Single Top Quark Production and Decay in Hadron Collisions at Next-to-Leading Order

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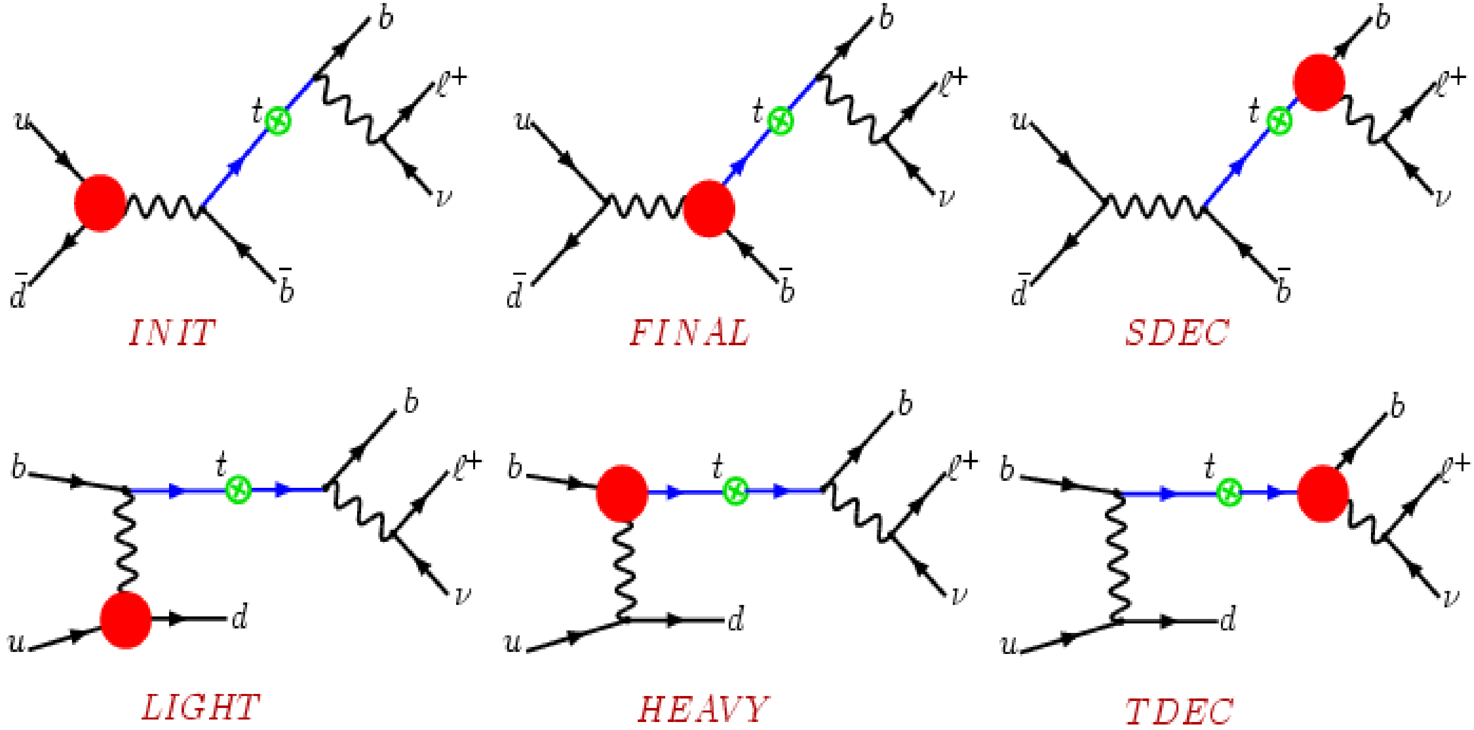
Single top at NLO

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



● includes the virtual and real emission corrections.

- Keeping track on each individual contribution is useful to compare event generators with exact NLO predictions.

Acceptance study

	s-channel				*t*-channel			
	σ [fb]		Accept. (%)		σ [fb]		Accept. (%)	
	LO	NLO	LO	NLO	LO	NLO	LO	NLO
(a)	22.7	32.3	73	64	65.6	64.0	66	61
(b)	19.0	21.7	61	46	56.8	48.1	57	46
(c)	14.7	21.4	47	45	31.1	34.0	31	32

Kinematics cuts:

$p_T^\ell \geq 15$ GeV
$|\eta_\ell| \leq \eta_\ell^{max}$
$\not{E}_T \geq 15$ GeV
$E_T^j \geq 15$ GeV
$|\eta_j| \leq \eta_j^{max}$
$\Delta R_{\ell j} \geq R_{\rm cut}$
$\Delta R_{jj} \geq R_{\rm cut}$

(a) loose cuts: $\eta_\ell^{\rm max} = 2.5, \eta_j^{\rm max} = 3.0,$ and $R_{cut} = 0.5$

(b) loose cuts: $\eta_\ell^{\rm max} = 2.5, \eta_j^{\rm max} = 3.0,$ and $R_{cut} = 1.0$

(c) tight cuts: $\eta_\ell^{\rm max} = 1.0, \eta_j^{\rm max} = 2.0,$ and $R_{cut} = 0.5$

The acceptances are sensitive to kinematics cuts:

- Large $R_{\rm cut}$ reduces acceptances significantly because of $\Delta R_{\ell j}$.
- With tight cuts, LO and NLO acceptances are almost same.
- With loose cuts, LO and NLO acceptances are quite different.

→ $NLO \neq LO \times K_{\rm FAC}$

→ Maximizing the acceptance.

Top quark reconstruction

- To study the kinematics and spin correlations, top quark needs to be reconstructed.

$$t \to W^+ b(g)$$

Tasks: (1) W boson reconstruction (determining p_z^ν)

$$M_W^2 = (p_e + p_\nu)^2 \longrightarrow p_{z1}^\nu \ , \ p_{z2}^\nu$$

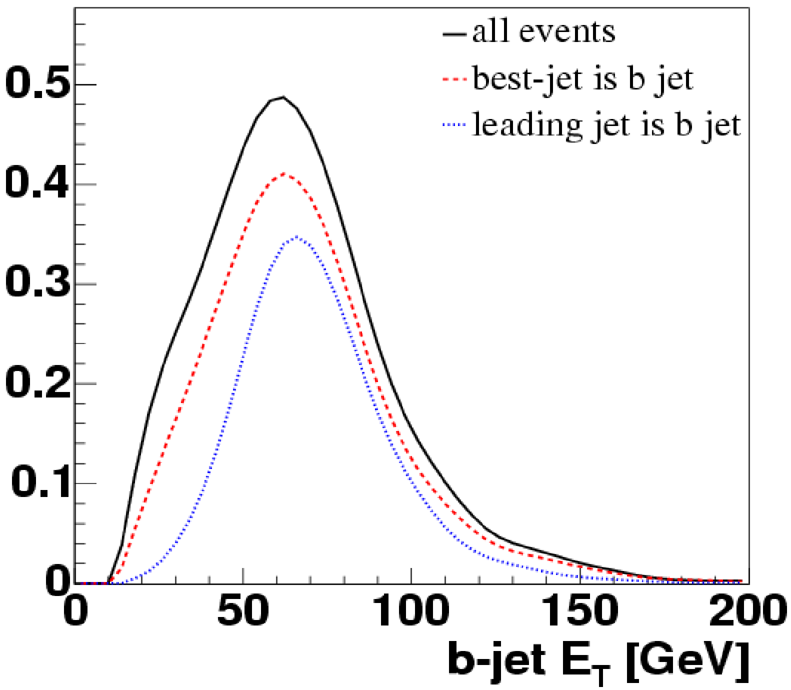
(2) Identifying b-jet (In the case of two b-jets in the final state, b-jet needs to be separated from $\bar{b}$-jet.)

- Two algorithms (determining p_z^ν based on the scenario of b identification)

	best-jet algorithm	leading b-tagged jet algorithm
b	using top mass constraint to pick up correct b-jet from top quark decay	using leading b-tagged jet to pick up correct b-jet from top quark decay
p_z^ν	smaller $\lvert p_z^\nu \rvert$	using top mass constraint to pick up correct p_z^ν
Eff. For p_z^ν	~70%	LO: 92% NLO: 84%

b identification efficiency: s-channel (two b-jets in final state)

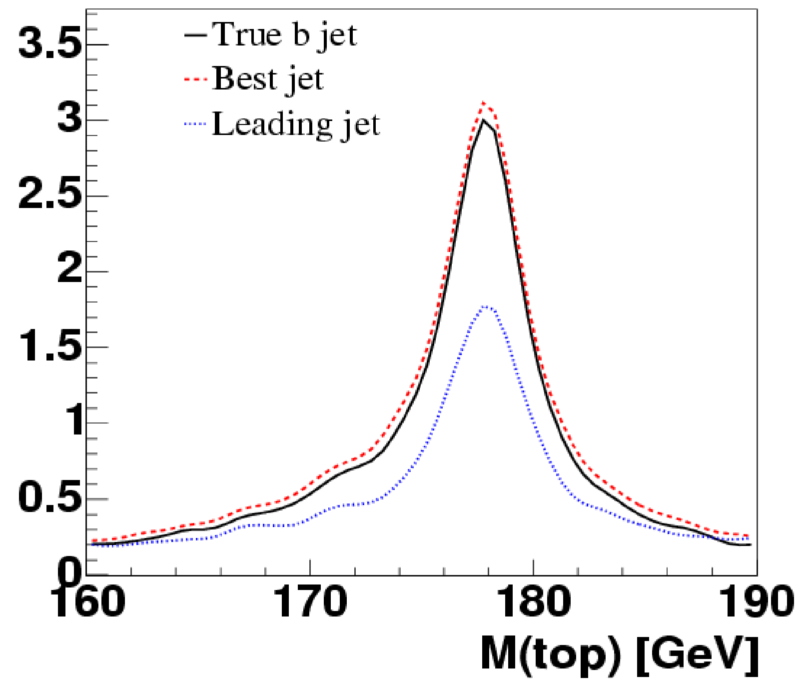
- Fraction of picking up correct b



Best-jet algorithm: 80%

Leading-jet algorithm: 55%

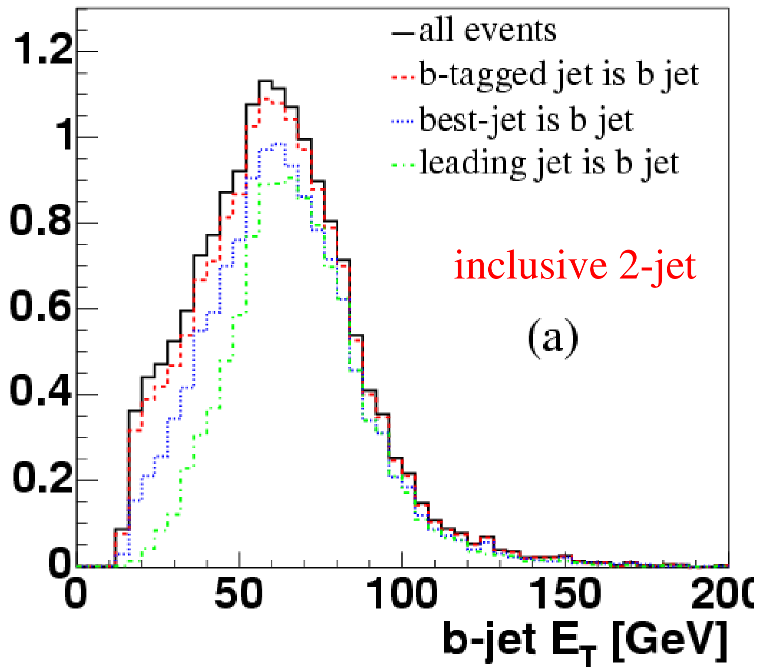
- Reconstructed top quark mass

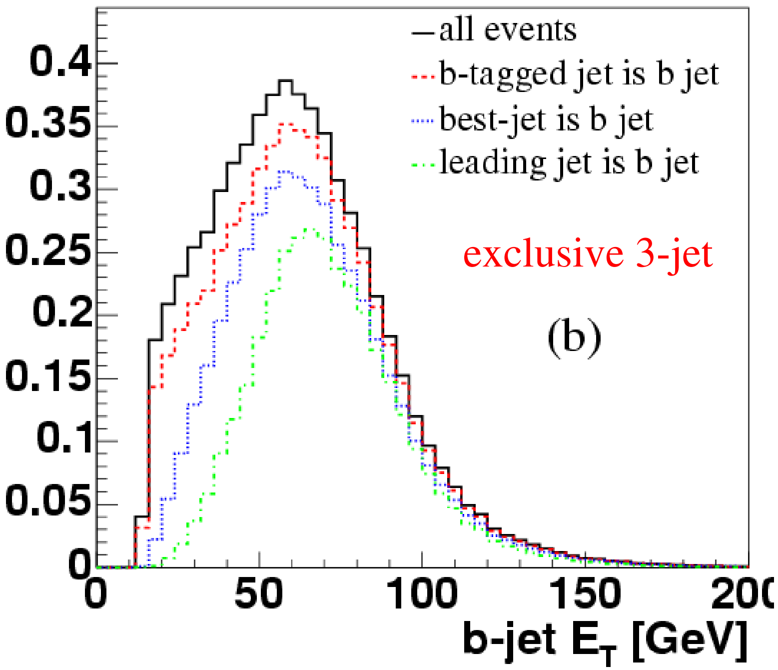


More evident

The best-jet algorithm shows a higher efficiency than the leading-jet algorithm.

b identification efficiency: t-channel (one or two b-jets in final state)

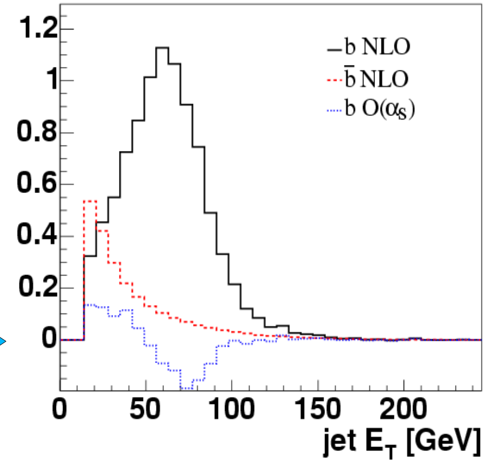




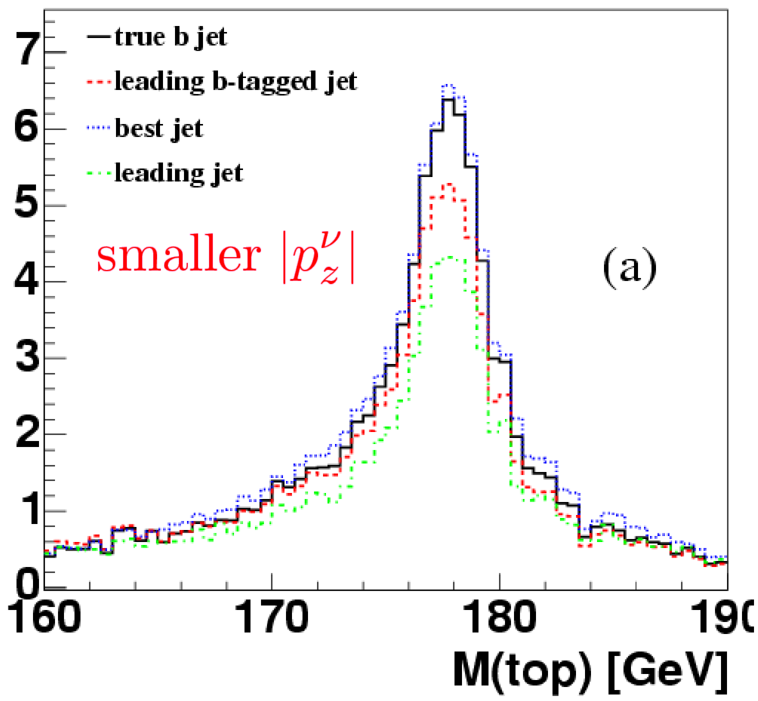
- Leading b-tagged jet corresponds to the b quark from top decay most of the time

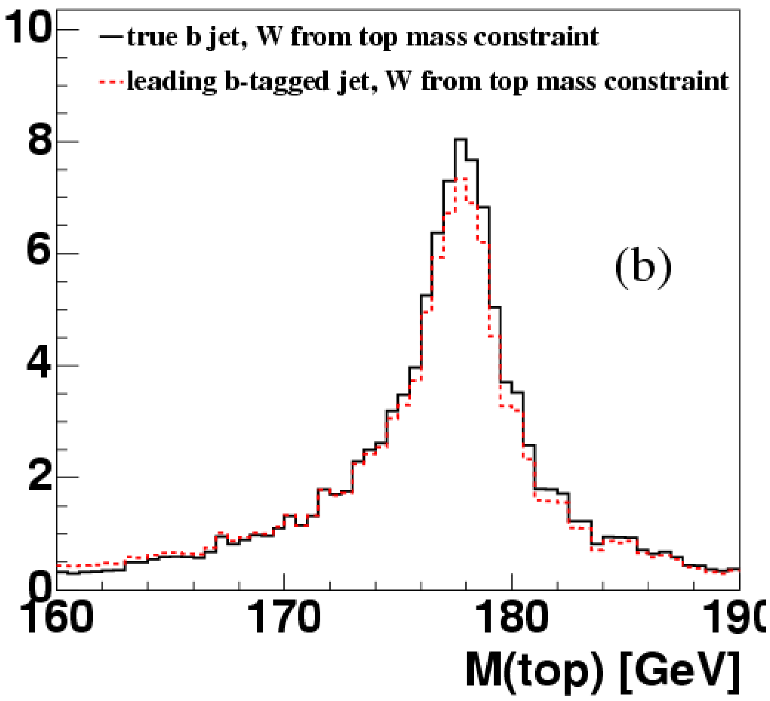
Leading b-tagged jet	Best-jet
inclusive 2-jet event: 95%	inclusive 2-jet event: 80%
exclusive 3-jet event: 90%	exclusive 3-jet event: 72%

works well due to the kinematical difference between b and $\bar{b}$



Smaller p_z^ν vs. Top quark mass constrained p_z^ν : *t*-channel





Leading jet :	worst
Leading *b*-tagged jet:	good
Best jet:	best

Best jet algorithm can pick up wrong jets to get correct top quark mass.

The overall height of the mass peak is higher than in the left figure indicating this method reconstruct *W* boson and *b*-jet correctly more often.

Top quark polarization (t-channel) : spin bases

- Helicity basis:

  tq(j)-frame

  z: along the top quark direction of motion in the c.m. frame of system

  tq-frame

  z: along the top quark direction of motion in the c.m. frame of top quark and the spectator

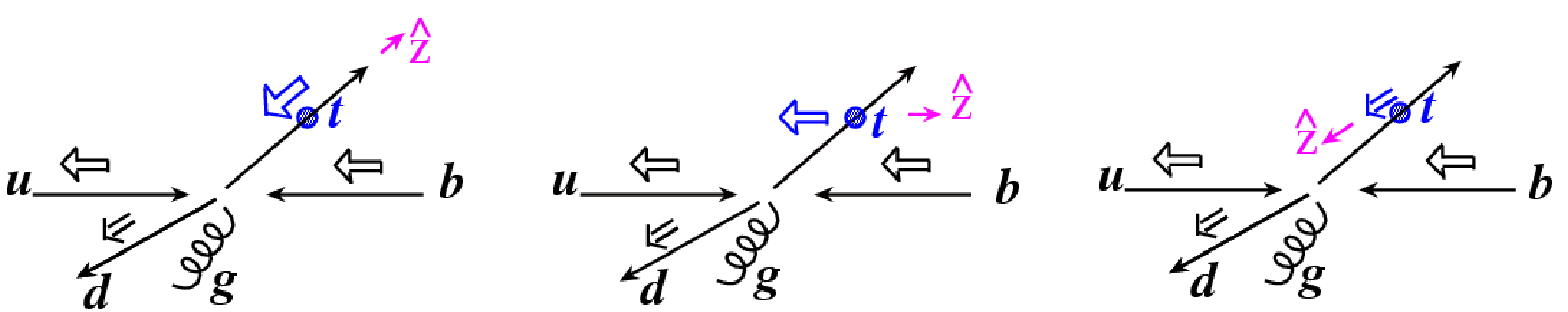
- Beamline basis:

  z: along the incoming proton direction

- Spectator basis:

  z: along the spectator direction of motion

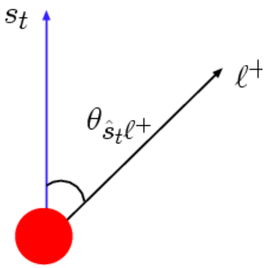
● top quark rest frame



Helicity basis　　Beamline basis　　Spectator basis

Degree and fraction of top quark polarization

- Among top quark decay products, charged lepton is maximally correlated with top quark spin.



$$\frac{1}{\Gamma}\frac{d\Gamma(t \to b\ell\nu)}{d\cos\theta} = \frac{1}{2}\left(1 + \mathcal{D}\cos\theta_{\hat{s}_t\ell}\right)$$

degree of polarization: $\mathcal{D} = \frac{N_- - N_+}{N_- + N_+}$

fraction of polarization: $\mathcal{F}_\mp = \frac{1 \pm \mathcal{D}}{2}$

		$\mathcal{D}$		$\mathcal{F}$	
		LO	NLO	LO	NLO
Helicity $tq(j)$	Parton level	0.96	0.74	0.98	0.87
	Recon. event	0.84	0.73	0.92	0.86
Helicity tq	Parton level	0.96	0.94	0.98	0.97
	Recon. event	0.84	0.75	0.92	0.88
Spectator	Parton level	-0.96	-0.94	0.98	0.98
	Recon. event	-0.85	-0.77	0.93	0.89
Beamline	Parton level	-0.34	-0.38	0.67	0.69
	Recon. event	-0.3	-0.32	0.65	0.66

At the parton level, tq-frame have larger d.o.p. than tq(j)-frame.

After event reconstruction, tq-frame and tq(j)-frame have almost the same d.o.p.

Helicity basis (tq-frame) give almost the same d.o.p. as the spectator basis.

☞ Beamline basis gives the worst degree of polarization of top quark.

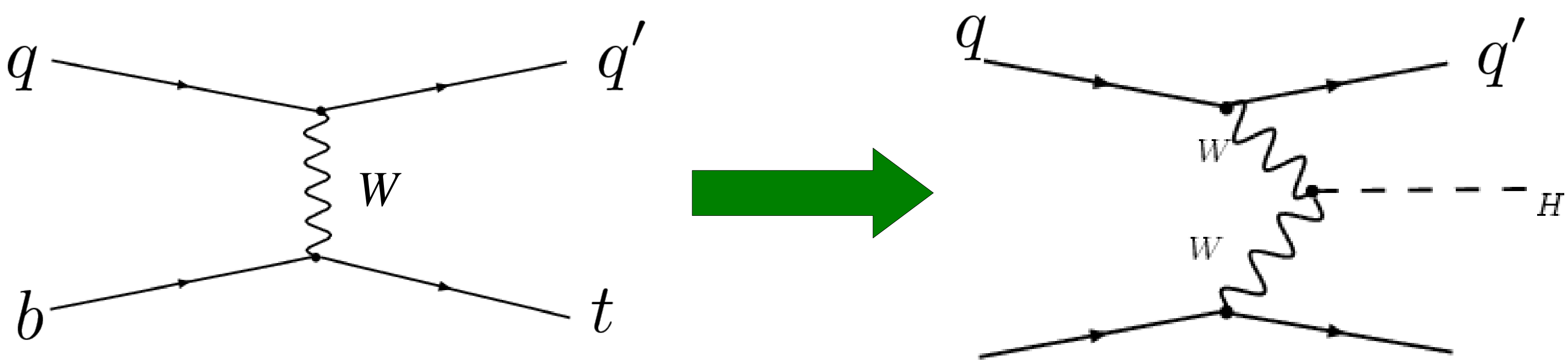
☞ High order QCD corrections blur the spin correlation effect.

Connection to Higgs boson search at LHC: light forward jet

- Asymmetric rapidity distribution of the spectator jet

  (Unique signature at Tevatron)

  $\Longrightarrow$ Its kinematics needs to be well studied.

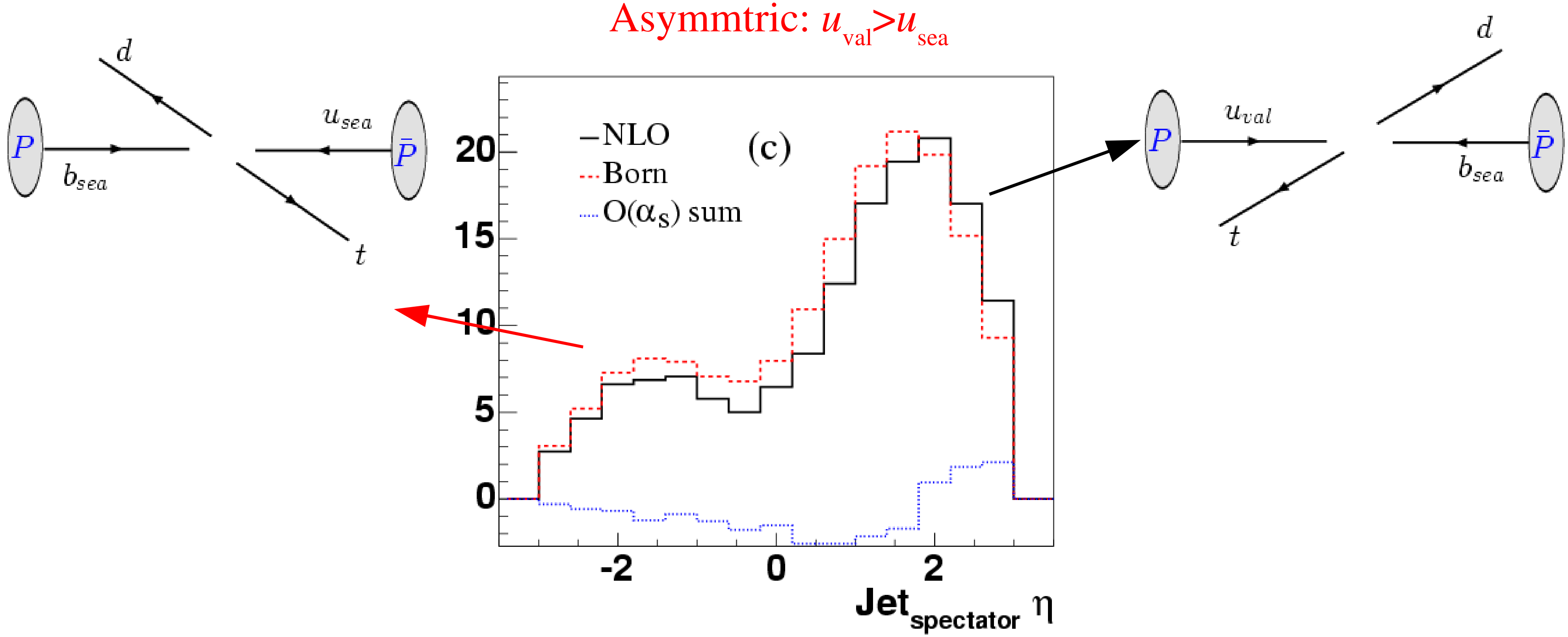
- 

To determine WWH coupling in W-fusion process

➡ needs to know forward jet detection efficiency

Rapidity distribution of the spectator jet at NLO: (t-channel)

Asymmtric: $u_{val}>u_{sea}$

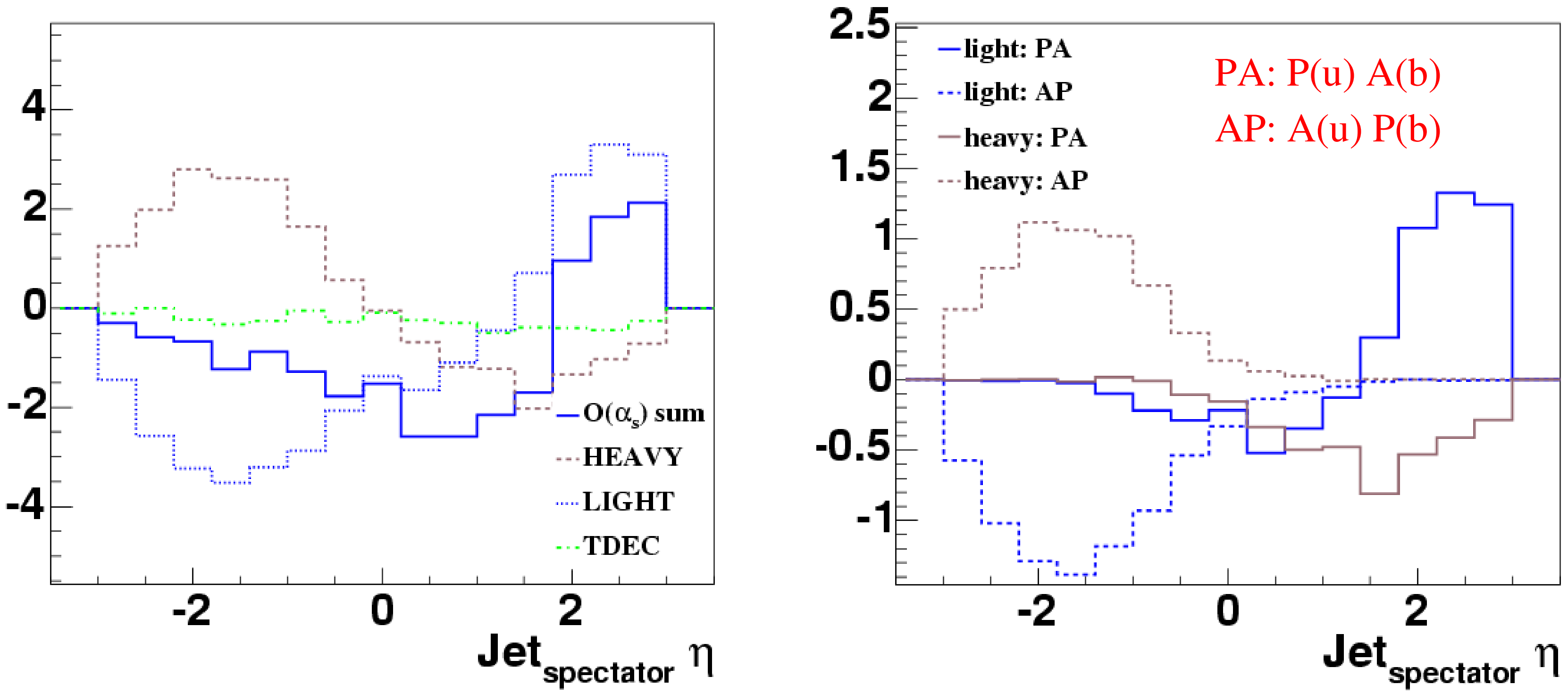


- The $O(\alpha_s)$ corrections shift the spectator jet to more forward direction due to additional gluon radiation.

  ➡ imposing harder cut on spectator jet's rapidity to suppress backgrounds

- The shift is small because the $O(\alpha_s)$ corrections are small.

Why so?



- LIGHT and HEAVY corrections have almost opposite behaviors.
- LIGHT shifts the spectator jet to the forward direction
  while HEAVY shifts it to the central region.
- TDEC contribution does NOT change the distribution.

Summary and outlook

❶ With loose kinematics cuts to maximize the acceptance, the full NLO kinematics needs to be studied. (A constant *K*-factor with LO kinematics won't work.)

❷ In order to reconstruct top quark event, the best-jet algorithm is better in the *s*-channel process, while the leading *b*-tagged jet algorithm is best in the *t*-channel process.

❸ Higher order corrections modify the kinematics and spin correlations.

After event reconstruction, for the degree of polarization of top quark,

Optimal basis $\simeq$ Helicity basis (*tb*-frame) in *s*-channel

Spectator basis $\simeq$ Helicity basis (*tq*-frame) in *t*-channel

❹ To determine *WWH* coupling in *W*-fusion process,

⇒ needs to study forward jet detection efficiency in the *t*-channel single top process.