Jet Substructures of boosted hadronic tops

Hsiang-nan Li

Academia Sinica

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In collaboration with Yoshio Kitadono

Outlines

- Review of boosted leptonic tops
- Boosted hadronic tops
- Top jet energy profiles
- Conclusion

Kitadono, Li,1403.5512

Review of boosted leptonic tops

Theoretically easy, but
experimentally hard

Boosted heavy particles

- Heavy particles (Higgs, W, Z, top, new particles) may be produced with large boost at LHC
- Decaying heavy particle with sufficient boost gives rise to a single jet
- If just measuring invariant mass, how to differentiate heavy-particle jets from ordinary QCD jets? How to reveal properties of heavy particles?
- Use different jet substructures resulting from different weak and strong dynamics

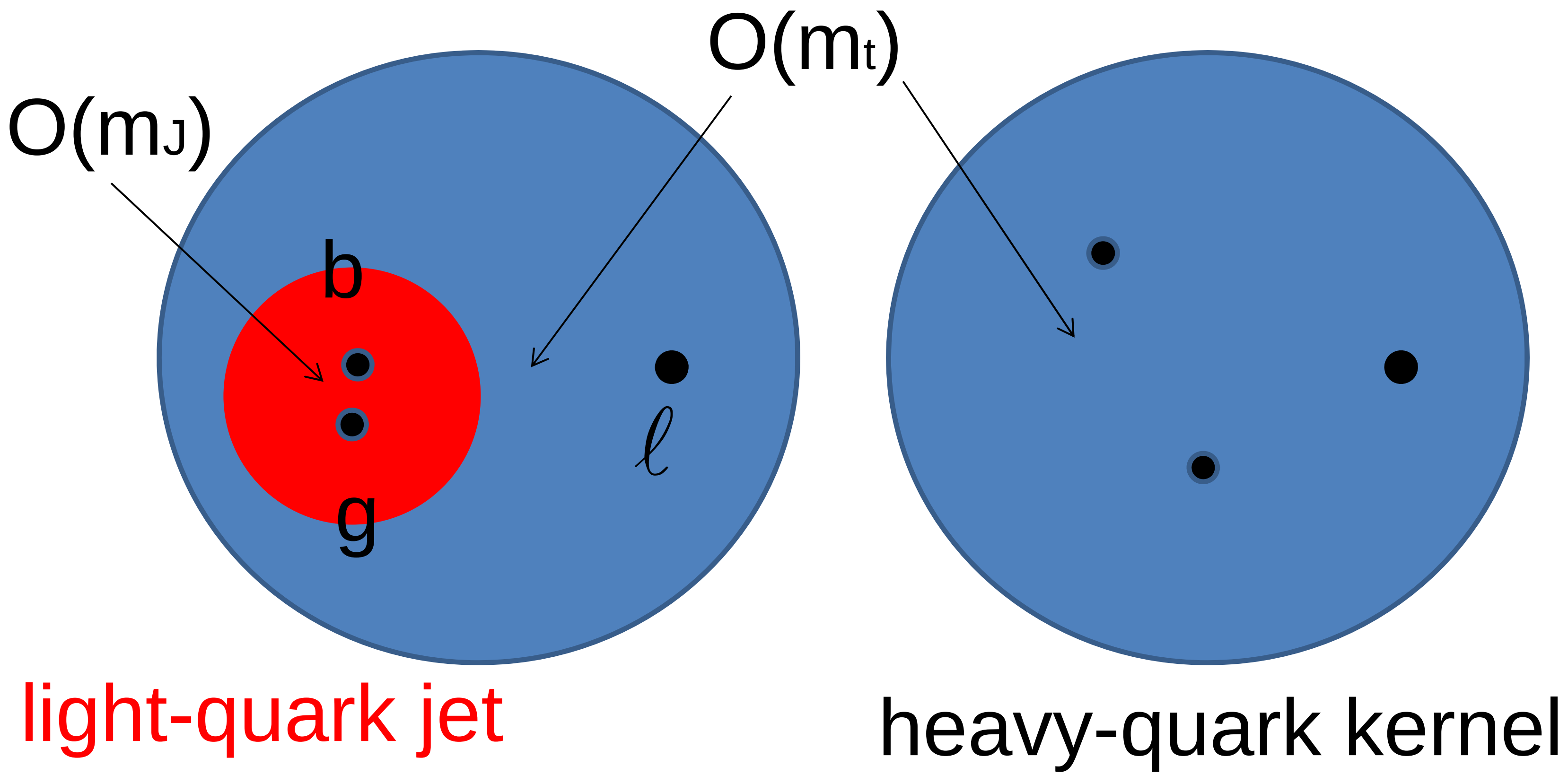
Chirality vs helicity

- BSM heavy particles decay into boosted tops
- Chirality of BSM physics revealed by helicity of boosted tops
- How to determine helicity of boosted tops?
- Polarization of rest top determined by angular distribution of decay products
- Propose to measure jet substructures---energy profiles depend on helicity
- Require no b-tagging, W reconstruction

Review articles: F.-P.Schilling (2012), W.Bernreuther (2008), etc.

Scale hierarchy $E \gg m_t \gg m_J$

- The two lower scales m_t and m_J characterize different dynamics, which can be factorized



Spin decomposition and boost

- Spin projector $w_t = \frac{1}{2}(\mathbf{1} + \gamma^5 \not{s}_t), \quad \bar{w}_t = \frac{1}{2}(\mathbf{1} - \gamma^5 \not{s}_t),$

Unpol. = spin up + spin down

$$(\not{k}_t + m_t) = (\not{k}_t + m_t) w_t + (\not{k}_t + m_t) \bar{w}_t$$

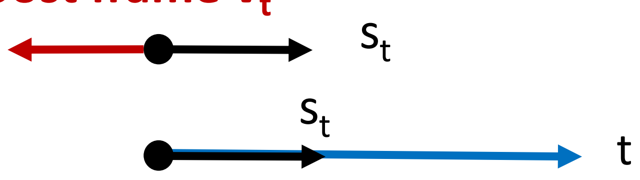
- **Easier to work in rest frame of top first, and then boost**
- **Helicity** (+ or R, - or L) and **Boost** from Lorentz transformation

$$s_t^\mu = (0, 0, 0, 1)$$

Z axis = top spin direction

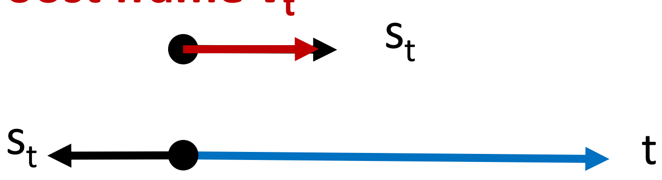
J. Shelton,
PRD 79, 014032 (2009)

Boost frame v_t



Right-handed

Boost frame v_t

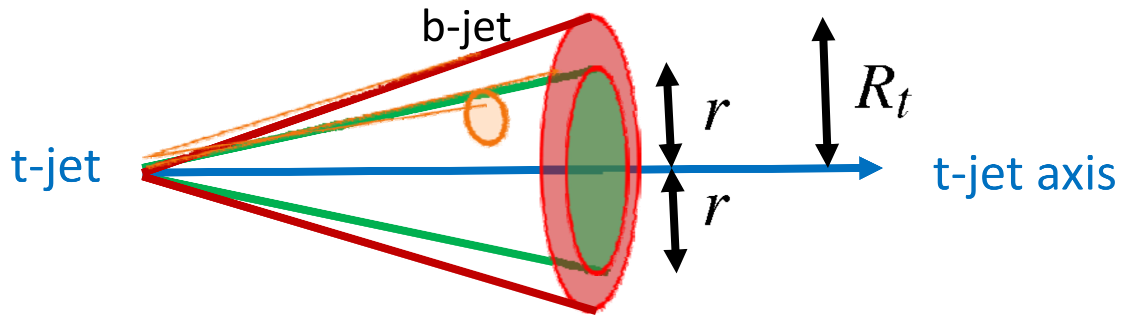


Left-handed

Jet energy profile

Li, Li, Yuan, 1206.1344

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



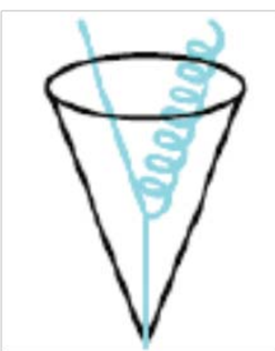
$$\text{Ratio}(E_{J_t}, R_t, r) \equiv \frac{\text{Jet (transeverse) energy in cone } r}{\text{Jet (transverse) energy in cone } R_t}$$

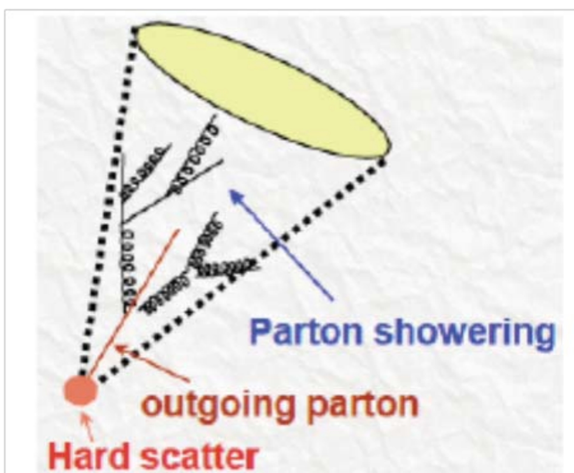
(Jet energy profile)

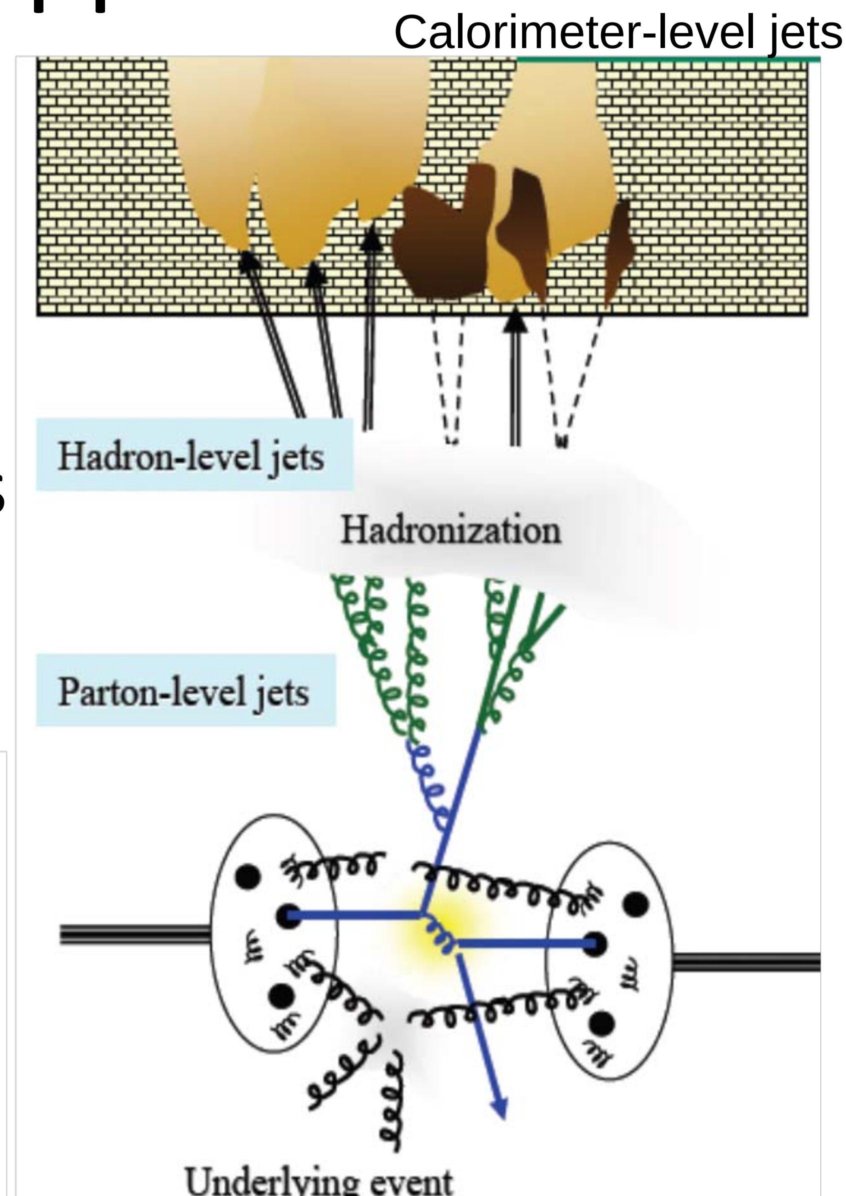
- This ratio describe a "spread" of energy in the small cone r caused by the sub-jet distribution

Resummation approach

- Monte Carlo: leading log radiation, hadronization, underlying events
- Fixed order: finite number of collinear/soft radiations
- Resummation: all-order collinear/soft radiations

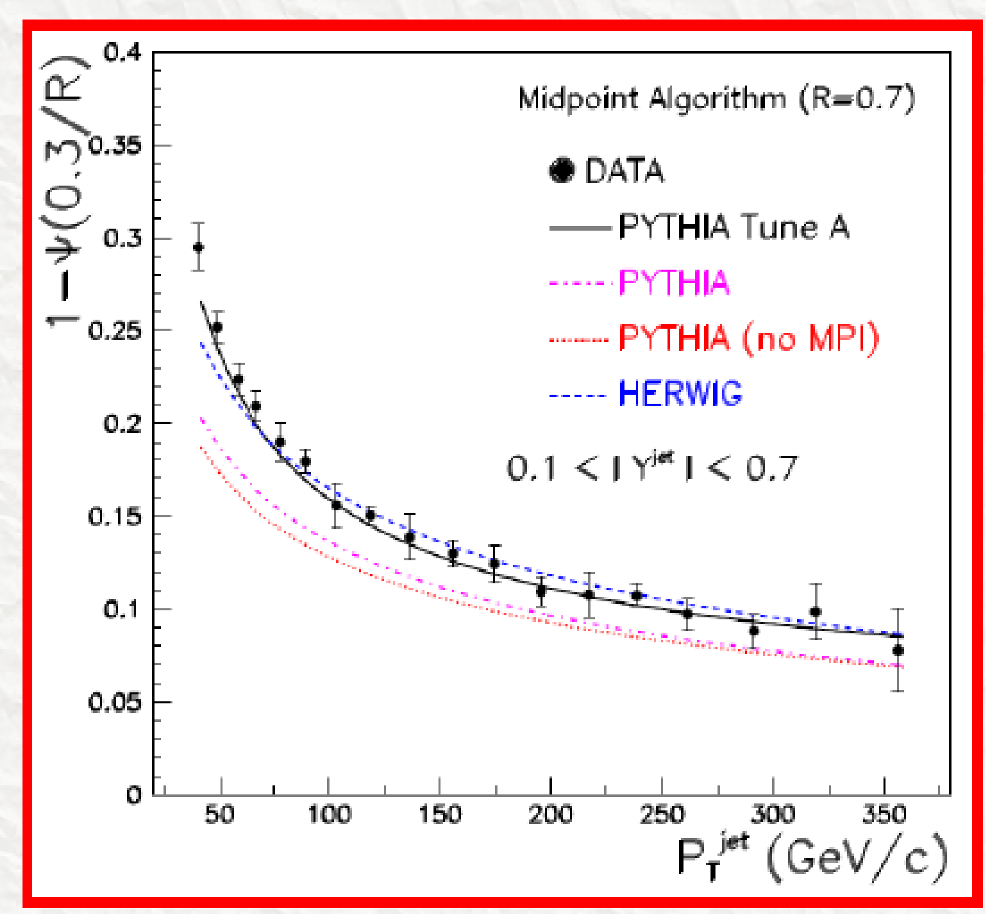






Why resummation?

- Monte Carlo may have ambiguities from tuning scales for coupling constant
- NLO is not reliable at small jet mass
- Predictions from QCD resummation are necessary

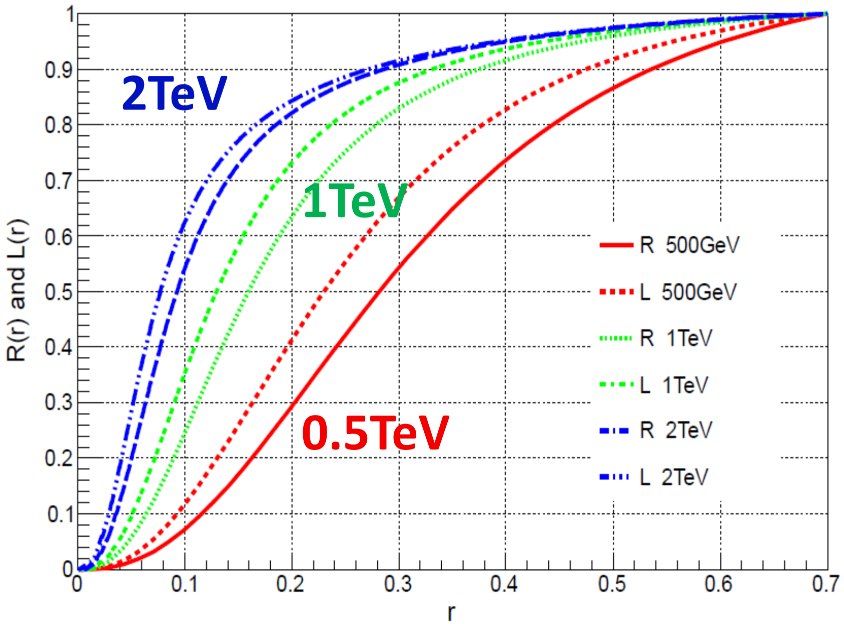


Tevatron data vs MC predictions

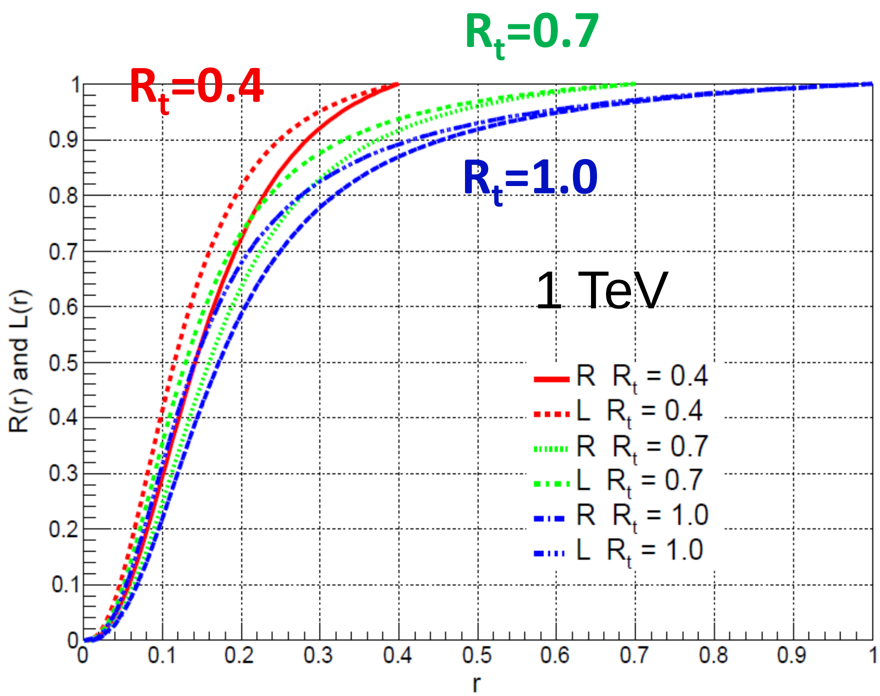
N. Varelas 2009

Top-jet energy profile

Top-jet energy dependence



Top-jet radius dependence



Left > Right due to V-A feature (b jet anti-correlated to top spin)

|L-R| difference decrease as E_{jt} increase.

Top-jet radius dependence is not significant.

Kitadono,
Li 2014

Kitadono, Li,1511.08675

Boosted hadronic tops

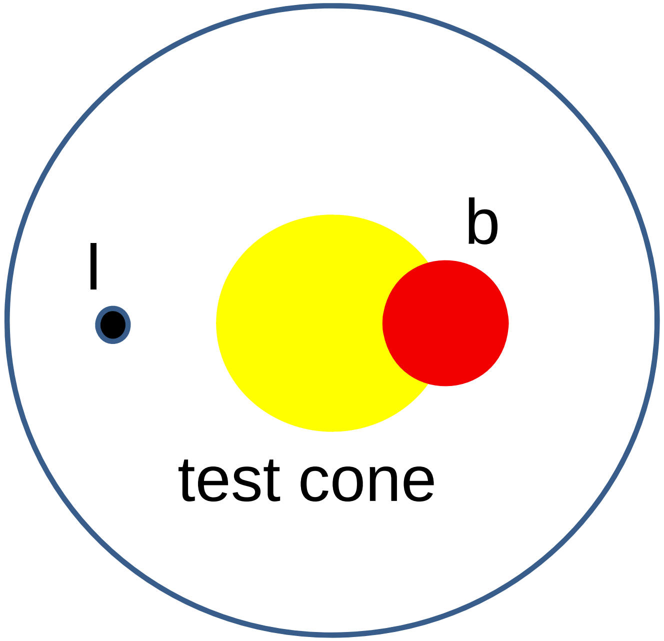
Theoretically hard, but
experimentally easy

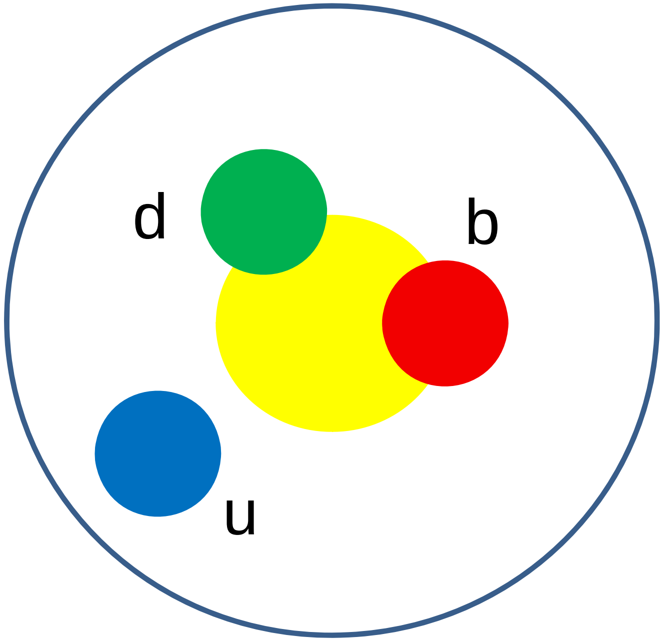
Difficulty 1

- Three-body kinematics in t -> bud
- In semileptonic decay neutrino kinematics is integrated out, basically two-body

$$k_l \sin\theta_l = k_b \sin\theta_b$$

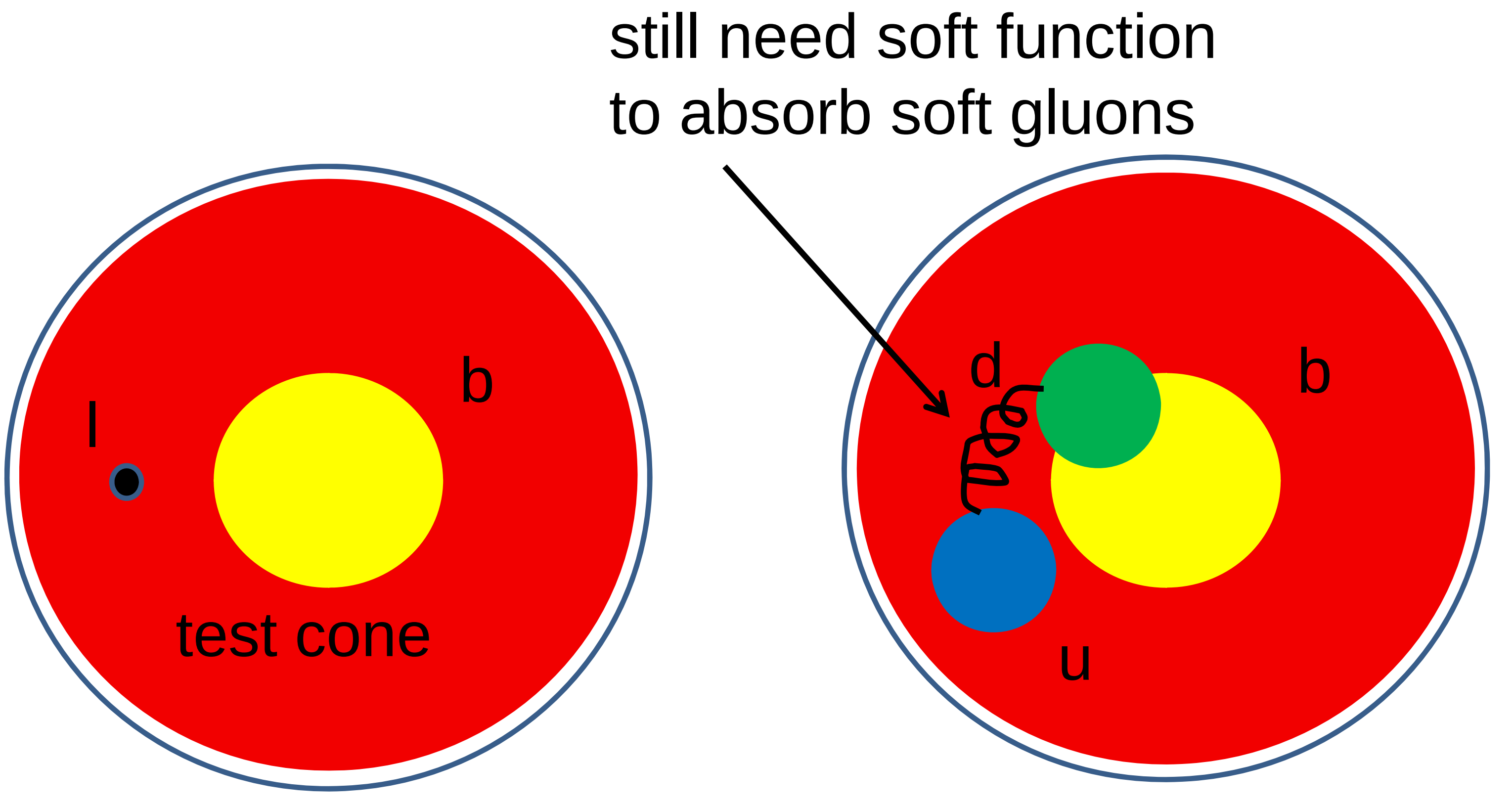
complicated angular relation





Difficulty 2

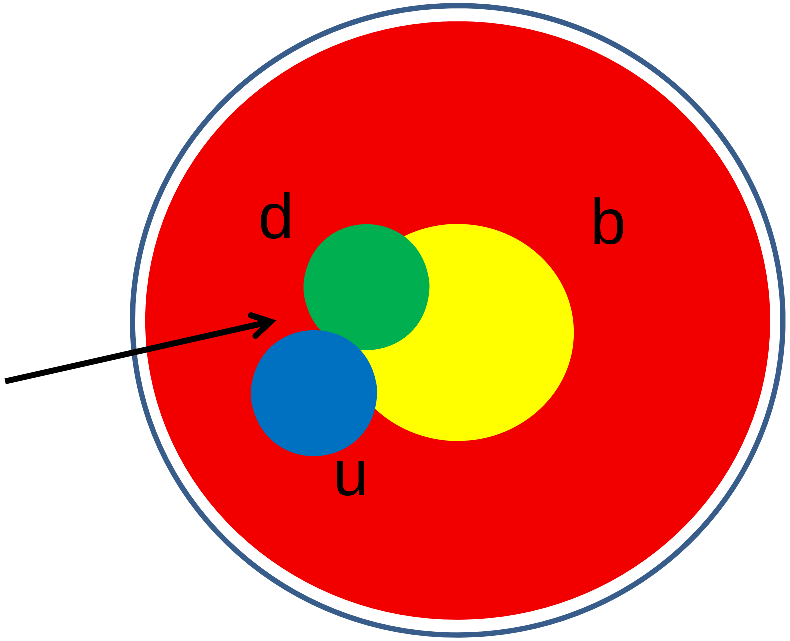
- Treatment of soft gluons
- Consider a fat b jet, which absorbs soft gluons in semileptonic case



Difficulty 3

- Jet merging
- No jet merging issue in semileptonic case
- When subjets overlap, how to count their contribution to test cone?
- Ambiguity to define subjet radii

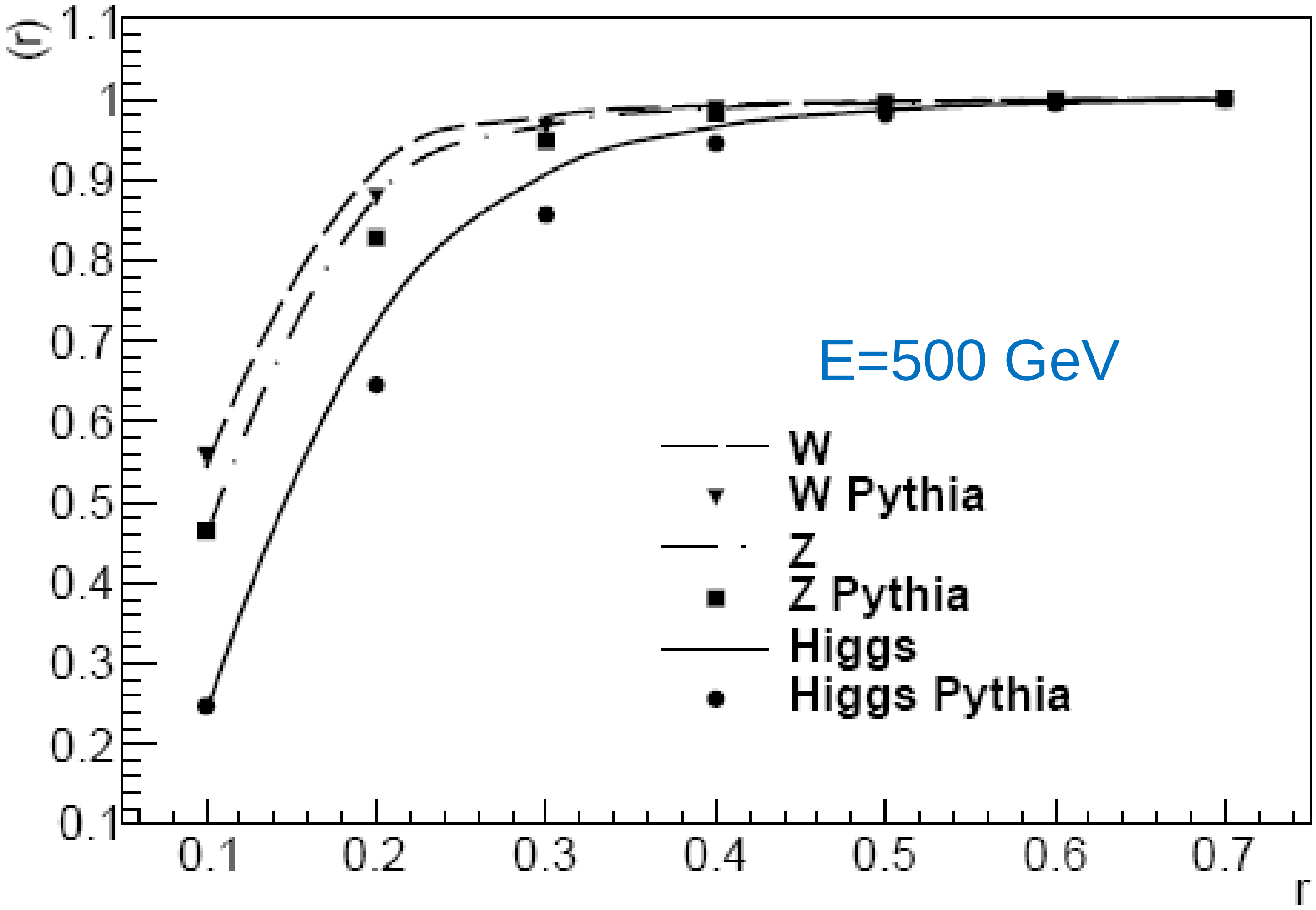
counted as single jet
or two jets?



Sequential factorization

- Factorization of top jet into fat W-boson jet, fat bottom jet, and top decay kernel
- Fat bottom jet obeys universality for leptonic (Kitadono, Li, 2014) and hadronic tops
- Factorization of fat W-boson jet into fat light-quark jet, thin light-quark jet and W decay kernel (Isaacson, Li, Li, Yuan, 2015)
- At each step of factorization, handle only two-body kinematics

Heavy-boson jet profiles



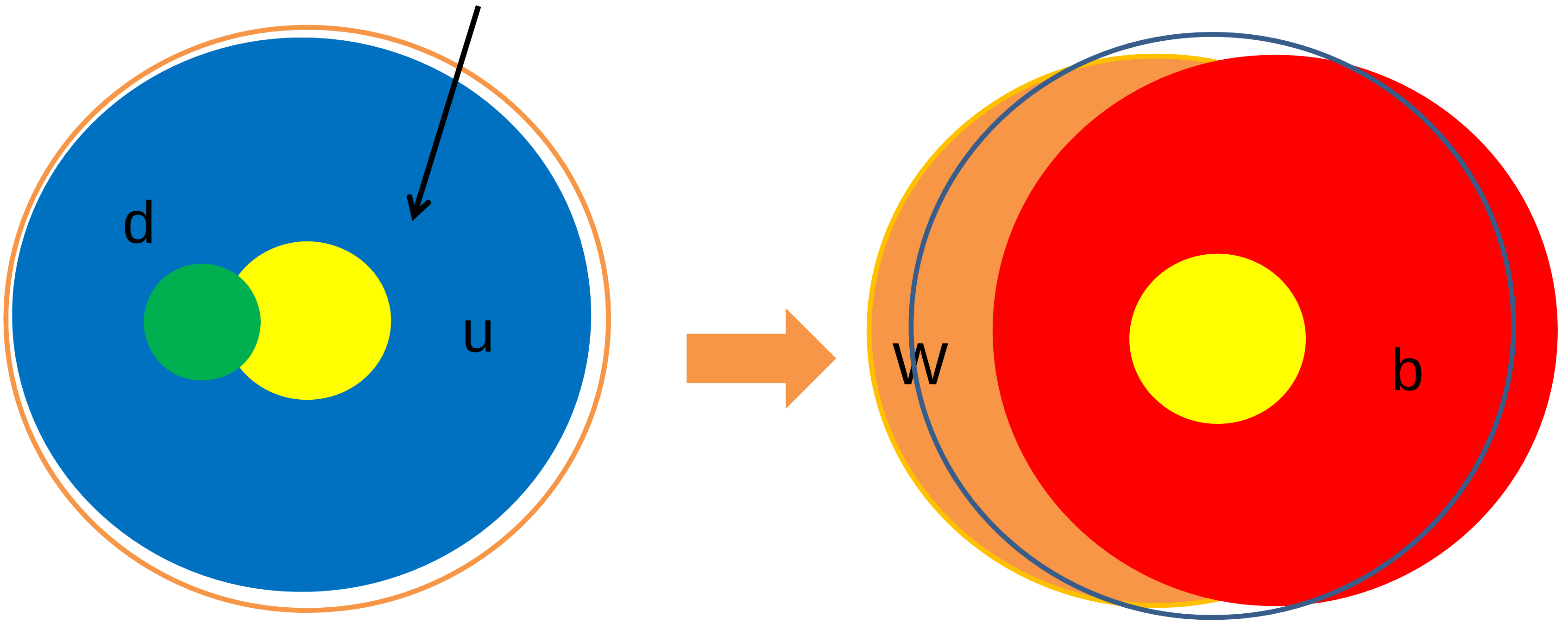
Isaacson, Li, Li and Yuan, 1505.06368

No soft function

- Construct W-boson jet

contain soft gluons

then construct top jet

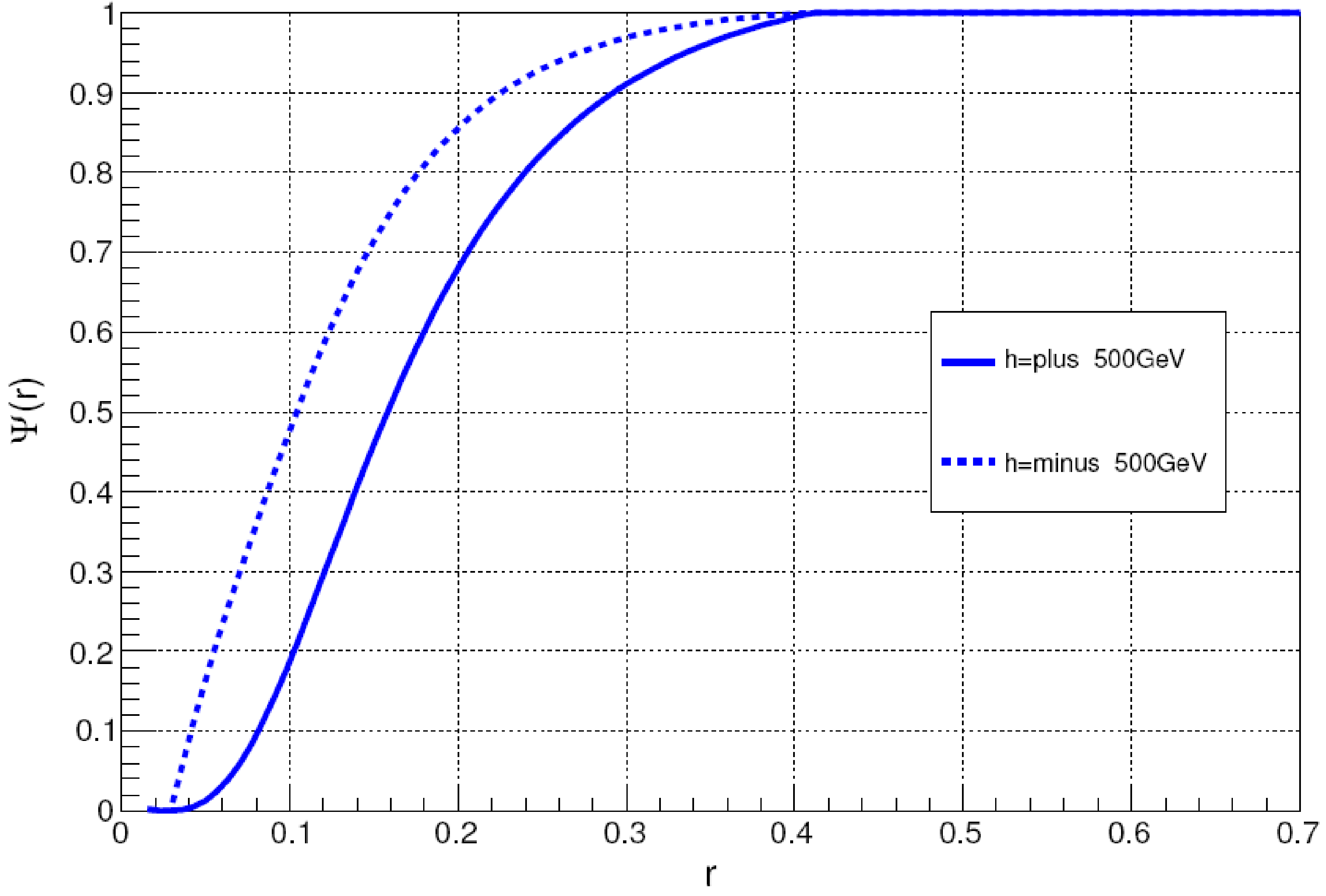


soft gluon exchanges between
b quark and color-singlet W boson
are suppressed

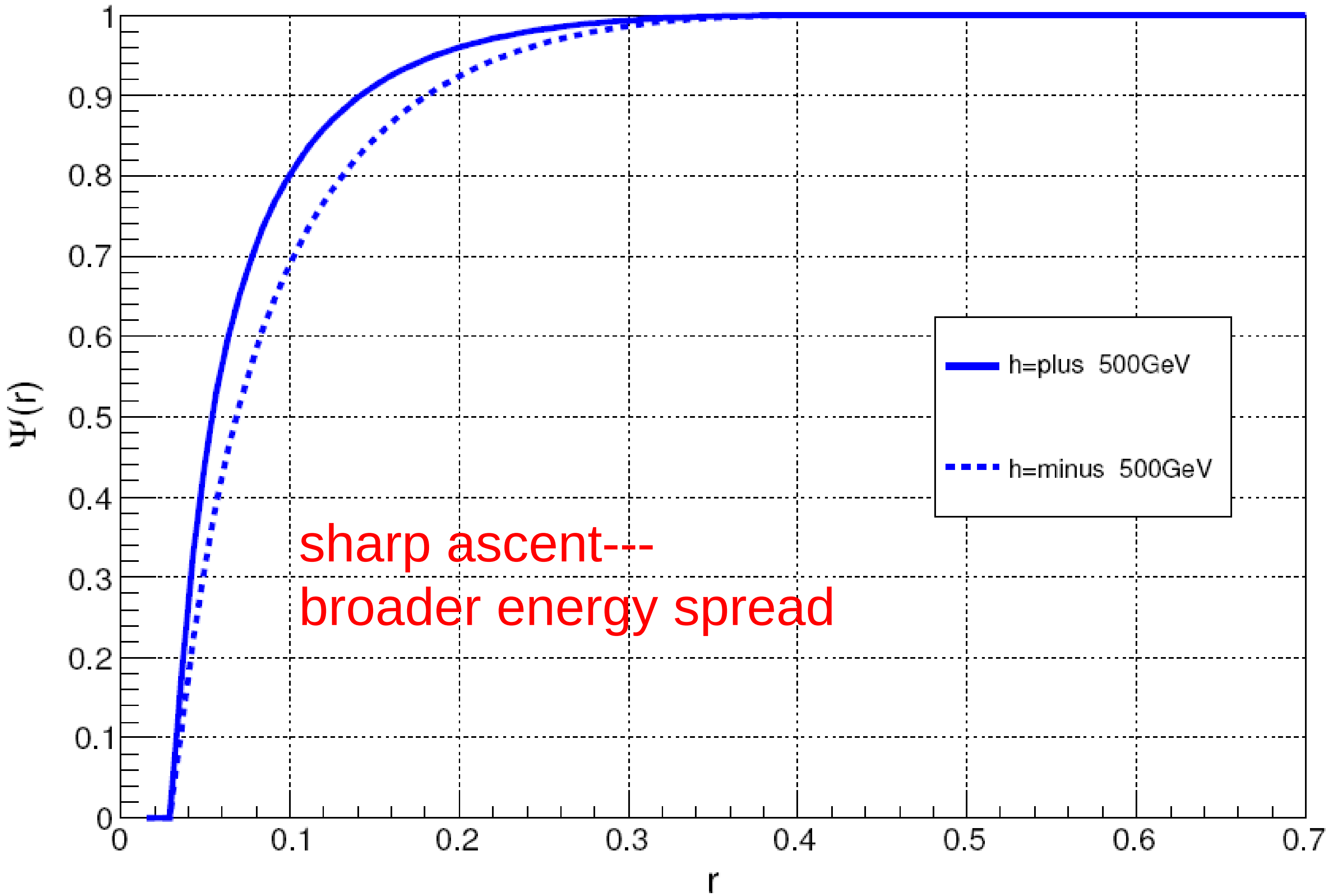
No jet merging

- Up (fat) and down (thin) jets completely overlap, no jet merging issue
- W-boson (fat) jet and bottom (fat) jet completely overlap, no jet merging issue
- Fat jet has radius R (top jet radius), and thin jet has radius r (test cone radius, focusing on energy profile at small r)
- No ambiguity to define jet radii
- Double counting of soft gluons is negligible at small r

Top jet energy profiles

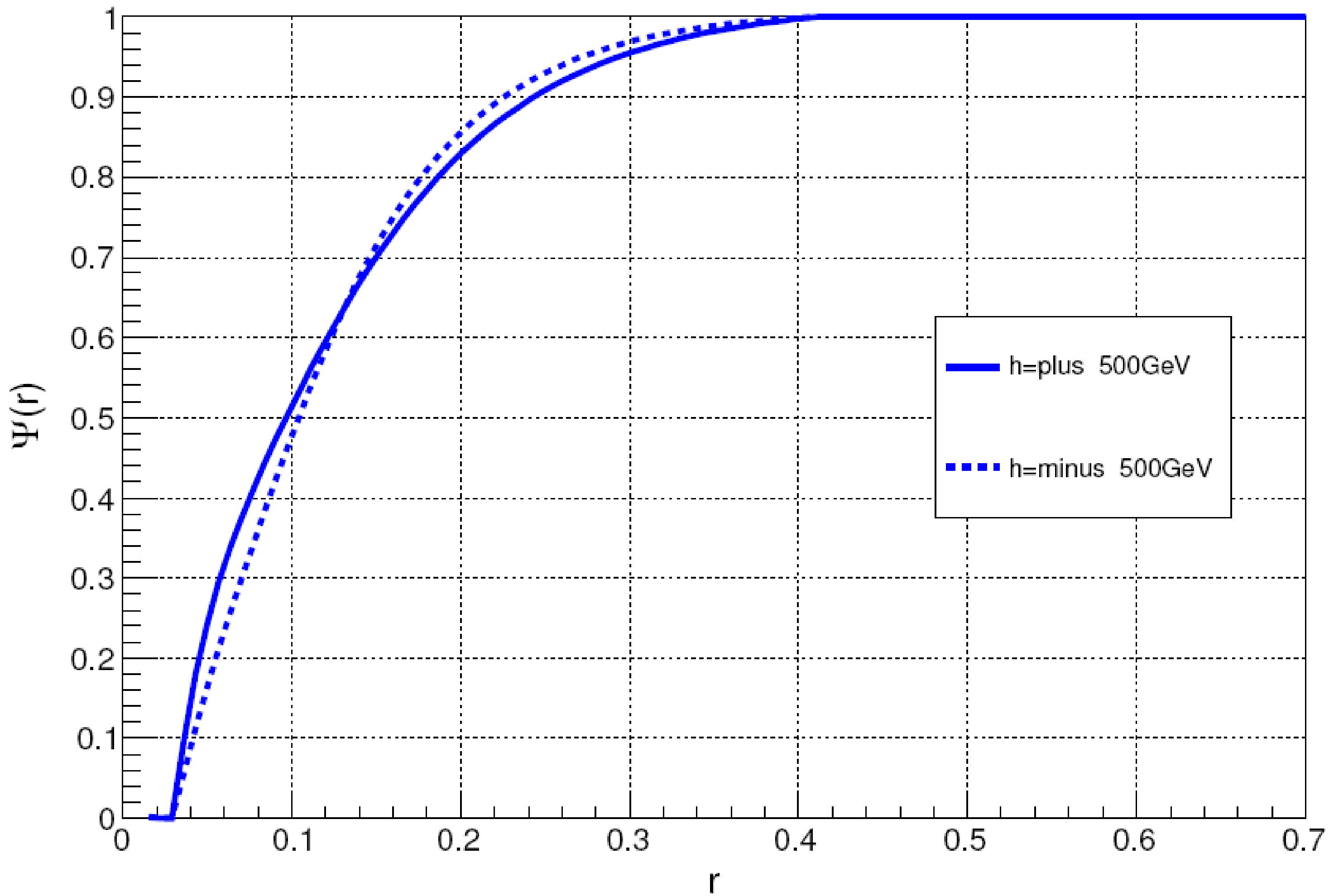


bottom jet contributes more to left-handed top
similar to energy profiles of leptonic top jet



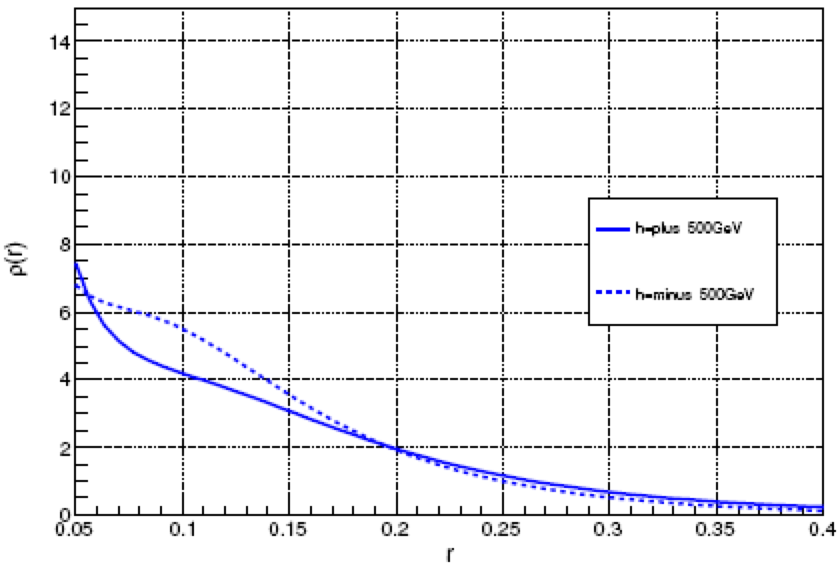
W jet shows obvious dead-cone effect, and contributes more to right-handed top

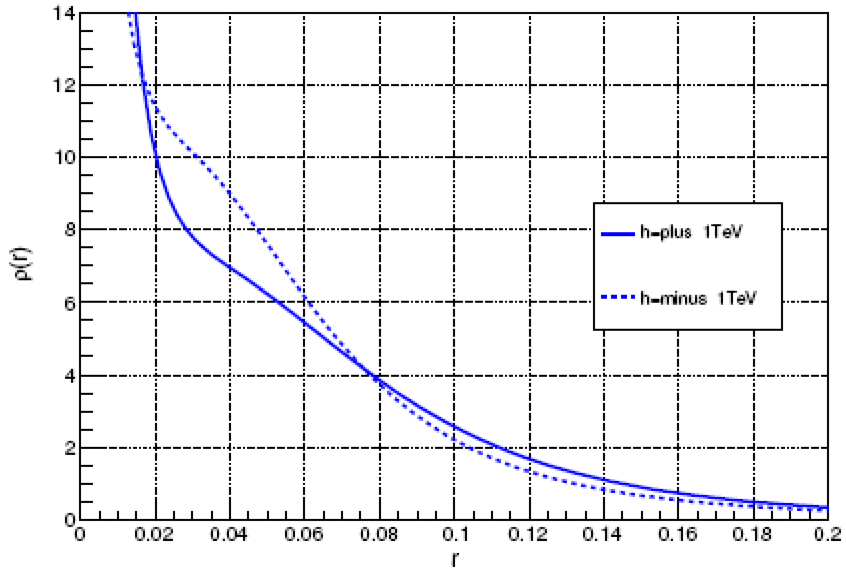
Energy profiles of hadronic top jet



due to compensation of b and W jet contributions, energy profile is not a useful discriminator

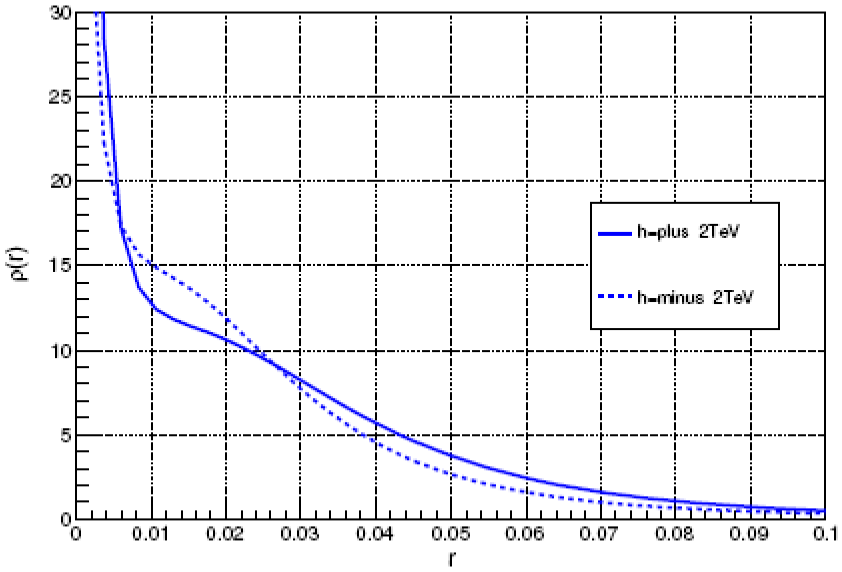
Differential energy profiles





interplay between b and W jet contribution leads to different differential profiles

maybe difficult to measure them at very small r



Conclusion

- Jet substructure helps identification of boosted particles
- can be studied by PQCD factorization and resummation technique
- Differential energy profile, instead of energy profile, is a useful discriminator for helicity of a boosted hadronic top
- Right-handed top jet shows quick descent with r
- Difference appears at very small r. Maybe difficult to measure?