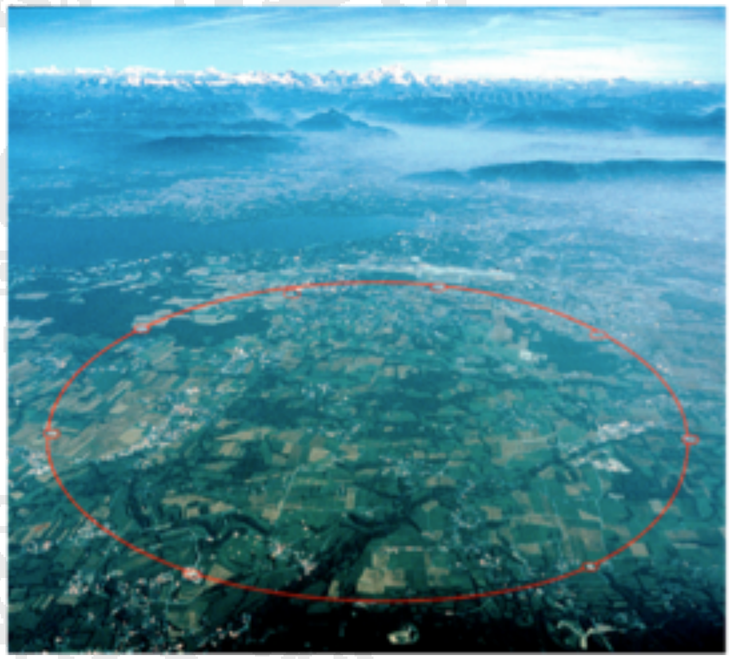
Top physics

from Tevatron to LHC



Elizaveta Shabalina
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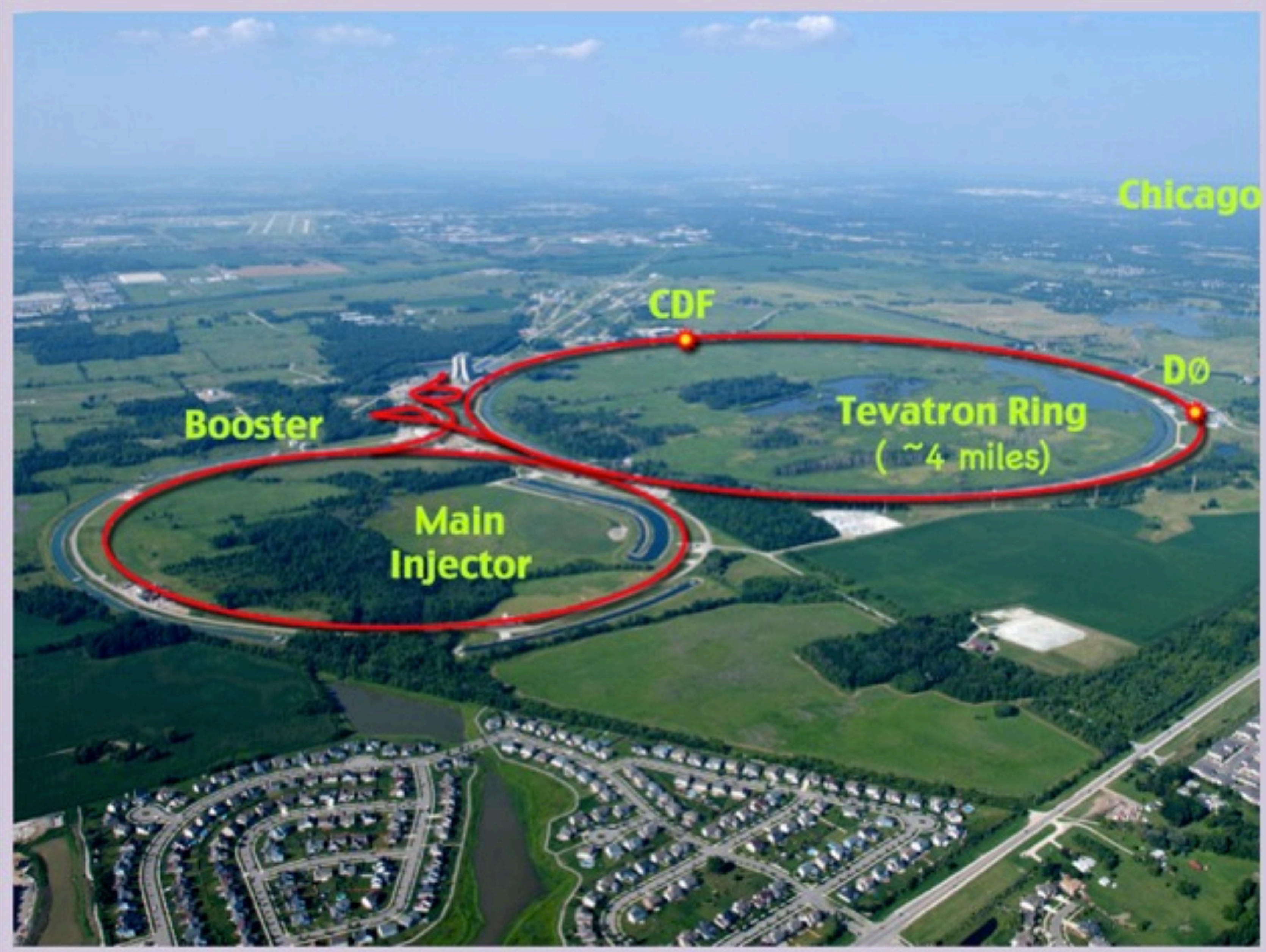
FSP 101 ATLAS

PHYSICS AT THE TERA SCALE Helmholtz-Alliance

The Fermilab Tevatron

- the birthplace of the top quark
- the highest energy collider in the world ...until December 2009
- $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV
- > 2fb^{-1}/year, peak luminosity ~4e^{32}
- expected 12 fb^{-1} by the end of 2011
- extension of the run till 2014 is under discussion



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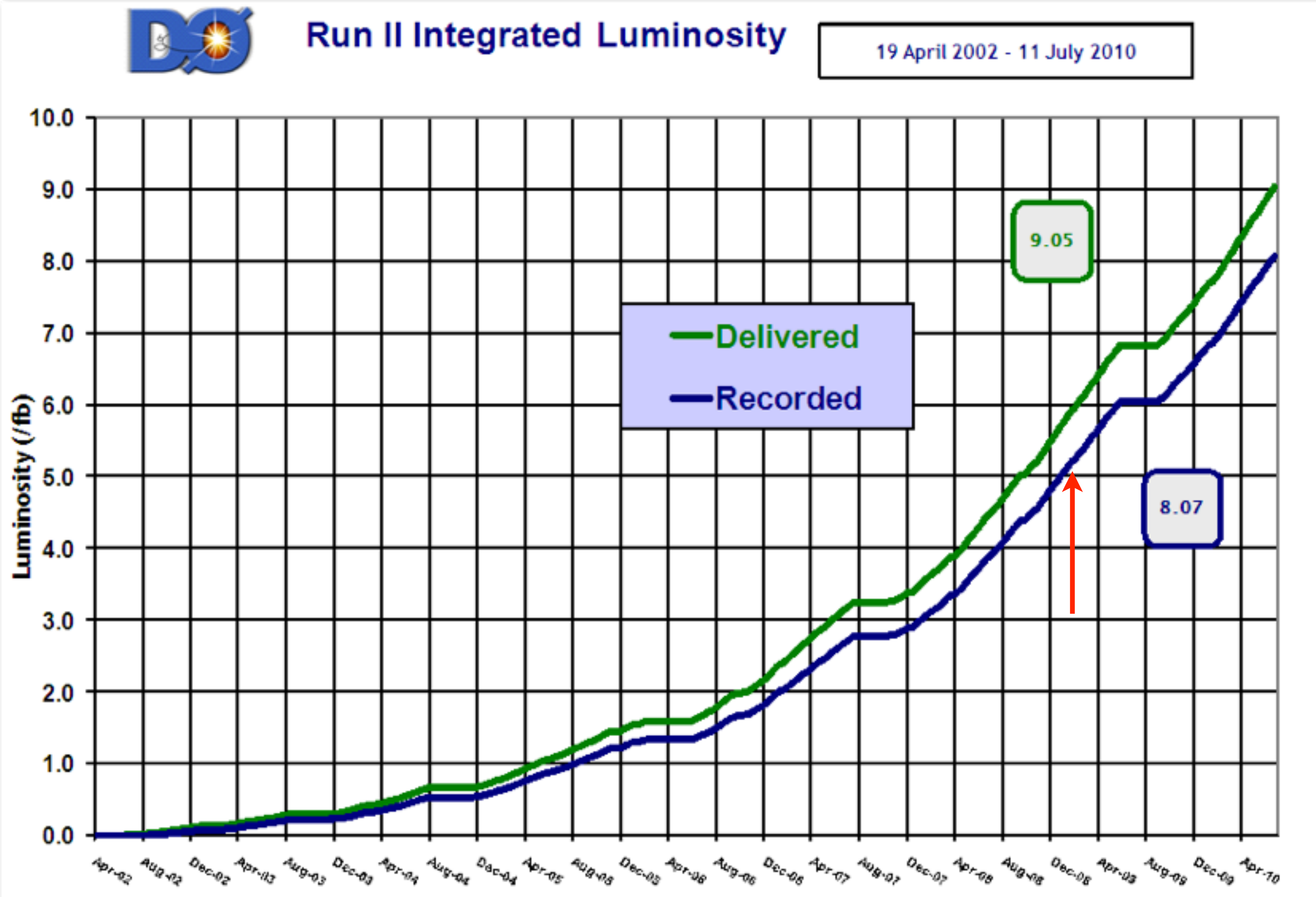
The only place where top quark are produced!

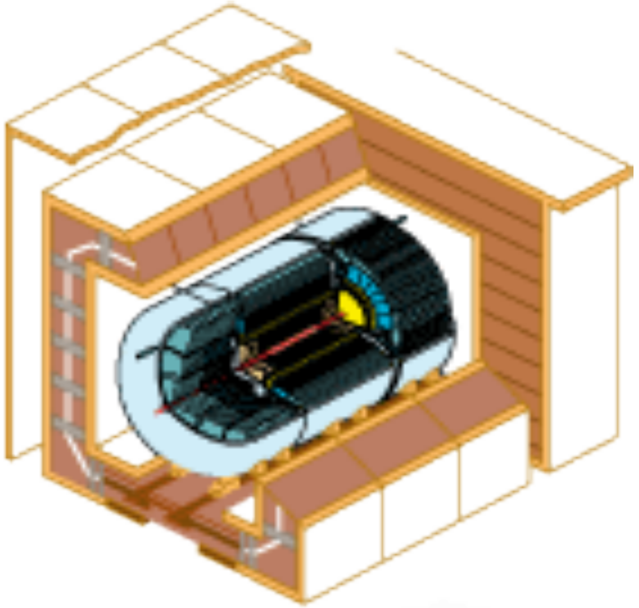
Tevatron luminosity



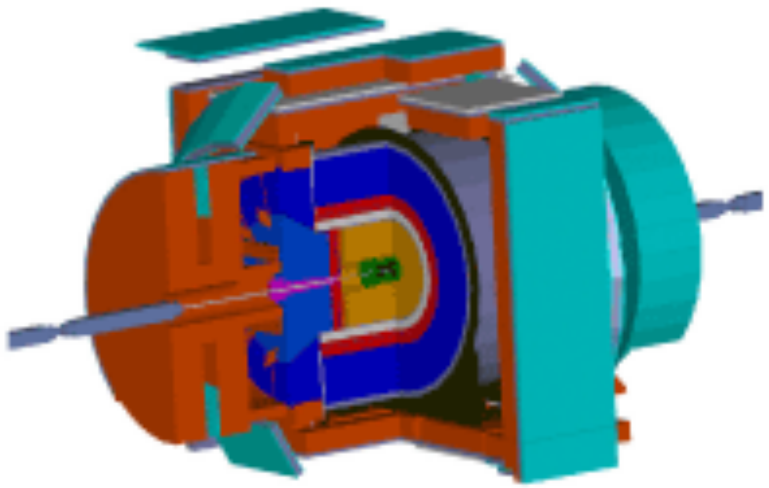
Top quark analyses up to 5.6 fb^{-1}

Experiments

Tevatron

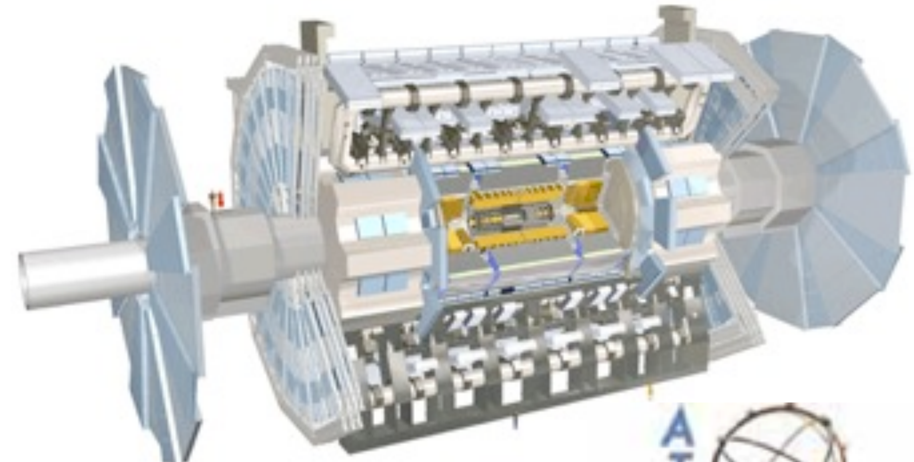


DØ

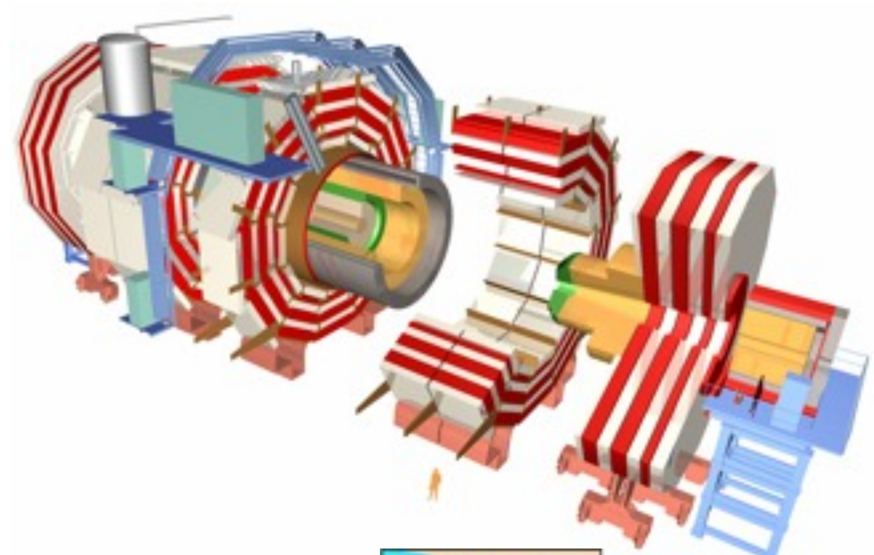


CDF

LHC



ATLAS



CMS

- Multipurpose collider detectors
  - high resolution inner detectors
  - calorimeters
  - outer muon system
  - magnetic field

Top quark physics

Top quark production

top quark pairs
electroweak single top quark

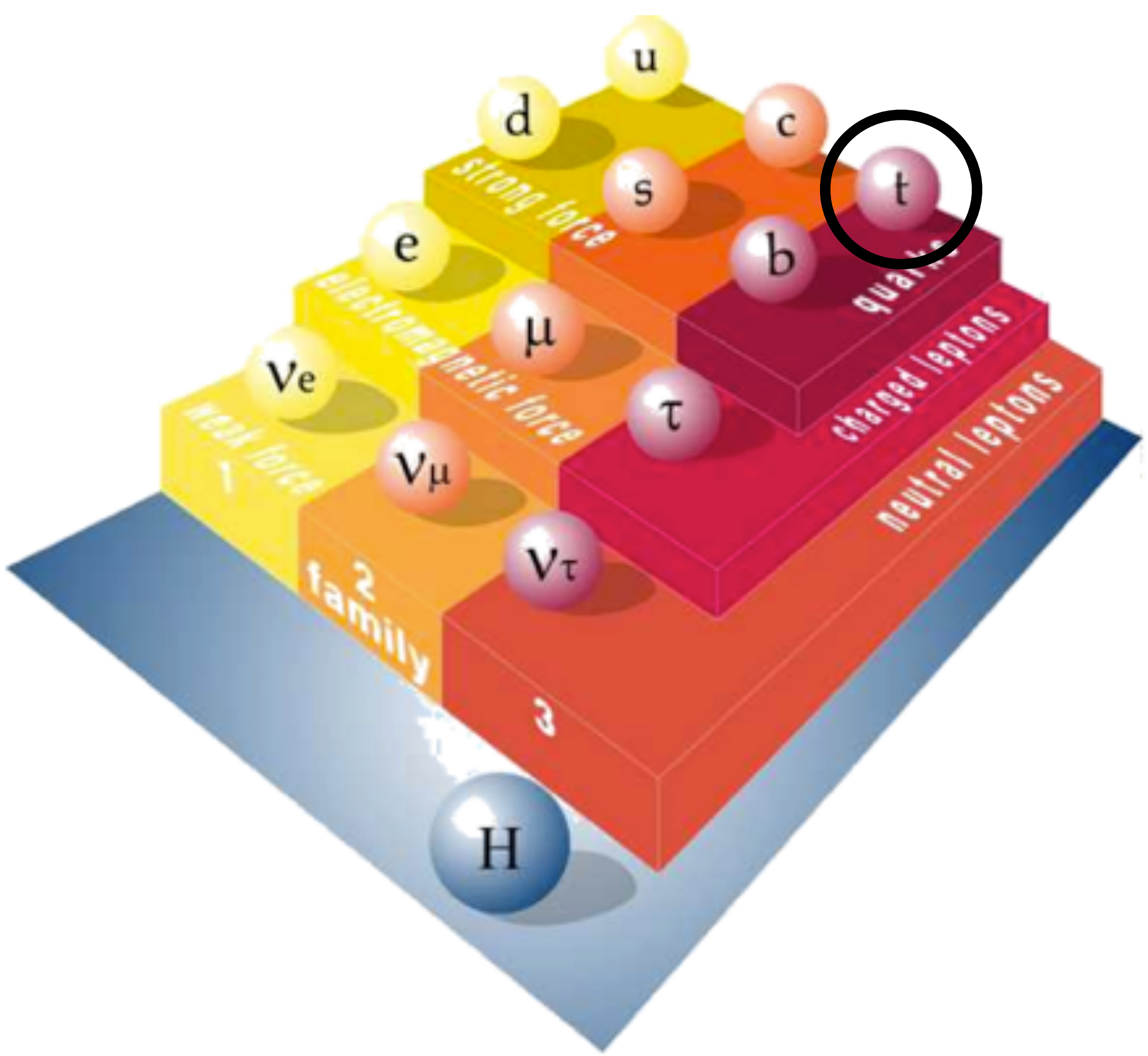
Top quark properties

mass
width
forward-backward asymmetry
spin correlations

Searches in top quark sector

The top quark

- Needed in theory as isospin partner of b-quark
- Properties well defined by the standard model
- Unknown - top quark mass



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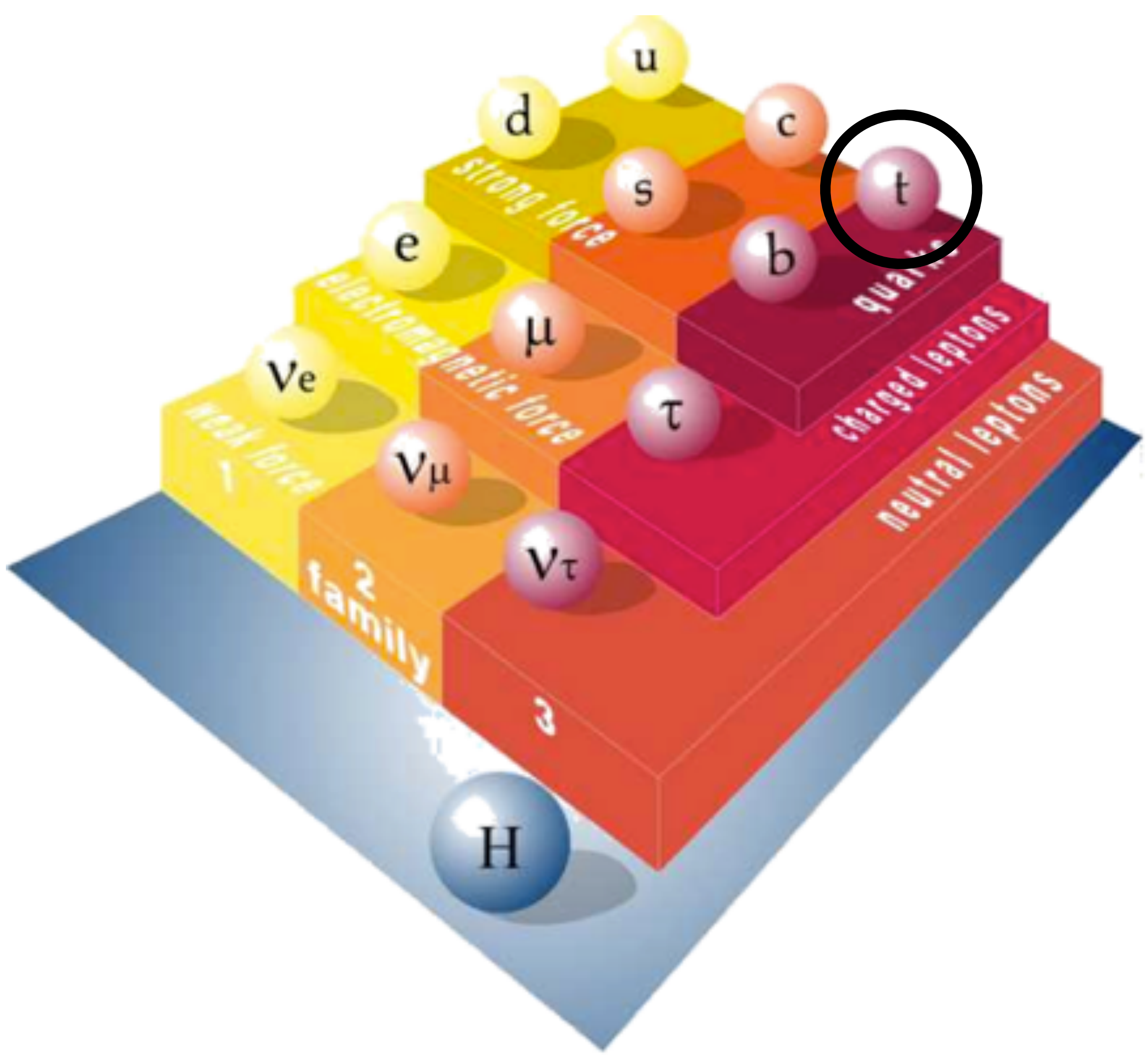
Discovered at Fermilab in 1995



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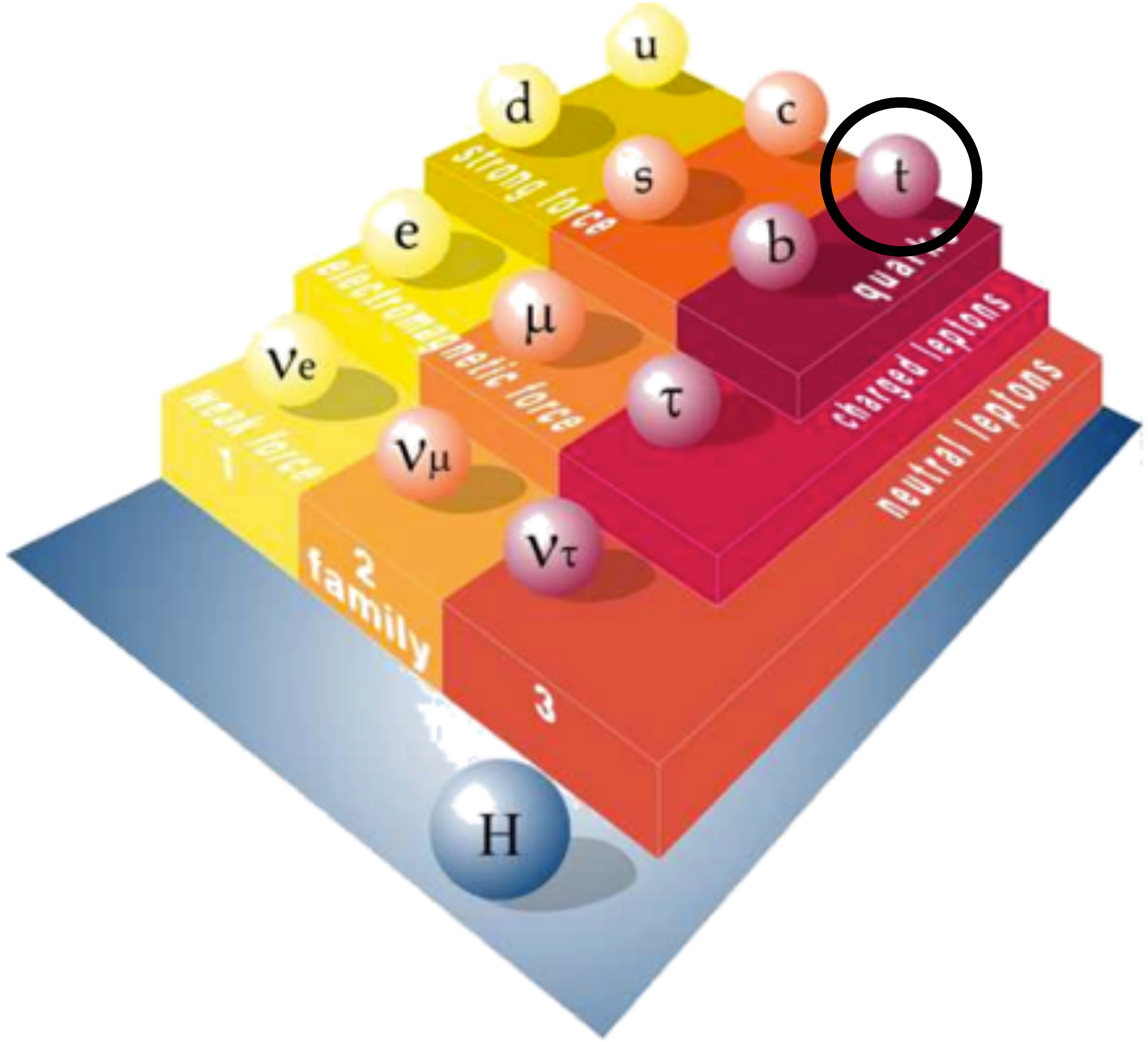

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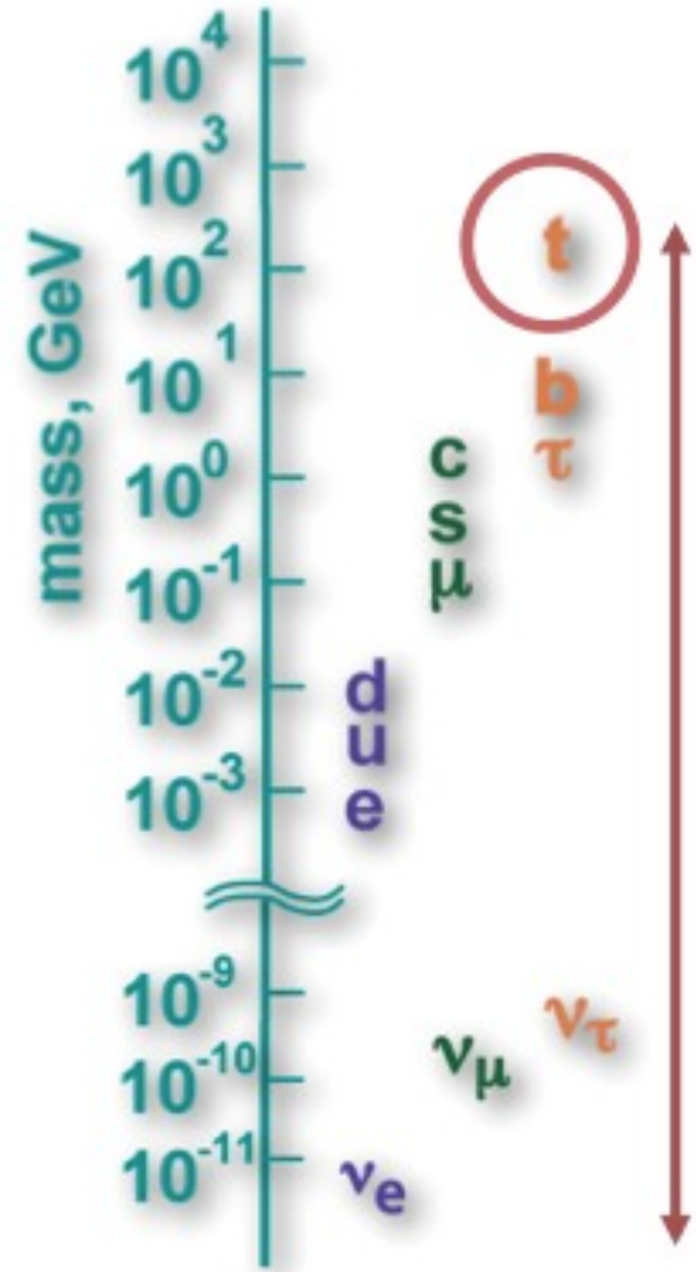
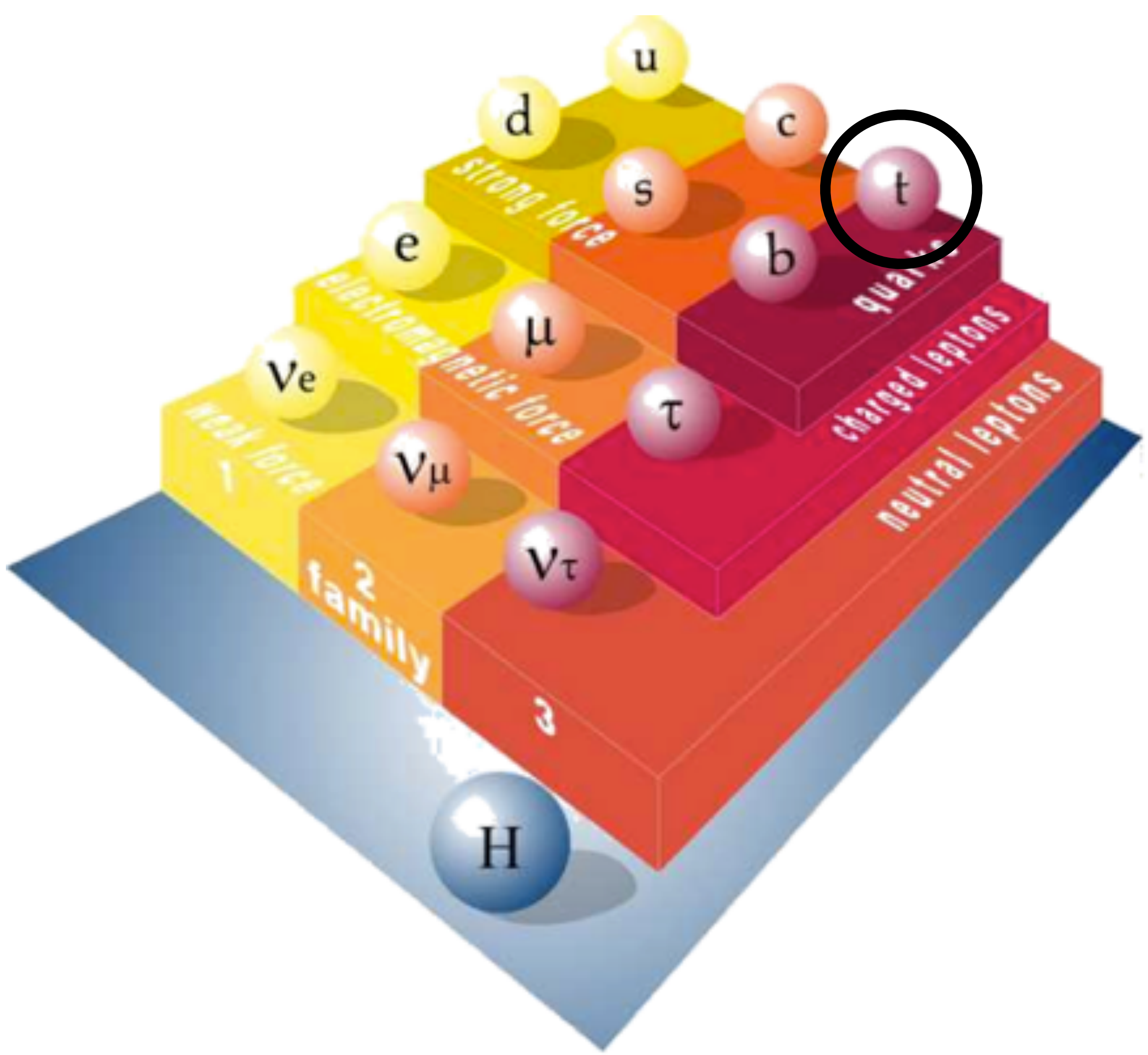


As heavy as the atom of gold

The top quark

- Needed in theory as isospin partner of b-quark
- Properties well defined by SM
- Unknown - top quark mass



- The heaviest fundamental particle with unique properties
  - Large coupling to Higgs boson (~1)
  - important role in electroweak symmetry breaking?
  - short lifetime: decays before fragmenting

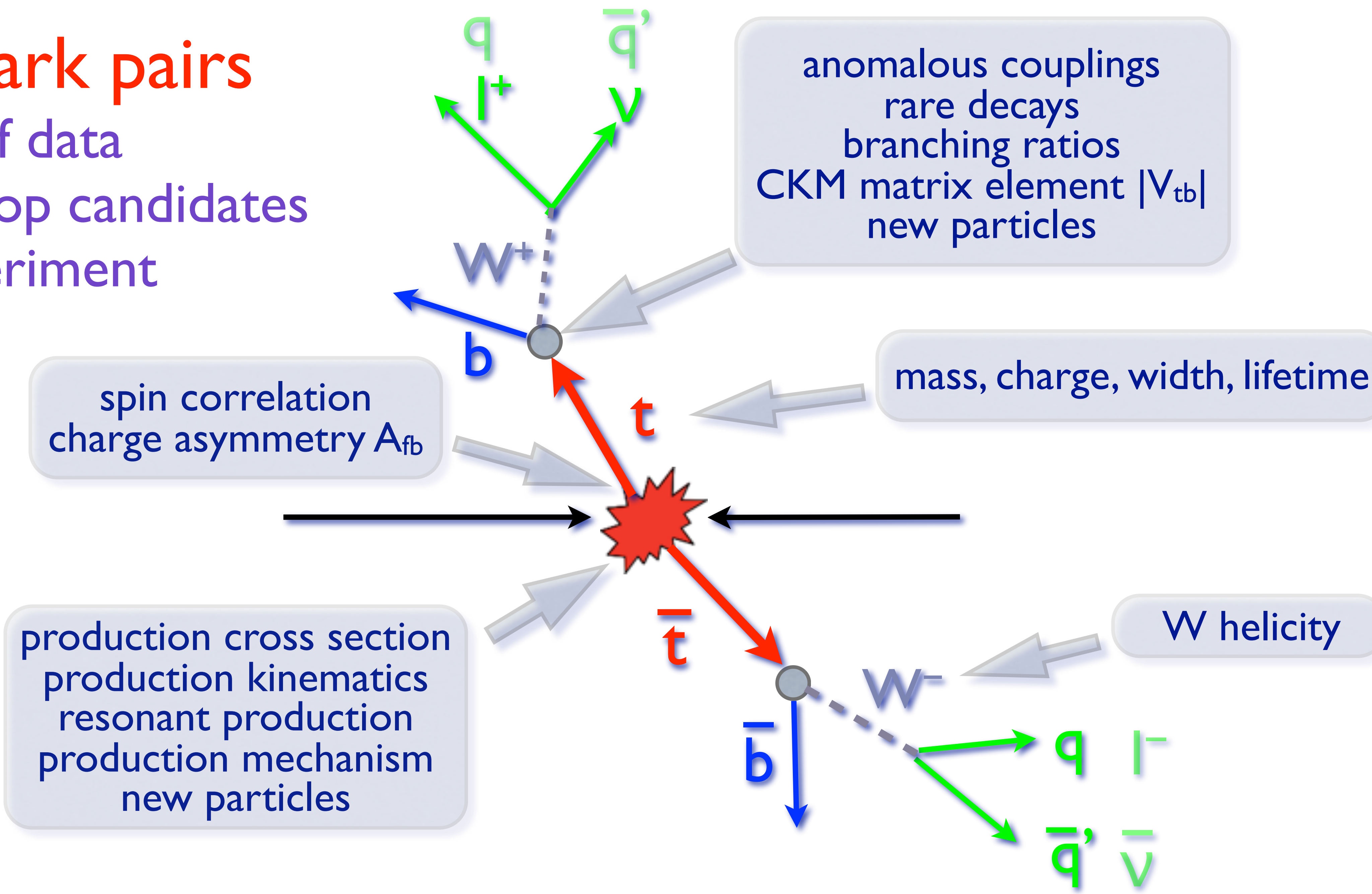
$$\tau \approx 5 \times 10^{-25} s << \Lambda_{QCD}^{-1}$$

The most probable place for new physics to show up?

What do we know about top?

top quark pairs

- >5 fb^{-1} of data
- >2,000 top candidates per experiment



Observed EW top quark production

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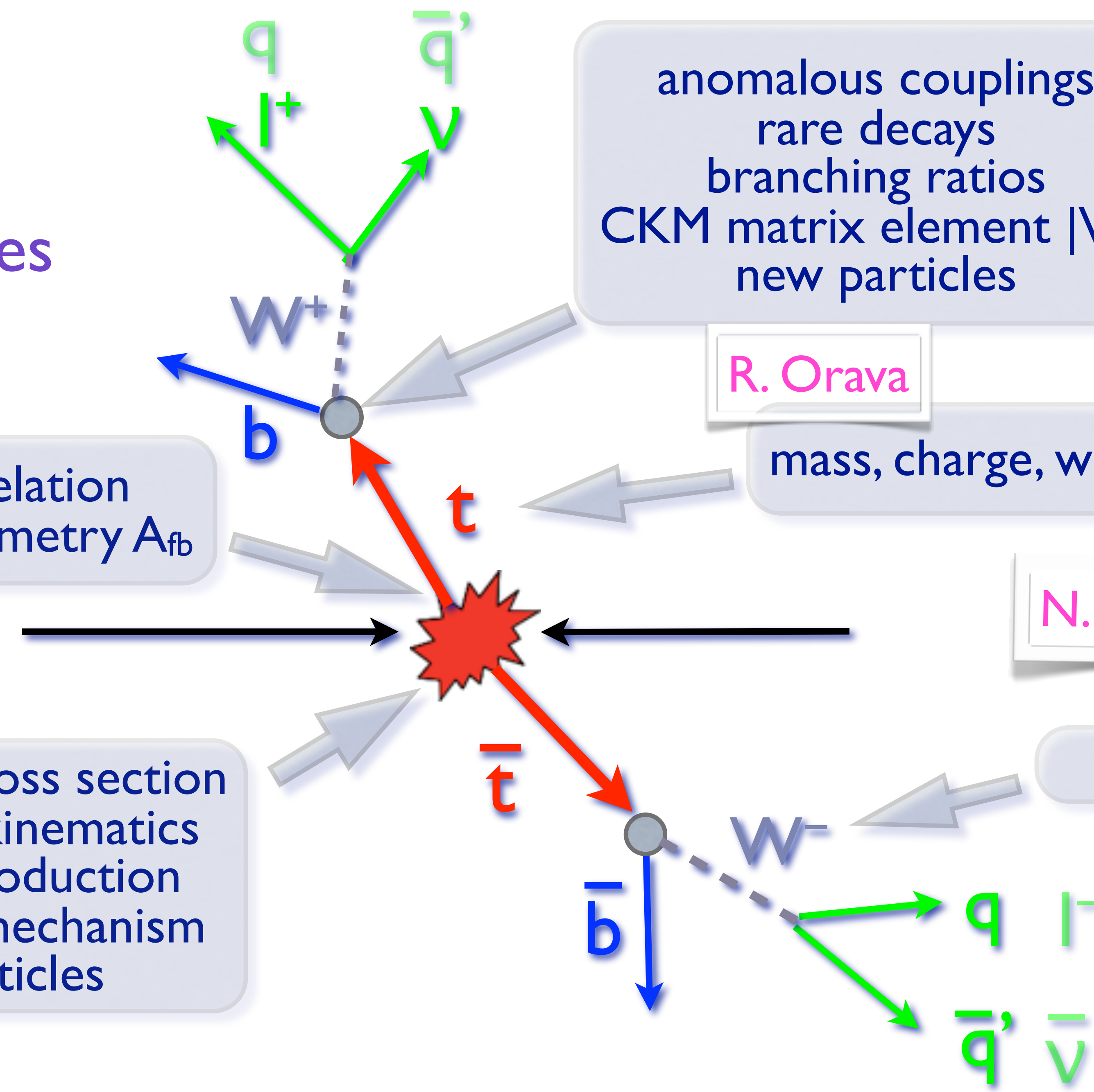

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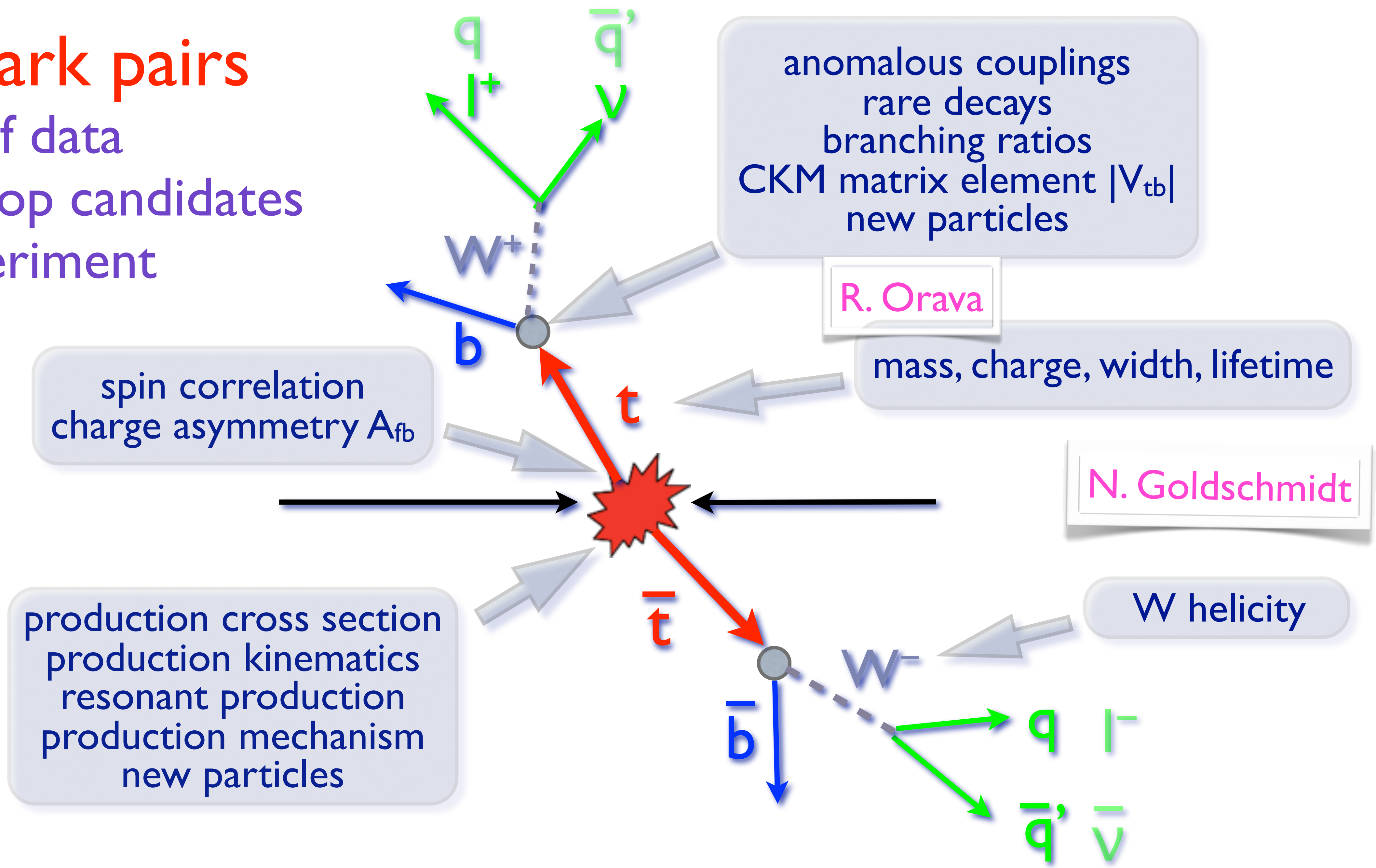


Observed EW top quark production

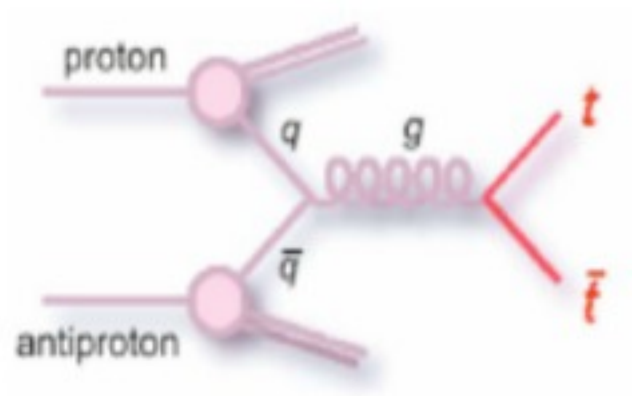
R. Schwienhorst

Is it the Standard Model top? Deviation can be a sign of new physics

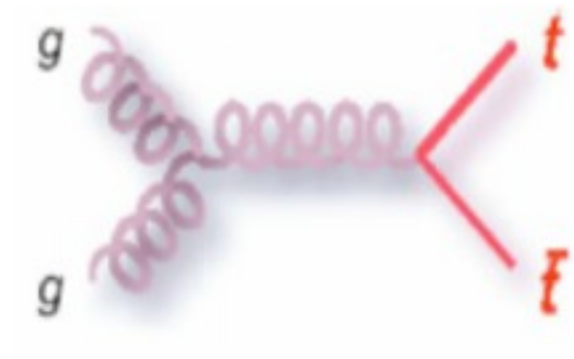
Top quark pair production

Main mechanism: pair production vis strong interaction

Tevatron



85%



15%

NNLO$_{approx}$ for m_t = 172.5 GeV, CTEQ 6.6 PDF

$\sqrt{s}$ (TeV)	2	7	14
$\sigma_{t\bar{t}}$ (pb)	7.46	160.8	886.3

~9% uncertainty

PRD 80, 054009 (2009)

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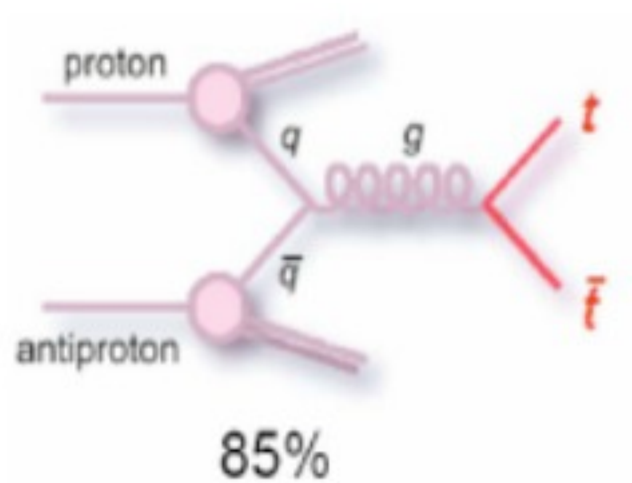
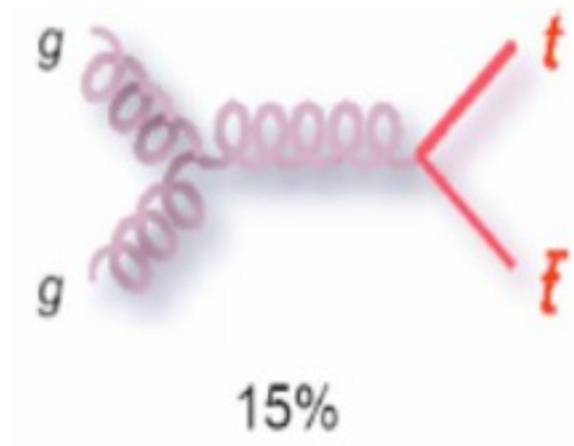
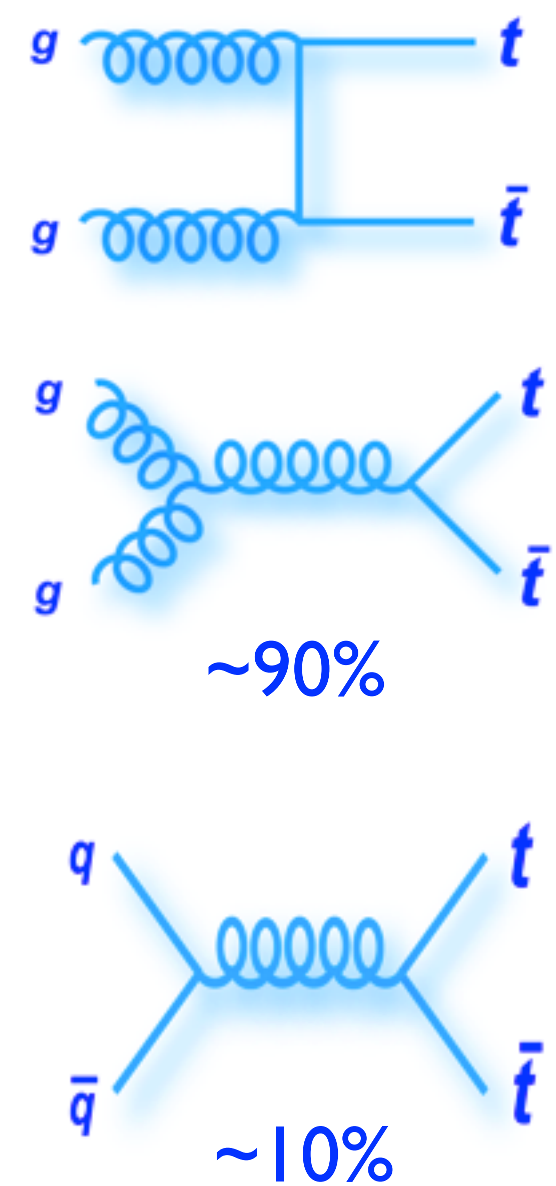




LHC



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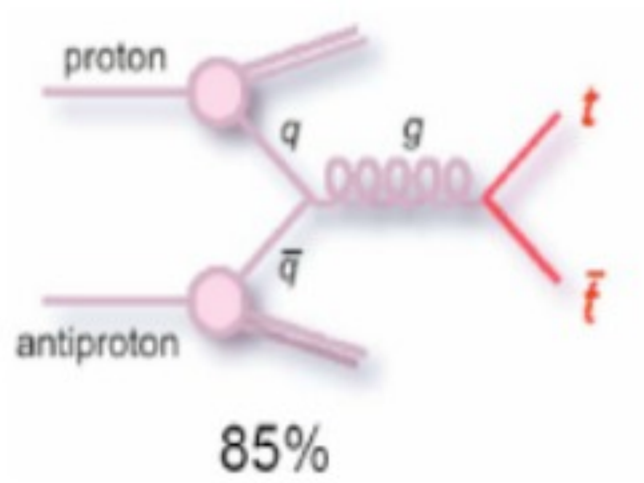

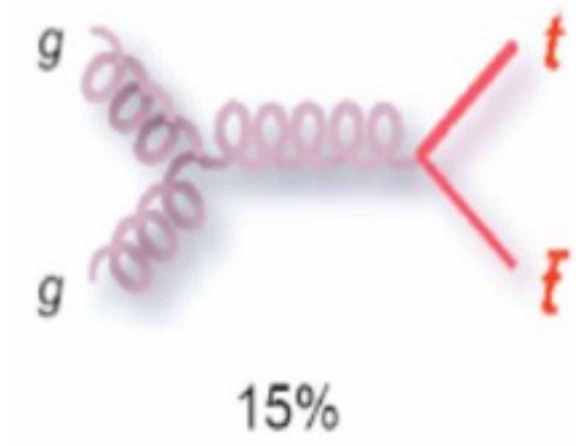

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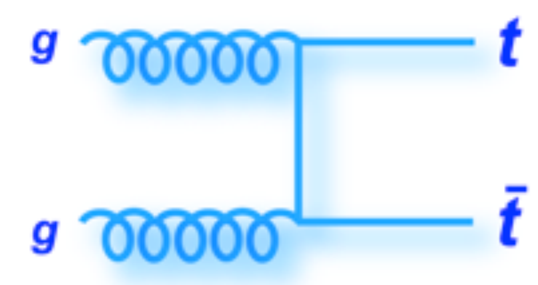

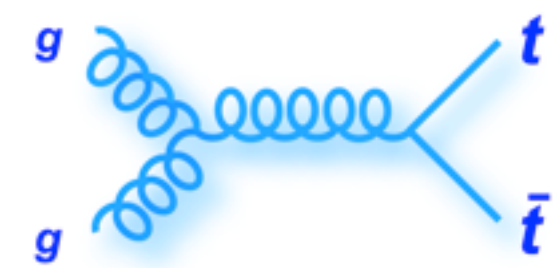

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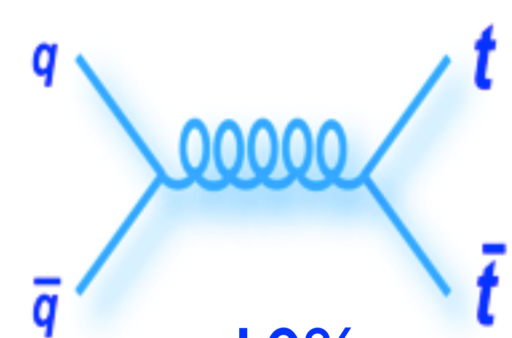

~10%

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~20 larger than at Tevatron

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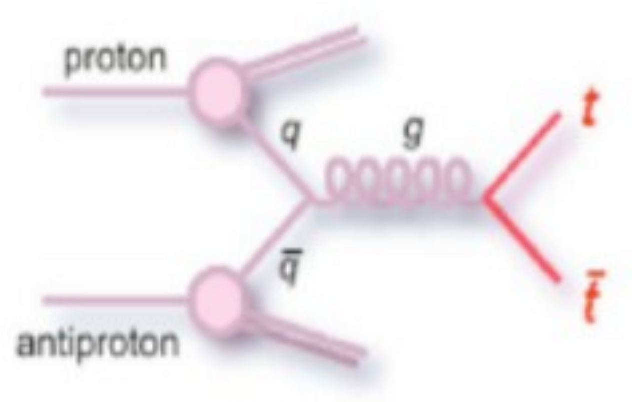

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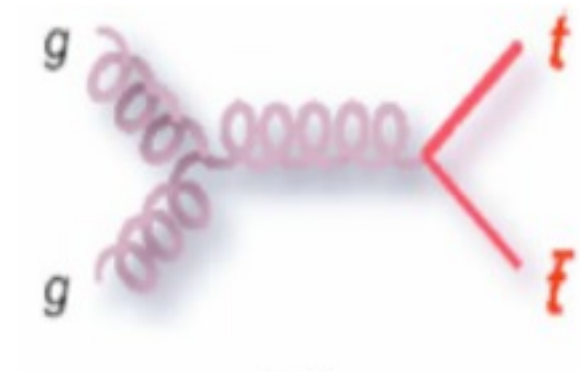
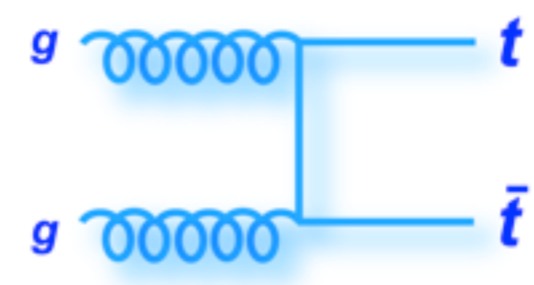
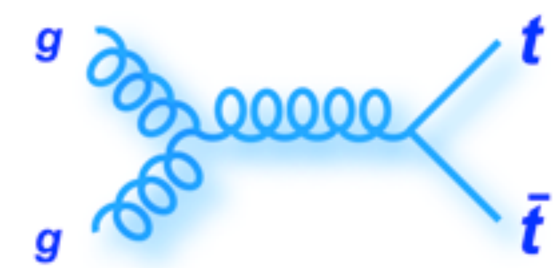


15%

LHC





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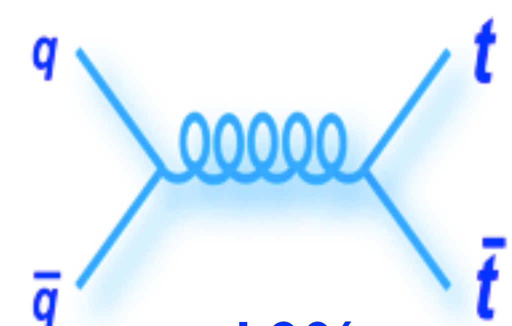

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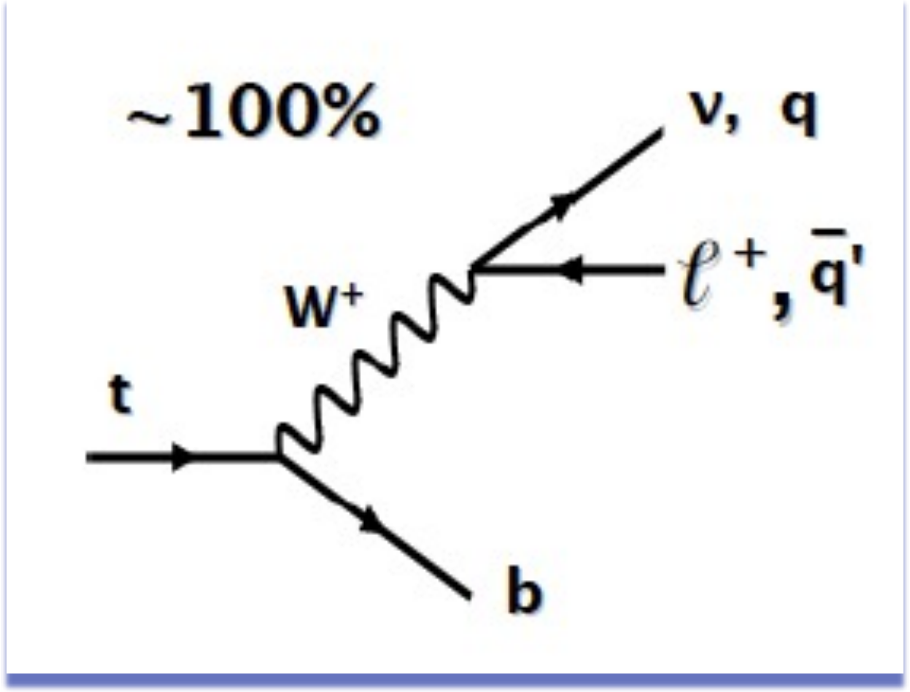
~20 larger than at Tevatron

250 pb^{-1} LHC sample ~ 5 fb^{-1} Tevatron sample

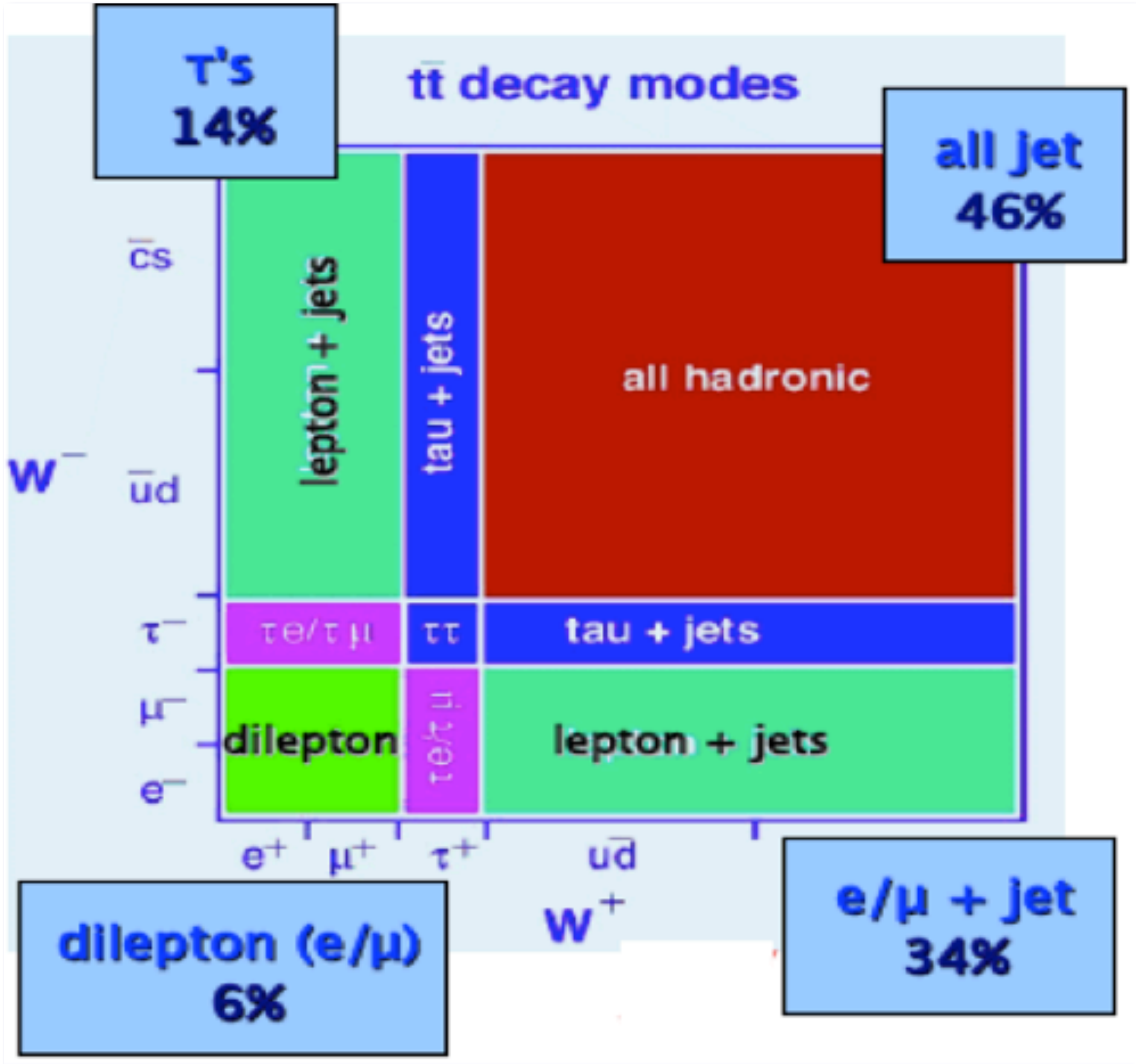
assuming similar efficiency

Top quark decay

In Standard Model

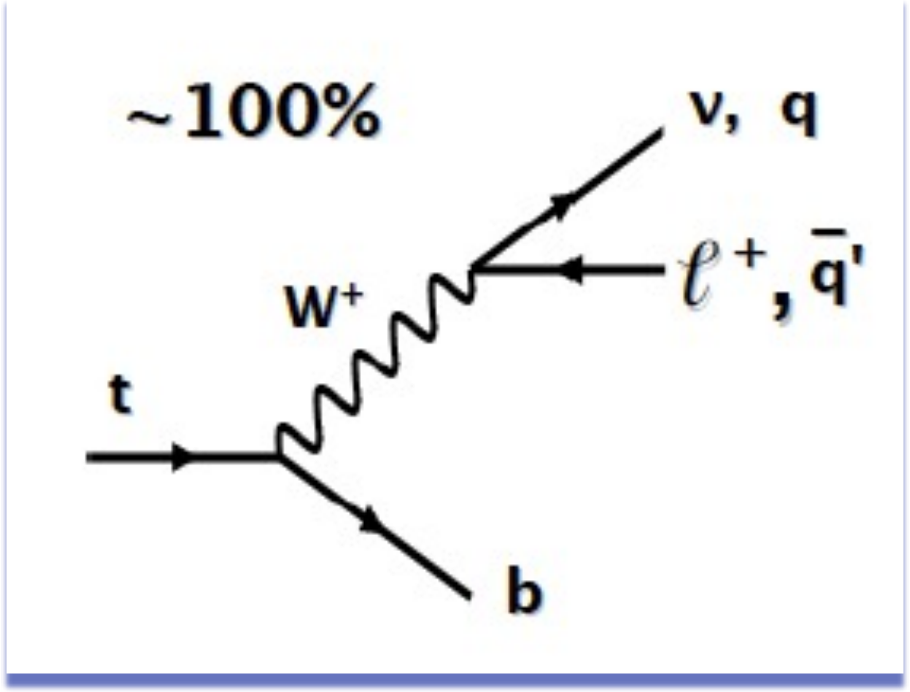


W decay mode defines top pair final state



Top quark decay

In Standard Model



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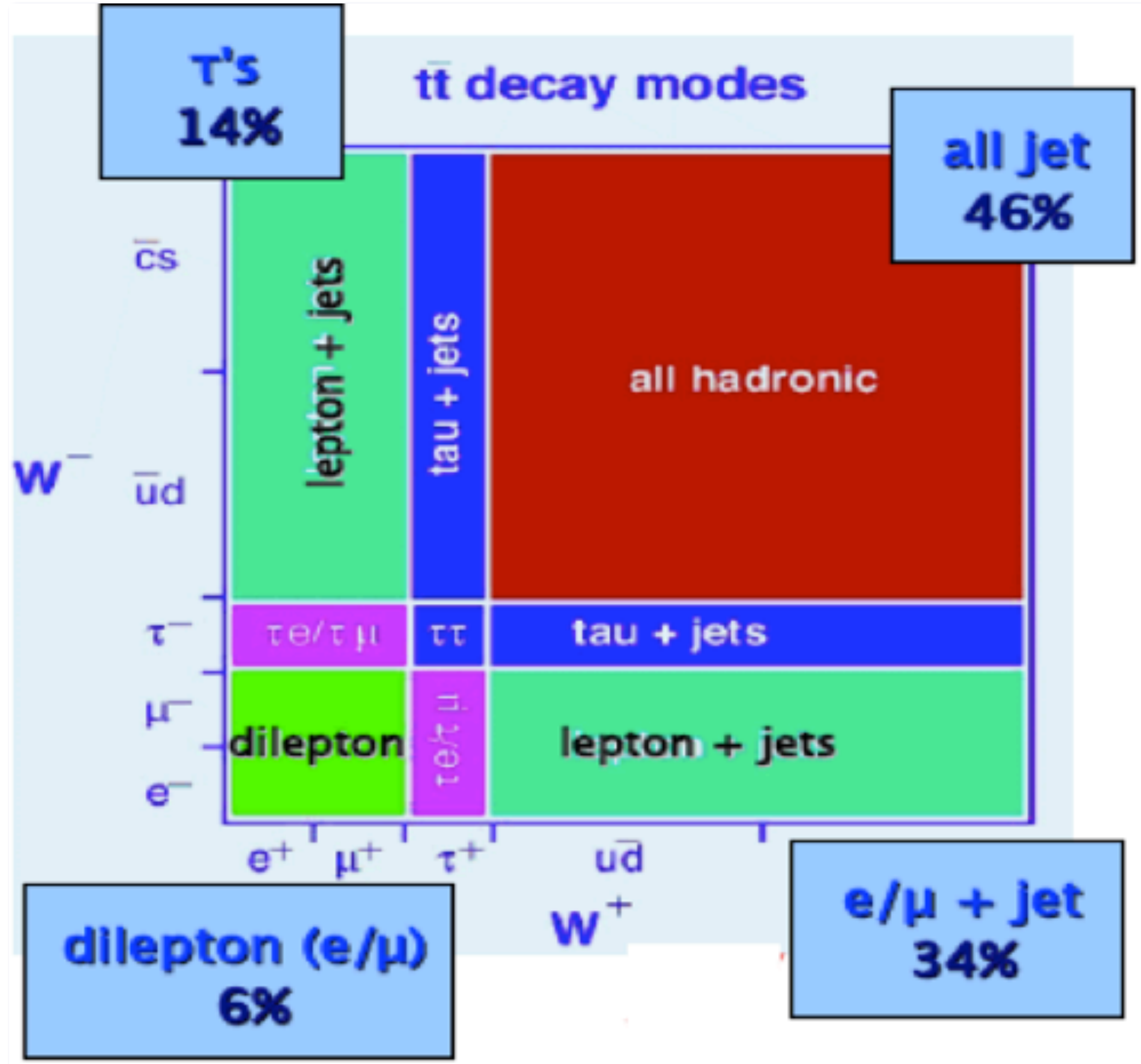
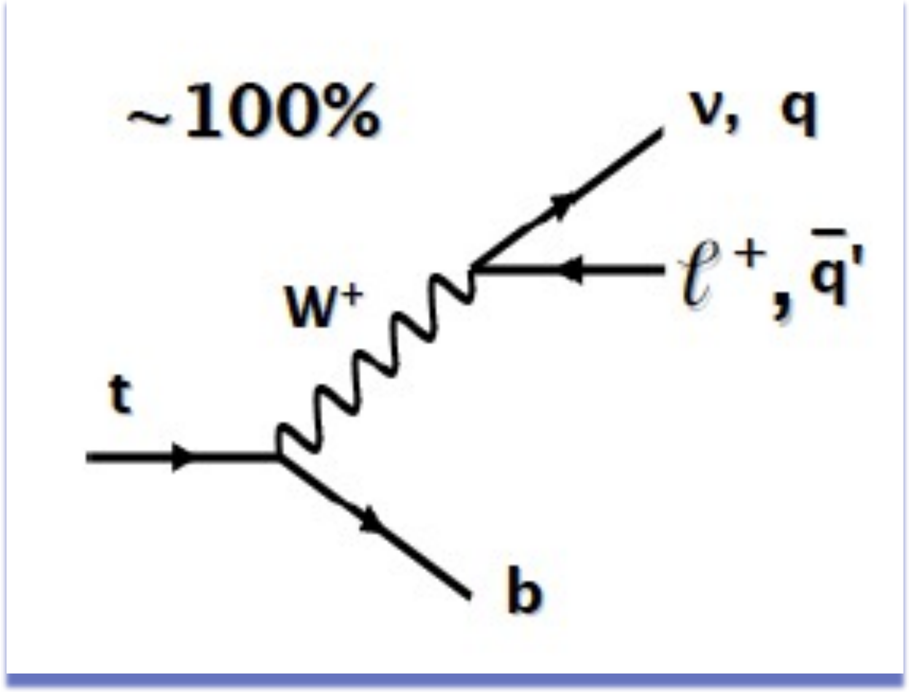


small rate, small background
main background: Drell-Yan

Top quark decay

In Standard Model



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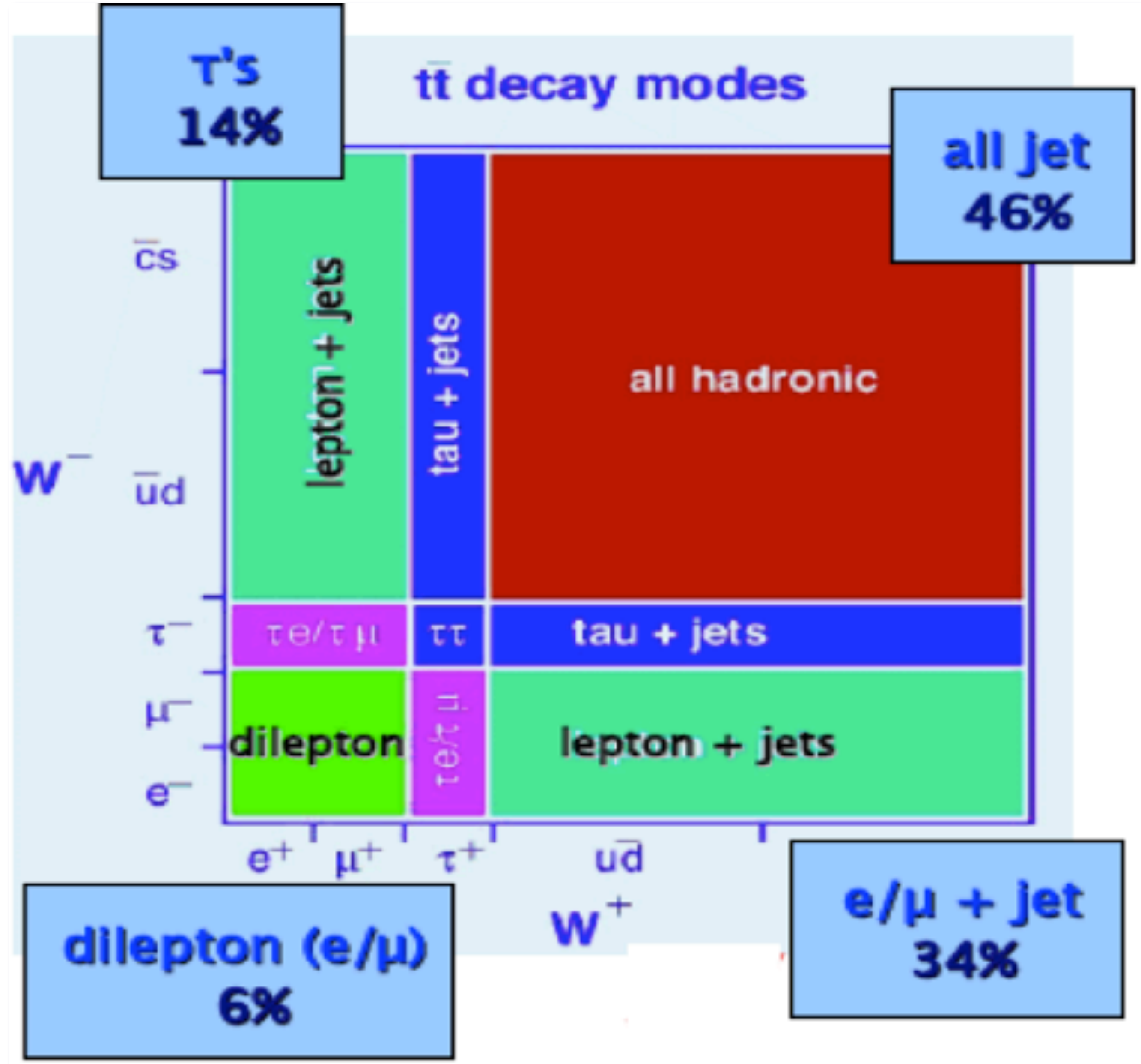


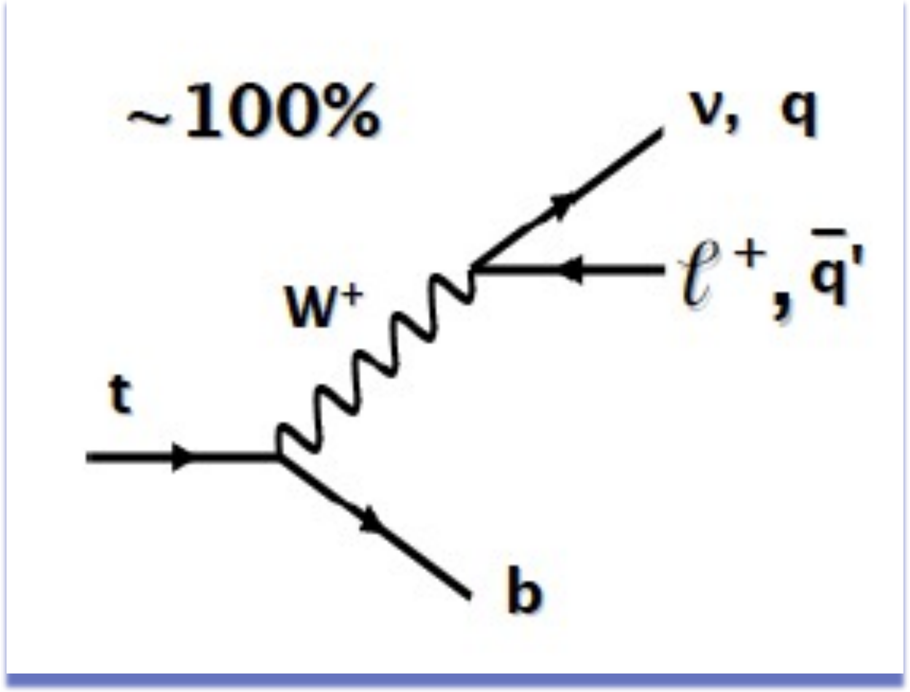
small rate, small background
main background: Drell-Yan

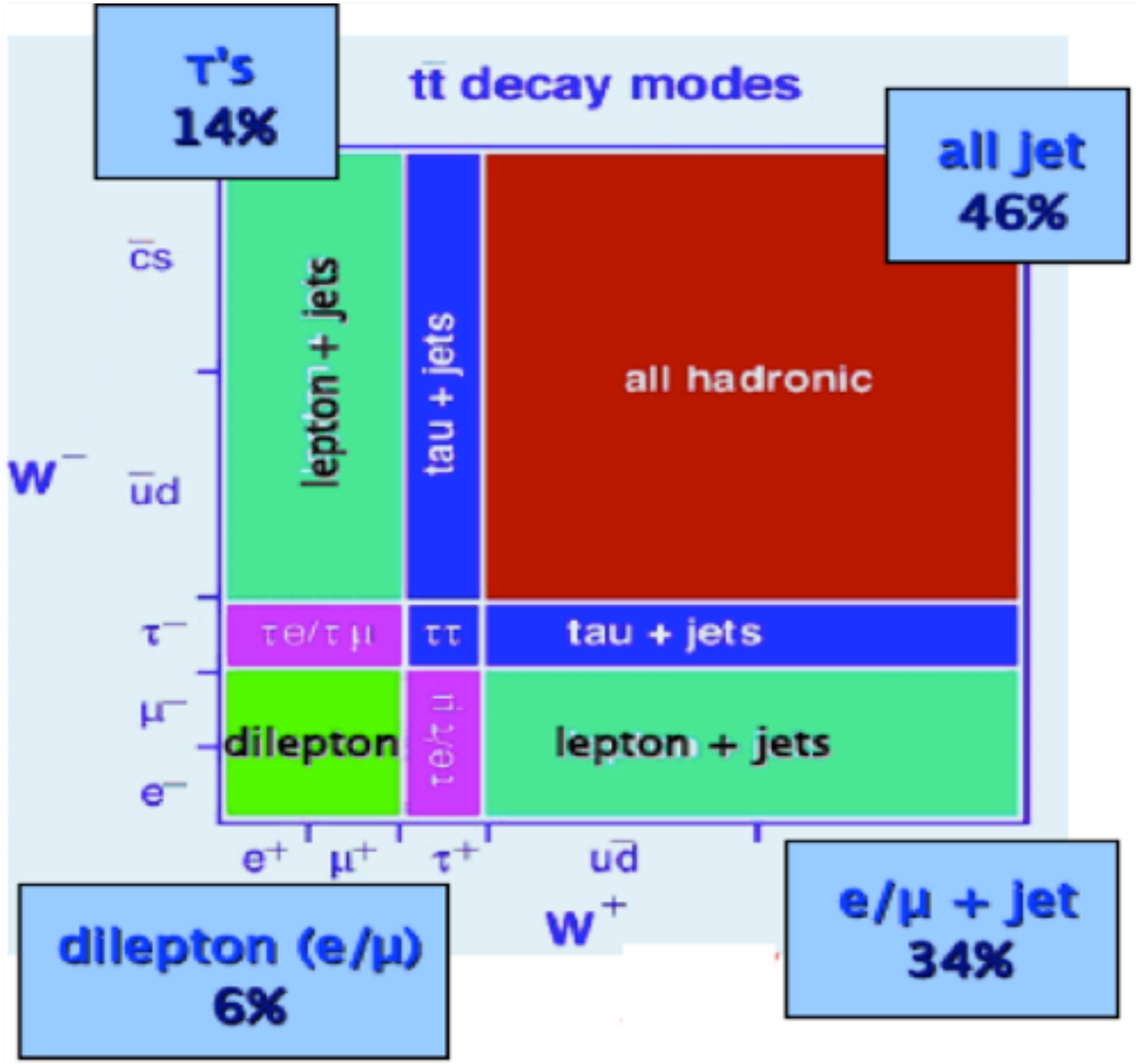
good rate, manageable background
main background: W+jets

Top quark decay

high rate, high background
main background: multijet

In Standard Model





W decay mode defines top pair final state

small rate, small background
main background: Drell-Yan

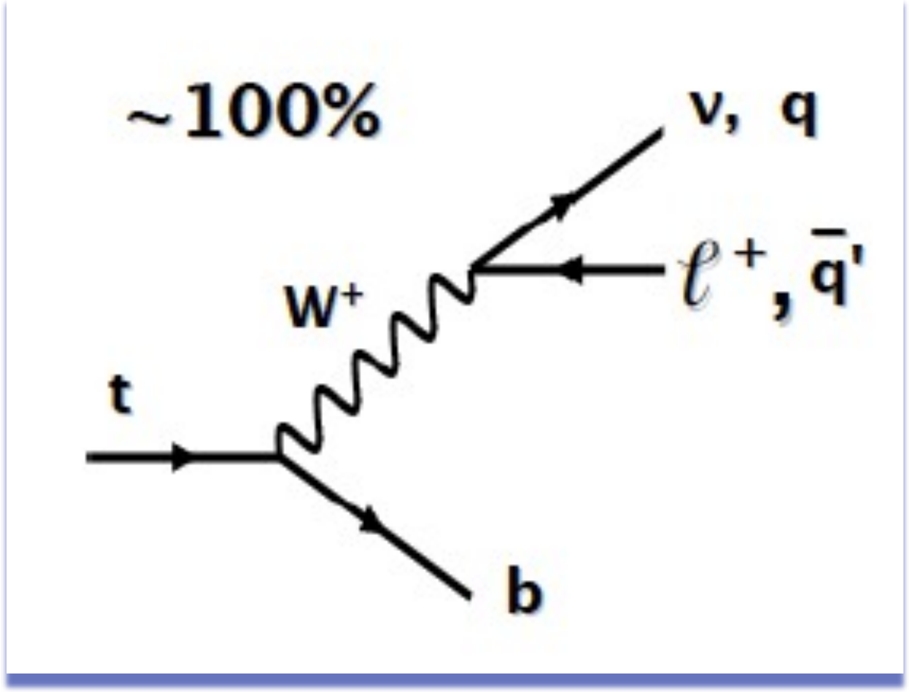
good rate, manageable background
main background: W+jets

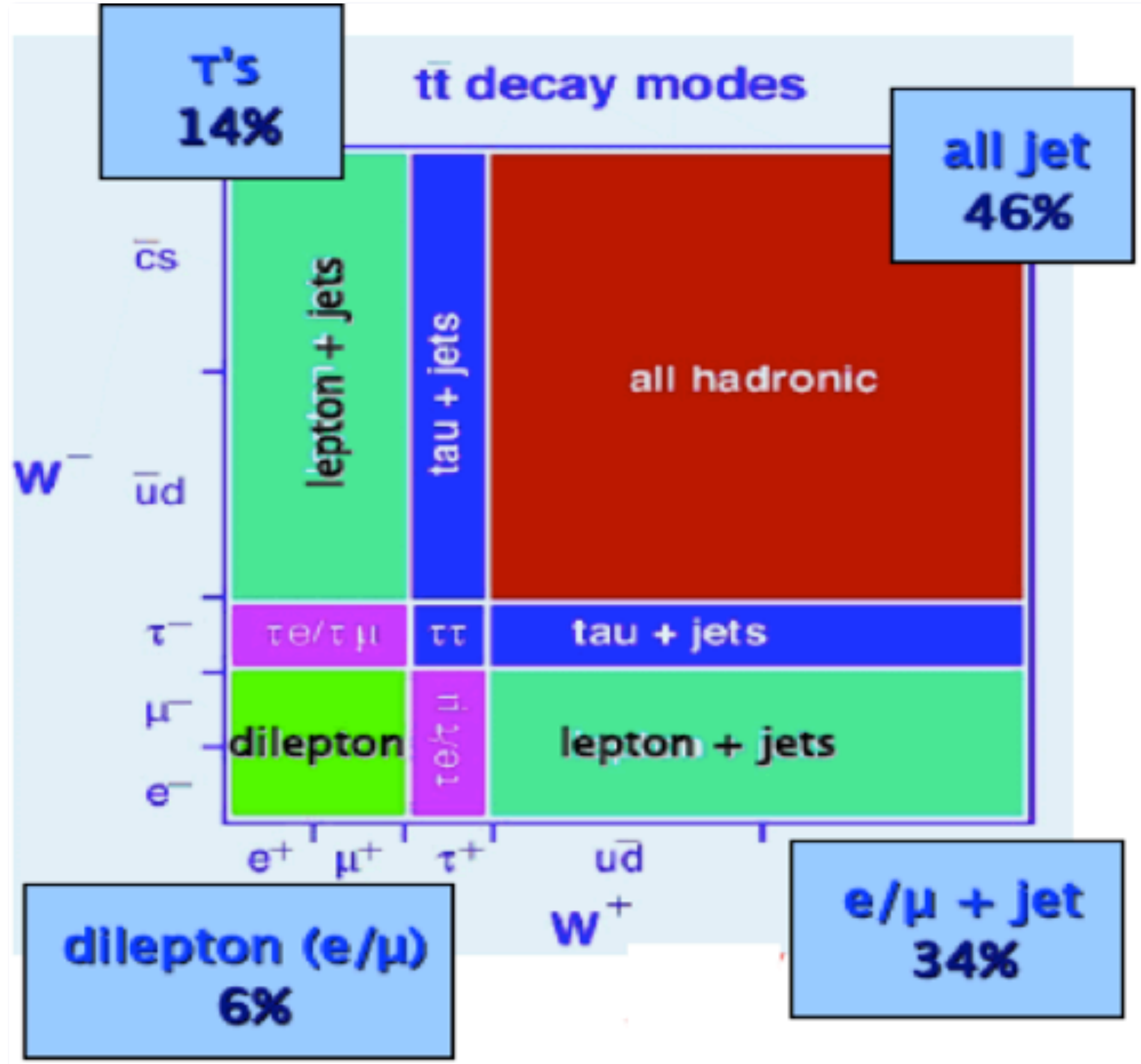
Top quark decay

small rate, high background
backgrounds: multijet, W+jets

high rate, high background
main background: multijet

In Standard Model





W decay mode defines
top pair final state

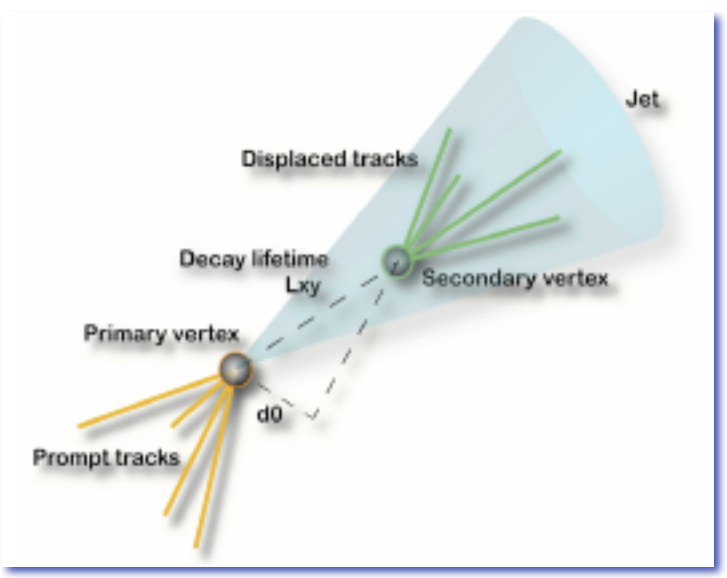
small rate, small background
main background: Drell-Yan

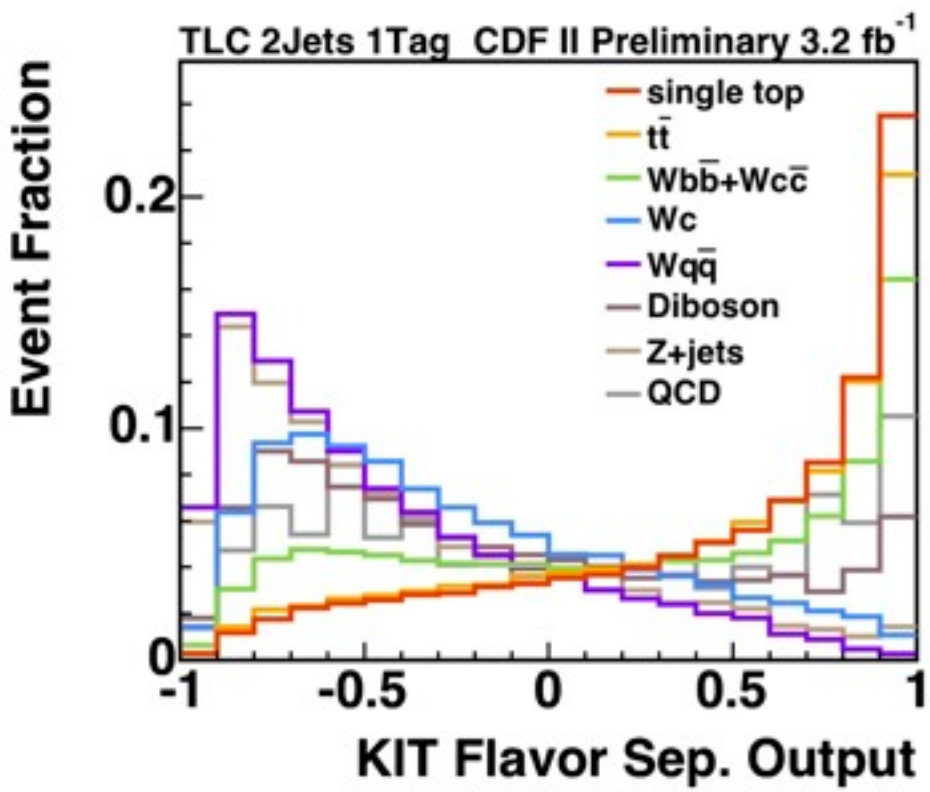
good rate, manageable
background
main background: W+jets

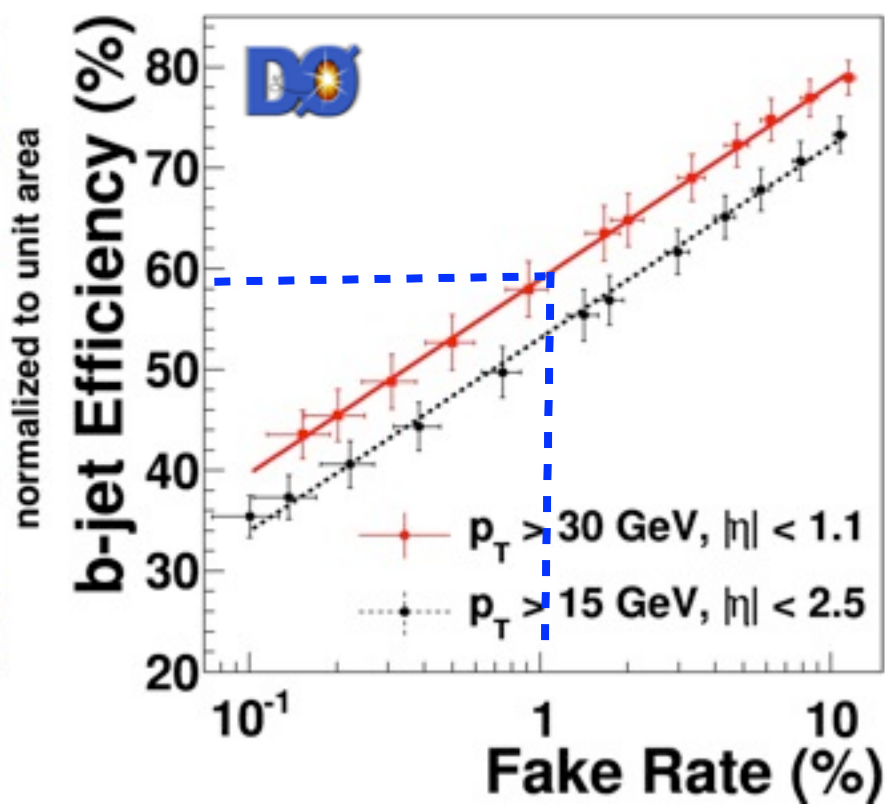
Finding top quarks: b-tagging

- Powerful tool to suppress backgrounds to top
- Utilizes
  - long live time of B-hadrons
  - semileptonic B decays
- CDF: Neural network heavy flavor separator applied after SVX tagger
  - separates b from charm and light
  - 25 input variables
- D0: Neural Network tagger
  - combines track and secondary vertex properties - 7 variables

NIM, A620, 400 (2010)

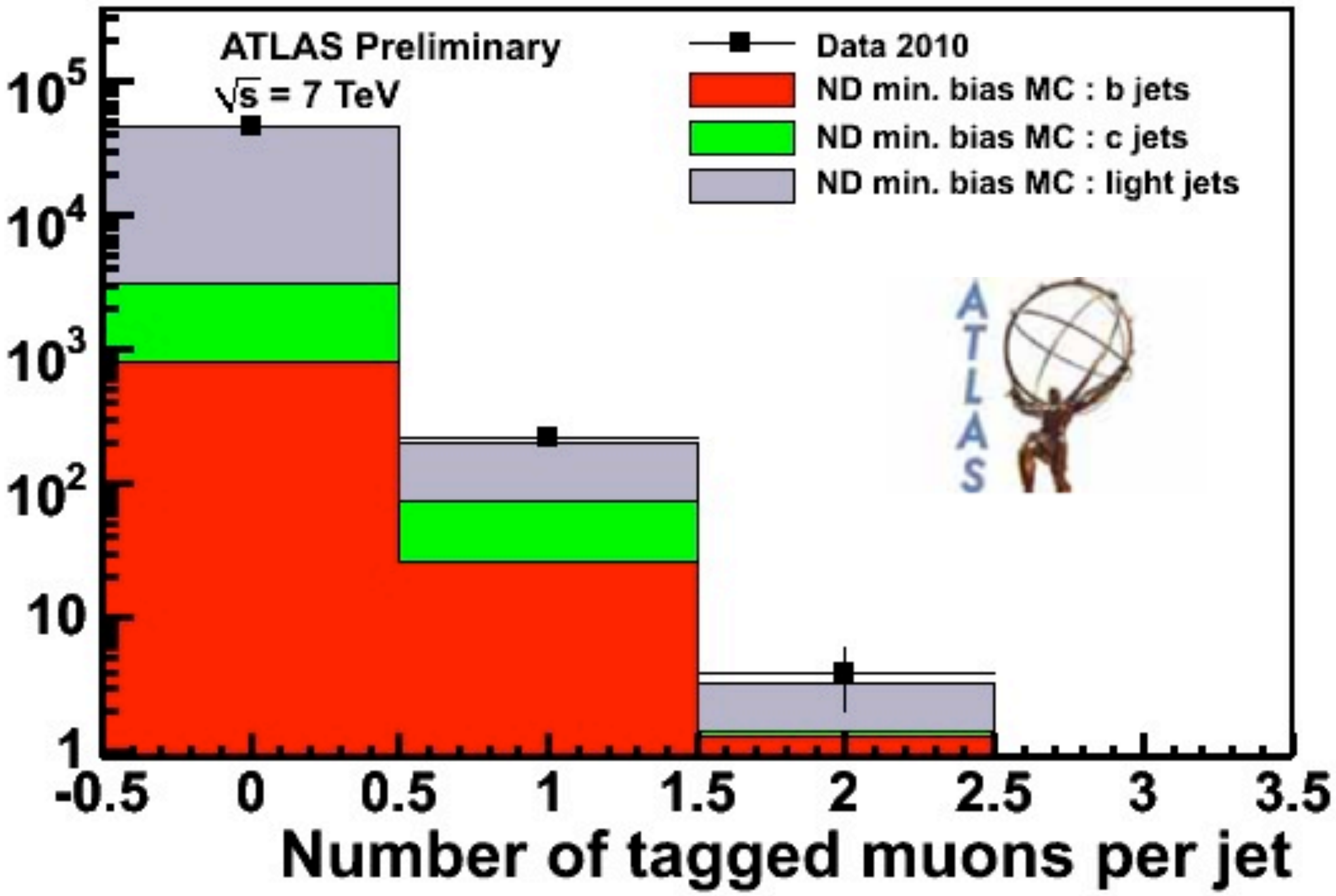


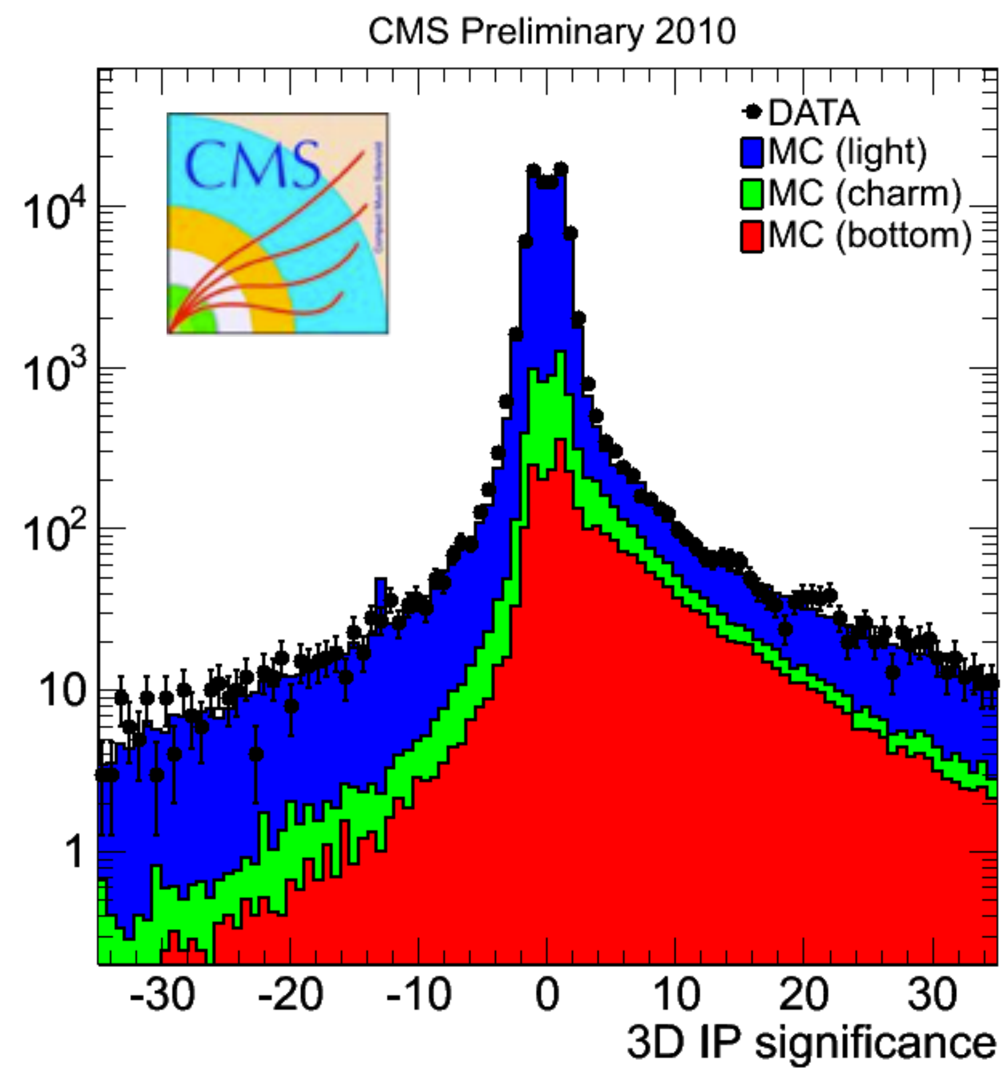




Tevatron experience: b-tagging usually improves the sensitivity

b-jet identification at LHC



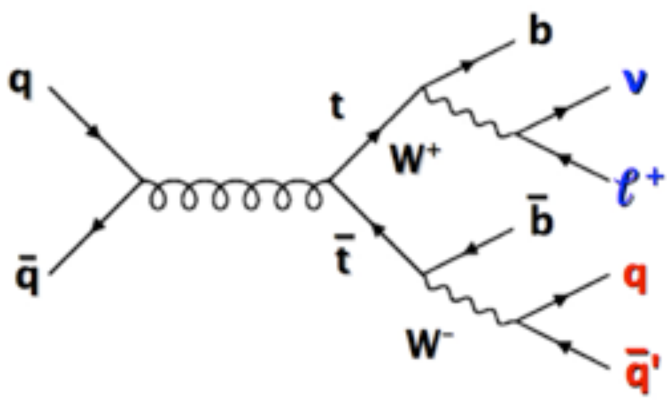


- Impressive agreement between data and simulation
- Looks very promising even for the first top analyses at LHC

Top quark production

top quark pairs
electroweak single top quark

Top pair cross section

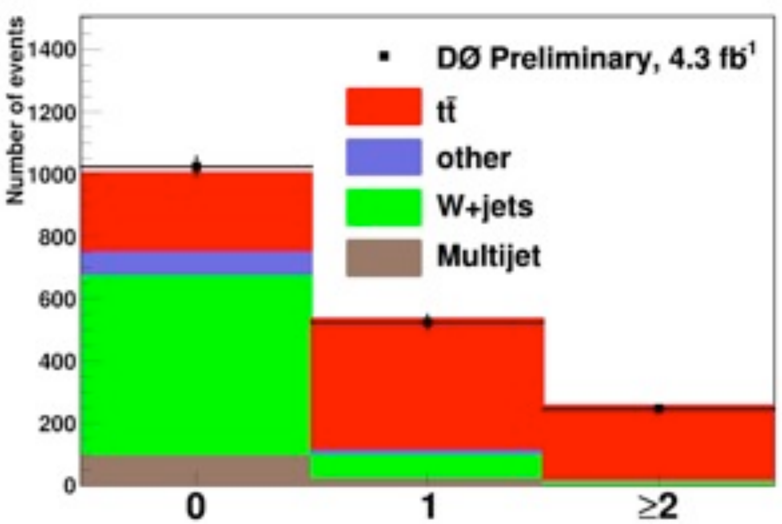


- First step in understanding selected top quark sample
- Test of theoretical QCD calculations

l+jets channel

Methods:

- kinematical information
- b-jet identification

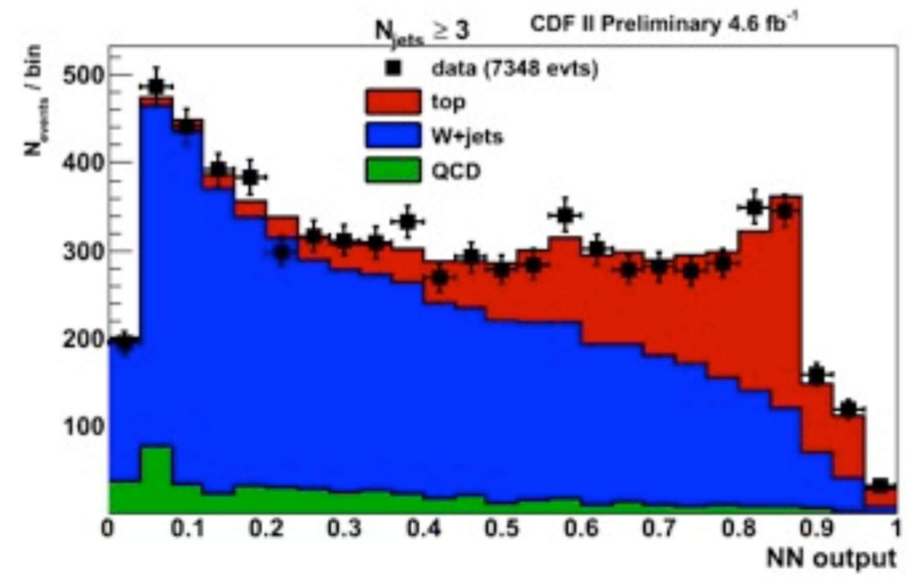


$$\sigma_{t\bar{t}} = 7.70^{+0.79}_{-0.70}(\text{total})\text{pb}$$

Total uncertainty ~10-12%

- Limited by systematics, luminosity dominates at ~6%.
- Take ratio to Z cross section: trade for Z theory uncertainty

4.6 fb^{-1}



PRL 105:012001,2010

$$\sigma_{t\bar{t}} = 7.63 \pm 0.37(\text{stat}) \pm 0.35(\text{syst}) \pm 0.15\ (\text{theory})\ \text{pb}$$

7% relative precision, 8.8% with luminosity uncertainty

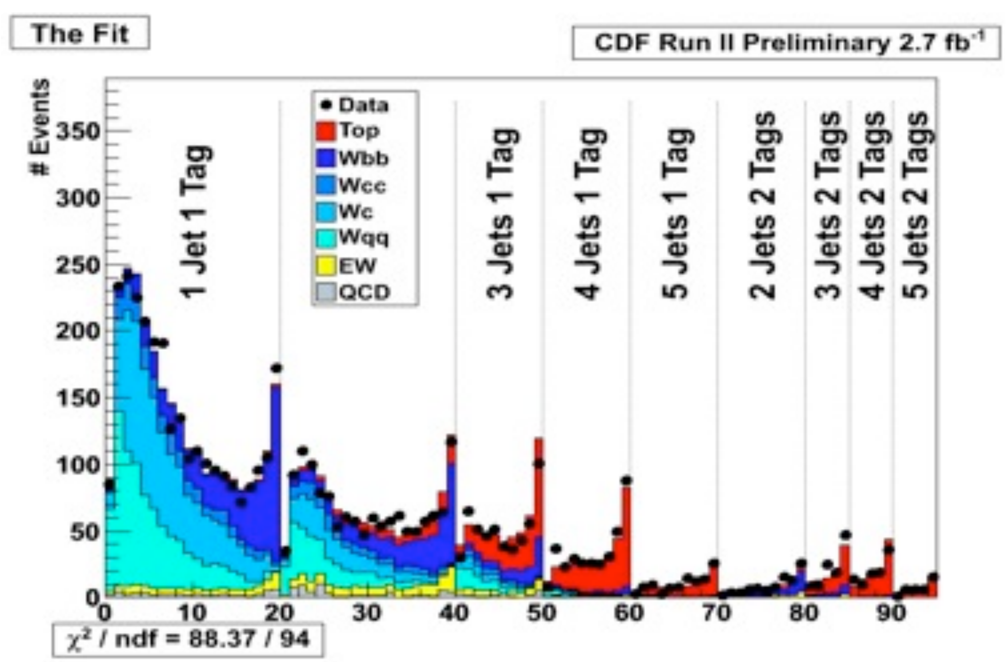
...to be compared to Tevatron goal of 10%

More on cross sections

- Simultaneous measurement of σ_{tt} and background normalization
- use NN flavor separator and N_{jets} distribution
  - 9% (15%) improvement of stat (syst) uncertainties
- measures K-factors for W+jets

$\sigma_{ttbar} = 7.64 \pm 0.57$ (stat+syst) ± 0.45 (lumi) pb

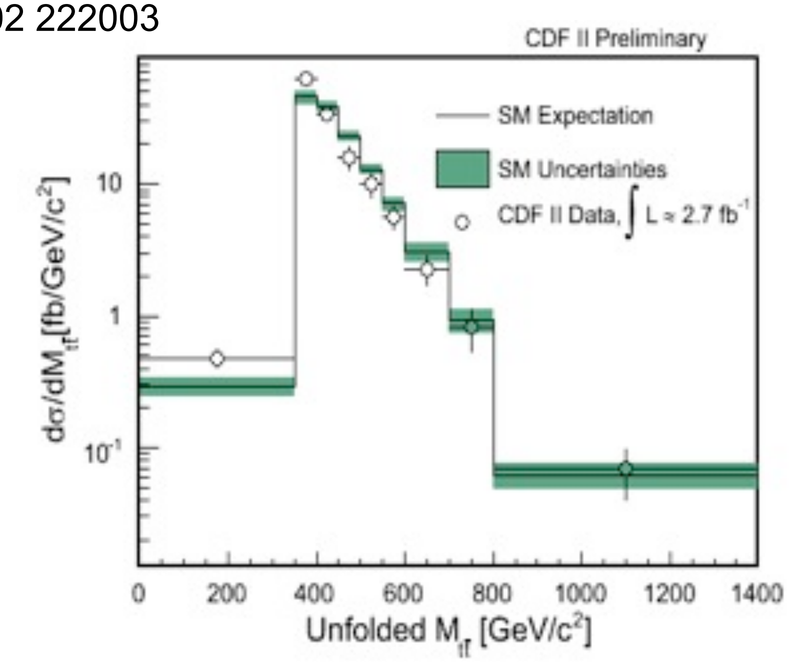
2.7 fb^{-1}



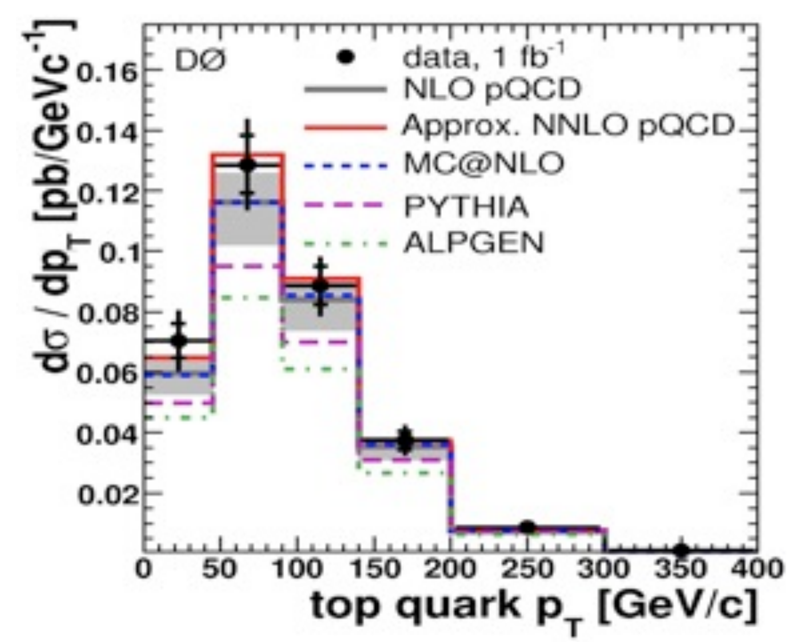
$$K_{W_{b\bar{b}}} = 1.57 \pm 0.25 \quad K_{W_{q\bar{q}}} = 1.10 \pm 0.29$$
$$K_{W_{c\bar{c}}} = 0.94 \pm 0.79 \quad K_{W_c} = 1.90 \pm 0.29$$

- Differential $t\bar{t}$ cross sections

PRL 102 222003

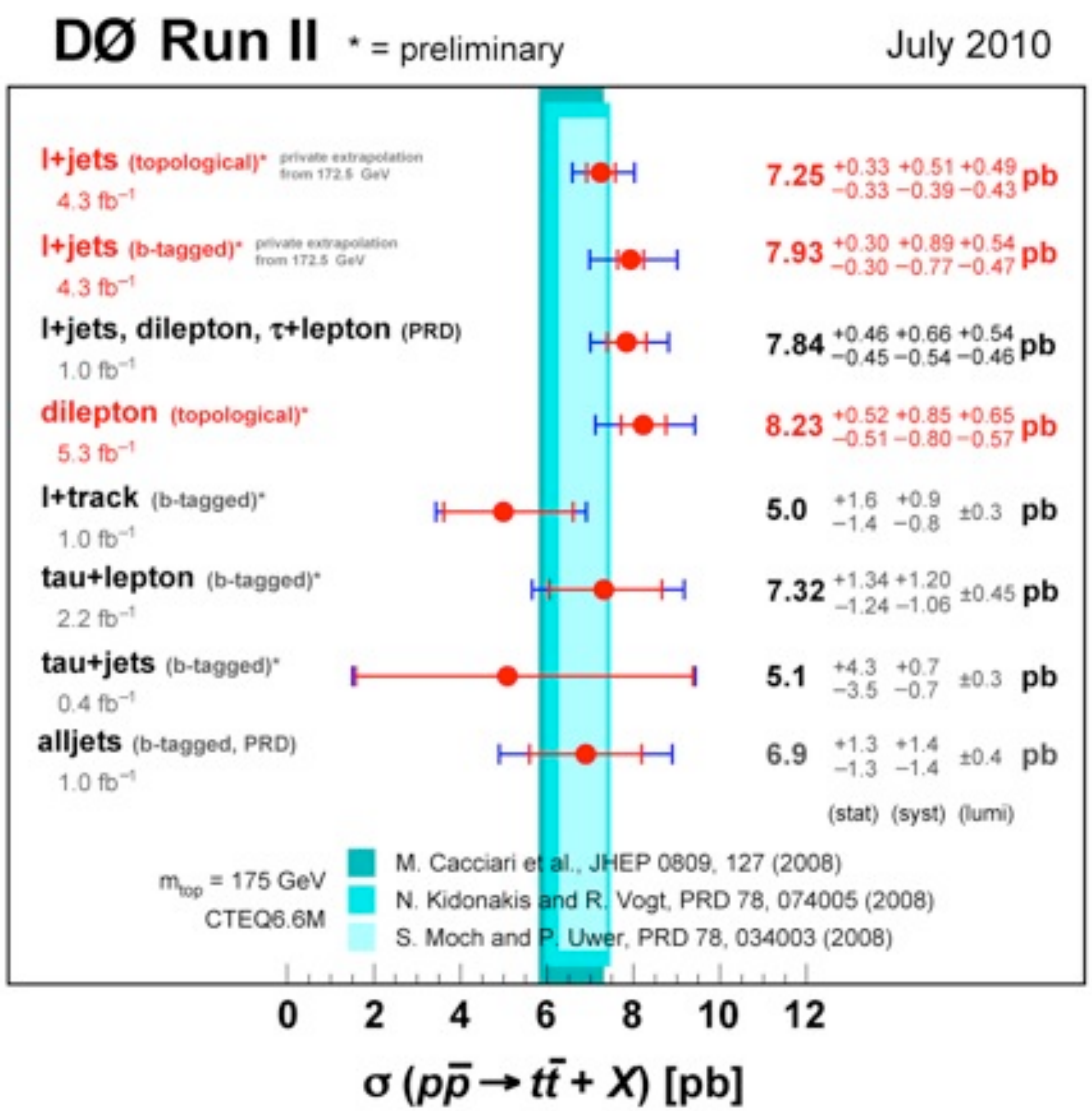


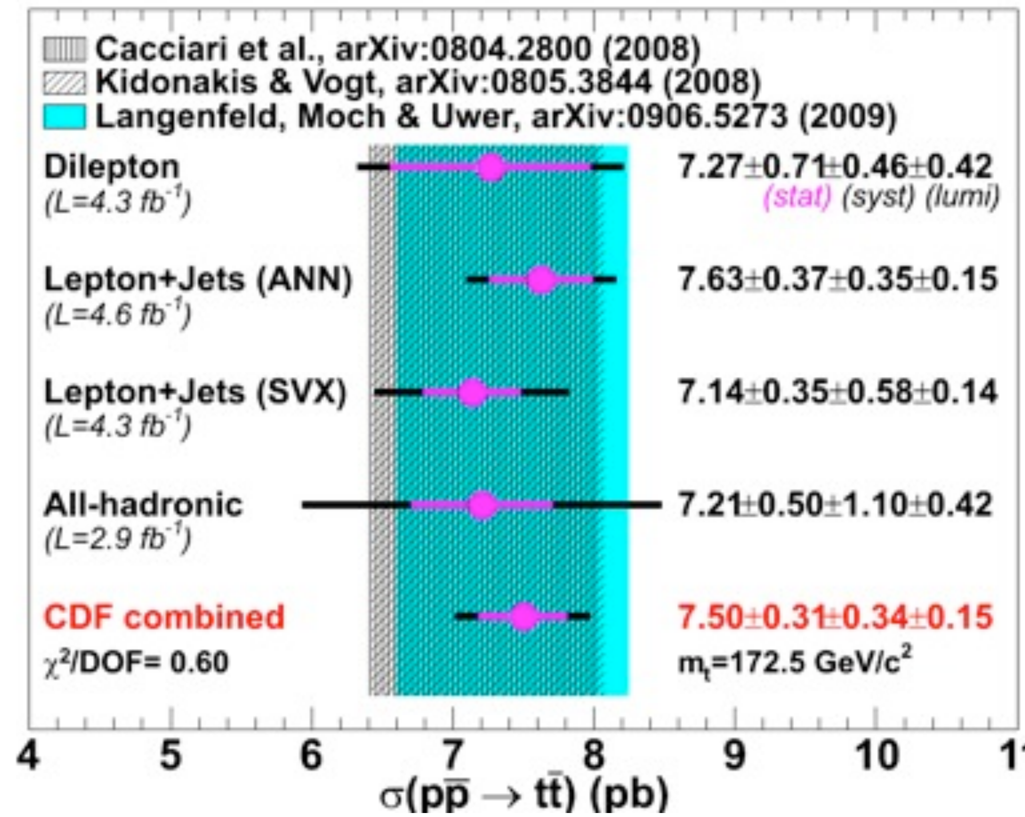
arXiv:1001.1900 [hep-ex]



No deviation from the SM

Cross sections summary



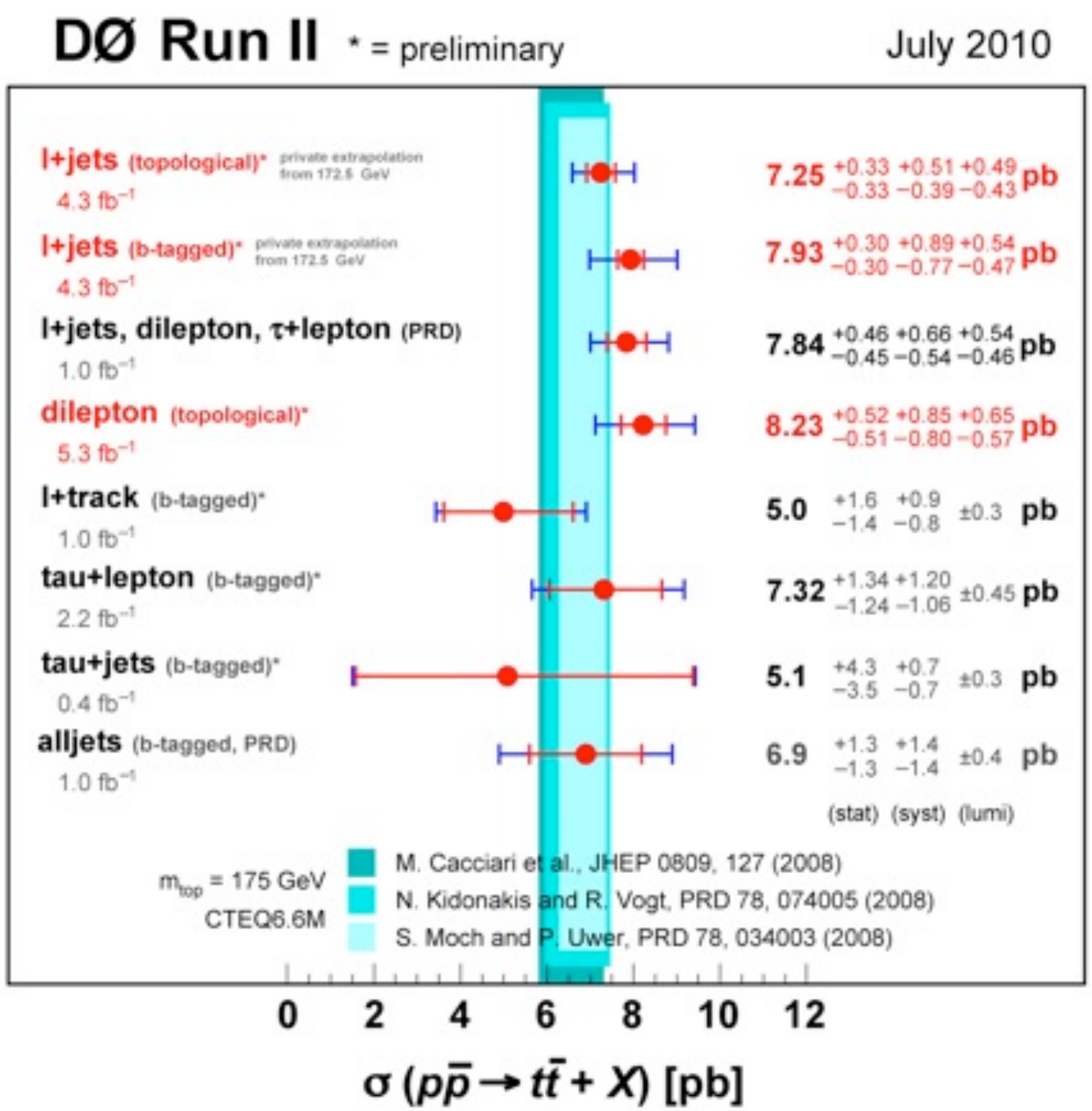


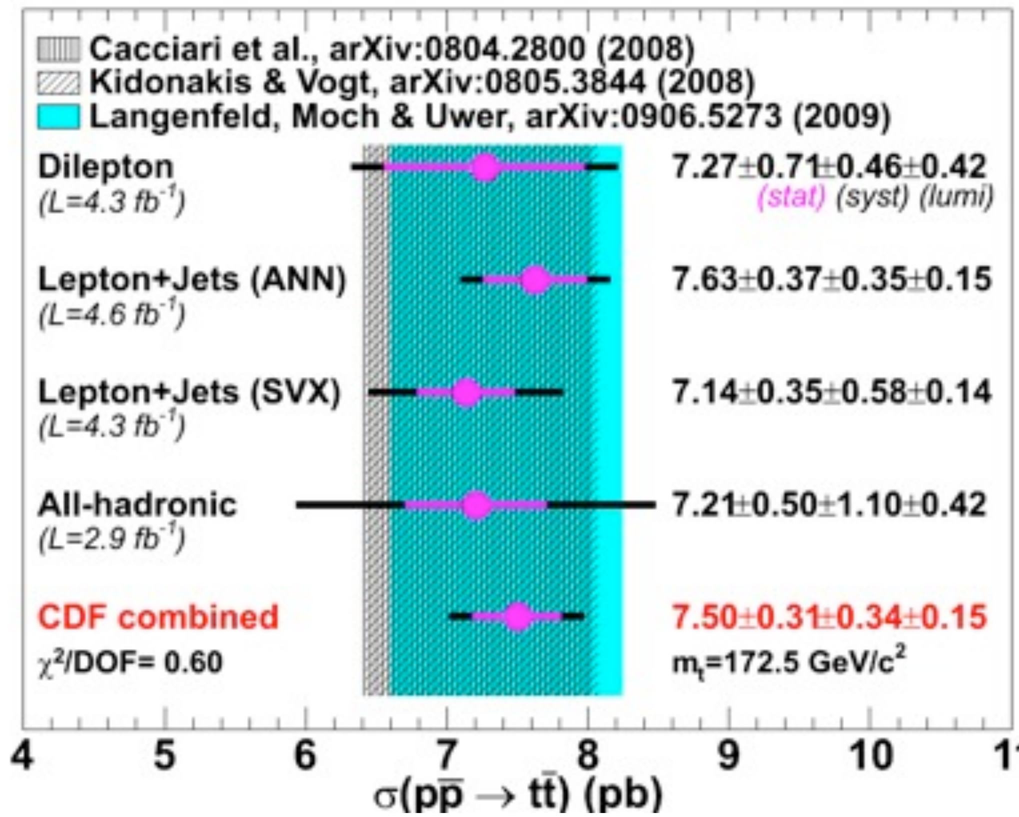
CDF combination: 6% precision!

Latest dilepton result not included

- Measured in all channels except for $\tau_{had}\tau_{had}$ channel
- Dilepton results achieving good precision (13-14%) (~350 events)

Cross sections summary





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- Measured in all channels except for $\tau_{had}\tau_{had}$ channel
- Dilepton results achieving good precision (13-14%) (~350 events)
- Consistent with theory prediction, challenges its precision
- Work on CDF-D0 combination is in progress

Electroweak top production

- Predicted 10 years before top discovery
- Observed 14 years after top discovery

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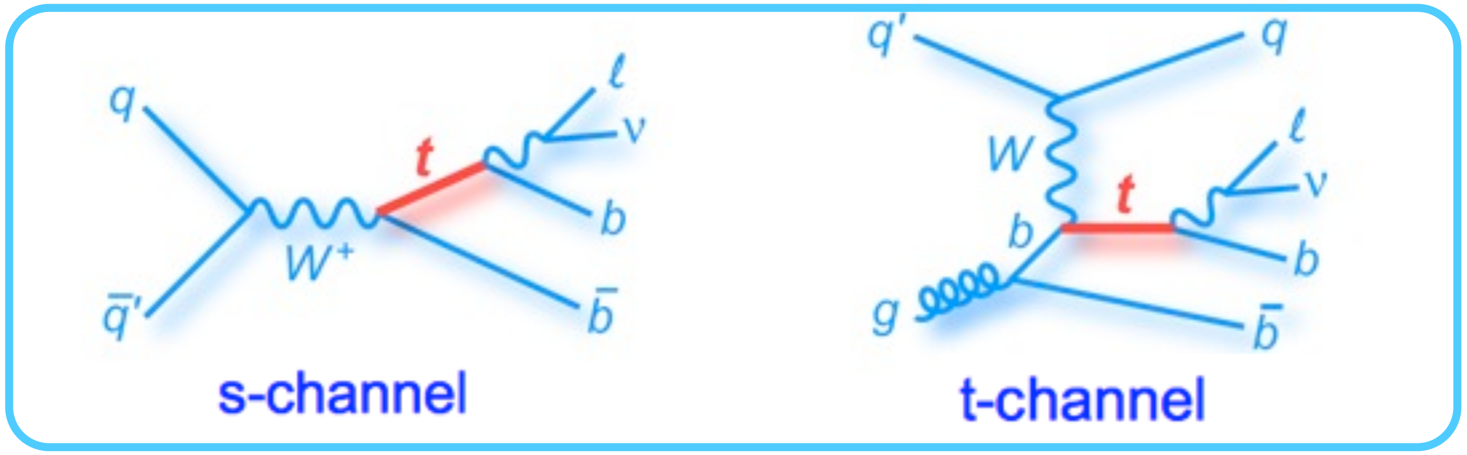
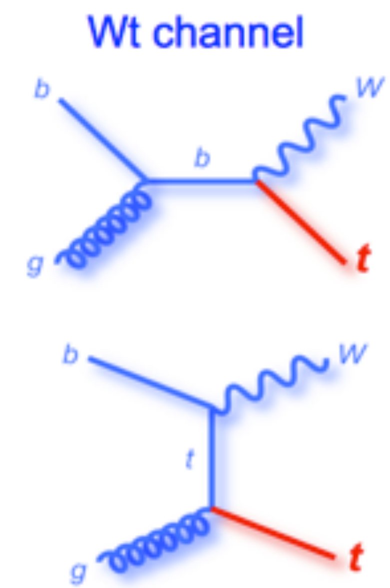


σ=1.04±0.04 pb σ=2.26±0.12 pb

$\text{NNNLO}_{\text{approx}}$, m_{top}=172.5 GeV



Small at Tevatron, important at LHC

Electroweak top production

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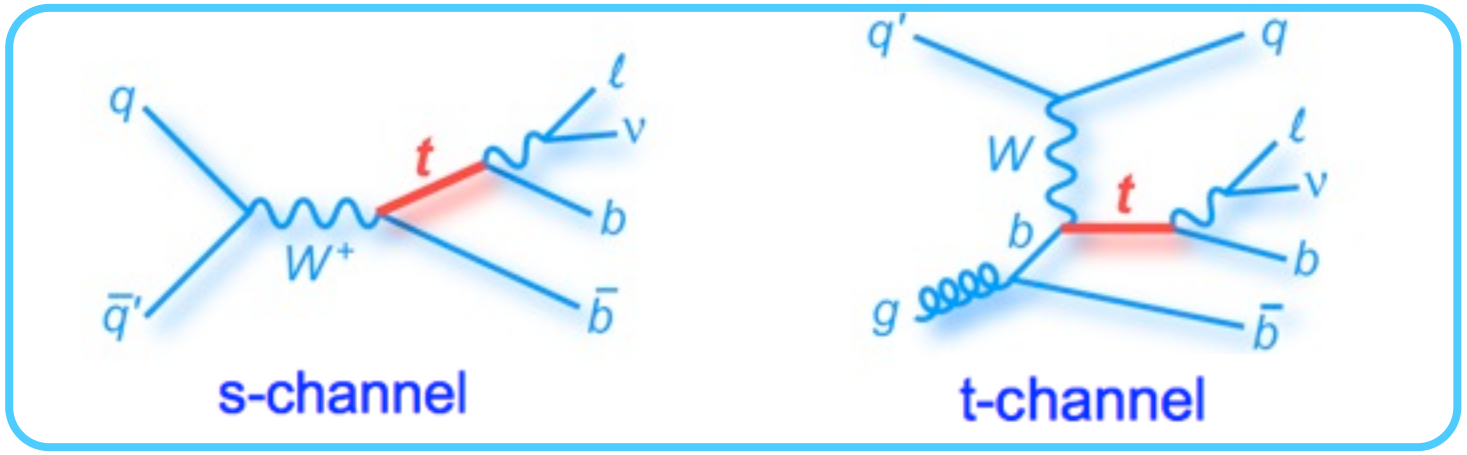

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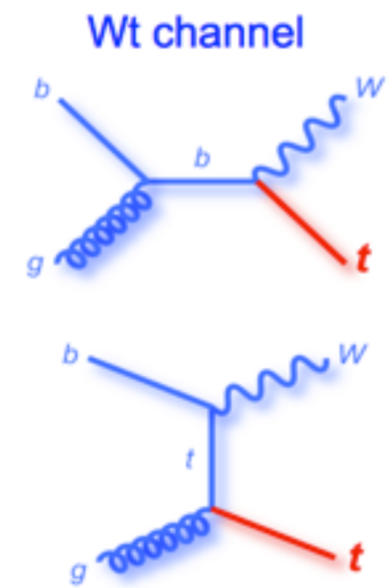
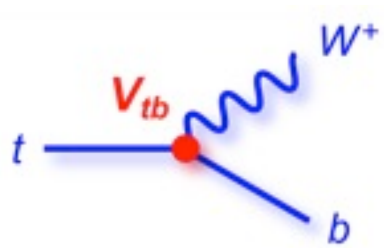


Small at Tevatron, important at LHC

$\sigma \sim |V_{tb}|^2$



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

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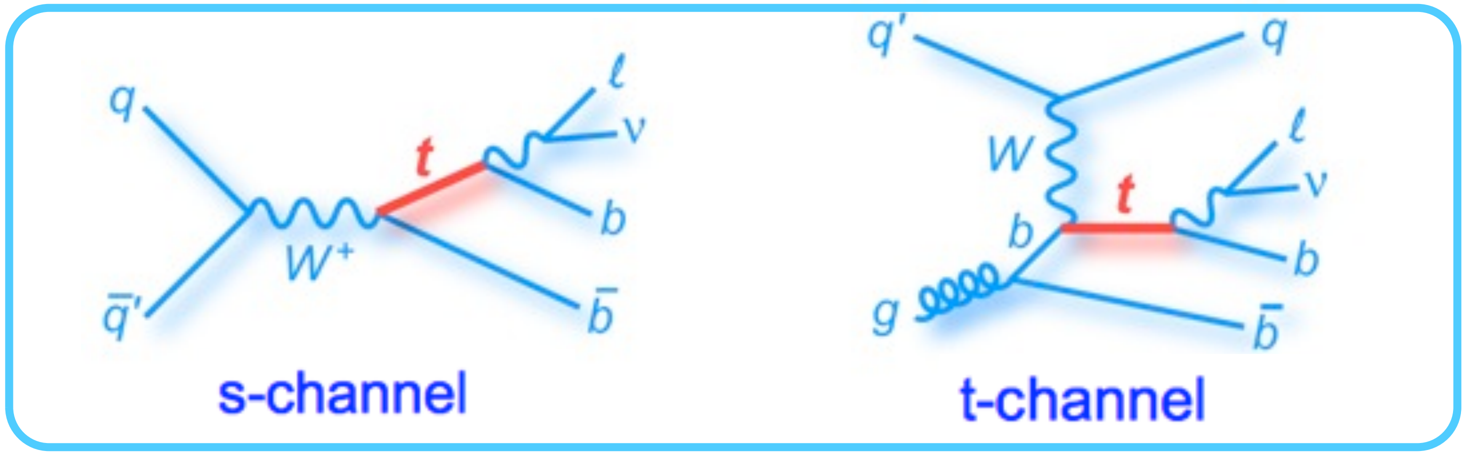

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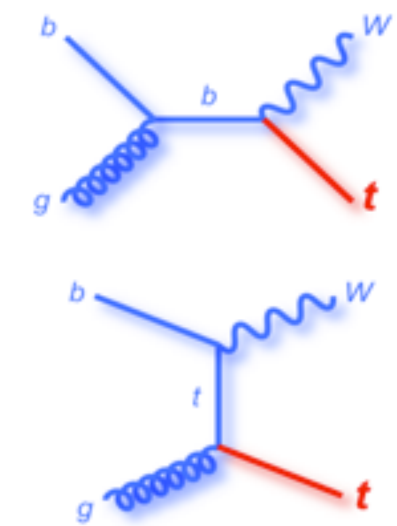
Wt channel



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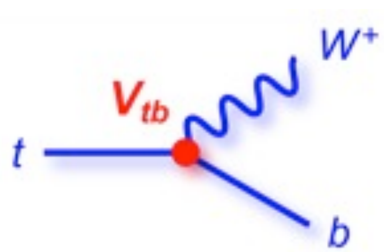

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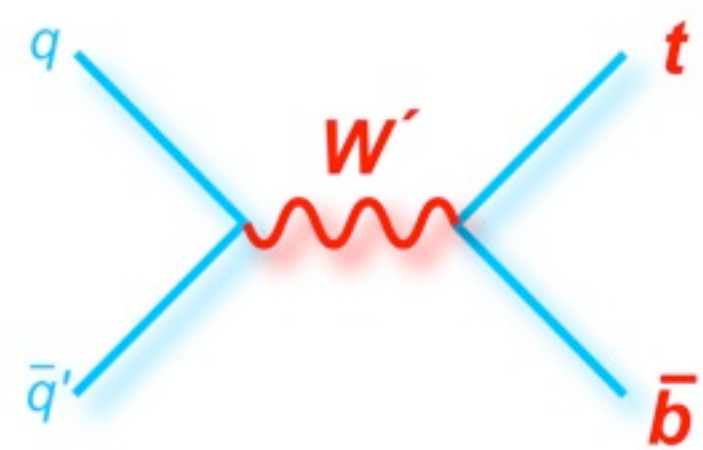

Sensitive to new physics in s-channel

Electroweak top production

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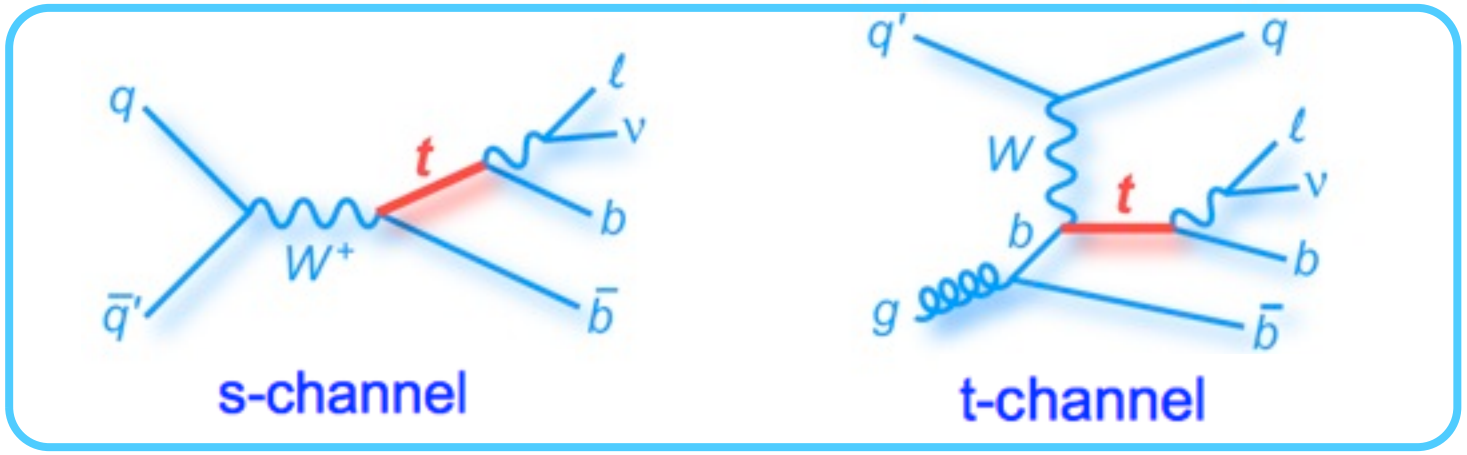

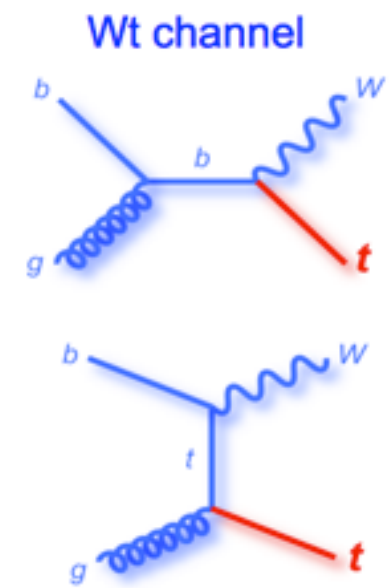

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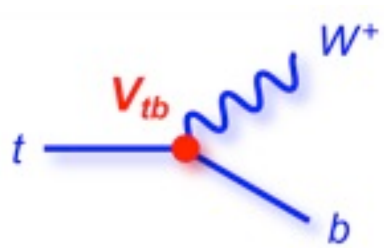

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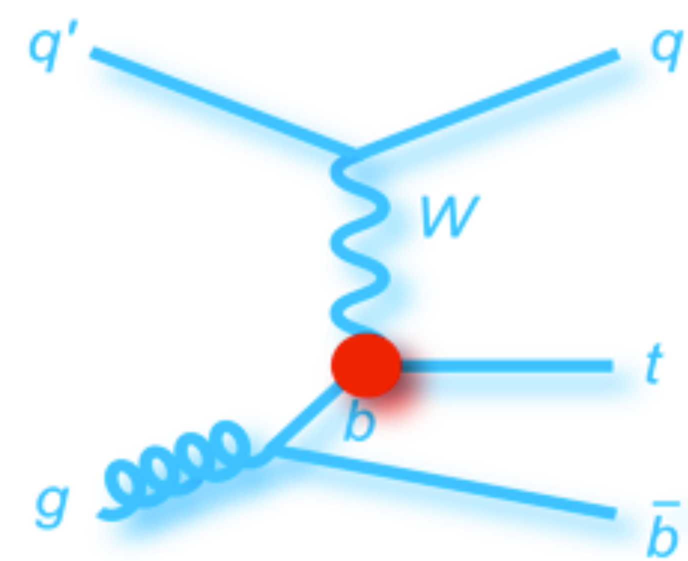
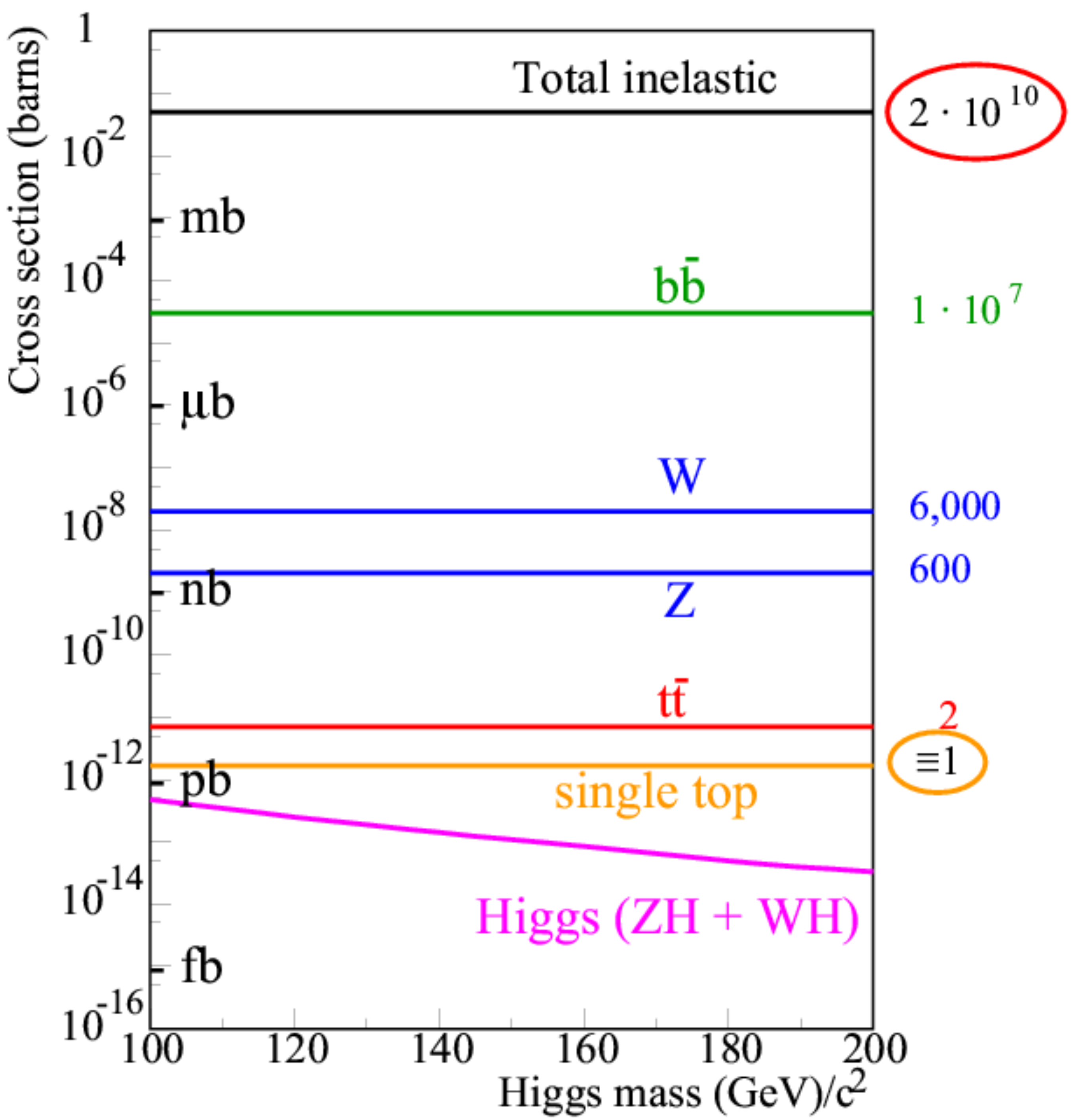
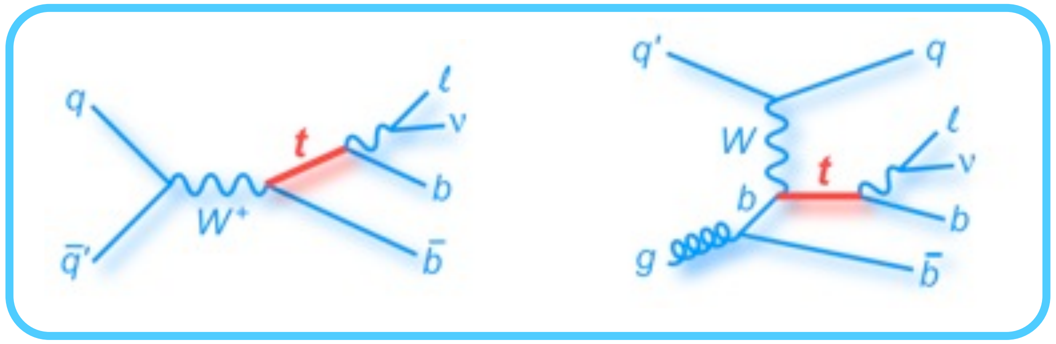


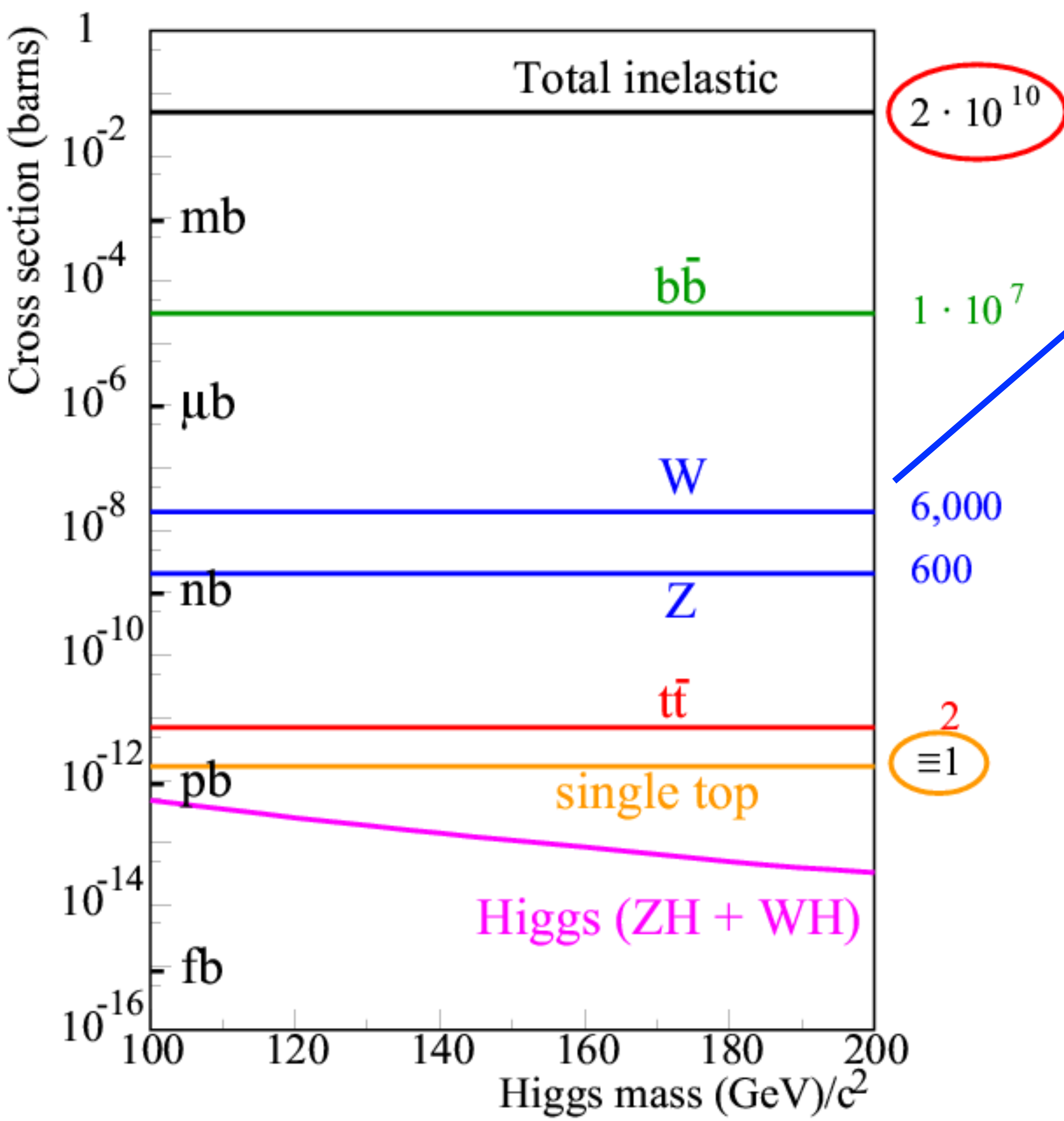
in t-channel

A challenge


Cross section (barns)
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
mb
μb
nb
pb
fb
Total inelastic
$2 \cdot 10^{10}$
$b\bar{b}$
$1 \cdot 10^{7}$
W
6,000
600
Z
$t\bar{t}$
2
single top
≡1
Higgs (ZH + WH)
100
120
140
160
180
200
Higgs mass $(GeV)/c^2$


q
$\bar{q}'$
W^+
t
ℓ
ν
b
$\bar{b}$
q'
q
W
b
g
t
ℓ
ν
b
$\bar{b}$

A challenge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Higgs mass (GeV)/c^2
$2 \cdot 10^{10}$
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600
2
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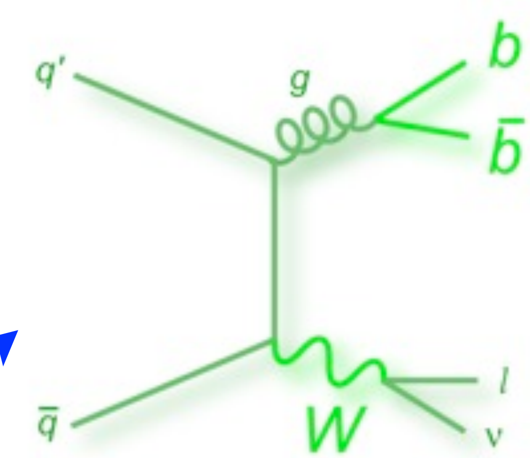
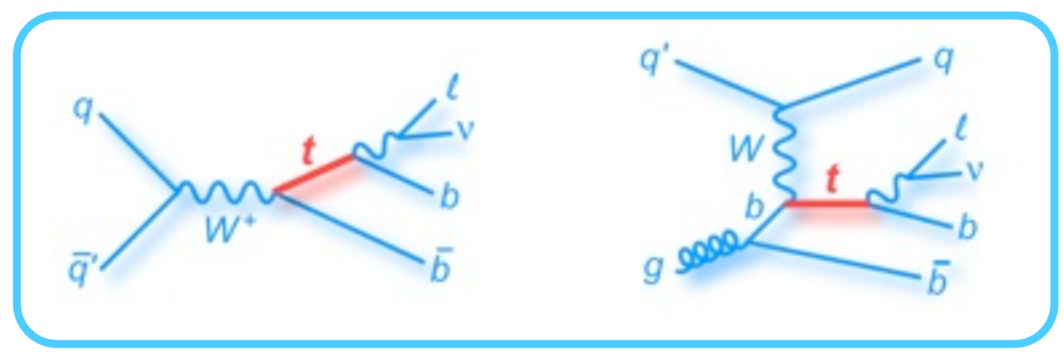

q'
g
b
$\bar{b}$
$\bar{q}$
W
l
ν


q
$\bar{q}'$
W^+
t
ℓ
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$\bar{b}$
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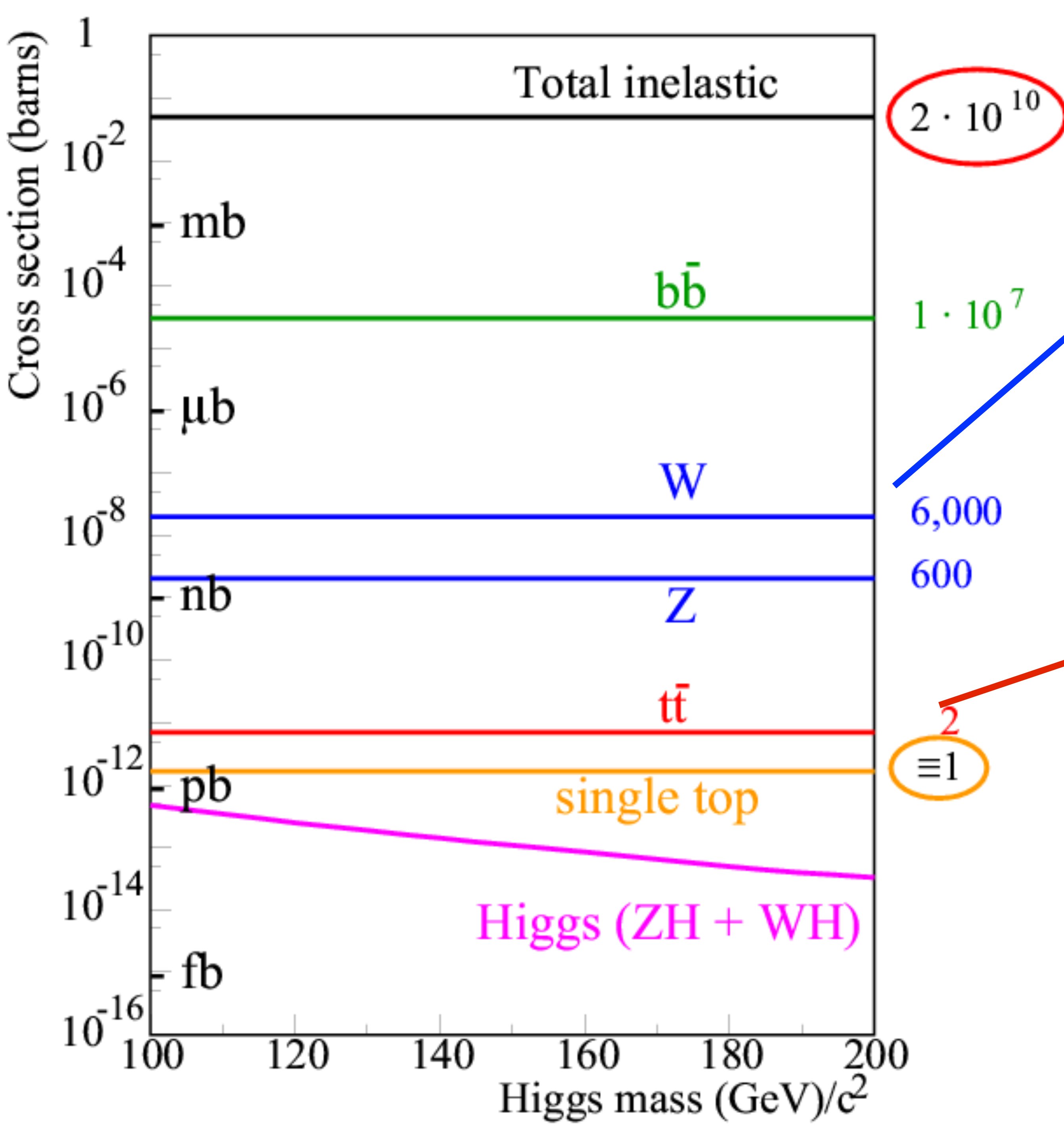
q
W
b
g
t
ℓ
ν
b
$\bar{b}$

A challenge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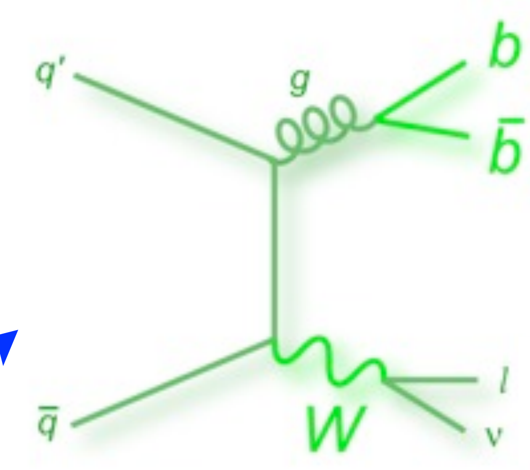
q'
g
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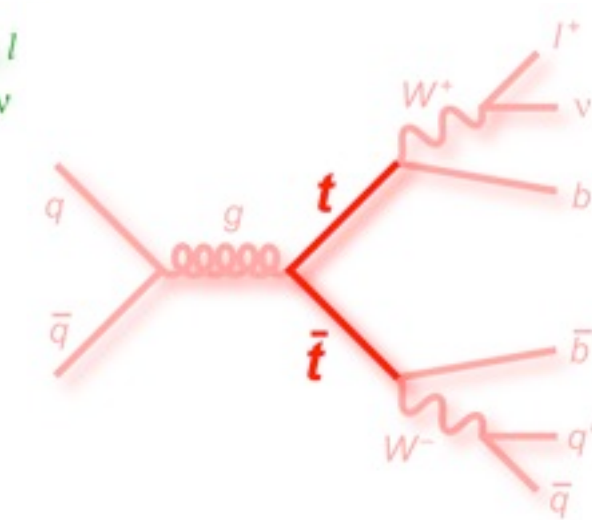
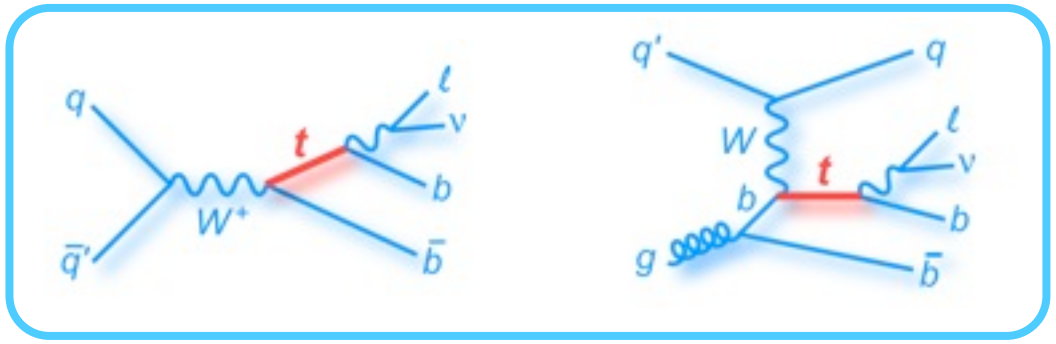
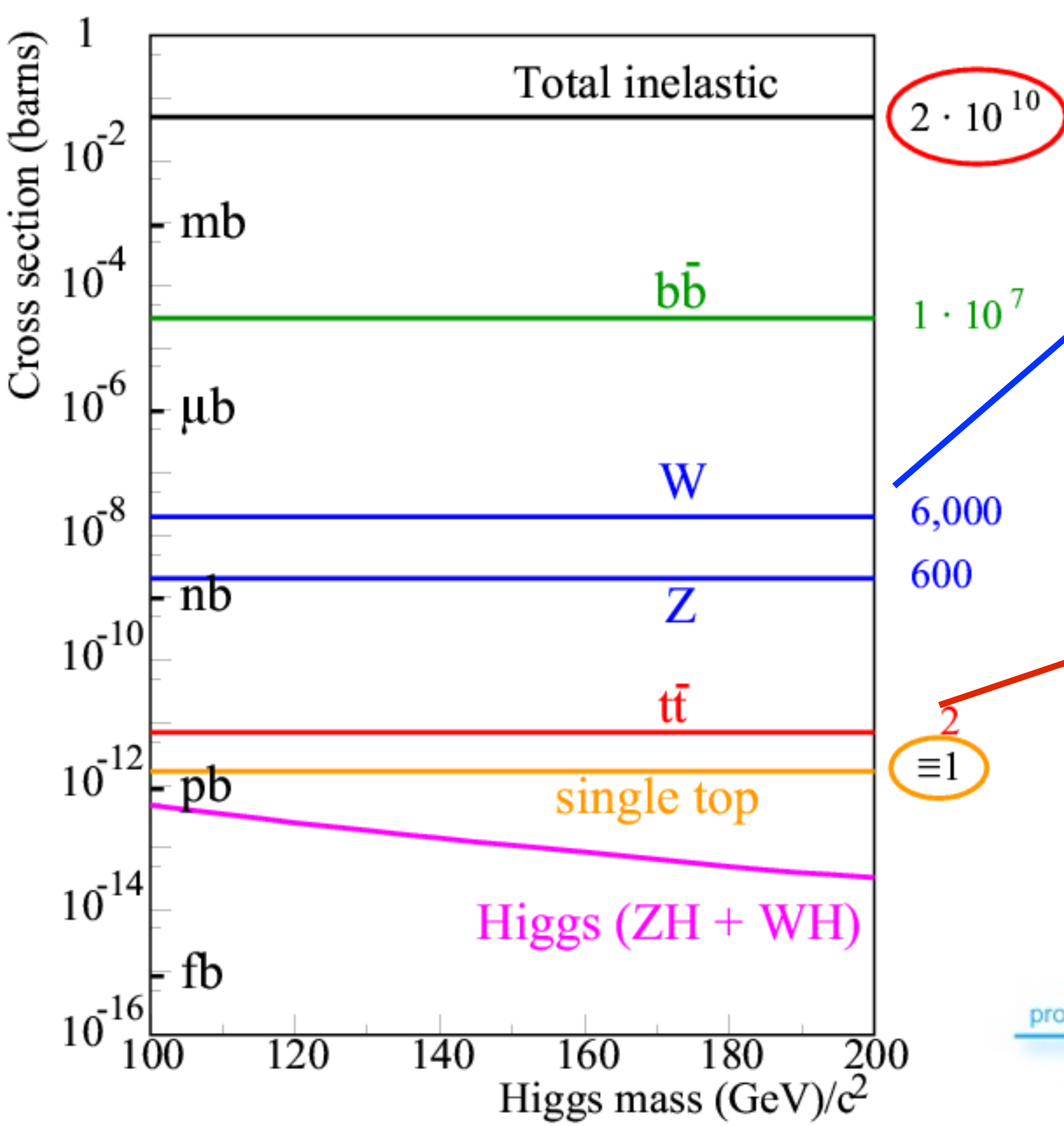
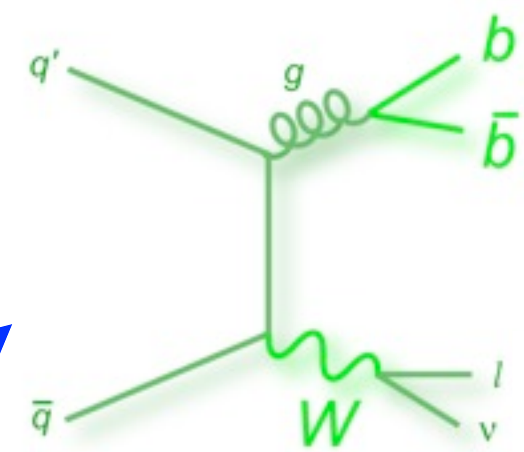
b̄
q̄
W
l
ν

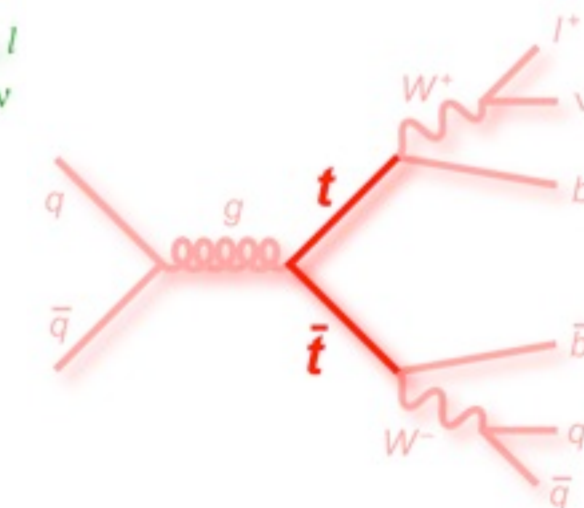

q
g
t
t̄
q̄
W⁺
W⁻
b
b̄

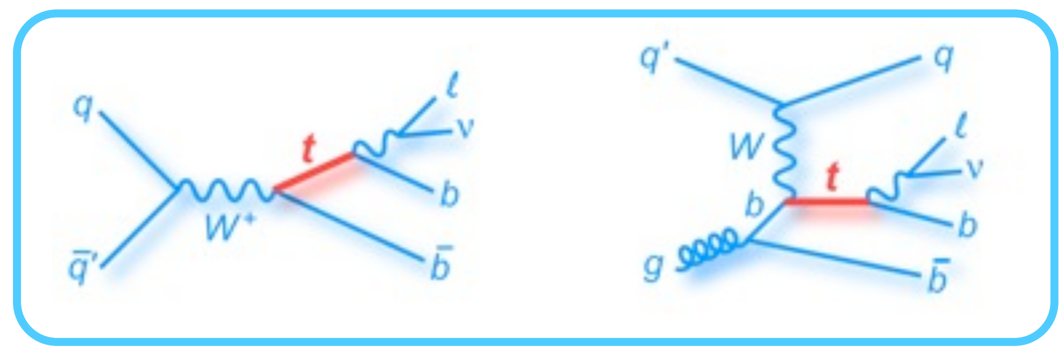

q
t
W⁺
q̄'
b
b̄
q'
W
b
g

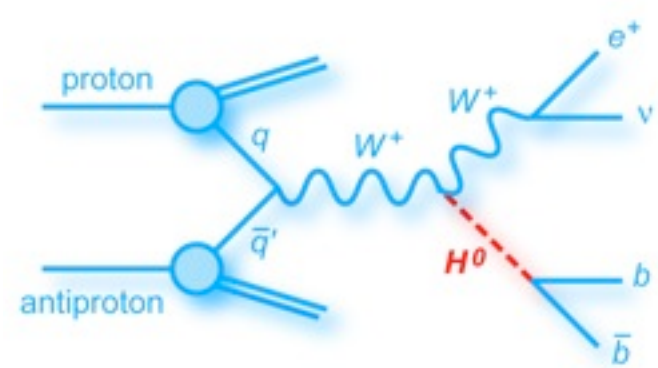
A challenge





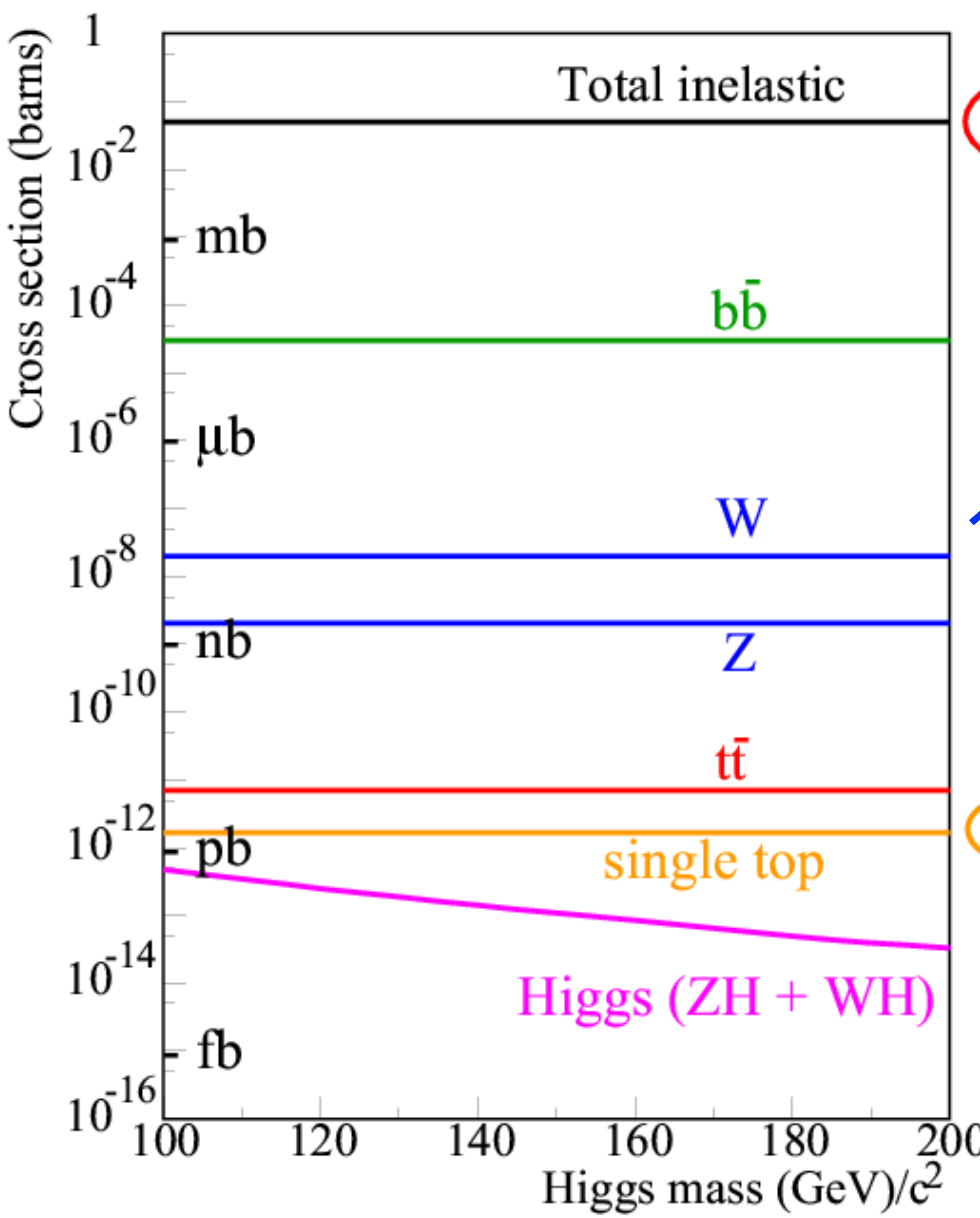






same signature as SM low mass Higgs

A challenge



$2 \cdot 10^{10}$

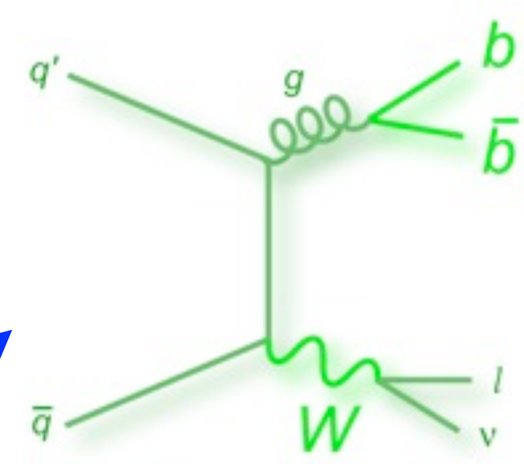
$1 \cdot 10^{7}$

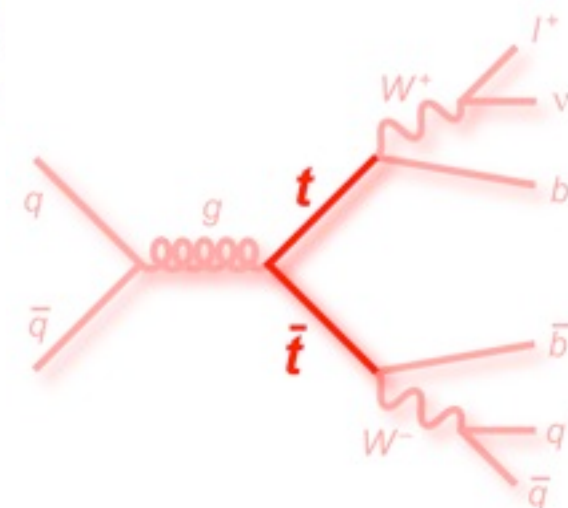
6,000

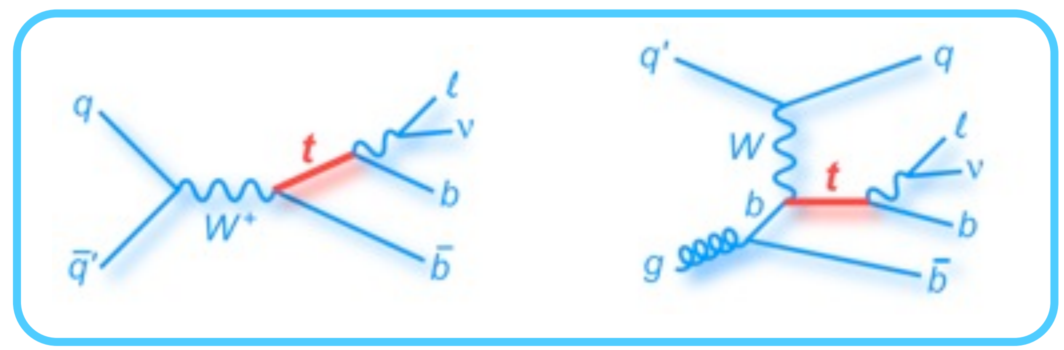
600

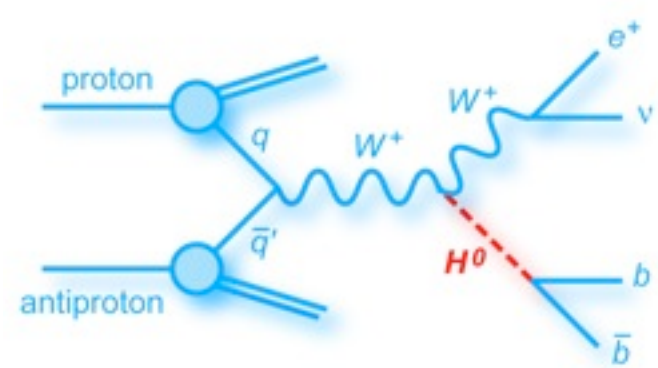
2

≡1







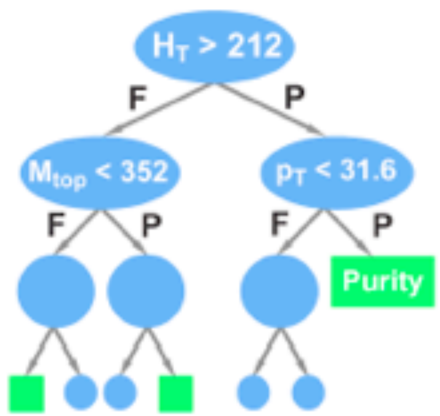


same signature as SM low mass Higgs

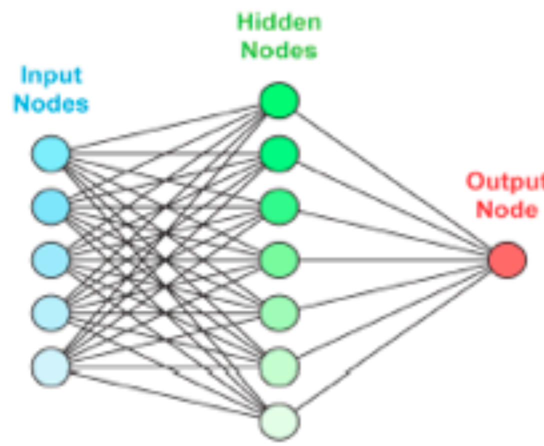
- Multivariate techniques to extract signal

Single top observation

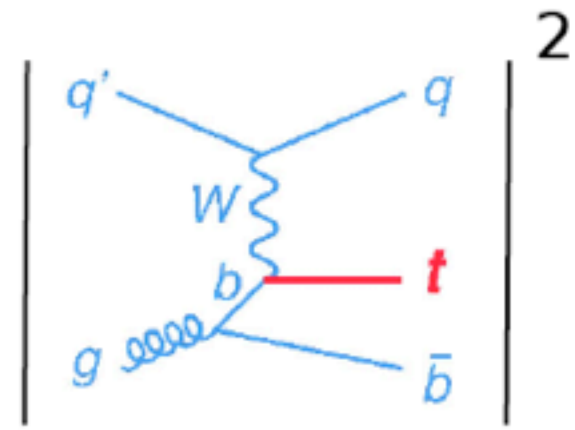
Decision Trees



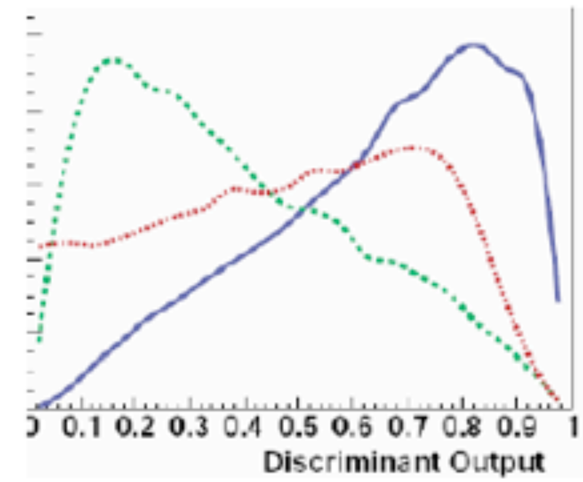
Neural Networks



Matrix Elements



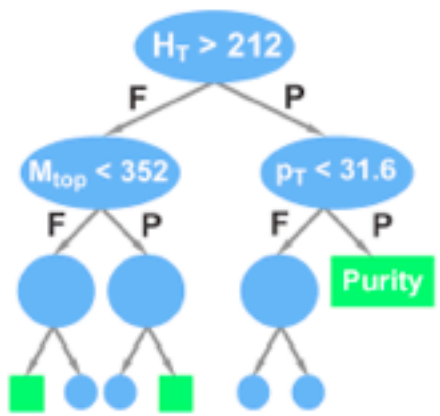
Likelihoods

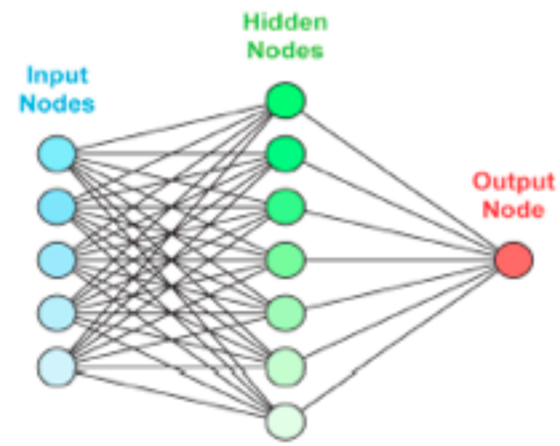


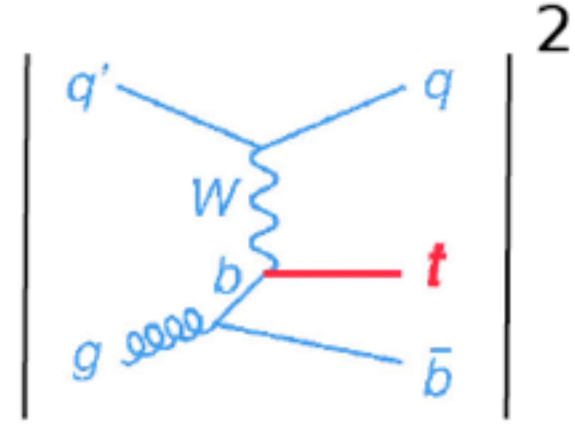
D0: PRL 103 092001 (2009)
CDF: 103, 092002 (2009)

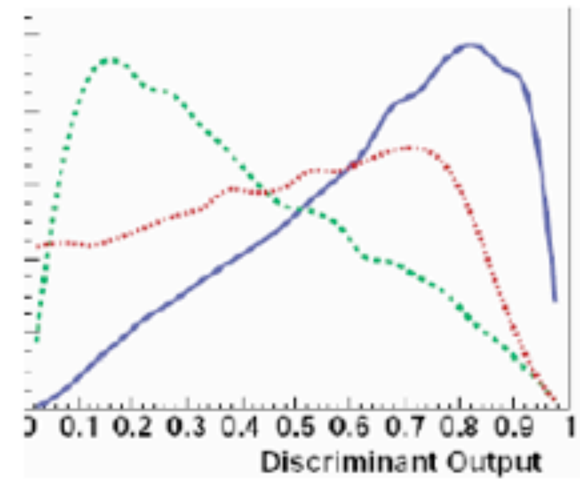
Single top observation

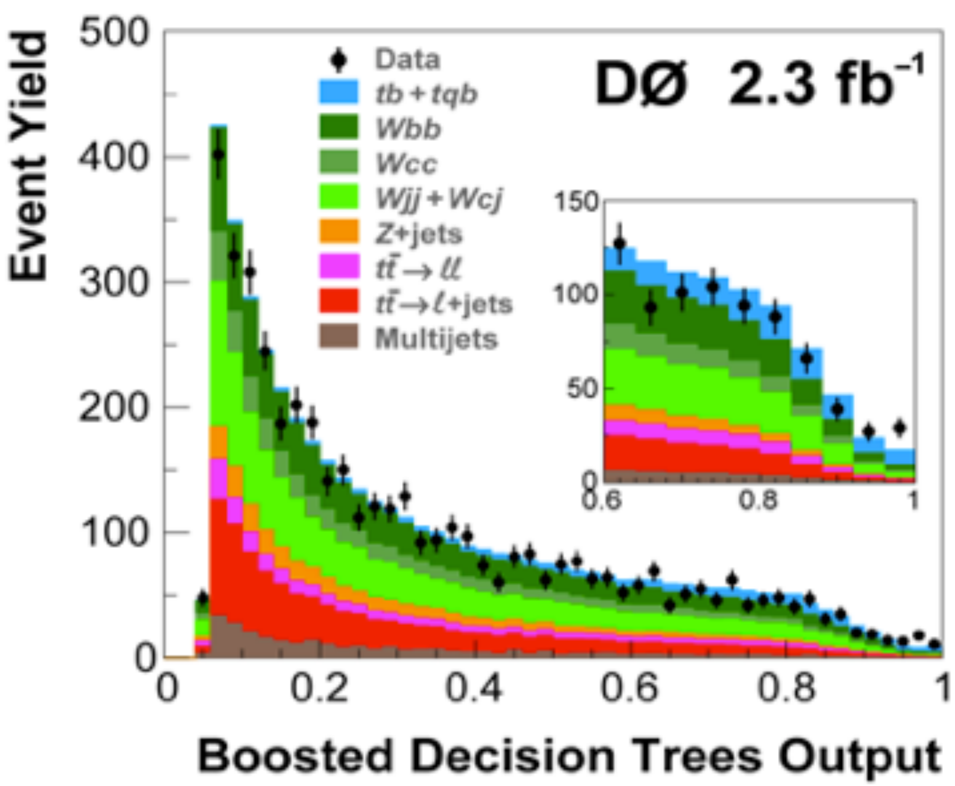
Decision Trees | Neural Networks | Matrix Elements | Likelihoods





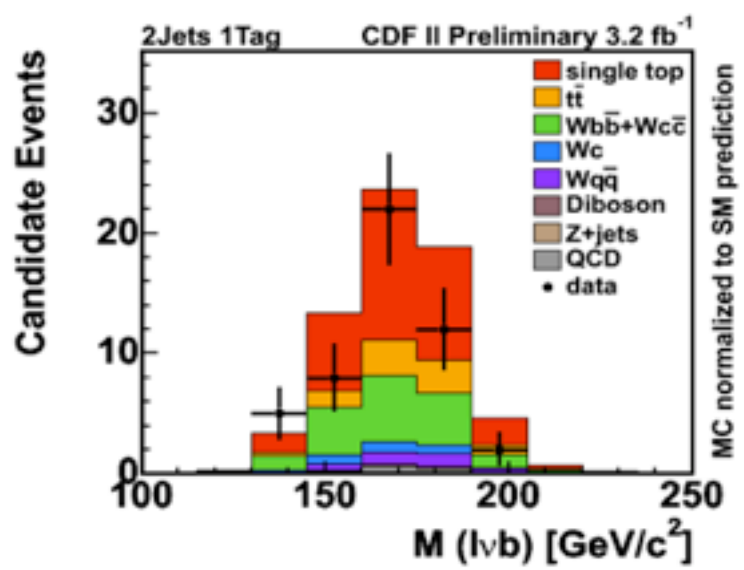


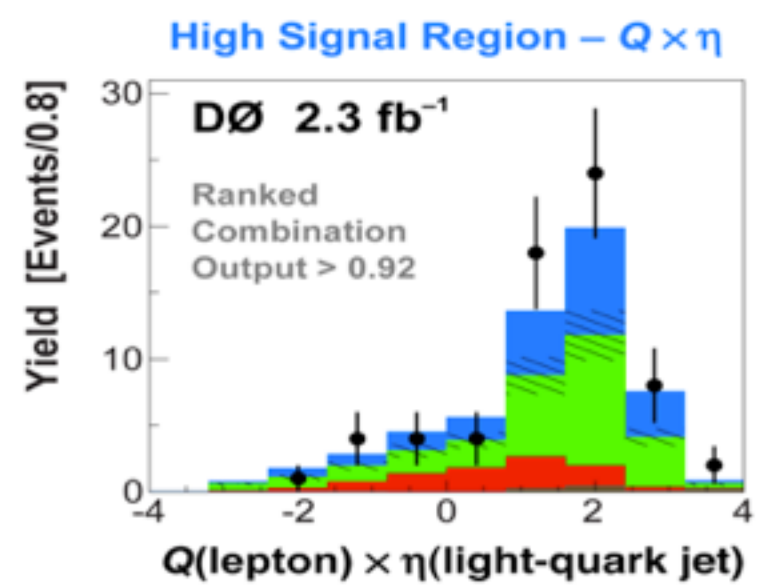




March 2009: CDF and D0 reported 5σ observation

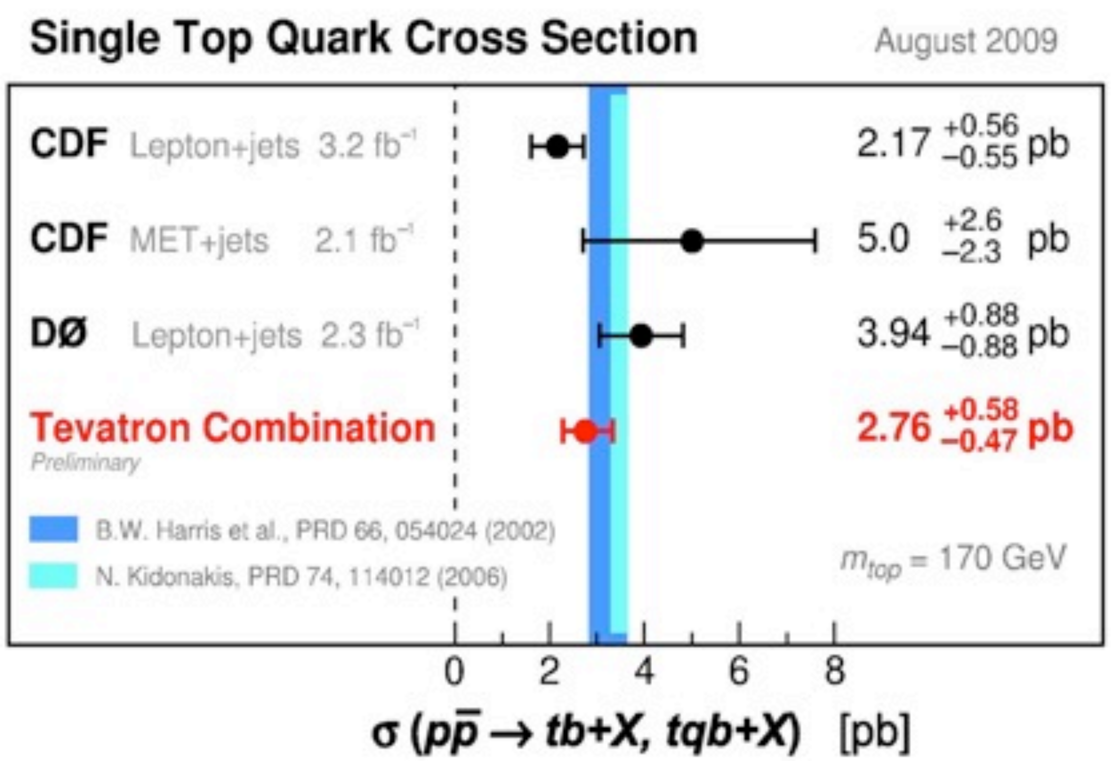
Combination of many channels and analyses





D0: PRL 103 092001 (2009)
CDF: 103, 092002 (2009)

After the discovery



CDF-D0 combination (3.2 fb^{-1})

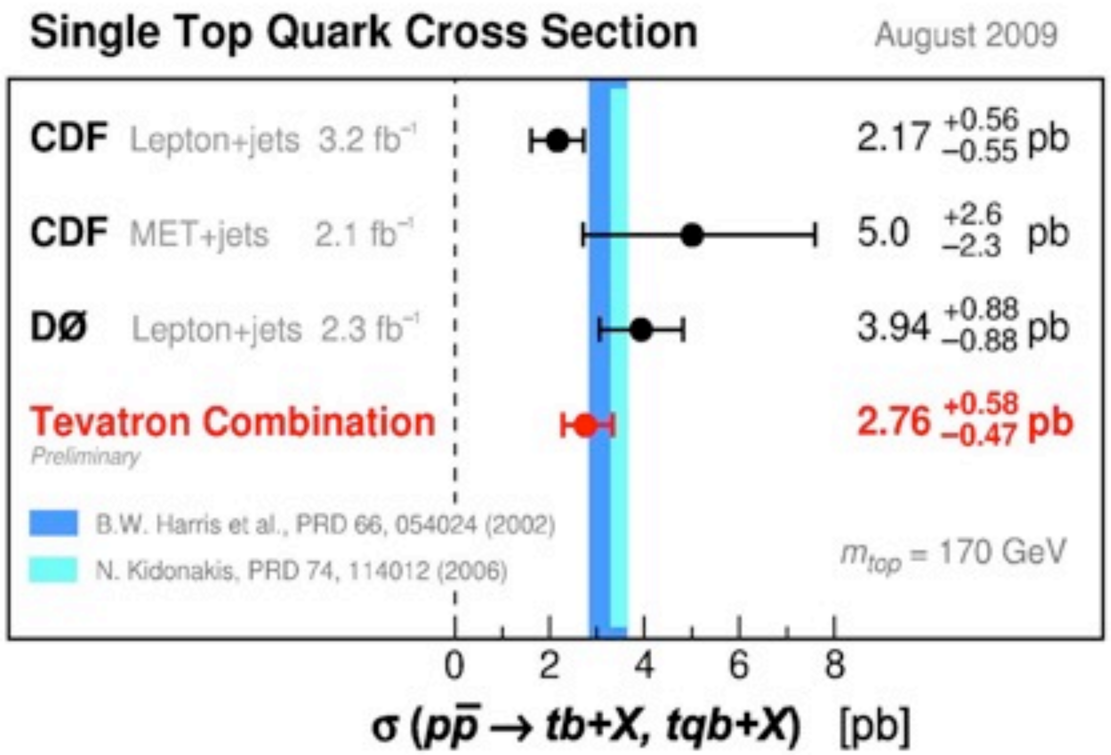
$$\sigma = 2.76^{+0.58}_{-0.47}(\text{stat} + \text{syst})\text{pb}$$

$|V_{tb}|$=0.91±0.08 (stat+syst)

arXiv:0908.2171v1 [hep-ex]

13% improvement

After the discovery



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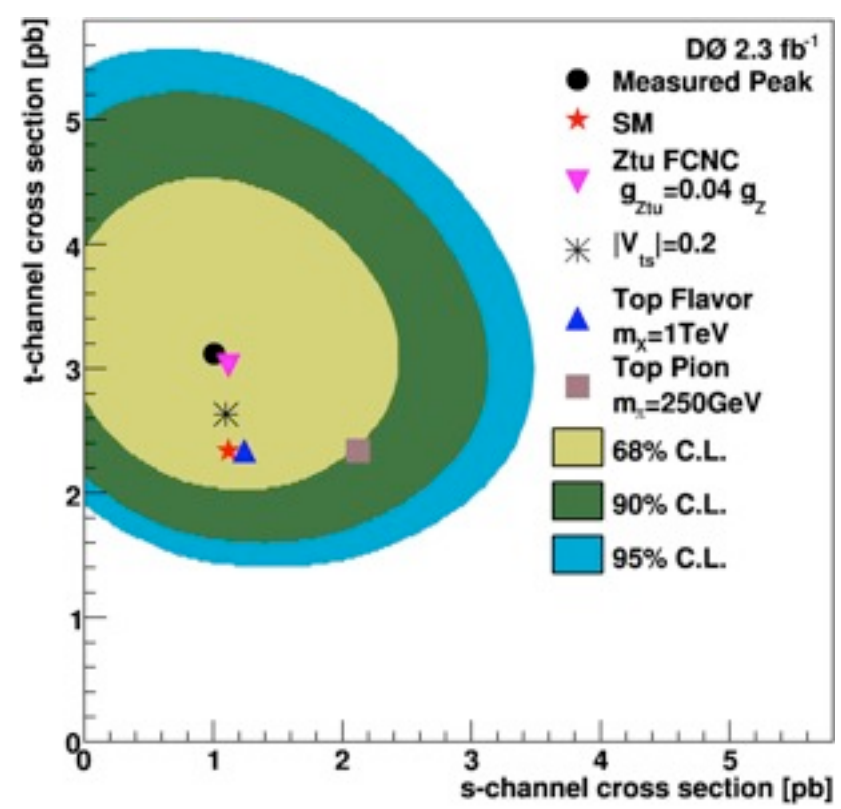
arXiv:0908.2171v1 [hep-ex]

13% improvement

- First evidence of t-channel single top production
  - drop assumption of SM s/t ratio
  - train discriminant for t-channel
  - measure s and t simultaneously



$$\sigma_{t-ch} = 3.14^{+0.94}_{-0.81}(\text{stat}+\text{syst})\text{pb}$$

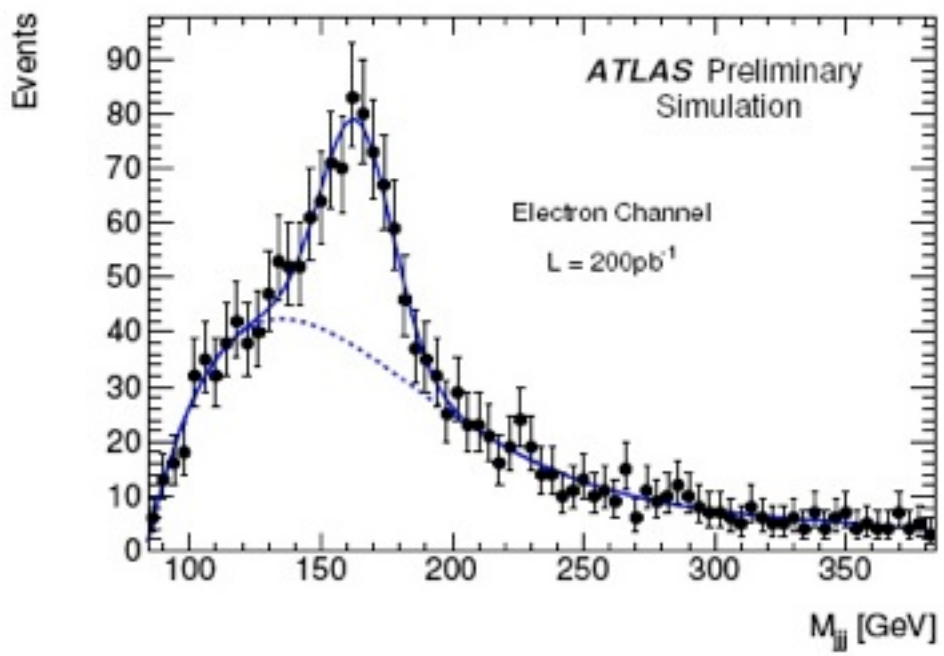
PLB 683 363 (2010)

4.8 σ evidence

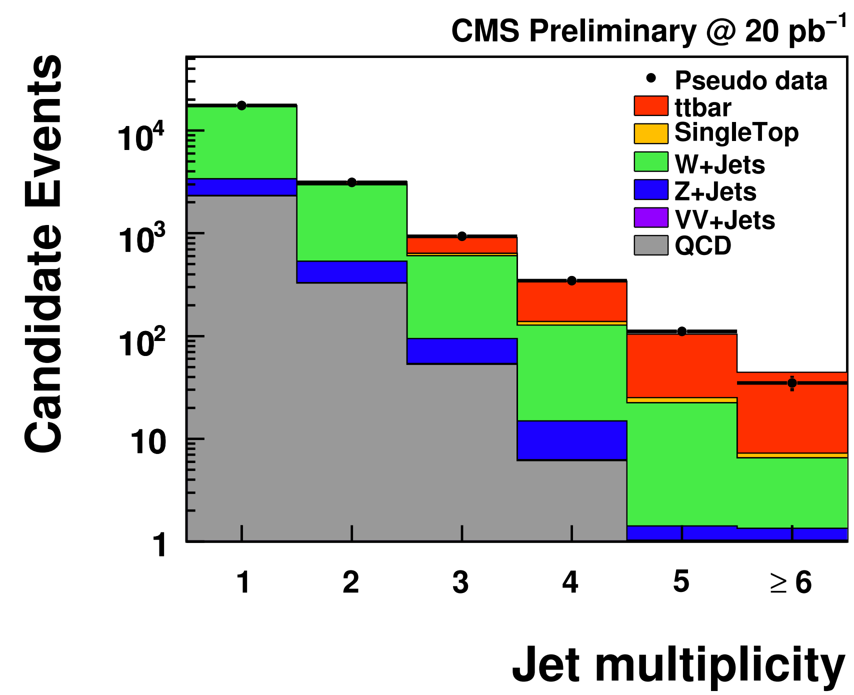
Top rediscovery at LHC

- Primary short term goal - establish top quark signal
- Rediscovery is possible with ~10 pb^{-1}
- Major milestone for detectors
  - trigger, lepton identification, jet and E_T^{miss} calibration

expect 60 $t\bar{t}$ events per lepton flavor per experiment in l+jets channel, ≥4 jets
background ~40 events



Equivalent to 50 pb^{-1} at 7 TeV →

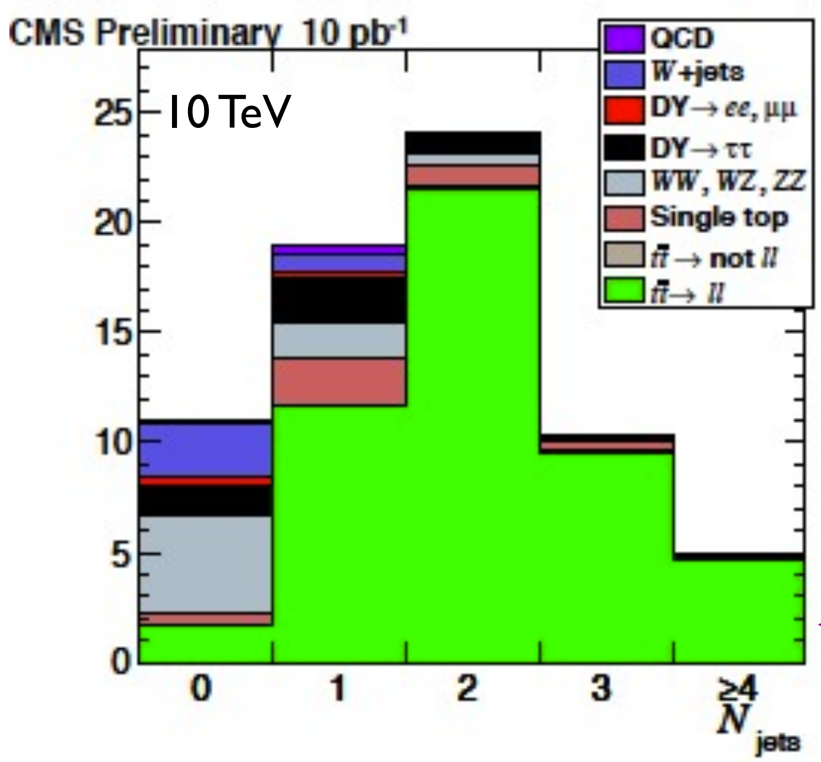


- General strategy:
  - simple analysis - cut and count
  - template fit of hadronic top mass
  - no b-tagging

Reference: at Tevatron 230 pb^{-1} $\Delta\sigma/\sigma$(b-tagged, l+jets) - 20%

Dilepton channel and single top

- Signal in dilepton channel can be established with ~5 pb^{-1} of data - 15 events over background of 3



Expected 10 pb^{-1} sensitivity (per experiment)

Channel	N(Signal)	N(background)
e - μ	14	2.5
e - e	4.3	1.1
μ - μ	6.6	1.9
Total	25	5.5

ATL-PHYS-PUB-2009-086 + scaling to 10 pb^{-1} @ 7 TeV.

P. Ferrari, talk at Top 2010

$\Delta\sigma/\sigma$=15%(stat)±10%(syst)±10%(lumi)

- Single top will be challenging

at 7 TeV
3σ excess with ~500 pb^{-1}
5σ with ~1 fb^{-1}

Atlas

@10 TeV,200 pb^{-1}	Cut based	Likel.
S	118	112
B	185	127
S/B	0.64	0.89

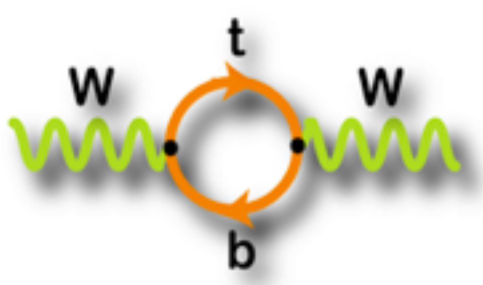
Talk by P. Pardo

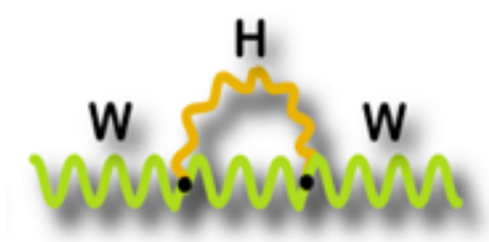
Top quark properties

mass
width
forward-backward asymmetry
spin correlation

Top quark mass

- Free parameter of the SM
- Together with W mass constrains SM Higgs mass
- Provides guideline for SM Higgs searches
- Constraint on Higgs mass can point to physics beyond the SM





$\Delta r_t \sim m_t^2$ $\Delta r_{Higgs} \sim \ln(m_H^2)$

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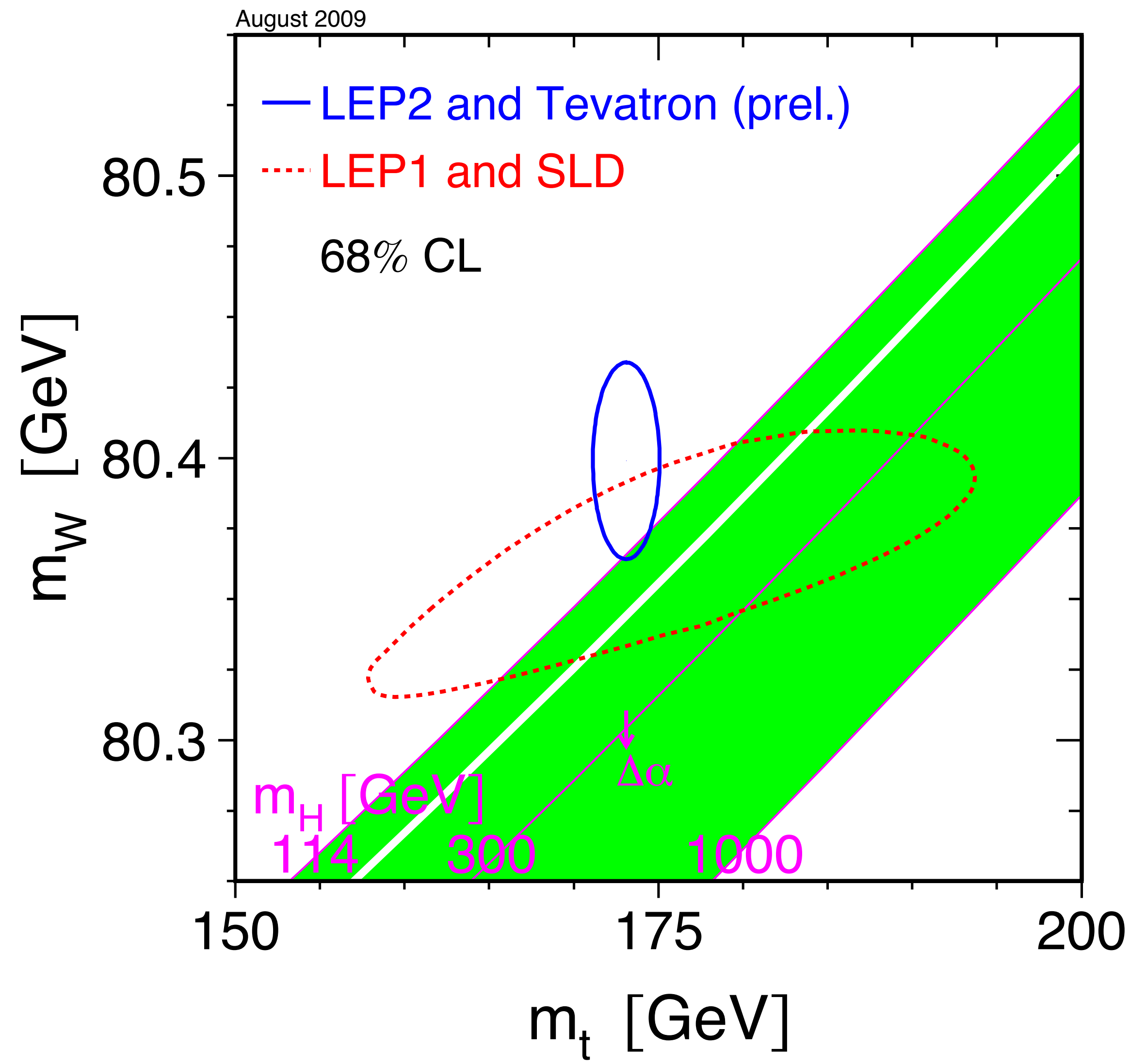

1 GeV change of m_{top} leads to ~10 GeV change of m_{Higgs}

Top quark mass

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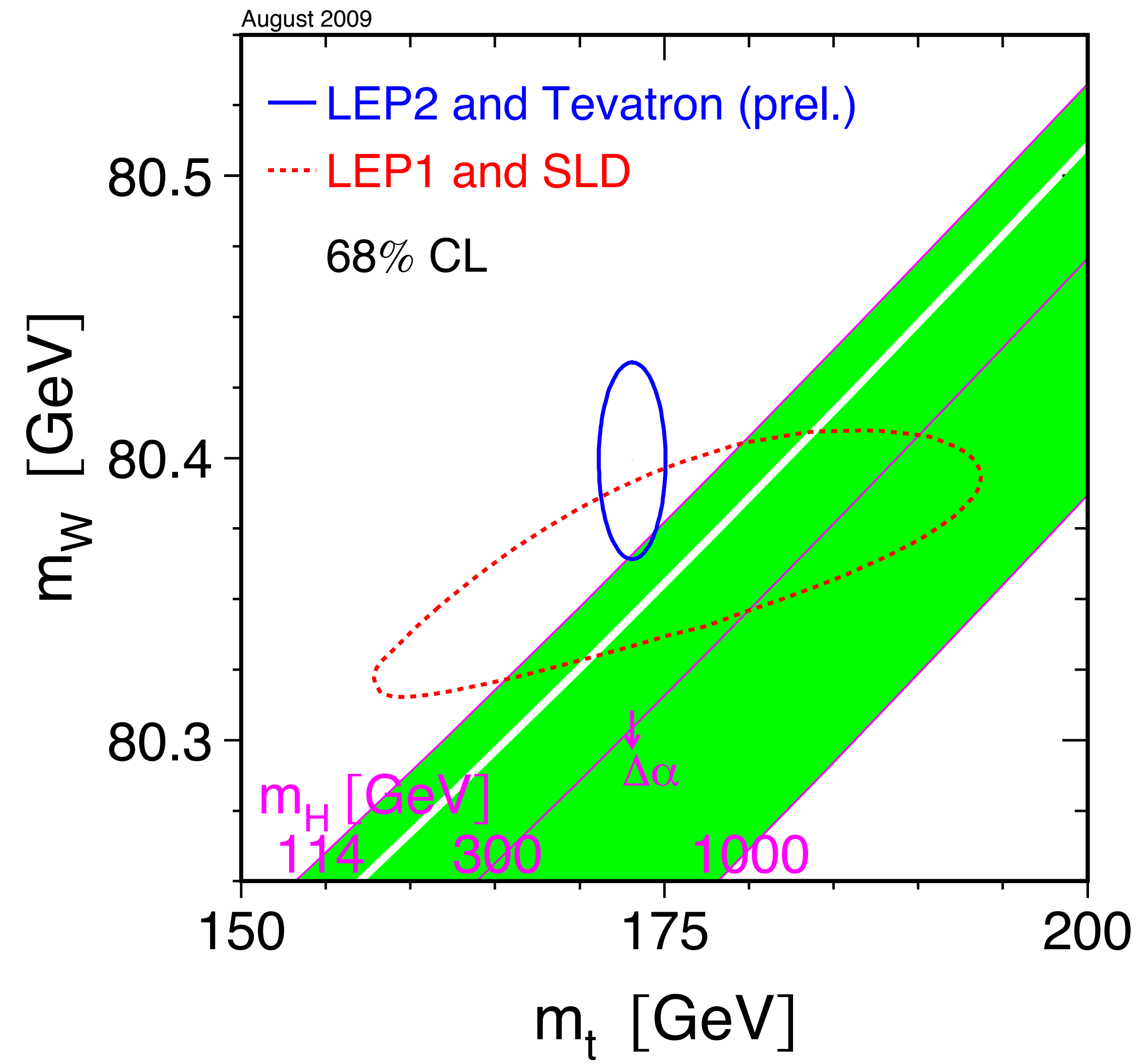
- Constraint on Higgs mass can point to physics beyond the SM

$\Delta r_t \sim m_t^2$ $\Delta r_{Higgs} \sim \ln(m_H^2)$

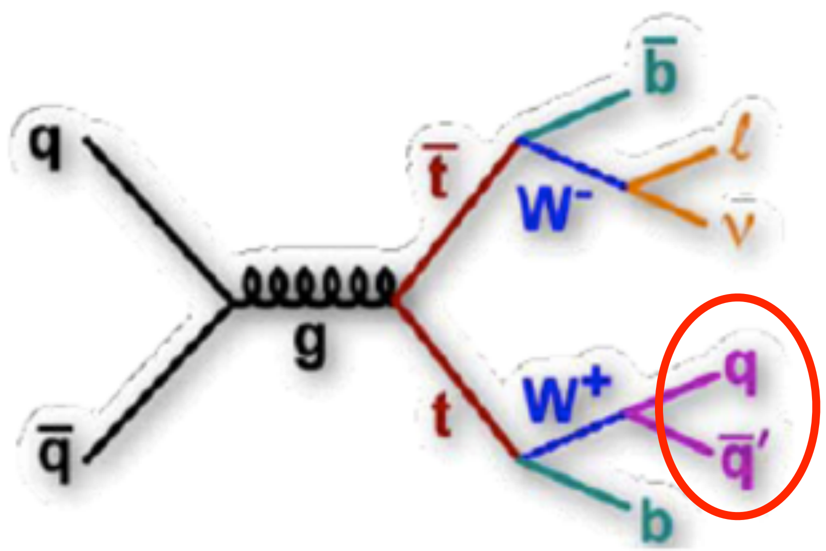


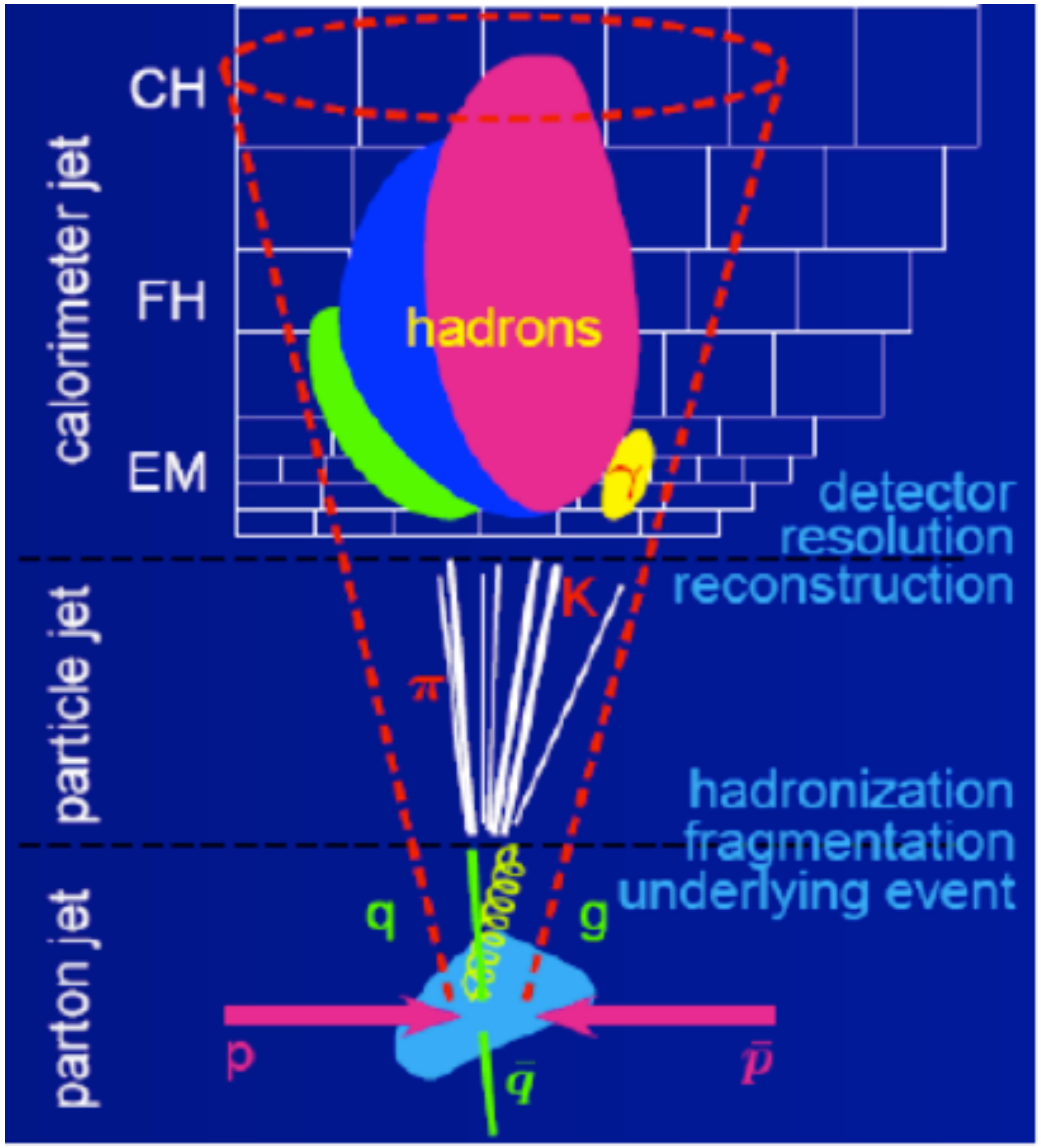
1 GeV change of m_{top} leads to ~10 GeV change of m_{Higgs}

The most precisely known top quark property

Experimental challenges

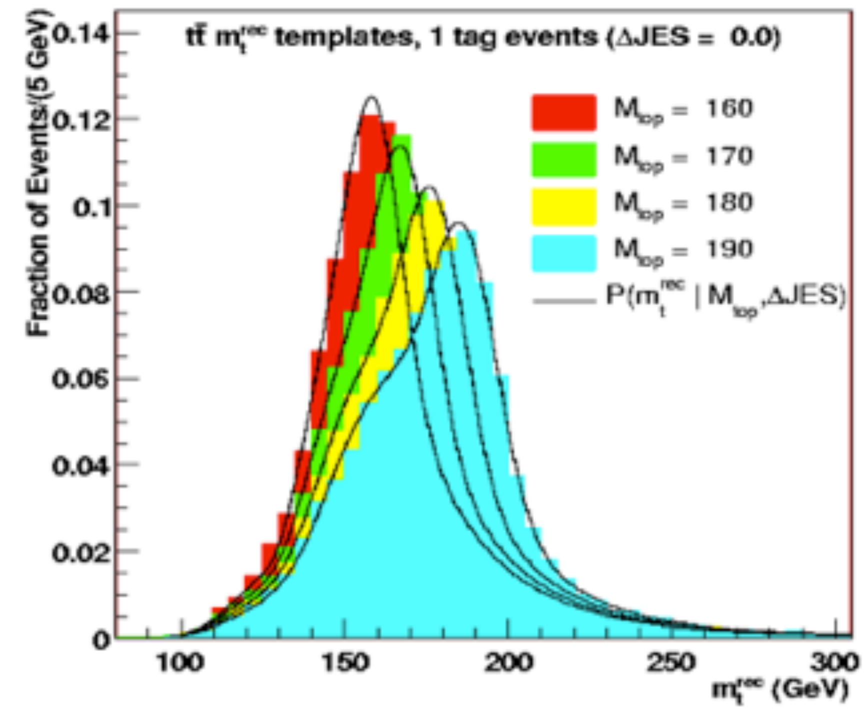
- only jets can be measured
- clean mapping between reconstructed objects and partons
- jet energy scale calibration to particle level
  - dominating uncertainty
- in-situ calibration using hadronic W mass



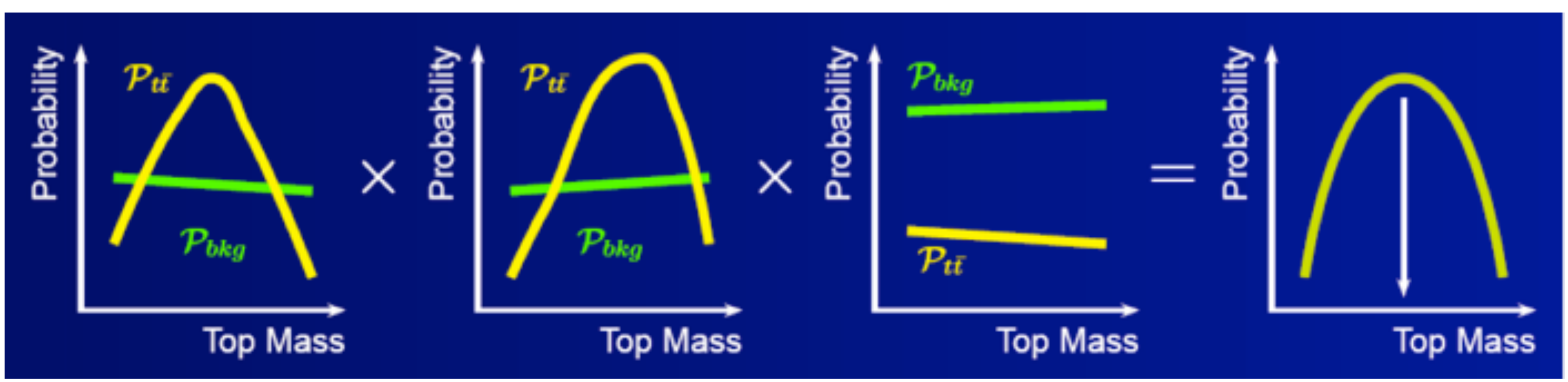


Jet scale used to be severely limiting factor for top physics

Mass extraction methods



- Template method
  - Choose variable strongly correlated with the top mass
  - Compare data to MC with different mass hypothesis
- Matrix element method
  - Calculate probability for event to be signal or background as a function of top mass
  - Multiply event probabilities to extract the most likely mass



Maximizes statistical power by using full event information

lepton+jets channel

Top mass and JES extracted simultaneously from maximum likelihood fit to data

DØ 3.6 fb^{-1}

m_{top}=173.7±0.8(stat)±1.6(syst) GeV

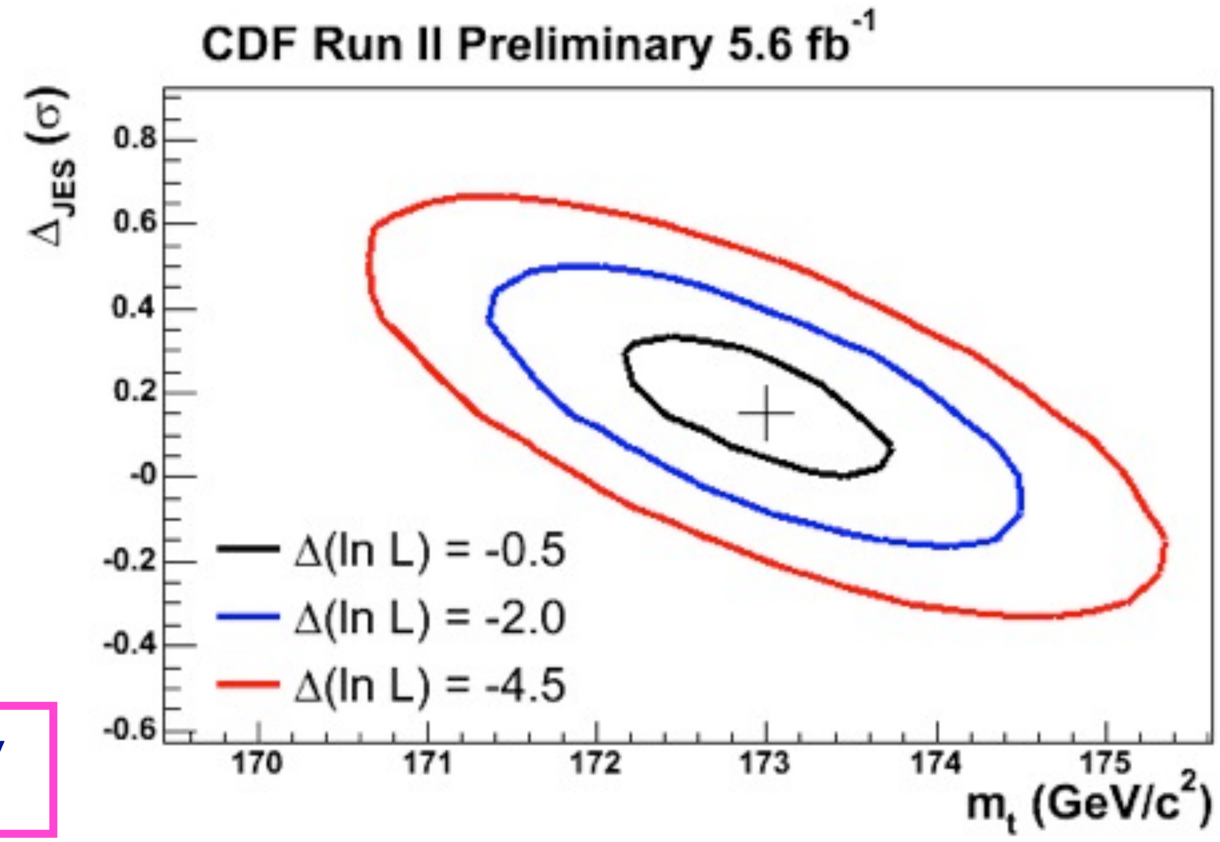
±1%

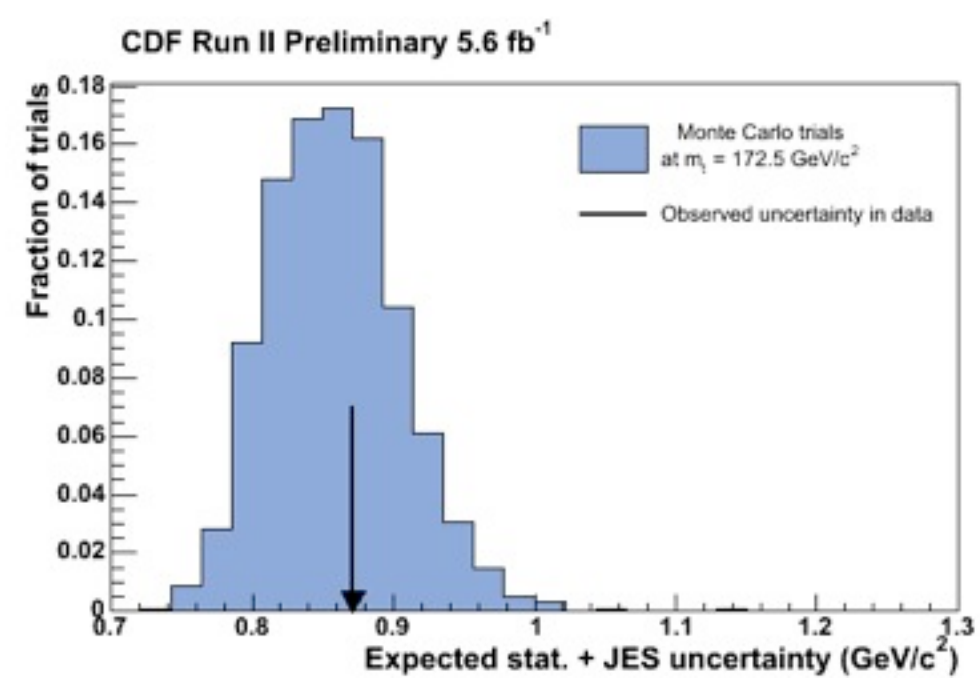
CDF 5.6 fb^{-1}

$\Delta_{JES} = 0.15 \pm 0.18\ \sigma$

m_{top}=173.0±0.7(stat)±1.1(syst) GeV ±1.2(total) GeV

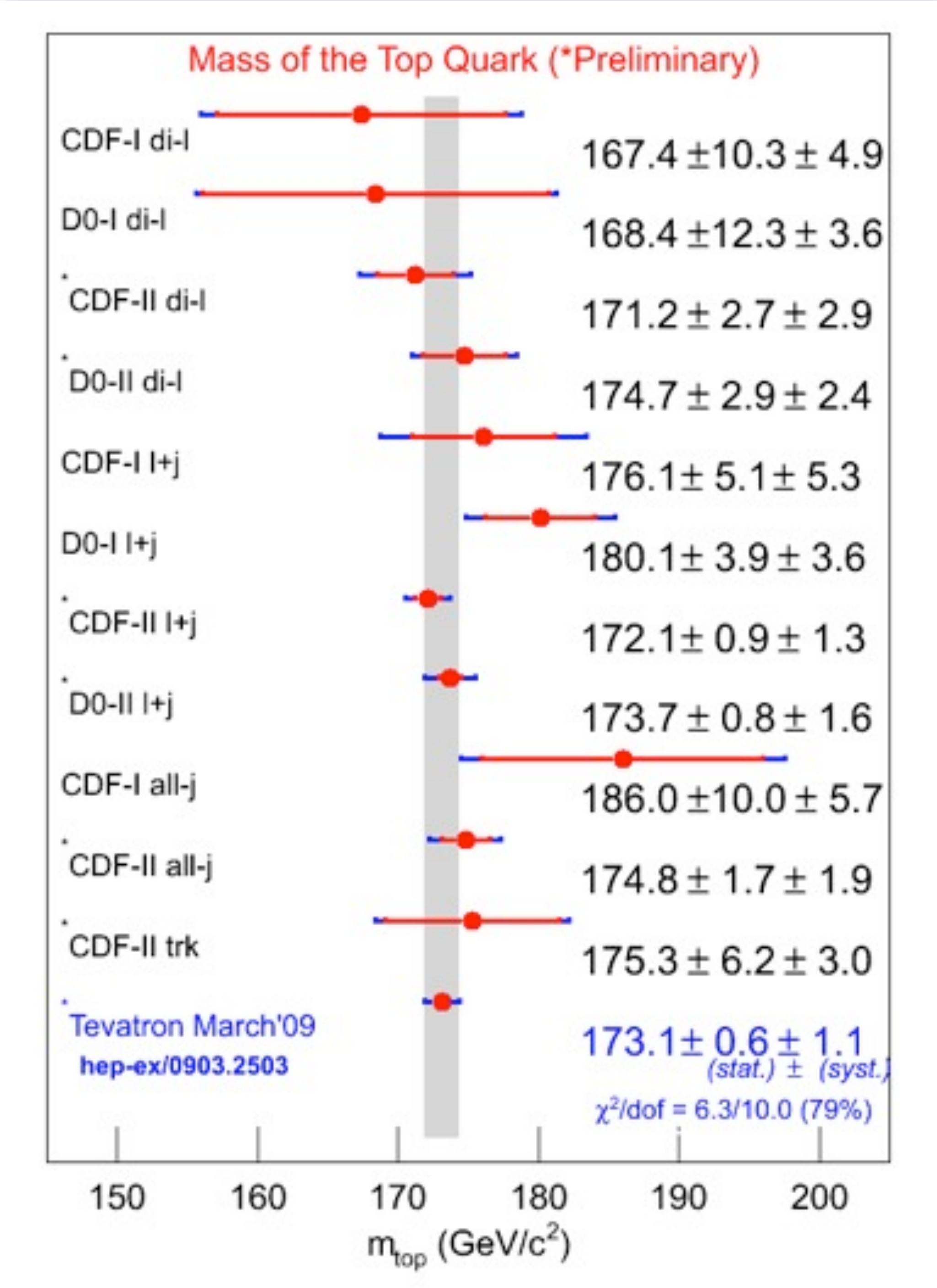
the most precise single measurement: ±0.7%





~1,000 top events with ≥1 b-tag

Tevatron mass combination



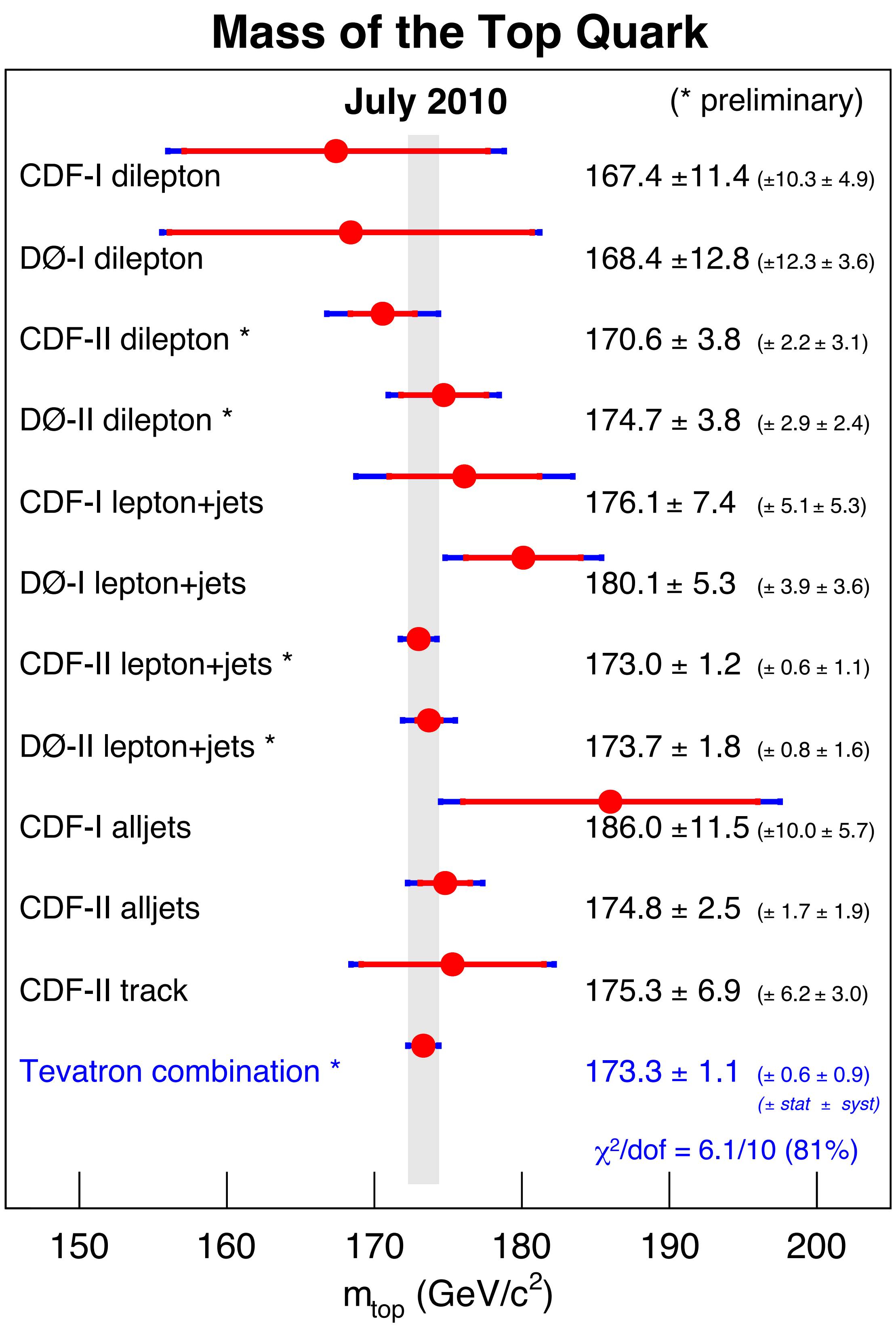
March 2009

- does not include the latest CDF result
- to be updated for ICHEP

m_{top}=173.1±1.3(total) GeV

- Improved understanding of systematics
- Measurement in different channels consistent with each other
- Different methods produce consistent results

Tevatron mass combination



~~March 2009~~

- ~~does not include the latest CDF result~~
- ~~to be updated for ICHEP~~

new

July 2010

m_{top}=173.3±1.1(total) GeV

0.6% relative uncertainty

- Improved understanding of systematics
- Measurement in different channels consistent with each other
- Different methods produce consistent results

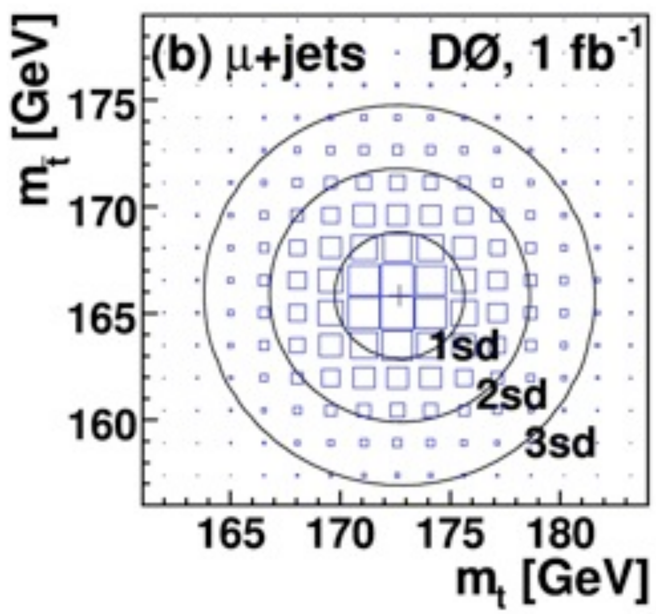
Probing CPT

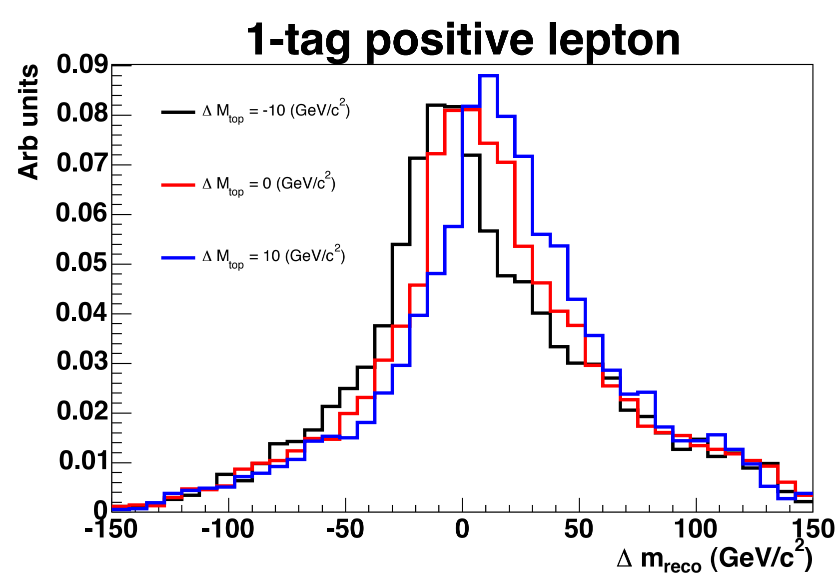
Is top quark mass equal to anti-top quark mass?

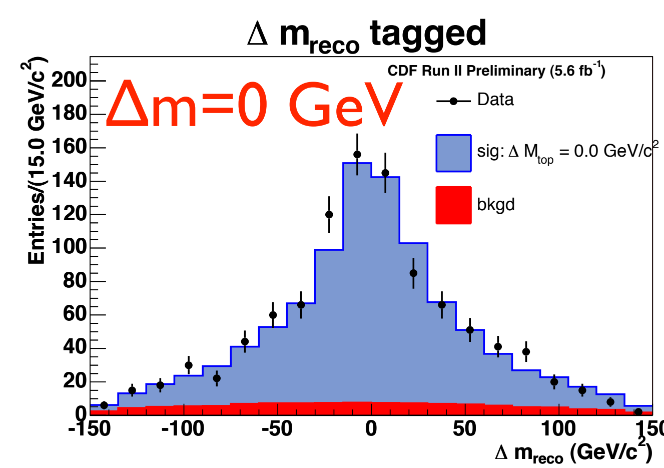
Drop assumption $m_t = m_{\bar{t}}$ in top mass measurement

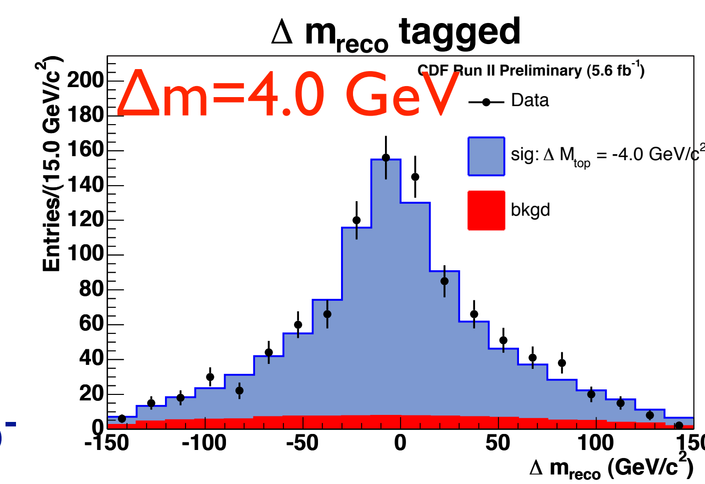
- Extension of ME mass analysis
- m_t, JES $\rightarrow$ m_t, $m_{\bar{t}}$

- Template method
- variables: Δm_{reco} and $\Delta m_{reco(2)}$









ΔM_{top} = 3.8 +/- 3.7 GeV/c²

PRL 103, 132001 (2009)

5.6 fb⁻

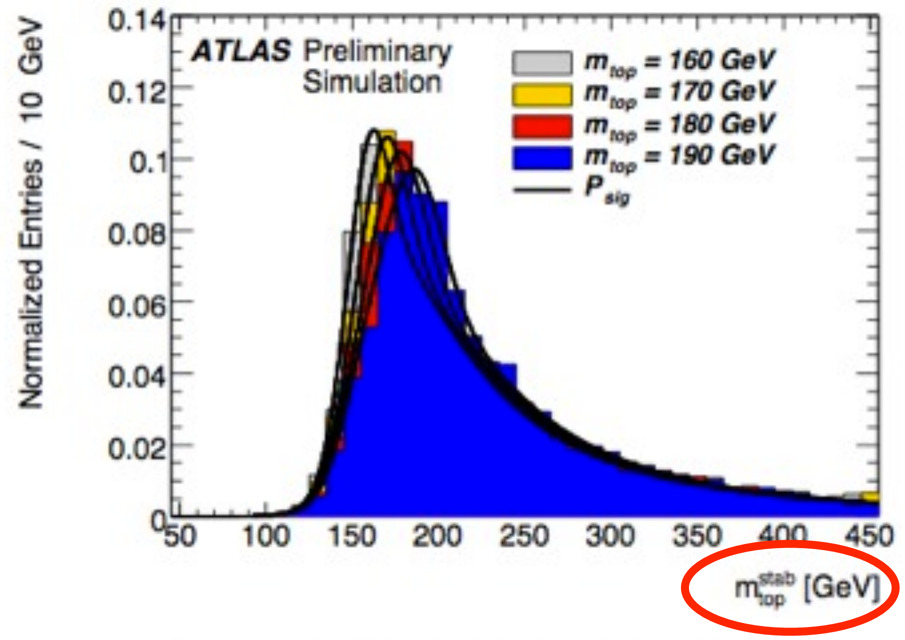
ΔM_{top} = -3.3 +/- 1.4(stat.) +/- 1.0 (syst.) GeV/c²

Top mass prospects at LHC

- Tevatron measurement dominated by systematics
- Time is needed to achieve similar precision at LHC

First measurements: template method

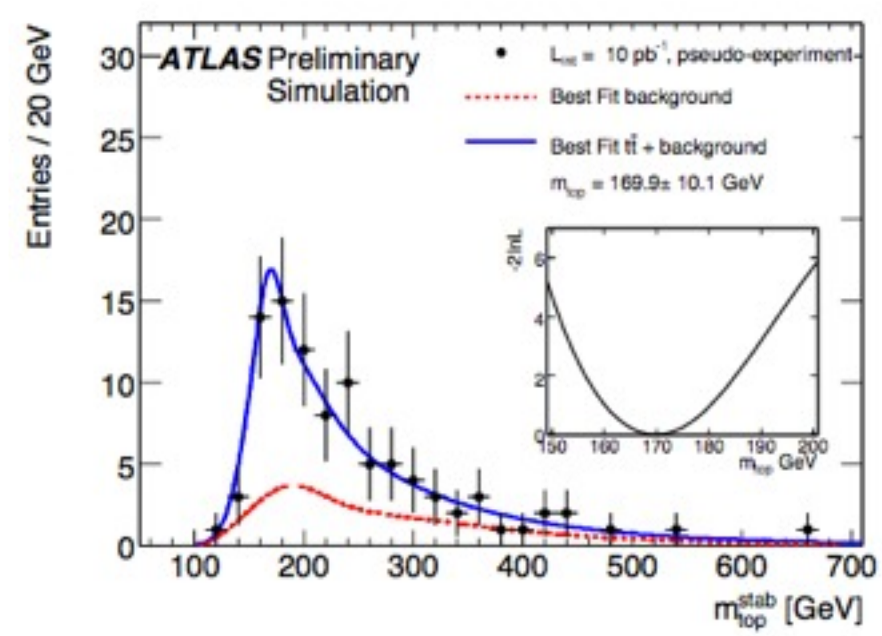
- 1D for ~100 pb^{-1}: stabilized top mass,
  $\Delta m/m$ = 2 GeV (stat) ±3.8 GeV (syst)
- 2D for ~1 fb^{-1}: b-tagged events, m_t and JES
  $\Delta m/m$ = 0.6 GeV (stat) ±2.0 GeV (syst)



$$m_{top}^{stab} \equiv \frac{m_{top}^{reco}}{m_W^{reco}} \cdot m_W^{PDG}$$

10 TeV

Statistical uncertainty [GeV] as a function of $\mathscr{L}_{int}$			
	10 pb^{-1}	30 pb^{-1}	100 pb^{-1}
Electron channel	10.8 ± 3.5	7.0 ± 2.1	2.7 ± 1.3
Muon channel	9.9 ± 3.9	5.8 ± 1.5	2.8 ± 0.8



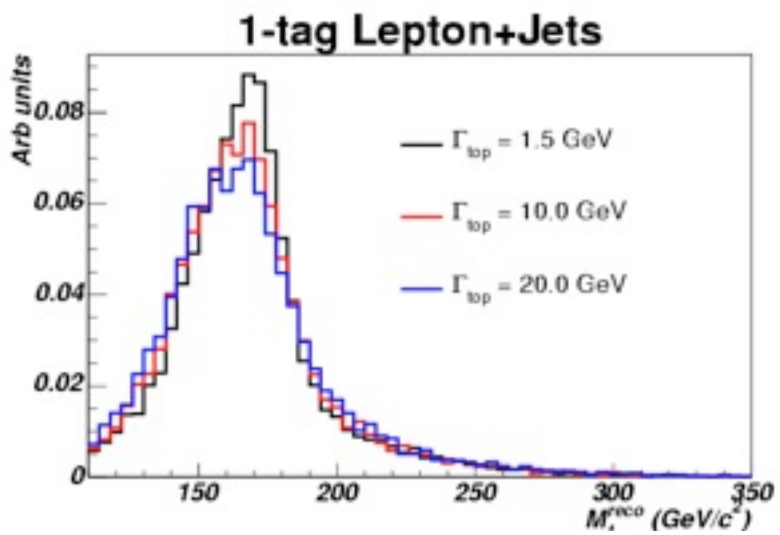
Talk by J.Parsons

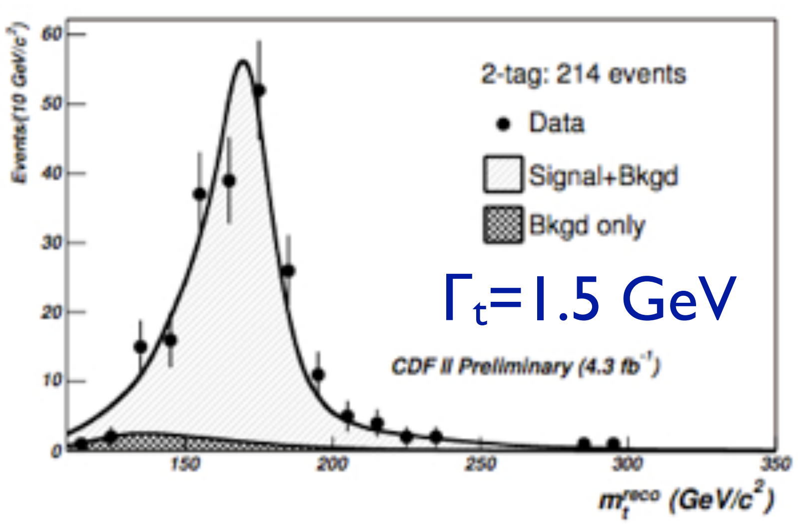
Top quark width

SM: Γ_t~1.5 GeV at NLO for m_t=172.5 GeV

Additional decay modes: $t \to H^+b$, $t \to dW^+$, $t \to sW^+$?

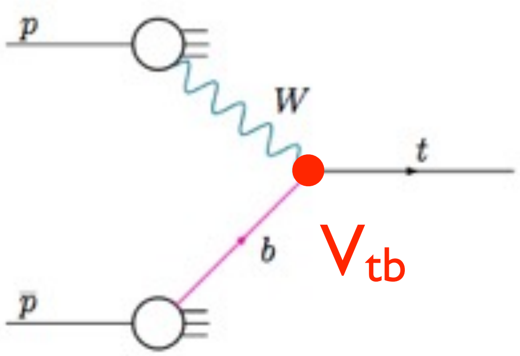
- Direct measurement: build templates in Γ_t
- reconstruct m_{reco} and m_W





$\Gamma_t < 7.5$ GeV at 95% C.L.

- Indirect measurement
- use single top t-channel cross section
- combine with measured branching ratio
- assumption: coupling in top production and decay is the same



$$\Gamma(t \to bW) = \sigma(t-ch)\frac{\Gamma(t \to bW)_{SM}}{\sigma(t-ch)_{SM}}$$

$$\Gamma_t = \frac{\Gamma(t \to bW)}{\mathcal{B}(t \to bW)} \leftarrow$$

Phys. Rev. Lett. 100, 192003 (2008)

$$\Gamma_t = (1.99^{+0.69}_{-0.55})GeV, \ \tau_t = (3.2^{+1.3}_{-0.9}) \times 10^{-25}s$$

new

Forward-backward asymmetry

- LO: top quark production angle is symmetric with respect to beam direction
- NLO: asymmetry due to interference effects
- At Tevatron charge asymmetry = forward-backward asymmetry

l+jets events, $p\bar{p}$ rest frame

$$A_{fb} = \frac{N(-Q \times Y_{had} > 0) - N(-Q \times Y_{had} < 0)}{N(-Q \times Y_{had} > 0) + N(-Q \times Y_{had} < 0)}$$

Q - lepton charge, Y_{had} - rapidity of hadronic top

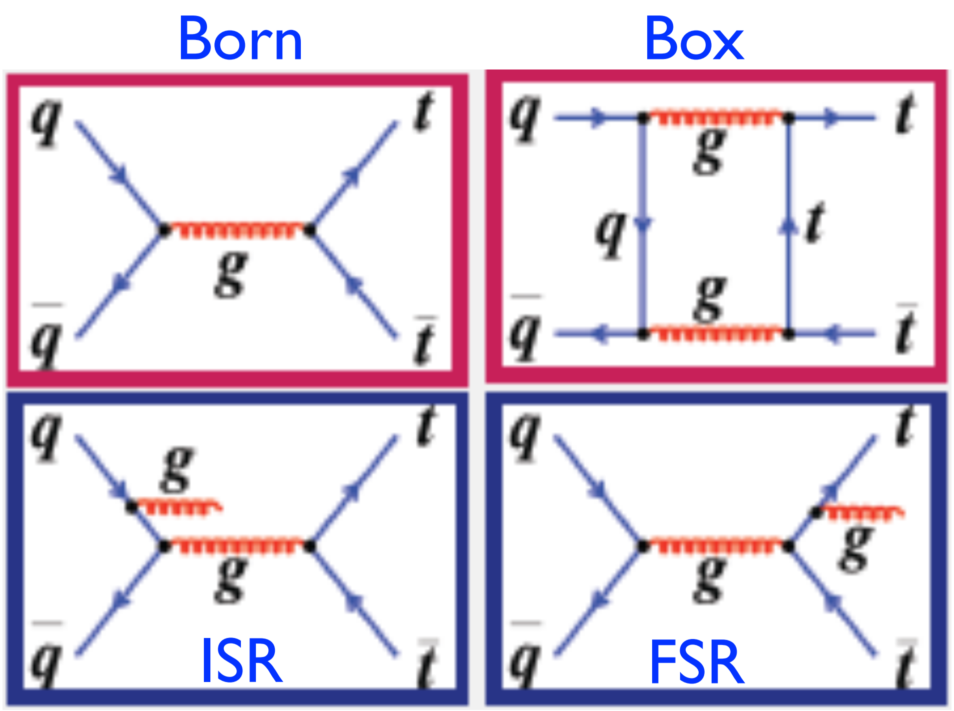
Correct for acceptance and reconstruction effects

new

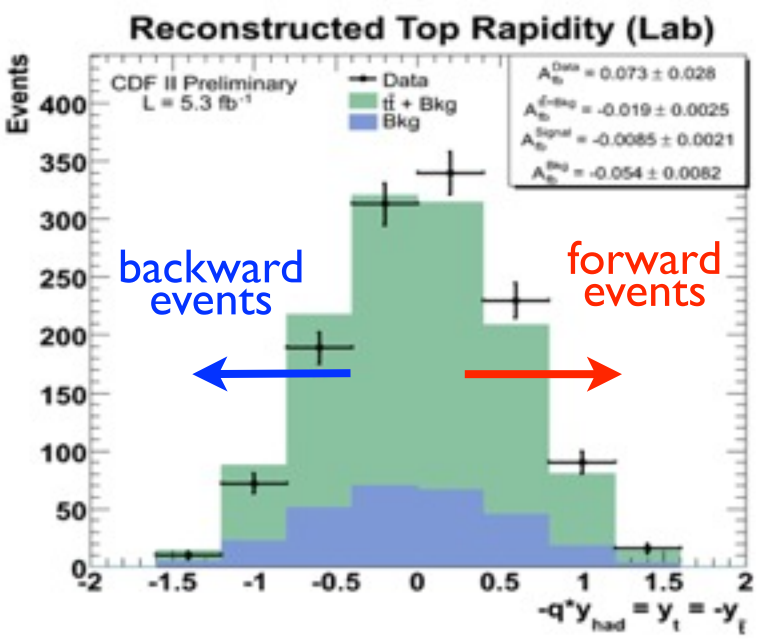
A_{fb} ($p\bar{p}$) = 0.150 ± 0.050 (stat) ± 0.024 (syst)
A_{fb} ($t\bar{t}$) = 0.158 ± 0.072 (stat) ± 0.017 (syst)

5.6 fb^{-1}

	MCFM
A_{fb} (|Δy|<1.0)= 0.026 ± 0.104(stat) ± 0.055(syst)	0.039 ± 0.006
A_{fb} (|Δy|>1.0)= 0.611 ± 0.210(stat) ± 0.141(syst)	0.123 ± 0.018



NLO: A_{fb}=0.05±0.015



A_{fb} (raw) = 0.073 ± 0.028

Forward-backward asymmetry

- LO: top quark production angle is symmetric with respect to beam direction
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- At Tevatron charge asymmetry = forward-backward asymmetry

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Correct for acceptance and reconstruction effects

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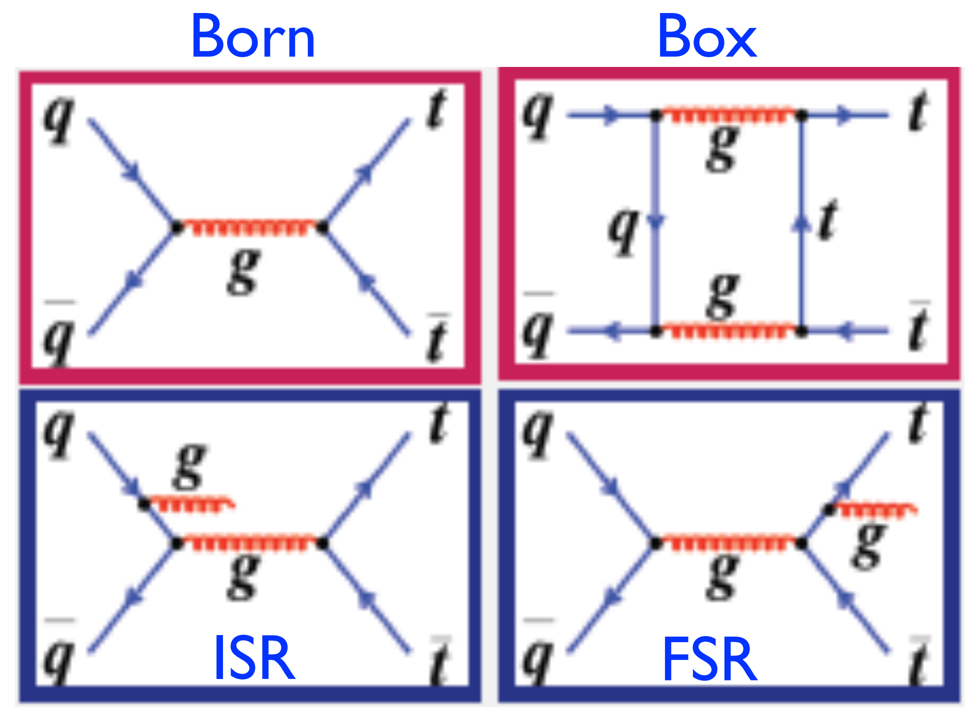
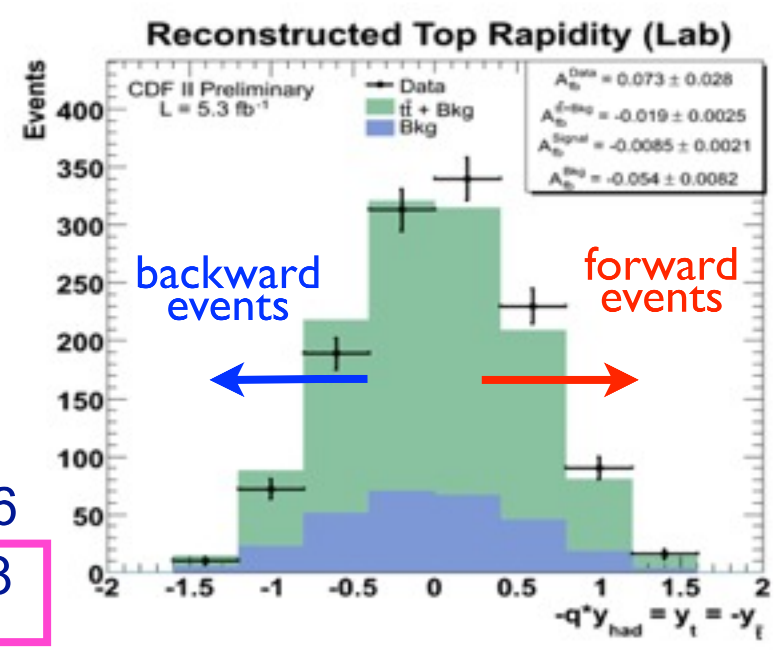
A_{fb} (|Δy|>1.0)= 0.611 ± 0.210(stat) ± 0.141(syst)	0.123 ± 0.018

Deviation from standard model ?
~30 theory papers in last 2 years!

new D0 update with 4.3 fb^{-1} for ICHEP!

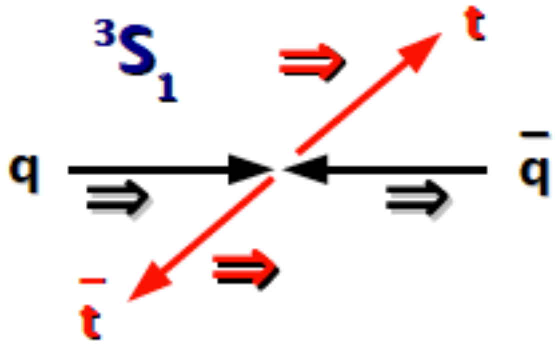


NLO: A_{fb}=0.05±0.015



A_{fb} (raw) = 0.073 ± 0.028

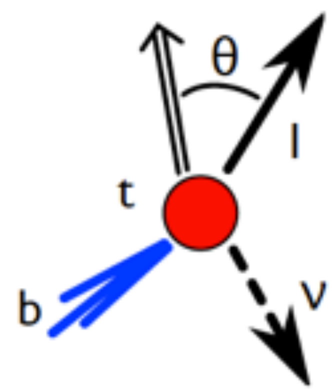
Spin correlations



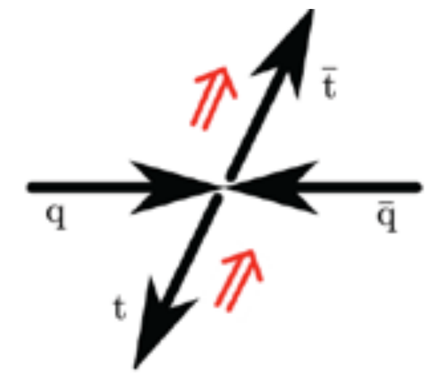
- Short lifetime
- Flight directions of top decay products carry information about top polarization at production

$$\kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\downarrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\downarrow\uparrow} + N_{\uparrow\downarrow}}$$

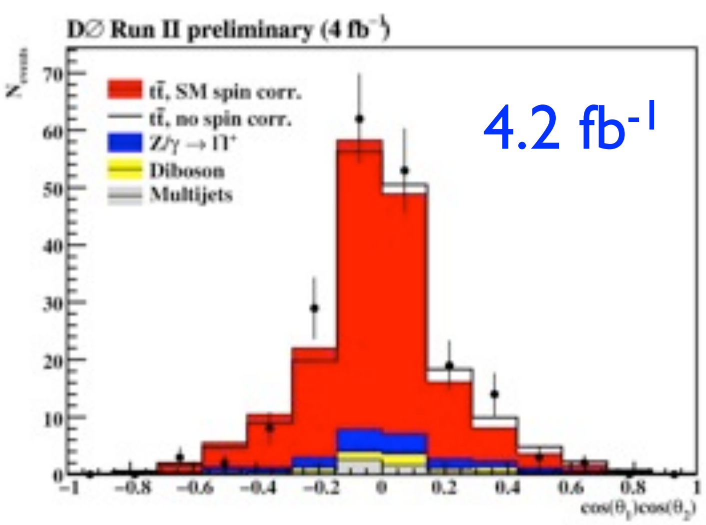
Strength depends on spin quantization axis:
beam line, helicity, off-diagonal



Lepton+jets channel



Dilepton channel



$\kappa = -0.17^{+0.64}_{-0.53}$

beam basis, NLO: κ=0.777

2.8 fb^{-1}

$\kappa = 0.32^{+0.55}_{-0.78}$

off-diagonal basis
NLO: κ=0.782

$\kappa = 0.48 \pm 0.48_{stat} \pm 0.22_{syst}$

helicity basis
NLO κ=0.4

5.3 fb^{-1} new

$\kappa = 0.72 \pm 0.64_{stat} \pm 0.26_{syst}$

beam basis

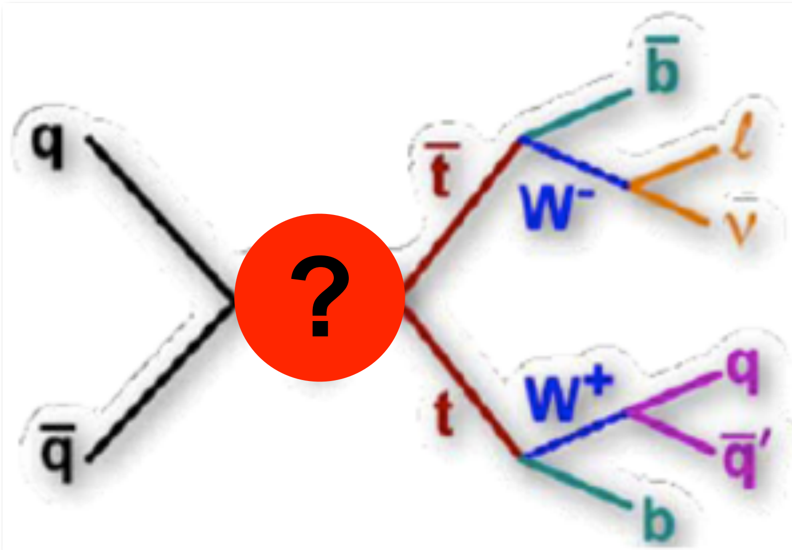
Three measurements in last year!

Searched in Top quark sector

Searches in top production

Searches in top decay

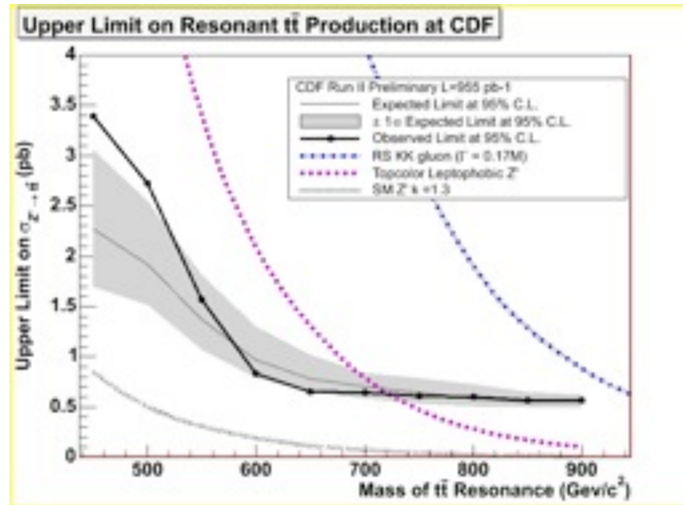
Searches in top production



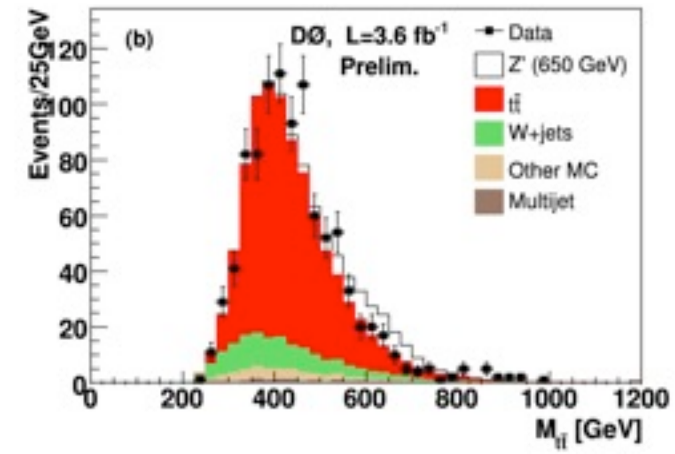
Single top

$t\bar{t}$ resonances (l+jets)

- $M_{Z'}$<820 GeV excluded

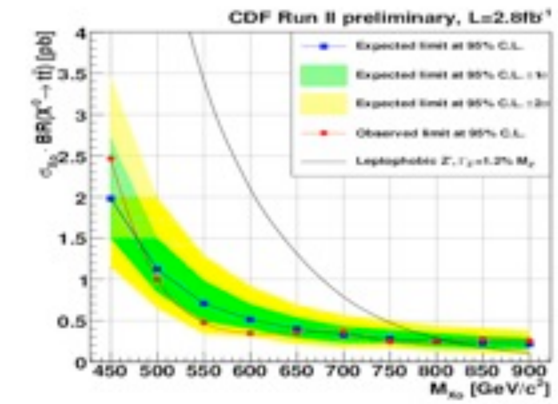


KK gluon excitation in RS theory

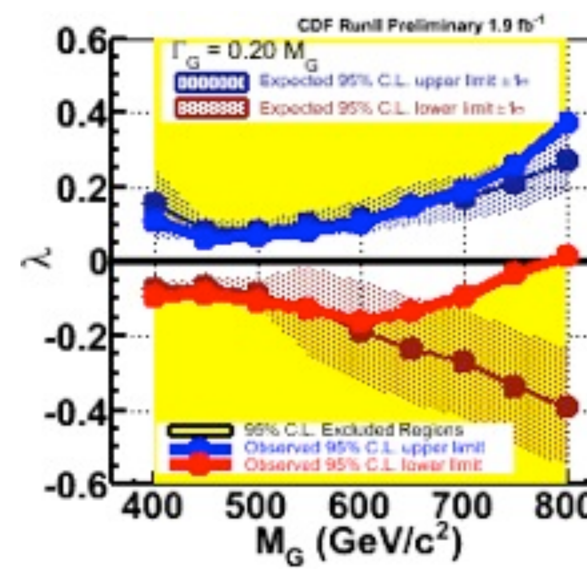


$t\bar{t}$ resonances(all hadronic)

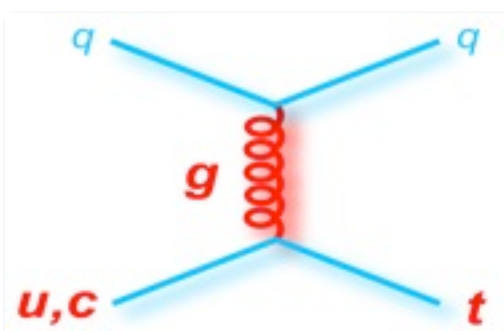
- $M_{Z'}$<805 GeV excluded

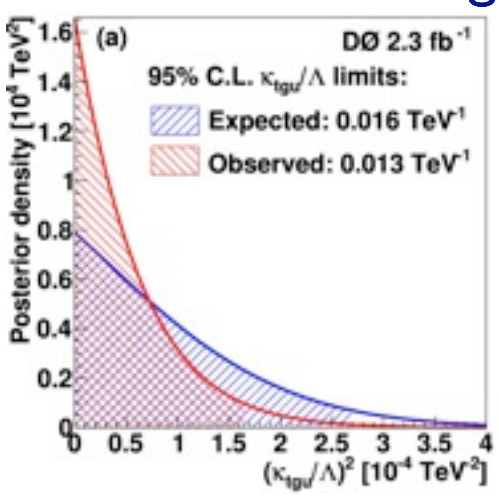


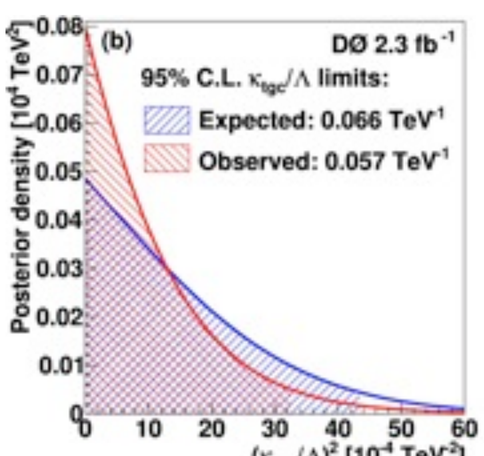
Heavy gluon search



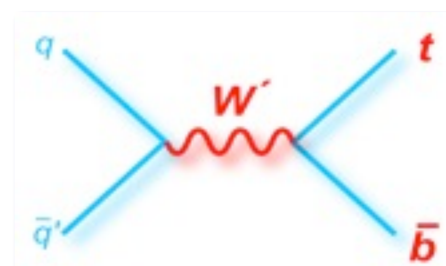
FCNC: t →gu, gc

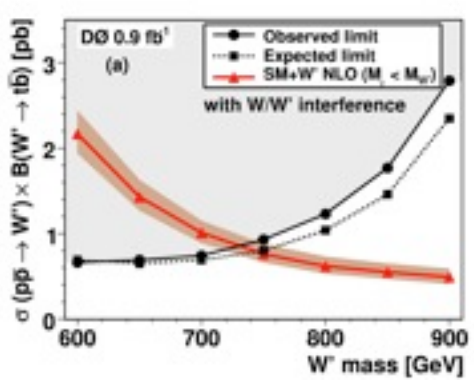


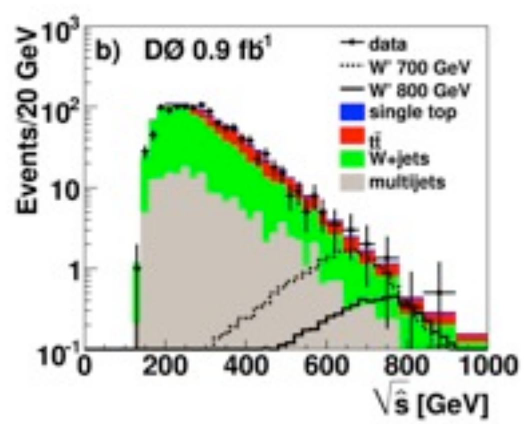




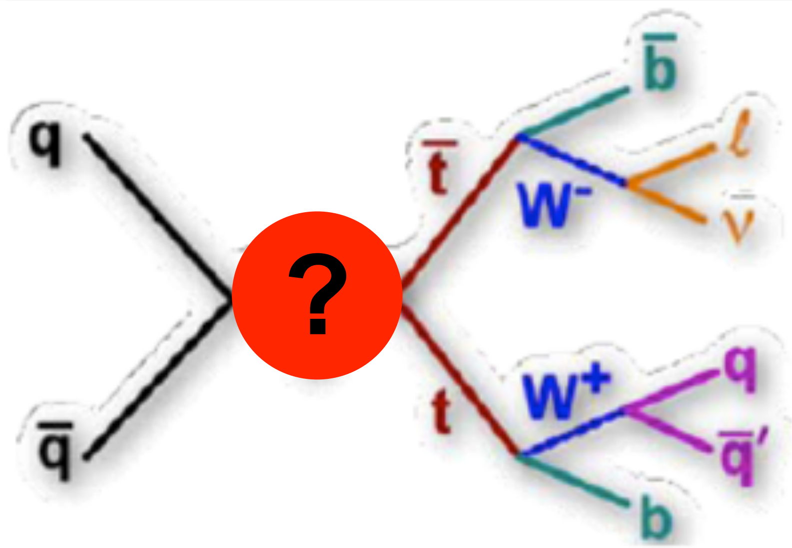
Single top s-channel







Searches in top production



Single top

$t\bar{t}$ resonances (l+jets)

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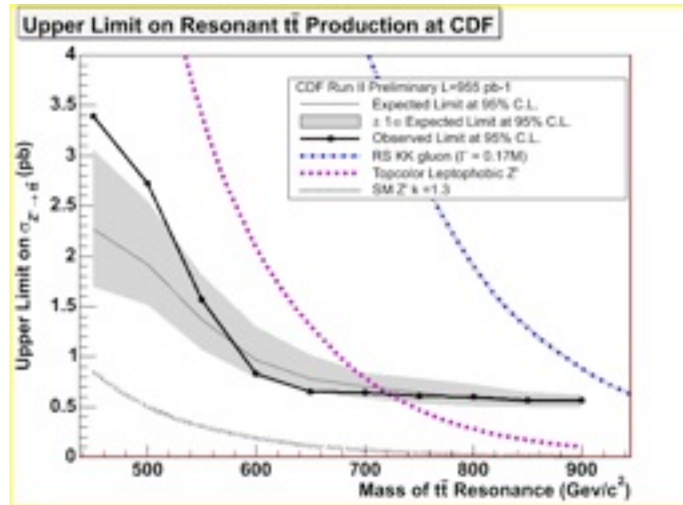

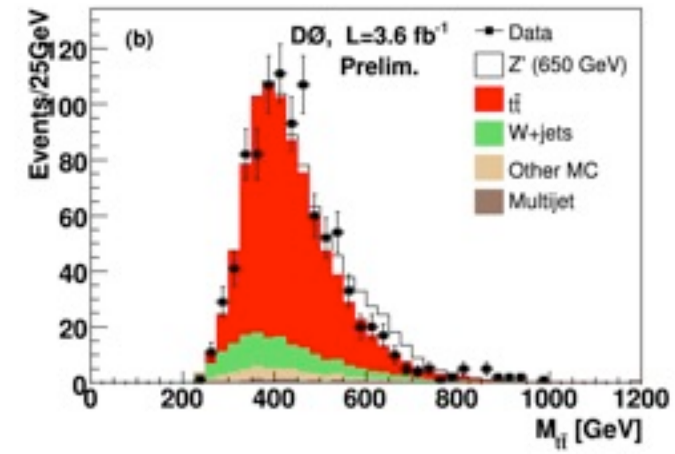

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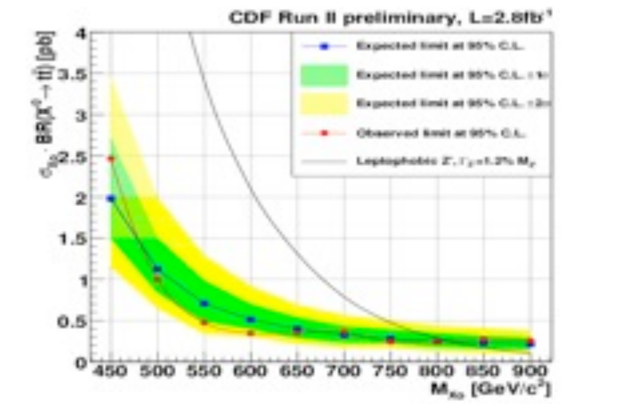
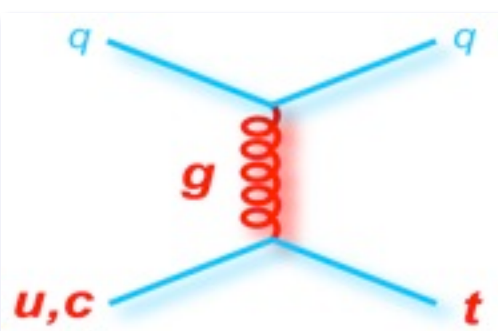
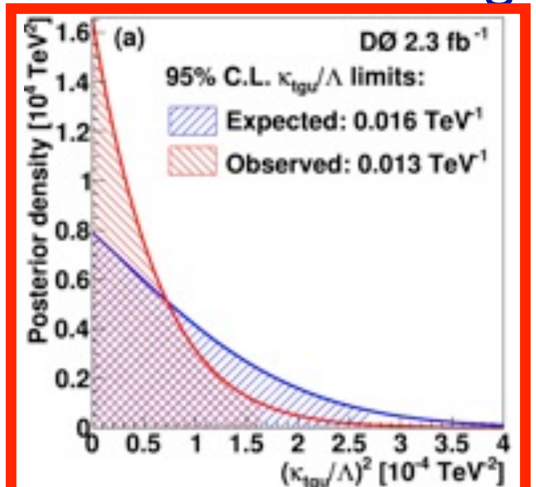
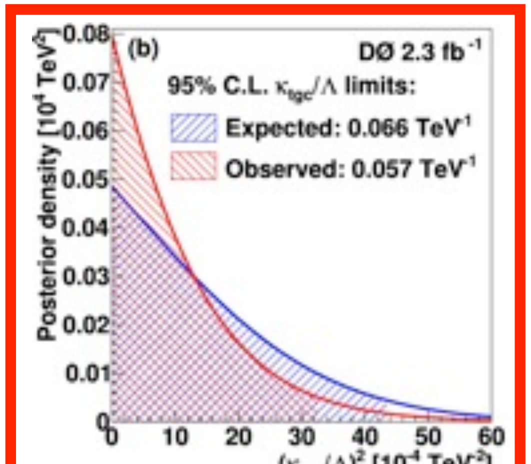


FCNC: t → gu, gc

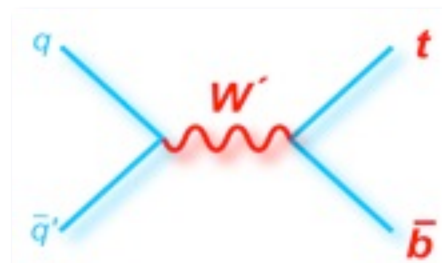


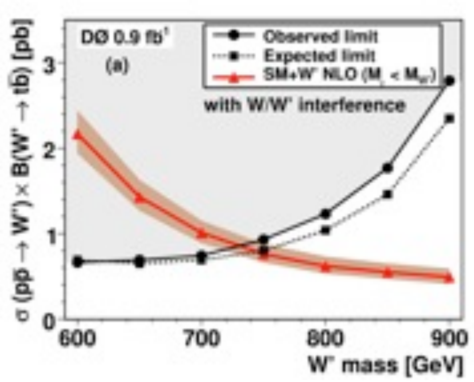


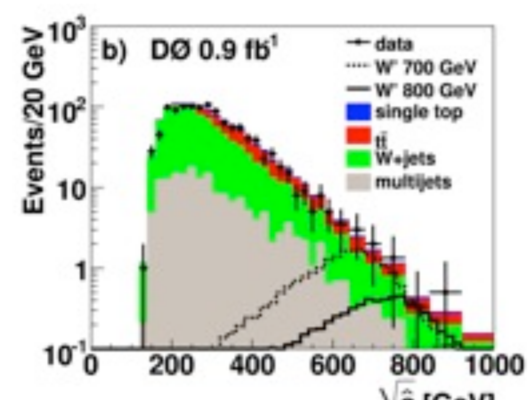


KK gluon excitation in RS theory

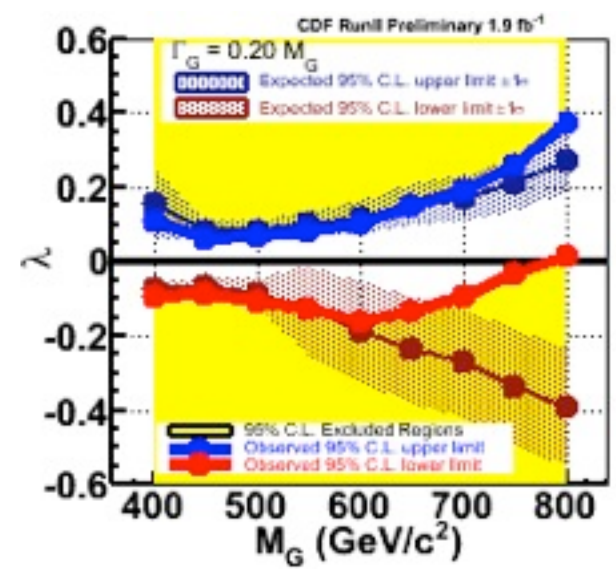
Single top s-channel



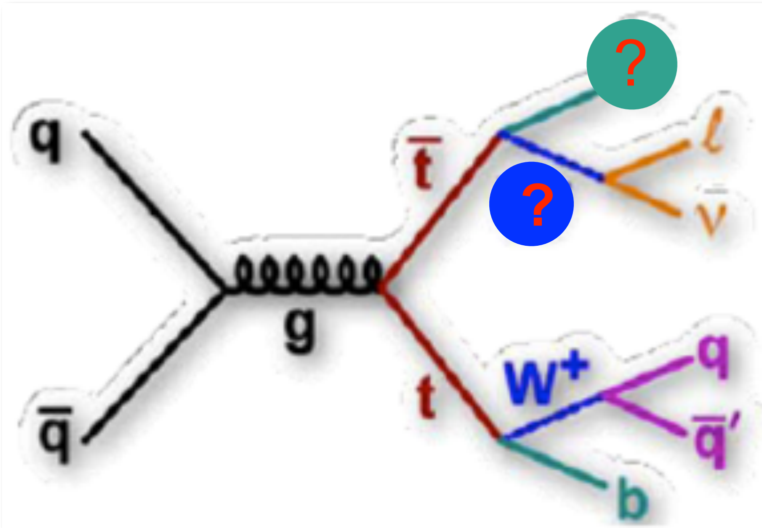




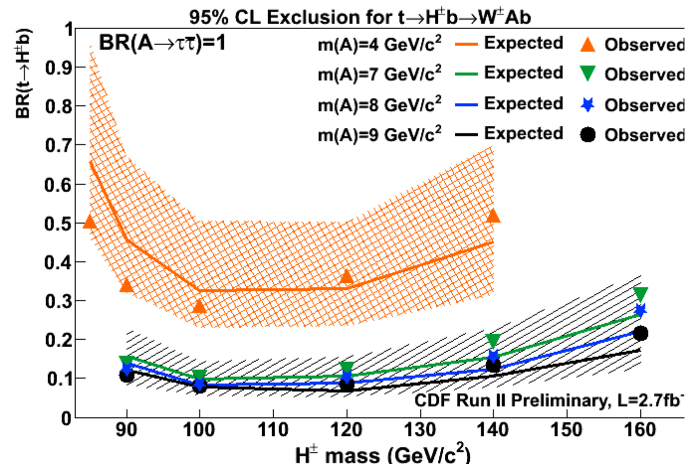
Heavy gluon search

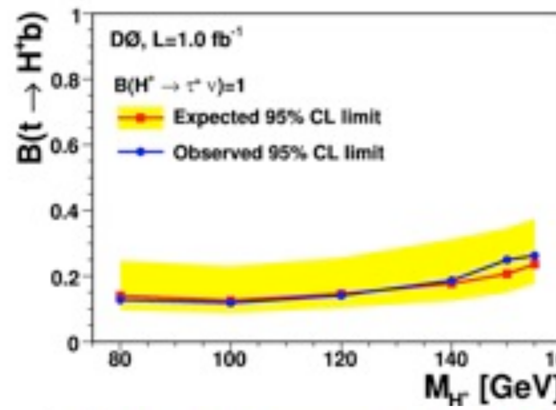


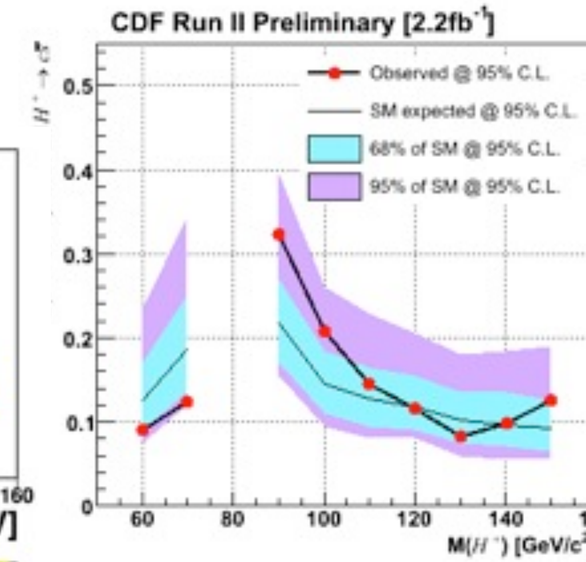
Searches in decay

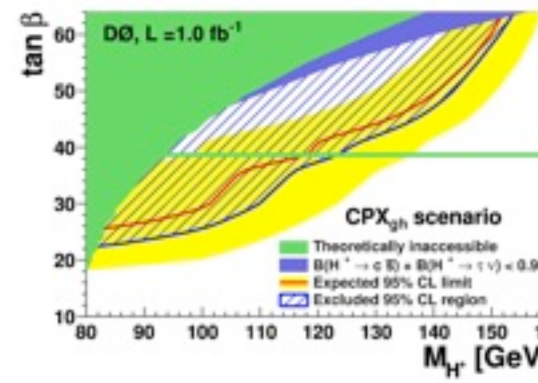


Charged Higgs: tauonic and leptophobic

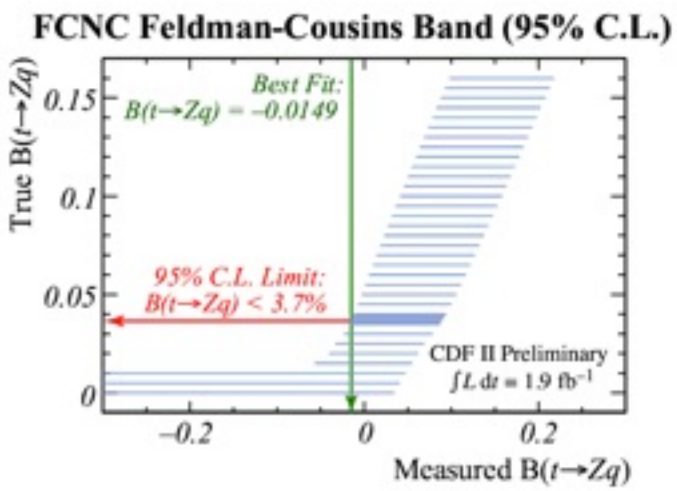


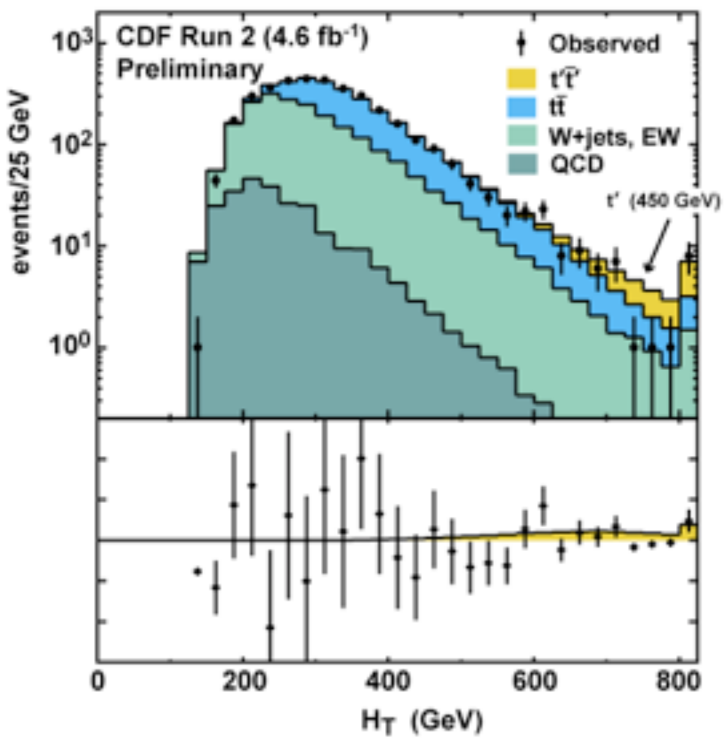




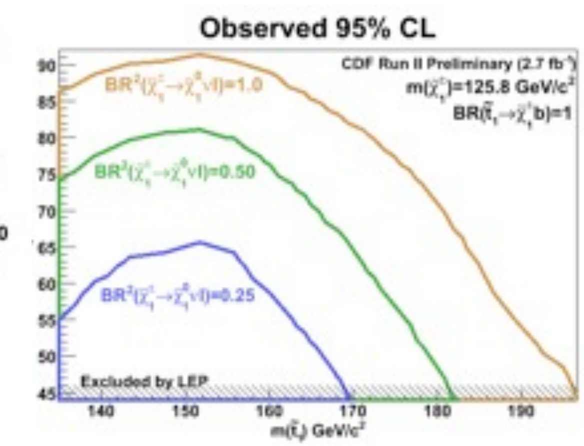


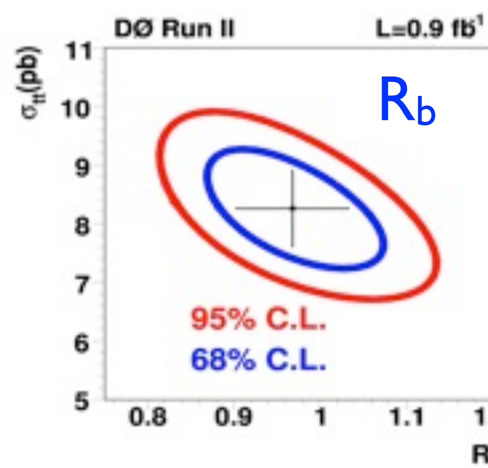
FCNC: t →Zq,Zc,γc,gc

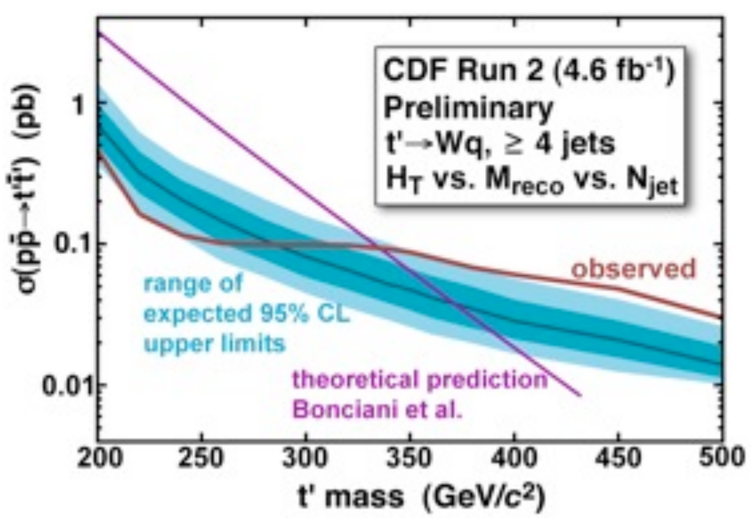




Stop



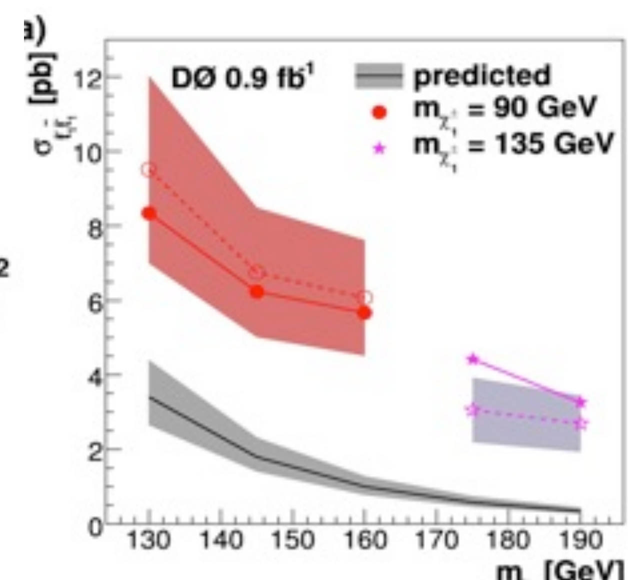




4th generation t' quark

- t'→Wq, M(t') - M(b') < M(W)
- $M_{t'}$<335 GeV excluded

New D0 t' search was approved yesterday



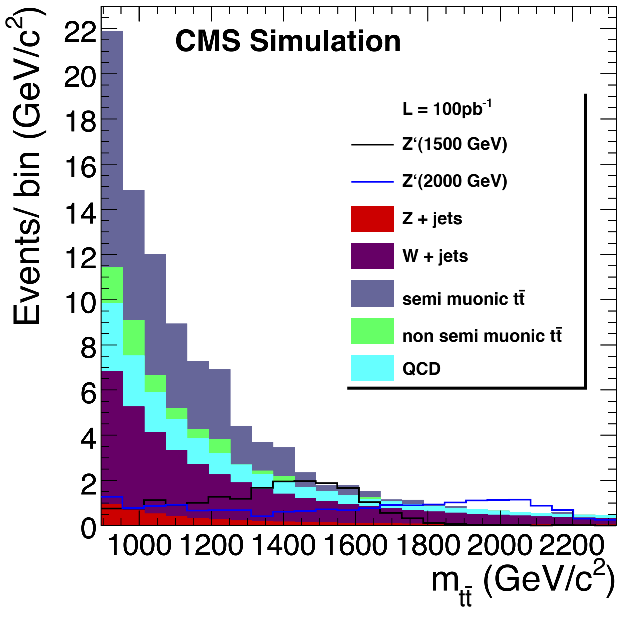
- Properties and searches are statistically limited
- Large samples at LHC will allow precise measurement
- Impact can be made with L~500 pb^{-1}

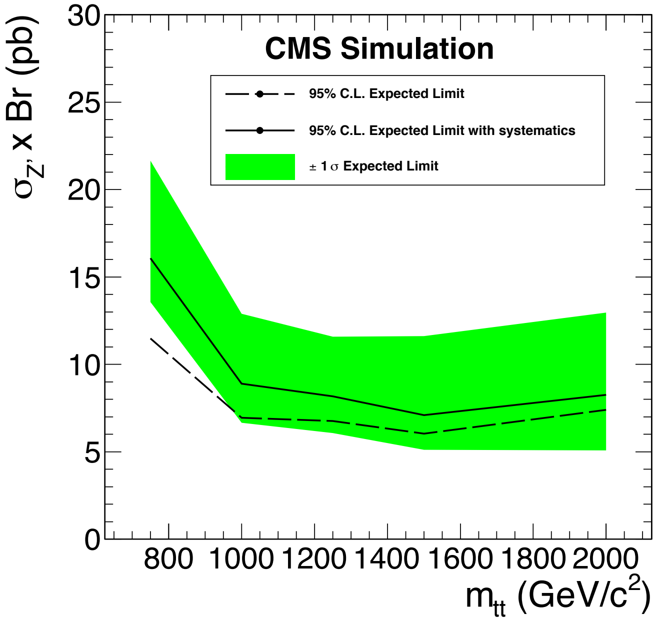
Early measurement

$t\bar{t}$ resonances

Techniques to reconstruct highly boosted top quarks are being developed

10 TeV, 100 pb^{-1}





Top properties and searches at LHC

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CDF result for boosted tops is expected for ICHEP

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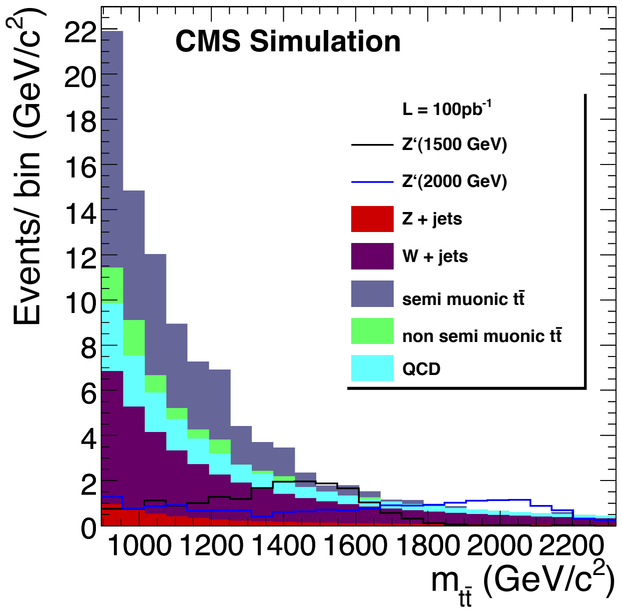

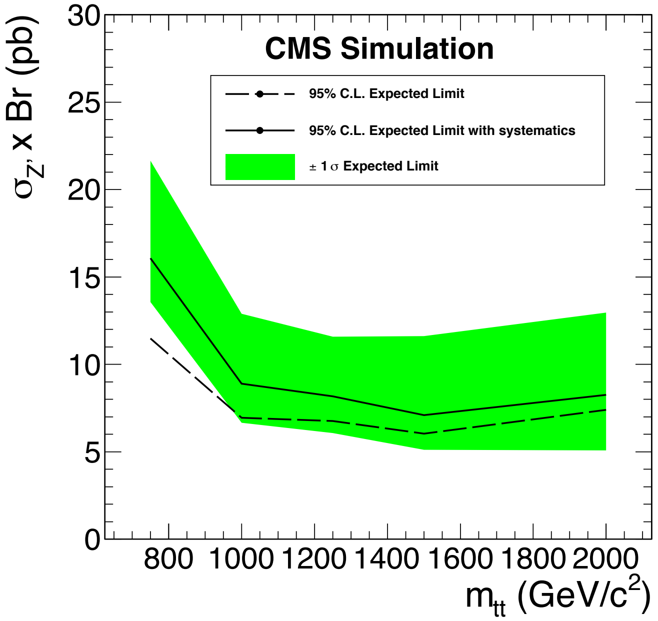

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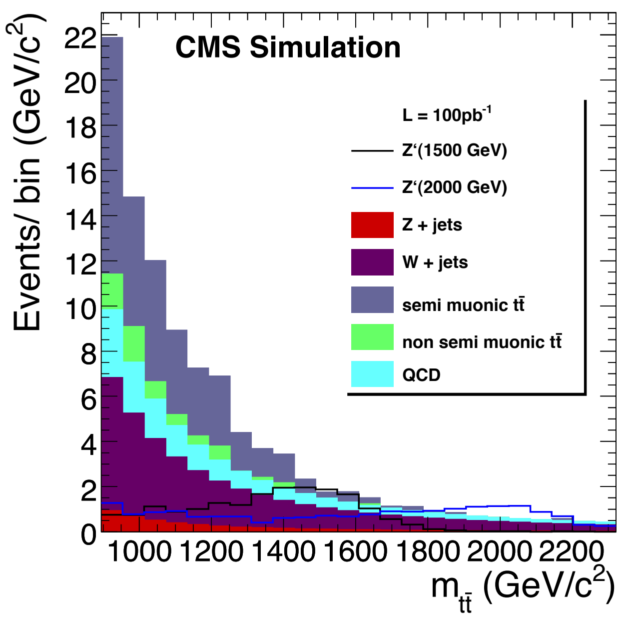
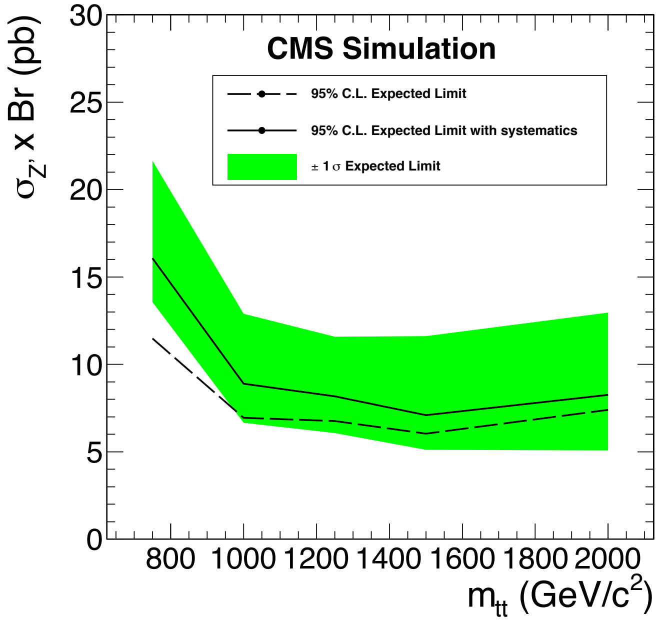


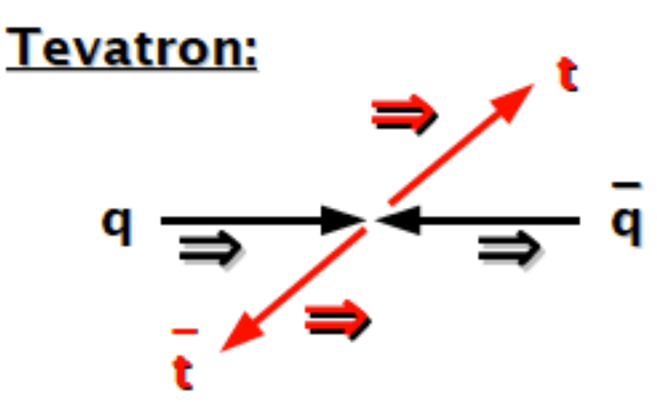


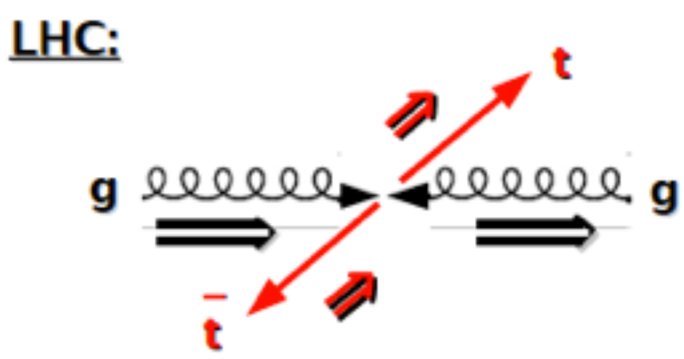
Techniques to reconstruct highly boosted top quarks are being developed

Can Tevatron help?

CDF result for boosted tops is expected for ICHEP

- Measurements complimentary to Tevatron





NLO: κ=0.78

NLO: κ=0.33

Conclusions and outlook

- Top quark physics today
  - unprecedented precision on top quark mass and cross section
  - significantly beyond Tevatron goals
  - Impressive number of studied properties
    - new measurements possible: spin correlations
    - only now reaching sensitivity
  - broad program of searches in top sector
- No significant deviation from standard model predictions so far

Conclusions and outlook

- Top quark physics today
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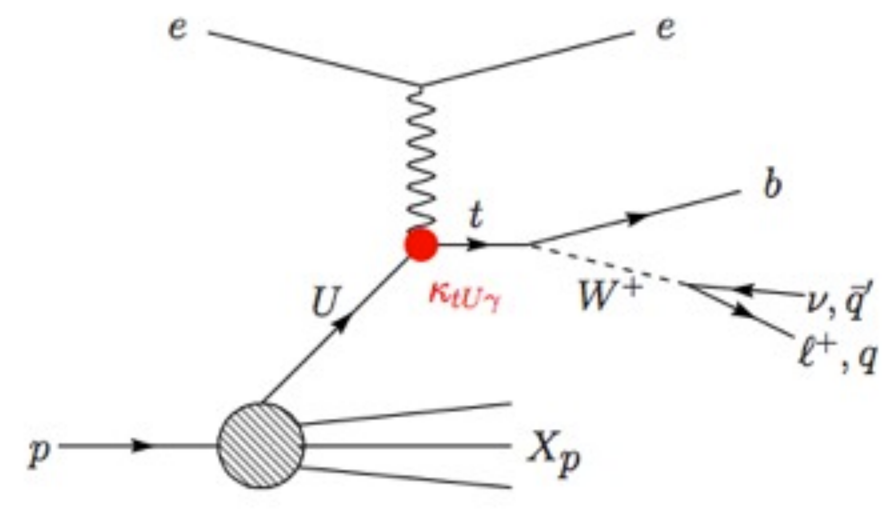
Looking forward for first top physics results from LHC this year

Backup

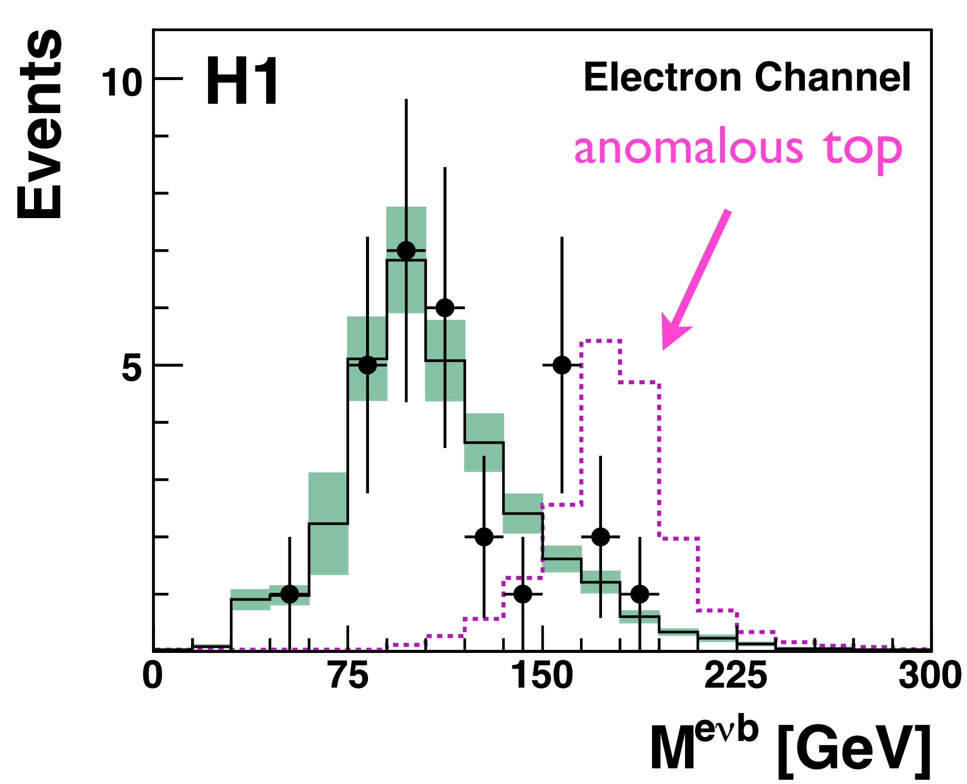
Single top quark at HERA

- Use the same selection as for W
- SM production is strongly suppressed
- Can be enhanced by FCNC
  - coupling of t to up-type quark U via γ or Z
- Background: single W production

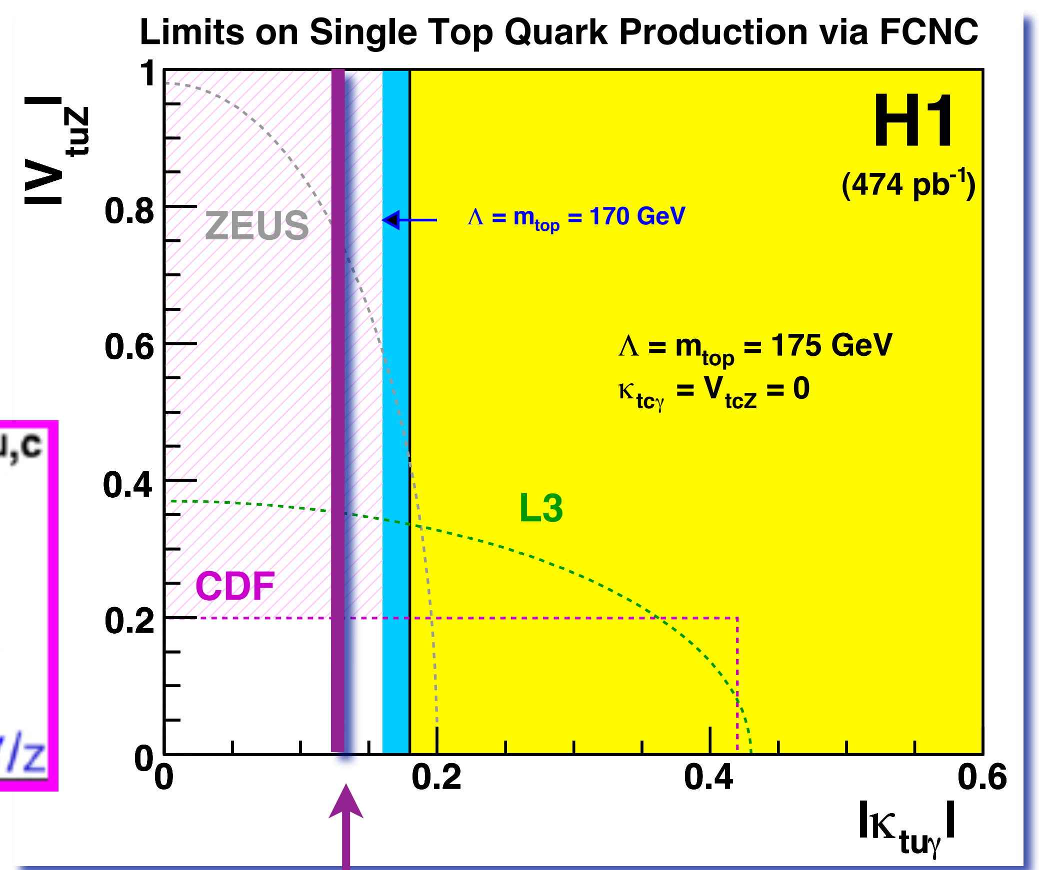


$\sigma(ep\rightarrow etX)<0.25$ pb — H1 — 474 pb^{-1}

$\sigma(ep\rightarrow etX)<0.23$ pb — ZEUS — 277 pb^{-1}



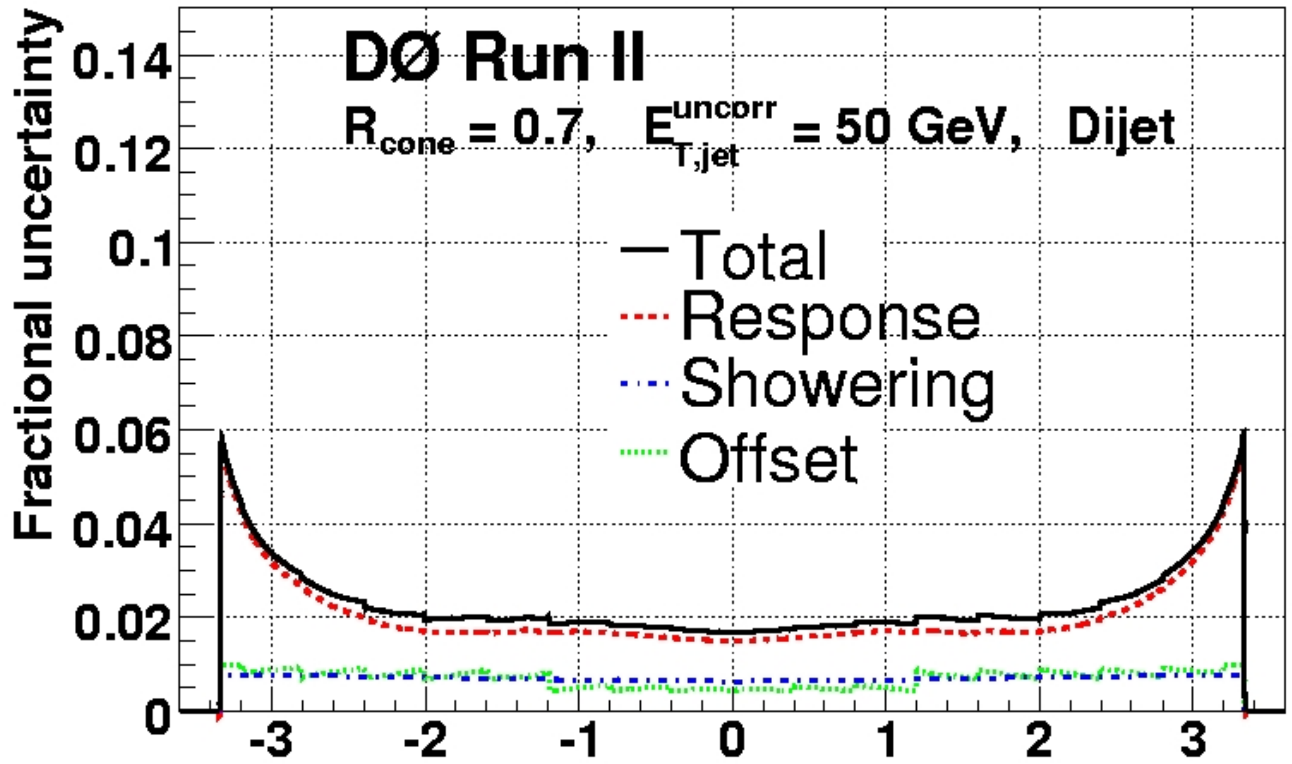
TEVATRON: top, u,c, κ_{γ}/V_Z, γ/Z



HERAI+HERAII, ZEUS, 359 pb^{-1}

$\sigma<0.13$ pb, $k_{tu\gamma}<0.13$

Understanding Jets



- Jet energy scales used to be severely limit top physics
- Has become less important with the $W \rightarrow jj$ calibration (simultaneous fit) in lepton+jets and all-hadronic, even applied to dilepton.
- Still limits some measurements, try to find creative ways around...

ME method details

$$P_{t\bar{t}}(x;m_t,JES) = \frac{1}{\sigma(m_t)} \int d^n\sigma(y,m_t)\, dq_1 dq_2 f(q_1) f(q_2)\, W(x,y,JES)$$

Normalization
acceptance
& efficiency

Differential cross section based on LO ME

Initial state
Probability distribution that a parton will have a momentum q

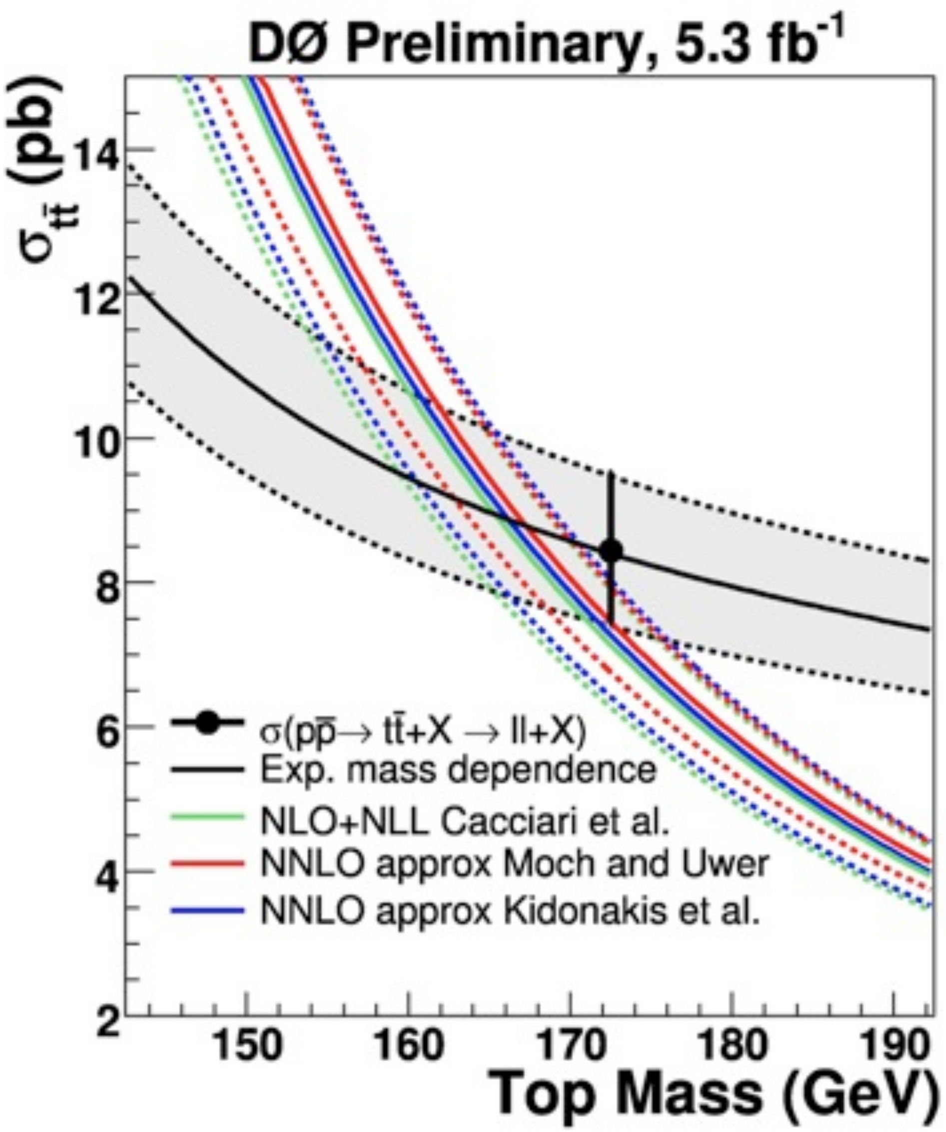
Transfer function
Probability to measure x when parton-level y was produced

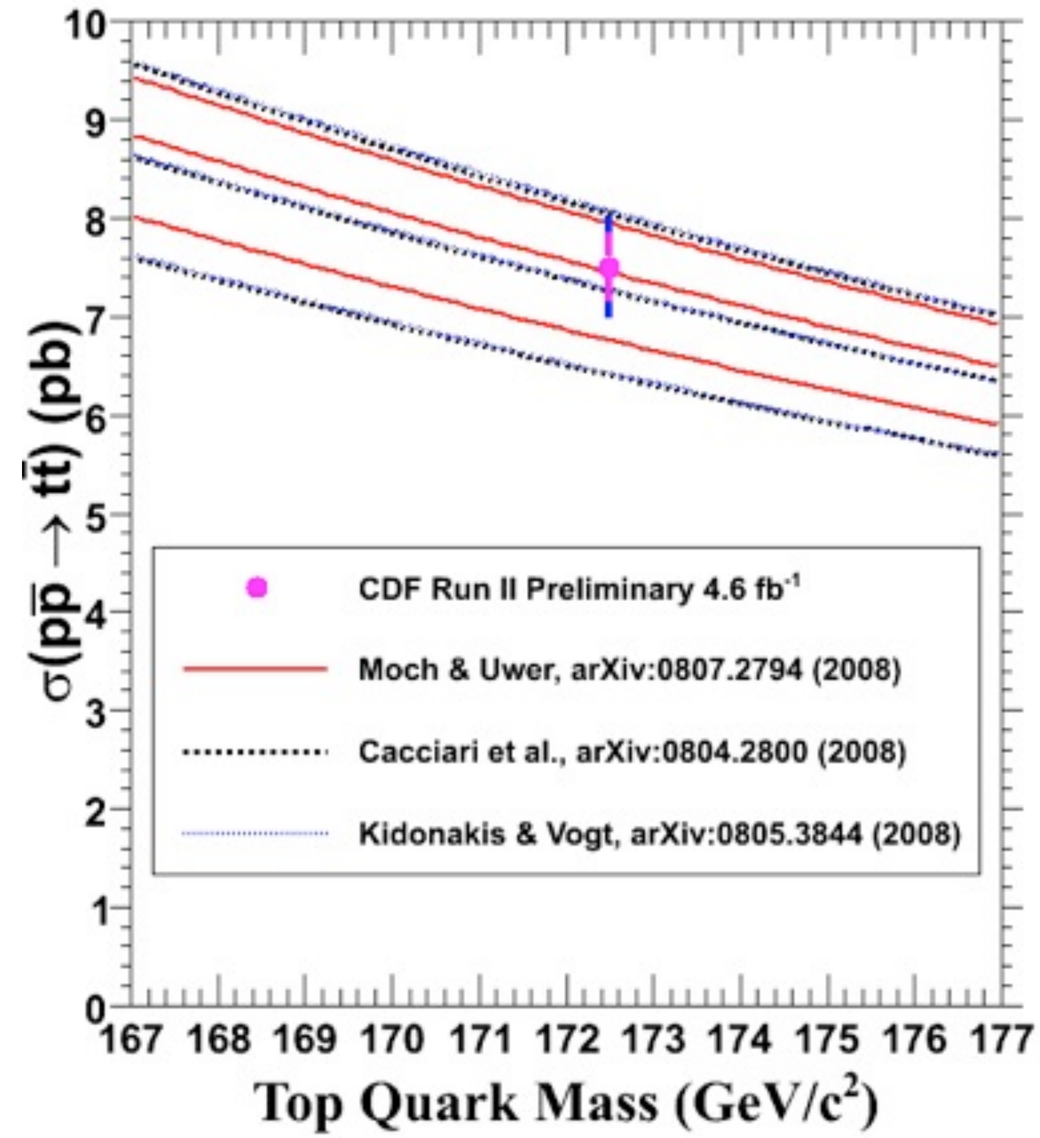
Probability to observe a set of kinematic variables x for a given mass and JES

- Integrate over unknown q_1, q_2, y
- The jet energy calibration (JES) is a free parameter in the fit, constrained in-situ by the mass of hadronically decaying W

$$\mathcal{P}_{\text{event}}(x; m_t, \text{JES}) = f_t\, \mathcal{P}_{t\bar{t}}(x; m_t, \text{JES}) + (1 - f_t)\mathcal{P}_{bkg}(x, \text{JES})$$

Testing the Theory





Extract top mass from cross section

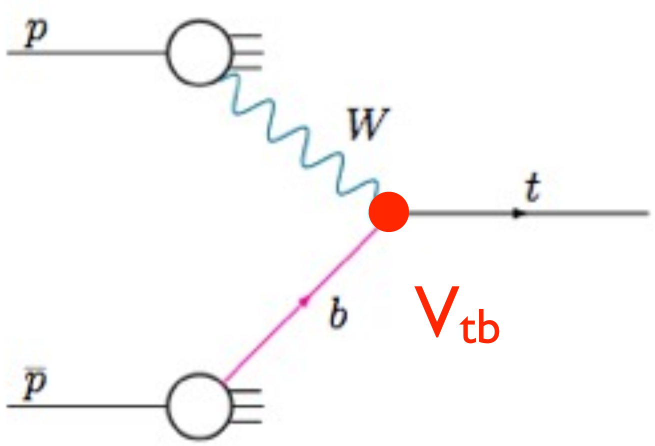
Compare measured mass and cross section

Sample composition

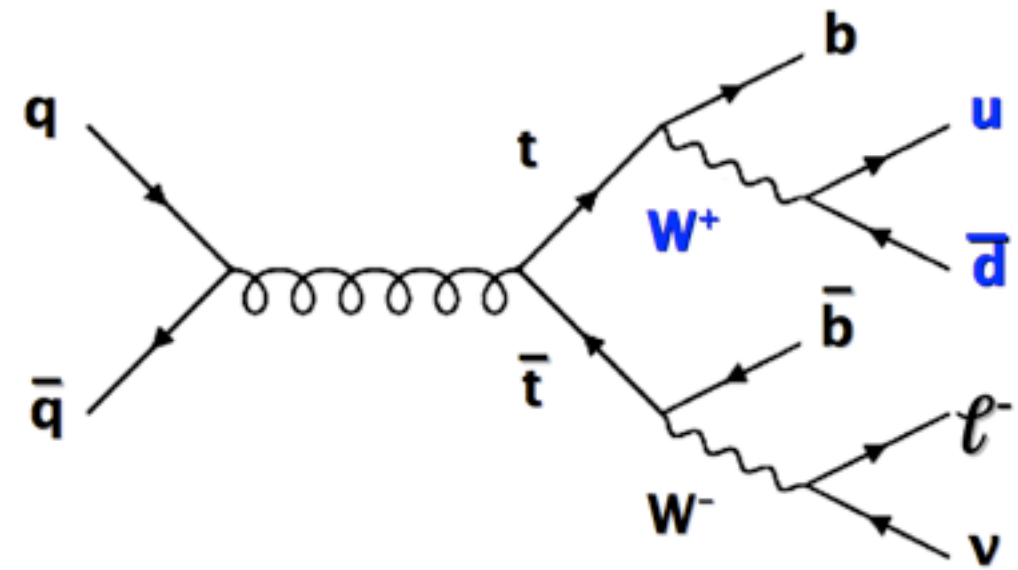
S/B at CDF	Dilepton (≥2 jets)	Lepton+Jets (≥4 jets)	All-hadronic (6-8 jets, after NN Selection)
0 b-tag	1:1	~1:4	~1:20
1 b-tag	20:1	4:1	1:4
2 b-tags		20:1	1:1

top width and new physics

t-channel cross section



branching ratio t→Wb

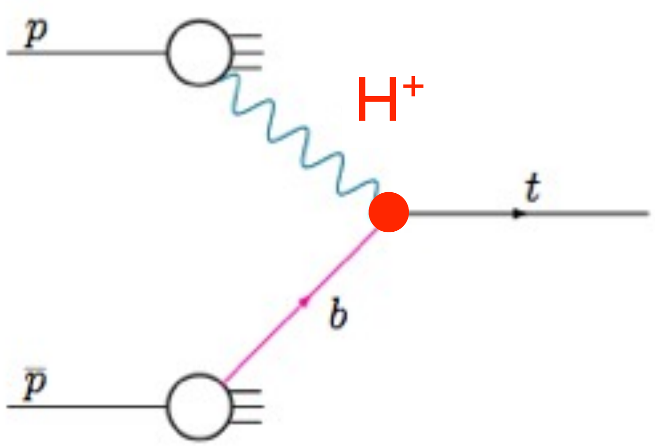


$$\Gamma_t = \frac{\sigma(t\text{--channel})\ \Gamma(t \to Wb)_{\rm SM}}{\mathcal{B}(t \to Wb)\ \sigma(t\text{--channel})_{\rm SM}}$$

top width and new physics

example: charged Higgs with $m_{H+} < m_t - m_b$

t-channel cross section



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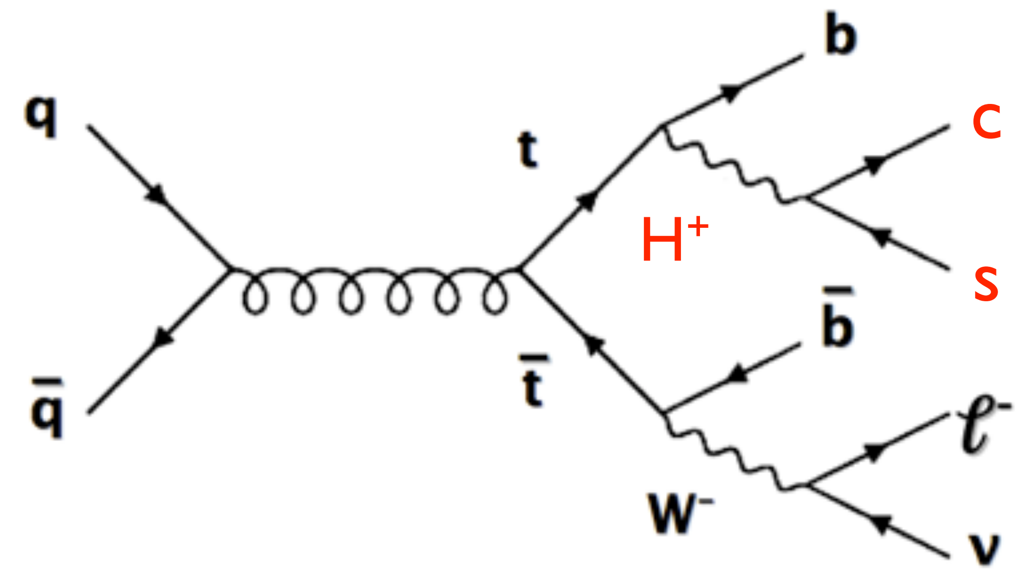

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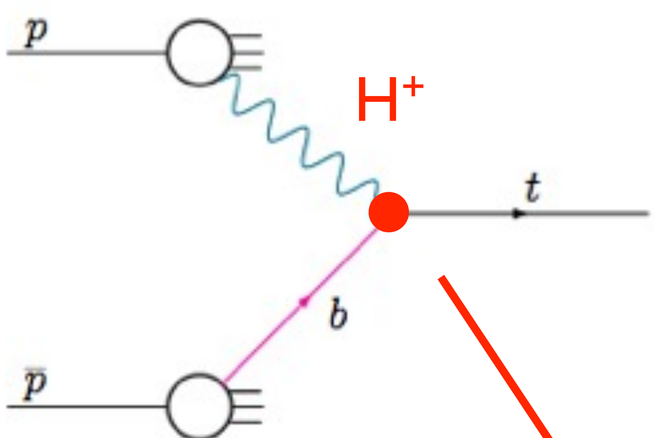

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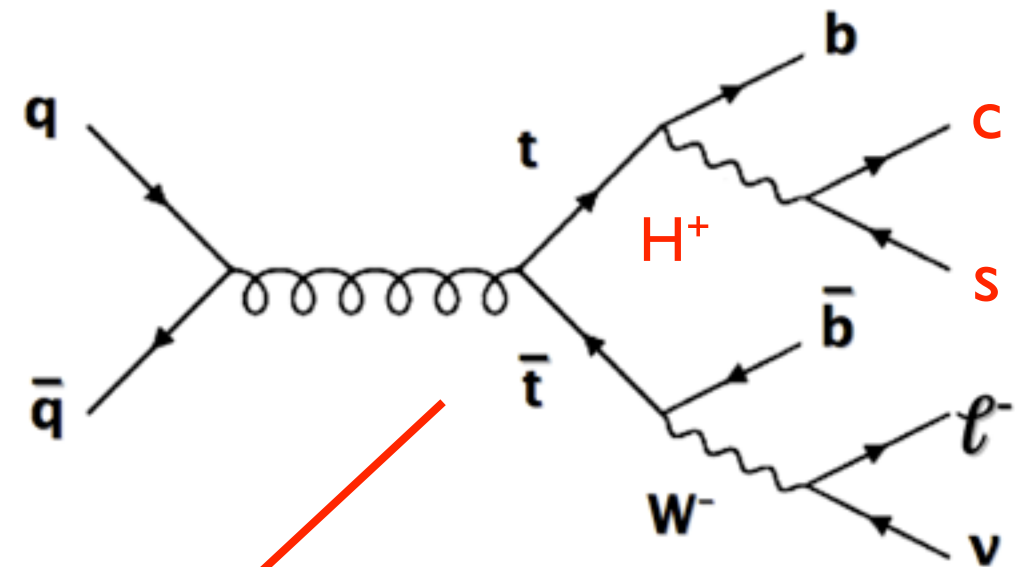


increase

≠1

$$\Gamma_t = \frac{\sigma(t\text{–channel})\ \Gamma(t \to Wb)_{SM}}{\mathcal{B}(t \to Wb)\ \sigma(t\text{–channel})_{SM}}$$

A_{fb} at Tevtaron

$$A_C = \frac{N_t(p) - N_{\bar{t}}(p)}{N_t(p) + N_{\bar{t}}(p)}$$

Charge asymmetry: number tops and anti-tops in a given direction (proton beam)

$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

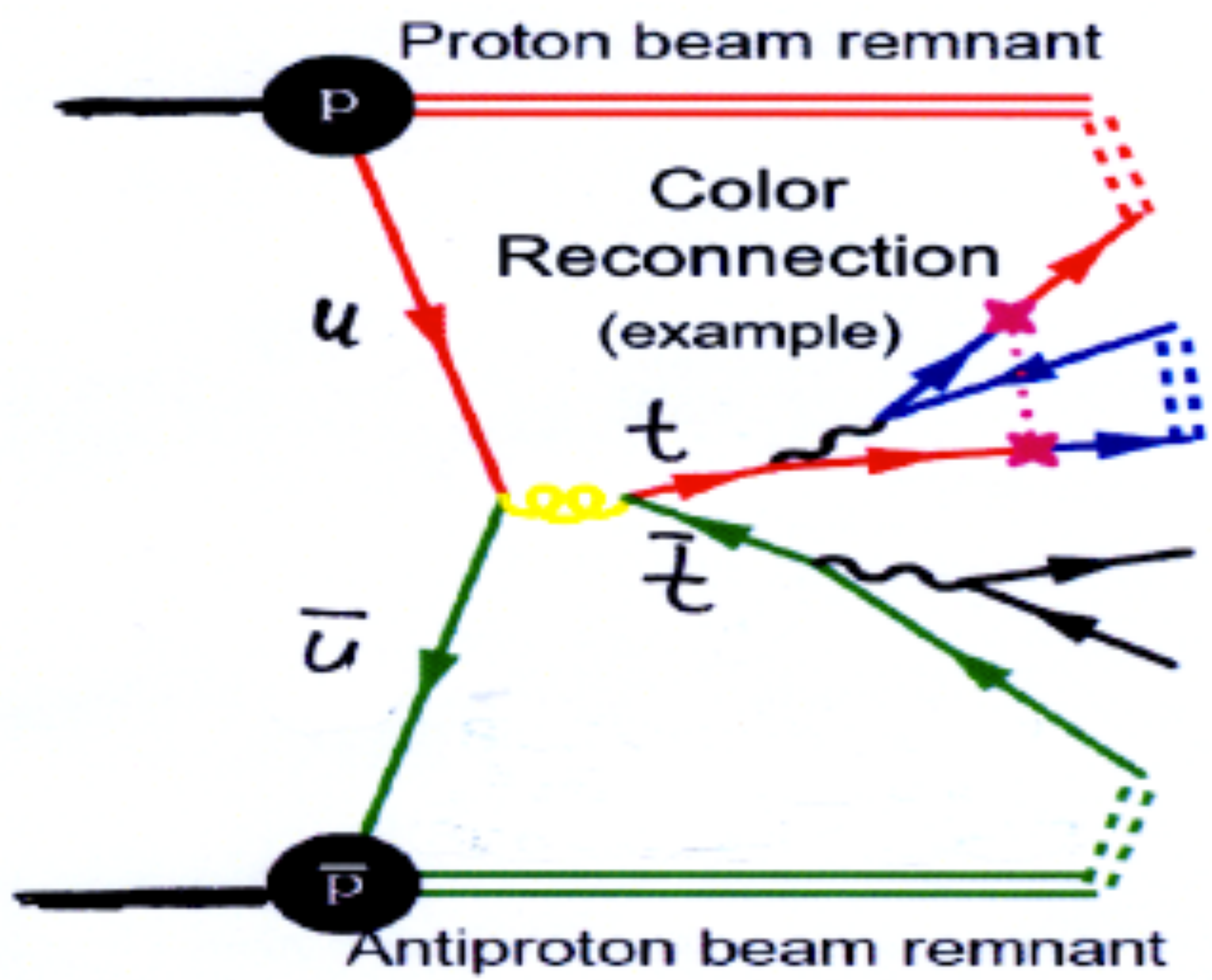
Forward-backward asymmetry: number of top and anti-top quarks moving for or against a given direction

For CP invariant system $N_{\bar{t}}(p)=N_t(\bar{p})$
$A_c = A_{fb}$

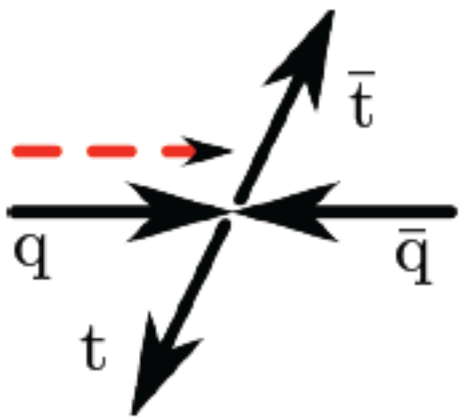
$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$

Δy=y(top)-y(anti-top)

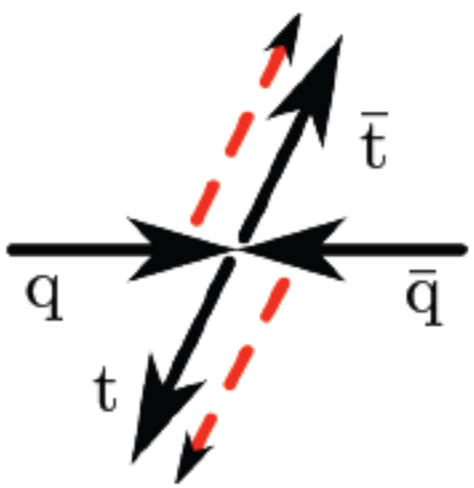
Color reconnection



Spin correlations: axis

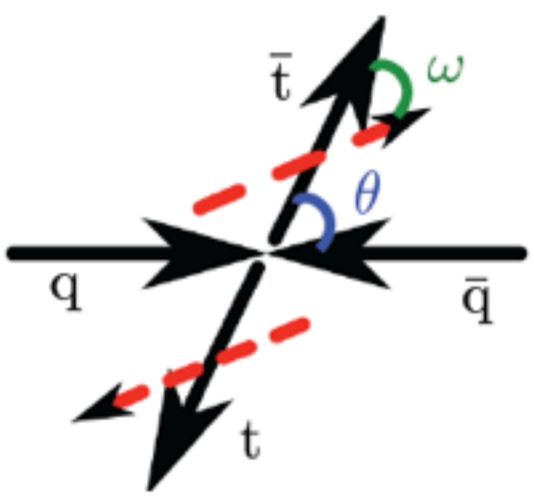


beamline: A = 0.777 at NLO
best for production at threshold



helicity: A = -0.352 at NLO
use direction of (anti)top quark in
$t\bar{t}$ rest frame to quantize the spin

Helicity angle: angle between decay product momentum in top rest frame and top quark momentum in $t\bar{t}$ rest frame



$$\tan\omega = \sqrt{1-\beta^2}\tan\theta$$

off-diagonal: A = 0.782 at MCNLO
good for pairs above threshold

Bernreuther, Brandenburger, Si and Uwer et al., Nucl. Phys. B 690, 81 (2004)

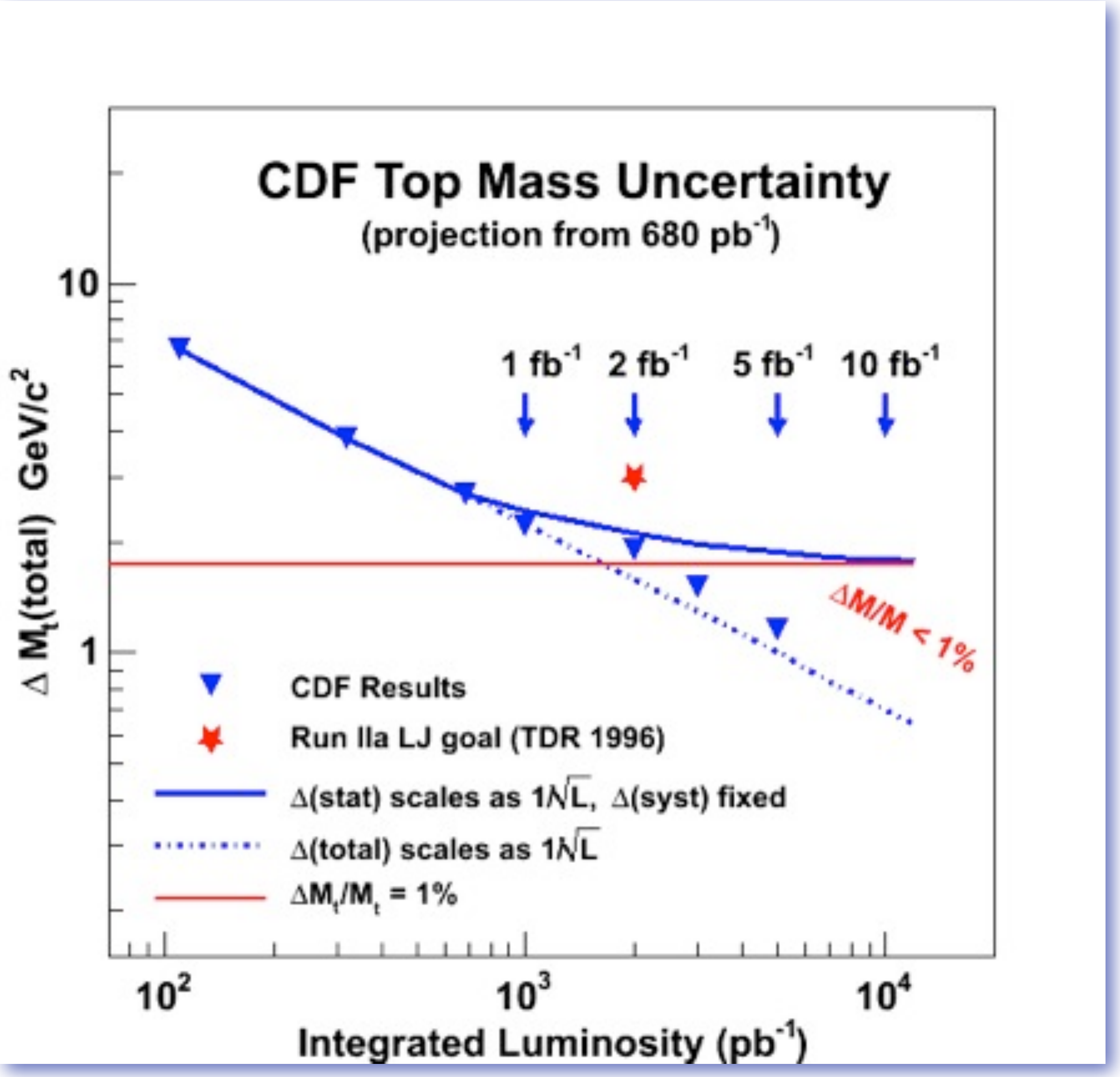
Wtb vertex

$$L_{tWb} = \frac{g}{2\sqrt{2}} W_\mu^- \bar{b} \gamma^\mu (f_1^L(1-\gamma_5) + f_1^R(1+\gamma_5))t$$
$$-\frac{g}{2\sqrt{2}M_W} \partial_\nu W_\mu^- \bar{b} \sigma^{\mu\nu} (f_2^L(1-\gamma_5) + f_2^R(1+\gamma_5))t$$

- In SM $f_1^L = V_{tb} \approx 1$, $f_2^L = f_2^R = f_1^R = 0$

Future precision

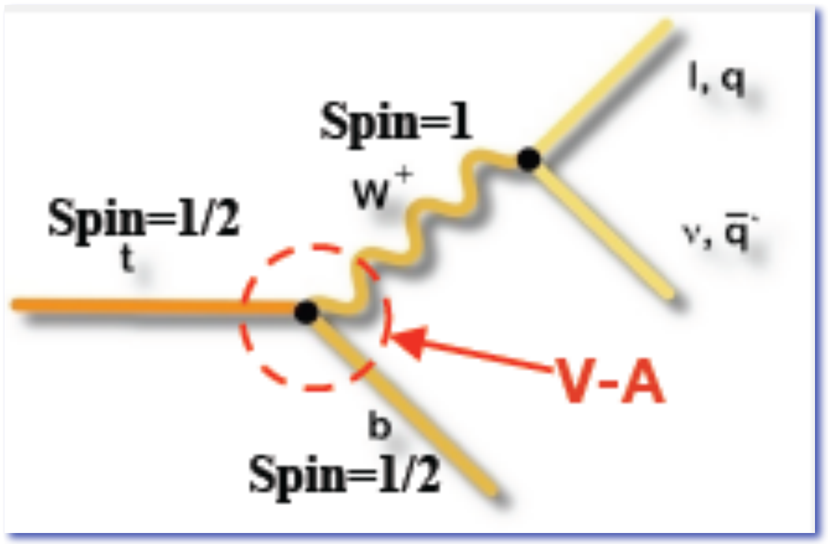
CDF example



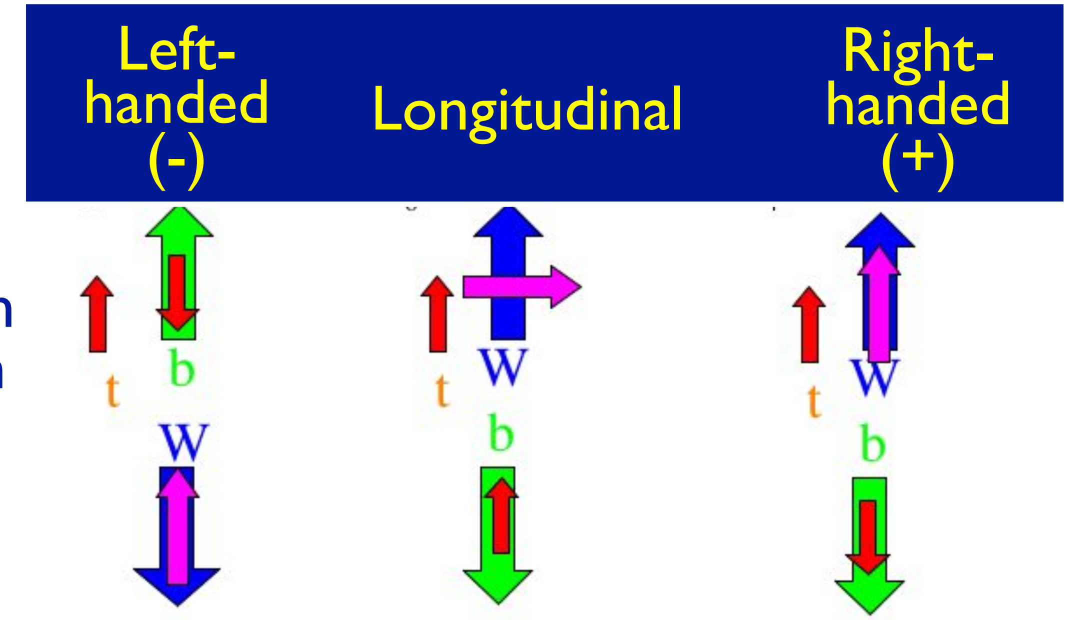
Systematic source	δm_{top} (GeV)
calibration	0.10
MC generator	0.37
Radiation	0.15
Residual jet energy scale	0.49
b-jet energy scale	0.26
Lepton p_T	0.14
Multiple hadron interactions	0.10
PDFs	0.14
Background	0.34
Gluon fraction	0.03
Color reconnection	0.37
Total	**0.88**

Approaching 1 GeV uncertainty on a single measurement

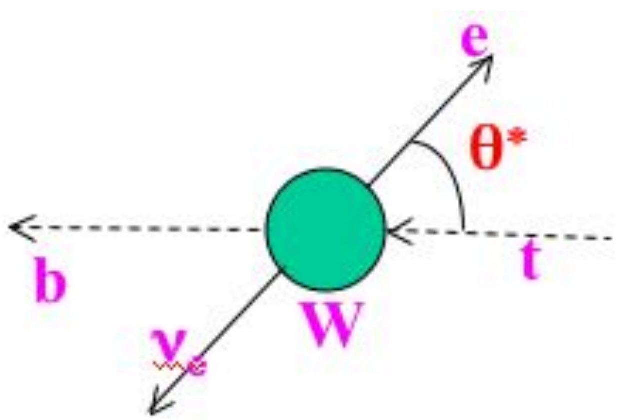
W helicity



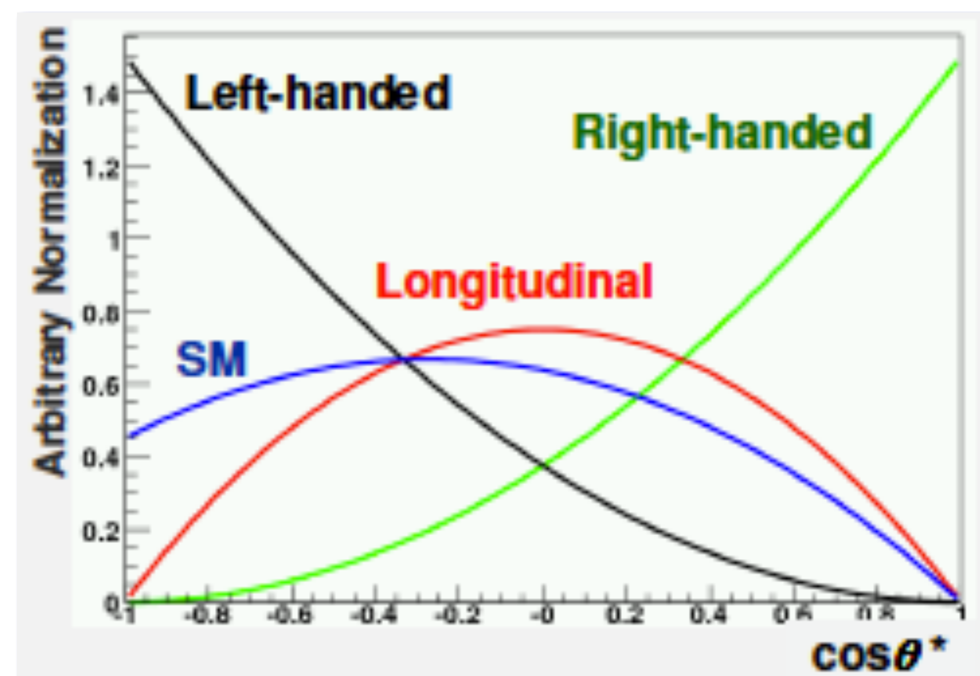
Relative direction between the spin and direction of motion



Lorentz structure of Wtb vertex predicts: 0.3 0.7 0



Measure angle between the momenta of d-type fermion and top quark in W rest frame



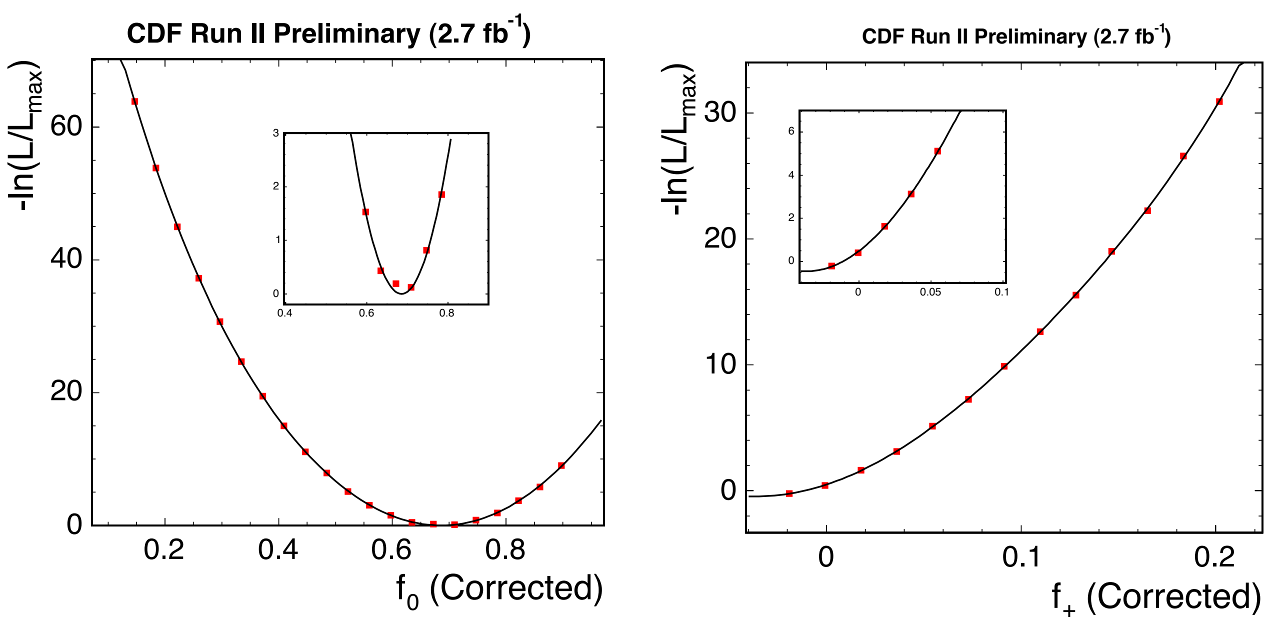
Other possible variables: lepton p_T and M_{lb}^2
Lower sensitivity than $\cos\vartheta^*$

W helicity results

- Matrix Element method in l+jets channel
- simultaneous fit of (f_0,f_+)

$f_0 = 0.88 \pm 0.11\ (stat) \pm 0.06\ (syst)$
$f_+ = -0.15 \pm 0.07\ (stat) \pm 0.06\ (syst)$
$\rho_{0+} = -0.59$

2.7 fb^{-1}

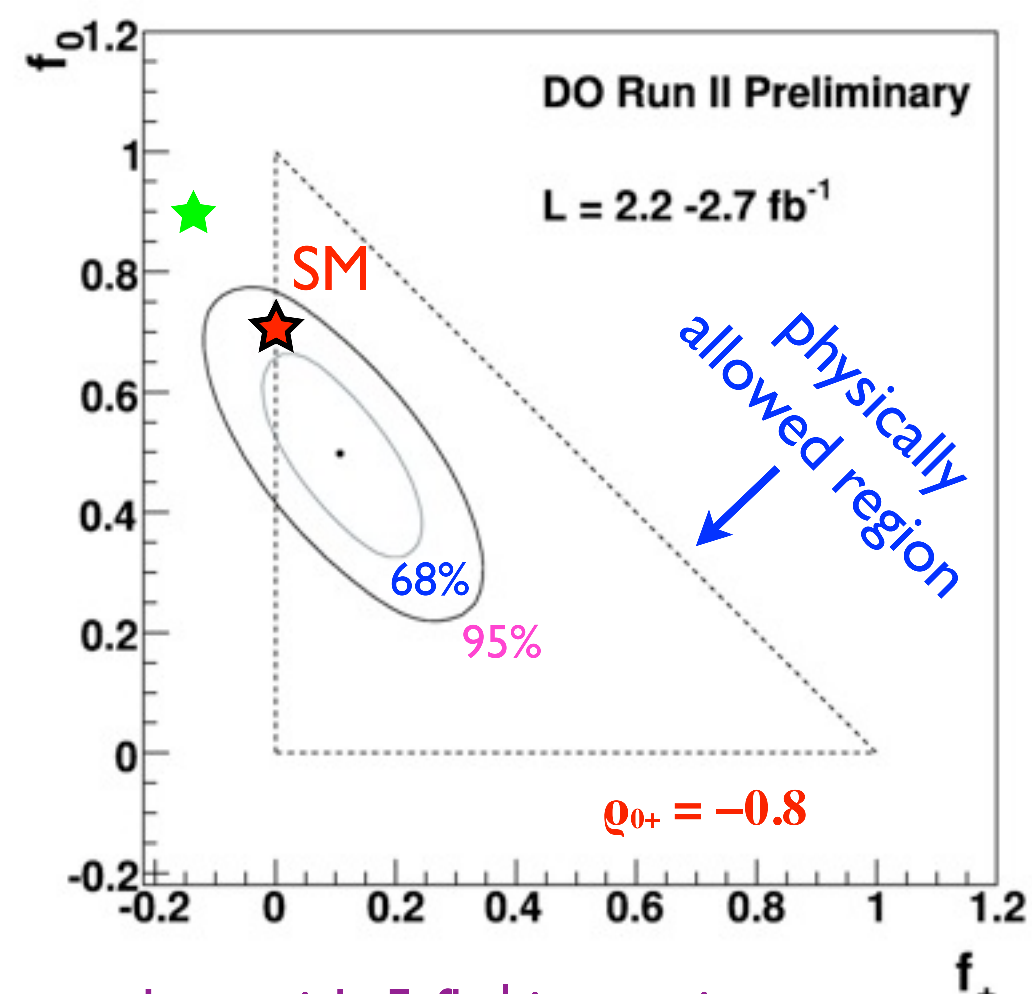


$f_0 = 0.70 \pm 0.07\ (stat) \pm 0.04\ (syst)$ for $f_+ = 0$
$f_+ = -0.01 \pm 0.02\ (stat) \pm 0.05\ (syst)$ for $f_0 = 0.7$
$f_+ < 0.12$ at 95% CL

- Template method in dilepton and l+jets channels
- simultaneous fit of (f_0,f_+)

$f_0 = 0.490 \pm 0.106\ (stat) \pm 0.085\ (syst)$
$f_+ = 0.110 \pm 0.059\ (stat) \pm 0.052\ (syst)$

Consistent with SM at 23%



update with 5 fb^{-1} is coming soon

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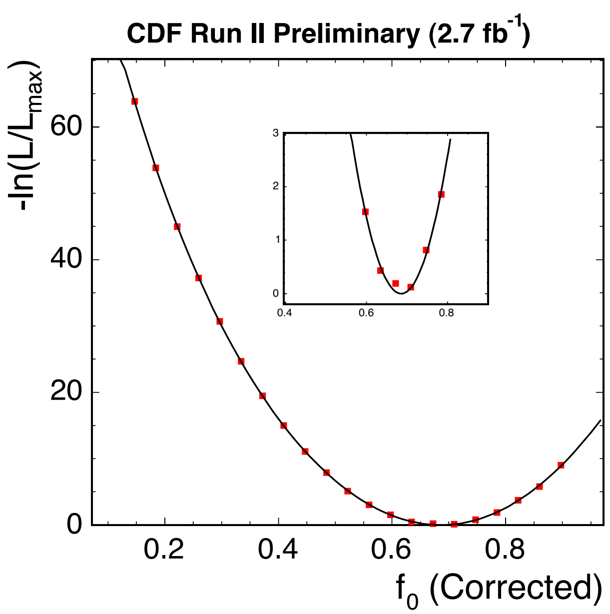

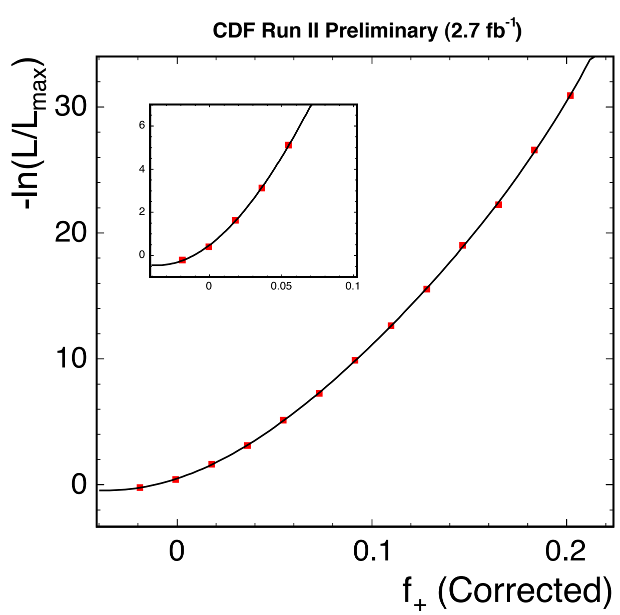

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Expected precision at 8 fb^{-1}