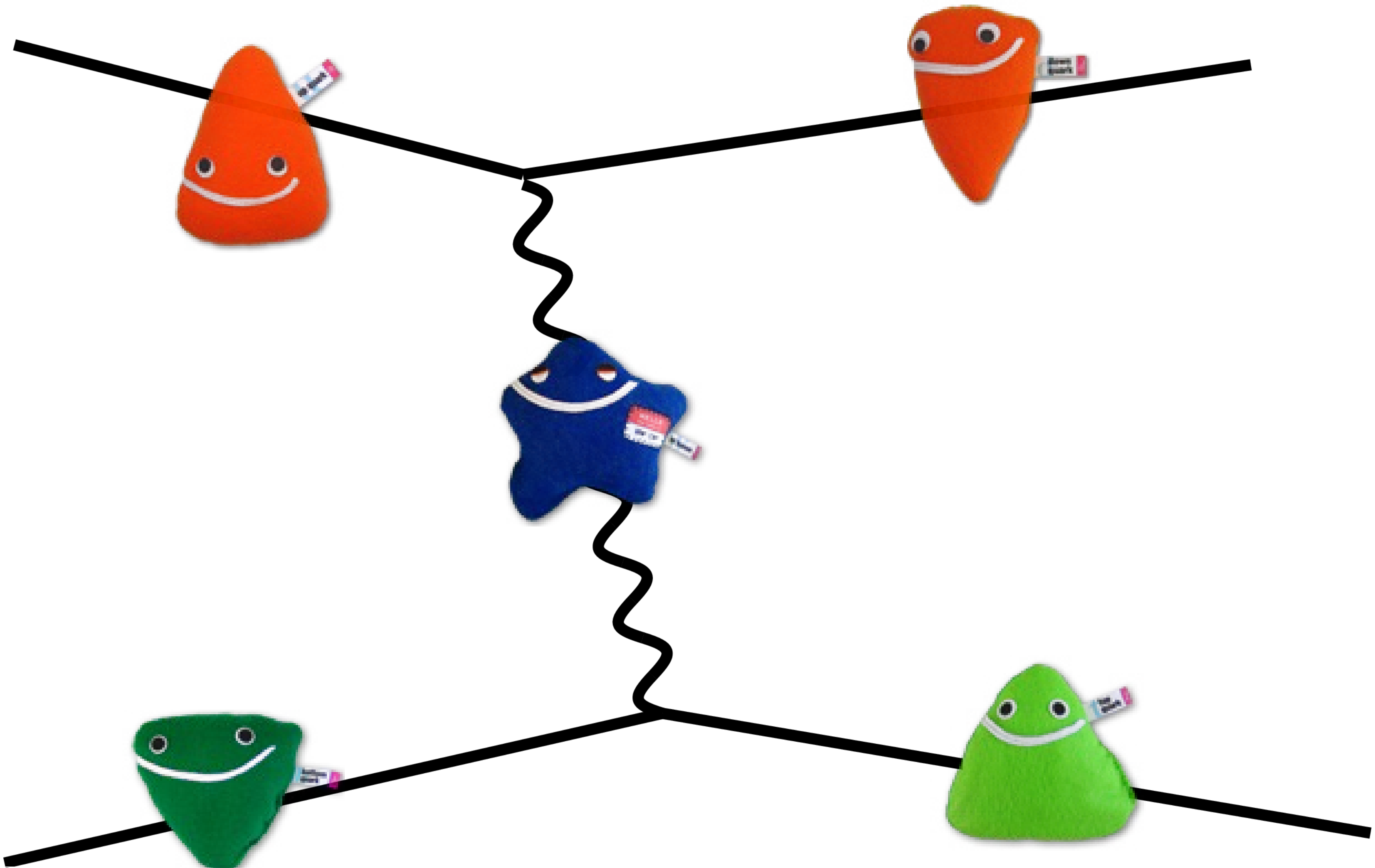
Single Top Production Hadron Colliders



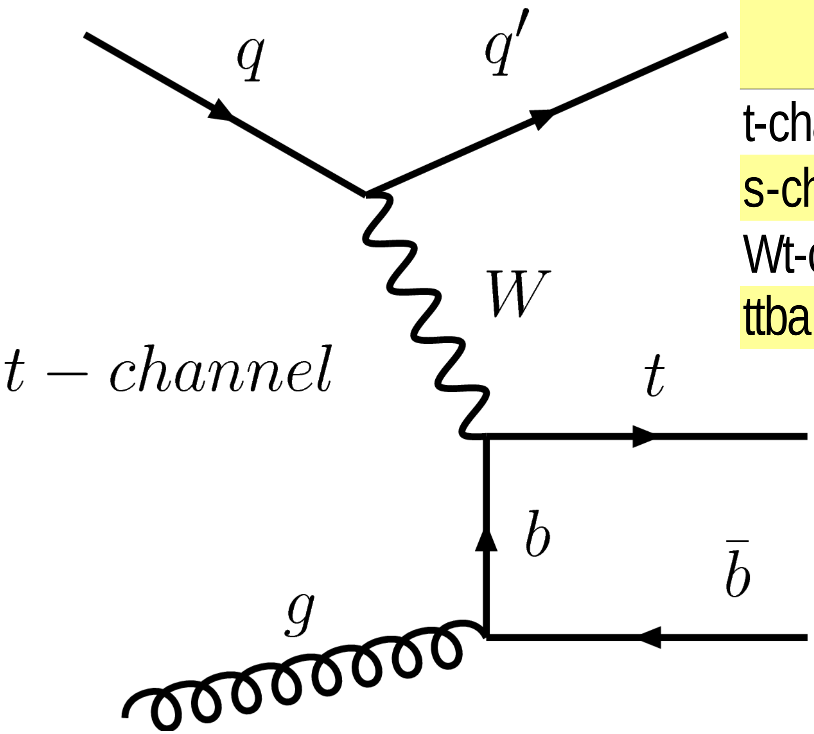
Birmingham Group Seminar
November 2009
C Curtis

Overview

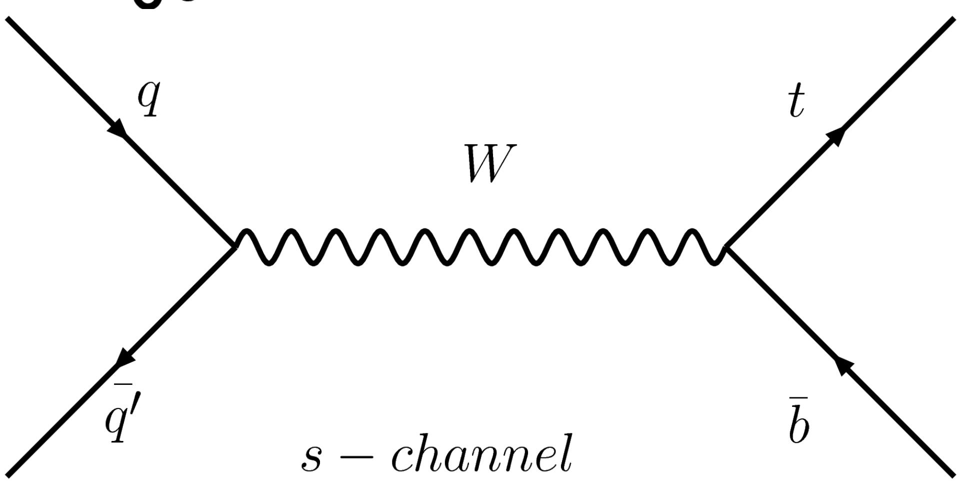
- Single Top Production
- Why is it worth studying?
- Experience at the Tevatron
- Expected performance of ATLAS

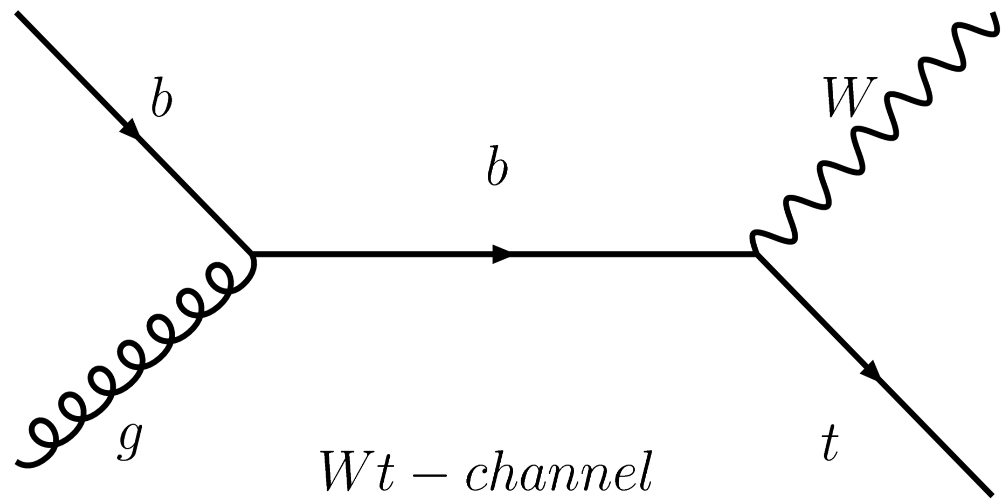
Single Top Production

	Tevatron (pb)	LHC (pb)	
	1.96 TeV	10 TeV	14 TeV
t-channel	2.0 ± 0.3	120 ± 10	250 ± 10
s-channel	0.9 ± 0.1	7 ± 1	11 ± 1
Wt-channel	-	33 ± 2	67 ± 2
ttbar	6.8 ± 0.4	400 ± 24	833 ± 52



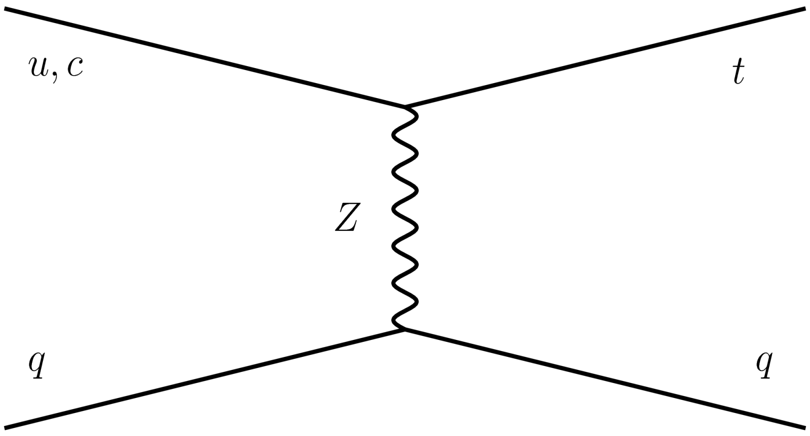
Z Sullivan - Phys Rev D 70 (2004) 114012
M Pleier - hep-ph/0810.5226

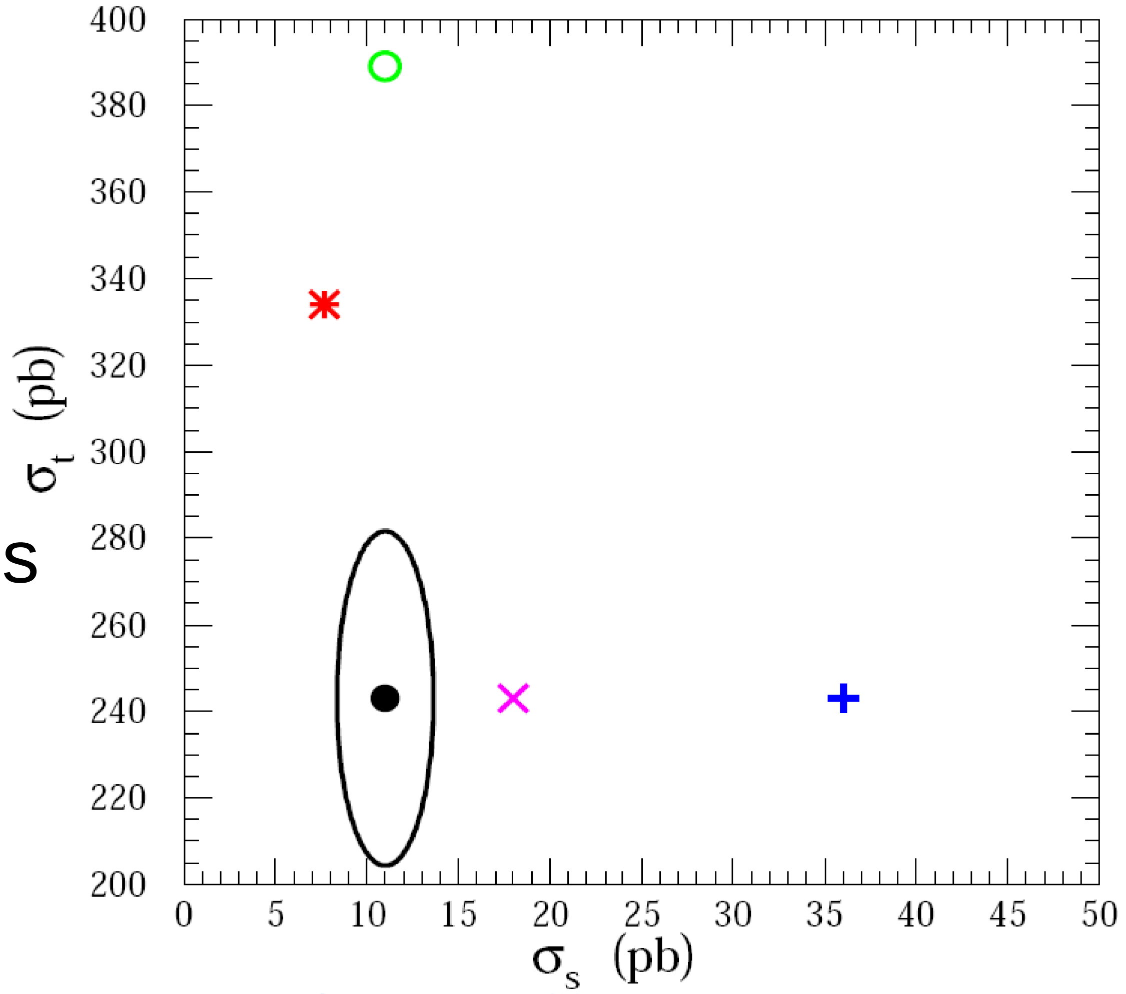




Why Is It Important?

- Cross section sensitive to BSM Physics
  - FCNC
  - 4^{th} family of quarks
  - Heavy Vector Bosons

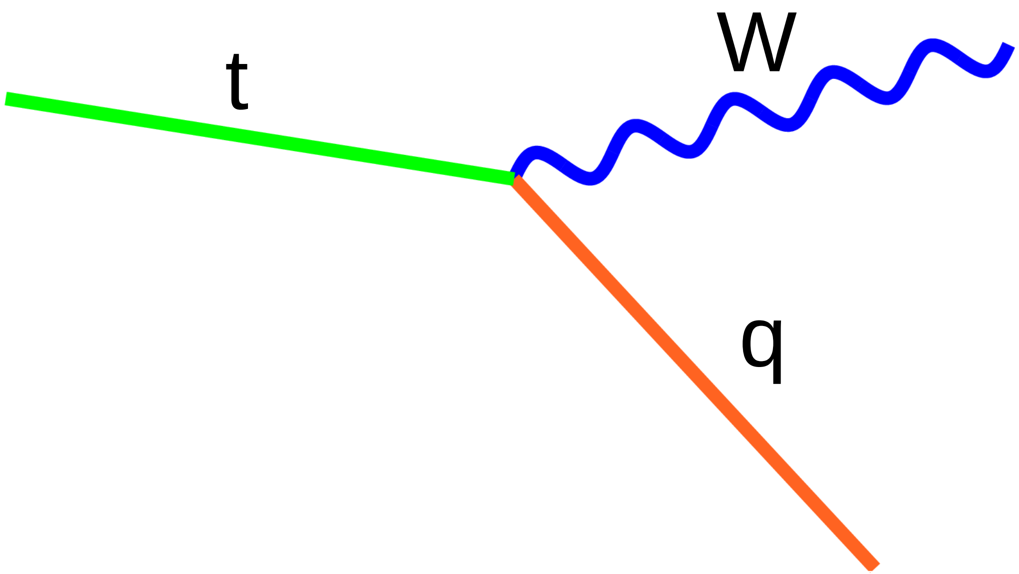




T. Tait and C. P. Yuan, Phys.Rev.D63:014018 (2001)

Why Is It Important?

- Enables measurement of $|V_{tb}|$ element



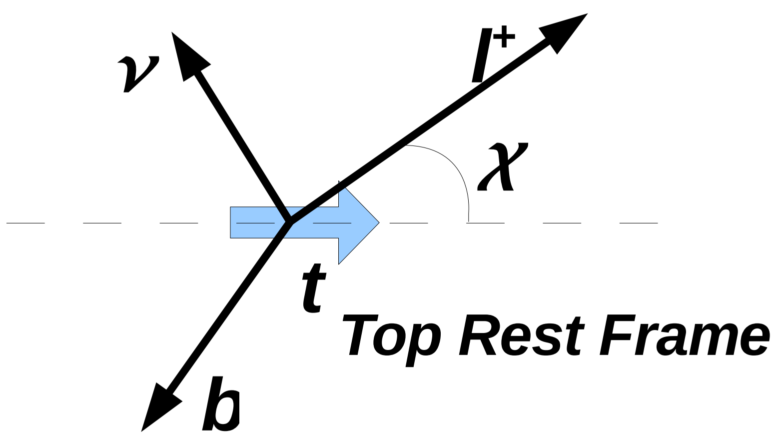
$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

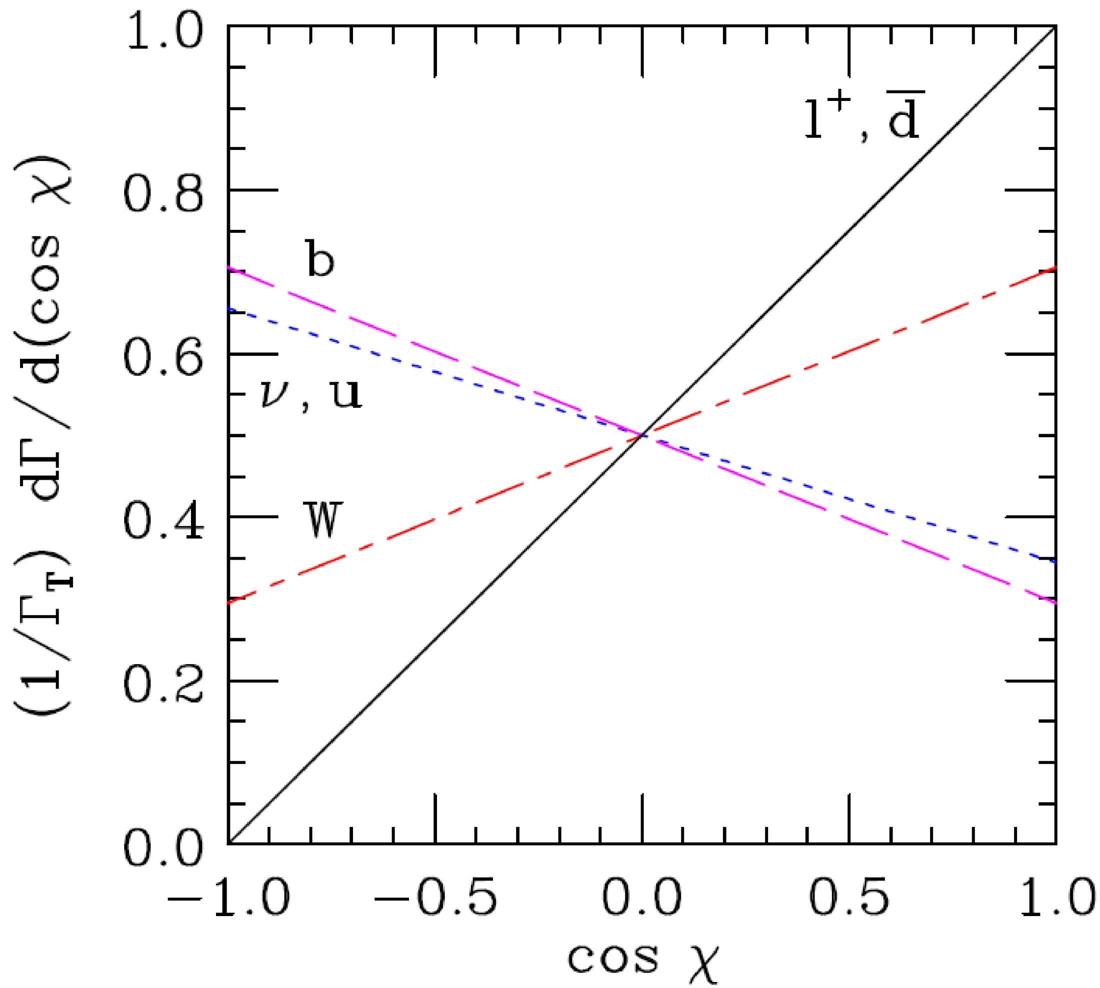
$$V_{td}, V_{ts} \ll V_{tb}$$

Angular Distributions

- Angular distribution of decay products
- Spin direction correlated with direction of d-quark



$$\frac{1}{\Gamma_T}\frac{d\Gamma}{d\cos\chi_i}=\frac{1}{2}(1+\alpha_i\cos\chi_i)$$



Ref: G Mahlon, hep-ph/0011349

Experience at the Tevatron

Experience at the Tevatron

...pretty good, given that they discovered it!

arXiv:0903.0850v1 [hep-ex]

2.3 fb^{-1} data analysed

$\sigma_{st} = 3.94 \pm 0.88\,\mathrm{pb}$

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arXiv:0903.0885v1 [hep-ex]

3.2 fb^{-1} data analysed

$\sigma_{st} = 2.3^{+0.6}_{-0.5}\,\mathrm{pb}$

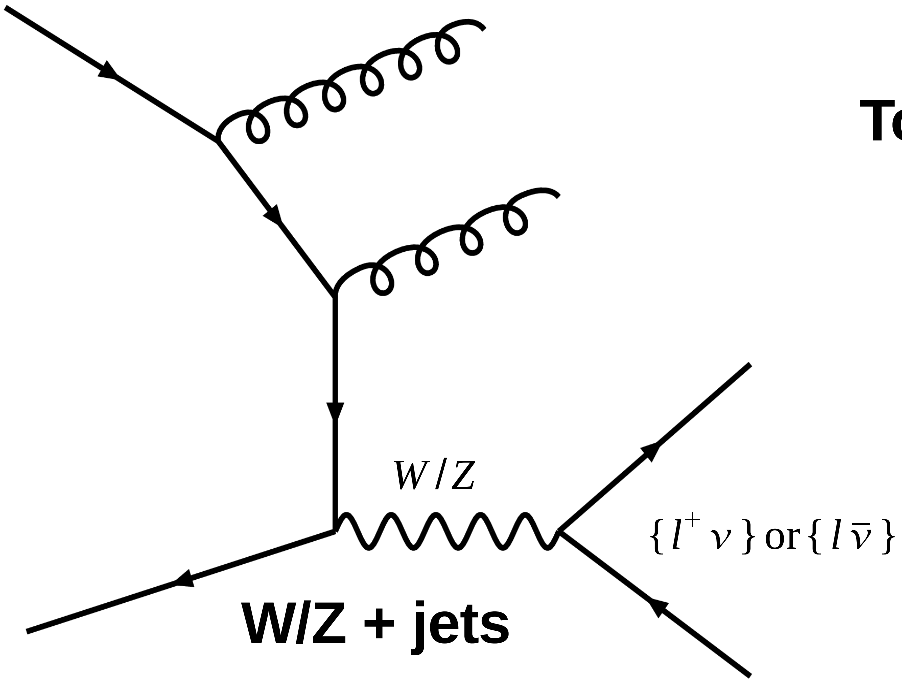
DØ Approach

- Split into 12 channels
- Apply event selection
- Calculate multivariate discriminants
  - Recombine those with improved sensitivity
- Calculate cross section

Percentage of single top *tb+tqb* selected events and S:B ratio (white squares = no plans to analyze)

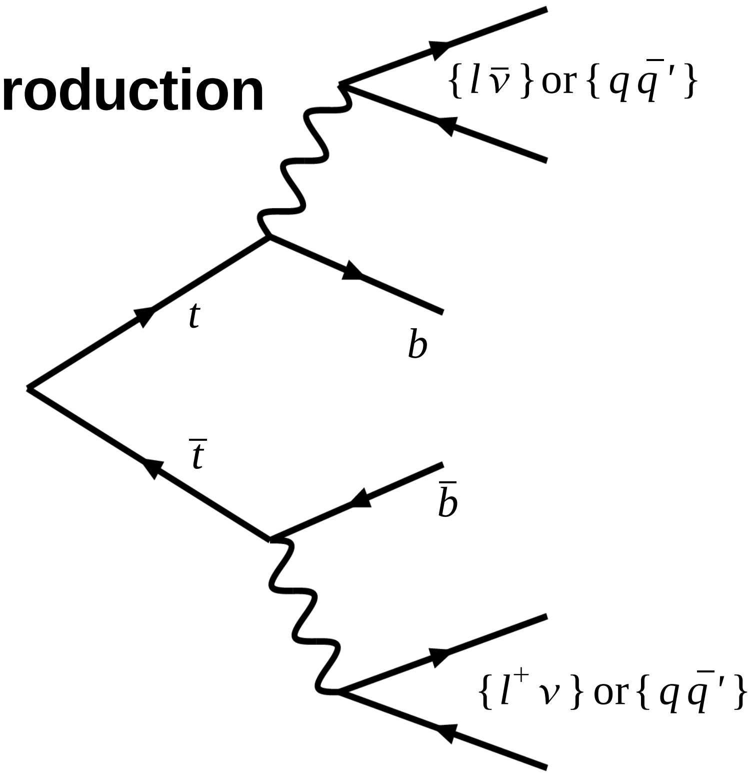
Electron + Muon	1 jet	2 jets	3 jets	4 jets	≥ 5 jets
0 tags	10% 1 : 3,200	25% 1 : 390	12% 1 : 300	3% 1 : 270	1% 1 : 230
1 tag	6% 1 : 100	21% 1 : 20	11% 1 : 25	3% 1 : 40	1% 1 : 53
2 tags		3% 1 : 11	2% 1 : 15	1% 1 : 38	0% 1 : 43

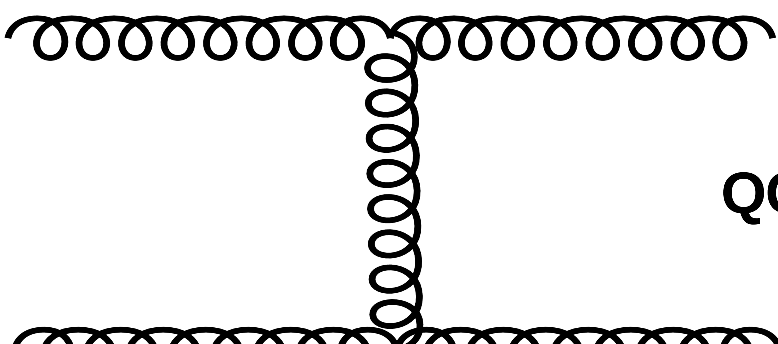
Major Backgrounds



W/Z + jets

Top pair production





QCD Jets

Background Normalisation

- Data driven methods to normalise W+jets and QCD backgrounds
- Defined loose and tight selections based on lepton ID

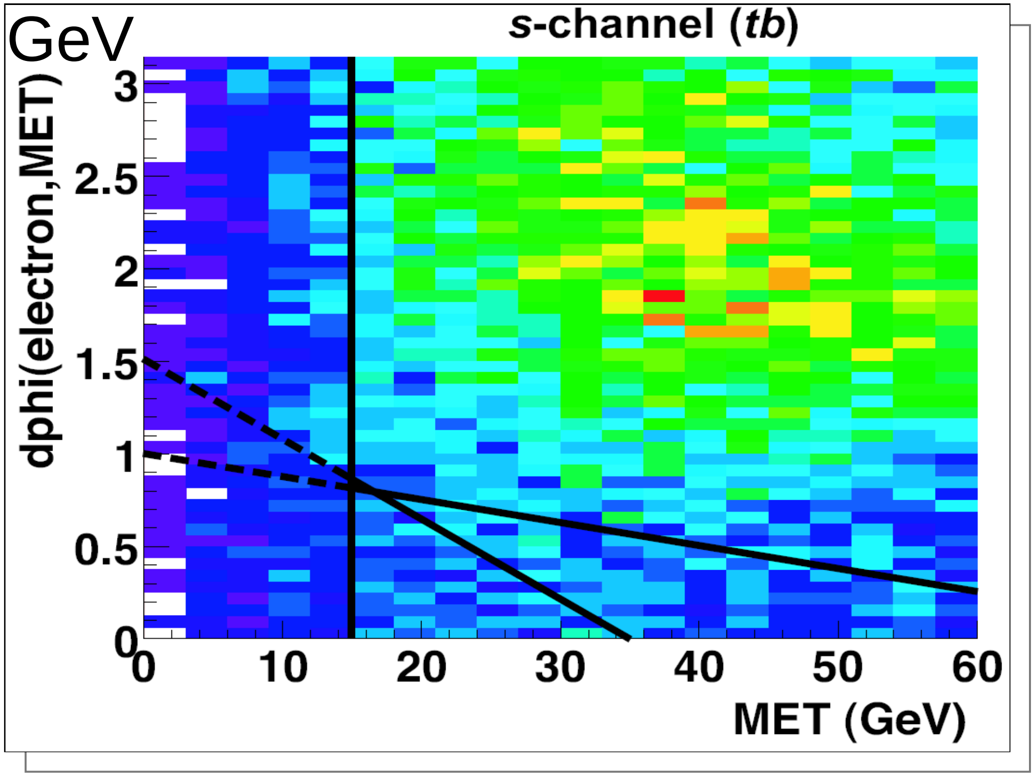
$$N_{Data}^{loose} = \epsilon_{W}^{loose} N_{W} + \epsilon_{QCD}^{loose} N_{QCD}$$

$$N_{Data}^{tight} = \epsilon_{W}^{tight} N_{W} + \epsilon_{QCD}^{tight} N_{QCD}$$

- Solve for N_W and N_{QCD}
- (Top Pair production from theory)

DØ Selection

- **Trigger**
  - (e P_T > 15 GeV && 2 jets P_T > 30 GeV)
  - (μ P_T > 3 GeV && 1 jet P_T > 35 GeV)
- **1 good lepton with P_T > 18 GeV**
  - Veto on others with P_T > 15 GeV
- **2-4 jets with P_T > 15 GeV**
  - Leading jet P_T > 25 GeV
- **15 < MET < 200 GeV**
- Various Δφ(l, MET) triangle cuts

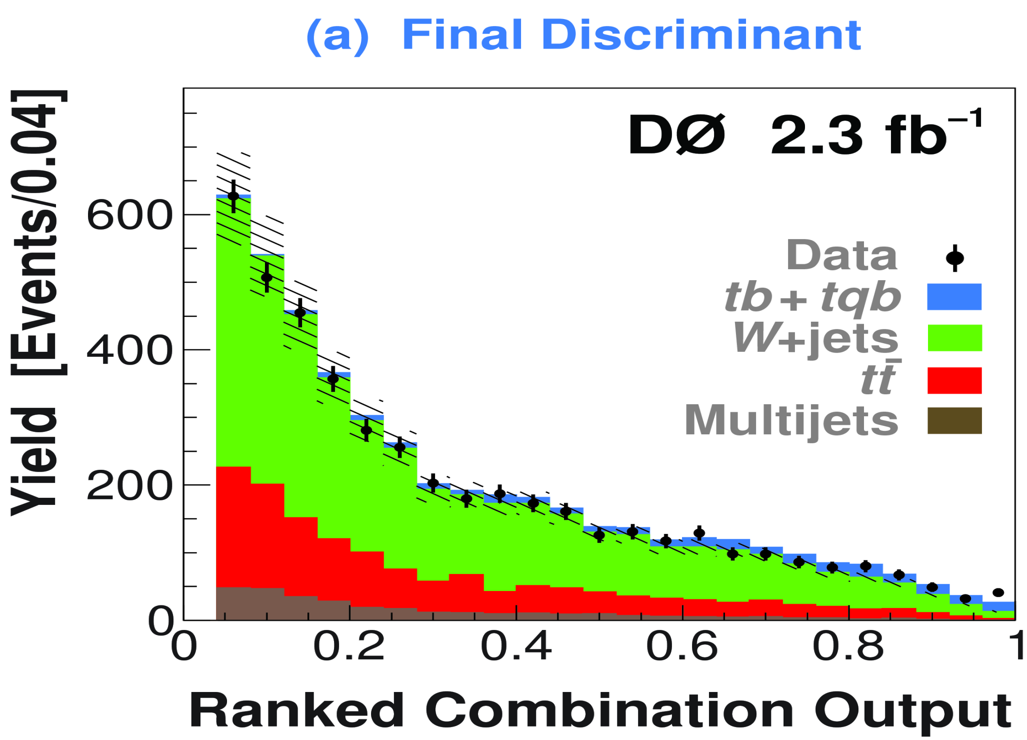


Multivariate Techniques

- Can't Cut 'n' Count
  - $\sigma_{back} > N_{signal}$

	2 Jets	3 Jets	4 Jets
Signal	139 ± 18	63 ± 10	21 ± 5
Total Prediction	2615± 192	1294 ± 107	742 ± 80
Data	2579	1216	724

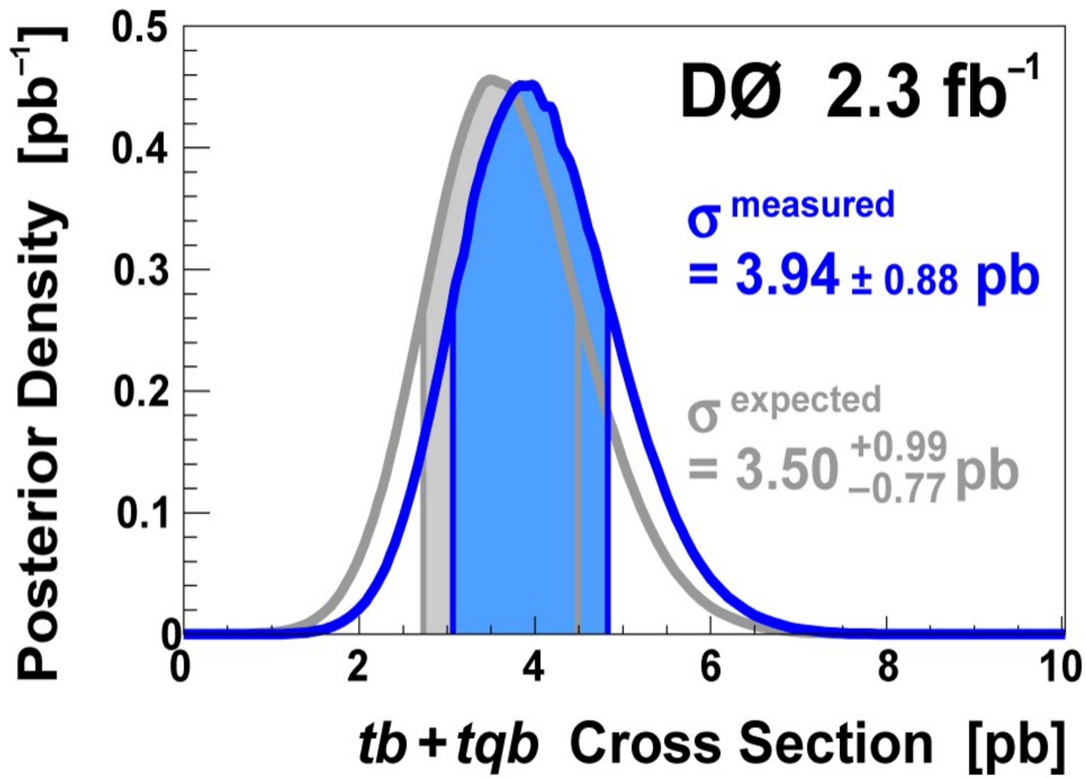
- Use multivariate methods to obtain discriminants



  - Boosted Decision Tree
  - Neural Network
  - Matrix Element
  - Up to 64 input variables

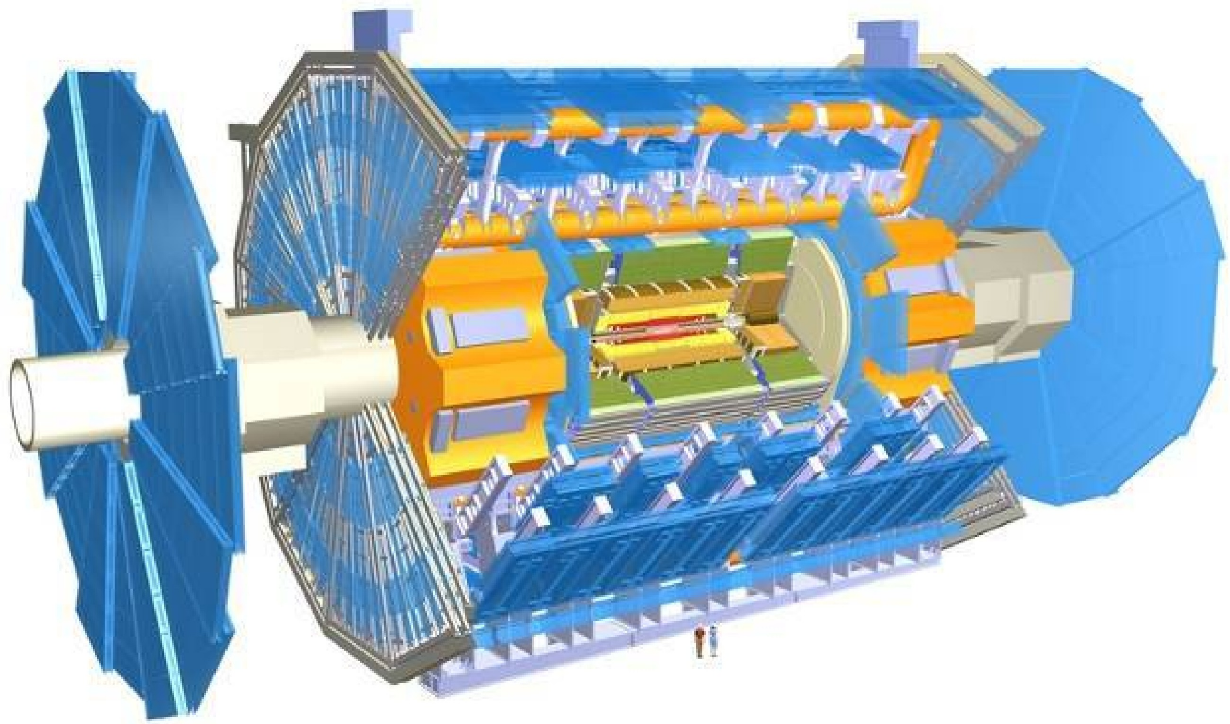
Cross Section Measurement

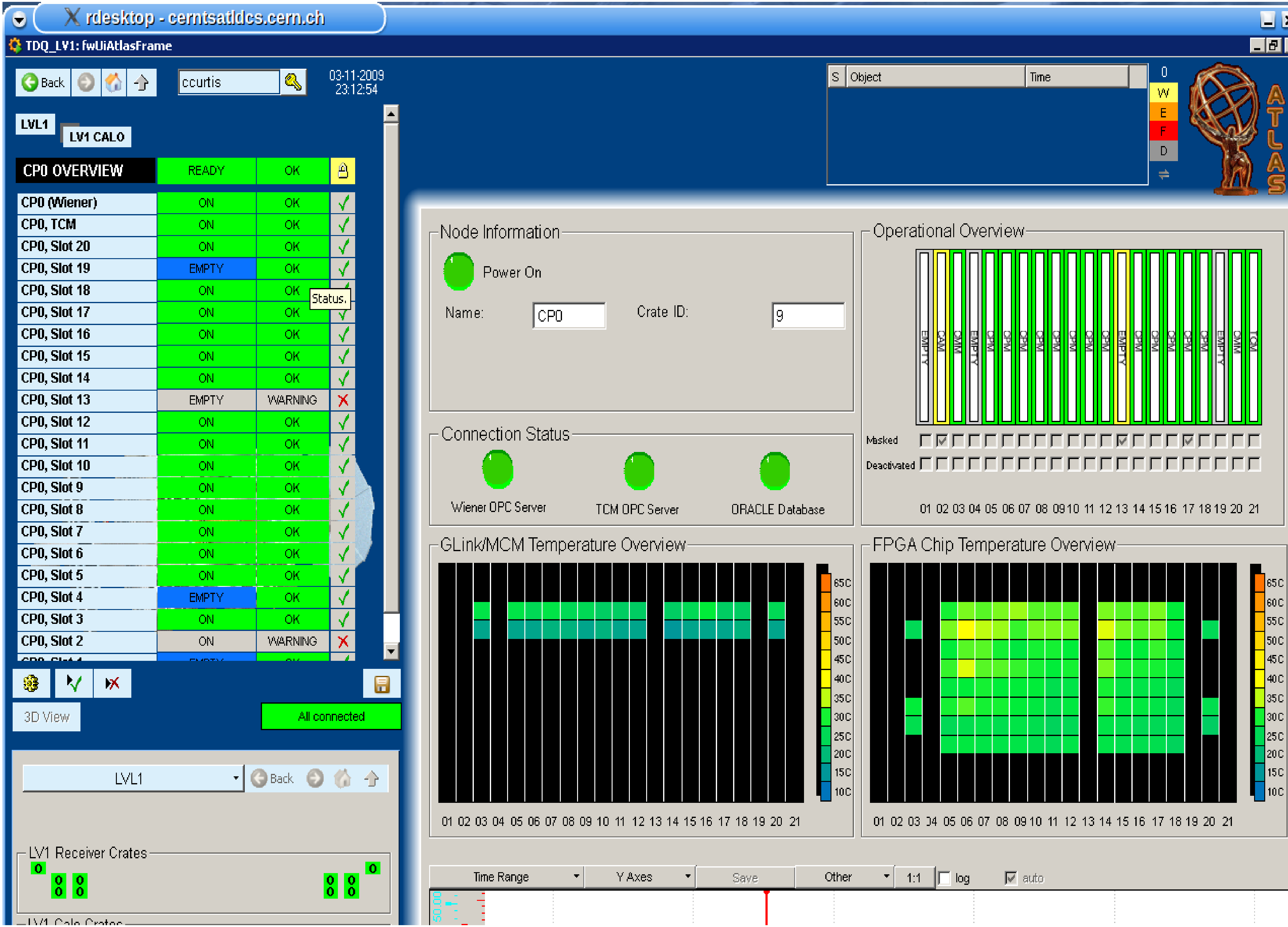
- Combine discriminants to get more precise estimate of cross section
- $P(H_0) = 2.5\times10^{-7}$, significance > 5.0σ
- $|V_{tb}| > 0.78$ at 95% confidence level
- $|V_{tb}| = 1.07 \pm 0.12$



ATLAS Expectations

- ATLAS strategy similar to the Tevatron
- Expect to suffer the same backgrounds
- Gain from much higher cross section





rdesktop - cerntsatldcs.cern.ch
TDQ_LV1: fwUiAtlasFrame
Back
ccurtis
03-11-2009
23:12:54
LVL1
LV1 CALO
CP0 OVERVIEW READY OK
CP0 (Wiener) ON OK
CP0, TCM ON OK
CP0, Slot 20 ON OK
CP0, Slot 19 EMPTY OK
CP0, Slot 18 ON OK
Status.
CP0, Slot 17 ON OK
CP0, Slot 16 ON OK
CP0, Slot 15 ON OK
CP0, Slot 14 ON OK
CP0, Slot 13 EMPTY WARNING
CP0, Slot 12 ON OK
CP0, Slot 11 ON OK
CP0, Slot 10 ON OK
CP0, Slot 9 ON OK
CP0, Slot 8 ON OK
CP0, Slot 7 ON OK
CP0, Slot 6 ON OK
CP0, Slot 5 ON OK
CP0, Slot 4 EMPTY OK
CP0, Slot 3 ON OK
CP0, Slot 2 ON WARNING
3D View
All connected
LVL1
Back
LV1 Receiver Crates
S Object Time
0
W
E
F
D
ATLAS
Node Information
Power On
Name: CP0
Crate ID: 9
Operational Overview
EMPTY CAM CMM EMPTY CPM CPM CPM CPM CPM CPM CPM CPM EMPTY CPM CPM CPM CPM CPM EMPTY CMM TCM
Masked
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01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21
Connection Status
Wiener OPC Server
TCM OPC Server
ORACLE Database
GLink/MCM Temperature Overview
65C 60C 55C 50C 45C 40C 35C 30C 25C 20C 15C 10C
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FPGA Chip Temperature Overview
65C 60C 55C 50C 45C 40C 35C 30C 25C 20C 15C 10C
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Time Range
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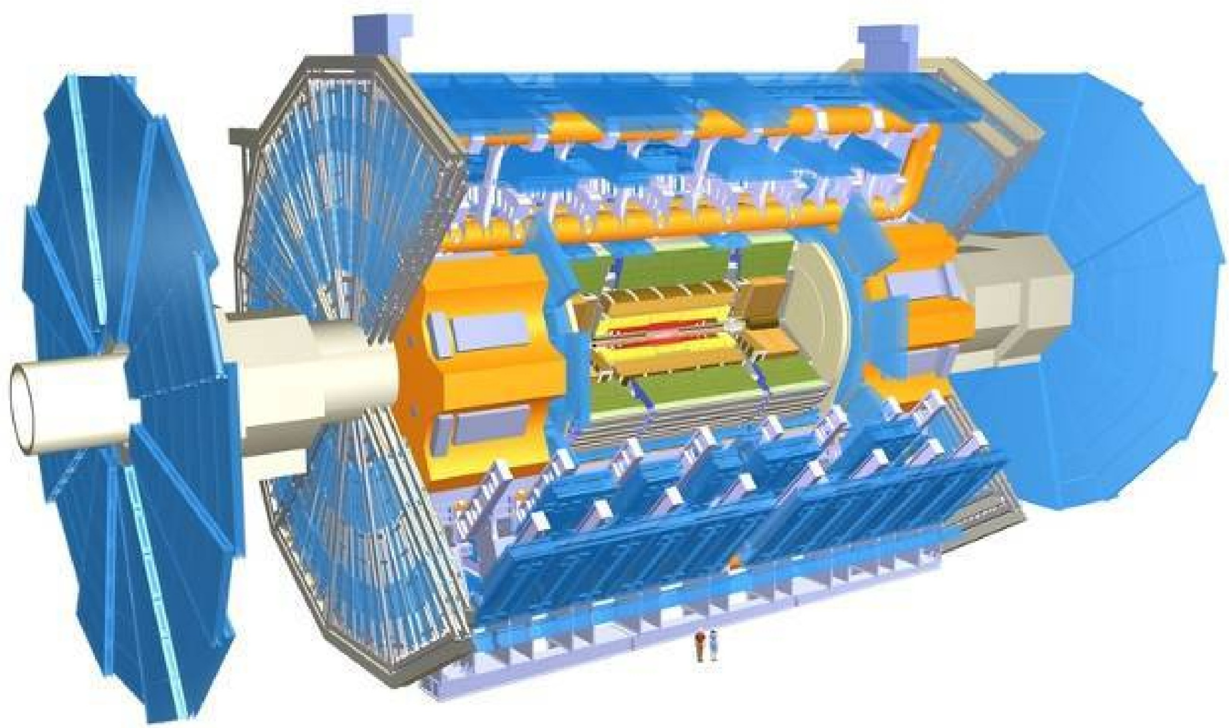
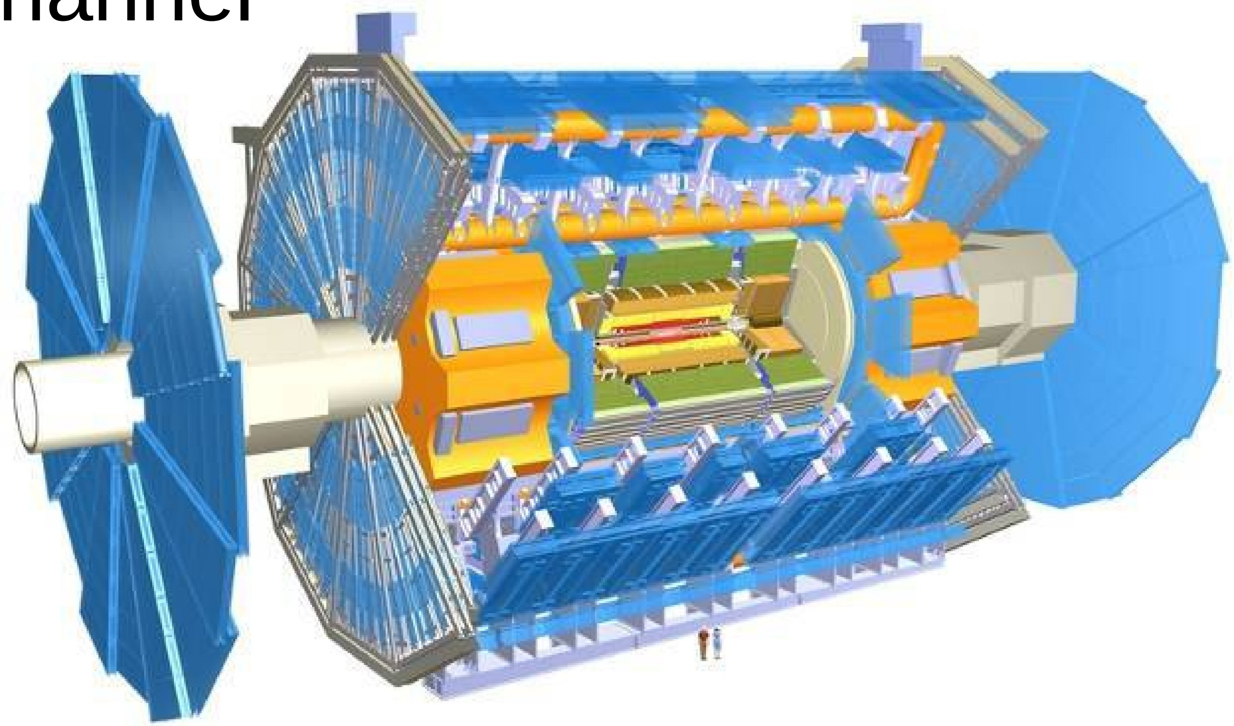


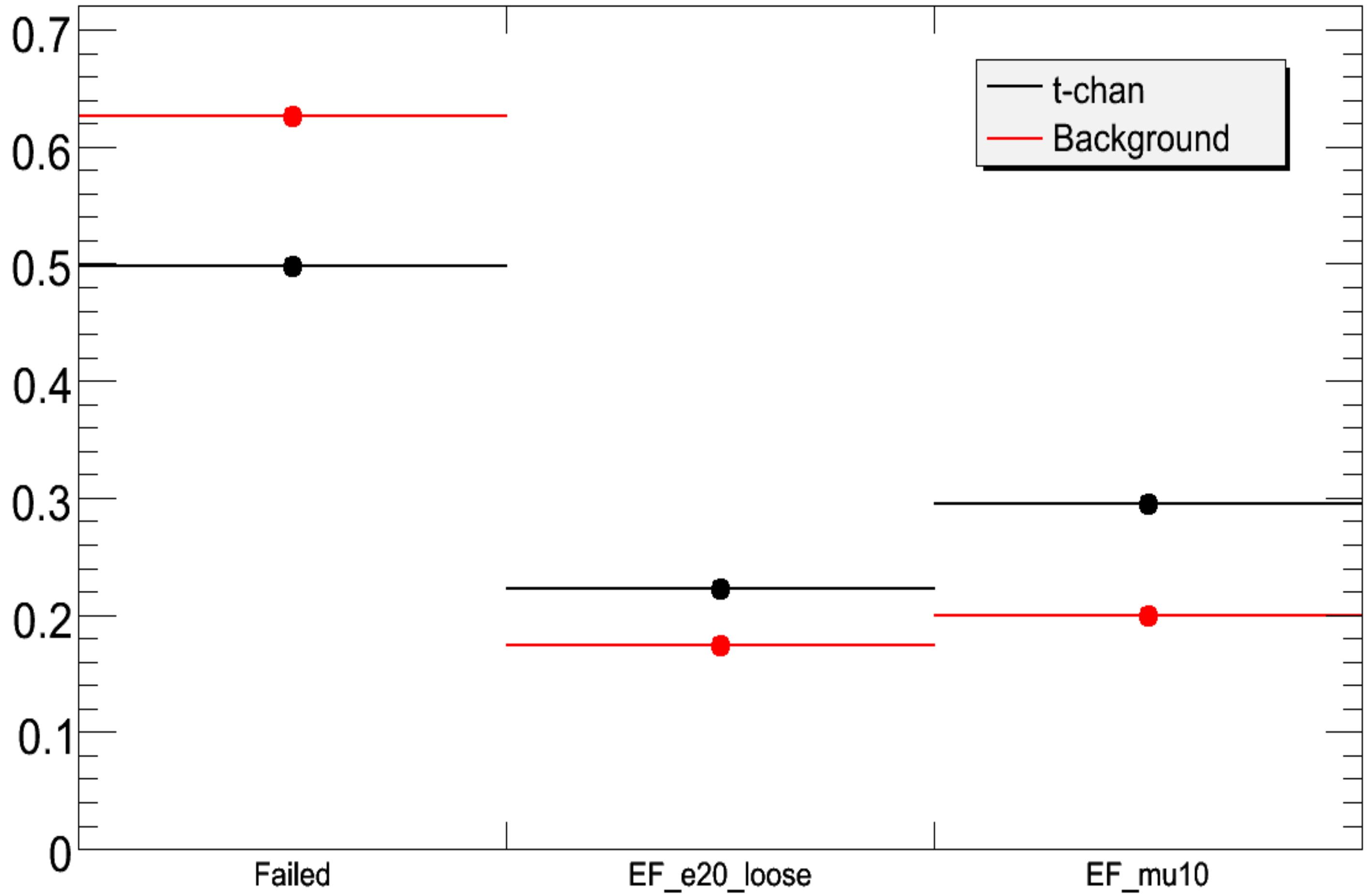
ATLAS Expectations

- Early data considerations:
  - 10 TeV collision energy, ~200 pb^{-1} data
  - Limited capacity of b-tagging
  - Large systematic uncertainties
- Limit study to t-channel



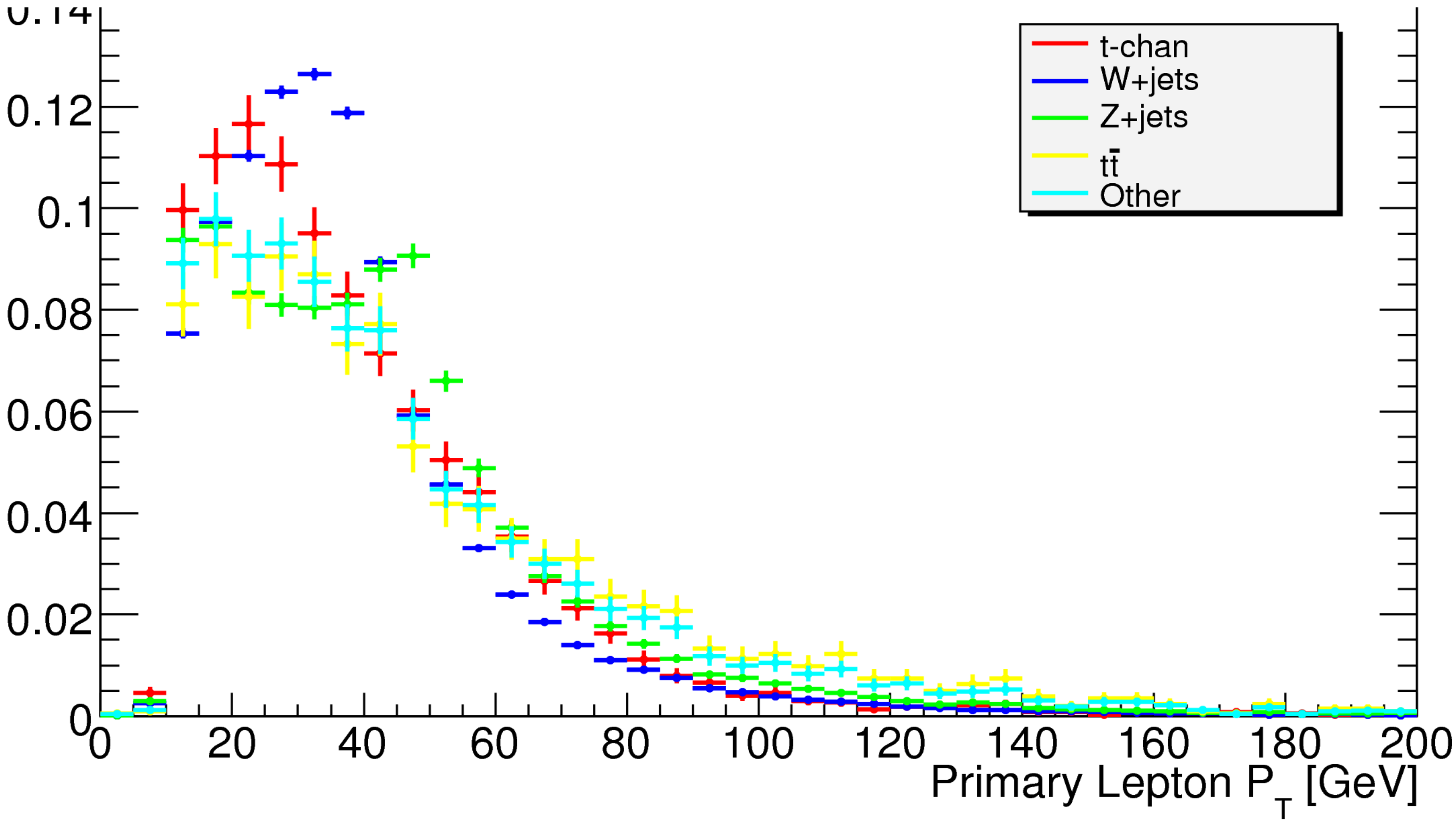
Trigger

- Rely on simple lepton triggers
- Small overlap between electron and muon events



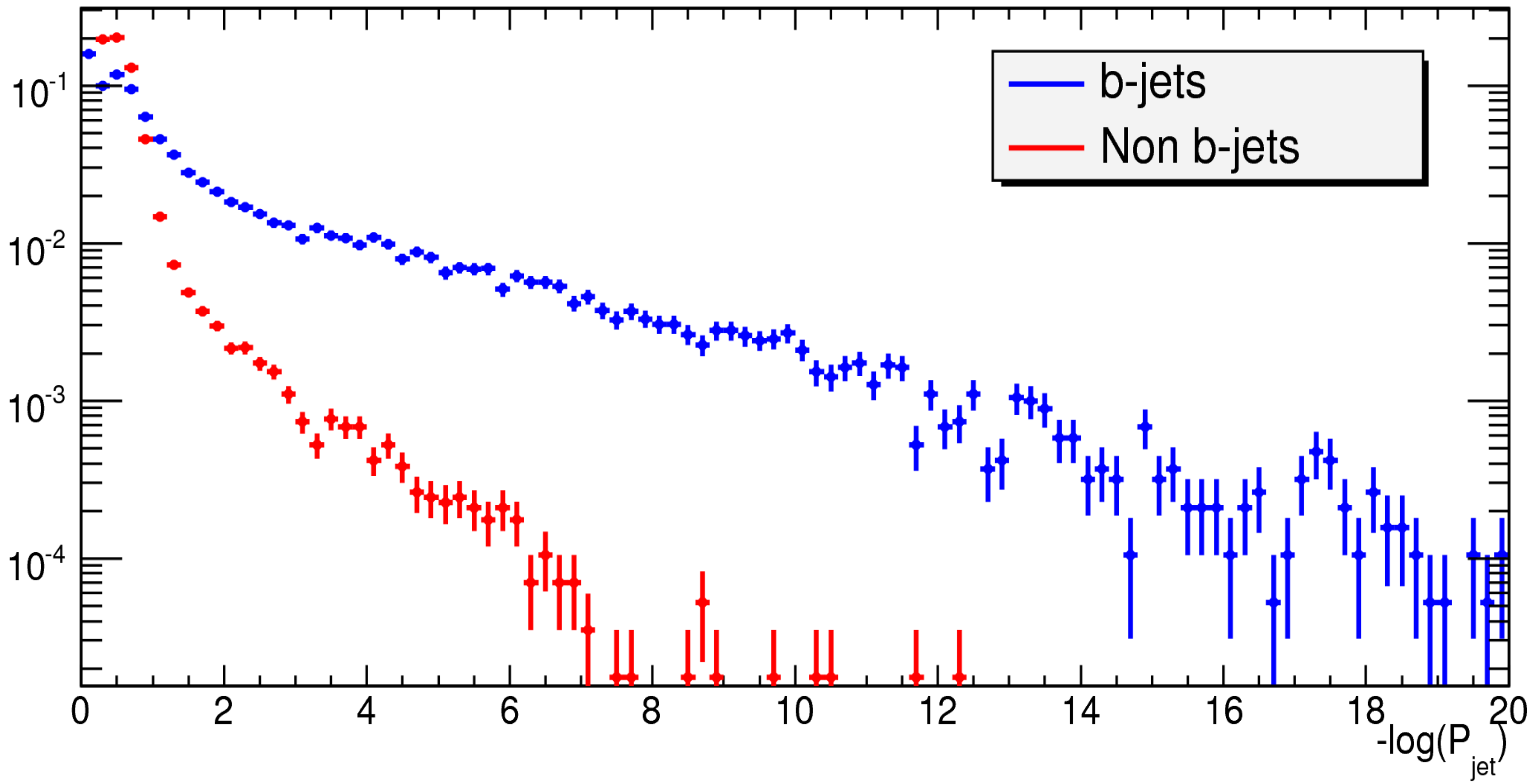
Lepton Selection

- Primary Lepton: 20 < Pt < 100 GeV
- Secondary Lepton: Pt < 10 GeV
- M_T(l,MET) > 30 GeV and M_T(l,l) < 70 GeV



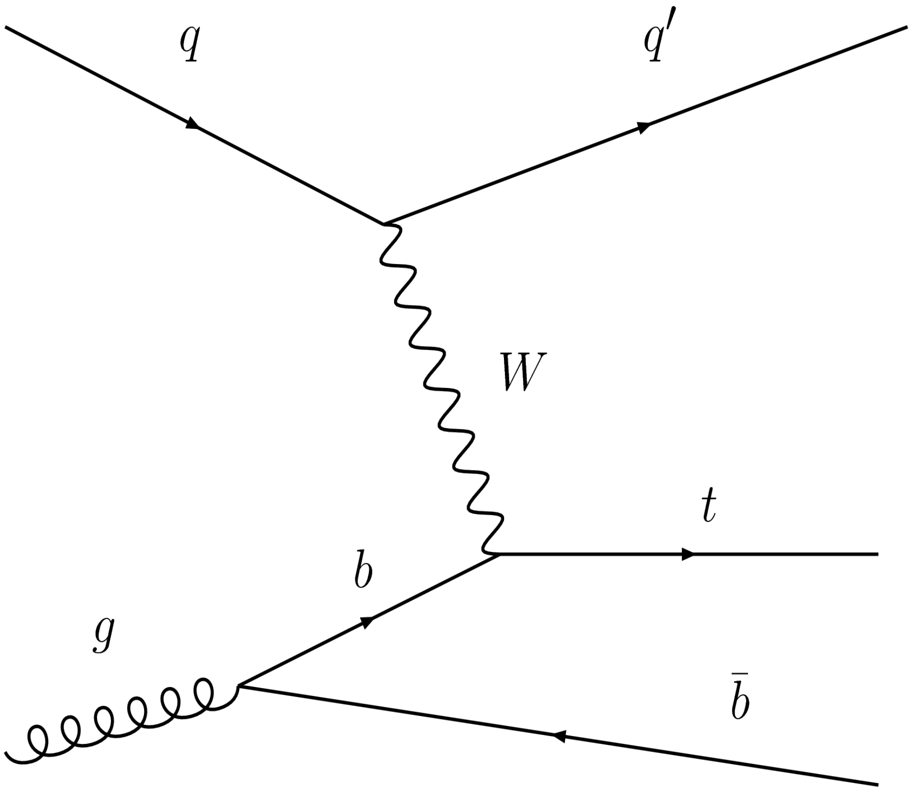
b-tagging

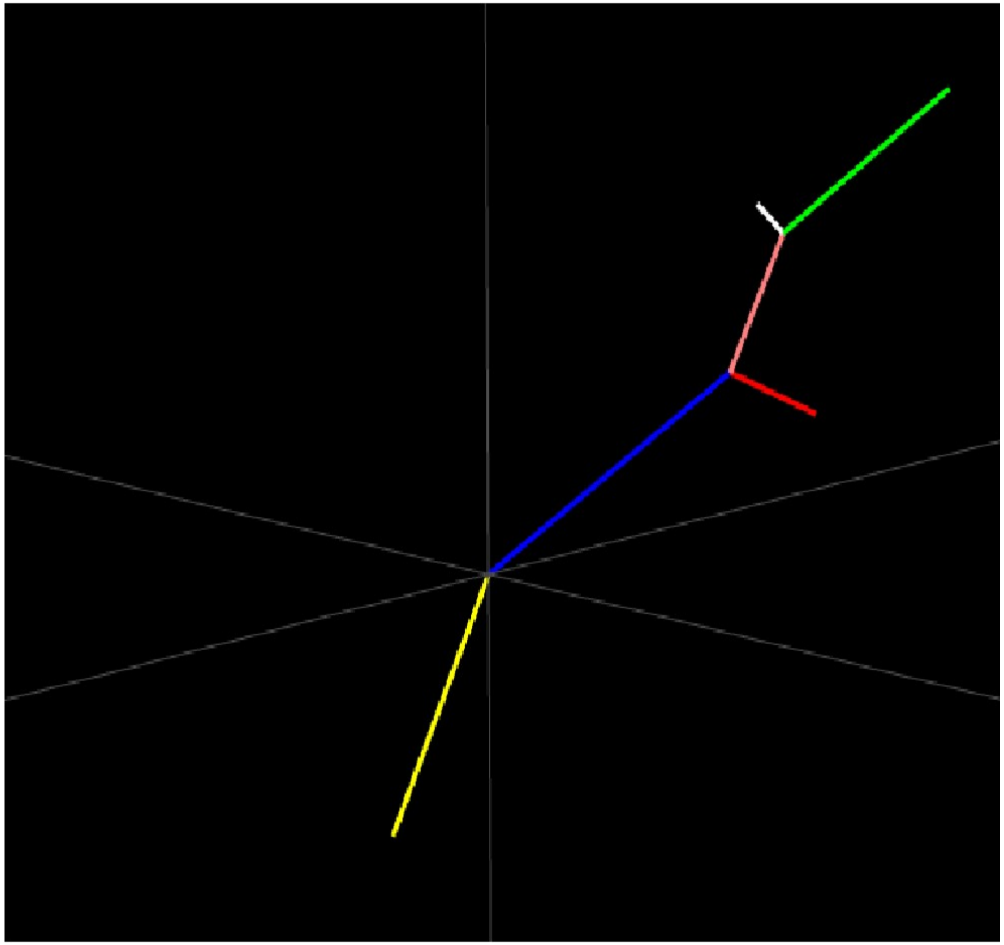
- JetProb tagger suitable for early data
- Tag efficiency 30%
- Rejection factor of 60



Jet Selection

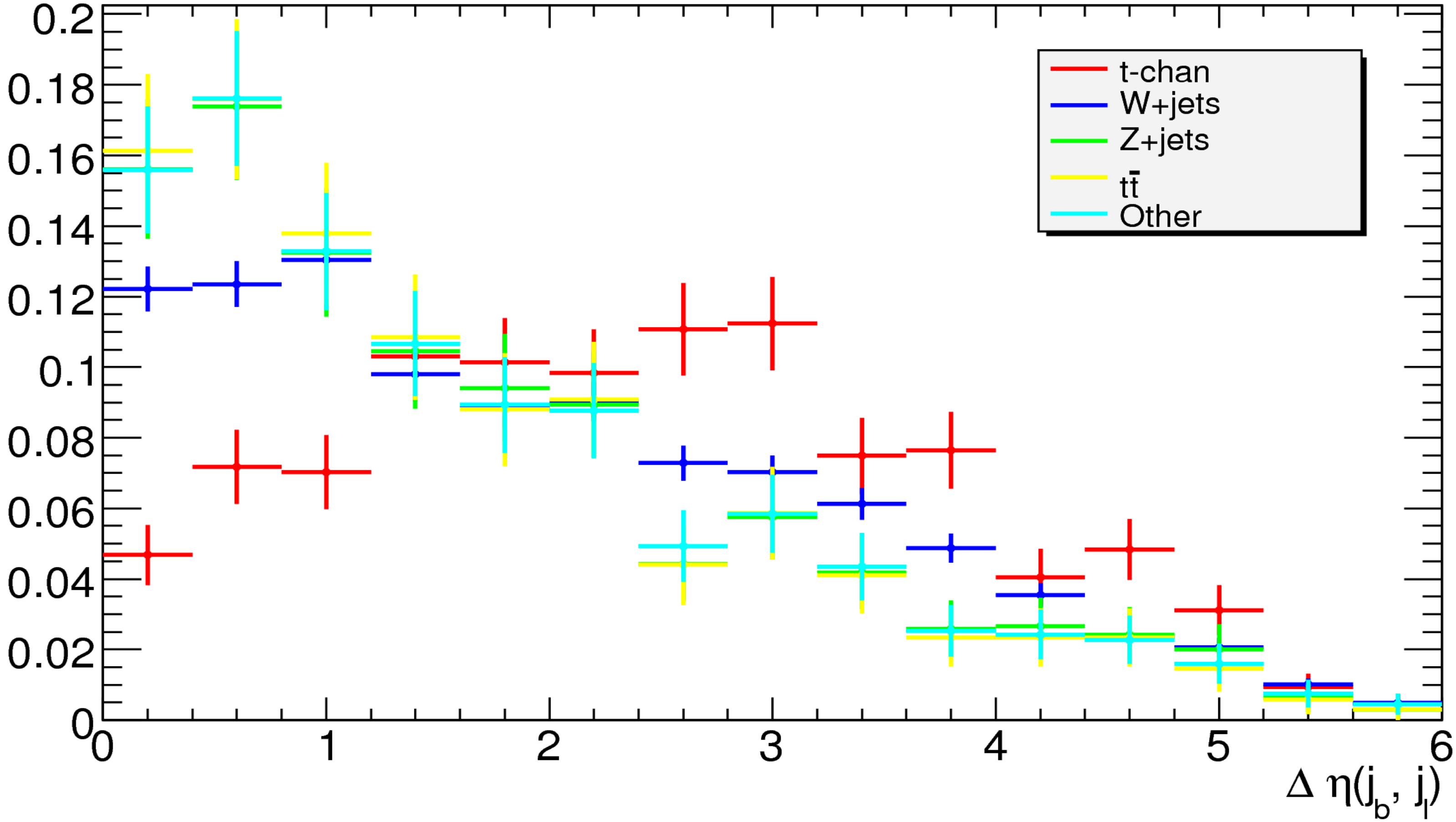
- At least 1 b-tagged jet, P_t > 30 GeV
- Between 2-4 other jets, P_t > 15 GeV





Further Selection

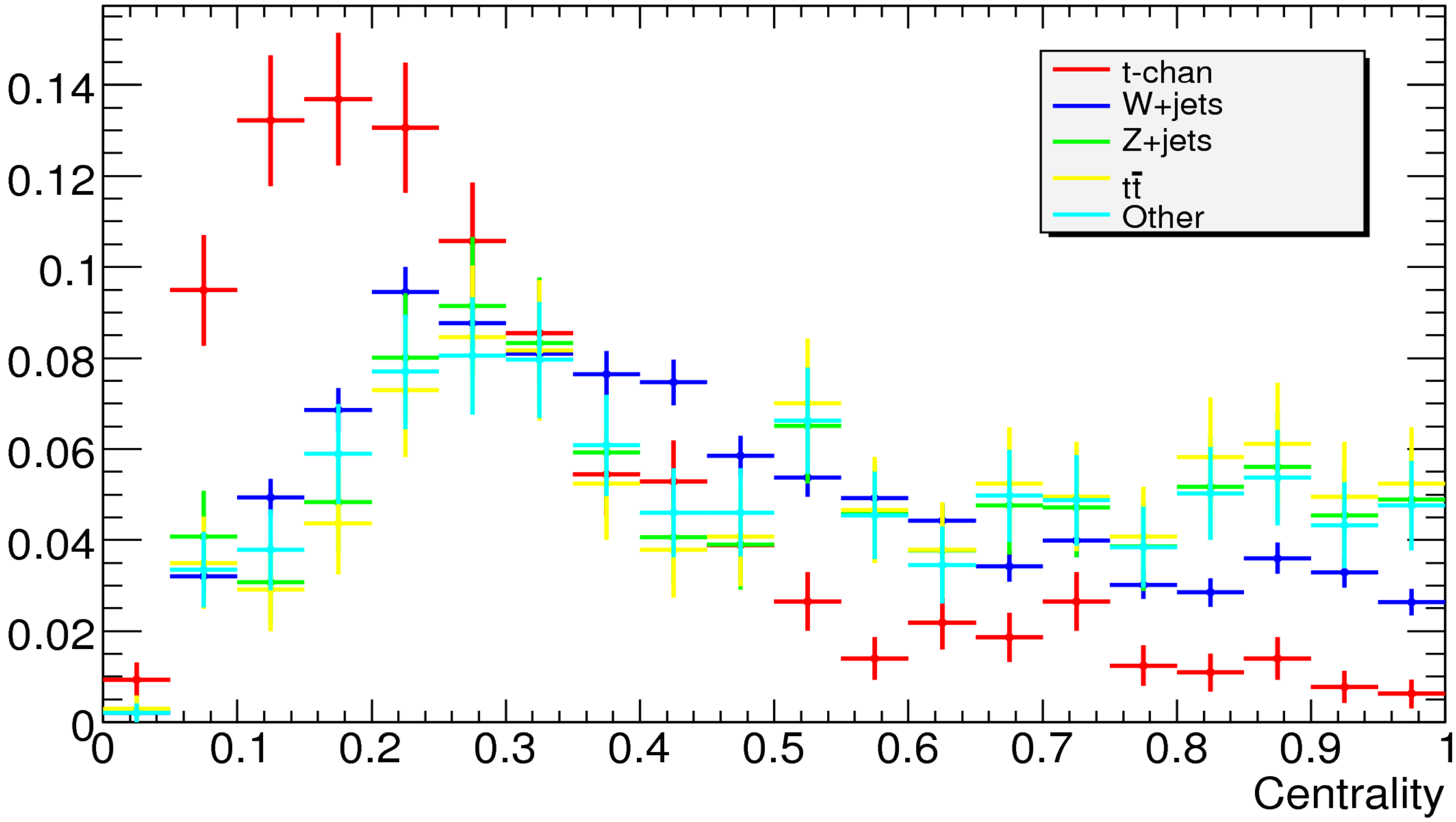
- Separation between primary objects
  - $1.4 < \Delta\eta(\, j_l, j_b\,) < 5.0$
  - $0.8 < \Delta\eta(\, j_l, l\,) < 4.0$



Further Selection

- Cut on centrality

$$\frac{E_T^b + E_T^j}{E^b + E^j} < 0.15$$



Cross Section Measurement

- After Selection:
  - N_{sig} = 105 ± 6
  - N_{back} = 369 ± 11
  - S/B = 0.28

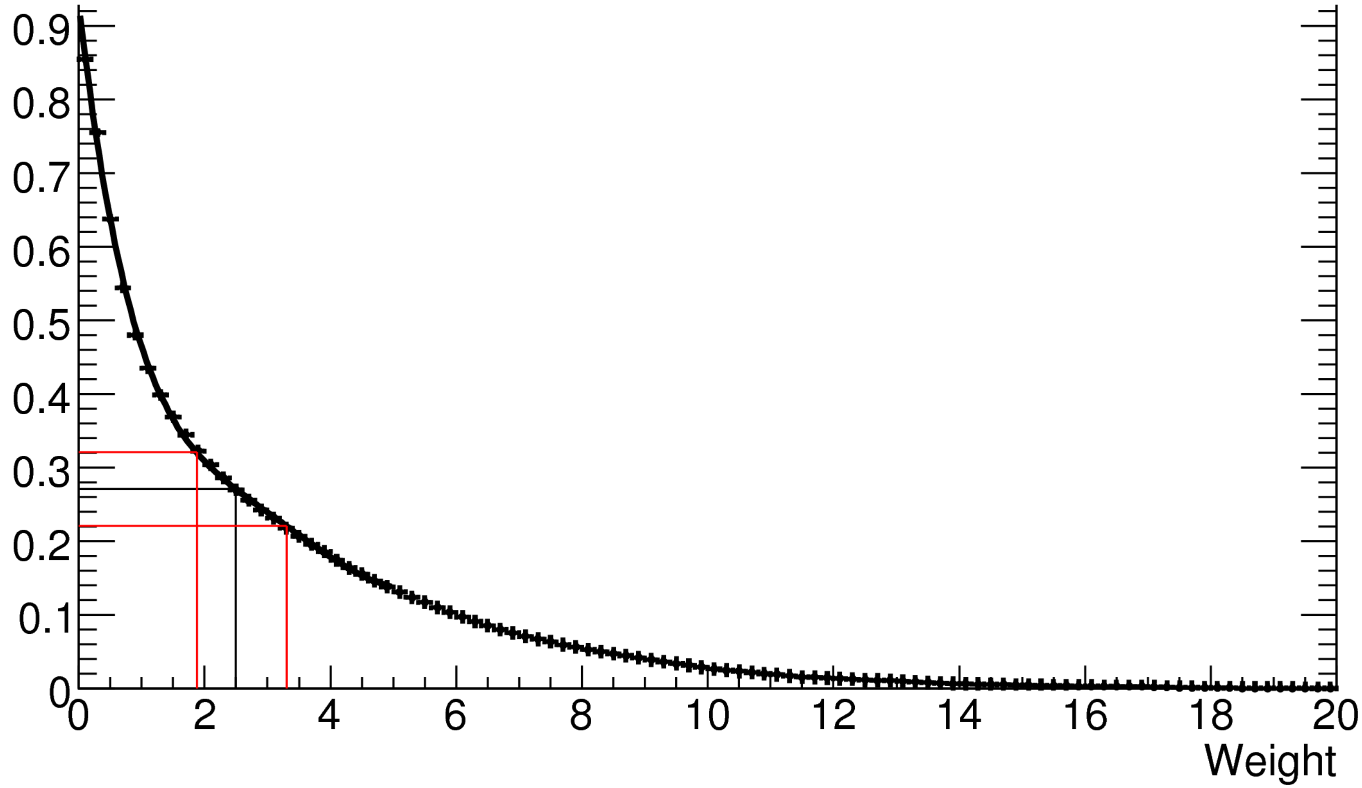
$$\sigma_t = \frac{N_{Data}}{\epsilon_s L} - \sum \frac{\epsilon_b \sigma_b}{\epsilon_s}$$

$$\boxed{\sigma_{t-chan} = 43.2 \pm 9.0\ pb}$$

- Systematic errors dominate...
  - B-tagging
  - Jet Energy Scale
  - Background Normalisation

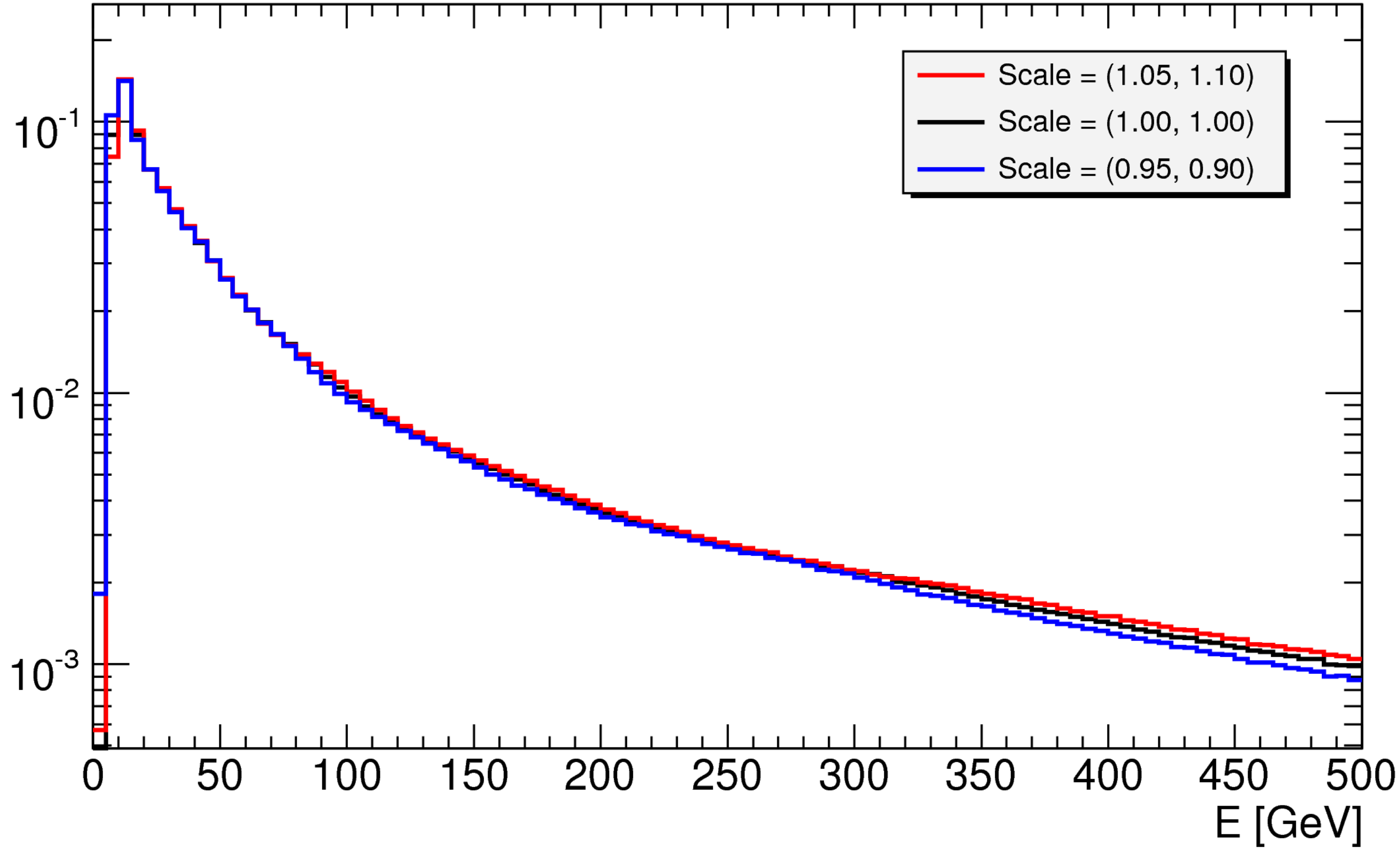
b-tagging

- Expect 5% error in b-tagging efficiency
  - Corresponds to 7% variation in signal efficiency
- 10% error in light jet rejection
  - Corresponds to 3% variation in background



Jet Energy Scale

- Scale between reconstructed and true jet energy poorly understood
- 6% effect on background acceptance



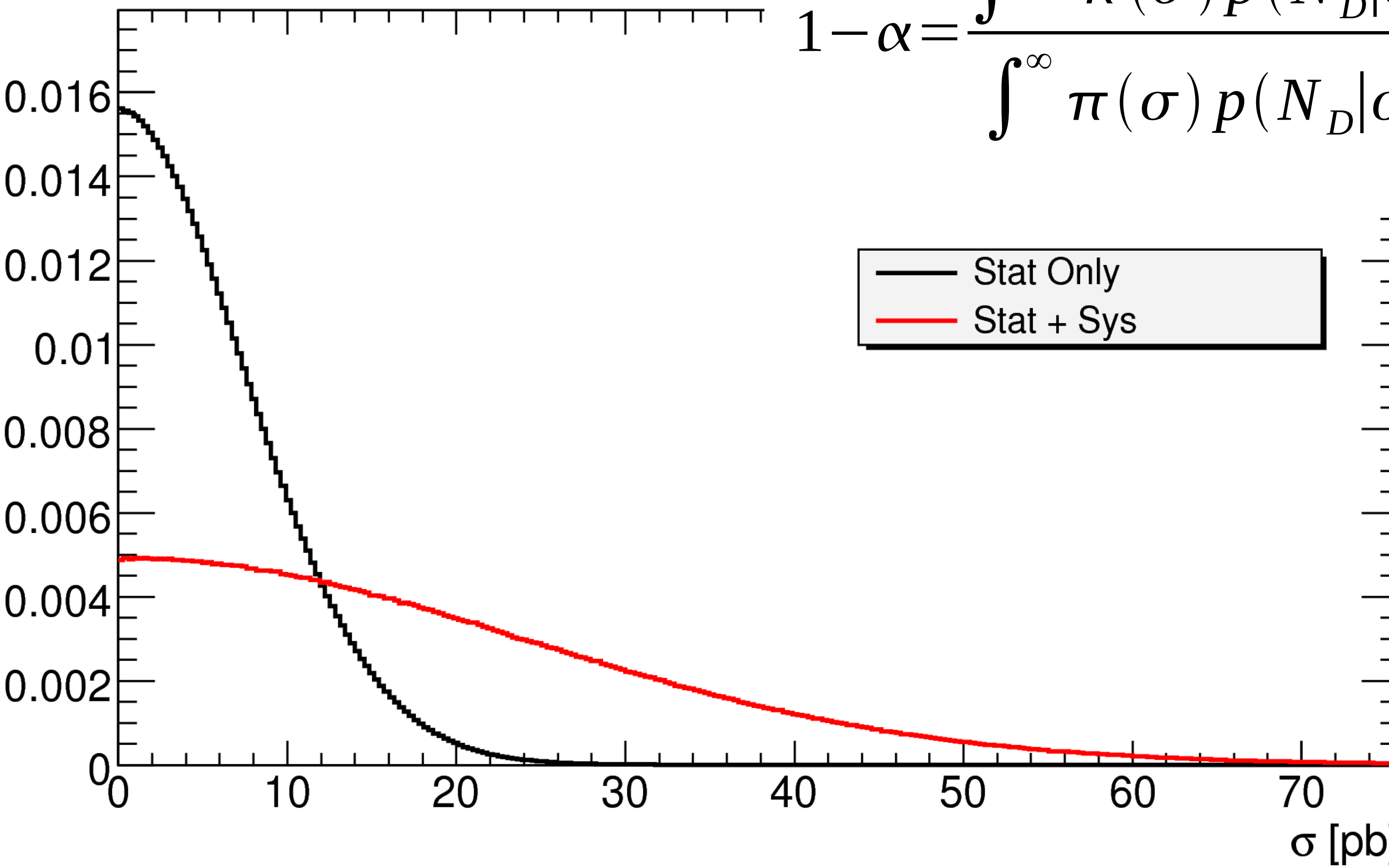
Other Dominant Systematics

- Luminosity expected between 5-20%
- Theoretical background cross section errors up to 20%
  - Expected to drop to ~5% using Data Driven Methods
- Parton Density Functions also contribute
  - CTEQ6M error set gives 6% effect in background

Upper Limit

- Calculate Bayesian upper limit

$$1-\alpha=\frac{\int^{\sigma_{CL}}\pi(\sigma)\,p(N_D|\sigma)\,d\sigma}{\int^{\infty}\pi(\sigma)\,p(N_D|\sigma)\,d\sigma}$$



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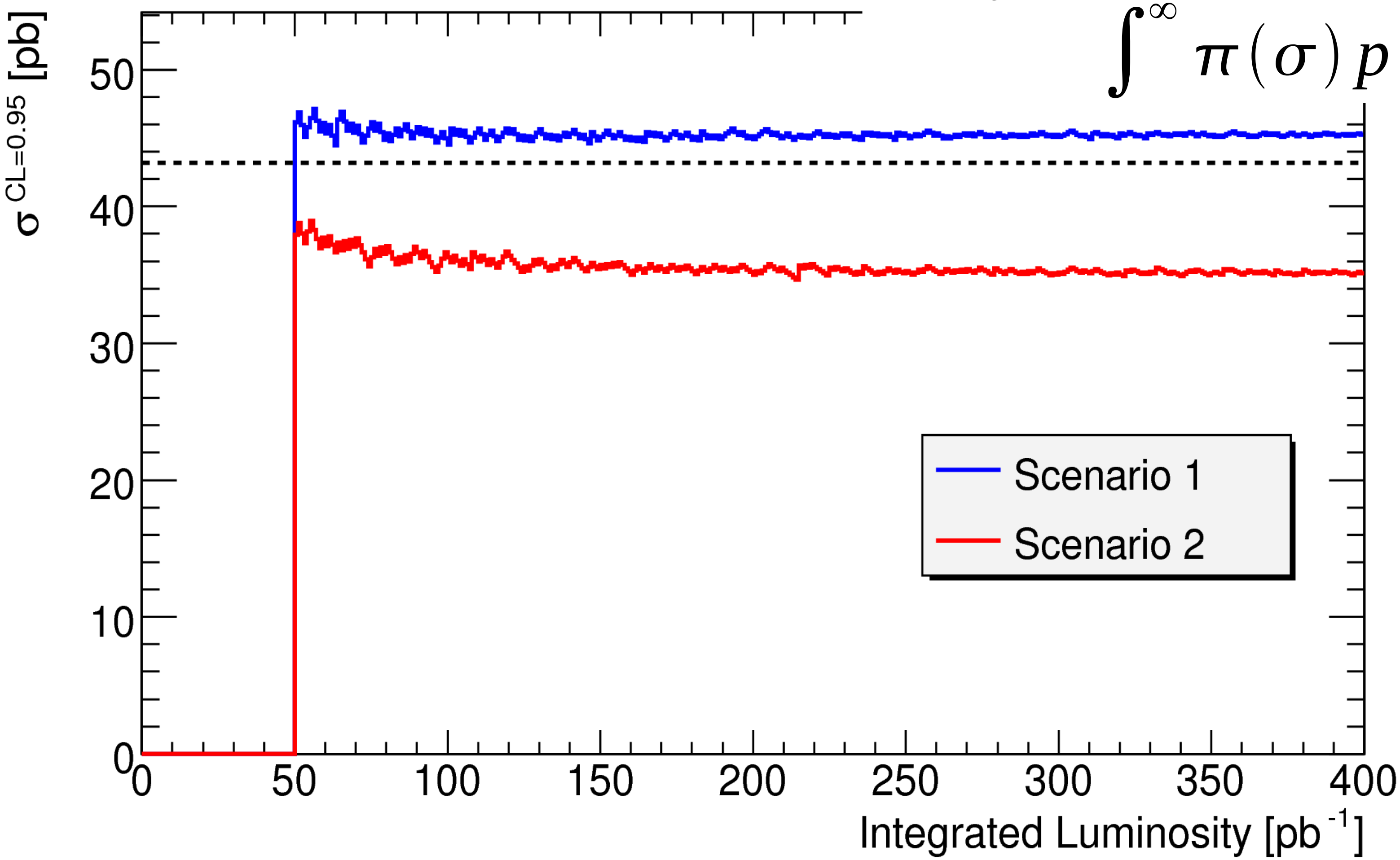
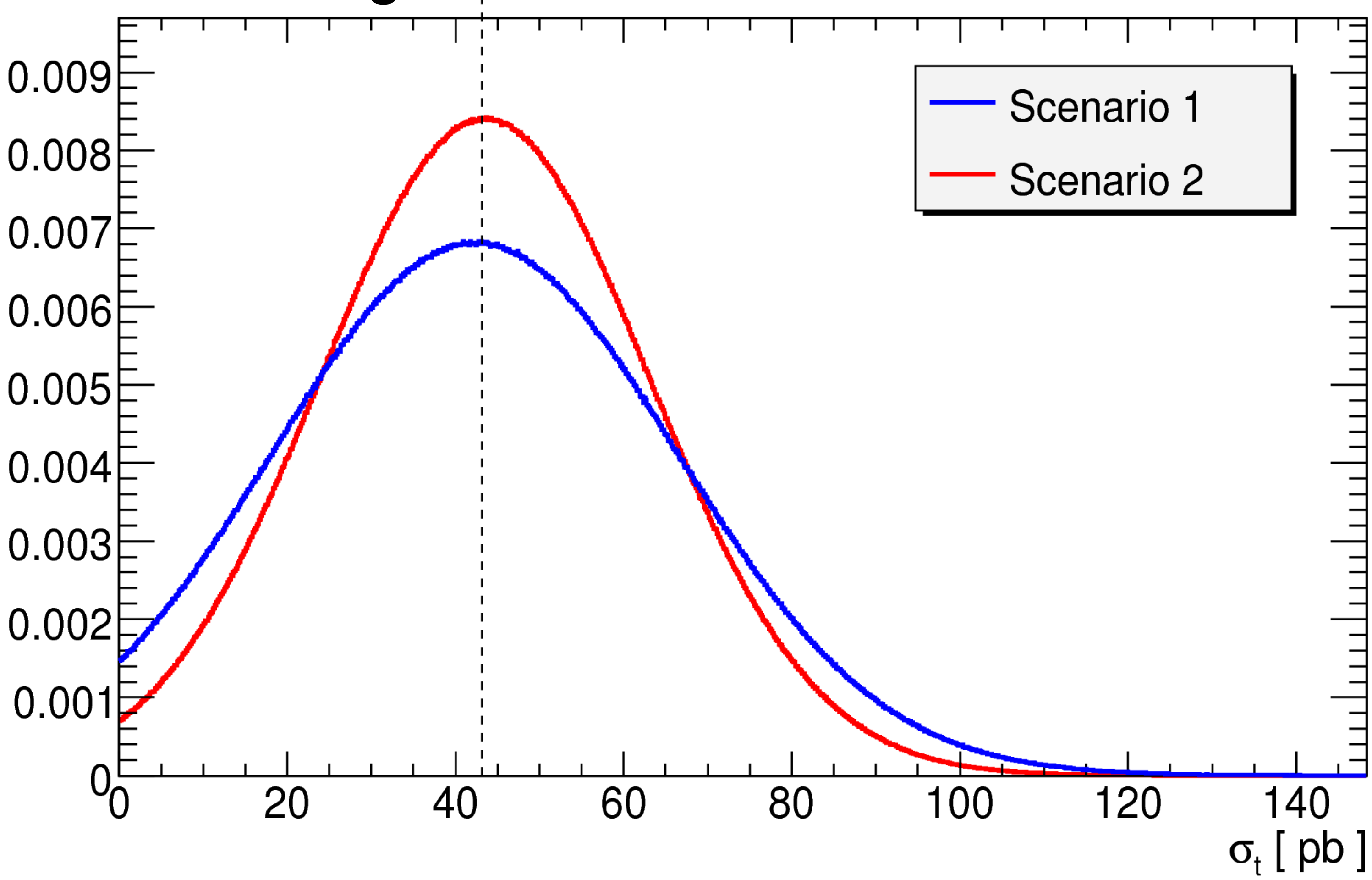
$$1-\alpha=\frac{\int^{\sigma_{CL}}\pi(\sigma)\,p(N_D|\sigma)\,d\sigma}{\int^{\infty}\pi(\sigma)\,p(N_D|\sigma)\,d\sigma}$$



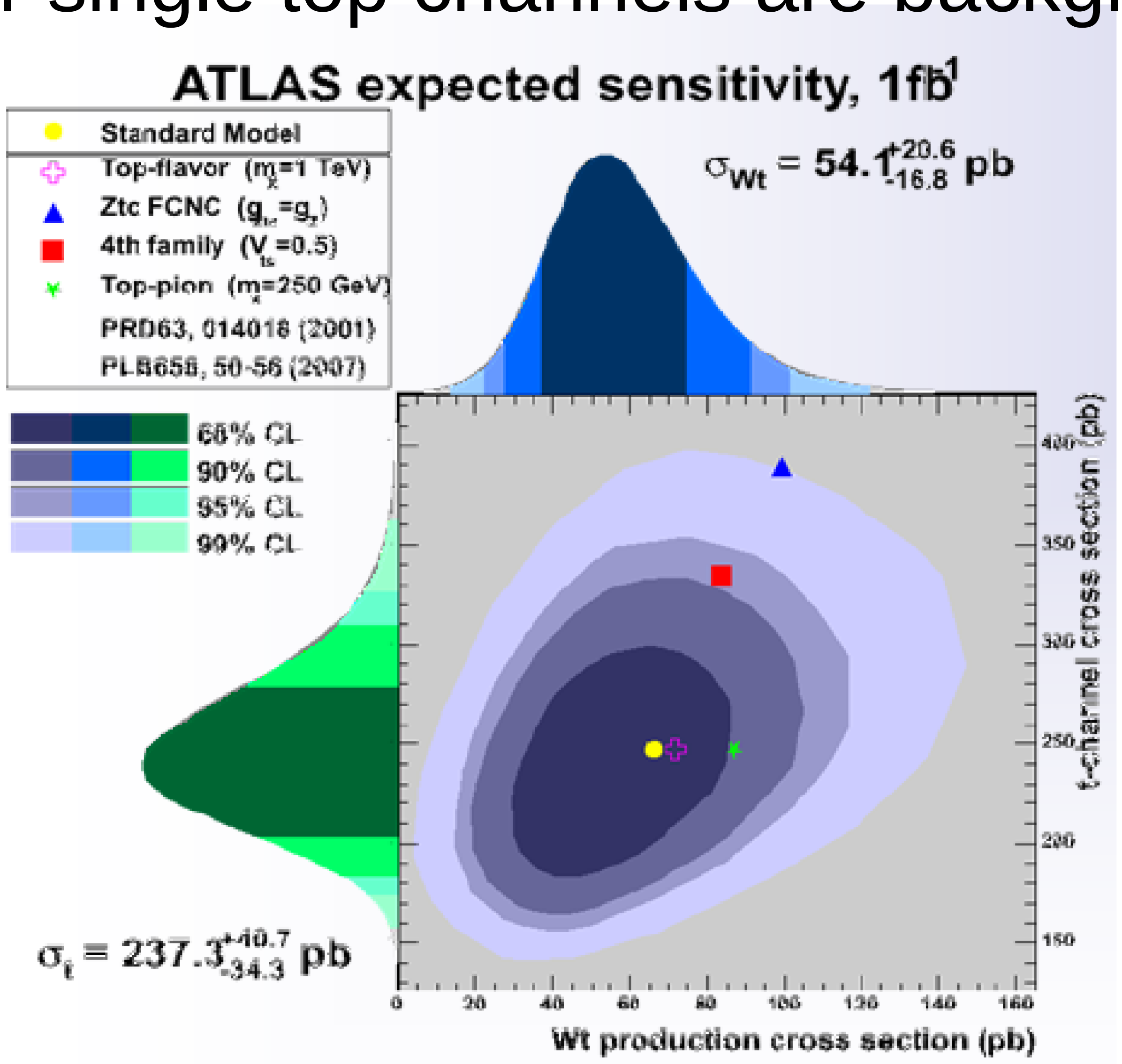
Upper Limit

- Assume standard model
  - P value greater than 1.23% ↔ 2.23σ



Simultaneous Fit

- Other single top channels are backgrounds!



Summary

- Electroweak top production long been predicted
- Discovered by the Tevatron
- ATLAS will benefit from higher statistics
- Evidence within first few years of LHC data