USING CHARGE ASYMMETRIES TO MEASURE LHC SINGLE TOP QUARK PRODUCTION

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Outline

- ‘A Series of Unfortunate Events’ at the Tevatron
- Using Parity Asymmetries at the Tevatron
- Using Charge Asymmetries at the LHC

Based on:
MB hep-ph/0503110
MB, S. Ellis, M. Strassler hep-ph/0412223

Endless List of References

- Willenbrock and Dicus, ’86
- Yuan, ’90
- Cortese and Petronzio, ’91
- Ellis and Parke, ’92
- Carlson and Yuan, ’93
- Stelzer and Willenbrock, ’95
- Heinson, Belyaev, and Boos ’97
- Stelzer, Sullivan and Willenbrock, ‘98
- Belyaev, Boos, and Dudko, ’99
- Tait and Yuan, ‘00
- …
- …

Short History of S:B at Tevatron

- 1998: SSW "classic" signal-to-background analysis
  - Ask for 1 lepton, MET, 2 jets, 1 or 2 b-tags
  - For 1 b-tag, Signal:W+jets:tt is ~1:4:4.5
- 2004: BES with slightly different cuts
  - for ≥1 b-tag, the ratio is ~ 1:15:6

What happened?!

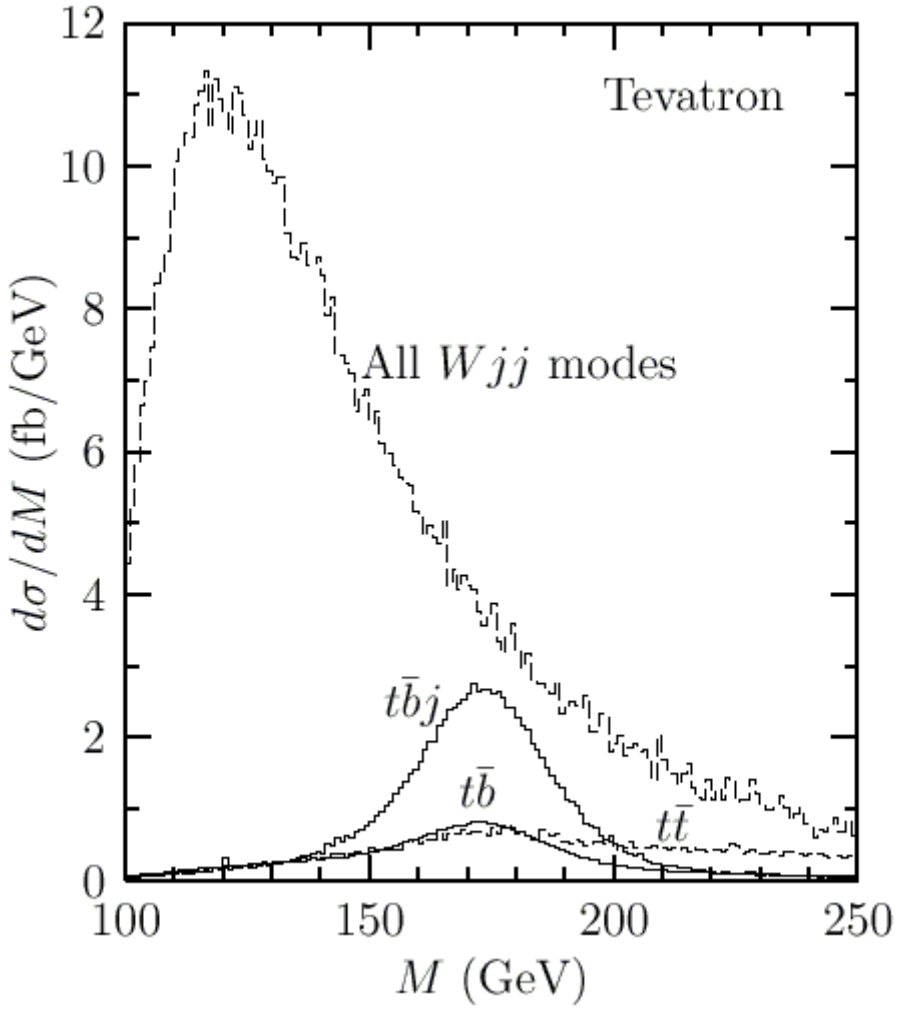
BES – MB, S. Ellis, M. Strassler hep-ph/0412223
SSW – T. Stelzer, Z. Sullivan, S. Willenbrock hep-ph/9807340

Series of Unfortunate Events

1. PDF error lowered NLO t-channel to 2.1pb from 2.4pb for 2 TeV Tevatron (Harris *et al*, '02)
2. Beam Energy – 1.96 TeV vs. 2 TeV
3. B-tagging currently not as good as in SSW
4. NLO calculation for W+2jets completed (Campbell, Ellis '02) – boosts Wjj by 50%
5. Accounting for effects of gluon-splitting to heavy flavor – another ~ 50% increase after tagging (WARNING: Large systematic uncertainties in both theory and experiment for g->cc and g->bb ~ 30%. See Backup Slides)

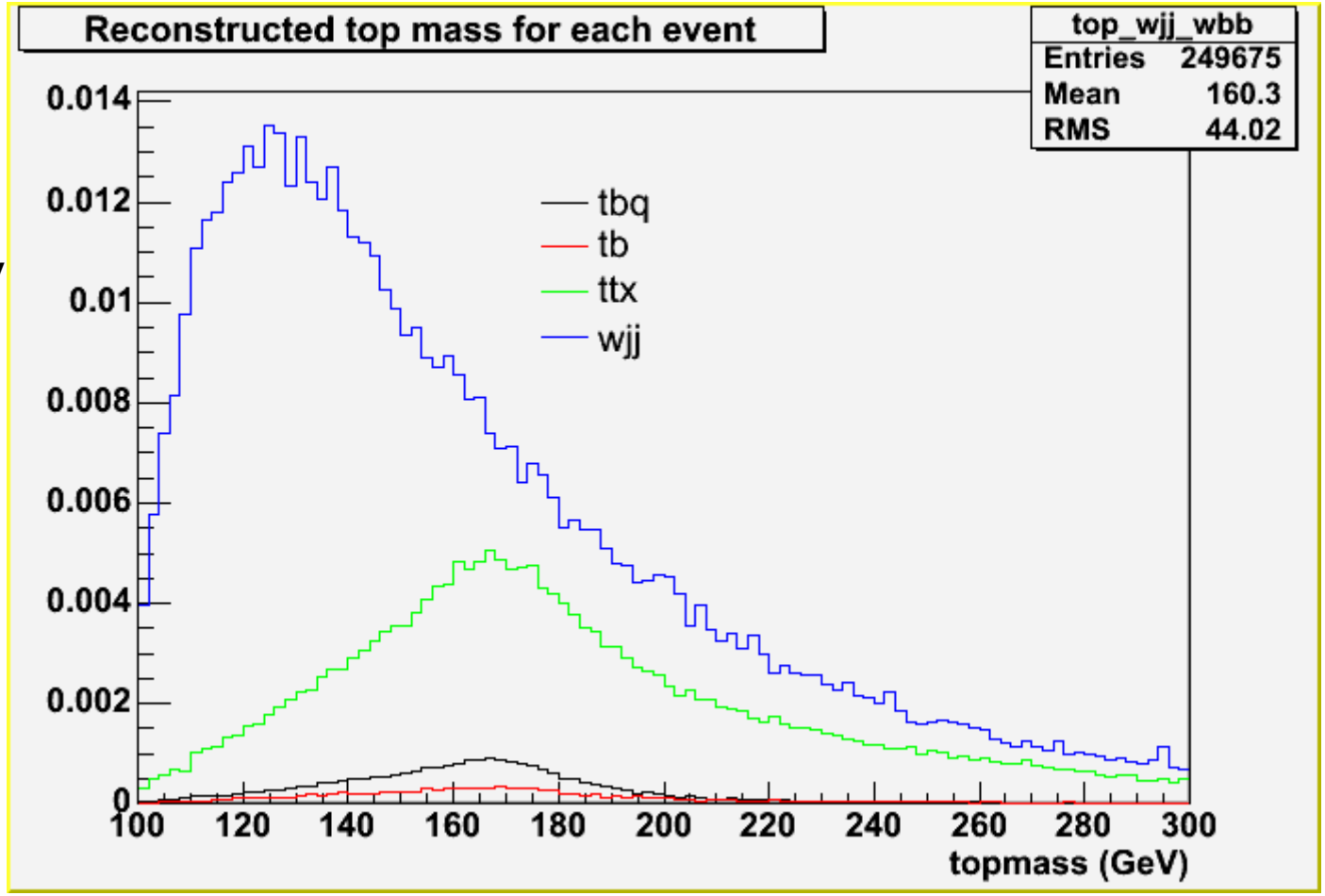
SSW Top Mass Reconstruction

- Top quark mass reconstruction after jet veto (from SSW)
- Sideband analysis looks possible



BES Top Mass Reconstruction

- Madevent-to-Pythia-to-PGS Detector Simulation
- Signal resolution 30 GeV (vs. 20 GeV in SSW)
- HT cut used to suppress tt
- Sideband looks "difficult"

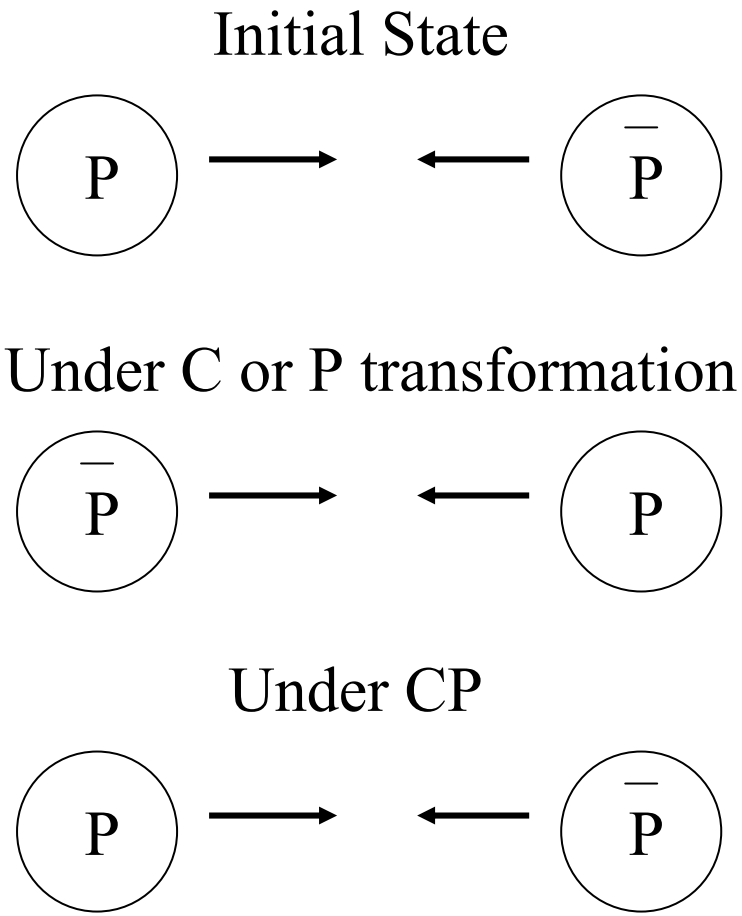


What can be done?

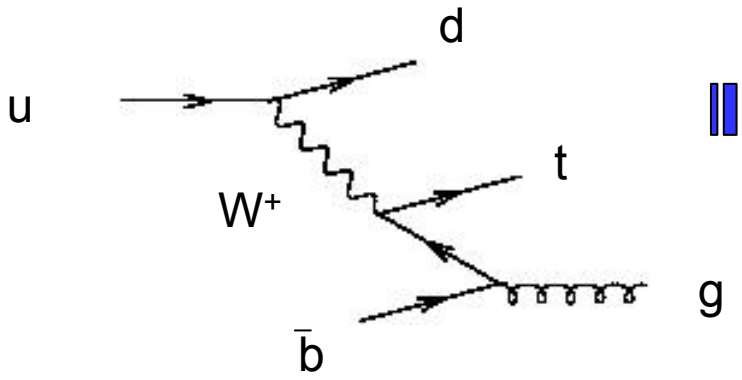
1. Our group's original goal: find a different method of reducing tt than jet veto
2. Found such a method, based on parity-asymmetries
3. Realized W+jets was major background
4. Technique appears to work moderately well for W+jets, but systematics are worrisome

CP Invariance of Tevatron

- Initial state is CP invariant, but not separately C or P invariant
- Final state distributions are CP invariant, but can also be C and P invariant

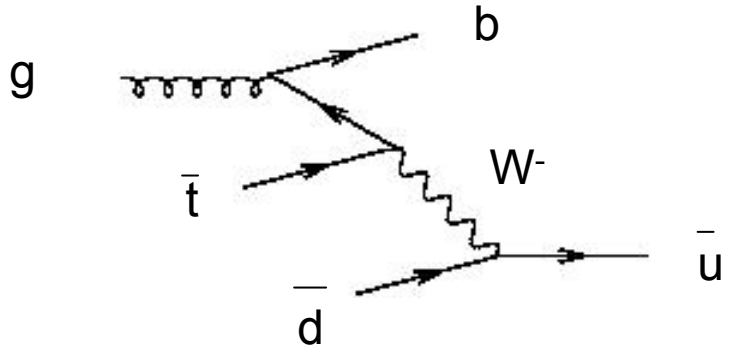


Focus on t-channel: Kinematic Boost



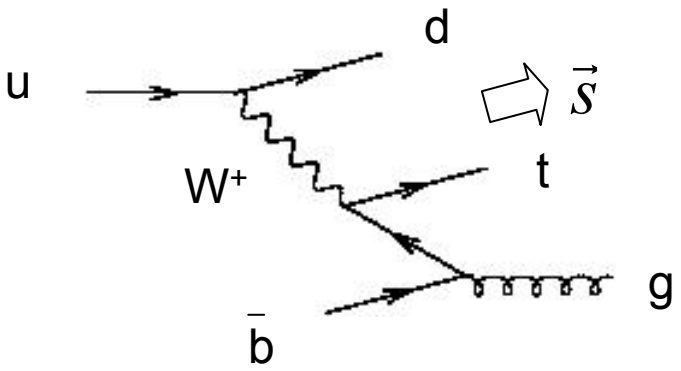
Top quark and light quark jet go in proton direction

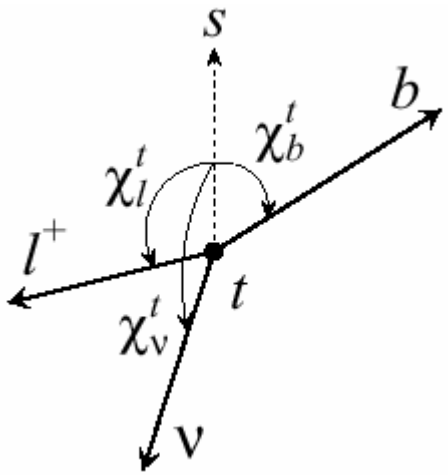
Anti-top quark and light quark jet go in anti-proton direction



Focus on t-channel: Spin Correlations

Top spin is aligned parallel to d quark momentum





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

α_l=1.0 implies lepton strongly decays in direction of top spin

from G. Mahlon hep-ph/0011349

η_j-η_ℓ Plot for t-channel

CP implies:

$\hat{\eta}_j$ Noted by Yuan '90, used by CDF '02

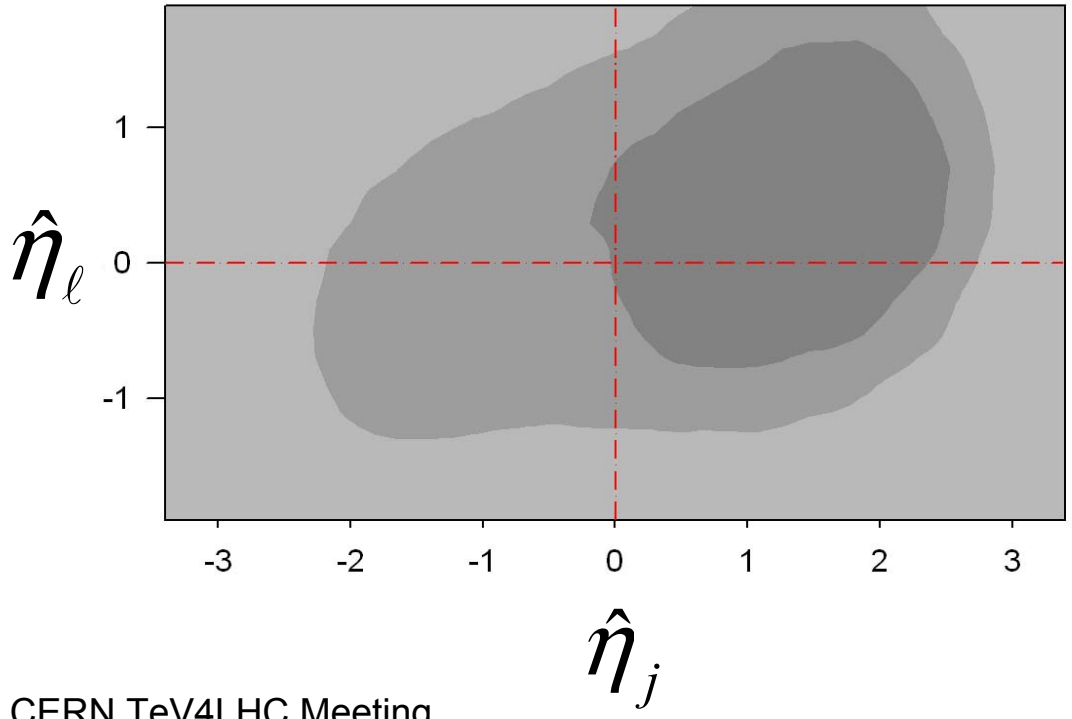
$$\frac{d^2\sigma^+}{d\eta_j d\eta_\ell}(\eta_j,\eta_\ell) = \frac{d^2\sigma^-}{d\eta_j d\eta_\ell}(-\eta_j,-\eta_\ell)$$

Define:

$$\hat{\eta}_j = Q_\ell \times \eta_j$$

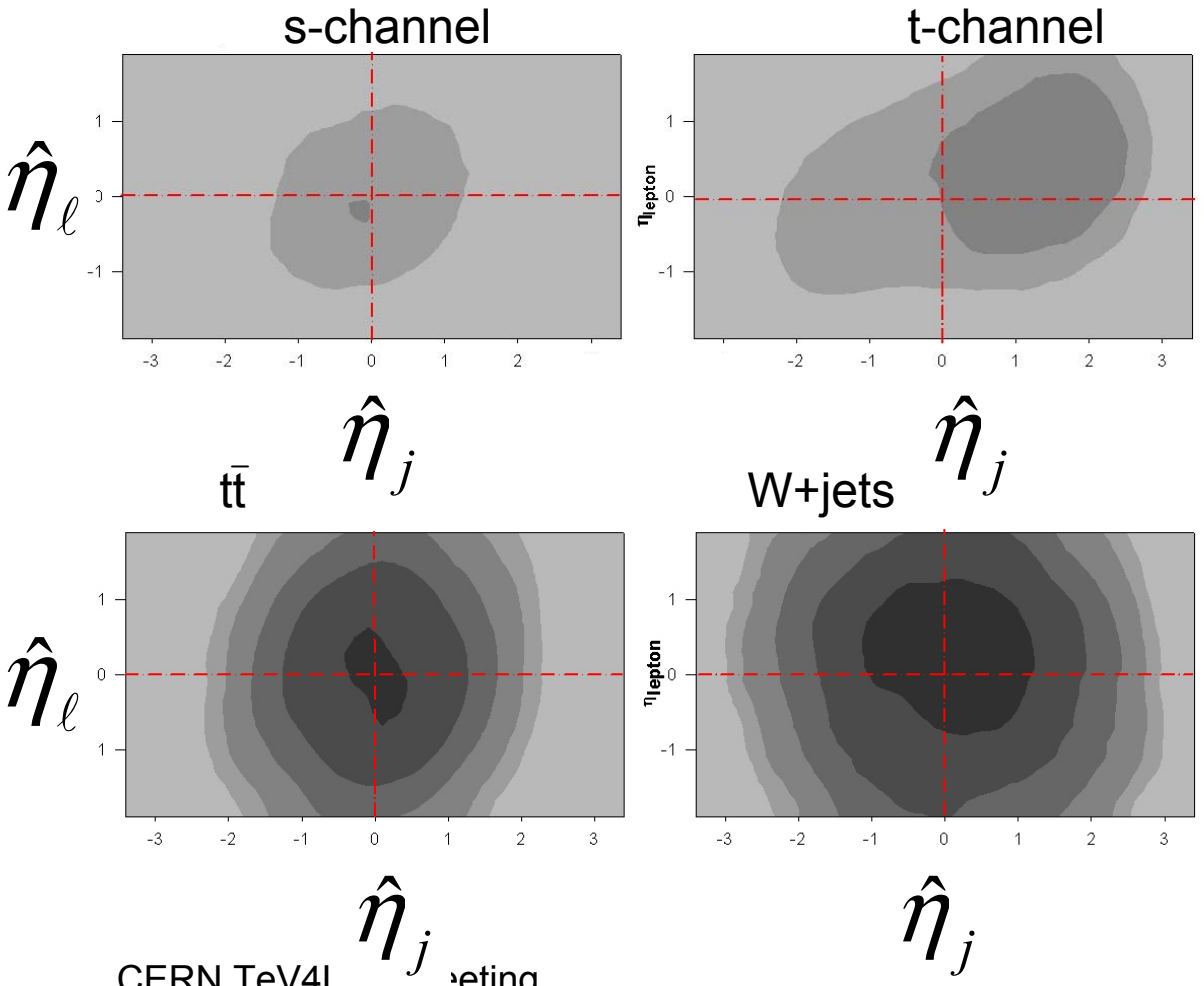
$$\hat{\eta}_\ell = Q_\ell \times \eta_\ell$$

$$\frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(\hat{\eta}_j,\hat{\eta}_\ell)$$



η_j-η_ℓ Plots for All Channels

- Sig«Bkg
- t-channel is asymmetric
- tt is symmetric
- W+jets is moderately symmetric



Parity-odd Observables

Parity Transformations

$$P: \hat{\eta}_j \to -\hat{\eta}_j, \hat{\eta}_\ell \to -\hat{\eta}_\ell$$

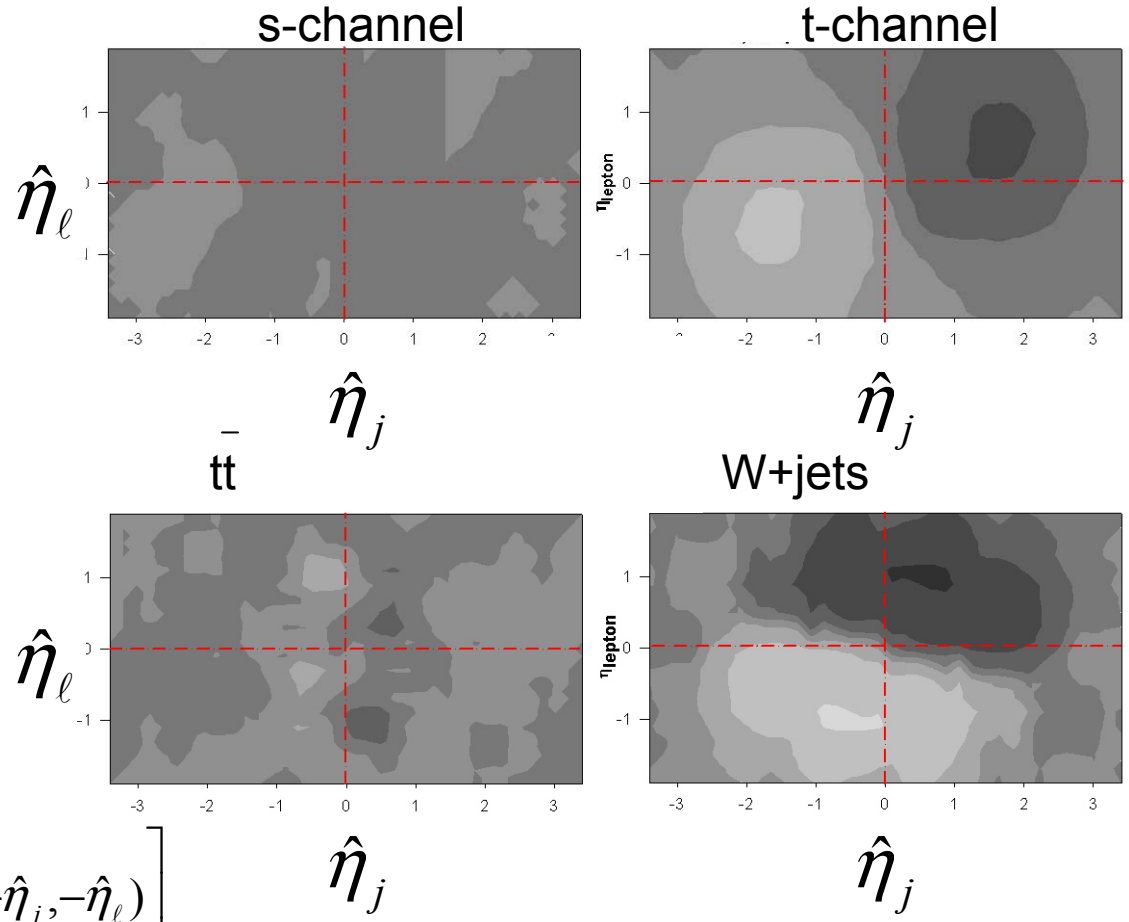
$$\text{Parity-symmetric} \Rightarrow \frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(\hat{\eta}_j, \hat{\eta}_\ell) = \frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(-\hat{\eta}_j, -\hat{\eta}_\ell)$$

Construct Parity-odd function:

$$F_-(\hat{\eta}_j, \hat{\eta}_\ell) = \frac{1}{2}\left[\frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(\hat{\eta}_j, \hat{\eta}_\ell) - \frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(-\hat{\eta}_j, -\hat{\eta}_\ell)\right]$$

F_- For All Channels

- At LO, tt removed
- t-channel and W+jets are comparable in size
- Caveat: NLO tt correction from Kuhn and Rodrigo, '98
- Expect QCD contribution to be small



$$F_- = \frac{1}{2}\left[\frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(\hat{\eta}_j,\hat{\eta}_\ell) - \frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(-\hat{\eta}_j,-\hat{\eta}_\ell)\right]$$

Conclusions at Tevatron

- W+jets is the problematic background
- Parity asymmetries can reduce tt and, to a lesser extent, W+jets
- S:B ratio of 1:1 can be reached for regions of F_{-}
- Systematic uncertainties in the prediction of W+jets (from gluon-splitting, etc..) remain challenging
- Even with 3 inverse femtobarns, statistical uncertainties are non-neglible for F_{-}

Very Hard!

What's the story at the LHC?

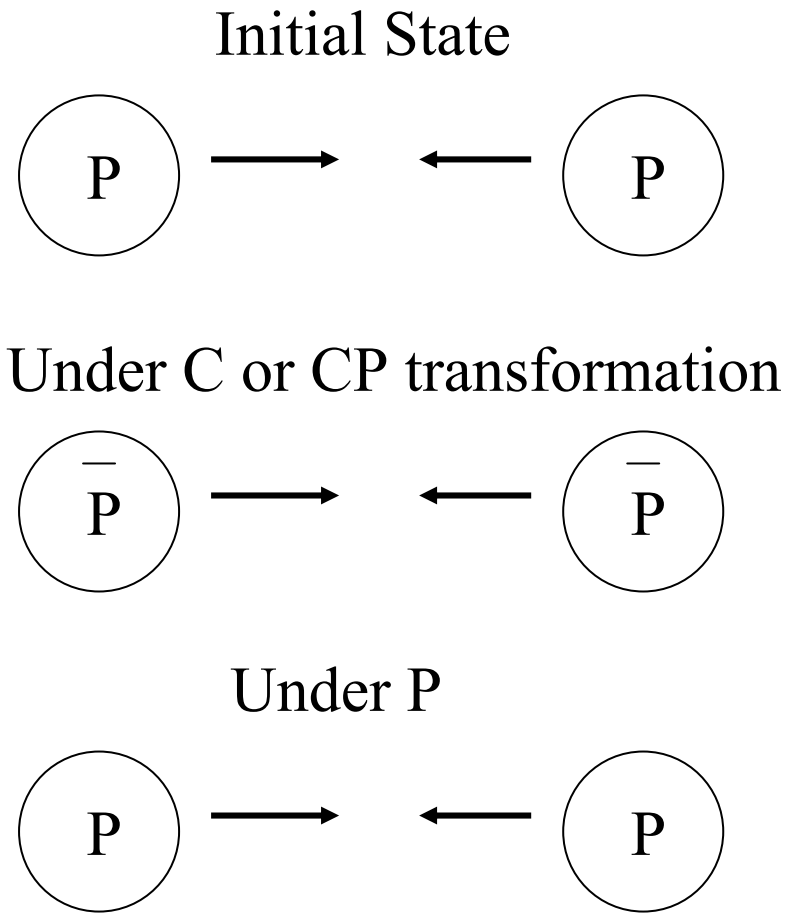
- Has anything similar happened with the theoretical status of the S:B at the LHC?
- So far, not really.
  - NLO signal cross-sections haven't changed
  - NLO W+2 jets does not appear to greatly increase Wjj rate (Campbell *et al.* '03), but does increase Wbb
  - Accounting for gluon-splitting doesn't appear to vastly increase W+jets after tagging
- All indications are tt really will be the dominant background
  - Which is great! (for using asymmetries)

ATLAS and CMS Studies

- Search for t-channel production
  - ATLAS – Ahmedov *et al.* (ATL-PHYS-2003-015)
  - CMS – Green *et al.* (CMS 1999/048)
  - Both confirm SSW result that jet veto + single-tag can study t-channel
  - QCD background unknown, systematics from jet veto remain
- Search for s-channel production
  - ATLAS – O'Neill *et al.* (J.Phys.,G 28 (2002) 2657-67
  - Jet veto + double-tag = S:B of 0.55
  - Will be much more difficult because of NLO Wbb result from Campbell *et al.* '03
- There is an alternative method that is more effective than a jet veto at reducing tt, QCD…

Parity Symmetry at LHC

- Initial state is P invariant, but not separately C or CP invariant
- Cross-sections are P invariant, but can also be C invariant



Definitions

- N_+: Number of events with only 1 high p_T positively-charged lepton
- N_-: Number of events with only 1 high p_T negatively-charged lepton
- Δ: $N_+ - N_-$
- Charge Asymmetry: $A_C = \frac{N_+ - N_-}{N_+ + N_-}$

➢s-channel and t-channel both have cross-sections with charge asymmetries $A_C \sim 0.25$

$t\bar{t}$ Pair Production

- Number of leptons produced, doesn't have to be equal to the number detected
- N_+ and N_- are functions of kinematic distributions and detector acceptance
- At Next-to-Leading-Order (NLO) anti-top quarks are slightly more central than top quarks
- Estimated* to be: $A_C < 0.0005$ in magnitude

*MB hep-ph/0503110 using Kuhn, Rodrigo '98

Single-Tag Sample

- S:B ~ 3:2
- Can't simulate QCD background, but it's charge-symmetric and shouldn't contribute to Δ

Item	p_T	$\lvert\eta\rvert$
lepton	≥20 GeV	≤2.5
MET	≥20 GeV	-
jets (b-tag)	≥30 GeV	≤2.5
jets (no b-tag)	≥30 GeV	≤4.5

Number of events for 10 fb-1

Channel	N_{total}	Δ	$\sqrt{N_{total}}$
s-channel	4,500	990	67
t-channel	116,000	30,900	340
Wbb	21,900	4,800	150
$W\bar{j}jj$	236,000	18,000	490
tt	958,000	-479	980

Prediction of Δ for tt has correct sign, but is an upper bound on the expected magnitude of the asymmetry

Single-Tag W+jets Subsets

- Tagging taken from ATLAS TDR (Fig 10-24) c~10%, g~1.3%, q~0.5%
- Advocate: Wjj subsets be studied individually
- Advocate: Factorization and renormalization scales be determined individually for Wjj subsets
- Mostly charm mistags (SSW)
- Cancellations mask systematics in Δ

Cross-section after single-tag

Channel	σ (fb)	A_C
Wcc	390	0.15
Wcg	7,900	-0.03
Wcq	6,200	0.02
Wgg	690	0.24
Wgq	7,400	0.22
Wqq	<1,600	-
Wjj	23,600	0.07

Not published – presently only for illustration purposes

Double-Tag Sample

- S:B ~ 5:2
- Single top can be studied in double-tag channel!

Warning: Wbb cross-section has LARGE NLO k-factors ~ 2.3, with LARGE uncertainties from scale variation ~20% (Campbell et al '03)

Number of events for 10 fb^{-1}

Channel	N_{total}	Δ	$\sqrt{N_{total}}$
s-channel	1,790	330	42
t-channel	15,100	4,030	120
Wbb	8,800	1,800	94
Wjj	1,550	30	40
$t\bar{t}$	336,000	-167	580

Prediction of Δ for tt has correct sign, but is an upper bound on the expected magnitude of the asymmetry

Possible Improvements

- Nothing fancy has been done here!
- Still can raise p_T cuts, do top quark mass reconstruction, etc… to reduce W+jets
- Optimize for charm rejection in single-tag sample (SSW)
- Ask for third jet in double-tagged sample? (light jet is visible ~ 75% of time in tbq)

LHC Conclusions

- Charge asymmetries eliminate tt more effectively than jet veto, allowing both single-tag and double-tag single top samples to be studied
- Also eliminate QCD backgrounds
- W+jets is the sole remaining background
- Single top quark production can be studied more extensively than previously thought!

Tev4LHC Conclusions

- tt and QCD are “special” backgrounds – symmetric at each collider
- W+jets is THE problem for single top quark searches at both colliders
- Parity asymmetries can help the challenging search at Tevatron for single top quarks
- Charge asymmetries at the LHC make the single top quark signal readily observable in both single-tag and double-tag samples

Gluon-splitting to Heavy Flavor

- LEP and SLD
  - A. Ballestrero et al., hep-ph/0006259
  - K. Abe et al (SLD) Phys. Lett. B507, 61 (2001)
  - R. Barate et al. (ALEPH), Phys. Lett. B 434, 437 (1998)
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  - M.H. Seymour, Nuc. Phys. B436, 163 (1995)
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