High granularity calorimeter simulation studies for a very large hadron collider at 100TeV: tau lepton tagging at truth level

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- Tau lepton tagging in ATLAS
- Analysis of simulated $Z \to \tau^+ \tau^-$ events at truth level

Future hadron colliders

Next goals in collider physics: HL-LHC and FCC.
Main focus on FCC at 100 TeV
$p \propto R\,B$
Tunnel length$\simeq 100 Km$
Large R implies:
- less energy losses by synchrotron emission in the storage ring.
- less magnetic field for keeping protons in orbit: $B \simeq 15\,T$

Nb_3Sn superconductor technology and main problems to solve

- New Nb_3Sn superconductor technology has **higher critical field** and critical temperature (18.3K) than NbTi. Nb_3Sn can withstand to the magnetic field of FCC.
- Main problem: the power dissipated in **synchrotron radiation** is 20 times LHC.
- It must be removed at cryogenic temperatures.

Why do we want achieve 100 TeV centre of mass energy?

- **Cross sections** of events that involve highly massive particles generally increase with the energy

- Up to which level of precision does the **Higgs boson** behave like predicted by the SM?

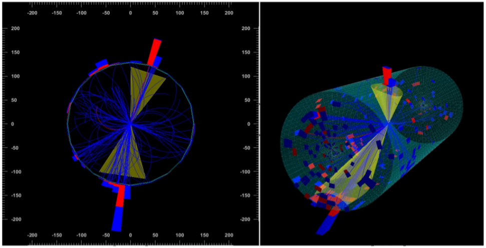
- What are the **new particles** that can explain neutrinos oscillation, dark matter, matter-antimatter asymmetry and the other phenomena beyond SM?

My current work: tau lepton tagging

- Why tau lepton is interesting in high energy physics?
- It is the heaviest lepton: $m_{tau} \simeq 1.777 GeV$.
- Higgs boson can decay into two tau leptons: tau tagging is important for a deeper understanding of the Higgs physics.

$$H \rightarrow \tau^+ \tau^-$$

How is detected tau lepton?



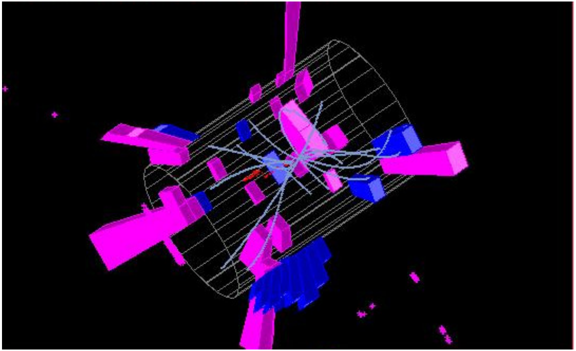
- Tau lifetime is short ($\simeq 10^{-13}s$)
- Tau decays either hadronically or leptonically

$$\tau \rightarrow hadrons\ \nu_\tau$$

$$\tau \rightarrow l\ \nu_\tau\ \bar{\nu}_l$$

tau lepton reconstruction algorithm

- Tau hadronic channel is **detected as an hadron jet**.
- Main source of **noise: quark-like jets**.
- Implementation of the tau reconstruction algorithm.
- **Topocluster** algorithm is the input:
  suppress both electronics and pile-up noise.

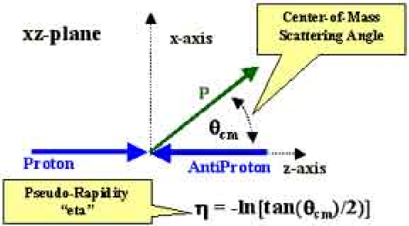


tau lepton reconstruction algorithm

- **Selection criteria** based on the their number of associated tracks, transverse momentum, pseudorapidity.

- This step leads to tau **hadron visible candidates** and to the coordinate system in the tau primary vertex.

- But this doesn't suppress quark-like jet noise.



Discrimination against jets

- Some variables (**discriminating variables**) are used for the discrimination against jets.

- For example: **’central energy fraction’**.

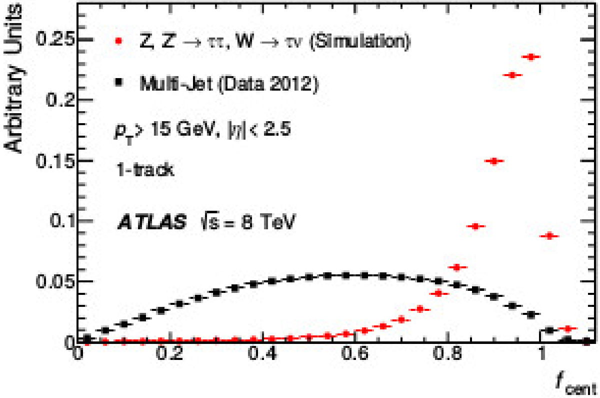
$$f_{cent} = \frac{\textit{transverse energy deposited in the region}\,\Delta\, R < 0.1}{\textit{energy deposited in the region}\,\Delta R < 0.2}$$

with

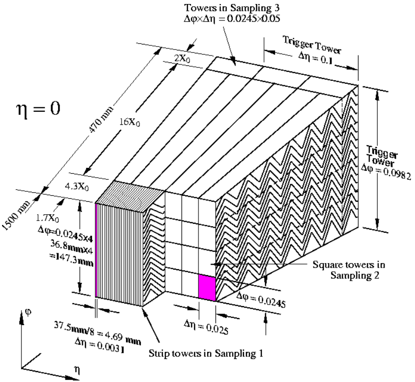
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

around the jet direction.

Central energy fraction



Final goal



- **Boost** of decaying particles and signal resolution are correlated quantities.
- Role of the pixel size in the detection.
- We want to estimate the **sufficient granularity** (as function of the centre of mass energy) for distinguishing two tau jets and a tau jet from a quark-like jet using simulations.

What are we studying?

- Electron-positron collision at 500 GeV

$$e^+ e^- \to Z^* \to \tau^+ \tau^-$$

- Truth level

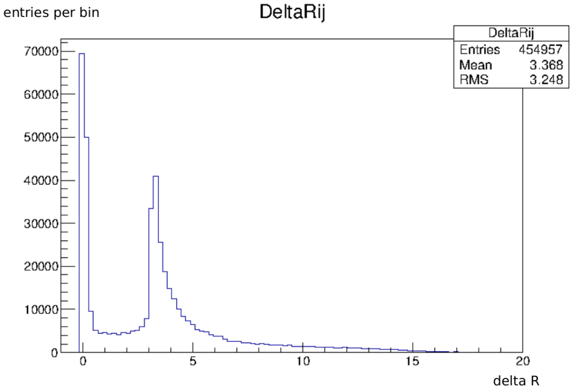
- π^0 decays very quickly:

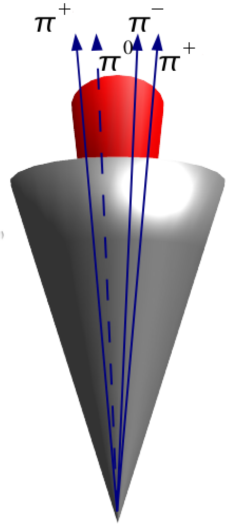
$$\pi^0 \to \gamma \gamma$$

PID	particle	charge
-16	$\bar{\nu_\tau}$	0
-14	$\bar{\nu_\mu}$	0
-13	μ^+	1
-12	$\bar{\nu_e}$	0
-11	e^+	1
11	e^-	-1
12	ν_e	0
13	μ^-	-1
14	ν_μ	0
16	ν_τ	0
22	γ	0
130	K_L^0	0
211	π^+	1
-211	π^-	-1
310	K_S^0	0
321	K^+	1
-321	K^-	-1

Splitting into two jets

- Distance between all possible pairs of particles present in the event.

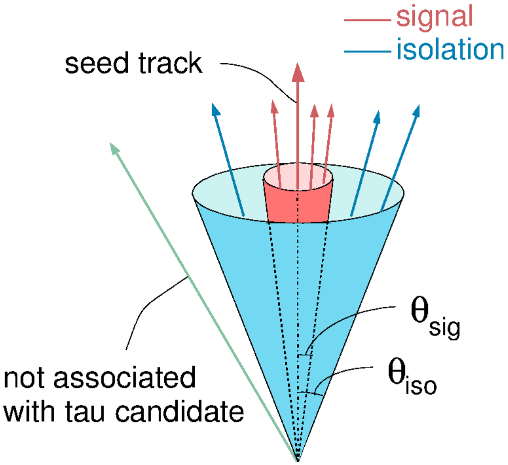




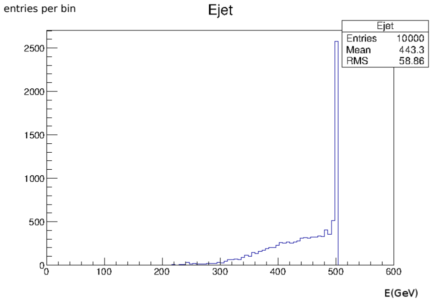
- Threshold: $\Delta R < 0.6$

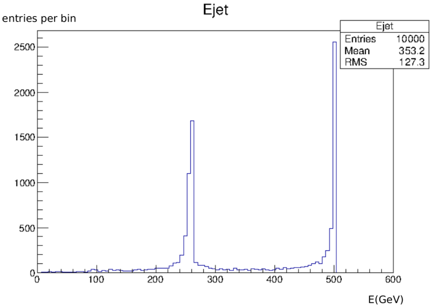
What do we choose as seed particle?

- $P_{t\ max}$-algorithm
- E_{max}-algorithm
- ν_τ-algorithm



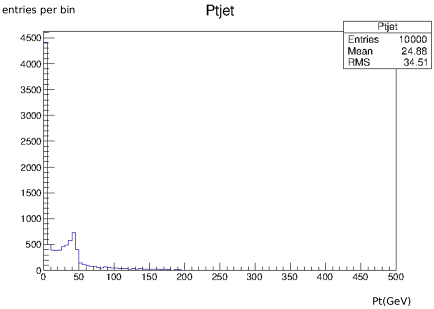
E_{max}-algorithm vs $P_{t\ max}$-algorithm: sum of the energies of the two jets



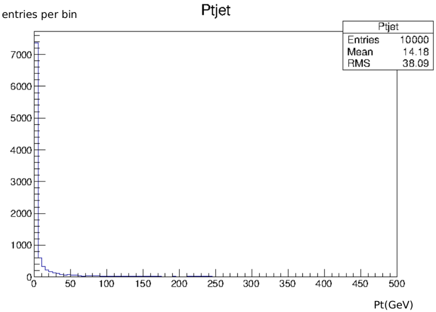


- using the E_{max}-algorithm
- using the $P_{t\ max}$-algorithm

E_{max}-algorithm vs $P_{t\,max}$-algorithm: transverse component of the total momentum of the two jets

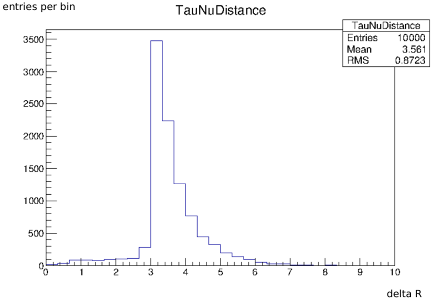


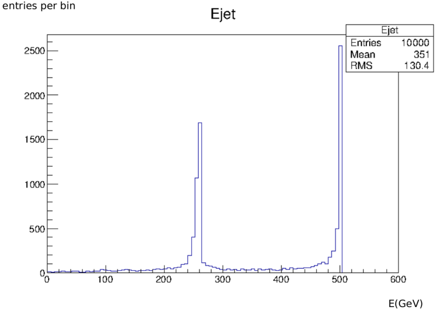
- using the E_{max}-algorithm



- using the $P_{t\,max}$-algorithm

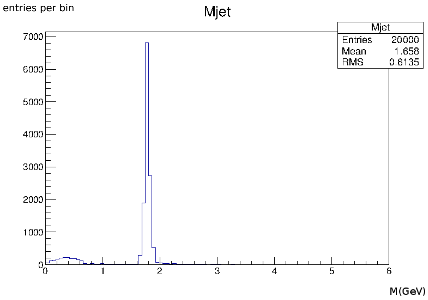
Clustering around neutrinos

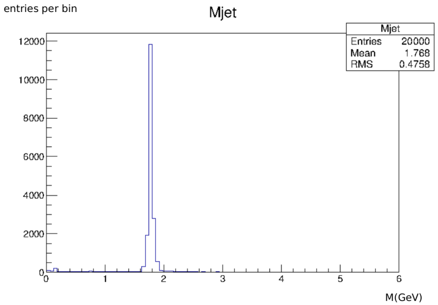




- $\nu_\tau - \bar{\nu_\tau}$ distance:consistent with the plot of the distances between all particles in the event
- Sum of the jet energies: very similar to the $P_{t\,max}$ one!

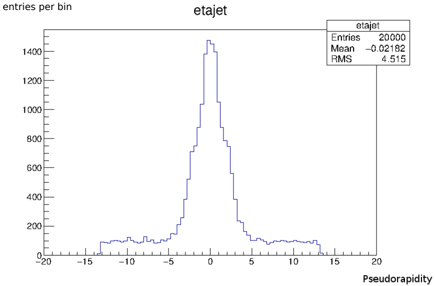
$P_{t\,max}$ works better than the E_{max}



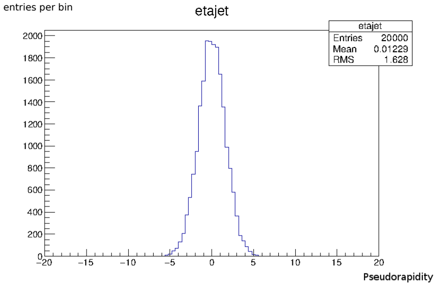


- jet mass using E_{max}
- jet mass using $P_{t\,max}$

Pseudorapidity of the jets

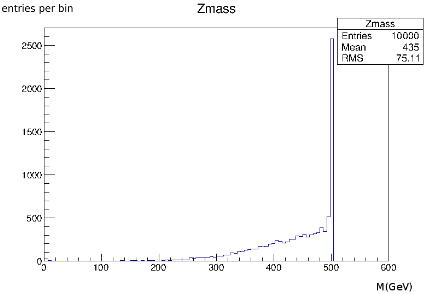


- using the E_{max}-algorithm: initial state radiation is included in the jets

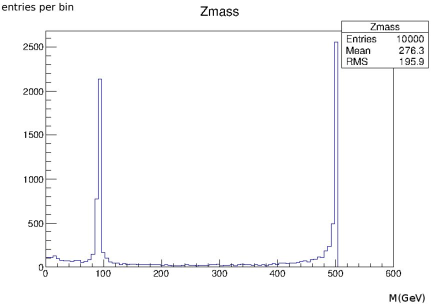


- using the $P_{t\ max}$-algorithm

Mass of the dijet system



- using E_{max} algorithm

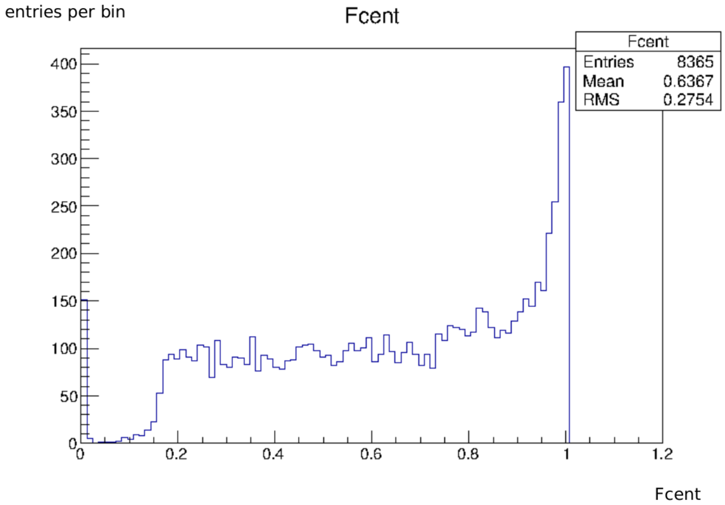


- using $P_{t\ max}$ algorithm: on-shell and off-shell Z bosons

Discriminating variables

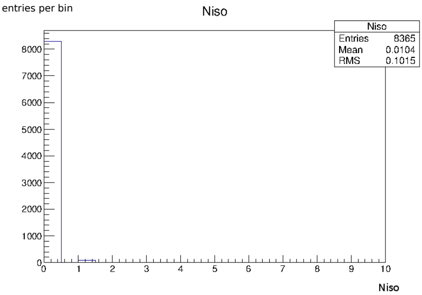
- Leptonic jet rejection
- $\eta < 2.5 \quad P_t > 15 GeV$
- We distinguish one and three track decays.
- π^0 reconstruction, iteratively coupling nearest photon pair to the seed direction
- Discriminating variables calculation:
  - central energy fraction
  - number of tracks in the isolation region
  - maximum ΔR in the core region
  - number of reconstructed π^0 in the core region
  - p_t-weighted mean distance between the tracks and the tau jet direction, core and isolation region
  - invariant mass of the tracks in the core and isolation regions, assuming a pion mass for each track
  - the highest p_t between the tracks in the core region, divided by the transverse energy sum in the core region.

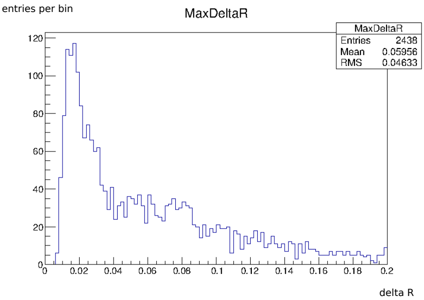
Discriminating variables



- Central energy fraction $\frac{E_t(\Delta R < 0.1)}{E(\Delta R < 0.2)}$

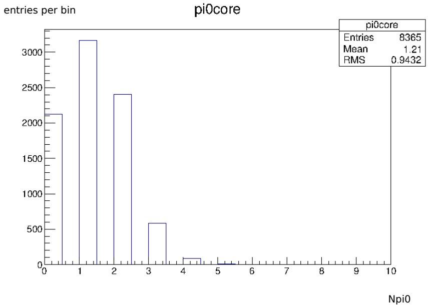
Discriminating variables



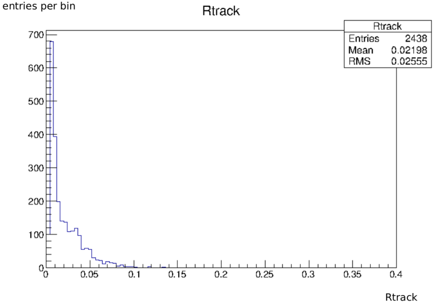


- Number of tracks in the isolation region
- ΔR_{max}, core region

Discriminating variables

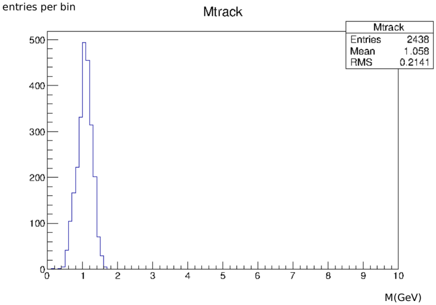


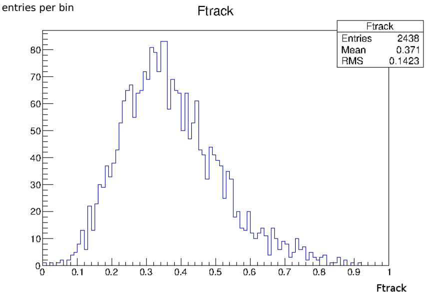
- Number of reconstructed π^0, core region



- R_{track}: p_t-weighted mean distance between the tracks and the tau jet direction, core and isolation region

Discriminating variables





- M_{track}: invariant mass of the tracks in the core and isolation regions, assuming a pion mass for each track.
- F_{track}: the highest p_t between the tracks in the core region divided by the transverse energy sum in the core region

SUMMARY AND RESULTS

- Tau lepton tagging at VLHC: need of high granularity calorimeter.
- Simulation studies at truth level, $e^+ e^- \to Z^* \to \tau \tau$ channel.
- Jet-clustering and jet-separation: $P_{t\,max}$-algorithm.
- A π^0 reconstruction has also been made coupling photon pairs.
- Discriminating variables calculation:
  central energy fraction; number of tracks in the isolation region; maximum ΔR in the core region; number of reconstructed π^0 in the core region; p_t-weighted mean distance between the tracks and the tau jet direction, core and isolation region; invariant mass of the tracks in the core and isolation regions, assuming a pion mass for each track; the highest p_t between the tracks in the core region, divided by the transverse energy sum in the core region.
- Starting point for a more complex study using detector simulations.

Thank you very much for your attention!!