Recent developments in jet finding for the Large Hadron Collider

Juan Rojo

INFN, Sezione di Milano

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Outline

1. Jets at the LHC
2. Recent developements
3. Performance in pp
4. Jets in Heavy Ion Collisions
5. Outlook
6. Extras

JETS AT THE LHC

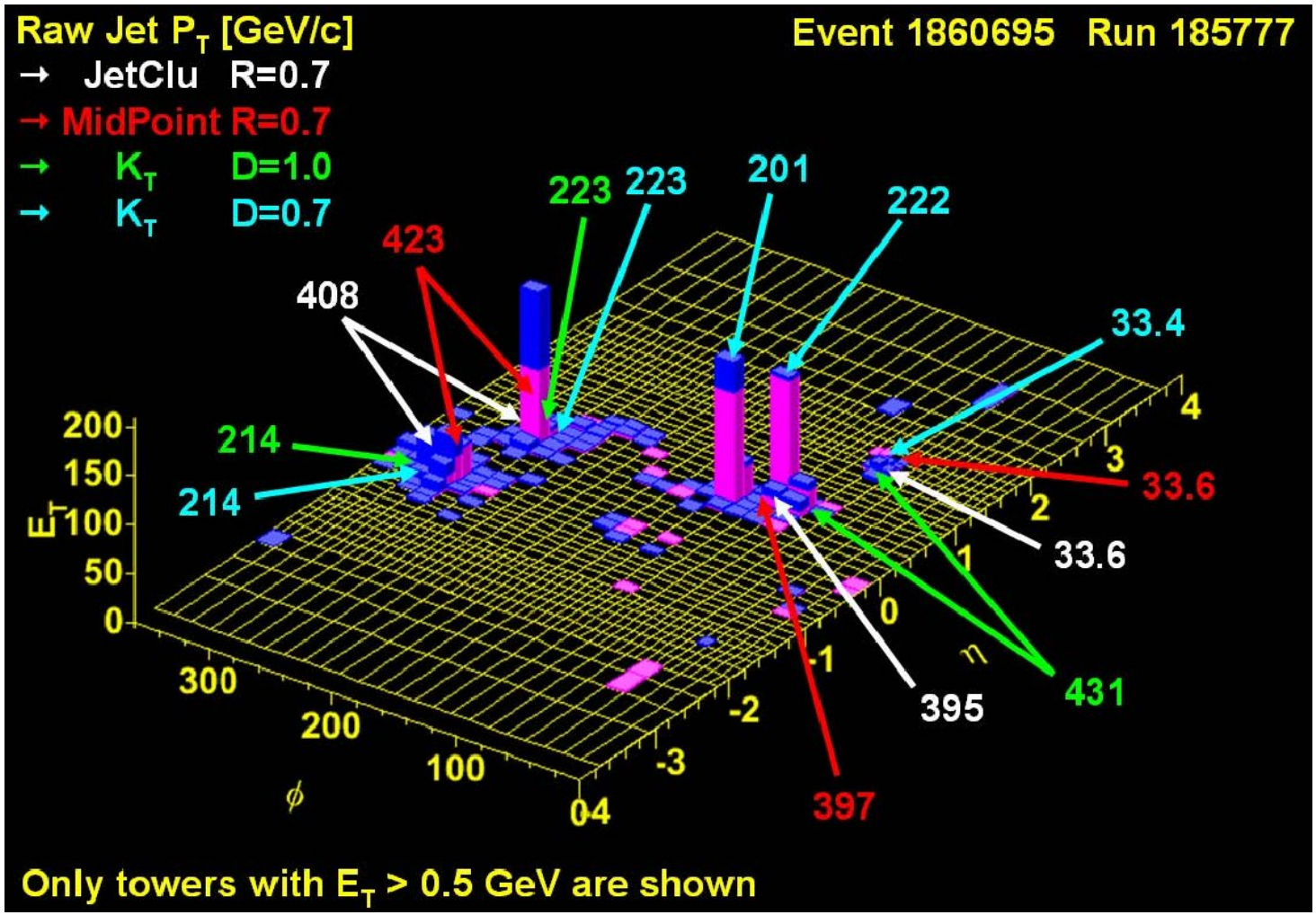
References:

Les Houches 2007, Tools and Jets Summary Report, arXiv:0803.0678

Huston review

J. R., ISMD08 review talk

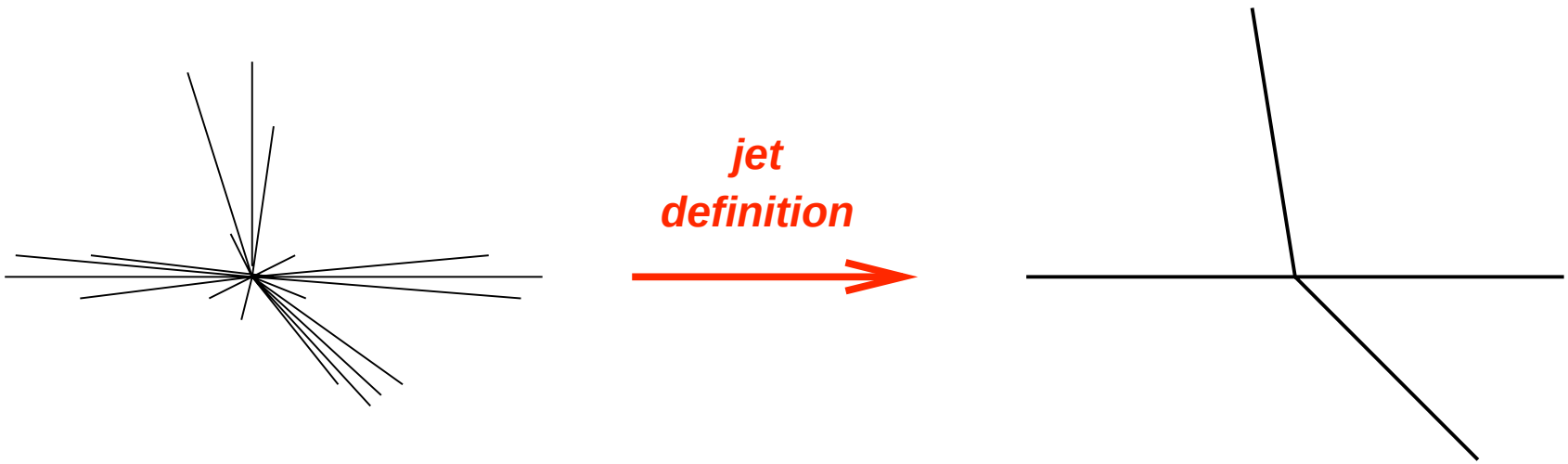
A typical hadronic collider event



Jet algorithms

A jet algorithm is a non-ambiguous mapping between observed hadrons (or calorimeter towers) and the original hard scattering partons

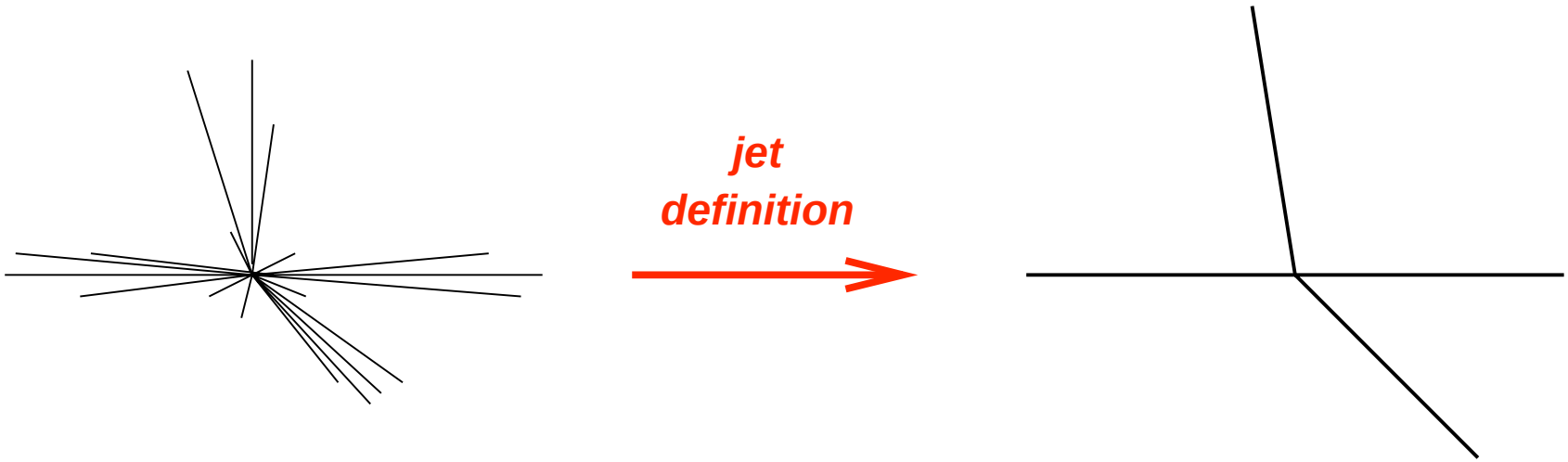
It is a systematic procedure that projects away the multi-particle dynamics, so as to leave a simple picture of the event



Jets are as close as we can get to a physical single quark or gluon

Jet algorithms

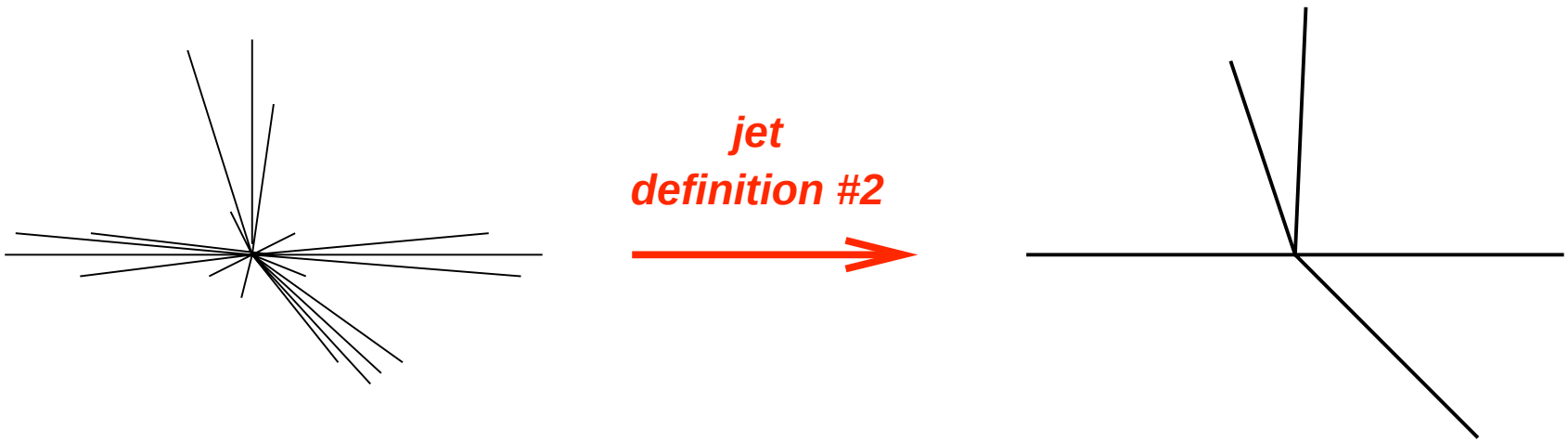
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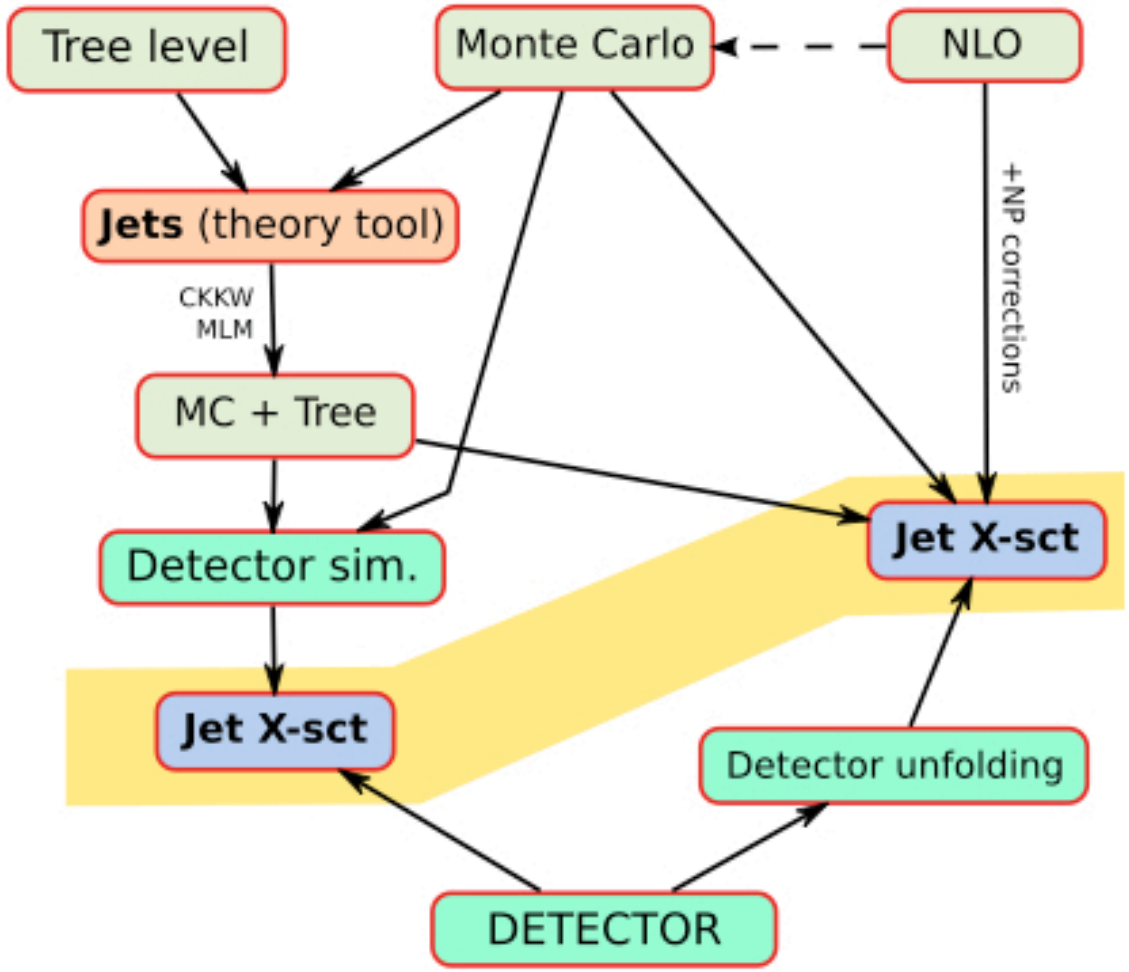
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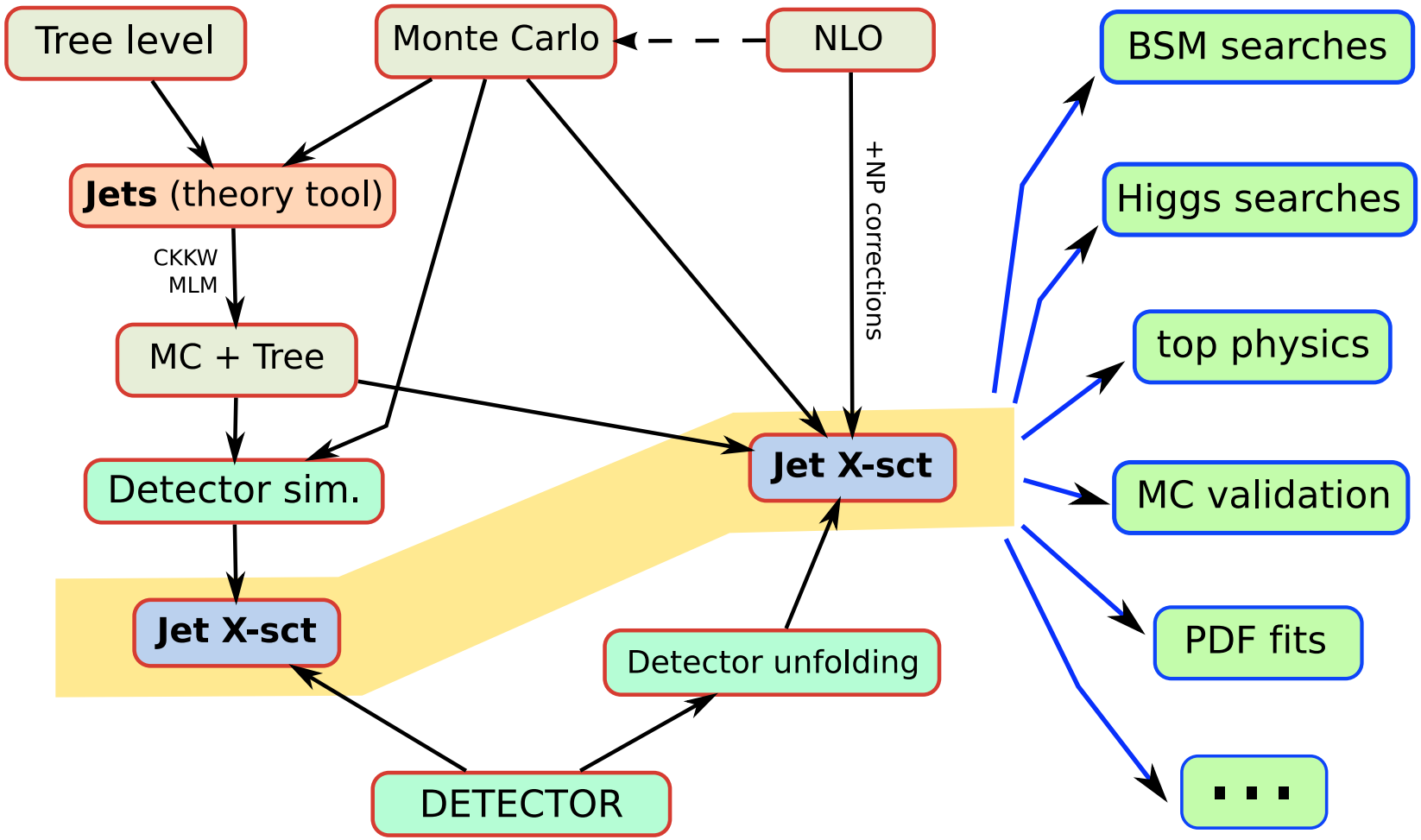
Analysis flowchart

Jet algorithms present in almost all analysis steps at the LHC ...



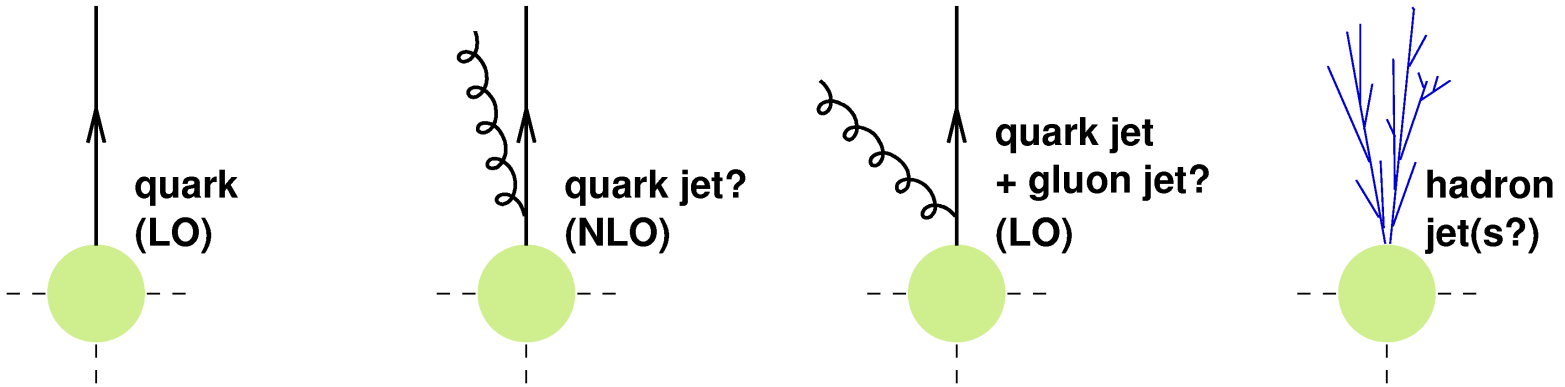
Analysis flowchart

... and essential input to most physics topics



Jets

Naively: a jet is a **bunch of collimated hadrons** ubiquitous in high energy collisions.
Electrons and muons are fundamental, weakly coupled particles — it makes sense physically and experimentally to think of them as concrete objects.
Partons (quarks, gluons) are not so simple...

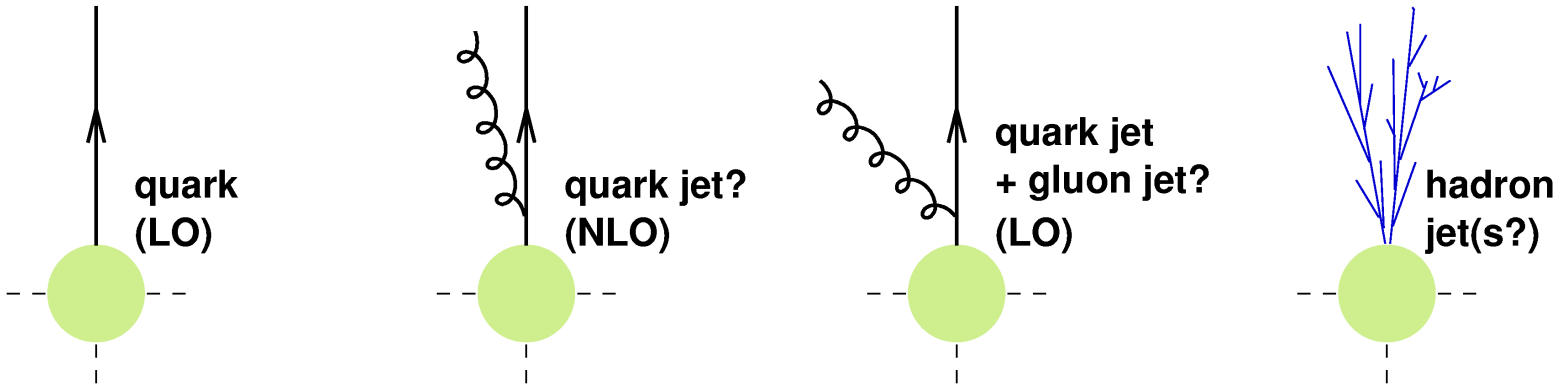


- Partons split into further partons
- Jets are a a way of thinking of the 'original parton'
- A 'jet' is a **fundamentally ambiguous concept** (e.g. requires a resolution)

Jets (and partons!) are only meaningful once you've defined a jet algorithm.

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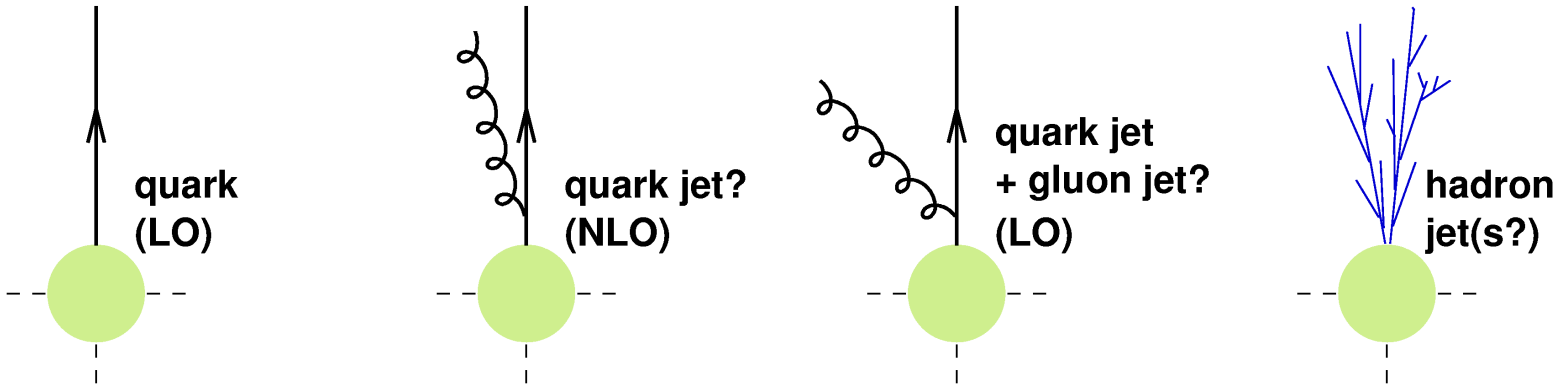


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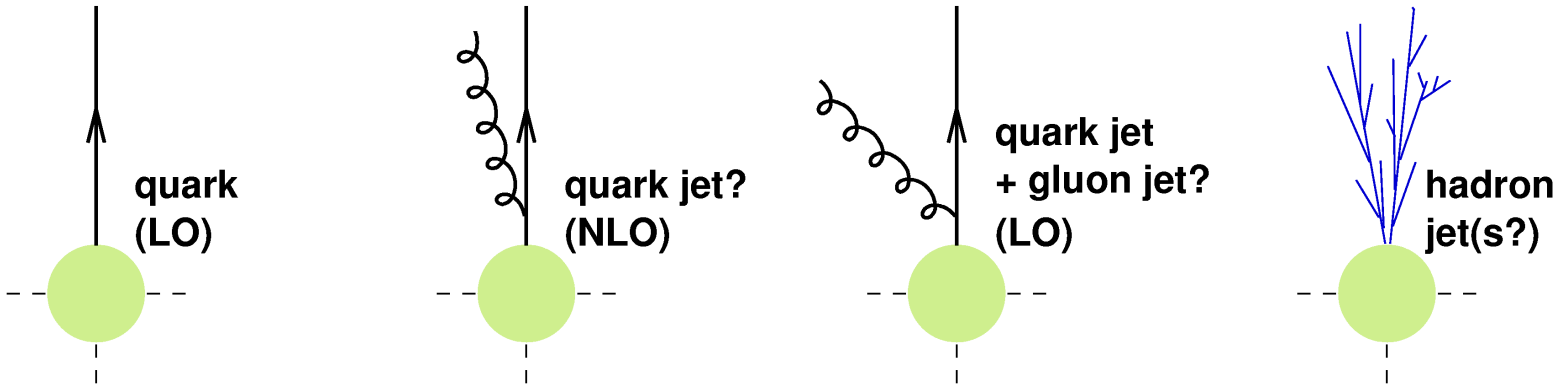


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Jet algorithm types

Mainstream jet-algorithms

- Iterative **cone** algorithms → (JetClu, ILCA/Midpoint, LHC cones,. . .)
  Searches for cones centered on regions of energy flow
  Dominant at hadron colliders
- Sequential **recombination** algorithms → (k_t, Cambridge/Aachen, Jade)
  Recombine closest pair of particles, next closest, etc.
  Dominant at e^+e^- and ep colliders (but now also default in ATLAS and CMS)

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Jet algorithm requirements

What is **needed** of a jet algorithm

- Must be infrared and collinear (IRC) safe
  soft emissions shouldn't change jets
  collinear splitting shouldn't change jets
- Must be identical procedure at parton level, hadron-level and experimental level
  So that theory calculations can be compared to measurements

What is **nice** for a jet algorithm

- Shouldn't be too sensitive to hadronization, underlying event and pileup, while being sensitive to perturbative radiation.
- Should be realistically applicable at detector level.
- Should allow fast implementations, to cope with the large particle multiplicities at hadronic colliders.

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Sequential recombination algorithms

Example: the k_t algorithm:

1. Calculate (or update) distances between all particles i and j, and between i and beam:

$$d_{ij} = \min(k_{ti}^2, k_{tj}^2)\frac{\Delta R_{ij}^2}{R^2}, \qquad d_{iB} = k_{ti}^2\,, \qquad \Delta R_{ij}^2 = \Delta y_{ij}^2 + \Delta\phi_{ij}^2$$

2. Find smallest of d_{ij} and d_{iB}
   - If d_{ij} is smallest, recombine i and j (add result to particle list, remove i, j)
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3. If any particles are left, repeat from step 1.

Single parameter: R (like cone radius), whose natural value is $\mathcal{O}(1)$

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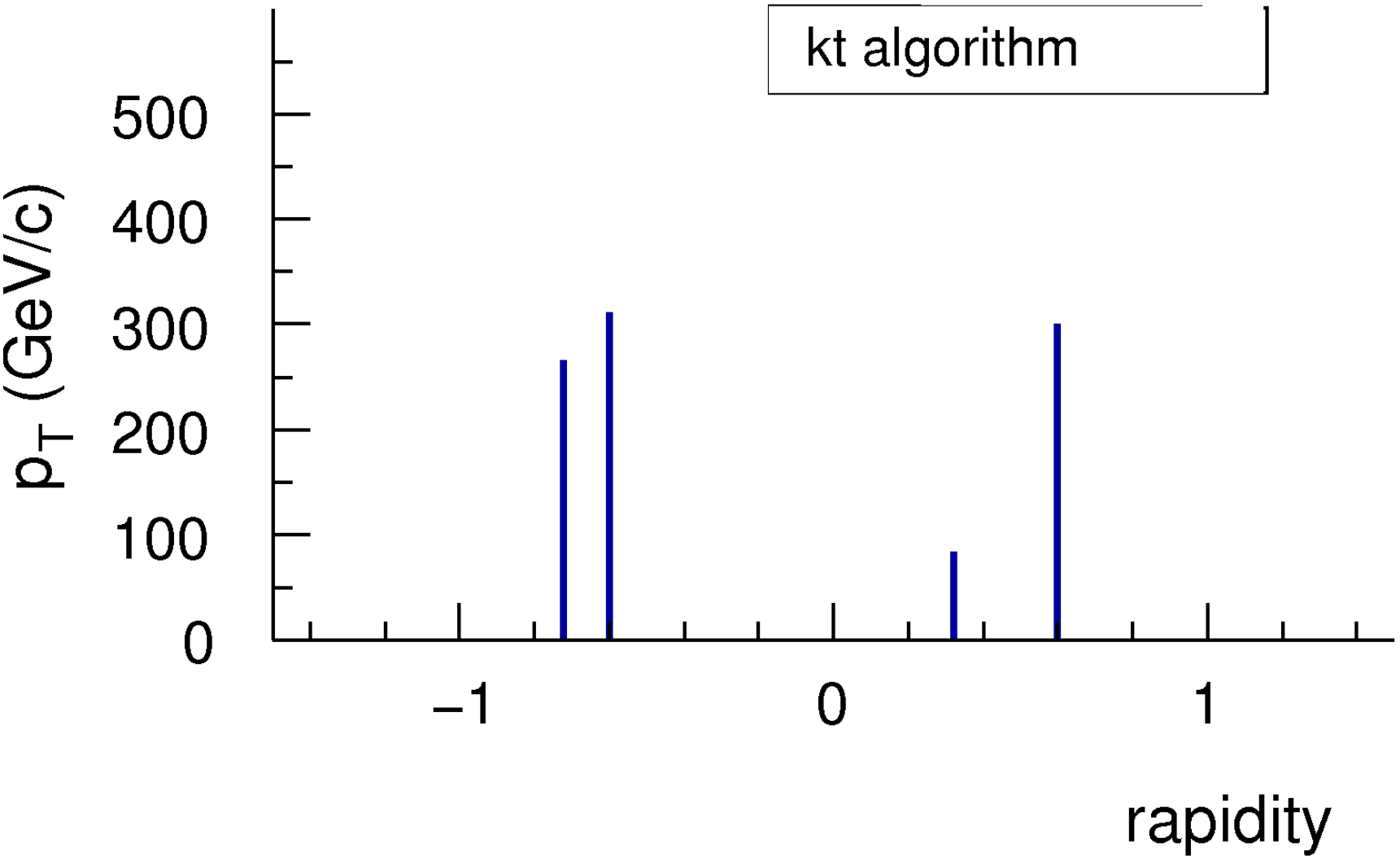
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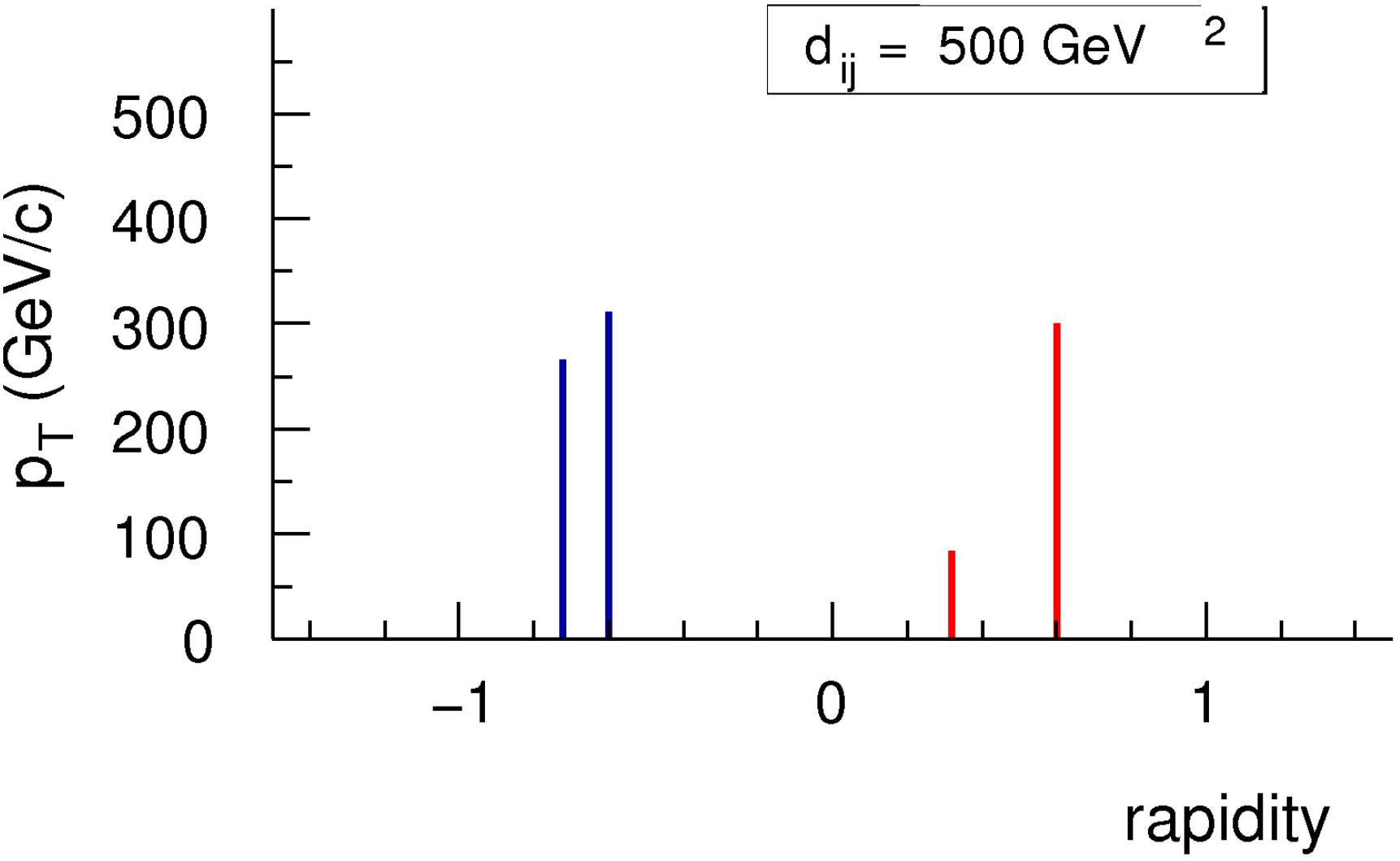
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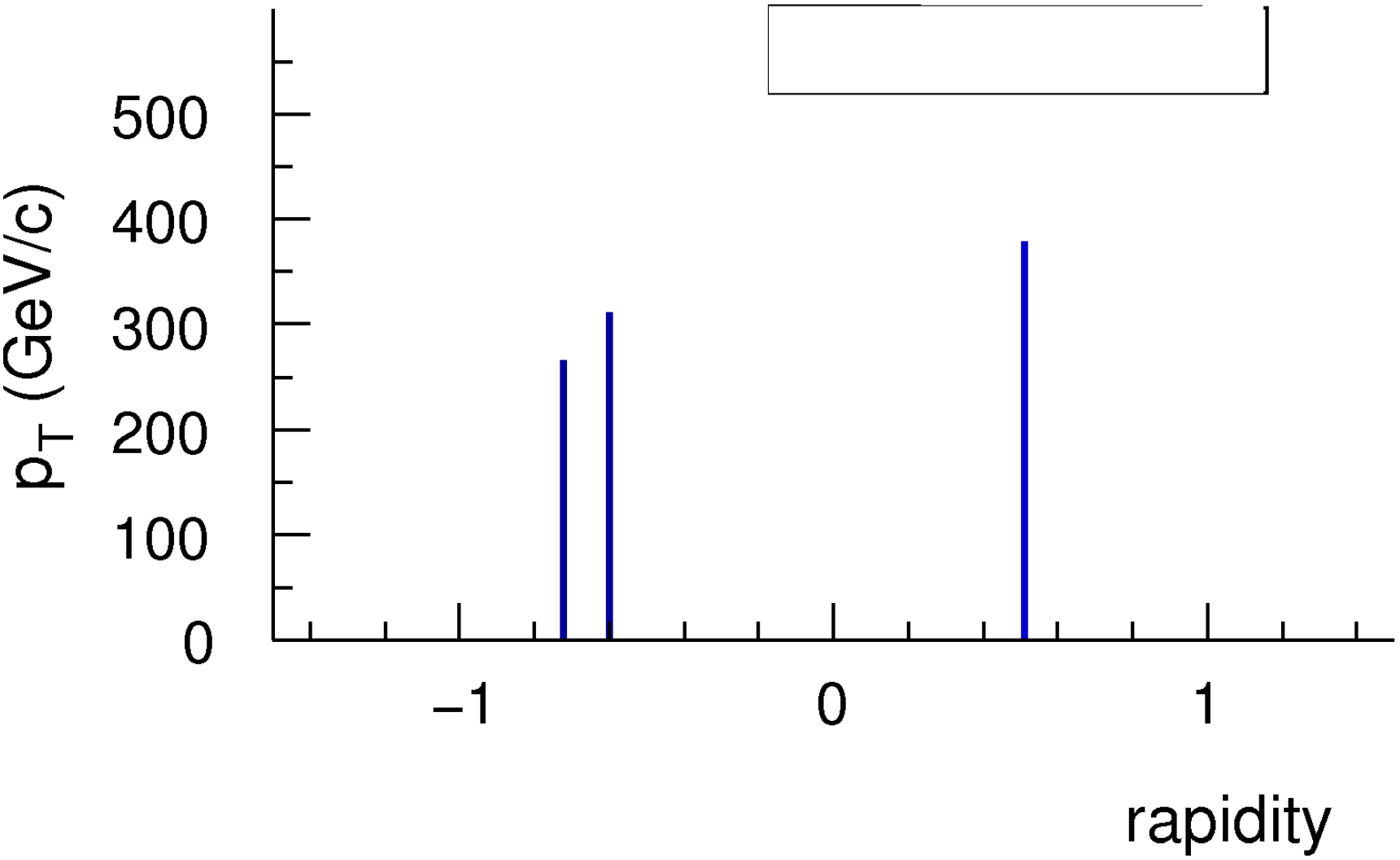
k_t algorithm in action ($R = 1$)



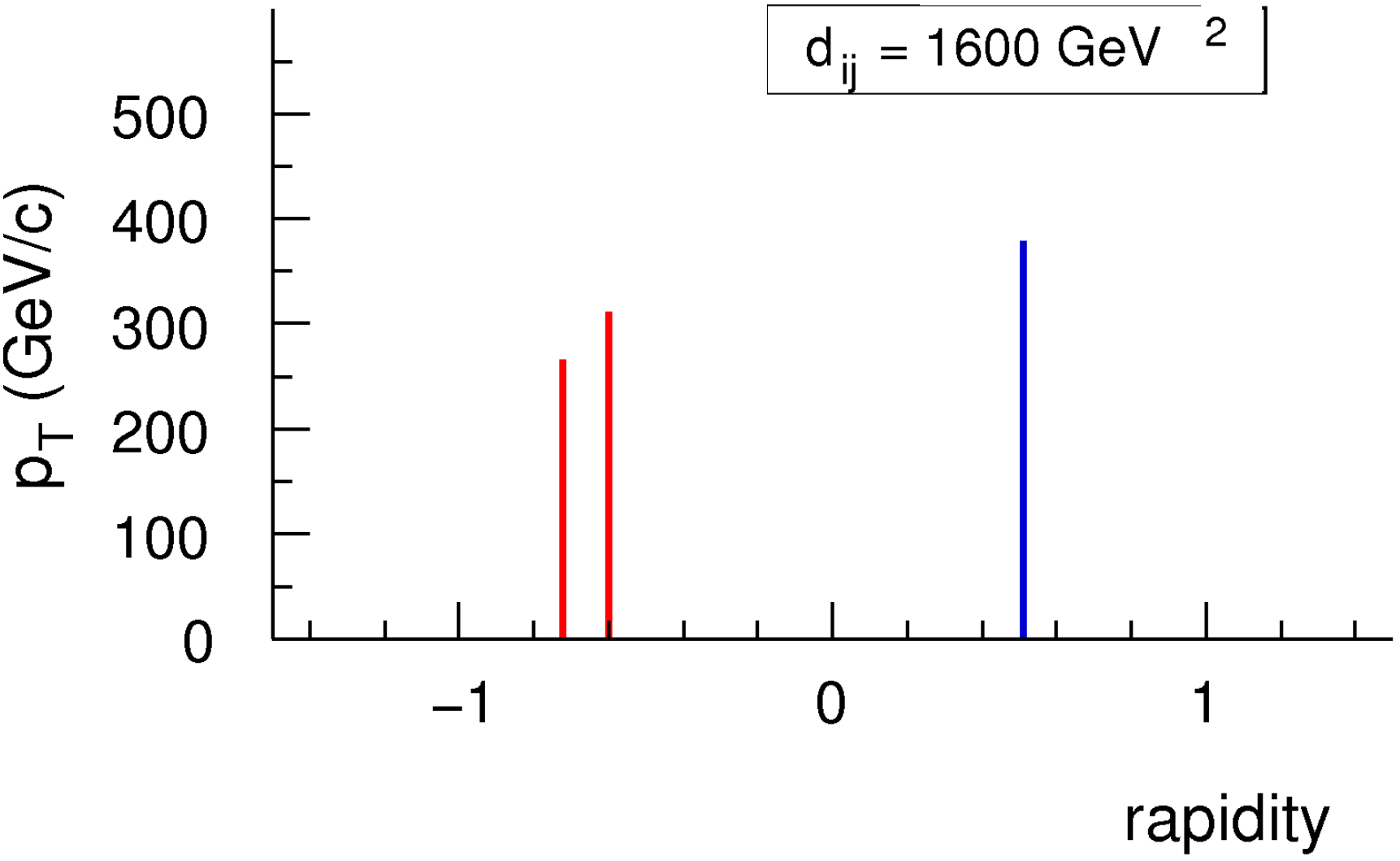
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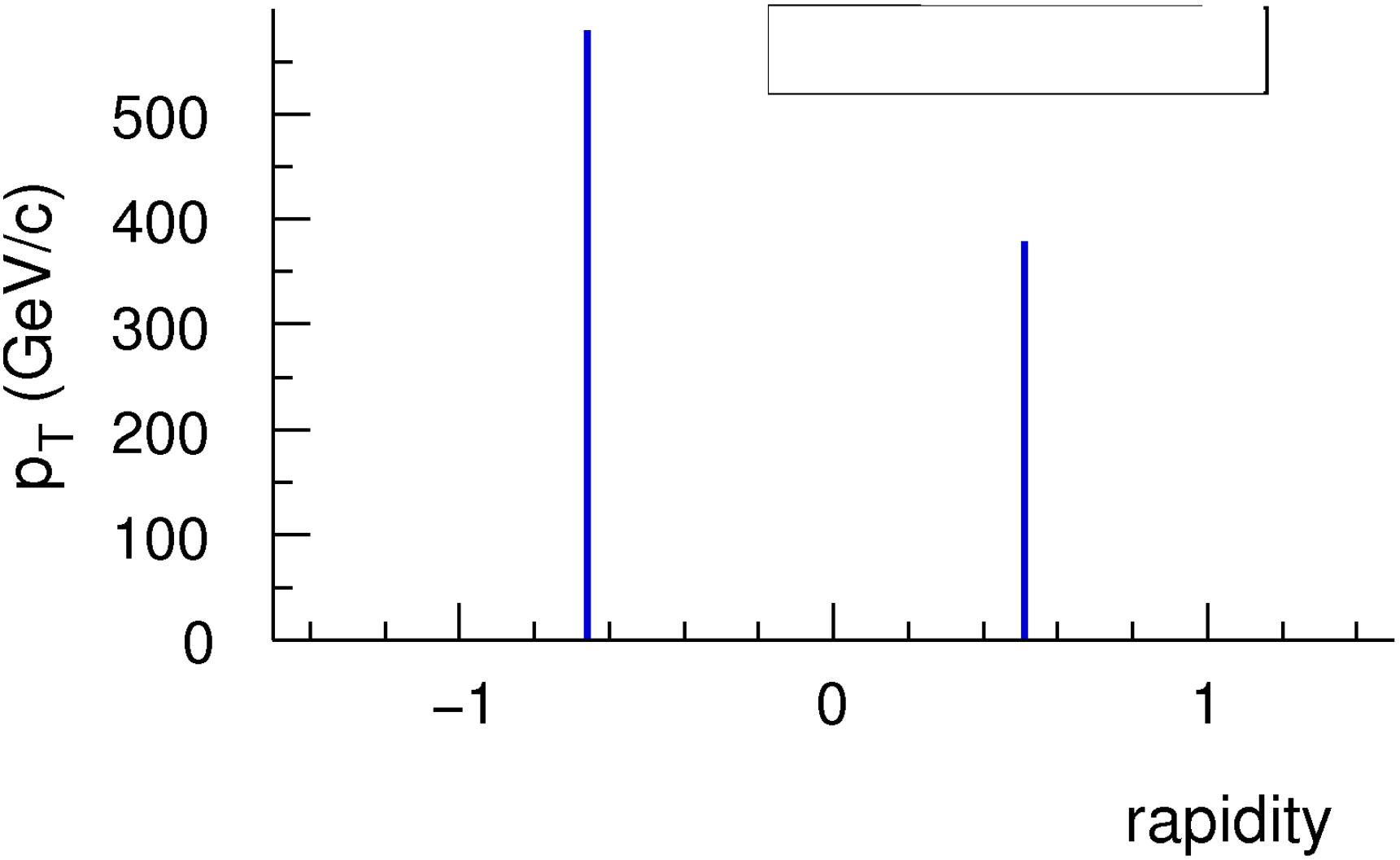
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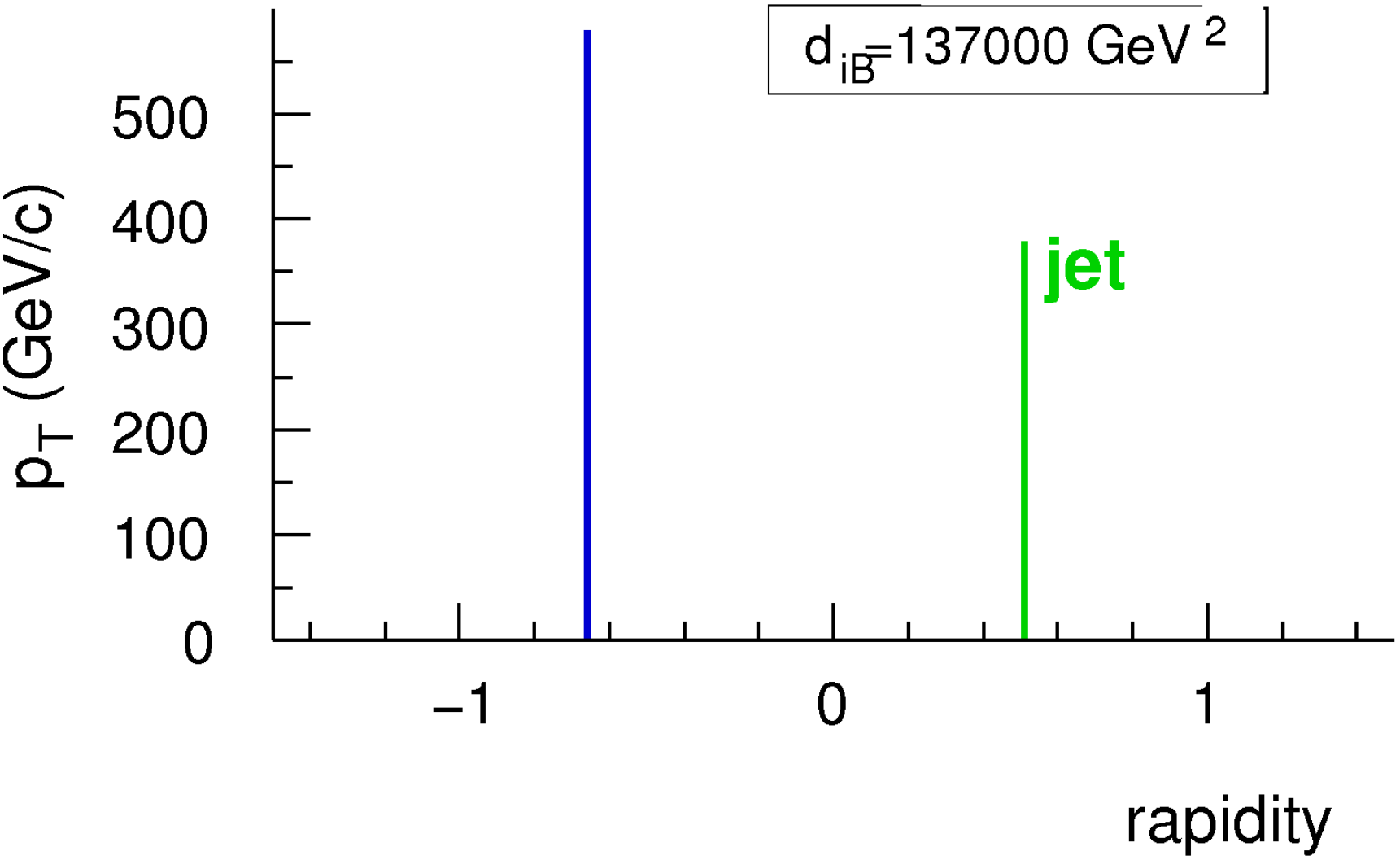
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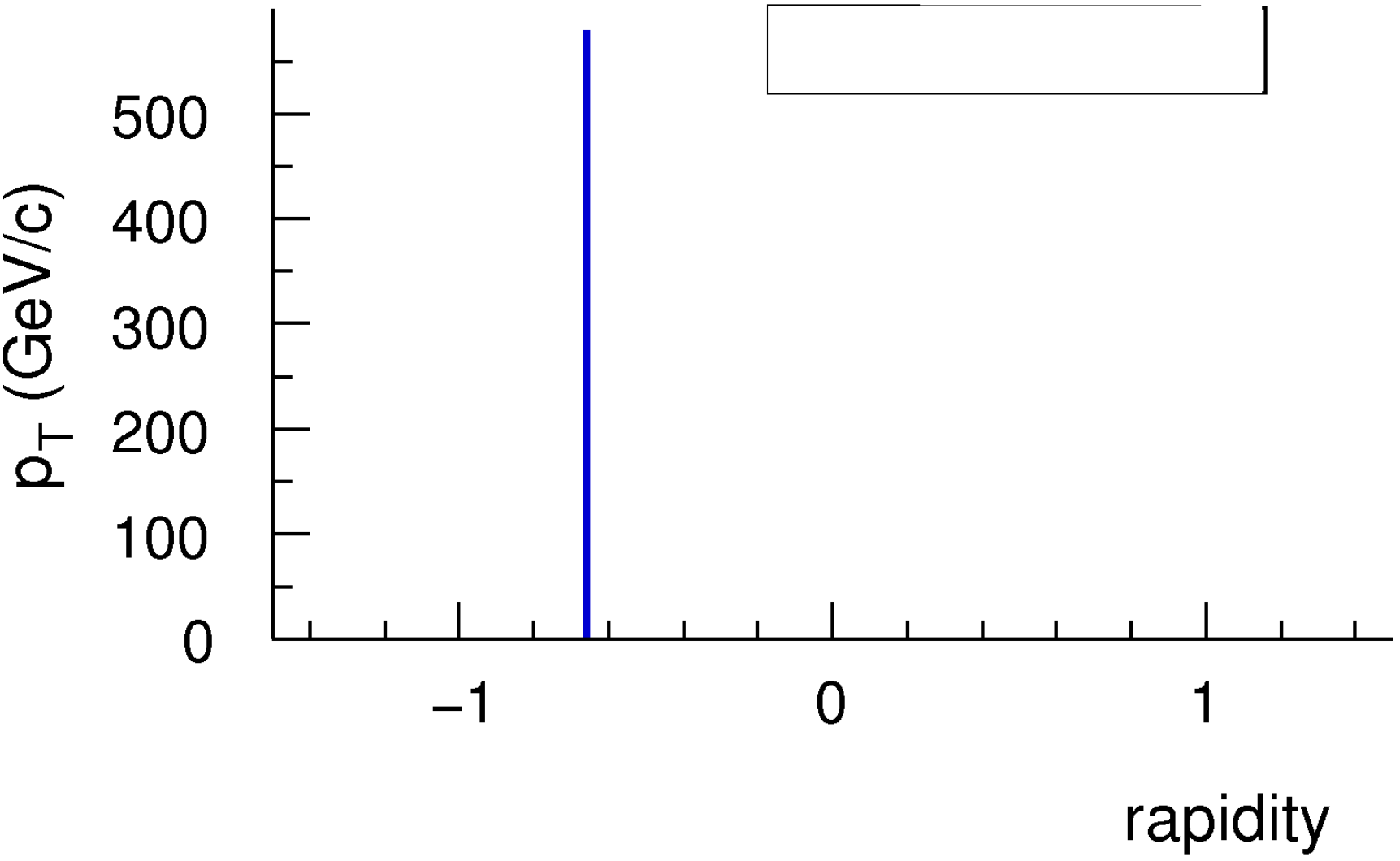
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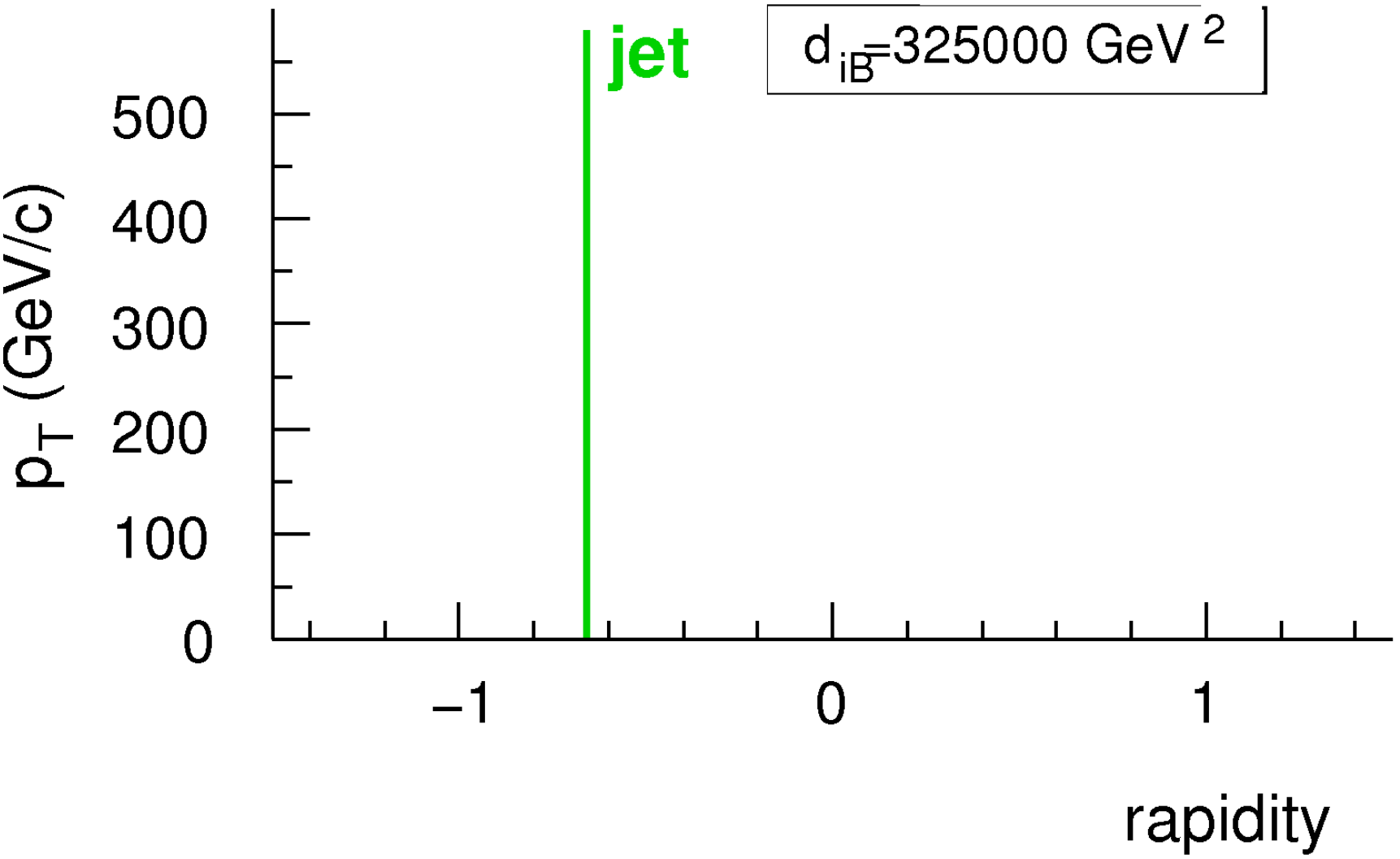
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Why k_t?

k_t distance measures

$$d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2, \qquad d_{iB} = k_{ti}^2$$

are closely related to structure of divergences for QCD emissions

$$[dk_j]|M^2_{g\to g_i g_j}(k_j)| \sim \frac{\alpha_s C_A}{2\pi}\frac{dk_{tj}}{\min(k_{ti}, k_{tj})}\frac{d\Delta R_{ij}}{\Delta R_{ij}}, \quad (k_{tj} \ll k_{ti}),$$

and

$$[dk_i]|M^2_{Beam\to Beam+g_i}(k_i)| \sim \frac{\alpha_s C_A}{\pi}\frac{dk_{ti}}{k_{ti}}\, d\eta_i, \qquad (k_{ti}^2 \ll \{\hat{s}, \hat{t}, \hat{u}\})$$

k_t algorithm attempts approximate inversion of the QCD shower branching process $\longrightarrow$ Theoretical sound basis.

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MidPoint: a (widely used)IRC unsafe cone

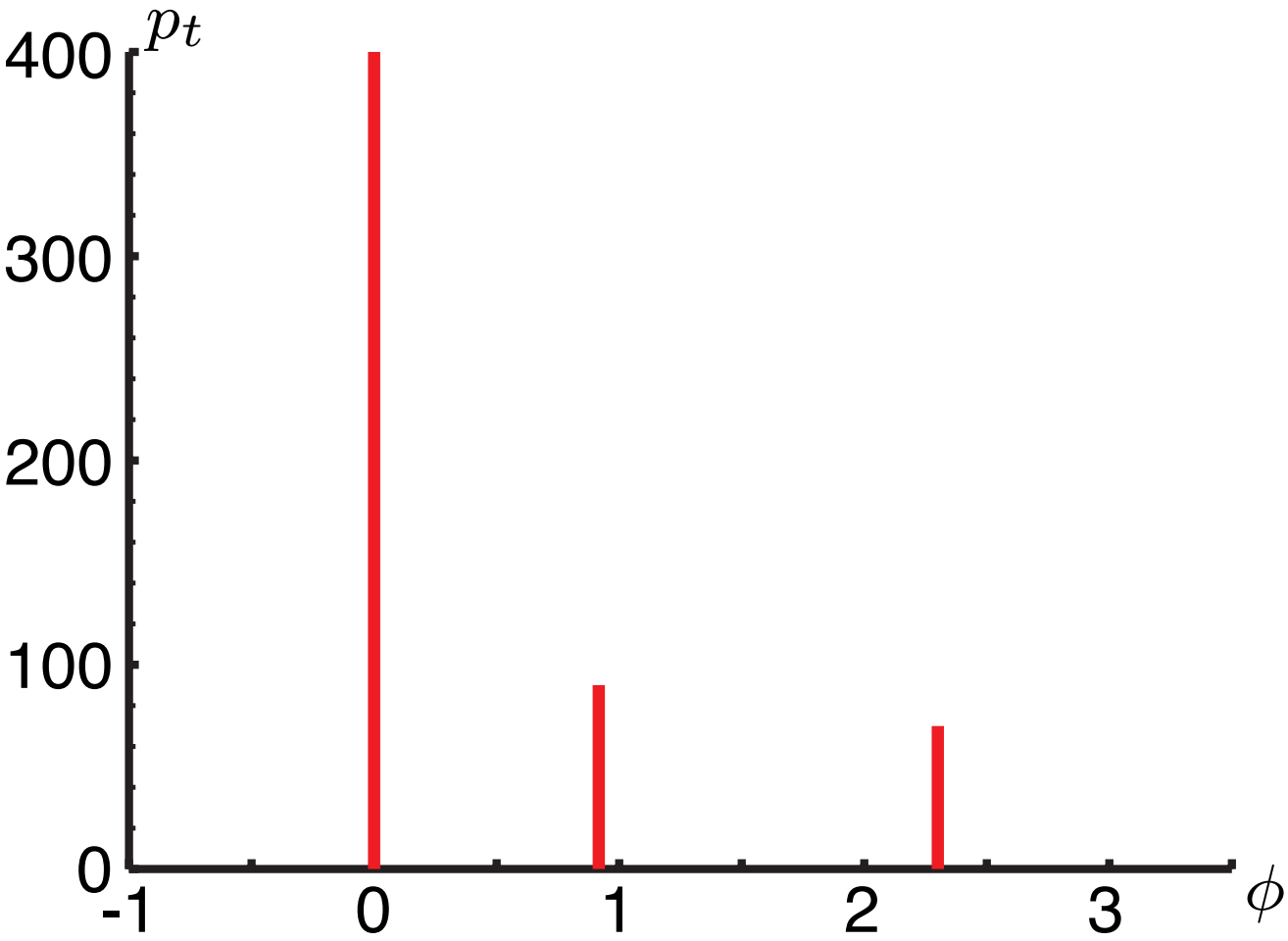
The MidPoint Iterative Cone jet algorithm has been widely used at Run II at Tevatron

- Define a radious parameter R
- Find all stable cones
  Schematically $(y,\phi)_{\rm cone} = \sum_{i\in R}(y,\phi)_{\rm cone}$
- Use all particles as initial seeds ...
- and also midpoints between each pair of particles
- (Technical) Split-merge procedure

But is is easy to see that this procedure is IRC unsafe at NNLO pQCD!

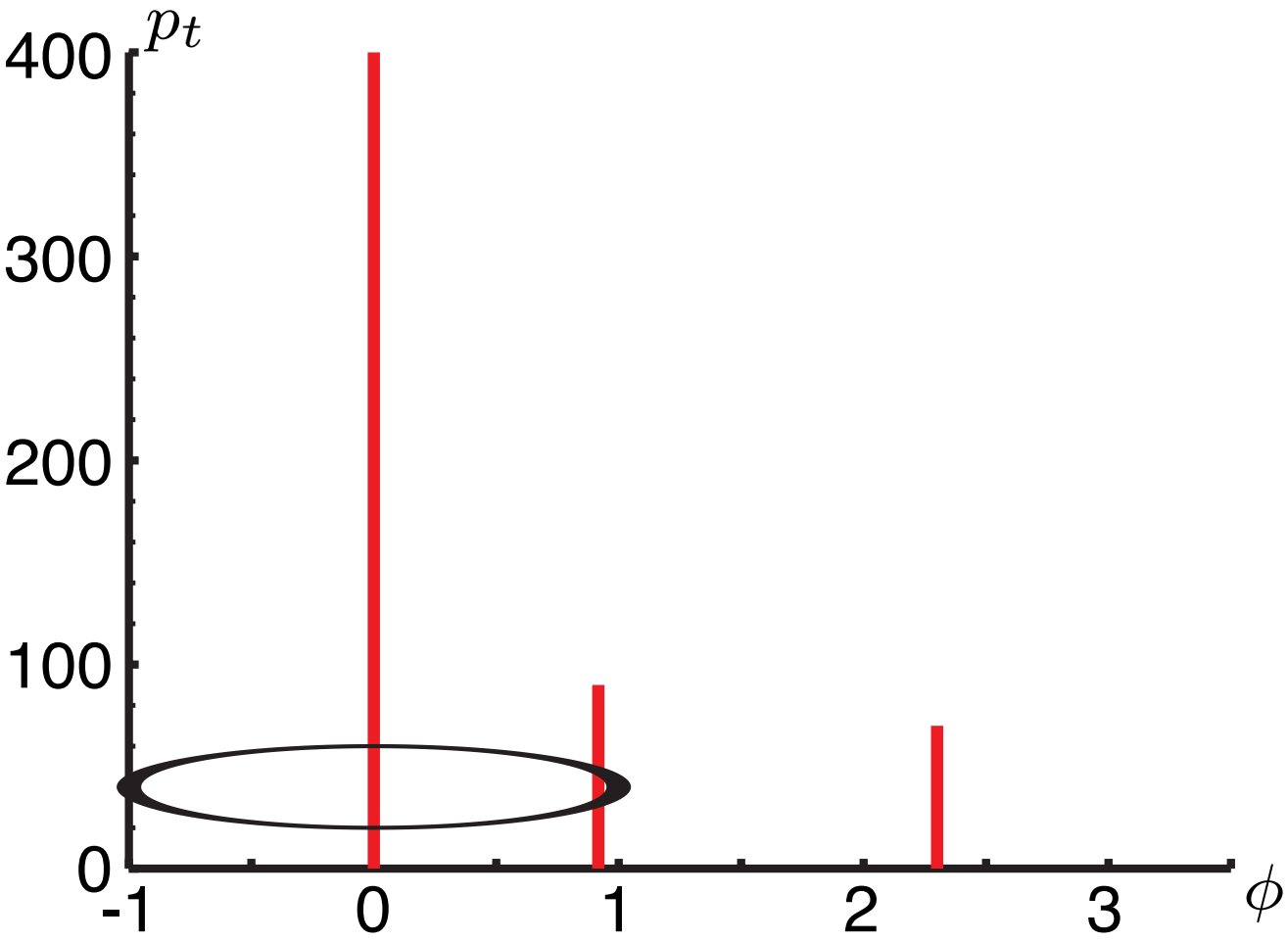
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Widely used MidPoint Cone algorith is Infrared and Collinear Unsafe ($R = 1$)



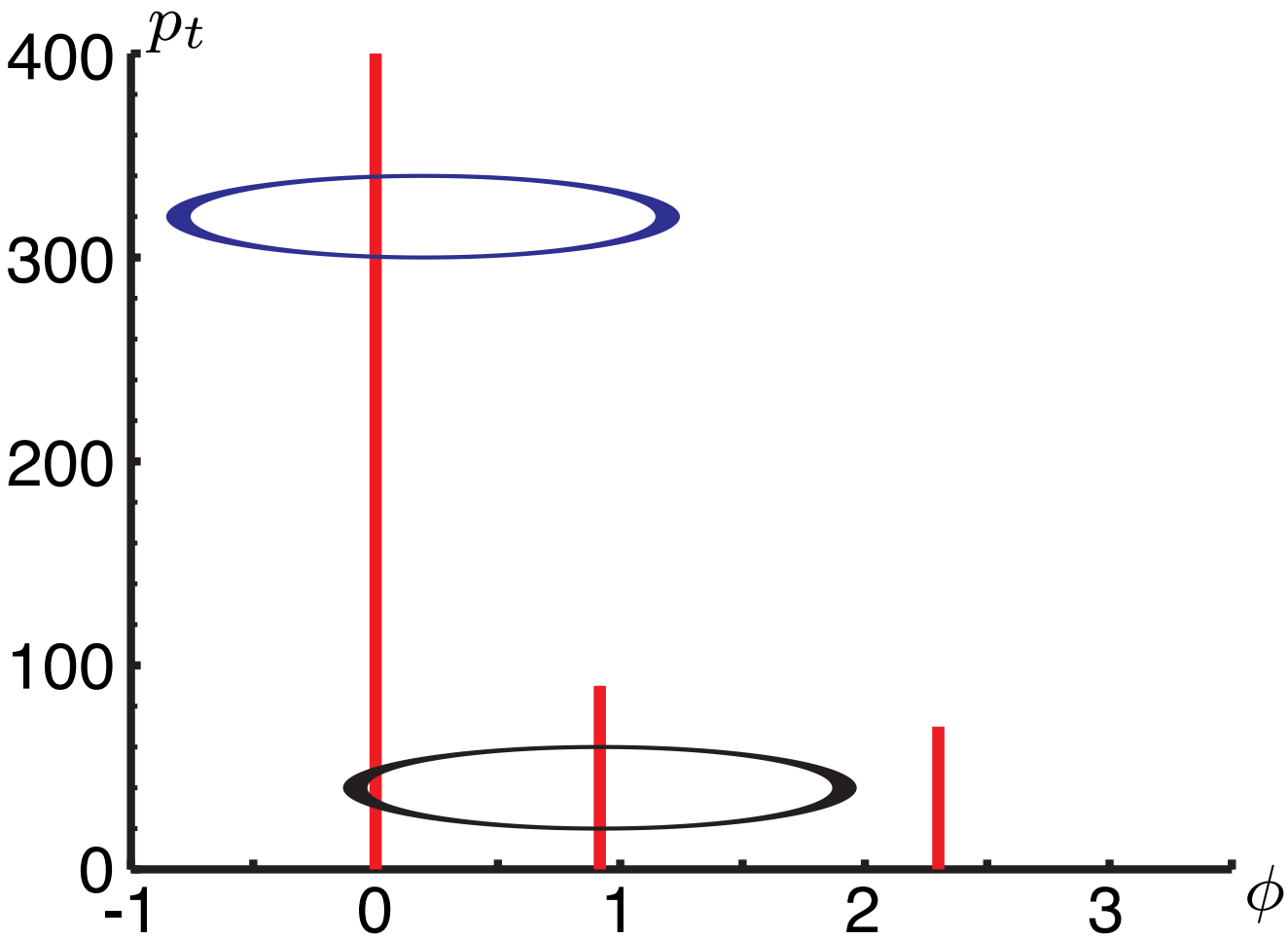
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Only hard radiation



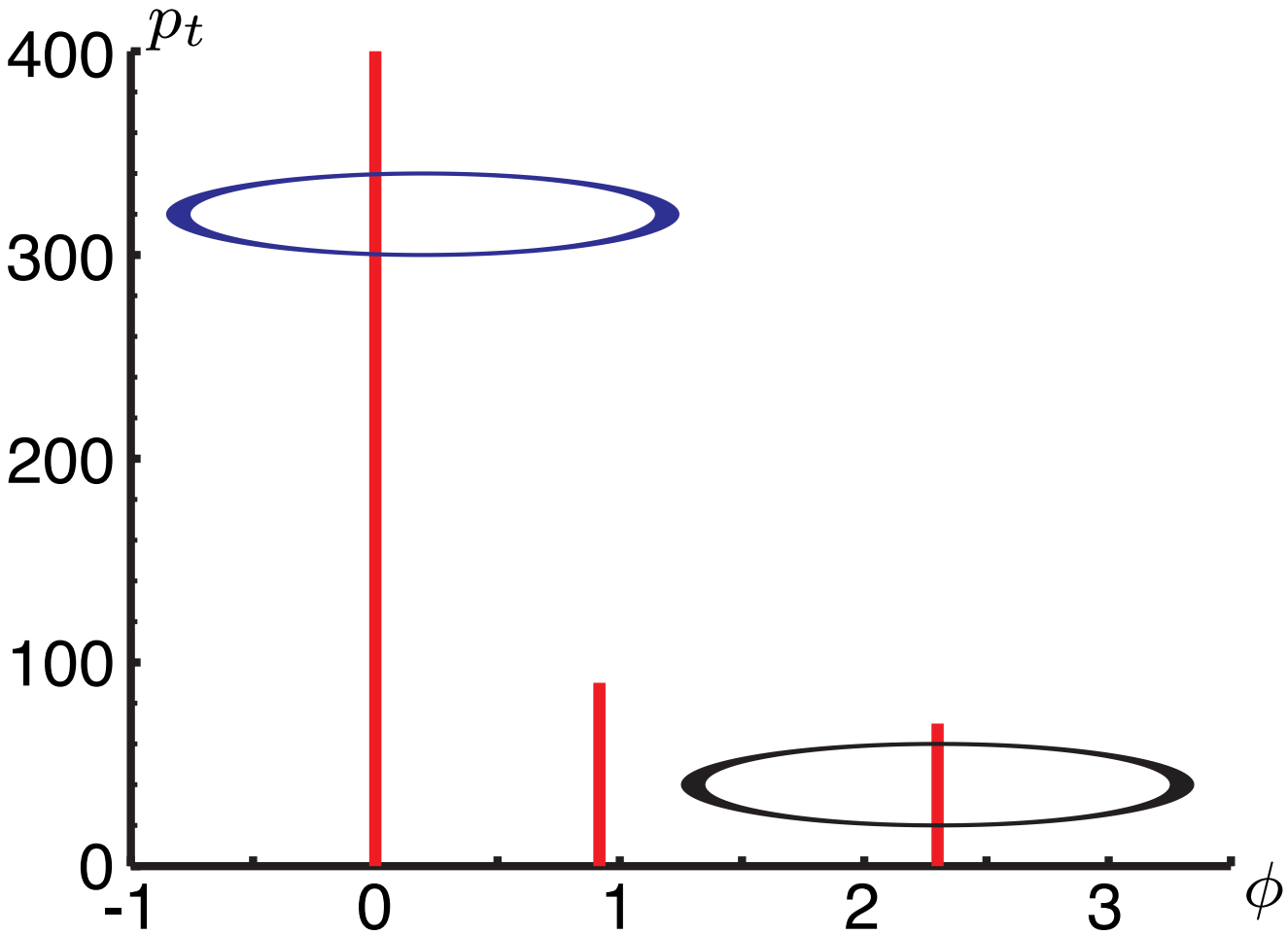
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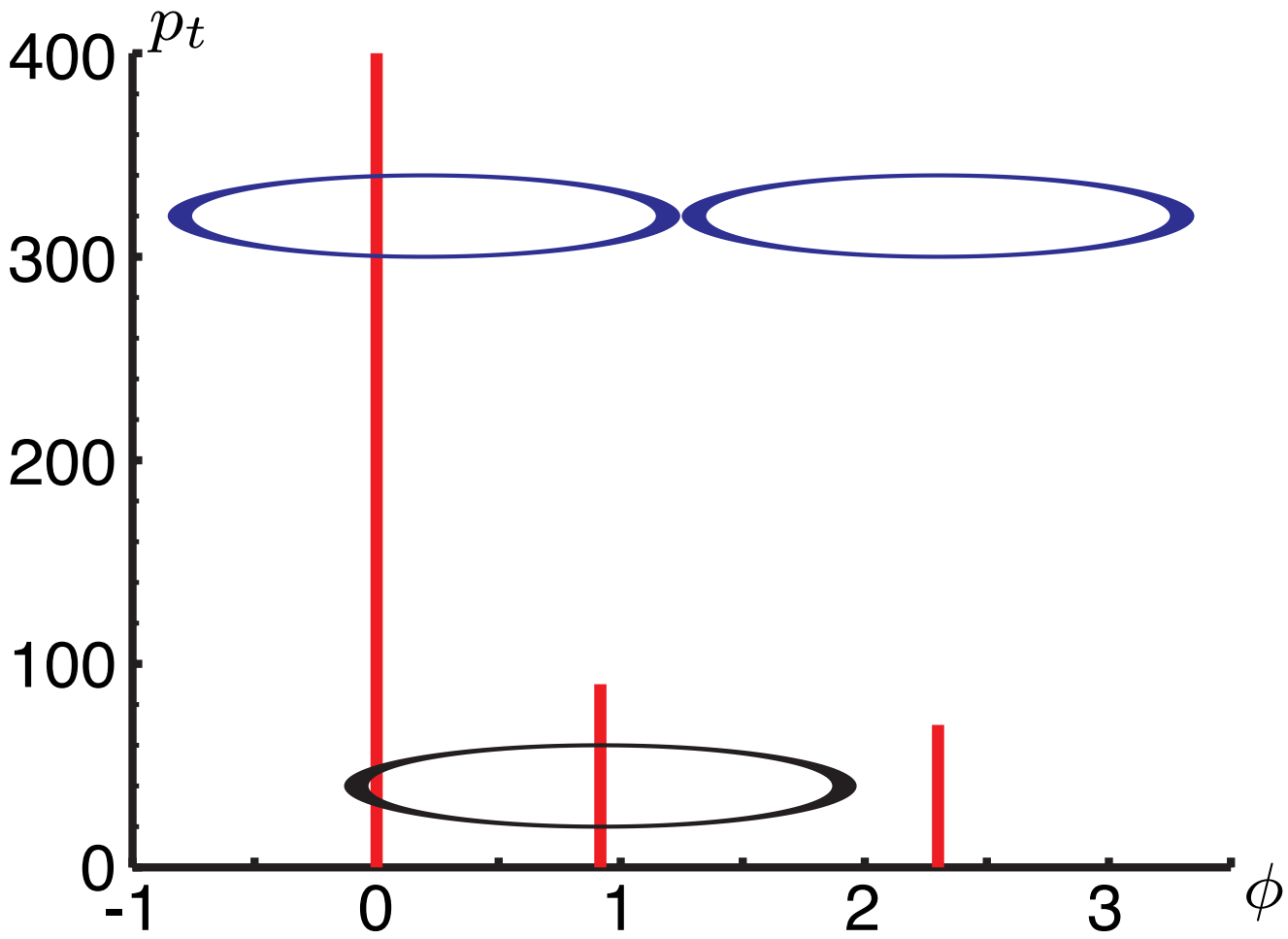
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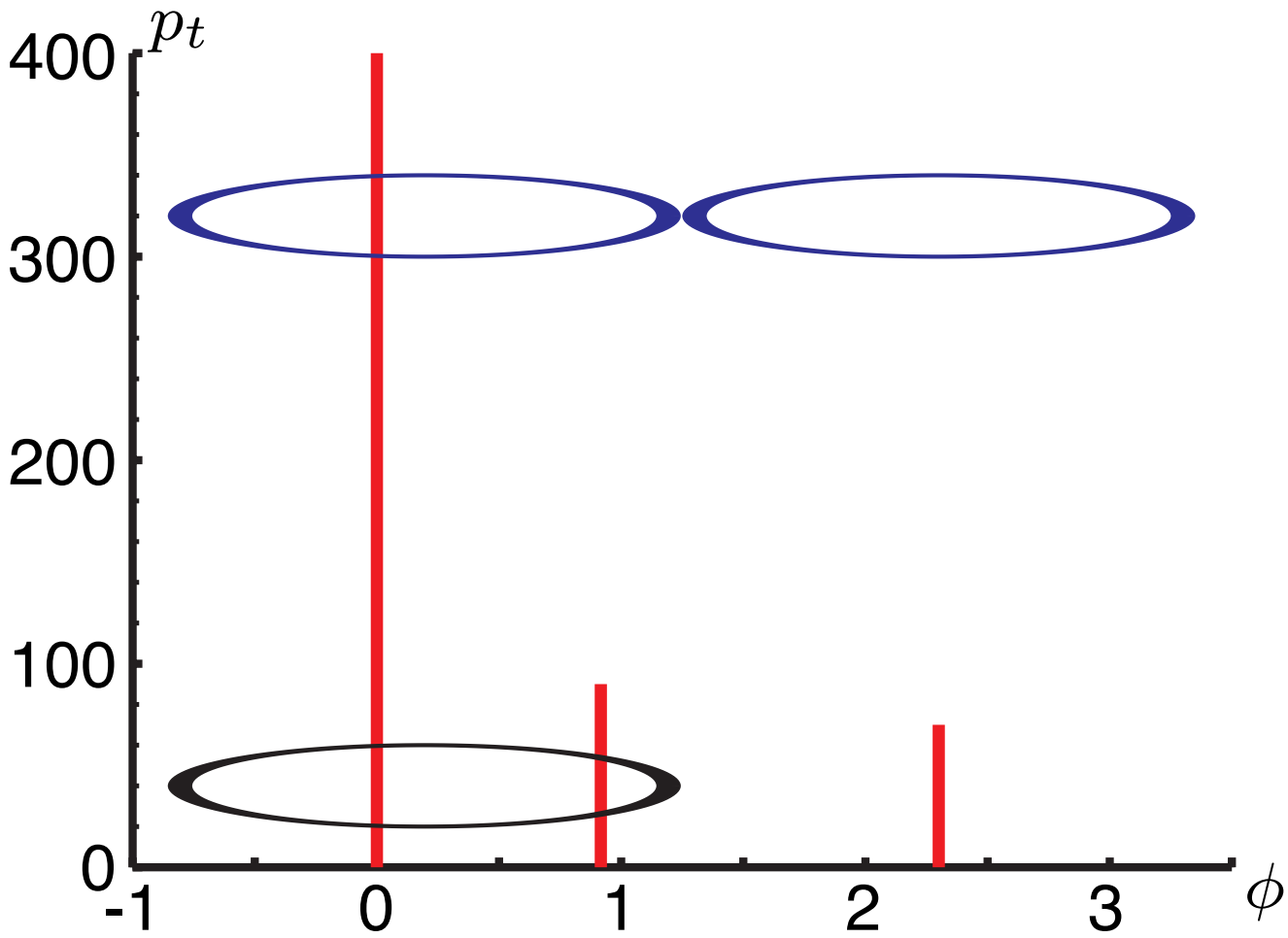
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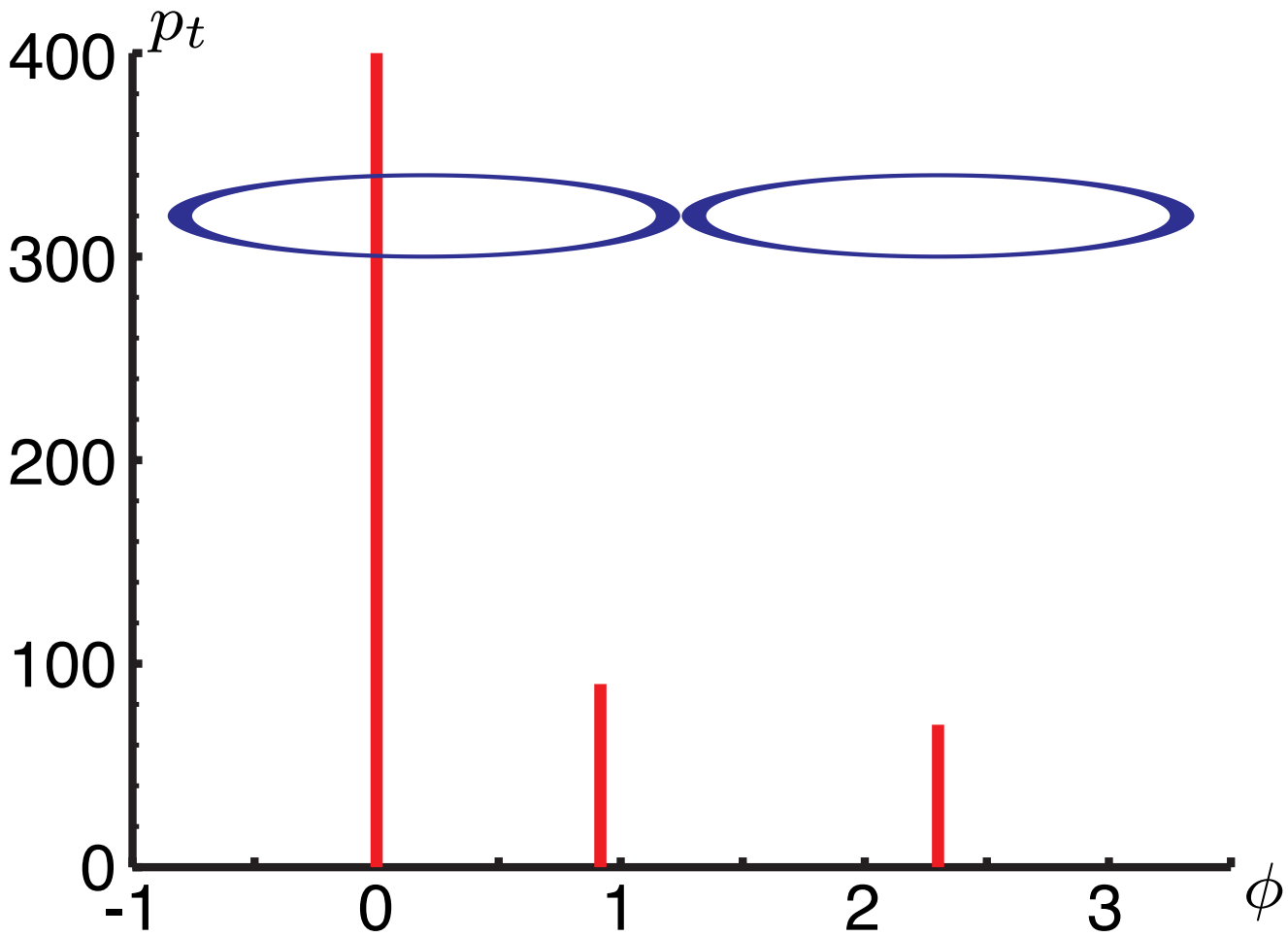
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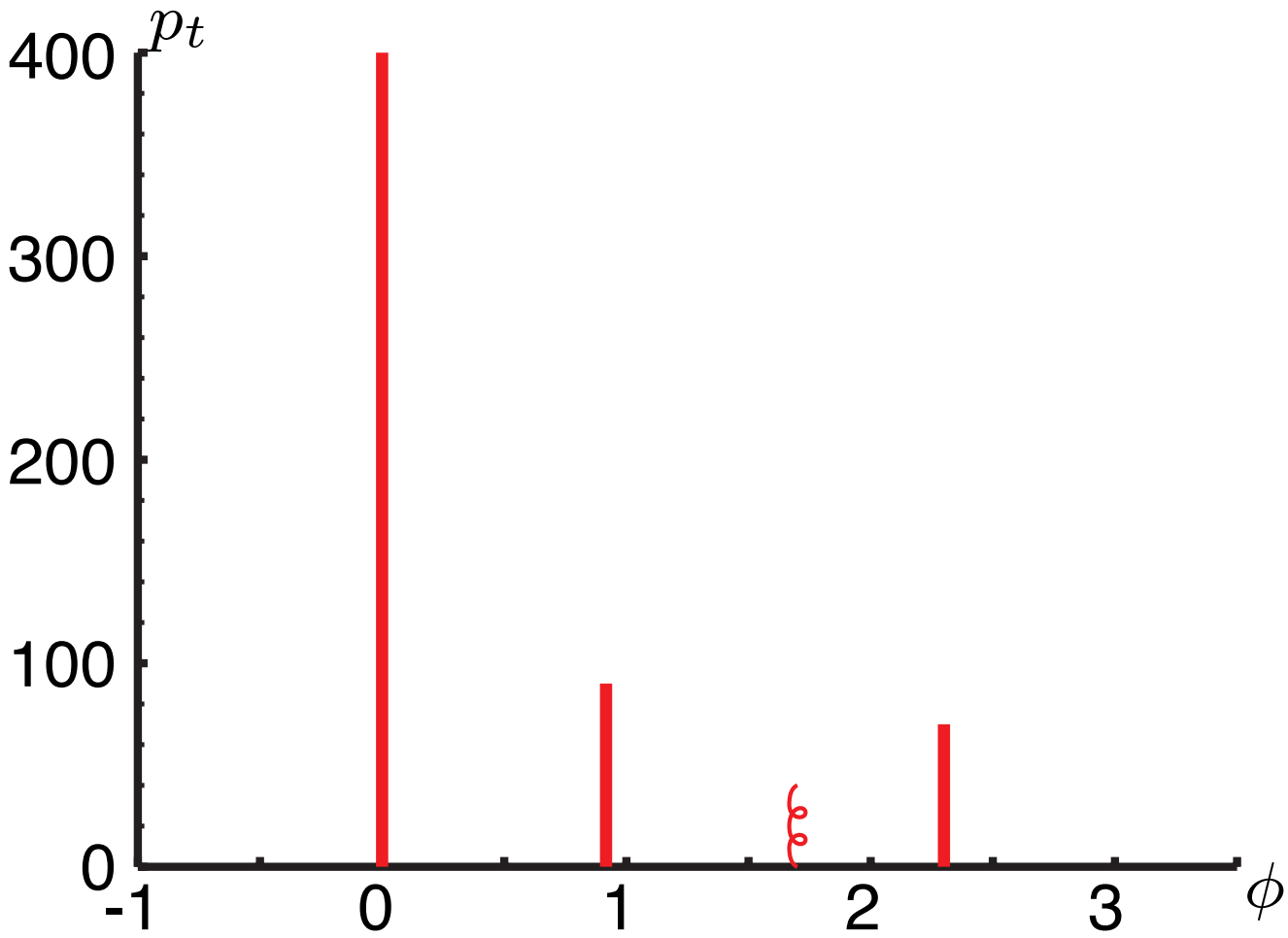
MidPoint: a (widely used)IRC unsafe cone

Only hard radiation .... Two stable cones



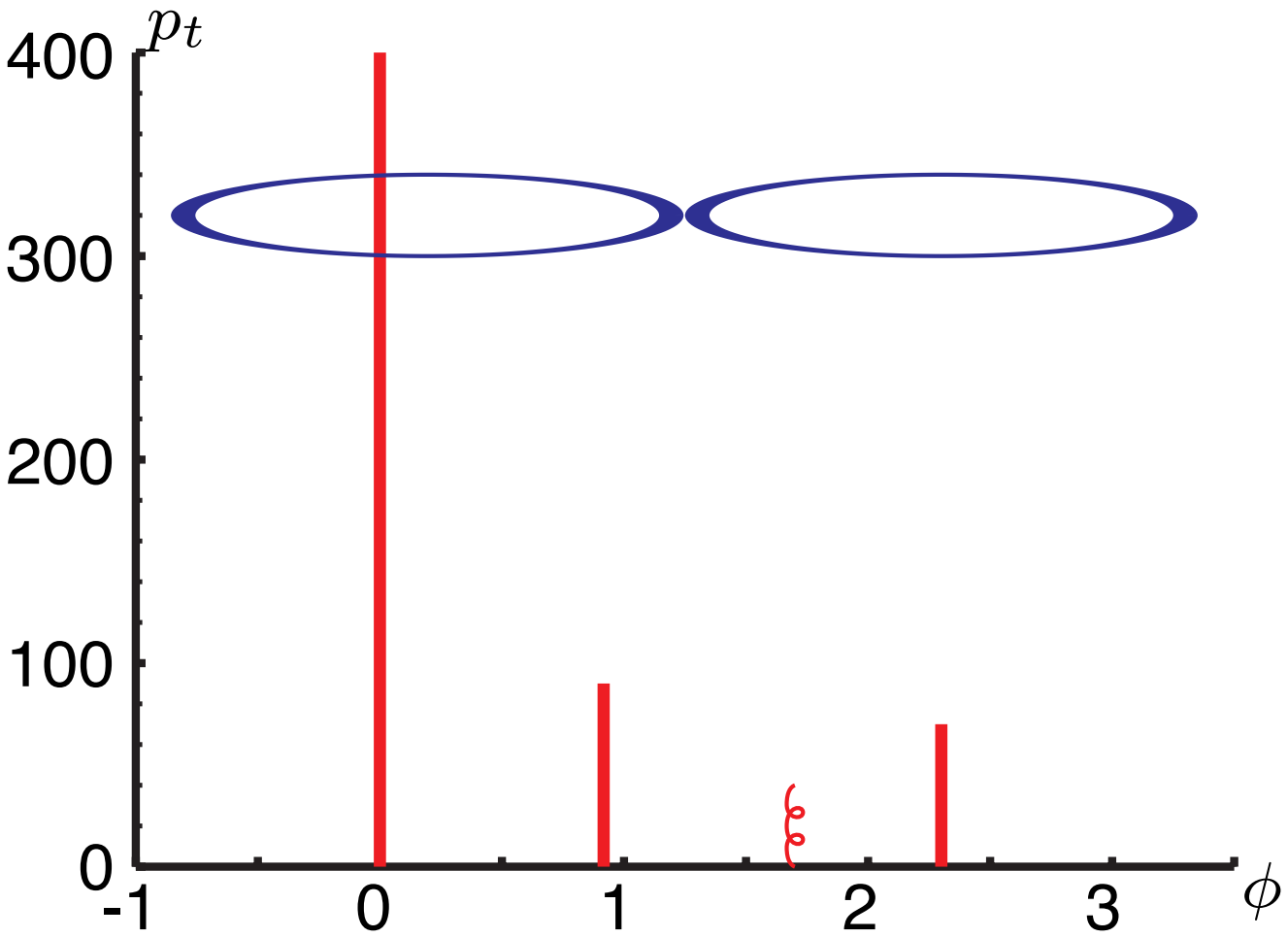
MidPoint: a (widely used)IRC unsafe cone

Now add soft radiation (IRC safe definitions insensitive to this)



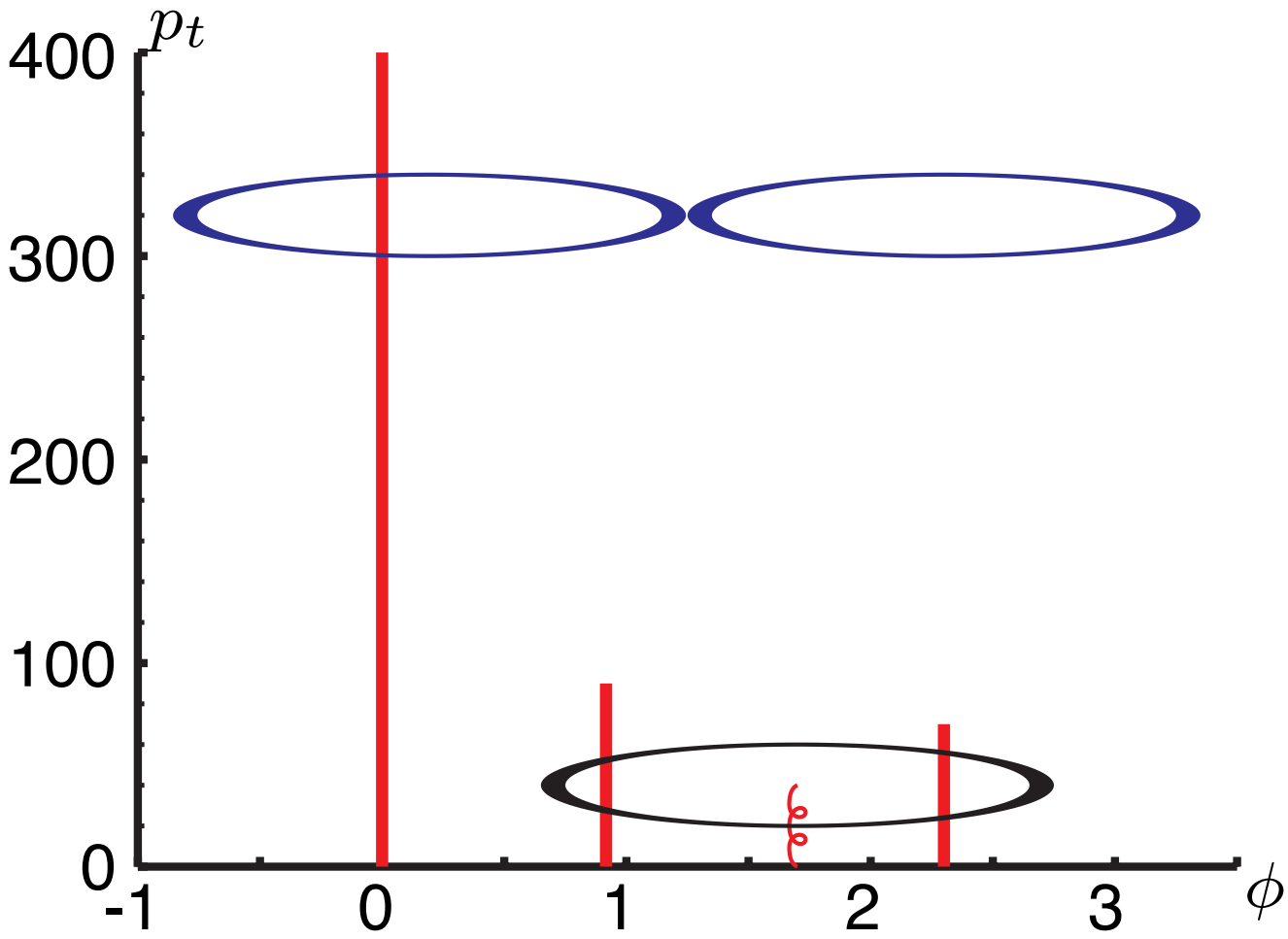
MidPoint: a (widely used)IRC unsafe cone

Add soft radiation ...



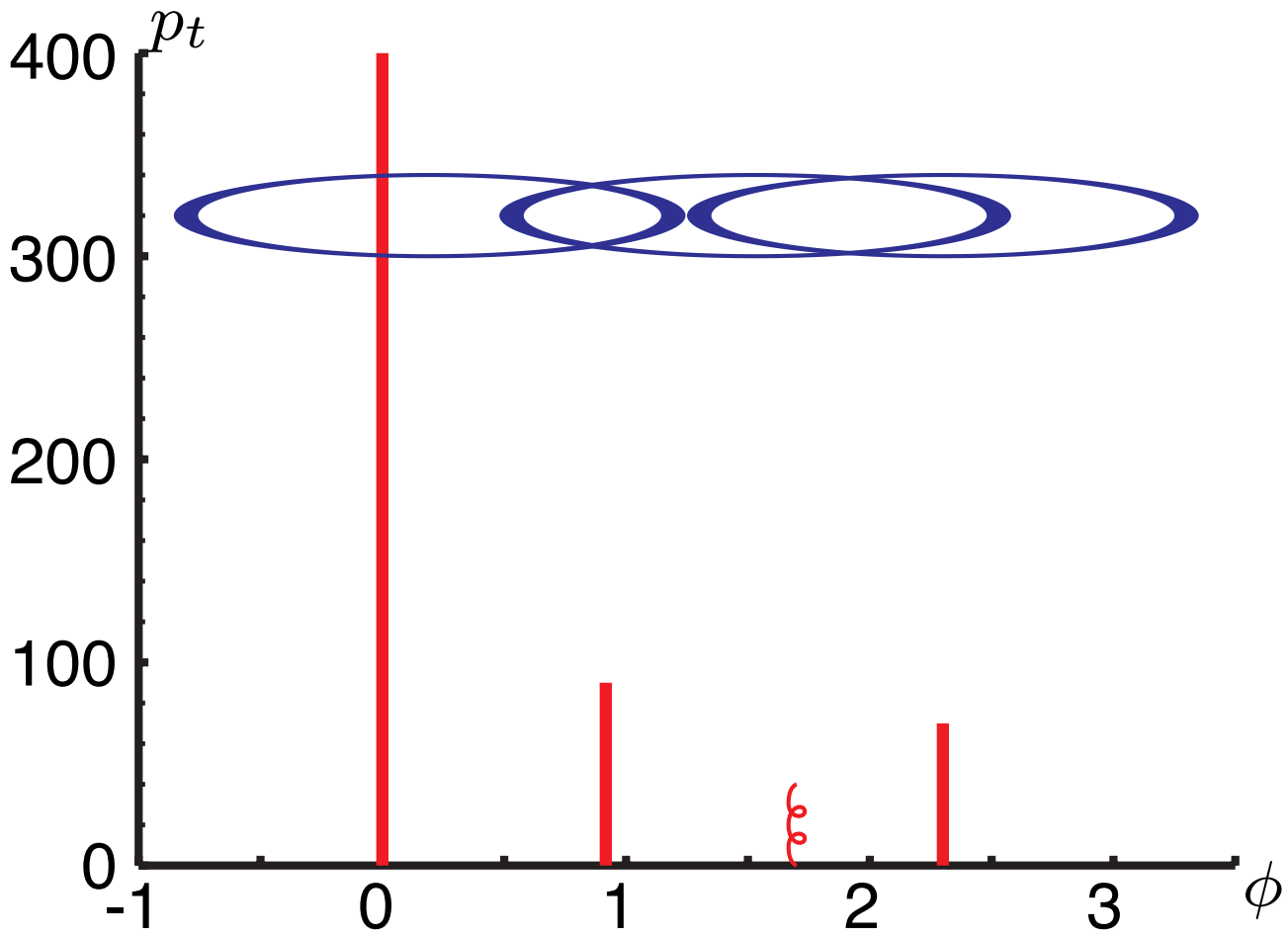
MidPoint: a (widely used)IRC unsafe cone

Add soft radiation ...



MidPoint: a (widely used)IRC unsafe cone

Add soft radiation ... Three stable cones!

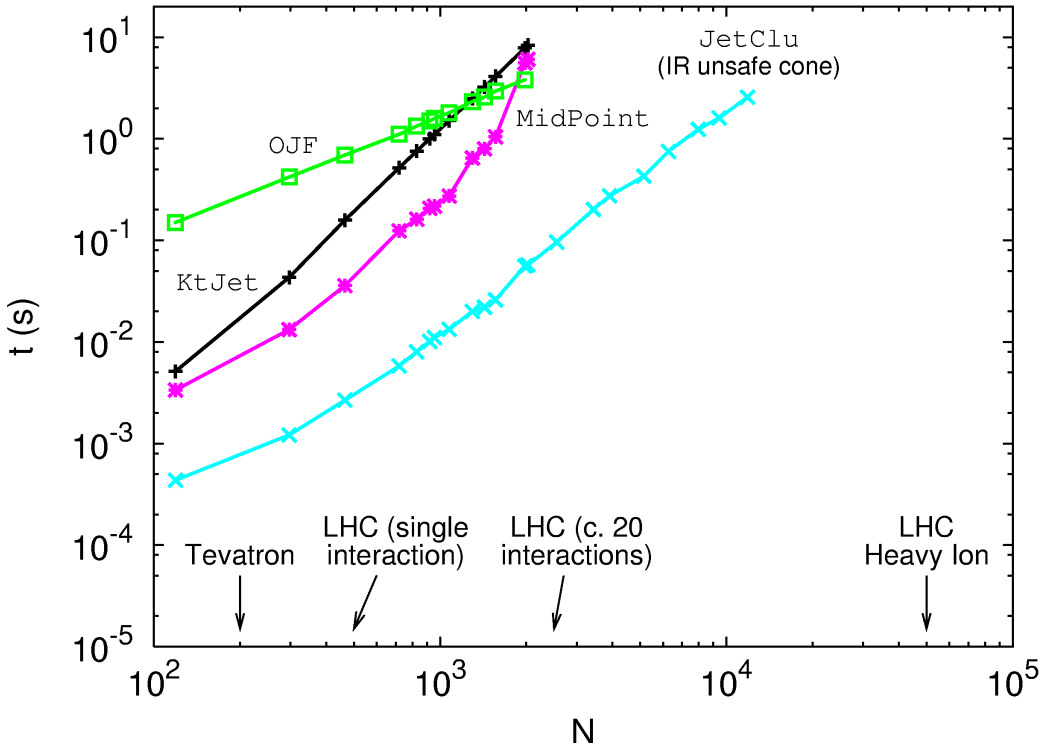


RECENT DEVELOPEMENTS IN JET ALGORITHMS

Developements in jet algorithms

- The `FastJet` package: fast implementation of k_T and Cam/Aa algorithms (based on computational geometry) with background subtraction methods and external jet finders as plug-ins (Cacciari, Salam and Soyez 05-08).

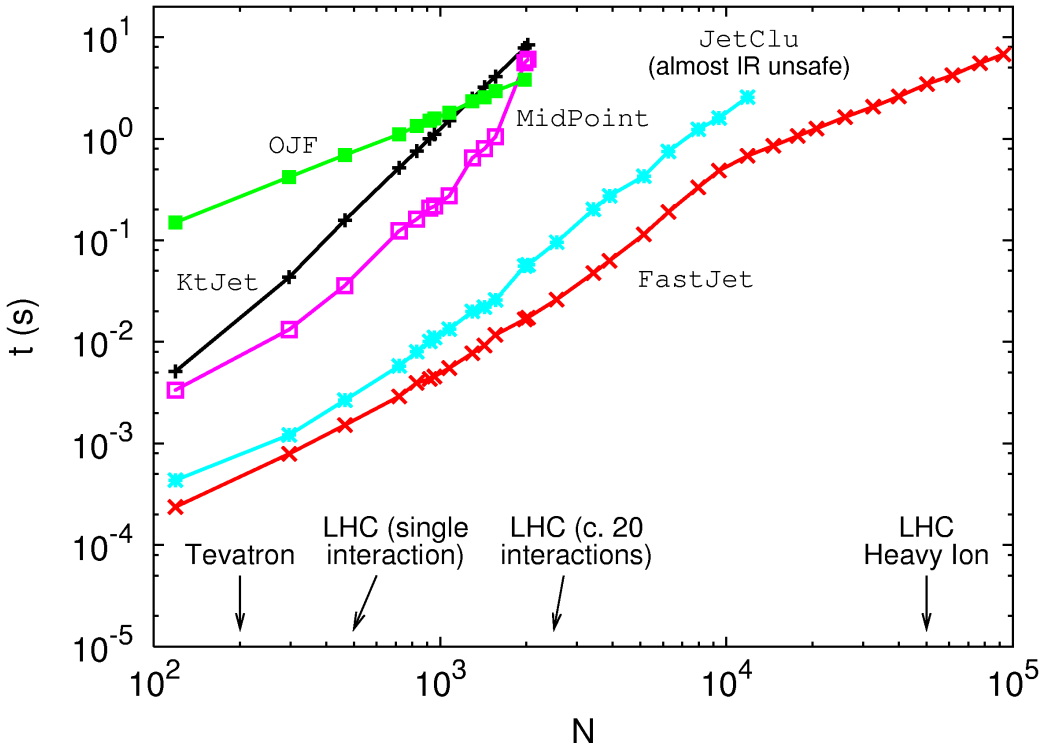
`http://www.lpthe.jussieu.fr/~salam/fastjet/`



Developements in jet algorithms

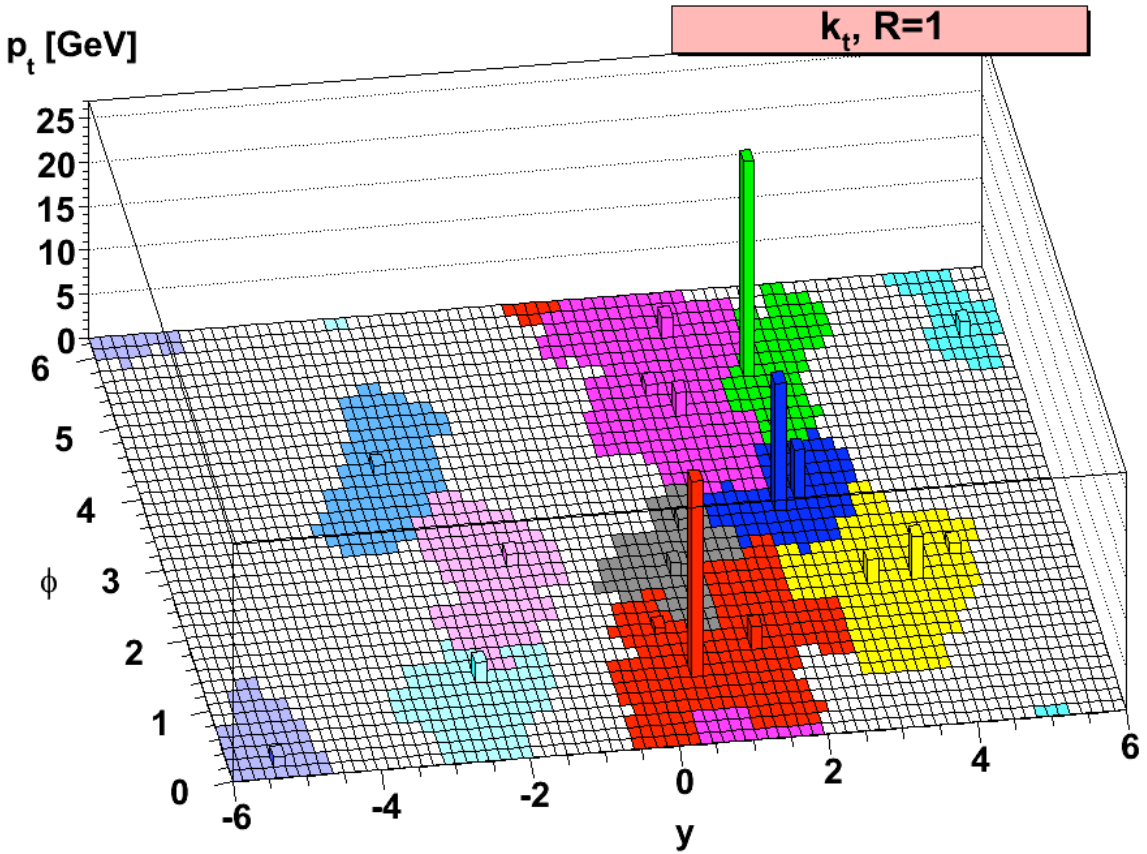
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`http://www.lpthe.jussieu.fr/~salam/fastjet/`



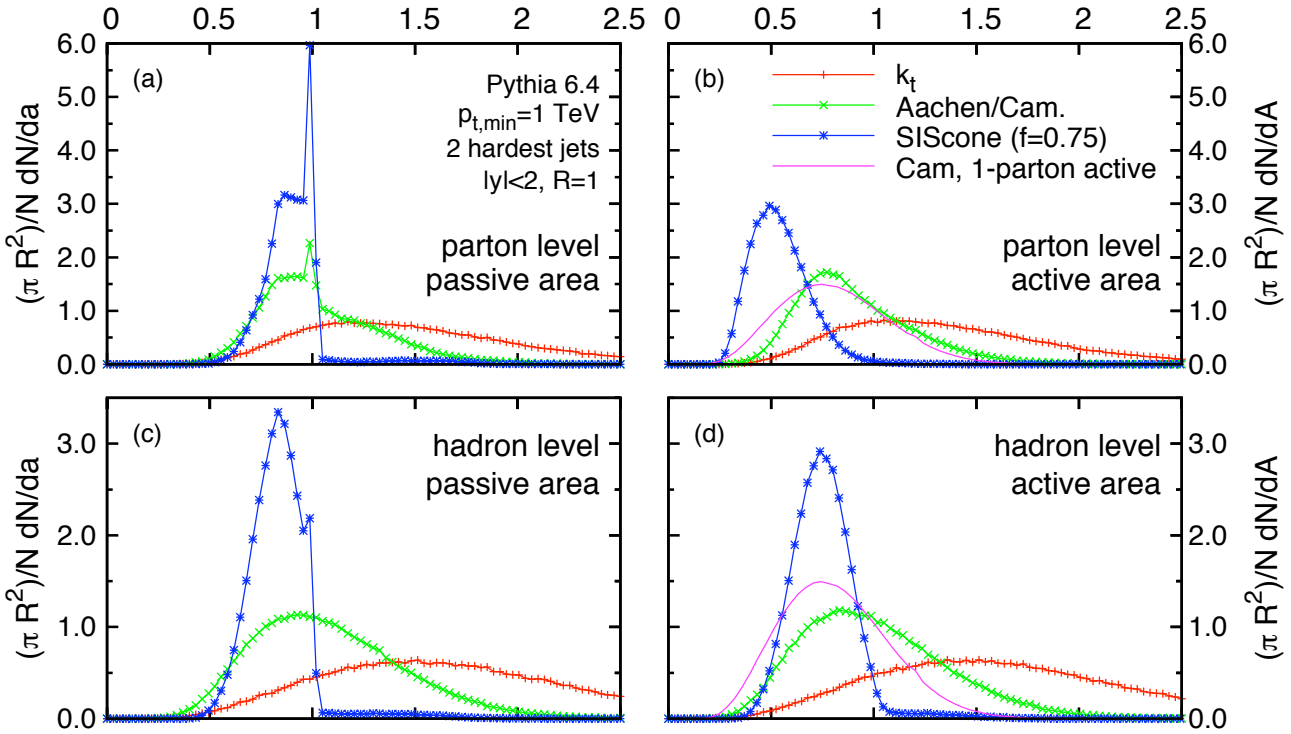
Developements in jet algorithms

- Quantitative definition of jet areas and related methods to UE and PU subtraction (Cacciari, Salam and Soyez 07-08). Deviations from naive expectation $A_{\rm jet} = \pi R^2$



Developements in jet algorithms

- Quantitative definition of jet areas and related methods to UE and PU subtraction (Cacciari, Salam and Soyez 07-08). Deviations from naive expectation $A_{\rm jet} = \pi R^2$



Developements in jet algorithms

- Solution for IRC unsafe cones: `SISCone`: A Seedless and Infrared Safe Cone algorithm (Salam and Soyez 07). IRC safe at all orders of pert. theory. Finds all stable cones using geometrical techniques.

Observable	1st miss cones at	Last meaningful order
Inclusive jet cross section	NNLO	NLO
$W/Z/H$ + 1 jet cross section	NNLO	NLO
3 jet cross section	NLO	LO
$W/Z/H$ + 2 jet cross section	NLO	LO
jet masses in 3 jets, $W/Z/H$ + 2 jets	LO	none

Table 2: Summary of the order (α_s^4 or $\alpha_s^3\alpha_{EW}$) at which stable cones are missed in various processes with a midpoint algorithm, and the corresponding last order that can be meaningfully calculated. Infrared unsafety first becomes visible one order beyond that at which one misses stable cones.

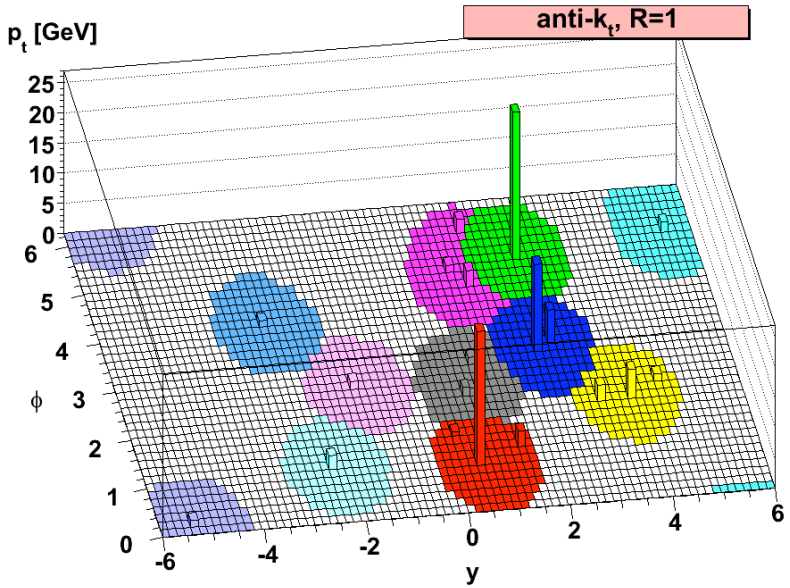
Previous cone algorithms suffer from Infrared and Collinear unsafety
Table for CDF MidPoint cone algorithm (even worse in other cases, *i.e.* for ATLAS Iterative Cone) $\longrightarrow$ IRC safe jet algorithms now available to replace IRC unsafe ones

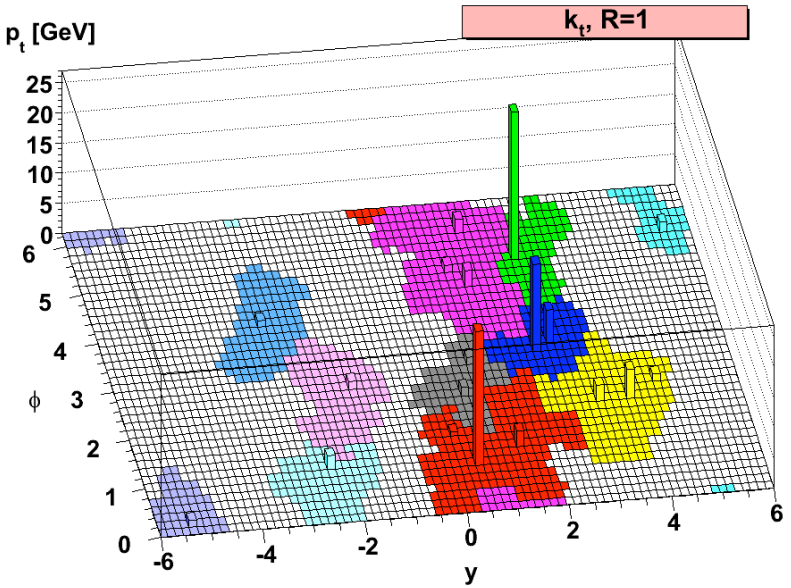
Developements in jet algorithms

- The anti-k_T algorithm: A generalization of the k_T algorithm with measure:

$$d_{ij} = \min(k_{ti}^{2n}, k_{tj}^{2n})\Delta R_{ij}^2/R^2 \ , n = -1 \qquad , d_{iB} = k_{ti}^2$$

which acts like a perfect cone algorithm with area $A_{\rm jet} = \pi R^2$ (Cacciari, Salam, Soyez 08). For $n = 1$ one recovers k_T , while for $n = 0$ one has Cam/Aa.





Progress in jet algorithms

From 2006 $\rightarrow$ Many choices, but all cones IRC unsafe + slow k_T ...

Algorithm	Type	IRC status	Notes
exclusive k_t	$SR_{p=1}$	OK	
inclusive k_t	$SR_{p=1}$	OK	widespread: QCD-th, HERA
Cambridge/Aachen	$SR_{p=0}$	OK	
Run II Seedless cone	SC-SM	OK	slow: $N2^N$!!
CDF JetClu	IC_r-SM	IR_{2+1}	for top physics, searches
CDF MidPoint cone	IC_{mp}-SM	IR_{3+1}	$\simeq$ Tev Run II recommend^n
CDF MidPoint searchcone	$IC_{se,mp}$-SM	IR_{2+1}	
D0 Run II cone	IC_{mp}-SM	IR_{3+1}	Tev Run II + cut on cone p_t
ATLAS Cone	IC-SM	IR_{2+1}	
PxCone	IC_{mp}-SD	IR_{3+1}	has cut on cone p_t,
CMS Iterative Cone	IC-PR	$Coll_{3+1}$	
PyCell/CellJet (from Pythia)	FC-PR	$Coll_{3+1}$	widespread in BSM theory
GetJet (from ISAJET)	FC-PR	$Coll_{3+1}$	likewise

SR = seq.rec.; IC = it.cone; FC = fixed cone;
SM = split–merge; SD = split–drop; PR = progressive removal

IR_{n+1}: for n nearby hard partons, 1 soft emitted gluon can change hard jets
$Coll_{n+1}$: for n nearby hard partons, 1 collinear splitting can change hard jets

Progress in jet algorithms

... to 2008 $\longrightarrow$ IRC safe replacements for jet algorithms + fast k_T

Algorithm	Type	IRC status	Evolution
exclusive k_t	$SR_{p=1}$	OK	$N^3 \longrightarrow N \ln N$
inclusive k_t	$SR_{p=1}$	OK	$N^3 \longrightarrow N \ln N$
Cambridge/Aachen	$SR_{p=0}$	OK	$N^3 \longrightarrow N \ln N$
Run II Seedless cone	SC-SM	OK	$\longrightarrow$ SISCone
CDF JetClu	IC_r-SM	IR_{2+1}	[$\longrightarrow$ SISCone]
CDF MidPoint cone	IC_{mp}-SM	IR_{3+1}	$\longrightarrow$ SISCone
CDF MidPoint searchcone	$IC_{se,mp}$-SM	IR_{2+1}	[$\longrightarrow$ SISCone]
D0 Run II cone	IC_{mp}-SM	IR_{3+1}	$\longrightarrow$ SISCone [with p_t cut?]
ATLAS Cone	IC-SM	IR_{2+1}	$\longrightarrow$ SISCone
PxCone	IC_{mp}-SD	IR_{3+1}	[little used]
CMS Iterative Cone	IC-PR	$Coll_{3+1}$	$\longrightarrow$ anti-k_t
PyCell/CellJet (from Pythia)	FC-PR	$Coll_{3+1}$	$\longrightarrow$ anti-k_t
GetJet (from ISAJET)	FC-PR	$Coll_{3+1}$	$\longrightarrow$ anti-k_t

SR = seq.rec.; IC = it.cone; FC = fixed cone;

SM = split–merge; SD = split–drop; PR = progressive removal

Jet substructure

Jet substructure is a very promising tool to improve signal significance in various channels: boosted top quarks (D. Kaplan et al., arXiv:0806.0848), Higgs bosons (Butterworth et al., arXiv:0802.2470)...

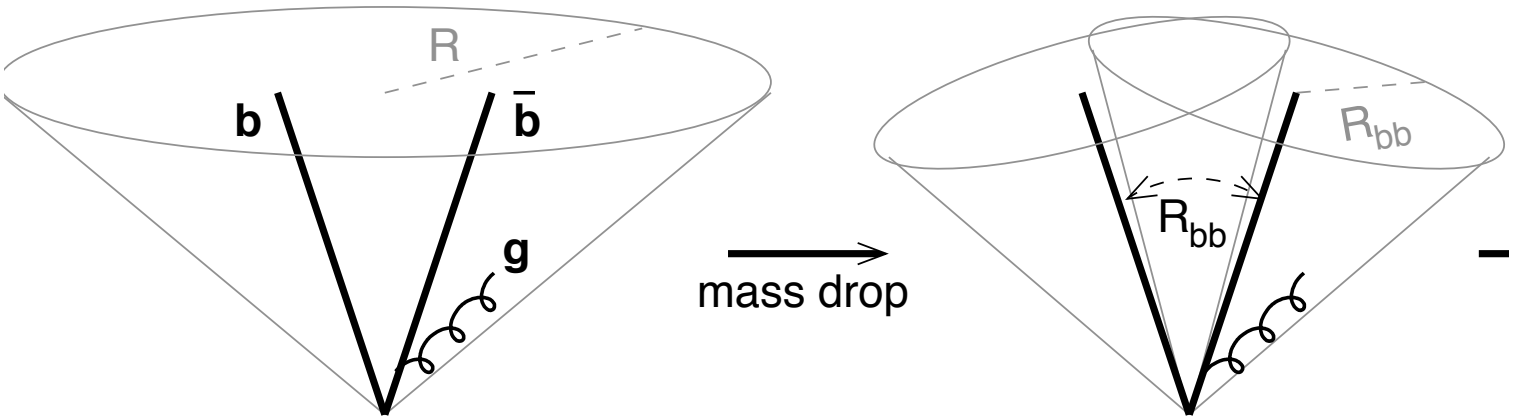
Kaplan et al. use the subjet mass drop technique of Butterworth et al. to improve top-tagging

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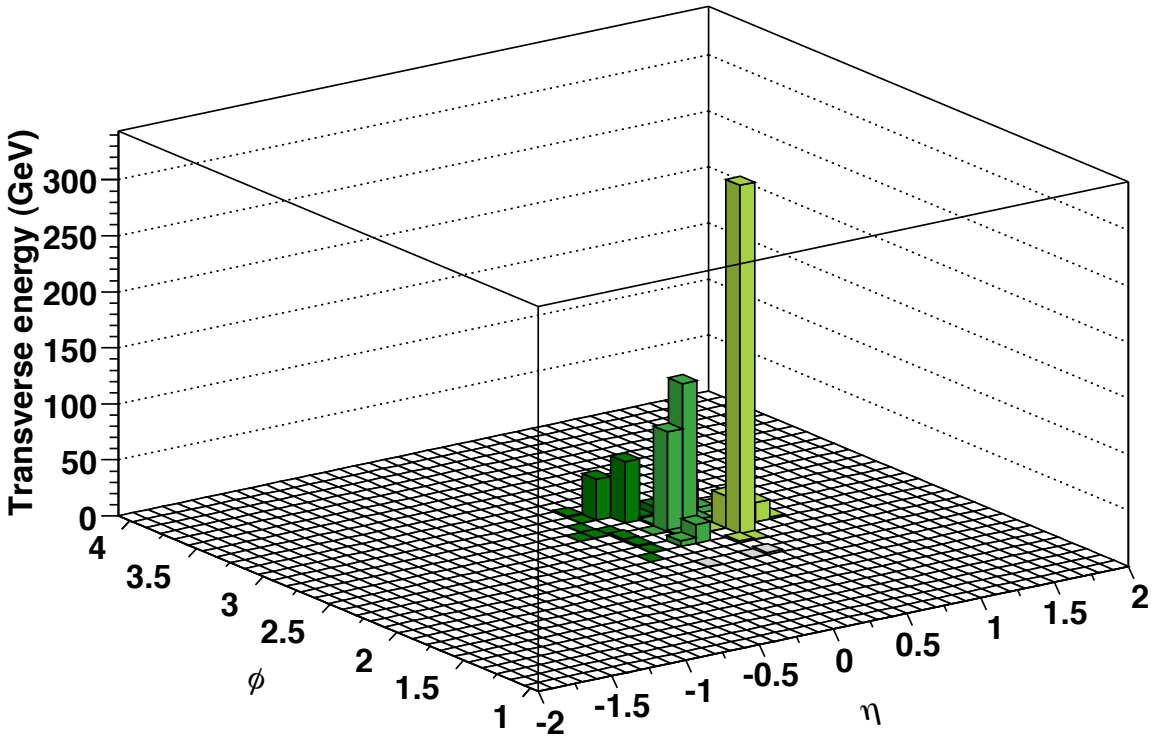
Mass drop technique with Cam/Aa jet algorithm:



Jet substructure

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Kaplan et al. use the subjet mass drop technique of Butterworth et al. to improve top-tagging



PERFORMANCE OF JET ALGORITHMS IN PP

References:

M. Cacciari, J. R., G. Soyez and G. Salam

Les Houches 2007, Tools and Jets Summary Report, arXiv:0803.0678

Quantifying the performace of jet definitions for kinematic resconstructions at the LHC, accepted in JHEP

The performance of jet algorithms

How to determine which jet definition (jet alg + R) for a given process? And which is the impact of wrong choices?
We need quality measures that (unlike what is commonly done):

- Do not depend on ill-defined quantities (like original parton p_T or direction, a parton is an ambiguous concept in pQCD)
  Monte Carlo partons are NOT physical quantities to reconstruct!
- Do not assume any underlying probability distribution of (MC) data, *i.e.*, whether the reconstructed mass distribution is gaussian, asymmetric, ...

Processes studied:

- Mono-energetic quark jets from fictitious narrow width $Z' \to q\bar{q}$ decays for various $M_{Z'}$ (100 GeV - 4 TeV)
- Mono-energetic gluon jets from fictitious narrow width $H \to gg$ decays for various M_H (100 GeV - 4 TeV): Source of
- Hadronic $t\bar{t}$ decays: Complex multijet environment

Quality measures

1. $Q^{w}_{f=z}(R) \rightarrow$ The **width of the smallest (reconstructed) mass window** that contains a fraction $f = z$ of the generated massive objects:

$$f = \left(\frac{\#\text{ reco. massive objects in window of width } w}{\text{Total } \#\text{ generated massive objects}} \right)$$

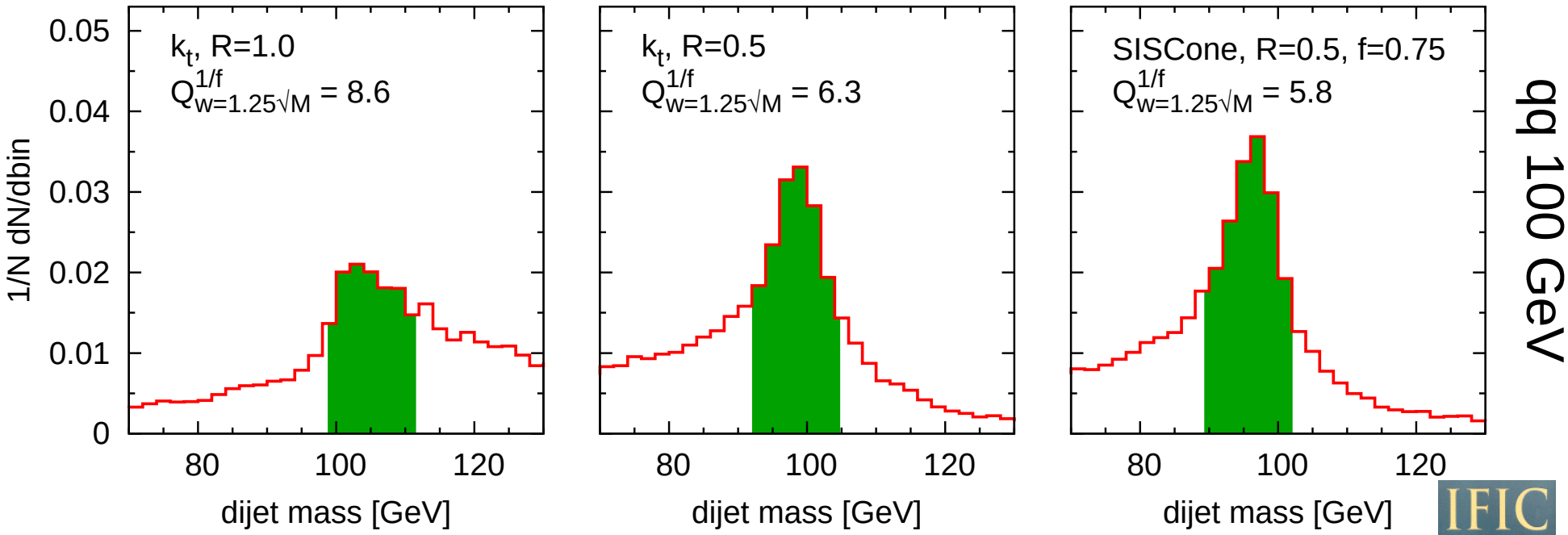
2. The **max. fraction of evs.** f in window of width $w = x\sqrt{M}$:

$$Q^{1/f}_{w=x\sqrt{M}}(R) \equiv \left(\frac{\text{Max } \#\text{ reco. mass. obj. in width } w = x\sqrt{M}}{\text{Total } \#\text{ generated massive objects}} \right)^{-1}$$

Consistent results obtained with both measures

Quality measures

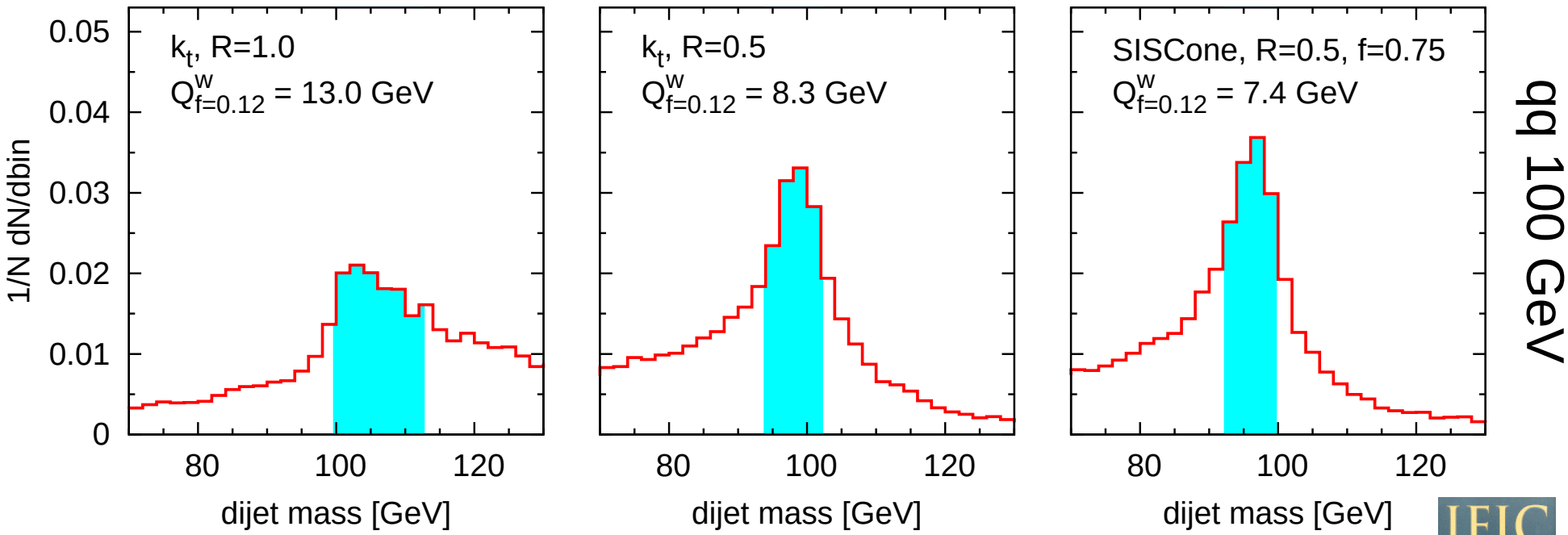
$$Q^{1/f}_{w=x\sqrt{M}}(R) \equiv \left(\frac{\text{Max \# reconstructed massive objects in window of width } w = x\sqrt{M}}{\text{Total \# generated massive objects}} \right)^{-1}$$



Quality measures

$Q^w_{f=z}(R) \rightarrow$ **width of the smallest (reconstructed) mass window** with fraction $f = z$ of the generated objects:

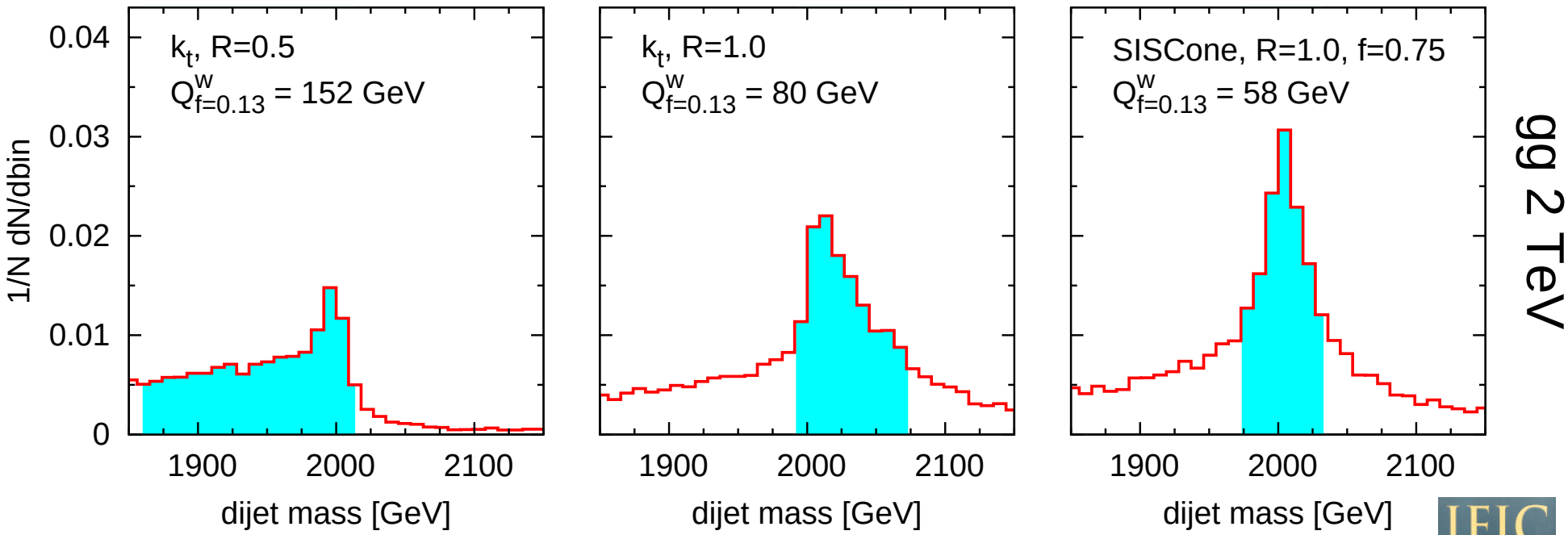
$$f = \left(\frac{\#\ \text{reconstructed massive objects in window of width } w}{\text{Total } \#\ \text{generated massive objects}} \right) .$$



Quality measures

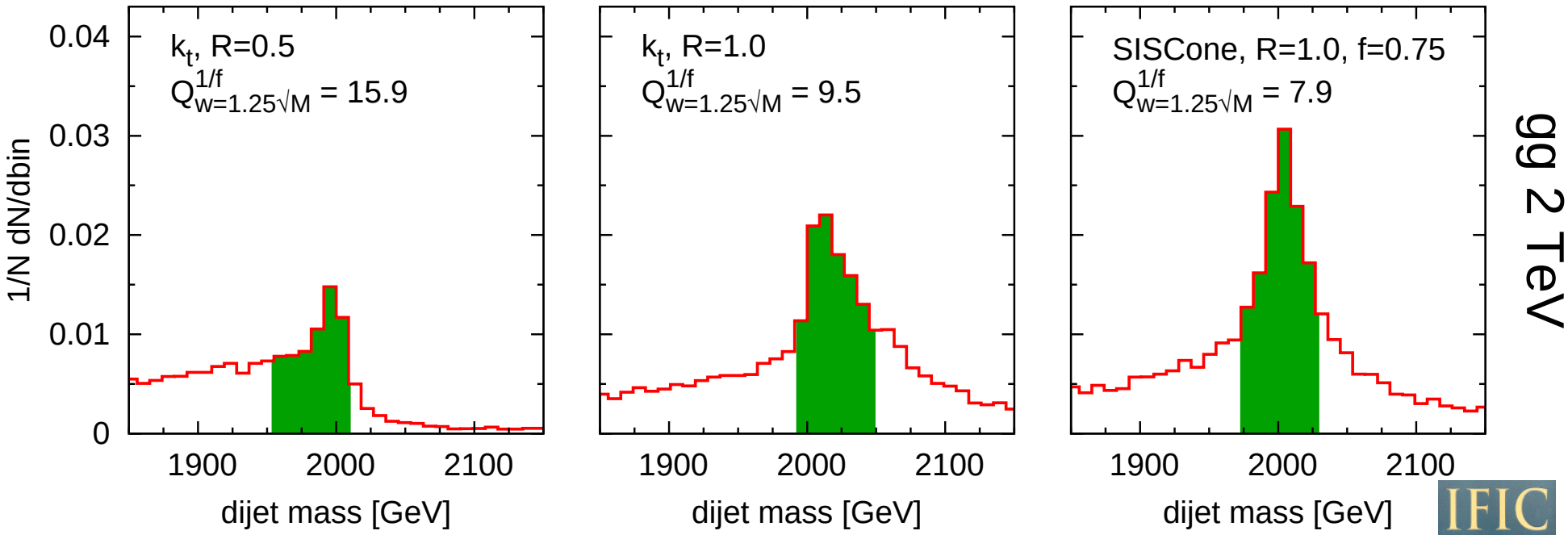
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Quality measures

$$Q^{1/f}_{w=x\sqrt{M}}(R) \equiv \left(\frac{\text{Max \# reconstructed massive objects in window of width } w = x\sqrt{M}}{\text{Total \# generated massive objects}} \right)^{-1}$$



Effective luminosity ratio

- Signal significance is defined as

$$\Sigma\,(\mathrm{JD}) \equiv \frac{N^{\mathrm{JD}}_{\mathrm{signal}}}{\sqrt{N^{\mathrm{JD}}_{\mathrm{bkgd}}}}\ ,$$

- Define effective luminosity ratio $\rho_{\mathcal{L}}(\mathrm{JD}_2/\mathrm{JD}_1)$ between jet definitions

$$\rho_{\mathcal{L}}(\mathrm{JD}_2/\mathrm{JD}_1) \equiv \frac{\mathcal{L}(\text{needed with } \mathrm{JD}_2)}{\mathcal{L}(\text{needed with } \mathrm{JD}_1)} = \left[\frac{\Sigma\,(\mathrm{JD}_1)}{\Sigma\,(\mathrm{JD}_2)}\right]^2$$

  Given a signal significance with JD_2, $\rho_{\mathcal{L}}(\mathrm{JD}_2/\mathrm{JD}_1)$ indicates the factor more luminosity needed to obtain the same significance with JD_1

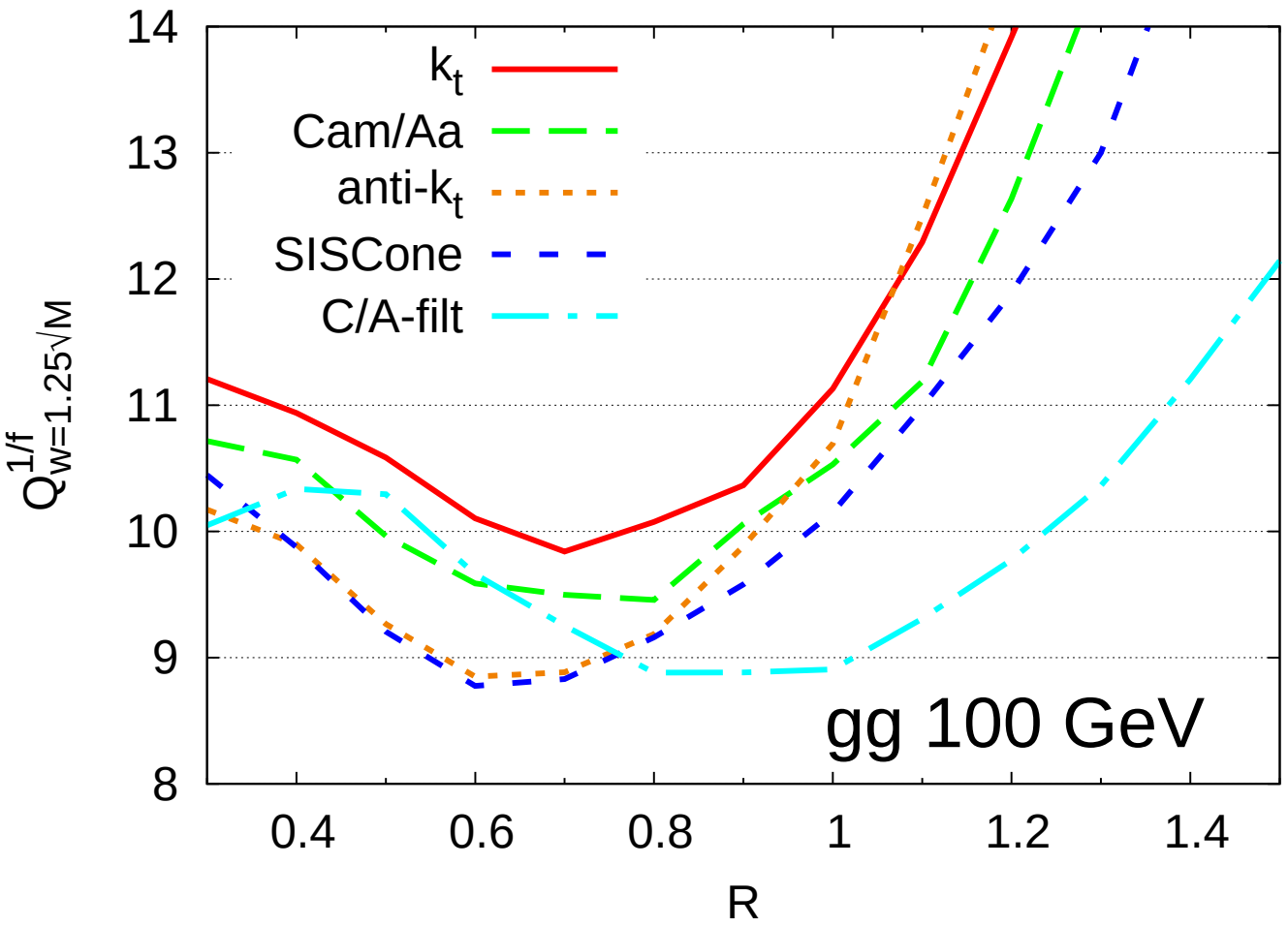
- Example: for the $Q^w_{f=z}$ quality measure

$$\rho_{\mathcal{L}}(\mathrm{JD}_2/\mathrm{JD}_1) = \frac{Q^w_{f=z}\,(\mathrm{JD}_2)}{Q^w_{f=z}\,(\mathrm{JD}_1)}$$

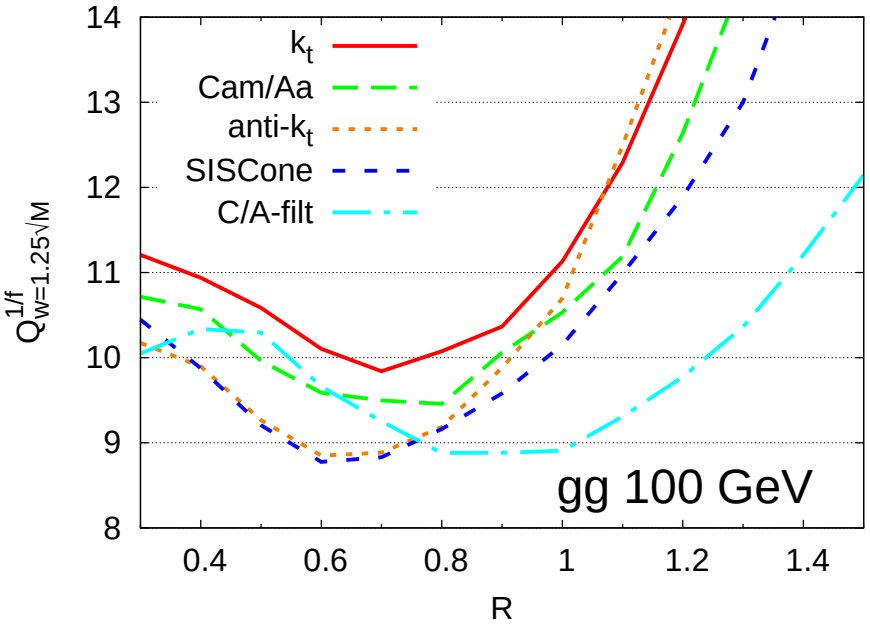
- Implicit assumption: background either unaffected by jet definition or with a shift proportional to signal peak

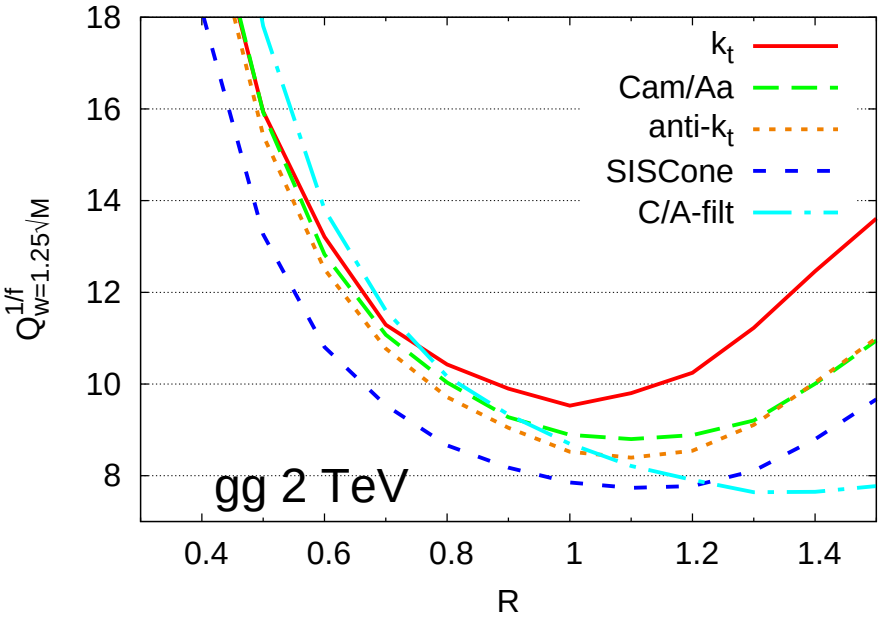
The performance of jet algorithms - Gluon jets

Smaller quality measure → Better jet definition performance



The performance of jet algorithms - Gluon jets



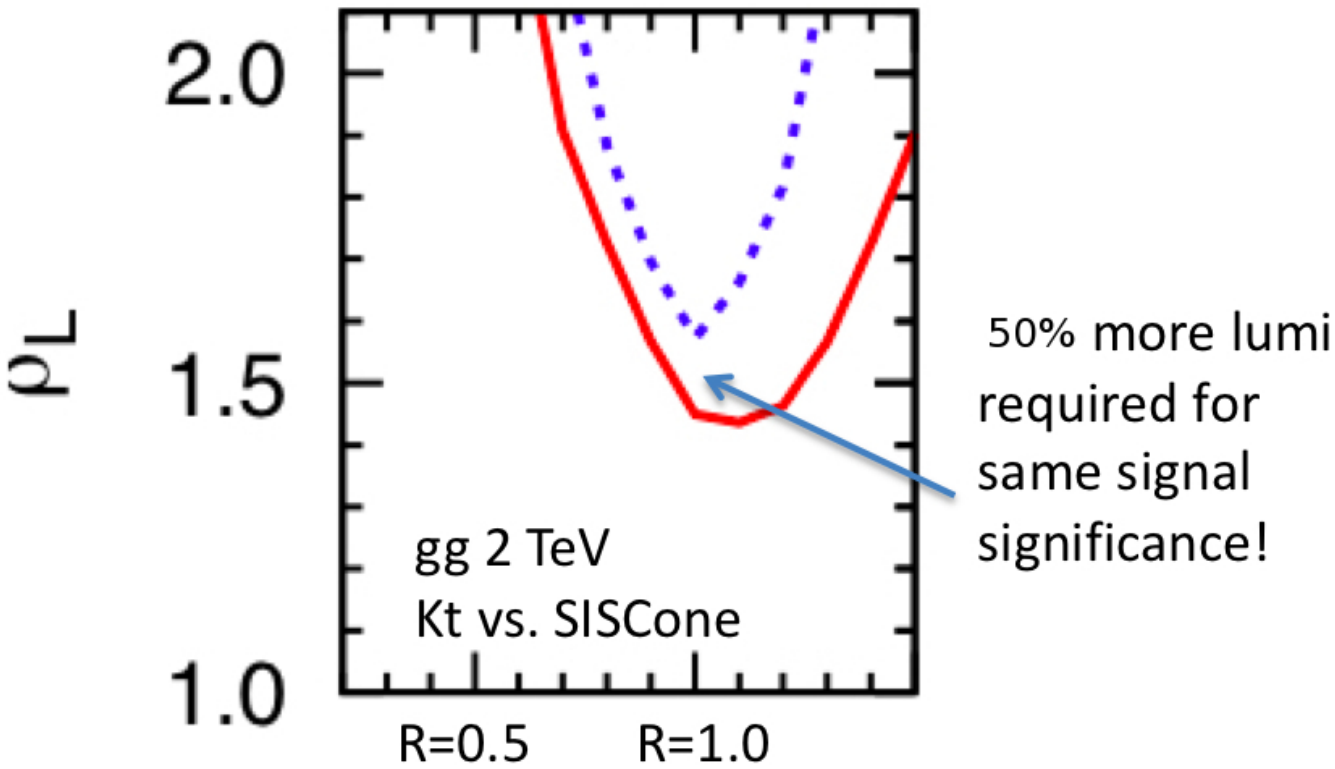


Less favored choices for the $M_H = 2$ TeV case:

1. Use SISCone, but $R^{100\ \mathrm{GeV}}_{\mathrm{best}} = 0.6$ instead of $R^{2\ \mathrm{TeV}}_{\mathrm{best}} = 1.1 \rightarrow \rho_{\mathcal{L}} \sim 1.8$
2. Use $R^{2\ \mathrm{TeV}}_{\mathrm{best}}$, choose not SISCone, C/A-filt but $k_T \rightarrow \rho_{\mathcal{L}} \sim 1.5$

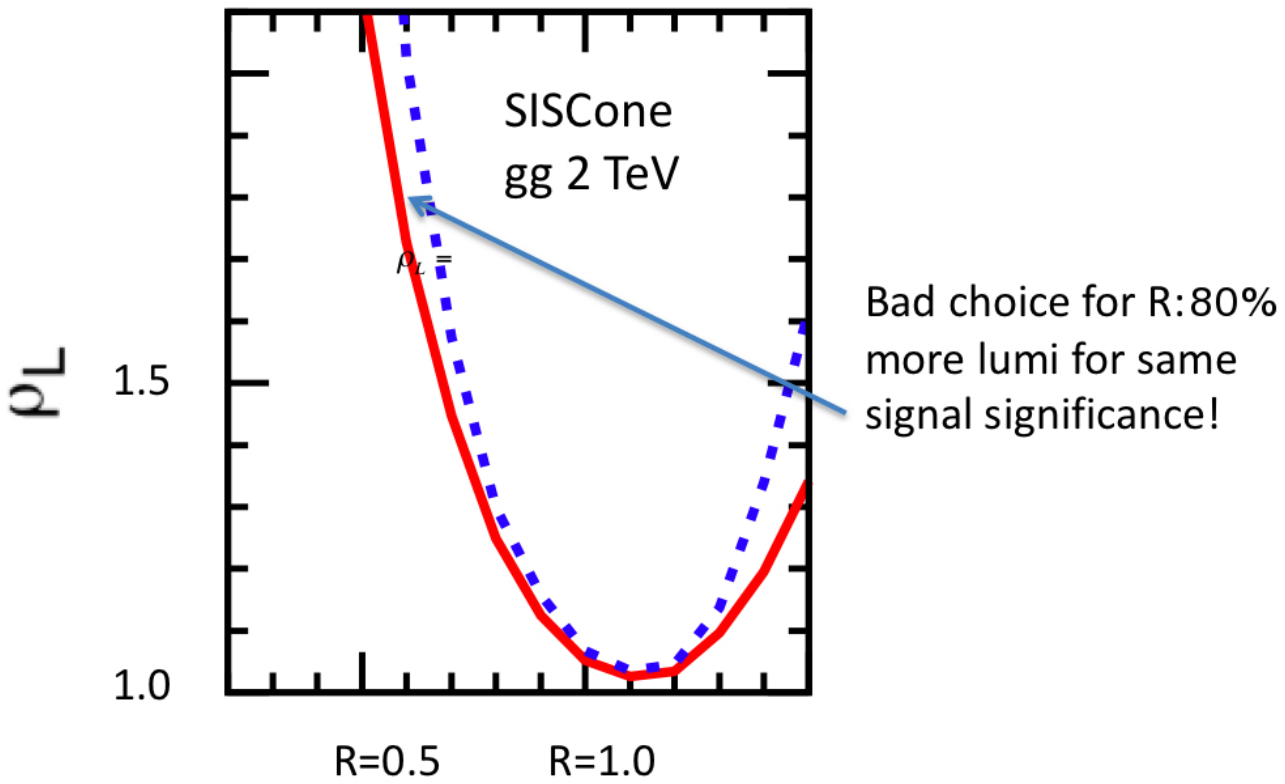
In both cases $\rightarrow$ Sizably more luminosity required to achieve same signal significance

The performance of jet algorithms - Gluon jets



Use $R^{2\ \mathrm{TeV}}_{\mathrm{best}}$, choose not SISCone, C/A-filt but $k_T \rightarrow \rho_{\mathcal{L}} \sim 1.5 \rightarrow$ 50% more luminosity required to achieve same signal significance

The performance of jet algorithms - Gluon jets

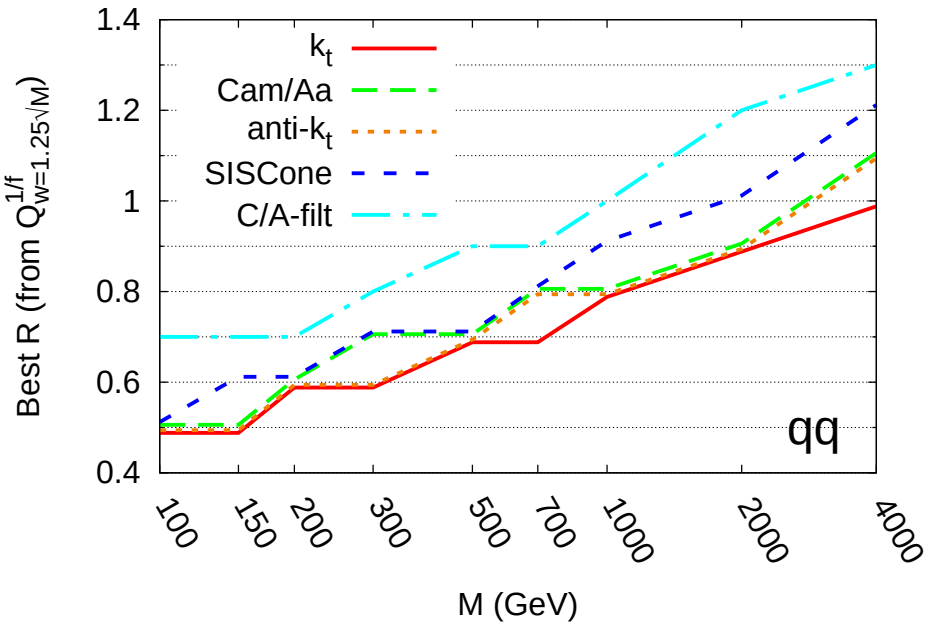


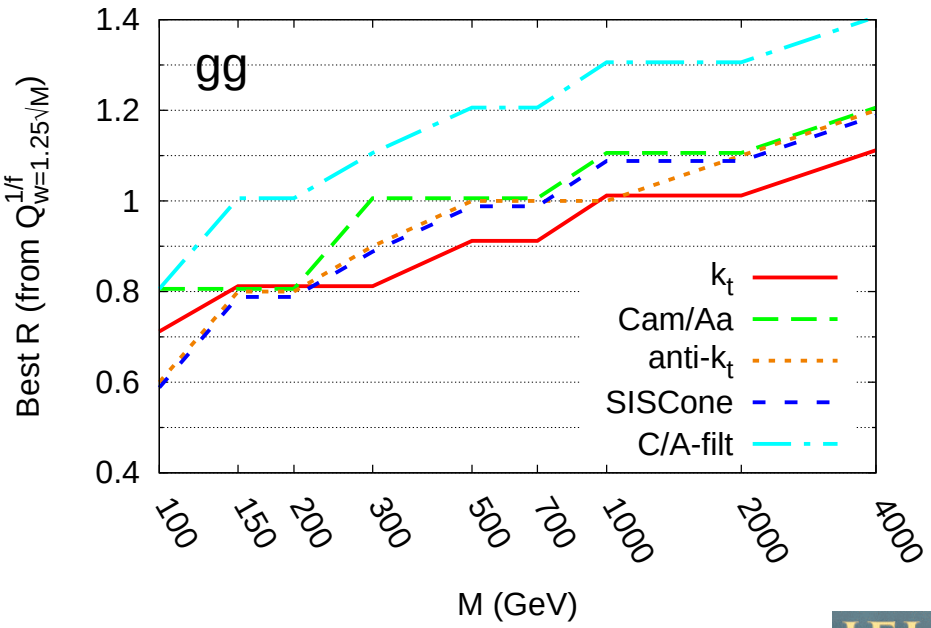
Use SISCone, but $R^{100\ \mathrm{GeV}}_{\mathrm{best}} = 0.6$ instead of $R^{2\ \mathrm{TeV}}_{\mathrm{best}} = 1.1 \rightarrow \rho_{\mathcal{L}} \sim 1.8 \rightarrow$ 80% more luminosity required to achieve same signal significance

The performance of jet algorithms - $R_{\rm best}$

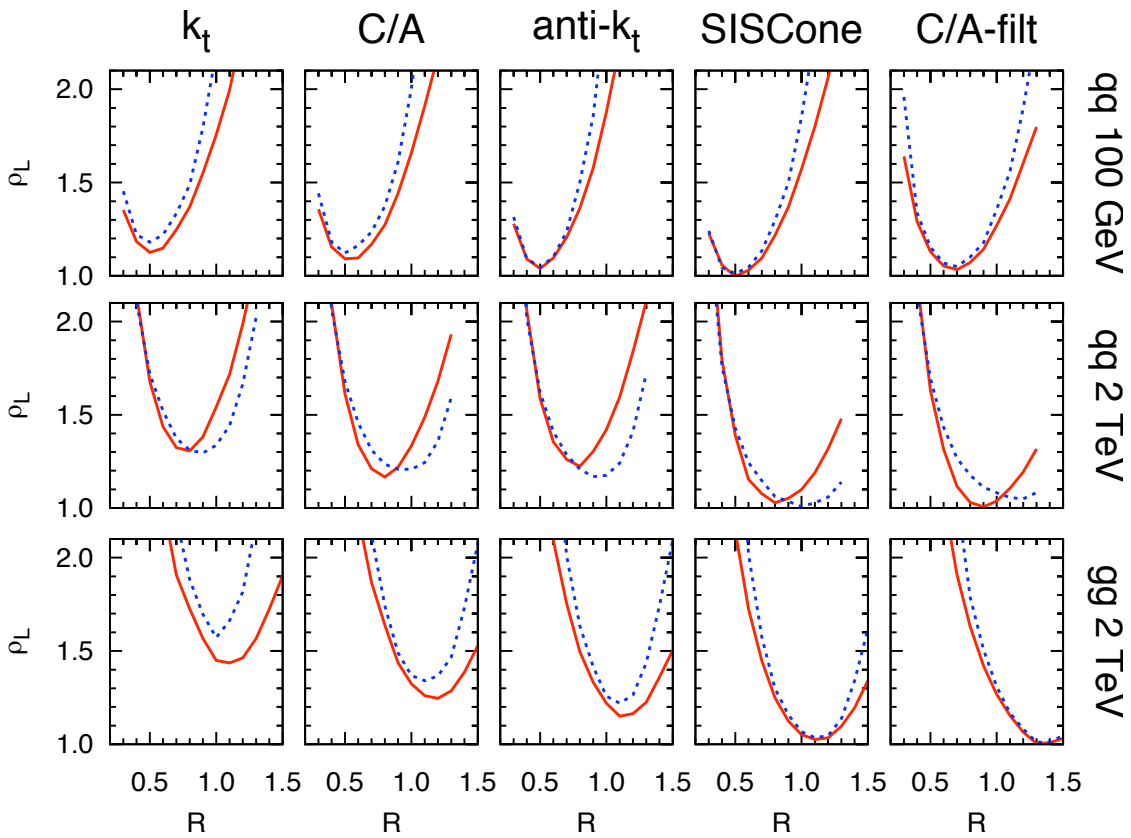
Gluon jets require larger values of $R_{\rm best}$ than quark jets.
For quark jets with $p_T \geq 250$ GeV $\rightarrow$ $R_{\rm best} \geq 0.7$
For gluon jets with $p_T \geq 250$ GeV $\rightarrow$ $R_{\rm best} \geq 0.9$
Good jet resolution requires large values of R

Growth of $R_{\rm best}$ with M from interplay between pert. and non pert. effects



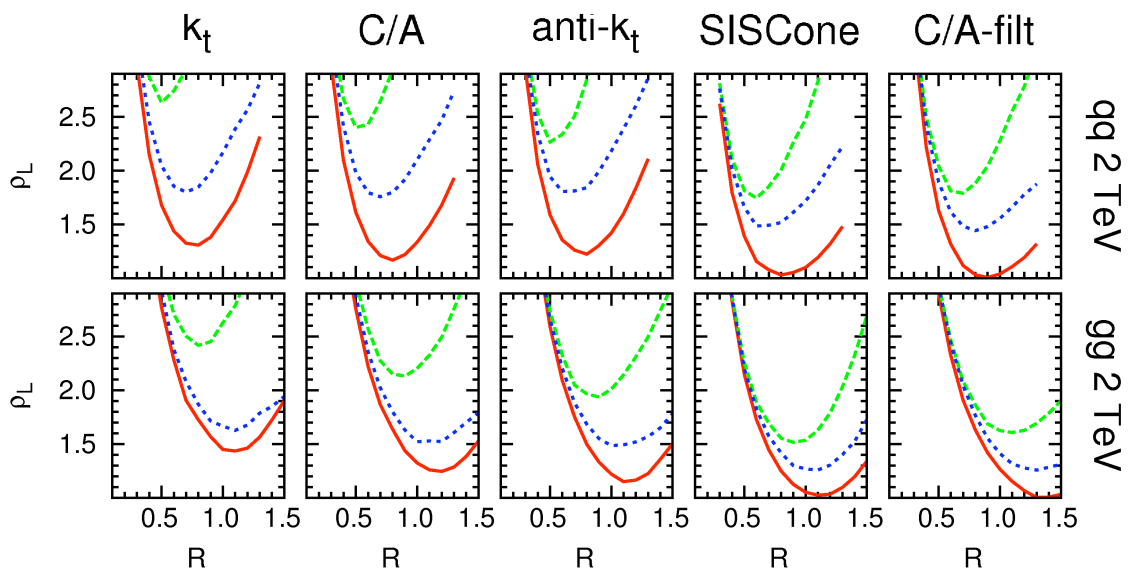


Summary - Effective lumi ρ_L



- Jet algorithms with better performance → SISCone and Cam/Aa-filt
- Sizable difference of quality (summarized by $\rho_L \gg 1$) both between jet algorithms and between values of R
- Important loss in effective luminosity for less favored choices → Important consequences at the LHC
- Similar quantitative results even with high luminosity Pile-Up

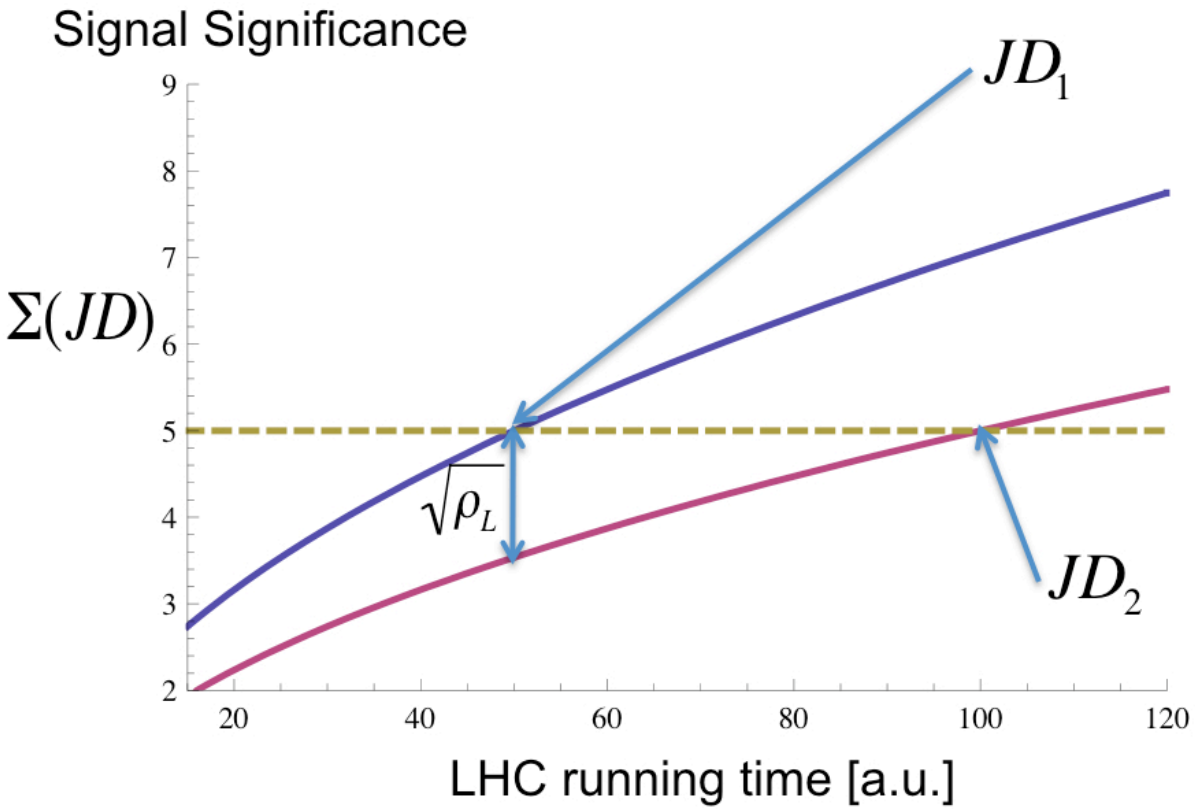
Summary - Effective lumi ρ_L



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- Important loss in effective luminosity for less favored choices → Important consequences at the LHC
- Similar quantitative results even with high luminosity Pile-Up

A possible scenario?

What is some collaboration (ATLAS or CMS) uses less favored jet defs?



Not an academic example: Exp 2 reconstructs a TeV scale object which decays into gluons with $R = 0.5$ $\longrightarrow$ Flexibility in jet finding at LHC good investment!

JetQuality Interactive Tool

What if I want to play myself with the various jet definitions?

Use the JetQuality Interactive Tool!

http://quality.fastjet.fr

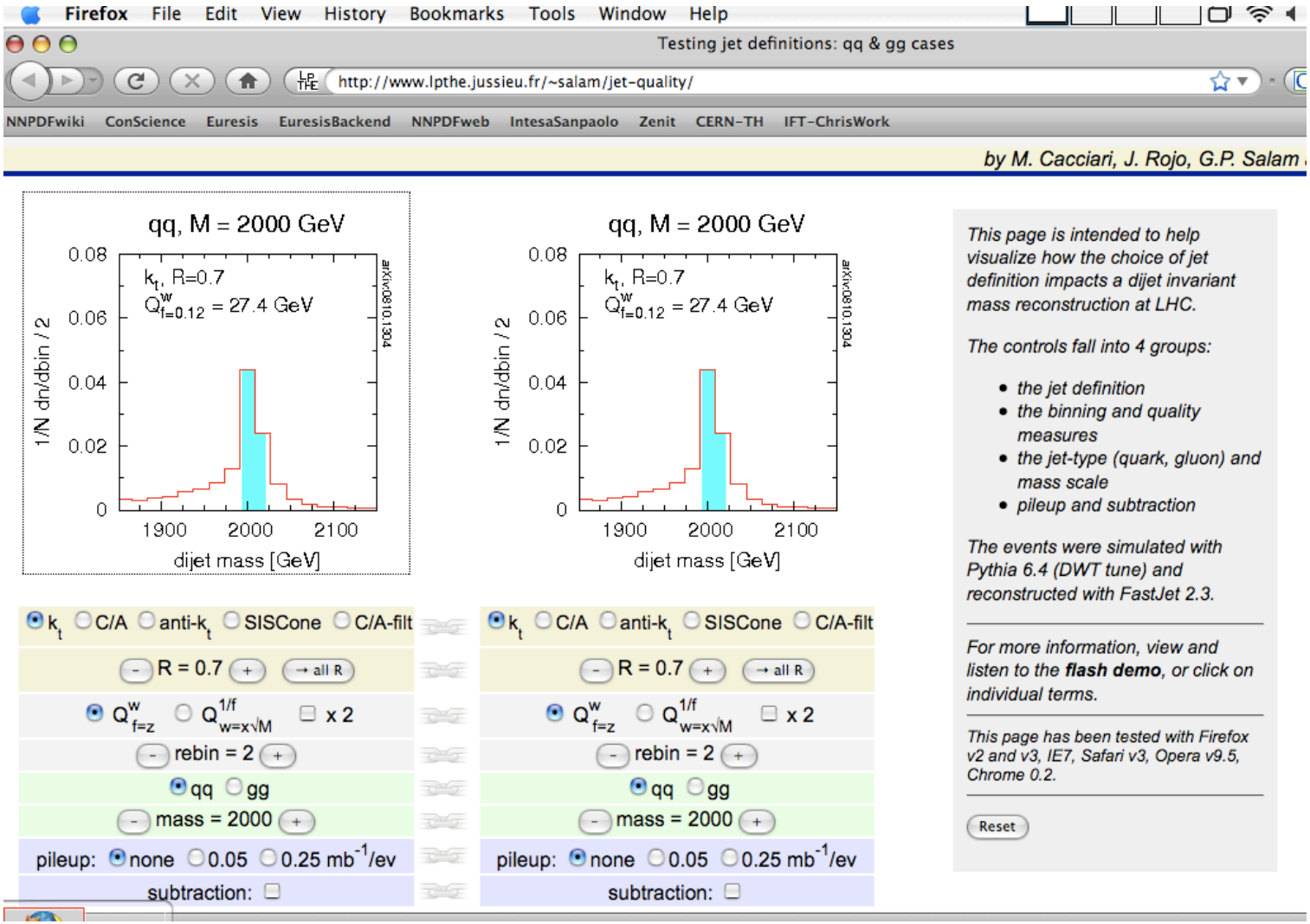
JetQuality Interactive Tool

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Use the JetQuality Interactive Tool!

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JetQuality Interactive Tool

(if Internet not available ...)



JET ALGORITHMS AND SUBTRACTION IN HEAVY ION COLLISIONS

References:
M. Cacciari, J. R., G. Soyez and G. Salam
Talks at Hard Probes 2008
+ Work in progress

Jets in heavy ion collisions

Jets will be of paramount importance to fully exploit the potential of the HIC program at the LHC

- Jets will be most abundant hard probes in HIC at the LHC
  From CMS HIC TDR (J. Phys. G: Nucl. Part. Phys. 34 2307)

Table 1.1. The expected yield of several hard probes in 10^6 s PbPb and pPb LHC runs

	PbPb $\sqrt{s_{NN}} = 5.5$ TeV $\mathcal{L} = 5 \times 10^{26}$ cm^{-2} s^{-1}		pPb $\sqrt{s_{NN}} = 8.8$ TeV $\mathcal{L} = 1.4 \times 10^{30}$ cm^{-2} s^{-1}	
Process	Yield/10^6 s	Ref.	Yield/10^6 s	Ref.
	$\|\eta\| \leqslant 2.4$			
jet ($p_T > 50$ GeV/c)	2.2×10^7	[47]	1.5×10^{10}	[48]
jet ($p_T > 250$ GeV/c)	2.2×10^3	[47]	5.2×10^6	[48]
Z^0	3.2×10^5	[49]	6.8×10^6	[48]

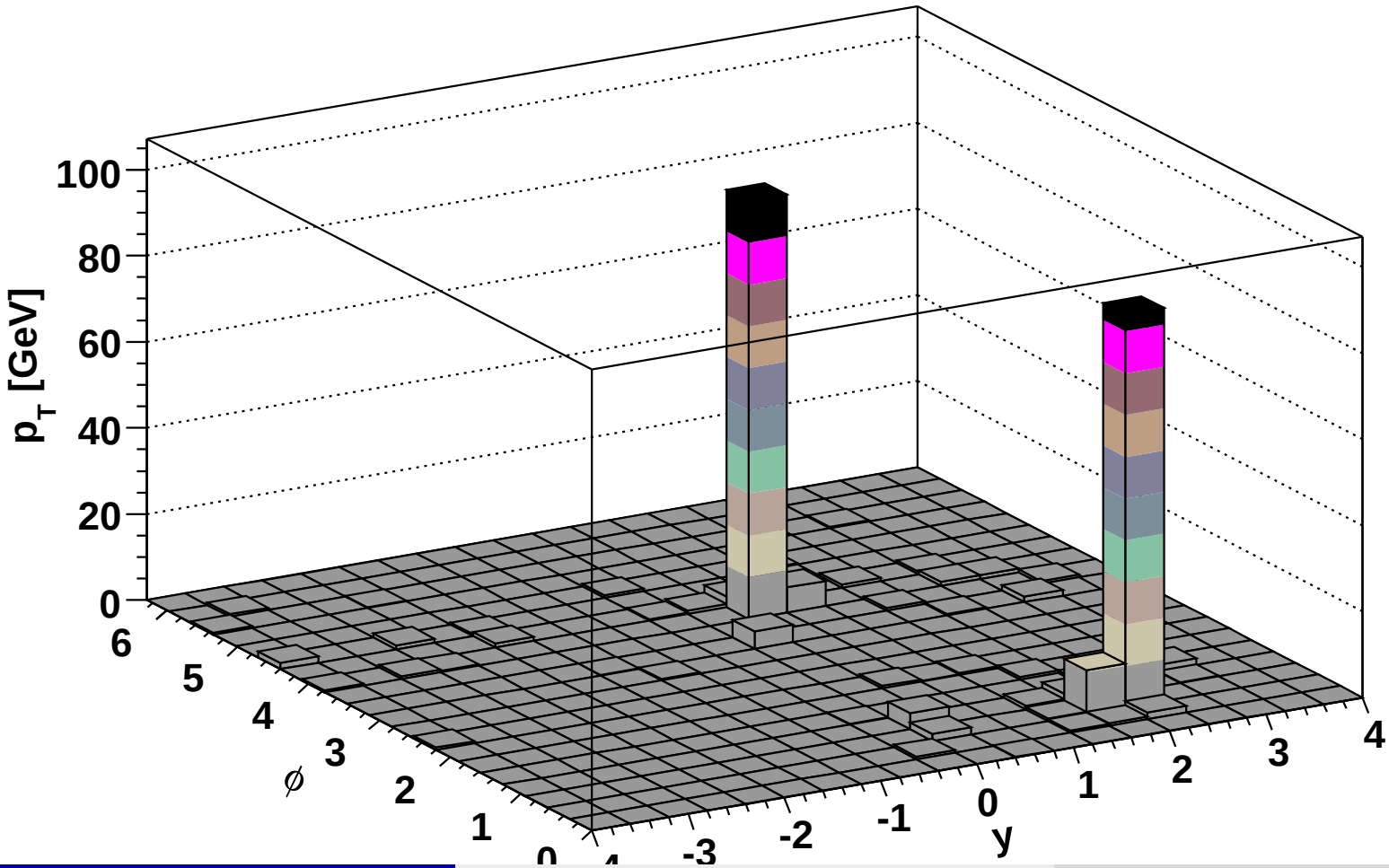
Jets in heavy ion collisions

Jets will be of paramount importance to fully exploit the potential of the HIC program at the LHC

- Jets will be most abundant hard probes in HIC at the LHC
- Jets free of inclusive particle measurements biases
- A solid pQCD baseline is required to detect and quantify medium effects
- Need to asses to which extend can reconstructed QCD jets be disentangled from background, and which is the minimum size of medium effects which could then be probed
- All the successful jet technology from *pp* can be transferred to the extremely dense environment of heavy ion collisions
- The feasibility of real QCD jets in a Heavy Ion environment has been recently shown by STAR @ RHIC

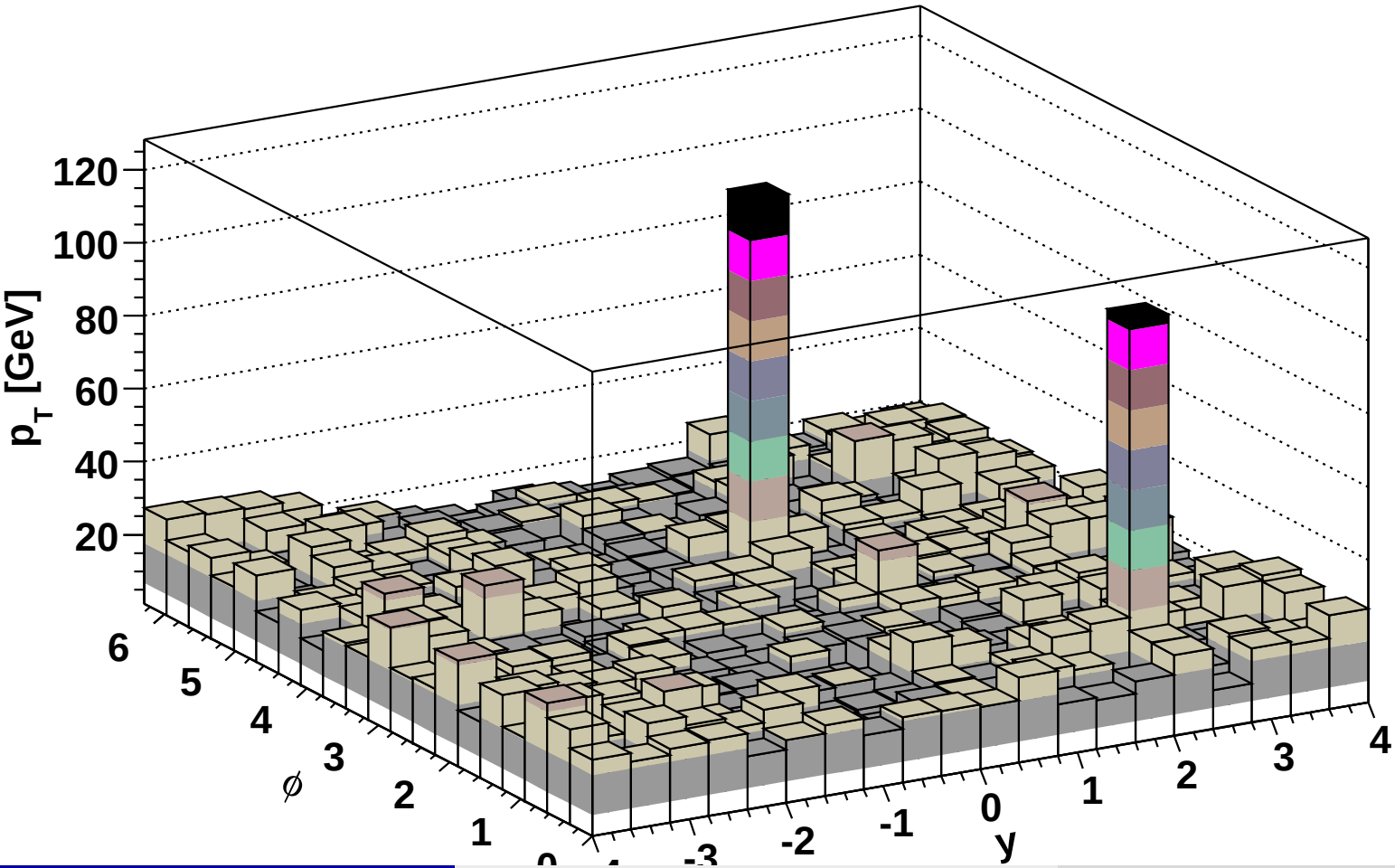
A messy environment

From a quiet pp collision ...



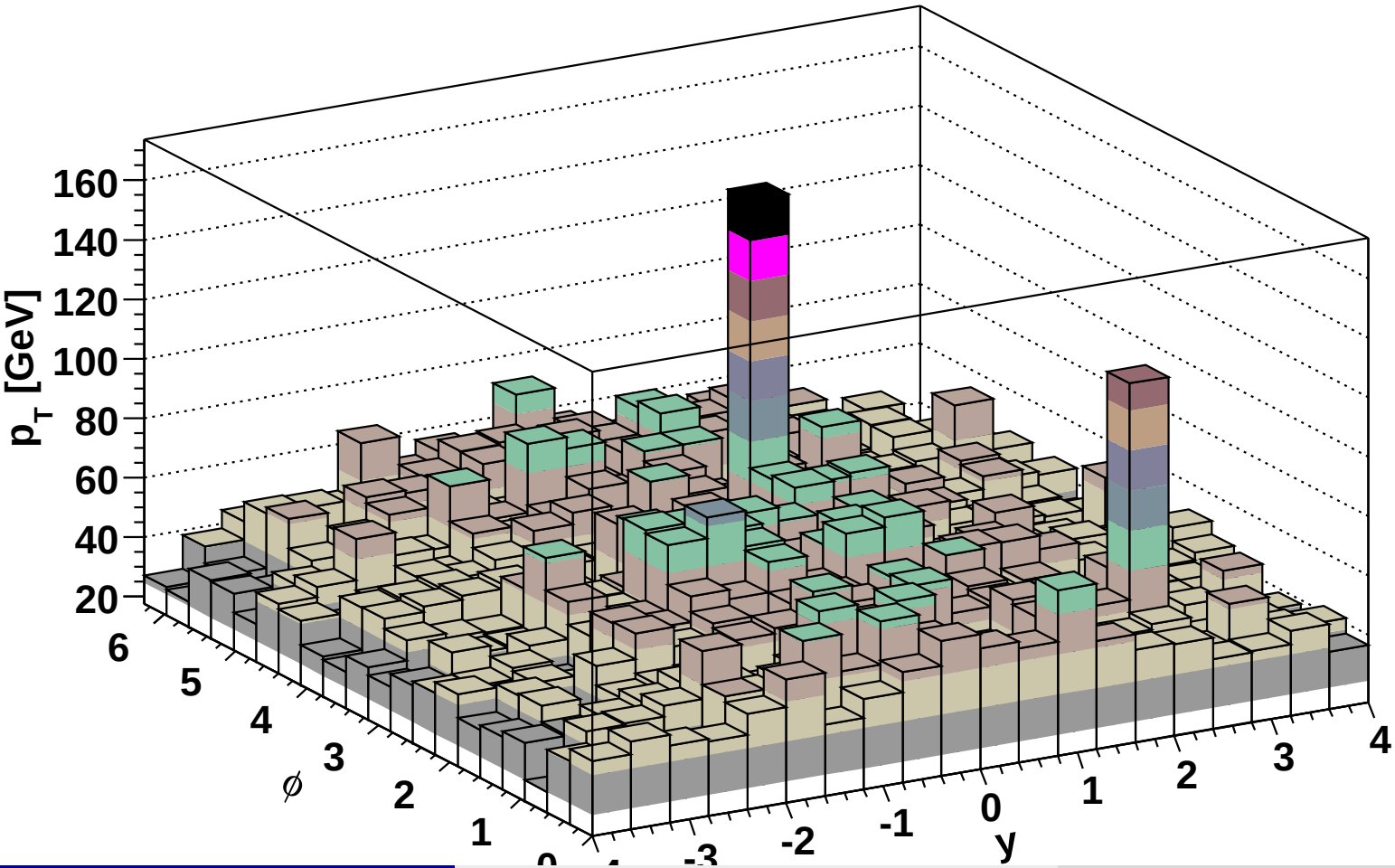
A messy environment

... to a busy AA collision (small multiplicity scenario)



A messy environment

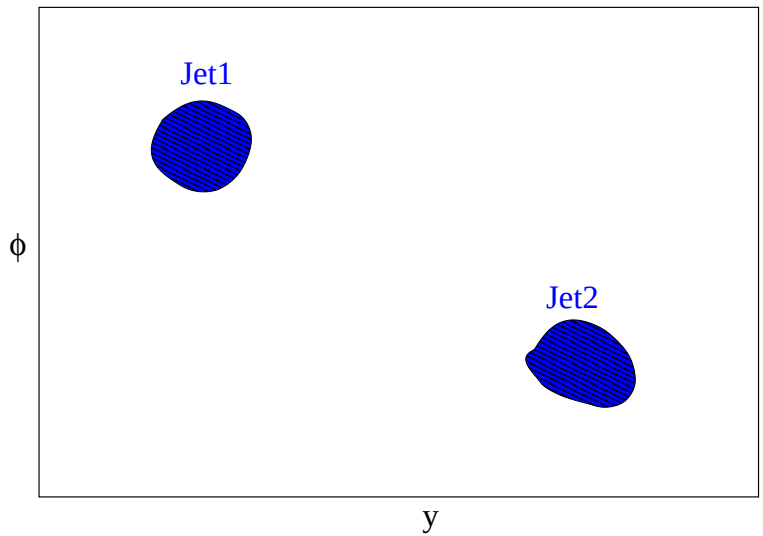
... to a busy AA collision (high multiplicity scenario)



Background subtraction

The large UE in HIC can be subtracted with the `FastJet` area technique
Different possibilities to determine $\rho = \langle p_T^{UE}/A \rangle$

- Global range $\longrightarrow$ Assume parabolic dependence $\rho(y) = a + by^2$
  Large statistics, but sensitive to background fluctuations
- Local range $\longrightarrow$ Reduce sensitivity to background structure details
  Ex: `CircularRange` of $D = kR$ centered on jet axis.

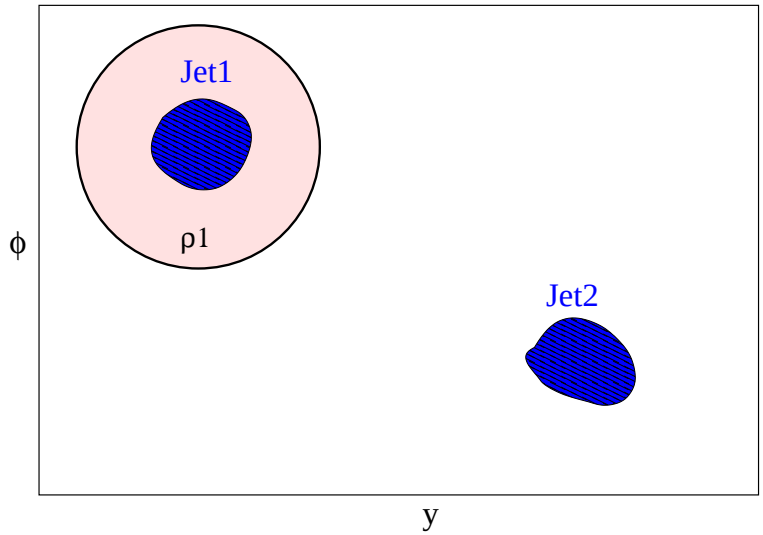


Improve removing bias from hard jets (`DonutRange`, `RapidityStrip`, ...)

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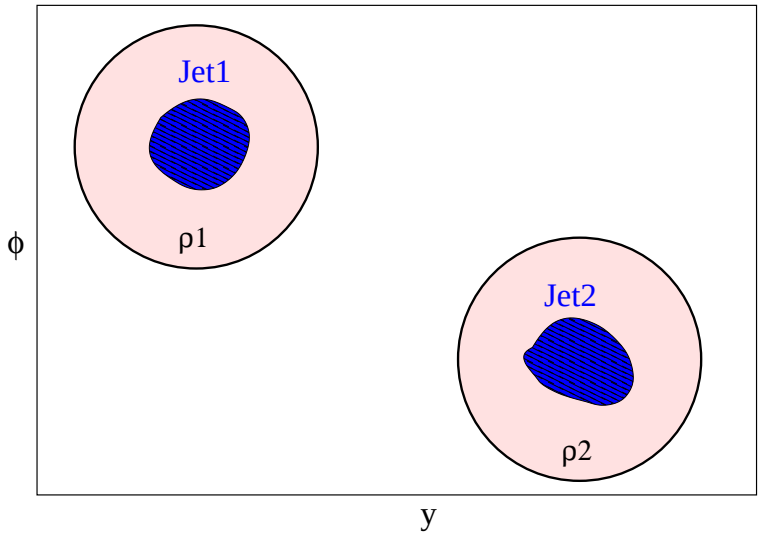


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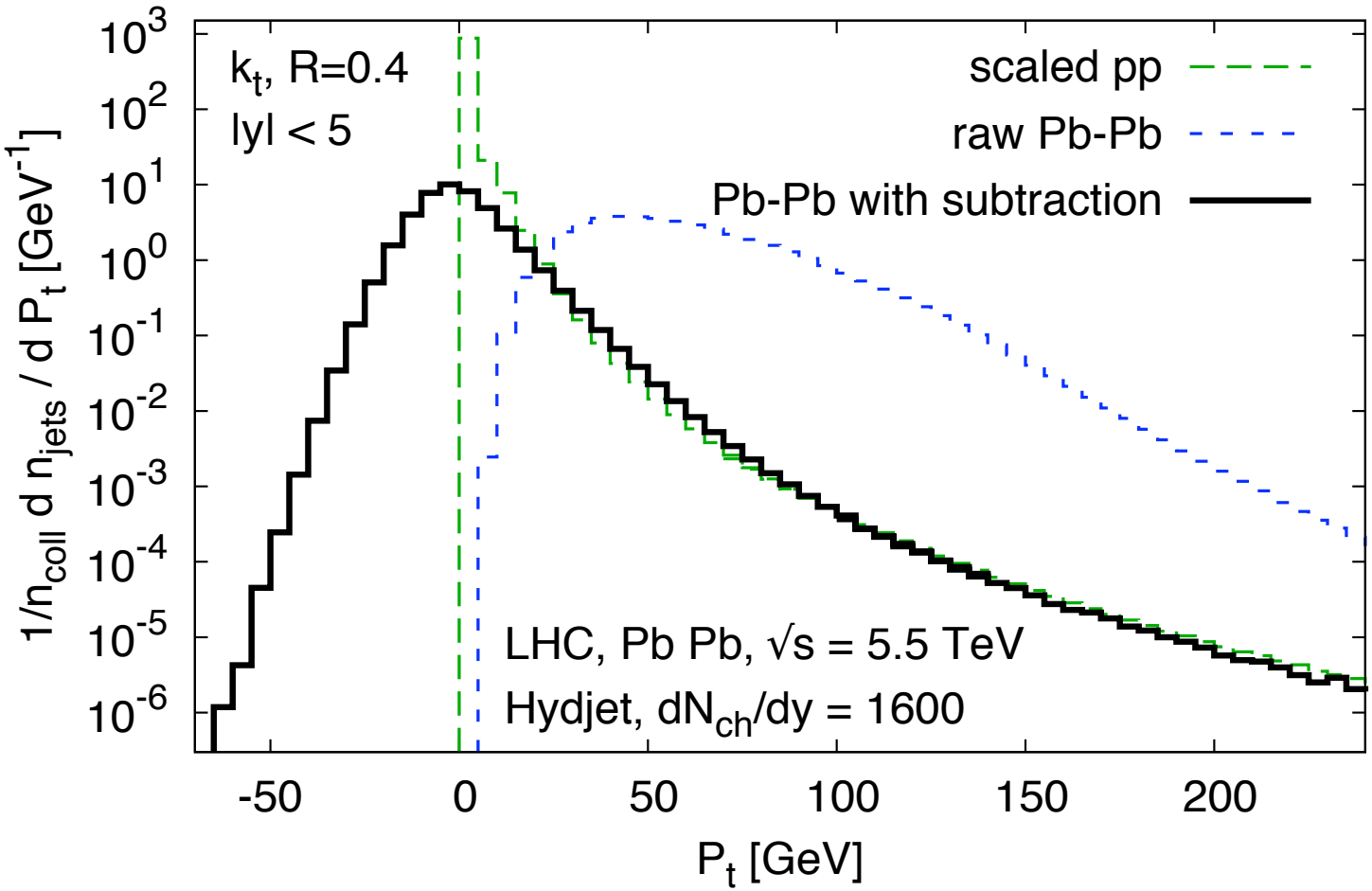
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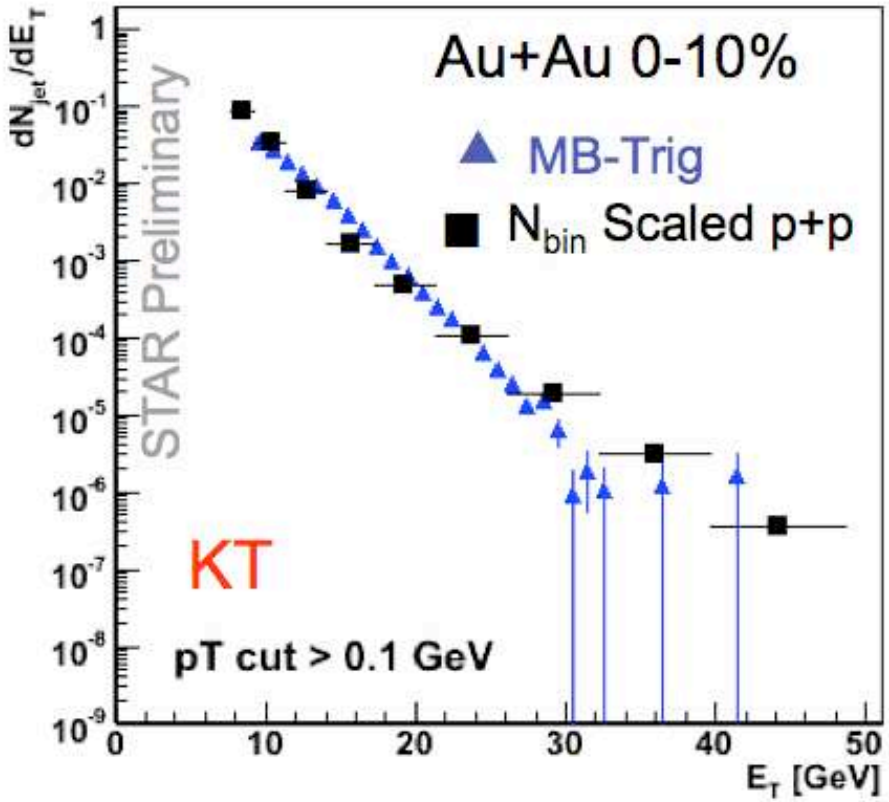
Jets in heavy ion collisions

Huge UE background in HIC $\longrightarrow$ $\rho_{\mathrm{LHC}} \equiv \left\langle p_T^{\mathrm{UE}}/\mathrm{Area} \right\rangle \sim 200$ GeV
Can be subtracted with the `FastJet` techniques (Cacciari and Salam 07) ...

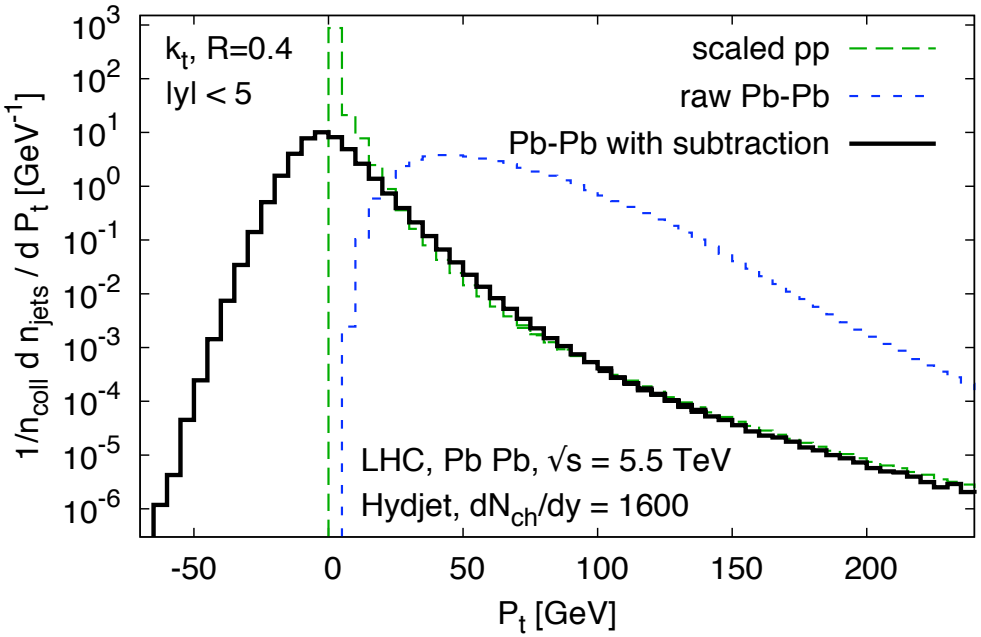


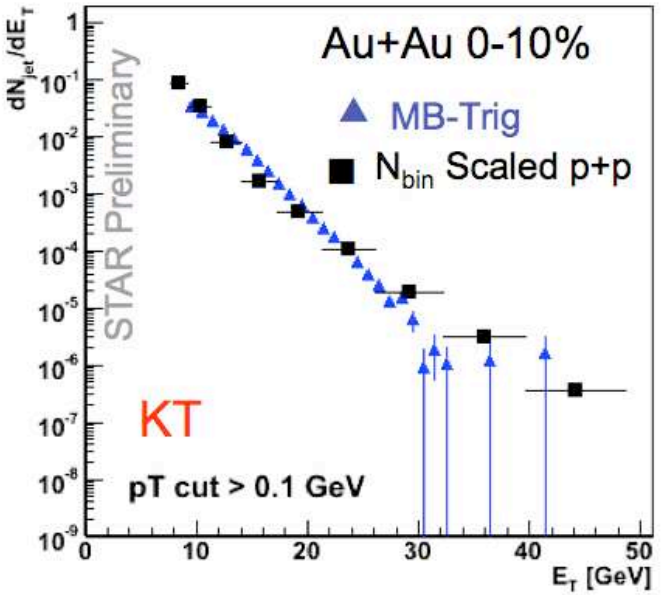
Jets in heavy ion collisions

... as has been actually done for STAR @ RHIC in the first-ever jet measurement in HIC
Important implications for Quark-Gluon Plasma characterization!



Jets in heavy ion collisions

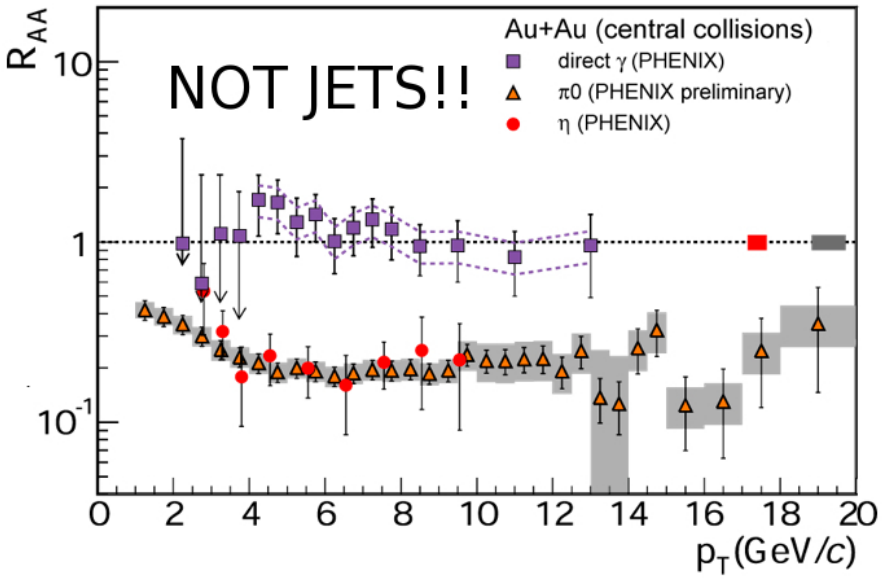


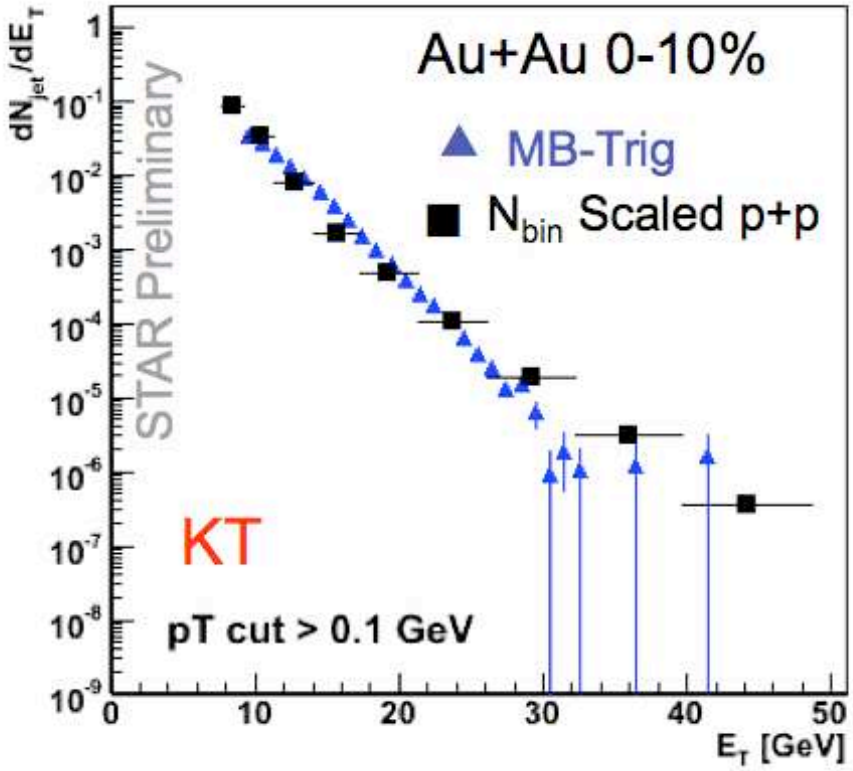


Accurate jet reconstruction in HIC is essential to characterize medium properties at RHIC and at the LHC

Notice huge p_T shift due to UE at LHC

Jets in heavy ion collisions



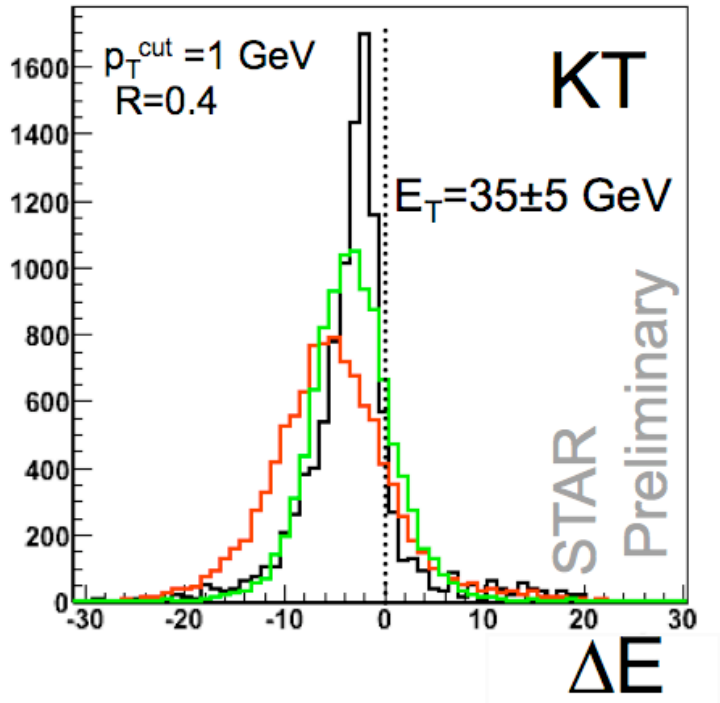


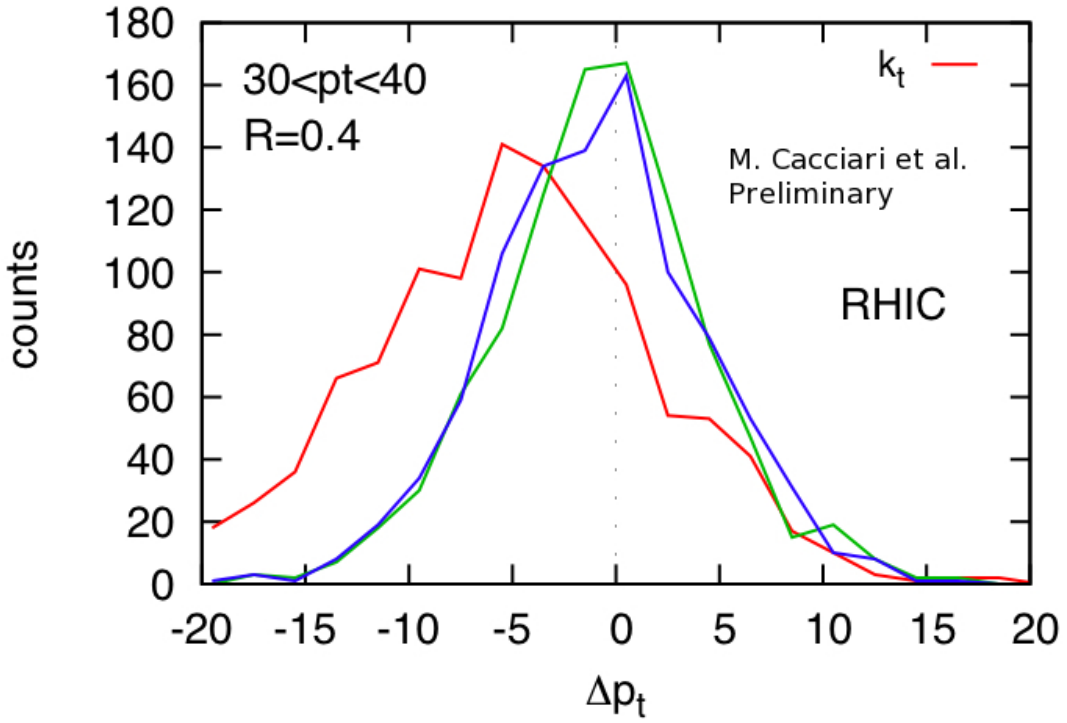
Accurate jet reconstruction in HIC is essential to characterize medium properties at RHIC and at the LHC

Jets free from inclusive particle measurements biases

Improving jets in AA

Known how to succesfully subtract most of the huge UE background in HIC
With k_T algorithm $p_T^{\text{jet}} \sim -5$ GeV @ RHIC
Goal is to improve the p_T^{jet} resolution down to the $\mathcal{O}(1/2-3)$ GeV at RHIC/LHC

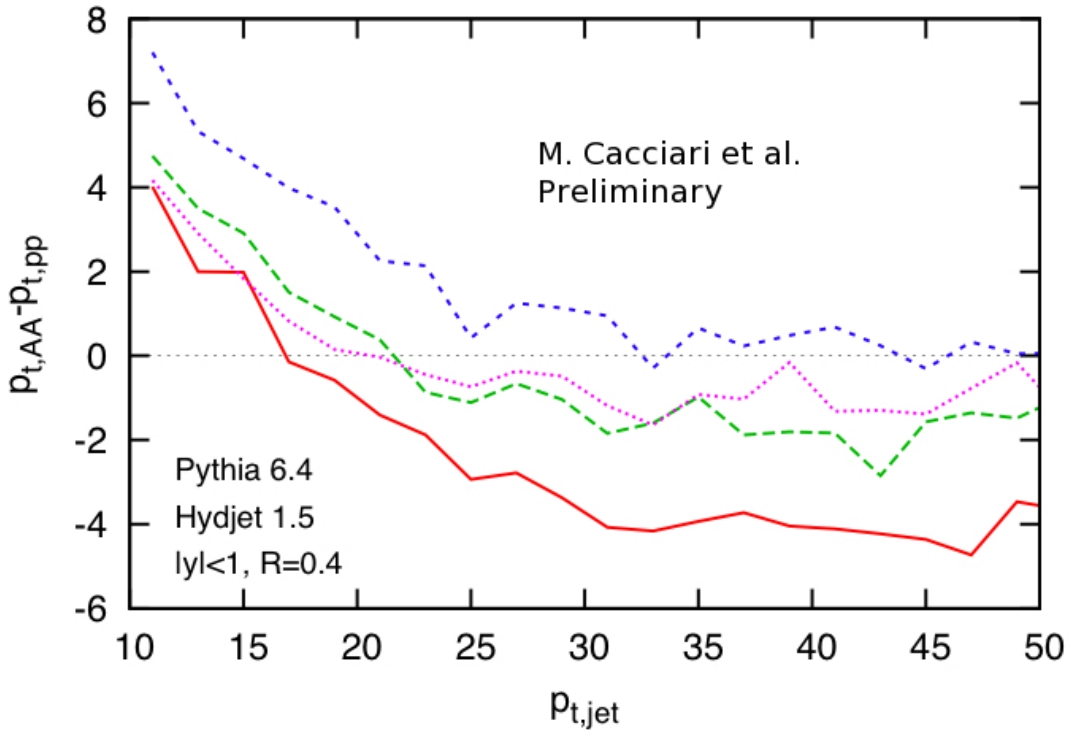




Investigate in detail optimal jet definition and ranges to determine ρ $\longrightarrow$ Work in progress

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$\mathcal{O}(1)$ GeV accuracy in p_T^{jet} reconstruction at RHIC achievable!

Assessment of medium effects

Once jet finding in HIC has been validated $\rightarrow$ Study different jet observables to discriminate between medium models

1. Generate pp LHC dijet events with `Pythia`, embedd them in PbPb events
2. Medium-induced radiative energy loss from Quenched Pythia, Armesto et al., (arXiv:0710.3073 [hep-ph])
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4. `FastJet` subtraction with `CircularRange` ($D = 3R$)
5. Repeat for different medium models ....

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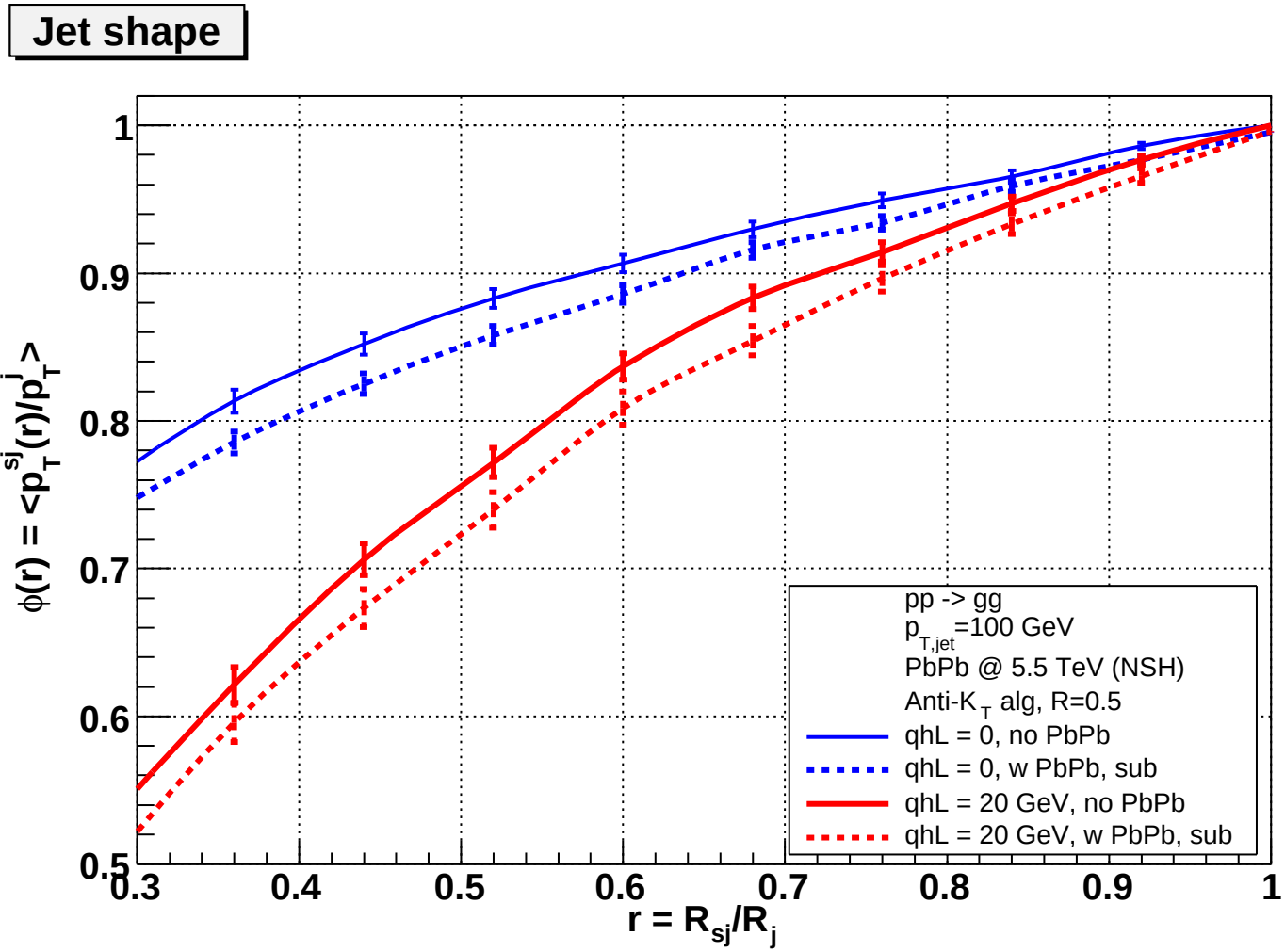
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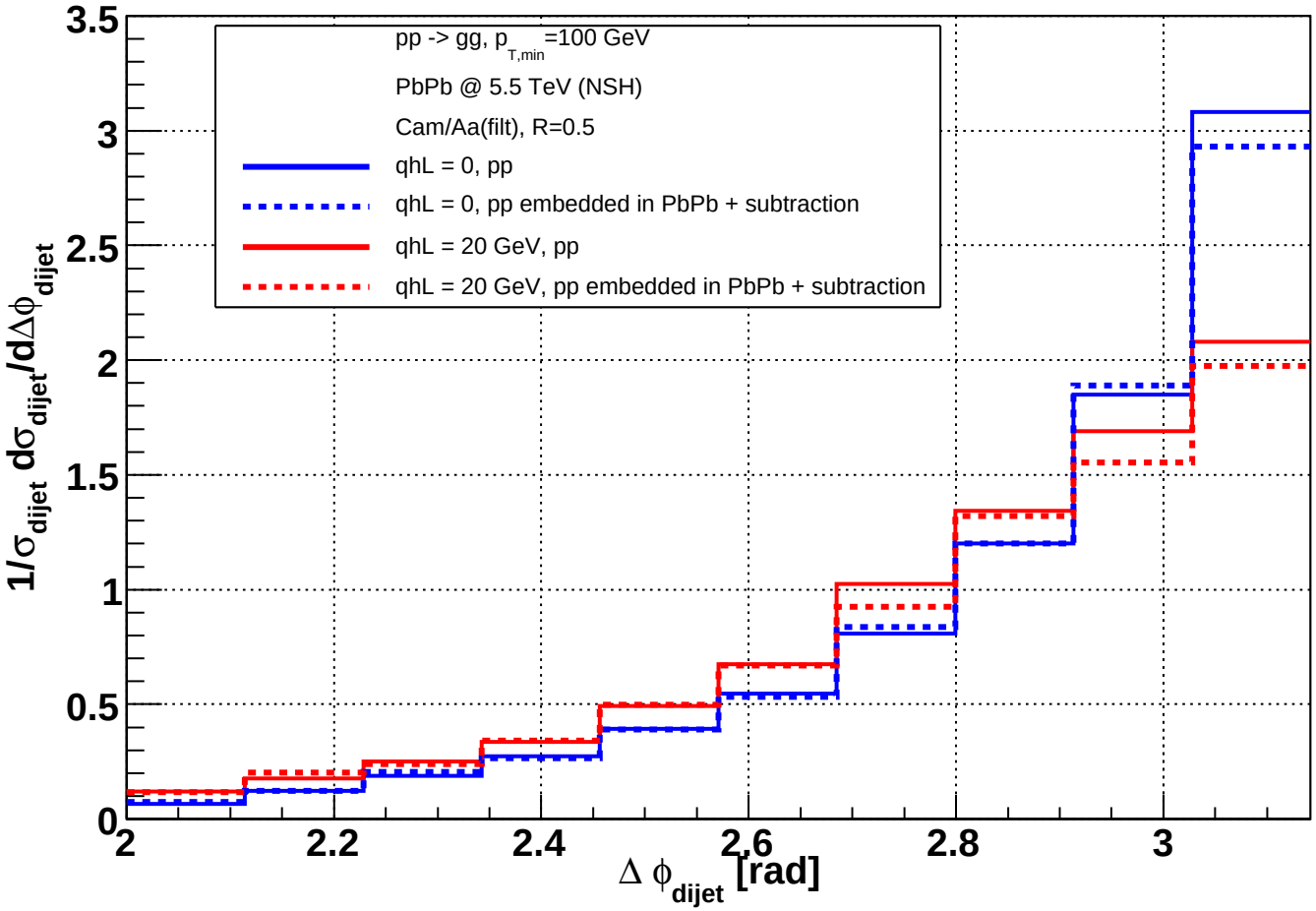
Assessment of medium effects

Jet shape → Medium induced radiation broadens significantly the jet



Assessment of medium effects

Azimuthal correlation $\longrightarrow$ Medium induced radiation softens away-side correlations



Outlook

Sizable progress in jet algorithms in the recent years:

- New IRC safe jet algorithms, fast implementations, jet areas,...
- Jet substructure for searches at the LHC

Summary from *pp* studies:

- Strong R dependence $\longrightarrow$ Sizable effective lumi loss away from $R_{\rm best}$
- SISCone and Cam/Aa(filt) $\longrightarrow$ Optimal jet algs
- Larger $p_T^{\rm jet}$ requires larger $R_{\rm best}$, more so for gluons

Summary from *AA* studies:

- More challenging background $\longrightarrow$ Tune subtraction ranges and choose optimal jet definitions to determine ρ for $\mathcal{O}\left(1/2\mathrm{GeV}\right)$ accuracy at RHIC/LHC
- First jet measurements in HIC by STAR

Thanks for your attention and Merry Christmas!

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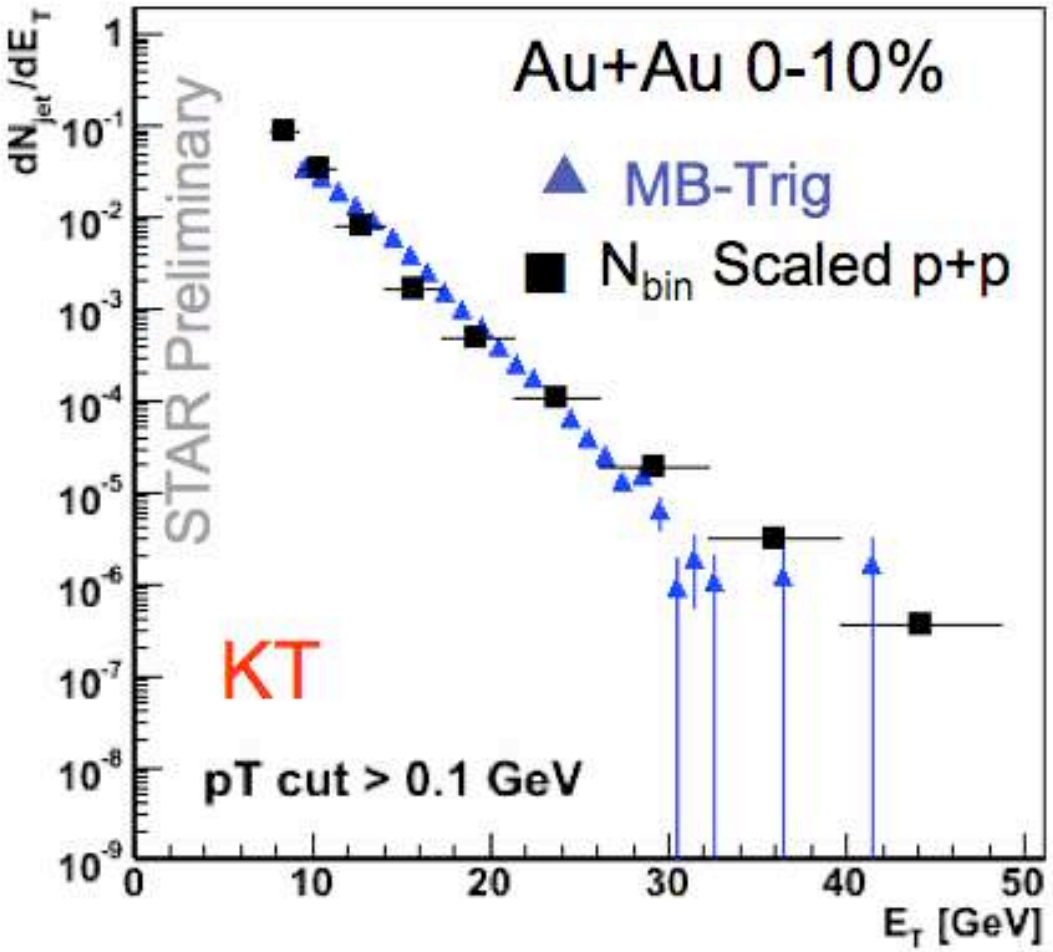
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EXTRA MATERIAL

Jet algorithms in HIC



- Mayor recent breakthrough → First ever measurement of full QCD jets in Heavy Ion Collisions by STAR @ RHIC
- Both with the k_T algorithm and with a cone algorithm
- See talks at Hard Probes 2008 and S. Salur, arXiv:0809.1609

Progress in jet algorithms

Additional studies include:

- Jet flavour and *b*-jets: Banfi, Salam and Zanderighi, hep-ph/0601139, arXiv:0704.2999
- Analytical studies of jet algorithms: Dasgupta, Magnea and Salam, arXiv:0712.3014
- Strategies to asses jet algorithms performance, Rabbertz et al., Campanelli et al. in arXiv:0803.0678
- More studies of jet substructure at LHC: G. Sterman et al, arXiv:0807.0234, J. Thaler et al., arXiv:0806.0023, Brooijmans et al. in the Les Houches 2007 proceedings ...
- Jet algorithms in top reconstruction: Seymour and Tevlin, hep-ph/0609100, N. Nojiri et al., arXiv:0802.4142 ...
- and many more ...

Back-reaction

Two different effects of UE particles:

1. Add extra p_T^{UE} to p_T^{jet} $\rightarrow$ Cured by **subtraction**
2. **Back-reaction**: UE particles affect the jet clustering of non-UE particles from hard scattering (Sizable effect in HIC)
   Anti-k_T: very small backreaction $\rightarrow$ Suitable for HIC jet finding

