# Proposals for single top at CMS

Andrea Giammanco – SNS & INFN Pisa

Topics that I would like to discuss at Les Houches:

- $V_{tb}$ extraction
- S-channel, T-channel: proposed selection strategies
- Top reconstruction criteria
- Polarization from T-channel events
- Wt and light SUSY
- Top quark charge
- Systematics

# S/B: Tevatron -> LHC

| | 1.96 TeV | 14 TeV | |
|---|---|---|---|
| Single top (s-channel) | 0.88±0.12 pb | 10±1 pb | (x10) |
| Single top (t-channel) | 1.98±0.22 pb | 245±17 pb | (x120) |
| Single top (Wt channel) | 0.15±0.04 pb | 60±10 pb | (x400) |
| ttbar pairs | $6.70^{+0.71}_{-0.88}$ pb | 825±150 pb | (x120) |
| Wjj (*) | ~1200 pb | ~7500 pb | (x6) |
| bb+other jets (*) | ~$2.4 \times 10^5$ pb | ~$5 \times 10^5$ pb | (x2) |

(*) Belyaev, Boos, and Dudko [hep-ph/9806332]

# Direct $|V_{tb}|$ extraction

$\sigma \sim |V_{tb}|^2$ → $\Delta V_{tb}/V_{tb} = \frac{1}{2}\Delta\sigma/\sigma = \frac{1}{2}[(S+B)^{1/2}/S + \textit{th. err.}]$

| | s-channel: | t-channel: |
|---|---|---|
| PDF | 4% | 10% |
| renorm. scale | 4% | 5% |
| $\Delta M_t$ (±2GeV) | 5% | 2% |

**We need to know better the gluon and b PDFs**

Wt-channel: 50% th. error (range of values in literature)

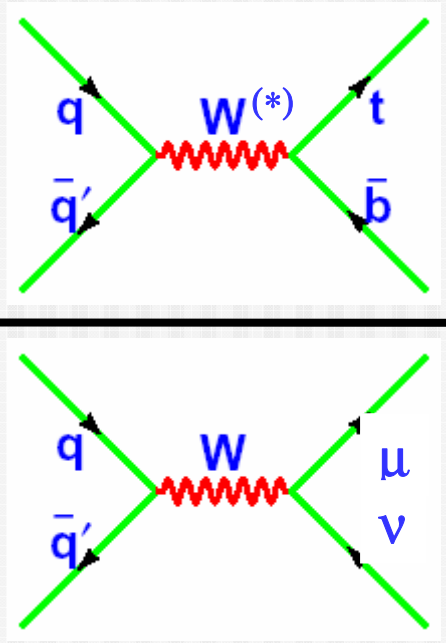
(ATLAS stat. err.: s-ch. 5.4%, t-ch. 0.7%, Wt 2.8%)

→ This makes s-channel preferred

# Direct $|V_{tb}|$ extraction: single top / single W

Moreover, in principle, many theoretical errors would disappear by normalising s-channel events over single W events:

$$R(|V_{tb}|) = \frac{}{}$$




(with care in choosing coherent cuts for the two processes, to avoid the reintroduction of the same errors in a subtler way)

# Challenges in single top selection

- Backgrounds are on both sides w.r.t. the signal for most discriminating variables!
- No single variable gives a decisive separation for s-channel (situation more favourable for t-channel due to the characteristic topology)
- Using NN or other "smart" multivariate techniques usually give a decisive advantages in difficult cases like this; the price to pay is the introduction of a strong model dependence (very serious drawback, given the poor knowledge of W+jets bkg and the impossibility to calibrate with data until LHC starts…)
- Selections based on number of jets, MET, $H_t$, and using MET and jets to reconstruct the top: understanding jet (and MET) calibration is crucial

# M(lνb): ambiguities

$P_z(\nu)$ reconstucted from W mass constrain $M_W^2=E_W^2-P_{Wx}^2$: quadratic equation, 2-fold ambiguity.

- min $|M(l\nu b)-M_t|$ — **pro:** best resolution, **con:** obvious bias
- $\Delta R(W,b)$
- min $P_z(t)$

} Effectiveness and bias on mass have to be investigated.

When both selected jets are b-tagged, another 2-fold ambiguity in the assignment to the top.

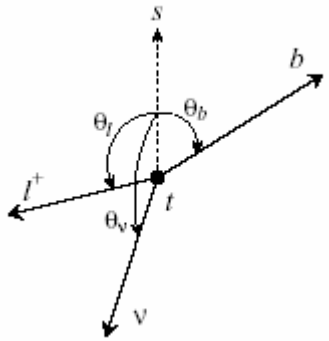
- min $|M(l\nu b)-M_t|$
- highest b-tag value — It makes sense for t-channel search.
- min $P_z(t)$
- max $P_t(t)$ — Most used in literature.
- "b-jet charge" opposite to lepton charge — Why not? Maybe combined with the above, e.g. making use of a "Decision Tree"…

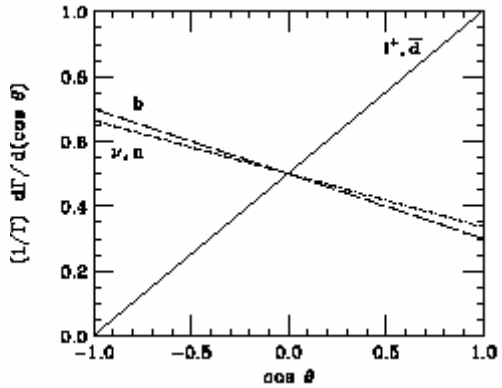
# s-channel/t-channel separation: ideas

- Of course, 2 vs 1 b-tagged jets
- $|\eta(j)|$ (j: "worst" b-jet)
- $\Delta R(b,j)$ (b: "best" b-jet)
- Invariant mass of the $l\nu bj$ system?
- (Note: if we want to extract $M_t$, we have to beware of the biases from the last two items…)
- Orthogonal shape variables (Matt Bowen et al.)

# Polarization in t-channel

- Standard Model consistency check: single tops have to be polarized
- Many new physics scenarios give $|g_R|>0$




**$(d\Gamma/\Gamma)/d(\cos\theta)=\frac{1}{2}(1+A\cos\theta)$**

**A(l)=+1, A(b)=-0.40 , A(ν)=-0.33**

**θ: lepton/chirality axis angle**

**In the ultrarelativistic limit, chirality~elicity. Not the top case!**

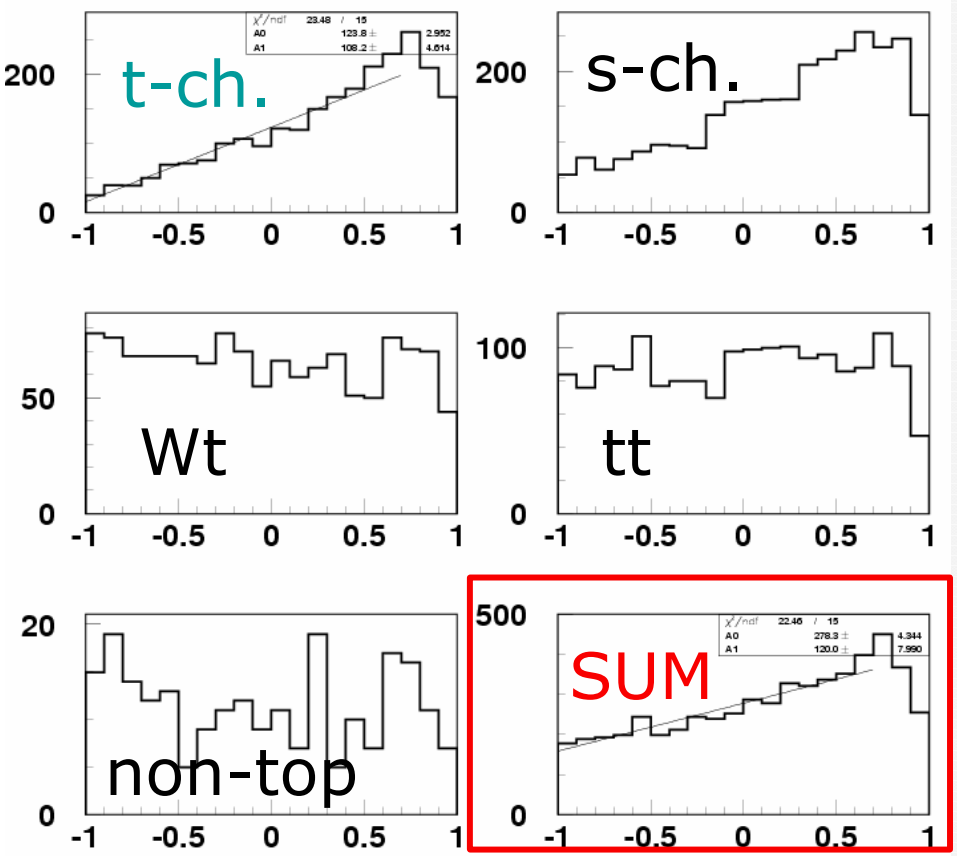
Mahlon (hep-ph/9811219): in the top r.f., spin axis is always parallel to the "down" quark direction.
In t-channel its better approximation is the recoil jet axis.

ATLAS: ±1.6% precision on top polarization @10 $fb^{-1}$

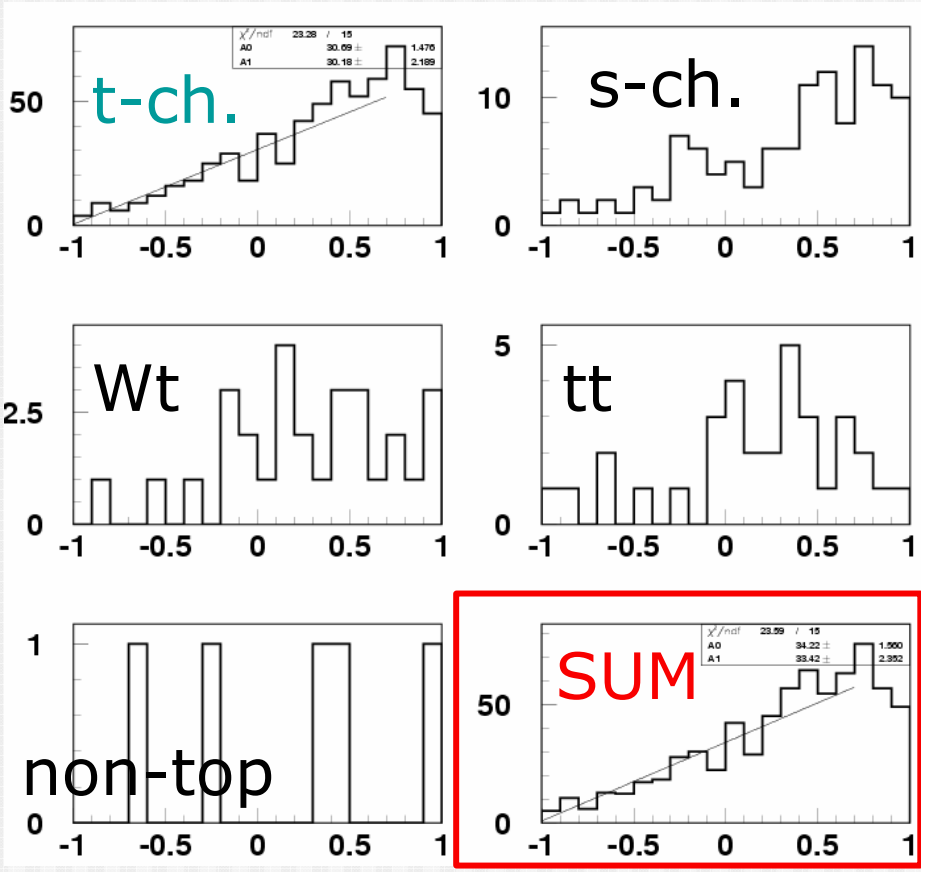
# cos $\theta_{lj}$ distributions in top rest frame

**(Unofficial result using old CMS fortran fast sim.)**

**After preselection:**

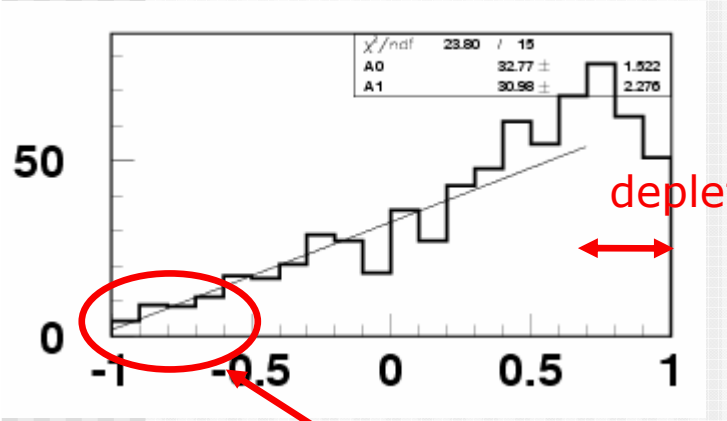



**After t-enrichment:**




Norm. slope: 0.97±0.08

# Polarization: Interpretation




depleted region (due to lepton isolation cut)

To be taken into account if considering

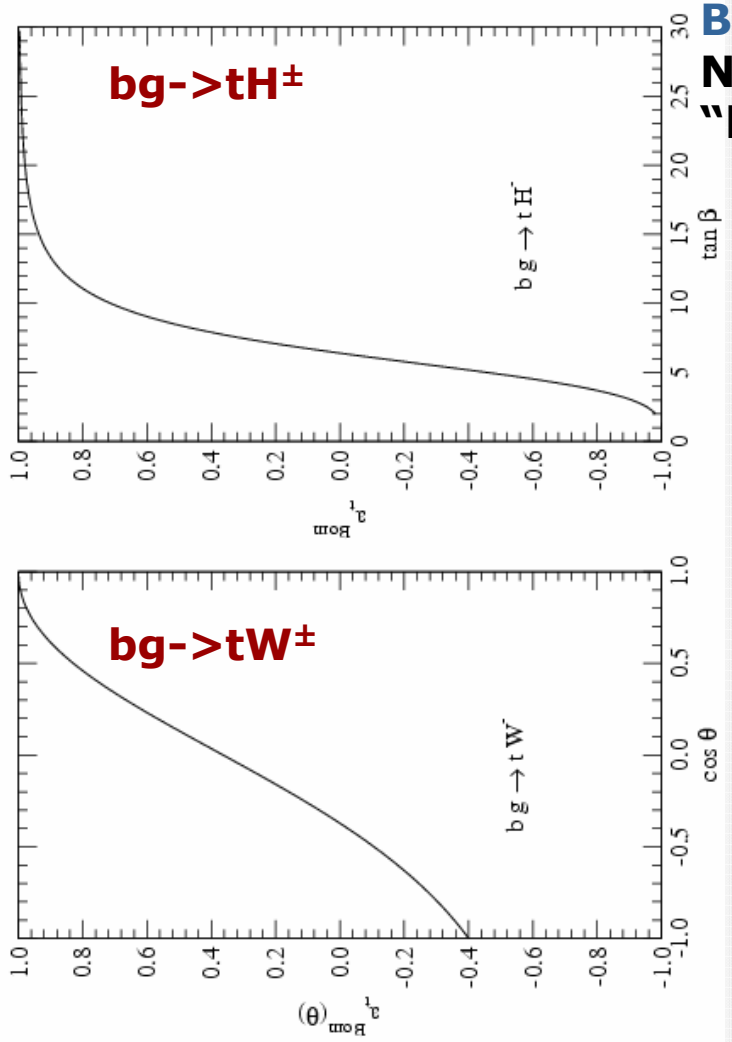
$$A_{FB}=(\sigma_F-\sigma_B)/(\sigma_F+\sigma_B)$$

Non-zero $g_R$ would be visible mostly here

In case of an excess in the first bins, carefully check:

- that the background contamination is under control
- that the top direction is well reproduced (missing $E_t$ -> $\nu$!)
- that jet-finding algorithm is reliable
  - how well the recoil jet approximates the parton direction?
  - try different jet algos to estimate a systematic effect?

# Single top and SUSY




**Beccaria, Renard, Verzegnassi (hep-ph/0410089)**

**NLL computation of single top production in a "light" SUSY scenario (350-400 GeV).**

Main consideration: the only relevant SUSY parameter is *tanβ*

**Effects: >10% in any channel, in particular in <u>associated production</u> (bg->tY, Y=W,H). Strong dependence on *tanβ*.**

bg->tW±:

- *cosθ* asimmetry
- no *tanβ* dependence

bg->tH±:

- no *cosθ* asimmetry
- *tanβ* dependence

# Top charge

- Is the discovered "top quark" **a charge 4/3 pseudo-quark?**

**D. Chang, W.F. Chang, E. Ma, Physical Review D 59 091503**

- Global EW fit is consistent with this hypothesis, given a "true top" mass ~230 GeV
- In Run I, CDF and D0 were not able to distinguish among $(W^+b)(W^-\bar{b})$ and $(W^-b)(W^+\bar{b})$: angular correlations + jet charge determination is a very difficult task.

The two competing hypotheses on $|Q_t|$ may be tested from:

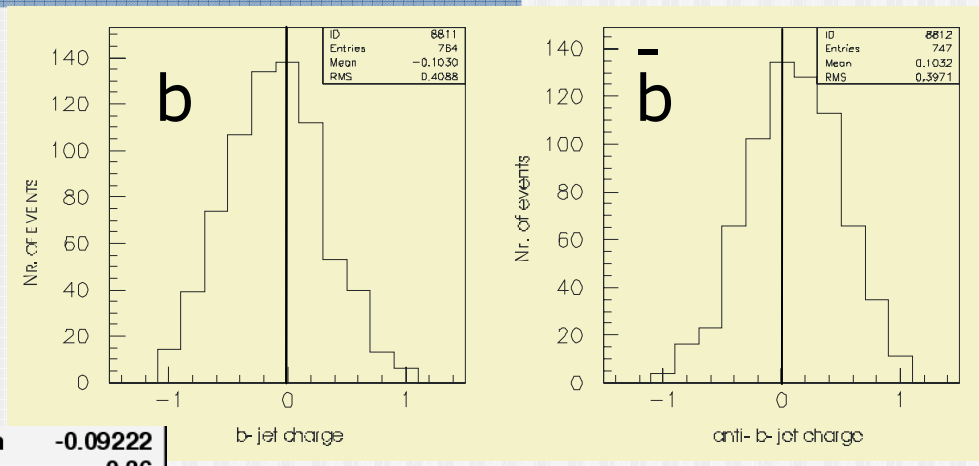
- QED coupling: rate of $tt\gamma$ and $t\to bW\gamma$ evts
- estimation of b-jet charge in ttbar events
- " " " in single top events?
  - ✓ Cross section at LHC is not that small (250 pb, against 825 pb for ttbar)
  - ✓ Very characteristic topology allows selection of high purity samples
  - ✓ Top may be reconstructed with very little ambiguity (usually only 1 b in acceptance)
  - ✓ Determination of b flavour (b/bbar) in semileptonic top is a determination of |Q(t)| (assuming |Q(b)|=1/3)

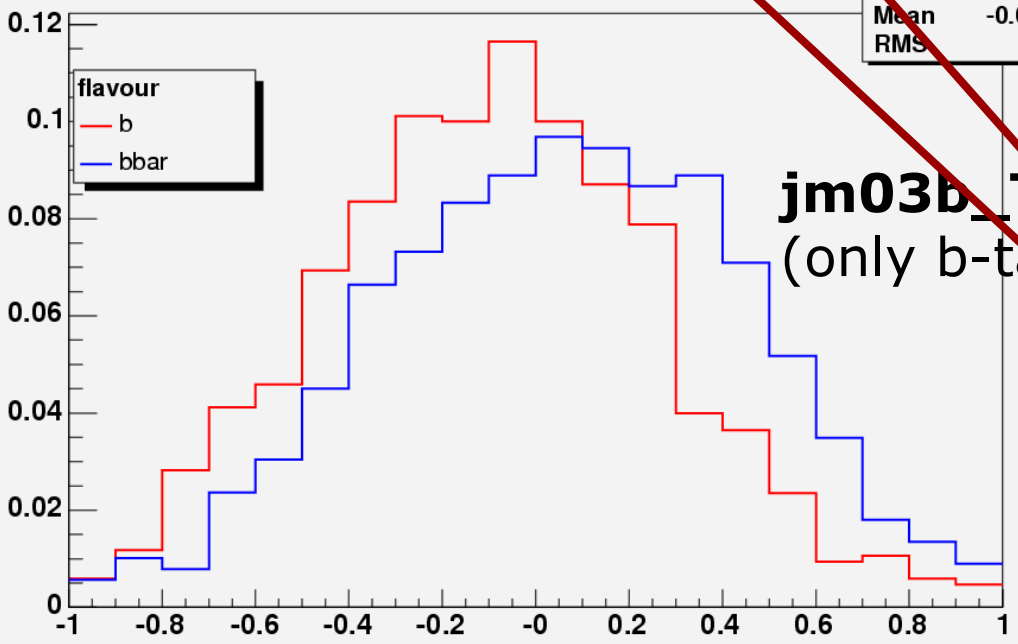
# "Jet charge" method

**ATLAS:**

$$q_{bjet} = \frac{\sum_i q_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}{\sum_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}$$

Systematics: fragmentation, UE, PU,…



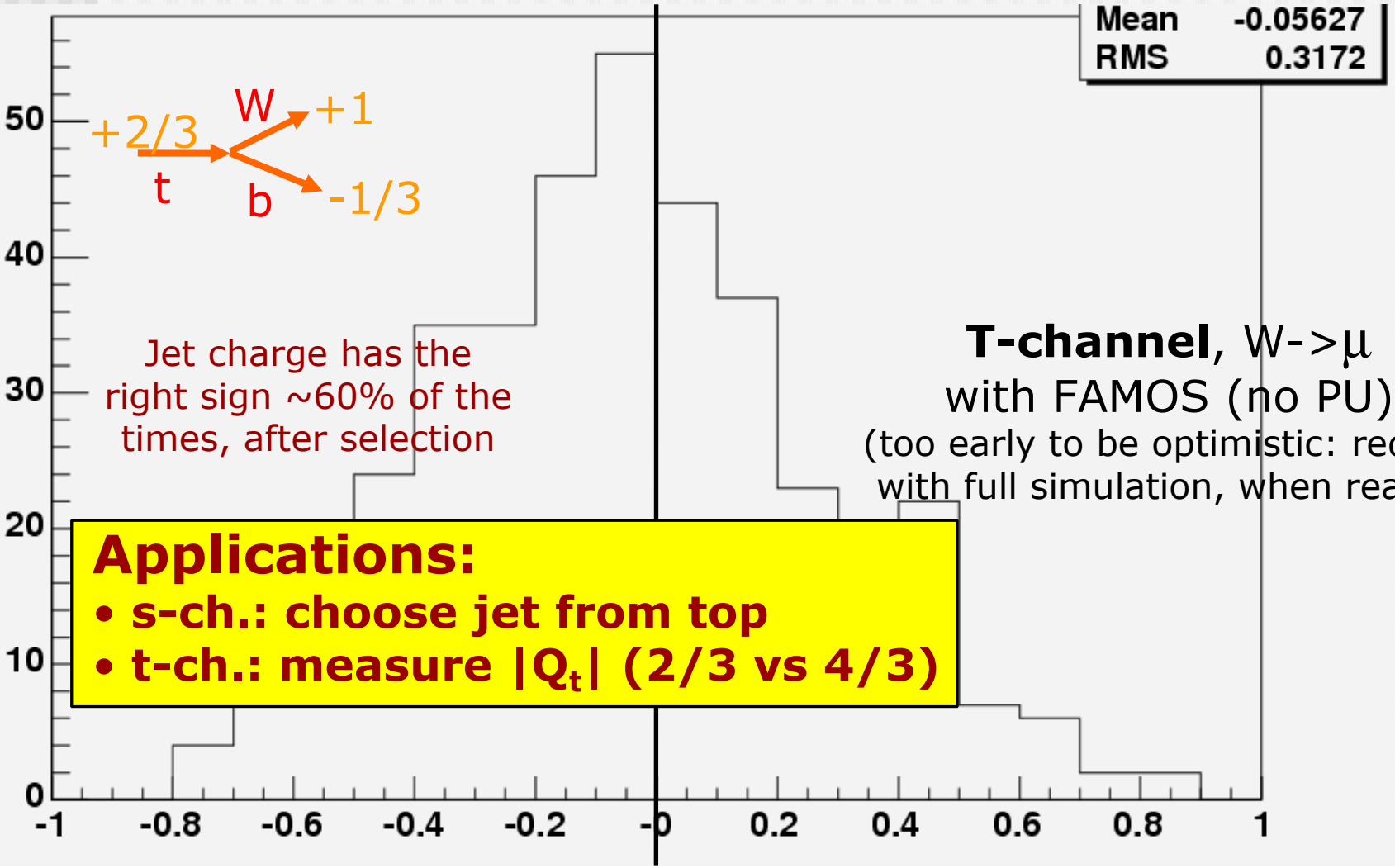




**jm03b_TTbar_leptonic** official sample (only b-tagged jets), PU@L=2x10$^{33}$

Here: k=1.
Optimize?

Weigh by IP signif. instead of $P^L$?

# Jet charge x lepton charge




Jet charge has the right sign ~60% of the times, after selection

**T-channel**, W->μ
with FAMOS (no PU)
(too early to be optimistic: redraw with full simulation, when ready)

**Applications:**
- **s-ch.: choose jet from top**
- **t-ch.: measure $|Q_t|$ (2/3 vs 4/3)**

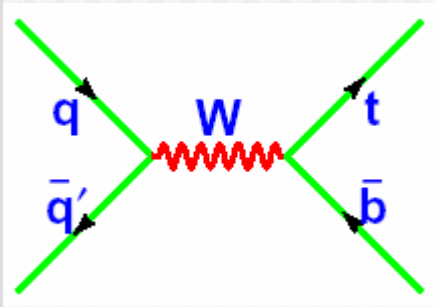
# Systematics

- Influence of PDFs on the analysis (most important for $V_{tb}$ extraction)
- b fragmentation (variate/optimize cone opening?)
- FSR (variate/optimize cone opening and recover soft jets?)
- b-tagging
- Jet energy scale & resolution
- Trigger effects
- UE modeling (forward jet in t-channel)
- Background modeling (W+jets)

# Backup slides

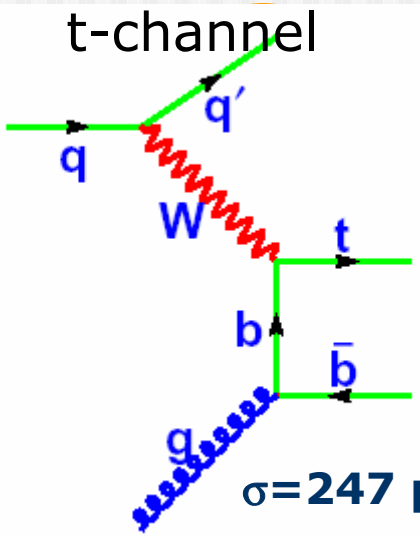
# Single top

s-channel



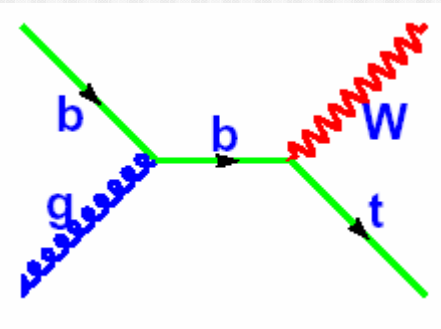

**σ=10 pb**

t-channel




**σ=247 pb**

Wt-channel




**σ=56 pb**

- Never observed so far
- Directly related to $|V_{tb}|$ (not a $\mathbf{V_{tb}/\Sigma V_{ti}}$ ratio -> no assumption on the number of quark generations)
- Sensitivity to new physics: FCNC (t-ch.), new gauge bosons (s-ch.), $H^{\pm}$->tb …
- Background to tt and several searches (ttH, WH->lνbb, …)
- Possibility to study top properties (mass, polarization, charge) with very little reconstruction ambiguities

# Single top: "how to"

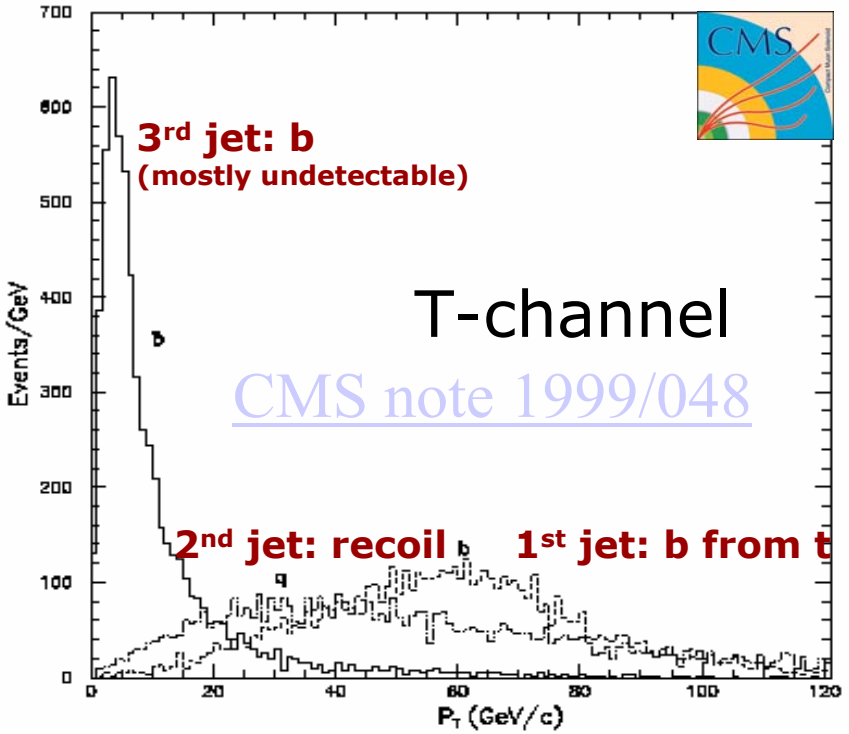
General strategy (both s/t-ch.):

- 1 isolated lepton
- 2 high $E_t$ jets
- at least 1 tagged b-jet
- missing $E_t$
- l+MET: $M_T$ compatible with W
- $H_t$ (scalar sum of all $E_t$'s)
- M(lνb) in a window around $M_t$

s/t-channel separation:

- 2(b-t-b)/1 tagged b-jets
- 0/1 jets in the forward calo
- 2/1 central jets
- angular distance between the reco top and the remaining jet

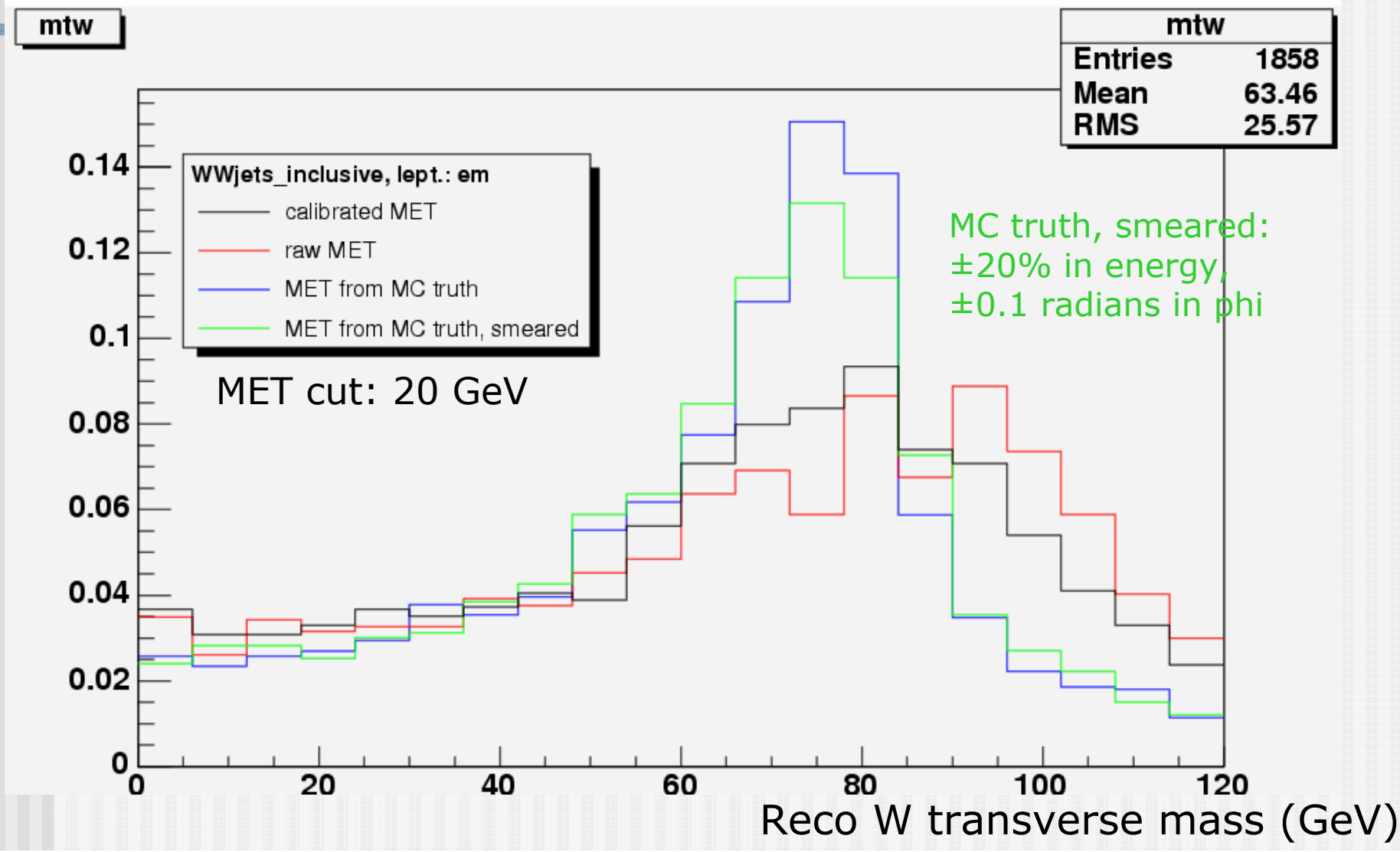
For MET and $H_t$, single top lies in the middle between non-top and ttbar bkgs.
S-channel: S/B<0.2, main bkgs: ttbar->2l (1 lost), Wbb, t-channel.
T-channel is much easier to select, due to higher cross section and unique topology.



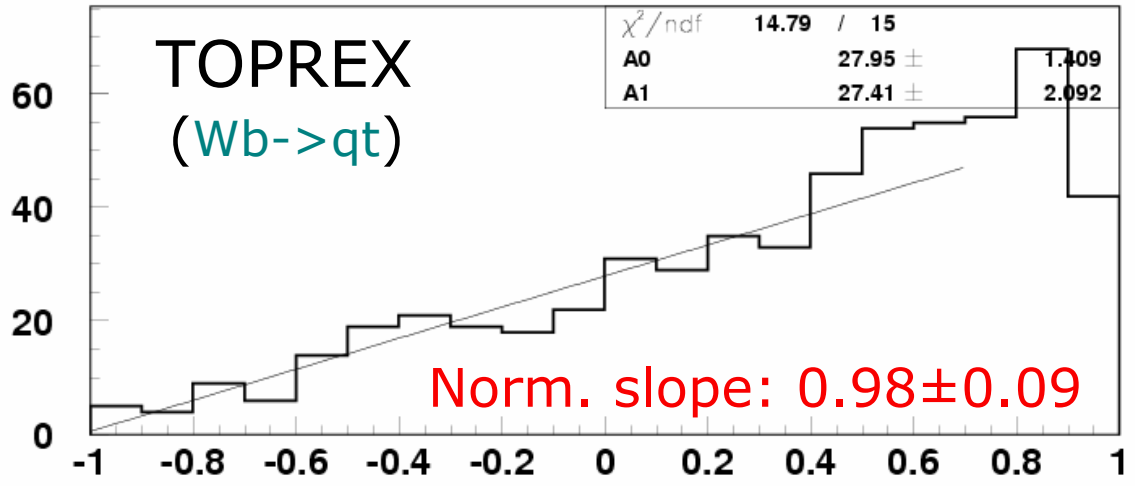
# W mass constraint: what if it has no real solution?

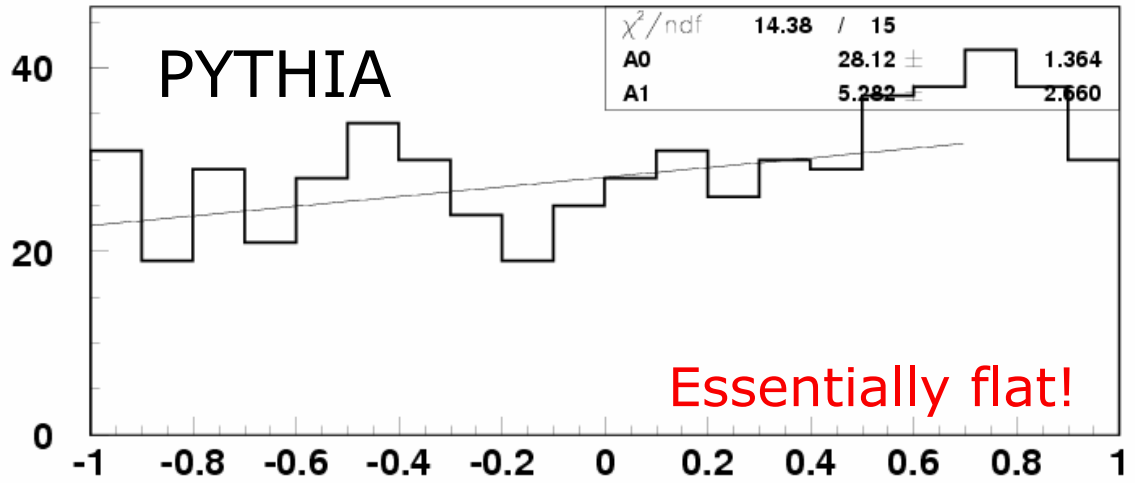
- ATLAS takes the real part of the solutions; is this motivated?
- What is the cause of $\Delta<0$?
- (Suspect: overestimated MET)
- Using MET from jets: ~1/3 of the signal events have no real solution
- Using MET from MC particles: <1/4

# W transv. mass



# Polarization: Consistency check

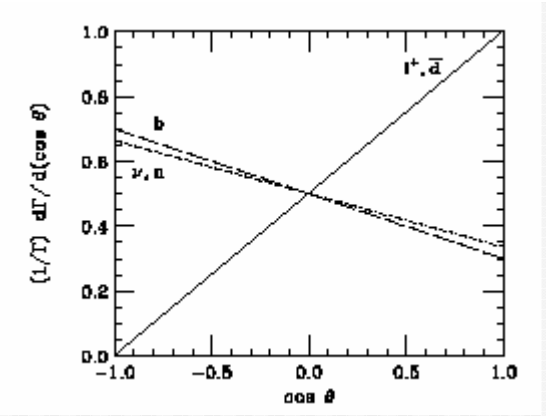


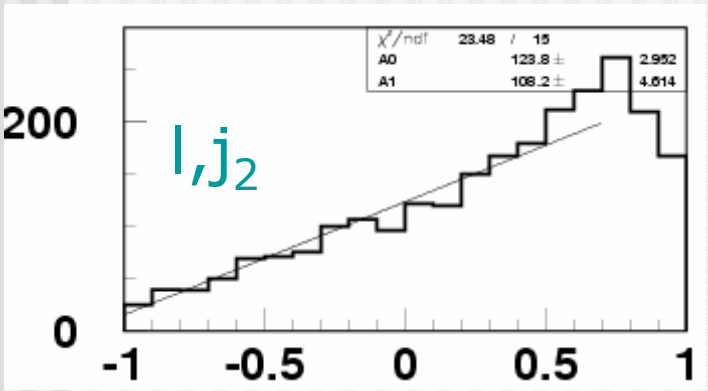




To be sure that this shape is not an analysis artifact, I compare Wb->qt samples produced with PYTHIA (i.e. unpolarized) and TOPREX (the NLO diagram Wg->qtb is not taken into account in PYTHIA)

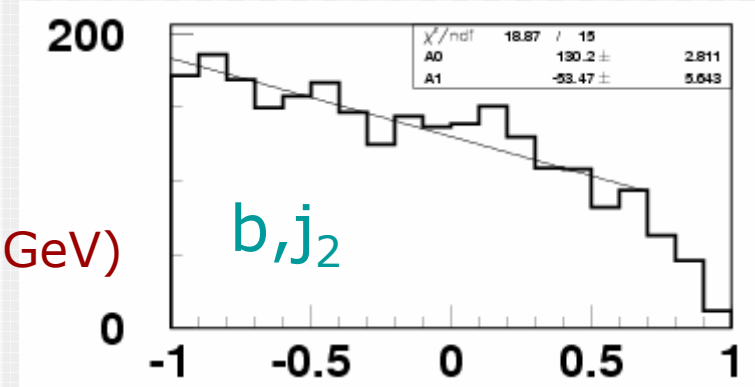
**t-channel:**
Wb->qt **+** Wg->Wbb->qtb

# Polarization: MC vs theory

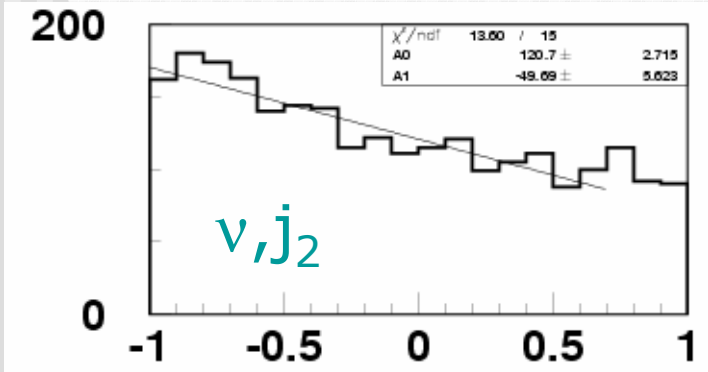



MC: slope = 0.97±0.08
Th.: slope = 1 (independent from $M_t$)




MC: slope = -0.41±0.04
Th.: slope = -0.40 (for $M_t$=175 GeV)




MC: slope = -0.41±0.05
Th.: slope = -0.33 (for $M_t$=175 GeV)

Error is statistical only.
Reconstruction uncertainty on top and ν is not included!

# Top charge: "fully reconstructed top"?

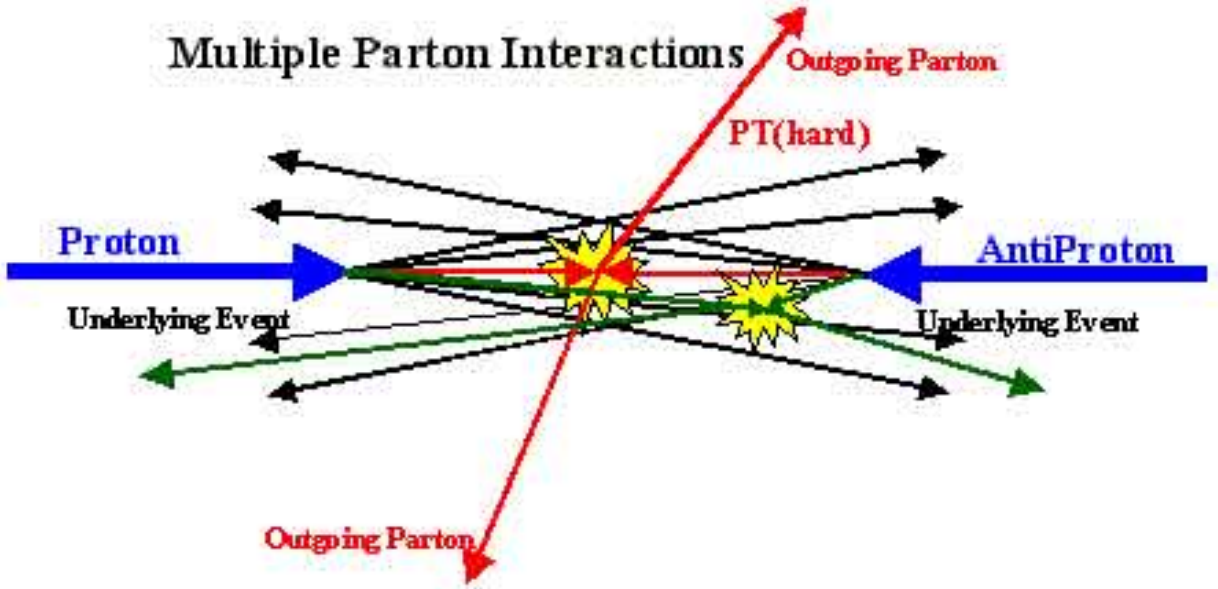
- Only one event would be sufficient!!!
- Idea: t-channel enriched sample, t->lνb, no other b in the acceptance, B meson fully reconstructed
- E.g.: $B_s$->$D_s\pi$, with (a) $D_s$->$\phi\pi$, $\phi$->$K^+K^-$, or (b) $D_s$->$K^{*0}K$, $K^{*0}$->$K\pi$
- P(b->$B_s$)=10.5%, BR(B->$D_s\pi$)=3x$10^{-3}$,

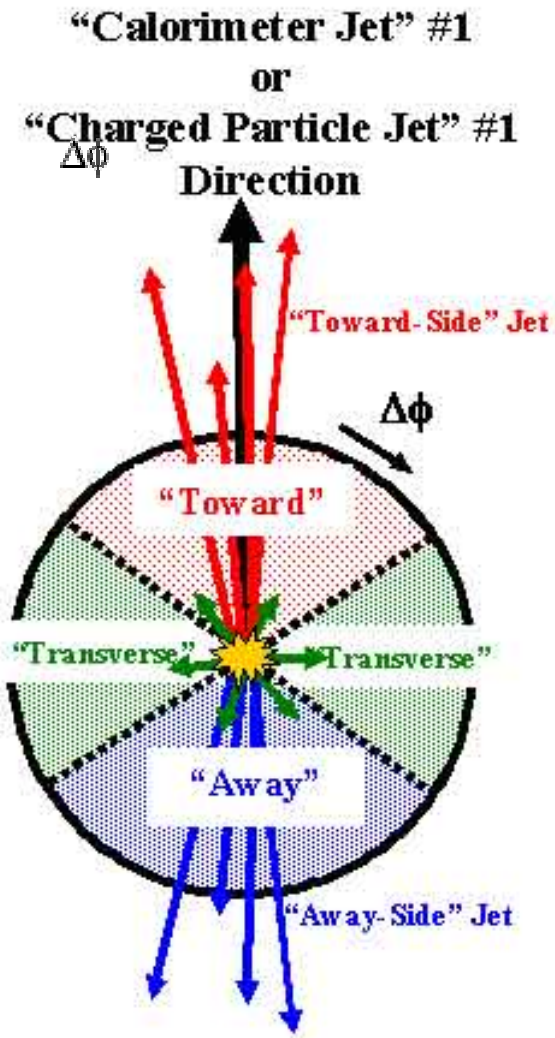
(a) BR($D_s$->$\phi\pi$)=3.6%, BR($\phi$->$K^+K^-$)=50%,

(b) BR($D_s$->$K^{*0}K$)=3.3%, BR($K^{*0}$->$K\pi$)=66%

- CMS-NOTE 2000/038: mass & vtx quality cuts give ε(a)=13%, ε(b)=9% (trigger not included)
- Assuming 10k (after selection) t-channel top quarks @30 $fb^{-1}$ (realistic, maybe we can do better): 1050 $B_s$, 3 $D_s$, ~0.06 of which fully reconstructed.
- Too few for the low luminosity phase. High lumi? (What are the efficiencies for the exclusive channels???)

# Underlying Event

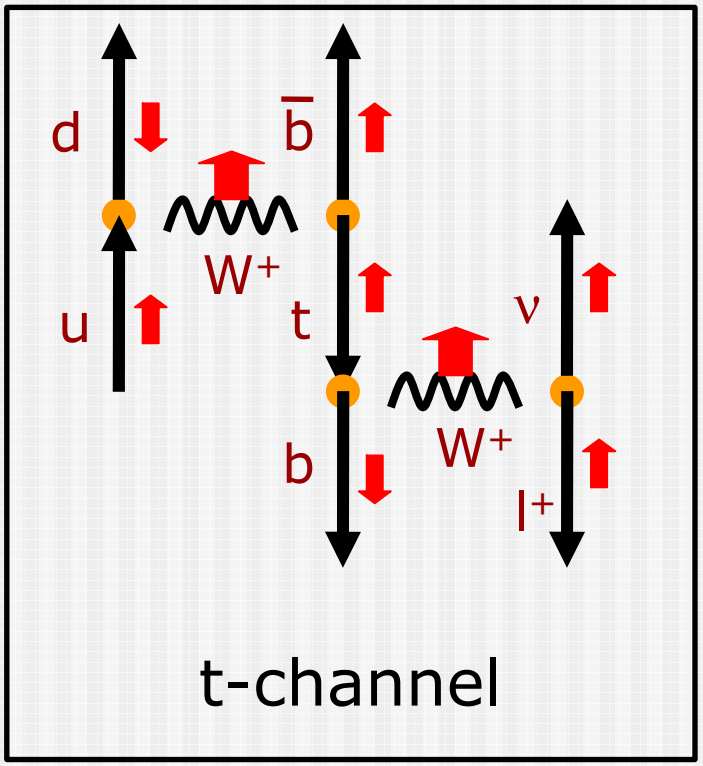


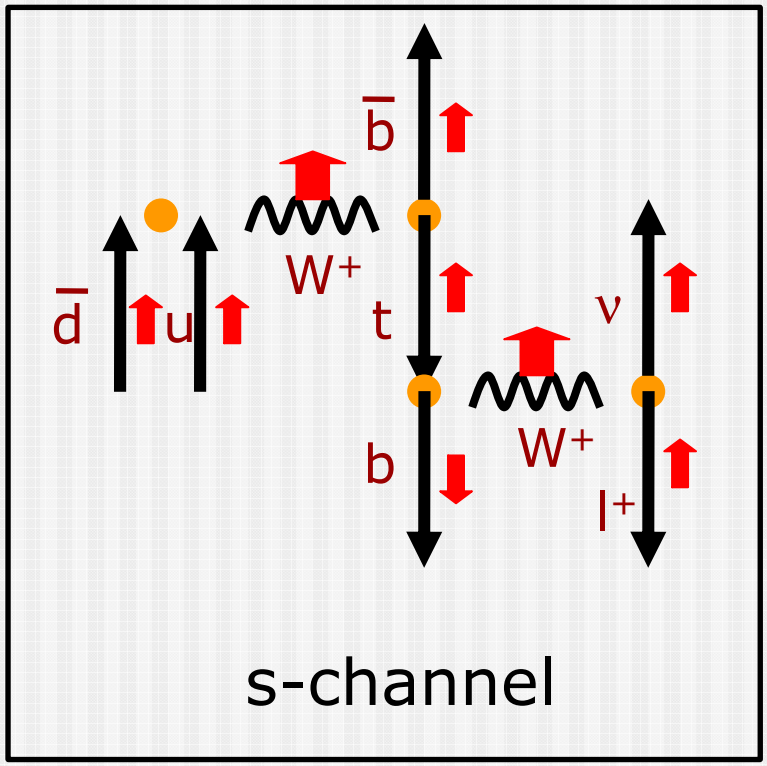

The "transverse" region is defined by $60^{o}<|\phi|<120^{o}$ and $|\eta|<1$.

The "transverse" region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the "underlying event" component of the QCD Monte-Carlo models.

# Spin flow for single top




t-channel




s-channel

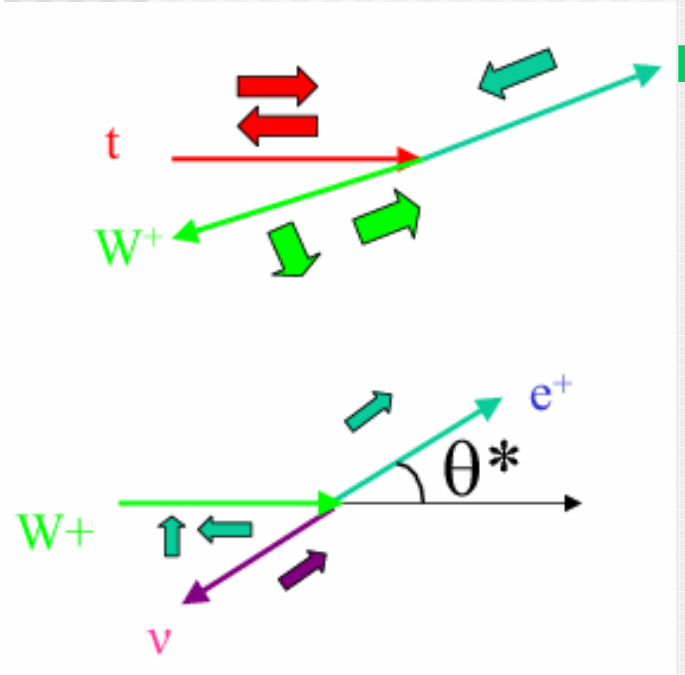
EW vertex

momentum

spin ½

spin 1

# Angular distrib. t->W->l




b is relativistic and left-handed.
W can be left-handed or longitudinal.

In W's r.f.: final state of +1 elicity from (1,0) or (1,-1).

$$d^1_{1,0} = \frac{-\sin\theta^*}{\sqrt{2}}, d^1_{1,-1} = \frac{1.-\cos\theta^*}{2}$$

$$\frac{dN}{d\cos\theta^*} = \frac{3}{4(m_t^2+2M_W^2)}\left[m_t^2\sin^2\theta^* + M_W^2(1-\cos\theta^*)^2\right]$$

# What can Tevatron do for LHC?

- Very similar environment: ideal to test analysis strategies and understand similar systematics (e.g. Underlying Event)
- W+jets, in particular Wbb(X), Wcc(X), Wc(X), are significant backgrounds for Top analyses at both accelerators; different MC models give different kinematics => sizeable differences in efficiency estimates. Improvement by tuning generators to Tevatron data?
- PDFs for LHC are currently extrapolated from a global fit heavily relying on HERA ep data.
- But Tevatron $p\bar{p}$ data contribute with a richer menu (e.g. constraints to gluon PDF)
- Impression from the outside(*): Currently relatively few studies at CDF+D0 to constrain PDFs. Is it true?

(*) I.e. by watching public results:
http://www-cdf.fnal.gov/physics/physics.html
http://www-d0.fnal.gov/Run2Physics/WWW/