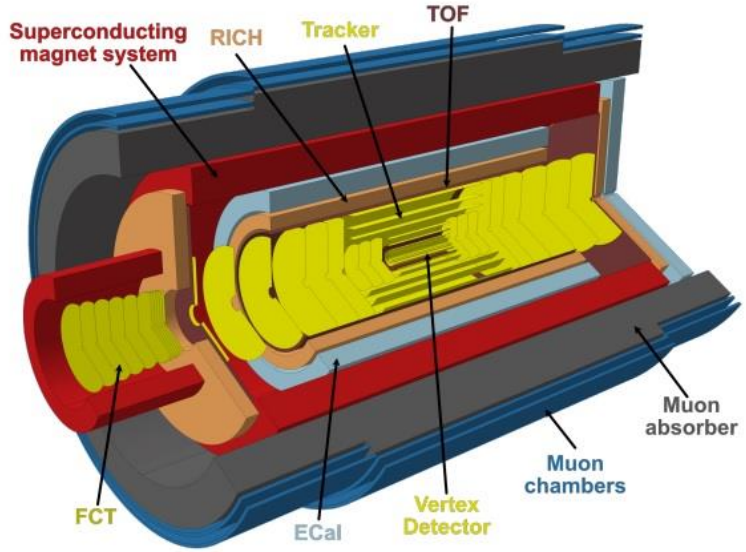
Feasibility studies of open charm production in future ALICE-3 experiment at HL-LHC

Mikhail Malaev

МФТИ



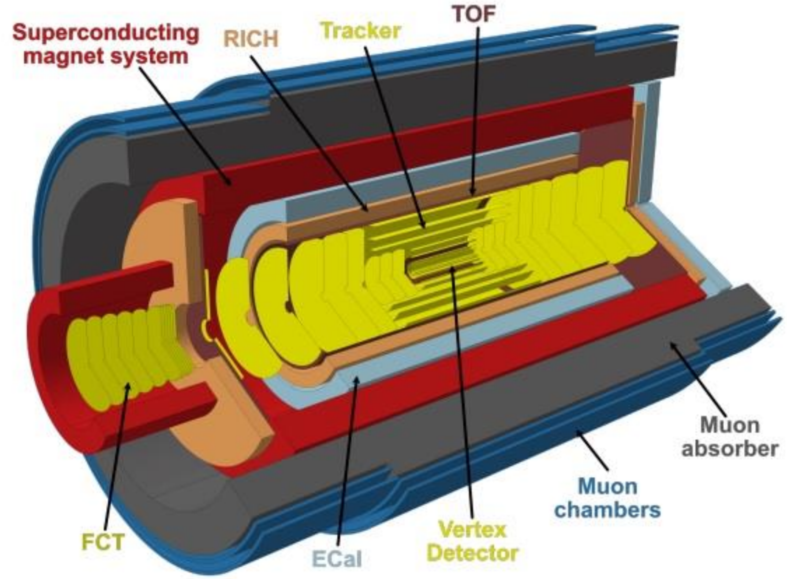
PNPI

* This work was supported by RSF according to the research project № 22-42-04405

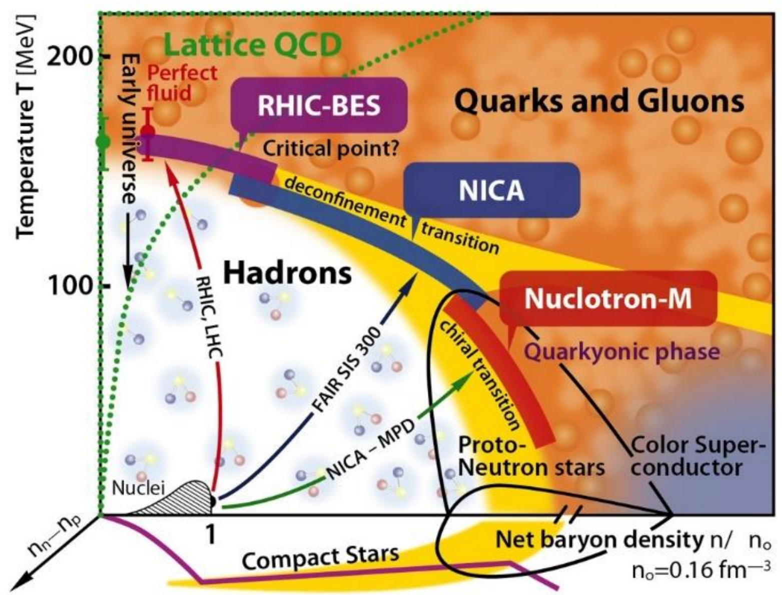
Introduction

Advanced detector:

- Compact all-silicon tracker with high-resolution vertex detector
- Superconducting magnet system
- Particle Identification over large acceptance:
- muons, electrons, hadrons, photons
- Fast read-out and online processing

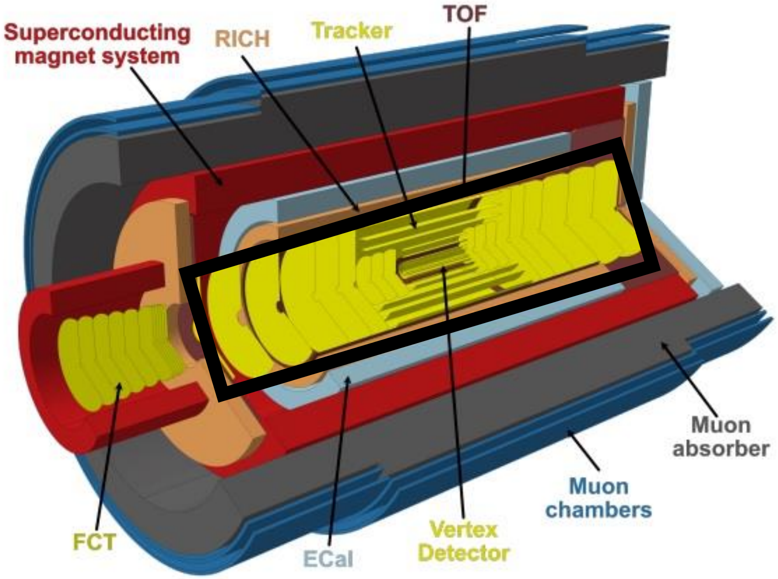


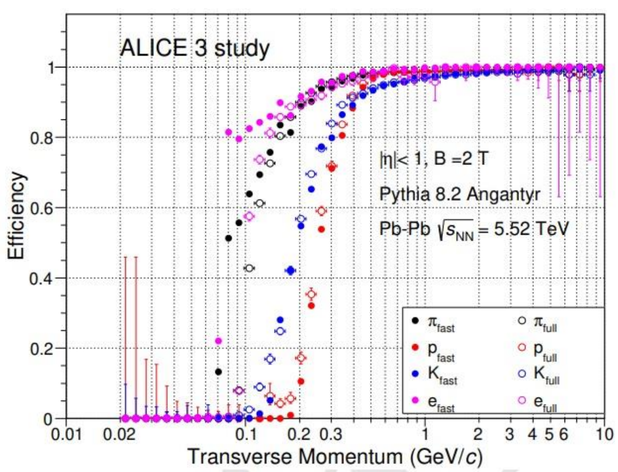
- ✓ Heavy quarks, like charm and beauty, are sensitive probes to investigate the colour-deconfined medium created in high-energy heavy-ion collisions
- ✓ Because of their large mass, heavy quarks are mainly produced in the early times of the collision, before the formation of the QGP
- ✓ High p_T – in-medium parton energy loss
- ✓ Comparison to light-flavor – dependance of the energy loss on the color charge and quark mass
- ✓ Hadronisation mechanisms studies

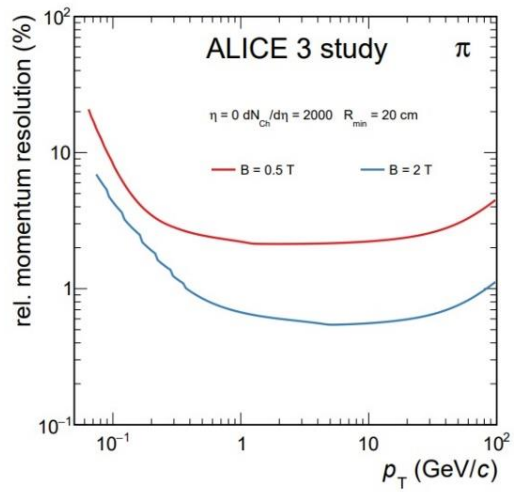


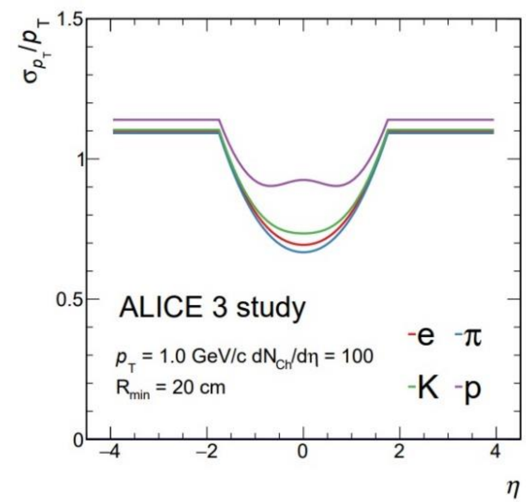
ALICE3 concept: tracker

Layer	Material thickness ($\%X_0$)	Intrinsic resolution (µm)	Barrel layers Length ($\pm z$) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position ($\lvert z \rvert$) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.50	3
1	0.1	2.5	50	1.20	30	0.50	3
2	0.1	2.5	50	2.50	34	0.50	3
3	1	10	124	3.75	77	5	35
4	1	10	124	7	100	5	35
5	1	10	124	12	122	5	35
6	1	10	124	20	150	5	80
7	1	10	124	30	180	5	80
8	1	10	264	45	220	5	80
9	1	10	264	60	279	5	80
10	1	10	264	80	340	5	80
11	1				400	5	80





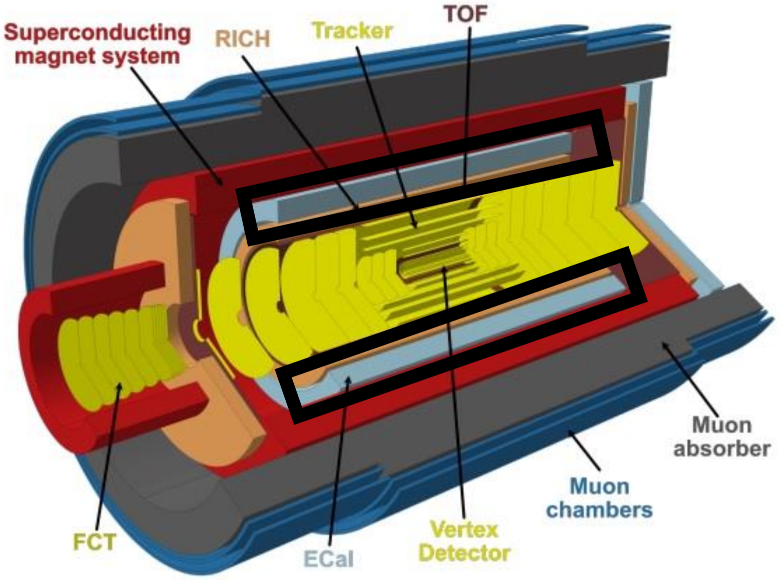




ALICE3 LOI - 2211.02491.pdf (arxiv.org)

ALICE3 concept: ECAL

- The Electromagnetic Calorimeter (ECAL) is planned to cover the full central barrel region and one forward region, i.e. the rapidity range of $-1.6 < \eta < 4$
- Most of the rapidity range will be instrumented with a samplin calorimeter (ECAL)
- A fraction of the central barrel will be covered by existing $PbWO_4$ crystal for the high precision measurements



ECAL energy resolution:

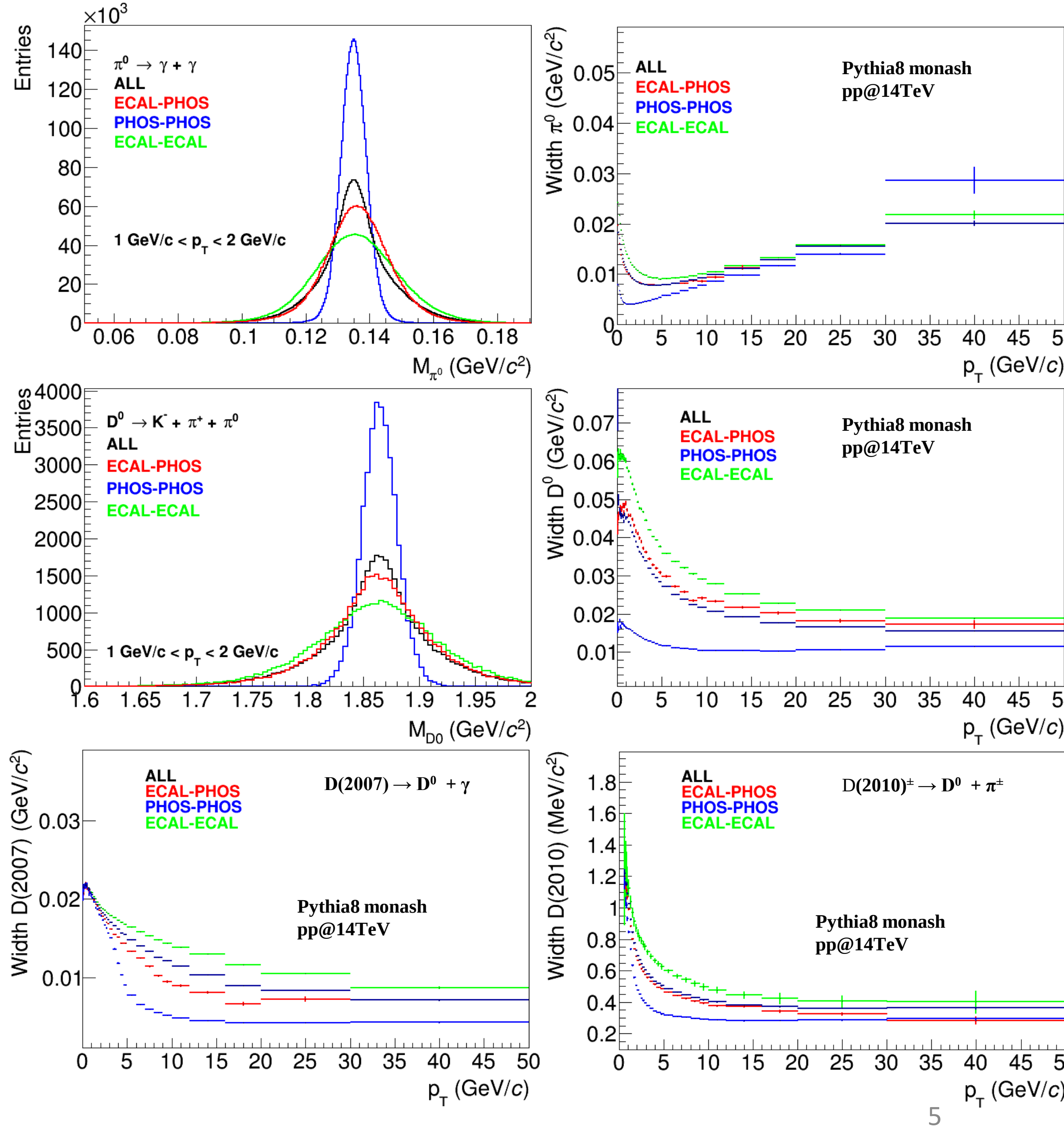
$$\frac{\sigma_E}{E} = \frac{a}{E} \oplus \frac{b}{\sqrt{E}} \oplus c$$

ECal module	Barrel sampling	Endcap sampling	Barrel high-precision
acceptance	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 1.5$	$\Delta\varphi = 2\pi$, $1.5 < \eta < 4$	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 0.33$
geometry	$R_{in} = 1.15$ m, $\lvert z\rvert < 2.7$ m	$0.16 < R < 1.8$ m, $z = 4.35$ m	$R_{in} = 1.15$ m, $\lvert z\rvert < 0.64$ m
technology	sampling Pb + scint.	sampling Pb + scint.	$PbWO_4$ crystals
cell size	30×30 mm^2	40×40 mm^2	22×22 mm^2
no. of channels	30 000	6 000	20 000
energy range	$0.1 < E < 100$ GeV	$0.1 < E < 250$ GeV	$0.01 < E < 100$ GeV

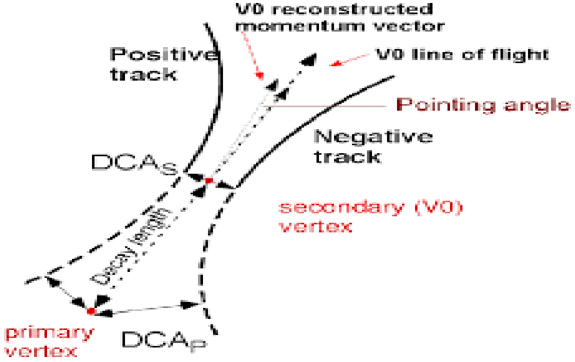
ALICE3 LOI - 2211.02491.pdf (arxiv.org)

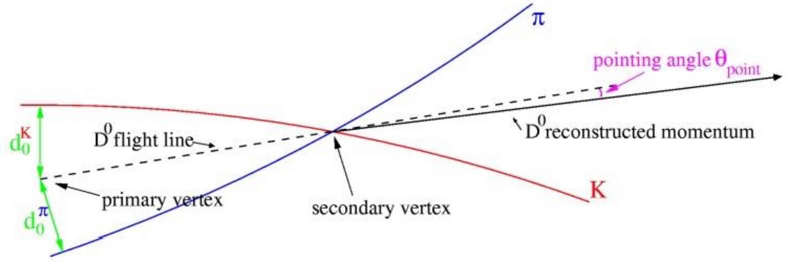
Simulation

- Pythia8 (Monash 2013 tune) pp@14TeV
- Pythia8 (Angantyr mode) PbPb@5.5TeV
- $D^0 \rightarrow \pi^\pm + K^\pm + \pi^0$ ($\pi^0 \rightarrow \gamma + \gamma$) (BR ~ 14%)
- $D(2007) \rightarrow D^0 + \gamma$ (BR ~ 38%)
- $D(2010)^\pm \rightarrow D^0 + \pi^\pm$ (BR ~ 68%)
- 2 γ in High precision part of the calorimeter – PHOS-PHOS
- 2 γ in ECAL acceptance – ECAL-ECAL
- 1 γ in high precision part and 1 outside – ECAL-PHOS



Simulation: Cut optimization





DCA (distance of closest approach) cut:

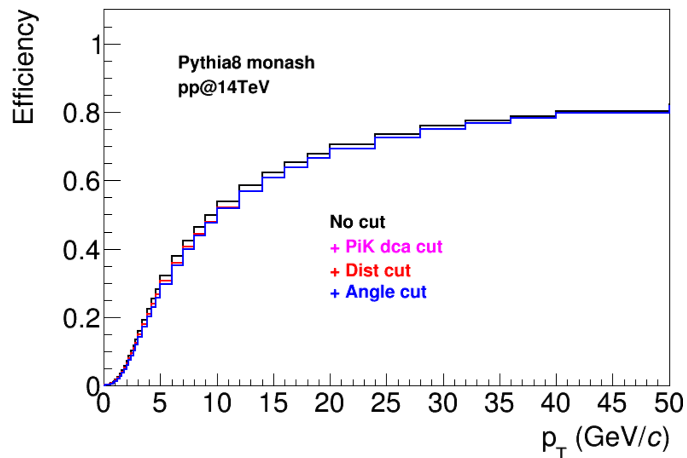
- All prompt particles go from 0 (primary vertex)
- Tracks from D^0 decay have non-zero DCA
- p_T dependent cut equal to DCA resolution estimation (2211.02491.pdf (arxiv.org)))

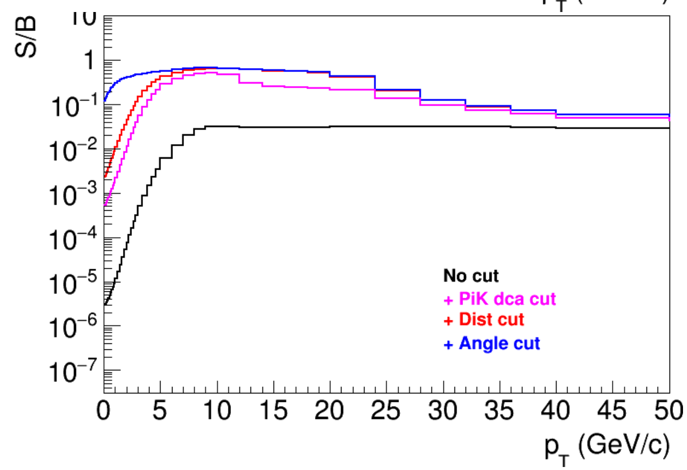
Distance cut:

- Signal - distance between tracks always 0
- Background - pairs distributed in wide range
- Distance < 50 μm

Pointing angle cut:

- Signal – close to 1
- Background – from -1 to 1
- Cos(p.angle) > 0.9



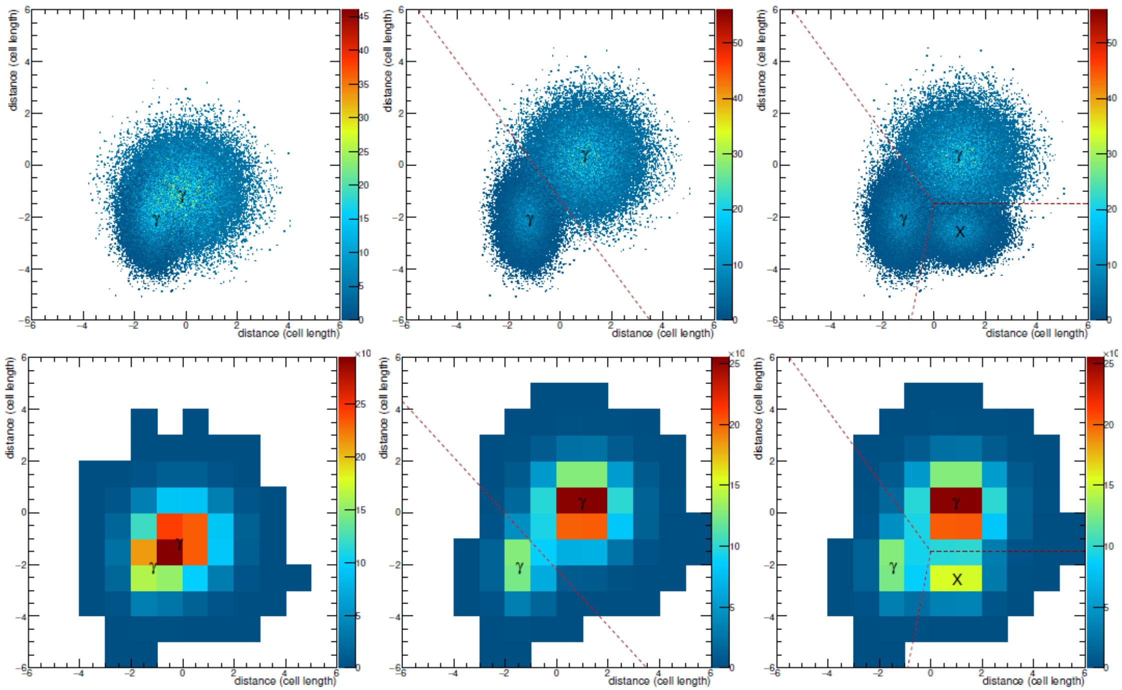


Merged Clusters in calorimeter

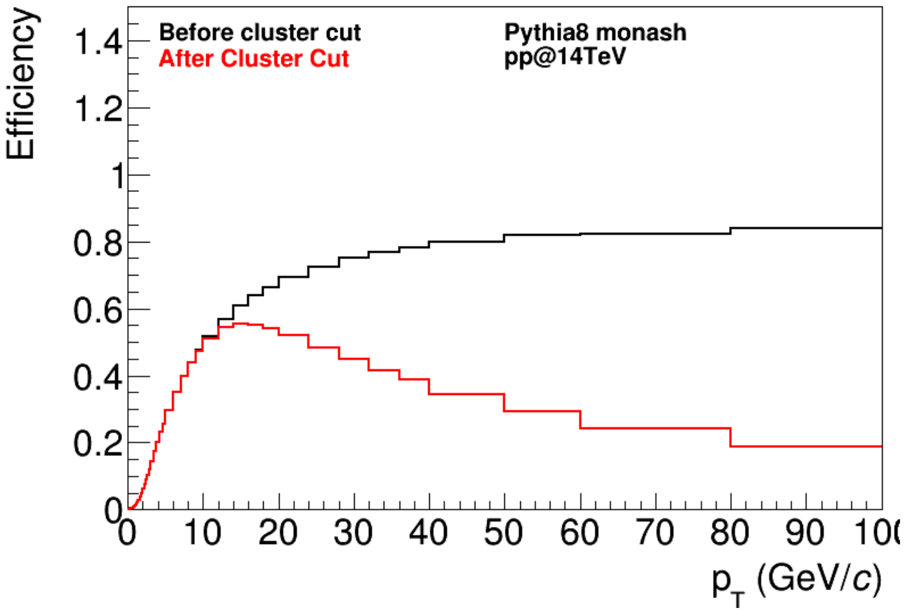
- Non-zero calorimeter cell size
- 1 cluster may contain signal from more than 1 photon (Merged clusters)
- Higher p_T of π^0 $\rightarrow$ higher possibility for merged clusters for decay photons
- Merged clusters more elliptic form than "round"
- The shower shape of a cluster is described using an ellipsoidal parametrization by the axis of the shower surface ellipse (λ_0 – long axis, λ_1 – short axis)

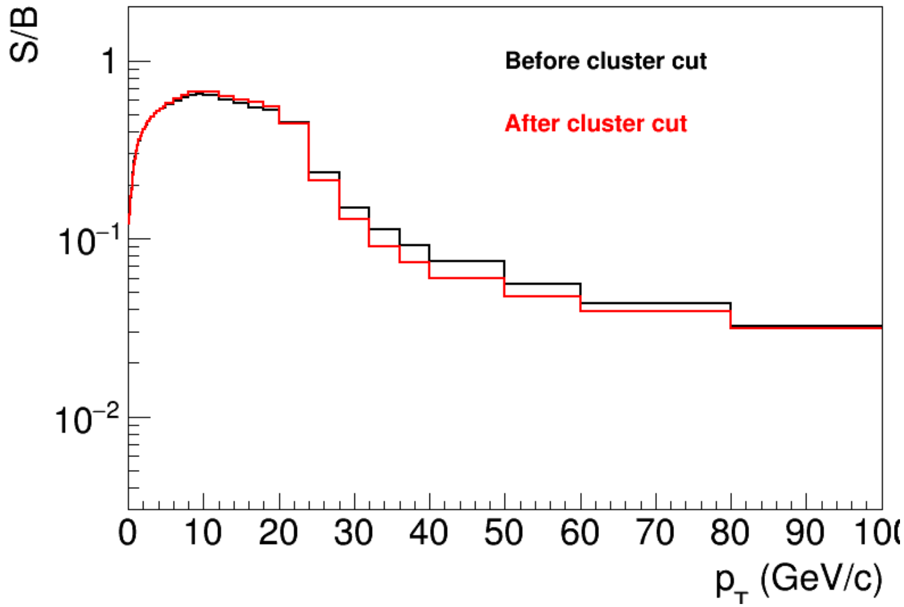
Simple Clusterizer

- Min E_γ cut (ECAL – 100 MeV, PHOS – 10 MeV)
- Points where photons cross calorimeter surface (R = 115 cm)
- If distance between two points < 1.5*Cell_Size (ECAL – 30 mm, PHOS – 22 mm) than Merged cluster with center closer to photon with higher energy (weights)
- Look for possible candidates to merge with this cluster
- And again



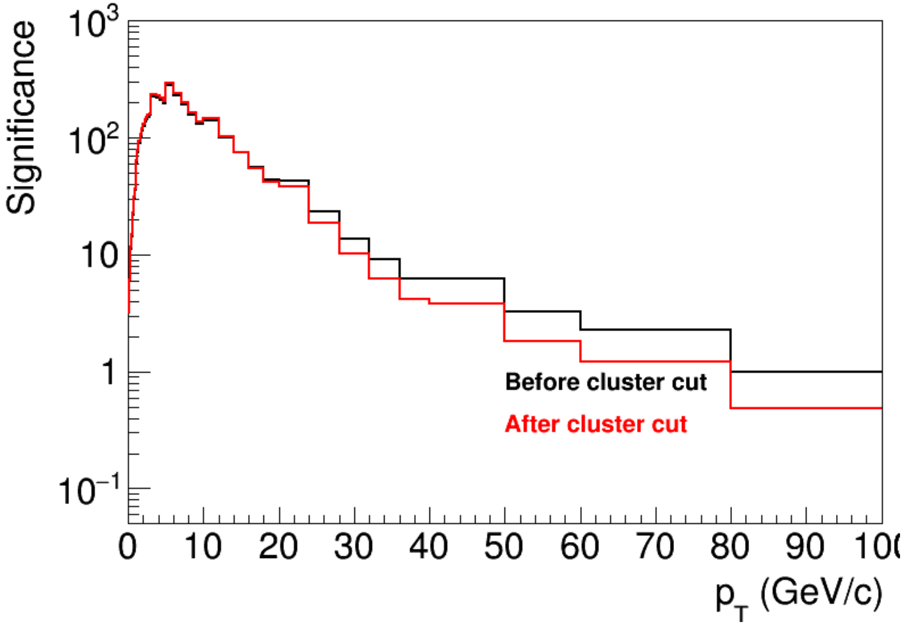
Approach A: NO merged clusters (D^0)



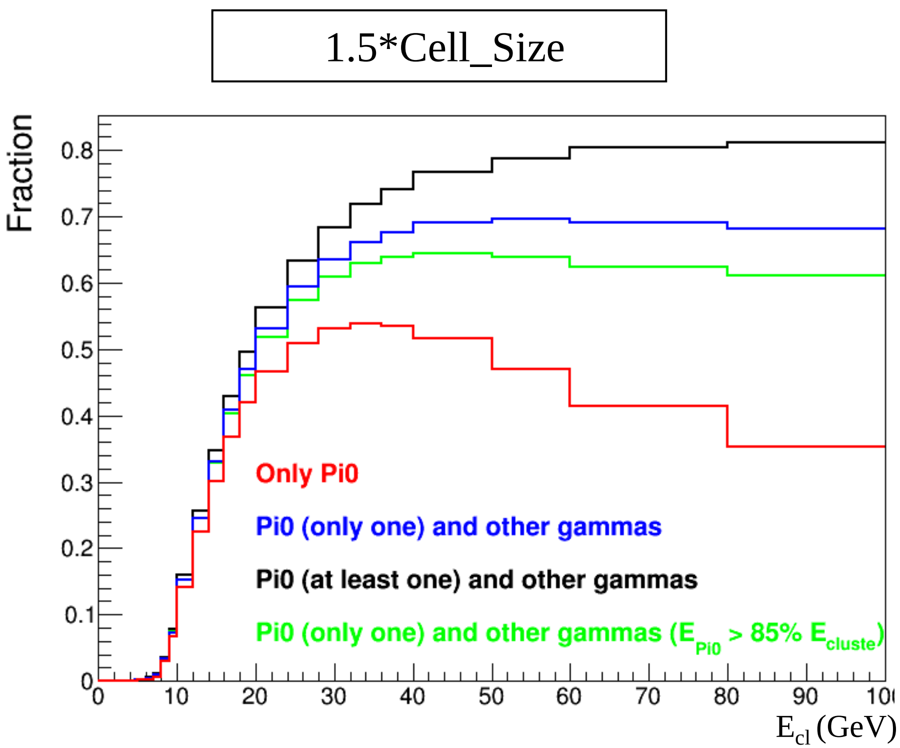


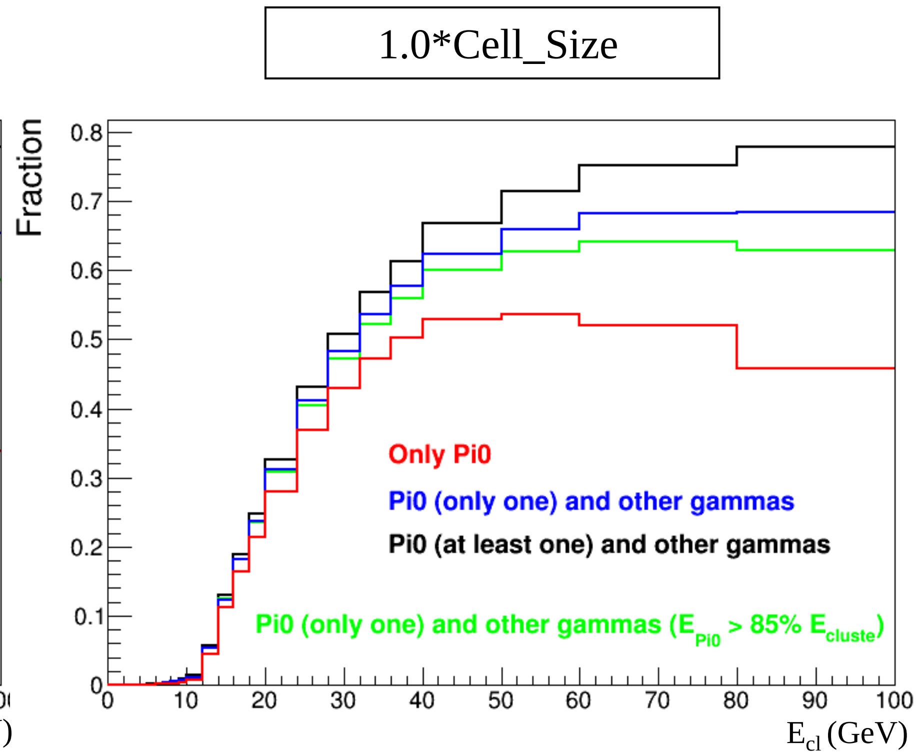
SIGNAL - If distance between points from 2 gamma quants on the calorimeter surface less than 1.5*Cell_Size (PHOS and ECAL) π^0 is excluded from the analysis – lost signal

BGR – Merged clusters used as single photon for π^0 reconstruction



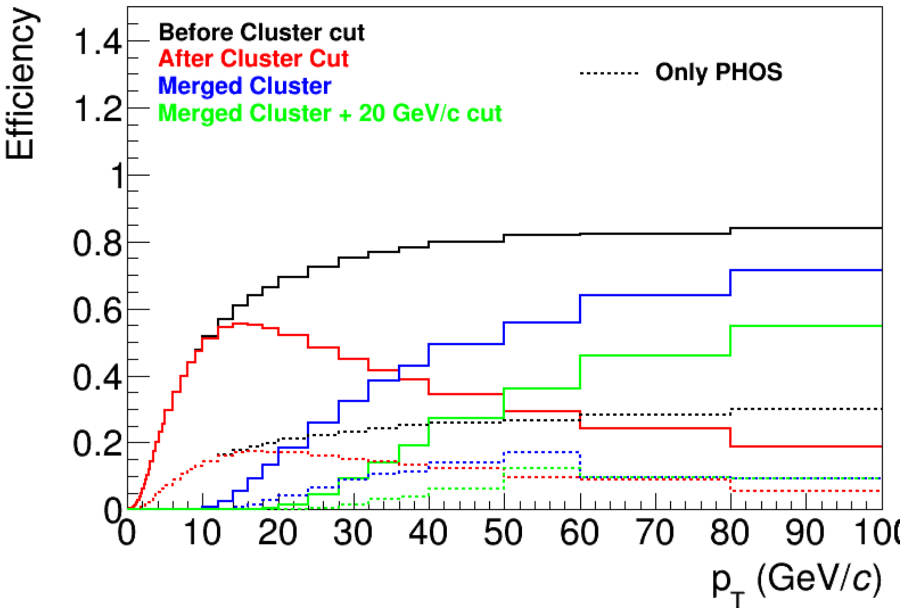
Approach B: Only merged clusters (sources of clusters)

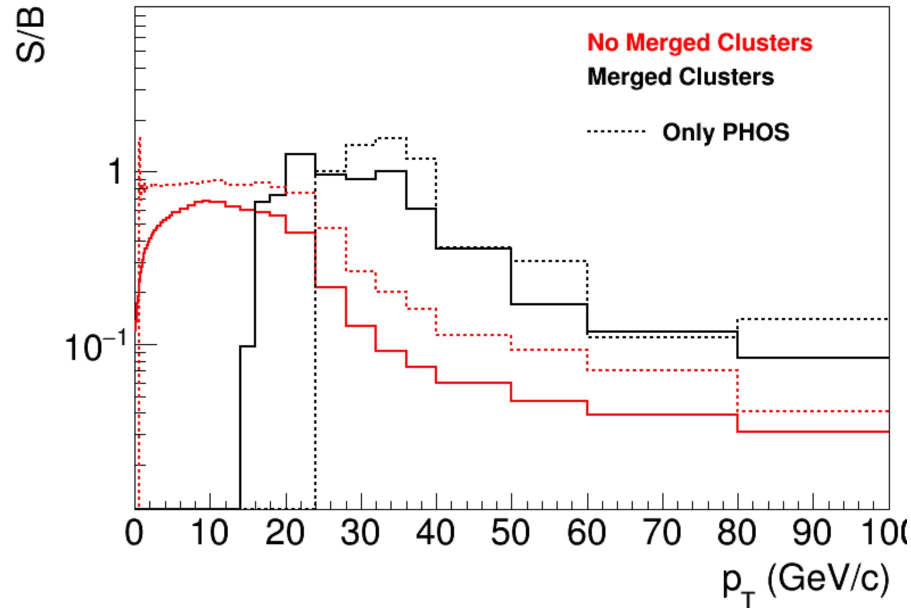




- Cell_Size = 22(30) mm for PHOS(ECAL)
- E_{cl} > 20 GeV: Most of the merged clusters from neutral pions decays
- E_{cl} > 20 GeV: Dominant contribution to the energy of the cluster is from π^0
- Tighter conditions for clusterizer do not considerably improve results
- Additional cut on π^0 transverse momentum 20 GeV/c

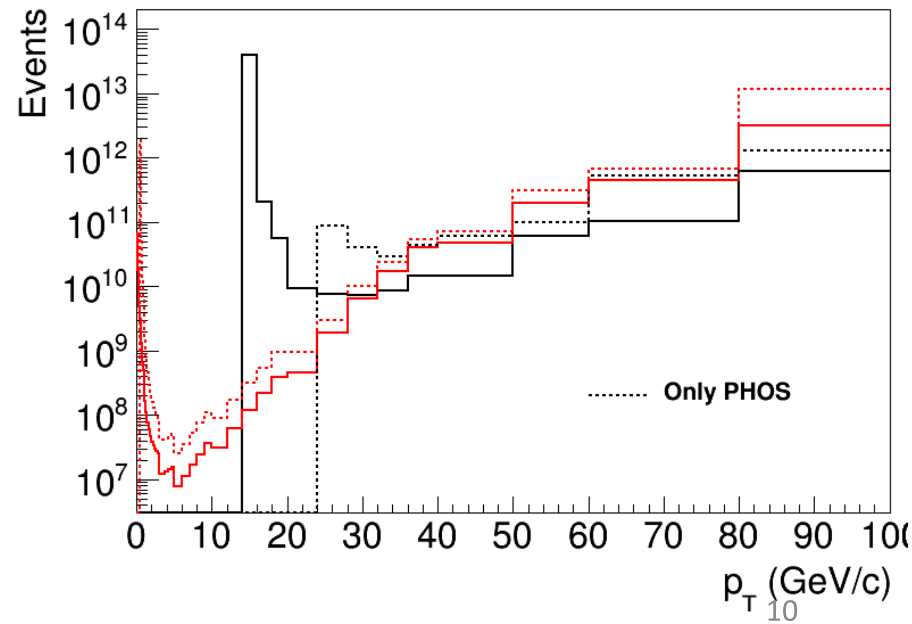
Approach B: Only merged clusters (D^0)





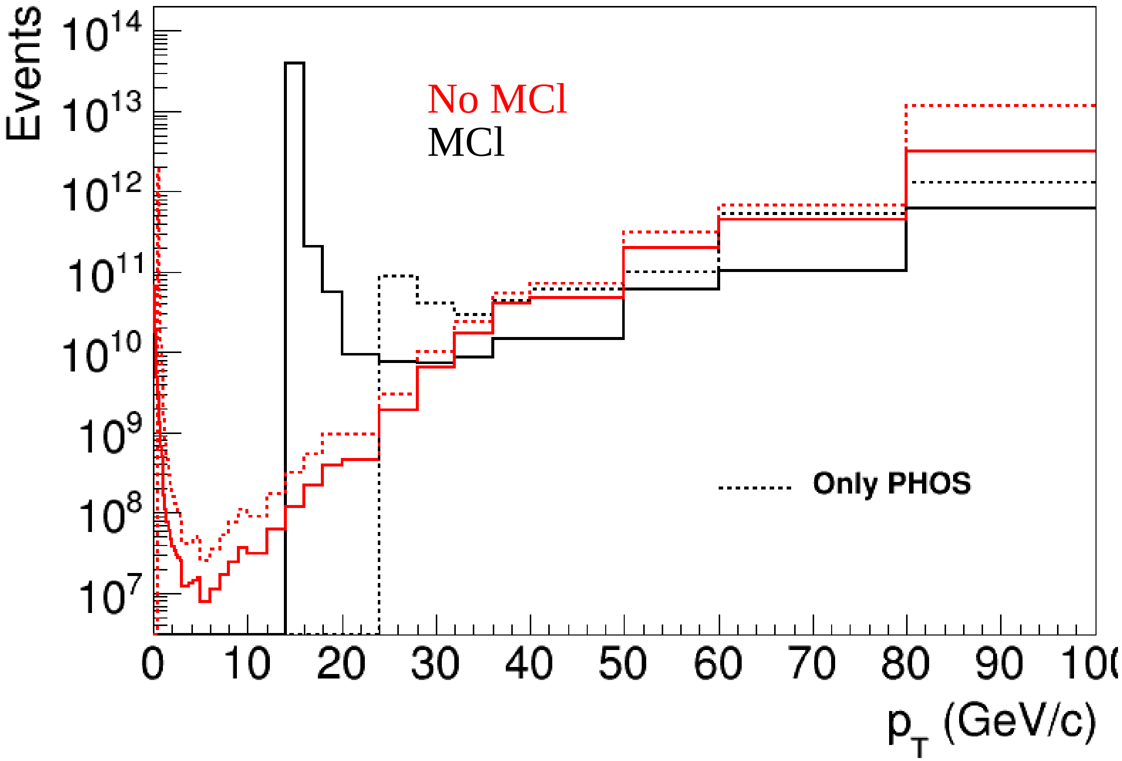
SIGNAL – If two gamma quants from π^0 decay do not merge in one cluster such π^0 is excluded from the analysis – lost signal

BGR – Signal from calorimeter is used as π^0 (assumption that this signal consist of 2 gamma quants from the same neutral pion)



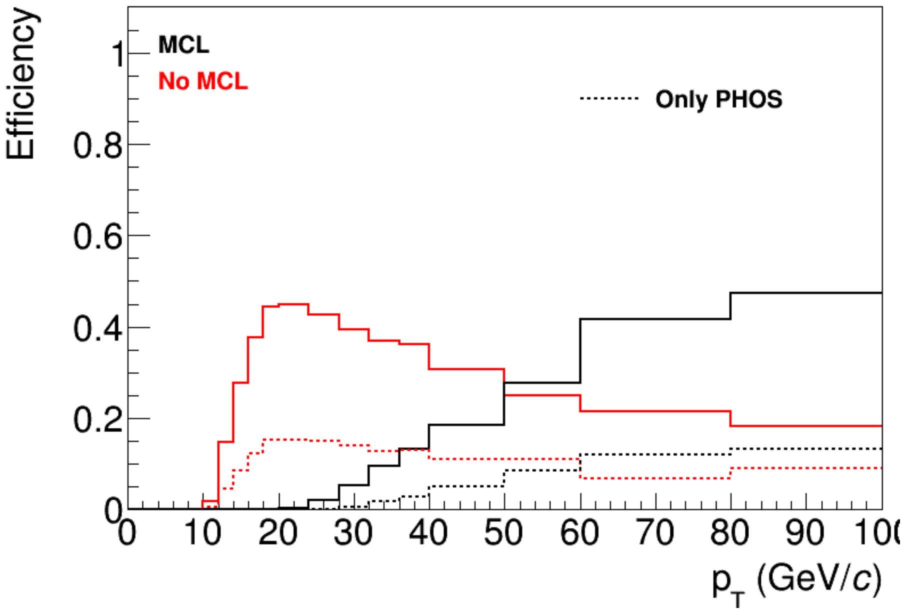
Comparison of approaches (D^0)

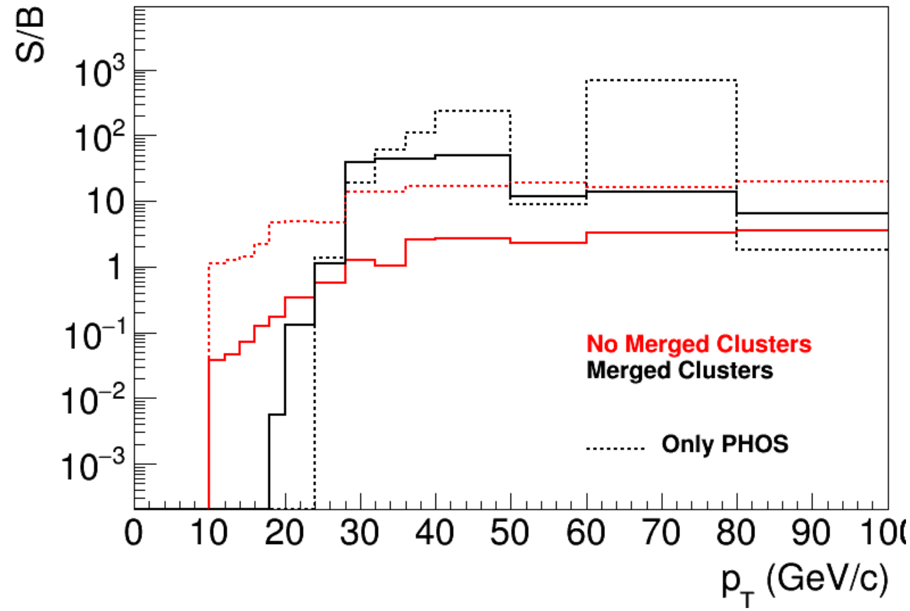
How many events needed to extract signal in each p_T bin with significance equal to 10 with two different approaches?



- No merged clusters approach is preferable at low p_T
- Only merged clusters approach is preferable from ~ 30 GeV/c and dominate at higher p_T

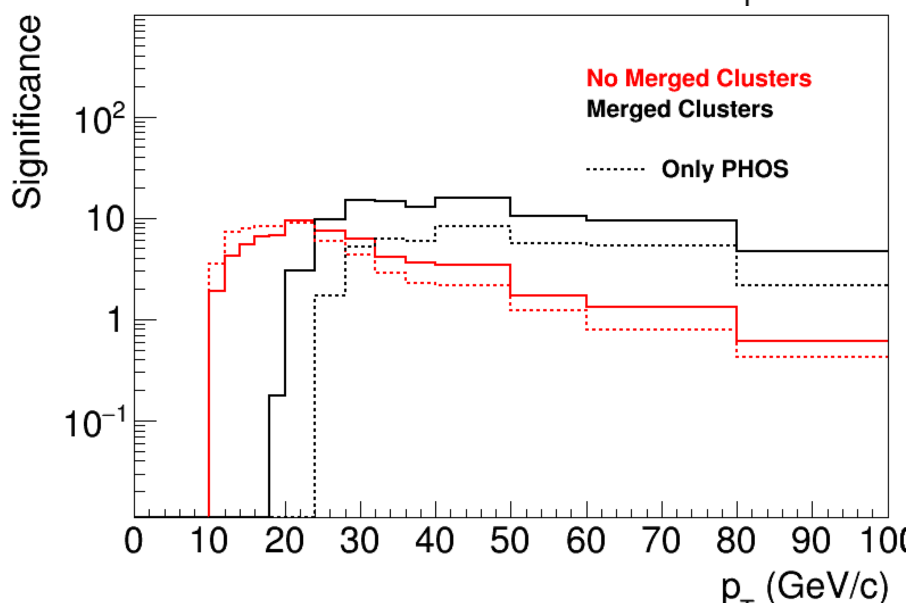
D(2010): Pb-Pb@5.5TeV





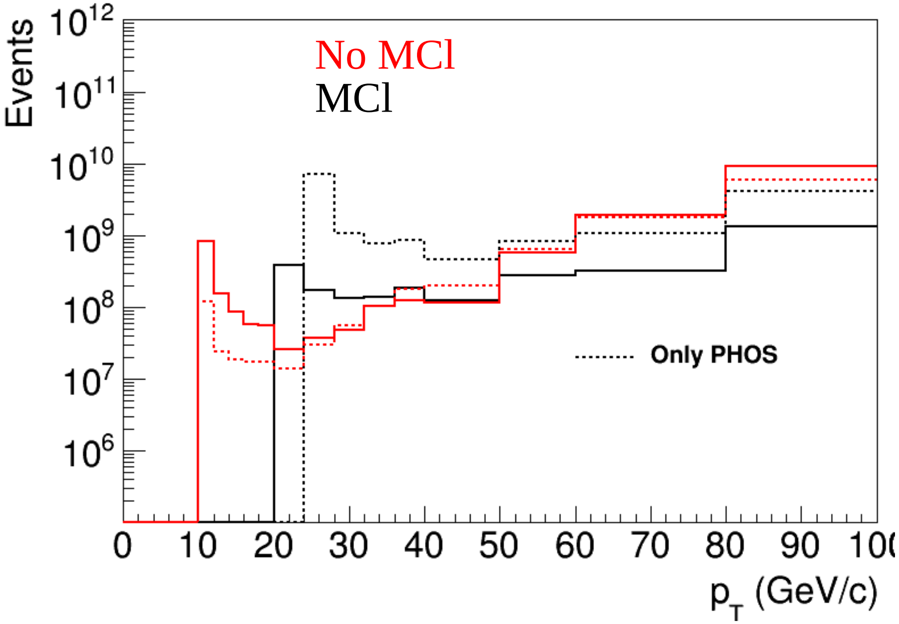
SIGNAL – If two gamma quants from π^0 decay do not merge in one cluster such π^0 is excluded from the analysis – lost signal

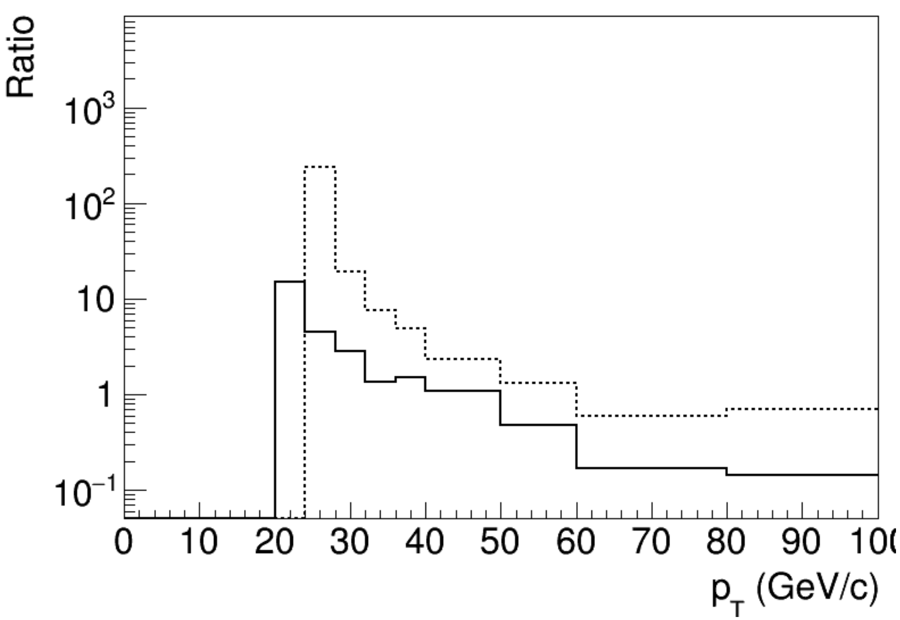
BGR – Signal from calorimeter is used as π^0 (assumption that this signal consist of 2 gamma quants from the same neutral pion)



D(2010): Pb-Pb@5.5TeV

How many events needed to extract signal in each p_T bin with significance equal to 10 with two different approaches?





- No merged clusters approach is preferable at low p_T
- Only merged clusters approach is preferable from ~ 40 GeV/c and dominate at higher p_T

Summary

- Measurement of heavy quarks will contribute to the ALICE3 physical program
- $D^0 \rightarrow \pi^{\pm} + K^{\pm} + \pi^0$ advantages in relatively large BR (~14%) and electromagnetic calorimeter usage
- First estimations of detector resolution, reconstruction efficiency and cuts efficiency provided
- Principal possibility for D^0, D(2007), D(2010) - mesons reconstruction in ALICE3 experimental setup demonstrated
- Merged clusters analysis is preferable for high p_T results

This work was supported by RSF according to the research project № 22-42-04405