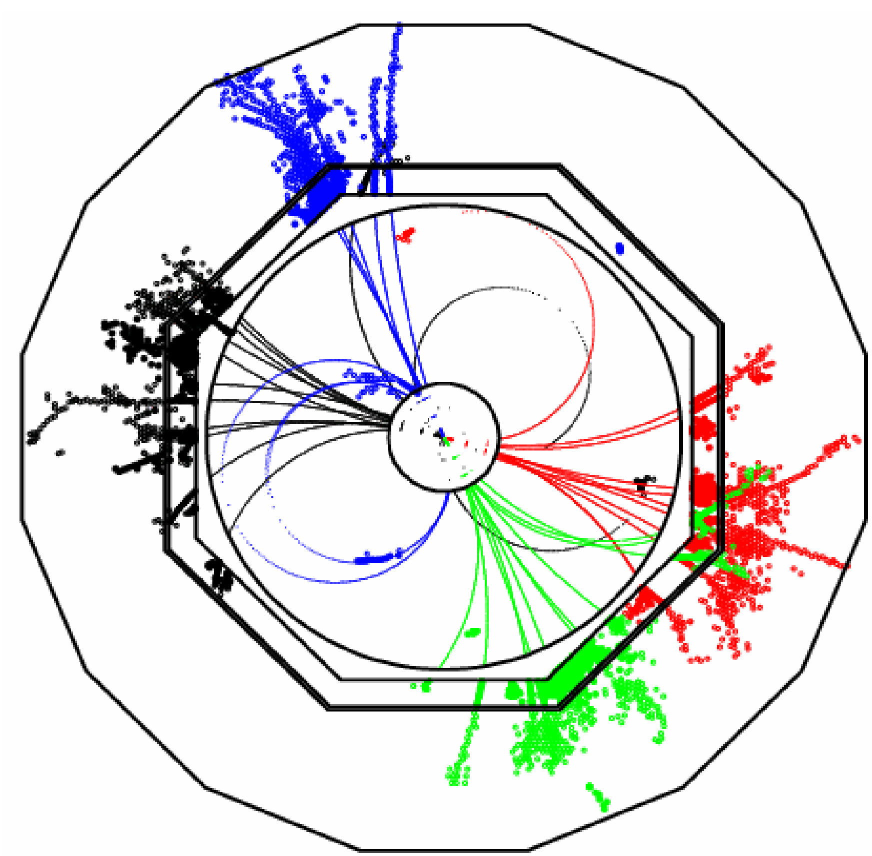
Particle Flow and ILD Detector Optimisation Studies

Mark Thomson
University of Cambridge



This Talk:

❶ PandoraPFA Performance
❷ Understanding PFA
❸ Optimisation Studies
  i) HCAL depth
  ii) B-field vs R_{TPC}
  iii) TPC aspect ratio
  iv) HCAL segmentation
  v) ECAL segmentation
  vi) LDCPrime vs GLDPrime
❹ Tau decays
❺ Summary and Conclusions

❶ PFA Performance

Studies in this talk start from:

★ Use standard Mokka LDCPrime model : LDCPrime_02Sc

★ OPAL tune of Pythia

★ Full reconstruction chain:

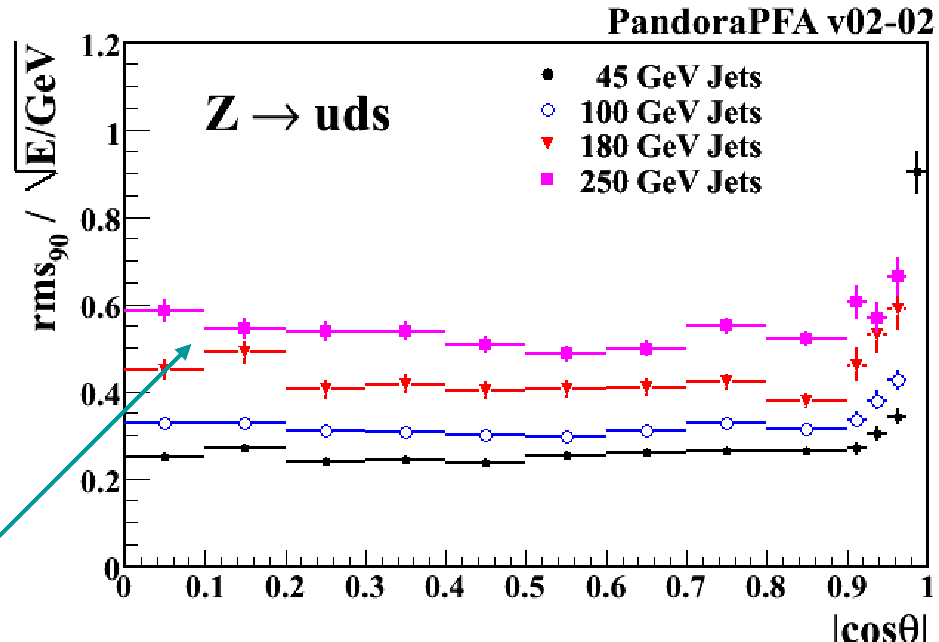
- PandoraPFA v02-02 (essentially the released version)
- FullLDCTracking

★ Non-standard: muon chamber clustering/hits used in PFA

- not very important, discussed later in talk

PandoraPFA v02-02

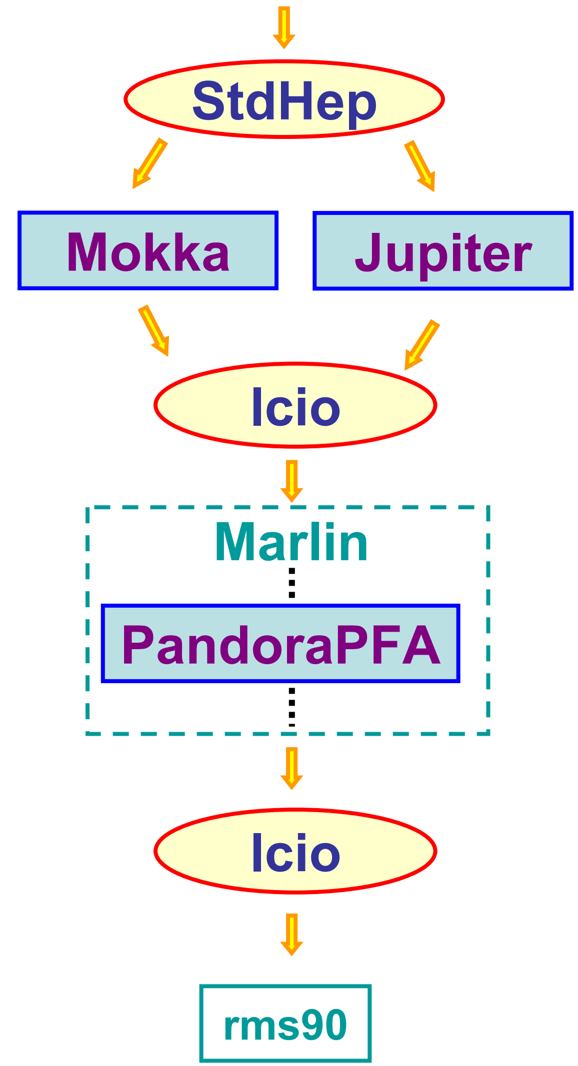
E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	24.9 %	3.7 %
100 GeV	30.7 %	3.1 %
180 GeV	43.0 %	3.2 %
250 GeV	52.2 %	3.3 %



Leakage not completely negligible ?

LDCPrime vs GLDPrime

★ Magic of LCIO allows a direct comparison of GLDPrime and LDCPrime
- same reconstruction : PandoraPFA
- same STDHep events



Results

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	
	LDCPrime	GLDPrime
45 GeV	24.9 %	25.9 %
100 GeV	30.7 %	35.1 %
180 GeV	43.0 %	49.5 %
250 GeV	52.2 %	61.0 %

★ Similar performance at 91 GeV.
- good sanity check

★ GLDPrime approx. 15 % worse for E_{JET} > 100 GeV

!
+ PandoraPFA optimised for LDC
– GLDPrime simulated with 1x1 cm^2 ECAL not 4×1 cm^2 strips

❷ Understanding PFA

★ Try to use various “Perfect PFA” algorithms to pin down main performance drivers (resolution, confusion, …)

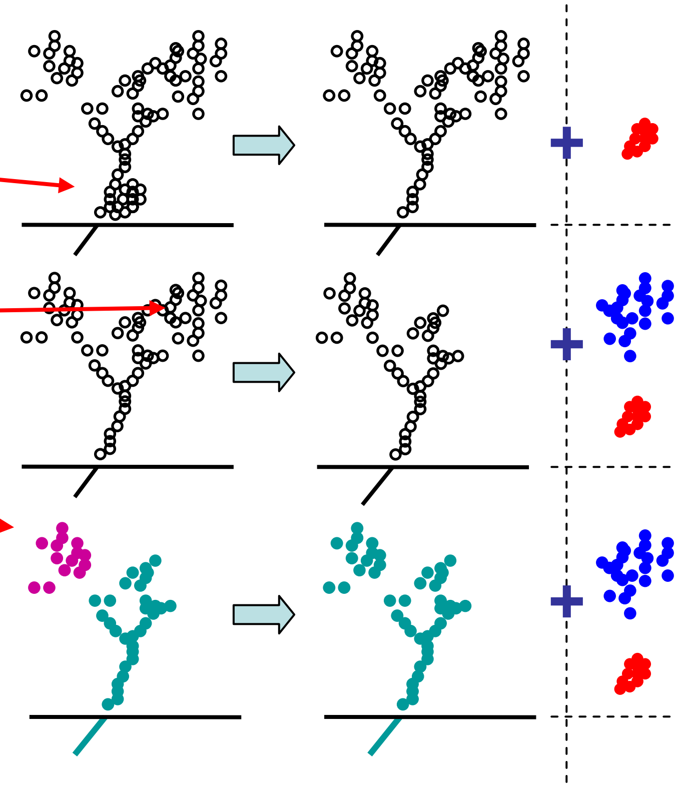
★ Aim : understand main features of studies presented here

★ Developed new version of PandoraPerfectPFA

(in PandoraPFA v03-α)

PandoraPFA options:

- **PerfectPhotonClustering**
  hits from photons clustered using MC info and removed from main algorithm
- **PerfectNeutralHadronClustering**
  hits from neutral hadrons clustered using MC info…
- **PerfectFragmentRemoval**
  after PandoraPFA clustering “fragments” from charged tracks identified from MC and added to charged track cluster
- **PerfectPFA**
  perfect clustering and matching to tracks



★ Can see how jet energy resolution evolves with increased level of "perfection"

Algorithm	σ_E/E			
	45 GeV	100 GeV	180 GeV	250 GeV
PandoraPFA	3.7 %	3.1 %	3.2 %	3.3 %
+CheatedTracks	3.6 %	3.0 %	3.1 %	3.2 %
+CheatedPhotons	3.6 %	2.8 %	2.7 %	2.7 %
+CheatedNeutralHs	3.4 %	2.4 %	2.1 %	2.0 %
+PerfectFragRem	3.2 %	2.3 %	2.1 %	2.0 %
PerfectPFA	3.1 %	2.1 %	1.7 %	1.6 %

★ Using these results (and others) can then obtain estimates of main contributions to PFA performance

!

★ The PerfectParticleFlow algorithms aren't perfect…
★ …So these resulting numbers are just estimates
- but probably good enough to understand main features

Contribution	σ_E/E 45 GeV	100 GeV	180 GeV	250 GeV
Calo. Resolution	3.1 %	2.1 %	1.5 %	1.3 %
Leakage	0.1 %	0.5 %	0.8 %	1.0 %
FullLDCTracking	0.7 %	0.7 %	1.0 %	0.7 %
Photons "missed"	0.4 %	1.2 %	1.4 %	1.8 %
Neutrals "missed"	1.0 %	1.6 %	1.7 %	1.8 %
Charged Frags.	1.2 %	0.7 %	0.4 %	0.0 %
"Other"	0.8 %	0.8 %	1.2 %	1.2 %

Comments:

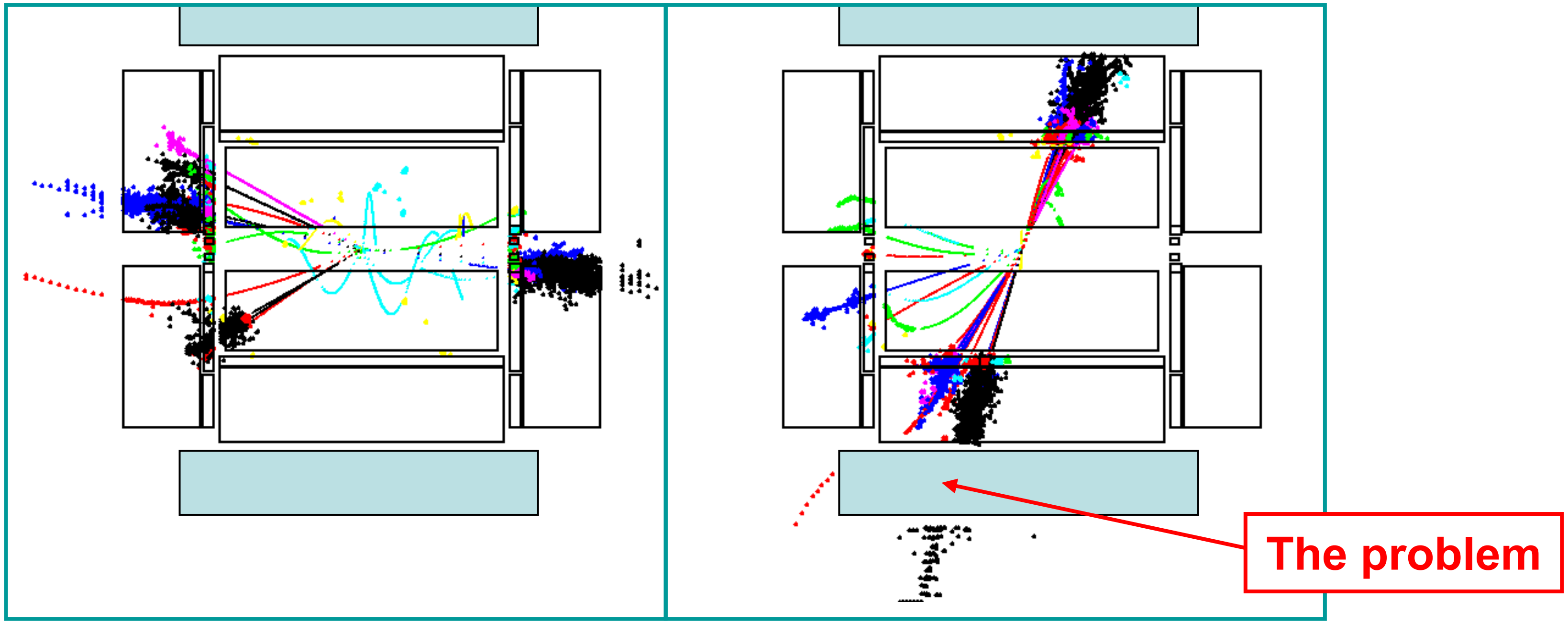
- ★ For 45 GeV jets, jet energy resolution dominated by ECAL/HCAL resolution
  - don't expect much dependence of σ_E/E on B, R etc.
- ★ Track reco. not a large contribution (FullLDCTracking ≈ CheatedTracking)
- ★ "Satellite" neutral fragments not a large contribution
  - efficiently identified and removed by normal FragmentRemoval alg.
- ★ Leakage only becomes significant for high energies (more on this later)
- ★ Missed neutral hadrons dominant confusion effect
- ★ Missed photons, important at higher energies (somewhat surprising !)

❸ Optimisation Studies: ① HCAL Depth

Two interesting questions:

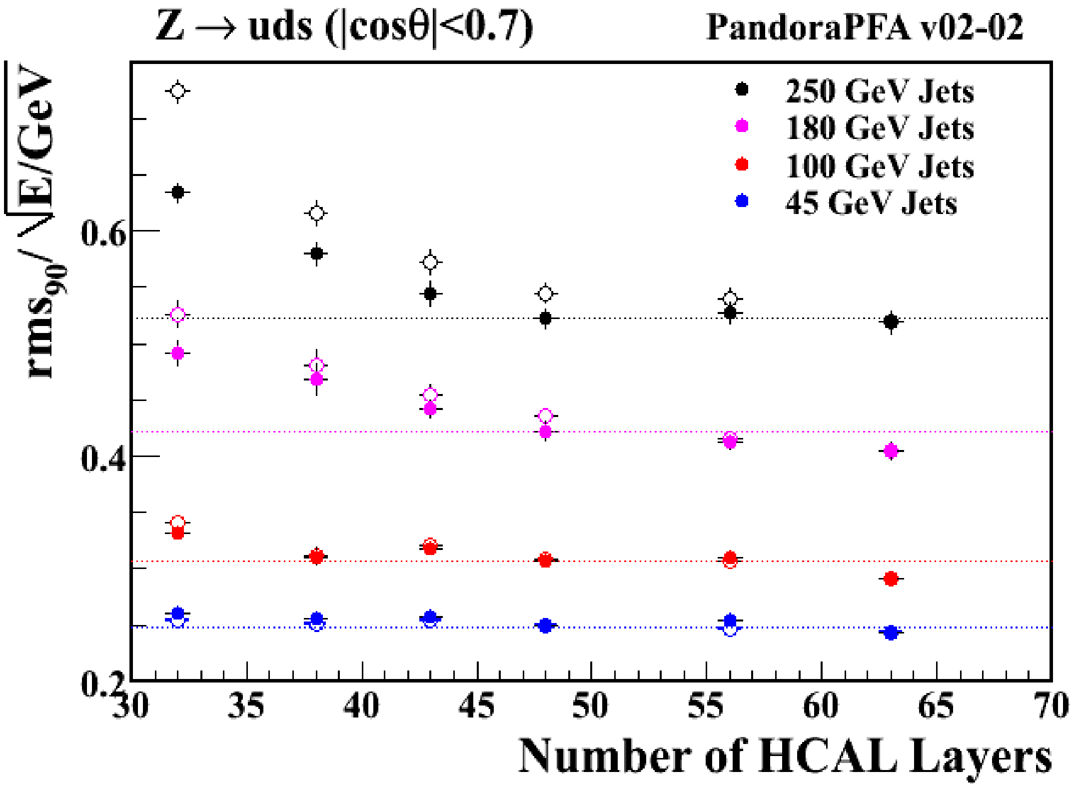
- ★ How important is HCAL leakage ?
  - vary number of HCAL layers
- ★ What can be recovered using MUON chambers as a “Tail catcher”
  - PandoraPFA now includes MUON chamber reco.
  - Switched off in default version
  - Simple standalone clustering (cone based)
  - Fairly simple matching to CALO clusters (apply energy/momentum veto)
  - Simple energy estimator (digital) + some estimate for loss in coil

e.g.



HCAL Depth Results

- **Open circles** = no use of muon chambers as a "tail-catcher"
- **Solid circles** = including "tail-catcher"



HCAL Layers	λ_I	
	HCAL	+ECAL
32	4.0	4.8
38	4.7	5.5
43	5.4	6.2
48	6.0	6.8
63	7.9	8.7

ECAL : λ_I = 0.8
HCAL : λ_I includes scintillator

★ Little motivation for going beyond a 48 layer (6 λ_I) HCAL
★ Depends on Hadron Shower simulation
★ "Tail-catcher": corrects ~50% effect of leakage, limited by thick solenoid

For 1 TeV machine "reasonable range" ~ 40 – 48 layers (5 λ_I - 6 λ_I)

Optimisation Studies : ② B vs R

★ Studied jet energy resolution for various detector models:
- LDCPrime: LDCPrime_02Sc
- LDC: LDC01_06Sc
- GLD-sized: modified LDCPrime_02Sc
- Two smaller detectors: modified LDCPrime_02Sc with increased B

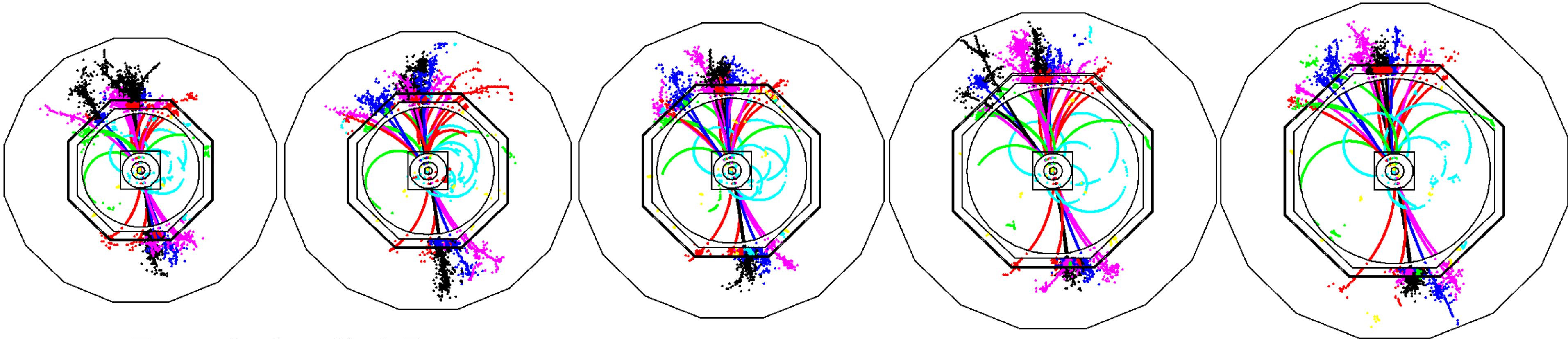
All: 5x5 mm^2 ECAL seg
30x30 mm^2 HCAL seg

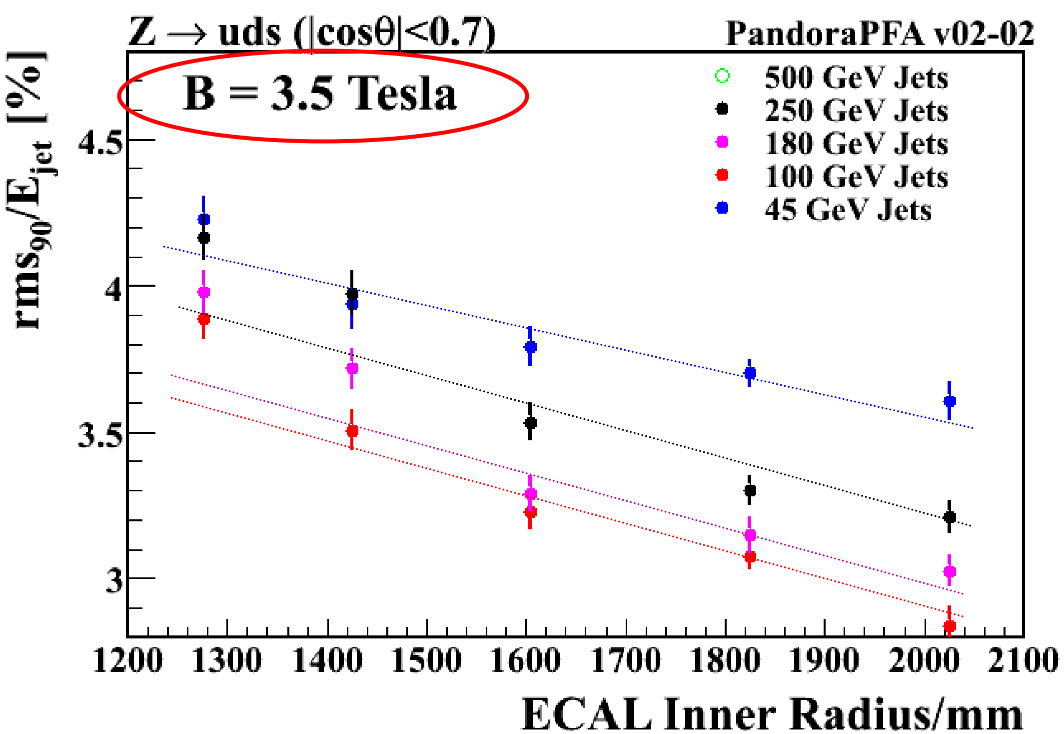
★ In addition, study performance as function of B and R starting near to LDCPrime parameters

Test	Change	Parameters				
B and R	Model=	SiD-like	small	LDC	LDCPrime	GLD
B-field	B =	2.5 T	3.0 T	3.5 T	4.0 T	4.5 T
Radius	R_{ECAL} =	1280 mm	1420 mm	1600 mm	1820 mm	2020 mm

Radius

★ Start from LDCPrime – vary ECAL inner radius, fixed TPC aspect ratio

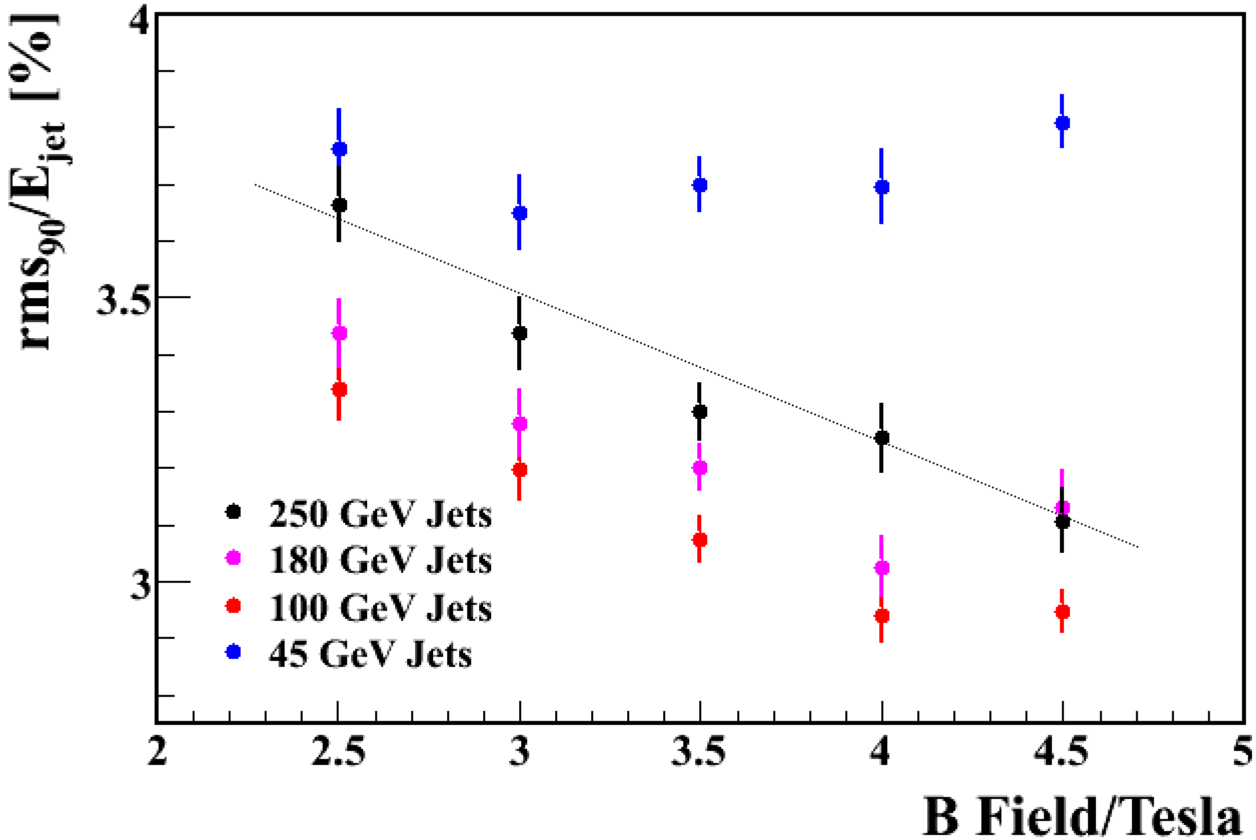




★ LDC ➞ LDCPrime ➞ LDC4GLD :
- ~10 % variation

B-field

★ Start from LDCPrime – fix geometry, vary B-field



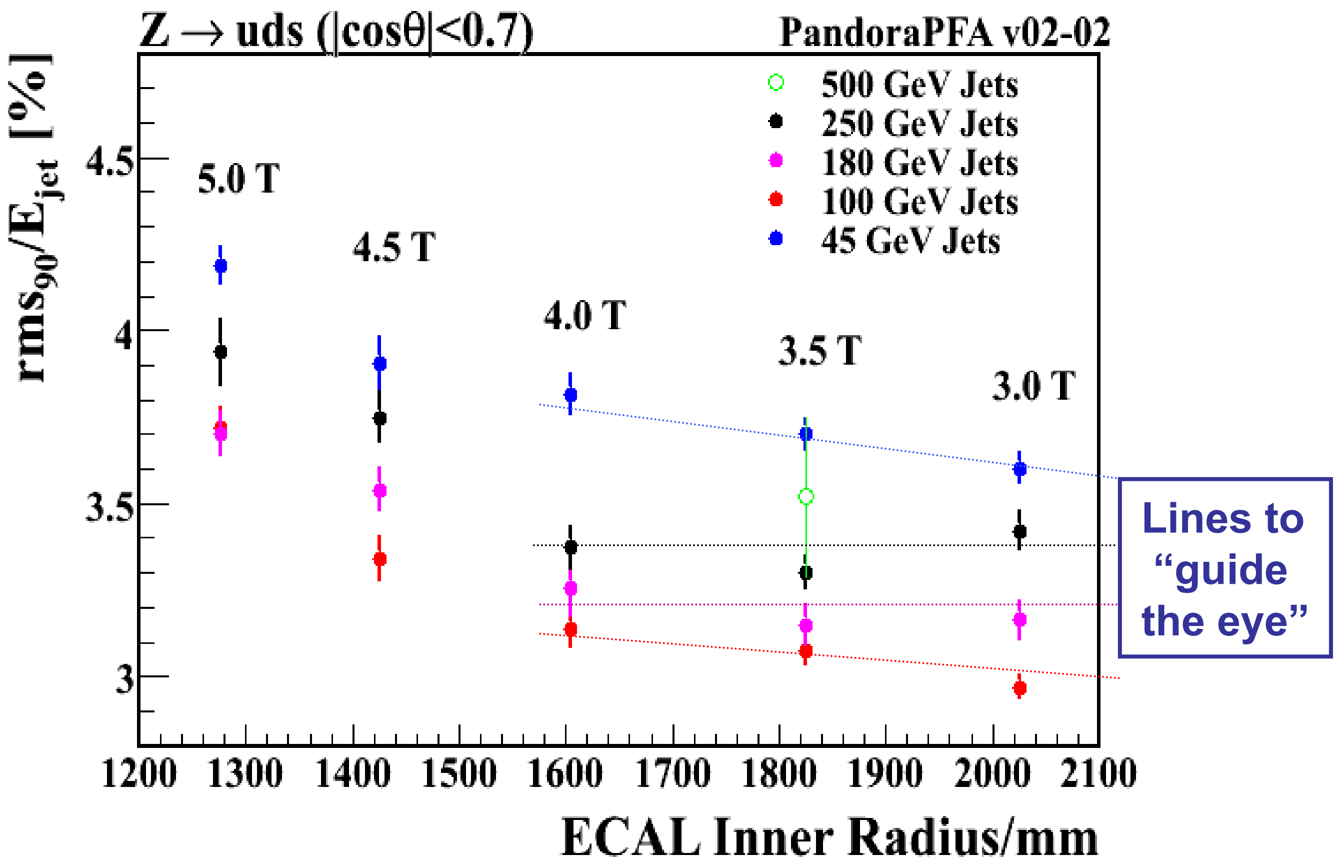
★ As expected, no dependence for 45 GeV jets (not dominated by confusion)

★ For higher energies, higher field helps, e.g.

- At 500 GeV going from 3.0 T → 4.0 T : ~ 10 % improvement in resolution

LDC vs LDCPrime vs LDC4GLD

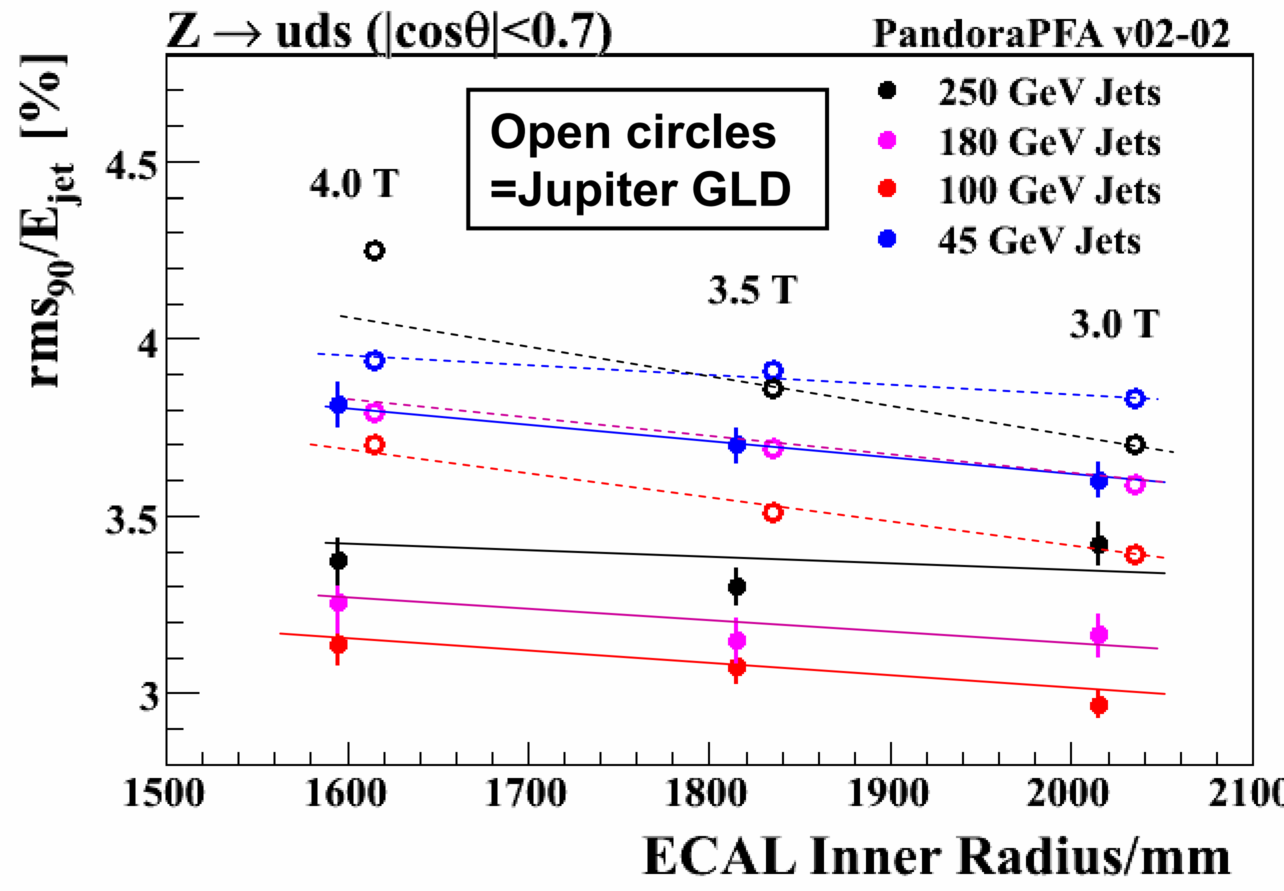
★ Direct Comparison of LDC, LDCPrime and GLD



★ In terms of jet energy resolution: LDC ≈ LDCPrime ≈ "LDC4GLD"

GLD vs GLDPrime vs J4LDC

★ Can compare with similar J4LDC, GLDPrime, GLD studies (Taikan Suehara)



JUPITER models

★ In terms of jet energy resolution: GLDPrime ≈ "GLD"

: J4LDC worse but thin HCAL

B vs. R Interpretation

★ All results shown are **fairly** well described by (best fit)

$$\frac{\sigma_E}{E} = \frac{0.021}{\sqrt{E}} \oplus 0.01 \oplus 0.02 \left(\frac{R}{1825}\right)^{-1.0} \left(\frac{B}{3.5}\right)^{-0.35} \left(\frac{E}{100}\right)^{+0.4}$$

Resolution — Tracking/Leakage/Fragments — Confusion

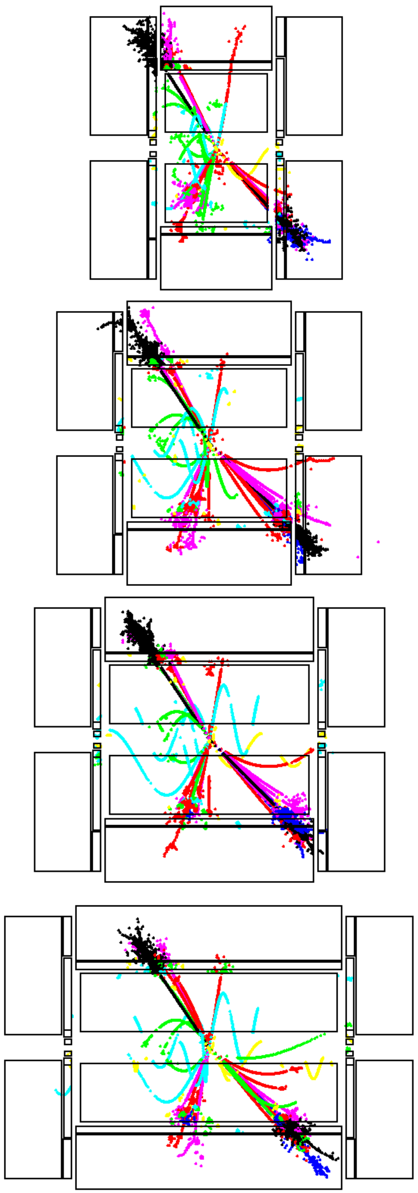
★ **R** is more important than **B**

★ Use parameterisation for comparison of LDC, LDCPrime, LDC4GLD

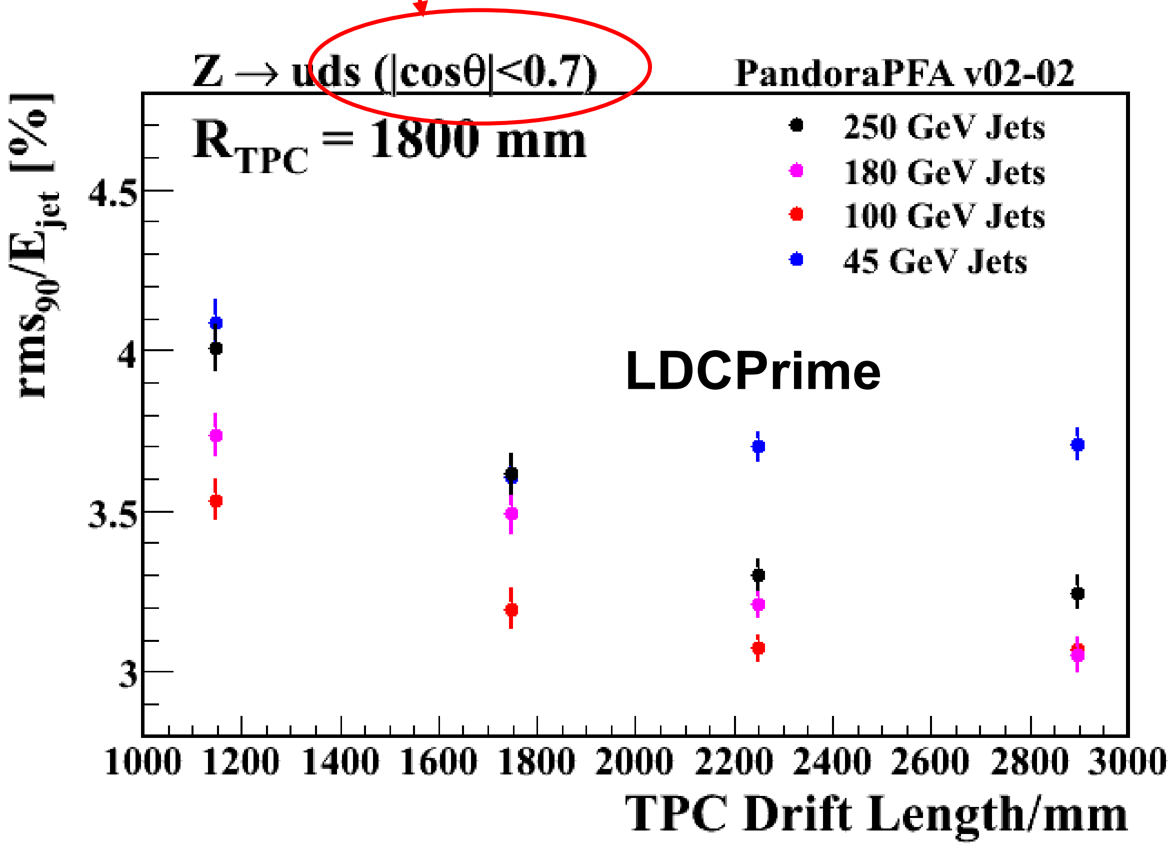
Relative to LDCPrime	Confusion	Relative σ_E/E vs E_{JET}/GeV			
		45	100	180	250
LDC	1.06	1.02	1.03	1.05	1.06
LDCPrime	1.00	1.00	1.00	1.00	1.00
LDC4GLD	0.95	0.99	0.98	0.97	0.96

- **LDC4GLD** slightly **(< 4 %)** better than LDCPrime
- But **LDC, LDCPrime, LDC4GLD** differences are small

Optimisation: ③TPC Aspect Ratio



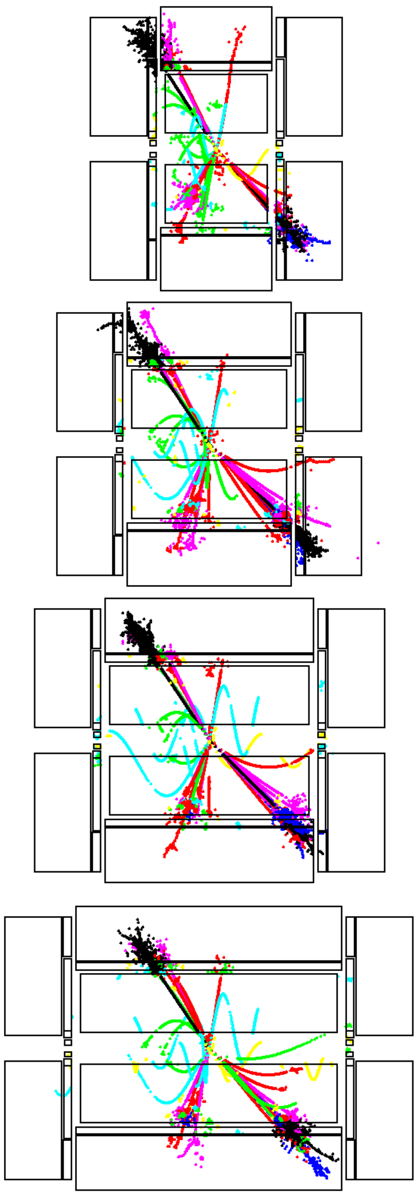
★ First: look at "central" performance



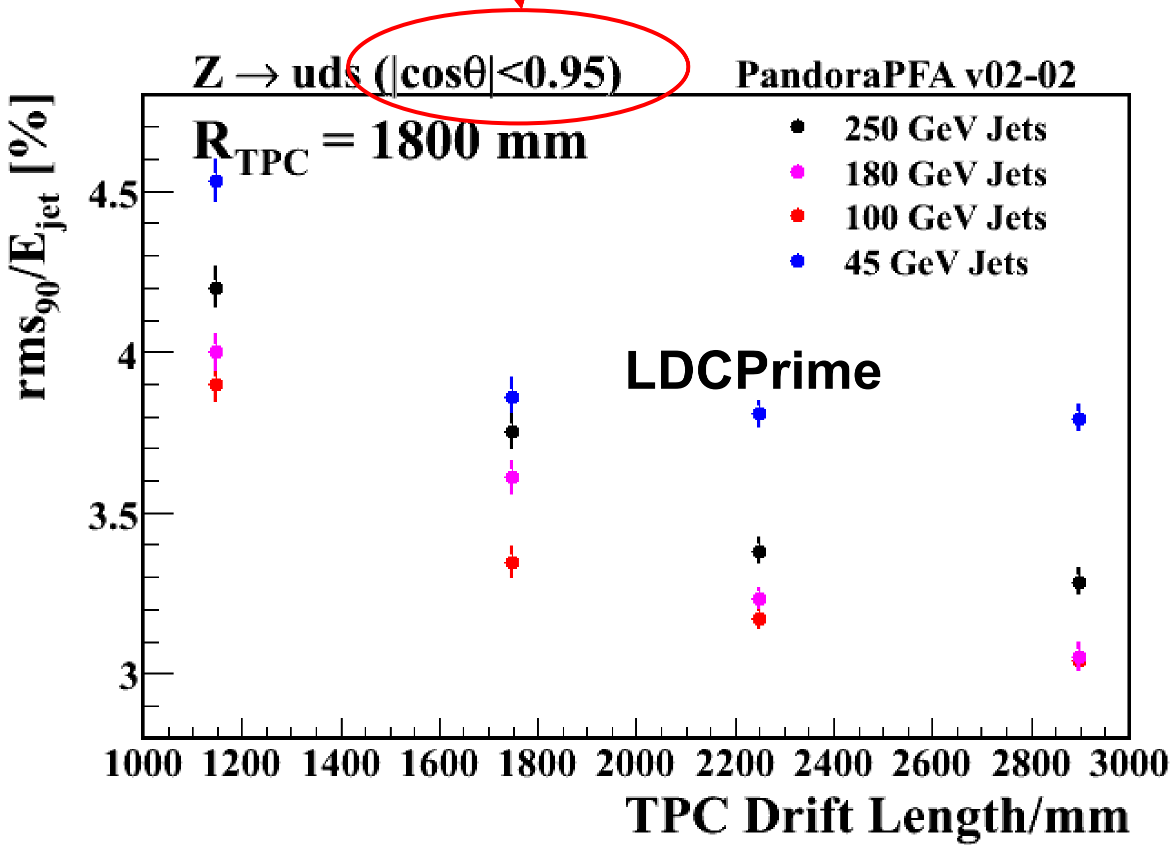
★ For reasonable values – little variation in PFlow perf.

★ But also need to consider full acceptance

TPC Aspect Ratio cont.

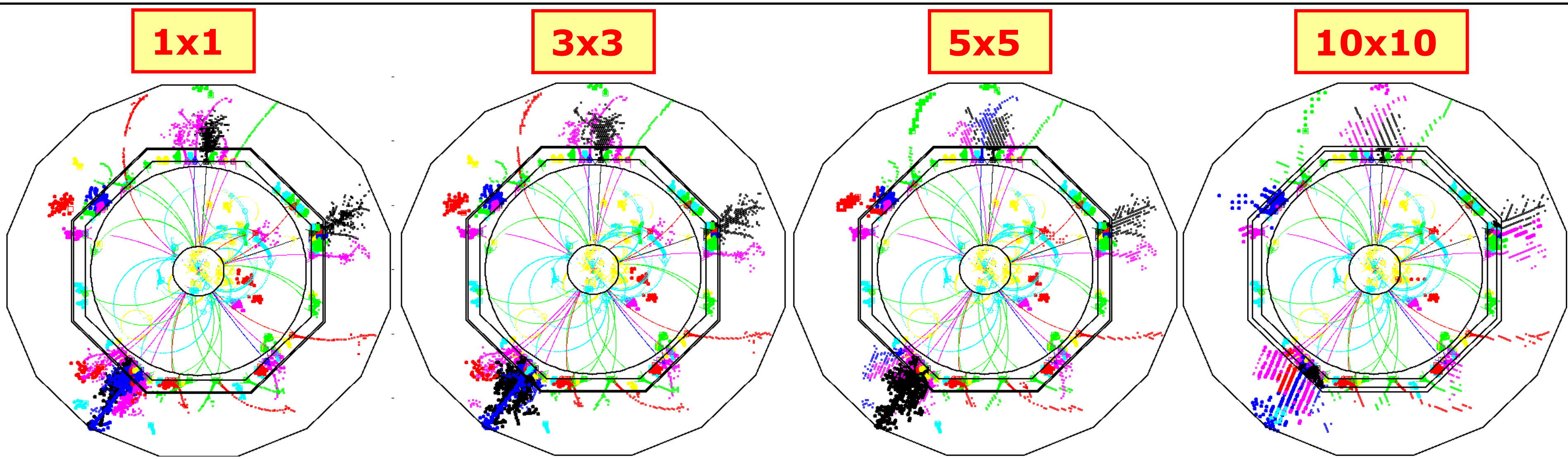


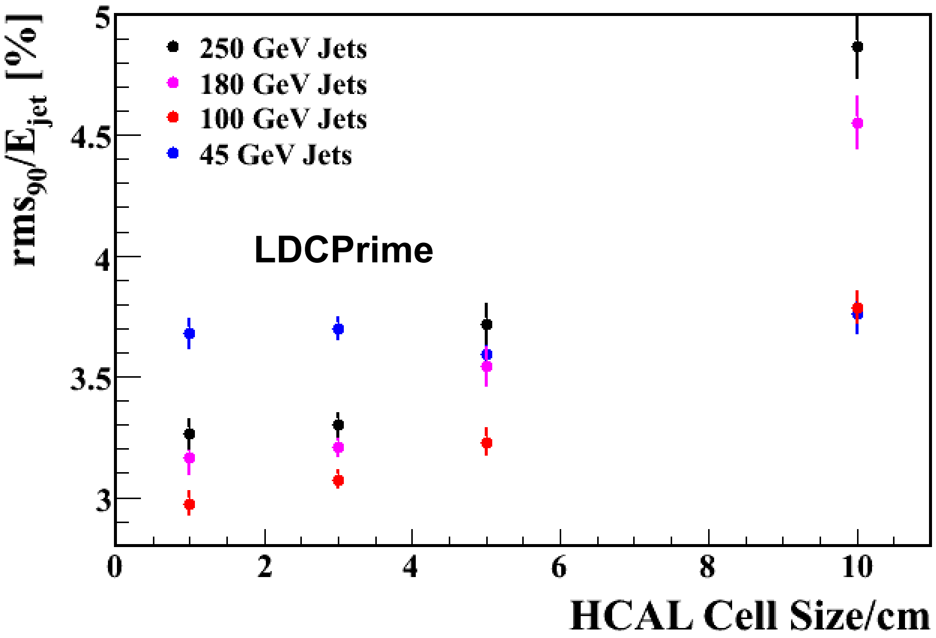
★ Next: look at "full acceptance" performance



★ Little advantage in making TPC longer
★ Significant disadvantage in making it shorter

Optimisation: ④HCAL Segmentation





★ For now scintillator HCAL

★ Start from LDCPrime with 3×3 cm^2 tiles

★ 1×1cm^2, 5×5cm^2 and 10×10cm^2

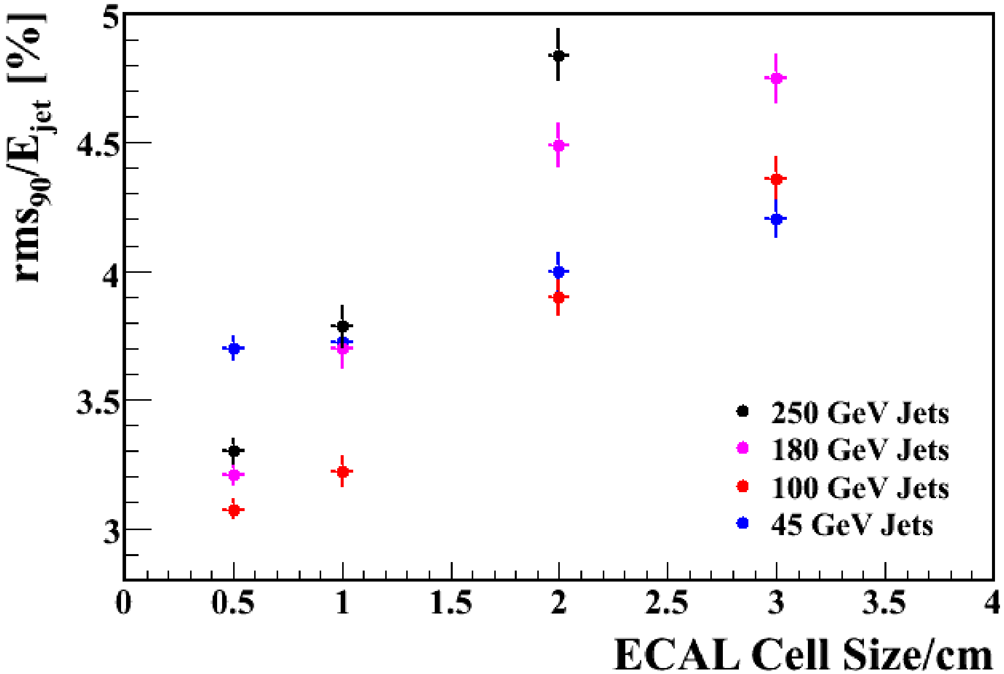
- 3×3cm^2 looks reasonable
- Hint of gain going to 1×1cm^2
- Significant degradation for larger tile sizes, e.g. 5×5cm^2

Optimisation: ⑤ ECAL Segmentation

★ Start from LDCPrime with 5×5 mm² SiW ECAL pixel size

★ Investigate 10×10mm², 20×20mm² and 30×30mm²

- Note: required changes in PandoraPFA clustering parameters



★ Performance is a strong function of pixel size

★ Probably rules out segmentation of >10×10mm² !!!!

Is latest version of PandoraPFA optimal for larger pixels ?

- no obvious problems seen yet…

★ What changes when going from 5×5 mm^2 to 10×10mm^2 ?

- Use "perfect" reco algorithms

	σ_E/E	
	5x5 mm^2	10x10 mm^2
PandoraPFA	3.2 %	3.72 %
+CheatedTracks	3.1 %	3.55 %
+CheatedPhotons	2.7 %	3.06 %
+CheatedNeutralHs	2.1 %	2.39 %
+PerfectFragRem	2.1 %	2.29 %
PerfectPFA	1.7 %	2.07 %

180 GeV Jets	σ_E/E	
	5x5 mm^2	10x10 mm^2
Resolution	1.5 %	1.5 %
Leakage	0.8 %	0.8 %
FullTracking	1.0 %	1.1 %
"missed" photons	1.4 %	1.8 %
"missed neutrals"	1.7 %	1.9 %
Charged fragments	0.4 %	0.7 %
Other	1.7 %	2.1 %

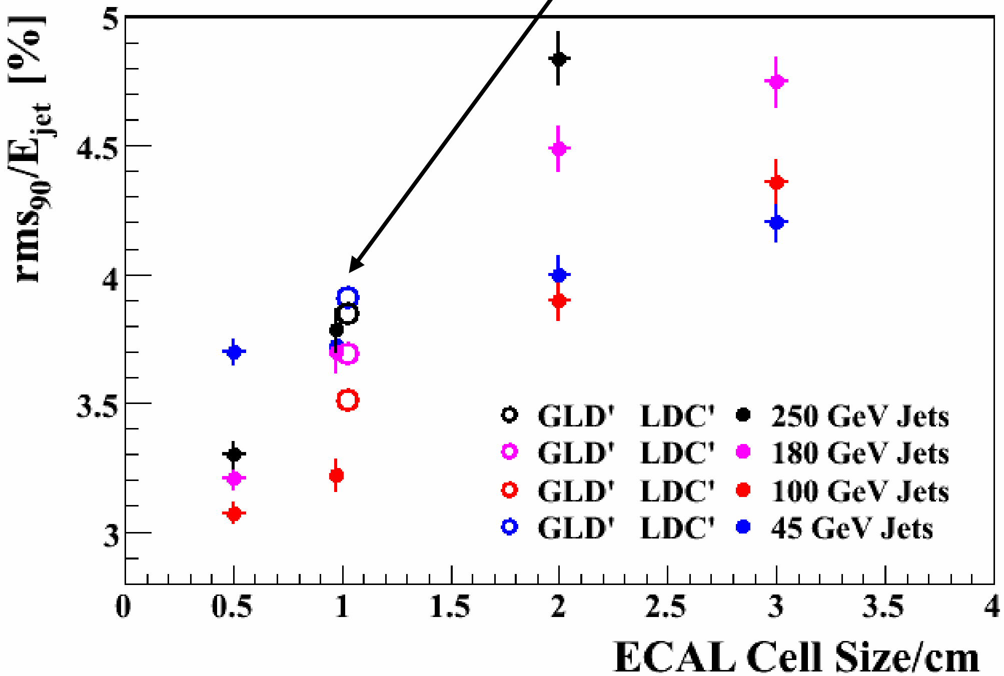
★ Confusion (particularly in photon reconstruction) increases

★ Looks reasonable, but needs checking

Optimisation: ⑥ LDCPrime vs GLDPrime

★ ECAL segmentation dependence probably explains main differences between GLDPrime and LDCPrime PFA performance

★ GLD simulation "assumes" 10×10mm² ECAL scint. tiles



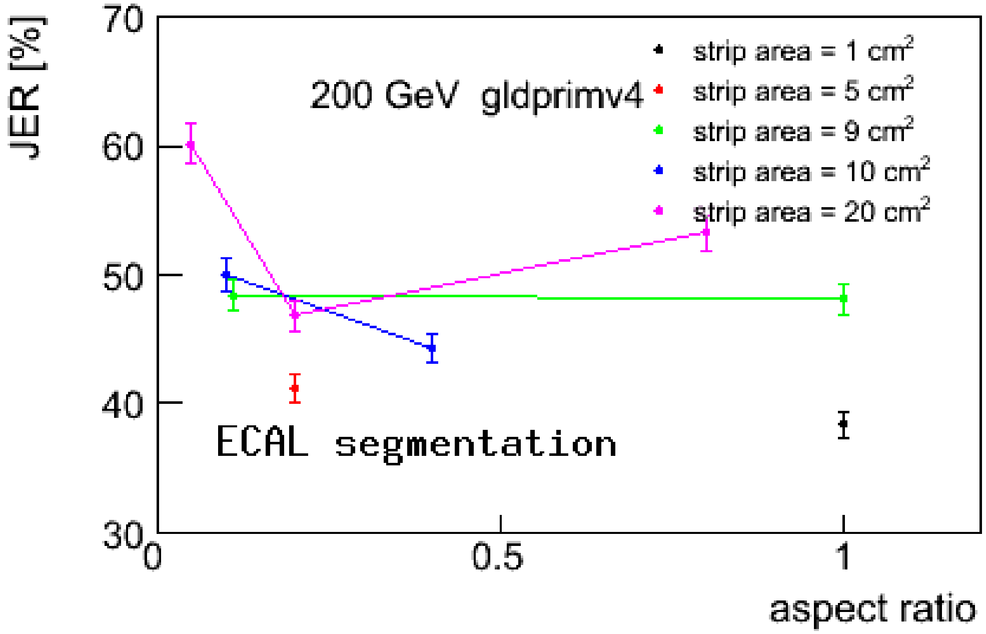
★ For 180 GeV and 250 GeV jets obtain essentially same performance with LDCPrime and GLDPrime for 10×10mm² segmentation

★ Small residual differences due to tracking (optimised for LDC) ?

★ Appears that **5×5 mm²** is one reason why GLDPrime PFlow performance is somewhat worse than LDCPrime

★ Although Jupiter GLDPrime simulation uses **10×10 mm²** scintillator tiles rather than strips

★ Studied by D. Jeans, using strip clustering e.g.



★ Impressive results – crossed strips of **1x5 cm²** approach **1x1cm²** perf.

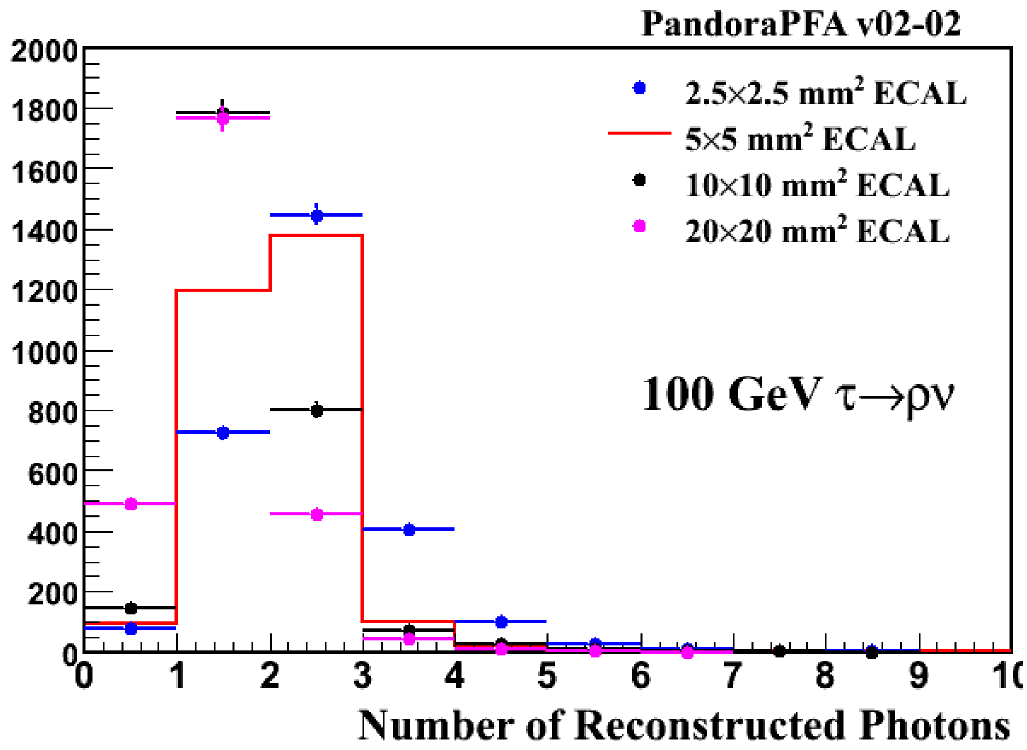
★ What about higher energy jets when confusion more important ?

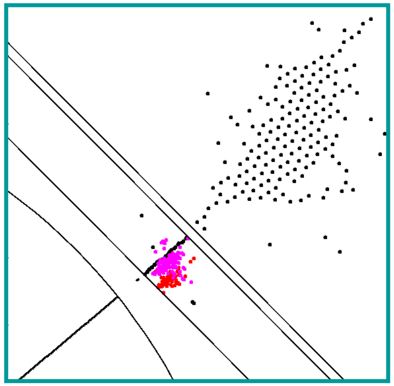
Opinion : strip concept not yet proven

❹ ECAL Segmentation and taus

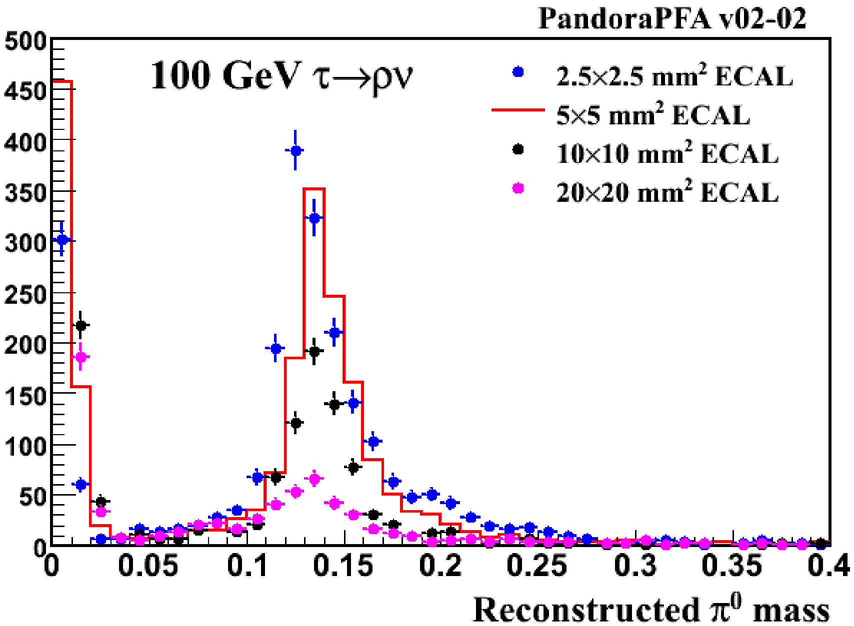
- ★ Tau reconstruction studies for LDCPrime, GLD, GLDPrime, and J4LDC will be presented by Taikan tomorrow
- ★ Here, vary ECAL segmentation and look at $\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^+ \pi^0 \nu_\tau$
- ★ Generate single **100 GeV and 250 GeV** taus
- ★ Look at reconstucted PFOs

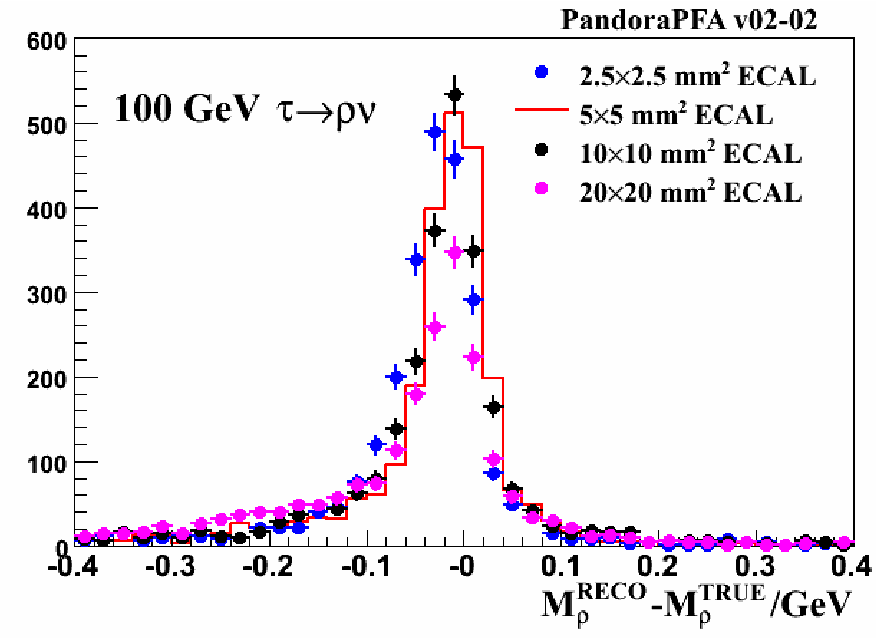
  e.g. Number of photons (E > 1GeV)





★ **Mass distributions:** $\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^+ \pi^0 \nu_\tau$





- ★ Studies preliminary
- ★ But clear advantages in smaller segmentation
- ★ See Taikan's talk for physics oriented discussion

❺ Conclusions

★ **Over to you….**