Single top quark production at the Tevatron

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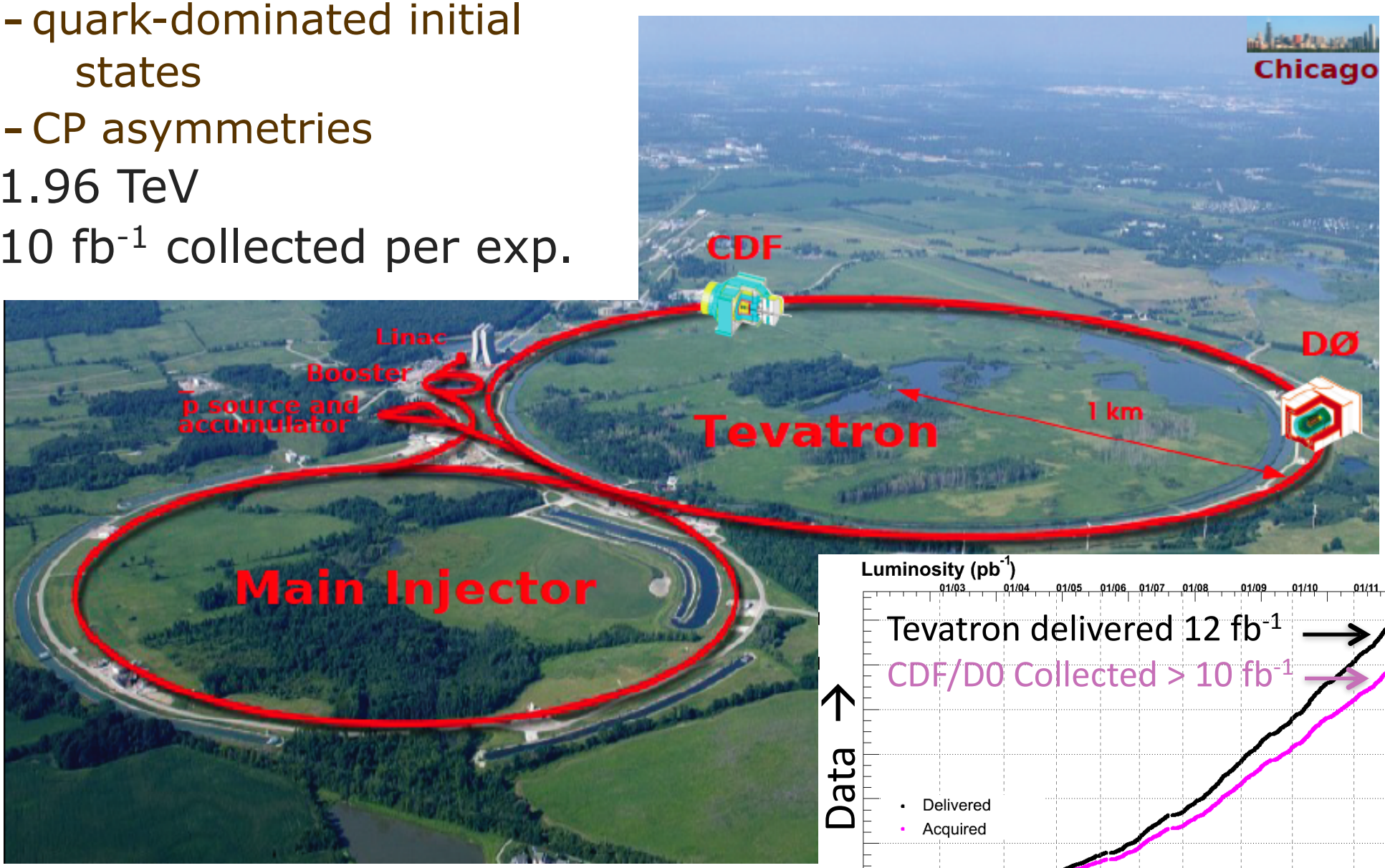
On behalf of the CDF and D0 collaborations

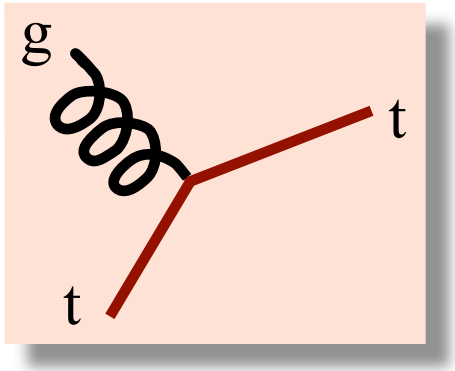
Outline

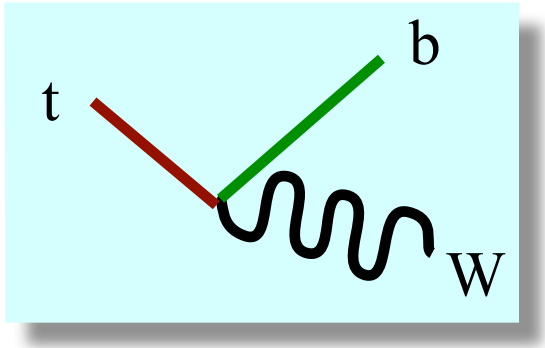
- Tevatron
- Top quark couplings
- Single top production
- Event selection
- s+t
- s-channel
- Tevatron s-channel combination
- Conclusions

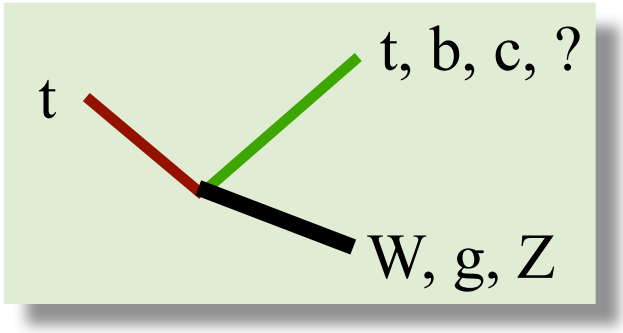
Tevatron collider in Run II

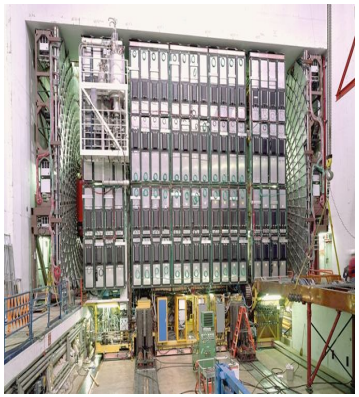
- proton-antiproton collider
  - quark-dominated initial states
  - CP asymmetries
- 1.96 TeV
- 10 fb^{-1} collected per exp.

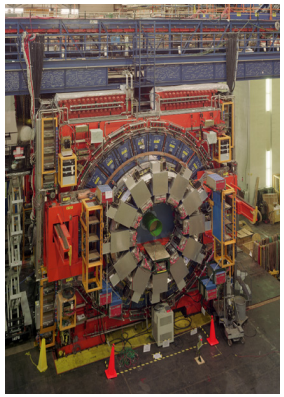


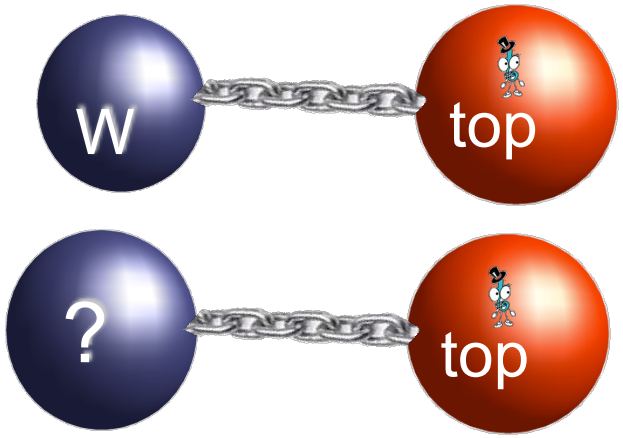












SM measurements:

- CKM matrix element $|V_{tb}|$
- PDFs

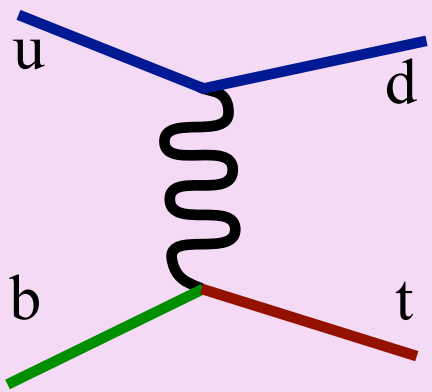
New physics:

- anomalous couplings
- FCNC
- New bosons
- Charged Higgs
- CP violation

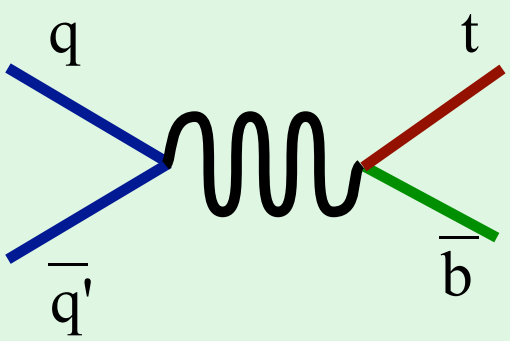
Background to Higgs fermion coupling measurements

Single top production

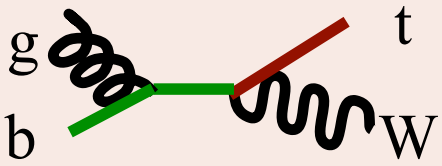
t-channel



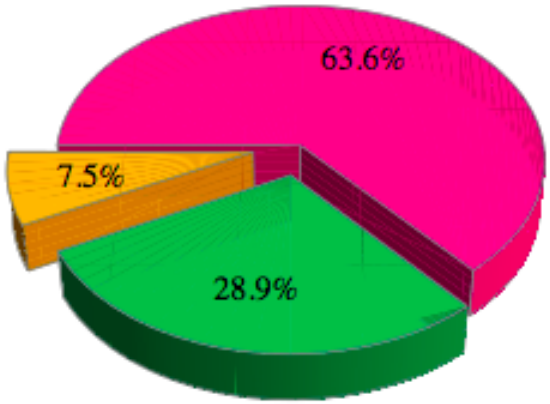
s-channel

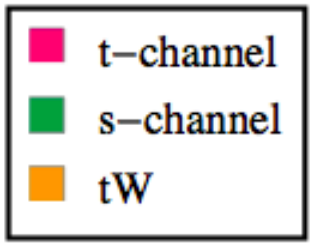


Associated production

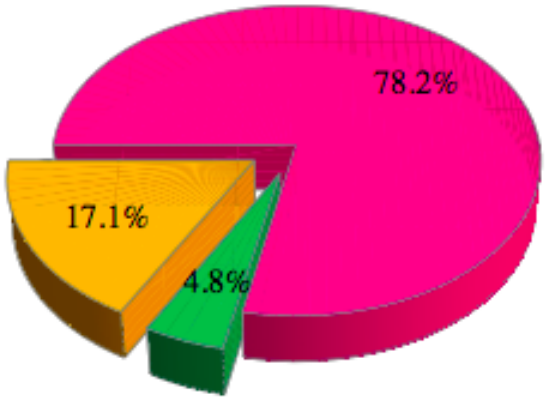


Tevatron: σ_{tot} = 3 pb

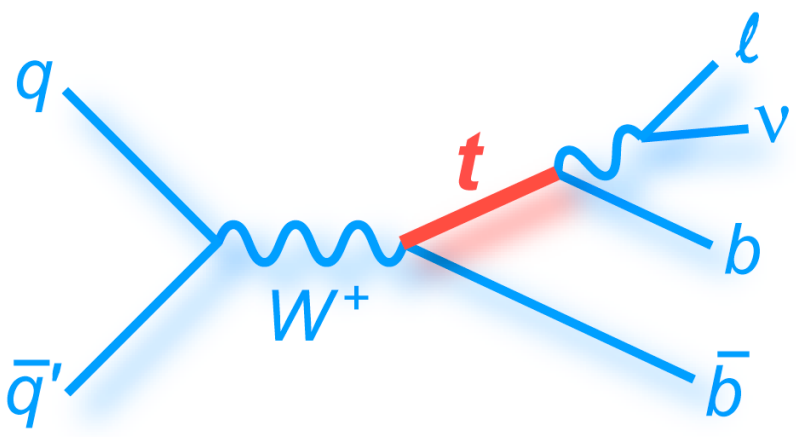


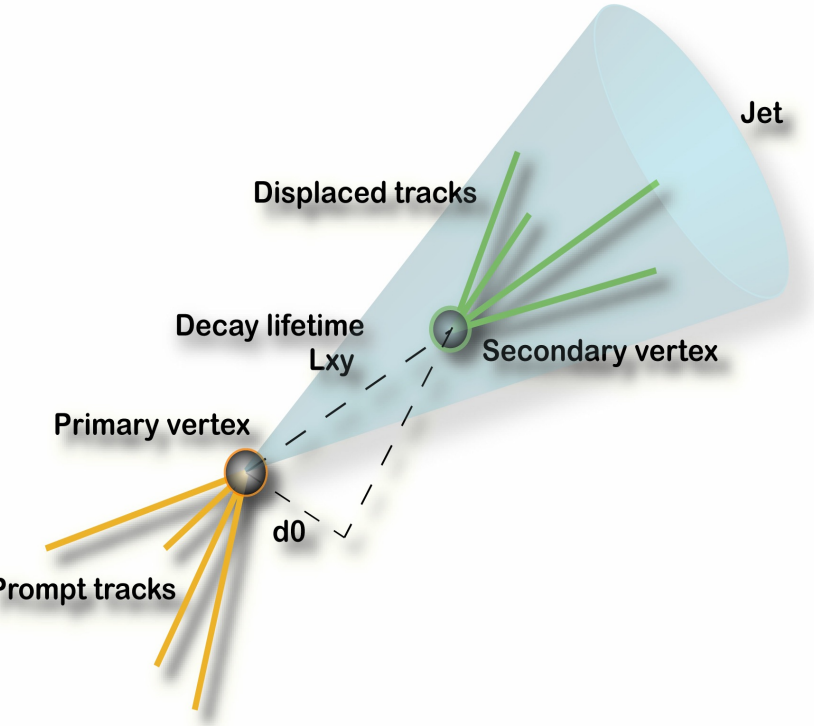


LHC: σ_{tot} = 114 pb @ 8 TeV



Event selection

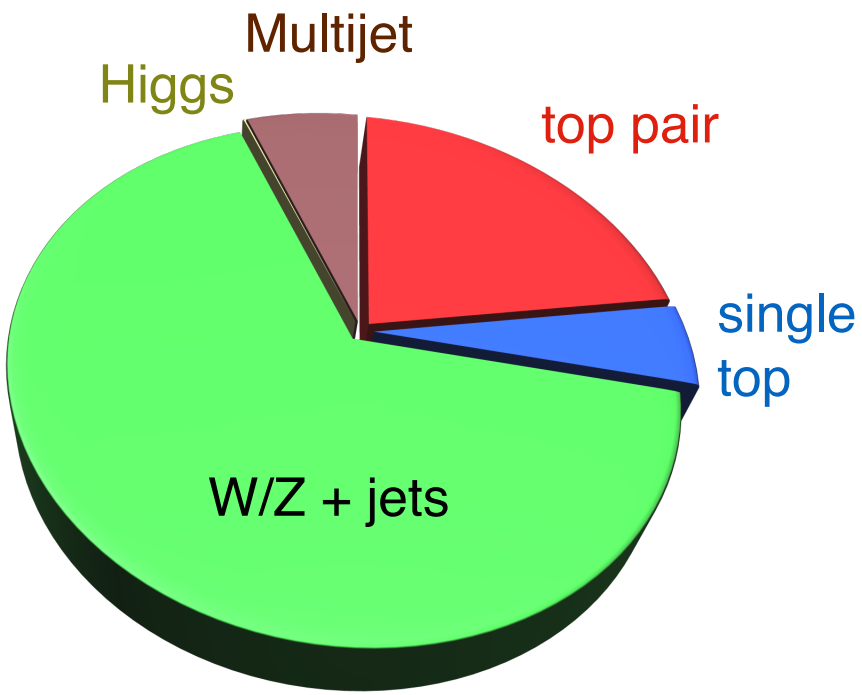




- Lepton + jets selection (CDF and D0):
  - 1 Lepton, large MET
  - 2 or 3 jets
  - ≥ 1 b-tagged jet
  - Veto "non-W", Z, dileptons, conversions, cosmics
- Expected signal events:
  - ~250 s-channel
  - ~400 t-channel

- MET + jets selection (CDF):
  - Large MET, veto leptons
  - 2 or 3 jets
  - ≥ 1 b-tagged jet
  - Neural network to suppress QCD background
  - ~250 s-channel events expected

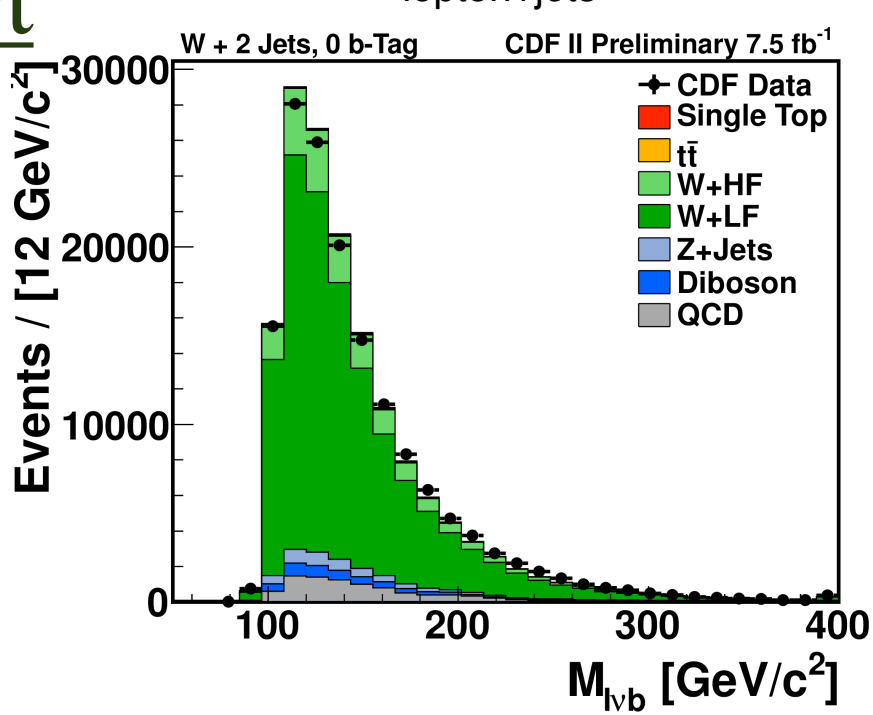
Background composition

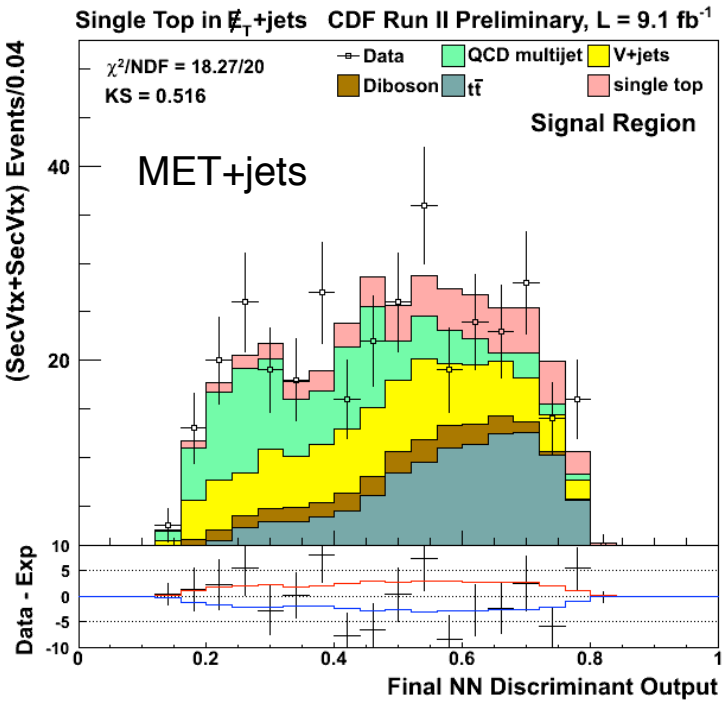


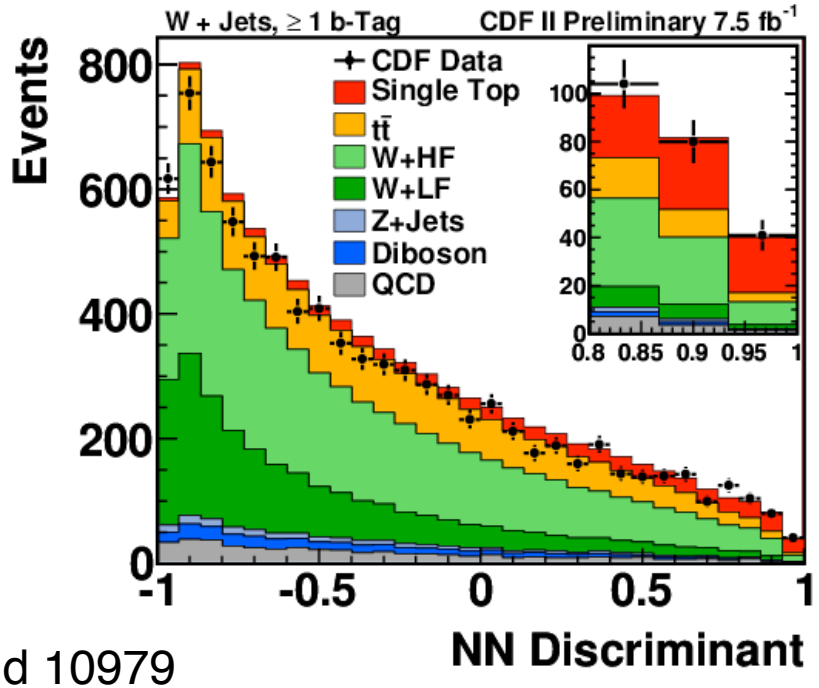
- W/Z+jets
  - W+jets Normalization and flavor composition from data
  - W+jets shape from simulation
  - Diboson from simulation
- top pair production
  - normalization to NNLO
  - Shape from Alpgen
- QCD multijet production
  - Normalization from data
  - Shape from data
- Total:
  - ~ 10^5 events (lepton+jets)
  - ~ 10^6 events (MET+jets)

CDF s+t

- lepton+jets with 7.5 fb^{-1}
  - # of b-tags to define samples
  - Neural network (NN) for s-channel or t-channel
- MET+jets with 9.1 fb^{-1}
  - # of b-tags to define samples
  - Neural network (NN) combination of other MVAs







CDF notes 10793 and 10979

CDF s+t

- lepton+jets with 7.5 fb^{-1}
  - # of b-tags to define samples
  - Neural network (NN) for s-channel or t-channel
- MET+jets with 9.1 fb^{-1}
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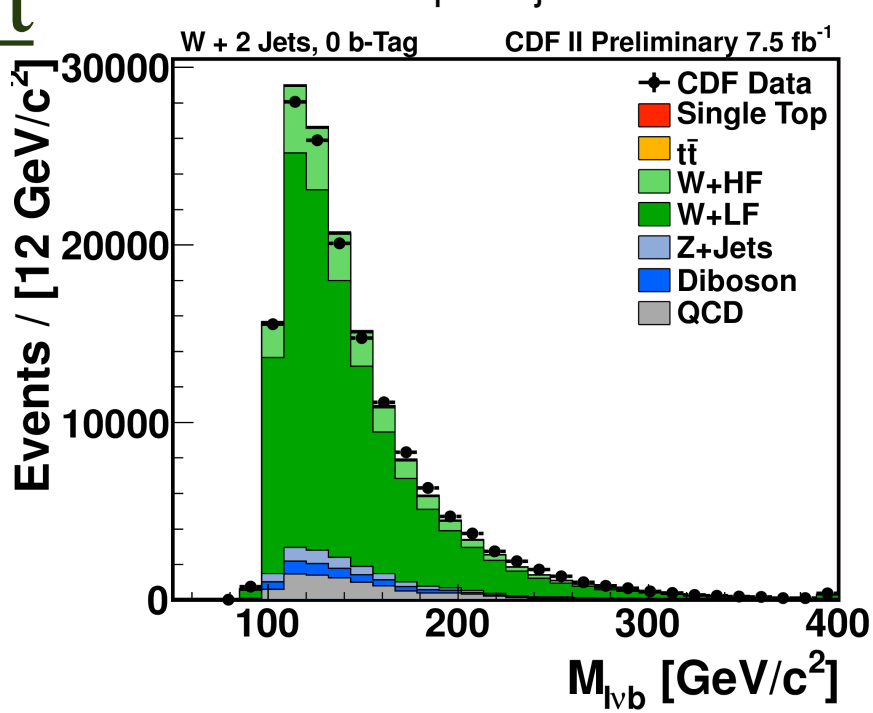
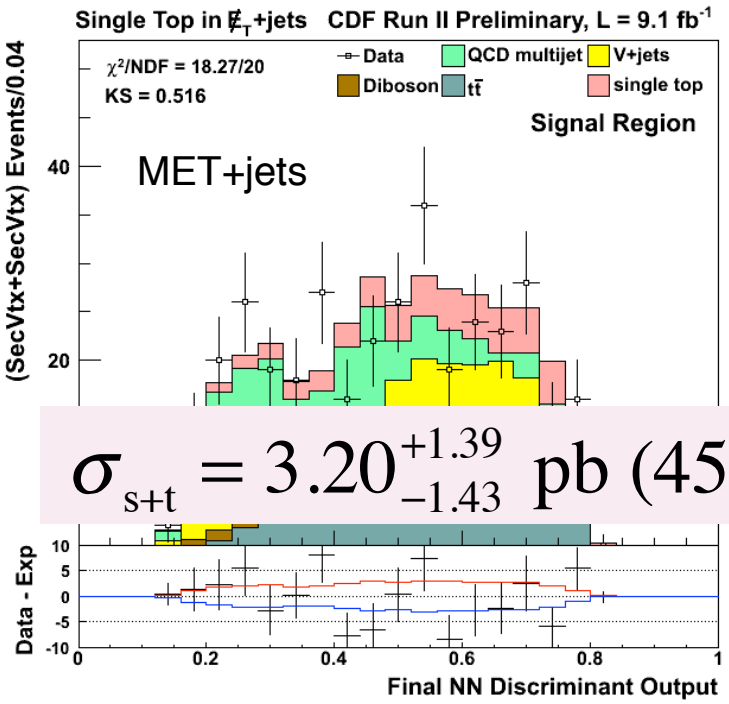
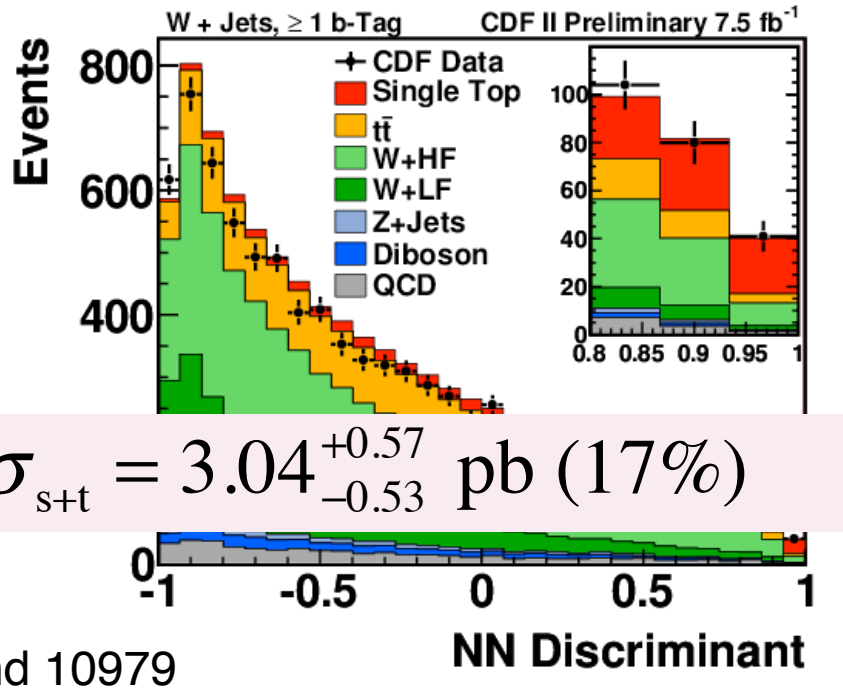




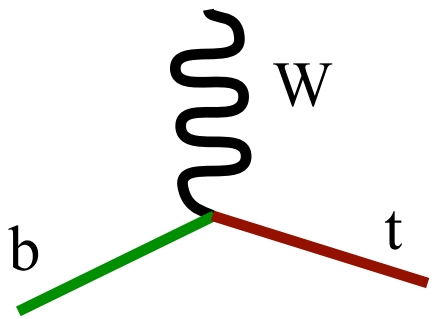
$$\sigma_{s+t} = 3.20^{+1.39}_{-1.43}\ \text{pb}\ (45\%)$$



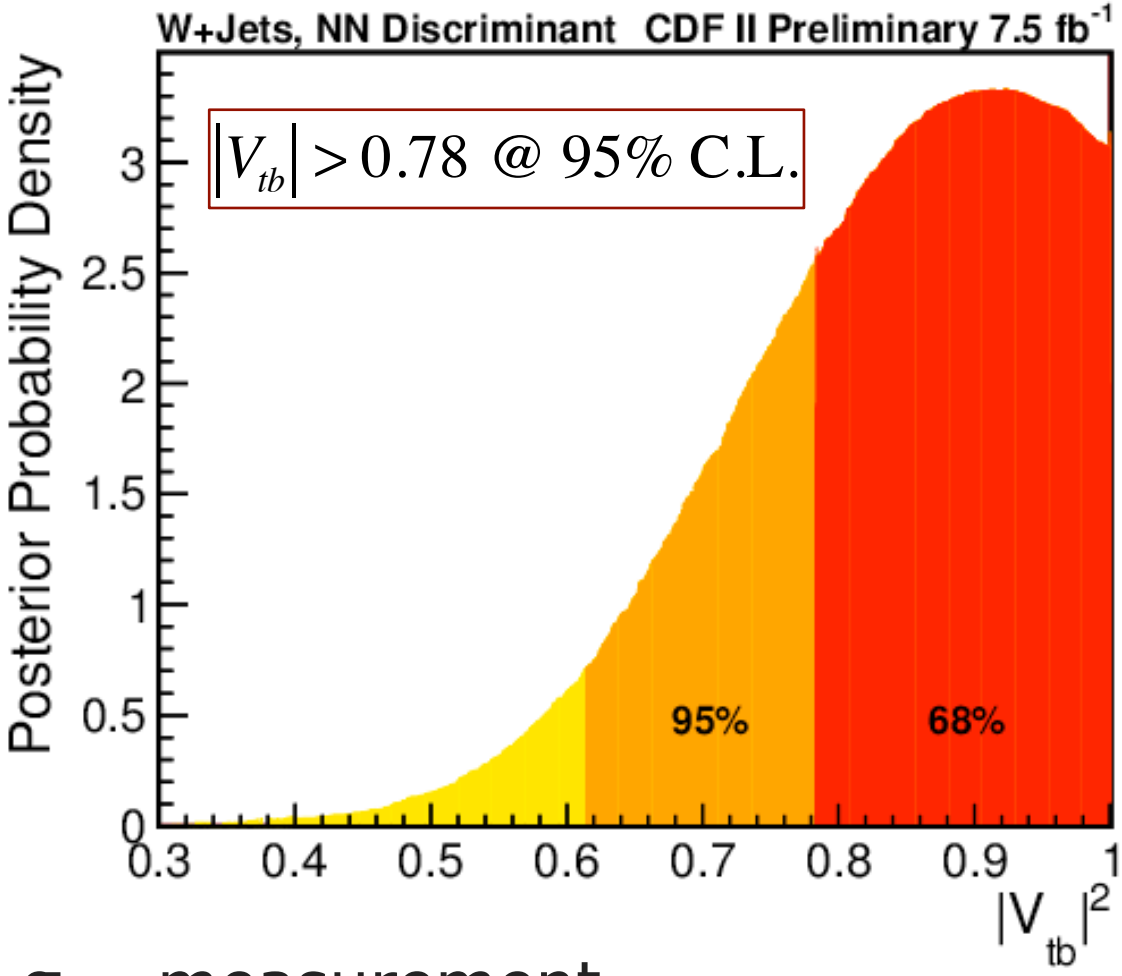
$$\sigma_{s+t} = 3.04^{+0.57}_{-0.53}\ \text{pb}\ (17\%)$$

CDF notes 10793 and 10979

CDF CKM matrix element $|V_{tb}|$



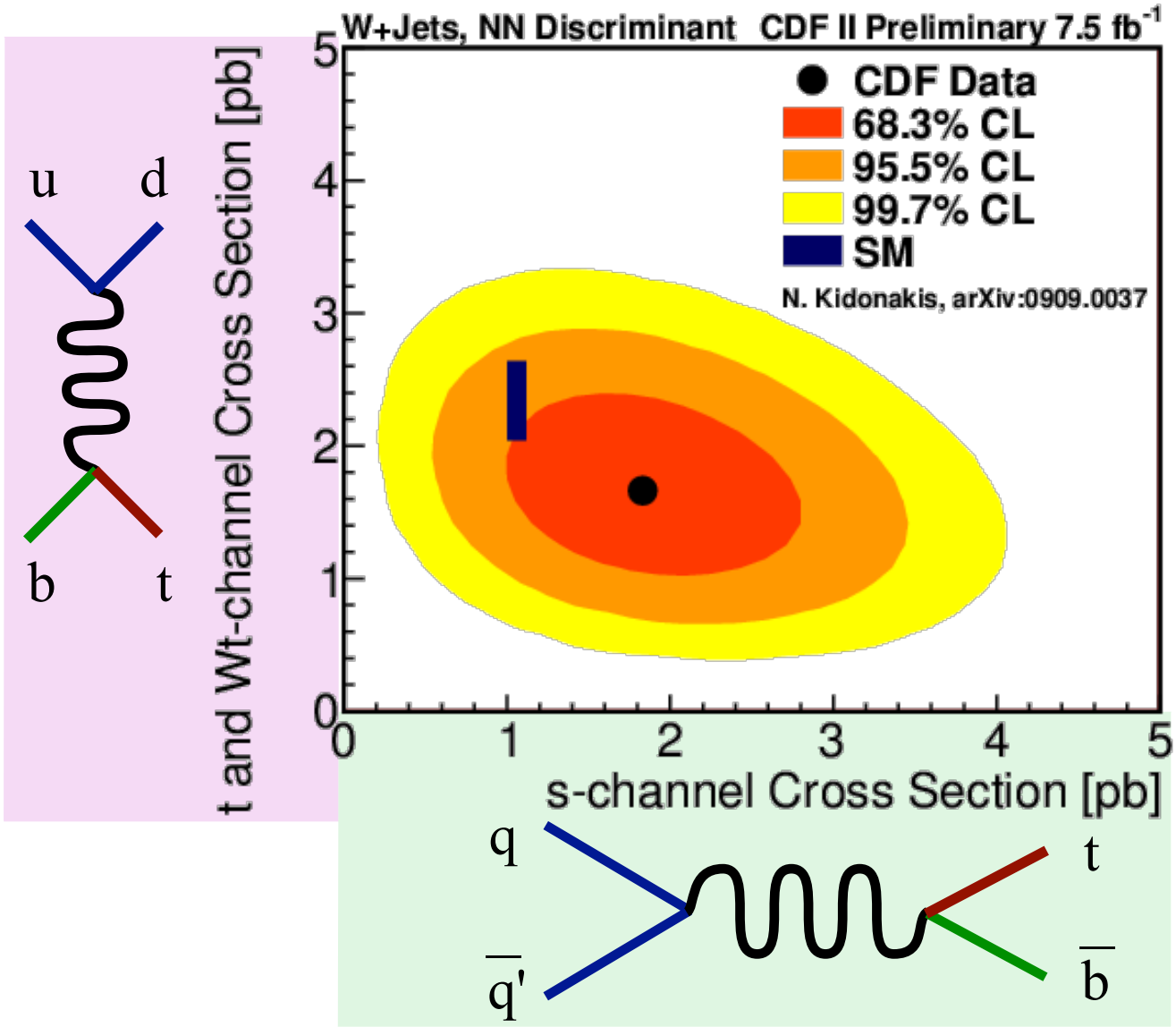
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}? \\ V_{Yd}? & V_{Ys}? & V_{Yt}? & V_{YX}? \end{pmatrix}$$



- Based on CDF lepton+jets σ_{s+t} measurement
- Divide observed σ_{s+t} by SM prediction
- No assumptions about unitarity or # of generations

CDF note 10793

CDF t-channel vs s-channel

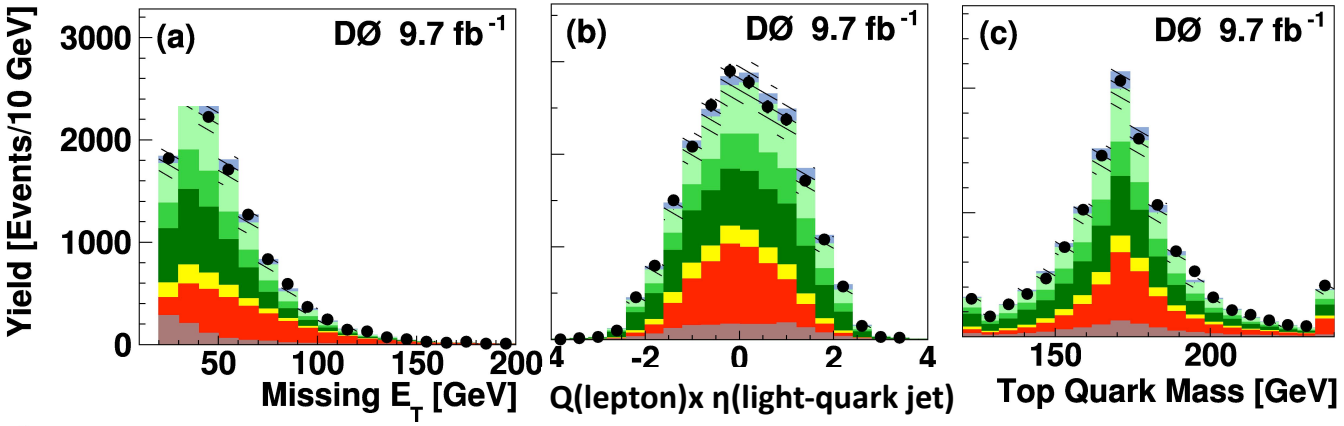


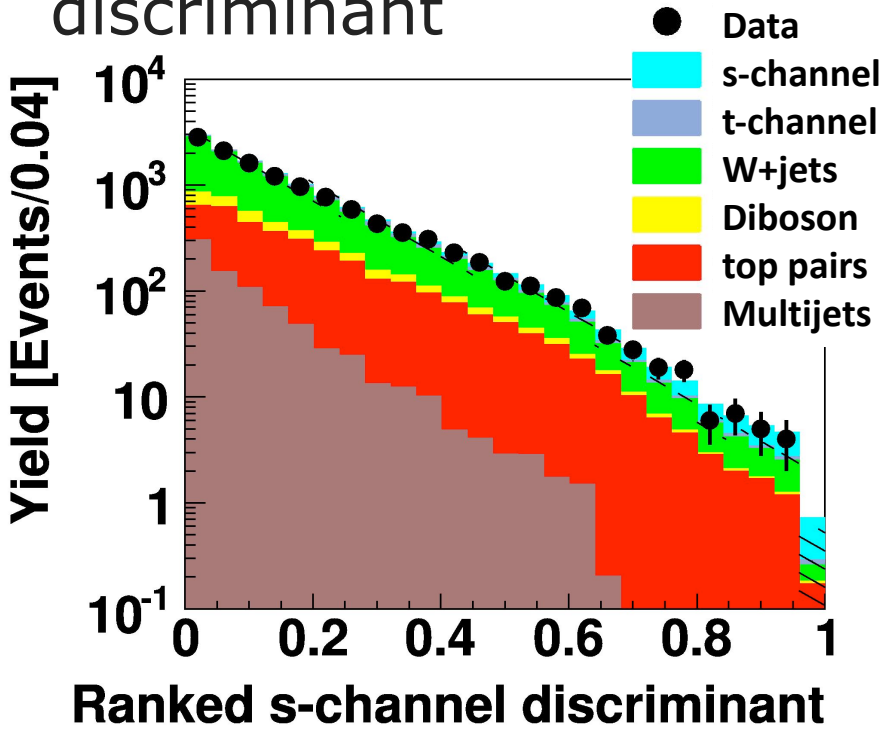
- Consistent with NLO+NNLL prediction

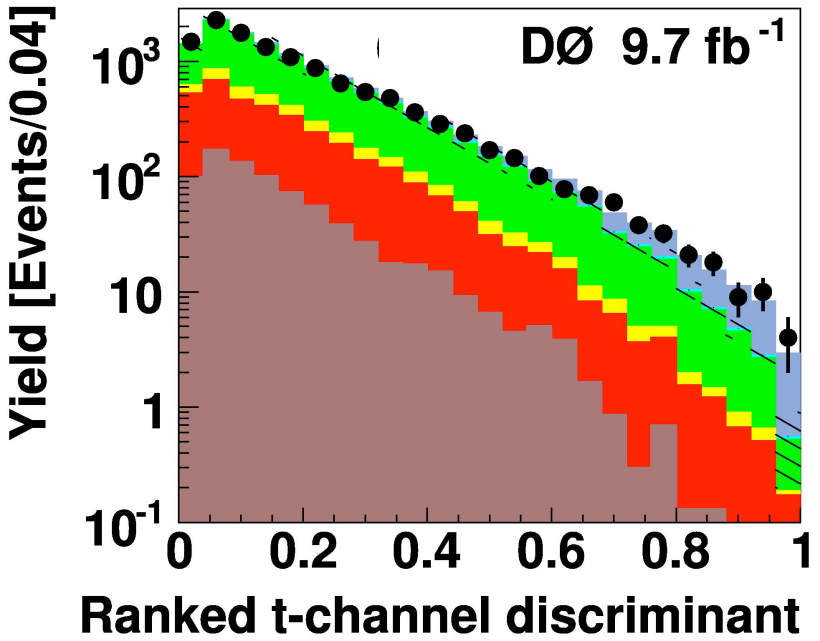
CDF note 10793

D0 lepton+jets

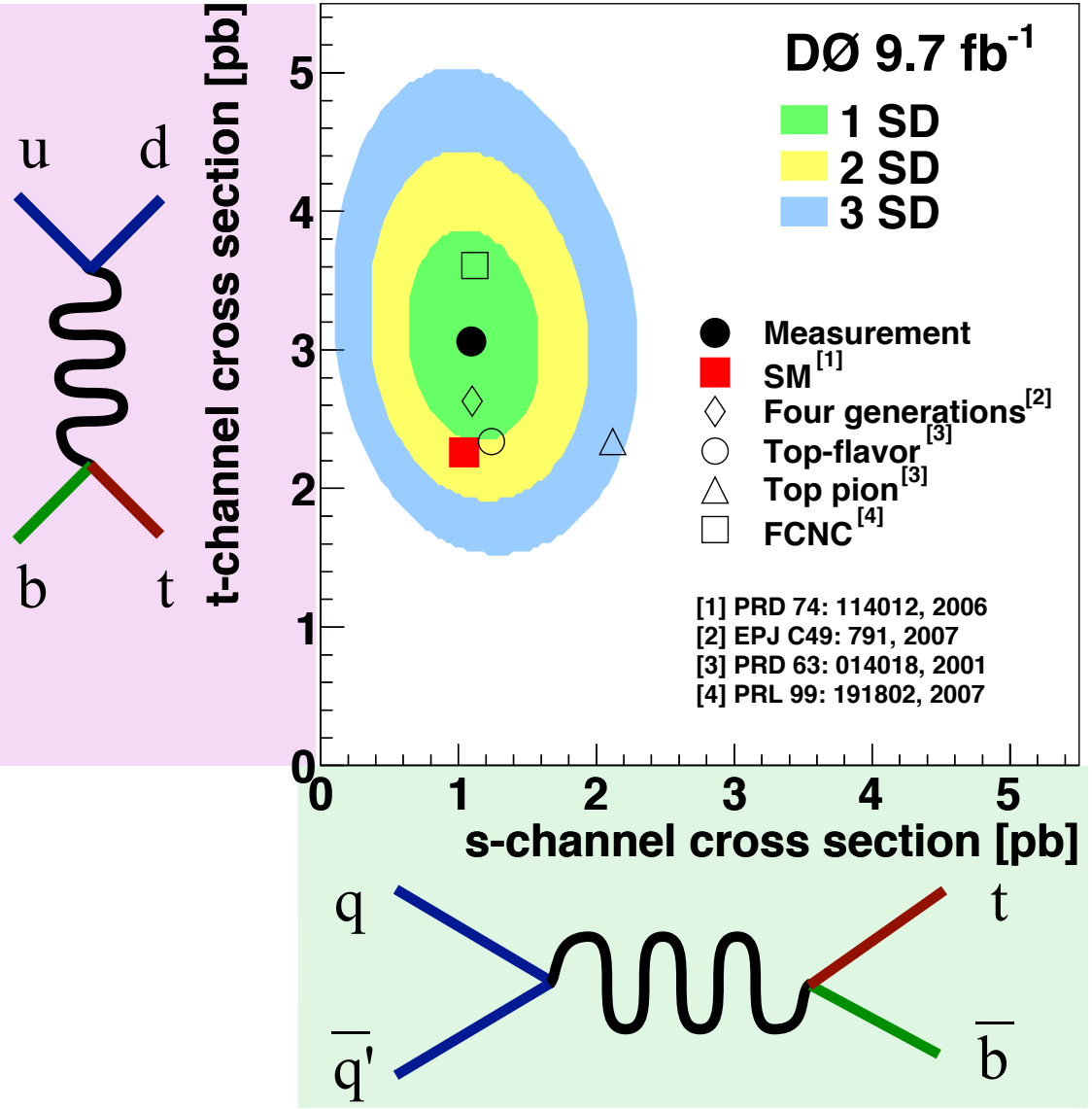
- Combination of boosted decision trees, Matrix elements and neural networks in a Bayesian neural network
- Train separately for s-channel and t-channel
- Use BNN output to form combined discriminant







D0 t-channel vs s-channel



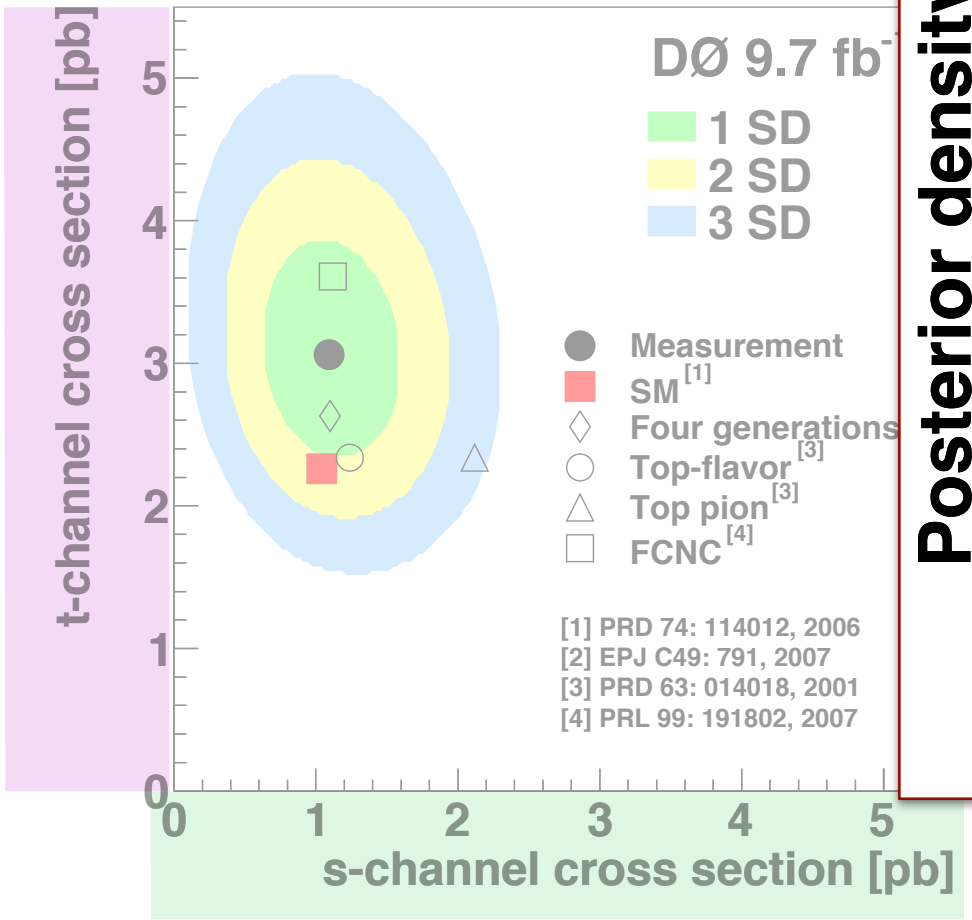
- Integrate over 2d posterior to obtain posterior for s+t-channel
- No assumption about s-channel/t-channel ratio

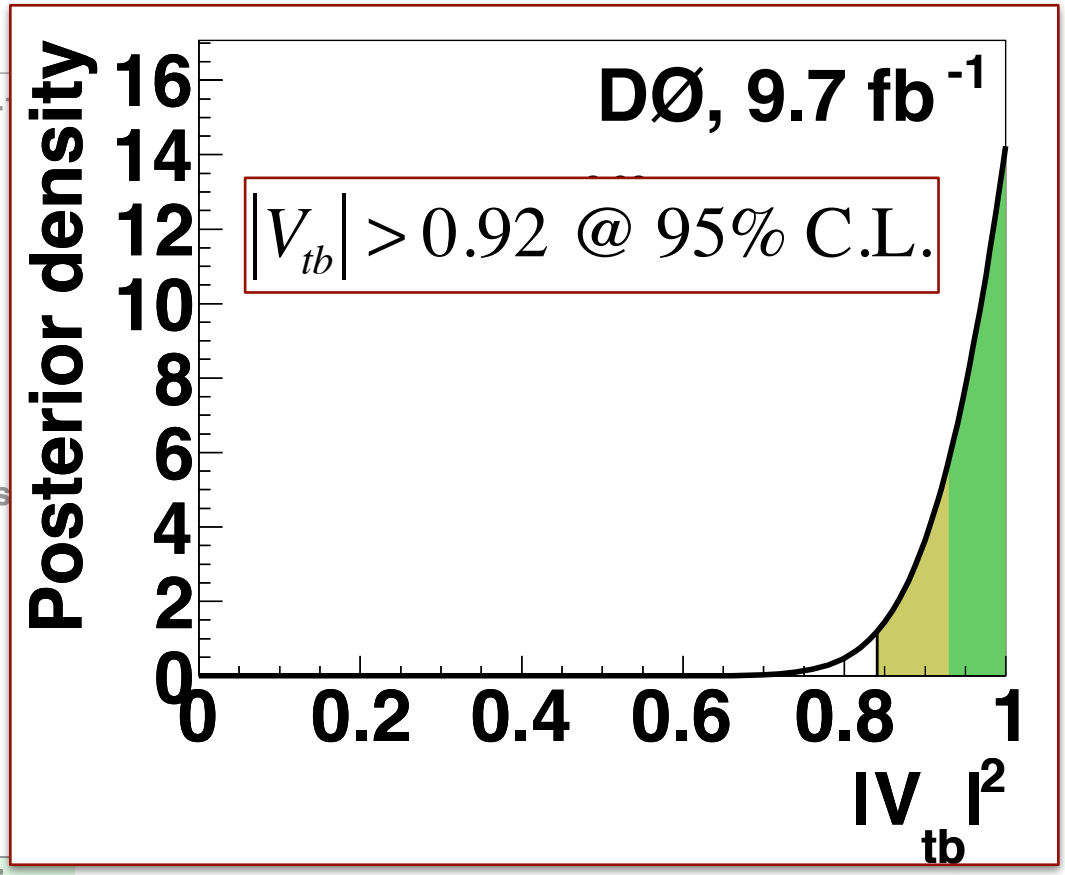
$$\sigma_{s+t} = 4.11^{+0.59}_{-0.55}\ \text{pb}$$

14%

PLB 726, 656 (2013)

D0 CKM matrix element $|V_{tb}|$

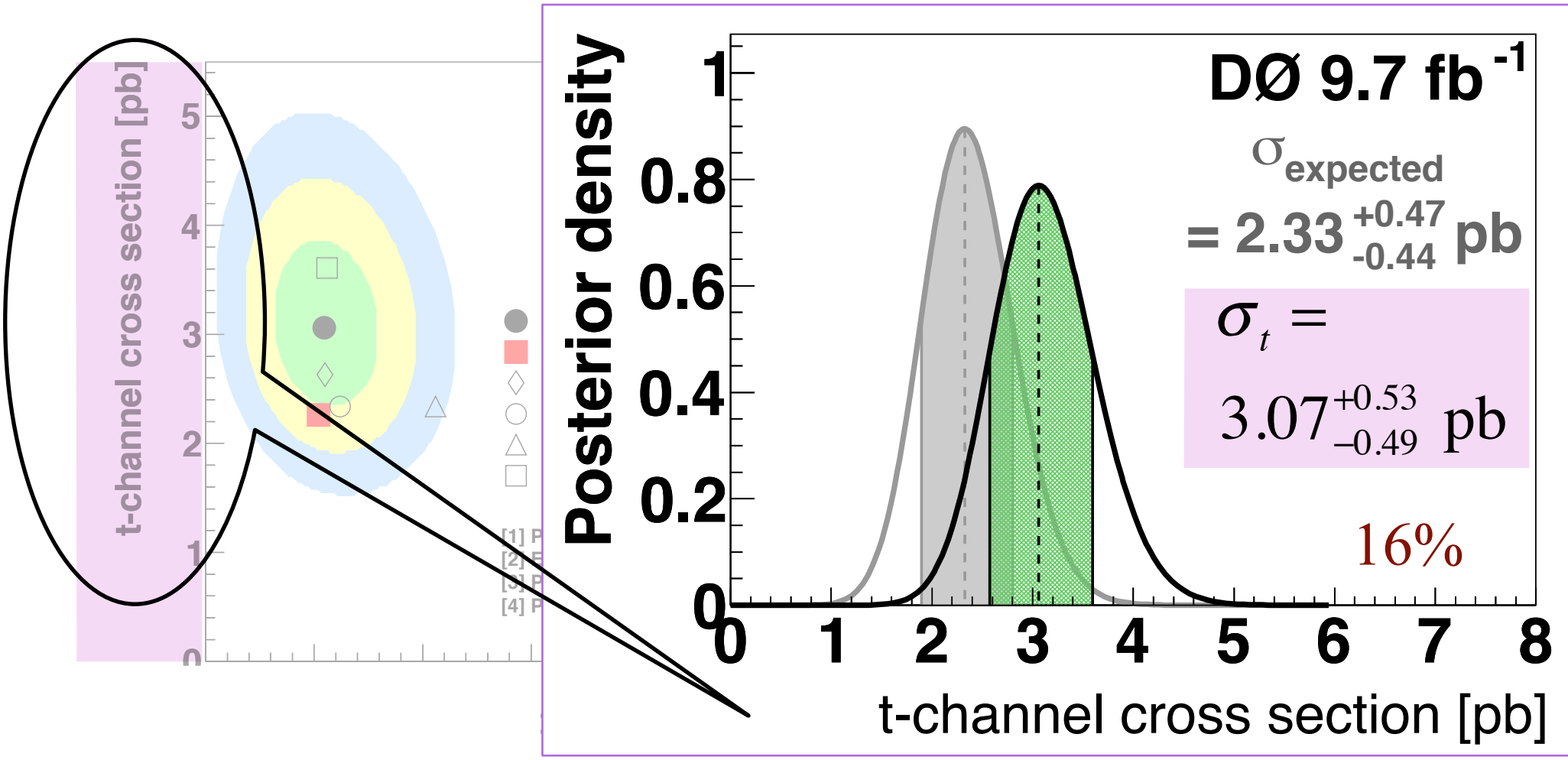




- Divide observed σ_{s+t} by SM prediction
- No assumption about s-channel/t-channel ratio

PLB 726, 656 (2013)

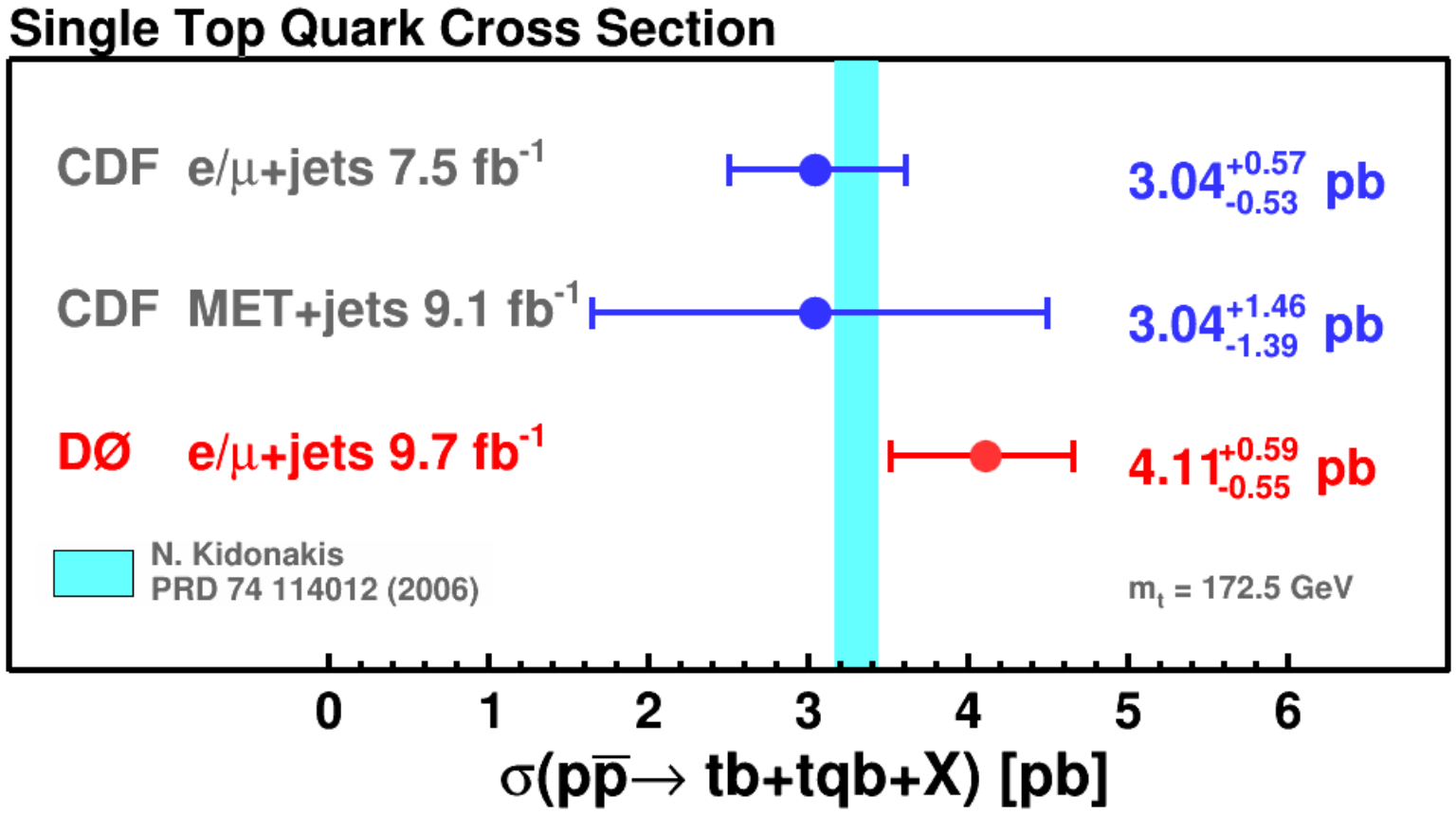
D0 t-channel



- No assumption about s-channel normalization

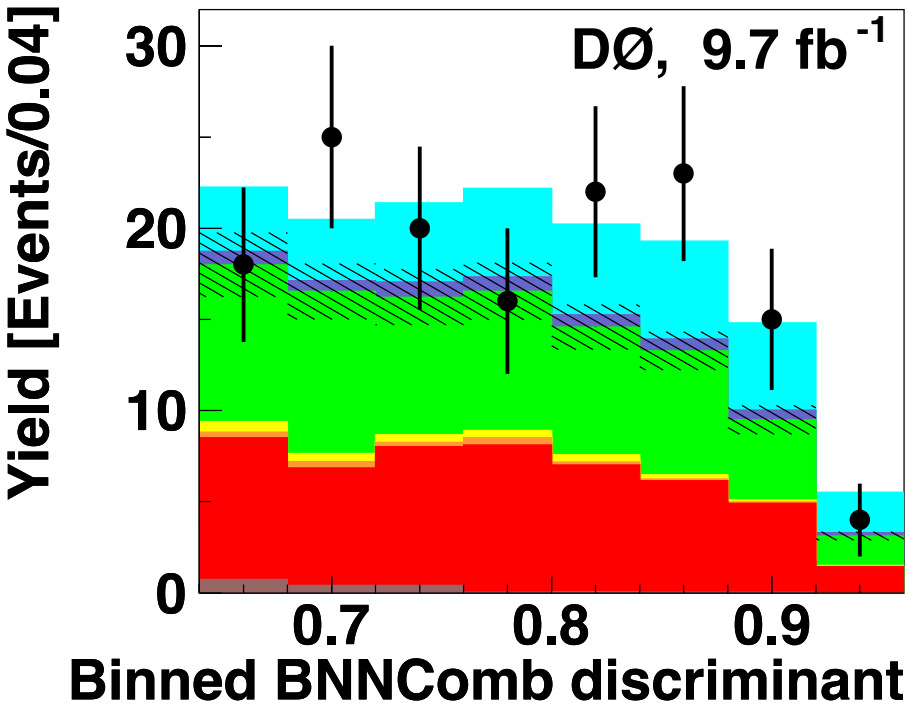
PLB 726, 656 (2013)

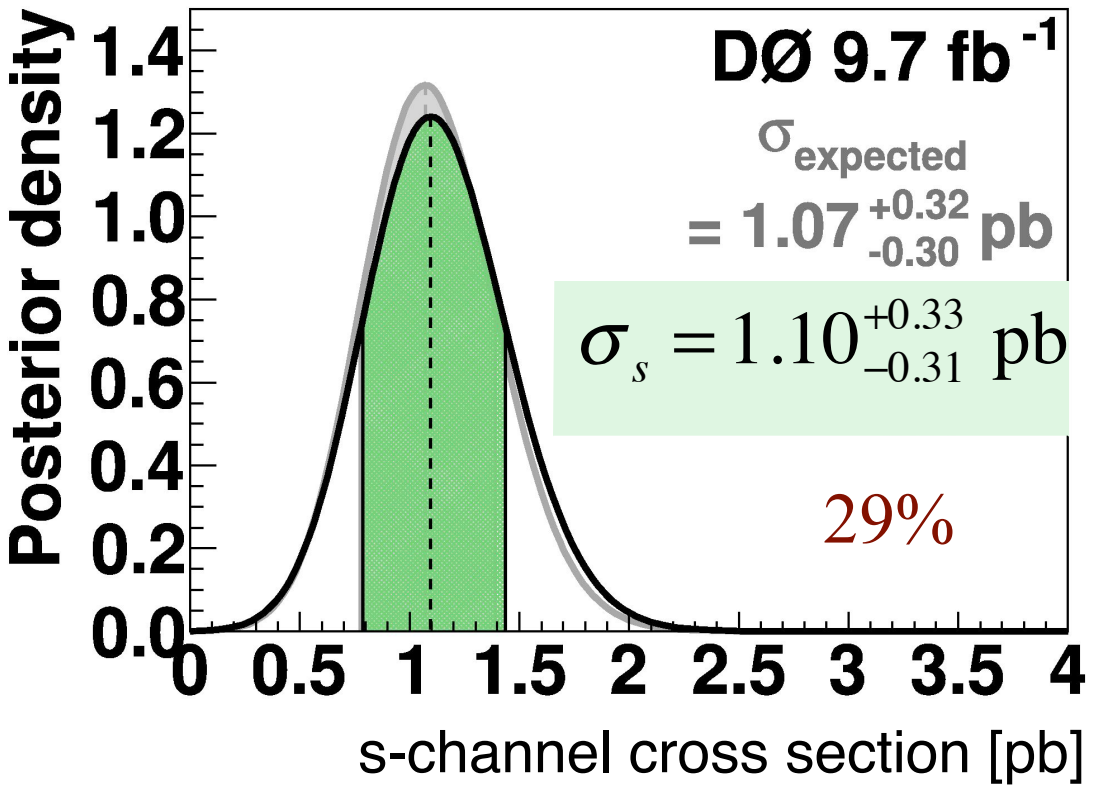
Tevatron summary s+t



- CDF lepton+jets measurement with 9.4 fb^{-1} in progress

D0 first evidence for s-channel



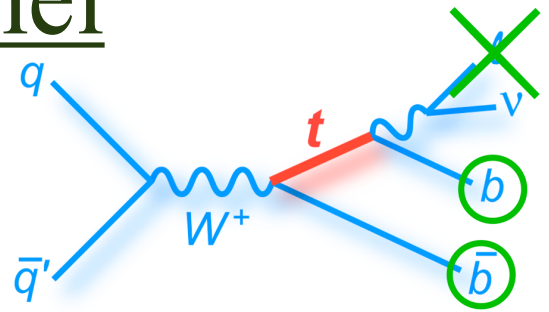


- No assumption about t-channel normalization
- 3.7 s.d. significance

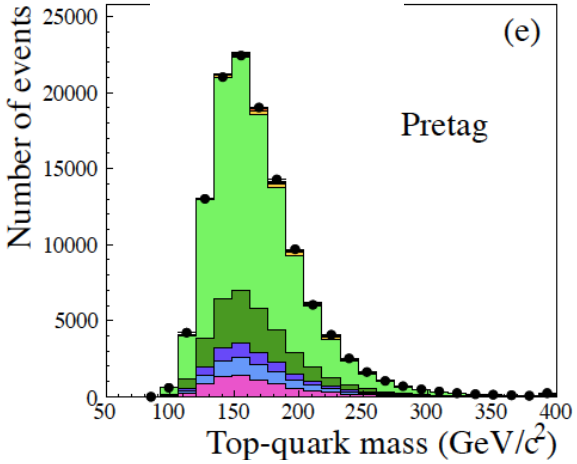
PLB 726, 656 (2013)

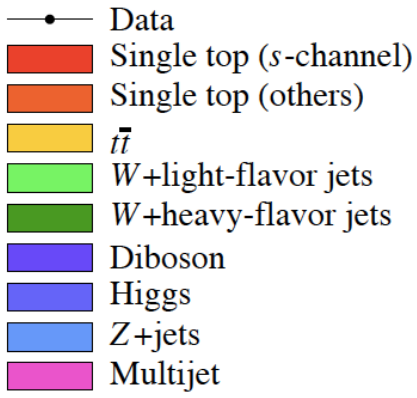
CDF evidence for s-channel

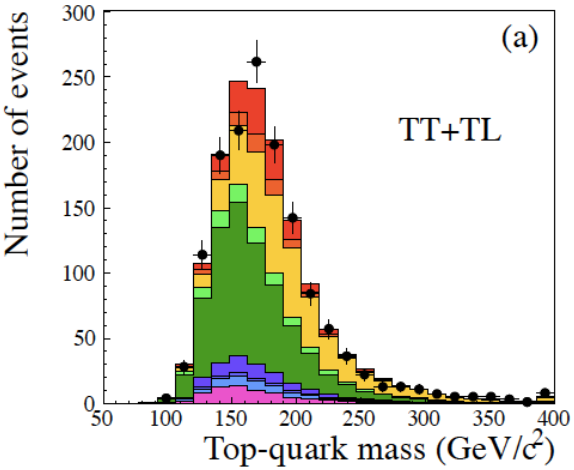
- Resolved lepton and MET+jets channels
- Based on Higgs analysis

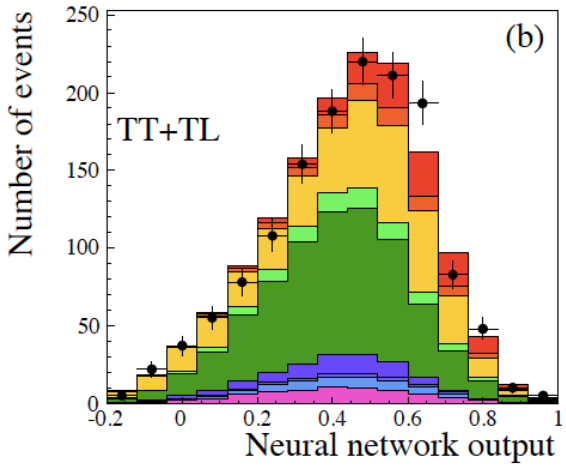


lepton+jets

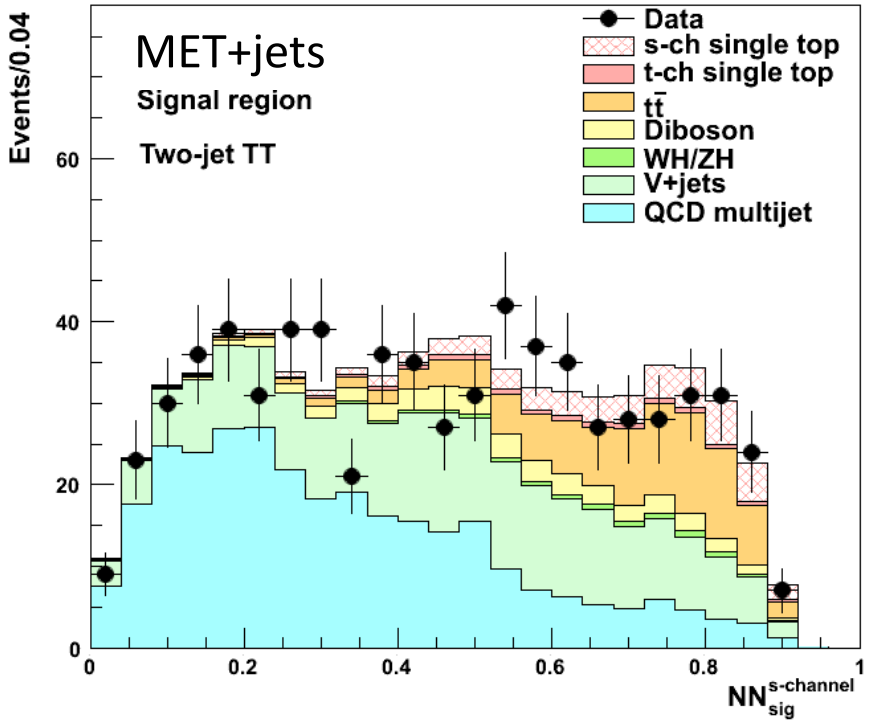








arXiv:1402.0484



- CDF combined:

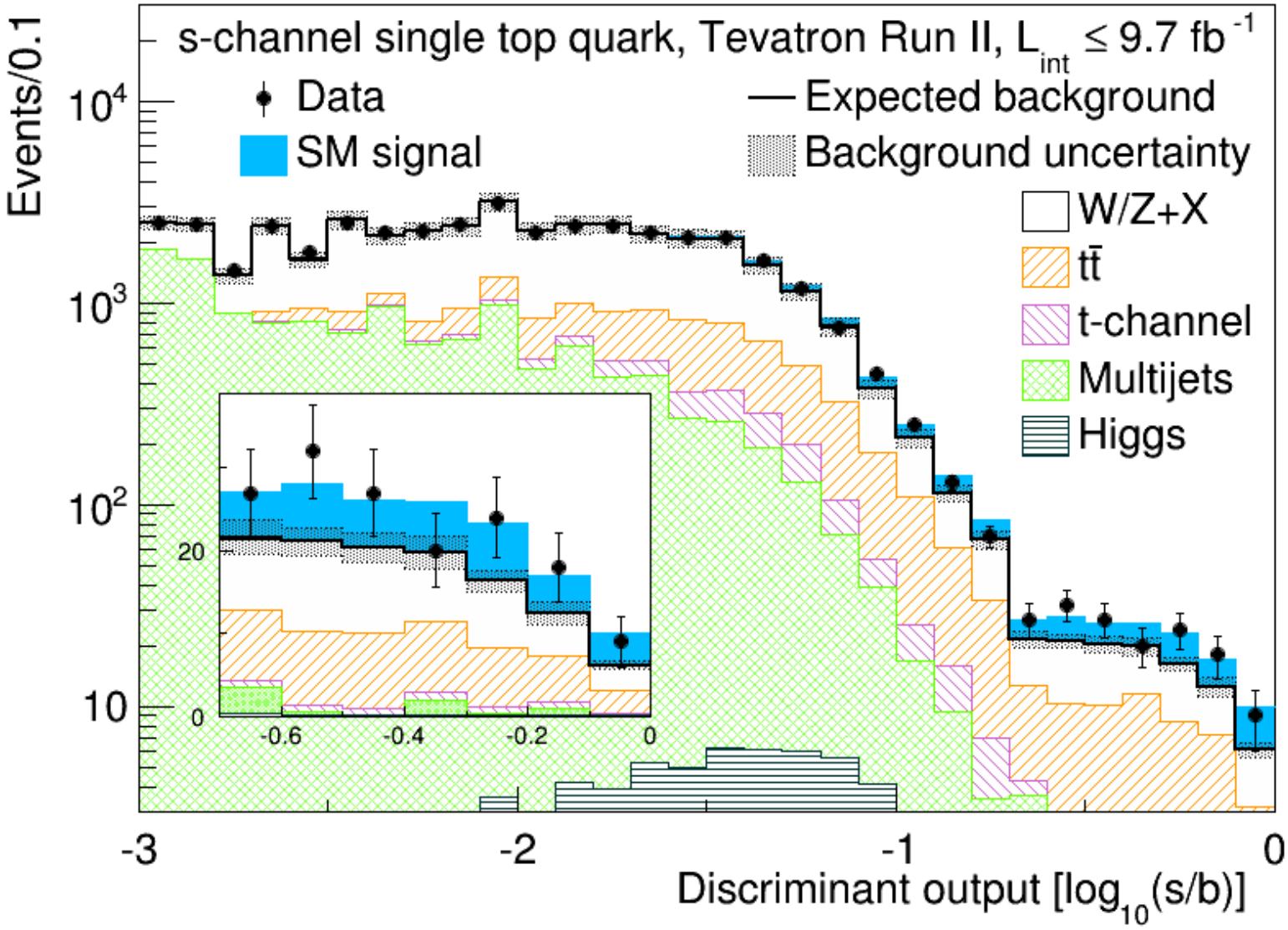
$$\sigma_s = 1.36^{+0.37}_{-0.32}\ \text{pb}\ (25\%)$$

- 4.2 s.d. significance

arXiv:1402.7356

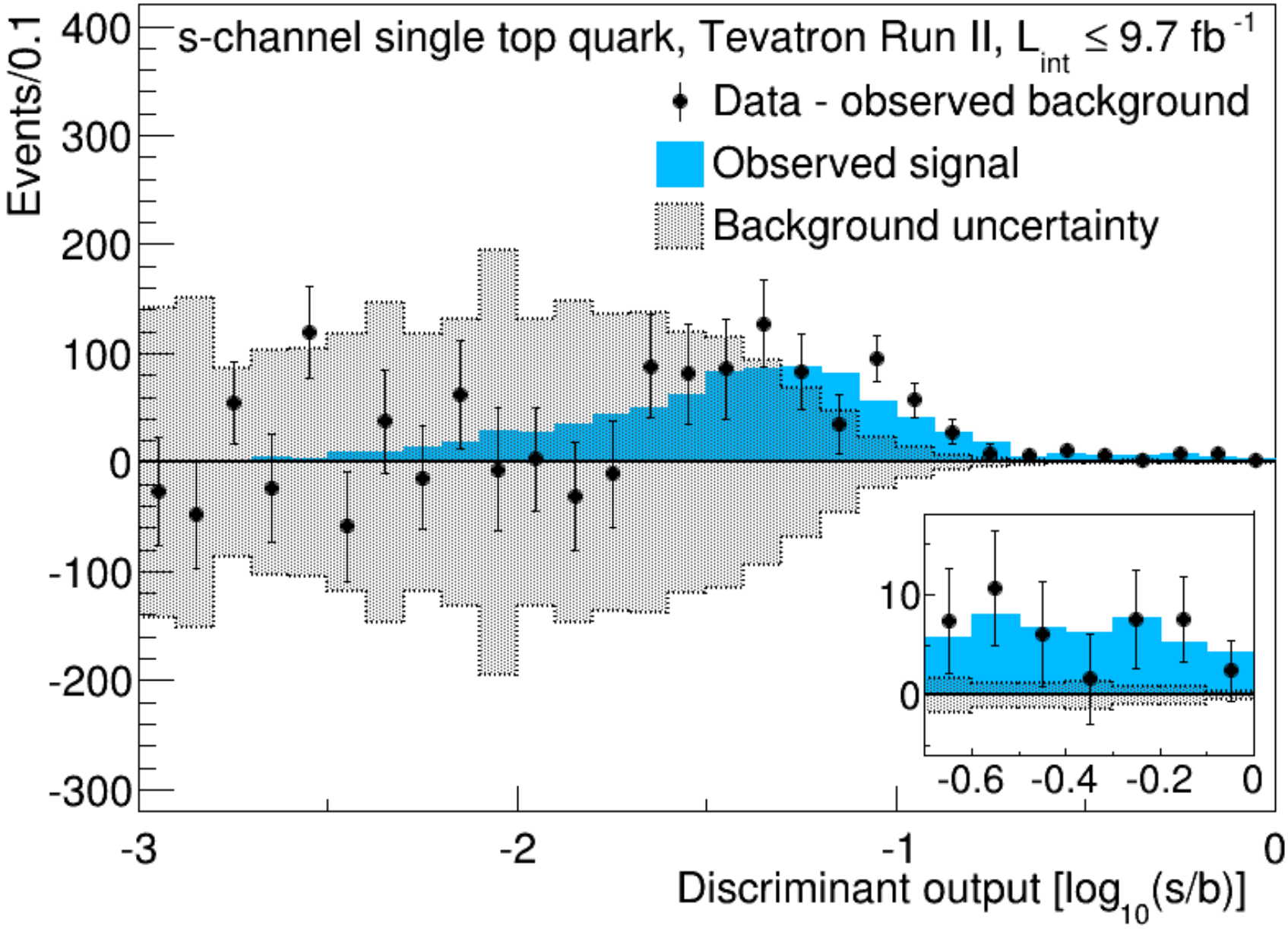
Tevatron s-channel combination

- Combine individual CDF and D0 discriminants
- Include all systematic uncertainties and their correlations



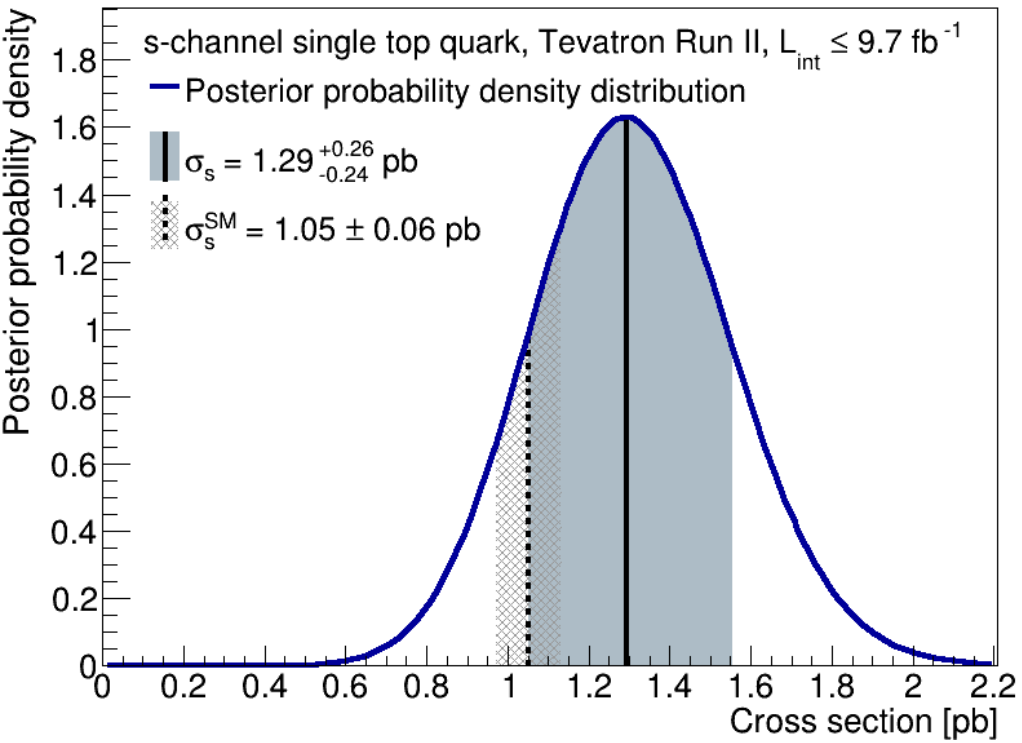
arXiv:1402.5126

Background-subtracted discriminant

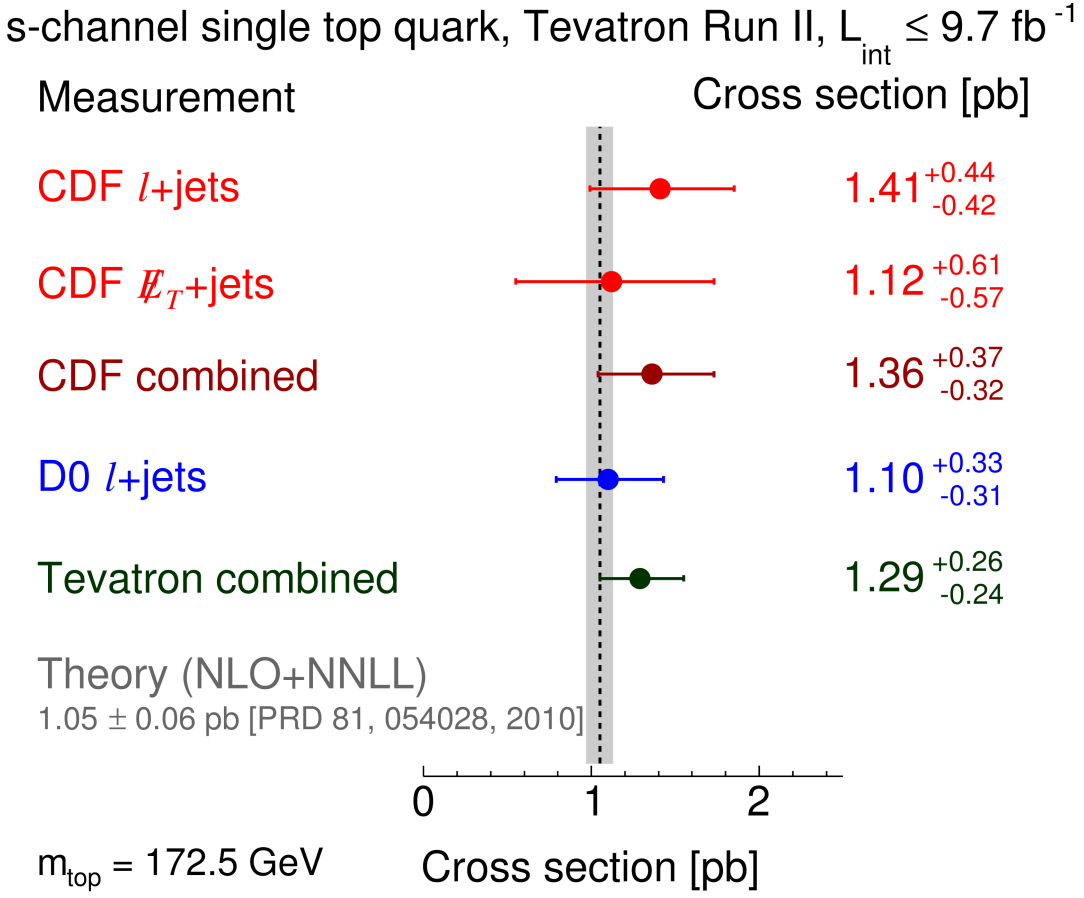


- Posterior normalizations and uncertainties

s-channel combined cross section



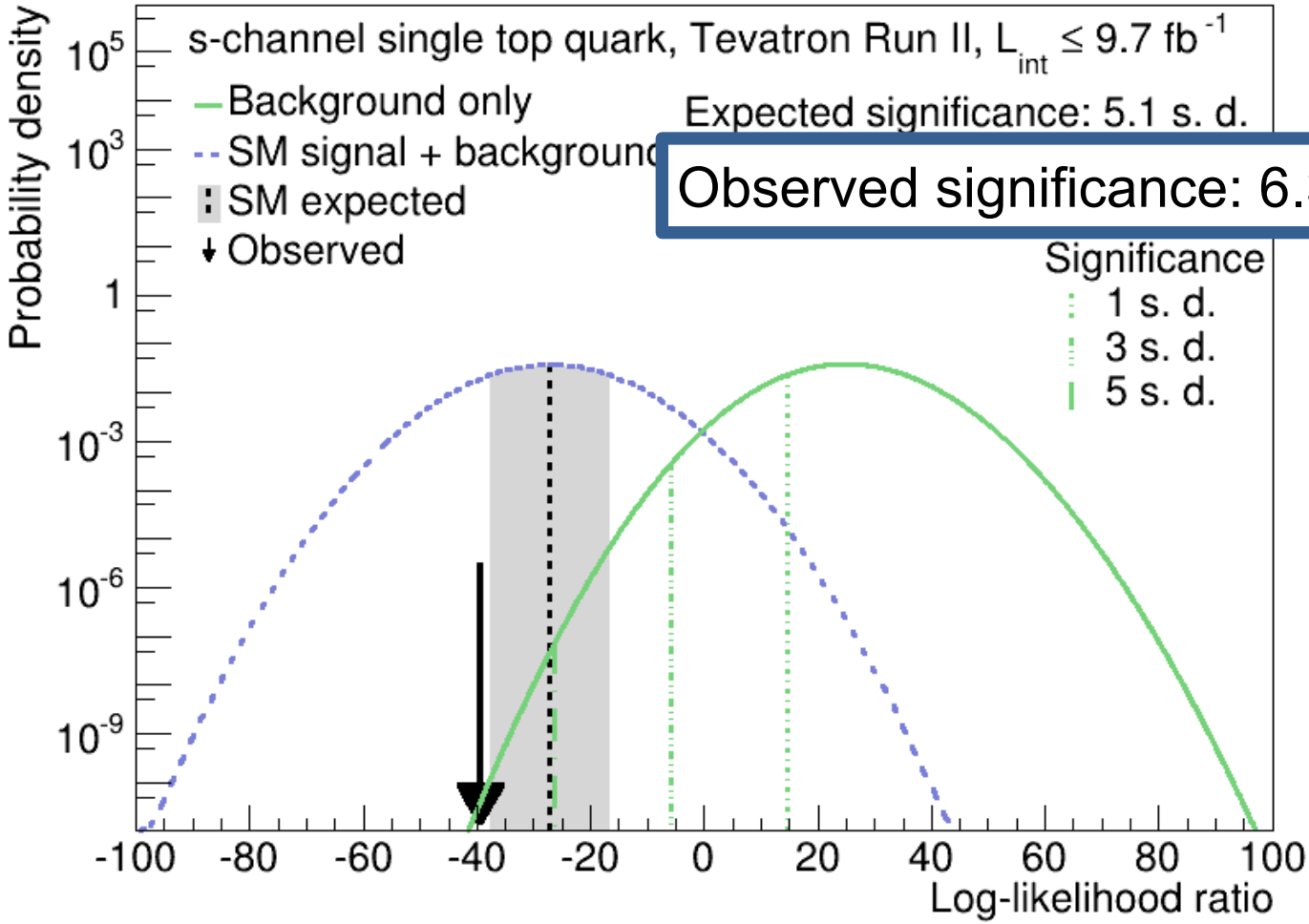
$$\sigma_s = 1.29^{+0.26}_{-0.24}\ \text{pb}\ (19\%)$$



- Equal contributions from CDF and D0
- Negligible top mass dependence
- Good agreement with theory predictions

arXiv:1402.5126

Significance



- LHC-style asymptotic approximation log-likelihood ratio
  - Observed p-value: 1.8×10^{-10}
- First Tevatron-combined observation of a new process

Conclusions

- Tevatron continues providing valuable top physics results
  - Well understood detectors and datasets

- Single top is the Tevatron's legacy
  - Single top observation in 2009
  - t-channel observation 2011
  - s-channel observation 2014

- Expect more!
  - CDF t-channel and s+t and $|V_{tb}|$
  - Tevatron combination

Thanks!

- Tevatron physics for the informed public
  http://www.fnal.gov/pub/today/frontier_science_result
- Tevatron single top combinations
  http://tevewwg.fnal.gov/singleTop/
- CDF top physics results:
  http://www-cdf.fnal.gov/physics/new/top/top.html
- DØ top physics results:
  http://www-d0.fnal.gov/Run2Physics/top/

Backup slides

Systematic uncertainties

- Uncertainty range for individual backgrounds:

Systematic uncertainty	CDF		D0		Correlated
	Norm	Dist	Norm	Dist	
Lumi from detector	4.5%		4.5%		No
Lumi from cross section	4.0%		4.0%		Yes
Signal modeling	2–10%	•	3–8%		Yes
Background (simulation)	2–12%	•	2–11%	•	Yes
Background (data)	15–40%	•	19–50%	•	No
Detector modeling	2–10%	•	1–5%	•	No
b-jet-tagging	10–30%		15–40%	•	No
JES	0–20%	•	9–40%	•	No

- Total background uncertainty: 15% to 20%