Direct Measurement of Top Polarization

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Acknowlegement

I'd like to thank...

My supervisors:

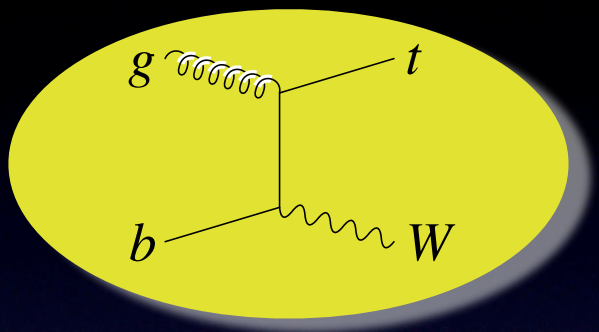
Steve Lloyd and Graham Thompson

My colleague:

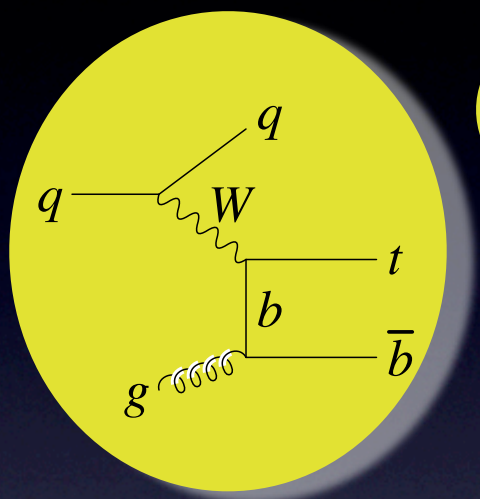
Lucio Cerrito

For lots of help and advice.

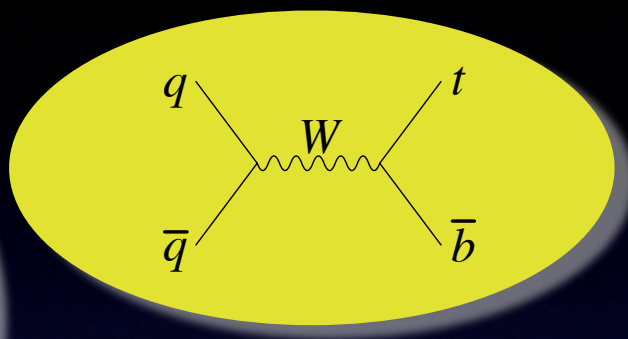
Single Top Production



W-t associated
~ 60 pb



W-gluon fusion
~ 240 pb



S-channel
~10 pb

Sullivan,2004
Campbell, 2004
Campbell, 2005

- Not seen by Tevatron yet but the LHC should really see it. (~ 2 million/year @ low lumi)
- Source of polarized top quarks!

Motivation

Theoretical:

- Energy scale at EWSB, probe to search new physics.
- Probe to V-A structure of the charged current.
- Determine W and Z boson coupling to top.

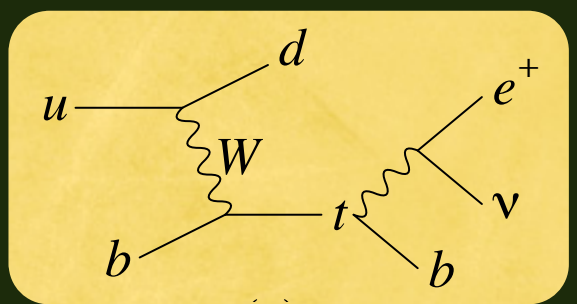
Experimental:

- No strong interaction before top decay: Laboratory for isolated quark.
- Large cross section, well reconstructed top and large degree of polarization.
- Useful for improved selection for single top. Precision selection of Wt channel.

Single Top Polarization

In W-g channel

$$|\mathcal{M}(+)|^2 = g_W^4 \,|V_{ud}|^2 N_C^2 \frac{(2d\cdot t_2)(2u\cdot b)}{(2u\cdot d - m_W^2)^2 + (m_W\Gamma_W)^2}$$: Spin up



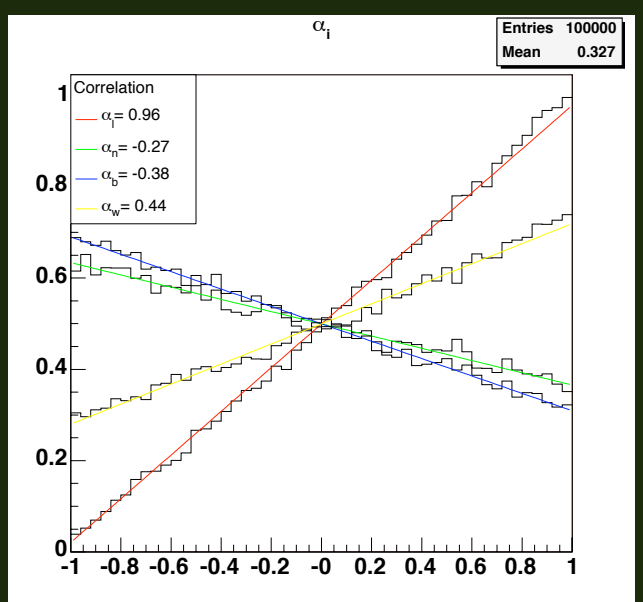
$$|\mathcal{M}(-)|^2 = g_W^4 \,|V_{ud}|^2 N_C^2 \frac{(2d\cdot t_1)(2u\cdot b)}{(2u\cdot d - m_W^2)^2 + (m_W\Gamma_W)^2}$$: Spin down

$$(t_1 \equiv \frac{1}{2}(t + m_t s), t_2 \equiv \frac{1}{2}(t - m_t s))$$

Mahlon, 1997

In the top frame, with $\hat{s} = \hat{d}$, $\frac{1}{\Gamma_T}\frac{d\Gamma}{d(\cos\chi_i^t)} = \frac{1}{2}(1 + \mathcal{A}_{\uparrow\downarrow}\alpha_i \cos\chi_{d-i}^t)$

TopRex Generator



$DecayProduct$	α_i
W	0.403 ± 0.025
b	-0.403 ± 0.025
ν_l, u, c	-0.324 ± 0.040
$\bar{l}, \bar{d}\bar{s}$	1.000

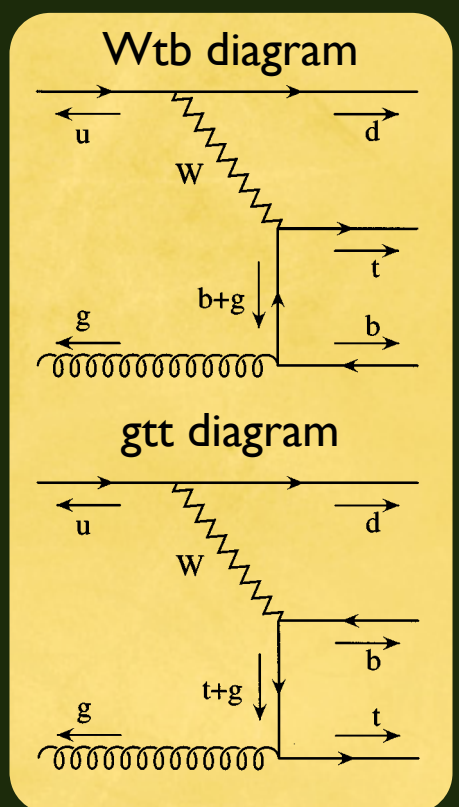
Angle between d-type quark and the lepton

$$\mathcal{A}_{\uparrow\downarrow} = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\uparrow}$$

Single Top Polarization

➡D-type quark is the best basis to measure top polarization (100% polarization.)

➡The lepton is the best spin analyzer.



Boos, 2002

In more detail:

- gtt production is not polarized but contribution is much smaller than Wtb diagram.
- Interference term cancels.
- >95% polarization after all.
- How do we find the d-type quark?

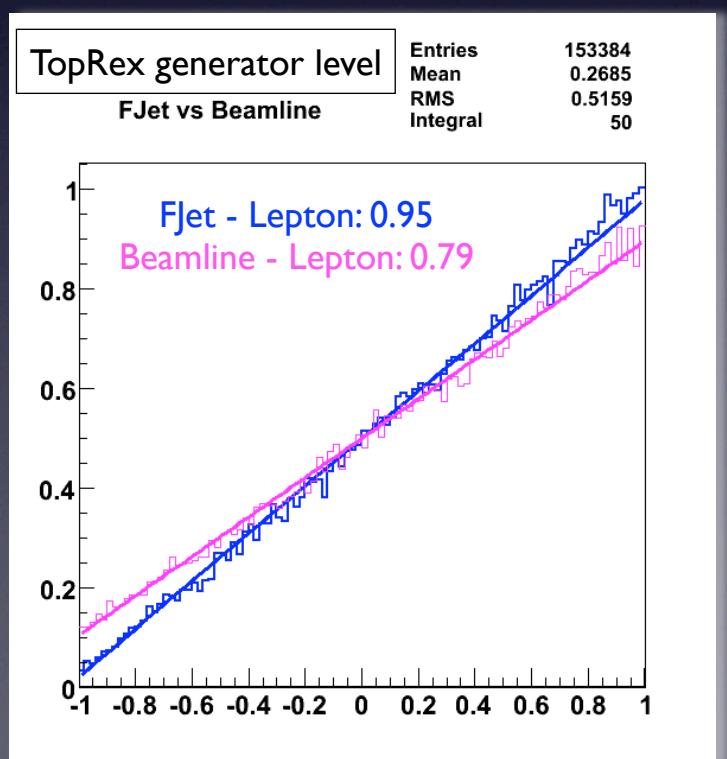
Measuring Polarization

$$\frac{1}{\Gamma_T}\frac{d\Gamma}{d(\cos\chi_i^t)} = \frac{1}{2}(1 + \mathcal{A}_{\uparrow\downarrow}\cos\chi^t_{l+fj}) \qquad \mathcal{A}_{\uparrow\downarrow} = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\uparrow}$$

Asymmetry factor, $\mathcal{A}_{\uparrow\downarrow}$, is the degree of polarization.
Right handed coupling can cause, $\mathcal{A}_{\uparrow\downarrow} < 1$
mismeasurement limits the measurement of asym.

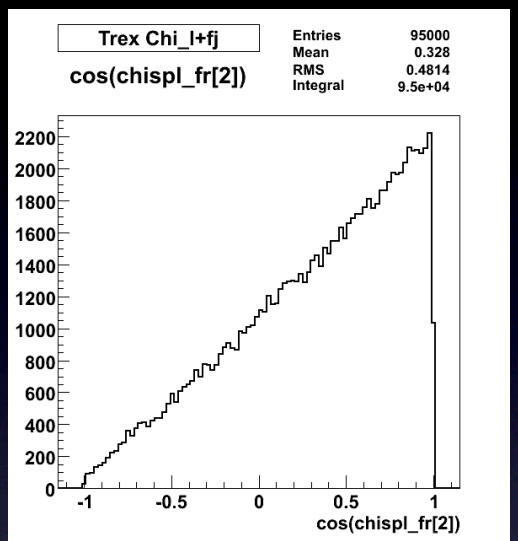
~70% d-type quark in forward jet in top production. The rest is in the beam. Though $\hat{p} \simeq \hat{fj}$, measured asym. gets diluted. Always measuring angle(FJet/Lepton) and get 0.9 average.

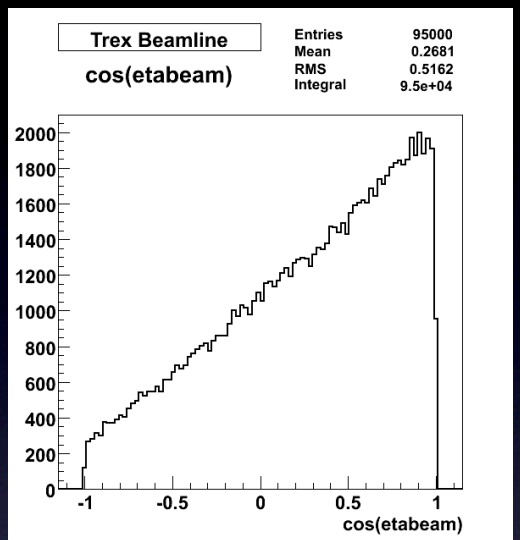
Crucial to identify the right jet.

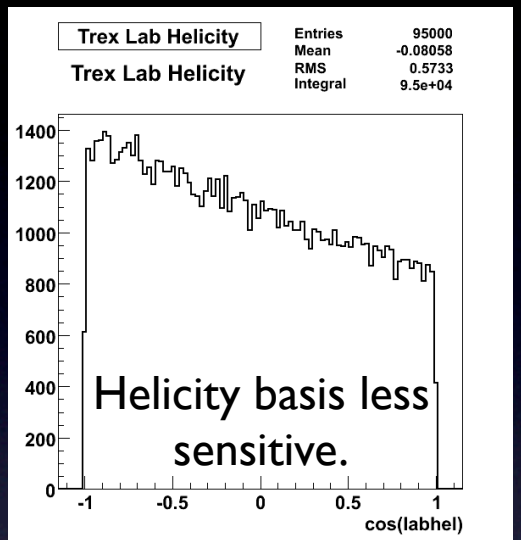


Polarization and bases

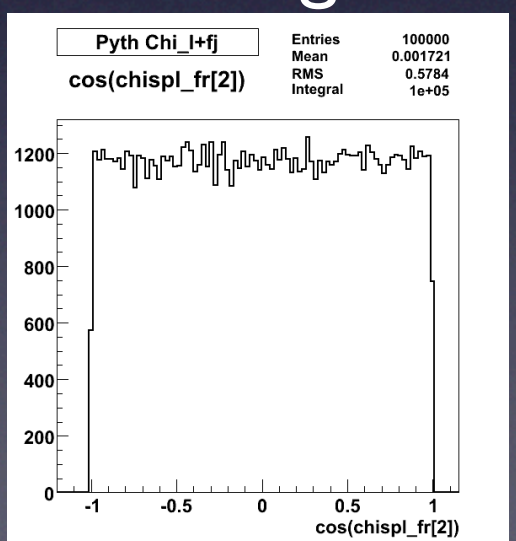
TopRex, with angular correlation

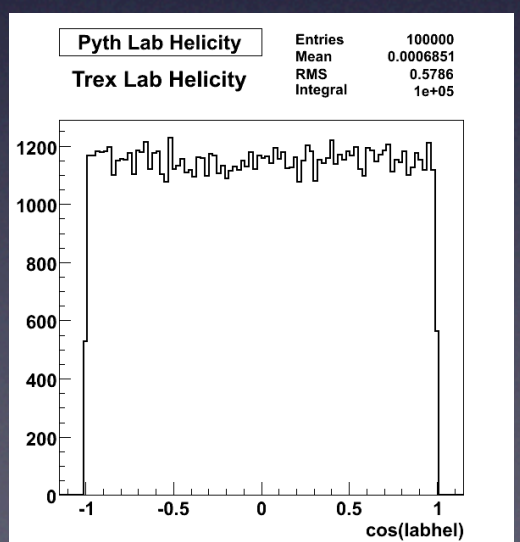


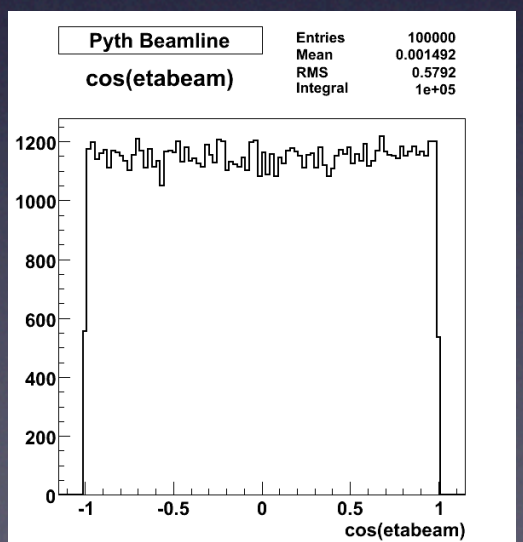




Pythia, no angular correlation







More generators implementing single top: AcerMC, MC@NLO and AlpGen.

Dataset / Software

Sample Used:
Rome prod.

4511(TRex): W-gluon; W decay leptonically (69pb)
4540 (TRex): S-channel (1.5 pb)
4530/31(TRex): W-top associated (15 pb)
T1(MC@NLO): ttbar(422 pb)
A7(AlpGen): W+4jets (1200 pb)

Missing W+1,2,3 jets, Wbb, QCD multijet and WZ.

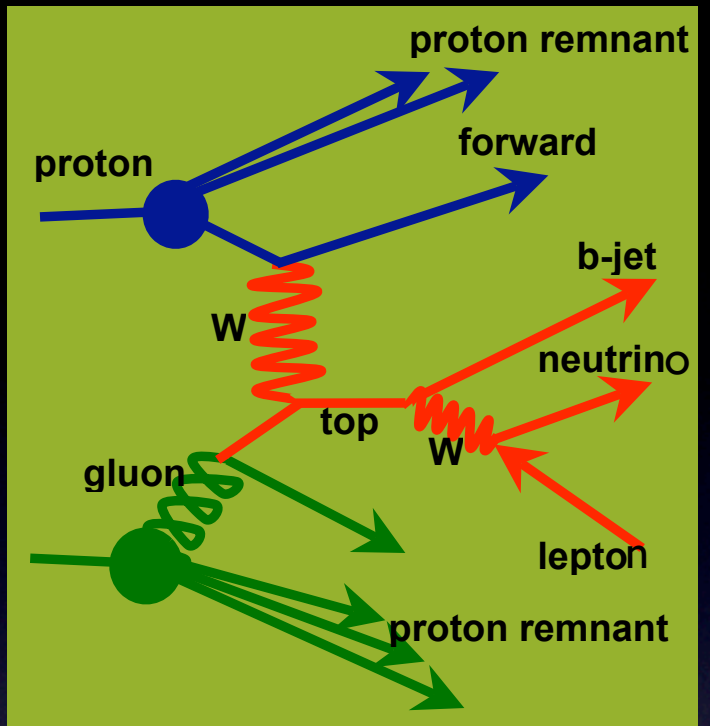
Data retrieved from NIKHEF through http.
Used 10.0.4/EventView to do most of the analysis and plotting in ROOT.
No truth match could be done due to sample problems.

→ use TopView/DQ2/Grid for CSC analysis!

I have been writing common analysis framework for top physics analysis and developing working analysis model using the distributed analysis system. (See my talk in SW week PAT session)

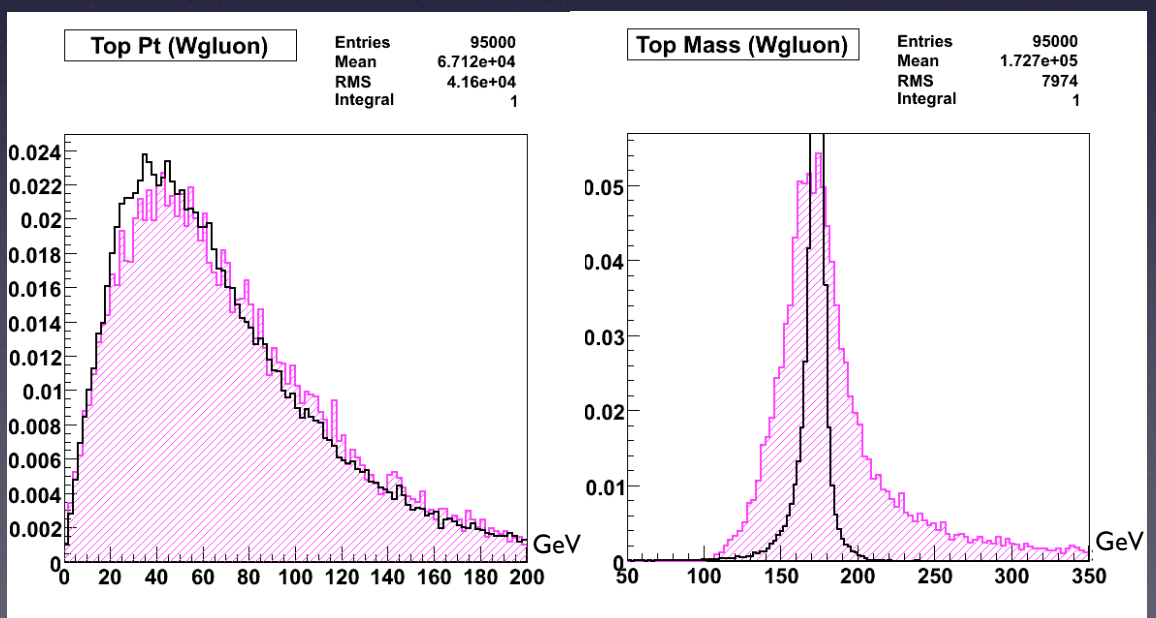
Reconstruction Procedure

Isolated lepton with Pt > 20GeV.
Used Cone0.7 jets (better single top mass), Pt > 30GeV.
BJet defined with Pt > 50GeV and LhSig > 0.5 (typical choice: LhSig > 0.9)



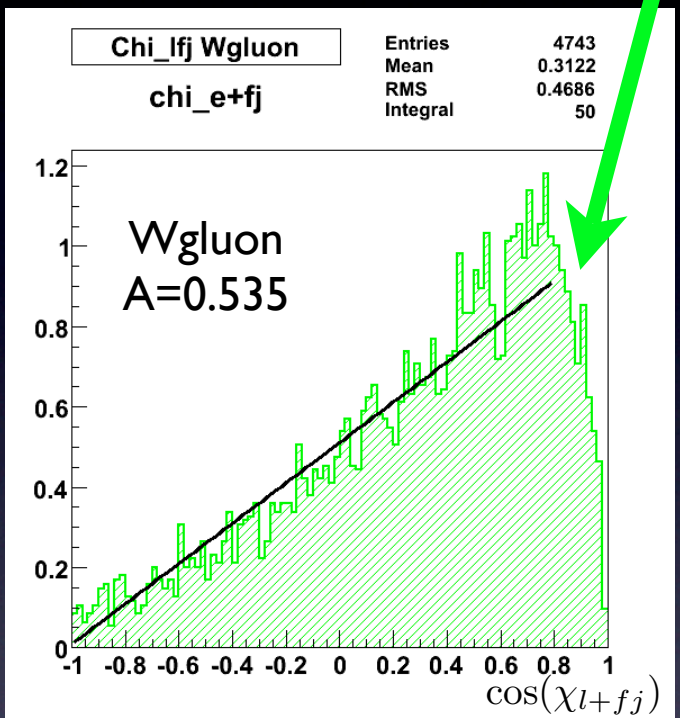
An experimentalist's view of W-gluon production.

1. Reconstruct W from the lepton and missing Et using W mass constraint (chose small |pz| solution.)
2. Reconstruct top from W and a bjet (chose nearest bjet).
3. Boost into top's rest frame.
4. Measure angles.



$\cos(\chi_{l+fj})$ distribution

Fall due to lepton isolation cut.



Define A, (experimental) angular distribution asymmetry:
(zero means no asymmetry, one maximum)

$$A = \frac{N_+ - N_-}{N_+ + N_-} \text{ with error: } \sigma_A = 2\sqrt{\frac{N_+ N_-}{(N_+ + N_-)^3}}$$

$$(N_+ = \sigma(-1 < \cos\chi_{l+fj} < -0.1), N_- = \sigma(-0.1 < \cos\chi_{l+fj} < 0.8))$$

Stelzer, 1998

Background

Types of Background
- Single top (s-channel and Wt)
- ttbar
- W+jets (W+Njets and WQQ)
- diboson (WW, ZZ and WZ)

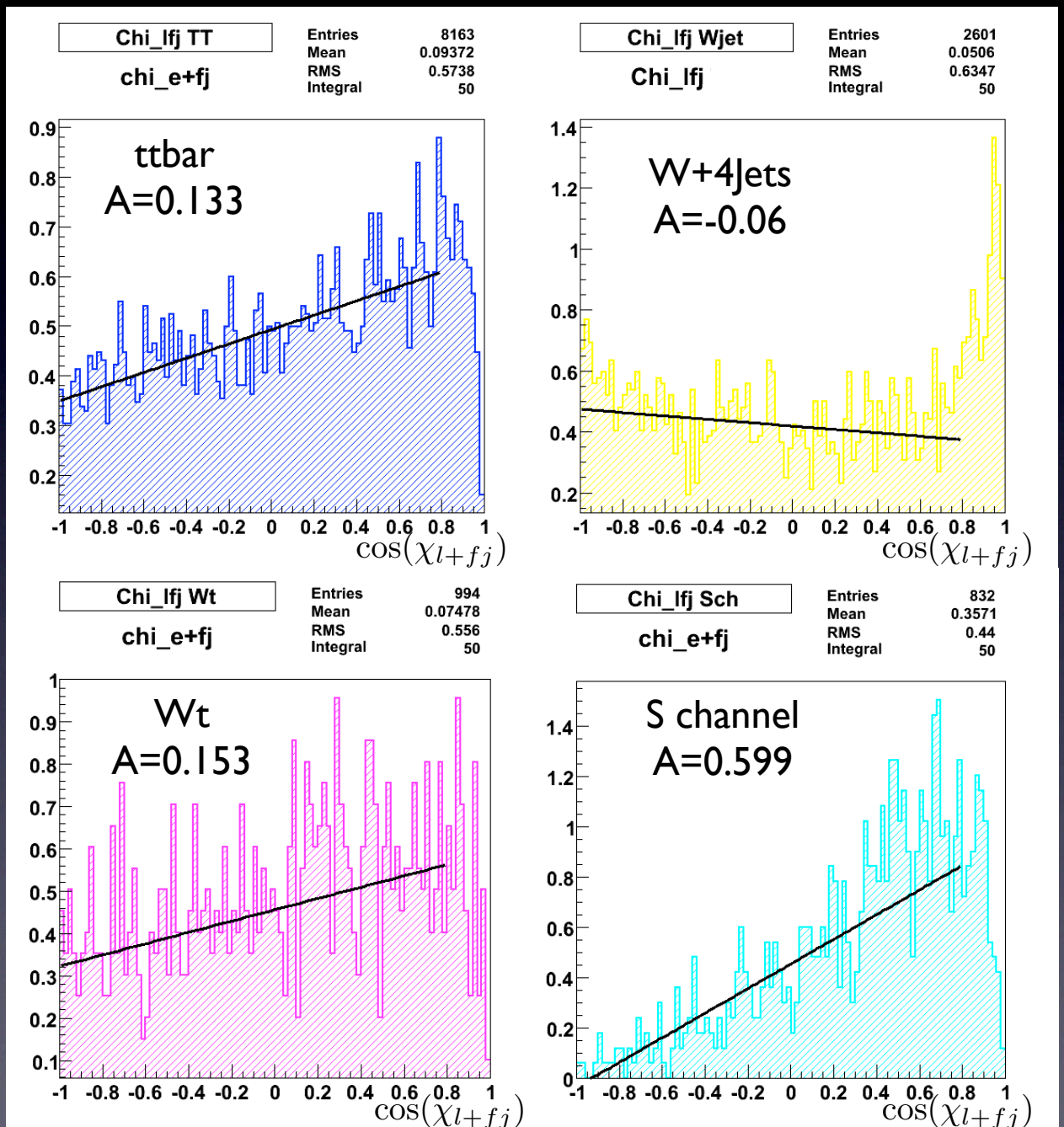
In this analysis, single top, ttbar and part of W+jets were analyzed.

Missing background (W +Njets) will be estimated later with toy MC.

Channel	x-sec x BR (pb)
Signal	
W-gluon	69 (^)
top background	
S channel	1.5 (^)
Wt	15 (^)
ttbar	422 (^)
W/Z + jets	
Wjj	1160 (*)
Zjj	105 (*)
WQQ (Q=b)	5.17 (*)
ZQQ (Q=b)	2.28 (*)
diboson	
WW	18.5 (*)
ZZ	0.34 (*)
WZ	0.43 (*)

(^) Numbers as quoted in Rome production wiki
(*) Numbers as quoted in Lucotte et al (2006)

Background Distribution



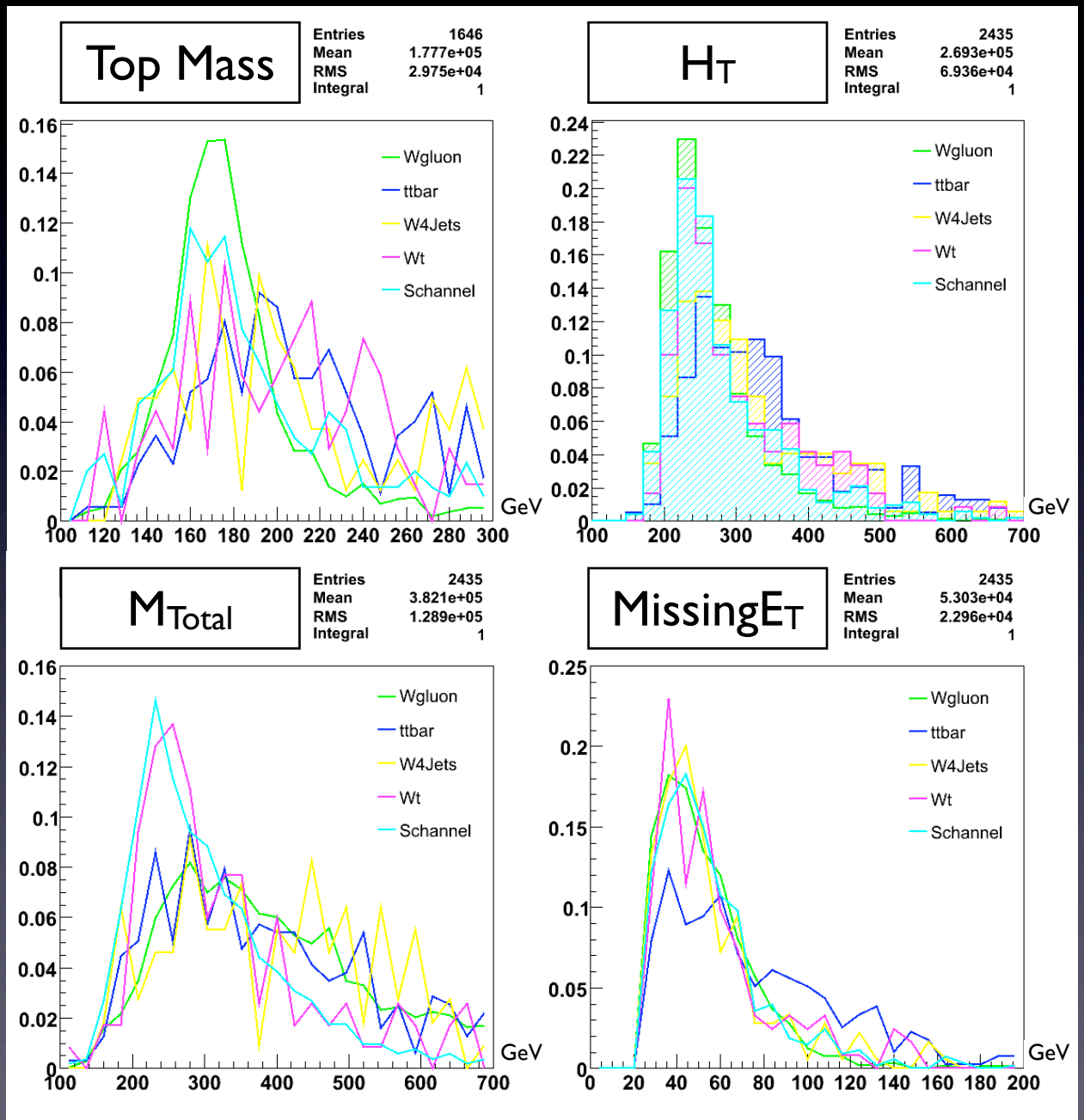
Before selection cuts:

Peak at 1 in W+4jets, not understood.

ttbar & Wt has slight trend of +ve A.

Schannel: very similar structure to signal. Maybe the same correlation effect? Keep it as background for now.

Discriminant Variables



Plots show distribution after:

Missing Et > 25 GeV
N_lepton ≧ 1
N_jet ≧ 2
N_bjet ≧ 1
N_jet = 2
N_fjet = 1

(from TDR)

Applied the following:
MTotal > 250 GeV
HT < 300 GeV
N_top = 1
Top mass > 150 GeV
Top mass < 200 GeV

(adjusted from TDR)

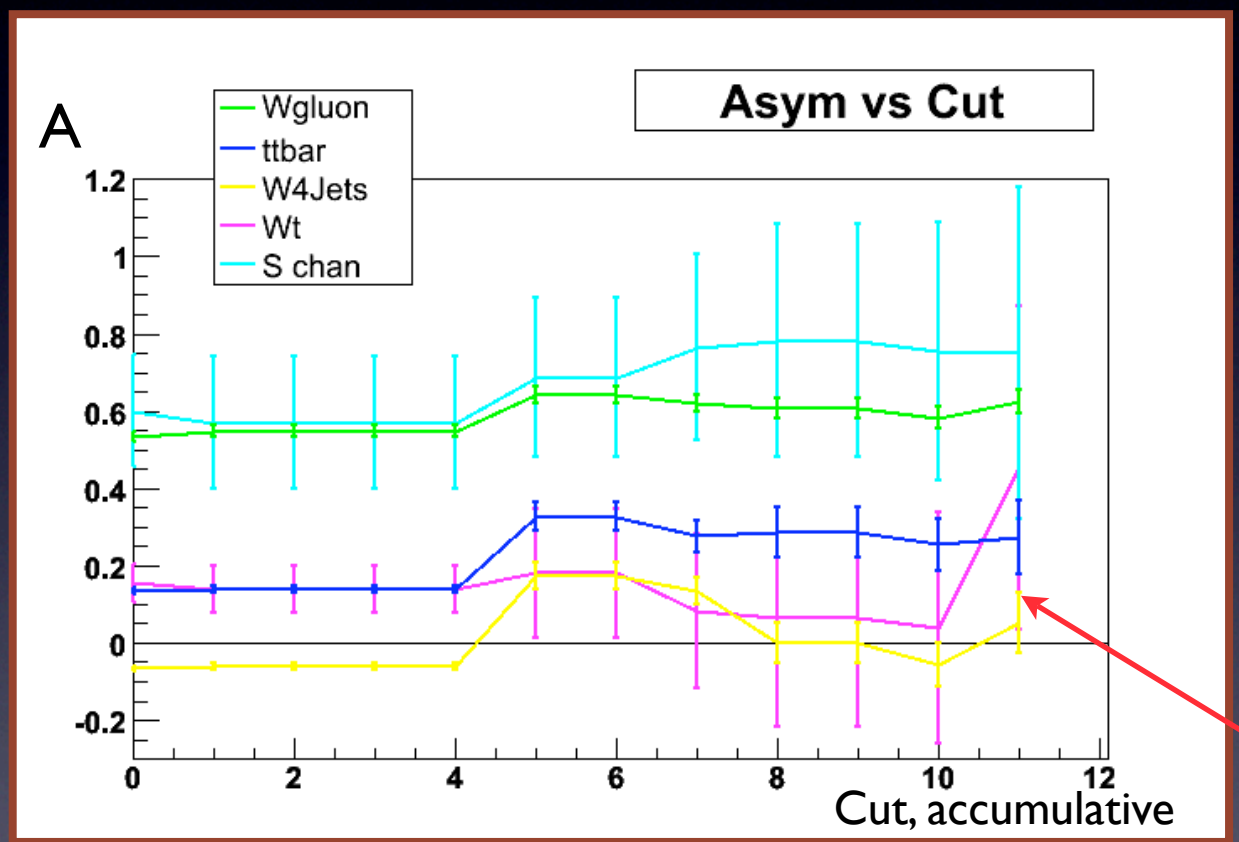
Cut Flow

(%)	Wg	tt	W+4jet	Wt	Sch	S/B
MET > 25	85.7	87.6	84.3	84.4	85.8	0.039
Nlep ≧ 1	46.4	41.4	37.7	49.9	43.1	0.045
NJet ≧ 2	35.9	39.7	36.5	45.7	31.6	0.037
NBjet ≧ 1	21.7	30.9	9.39	28.0	23.0	0.051
Njet = 2	11.9	5.18	1.22	9.83	15.68	0.18
Nfjet = 1	2.87	0.33	0.11	0.29	1.23	0.60
MTot > 250	2.50	0.27	0.10	0.22	0.79	0.61
HT < 300	1.86	0.08	0.05	0.10	0.42	1.22
Ntop = 1	1.29	0.06	0.03	0.07	0.28	1.27
Mtop > 150	1.12	0.06	0.03	0.06	0.23	1.21
Mtop < 200	0.93	0.03	0.01	0.03	0.15	2.14
Ratio (before)	1	8.34	17.4	0.22	0.02	
Ratio (after)	1	0.23	0.23	0.007	0.004	

Rejecting background well but need to see W+2,3 Jets.

Effect of selection cuts

Cuts may affect the asymmetry which biases the polarization measurement:

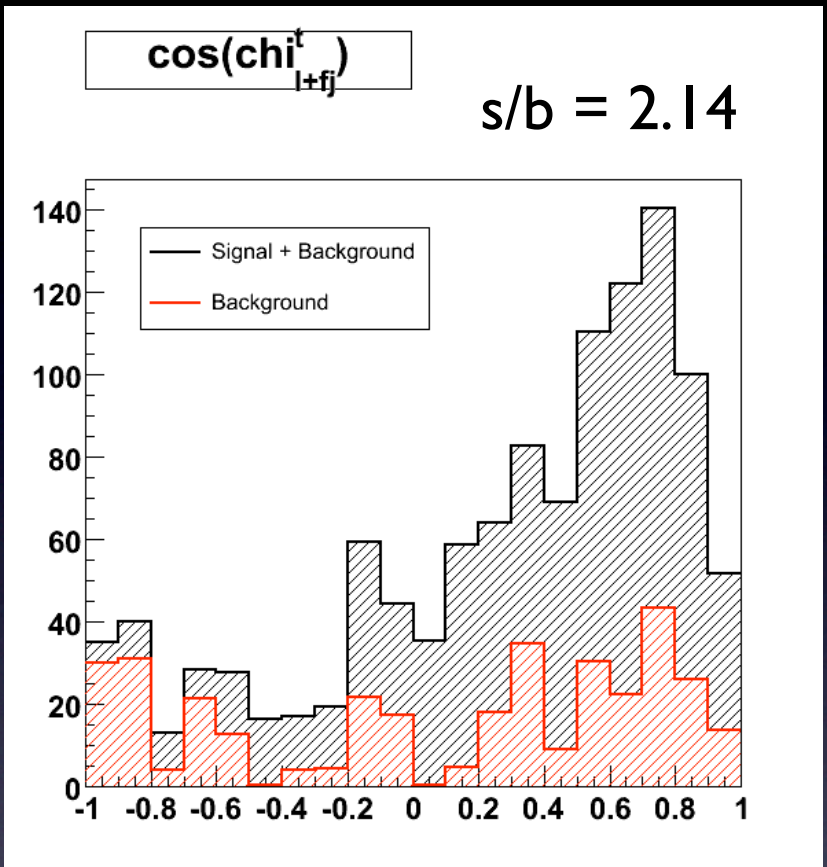


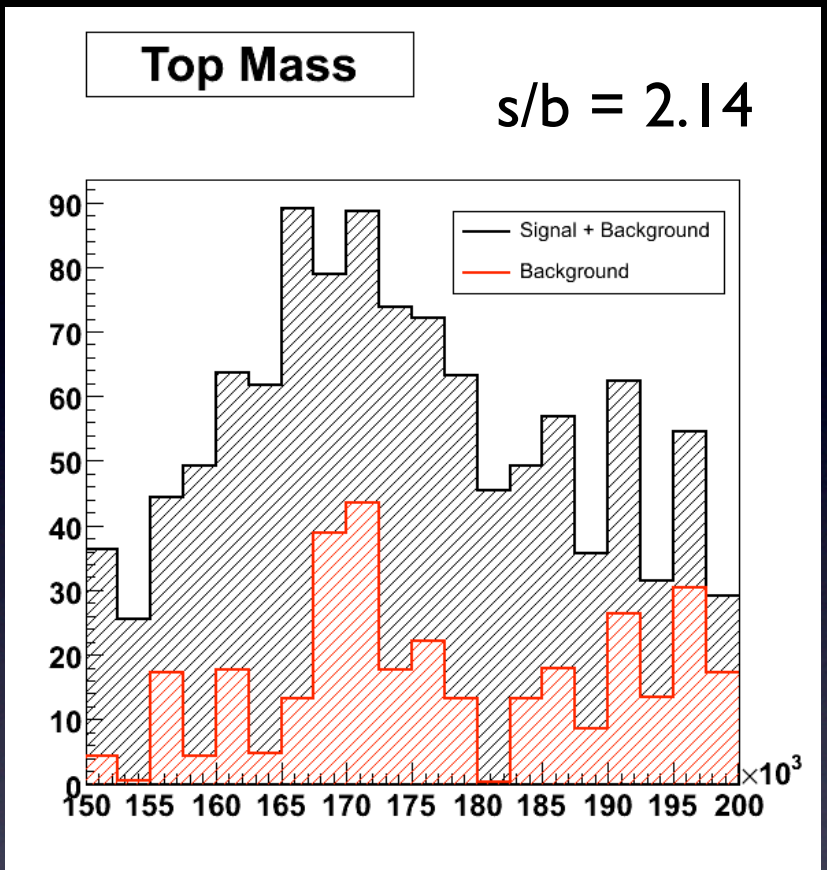
#	Cut
0	None
1	MET > 25
2	Nlep ≧ 1
3	NJet ≧ 2
4	NBjet ≧ 1
5	Njet = 2
6	Nfjet = 1
7	MTot > 250
8	HT < 300
9	Ntop = 1
10	Mtop > 150
11	Mtop < 200

Error source of systematics

Fairly linear. Njet=2 tends to increase asymmetry.
Cuts do not ruin the correlation.

Signal + Background





Spikes due to scaling. Scaled to 1.23fb^{-1} (~14days @ low lumi)

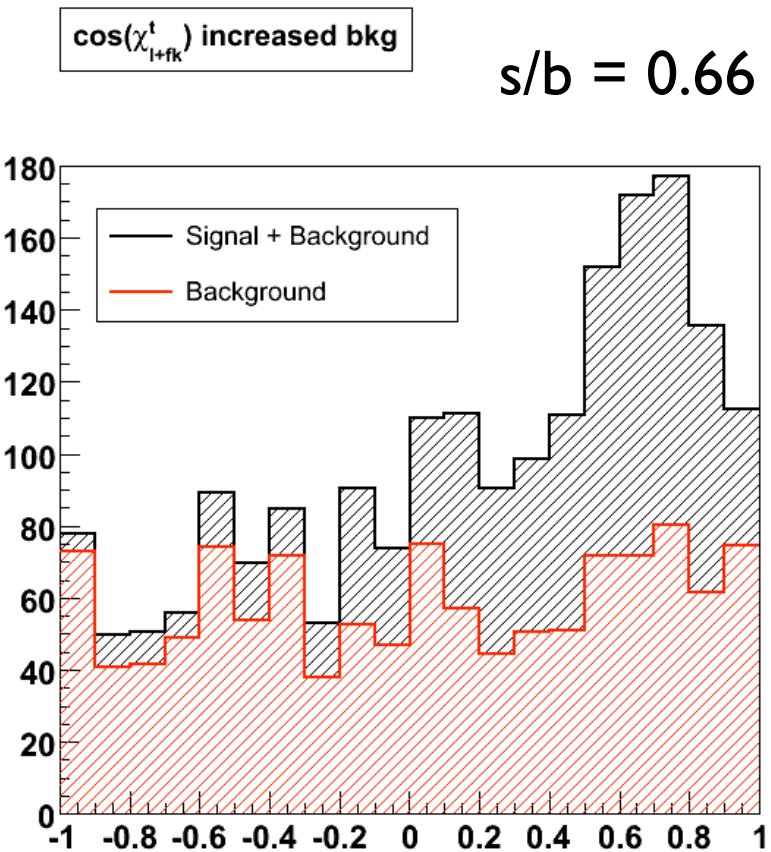
$\cos(\chi_{l+fj})$	A
background	0.16 ± 0.06
s+b	0.48 ± 0.03

Significance: $\dfrac{A_{sig+bkg} - A_{bkg}}{\sqrt{\Delta A^2_{sig+bkg} + \Delta A^2_{bkg}}}$

→ 5.1ΔA? Not the whole story...

Toy Monte Carlo

- Estimating the Background -



Lucotte et al (2006): After all cuts (somewhat similar to mine) Wjj is as large as ttbar contamination. WQQ is ~1/4 as large as ttbar.

Asymmetry for these background not estimated but let's assume the same as W +4jets.

$\cos(\chi_{l+fj})$	A
background	0.052 ± 0.03
s+b	0.276 ± 0.02

Scaled the number of entries from W+4Jet by 4.5 (Wj:Wjj:Wjjj:Wjjjj:Wbb=1:1:1:1:0.5) - rough estimate and randomly filled histogram with A of W+4jet

Uncertainty Summary

I depend on MC to estimate bkg distribution.

1. Uncertainty on x-section → $\Delta A^{bkg}_{sys(xsec)} = 0.003$

Channel	uncertainty
Signal	
W-gluon	3.8 (*)
top background	
S channel	5% (*)
Wt	8% (*)
ttbar	6%(*)
W/Z + jets	
Wj	15% (^)
Wjj	15% (^)
Wjjj	15% (^)
Wjjjj	15% (^)
Wbb	15% (^)

(*) Numbers as quoted in Lucotte et al (2006)
(^) Educated estimate

A, not sensitive to x-section.

2. Systematics due to physics model.

$$\Delta A^{bkg}_{sys(MC)} = 0.05$$

This can be reduced with more statistics but need to estimate error from physics models. Play with generators or estimate distribution from data.

3. Statistical Errors

$$\Delta A_{stat} = 0.02$$

→ $\Delta A^{total} = 0.055$

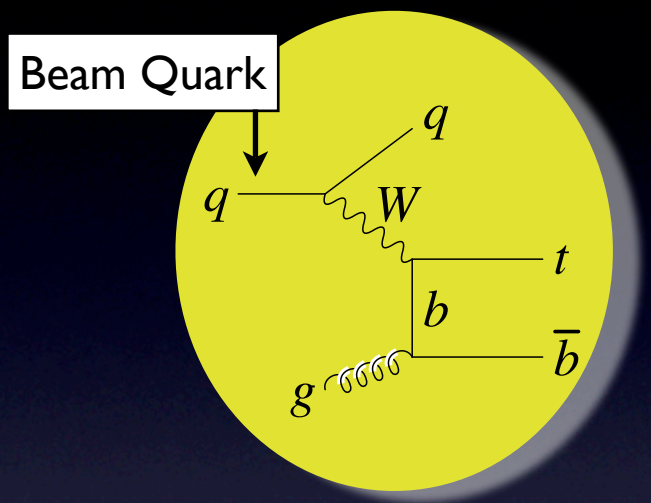
$4.06 \Delta A @ 1.23 fb^{-1}$

Shopping List

- Detector effect in more detail (effect of miscalibration/misidentification in measuring asymmetry)
- Systematics from acceptance.
- Estimate error from MC models.
- Estimate bkg. dist. with real data.
- Sensitivity to polarization (introduce V+A admixture.) Relate A to $\mathcal{A}_{\uparrow\downarrow}$.
- Study beamline basis as well.
- Separate t from tbar.

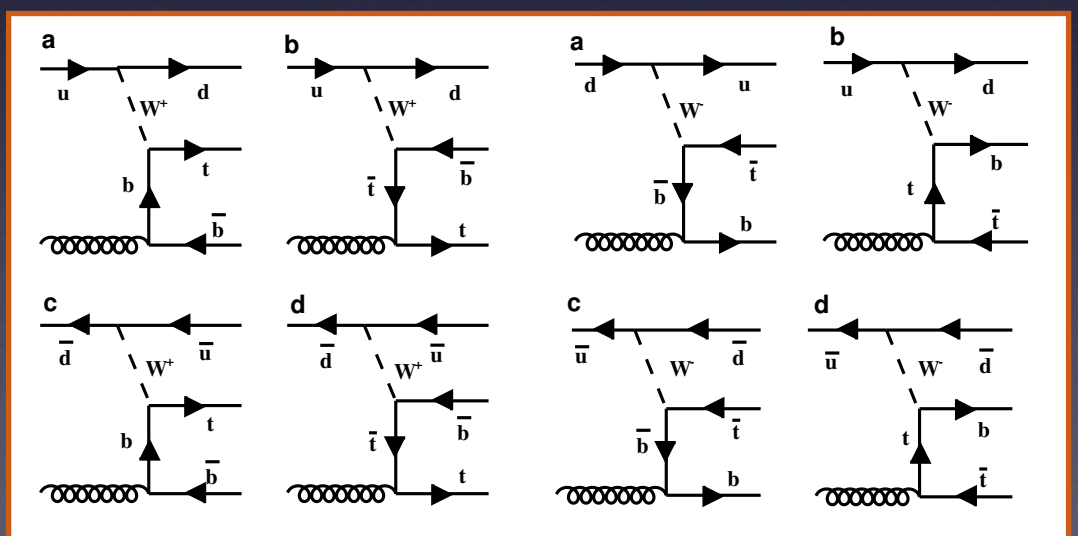
Backup Slides

Spin Measurement Bases



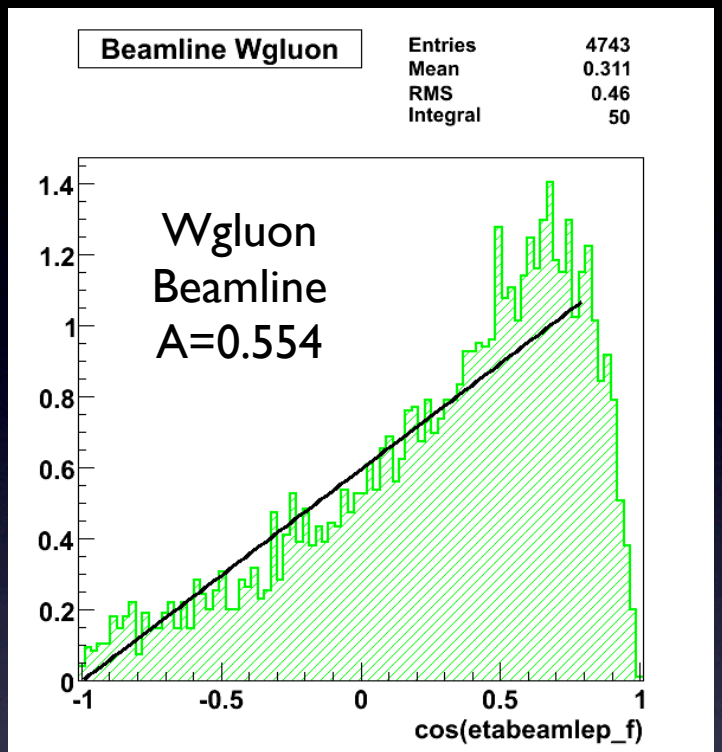
Beam quark		t (61.8%)		tbar (38.2%)	
d	dbar	0%	13.2%	61.7%	0%
u	ubar	73.7%	0%	0%	17.4%
s	sbar	0%	8.4%	12.8%	0%
c	cbar	4.8%	0%	0%	8.1%

Flavour of the beam quark in W-gluon diagrams. (TopRex)



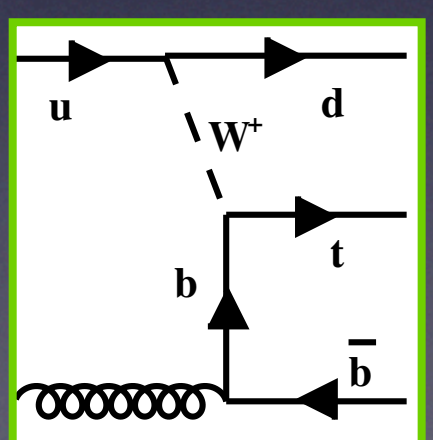
For t d-type quark is mostly in forward jet, for tbar, it's mostly in the beam proton. (a) is the most dominant, then (c).

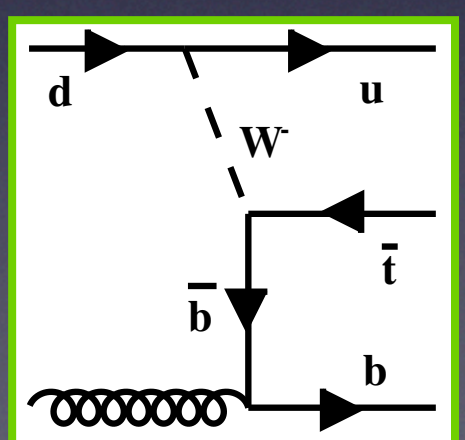
Beamline Basis



Beam selected from lepton direction:
(0, 0, 7.0TeV, 7.0TeV) if $\eta_{lep}>0$
(0, 0, -7.0TeV, 7.0TeV) if $\eta_{lep}<0$
(px,py,pz,E)

Looks as good as forward jet basis. Background distribution also similar to forward jet basis. Well worth investigating.

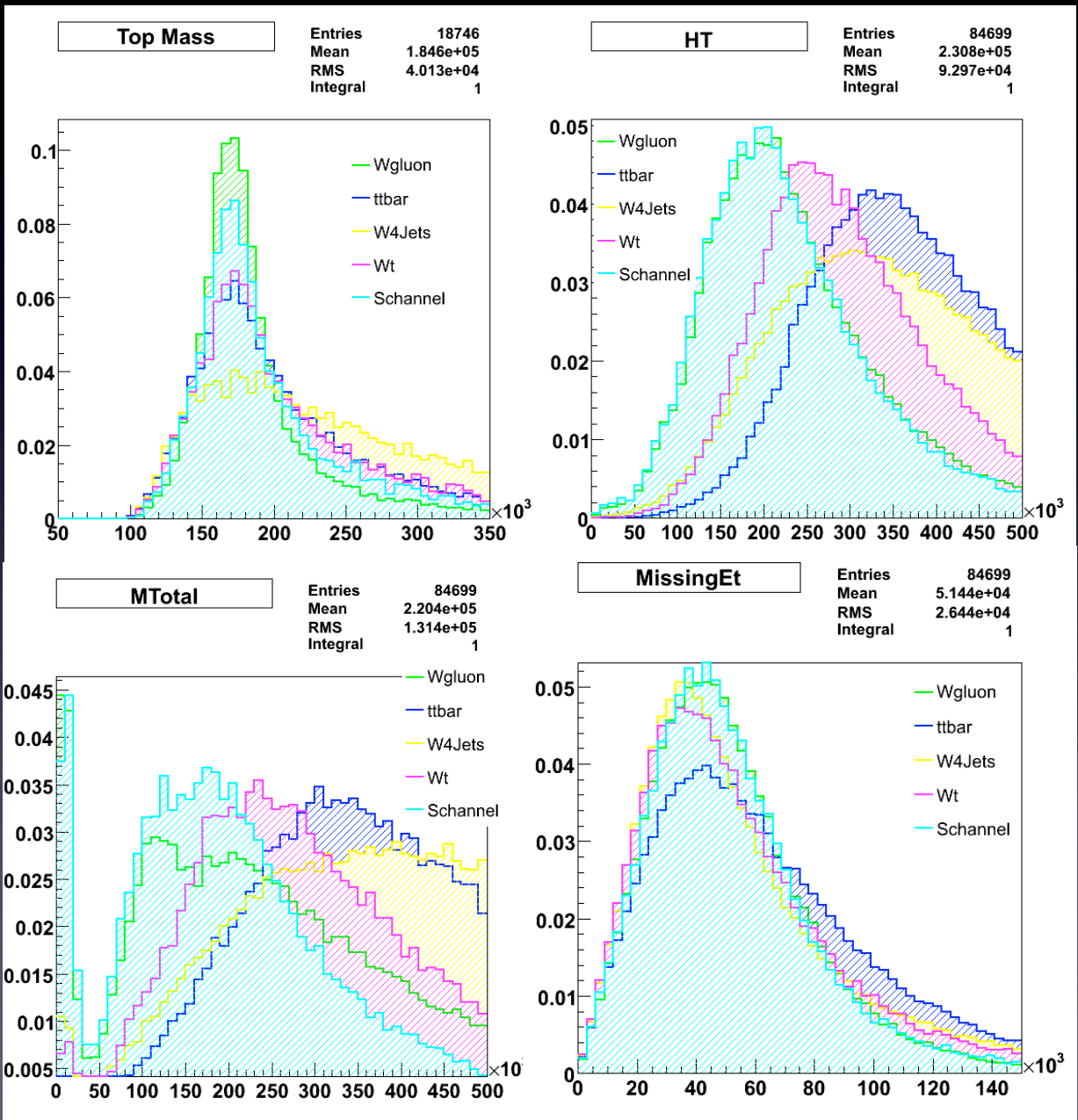




Makes sense to use beam basis for tbar and forward jet for t. Left, dominant t production diagram. Right, dominant tbar production diagram.

Selection Cuts

Distribution before any cuts.



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Marcello Barisonzi, Systematic effects of selection cuts for t-channel Single Top, Dec 05