Study of the Underlying Event at LHC

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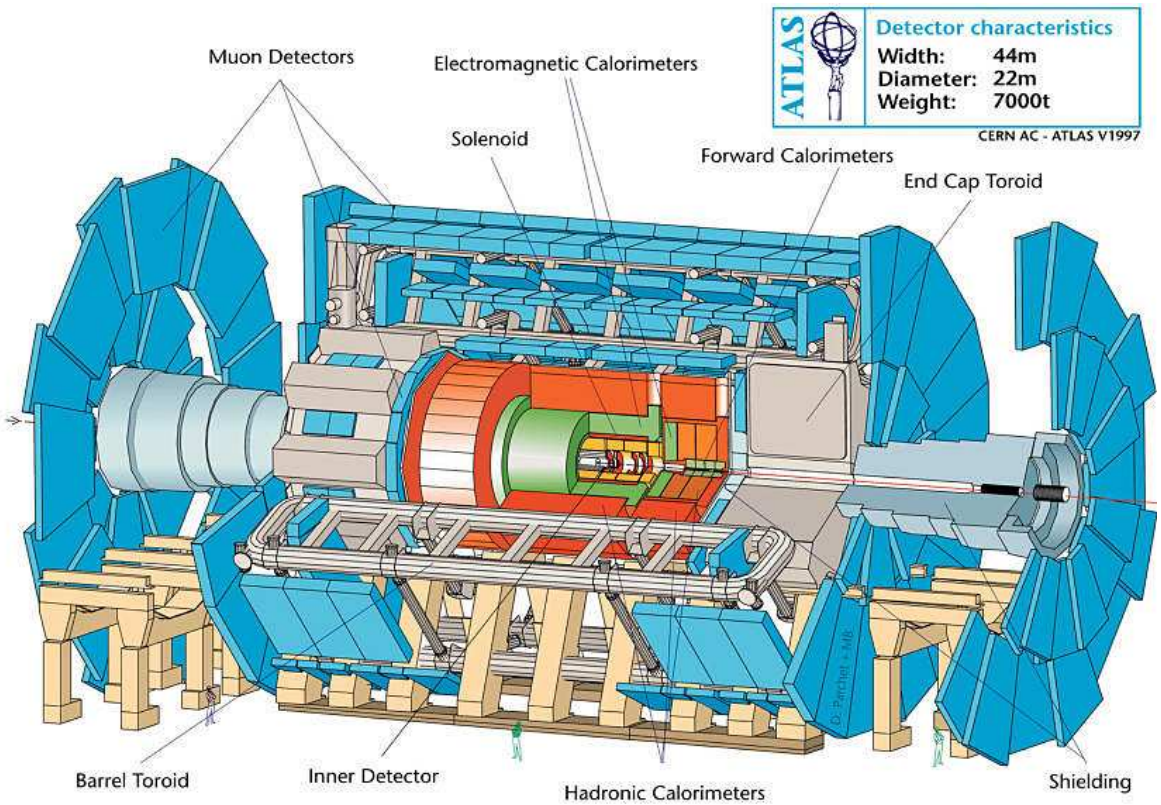
Outline

- Introduction
  - ATLAS
  - Minimum Bias
  - Underlying Event
- Analysis Tools
- Studies of the UE
  - Characteristics
  - Subtraction Method
- Summary

The ATLAS Experiment at the LHC

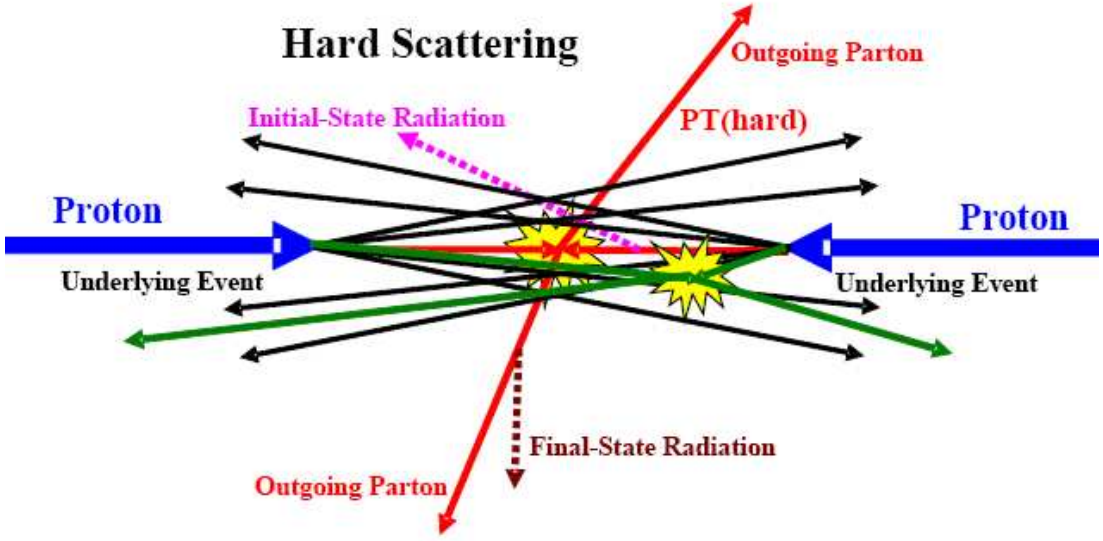


- Universal Detector
- Width: 44 m
- Diameter: 22 m
- Weight: 7000 t

What happens at a bunch crossing?

- bunch crossing every 25 ns
- usually no hard interaction,
  but soft interactions between the hadrons:
  - no big change of the direction of the outgoing particles in comparison to the initial hadrons
  - small momentum transfer
  - soft inelastic interactions are called **Minimum Bias** (MB)
  - about 23 MB events per bunch crossing are expected!

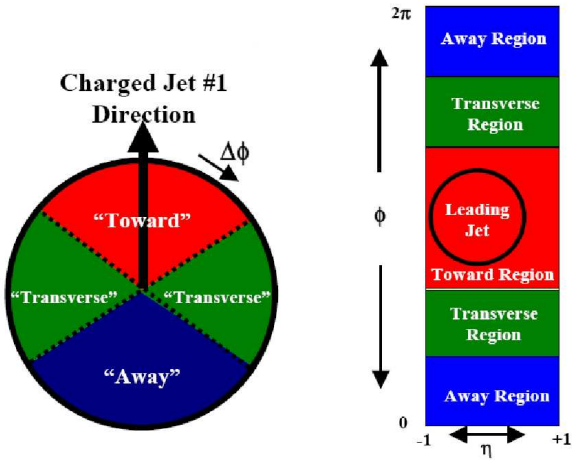
Hard scattering



- particles from hard 2 *Parton* $\rightarrow$ 2 *Parton* collision
- Initial and Final State Radiation
- additional, soft contributions - the **Underlying Event** (UE)
  - Beam remnants
  - Multiple Interactions

PYTHIA

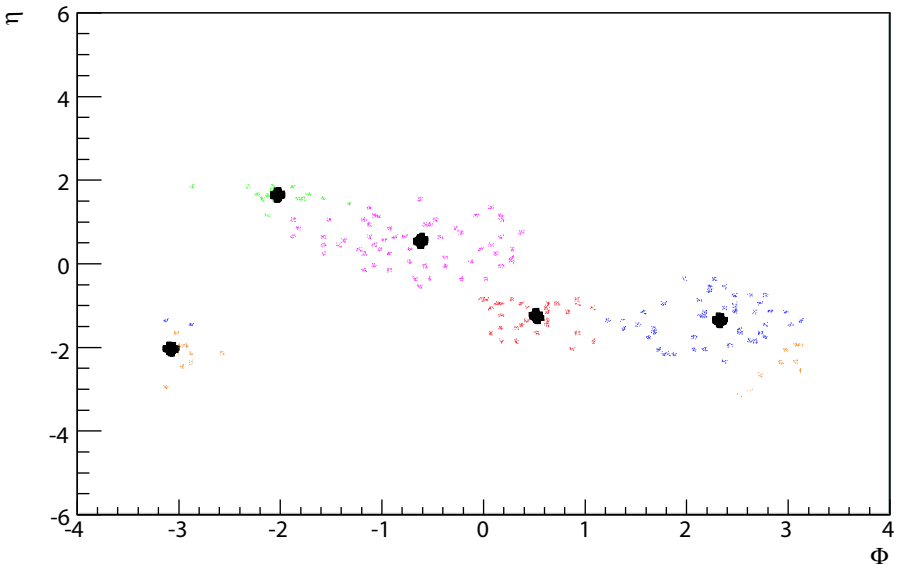
- MC Generator PYTHIA (6.4.10) was used for this analysis
- perturbation theory can't be applied at low $\mathrm{p_T}$
- models are needed to describe the Underlying Event
- different Tunes (set of parameters) which fit UE-data of previous collider experiments (at Tevatron) have been set up (by Rick Field) and extrapolated to LHC
- Tunes were obtained from "transverse region" in respect to leading jets at CDF run1 and run2:

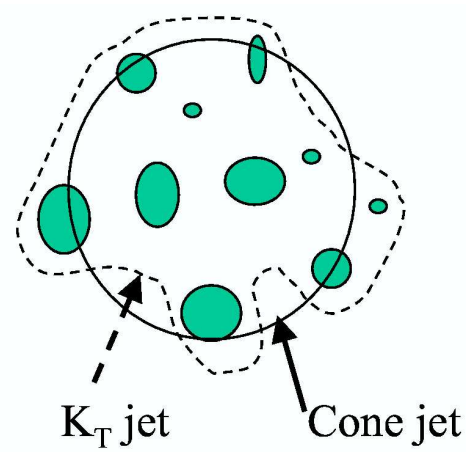


Shape of the jets

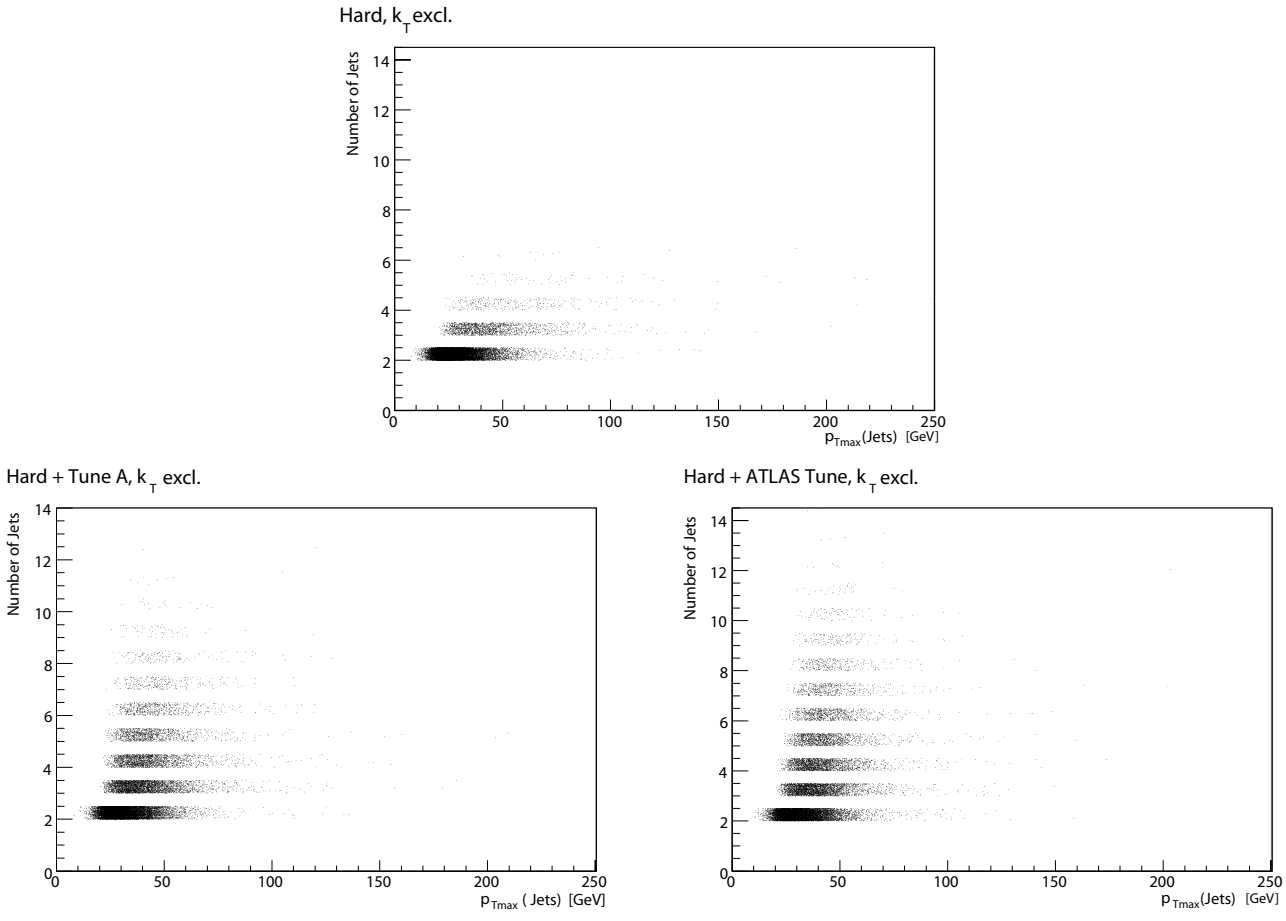
- hard scattering of $\mathrm{p_{Tmin}} = 20$ GeV
- Hard and Tune A simulated at same time (Hard+Tune A)
- take single event
- assign particles to jets (same colour = same jet)

$\mathrm{k_T}$ exclusive, $\mathrm{d_{cut}} = 400\ \mathrm{GeV}^2$





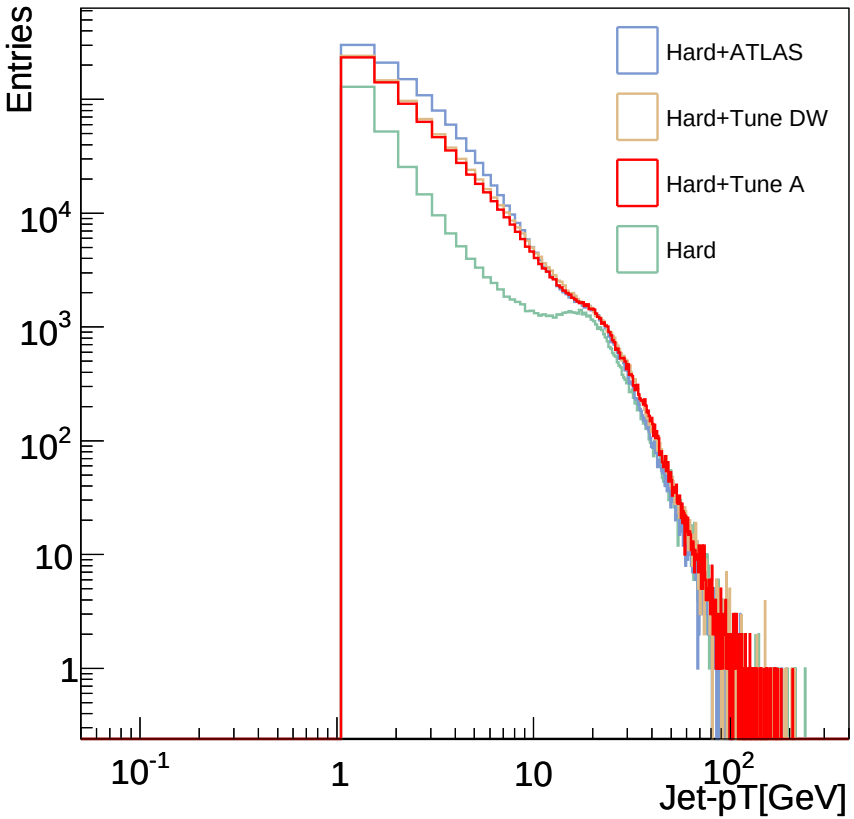
Number of jets



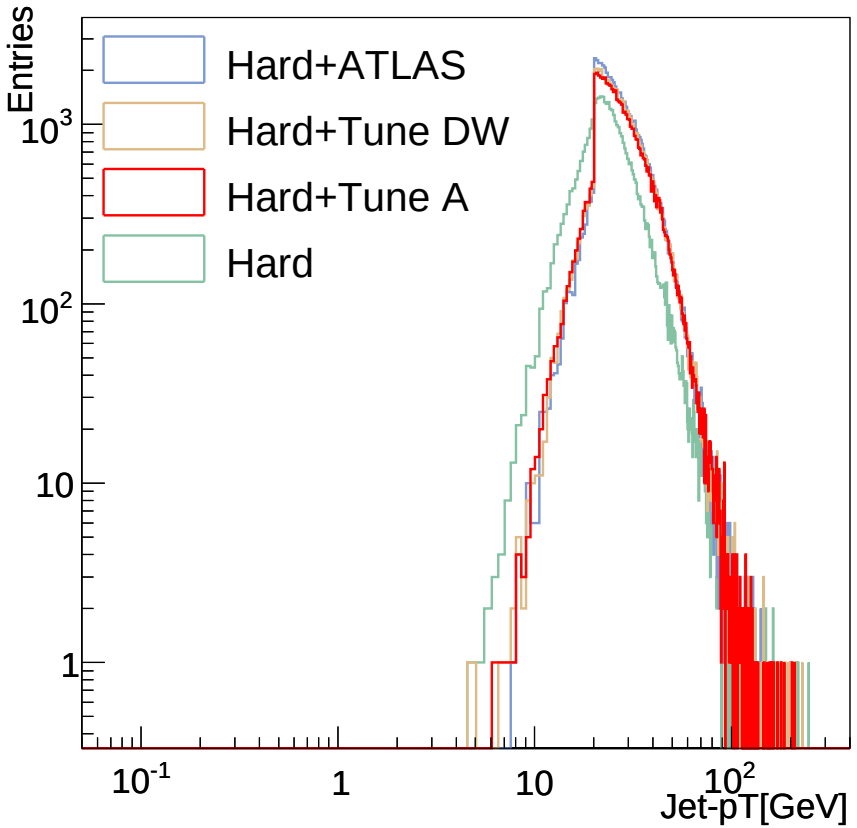
Hard alone has on average 2.1 $\pm$0.4 jets, (Hard+Tune A) 2.9 $\pm$1.3 and (Hard+ATLAS Tune) 3.2 $\pm$1.7 jets

Jet-p_T

Cone 0,4



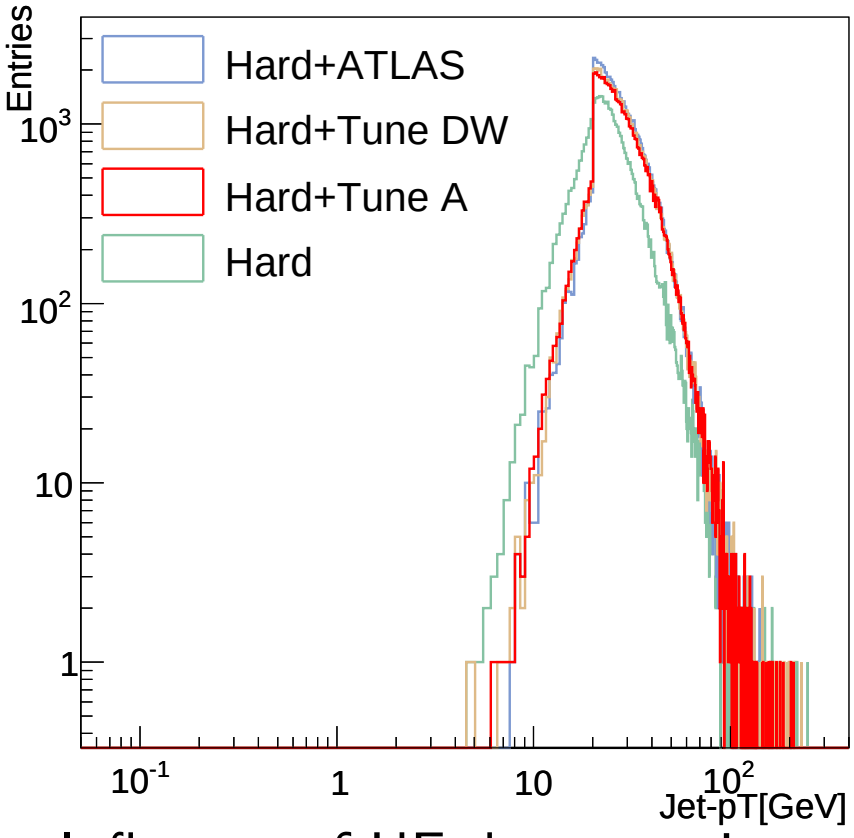
k_T exclusive



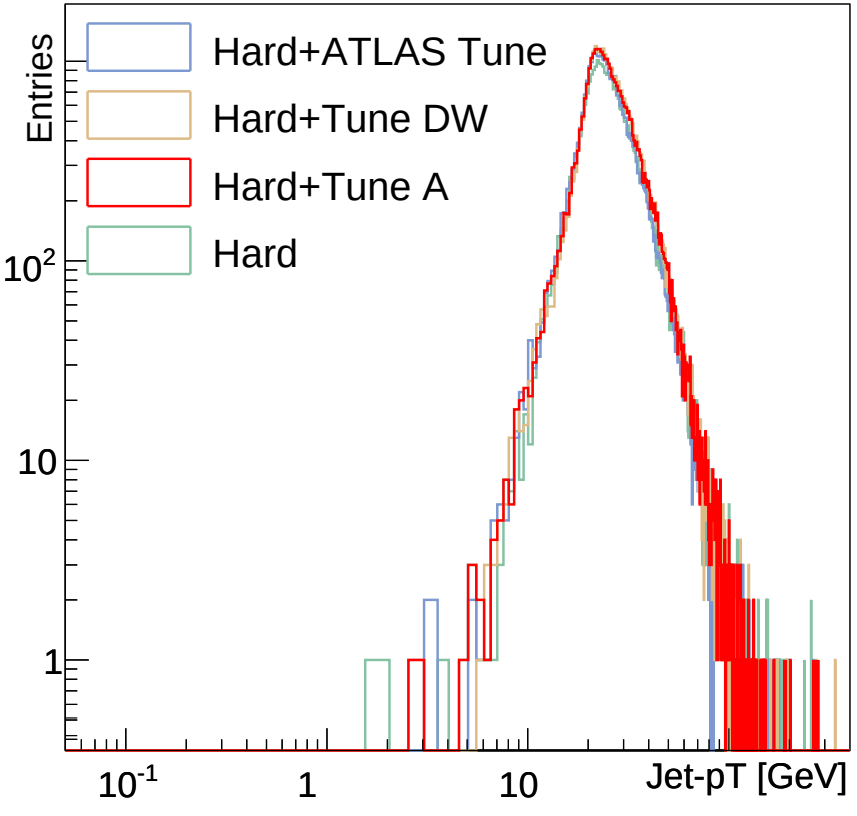
UE leads to higher p_T(jets)

Detectorlevel

PYTHIA

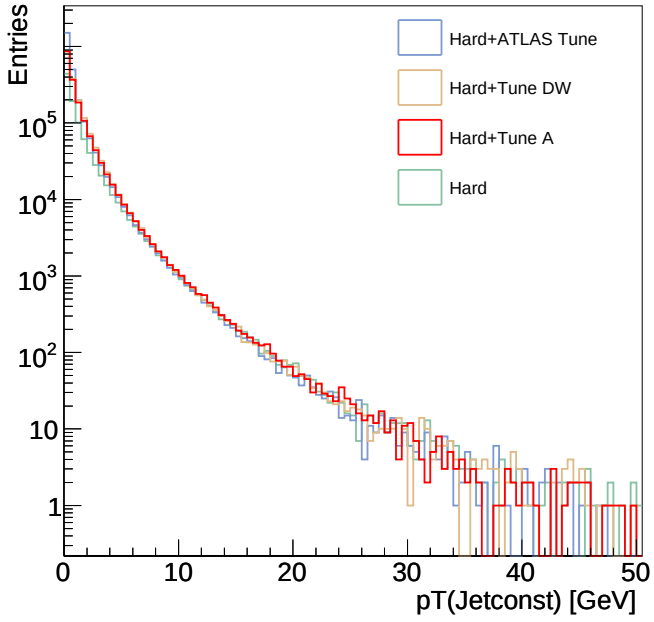


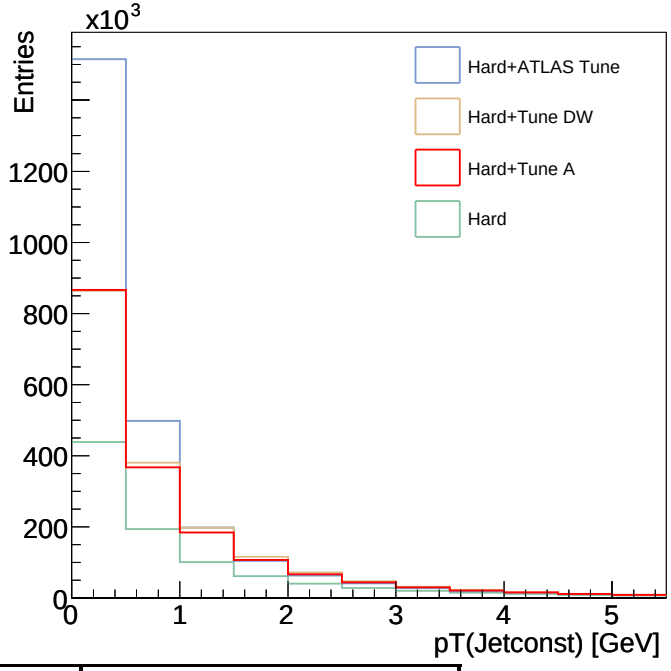
PYTHIA + ATLFAST



Influence of UE decreases in comparison to generator-level

p_T (constituents)



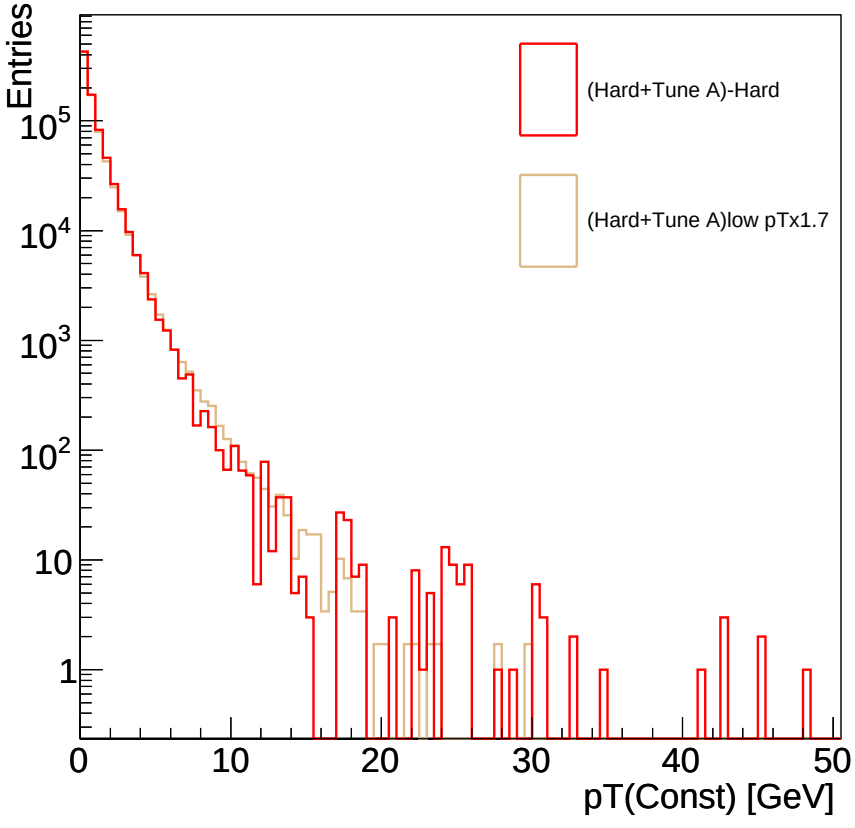


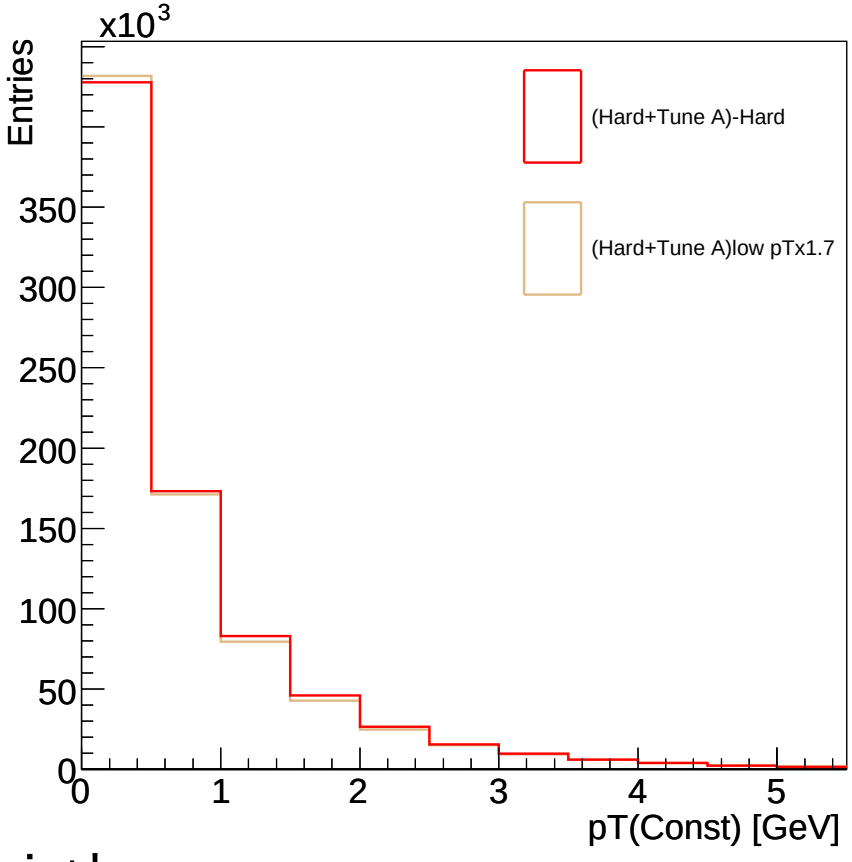
	$< p_T >$ (GeV)	p_{Tsum} (GeV)	p_T fraction of UE/event
Hard	1.208	57.9	0
Hard+Tune A	1.011	88.9	0.35
Hard+ATLAS	0.7672	97.2	0.40

Subtraction of UE: low-p_T-method

- (Hard+Tune A) – Hard approximates the fraction of UE in a hard process
- How to describe the UE in a real event, when no possibility to get solely particles from hard scattering (without contribution of UE)?
- idea: UE $\approx$ soft collision $\longrightarrow$ low-$\mathrm{p_T}$ jets
- select low-$\mathrm{p_T}$ jets in hard collision:
  - if only 2 jets in an event $\rightarrow$ force 3 jets
  - jet with lowest $\mathrm{p_T}$ is called low-$\mathrm{p_T}$ jet

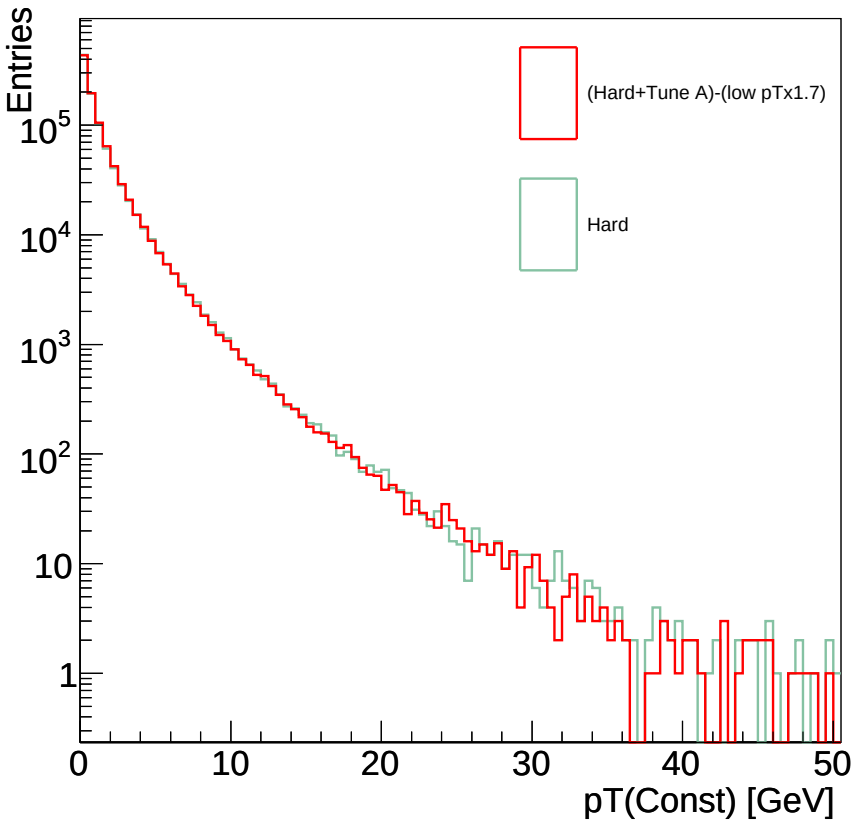
comparison: "low-p_T jets" to "UE $\approx$ (Hard+Tune A) – Hard"
scalefactor needed: low-p_T $\times$ 1.7 (ATLAS Tune: $\times$ 2.75)

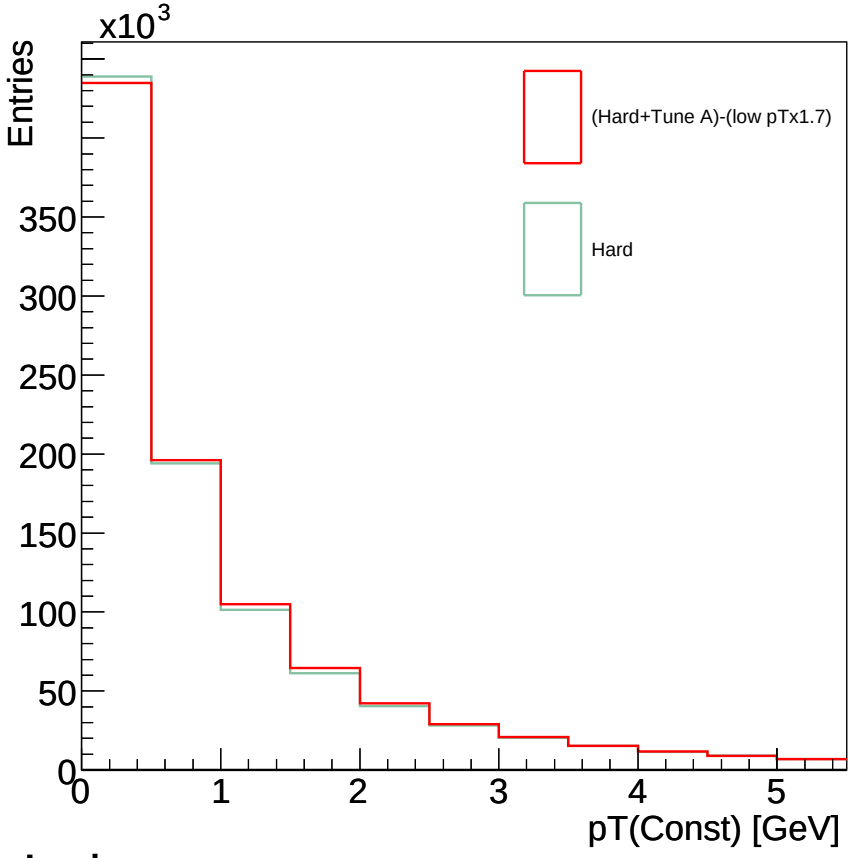




UE can be approximated by low-p_T-jet!

comparison: "(Hard+TuneA) – (1.7xlow-p_T)" to "Hard"

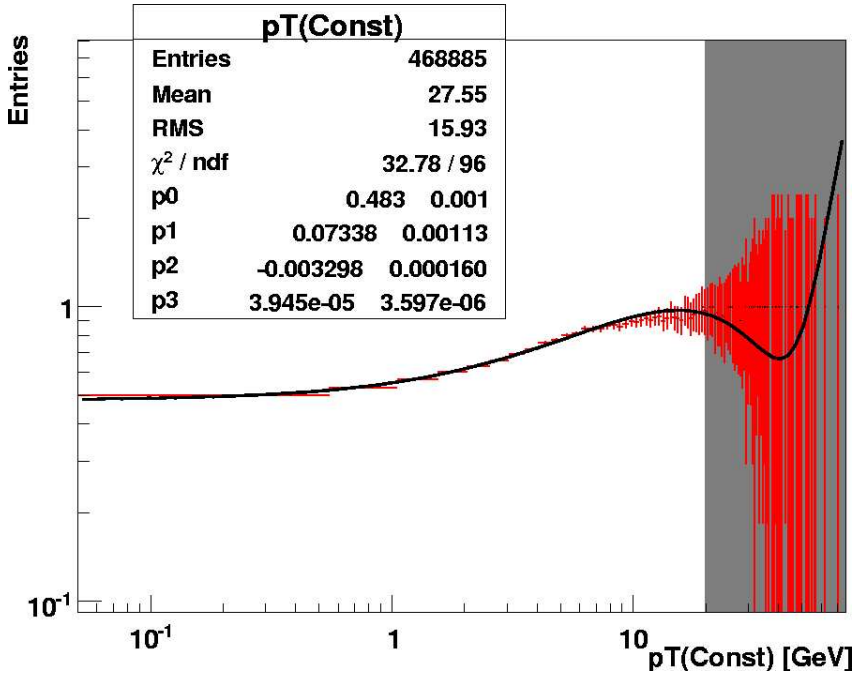


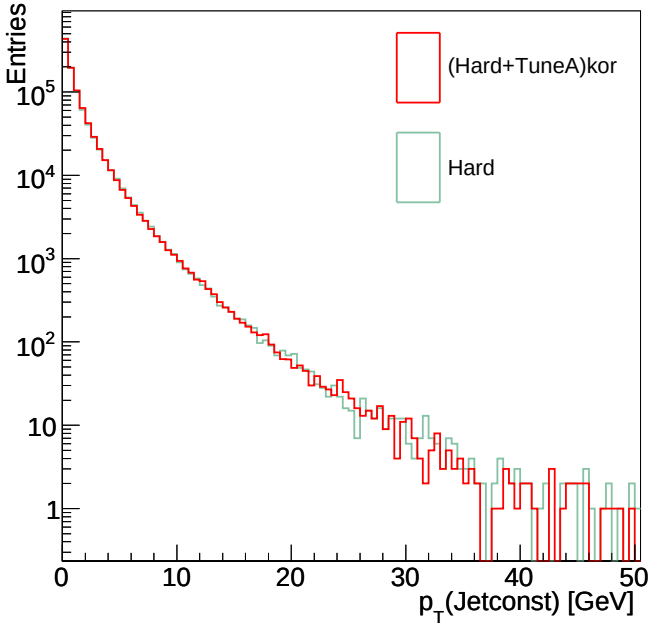


UE can be approximated by low-p_T-jet!

How to correct k_T jets for UE ?

- weight each particle in jet by probability not to come from UE
- weighing-factors from
  [(Hard+Tune A)–(1.7×low-p_T)]/(Hard+Tune A)





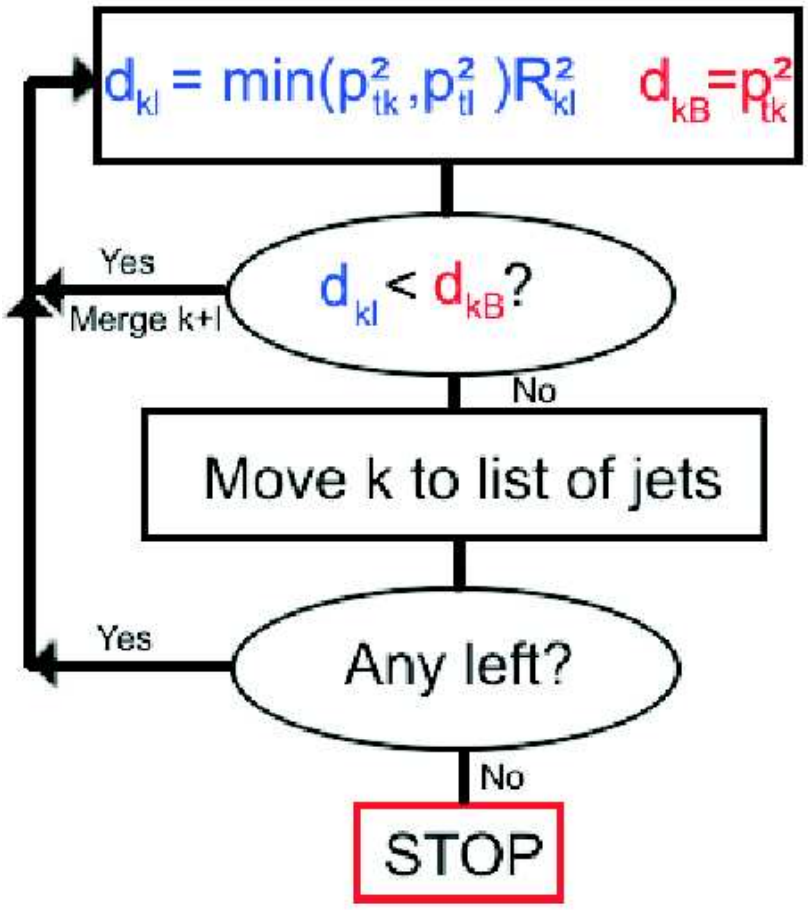
$\longrightarrow$ perfect correction up to $\sim$ 20 GeV !

Summary

- characteristics of the UE for $\mathrm{k_T}$ algorithm:
  - $\mathrm{p_{Tsum}}$ of UE per event: 30-40 GeV
  - increase of jet-$\mathrm{p_T}$ (about 10 GeV) and number of jets (about 1 additional jet) due to UE
- low-$\mathrm{p_T}$-jets describe UE
- weighting method corrects $\mathrm{k_T}$-jets for UE
- $\mathrm{k_T}$-jets can be used at hadron collider experiments

Backup

Exclusive $\mathrm{k_T}$-algorithm, ΔR-scheme



$$R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$$

- d_{min}: smallest value among d_{kB} and d_{kl}
- $\mathrm{d_{Cut}}$: cut-off parameter until jets are merged (here: $\mathrm{d_{Cut}}$=400 GeV)
- $\mathrm{d_{min}} > \mathrm{d_{Cut}}$: all remaining objects are classified as jets
- if d_{kl} is smallest, k and l are combined
- if d_{kB} is smallest, k is included in beam jet
- jet-size is dynamic, no overlapping jets

Simulated processes

hard scattering:

Parameter	Process
MSUB (53,1)	$g + g \rightarrow f + \bar{f}$
MSUB (11,1)	$f + f' \rightarrow f + f'(QCD)$
MSUB (12,1)	$f + \bar{f} \rightarrow f' + \bar{f}'$
MSUB (13,1)	$f + \bar{f} \rightarrow g + g$
MSUB (28,1)	$f + g \rightarrow f + g$
MSUB (68,1)	$g + g \rightarrow g + g$
CKIN(3,20)	p_{Tmin} in hard $2 \rightarrow 2$ scattering (20 GeV)

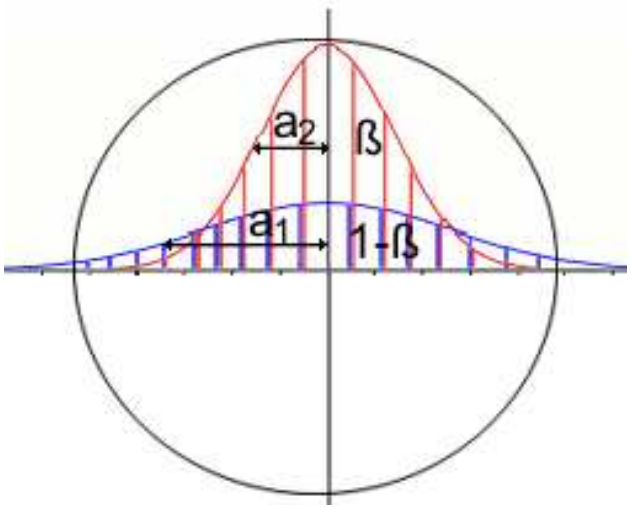
Parameter	Tune A	Tune ATLAS
PARP 82	2.0	1.8
PARP 83	0.5	0.5
PARP 84	0.4	0.5
PARP 85	0.9	0.33
PARP 86	0.95	0.66
PARP 89	1800	1000
PARP 90	0.25	0.16
PARP 62	1.0	1.0
PARP 64	1.0	1.0
PARP 67	4.0	1.0
MSTP 91	1	1
PARP 91	1.0	1.0
PARP 93	5.0	5.0

- MSTP(51,1): chosen PDF (CETEQ 5L)
- MSTP(81,1): MPI on
- MSTP(82,4): further MPI switches on

UE-Parameter
ISR-Parameter
intrinsic k_T

Explanation of some parameters

double Gaussian matter distribution inside proton:
$\rho(r) \propto \frac{1-\beta}{a_1^3} exp(-\frac{r^2}{a_1^2}) + \frac{\beta}{a_2^3} exp(-\frac{r^2}{a_2^2})$



Proton

β=PARP(83)
a_2/a_1=PARP(84)

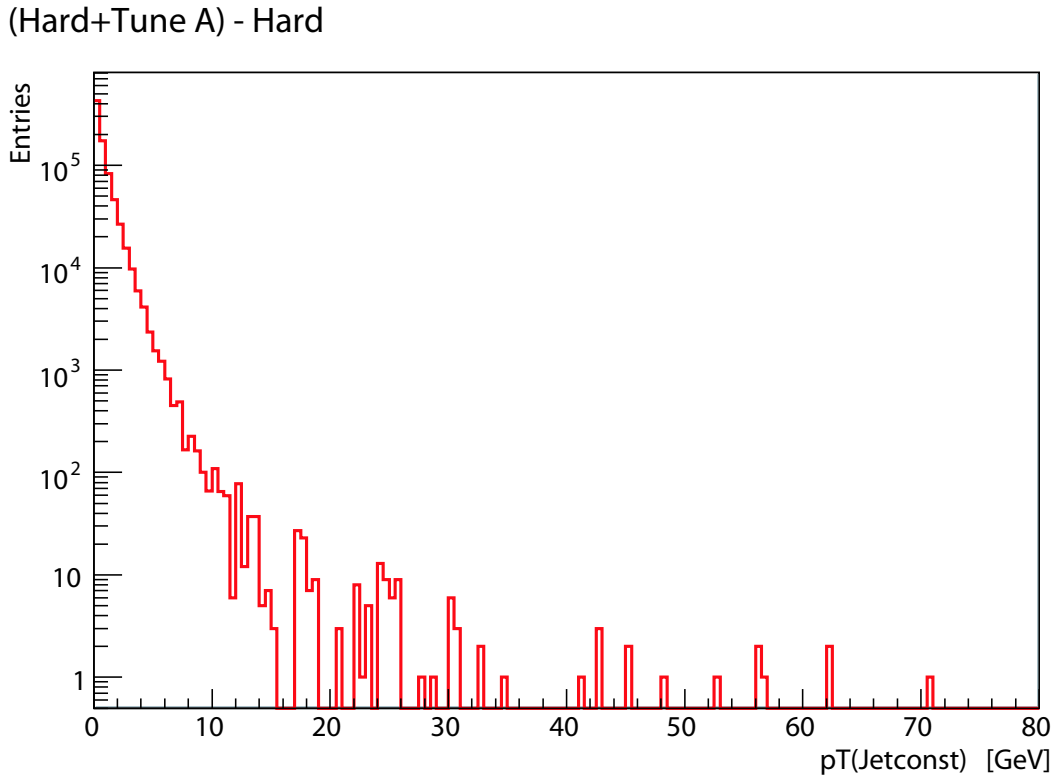
Energy-dependency of p_{T0}
$p_{T0}(E_{cm}) = p_{T0}(\frac{E_{cm}}{E_0})^{\epsilon}$

with p_{T0}=PARP(82),
E_0=PARP(89),
$\epsilon = PARP(90)$

Particles from UE

How does the UE in a hard process look like?

$\longrightarrow$ assumption: UE in a hard process fits (Hard+Tune A) - Hard



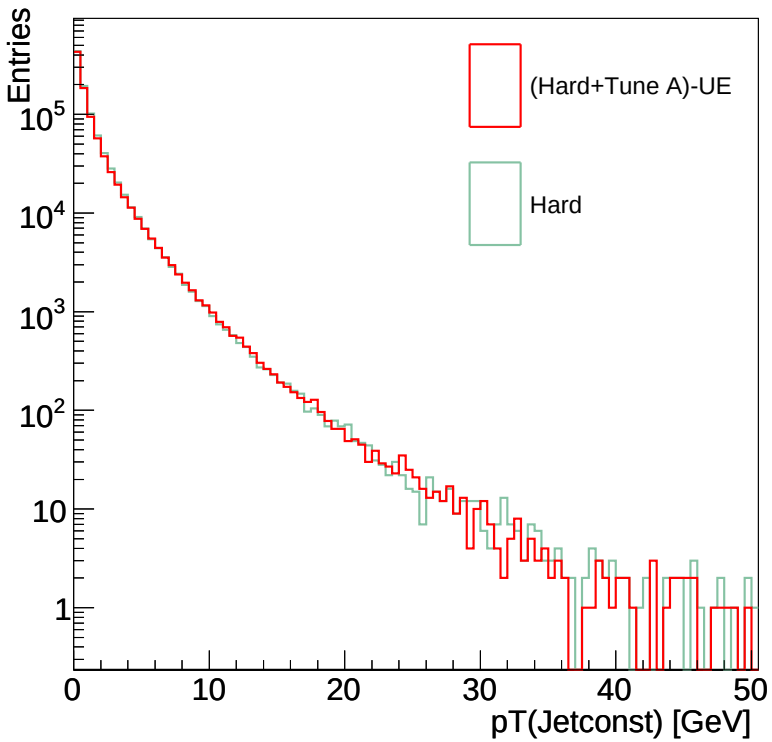
- check: backtrack final particles to find out origin
- method works until string
- problem: information about motherparticle of "first particle after string" gets lost due to hadronisation

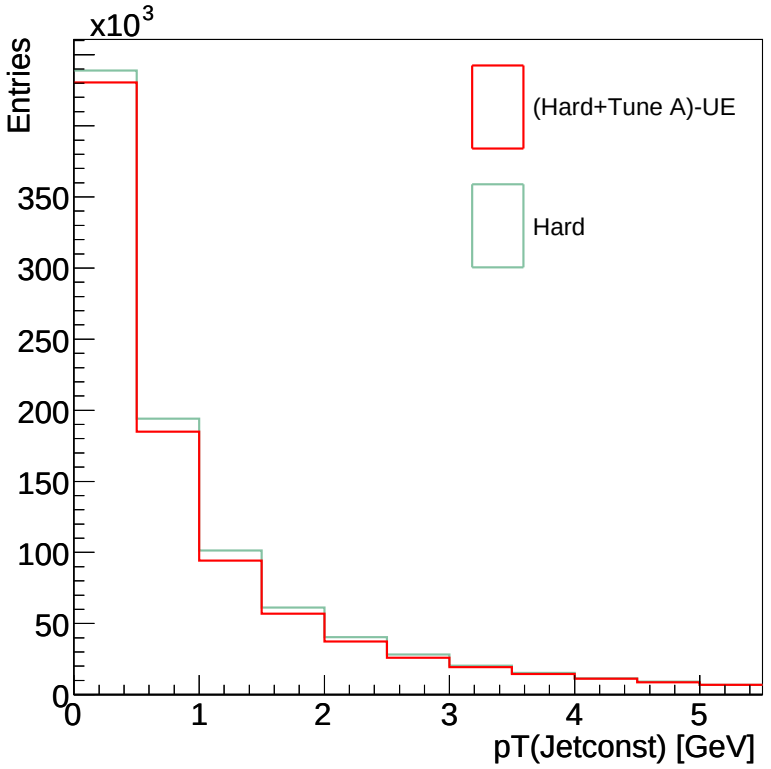
I	particle/jet	K(I,3)	K(I,4)
1	!p+!	0	0
2	!p+!	0	0
3	!u!	1	0
4	!g!	2	0
5	!u!	3	0
6	!g!	4	0
7	!u!	0	0
8	!g!	0	0
9	(u)	A 7	54
10	(g)	I 7	54
11	(g)	I 7	54
12	(g)	I 7	54
13	(g)	I 0	54
14	(g)	I 0	54
15	(g)	I 8	54
16	(g)	I 8	54
17	(g)	I 8	54
18	(g)	I 8	54
19	(g)	I 8	54
20	(g)	I 8	54
21	(g)	I 0	54
22	(g)	I 0	54
23	(g)	I 0	54
24	(g)	I 0	54
25	(g)	I 0	54
26	(g)	I 0	54
27	(g)	I 0	54
28	(g)	I 0	54
29	(g)	I 0	54
30	(uu_1)	V 2	54

54	(string)	9	55
55	(pi0)	54	156
56	(omega)	54	158
57	(Delta++)	54	161
58	(omega)	54	163
59	(Deltabar--)	54	166
60	(K*+)	54	168
61	(Kbar0)	54	170
62	(omega)	54	171
63	(omega)	54	174
64	pi-	54	0
65	(pi0)	54	177
66	pi+	54	0
67	(eta)	54	179
68	(pi0)	54	182
69	(rho-)	54	185
70	p+	54	0
71	nbar0	54	0

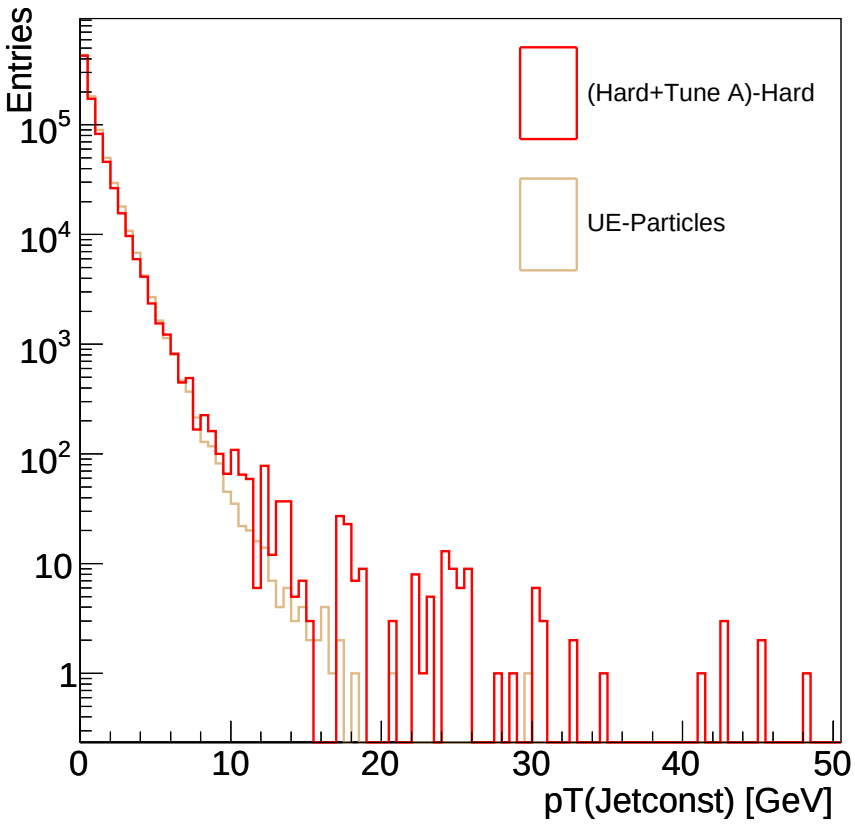
idea: associate "first particle after string" with particle in string via certain criteria:
$(\Delta R * (\Delta p_T)^2)_{min} \leq 25$

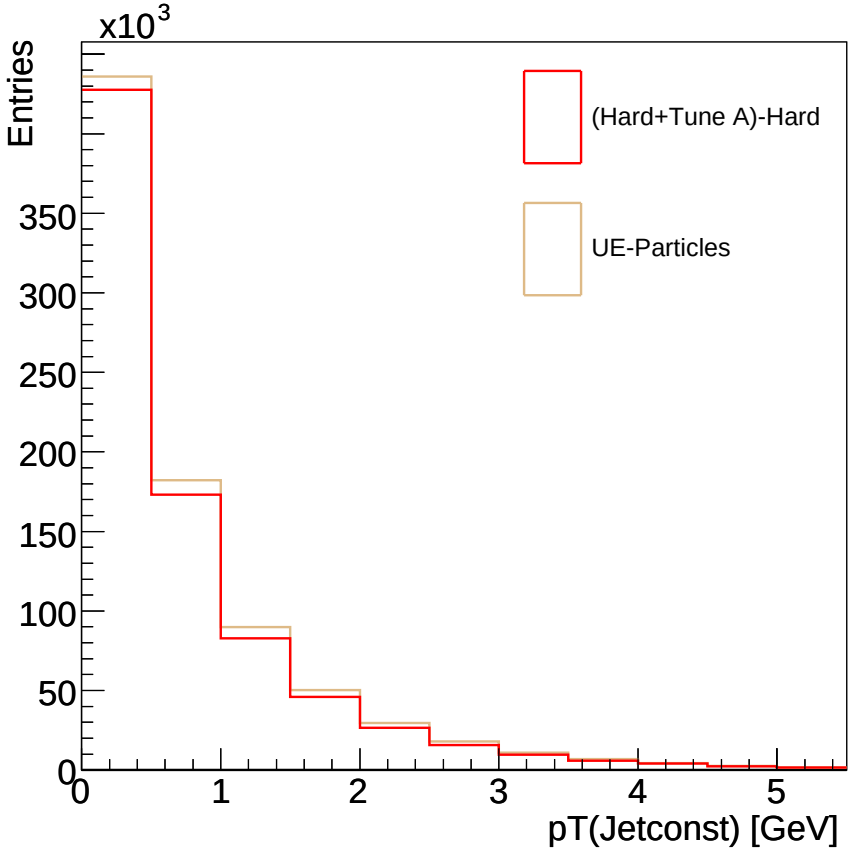
$\longrightarrow$ subtraction of UE-particles from (Hard+TuneA) and comparison to Hard:





UE-particles are in good agreement with (Hard+Tune A) - Hard





UE adds on average 11.4 GeV to a jet!