Top perspectives @HL-LHC

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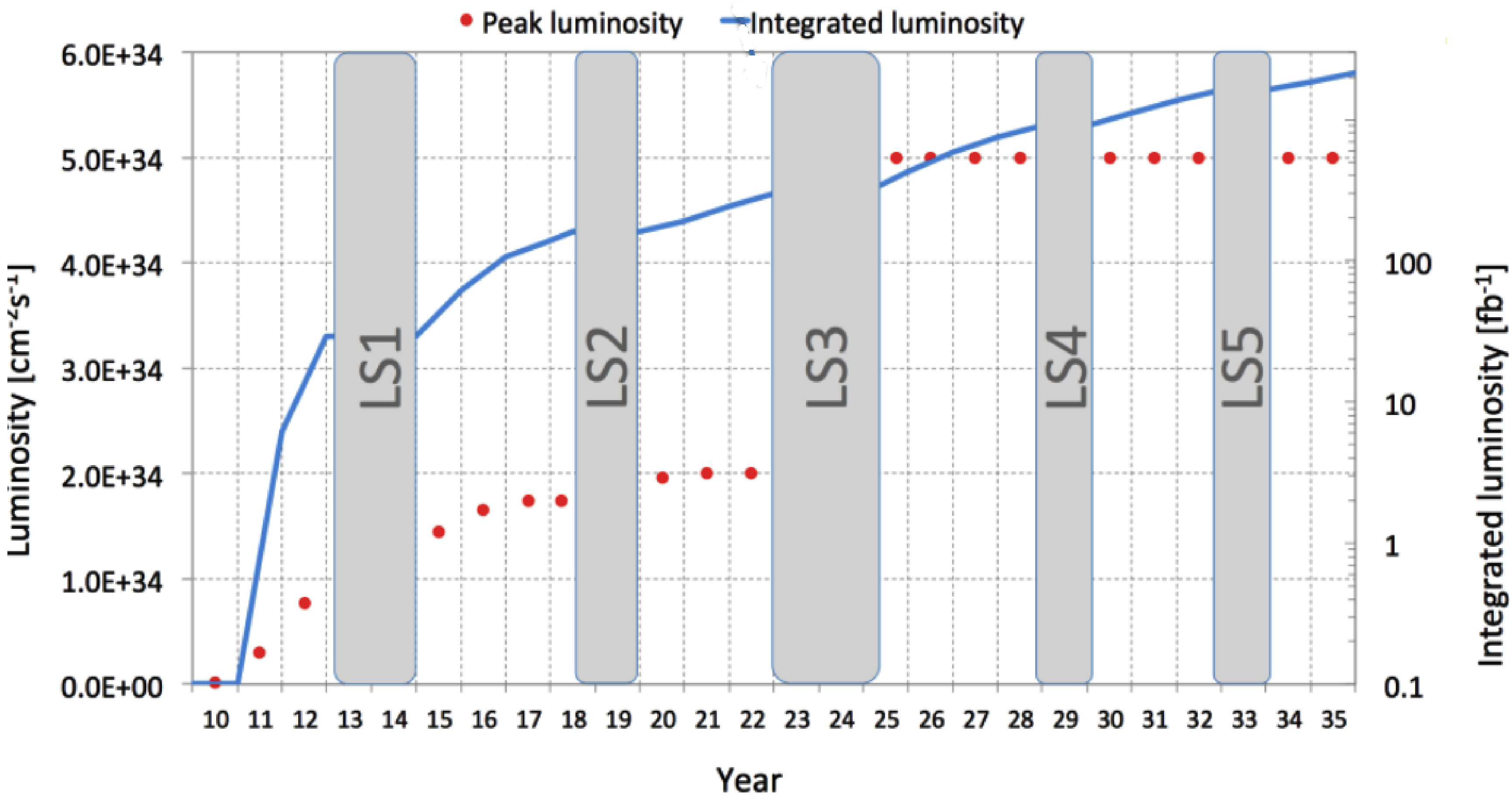
HL-LHC

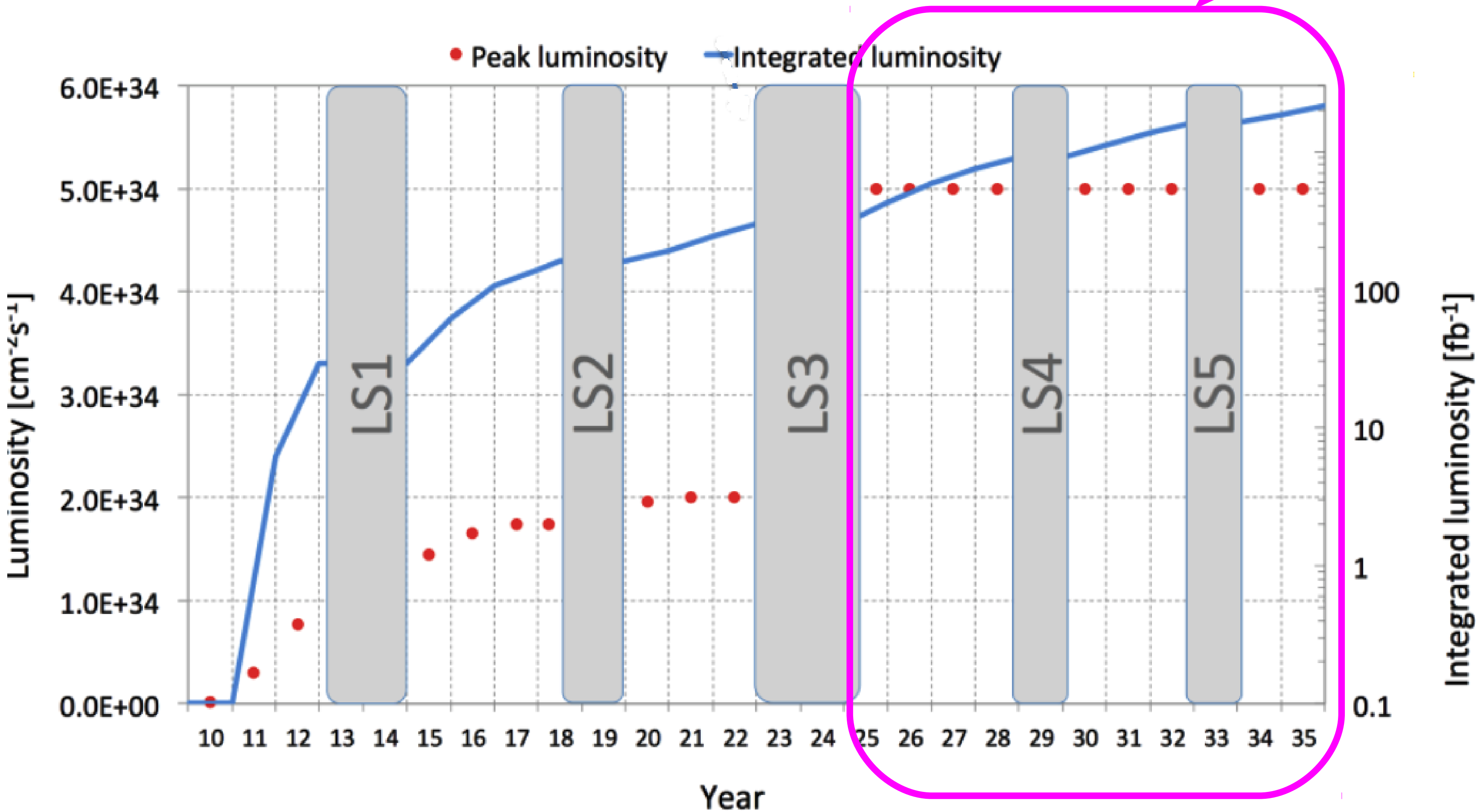


CERN-LHCC-2015-010

HL-LHC

$L_{int} = 3\ ab^{-1}$

$300\ fb^{-1}/year$



CERN-LHCC-2015-010

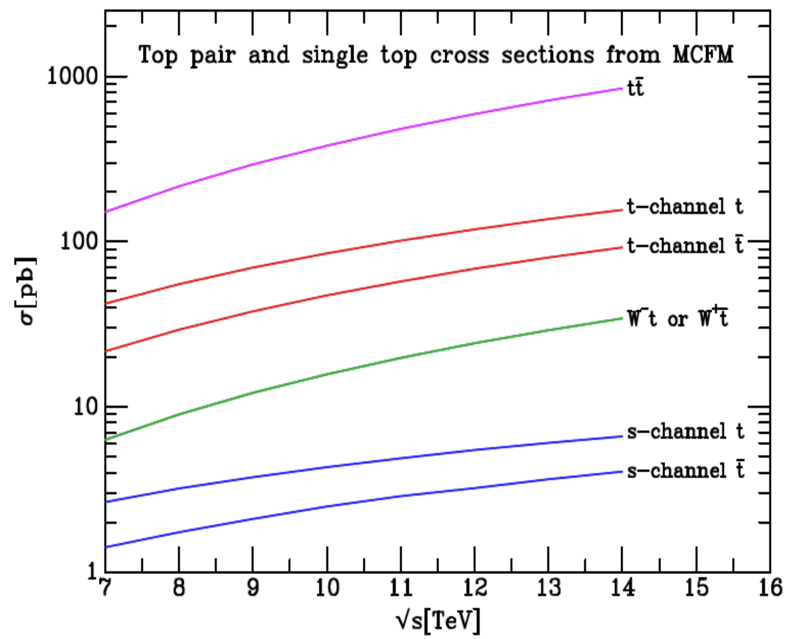
Why study tops @ HL-LHC ?

Large number of tops @ LHC, 10x more @ HL-LHC !

3 ab^{-1}

σ_{tt}	~ 1 nb	→	3B top pairs
$\sigma_{t\text{-channel}}$	~ 200 pb	→	600M tops
σ_{tW}	~ 75 pb	→	200M tops
$\sigma_{s\text{-channel}}$	~ 10 pb	→	30M tops
$\sigma_{tt\gamma/V/H}$	~ 1 pb	→	3M top pairs
σ_{tZ}	~ 100 fb	→	300k tops
σ_{tH}	~ 10 fb	→	30k tops

Adelman et. al [1309.1947]



HL-LHC is great laboratory for doing high precision top physics

Outline

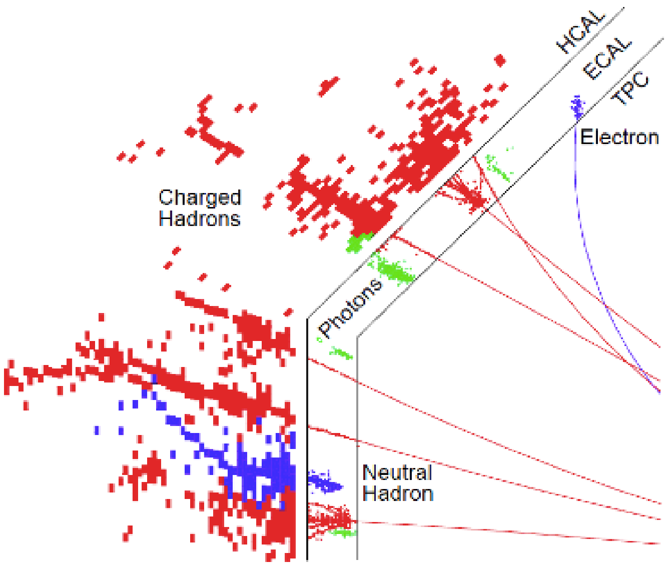
- Experimental aspects
- Top Measurements @ HL-LHC

Detectors

High luminosity comes with high pile-up (150 – 200), event rates and radiation damage:

- ATLAS and CMS will implement track triggers (event rates)
- High granularity pixel detectors (PU rejection, b-tagging)
- Extended tracker coverage up to |eta| < 4 (b-tagging, pile-up removal, fwd jet tagging, MET resolution)
- Extended muon coverage
- High Granularity Calorimeters (PU, high p_T)

High angular resolution is key in high pile-up, high p_T environment



Exp. issues (low p_T)

Pile-up can affect top measurements at low top p_T (~ 100 GeV):

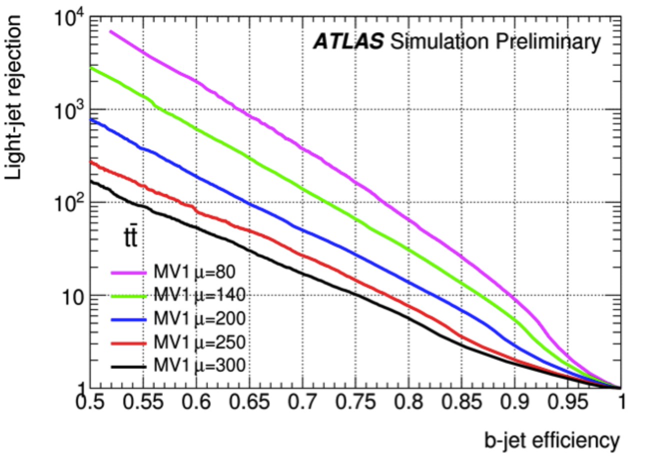
- b-tagging efficiency
- Jet energy resolution
- Missing E_T resolution

→ more granular detector

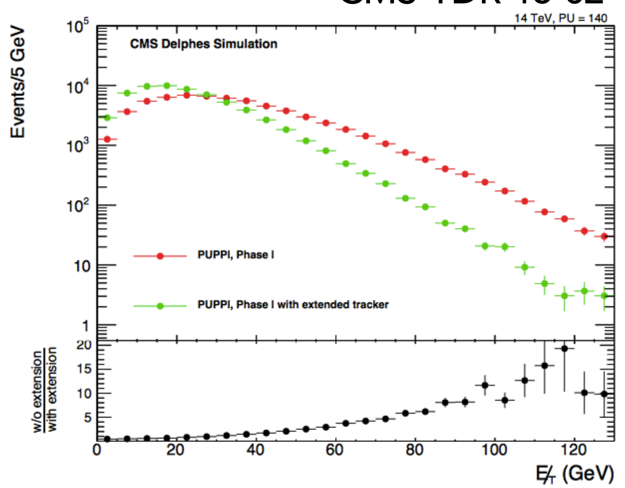
→ efficient PU subtraction methods (cf. PUPPI)

Bertolini et. al 1407.6013

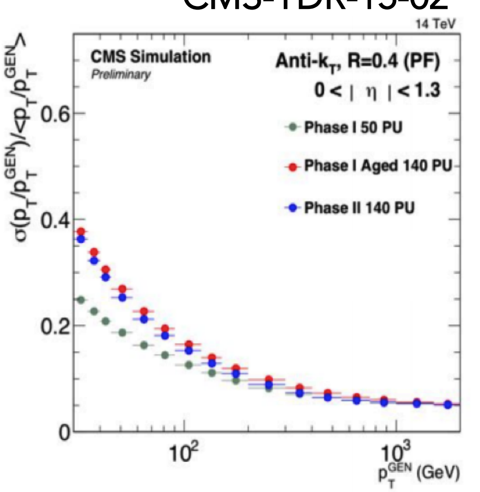
ATLAS-PHYS-PUB-2013-009



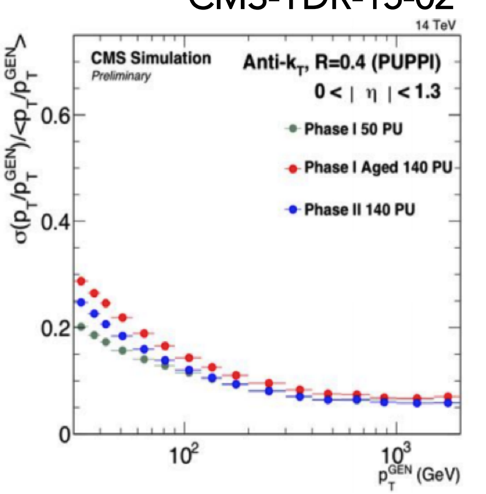
CMS-TDR-15-02



CMS-TDR-15-02



CMS-TDR-15-02

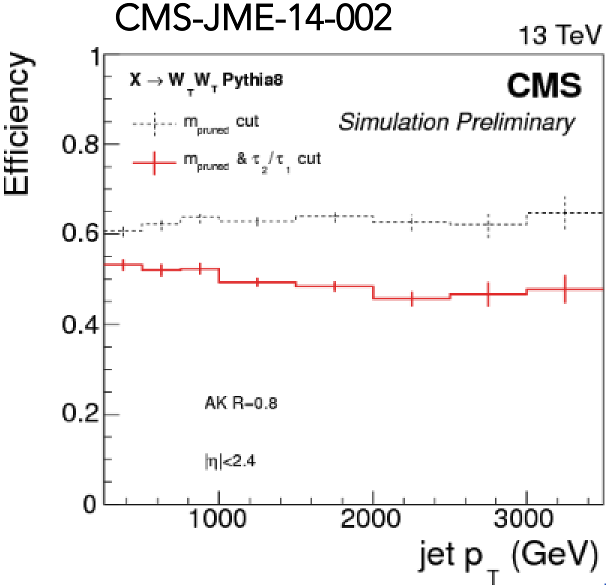


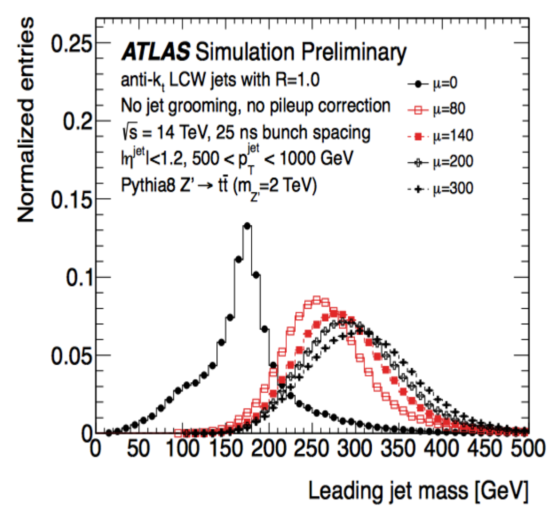
Exp. issues (high p_T)

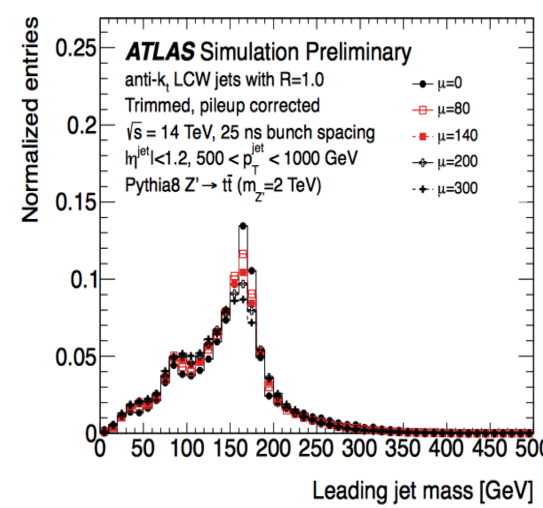
High luminosity comes with high p_T tops as well..

- Top decay products become more collimated:
  R (W,b) ~ 2 m / p_T (for ΔR ~ 0.4 for p_T=1 TeV) (cf. M. Spannowsky 'talk)
  → need jet substructure techniques, and high detector granularity
- At high top pT , less impact of pile-up on jet pT, but QCD and pile-up can affect other observables (ex: jet mass, shape)
  → need grooming techniques

CMS-JME-14-002







Top Measurements @ HL-LHC

Top studies

SM → BSM

mass	kinematics	(anomalous) couplings	FCNC rare decays	direct search
Inv mass	spin corr.	gtt	t→qZ	SUSY stops
EndPoint	A_{FB}	tWb(d/s)	t→qH	T-partners
J/Ψ	differentials	ttγ/Z	t→qg	Z'→t t
L_{xy}		ttH	(q = u/c)	...
cross sec.			t→W(d/s)	

Top studies

SM → BSM

mass
- Inv mass
- EndPoint
- J/Ψ
- L_{xy}
- cross sec.

kinematics
- spin corr.
- A_{FB}
- differentials

(anomalous) couplings
- gtt
- tWb(d/s)
- ttγ/Z
- ttH

FCNC rare decays
- $t \to qZ$
- $t \to qH$
- $t \to qg$
- $(q = u/c)$
- $t \to W(d/s)$

direct search
- SUSY stops
- T-partners
- $Z' \to t\ t$
- ...

The EFT approach

A Standard Model measurement can be seen as a search for deviation from D=4 SM lagrangian:

$$\mathcal{L}_{SM}^{(6)} = \mathcal{L}_{SM}^{(4)} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \ldots$$

Grzadkowsky et. al [1008.4884]

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu\varphi)^\star(\varphi^\dagger D_\mu\varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

- Valid for $m_t \ll \Lambda$
- Top anomalous (and flavour violating) couplings can be derived from EFT:

$$O_{uG\phi}^{33} = (\bar{q}_{L3}\lambda_a\sigma^{\mu\nu}t_R)\tilde{\phi}\, G_{\mu\nu}^a$$

$$\rightarrow \frac{g_s}{m_t}\bar{t}\sigma^{\mu\nu}(d_V + i d_A\gamma_5)\frac{\lambda_a}{2}t\, G_{\mu\nu}^a$$

g t t coupling

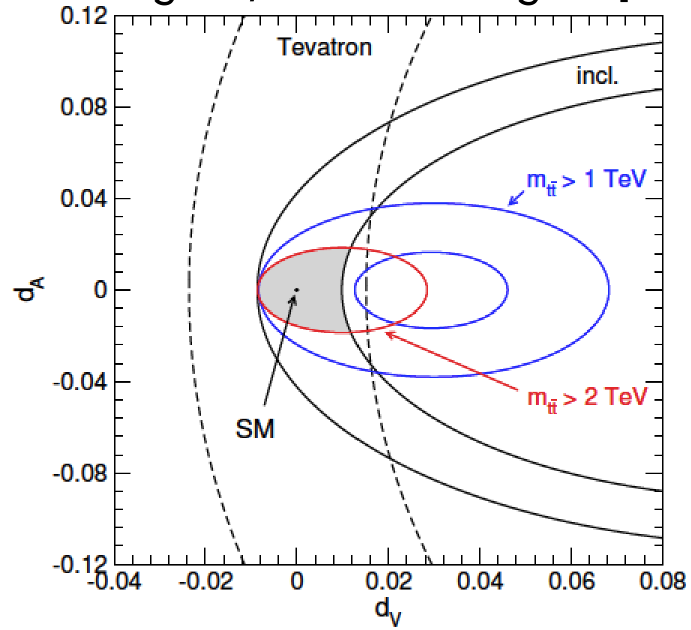
$$\mathcal{L}_{tg} = -g_s \bar{t}\gamma^\mu \frac{\lambda_a}{2} t\, G^a_\mu + \frac{g_s}{m_t} \bar{t}\sigma^{\mu\nu}(d_V + i d_A \gamma_5)\frac{\lambda_a}{2} t\, G^a_{\mu\nu}$$

SM (~ α_S)

BSM
SM via loop

Enhance chromo-electric/magnetic contribution by going at p > m_t

Aguilar, Fuks and Mangano [1412.6654]



Strategy:

- use boosted techniques to tag tops and reduce QCD background
- measure σ_{tt} **(m > 1(2) TeV) to constrain d_A and d_V**

see MLM's talk for 100 TeV projections ...

tWb coupling

enhance at $q > M_W$

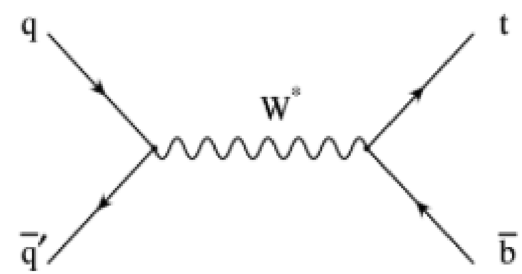
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + h.c.\,,$$

thanks to F. Demartin and G. Durieux

SM

- $V_L = V_{tb}$ in the SM
- **ΔV_{tb} ~ 5 % well constrained**
- **ΔV_{tb} ~ 2.5 % with 300 fb^{-1} (3 ab^{-1})**

Agashe et. al [1311.2028]

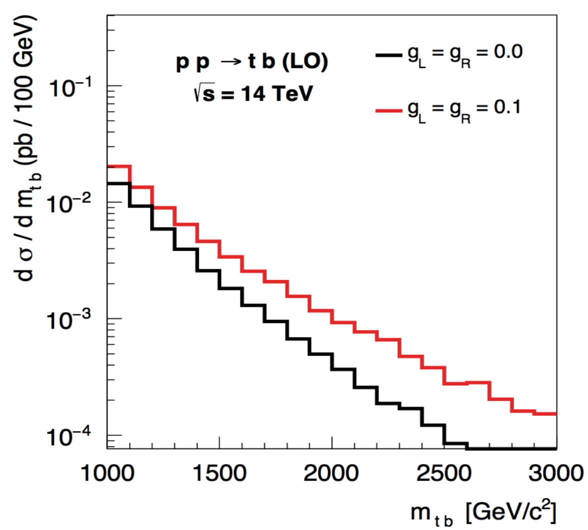


Strategy (*suggested by M.Mangano*):

- s-channel single top production perfect candidate
- **probe off-shell region $q^2 >> M_W^2$ by selecting events such that $m_{tb} > 1(2)$ TeV**

→ enhance sensitivity of cross section to g_L, g_R

→ reduce QCD backgrounds



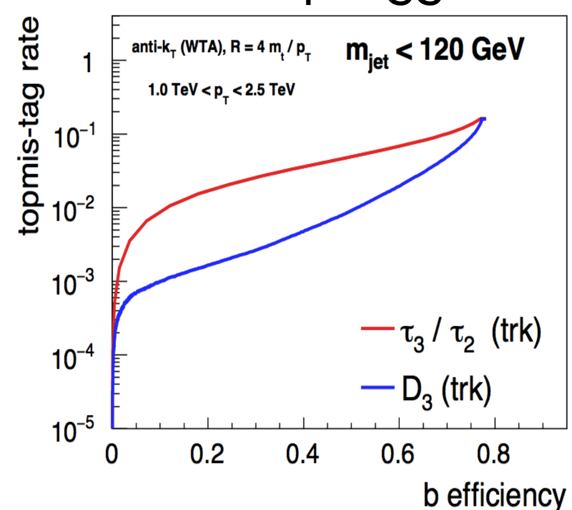
tWb coupling

- At m_{tb} > 1-2 TeV, top decay products will be very collimated, need boosted techniques, also b-tagging tricky, but possible
- Backgrounds: QCD (dijet), ttbar

<u>VERY PRELIMINARY (LO parton level) analysis</u>:

- 2 central jets, p_T > 600 GeV, |eta| < 2.0
- m_{jj} > 2 TeV
- 1 top-tagged (eff = 30% , mis = 0.1%)
- 1 b-tagged (eff = 50 (30)% , mis = 1(0.1)%) and *Anti-top tagged* (eff = 50(50)%, mis = 0.5(0.1)%)

Anti-top tagger



conservative

aggressive

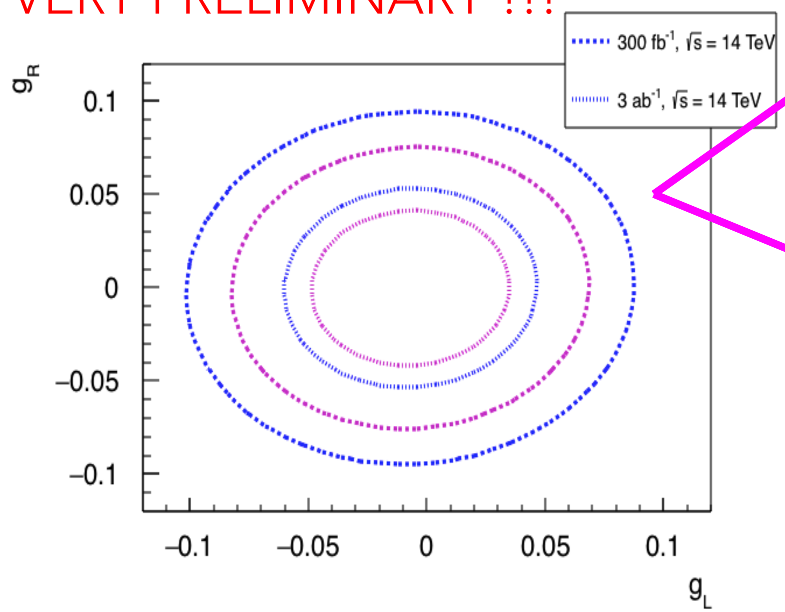
tWb coupling

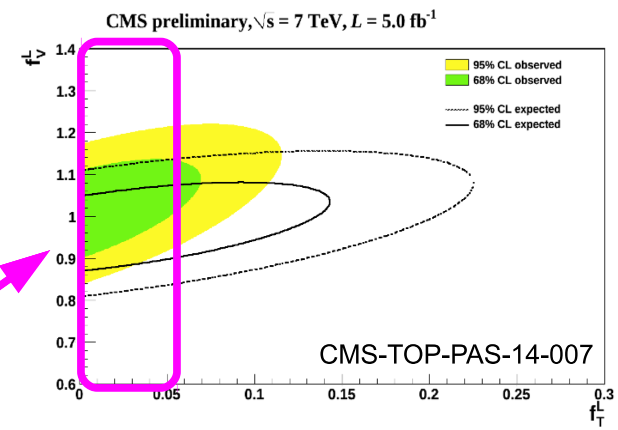
m_{tb} > 2 TeV	s-channel ST	ttbar	dijet
$\sigma_{fiducial}$ (fb)	82 (50) ab	105 (12) ab	750 (80) ab

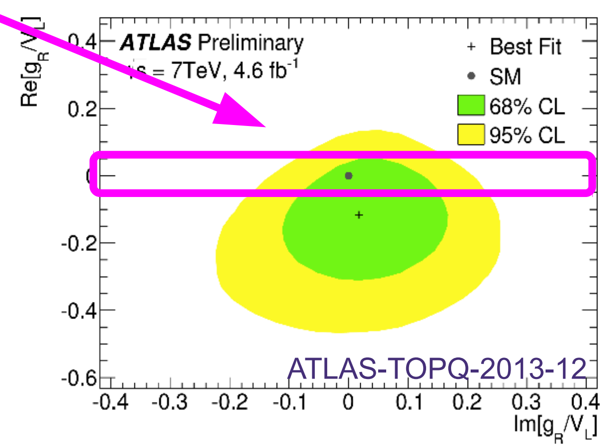
conservative
aggressive

$\Delta\sigma/\sigma_{stat}$ (300 fb^{-1})	$\Delta\sigma/\sigma_{stat}$ (3 ab^{-1})
68 (43) %	21 (13) %

VERY PRELIMINARY !!!







Can do better by:

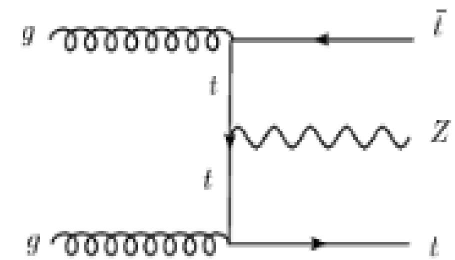
- going NLO
- include tW channel

ttZ coupling

enhance at $q \gg M_z$

$$\mathcal{L}_{t\bar{t}Z} = e\bar{u}(p_t)\left[\gamma^{\mu}(C^{Z}_{1,V} + \gamma_5 C^{Z}_{1,A}) + \frac{i\sigma^{\mu\nu}q_{\nu}}{M_Z}(C^{Z}_{2,V} + i\gamma_5 C^{Z}_{2,A})\right]v(p_{\bar{t}})Z_{\mu}$$

SM

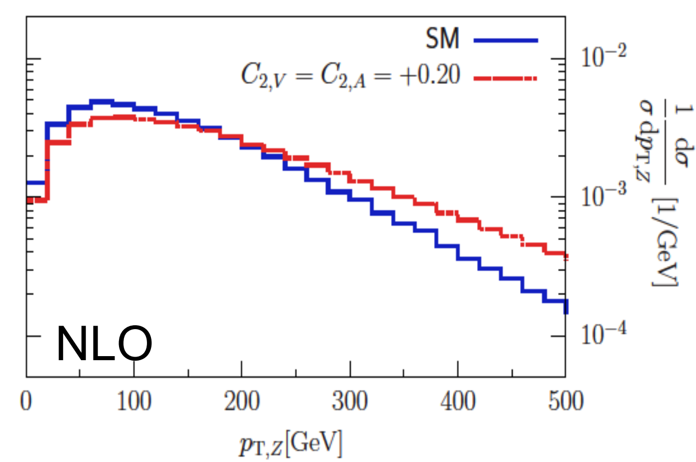


- $C^{Z}_{2,V} = 0.24$, $C^{Z}_{2,A} = -0.60$ in SM
- ttZ rate (x4) from 8 to 14 TeV

Strategy:

- process: t t Z production (no background!)
- when has significant boost, enhance sensitivity of cross section to $C^{Z}_{2,V}$, $C^{Z}_{2,A}$
- $\sigma_{ttZ} \sim 800$ fb^{-1}, but clean signal in 3 leptons, with $m_{ll} \sim m_Z$

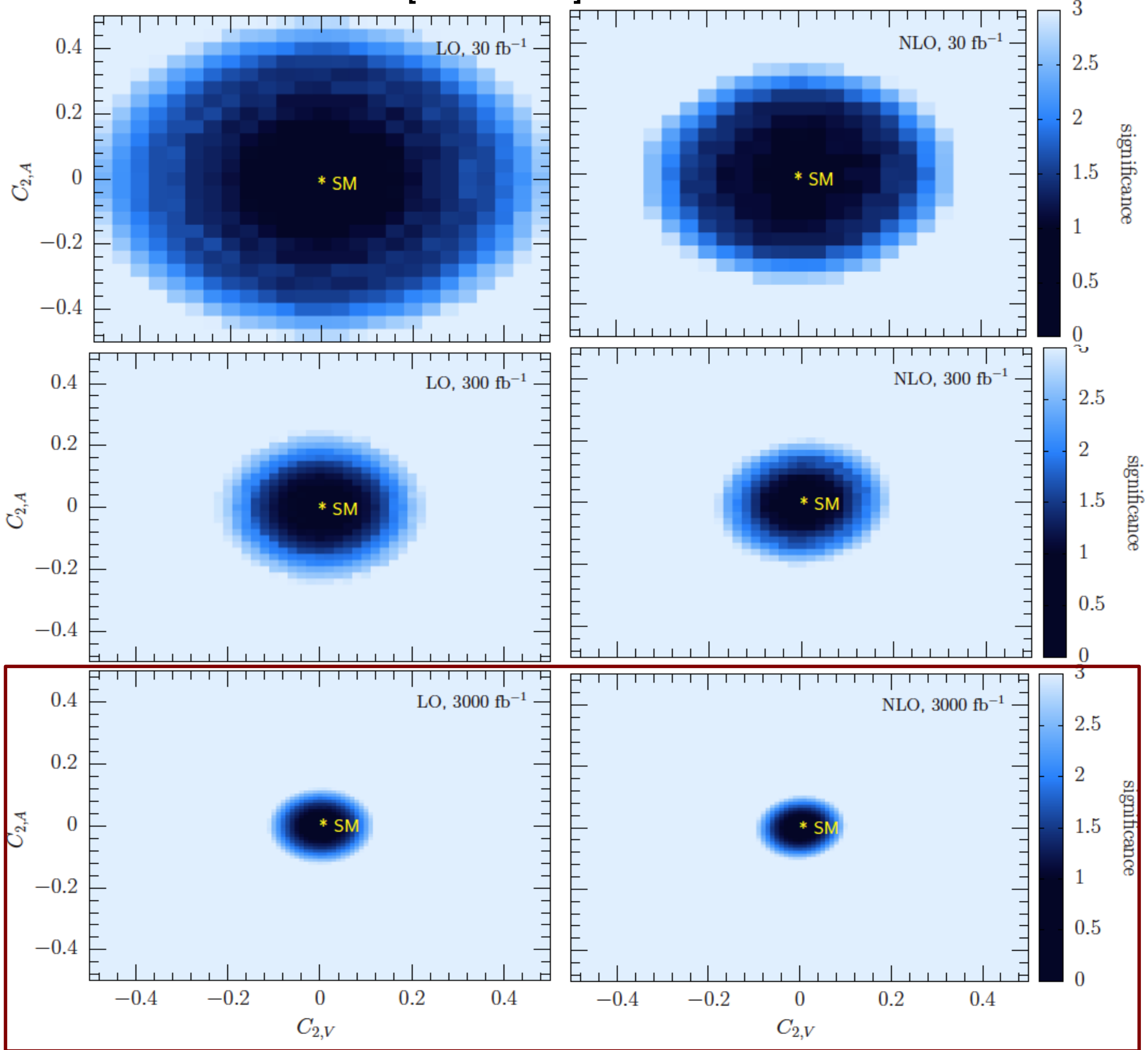
Rontsh and Shulze [1404.1005]



(see. M. Shulze's talk)

ttZ coupling

Rontsh and Shulze [1404.1005]



30 fb^{-1}

$|C^Z_{2,V}|, |C^Z_{2,A}| < 0.3$ @ 95% CL

300 fb^{-1}

$|C^Z_{2,V}|, |C^Z_{2,A}| < 0.15$ @ 95% CL

3000 fb^{-1}

$|C^Z_{2,V}|, |C^Z_{2,A}| < 0.08$ @ 95% CL

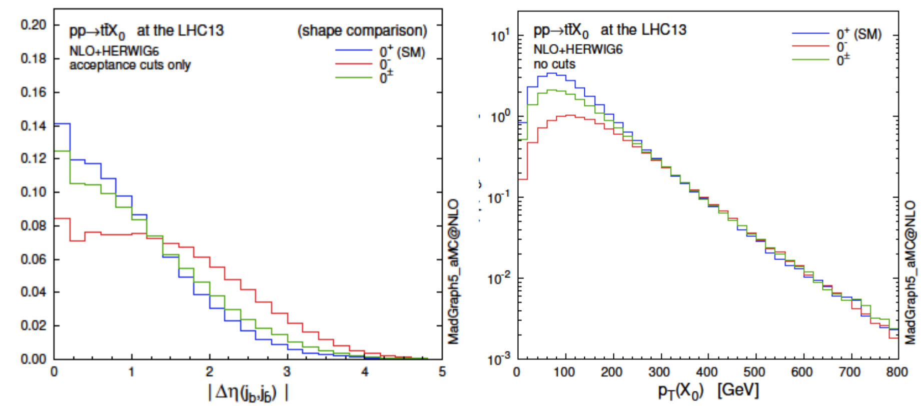
ttH

$$\mathcal{L}_{\rm ttH} = -\frac{g_w m_t}{2M_w}\ \bar{t}(a + ib\gamma^5)t\ H$$

- ttH not observed yet at the LHC
- $\sigma_{\rm ttH} \sim 700\ {\rm fb}^{-1}$ @14 TeV
- Eventually, sensitivity driven by

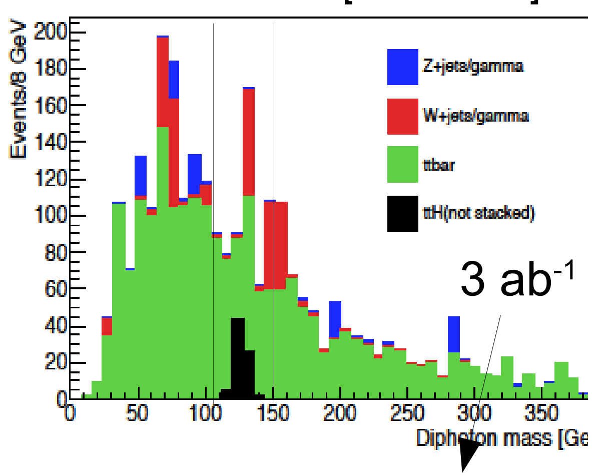
  $H \rightarrow \gamma\gamma$ (almost syst. free)

Demartin, Maltoni, Mawatari and Zaro [1407.5089]

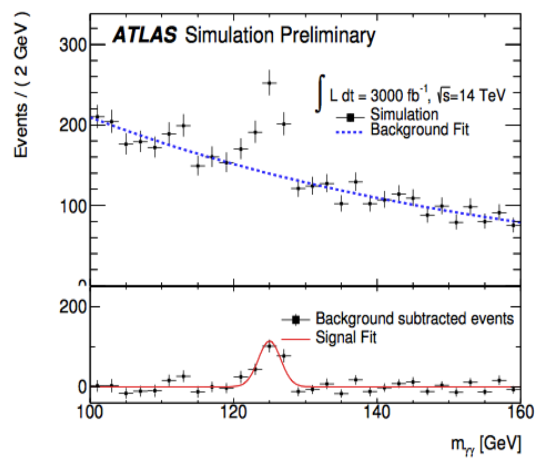


rate/shape sensitive to CP-structure of the coupling

Adelman et. al [1308.5274]

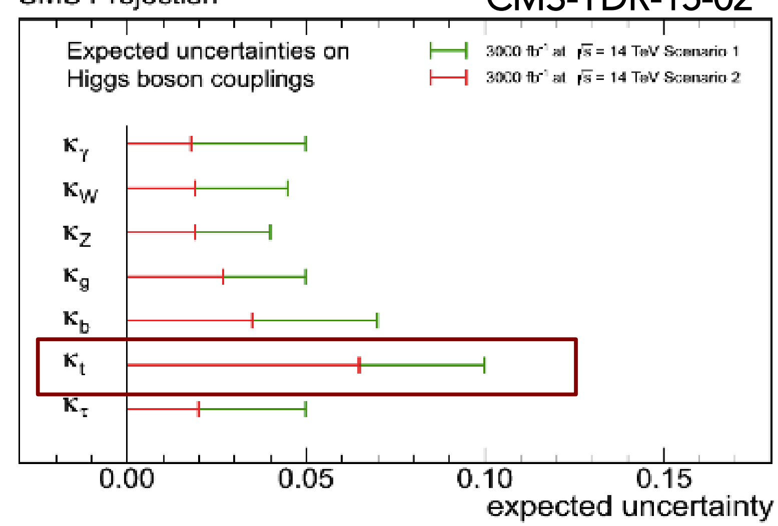


ATL-PHYS-PUB-2014-012



CMS Projection

CMS-TDR-15-02



$\Delta\sigma/\sigma_{\rm stat}$ (3 ab $^{-1}$)	$\Delta y_t/y_t\,{\rm stat}$ (3 ab $^{-1}$)
25 %	15 %

Top FCNCs

- FCNC appear through loop correction in the SM, and are heavily suppressed by GIM
- Can probe through flavour violating couplings in EFT:

$$
\begin{aligned}
-\mathcal{L}_{eff} \;&= \frac{g}{2c_W} X_{qt}\bar{q}\gamma_\mu(x^L_{qt}P_L + x^R_{qt}P_R)tZ^\mu + \frac{g}{2c_W}X_{qt}\kappa_{qt}\bar{q}(\kappa^v_{qt} + \kappa^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t}tZ_\mu \\
&+ e\lambda_{qt}\bar{q}(\lambda^v_{qt} + \lambda^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t}tA^\mu + g_s\zeta_{qt}\bar{q}(\zeta^v_{tq} + \zeta^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t}T^a qG^{a\mu} \\
&+ \frac{g}{2\sqrt{2}}g_{qt}\bar{q}(g^v_{qt} + g^a_{qt}\gamma_5)tH + h.c.
\end{aligned}
$$

- Any measurable BR is a compelling indication for new physics

Agashe et. al [1311.2028]

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

Top FCNCs

- FCNC appear through loop correction in the SM, and are heavily suppressed by GIM
- Can probe through flavour violating couplings in EFT:

$$
\begin{aligned}
-\mathcal{L}_{eff} \;=\; & \frac{g}{2c_W} X_{qt}\bar{q}\gamma_\mu (x_{qt}^L P_L + x_{qt}^R P_R) t Z^\mu + \frac{g}{2c_W} X_{qt}\kappa_{qt}\bar{q}(\kappa_{qt}^v + \kappa_{qt}^a\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t Z_\mu \\
& + e\lambda_{qt}\bar{q}(\lambda_{qt}^v + \lambda_{qt}^a\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t A^\mu + g_s\zeta_{qt}\bar{q}(\zeta_{tq}^v + \zeta_{qt}^a\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} T^a q G^{a\mu} \\
& + \frac{g}{2\sqrt{2}} g_{qt}\bar{q}(g_{qt}^v + g_{qt}^a\gamma_5) t H + h.c.
\end{aligned}
$$

Aguilar-Saavedra [0811.3842]

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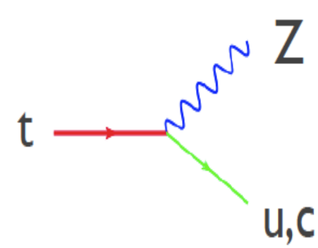
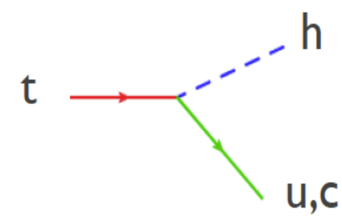
Agashe et. al [1311.2028]

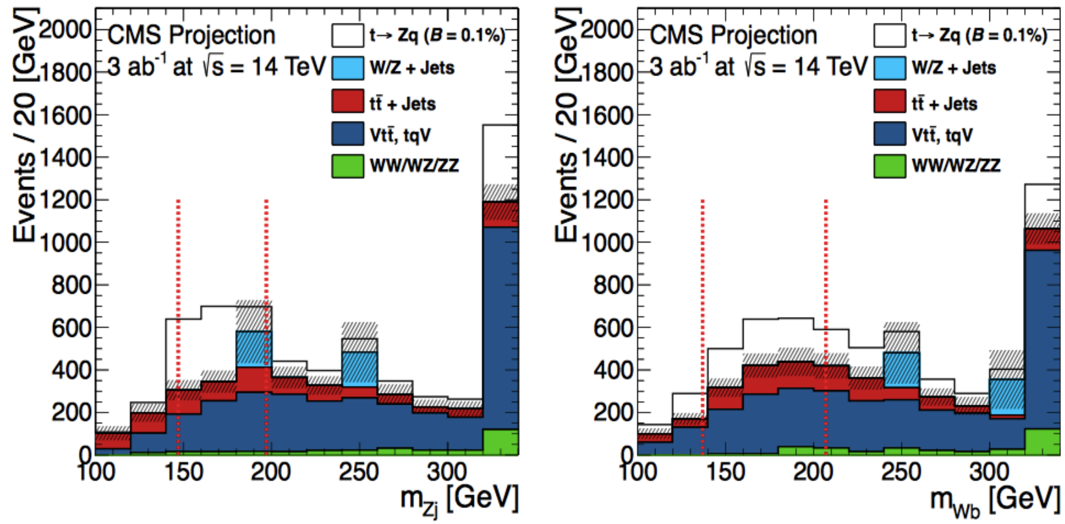
Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\lesssim 10^{-7}$	$\lesssim 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\lesssim 10^{-6}$	$\lesssim 10^{-10}$	$\lesssim 10^{-7}$	$\lesssim 10^{-6}$	$\lesssim 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\lesssim 10^{-7}$	$\lesssim 10^{-6}$	–
$t \to gc$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





$t \to Z q$

CMS-FTR-13-016



Signal: $t\,t \to W\,b\,Z\,q$

Backgrounds: tt, VV, ttV

Selection:

- 3 leptons + MET + 2 jets (1 btag)
- m (Z j) ~ m_{top}
- m (W b) ~ m_{top}

Systematics

Uncertainty (%)	19.5 fb^{-1} @ 8 TeV	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Jet energy scale	13.5	3.5	3.4
$\not\!\!E_T$ resolution	3.2	3.2	3.2
MC Statistics	5.3	1.4	1.3
σ(tqZ)/ σ($Vt\bar{t}$)	3.1	1.0	0.8
b-tagging	17.7	4.5	4.2
Total	23	7	7

< 0.05 %

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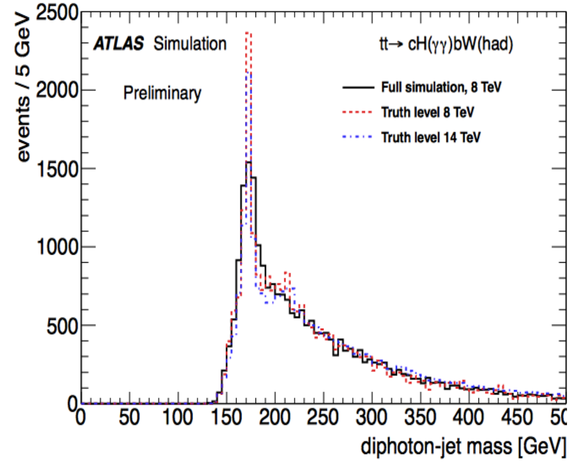
$\mathcal{B}(t \to Zq)$	19.5 fb^{-1} @ 8 TeV	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Exp. bkg. yield	3.2	26.8	268
Expected limit	< 0.10%	< 0.027%	< 0.010%
1 σ range	0.06 – 0.13%	0.018 – 0.038%	0.007 – 0.014%
2 σ range	0.05 – 0.20%	0.013 – 0.051%	0.005 – 0.020%

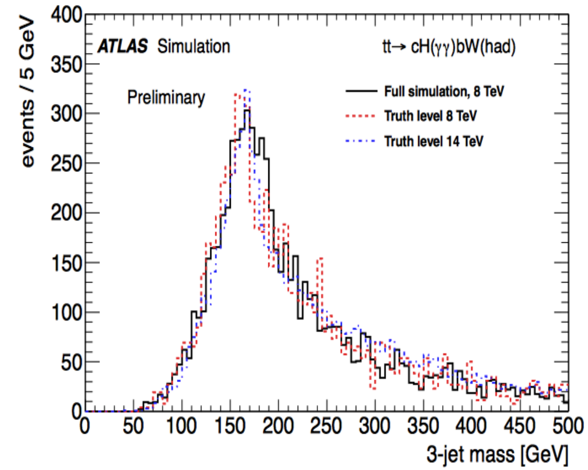
t → c H

ATLAS-PHYS-PUB-2013-012

Signal: t t → $t_{lep(had)}$ c γγ

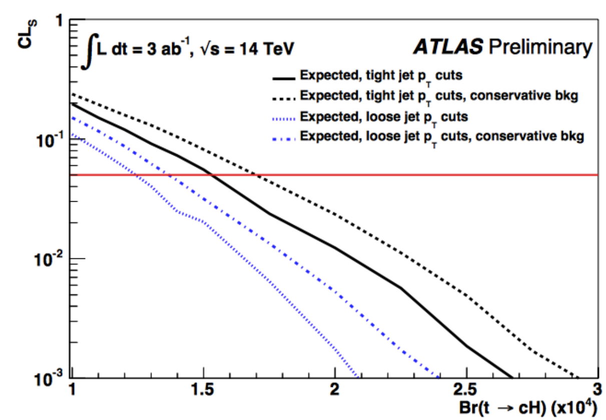
Backgrounds: ttH, W/Z+ jets, γγ+jets

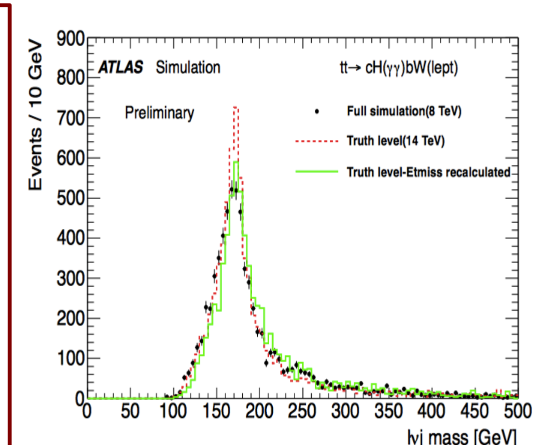




Selection:

- 4 jets (1 b) + 2 photons (had)
- > 2 jets (1b), 2 photons (lep)
- m (c H) ~ m_{top}
- m (W b) ~ m_{top}





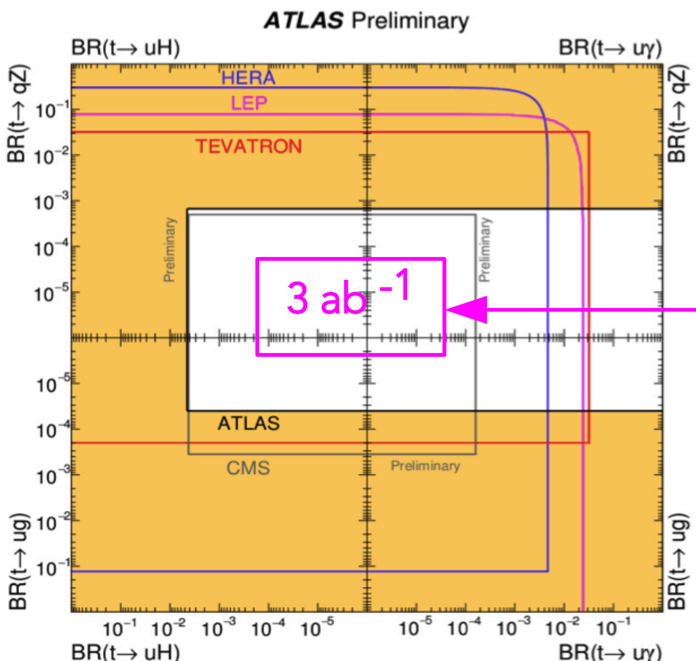
Yields

		Expected FCNC signal	SM sources	Background
std cuts	Hadronic events	34	61	1750
	Leptonic events	11	21	37
tight cuts	Hadronic events	13	24	350
	Leptonic events	7	14	25

B(t→ c H) < 1.5 10^{-4}

Other FCNC's

Current limits



K Skopven's talk

Future limits

Process	Br Limit	Search	Dataset
$t \to Zq$	2.2×10^{-4}	ATLAS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	300 fb^{-1}, 14 TeV
$t \to Zq$	7×10^{-5}	ATLAS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	3000 fb^{-1}, 14 TeV
$t \to Zq$	$5\,(2) \times 10^{-4}$	ILC single top, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 250 GeV
$t \to Zq$	$1.5\,(1.1) \times 10^{-4\,(-5)}$	ILC single top, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 500 GeV
$t \to Zq$	$1.6\,(1.7) \times 10^{-3}$	ILC $t\bar{t}$, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 500 GeV
$t \to \gamma q$	8×10^{-5}	ATLAS $t\bar{t} \to Wb + \gamma q$	300 fb^{-1}, 14 TeV
$t \to \gamma q$	2.5×10^{-5}	ATLAS $t\bar{t} \to Wb + \gamma q$	3000 fb^{-1}, 14 TeV
$t \to \gamma q$	6×10^{-5}	ILC single top	500 fb^{-1}, 250 GeV
$t \to \gamma q$	6.4×10^{-6}	ILC single top	500 fb^{-1}, 500 GeV
$t \to \gamma q$	1.0×10^{-4}	ILC $t\bar{t}$	500 fb^{-1}, 500 GeV
$t \to gu$	4×10^{-6}	ATLAS $qg \to t \to Wb$	300 fb^{-1}, 14 TeV
$t \to gu$	1×10^{-6}	ATLAS $qg \to t \to Wb$	3000 fb^{-1}, 14 TeV
$t \to gc$	1×10^{-5}	ATLAS $qg \to t \to Wb$	300 fb^{-1}, 14 TeV
$t \to gc$	4×10^{-6}	ATLAS $qg \to t \to Wb$	3000 fb^{-1}, 14 TeV
$t \to hq$	2×10^{-3}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \ell\ell qX$	300 fb^{-1}, 14 TeV
$t \to hq$	5×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \ell\ell qX$	3000 fb^{-1}, 14 TeV
$t \to hq$	5×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \gamma\gamma q$	300 fb^{-1}, 14 TeV
$t \to hq$	2×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \gamma\gamma q$	3000 fb^{-1}, 14 TeV

Agashe et. al [1311.2028]

Summary and outlook

HL-LHC comes with important experimental challenges and opportunities:

- pile-up
- high p_T events

$\rightarrow$ In order to maintain present performance need to extend capabilities of our detector

HL-LHC will deliver up billions of tops:

$\rightarrow$ great opportunity to challenge the SM by measuring as best as we can:

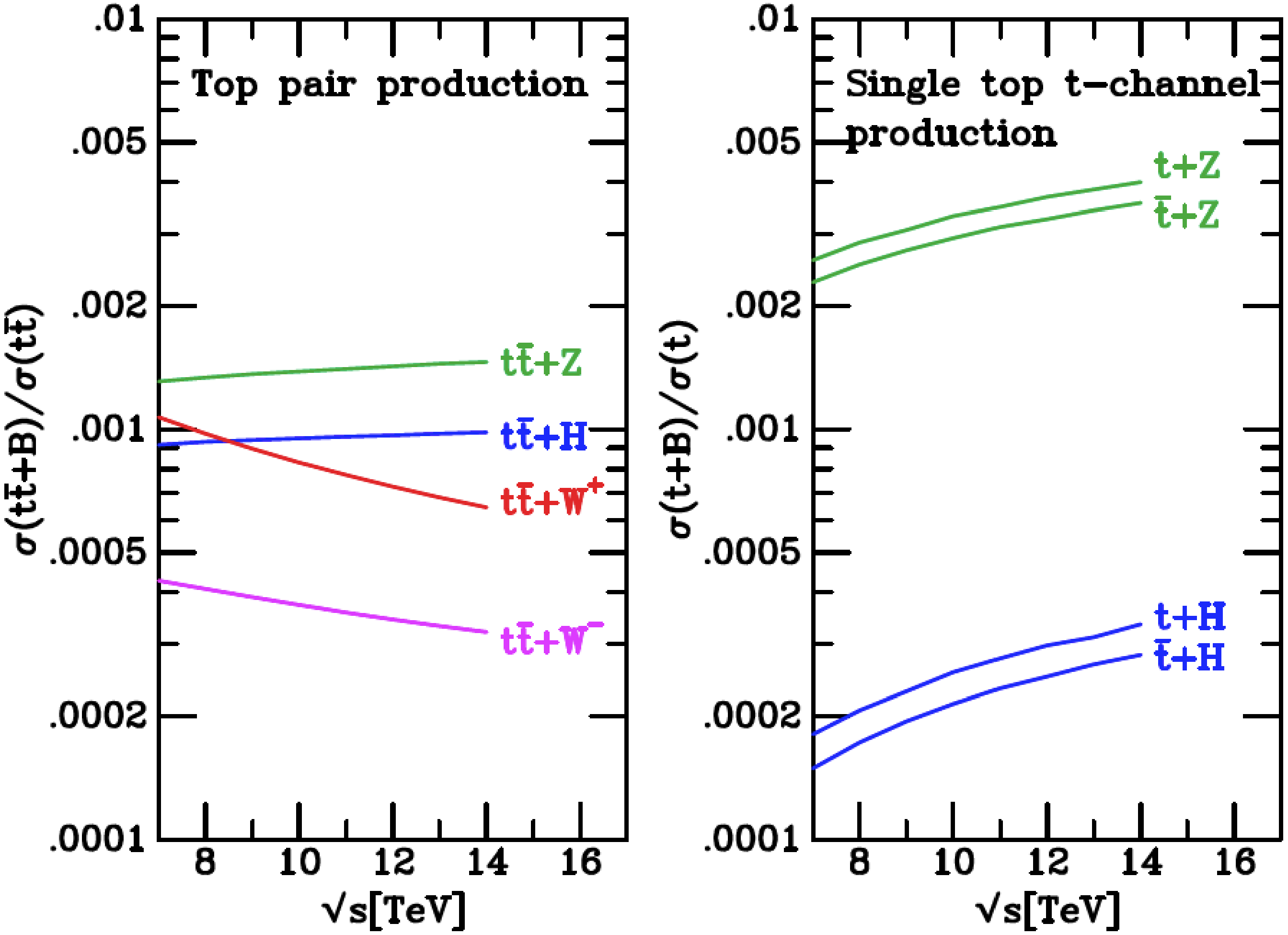
- top properties (mass, couplings, FW-BW asym., spin correlation , etc...)
- rare decays (FCNC, t$\rightarrow$ Ws/d, tZ, tH, V V $\rightarrow$ t t)
- explore new ideas in the boosted regime to enhance sensitivity to anomalous couplings (cf. ttg, tWb ..)

More info on SnowMass reports: [1311.2028], [1308.5274]

Thanks !

Backup

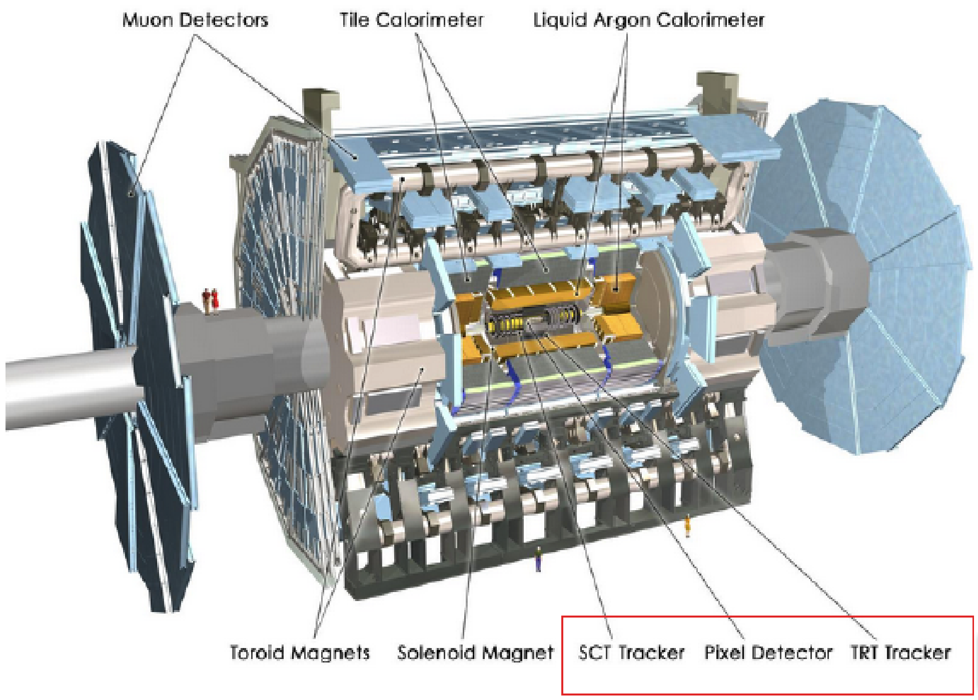
Rare top processes

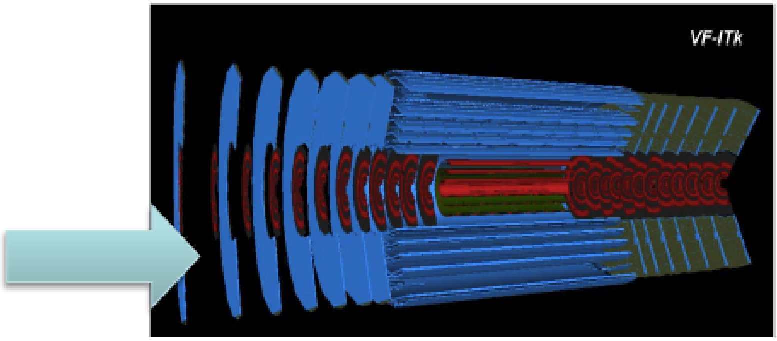


ATLAS Phase II upgrades

- Essential to upgrade ATLAS
  - Mitigate radiation damage
  - Cope with higher pile-up
  - Maintain or improve performance

- Main upgrades towards HL-LHC
  - Read-out electronics and DAQ
  - Updated trigger system
    - Finer granularity
    - Two hardware trigger levels (L0\L1)
    - Tracking in lower level trigger
  - New forward muon detectors
  - **New inner tracking detector**





CMS Phase II upgrades

Muon System
- new DT FE electronics, CSC FEBs in inner rings
- extended η region (GEM & iRPC)
- investigate Muon-tagging up to η ~ 3

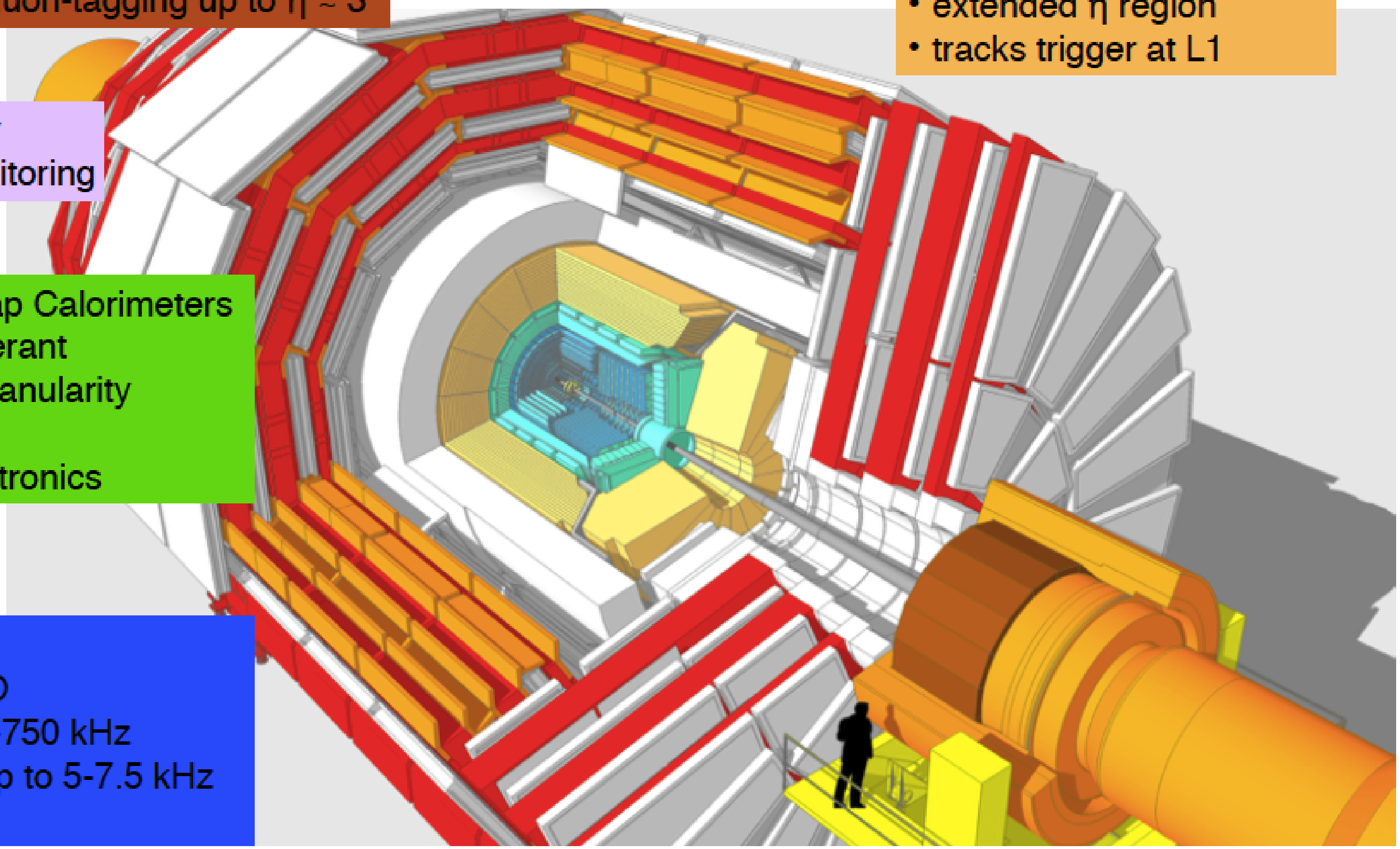
Tracker
- higher granularity
- less material
- better p_T resolution
- extended η region
- tracks trigger at L1

New luminosity and beam monitoring

Replace Endcap Calorimeters
- radiation tolerant
- increased granularity

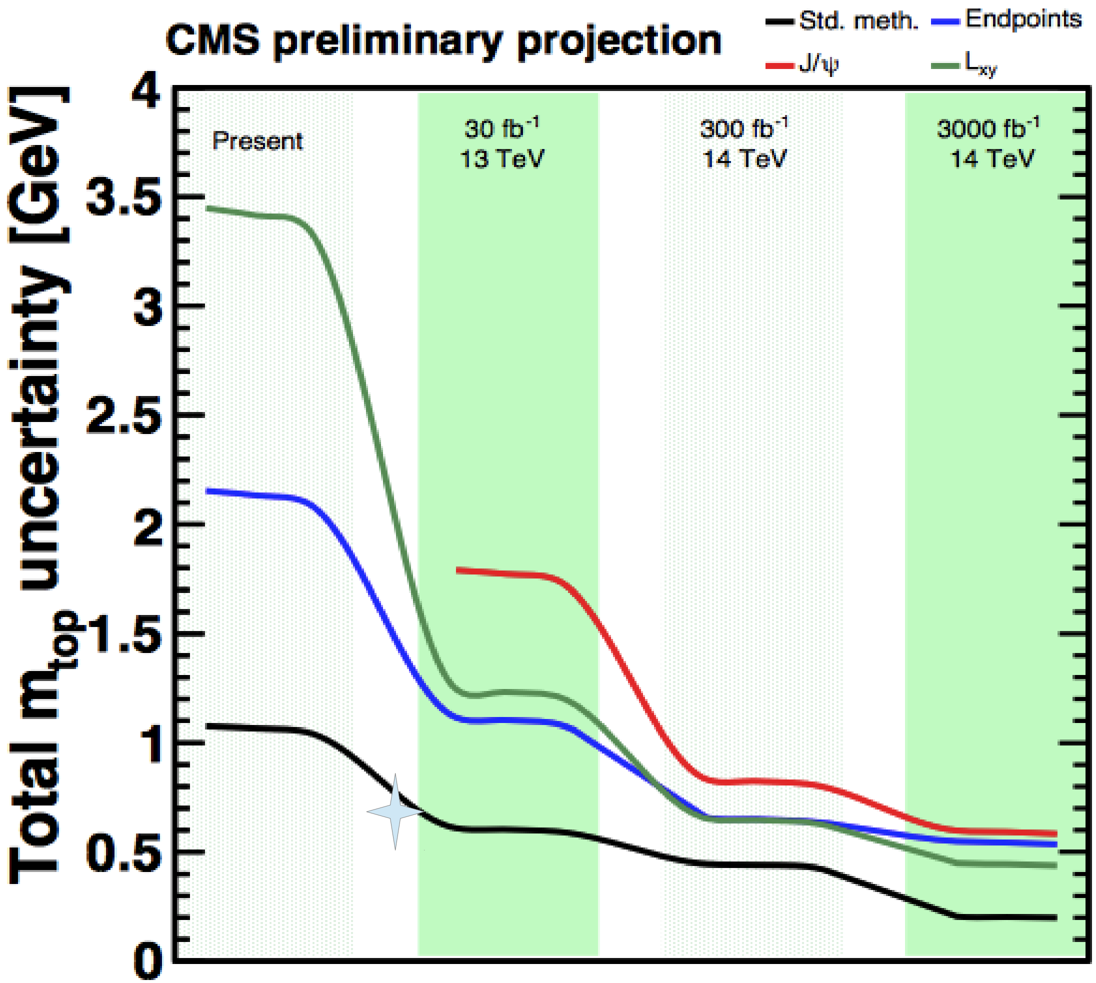
Barrel ECAL
- new FE electronics

Trigger/DAQ
- new FE & RO
- L1 up to 500-750 kHz
- HLT output up to 5-7.5 kHz
- tracking @L1



M. Klute

Top Mass


CMS preliminary projection
Std. meth.
Endpoints
J/ψ
L_xy
Present
30 fb-1
13 TeV
300 fb-1
14 TeV
3000 fb-1
14 TeV
Total m_top uncertainty [GeV]
0
0.5
1
1.5
2
2.5
3
3.5
4

$t\bar{t}\gamma/t\bar{t}Z$

Collider	LHC		ILC/CLIC
CM Energy [TeV]	14	14	0.5
Luminosity [fb^{-1}]	300	3000	500
SM Couplings			
photon, F_{1V}^{γ} (0.666)	0.042	0.014	0.002
Z boson, F_{1V}^{Z} (0.24)	0.50	0.17	0.003
Z boson, F_{1A}^{Z} (0.6)	0.058	–	0.005
Non-SM couplings			
photon, F_{1A}^{γ}	0.05	–	–
photon, F_{2V}^{γ}	0.037	0.025	0.003
photon, F_{2A}^{γ}	0.017	0.011	0.007
Z boson, F_{2V}^{Z}	0.25	0.17	0.006
Z boson, ReF_{2A}^{Z}	0.35	0.25	0.008
Z boson, ImF_{2A}^{Z}	0.035	0.025	0.015

Table 1-5. *Expected precision of the top quark coupling measurements to the photon and the Z boson at the LHC [62, 31] and the linear collider [22]. Expected magnitude of such couplings in the SM is shown in brackets. Note that the "non-standard model" couplings appear in the Standard Model through radiative corrections; their expected magnitude, therefore, is 10^{-2}.*