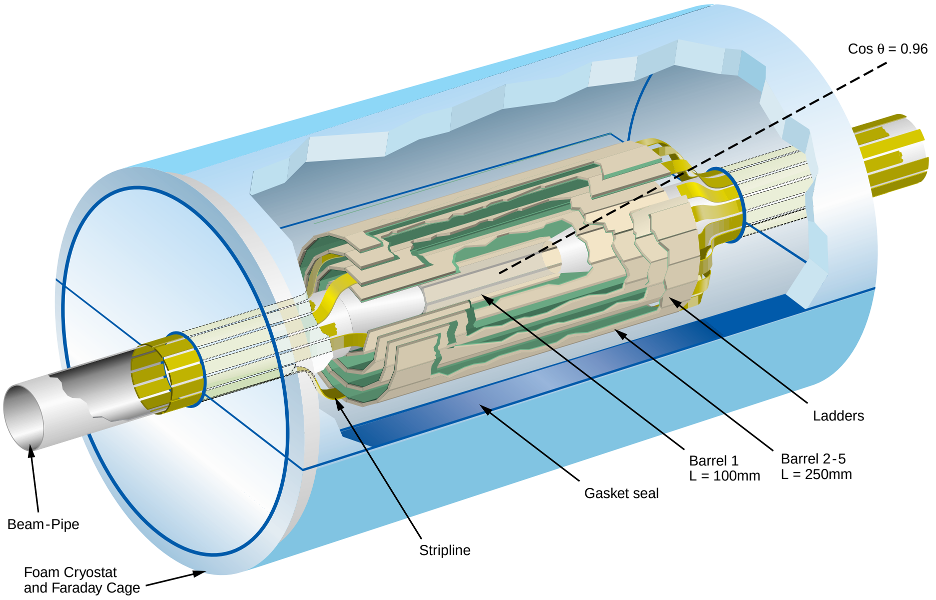
High performance vertex detector for the future linear collider



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http://hep.ph.liv.ac.uk/~green/lcfi/home.html

PPESP meeting – 26 March 2001
Rutherford Appleton Laboratory

Next Linear Collider

The next LC will be operating at an energy of 500 GeV and more (up to ~1 TeV).

It will perform high precision measurements of Standard Model and Beyond SM processes (investigated in parallel by hadronic machines).

It will be a next generation machine/experiment, after the LEP and SLD machines.

Very complicated topologies in observable events:

* e+e- → tt 6 jets, 2 b-flavoured and
2 c-flavoured

* e+e- → AH 12 jets, 4 b-flavoured

→ highly efficient and pure jet flavour tagging is a crucial required performance for a detector operating in these conditions

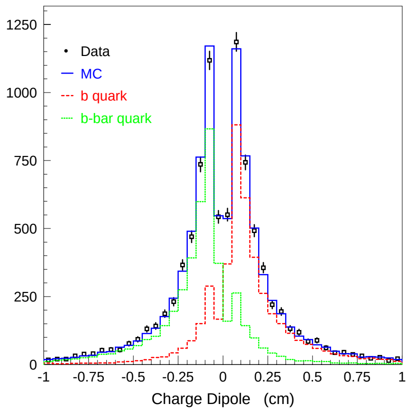
What did previous experiments teach us about flavour tagging ?

SLD : Vertex informations are essential to reach high efficiency and purity in jet flavour tagging. Pixel detectors provide us with unexpected powers.

Vertex mass Method :

	b	c
Eff.	60%	20%
Purity	98%	85%

Vertex charge method



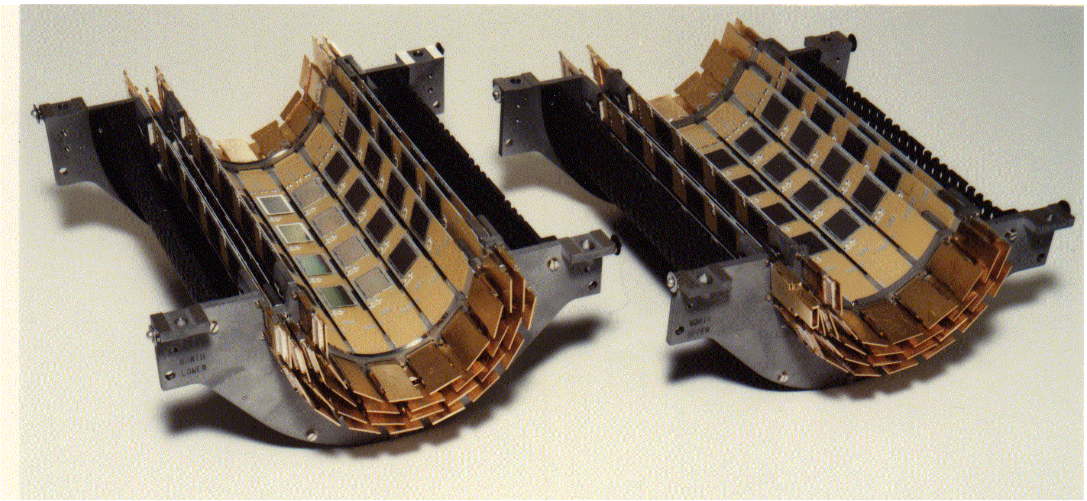
b/c separation

B+/B0 separat. (D+/D0 ?)

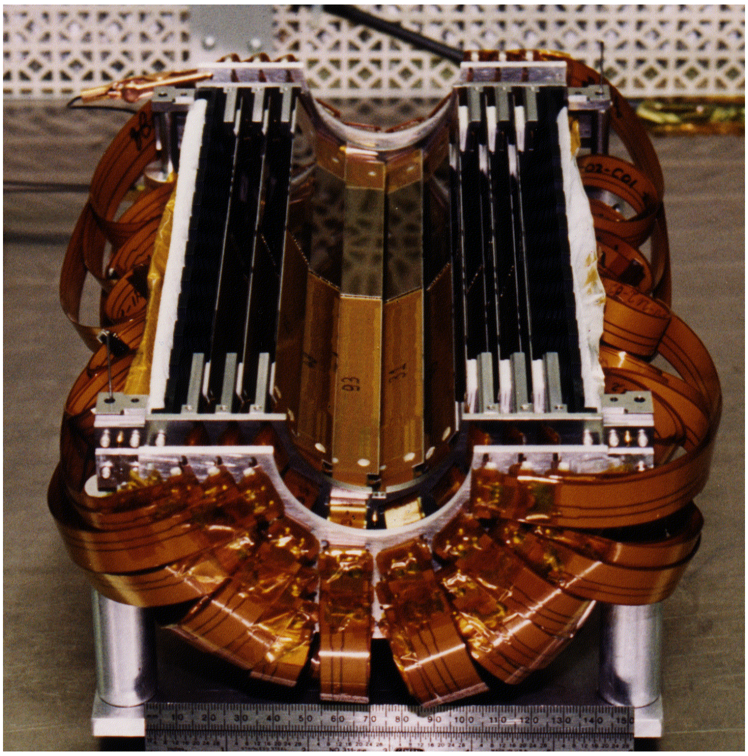
Charge dipole method (B0/B0bar)

SLD Charged Coupled Device (CCD) silicon vertex detector is the vertex detector giving the highest performance in e+e- machines.

SLD VXD2 (1992)

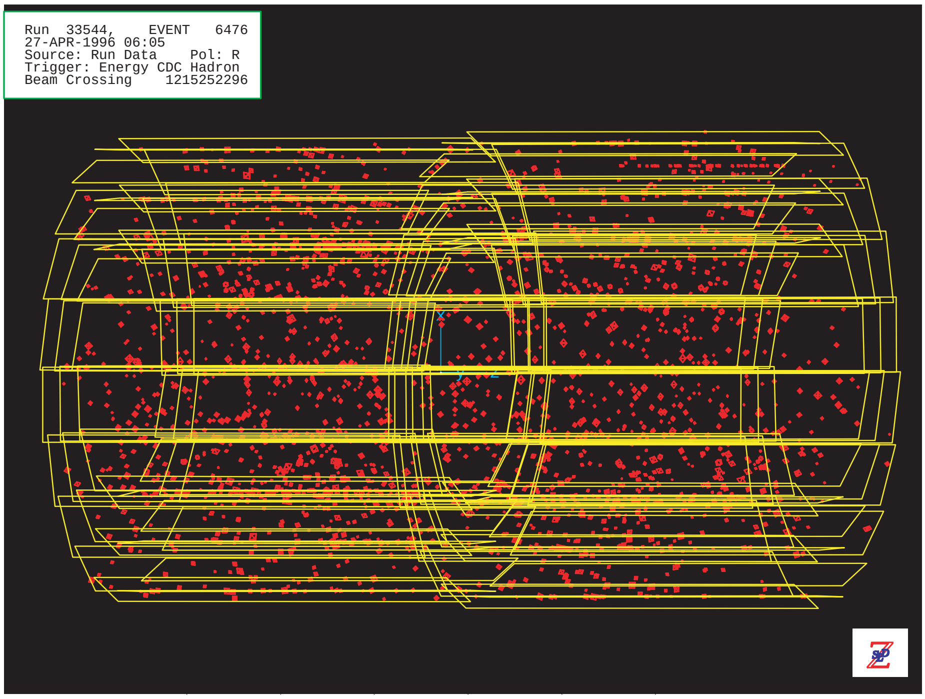


SLD VXD3 (1996)



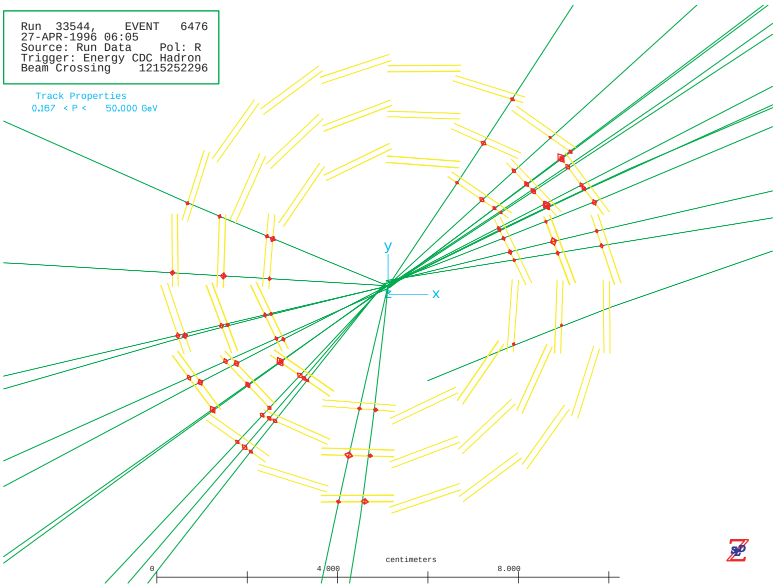
The CCDs for VXD2 and the upgrade VXD3 were produced at Marconi (Chelmsford) and assembled by RAL in collaboration with partner institutes.

Raw b-$\bar{b}$ event in SLD VXD3



Run 33544, EVENT 6476
27-APR-1996 06:05
Source: Run Data Pol: R
Trigger: Energy CDC Hadron
Beam Crossing 1215252296

Reconstructed b-$\bar{b}$ event in SLD VXD3



Run 33544, EVENT 6476
27-APR-1996 06:05
Source: Run Data Pol: R
Trigger: Energy CDC Hadron
Beam Crossing 1215252296

Requirements in new LC environment

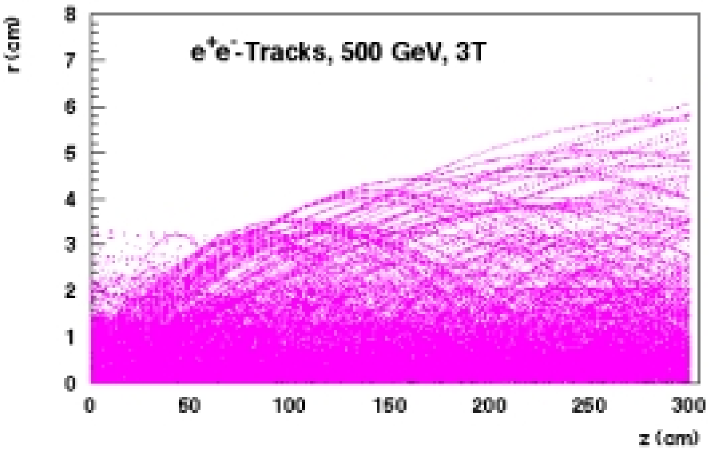
Most natural step: use RAL experience with CCDs to lead LC experiments into a new era of high precision measurements.

But : next LC: higher energy and luminosity, i.e. richer event topologies and backgrounds

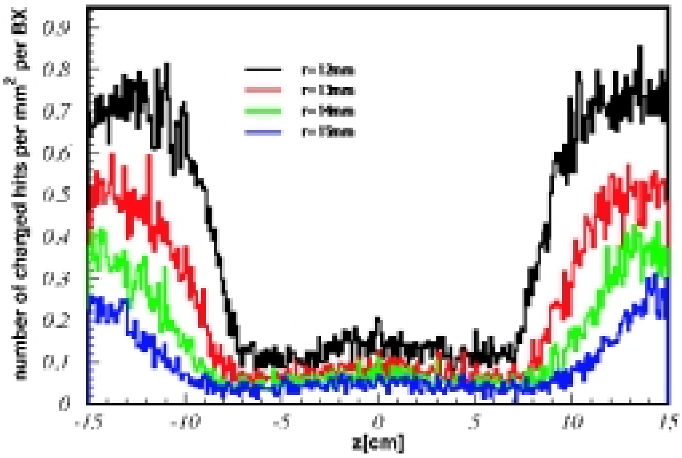
=> upgrade of the SLD idea needed.

- Small pixels (20 x 20 um), thinner detector (0.4% X0 => 0.06% X0 per layer, hence less multiple scattering) and closer to IP (hence smaller extrapolation distances) to achieve higher track parameters resolution
- More point measurements (3 => 5 layers), to allow more robust local and global alignment and to suppress more effectively gamma conversions
- Faster readout (216 ms => 8 ms NLC, 50 μs), to sustain higher integrated background due to higher luminosity requirements

Backgrounds at the next LC

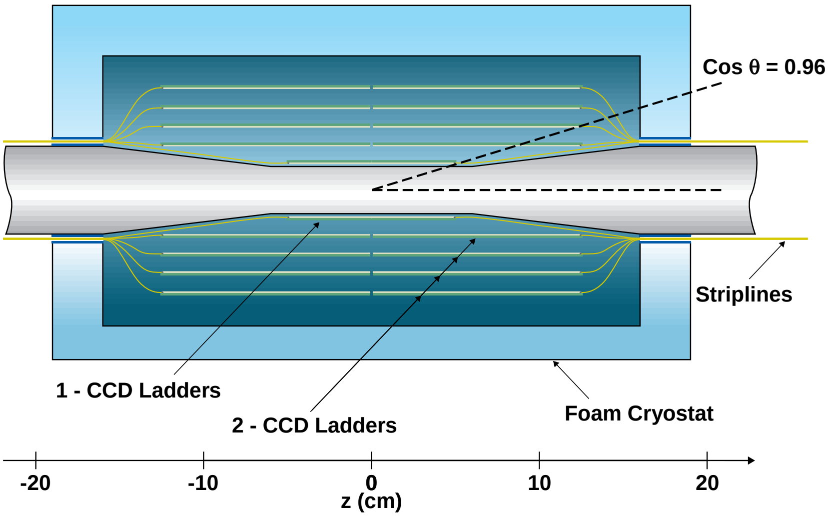


Beamstrahlung photons at ~0° interacting with incoming e- generate e+e- pairs with significant p_T. During readout time on layer1, estimated 4 charged bkgd hits/mm^2 (Tesla).

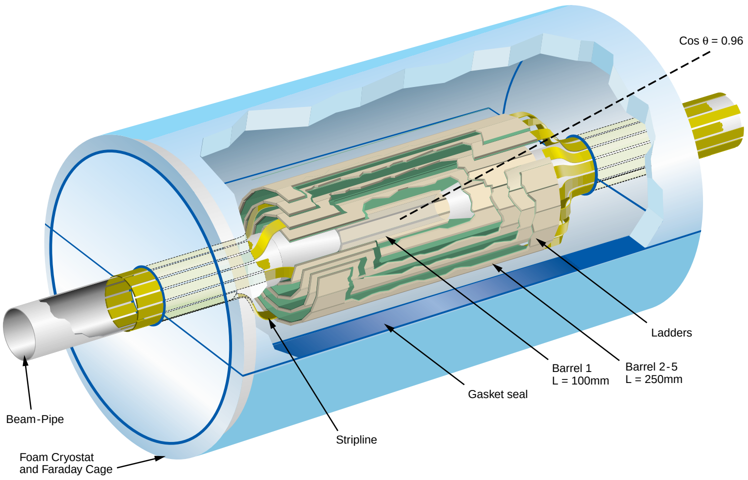


Radiation damage : e+e- background is negligible, neutron background is considerable, but estimated to be at safe values: 3.8×10^8 n cm^{-2} yr^{-1}.

Detector design overview



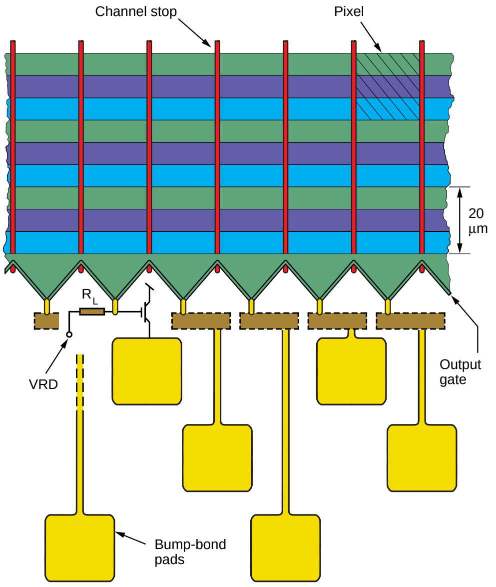
- ❖ 5 layers, 1^{st} layer starting at 1.5 cm radius from beam line and being 10 cm long in z direction
- ❖ standalone tracking with 5 hits up to $|\cos\theta| = 0.90$
- ❖ 3 hit coverage with first 3 layers up to $|\cos\theta| = 0.96$

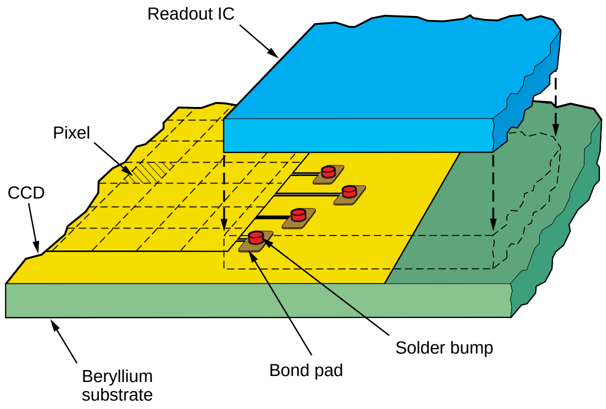


Comparison VXD3 vs. new LC design

Detector	VXD3	Future LC
CCDs	96	120
CCD active area (cm^2)	12.8	27.5
Number of Pixels (10^6)	307	799
N. of layers	3	5
Inner layer Radius (mm)	28	15
Layer Thickness (% X0)	0.4	0.06
Cos(θ) max	0.90 (2 - hits)	0.96 (3 - hits)
Readout time	216 ms	50 μs (8 ms NLC)

Detector readout



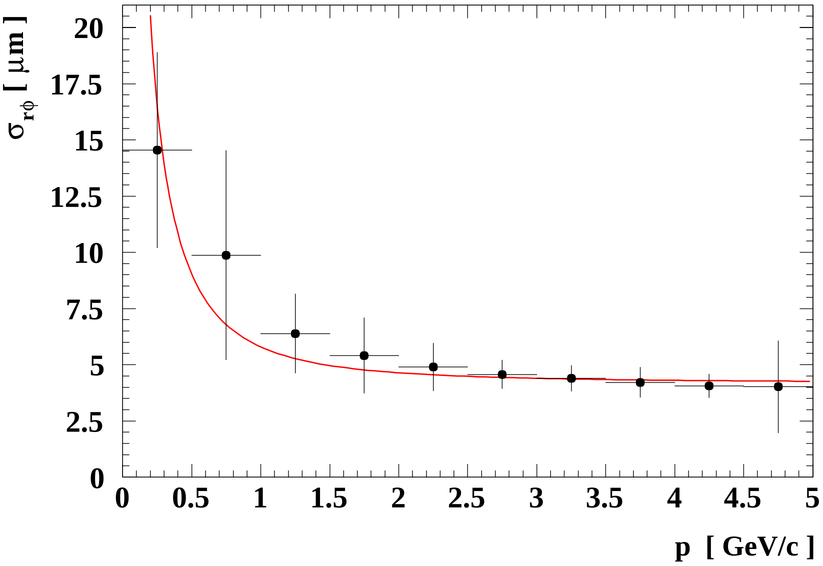


Due to high luminosity per train at Tesla, it is necessary to read out several times during 1 train (wich is 950 µsec long)

⇨ Idea of column parallel CCD readout, where each single column of 20 µm pixel width is readout in 50 µs.
This means 1000 faster than at SLD !
This is an improvement from which other application areas would take advantage

Physics performances of new detector design

Single track impact parameters precision



Impact Param res.	VXD3	New LC
σ _rφ (µm)	$9 \oplus 33/p\sin^{3/2}\theta$	$4.2 \oplus 4.0/p\sin^{3/2}\theta$

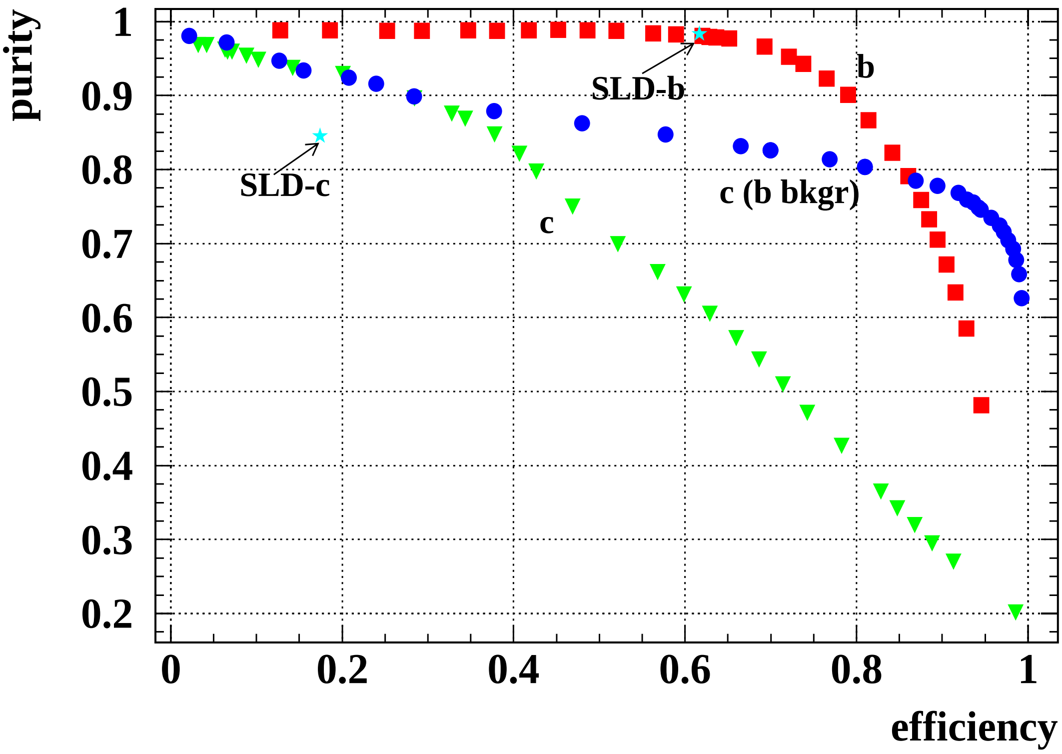
This and the following performance study are done using the Tesla simulation package BRAHMS, and may be found in the Tesla Technical Design Report. The new vertex detector design was used.

Jet flavour tagging performance

A very important performance for LC is the jet flavour tagging.

To discriminate powerfully both b and c against uds:
* Vertex informations are crucial
* Impact parameters significances and transverse momentum are also needed(e.g. 1-prong charm decays).

A neural network approach to tagging is giving the best results. Here we see results on e+e- -> q q at 91 GeV. SLD points are shown for comparison.

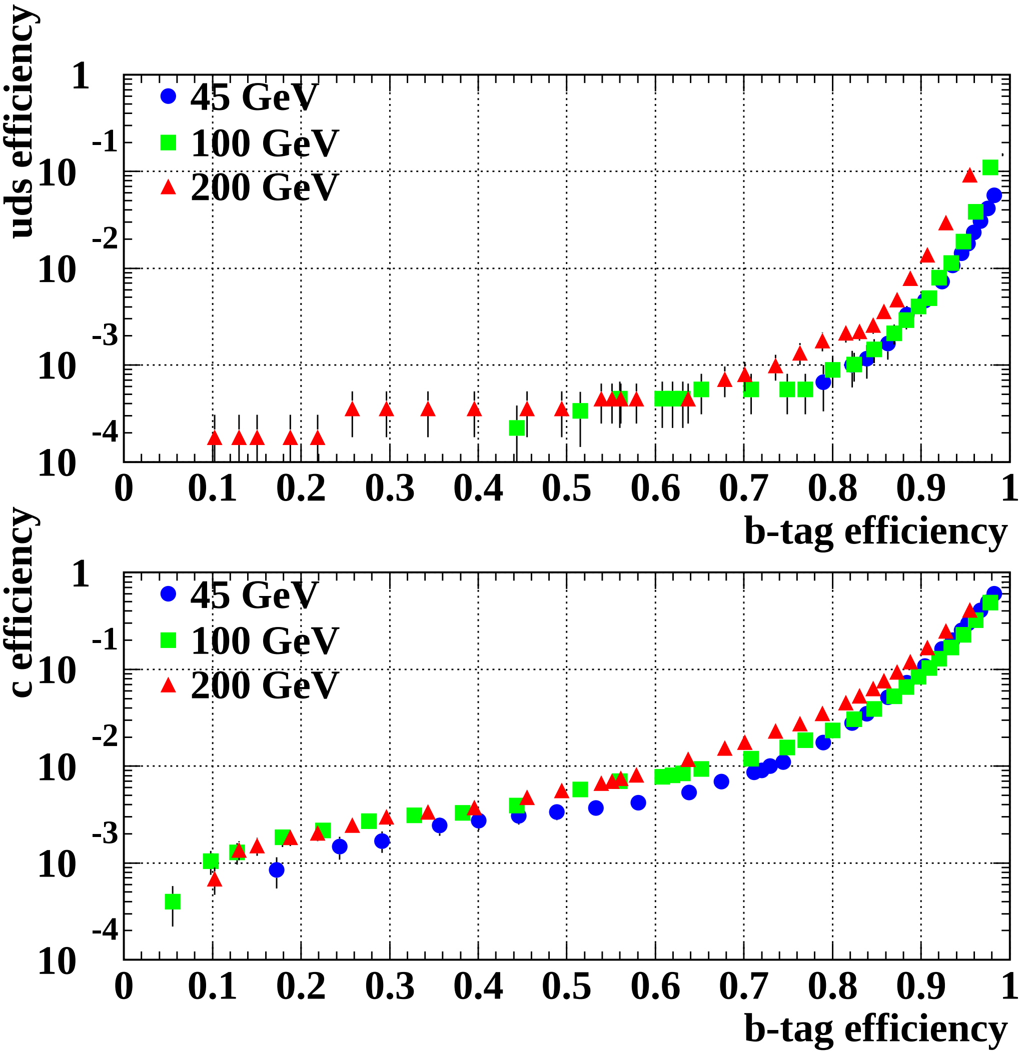


Flavour tagging for various energies

It is also important to see how stable the tagging power of the NN algorithm is with increasing energy.

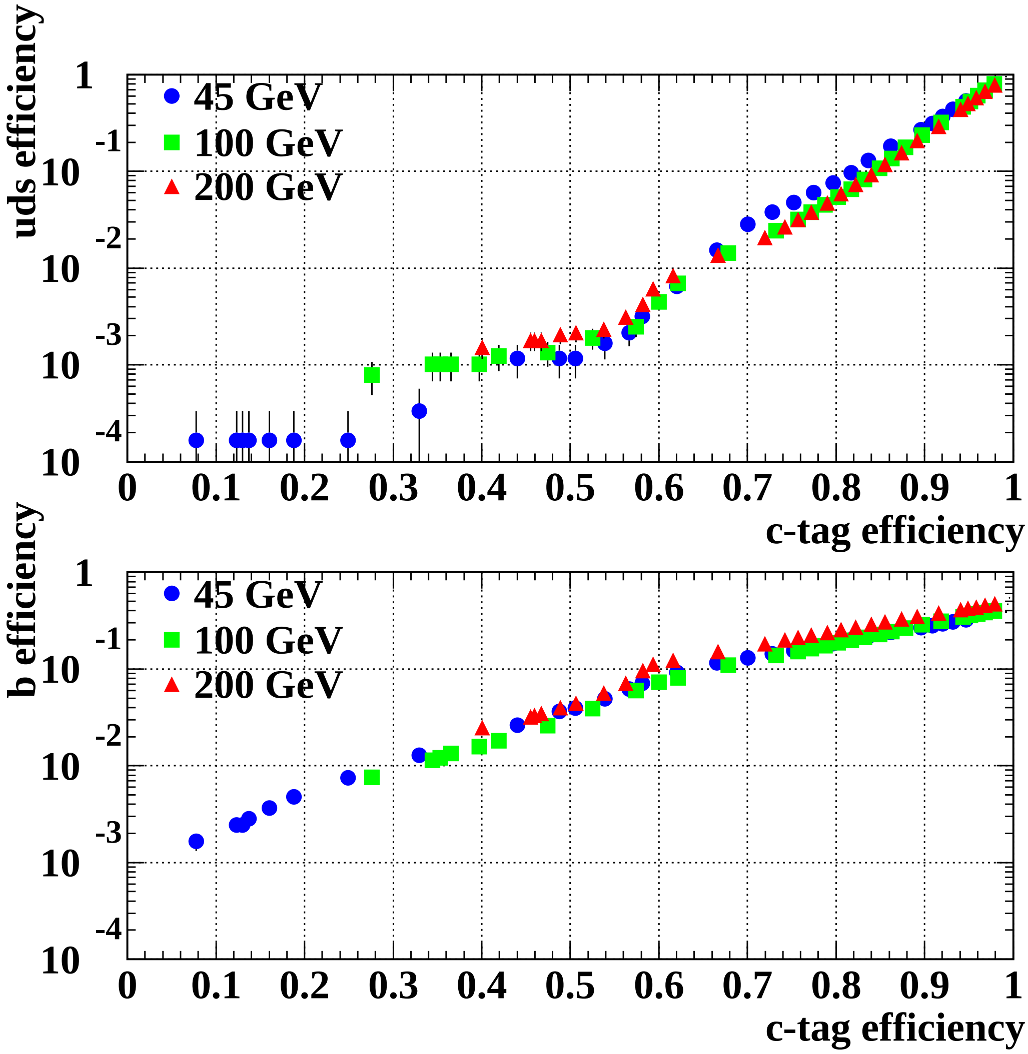
Using monojets of different flavours and energies.

Here we see b-tag efficiency versus efficiency of unwanted flavours (uds,c)



Flavour tagging for various energies(II)

Here we see c-tag efficiency versus efficiency of unwanted flavours (uds,b)



Summary

Clearly

- ✓ High precision
- ✓ Thin layers
- ✓ Fast readout

are a winning combination !

Studies of physics performance of the new vertex detector for the next LC (Tesla environment) have just started, nonetheless they already show us how valuable the new detector would be for physics.

⇨ Many encouraging reasons to push forward the present R&D to reach the final design goals.

About this ….

LCFI collaboration

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