A jet substructure in hadronic decay of boosted top quarks

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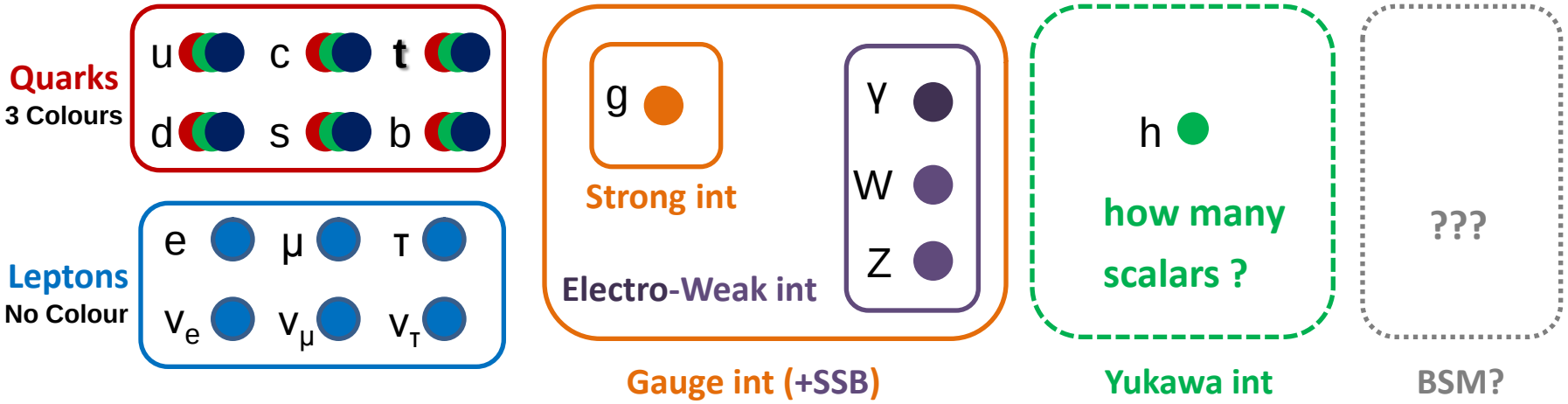
Top quark in SM

- Top quark



- Mass and width

Mass (pole) = 173.21±0.51±0.71 [GeV]

Mass(MS) = 160 +5-4 [GeV]

Mt - Mt̄ = - 0.2 ±0.5 [GeV]

Width = 1.41±0.2 [GeV]

PDG 2014

Heaviest in SM !

Stability of Higgs potential

CPT invariance

Weak vertex

Unique Nature of Top

- Top decay (100% t → bW)

$$\Gamma(t \to bW)_{\mathrm{SM}} = \frac{G_F m_t^3 |V_{tb}|^2}{8\pi\sqrt{2}} \simeq 1.5\ \mathrm{GeV} > \Lambda_{\mathrm{QCD}} \simeq 0.2\ \mathrm{GeV}$$

Life time vs. Hadronisation time

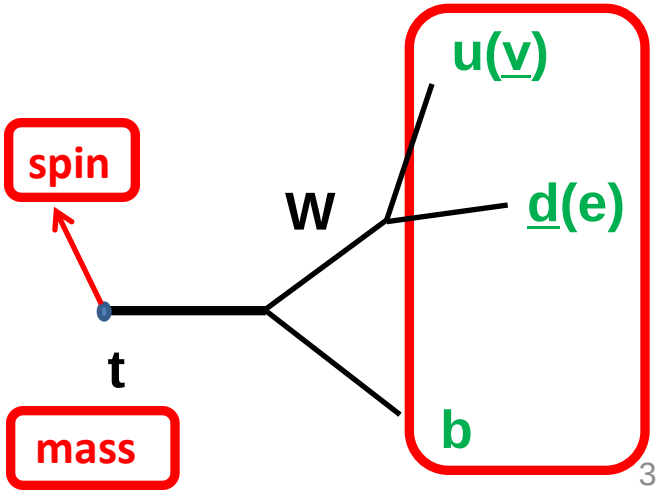
$$\tau_{\mathrm{top}} = 1/\Gamma < \tau_{\mathrm{had}} = 1/\Lambda_{\mathrm{QCD}}$$

- Top decays before the hadronisation:

angles, energy distribution reflects the information of the "bare top quark".

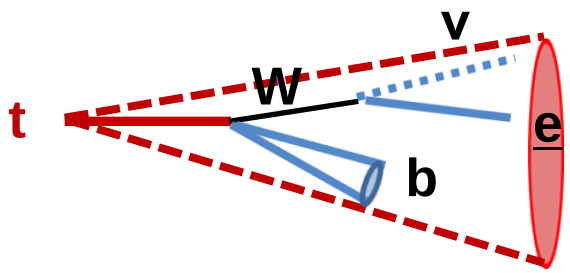
Measurement of bare quark indirectly

(different from other quarks !)

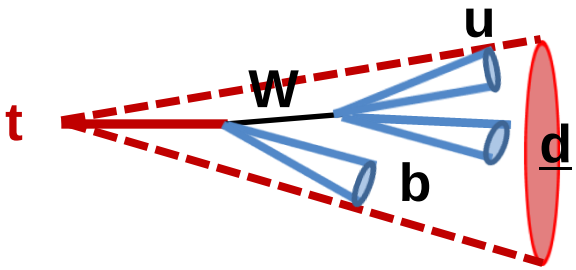


Ref. W.Bernreuther (2009)

- Decay particles from boosted top collimated in a cone.
  In such case, difficult to distinguish them from background



leptonic top decay (1-jet)
No isolated lepton !

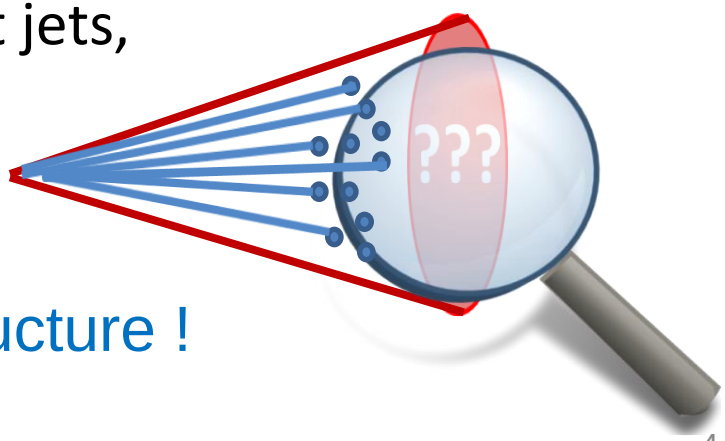


hadronic top decay (3-jets)
Collimated jet structure !

- We need information more about jets, especially inside of jets.

Take a look at a detail in the jet

= Study of the Jet Substructure !



Motivation

- Highly boosted top:

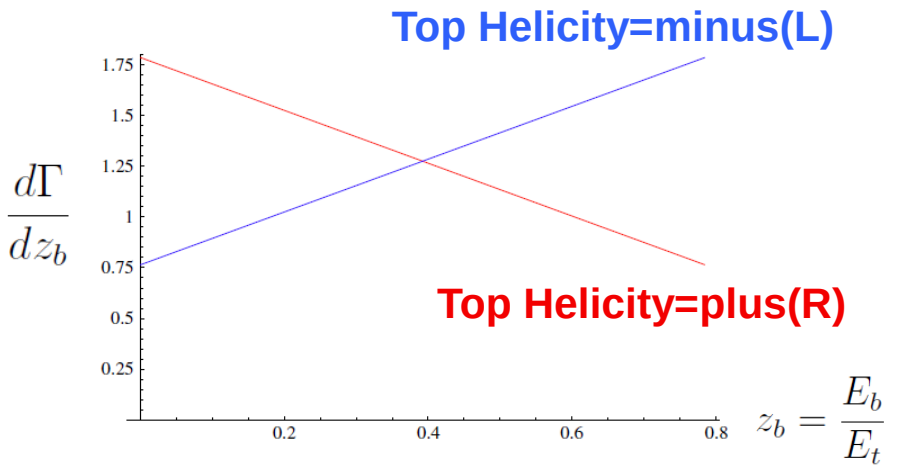
  Helicity plus(minus) = Chirality R(L).

  → Useful to study chiral structures in top sector !

- Helicity dependence in top decay:

  J.Shelton. PRD79 014032 (2009)

  - top→ b + lep + ν
  - boosted top (β=1)
  - Helicity dependence in energy distributions

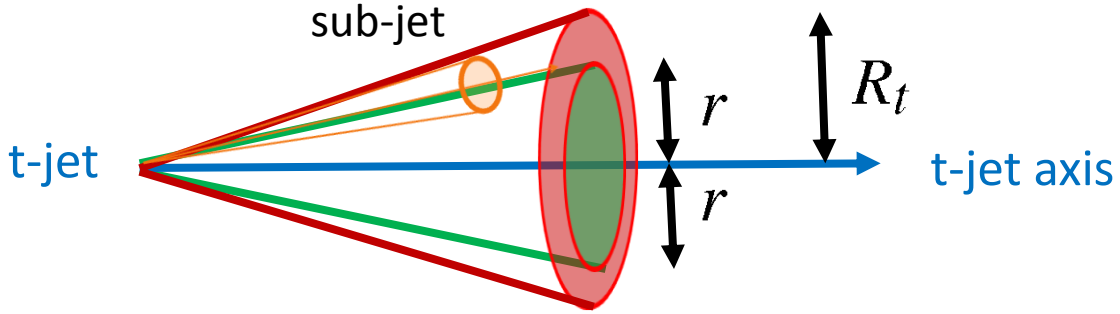


- Is there any such a difference (R and L) in a jet substructure in top decay ?

Jet energy profile (one of jet substructures)

S.D.Ellis, Z.Kunszt, D.E.Soper, PRL69,3615 (1992)

- Consider a small cone (angle r: $0 < r < R_t$) in top-jet.
  Accumulate the sub-jet energy in the small cone.



$$\text{Ratio}(E_{J_t}, R_t, r) \equiv \frac{\text{Jet (transeverse) energy in cone } r}{\text{Jet (transverse) energy in cone } R_t}$$

(Jet energy profile)

- This ratio describes a ”spread” of the accumulation of the sub-jet energy in the small cone r.
- Its derivative describes is also useful.

Information of Jets

- "**Jet functions**" **{J_t, J_b, J_W }** contain information of each jets:

$$J_t(m^2_{J_t}, E_{J_t}, R) = \int dm^2_{J_W} dE_{J_W} d^2\hat{n}_{J_W} \int dm^2_{J_b} dE_{J_b} d^2\hat{n}_{J_b} H_t \times J_W(m^2_{J_W}, E_{J_W}, R) J_b(m^2_{J_b}, E_{J_b}, R) \times \delta\left(m^2_{J_t} - (k_{J_W} + k_{J_b})^2\right) \delta\left(E_{J_t} - E_{J_W} - E_{J_b}\right) \times \delta^{(2)}\left(\hat{n}_{J_t} - \frac{\vec{k}_{J_W} + \vec{k}_{J_b}}{|\vec{k}_{J_W} + \vec{k}_{J_b}|}\right).$$

"**Hard kernel**" **H_t** can be extracted from Fenyman diagram of top quark decay (Leading order: LO).

- Light Jet functions (u,d,b) are evaluated at **LO to mimic NLO resummation** results by choosing a geometrical factor.

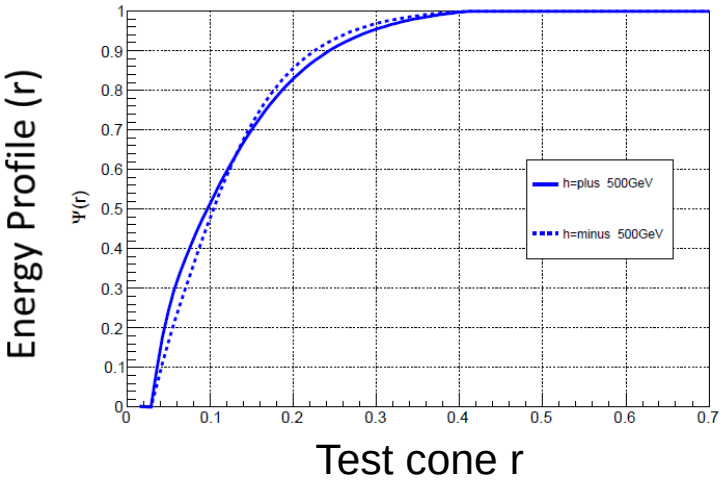
J.Issacson,C.P.Yuan, H.-n.Li, 1505.06368.

Result 1

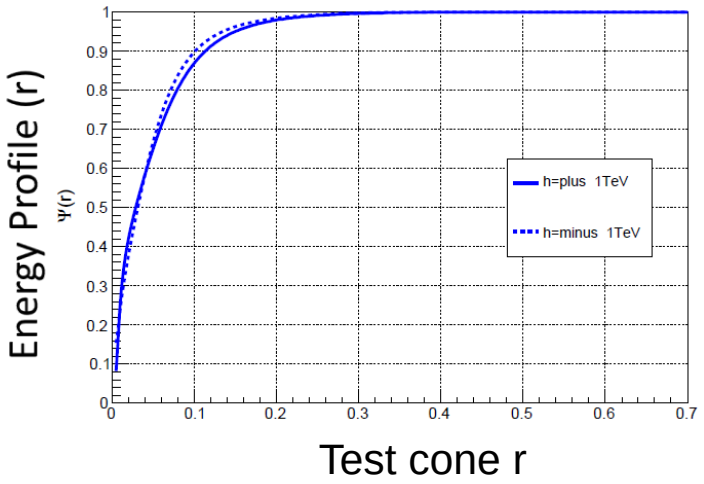
Y.K., H.-.n. Li, PRD93,054043 (2016)

- energy profile (**dash line = minus, solid line = plus**)

E_{jt} = 500 GeV (b+W jets)



E_{jt} = 1 TeV (b+W-jets)



- Smallness of helicity differences:

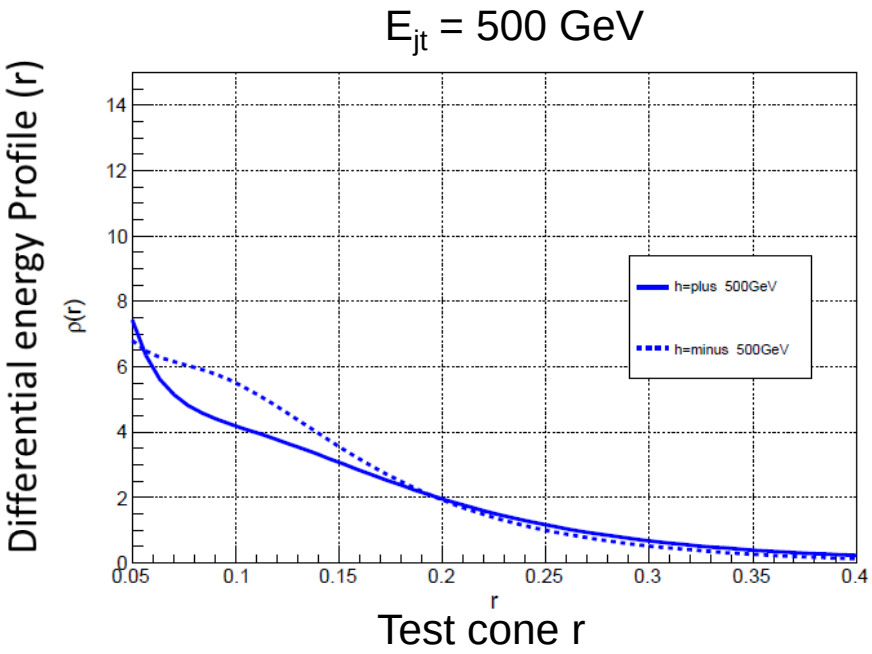
  b and W-jet have **opposite tendency** → cancellation

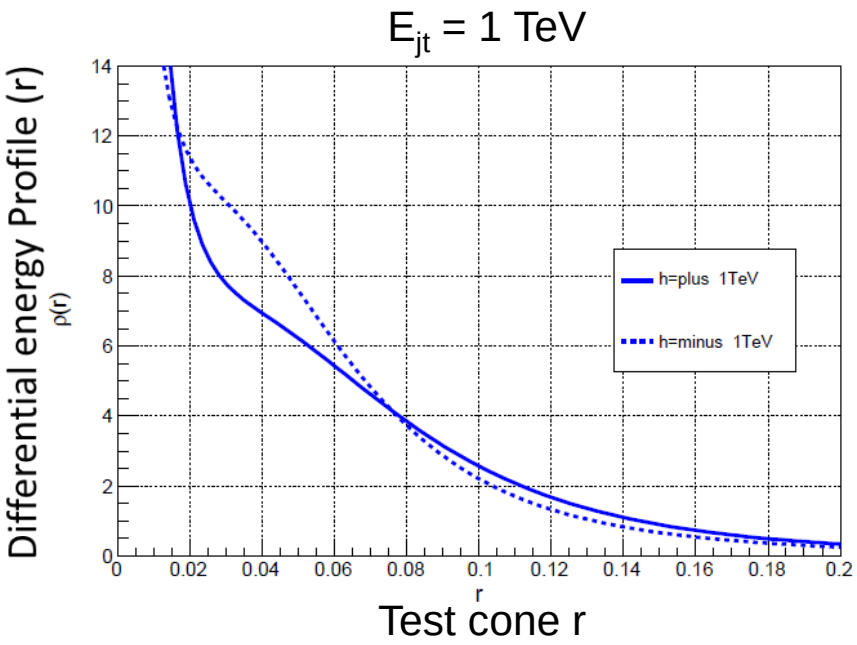
This cancellation reflects V-A structure in the weak interaction,

(b and W have **opposite decay property**)

Results 2

- differential energy profile (jet shape) will be useful:





(**dash line = minus, solid line = plus**)

- Helicity difference appears at small-r region,
  but decrease as E_{jt} increases.

Summary

- Boosted top is sensitive to chiral structures in top sector.
- We investigated a jet substructure of jets in top decay (boosted top).

- Jet energy profile and differential energy profile were studied.
- [**helicity plus > helicity minus structures**] appears at small r-region in the differential energy profile.

- Differential one will be more useful (our case),
  but challenging actual measurements at small angle region.

  → **How about other jet substructures ???**

Extra Slide

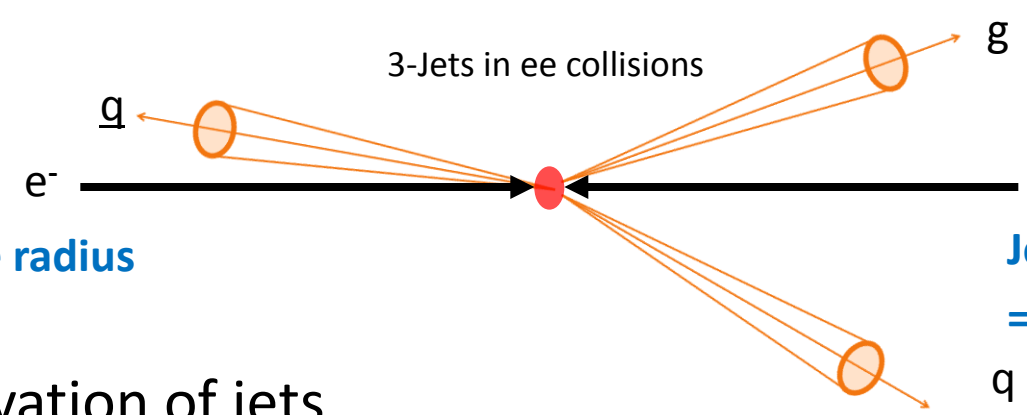
What is a jet ?

Jets = Phenomena that energetic hadrons move along an axis.
(typically we don't care the particle content)

- QCD theory for jets

G.Sterman, S.Weinberg, PRL 39,1436(1977).

Sterman (Weinberg) introduced the jets in $e^+e^- \rightarrow$hadrons process within QCD.



Jet energy
= (Σ energy in cone)

Jets have radius

Jet mass
= (Σ momenta in cone)²

- Observation of jets

Experimentally, 2jets at SPEAR(SLAC), 3-jets(qq̄+g) at PETRA

(3-jets contribute to the "discovery" of gluon)

G.Hanson et al, PRL 35,1609(1975).

TASSO, MARK, PLUTO, JADE (1979-1980).

Top decay property

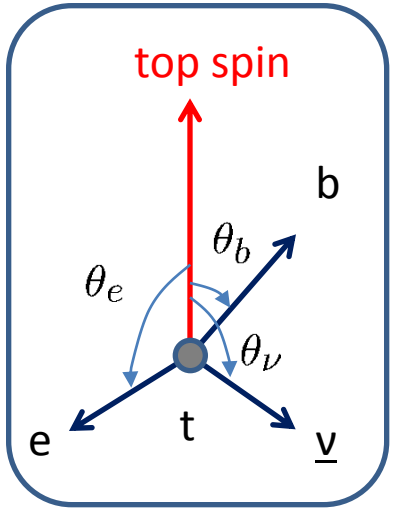
- Why is **Left (h=minus)** larger than **Right (h=plus)** ?

→ Angular distribution is related to **V-A interaction**

- Let's start with top spin (spin analysing power κ_i) at the rest frame of top.

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_i} = \frac{1}{2}(1 + \kappa_i \cos\theta_i) \qquad \langle\cos\theta_i\rangle = \frac{\kappa_i}{3}$$

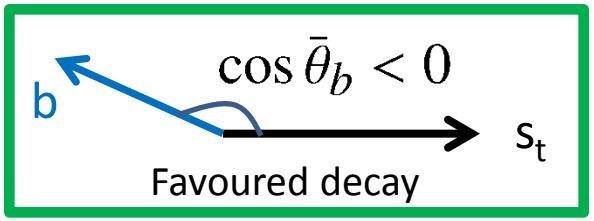
Spin analyzing power

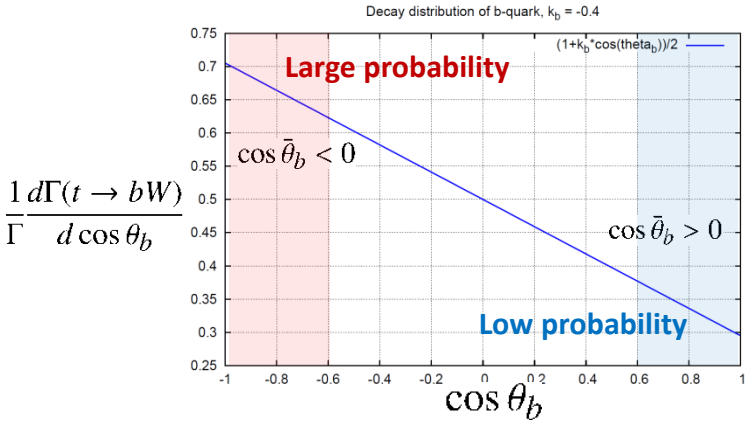


	lep	d	u	b	J_{least}	J_{thrust}
κ_i	0.999	0.97	-0.31	**-0.37**	0.47	-0.31

Brandenburg,Si,Uwer (2002),
Fisher,Groote,Koerner,Mauser,Lampe (1999).

- b-quark goes to opposite direction to t-spin:

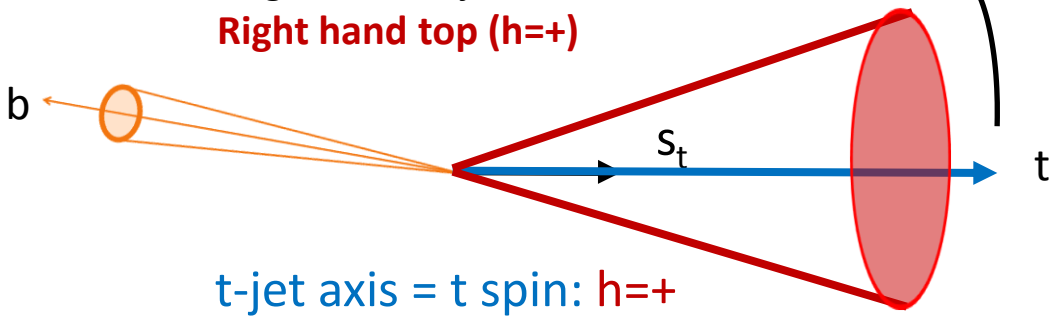




- Small (or middle) boost for top quark:

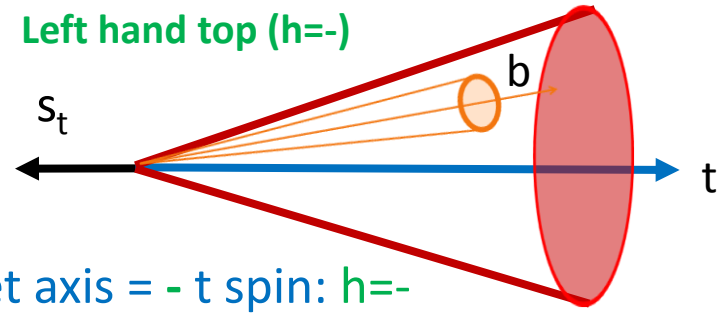
b-quark has a smaller chance to go into the jet cone for **Right hand top (h=+)**

Integration range



t-jet axis = t spin: h=+

b-quark has a larger chance to go into the jet cone for **Left hand top (h=-)**

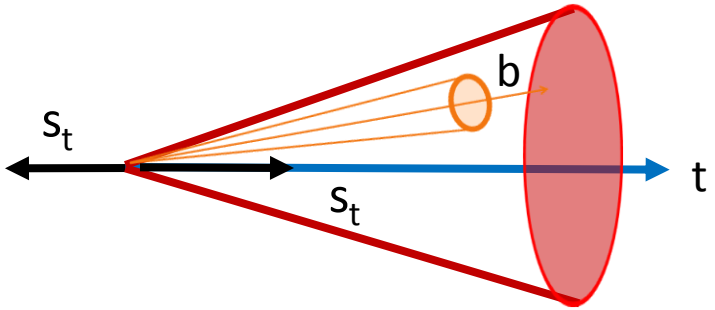


t-jet axis = **-** t spin: h=-

- Large boost for top quark:

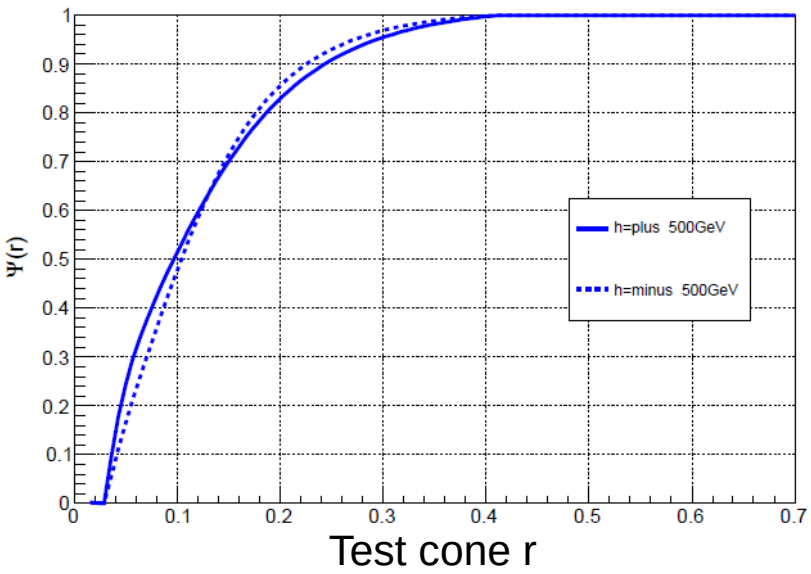
Both R and L go into the jet cone

→ **No difference between R and L for favoured angle of b-quark**



- Smallness of helicity difference in top jets energy profiles

E_{jt} = 500 GeV (b+W jets)

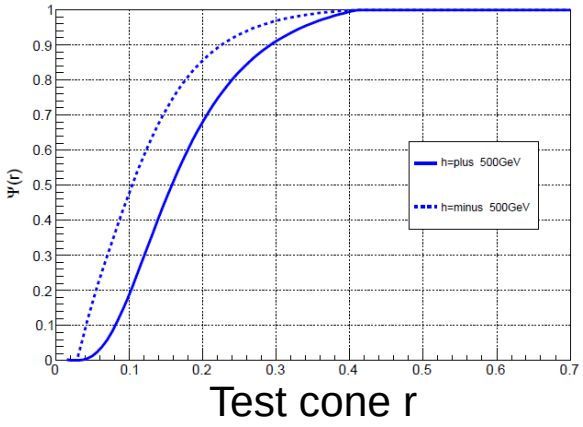


dash = top helicity (neg)

solid = top helicity (pos)

b-jet (500 GeV) ← **cancellation** → W-jet (500 GeV)

=



+