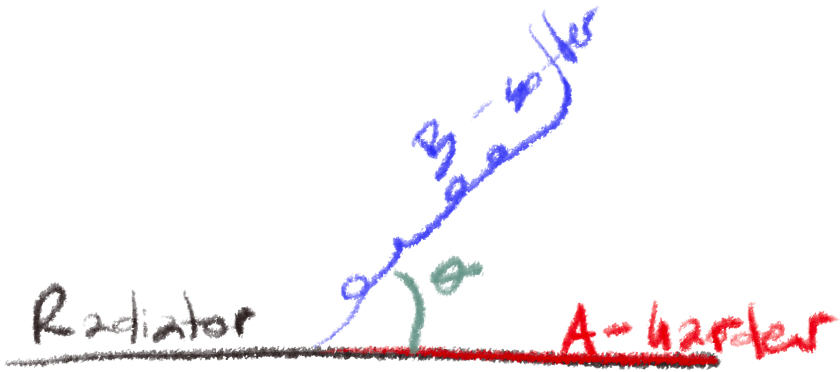
On connections between Lund Plane and energy-energy correlators

“What do we want to measure? What do we measure?”
Depending on the order this is a positive note or less so….

Mateusz Ploskon

Traversing
Lund Plane
and
thinking of EECs
at the same time

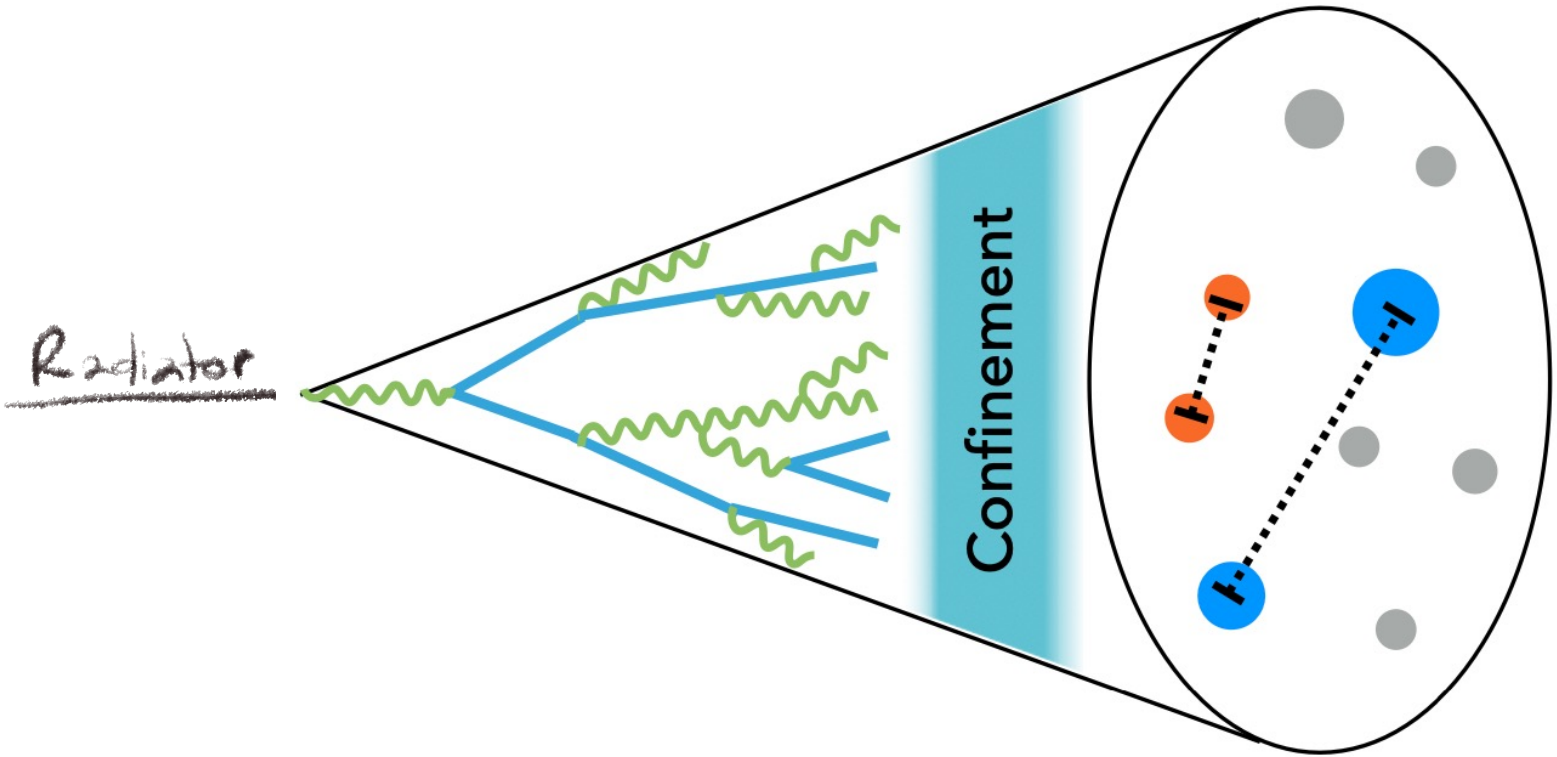
Looking at: anti-kT jets R=0.4; we stay with jet pT ~100GeV (for the most part)
Primary Lund: C/A clustering
EECs: particles with pT > 1GeV/c

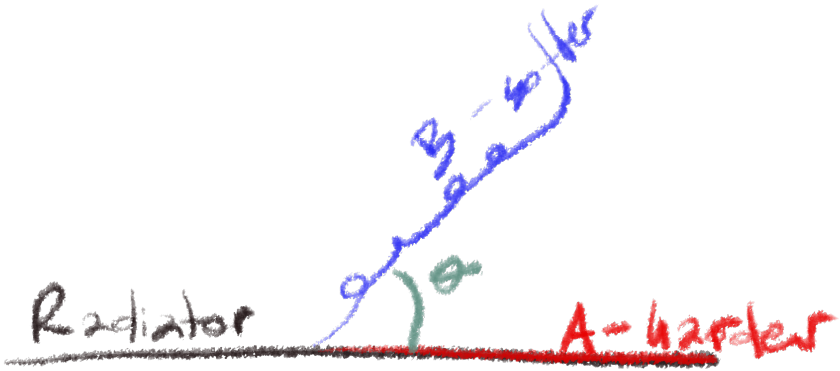


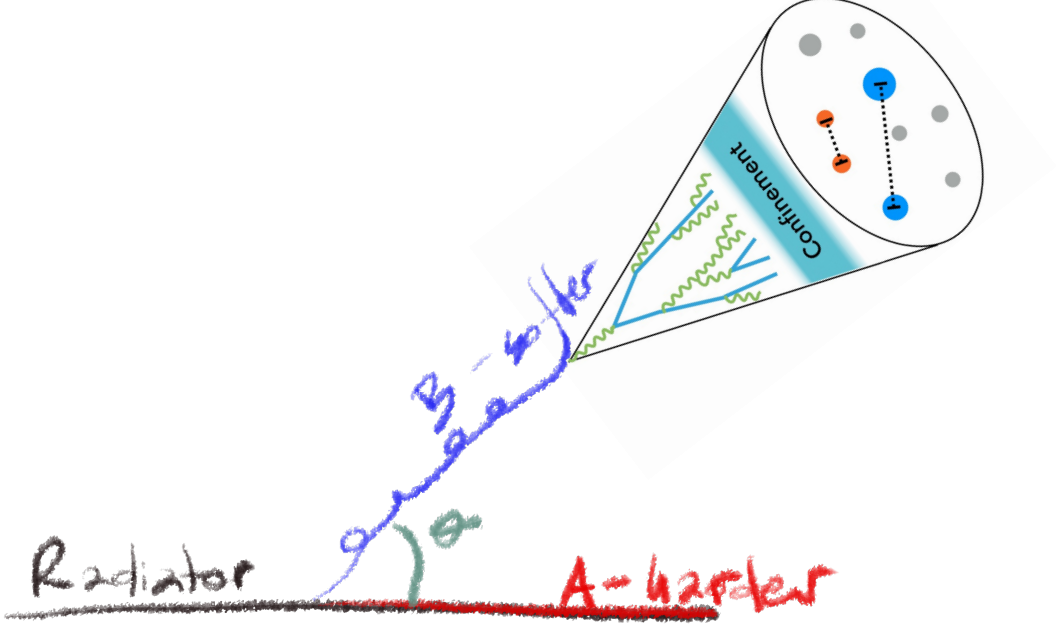
$$p_T^R = p_T^B + p_T^A$$

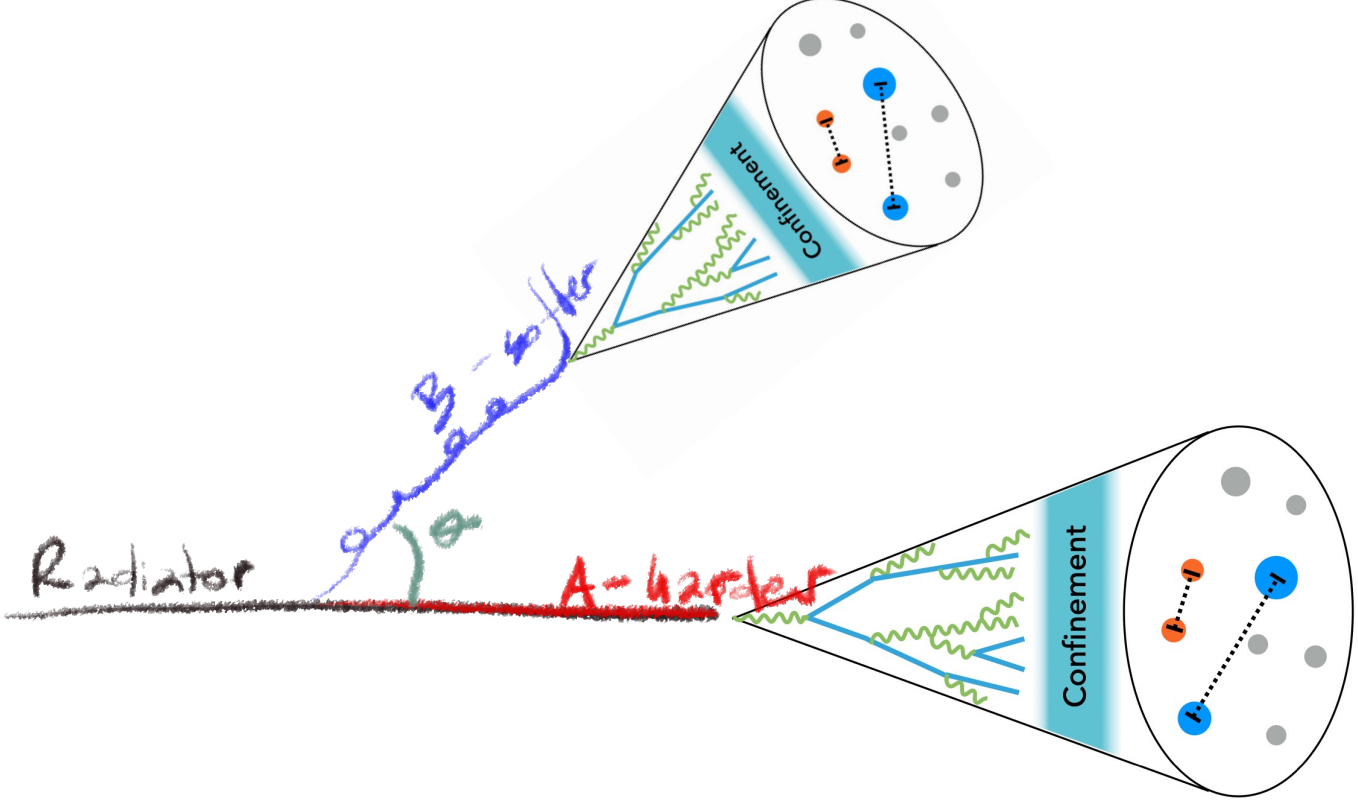
$$p_T^A > p_T^B$$

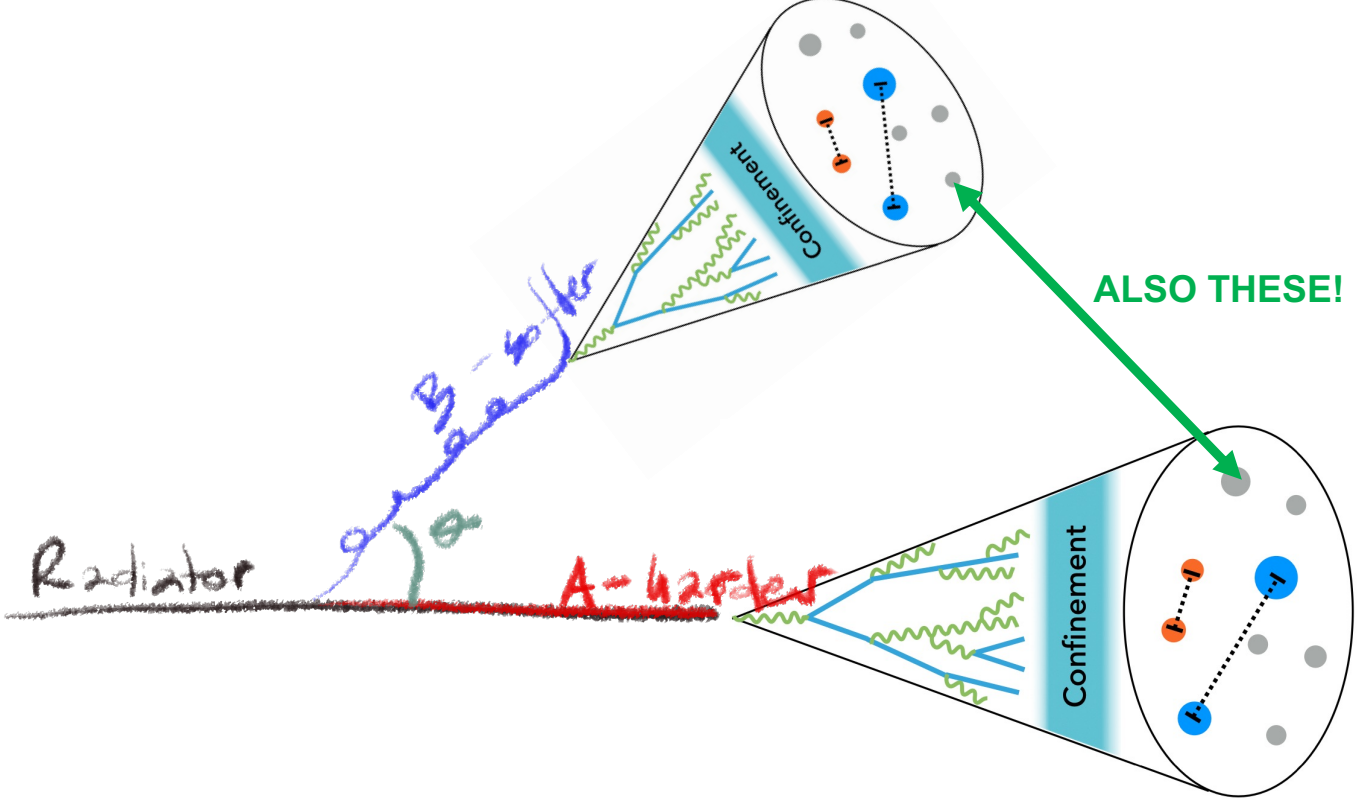
$$k_T = p_T^B \times \theta$$


Radiator
Confinement


Radiator
θ
A-Heater

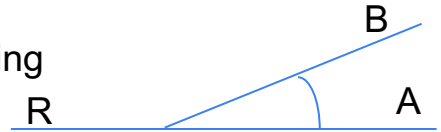

Confinement
Radiator
A-quarter

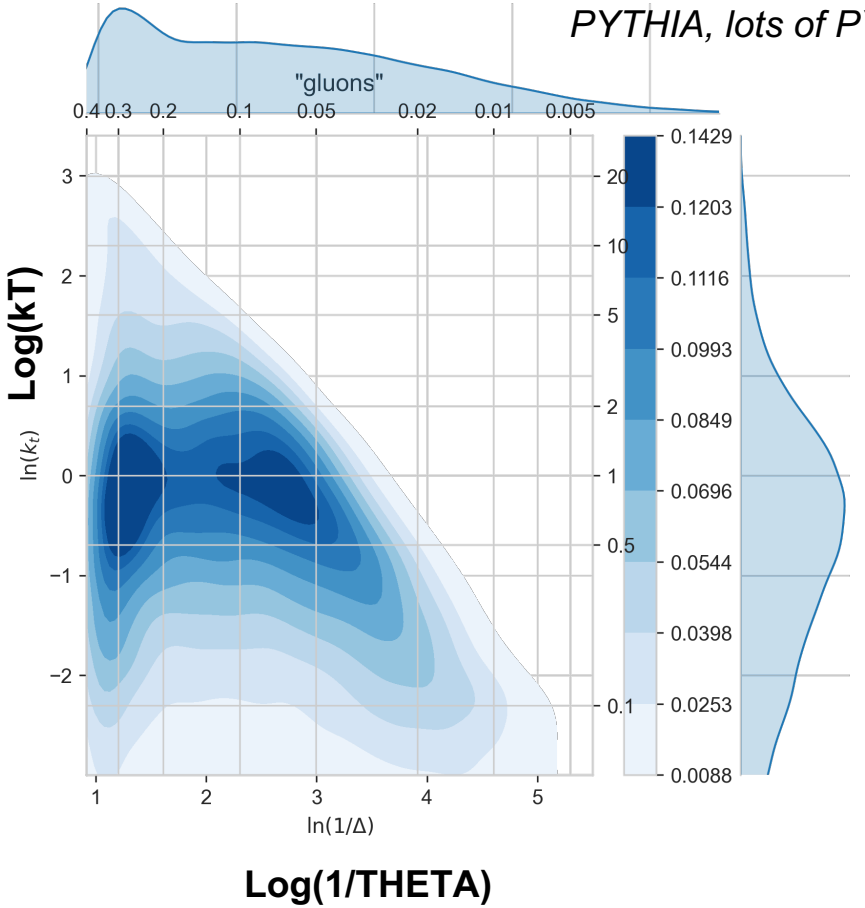

Confinement
Radiator
Confinement


Confinement
ALSO THESE!
Radiator
Confinement

Gluons only – jets of 100 GeV – anti-kT R=0.4 – C/A re/declustering

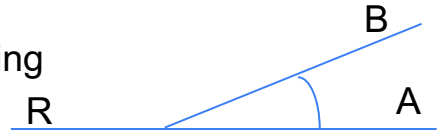
PYTHIA, lots of PYTHIA in this one…

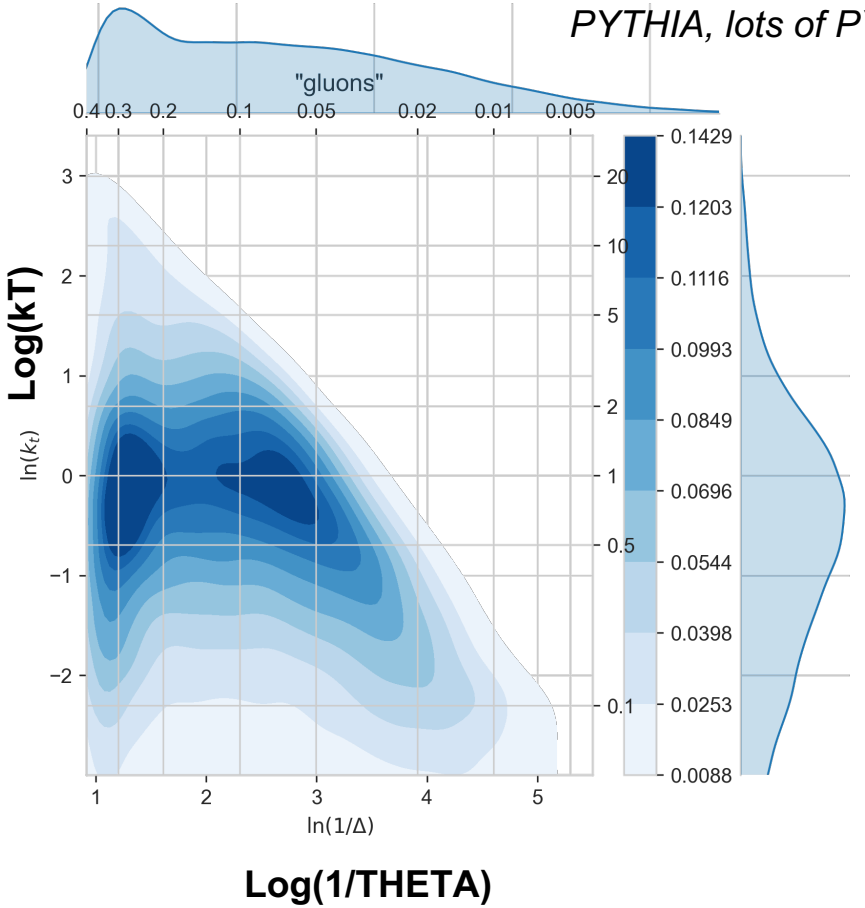


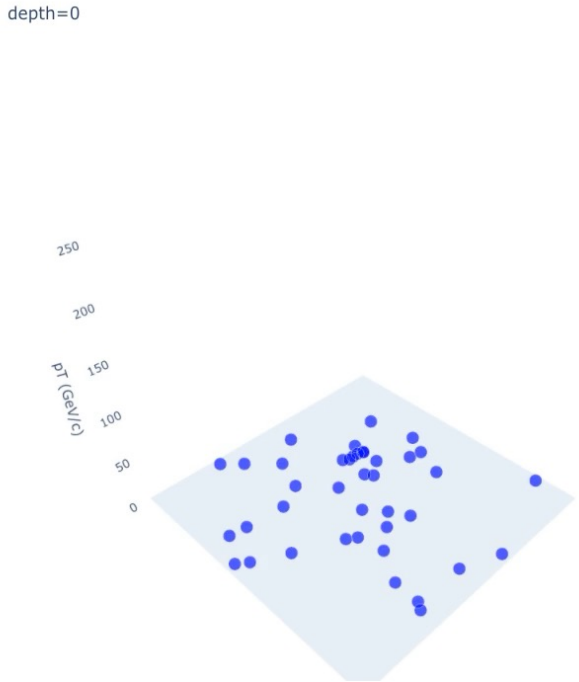


Gluons only – jets of 100 GeV – anti-kT R=0.4 – C/A re/declustering

PYTHIA, lots of PYTHIA in this one…

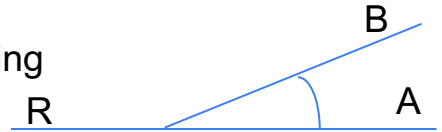


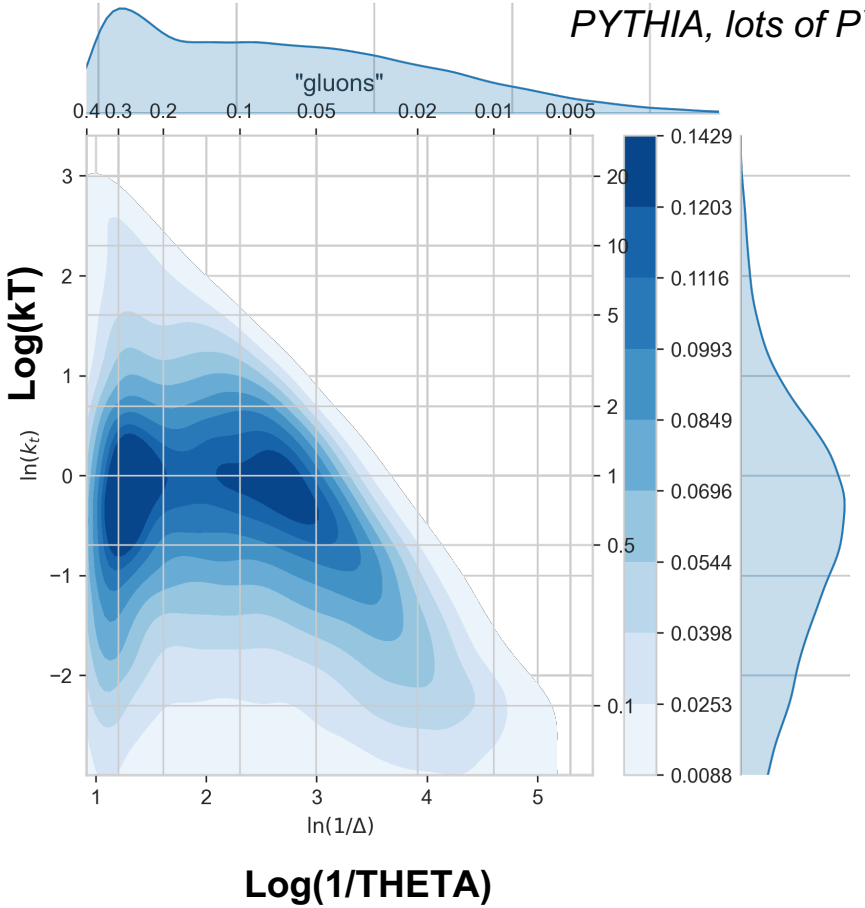


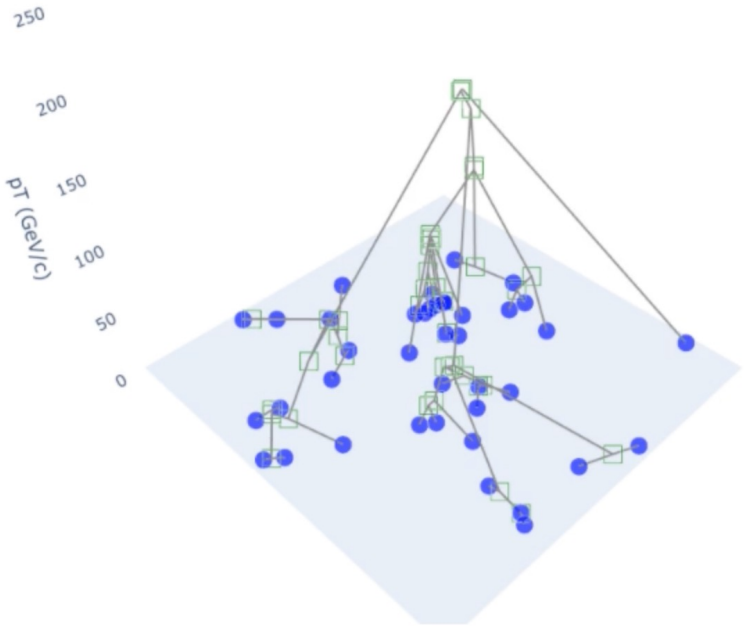


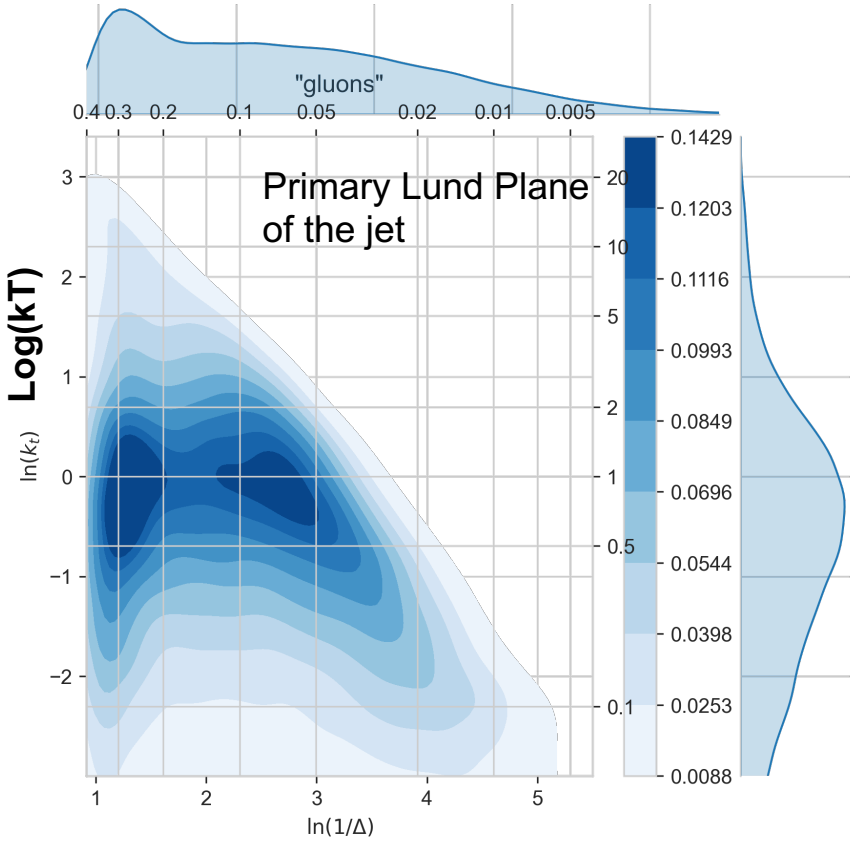
Gluons only – jets of 100 GeV – anti-kT R=0.4 – C/A re/declustering

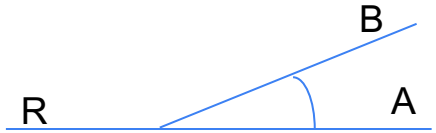
PYTHIA, lots of PYTHIA in this one…

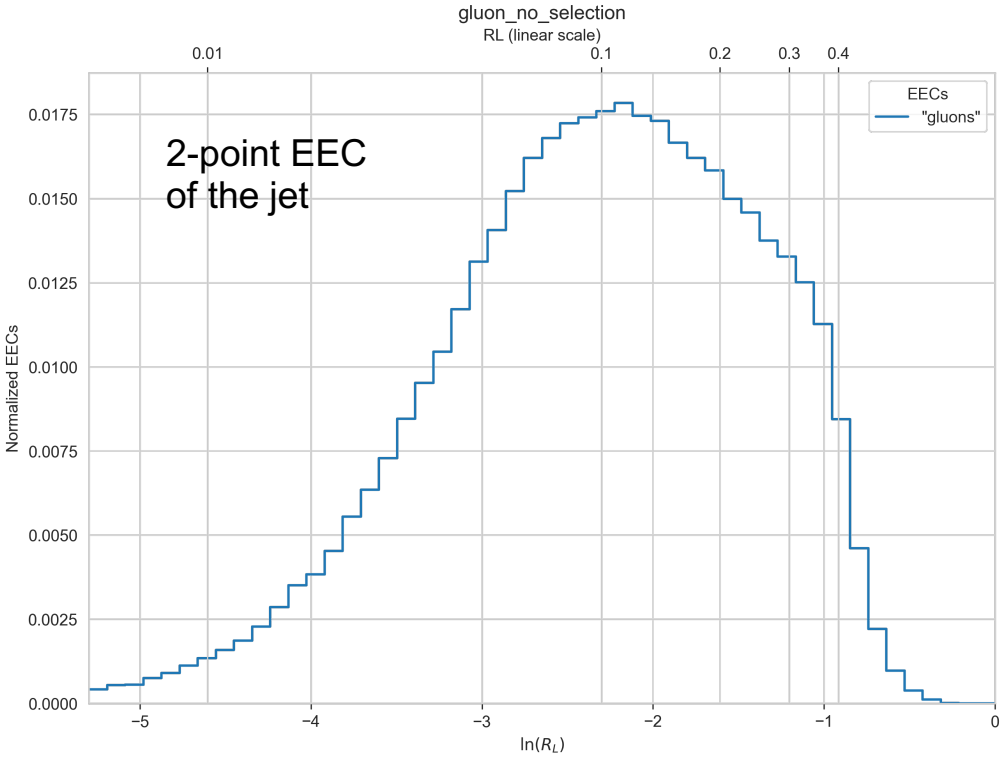


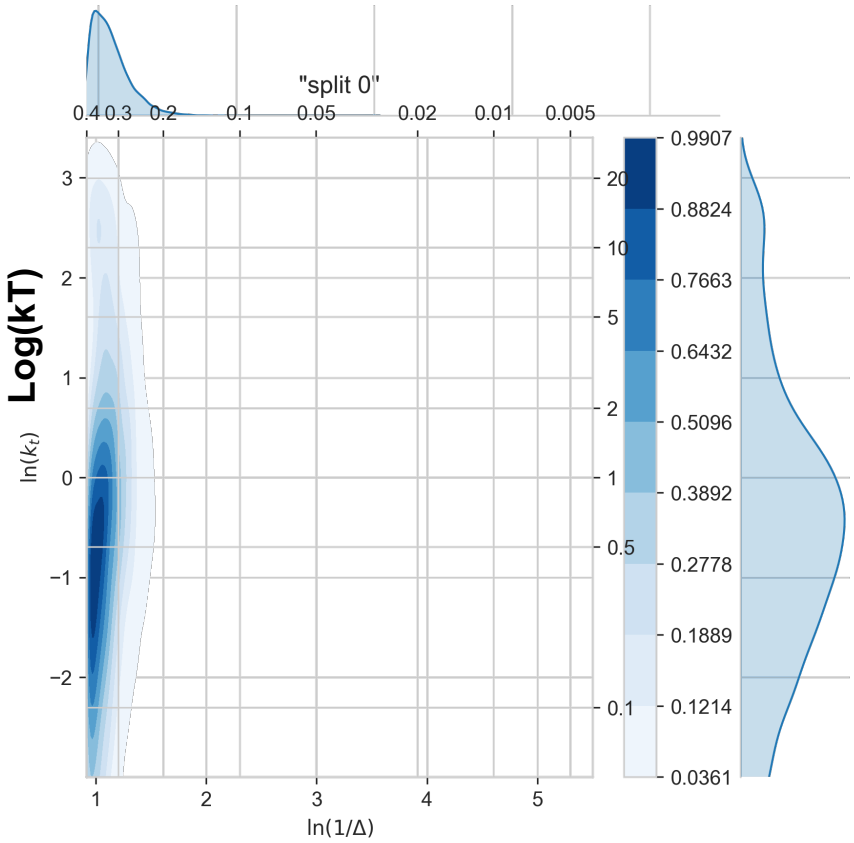


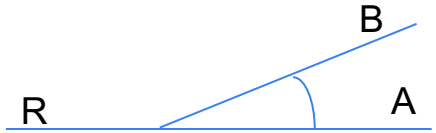


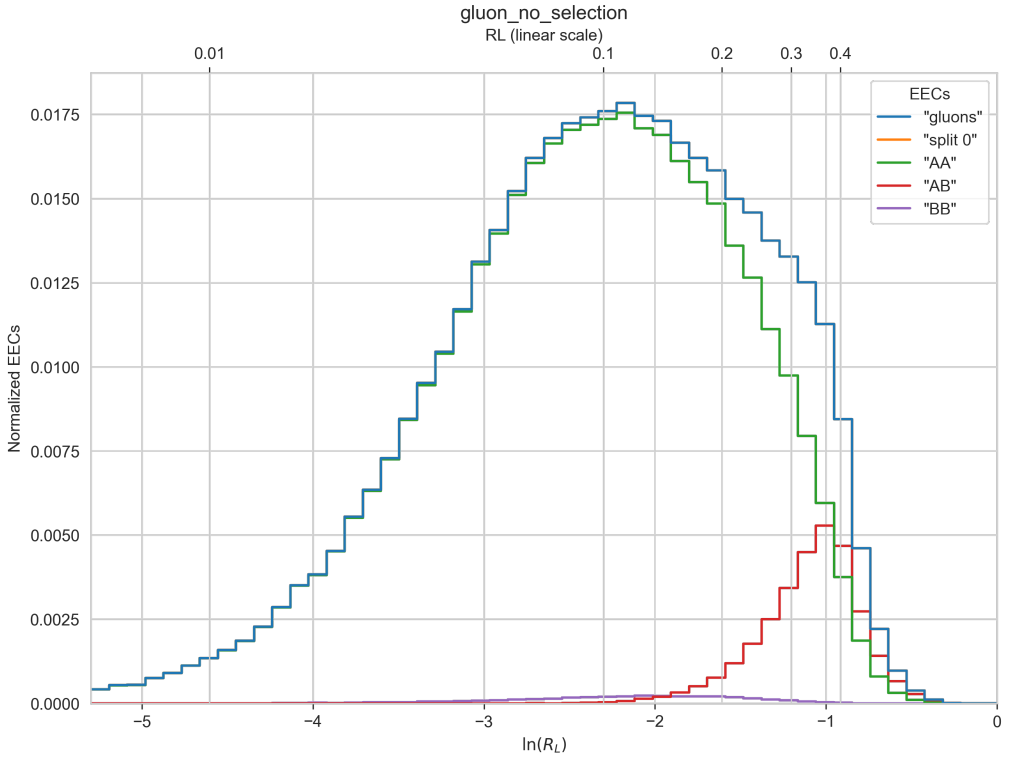

"gluons"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
Primary Lund Plane
of the jet
Log(kT)
ln(k_t)
ln(1/Δ)
Log(1/THETA)
0.1429
0.1203
0.1116
0.0993
0.0849
0.0696
0.0544
0.0398
0.0253
0.0088


B
R
A

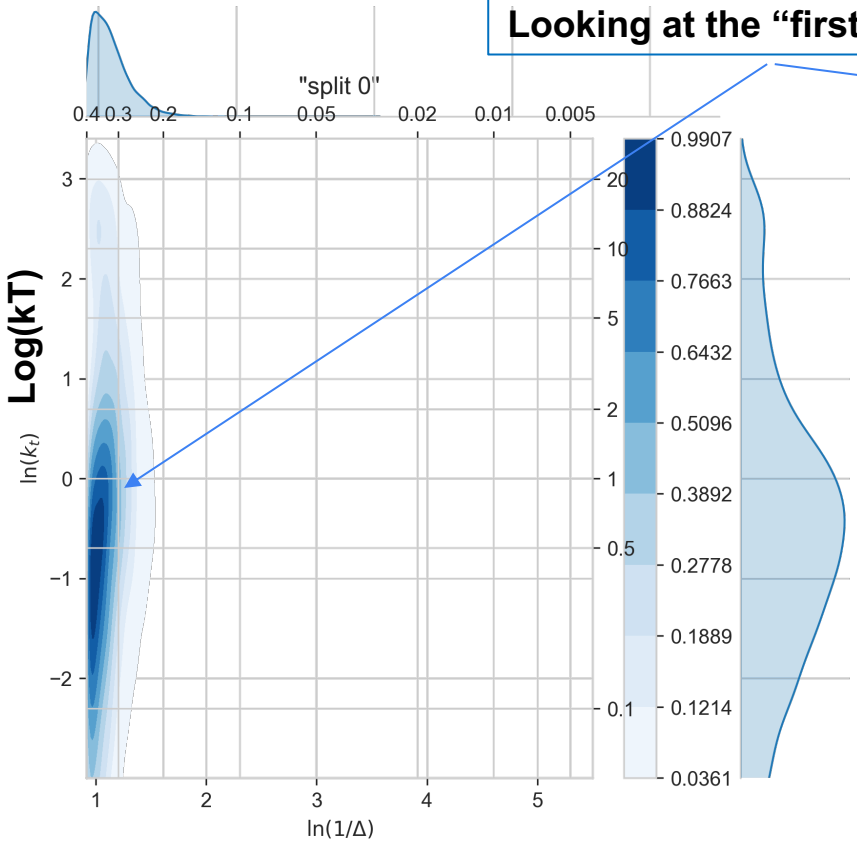

gluon_no_selection
RL (linear scale)
2-point EEC
of the jet
EECs
"gluons"
Normalized EECs
ln(R_L)
Log (RL)

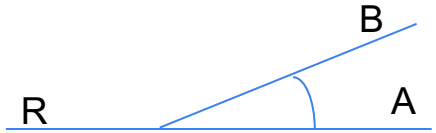

"split 0"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
Log(kT)
ln(k_t)
3
2
1
0
−1
−2
20
10
5
2
1
0.5
0.1
0.9907
0.8824
0.7663
0.6432
0.5096
0.3892
0.2778
0.1889
0.1214
0.0361
1
2
3
4
5
ln(1/Δ)
Log(1/THETA)

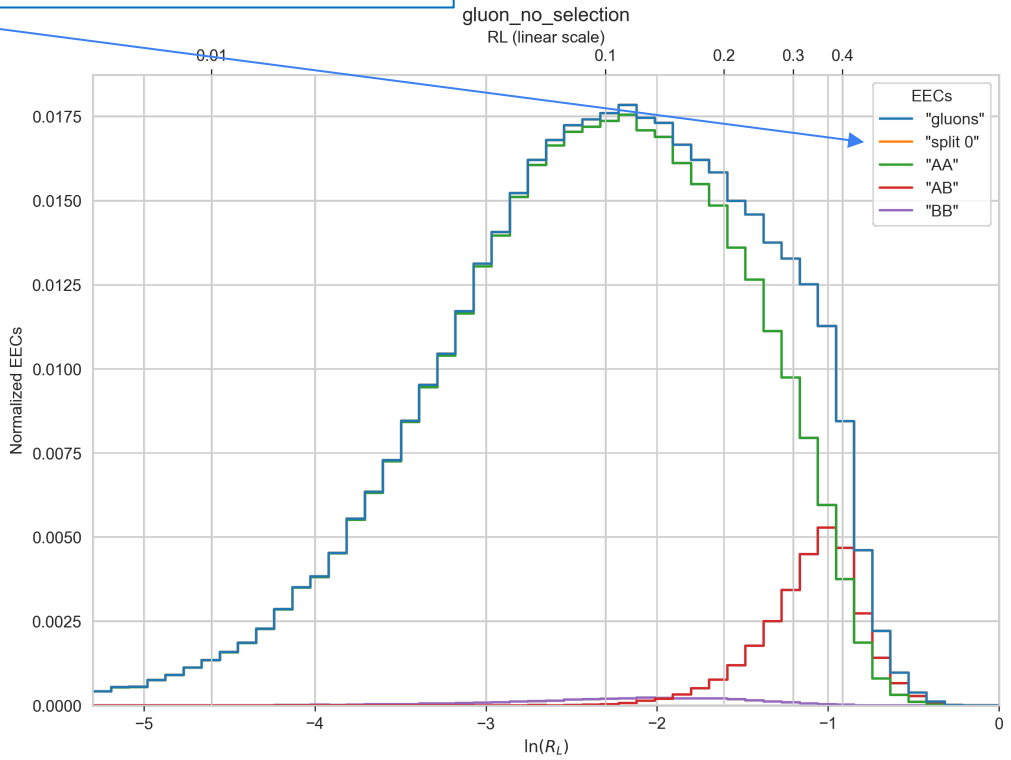

B
R
A


gluon_no_selection
RL (linear scale)
0.01
0.1
0.2
0.3
0.4
EECs
"gluons"
"split 0"
"AA"
"AB"
"BB"
Normalized EECs
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
−5
−4
−3
−2
−1
0
ln(R_L)

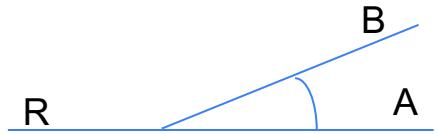
Looking at the “first” split – LAST clustering

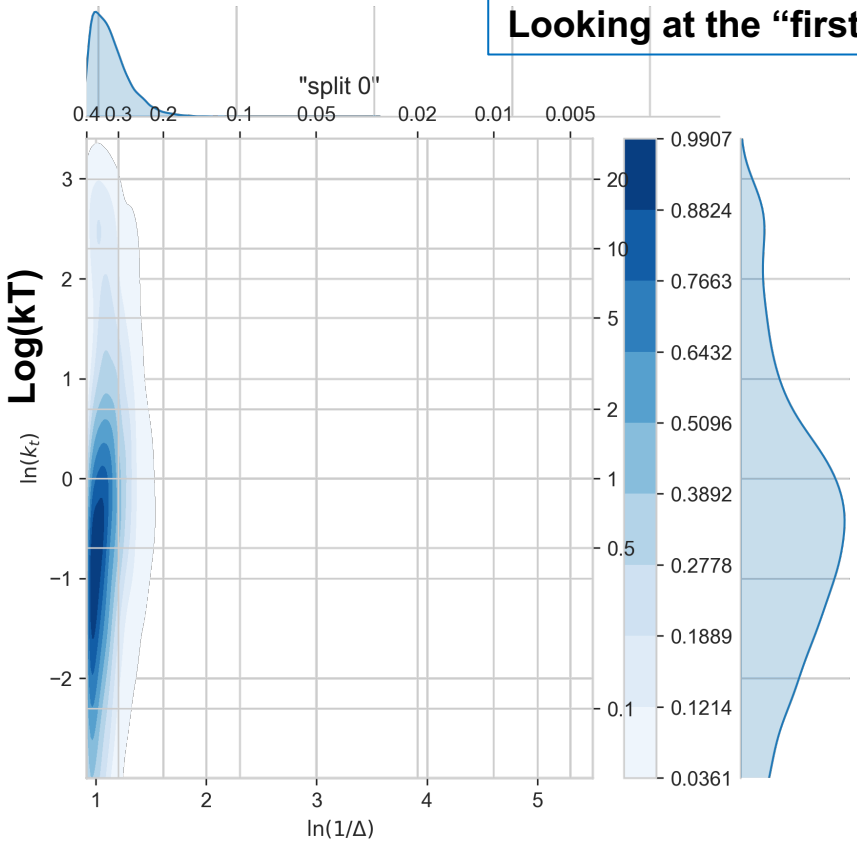


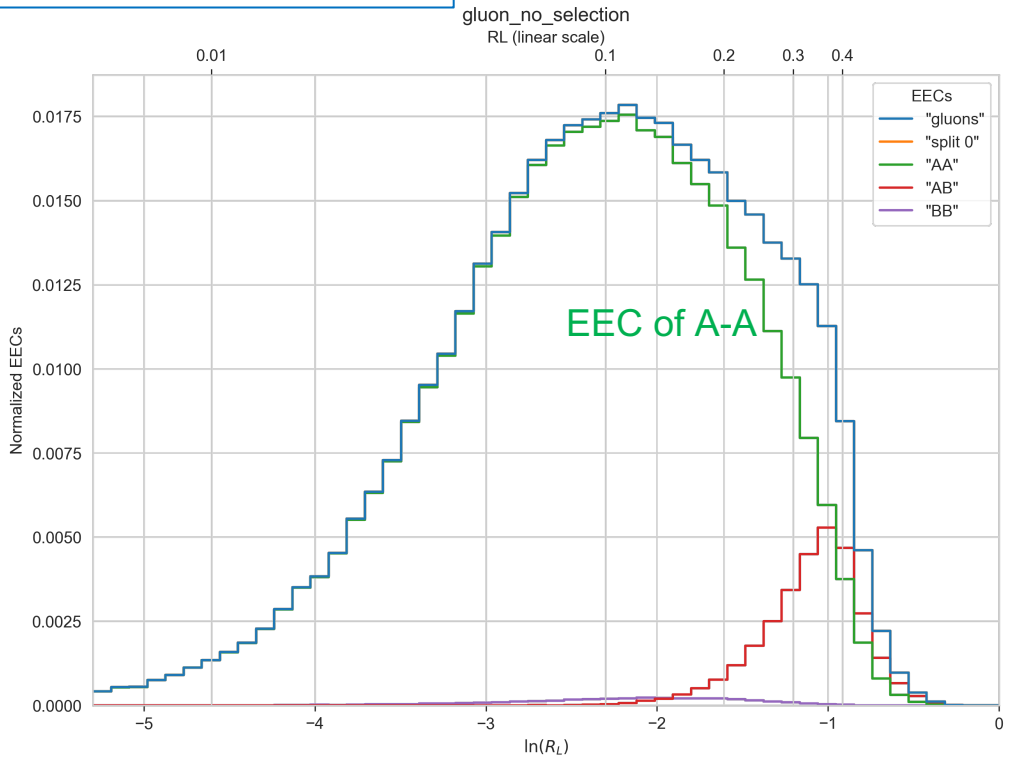




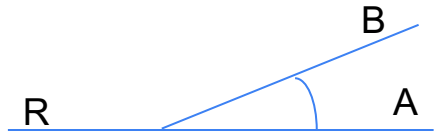
Looking at the “first” split – LAST clustering

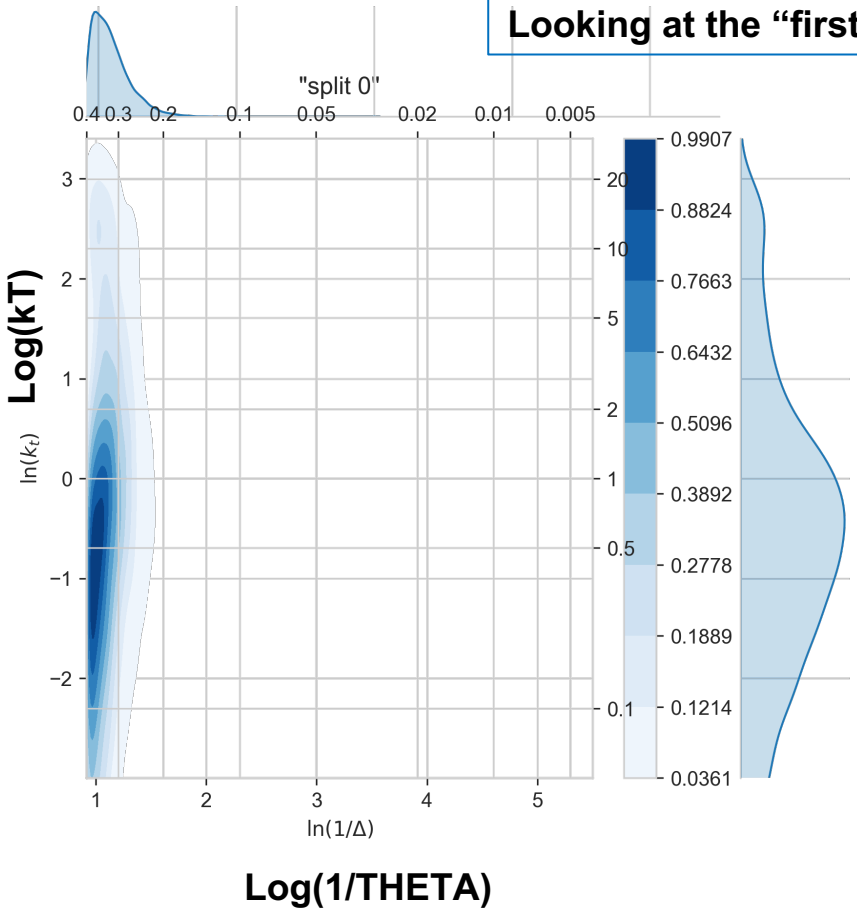


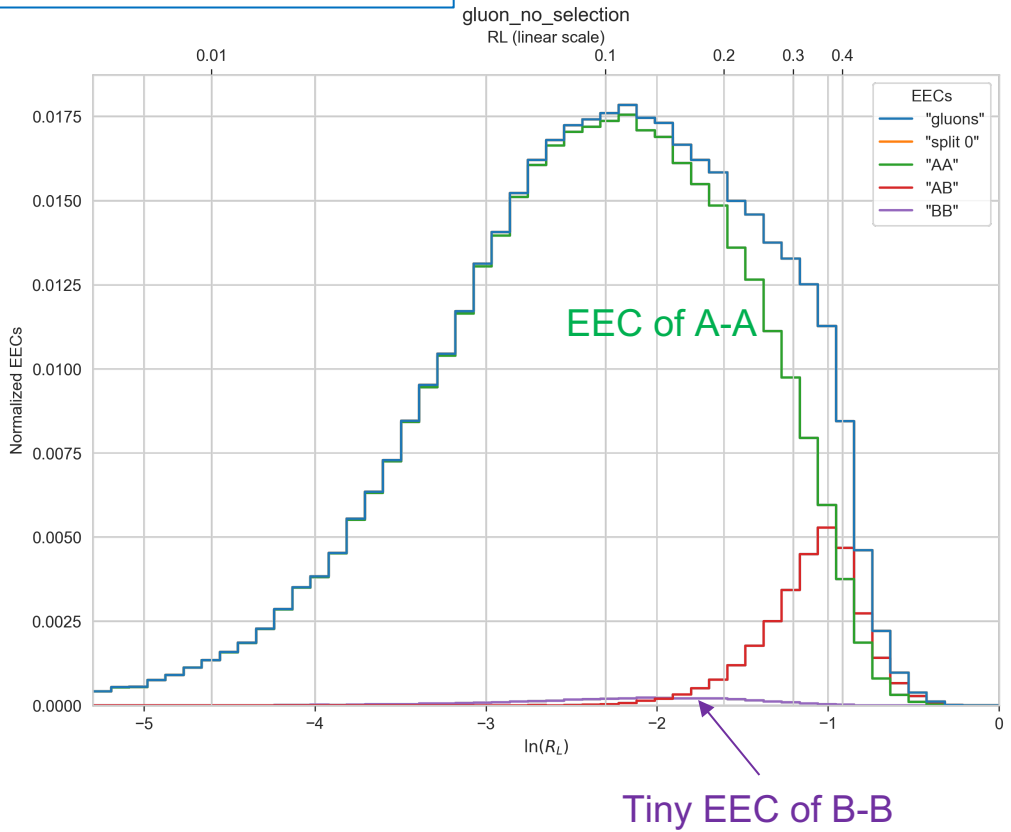




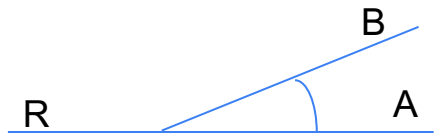
Looking at the “first” split – LAST clustering

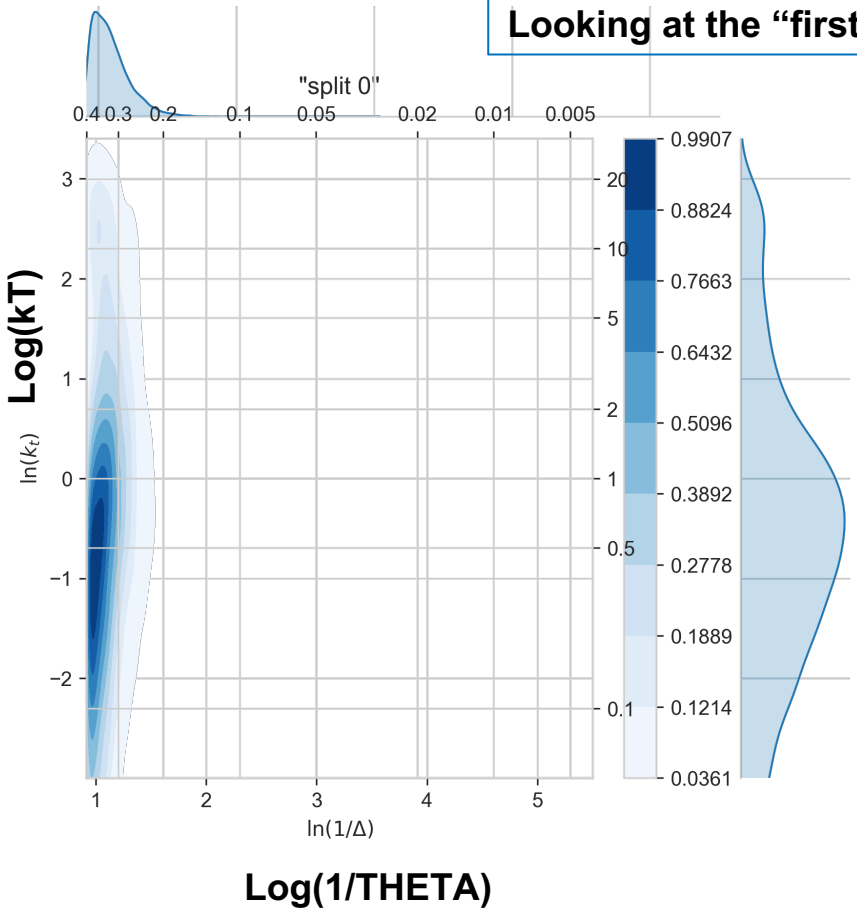


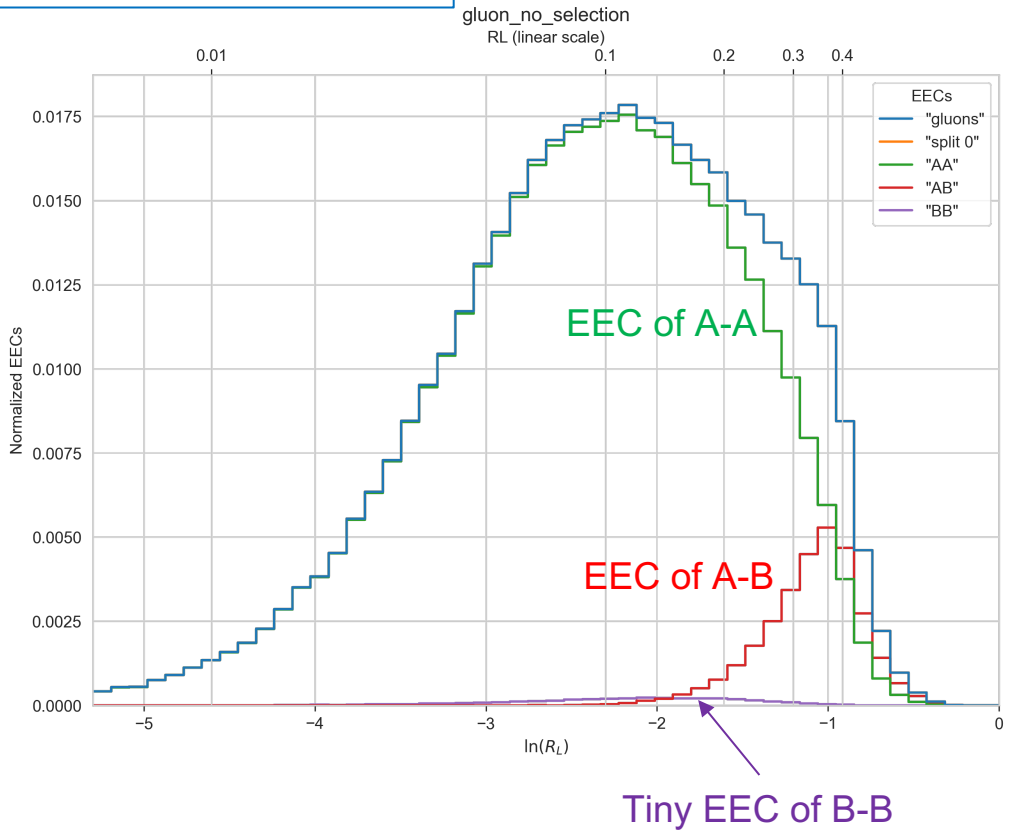




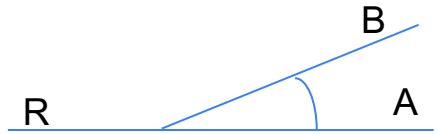
Looking at the “first” split – LAST clustering

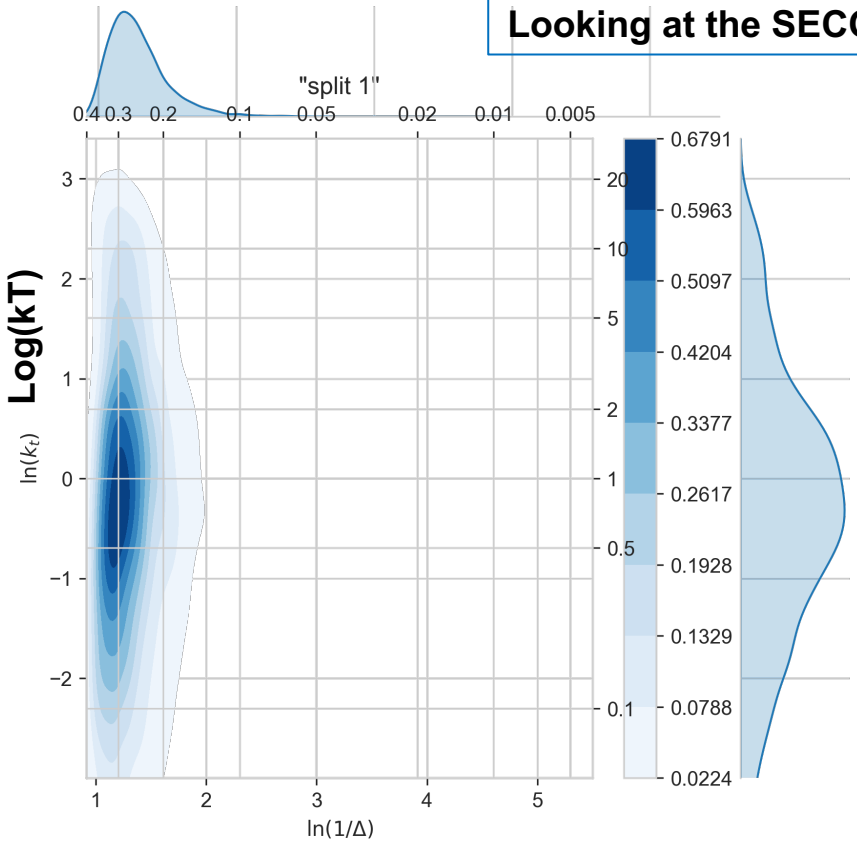


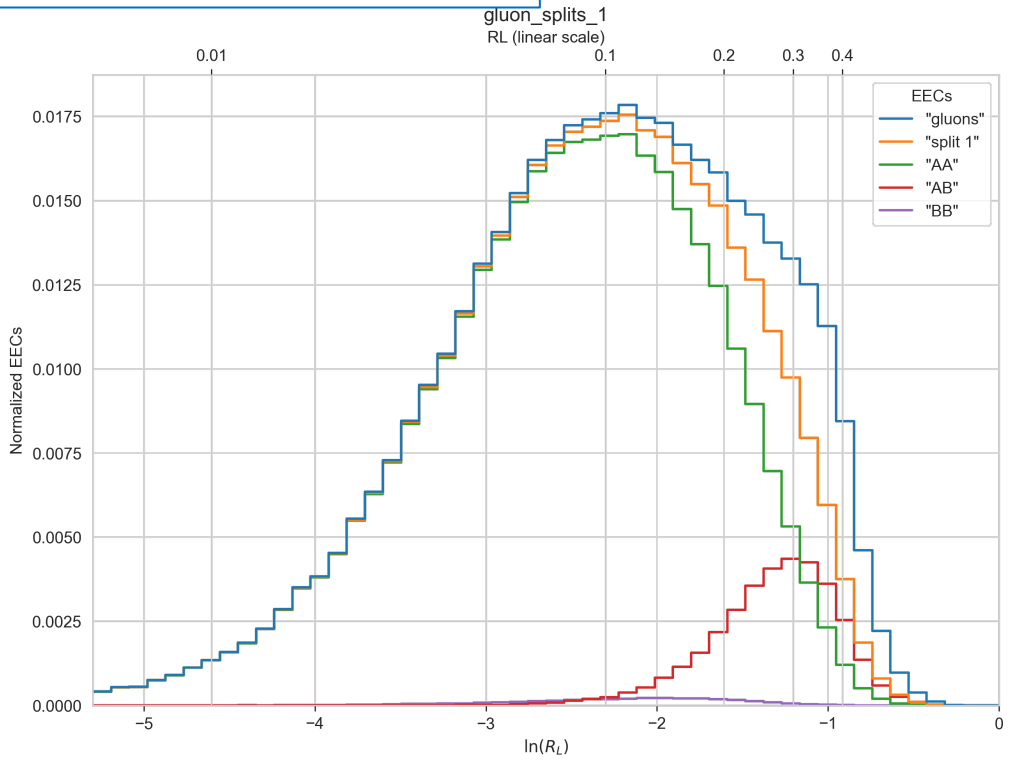


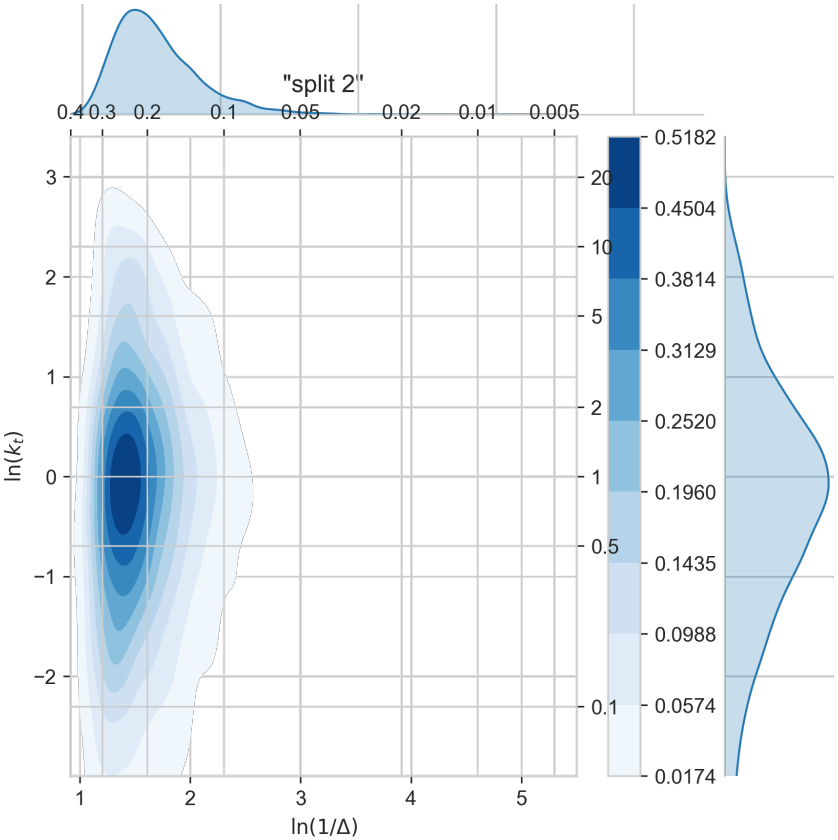


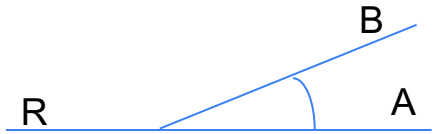
Looking at the SECOND split – LAST-1 clustering

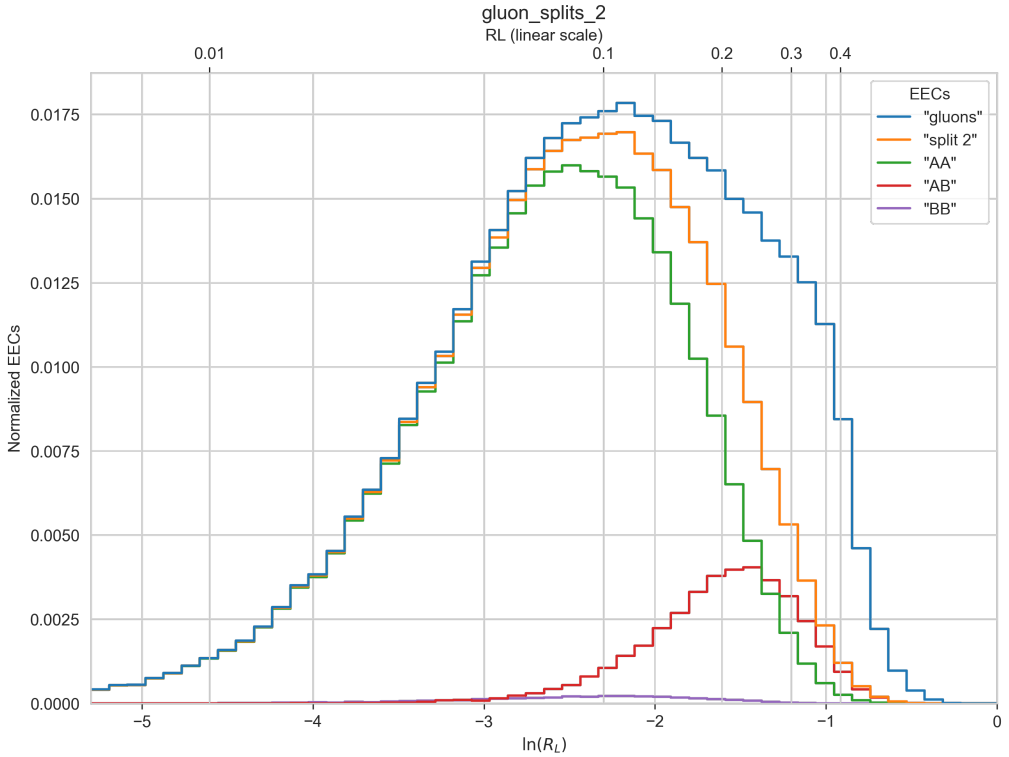


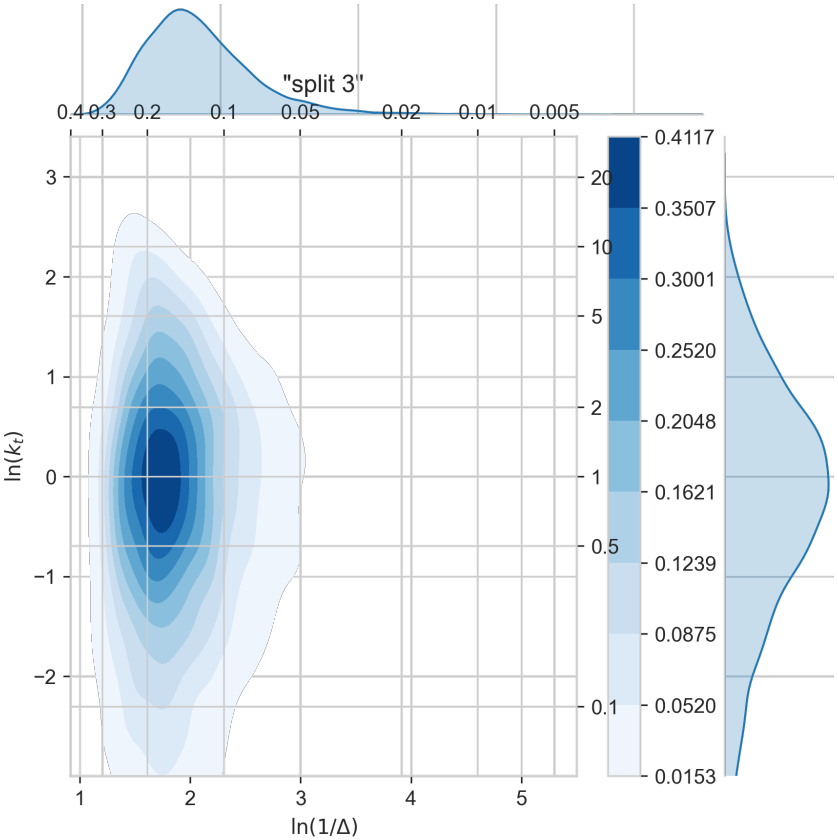


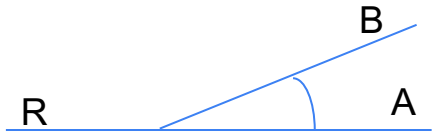


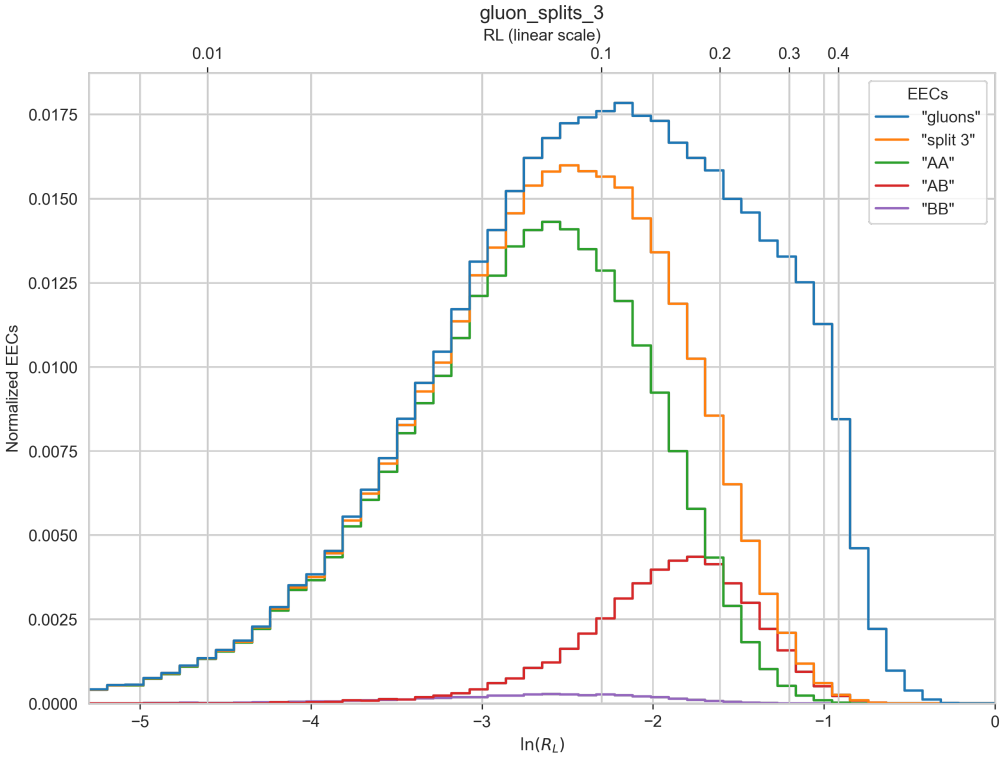

"split 2"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.5182
0.4504
0.3814
0.3129
0.2520
0.1960
0.1435
0.0988
0.0574
0.0174

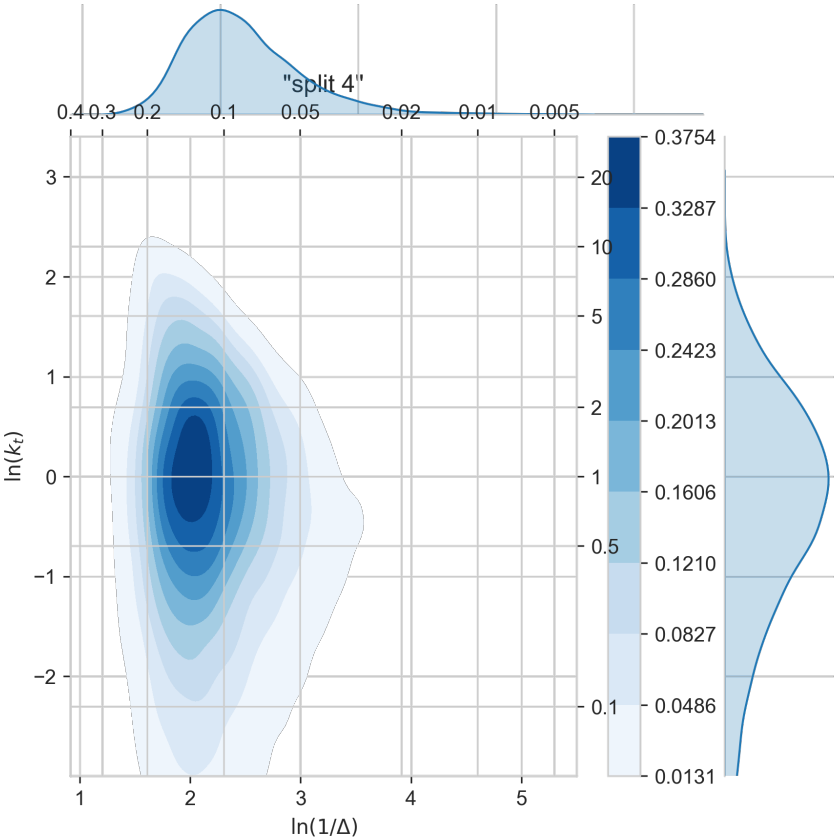

B
R
A

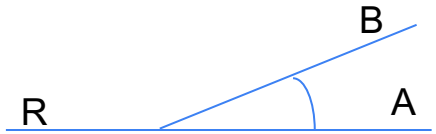

gluon_splits_2
RL (linear scale)
EECs
"gluons"
"split 2"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

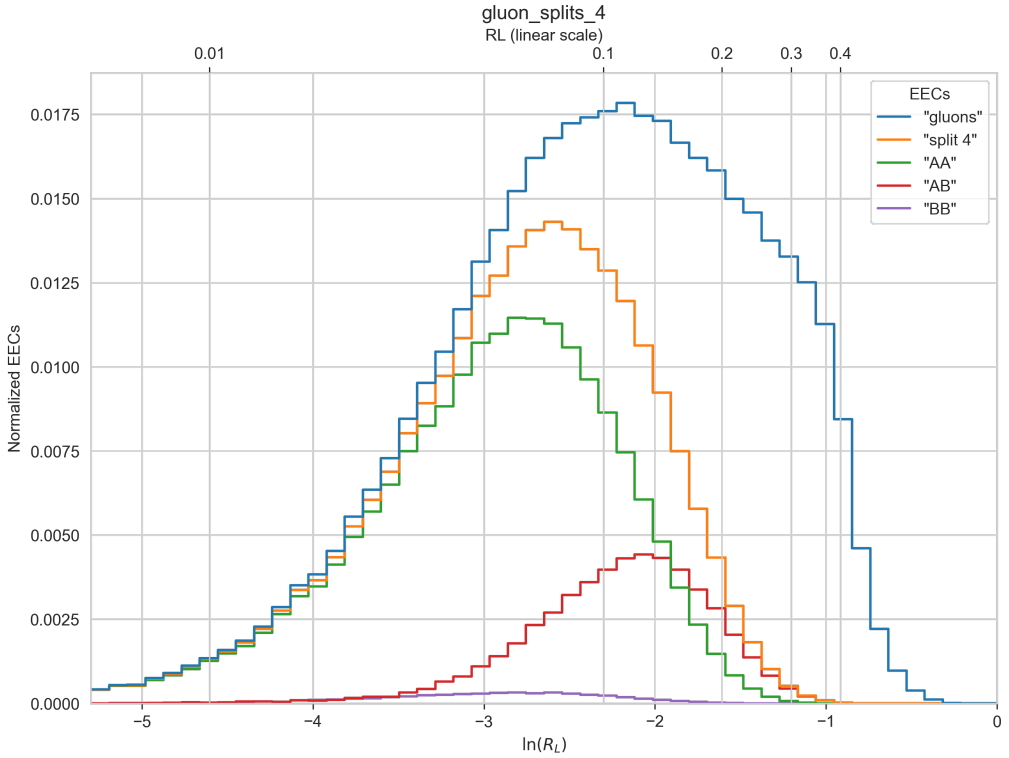

"split 3"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.4117
0.3507
0.3001
0.2520
0.2048
0.1621
0.1239
0.0875
0.0520
0.0153

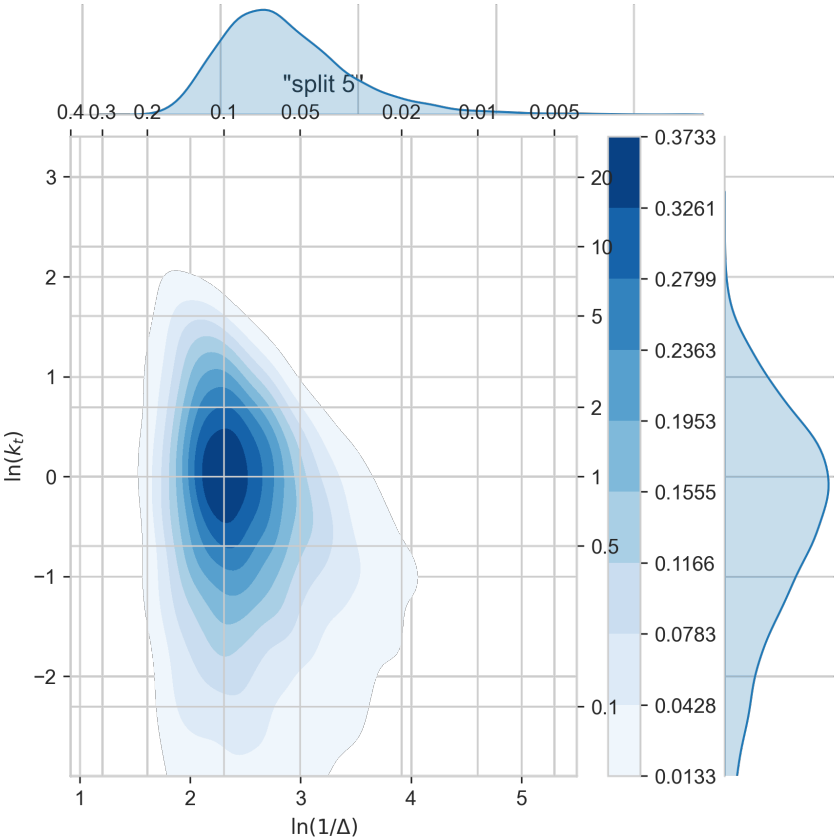

B
R
A

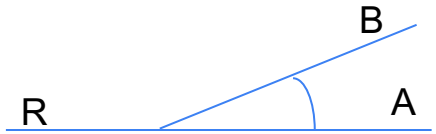

gluon_splits_3
RL (linear scale)
EECs
"gluons"
"split 3"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

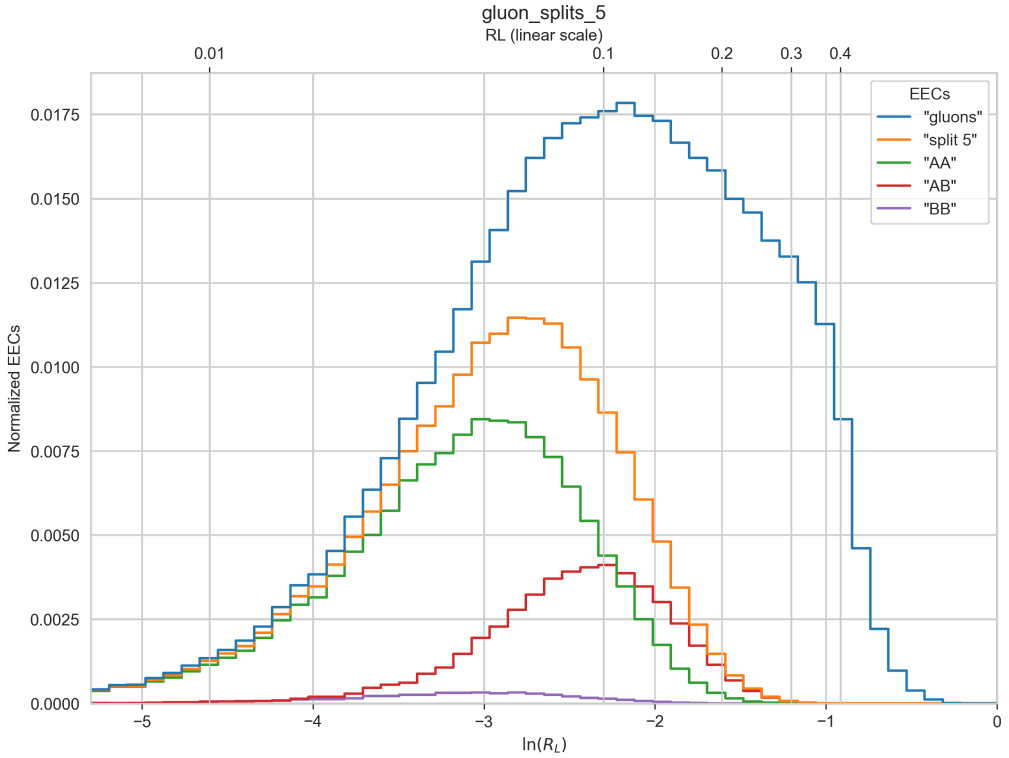

"split 4"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.3754
0.3287
0.2860
0.2423
0.2013
0.1606
0.1210
0.0827
0.0486
0.0131

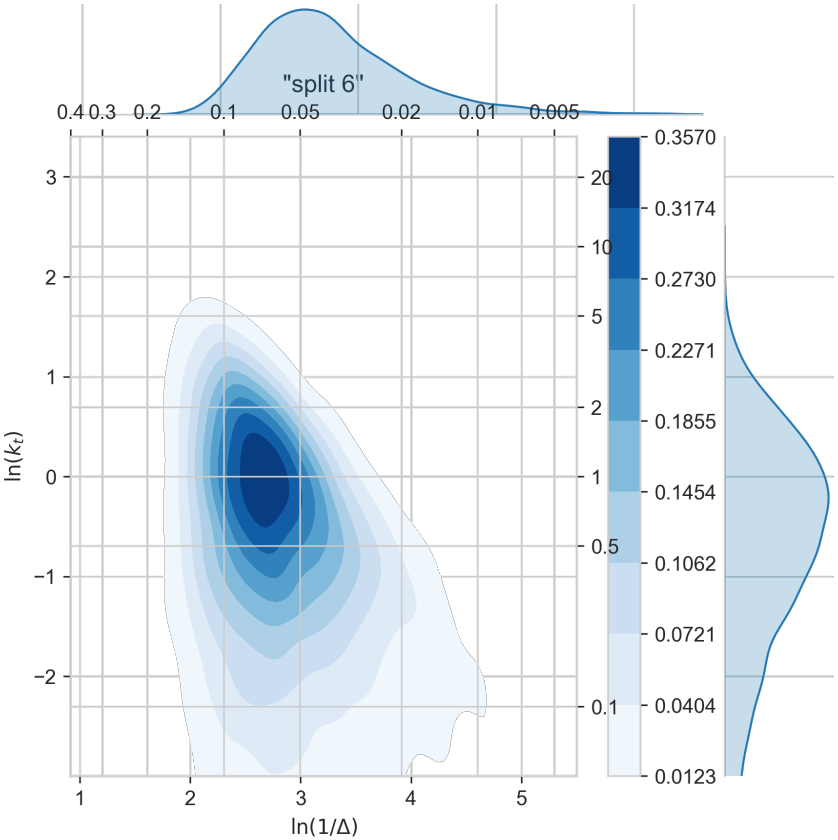

B
R
A

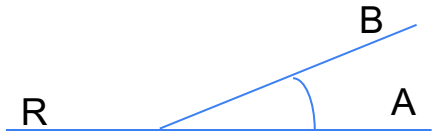

gluon_splits_4
RL (linear scale)
EECs
"gluons"
"split 4"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

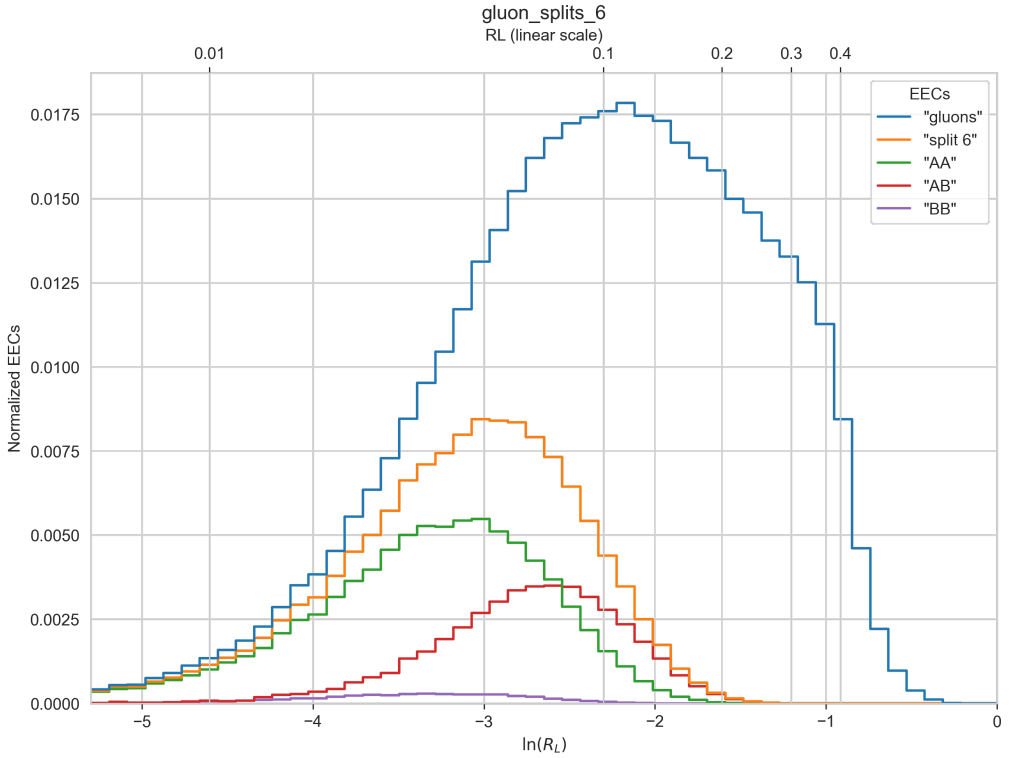

"split 5"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.3733
0.3261
0.2799
0.2363
0.1953
0.1555
0.1166
0.0783
0.0428
0.0133

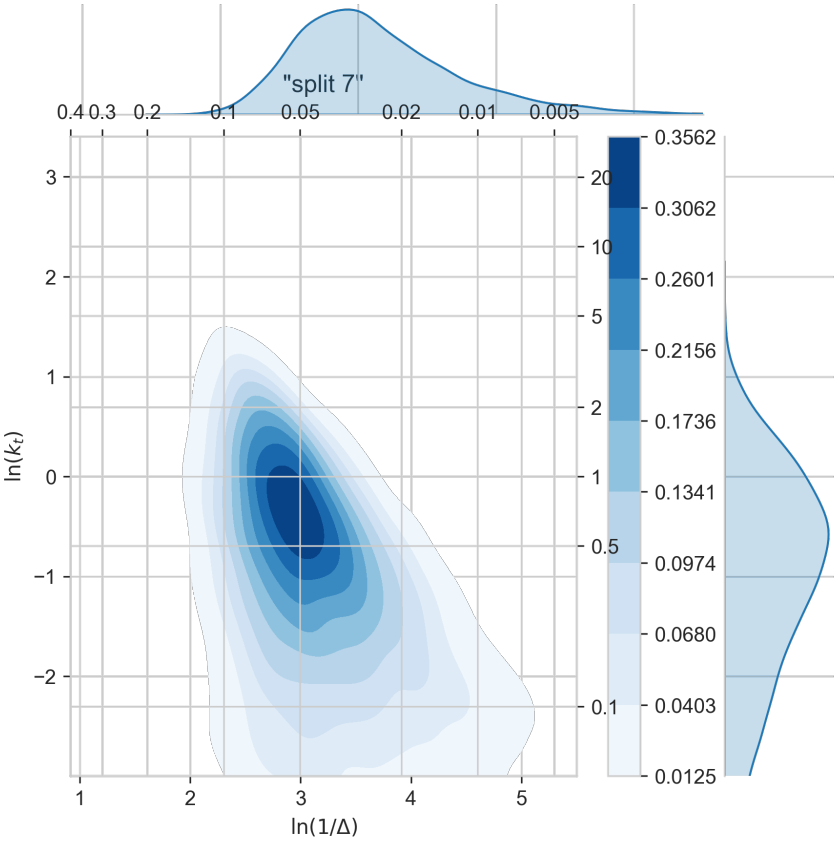

B
R
A

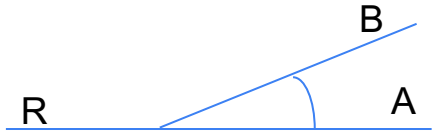

gluon_splits_5
RL (linear scale)
EECs
"gluons"
"split 5"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

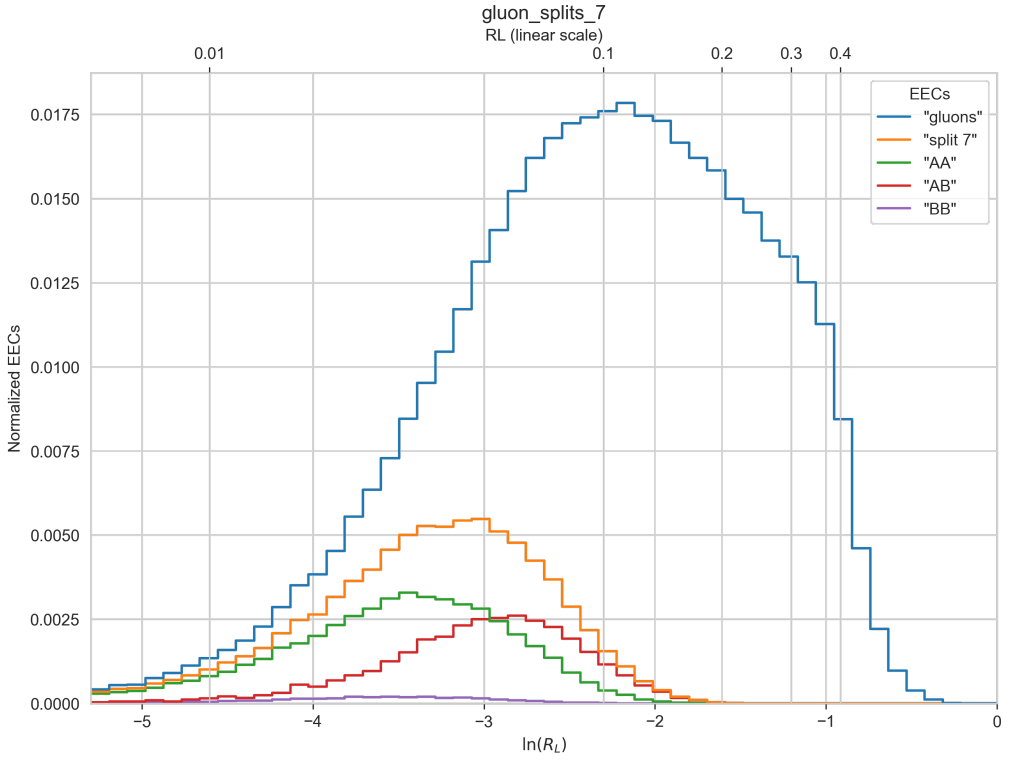

"split 6"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.3570
0.3174
0.2730
0.2271
0.1855
0.1454
0.1062
0.0721
0.0404
0.0123

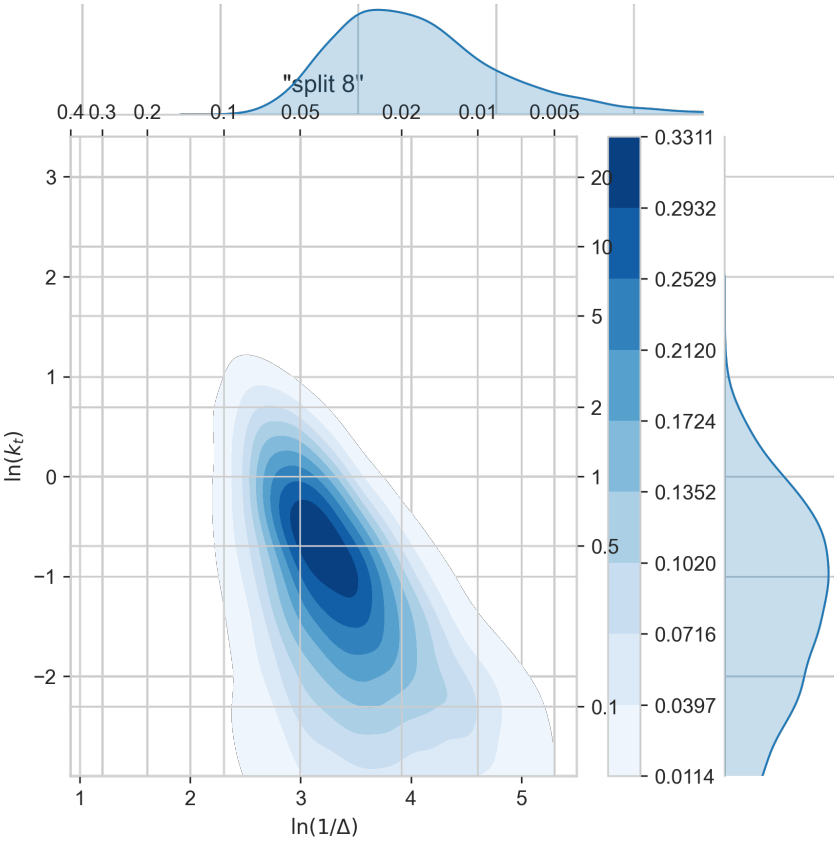

B
R
A

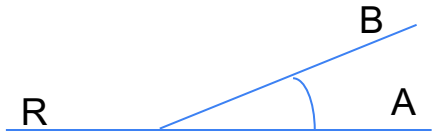

gluon_splits_6
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
Normalized EECs
ln(R_L)
EECs
"gluons"
"split 6"
"AA"
"AB"
"BB"

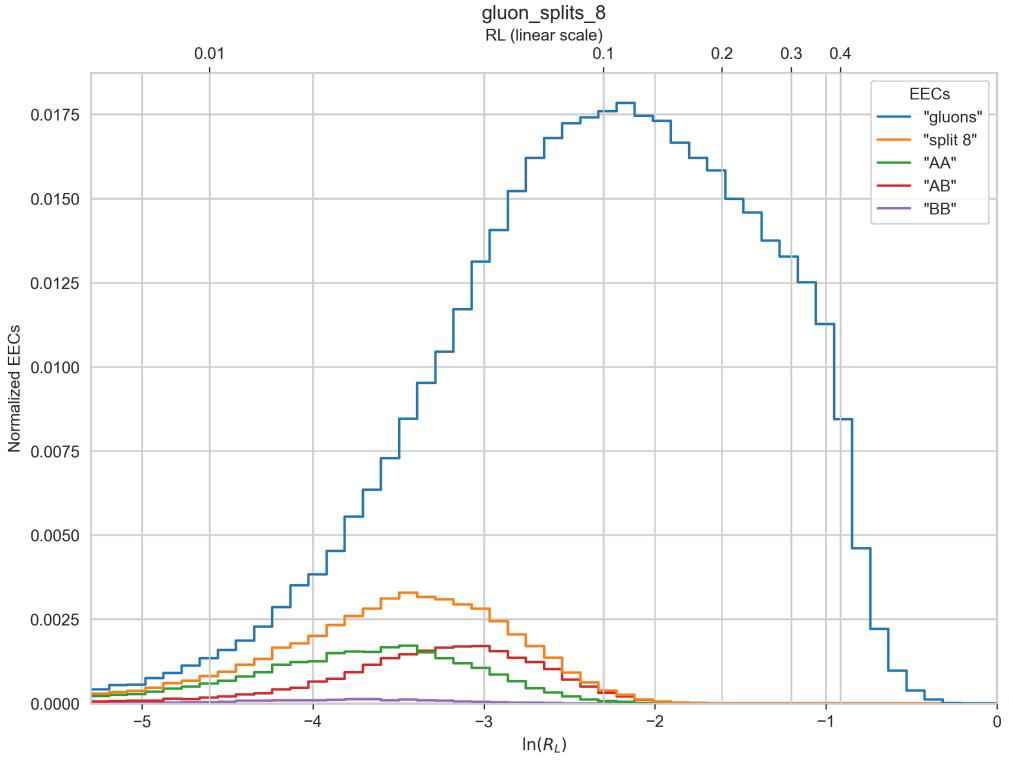

"split 7"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.3562
0.3062
0.2601
0.2156
0.1736
0.1341
0.0974
0.0680
0.0403
0.0125

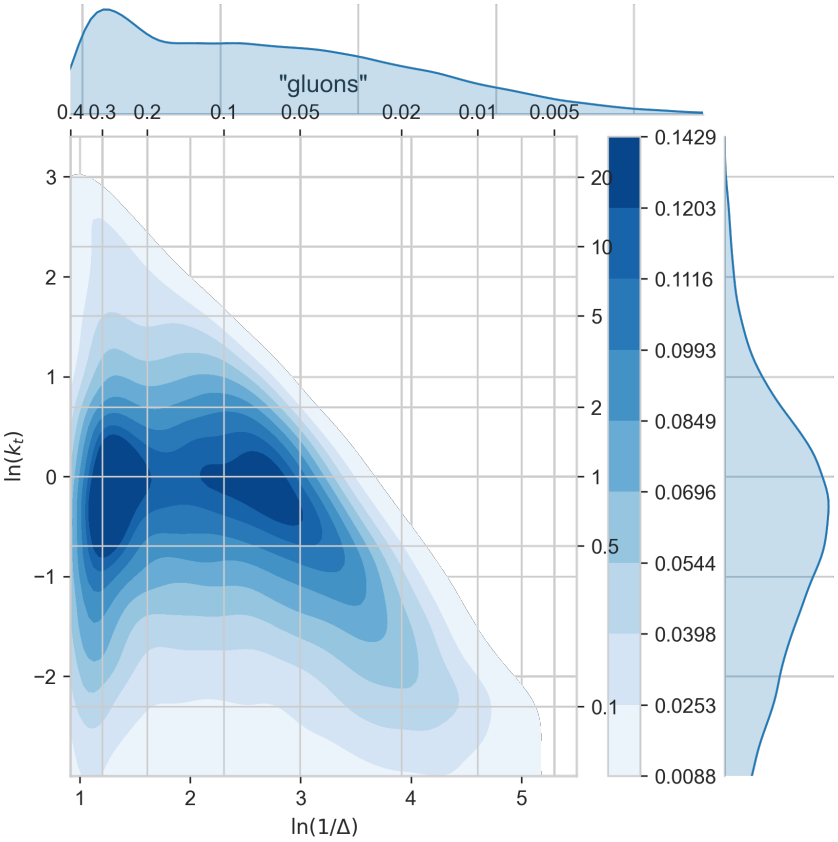

B
R
A

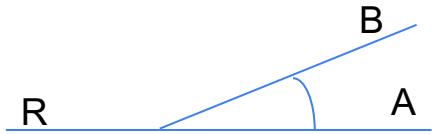

gluon_splits_7
RL (linear scale)
EECs
"gluons"
"split 7"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

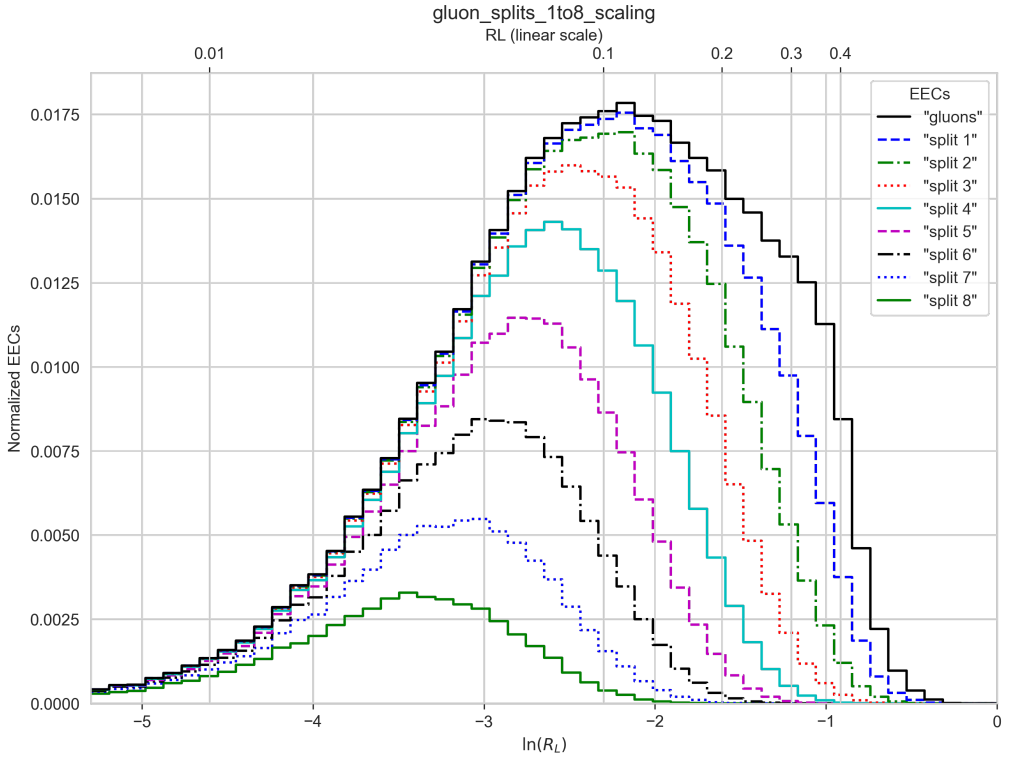

"split 8"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
3
2
1
0
−1
−2
$\ln(k_t)$
1 2 3 4 5
$\ln(1/\Delta)$
20
10
5
2
1
0.5
0.1
0.3311
0.2932
0.2529
0.2120
0.1724
0.1352
0.1020
0.0716
0.0397
0.0114


B
R
A


gluon_splits_8
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
EECs
"gluons"
"split 8"
"AA"
"AB"
"BB"
Normalized EECs
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
−5 −4 −3 −2 −1 0
$\ln(R_L)$

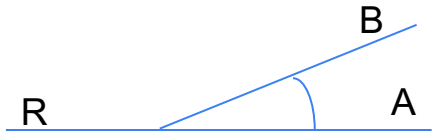

"gluons"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.1429
0.1203
0.1116
0.0993
0.0849
0.0696
0.0544
0.0398
0.0253
0.0088

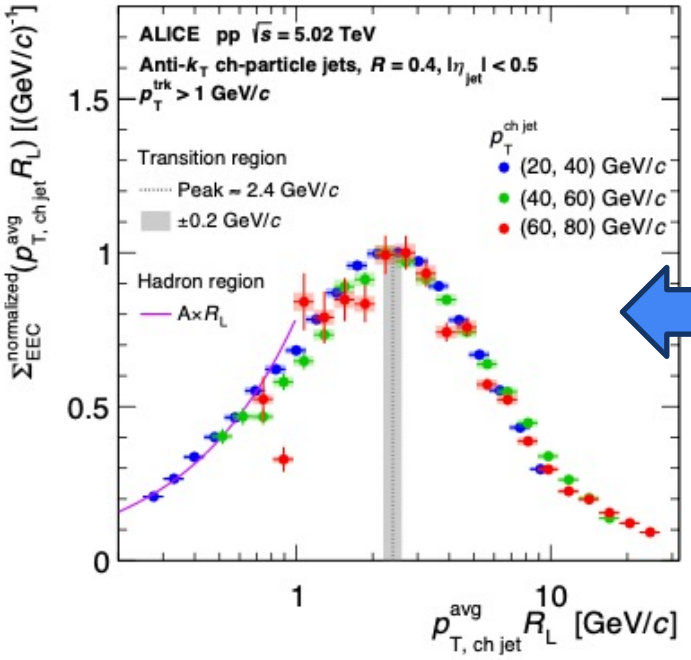

B
R
A

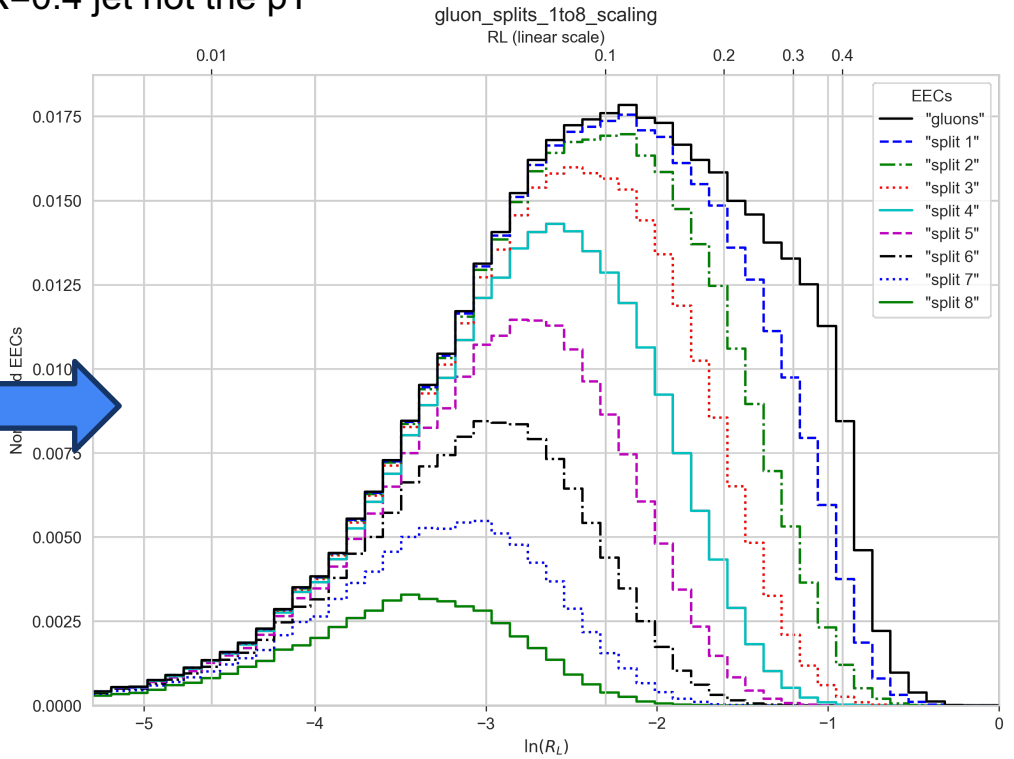

gluon_splits_1to8_scaling
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
Normalized EECs
ln(R_L)
EECs
"gluons"
"split 1"
"split 2"
"split 3"
"split 4"
"split 5"
"split 6"
"split 7"
"split 8"

Side comment: Can we tes the scaling / **break down of it at low-pT**?
In principle each of those subjet EEC's should follow the RL x pT scaling (RIGHT: "wrongly" normalized to pT of the R=0.4 jet not the pT of the subjet…)

?



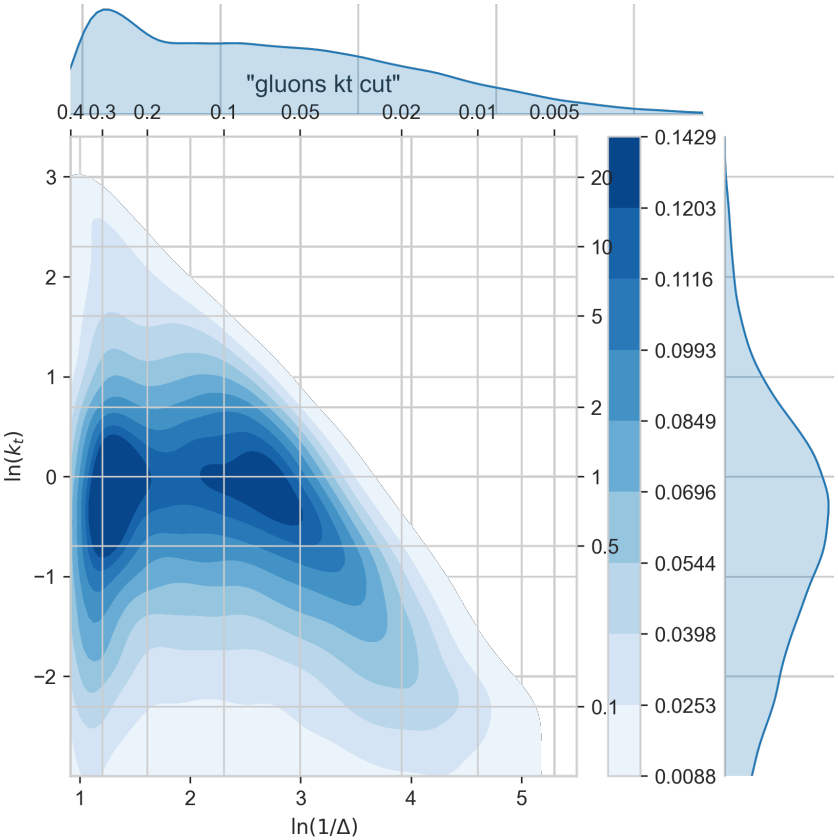


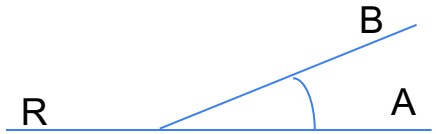


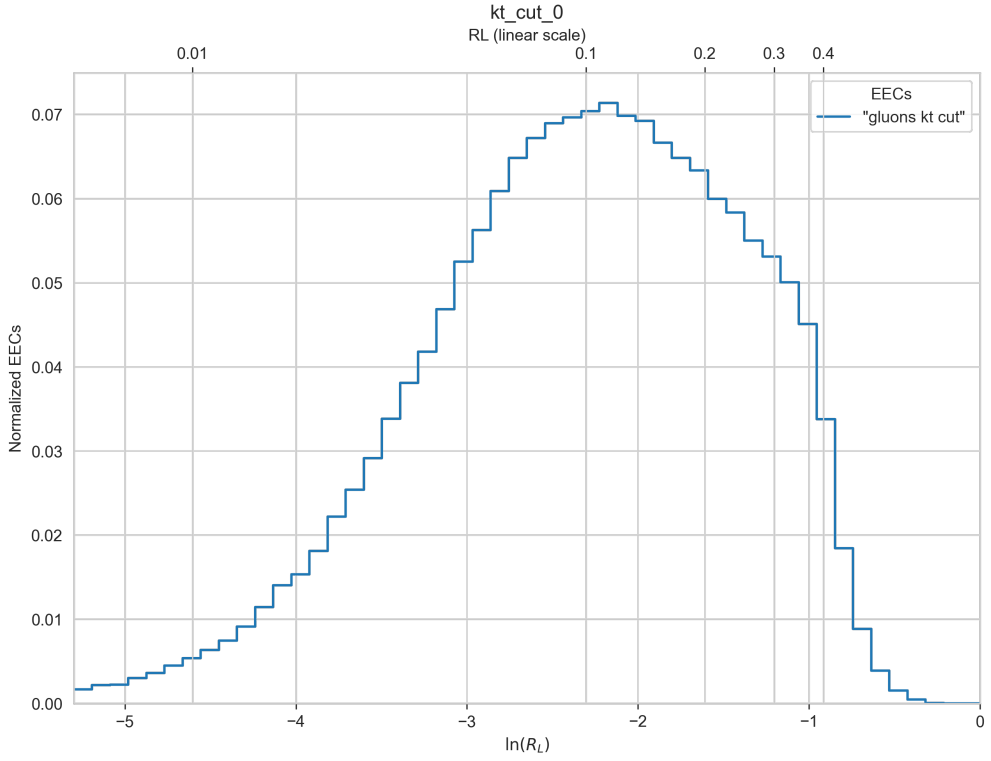
Traversing **Lund Plane *and* EECs – inter-summary**

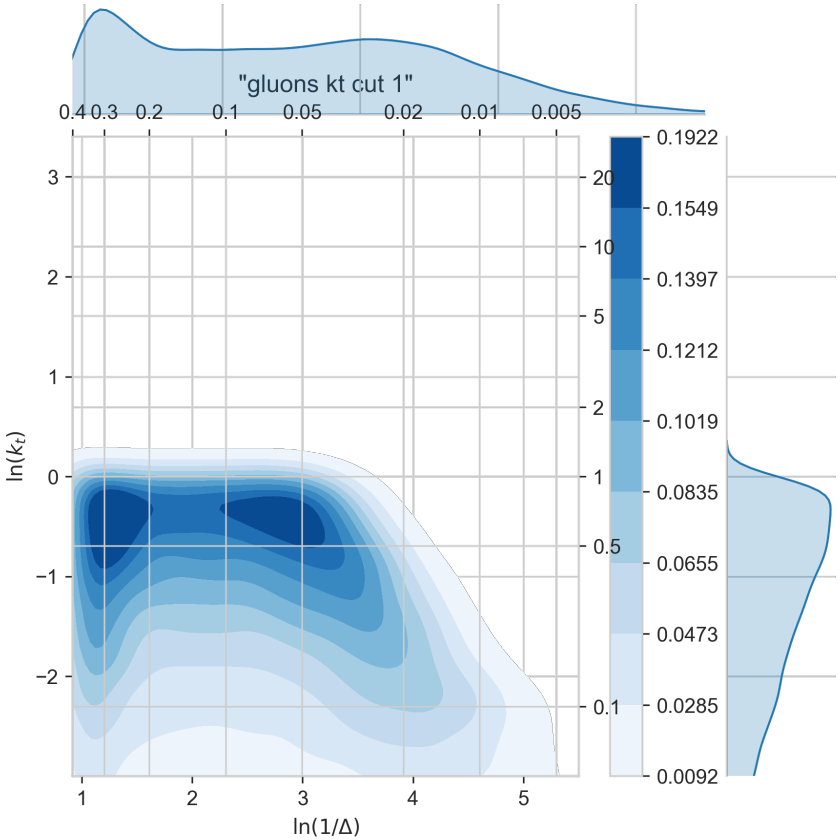
- “Last” clusterings (first in the declustering chain) – large angle / small – kT – few particles – still contribute to the large angle EECs
  - Not necessarily “early” splittings – pickup from UE works the same way…
- Further into the declustering tree:
  - Smaller angle EEC for the radiator (expected)
  - Clearly AB pairs **dominate** to large RL behavior (somewhat expected)
  - AA and BB (within-the-same-subjet” EECs) drive the low-angle EECs (expected)
- Can we use such a tool?
  - Caveats: backgrounds (breakdown of the clustering – mismatches/false branch/branch swap)
  - Additional info on parton-hadron transition?
  - What about jets in-QGP?

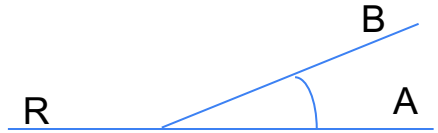
Suppress *OR* study
hadronization/non-perturbative [regions]
a) select on kT in the Lund Plane

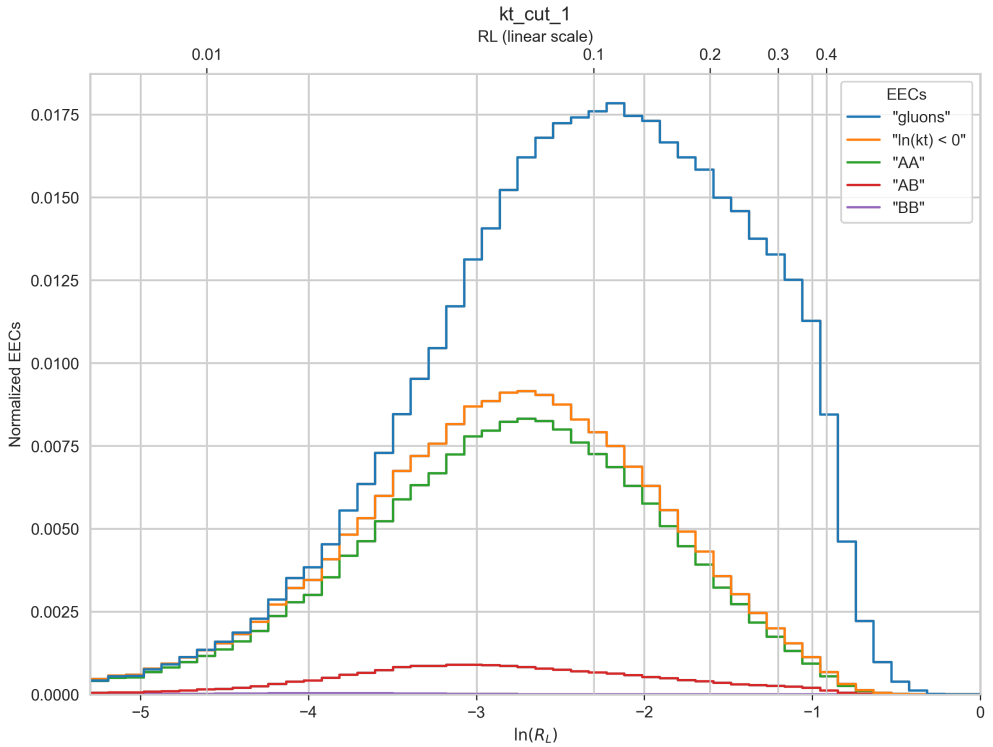

"gluons kt cut"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.1429
0.1203
0.1116
0.0993
0.0849
0.0696
0.0544
0.0398
0.0253
0.0088

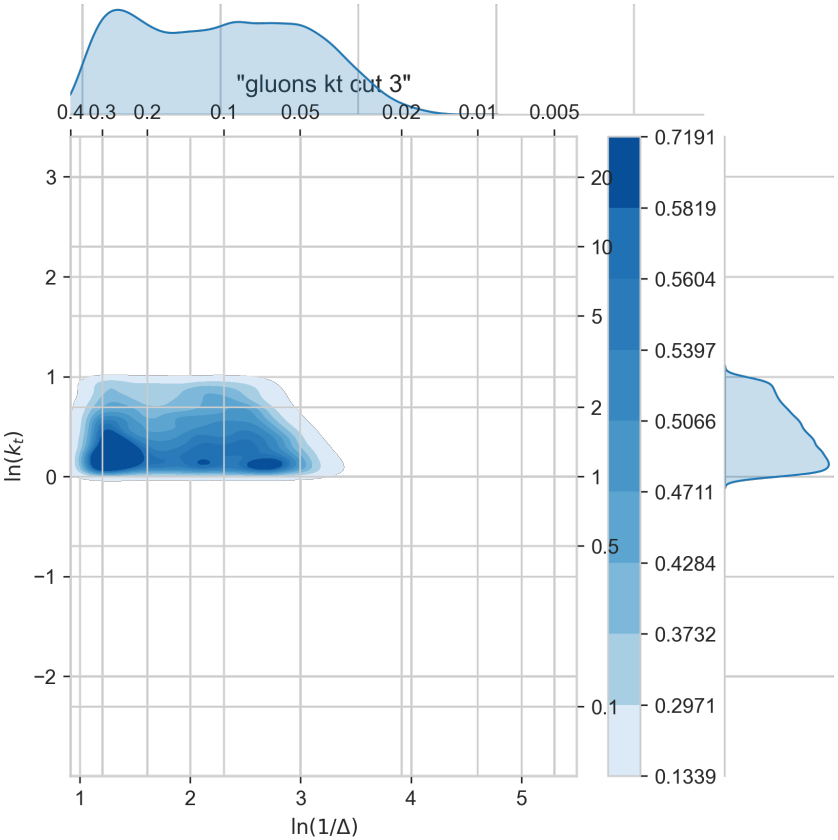

B
R
A

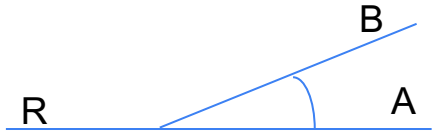

kt_cut_0
RL (linear scale)
EECs
"gluons kt cut"
Normalized EECs
ln(R_L)

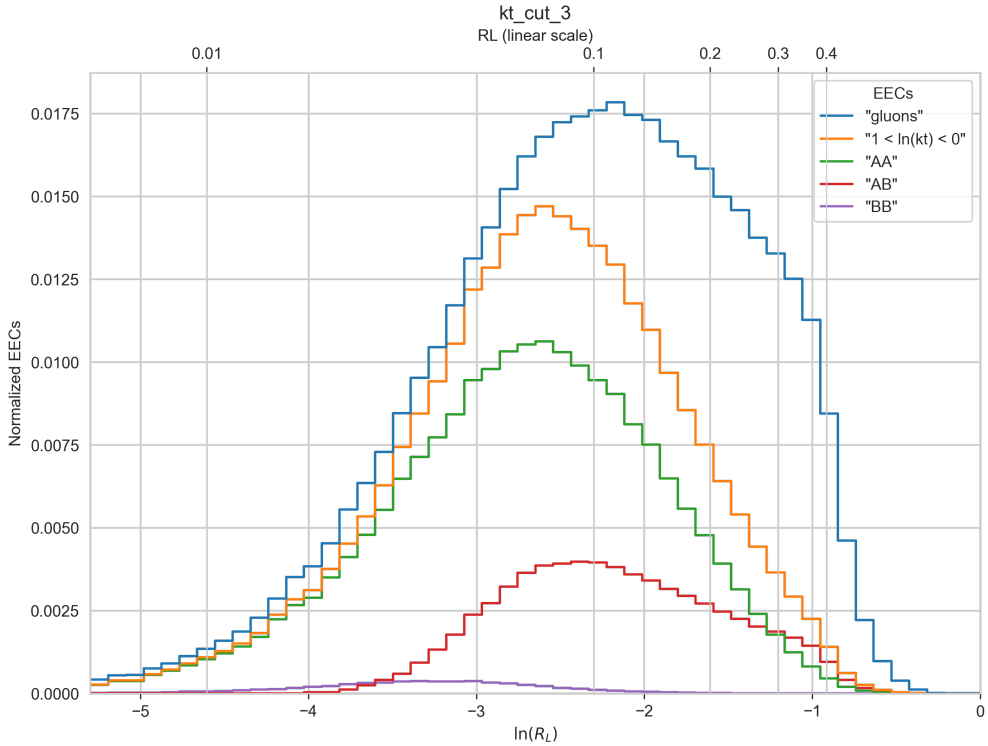

"gluons kt cut 1"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.1922
0.1549
0.1397
0.1212
0.1019
0.0835
0.0655
0.0473
0.0285
0.0092

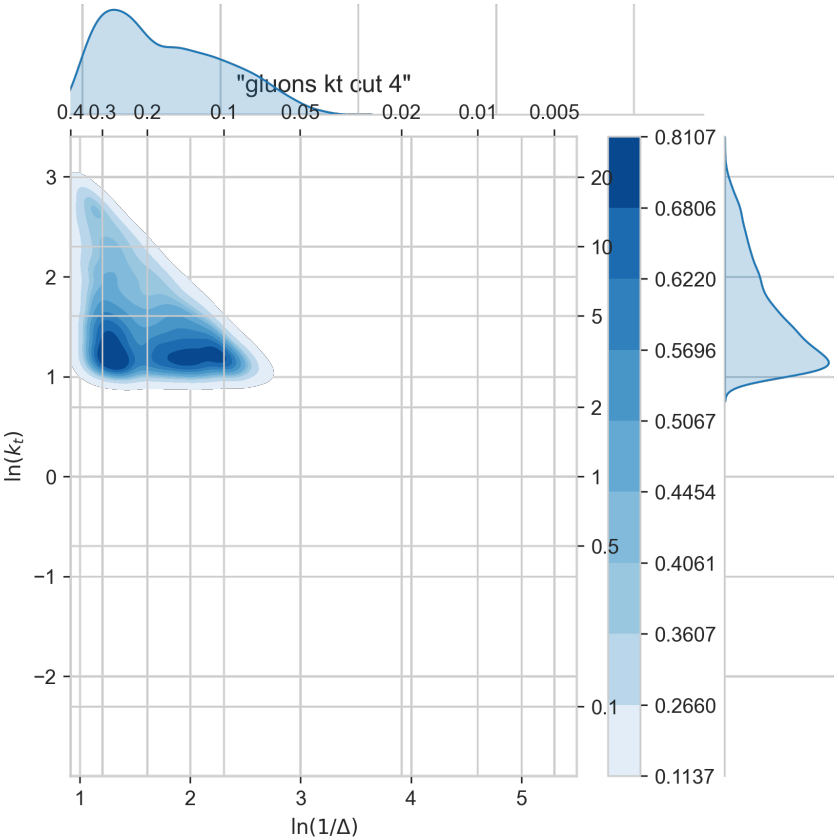

B
R
A

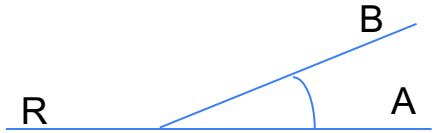

kt_cut_1
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
Normalized EECs
ln(R_L)
EECs
"gluons"
"ln(kt) < 0"
"AA"
"AB"
"BB"

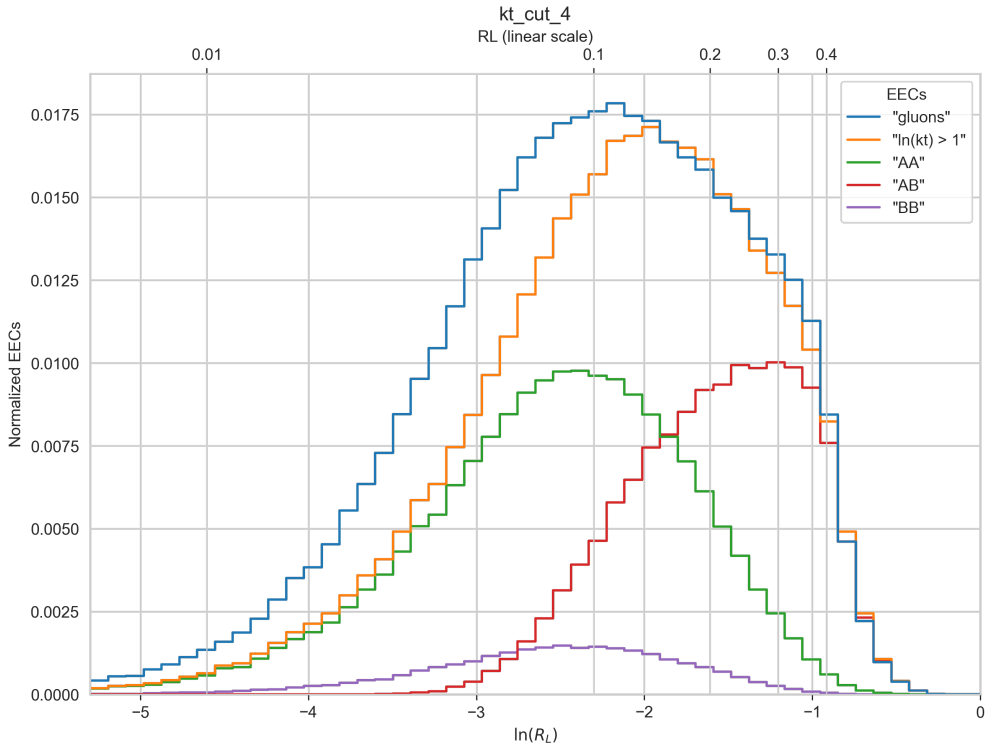

"gluons kt cut 3"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(k_t)
ln(1/Δ)
0.7191
0.5819
0.5604
0.5397
0.5066
0.4711
0.4284
0.3732
0.2971
0.1339


B
R
A


kt_cut_3
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
EECs
"gluons"
"1 < ln(kt) < 0"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)


"gluons kt cut 4"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(k_t)
ln(1/Δ)
0.8107
0.6806
0.6220
0.5696
0.5067
0.4454
0.4061
0.3607
0.2660
0.1137


B
R
A

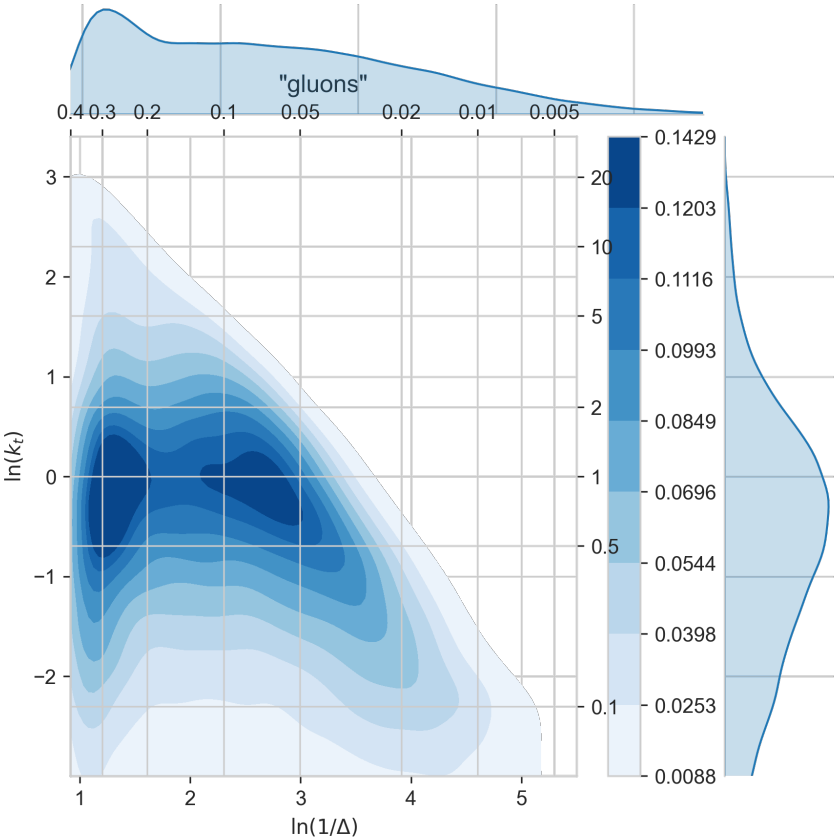

kt_cut_4
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
EECs
"gluons"
"ln(kt) > 1"
"AA"
"AB"
"BB"
Normalized EECs
ln(R_L)

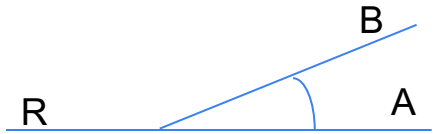
Suppress *OR* study

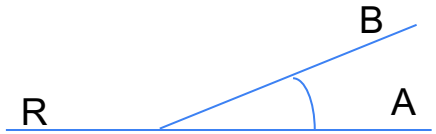
hadronization/non-perturbative [regions]

a) select on kT in the Lund Plane

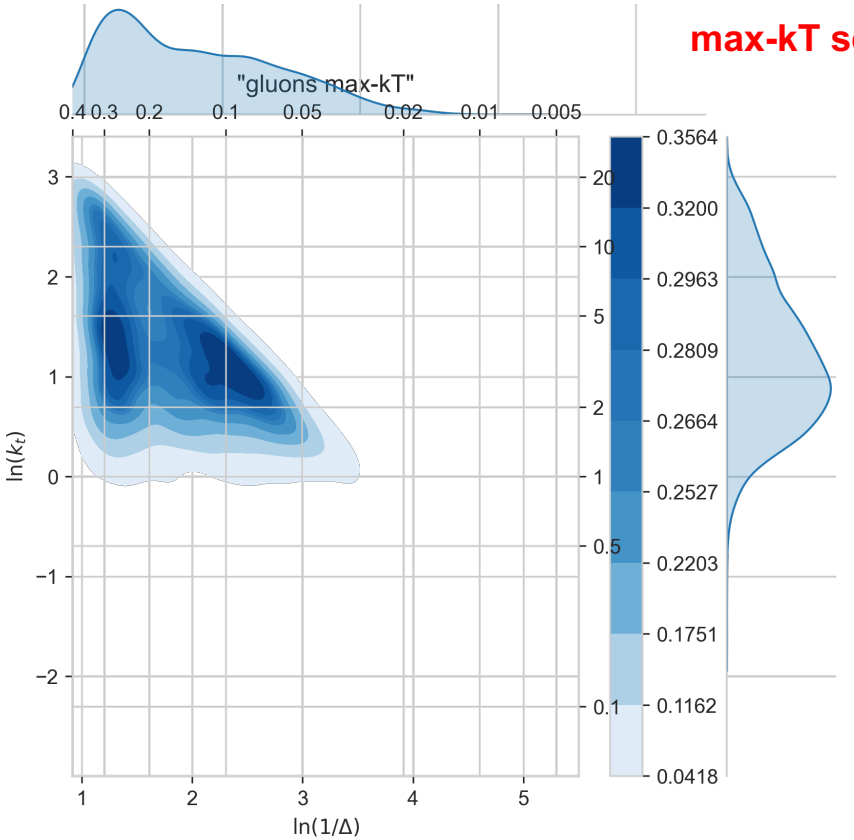
b) employ groomer(s)?


"gluons"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
3
2
1
0
−1
−2
ln(k_t)
1 2 3 4 5
ln(1/Δ)
20
10
5
2
1
0.5
0.1
0.1429
0.1203
0.1116
0.0993
0.0849
0.0696
0.0544
0.0398
0.0253
0.0088

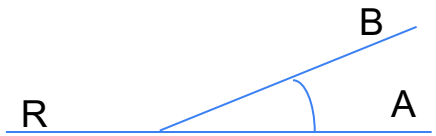

B
R
A

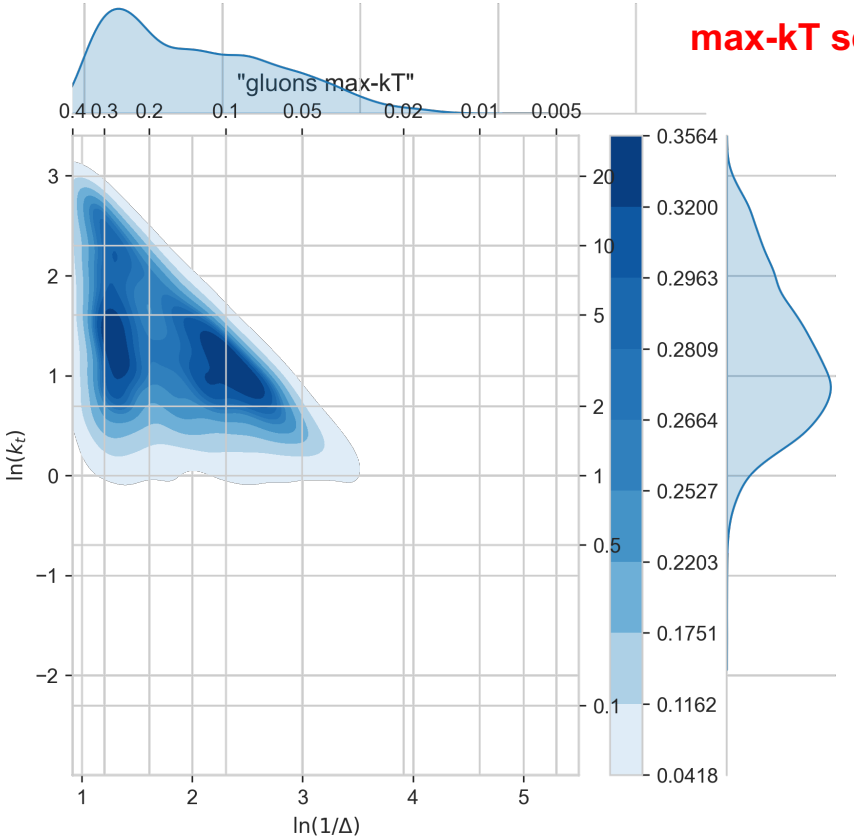


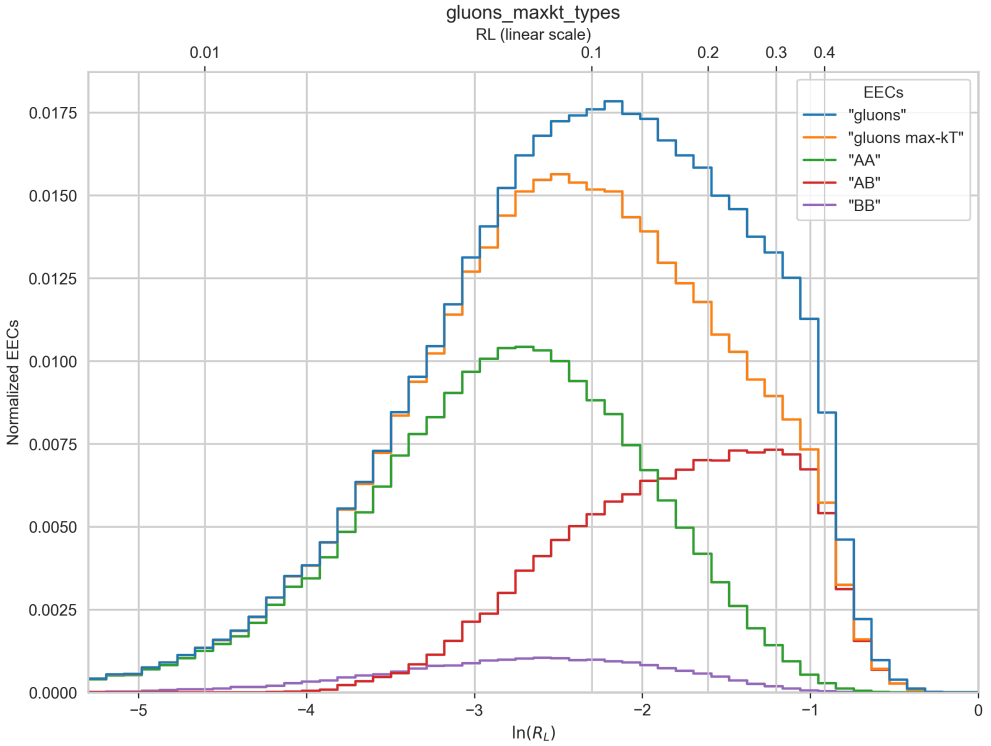
max-kT selection



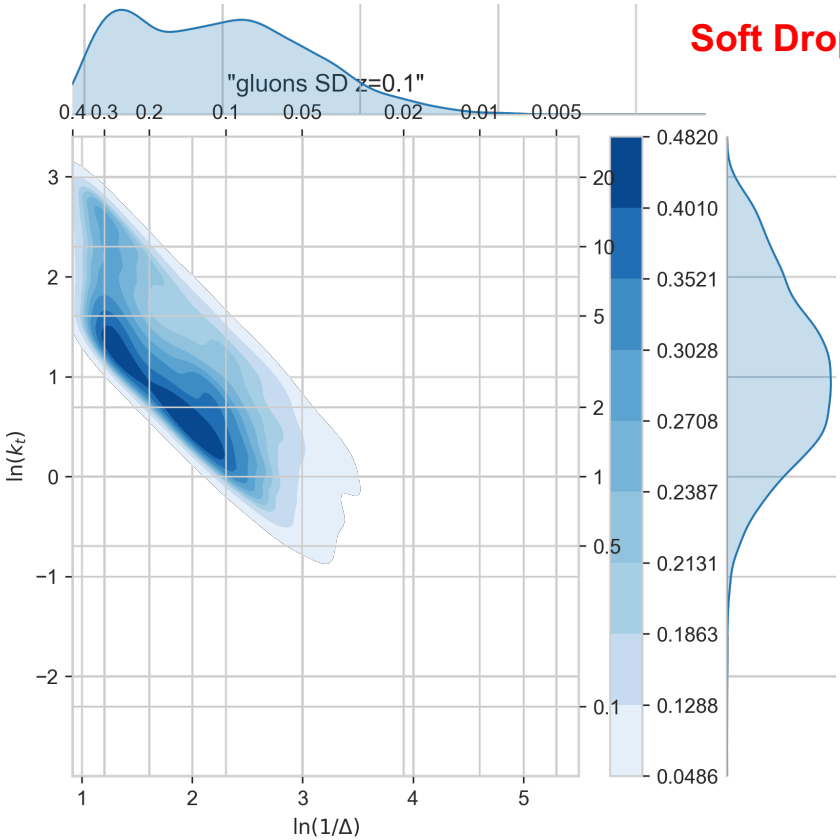
max-kT selection

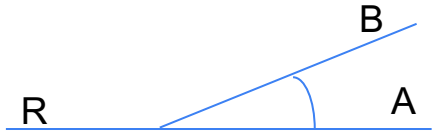


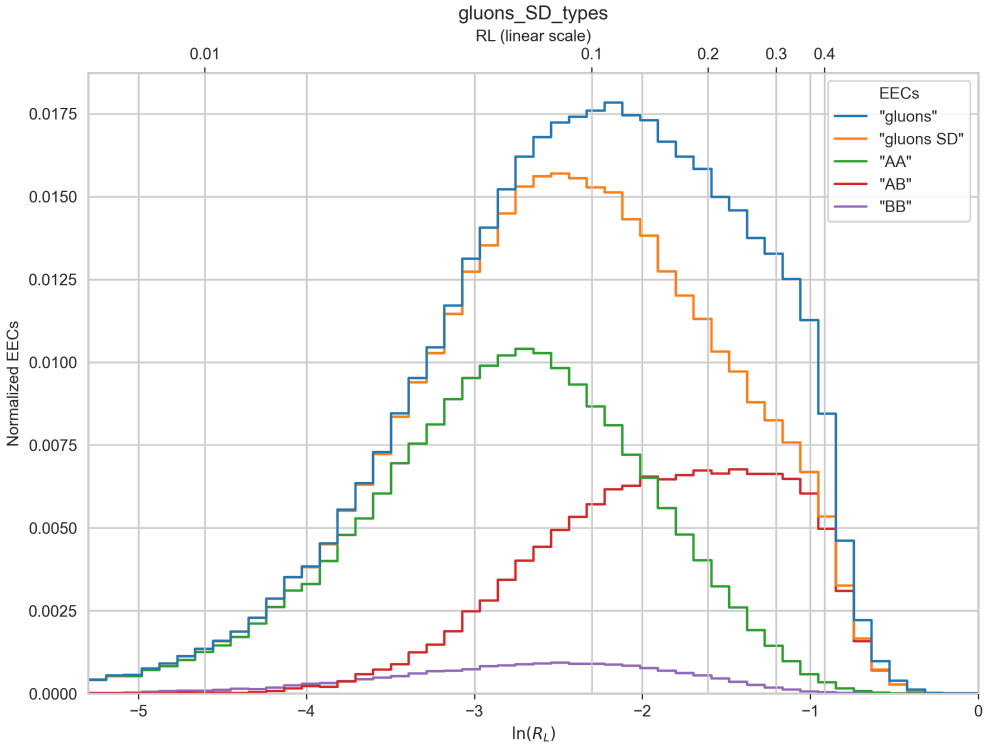




Soft Drop z=0.1 selection







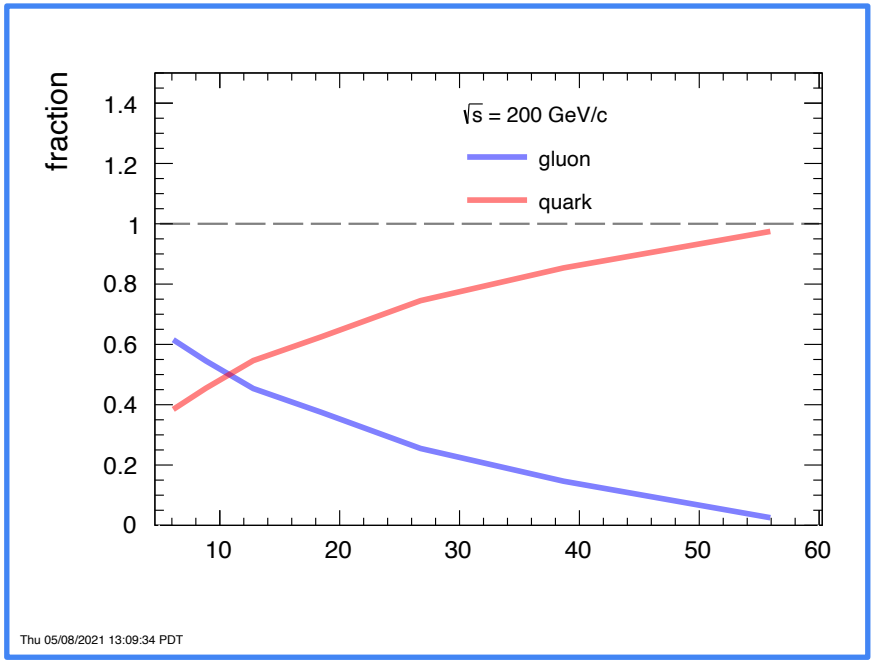
Traversing **Lund Plane with kT – inter-summary**

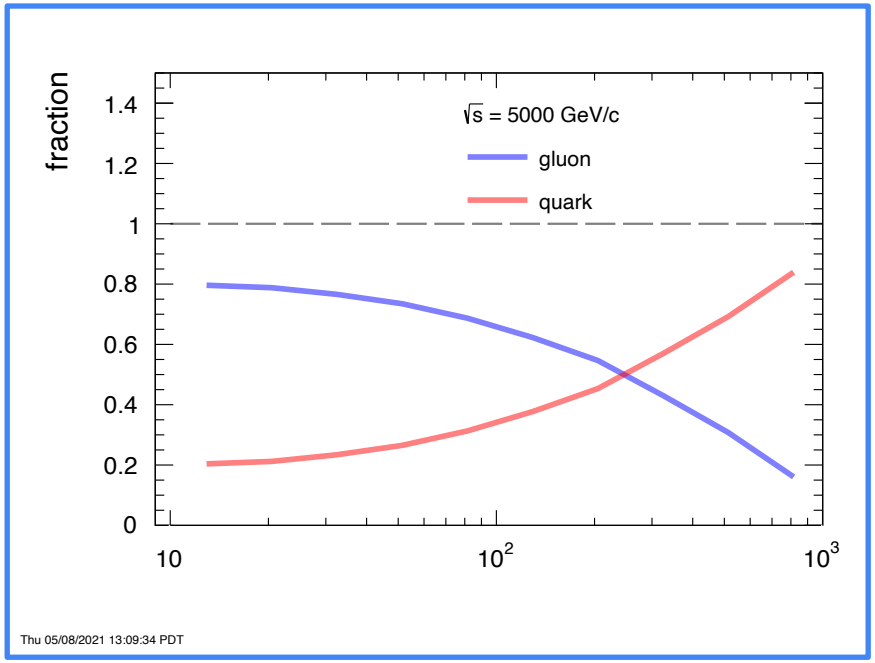
- Small kT Lund Splittings generate control the “free hadron” EECs
- Large kT Lund Splittings clearly drive the perturbative EEC region (expected but now very clear) – also:
  - AB pairs dominate/exhaust the largest angle EEC (”pure” pQCD)
  - AA, BB pairs drive the “free hadron” section of the per-jet total EECs
- Groomers focusing on perturbative splittings – symmetrize log(RL)
  - Isolate AA, AB, BB and leverage this feature for jet quenching studies?
- *Note: variation of the analysis not with Lund splittings but ‘inclusive’ subjets*

A variation: EECs and flavor/mass

- quark and gluons at the LHC
- EEC's differ for q and g
  – notably g closer to HF
- looking for a universal (scale) parton-hadron transition in RL…
- can we leverage it for QGP studies?
- test for quark/glue mixture change?

Parton mix in the inclusive sample at the LHC (and RHIC)

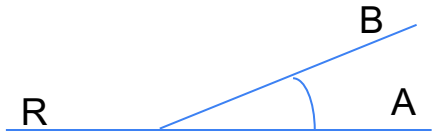


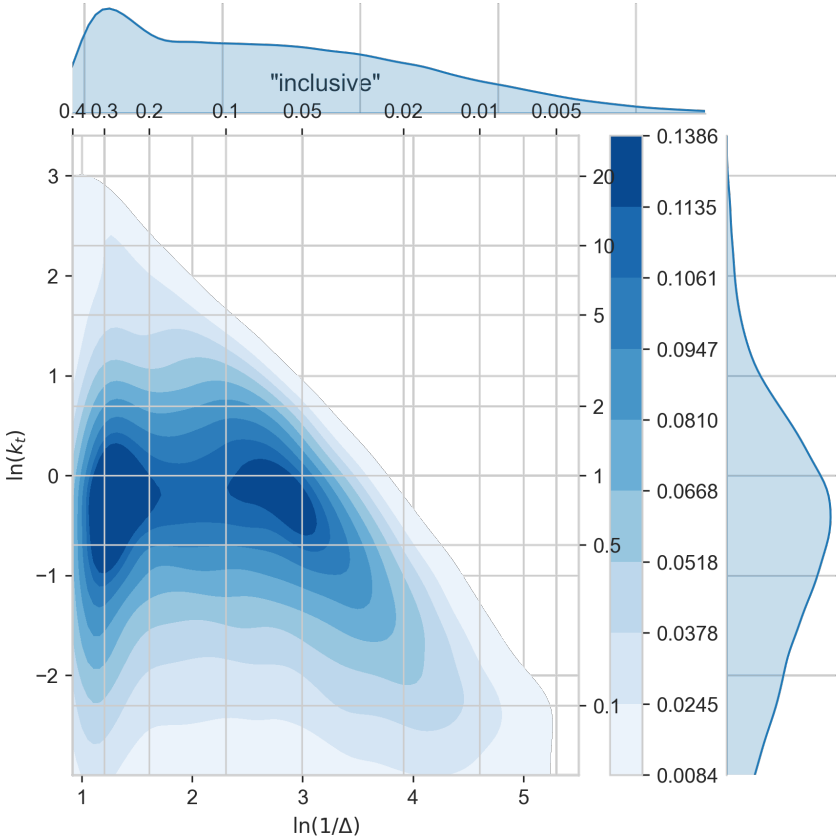


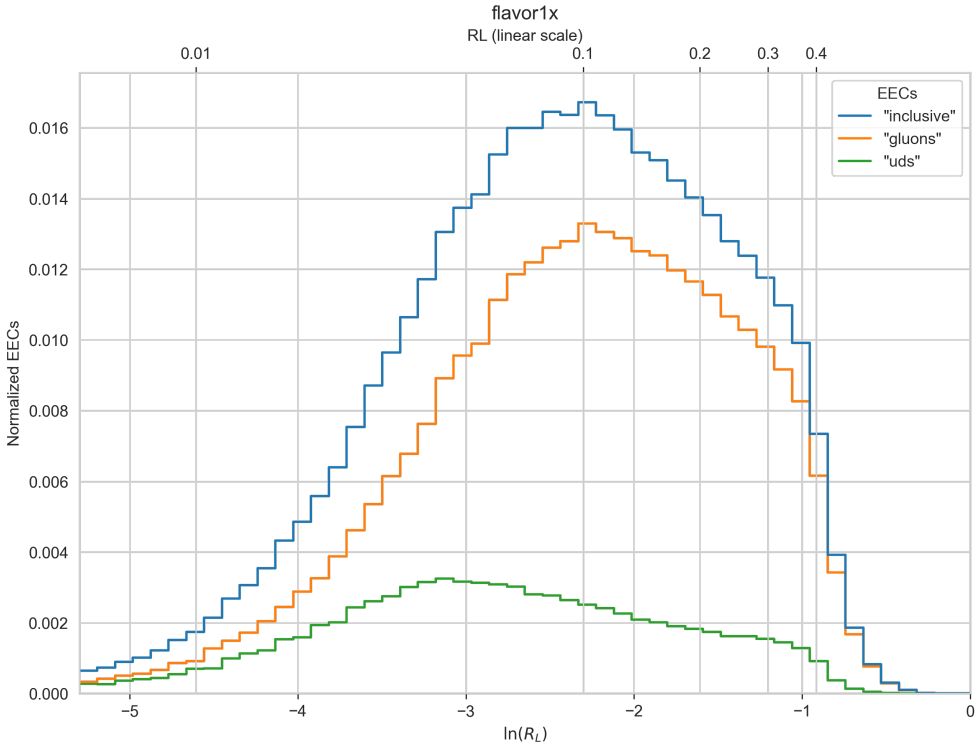
RHIC vs LHC - interpretability
… not only an experimental issue

RHIC: quark dominated
LHC: glue at low-pT – more quarks at high-pT
=> Importance of gamma-jet and Z-jet studies;

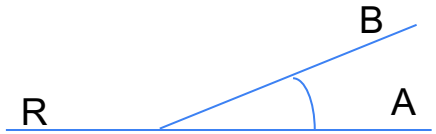
Parton mix in the inclusive sample at the LHC

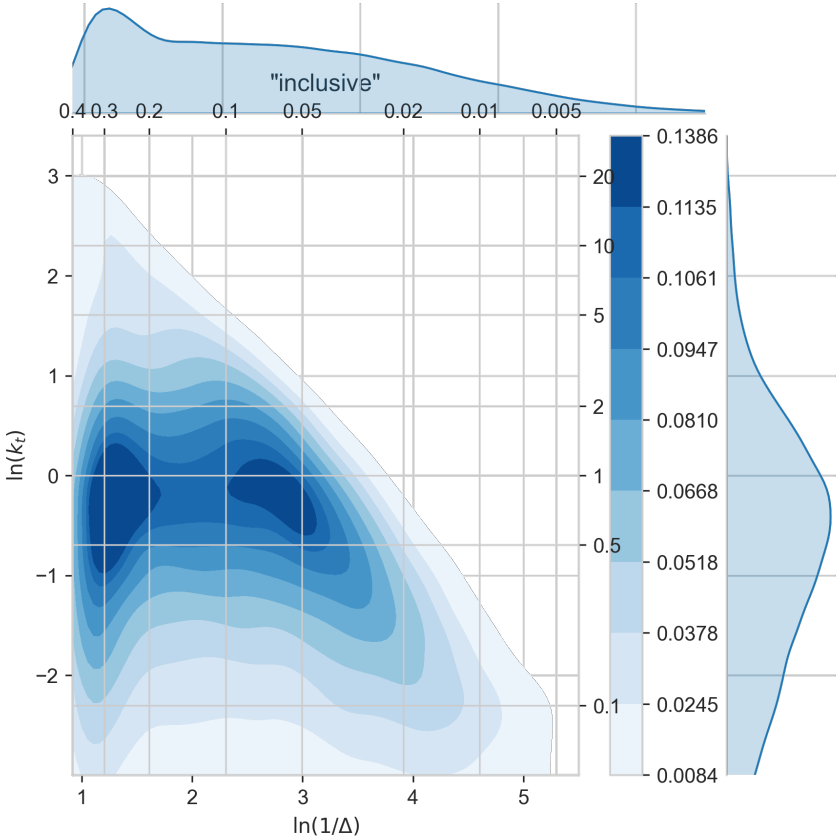


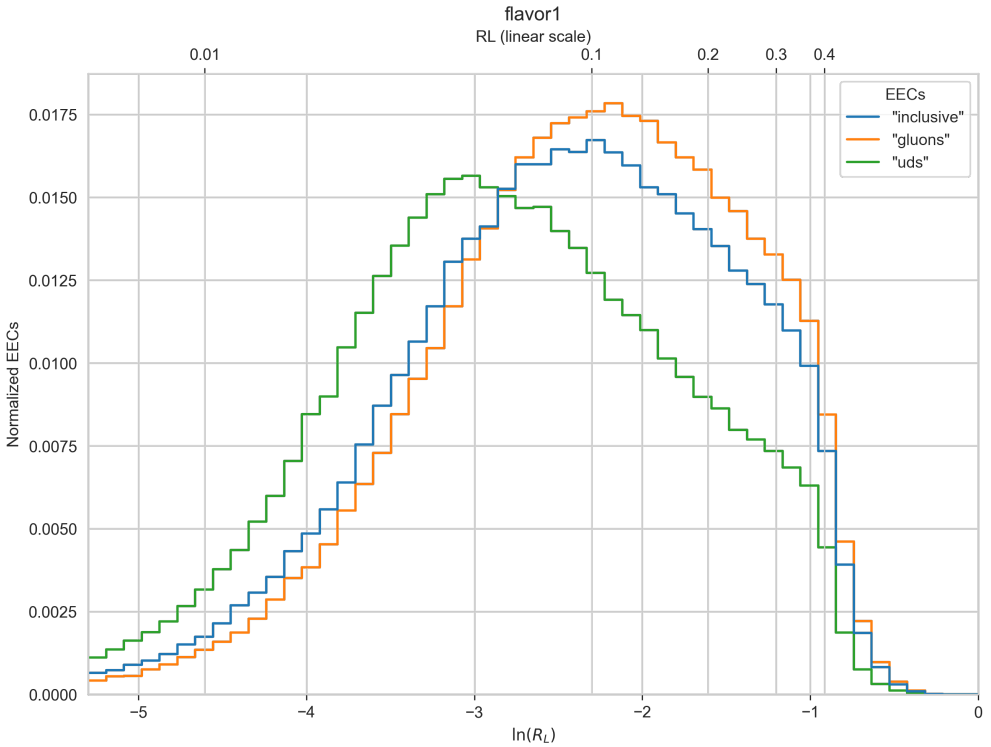




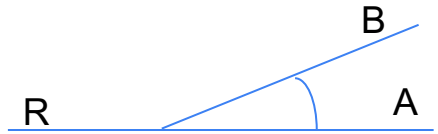
EEC's differ with parton type/mass

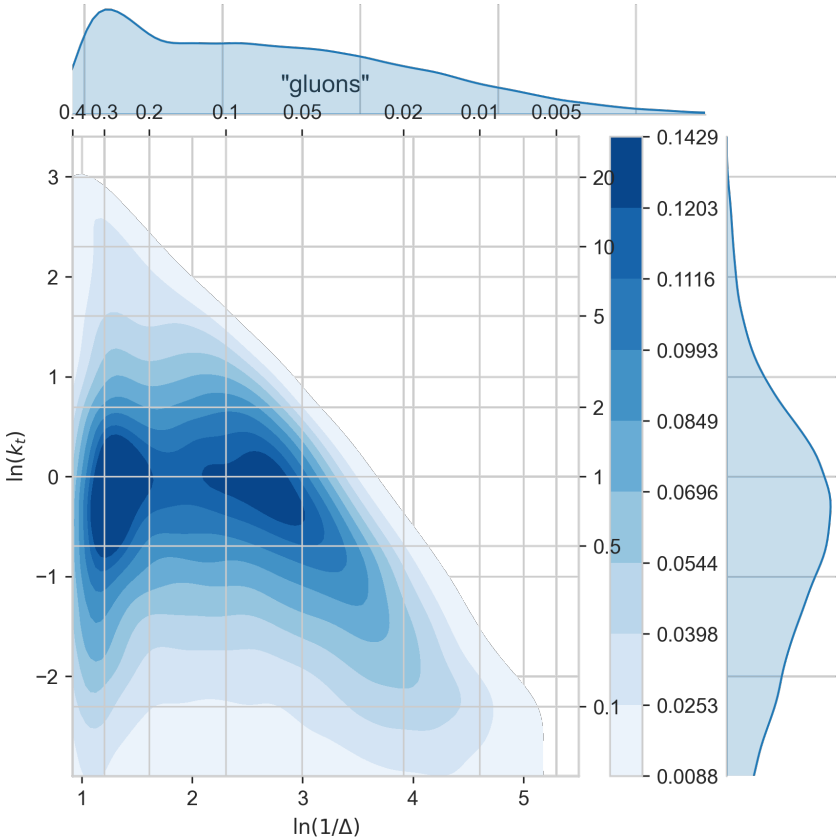


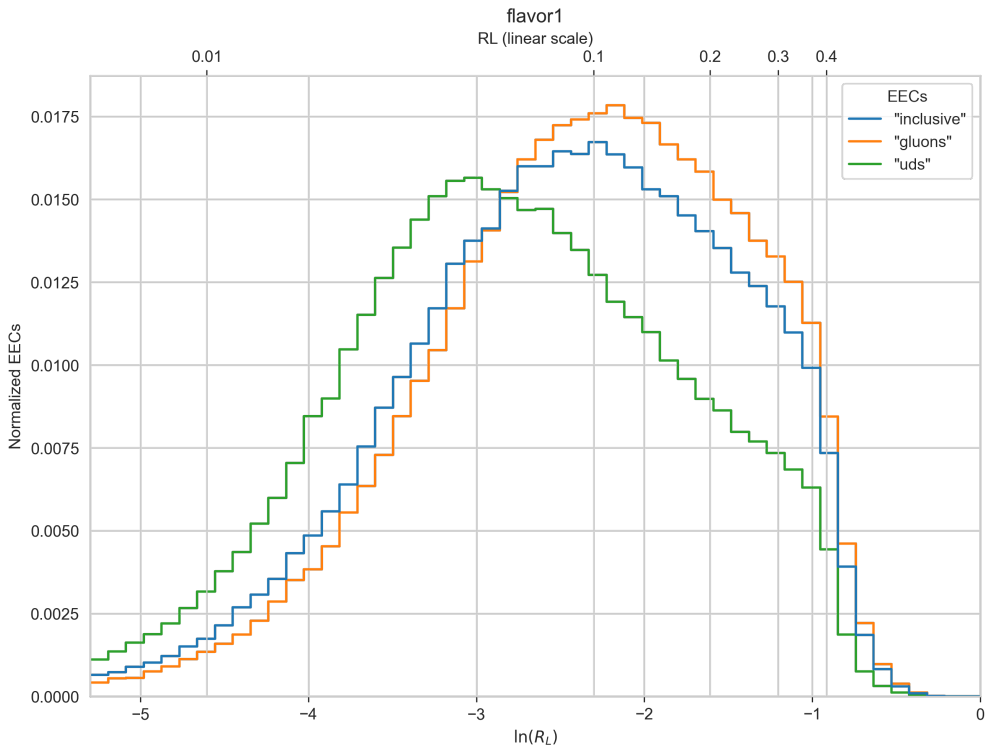




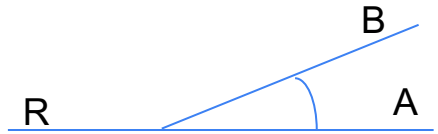
EEC's differ with parton type/mass

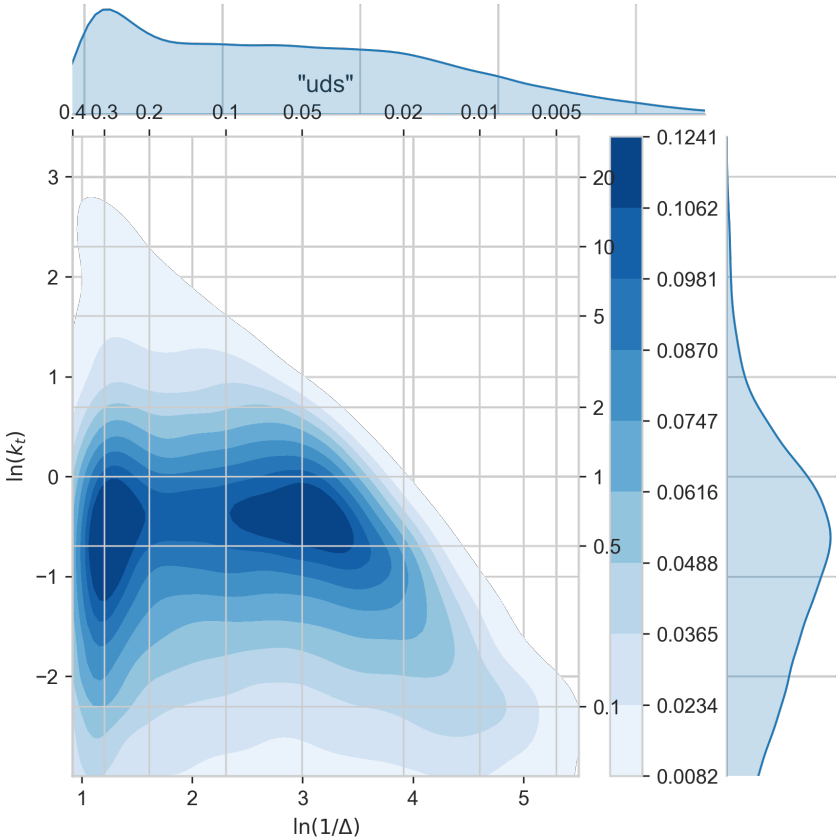


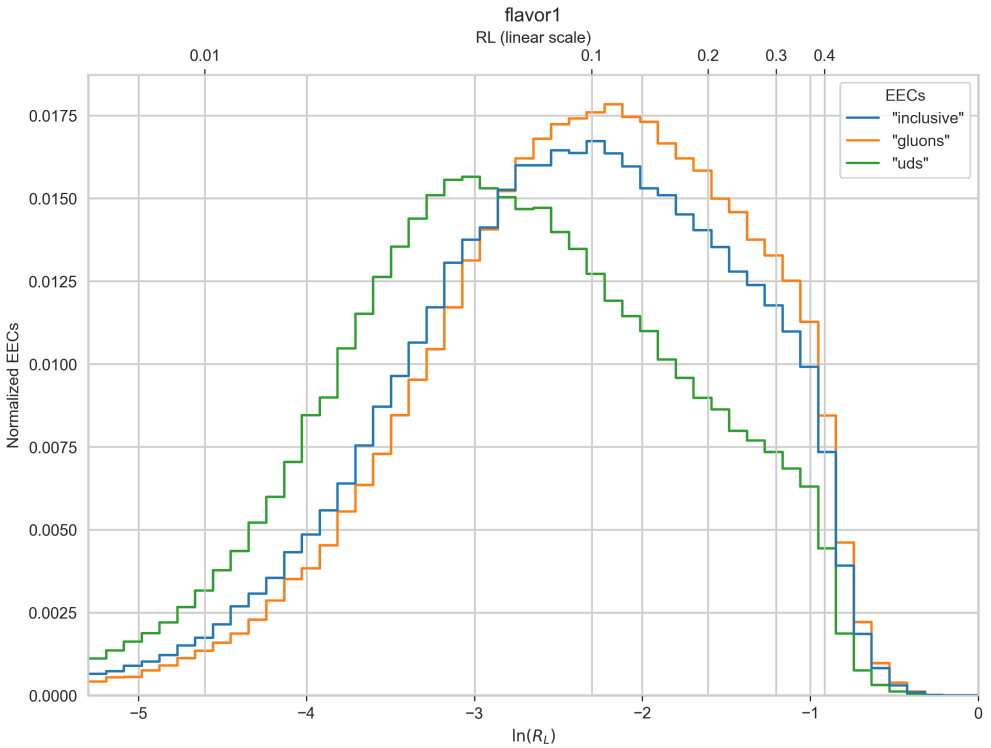




EEC's differ with parton type/mass







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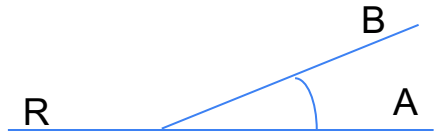

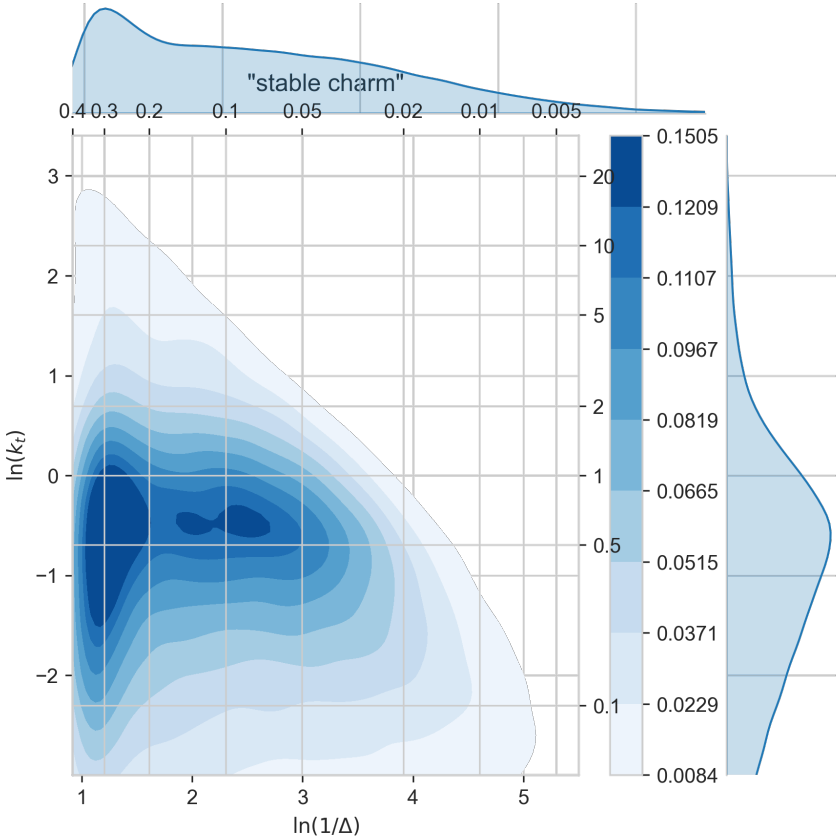

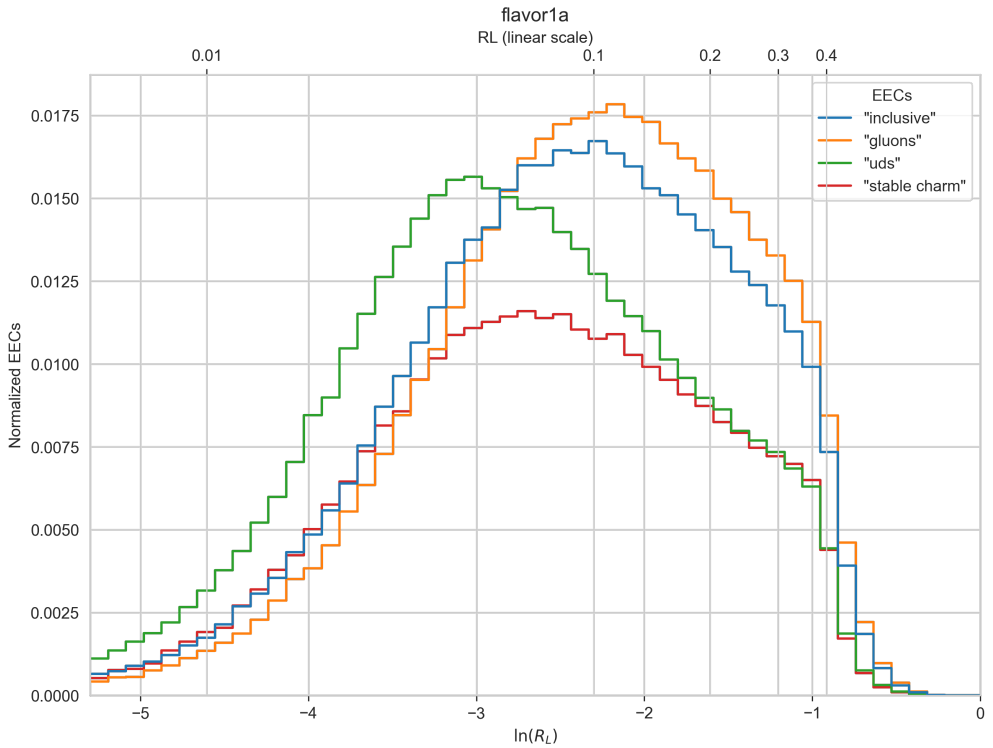

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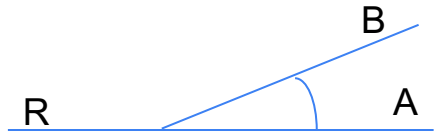

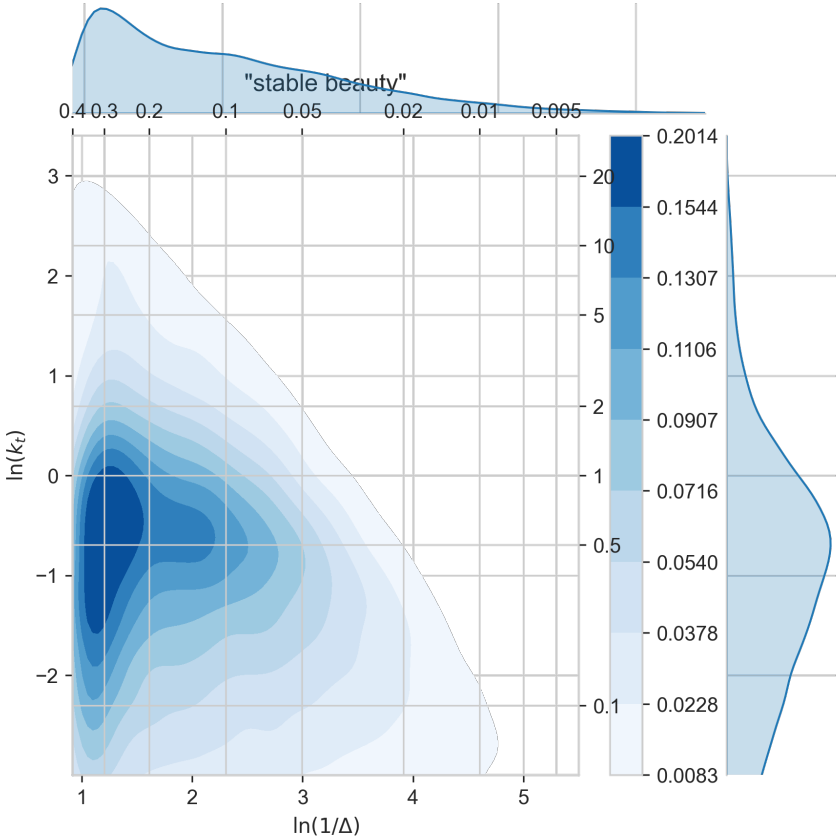

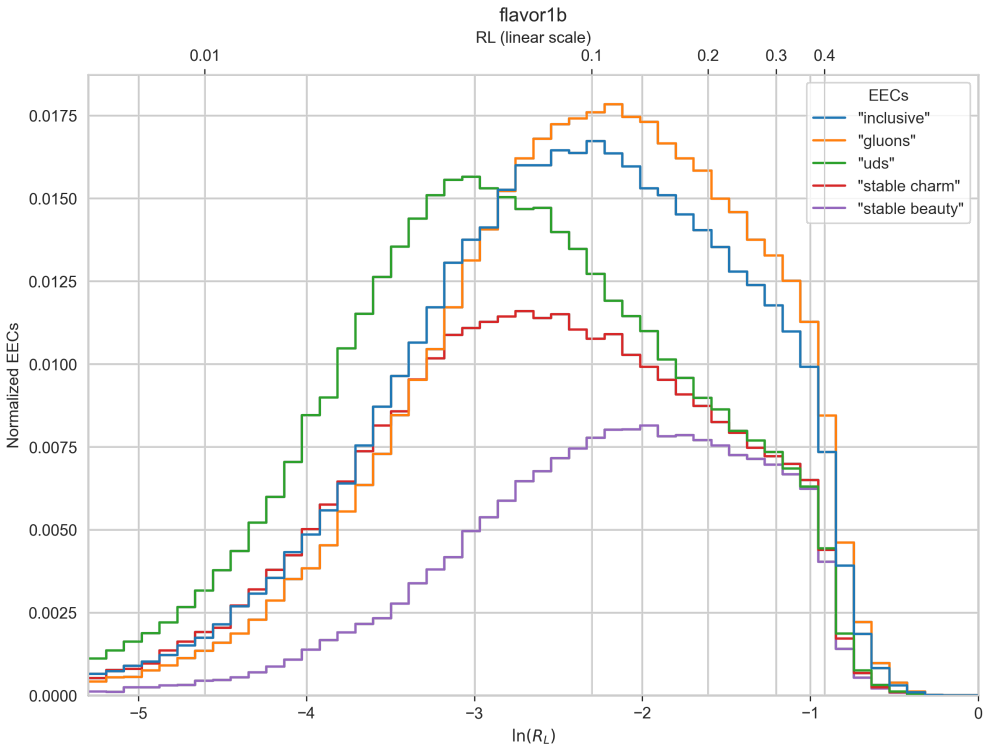

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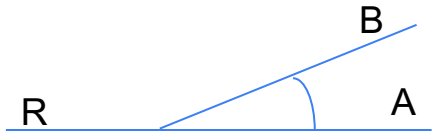
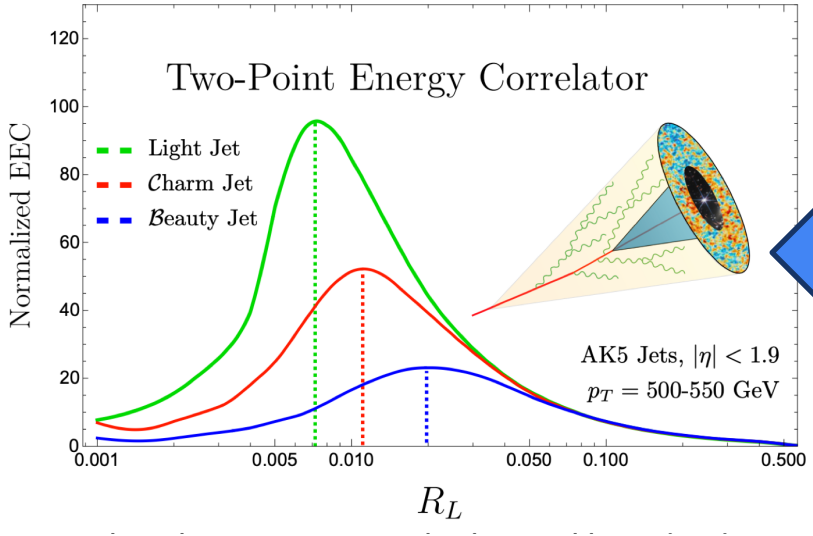
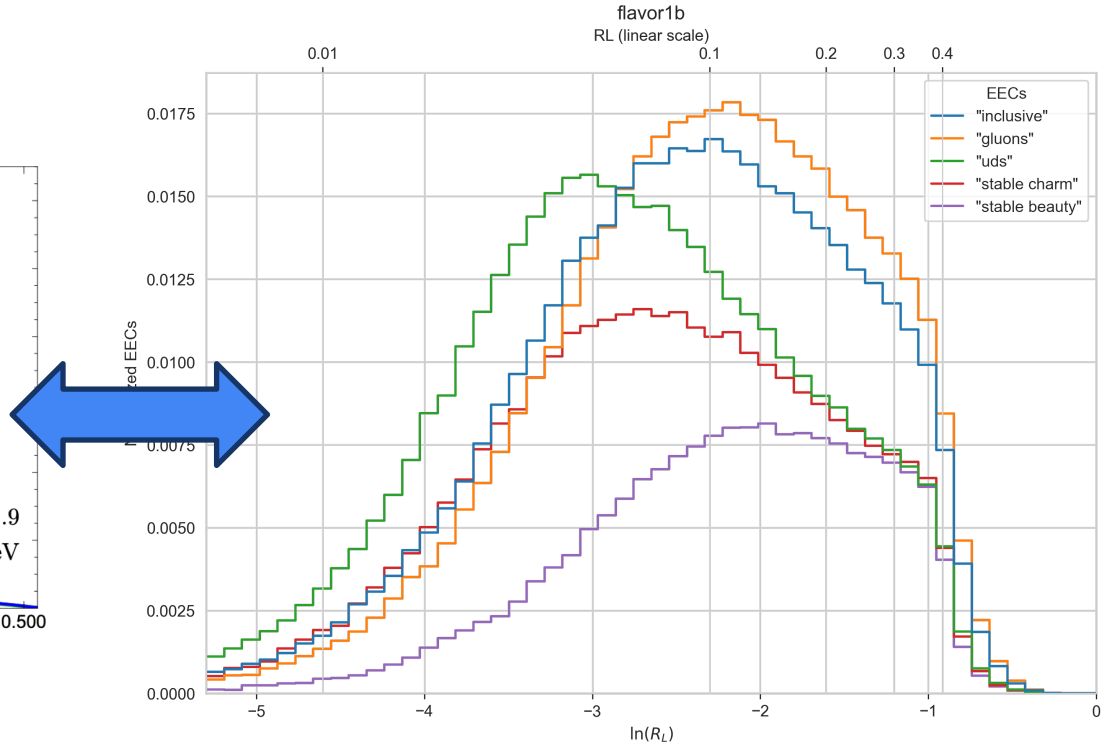
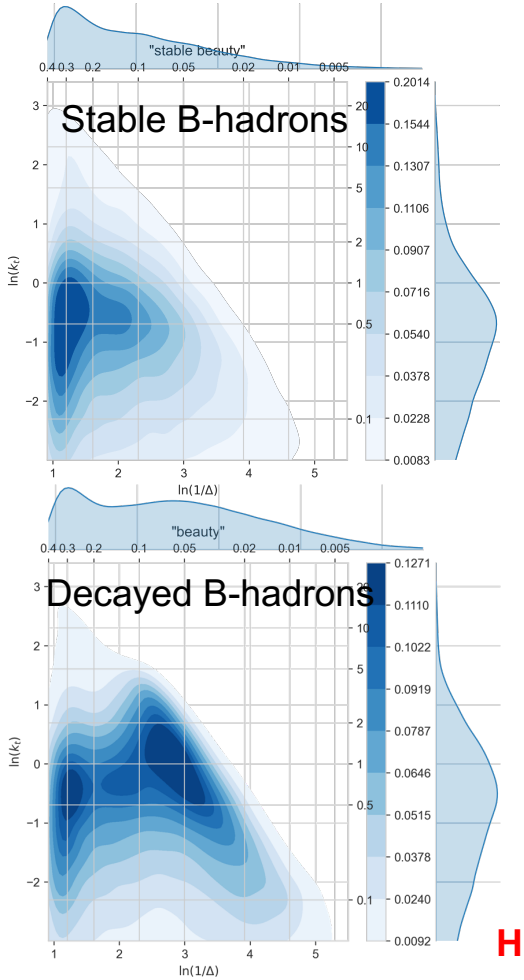
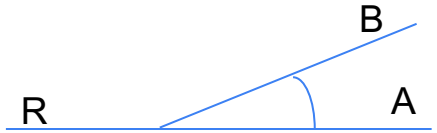
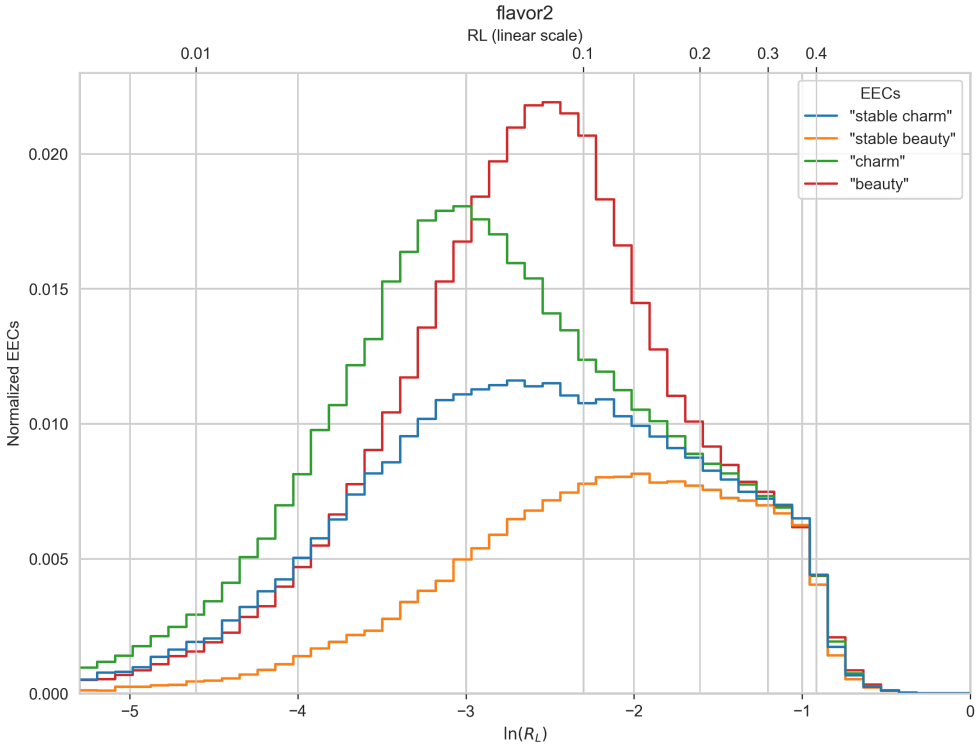




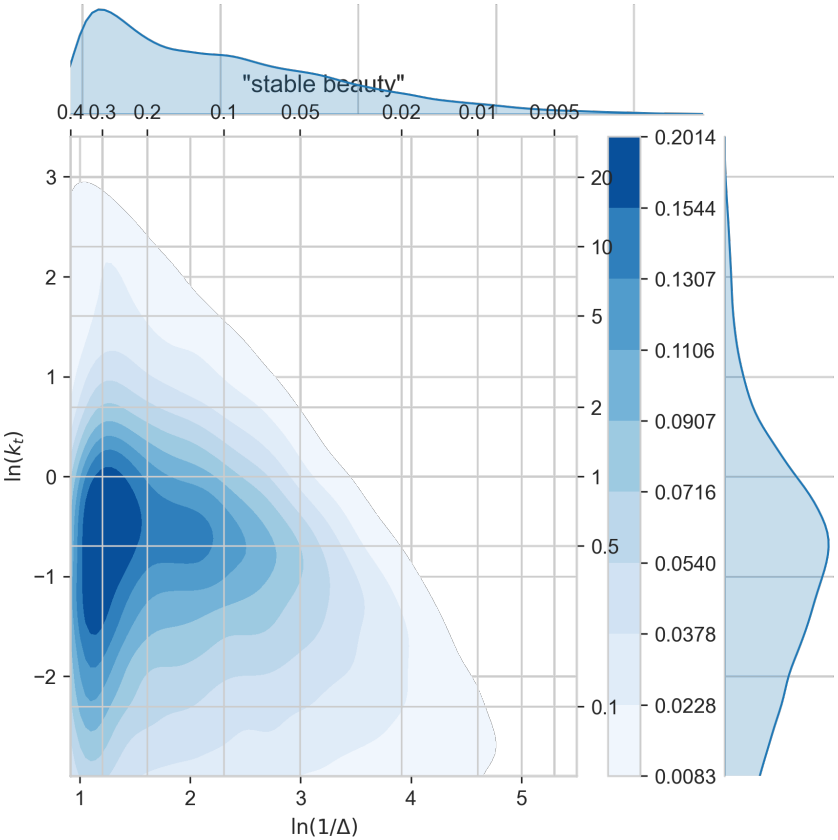


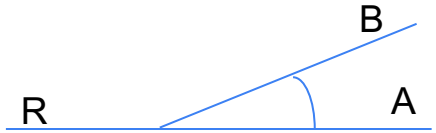


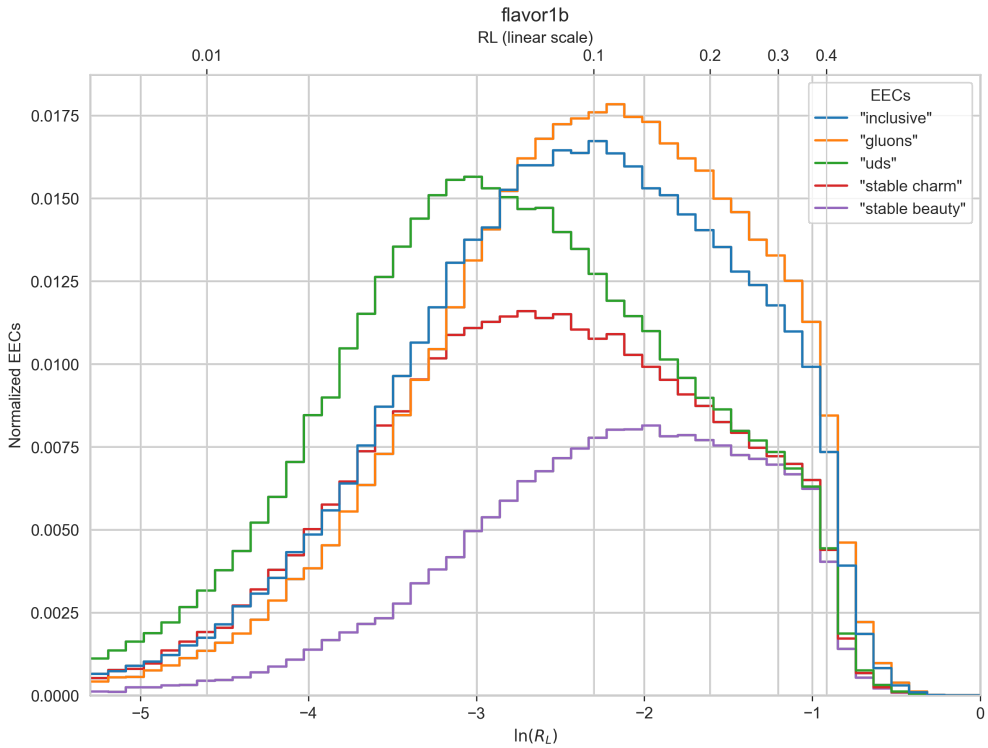


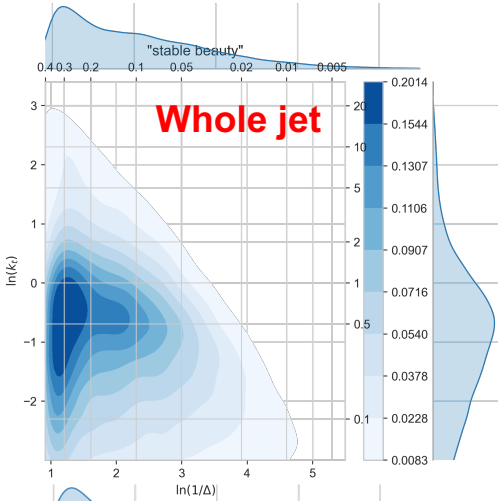


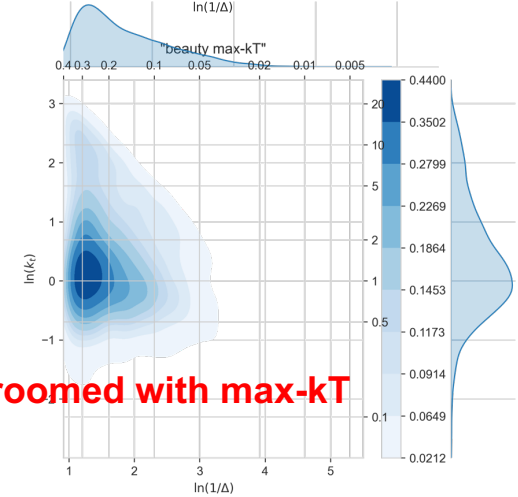
HF EECs w/o explicit hadron reconstruction complicated/not useful(?)


"stable beauty"
0.4 0.3 0.2 0.1 0.05 0.02 0.01 0.005
ln(1/Δ)
ln(k_t)
0.2014
0.1544
0.1307
0.1106
0.0907
0.0716
0.0540
0.0378
0.0228
0.0083

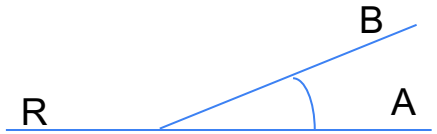

B
R
A

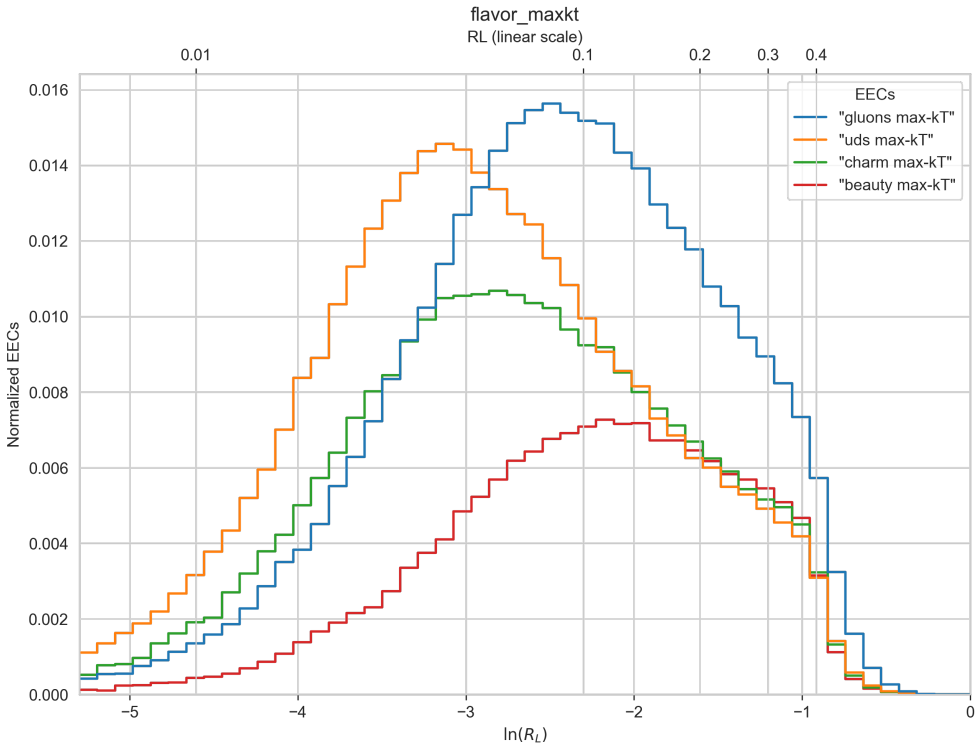

flavor1b
RL (linear scale)
0.01 0.1 0.2 0.3 0.4
EECs
"inclusive"
"gluons"
"uds"
"stable charm"
"stable beauty"
Normalized EECs
ln(R_L)





Groomed with max-kT





Using max-kT good alignment of quarks in high-RL's

Thoughts on understanding in-medium effects in EECs - only some considerations…

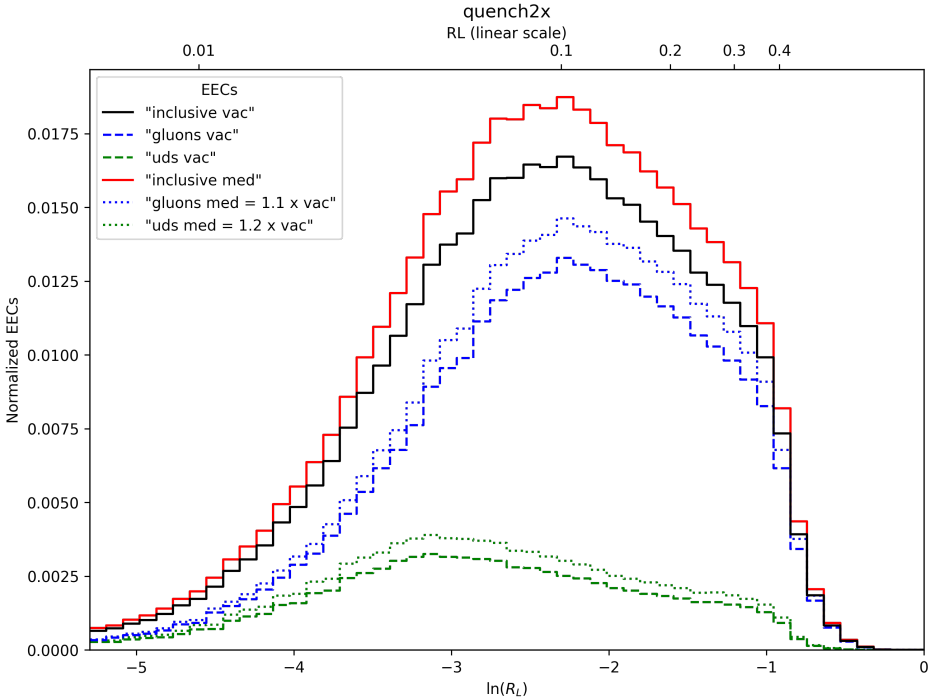
- quark/glue ratio (~survival bias?)
- backgrounds/UE also “wake” => EECs
- how to look for it with Lund x EECs?
- not mixed with medium induced radiation?

What’s the difference?
a) medium induces jet to radiate (modifies its vacuum radiation pattern, probs)
b) jet knocks out medium scattering points – induces it to radiate
⇔ who “owns it” ? ;-)

Some trivial ”in-medium” modifications - simulation test

- Vary quark/gluon ratio – no real e-loss / no real modifications

More gluons
More quarks



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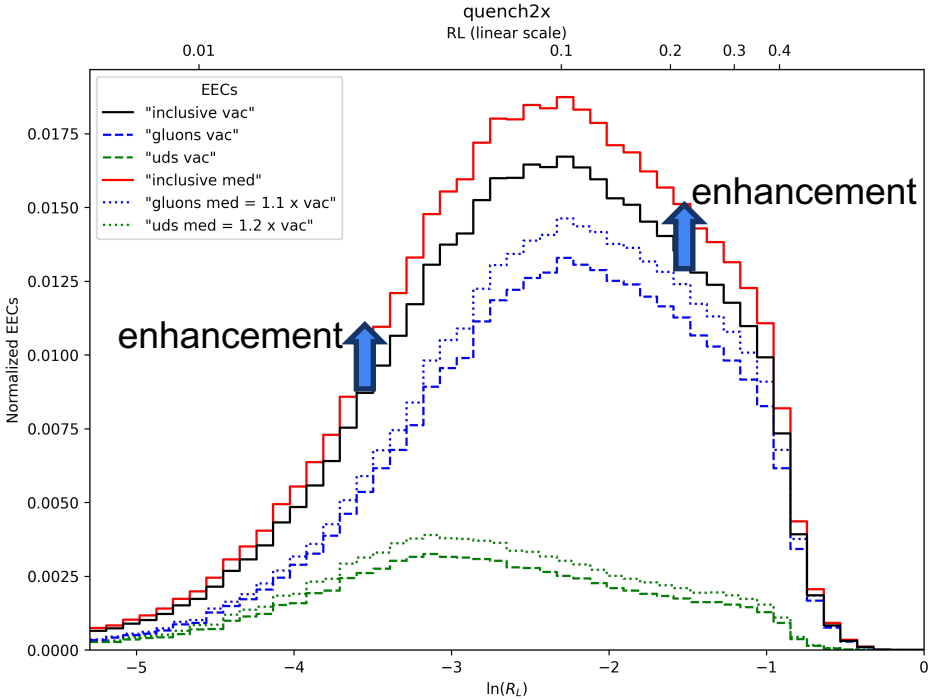

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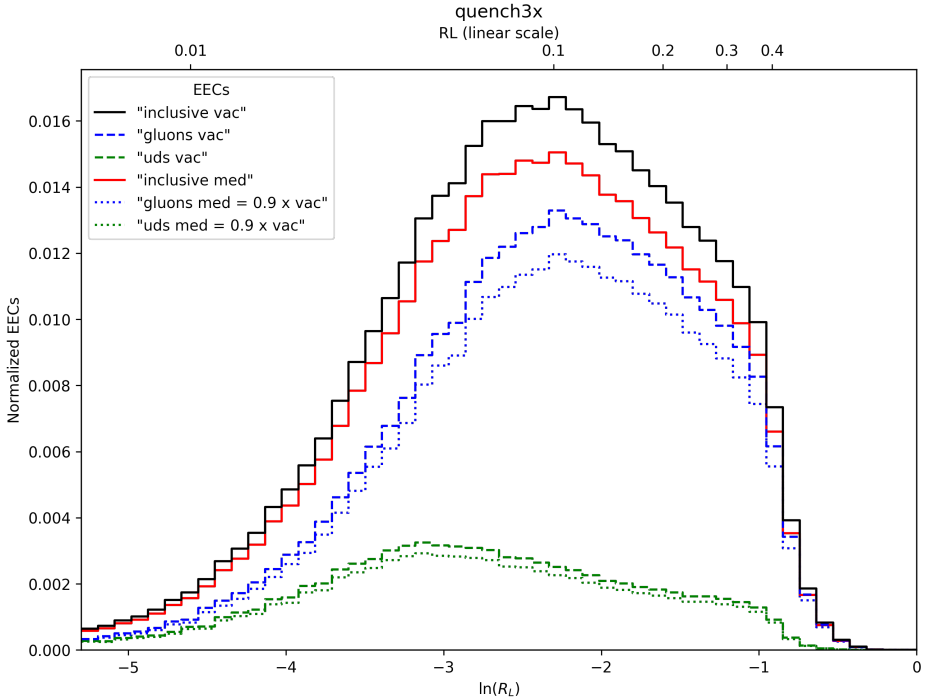

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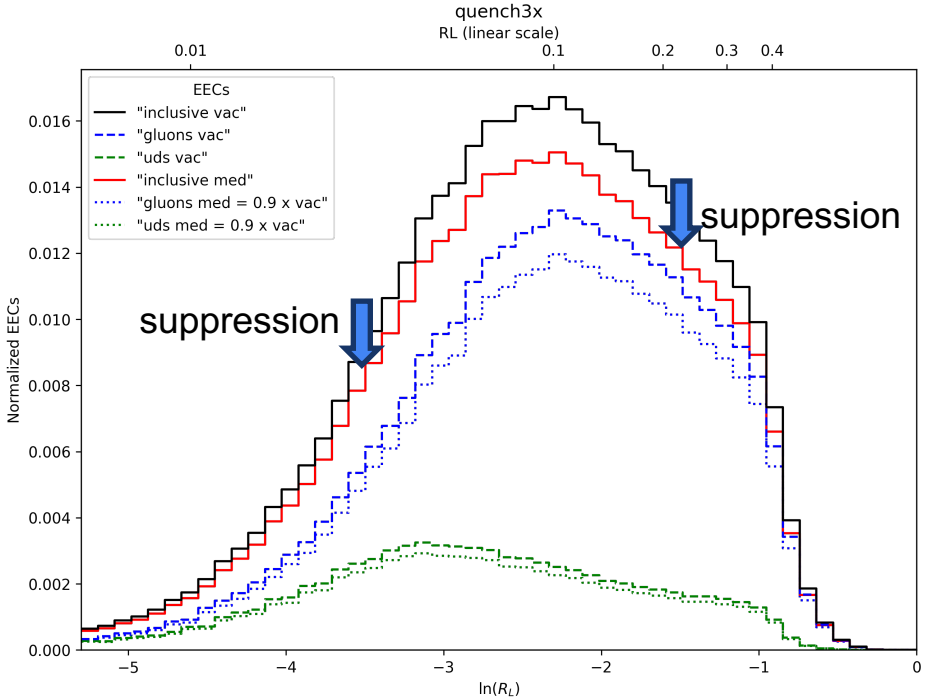

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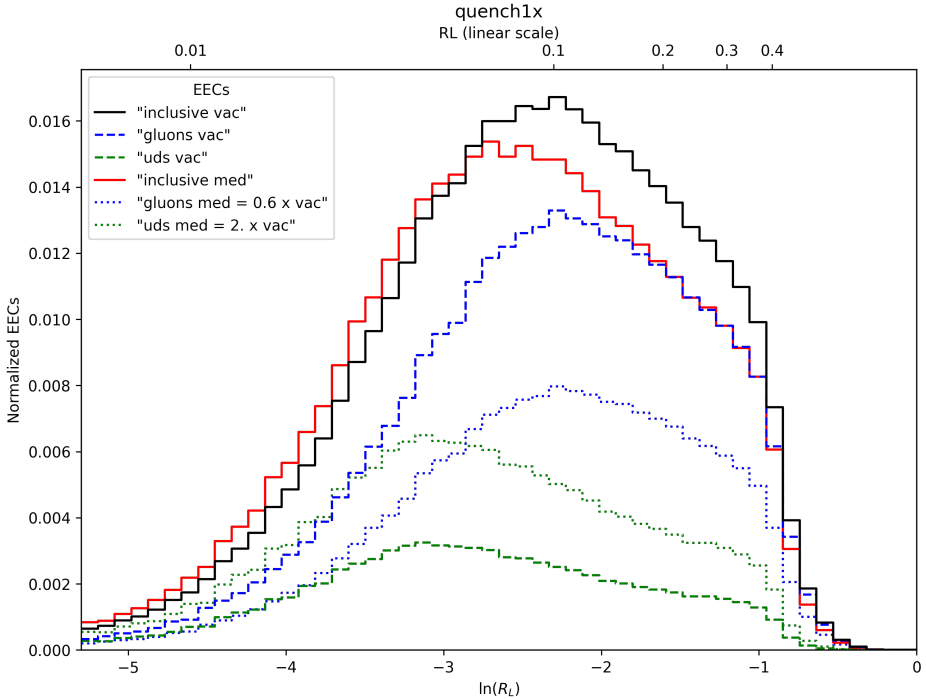

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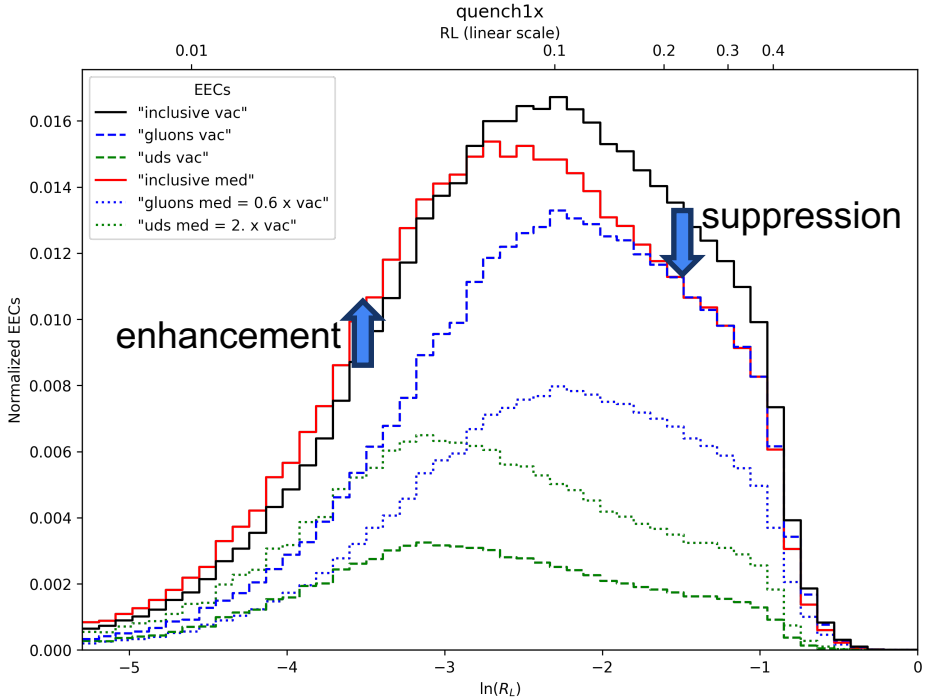

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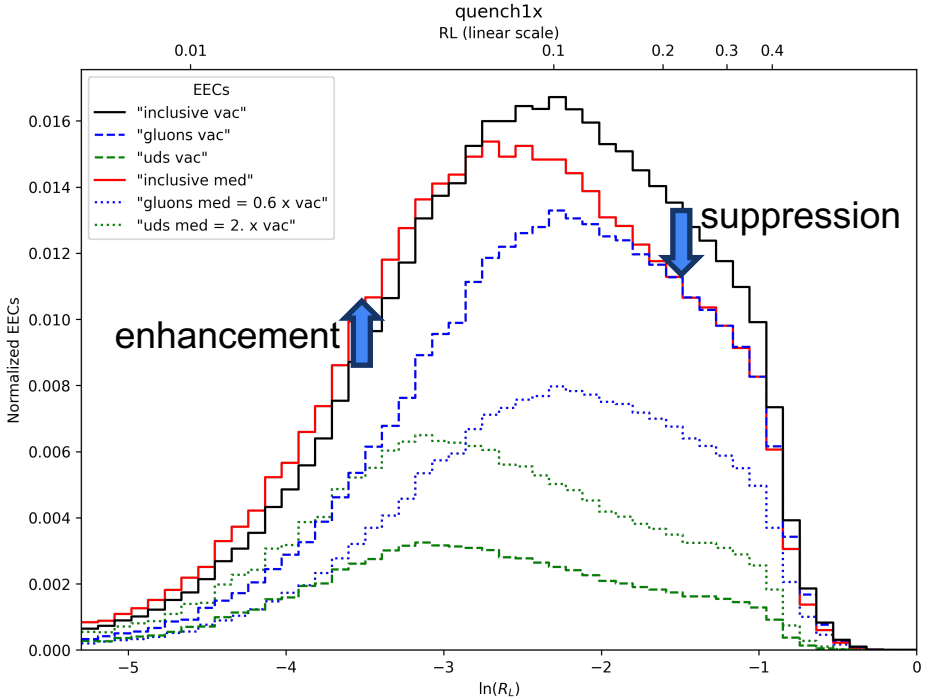


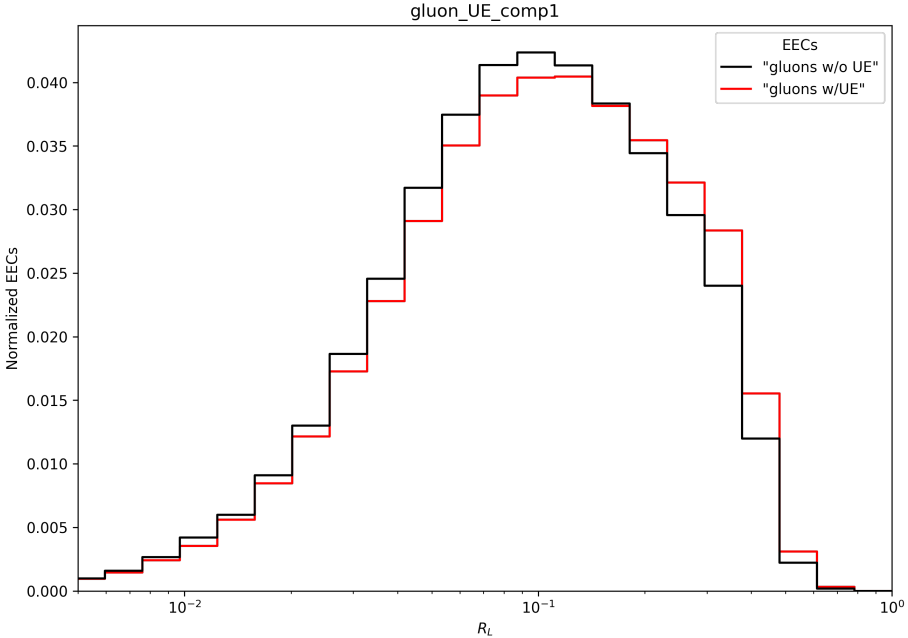
Intriguing note:
It is difficult to get a “suppression-enhancement” pattern

Backgrounds / UE
/ “wake”
== additional correlated stuff?

UE and no UE – even in pp collisions

- Small but sizeable contribution… wake will have a similar one?
  - Similar to BG under-subtraction
  - It appears where what we call ~perturbative region of EECs …

UE = ISR + MPI



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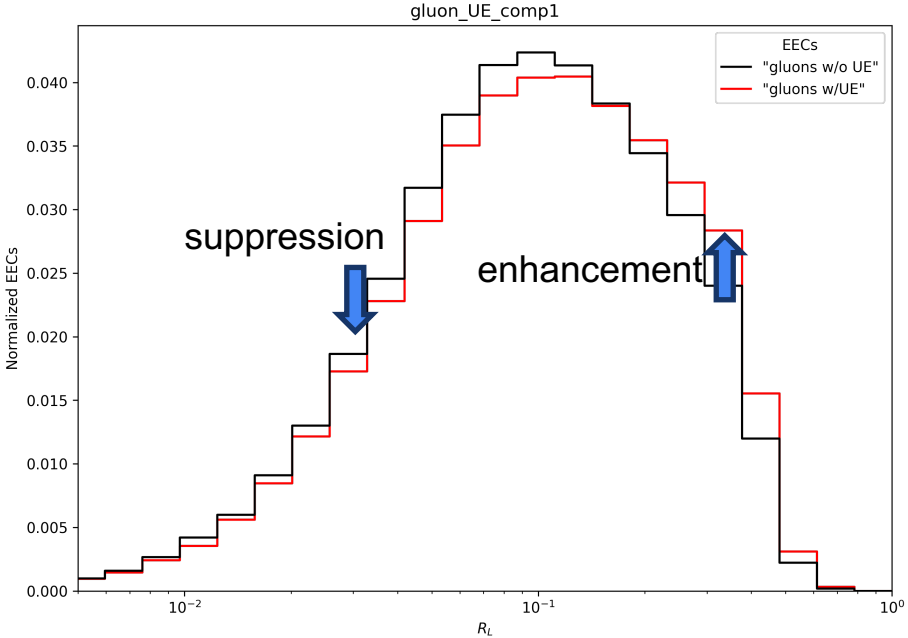

Intriguing note:
UE has qualitatively very different effect as rebalanced q/glue ratio (!)

The plot thickens…

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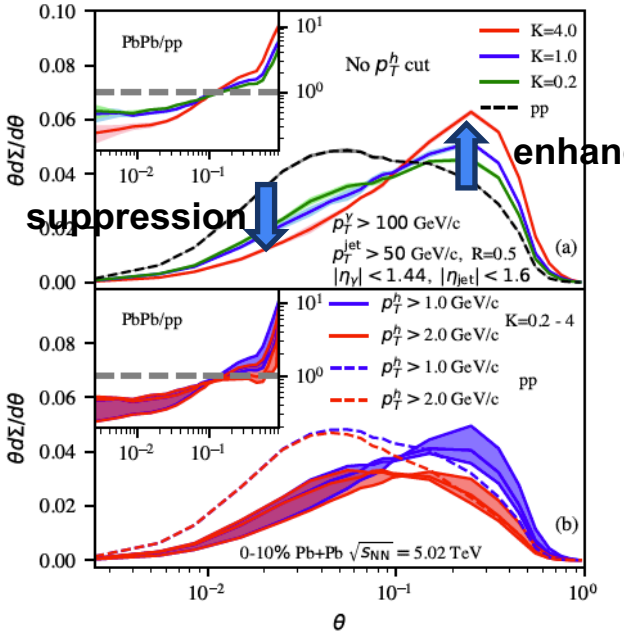

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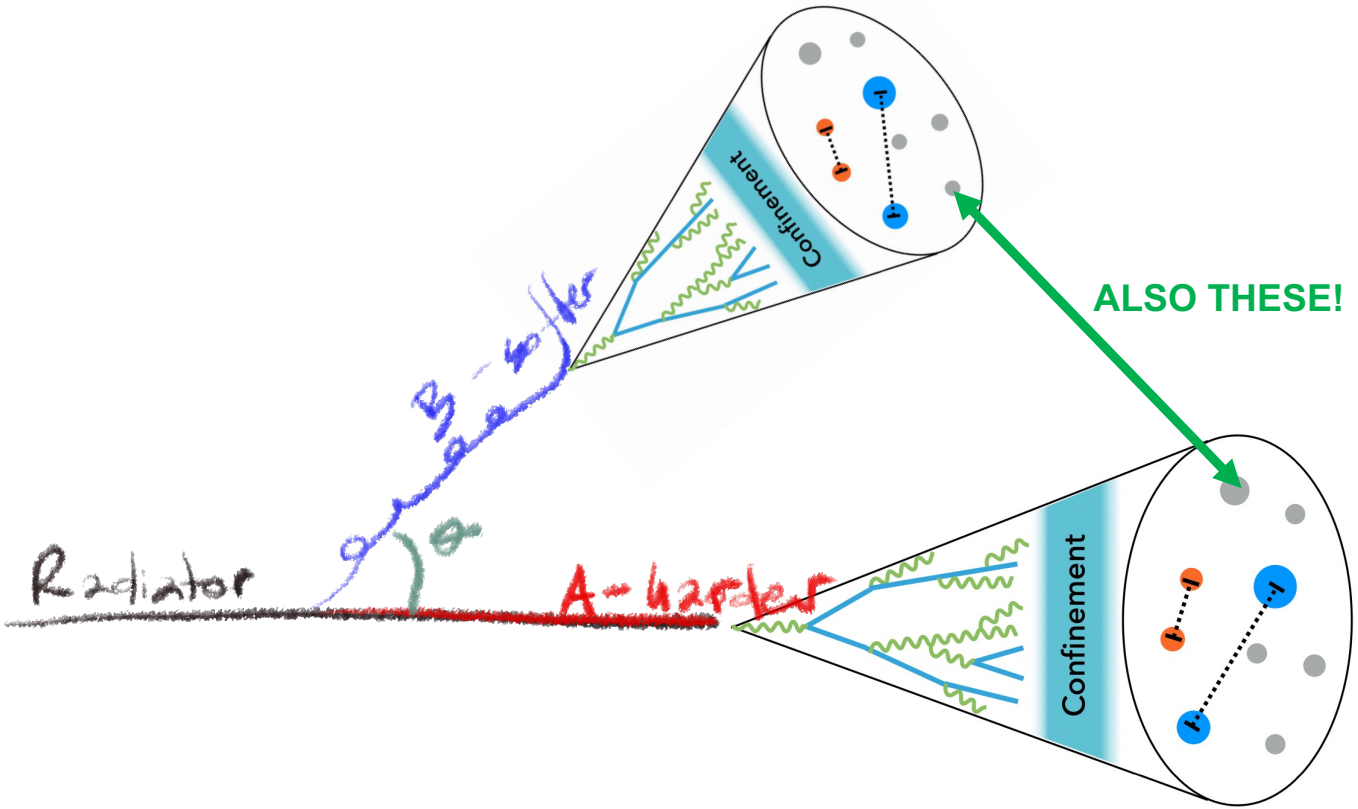
Yang, He, Moult, Wang arXiv:2310.01500

Instead of a summary…

Lund x EEC for jet quenching



Lund x EEC for jet quenching

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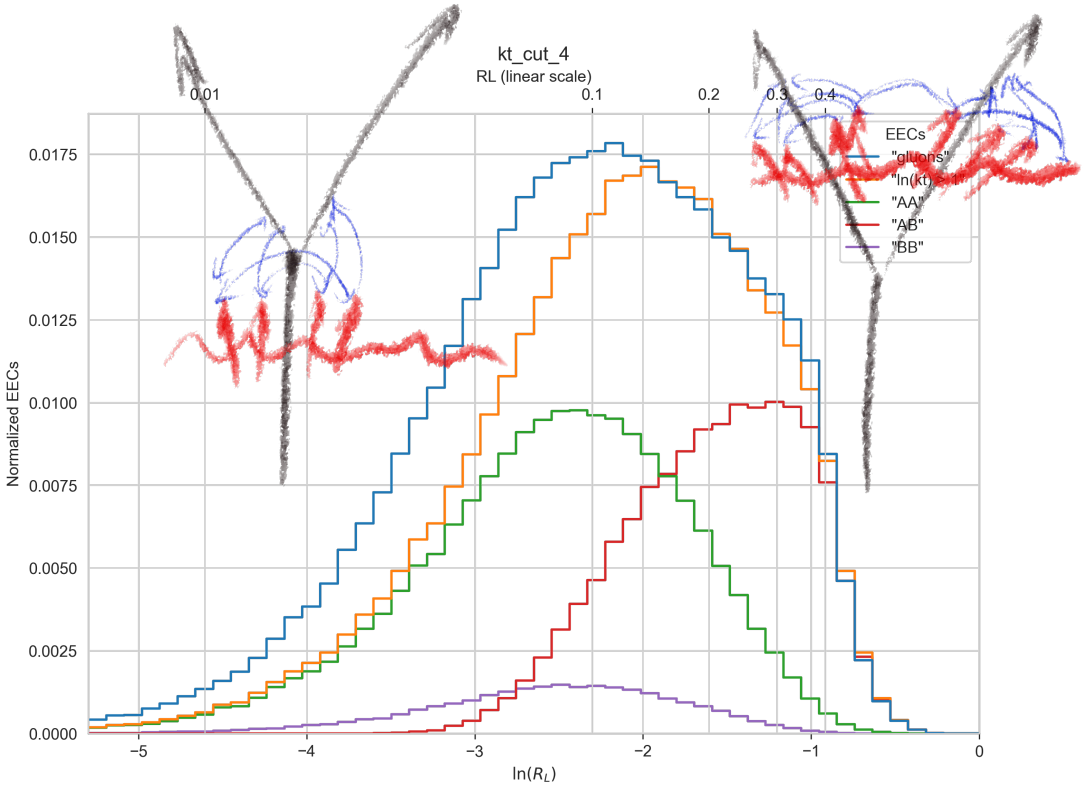

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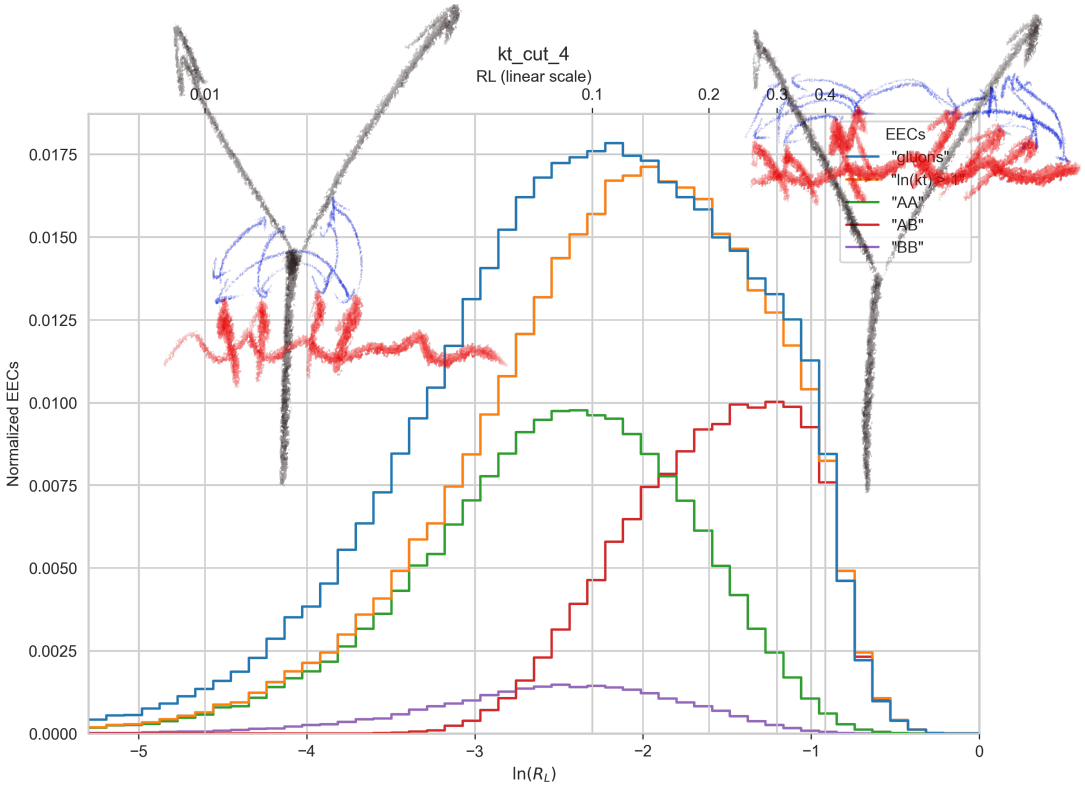

Can we…?

…

N>2-point EEC

pT part cut lower

Thanks!