

JET SUBSTRUCTURE OBSERVABLES WITH DYNAMICAL GROOMING

Alba Soto-Ontoso, CNFS postdoc since Oct 2018

[Yacine Mehtar-Tani, ASO, Konrad Tywoniuk, arXiv:1911.00375]

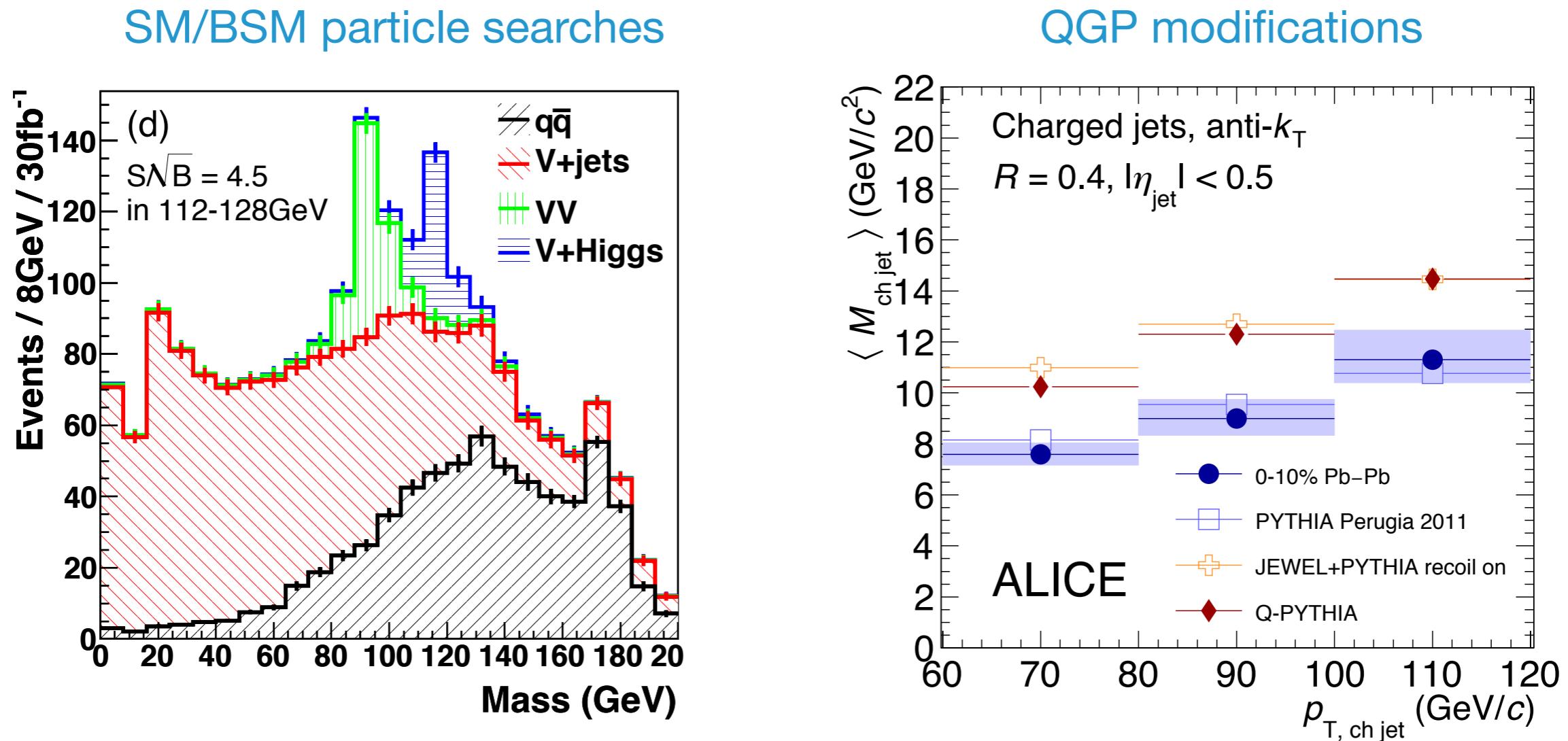
CFNS annual review

BNL, 5th December, 2019



Jet substructure's golden age

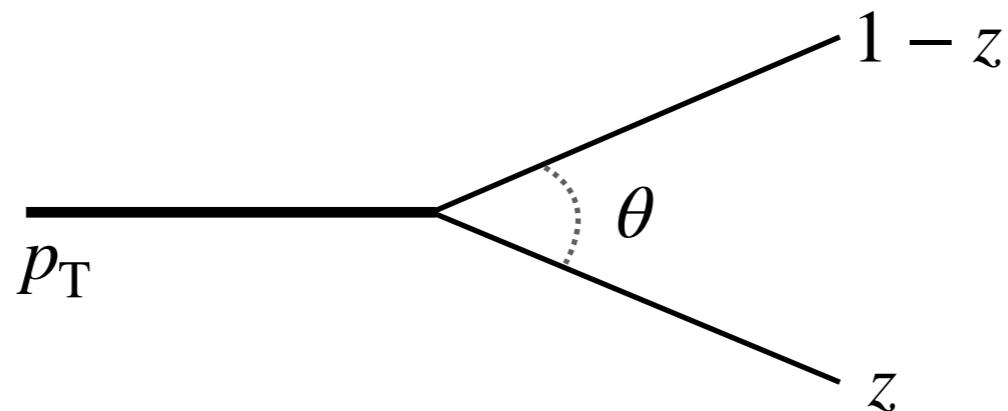
From a semantic point of view e.g. trimming, pruning, grooming, filtering...



At the EIC? [See Kolja Kauder's talk]

Building block of a QCD shower

Generic $1 \rightarrow 2$ (on-shell) splitting in QCD:

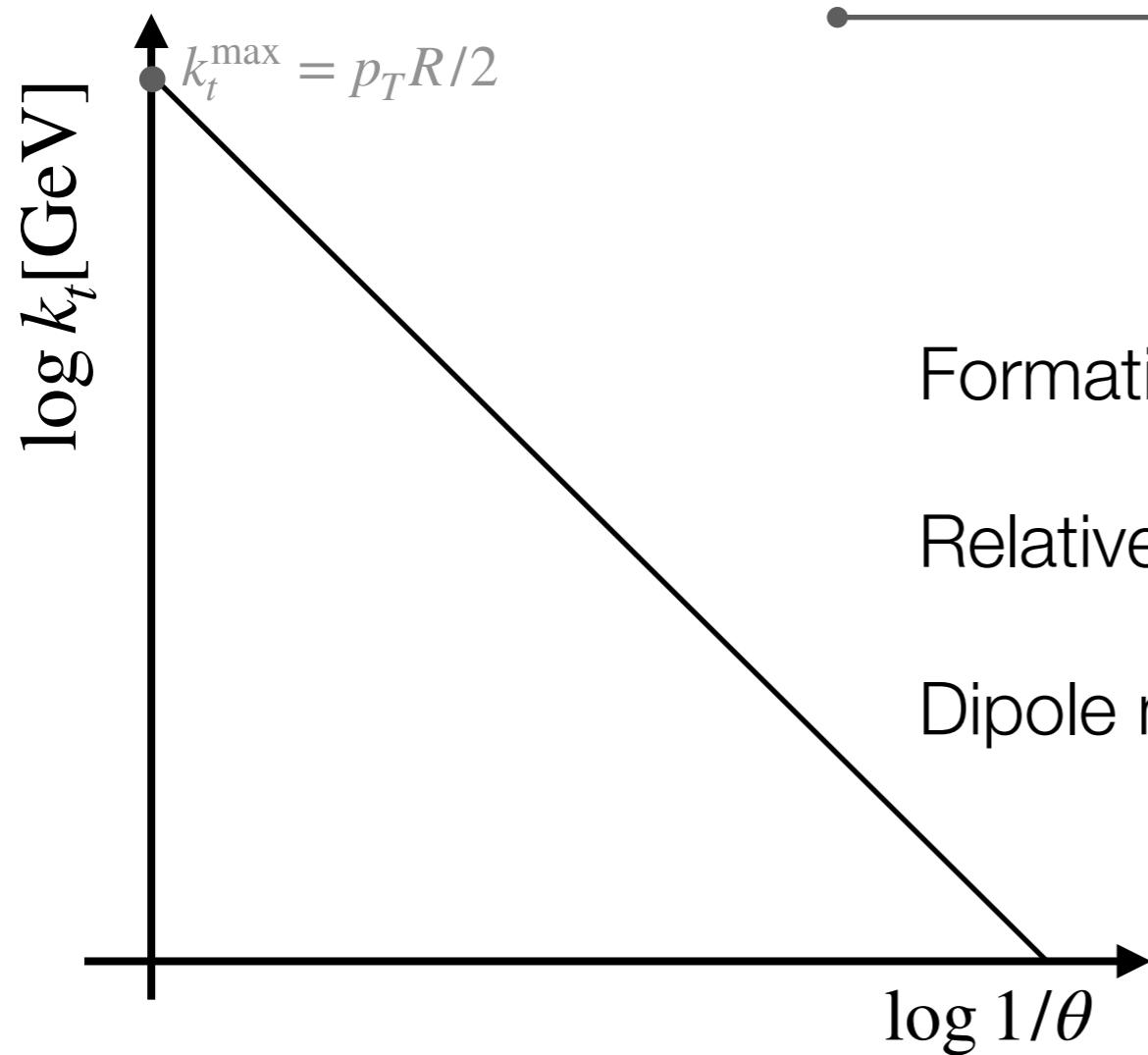


$$d\Pi_{a \rightarrow bc} = \frac{\alpha_s}{\pi} \frac{d\theta}{\theta} P_{ba}^{(c)}(z) dz \approx \frac{2\alpha_s C_R}{\pi} \frac{d\theta}{\theta} \frac{dz}{z}$$

Self-similar subsequent emissions (modulo running coupling) follow angular ordering as due to color coherence

Space-time picture of a jet

[Andersson, Gustafson, Lönnblad, Pettersson Z.Phys.C (1989)]



Formation time \sim splitting time $t_f = \frac{2z(1-z)p_T}{k_t^2}$

Relative transverse momentum $k_t = z(1-z)\theta p_T$

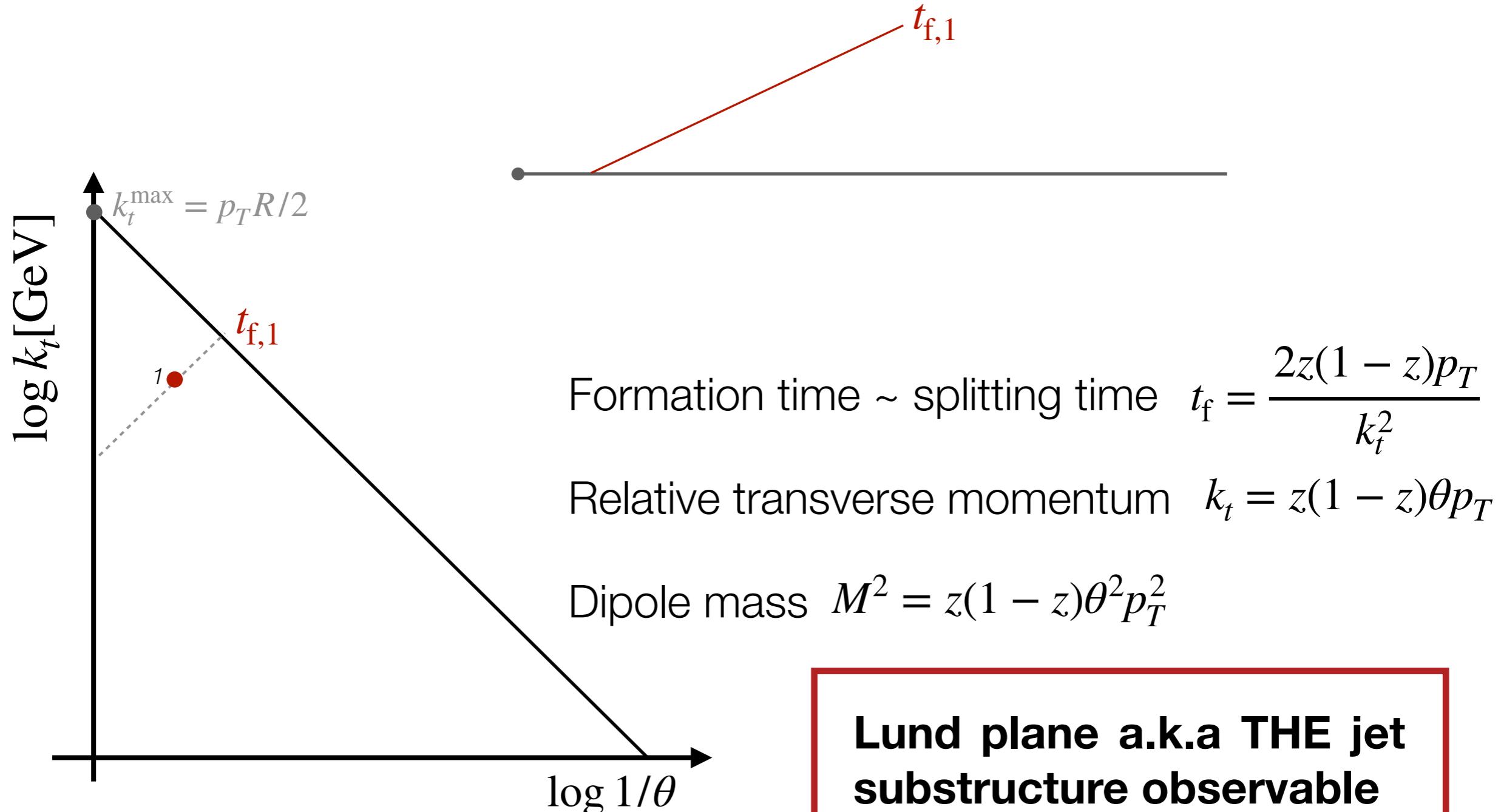
Dipole mass $M^2 = z(1-z)\theta^2 p_T^2$

Lund plane a.k.a THE jet substructure observable

Courtesy of K.Tytoniuk

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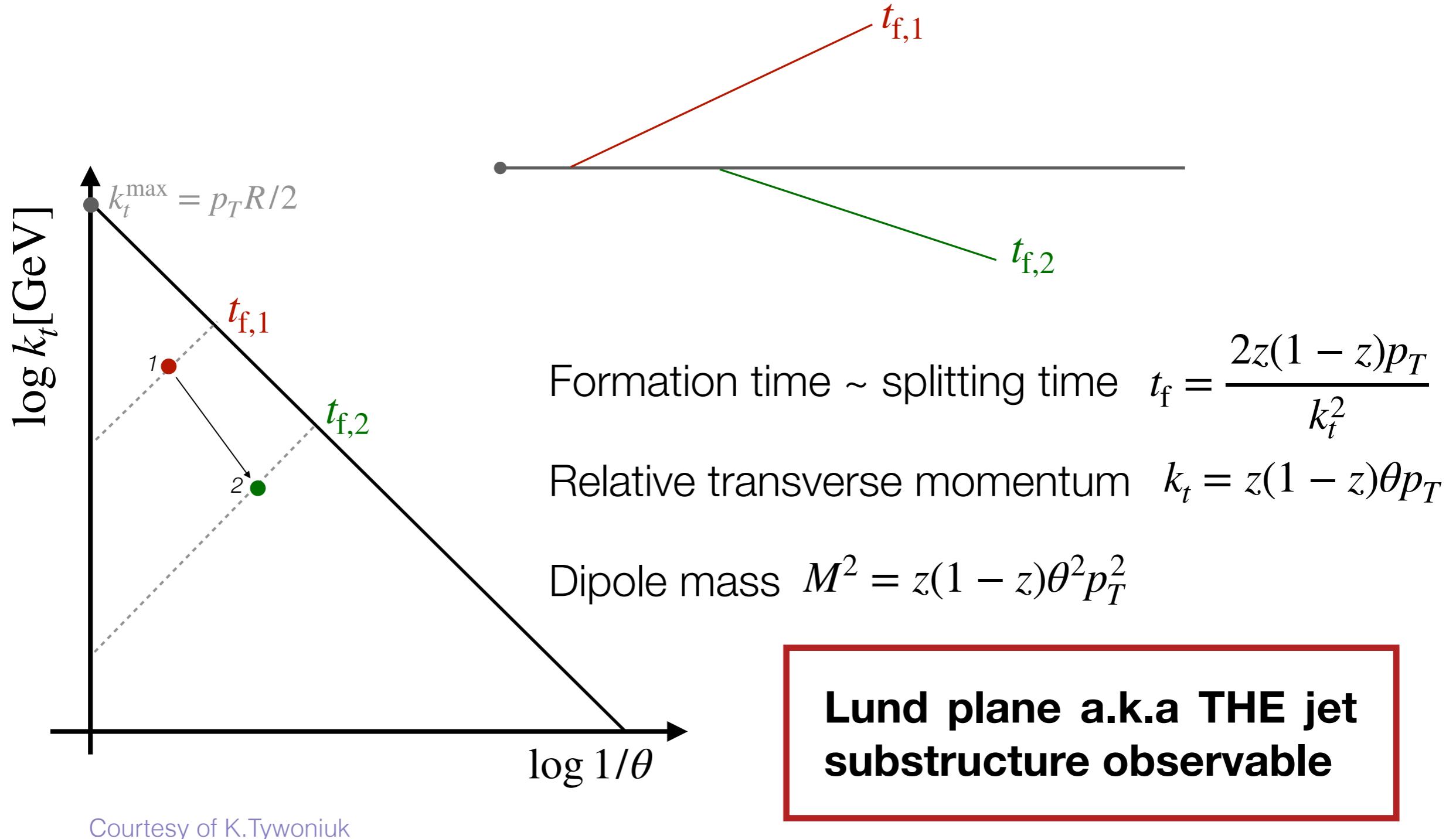
[Andersson, Gustafson, Lönnblad, Pettersson Z.Phys.C (1989)]



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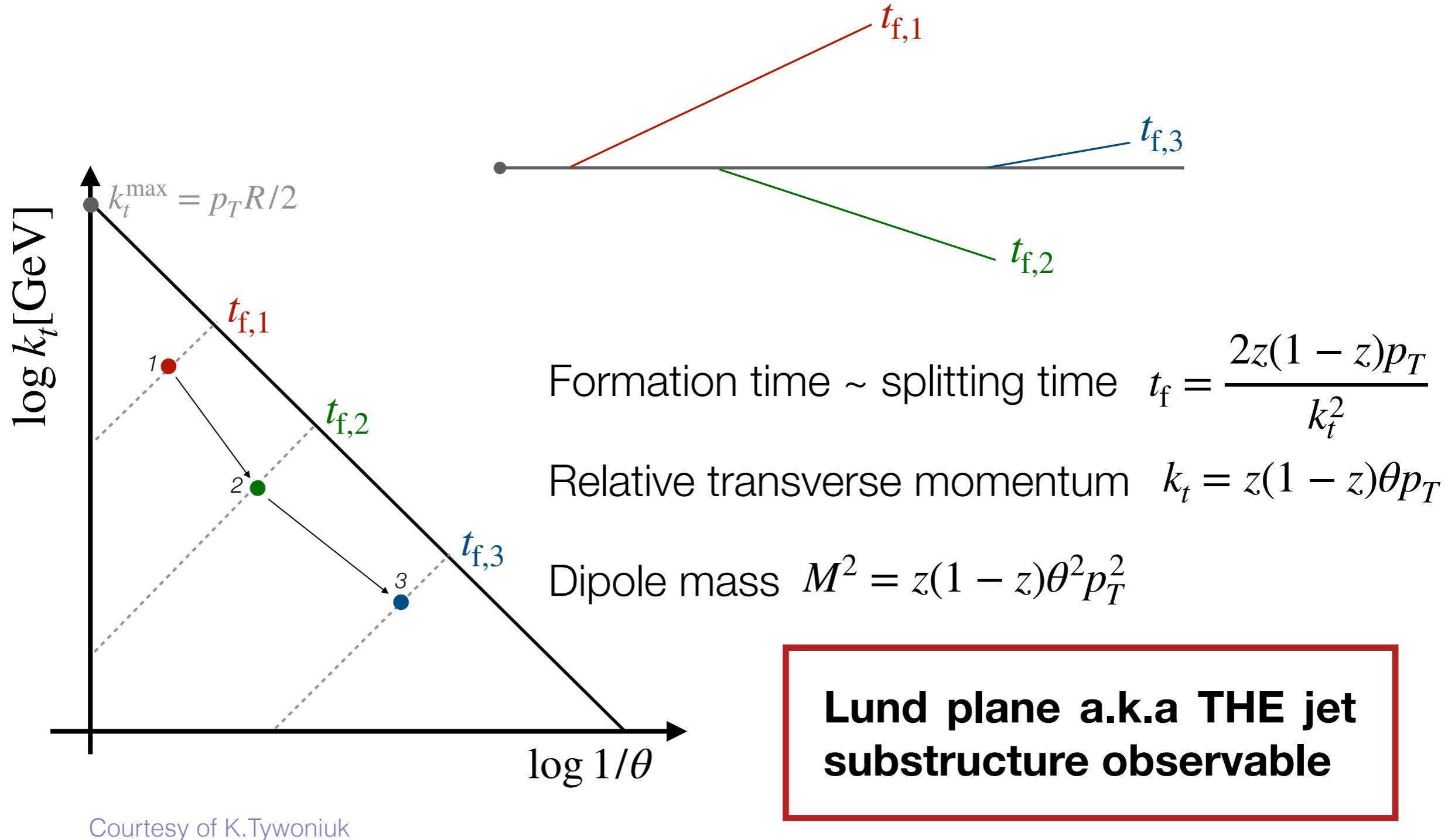
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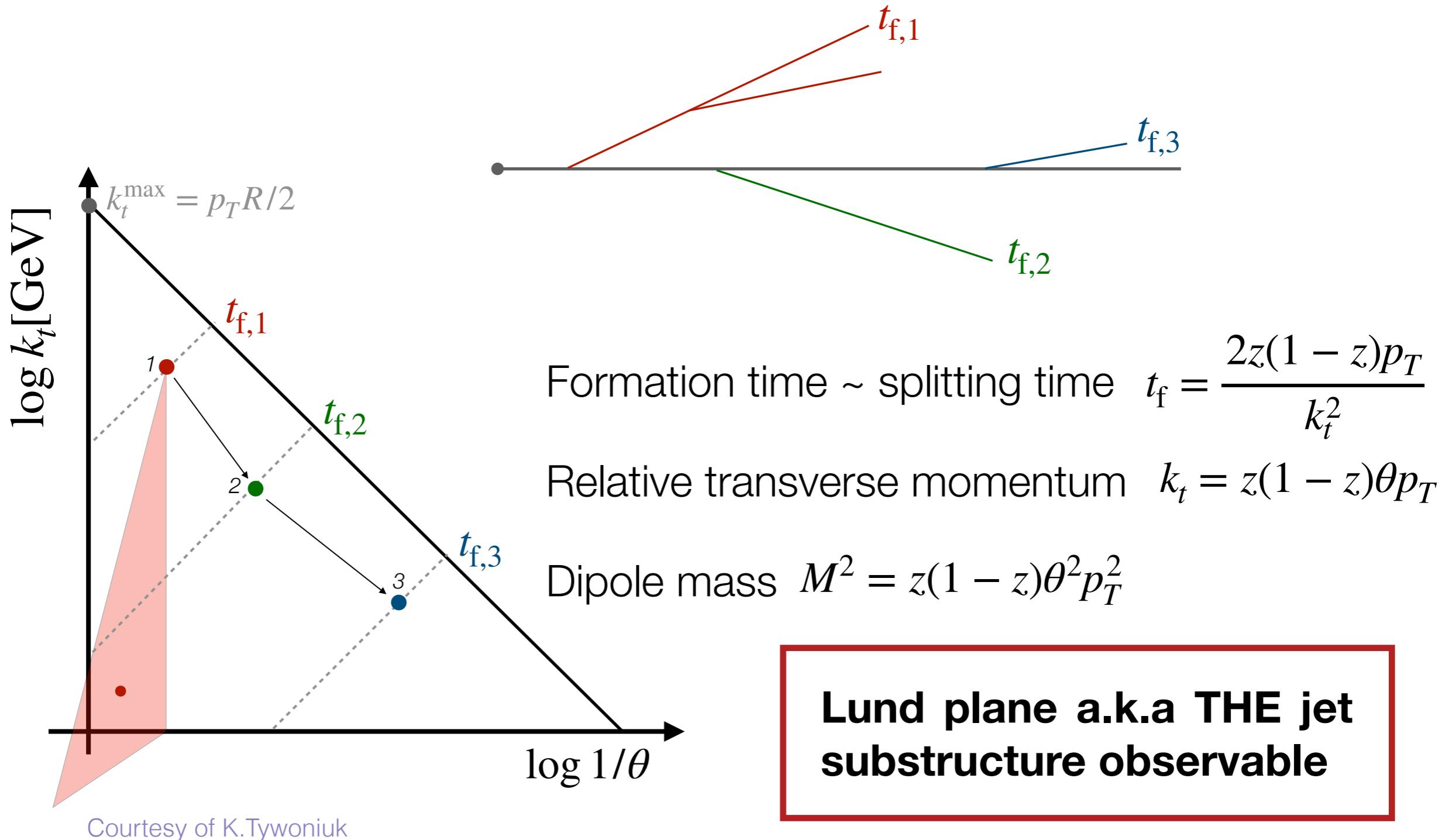
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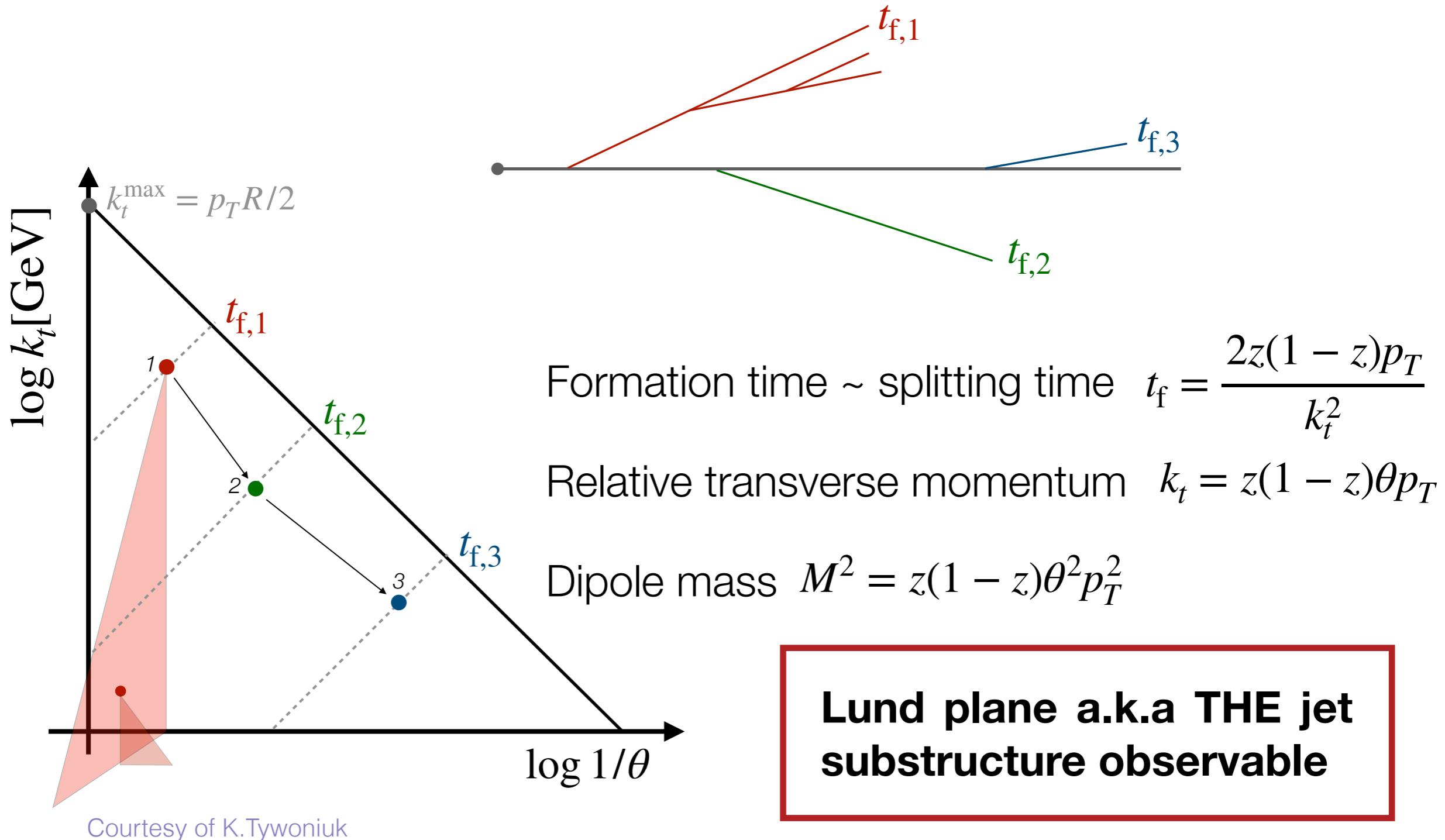
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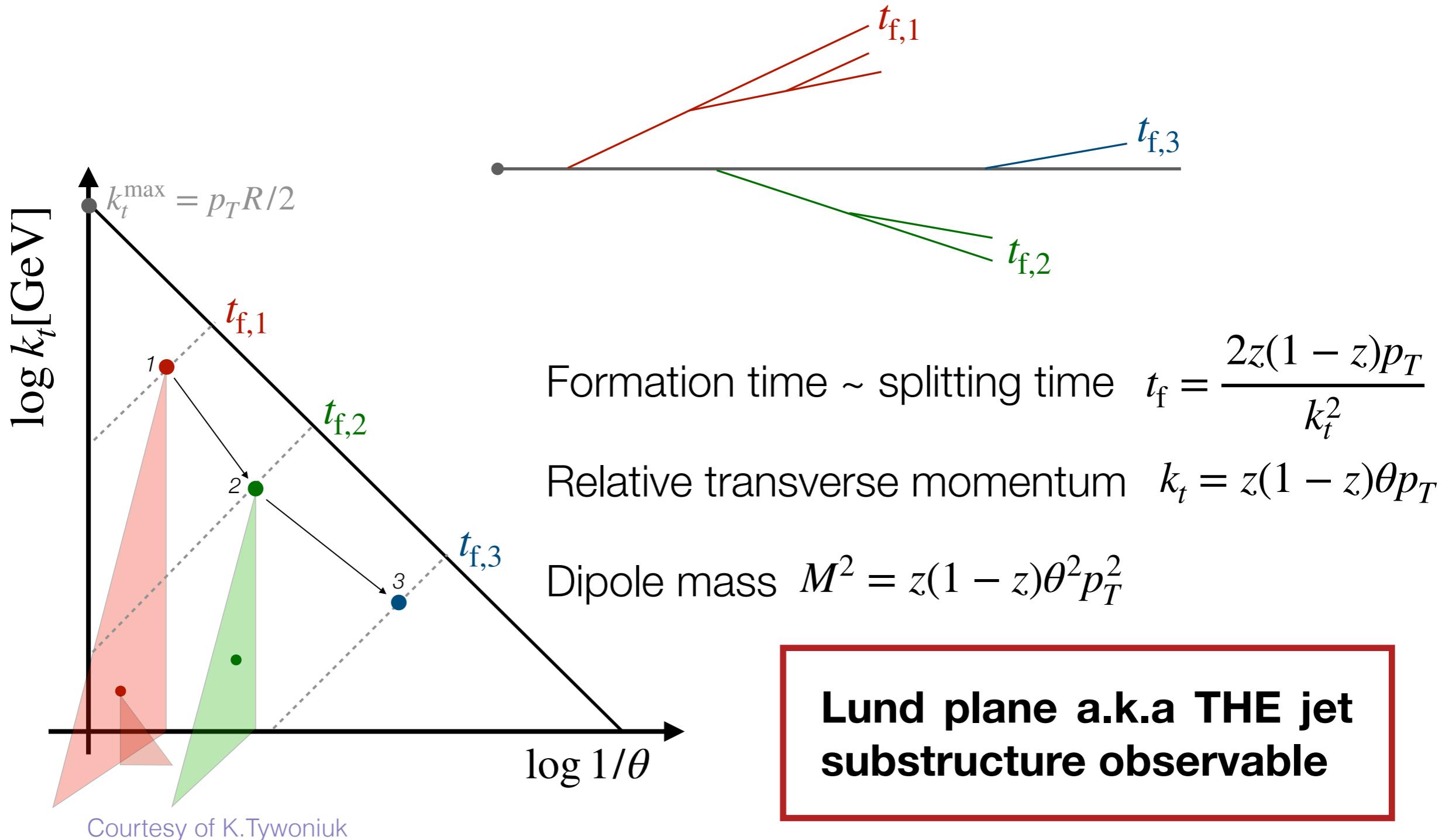
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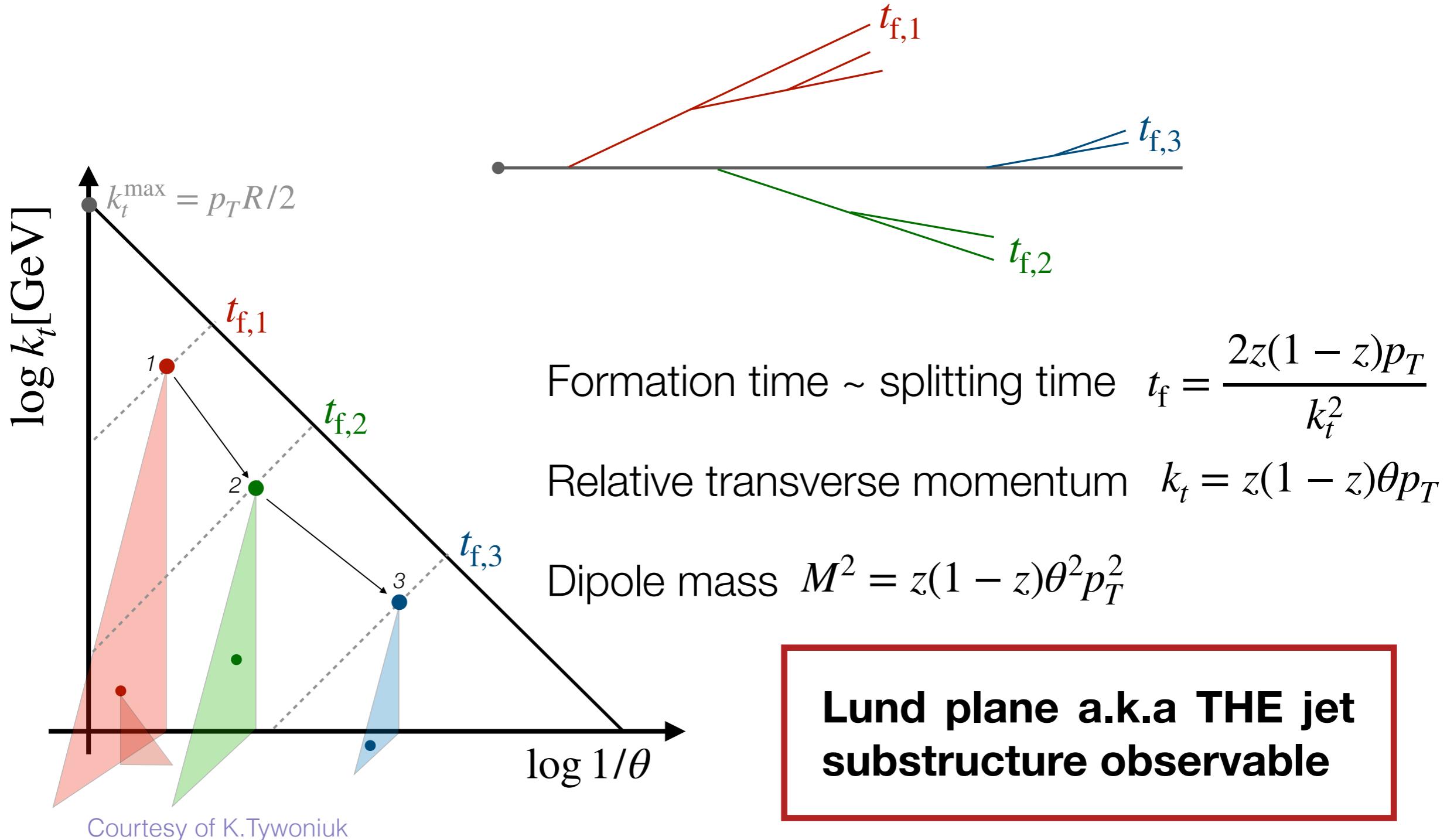
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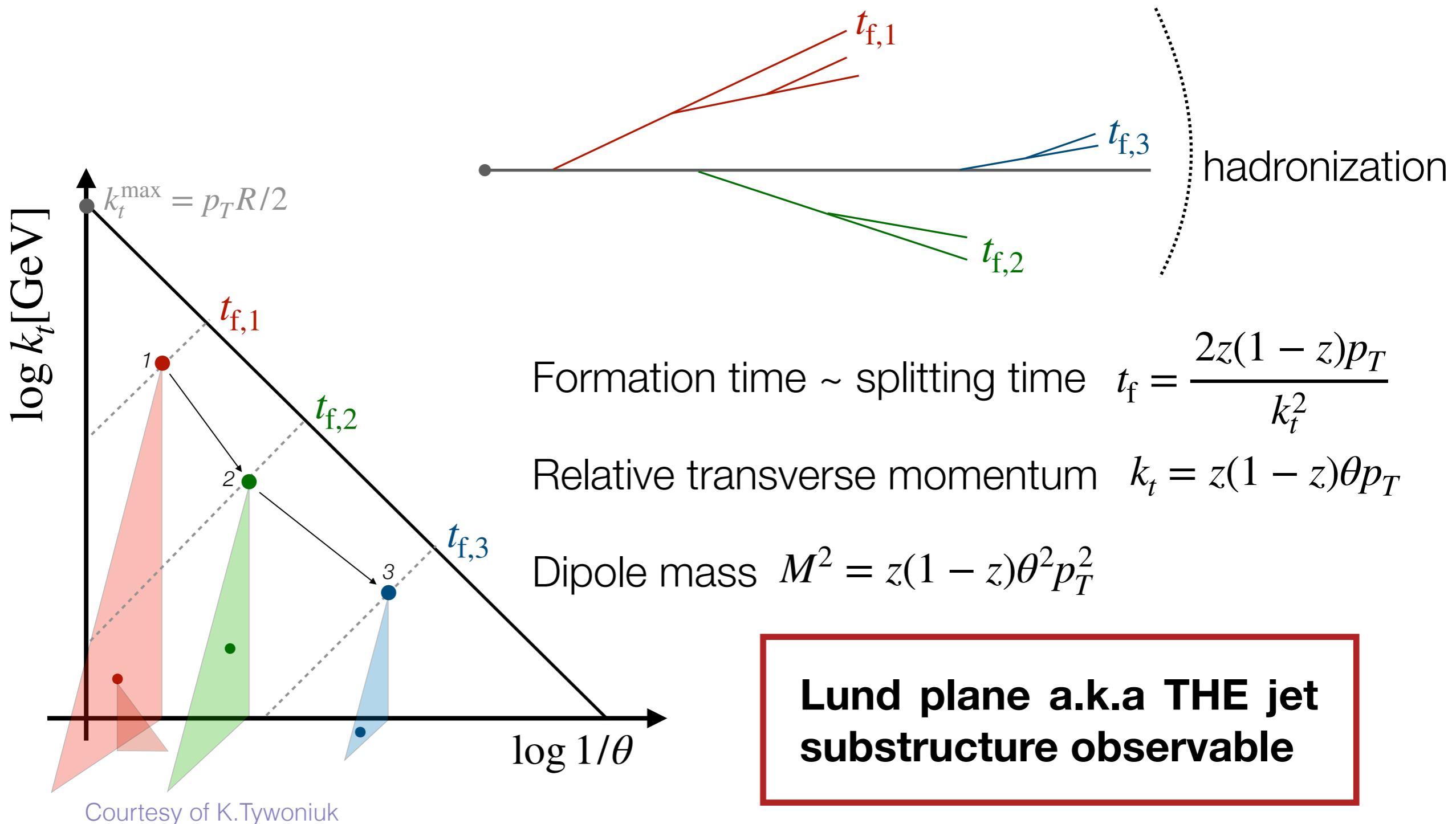
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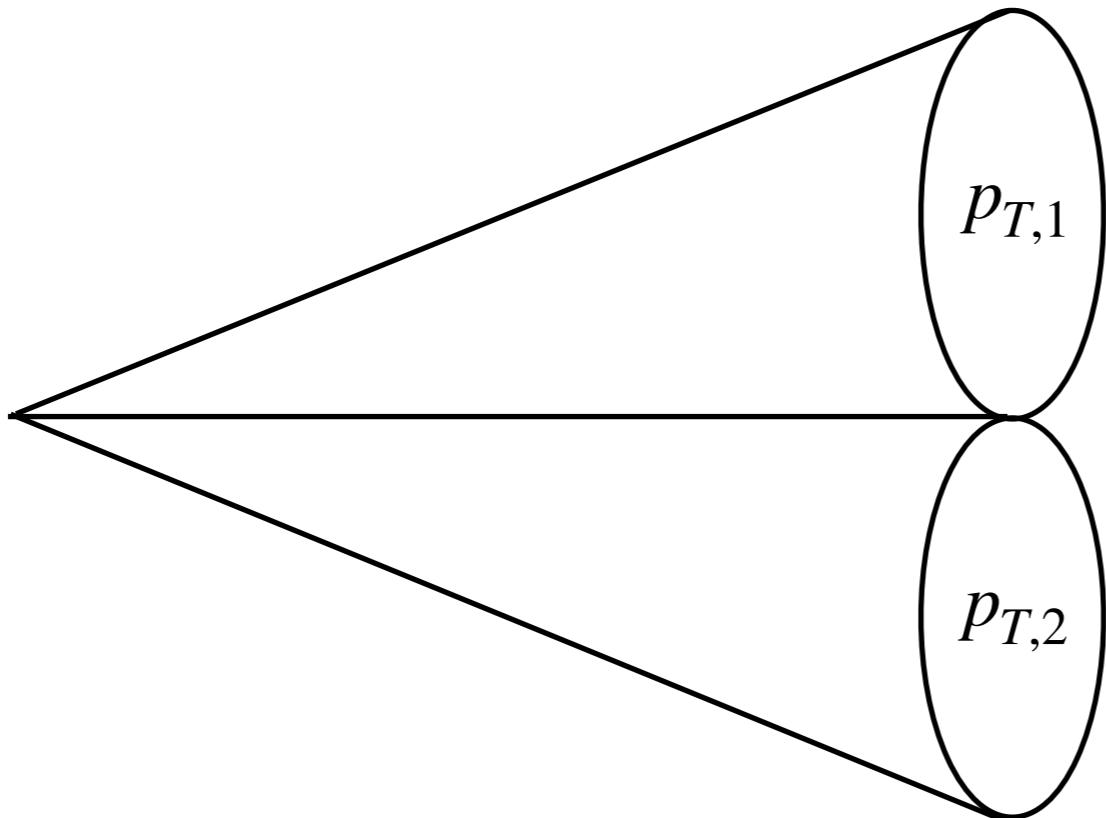
Primary Lund plane: MC and data

1

(Re)-cluster the jet with Cambridge/Aachen algorithm

2

Un-do the last clustering step (largest angular separation)



Lund-plane coordinates

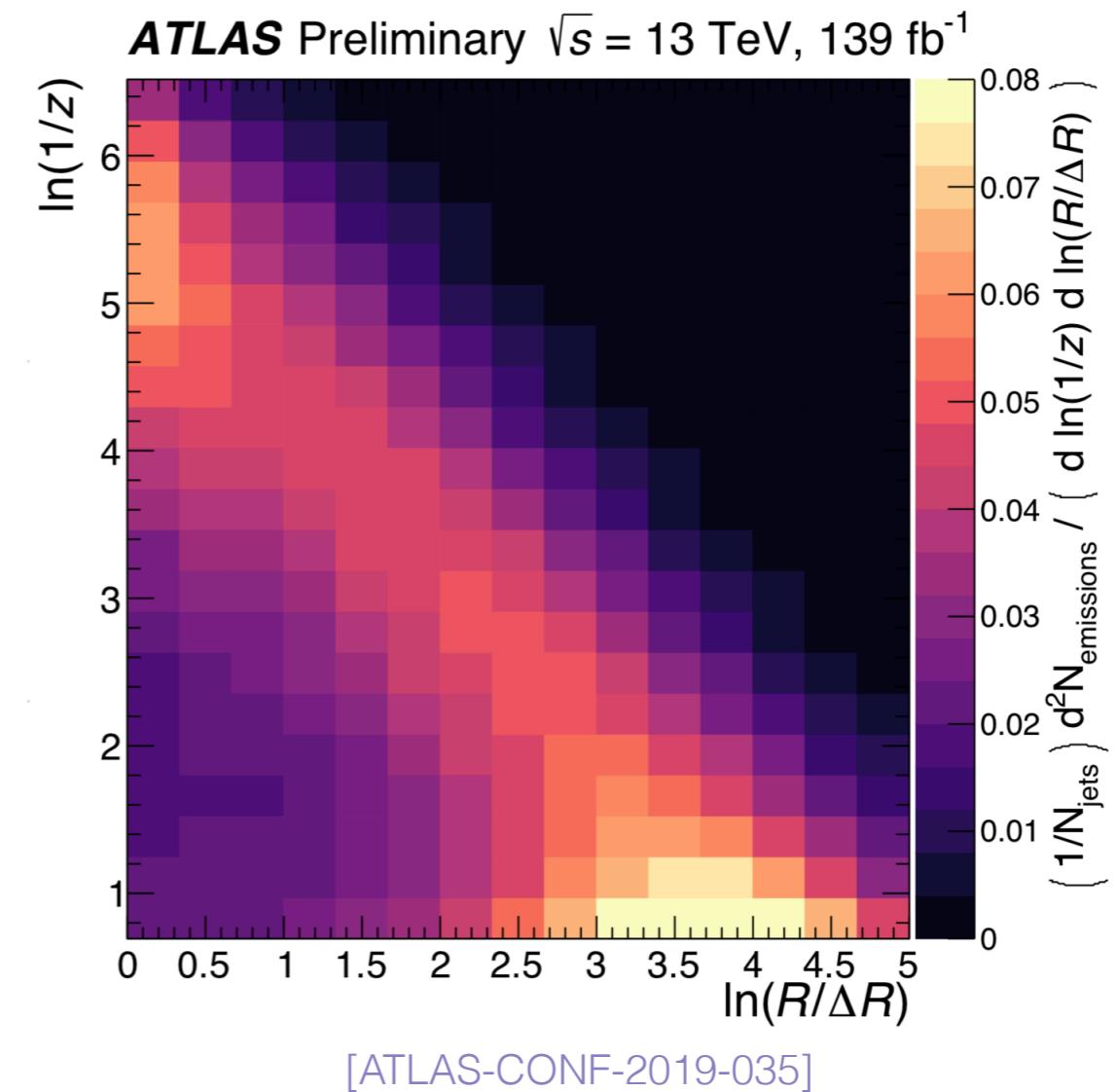
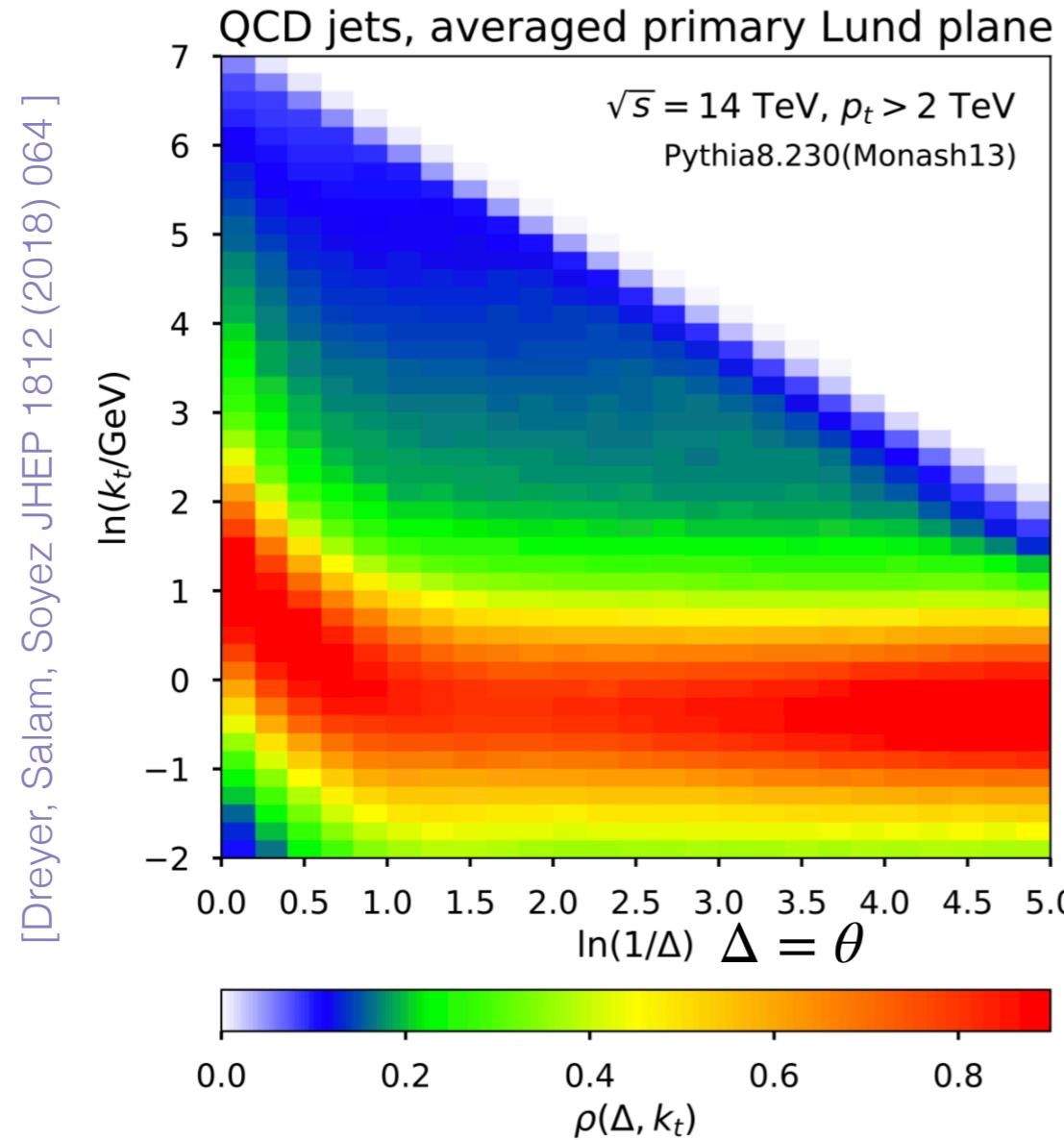
$$z = \min(p_{T,1}, p_{T,2}) / (p_{T,1} + p_{T,2})$$

$$\theta = \sqrt{(y_1 - y_2)^2 + (\phi_1 - \phi_2)^2}$$

3

Repeat step 2 for the hardest branch

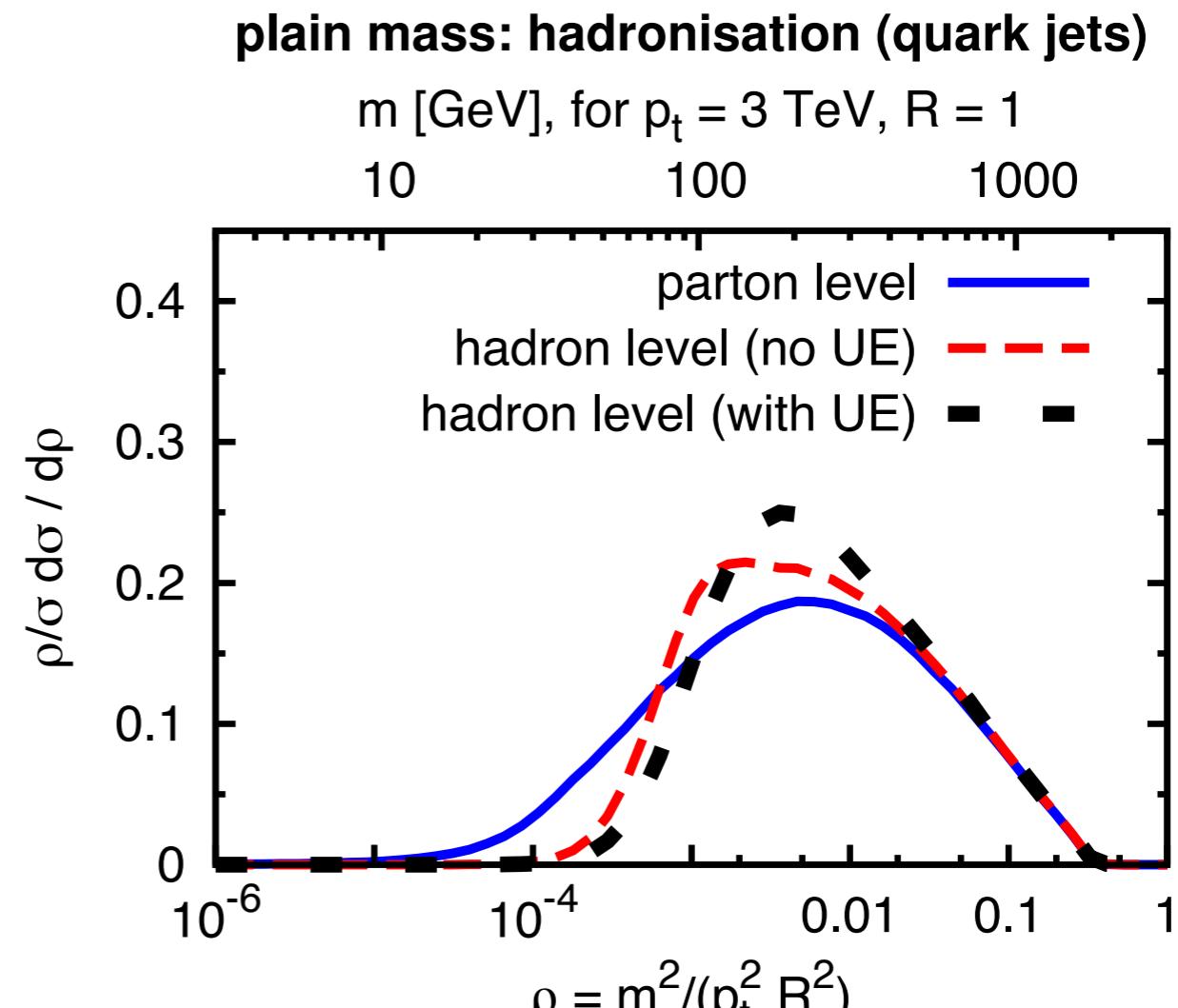
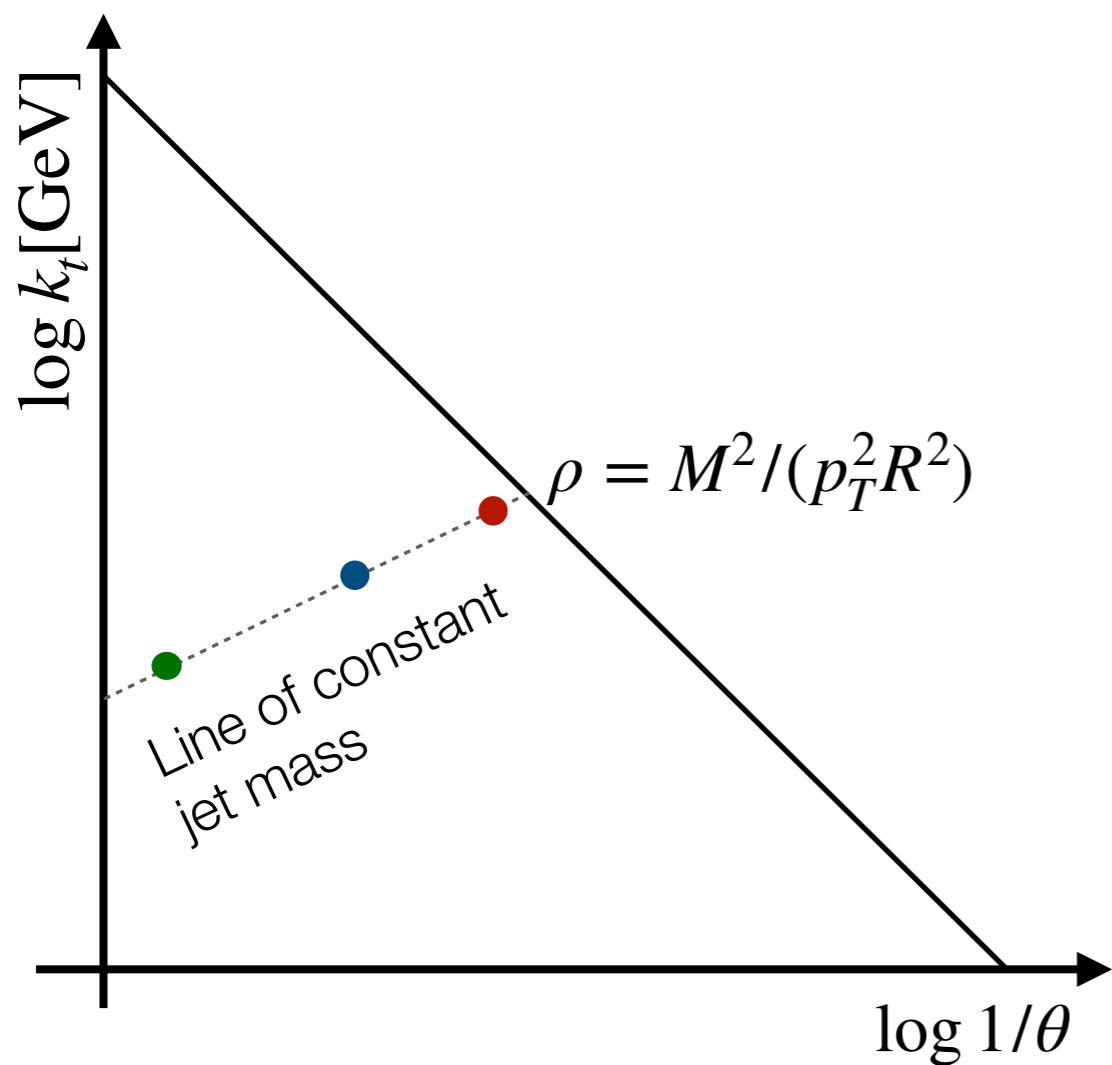
Primary Lund plane: MC and data



$$\text{LL: } \rho \approx \frac{2\alpha_s C_R}{\pi} d \ln \frac{1}{\theta} d \ln k_t$$

Promising way of constraining 1) p+p: non-perturbative physics in MC generators. 2) A+A: phase space for in-medium radiation

Going down in complexity: jet mass



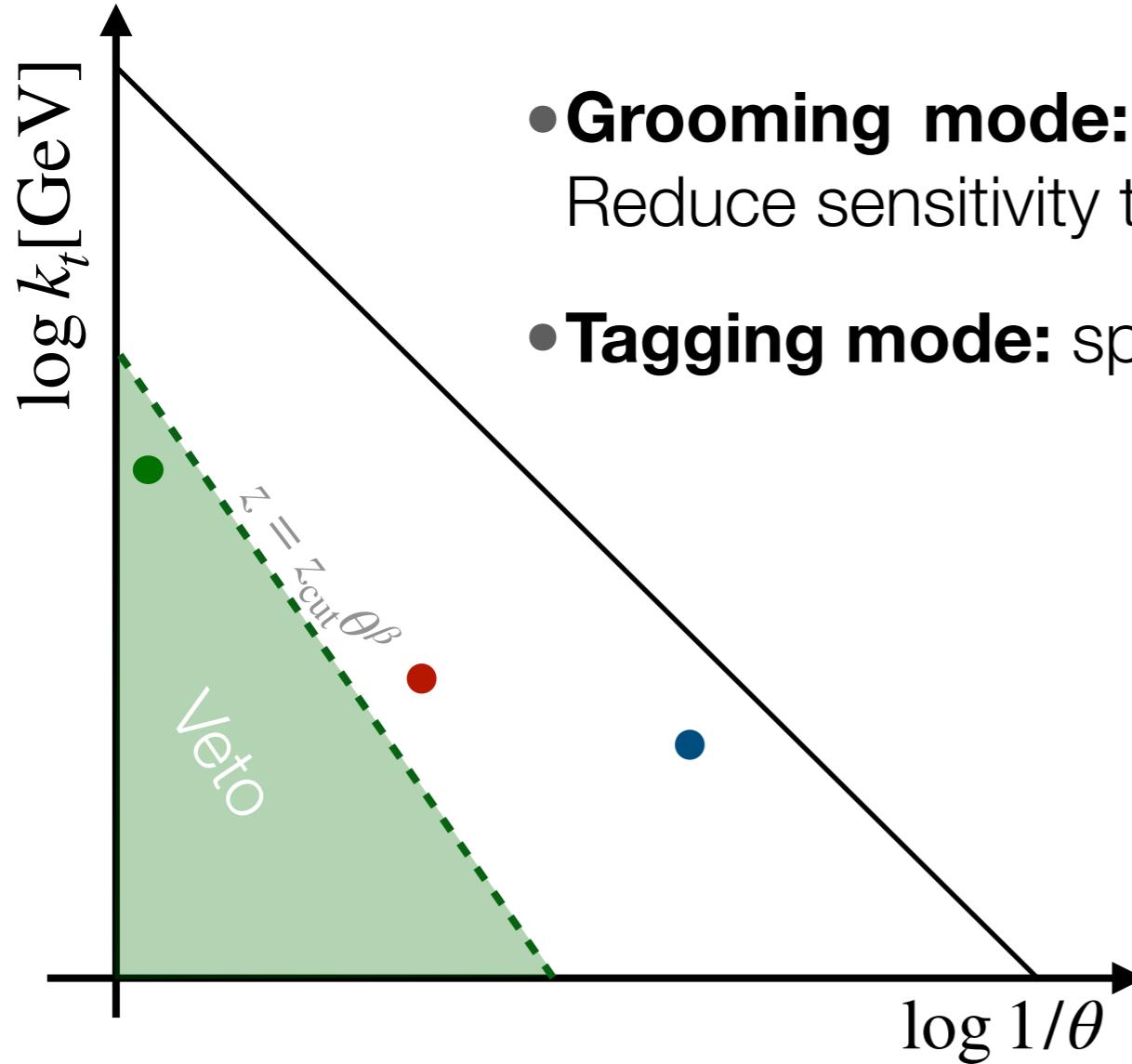
Grooming/tagging techniques goals: reduce sensitivity to non-perturbative physics + enable pQCD - data comparisons (no MC)

Soft Drop

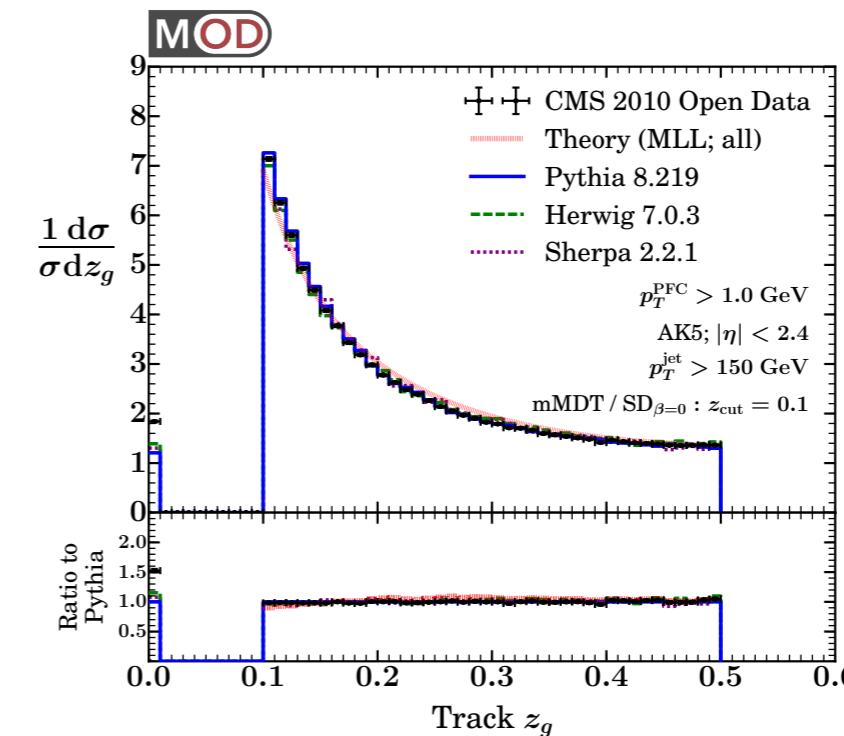
[Larkowski, Marzani, Soyez, Thaler, JHEP 1405 (2014) 146]

Find the first primary branch in the C/A tree that satisfies

$$z > z_{\text{cut}} \theta^{\beta}$$



- **Grooming mode:** remove all larger angles branches.
Reduce sensitivity to non-perturbative physics.
- **Tagging mode:** splitting defines observables.



[Larkowski et al PRL 119,(2017)]

How to choose (z_{cut}, β) ? $(p_T, R, \text{observable})$ -dependent?

Dynamical grooming

[Yacine Mehtar-Tani, ASO, Konrad Tywoniuk, arXiv:1911.00375]

Find hardest branch in the C/A tree i.e.

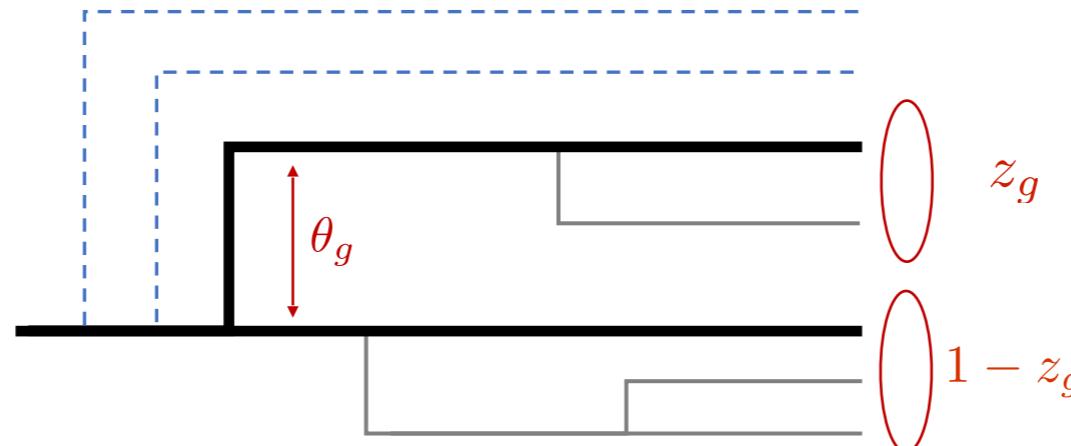
$$\kappa^{(a)} = \max_{i \in \text{C/A}} z_i(1 - z_i)(\theta/R)^a$$

with a being a continuous free parameter. Physical interpretation:

• $a=2$: TimeDrop

• $a=1$: k_T Drop

• $a \sim 0$: z Drop

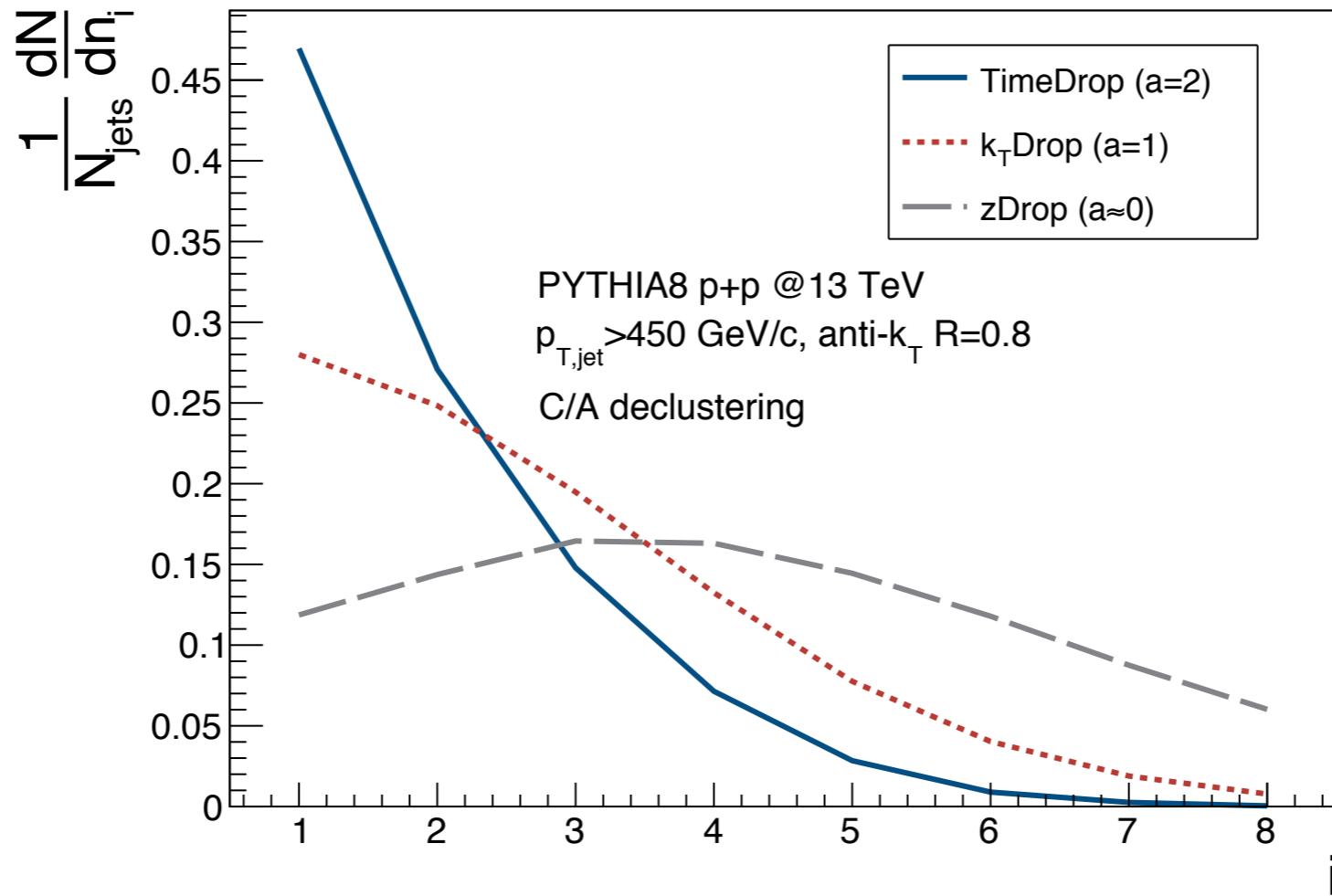


Conditions for tagging/grooming auto-generated on a jet-by-jet basis. No need to fine tune!

Tagged branching location on the C/A tree

Find hardest branch in the C/A tree i.e.

$$\kappa^{(a)} = \max_{i \in \text{C/A}} z_i(1 - z_i)(\theta/R)^a$$



$$\langle n_i \rangle \approx 2 \text{ (TimeDrop)}, 3 \text{ (k}_T\text{Drop)}, 5 \text{ (zDrop)}$$

Analytic understanding: vetoed showers

Normalized probability distribution of the hardest splitting

$$\mathcal{P}(z, \theta) = \frac{\alpha_s(k_t^2)}{\pi} P(z) \Delta(\kappa | a), \quad P_{gq}(z) = C_F \frac{1 + (1 - z)^2}{z}$$

with the Sudakov form factor

$$\Delta(\kappa | a) = \exp \left[- \int_0^R \frac{d\theta}{\theta} \int_0^1 dz P(z) \times \Theta(z(1-z)(\theta/R)^a > \kappa) \right]$$

that is IRC safe for $a > 0$. For fixed coupling and MLLA $P_{gq}(z) \approx \frac{2C_F}{z} \left(1 - \frac{3}{4}z \right)$

$$\Delta(\kappa | a) = \exp \left[-\frac{\bar{\alpha}}{a} \left(\ln^2 \kappa + \frac{3}{2} (\ln \kappa + 1 - \kappa) \right) \right]$$

Momentum sharing distribution

$$\frac{1}{\sigma} \frac{d\sigma}{dz} = \int_0^R \frac{d\theta}{\theta} \mathcal{P}(z, \theta) \xrightarrow{\text{MLLA}} = \frac{2\bar{\alpha}}{z} \left(1 - \frac{3}{4}z \right) \int_0^z \frac{dx}{x} e^{-\frac{\bar{\alpha}}{a} [\ln^2 x + \frac{3}{2}(\ln x + 1 - x)]}$$

DLA \downarrow

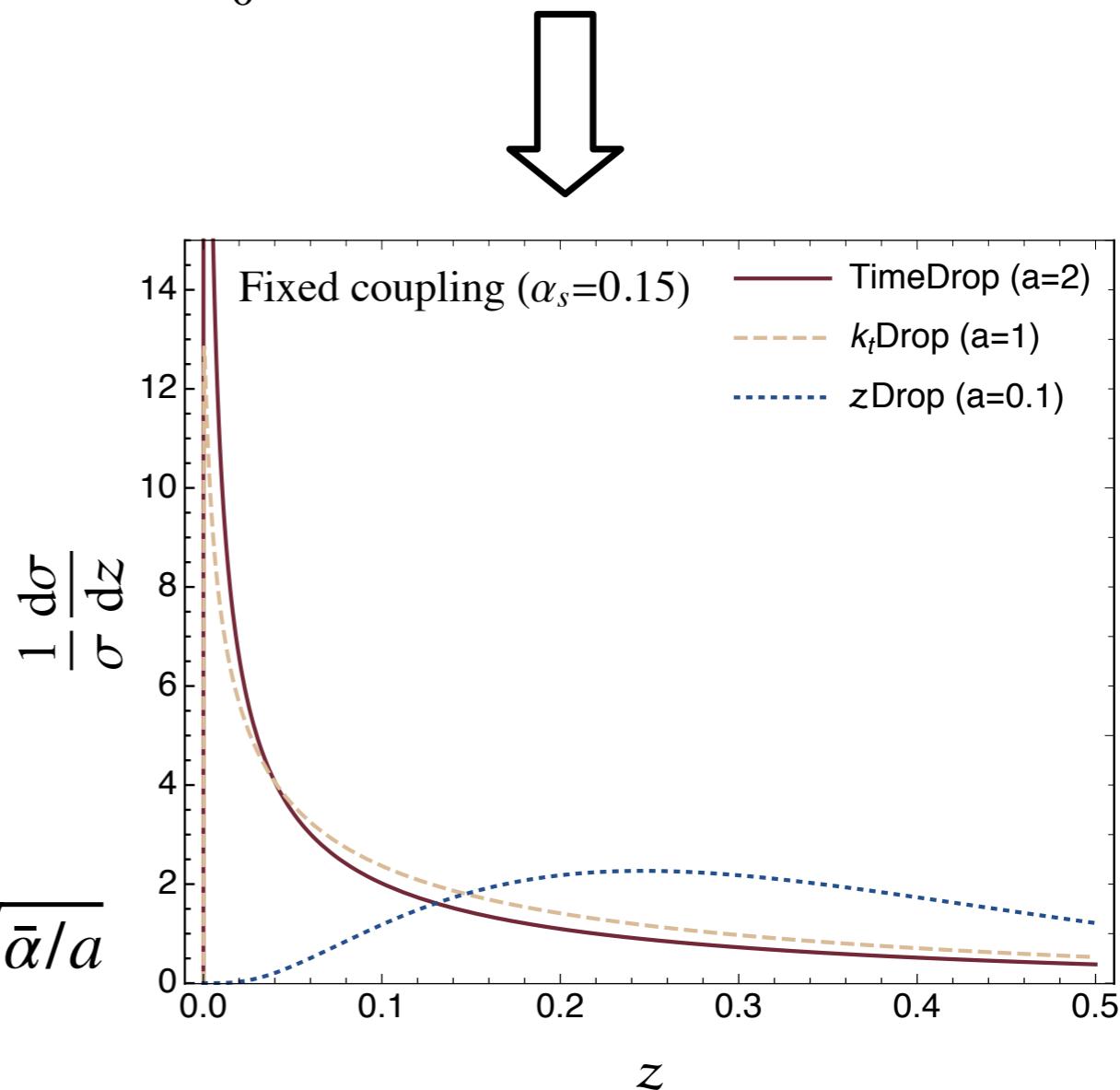
$$P_{gq}(z) \approx \frac{2C_F}{z}$$

$$= \frac{1}{z} \sqrt{\frac{\bar{\alpha}\pi}{a}} \left[\operatorname{erf} \left(\sqrt{\frac{\bar{\alpha}}{a}} \ln z \right) - 1 \right]$$

- Dynamical cut-off generated at

$$z_{\text{cut}} \approx e^{-\sqrt{a/\bar{\alpha}}}$$

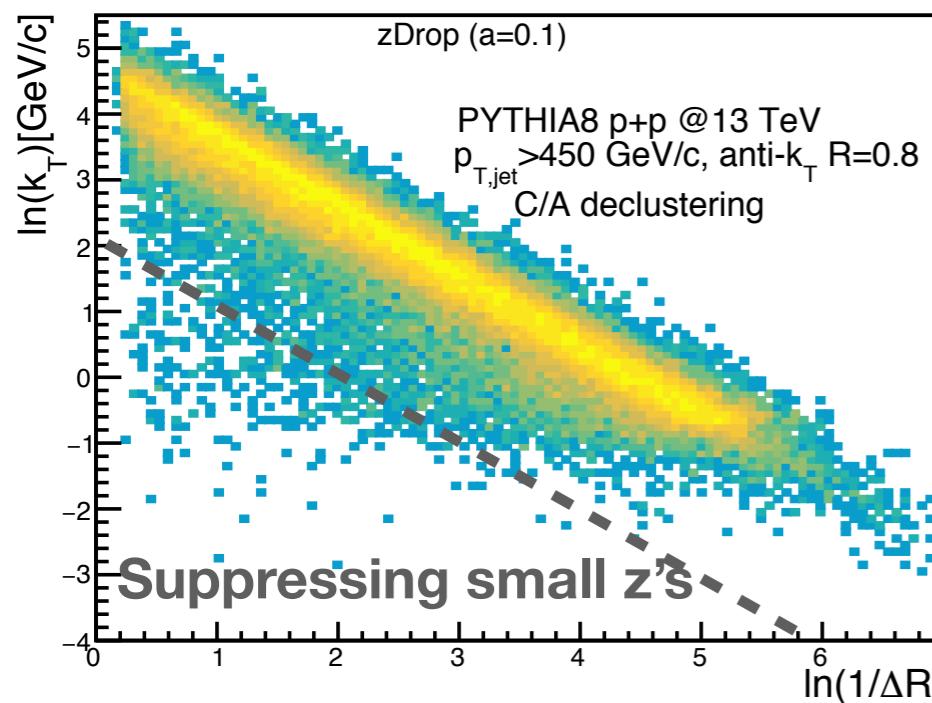
- For $z_{\text{cut}} < z < 0.5$ $\xrightarrow{\quad} \frac{1}{\sigma} \frac{d\sigma}{dz} \approx P(z) \times \sqrt{\bar{\alpha}/a}$



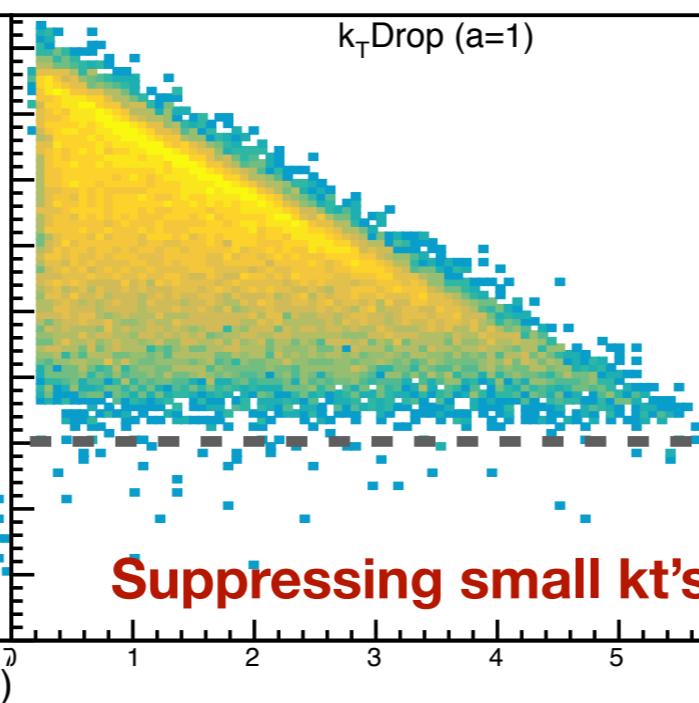
Possibility to measure $P(z)$ down to lower values of z

Monte Carlo study: primary Lund plane

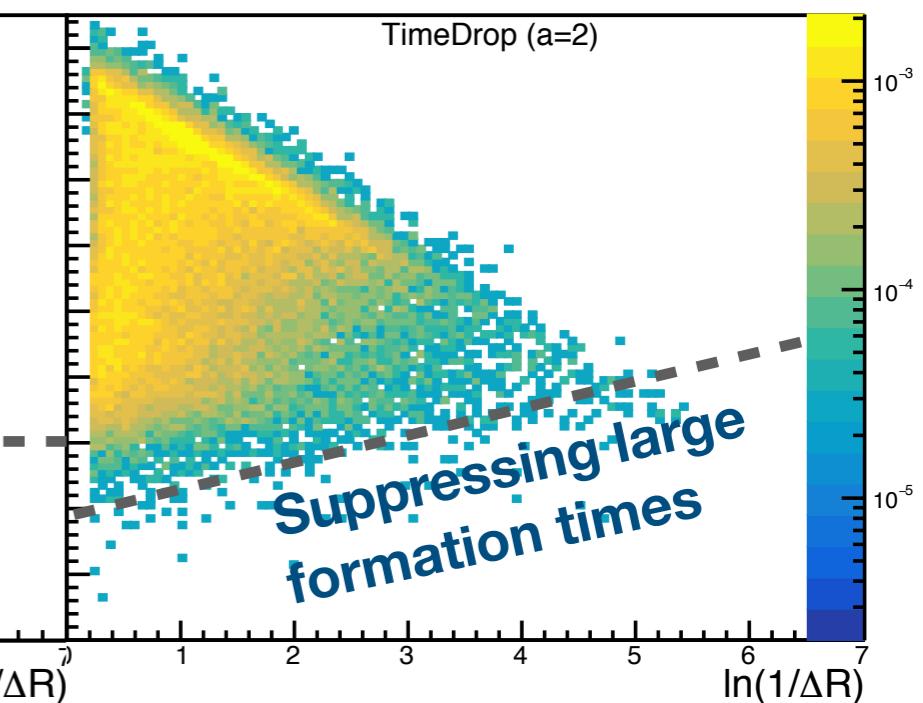
zDrop



k_T Drop

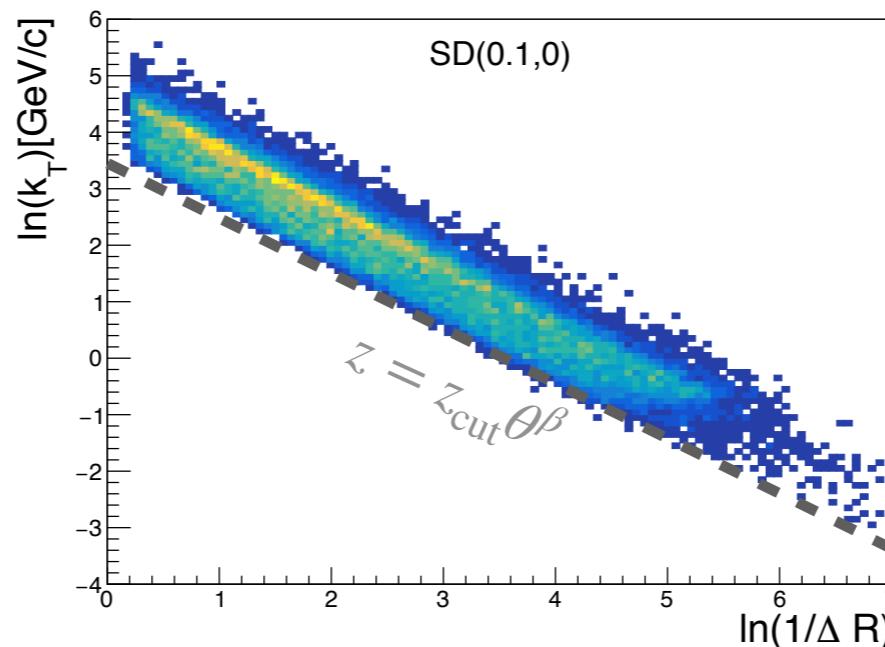


TimeDrop

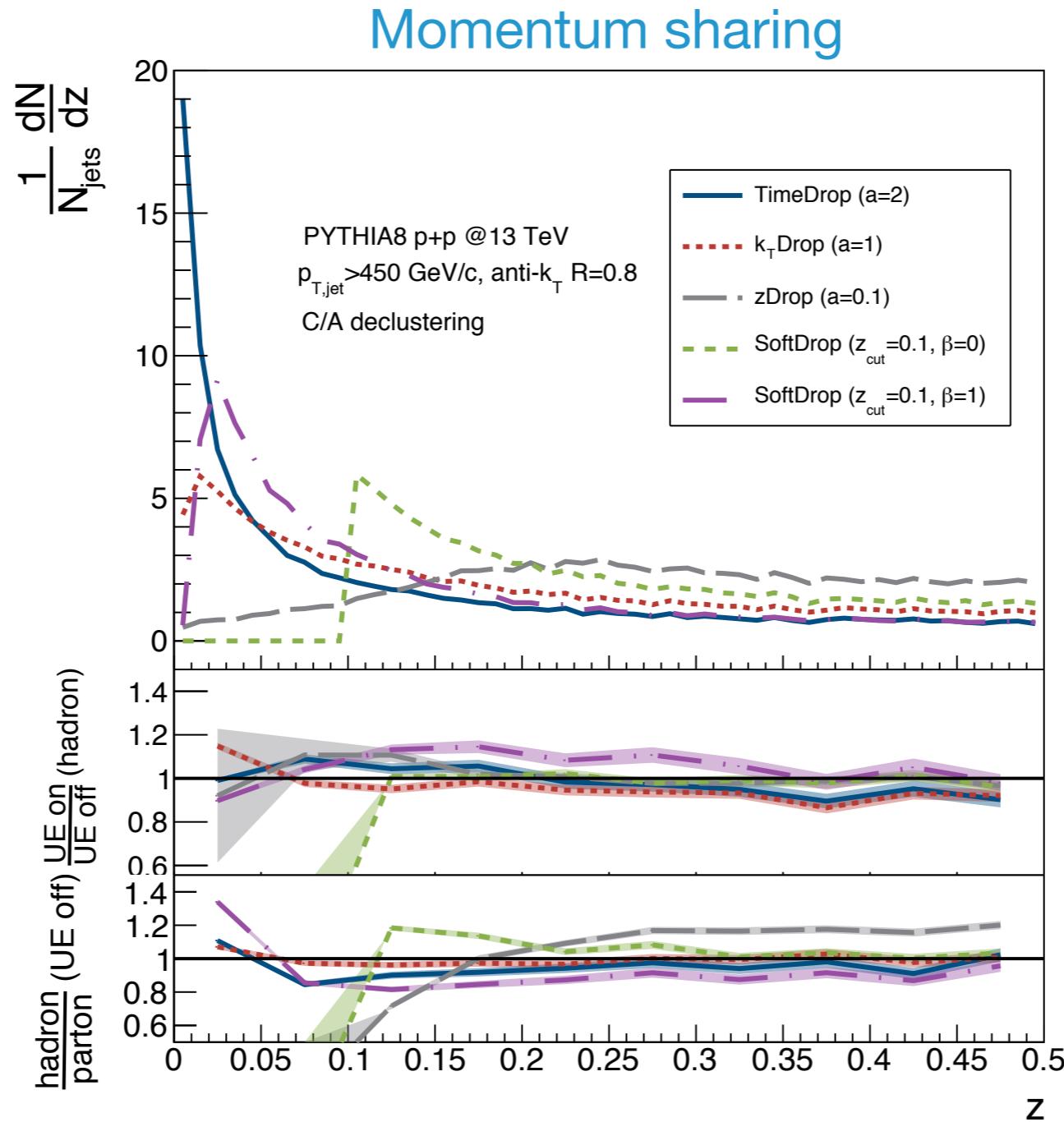


No sharp cuts

SoftDrop(0.1,0):



Monte Carlo study: resilience to NP physics



Overall similar behavior to SoftDrop.
 k_T Drop remarkably robust for hadronization

To-do list

- Performance study of the grooming mode on p+p physics including a recursive implementation
- Predictions for heavy-ions including in-medium modifications
- Potential use of dynamical grooming at EIC?

Keep tuned and find more on: <https://github.com/aontoso/JetToyHI>

Soon in FastJet/contrib

Productivity summary

1) Publications

Preprints

Dynamical grooming of QCD jets, Yacine Mehtar-Tani, Alba Soto-Ontoso, Konrad Tywoniuk *arXiv: 19011.00375 submitted to Phys. Rev. D*

Influence of the neutron skin effect on nuclear isobar collisions at RHIC, Jan Hammelmann, Alba Soto-Ontoso, Massimiliano Alvioli, Hannah Elfner, Mark Strikman. *arXiv:1908.10231 submitted to Phys. Rev. Lett.*

A background estimator for jet studies in heavy-ion collisions, Yacine Mehtar-Tani, Alba Soto-Ontoso, Marta Verweij. *arXiv:1904.12815 submitted to Phys. Rev. D*

In preparation

pTSampler: a background subtraction method for jet substructure studies, Yacine Mehtar-Tani, Alba Soto-Ontoso, Marta Verweij

2) Awards

Giersch Award Outstanding Doctoral Thesis 2018 - awarded by Stiftung Giersch together with HGS-HIRe

Productivity summary

3) Scientific talks

- Nov 2019 **RIKEN Lunch Seminar BNL.** *Seminar:* Revisiting the discovery potential of the isobar run at RHIC.
- Sep 2019 **Heavy Ion Coffee CERN.** *Seminar:* A new look into background subtraction for jet physics in p+p and A+A collisions.
- July 2019 **BOOST MIT.** *Lightning talk:* A background estimator for jet studies in p+p and A+A collisions.
- June 2019 **RHIC/AGS Users meeting BNL.** *Invited talk:* Jets and background subtraction.
- May 2019 **Nuclear Physics Colloquium Goethe University.** *Seminar:* Mitigating pileup and underlying event for jet studies in p+p and A+A at LHC energies.
- June 2019 **JetTools Bergen University.** *Invited talk:* Background subtraction techniques and jet substructure.
- May 2019 **Origins of correlations in high energy collisions INT Seattle.** *Invited talk:* The importance of transverse geometry from p+p to A+A.
- March 2019 **Nuclear Theory Seminar Stony Brook University.** *Seminar:* Background estimation for jets in high energy proton-proton and heavy ion collisions.
- Feb 2019 **Particle Physics Seminar City College NY.** *Seminar:* Background estimation for jets in high energy proton-proton and heavy ion collisions.
- Jan 2019 **RIKEN Lunch Seminar BNL.** *Seminar:* A novel background estimation method for jet studies in heavy ion collisions.
- Dec 2018 **III CAFPE-Fisica Teórica Christmas Workshop Universidad de Granada.** *Invited talk:* A novel background estimation method for jet studies in heavy ion collisions.
- Dec 2018 **Multiparton interactions at LHC Perugia.** *Invited talk:* Flow harmonic coefficients in small systems at the LHC: initial or final state effect?

6 seminars, 5 invited talks, 1 regular talk