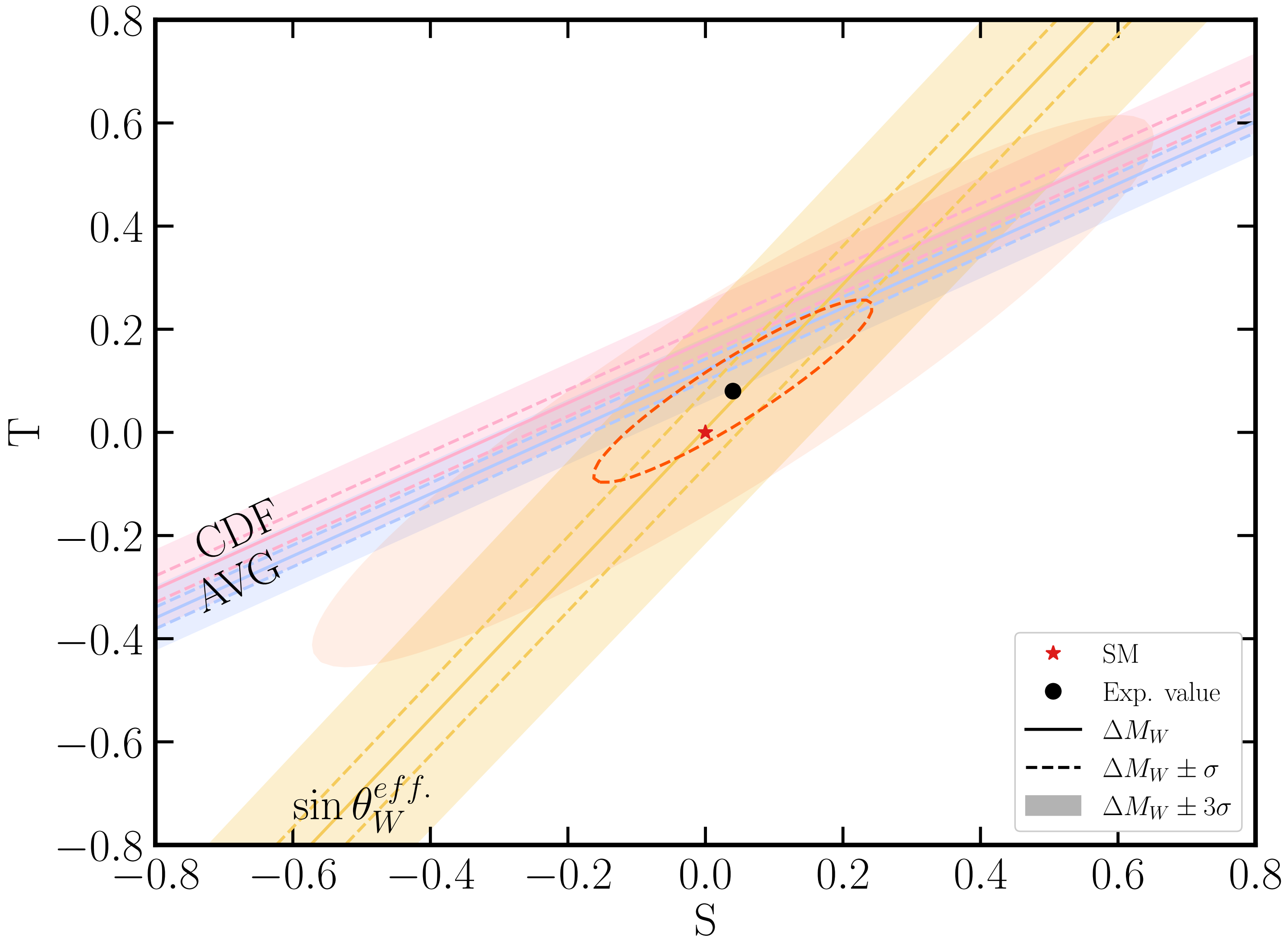
$$F(1,1) = \frac{1}{3}$$

$$\tilde{F}_7(y) = \frac{F_7(y^{-1})}{y} = \frac{1 - 6y + 3y^2 + 2y^3 + 6y^2\ln y}{12(1-y)^4}$$

$$\tilde{F}_7(1) = \frac{1}{24}$$

J. Haller et al, EPJC 2018
G. Cacciapaglia and F. Sannino, arXiv: 2204.04514

THE W BOSON MASS



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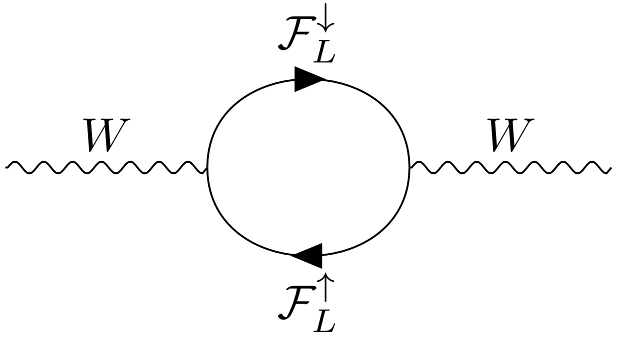
$$T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 M_Z^2}.$$

$$T = 0.08 \pm 0.07$$

$$S = 0.04 \pm 0.08$$

$$\rho = 0.92$$

THE W BOSON MASS



T and S take the following expression in this case

$$S = \frac{N_{TC}}{6\pi}\left\{2(4Y+3)x_1 + 2(-4Y+3)x_2 - 2Y log\frac{x_1}{x_2} + \left[\left(\frac{3}{2}+2Y\right)x_1 + Y\right]G(x_1) + \left[\left(\frac{3}{2}-2Y\right)x_2 - Y\right]G(x_2)\right\}$$

$$T = \frac{N_{TC}}{8\pi sw^2 cw^2}F(x_1, x_2)$$

Where

$$G(x) = -4\sqrt{4x-1}\; arctan\frac{1}{\sqrt{4x-1}}$$

$$F(x_1, x_2) = \frac{x_1 + x_2}{2} - \frac{x_1 x_2}{x_1 - x_2}\log\frac{x_1}{x_2}$$

M. E. Peskin and T. Takeuchi, PRD 1992 and PRL 1990
D. C. Kennedy and P. Langacker, PRL 1990
P. A. Zyla et al, PTEP 2020
T. Aaltonen er al, Science 2022
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