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HIGH RESOLUTION CRYSTAL CALORIMETRY AT LHC

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ABSTRACT

The search for HIGGS bosons above Lep200 reach could be one of the main tasks of the future pp and ee colliders. In the intermediate mass region, and in particular in the range 80-140 GeV/c^2, only the 2-photon decay mode of a HIGGS produced inclusively or in association with a W, gives a good chance of observation. A 'dedicated' very high resolution calorimeter with photon angle reconstruction and pion identification capability should detect a HIGGS signal with high probability. A crystal calorimeter can be considered as a conservative approach to such a detector, since a large design and operation experience already exists. The extensive R&D needed for finding a dense, fast and radiation hard crystal, is under way. Guide-lines for designing an optimum calorimeter for LHC are discussed and preliminary configurations are given.

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1- Introduction

The search for a neutral HIGGS bosons above Lep200 reach should be one of the main tasks of the future pp or ee colliders. In the intermediate mass region ($M_Z < M_H < 2M_Z$), as confirmed by recent studies [1], only two processes may allow the observation of a Standard Model Higgs boson at LHC:

$$pp \dashrightarrow (H^o \dashrightarrow \gamma\gamma) + X \qquad (1)$$

and

$$pp \dashrightarrow (H^o \dashrightarrow \gamma\gamma) + (W \dashrightarrow \ell\nu) + X \qquad (2)$$

Fig.1 shows the bridging of the gap in the intermediate mass region which can be expected from these 2 channels. A neutral MSSM Higgs boson could also give observable signals at LHC/SSC, in particular in the 2γ decay mode, but the coverage of a large region of parameter space seems difficult and is being studied in detail [2].

There are several physics arguments for high resolution calorimetry at LHC, but the detection of channel (1) and (2) being particularly demanding on detectors can be used for defining the characteristics of a high performance calorimeter. The justification of high resolution, of photon angle and pizero mass reconstruction in a 'dedicated' calorimeter will be only briefly summarized in this talk (more details in ref [3]).

2- Why a 'dedicated' calorimeter?

The $H^o \dashrightarrow \gamma\gamma$ signal rates seem rather comfortable, if one considers one year of LHC running at a luminosity of 10^{34} $cm^{-2} x s^{-1}$ (3-4000 events for 10^5 pb^{-1}). But the background is very large. The 'irreducible' background, which is the direct production of 2 photons by several processes ($q\bar{q}$, gg, bremsstrahlung) has to be reduced by severe kinematical cuts. Combinations of gammas from pizeros in di-jets are a second type of very large background, which can be reduced by isolation cuts and pizero identification.

The signal and background rates, calculated for SSC [4] and LHC [5] after cuts, are plotted in Fig.2 in terms of significance $S/\sqrt{B}$, for Higgs masses between 80 and 160 GeV. An excellent energy resolution of $2\%/\sqrt{E} \oplus 0.5\%$ is assumed and the rates are taken in a narrow mass window of $\sim$1.5% of M_H, optimized for best significance (contains $\sim$70% of the signal events). One observes signal rates of the order of 500-1000 events/year at LHC (10^5 pb^{-1}) as well as at SSC (10^4 pb^{-1}), with significance well above 5, except for 80 GeV masses.

On the other hand, S/B ratios are still small (1/5-1/30) and uncertainties on rates are large. Moreover, an excellent calorimeter with high energy resolution, good photon angle measurement and strong pizero rejection, has been assumed. Any degradation in resolution would cause a loss in significance. This could be compensated by an increase in data collection time, but long collection times make the control of the systematics more difficult, thus increasing the chances to smear the mass peak.

As was stressed at the Aachen workshop, a 'dedicated' calorimeter, i.e. optimized on the reconstruction of 2-photon invariant masses,should have following characteristics:

- An excellent E resolution ($\sigma/E=$ a%/$\sqrt{E} \oplus$ b%): it means a low a-term ($\leq$3%) as well as a very small b-term ($\leq$0.5%). In fact, the calculations show that in the considered γ energy range, an a-term rise from 2 to 10% causes a loss of significance similar to an increase from 0.5% to 1% in the b-term.

- A fine angular granularity: Aη x Aϕ $\leq$0.04x0.04 over a η range of ±2 at least. In fact, an acceptance for H^o-->$\gamma\gamma$ of $\eta=\pm2$ seems adequate but, since we also want to detect $e\gamma\gamma$ and 4e final states, a coverage in $|\eta|$ up to 2.5 or 3.0 is desirable. The fine granularity, which should match a small Moliere radius, is good for position resolution, particle identification and is essential for precise energy measurement at LHC by minimizing the effects of pile-up.

- A photon angle reconstruction to better than 10 mrad; it was shown that smearing by the vertex uncertainty ($\sigma_z \sim$5.5cm) brought a loss in significance as large as the loss caused by poor E resolution [5]. If σ_z is reduced to $\sim$1cm, the loss becomes acceptable and the vertex ambiguity can in general be solved, thus allowing the use of the precise vertex known from charged particles. Moreover,the 2-photon combinatorial background will be greatly reduced.

- A good 2-photon separation for pion identification. Photons from pizeros with tranverse momenta up to $\sim$50 GeV/c should be separated in order to reach the additional (to isolation cut) jet-rejection needed at LHC. This means a 2-photon separation down to $\sim$5 mrad.

- A fast readout: the energy smearing due to pile-up of events depends on the effective integration time. Integration over a single bunch crossing is highly desirable for an optimum detector. The fast radiation hard readout electronics needed is in itself a challenge, but since it is a common problem for many LHC detectors, we will not discuss it here.

- Radiation hard crystals are of course mandatory particularly at the largest rapidities considered. Their energy response should not be affected (less than a few percent) by photon doses of $\sim$1 MRad/year.

3- Why crystals and which crystals?

Crystal calorimeters can give the excellent energy resolution needed. The a-term is usually low for homogeneous calorimeters: 1-2%. If the crystal is a 'decent' scintillator, it gives enough light to keep the photostatistics and electronic noise (for photodiode readout) contributions negligible above a few GeV energy. The a-term then just reflects the slow variation of the 'constant' term (b) with energy.

The b-term is very difficult to bring down to $\sim$0.5% in any sort of calorimeter. This can only be achieved if a high priority is given to E resolution at all stages: choice of design parameters, details of construction, methods and frequency of monitoring and calibration of each tower, careful corrections at analysis level. If compromises with other constraints or detectors have to be made, which is usually the case inside large multipurpose experiments, the b-term will not be very small.

A 'dedicated' crystal calorimeter stands best chances to reach both low a and low b terms. In addition, granularity, segmentation and good hermiticity are straightforward with crystals.

In many respects, crystal calorimetry can be considered as a mature conservative technique. A large experience exists from several successful experiments such as Crystal Ball, Chloe, Cusb, L3. Some fast and radiation hard crystals are already known to exist, but more R&D work is needed in order to select the best crystals for LHC and develop economic production methods.

We consider that a crystal well suited to LHC should give a reasonable amount of light (>1% of NaI) preferably above 300nm, be dense ($\gtrsim$6 g/cm3) for compactness and small Molière radius, fast ($\lesssim$30ns with no slow component) to allow integration over 1 (or 2) bunch crossing and radiation resistant (>1MRad/year). Moreover, the temperature dependance of the crystal light output should be small (for low b-term) and the crystal should be chemically stable (no hygroscopicity) and mechanically resistant. The search for such a crystal is well under way [6] and the first results are reported in this conference [7].

4- Calorimeter design considerations

Despite the fact that a lot more R&D has to be performed to select the best crystals for LHC, we have taken three fast radiation hard crystals (see table 1) as bases for our calorimeter studies: BaF2 is listed for sake of comparison, CeF3 is a valid candidate and PbF2 illustrates a class of dense crystals, but is only a Cerenkov radiator at the moment.

From our past experience and having in mind the characteristics quoted above for a dedicated detector, we derive following guide-lines for a possible design:

a) The crystals, $\sim$25 RL long and pointing to the interaction region, should be displayed on a cylindrical barrel of sufficiently large radius to manage pile-up at a luminosity of $L=2\text{x}10^{34}$ $\text{cm}^{-2}\text{xs}^{-1}$. Crystals with a small Molière radius can be put nearer to the interaction point.

b) One should aim at a continuous coverage in pseudorapidity $|\eta|$ from 0.0 to 2.0 or 2.5, with constant fine steps such as for instance: $\Delta\eta \times \Delta\phi \approx$ 0.02×0.02. This is well satisfied by a long barrel with nearly square crystals of equal front face area.

c) In order to reduce the barrel length and thus the crystal volume, a cylinder up to $|\eta| \simeq 1.5$ could be continued by a conical part (see Fig.3) in which the crystal dimensions slowly decrease, keeping the number of phi rows constant. In this way, the fine granularity is preserved, large or sudden changes in the crystal transversal dimensions are avoided, the staggering of the front faces is limited and the radiation level for the large $|\eta|$ crystals is decreased with respect to a classical end-cap.

d) A longitudinal segmentation of all crystals into 2 pieces separately readout is planned for shower position determination and photon angle measurement and will also help for e-identification. To improve the position resolution in the front array, it is proposed to divide laterally each front segment into 4 pieces separately readout. Position resolutions below 1mm are expected in the front and in the back crystals, for photon energies larger than 20 GeV, yielding angular resolutions of 5-10mrad. This should give the vertex Z-coordinate to $\sim$5mm at 1m, for large theta angles.

e) A position detector between the 2 crystal segments, capable of separating 2 photons distant by a few mm only, is presently being studied. Such a detector will also help in particle identification and should yield a precise point on the shower axis. If such a point proves as efficient for photon angle measurement as the barycenter of the front segments, the lateral division into 4 pieces could be avoided.

The number of supercrystals NSC, of electronic channels NCH = 5xNSC (or 2xNSC if no division by 4) and the total crystal volume were evaluated for several configurations based on the previous principles (see table 2). Fig.3 illustrates a possible configuration at 1m radius with an $|\eta|$ coverage up to 2.5. A 1m radius seems adequate with CeF3 and leads already to big crystal volumes. Larger radii can be justified by better tracking and cleaner conditions at luminosities $\gtrsim 10^{34}$, but the crystal production price may not allow for the corresponding volumes.

A large $|\eta|$ coverage is relatively 'cheap' if the inside tracking can cope with a conical shape, but on the other hand, it is clear that problems due to pile-up or high radiation effects will start in the low theta region and might set a limit to the usable luminosity. The availability of very dense crystals, such as PbF2, would make a smaller internal radius and crystal volume possible, as can be seen in table 2.

5- Conclusion

We can conclude that a crystal calorimeter can indeed take the challenge and satisfy all the detection requirements for a Higgs boson in the intermediate mass region at LHC, provided an adequate and affordable crystal can be found. But where could such a detector be located at LHC? It could be integrated in one of the large projects being studied for a NEW LHC area. This makes sens only if electrons and photons are a priority of the project, and if no compromise has to be made on the quality of the detector. The integration in a possible LHC upgraded Lep experiment may bring prohibitive limitations, like small internal radius and depth. An attractive possibility could be the construction of a 'stand-alone' detector in a special LHC area reserved for 'specific' experiments. Such a detector should also include tracking capability in a magnetic field.

References

[1] For calculations and references on Higgs search at LHC/SSC, see for instance the summary talks of F.Denegri and of G.Altarelli, Proceedings of the ECFA/LHC Workshop, Vol I, AACHEN, Oct 90.
[2] F.Zwirner, Proceedings of the XXVIth Rencontres de Moriond,Les Arcs, France, March 91.
[3] M.Schneegans, Proceedings of the XXVIth Rencontres de Moriond, Les Arcs,France, March 91.
[4] L* Expression of Interest for SSC and Proceedings of the ECFA/LHC Workshop, Vol III, p.411, AACHEN, Oct 90.
[5] C.Seez et al, Proc. of the ECFA/LHC Workshop, Vol II, AACHEN,Oct 90.
[6] R&D Proposal for the study of new and radiation hard scintillators for calorimetry at LHC, Crystal Clear Collaboration, CERN/DRDC/P27, Project RD18.
[7] Progress and prospects in crystals for calorimetry in future high energy physics experiments, P.Lecoq et al, this conference.

Table caption

Table 1: Main properties of 3 fast radiation hard crystals.
Table 2: Parameters of some crystal calorimeter configurations. R_i is the internal radius of the cylinder (min radius for cone); Dim is the transversal dimension (front face) of the square crystals; NSC is the number of supercrystals (5 or 2 segments) and NCH is the number of electronic channels (5 or 2 xNSC).

Figure caption

Fig.1: Higgs detection in the intermediate mass region and bridging of the detection gap: 80-130 GeV/c^2 by the 2γ and $\ell 2\gamma$ modes.
Fig.2: Significance and rates for $H^0 \to \gamma\gamma$. Black squares are for 10^4 pb^{-1} collected at SSC and open circles for 10^5 pb^{-1} at LHC.
Fig.3: Possible geometry for a CeF3 crystal calorimeter for LHC. The crystal front faces are on a 1m radius barrel followed by a cone ending at a 50cm radius (see table 2). The preliminary Carbon composite mechanical structure, with each 'supercrystal' housed in a C-fiber cell is extrapolated from the existing L3/BGO structure.

CRYSTAL	Density g/cm^3	X^0 cm	$L(\sim 25X^0)$ cm	Molière R. cm	Peak nm	decay ns	Mechanic. Propert.
BaF2	4.9	2.06	51	3.4	210 310	0.6 620	POOR (Cleaves)
CeF3	6.2	1.68	40	2.6	300 340	5 20	GOOD
PbF2	7.7	0.94	23	2.2	Čerenkov		GOOD

TABLE 1

CRYSTAL	GEOM	R_i cm	Zmax cm	Coverage ηmax	ϕmax	$\Delta\eta$ x$\Delta\phi$	Dim cm	NSC	NCH	VOL m^3
BaF2	1/2Cyl	100	117	1.	40	0.02	2.0	4000	20k	5.0
at 1m	1/2Con	50	300	2.5	10	"	1.0	6000	30k	3.6
						TOTAL DET:		20000	100k	17.2
CeF3	1/2Cyl	80	139	1.3	30	0.02	1.6	~5400	27k	3.5
at 80cm	1/2Con	40	242	2.5	10	"	0.8	5000	25k	1.5
						TOTAL DET:		20800	104k	10.0
CeF3	(1/2) Cone	80	0.	0.	90	0.02	1.6			
Bicone	only	40	240	2.5	10		0.8	9600	48k	3.5
						TOTAL DET:		19200	96k	7.0
CeF3	1/2Cyl	100	173	1.3	30	0.016	1.6	9000	45k	5.2
at 1m	1/2Con	50	300	2.5	10	"	0.8	7000	35k	2.2
						TOTAL DET:		32000	160k	14.8
CeF3	1/2Cyl	130	280	1.5	25	0.012	1.6	17200	86k	8.2
at 1.3m	1/2Con	100	360	2.0	15	"	0.8	5200	26k	1.8
						TOTAL DET:		44800	224k	20.0
PbF2	(1/2) Cyl	70	254	2.0	15	0.03	2.0	16000	32k	1.8
at 70cm	only					TOTAL DET:		32000	64k	3.6

TABLE 2

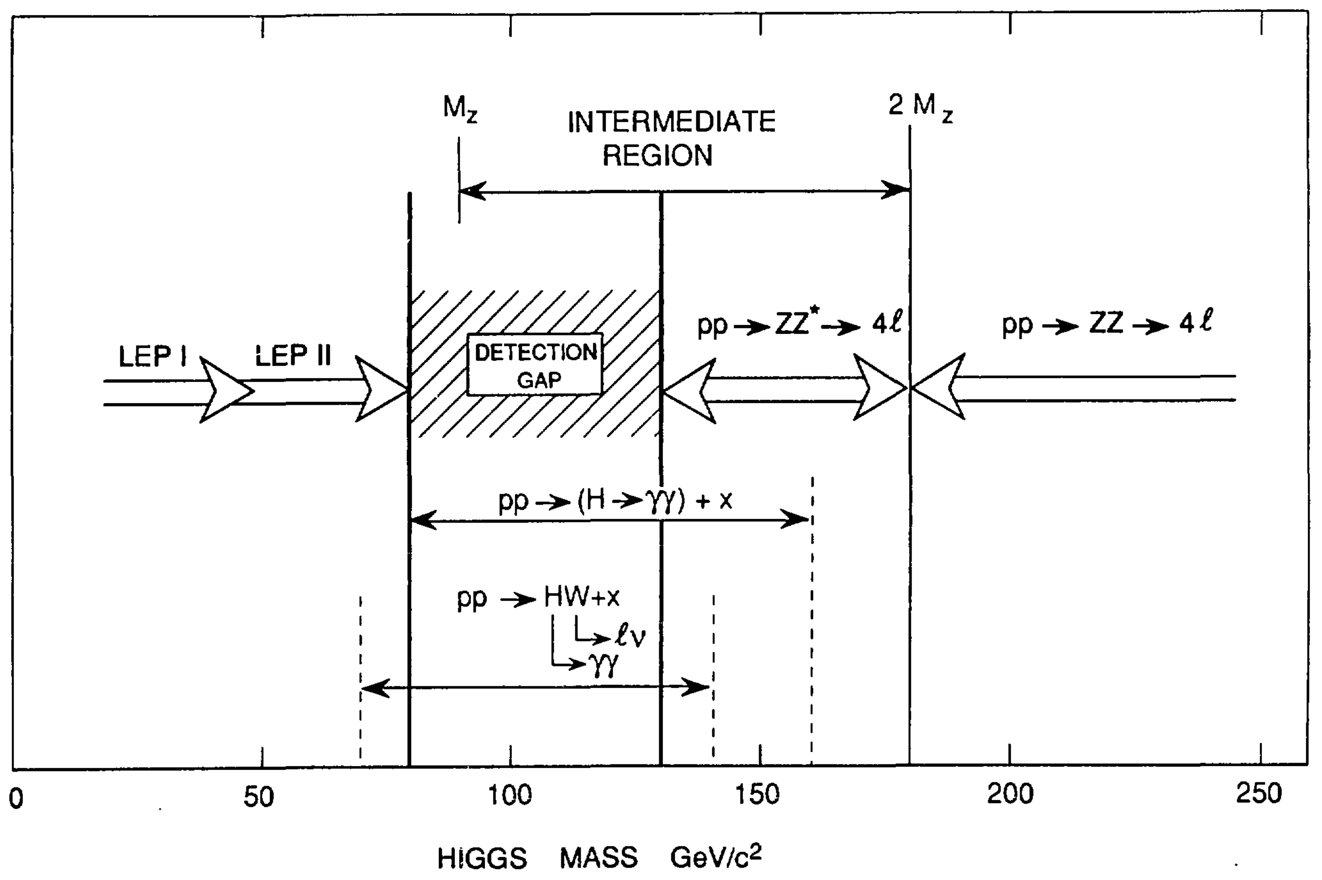
M_z
INTERMEDIATE REGION
$2 M_z$
LEP I
LEP II
DETECTION GAP
$pp \rightarrow ZZ^* \rightarrow 4\ell$
$pp \rightarrow ZZ \rightarrow 4\ell$
$pp \rightarrow (H \rightarrow \gamma\gamma) + x$
$pp \rightarrow HW + x$
$\rightarrow \ell\nu$
$\rightarrow \gamma\gamma$
0
50
100
150
200
250
HIGGS MASS GeV/c^2

FIG. 1

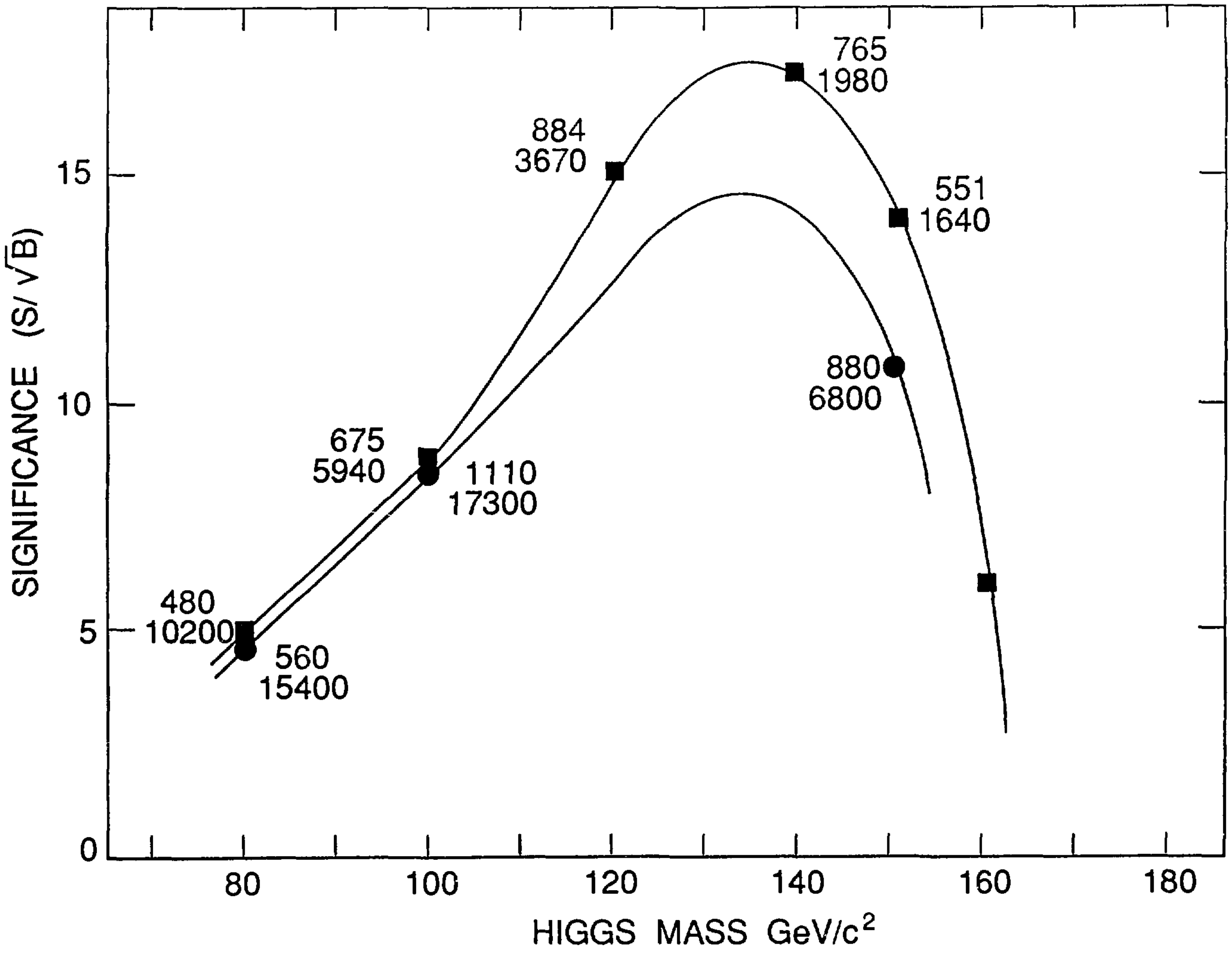
SIGNIFICANCE (S/ √B)
0
5
10
15
80
100
120
140
160
180
HIGGS MASS GeV/c²
765
1980
884
3670
551
1640
880
6800
675
5940
1110
17300
480
10200
560
15400

FIG. 2

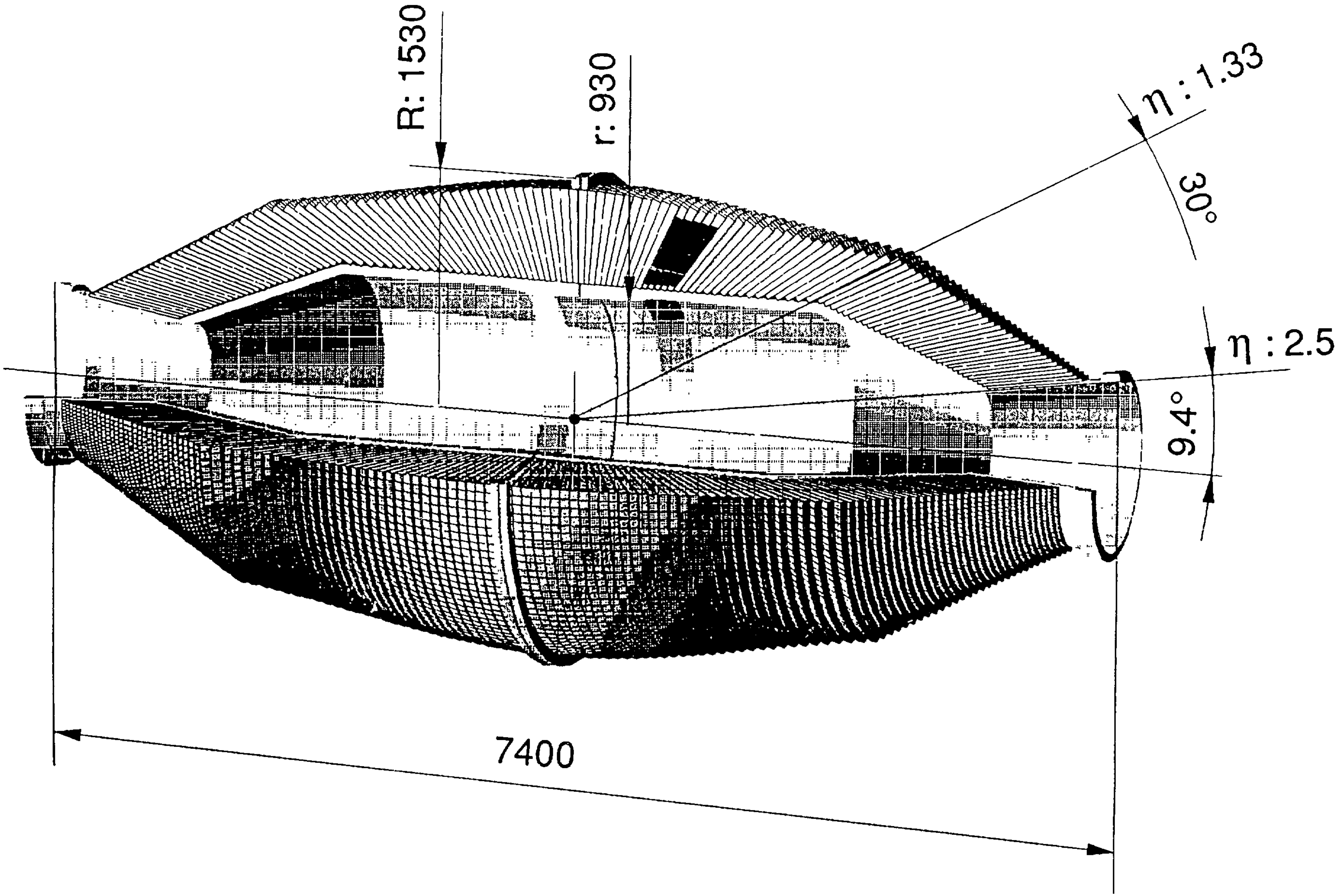

FIG. 3