

# NLO effects on single top quark angular asymmetries

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# Outline

- Introduction
- NLO simulation of Cao and Yuan
- NLO effects on “Lonely Top” (Bowen, *et al.*) Analysis
- Conclusions

- References:

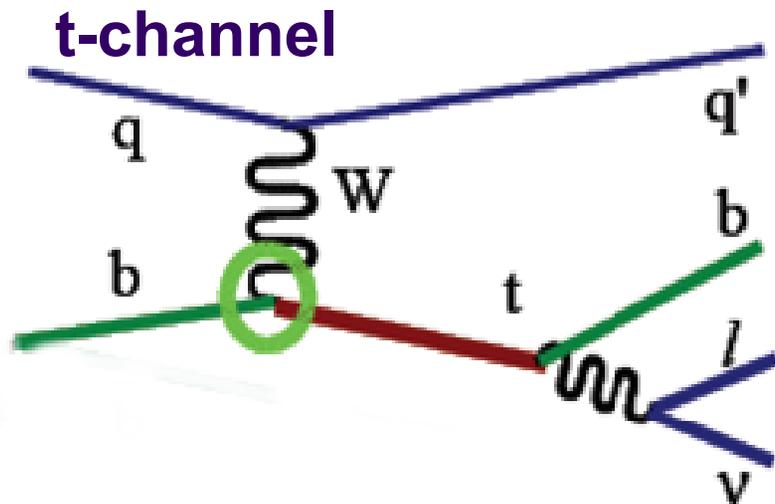
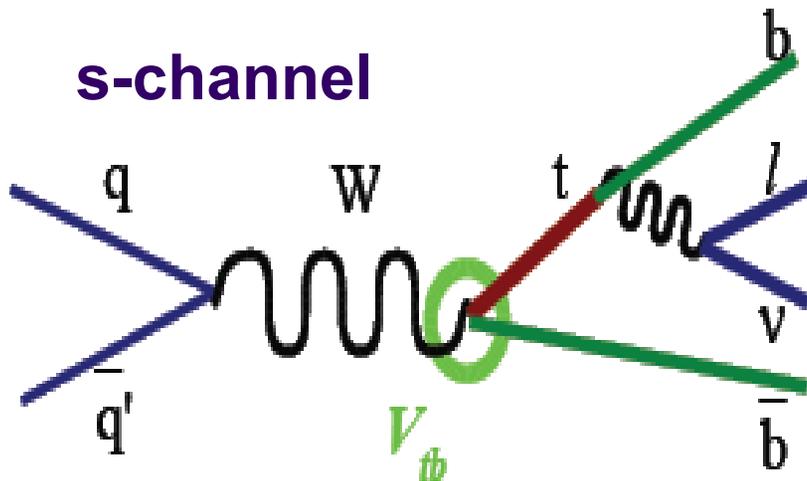
*NLO studies*

- [1] Phys. Rev. D71, (2005) 054022, Single Top Quark Production and Decay at Next-to-leading Order in Hadron Collision, Qing-Hong Cao and C.-P. Yuan
- [2] Phys. Rev. D71, (2005) 054023, NLO Corrections to Single Top Quark Production and Decay at the Tevatron: 1. s-channel Process, Qing-Hong Cao, Reinhard Schwienhorst, and C.-P. Yuan
- [3] Phys.Rev. D72 (2005) 094027 NLO Corrections to Single Top Quark Production and Decay at the Tevatron: 2. t-channel Process Qing-Hong Cao, Reinhard Schwienhorst, Jorge A. Benitez, Raymond Brock, and C.-P. Yuan

*Angular correlation functions*

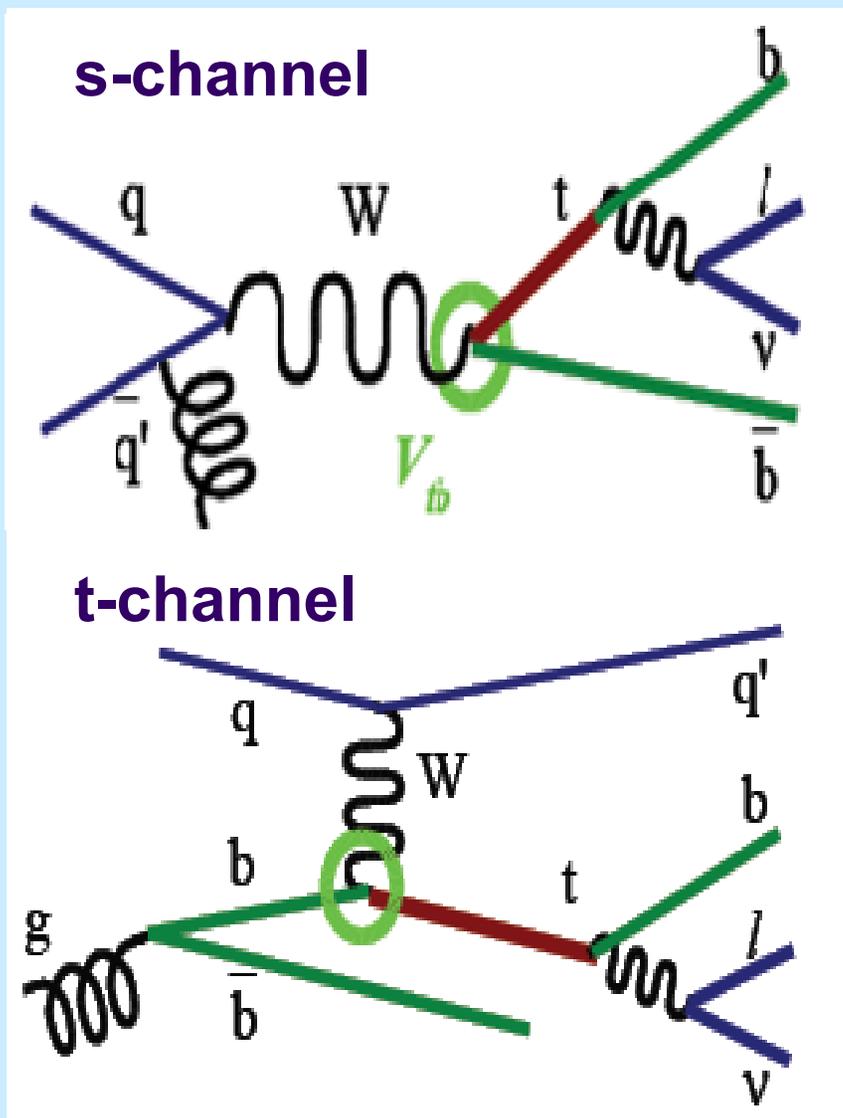
- [4] Acta Phys.Polon. B36 (2005) 271-282, hep-ph/0504186  
In Search of Lonely Top Quarks at the Tevatron Matthew T. Bowen, Stephen D. Ellis and Matthew J. Strassler
- [5] Phys. Rev. D72 (2005) 074016 In Search of Lonely Top Quarks at the Tevatron, Matthew T. Bowen, Stephen D. Ellis, and Matthew J. Strassler

# Single top quark signal

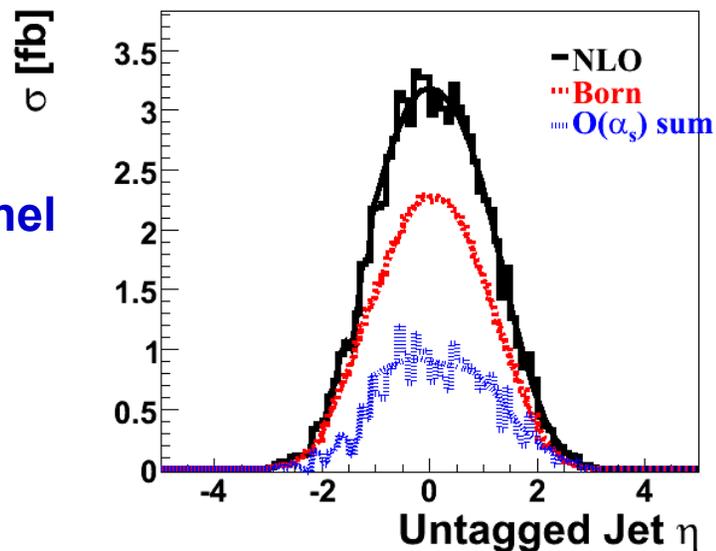


- Electroweak Interaction
- Process has never been observed before: The Run II “discovery”?
- Observe top quark polarization.
- Sensitive to new physics
- Would provide first and unique direct measurement of the  $V_{tb}$  CKM matrix element
- Large backgrounds

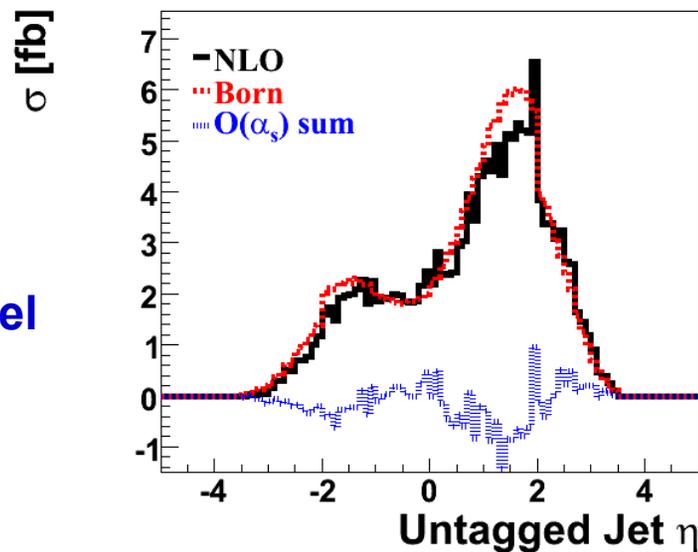
# Single top at NLO, Cao *et al.*<sup>[1,2,3]</sup>



S Channel



T Channel



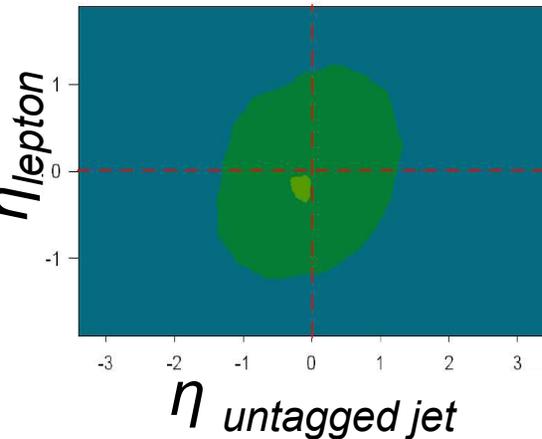
# NLO effects on angular correlation functions

# The “F” asymmetry functions

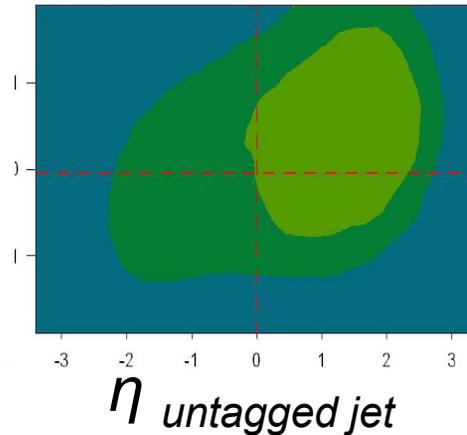
[4,5] Bowen et al

Diff cross sec

a) tb = s-channel



b) tbq = t-channel



- Orthogonal
- Symmetric:

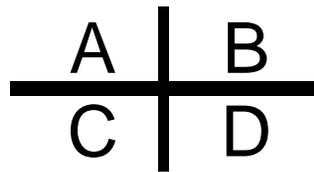
Even Parity: Fbar, Fplus

4 way symmetric

Odd Parity: Fminus

2 way symmetric

4 Quadrants:



Motivation:

How the NLO inclusion in the calculation affects the asymmetry functions?

$$\frac{d^2\sigma}{d^2\hat{\eta}_j d^2\hat{\eta}_l}(\hat{\eta}_j, \hat{\eta}_l) = F(\hat{\eta}_j, \hat{\eta}_l)$$

$$F(\hat{\eta}_j, \hat{\eta}_l) = \bar{F}(\hat{\eta}_j, \hat{\eta}_l) + F_+(\hat{\eta}_j, \hat{\eta}_l) + F_-(\hat{\eta}_j, \hat{\eta}_l)$$

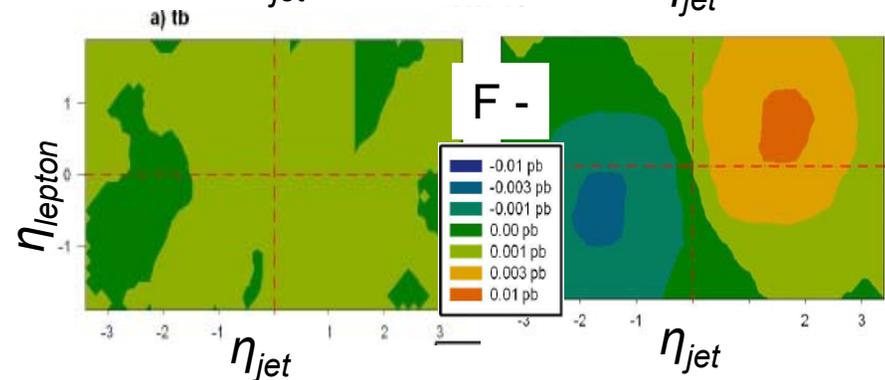
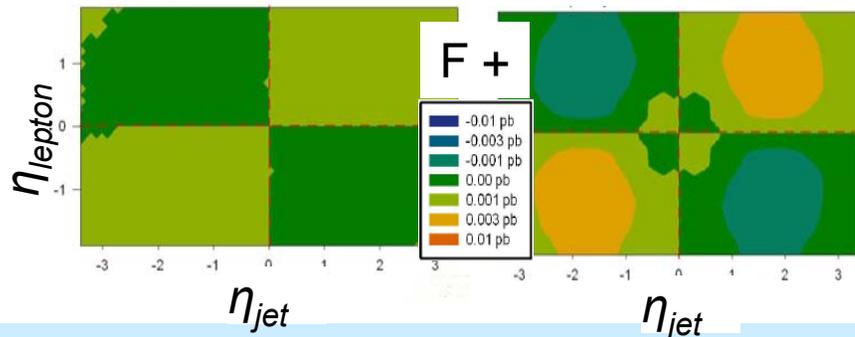
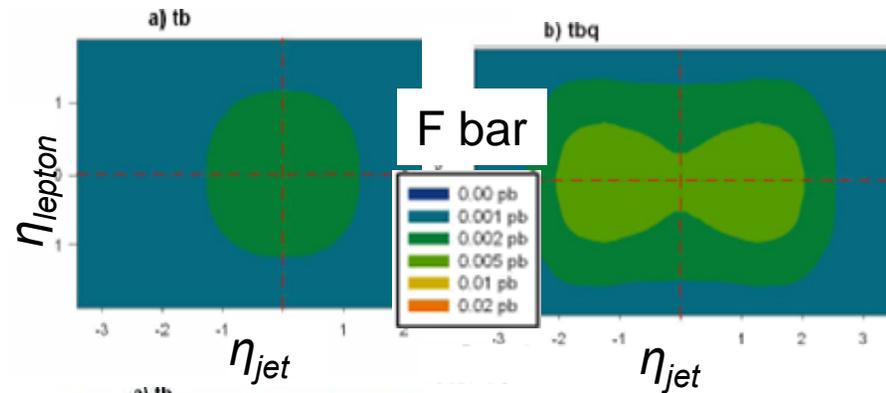
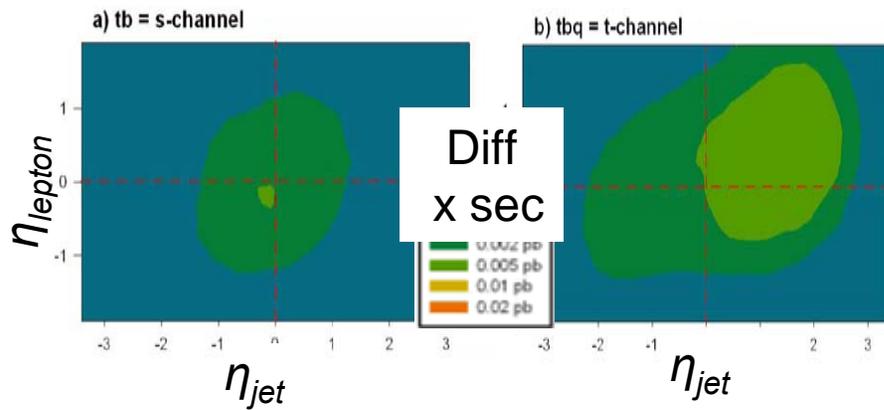
$$\bar{F}(B) = \frac{1}{4}[F(A) + F(B) + F(C) + F(D)]$$

$$F_+(B) = \frac{1}{4}[F(B) + F(C) - F(A) - F(D)]$$

$$F_-(B) = \frac{1}{4}[F(B) - F(C)]$$

# Bowen *et al.* results [4,5]

- Use distinctive shape of the signal to reduce backgrounds effectively, using as observables  $\eta_{\text{leading-untagged-jet}}$  and  $\eta_{\text{lepton}}$
- Distributions for the backgrounds are largely symmetric compared with the signal in the  $(\eta_{\text{jet}}, \eta_{\text{lepton}})$  plane



# s-channel 2-D Plots

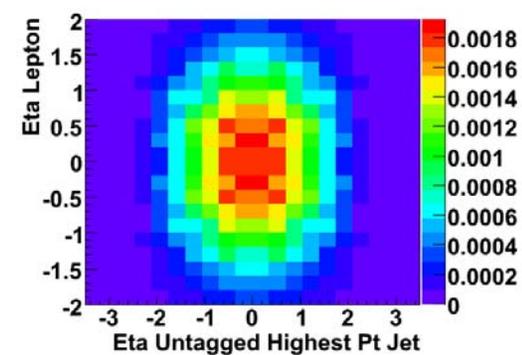
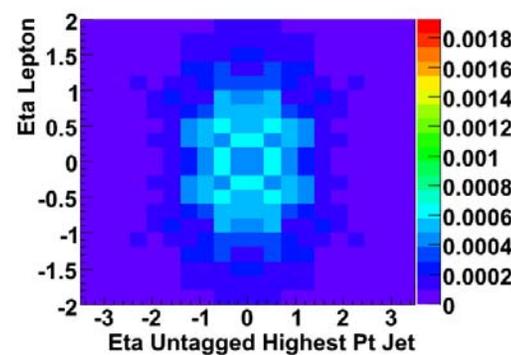
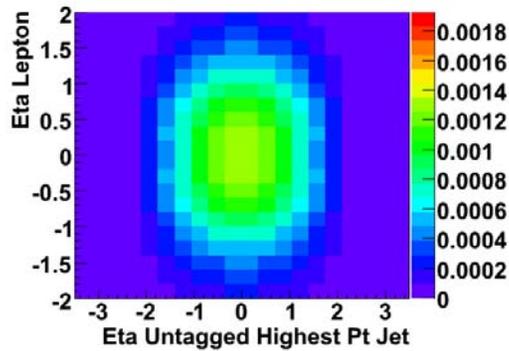
A	B
C	D

## TREE

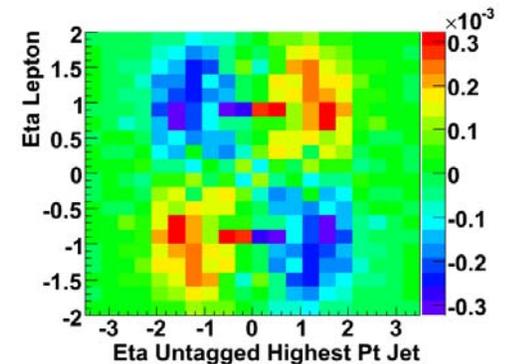
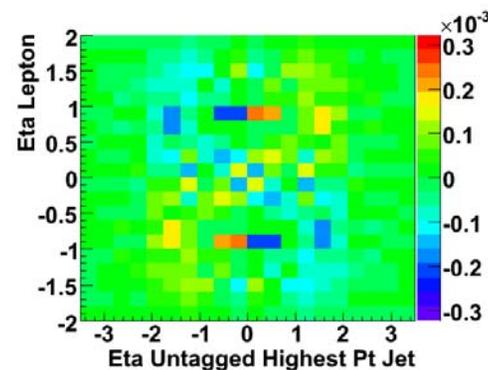
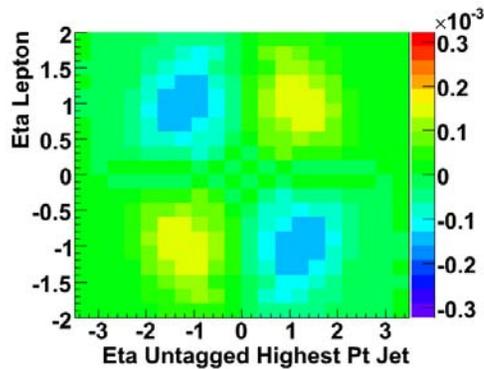
## NLO

## TREE + NLO

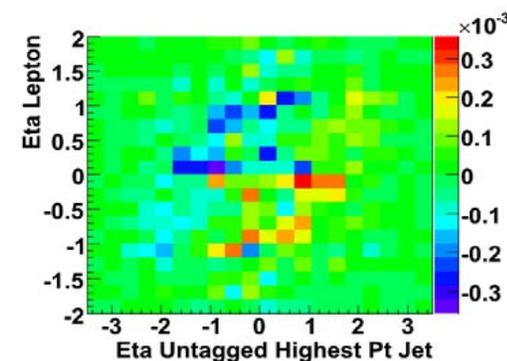
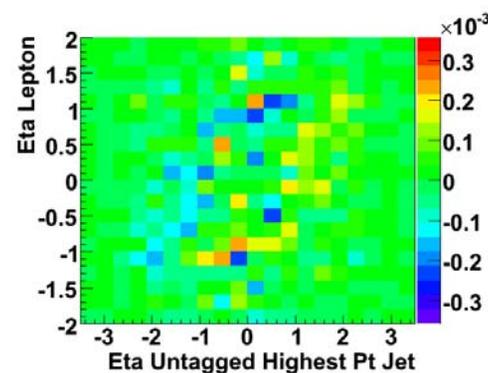
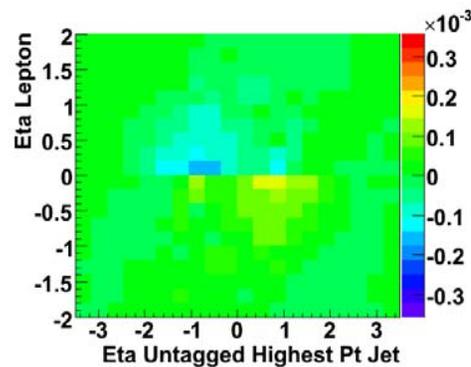
### F BAR



### F PLUS



### F MINUS



# t-channel 2-D Plots

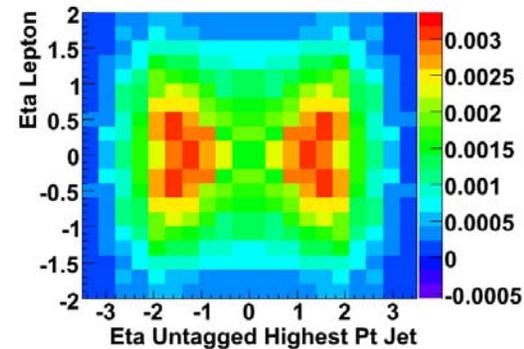
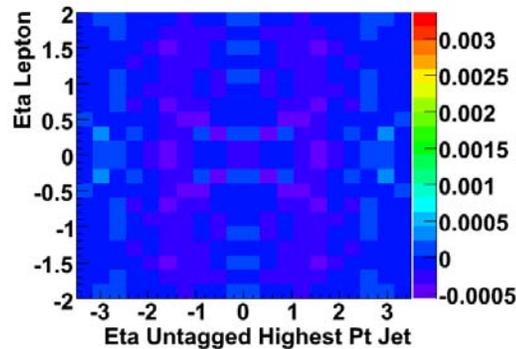
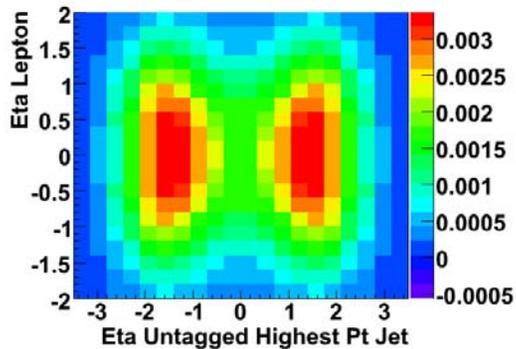
A	B
C	D

## TREE

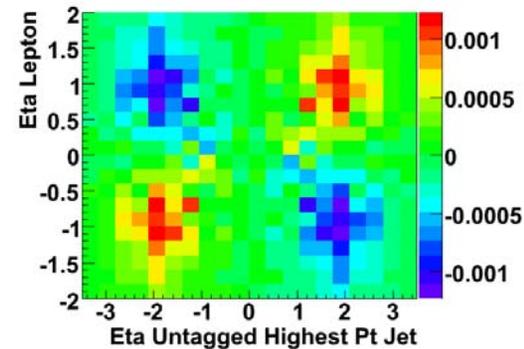
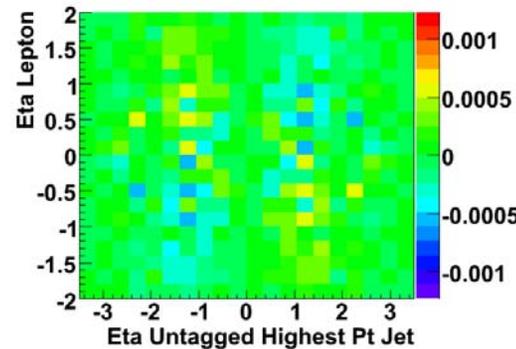
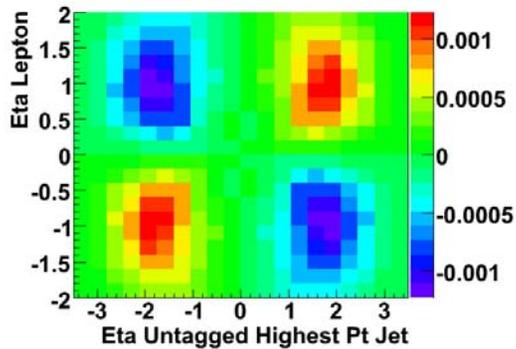
## NLO

## TREE + NLO

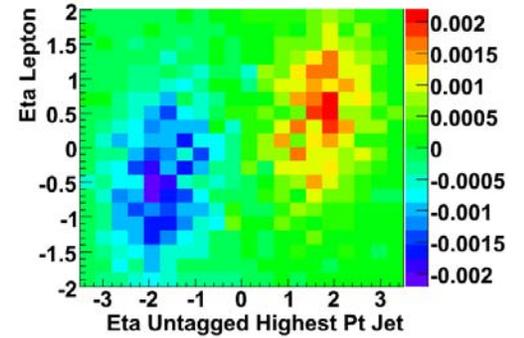
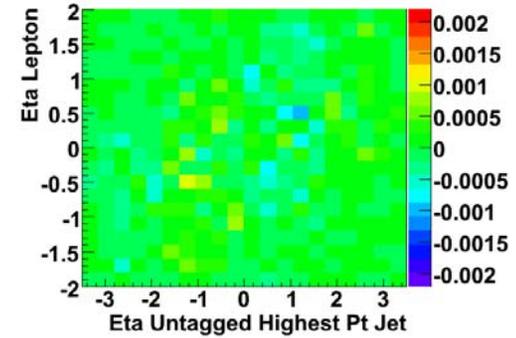
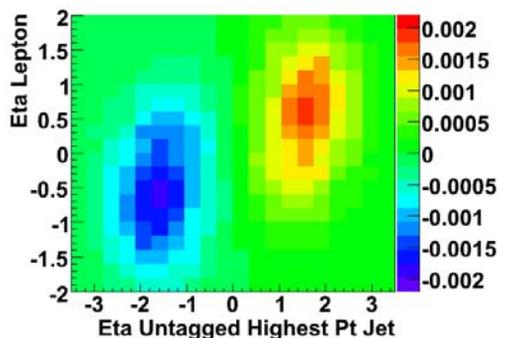
### F BAR



### F PLUS



### F MINUS



# Conclusions

- NLO corrections to single top quark production affects shapes and normalization of distributions
- We explore NLO effect on angular asymmetry functions introduced by Bowen et al.
- Shape of angular asymmetry functions is modified by NLO corrections

# References

- Q.H.Cao, C.P. Yuan, R. Schwienhorst, J. A. Benitez, R. Brock
  - [1] Phys. Rev. D71, (2005) 054022, (hep-ph/0408180)  
Single Top Quark Production and Decay at Next-to-leading Order in Hadron Collision, Qing-Hong Cao and C.-P. Yuan
  - [2] Phys. Rev. D71, (2005) 054023, (hep-ph/0409040)  
NLO Corrections to Single Top Quark Production and Decay at the Tevatron: 1. s-channel Process, Qing-Hong Cao, Reinhard Schwienhorst, and C.-P. Yuan
  - [3] Phys.Rev. D72 (2005) 094027 (hep-ph/0504230)  
NLO Corrections to Single Top Quark Production and Decay at the Tevatron: 2. t-channel Process  
Qing-Hong Cao, Reinhard Schwienhorst, Jorge A. Benitez, Raymond Brock, and C.-P. Yuan
- Matthew T. Bowen, Stephen D. Ellis, and Matthew J. Strassler
  - [4] Acta Phys.Polon. B36 (2005) 271-282, hep-ph/0504186  
In Search of Lonely Top Quarks at the Tevatron Matthew T. Bowen, Stephen D. Ellis and Matthew J. Strassler
  - [5] Phys. Rev. D72 (2005) 074016 (hep-ph/0412223)  
In Search of Lonely Top Quarks at the Tevatron, Matthew T. Bowen, Stephen D. Ellis, and Matthew J. Strassler

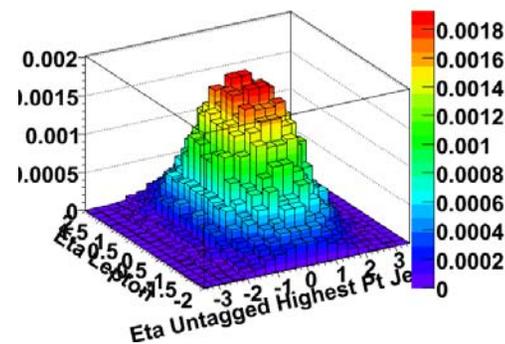
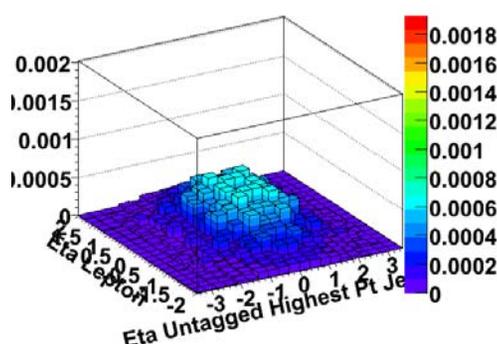
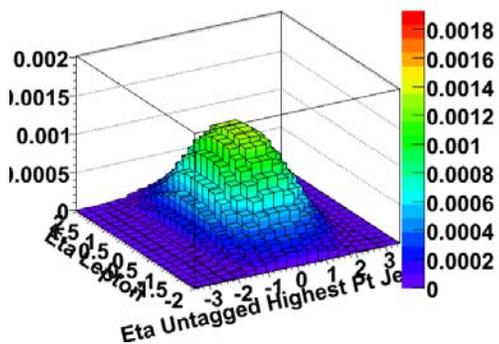
# S-Channel Lego Plots

## TREE

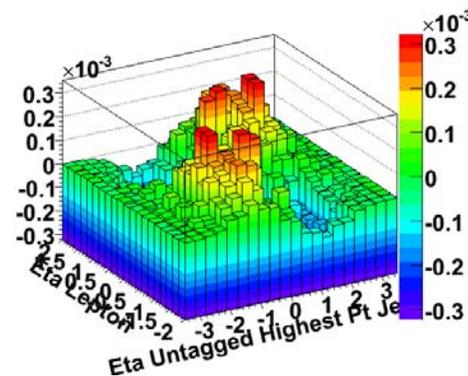
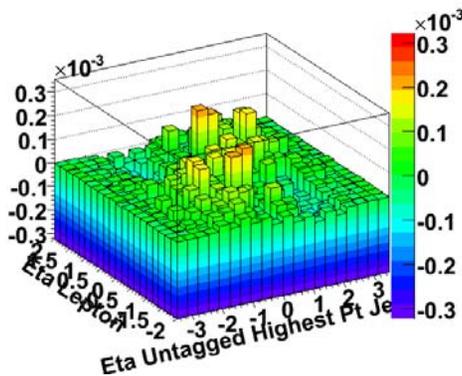
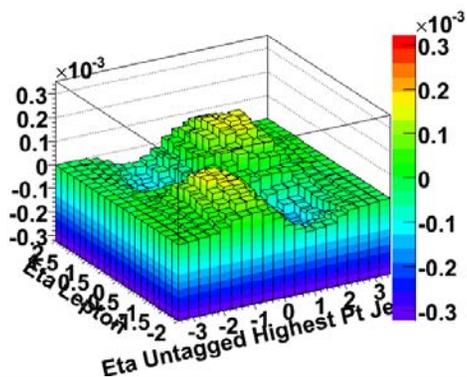
## NLO

## TREE + NLO

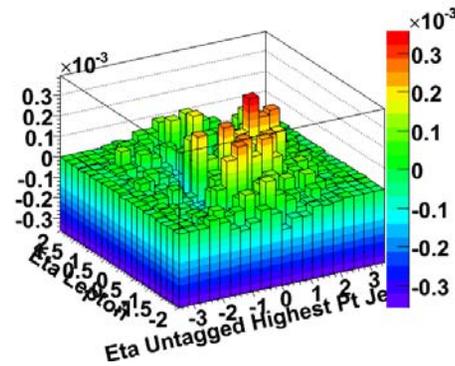
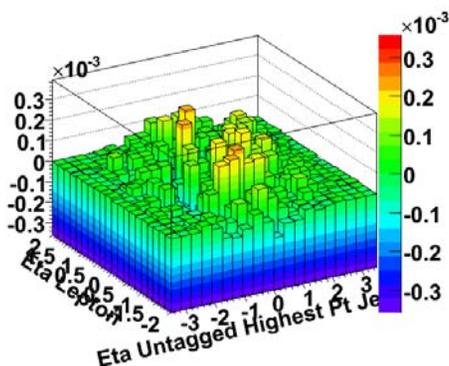
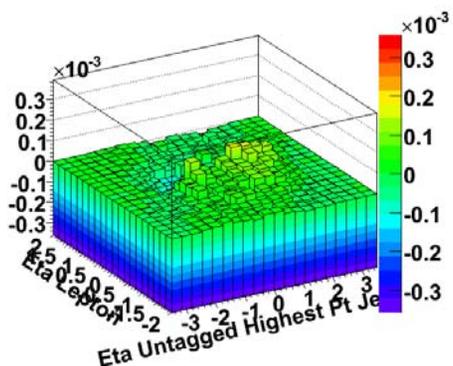
### F BAR



### F PLUS



### F MINUS



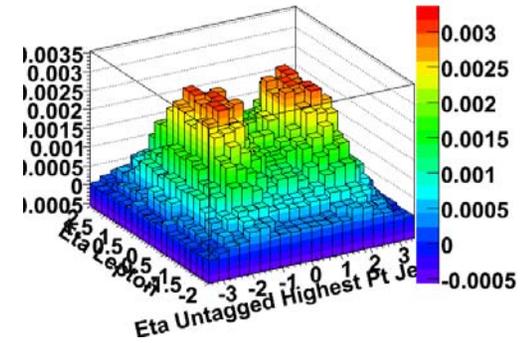
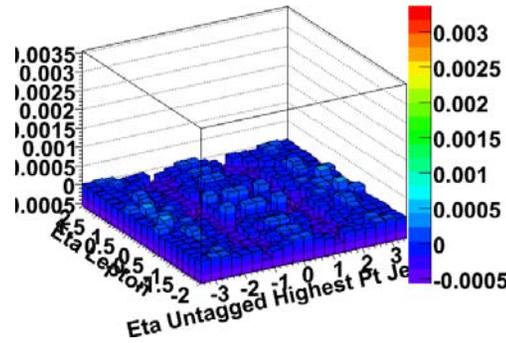
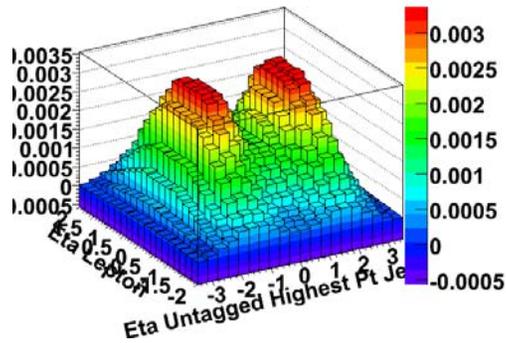
# T-Channel Lego Plots

## TREE

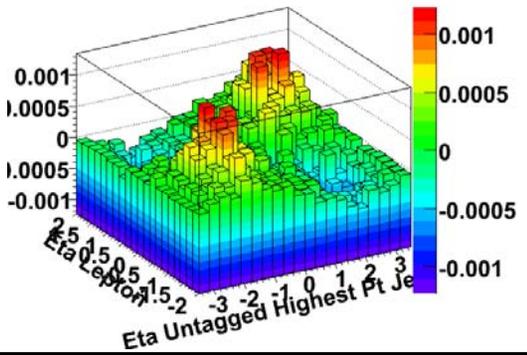
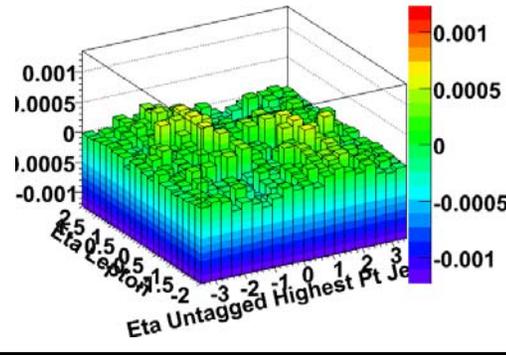
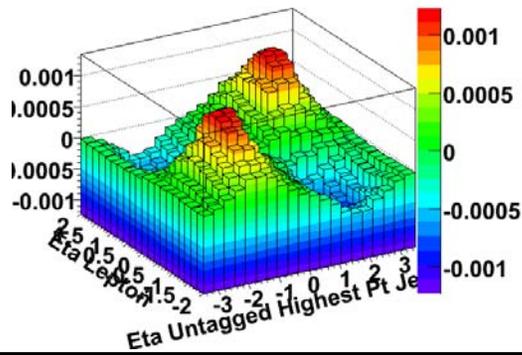
## NLO

## TREE + NLO

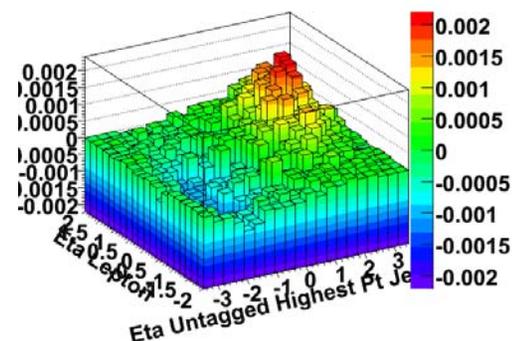
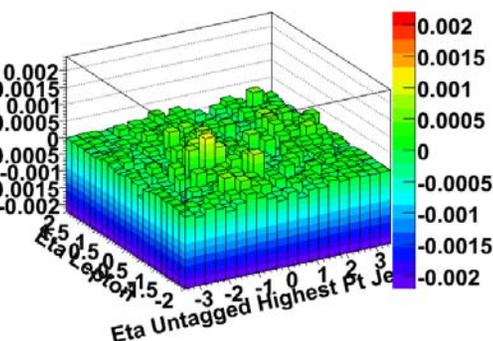
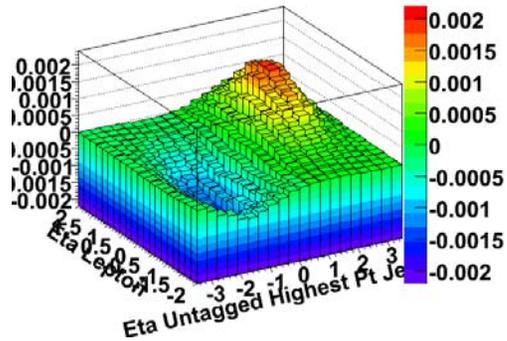
### F BAR



### F PLUS

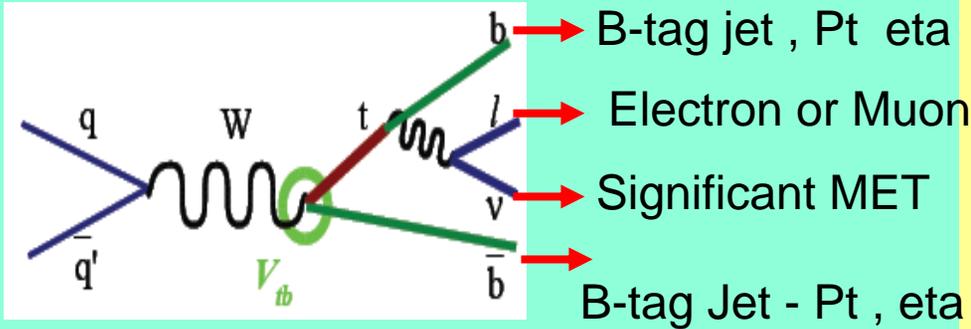


### F MINUS



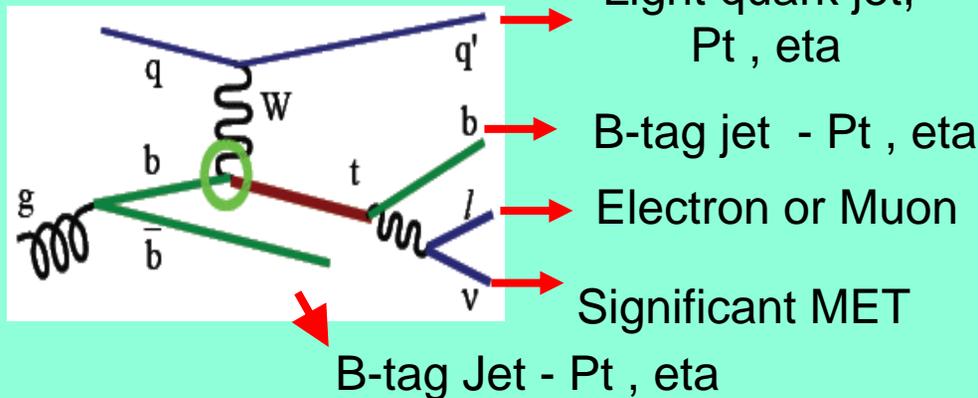
# Single top signal and background

## SIGNAL



### S-channel

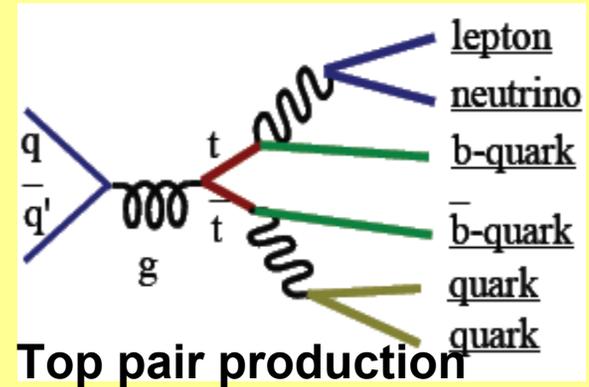
$$\sigma \sim 0.88 \pm 0.11 \text{ pb}$$



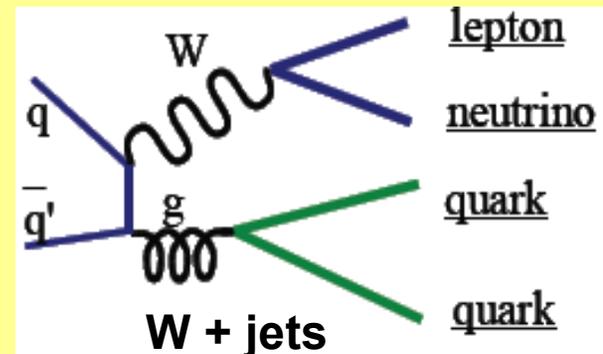
### T-channel

$$\sigma \sim 1.98 \pm 0.25 \text{ pb}$$

## BACKGROUND



$$\sigma \sim 6.8 \text{ pb}$$

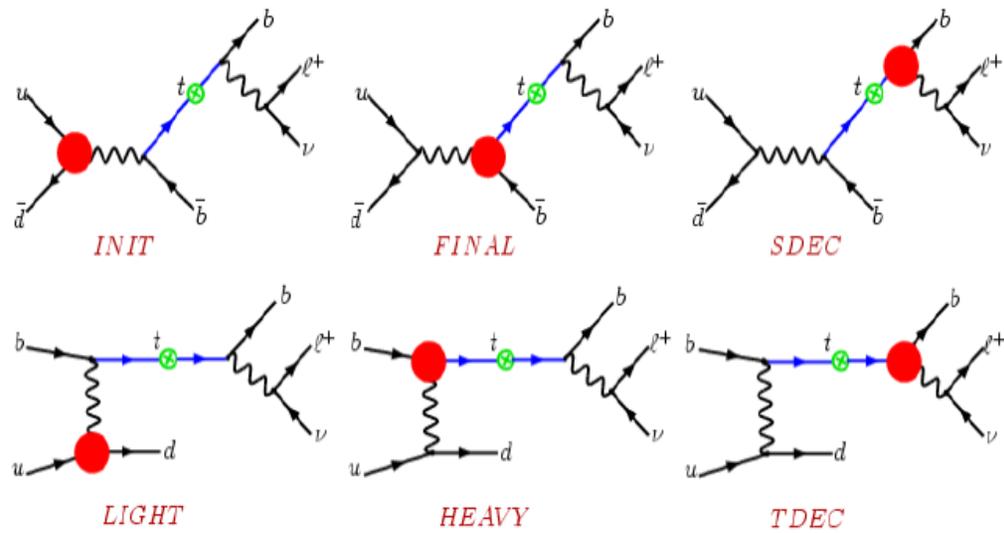


$$\sigma \sim 1000 \text{ pb}$$

# NLO Simulation

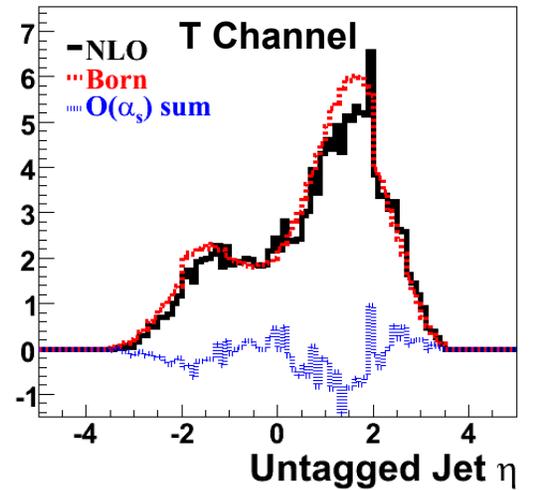
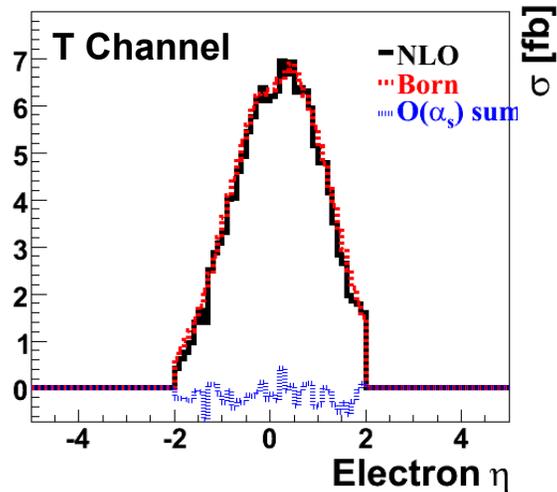
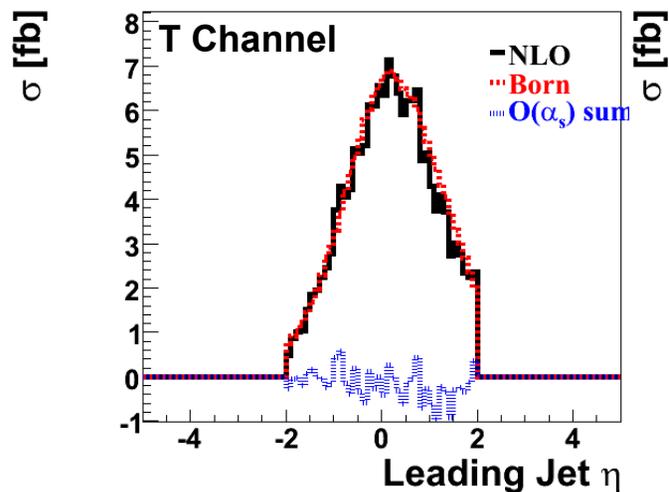
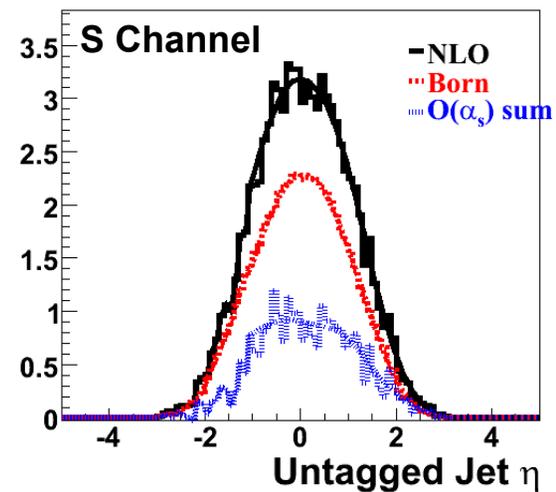
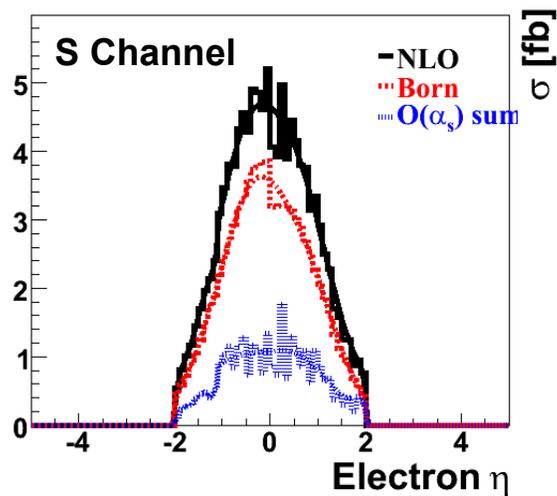
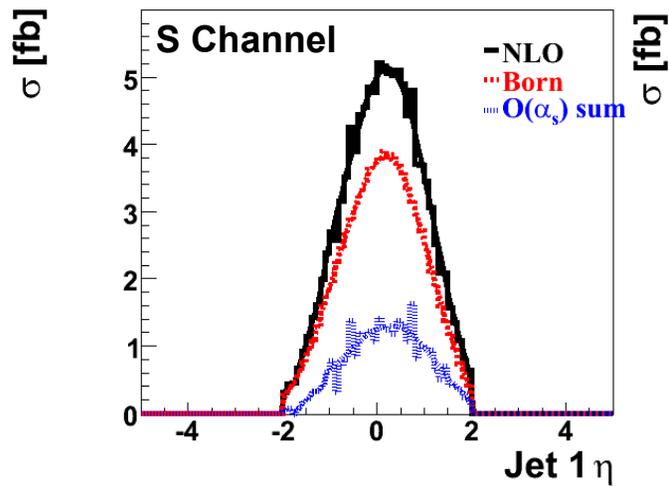
- Work by Q-H. Cao, C.P. Yuan, R. Schwienhorst
- One scale phase space slicing method
- Contributions from production and decay top quark
- W boson decay  $W \rightarrow e^- + \text{neutrino}$
- Narrow width approximation
- The decay branching ratio  $t \rightarrow e^- + W$  has been included
- Density matrix included throughout the decay
- t-bar not included

- We separate the single top quark processes into smaller gauge invariant sets to organize our calculations.

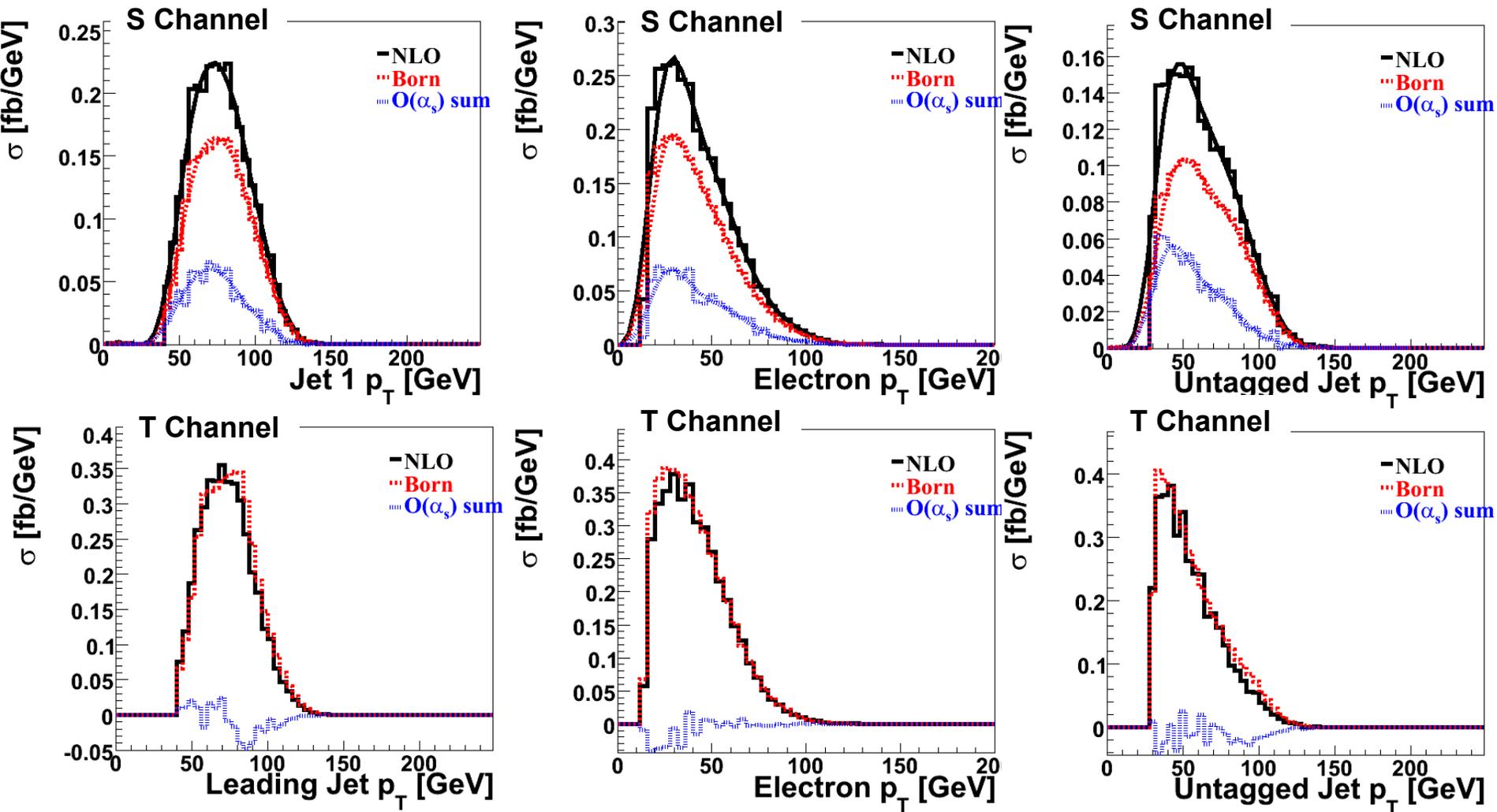


● includes the virtual and real emission corrections.

# Eta Distributions



# $p_T$ Distributions



# Signal modeling and selection cuts

## Cao et al

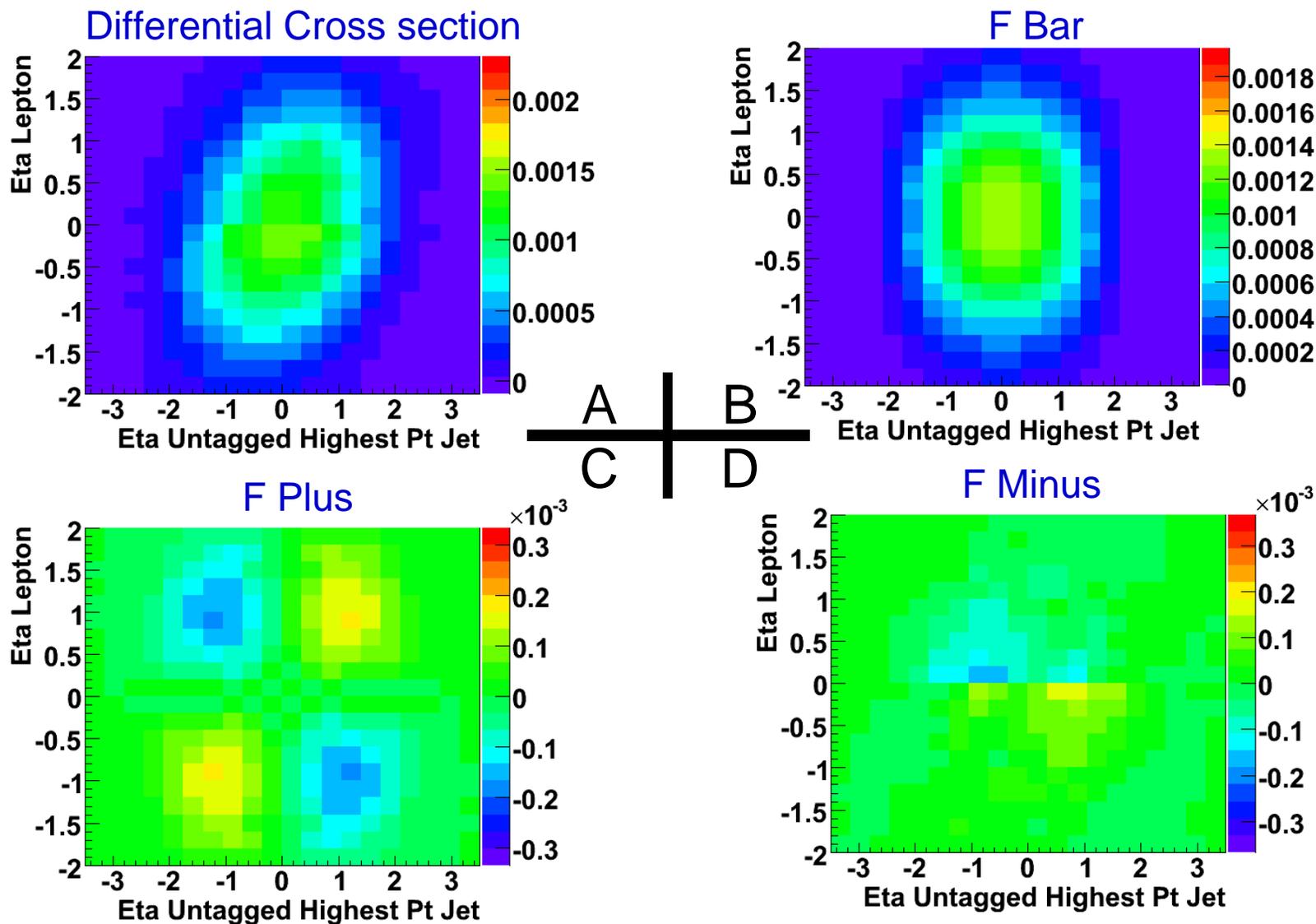
- **Lepton:**  $p_T > 15 \text{ GeV}$   $|\eta| < 2$
- **MET:**  $> 15 \text{ GeV}$
- **J(lead jet):**  $p_T > 40 \text{ GeV}$   $|\eta| < 2$
- **J(no-btag):**  $p_T > 30 \text{ GeV}$   $|\eta| < 3.5$
- **H<sub>T</sub>**  $< 300 \text{ GeV}$
- **m<sub>t</sub>**  $> 155 \text{ GeV}, < 200 \text{ GeV}$
- **B tagging** at least one bjet
  - b-quark:  $0.5 \tanh(p_T/36 \text{ GeV})$
  - c-quark:  $0.15 \tanh(p_T/42 \text{ GeV})$
  - mistagging:  $0.01 \tanh(p_T/80 \text{ GeV})$
- **Cone size** 0.5
- No detector simulation

## Bowen et al

- **Lepton:** same
- **MET:** same
- **J(b jet):**  $p_T > 40 \text{ GeV}$   $|\eta| < 2$
- **J(no-btag):** same
- **H<sub>T</sub>** same
- **m<sub>t</sub>** same
- **B tagging** same
- **Cone size** 0.4
- MadEvent, Pythia, PGS.
- Backgrounds included

- $H_T = \text{Sum}(p_{T(\text{jets},l)}) + \text{MET}$
- Cone:  $\Delta R$  def. jet cone
- MET: Missing transverse energy

# 2D distributions for the S-Channel Tree Level, Cao *et al.* Results [1,2,3]



# 2D distributions for the T-Channel Tree Level , Cao *et al.* Results [1,2,3]

