Review of progress on Lead Tungstate crystals for the CMS electromagnetic calorimeter

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Calor97

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Introduction

- R&D strategy and progress on radiation hardness
- Results on first batch in conditions of mass production
- Progress on yields for all important parameters
- Production plan
Some facts about Radiation Damage in PbWO4

- Scintillation properties are not modified by radiation
- There is a radiation induced absorption due to the formation of colour centres
- Irradiation does not change the uniformity profile of the light yield along the crystal
- There is no degradation of energy resolution
- The shift of peak position can be corrected by the monitoring system
Before and after...

- Resolution is not degraded by loss

Run 11094
\[ \sigma/E = 0.50\% \]

Run 11186
\[ \sigma/E = 0.52\% \]
Energy resolution can be retained

- All events during 650 rads irradiation corrected using LED values
  - For this study averages made of LED pulse over each run (=20 mins)
  - Added width < 0.2% due to use of monitoring

<table>
<thead>
<tr>
<th></th>
<th>Single runs</th>
<th>All</th>
<th>data</th>
</tr>
</thead>
<tbody>
<tr>
<td>standard rate (2k/burst)</td>
<td>high * intensity (17k/burst)</td>
<td>high intensity</td>
<td>calculated standard rate</td>
</tr>
<tr>
<td>0.53%</td>
<td>0.63%</td>
<td>0.65%</td>
<td>0.55%</td>
</tr>
</tbody>
</table>

* Note: this is a pileup effect due to non-LHC electronics.

E-flow (in burst) > 5x10^{34}
Interpretation of the PWO Radiation Damage

- No evidence of the role of extrinsic impurities

- Radiation damage is caused by host structure defects

- Primary defects in PWO are:
  - Lead vacancy $V_k(Pb)$
  - Oxygen vacancy $V(O)$

- Secondary defects are created for charge compensation
  - for $V(O)$
    - F and F$^+$ centres
  - for $V_k(Pb)$
    - O$^-$ + h
    - Pb$^{2+}$ + h
Strategy for Radiation Damage improvement

- Reduce concentration of primary defects
  - growth conditions
  - stoechiometry

- Compensate secondary defects
  - $\text{Nb}^{5+}$ for $\text{O}^{-} + \text{h}$
  - Trivalent for $\text{Pb}^{2+} + \text{h}$
    - (La, Lu, Y, Eu, Al ...)

10 Nov 97
Strong R&D effort on radiation damage following program decided in Oct.96

- Systematic stoichiometry scan in Bogoroditsk  *Done*
  - full size crystals
    - 20 standard
    - 13 PbO excess (up to 1% in the melt)
    - 10 small WO₃ excess
    - 8 large WO₃ excess (up to 1% in the melt)
  - CMS-Note 97-55

- Tests on pentavalent and trivalent doping in Bogoroditsk + Crytur  *Done*
  - full size crystals
    - 10 Niobium
    - 18 Lanthanum
    - 6 Lutetium
    - 3 Yttrium
    - 1 Aluminum
  - CMS-Note 97-54

- Reproducibility tests under way in Russia with 2 optimized conditions
  - full size crystals
    - 20 crystals optimized for La doping
    - 20 crystals optimized for Nb doping
Induced absorption at 500nm, 50krad (18krad/h) versus Stoechiometry for 29 full size russian PWO
Longitudinal & transversal transmission for undoped, Nb, Lu, La doped full size russian crystals
Induced absorption at 500nm, 50krad (18krad/h) for undoped, Nb, Lu, La doped full size russian crystals

- $^{60}$Co side irradiation
- Full saturation of damage at any place in the crystal
Low dose rate irradiation of full size Russian PWO

- Front irradiation, $^{60}$Co, 15 rad/h (LHC like?)
- Gives similar behavior than 120GeV electrons in test beam
- Optimized stoechiometry brings an improvement of factor 2
- Doping brings another improvement of factor 2
Comparison of La & Nb doping
LHC type radiation cycle

Irradiation of Nb doped crystal (PWO1773) at low dose rate $^{60}$Co source

1st irradiation
855 rad, 72h

new irradiations
190 rad, 15h

190 rad, 15h

% LY loss
95
90
85
80

total dose: 1435 rad on 6 days

source TIS
set-up PPE-TA2

Irradiation of La doped crystal (PWO1696) at low dose rate $^{60}$Co source

1st irradiation
760 rad, 62h

new irradiations
190 rad, 15h

250 rad, 24h

% LY loss
95
90
85
80

total dose: 1340 rad on 6 days

source TIS
set-up PPE-TA2

E.Audfray/CMS_Etal
18/07/97
Stabilisation of technology (condition #1)

- Optimization of stoechiometry
- Raw material optimized for La doping
- 20 crystals grown in conditions of mass production
- 3 ovens randomly chosen
  - #29: 7 crystals, serial numbers 1851 to 1857
    - 2 runs of 5 crystallizations each
  - #31: 5 crystals, serial numbers 1858 to 1862
    - 1 run of 6 crystallizations
  - #35: 8 crystals, serial numbers 1863 to 1870
    - 1 run of 5 crystallizations
    - 1 run of 10 crystallizations, but 2 power cuts
- Overall yield is 65% (objective for production is 75%)
Stabilisation of technology condition 1

Transmission

Longitudinal transmission

Theoretical transmission with Fresnel losses

Intrinsic absorption coefficient

Wavelength (nm)

Intrinsic absorption coefficient (m$^{-1}$)

Wavelength (nm)
Stabilisation of technology condition 1

Transparency

Light Yield

Statistics on 39 crystals
Mean value: 8.1 pe/MeV
standard deviation: 1.3 pe/MeV

Statistics on 65 crystals
Mean value: 8.8 pe/MeV
standard deviation: 2.4 pe/MeV

Statistics on 20 crystals
Mean value: 10.8 pe/MeV
standard deviation: 1.3 pe/MeV

LY measured in lab27/CERN with PM2262B, qe=13%,
gate=1000ns, T normalised at 18°C, wrapping tyvek
Stabilisation of technology condition 1

Decay time

![Graphs showing decay time](image-url)
Stabilisation of technology condition 1

Radiation hardness: High dose and dose rate (50 Krad, 25krad/h, lateral irradiation)

Induced absorption coefficient at 420nm after 50krad (18krad/h)
for serie 1851-1870

Statistic on 20 crystals
Mean value: 1.233 m\(^{-1}\)
Standard deviation: 0.56

Induced absorption coefficient at 420nm after 50krad versus N° crystallisation
for serie 1851-1870

- **Furnace 29**
- **Furnace 31**
- **Furnace 35**
Conclusions on first reproducibility test

- Conditions of mass production
- Overall yield of 65% to produce 20 full size crystals
- Out of 20 crystals
  - 17 are radiation hard (less than 5% LY loss at 200rads)
  - 2 are about OK (less than 10%)
  - 1 is probably not good enough
- All crystals are fast (90% light emitted in 30ns)
- Average light yield is 11 pe^-/MeV
- Similar test with Nb doping going on
Conclusions on first reproducibility test

- Conditions of mass production
- Overall yield of 65% to produce 20 full size crystals
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  - 17 are radiation hard (less than 5% LY loss at 200 rads)
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Progress on Mechanical Tolerances

Yield for ≤ 200μm tolerances
Progress on Optical Transmission

Yield for ≥ 1m attenuation length
Progress on Light Yield

Statistics on 39 crystals
Mean value: 8.1 pe/MeV
Standard deviation: 1.3 pe/MeV

95

Statistics on 20 crystals
Mean value: 10.8 pe/MeV
Standard deviation: 1.3 pe/MeV

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Yield for ≥ 10 pe-/MeV

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P. Lecoq CMS/ECAL
Progress on Decay Time

Yield for LY(100ns)/LY(1\,\mu s) \geq 0.9
Progress on Radiation Hardness
LY loss for $^{60}$Co front irradiation at 15 rad/h

Yield for $\leq 5\%$ LY loss at low dose rate
Production Yields

- Raw material Premelt yield
  Yield 75%

- Raw material Growth yield
  Yield 78%

**Total raw material yield 59%**

- Growth yield: Now: 85%  Objective: 90%
- Annealing: Now: 91%  Objective: 95%
- Mechanical processing:
  Now: 83%  Objective: 90%

**Total 64% 77%**
Production plan in Russia

- Preproduction period starts mid 98 till end 99
  - 1000 crystals produced in 98
  - 5000 crystals produced in 99

- CERN + ISTC R&D support organized to have infrastructure ready at the end of 99 for delivery of 8600 crystals per year assuming a yield of 75%
  - 105 growth furnaces (now 50)
  - 20 premelt furnaces
  - 10 spares
  - 2 lines of mechanical processing (5 machines each)

- Additional 45 ovens (35 for growth) can be made available to reach 55000 crystals in 2004

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<th>Years</th>
<th>98</th>
<th>99</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
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<td>5000</td>
<td>8000</td>
<td>8400</td>
<td>8500</td>
<td>8600</td>
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<td>11000</td>
<td>12000</td>
<td>2700</td>
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