

$J_{E_T}^{\text{II}}$ algorithm for two-prong jets

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ArXiv: 1509.07522 with Yang Bai and Zhenyu Han

Brookhaven Forum 2015

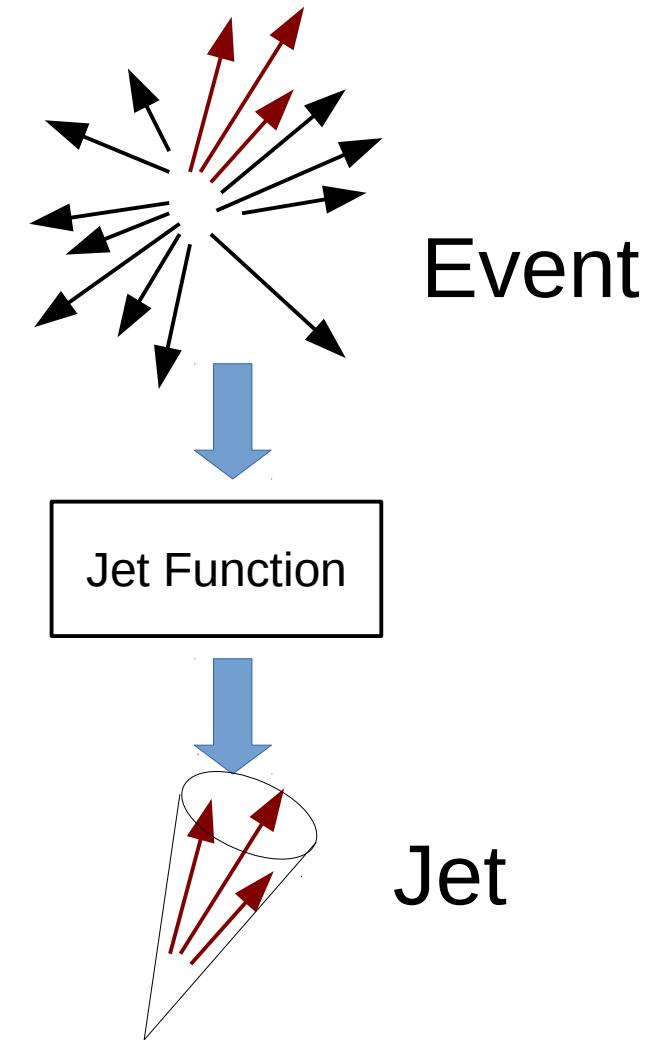
2015-10-08

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

- $E \rightarrow E_T$

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

$$E_T^2 = p_T^2 + m^2$$

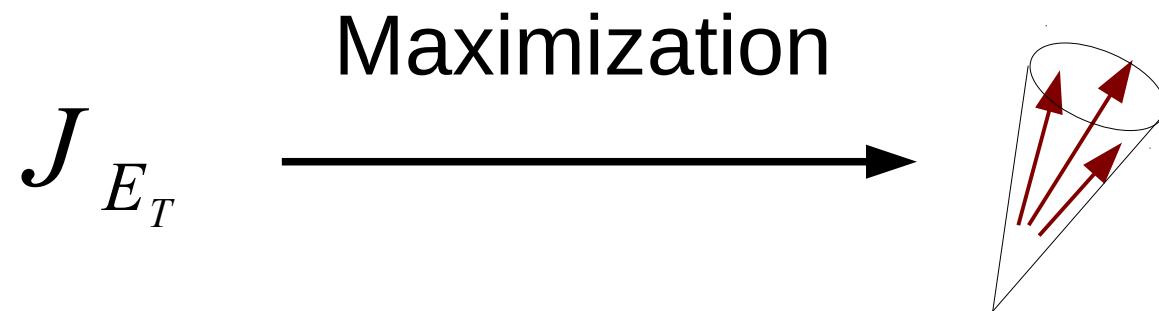
- Implementation (<https://github.com/LHCJet/JET>)

The screenshot shows the GitHub repository page for "LHCJet / JET". The top navigation bar includes links for "Explore", "Features", "Enterprise", "Blog", "Sign up", and "Sign in". The repository name "LHCJet / JET" is displayed with a star icon. On the right, there are buttons for "Watch" (2), "Star" (0), "Fork" (0), and "Code". The main area shows statistics: 109 commits, 1 branch, 3 releases, and 1 contributor. A dropdown menu shows the current branch is "master". Below this, a list of recent commits is shown:

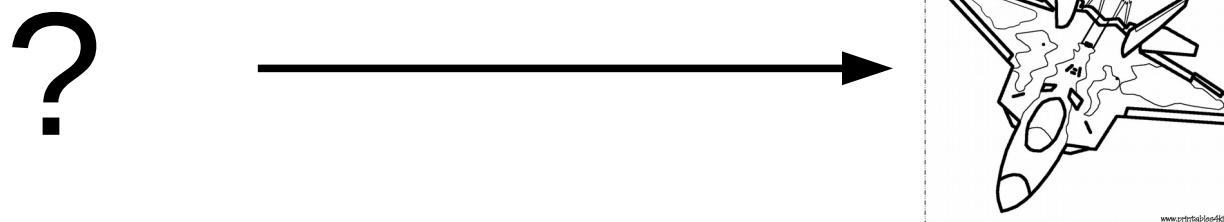
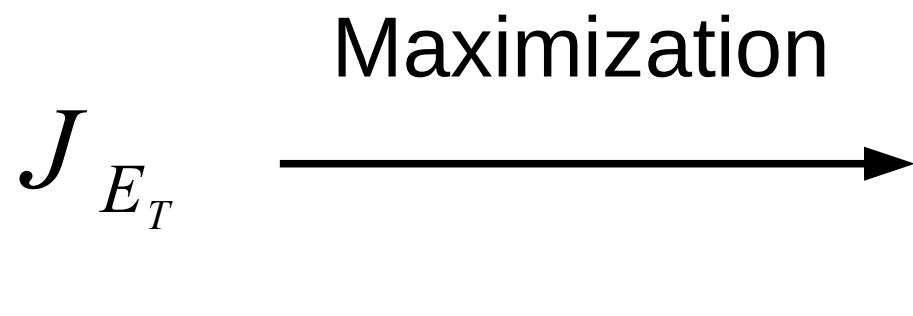
Commit	Author	Date	Message
777c3be730	ranlu	Mar 3	Fix memory leak in python binding
Summary.cmake adapted from Clementine	cmake/modules	4 months ago	
Forgot to add it	examples	4 months ago	
Separate examples and internal codes	fastjet	4 months ago	
Fix memory leak in python binding	python	2 months ago	
Some event sample to test with	sample	7 months ago	

On the right sidebar, there are links for "Code", "Issues" (0), "Pull requests" (0), "Pulse", and "Graphs". At the bottom, there is a "HTTPS clone URL" field containing the URL <https://github.com/LHCJet/JET>.

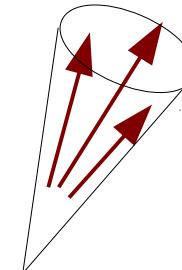
Generalization



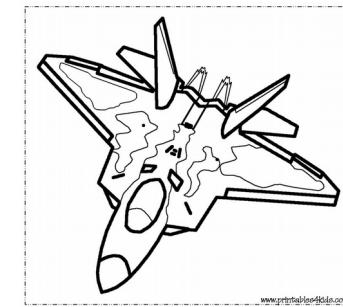
Generalization



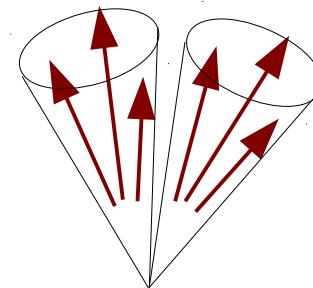
Generalization



?



$$J_{E_T}^{\text{II}}$$



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:
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Step 1

Step II



W tagging

$J_{E_T}^{\text{II}}$ → Two-prong Jet Step I

- Tagging variable
 - Mass Drop
 - Subjet Momentum Balance
 - N-subjettiness
 - Color Flow
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Step II

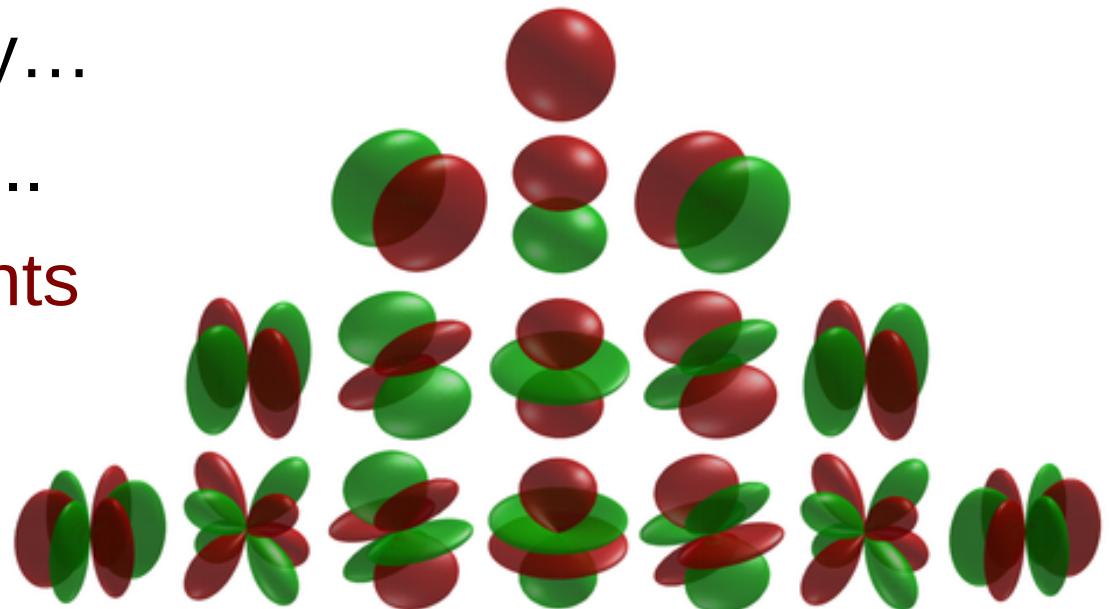


Jet Function of Two-prong Jets

- $J(P)$ 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
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 - 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:

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

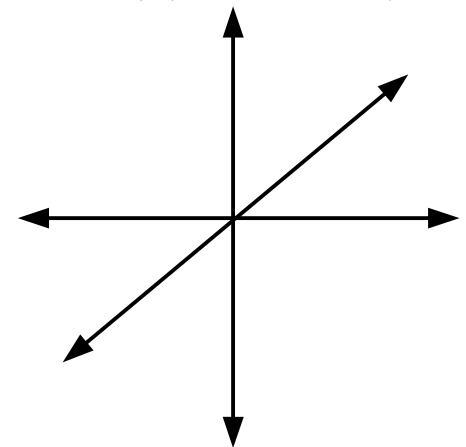
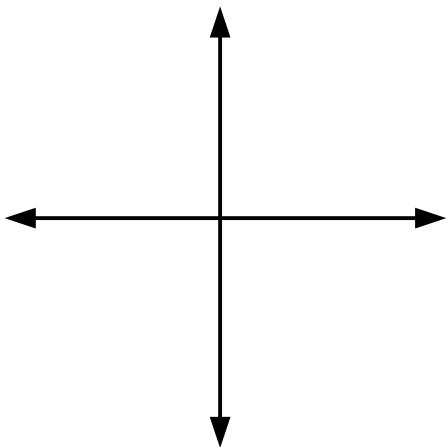
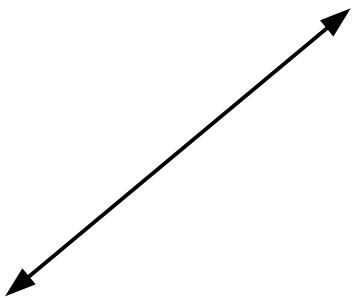
$$H_2 = \sum_{i,j} \frac{|p_i||p_j|}{E_J^2} \frac{(3\cos^2 \theta_{i,j} - 1)}{2}$$

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

\tilde{H}_2 Function

- Lab Frame Modification

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



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

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

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

$J_{E_T}^{\text{II}}$ Function

- Lab Frame Definition

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

- Characteristic Function of two-prong objects

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

Parameters

- Lab Frame Definition

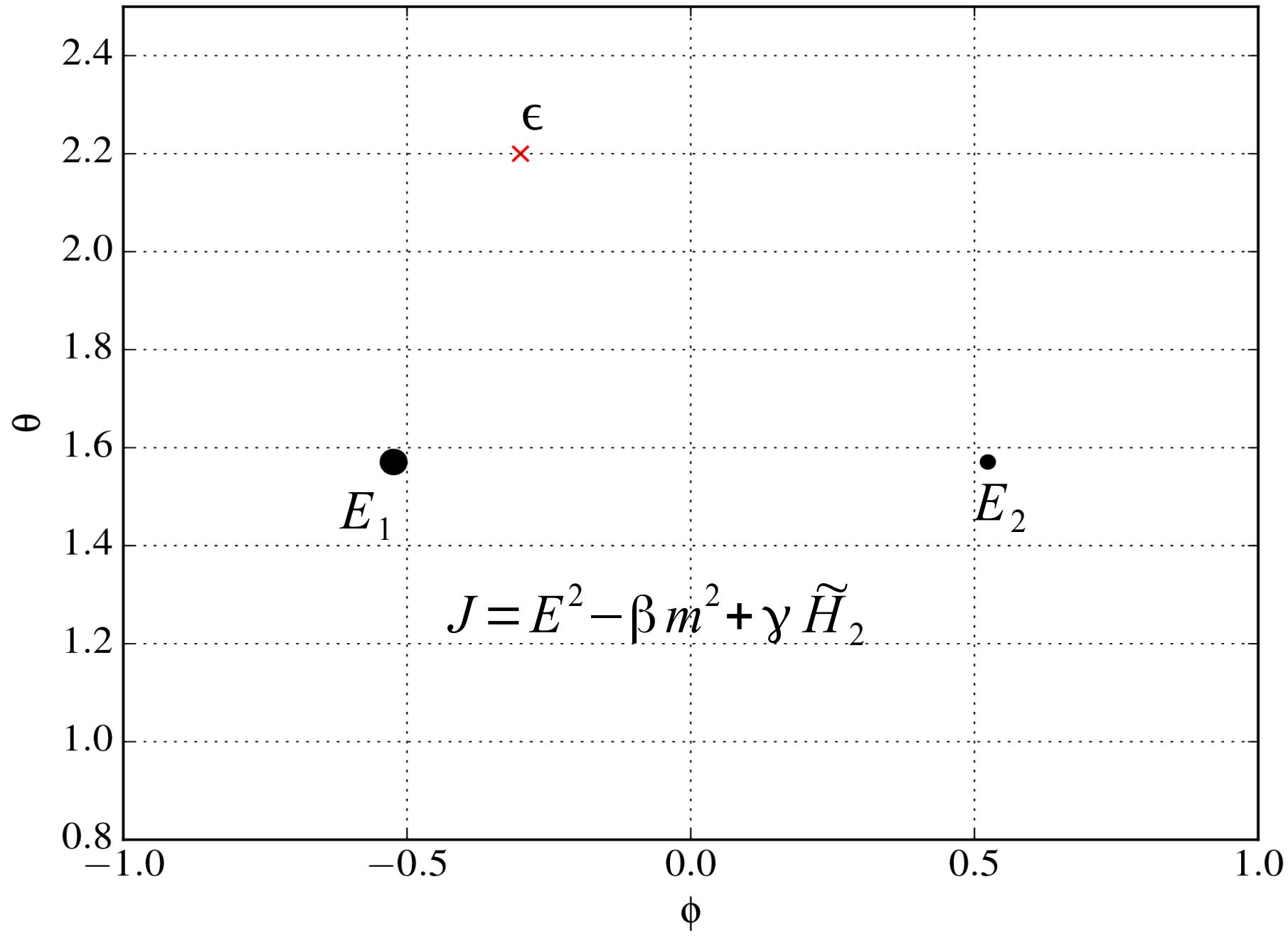
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- Characteristic Function of two-prong objects

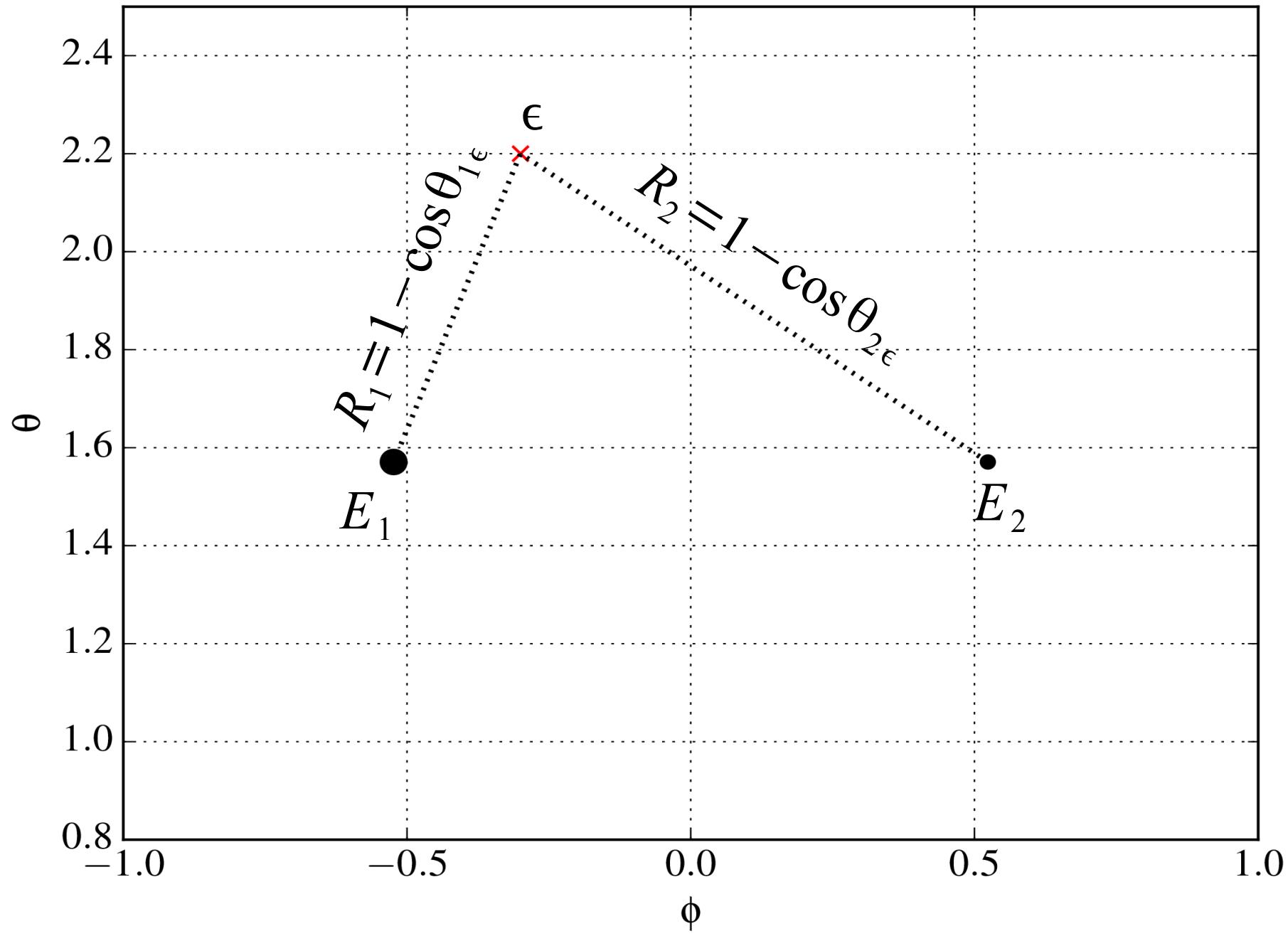
$$J_{E_T}^{\text{II}} = E_T^2 \left(1 - \beta \frac{m^2}{E_T^2} + \gamma \frac{\widetilde{H}_2}{E_T^2} \right) \approx E_T^2 \left(1 - (\beta - \gamma) \frac{m^2}{E_T^2} \right)$$

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

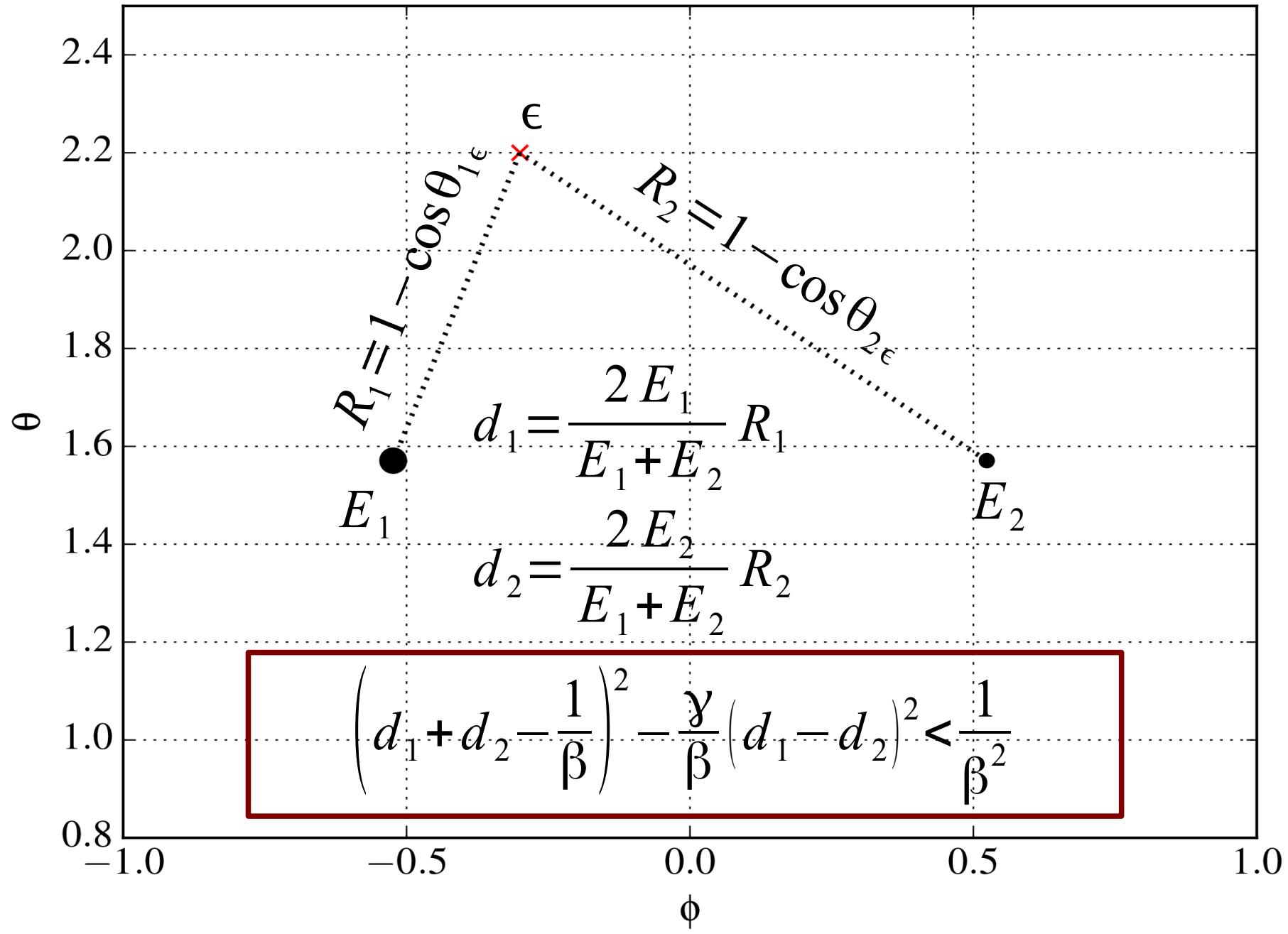
Toy System



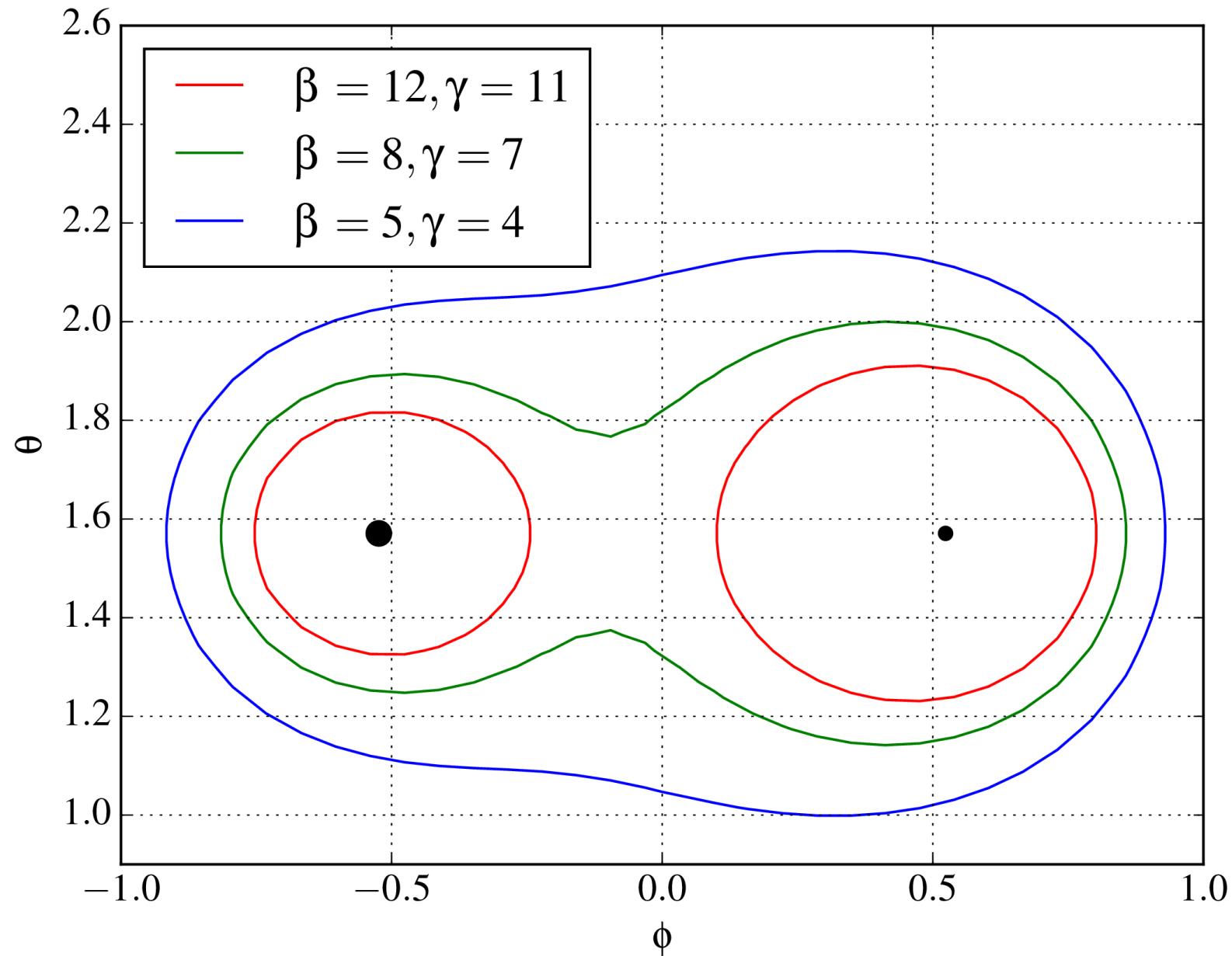
Maximization in $2+\epsilon$ system



Maximization in 2+ ϵ system



Passive Catchment Area

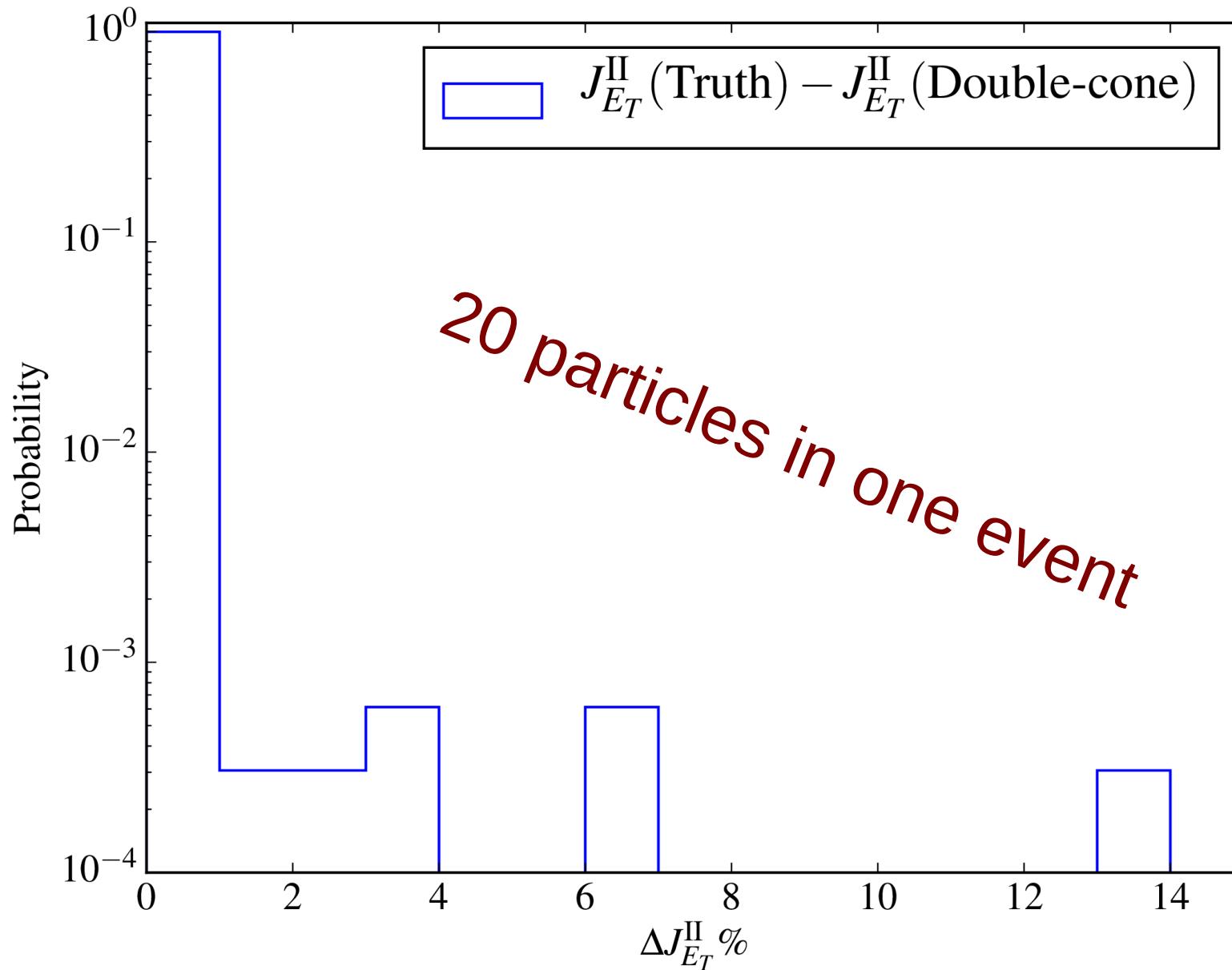


Approximation

- 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 $J_{E_T}^{\text{II}}$ function (overlapping)
- Implementation (<https://github.com/LHCJet/JETII>)

The screenshot shows the GitHub repository page for 'LHCJet / JETII'. The top navigation bar includes links for 'Explore', 'Features', 'Enterprise', 'Pricing', 'Sign up', and 'Sign in'. The repository name 'LHCJet / JETII' is displayed with a star icon. Below the header, a brief description states: 'A jet clustering algorithm for find 2-prong jets.' Key statistics are shown: 3 commits, 1 branch, 0 releases, and 2 contributors. A dropdown menu indicates the current branch is 'master'. The repository has 0 issues and 0 pull requests. On the left, there's a search bar and a 'Code' section with a 'Code' button. At the bottom, there's a 'Pulse' section.

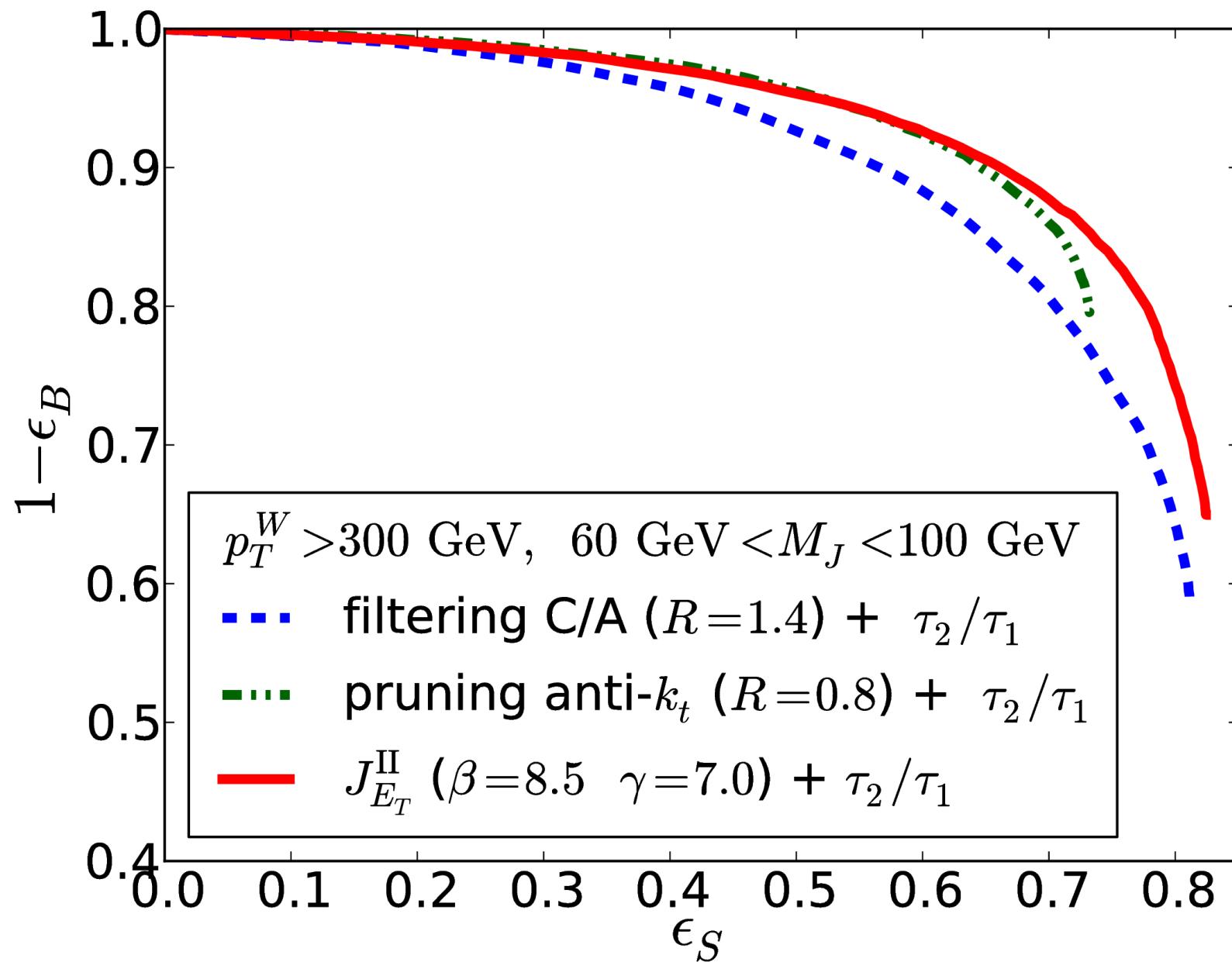
Approximation



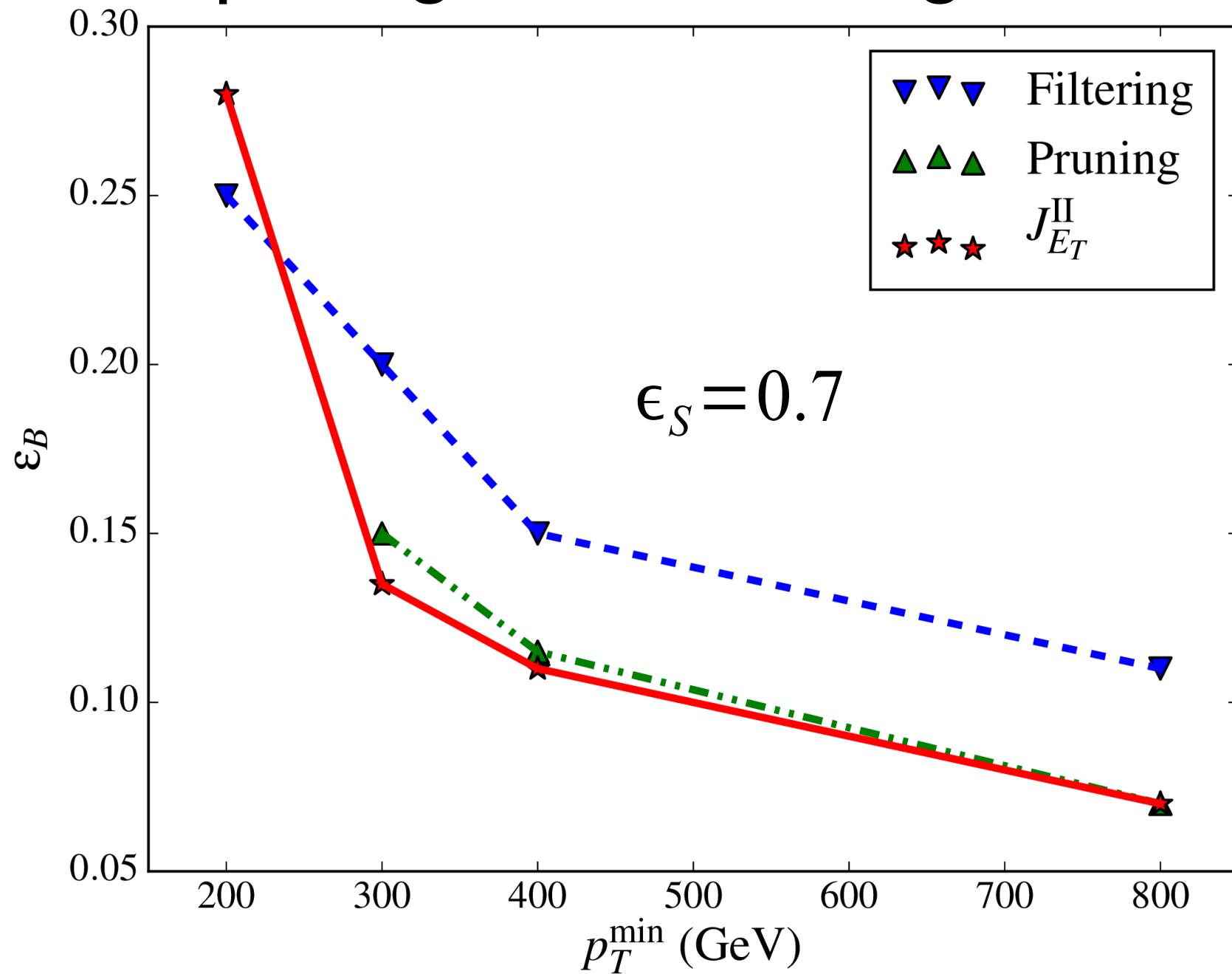
Comparing with Filtering/Pruning

- 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. $J_{E_T}^{\text{II}}$
- Optimize for maximal signal efficiency
- ROC curve using N-subjettiness variable τ_2/τ_1

Comparing with Filtering/Pruning



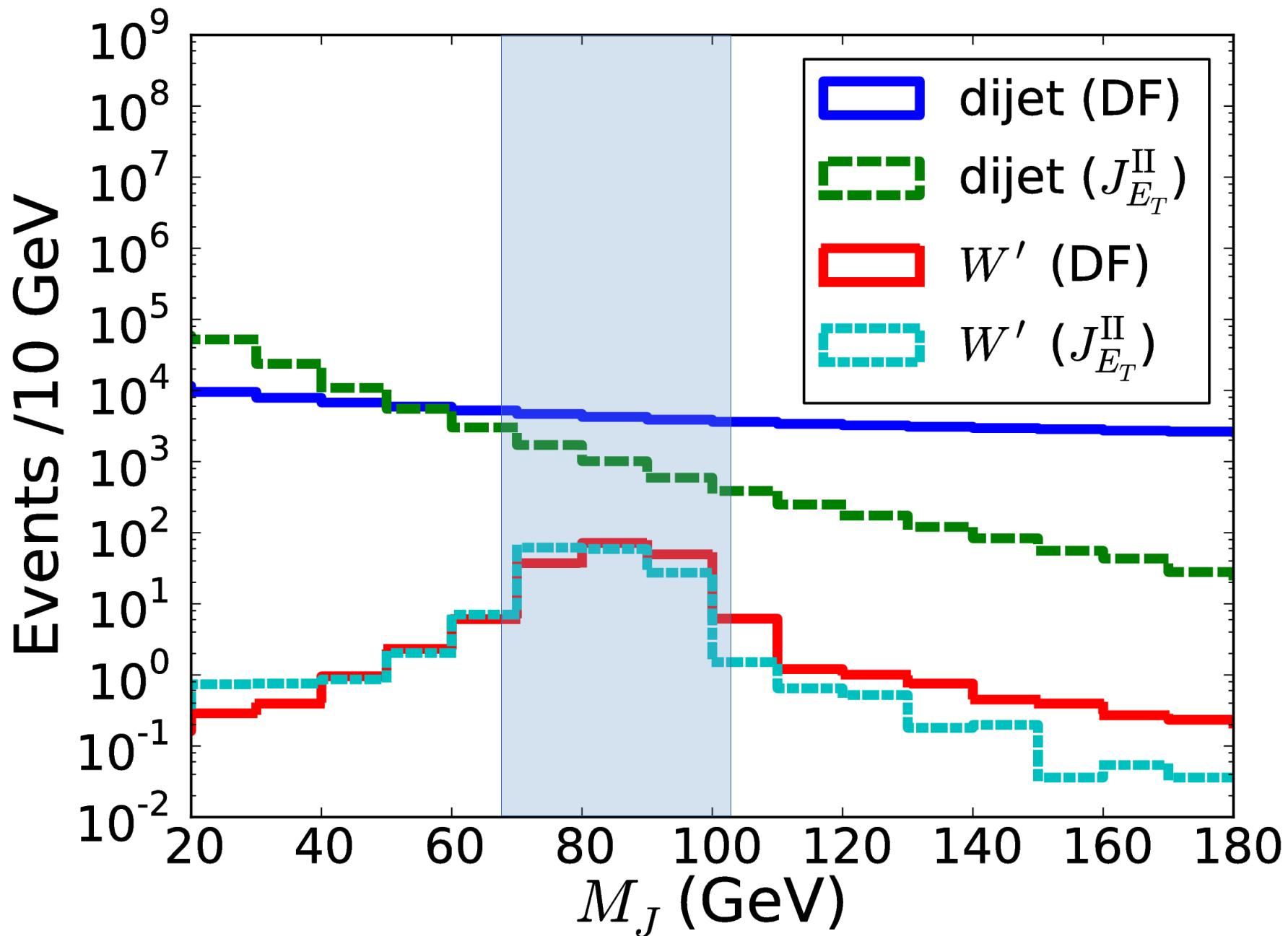
Comparing with Filtering/Pruning



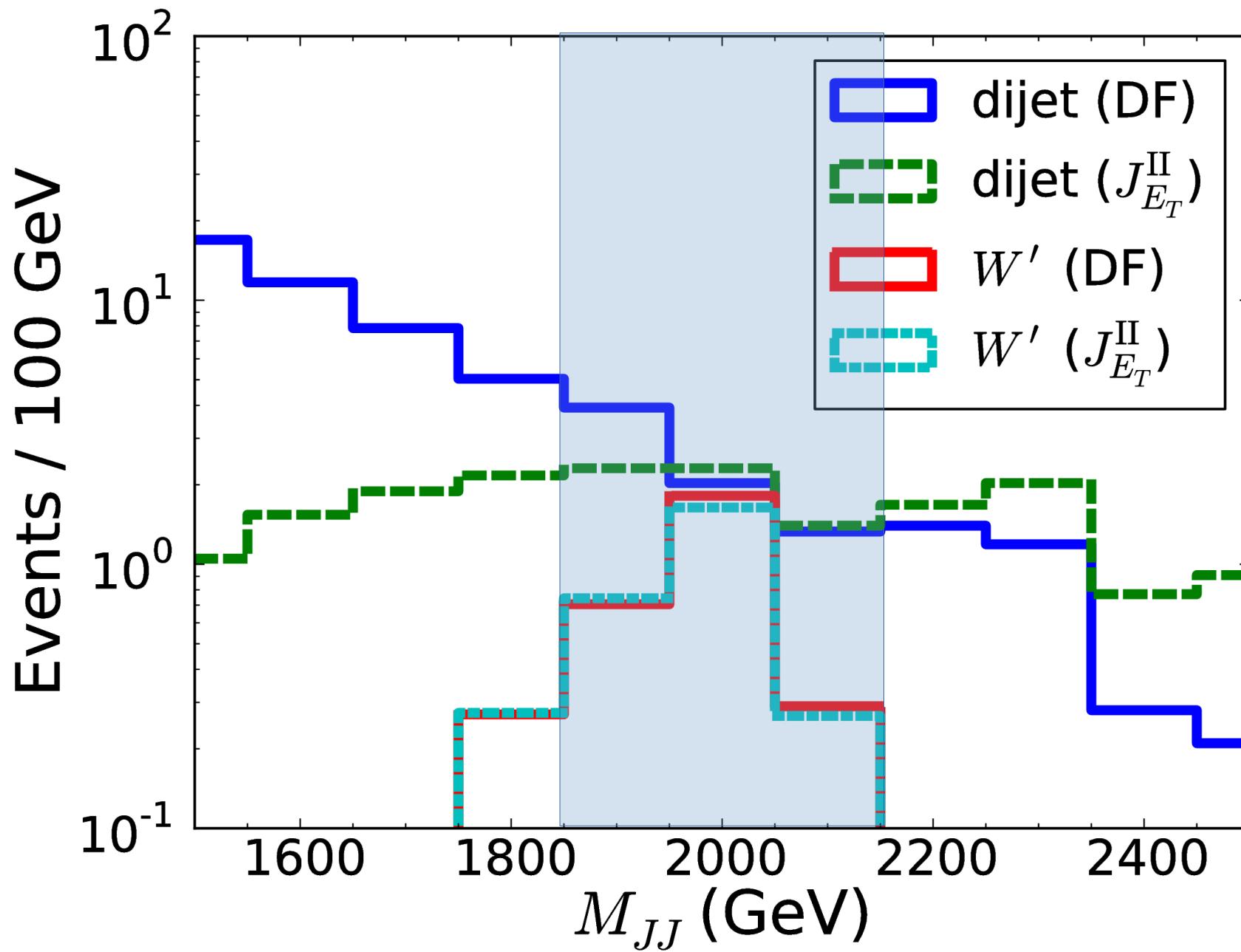
Diboson Resonance

- 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
- $J_{E_T}^{\text{II}}$ 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