Adam Para, Fermilab
CALOR 2010
Beijing, May 10, 2010

IMPRESSIONS FROM THE SECOND HOMOGENOUS HADRON CALORIMETRY WORKSHOP

See http://indico.ihep.ac.cn/conferenceTimeTable.py?confId=1470 for details

What is HHCAL and what for?

- Next generation of lepton colliders will be constructed to elucidate the new physics discovered at the LHC. 15-20 years, >$\$10^9$.
- (Multi-)Jet spectroscopy likely to be the key tool to understand new spectroscopy (W and Z playin a role of gammas of nuclear spectrosopy)
- A sensible challenge(given the magnitude of the investment in the machine construction): $\Delta E/E \sim 10\%/\mathrm{sqrt}(E)$, constant term below 1%

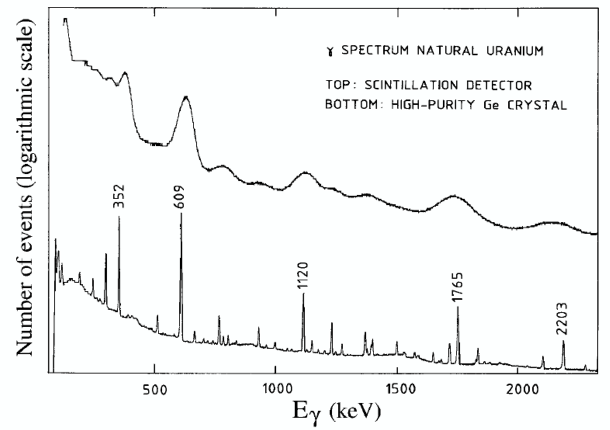


FIG. 1.1. Nuclear γ-ray spectrum of decaying uranium nuclei, measured with a bismuth germaniumoxide scintillation counter (*upper curve*) and with a high-purity germanium crystal (*lower curve*). Courtesy of G. Roubaud, CERN.

From R. Wigmans

Why Hadron Calorimeters are so Poor?

- $(\Delta E/E)_{EM}$ can be as good as 0.01 for total absorption calorimeters . The best hadron calorimeters have $(\Delta E/E)$~40-50%/√E for single particles, 70%-100%/ √E for jets. What's wrong with hadrons???
- Hadron calorimeters are sampling calorimeters
  - Sampling fluctuations (fluctuation of the energy sharing between passive and active materials)
  - Sampling fraction depend on the particle type and momentum (good example: a 'neutrons problem' in iron-scintillator calorimeter. SF ~ 0.02 at high energy, SF = 1 for thermal neutrons)
- A fluctuating fraction of the hadron energy is lost to overcome nuclear binding energy.
- Inhomogeneous calorimeters (typically: EM + HAD, with different responses)

Path to High Resolution Jet Calorimeter

- Homogeneous Calorimeter (EM/HAD combined).
- Total absorption calorimeter (No sampling fluctuations, SF = 1 for all particles and energies). This practically implies a light-collection based calorimeter.
- Correct (on the shower-by-shower basis) for the nuclear binding energy losses. This can be done, for example, by dual readout of scintillation and Cherenkov light signals.

High Resolution Jet Calorimeter?

- All the underlying principles are known/understood since a very long time (> 20 years). If it is so simple why we haven't built good hadron/jet calorimeters??
  - Low density scintillators ➔ huge detector size for total absorption
  - Bulky photodetectors ➔ cracks to bring the light out or further increase of the detector size
  - No photodetectors in the magnetic field
  - No physics-driven requirements (in hadron collider environment)
- Major advances in the detectors technology/enabling technologies:
  - High density scintillating crystals/glasses (λ~20 cm)
  - 'Silicon Photomultipliers' ~ robust compact, inexpensive

Challenging Questions

- Initial (but thorough) physics studies indicate that very high resolution hadron calorimeter is technically possible, the cost of the detector (scintillating materials, photodetectors) being the primary challenge. Typical volume of the calorimeter is in the range of 50-100 m^3!!
- Is it all true? Do we understand the underlying physics to a sufficient degree? Are there some limiting factors? Saturations, non-linearities, other systematic effects?
- Do we understand the scintillation, Cherenkov light creation, propagation and detection at the sufficient level?
- What is an optimal design of a complete detector, what are the rational compromises between various conflicting requirements
- What are the perspectives for development of new inexpensive scintillating materials? What are the fundamental limiting cost factors?
- Novel materials? Crystals? Glasses? Metamaterials? Ceramics?

HHCAL Workshops

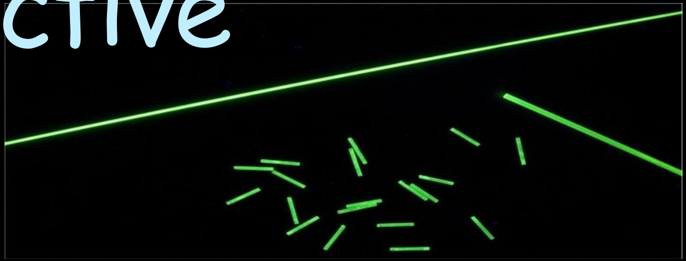
- First Workshop: Shanghai, February 2008 (Ren-Yuan Zhu)
- Broad based organizing committee with multidisciplinary representation
- Second Workshop: Beijing, yesterday (Ren-Yuan Zhu, Yifang Wang: Thank you!)
- The future:
  - Companion workshops at IEEE NSS Symposia (November 2010, Knoxville, October 2011, Valencia, Spain)
  - Dedicated sessions at various relevant conferences (SCINT-series, CALOR?)
  - Ad-hoc topical workshops
- Primary goal: develop better understanding of the issues, identify the principal problems, look for show-stoppers, intiate a brad R&D effort

Session 1

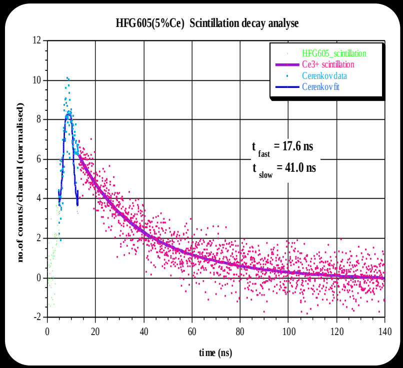
- Fermilab's History in the Development of Crystals, Glasses and Si Detector Readout for Calorimetry
  by Prof. H. EUGENE E FISK (Fermilab)
- Scintillating Materials for Homogenous Hadron Calorimetry
  by Adam PARA (Fermilab)
- Search for scintillating glasses and crystals for hadron calorimetry

  by Steve Derenzo (Lawrence Berkeley Nat'l Lab)
- A CERN contribution to the dual readout calorimeter concept
  by Dr. Paul LECOQ (CERN)

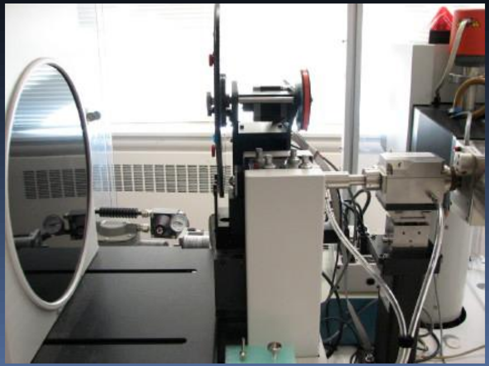
Laboratories Perspective



- Strong support/interest declared at CERN, Fermilab and LBL
- CERN/Crystal clear: metamaterials, heavy fluorinated glasses
- Fermilab: test beam studies, readout of photodetectors
- LBL: search for new scintillators, crystals and glasses with automated high-throughput facility



Pixels diameter 350 µm
Array surface 10 mm x10 mm



Session 2

- Crystal development for HHCAL: physical and technological limits
  by Dr. Alexander GEKTIN (Institute for Scintillation Materials, Kharkov, Ukraine)
  Search for Scintillation in Doped Lead Fluoride Crystals for the HHCAL Detector Concept
  by Dr. Liyuan ZHANG (California Institute of Technology)
  Development of Halide Scintillation Crystals for the HHCAL Detector Concept
  by Dr. GUOHAO REN (Shanghai Institute of Ceramics, Chinese Academy of Sciences)
  BSO Crystals Development with the Modified Multi-crucible Bridgman Method for the HHCAL Detector Concept
  by Dr. Hui YUAN (Shanghai Institute of Ceramics)

Industrial Perspective

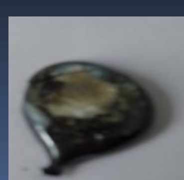
- Kharkov - A. Gektin
  - Almost everything is technically possible, but most of the things are prohibitively expensive
  - Need more complete specifications for cost optimization
  - Detailed understanding of the physics of sinctillation and Cherenkov light necessary
  - Transparency for the Cherenkov light is of prmary importnace
  - Glasses are more promising, but they may not be as cheap as we (some people) think
- PbF2 (SICCAS- Guohao Ren/Caltech - Liyuan Zhang):
  - excellent Cherenkov radiator, probably the most affordable crystal. Technology well established Attempts to make it scintillate inconclusive. PbClF may be a more promising candidate
- BSO (SICCAS)
  - An attractive alternative to BGO (cost-wise and performance-wise for dual mreadout). Steady preogress in improvement of crystals quality over past two years..

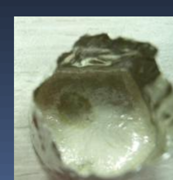
Session 3

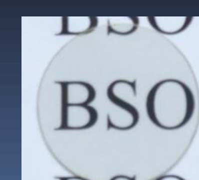
- R&D on Scintillation Crystals and Special Glasses at BGRI
  by Dr. Mingrong ZHANG (Beijing Glass Research Institute)
- Status of Scintillating Ceramics and Glasses at SIC and their potential applications for the HHCAL Detector Concept
  by Prof. Jing-Tai ZHAO (Shanghai Institute of Ceramics)
- Study of dense scintillating glass samples
  by Prof. Tianchi ZHAO (Unviersity of Washington)
- Some thoughts about homogeneous dual-readout calorimeters
  by Dr. Richard WIGMANS (Texas Tech University)
- Lively discussion

Industrial Perspective II

- Beijing Glass Research Institute - Mingrong ZHANG
  - Long history of large scale production of various scintillaing <u>CRYSTALS</u> for various experiments/customers
  - Very interested in development of new materials for HHCAL
- Shanghai Institute of Ceramics Jing-Tai Zhao
  - BSO <u>GLASS</u> an attractive alternative for the HHCAL
  - Transparency for Cherenkov need more work. Never, ever, ever,…..ever give up







Academic Perspective

- University of Washington - Tianchi ZHAO, Ningbo University -Zhang Yuepin
  - Pr^{3+} doped PbF_2 scintillating glasses
  - Eu^{3+} doped TeO_2-PbF_2 scintillating glasses
  - Ce^{3+} doped Gd_2O_3 scintillating glasses
  - Pr^{3+} doped PbO scintillating glasses
  - Small samples, evaluation at IHEP. Work in progress
- TTU – Richard Wigmans
  - We know/understand a lot about limitations of (hadron calorimetry)
  - It is all about nuclear physics (to a first order)
  - The principal concern: the neutron detection (performance)
  - The principal concern: COST (practical)

(Instead of) Summary

- A lot o challenges
- Rapid progress in understanding and identification of issues, challenges
- Very constructive interaction of various concepts and ideas
- Material aspects are in hands on material science people, but they need more precise guidance and specifications
- Role of neutrons must be analyzed and understood
- Other possible show stoppers (if any) must be identified
- Potentially/practically achievable performance limits should be analyzed and understood
- The club is open. Welcome!
- By the way.. Why not better than 10%/sqrt(E)????