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Pixel Track and PV Reconstruction

Danek Kotlinski
Paul Scherrer Institute

Introduction

1. In CMS standalone pixel reconstruction has been first applied for seeding by Nikita&Sasha and for B−physics channels by Andrei (see Vertex 2001).

2. Similar work has been done in ATLAS, e.g. A.Baratella et al. Pixel2000 in Genova, NIMA 465(2001)190.

   More emphasis on impact parameter tagging.
   Less use of the primary vertex constraint.

3. More details can be found in :
   CMS Internal Note 2000/22.

Introduction cont.

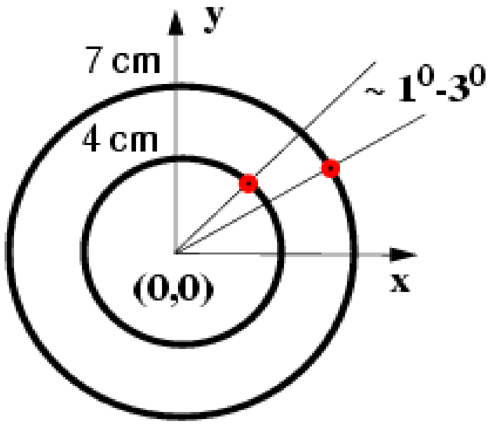
Pixel track candidates ("pixel lines") can be used for PV finding, track seeding and triggering (e.g. isolation cuts). These are similar tasks but the requirements are different. I will try to address these requirements.

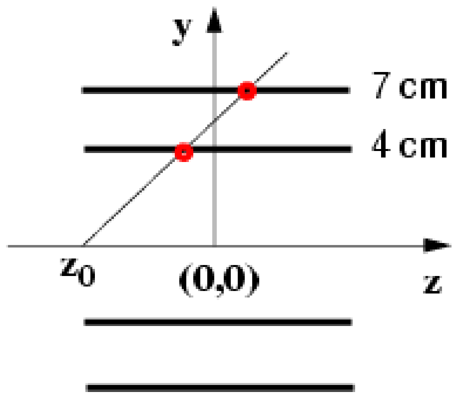
Teddy et al. have developed software which also generates pixel seeds. The main difference between these "combinatorial" algorithms and what I present here are :

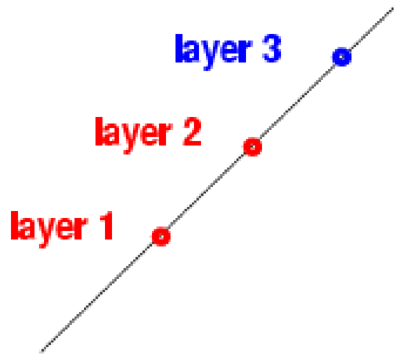
- primary vertex constraint
- track cleaning.

Reconstruct track candidates using pixel hits

Algorithm (using 3 pixel hits per track) :





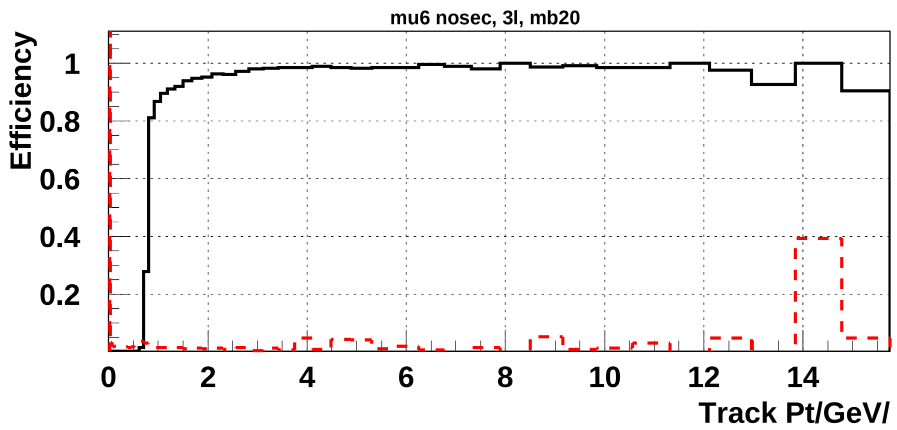


1. Match pixel hit pairs from the 1st two layers (barrel & endcaps) in r−Φ and z−r.
2. Valid hit pairs are matched with a hit in the 3rd layer forming track candidates.
3. Establish primary vertex candidates in z locations where at least 3 tracks cross the z axis.
4. Erase track candidates not pointing to any valid primary vertex.

Track reconstruction efficiency

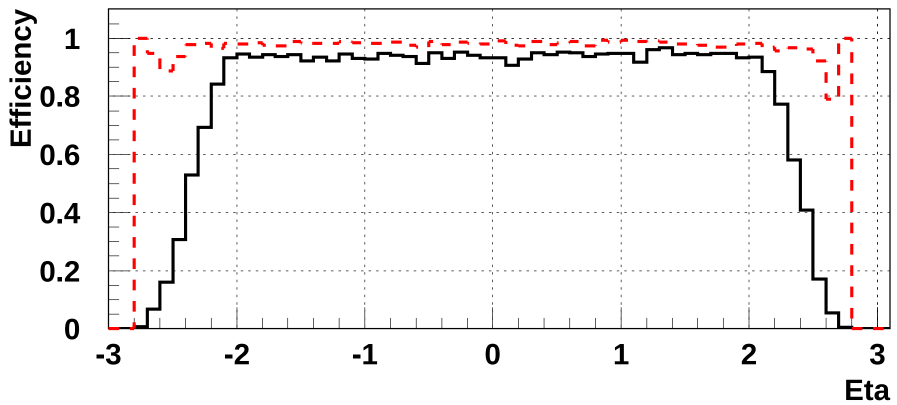
LHC high luminosity

High efficiency &
low background!



solid line − reconstruction efficiency

dashed line − ghost rate



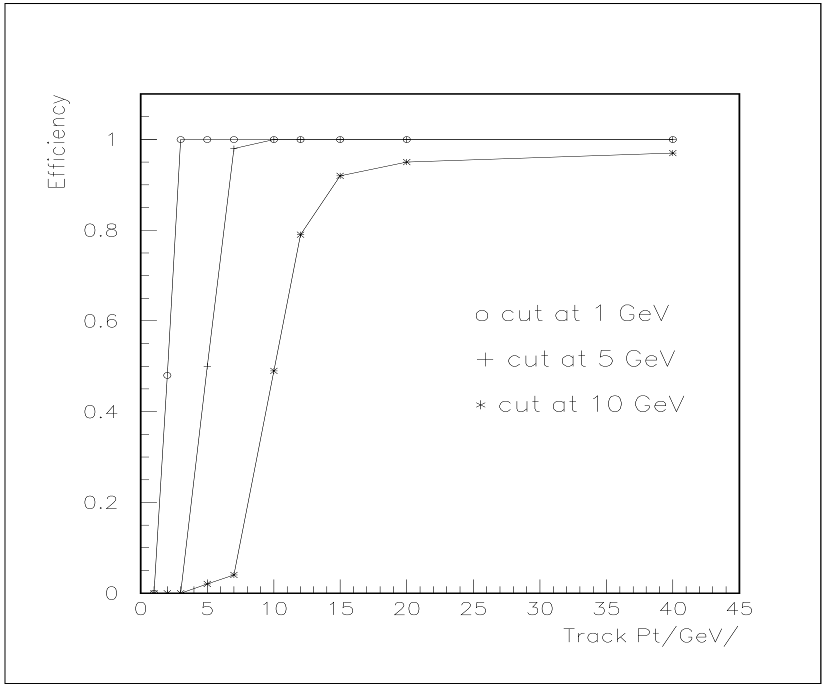
solid line − absolute efficiency

dashed line − relative (algorithmic) efficiency

Transverse momentum resolution

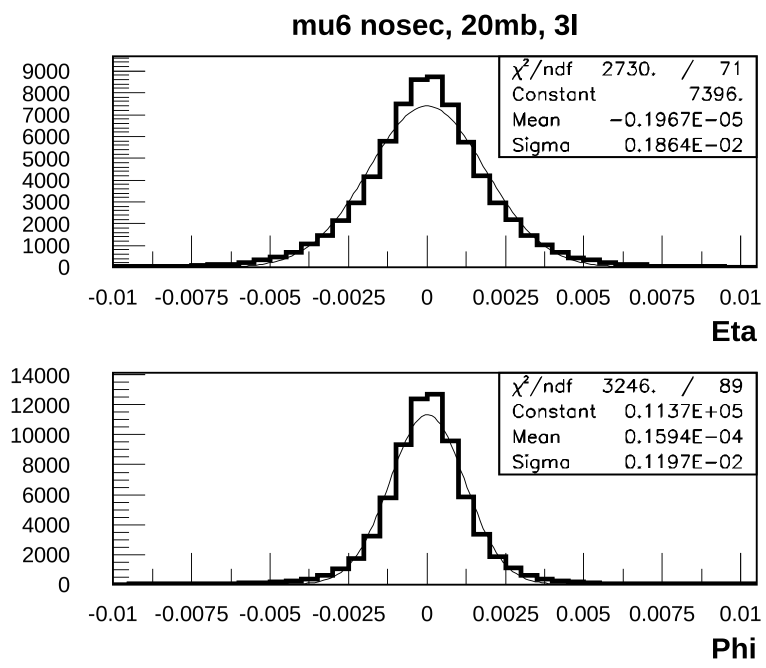
$\Delta p_T/p_T = 0.036 + (0.017 * p_T \text{ [in GeV]})$ is poor!

The resolution is shown in the plot below in form off the effectiveness of a p_T cut.



Unfortunately this means that the impact parameter resolution is also very poor!

Track direction resolution

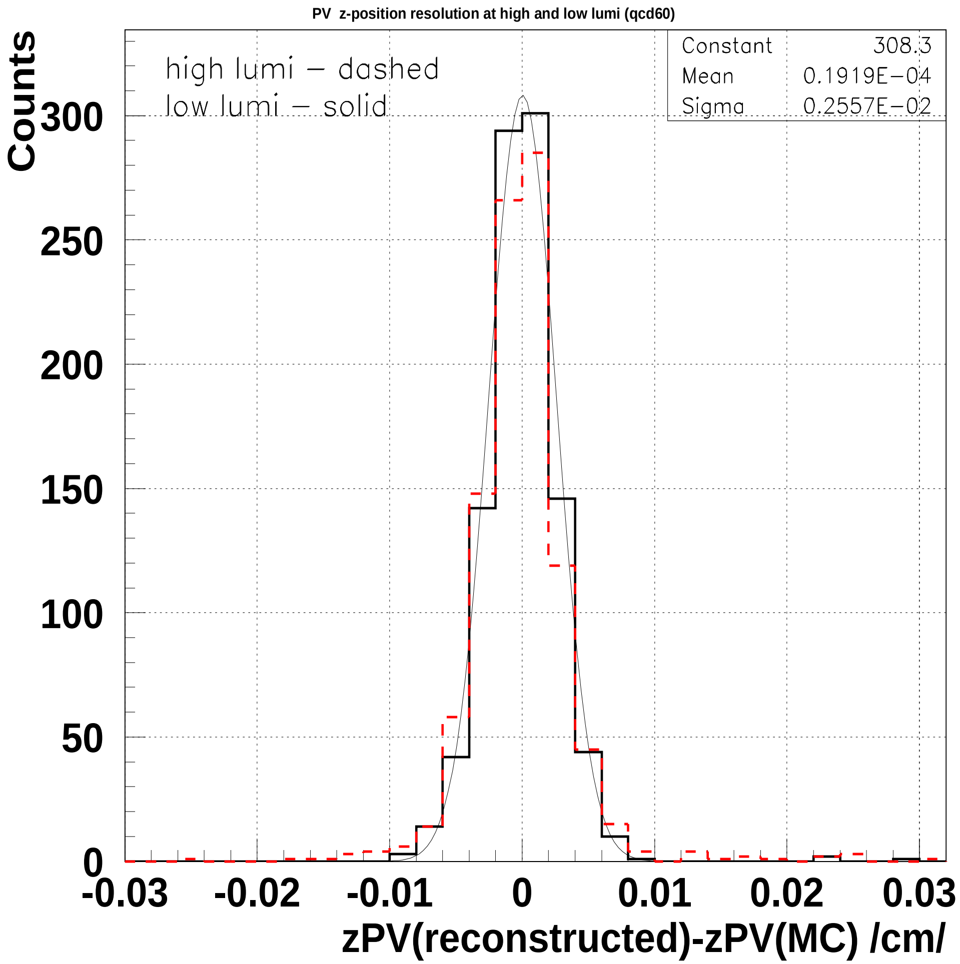


19 mradians in η

12 mradians in Φ

The track charge estimate is also very accurate.

Very good primary vertex reconstruction



In this case 26μm.
Very close to the best resolution with tracks!

For all channels studied the signal primary vertex position resolution is < 50μm.

Pile−up primary vertices can be also found if they have at least 2 charged tracks above 1GeV.

More details about the performance

- 2 hit recovery for 3 layer configuration,
- 2 layer configuration at 2x10^33,
- lower pt cuts,
- partial/regional reconstruction
- tau "merging" problem,
- CPU time.

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Some definitions

- Good track − a track which has 2 out of 3 rechits correctly assigned, for 2 layer pixel system 2 out of 2 (about 1−2% increase in efficiency).

- Absolute efficiency − the ratio of good signal tracks with $pt>1GeV$ and $eta<2.1$ to the MC tracks. Only tracks with $d0<1cm$ and $|z0|<11cm$ are used.

- Relative efficiency − the ratio of good signal tracks with $pt>1GeV$ to MC tracks with 3/2 pixel hits.

- Purity − the ratio of good tracks to all tracks found.

- PV found − the z position of the PV is within 0.5mm from the MC position.
- PV efficiency − the correct vertex was found in the list of reconstructed vertices, this does not mean that we know how to select this vertex.

Definitions cont.

- "3l" means 3 layer reconstruction using 3 pixel hits.
- "2l" means 2 layer reconstruction using 2 pixel hits.
- "2hit−recovery" means 3 hit reconstruction + recovery of tracks with 2 hits only.
- "no erase" − means that the track overlap cleaning is disabled.

- Many results are given for the "mu6 nosec" event sample. These are di−jet events with at least 1 muon p_T>6GeV and all secondary vertices killed.
- Other events used are :
  - mu6 − like above but with secondary vertices,
  - qcd − dijets with 60GeV jets,
  - tau − h(500) to 2 taus with hadronic tau decays,
  - hgg − H(120) to 2 gammas,
  - h_4e − H(250) to 4 electrons,
  - h0bb − H(100) to bb_bar,
  - bb100 − 100GeV bb jets,
  - tt100 − 100GeV tt jets,
  - 1bjet − tracks from 1 jet only from bb100 events.

A comment about inefficiencies

Most results presented here do not have the pixel readout inefficiencies included (because I wanted to have a clean case).

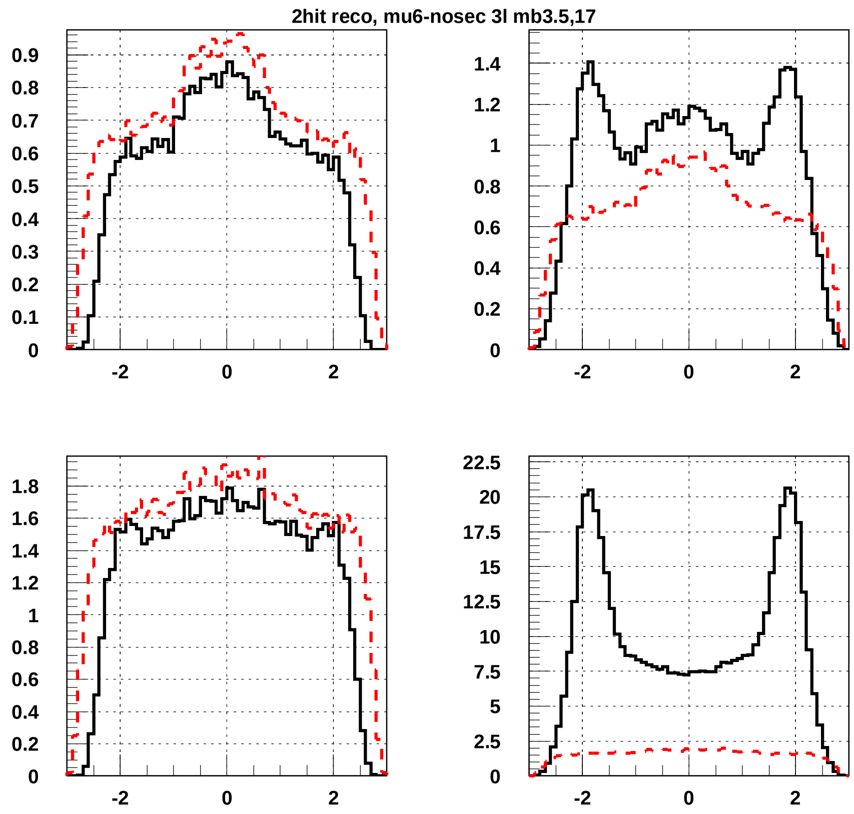
However the geometrical inefficiencies are there.

With the recent change of the geometry (cmsim125) the holes between detector modules got bigger.

The loss is now :

2.5% (detector holes) + 0.5% (threshold) = 3% per layer.

2 hit recovery



Low luminosity

High luminosity

Standard 3l

With 2 hit recovery

2 layer reconstruction at low luminosity

I used to claim that a 2 layer pixel system was sufficient at low luminosity.

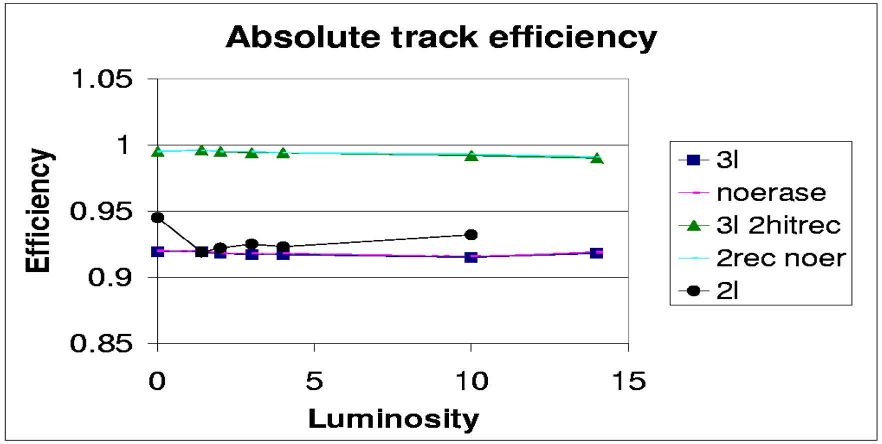
In the meantime :

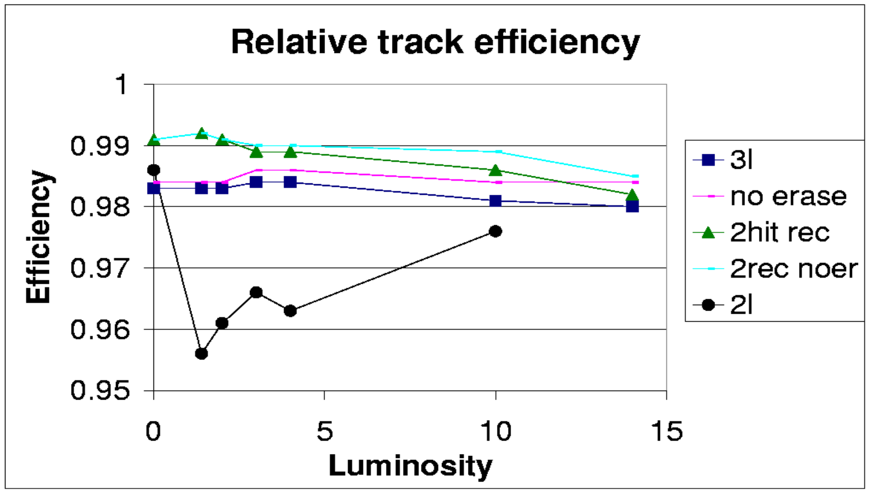
- the "low luminosity" has been redefined in CMS to 2*10^33
- "paolo's" minimum bias events have more tracks above 1 GeV.
- lower GEANT cuts, lower minimum pT and larger maximum eta.

All this results in a larger number of tracks/rechits per event. The 2 point reconstruction still works but in order to keep the number of ghost PVs I had to increase the cut defining the minimum number of tracks per PV.

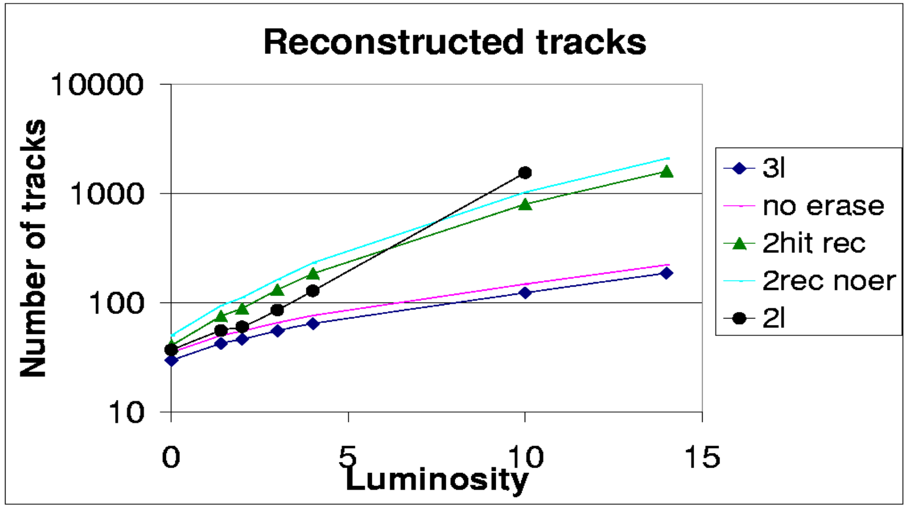
This lowers the reconstruction efficiency.

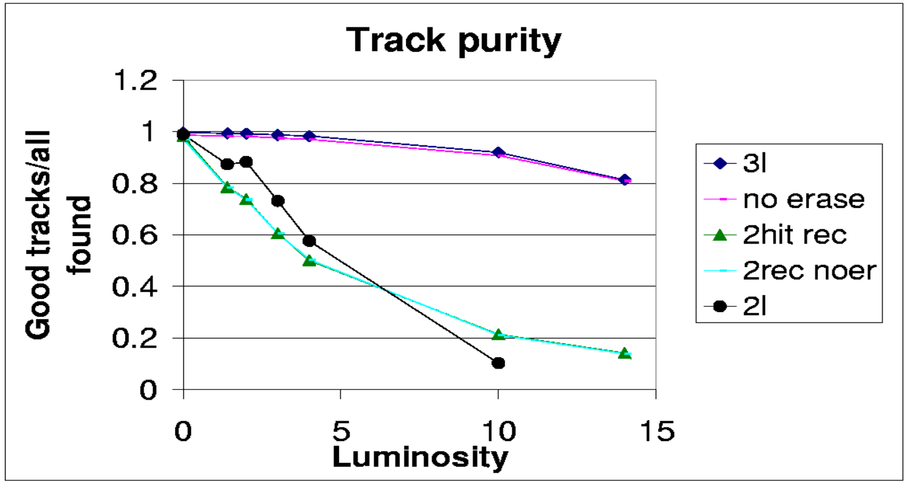
Luminosity dependence − tracks finding efficiency



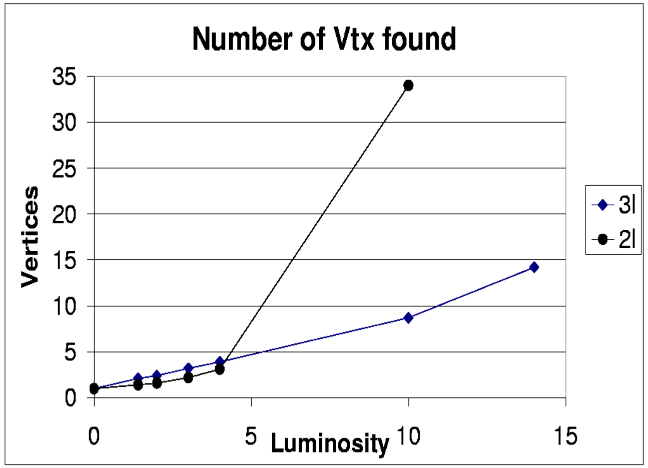


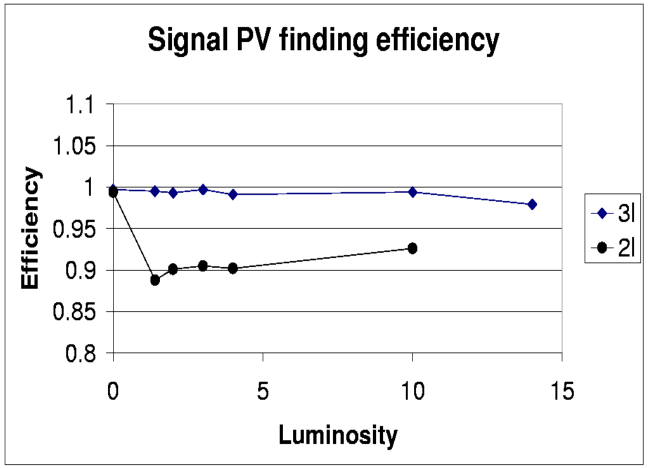
Luminosity dependence – track purity

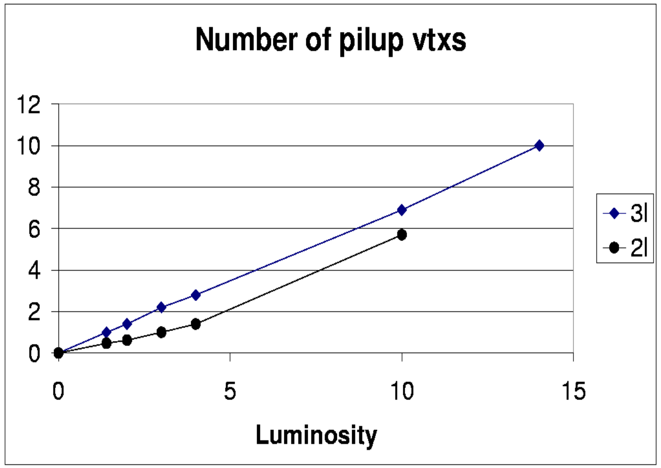




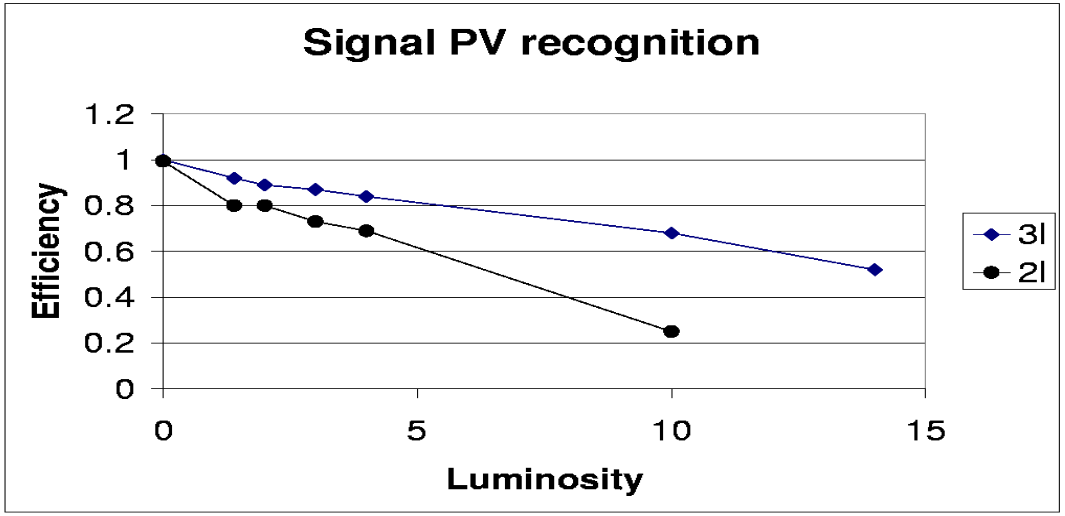
Luminosity dependence − PV finding

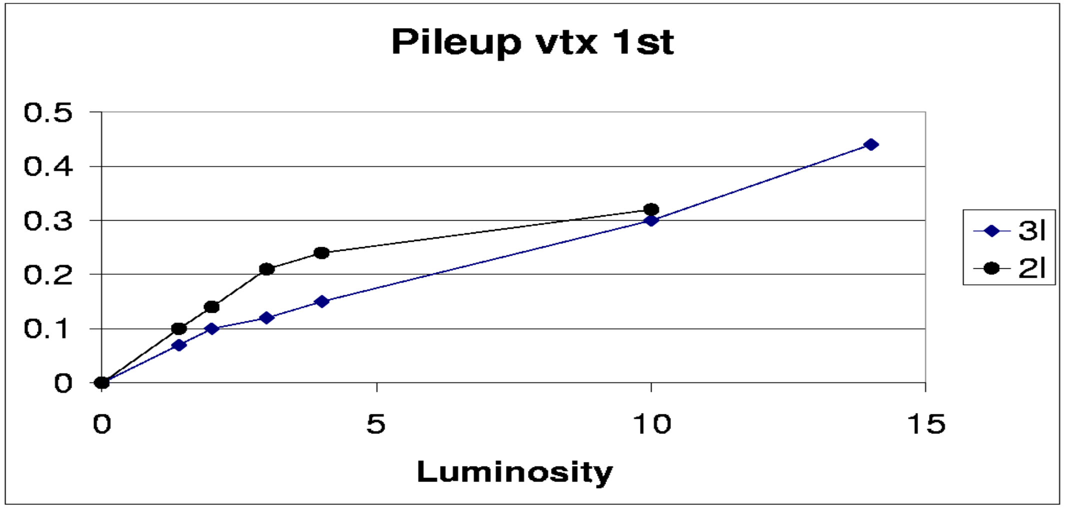




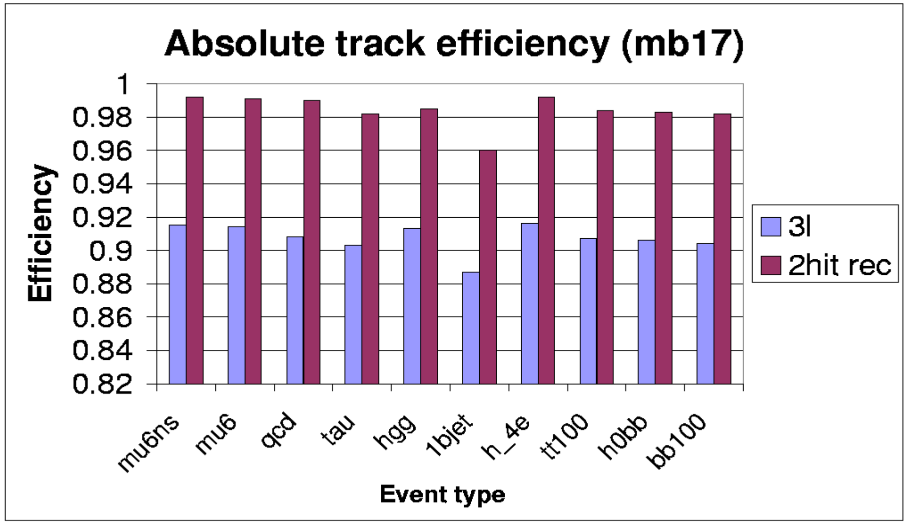


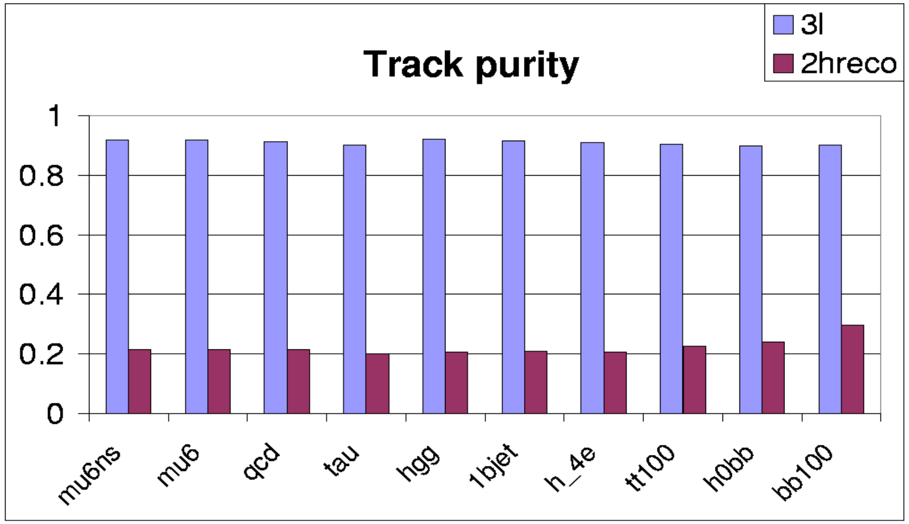
Luminosity dependence − PV signal finding



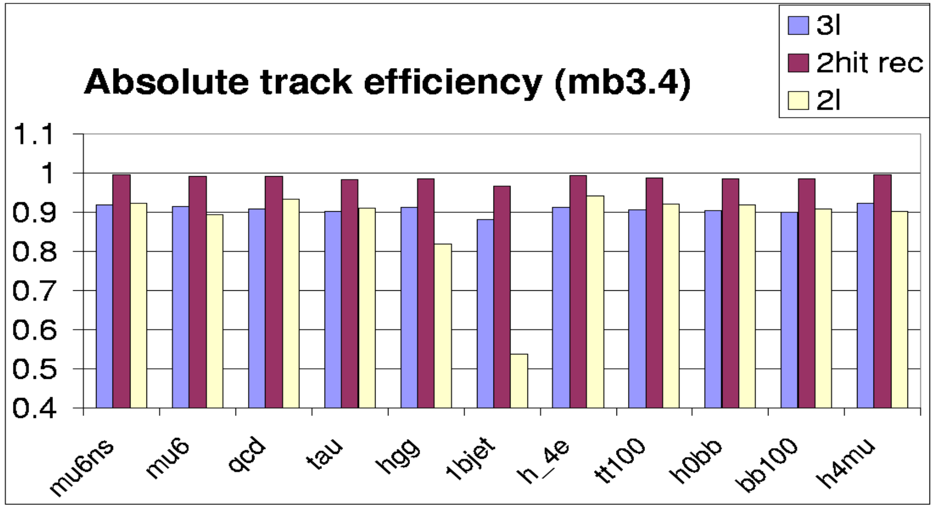


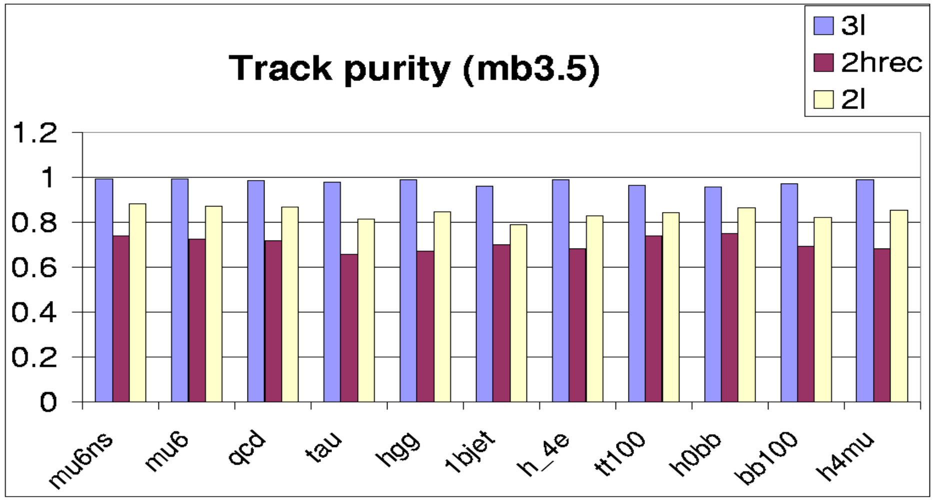
Different event types at high luminosity



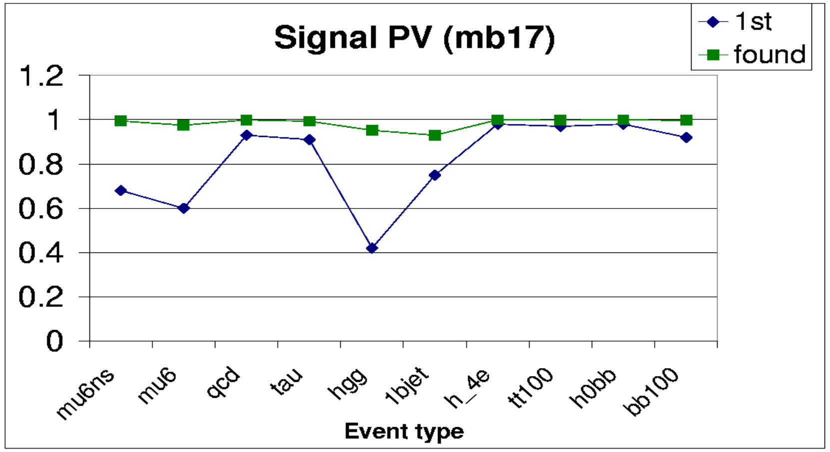


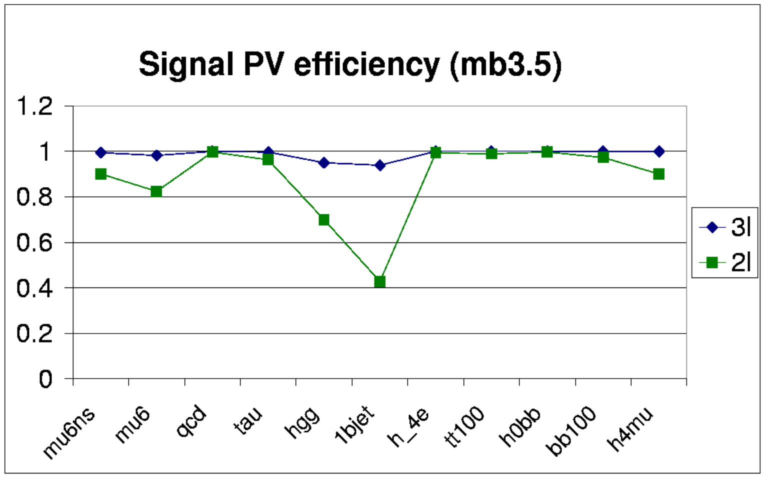
Different event types at low luminosity

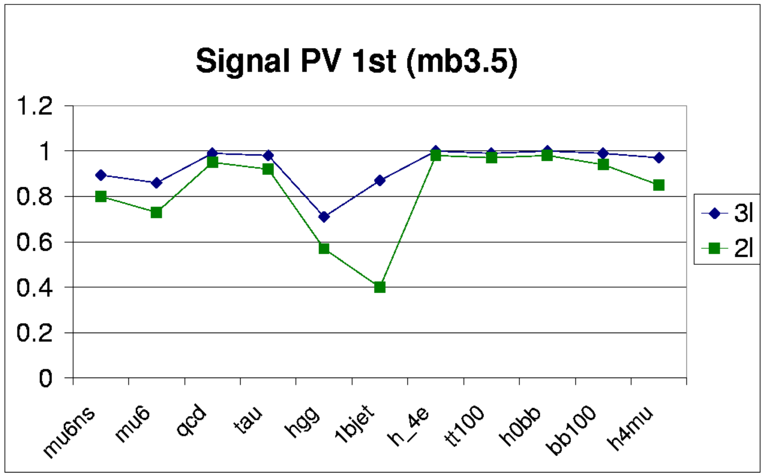




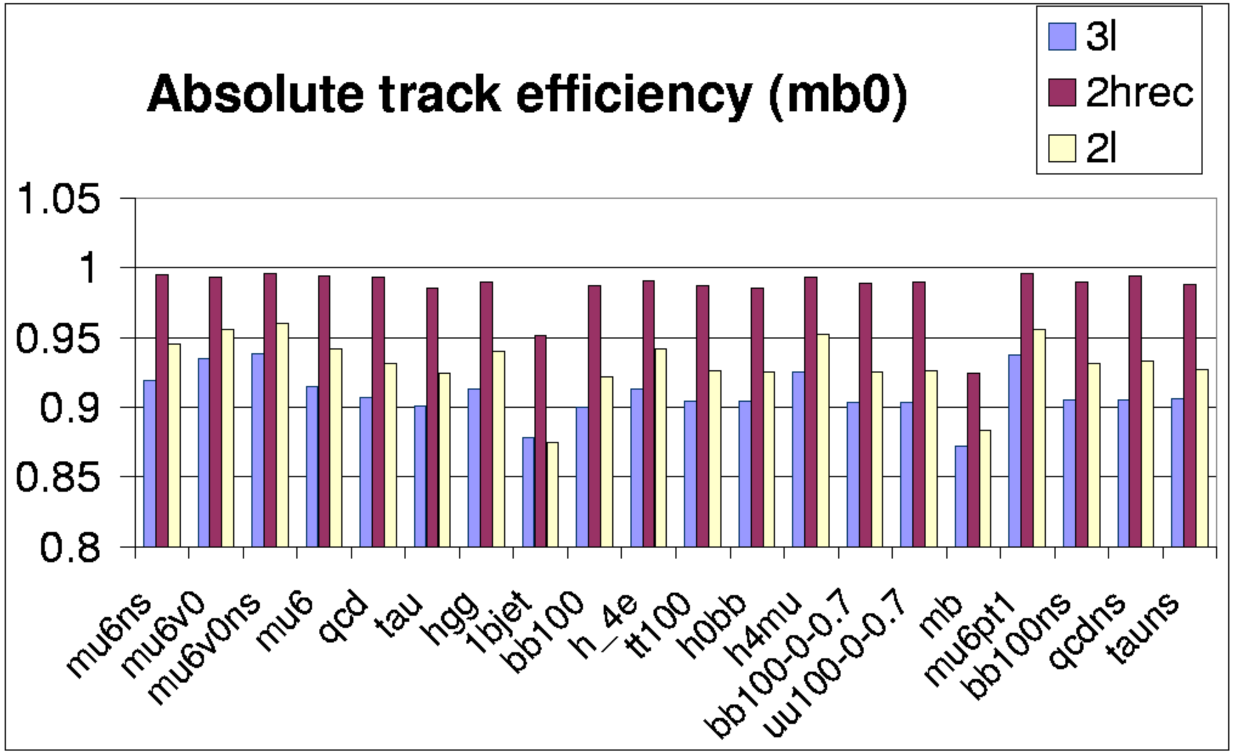
PV finding for different event types



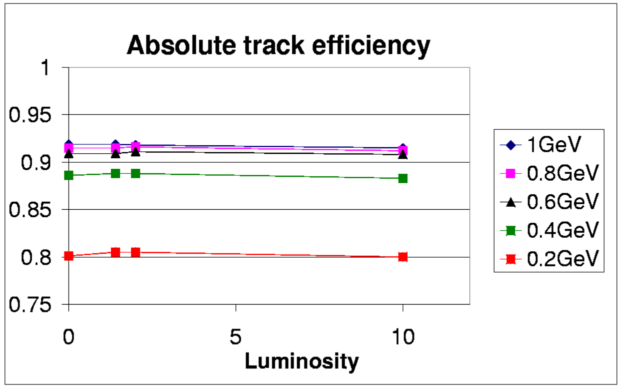


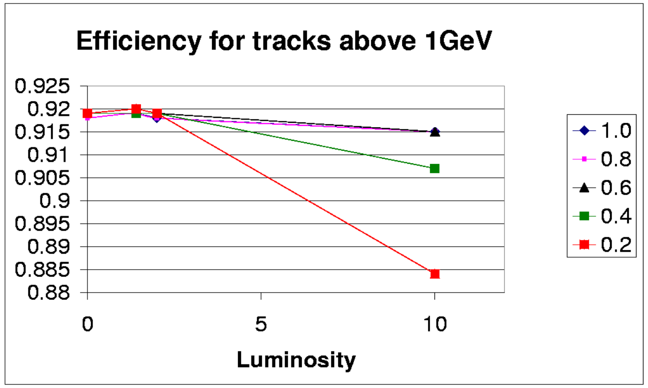


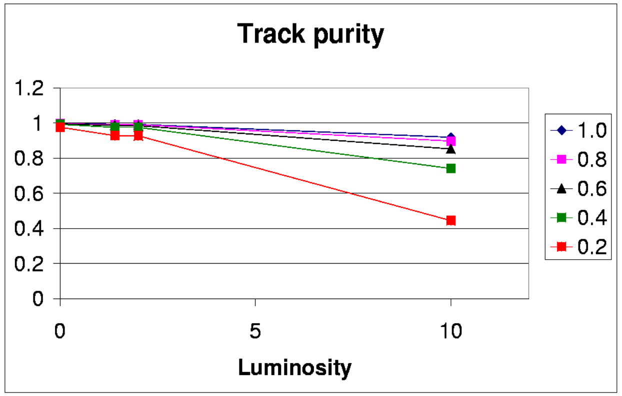
Track finding efficiency − signal only

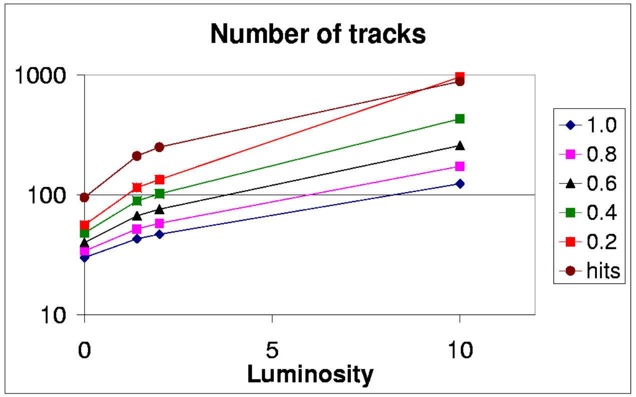


Lower minimum p_T threshold









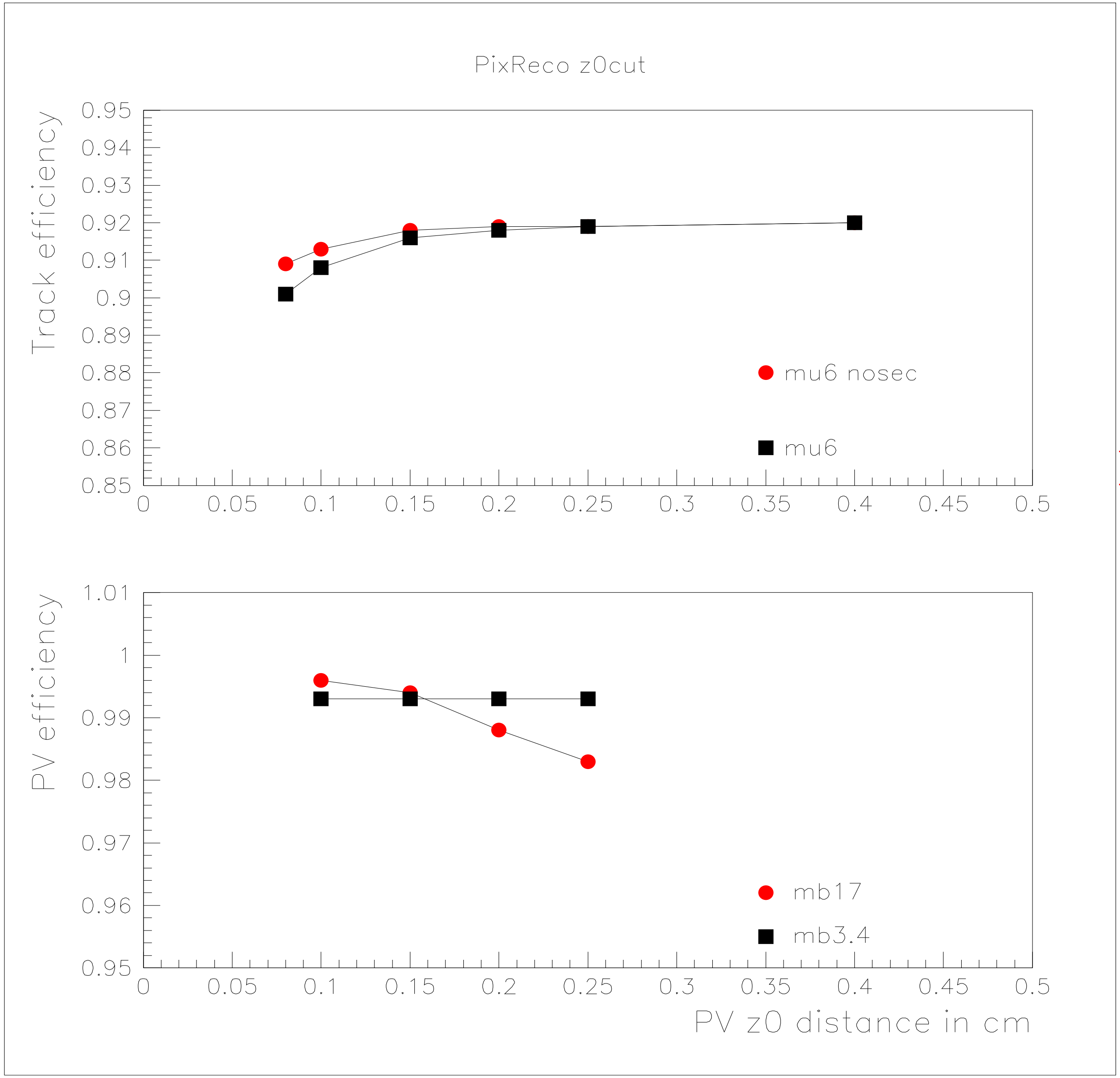
So a lower threshold down to 0.2GeV is possible.
But is it useful?

A quick test for h(500), qcd50−80 samples at 2x10^33.
Rm=0.1, Rs=0.07 and Ri=0.30.

Threshold (GeV)	Tau	QCD
1. (default)	0.73	0.12
0.8	0.70	0.11
0.6	0.65	0.088
0.4	0.58	0.088

Low statistics, not conclusive.

Optimizing the z0cut
(zPZ − z0)



Default = 0.15cm
one has to
compromise!

Partial/regional reconstruction

Take bb 100Gev events at high luminosity

	select 1 jet	all tracks
abs. track efficiency	0.89	0.90
purity	0.92	0.90
signal PV eff.	0.93	1.0
signal PV 1st.	0.75	0.92
time (for signal only)	4ms	20ms

Track overlaps in tau events

A pixel can be hit by 2 tracks (pixel overlaps)
−> small effect.

Two pixel clusters can touch or overlap (rechit overlaps)
−> bigger effect.

Overlaps at 4cm

	pixel overlaps	rechit overlaps
mb17	$6.4*10^{-4}$	$2.8*10^{-3}$
tt_100	$1.6*10^{-3}$	$5.6*10^{-3}$
taus (1)	$1.2*10^{-2}$	$3.8*10^{-2}$
taus (2)	$5.3*10^{-2}$	$19.*10^{-2}$

(1) central 100GeV taus decaying into 3 prongs.
(2) non central 50−300GeV taus decaying into 3 prongs.

At Pythia level 13% of events have at least 2 tracks closer than $R<0.003$ (1 pixel width at 4cm).
It is especially bad for 2 Kaon decays.

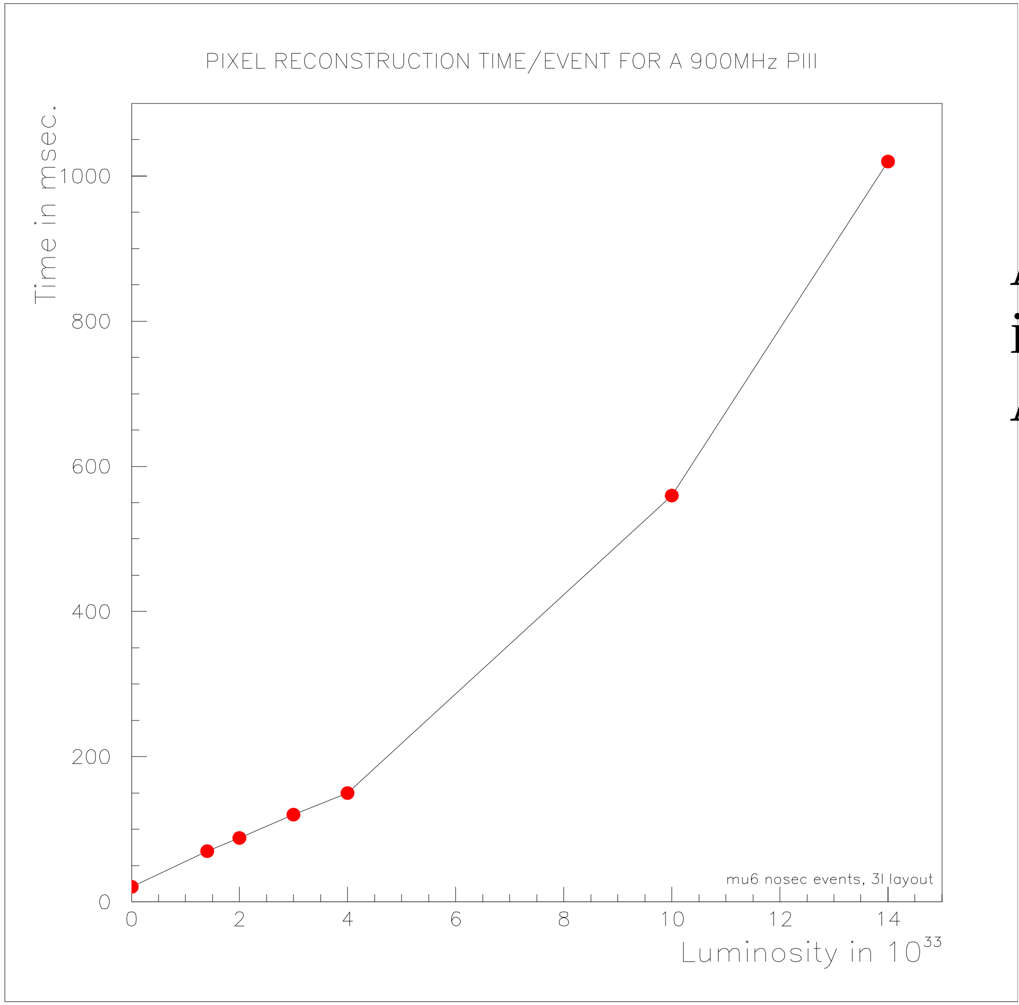
Track overlaps in tau event cont.

The effect on the pixel reconstruction is that for many events less then 3 tracks are reconstructed (e.g. in the 4cm layer there are only about 2.4 rechits per event instead of 3).

Reconstructed tracks :	0	1	2	3	>3
3l (3 layer) reconstruction					
All reconstructed tracks:	0.	0.17	0.20	0.31	0.31
Count only good tau tracks:	0.01	0.20	0.30	0.50	0
2hitreco reconstruction					
All reconstructed tracks:	0.	0.06	0.11	0.46	0.36
Count only good tau tracks:	0.01	0.10	0.19	0.71	0
2hitreco+noerase					
All reconstructed tracks:	0.	0.02	0.07	0.20	0.70
Count only good tau tracks:	0.0	0.06	0.15	0.78	0.01

Improvement –> smart rechit cluster building!

Execution Time



At high luminosity
it is a quadratic behavior.
At low luminosity linear.

Final remarks

1. PixelReconstruction is implemented in ORCA6 together with a set of "user" classes: PixelConeTrigger, PixelSeedGenerator, PixelSeedCleaner, PixelSelectiveSeeds & PVWithPixelRecHits.

2. 2 hit−recovery works well, it improves the track finding efficiency by 8% (from 91% to 99%) but generates many ghosts.
   The "no overlap cleaning" option does not bring very much.

3. Lowering of the p_T cut below 1 GeV is possible but is it useful?

4. 2 layer option for low luminosity is probably still OK but there is some loss of efficiency.

5. No simple way to decrease the CPU speed!

6. Most reconstruction options mentioned here can be now user selected in ORCA6 (e.g. 2hit recover, pTcut, etc.).

Final remarks continue

7. Option and cuts used should be tailored for the task:

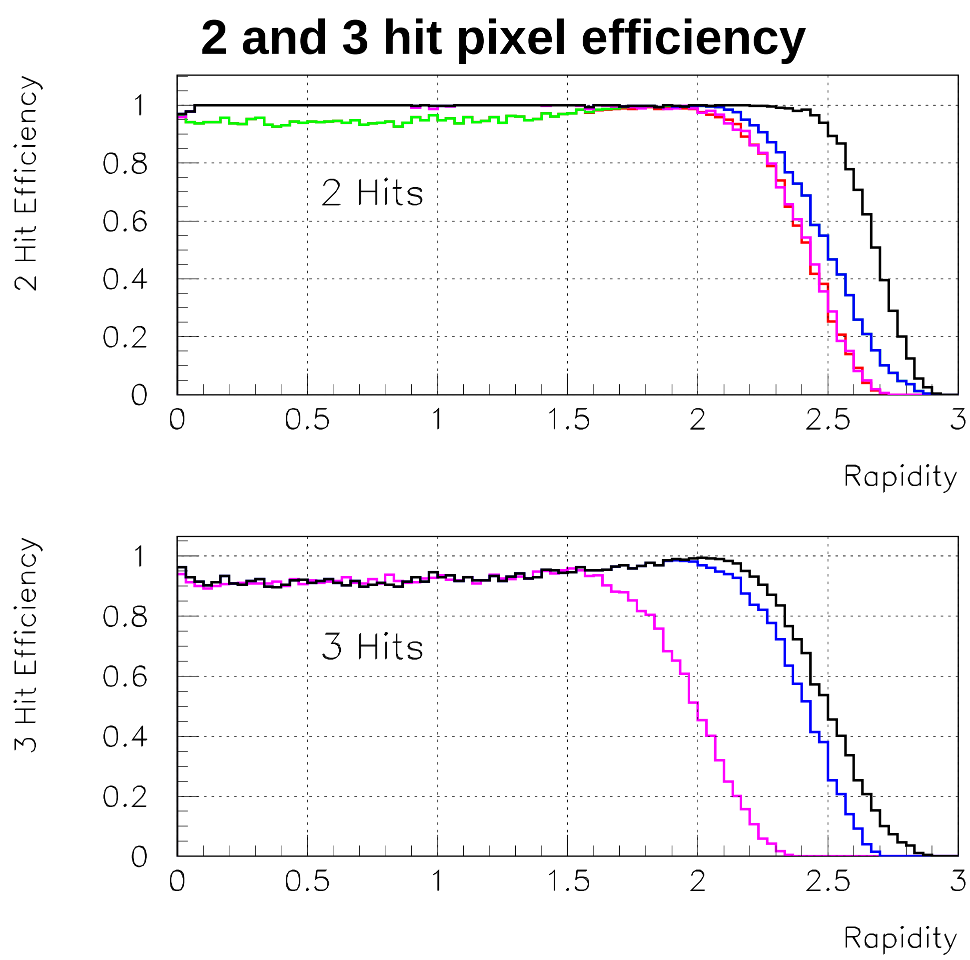
   for isolation triggers −> low track and vertex ghost rate (no 2 hit−recovery, use overlap cleaning, default cuts);

   for track seeds −> maximum track efficiency (use 2 hit recovery, no cleaning, lower cuts?);

   for PVs −> something in between the two (no 2 hit recovery, standard cuts, eliminate tracks with bad z0 resolution e.g. from large rapidity).

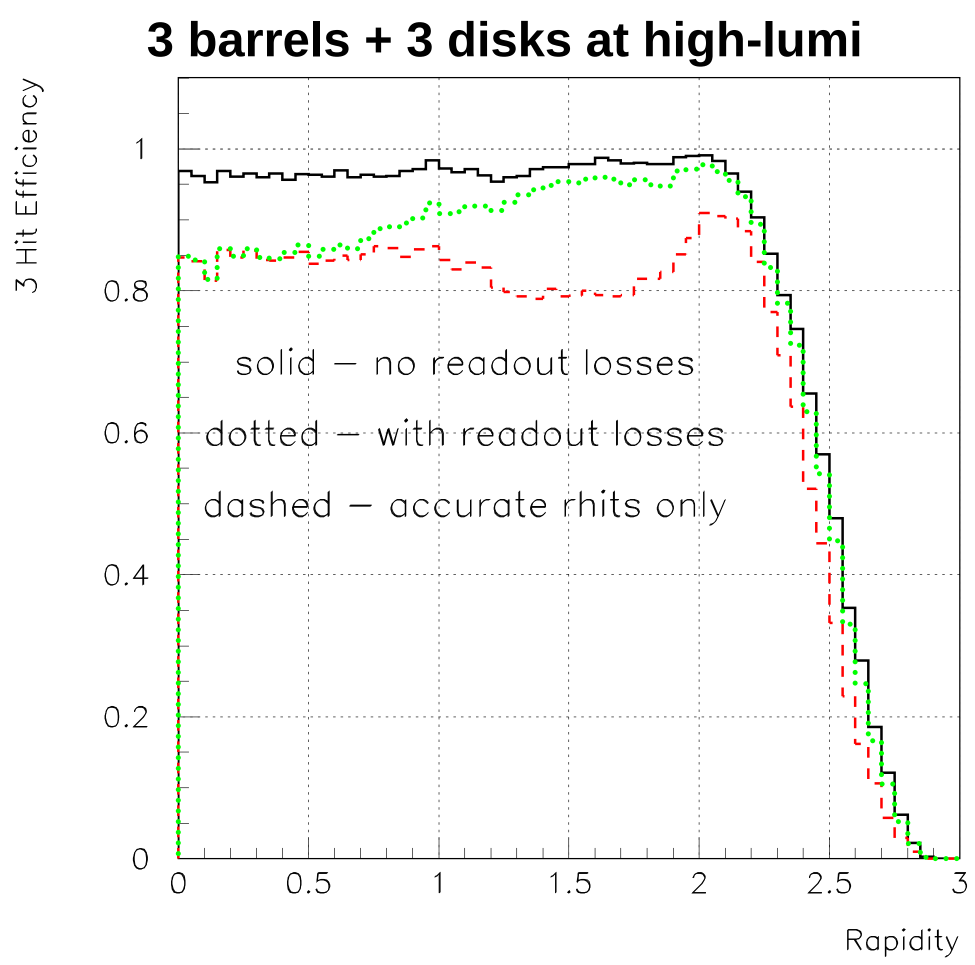
8. Possible improvements :
   - iterative lowering of the p_T cut and than a 2 hit recovery,
   - maybe something similar would work for 2 layer configuration and a 1 hit recovery?
   - use the cluster (rechit) shape and charge information.

PIXEL HIT COVERAGE
(no readout losses)

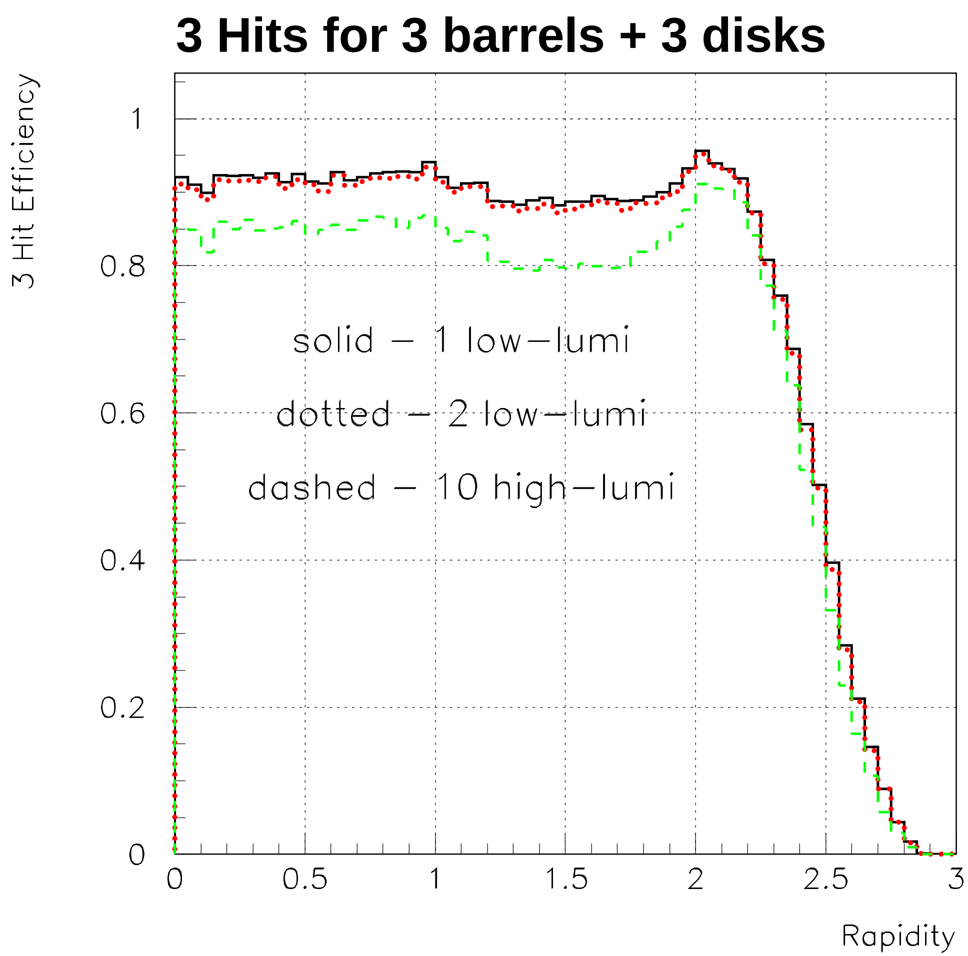


Configuration:
b2d1 − read
b2d2 − green
b3d1 − pink
b3d2 − blue
b3d3 − black

The effect of readout losses on pixel hit coverage (3 pixel hits at high luminosity)



Pixel hit efficiency as a function of luminosity (2 pixel hit coverage)



ETA COVERAGE

Pixel track and PV finding

	Track finding efficiency 2 hits eta<2.1/2.4	3 hits eta<2.1/2.4	Ghost rate 2/3 hits	PV finding
b3d2	0.98/0.96	0.90/0.87	0.030/0.004	0.96
b3d1	0.97/0.94	0.83/0.74	0.025/0.004	0.93
b3d0	0.88/0.78	0.70/0.61	0.020/0.003	0.90
b2d2	0.93/0.92	− / −	0.015/ −	0.97
b2d1	0.93/0.91	− / −	0.011/ −	0.96
b2d0	0.85/0.76	− / −	0.007/ −	0.91

hgg 120, mb0