Comparing the Run II Cone Algorithms

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TeV4LHC Workshop, Fermilab, October 2005

- Description of the Run II Cone Algorithms
- Non-Perturbative Effects
- Hadron-Parton Correlation
- Distances between Jets

initial statement

We would not have discussions like this one,

if we were only using the $k_\perp$ algorithm!!

Two Cone Jet Algorithms in Run II

Run II Workshop had proposed the infrared-safe Midpoint Cone Algorithm:

Iterative cone algorithm, using midpoints between jets as additional seeds
three parameters: R_{cone} (jet cone), f_{overlap}, $p_{T\,\text{min}}$ (fractional energy in overlap treatment)

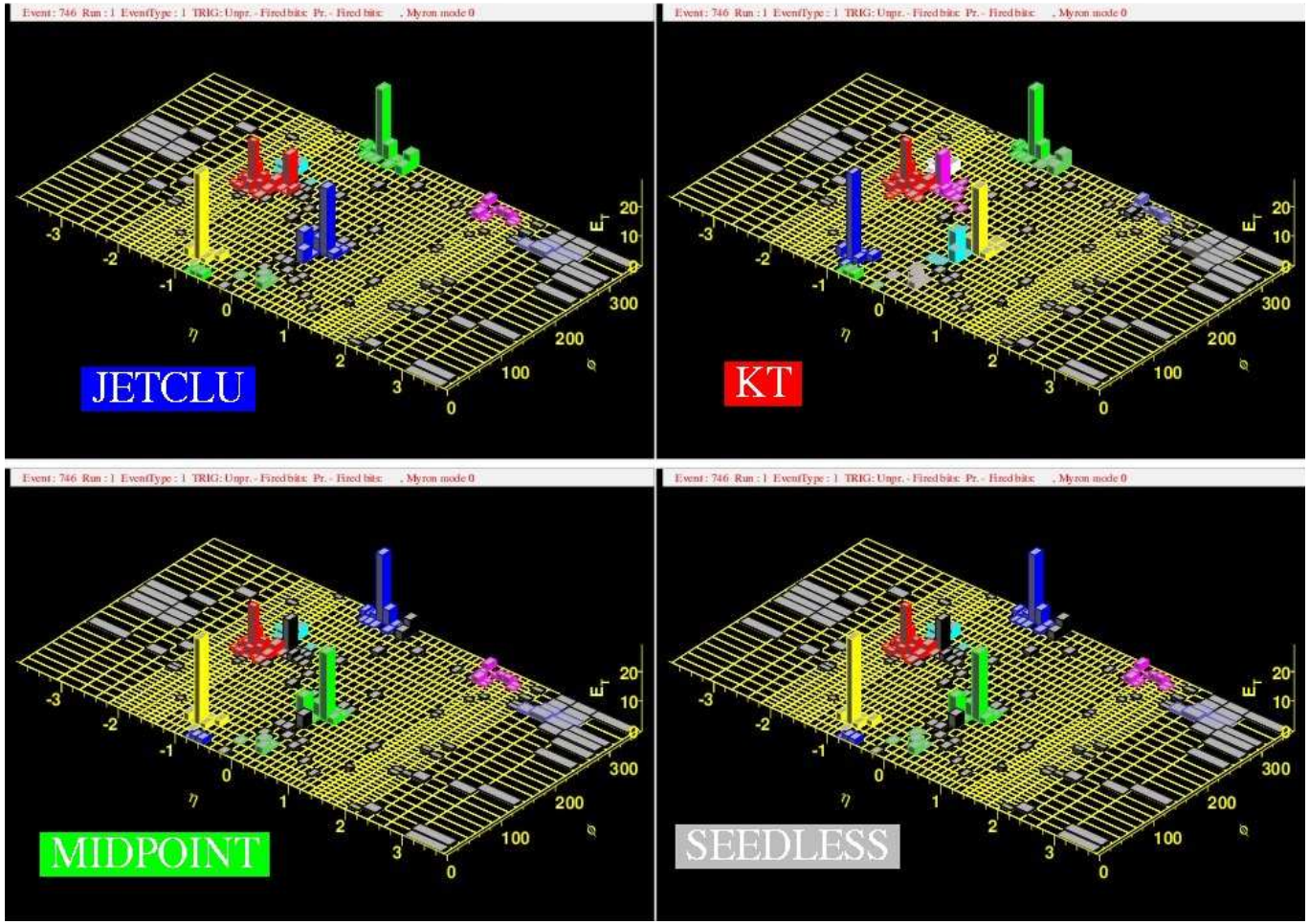
- use every particle as seed:
  – seed specifies cone axis / draw cone with R_{cone} around cone axis
  – define proto-jet fourvector from particle four-vectors (in E-Scheme)
  – use proto-jet axis as new cone axis
  – iterate until jet axis = cone axis
- now use all midpoints between pairs of jets as additional seeds
  $\Rightarrow$ repeat iterative procedure
- Overlap treatment: (only for jets with $p_T > p_{T\,\text{min}}$)
  – if a jet shares more than a fraction f_{overlap} of it's p_T with a higher p_T jet $\longrightarrow$ merge jets
  – if the fractional overlapping p_T is below f_{overlap} $\longrightarrow$ split jets

comments
– usually: jet axis = cone axis — not when overlap treatment is used
– jets are basically defined by iterative procedure – overlap treatment is an exception

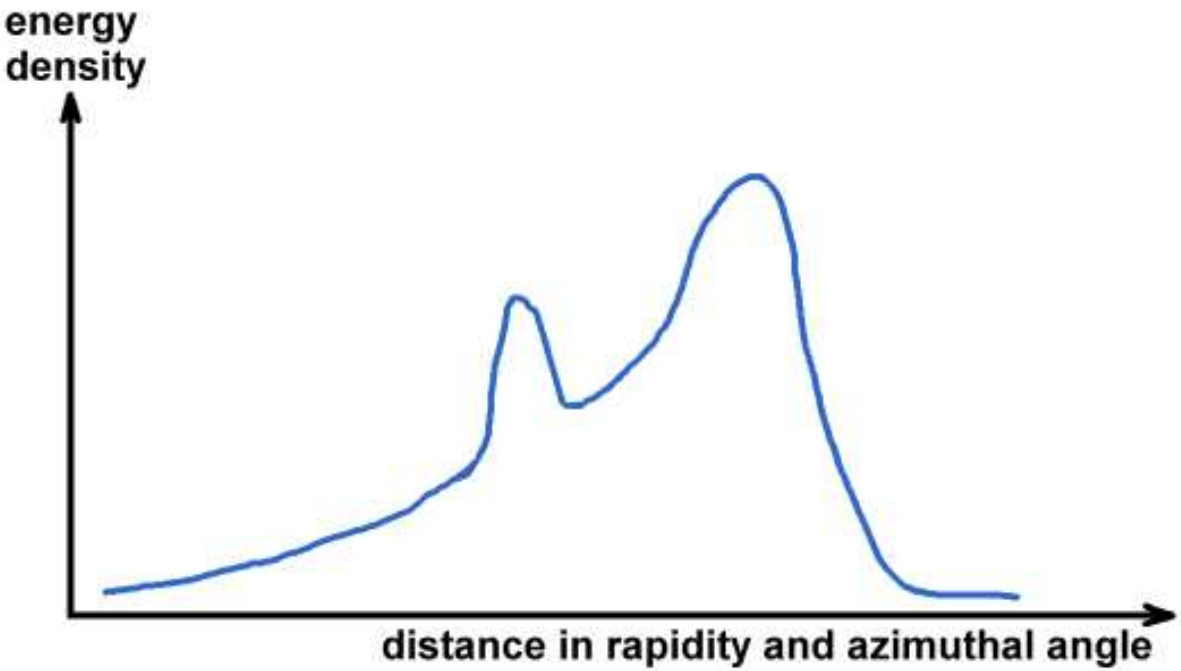
$\Longrightarrow$ Midpoint Algorithm is used by DØ

The Discovery

CDF saw that the midpoint cone algorithm can leave some towers unclustered (“dark towers”)



Feature of Midpoint Cone Algorithm



energy density in an event

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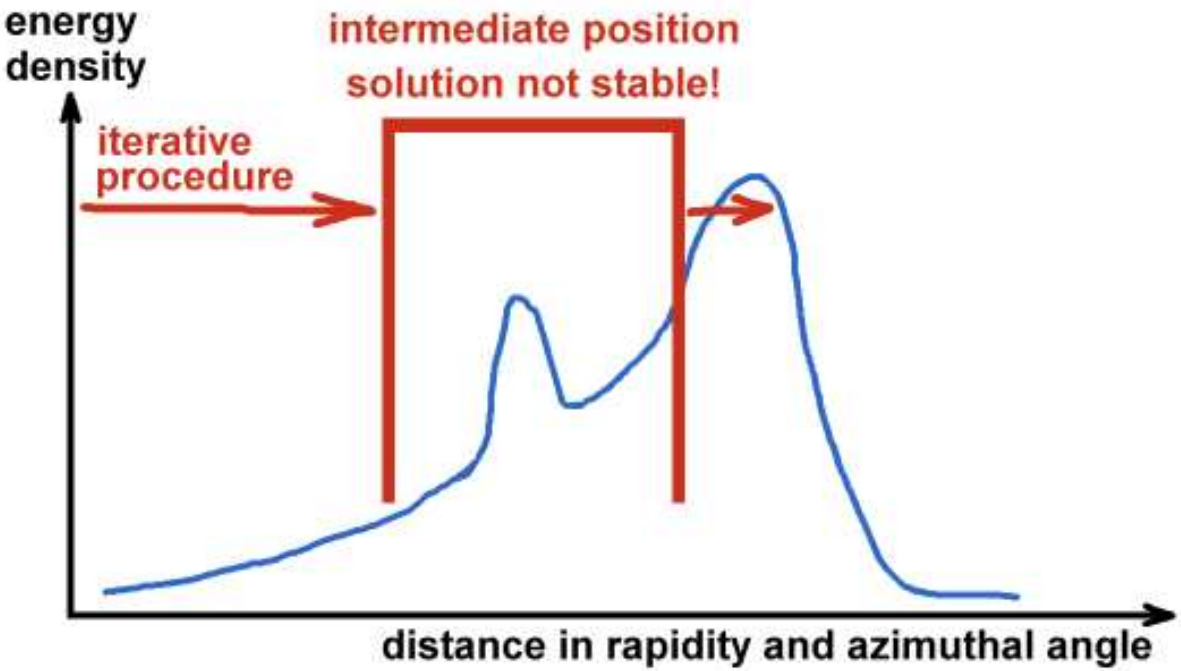
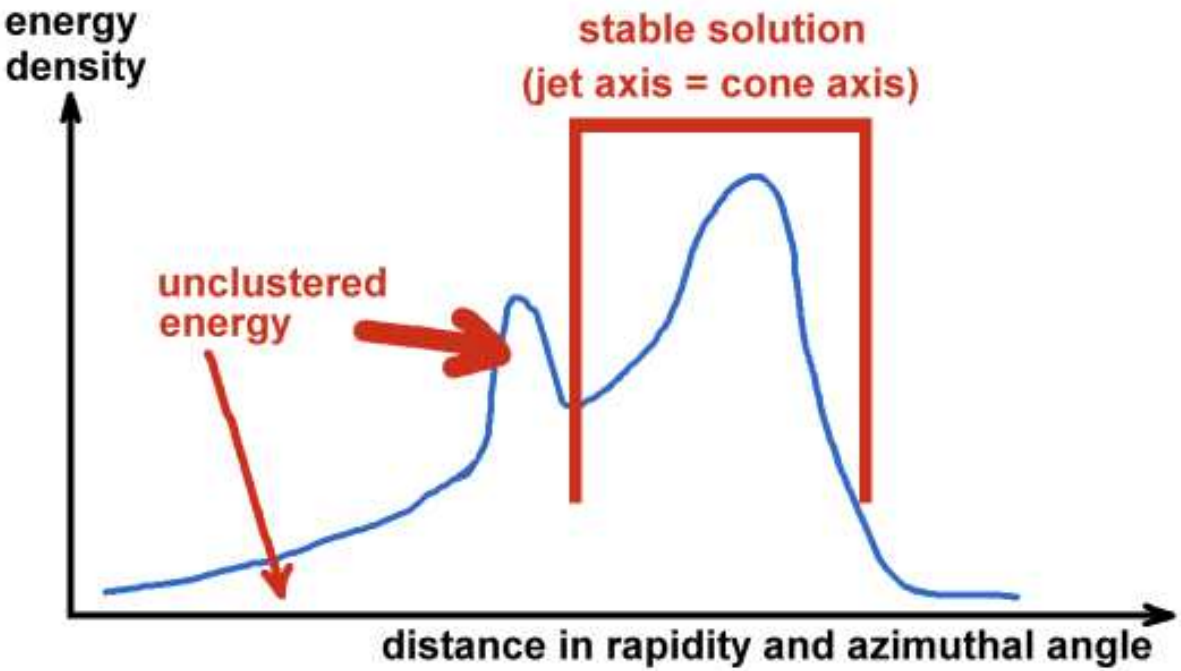


energy density in an event

iterative cone algo ...

Feature of Midpoint Cone Algorithm

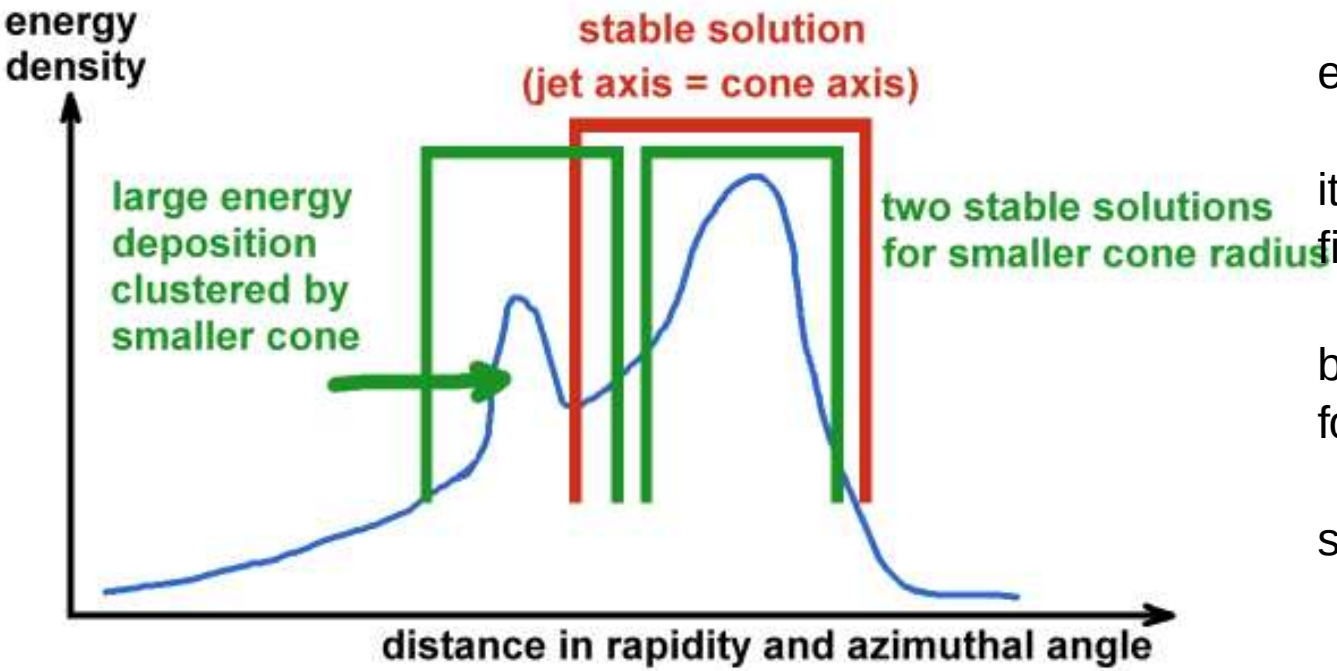


energy density in an event

iterative cone algo ...
finds maximum

but no stable solution
for 2_{nd} local maximum

Feature of Midpoint Cone Algorithm



energy density in an event

iterative cone algo ...
finds maximum

but no stable solution
for 2_{nd} local maximum

smaller cone finds both!

Solution: CDF "searchcone algorithm"

solution proposed: S.D. Ellis, J. Huston, M. Tonnesmann, hep-ph/0111434

- introduce smaller "search cone" in iterative procedure to define jet direction
  $\Rightarrow$ stable jet solutions can be closer

- once a stable solution is found, use the **full** cone radius to define the jet
  $\Rightarrow$ consequence: jet axis $\neq$ cone axis

- "midpoint step" uses full cone radius (otherwise not infrared-safe)
  (this is not correctly described in the first CDF Run II jet publication!! hep-ex/0505013)

- Since initial stable solutions can be closer, overlap treatment is more often needed to define the final jet configuration $\rightarrow$ overlap treament becomes a standard-procedure

- overlap treatment may merge many nearby jets
  $\Rightarrow$ this results in merged jets with huge spacial extension (CDF: "fat jets")
  $\rightarrow$ way out: increase f_{overlap} parameter from 0.5 to 0.75
  $\Rightarrow$ largely overlapping jets are still counted separately

$\Longrightarrow$ Searchcone Algorithm is used by CDF (confusingly also called "Midpoint Algorithm")

The Situation

... as before in Run I:

CDF and DØ are using different jet algorithms!!!!

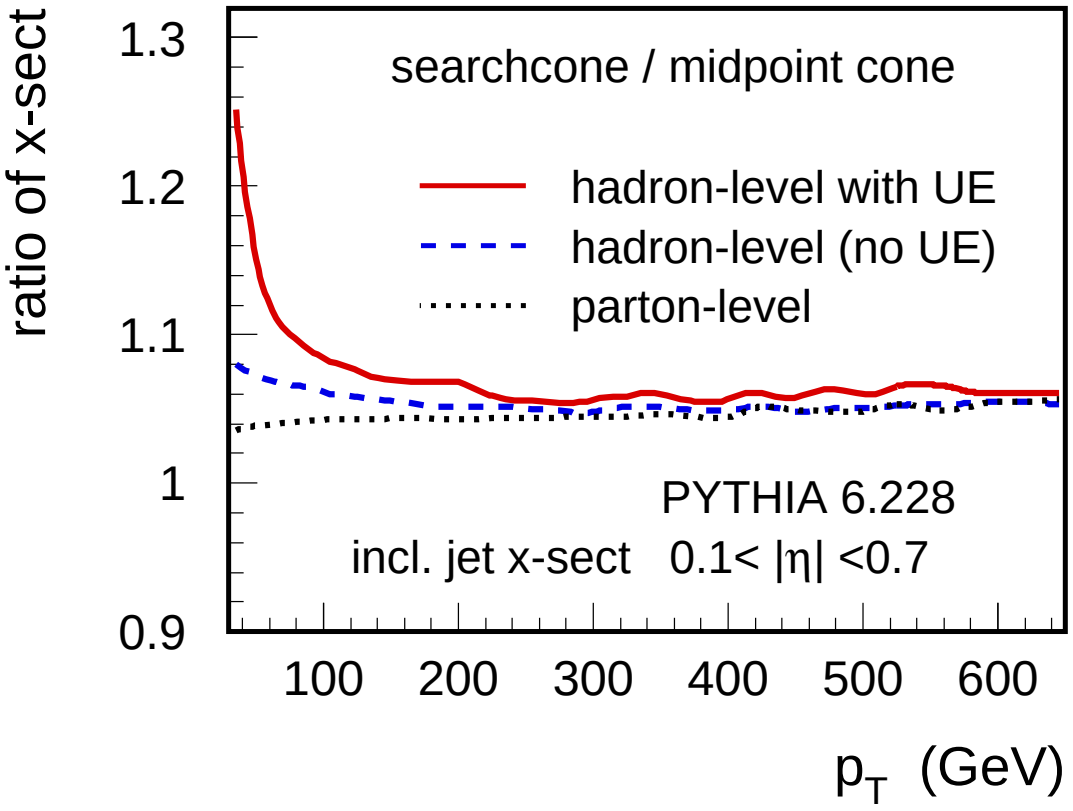
- obvious difference: clustering of “dark towers”
  (not essential for QCD jets – see talk by Zdenek Hubacek at the TeV4LHC CERN meeting)

- this talk: try to compare properties of the algorithms to judge which one is ’better’
  – non-perturbative effects
  – hadron-parton correlation
  – distances between jets

Direct Comparison of the two Algorithms

ratio of cross sections for both algorithms at sqrt(s)=1960 GeV

- on full MC simulation
  incl. underlying event
- on hadron-level
  (but w/o underlying event)
- on parton level

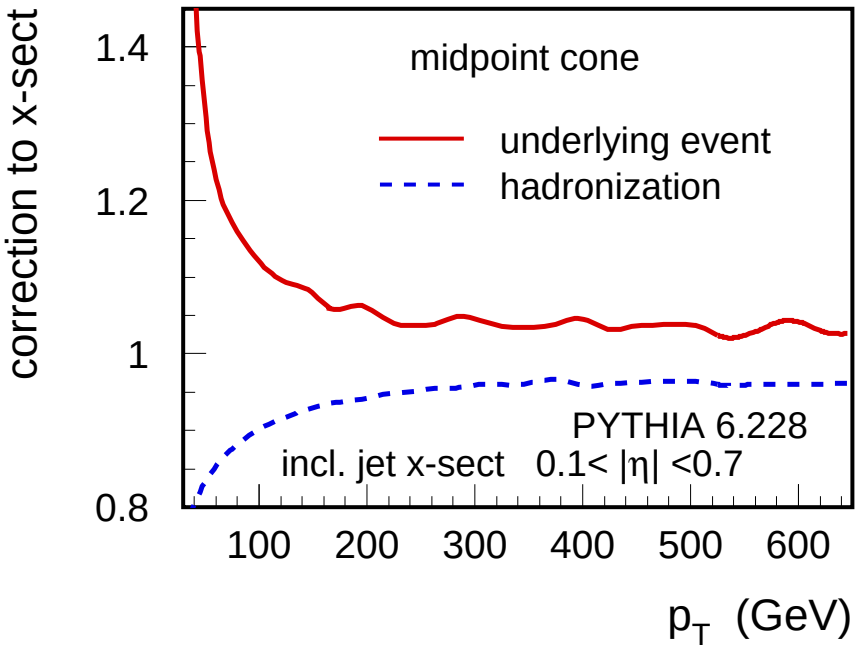


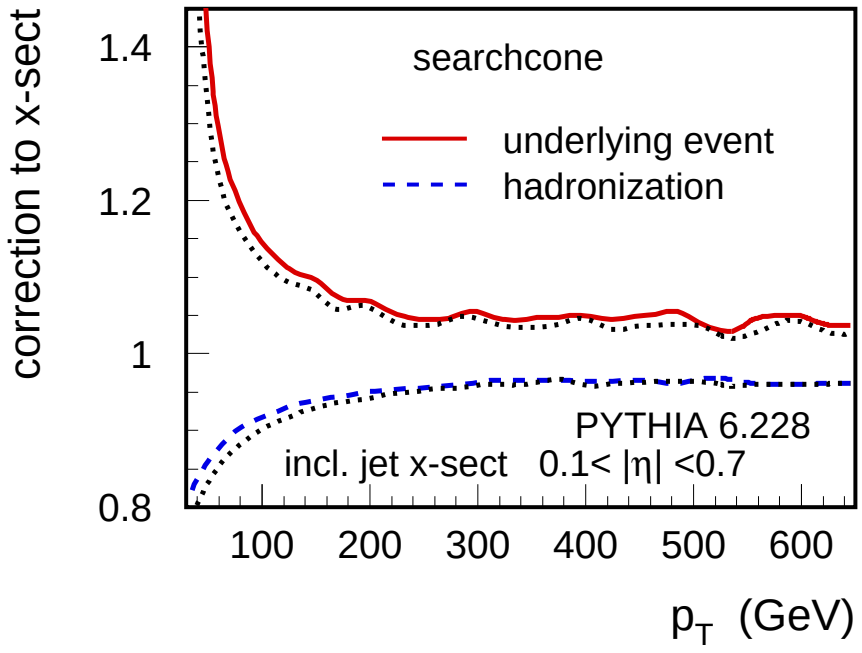
similar on parton-level but large differences in 'real-world'

$\Rightarrow$ ... but at high p_T: agreement within 6% !!

Non-Perturbative Effects

study separately: hadronization and underlying event correction for both algorithms





similar corrections – searchcone more sensitive to UE

but not relevant at high p_T (results are consistent with plots from CDF QCD webpage)

$\Rightarrow$ higher cross section for searchcone is caused by slightly lower hadronization correction and slightly larger underlying event effects

Details of Comparison

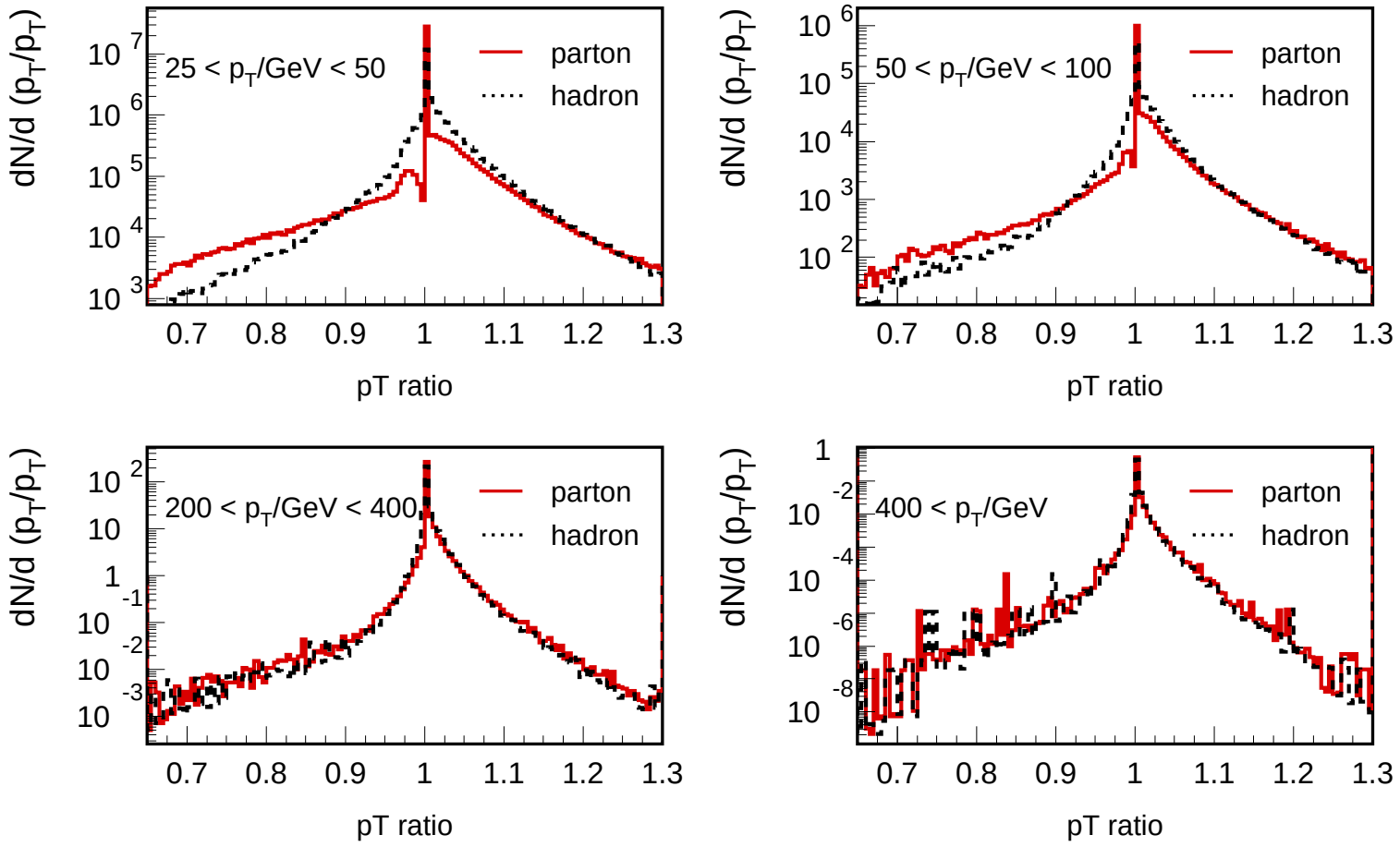
event-by-event:

- leading jet pT (between algorithms, and parton vs. hadron) — as a function of p_T
- distances between jets (between algos, and parton vs. hadron) as function of p_T and z
- use five p_T bins: $25 - 50 - 100 - 200 - 400 - 960$ GeV
- use PYTHIA 6.228 w/ tune A

here: no restriction on jet rapidity! $\longrightarrow$ dominated by central region

Compare Leading Jet p_T: Searchcone vs. Midpoint

event-by-event: plot ratio p_T-searchcone over p_T-midpoint for leading jet



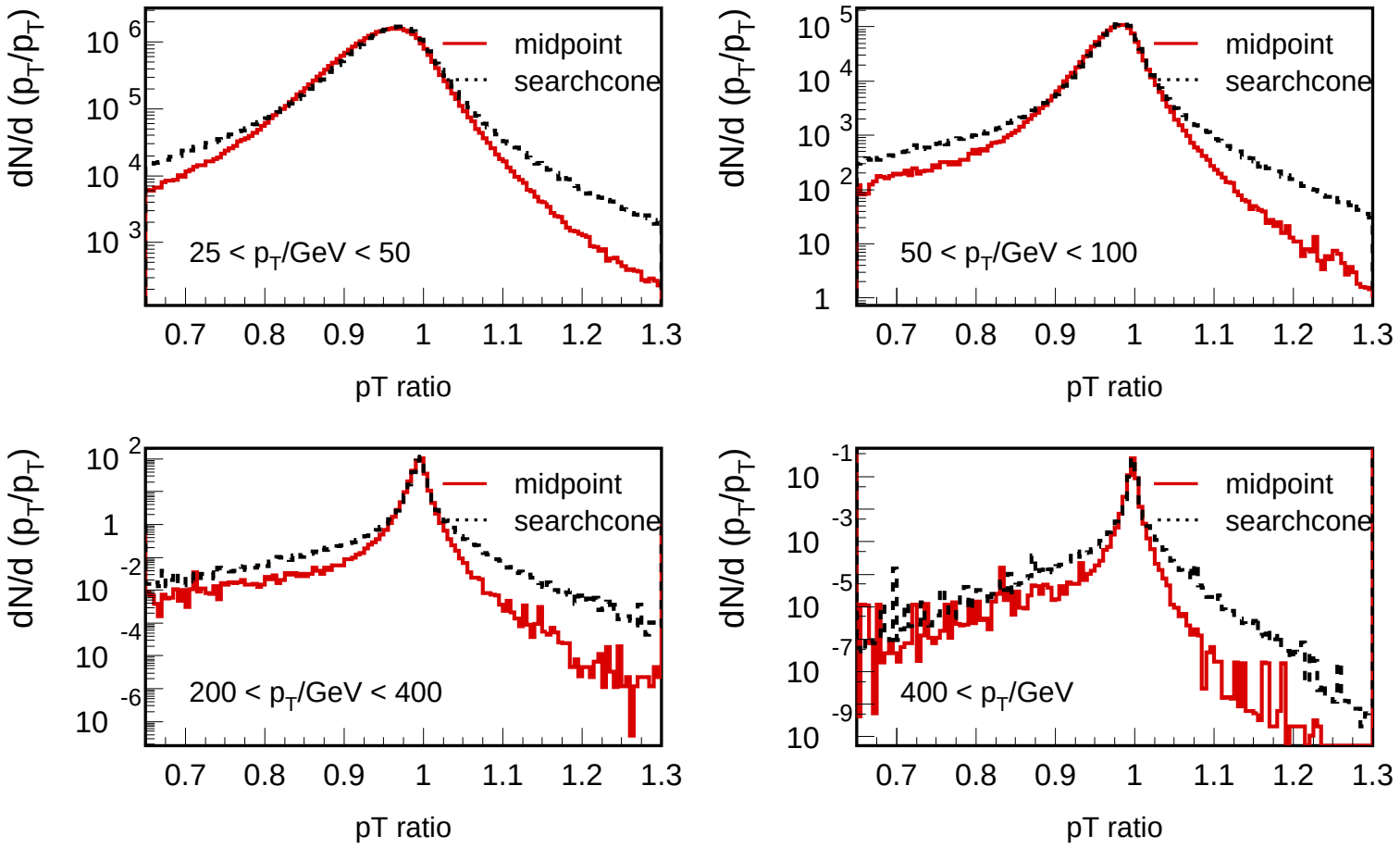
⇒ both algorithms agree better with each other on parton-level than on hadron-level

⇒ interesting feature: dip at 0.98–1.0 at low p_T – on parton-level only

⇒ not symmetric – tail to larger values for searchcone

Compare Leading Jet p_T: Hadron vs. Parton-Level

event-by-event: plot ratio p_T-hadron-jet over p_T-parton-jet for leading jet



⇒ better correlation between hadron- and parton-level p_T for midpoint algorithm

⇒ only at lowest p_T: ratio is slightly broader for midpoint (but also here: smaller tails)

Distances between Jets

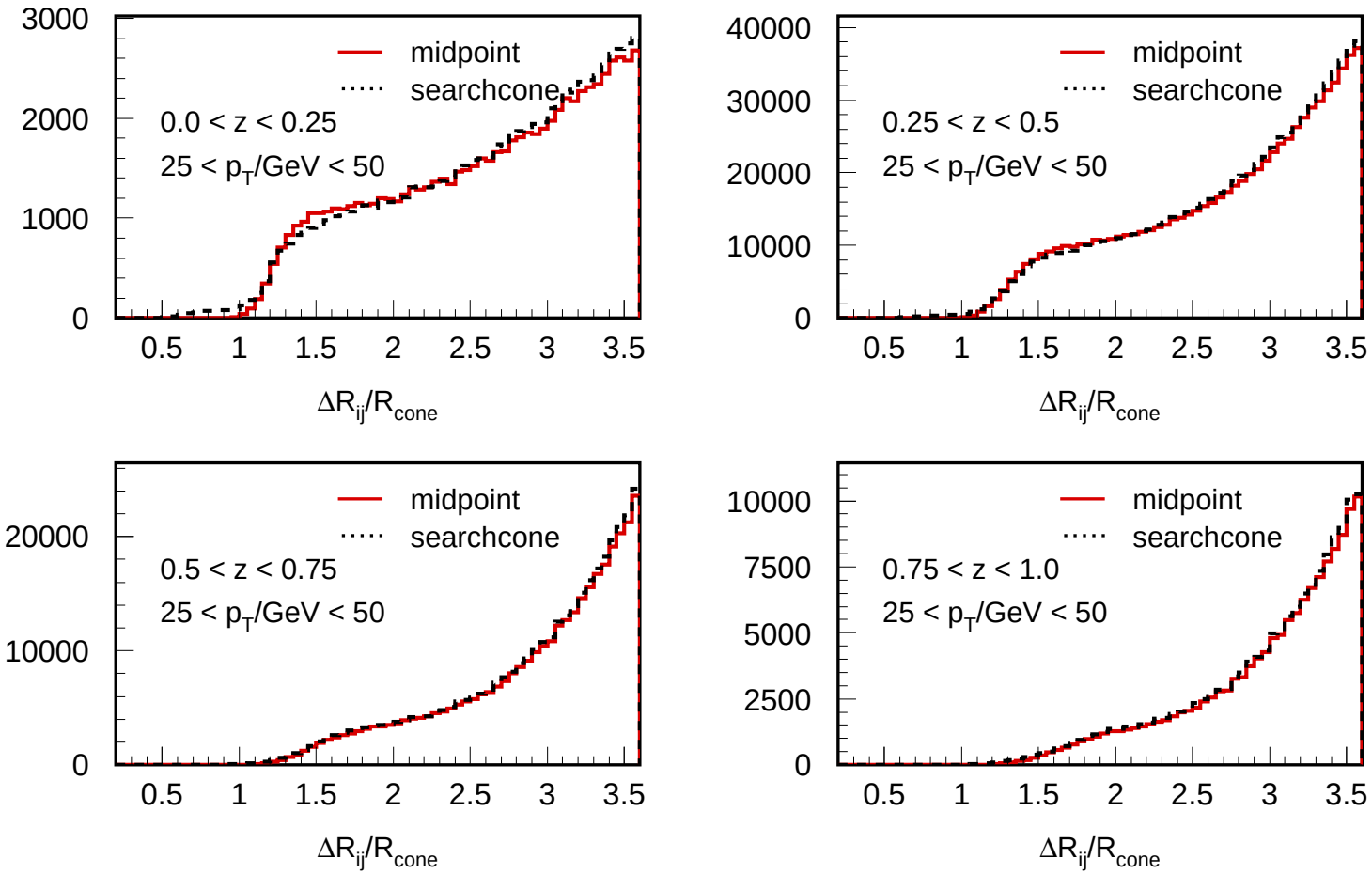
- pQCD picture:
  investigate the transition where a hard gluon emission is resolved as a separate jet
  $\Rightarrow$ defined by resolution parameter of the jet algorithm

- in the 'experiment':
  for every jet: plot the distances to all other jets with lower p_T

- as a function of p_T (of the higher p_T jet)
  $\rightarrow$ in five p_T bins $25 - 50 - 100 - 200 - 400 - 960$ GeV

- in addition:
  as a function of $z = p_{T\,\text{low}}/p_{T\,\text{high}}$
  $\rightarrow$ in four regions of z: $0.0 - 0.25 - 0.5 - 0.75 - 1.0$
  Motivation: compare later with pQCD LO/NLO predictions (R_{sep} parameter studies)

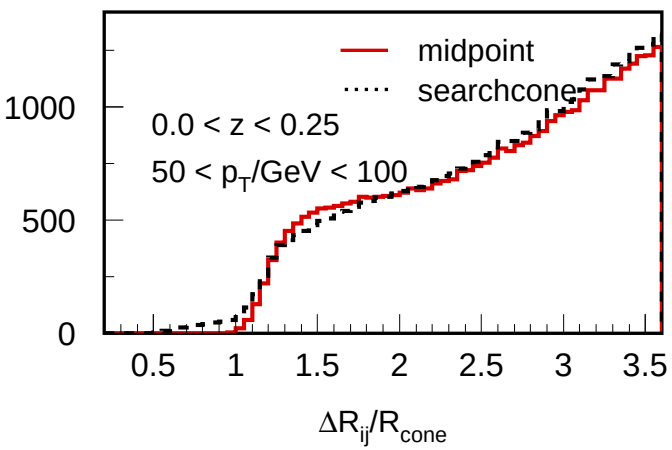
Distances between Parton-Jets (1)

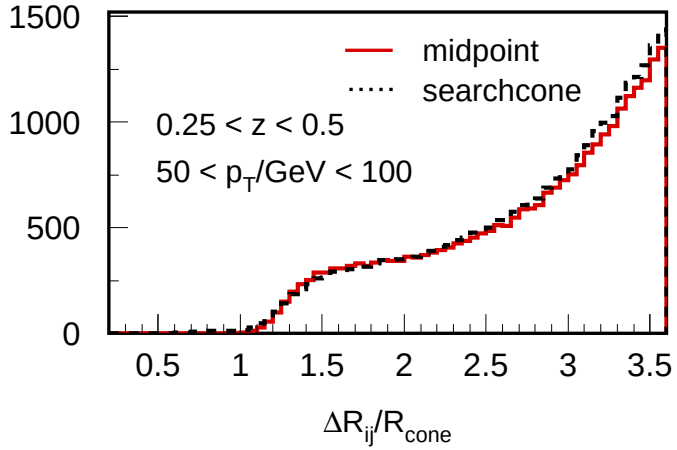


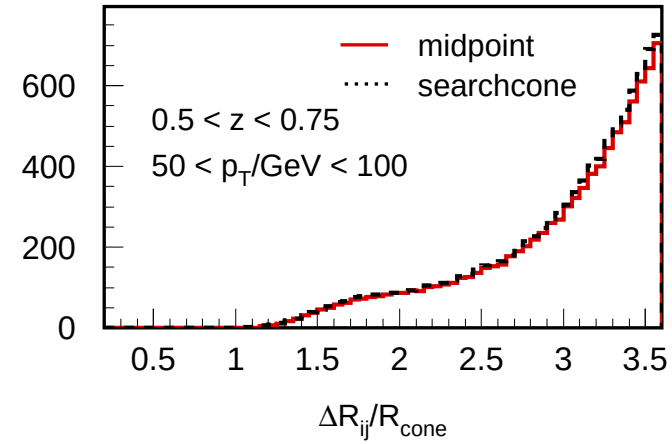
⇒ similar distributions for both algorithms

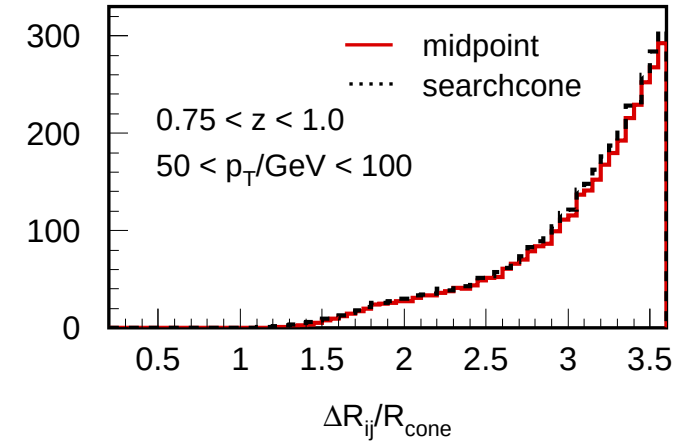
⇒ but at low z, the searchcone has a suspicious tail towards small ΔR (down to $R_{\text{cone}}/2$)

Distances between Parton-Jets (2)









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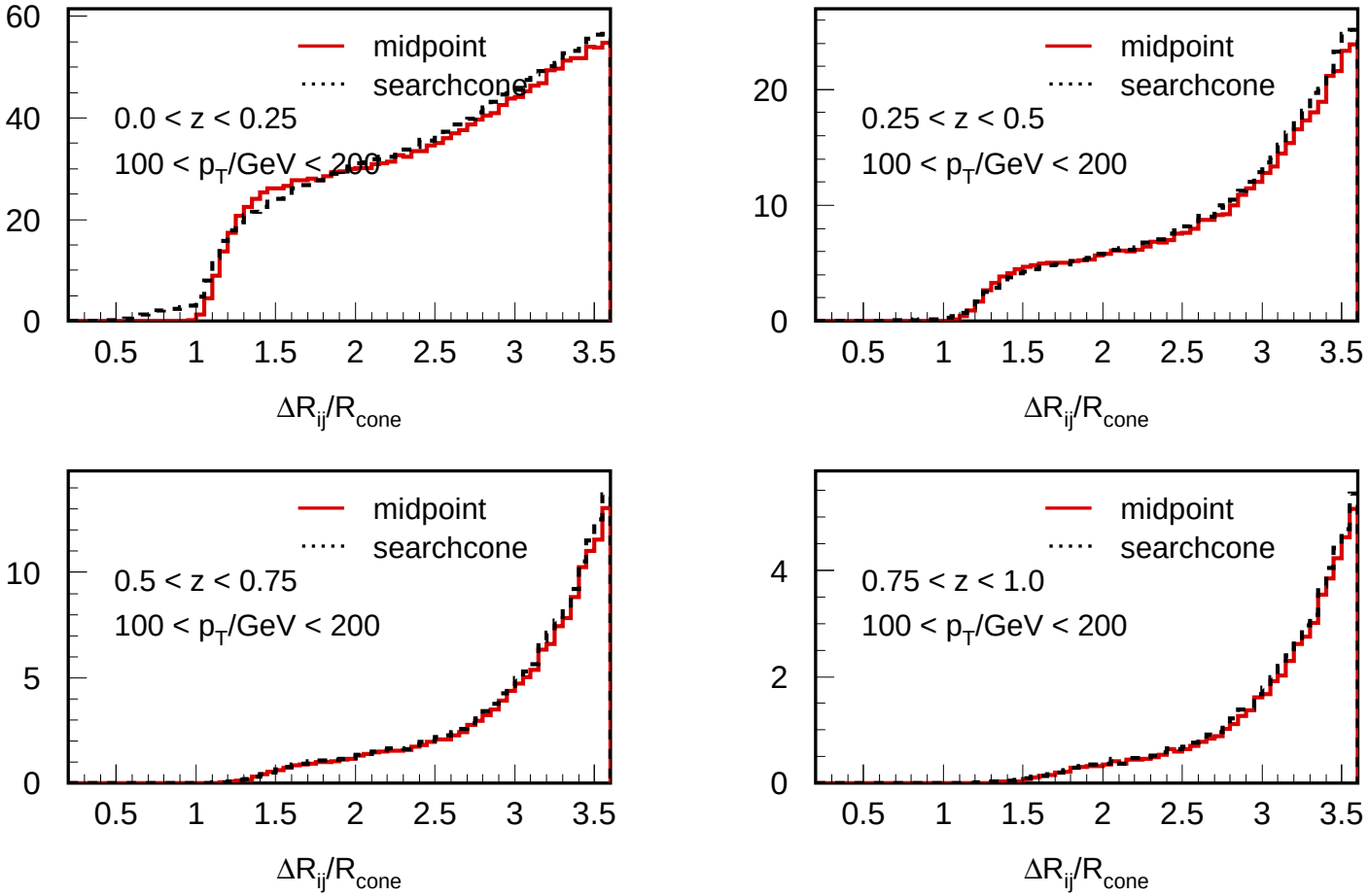

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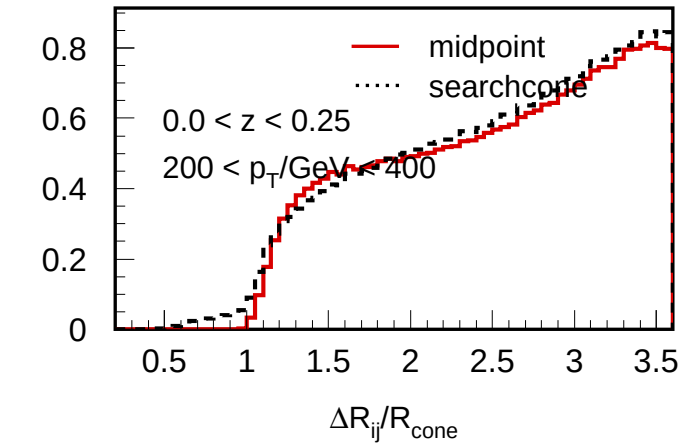

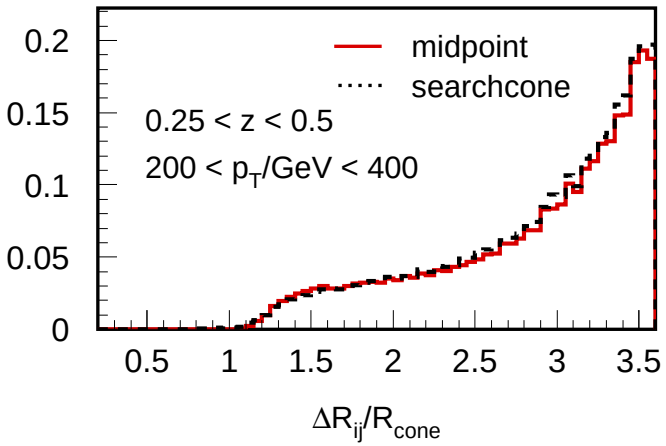

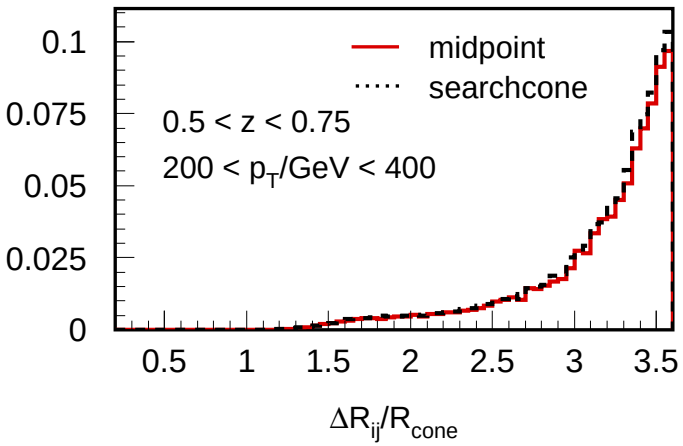

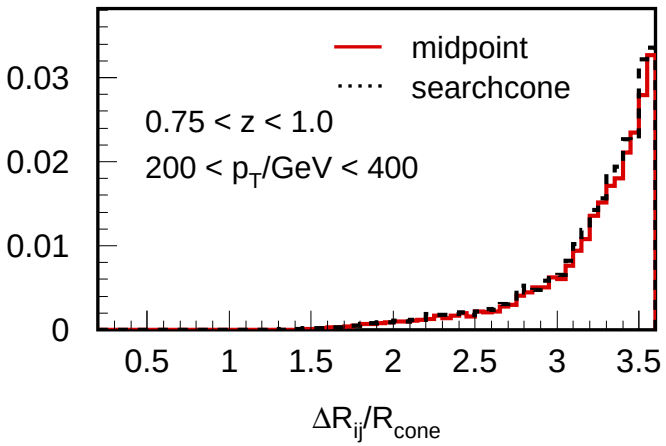

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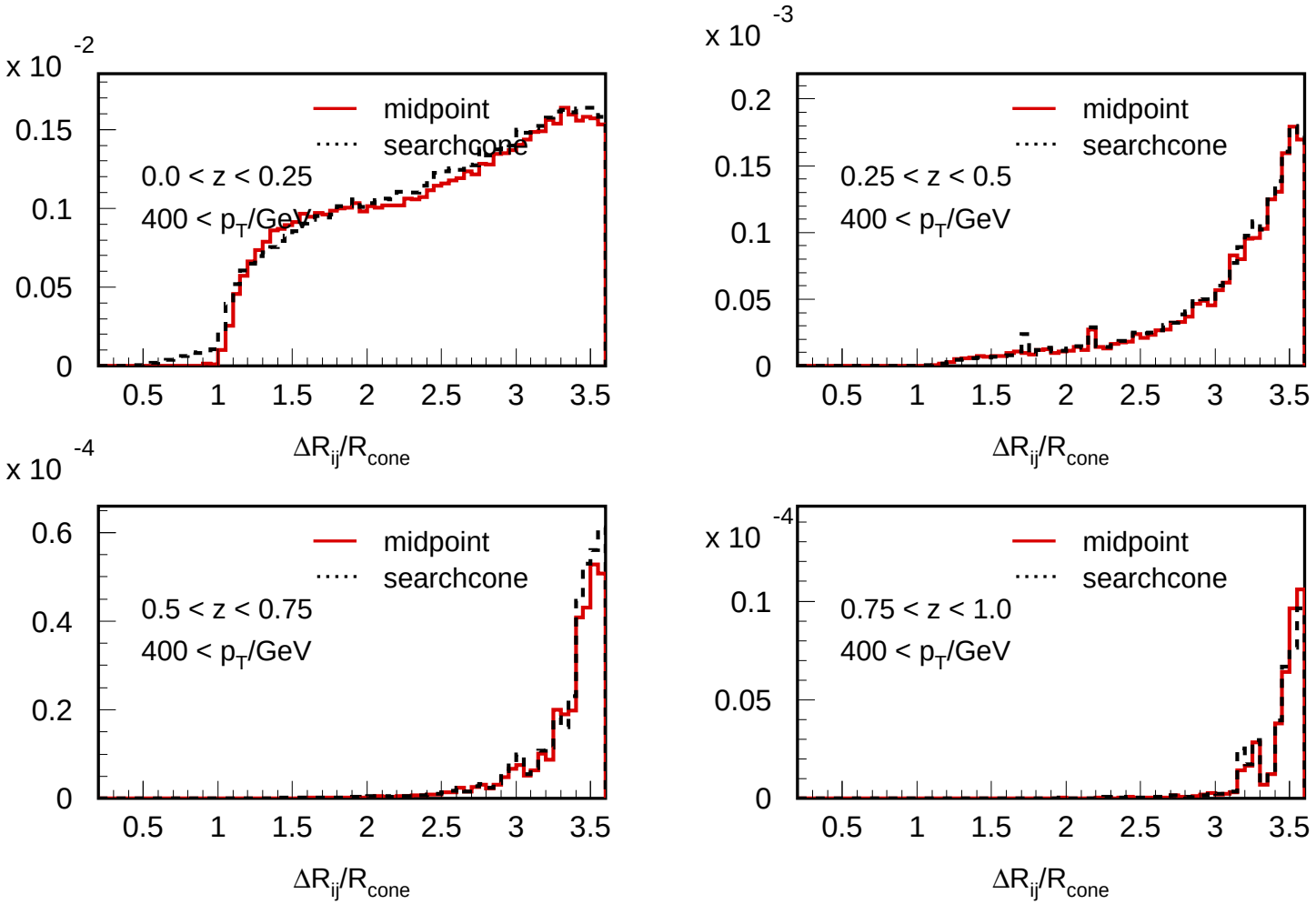

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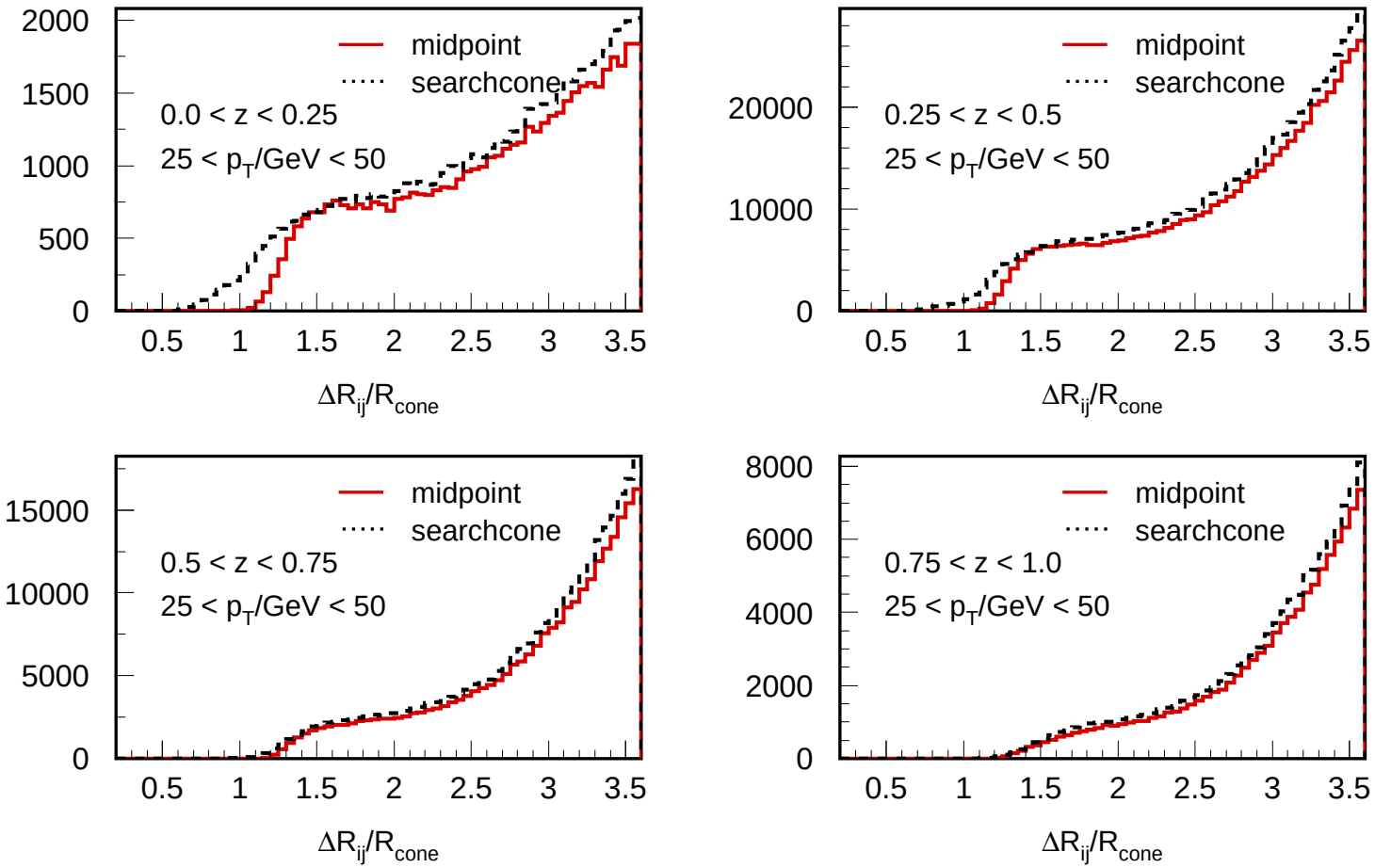

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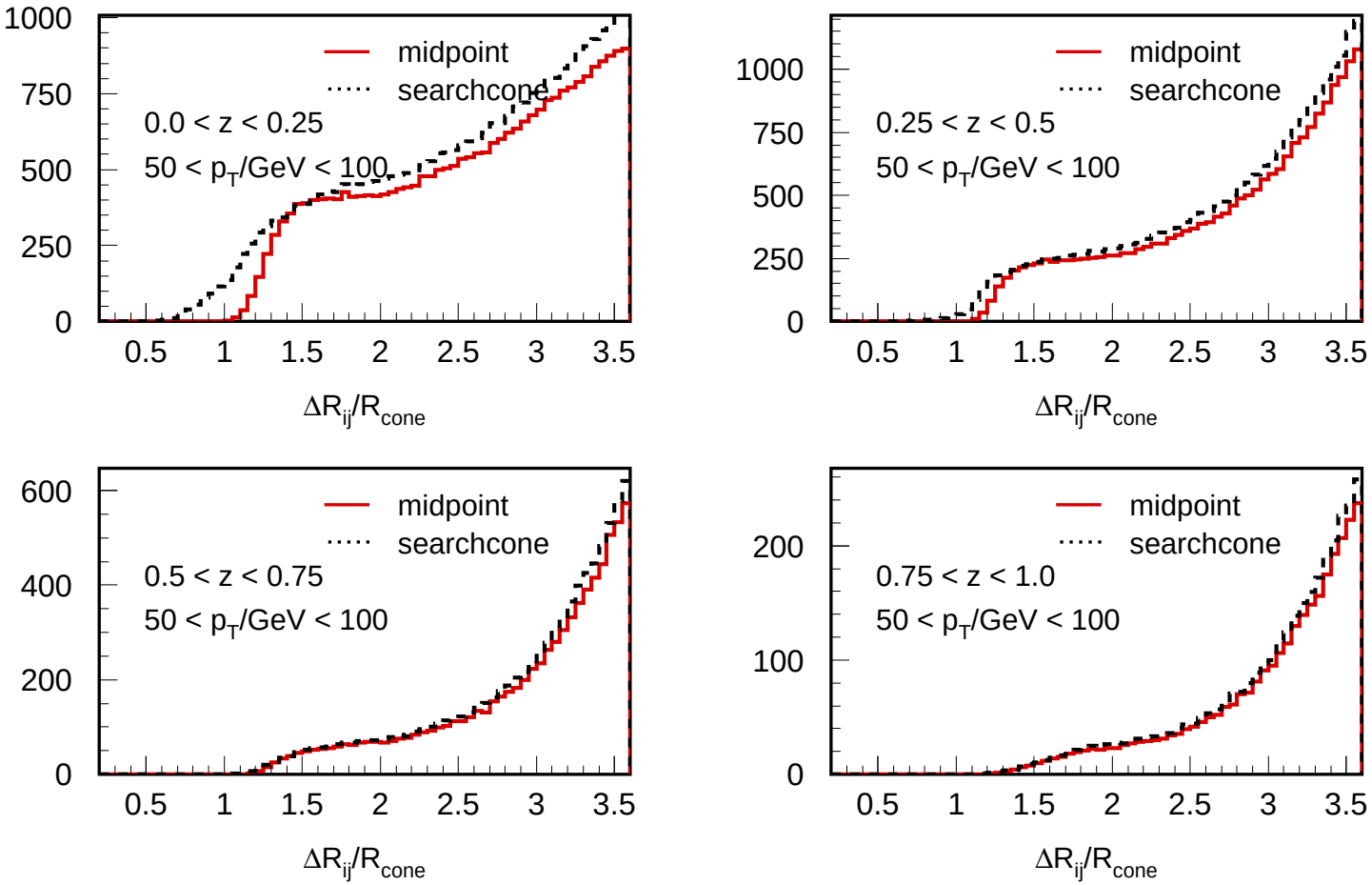
⇒ but at low and medium z, the searchcone has a significant tail towards small ΔR (down to $R_{\text{cone}}/2$)

Distances between Hadron-Jets (2)



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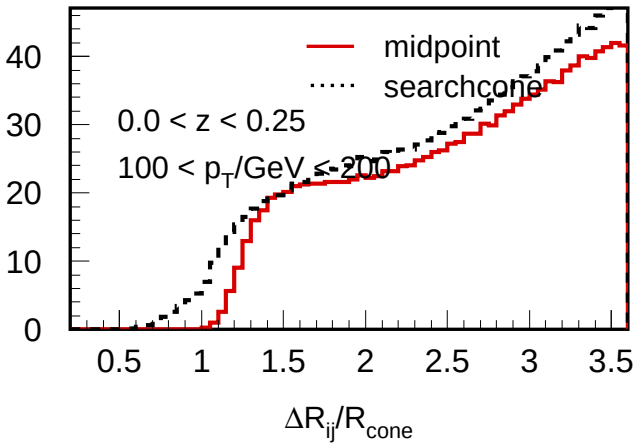

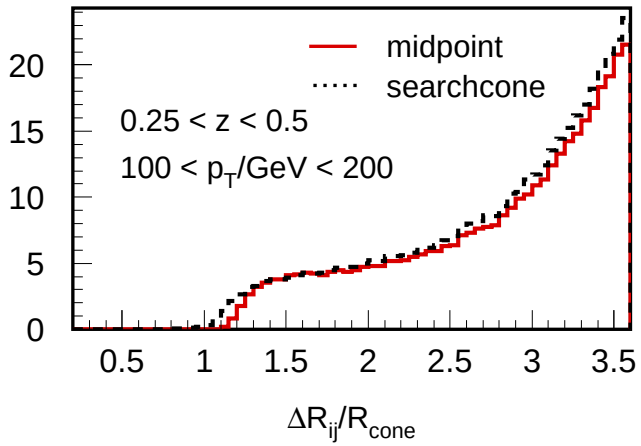

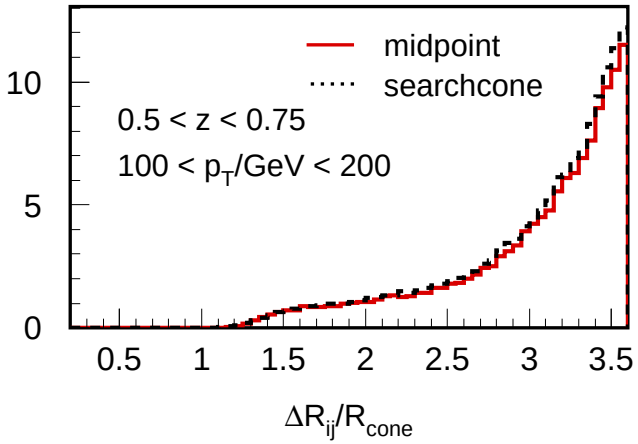

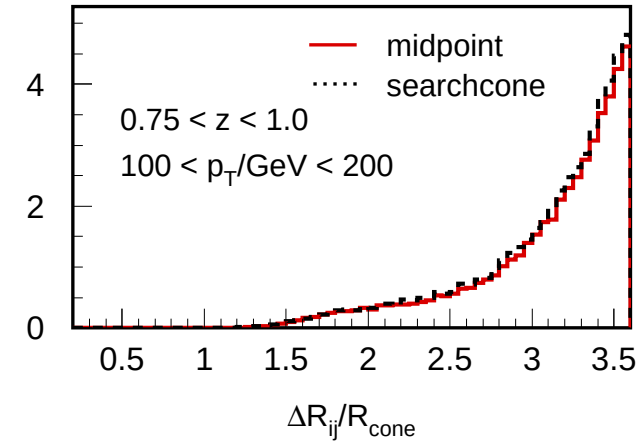

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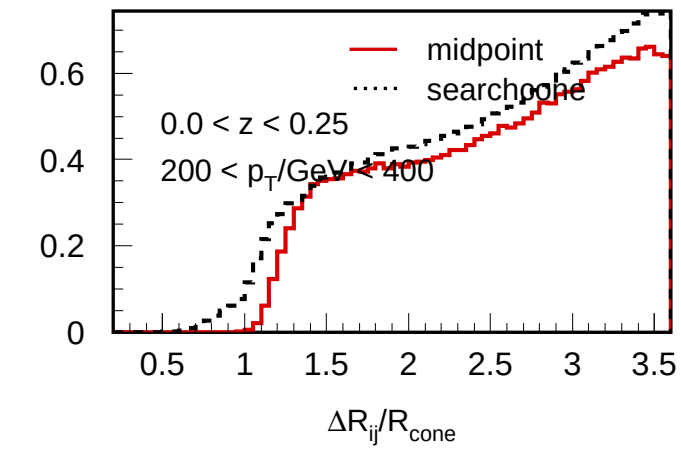

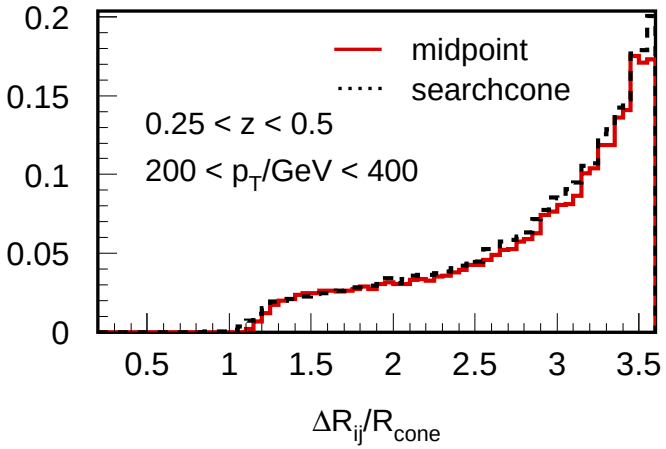

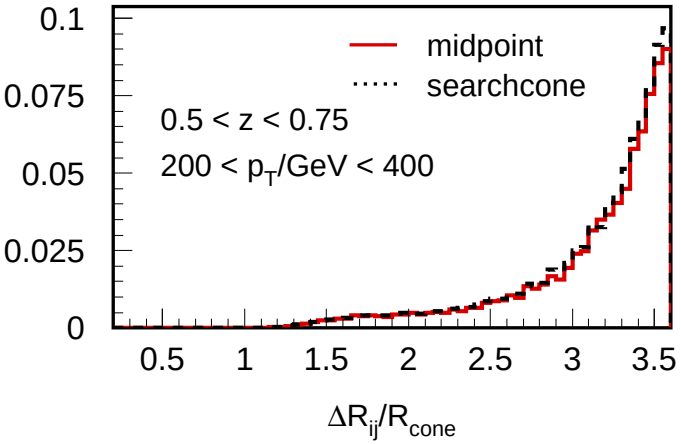

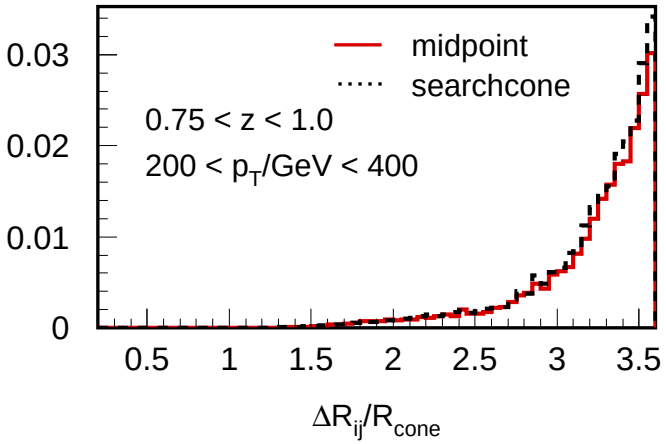

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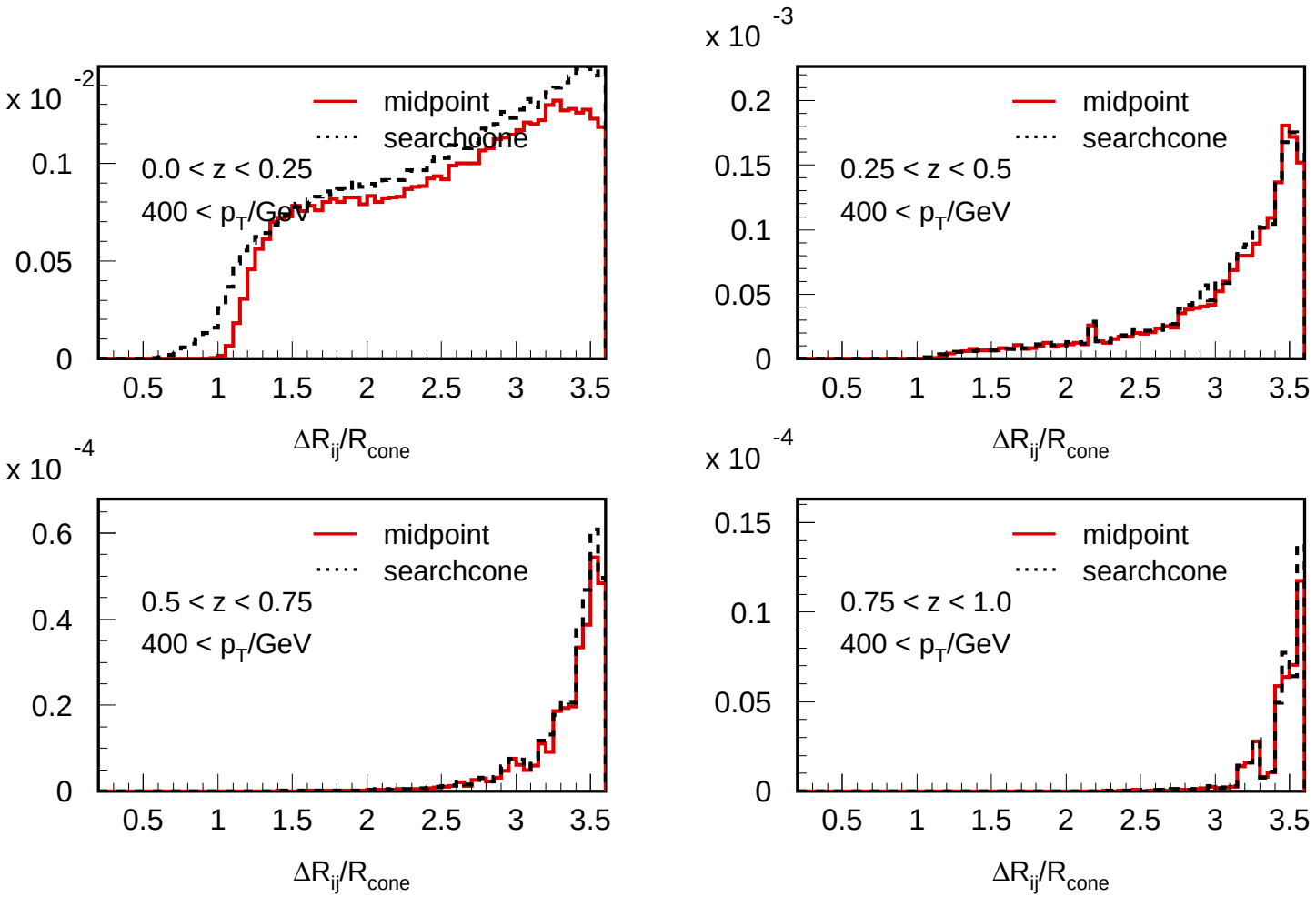

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Summary

- searchcone has slightly larger cross section – three contributions:
  (1) 6% higher on parton-level – in parton-shower MC! – (at NLO identical)
  (2) slightly smaller (negative) hadronization corrections
  (3) slightly larger (positive) underlying event corrections
  $\Rightarrow$ at high p_T only (1) is relevant

- comparison of leading jet p_T between algorithms:
  – on parton-level: strong peak at one – both algorithms are most of the time identical
  – on hadron-level: peak at one – but searchcone has more often a higher p_T

- comparison of leading jet p_T between hadron- and parton-jets:
  better correlation in p_T between hadron- and parton-level jets for midpoint algorithm

- distances between jets:
  midpoint algorithm has a natural transition at $\Delta R = R_{\text{cone}}$
  searchcone has no clear transition between jets at the cone radius
  – it allows jets to be resolved even if $\Delta R = R_{\text{cone}}/2$
  – this effect is very different on parton- and hadron-level

Conclusion

- In most aspects studied the searchcone algorithm is slightly worse than the midpoint algorithm – and sometimes it is not intuitive ($\rightarrow$ jet-jet separation)

- However, for QCD jet cross sections the consequences are very small
  $\Rightarrow$ only 6% difference between the inclusive jet cross sections for both algorithms

- But beware: The effect may be much larger for multi-jet production!!
  3-jet, 4-jet – when the jet-jet separation is more critical – not been studied so far!

- Totally unrealistic to assume that either CDF or DØ would change
  to the other algorithm during Run II

- The difference of 6% is not a huge effect (same as luminosity uncertainty)

- But important to settle this issue for the LHC experiments!!

last statement

We would not have discussions like this one,

if we were only using the $k_\perp$ algorithm!!

- very important goal for the LHC experiments!!