TOP PROPERTIES AND DECAY STUDIES AT FCC-hh

DANIEL STOLARSKI

1st FCC Physics Workshop — Jan 19, 2017

DISCLAIMERS

- Only starting thinking about this when I was invited to give this talk last month.

- Do not claim to be exhaustive, almost certainly other interesting things to say about top quarks at FCC-hh.

- Top quarks are interesting and important, won't give any other motivation.

TOP QUARK AT FCC-HH

	Energy	Luminosity	σ (pb)	$N_{t\bar{t}}$
LHC I	8 TeV	20 fb^{-1}	250	$5 \cdot 10^6$
HL-LHC	14 TeV	3 ab^{-1}	1,000	$3 \cdot 10^9$
FCC	100 TeV	1 ab^{-1}	$3 \cdot 10^4$	$3 \cdot 10^{10}$
FCC-HL	100 TeV	30 ab^{-1}	$3 \cdot 10^4$	10^{12}

Enormous sample of top pairs at FCC.

RARE DECAYS

Use large sample of tops to search for flavour violating decays:

Process	SM
$t \to Zu$	7×10^{-17}
$t \to Zc$	1×10^{-14}
$t \to gu$	4×10^{-14}
$t \to gc$	5×10^{-12}
$t \to \gamma u$	4×10^{-16}
$t \to \gamma c$	5×10^{-14}
$t \to hu$	2×10^{-17}
$t \to hc$	3×10^{-15}

Aguilar-Savedra, hep-ph/0409342.
Snowmass Top Quark Report, arXiv:1311.2028.

Decays essentially forbidden in SM, discovery would be definite sign of new physics.

RARE DECAYS

Use large sample of tops to search for flavour violating decays:

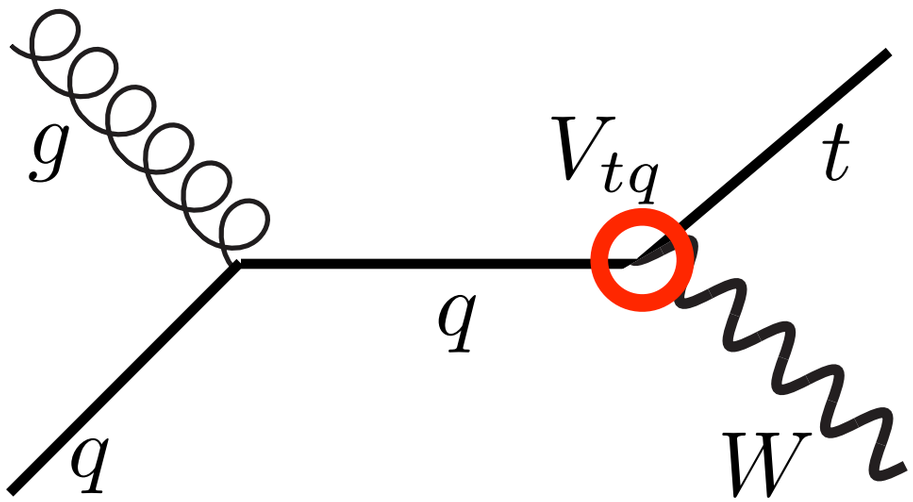
Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

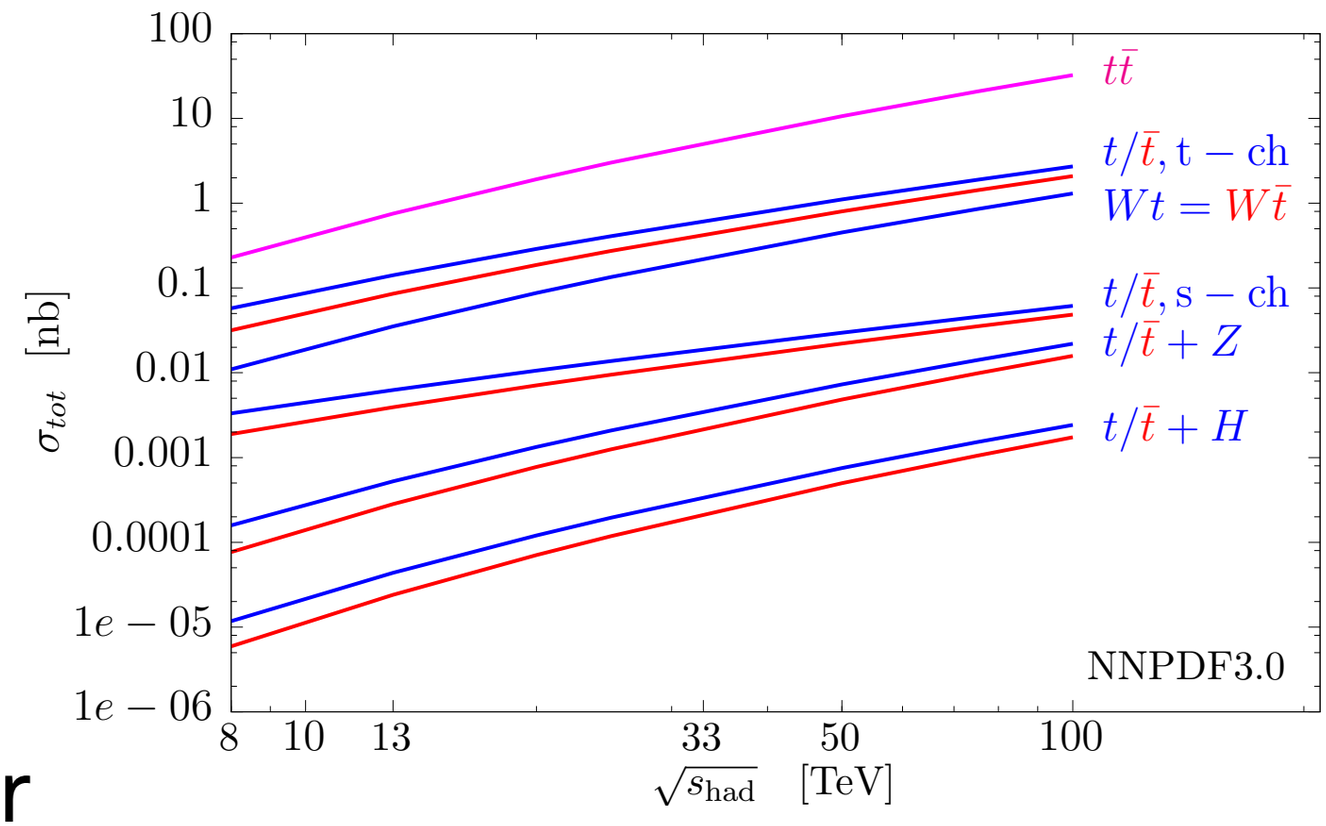
Snowmass Top Quark Report, arXiv:1311.2028, and references therein.

Many models of new physics can accommodate much larger rates.

CKM ELEMENTS

Also charged current rare decays, $t \to Wq$ $(q \neq b)$.
Can also be probed in single top processes.



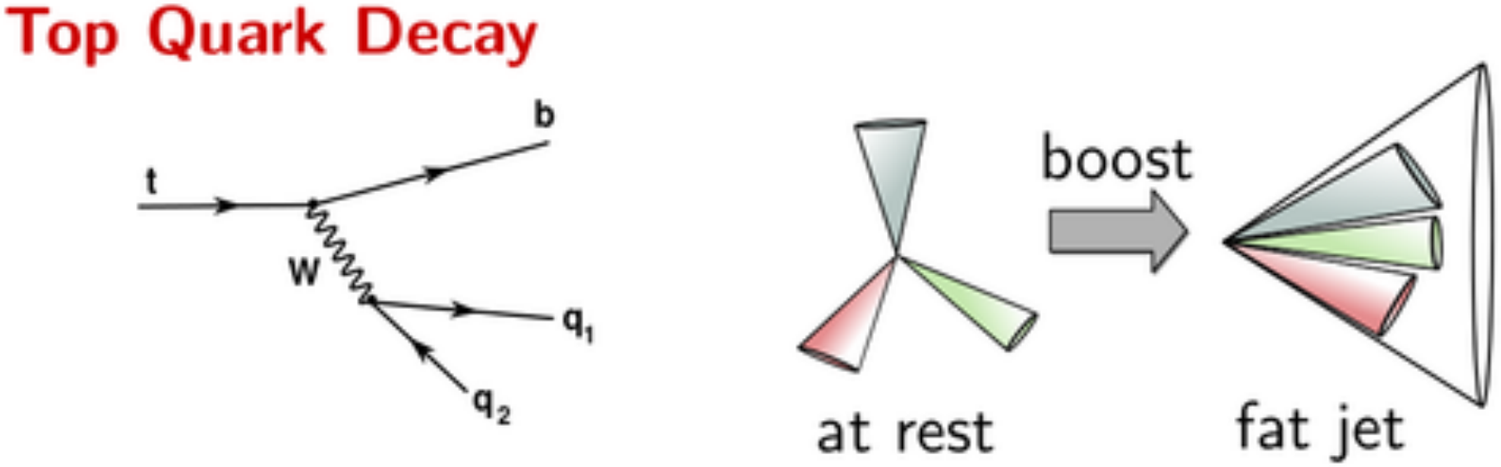


Cross section much bigger at FCC.

1607.01831

HIGH ENERGY TOP QUARKS

If top quark is very boosted, decay products are very collimated.



Granular calorimeter eventually loses ability to find sub-jets.

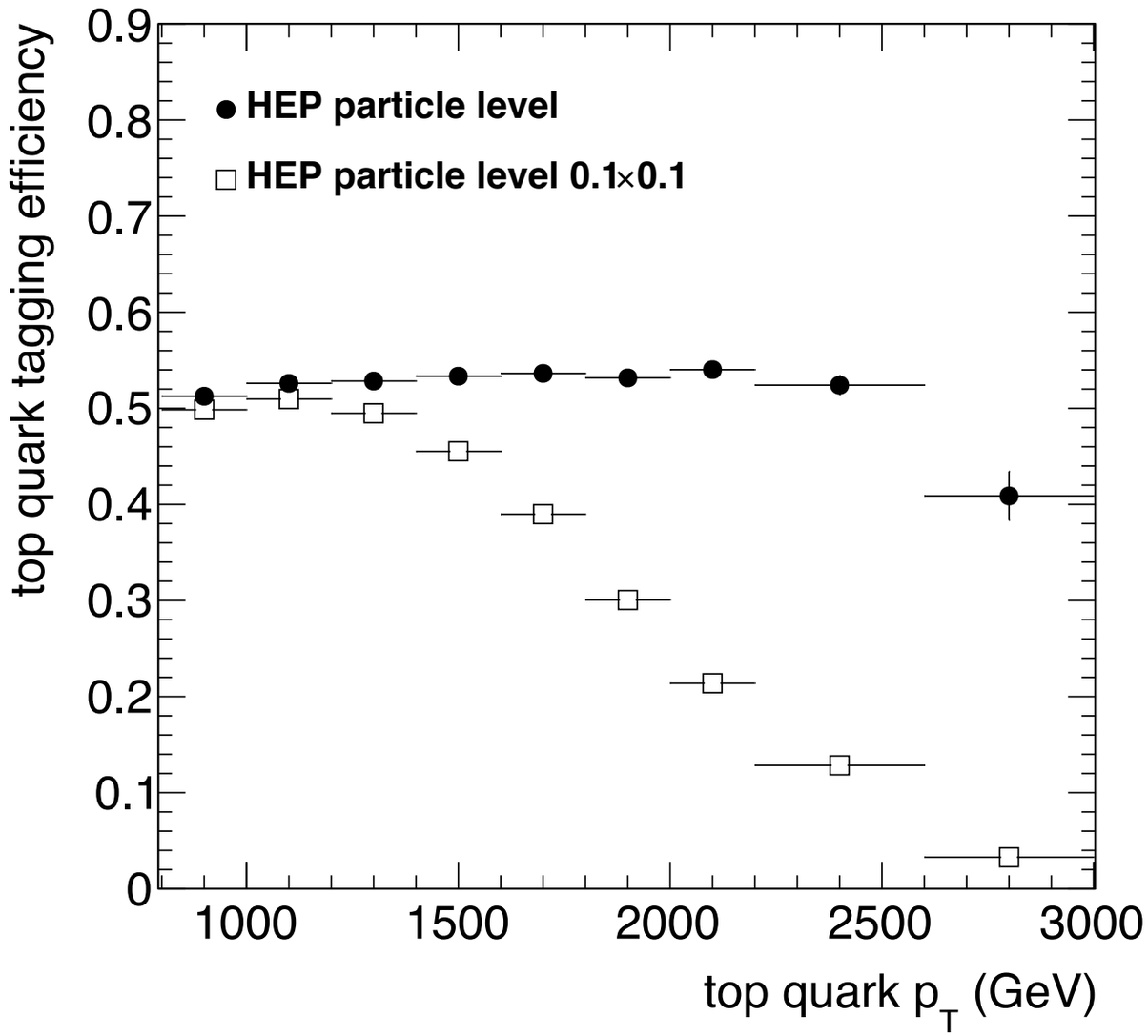
Bressler, Flacke, Kats, Lee, Perez, arXiv:1506.0265.

HIGH ENERGY TOP QUARKS

HPTTopTagger using tracking information can work at very high boost.

Motivates very granular tracker.

Further detector studies needed.

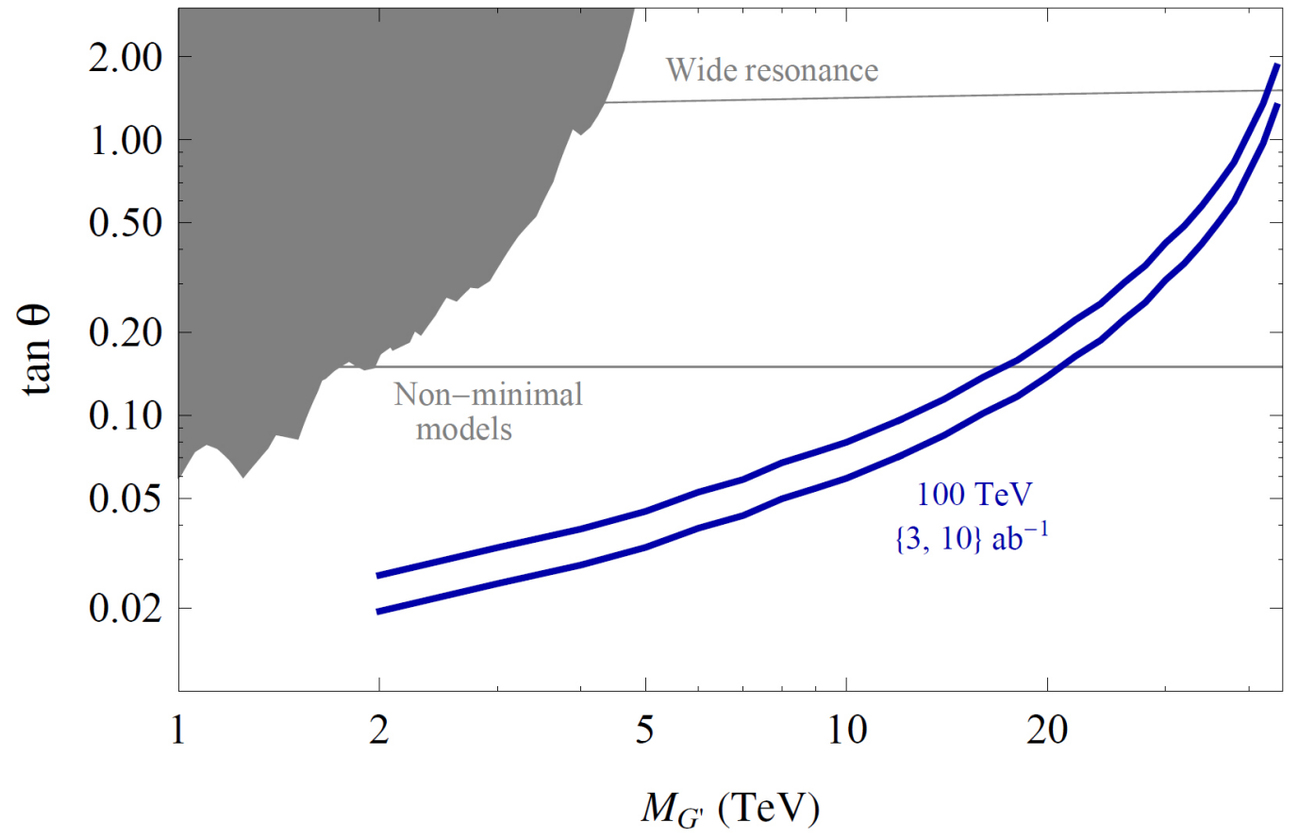


Schatzel, Spannowski, arXiv:1308.0540.
Larkoski, Maltoni, Selvaggi, arXiv:1503.03347.
See also talk by Pagani.

TOP RESONANCES

Use top tagging techniques to look for resonances.

High mass tt resonances predicted in many BSM models (RS/composite Higgs for example).

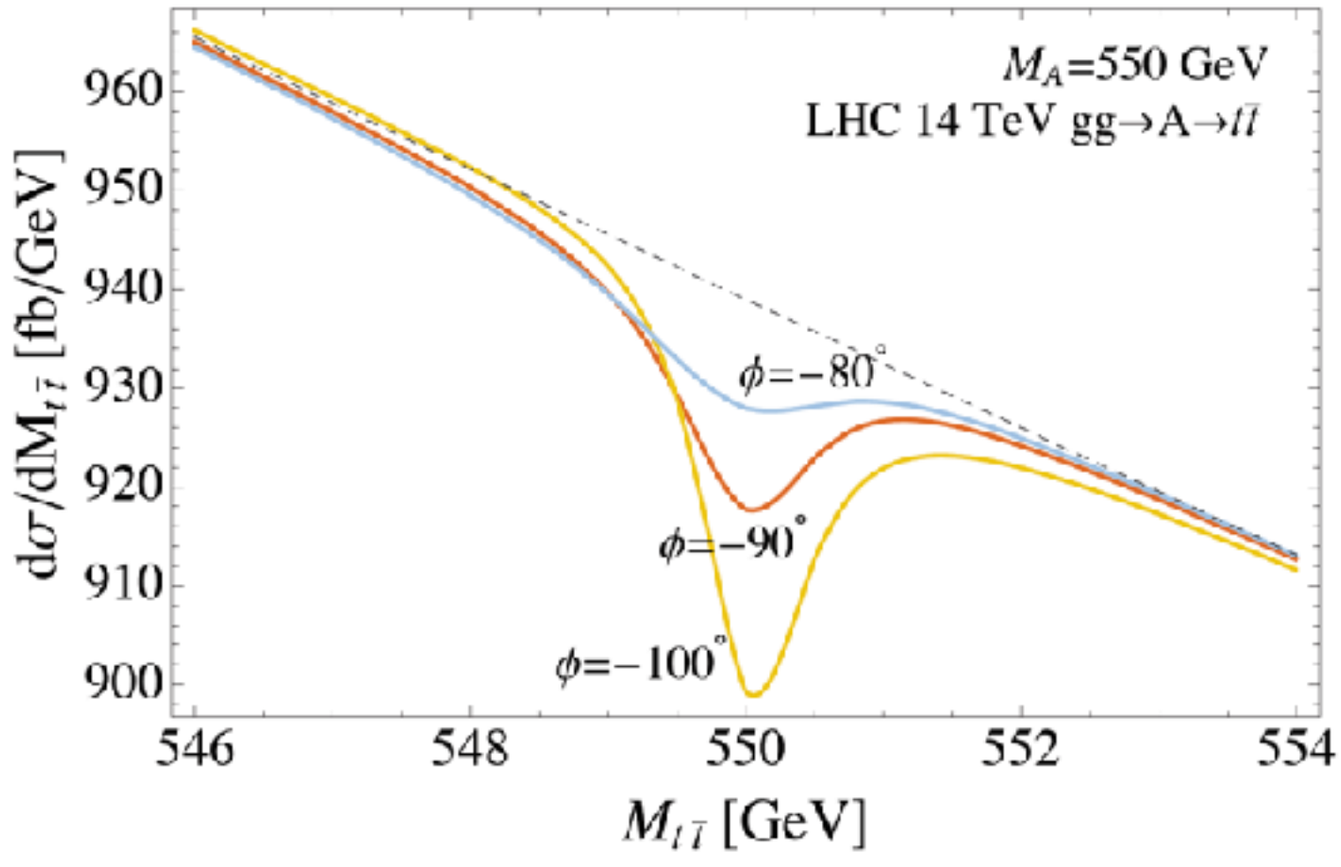


1606.00947.
See also talk by Vignaroli.

STRANGE FEATURES

Can also have dips and other strange features in spectrum.

Further study necessary.



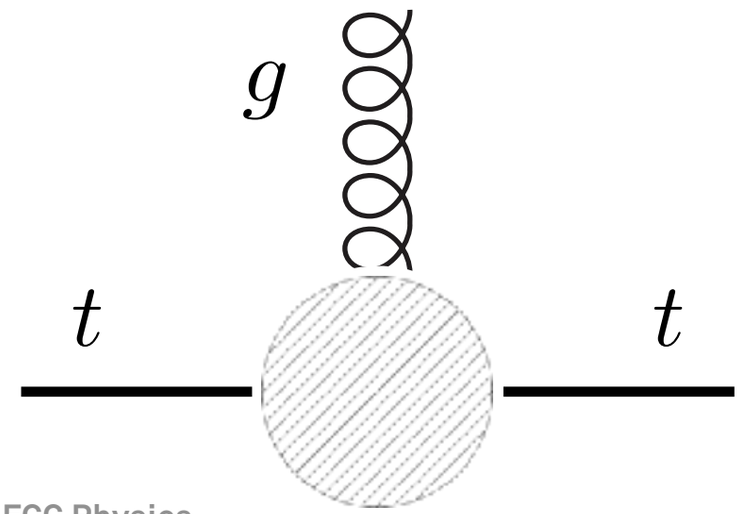
Jung, Song, Yoon, arXiv:1505.00291.

CHROMO-MOMENTS

Top can have chromo-electric or chromo-magnetic dipole moment.

$$\frac{g_s}{m_t}\bar{t}\,\sigma^{\mu\nu}(d_V + id_A\gamma_5)\frac{\lambda_a}{2}t\,G^a_{\mu\nu}$$

Generic if new coloured fields that talk to top exist.

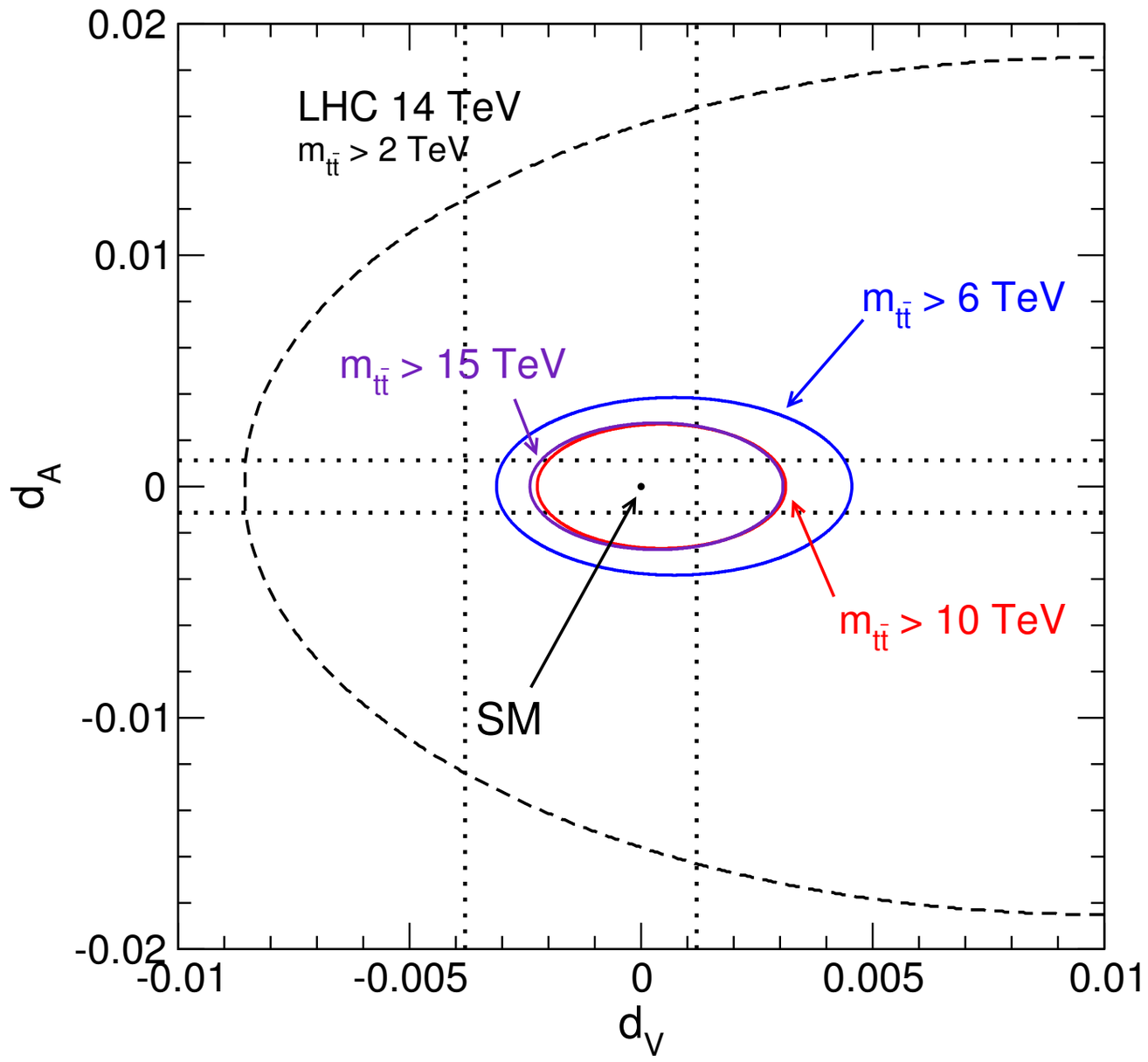


CHROMO-MOMENTS

Use boosted top quarks to look for these effects.

High invariant mass gives better sensitivity.

Sensitive to EFT scale ~ 50 TeV.



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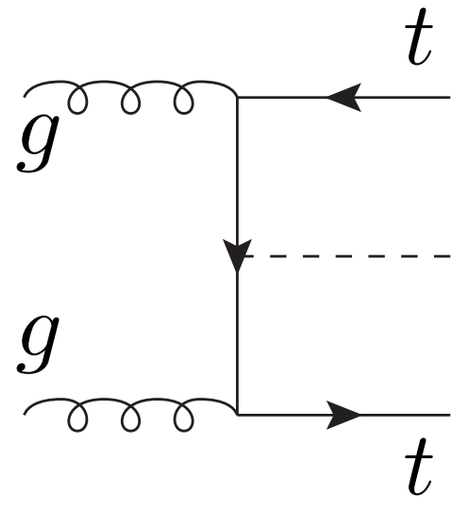
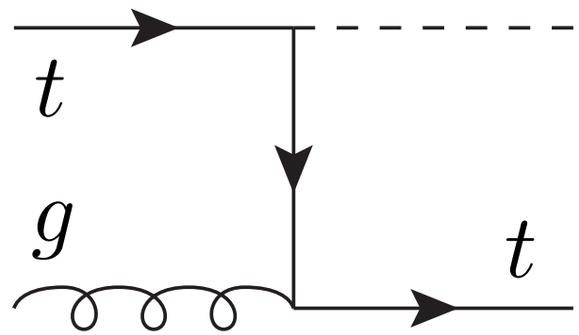
TOP QUARK PDF

$$100\ \mathrm{TeV} \gg m_t$$

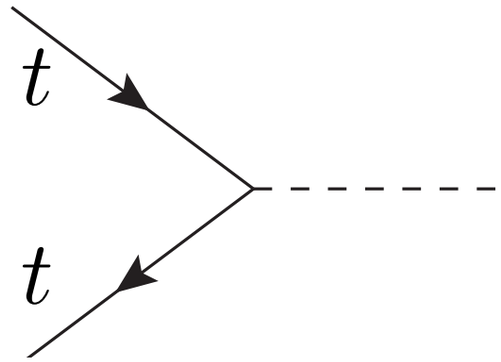
Is there top content in the proton at 100 TeV?



Useful in producing resonances that couples to Higgs.



Formally resumming logs.



Dawson, Ismael, Low, arXiv:1405.6211.
Han, Sayre, Westhoff, arXiv:1411.2588.

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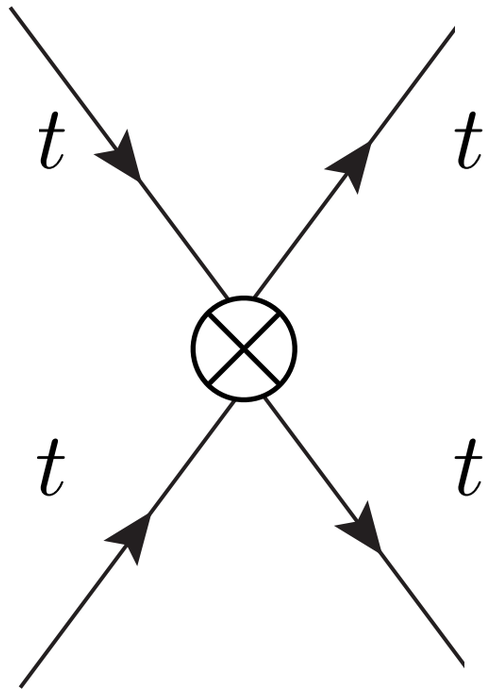


Can also use to probe top compositeness.

Pomarol, Serra, arXiv:0806.3247.
Zhou, Whiteson, Tait, arXiv:1203.5862.
Wulzer talk from yesterday.

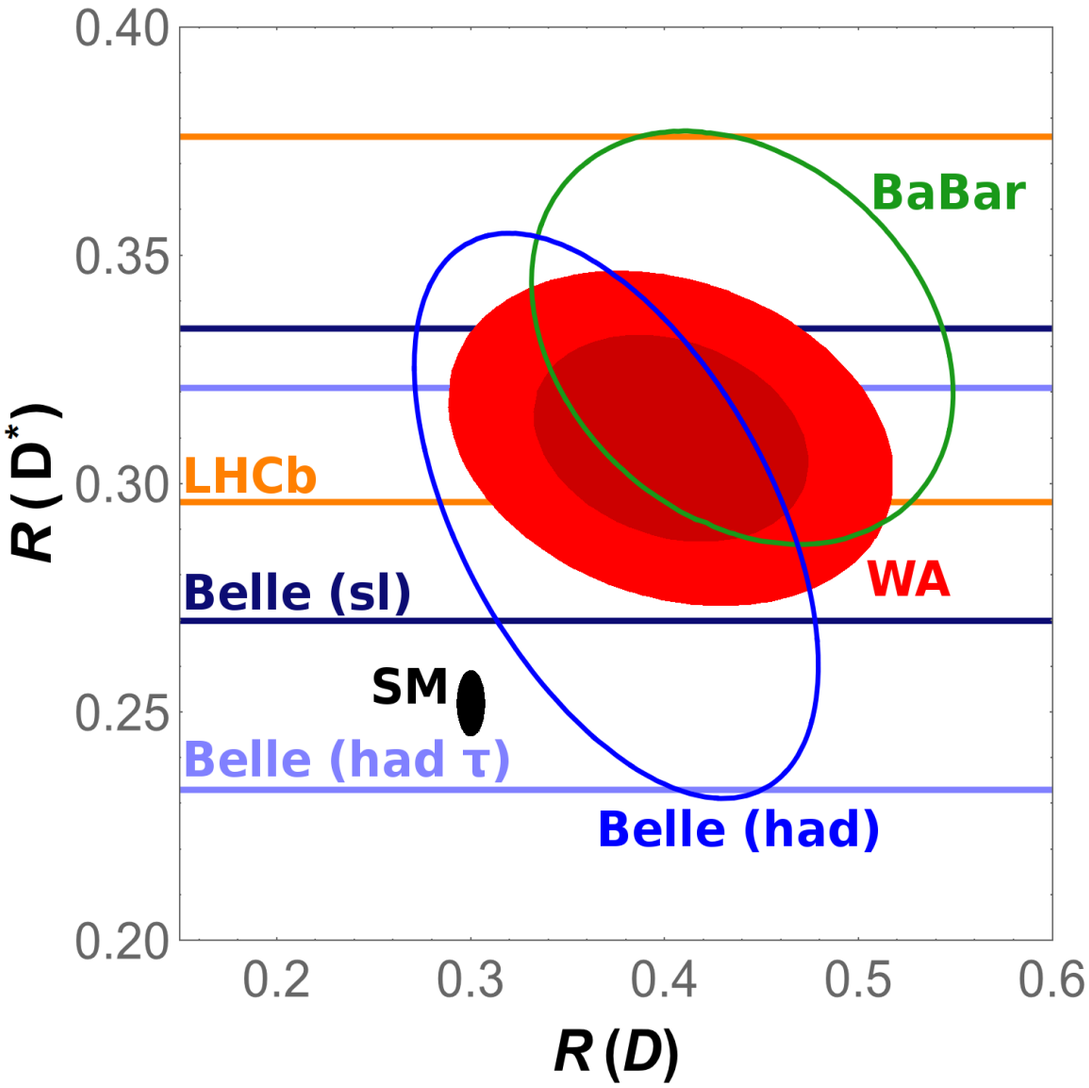
FLAVOUR ANOMALY

$$R(D^{(*)}) = \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)}$$

Anomaly in lepton flavour universality seen in 3 expts.

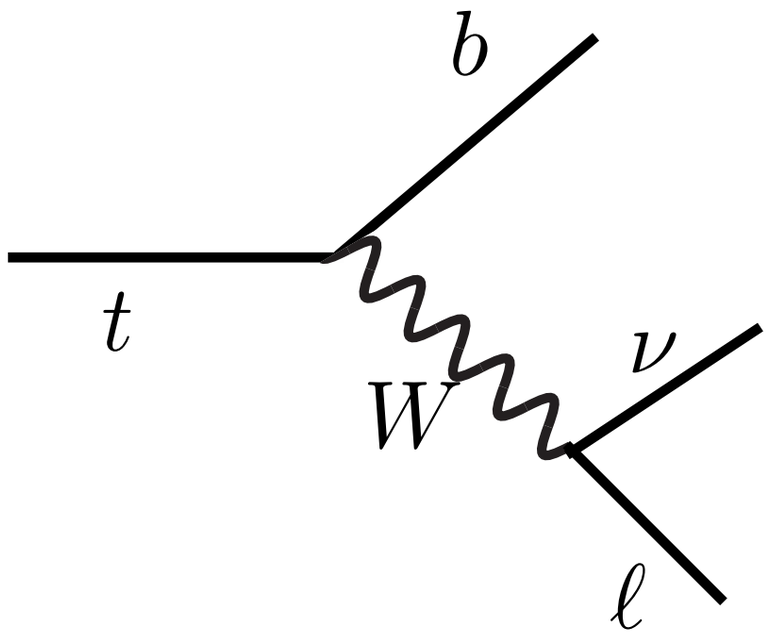
More work to do to confirm.

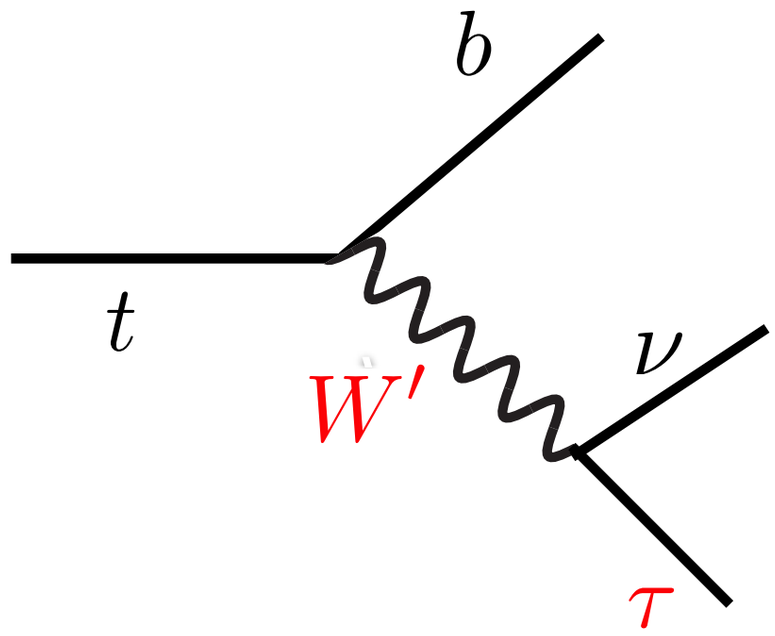
If its from new physics, should couple to top quarks.



Celis, Jung, Li, Pich, arXiv:1612.07757

EXAMPLE EXPLANATION



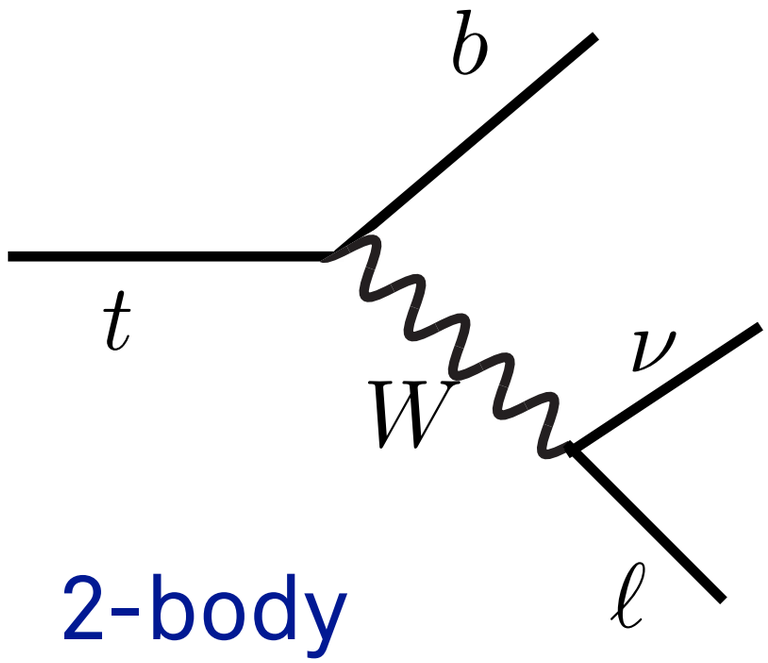


Greljo, Isidori, Marzocca, arXiv:1506.01705.

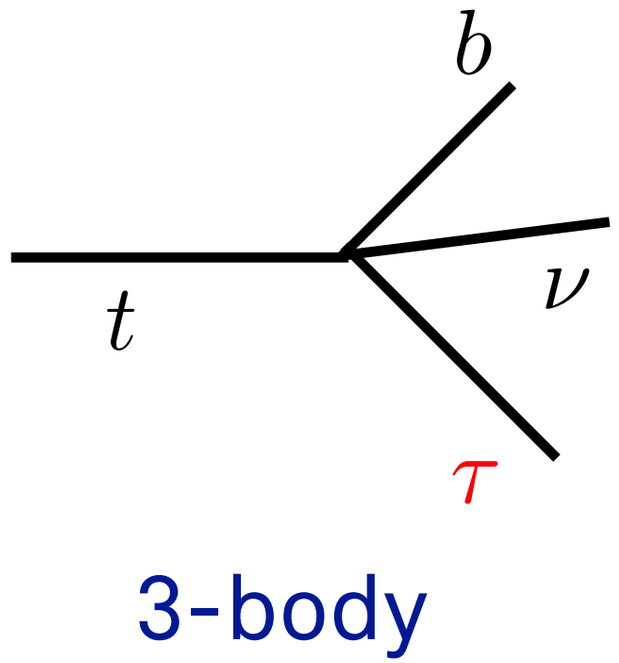
Left-handed charged current coupling dominantly to third generation can potential explain anomaly.

Gives new contribution to $t \to b\tau\nu$, but its very small O(10^{-3}) contribution to the rate.

NEW CHARGED CURRENT



2-body

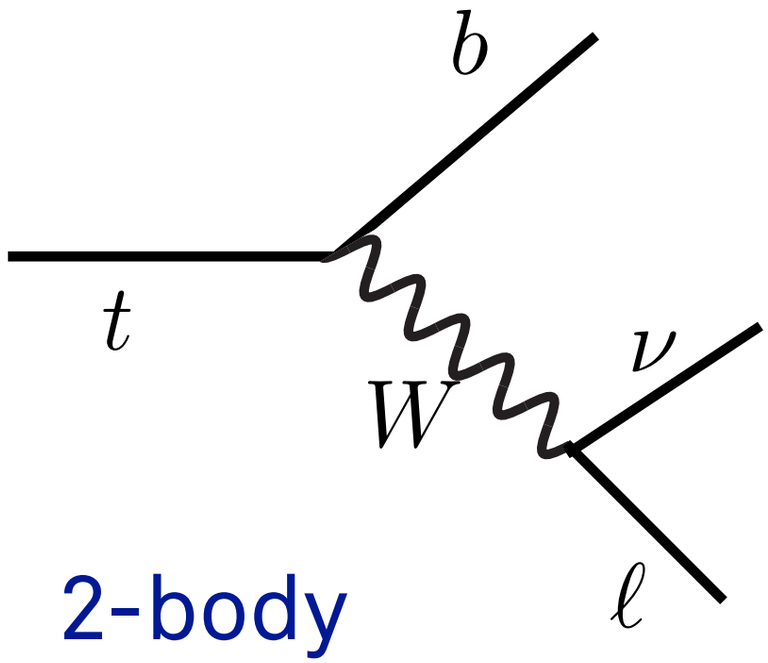


3-body

$m_{W'} > m_t$, can integrate it out.

NP decay has very different kinematics.

NEW CHARGED CURRENT



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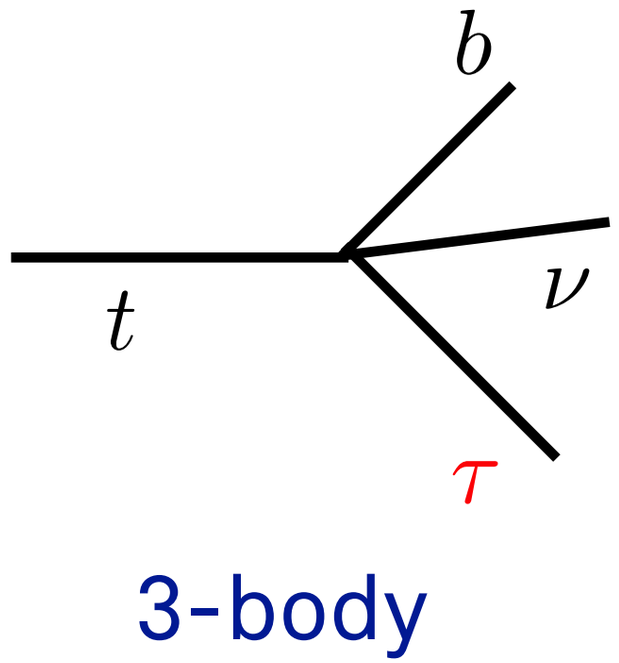


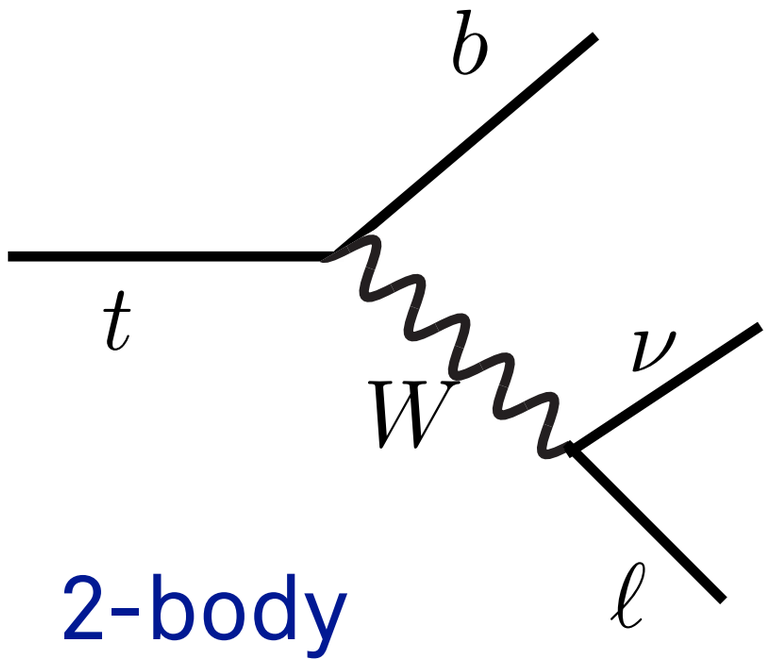
3-body

Very precise measurement of *b*-quark energy spectrum can be sensitive to this effect.

Do not have measure tau energies.

Work in progress with J. Kamenik and A. Katz.

NEW CHARGED CURRENT



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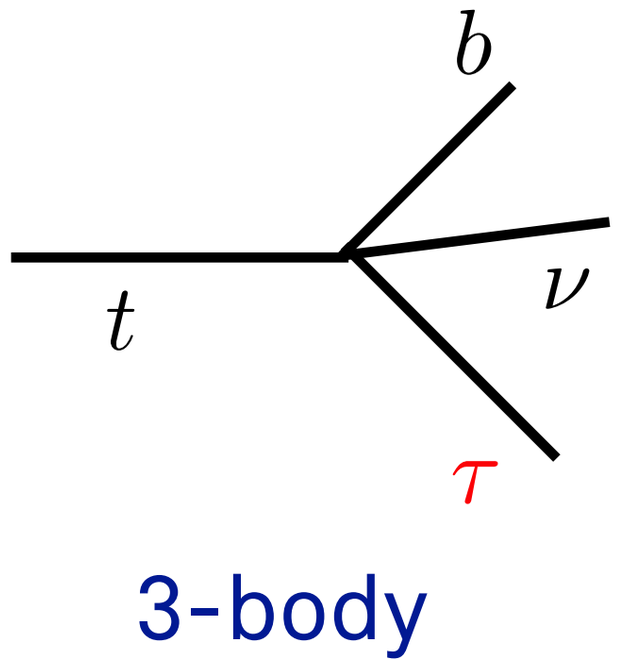

3-body

Helped by large rate at FCC.

General probe of structure of third generation.

Work in progress with J. Kamenik and A. Katz.

THANK YOU