Top asymmetries & New physics
moving forward or backward?

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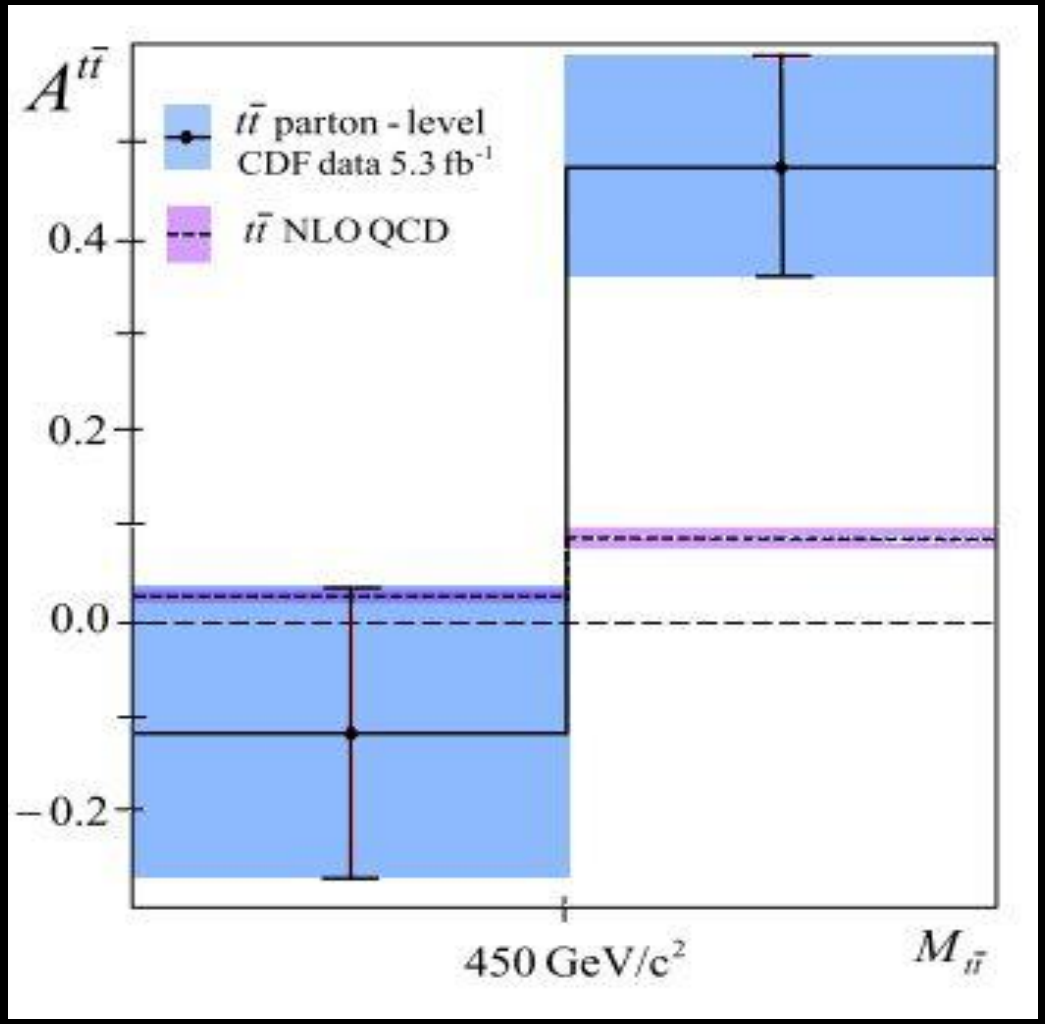
forward?



A_{FB}~50%

CDF on Jan'11

or backward?

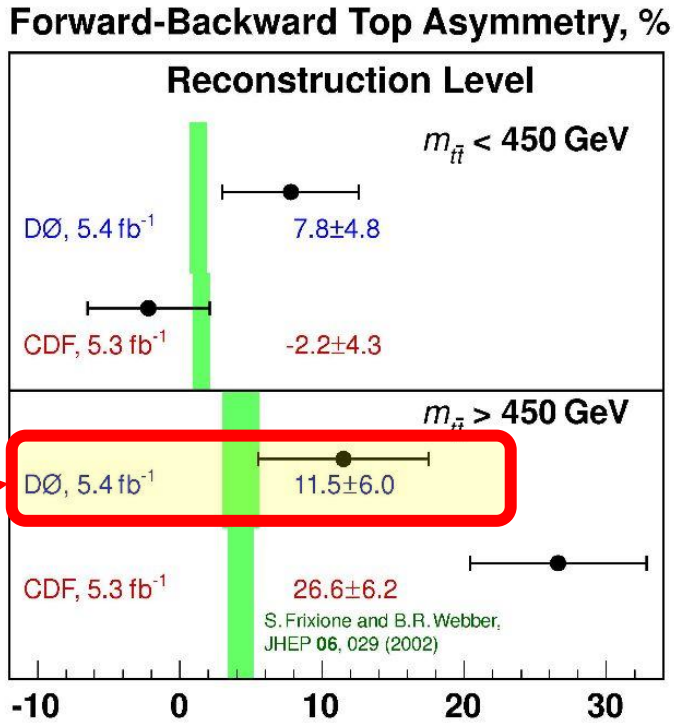
CDF10807 on Mar '12

		CDF Run II Preliminary L = 8.7 fb^{-1}	
Parton Level NLO (QCD+EW) $t\bar{t}$		5.3 fb^{-1}	8.7 fb^{-1}
$\lvert\Delta y\rvert$	A_{FB}	A_{FB} ($\pm$[stat.+syst.])	A_{FB} ($\pm$[stat.+syst.])
Inclusive	0.066	0.158 $\pm$ 0.074	0.162 $\pm$ 0.047
< 1.0	0.043	0.026 $\pm$ 0.118	0.088 $\pm$ 0.047
≥ 1.0	0.139	0.611 $\pm$ 0.256	0.433 $\pm$ 0.109
Parton Level NLO (QCD+EW) $t\bar{t}$		5.3 fb^{-1}	8.7 fb^{-1}
$M_{t\bar{t}}$	A_{FB}	A_{FB} ($\pm$[stat.+syst.])	A_{FB} ($\pm$[stat.+syst.])
$< 450\text{GeV}/c^2$	0.047	-0.116 $\pm$ 0.153	0.078 $\pm$ 0.054
$\geq 450\text{GeV}/c^2$	0.100	0.475 $\pm$ 0.112	0.296 $\pm$ 0.067

TABLE XIX: Differential parton level asymmetries compared to t

CDF measurement went down

DO much smaller
(but not unfolded...)



Why is top AFB interesting?

- Naturalness: top quark feels EWSB with o(1) strength → non-SM behavior expected

  (caveat: up quark *a priori* insensitive to NP)

- QCD prediction is suppressed ~o(α_s)

  → "clean" measurement

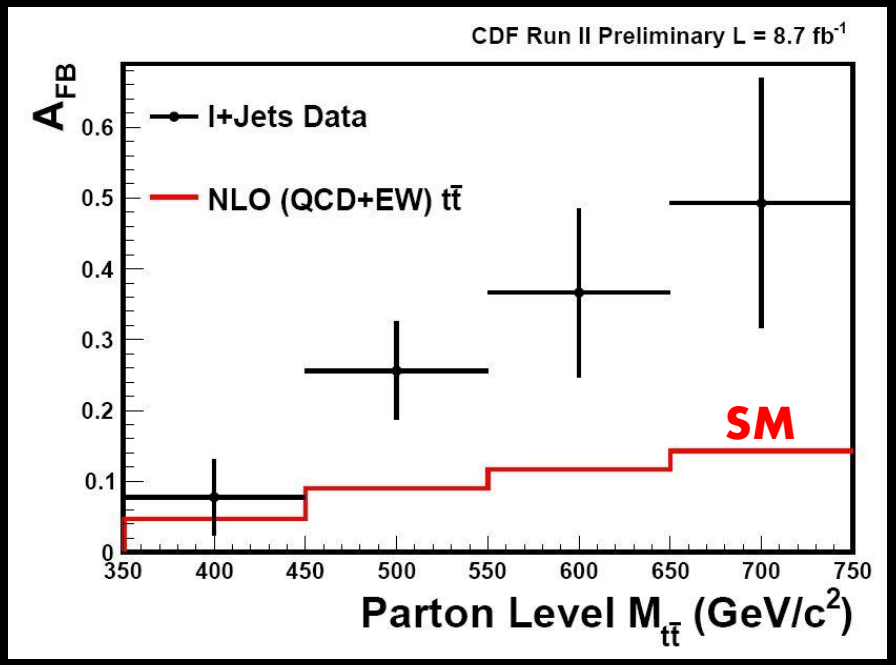
- After 2 years of LHC NP's still out of sight, so any indirect evidence is worth exploring…

  top A_{FB} = most significant "anomaly" we have

Tevatron facts

As observed in several channels:

"tops fly forward, even more at higher energies"



CDF+DO results: $A_{FB}^{\text{inclusive}} \approx (18\pm4)\%$ *in ttbar rest frame*

post-Moriond 2012 $A_{FB}^{>450\text{GeV}} \approx (28\pm6)\%$

QCD+EW state of the art: $A_{FB}^{[\text{incl}|>450]} \approx [6.6|10]\% \pm??$

$\rightarrow \sim 3\sigma$ tension **Q: *is it new physics?***

Could there be experimental mistake(s)?

- yes, in principle. But effect observed in different channels (l+j & dil) by CDF&DO at inclusive level

  (not to mention lepton asymmetries)

- "I heard DO's disproving CDF at differential level?"

  well, careful. DO did not provide parton level data!

Reconstructed level CDF Run II Preliminary L = 8.7 fb^{-1}

$M_{t\bar{t}}$	Data A_{FB} (± [stat.+syst	NLO (QCD+EW) $t\bar{t}$
$< 450\text{GeV}/c^2$	0.025 ± 0.031	
$450 - 550\text{GeV}/c^2$	0.174 ± 0.051	
$550 - 650\text{GeV}/c^2$	0.194 ± 0.087	
$\geq 650\text{GeV}/c^2$	0.384 ± 0.132	
	Data	
Slope $\alpha_{M_{t\bar{t}}}$ of Best-Fit Line	$(11.2 \pm 3.1) \times 10^{-}$	

Parton level CDF Run II Preliminary L = 8.7 fb^{-1}

Parton Level $M_{t\bar{t}}$	Data A_{FB} (± stat. ± syst.)	NLO (QCD+EW) $t\bar{t}$ A_{FB}
$< 450\text{GeV}/c^2$	$0.078 \pm 0.048 \pm 0.024$	0.047
$450 - 550\text{GeV}/c^2$	$0.256 \pm 0.063 \pm 0.028$	0.090
$550 - 650\text{GeV}/c^2$	$0.366 \pm 0.085 \pm 0.083$	0.117
$\geq 650\text{GeV}/c^2$	$0.493 \pm 0.159 \pm 0.076$	0.143
$< 450\text{GeV}/c^2$	$0.078 \pm 0.048 \pm 0.024$	0.047
$\geq 450\text{GeV}/c^2$	$0.296 \pm 0.059 \pm 0.031$	0.100
	Data	NLO (QCD+EW) $t\bar{t}$
Slope $\alpha_{M_{t\bar{t}}}$ of Best-Fit Line	$(15.6 \pm 5.0) \times 10^{-4}$	3.3×10^{-4}

o(1) "unfolding factor"

(not as much in the error bars)

Could it be QCD(+EW)?

- CP invariant top dynamics: $A_{FB} = A_C$ (charge asymetry)
- $\mathcal{L}_{QCD}$ is C (&P) invariant: A_{FB} arises @higher-orders

$$A_{FB}^{QCD} = \frac{\alpha_s^3 \sigma_A^{(0)} + \alpha_s^4 \sigma_A^{(1)} + \dots}{\alpha_s^2 \sigma_S^{(0)} + \alpha_s^3 \sigma_S^{(1)} + \dots} \simeq \alpha_s \frac{\sigma_A^{(0)}}{\sigma_S^{(0)}}$$

- Use LO or NLO cross-section? experiments use NLO
  A_{FB} **under**estimated by ~30-40% = estimate of TH error

- NNLO isn't known yet *(ask A.Mitov)* but large log from extra soft gluon emission has been resummed:

[NLO+NLL] *Almeida, Sterman & Vogelsang '08*
[NLO+NNLL] *Ahrens et al. '10-11 | Kidonakis '11*

→ small effects ~10%

Rest of talk

Disclaimer 1:

"I won't cover all viable top A_{FB} models in the literature"

See *e.g.* Inspire & Refs therein…

Disclaimer 2:

"I won't cover lepton asymmetries,
nor tricks to decouple A_C from A_{FB}"

Ask *e.g.* Gilad, Jernej, Alex, Jure & Jure

Rest of talk

"anomalous A_{FB} is an indirect sign of new physics"

- model independent lessons straight from data

- generic lessons for "hard" new physics
- generic LHC predictions from "hard" new physics

- what does A_{FB} tell us about naturalness?
  - Compositeness @TeV scale

Model independent lesson

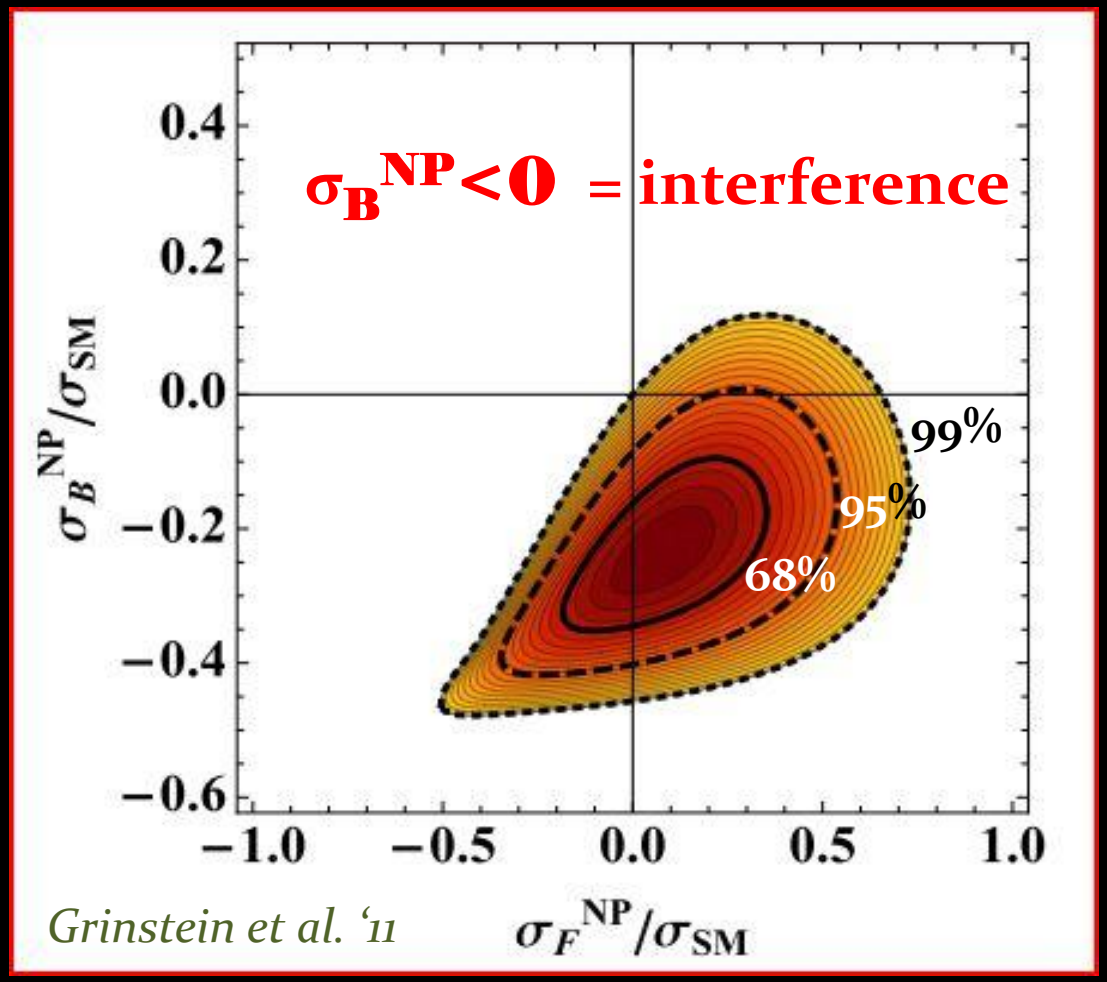
fit to A_{FB} & Xsec data (m_{tt}>450GeV)

Xsec=**F+B**
A_{FB}=**F-B**

data:
F+B~0
F-B>0

↓

B<0 !



"New physics (tree) amplitude better interferes with LO QCD"

Model independent lesson

fit to A_{FB} & Xsec data (m_{tt}>450GeV)

Xsec=**F+B**
A_{FB}=**F-B**

data:
F+B~0
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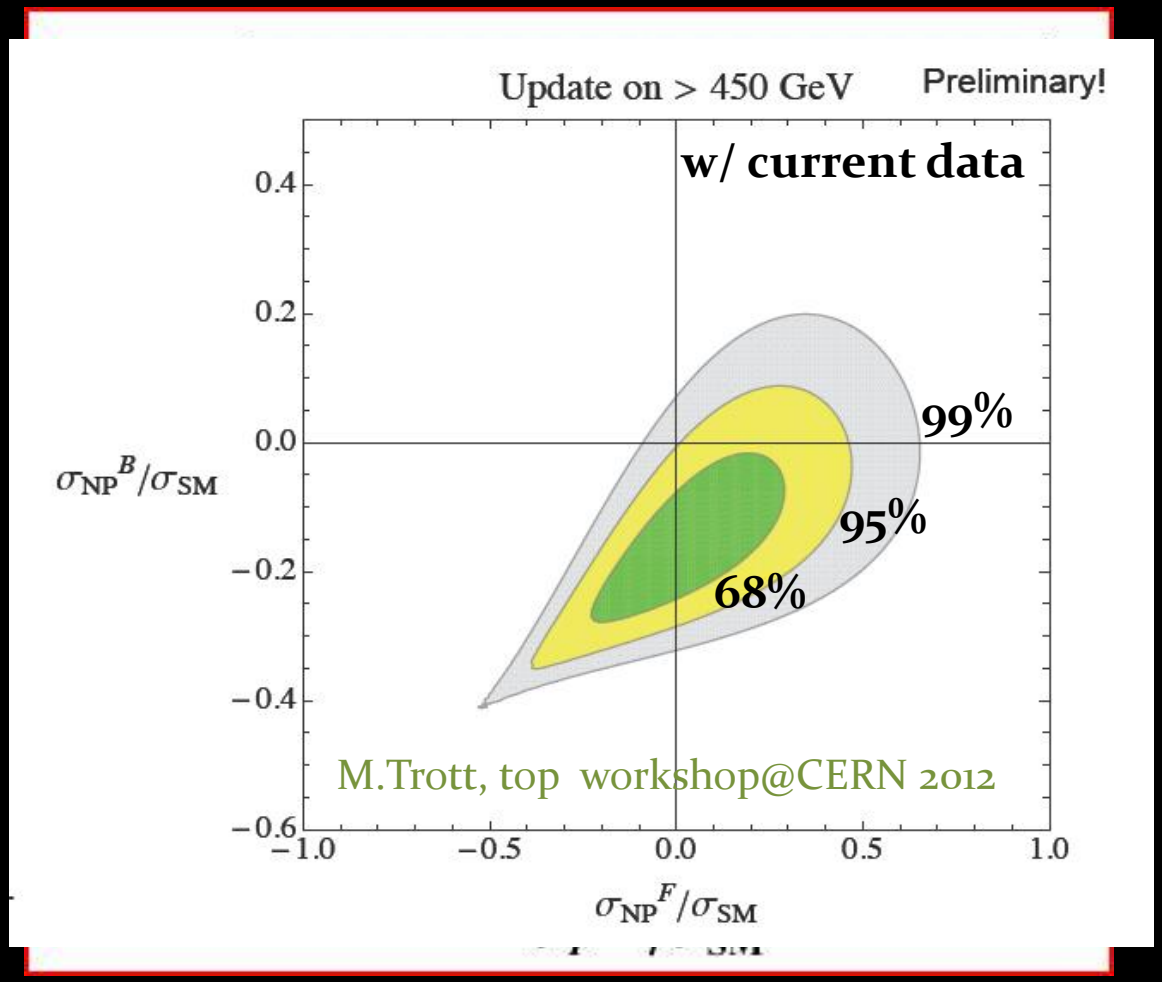


"New physics (tree) amplitude better interferes with LO QCD"

EFT for hard top physics

CD, Gedalia, Hochberg, Perez & Soreq '11
(see also Degrande et al. '10)

Λ_{NP}>TeV : $\mathcal{L}_{top} = \mathcal{L}_{SM} + \mathcal{L}_{d=6} + \mathcal{L}_{d=8} + \ldots$ (up to $1/\Lambda_{NP}^4$)

operators relevant to $q\bar{q} \to t\bar{t}$ transition @high m_{tt}

above 450GeV $q \simeq u$ since PLF ratio $d\bar{d}/u\bar{u} \lesssim 20\%$

$\mathcal{L}_{d=6}$

$$\mathcal{O}_A^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)\,,$$
$$\mathcal{O}_V^8 = (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)\,.$$

interfere w/ QCD gluon exchange

$$\mathcal{O}_{AV}^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)\,(\bar{t}\gamma^\mu T^a t)\,, \qquad \mathcal{O}_{VA}^8 = (\bar{u}\gamma_\mu T^a u)\,(\bar{t}\gamma^\mu\gamma^5 T^a t)$$

$$\mathcal{O}_V^1 = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}_A^1 = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,,$$
$$\mathcal{O}_{AV}^1 = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}_{VA}^1 = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,.$$

don't interfere w/ QCD

$$\mathcal{O}_S^{1,8} = (\bar{u}\,T_{1,8}u)\,(\bar{t}\,T_{1,8}t)\,, \qquad \mathcal{O}_P^{1,8} = (\bar{u}\,T_{1,8}\gamma^5 u)\,(\bar{t}\,T_{1,8}\gamma^5 t)\,,$$
$$\mathcal{O}_{SP}^{1,8} = i\,(\bar{u}\,T_{1,8}u)\,(\bar{t}\,T_{1,8}\gamma^5 t)\,, \qquad \mathcal{O}_{PS}^{1,8} = i\,(\bar{u}\,T_{1,8}\gamma^5 u)\,(\bar{t}\,T_{1,8}t)\,,$$
$$\mathcal{O}_T^{1,8} = (\bar{u}\,T_{1,8}\sigma^{\mu\nu}u)\,(\bar{t}\,T_{1,8}\sigma_{\mu\nu}t)\,,$$

EFT for hard top physics

Λ_{NP}>TeV : $\mathcal{L}_{top} = \mathcal{L}_{SM} + \mathcal{L}_{d=6} + \mathcal{L}_{d=8} + \ldots$ (up to $1/\Lambda_{NP}^4$)

$\mathcal{L}_{d=6}$

$$\mathcal{O}_{hg} = \left[\left(H\bar{Q}\right)\sigma^{\mu\nu}T^A t\right] G^A_{\mu\nu}\,,$$

chromo-magnetic operator

effect falls like QCD due to chirality flipping → not important

$\mathcal{L}_{d=8}$ *@LO only non-trivial operators = 4F with 2 derivatives*

however if NP couplings are large NDA rules:
(d=8) are *parametrically* smaller than $(d=6)^2$

$$C_8 \sim C_6^2/16\pi^2$$

→ d=8 not important (let's set them to zero)

First EFT lessons

Blum, CD, Gedalia, Hochberg, Lee, Nir,Perez & Soreq '11
CD, Gedalia, Hochberg, Perez & Soreq '11

interference effects $\mathcal{O}(\alpha_s/\Lambda^2)$ dominates

accomodating $A_{FB}^{>450} \simeq 28\%$ requires $c_A^8 \sim \frac{1}{\mathrm{TeV}^2}$

we learn that:

- NP couplings to up & top are sizable
- but still perturbative $\Lambda_{\mathrm{NDA}} \sim 4\pi \times \mathrm{TeV} \sim 10\,\mathrm{TeV}$
- pure NP effects $\mathcal{O}(1/\Lambda^4)$ are non-negligible

- NP couplings are not flavor universal

dijet searches contraint: $g_{up}/g_{top} \sim 1/6$

$\rightarrow$ large flavor hierarchy

EFT fit to Tevatron data

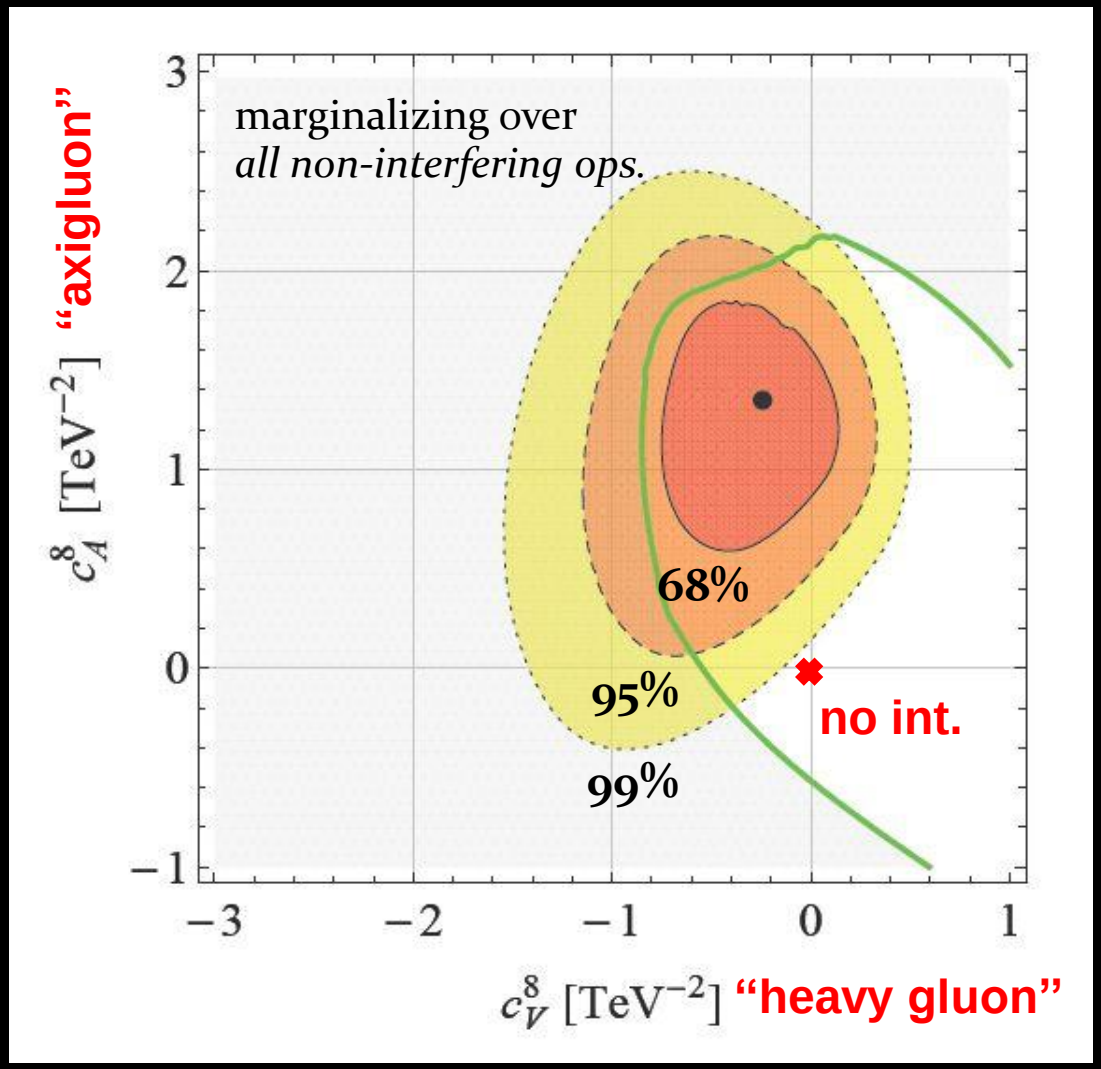
CD, Gedalia, Hochberg & Soreq '12

- fitted data:
  - inc. XS@DO
  - diff. XS@CDF
  - inc. A_{FB}@DO l+j & CDF dil
  - diff. A_{FB}@CDF l+j

- generic lessons:
  - interference (via axigluon) established @99%CL
  - not much freedom from non-interfering operators

merely one operator is important!

O_A^8

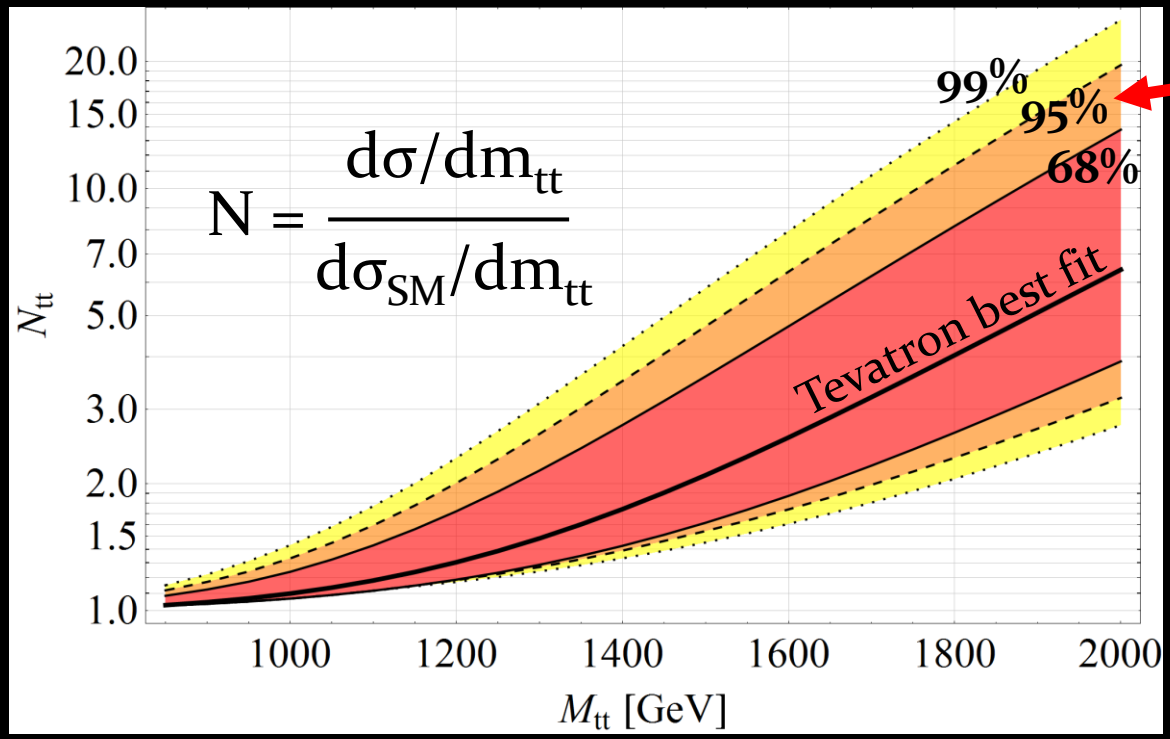


EFT prediction @LHC | ttbar spectrum

- LHC higher energies could unveil the hard NP for A_{FB}
- yet ttbar is gg dominated → "A_{FB} dynamics" is diluted
- more sensitivity to qqbar at high invariant masses

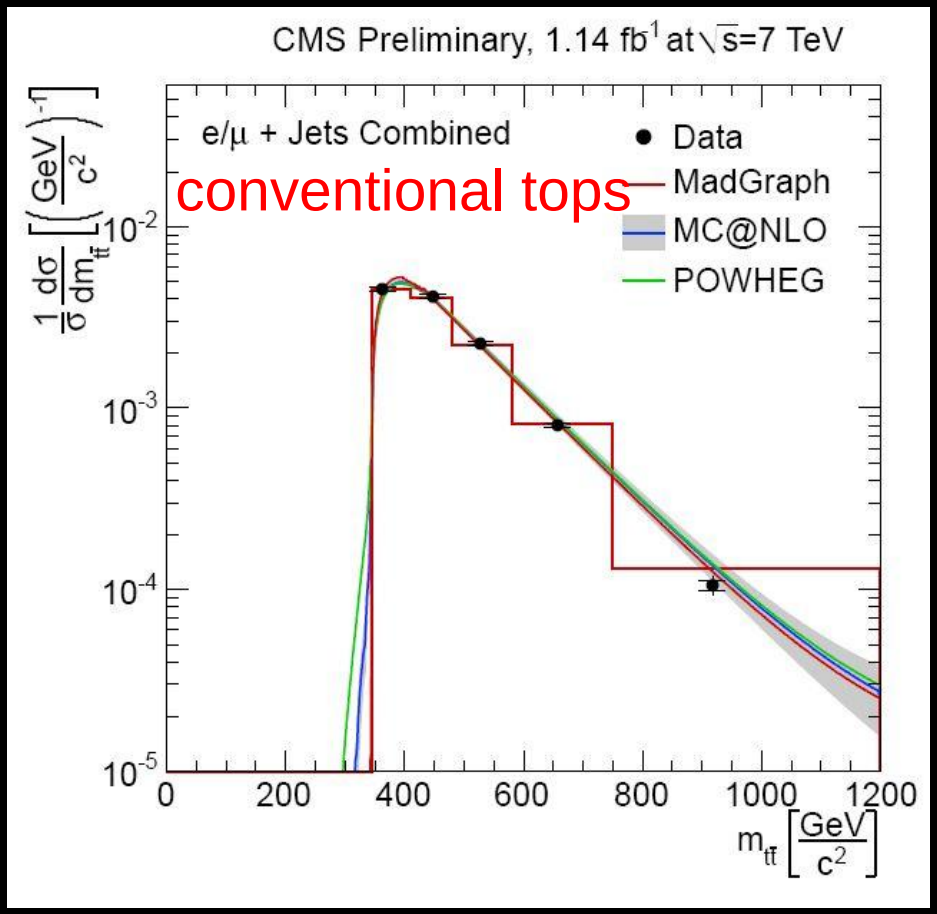
→ EFT leaves a visible imprint in ttbar spectrum tail

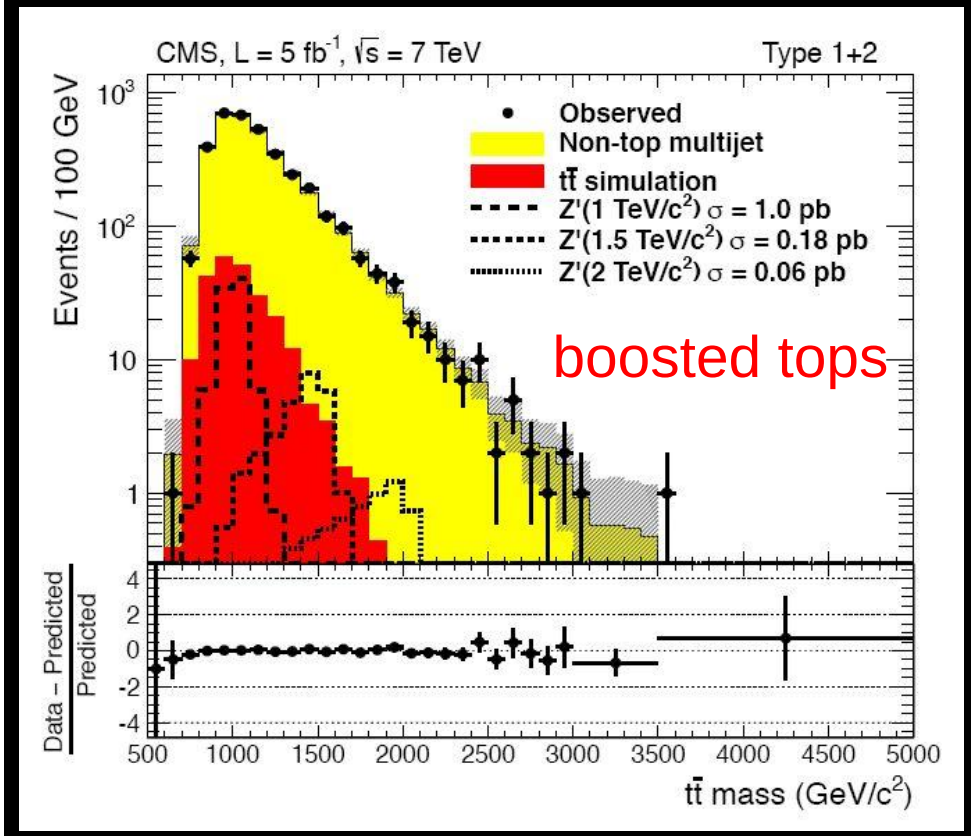
CD, Gedalia, Hochberg & Soreq '12



contours consistent with Tevatron fit's CLs

EFT prediction @LHC | ttbar spectrum





largest effects are excluded, but bkg not substracted, not unfolded
→ good for resonance search, harder to test shape distortion

EFT prediction @LHC | ttbar spectrum

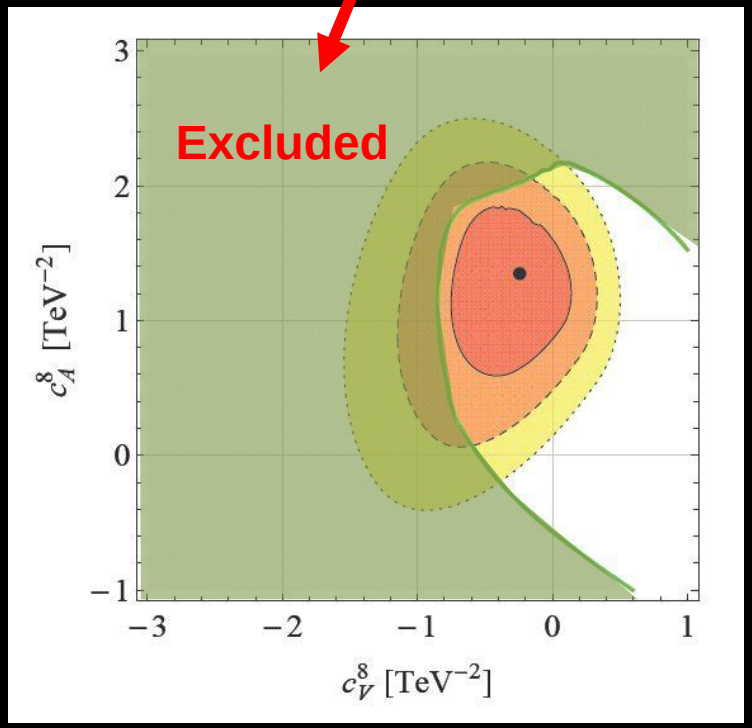
CMS bound on the integrated ttbar tail above 1TeV:

(boosted all hadronic sample)

arxiv:1204.2488

$$\mathcal{S} = \frac{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM+NP}}{dm_{t\bar{t}}} dm_{t\bar{t}}}{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM}}{dm_{t\bar{t}}} dm_{t\bar{t}}}$$

< 2.6 @95%CL



bulk of EFT survives LHC7 data

but LHC8 run will probably test it

CD, Gedalia, Hochberg & Soreq '12

EFT prediction @LHC | charge asymmetry

@pp coll. no A_{FB}, but sensitivity to A_C *for large ttbar boost*!

though suppressed by gg fusion

arXiv:1207.0065

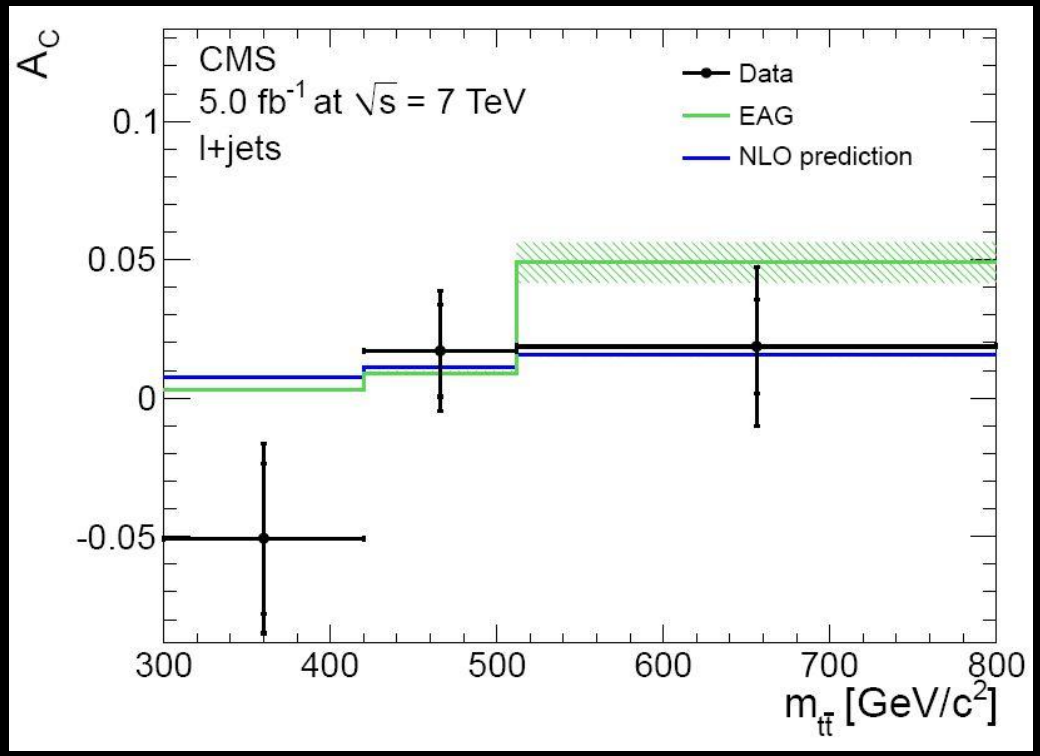
$A_C^{\text{inclusive}} \approx (0.4 \pm 1.0[\text{stat}] \pm 1.1[\text{syst}])\%$ CMS (5/fb)

$A_C^{\text{inclusive}} \approx (-1.8 \pm 2.8[\text{stat}] \pm 2.3[\text{syst}])\%$ ATLAS (1.04/fb)

QCD $A_C^{\text{inclusive}} \approx 0.6\%$

→ consistent with QCD but large uncertainties, could be consistent with many things...

...hard to interpret



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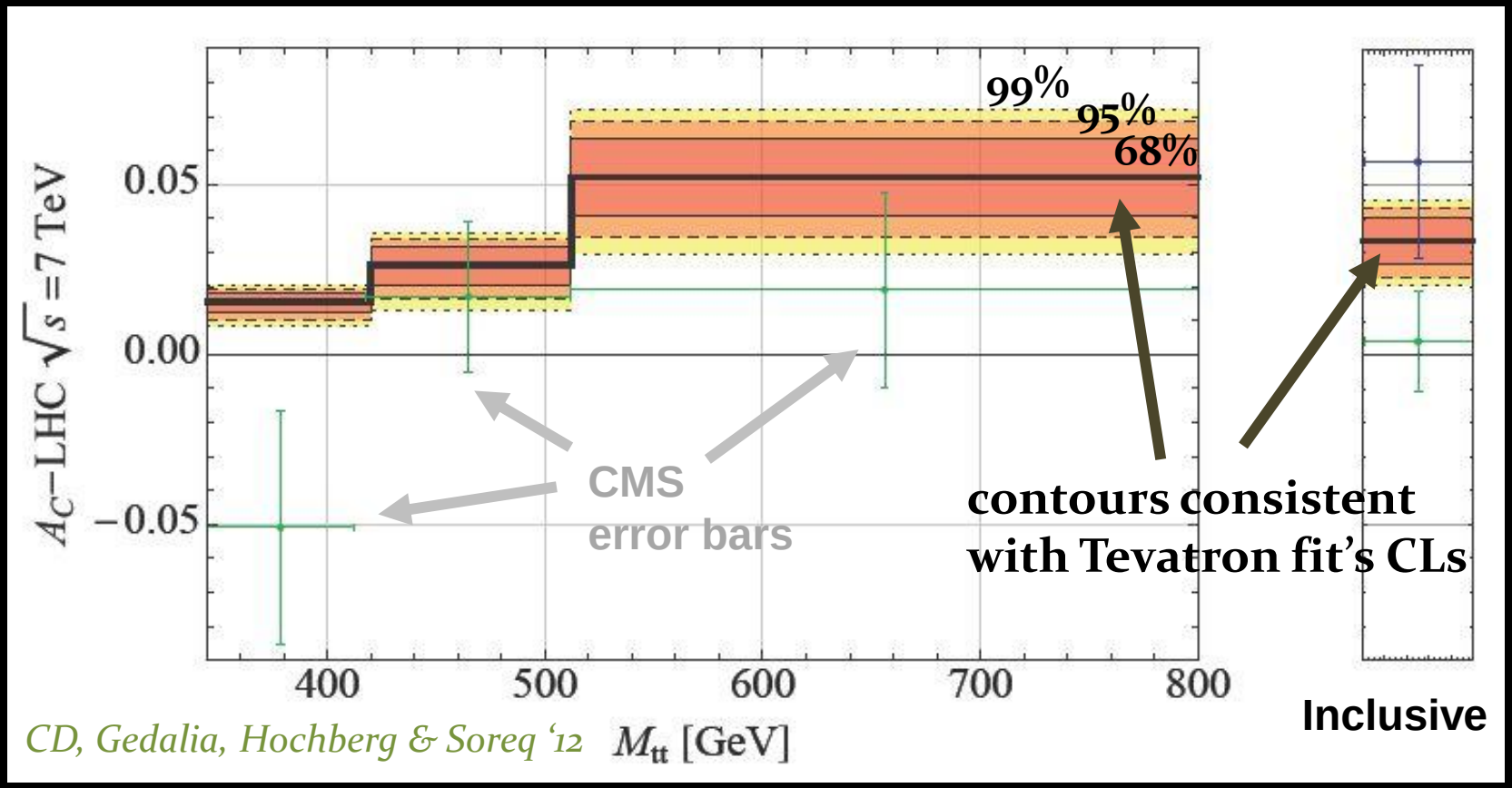


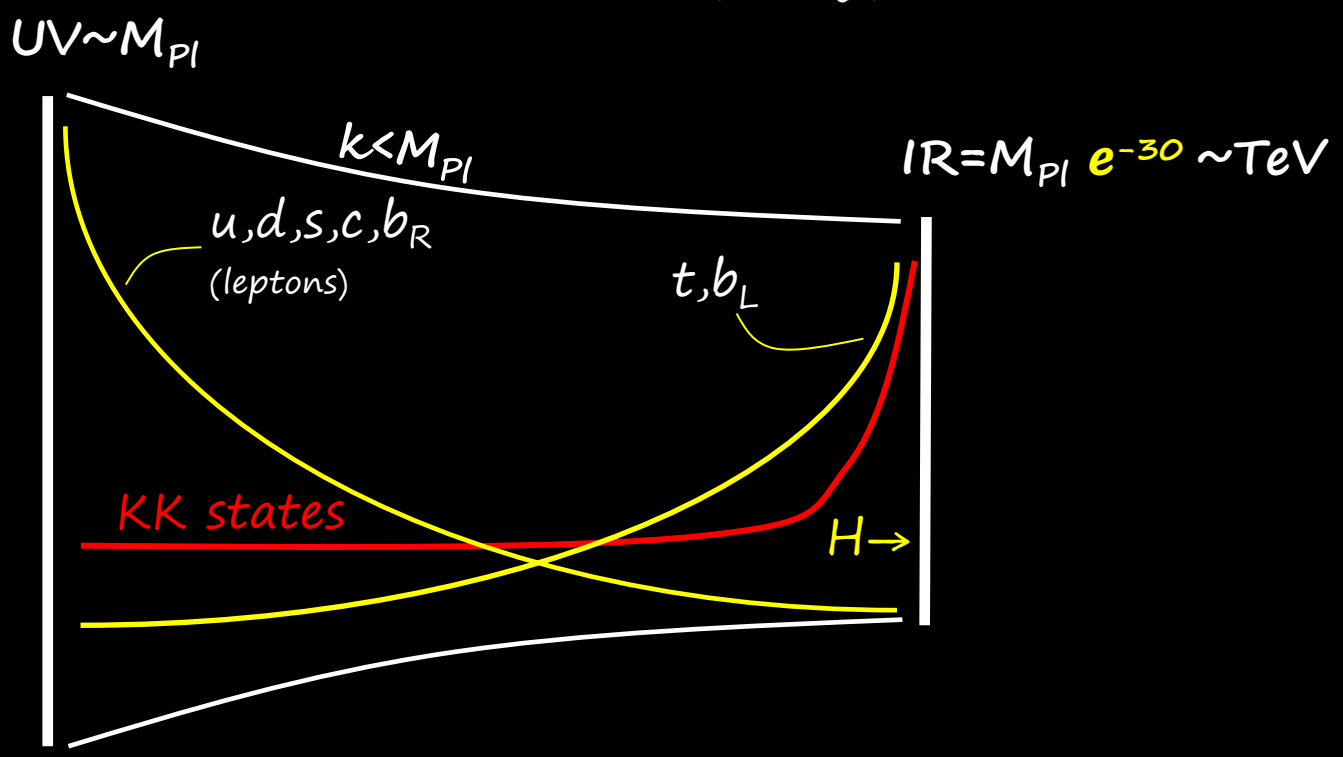
CD, Gedalia, Hochberg & Soreq '12

top A_{FB} from EFT predicts *positive* A_C @LHC
which *is still consistent* with LHC7 data
→2012 data should settle the case

Warped/composite essentials

RS'99: « Hierarchy problem is solved in AdS5 bckg: $ds^2 = e^{-2ky}\, dx^2 - dy^2$ »

Flavor anarchy = $Y_{u,d}$ & $C_{Q,u,d}$ are generic, structureless flavor matrices



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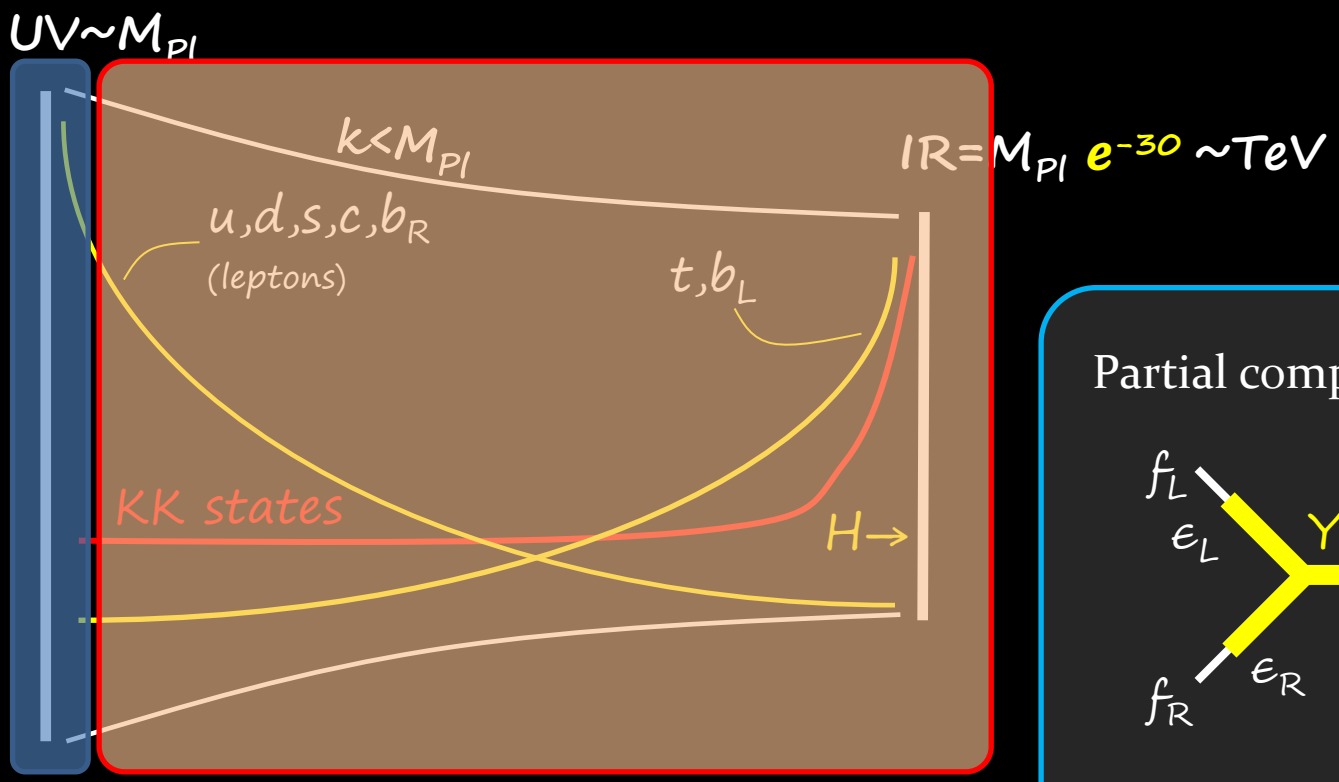
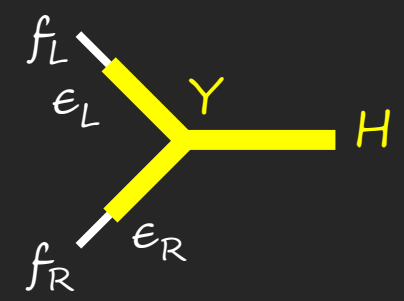


elementary sector ← linear mixing → strong sector

Partial compositeness in 4D:



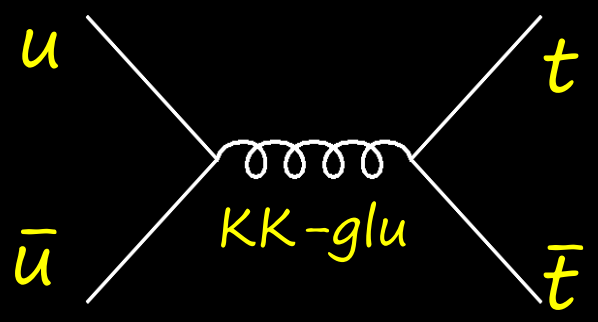
$$Y_{SM} = \epsilon_L Y \epsilon_R$$

→ light quarks are ~elementary

A_{FB} *from strong dynamics near the TeV scale*

EFT → we need $1/\mathrm{TeV}^2$ axial color octet 4F operator

leading contribution from



- 5D flavor anarchy → up is ~elementary →suppressed (+vector-like) KK-gluon production → no A_{FB}!
- way out? increase up compositeness (EWPT → u_R)

  yet only RRLL induced → $d\sigma/dM_{tt}$ distorded

  + up coupling further constrained by dijets searches

e.g. CMS-EXP-11017

→ $\delta A_{FB}^{>450} < 5\%$

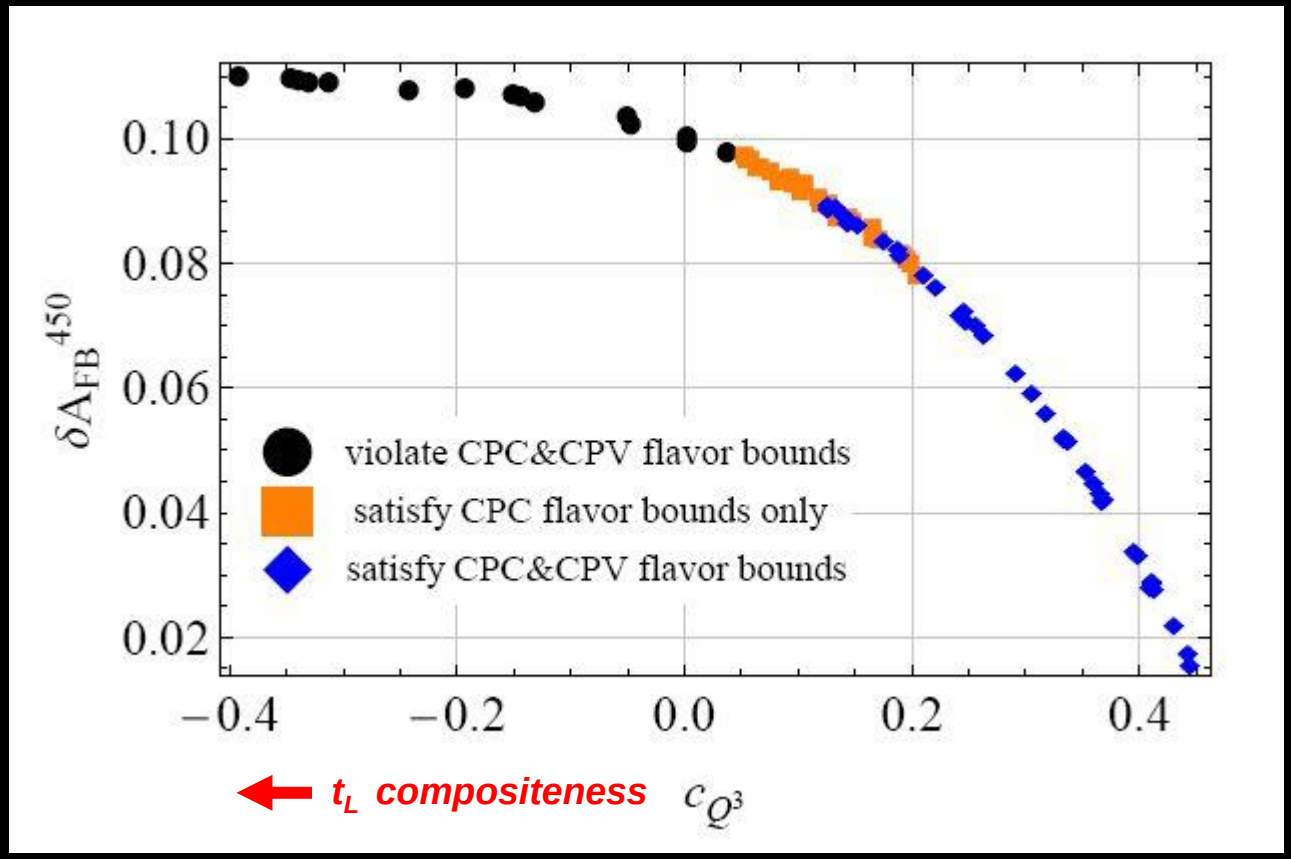
could be enough, but what if not?

Larger A_{FB} from strong dynamics?

- let's add an axial resonance

  → color SU3 extended to $SU3_L x SU3_R$ in the bulk broken to $SU3_V$ in the IR by $\langle\phi\rangle=(3,3^*)$ to get quark masses

Da rold, CD, Grojean & Perez '12



total $A_{FB}^{>450} \sim 20\%$

consistent w/ ttbar cross section + flavor & dijet constraint

Outro

- A_{FB} is still "anomalous", yet not necessarily a sign of NP
  (could be pure QCD and/or a nearly shutdown Tevatron on crack)

- Light (<TeV) NP could be driving top A_{FB} (but invisible everywhere else → smells like Maxwell's demon…)

- Heavy (multi TeV) NP is still a plausible explanation
  - best Tevatron fit points to an axigluon-like state
  - EFT offers 2 (sanity) LHC checks: XS tail enhancement + diff. A_C

- A_{FB}'s hard to connect to Naturalness because of up-quark
  - yet, if (partial) compositeness is ***the*** theory of TeV scale, A_{FB} points towards composite light flavors & thus exhiliarating flavor physics!

Outro

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