Jets with electrons from boosted top quarks

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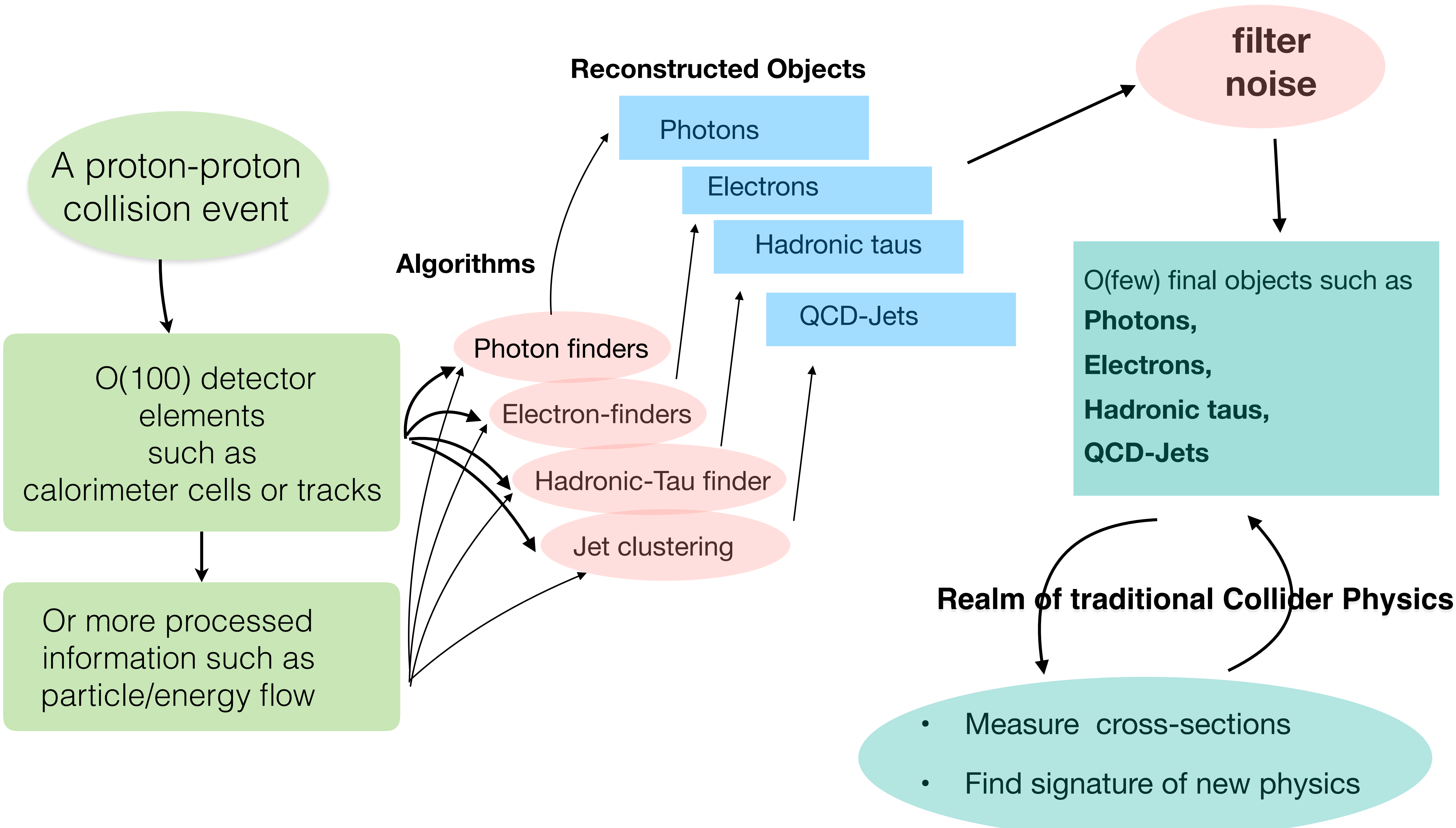
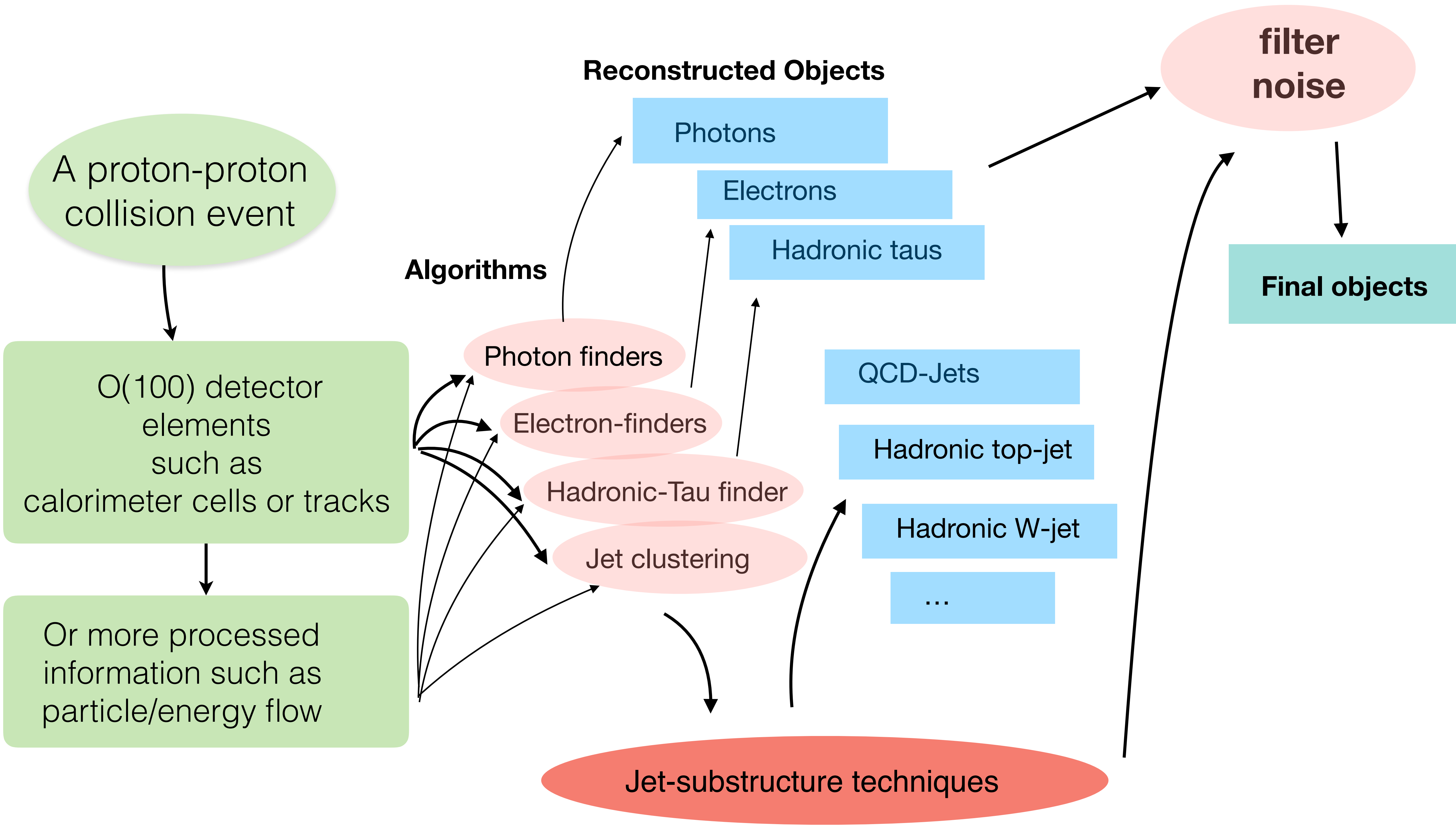
With Chatterjee and Godbole

1909.11041, JHEP

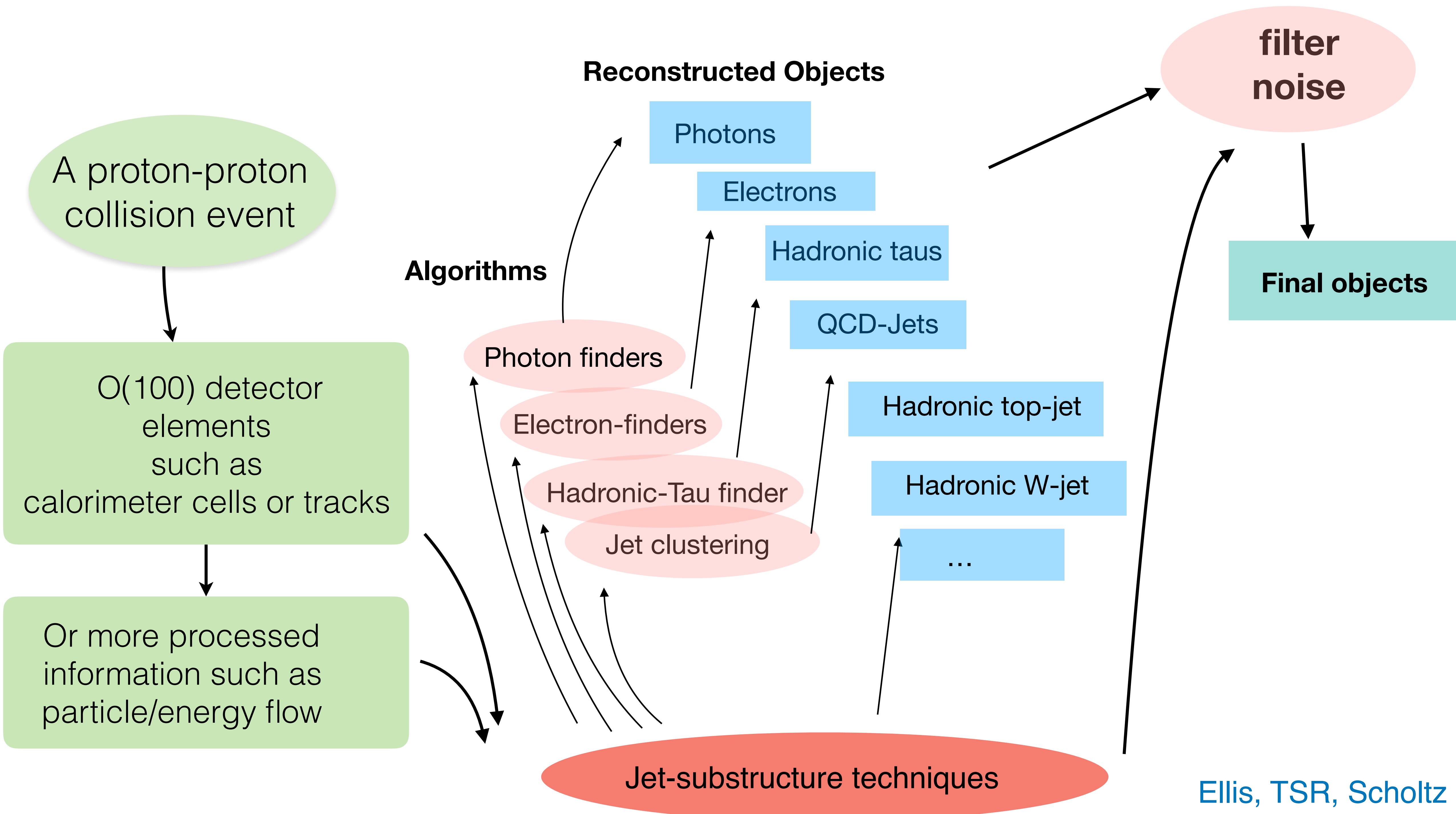
Anatomy of a collider study



Anatomy of a collider study

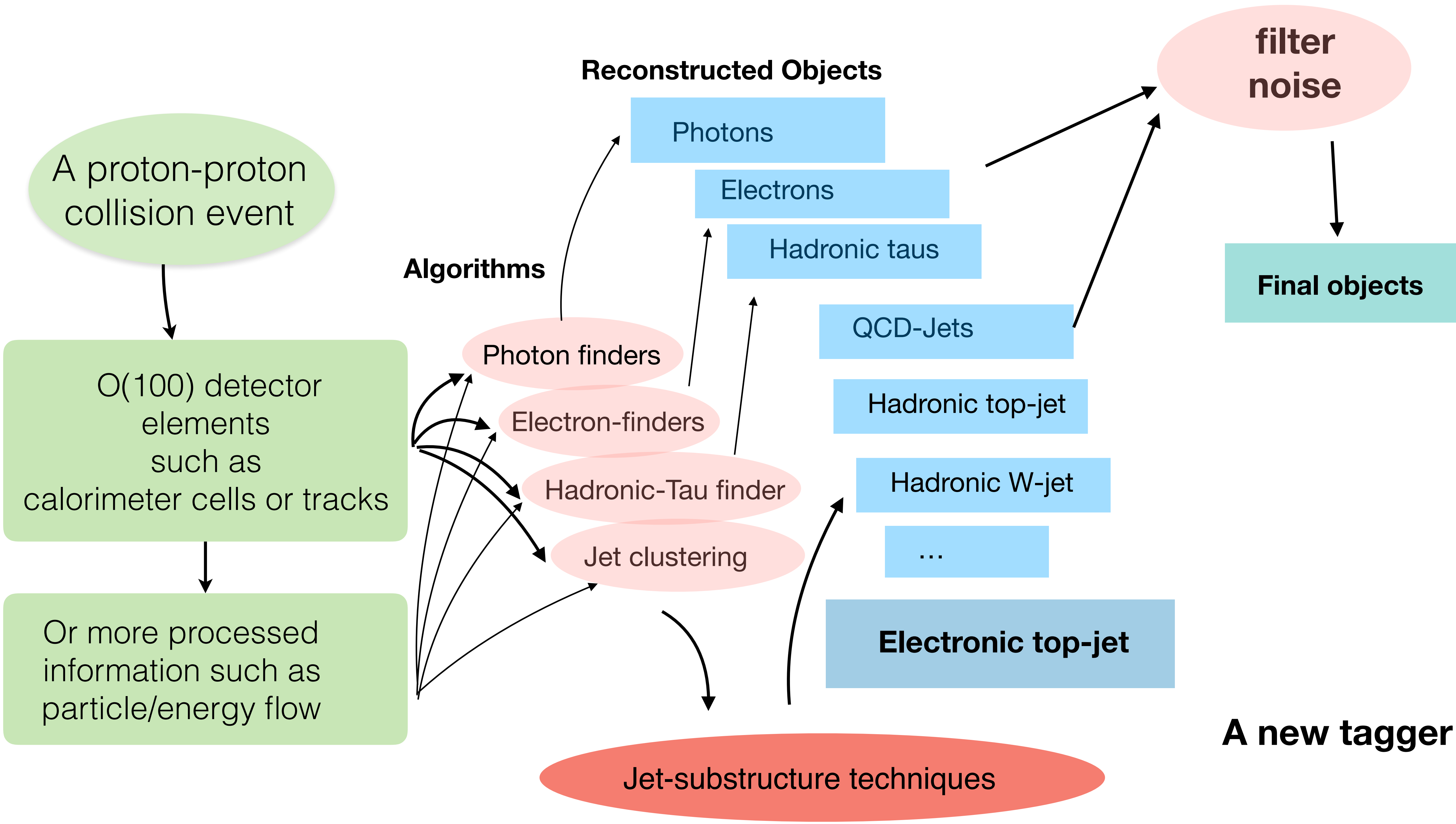


Anatomy of a collider study



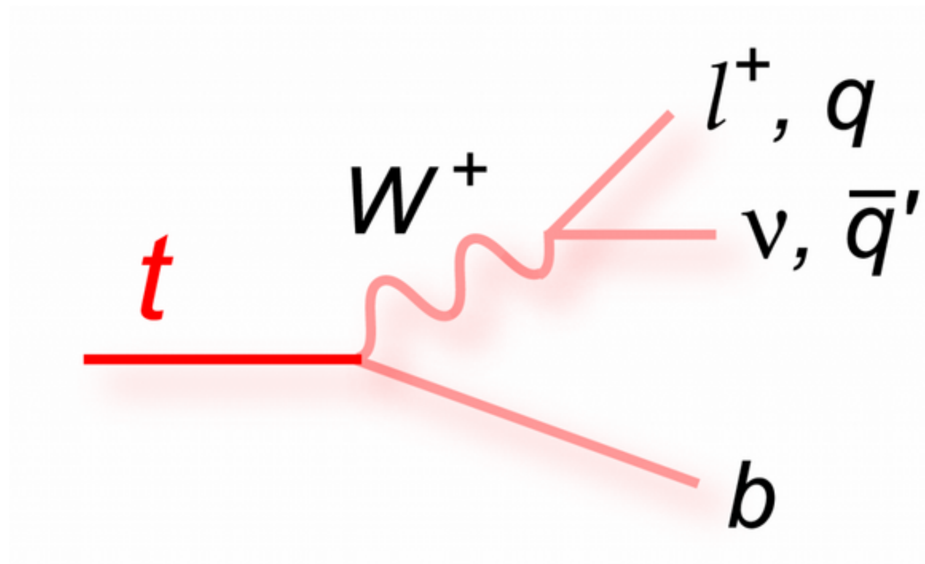
Ellis, TSR, Scholtz
1210.1855

Object of this work



Object: tagging an electronic top

A boosted top implies all decay products end up in a jet — a top-jet



Inevitable: if top comes from decay of boosted massive particle from new physics

Invaluable: to solve combinatorial problems in events with a number of top particles

Object: tagging an electronic top

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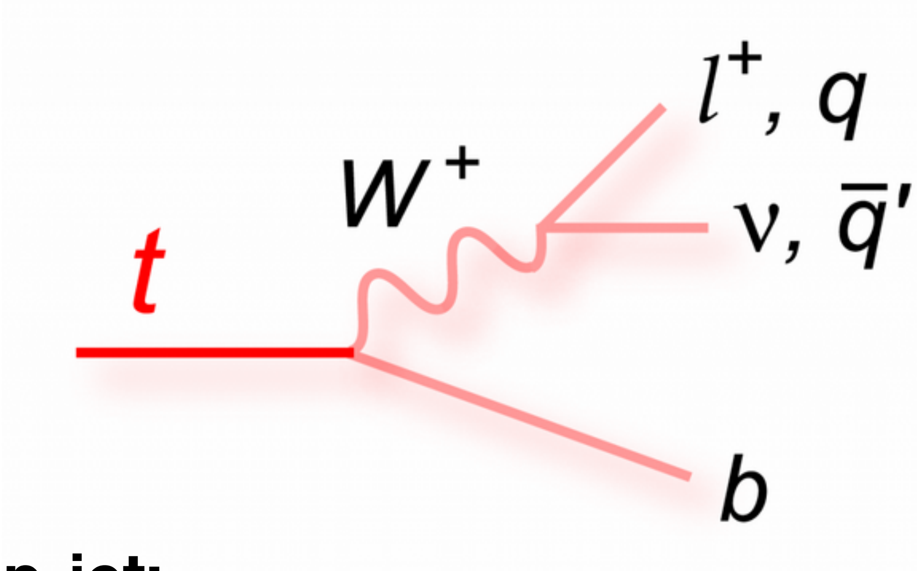

Tagging a hadronic top-jet:

- Easy, since full reconstruction of decay products possible
- Several techniques exist

Tagging an electronic top-jet:

- Difficult: missing neutrinos carry away mass, momenta
- Difficult to identify electrons inside a jet (especially for overlapping showers)

Tagging muonic top-jet slightly easier: identifying muon and mini isolation work well

Rehermann and B. Tweedie (1007.2221), Brust, Maksimovic, Sady, Saraswat, Walters, and Xin (1410.0362), Agashe, Collins, Hong, Kim, and Mishra (1809.07334)

Object: tagging an electronic top

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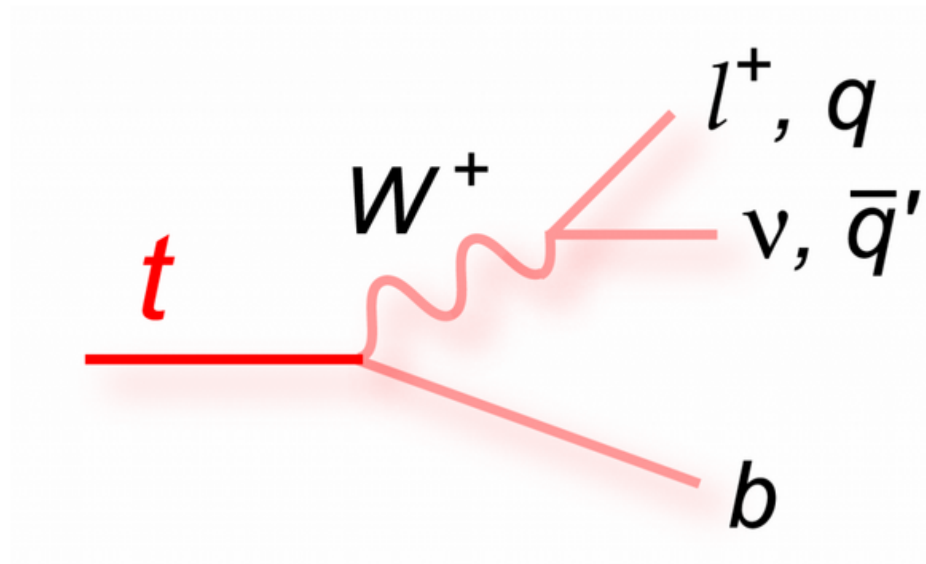

Tagging an electronic top-jet:

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- Difficult to identify electrons inside a jet (especially for overlapping showers)

Who do we fear?

- b-jets, light flavor jets, hadronic top jets
- Also take a challenge: introduce a stop-jet:
  - Ex. decay of a 200 GeV stop to 100 GeV neutralino ($\tilde{t} \rightarrow be\nu\chi_0$)

Object: tagging an electronic top

Tagging an electronic top-jet:

- Difficult: missing neutrinos carry away mass, momenta
- Difficult to identify electrons inside a jet (especially for overlapping showers)

Procedure:

- **Step1:** Identify an input jet to be interesting (may contain overlapping showers due to an electron and a b).
- **Step2:** Estimate momenta of the electron candidate and the b-candidate
- **Step3:** Use an ansatz that there exists a massless 4-momentum collimated with the electron, that reconstructs a W when combined with the e-candidate and top when combined with b+e candidates.
  - Allows reconstruction of new observables which have physics interpretations only if the interesting jet is an electronic top-jet.

Step 1: What makes a jet interesting?

- The jet should contain a lot of energy deposited in EMCal

$$f_{1-h} \equiv 1 - f_h \quad \text{where} \quad f_h = \sum_{k \in \textbf{HCal}} E^k / E_J$$

- The jet should have two prongs ideally (i.e. a small $\tau_{21} \equiv \tau_2/\tau_1$)
- One subject should be rich in Hadronic energy and the other in electro-magnetic

$$A_h \equiv \frac{(f_{\rm h}^1 - f_{\rm h}^2)^2}{(f_{\rm h}^1 + f_{\rm h}^2)^2} ,$$

- EM energy deposits not matched to tracks should be small fraction of jet EM-energy

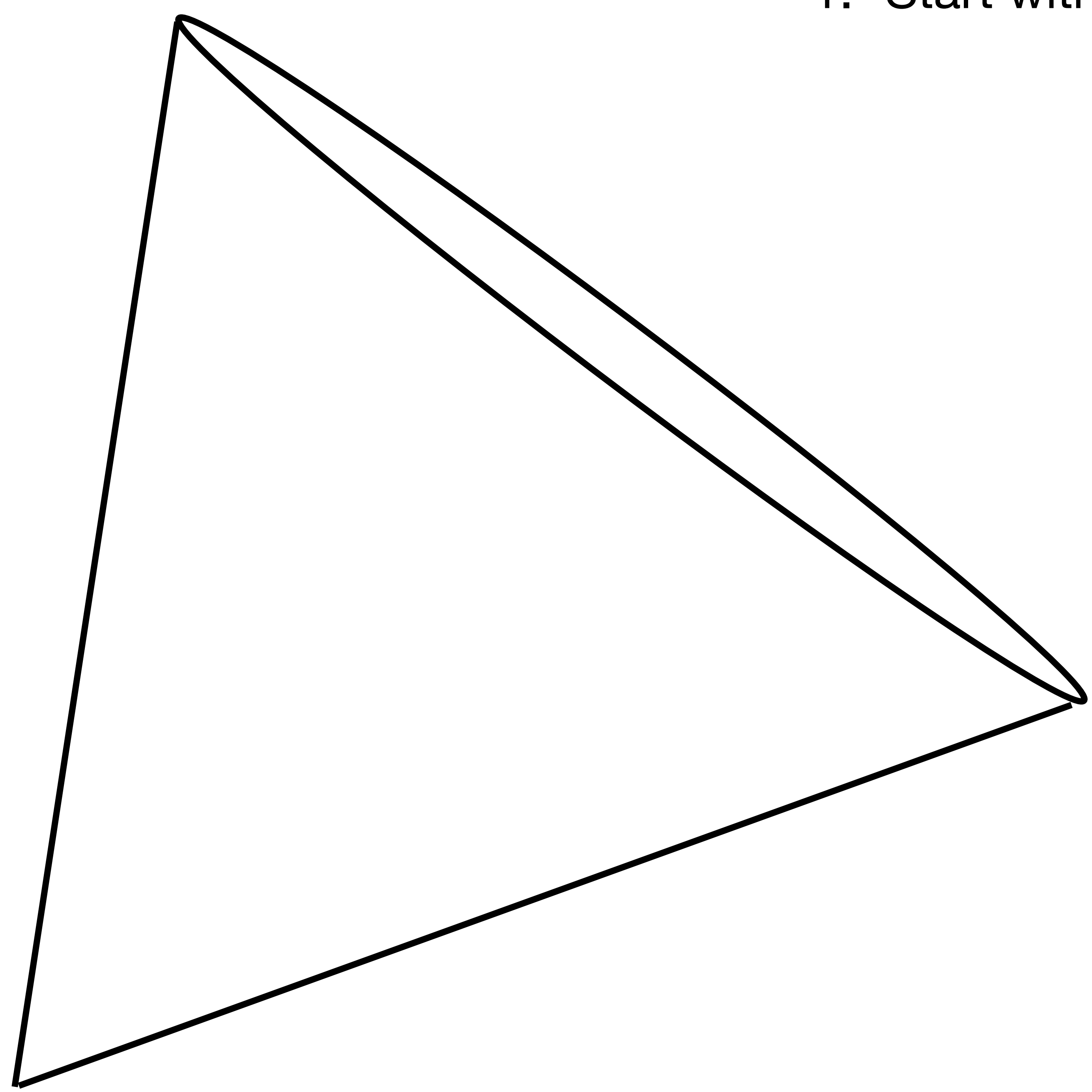
$$f_{\text{1-h}}^{\rm N} \equiv \frac{1}{E_J \times f_{1-h}} \sum_{k \in \rm ECal} \delta_{q^{(k)},0} \, E_J^{(k)} ,$$

- Jet should have a decent charge-radius

$$r_C \equiv \frac{1}{d_0} \sum_{k \in \rm tracks} q^{(k)} \, p_T^{(k)} \, \Delta R_{kJ} , \quad \text{where} \quad d_0 = \sum_k p_T^{(k)} ,$$

- Jetmass not too large (like hadronic top) and not too small

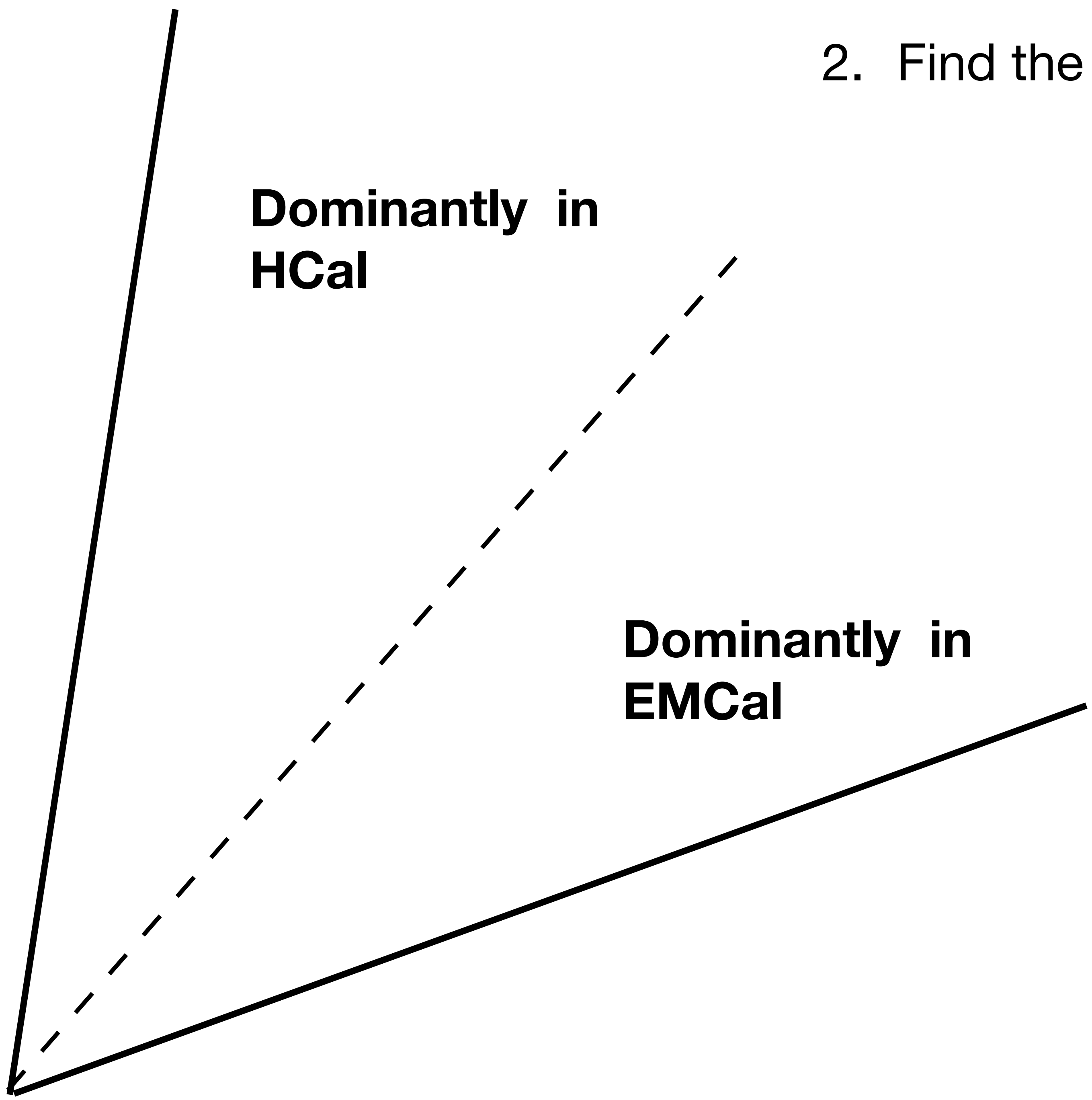
Step 2: Identify e-candidate



1. Start with a groomed jet with k_T history

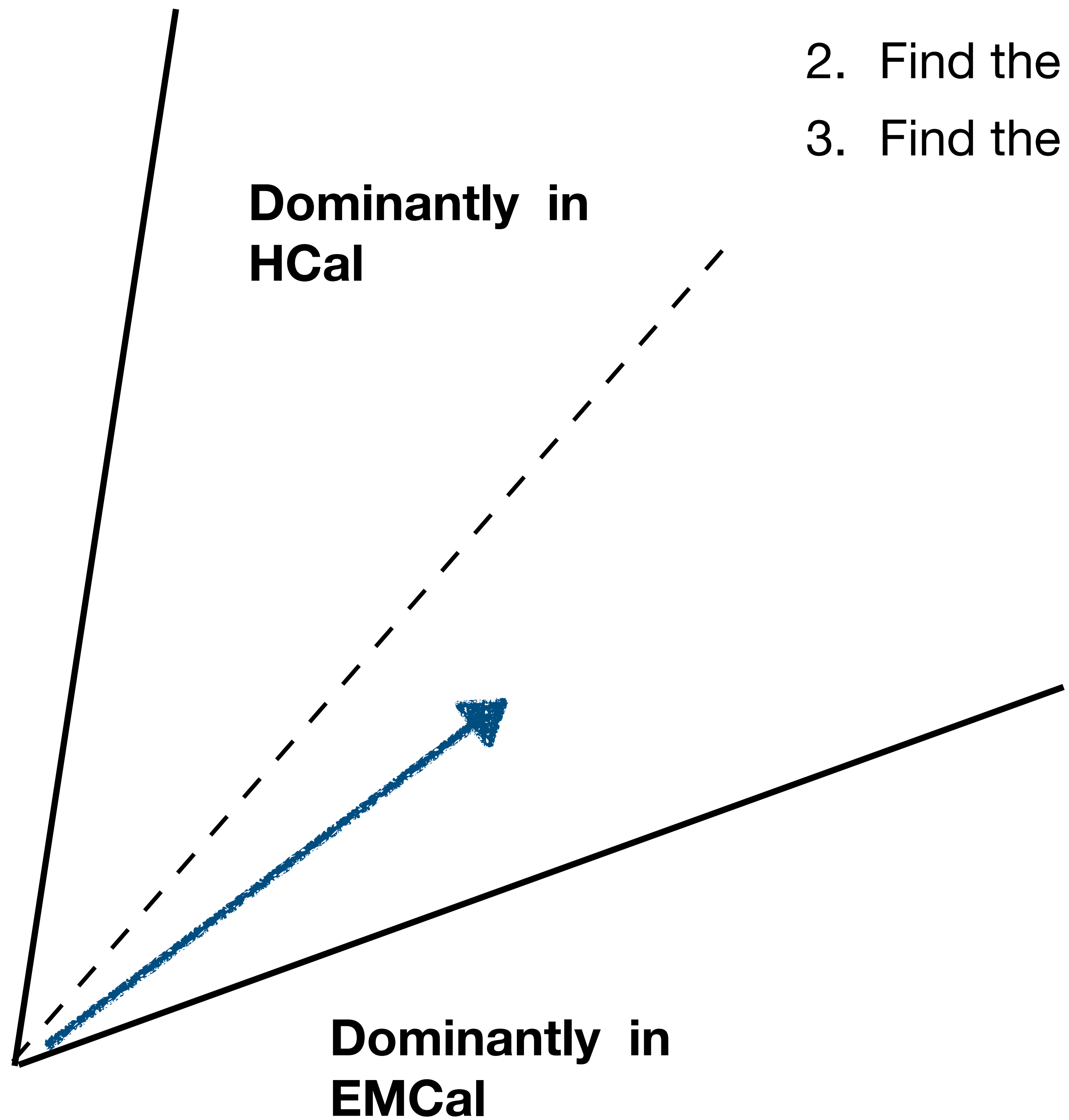
Step 2: Identify e-candidate

1. Start with a groomed jet with k_T history
2. Find the EM rich subjet

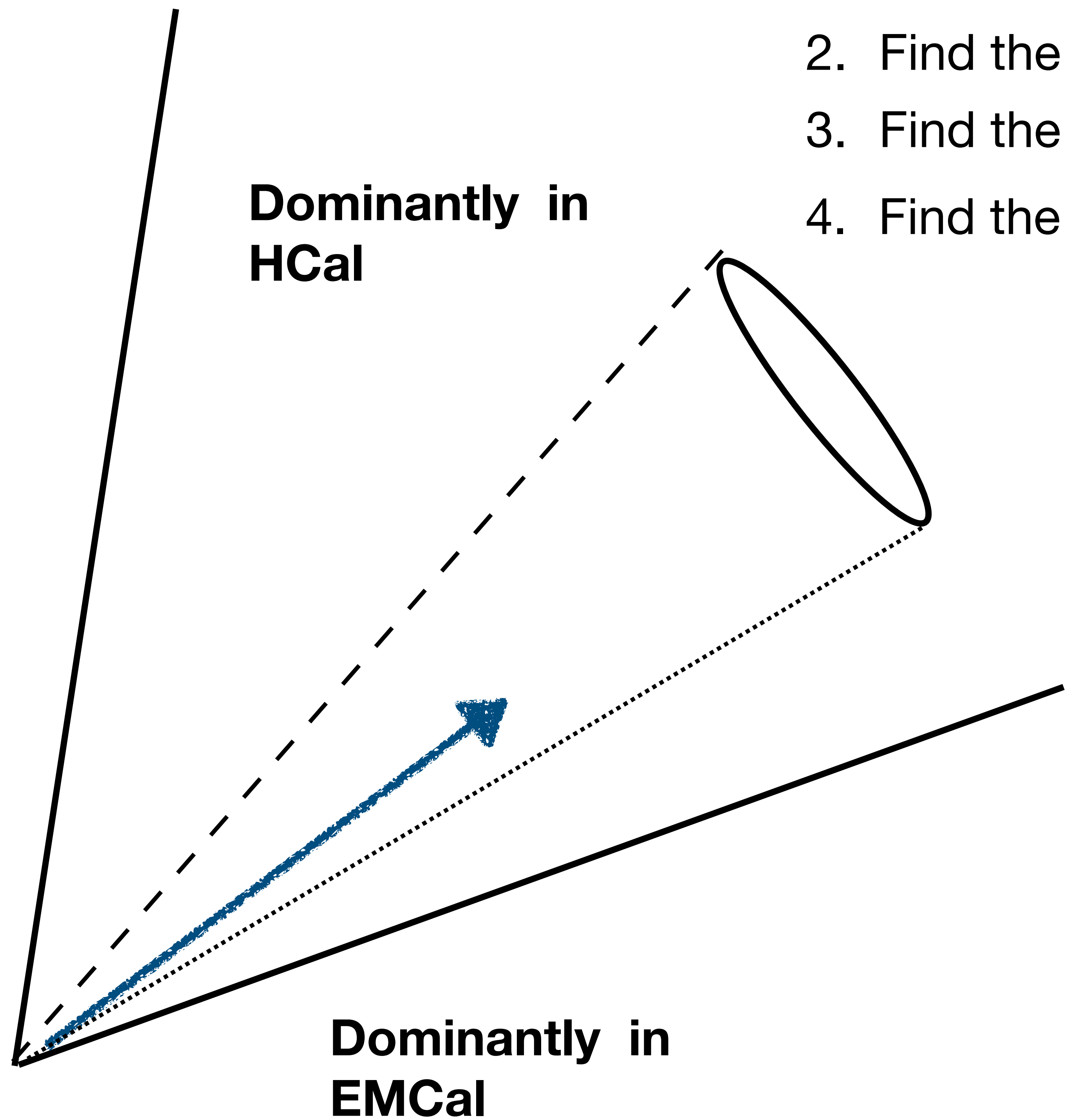


Step 2: Identify e-candidate

1. Start with a groomed jet with k_T history
2. Find the EM rich subjet
3. Find the hardest track in the EM-subjet



Step 2: Identify e-candidate



1. Start with a groomed jet with k_T history
2. Find the EM rich subjet
3. Find the hardest track in the EM-subjet
4. Find the k_T subjet that contains the track

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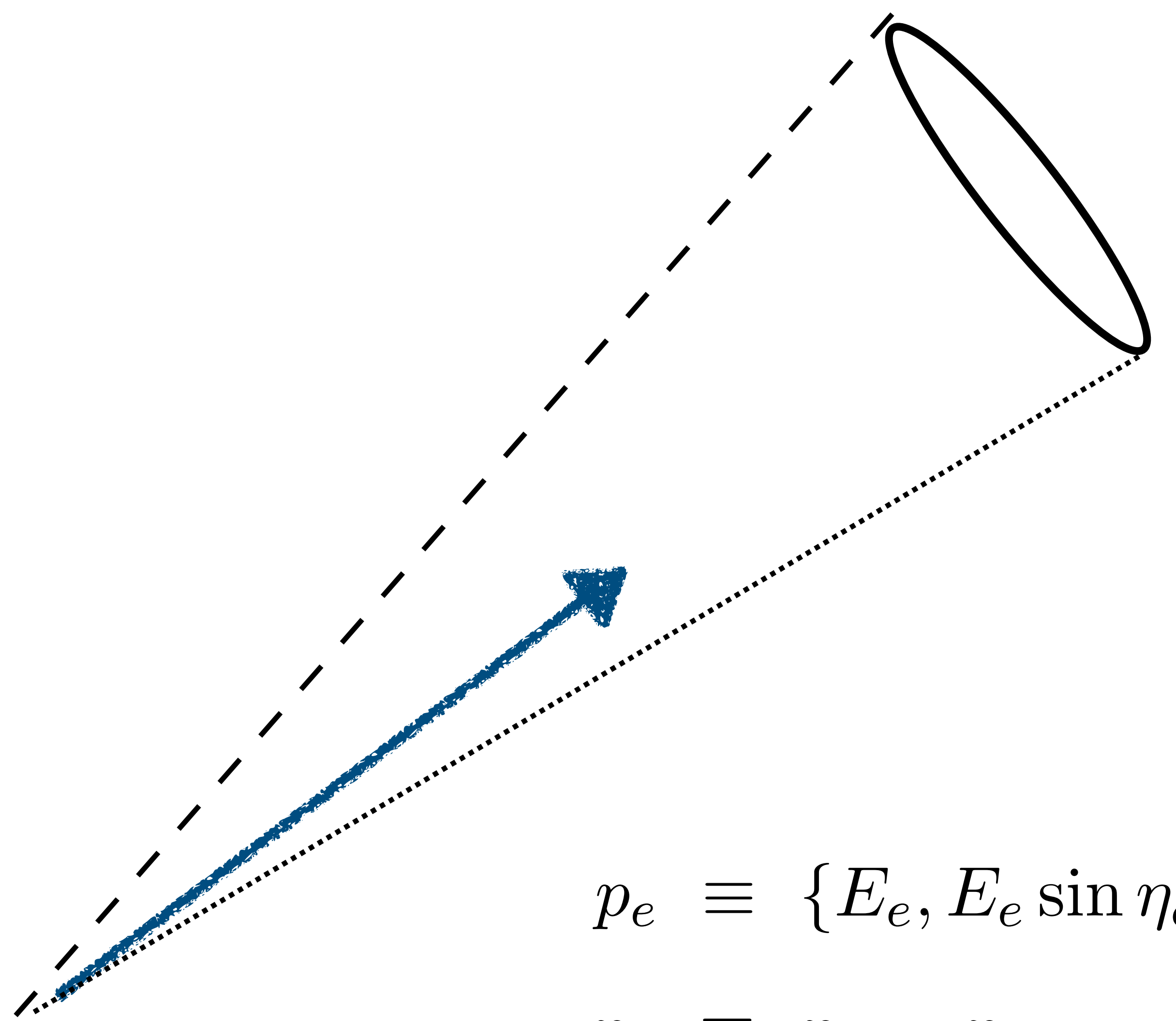


energy from the subjet

direction from the track

$$p_e \equiv \{E_e, E_e \sin\eta_e \cos\phi_e, E_e \sin\eta_e \sin\phi_e, E_e \cos\eta_e\} \ ,$$

$$p_b \equiv p_J - p_e \ .$$

Step 3: Ansatz of a collimated neutrino

$$p_\nu \;\equiv\; E_\nu \left(1, \frac{\vec{p}_\nu}{E_\nu}\right) \;, \qquad \text{with } \vec{p}_\nu \;\equiv\; p_{\parallel}\, \hat{e} + \vec{p}_\perp \quad \text{where} \quad \hat{e}\cdot\vec{p}_\perp = 0 \;.$$

The key assumption is that the neutrino is mostly collimated with the e candidate. More specifically,

$$r \;\equiv\; \frac{|\vec{p}_\perp|}{p_{\parallel}} \;=\; \frac{p_\perp}{p_{\parallel}} \;\ll\; 1 \;.$$

Easy to show that:

$$E_\nu \;\simeq\; \frac{1}{2}\frac{m_t^2 - \Delta^2}{(E_b - p_b\cdot\hat{e})} \qquad \text{where } \Delta^2 \equiv \left(m_W^2 + m_b^2 + 2p_b\cdot p_e\right)$$

$$Z_b \;\equiv\; \frac{E_b}{E_e + E_\nu} \longrightarrow \frac{E_b}{E_W}$$

For t(e)

$$\Theta_{b/e} \;\equiv\; \frac{E_e\left(m_t^2 - \Delta^2\right)}{E_b m_W^2} \longrightarrow \frac{1-\cos\theta_{\nu b}}{1-\cos\theta_{\nu e}}$$

Object: tagging an electronic top

Two sets of variables:

$$\mathcal{V}_e \equiv \left\{ f_{\text{1-h}}, A_h, f_{\text{1-h}}^{\text{N}}, \tau_{21} \equiv \frac{\tau_2}{\tau_1}, r_C, m_{\text{SD}} \right\}$$

$$\mathcal{V}_\nu \equiv \left\{ Z_b, \Theta_{b/e} \right\} .$$

Two BDTs for discriminating:

$$\mathcal{B}_e^{t/b} \equiv \text{ A BDT to discriminate } t \text{ from } b \text{ using variables in } \mathcal{V}_e ,$$

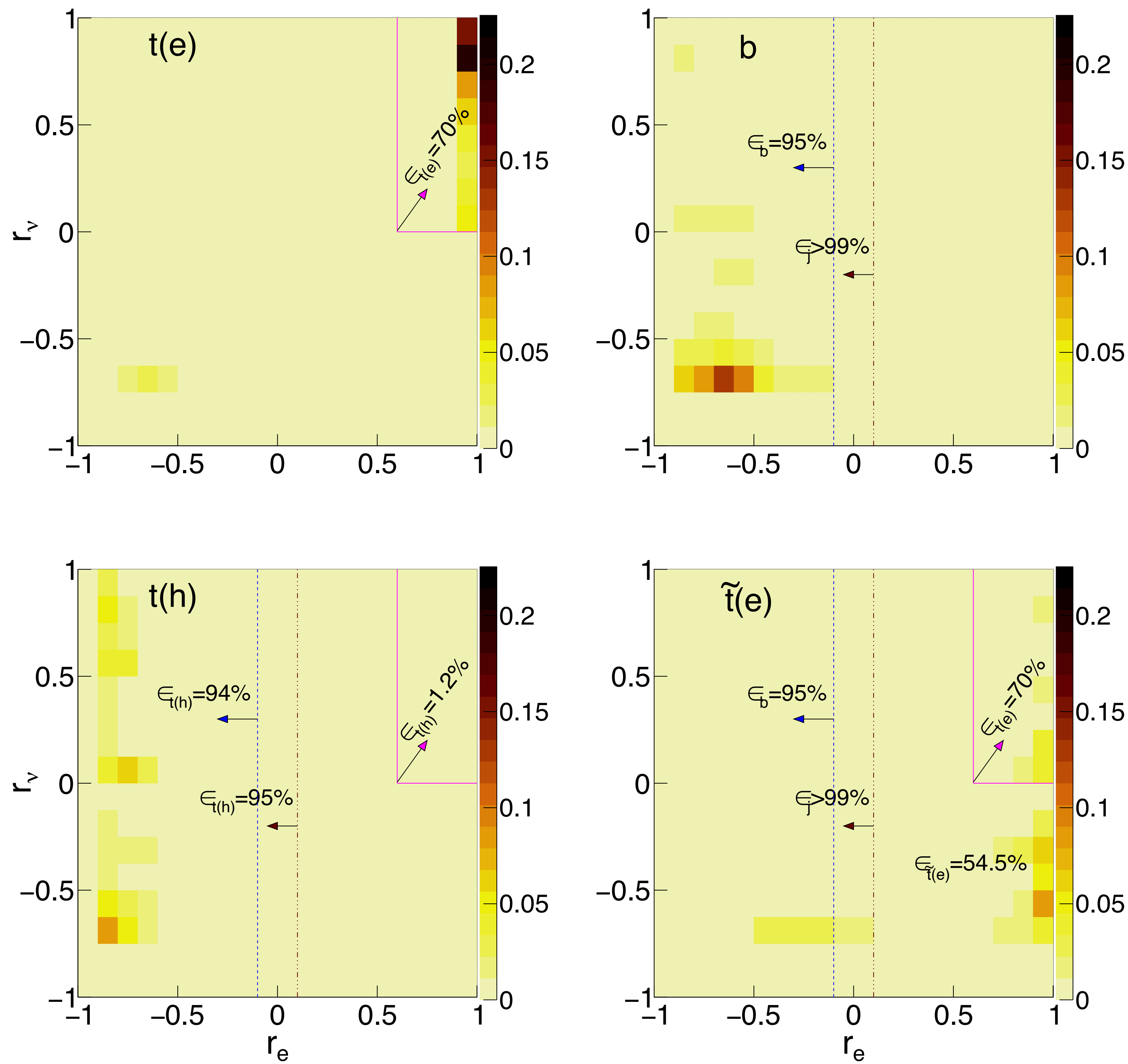
$$\mathcal{B}_\nu^{t/b} \equiv \text{ A BDT to discriminate } t \text{ from } b \text{ using variables in } \mathcal{V}_\nu .$$

Two responses for conquering:

$$r_e \equiv \text{ response of } \mathcal{B}_e^{t/b} \text{ in the range } \{-1, +1\} ,$$

$$r_\nu \equiv \text{ response of } \mathcal{B}_\nu^{t/b} \text{ in the range } \{-1, +1\} ,$$

Object: tagging an electronic top



Object: tagging an electronic top

$$t(e)\text{ zone } \equiv r_e > 0.6 \qquad \text{and} \qquad r_\nu > 0\ .$$

$$\text{Anomalous zone } \equiv \begin{cases} \texttt{Case 1} : \text{ if } r_\nu < 0, \quad r_e > -0.1 \quad \text{else} \quad -0.1 < r_e < 0.6 \\ \texttt{Case 2} : \text{ if } r_\nu < 0, \quad r_e > +0.1 \quad \text{else} \quad +0.1 < r_e < 0.6 \end{cases}$$

Efficiency	$t(e)$ zone	Anomalous zone	
		`Case 1`	`Case 2`
ϵ_b	$< 1\%$	3.8%	2.1%
ϵ_j	$< 1\%$	1.1%	$< 1\%$
$\epsilon_{t(h)}$	1.2%	5.0%	3.4%
$\epsilon_{t(e)}$	**70%**	12.1%	10.4%
$\epsilon_{\tilde{t}(e)}$	17.2%	**60.0%**	**54.5%**

Conclusion

Tagging a boosted top where top decays to electron is quite realistic and can be done with good efficiency

- can even pave the way to find anomalous objects (electron-rich jets but not due to top)

Simulation

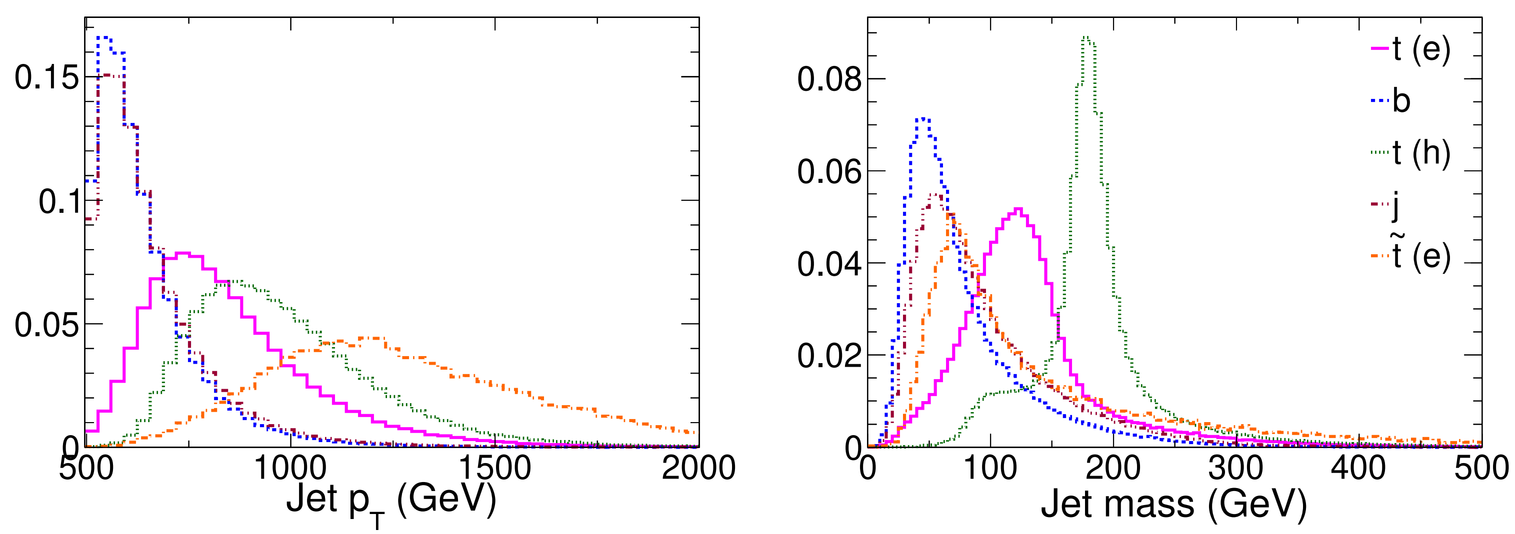
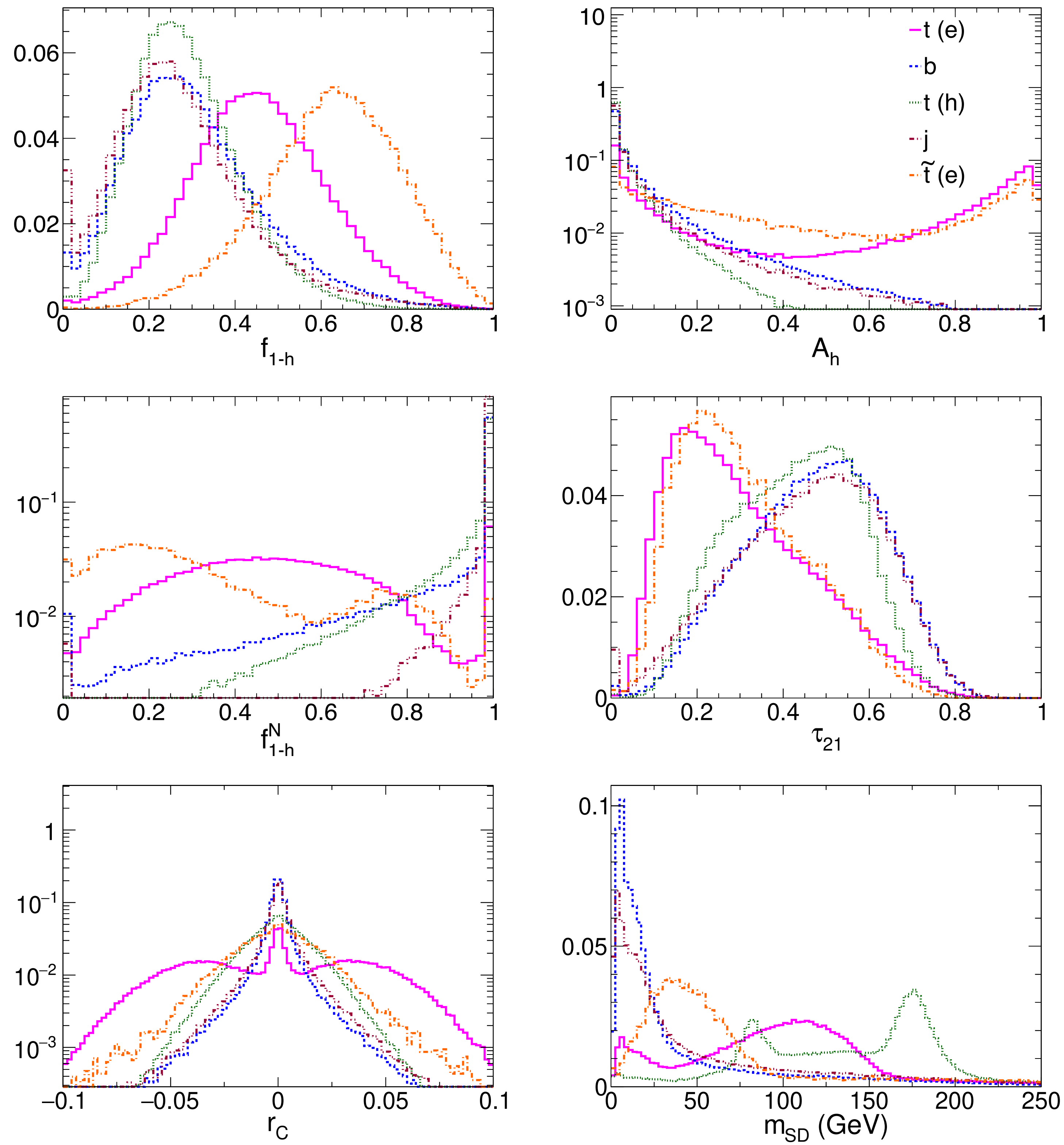


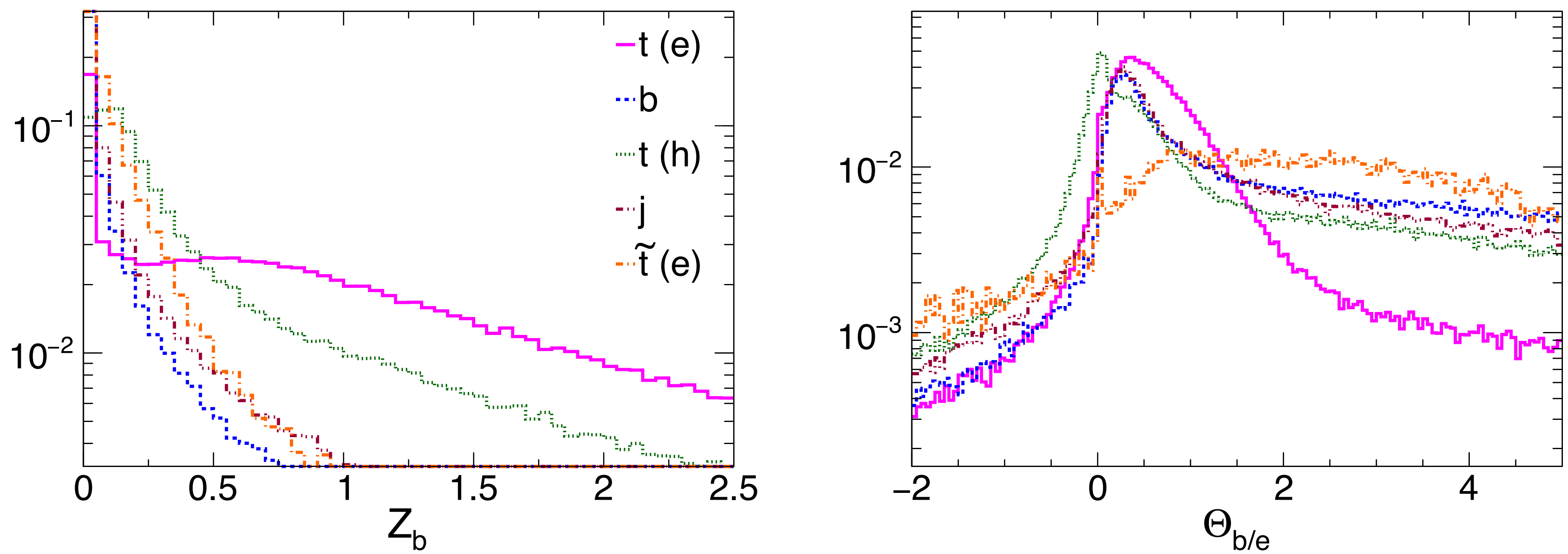
Figure 1. Distribution of p_T (left), and mass (right) of the ungroomed jet for all the event samples.

$$R = 0.8 \text{ with } p_{T_{\min}} = 500 \text{ GeV.}$$

Observables in $\mathscr{V}_e$

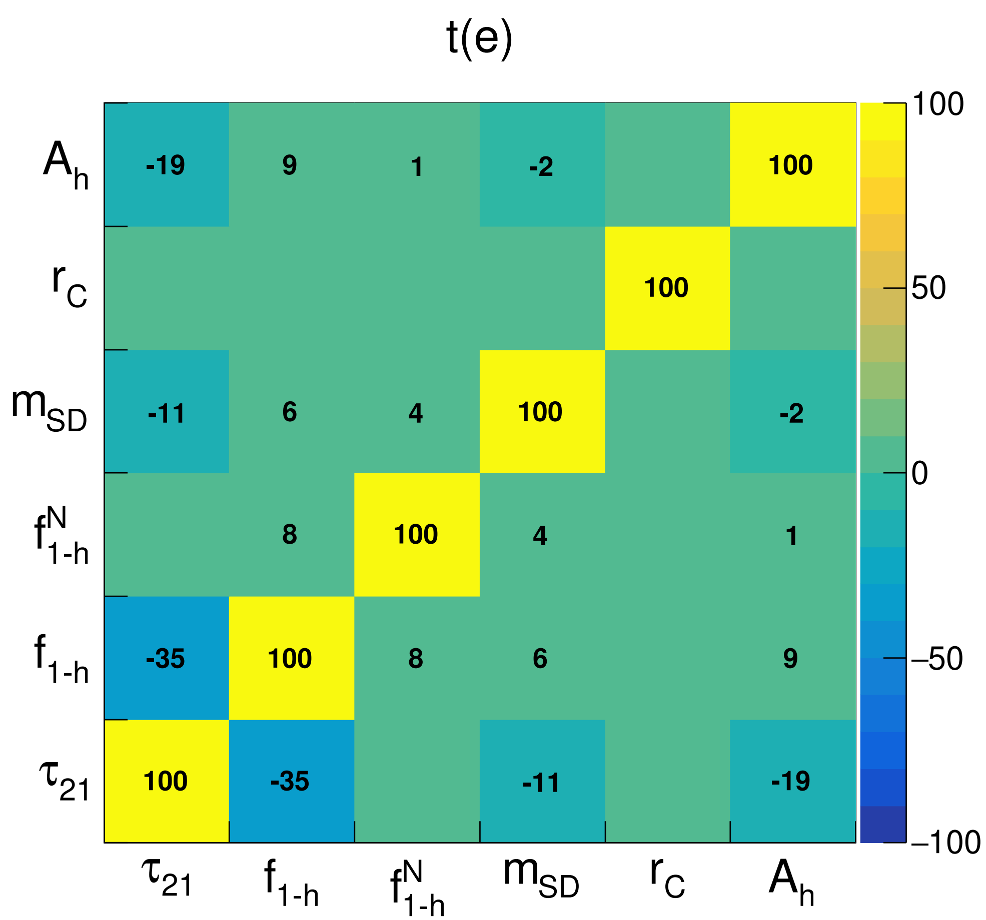


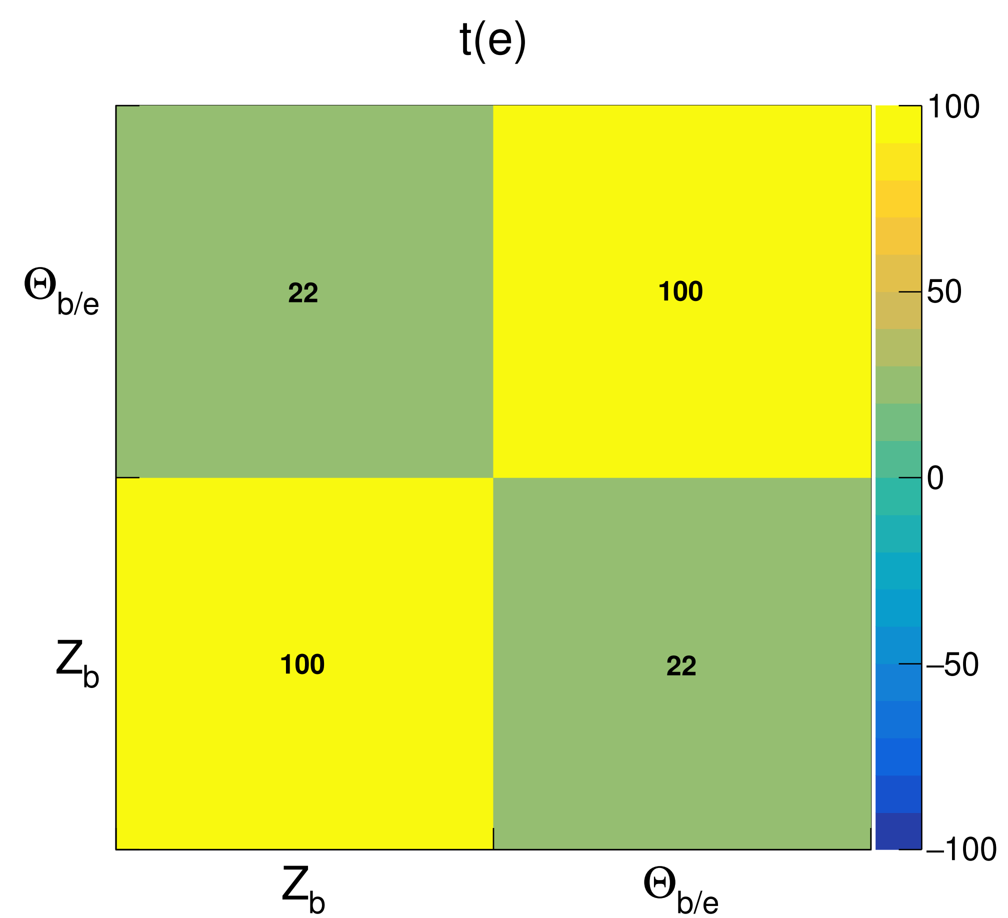
Observables in $\mathcal{V}_\nu$



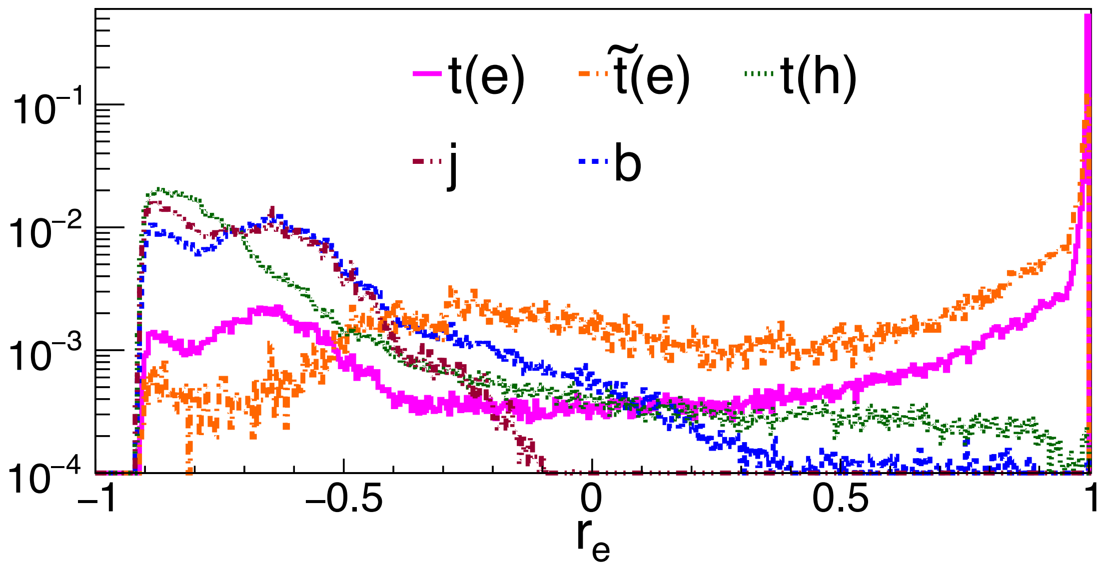
Correlations in Observables

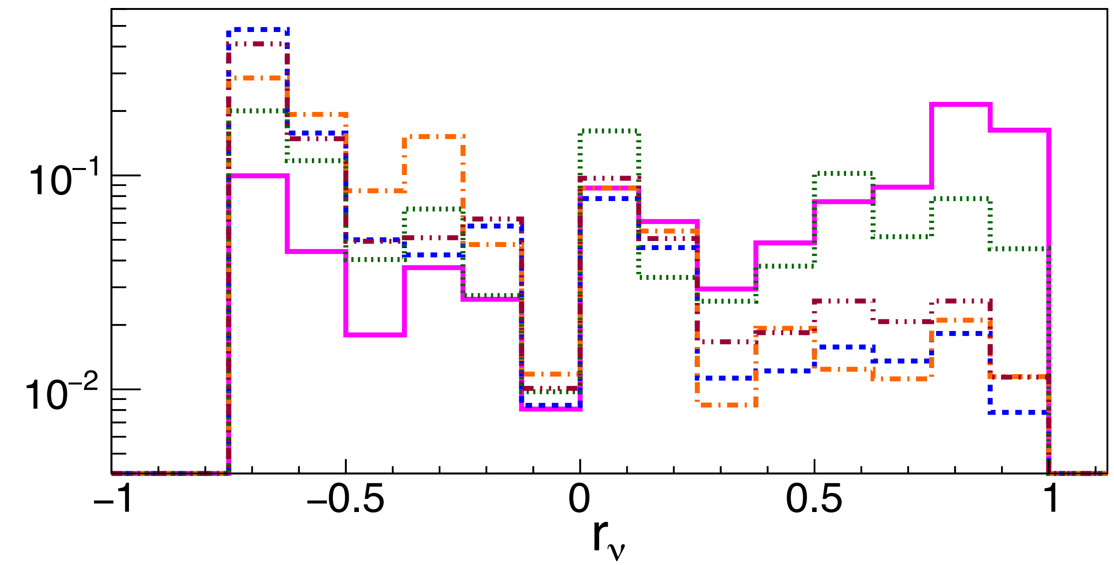
$$\rho(A,B) \equiv \frac{E(AB) - E(A)E(B)}{\sigma(A)\sigma(B)} ,$$





BDT Responses





ROCs using cuts in r_e