Evaluation of PFO timing cuts at √s = 380 GeV

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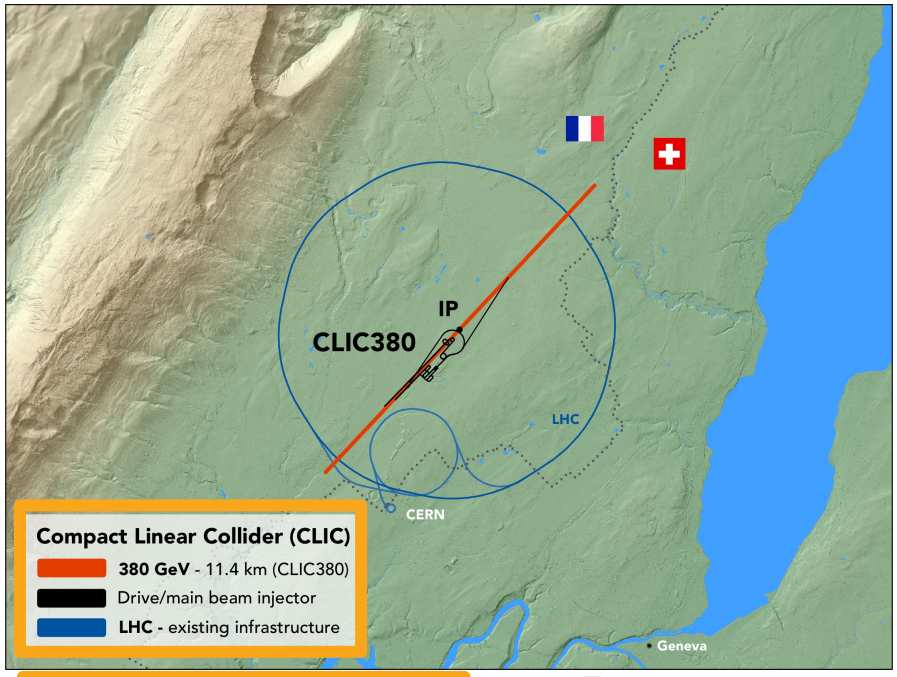
The 380 GeV stage at CLIC

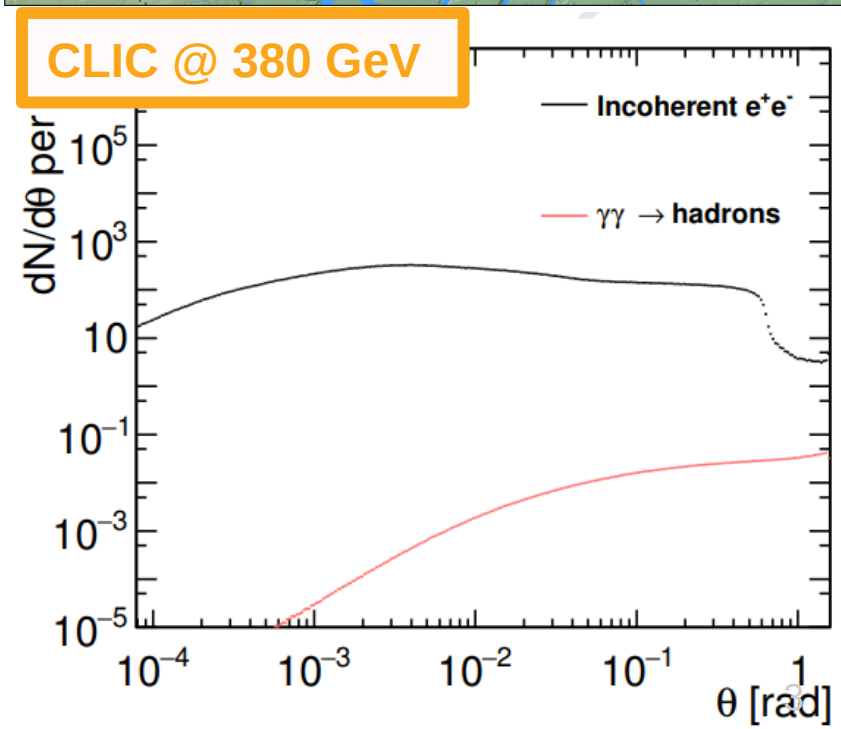
- In the first stage, CLIC will mainly operate at centre-of-mass energy of **380 GeV** with the aim to measure the **top quark** and the **Higgs boson** with high precision.

- **Machine parameters** for the first stage of CLIC are reported in the back-up.

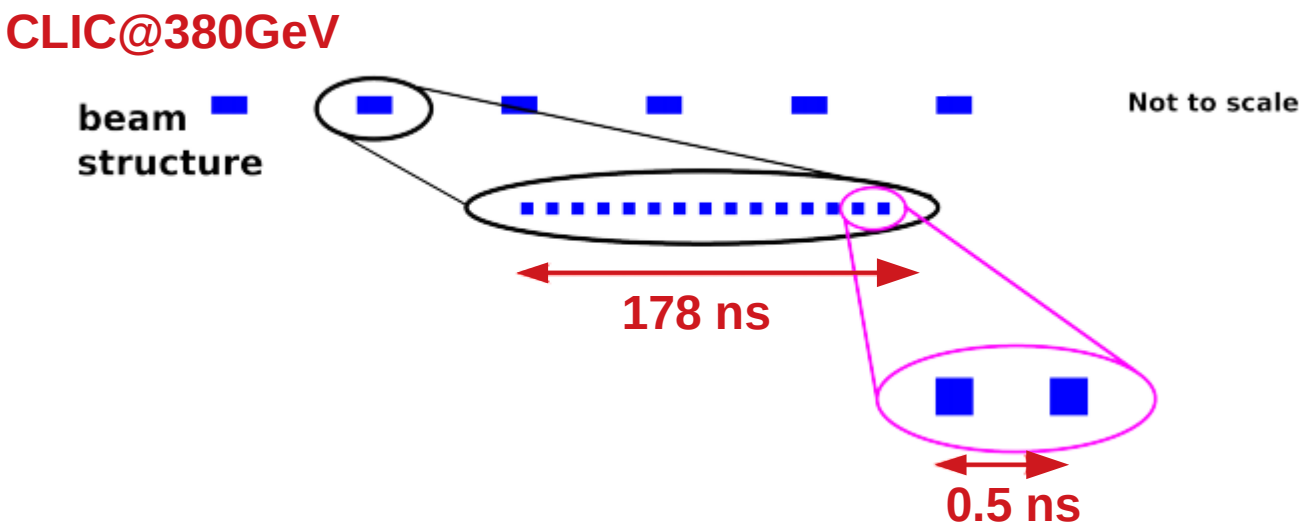
- The background at CLIC is produced by **beamstrahlung radiation** from the electron and positron bunches traversing the high field of the opposite beam.

- Photons then convert to two main types of background:
  - **Incoherent e^+e^- pairs**
  - **$\gamma\gamma \rightarrow$ hadrons**
- At the 380 GeV energy stage, 0.16 $\gamma\gamma \rightarrow$ hadrons interactions occur per bunch crossing





Bunch separation and reconstruction



Property √s	380 GeV	1.5/3 TeV
Train repetition rate	50 Hz	50 Hz
Bunches / train	356	312
Train duration	178 ns	156 ns
Bunch separation	0.5 ns	0.5 ns

Linear colliders operate in bunch trains:

- Detector is in triggerless readout mode
- Bunch separation drives timing requirement of detector:
  < 10 ns hit time-stamping in tracking
  < 1 ns accuracy for calorimeter hits

Software reconstruction:

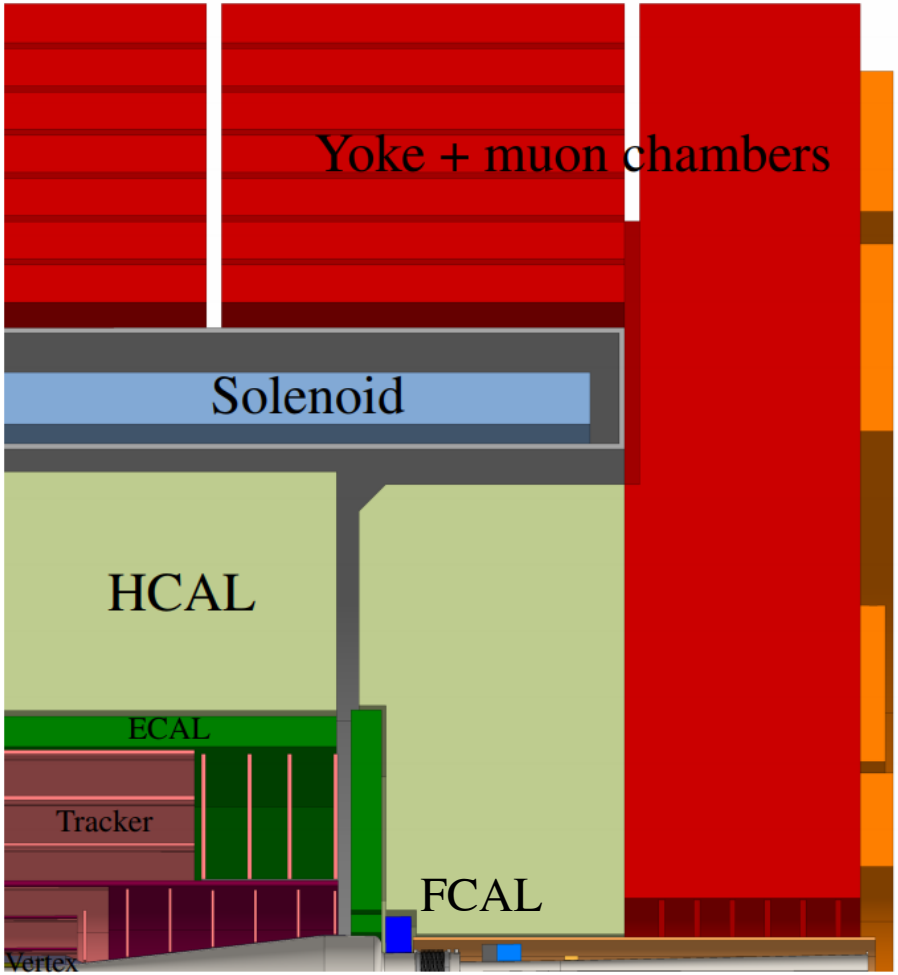
- Overlay the expected number of $\gamma\gamma \rightarrow$ hadrons for 30 BX to the signal event.
- Signal event is placed in bunch crossing 11 at t = 0 ns.

CLICdet

Designed for Particle Flow Analysis and optimised for CLIC environment

Basic characteristics:

- B-field: 4 T
- Vertex pixel detector with 3 double layers
- Silicon strip tracking system (R ~ 1.5 m)
- Si-W ECAL with 40 layers (22 X_0)
- Scint-Fe HCAL with 60 layers (7.5 λ_I)
- Muon chambers for Muon ID



Precise timing for background suppression

(bunch crossings 0.5 ns apart)**:**

- < 10 ns hit time-stamping in tracking
- < 1 ns accuracy for calorimeter hits

The Particle Flow approach

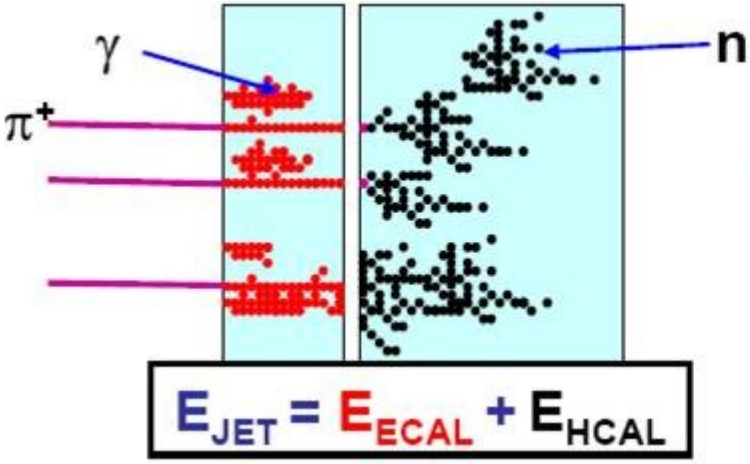
Main idea of Particle Flow approach:

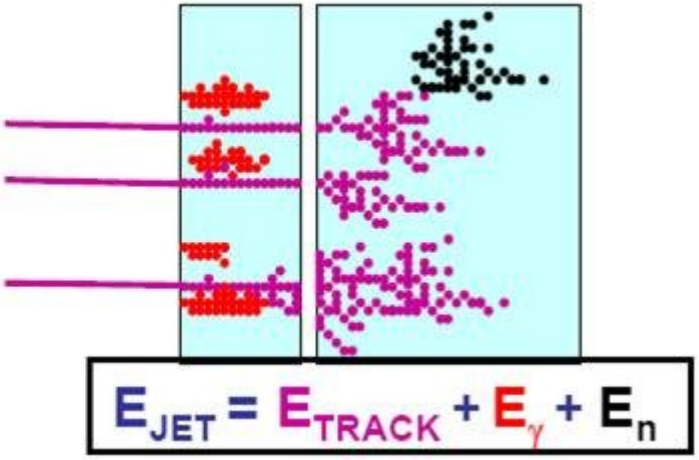
- **Average jet composition:** → Use the best information
  60% charged particles → tracker
  30% photons → ECAL
  10% neutral hadrons → HCAL

- **Hardware:**
  Resolve energy deposits from different particles
  → High granularity calorimeters

- **Software:**
  Associate energy deposits to the correct individual particle
  → Sophisticated reconstruction software

- **Output collection:** *particle flow objects* (PFOs)

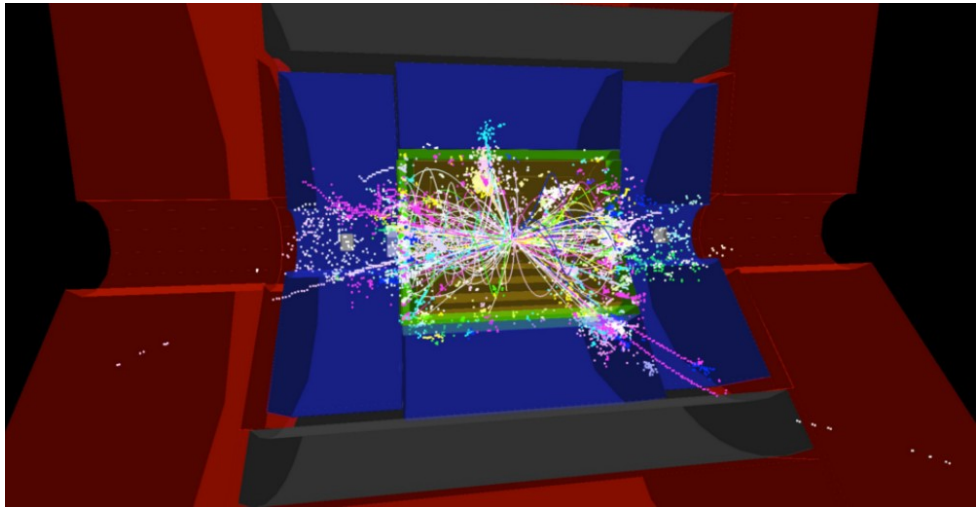




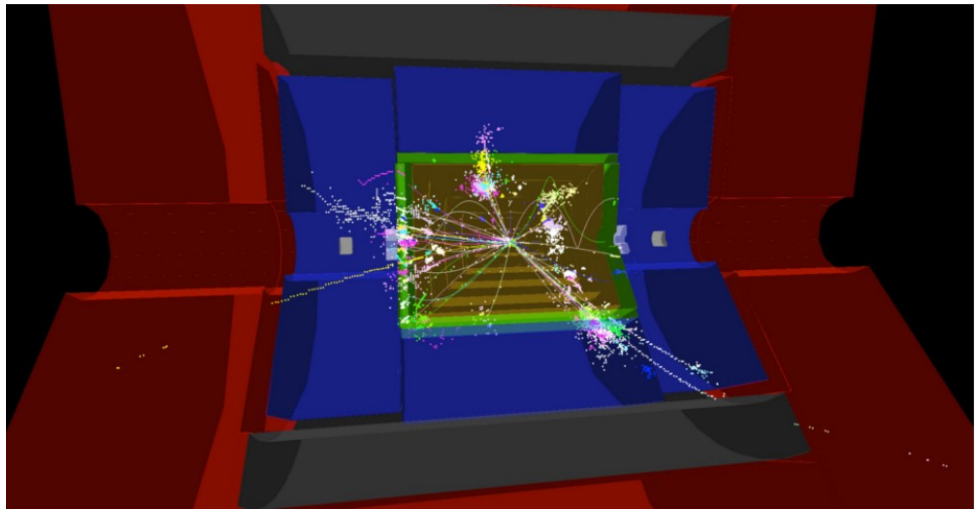
Beam-induced background rejection

- **PFO information** used:
  - particle type
  - reconstructed polar angle (cosθ)
  - reconstructed transverse momentum (p_t)
  - cluster time obtained by combining hit timing information (and correcting with time-of-flight)
- It is used to reduce the beam-induced background from γγ → hadrons
  → apply **p_t vs. time selections** on individually reconstructed PFOs.
- Three sets of selections: *Loose*, *Selected*, and *Tight*.
- **In the context of a 380 GeV CLIC machine, a preliminary set of p_t vs. time selections are already defined but the precise performance has yet to be studied.**

Before the p_t vs. time selections



After the p_t vs. time selections

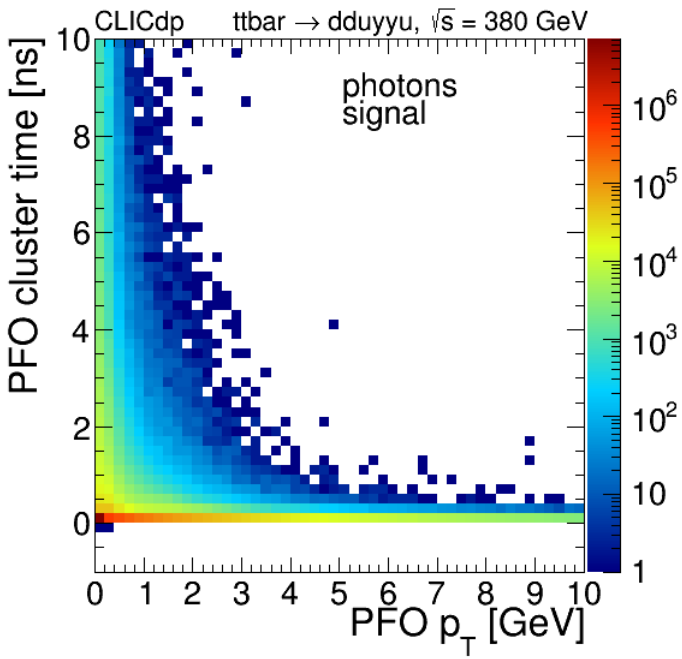


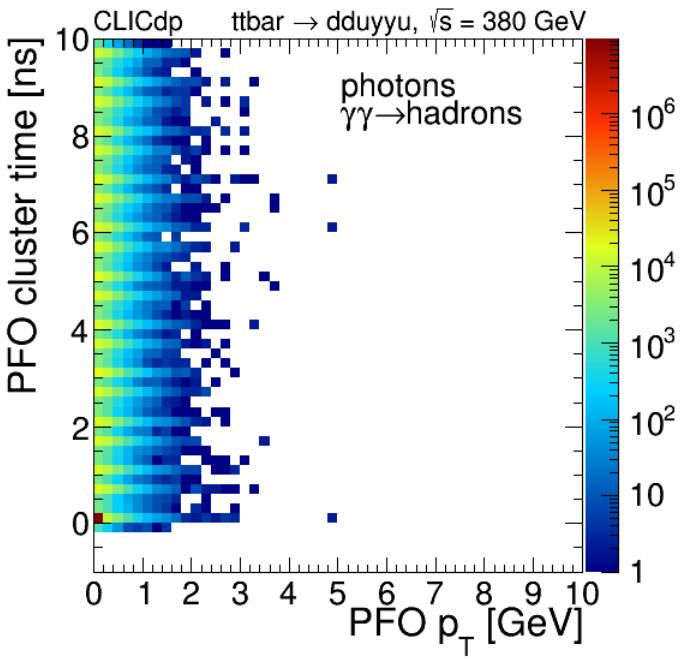
Example: e+e− → ttH → Wb Wb H → qqb τνb bb at 1.4 TeV

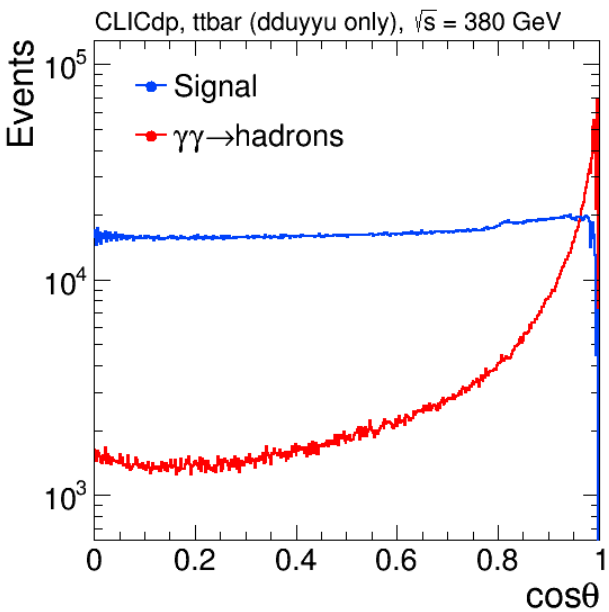
p_t vs. time distribution

- **Motivation**: Evaluation of p_t vs. time selections **at √s = 380 GeV** with more realistic estimation of **0.16 γγ→hadrons interactions** (before was 0.04)
- **Sample used**:
  - Signal: $t\bar{t} \rightarrow$ dduyyu (with y = d,s,b) with centre of mass energy at 380 GeV
  - Background: γγ → hadrons at 350 GeV
- The PFO is considered signal if it is associated to **at least one MCPhysicsParticle**
- p_t vs. time distribution **signal/background** (example with photons)

  → Discrimination is particularly challenging!
- Regional distribution







p_t vs. time selections

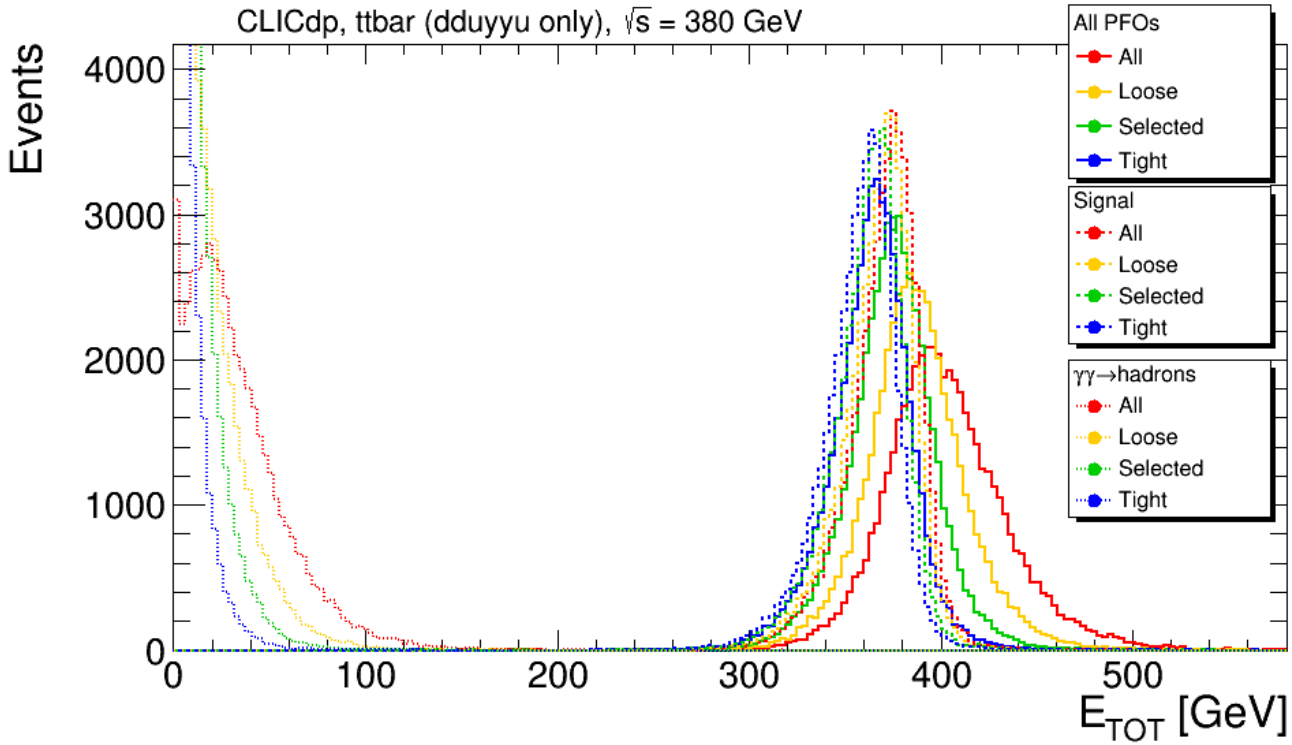
p_t vs. time cuts for *Loose* selection:

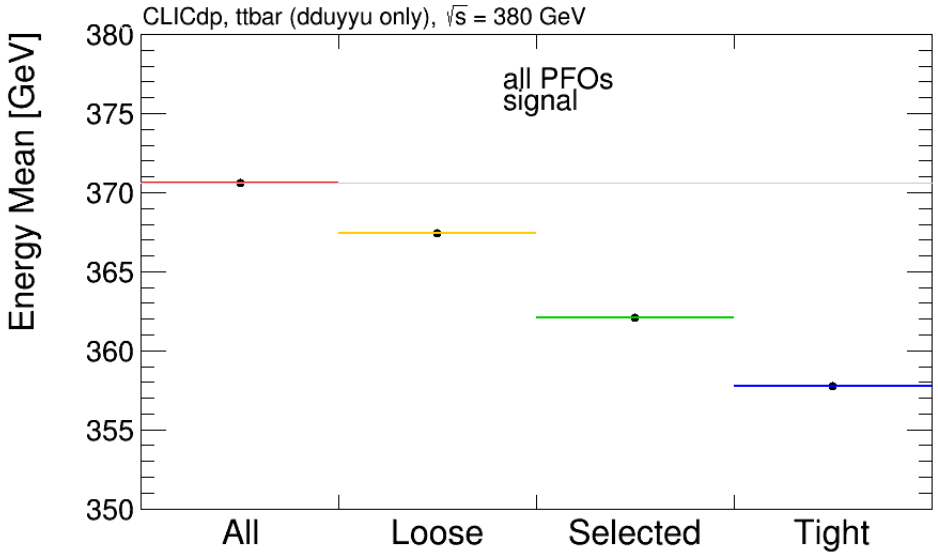
Table 4: *Loose* selections used for 380 GeV CLIC machine.

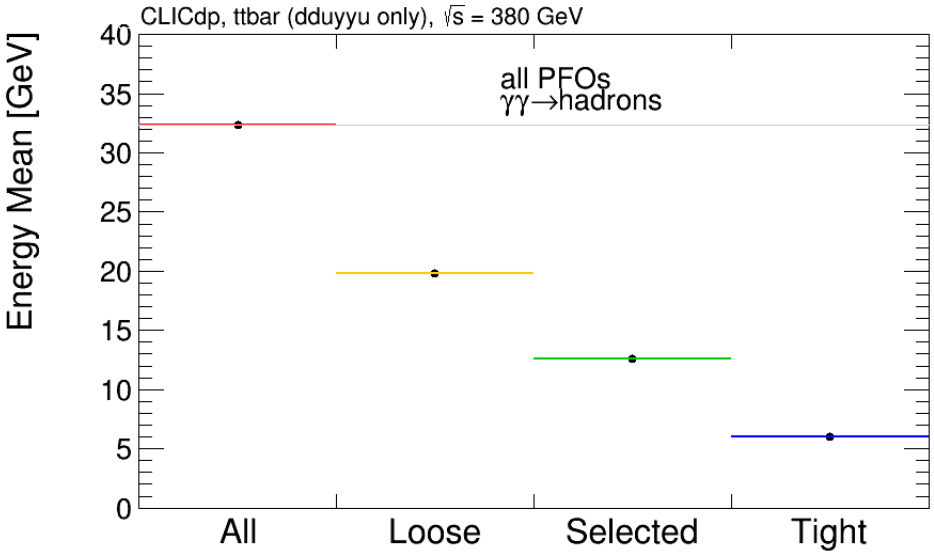
Particle category	Region	p_T range [GeV]	time cut [ns]
Photons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 2.0$	$t < 10.0$
		$0 \leq p_T < 0.75$	$t < 2.5$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 2.0$	$t < 2.0$
		$0 \leq p_T < 0.75$	$t < 1.0$
Neutral hadrons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 2.0$	$t < 10.0$
		$0 \leq p_T < 0.75$	$t < 5.0$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 2.0$	$t < 10.0$
		$0 \leq p_T < 0.75$	$t < 5.0$
Charged particles	all	$0.75 \leq p_T < 2.0$	$t < 10.0$
		$0 \leq p_T < 0.75$	$t < 5.0$

Selected and *Tight* selection tables in backup.

p_t vs. time selection







Signal contribution

- **Evaluate energy mean for each particle category and polar angle group**
  → Search for possible improvements in Loose selection

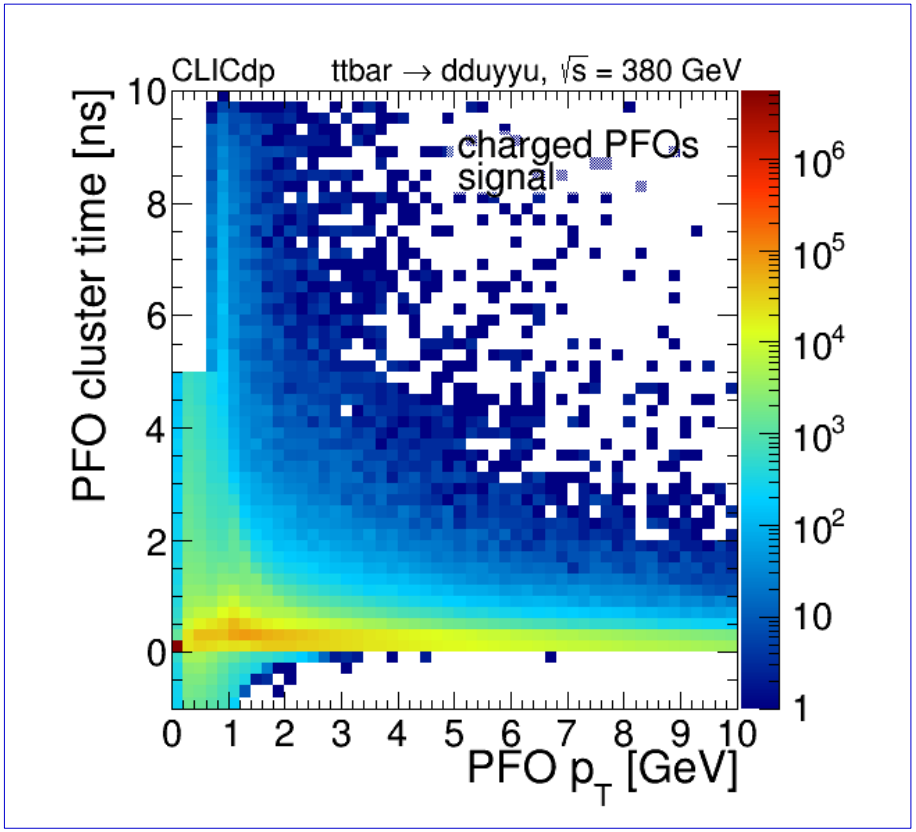
Particle	Region	Mean energy			
		NO CUT	TIGHT	DEFAULT	LOOSE
		370	358	361.5	368
Photons	$\cos\theta \leq 0.975$	104	103	103.5	103.8
	$\cos\theta > 0.975$	2	1.9	1.9	1.9
Charged PFOs	$\cos\theta \leq 0.975$	202	193	196	200
	$\cos\theta > 0.975$	3.4	3	3.3	3.4
Neutral hadrons	$\cos\theta \leq 0.975$	57	54	54.5	56
	$\cos\theta > 0.975$	2.5	2	2	2.5

Optimization of *Loose* selection

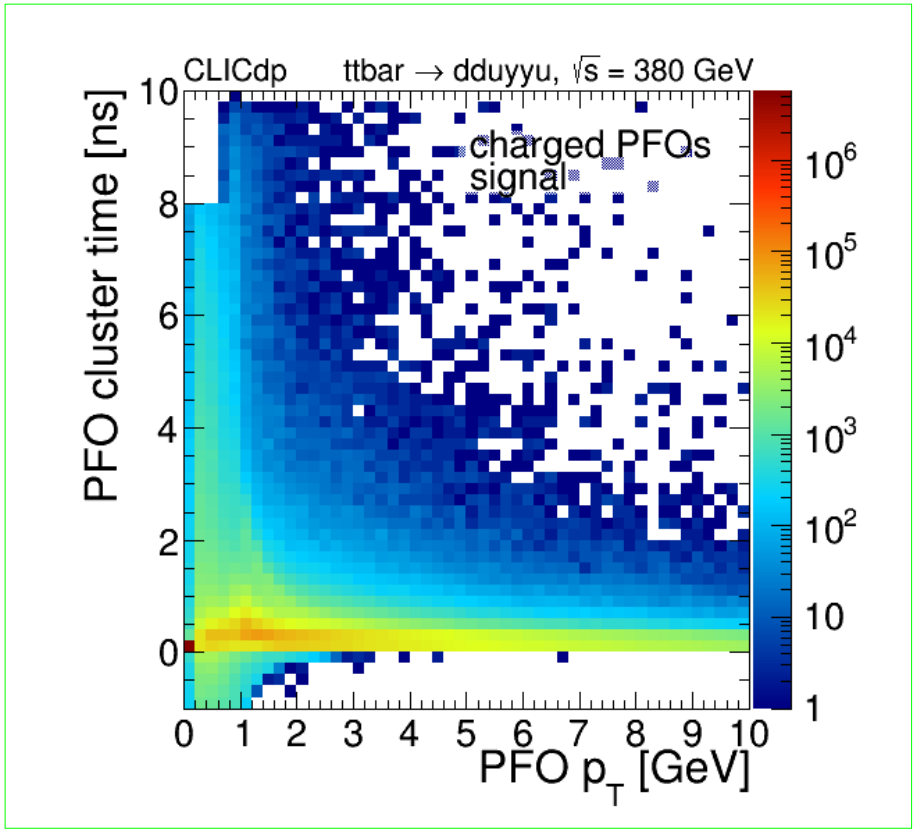
- The following relaxed Loose selections are applied:
  - increasing time cut from 5 ns to 6 ns for charged PFOs (**time+**)
  - increasing time cut from 5 ns to 8 ns for charged PFOs (**time++**)
  - decreasing p_t cut from 0.75 GeV to 0.5 GeV for all particle catgories (**pt-**)
  - decreasing p_t cut from 0.75 GeV to 0 GeV for all particle catgories (**pt--**)

  The current Loose selection is referred to as **vanilla**.

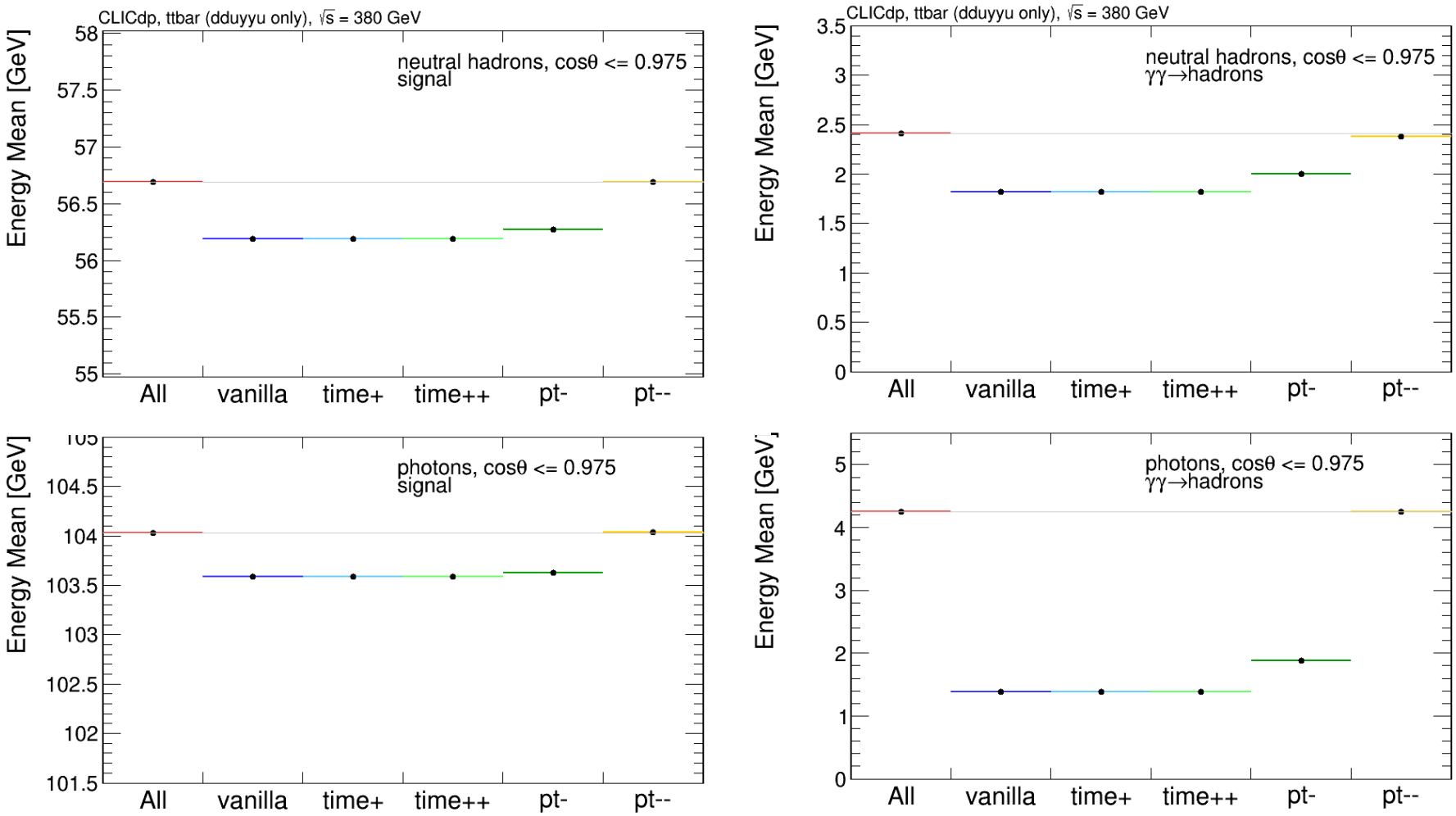
Charged PFOs, vanilla



Charged PFOs, time++

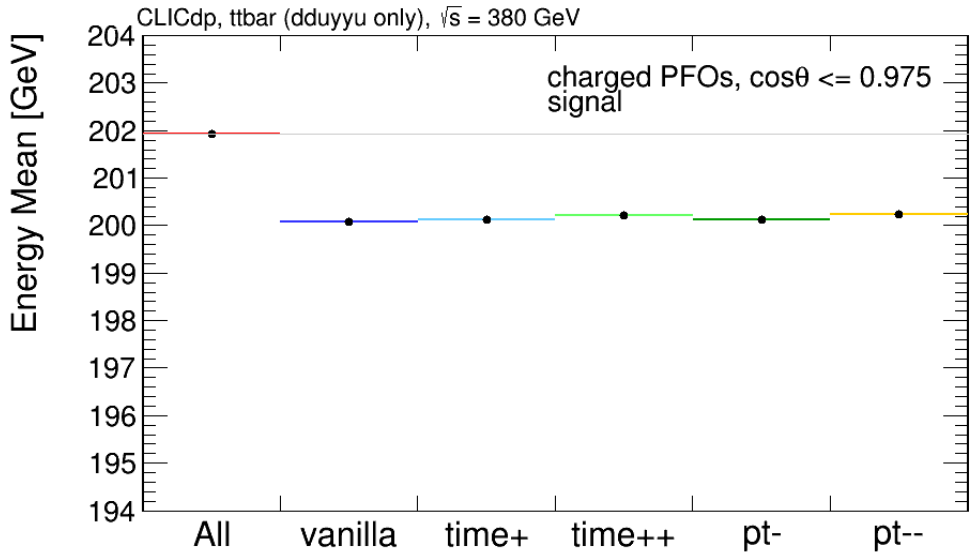


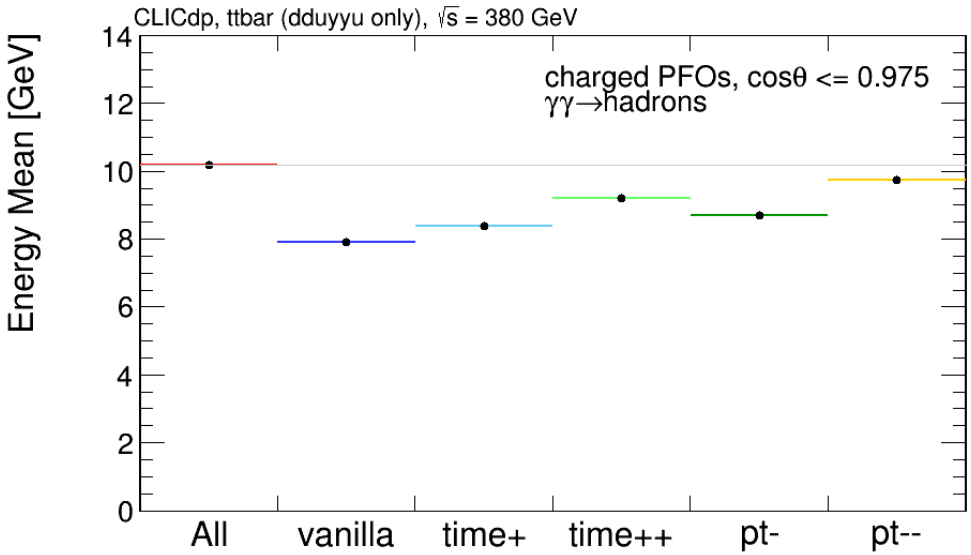
Results of *Loose* selection



- Increment of background component for all particle categories
- In the case of neutral hadrons and photons, pt-- selection recovers signal, but level of background is ~unchanged w/ no cut
- Similar conclusions for cosθ > 0.975

Results of *Loose* selection





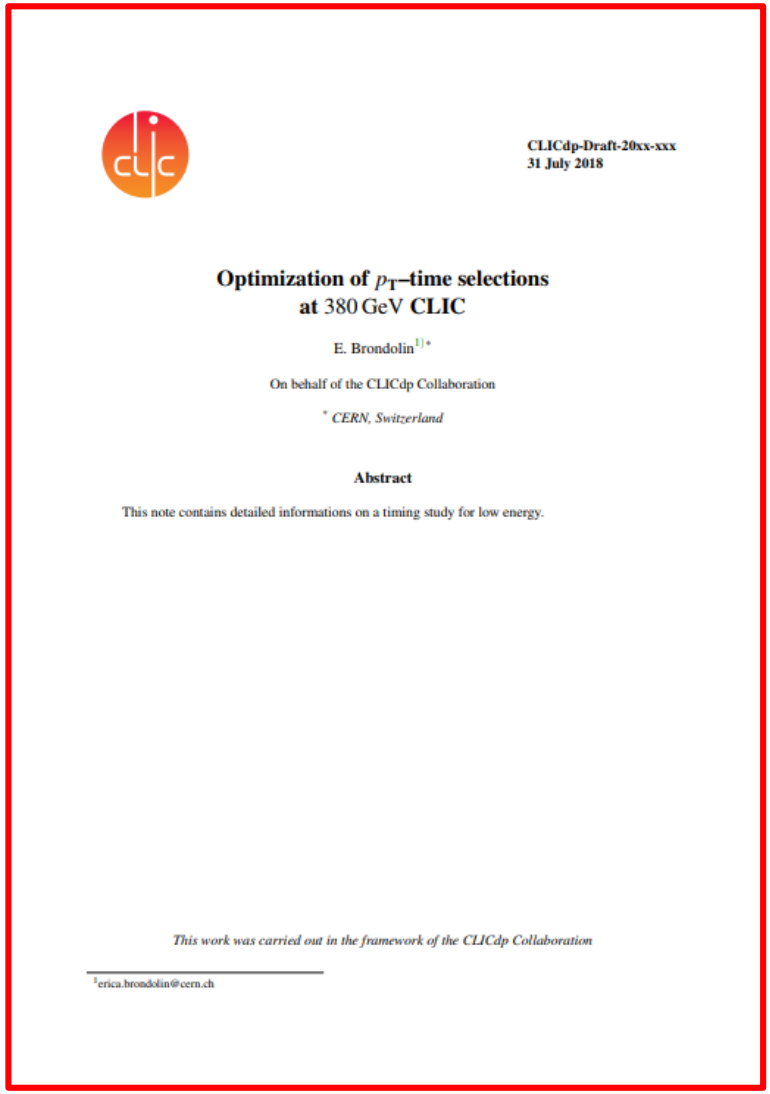
- Increment of background component for all particle categories
- Signal component cannot be recovered only with relaxing the cuts

  → in some cases the track and the clusters associated do not belong to the same MC particle

  → the PFO cluster time is therefore mis-corrected
- Similar conclusions for cosθ > 0.975

Conclusions

- Evaluation of p_t vs. time selections **at √s = 380 GeV** with more realistic estimation of **yy → hadrons background**
- Detailed study based on the **total energy reconstructed** in the event
- Good understanding of p_t vs. time selections for each category and region
- Search for improvement with relaxed cuts
  → increment of background at the same level as no selections
  → PFO cluster time is partially mis-corrected for charged PFOs
- Analysis software provided for future studies, if needed
- Final note is on-going



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31 July 2018

Optimization of p_T–time selections at 380 GeV CLIC

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Abstract

This note contains detailed informations on a timing study for low energy.

This work was carried out in the framework of the CLICdp Collaboration

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Thank you for the attention!

The 380 GeV stage at CLIC

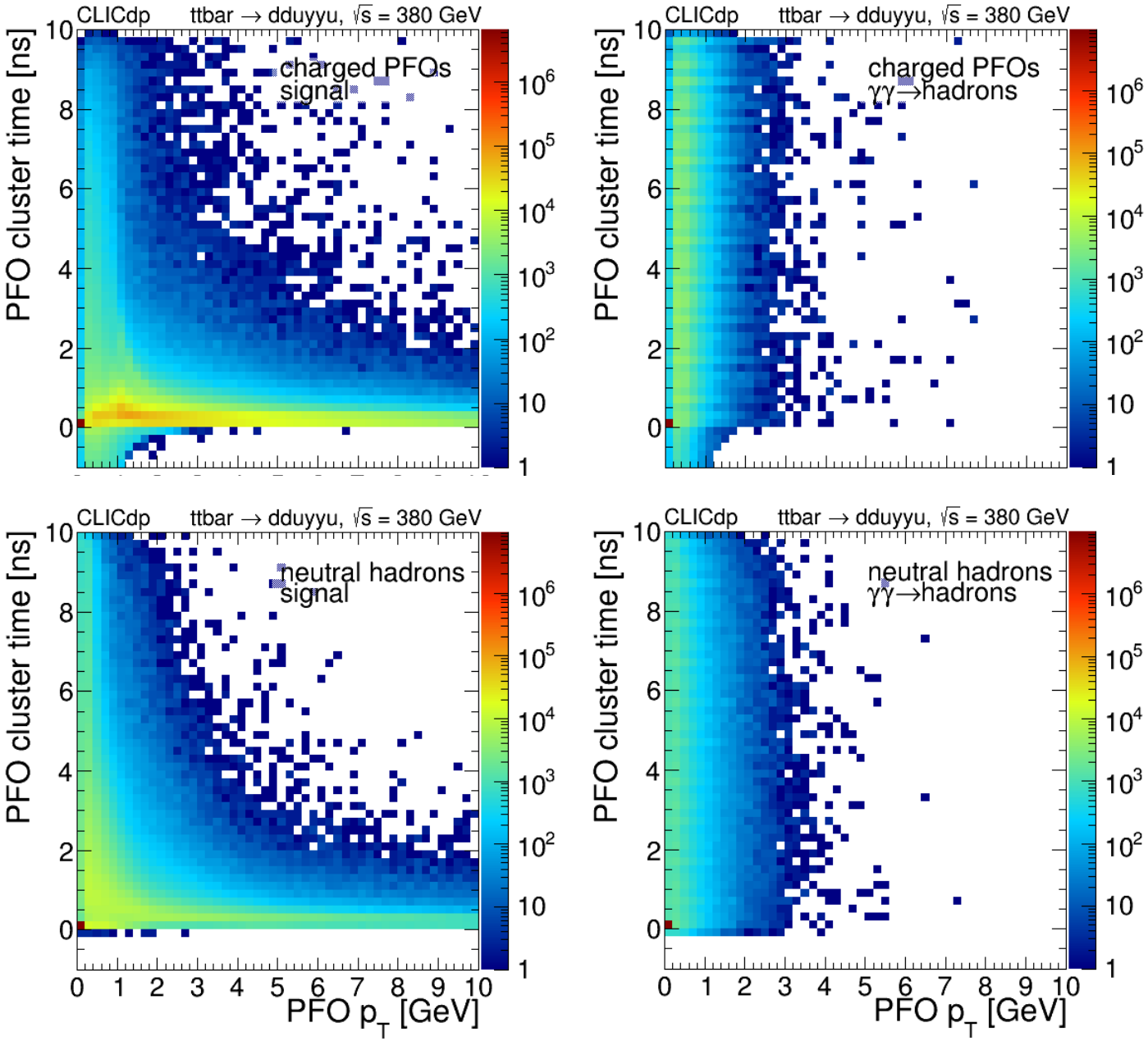
- **CLIC machine parameters**

Table 1: Machine parameters for the first stage of CLIC.

Parameter	Stage 1
Centre-of-mass energy [GeV]	380
Main tunnel length [km]	11.4
Repetition frequency [Hz]	50
Number of bunches	352
Bunch separation [ns]	0.5
Number of particles per bunch [10^9]	5.2
IP beam size (horizontal) [nm]	$\simeq$149
IP beam size (vertical) [nm]	2.9
Bunch length [μm]	70
Total luminosity [10^{34} cm^{-2} s^{-1}]	1.5
Luminosity above 99% of $\sqrt{s}$ [10^{34} cm^{-2} s^{-1}]	0.9
Number of beamstrahlung photons per beam particle	1.4
Number of $\gamma\gamma \rightarrow$ hadron events per BX ($\sqrt{s} > 2$GeV)	0.17

p_t vs. time distribution

- Distribution signal/backgound (charged PFOs and neutral hadrons)



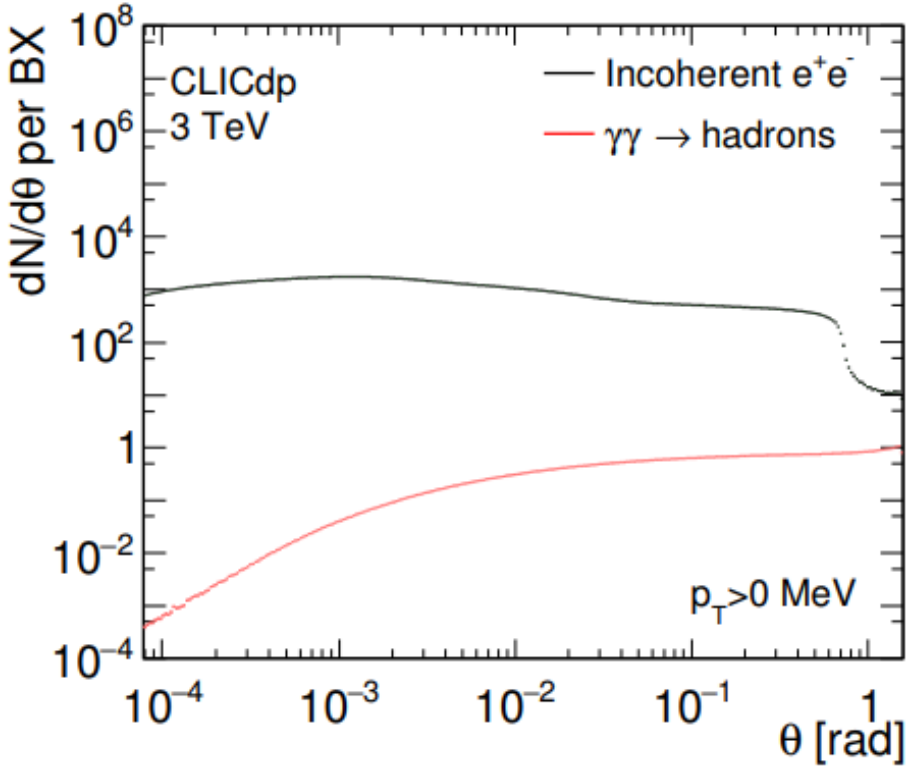
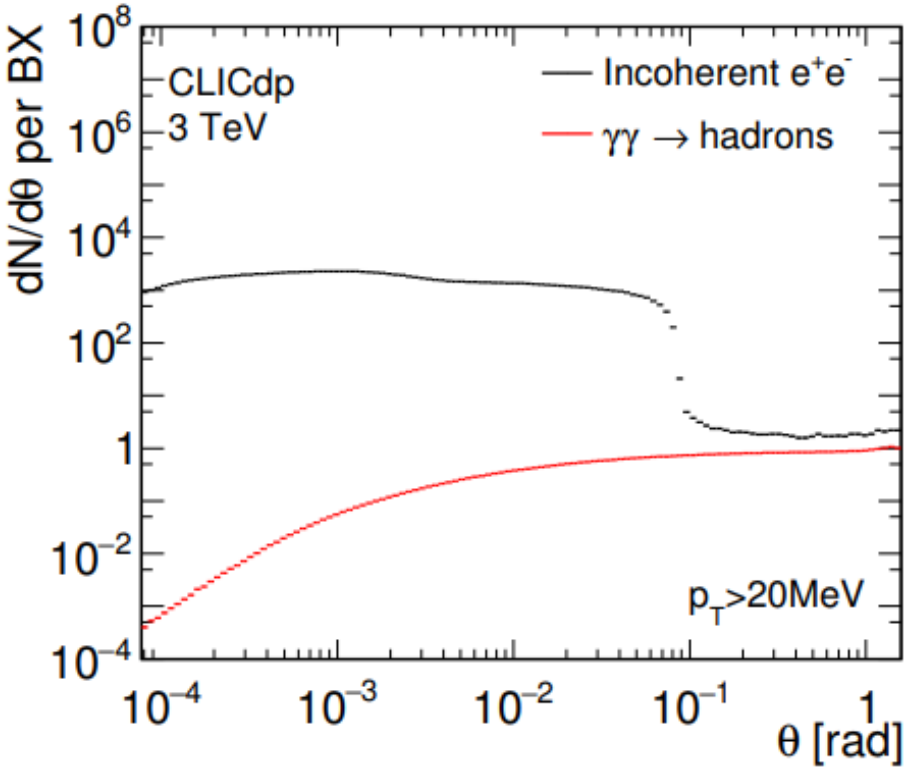
p_t vs. time selection

Table 5: *Selected* selections used for 380 GeV CLIC machine.

Particle category	Region	p_T range [GeV]	time cut [ns]
Photons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 2.0$	$t < 5.0$
		$0 \leq p_T < 0.75$	$t < 1.0$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 2.0$	$t < 2.0$
		$0 \leq p_T < 0.75$	$t < 1.0$
Neutral hadrons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 2.0$	$t < 5.0$
		$0 \leq p_T < 0.75$	$t < 2.5$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 2.0$	$t < 4.0$
		$0 \leq p_T < 0.75$	$t < 2.0$
Charged particles	all	$0.75 \leq p_T < 4.0$	$t < 10.0$
		$0 \leq p_T < 0.75$	$t < 3.0$

Table 6: *Tight* selections used for 380 GeV CLIC machine.

Particle category	Region	p_T range [GeV]	time cut [ns]
Photons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 2.0$	$t < 1.0$
		$0 \leq p_T < 0.75$	$t < 1.0$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 2.0$	$t < 2.0$
		$0 \leq p_T < 0.75$	$t < 1.0$
Neutral hadrons	$\cos\theta \leq 0.975$	$0.75 \leq p_T < 3.5$	$t < 4.0$
		$0 \leq p_T < 0.75$	$t < 2.0$
	$\cos\theta > 0.975$	$0.75 \leq p_T < 3.0$	$t < 2.0$
		$0 \leq p_T < 0.75$	$t < 2.0$
Charged particles	all	$0.75 \leq p_T < 3.0$	$t < 4.0$
		$0 \leq p_T < 0.75$	$t < 2.0$

Background components

CLIC @ 3 TeV