Single top: a window to top quark electroweak interactions

- Introduction
- Single top quark cross section
- Study in Wtb interaction
- Conclusions

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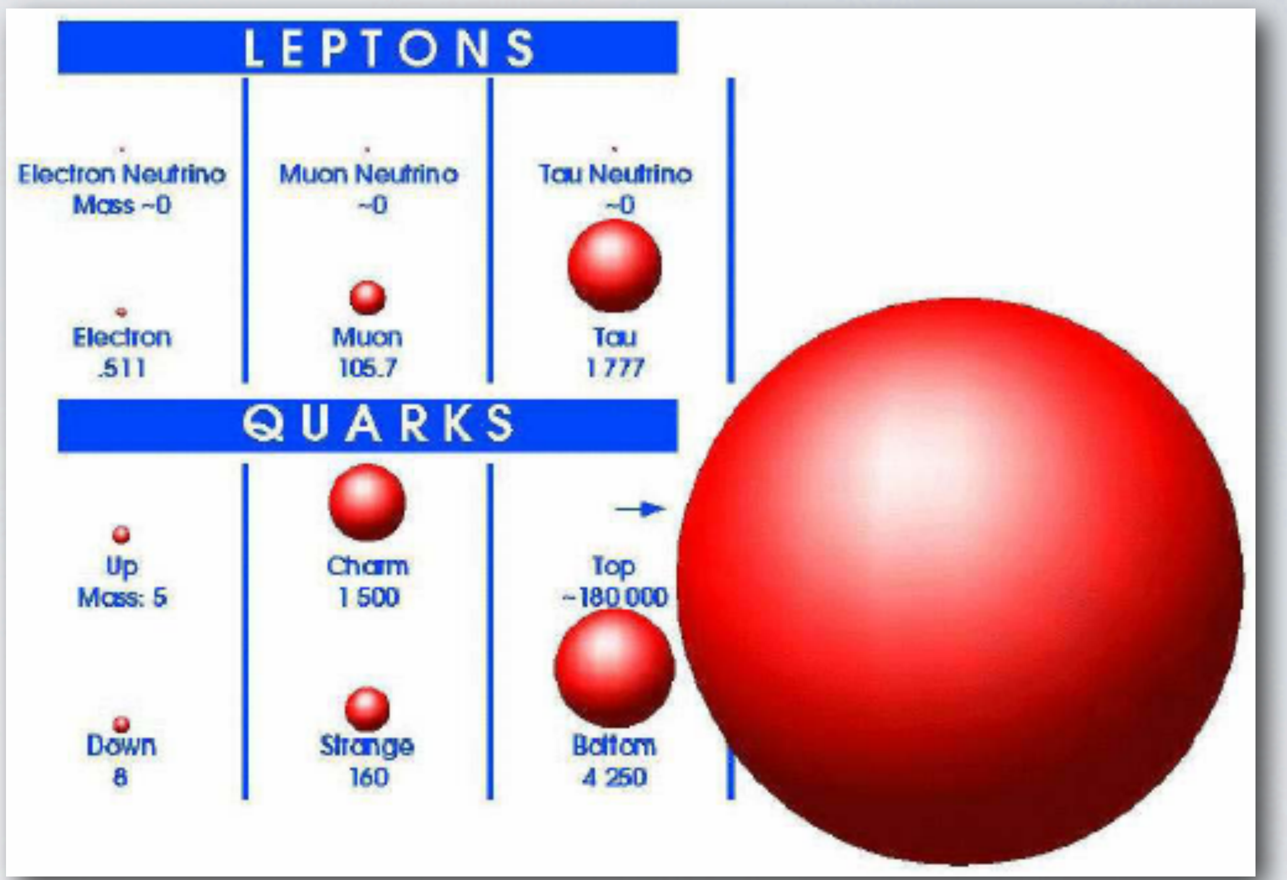
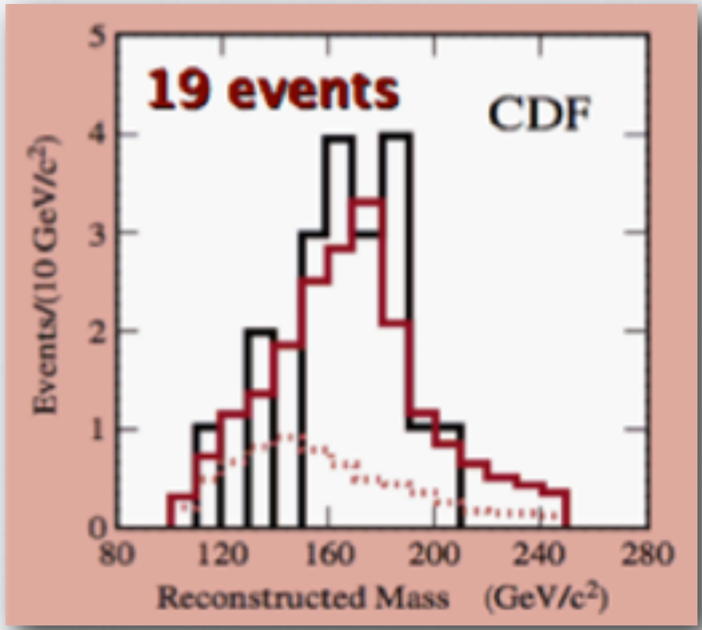
Top quark at the Tevatron

- Predicted by the standard model (SM), top quark can be produced by strong and electroweak interactions.
- Strong pair production of top (double top) quark was observed by CDF and DØ in 1995.
- However, the observation of the electroweak single top production was done very recently in 2009.
- It took 14 years and 50 times more data than the observation of double top, plus the development of new analysis techniques such Multivariate Analysis (MVA) to make this observation possible.

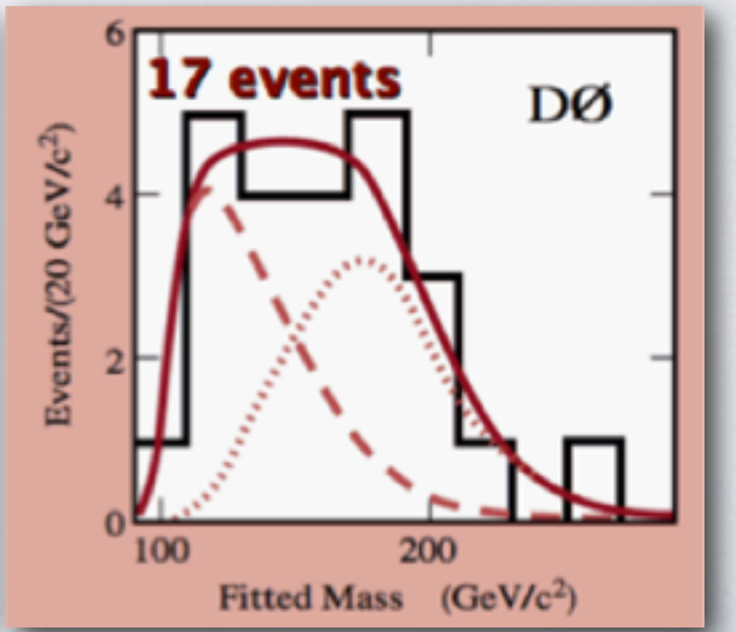


Observation of the top quark

PRL 74 2626 (1995)

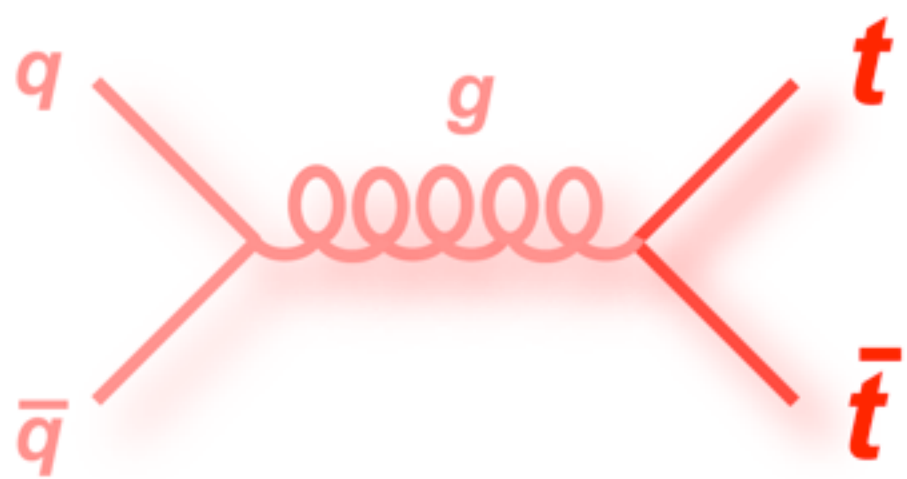


PRL 74 2632 (1995)



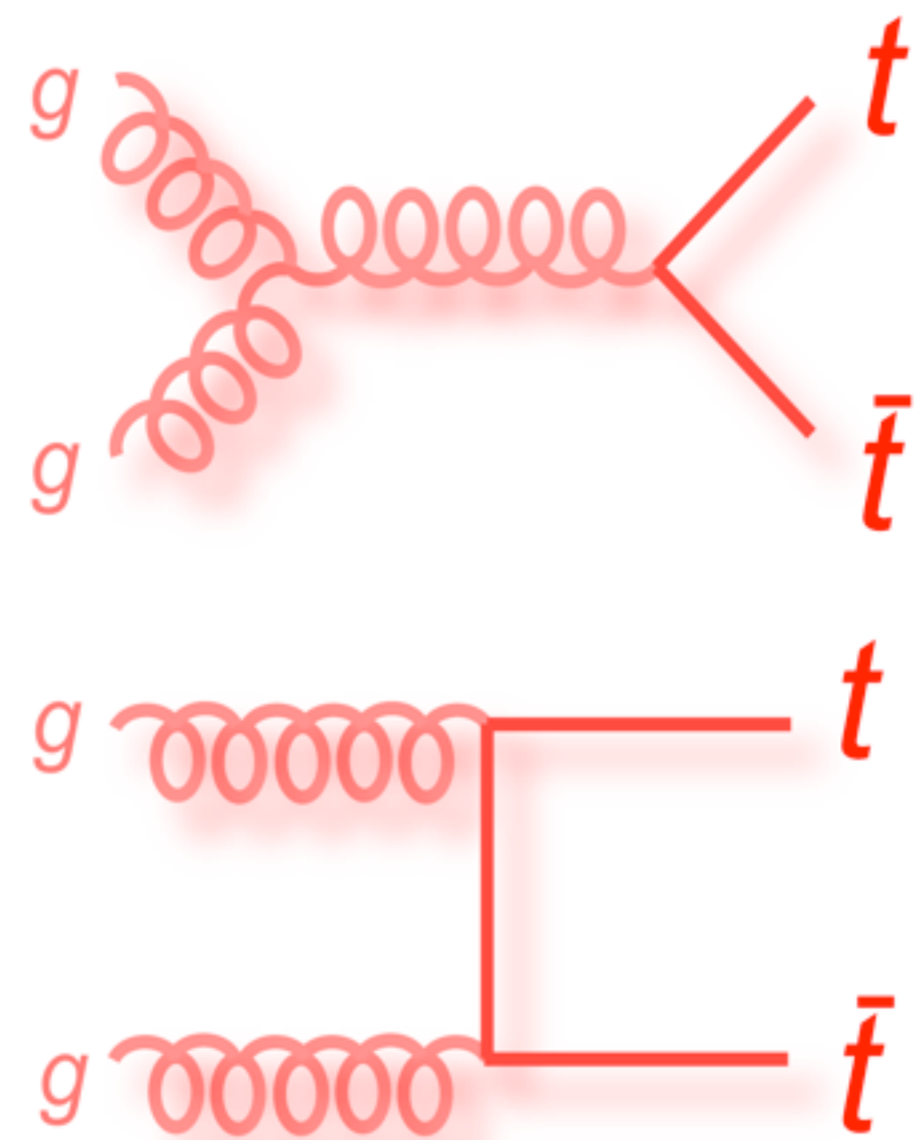
Top pair production channels

q$\bar{q}$ annihilation ($qq \rightarrow t\bar{t}$)



Main production at Tevatron

Gluon fusion ($gg \rightarrow t\bar{t}$)

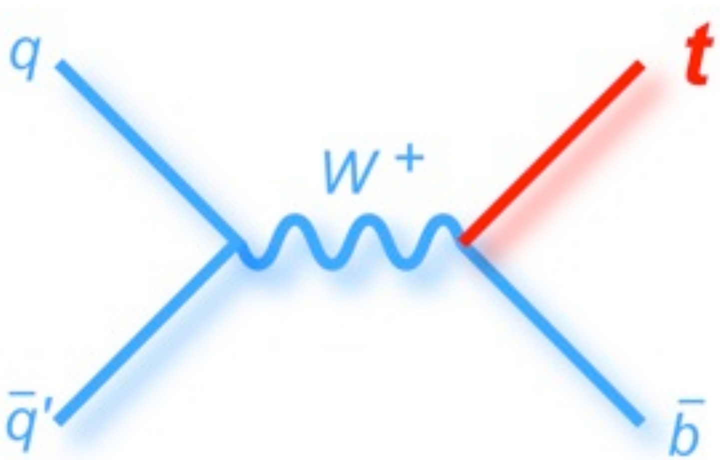


	qq→tt	gg→tt	xsec [pb]
Tevatron[1] (1.96 TeV)	81%	19%	7.46
LHC[2] (7 TeV)	15%	85%	163

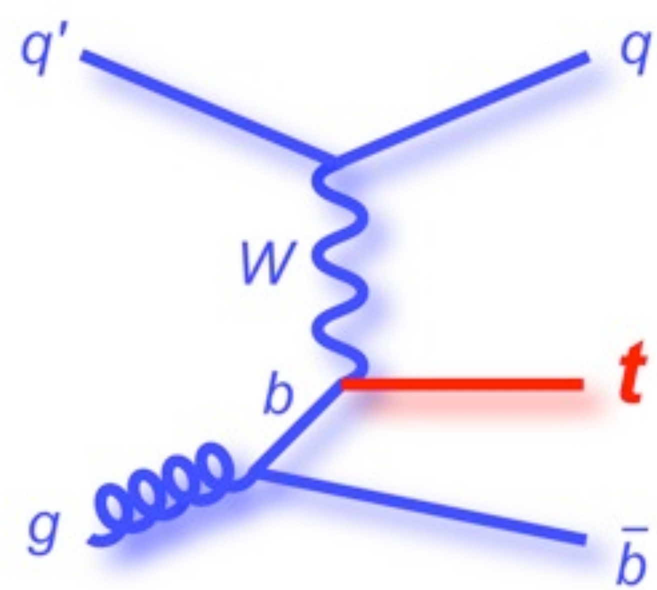
1: PRD 78, 034003 (2008)
2: PRD 82, 114030 (2011)

Single top production channels

s-channel (tb)

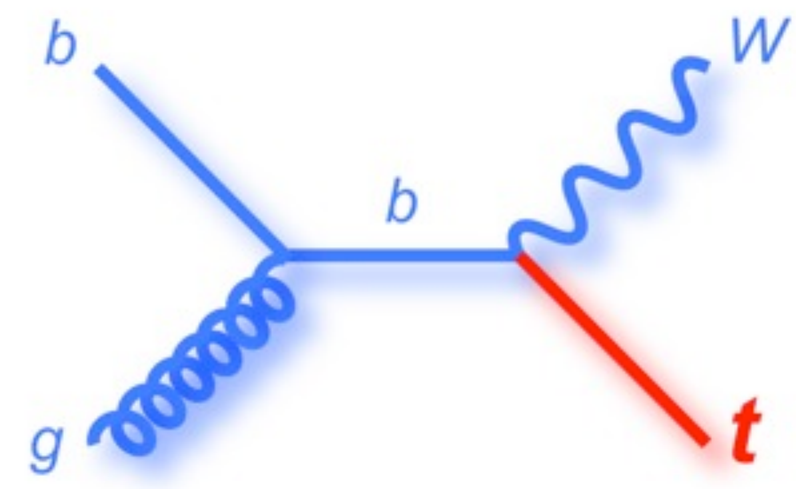


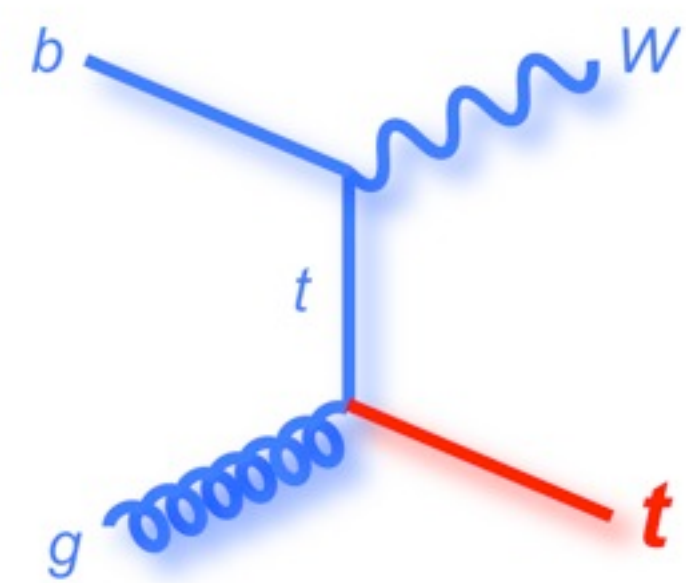
t-channel (tqb)



Main production at Tevatron

Associated tW



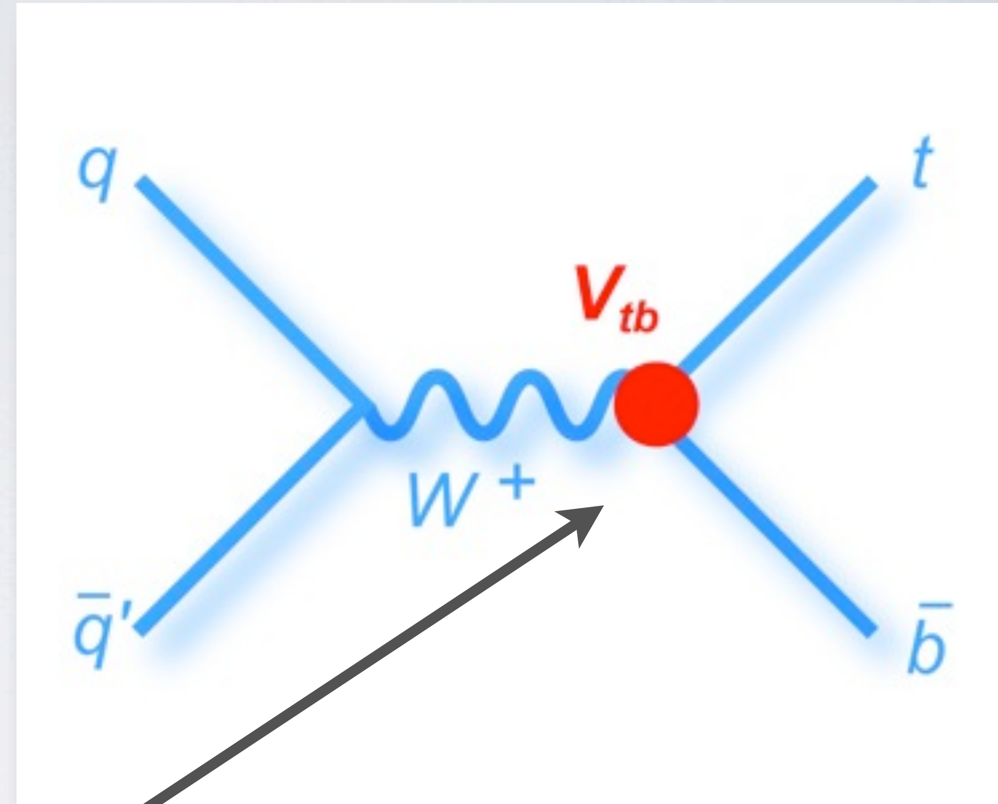


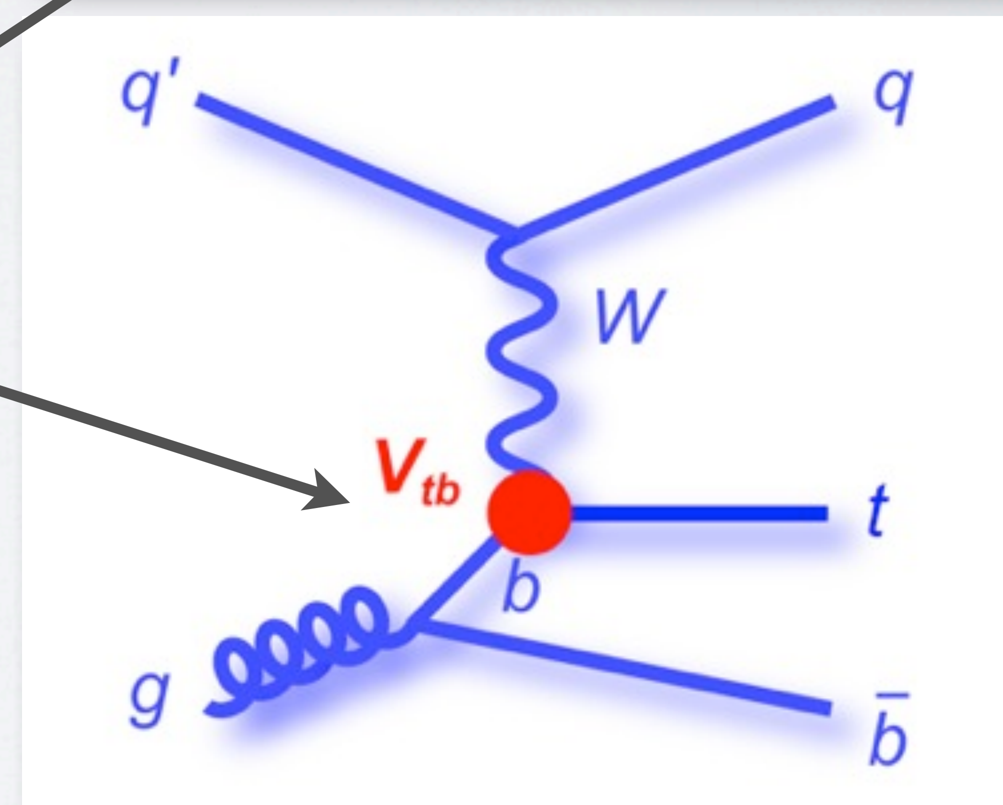
s-channel is not enhanced much →	tb [pb]	tqb [pb]	tW [pb]
Tevatron[1] (1.96 TeV)	1.04	2.26	0.30
LHC[2] (7 TeV)	↓ x4.4 4.59	↓ x28 64.2	↓ x26 7.8

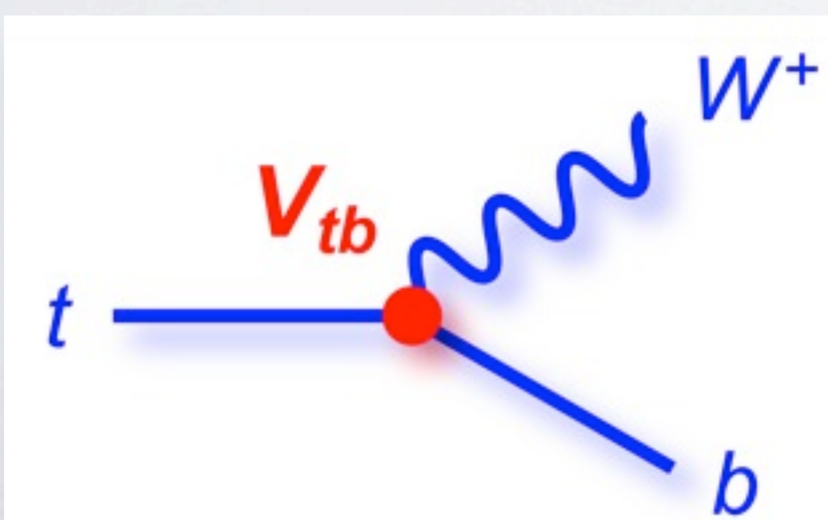
1: PRD 74, 114012 (2006)
2: PRD 81, 054028 (2010)
PRD 83, 091503 (2011)

Why study single top quark production ?

- Although the single top quark production was observed in 2009 the details of its production can be better measured.
- Beyond SM (BSM) processes can look like single top production.
- **Direct probe of the Wtb electroweak interaction with only few assumptions.**

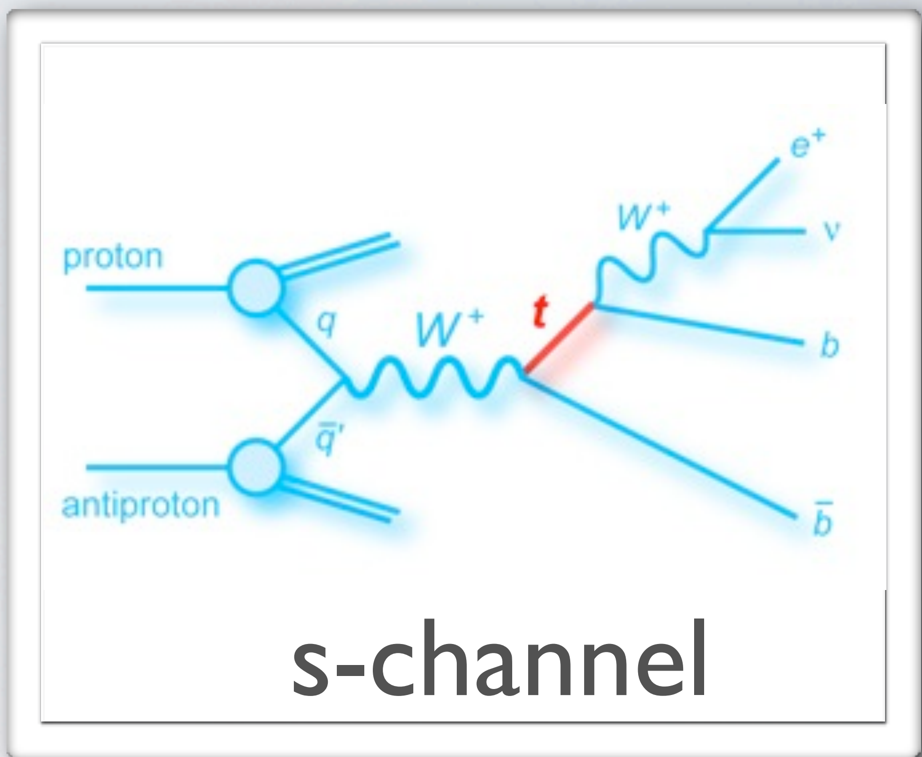


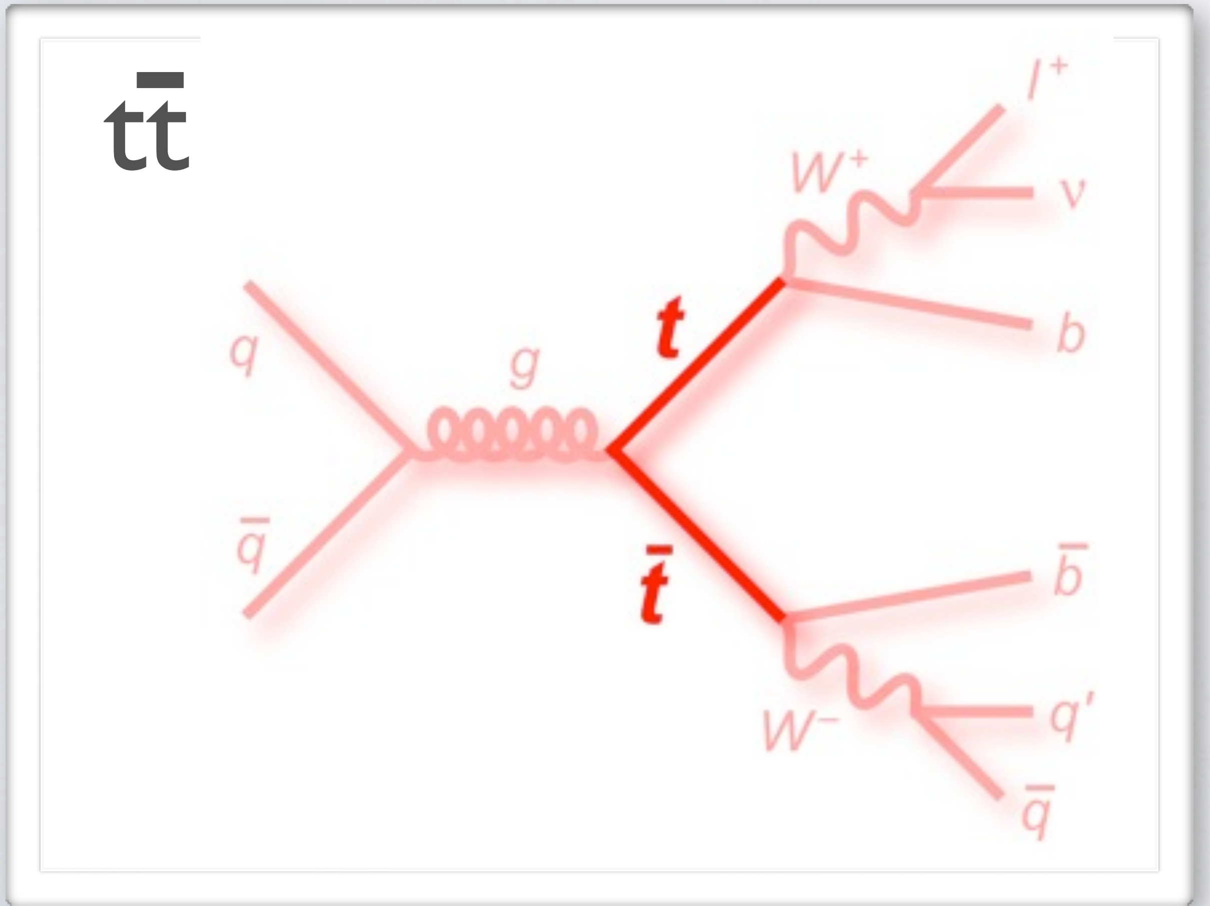


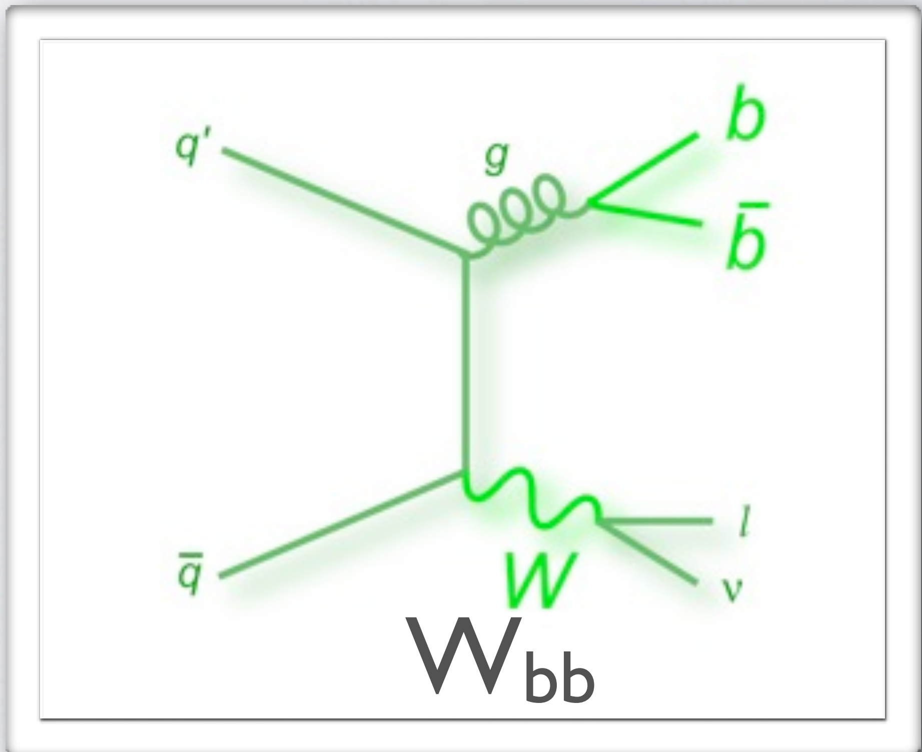


Challenge of the analysis

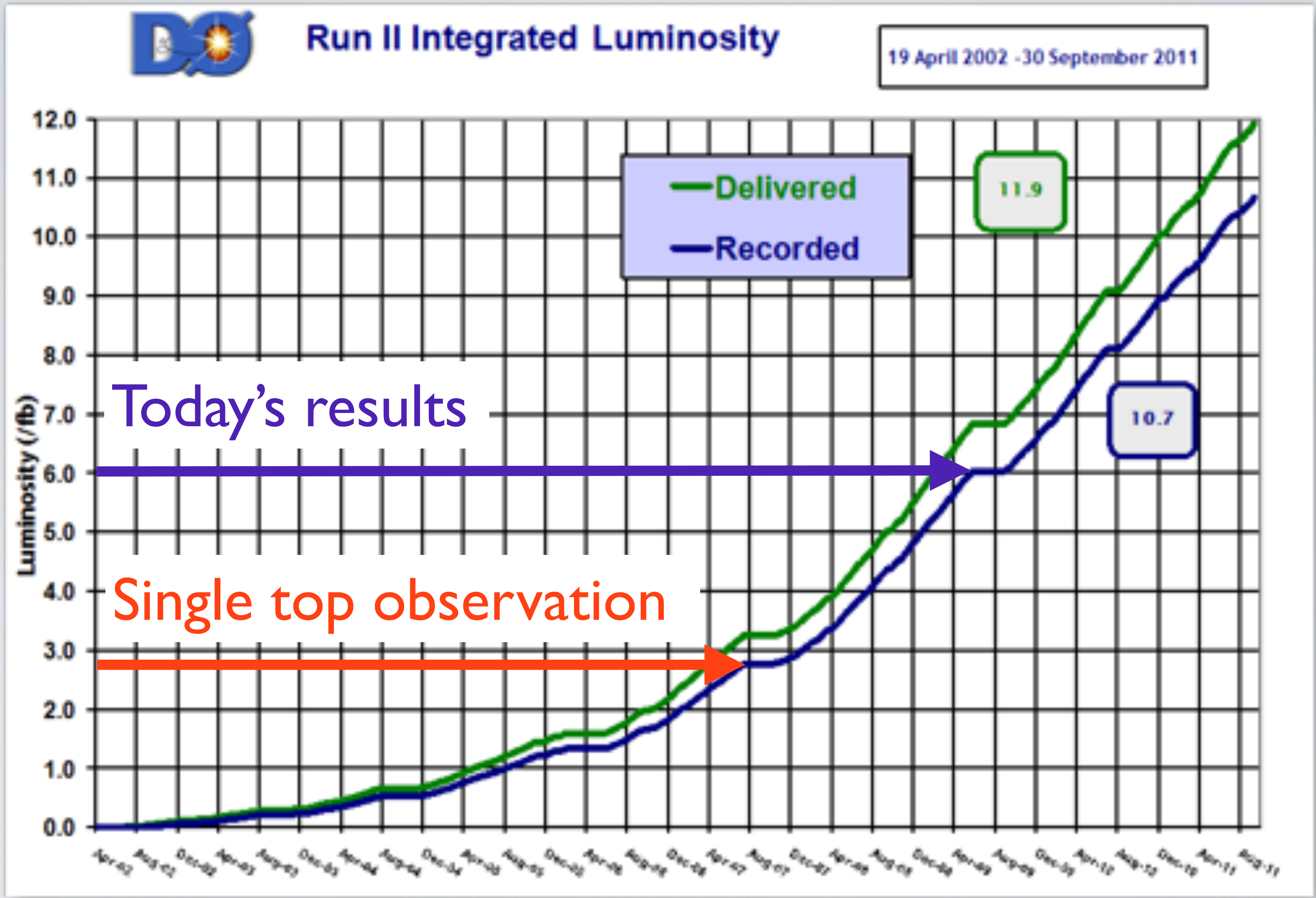
- Smaller production rate ~ 1/2 of top pair production.
- Some backgrounds have similar final states to single top.







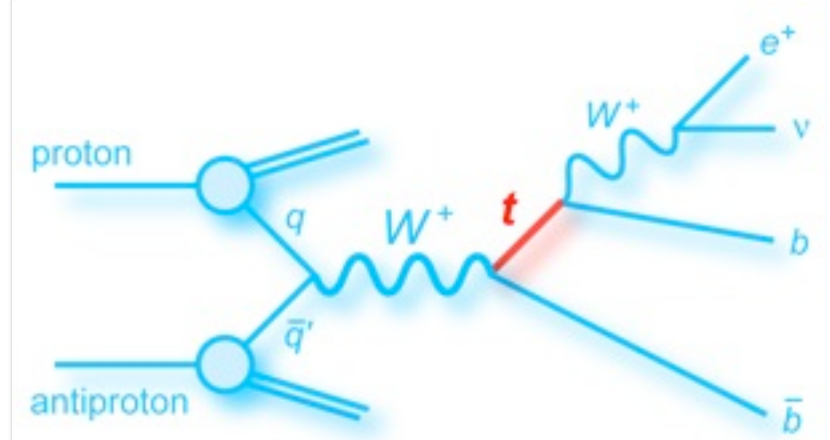
Dataset



Many thanks to the accelerator division!

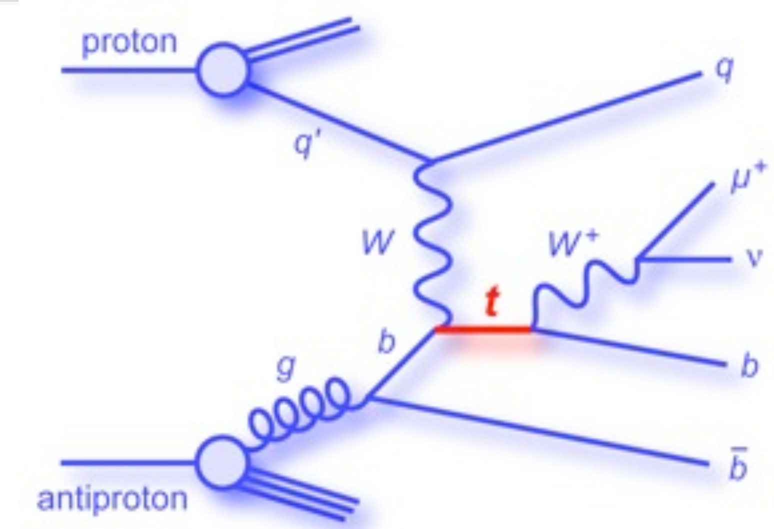
Event selection

- One high-p_T isolated electron or muon.
- Large missing transverse energy.
- Two, three and four jets.
- Total transverse energy cut to reject multijet background.
- b-jets identification.



s-channel

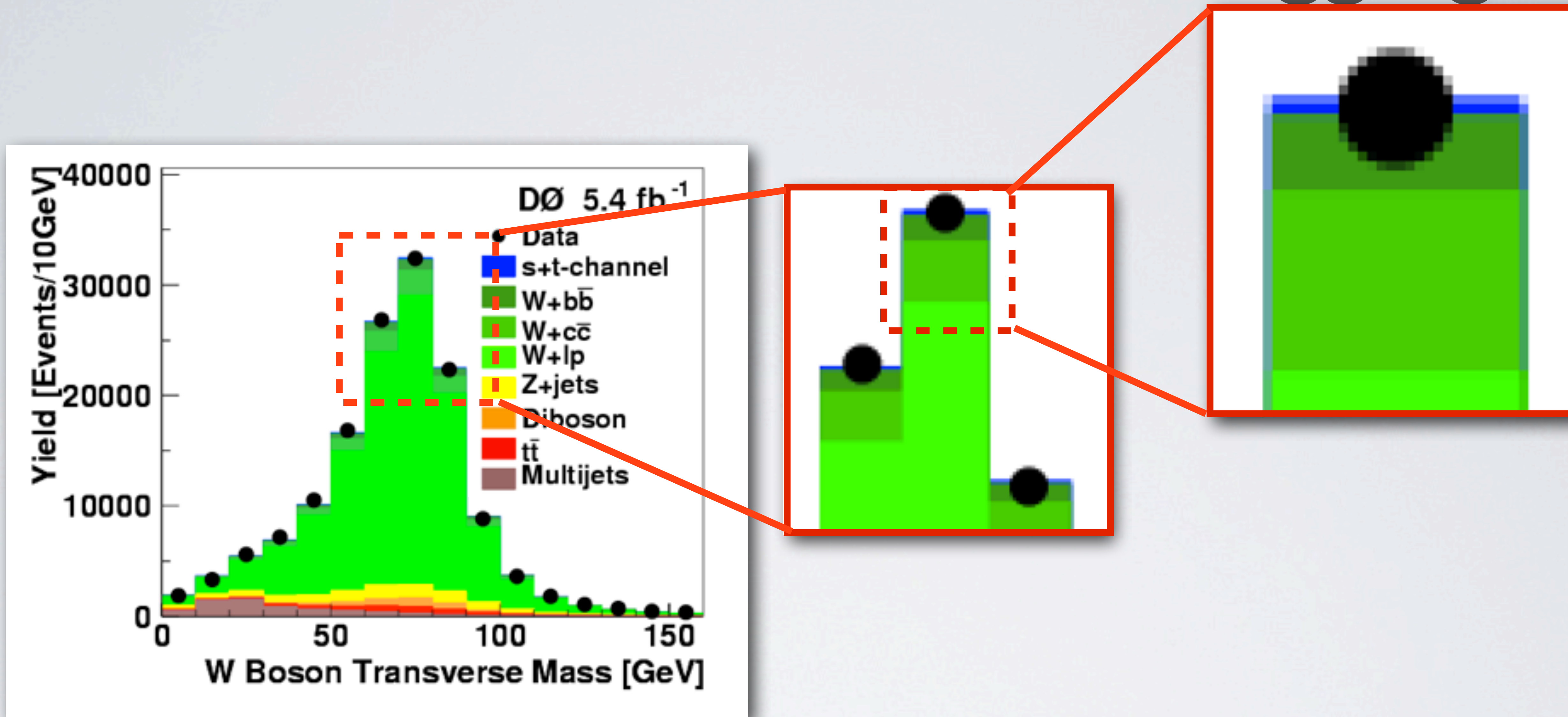
σ_{SM} = 1.04 ± 0.04 pb



t-channel

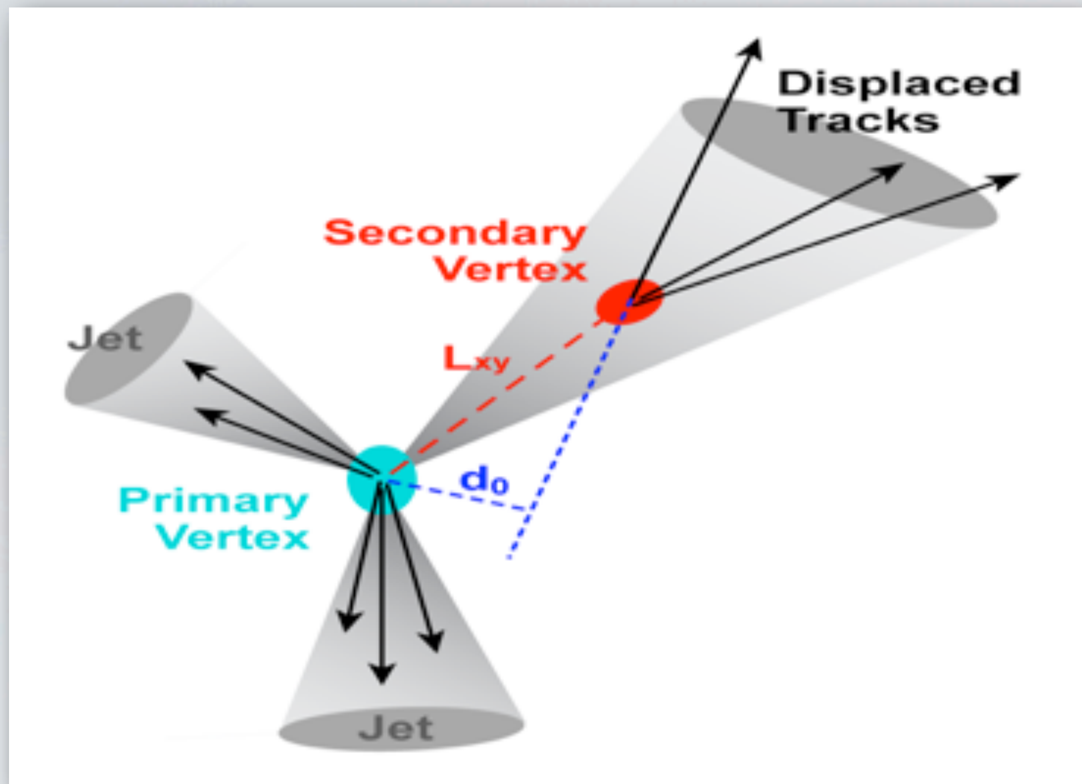
σ_{SM} = 2.26 ± 0.12 pb

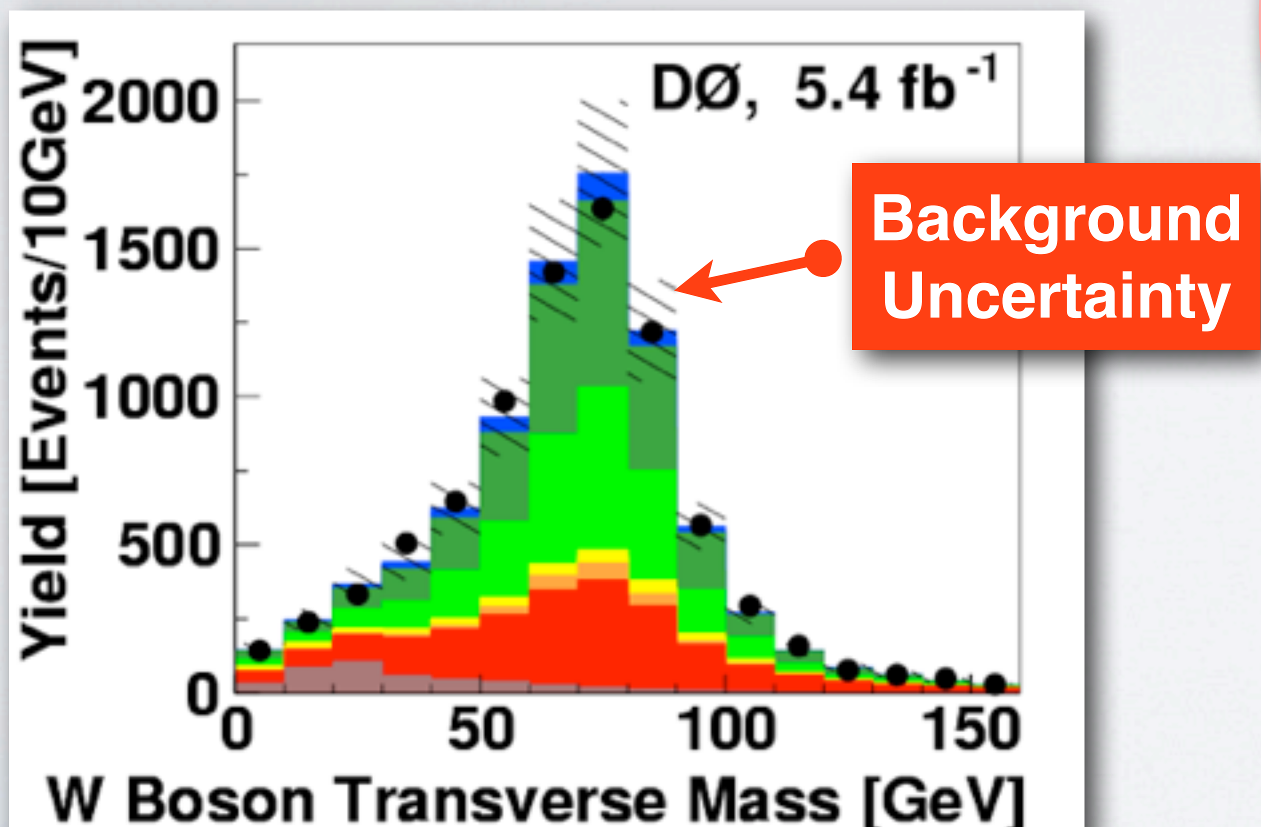
Event selection before b-tagging



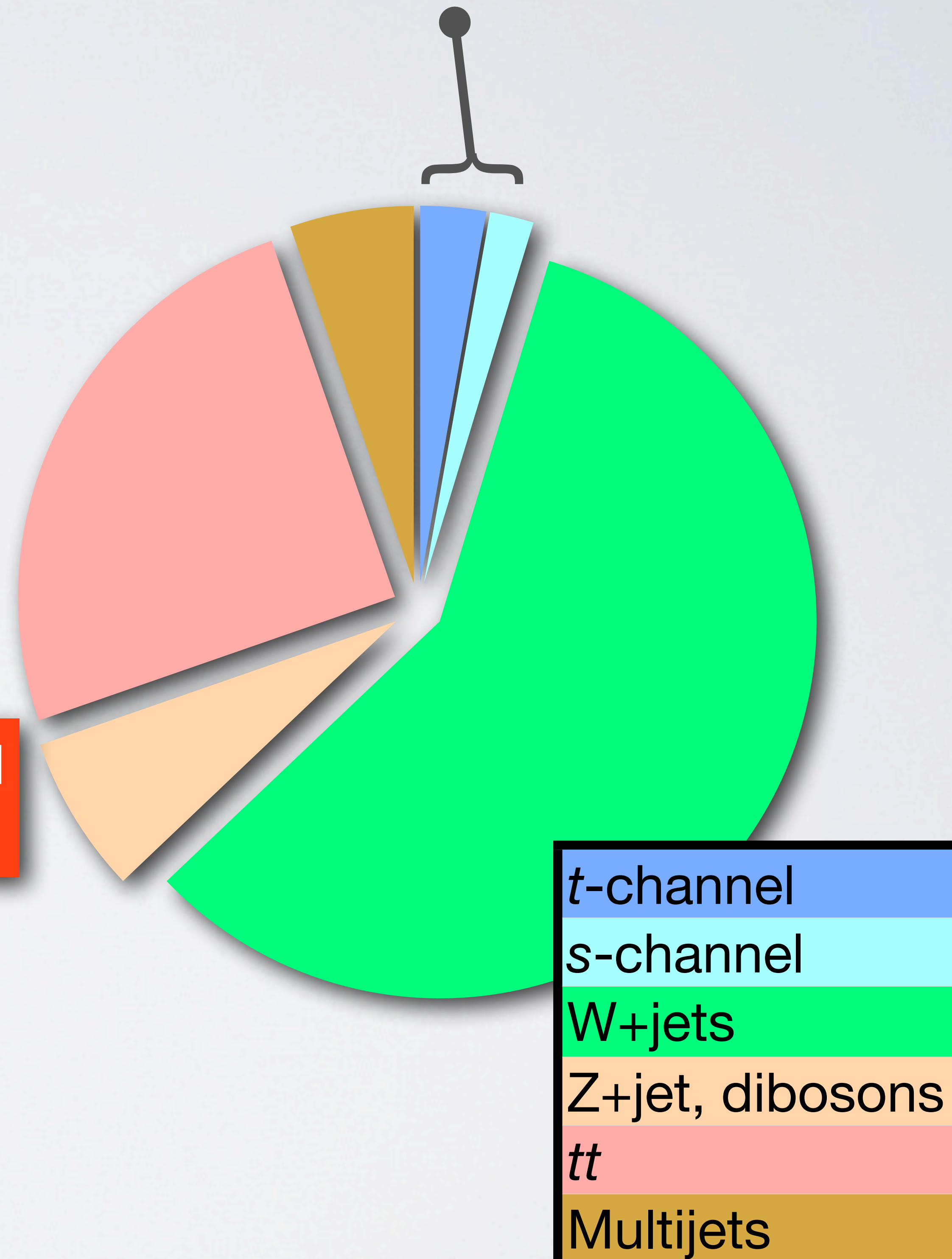
Signal (single top) : Background ~ 1:185.

Event selection after b-tagging



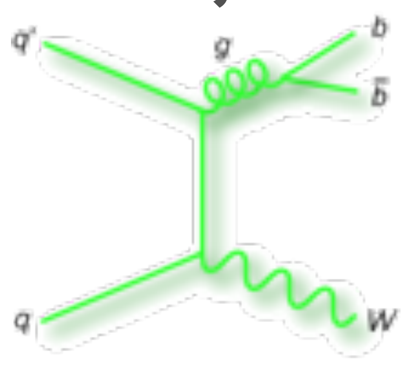


S:B ~ 1:20



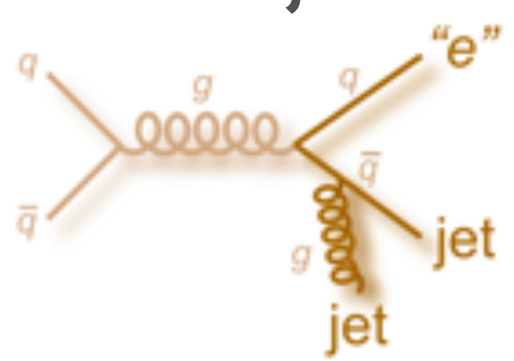
Backgrounds and Event yields

W+jets



Modeled by Alpgen
Kinematics corrected to data
Normalized to data

Multijets



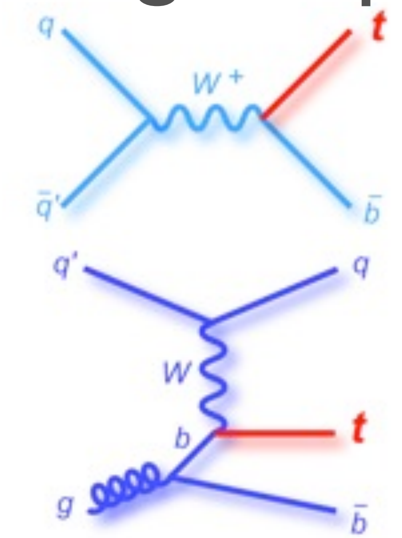
Modeled using data
Normalized to data

Event yields in 5.4/fb DØ data

e,μ, 2,3,4-jets 1,2-tags combined

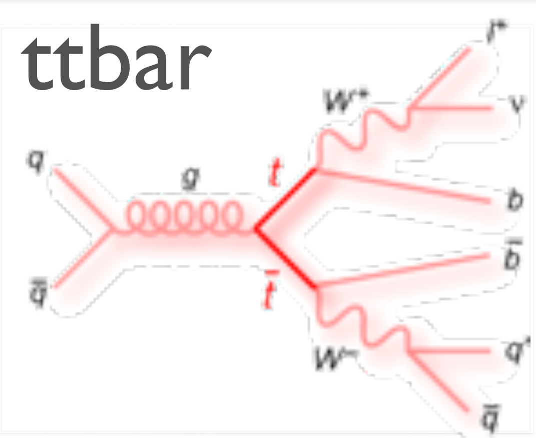
t-channel	239 ± 28
s-channel	160 ± 27
W+jets	4943 ± 598
Z+jet, dibosons	576 ± 113
tt	2124 ± 383
Multijets	451 ± 56
Total prediction	8492 ± 987
Data	8471 ± 92

Single top



Modeled using Comphep
Normalized to ~NNLO

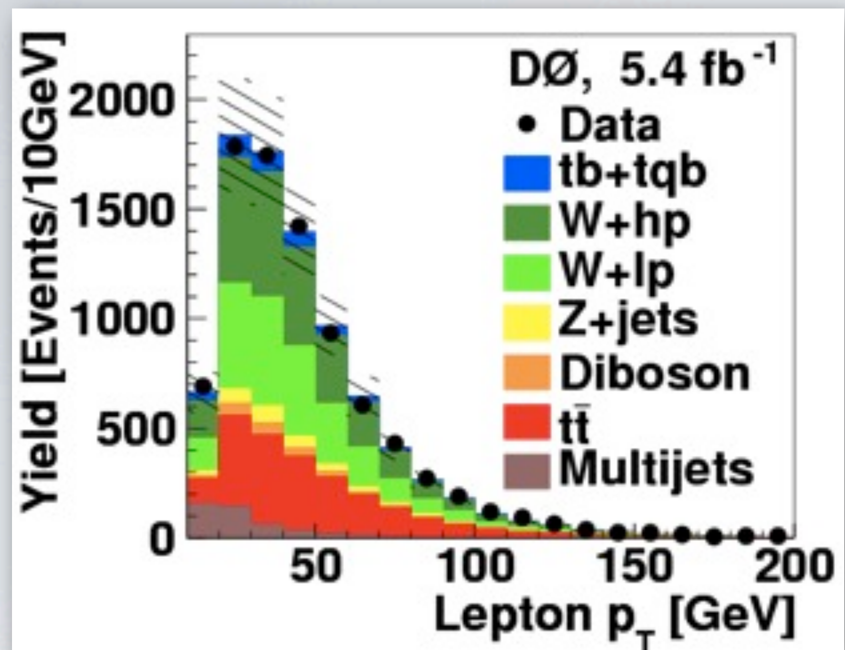
ttbar



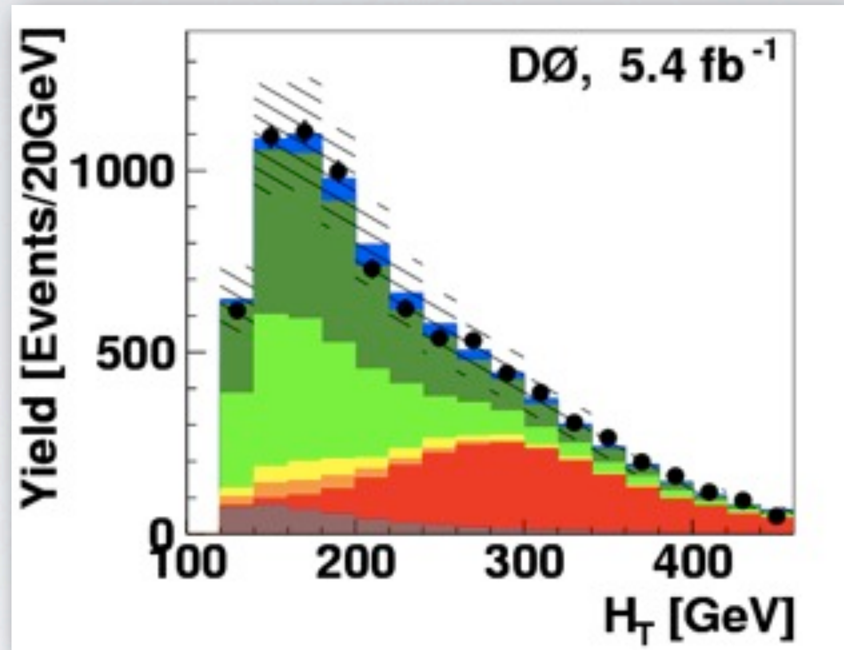
Modeled using Alpgen
Normalized to ~NNLO

Data/simulation agreement

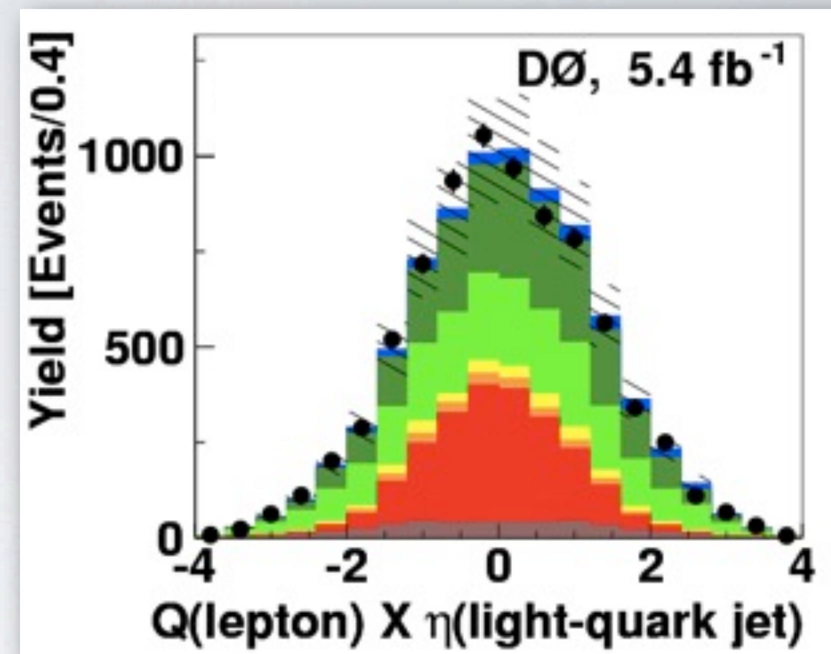
Lepton kinematics



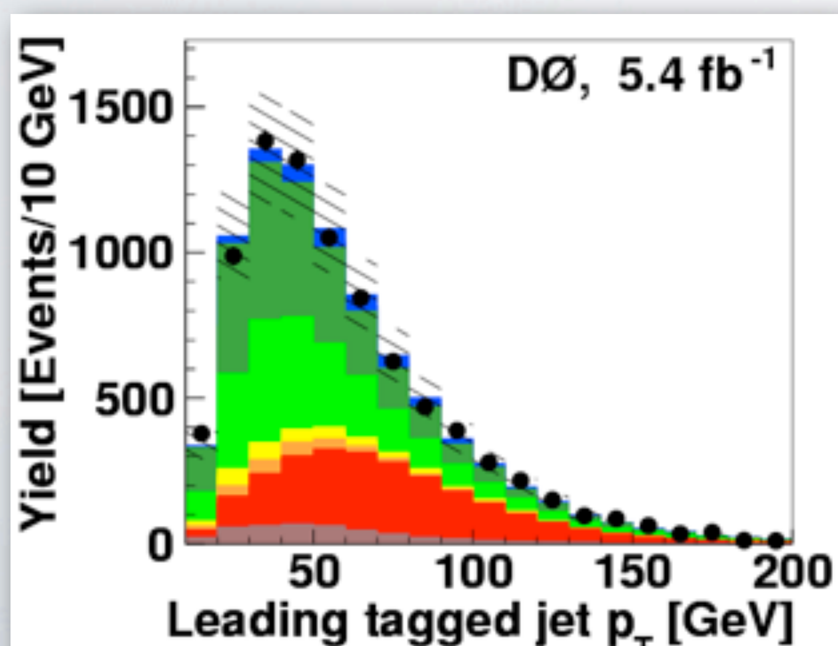
Event kinematics



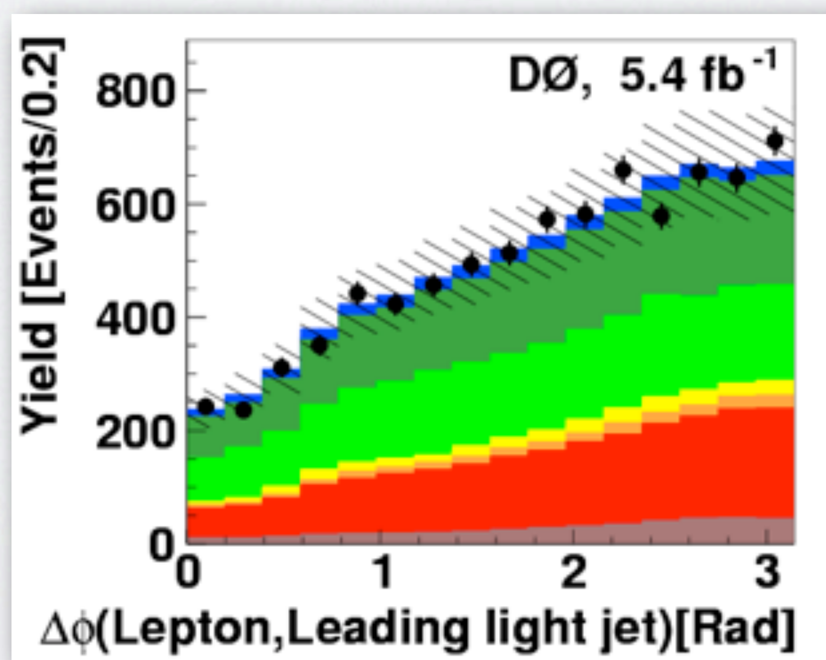
Powerful variables



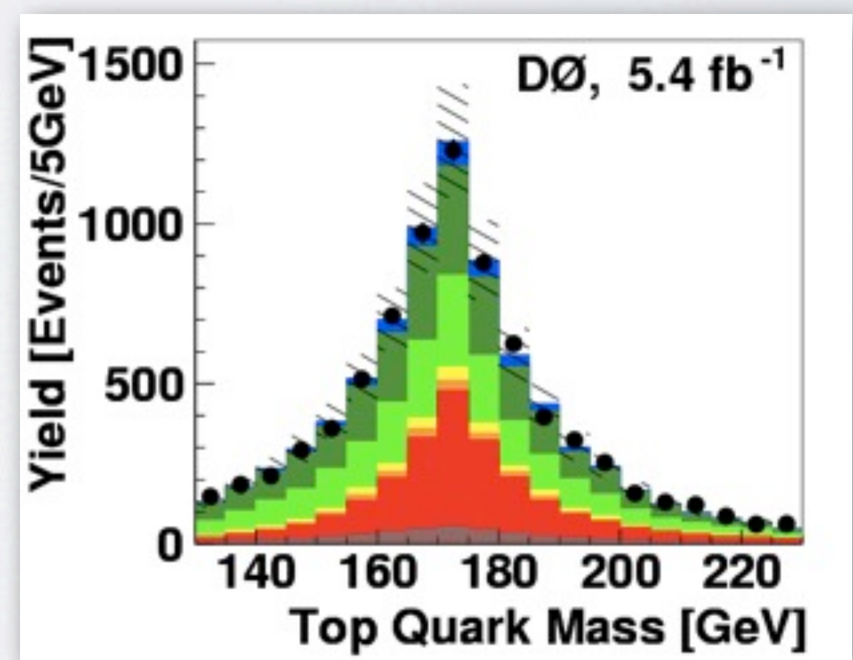
Jet kinematics



Angular correlations



Top quark reconstruction

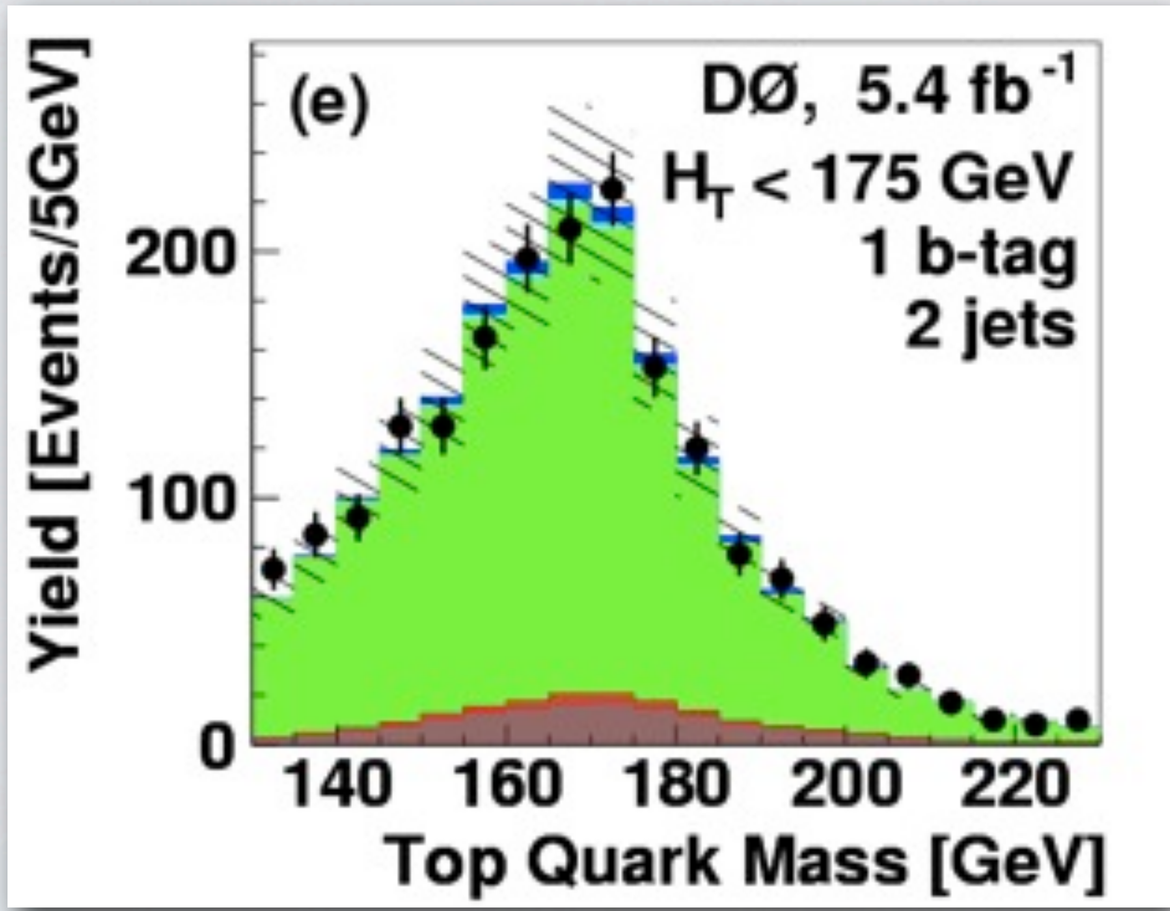


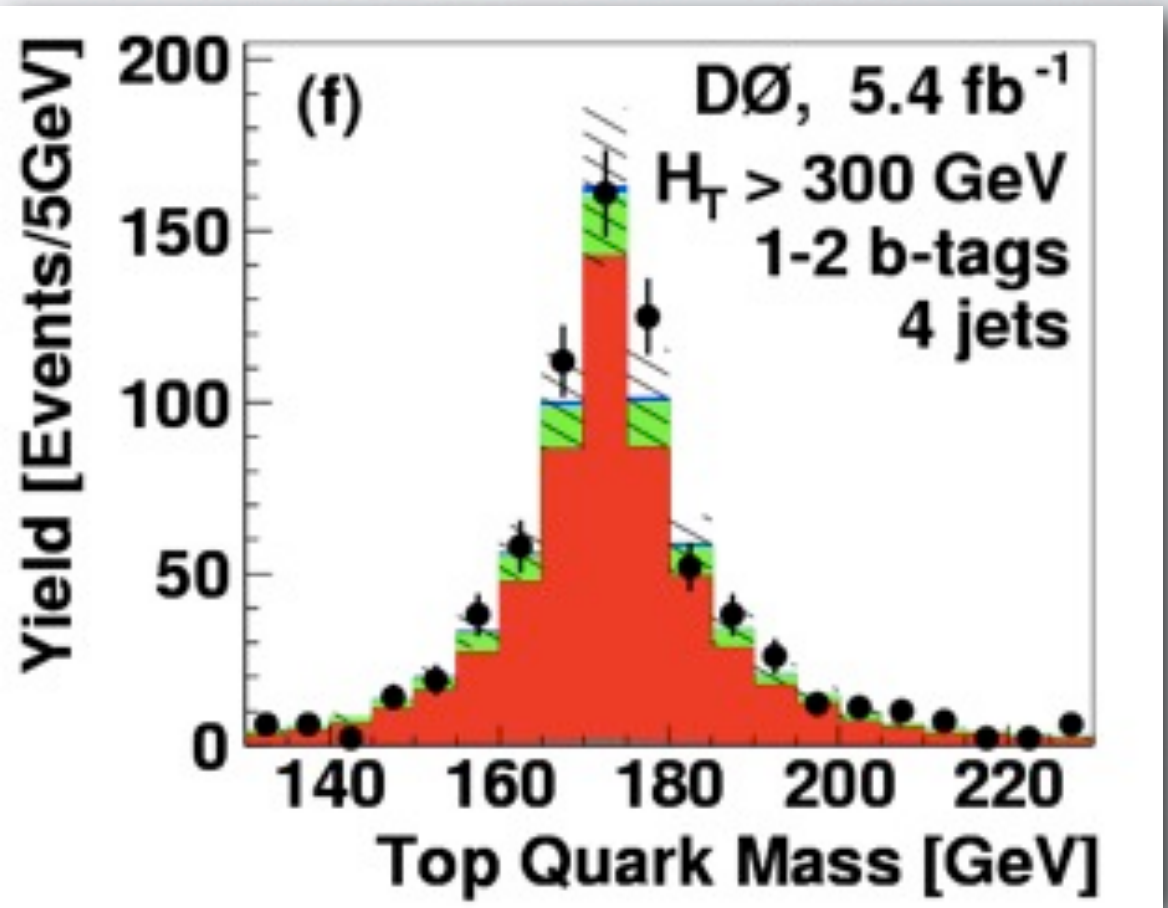
Background modeling

We select events to enhance two of the main backgrounds W+jets and top pairs. Data is well described by the simulation.

W+jets enriched

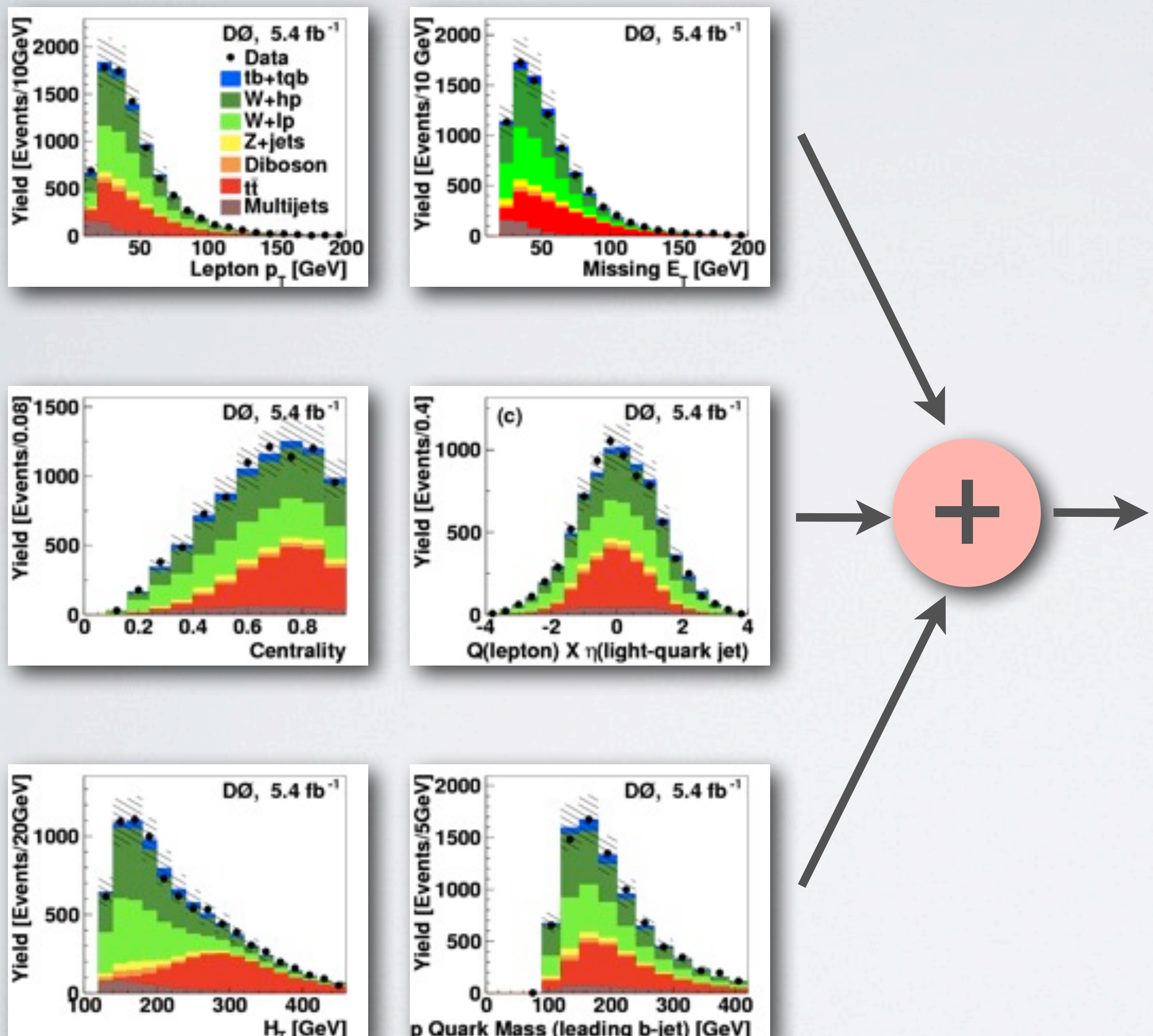
top pair enriched



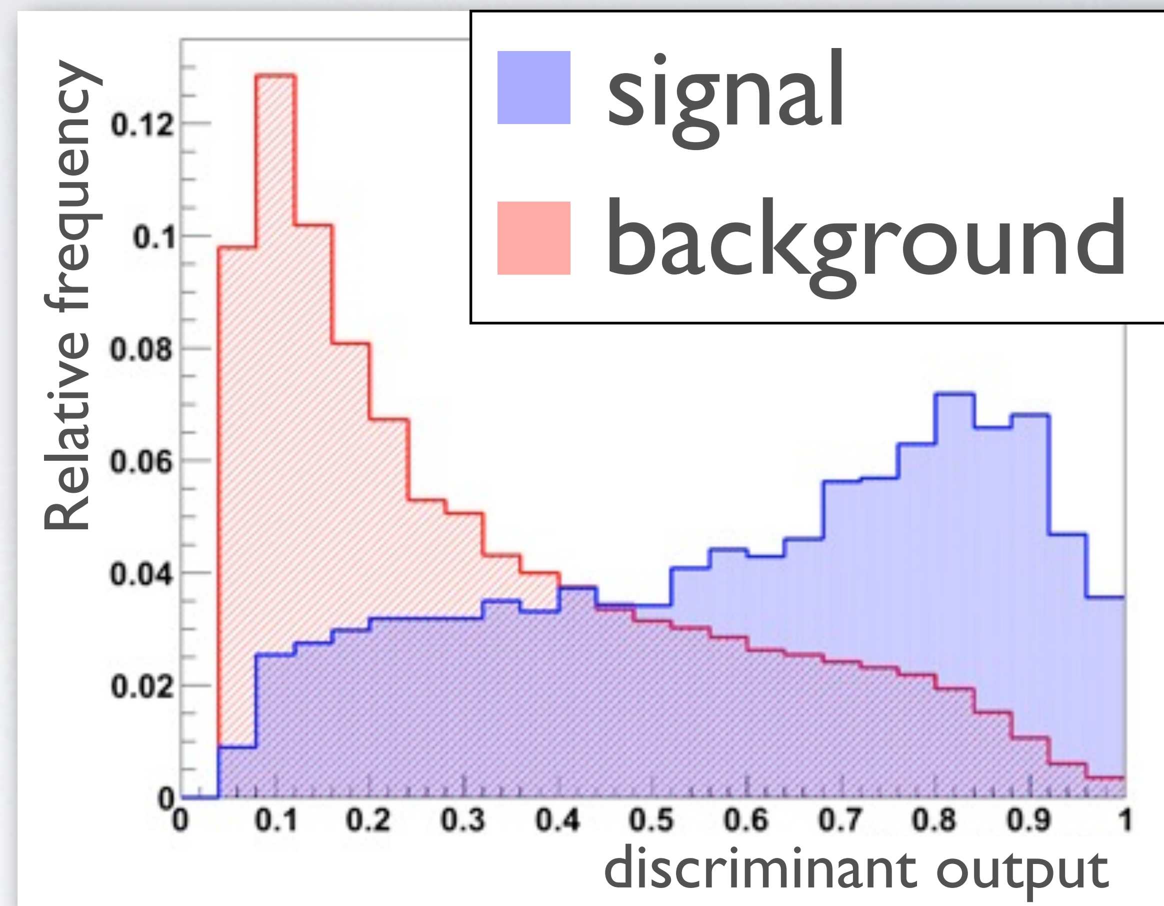


Multivariate Analyses

Combine different kinematic variables with some discrimination power into one variable with larger discrimination.



After training

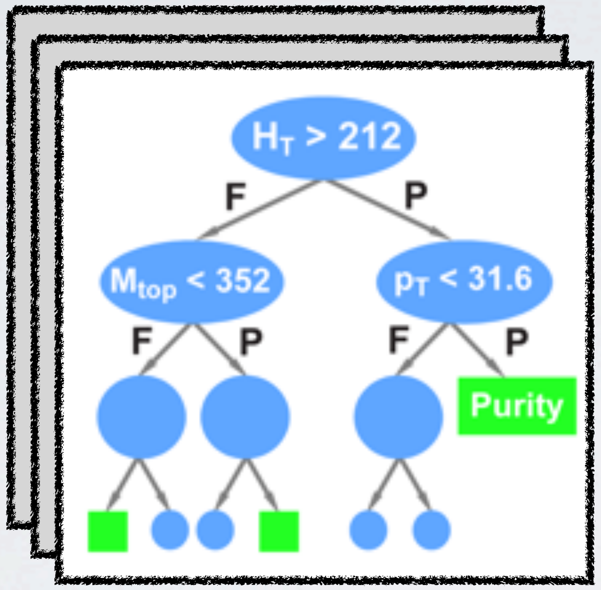


All these methods have a *training process* where they learn to discriminate between signal and background events

Multivariate analyses

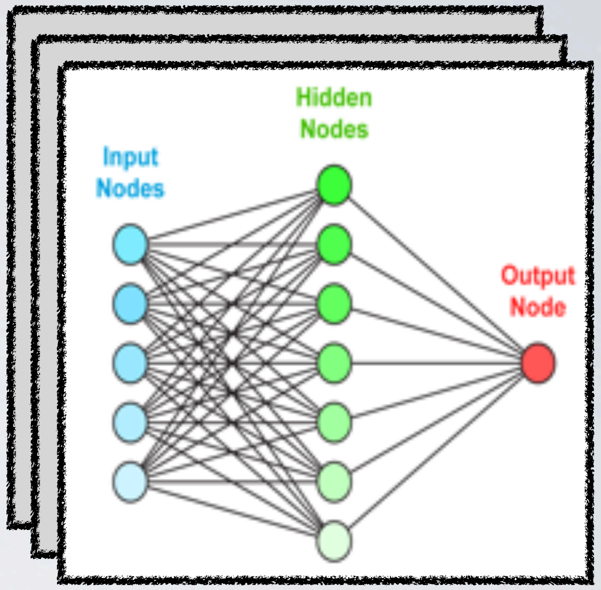
Boosted Decision Tree (BDT)

- Apply sequential cuts keeping failing events.
- Performance is boosted by averaging multiple trees produced by enhancing misclassified events.



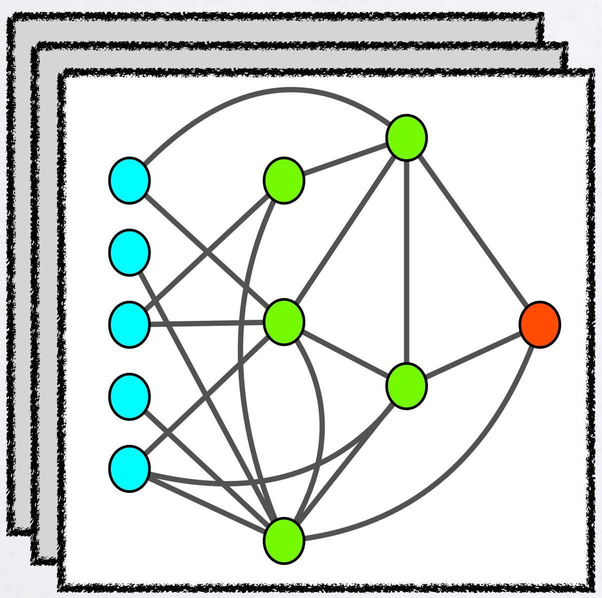
Neural Networks (BNN)

- Bayesian NN (BNN) averaged over many networks, improving the performance.



Neuroevolution of Augmenting Topologies (NEAT)

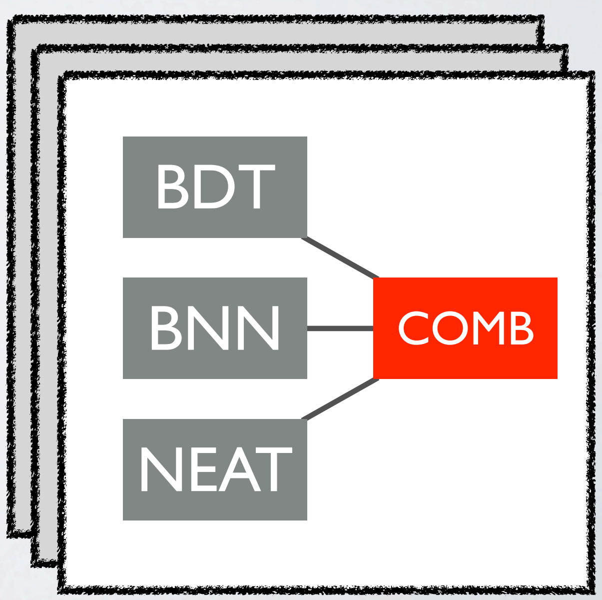
- Genetic algorithms evolve a population of NN.
- Topology of the NN is also part of the training.



BNN Combination

Correlation between methods ~70%

- Different discriminants are combined into one.

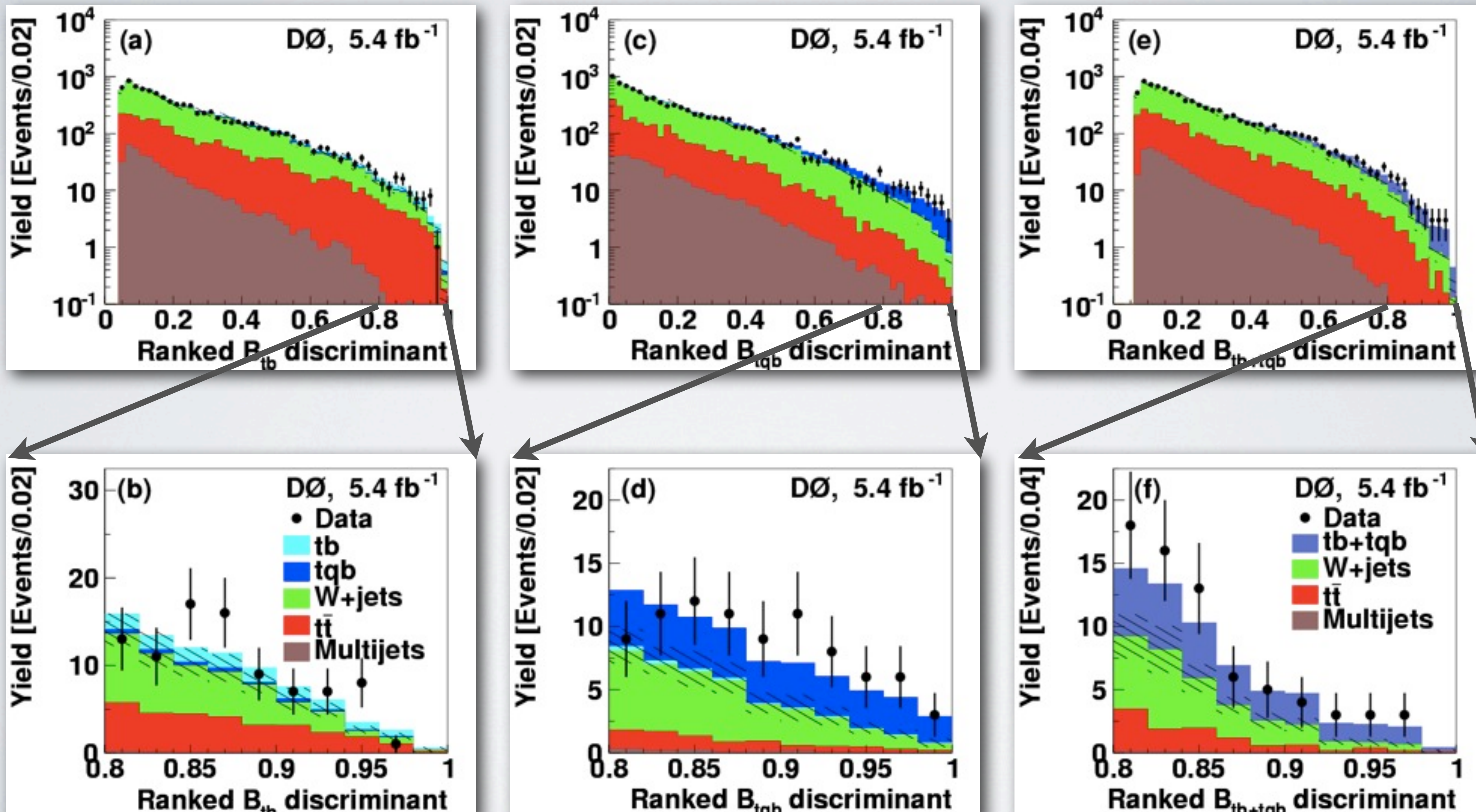


Single top discriminants

s-channel discriminant

t-channel discriminant

s+t-channel discriminant



Cross Section Measurement

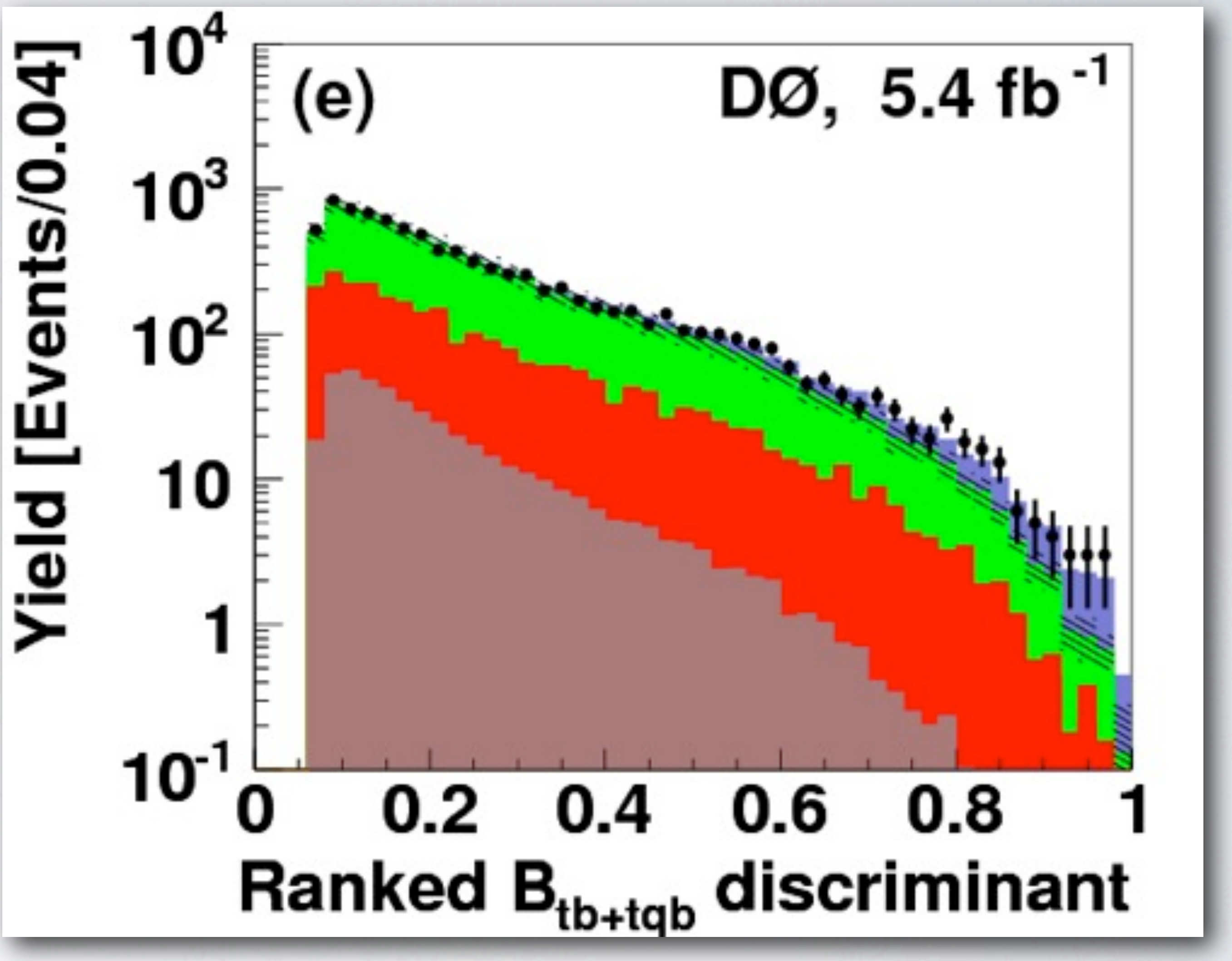
Binned likelihood

$$L(\boldsymbol{D}|\boldsymbol{d}) = \prod_i \frac{e^{-d_i} d_i^{D_i}}{\Gamma(D_i + 1)}$$

Mean event count

$$\boldsymbol{d} = \sigma \overbrace{\boldsymbol{a}}^{\text{signal acceptances}} + \underbrace{\boldsymbol{b}}_{\text{background event yields}}$$

signal production rate (σ)

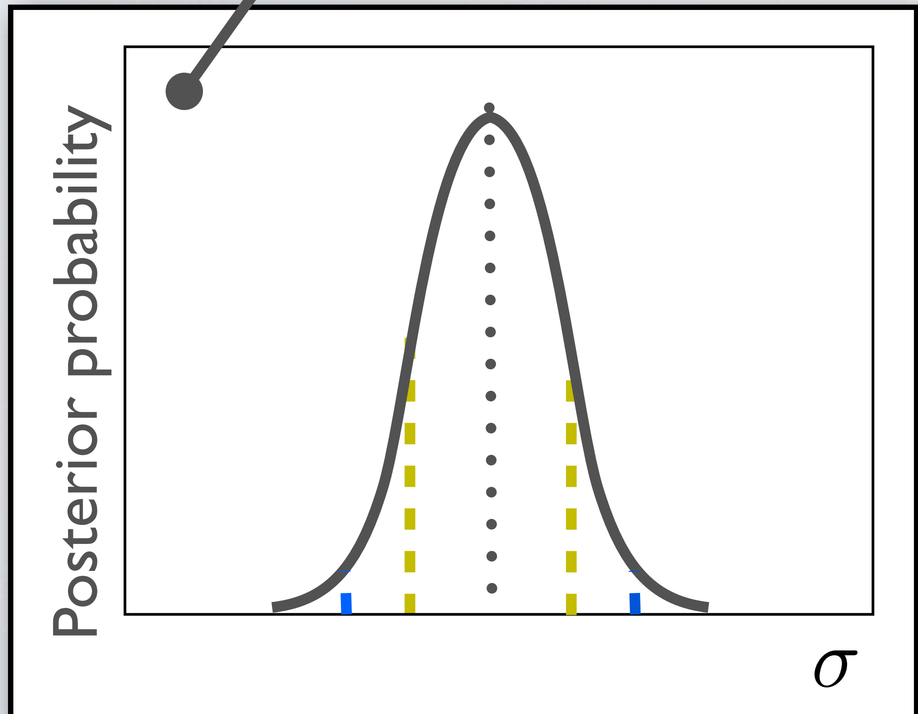


Bayesian statistical analysis

The prior distribution is updated by the likelihood that depends on the data.

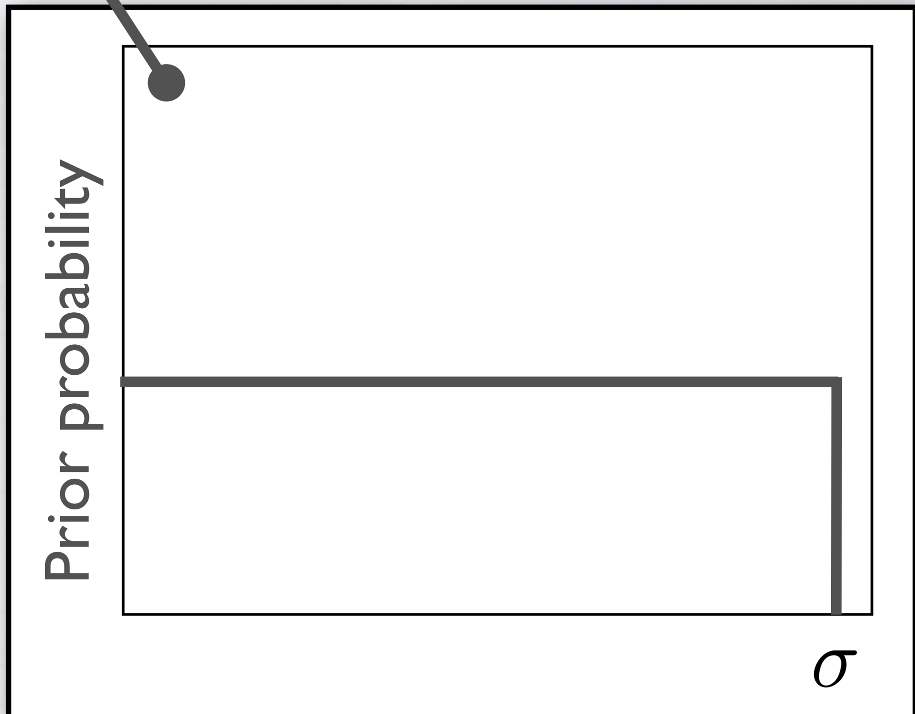
Average the likelihood over the background uncertainties assuming Gaussian priors.

$$p(\sigma) = \frac{1}{\mathcal{N}} \int L(\boldsymbol{D}|\sigma, \boldsymbol{a}, \boldsymbol{b})\pi(\sigma)\pi(\boldsymbol{a}, \boldsymbol{b})d\boldsymbol{a}d\boldsymbol{b}$$



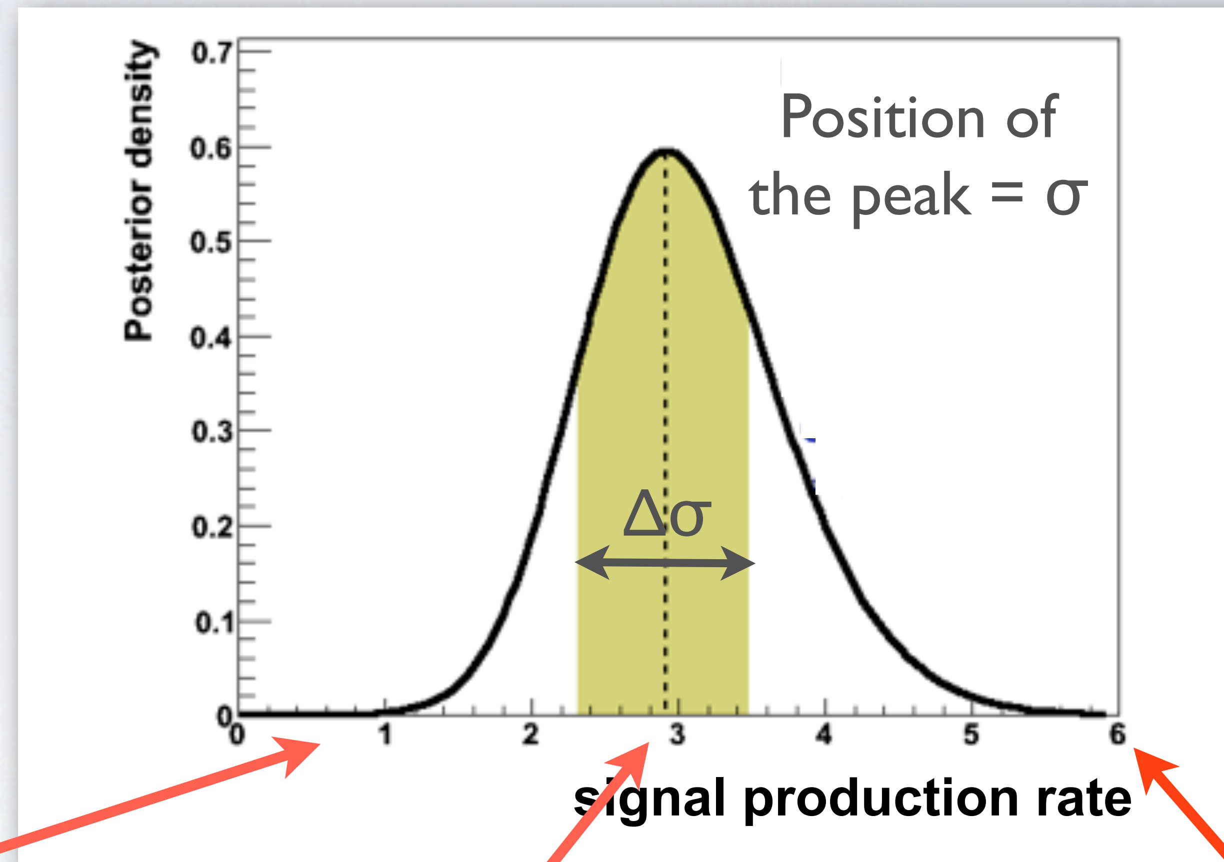
Update

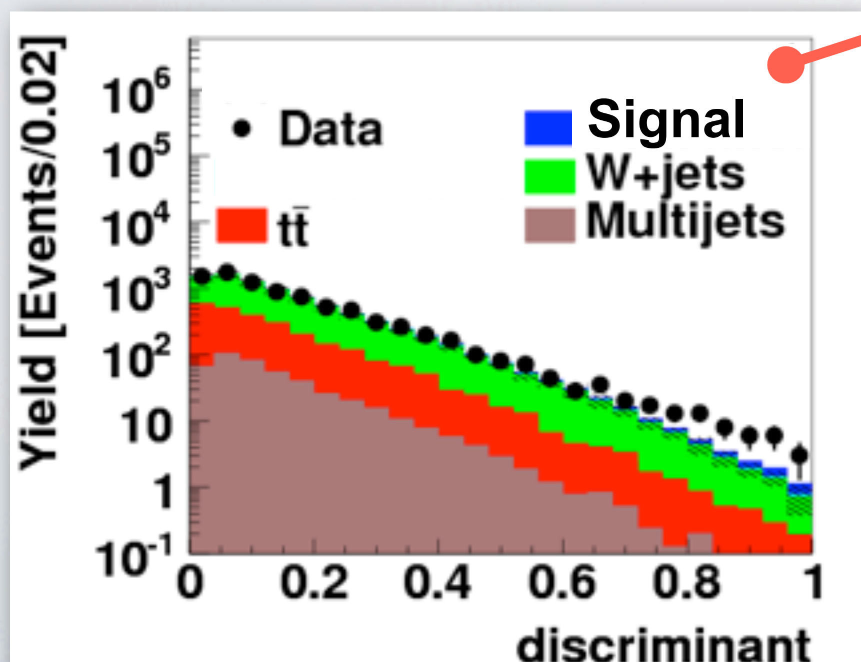
$$L(\boldsymbol{D}|\sigma, \boldsymbol{a}, \boldsymbol{b})$$

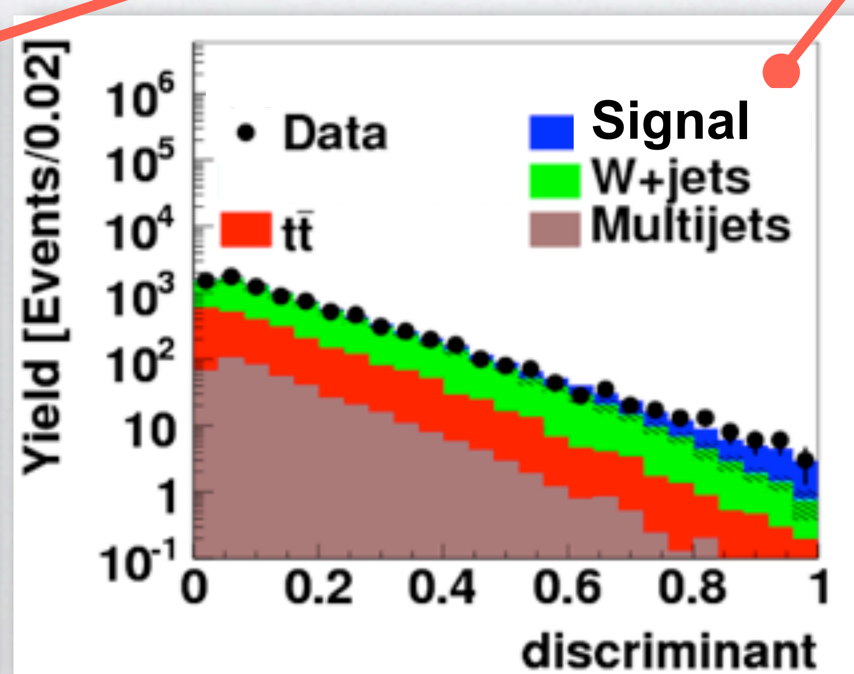


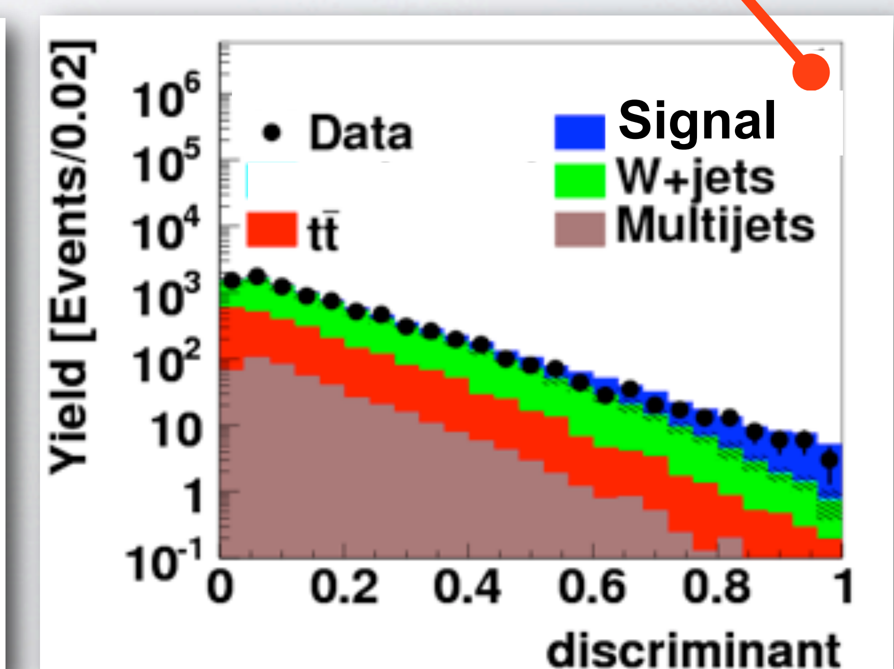
Single top production rate

The single top cross section is given by the position of the posterior density *peak*, with *68% asymmetric interval* as uncertainty.



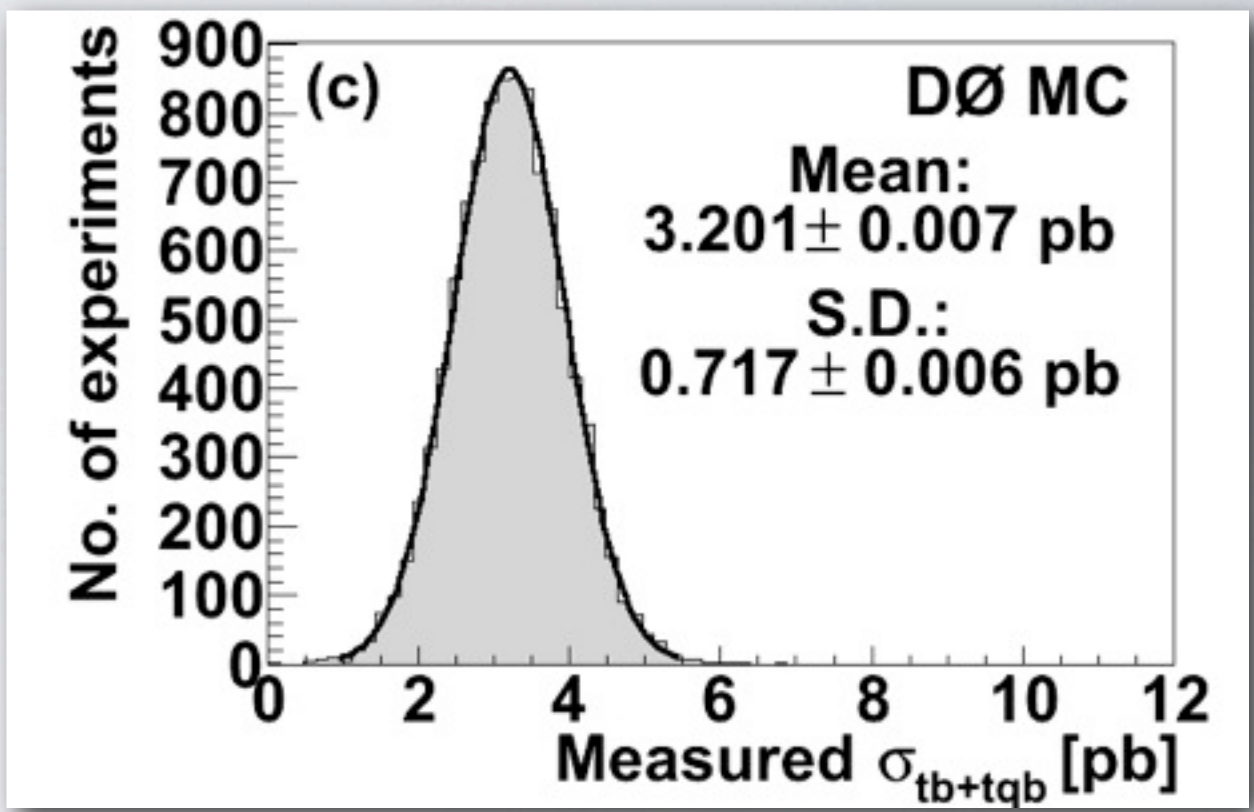


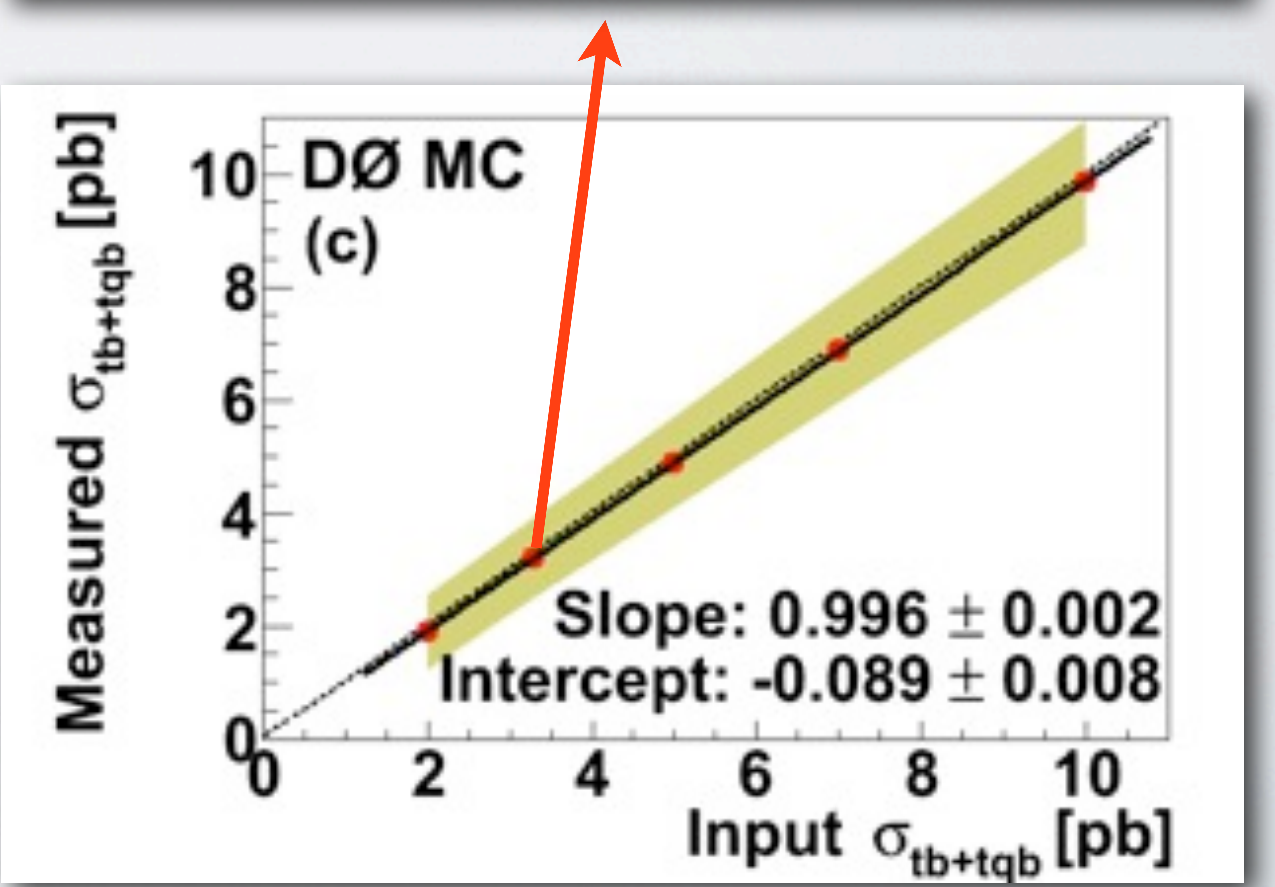




Linearity Test and Ensemble Distribution

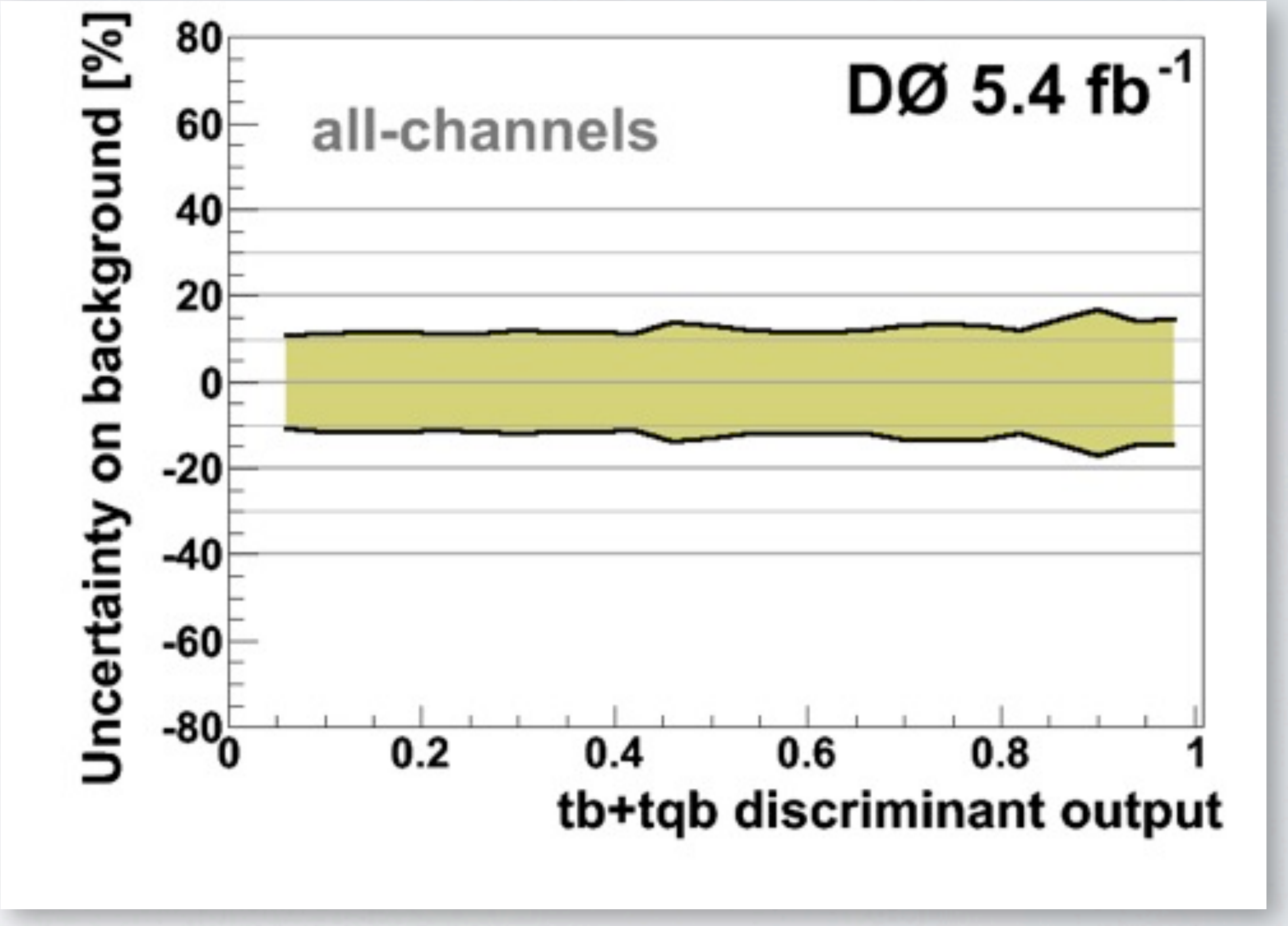
- We use ensembles of pseudo-experiments assuming different cross section values for single top quark process.
- We verify that on average the method measures the same value that was used for top quark cross section in the pseudo-experiments.



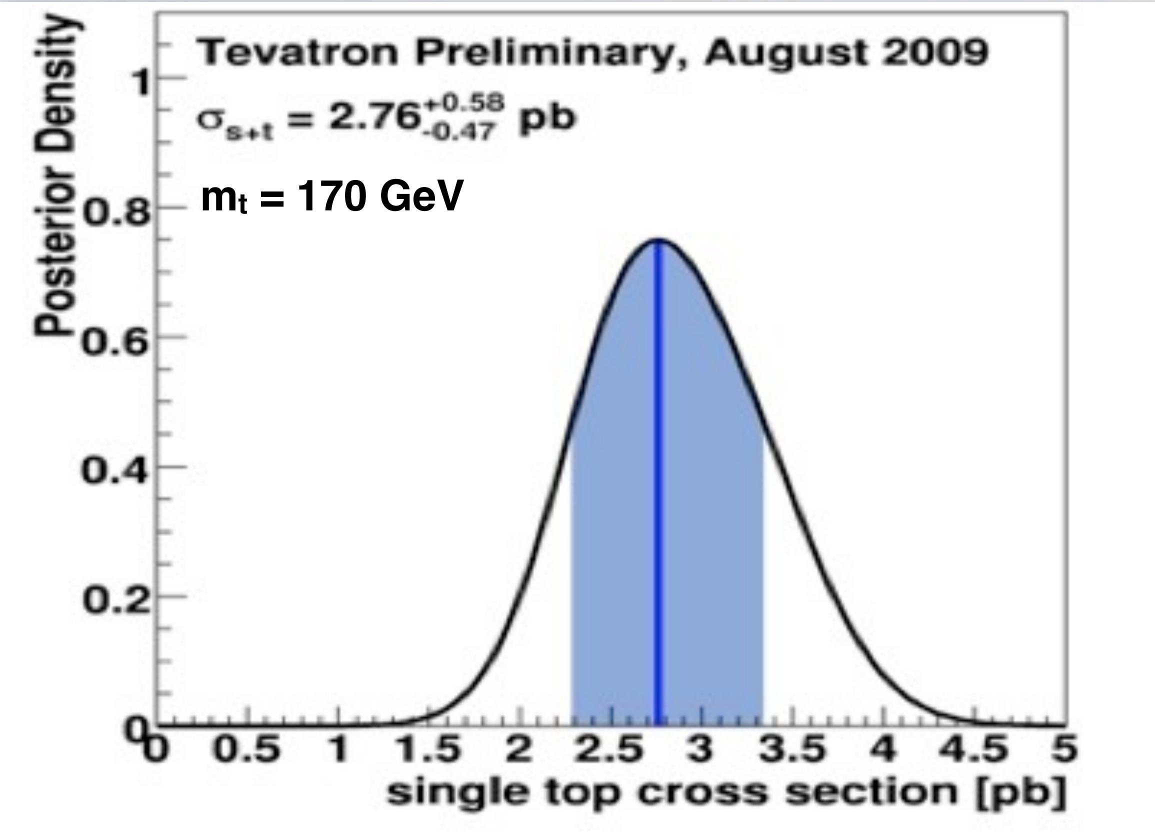


Systematic uncertainties

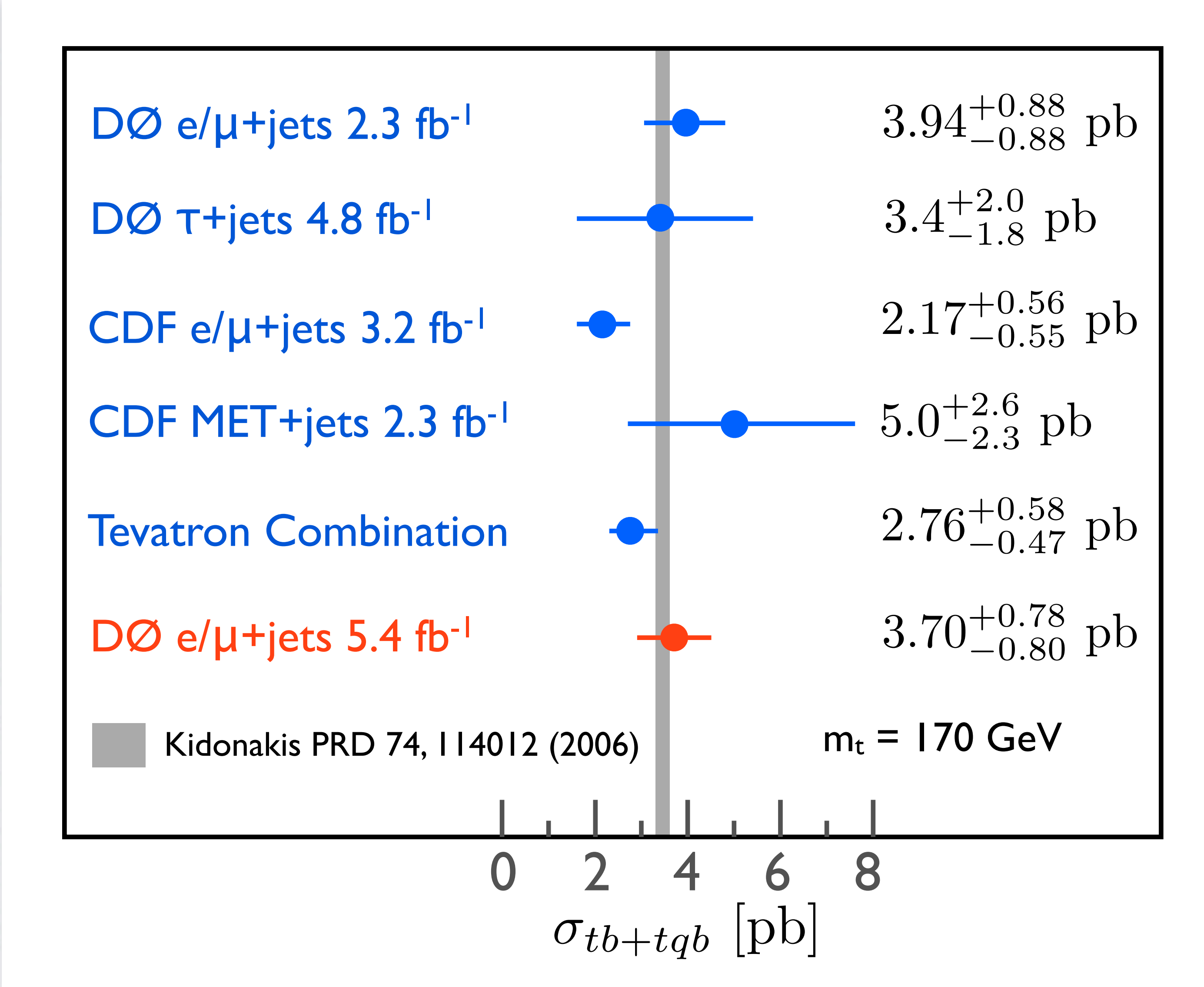
- Main uncertainties affecting normalization only
  - Integrated luminosity
  - W+jets heavy-flavor scale factor correction
- Main uncertainties affecting normalization and kinematics
  - Jet energy resolution
  - Jet energy scale
  - Correction to b-identification

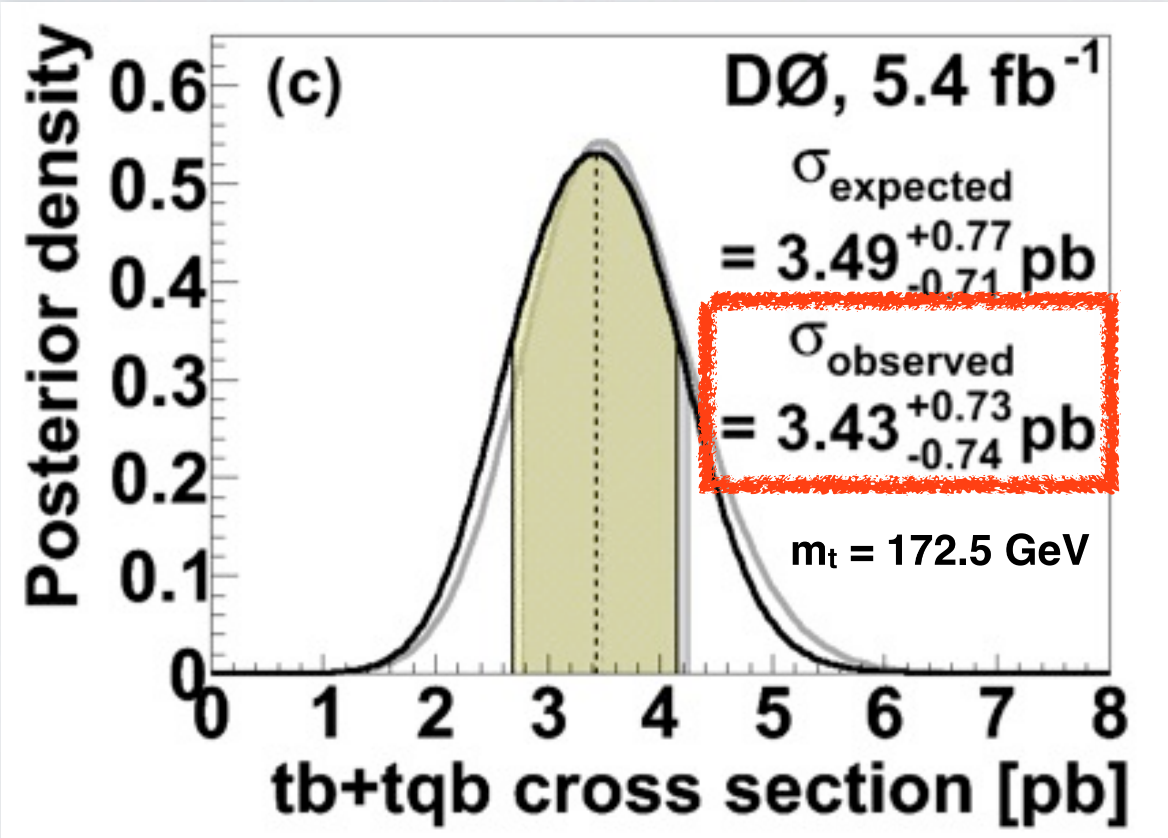


Single top total cross section



Arxiv: 0908.2171 (2009)

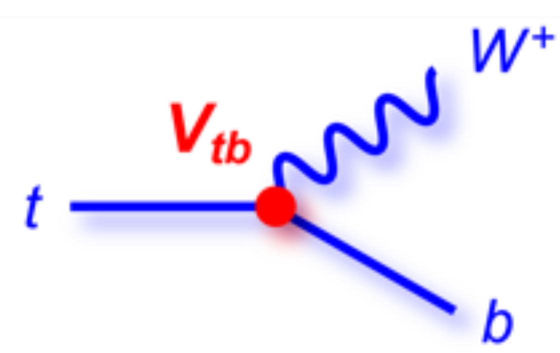




PRD 84, 112001 (2011)

Measurement of CKM matrix element |Vtb|

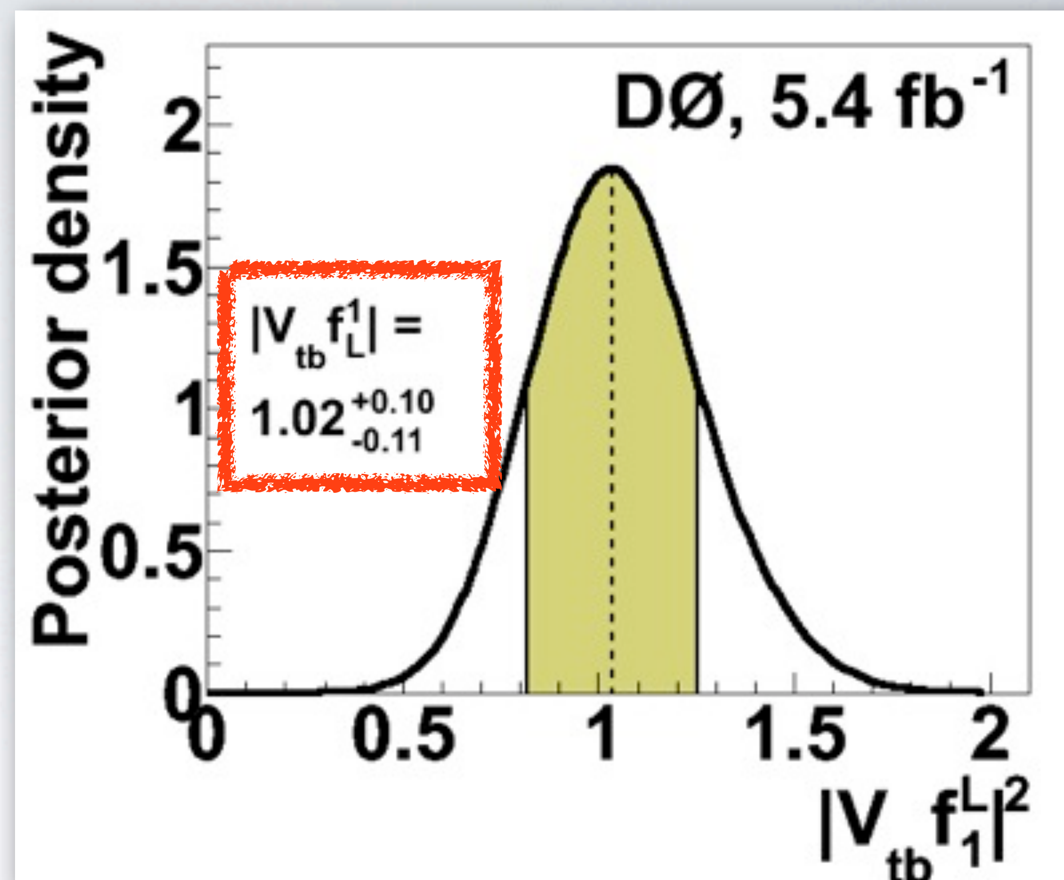
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

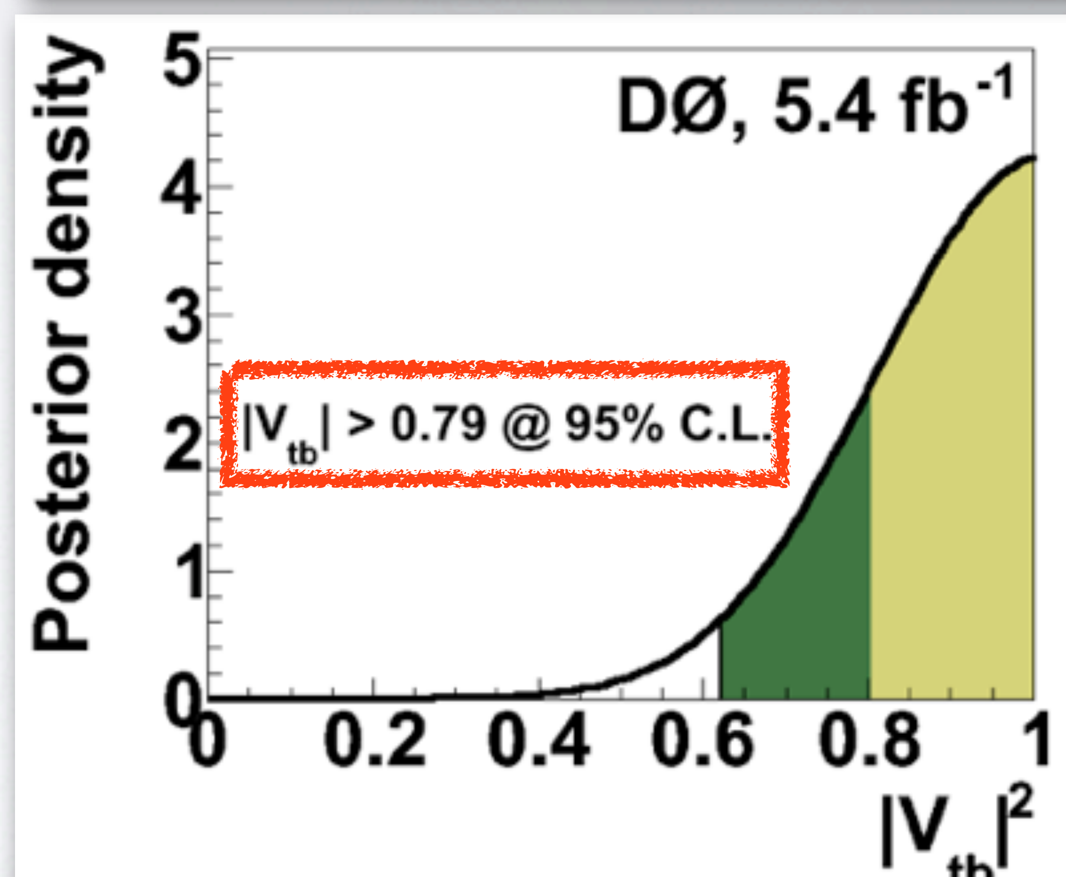


$$|V_{tb} f_L^1|^2 \propto \sigma(s + t\text{-channel})$$

- Measurement assumes SM production mechanisms.
- Pure V–A and CP-conserving interaction.
- $|Vtd|^2 + |Vts|^2 << |Vtb|^2$.
- Does not assume 3 generations or unitarity of the CKM matrix.

PRD 84, 112001 (2011)



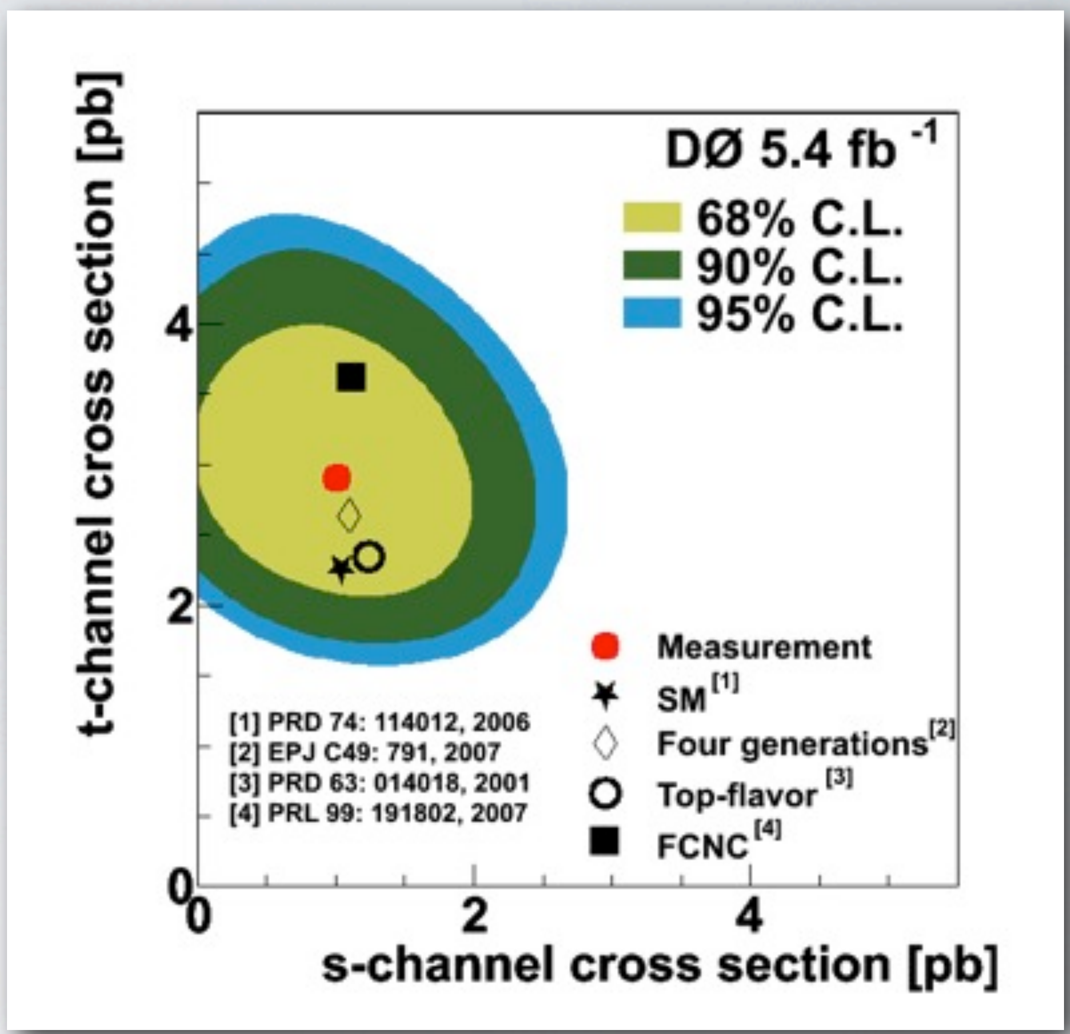


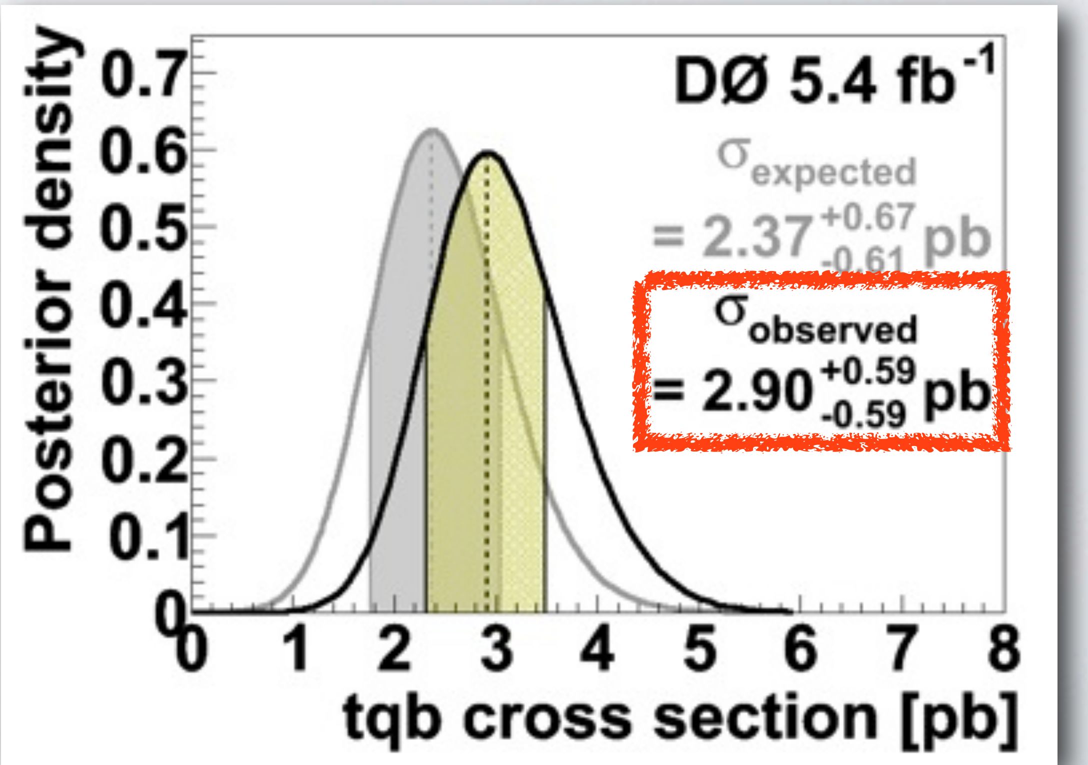
Single top t-channel cross section

- A 2D Bayesian posterior probability density is computed.
- A 1D posterior density can be obtained by integrating over the s-channel production rate.
- The estimated significance of 5.5σ.
- The total error of 20% with a systematic uncertainty of 11%.

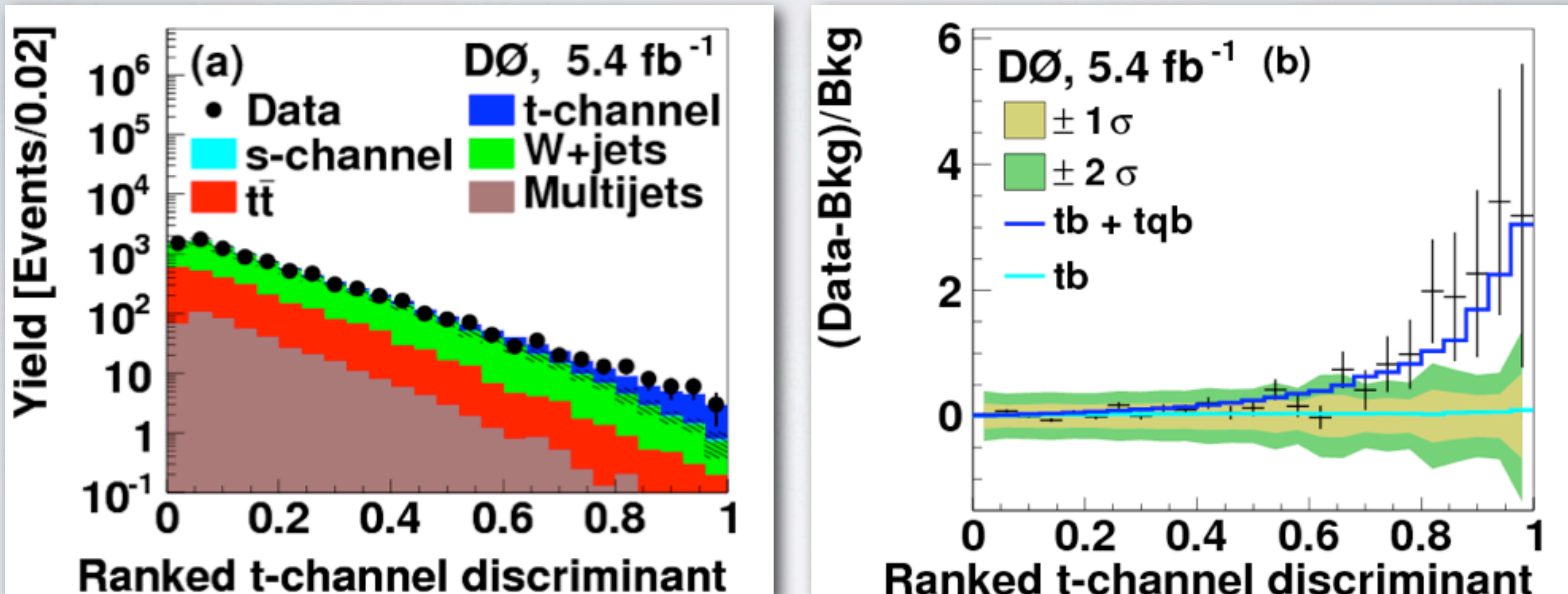
$$\sigma(t\text{-channel}) = 2.90 \pm 0.59 \text{ pb}$$

PLB 705, 313 (2011)

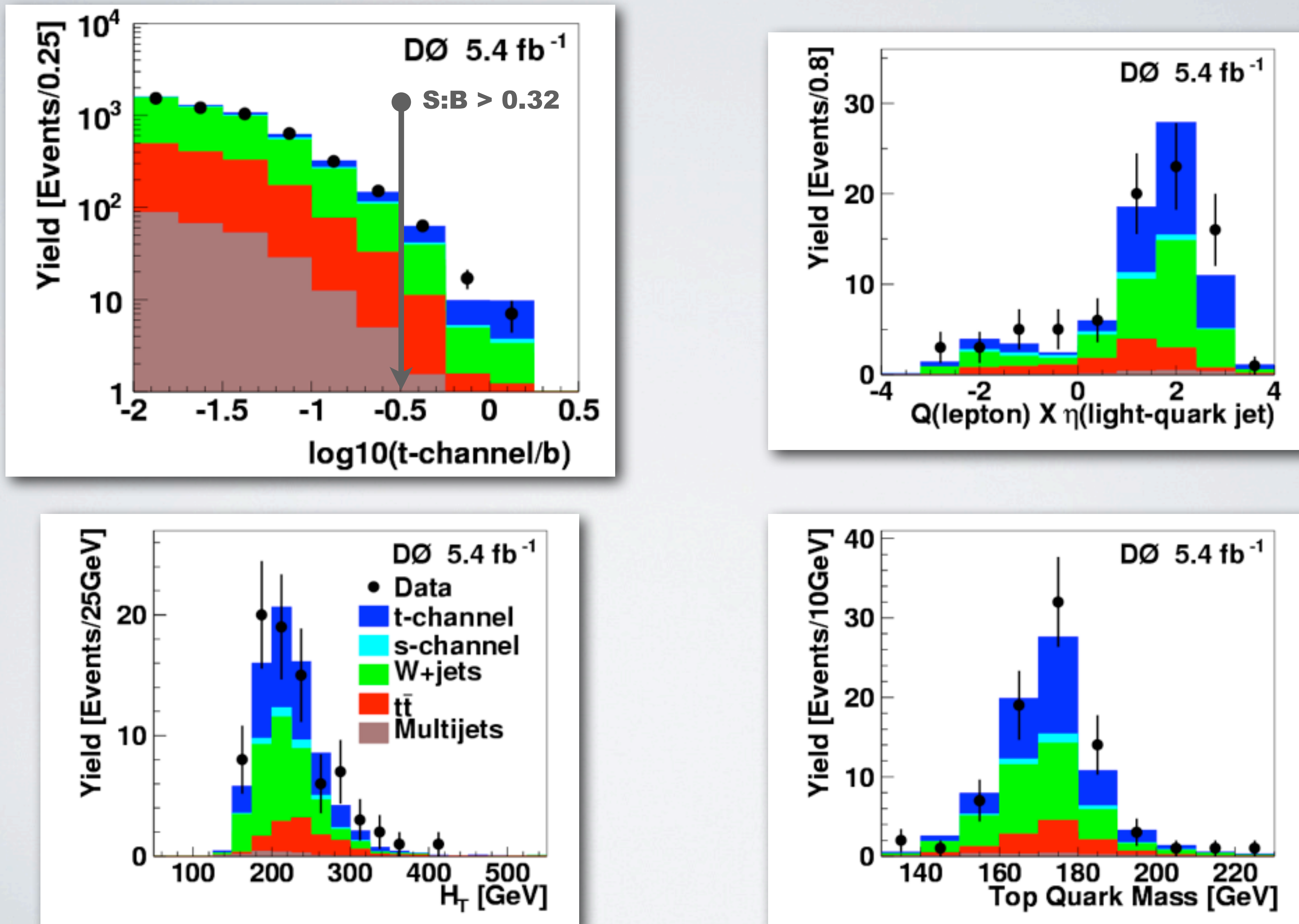




Single top t-channel present in the data



Single top t-channel enriched distributions

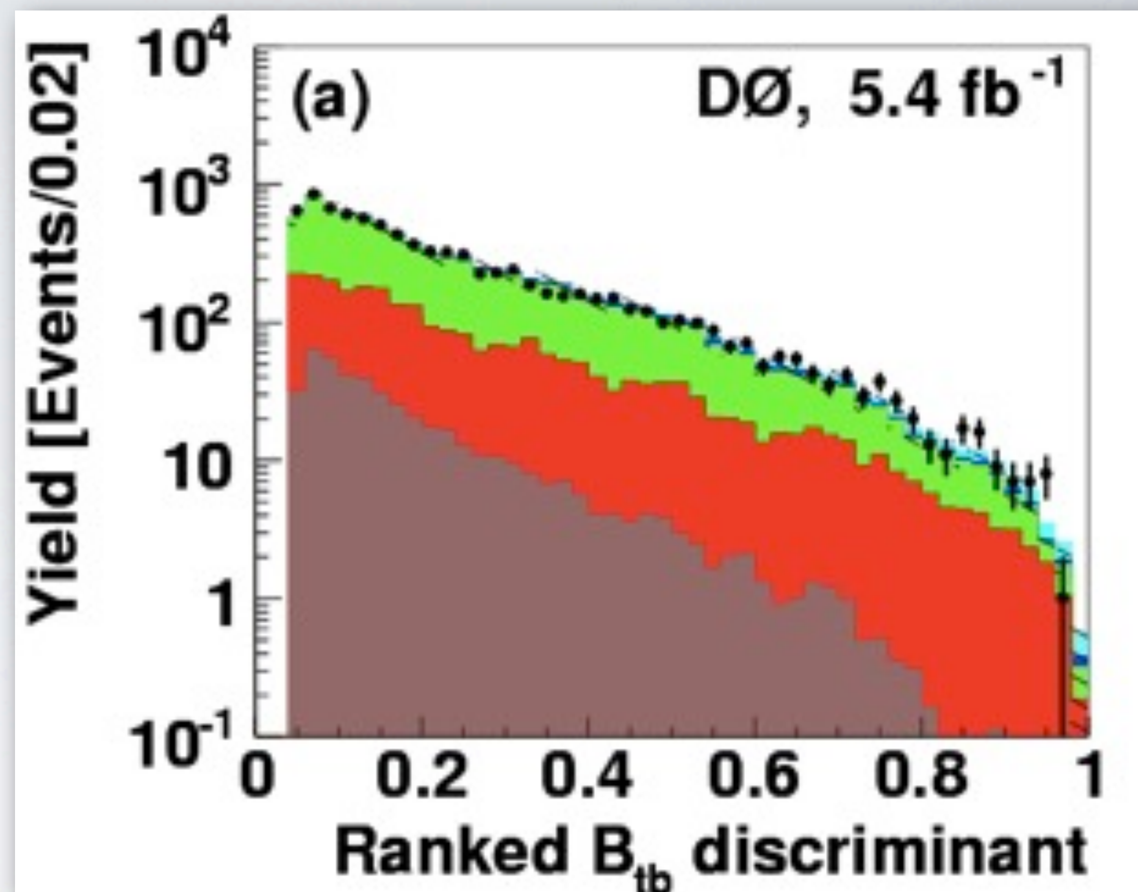


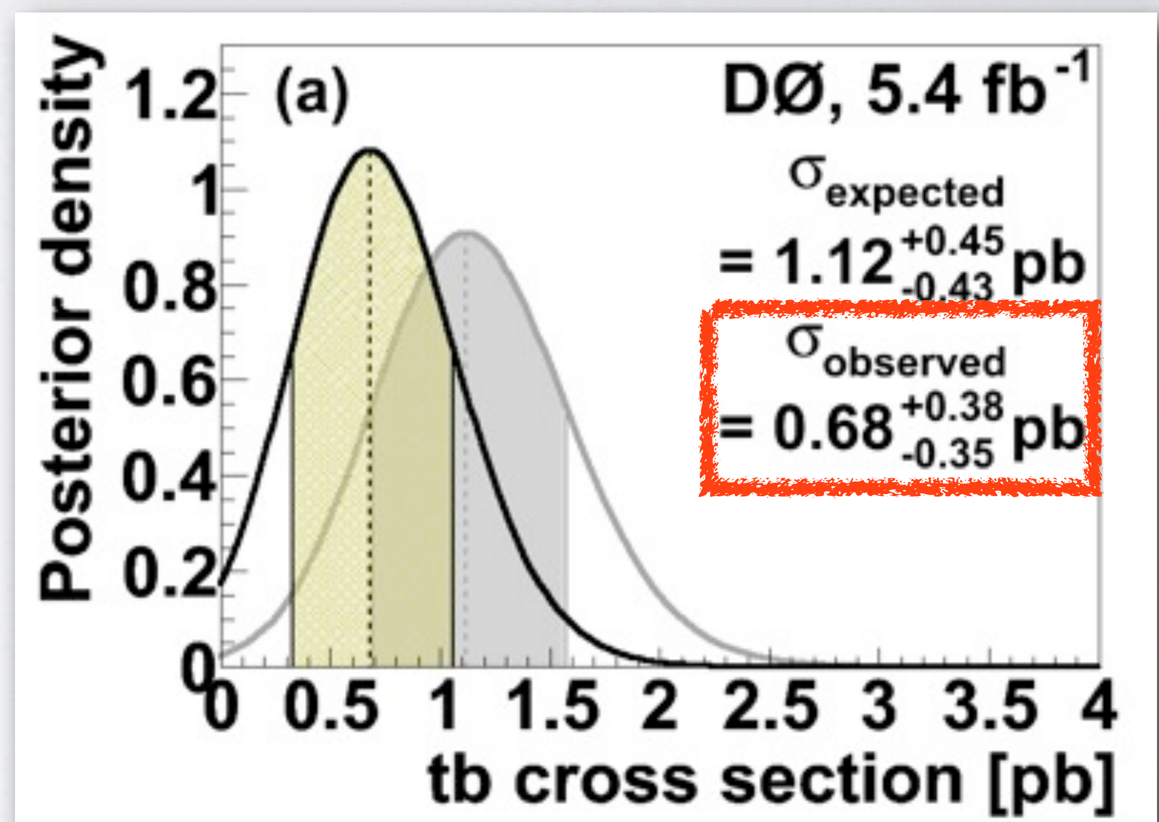
Search for single top s-channel

- We apply the same method to search for s-channel single top.
- The result still has low significance.

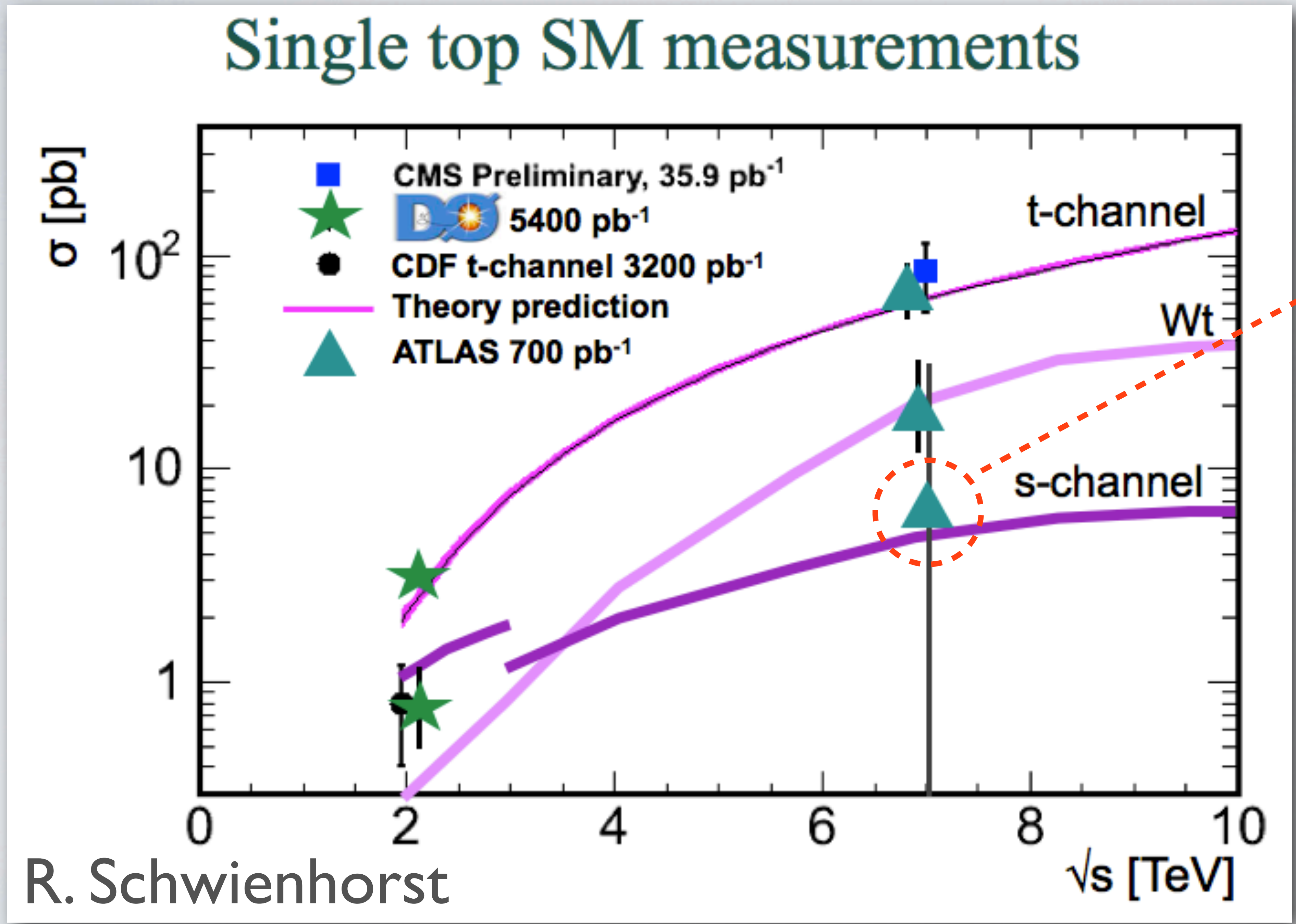
$$\sigma(s\text{-channel}) = 0.68^{+0.38}_{-0.35}\ \text{pb}$$

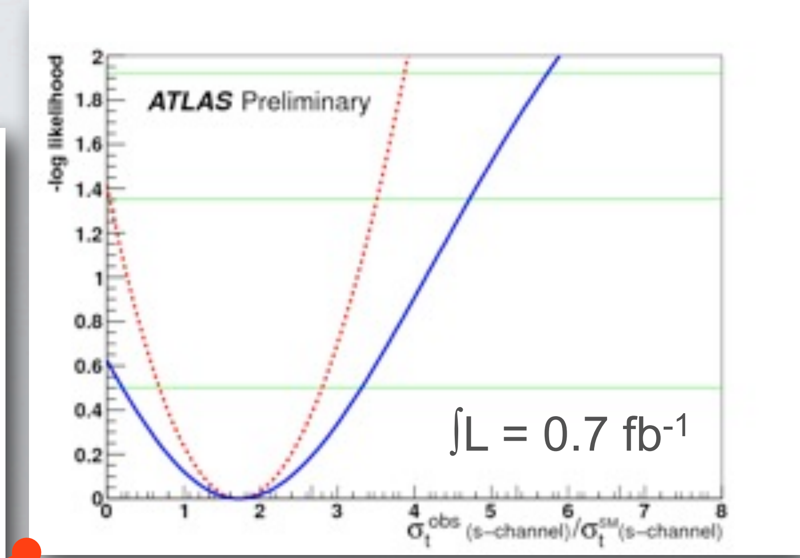
PRD 84, 112001 (2011)





Single top quark studies at LHC

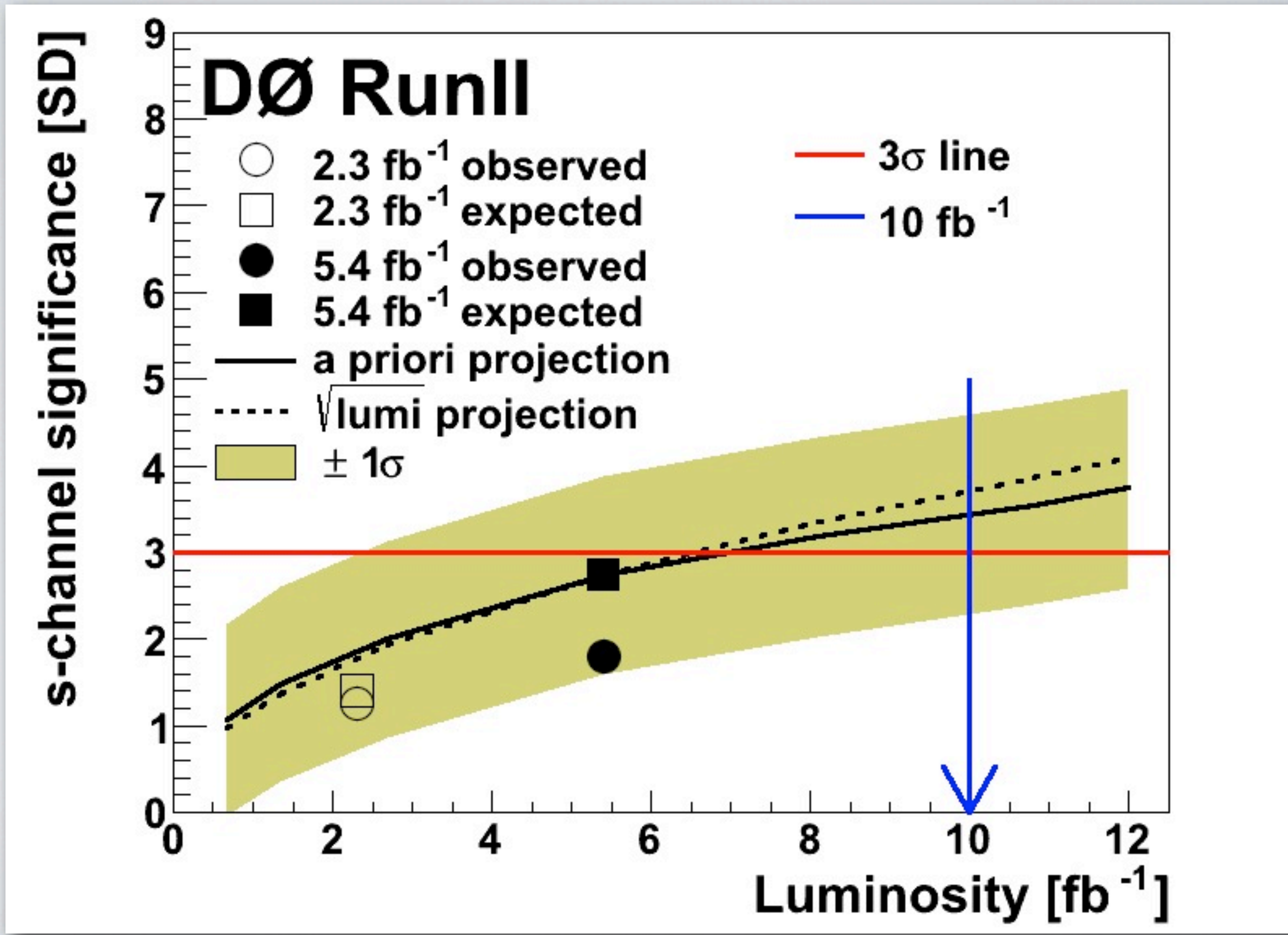




$\sigma_s < 26.5$ pb @ 95% C.L.

ATLAS-CONF-2011-118

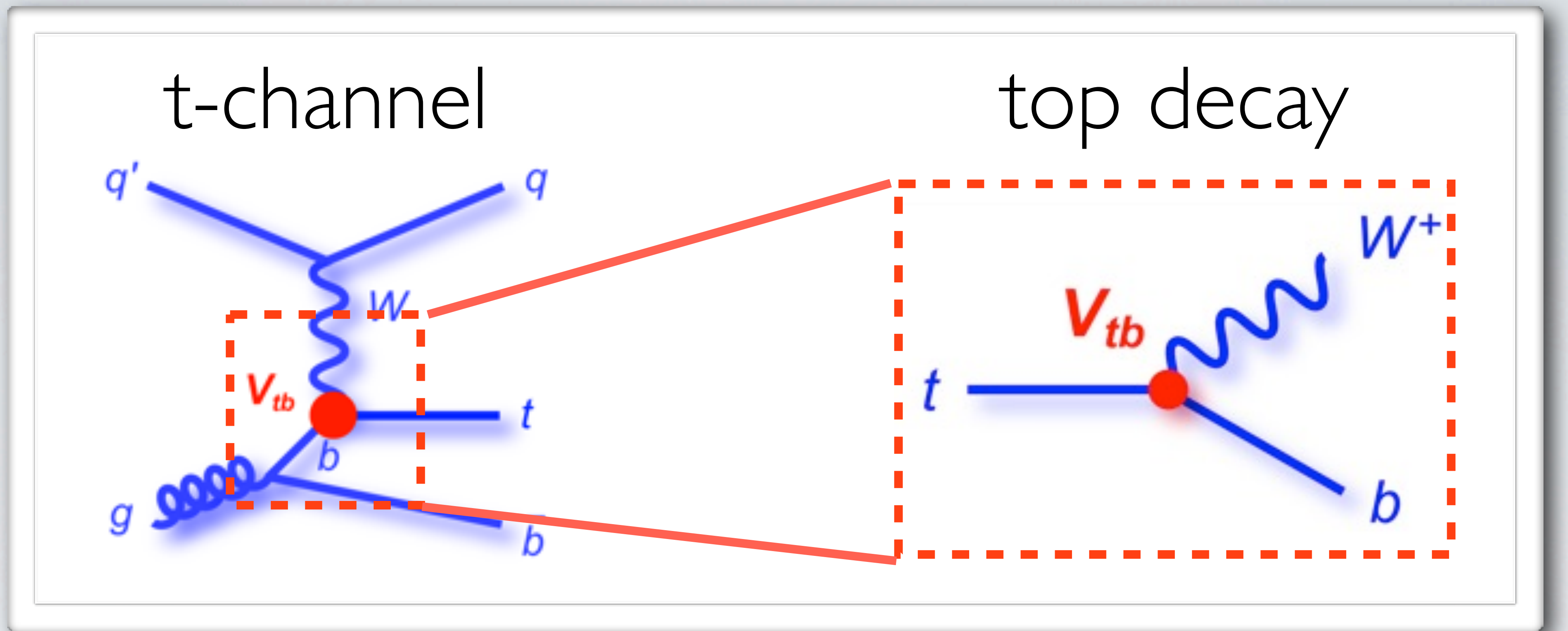
In pursuit of single top s-channel



Studying the top electroweak interactions

- After measuring single top quark production we can:
  - Measure the top quark decay rate.
  - Probing for extension to the top electroweak interaction.

Determination of top quark decay rate



- Top quark decay rate is proportional to single top quark t-channel cross section.
- The proportionality constant can be taken from theory.
- For this we need to combine the t-channel cross section measurement with a determination of the branching fraction of t → Wb.

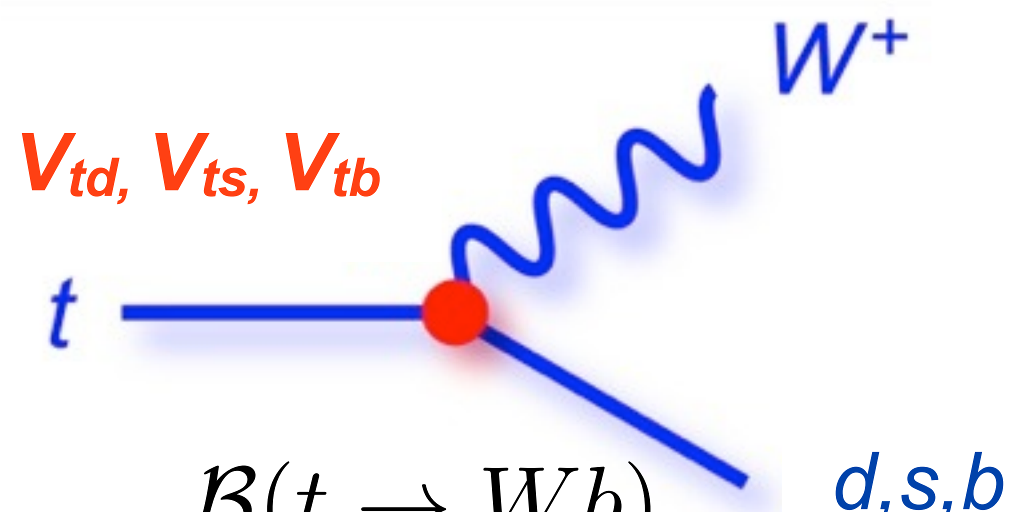
$$\Gamma(t \to Wb) = \sigma(t\text{−channel}) \frac{\Gamma(t \to Wb)_{\rm SM}}{\sigma(t\text{−channel})_{\rm SM}}$$

$$\sigma_t^{\rm meas} = \sigma(t\text{-channel})\mathcal{B}(t \to Wb)$$

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

$$\tau_t = \hbar/\Gamma_t$$

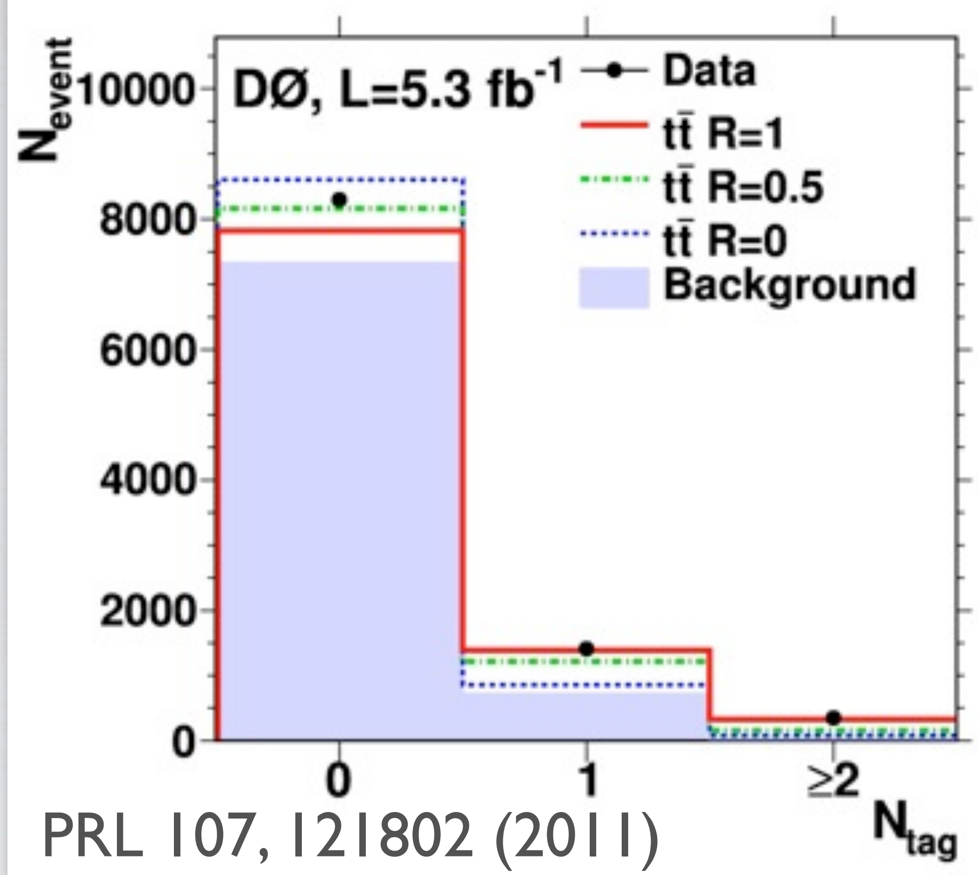
Determination of the top branching fraction



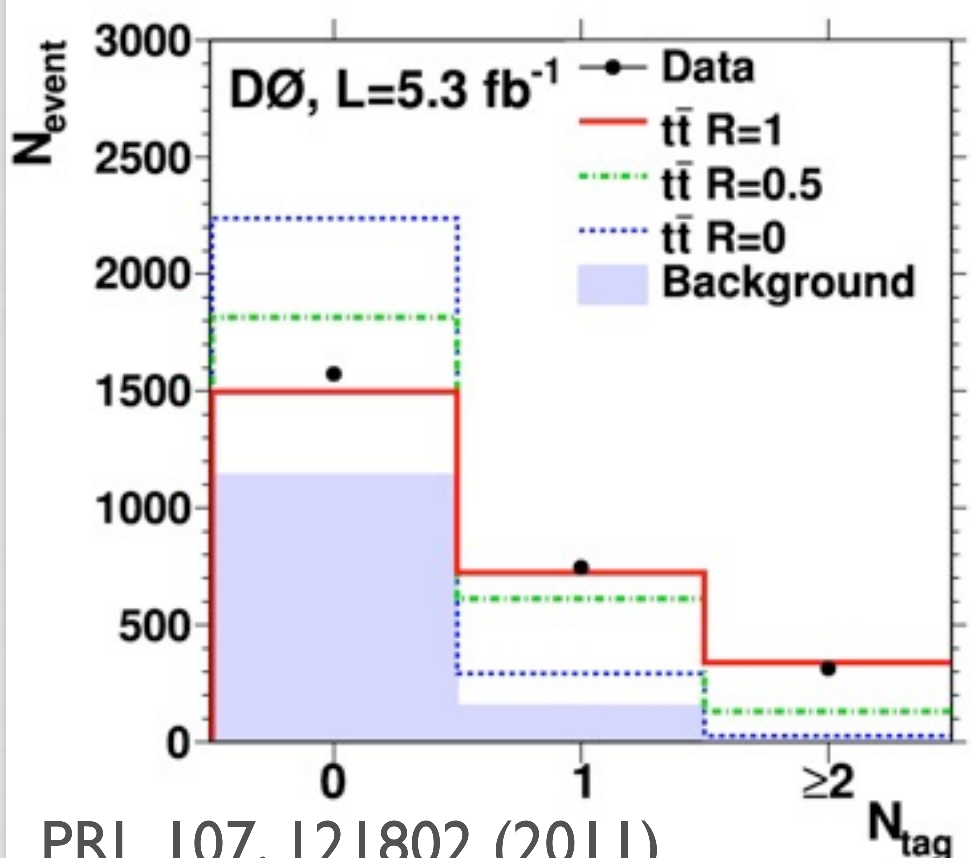
$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)}$$

- Analyzing data from top pair production in the semiletonic final state.
- We extract the total cross section and the fraction of t → Wb

$$R = 0.95 \pm 0.07 \ (\mathrm{stat{+}syst})$$



PRL 107, 121802 (2011)

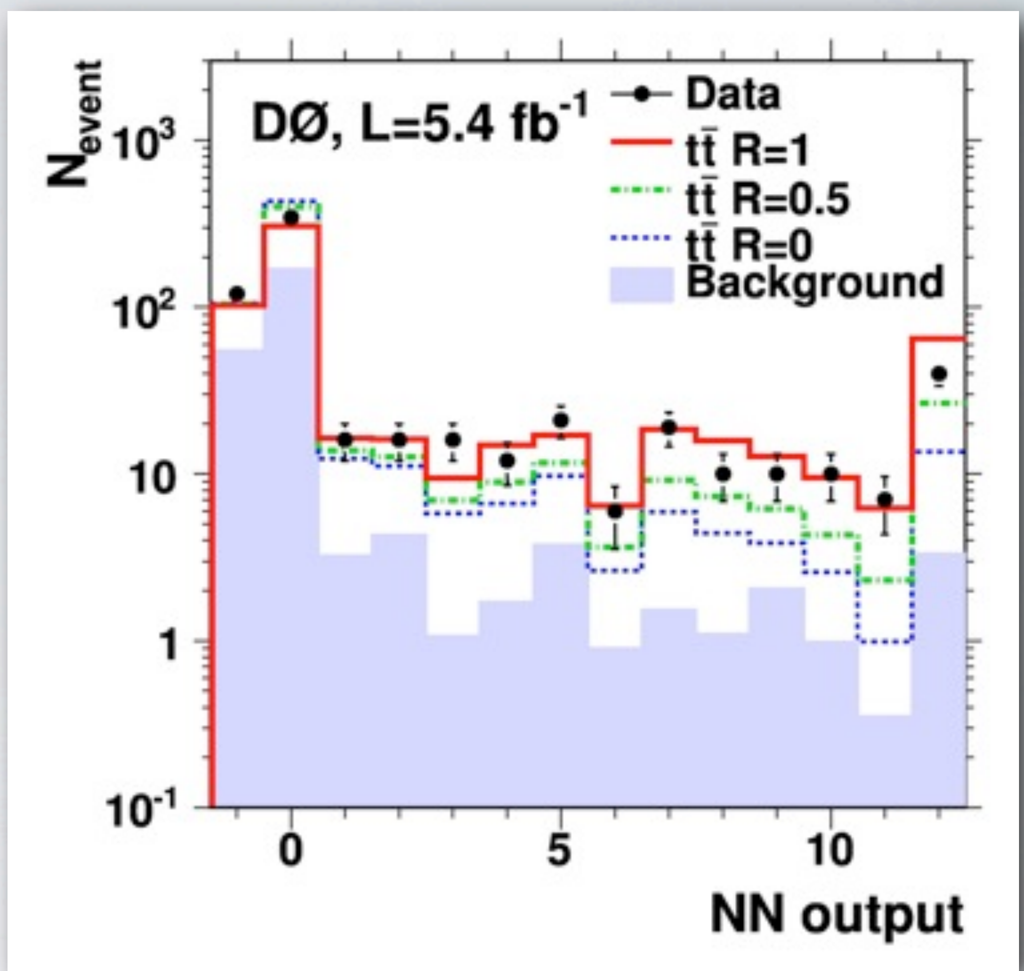


PRL 107, 121802 (2011)

Determination of the top branching fraction

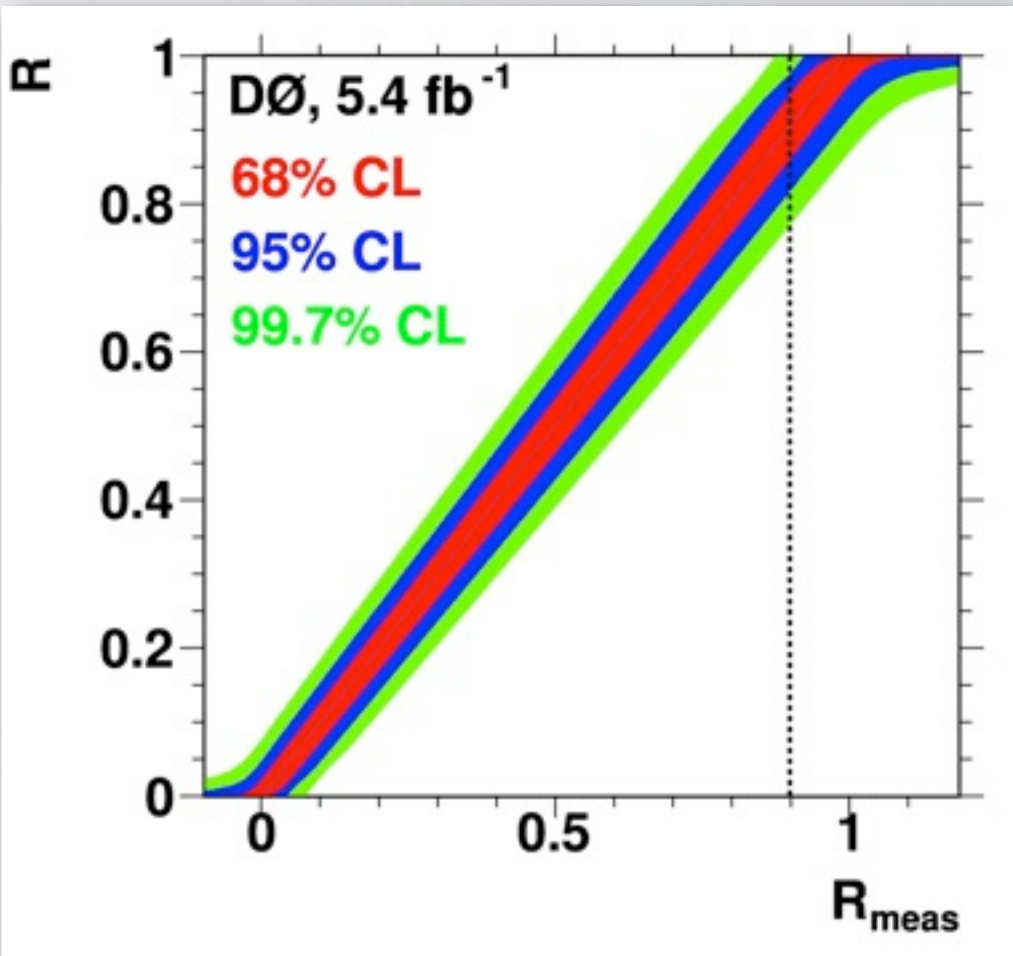
- Analyzing data from top pair production in the dilepton final state.
- We extract the total cross section and the fraction of $t \to Wb$

$$R = 0.86 \pm 0.05 \ (\text{stat+syst})$$



- After combining the two results

$$R = 0.90 \pm 0.04 \ (\text{stat+syst})$$



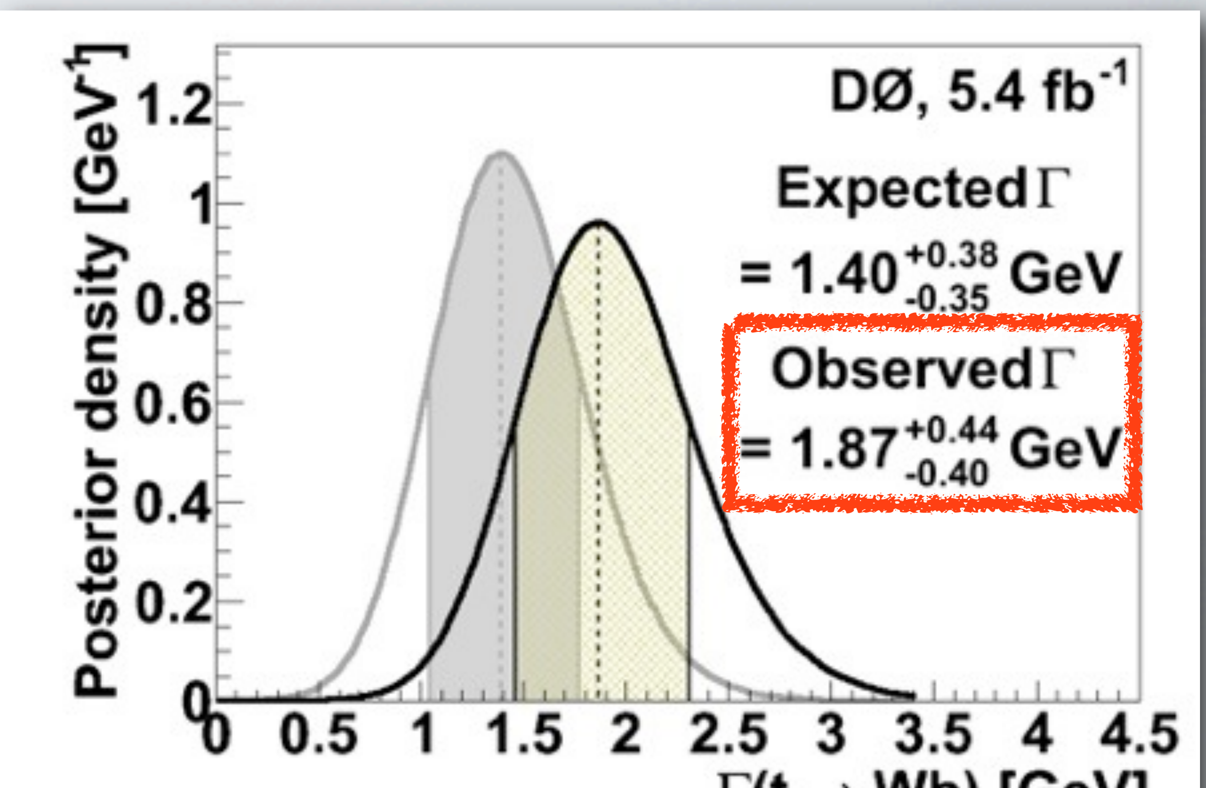
Determination of top quark decay rate

Mean event count

$$\mathbf{d}(\Gamma_{\{p,t\}}, \sigma'_s, \mathbf{a}_t, \mathbf{a}_s, \mathbf{b}) = c_{\{p,t\}}\Gamma_{\{p,t\}}\mathbf{a}_t + \sigma'_s\mathbf{a}_s + \mathbf{b}$$

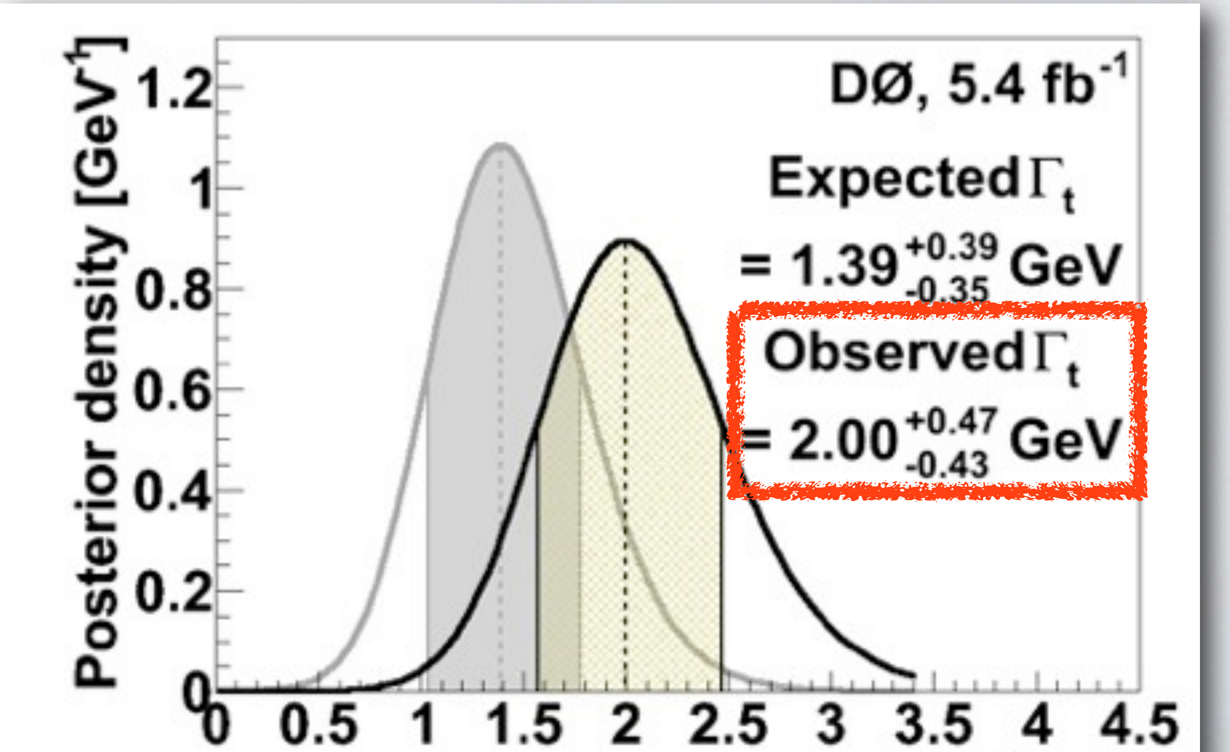
$$c_p = \frac{\mathcal{B}(t \to Wb)\sigma(t\text{−channel})_{SM}}{\Gamma(t \to Wb)_{SM}}$$

$$c_t = \frac{\mathcal{B}^2(t \to Wb)\sigma(t\text{−channel})_{SM}}{\Gamma(t \to Wb)_{SM}}$$



arXiv:1201.4156 (2012)

Systematic uncertainties correlation between both analysis are included



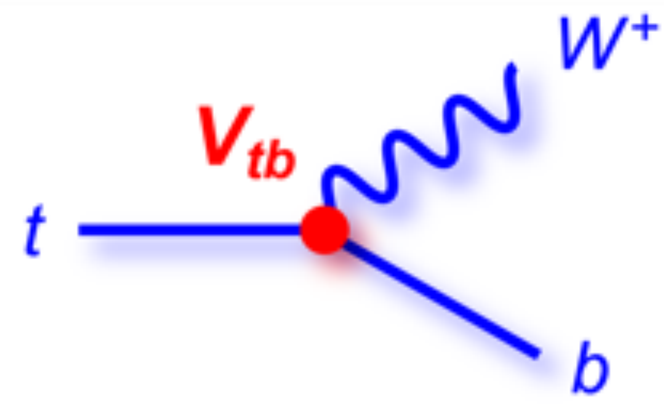
arXiv:1201.4156 (2012)

Top quark lifetime

$$\tau_t = (3.29^{+0.90}_{-0.63}) \times 10^{-25}\ \text{s}$$

Another measurement of CKM matrix element |Vtb|

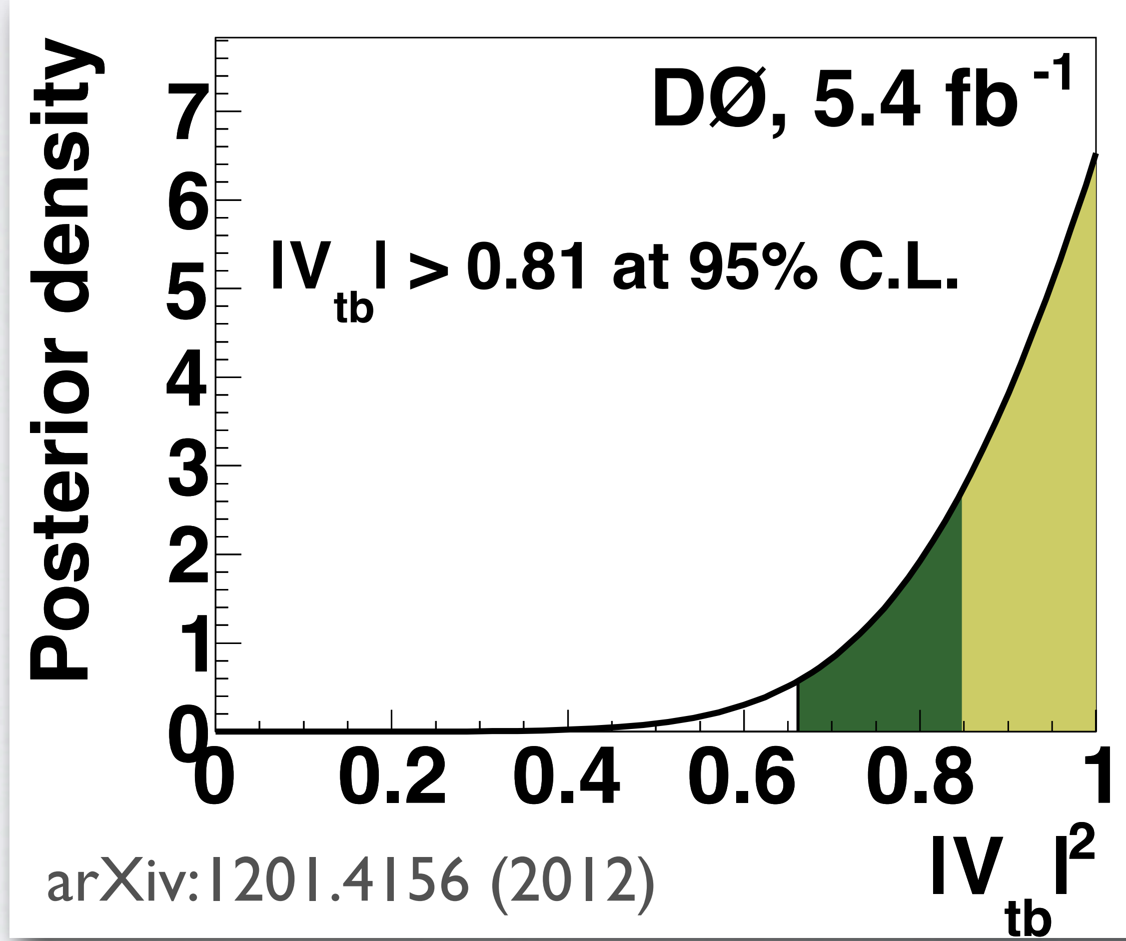
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



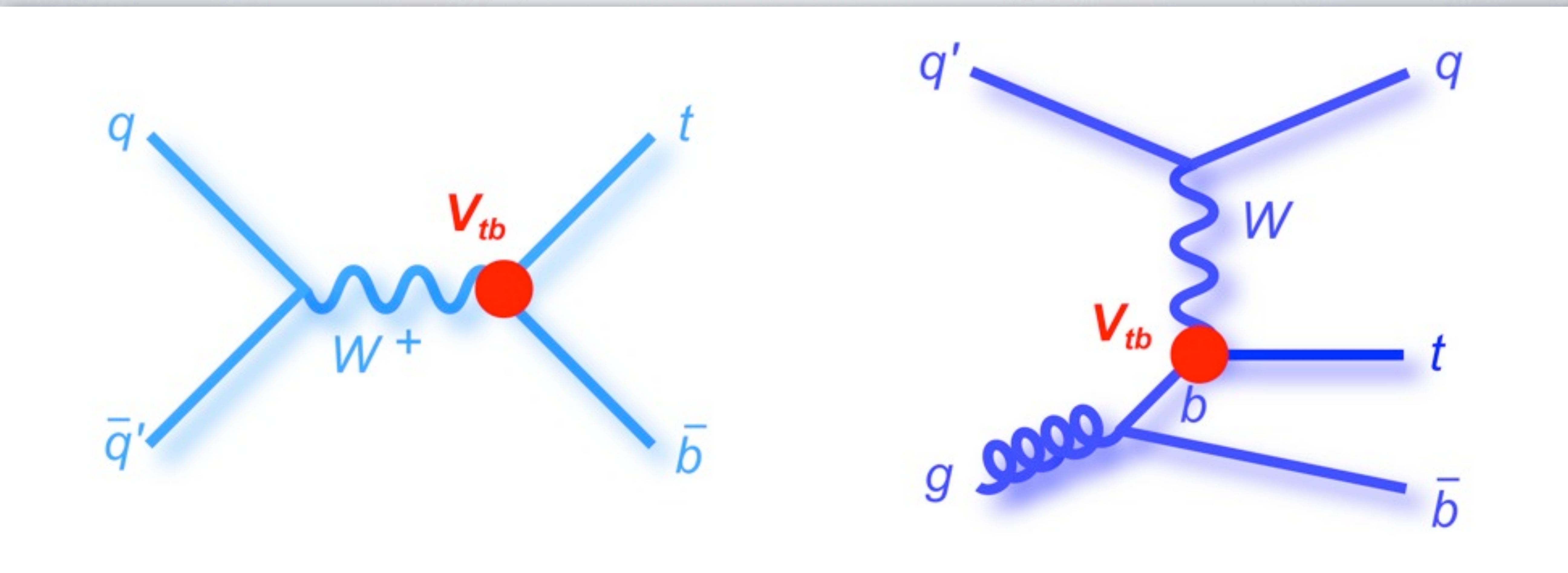
$$|V_{tb}|^2 \propto \Gamma(t \to Wb)$$

- Measurement assumes SM production mechanisms.
- Pure V–A and CP-conserving interaction.
- Does not assume 3 generations or unitarity of the CKM matrix.
- Does not assume SM ration between s- and t-channel.
- Does not assume

$$|V_{td}|^2 + |V_{ts}|^2 << |V_{tb}|^2$$



SM single top quark production

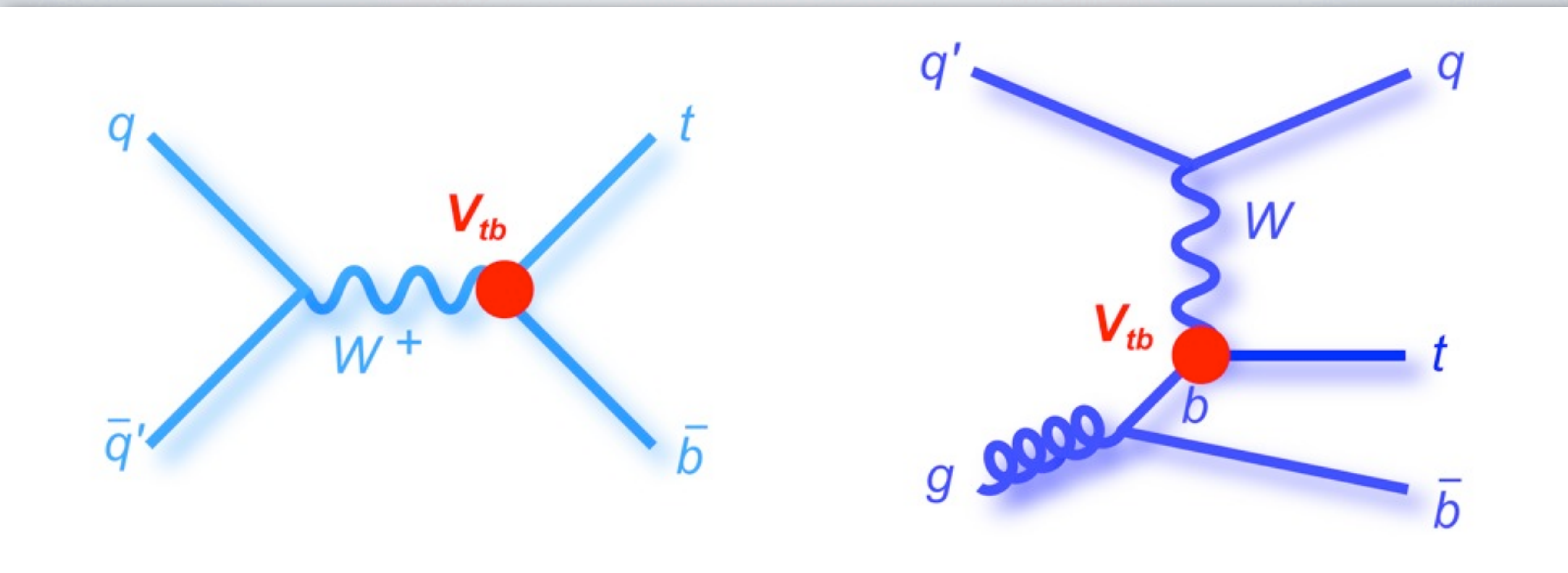


$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu} L_V P_L t W^{-}_{\mu}$$

$L_V = V_{tb} f_{L_V}$

$P_L = (1 - \gamma_5)/2$

SM single top quark production



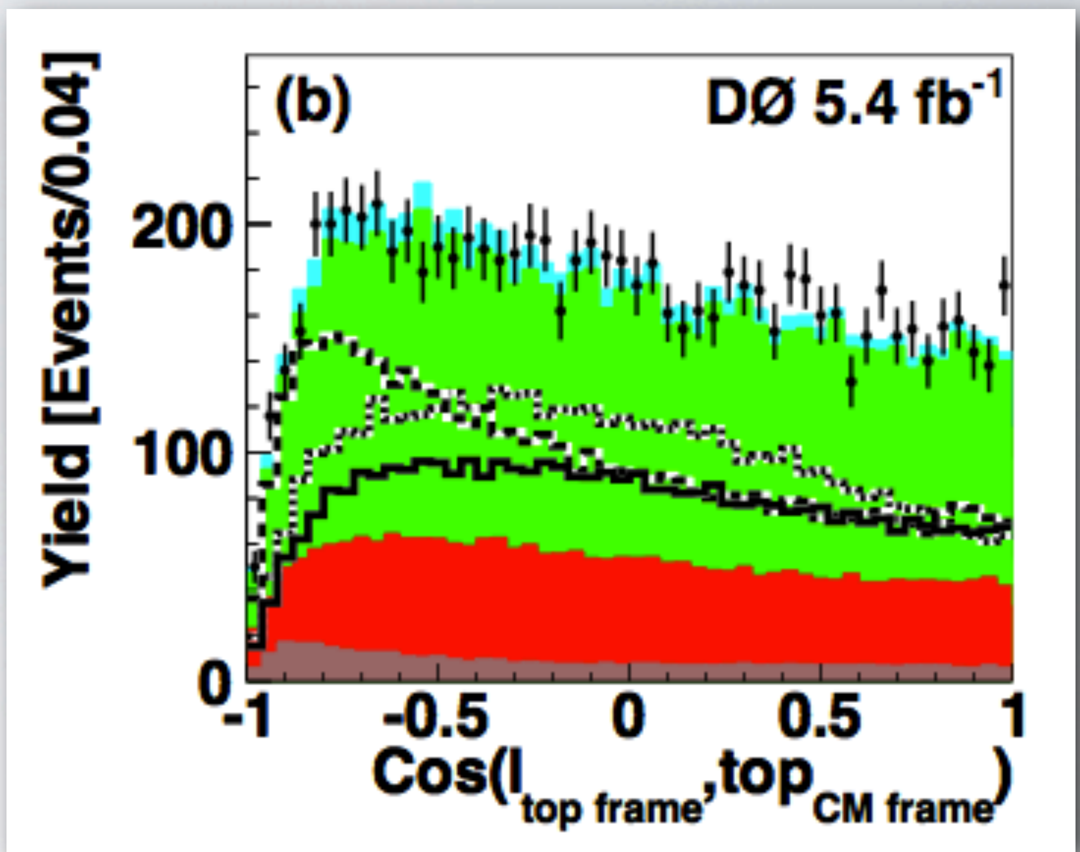
Anomalous couplings

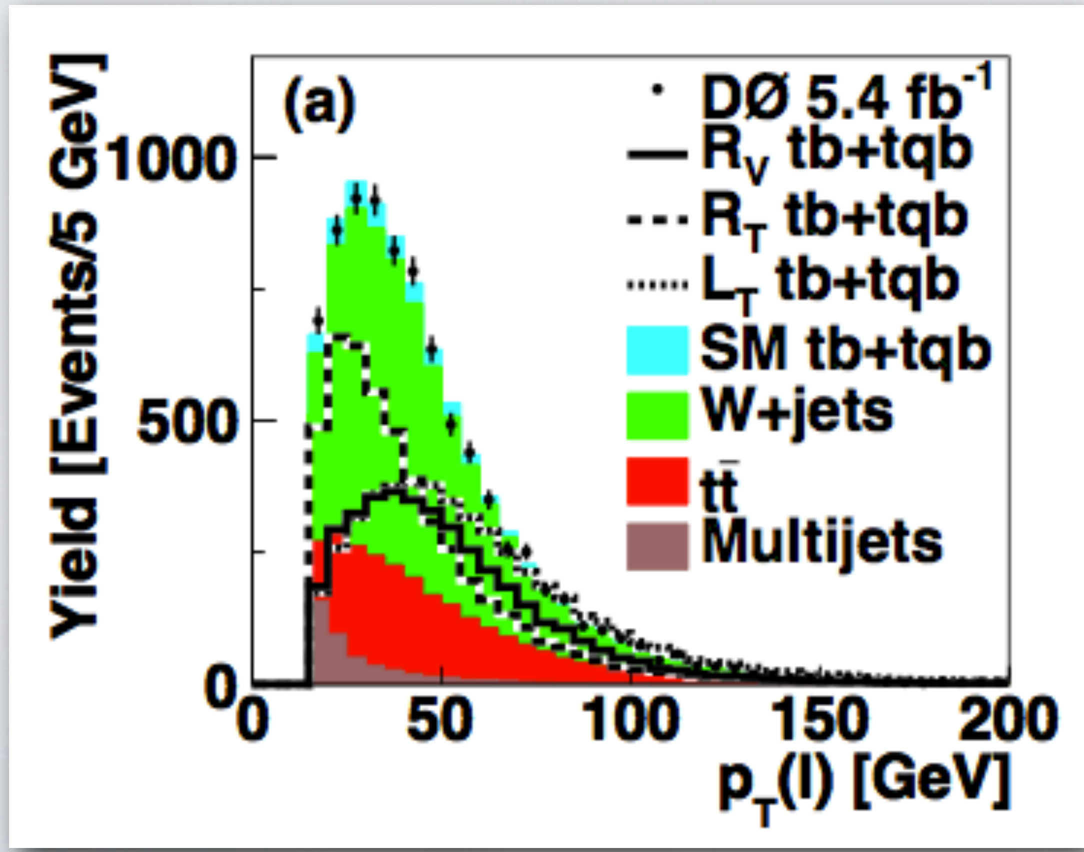
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(L_V P_L + \boldsymbol{R_V P_R})tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(\boldsymbol{L_T P_L} + \boldsymbol{R_T P_R})tW_{\mu}^{-} + h.c.$$

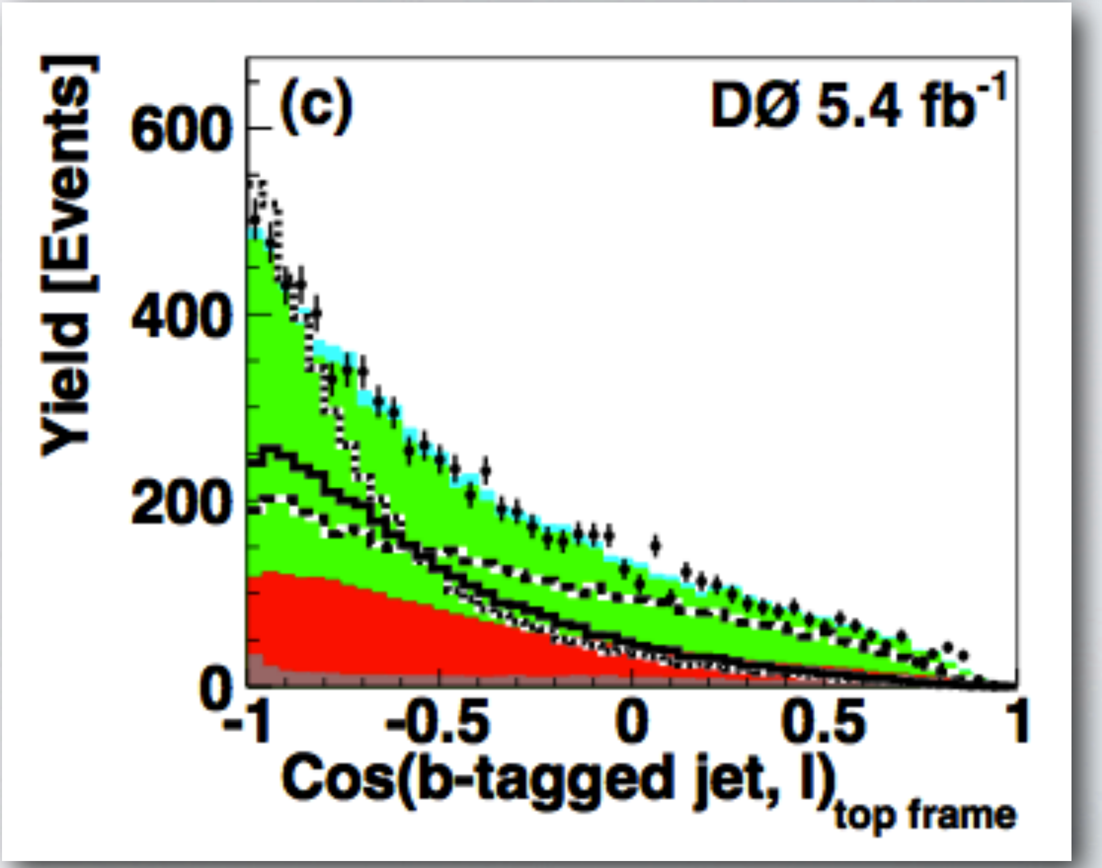
$$R_V = V_{tb} f_{R_V} \qquad L_T = V_{tb} f_{L_T} \qquad R_T = V_{tb} f_{R_T}$$

Search for anomalous couplings

- We train a BNN to discriminate between anomalous single top quark production from background that includes SM single top.

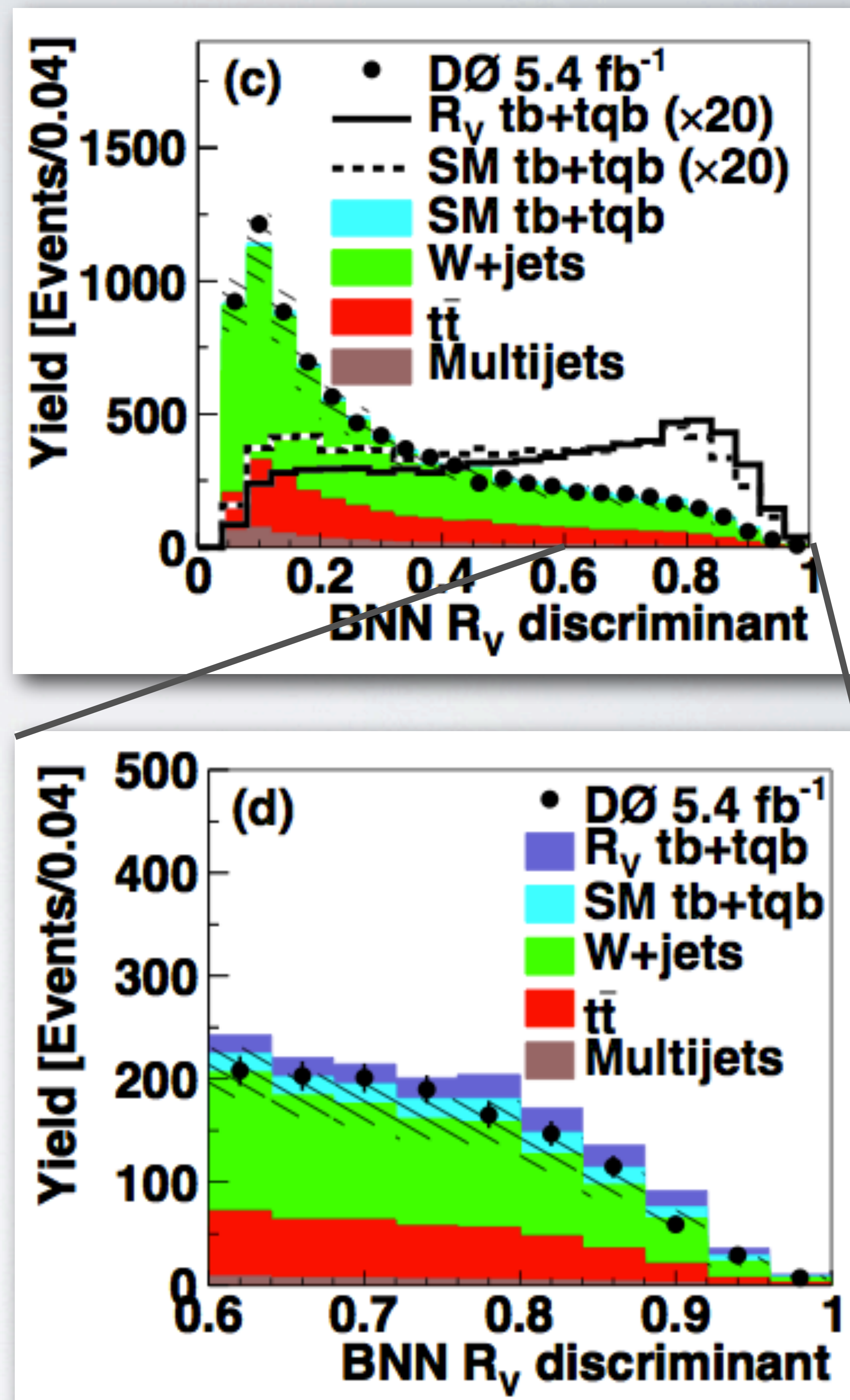


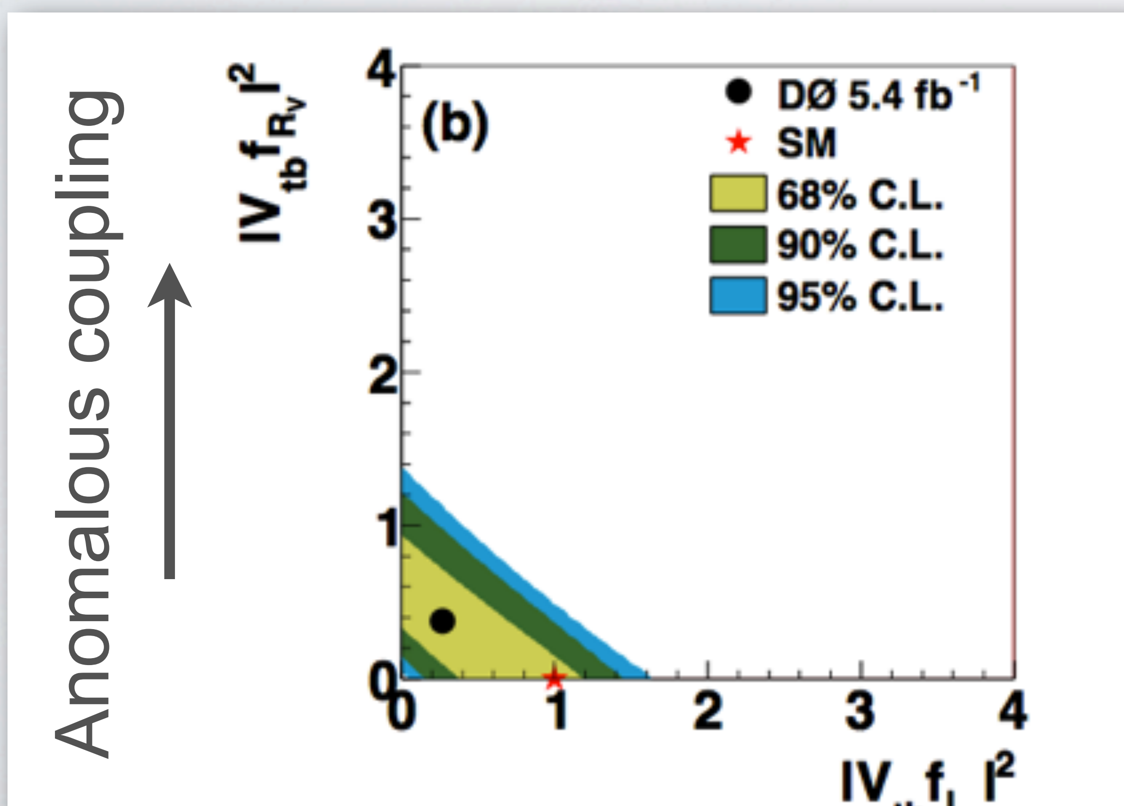




Search for anomalous R_V

- Data disfavor the presence of right-vector coupling (R_V) in single top quark production.

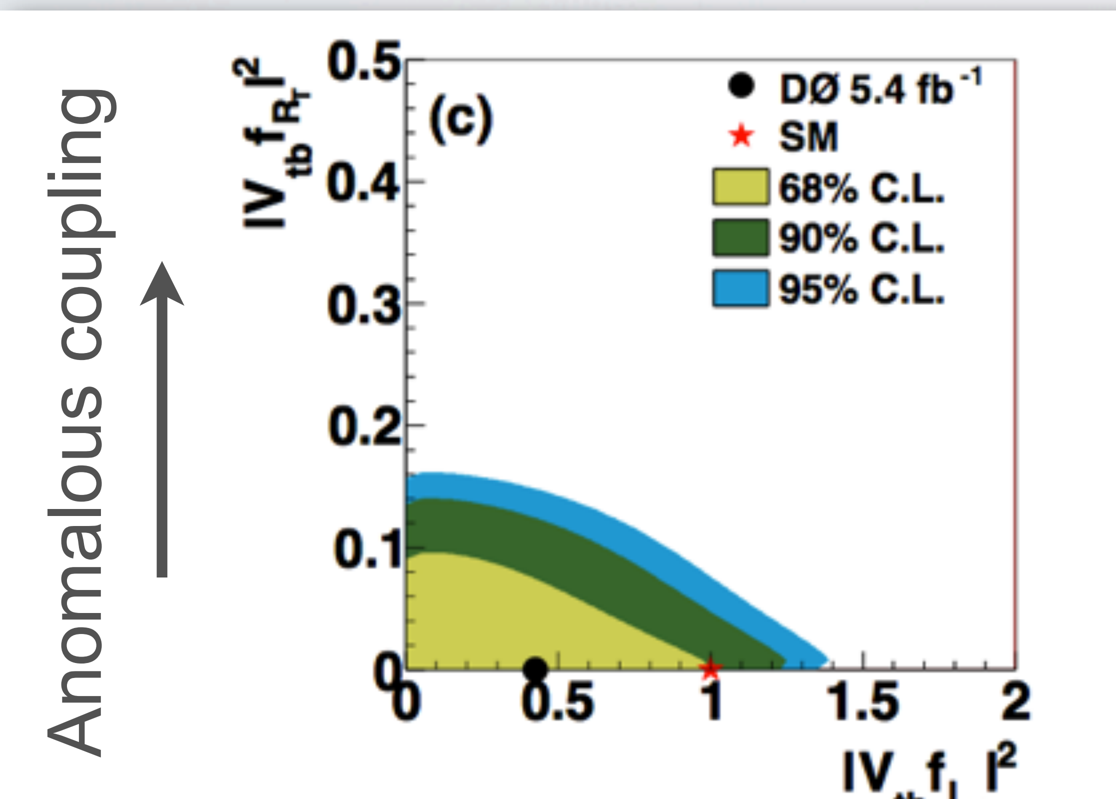




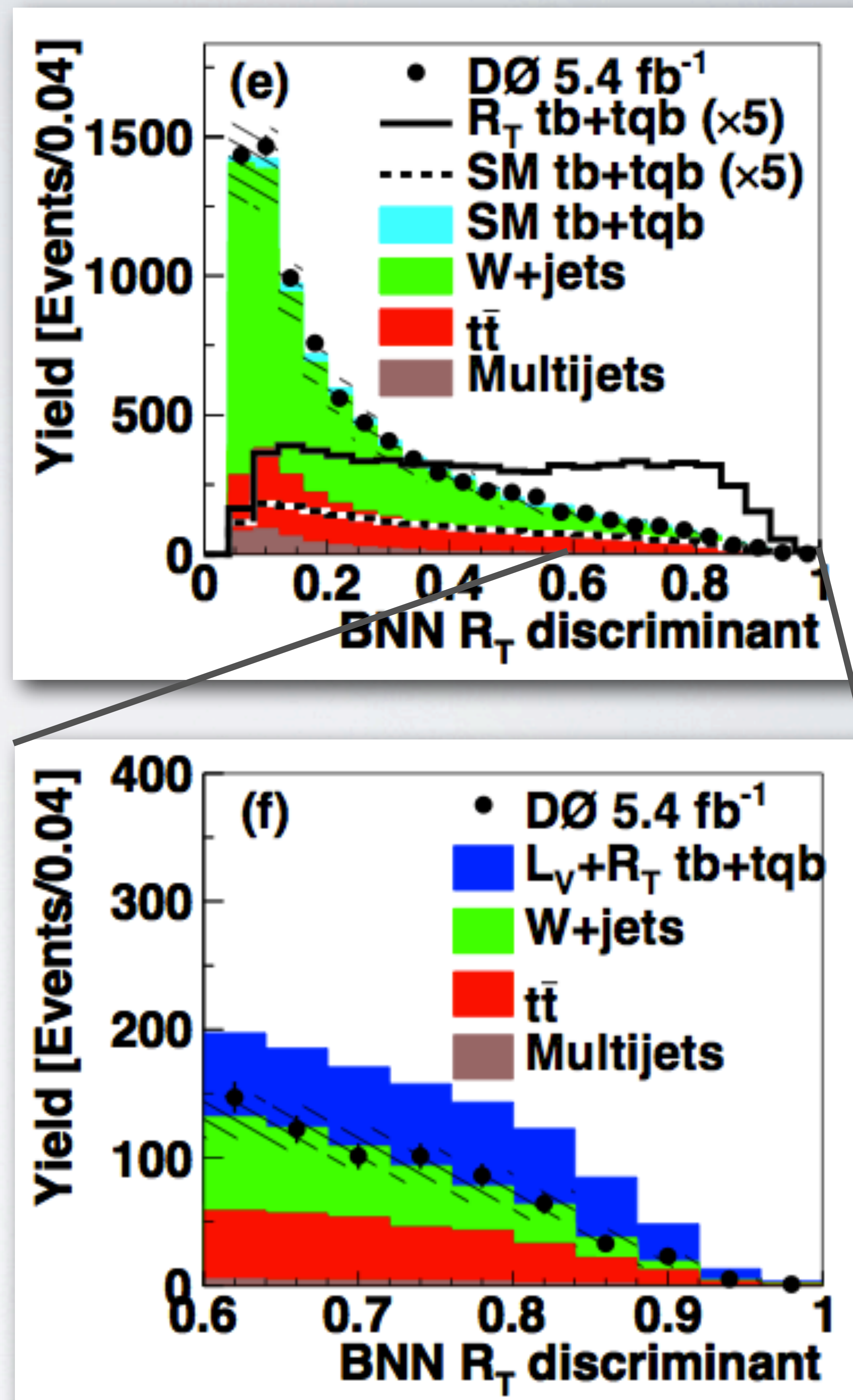
$$|R_V|^2 < 0.93 \text{ @ } 95\% \text{ C.L.}$$

Search for anomalous R_T

- Data disfavor the presence of right-tensor coupling (R_T) in single top quark production.

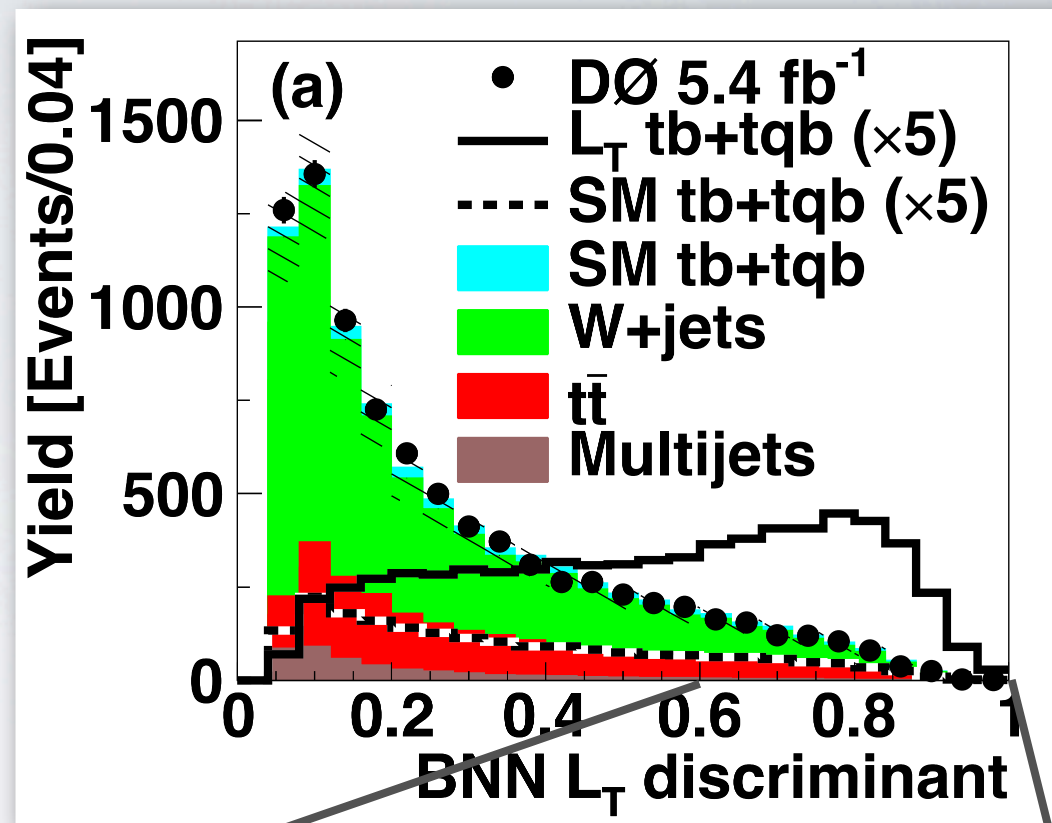


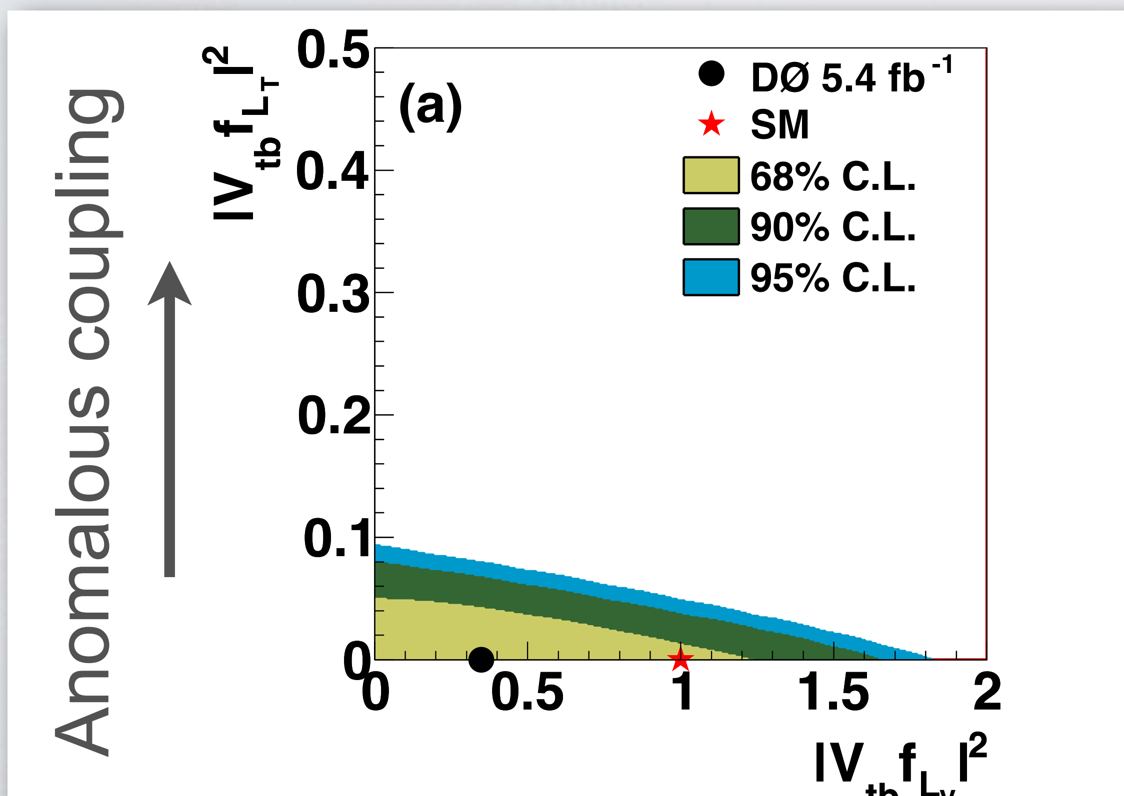
$$|R_T|^2 < 0.13 \text{ @ } 95\% \text{ C.L.}$$



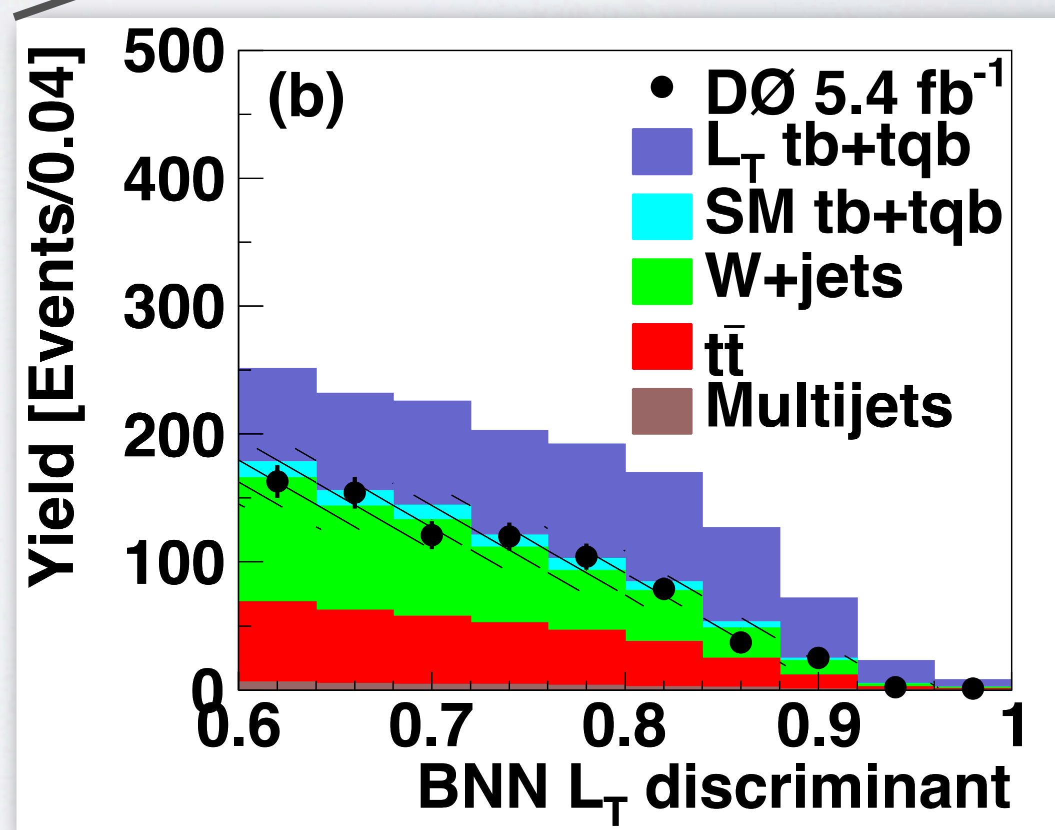
Search for anomalous L_T

- Data disfavor the presence of left-tensor coupling (L_T) in single top quark production.



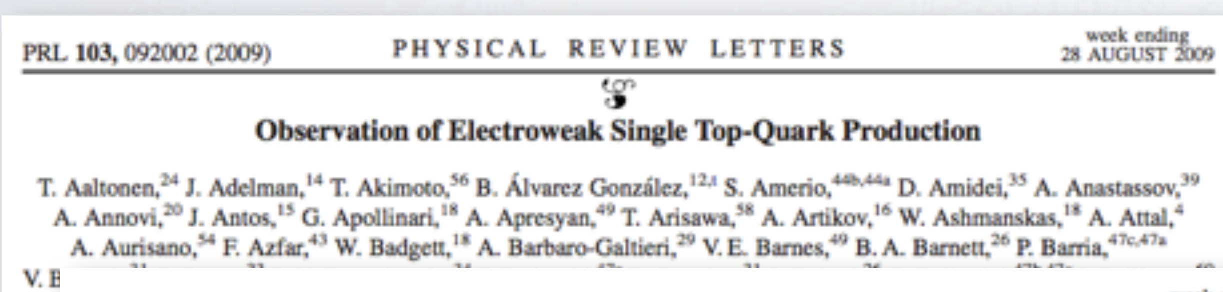


$$|L_T|^2 < 0.06 \text{ @ } 95\% \text{ C.L.}$$



Single top as legacy of the Tevatron

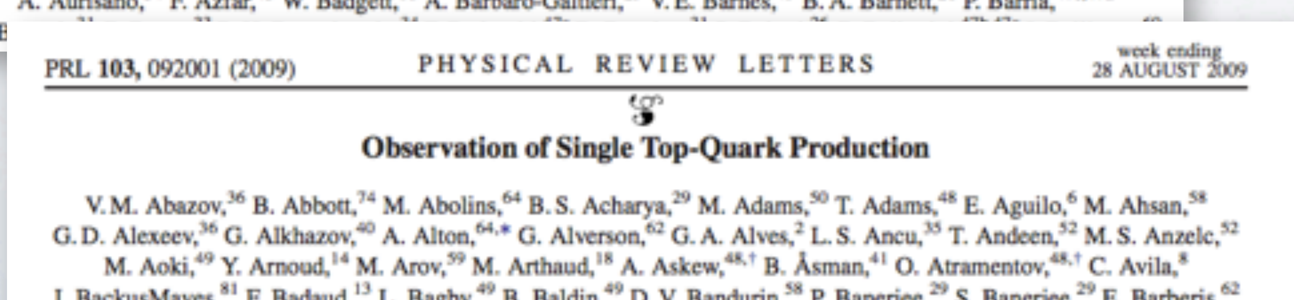
- Search: PRD 65, 091102 (2002)
- W': PRL 90, 081802 (2003)
- Search: PRD 69, 052003 (2004)
- Search: PRD 71, 012005 (2005)
- **Evidence: PRL 101, 252001 (2008)**
- FCNC: PRL 102 151801 (2009)
- W': PRL 103 041801 (2009)
- **Observation: PRL 103 092002 (2009), PRD82 112005 (2009)**
- **Tevatron combination: arxiv:0908.2171 (2009)**
- Search of s-channel: conf. note 9712 (2009)
- Wtb: conf. note 9920 (2009)



PRL 103, 092002 (2009) PHYSICAL REVIEW LETTERS week ending 28 AUGUST 2009

Observation of Electroweak Single Top-Quark Production

T. Aaltonen,[24] J. Adelman,[14] T. Akimoto,[56] B. Álvarez González,[12,t] S. Amerio,[44b,44a] D. Amidei,[35] A. Anastassov,[39] A. Annovi,[20] J. Antos,[15] G. Apollinari,[18] A. Apresyan,[49] T. Arisawa,[58] A. Artikov,[16] W. Ashmanskas,[18] A. Attal,[4] A. Aurisano,[54] F. Azfar,[43] W. Badgett,[18] A. Barbaro-Galtieri,[29] V.E. Barnes,[49] B.A. Barnett,[26] P. Barria,[47c,47a]



PRL 103, 092001 (2009) PHYSICAL REVIEW LETTERS week ending 28 AUGUST 2009

Observation of Single Top-Quark Production

V.M. Abazov,[36] B. Abbott,[74] M. Abolins,[64] B.S. Acharya,[29] M. Adams,[50] T. Adams,[48] E. Aguilo,[6] M. Ahsan,[58] G.D. Alexeev,[36] G. Alkhazov,[40] A. Alton,[64,*] G. Alverson,[62] G.A. Alves,[2] L.S. Ancu,[35] T. Andeen,[52] M.S. Anzelc,[52] M. Aoki,[49] Y. Arnoud,[14] M. Arov,[59] M. Arthaud,[18] A. Askew,[48,†] B. Åsman,[41] O. Atramentov,[48,†] C. Avila,[8] J. BackusMayes,[81] F. Badaud,[13] L. Bagby,[49] B. Baldin,[49] D.V. Bandurin,[58] P. Banerjee,[29] S. Banerjee,[29] E. Barberis,[62]

- 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)
- Wtb: DØ Note 5838-CONF (2009)
- H+: PRL 102, 191802 (2009)
- **Observation: PRL 103, 092001 (2009)**
- **Tevatron combination: arxiv:0908.2171**
- Search of t-,s-channel: PLB 682, 363 (2010)
- Cross section (tau+jets): PLB 690, 5 (2010)
- FCNC: PLB 693, 81 (2010)
- W': PLB 699, 145 (2011)
- Top width and lifetime: PRL 106, 022001 (2011)
- Cross section of t-channel: PLB 705, 313 (2011)
- Cross section of s+t- and s-channel: PRD 84, 112001 (2011)
- Wtb: PLB 708, 21 (2012)
- Top width and lifetime: submitted to PRD-RC.

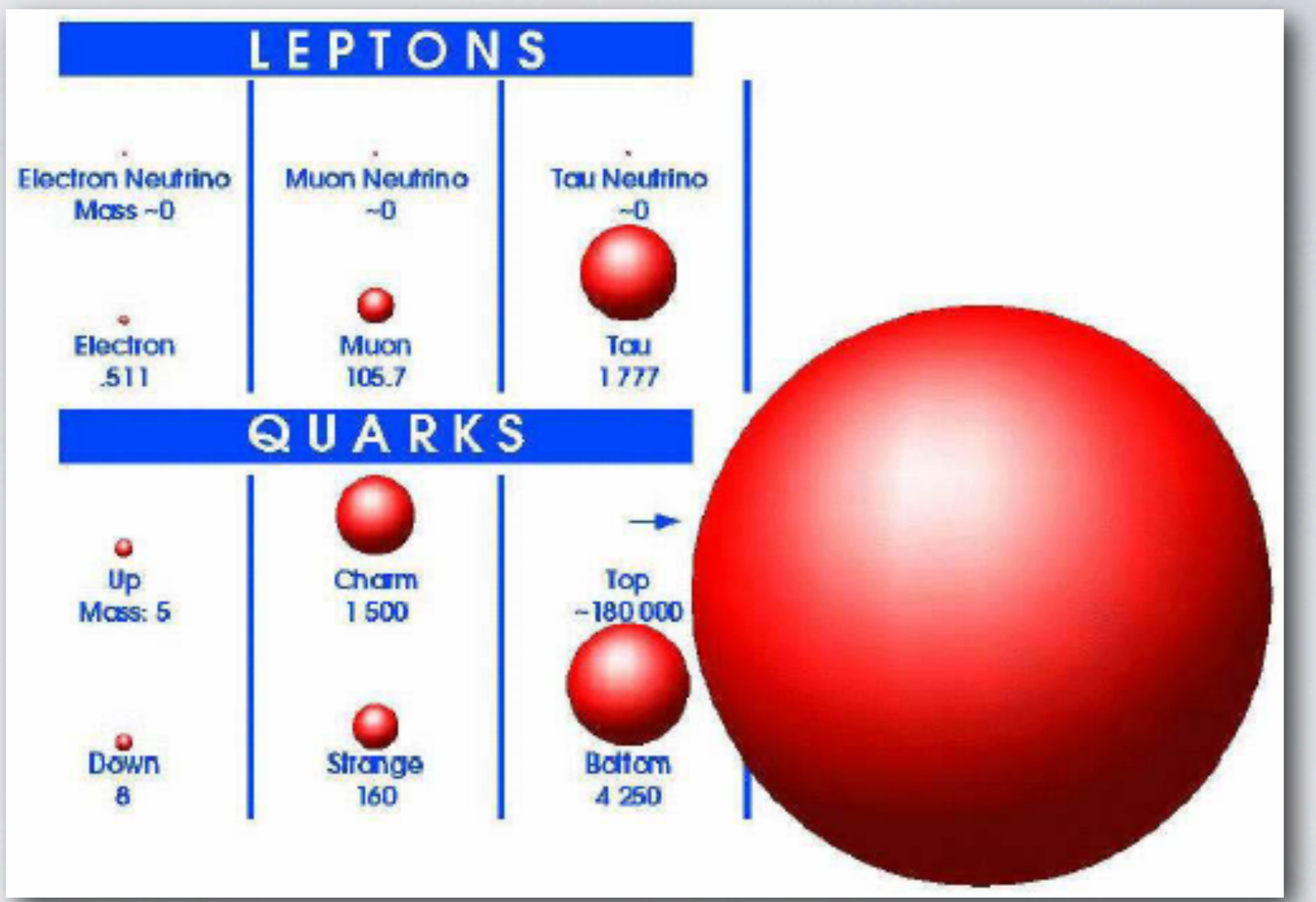
Conclusions

- Single top quark production provides us with a window of the top quark electroweak interaction.
- Searching for and measuring the different production channels are important to test the SM predictions.
- It also allows us to determine top quark properties such us its decay rate and lifetime.
- We can also prove for extensions of the electroweak interaction by searching for anomalous single top quark production.
- We are now searching for s-channel single top quark production using the 9.7 fb^{-1} dataset.

BACKUP SLIDES

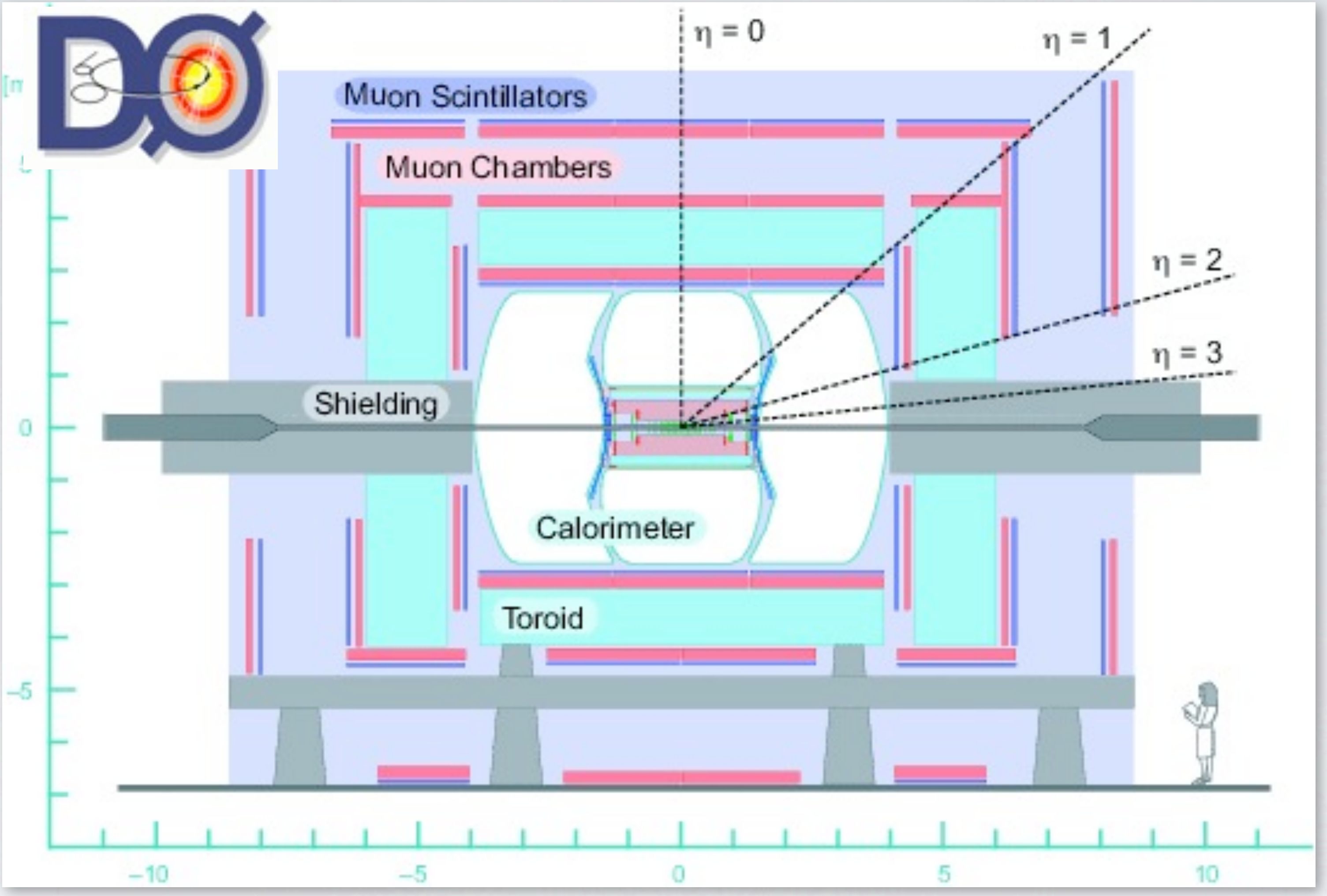
Top quark at the Tevatron

- Predicted by the SM, top quark can be produced by strong and electroweak interactions.
- Due to its large mass:
  - Top quarks strongly couple to Higgs and may provide information about the mechanism for mass generation.
  - it also plays a special role in several beyond the Standard Model (BSM) theories where they couple preferentially to top.
- Strong pair production of top (double top) quark was observed by CDF and D0 in 1995.
- A very successful program to measure the top quark properties such its mass, production rate and decay properties were possible by studying the double top production.



- However, the observation of the electroweak single top production was done very recently in 2009.
- It took 14 years and 50 times more data that the observation of double top, plus the development of new analysis techniques such Multivariate Analysis (MVA) to make this observation possible.

The D0 detectors



- **Tracking**
  - Momentum measurement of charged particles.
  - Vertex and b-jet identification
- **Calorimeter**
  - Energy measurement of jets, electrons and neutrinos.
- **Muon system**
  - Momentum measurement of muons
- **Three level trigger system.**

Single top cross section

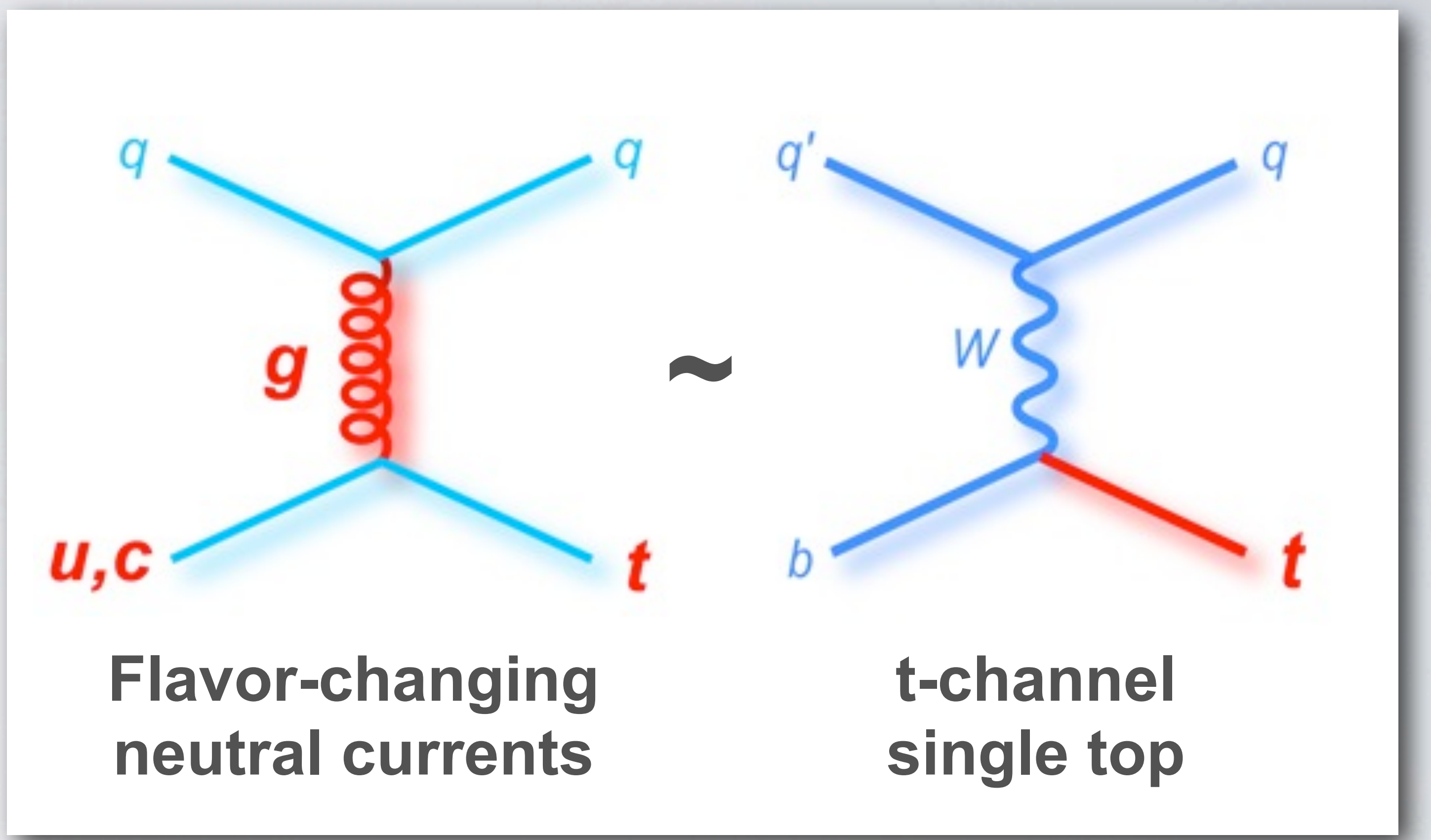
- Expect enhancements of x28(117) and x26(139) for t-channel and tW productions between Tevatron and LHC@7(14)GeV.
- However, for s-channel the xsection is only increase x4.5(11).
- Note that the xsection for top and antitop are not the same at LHC.

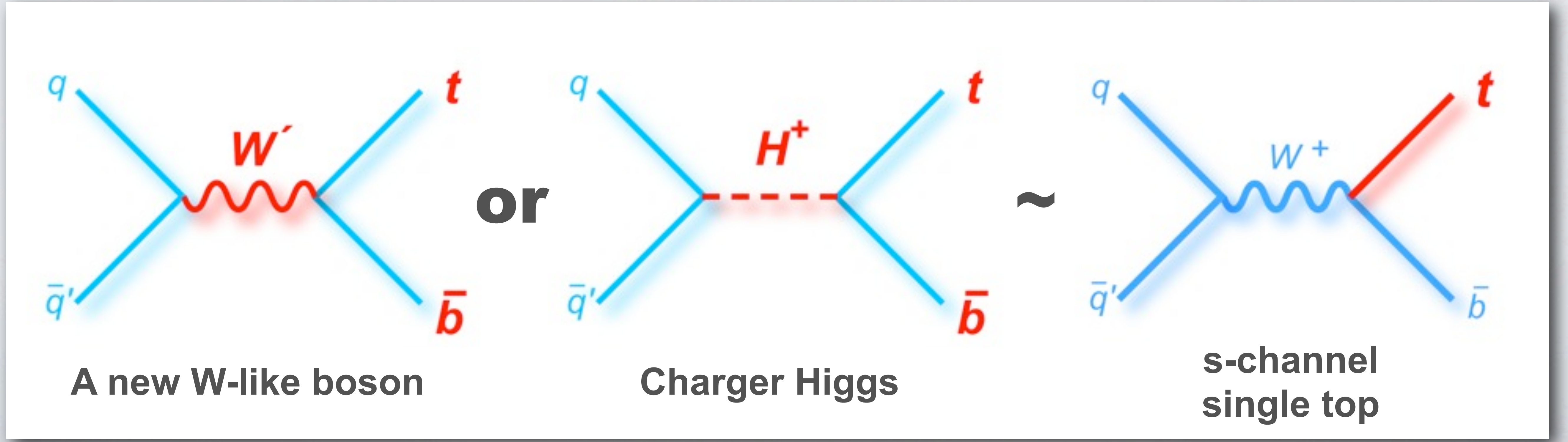
m_t = 173 GeV m_t = 172.5 GeV	s NNLO	t NNLO	tW NNLO
	t+tbar = total [pb]	t+tbar = total [pb]	t+tbar = total [pb]
Tevatron (1.96 TeV)	1.04	2.26	0.30
LHC (7 TeV)	3.17 + 1.42 = 4.59	41.7 + 22.5 = 64.2	7.8
LHC (14 TeV)	7.93 + 3.99 = 11.92	151 + 92 = 243	41.8

Kidonakis arxiv: PRD 81, 054028 (2010); PRD 83, 091503(2011)

Why study single top quark production ?

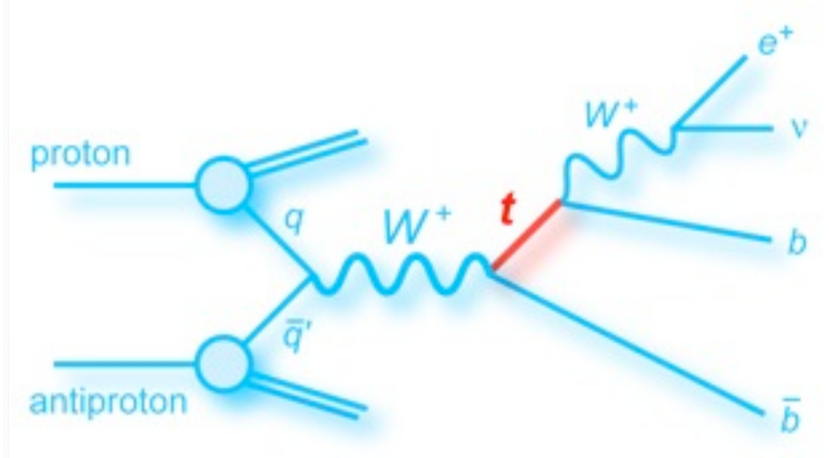
- Although the single top quark production was observed in 2009 the details of its production can be better measured.
- Beyond SM (BSM) processes can look like single top production.
- Direct probe of the Wtb interaction with few assuptions.





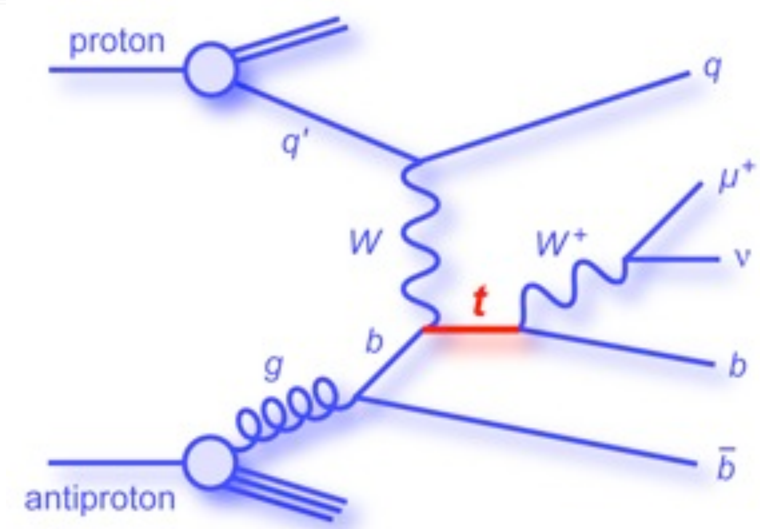
Event Selection

- A dataset of 5.4 fb^{-1}.
- One high-pT isolated electron or muon.
  - $p_T > 15GeV, |\eta| < 1.1(e) < 2.0(\mu)$
- Large missing transverse energy.
  - $\not{E}_T > 20\text{GeV}$
- Two, three and four jets.
  - $p_T > 25$ GeV (jet1), > 15 GeV (other jets)
  - $|\eta_{\text{det}}| < 3.4$
- Total transverse energy and triangular cuts.
  - $H_T > 110 - 160$ GeV
  - $|\Delta\phi(\text{jet1}, \not{E}_T)|$ vs $\not{E}_T$, $|\Delta\phi(\text{lepton}, \not{E}_T)|$ vs $\not{E}_T$
- b-jet identification:
  - One "tight" b-tagged jet or two "loose" b-tagged jets



s-channel

$\sigma_{SM} = 1.04 \pm 0.04$ pb

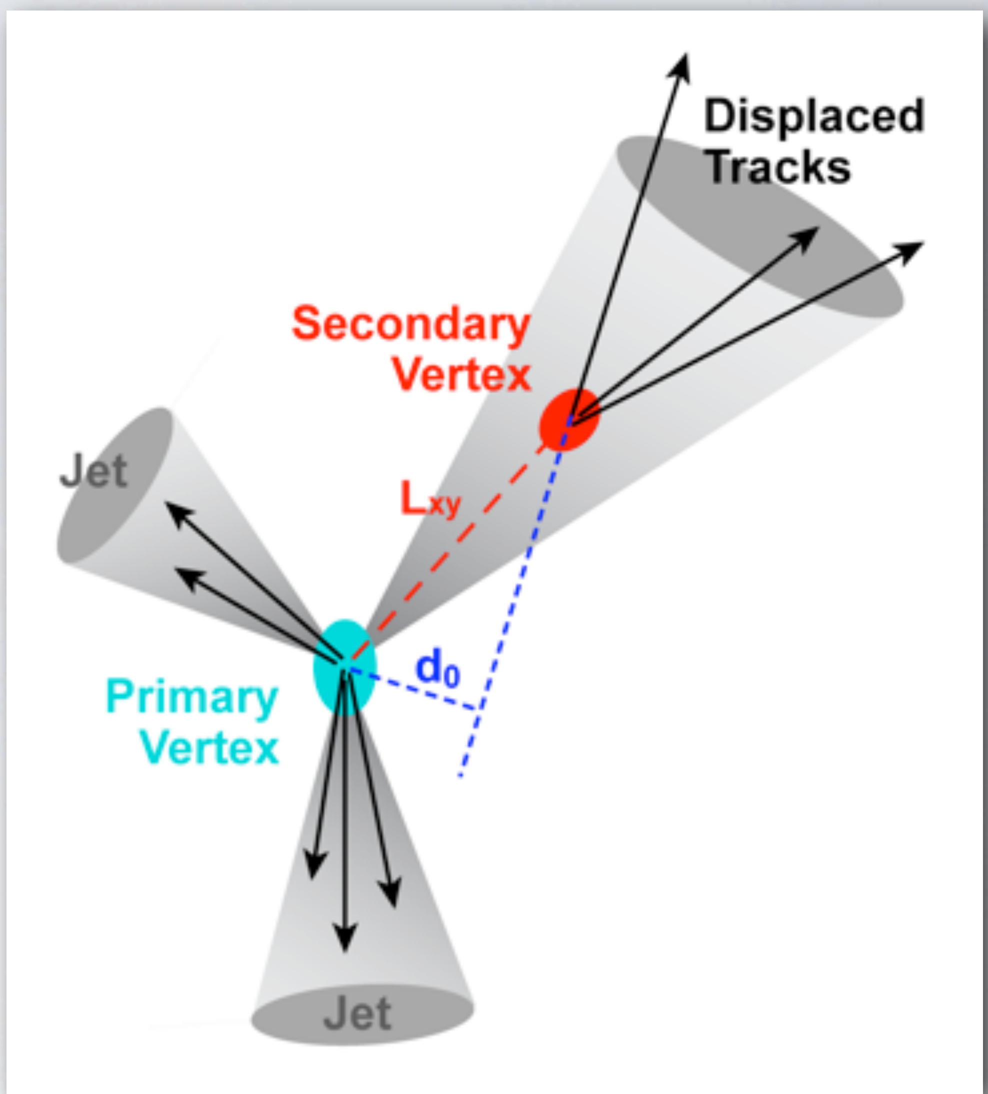


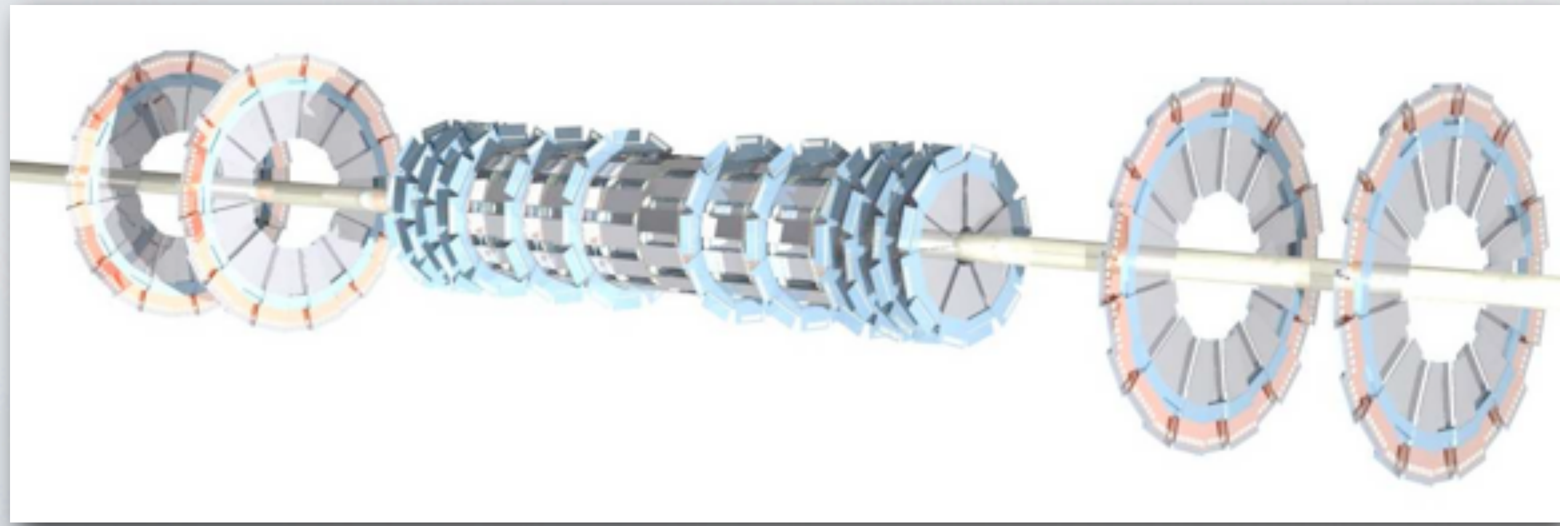
t-channel

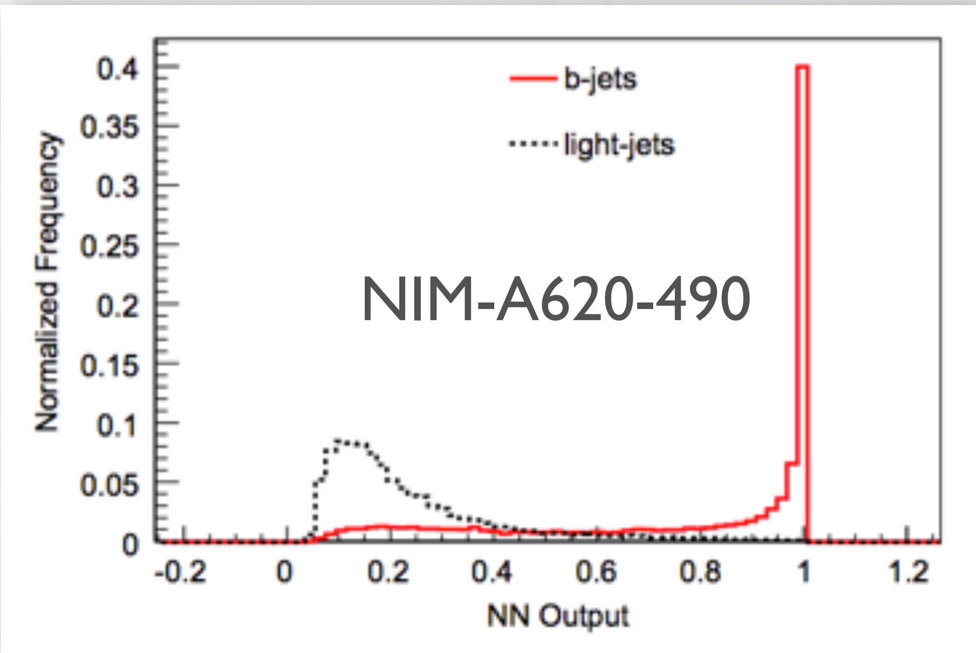
$\sigma_{SM} = 2.26 \pm 0.12$ pb

Event selection before b-tagging

- Neural Network tagger using as input:
  - decay length significance of the secondary vertex
  - χ2 per degree of freedom of the secondary vertex fit
  - weighted combination of the tracks impact parameter significances
  - probability that the jet originates from the primary interaction vertex
  - number of tracks used to reconstruct the secondary vertex
  - mass of the secondary vertex
  - number of secondary vertices found inside the jet



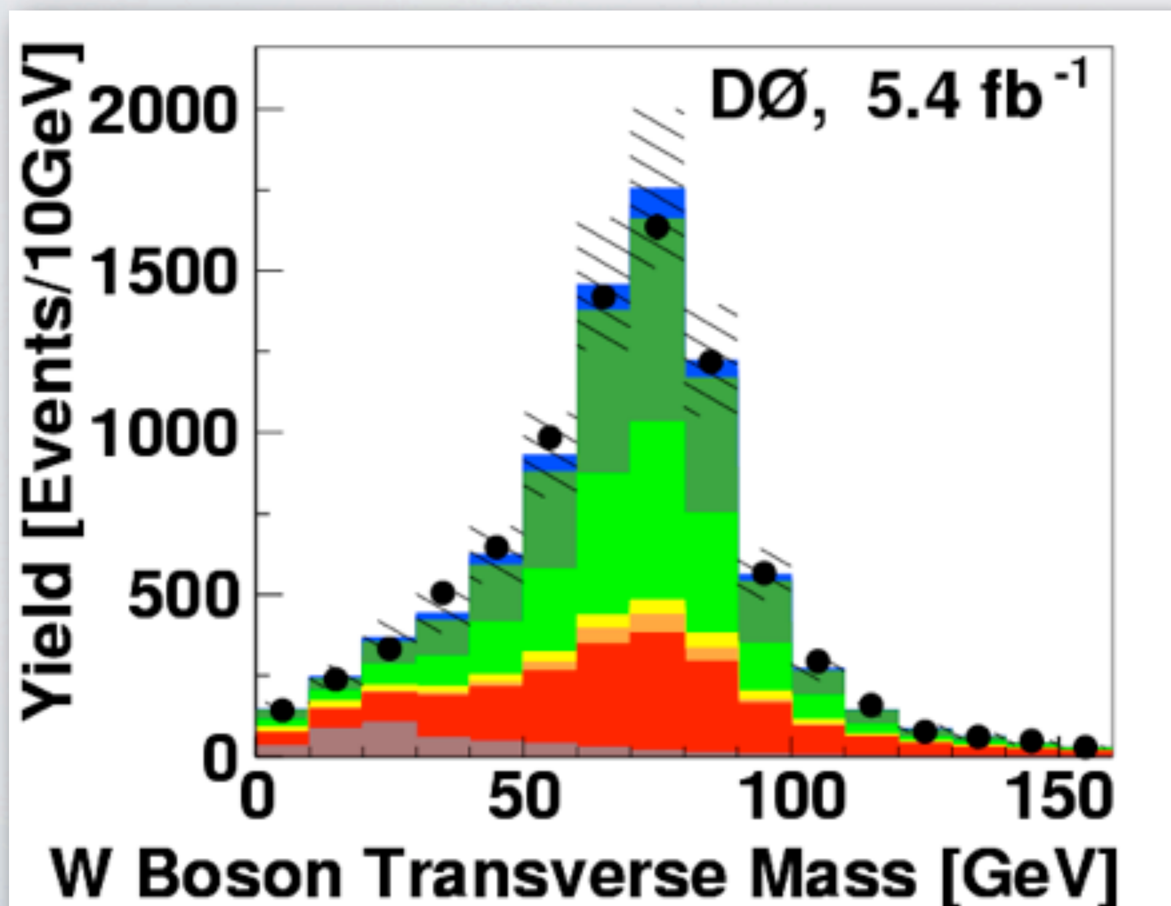




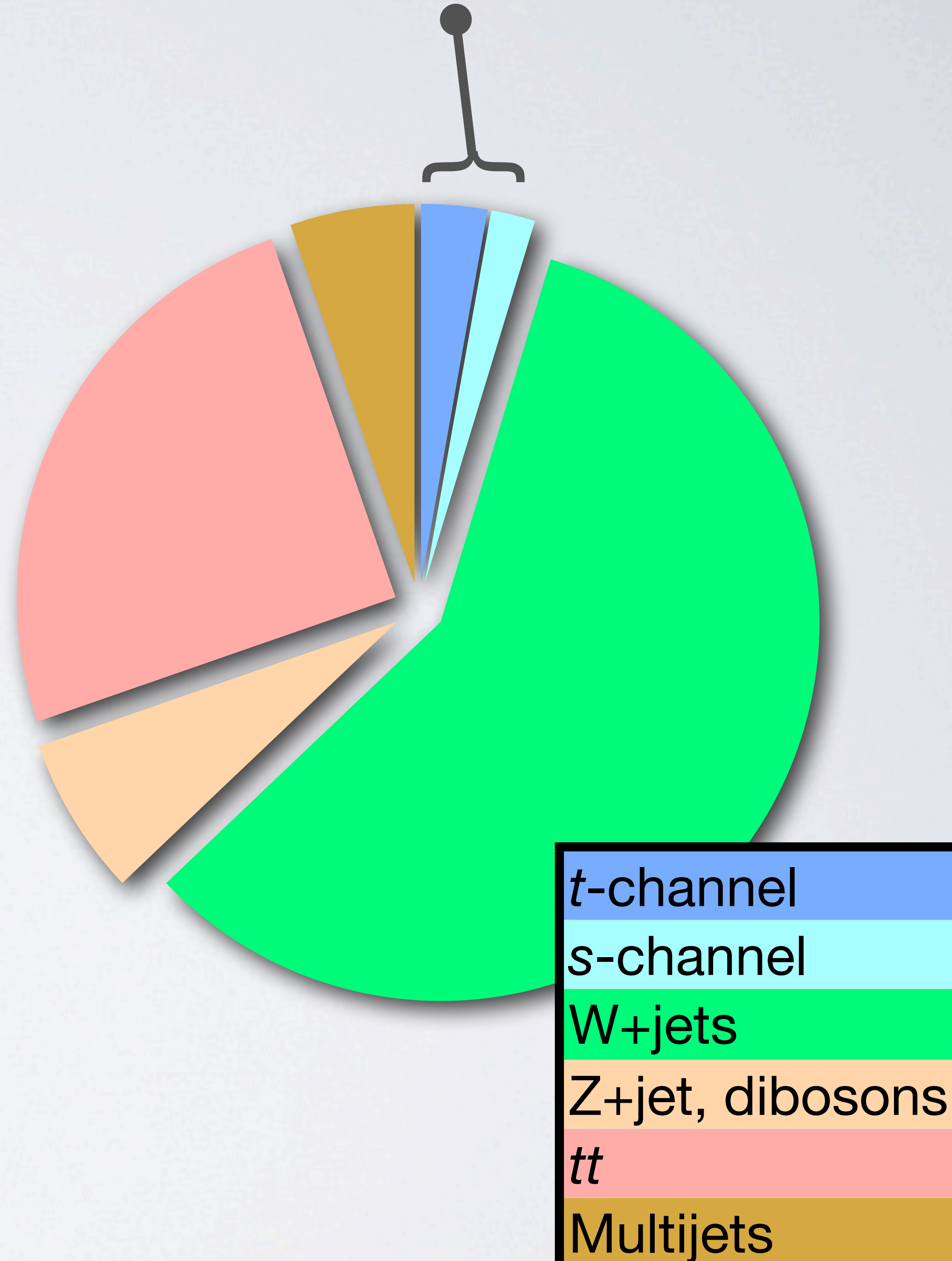
NIM-A620-490

Event selection after b-tagging

- Two operating points used in analysis:
  - ***tight*** (ε_b = 40%, ε_{light} = 0.4%)
  - ***loose*** (ε_b = 50%, ε_{light} = 1.5%)
- Define two exclusive samples
  - One ***tight*** b-jet no ***loose*** b-jet.
  - Two ***loose*** b-jets.

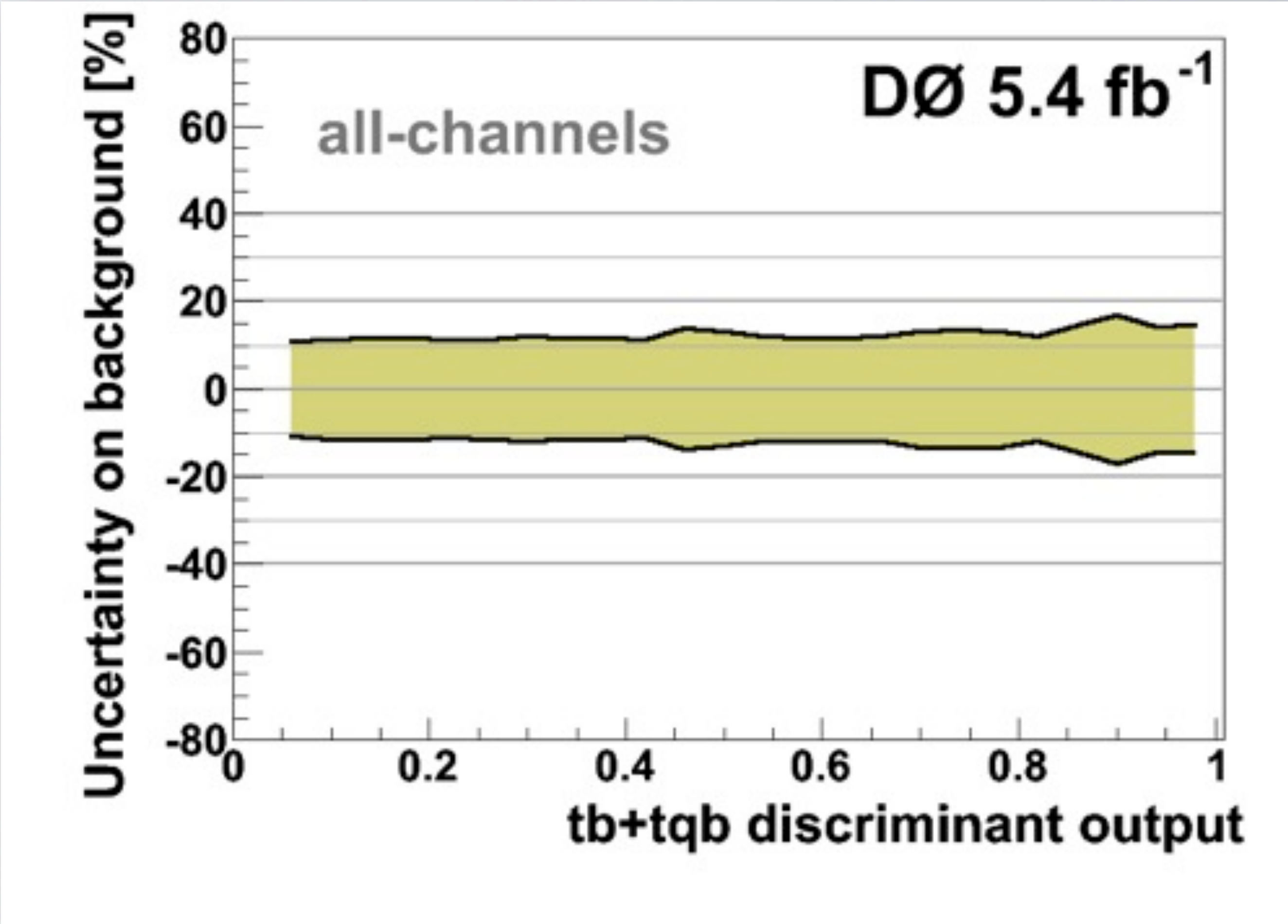


S:B ~ 1:20



Systematic uncertainties

- Uncertainties affecting normalization only
  - **Integrated luminosity**
  - Theory cross sections
  - Branching fractions
  - Parton distribution functions
  - Trigger efficiency
  - Primary vertex modeling and selection
  - Color Reconnection
  - Relative b/light jet response
  - Electron reconstruction and identification efficiency
  - Muon reconstruction and identification efficiency
  - Jet Fragmentation and higher-order effects
  - Initial-state and final-state radiation
  - b-jet fragmentation
  - **W+jets heavy-flavor scale factor correction**
  - Z+jets heavy-flavor scale factor correction
  - W+jets and multijets normalization
  - Sample statistics
  - V+jets angular correction



- Uncertainties affecting normalization and kinematics
  - Jet reconstruction and identification
  - **Jet energy resolution**
  - **Jet energy scale**
  - Vertex confirmation
  - **Correction to b-identification**

Bayesian statistical analysis in 2D

In this case both the signal prior and posterior distributions have 2 dimensions

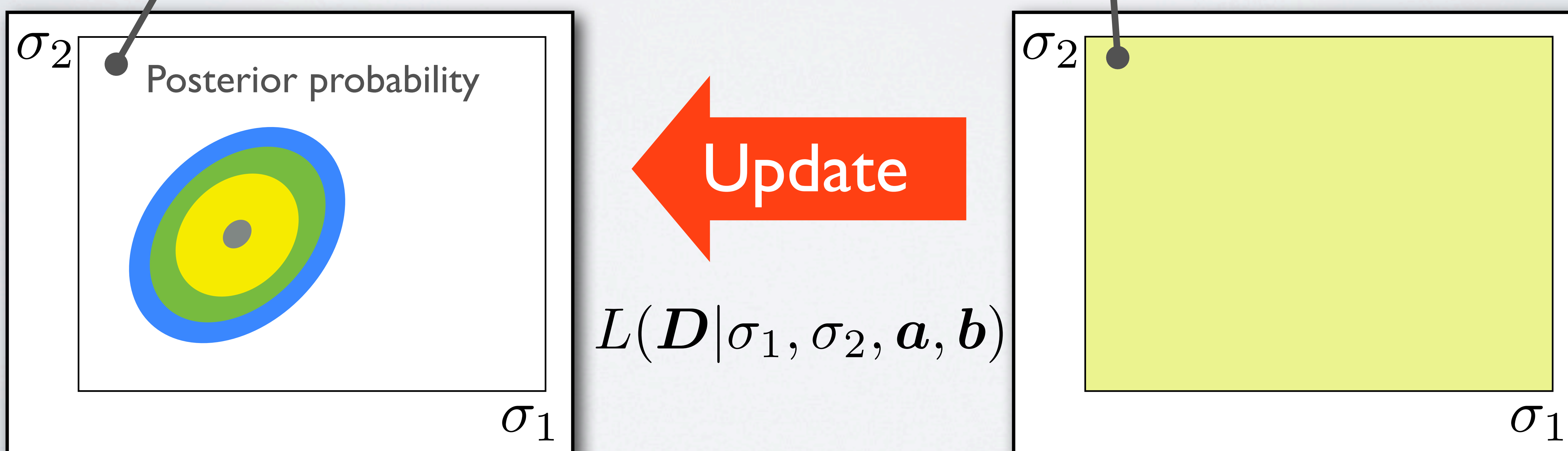
Mean event count

signal acceptances

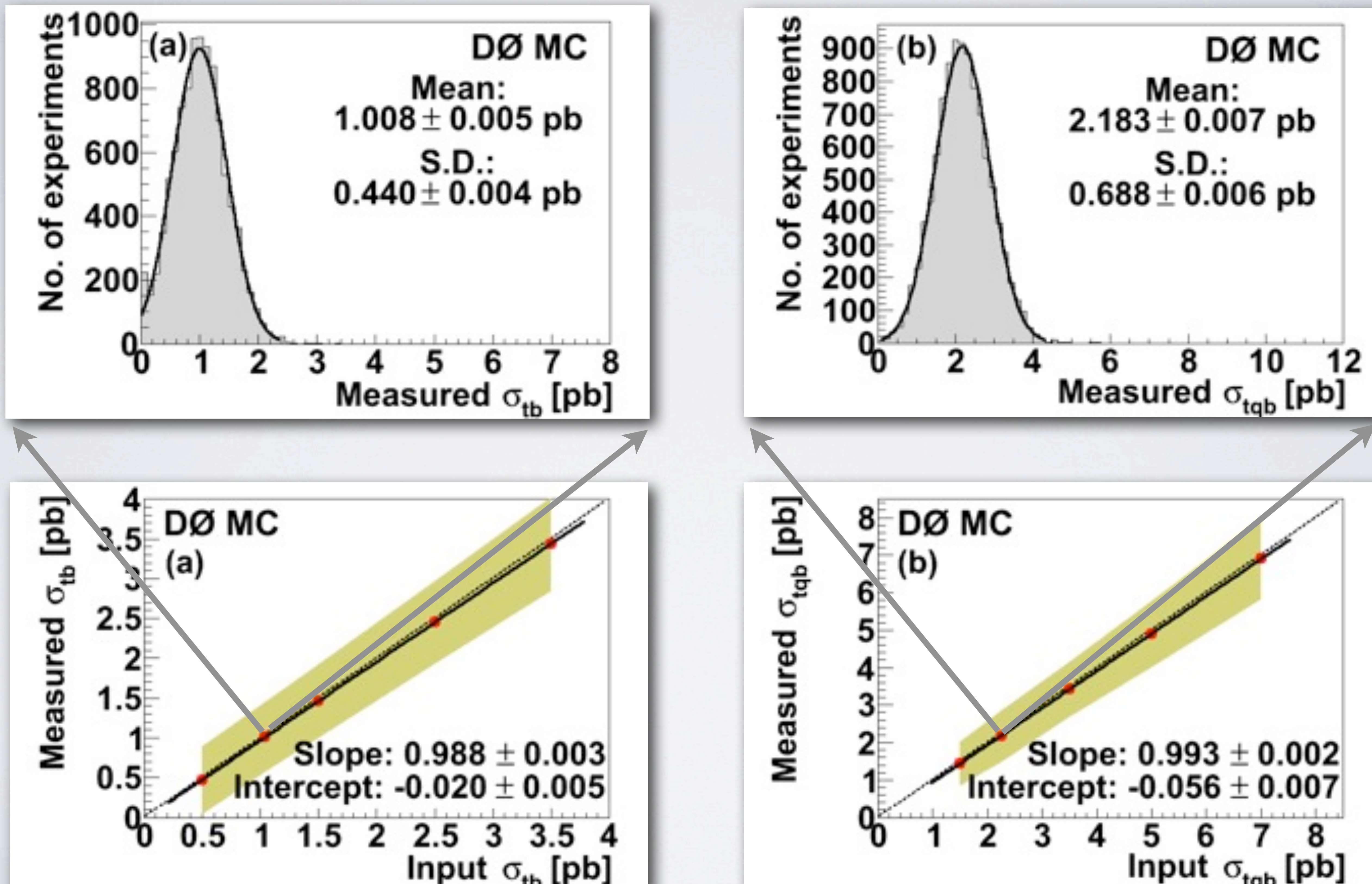
$$\boldsymbol{d} = \sigma_1 \overbrace{\boldsymbol{a}_1} + \sigma_2 \overbrace{\boldsymbol{a}_2} + \underbrace{\boldsymbol{b}}$$

signal production rates   background event yields

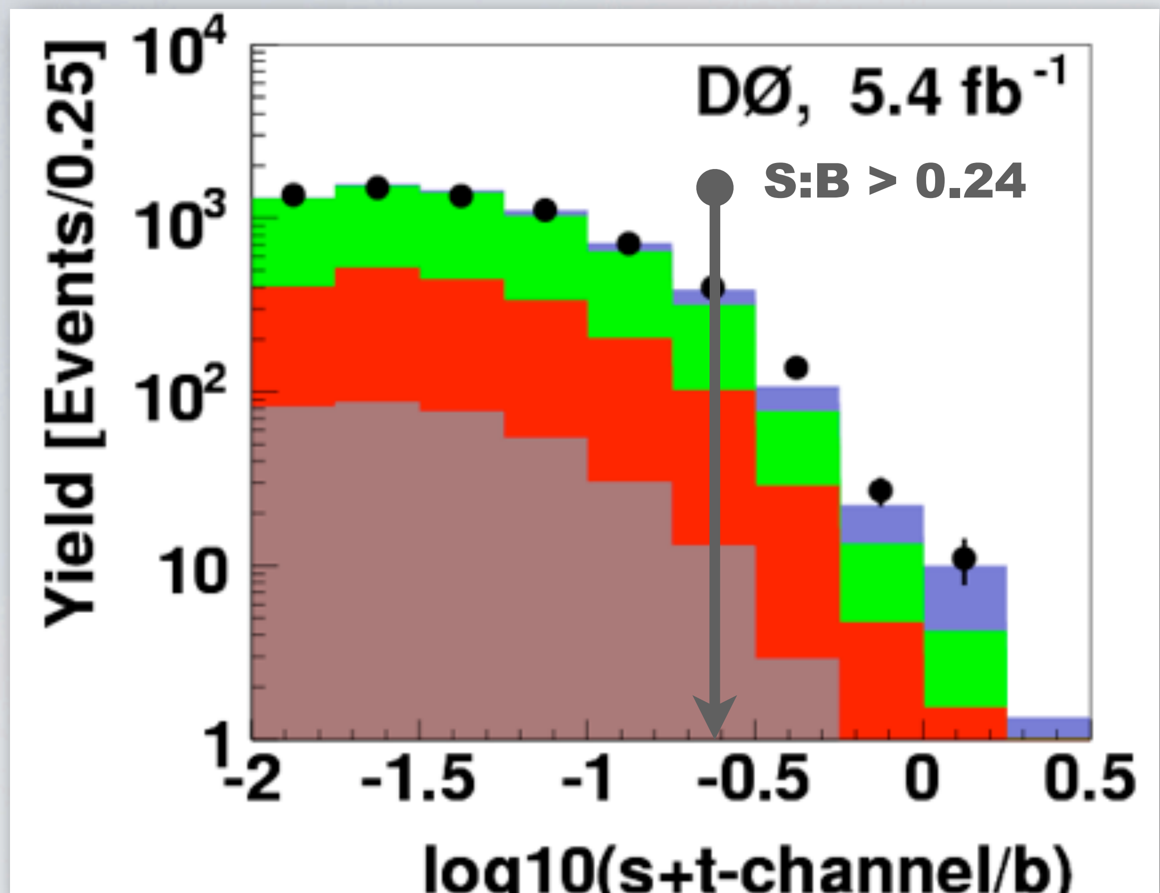
$$p(\sigma_1, \sigma_2) = \frac{1}{\mathcal{N}} \int L(\boldsymbol{D}|\sigma_1, \sigma_2, \boldsymbol{a}, \boldsymbol{b}) \pi(\sigma_1, \sigma_2) \pi(\boldsymbol{a}, \boldsymbol{b}) d\boldsymbol{a} d\boldsymbol{b}$$

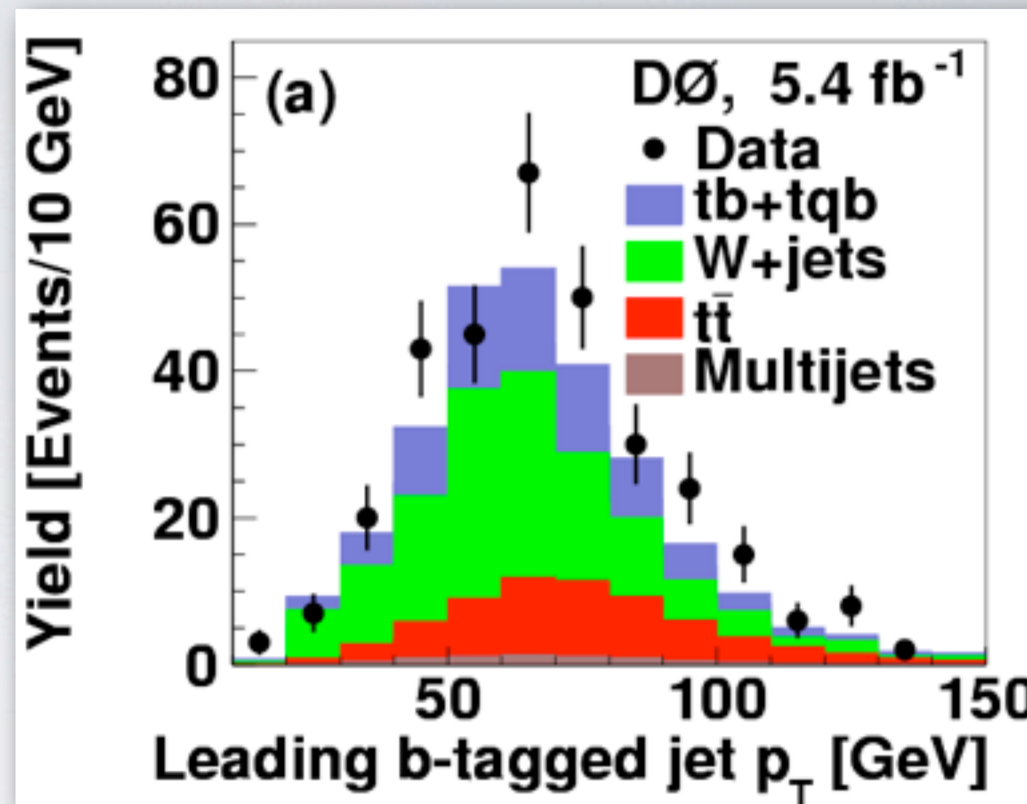


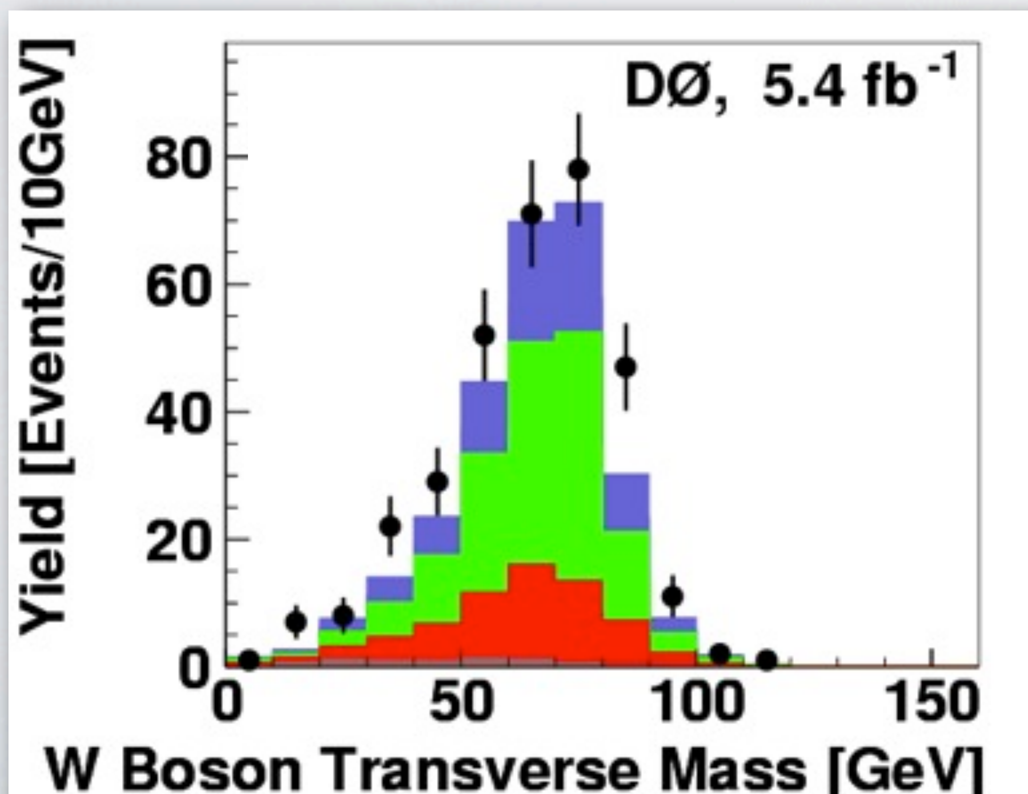
Linearity Test and Ensemble Distribution

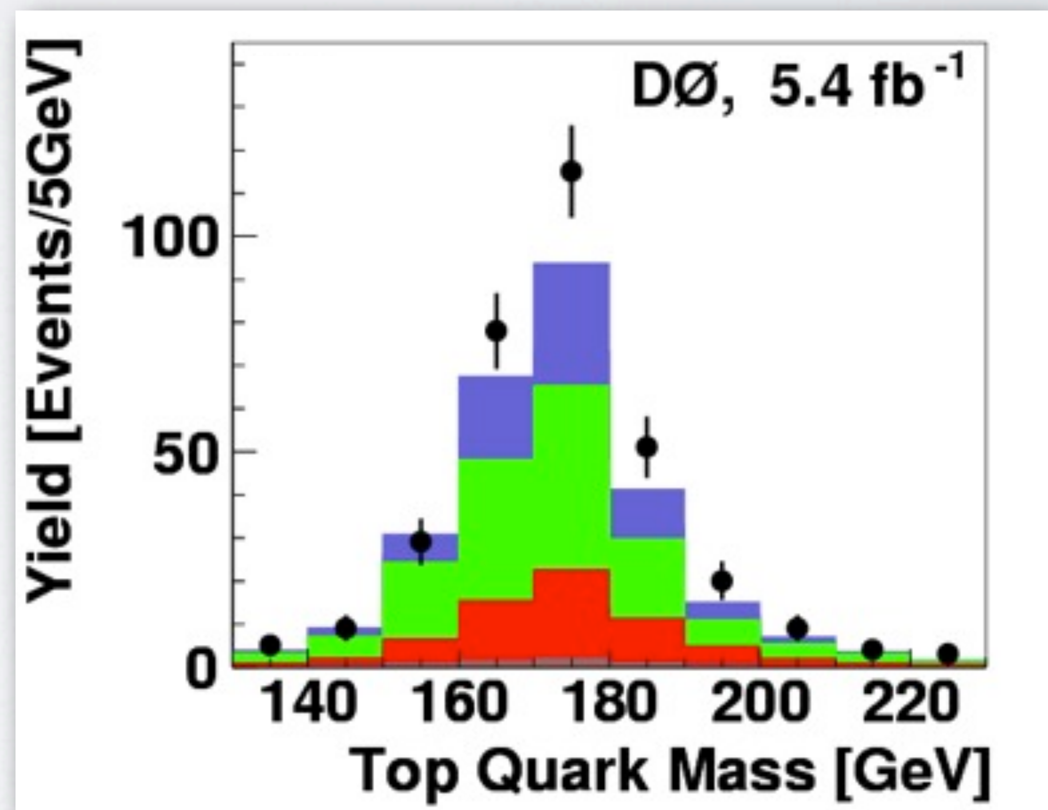


Single top enriched distributions





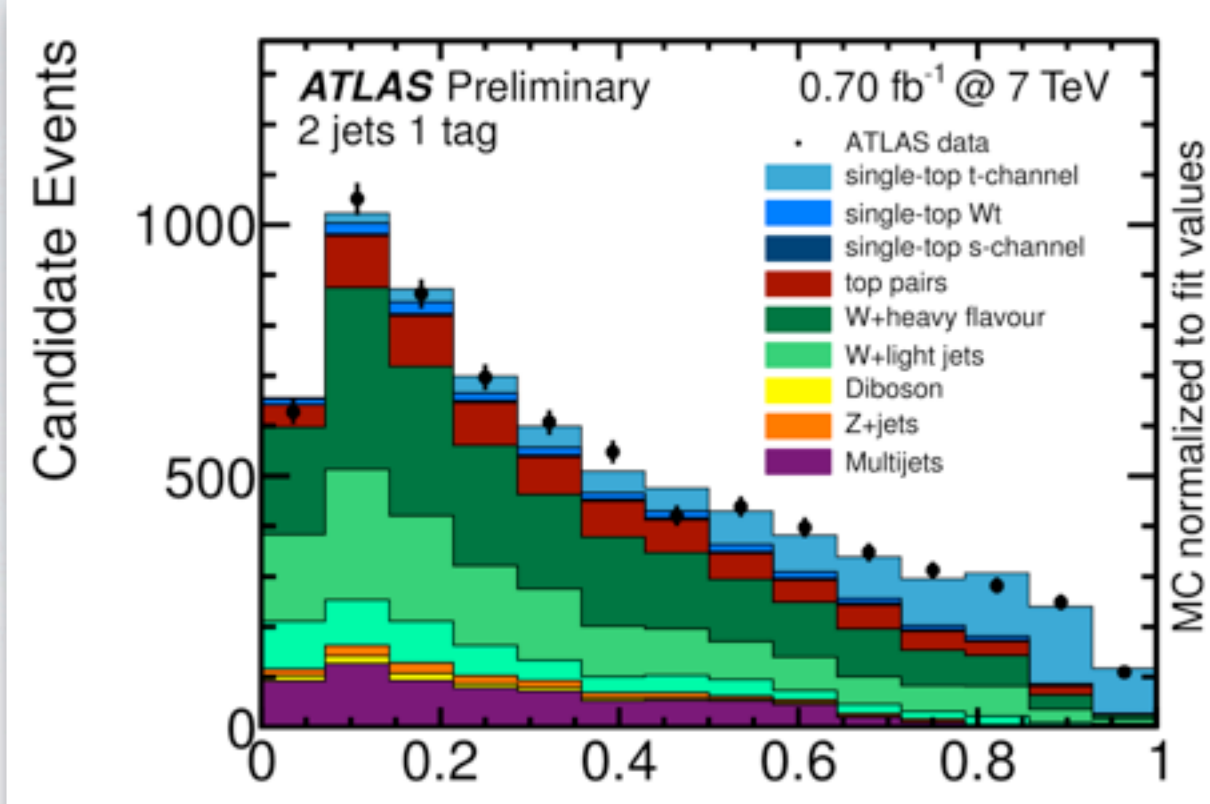




Single top t-channel studies at LHC

$$\sigma_t = 90^{+9}_{-9}(\text{stat})^{+31}_{-22}(\text{syst})\ \text{pb}$$

$$\text{significance} = 5.4\sigma$$



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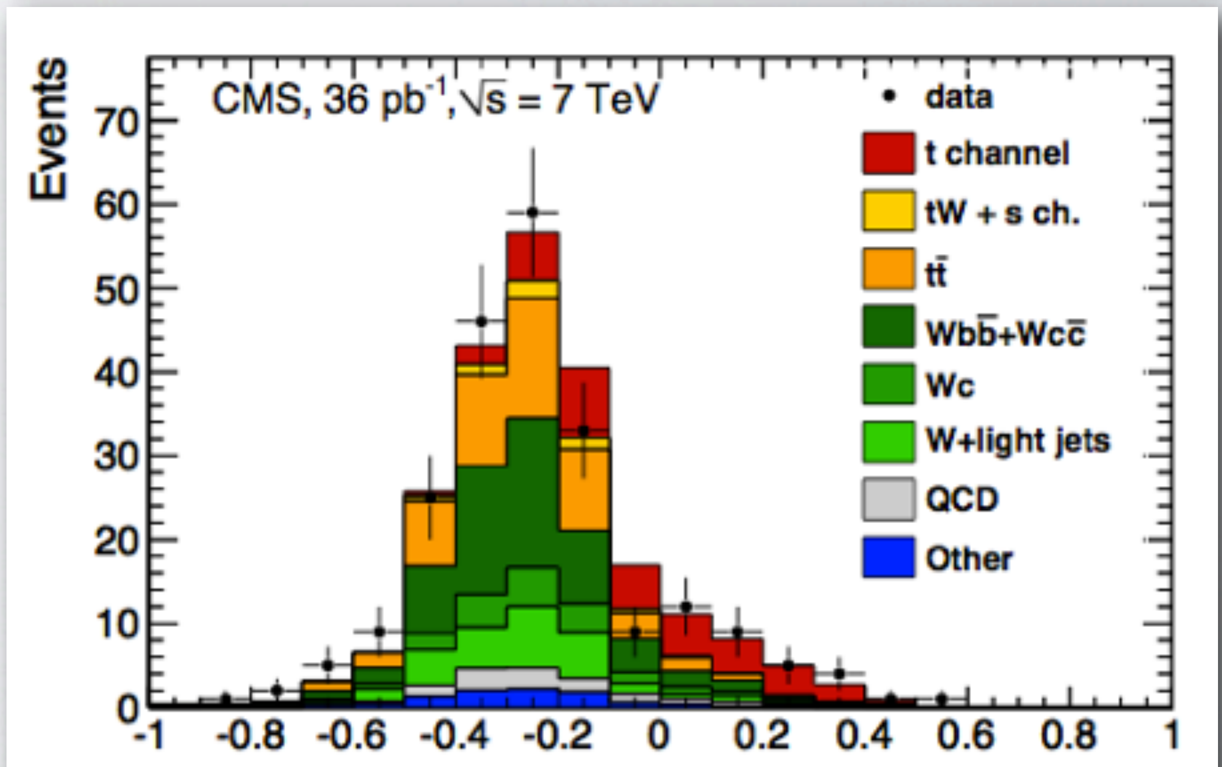
$$\sigma_t = 83.6 \pm 30(\text{stat}) \pm 3.3(\text{lumi})\ \text{pb}$$

$$\text{significance} = 3.5\sigma$$



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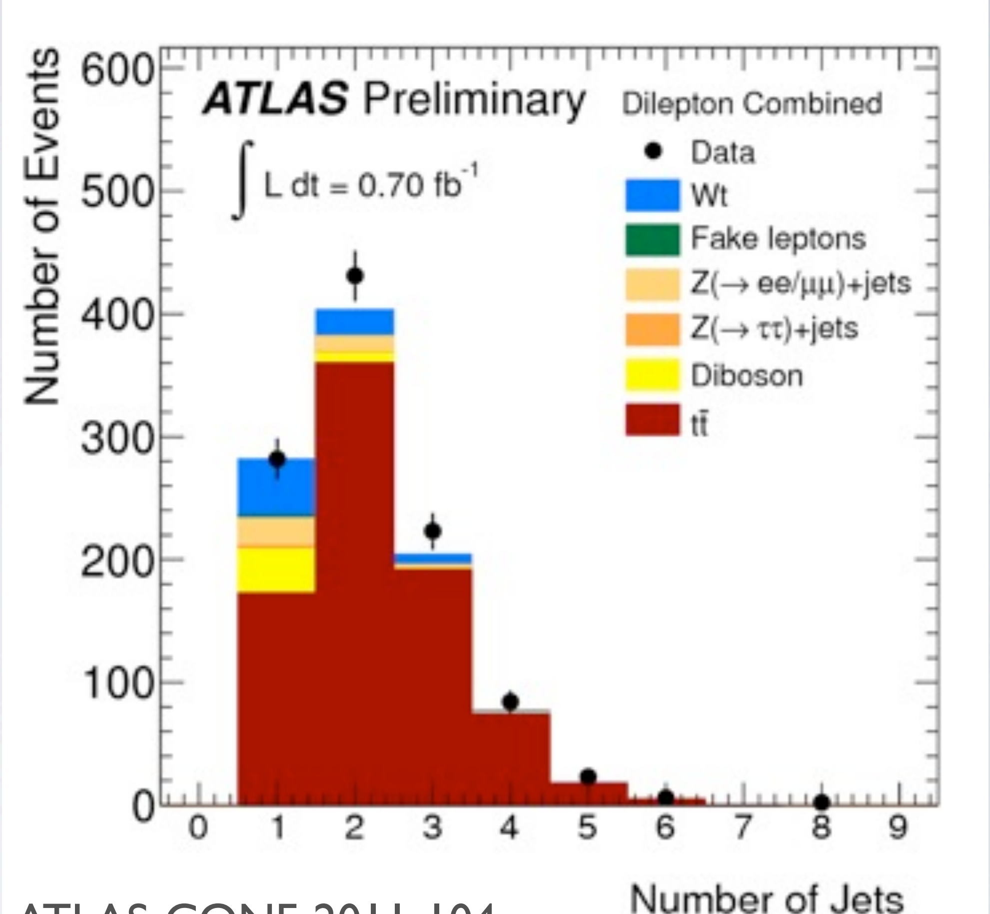
Single top tW-channel studies at LHC

$$\sigma_{tW} = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})\ \text{pb}$$

$$\text{significance} = 1.2\sigma$$



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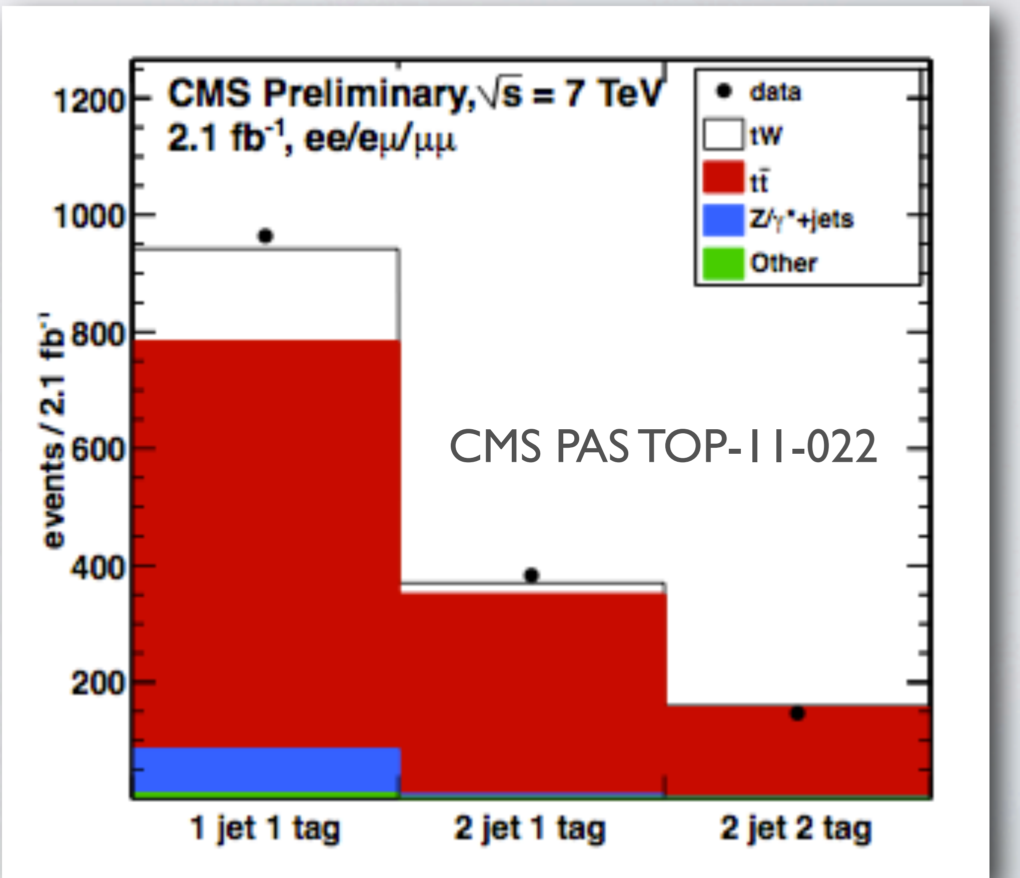
$$\sigma_{tW} = 22^{+9}_{-7}\ \text{pb}$$

$$\text{significance} = 2.7\sigma$$



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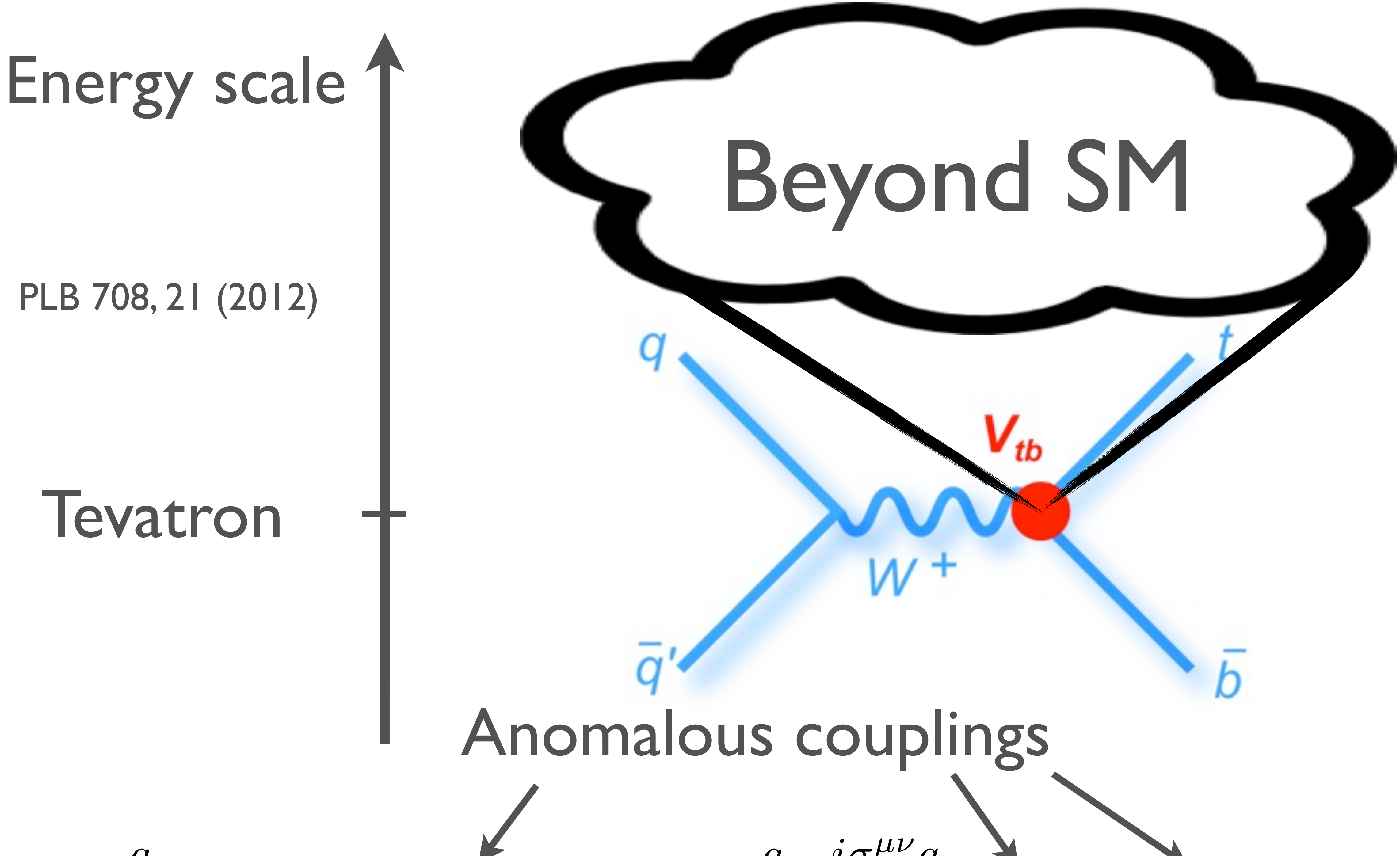
Search for BSM physics



$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(L_V P_L + \boldsymbol{R_V P_R})tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(\boldsymbol{L_T P_L} + \boldsymbol{R_T P_R})tW_{\mu}^{-} + h.c.$$

SM : $L_V = 1 \; \boldsymbol{R_V} = \boldsymbol{L_T} = \boldsymbol{R_T} = 0$

$P_{L,R} = (1 \mp \gamma_5)/2$