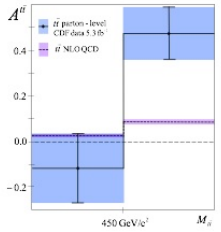
Searches for same-sign top pair production at the LHC

Freya Blekman
for ATLAS and CMS collaborations

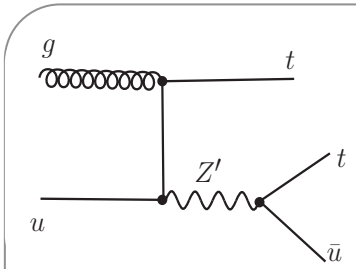
TOP2011 - Sant Feliu de Guixols, Spain

Vrije Universiteit Brussel

Outline



Experimental Motivation



Possible Explanation from Theory → LHC predictions

CMS results

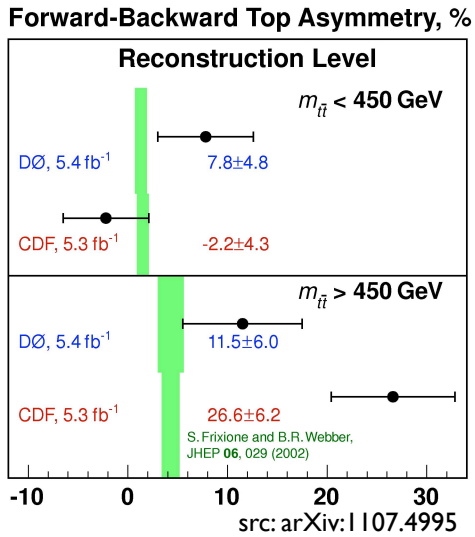
ATLAS results

New!

Physics motivation

- Measurements of the forward-backward assymmetry A(tt) in top quark pair production at the Tevatron colider
  - Standard Model: A(tt) = 0.088±0.013
- CDF: (Phys.Rev.D83:112003,2011)
  - Asymmetry increases with tt rapidity difference
  - Asymmetry increases with invariant mass of tt system

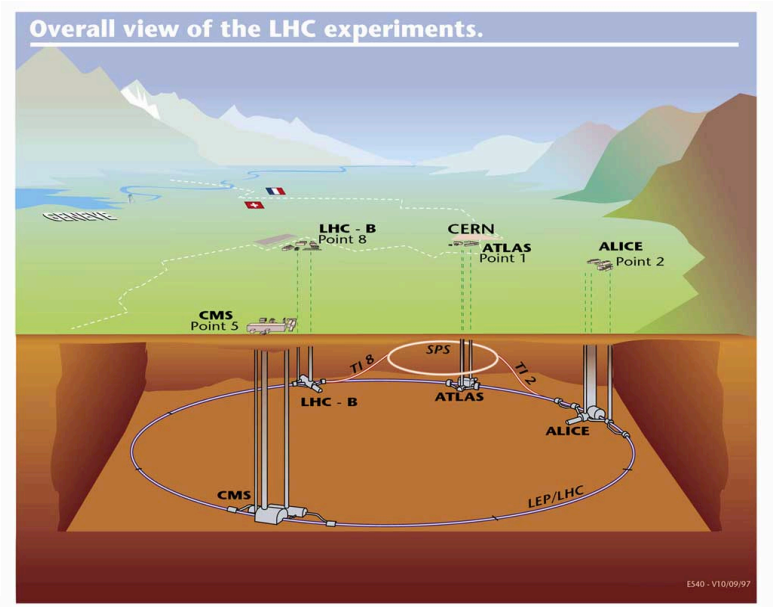
  At high (>450 GeV/c^2) invariant mass: A(tt)=0.475 ± 0.11
- D0: (Subm. to Phys.Rev.D, arXiv:1107.4995)
  - No dependence on rapidity or invariant mass system
  - A(tt) = (19.6 ± 6.5)%

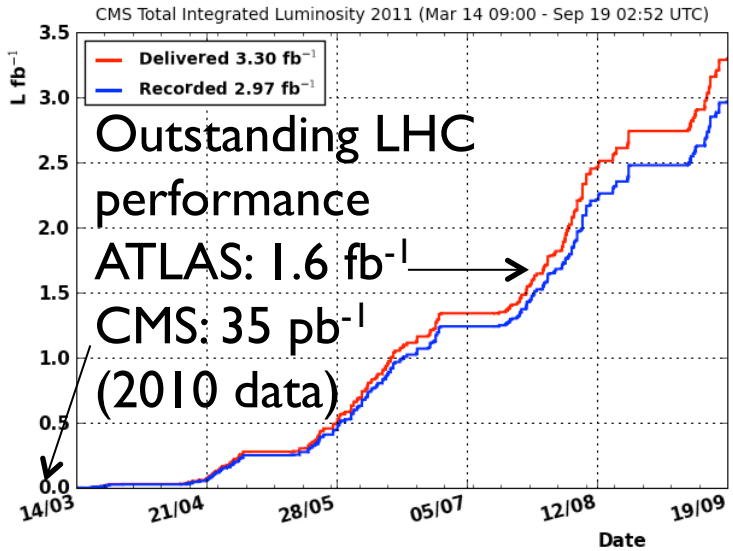


- Many (**) attempts to explain A(tt) invoke flavor-changing neutral currents (FCNC) mediated by a new massive Z' boson
  - Here I present the current LHC searches in the top sector for such a Z' boson

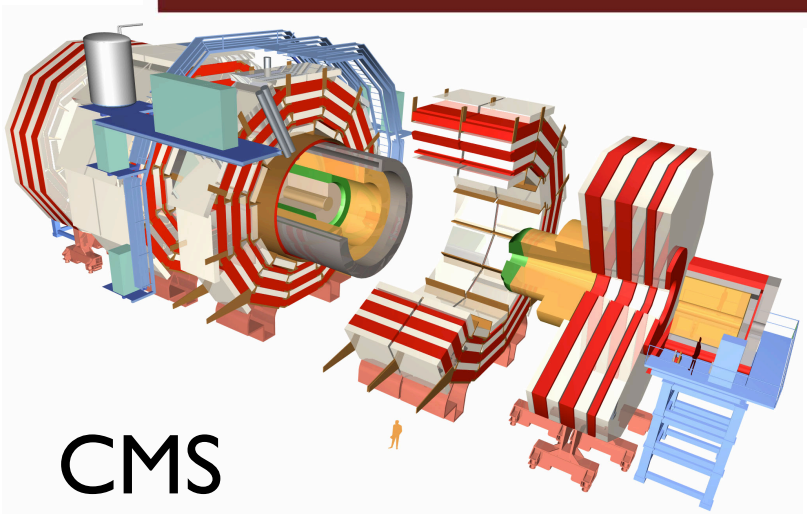
** See backup

Large Hadron Collider

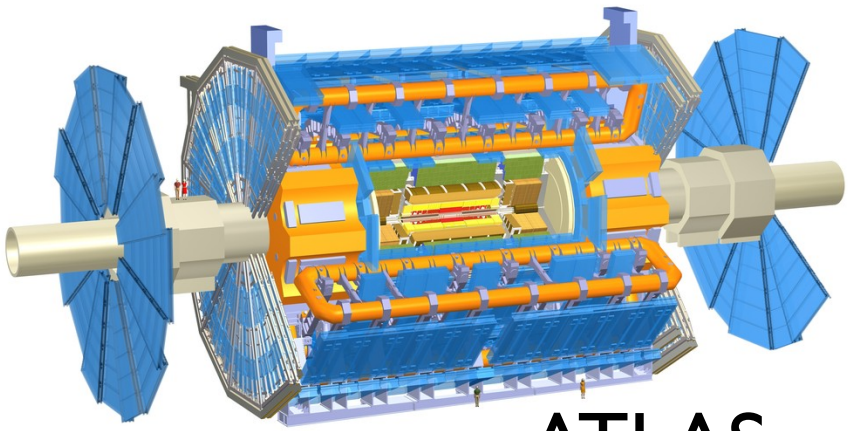




Outstanding LHC performance
ATLAS: 1.6 fb^{-1}
CMS: 35 pb^{-1}
(2010 data)



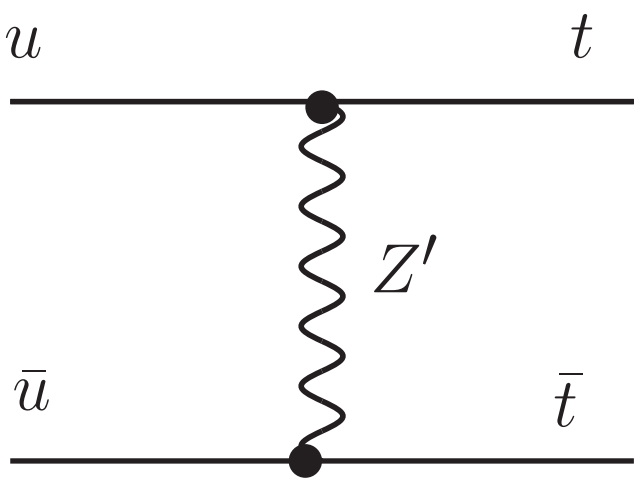
CMS



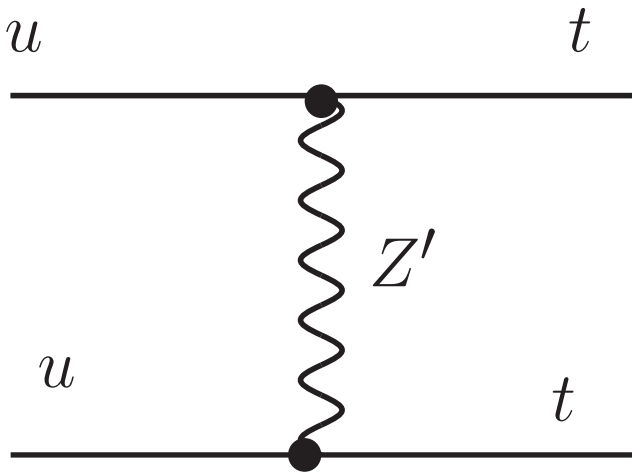
ATLAS

FCNC through Z' model – basic idea

Tevatron
(proton-antiproton)



LHC
(proton-proton)

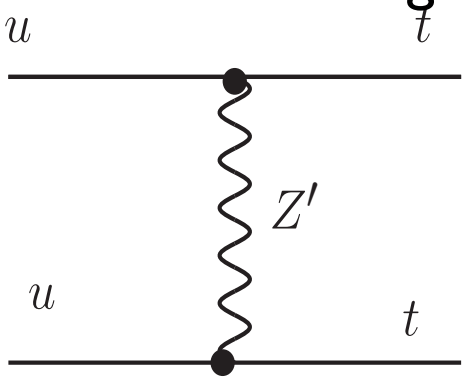


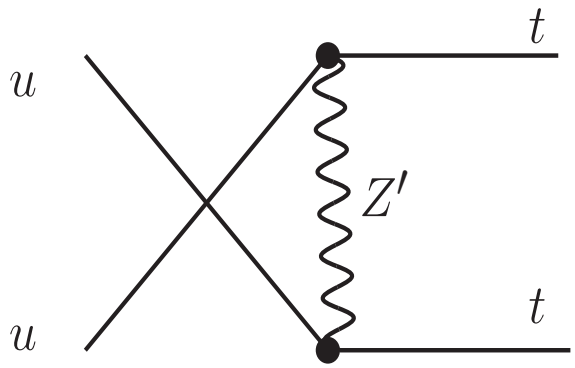
Such a Z' exchange would create a high inv. mass asymmetry at the Tevatron

- and can be made to also explain some other SM discrepancies like CDF W+2j bump

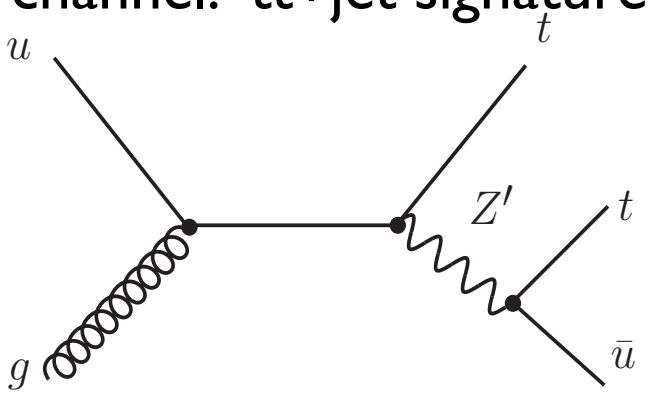
LHC production mechanism

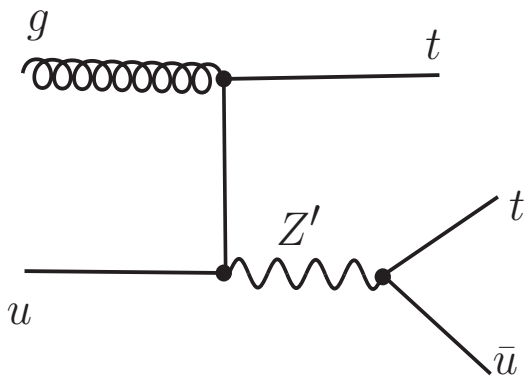
Production in t-channel: tt signature





Production in s-channel: tt+jet signature





FCNC Z': constraints from experiment

$$\mathcal{L} = g_W \bar{u}\gamma^\mu(f_L P_L + f_R P_R)tZ'_\mu + h.c$$

- Consider the effective Lagrangean of the utZ' interaction
  - u quarks from proton to t quarks only
  - consists of a left- and right-handed coupling to the boson
  - with g_W the weak coupling strength, f_L and f_R the coupling strengths and Z' the mass of the hypothetical boson
- The left-handed coupling is experimentally constrained to ≈0 by measurements of B_d-B_d mixing, leaving only the right-handed fermion coupling

Experimental signature: two top (not antitop!) in final state

Search for SS top pairs (CMS)

- Analysis CMS-EXO-11-065 based on generic same-sign lepton search
  - CMS-SUS-10-004, JHEP 1106(2011)077, arXiv:1104.3168
  - Analysis uses 35 pb^{-1} integrated luminosity (2010 sample)
  - Specific model considered from E.L Berger et.al, arXiv:1101.5626

- All main backgrounds data-driven:
  - Background dominated by jets faking leptons:
    - Ttbar lepton+jets with one fake lepton
    - Mis-measurement charge in di-lepton Drell-Yan and ttbar di-lepton
  - $W\gamma$, WZ, ZZ, qqWW, 2x(qW), ttW and WWW production from Monte Carlo (sum % level contribution) with 50% uncertainties on theory cross section

Search for SS top pairs (CMS)

Trigger:
Single-lepton triggers
Di-lepton triggers
Triggers on H_T (= Σ jet p_T)

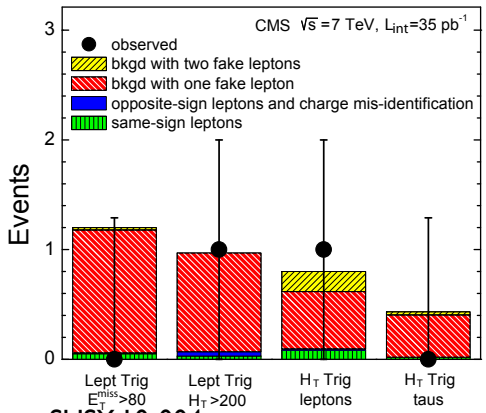
2010 dataset: rapidly increasing lumi so thresholds tighten over time

Lepton selection:
p_T > 20 GeV/c
Leading: p_T> 30 GeV/c in ee, mumu
$|\eta| < 2.4$
Both leptons positive

Muon requirements:
Isolation
Match to PV
hits in silicon tracker
fit quality
MIP consistent in calorimeter
Check tracks near (Bremsstrahlung)

Electron requirements:
Isolation
Match to PV
No missing hits in silicon tracker
shower shape in ECAL
track -ECAL cluster match
Check tracks near (photon veto)

CMS **particle flow** algorithm
<u>Jet selection: Require 2 jets</u>
Anti-k_T with R=0.5
p_T > 30 GeV/c
Jet energy scale corrected
Calorimeter noise veto and similar cleanup ID cuts
<u>Missing E_T selection</u>:
MET > 20 GeV/c
> 30 GeV/c in ee, mumu

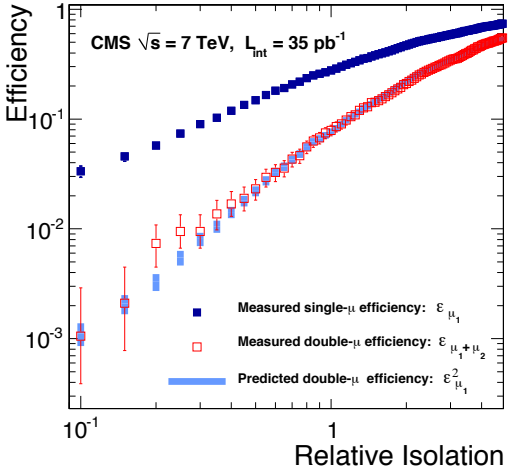


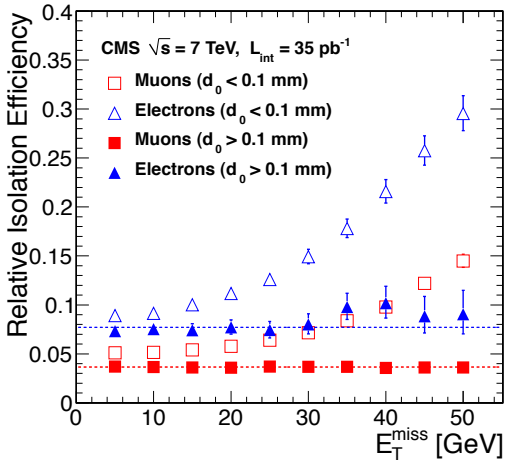
SUSY-10-004
Looser selection: lepton pT>10,20 GeV/c!!
Only requirement on opp-sign

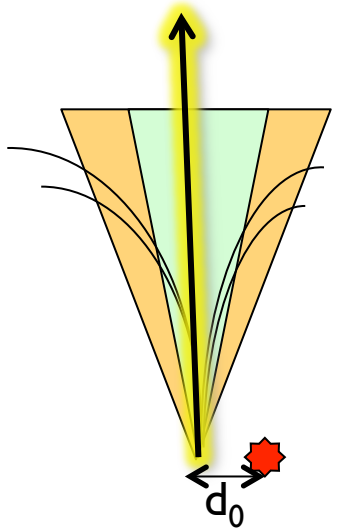
Vrije Universiteit Brussel

JHEP 1108 (2011) 005
JHEP 1106 (2011) 077

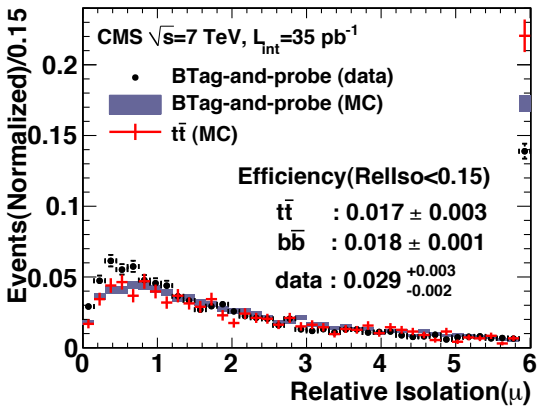
Search for SS top pairs (CMS)

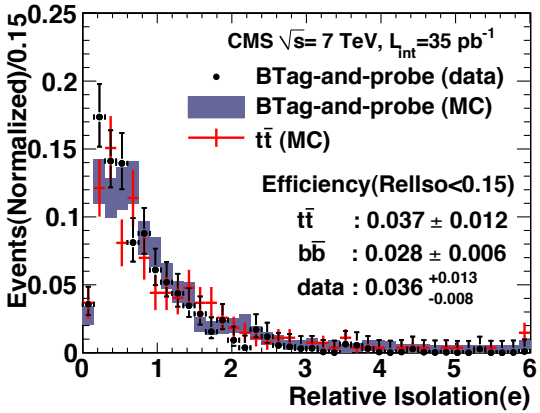






- Fake leptons studied by variation of the lepton isolation and distance wrt primary vertex (d_0)





Vrije Universiteit Brussel

JHEP 1108 (2011) 005
JHEP 1106 (2011) 077

Search for SS top pairs (CMS)

- Observed and expected events:
  - Positive sign:
    - Data: 2 events
    - Expected: 0.9 ± 0.6 (syst) events
  - Negative sign:
    - Data: 0 events
    - Expected: 0.9 ± 0.6 (syst) events
- Used MADGRAPH+PYTHIA showering to implement Berger et.al. model
  - LO, tt, ttj diagrams
  - CTEQ6L pdfs
  - Event selection efficiency

    (0.95 ± 0.13)%

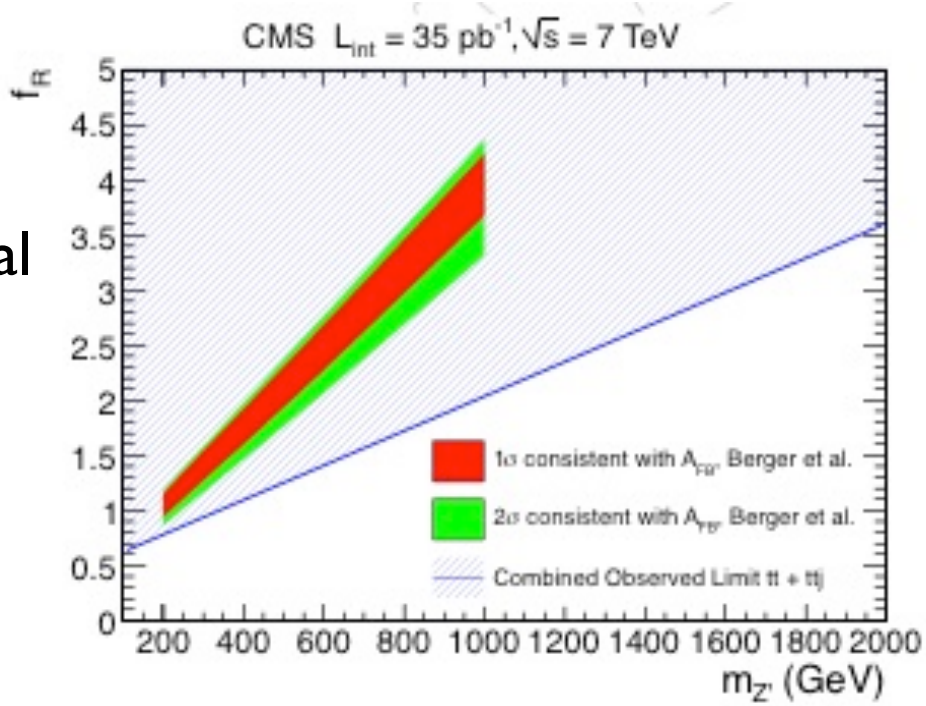
    includes BR, $\tau \rightarrow l\nu$ included in acceptance

Syst. Uncertainties on selection Z'→ tt(j):

Source	ee	$\mu\mu$	$e\mu$	all
Lepton selection	11.8%	10.6%	10.8%	10.7%
Energy scale	8%	8%	8%	8%
ISR/FSR and PDF	3%	3%	3%	3%
Total without luminosity	14.6%	13.6%	13.8	13.7%
Integrated luminosity	4%	4%	4%	4%
Total	15%	14%	14%	14%

Search for SS top pairs (CMS)

- Selection efficiency independent of Z' mass
- Using flat bayesian prior for signal and log-normal for uncertainties (nuisance parameters)
- 95% CL limit: 5.7 events
  - (expected limit: 4.4 ± 1.4 events)
  - CLs method: 5.6 events
  - Cross section limit: $\sigma(Z' \rightarrow ttX) < 17.0$ pb



- This FCNC Z' production limit inconsistent with the Tevatron Forward-Background Asymmetry

  → <u>disfavoured</u> in full parameter space

CMS limit: interpretation on scale

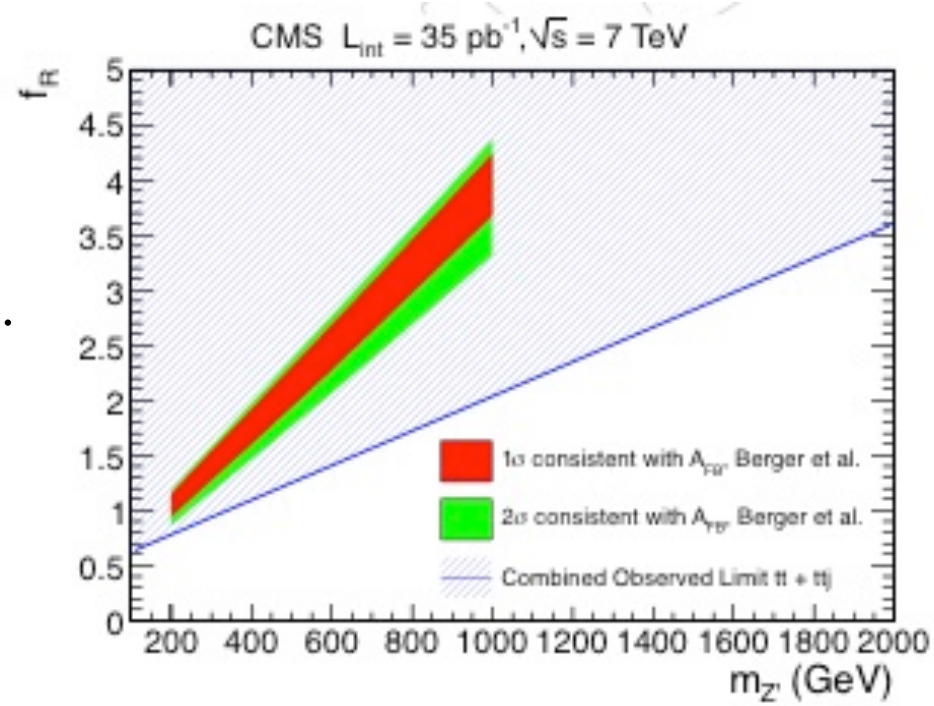
$$\mathcal{L} = g_W \bar{u}\gamma^\mu (f_L P_L + f_R P_R) t Z'_\mu + h.c$$

At high-mass Z'

$$\mathcal{L} = -\frac{1}{2}\frac{C_{RR}}{\Lambda^2}[\bar{u}_R\gamma^\mu t_R][\bar{u}_R\gamma_\mu t_R] + \text{h.c.}$$

Limit on coupling

$$\frac{C_{RR}}{\Lambda^2} = \frac{2 g_W^2 f_R^2}{M_{Z'}^2}$$

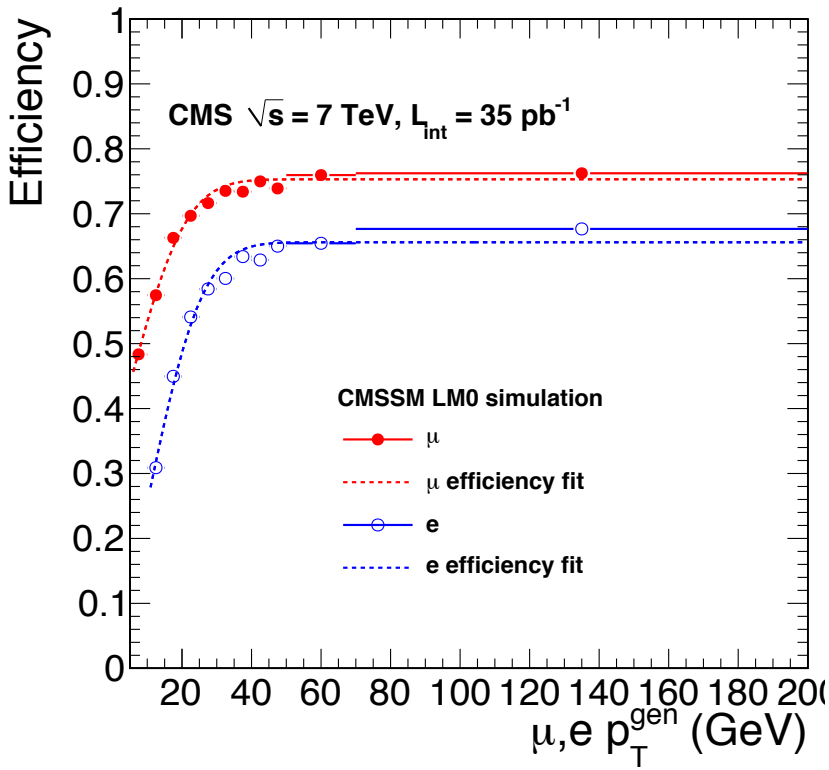


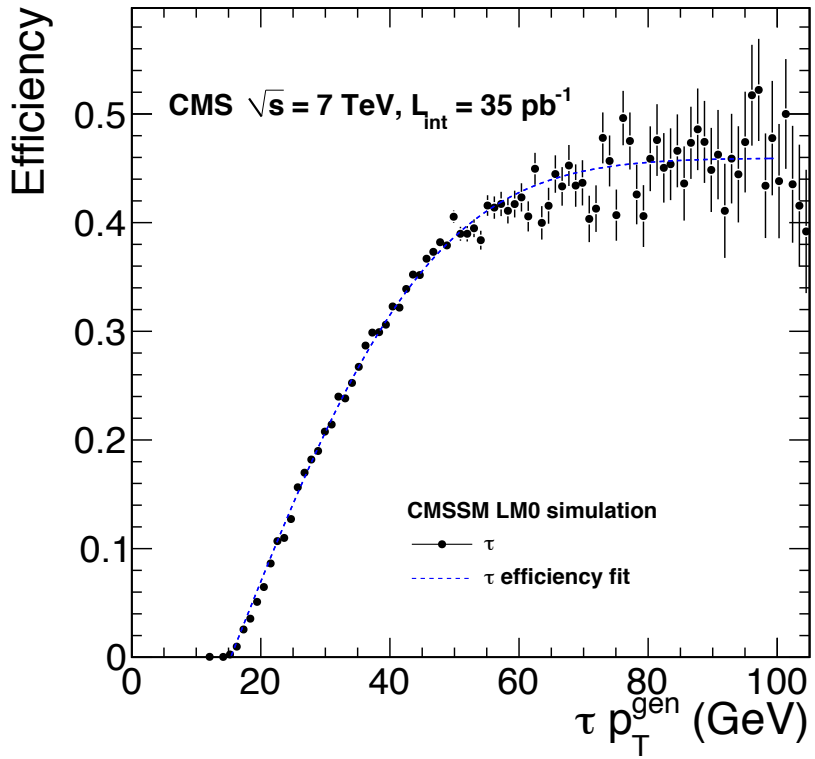
CMS limit:

$$\frac{C_{RR}}{\Lambda^2} < 2.7\ \text{TeV}^{-2}$$

$$\left(\text{CDF: } \frac{C_{RR}}{\Lambda^2} < 3.7\ \text{TeV}^{-2} \right)$$

CMS supplying efficiency for comparison to theory





- Allow comparison to different models, application of efficiency to generator information gives handle on model feasibility for phenomenology

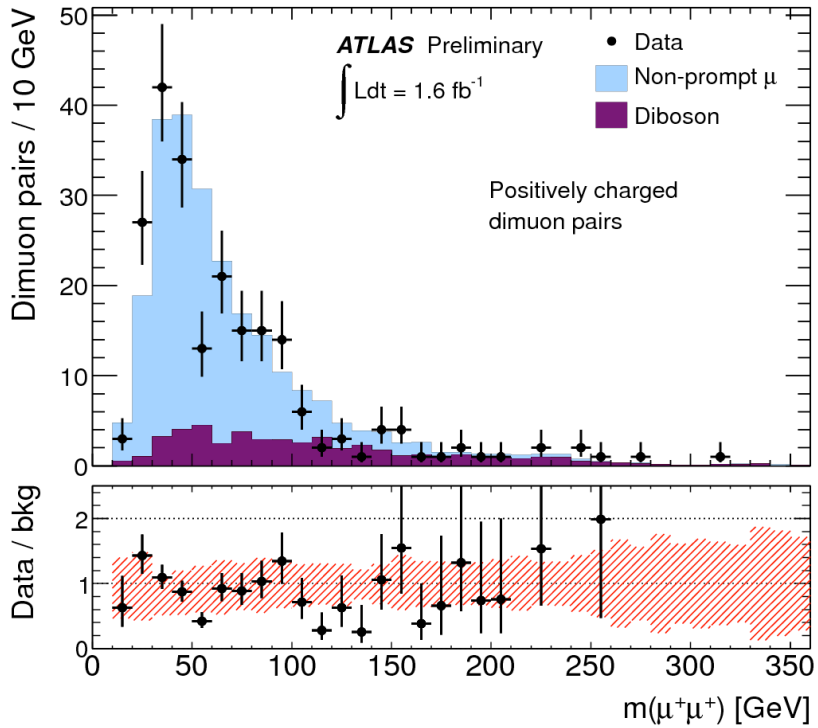
Vrije Universiteit Brussel

JHEP 1108 (2011) 005
JHEP 1106 (2011) 077

Search for SS top pairs (ATLAS)

New!

- ATLAS studies Z'→tt models in context of same-sign di-muon search using 1.6 fb^{-1}
- Preliminary result from Sep. 2011
- Similar analysis strategy as CMS result but examining the di-mu+ invariant mass spectrum
  - using same samples as ATLAS-CONF-2011-126

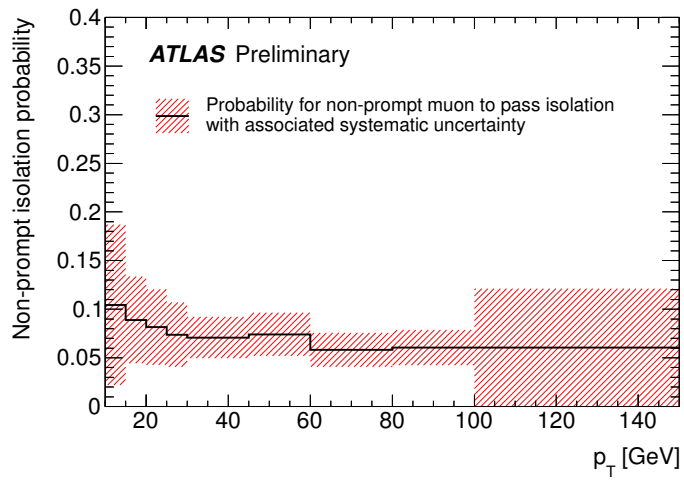


Warning: no overflow bin, one event at 492 GeV/c^2

ATLAS-CONF-11-139

Search for SS top pairs (ATLAS)

- Prompt backgrounds WZ, ZZ, WW from simulation, using HERWIG
- Prompt backgrounds WW, ttW from simulation, using MC@NLO and MADGRAPH+PYTHIA
- Prompt backgrounds like Drell-Yan processes from simulation, using ALPGEN
  - Differences between samples used as systematic uncertainties on MC model
  - In addition a 50% uncertainty on the MC cross section is included
- Non-prompt backgrounds (from HF) are modeled from data using a matrix method
- Charge misidentification is derived on Drell-Yan data



ATLAS CONF-11-139

Search for SS top pairs (ATLAS)

Muon selection:
Leading muon: p_T>20 GeV/c, | η |<2.5
Other muon: p_T>10 GeV/ , | η |<2.5
At least one muon | η | < 2.4
IP and isolation cuts
Both muons positive

Jets only used for muon isolation!
Anti-kT jets, R=0.4,
p_T > 7 GeV/c required no overlap with muon by ΔR>0.4
No further requirements on jets

Mass range [GeV]	Number of pairs expected	Number of pairs observed
$m(\mu^+\mu^+) > 15$ GeV	243^{+58}_{-102}	218
$m(\mu^+\mu^+) > 100$ GeV	47^{+10}_{-11}	34
$m(\mu^+\mu^+) > 200$ GeV	$9.2^{+1.8}_{-1.7}$	9
$m(\mu^+\mu^+) > 300$ GeV	$1.68^{+0.57}_{-0.48}$	2

Z' → tt modeled with PROTOS generator is used to set limits:

Mass range [GeV]	$\sigma_{95}(tt)$ (pb) $m(Z') = 100$ GeV exp.	obs.	$m(Z') = 150$ GeV exp.	obs.	$m(Z') = 200$ GeV exp.	obs.	$m(Z') \gg 1$ TeV exp.	obs.
$m(\mu^+\mu^+) > 15$ GeV	24.8	21.8	23.0	20.3	22.4	19.7	36.6	32.2
$m(\mu^+\mu^+) > 100$ GeV	5.4	3.6	4.7	3.1	4.4	2.9	6.1	4.1
$m(\mu^+\mu^+) > 200$ GeV	4.1	4.1	3.3	3.3	3.0	3.0	2.9	2.9
$m(\mu^+\mu^+) > 300$ GeV	5.5	5.5	4.1	4.1	3.7	3.7	2.8	2.8

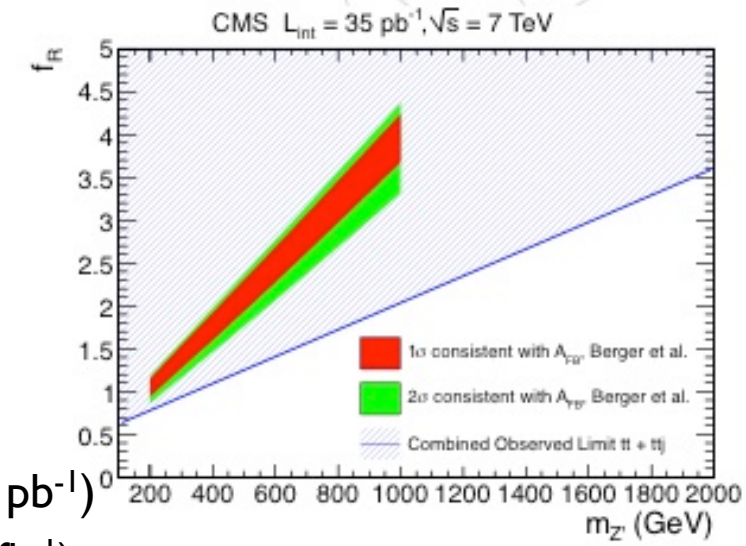
Considerable improvement in constraining this model

Vrije Universiteit Brussel

ATLAS CONF-11-139

Conclusion

- ATLAS and CMS have searched for flavor-changing neutral currents in the top sector
  - CMS EXO-11-065, JHEP 1108 (2011) 005
  - ATLAS CONF-2011-169
- Limits are set on cross section of m positive-sign top pairs
  - CMS, ee,mumu, emu: $\sigma(Z' \rightarrow ttX) < 17.0$ pb (35 pb^{-1})
  - ATLAS, mumu: $\sigma(Z' \rightarrow ttX) < 2.9 - 4.0$ pb (1.6 fb^{-1})



- Relevant in context of Z' models motivated by top-forward-backward asymmetries at Tevatron
  - Both experiments exclude Z'→tt production consistent with Tevatron A_{FB}, ruling out this BSM process as an explanation
  - ATLAS also sets limit on xsec for 4-fermion Z' interactions ($m_{Z'} \cong 1$ TeV/c^2)

Many thanks to the ATLAS and CMS top and exotica convenors

and thanks to the organizers for this delightful conference!

Backup slides

Theory references (1)

S. Jung, H. Murayama, A. Pierce et al., "Top quark forward-backward asymmetry from new t-channel physics", *Phys. Rev.* **D81** (2010) 015004, arXiv:0907.4112. doi:10.1103/PhysRevD.81.015004.

D.-W. Jung, P. Ko, and J. S. Lee, "Longitudinal top polarization as a probe of a possible origin of forward-backward asymmetry of the top quark at the Tevatron", *Phys. Lett.* **B701** (2011) 248–254, arXiv:1011.5976. doi:10.1016/j.physletb.2011.05.058.

D. Choudhury, R. M. Godbole, S. D. Rindani et al., "Top polarization, forward-backward asymmetry and new physics", arXiv:1012.4750.

K. Cheung and T.-C. Yuan, "Top Quark Forward-Backward Asymmetry in the Large Invariant Mass Region", *Phys. Rev.* **D83** (2011) 074006, arXiv:1101.1445. doi:10.1103/PhysRevD.83.074006.

J. Cao, L. Wang, L. Wu et al., "Top quark forward-backward asymmetry, FCNC decays and like-sign pair production as a joint probe of new physics", arXiv:1101.4456.

E. L. Berger, Q.-H. Cao, C.-R. Chen et al., "Top Quark Forward-Backward Asymmetry and Same-Sign Top Quark Pairs", *Phys. Rev. Lett.* **106** (2011) 201801, arXiv:1101.5625. doi:10.1103/PhysRevLett.106.201801.

Theory references (II)

Y. Bai, J. L. Hewett, J. Kaplan et al., "LHC Predictions from a Tevatron Anomaly in the Top Quark Forward-Backward Asymmetry", *JHEP* **03** (2011) 003, arXiv:1101.5203. doi:10.1007/JHEP03(2011)003.

J. Shelton and K. M. Zurek, "Maximal flavor violation from new right-handed gauge bosons", *Phys. Rev.* **D83** (2011) 091701, arXiv:1101.5392. doi:10.1103/PhysRevD.83.091701.

V. Barger, W.-Y. Keung, and C.-T. Yu, "Tevatron Asymmetry of Tops in a W′,Z′ Model", *Phys. Lett.* **B698** (2011) 243, arXiv:1102.0279. doi:10.1016/j.physletb.2011.03.010.

B. Bhattacherjee, S. S. Biswal, and D. Ghosh, "Top quark forward-backward asymmetry at Tevatron and its implications at the LHC", *Phys. Rev.* **D83** (2011) 091501, arXiv:1102.0545. doi:10.1103/PhysRevD.83.091501.

K. Blum et al., "Implications of the CDF $t\bar{t}$ Forward-Backward Asymmetry for Boosted Top Physics", arXiv:1102.3133.

B. Grinstein, A. L. Kagan, M. Trott et al., "Forward-backward asymmetry in t anti-t production from flavour symmetries", arXiv:1102.3374.

Theory references (III)

K. M. Patel and P. Sharma, "Forward-backward asymmetry in top quark production from light colored scalars in SO(10) model", *JHEP* **04** (2011) 085, `arXiv:1102.4736`. `doi:10.1007/JHEP04(2011)085`.

M. I. Gresham, I.-W. Kim, and K. M. Zurek, "On Models of New Physics for the Tevatron Top A_{FB}", (2011). `arXiv:1103.3501`.

M. R. Buckley, D. Hooper, J. Kopp et al., "Light Z' Bosons at the Tevatron", *Phys. Rev.* **D83** (2011) 115013, `arXiv:1103.6035`. `doi:10.1103/PhysRevD.83.115013`.

Z. Ligeti, M. Schmaltz, and G. M. Tavares, "Explaining the t tbar forward-backward asymmetry without dijet or flavor anomalies", (2011). `arXiv:1103.2757`.

J. A. Aguilar-Saavedra and M. Perez-Victoria, "Probing the Tevatron t tbar asymmetry at LHC", *JHEP* **05** (2011) 034, `arXiv:1103.2765`. `doi:10.1007/JHEP05(2011)034`.

Theory references (IV)

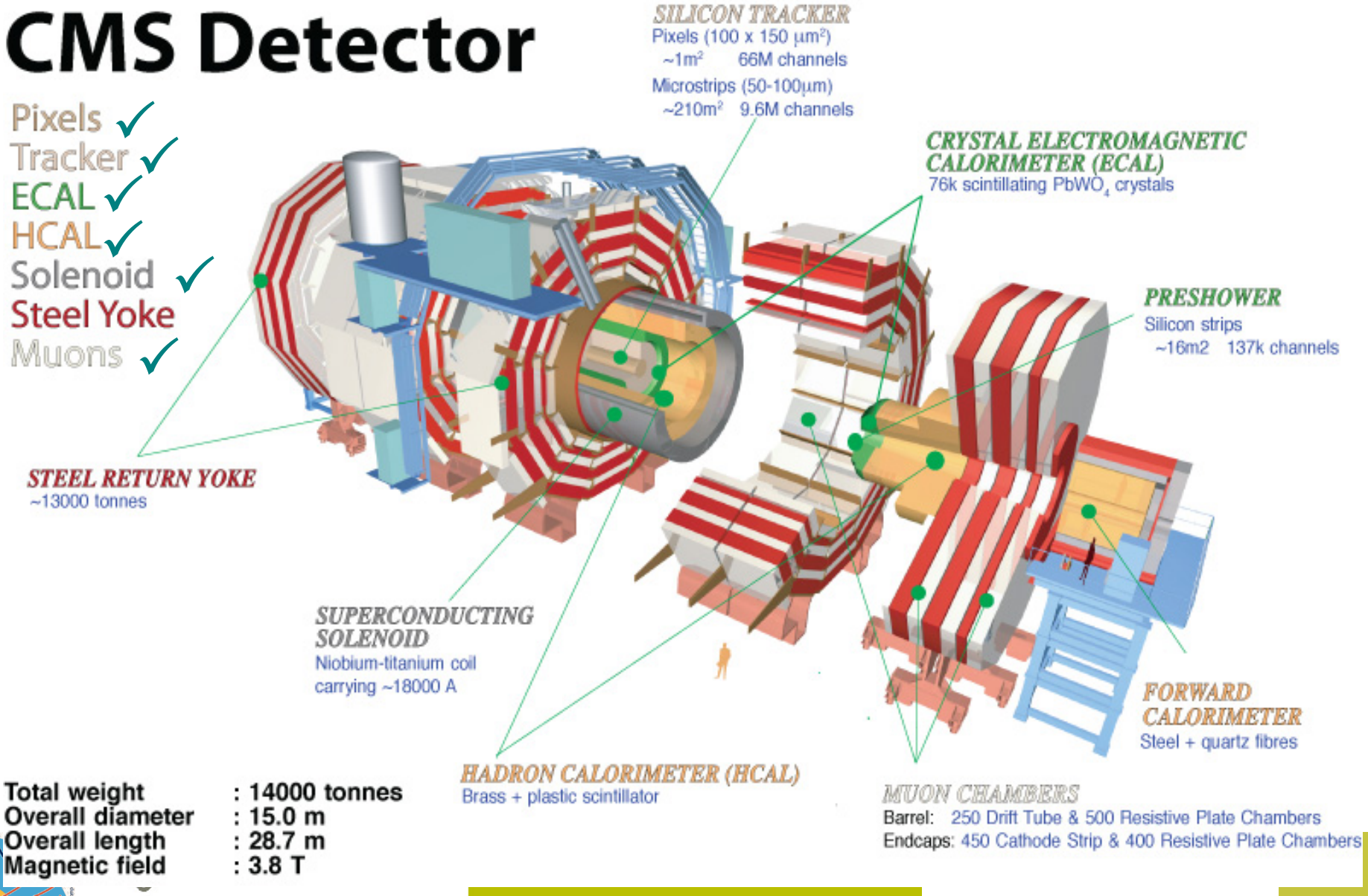
S. Jung, A. Pierce, and J. D. Wells, "Top quark asymmetry and dijet resonances", (2011). arXiv:1104.3139.

D.-W. Jung, P. Ko, and J. S. Lee, "A Possible Common Origin of the Top Forward-backward Asymmetry and the CDF Dijet Resonance", (2011). arXiv:1104.4443.

P. J. Fox, J. Liu, D. Tucker-Smith et al., "An Effective Z'", (2011). arXiv:1104.4127.

K. Cheung and J. Song, "Baryonic Z' Explanation for the CDF Wjj Excess", *Phys. Rev. Lett.* **106** (2011) 211803, arXiv:1104.1375.

Compact Muon Solenoid



A Toroidal Lhc ApparatuS