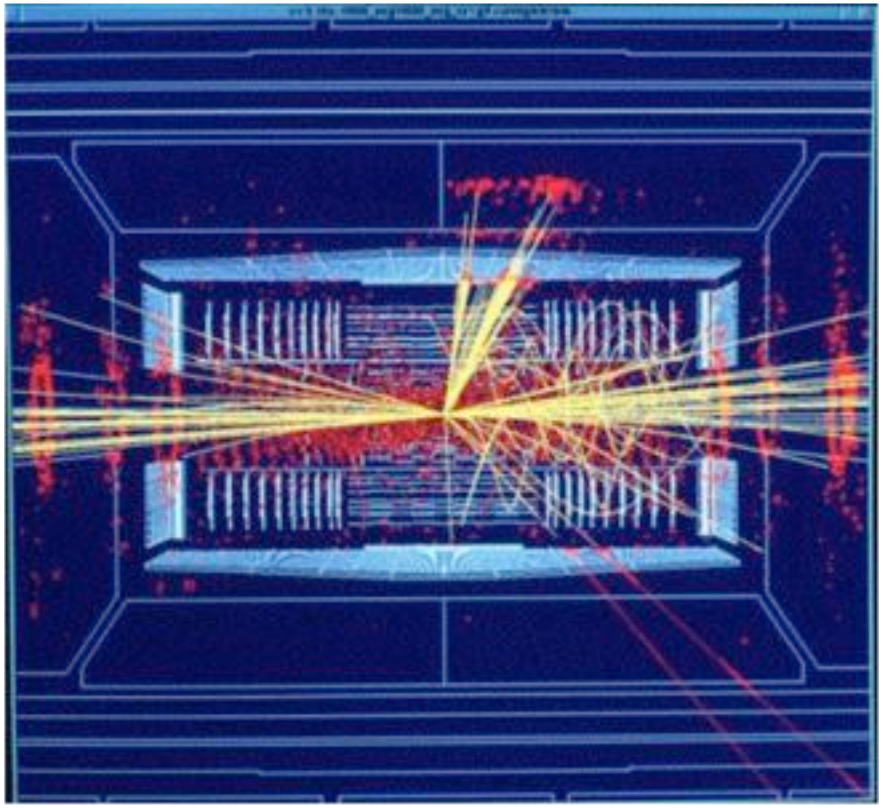
Clear Fiber Calorimetry

R&D for LHC

Boston University

1994 -1996

Looking for SUSY: from a bizarre idea to CMS calorimetry



- The situation before LHC
- LHC: SUSY or not SUSY
- Calorimetry at

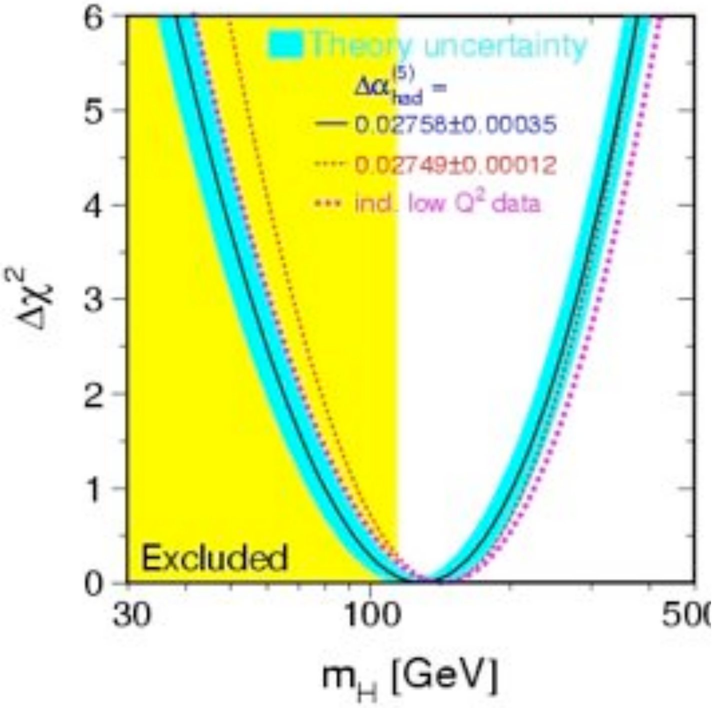
  $2.6 < |\eta| < 5$
- The PPC solution
- The 45 ° solution
- The 0 ° solution

Boston University 21 October 2005 A. Rosowsky CEA-DAPNIA-SPP

The situation before LHC

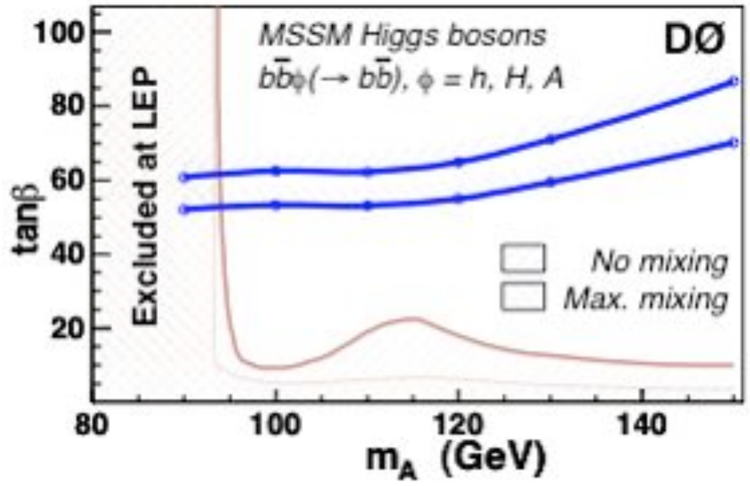
- LEP - SLC extensive check and metrology of SM
  - Z^0 and $W^{\pm}$ physics and metrology
- TEVATRON observation of the Top quark at 175 GeV
- Extensive Higgs searches with no success …
  - SM Higgs mass limit ≥ 115 GeV
  - SUSY Higgs mass limit(s) ≥ 90 GeV

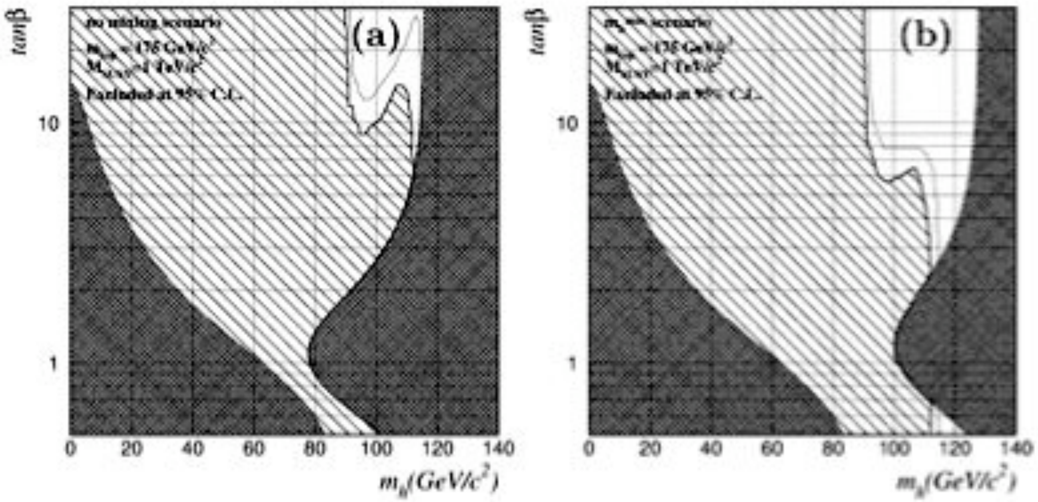
Standard Higgs search at LEP



But ... no Higgs found !!

SUSY Higgs search at TEVATRON





ALEPH Collaboration / Physics Letters B 526 (2002) 191–205

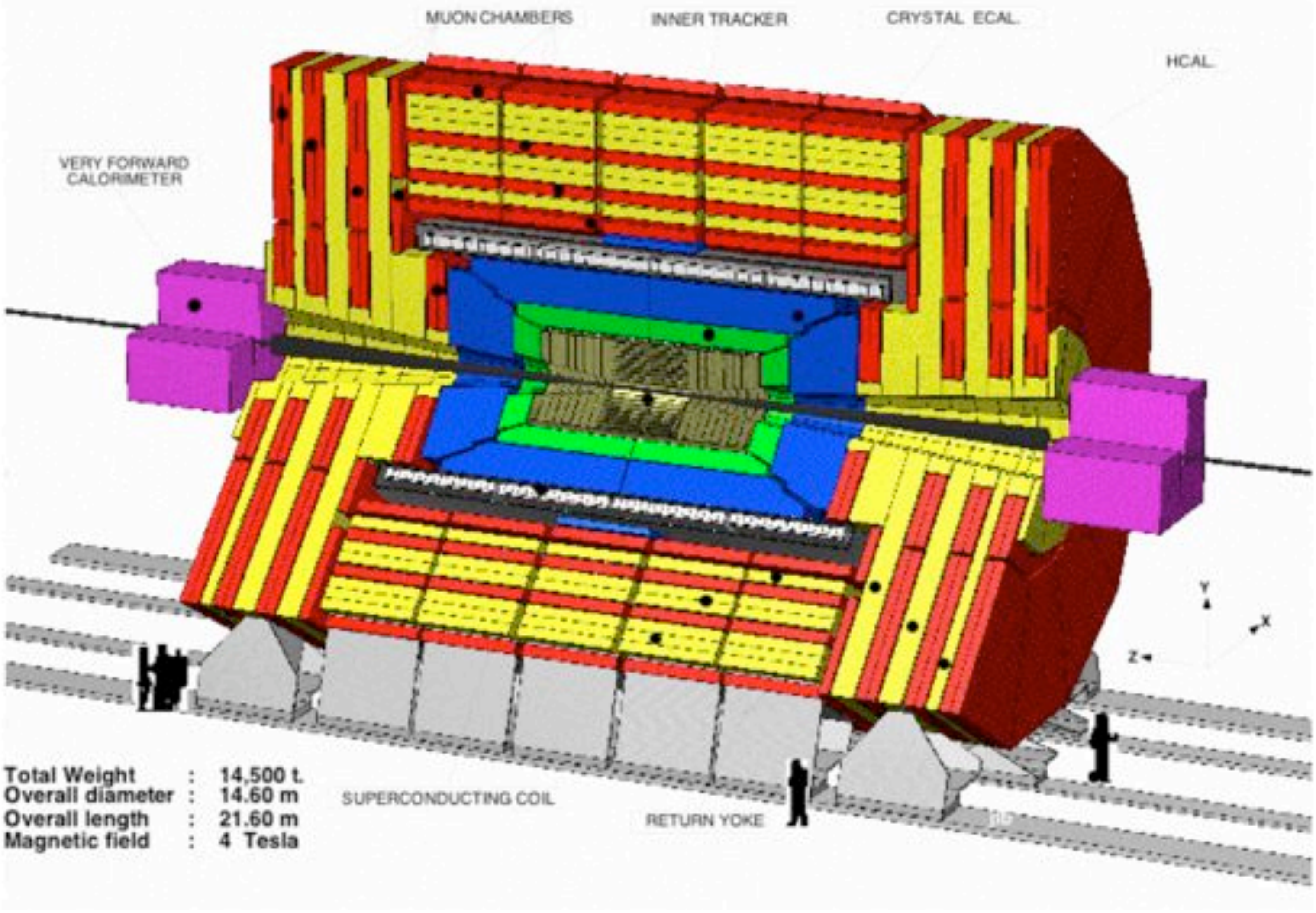
SUSY Higgs search at LEP

LHC: SUSY or not SUSY ?

- 1st case: Standard Model Higgs discovery
- 2nd case: SUSY Higgs discovery
- 3rd case: no SM and no SUSY => WW and ZZ

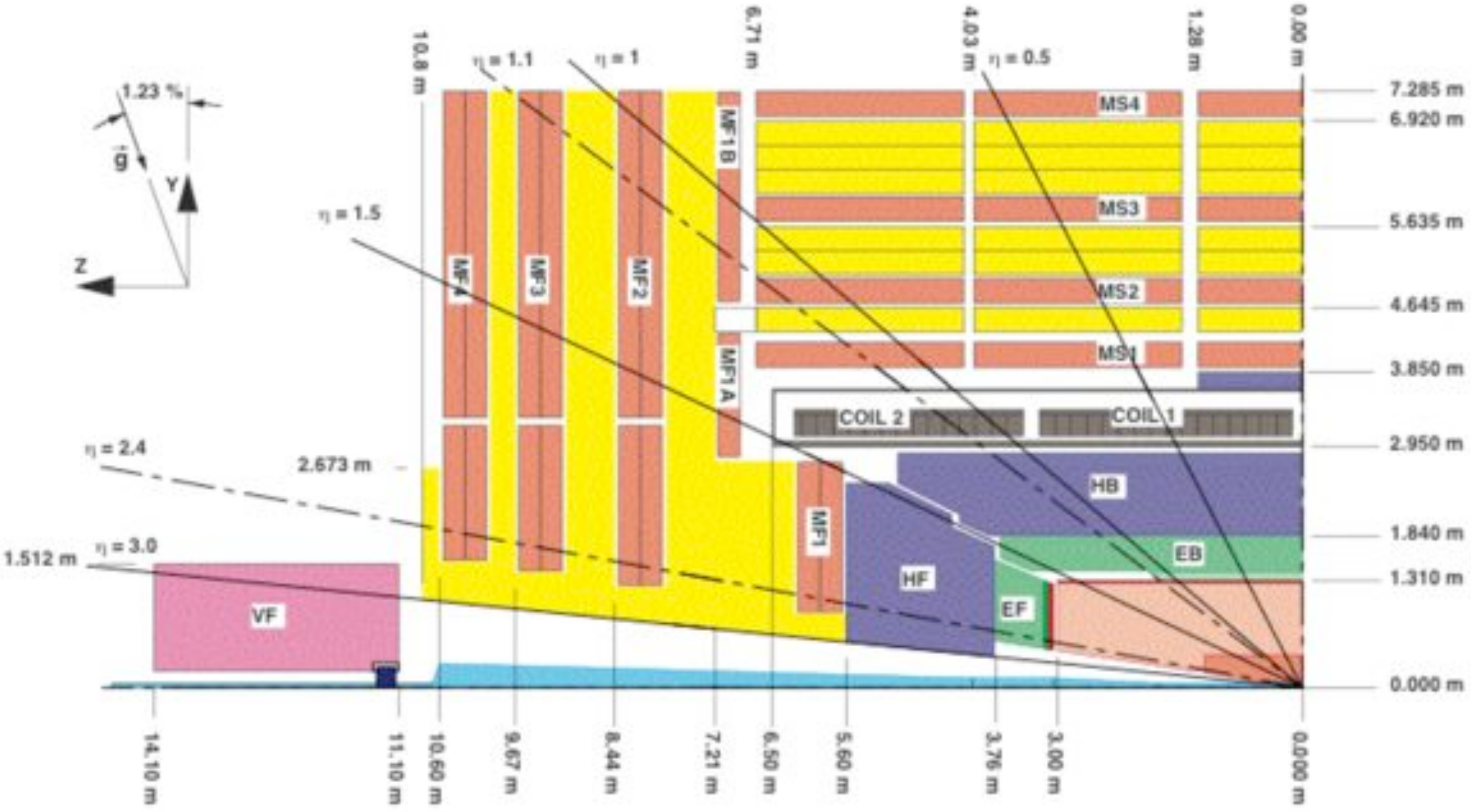
⇒ The need for forward jet tagging

VFCAL and the CMS apparatus



Total Weight	:	14,500 t.
Overall diameter	:	14.60 m
Overall length	:	21.60 m
Magnetic field	:	4 Tesla

VFCAL angular region



Longitudinal View

CMS - PARA- 008 22/11/94 P.P.

Standard Model Higgs

ATLAS TDR: $W\,W \to l\,\nu\,j\,j$

$M_H = 600$ GeV

After all other cuts

2 forward jets tagging $2 < |\eta| < 4$ $E_{tag} > 600$ GeV

- With S/B = 0.36
- Without S/B = 0.015

Example with SUGRA

ATLAS TDR H/A → $\chi\chi$

- $m_0 = 200$ GeV
- $m_{1/2} = 100$ GeV
- $A = 0$
- $\tan\beta = 2$
- sign $\mu = -1$
- $m_H = m_A = 375$ GeV

After all other cuts:

jet veto cut $P_t > 20$ GeV

η up to 5

- With S/B = 0.57
- Without S/B = 0.001

Example: vector boson scattering

ATLAS TDR: $W_L Z_L \to W_L Z_L \to l\, l\, j\, j$

$M\rho = 1.5$ TeV

After all other cuts

Forward jet tagging $2 < |\eta| < 5$

- With $S/B = 6.15$
- Without $S/B = 0.77$

Calorimetry at $2.6 < |\eta| < 5$

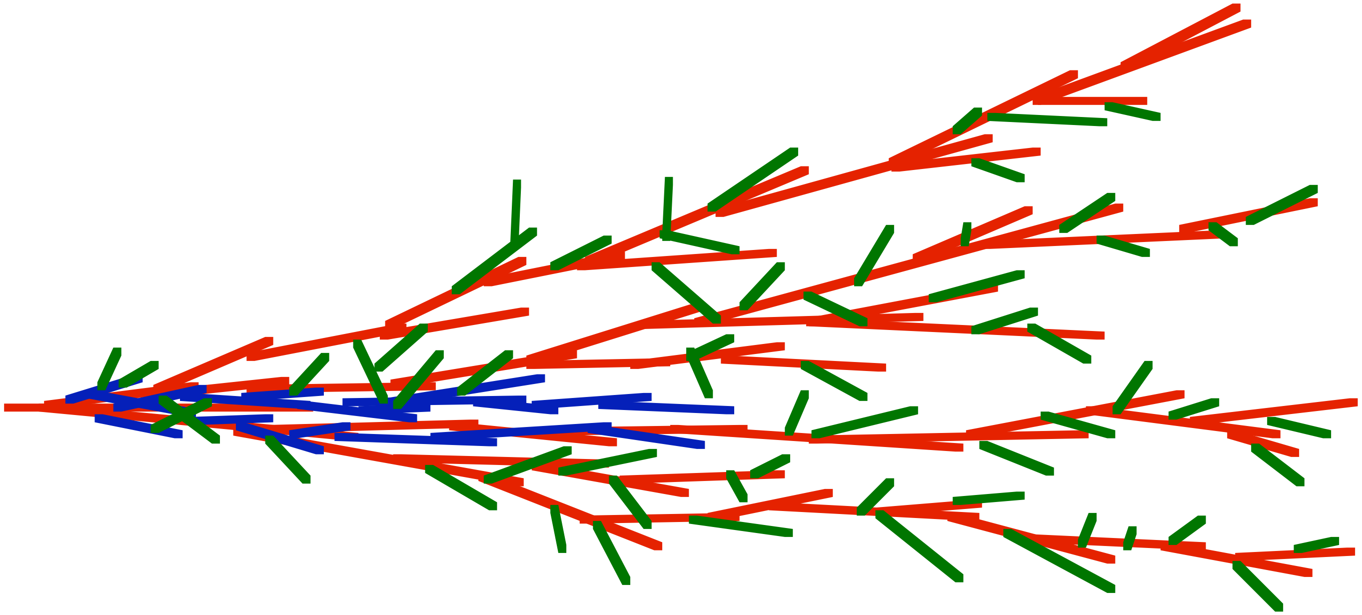
- small volume separated from the main apparatus
- ~ 1/2 Higgs mass range search

But … at $|\eta| = 5$

- neutron flux ~ 10^8 cm^{-2} s^{-1}
- gamma radiation dose 500 Mrad for $L = 5 \times 10^5$ pb^{-1}

Very few materials can resist ….

What is detected …



🟩 low energy electrons -> large angle

🟥 pions -> large angle, long distances

🟦 high energy electrons Ec > 10 MeV

The PPC solution

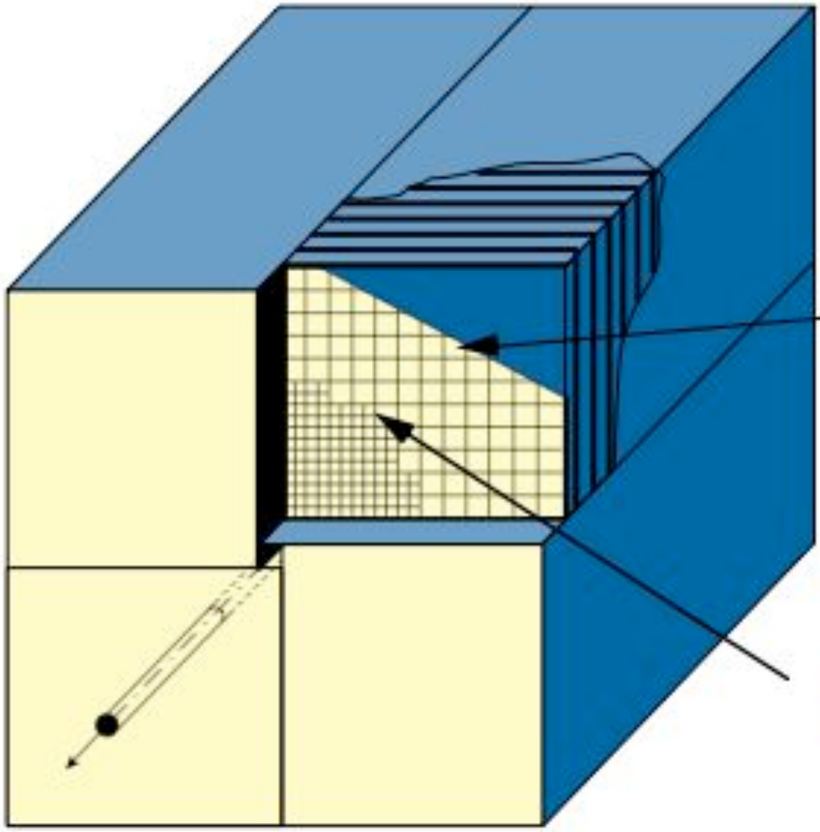
Predicted performance

electrons

$\sigma/E \approx 55\%/\sqrt{E}$

pions

$\sigma/E \approx 70\%/\sqrt{E} + 2\%$



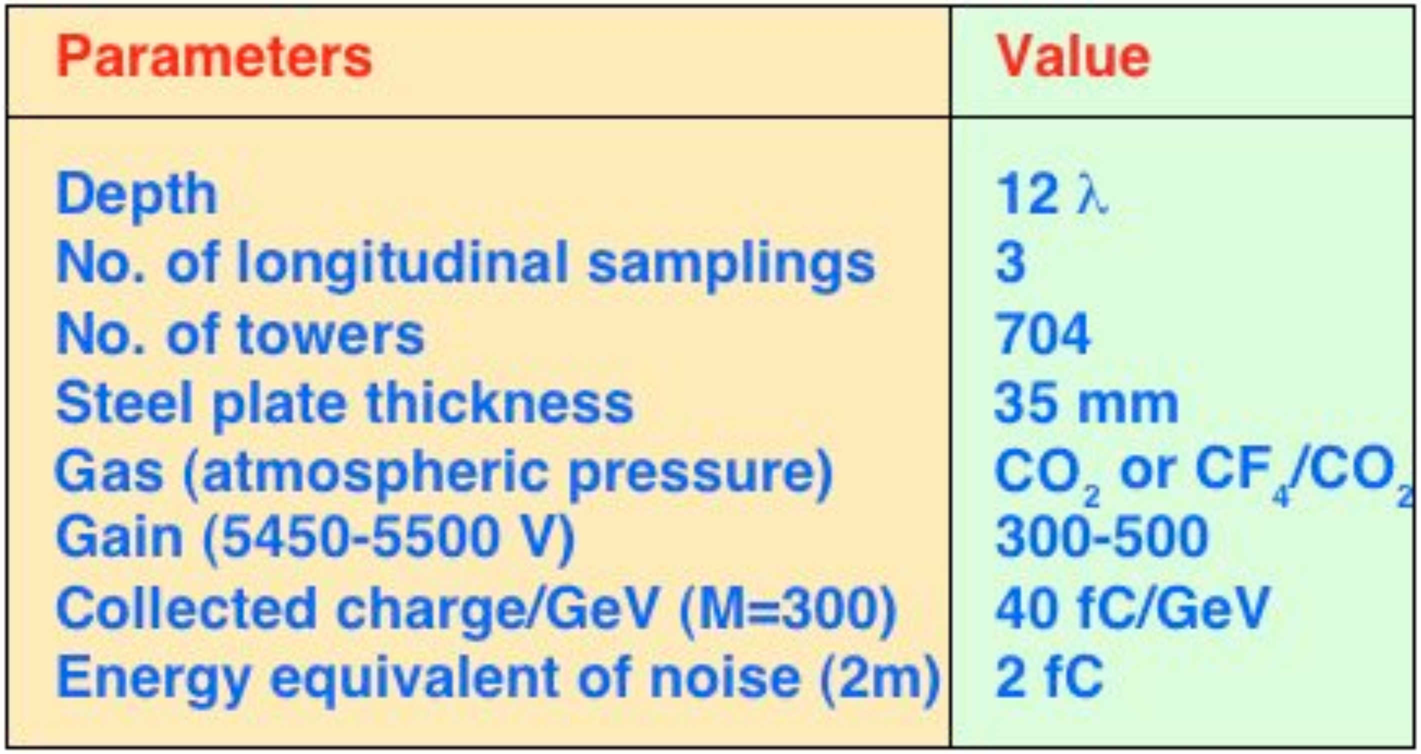
$3 < |\eta| < 4$

10 x10 cm^2

$4 < |\eta| < 5$

5 x5 cm^2

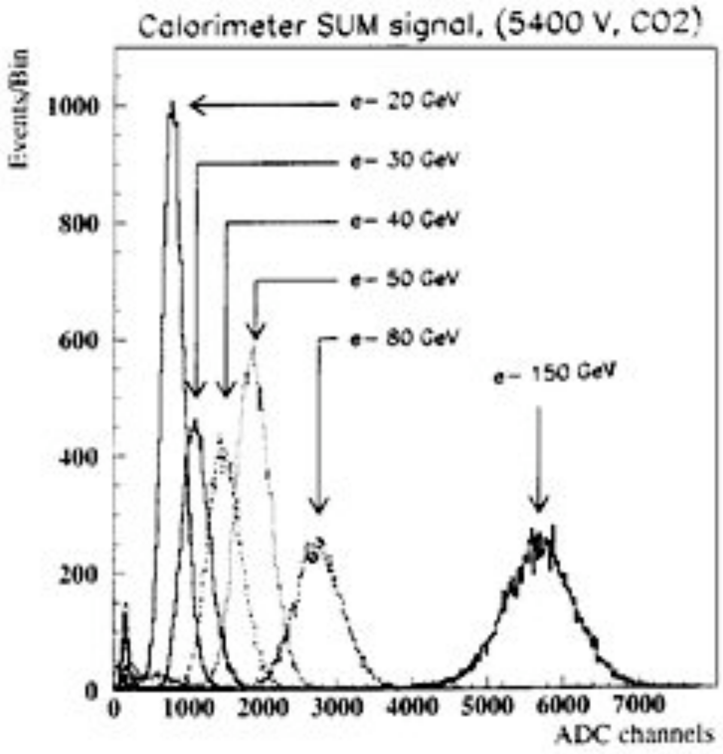
The PPC solution

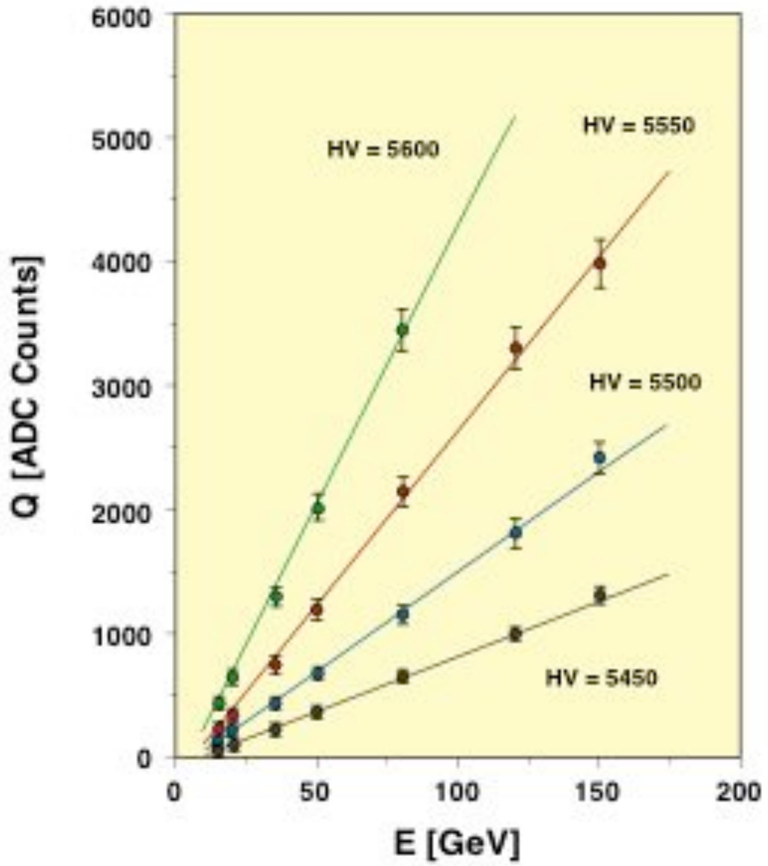


Parameters	Value
Depth	12 λ
No. of longitudinal samplings	3
No. of towers	704
Steel plate thickness	35 mm
Gas (atmospheric pressure)	CO_2 or CF_4/CO_2
Gain (5450-5500 V)	300-500
Collected charge/GeV (M=300)	40 fC/GeV
Energy equivalent of noise (2m)	2 fC

The PPC solution

Electrons : 15 X_0 : 8 planes of Ceramic PPC

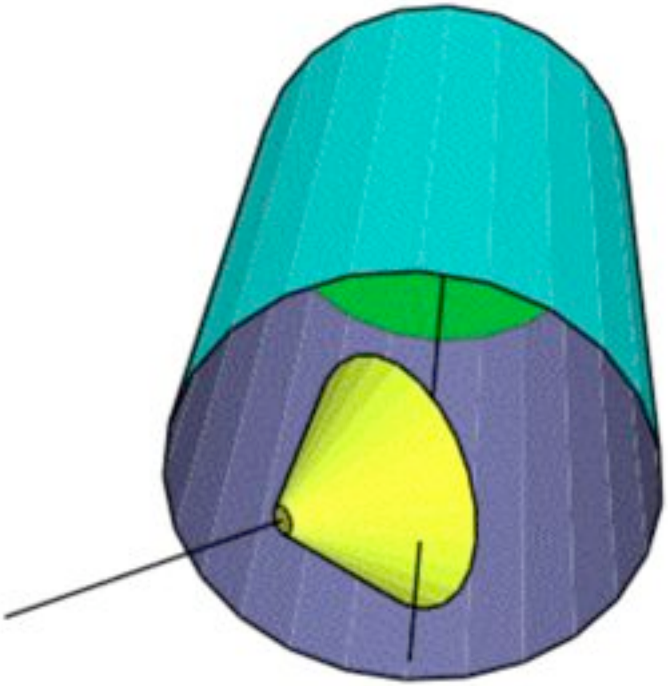


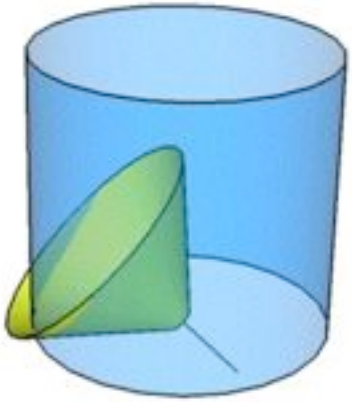


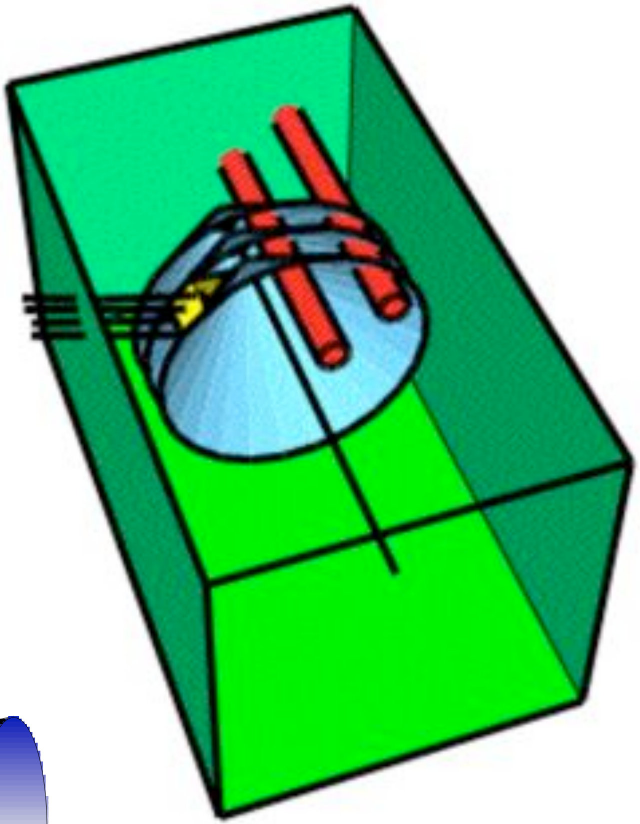
The PPC solution

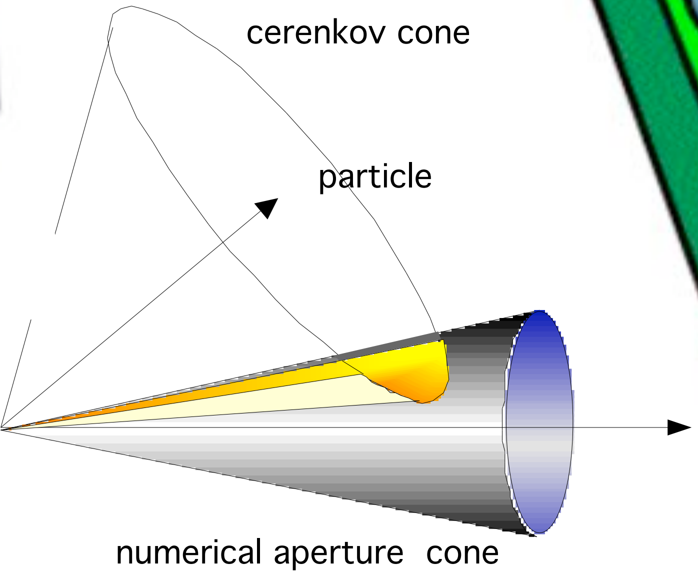
- gas detection via ~ few 100 keV electrons
  - large transversal shower detection → shower overlap
  - material & gas selection to avoid inducing radioactive signal
- requires high mechanical precision → cost
- gas impurity monitoring and control for 10 years.

The 45° fibers solution





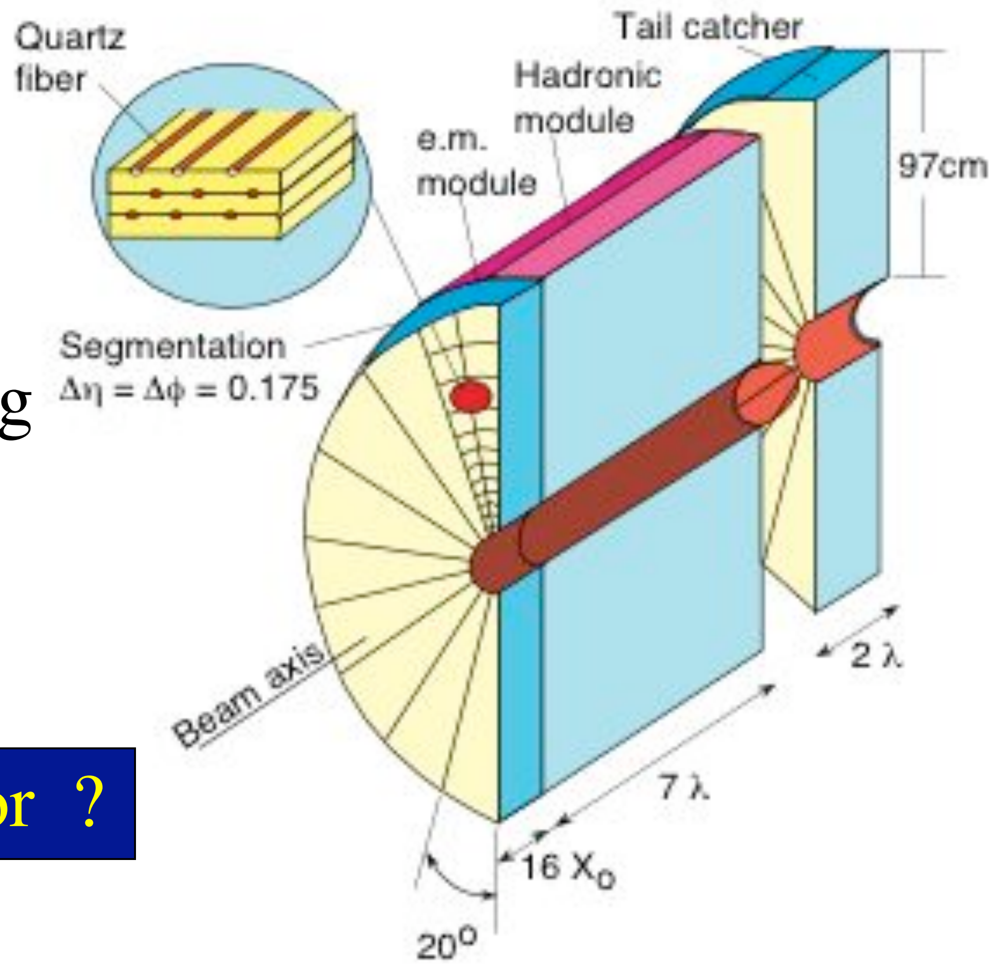




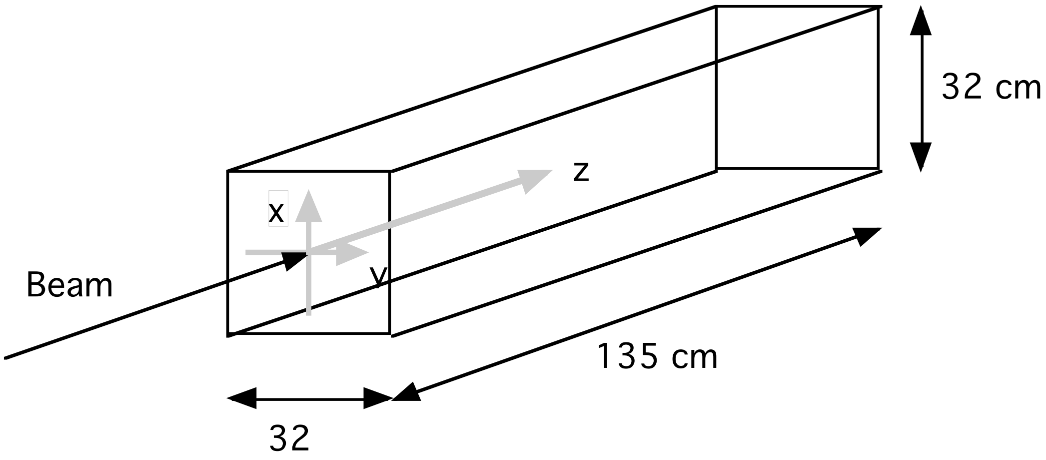
The 0° fiber solution

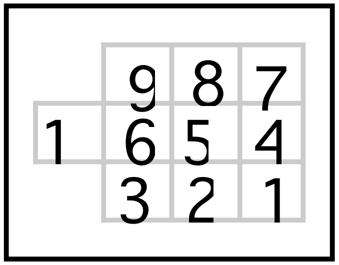
- fibers along beam axis
- only plates + grooves
- simple PMs, no ns timing

But .. Is it a blind detector ?

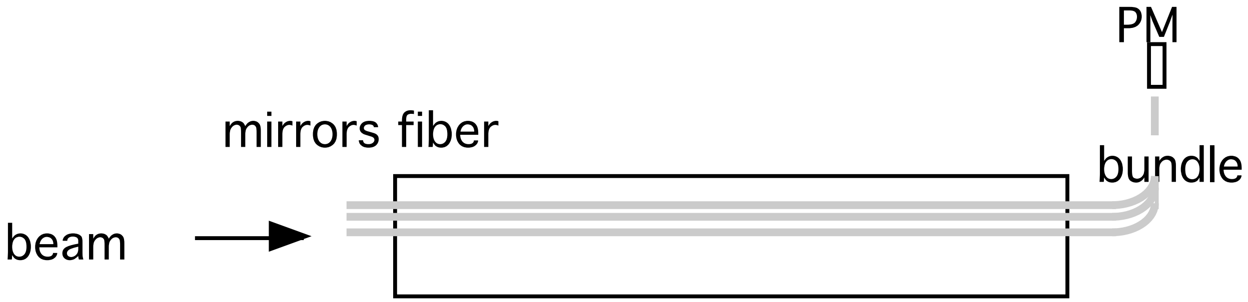


The prototype design

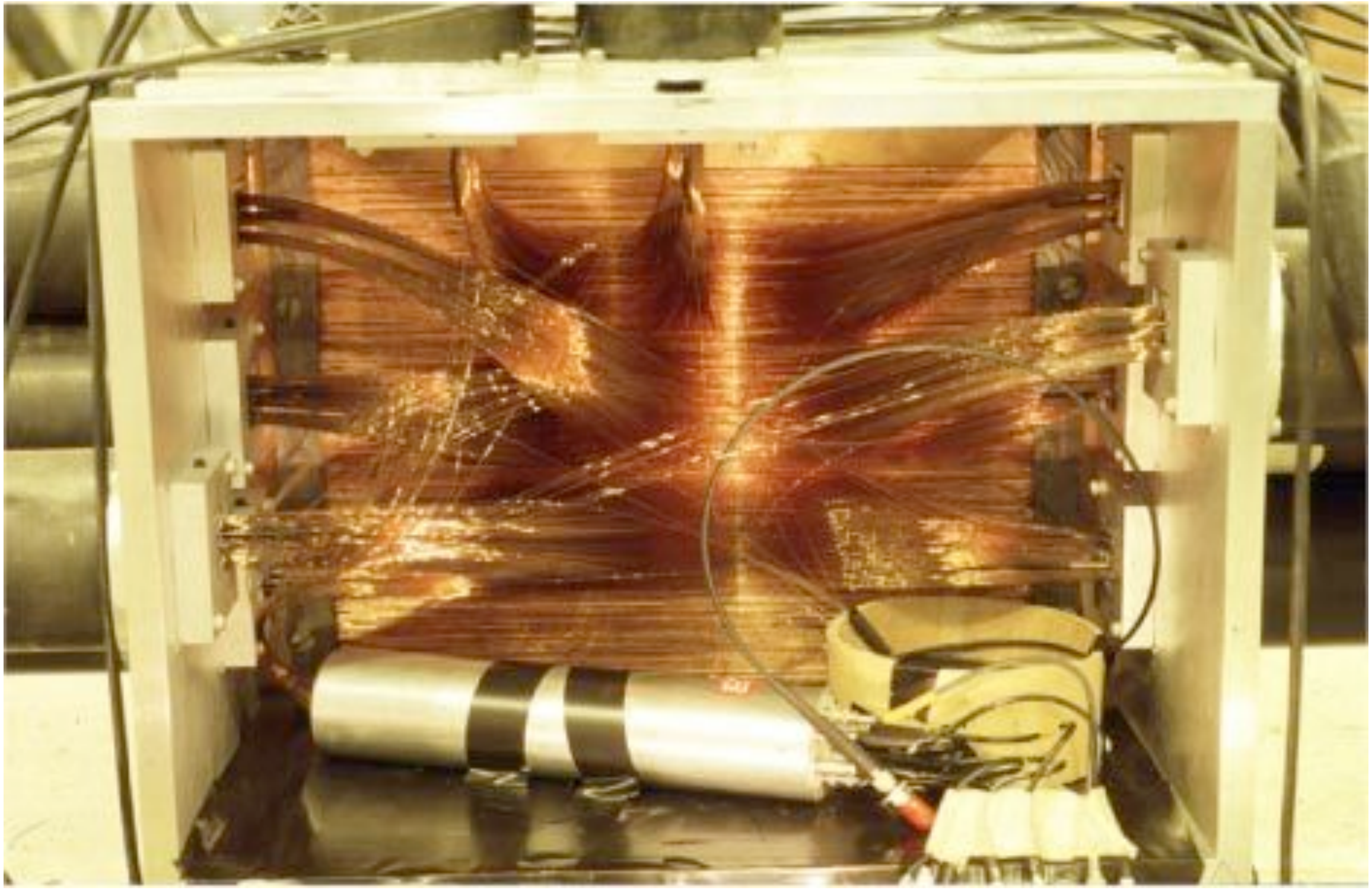




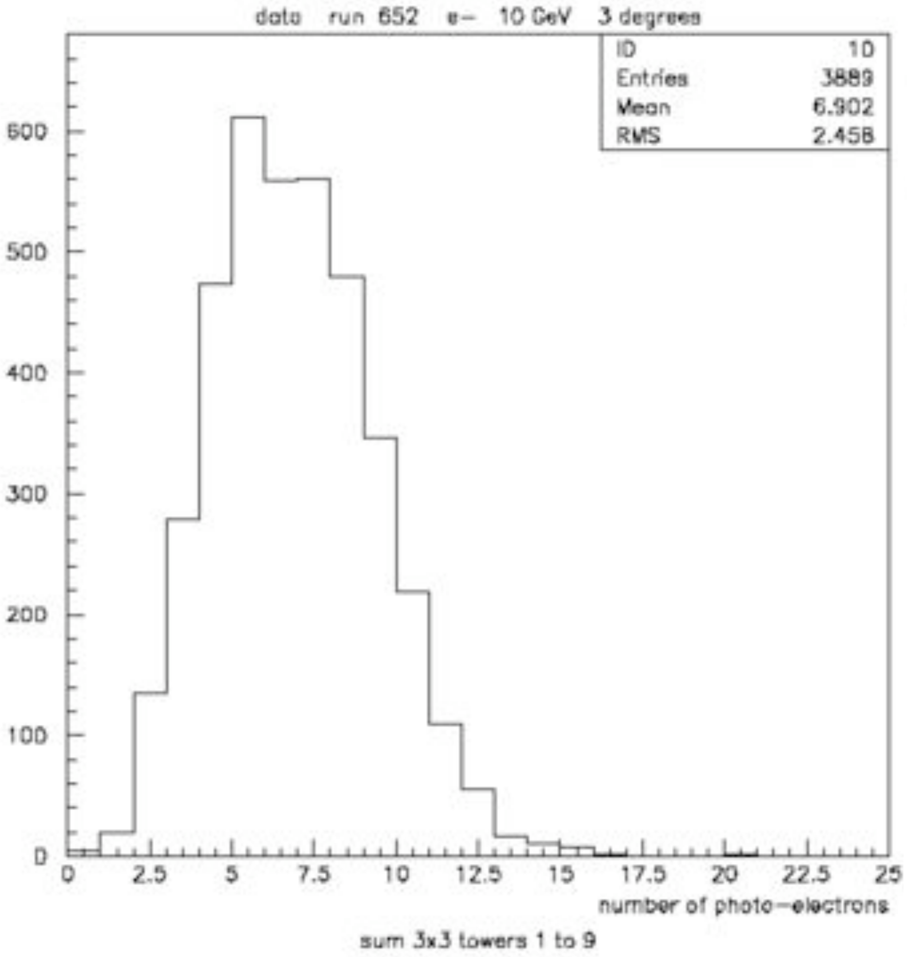
towers map
seen from the beam side

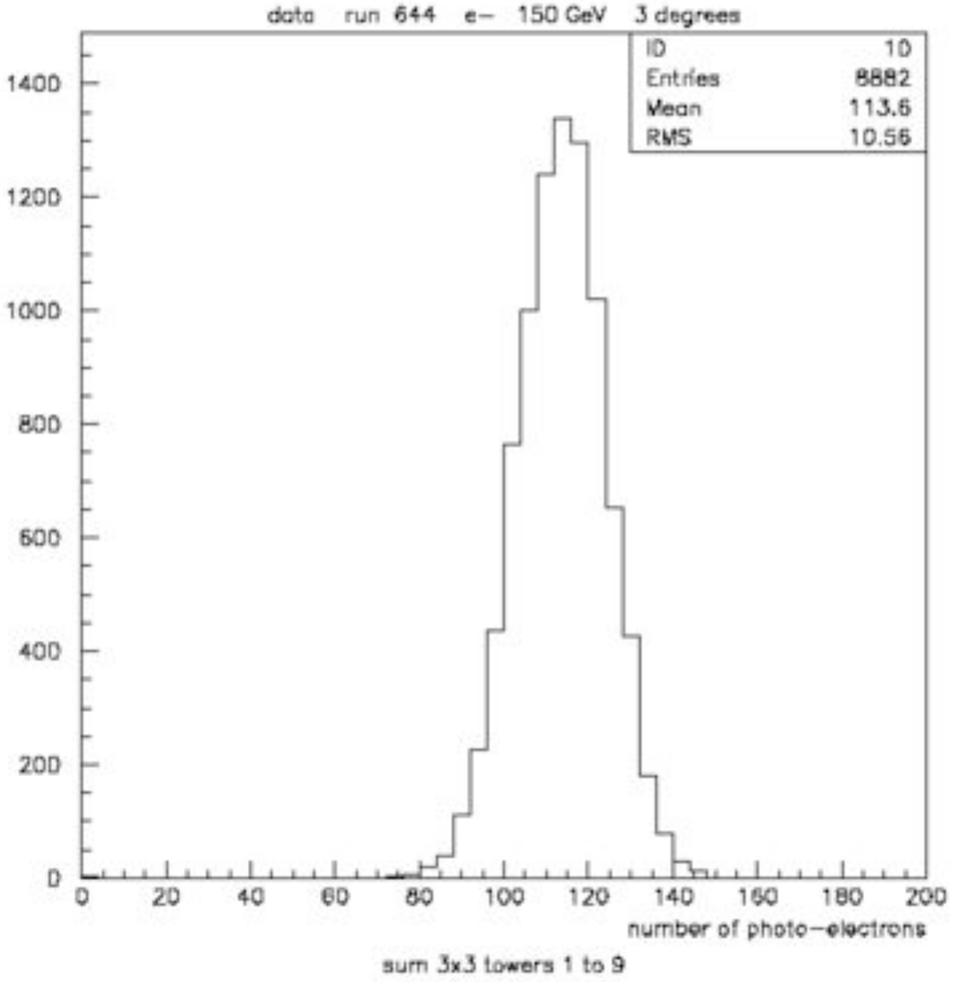


16 months later … the prototype

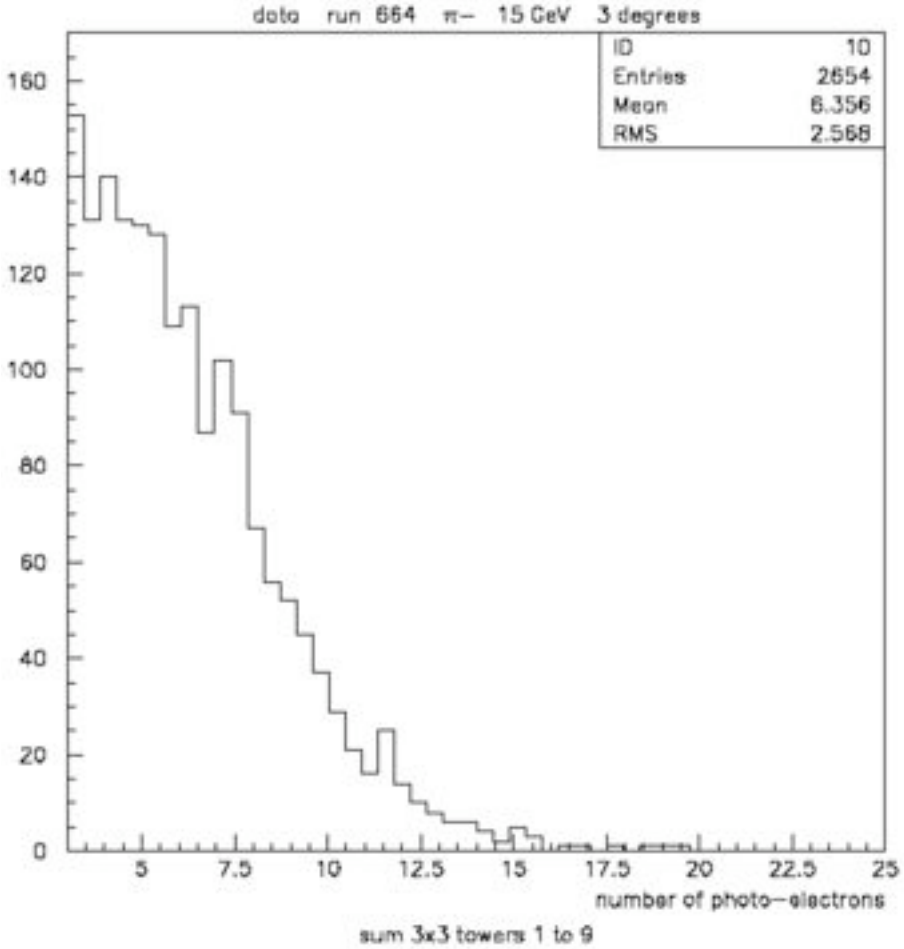


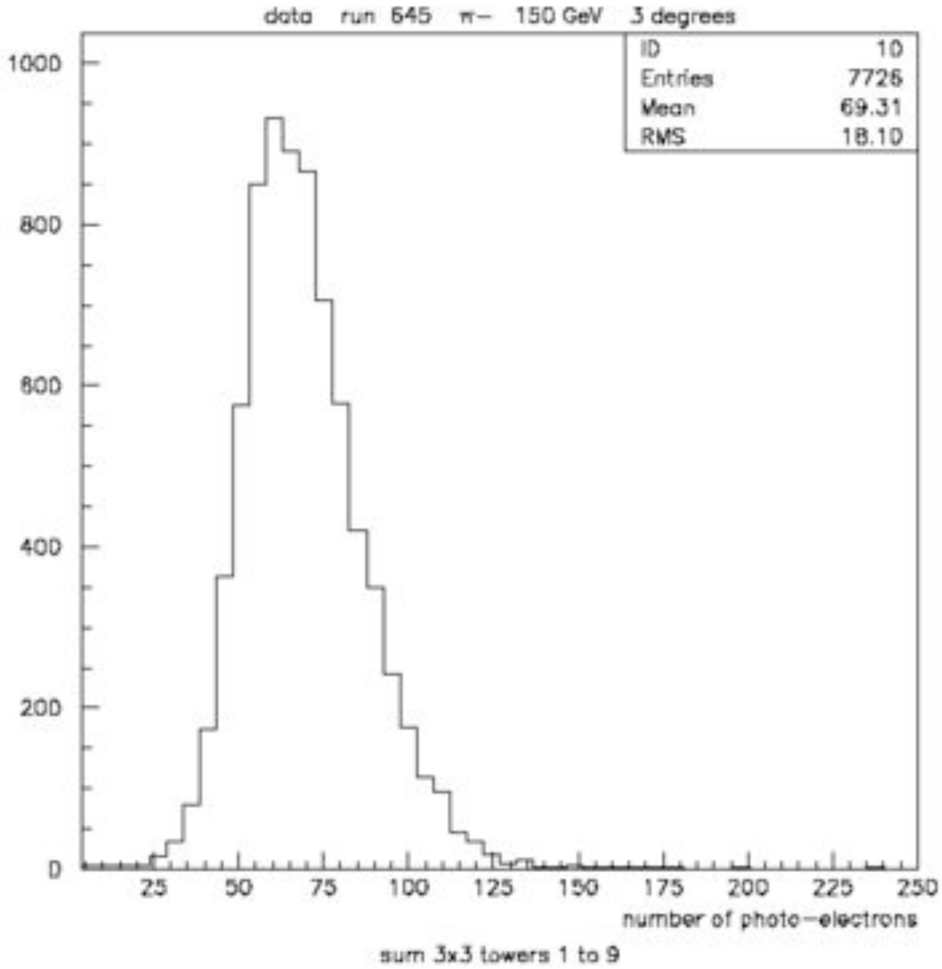
Test beam: electrons



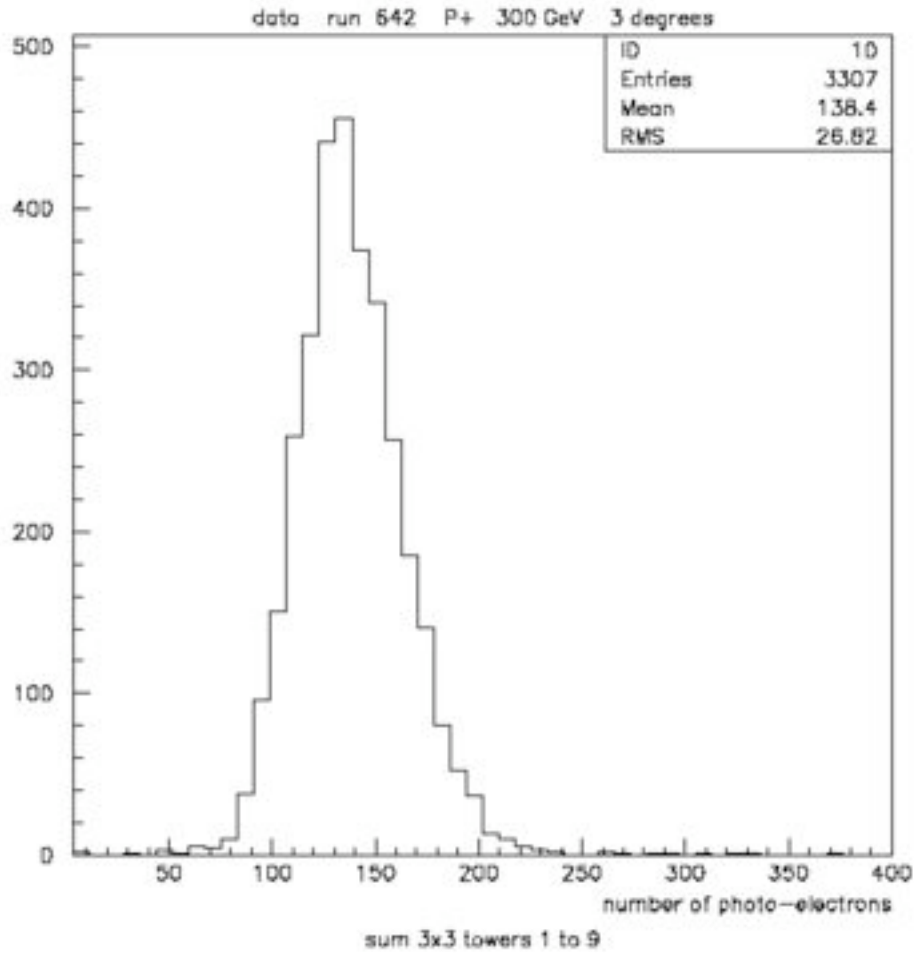


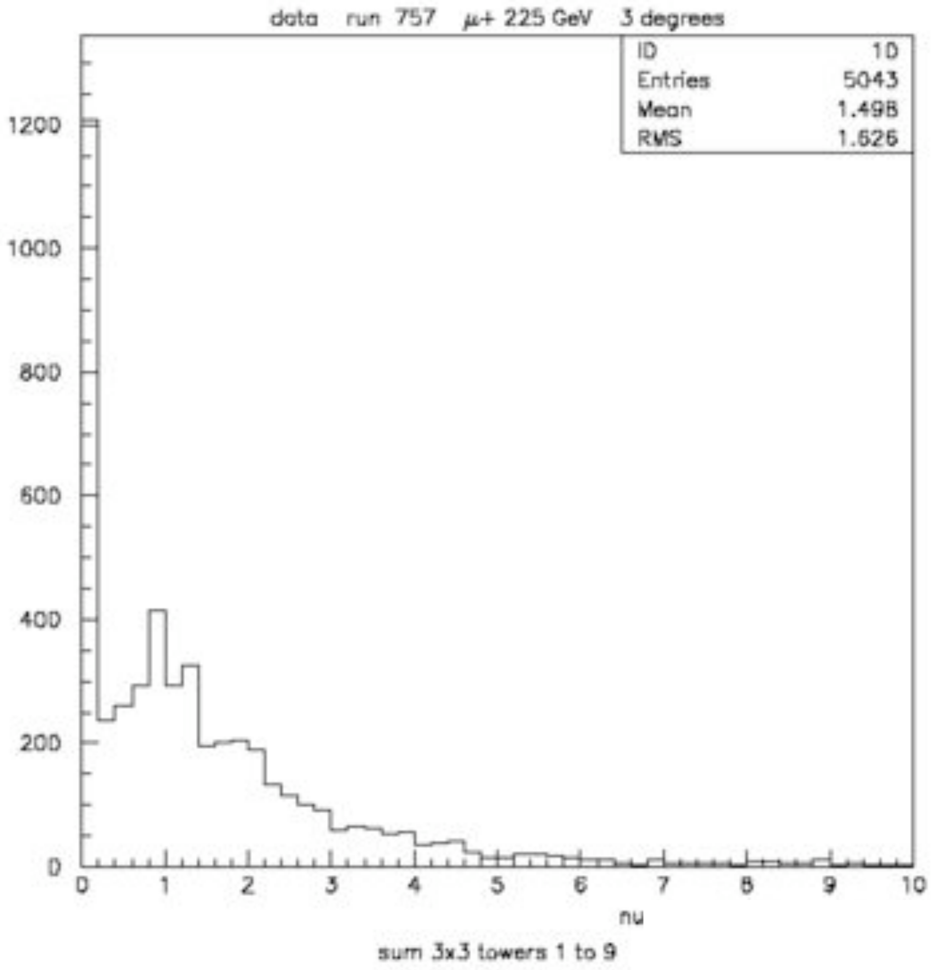
Test beam: pions



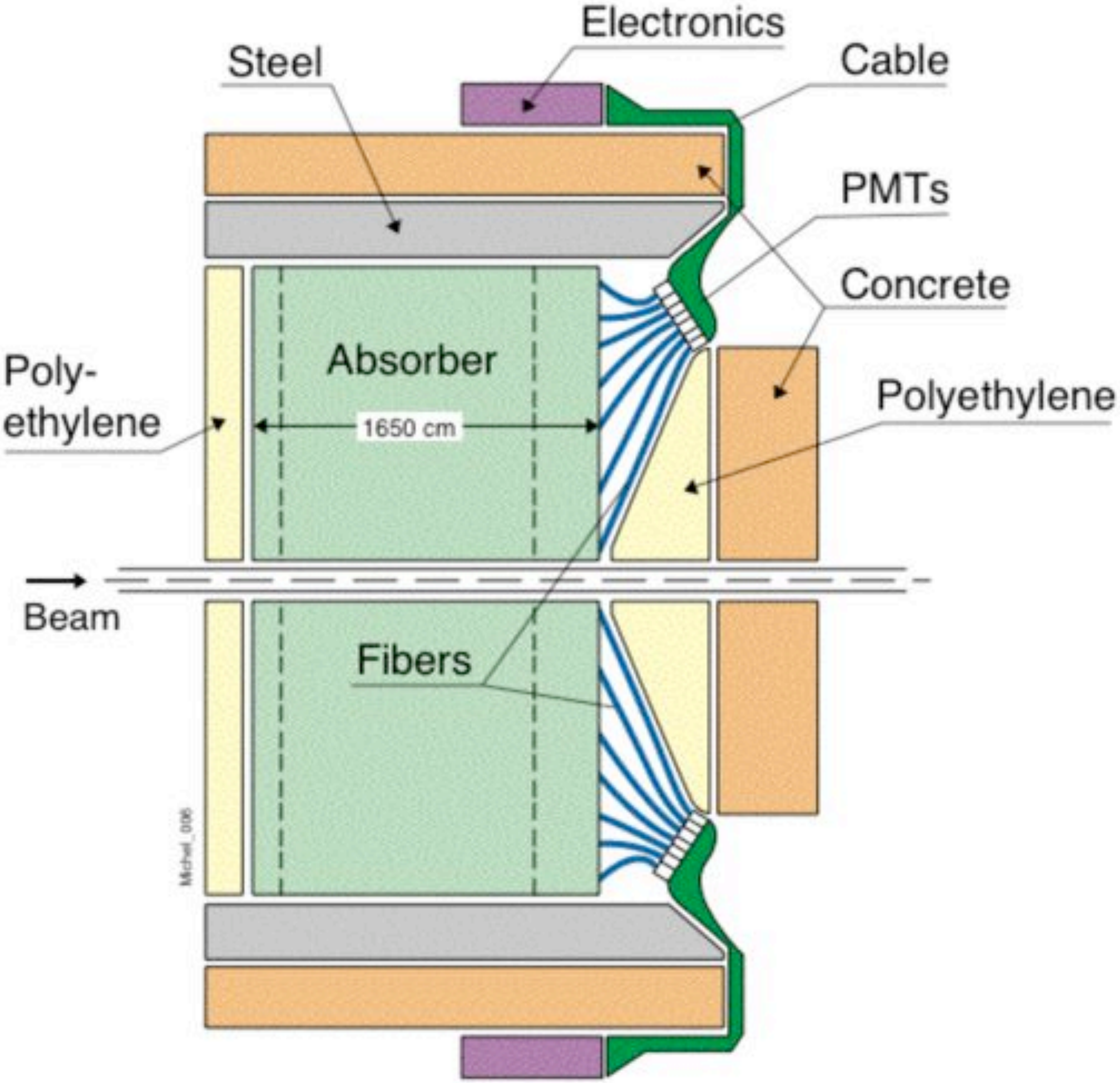


protons, muons…

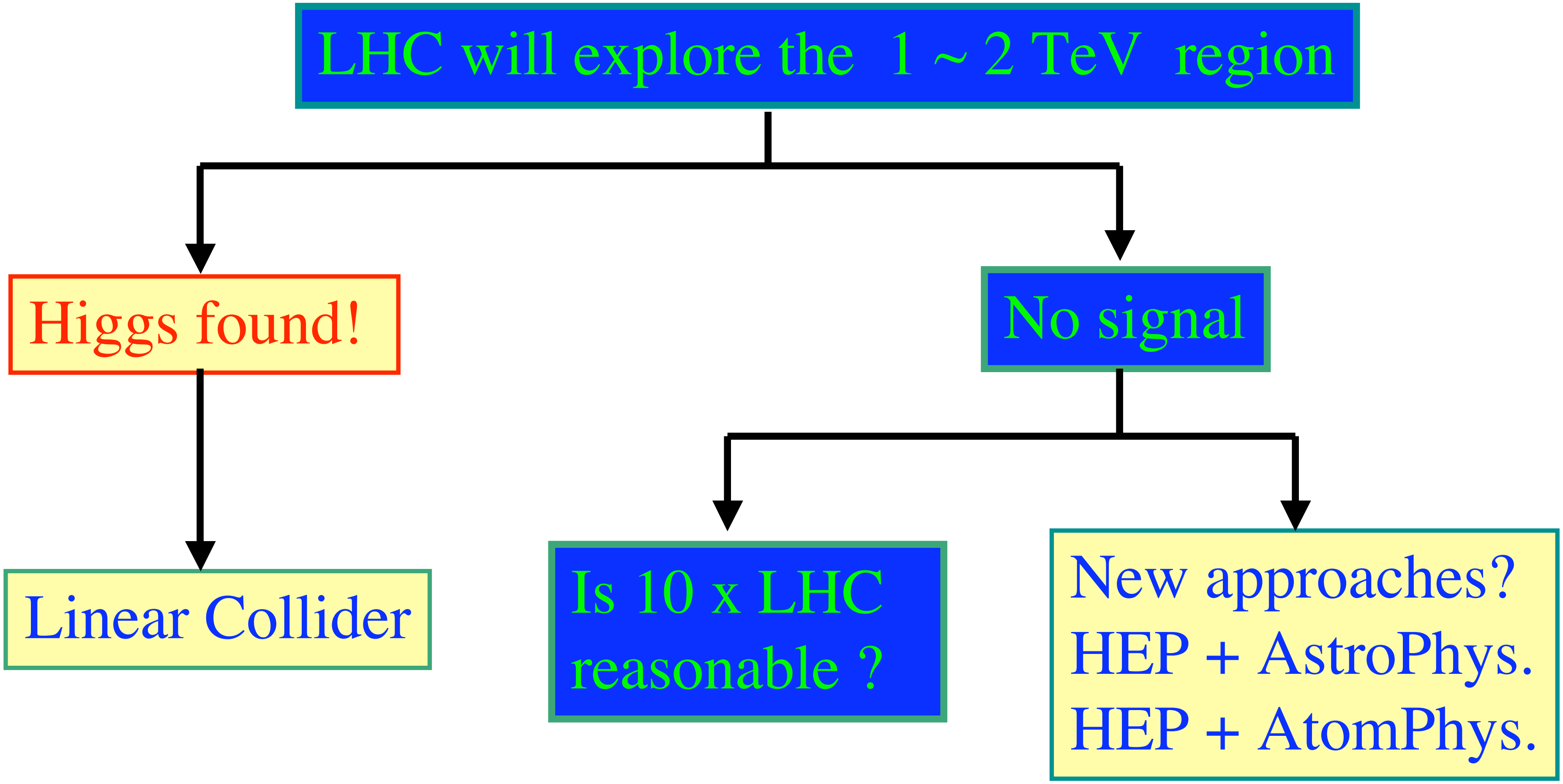




The final detector


Electronics
Steel
Cable
PMTs
Concrete
Poly-
ethylene
Absorber
1650 cm
Polyethylene
Beam
Fibers
Michel_006

Golden age, Legacy …



LHC will explore the 1 ~ 2 TeV region

Higgs found!

Linear Collider

No signal

Is 10 x LHC reasonable ?

New approaches?
HEP + AstroPhys.
HEP + AtomPhys.

Back to trial & error …

- HEP + Astro Phys = Astroparticle Physics
  - experimental detectors, satellites, deep underwater experiments

- HEP + Atomic Phys + Plasma Phys + Chemistry = Antimatter Phys.
  - Hbar atoms, Positronium, Ps^-
  - Ps_2 ? Hbar at rest ? $Hbar^+$?
  - stable antimatter compounds ? single atom gravity experiments ?

⇩

Exploratory Physics with exploratory techniques :
re-introduce small,unusual experimental techniques in HEP !!

Rev. Mod. Phys. Vol 64 pp237-257

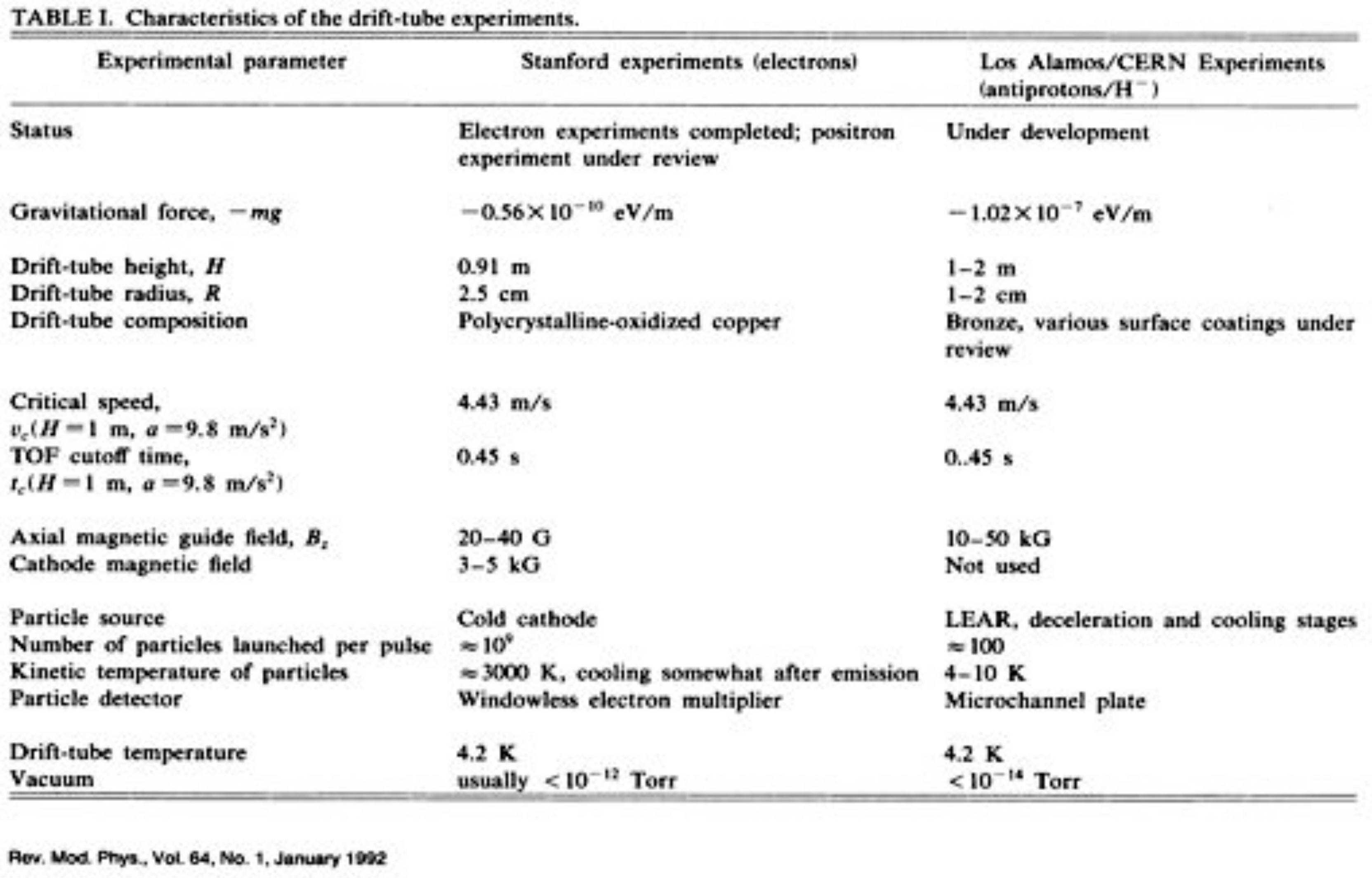


TABLE I. Characteristics of the drift-tube experiments.

Experimental parameter	Stanford experiments (electrons)	Los Alamos/CERN Experiments (antiprotons/H$^-$)
Status	Electron experiments completed; positron experiment under review	Under development
Gravitational force, $-mg$	-0.56×10^{-10} eV/m	-1.02×10^{-7} eV/m
Drift-tube height, H	0.91 m	1–2 m
Drift-tube radius, R	2.5 cm	1–2 cm
Drift-tube composition	Polycrystalline-oxidized copper	Bronze, various surface coatings under review
Critical speed, $v_c(H=1\text{ m},\ a=9.8\text{ m/s}^2)$	4.43 m/s	4.43 m/s
TOF cutoff time, $t_c(H=1\text{ m},\ a=9.8\text{ m/s}^2)$	0.45 s	0..45 s
Axial magnetic guide field, B_z	20–40 G	10–50 kG
Cathode magnetic field	3–5 kG	Not used
Particle source	Cold cathode	LEAR, deceleration and cooling stages
Number of particles launched per pulse	$\approx10^9$	≈100
Kinetic temperature of particles	≈3000 K, cooling somewhat after emission	4–10 K
Particle detector	Windowless electron multiplier	Microchannel plate
Drift-tube temperature	4.2 K	4.2 K
Vacuum	usually $<10^{-12}$ Torr	$<10^{-14}$ Torr

Rev. Mod. Phys., Vol. 64, No. 1, January 1992

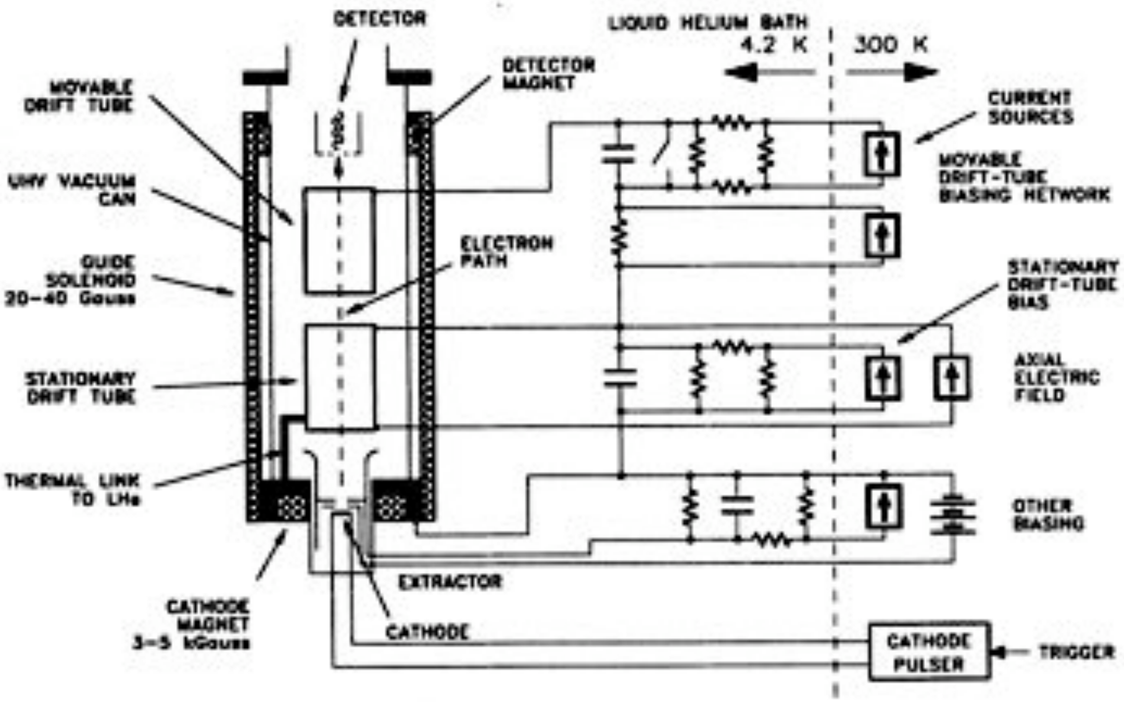


FIG. 1. Drift-tube apparatus used by the Stanford group in their free-fall experiments with electrons. Not shown is a second movable drift tube, located above the stationary drift tube. The second drift tube was used in an alternative technique, but was not as successful as the single-drift-tube method (Fairbank *et al.*, 1974). Normally it was electrically biased so as to have no significant effect on the time of flight of electrons, and it is ignored in this review. Reproduced from Lockhart (1976).

The fall of charged particles under gravity: A study of experimental problems

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There are currently proposals to test the weak equivalence principle for antimatter by studying the motion of antiprotons, negative hydrogen ions, positrons, and electrons under gravity. The motions of such charged particles are affected by residual gas, radiation, and electric and magnetic fields, as well as gravity. The electric fields are particularly sensitive to the state of the "shielding" container. This paper reviews, and extends where necessary, the physics of these extraneous influences on the motion of charged particles under gravity. The effects considered include residual gas scattering; wall potentials due to patches, stress, thermal gradients, and contamination states; and image-charge-induced dissipation.

IX. SUMMARY

We have exhaustively listed and studied the various influences on the motion of a charged particle under gravity in a drift-tube apparatus. The great importance of such experiments, testing the weak equivalence principle for antimatter, requires that these influences be carefully studied. By use of the clever techniques developed by the Stanford and Los Alamos/CERN groups, most spurious interactions can be rendered negligible. However, uncertainty remains over electric fields produced by the patch effect and gravitationally induced strain gradients in the drift tube (the DMRT field). While the temperature-dependent shielding effect claimed by the Stanford group may be genuine, it has not been independently verified, despite various attempts to do so. The preliminary experiments by the Los Alamos/CERN group with H^- and heavier ions may shed more light on this issue. A great advantage of the antiproton experiment is that only a differential measurement against H^- is proposed. We anticipate exciting results that may be forthcoming in the near future.