LCWS 2000 Calorimetry Summary

R. Frey

Dec 12, 2000

- Based mostly on Summary Talk by J.C. Brient
- I won't discuss all topics or go into much detail

First informations

1 - The jet energy flow measurement is now intensively studied (about 50% of the talks)

2 - All the 3 regions attack this problem.

3 - Experts in reconstruction/Eflow begins to speak to experts in calor.design/hardware

Physics ⟺ **Eflow** ⟺ **Hardware**

Almost missing up to now

The quantitative test of a device must include the Eflow and **not only single particle results**

For one design $\Longrightarrow \Delta M \,,\, \Delta E_{jet}$

- 2-b jets, WW , mass resolution (Higgs)
- WW/ZZ separation
- $t\bar{t}$ final state (large number of jets) • • •

Presentation of the session

1. Pascal Gay (LPC-Clermont)
Eflow with granular calorimeter

2. Raymond Frey (Univ. Oregon)
Eflow jet reconstruction: Fast and full simulation studies

3. Yoshiaki Fujii (KEK)
Jet reconstruction studies

4. Vasiliy Morgunov (DESY)
HCAL reconstruction

5. Gary Bower (SLAC)
Calorimetry and jet reconstruction

6. Norman Graf (SLAC)
Clustering algorithm studies

7. Henri Videau (LPNHE-Ecole Polytechnique)
The W-Si electromagnetic calorimeter

8. Volker Korbel (DESY)
Tile hadronic calorimeter

9. Paolo Checchia (INFN-Padova)
The ECAL Shashlik design

10. Toru Takeshita (Univ. Shinshu)
Tile/Fiber hadron calorimeter performance

11. Kiyotomo Kawagoe (Univ. Kobe)
Performance of preshower/showermax detectors

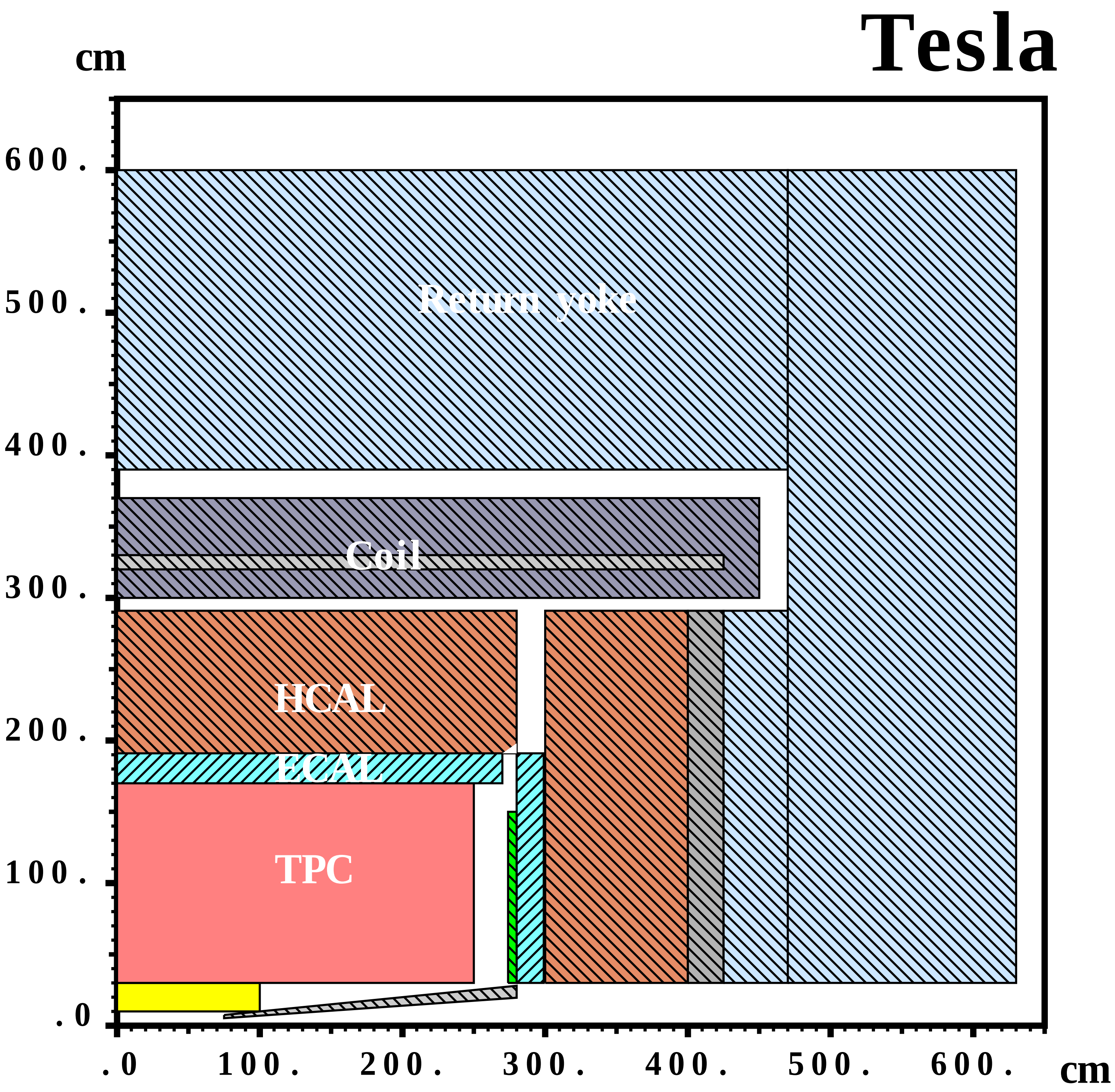
EFLOW studies
with ECFA/DESY TDR
Calorimeter

ECAL A • W-Si sampling cal.
B • Shashlik

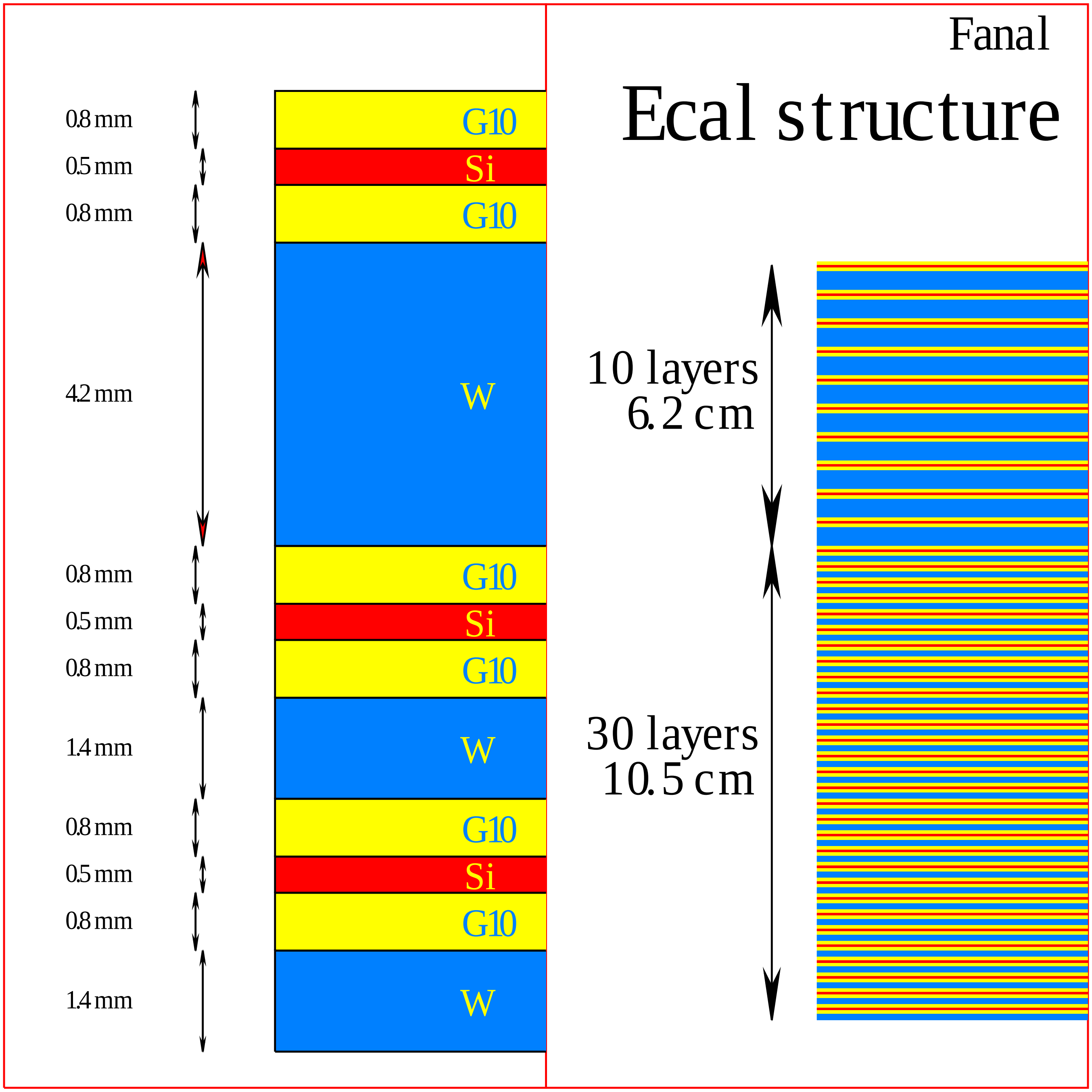
HCAL C • TiLE - INOX
D • Digital cal.

Report on EFLOW
on A - C Wsi - Tile
and A - D Wsi - Digital

view of the detector



configuration



Energy Flow

with high granularity calorimeters

P. Gay

JC. Brient P. Cloarec V. Djordjadze P. Mora de Freitas
F. Le Diberder S. Monteil D. Orlando D. Reid H. Videau

FRAMEWORK

consists in ECAL and HCAL design and Jet reconstruction algorithm

- detectors

ECAL Si/W sampling calorimeter

Known principle

all requests fulfilled

$\Delta E_\gamma/E_\gamma \sim 10.3\%/\sqrt{E_\gamma}$

1x1cm^2 pad size

HCAL Digital calorimeter

sampling calorimeter (inox) with digital pad read-out

energy reconstructed from pad multiplicity (principle tested w/ ALEPH data)

1x1cm^2 pad size

- EFLOW algorithm

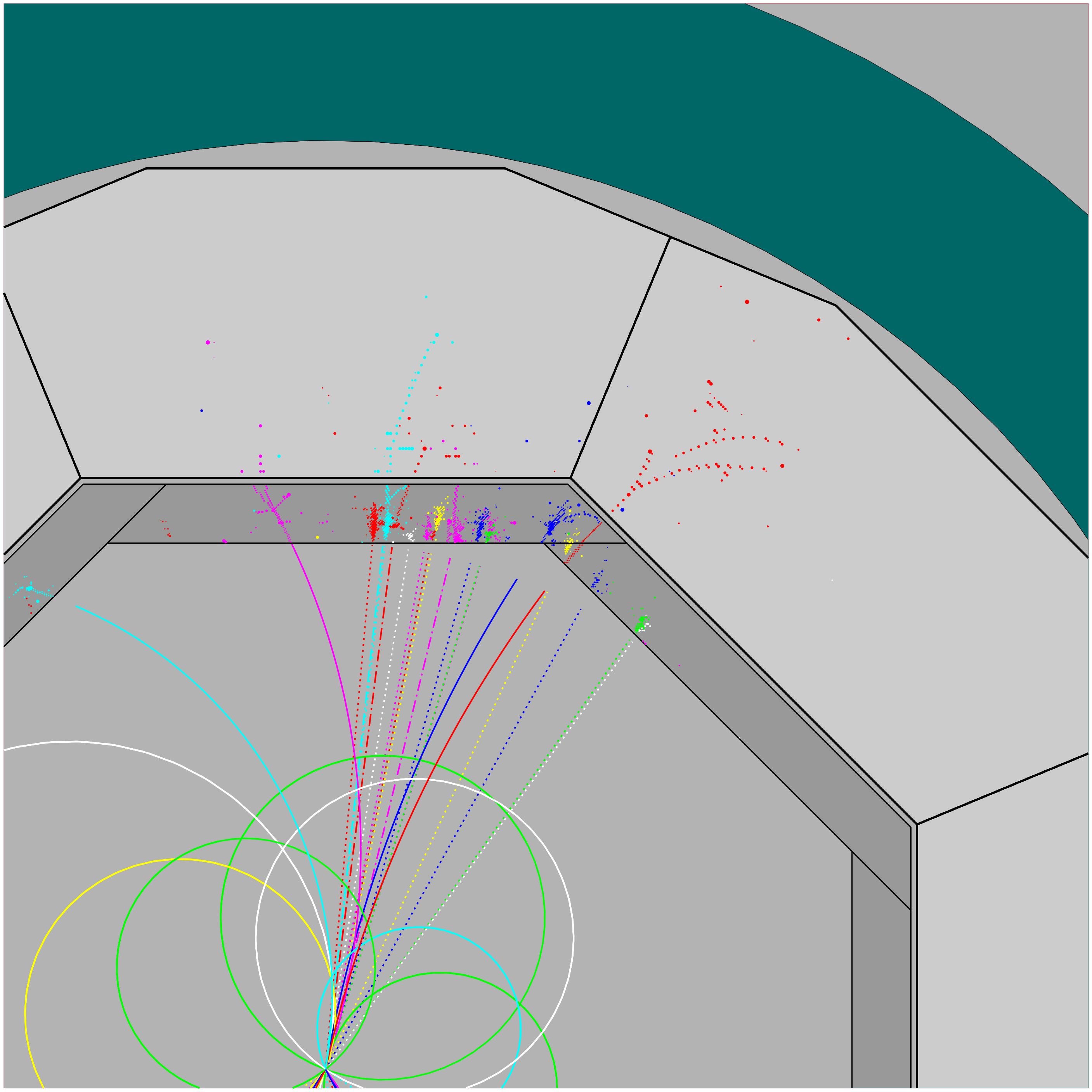
$$E_{\rm jet} = \Sigma\ E_{\rm ch} + \Sigma\ E_\gamma + \Sigma\ E_{\rm neutralh}$$

Identification and reconstruction of all eflow objects

- Charged tracks from tracker system
- Photons from ECAL ⇛ photon reconstruction★
- Neutral hadrons (K_L, neutron) from ECAL & HCAL ⇛ neutral hadron reconstruction★

★ w/ rejection of debris from charged hadron interaction

GRANULARITY



Zoom on the transverse view of the detector

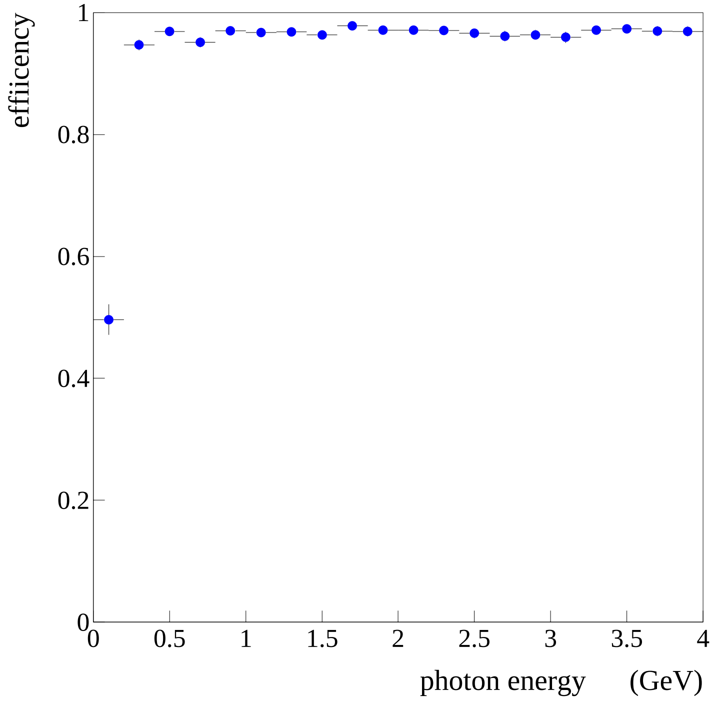
Visualization performed w/ `FANAL` package developed by H.Videau

PHOTONS

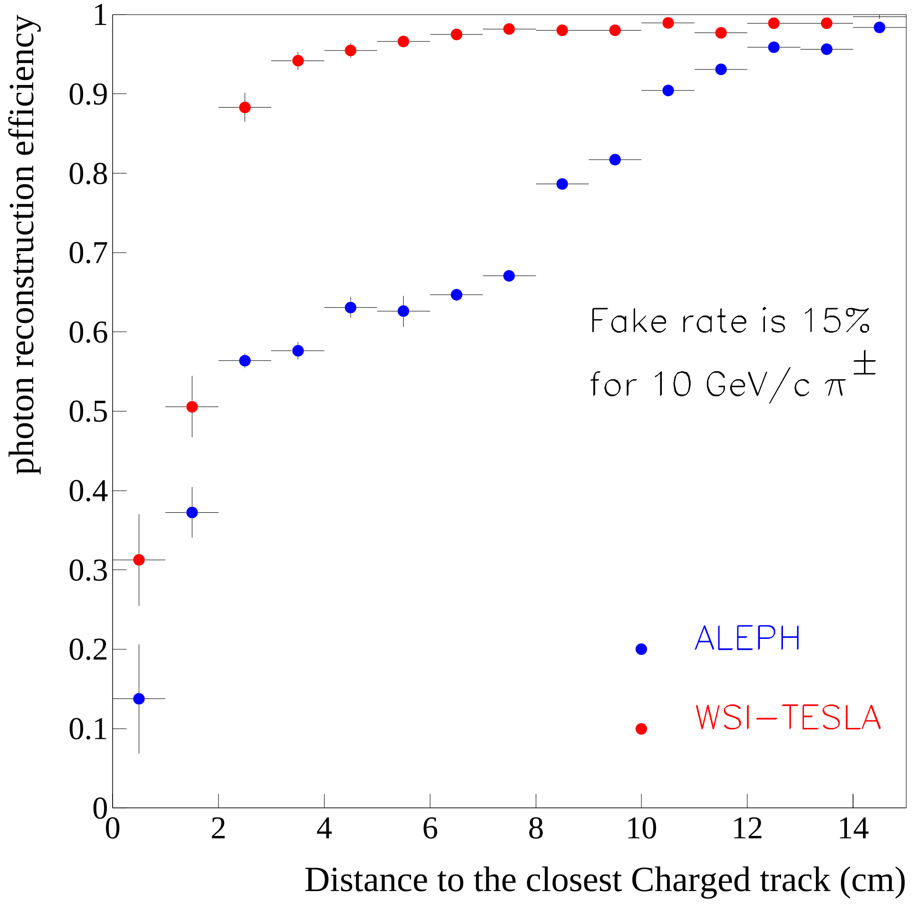
Anyway some benchmarks are needed

PFD efficency to find photon in the low energy region

$\sim$ 99% above 0.25 GeV



ALEPH/WSI-TESLA for the same rate of fake



Photon reconstruction efficiency as a function of the distance to charged tracks ($\pi^\pm$)

Eff. greater than 85% since 3 cm and 50% at 2 cm

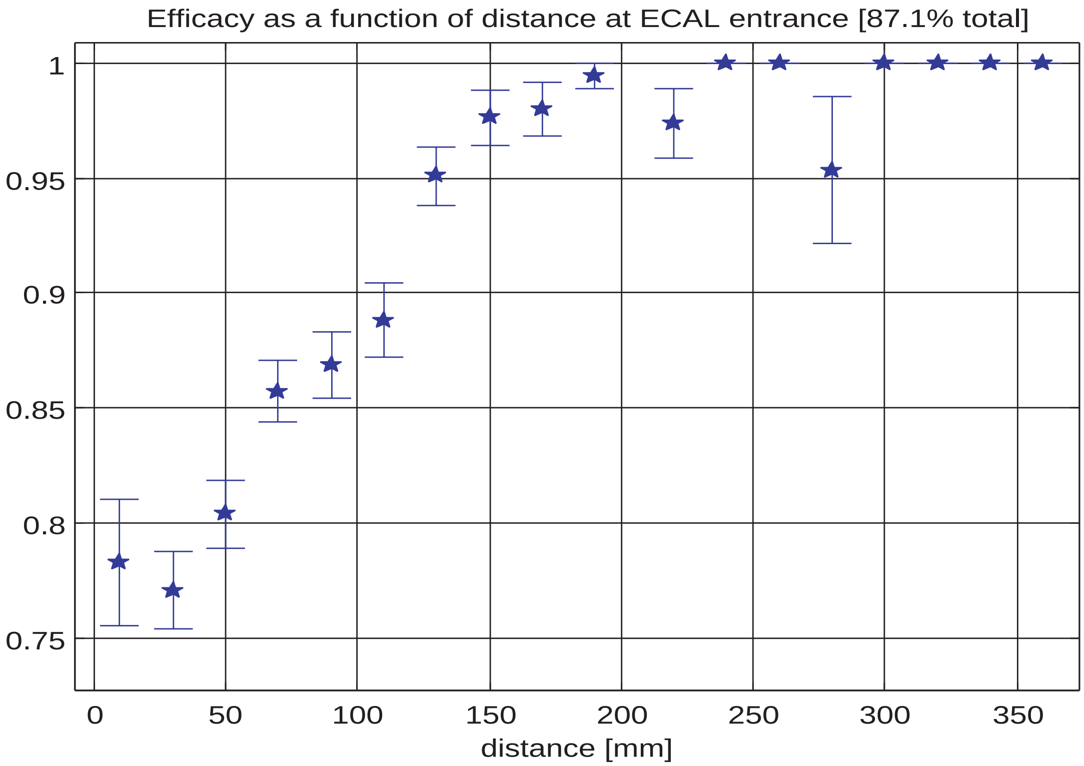
(for a fake rate $\sim$ 15%)

Largely better than ALEPH

up to 10 cm

NEUTRAL HADRONS

Reconstruct a neutral hadron very close to a charged track is possible
with a reasonable efficiency : ~75% @ 1 cm



Full simulation and reconstruction

no use of $\pi^{\pm}$momentum

code not yet adapted for jets (very slow)

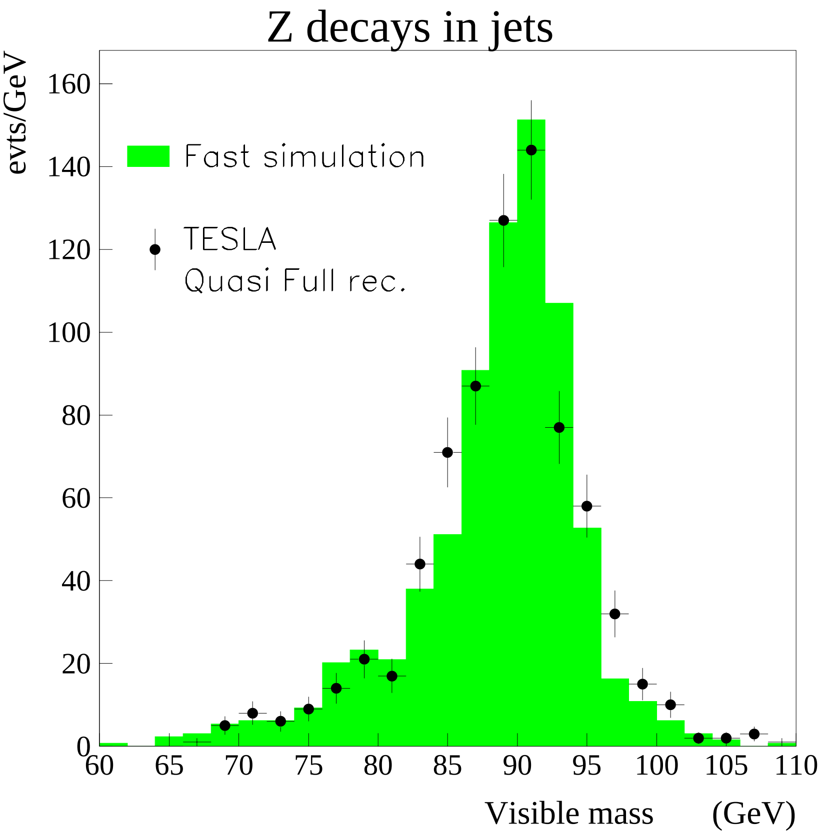
thus a fast simulation based on output from full reconstruction has been used for jets

JETS (1)

Quasi-full reconstruction

- **Charged tracks**
  fast simulation
  $\mathcal{E}_{\mathrm{track}}$**=99.7%**
  $\mathrm{P}_{\mathrm{min}}$**=0.2GeV/**$\mathrm{c}^2$
- **Photons**
  full reconstruction
  $\mathrm{E}_{\mathrm{min}}$**=200 MeV**
  no calibration
- **Neutral hadrons (**K_{L}**, neutrons)**
  fast simulation
  fake rate and $\mathcal{E}(\mathrm{E}, \mathrm{dist})$ **from full reconstruction**
  $\mathrm{E}_{\mathrm{min}}$**=500 MeV**

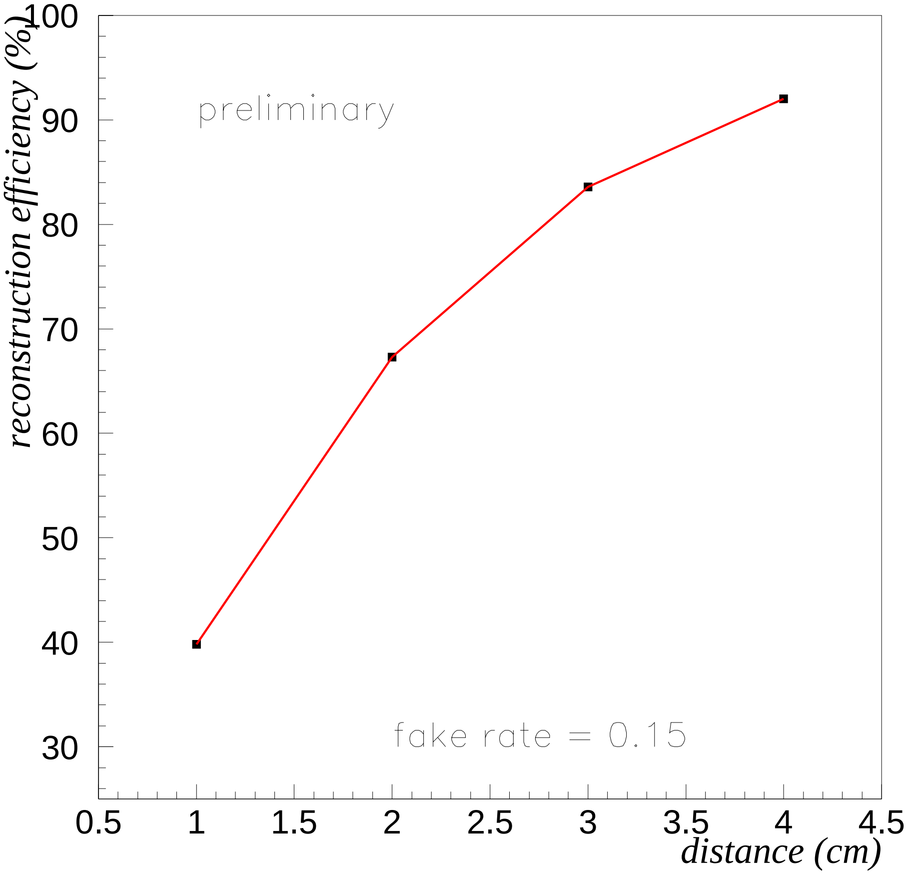
Test



PROSPECTS

with a crude vertexing method and branch definition for γ(1GeV)/$\pi^{\pm}$(10GeV)

eff.$_{\gamma}$ as a function of the distance



potential gain

NB.

ΔM_{vis}	e.m.	neutral h	$h^{\pm}$
4.2 GeV/c^2	1.7 GeV/c^2	3.9 GeV/c^2	-

'vertex' reconstruction in ECAL/HCAL would be a solution to improve the K/$\pi^{\pm}$separation

Summary of the Eflow studies

1- Using a small granularity calorimeter

Cf. P.Gay

▷ relative contribution from energy resolution , reconstruction
⟹ reconstruction is the major part

▷ Granular calorimeters (all pads are 1x1 cm) are very powerfull detectors for jets Eflow

- about 75% of the K0 are reconstructed at 3 cm from a charged track (about 99% at 20cm)
- about 90% of the photon are reconstructed at 3 cm from a charged track (about 99% at 10cm)

Full reconstruction with classical approach (clustering) gives already **about a factor 2 improvement** compared to LEP detectors

For jets, ΔE $\sim$ 40% $\sqrt{E}$

Prospect for improvment

Based on 3-D pattern and statistical approach, 30% $\sqrt{E}$ could be reached !!

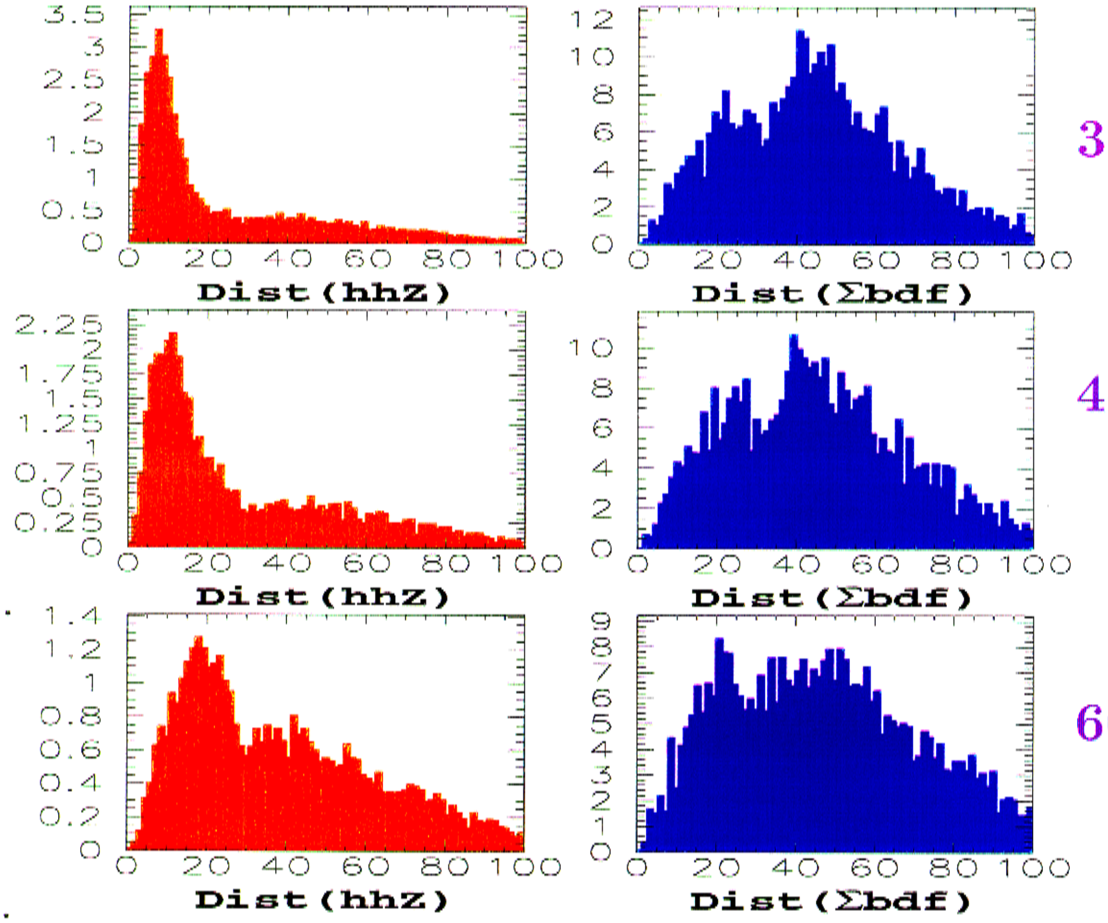
Summary of the Eflow studies

▷ Impact on Physics

P.Gay uses the measurement of the Higgs self-coupling to study the impact of the jets resolution.

Running from 60% to 30% for the jet energy resolution

- the background changes by a factor 6
- the precision on the cross section hhZ, by a factor 1.6



$30\% \sqrt{E}$

$40\% \sqrt{E}$

$60\% \sqrt{E}$

At least $40\% \sqrt{E}$ for jets energy resolution seems to be mandatory for this measurement

Study of Energy Flow in Jet Reconstruction

R. Frey & M. Iwasaki, Univ. of Oregon

- Good jet reconstruction essential to explore and make use of all decay modes
  - ○ multi-jet masses: e.g. Zh *vs* ZZ *vs* WW
  - ○ reconstruct parton angles to extract quantum numbers, anomalous moments, e.g. WW, $t\bar{t}$, $t \rightarrow bqq'$
- Use combination of tracker and calorimeter which provides best resolution: tracker for $h^{\pm}$, EM cal. for π^0 (, HAD cal. for K_L^0, etc.)
- Requires excellent $\gamma - h^{\pm}$ id. ⇒ EM Cal. segmentation
- Realistic modelling requires more-than-primitive cal. clustering algorithm(s)

This Study:

- Develop EFlow technique in LCD simulation
- Implications for detector design in terms of physics benchmarks
- Compare to other techniques for jet recon.

- Start with LCD Fast Simulation
- Move to Full Sim. (Gizmo/GEANT 4), clustering alg. (*c.f.* N. Graf talk)

Ident. and measurement of Photons

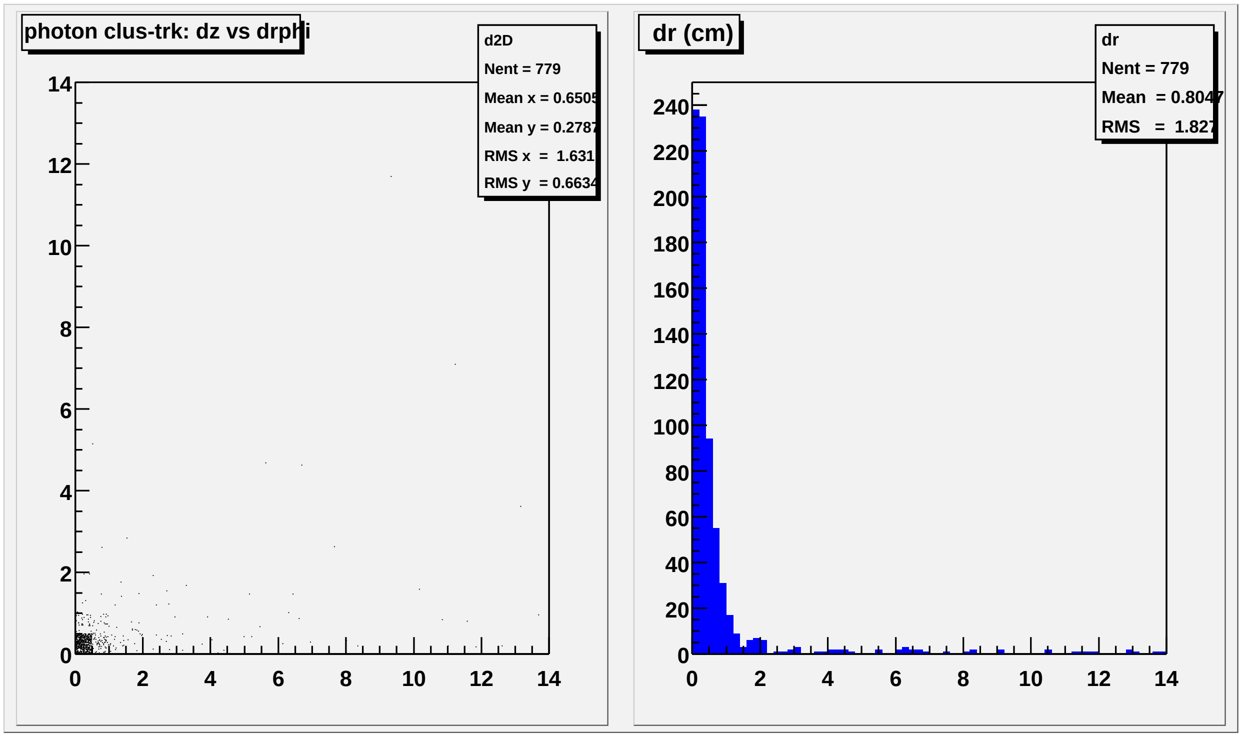
- Here, used $e^+e^- \to ZZ \to 4q$
- Start by looking at all Cal. clusters. Use to id. photons:
- Longitudinal depth of shower max. (cluster max. or shower start)
- No charged tracks overlap with cluster
  - helical extrapolation of tracks to cluster position
  - 2-D separation (bend, non-bend)
- Nearest charged track does not give $p = E$
- Combine these photon candidates with charged tracks → find jets

Separation of Cluster and nearest charged track (extrapolated)

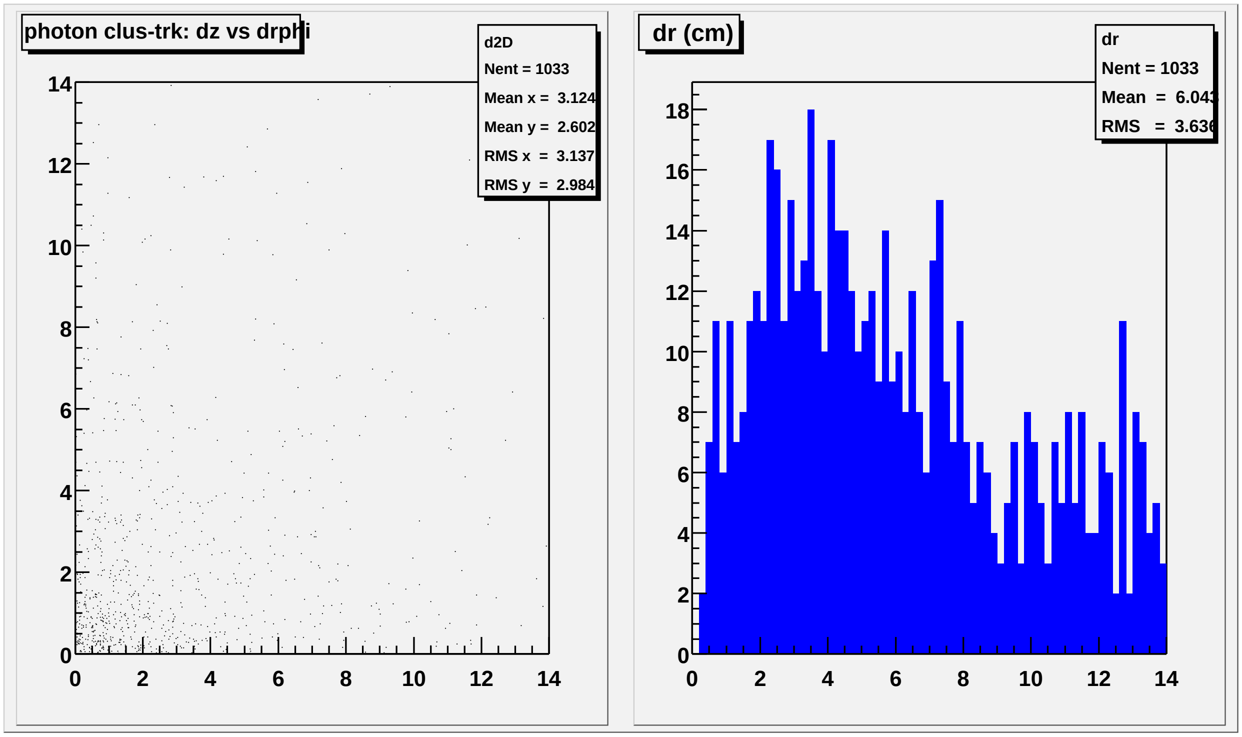
Small Detector: $BR^2 = 3.4$ T-m^2 , $R_m = 0.9$ cm

($dr \equiv$ bend $\oplus$ non-bend separations)

- Cluster is due to a $\pi^{\pm}$:



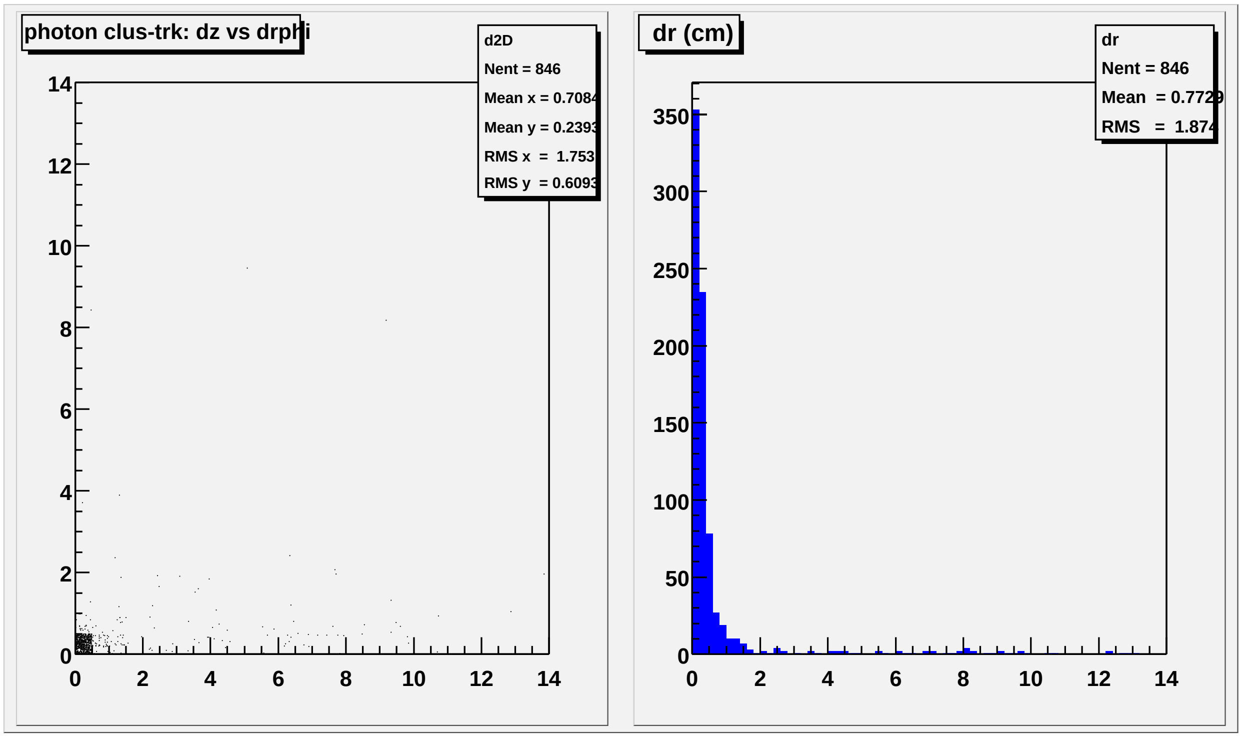
- Cluster is due to a γ:



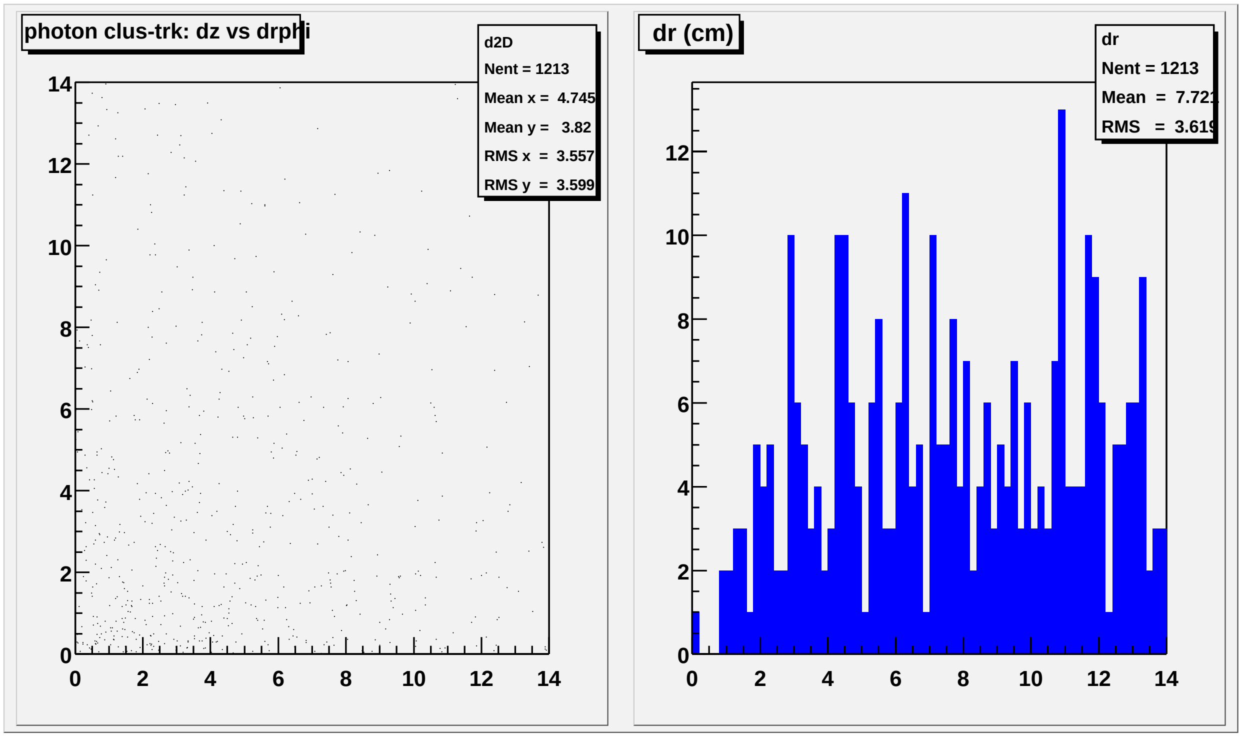
Separation of Cluster and nearest charged track (extrapolated)

Large Detector: $BR^2 = 12$ T-m^2 , $R_m = 1.6$ cm

- Cluster is due to a $\pi^{\pm}$:



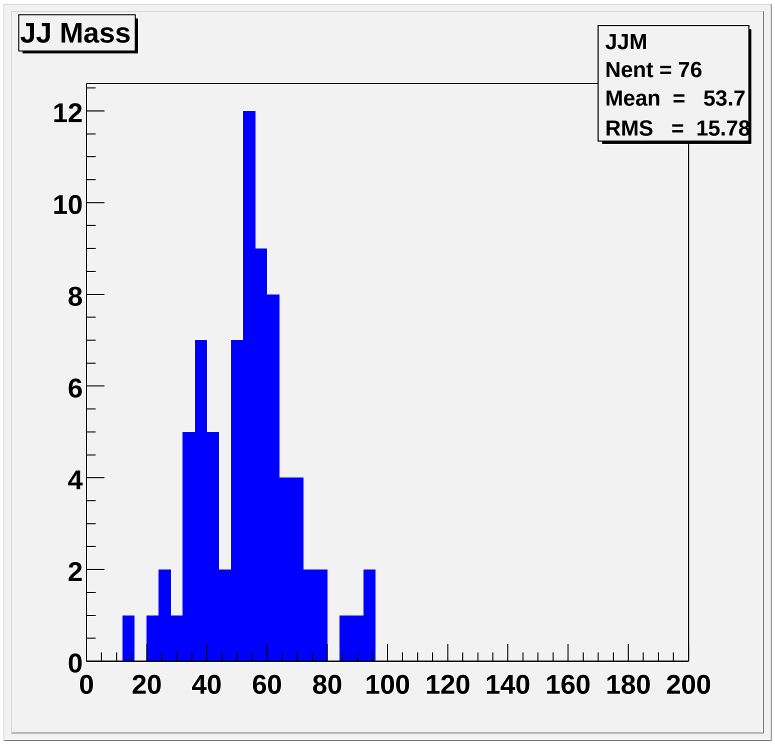
- Cluster is due to a γ:



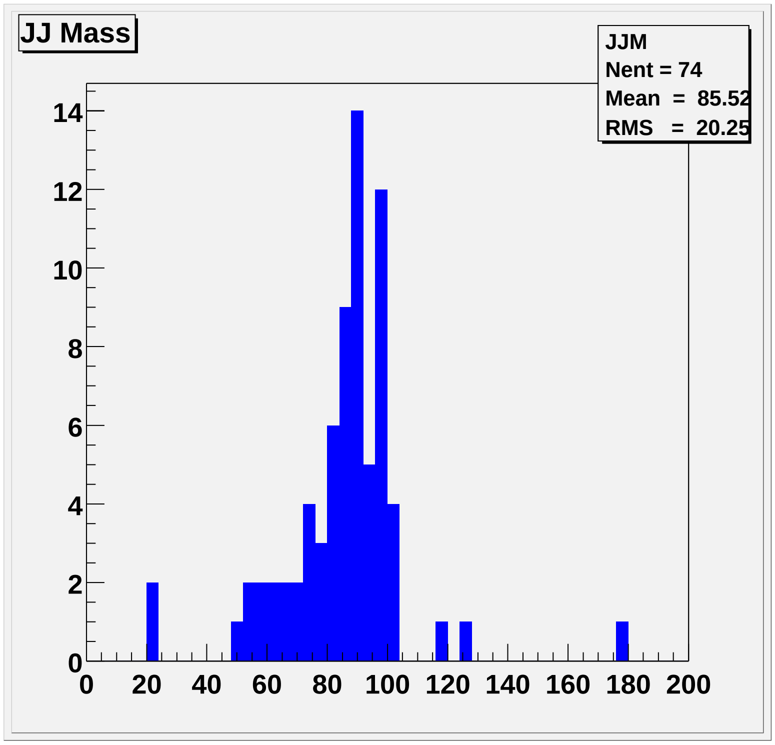
f is fraction of photon clusters which have at least one charged track within a radius d (transverse plane)

d (cm)	f (%), Small Det	f (%), Large Det
1.0	97.5	99.8
2.0	92.7	98.6
3.0	86.0	96.7
5.0	73.2	92.3
10	53.0	81.9
20		61.2

- Fast MC Simulation – Charged Tracks Only::



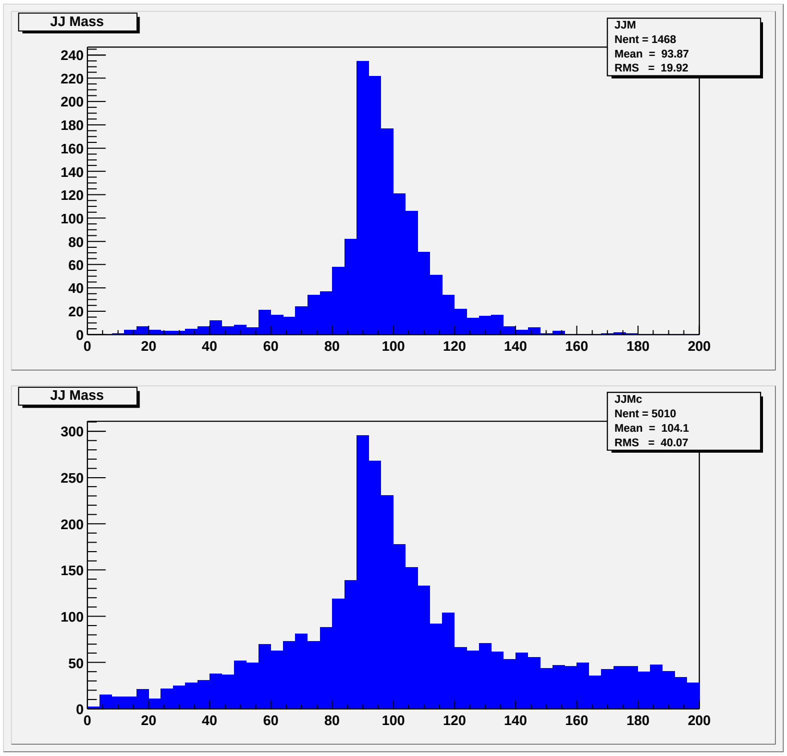
- Fast MC Simulation – Cal. Clusters Only::



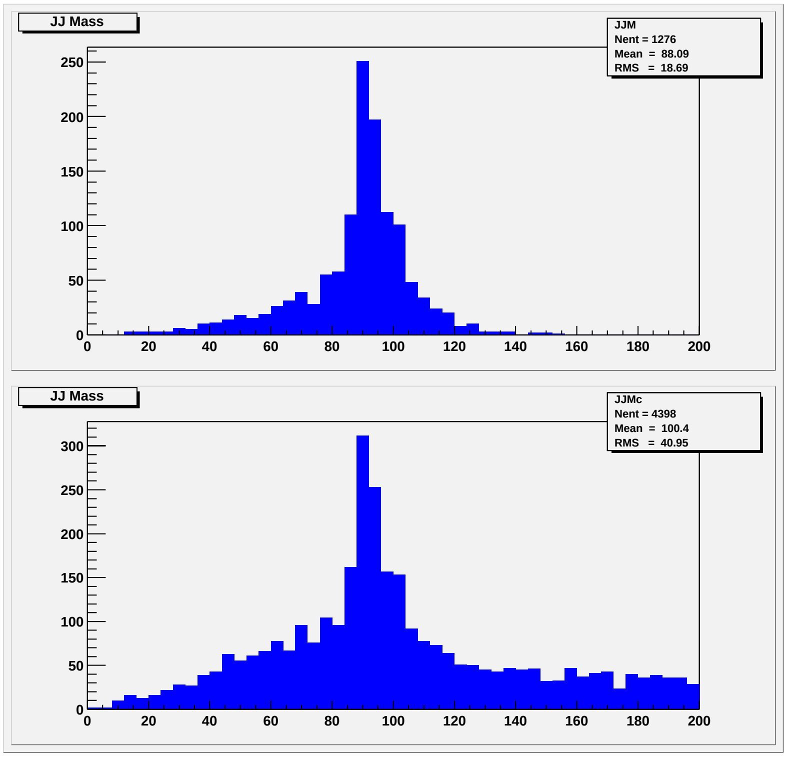
- Energy Flow - Detector S; $dr > 0.5$ cm:

  Top: Only one 2-jet combination per hemisphere.

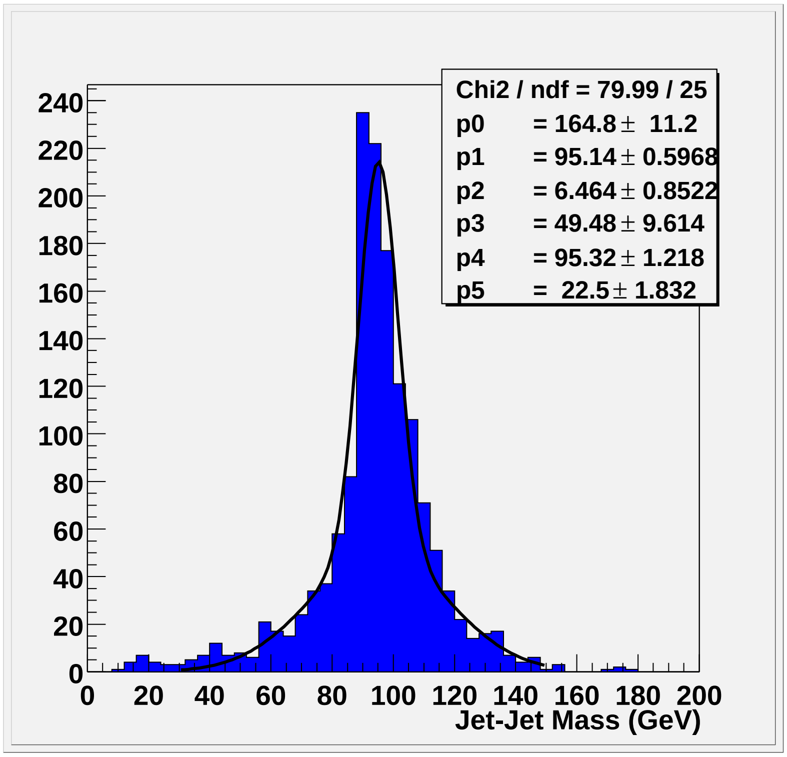
  Bottom: Form all 2-jet combinations (4-jet events).



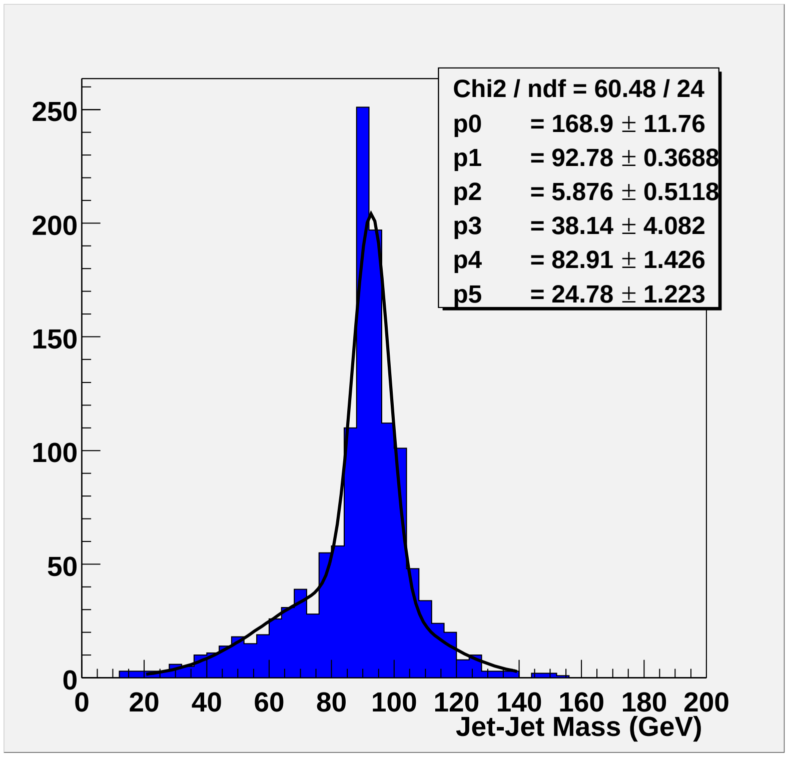
- Energy Flow - Detector L; $dr > 1.0$ cm:



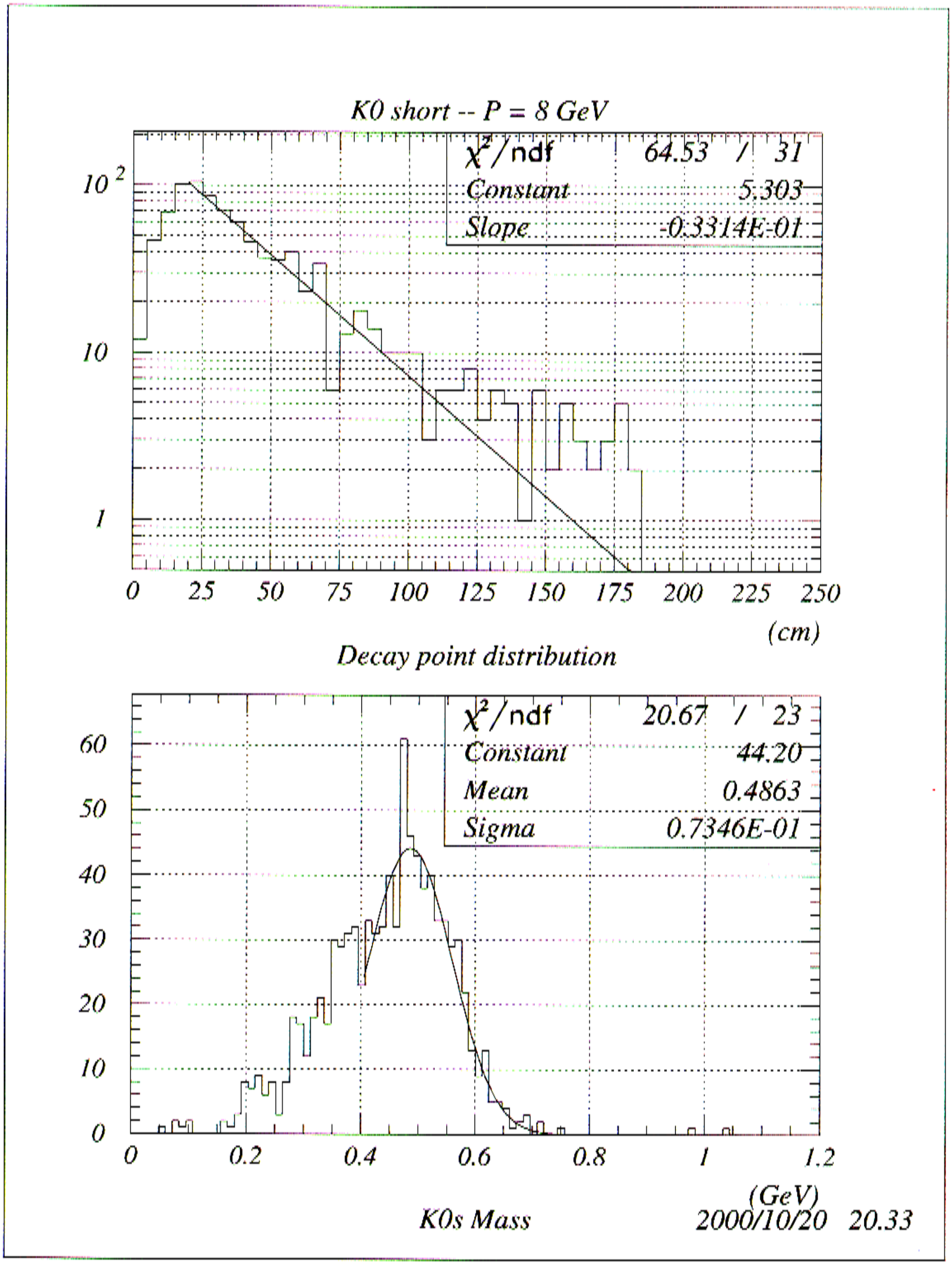
- Energy Flow - Detector S; $dr > 0.5$ cm:



- Energy Flow - Detector L; $dr > 1.0$ cm:



$K_s^0 \rightarrow \pi^0 \pi^0 \rightarrow \gamma\gamma\gamma\gamma$



– no kinematic constraint was used at this stage

2. CAL design in the Simulator

Tile-fiber sampling calorimeter with hardware compensation ratio (EM=4:1,Had=8:2)

Design Energy Resolution (not input)

$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$ for EM

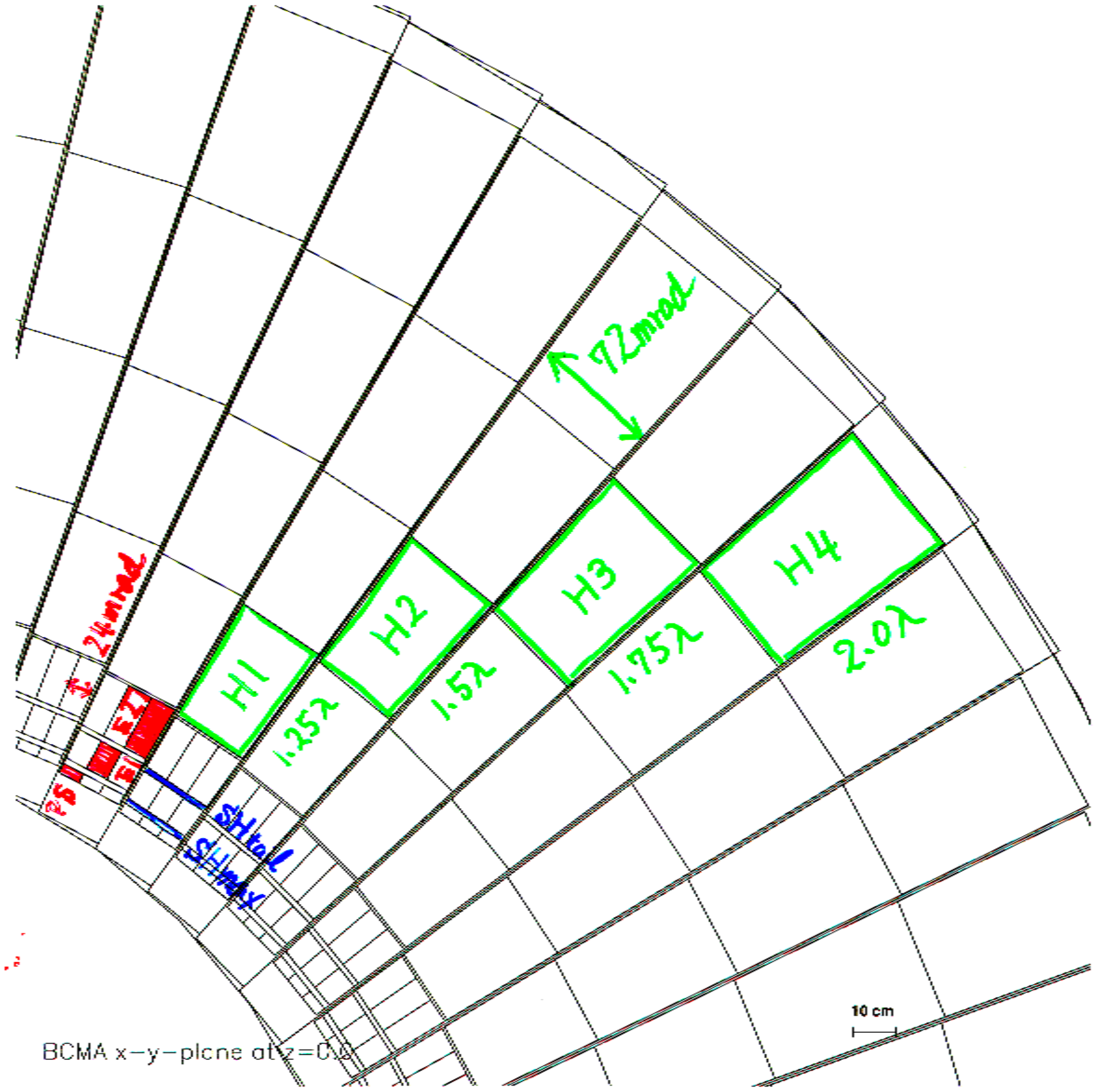
$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$ for Hadron

Configuration

PreSH +SHmax + EM1 +SHtail + EM2
+HCAL1 +HCAL2 +HCAL3 +HCAL4

Transverse segment size

- EM ; 4cm x 4cm = 24mrad
- Had; 12cm x 12cm = 72mrad



TESLA-TDR detector design

The tungsten-silicon pads ECAL

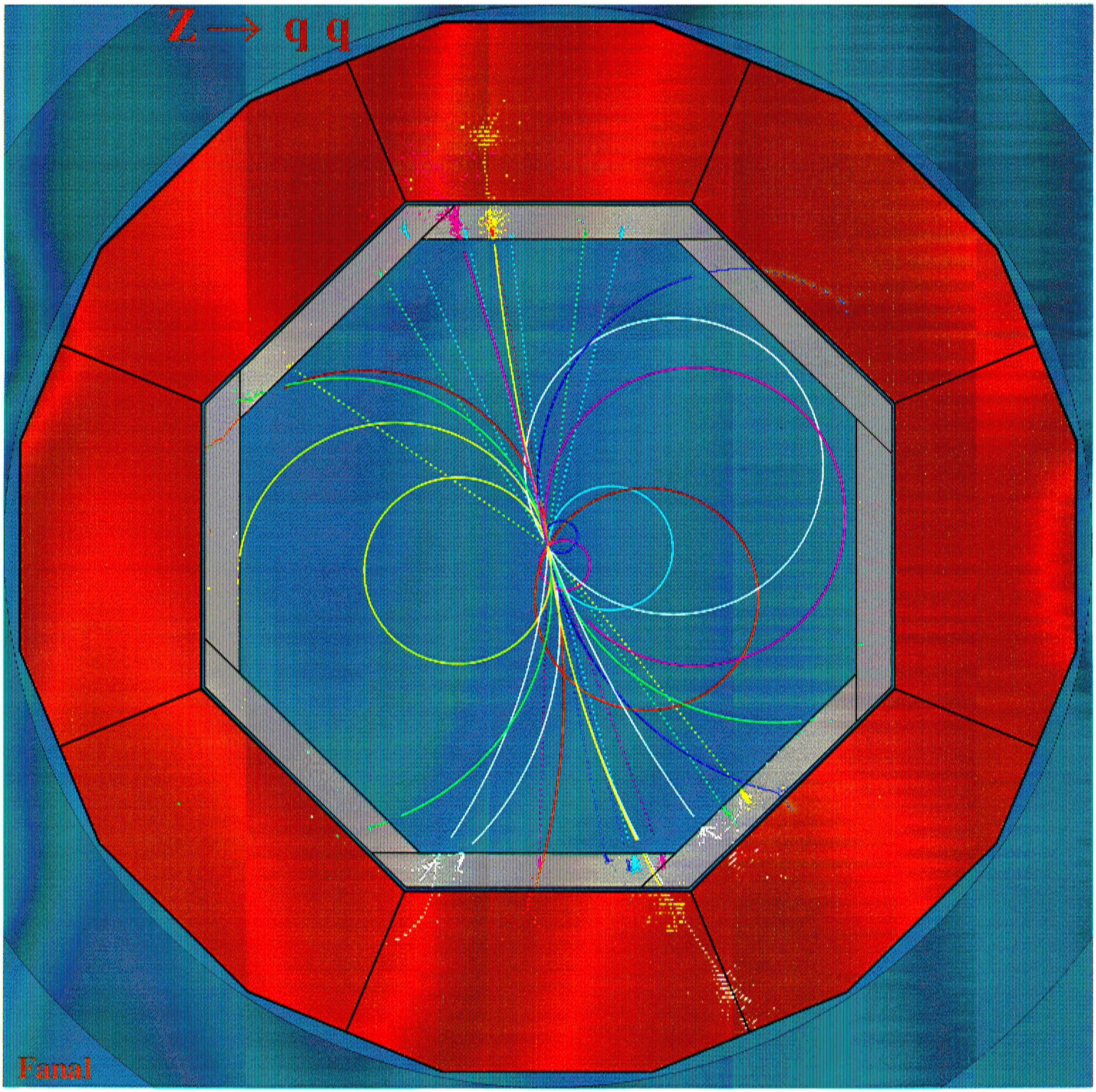
Geometry: A "no-crack" design is proposed.

Mechanics: It is based on tungsten wrapped by carbon(?) fiber with alveoli for the active slabs (with Si pads)

Electronics : auto-trigger for each pad and BX, analogic zero supress, multigain preamps., and after multiplexing ~700 ADC's 10 bits with digital pipeline during the beam train.

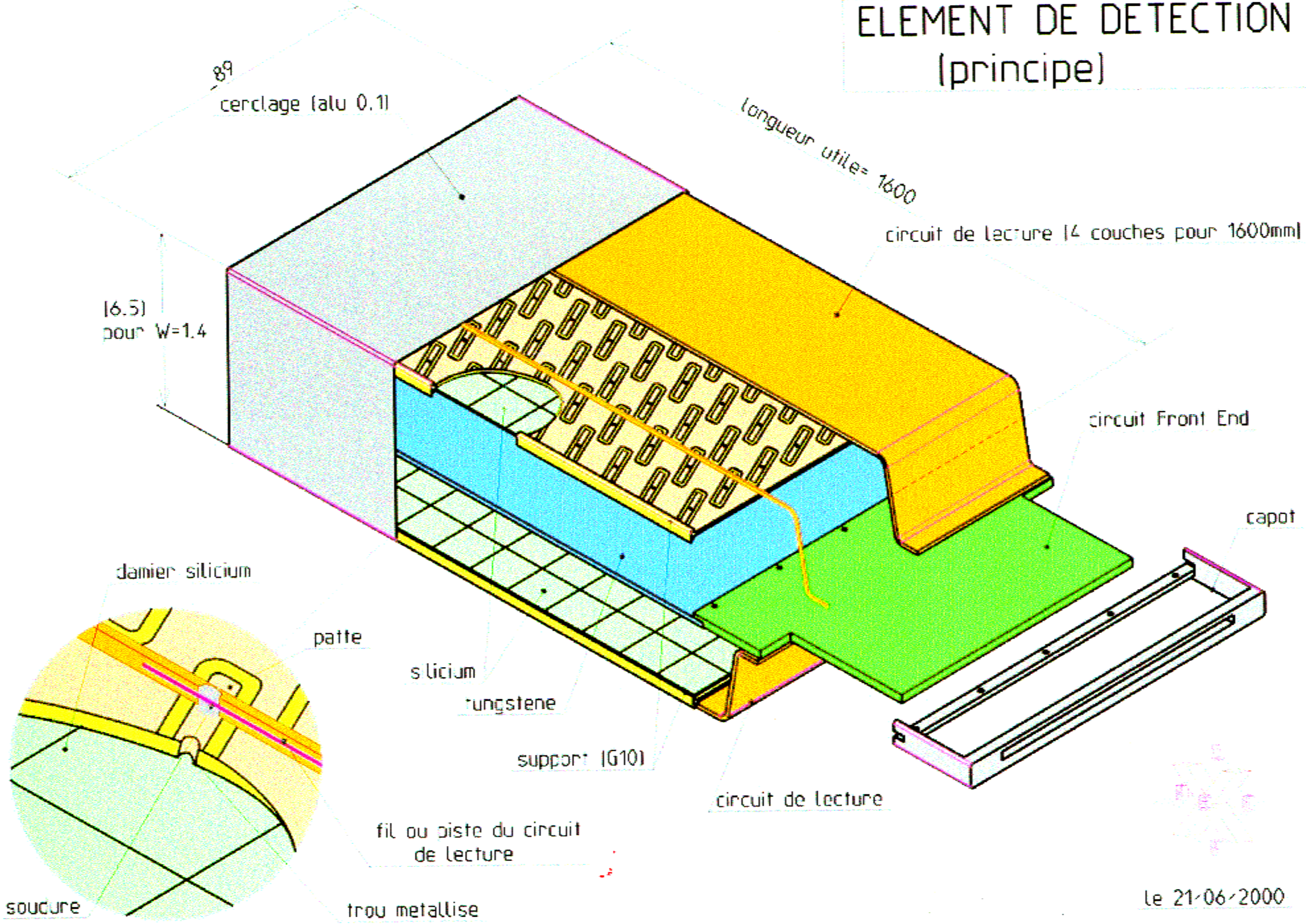
Recons. software : See talks of P.Gay and V.Morgunov

The eightfold way



HV4.5

ELEMENT DE DETECTION
(principe)



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Electronics and read out

large # of channels with small occupancy.

Dynamics from a fraction of a m.i.p. to max deposit in a cell by 500GeV electron
$\Longrightarrow$ 15 bits

precision $\Longrightarrow$ 2 gains of 10bits each

in Tesla quite some time to integrate signal (150 ns)
incoherent noise ~ 1/10 of a mip (tested)
coherent ? !

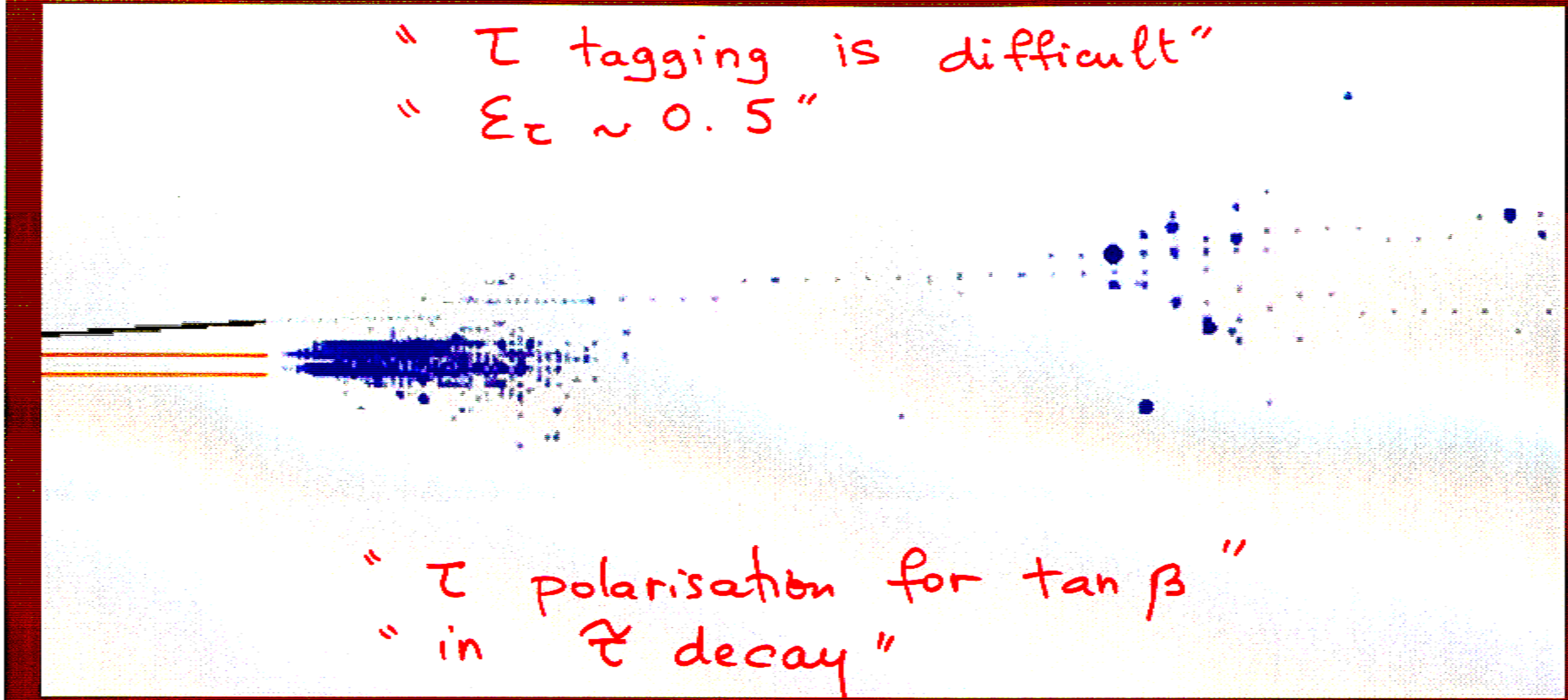
Functions amplify
cut locally at ~ 2/3 of a mip ε = 97%
stamp bunch # address (analogically)
stores

Packaging a detector slabs contains about 2 x 8 x 140 cells
to be treated in a tiny space by (2) x 8 chips

Read-out a set of 40 detector slabs can be readout (through a token ring)
and digitized in few ms by one ADC $\Longrightarrow$ ~ 700 10bit ADC's + storage

a full train ⟶ DAQ

HV6.



" τ tagging is difficult"
" $\varepsilon_\tau \sim 0.5$ "

" τ polarisation for tan β "
" in $\tilde{\tau}$ decay "

300 GeV $\tau \rightarrow \nu_\tau \rho$

$\rho \rightarrow \pi^\pm \pi^0$

TESLA

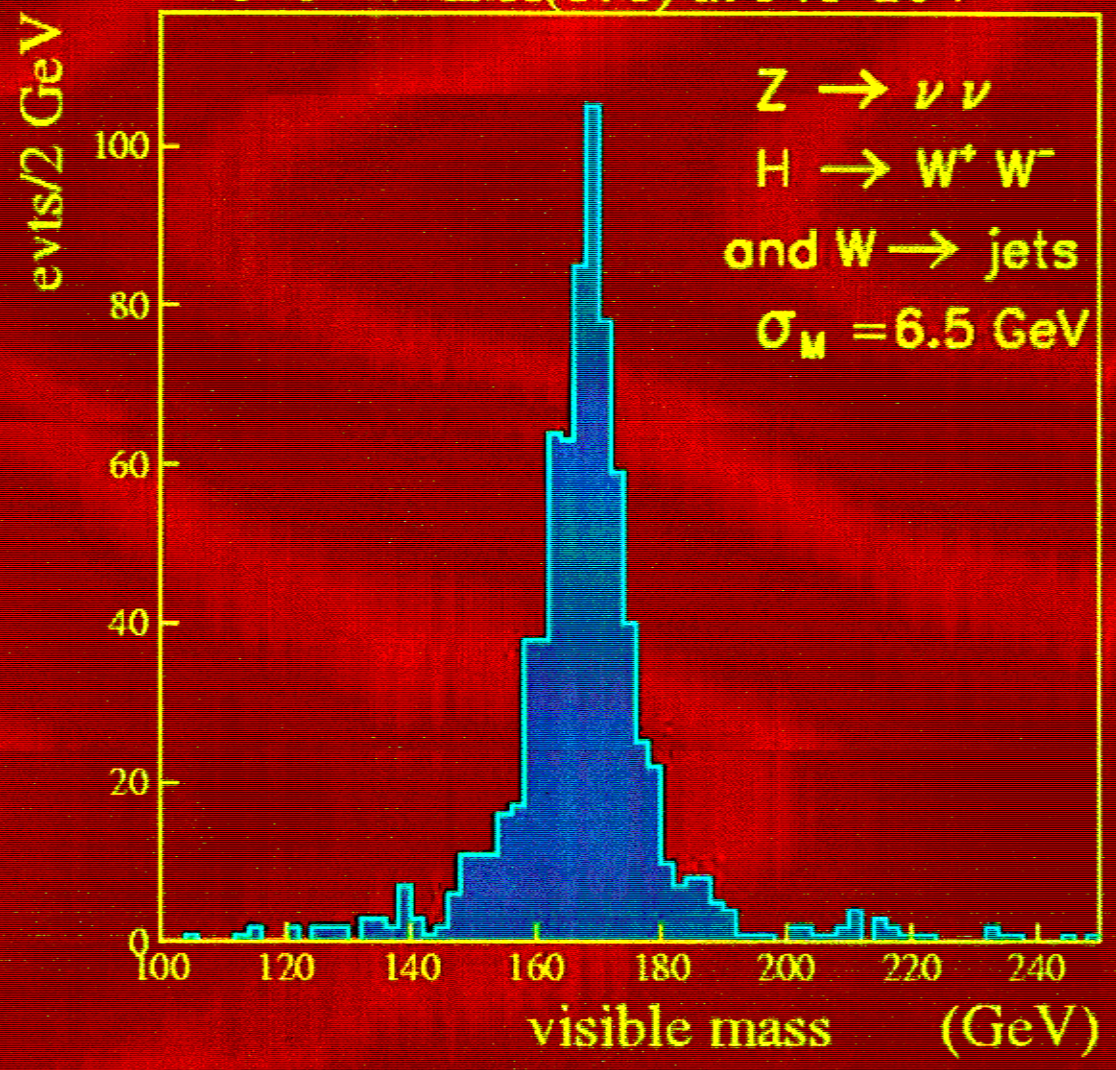
A high granularity ECAL and HCAL

Cell size 1x1x0.5 cm^3

Back to bubble chambers?

HU

$e^+ e^- \rightarrow Z\,H(170)$ at 340 GeV



Conclusions

We have a precise ECAL design for Higgs physics

It seems technically feasible with some delicate areas

- the detector slab or getting the signals out
- the front end electronics integration
- the industrialization of the Si processing to reduce cost.

being prototyped
chip in 2001

It remains to be optimised, in particular in its layer structure

The software to exploit its capabilities is an interesting challenge
may bring a lot

The price, as of today (130 M€), is totally dominated by the silicon area.
Its probable evolution is under study - May bring a factor 3

Read the Tesla TDR
when released.

V. Korbel

TILE HCAL
(TDR ECFA/DESY)

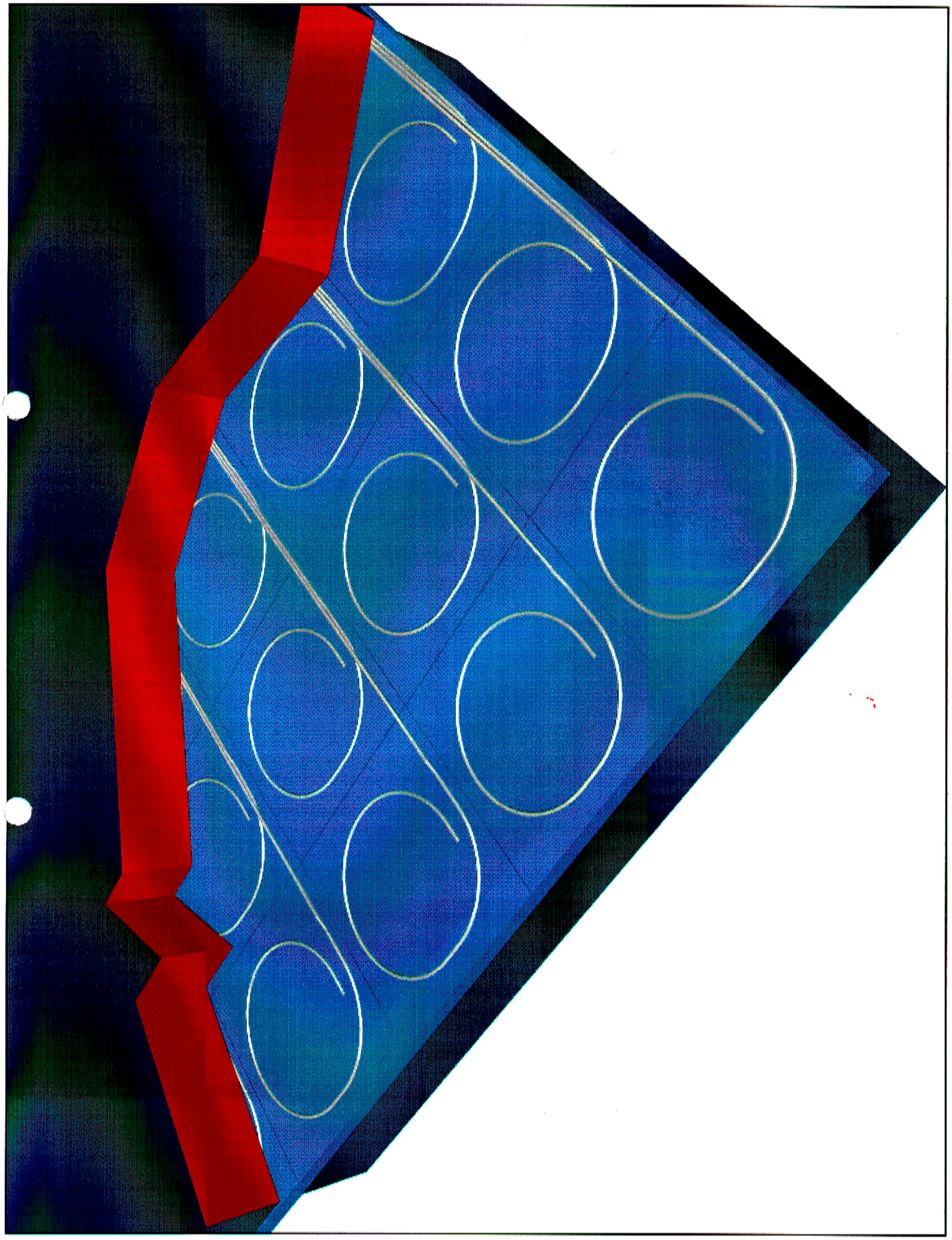
- TILE / INOX
  0.5 / 2 cm
- 5x5 cm TILE (entrance)
  to 20x20 cm (exit)
- 9 read-out layers

⇝ mechanics and design

⇝ read-out and electronic

⇝ Installation with ECAL w-si

⇝ Future R&D, Test...



P. Checcia

Shashlik design

→ SITGES : caleido 1

→ CALEIDO 2

2 segmentations in depth using scintillators with different time response

↓

TEST BEAM

- Nice results on single particle

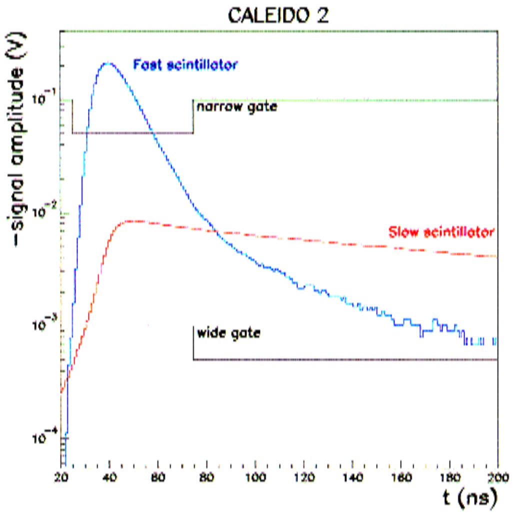
  * $\frac{\Delta E}{E}^{e.m.} \sim \frac{15\%}{\sqrt{E}}$

  * e/π separation

CALEIDO 2 (1999 prototype)

2 Scintillators with different time response

- First 5 X_0 with long τ scintillator
  same geometry, WLS fibers ....



- Slow scint.: BC444 from Bicron $\tau \sim 250$ ns
- e/γ: early shw.$\Rightarrow$ high E_{slow} and E_{fast}
  hadrons: late shw. $\Rightarrow$ small E_{slow}
- 9 counters (3 × 3) with (fast) PM's
  FEU-84-3 FEU-115M
- RO: narrow and wide gate (50 and 150 ns)
- Q_n and Q_w mix the two components

Testbeam Summary

First prototype:

- Energy Resolution: $< \frac{10\%}{\sqrt{E}}$, $< 1\%$ c.t.
- e/π separation with lateral diode works:
  $< 5.0 \times 10^{-4}$ at 50 GeV
- Good Position Reconstruction
- No significative cracks

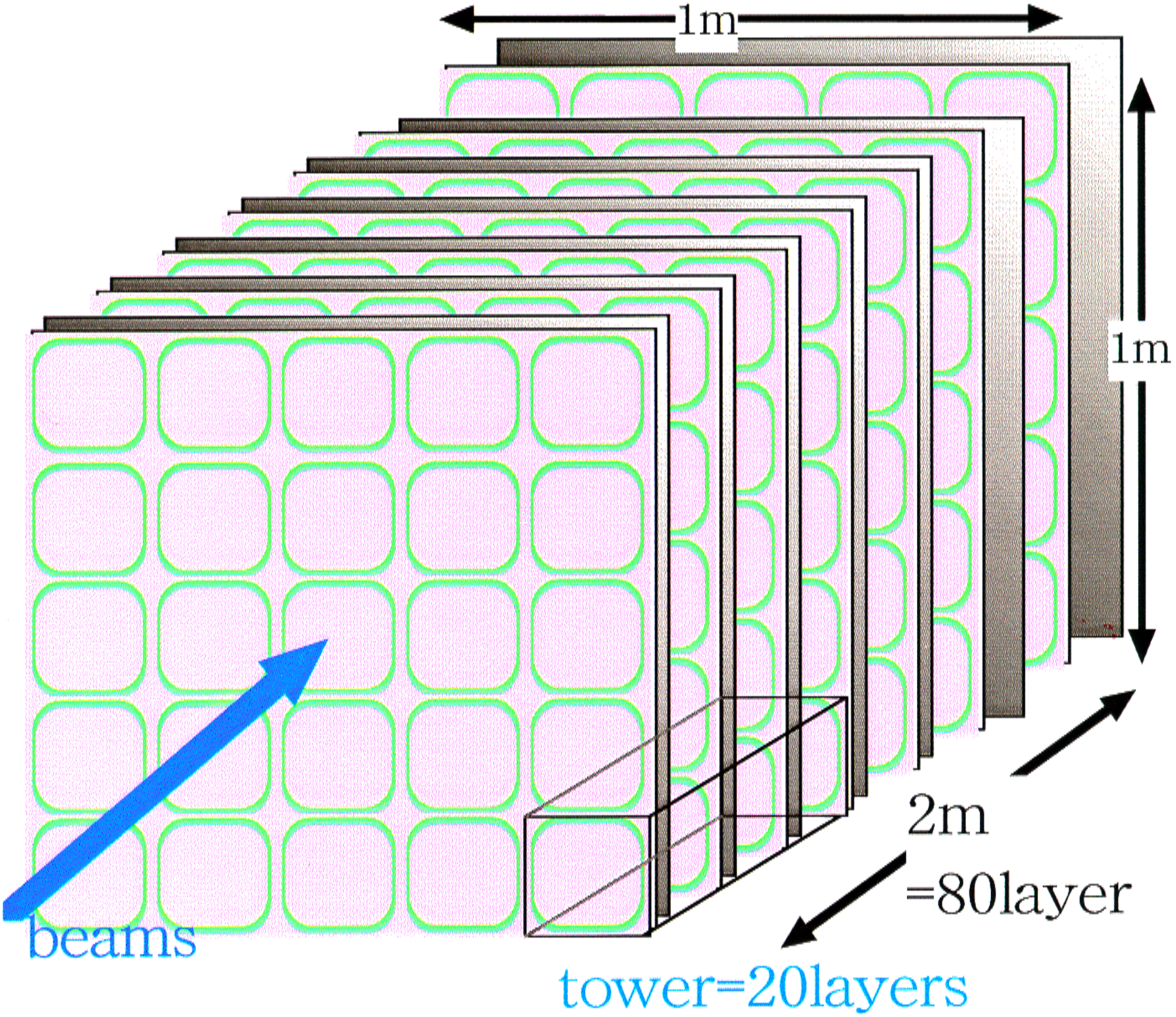
Second prototype:

- Energy Resolution: $< \frac{15\%}{\sqrt{E}}$, $< 1\%$ c.t.
- e/π separation with 2 decay time scint. works:
  $< 6.0 \times 10^{-4}$ at 50 GeV
- See prototype 1...
- Possibility for more compact mechanics

Both prototypes meet requirements!

JLC-HCAL test module

tile/fiber



5x5 towers X 4sectios

scinti.2mm+Pb8mm

$127X_0, 4.2\lambda_I$,9t

$+1.7\lambda_I$

+Straight groove CAL

Tile/fiber hadron calorimeter performace JLC-CAL

sandwitch Hp-CALs of Pb and plastic scintillator have been tested

energy resolution for 1-150GeV pions :

$$\sigma/E = 46.6\%/\sqrt{E} \oplus 0.8\ \%$$

e/p ratio for1-150GeV :

=1.0

need EM-fine sampling test

simulation

My conclusion

(Pr. K. Fujii is waiting for)

- Eflow is a part of the calor. design
- Full simulation is recommanded to test any design
- $\lesssim 30\%/\sqrt{E}$ for JET is mandatory for the physics program of FLC

- 2 approaches for the calorimeter design

A • Compensated calorimeter

B • highly segmented calorimeter

At least one of the B design reach the $\sim \frac{30\%}{\sqrt{E_{jet}}}$

And now

A lot of work remains on

- ΔE_{jet}, ΔM
- Cost estimate
- Technological challenges