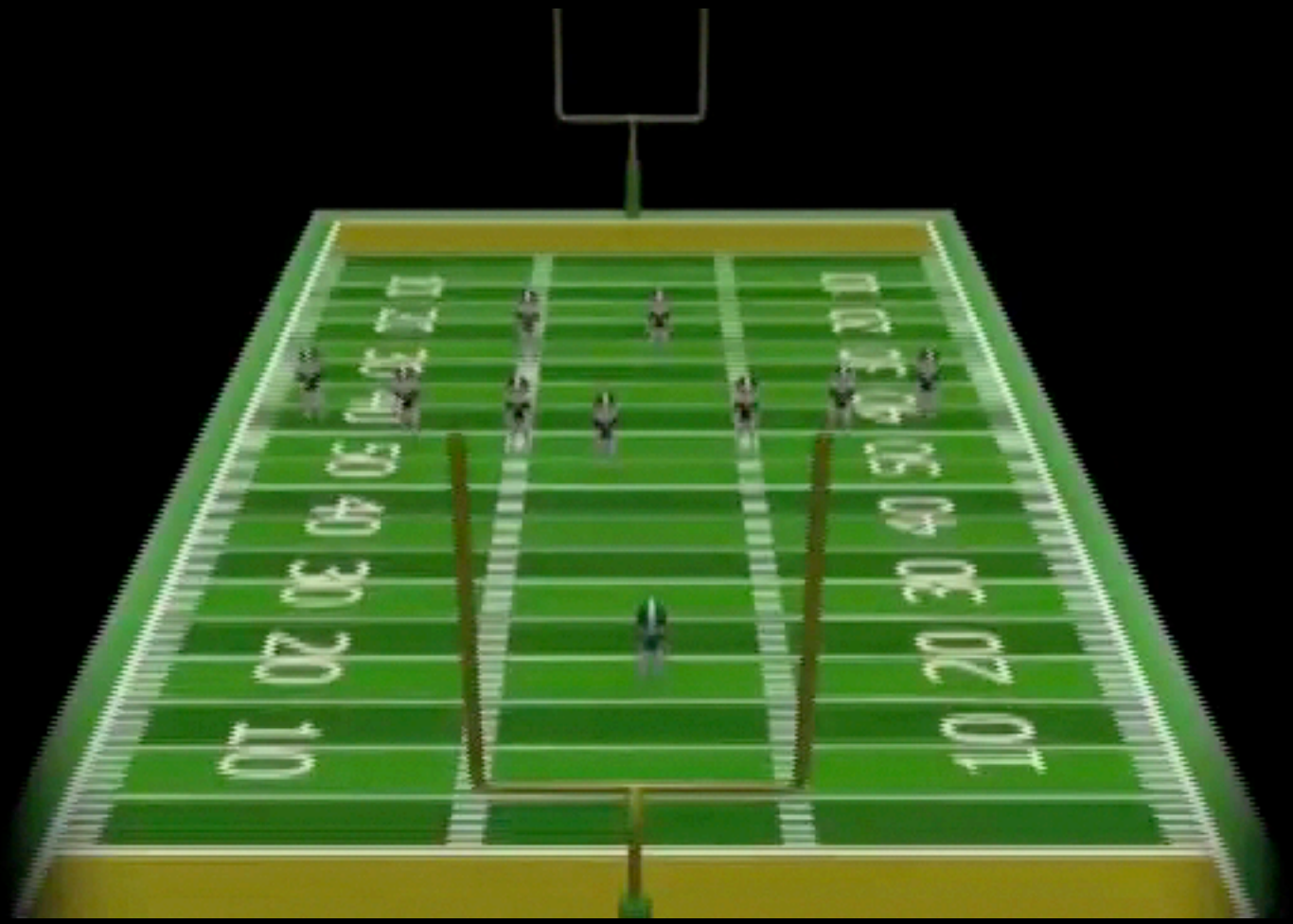
Top quark physics

Reinhard Schwienhorst
Michigan State University

MSU Physics colloquium 1/5/2012

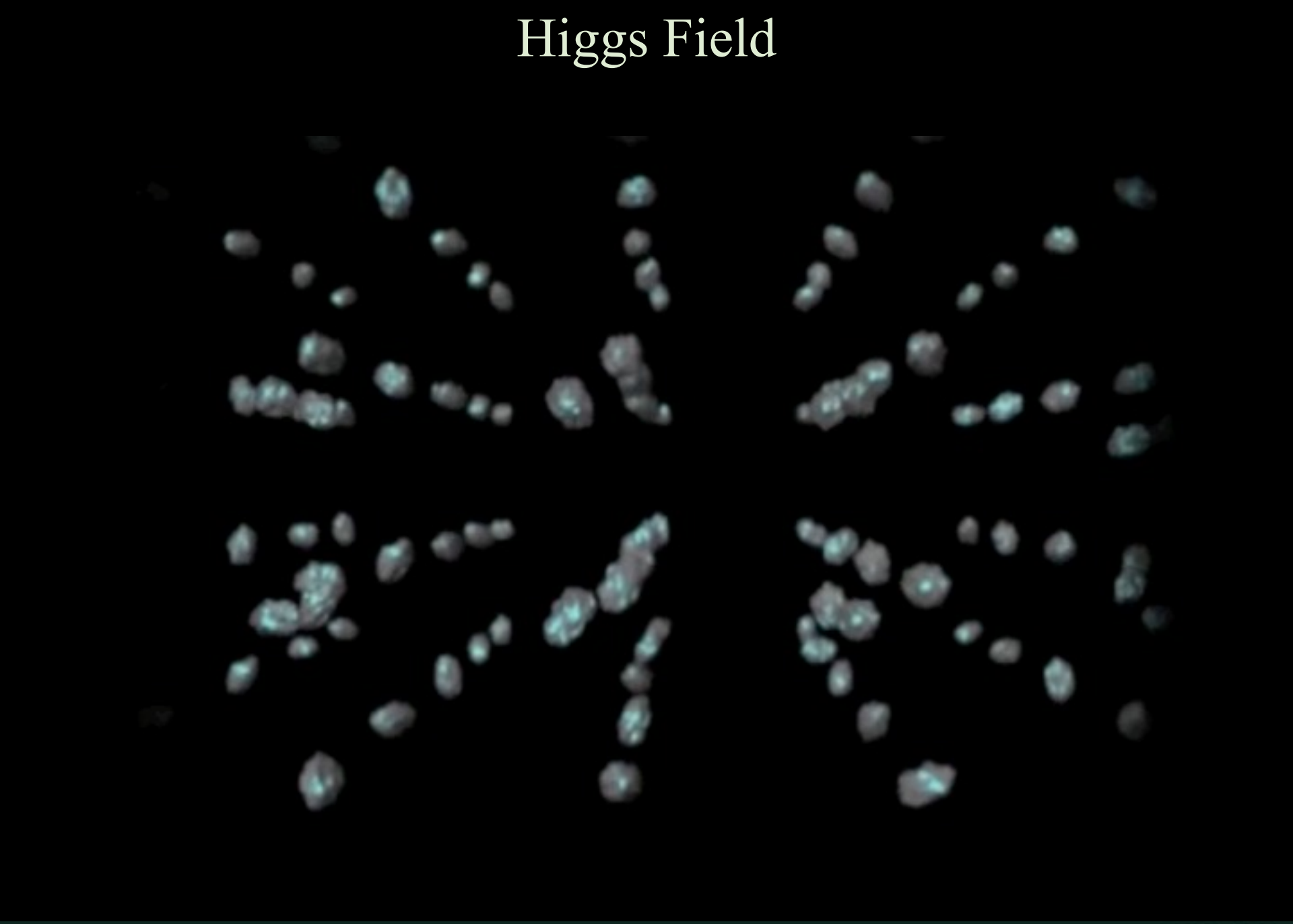
The LHC question

The LHC question



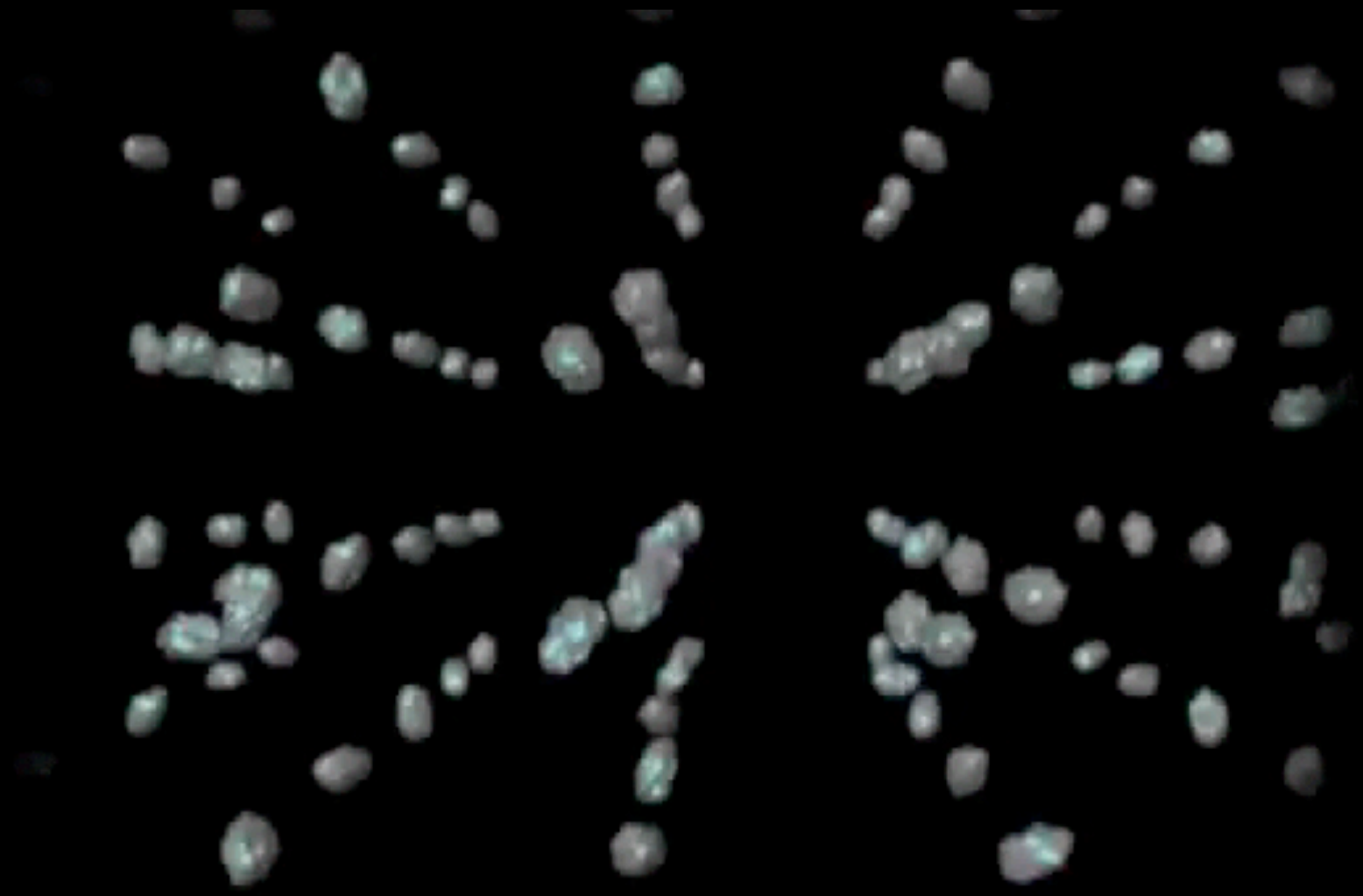
Why are particles not moving at the speed of light?

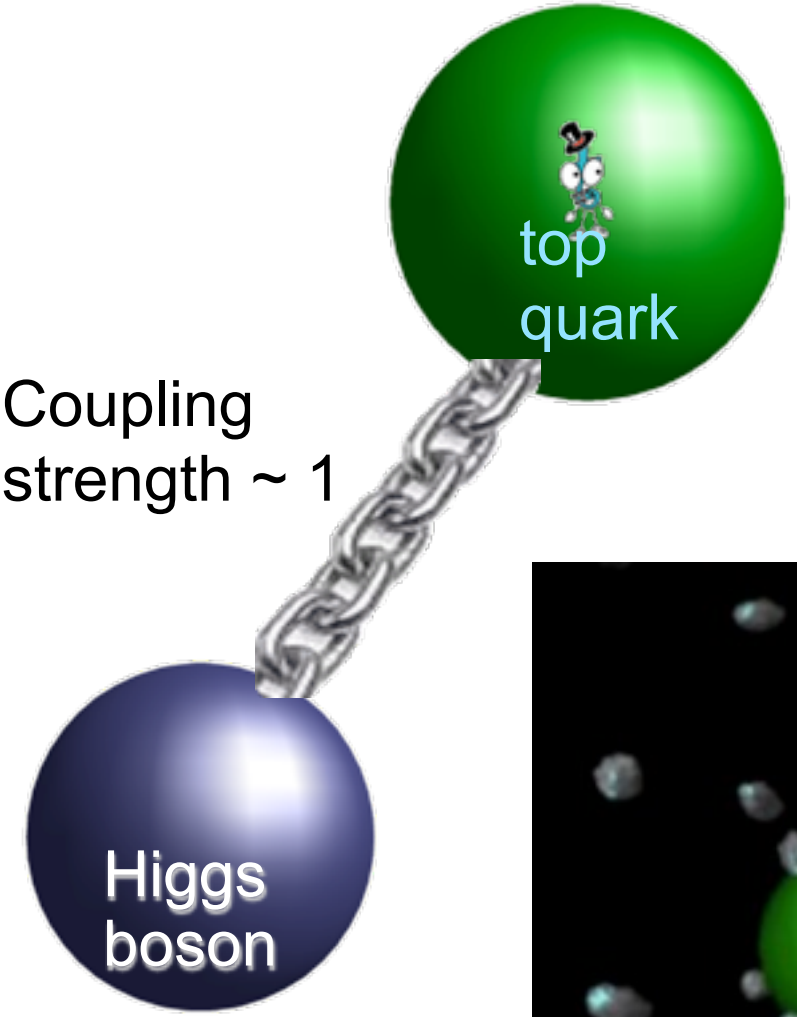
Higgs Field



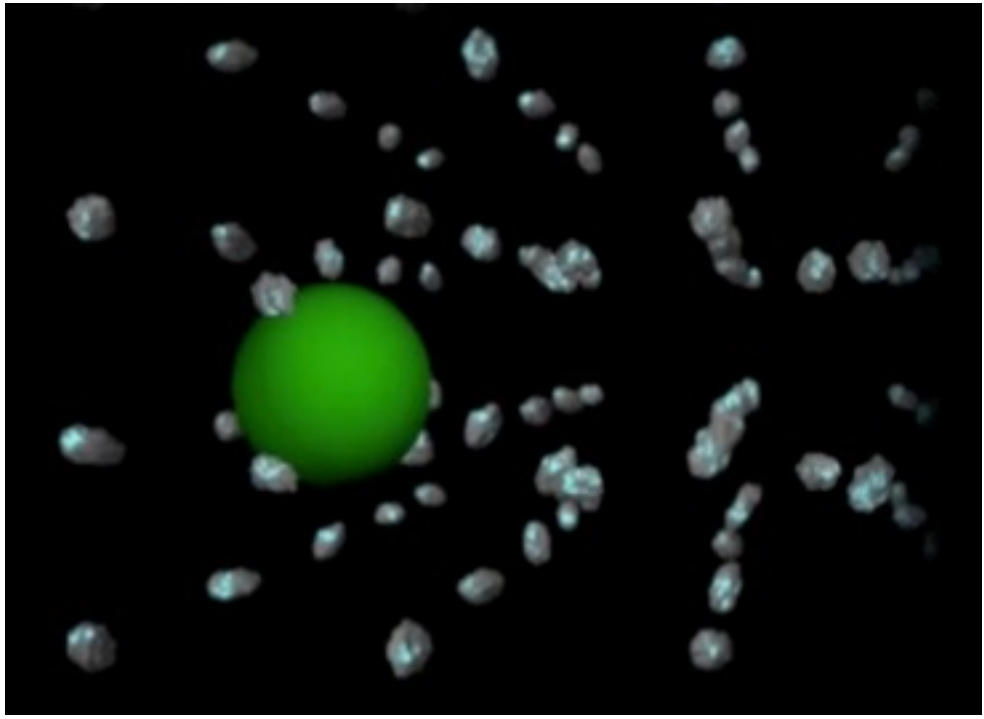
Fermion in Higgs field

Fermion in Higgs field



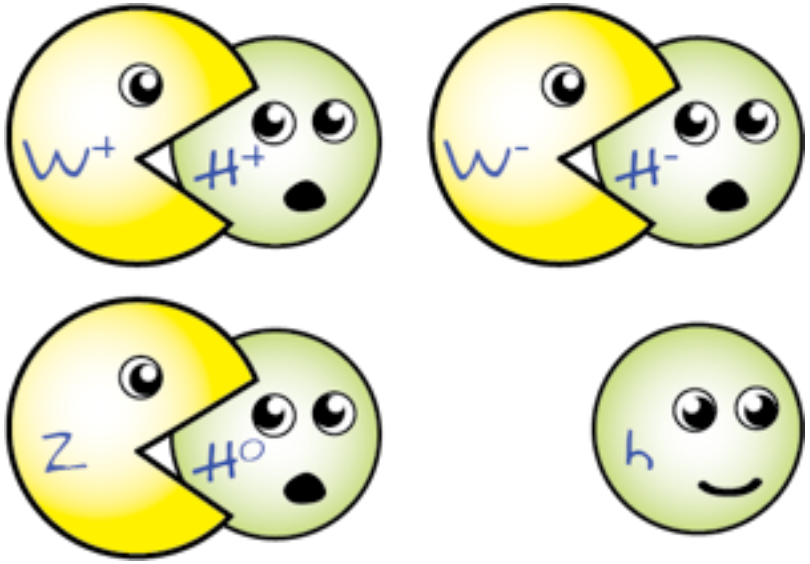


Coupling
strength ~ 1

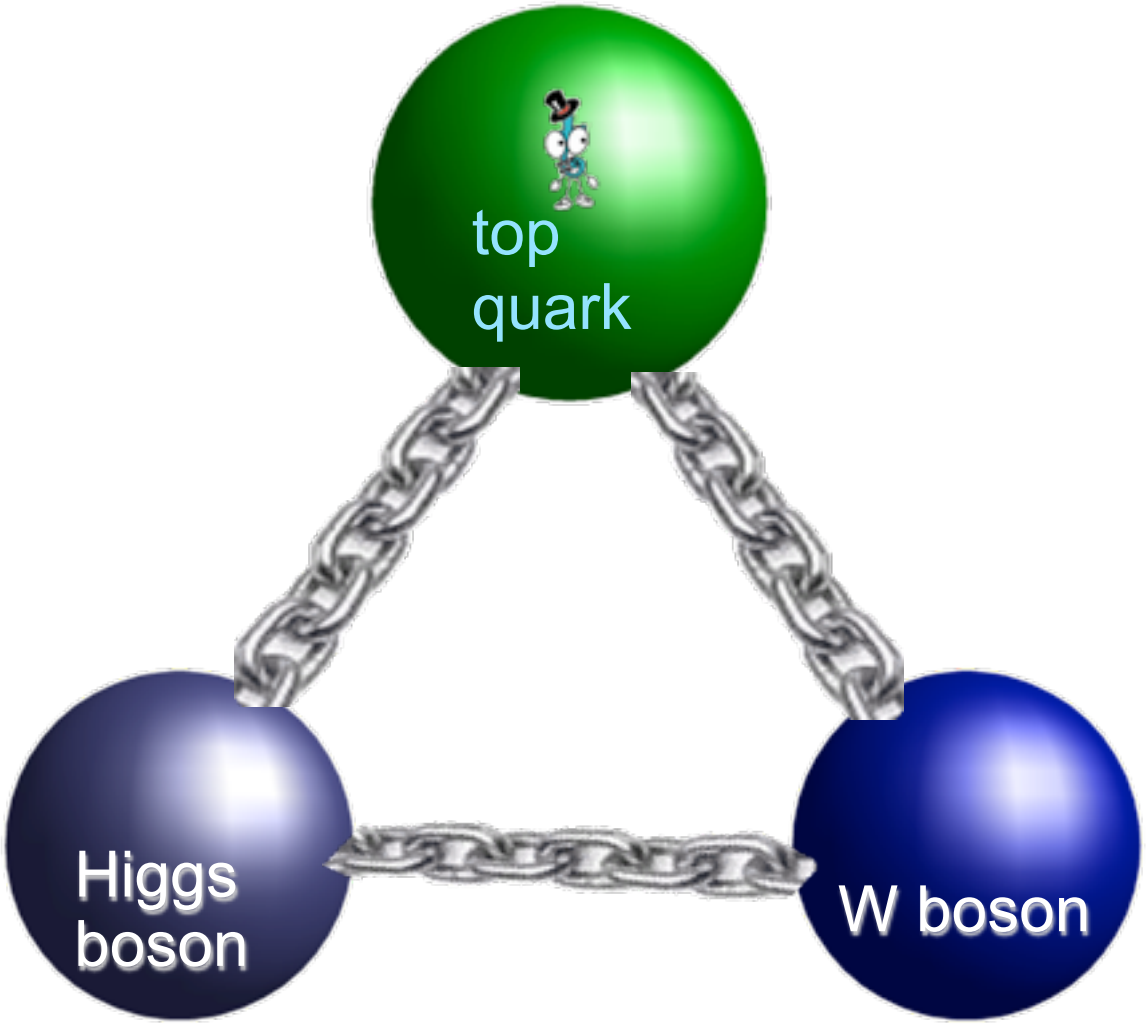


Electroweak symmetry breaking - Why is the weak force so weak?

Gauge boson coupling to Higgs field



Key to electroweak symmetry breaking



modified couplings

top-gluon interaction

top - W boson interaction

anomalous CKM matrix

anomalous Wtb couplings

CP violation

Flavor-changing neutral currents

new couplings

b'

t'

4th generation quarks

other new fermions

new heavy fermions

vector quarks

W'

Z'

charged Higgs

new heavy bosons

Supersymmetry

Extra dimensions

Higgs-less models

Other new physics models

Central to new physics searches

modified couplings

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top - W boson interaction

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Flav
neu

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new couplings

King of the Fermions

Supersymmetry

Extra dimensions

Higgs-less models

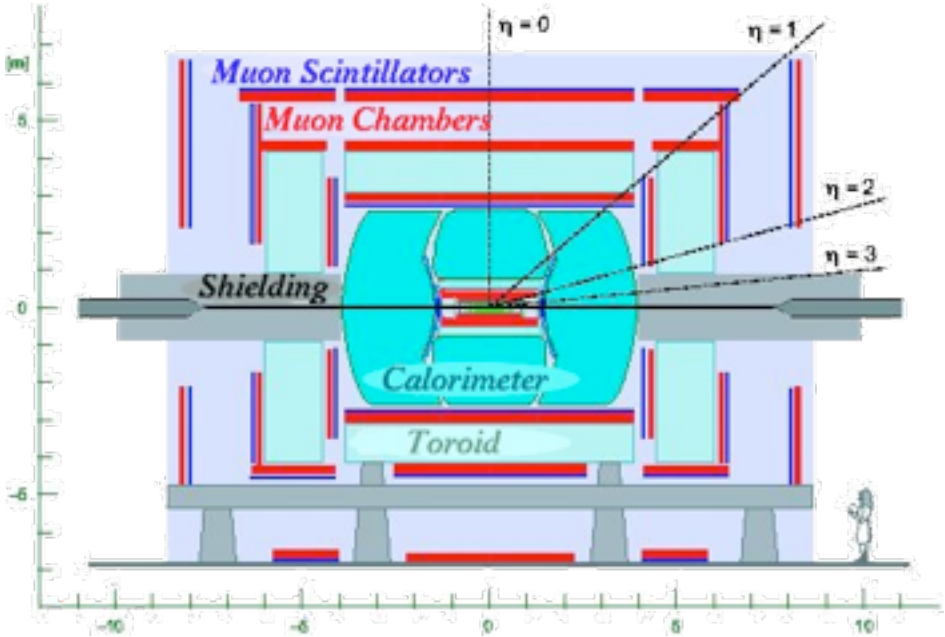
Other new physics models

Experimental Setup

Tevatron proton-antiproton collider at Fermilab

Tevatron proton-antiproton collider at Fermilab

D0 detector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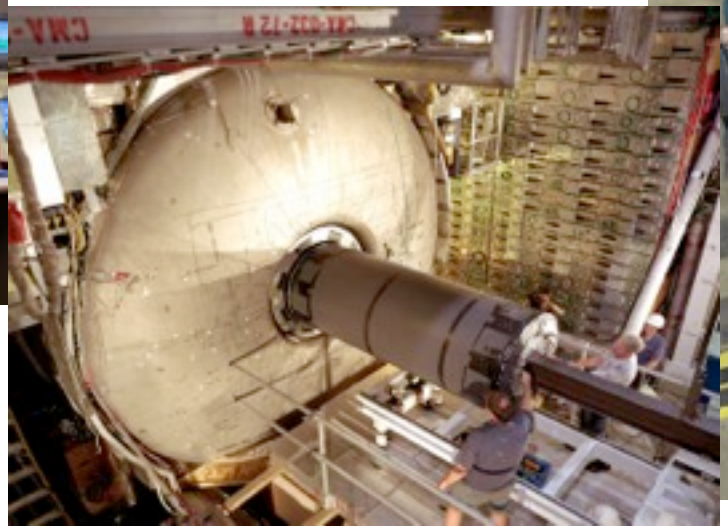
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
[m]
5
0
-5
-10
-5
0
5
10

2003/03/25

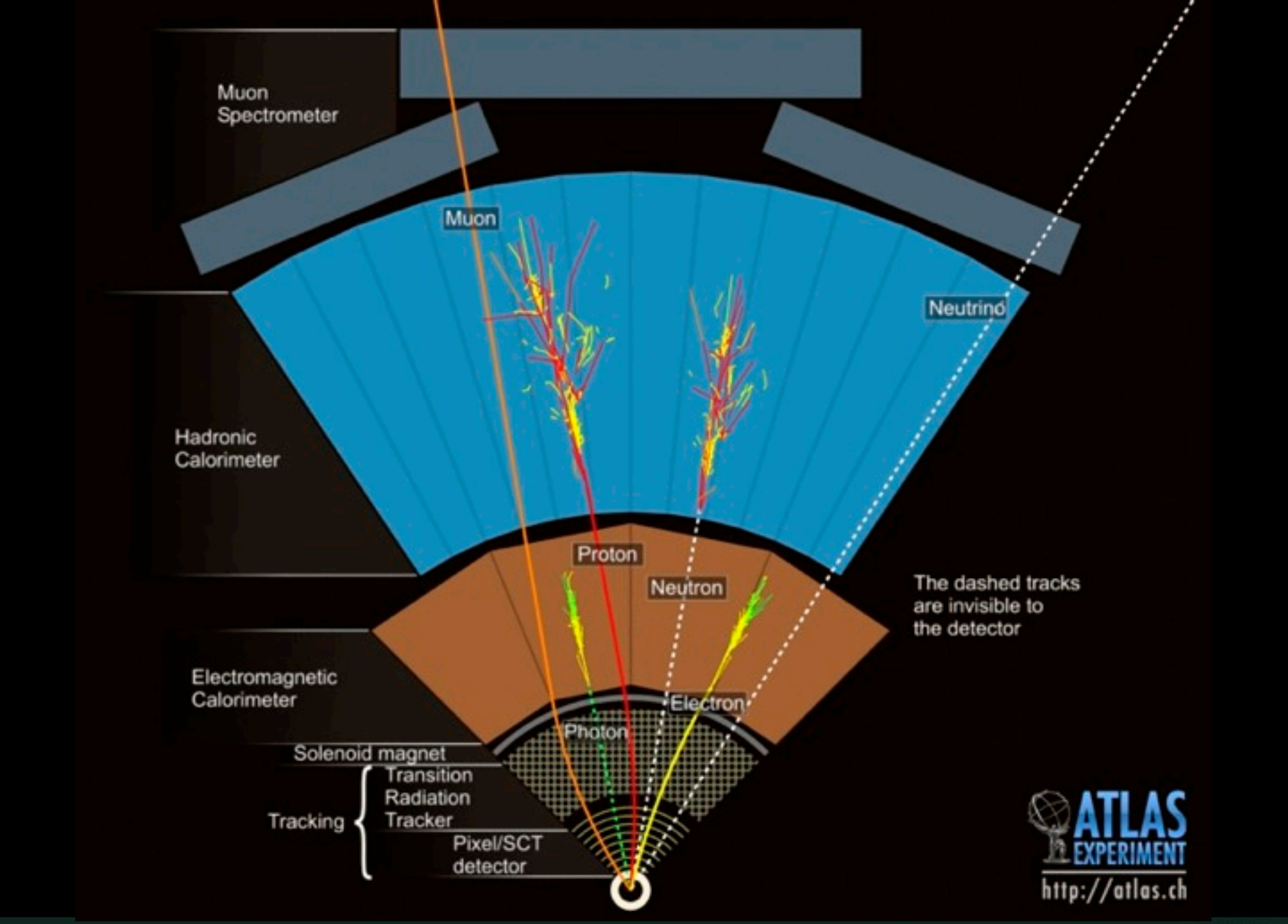


Large Hadron Collider

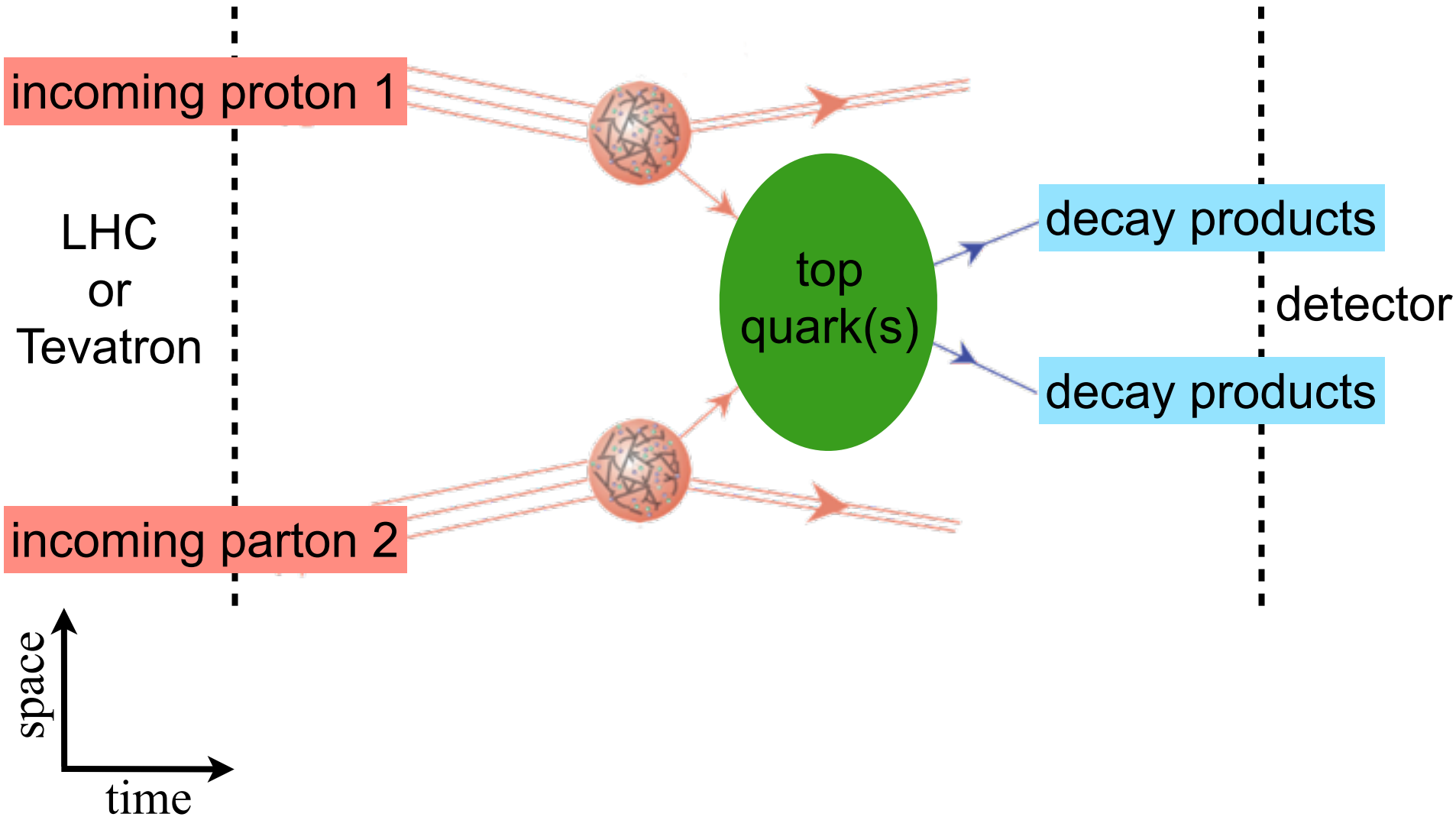
Large Hadron Collider

ATLAS detector

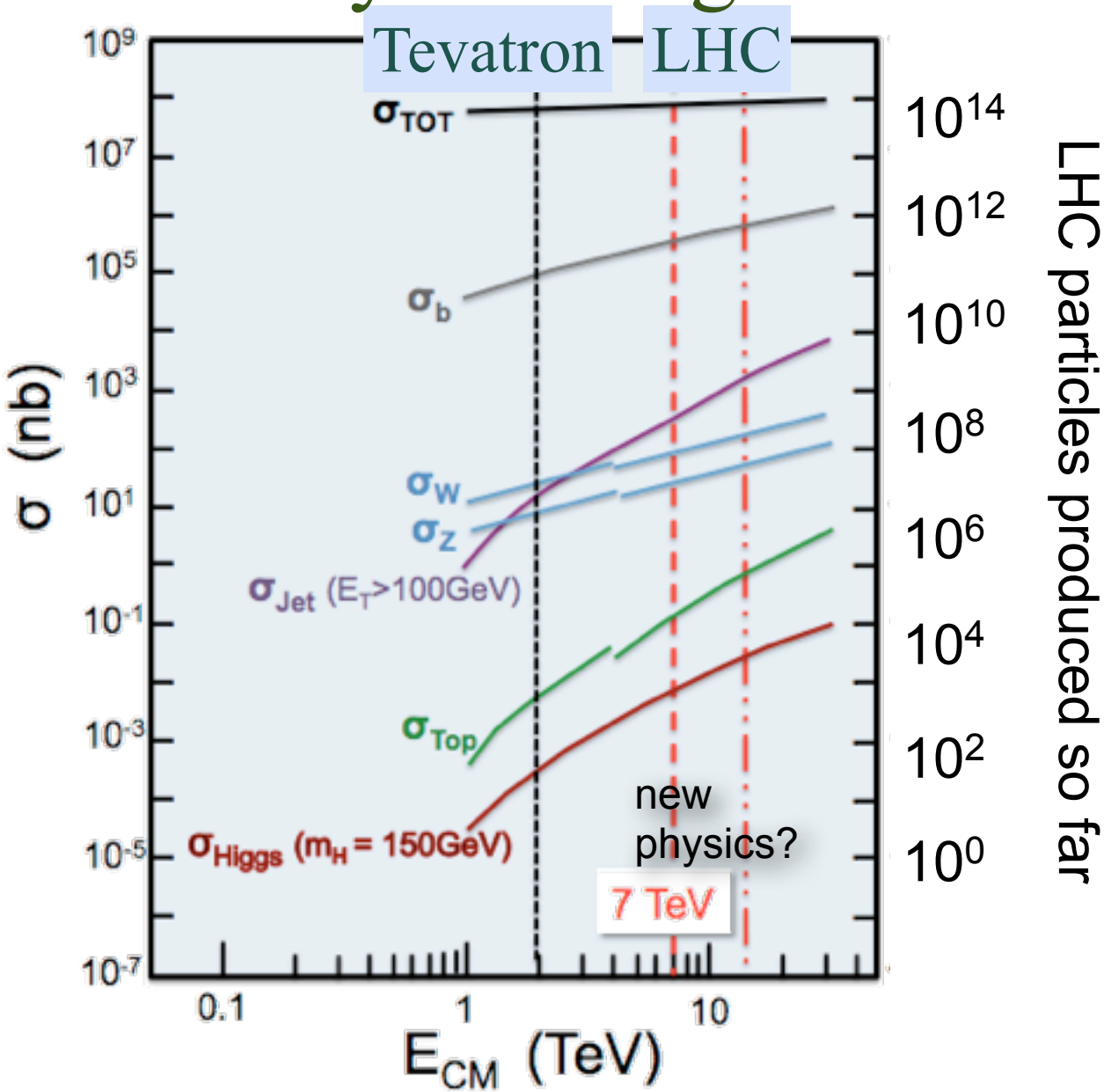
ATLAS detector


Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch

Top quark production and decay



Physics Program



Top pair production

Tevatron: $\sigma_{tot} = 7$ pb

LHC: (7 TeV) $\sigma_{tot} = 170$ pb

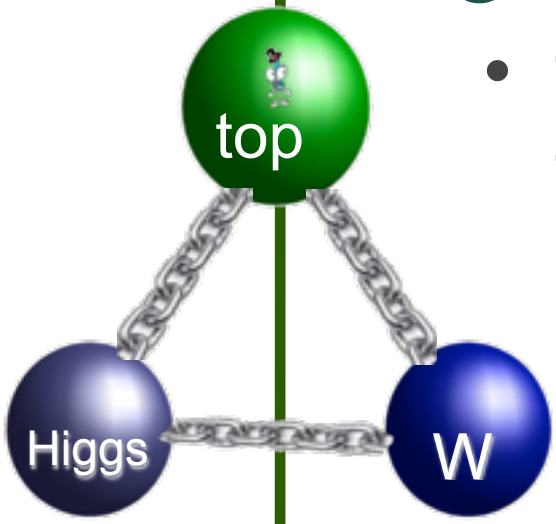
Single top production

$\sigma_{tot} = 3$ pb

$\sigma_{tot} = 75$ pb

Top pair production

- Top mass measurement
  - predict Higgs mass
- CKM matrix element ratio
- tWb coupling - W helicity
- top-gluon coupling - total cross section measurement
- top quark charge
  - electromagnetic coupling



Single top production

- tWb coupling - total cross section measurement
- measure CKM matrix element |Vtb| directly
- tWb coupling - top quark spin
- b-quark content of proton

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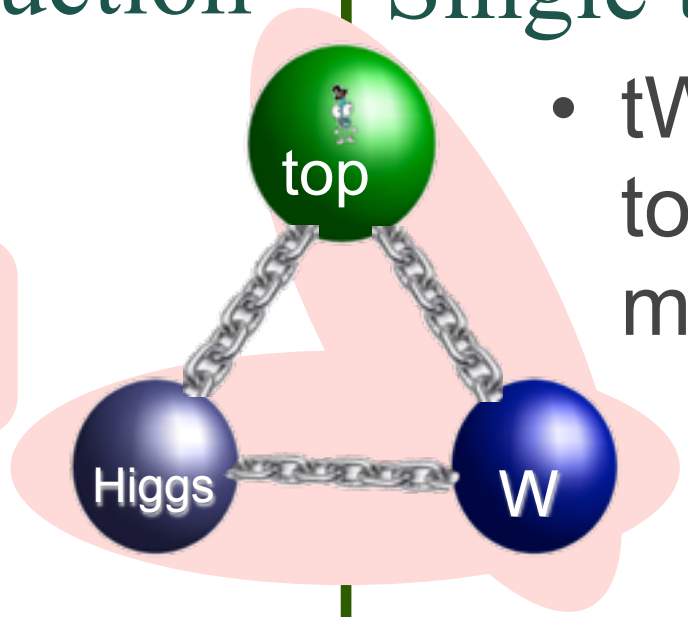

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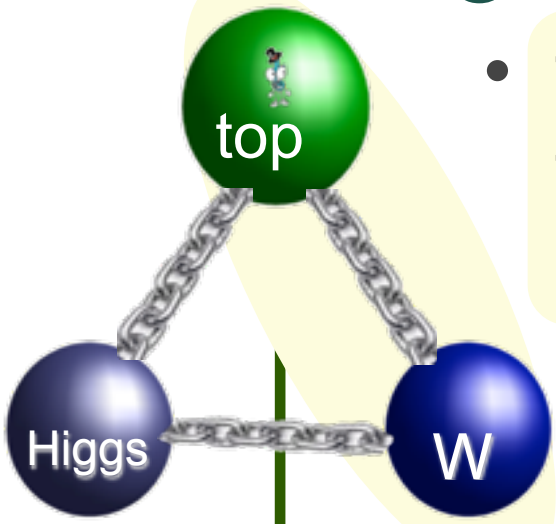

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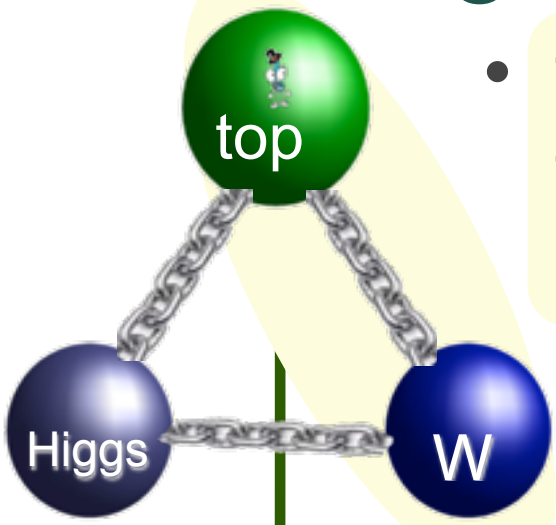

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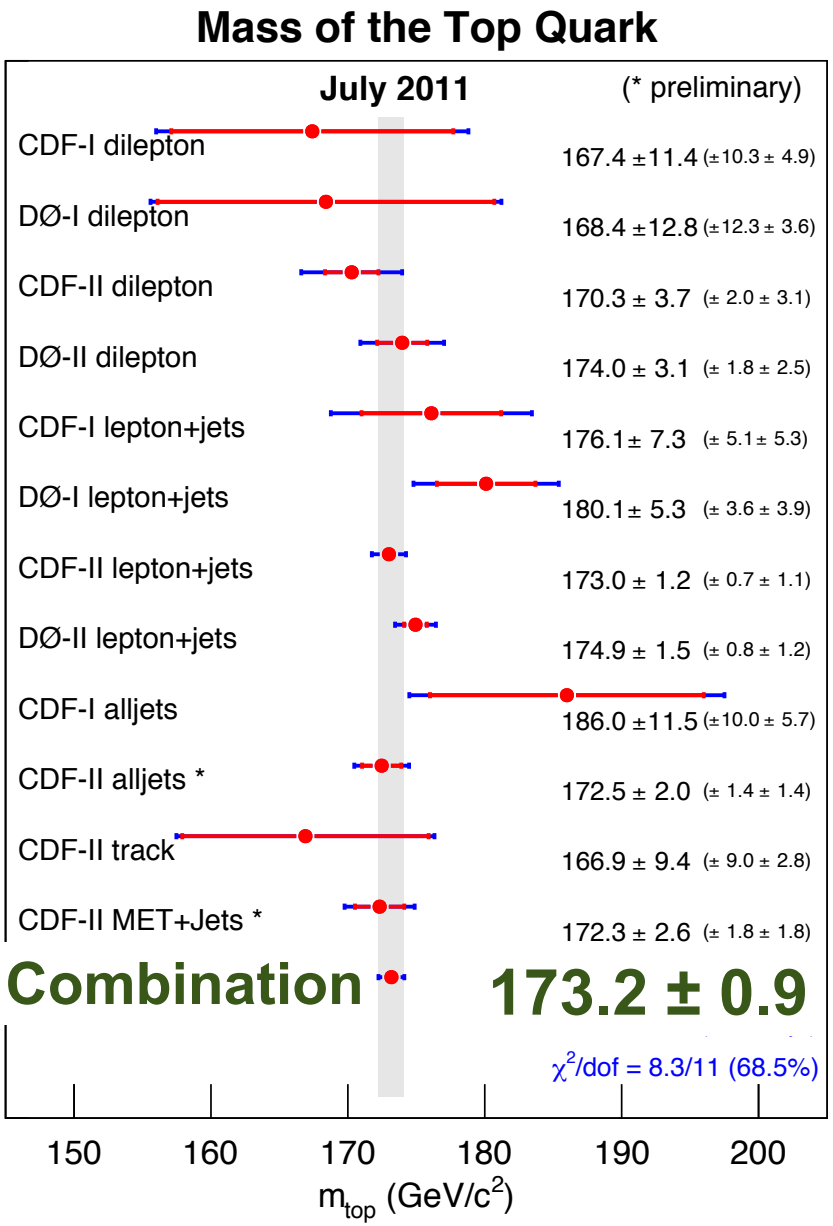
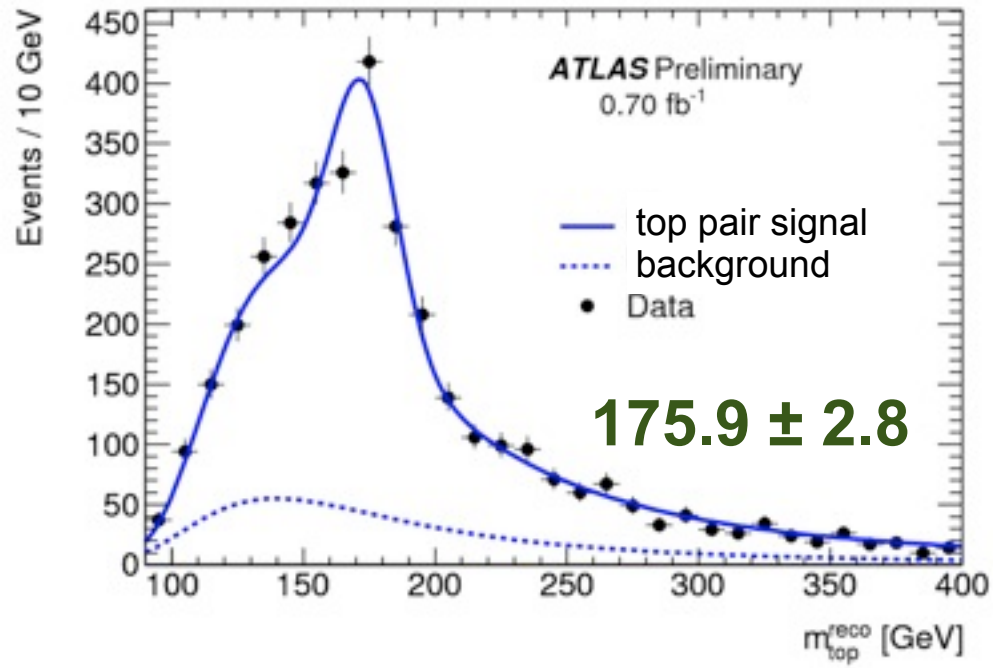
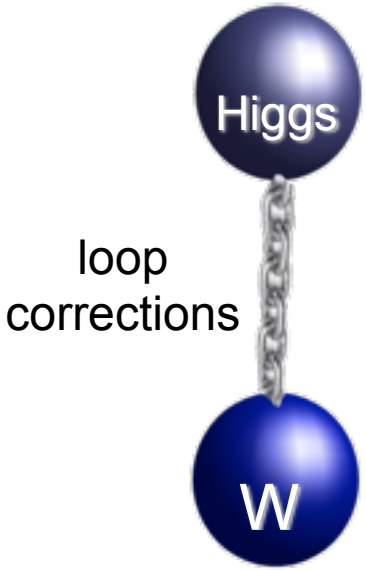
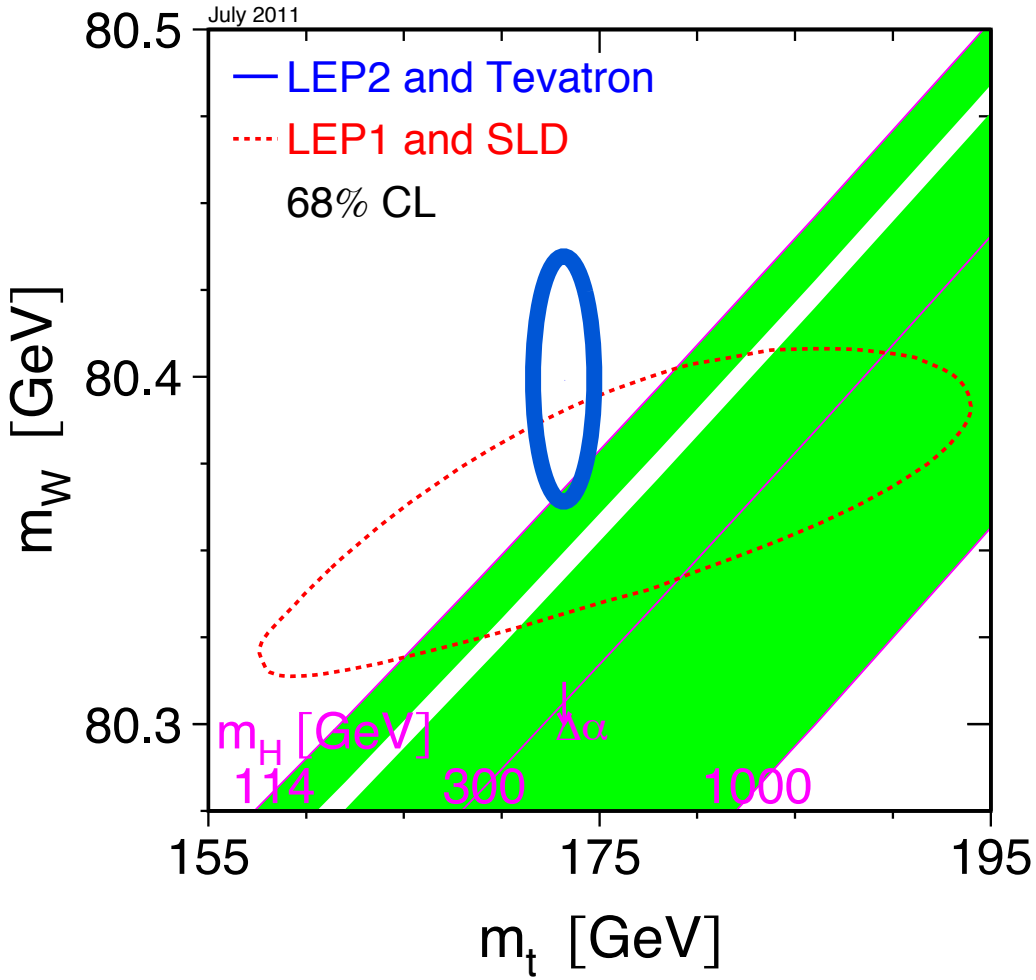
Top quark mass measurement





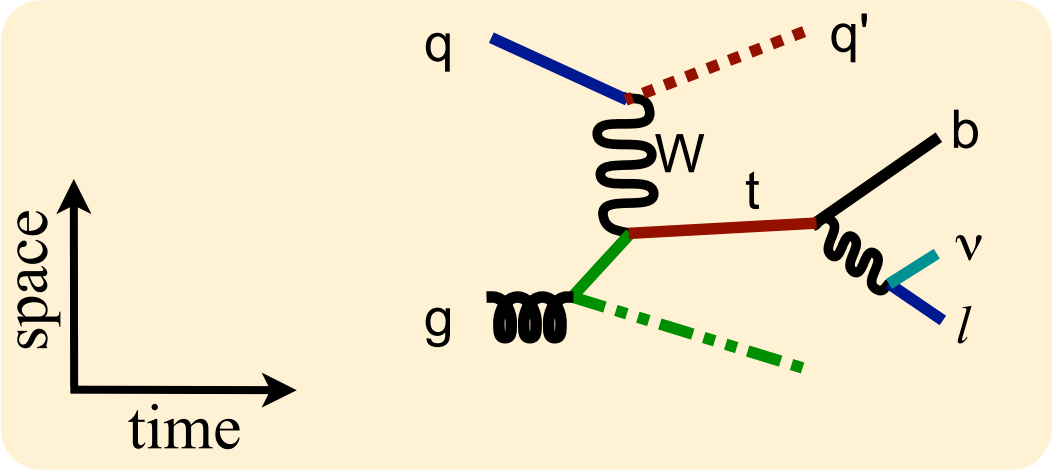
Higgs constraints from top quark mass

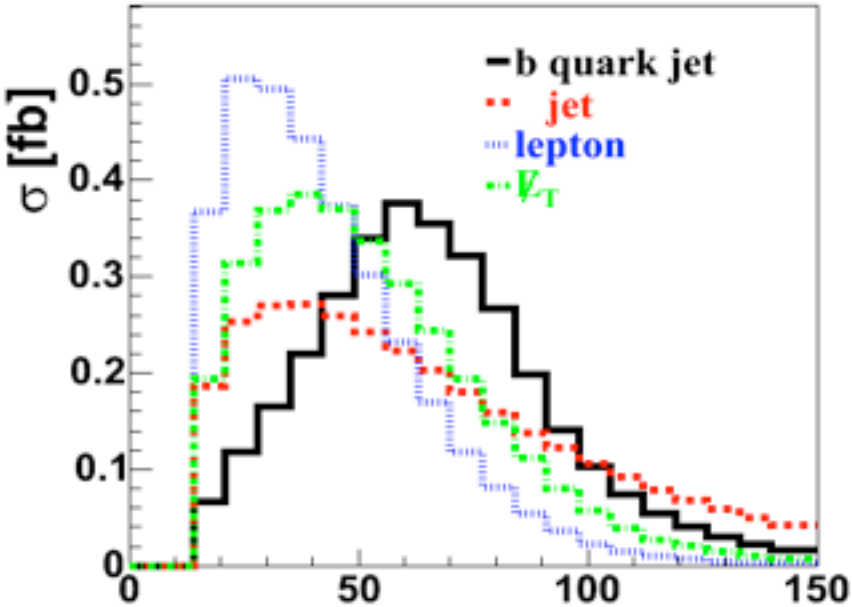




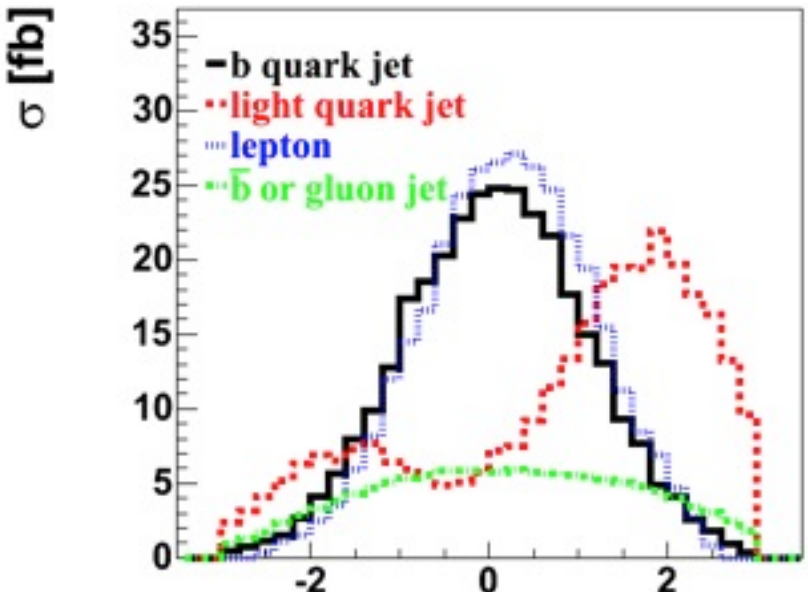
Single top analysis

Single top quark event signature





Transverse particle energy [GeV]

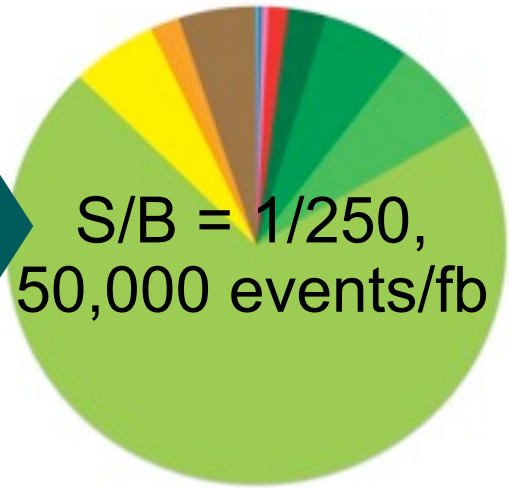


Angle with respect to beam direction

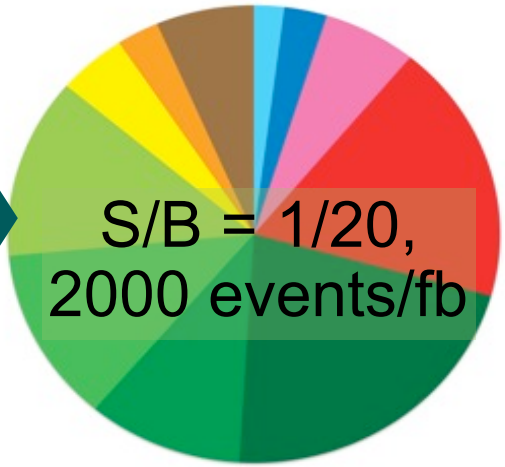
Tevatron single top analysis

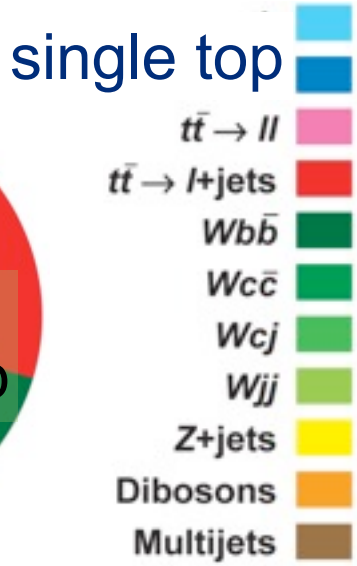
Trigger selection

event kinematics

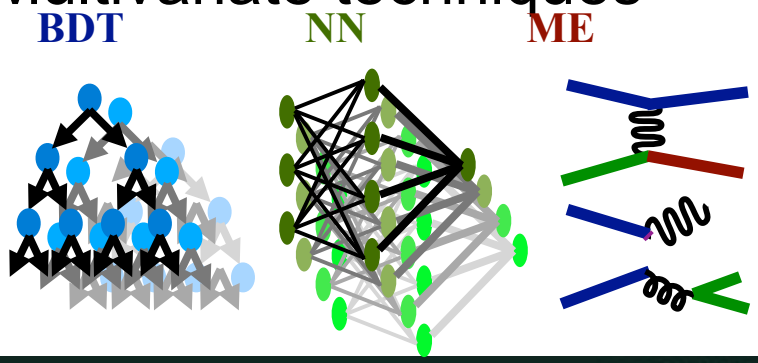


b-quark tagging

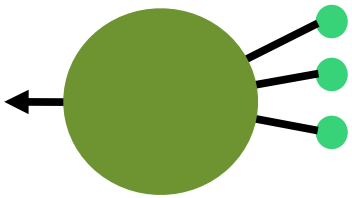




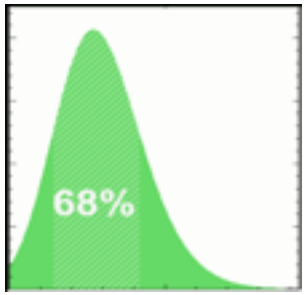
Multivariate techniques



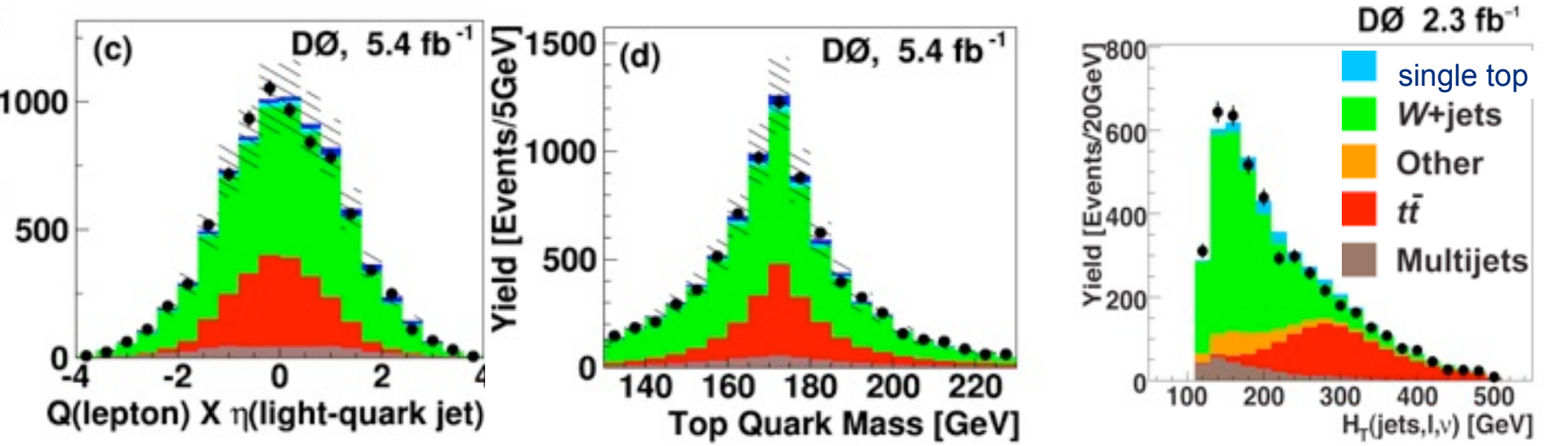
Combination



Statistical analysis

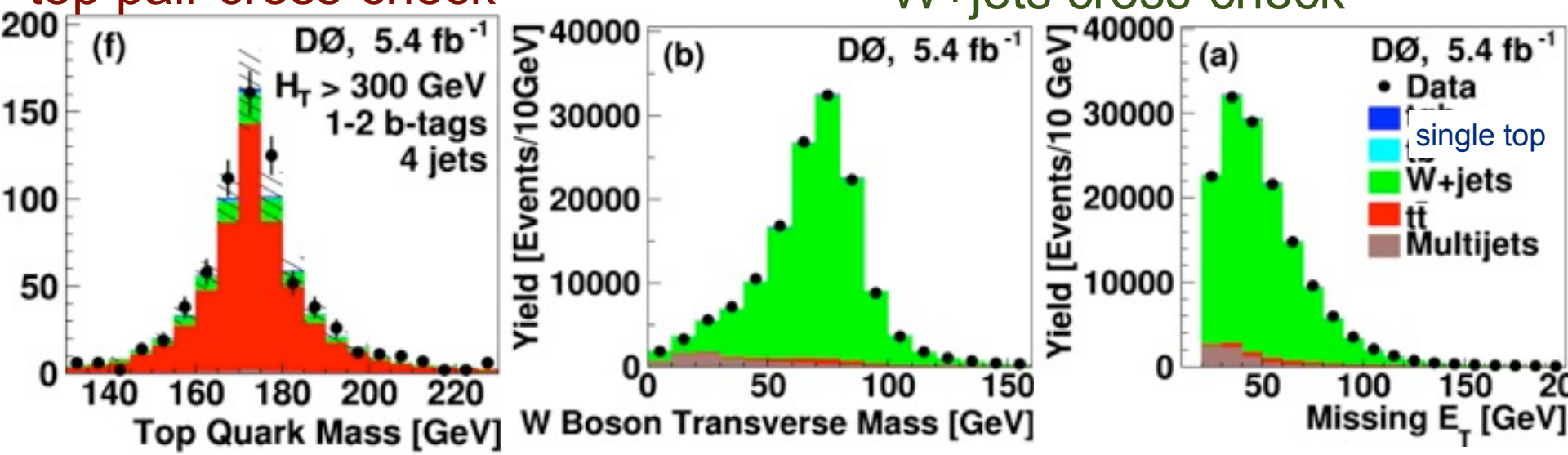


kinematic variables to distinguish signal from background



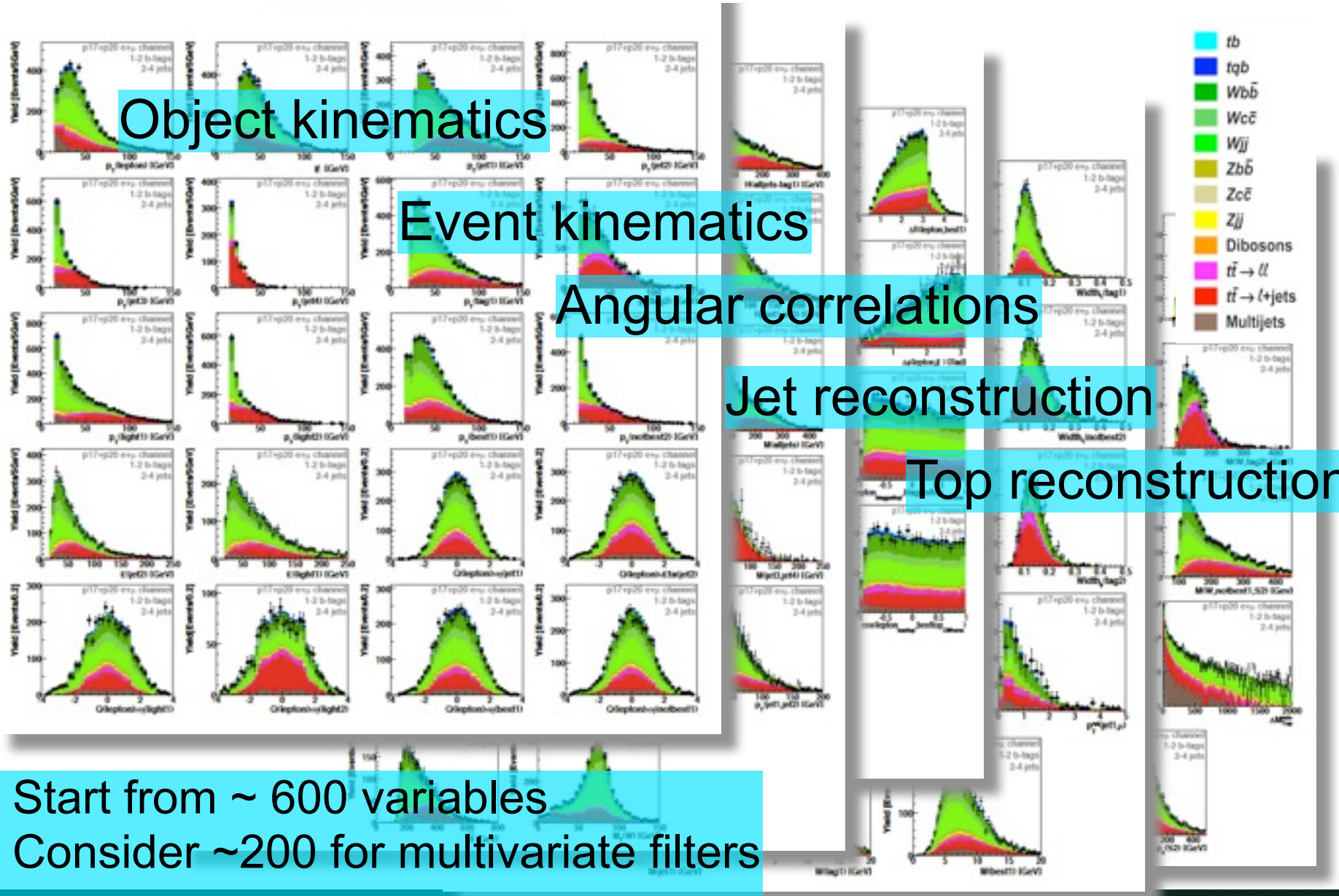
top pair cross-check

W+jets cross-check



Discriminating variables

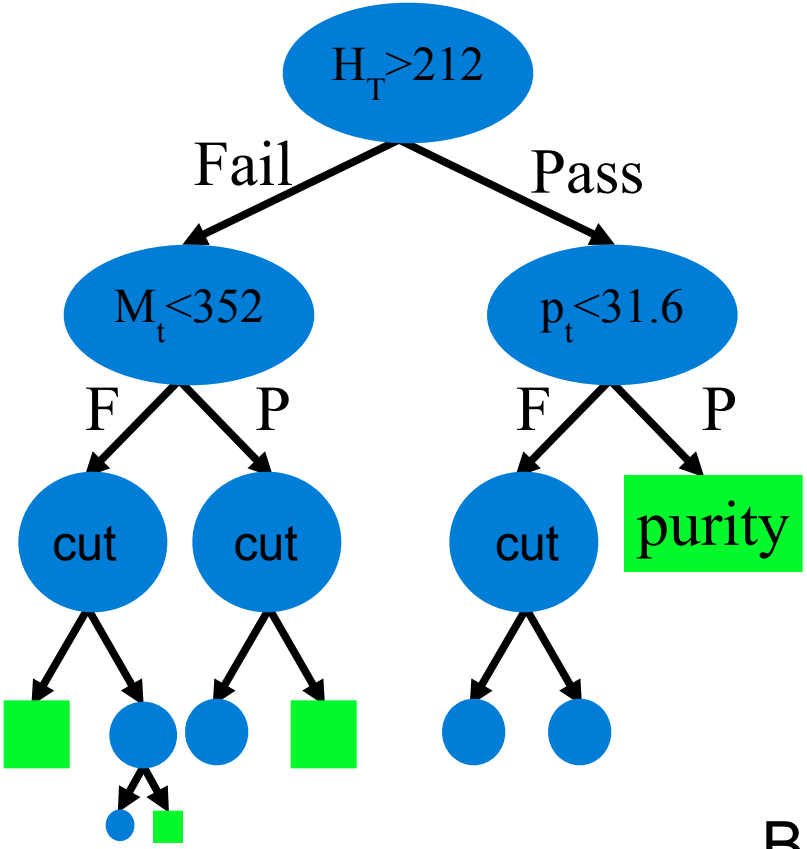
Discriminating variables



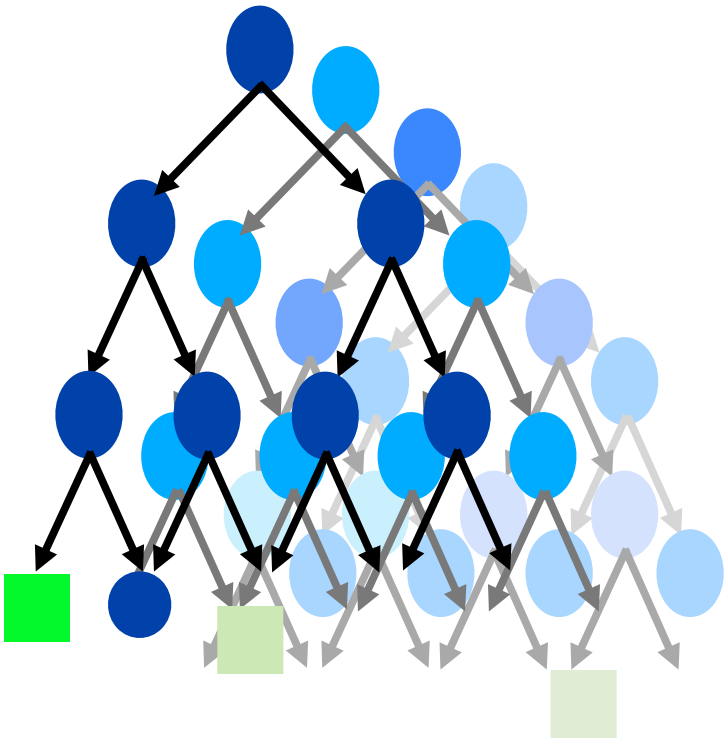
- Start from ~ 600 variables
- Consider ~200 for multivariate filters

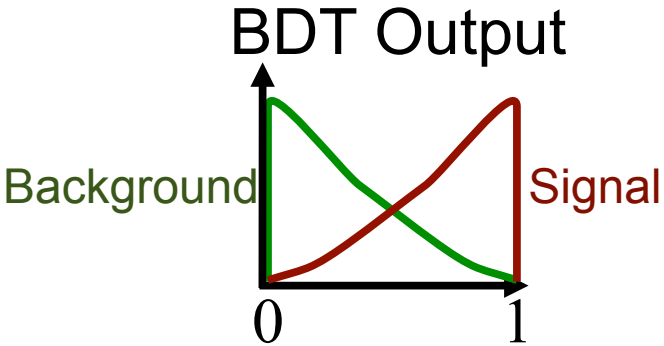
Multivariate analysis

Decision Tree

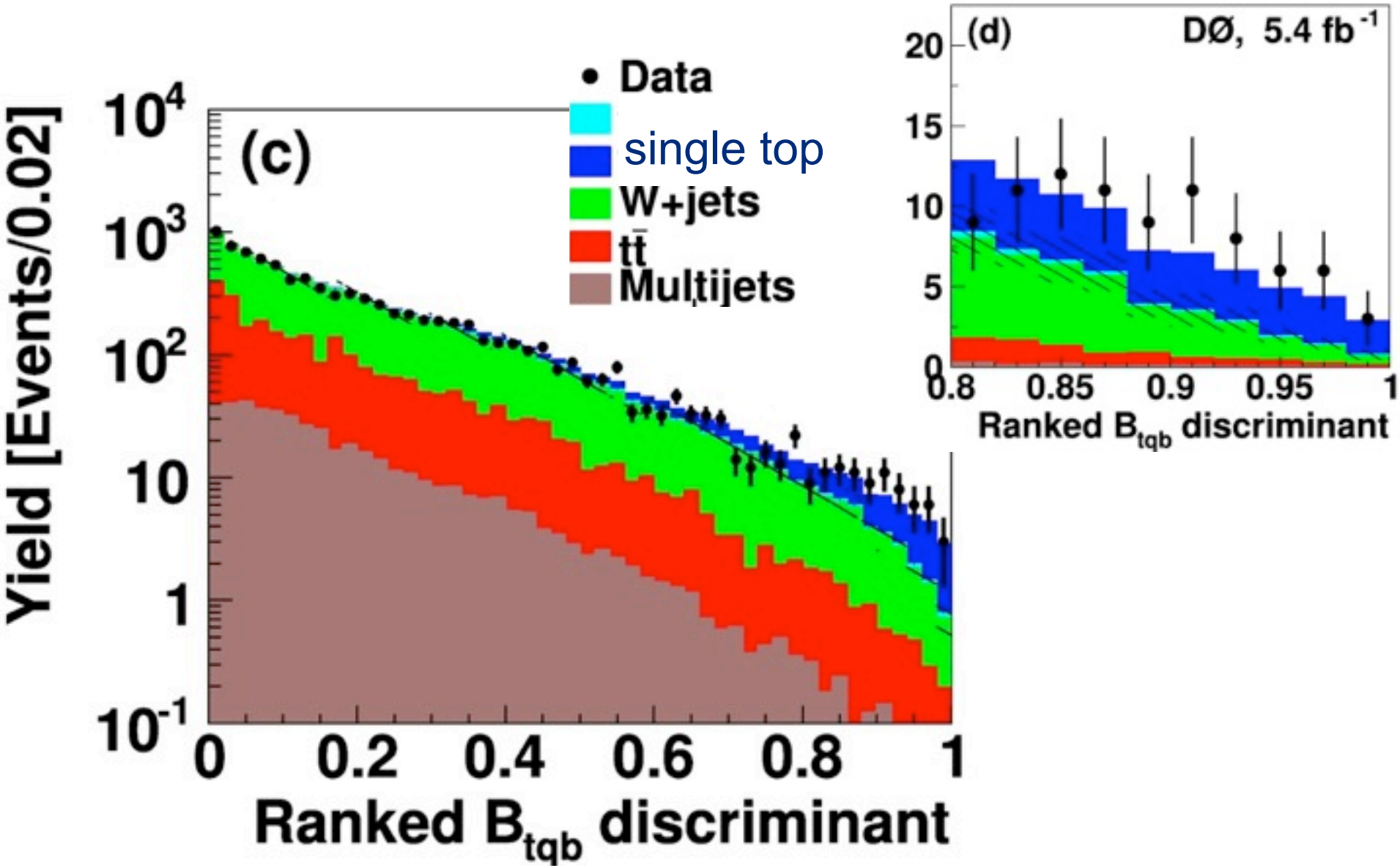


Boosted Decision Trees

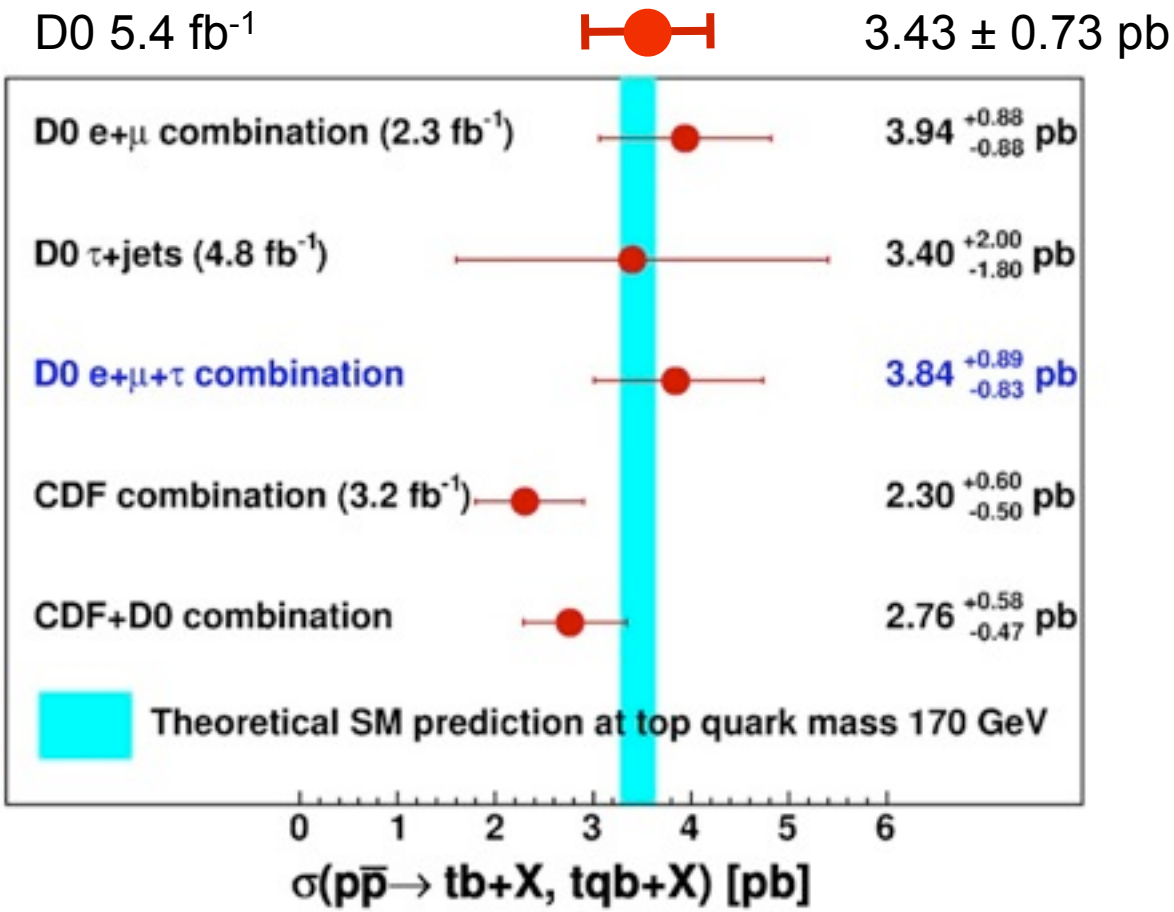




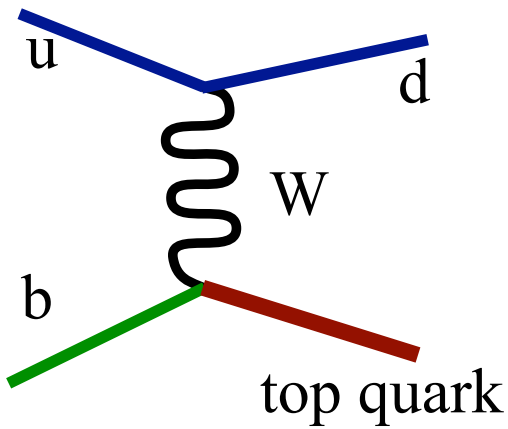
Multivariate filter output

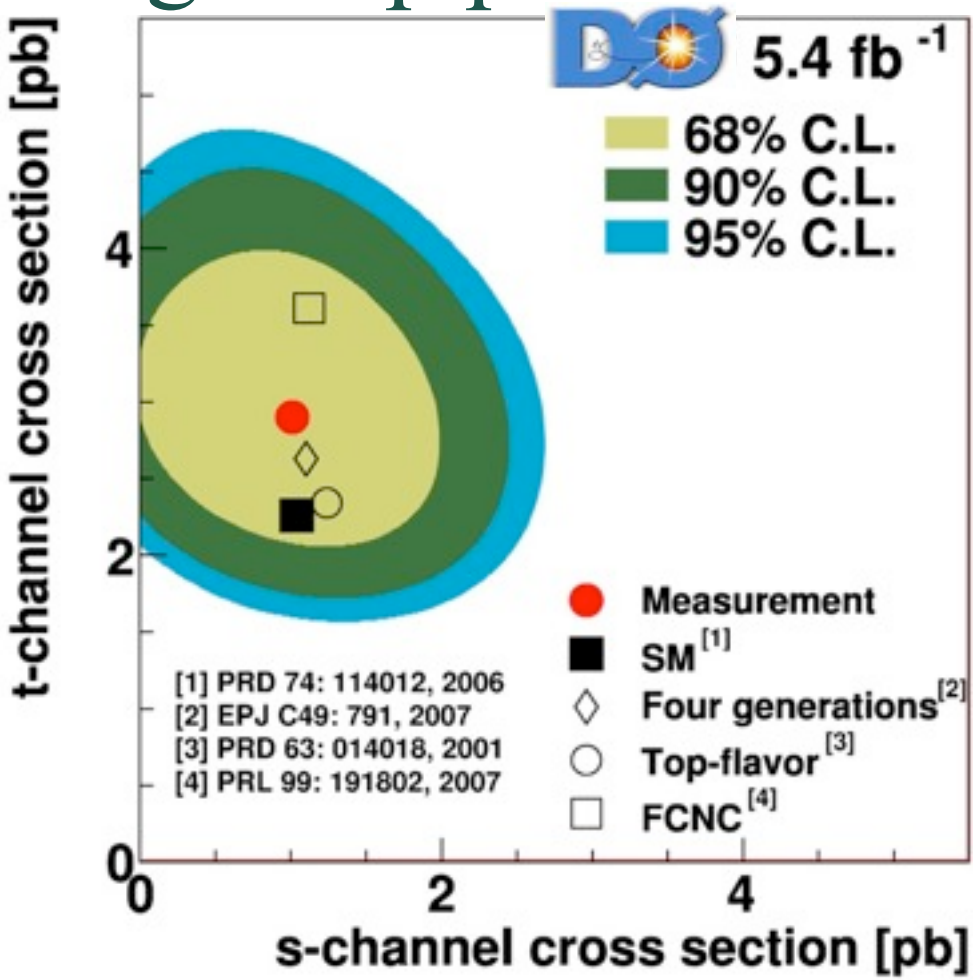


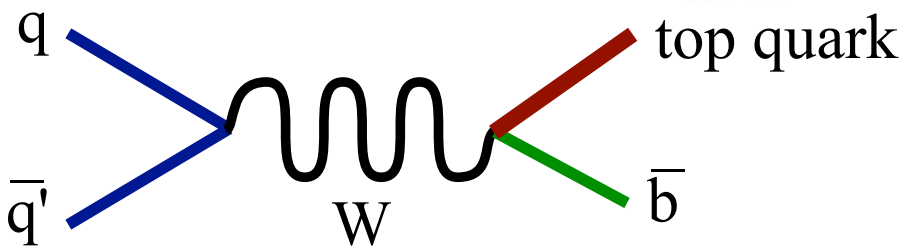
Tevatron single top cross section



Separate single top production modes







CKM matrix element $|V_{tb}|$

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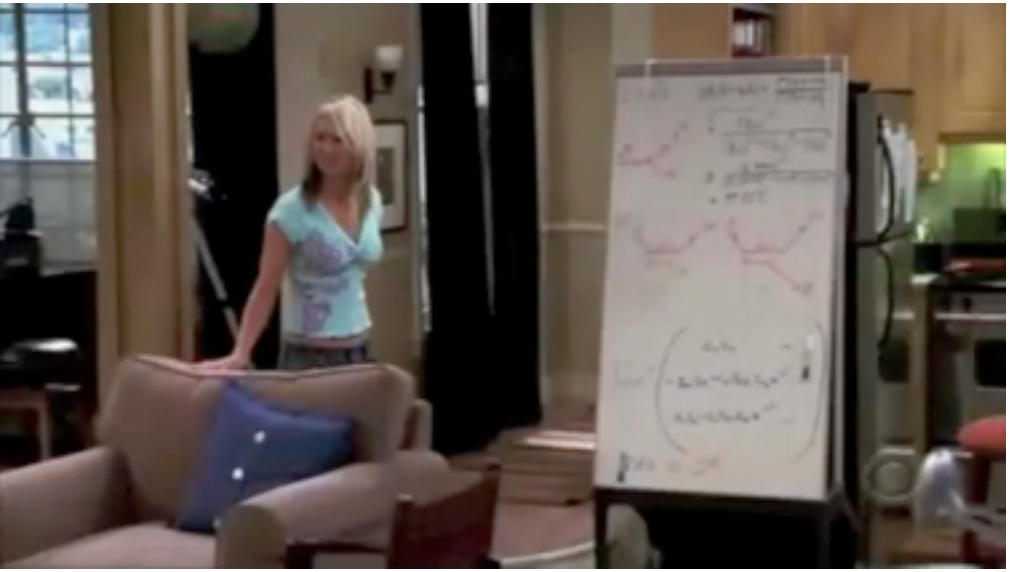
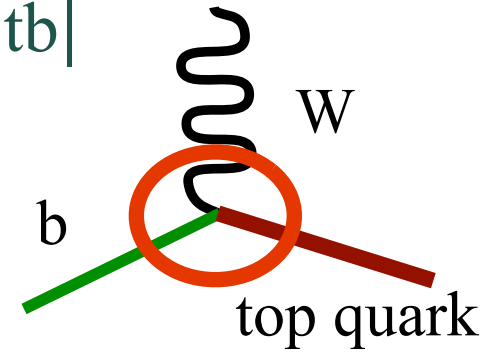
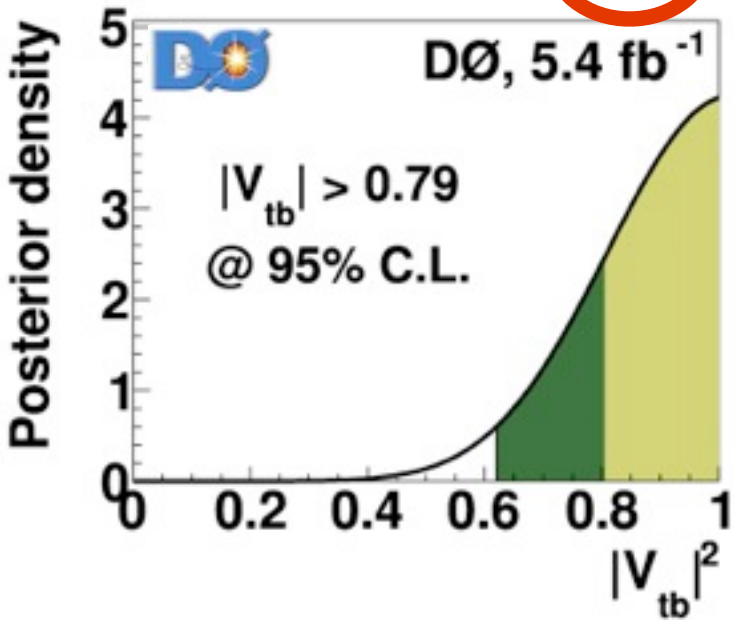




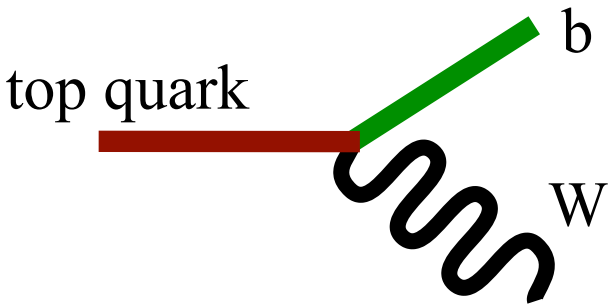
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

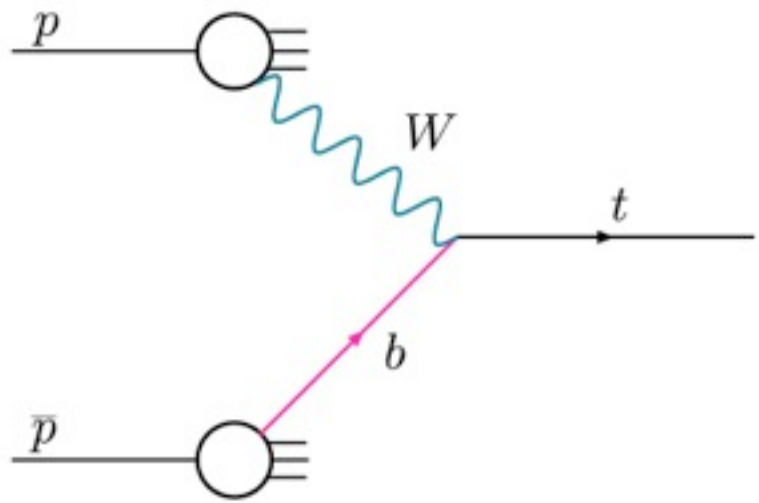
- Cabbibo-Kobayashi-Maskawa quark mixing matrix
- Single top cross section proportional to $|V_{tb}|^2$
- No assumptions about number of generations or unitarity of CKM matrix



Top quark decay width and lifetime

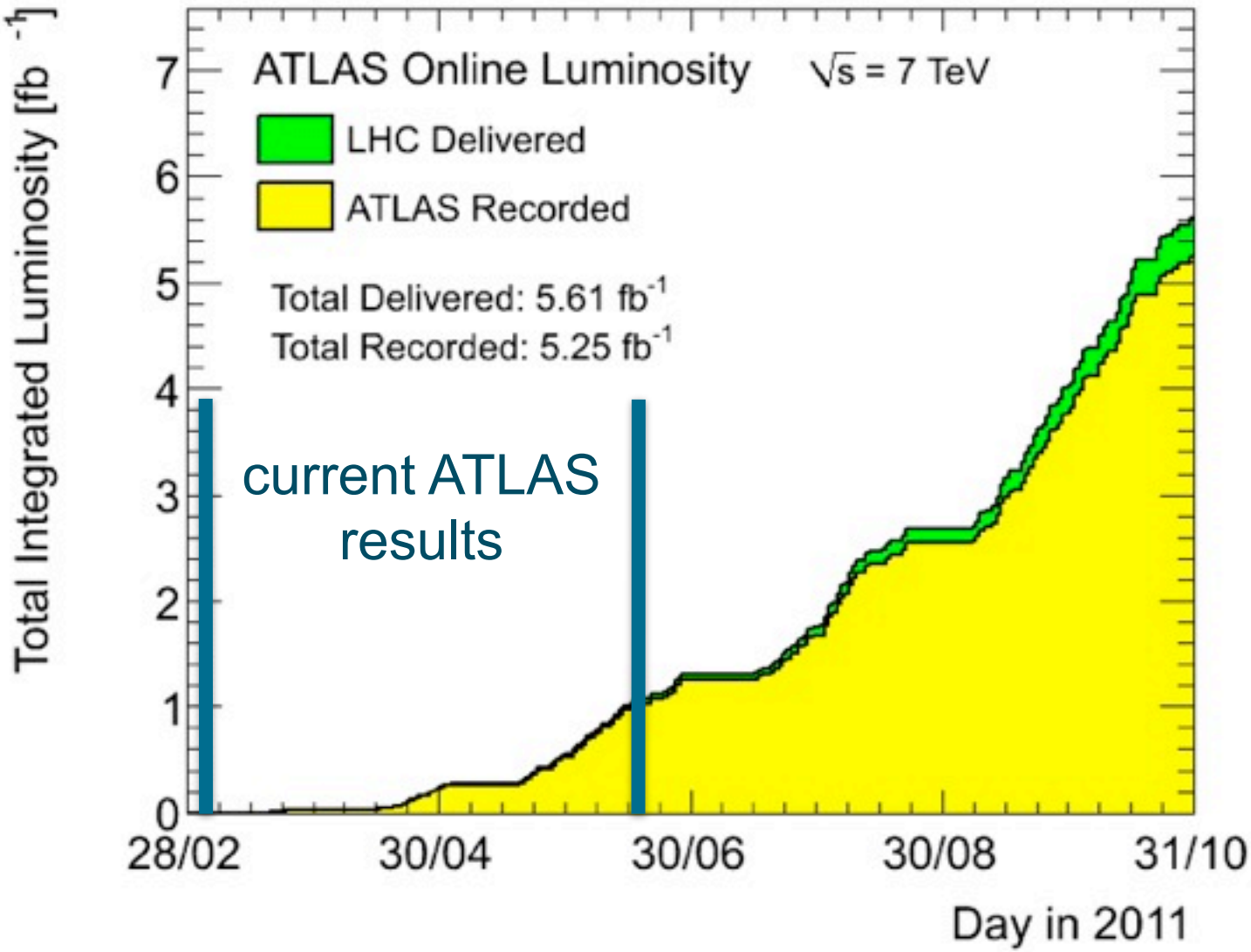
top quark decay



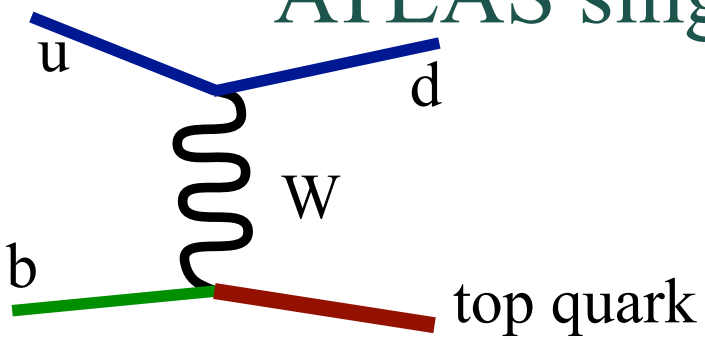


- Decay width 1.99 GeV = 1% of mass
- Lifetime $\tau_t = (3.2^{+1.1}_{-0.7}) \times 10^{-25}\,\mathrm{s}$
- Limit on 4th generation coupling |Vtb'| < 0.63

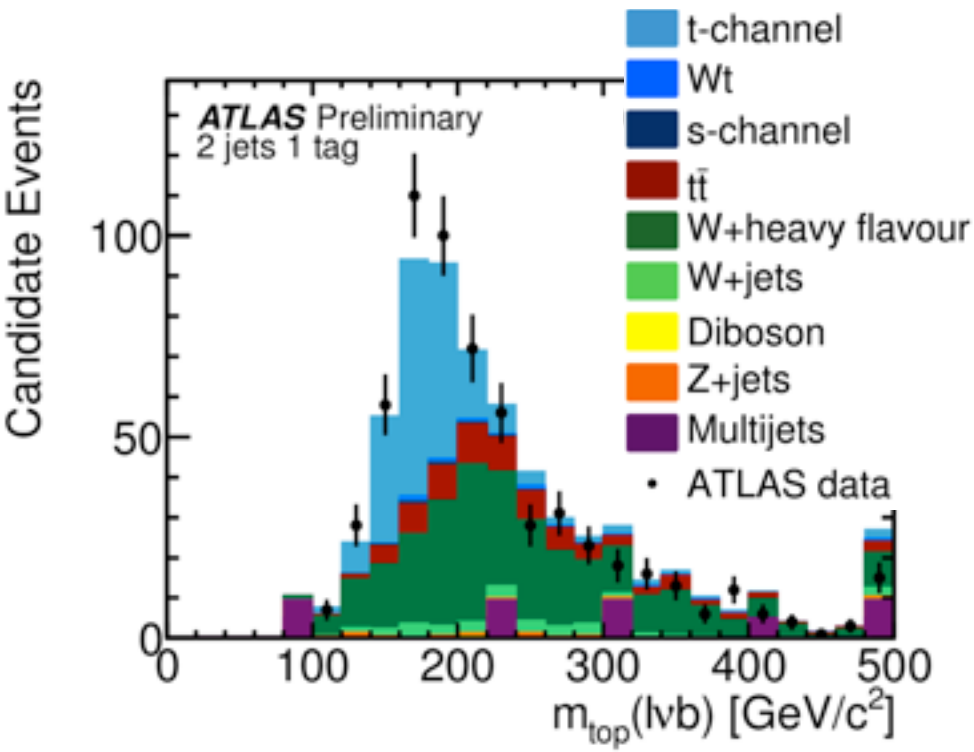
ATLAS data taking

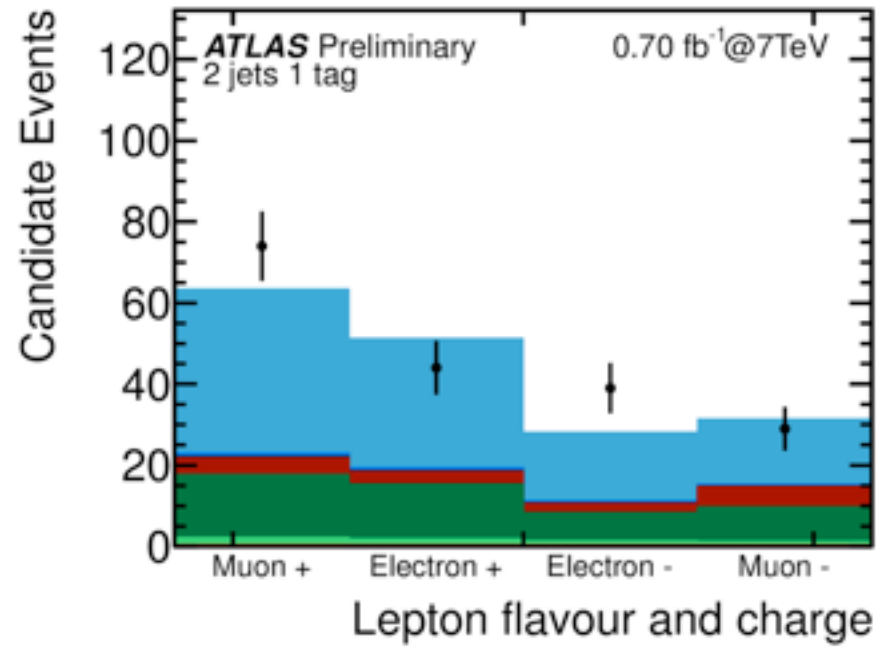


ATLAS single top measurements



- Cut-based analysis and Neural network analysis

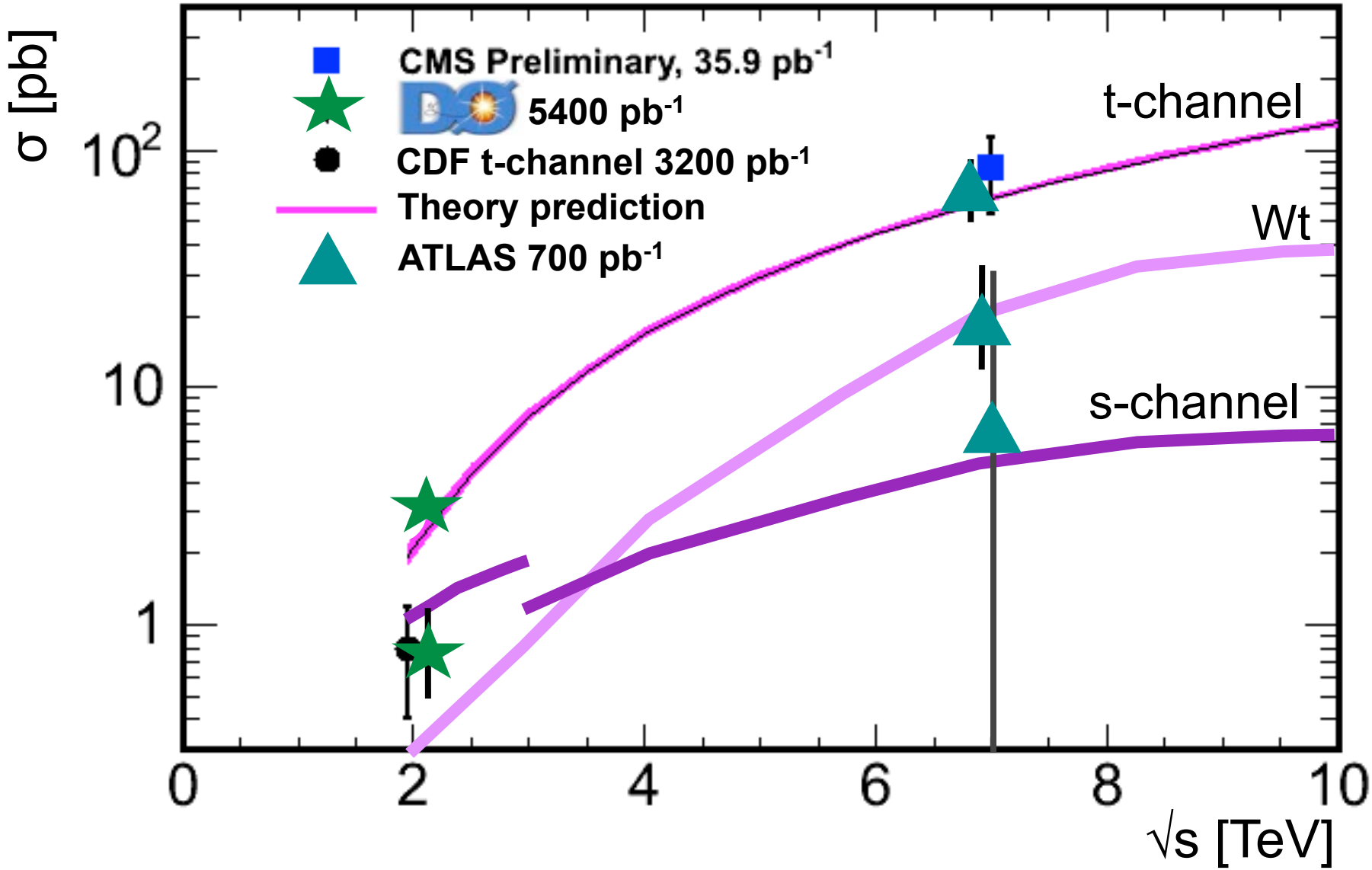




SM expectation: 65 pb

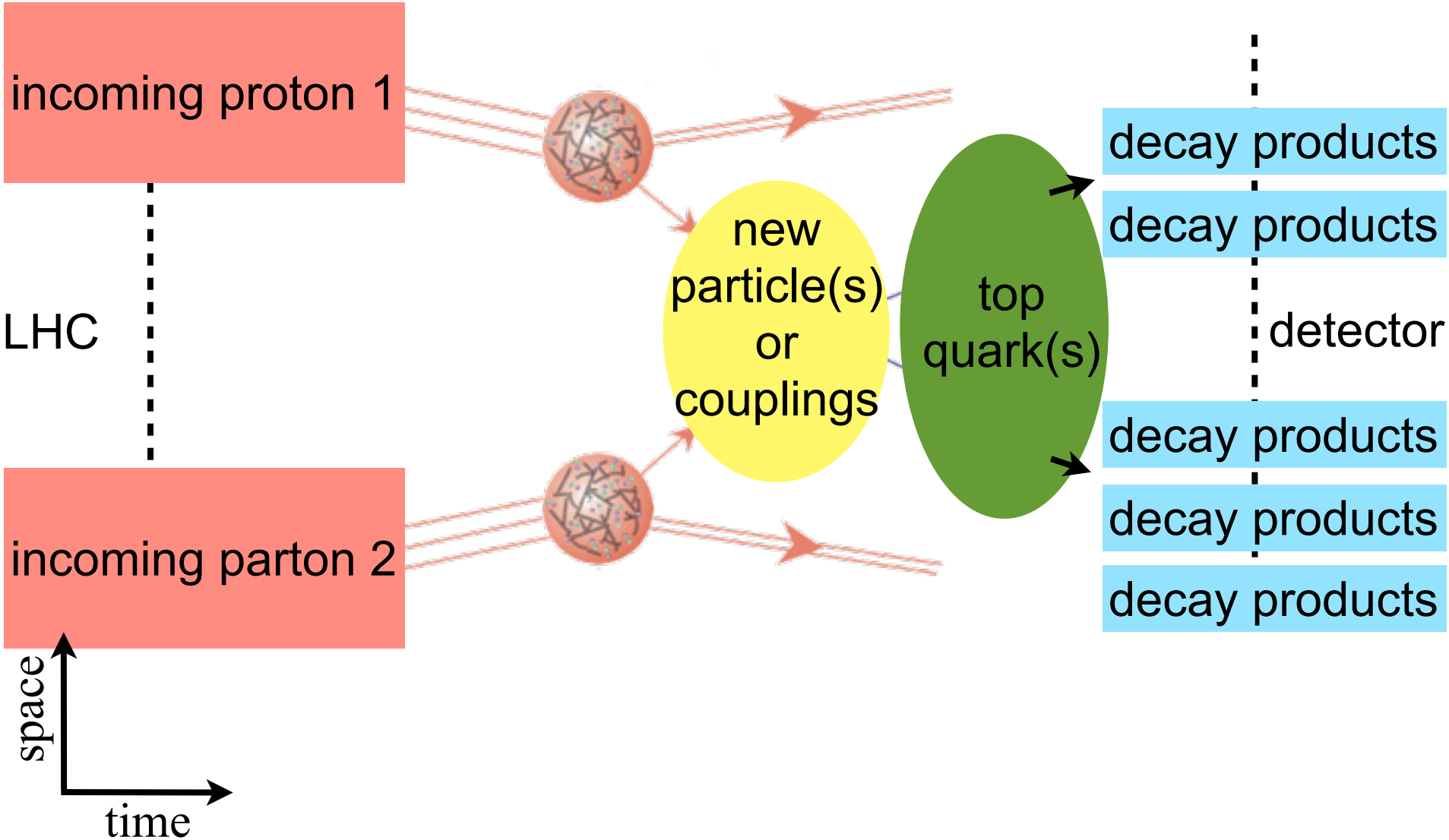
Observed cross section:
$\sigma_t = 90\ ^{+32}_{-22}$ pb

Single top SM measurements

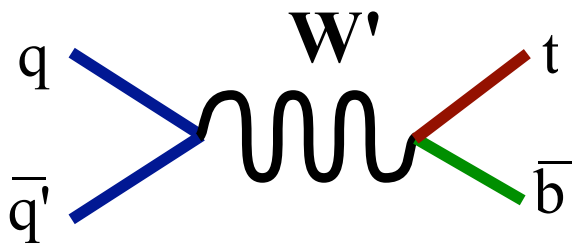


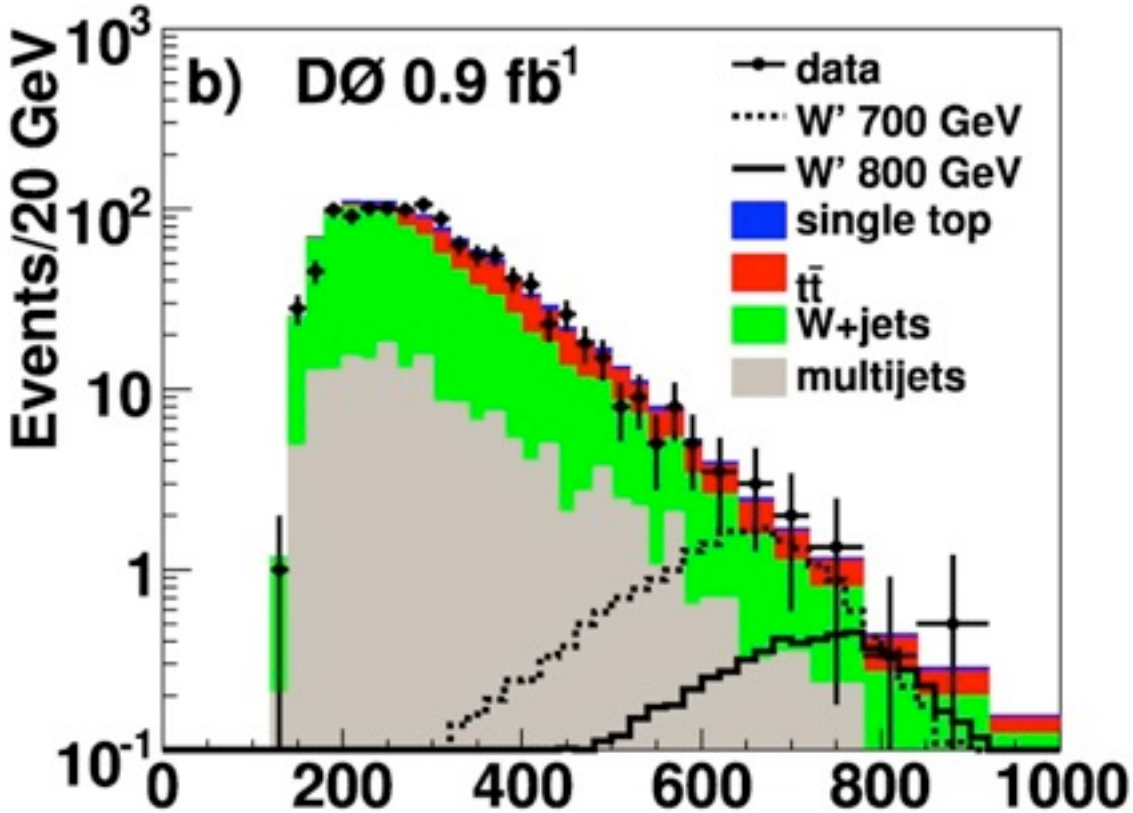
Searches for new physics

New physics production with tops



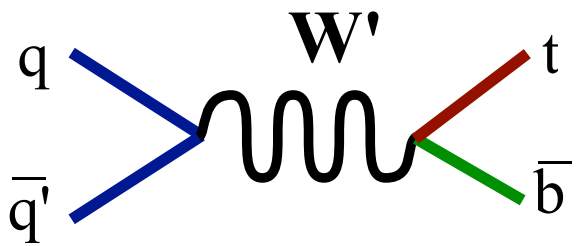
New heavy resonance production

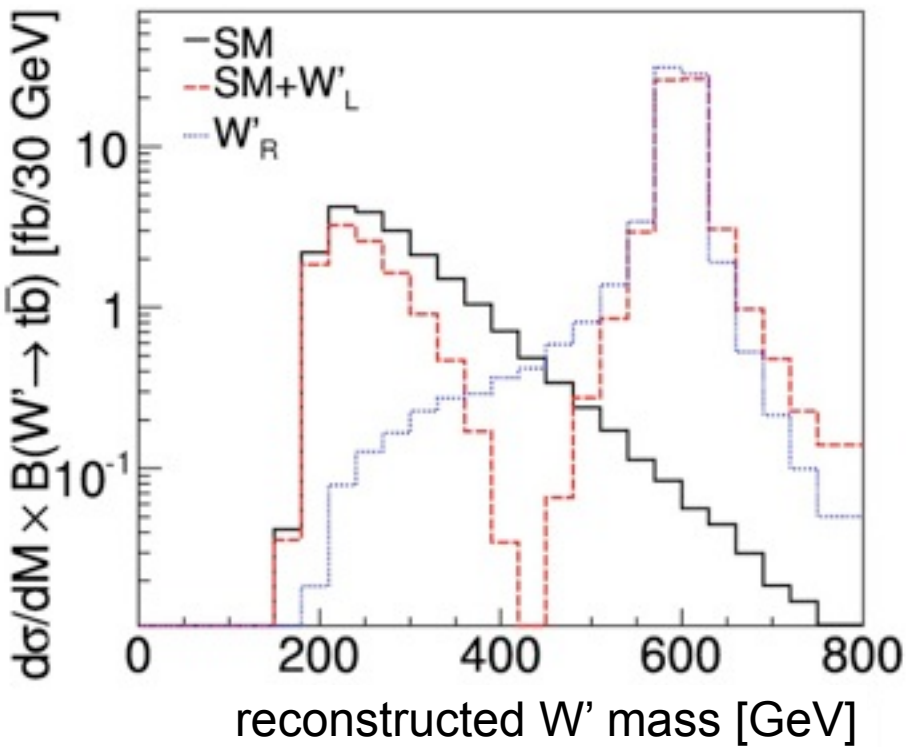


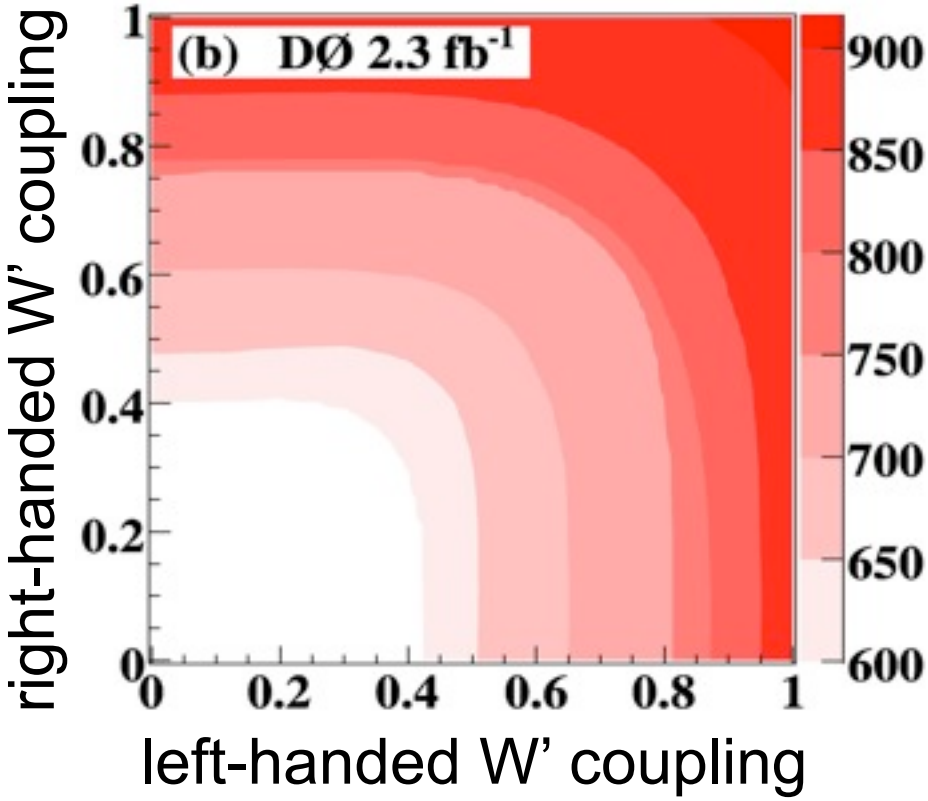


reconstructed W' mass [GeV]

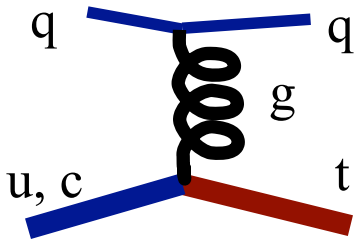
New heavy resonance production

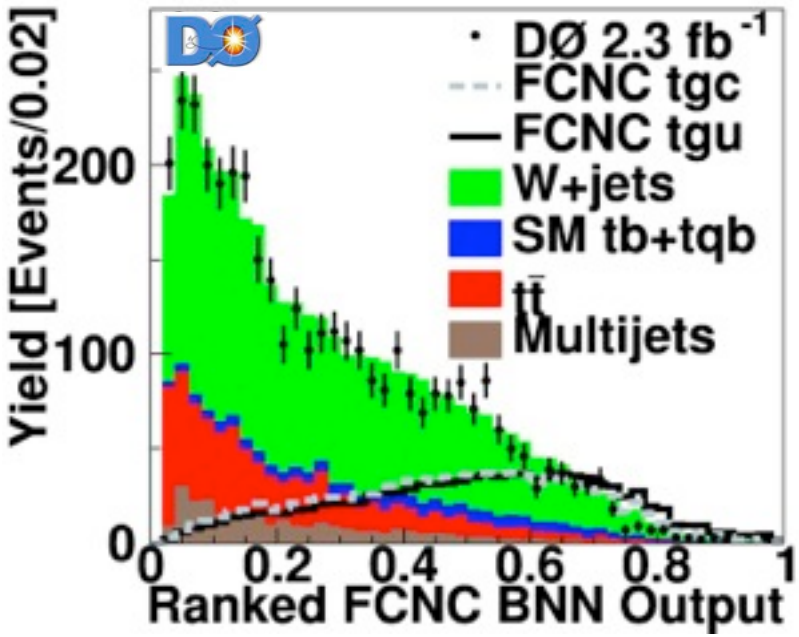


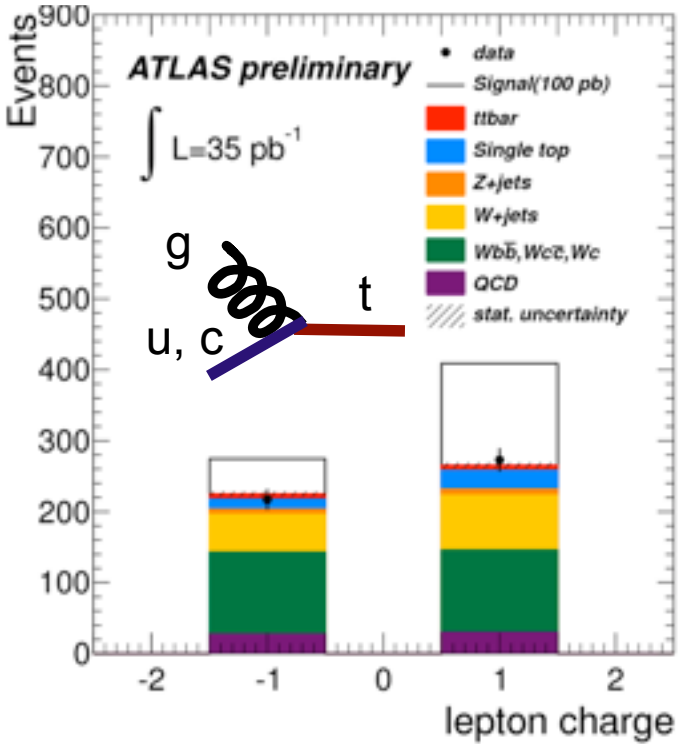




Flavor-Changing Neutral Currents

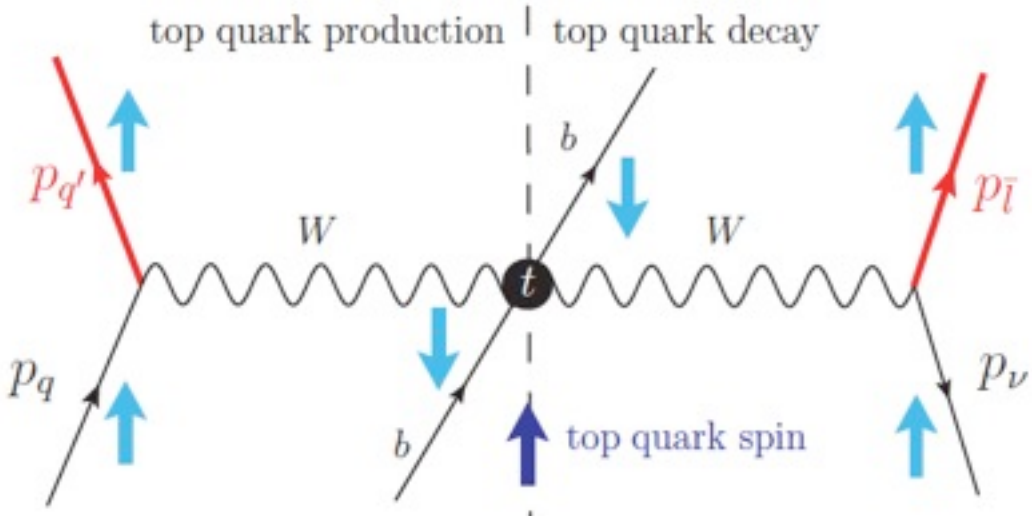


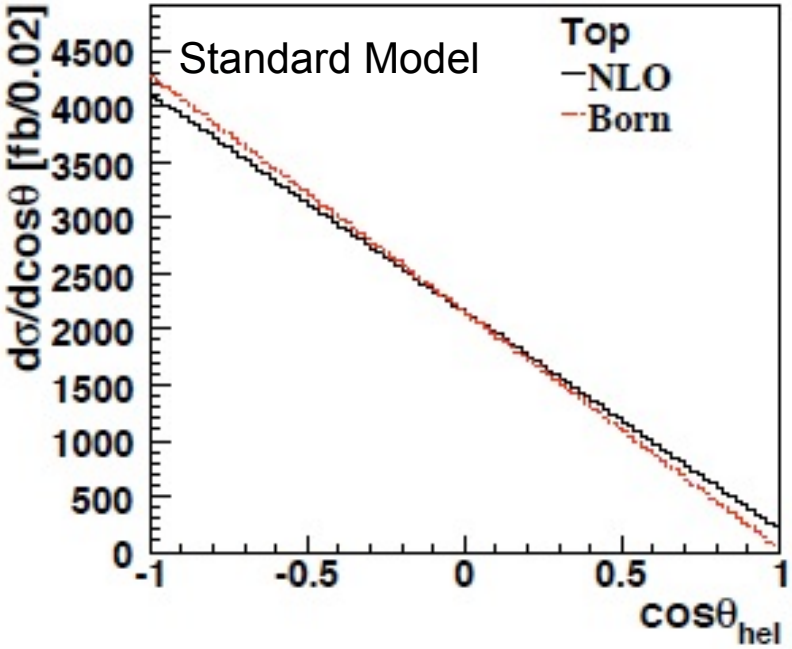




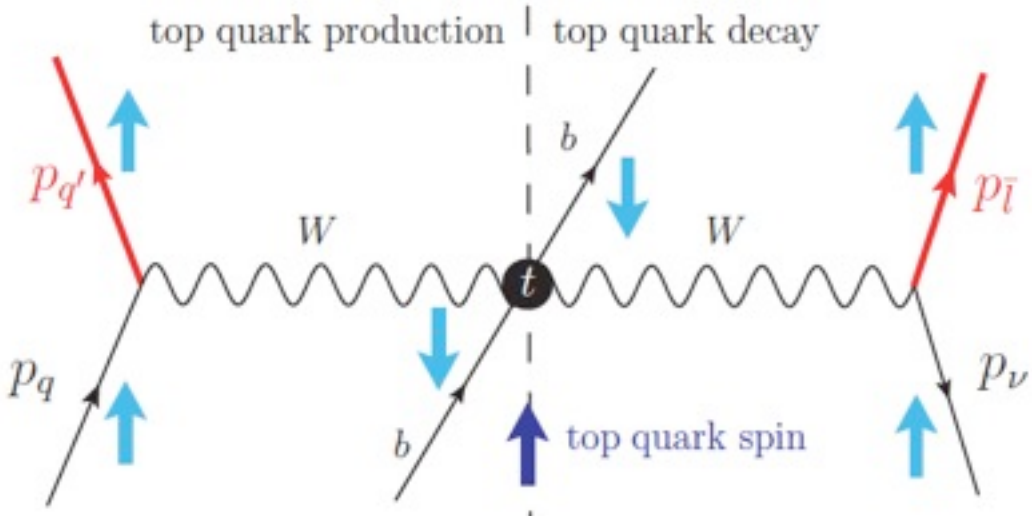
	tgu	tgc
Cross section	0.20 pb	0.27 pb
κ_{tgf}/Λ	0.013 TeV^{-1}	0.057 TeV^{-1}
$\mathcal{B}(t \to qg)$	2.0×10^{-4}	3.9×10^{-3}

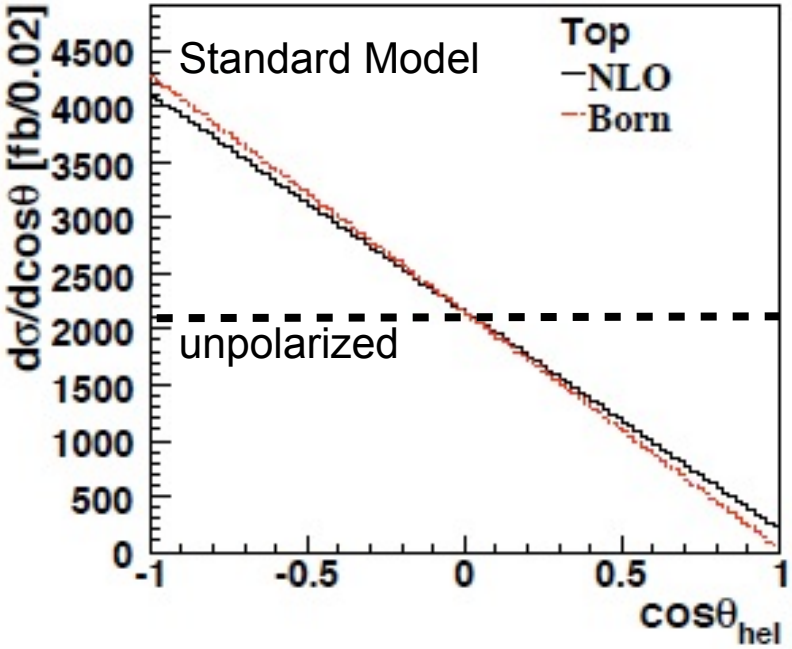
top quark spin correlations



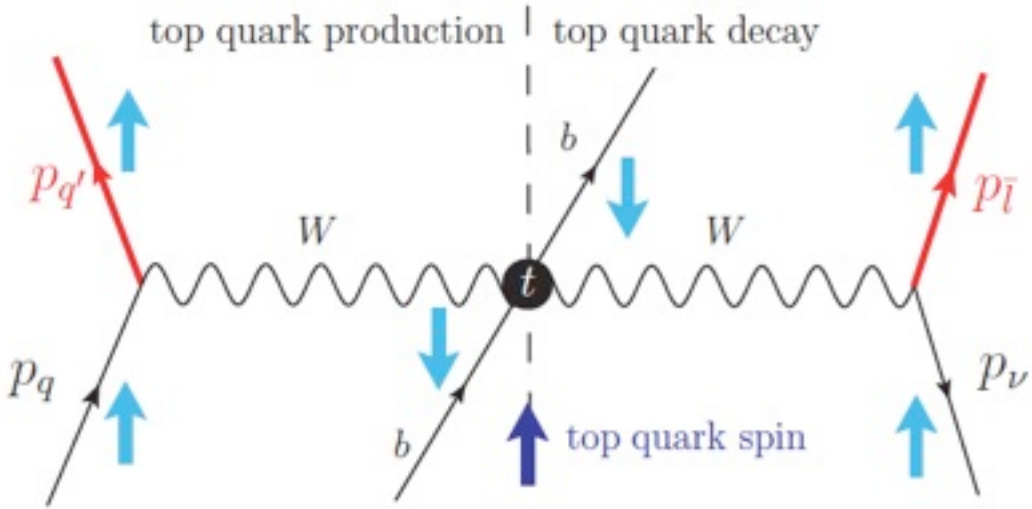


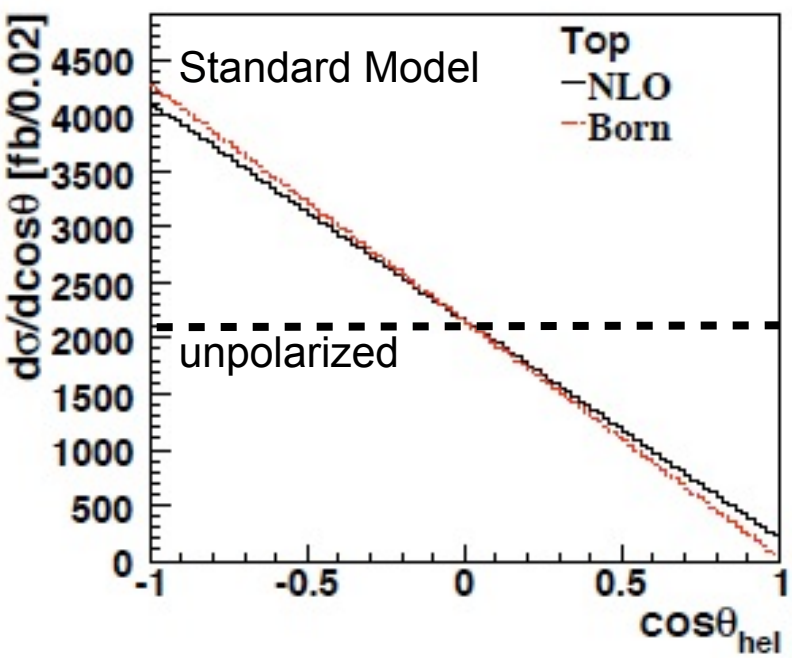
top quark spin correlations

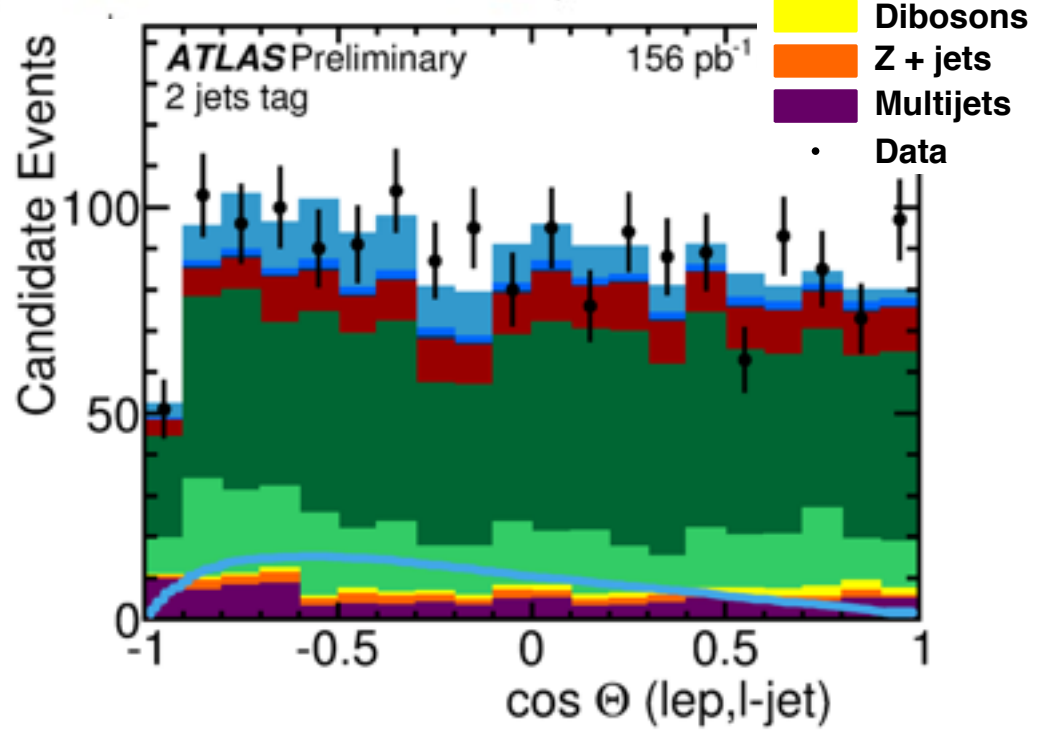




top quark spin correlations





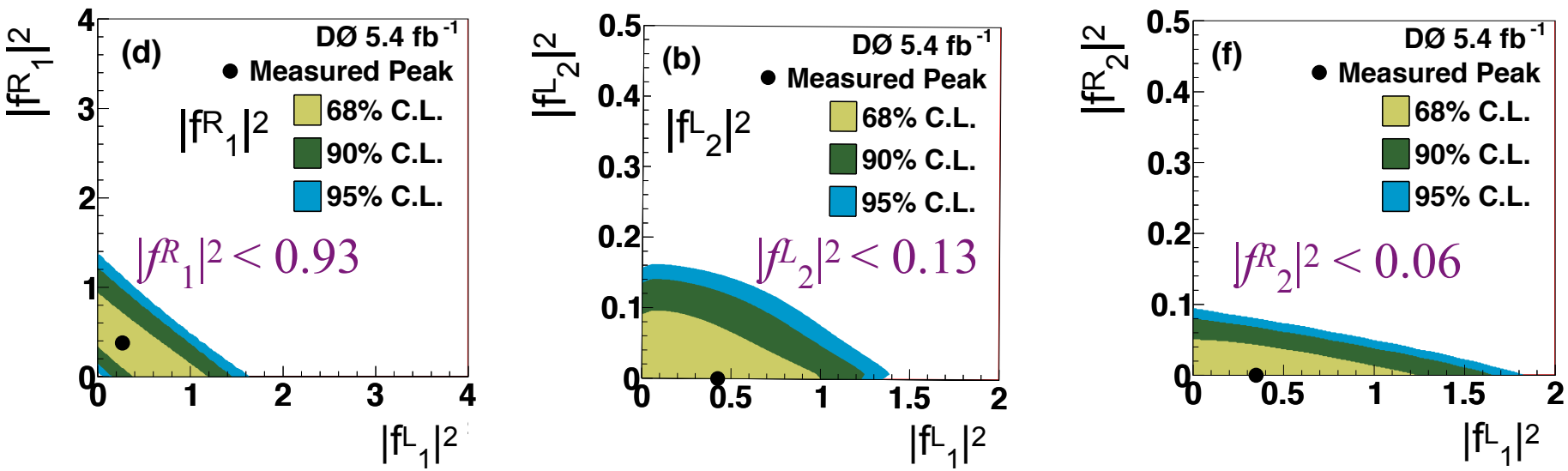


Single top anomalous coupling

- Left-vector (f^L_1, =1 in SM), right-vector (f^R_1), left-tensor (f^L_2), right-tensor (f^R_2)

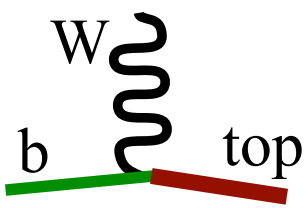
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu V_{tb}(f_1^L P_L + f_1^R P_R)tW_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}(f_2^L P_L + f_2^R P_R)tW_\mu^- + h.c.$$

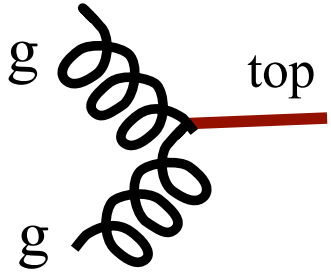
- Also combine with W helicity measurement from top decay (PRL 102, 092002 (2009))



Top quark future

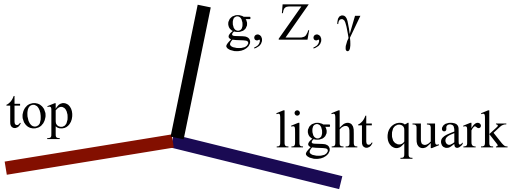
Precision Measurements

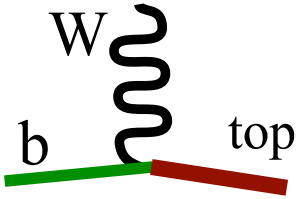




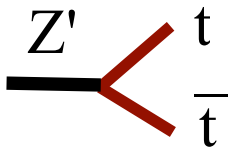
- couplings
- CKM matrix
- CP violation
- top spin
- top mass

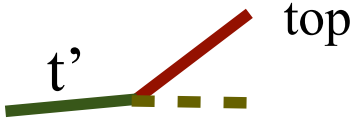
Modified/new couplings

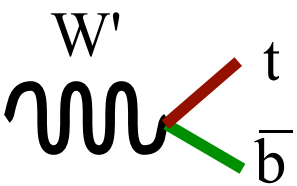


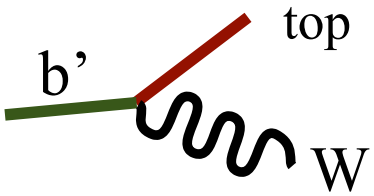


New particles



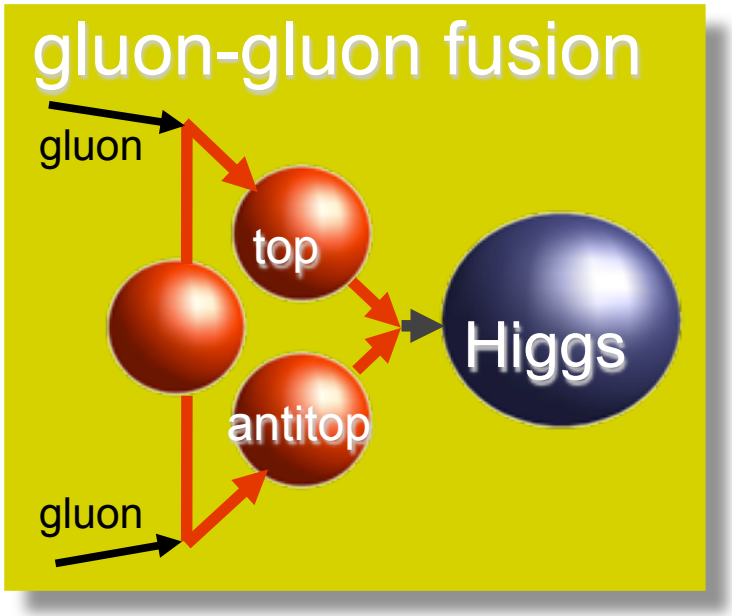


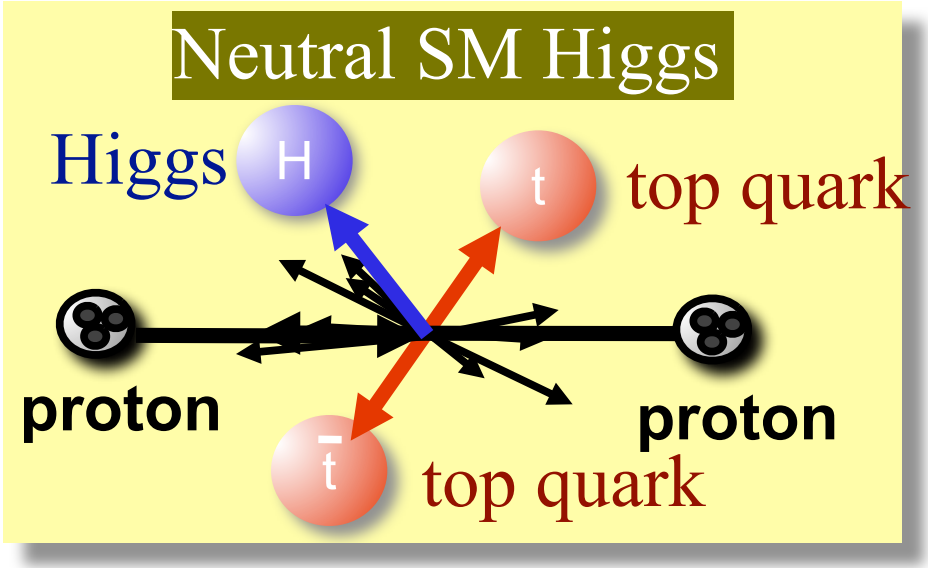


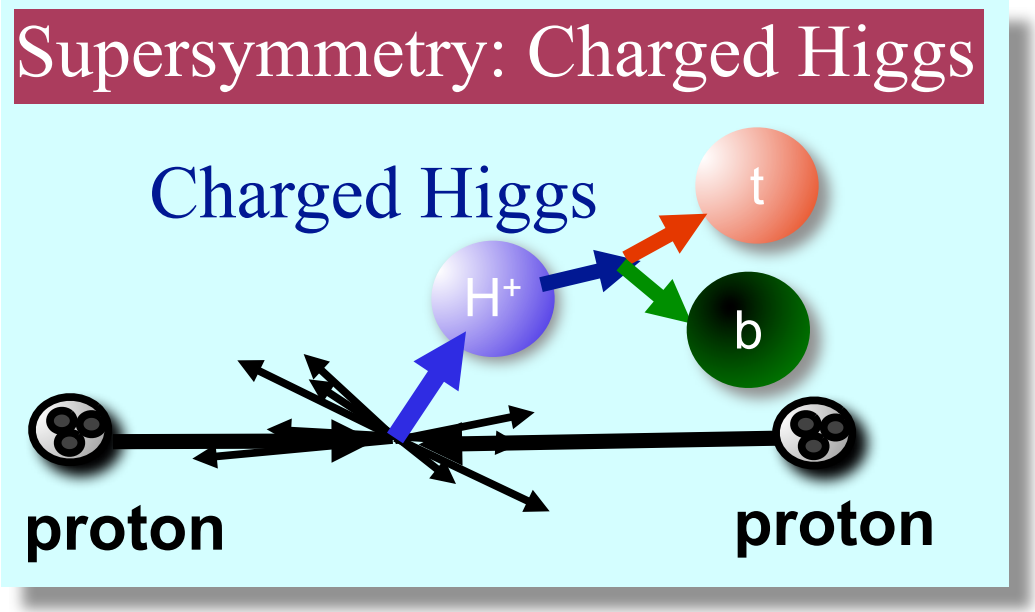


Coupling to new particles discovered first elsewhere

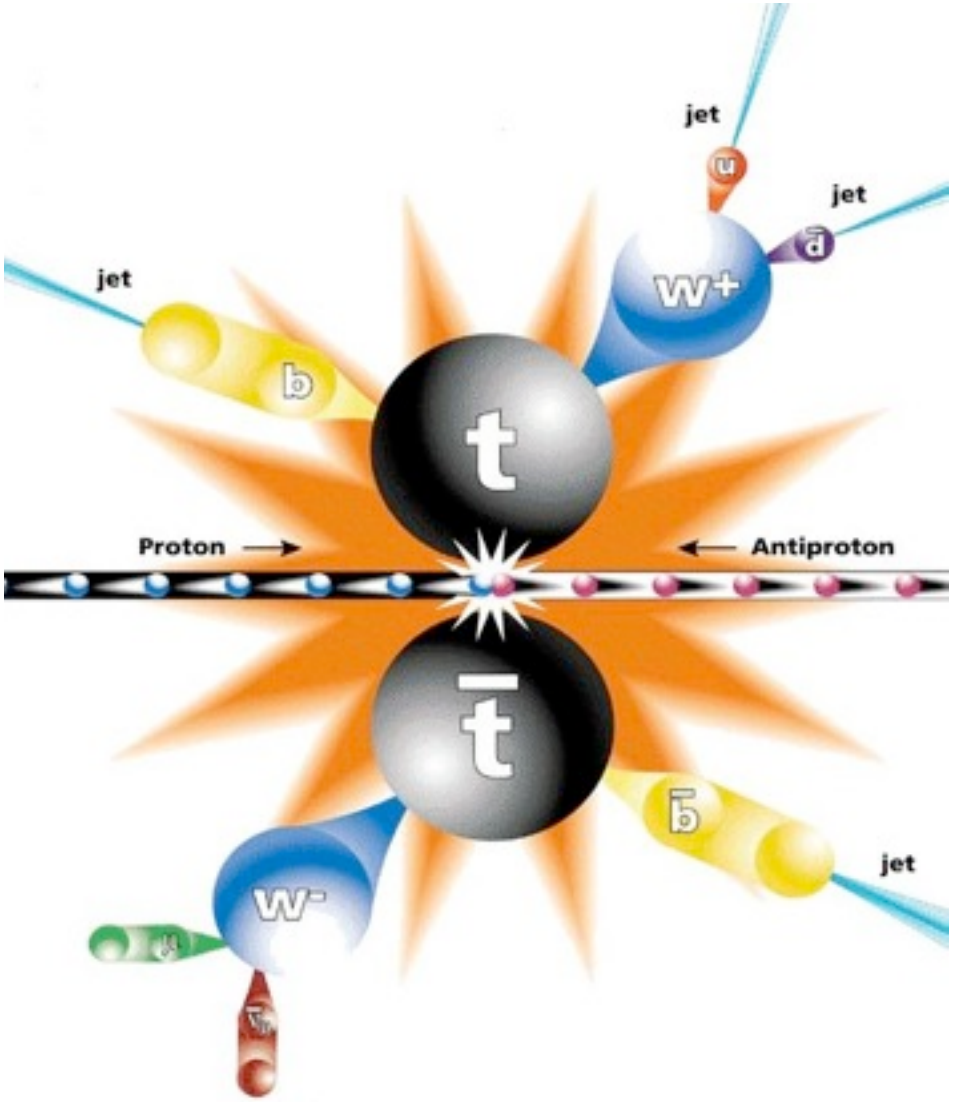
Higgs boson production at the LHC



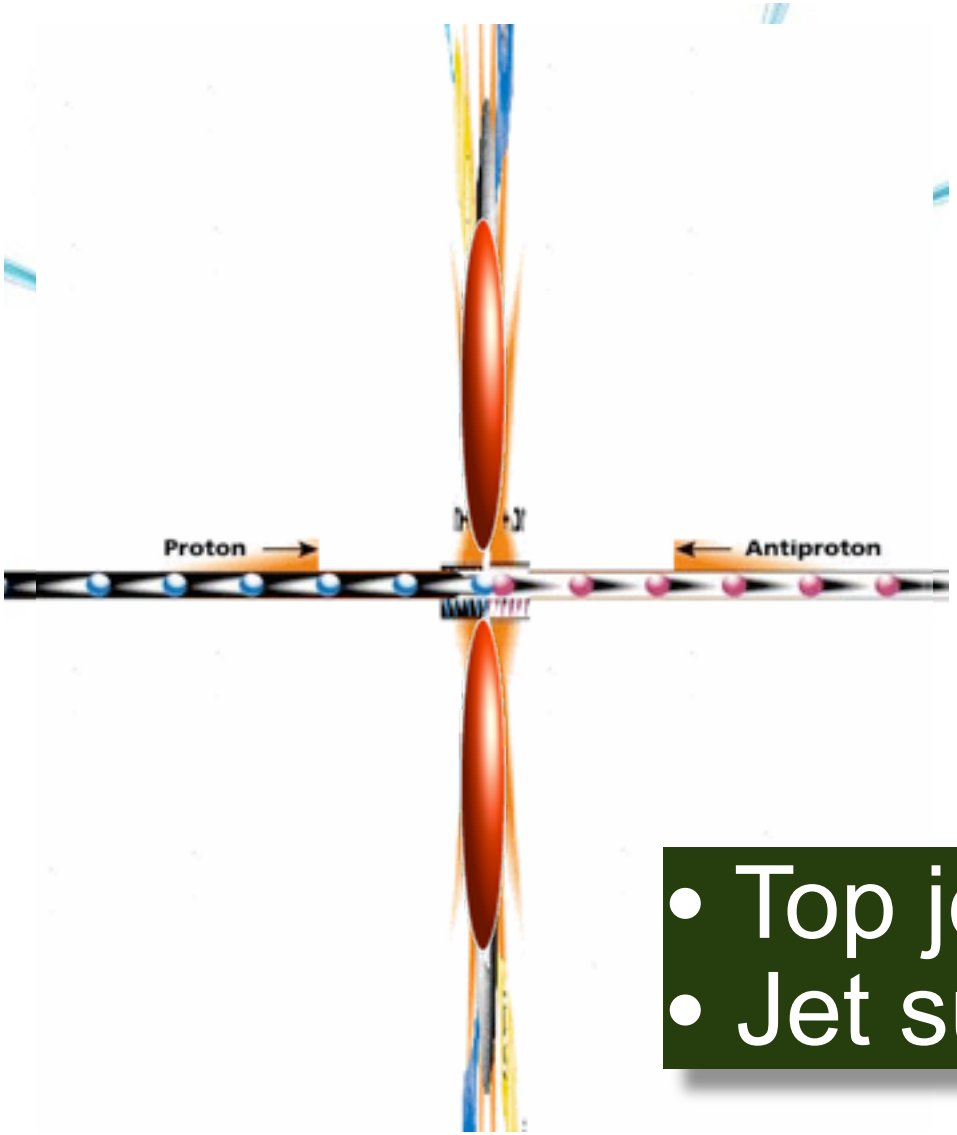




New challenges



New challenges



- Top jets
- Jet substructure

Summary

- Many top quark results from Tevatron
- LHC top measurements are just starting
- Top is a sensitive probe to many new physics models
- Top quark: key to origin of particle mass

· Search:	PRD 63, 031101 (2000)
· Search:	PLB 517, 282 (2001)
· Search:	PLB 622, 265 (2005)
· W':	PLB 641, 423 (2006)
· Search:	PRD 75, 092007 (2007)
· Evidence:	PRL 98, 181802 (2007)
· FCNC:	PRL 99, 191802 (2007)
· W':	PRL 100, 211802 (2007)
· Evidence:	PRD 78, 012005 (2008)
· Wtb:	PRL 101, 221801 (2008)
· Wtb:	PRL 102, 092002 (2009)
· H^+:	(PRL) arXiv:0807.0859
· Observation:	(PRL) arXiv:0903.0850
. tau search	PLB 690, 5 (2010)
. t-chan meas.	PLB 682, 363 (2010)
. FCNC	PLB 693, 81 (2010)
. top width	PRL 106, 22001 (2011)
. W'	PLB 699, 145 (2011)
. t-chan obs.	PLB 705, 313 (2011)
. s+t meas	PRD 84, 112001 (2011)
. Wtb coupl.	(PLB) arXiv:1110:4592

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- Chip Brock, Jim Linnemann, Bernard Pope, Kirsten Tollefson, C.-P. Yuan
- Barbara Alvarez, Seth Caughron, Ike Hall, Dugan O'Neil, Pat Ryan, Huaqiao Zhang
- Jorge Benitez, Qing-Hong Cao, Weigang Geng, Sarah Heim, Jenny Holzbauer, James Koll, Patrick True
- D0 single top working group
- ATLAS single top working group

Single top observation party