Jet Flavour Tagging for TeV Jets

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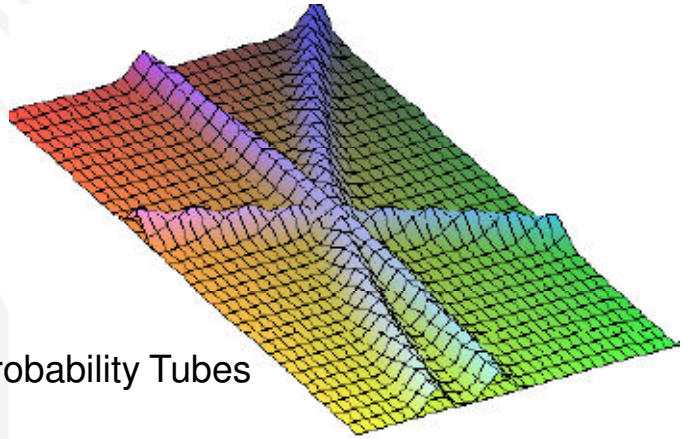
Overview

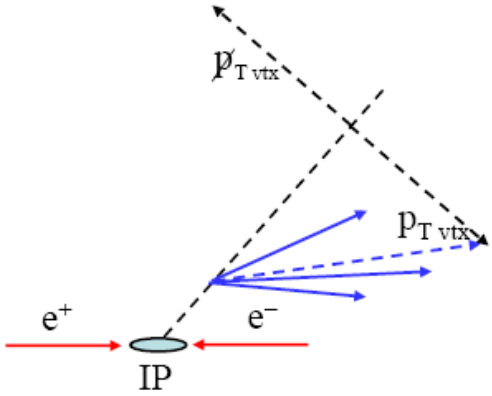
- LCFI Package
- Monte Carlo Samples
- Jet Tag Performance and Comparisons
- Neural Net Inputs and Optimisation
- Current and Future Work
- Summary

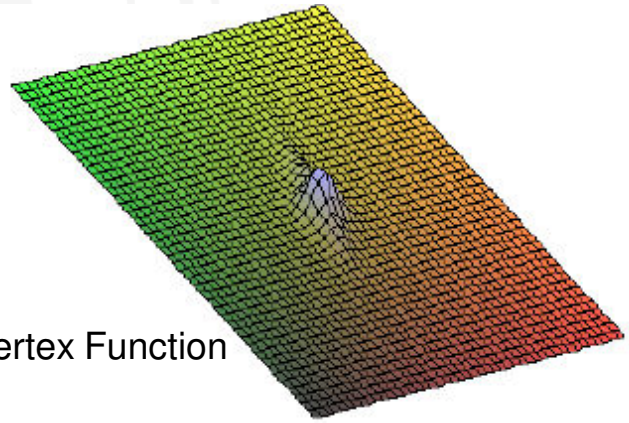
LCFI Package

- Used for jet flavour tagging and secondary vertex reconstruction.
- Topological vertex finder ZVRES.
- Standard LCIO input/output
  - Marlin environment (used for both ILD/SiD)
- Flavour tagging based on Neural Nets.
  - Combine several variables (more details later)



Probability Tubes

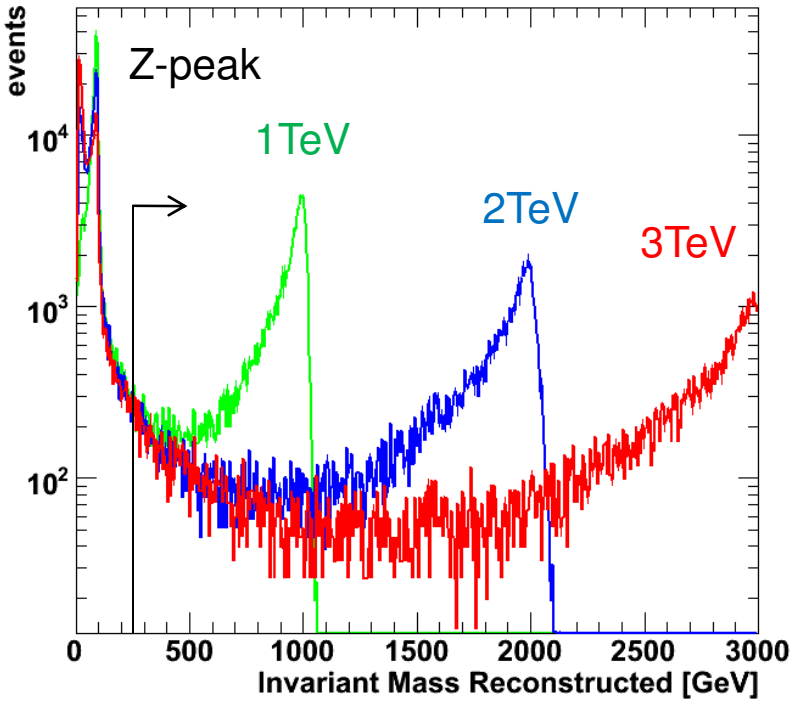




Vertex Function

Monte Carlo Samples I

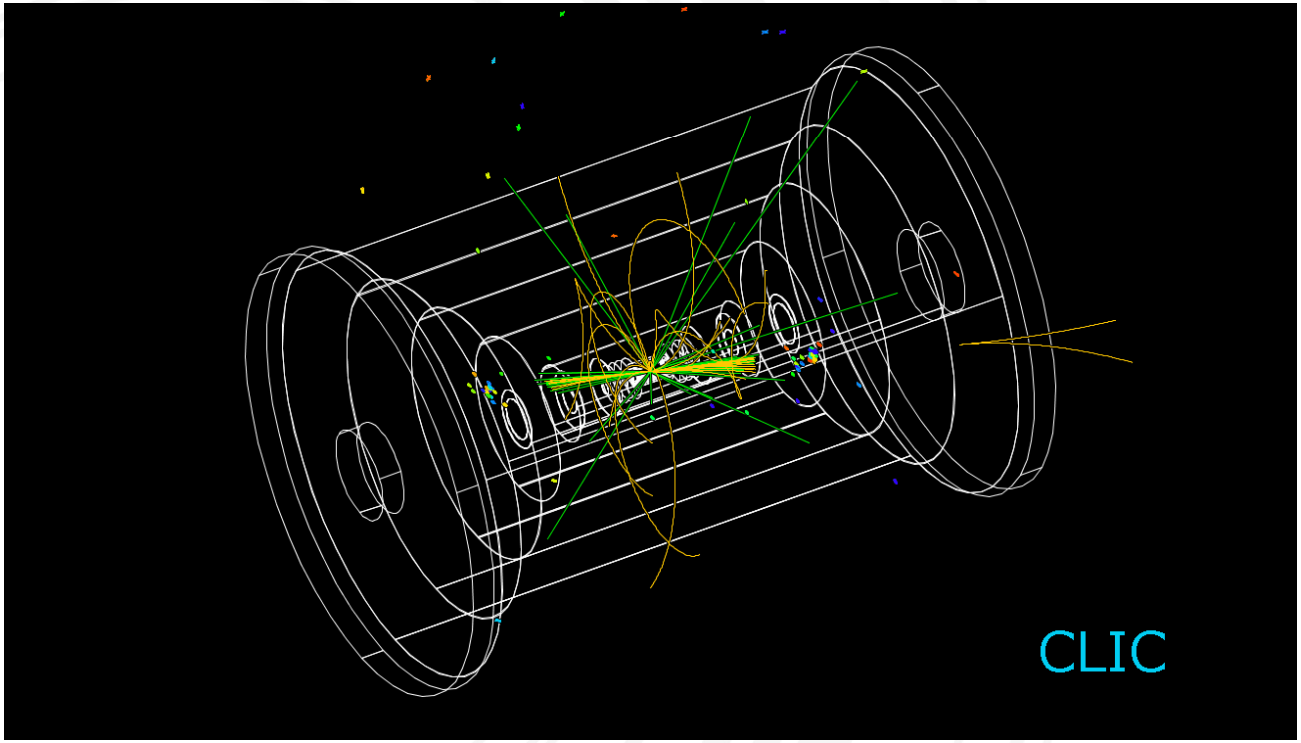
- Generated with CalcHEP 2.5.j
  - 500GeV, 1TeV, 2TeV, 3TeV center of mass energy
  - di-jets (e^+e^- → qqbar) with ISR, no beamstrahlung
- Decayed and fragmented with Pythia 6.4.10
- 50k events for b,c and {u,d,s}
  - event weights are accounted for
- s-channel events frequently intensively "boosted" along z-axis due to high energy ISR
  - radiative return to the Z-peak
  - ~80% of s-channel b-events
  - cut on invariant mass (>250GeV)



Monte Carlo Samples II

- Events passed to FastMC using both SiD **(sid02)** and CLIC **(clic01_sid)** geometries.
- LCFI package run locally in Oxford (2x4x3x50k = 1.2M events in about 2 days)

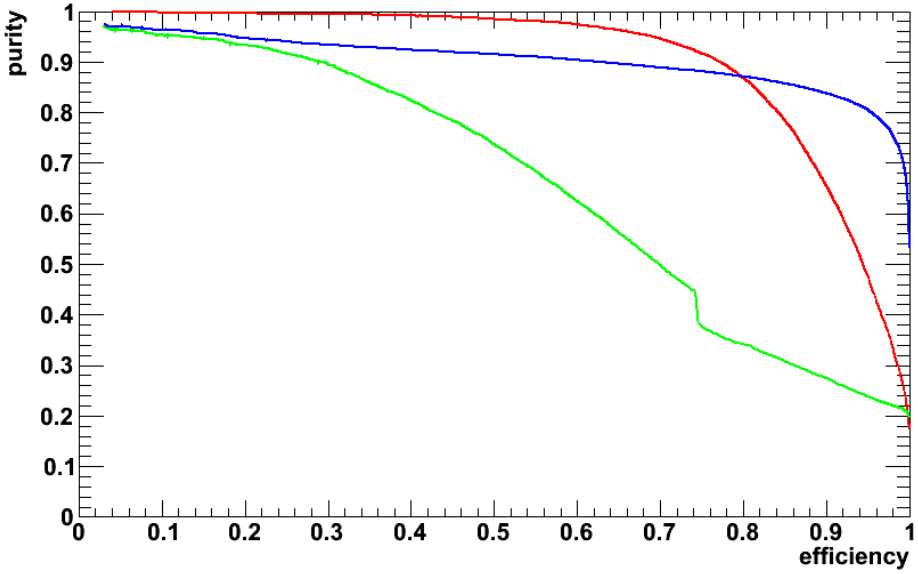
3TeV
bB-event
vtx+tracker



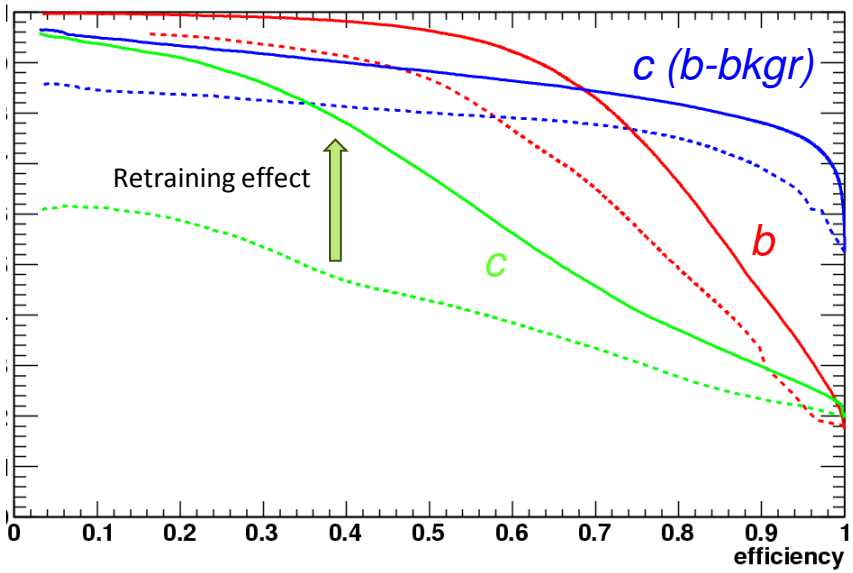
500GeV SiD

- A comparison to the previous (LoI) SiD result which was done with full digitisation/simulation, PFA and beamstrahlung effects.
  - Neural Nets need to be retrained (see dashed (default NNs) vs full line)
  - b-tag slightly better while c-tag is slightly worse, generally reasonable agreement.

Fast MC, no beamstrahlung

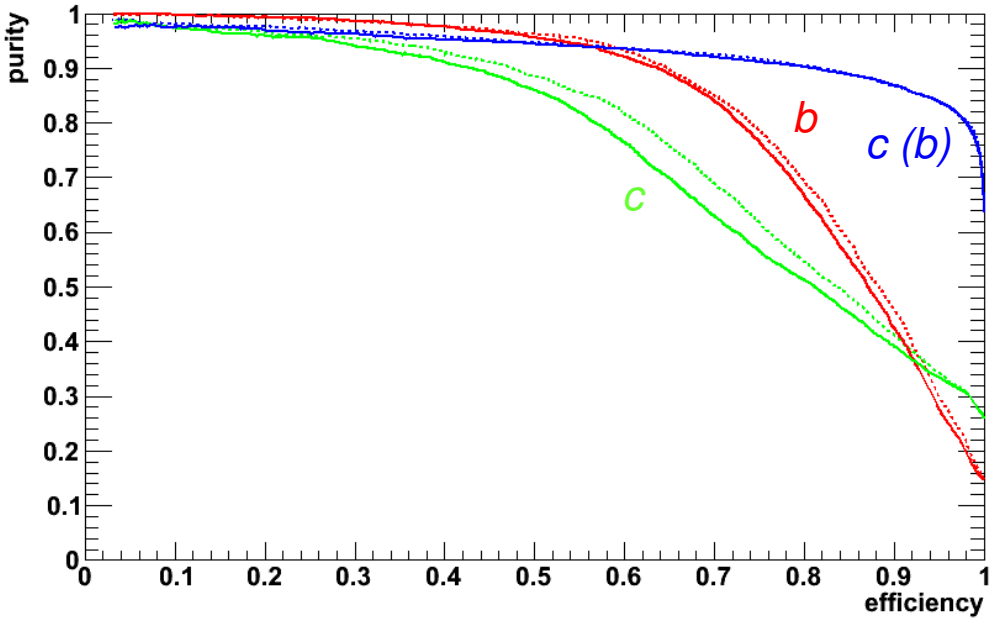


SiD LoI, full sim/dig/rec



3TeV SiD vs. CLIC Geometry

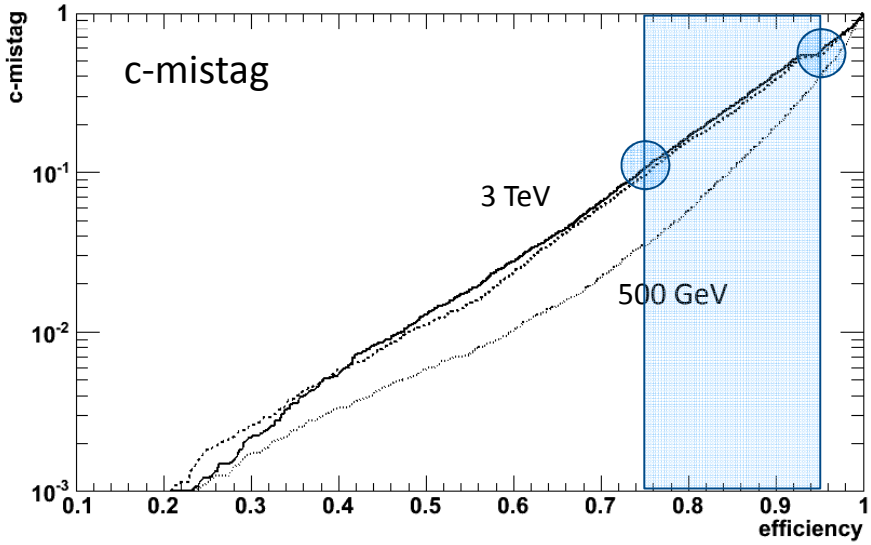
- Purity vs. efficiency is perhaps not the best plot to look at, it involves cross sections and various acceptance effects.
- Comparison of SiD and CLIC geometry at 3 TeV (Z-peak removed)
  - SiD geometry slightly over-performs CLIC geometry due to better resolution (especially where light quarks are involved) – keep in mind that this is FastMC
  - At 3TeV more b-quarks decay after 15mm (1st SiD vtx layer) – needs full sim/rec to study.

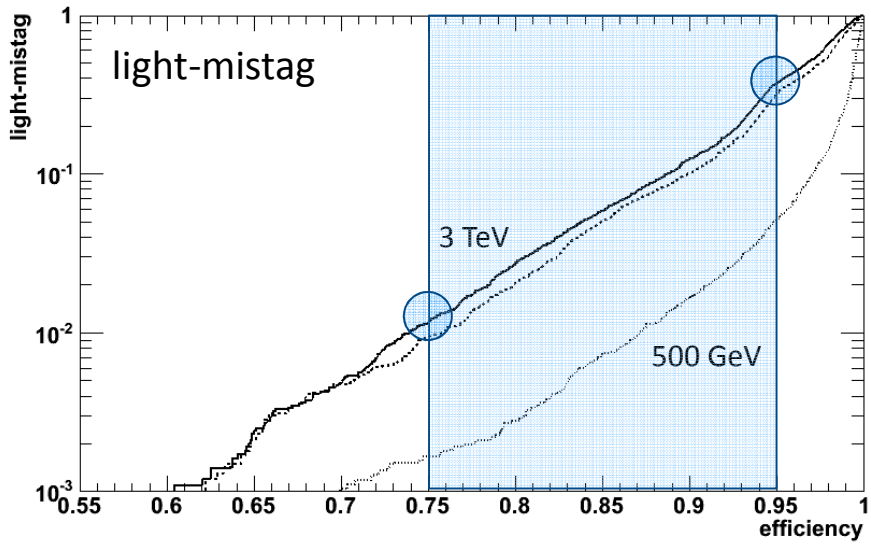


CLIC (full)
SiD (dashed)

Mistag Efficiency vs. B-tag Efficiency I

- Mistag efficiency vs. tag efficiency are less affected by cross sections/acceptance effects.
- B-tag NN example
  - This net was trained to separate b jets from both light and c-jets, not against c-jets only

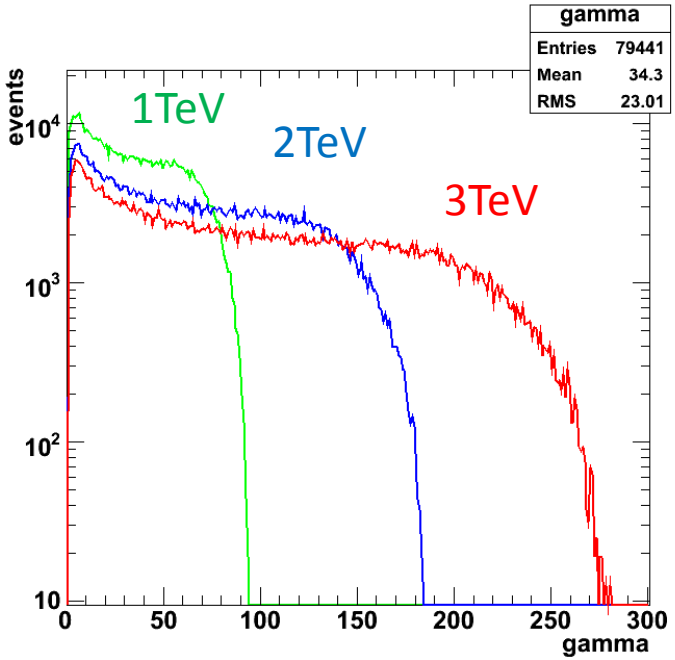


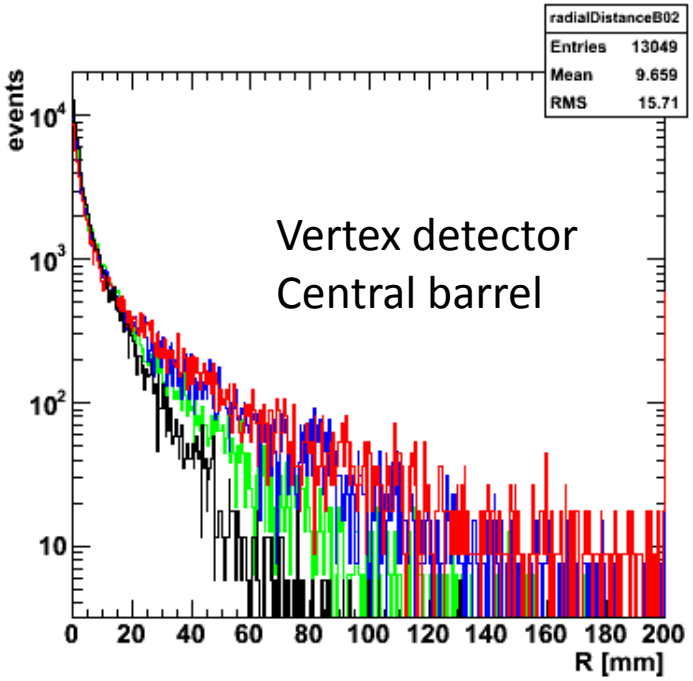


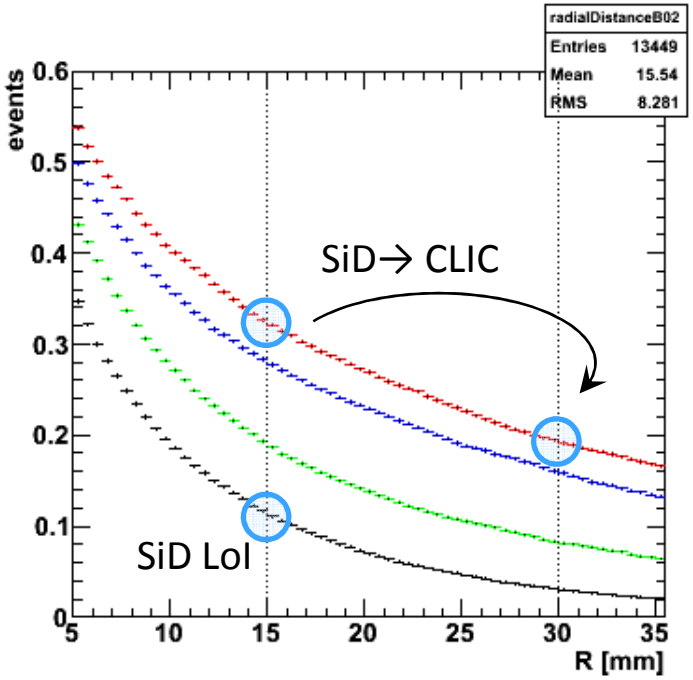
B-Tag efficiency region discussed yesterday by Marco for H^0A^0
Mistag rate runs from 10% (1%) to huge 60% (40%) for c (light) jets !

Decay Vertices of B-mesons

- B-mesons are significantly more boosted at 3TeV.
  - And decay further from the interaction point.
  - In the central region, about 33% of B0s decay after 15mm (1st SiD layer) and 20% after 30mm @ 3TeV.

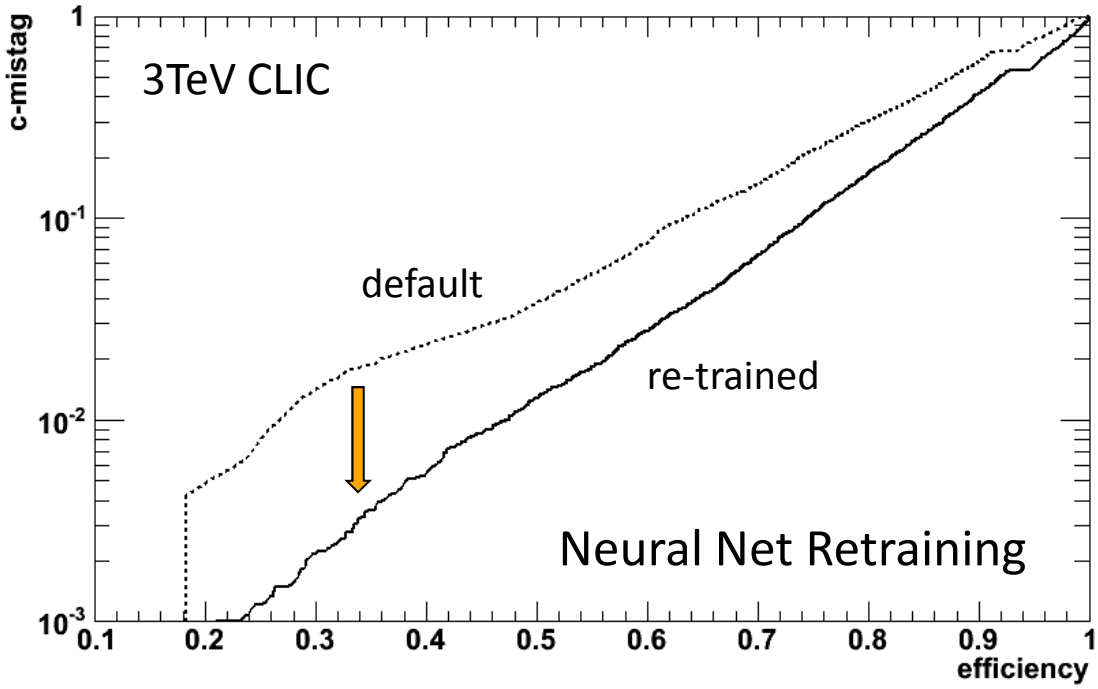






LCFI Package Optimisation I

- LCFI package optimisation for 3TeV case is important
  - Neural Net re-training absolutely essential
  - Package parameters to be tuned and (very likely) new ideas needed
  - Forward regions to be studied more carefully



LCFI Package Optimisation II

- Optimisation is not only a matter of Neural Net retraining. The package has plenty of parameters:
  - Track selection params
  - ZVRES params
  - Flavour Tag params
  - Vertex Charge params

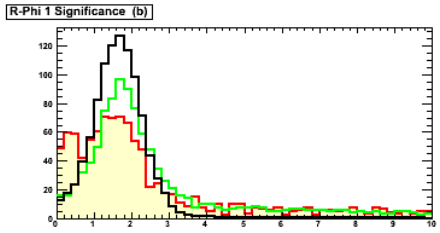
ZVRES		*flavour tag*		*vertex charge*	
parameter	value	parameter	value	parameter	value
w_{IP}	1	N_L	5	$T_{\mathrm{qb,max}}$ (mm)	1
k	0.125	$p_{\mathrm{trk,NL,min}}$ (GeV)	1	$(L/D)_{\mathrm{qb,max}}$	2.5
R_0	0.6	$p_{\mathrm{trk,NL-1,min}}$(GeV)	2	$(L/D)_{\mathrm{qb,min}}$	0.18
χ^2_{TRIM}	10	$N_{\mathrm{trks,min}}$	1	$T_{\mathrm{qc,max}}$ (mm)	1
χ^2_0	10	$\chi^2_{\mathrm{norm,max}}$	20	$(L/D)_{\mathrm{qc,max}}$	2.5
		T_{max} (mm)	1	$(L/D)_{\mathrm{qc,min}}$	0.5
		$(L/D)_{\mathrm{max}}$	2.5		
		$(L/D)_{\mathrm{min}}$	0.18		
		$N_{\sigma,\mathrm{max}}$	2		
		$w_{\mathrm{PT,max}}$	3		
		$w_{\mathrm{corr,max}}$	2		
		$(b/\sigma_b)_{\mathrm{cut}}$	200		

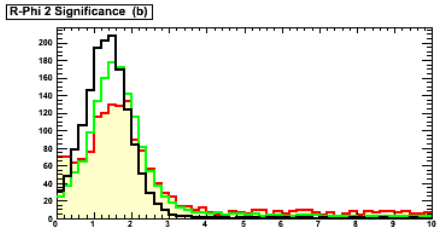
Track Selection Parameters				
Parameter	$\gtrless$	*IP Fit*	*Vertexing*	*Flavour Tagging*
χ^2/ ndf of track fit	$<$	5	4	-
$R-\phi$ impact parameter d_0 (mm)	$<$	20	2	20
z impact parameter z_0 (mm)	$<$	20	5	20
d_0 uncertainty (mm)	$<$	-	0.007	-
z_0 uncertainty (mm)	$<$	-	0.025	-
track p_T (GeV)	$>$	0.1	0.2	0.1

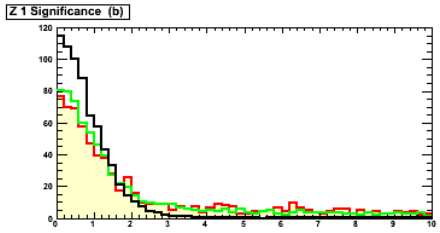
Neural Net Inputs

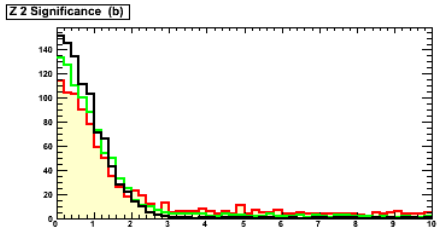
- LCFI package classifies jets in one of three Neural Nets based on #vtx
  - **1 vertex** (only IP vertex), 8 Inputs
    - R-Phi and Z significance of 2 leading tracks and their momenta
    - Joint R-Phi and Z Probability
  - **2 vertices**
    - Decay Length and its significance
    - Pt mass correction
    - Raw momentum
    - Number of tracks in vertices
    - Secondary vtx probability
    - Joint R-Phi and Z Probability
  - **3+ vertices**, NN Inputs just as for the 2 vertices but separate NN.

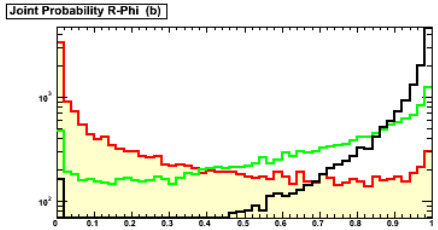
Neural Net Inputs 3TeV – CLIC Geometry

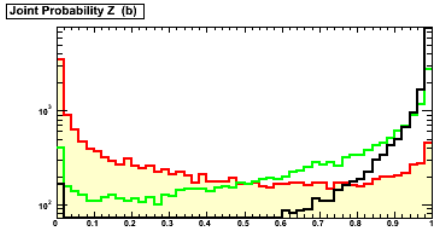


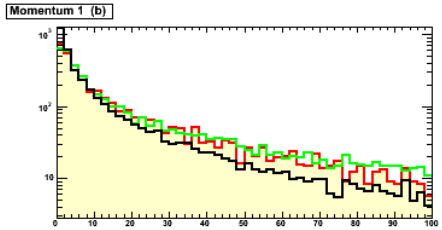


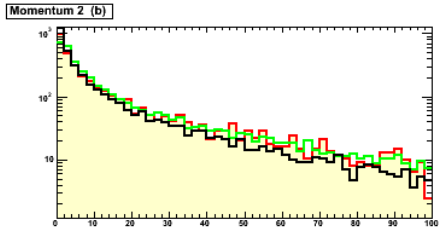


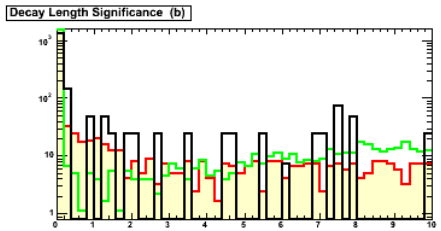


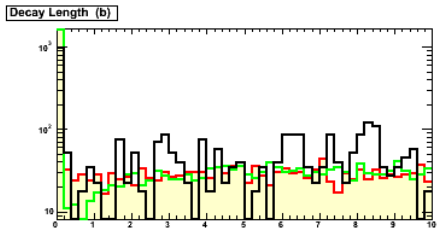


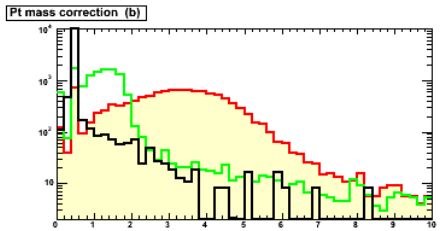


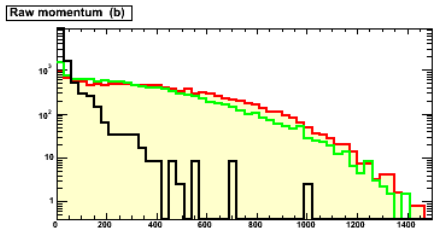


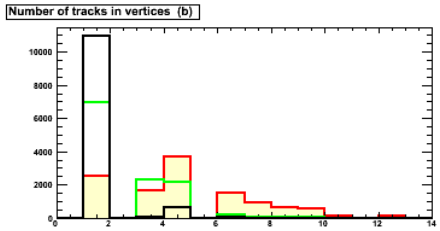


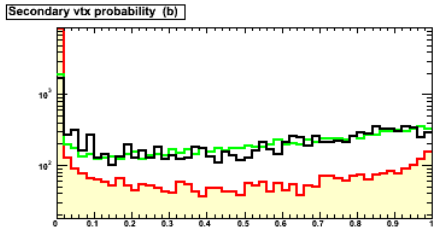


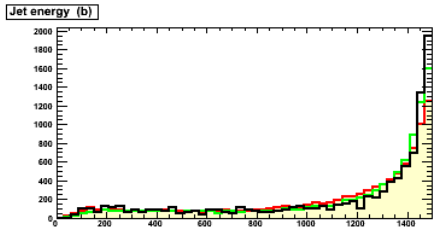


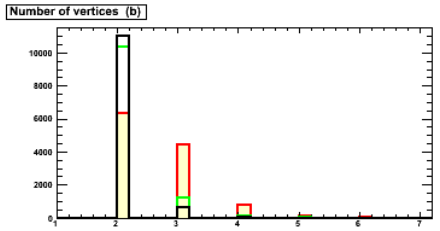




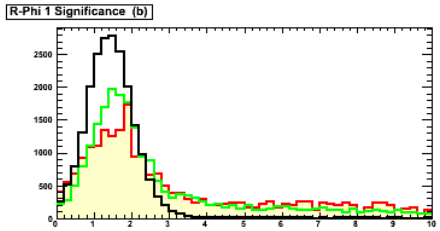


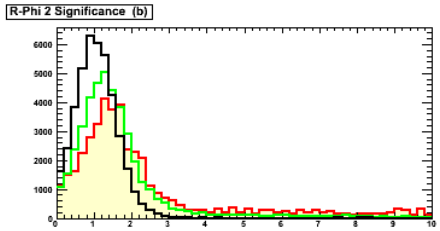


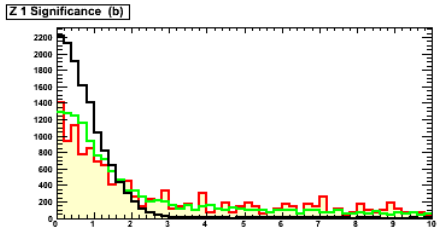


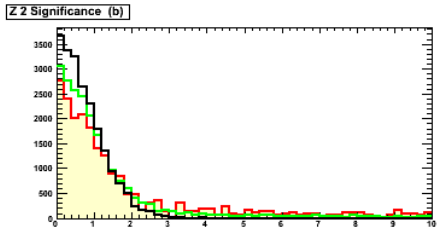


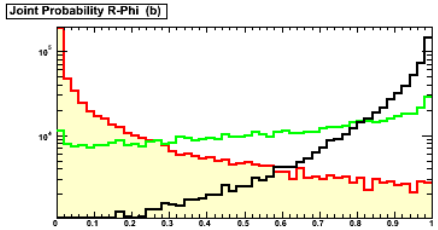
Neural Net Inputs 500GeV - SiD

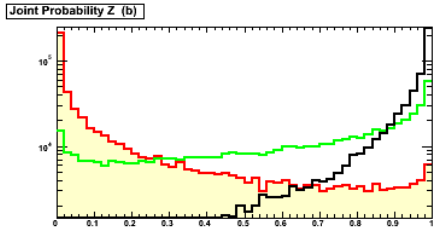


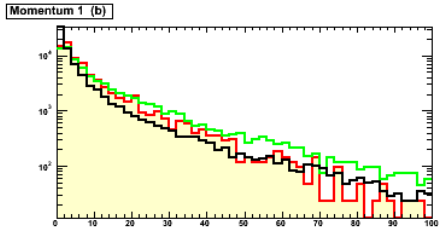


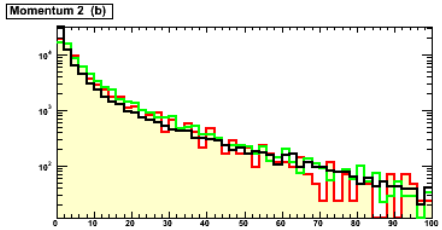


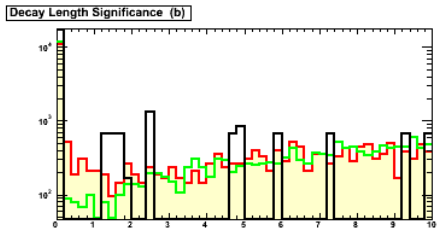


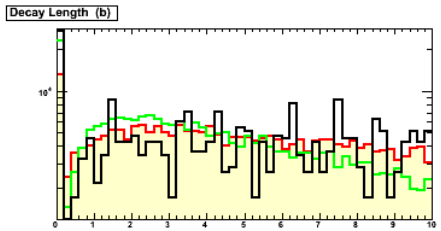


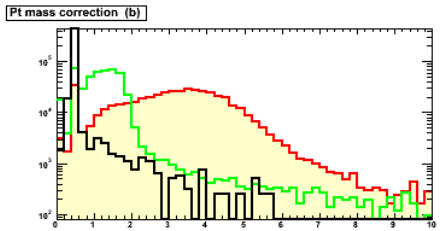


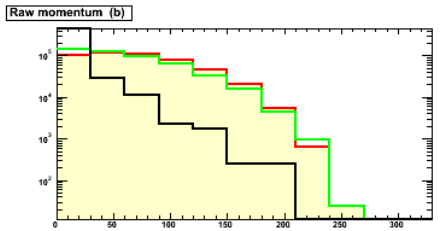


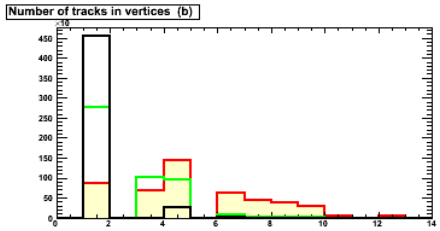


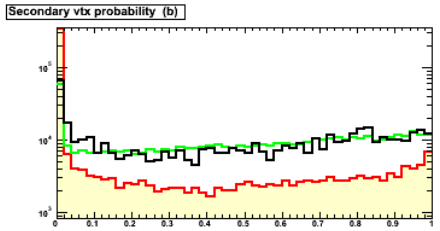


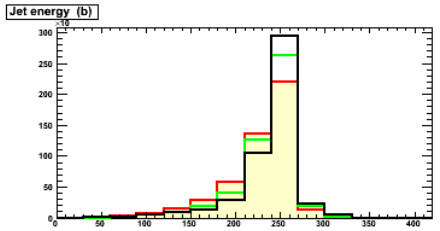


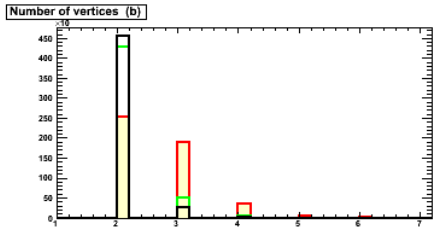






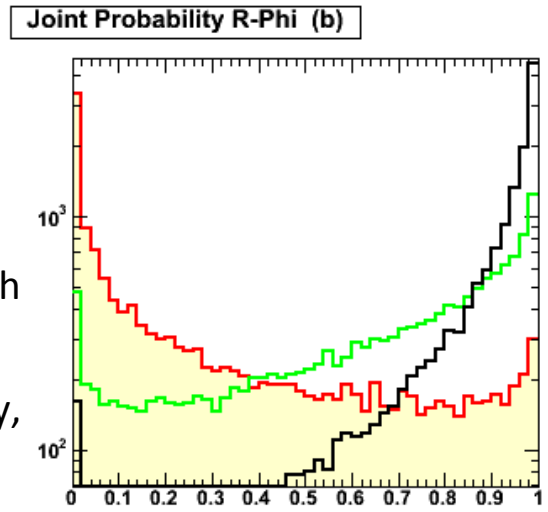


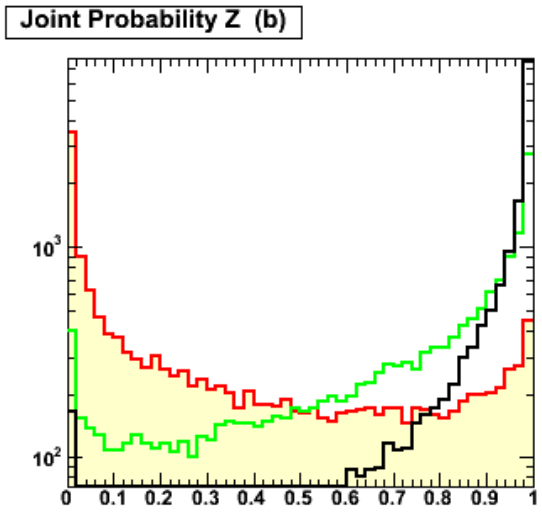


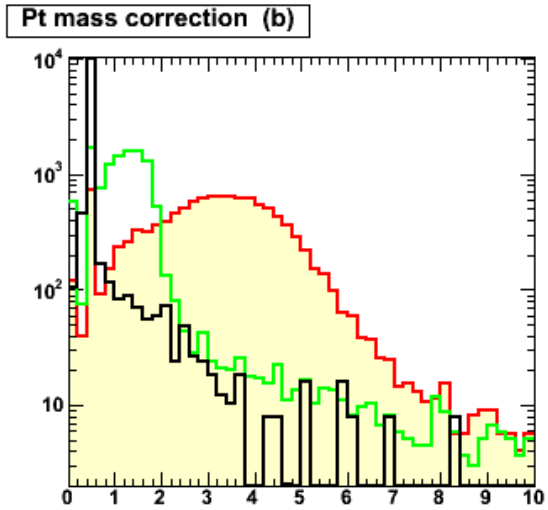


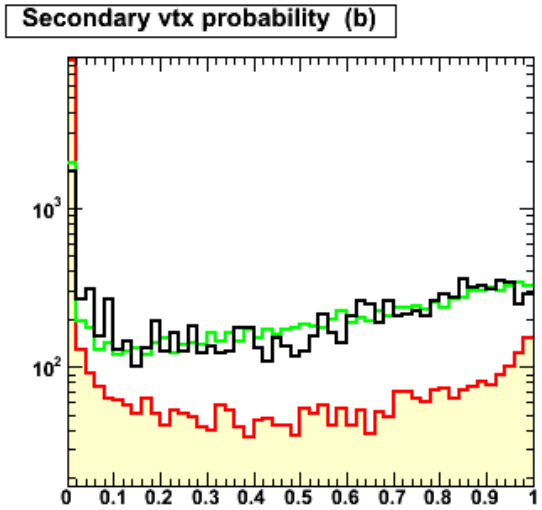
Selected Neural Net Inputs

- Most relevant NN inputs are
  - joint probabilities in both R-Phi and Z coordinates
  - Pt mass corrections for cases with secondary vertices.
  - Also secondary vertex probability, raw vertex momentum etc.









Current Work

- Neural Net training automatised
  - FANN package used instead of default LCFI NN package
    - Much faster and better training algorithms.
    - No need for GRID, can be quickly run on a laptop.
  - Options to go for 3x3 neural nets (LCFI default)
  - Or simply 3 nets, 1 per tag (SiD LoI preffered)
- XML writer written for FANN
  - To write out NNs in LCFI NN xml format
  - Not tested yet.
- FANN setup can be used for physics analyses (and it was for SiD LoI).

Future Work

- LCFI Package Optimisation
  - First draft version of parameter+nets based on FastMC
  - Full Sim/Rec studies required
- Forward tagging
  - “Neglected” for 500GeV ILC where tagging based on central events.
  - Important for 3TeV physics.
- Physics
  - Test the tagging performance with all backgrounds, PFA, …
  - Examples: H^0A^0, $\nu\nu H$, $\nu\nu H^0H^0$, Higgs branching ratios, bB, tT, …
    - Don’t forget about c-tagging: for 120GeV SM Higgs BR is ~3% vs ~70% for bB
  - Essential for tagging evaluation!

Summary

We have analysed FastMC so far: experience from LoI tells us that the full simulation and reconstruction is essential as well as full inclusion of beam backgrounds.

At this stage, 3TeV CLIC b- and c- tagging requires future work, LCFI package can't be used in its 500GeV version.

The package must be optimised for 3TeV CLIC and its neural nets retrained.

Physics analyses will provide a real benchmark of the tagging performance in a more realistic environment.

Challenge