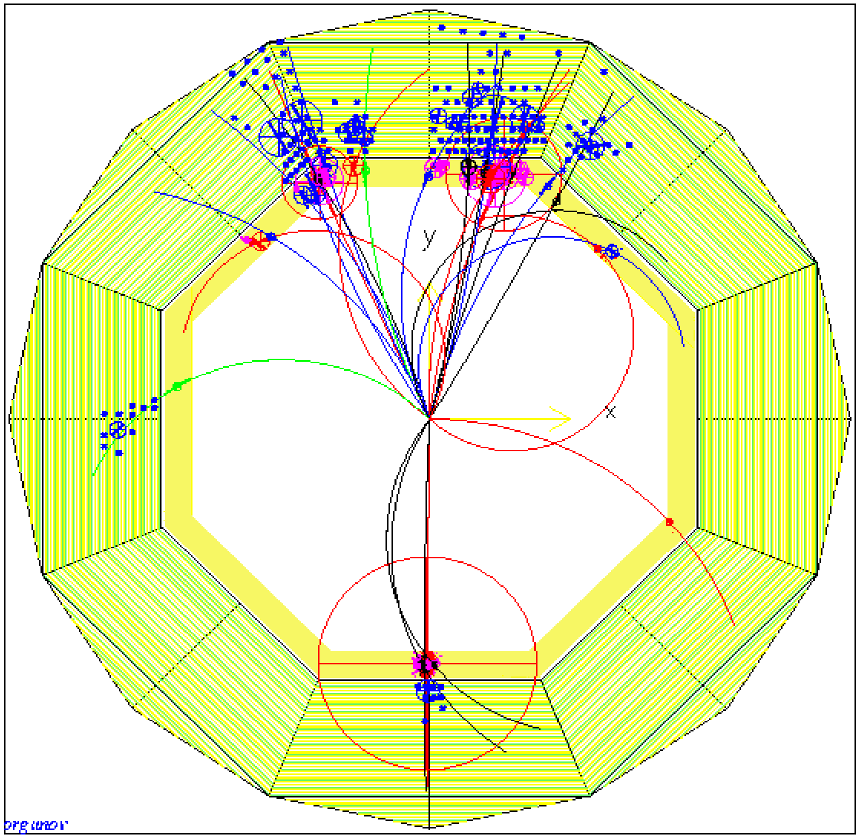
SIMULATION and RECONSTRUCTION for a LC DETECTOR: the European Framework

Ties Behnke, SLAC/ DESY

- The european framework
- The tracking reconstruction
- Calorimeter reconstruction:
  - Energy Flow

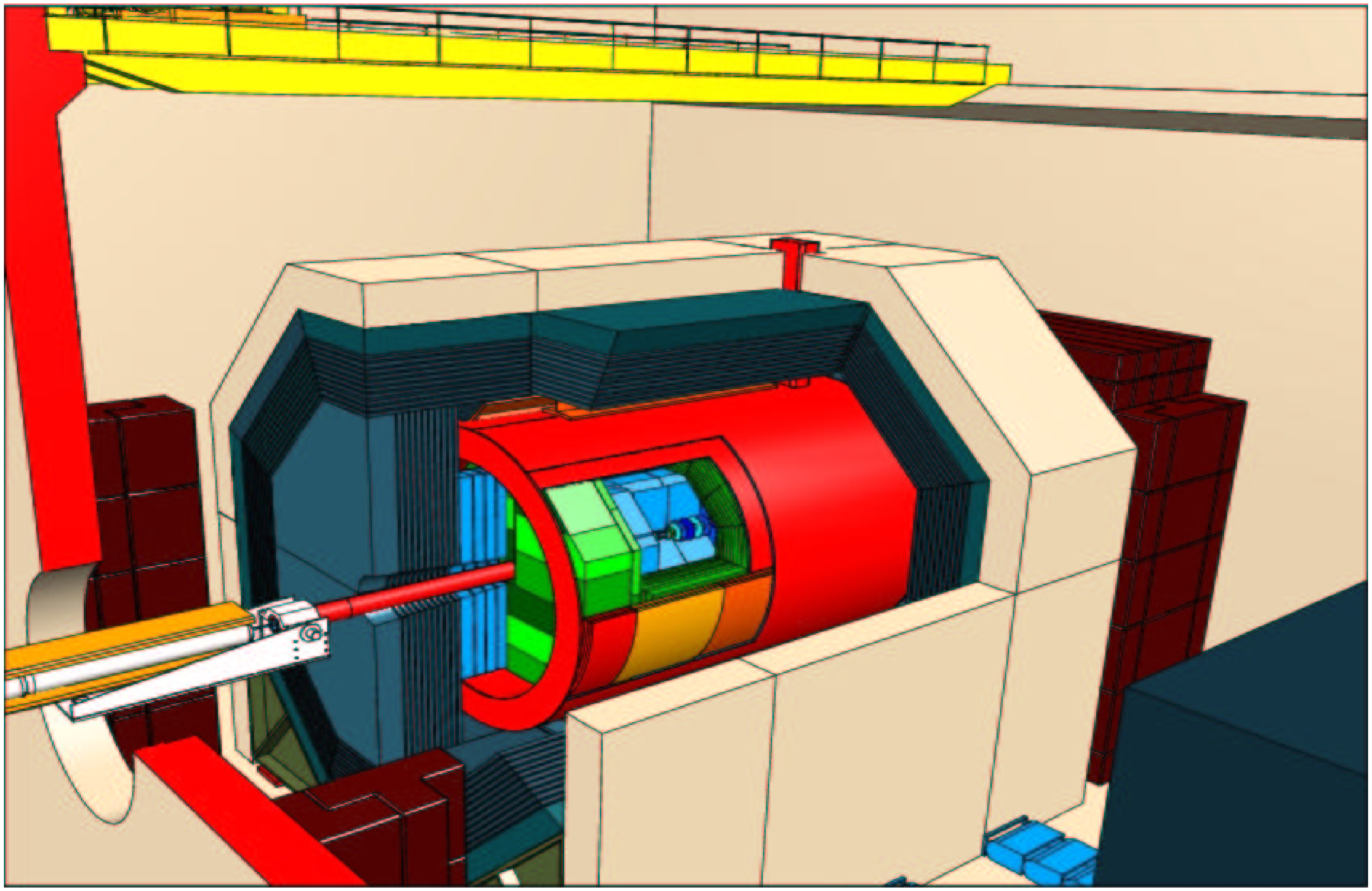


Note: a lot of the things I show is very much in the spirit of "work in progress", and are not necessarily final results

The "TESLA" Detector

"Large" Detector:

- Tracking and calorimetry in 3-4T magnetic field
- Large volume tracking, combined SI and gaseous
- High precision calorimetry with excellent hermeticity and excellent granularity



This is in many ways very similar to the US "L" Detector

Key Requirements

- Momentum resolution: $\delta(1/p_t) \leq 5\ 10^{-5}/(\mathrm{GeV}/c)$

  Benchmark: Lepton recoil spectrum in HZ->llX events

  Less immediate benchmarks:
  - Overall tracking performance
  - Robustness
  - Redundancy
  - Interplay tracking - calorimetry

TPC only

Full tracking system

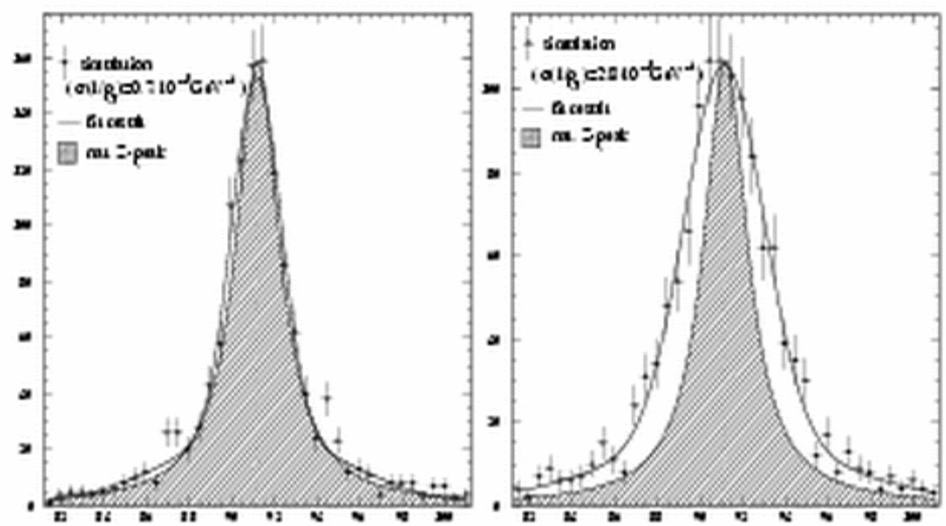
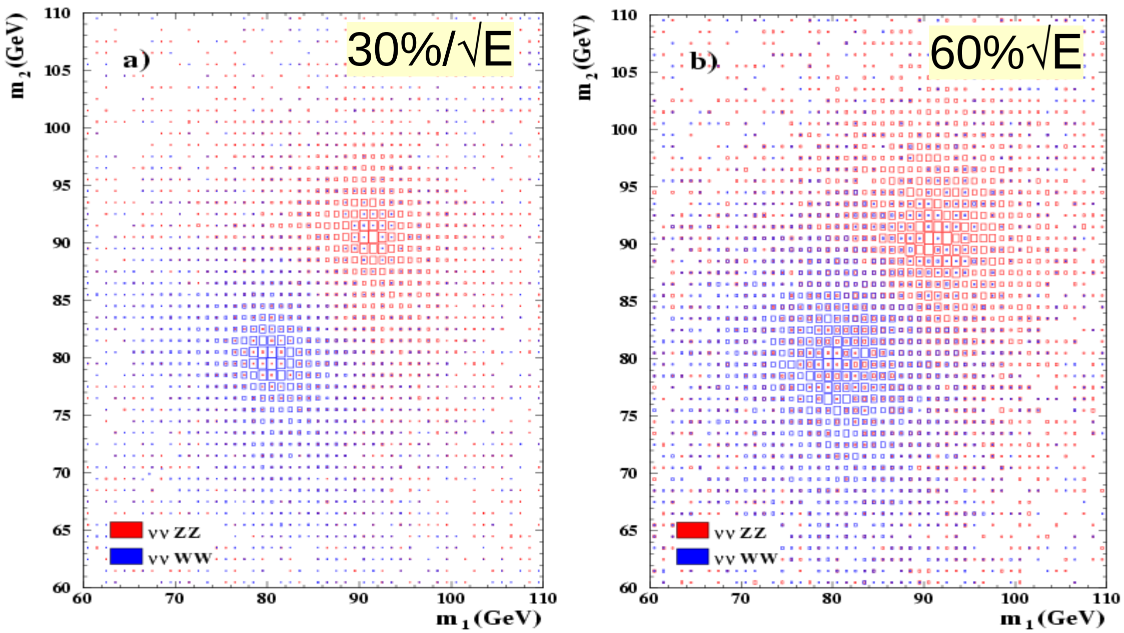


Figure 7: Reconstructed Z peak for a momentum resolution of $\sigma(p_T)/p_T^2 = 0.7 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ and $2.8 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$.

Key Requirements

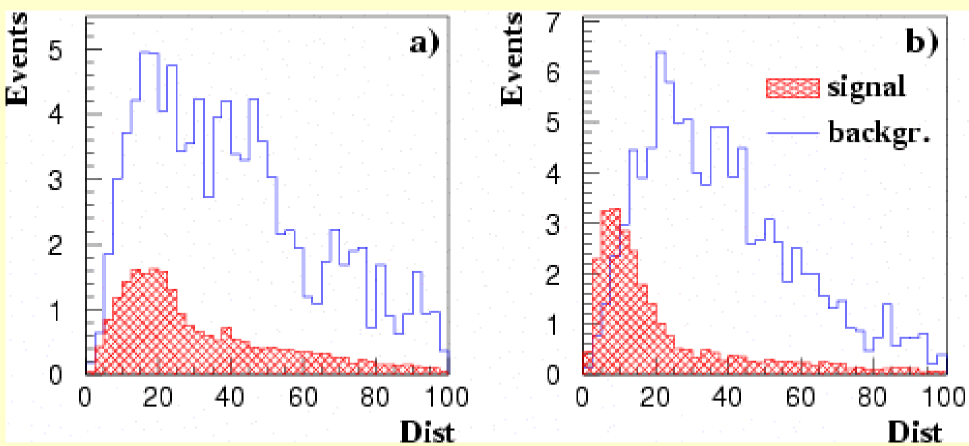
Energy Flow resolution: 30%/√E



Separation of W and Z: Important for many analyses, important for background rejection

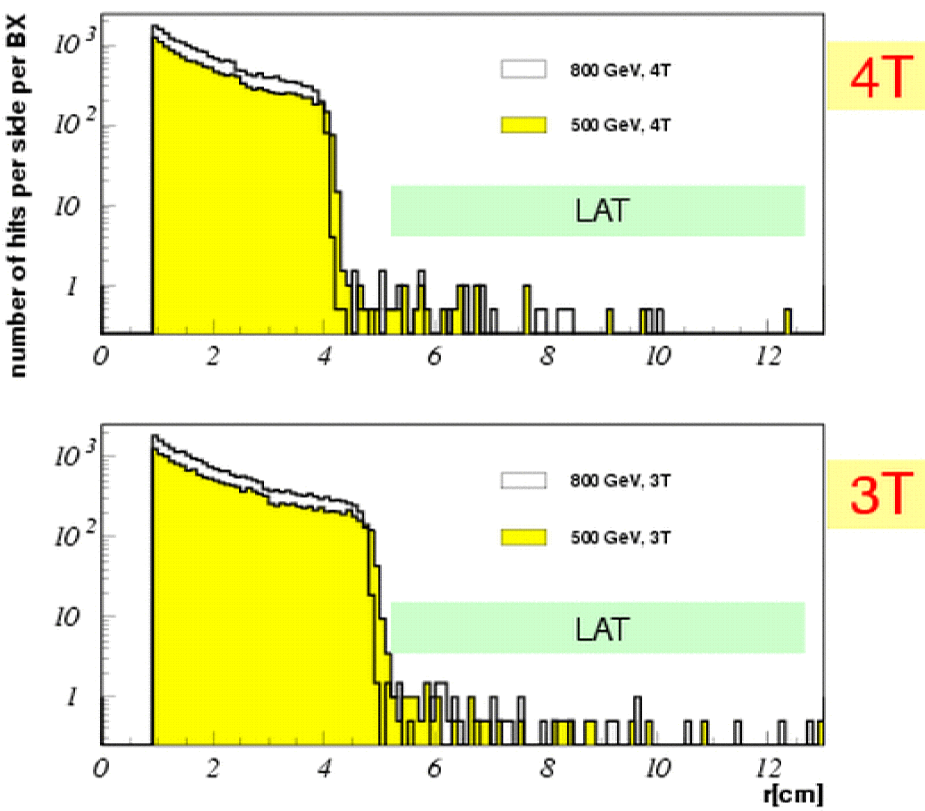
Measurement of Higgs selfcoupling HHZ events (6 Jet final state)

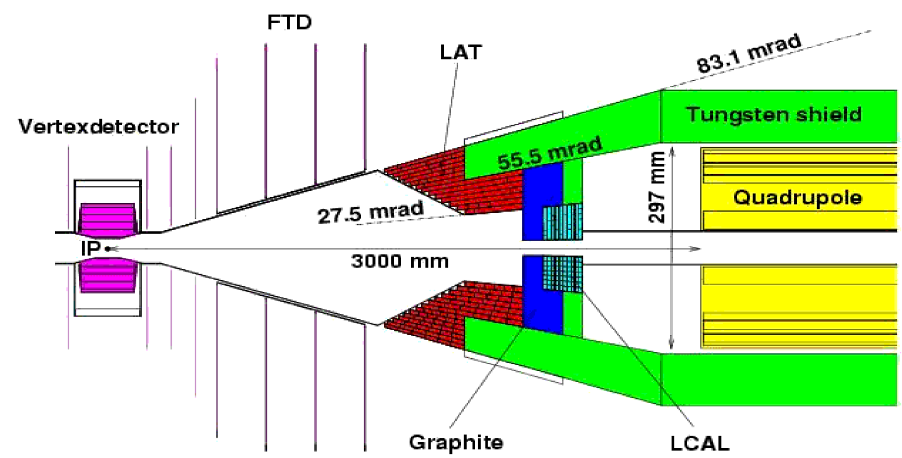
main problem: separation signal - background



Coverage

Want large angular coverage: special attention given to small angle region
- Beamstrahlungs background
- Beam aperture

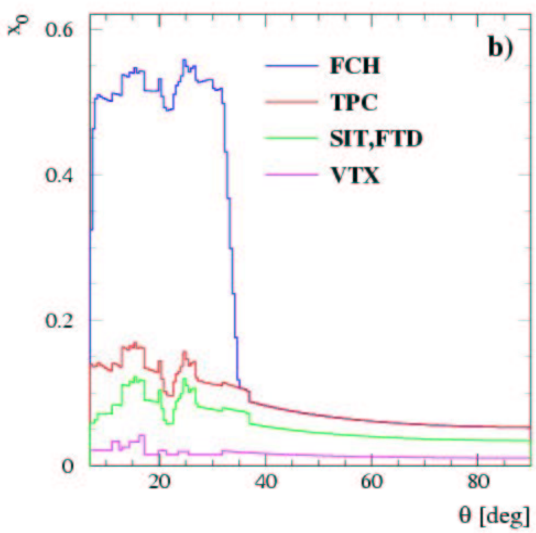


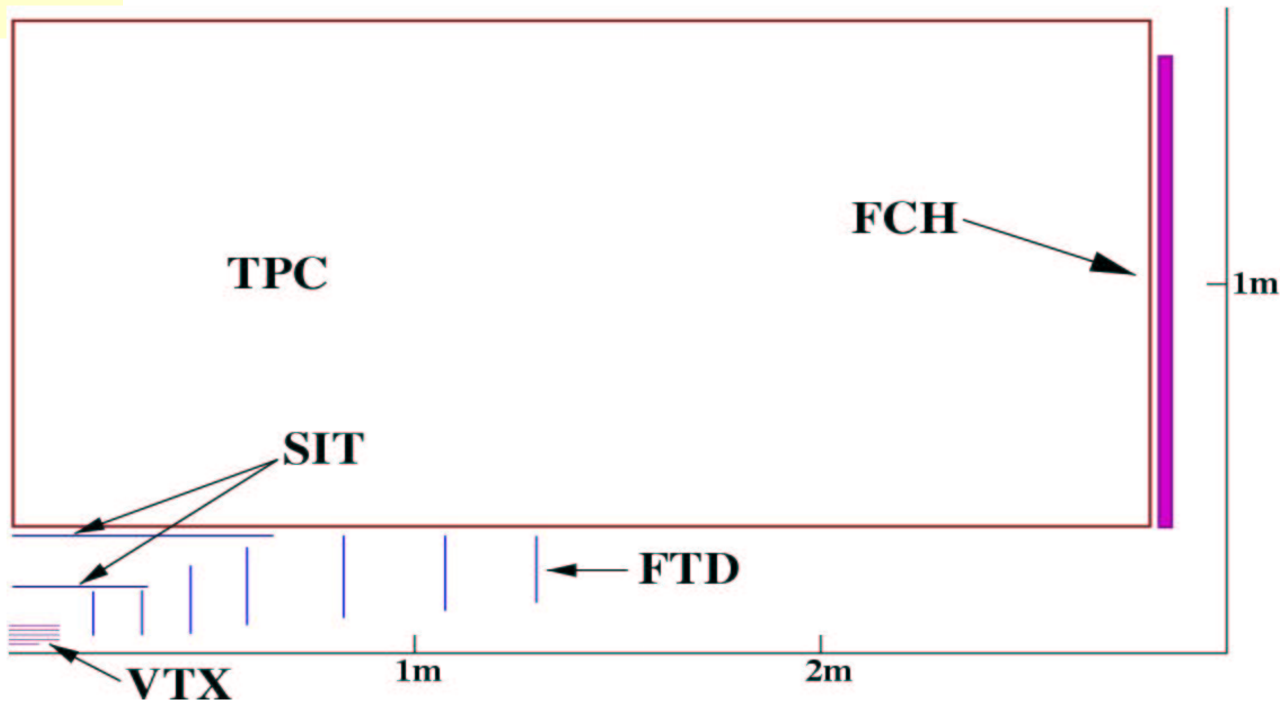


Inner LAT acceptance: 27.5 mrad
inner LCAL acceptance: 5 mrad

Tracking

- high quality vertexing
- SI detectors in forward direction
- intermediate SI tracking
- large volume TPC
- backed up by FCH in forward direction





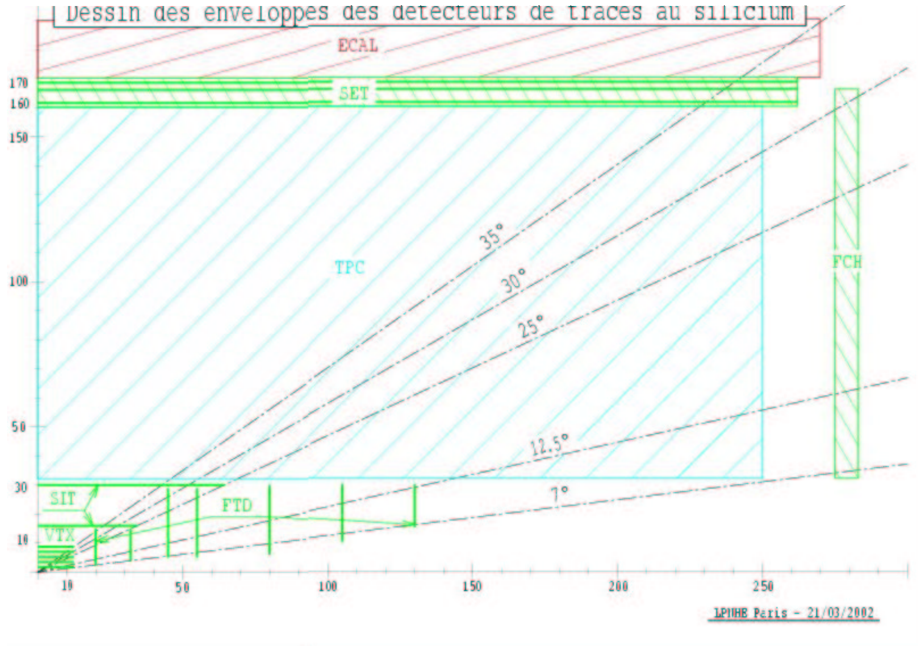
New: option of SI envelope outside TPC (barrel and endcap)

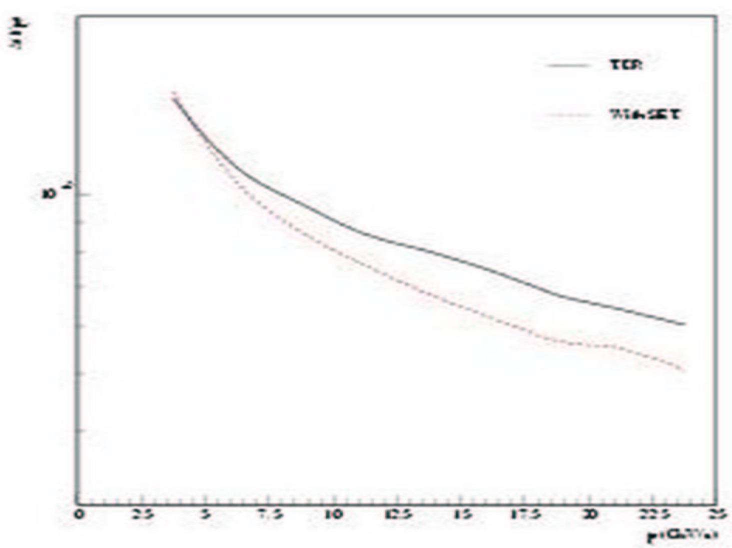
Silicon External Tracker SET

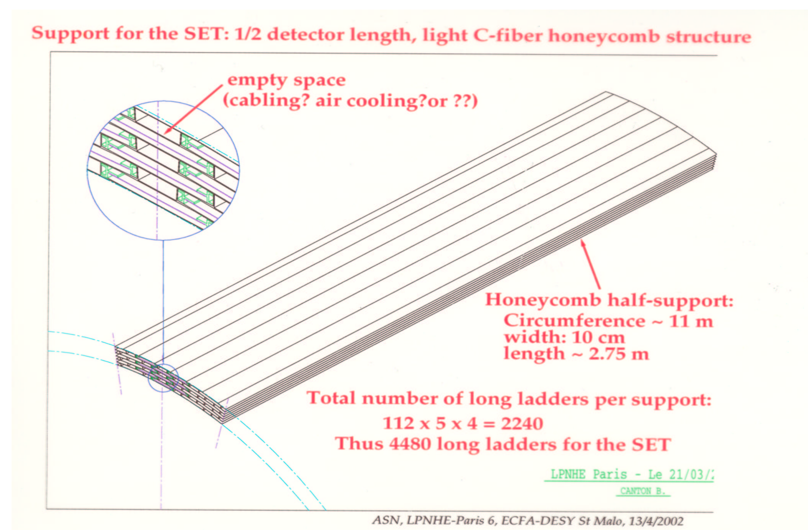
Studies of the detector and its realisation have started

a rather detailed technical design of
- mechanics
- readout electronics
- simulation

has started in Paris



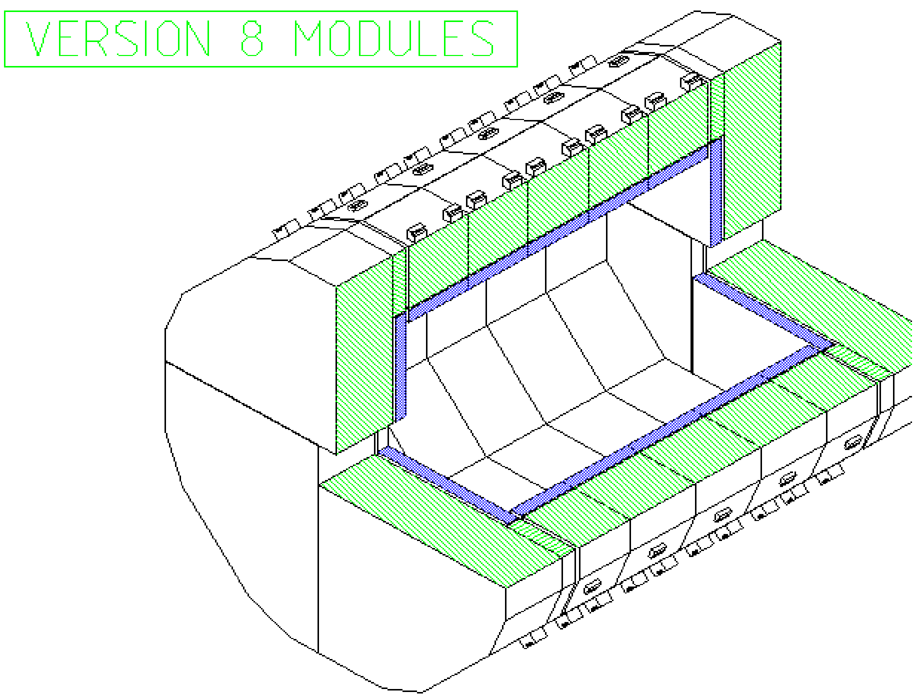


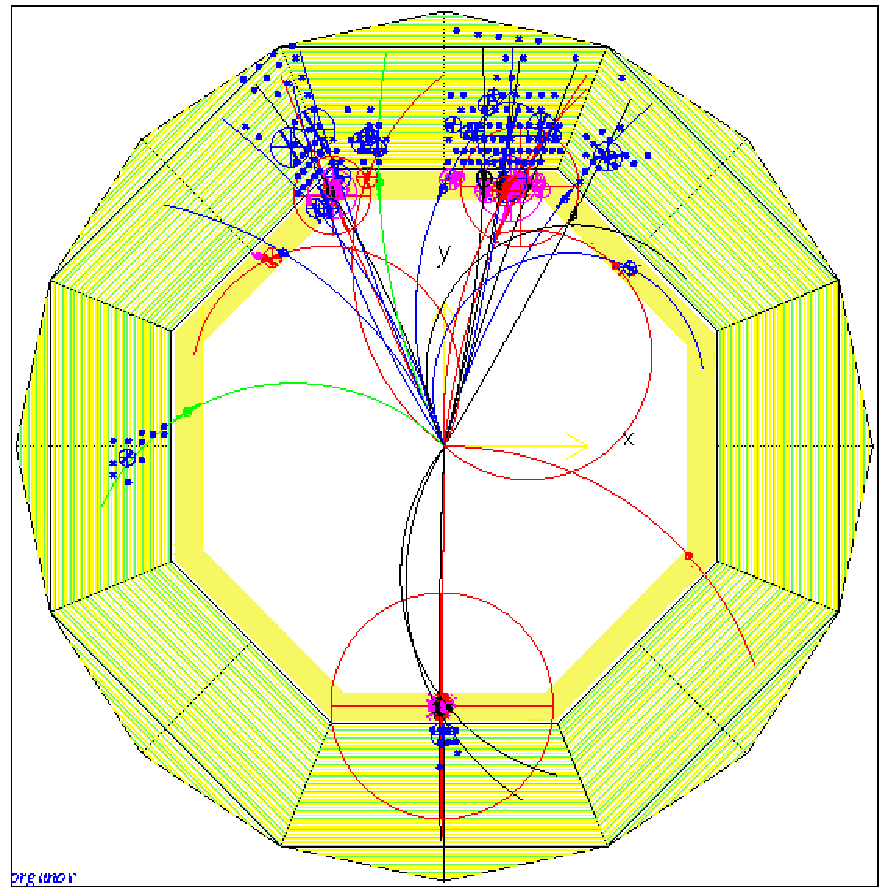


Calorimetry

- high granularity calorimeter design
- moderate energy resolution
- excellent segmentation both transverse and longitudinal

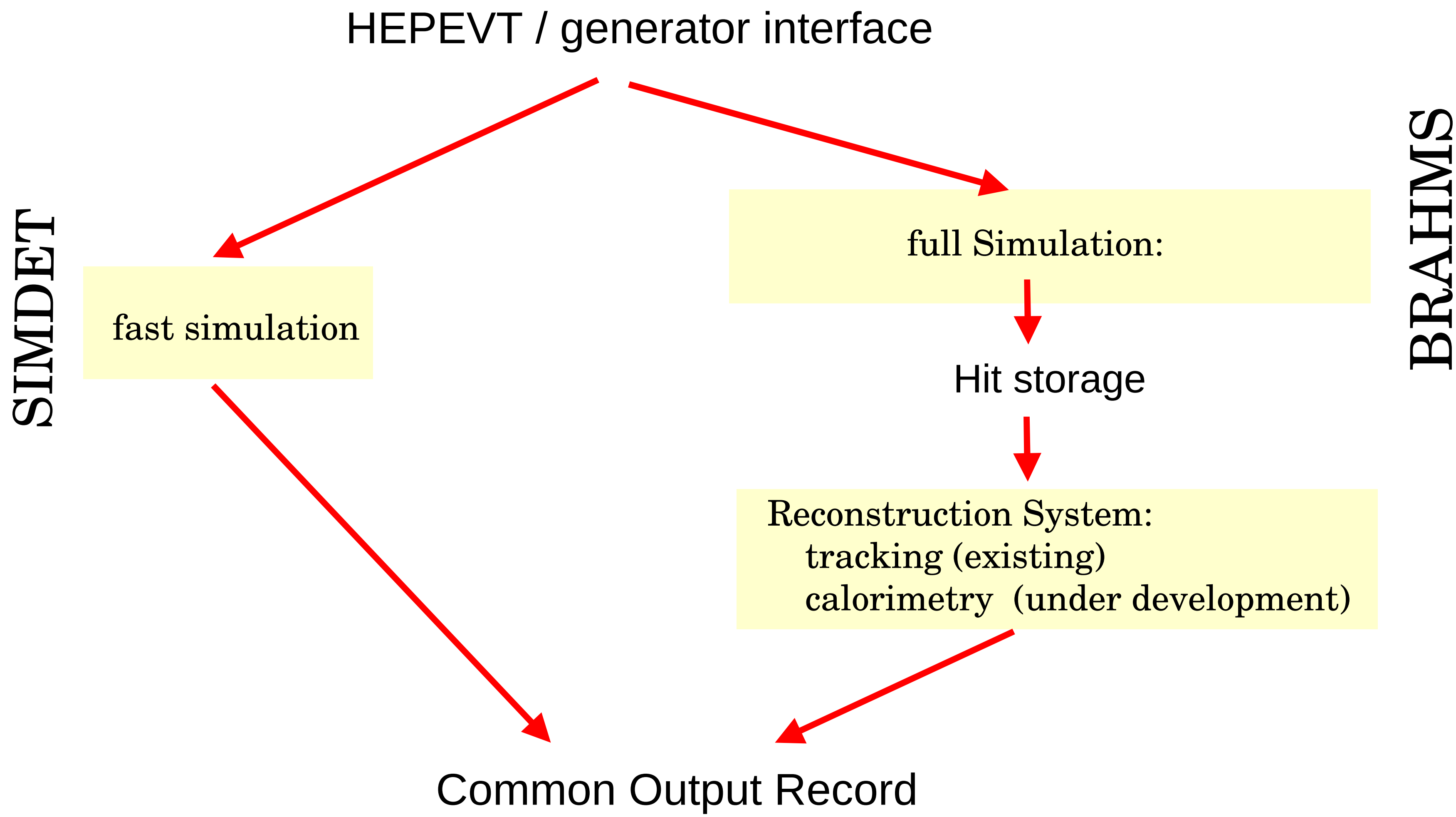
chosen technology
SI-W sampling for the ECAL
cheaper Szintillator / digital for HCAL





Note: these are the choices for the TDR .... not for a real detector!

The simulation framework



We are working on defining a common hit storage format between BRAHMS and MOKKA, and between the European and the US frameworks

BRAHMS

The BRAHMS suite contains two programs:

- GEANT3 based simulation code (“BRAHMS proper”)
- The reconstruction program RERECO

technical detail:
simulation and reco may be run together or separately

BRAHMS: The **simulation** program:

- complete implementation of the TDR tracker
- full implementation of the TDR calorimeter
- full implementation of the forward system
- full implementation of the muon system

communication between simulation and reconstruction via simple serial gzipped, files

RERECO: The **reconstruction** program

- full track reconstruction and detector merging code
- calorimeter reconstruction code
- full energy flow algorithms (a version of..)

most code is still FORTRAN based

The Goal

- The goal: develop and maintain a modern simulation environment which is
  - flexible
  - maintainable for a long time to come
  - scalable
- At the same time:
  - continue the support for the existing system for still some time to come
- Ideally: maintain a link between the programs to avoid duplication and translation errors

Fortran → object orientation

BRAHMS 3xx

GEANT3 kernel → common hit format ← GEANT4 kernel

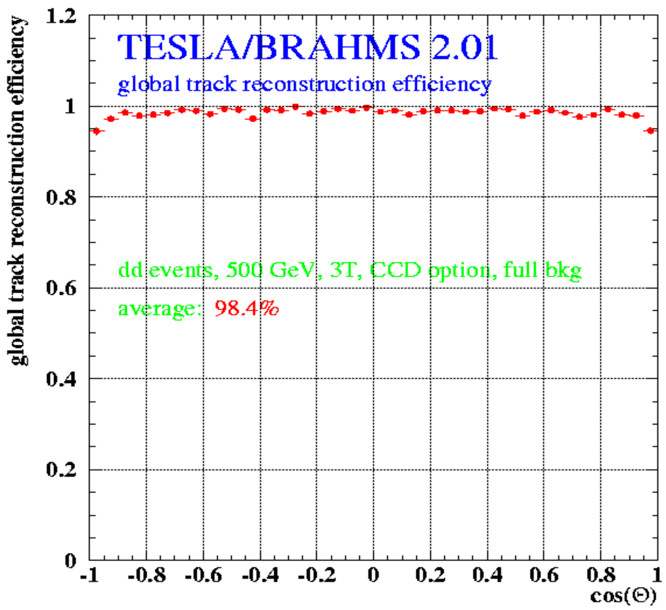
common hit format → • tracking package • calorimeter package

common hit format → • object oriented tracking package • object oriented calorimeter package

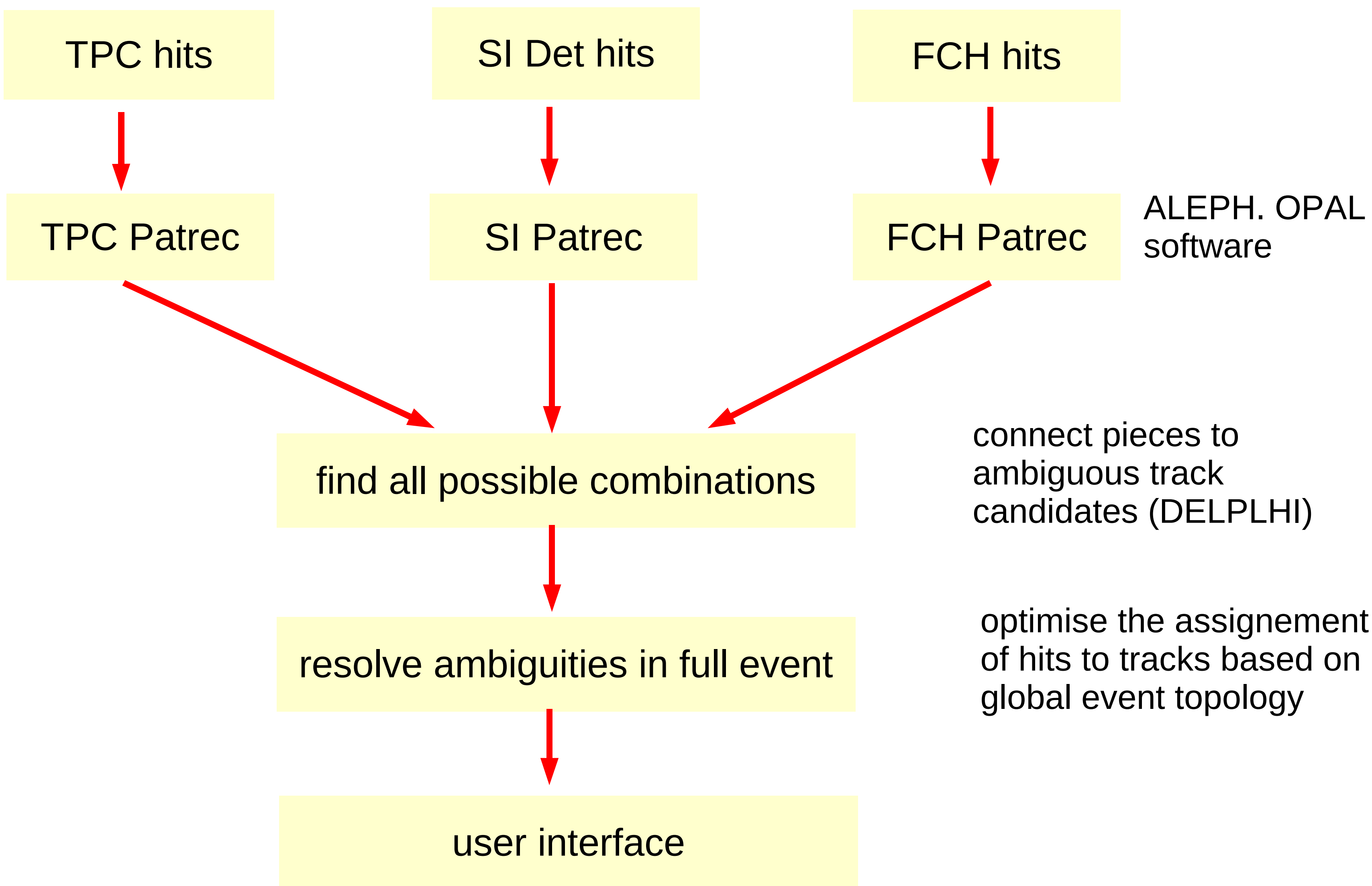
The Tracking Package

Tracking package is a collection of software tools:

- 2 pattern recognition programs
  - one optimised for a TPC: “bad” resolution, closeby hits, many points on track
  - one optimised for a SI detector: excellent resolution, excellent hit separation, small number of hits
- Merging processor: connect tracks from different subdetectors
- Overall Optimisation processor:
  - resolve any remaining ambiguities
  - improve the merging
  - improve the tracking



The Tracking Package



main authors of package: Kristian Harder, Markus Elsing, Daniel Wicke, Richard Hawkings

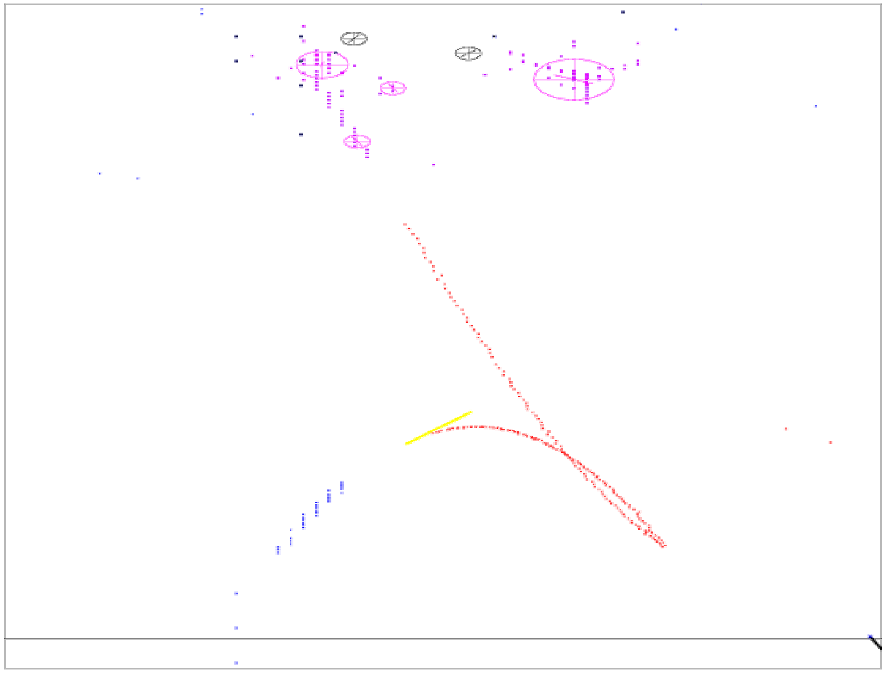
The TPC Simulation

Number of readout rows simulated: 200

GEANT hits are smeared according to

- point resolution
- diffusion is added
- readout resolution (pad response function) is added
- if two hits are too close, the resolution is made worse by a factor (2 at the moment)

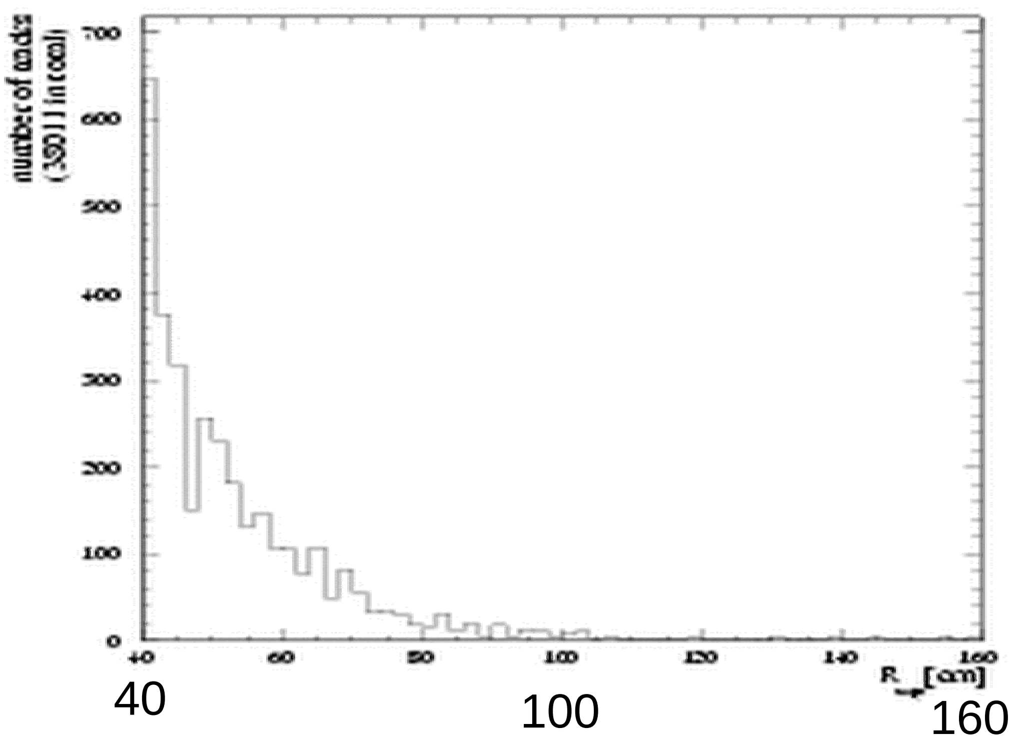
  (this is very simple minded and should be improved)



A K0_L decaying in the TPC

The TPC pattern recognition

- Program is based on ALEPH pattern recognition
  - start from the outside of the TPC, find tracks.
  - remove “outliers”: drop hits with > n sigma from the track
  - treat close by tracks/ hits: drop any hits from the “confusion” region



number of tracks with “closeby” hits in dd events, vs. radius of last closeby hit found

approx. fraction of hits dropped: <5 %

Simulation of SI Detectors

Vertex Detector:

- pixel device: simple to simulate
- somewhat simplified geometry: cylinders
- support material etc as in TDR
- GEANT hits are smeared with the intrinsic resolution
- no special treatment for close-by hits

SIT/ FTD:

- design assumes (partial) strip detector
- no ghost hits are assumed at the moment
- no special treatment for closeby hits

Study is needed of the role of the double hit resolution
Study is needed on the role of the cluster shape
Study is needed on the role of ghost hits etc.

We expect the influence of all these to be small, but this has to be demonstrated!

The track fit

Track fit is based on a KALMAN filter algorithmus

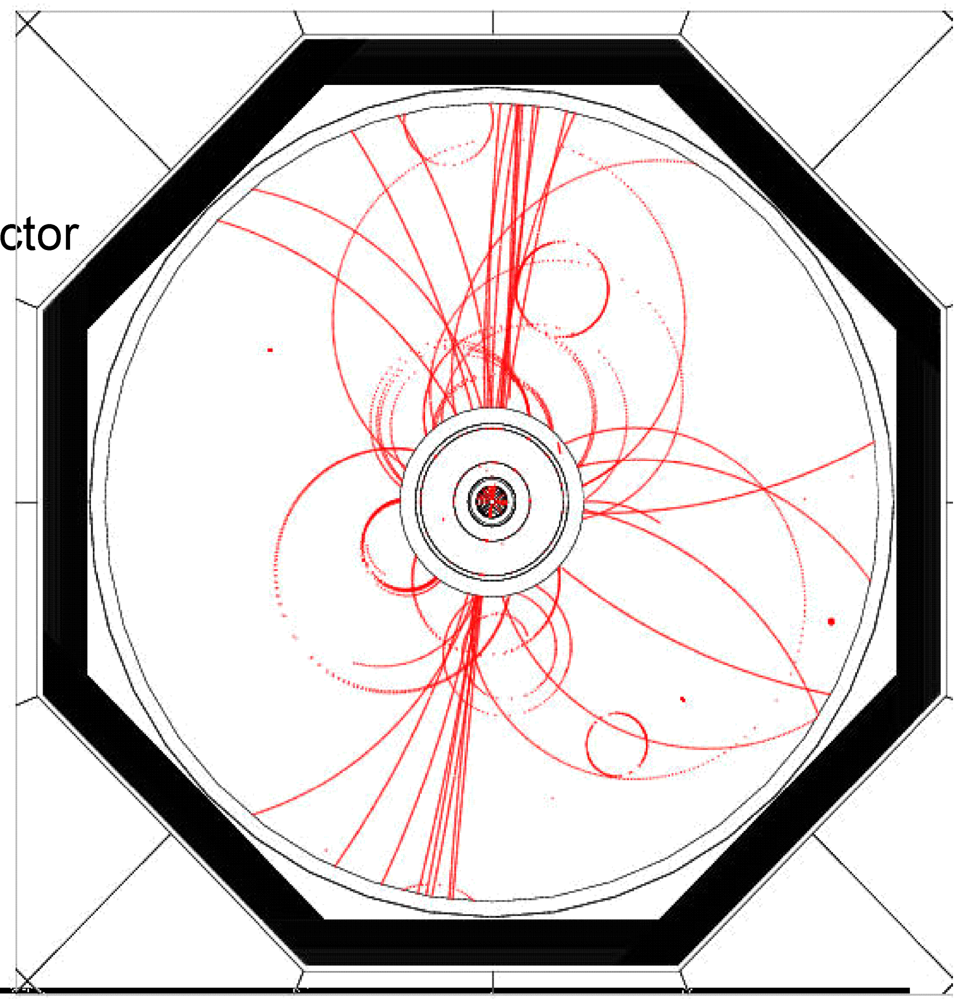
- fast implementation taken from DELPHI software
- transformation into the helix track parameter space is done by a Taylor expansion around a reference trajectory.
- Iteration to obtain good convergance
- Material in the detector is modelled by simple surfaces (cylinders, disks, cones)
- The fit itself removes outliers
  - up to 3 measurement per candidate (chi^2 < 0.1%)
  - use detector ranking (make sure the less precise element is removed)

Fit has proven to be
very fast
very stable and robust

What needs to be done:
more systematic evaluation of the performance of the outlier removal logic
influence of the ranking in the tracking has to be studied

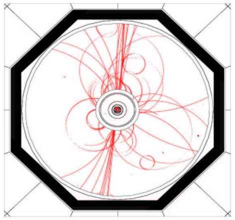
Performance Analysis

- Events used: dd events, 500 GeV
  tau events, 500 GeV, 3 charged particle decay
- Simulation includes backgrounds:
  - simulate random hits according to expected occupancy
  - not included: background tracks (they are tracks as all others...)
- For simulated tracks to be used:
  - p > 1 GeV
  - |cos(theta)| < 0.998
  - tracks from secondaries are rejected
  - should have left at least 3 hits in a detector
- For reconstructed tracks to be used
  - at least 3 hits on a track reconstructed



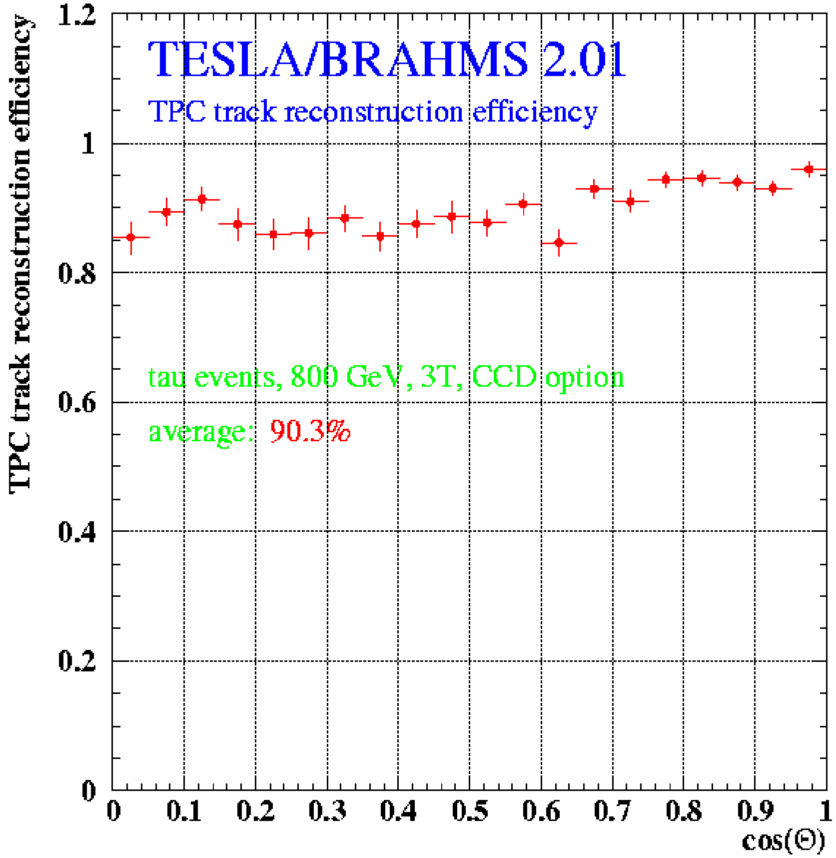
performance analysis done by
Kristian Harder, DESY
Details: LC-DET-2001-029

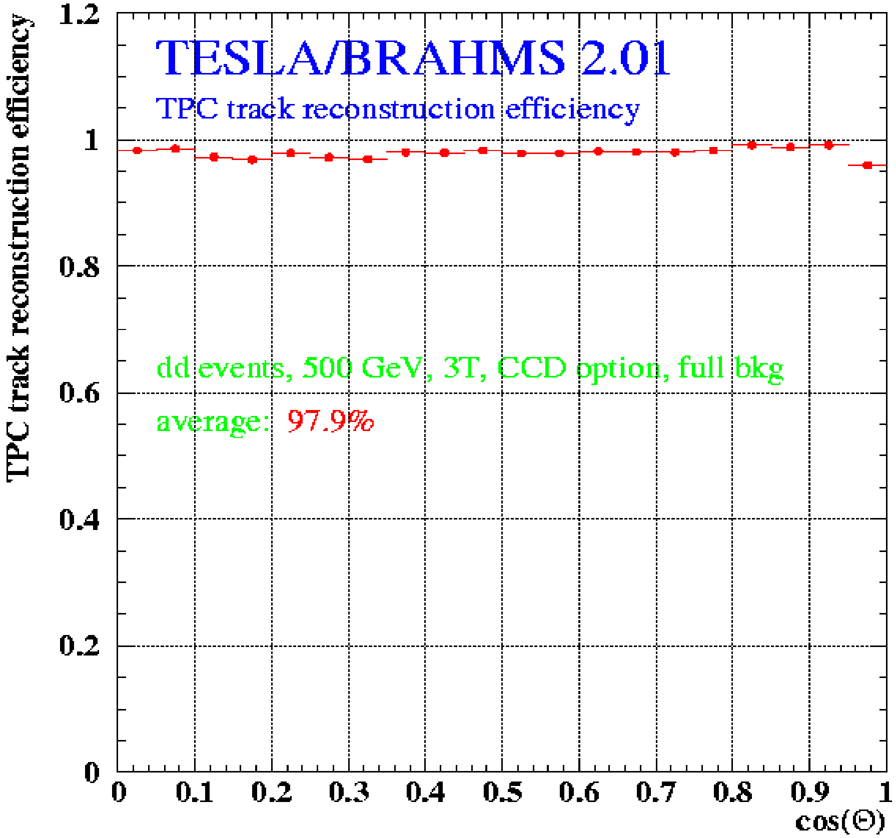
Performance of TPC Patrec I



tau events at 800 GeV, 3T
TPC only patrec
1% background

dd events, 500 GeV, 3T
TPC only patrec
1% background





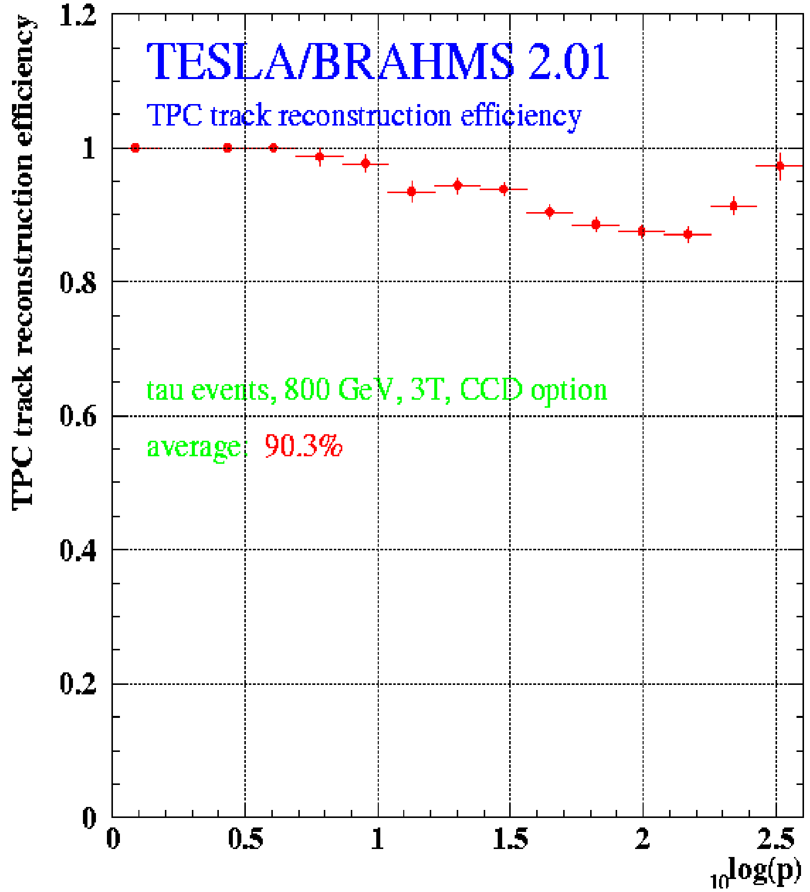
90% efficiency

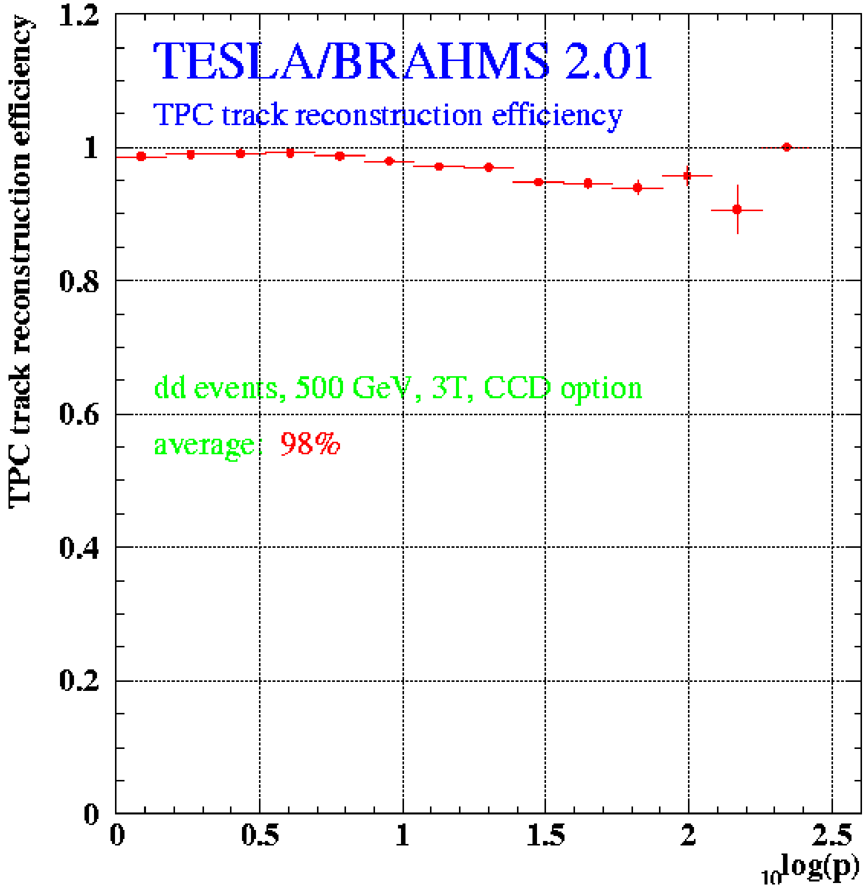
98% efficiency

Performance of the TPC Patrec II

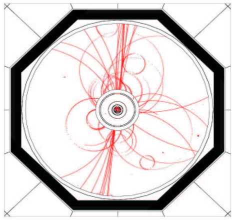
drop in efficiency at high momenta:

close-by tracks remain close-by tracks, problems with double track resolution (note: part of this can be re-couperated with a more sophisticated double hit treatment)



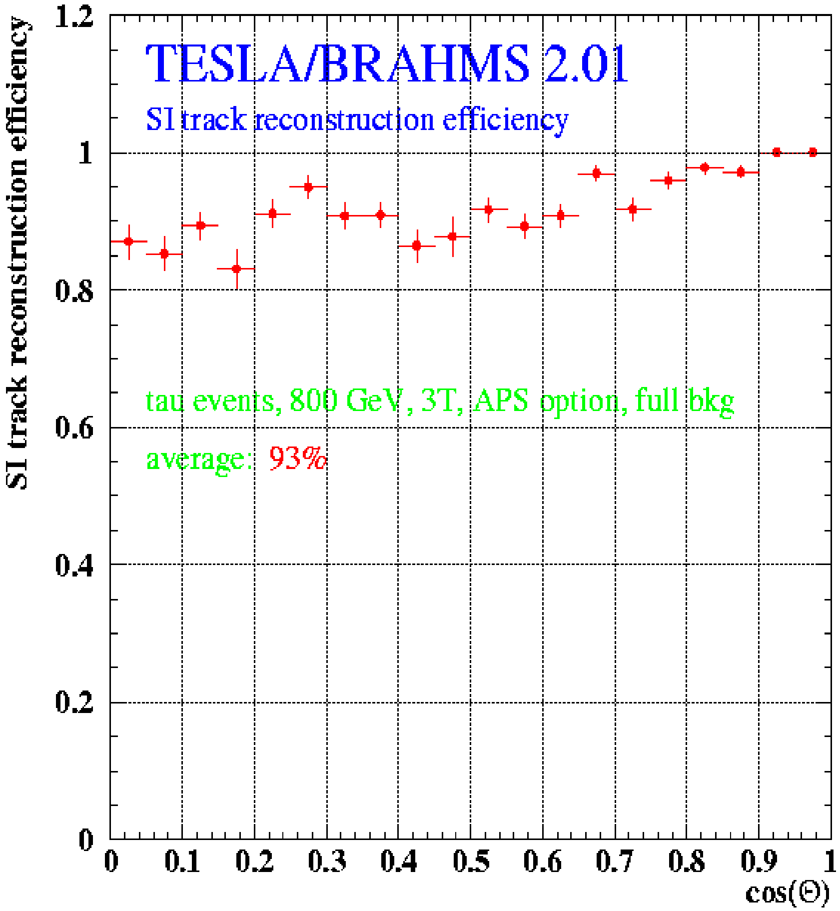


Performance of SI Patrec



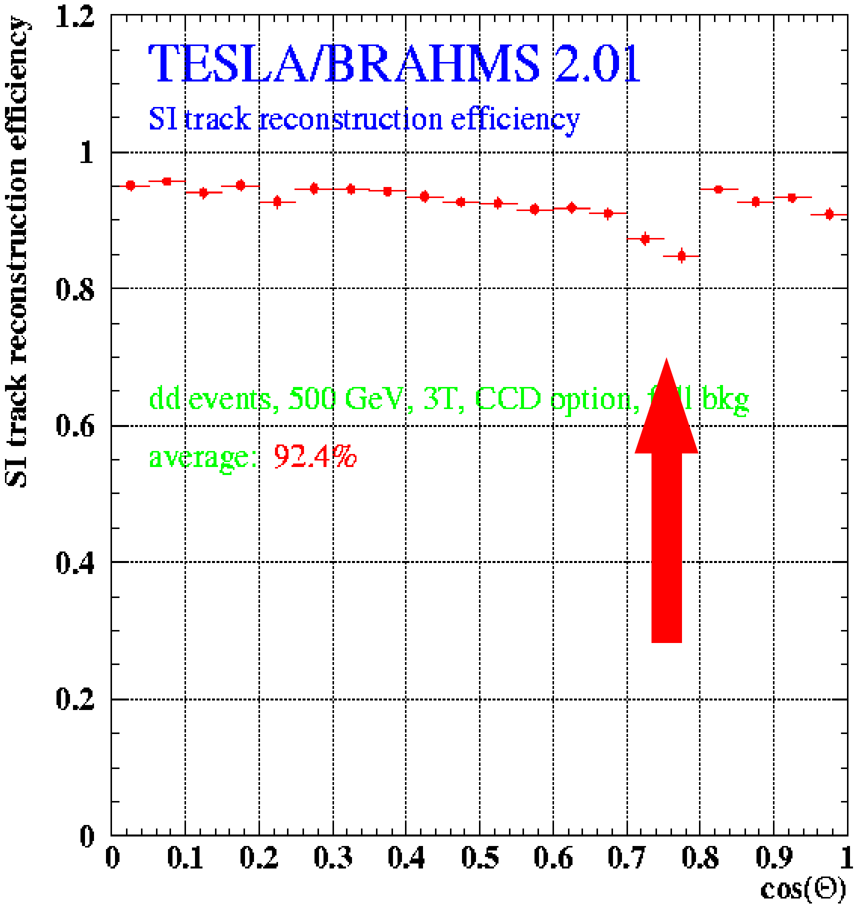
Detectors included: SI, FTD, SIT

tau events, 800 GeV
full background (60BX)



93% efficiency

dd events, 500 GeV
full background

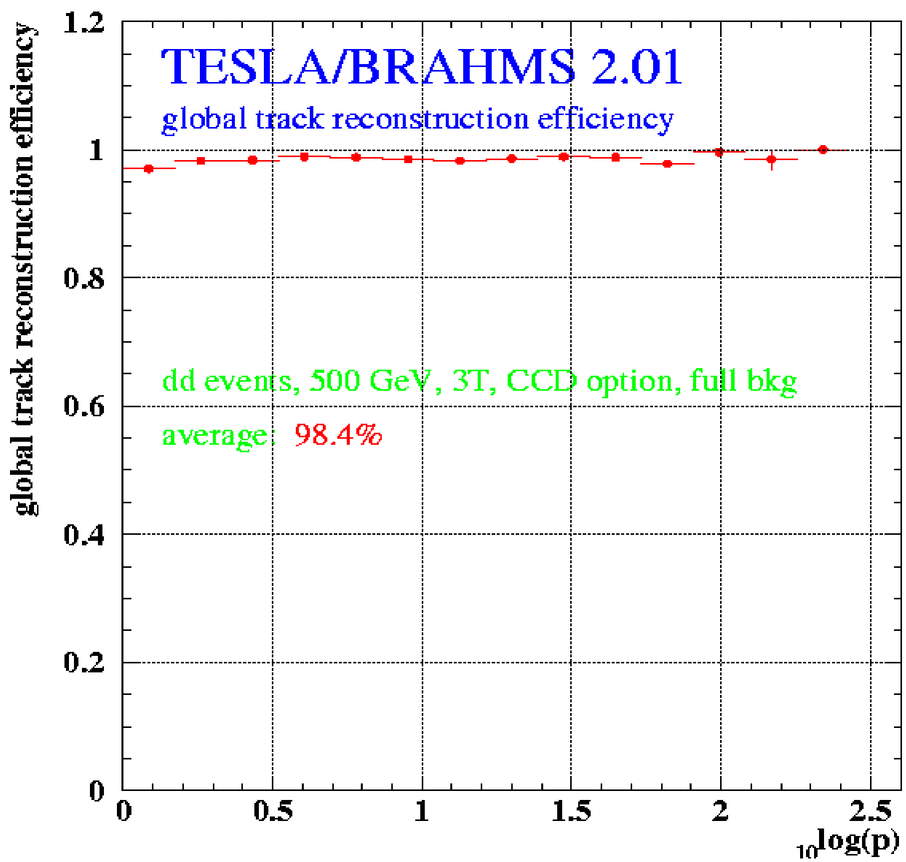


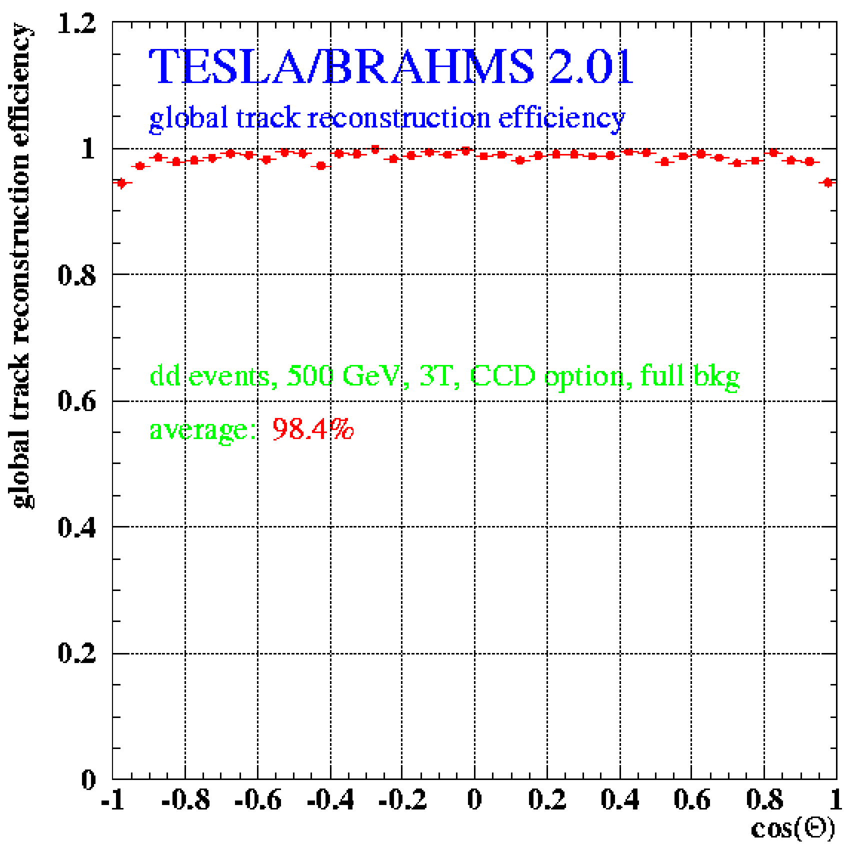
92% efficiency

Overall Patrec Performance I

Overall tracking system, **dd events**, 500 GeV, 3T field, “full” background

- The merging step recouperates the (small) losses of efficiency at large p
- Moderate overall increase in efficiency



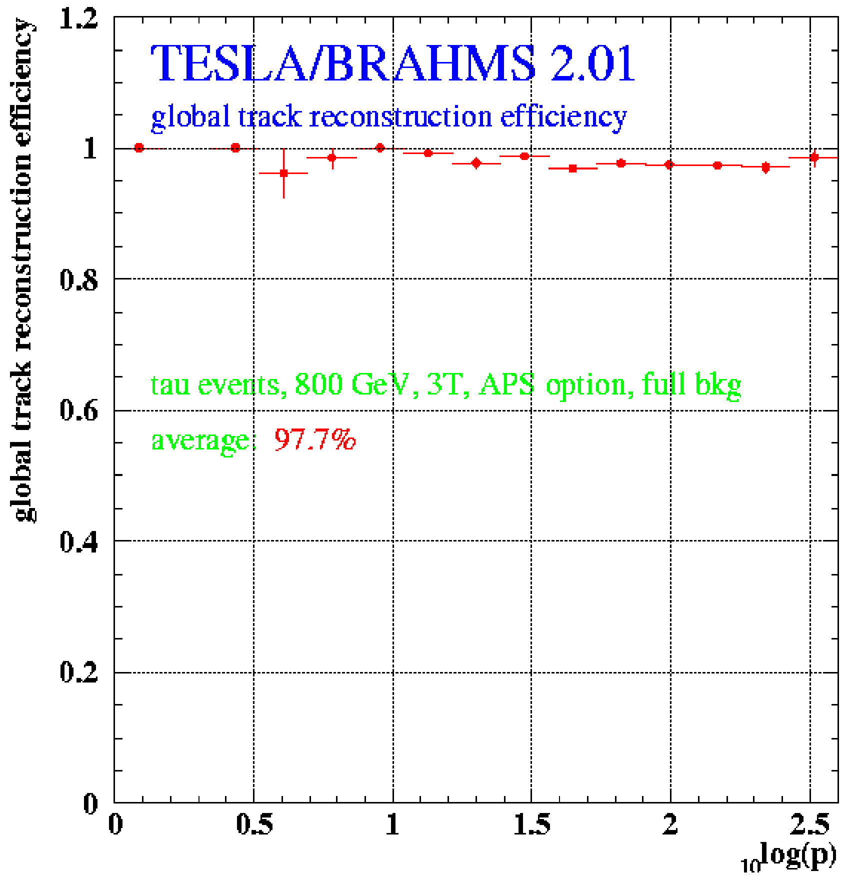


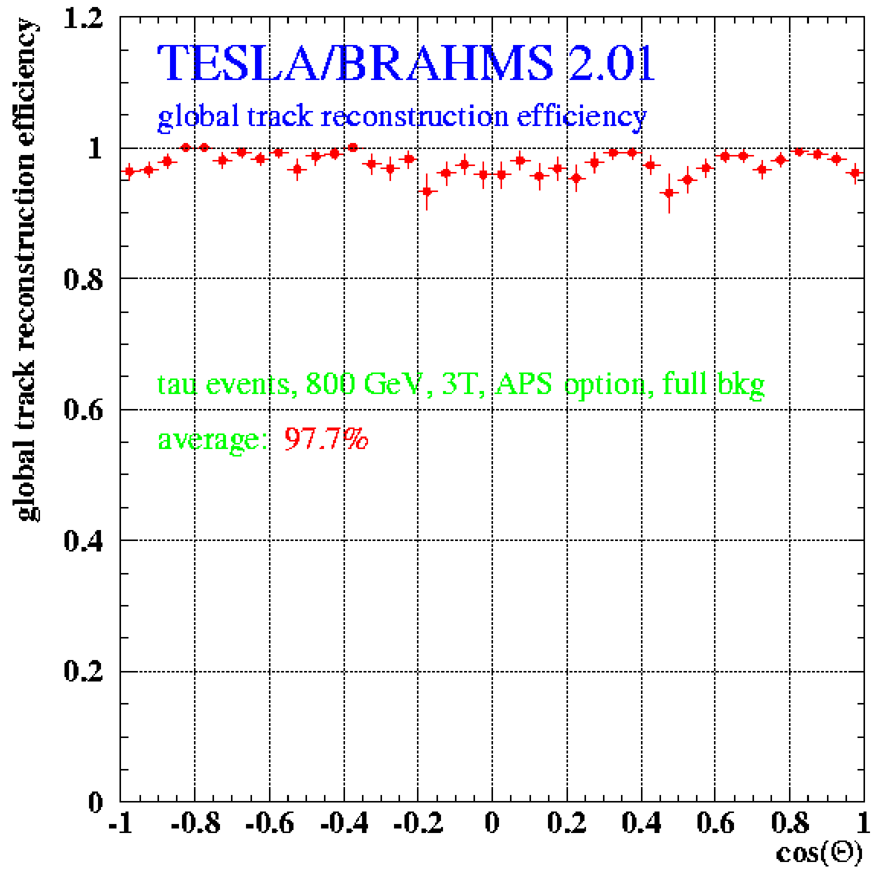
Efficiency: 98.4%

Overall Performance, tau

tau events, 800 GeV, full background

efficiency: 97.7%



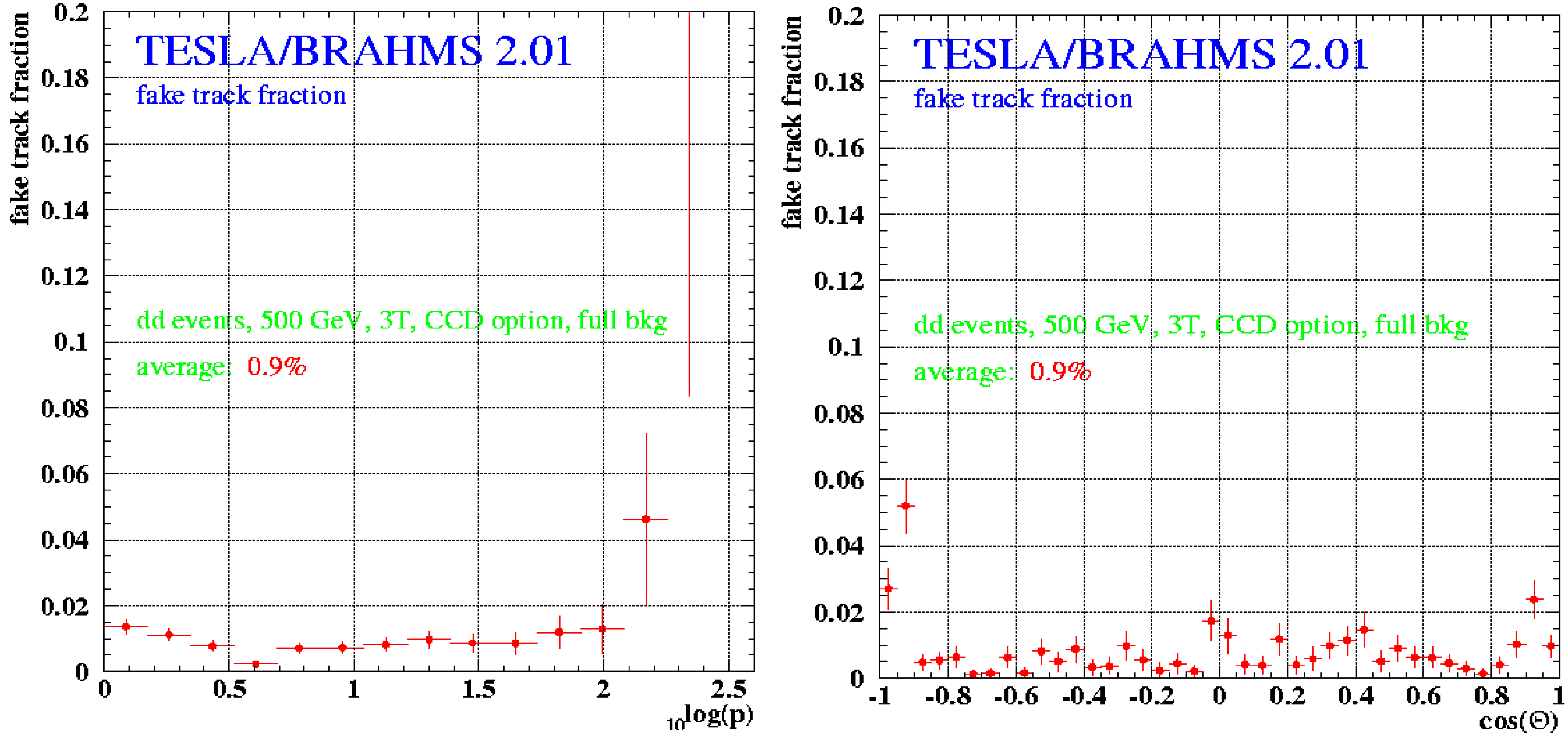


Overall Performance: Fake Rates, dd

- Fake tracks: produce extra tracks (split tracks) to same parent

dd events, 500 GeV, full background

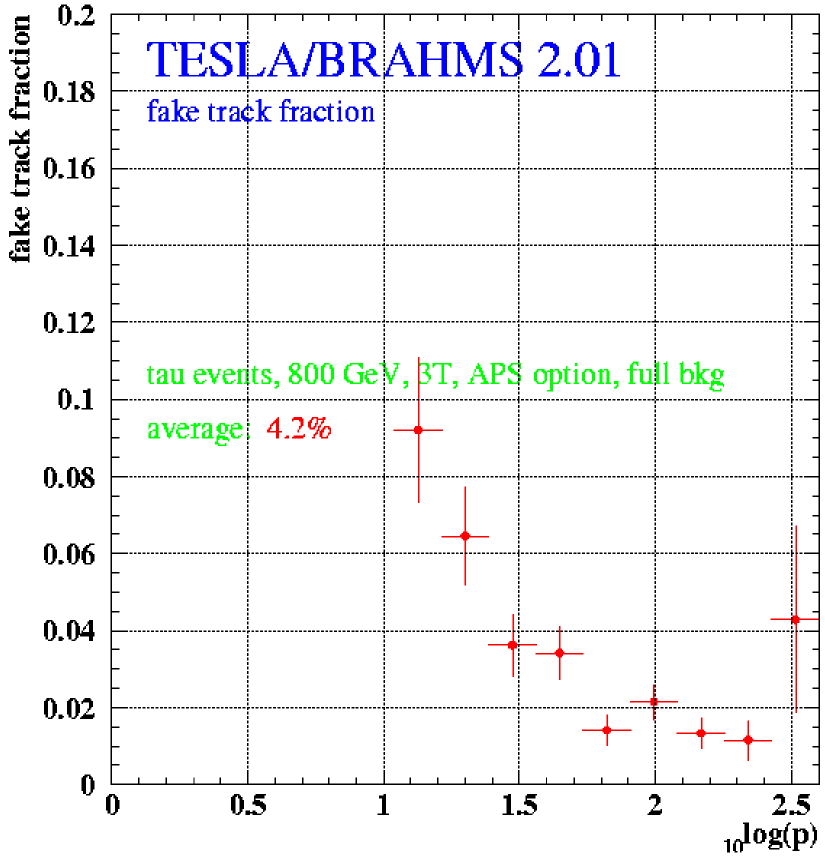
fake rate 0.9%, fairly flat

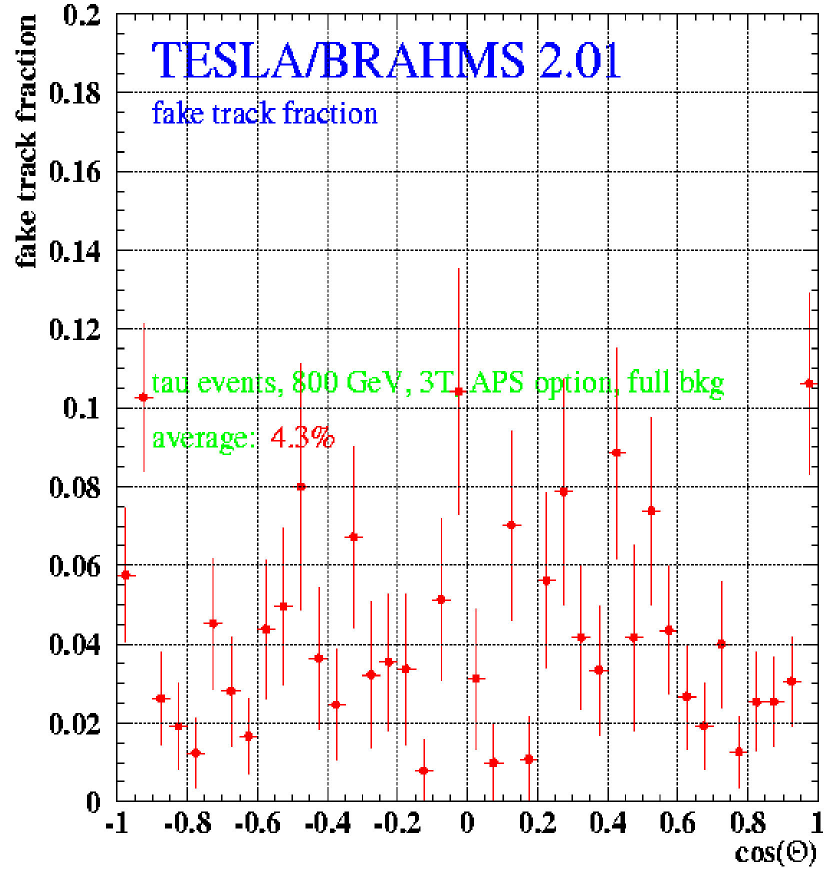


Overal Performance, Fake Rate, tau

tau events, 800 GeV, full background

fake rate: 4.2%, peaking at small momenta





Performance of Patrec

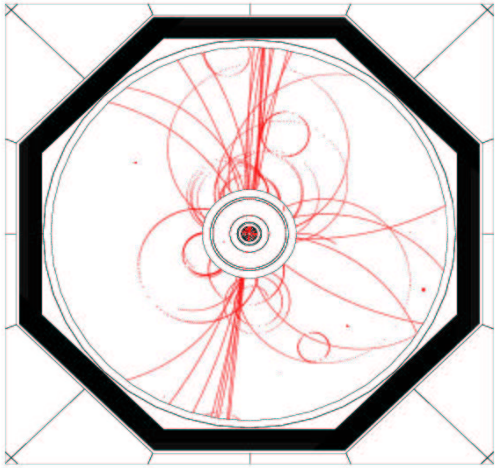
Sources of tack splitting:

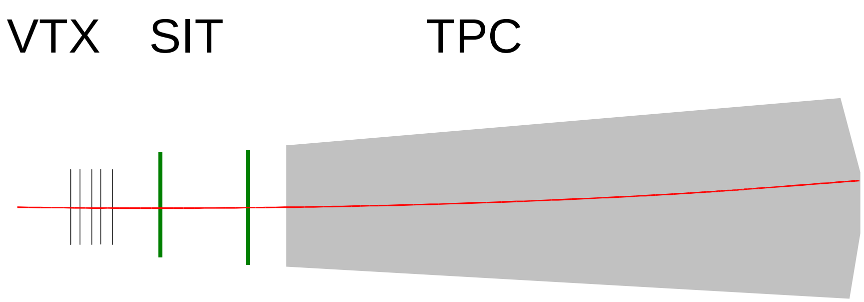
within the TPC 87%

2.7% + 2.7% between TPC and SIT2

2.0% between SIT2 and SIT1

5.4% between SIT1 und VTX





Tracking Performance Summary

A complete tracking reconstruction has been constructed and tested

Overall performance:

- tracking efficiency > 98% at 500 GeV (dd events, tau events)
- fake track fraction between 0.9 and 5%

- System has been tested with and without background
- System is stable against reasonable amounts of random hit background

things to be done:

- more realistic background simulation: cluster, curlers, etc
- how about reconstruction of the correct BX?
- how about separation of signal from background?
- need a more thourough investigation of “V0” events
- speed needs to be improved in the presence of background (SI-VTX patrec)

The system is a reasonable starting point and can be used for fairly realistic tracking studies.

The Calorimeter

- The need for excellent calorimetry has long been recognised

Z-experiments have shown that “energy flow” is a viable concept:
- combine the best from the tracker with the best from the calorimeter
- treat the tracker / calorimeter as one detector, not as competing ones

Logical consequence:

tracking/ imaging calorimeter

Many different concepts have been discussed
- liquid “TPC” calorimeters
- fiber calorimeters
- heavy liquid calorimeters

Si-W sampling calorimeter
as a feasible approximation
(though somewhat expensive)

The “TESLA-TDR” Calorimeter

Main parameters of the Calorimeter:

ECAL: SI-W sampling

30 layers 0.4 X0 absorbers = 1.4 mm W
12 layers 1.2 X0 absorbers = 4.2 mm W

readout gap thickness: 4.9mm including SI

cell size about 1x1 cm^2 (< Moliere Radius)

HCAL: Fe (Co) – XX sampling

38 layers, min 4.5 λ (barrel, more in endcap)

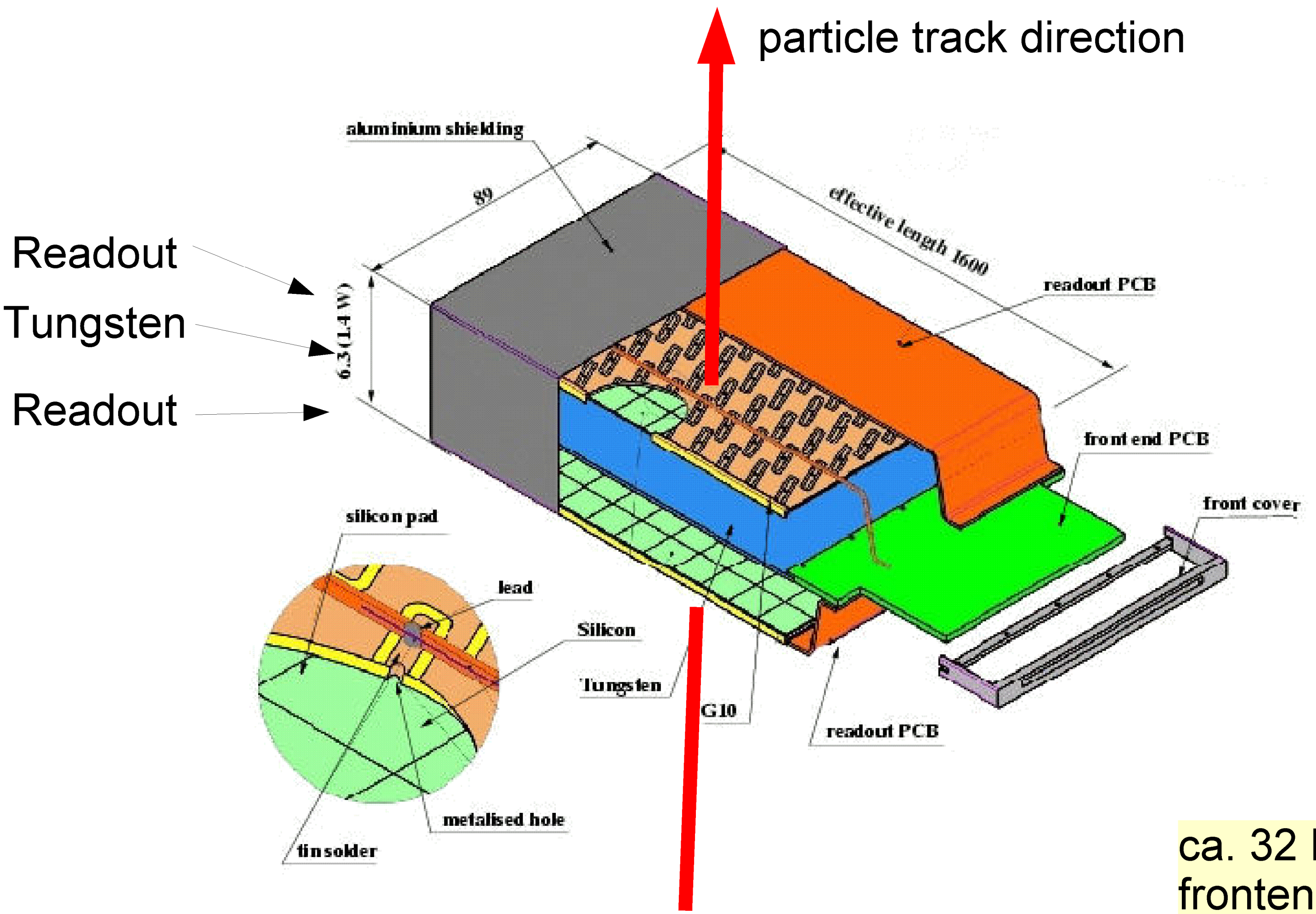
readout with Szintillator (min 5x5 cm^2 cells)

or as “digital” device: (1x1 cm^2 cells, 1 bit readout)

This is of course an “ideal” device
A lot of work is currently going into investigating the need for such a device, and into optimising the cost: CALICE collaboration

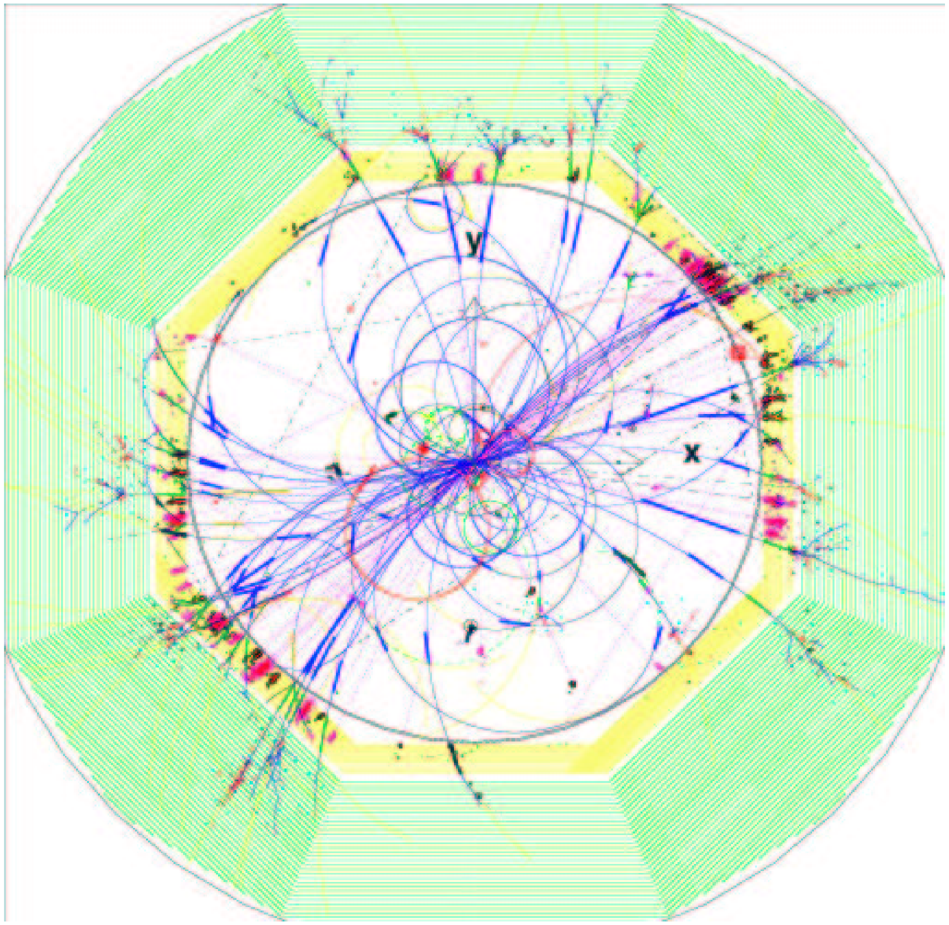
The ECAL Calorimeter “Cell”

Drawing of the smallest mechanical element, a “drawer” of the ECAL



ca. 32 Mio channels
frontend on detector
highly multiplexed readout

Calorimeter Reconstruction



tt event at 350 GeV, no ISR

The Goal:

Reconstruct the 4-momentum of all particles (charged and neutral) in the event

This is traditionally called "Energy Flow"

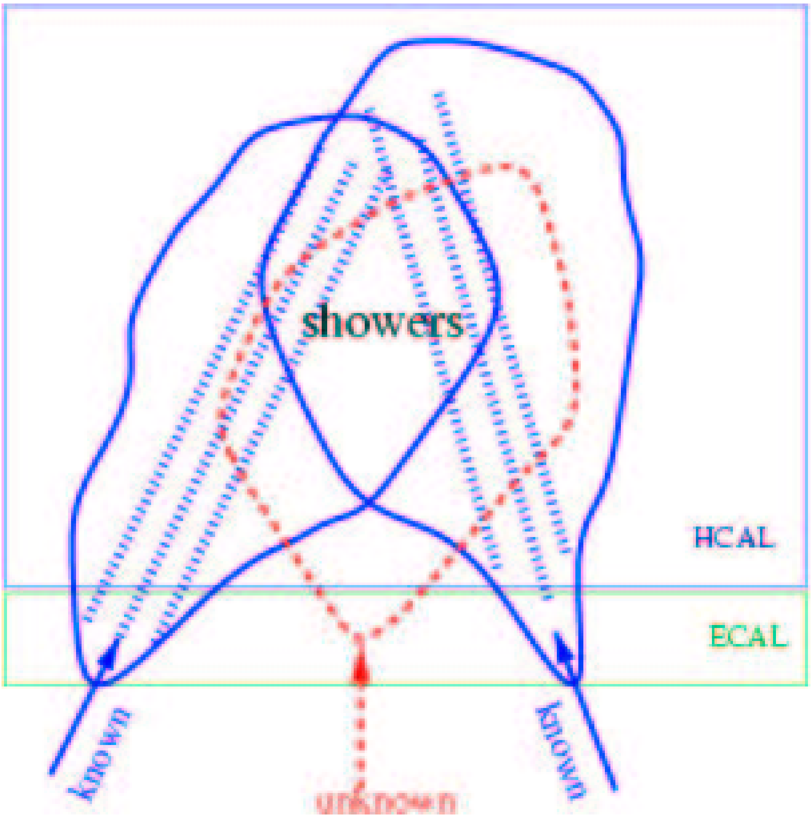
which is misleading.

It should really be called "**Particle Flow**"

Particle / Energy Flow in this context does not deal with eventproperties

but only with particles
Event properties are part of the analysis

The Algorithm: “SNARK”



A version of the energy flow
has been realised in a recosntruction
program:

SNARK, Author Vassilly Morgunov

which is part of the BRAHMS suite

- Tracks from charged particles in the tracker are linked to clusters in the calo
  Calo clusters have MAGNITUDE and DIRECTION!
- The associated energy in the calo is **substituted** by the more precise energy from the tracker
- Overlaps of showers are estimated based on magnitude and direction. Charged particle clusters are subtracted, to measure the neutral particles

The Algorithm II

1. Collect hits in the calorimeter along the predicted track (track core) within a distance of +/- one electronic cell.

2. Make a first particle hypothesis (e.g. MIP, ...)

3. Predict the transverse shower profile, collect more hits within the expected road

4. Iterate, until measurement and expectation agree best

5. Any hits which at the end of the procedure are not associated belong to a neutral particle. Run “conventional” clustering, determine properties of neutral particle

The system depends on

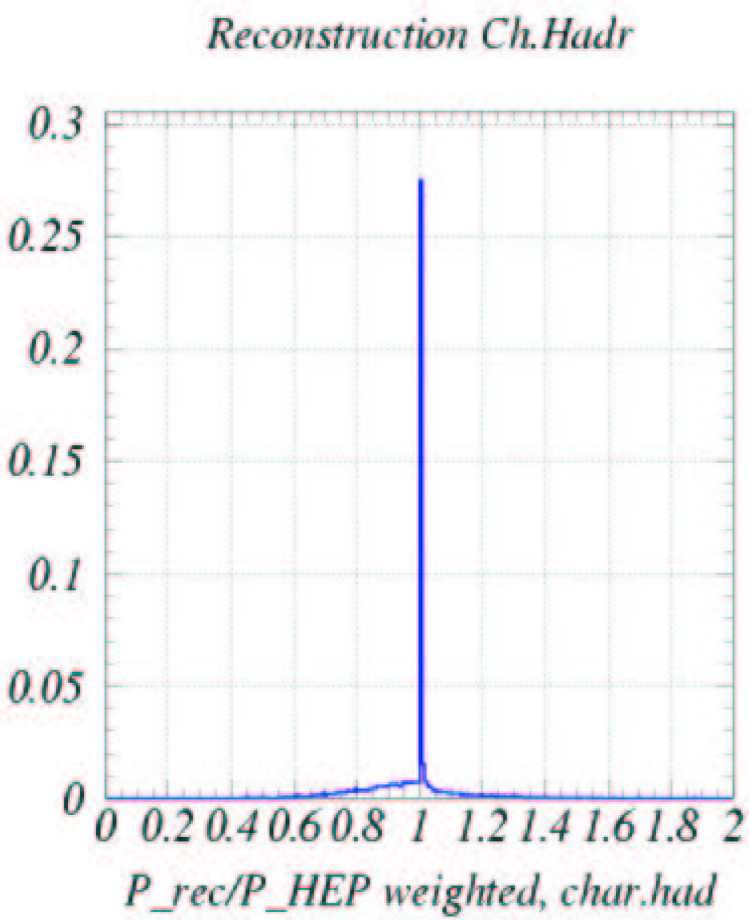
- high granularity both in ECAL and HCAL
- excellent linking between Tracker – ECAL – HCAL
- extensive use of amplitude info (optimised for tile HCAL)

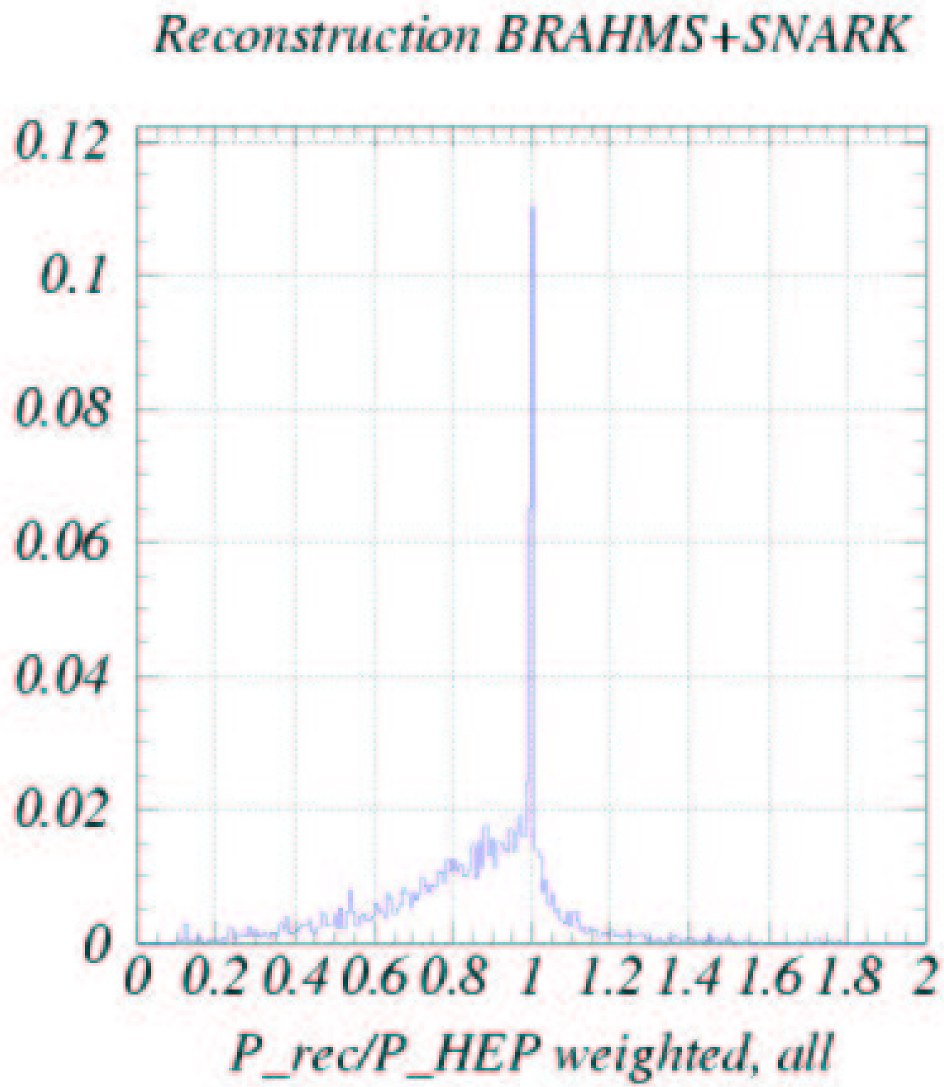
Note: a similar program, but optimised for the digital HCAL, is also under development (Ecole Polytechnic)

Some results

Compare reconstructed to expected Momentum: P_rec/ P_MC

ZH -> hadron events at 500 GeV

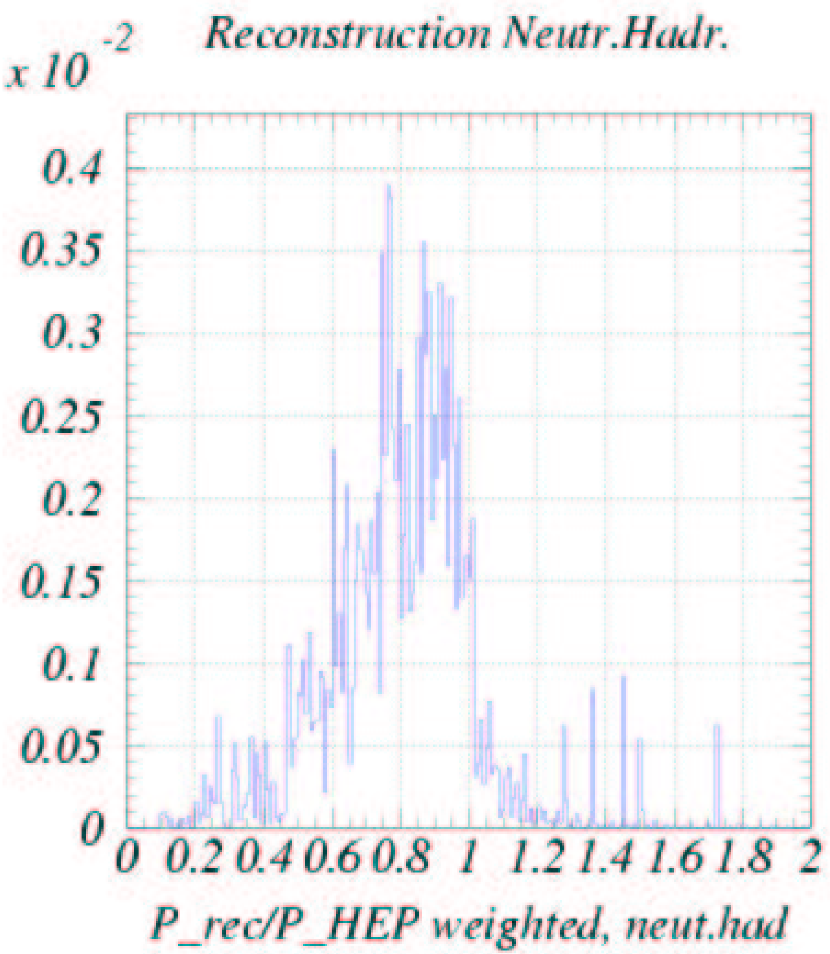




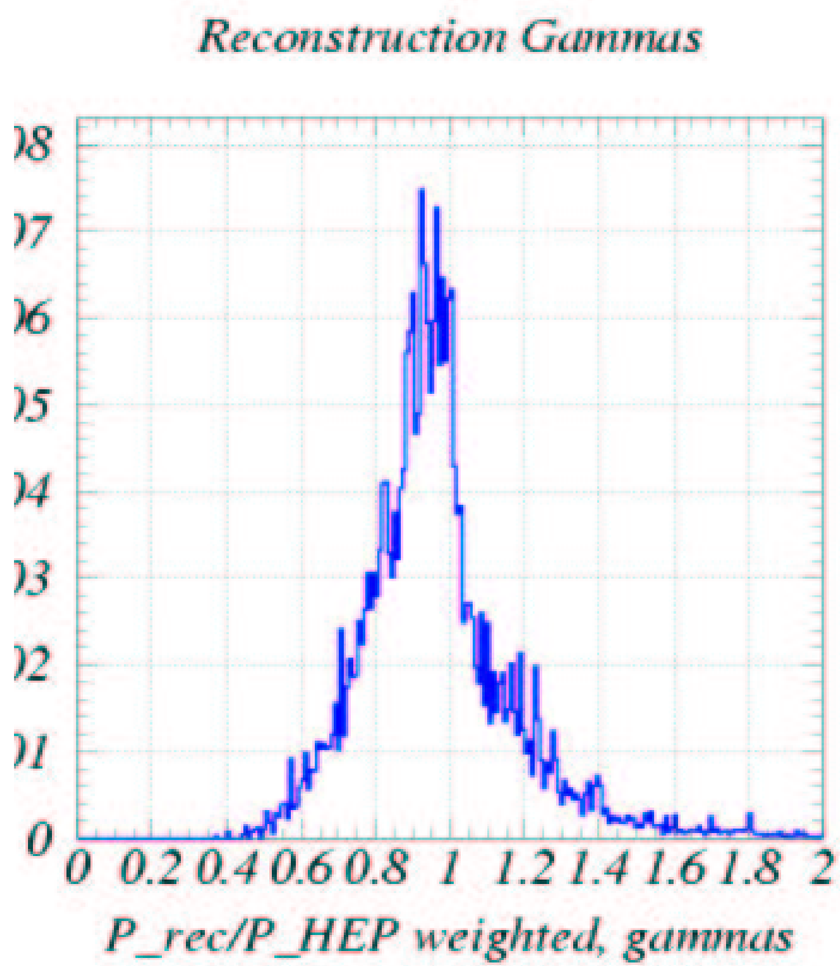
Neutrals/ Photons

Tails are from neutral particles:

Neutral hadrons



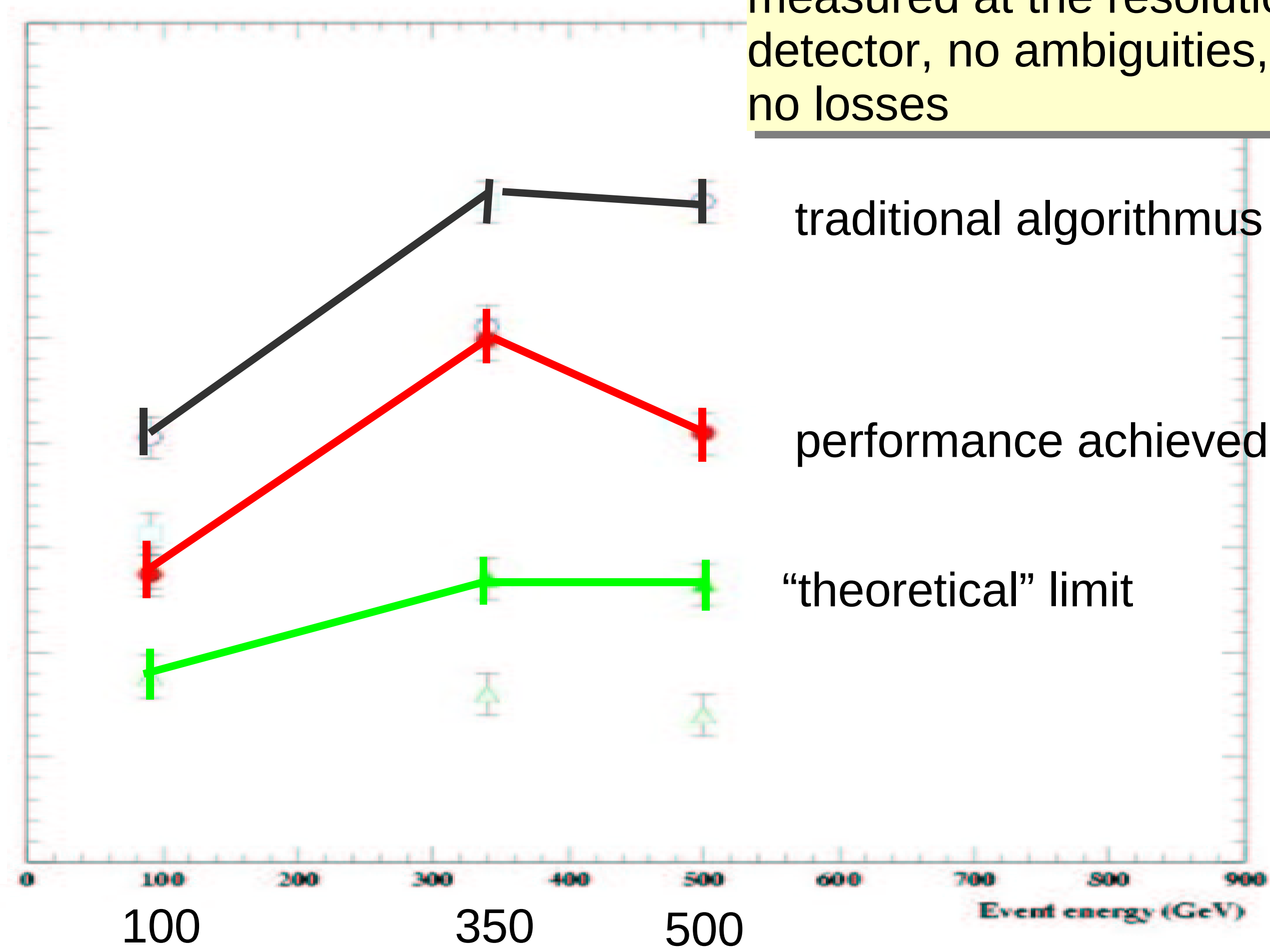
Photons



Overall Performance

Overall performance rather difficult to estimate
- depends on the physics
- depends on the implementation details

take TDR detector geometry
traditional: no energy flow
limit: assume all particles are measured at the resolution of the detector, no ambiguities, no overlaps, no losses



Summary and Conclusion

- A rather detailed (though inflexible) simulation program exists for the TESLA TDR detector
- A fairly complete tracking package has been developed for a LC detector
  - more work needed in tuning
  - more work needed in investigating details (split tracks)
  - work needed on speeding up
- Several approaches are being followed for a energy / particle flow reconstruction package
  - SNARK: Vassilly Morgunov
  - REPLIC: Jean Claude Brient

  - both based on energy / particle flow concept
  - differences in detailed assumptions and procedures

  - optimisation needed
  - quantification of the performance is needed
  - in-depth study of the different calorimeter designs is the goal

What do we really need?

Work on making interfaces to these packages are under way