$J^{\mathrm{II}}_{E_T}$ *algorithm for two-prong jets*

Ran Lu

Univerity of Wisconsin-Madison

ArXiv: 1509.07522 with Yang Bai and Zhenyu Han

Brookhaven Forum 2015

2015-10-08

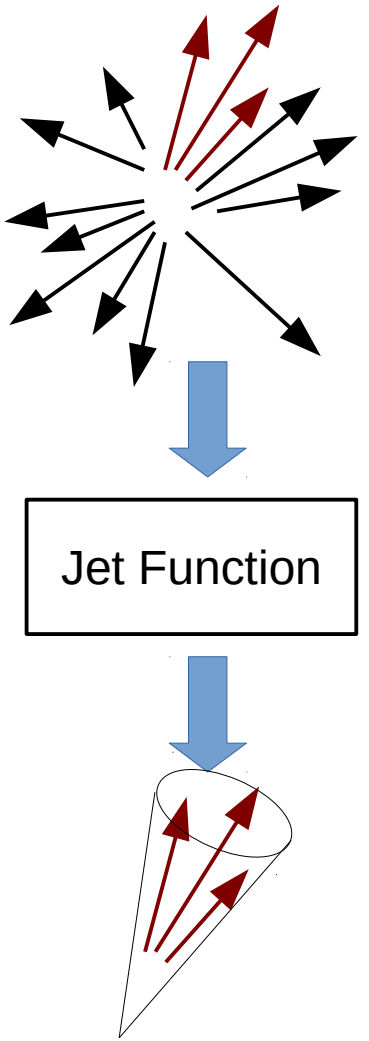
Jet and Maximization

- Jets Maximize the Jet Function
- Function of Jet 4-momentum $J(P)$
  - Increases with increasing energy
  - Decreases with increasing mass
- Concrete Example:

$$J = E\left(1 - \beta \frac{m^2}{E^2}\right), \beta \geq 0$$

- Cone Jet: opening angle $\sin\theta \leq \sqrt{\frac{1}{\beta}}$

$\beta = 6 : \theta = 0.4$ $\beta = 100 : \theta = 0.1$



H. Georgi, arXiv:1408.1161; S. Ge, arXiv:1408.3823;
T.Kaufmann et. al. arXiv:1412.0298; J. Thaler, arXiv:1506.07876

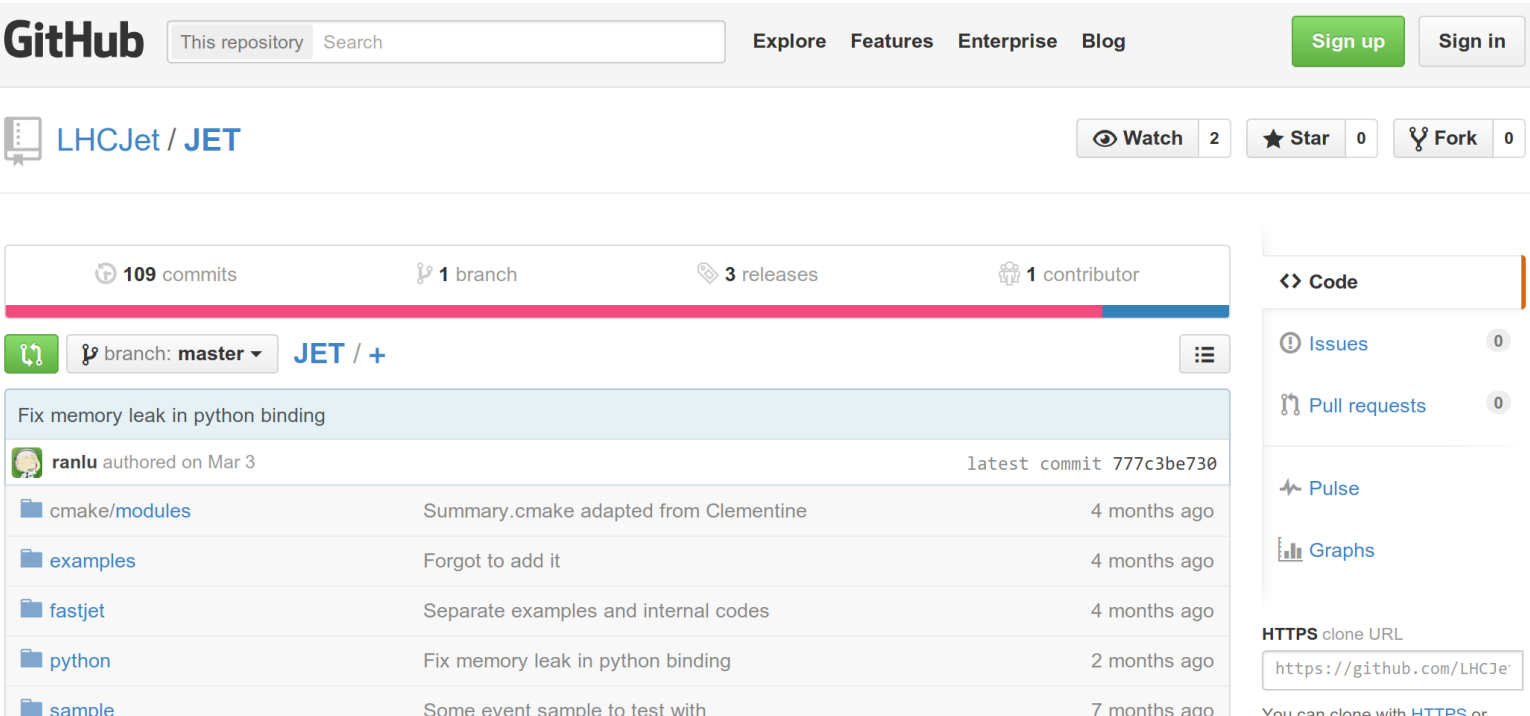
J_{E_T} algorithm for hadron collider

Y. Bai, Z. Han, RL, arXiv: 1411.3705

- E → E_T

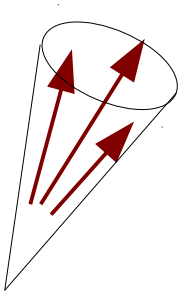
$$J_{E_T^\alpha} = E_T^\alpha \left(1 - \beta \frac{m^2}{E_T^2}\right) \qquad E_T^2 = p_T^2 + m^2$$

- Implementation (https://github.com/LHCJet/JET)



Generalization

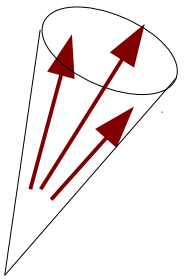
J_{E_T} Maximization



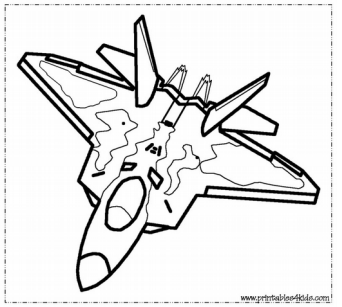
Generalization

Maximization

J_{E_T} →



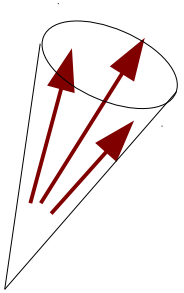
? →



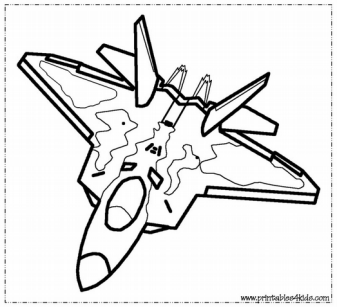
Generalization

Maximization

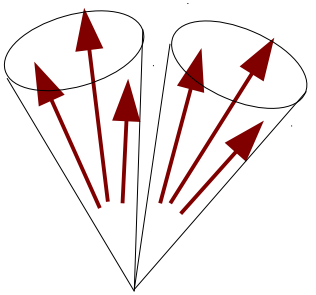
J_{E_T} →



? →



$J^{\mathrm{II}}_{E_T}$ →



W/Z/H

W tagging

- Fat jet + jet grooming:
  - Filtering
  - Pruning
  - Trimming
  - Soft Drop
  - ...
- Tagging variable
  - Mass Drop
  - Subjet Momentum Balance
  - N-subjettiness
  - Color Flow
  - Jet Charge
  - Energy Correlation Function
  - Planar Flow
  - Q-jet
  - ...

Step I

Step II

Y. Cui, Z. Han and M. Schwartz Phys.Rev. D83, 074023
CMS Collaboration, JHEP 12 (2014), 017

W tagging

- Fat jet + jet grooming:
  - Filtering
  - Pruning
  - Trimming
  - Soft Drop
  - ...
- Tagging variable
  - Mass Drop
  - Subjet Momentum Balance
  - N-subjettiness
  - Color Flow
  - Jet Charge
  - Energy Correlation Function
  - Planar Flow
  - Q-jet
  - ...

Step I

Step II

Y. Cui, Z. Han and M. Schwartz Phys.Rev. D83, 074023
CMS Collaboration, JHEP 12 (2014), 017

W tagging

$J^{\mathrm{II}}_{E_T}$ ⟶ Two-prong Jet

Step I

- Tagging variable
  - Mass Drop
  - Subjet Momentum Balance
  - N-subjettiness
  - Color Flow
  - Jet Charge
  - Energy Correlation Function
  - Planar Flow
  - Q-jet
  - ...

Step II

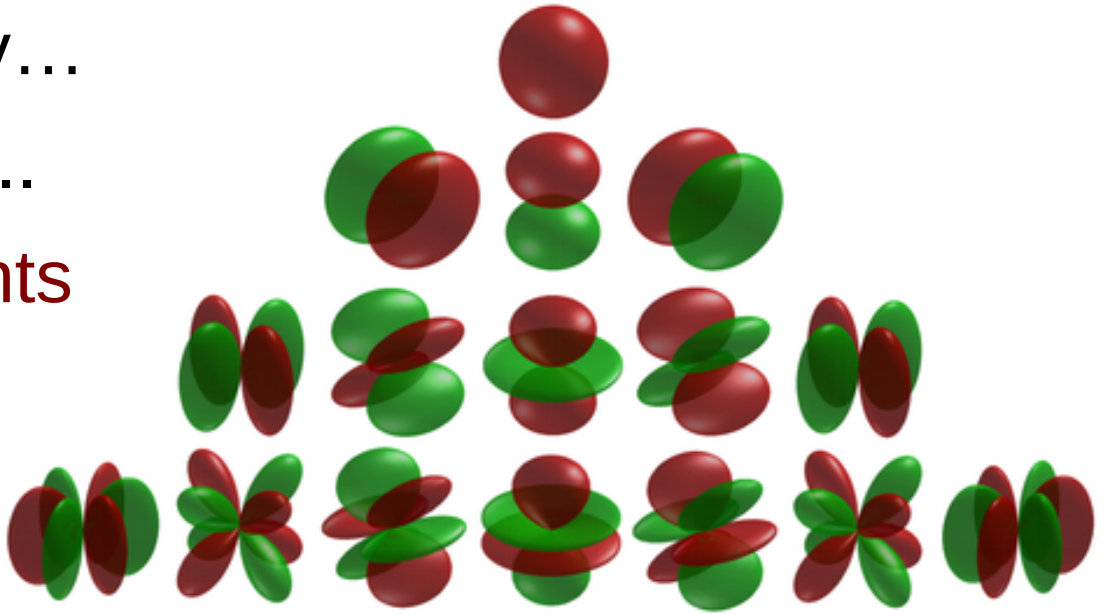
Y. Cui, Z. Han and M. Schwartz Phys.Rev. D83, 074023
CMS Collaboration, JHEP 12 (2014), 017

Jet Function of Two-prong Jets

- $J(P)$ is not enough
- 4-momentum: mass and velocity (point particle)
- “Shape” variables of the object
- Event/Jet shape variables
  - Sphericity, Aplanarity…
  - N-subjettiness, Energy correlation function...
  - Fox-Wolfram Moments

Jet Function of Two-prong Jets

- $J(P)$ is not enough
- 4-momentum: mass and velocity (point particle)
- “Shape” variables of the object
- Event/Jet shape variables
  - Sphericity, Aplanarity…
  - N-subjettiness, ECF...
  - Fox-Wolfram Moments



Fox-Wolfram Moments

- General definition:

$$H_n = \sum_{i,j} \frac{|p_i||p_j|}{E_J^2} P_n(\cos\theta_{i,j})$$

- Examples:

$$J = E\left((1-\beta)H_0 + \beta H_1\right)$$

$$H_2 = \sum_{i,j} \frac{|p_i||p_j|}{E_J^2} \frac{\left(3\cos^2\theta_{i,j} - 1\right)}{2}$$

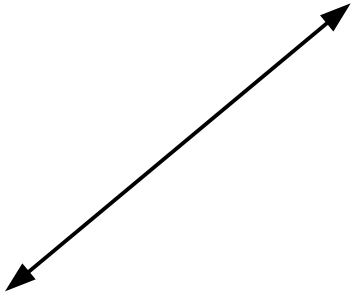
- H_2 only constrains $\cos^2\theta_{i,j}$
- Optimizing H_2 → Two-prong structure?

G. Fox and S. Wolfram, Phys.Rev.Lett. 41 (1978) 1581

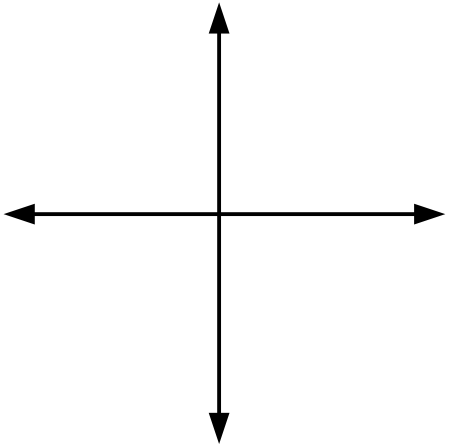
$\tilde{H}_2$ Function

- Lab Frame Modification

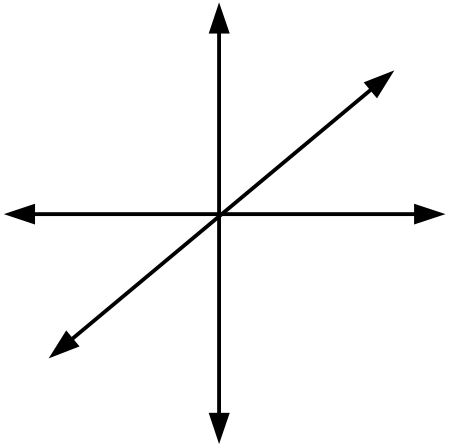
$$\tilde{H}_2 = \left(\sum_{i,j} |p_i||p_j| P_2\left(\cos\left(\theta_{i,j}\right)\right) \right)_{\text{rest frame}} \equiv m^2 \sum_{i,j} \frac{\left(p_i^{\mu} p_{j\mu}\right)^2}{\left(P^{\mu} p_{i\mu}\right)\left(P^{\nu} p_{j\nu}\right)} - m^2$$



$$\tilde{H}_2 = m^2$$



$$\tilde{H}_2 = \frac{1}{2} m^2$$



$$\tilde{H}_2 = \frac{1}{3} m^2$$

$J^{\mathrm{II}}_{E_T}$ Function

- Lab Frame Definition

$$\widetilde{H}_2 = \left(\sum_{i,j} |p_i||p_j| P_2\left(\cos\left(\theta_{i,j}\right)\right) \right)_{\text{rest frame}} \equiv m^2 \sum_{i,j} \frac{\left(p_i^{\mu} p_{j\mu}\right)^2}{\left(P^{\mu} p_{i\mu}\right)\left(P^{\nu} p_{j\nu}\right)} - m^2$$

- Characteristic Function of two-prong objects

$$J^{\mathrm{II}}_{E_T} = E_T^2 \left(1 - \beta \frac{m^2}{E_T^2} + \gamma \frac{\widetilde{H}_2}{E_T^2} \right)$$

Parameters

- Lab Frame Definition

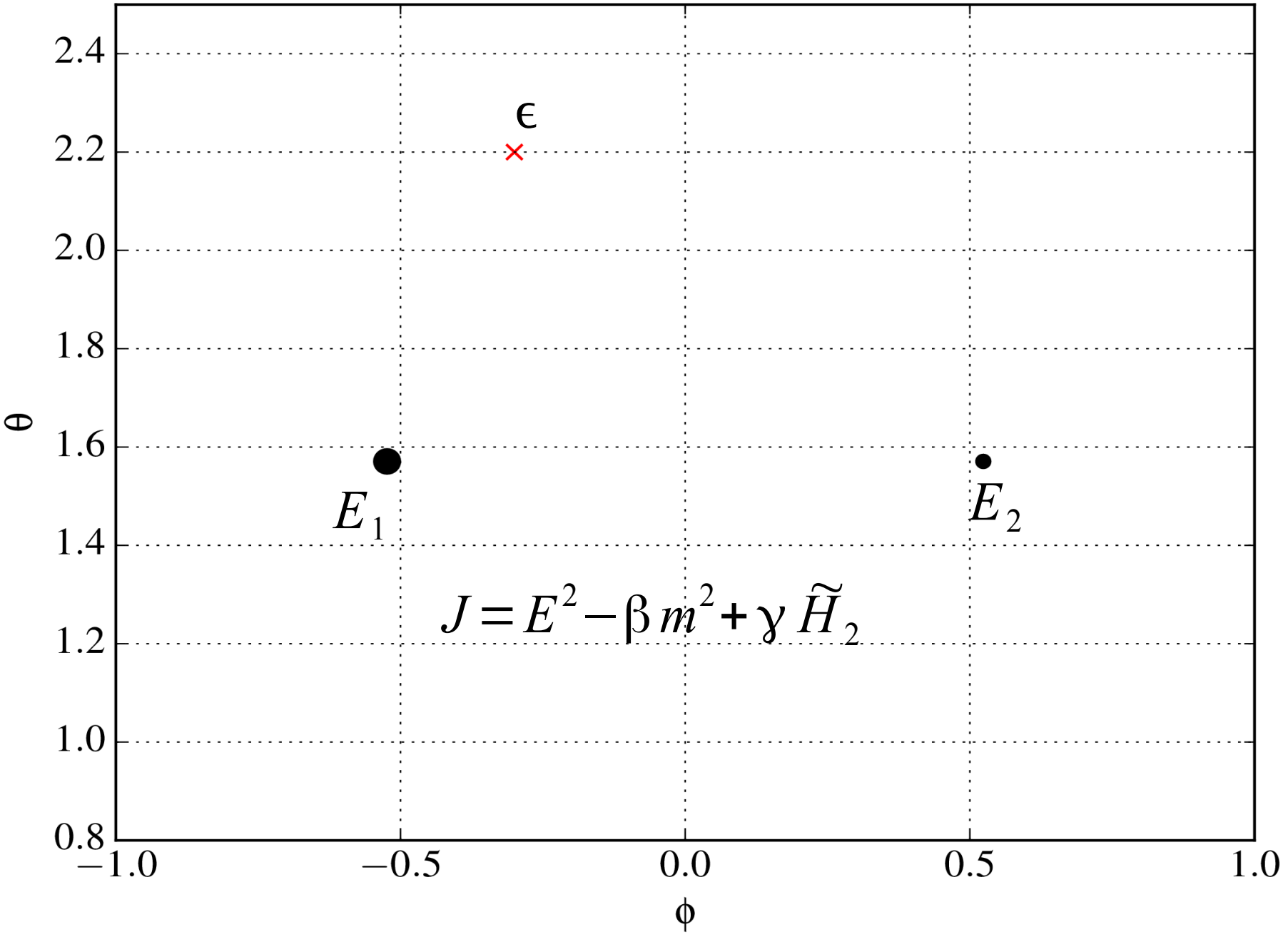
$$\widetilde{H}_2 = \left(\sum_{i,j} |p_i||p_j| P_2\left(\cos\left(\theta_{i,j}\right)\right) \right)_{\text{rest frame}} \equiv m^2 \sum_{i,j} \frac{\left(p_i^{\mu} p_{j\mu}\right)^2}{\left(P^{\mu} p_{i\mu}\right)\left(P^{\nu} p_{j\nu}\right)} - m^2$$

- Characteristic Function of two-prong objects

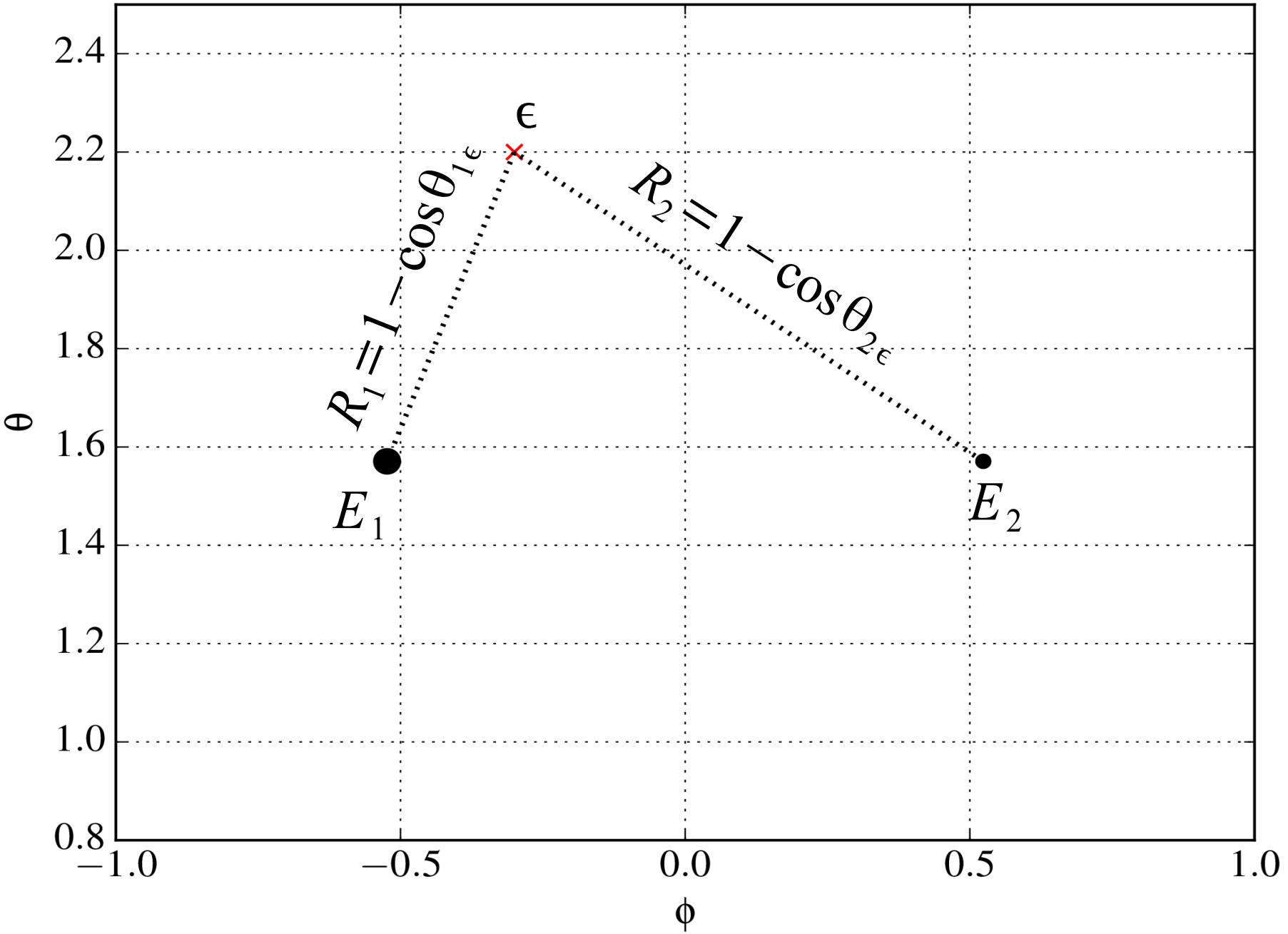
$$J^{\mathrm{II}}_{E_T} = E_T^2 \left(1 - \beta \frac{m^2}{E_T^2} + \gamma \frac{\widetilde{H}_2}{E_T^2}\right) \approx E_T^2 \left(1 - (\beta - \gamma) \frac{m^2}{E_T^2}\right)$$

- $\beta - \gamma$: overall size of the object

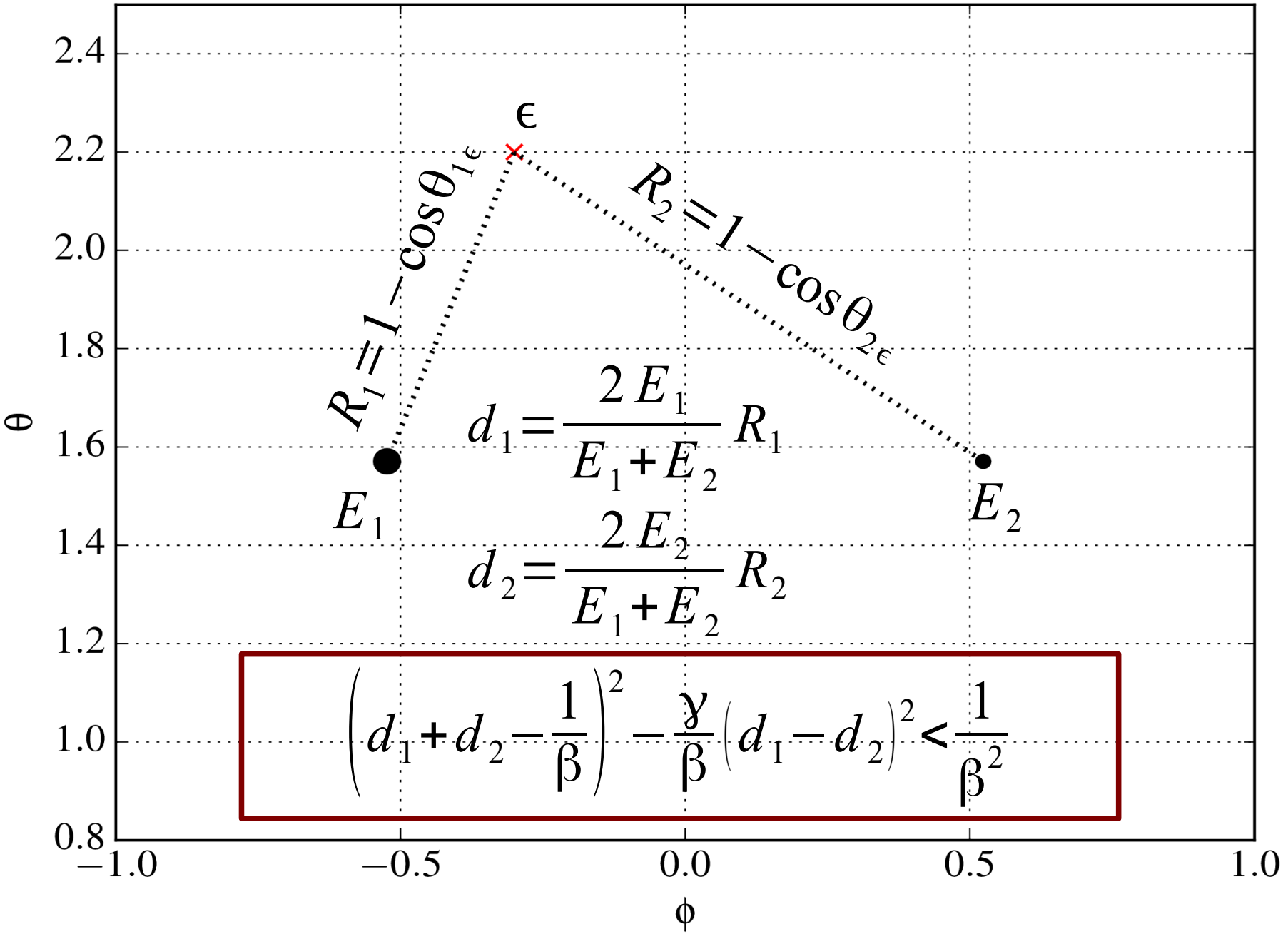
Toy System


ϵ
E_1
E_2
$J = E^2 - \beta m^2 + \gamma \tilde{H}_2$
θ
ϕ
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
−1.0
−0.5
0.0
0.5
1.0

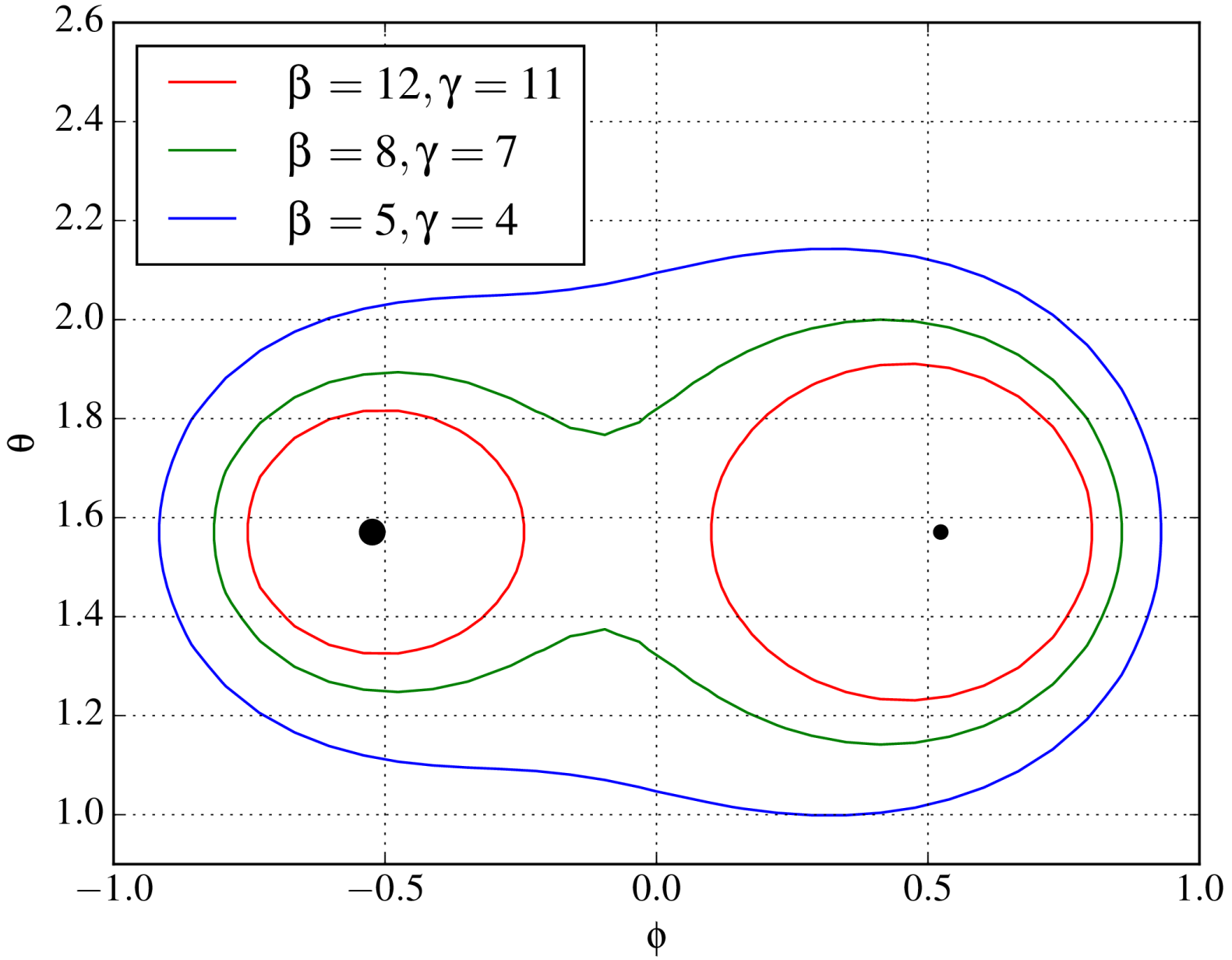
Maximization in 2+ε system



Maximization in 2+ε system

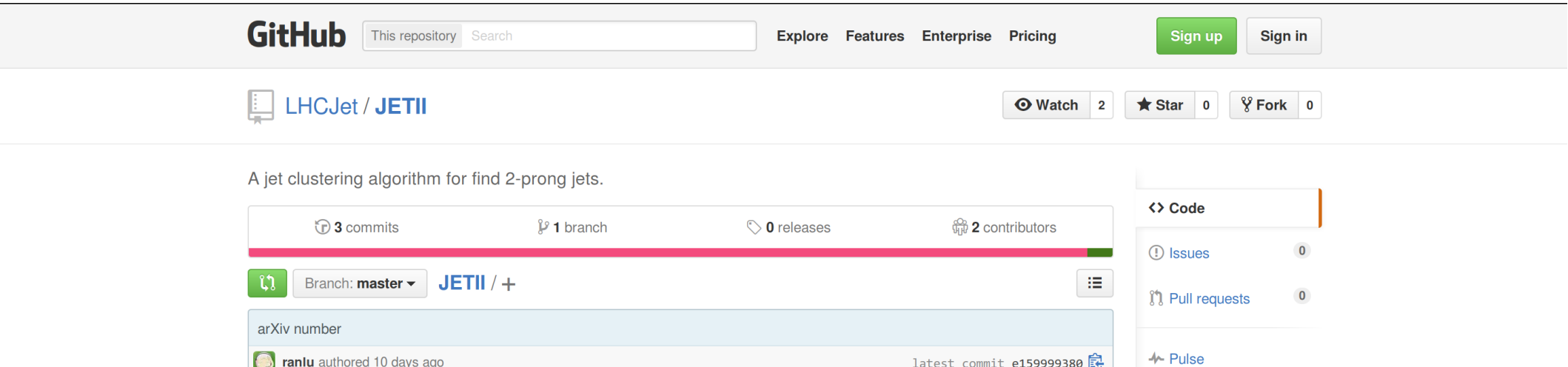


Passive Catchment Area

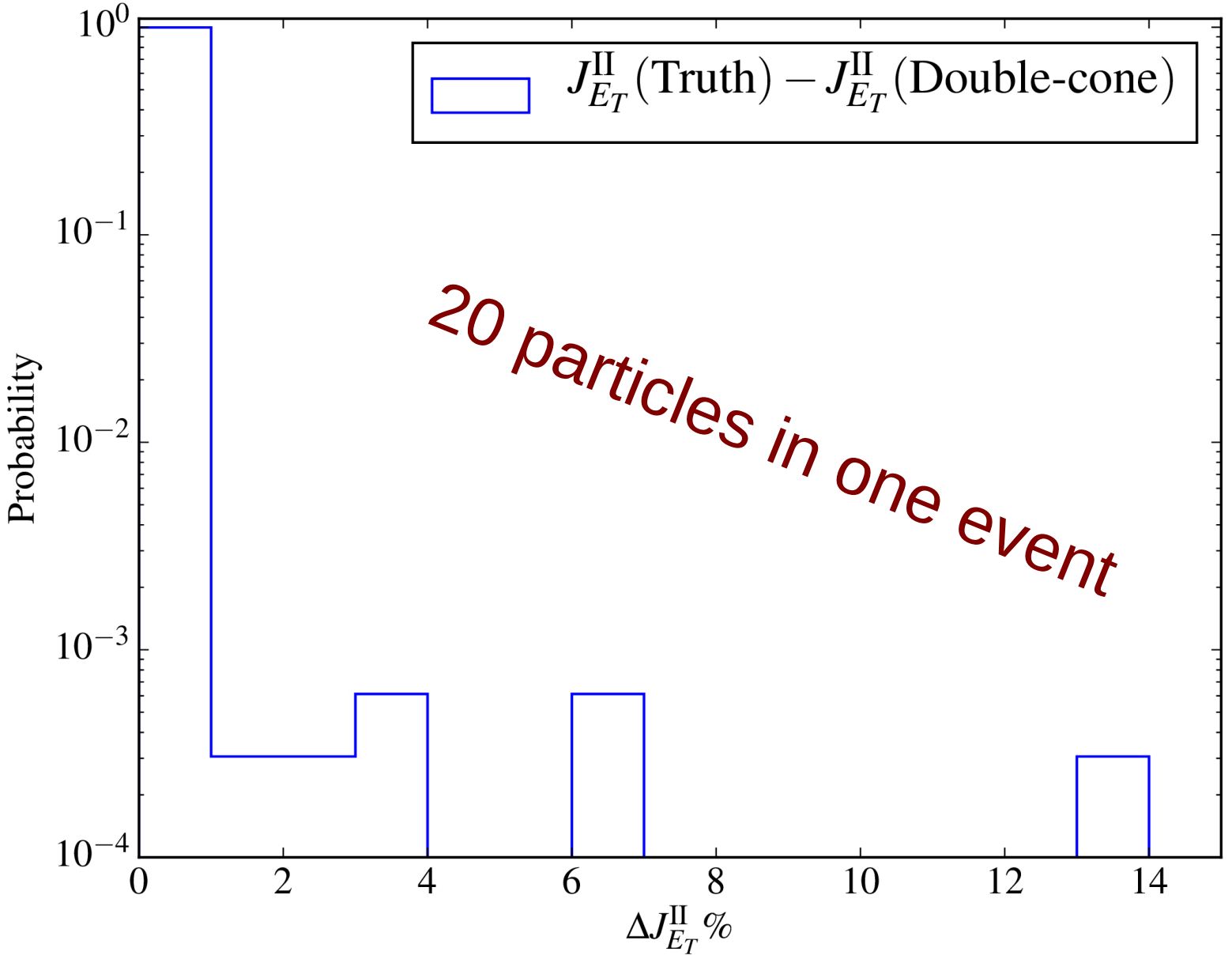


Approximation

- Global maximization is still NP
- Approximate solution (double cone intuition)
  - Start with large cone (e.g. C/A R=1.8)
  - Collect many anti-kt subjets with different R
  - Find the pair maximize $J^{\mathrm{II}}_{E_T}$ function (overlapping)
- Implementation (https://github.com/LHCJet/JETII)



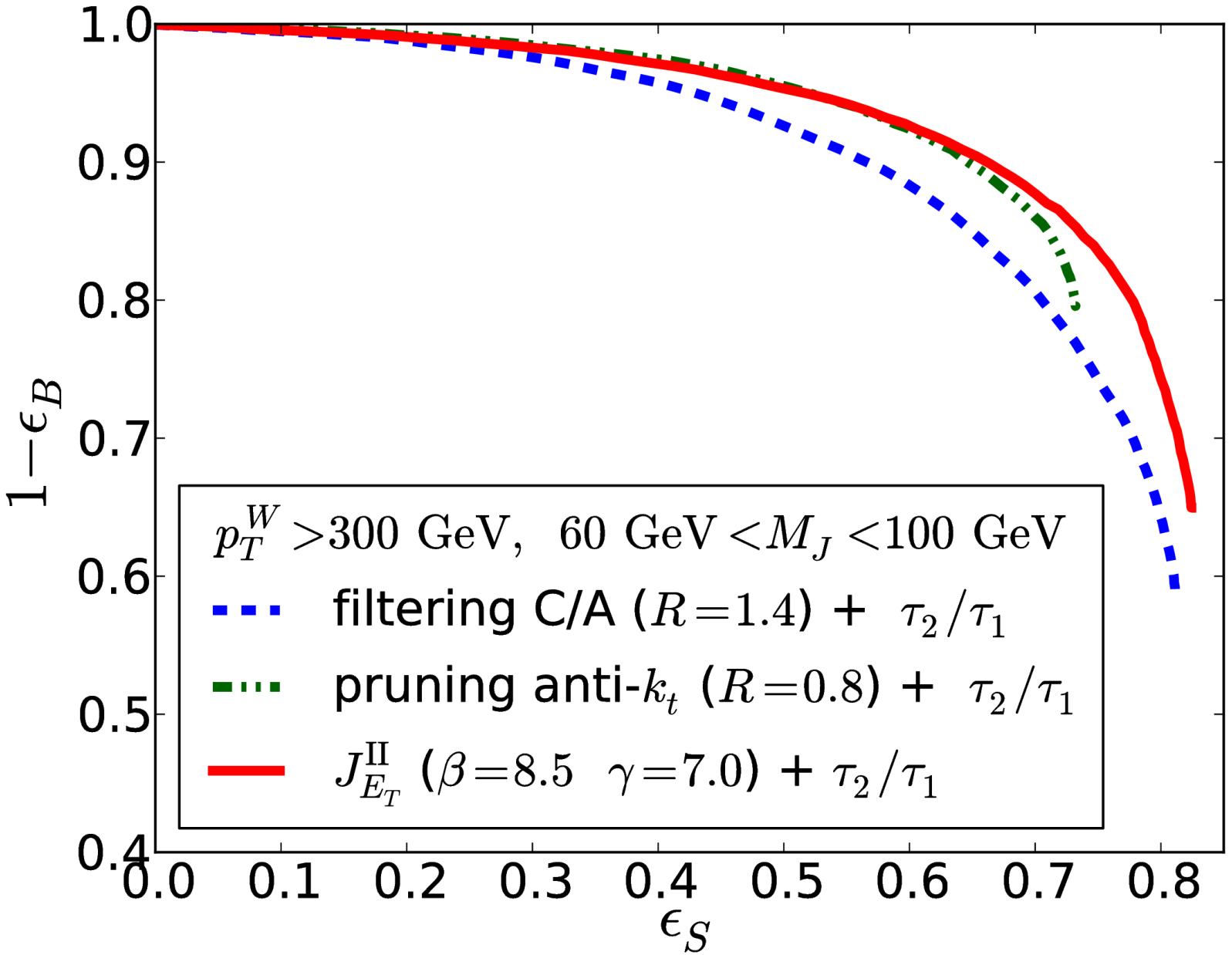
Approximation



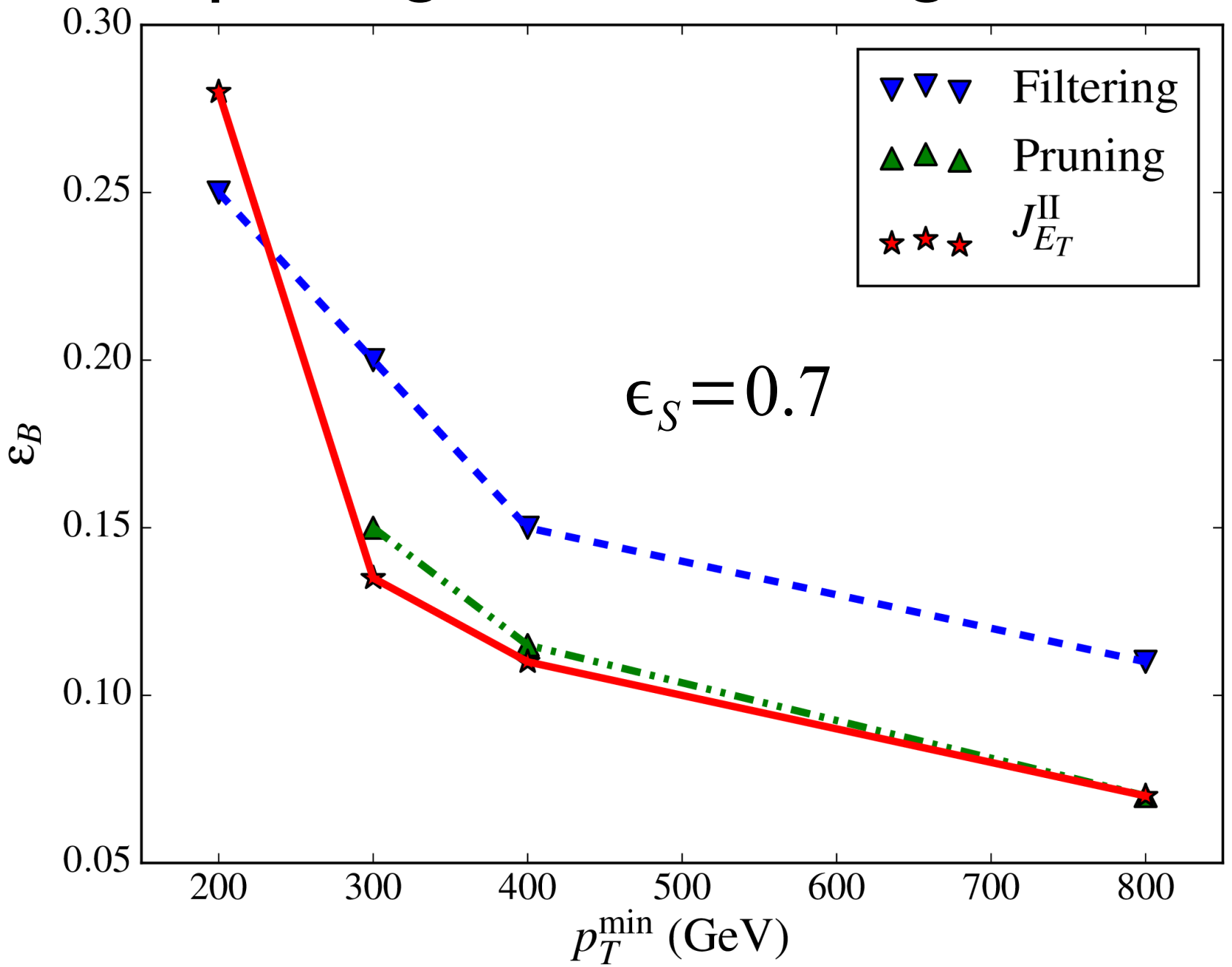
Comparing with Filtering/Pruning

- Signal: WW; Background: QCD dijet $\hat{p}_T > p_T^{min}$
- 14 TeV LHC, PYTHIA 8, 20 SoftQCD pile up
- Fat jet + filtering/pruning v.s. $J^{\mathrm{II}}_{E_T}$
- Optimize for maximal signal efficiency
- ROC curve using N-subjettiness variable τ_2/τ_1

Comparing with Filtering/Pruning



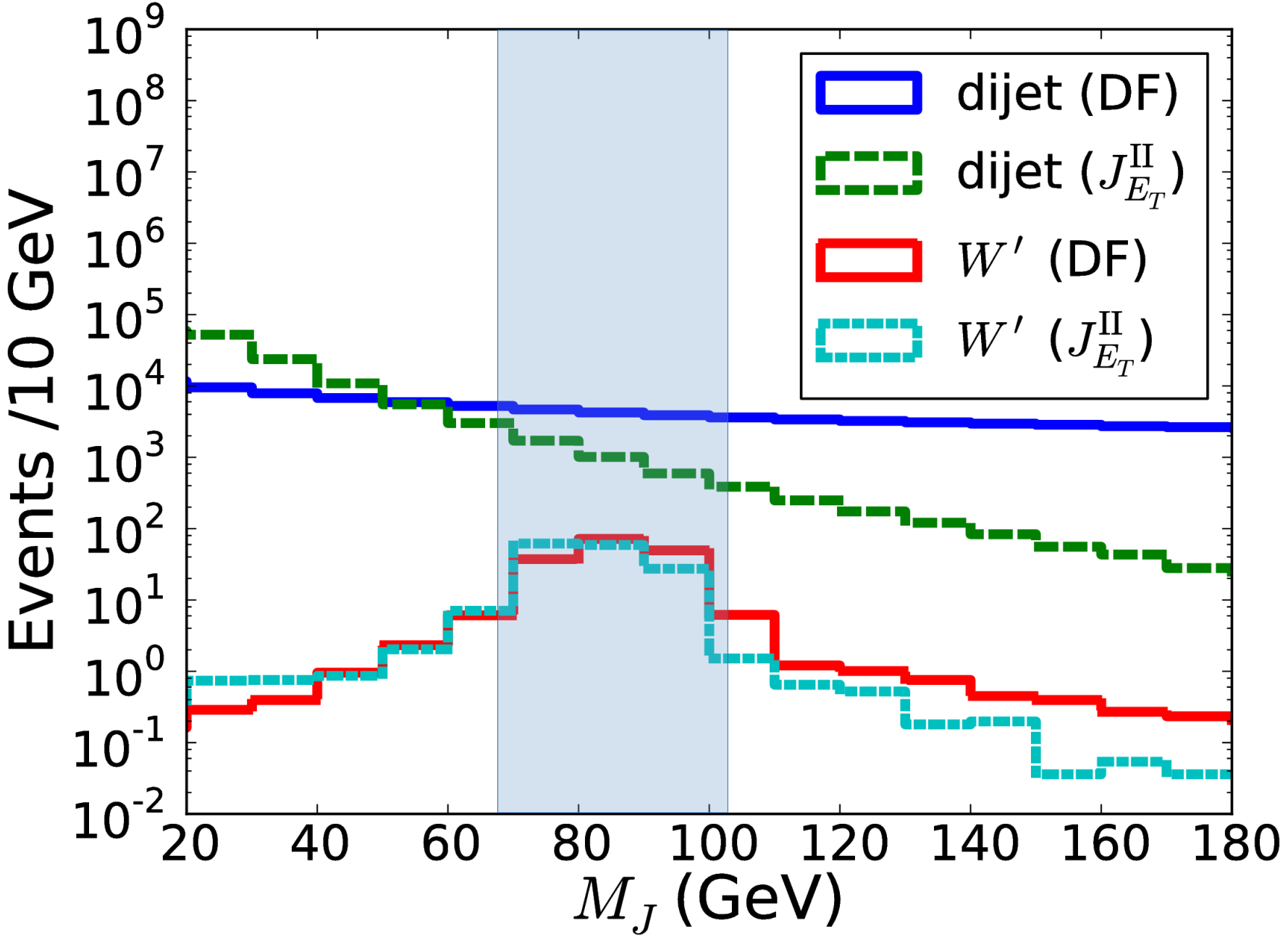
Comparing with Filtering/Pruning



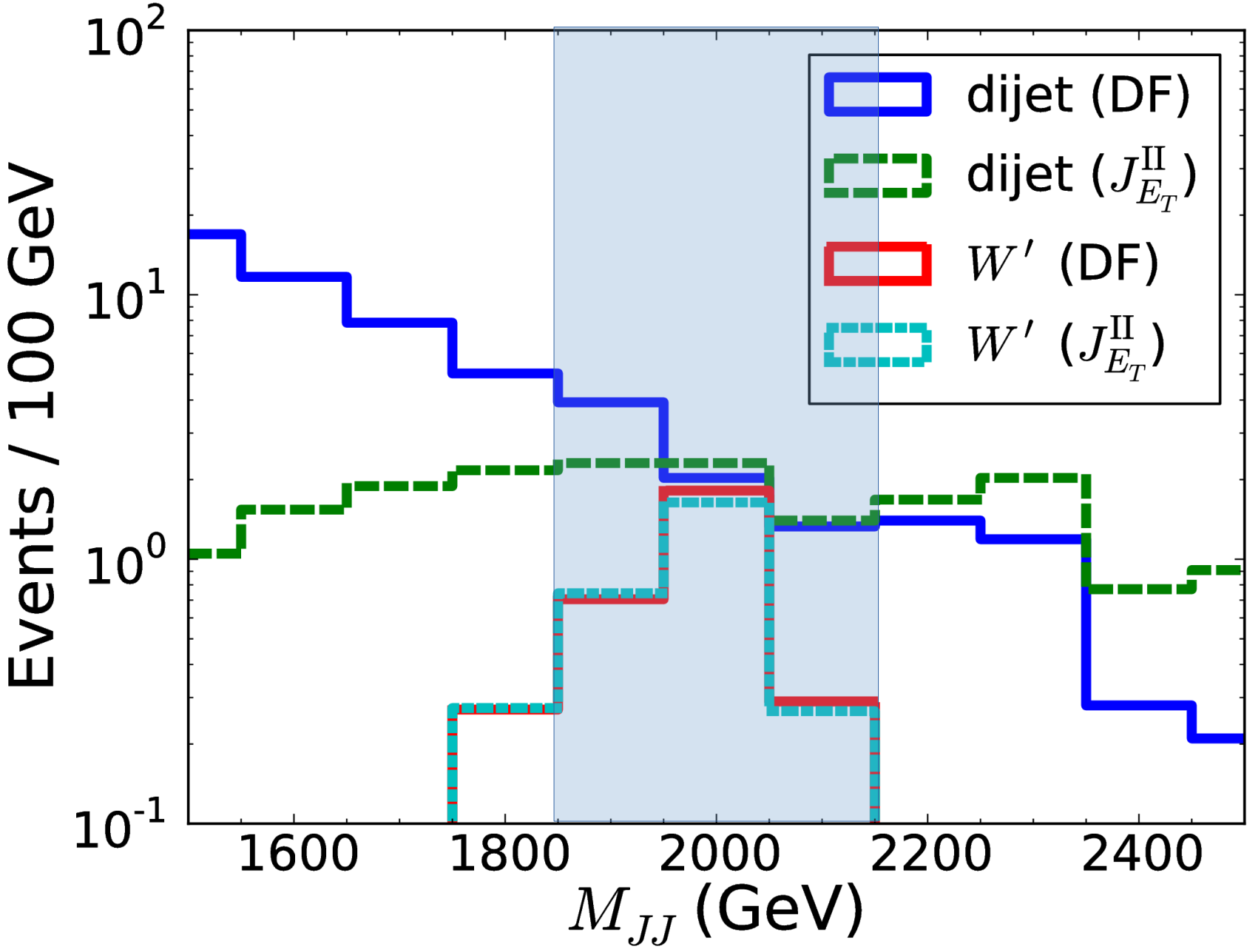
Diboson Resonance

- 2 TeV W' decaying into W+Z
- 8 TeV LHC, PYTHIA 8, 20 SoftQCD pileup
- Following ATLAS cuts as close as possible
- No detector effects, no #tracks cut
- $J^{\mathrm{II}}_{E_T}$ v.s. Fat jet + declustering-filtering (DF)

Diboson Resonance



Diboson Resonance



Conclusion and Future Directions

- New approach to study jets/objects
- Jet function for two-prong jet
- Potentially useful for W/Z/H tagging
- Realistic tests/applications
- General framework for other objects
- Better/Faster approximation