Electromagnetic Calorimeter of the BTeV Experiment

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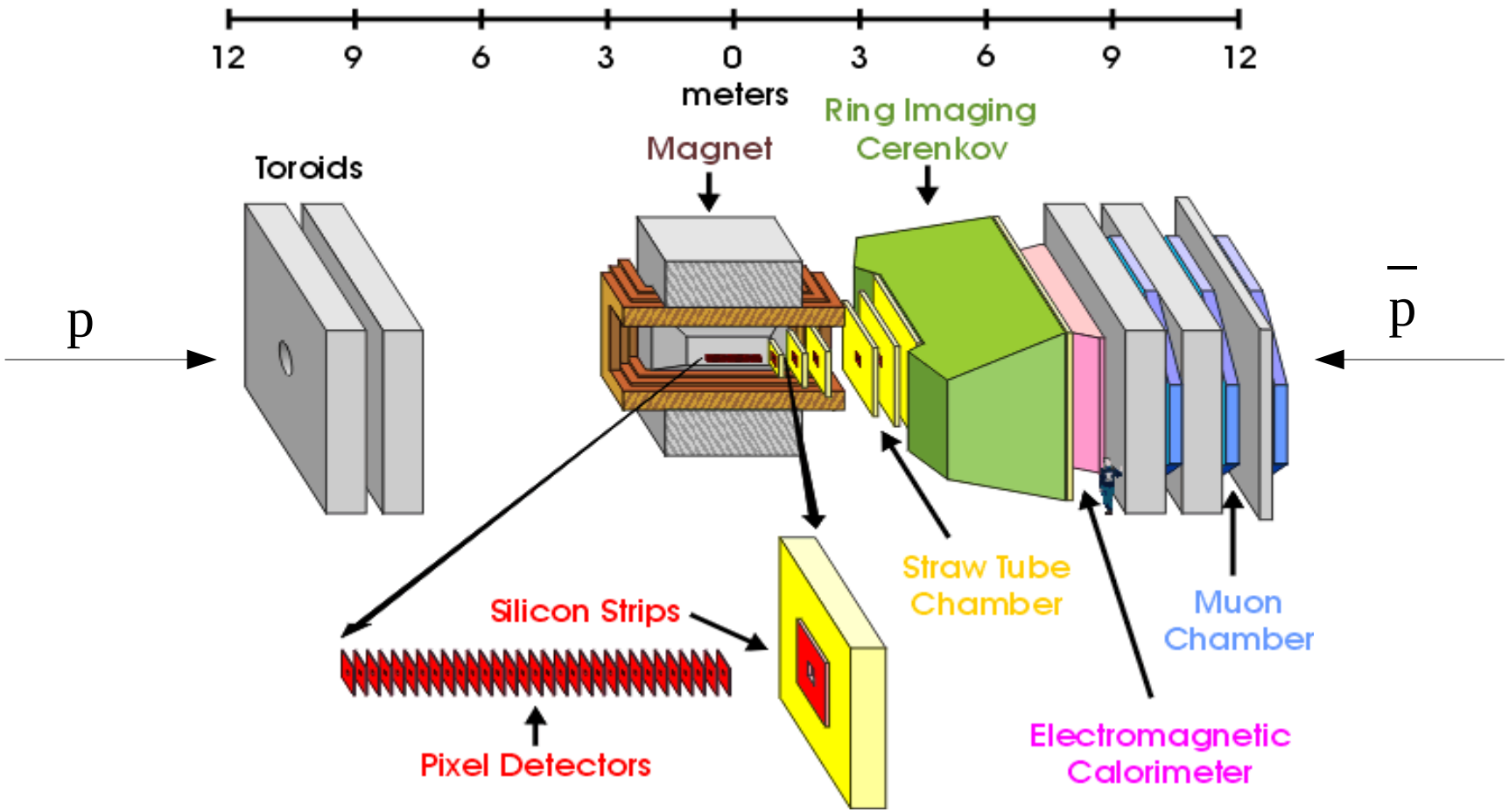
What is BTeV ?

- At the Tevatron p-pbar collider, at Fermilab :
  - Forward Spectrometer
  - Beauty and Charm Physics :
    - Precision measurements
    - Search for rare and forbidden phenomena
- BTeV is a part of broad program to address fundamental questions in flavor physics
- For details : http://www-btev.fnal.gov

BTeV Detector Layout



Important B Decay Modes

$$B^0 \to (\rho\pi)^0 \to \pi^+\pi^-\pi^0$$

The cleanest way to extract in the unitary triangle

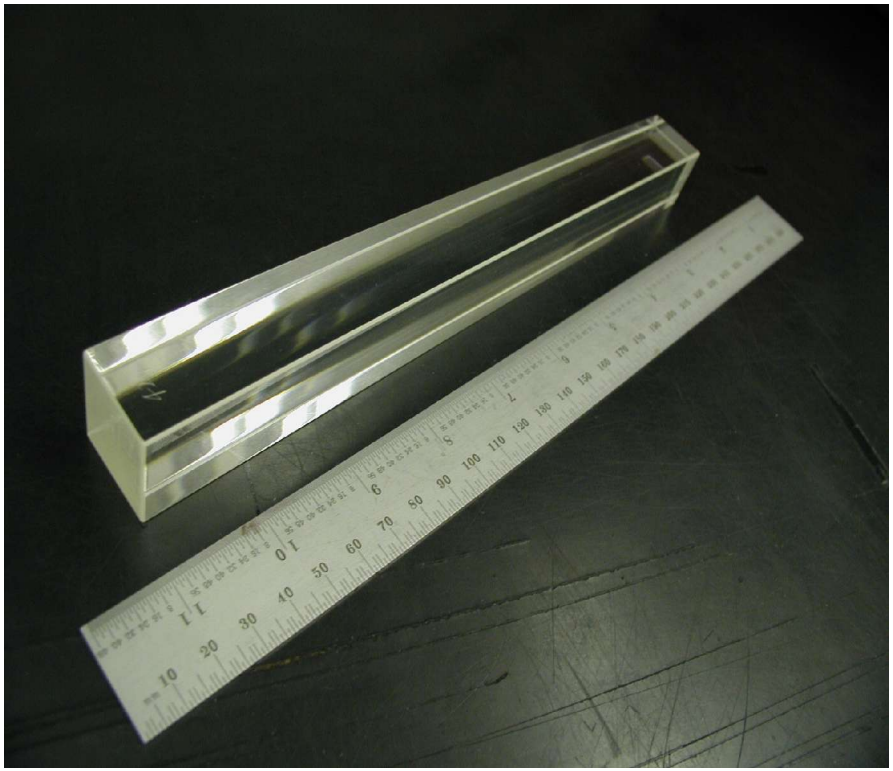
$$B_s^0 \to \psi\eta \ , \ \psi\eta'$$

$$B^0 \to K^*\gamma \ , \ \rho^0\gamma$$

Excellent reconstruction of neutrals is needed !

Choice of Technology

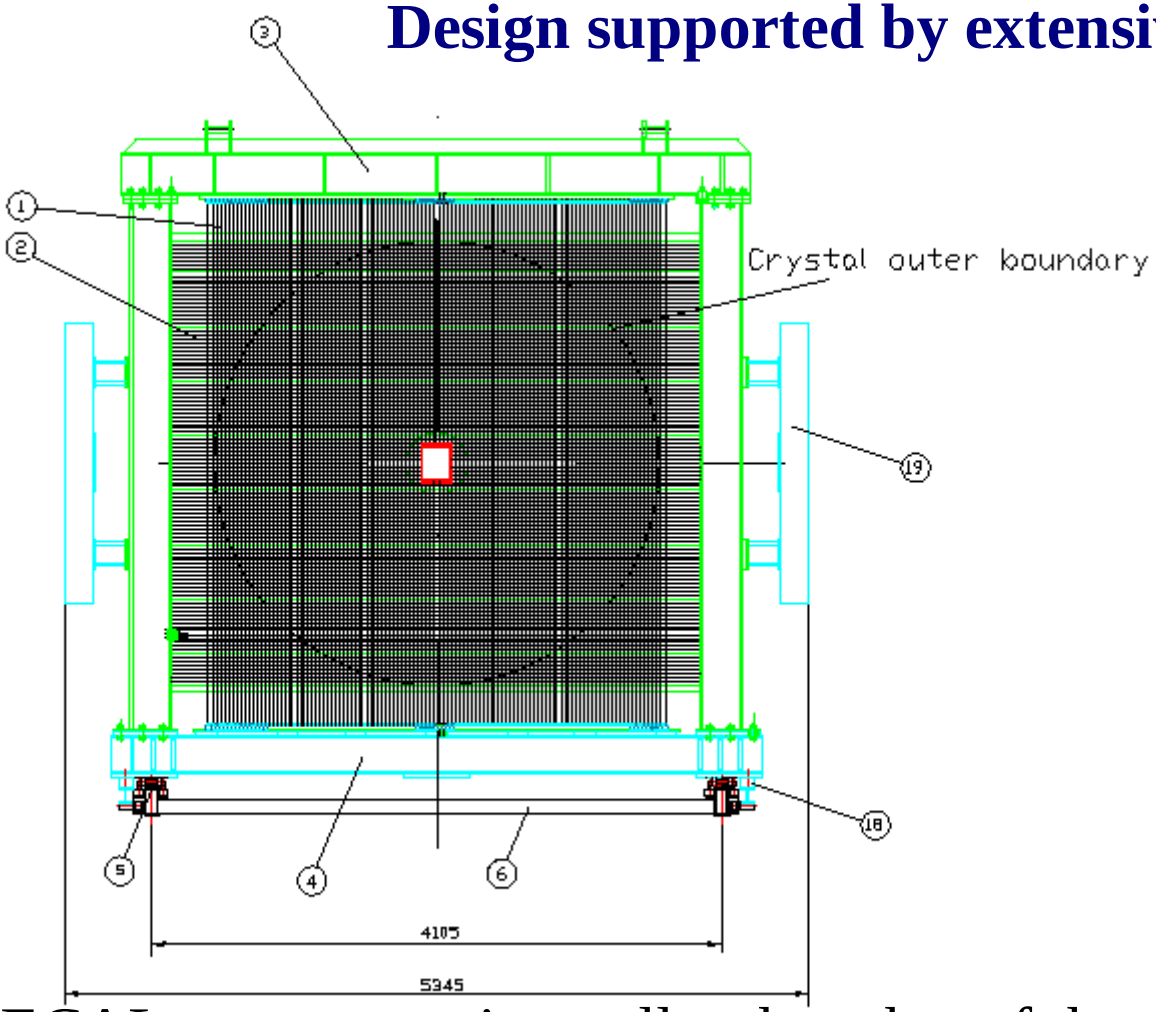
- **Choice of crystals :**
  - Excellent energy resolution
  - Structural compactness
- **Choice of $PbWO_4$:**
  - Radiation hardness
  - Fast signal
  - Compact shower size
- **Choice of PMT's :**
  - Better energy resolution
  - Possible since away from B



Potential producers :
Bogoroditsk, Shanghai, Apatity, Beijing

ECAL Mechanical Structure

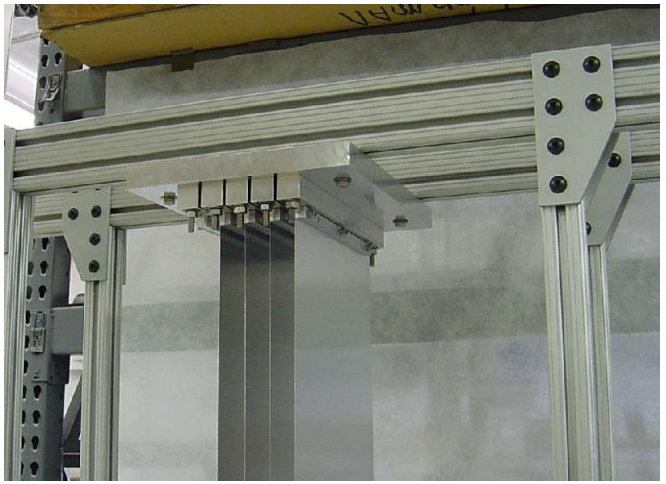
Design supported by extensive MC studies



- Tapered crystals off-pointing at IR
- AL strips support cell structure
- Outer "radius" 160cm
- Square beam hole ±10.88cm in x and y
- Distance from IR 750cm
- Cooling and humidity control design underway

ECAL acceptance is smaller than that of the tracking system (300mrad); this leads to about 20% signal loss for most final states

Prototype Mechanical Structure



To get better sense of the strips assembly

To estimate production cost and schedule

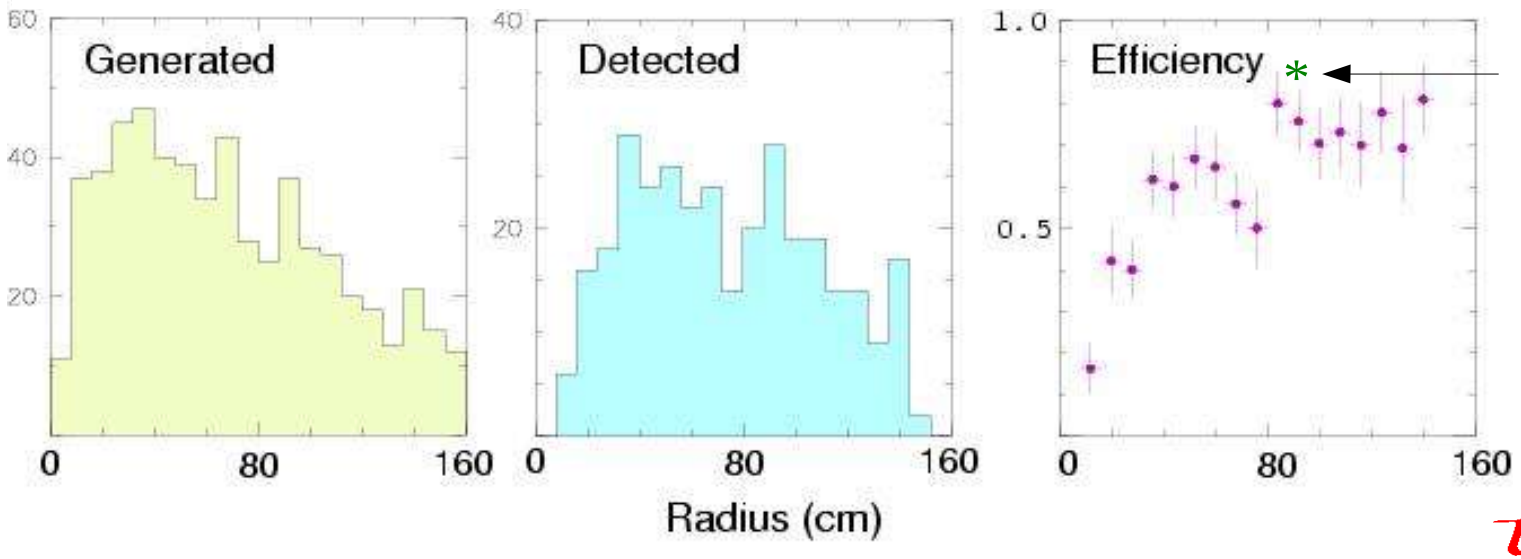
Expected Performance

$\sigma(E)/E = 1.7\% / \sqrt{E} \oplus 0.55\%$ $\sigma(x) = 2770\,\mu m / \sqrt{E} \oplus 170\,\mu m$

Reconstruction of γ's

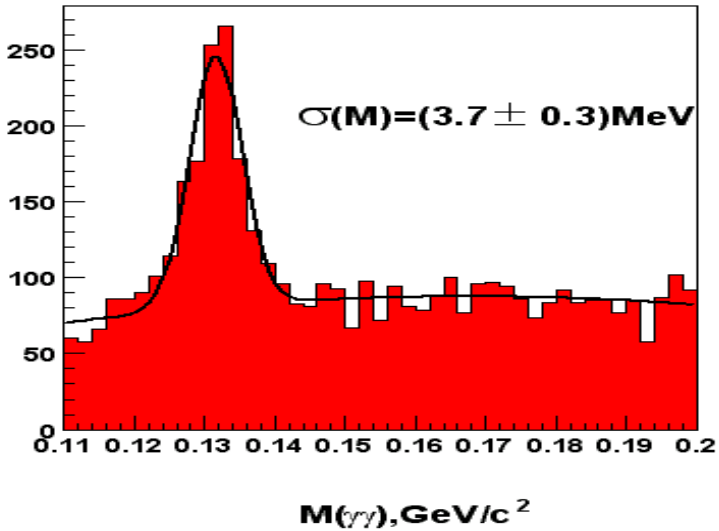
- Clustering algorithm
- Partition of showers overlap
- "Fine" corrections
- Charged hadrons rejection
- More sophisticated handling of showers overlap underway

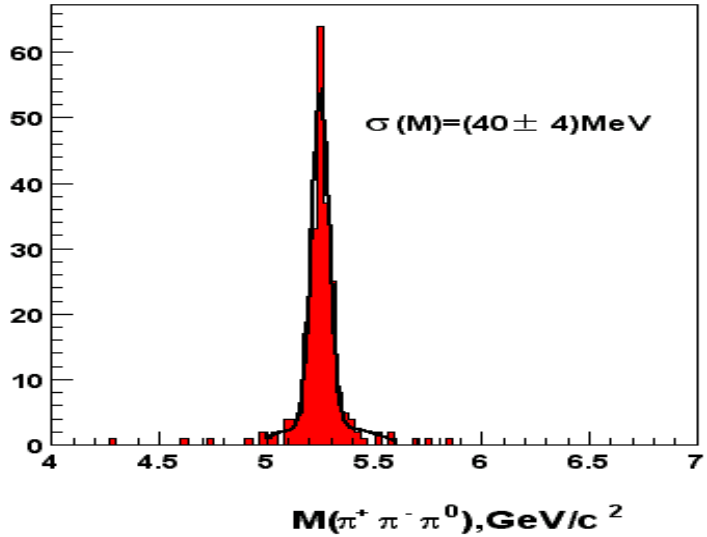
Generated and detected γ's from $B^0 \rightarrow K^*\gamma$ (G3+rec.tools)

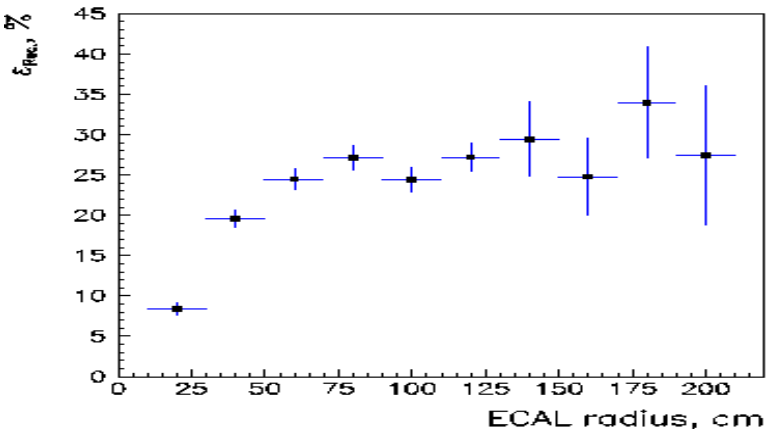


Expected Performance

Reconstruction of π^0's from $B^0 \to \rho^+ \pi^-$ (G3 + BTeV rec. tools)







- + min bias events : Poisson distributed, mean = 2 /beam crossing
- B-mass plot is for events in which the charged tracks and the $\gamma\gamma$–pairs pass all cuts

ECAL Test Beam Program at IHEP(Russia)

5 test beam runs since April 2001

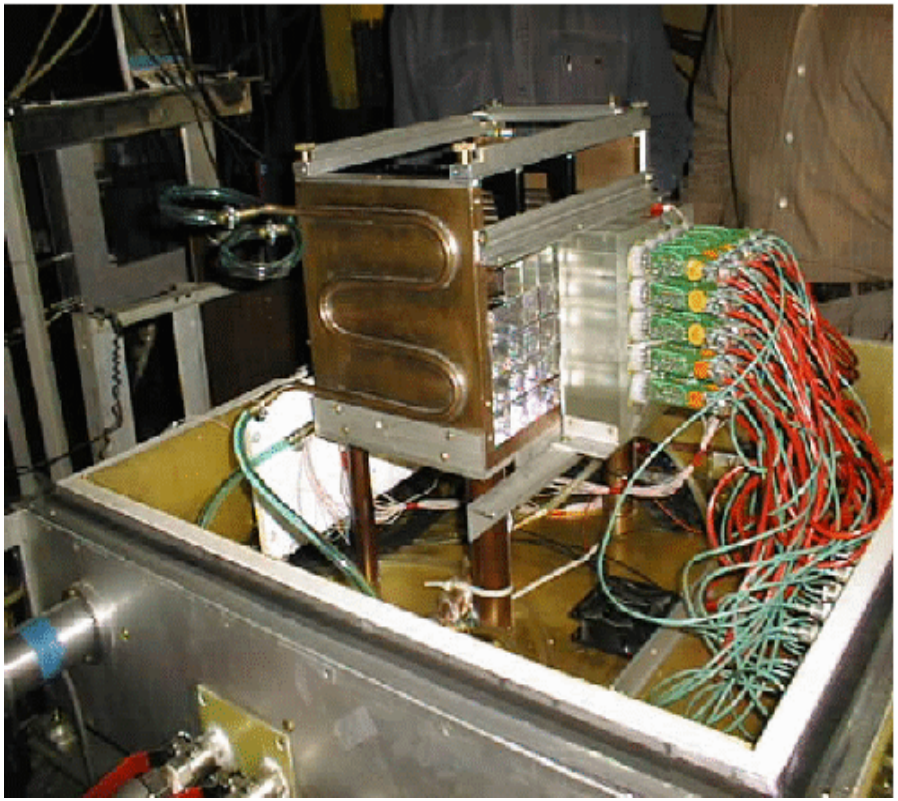
Tested crystals from all 4 potential producers

- **Prove expected energy/position resolution**
- **Study uniformity of light output**
- **Study behavior vs time :**
  - **effect of irradiation**
  - **readout stability**
- **Steps towards monitoring and calibration**
- **Steps towards quality control**

Test Beam Facility at IHEP

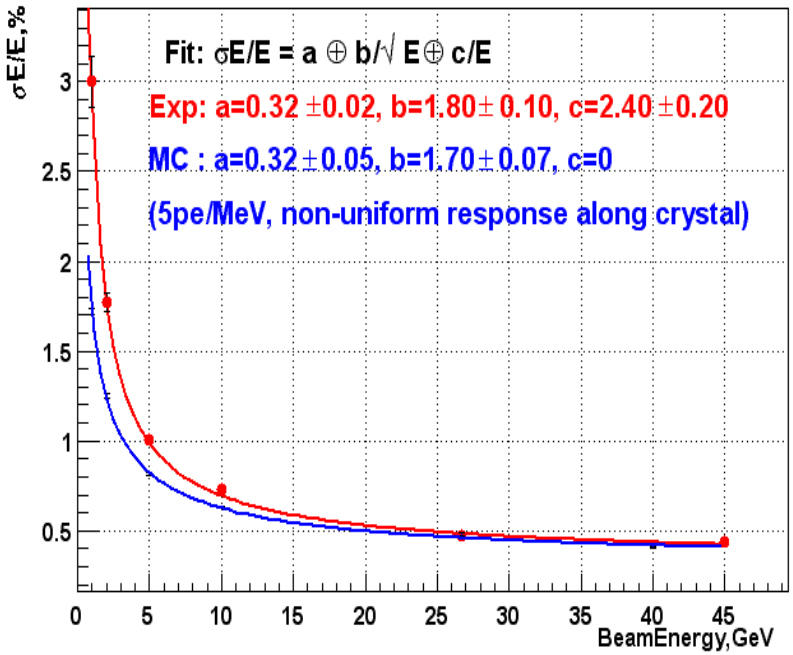
- 2B channel at U70
- Beam momentum tagging
- Trigger (scint.counters)
- Electron beam :
  - Energy : 1 to 45 GeV
  - Intensity up to 10^6 e-/spill
  - Radiation rate to 25rad/hr
- Pion beam :
  - Energy : 40GeV
  - Intensity up to $8x10^6$ π-/spill
  - Radiation rate to 60rad/hr
- Dedicated irradiation facility (70GeV p beam on Be target)

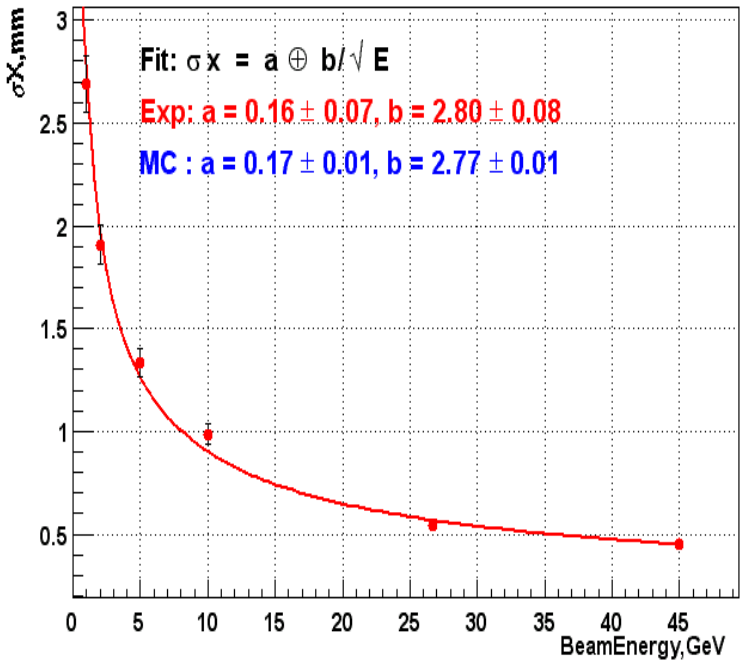
BTeV/ECAL Test Beam Setup



- 5x5 array of crystals, each $27x27x220mm^3$ (BTeV will use tapered crystals)
- Tyvek wrapping (to enhance light output)
- PMT's 10- or 6-stage (Hamamatsu R5800 or R5380Q)
- Thermal insulation (+ temperature control)
- LED-based monitoring system

Energy and Position Resolution





Stochastic term (1.8±0.1)% in the enegy resolution is so far the best experimental result for $PbWO_4$

Both energy and position resolutions depend on angle; will be taken care of by projective geometry

References : NIM A 510/3, pp. 211-218, pp. 248-261

PbWO4 Irradiation : Test Motivation

Simulation of BTeV/ECAL radiation env. - MARS-IHEP

Radiation env. very non-uniform across ECAL :

- **different doses vs distance from beam line (0.11-720rad/hr => 0.3-2000krad/year in crystals)**
- **different particle spectra along X & Y => different dose profile along crystals**

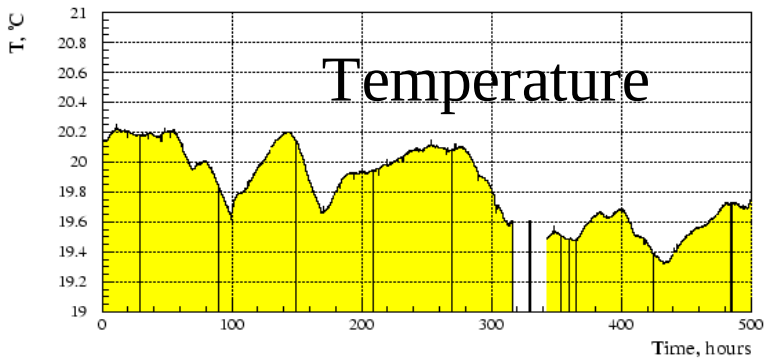
Motivated :

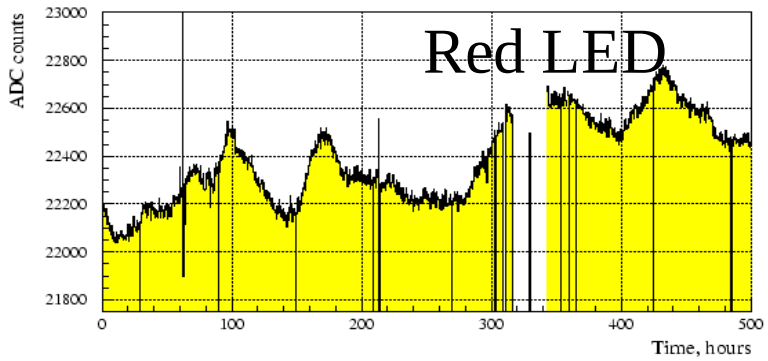
- **Use of both e- and π- beams to study radiation damage**
- **Use of beam of various intensity**
- **Super-intensive irradiation at dedicated facility**
- **Use of Cs-137 source**

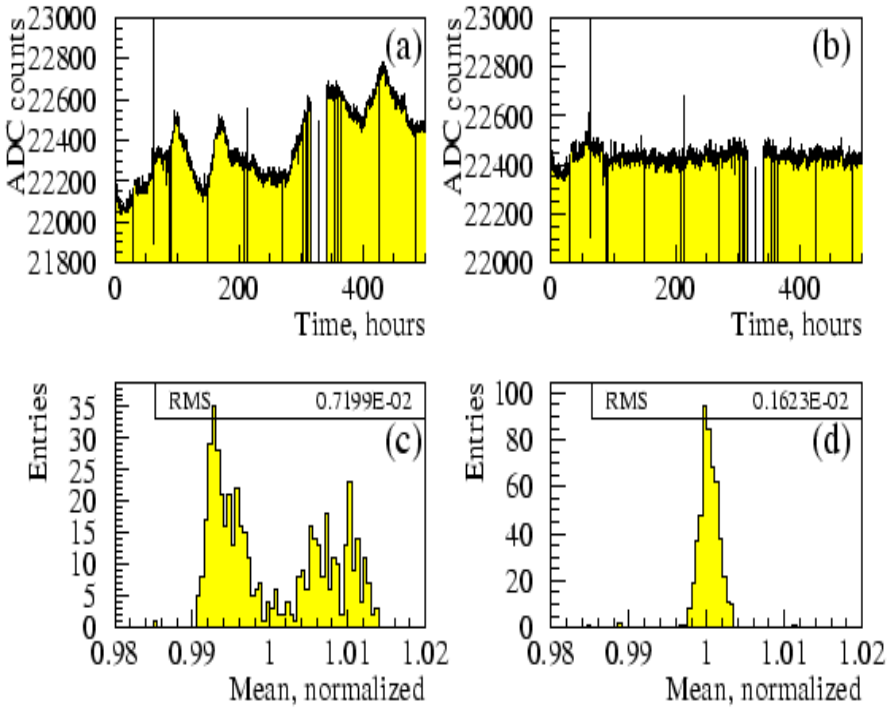
Monitoring Light Output Changes : Purpose, Components

- **Monitor light output under irradiation**
- **Monitor gain drift of PMT's (unexpected effect; later confirmed at 3% at dedicated stand)**
- **Blue LED to monitor transparency of crystals**
- **Red LED to monitor PMT's (much less sensitive to the rad. damage effect)**
- **Plastic fiber light guides**
- **PIN- and α-monitoring of LED's**

Stability of the Monitoring System







Before and after corrections for temp.var.

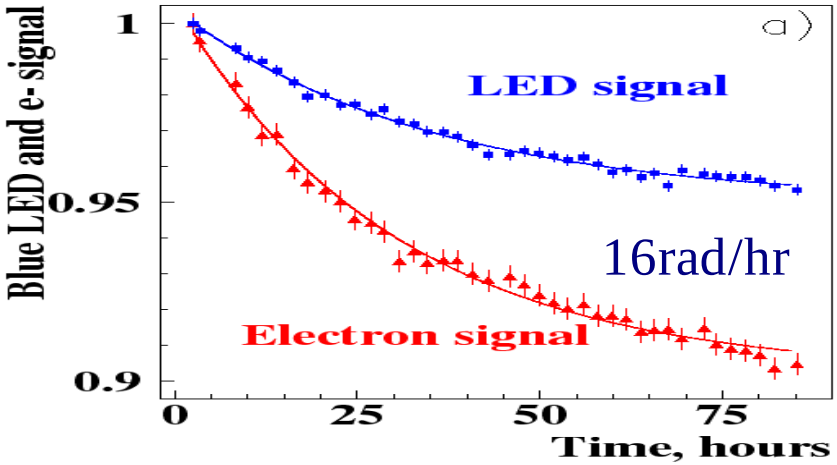
System is stable within :

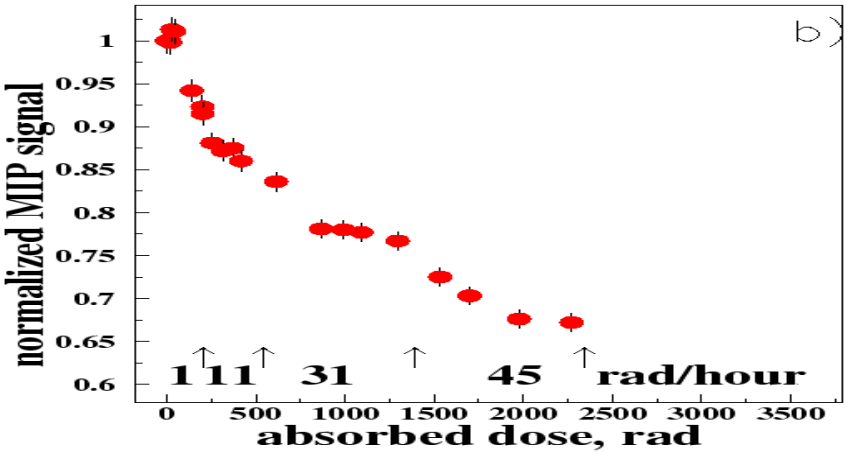
- **0.1-0.2% over 1 day**
- **0.5% over 1 week**
- **1% over several months**

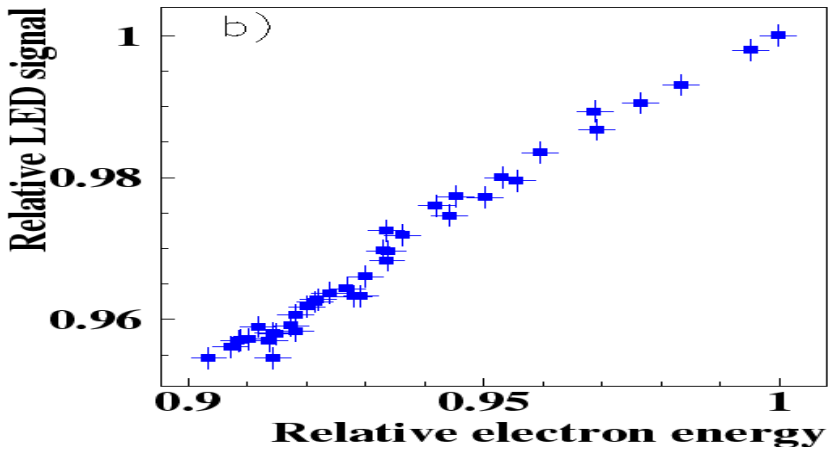
Major source of long term instability were temperature variations (over 2000hr)

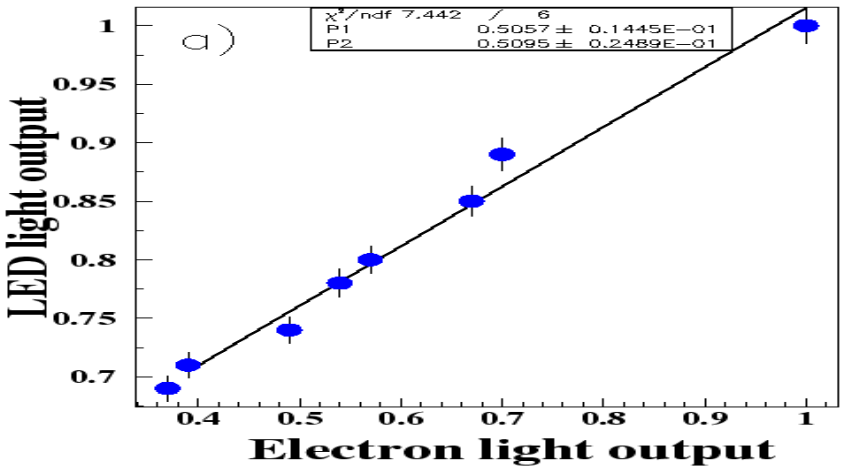
$PbWO_4$ Irradiation : beam

27GeV e-, dose rate 8-25rad/hr **40GeV π-, dose rate 1-60rad/hr**



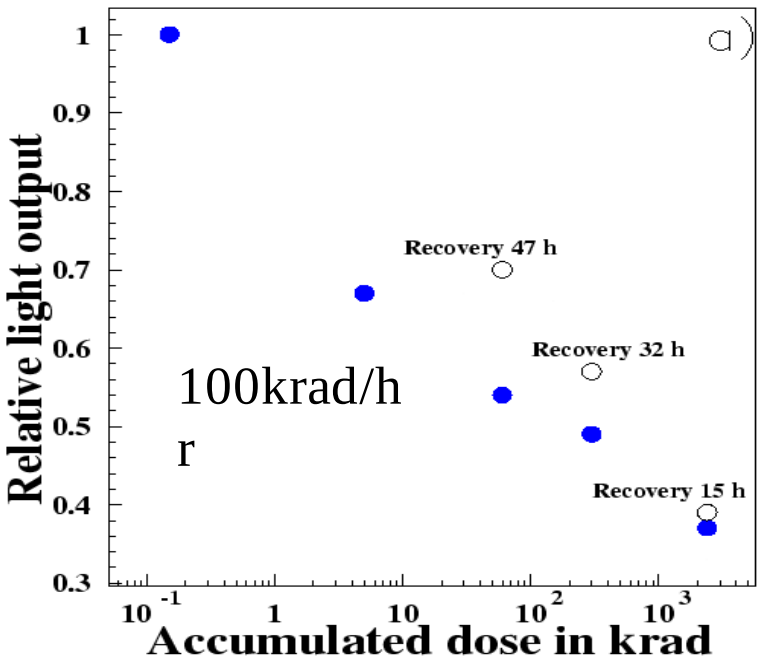






- **Under π- irrad. larger light loss under the ``same'' dose rate**
- **For both clear corr. LED vs e-, but large spread of corr. coeff.**

$PbWO_4$ Irradiation : super-intensive



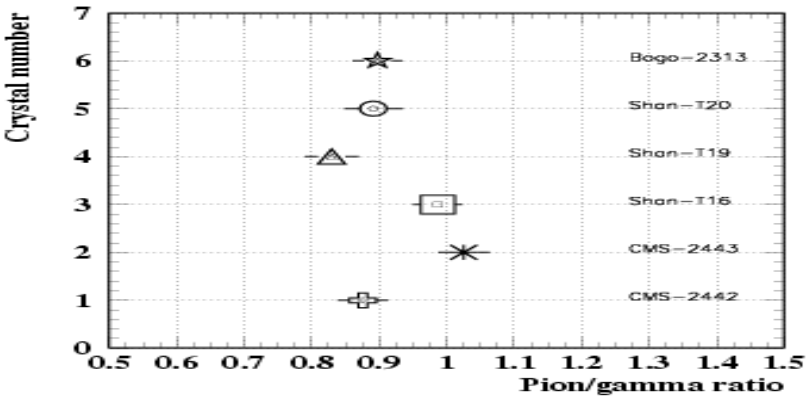
- **Dedicated facility : 70GeV p beam at Be internal target**
- **Secondary particles spectra similar to expected in BTeV**
- **Dose rates 1-100krad/hr**
- **Absorbed doses up to 3Mrad**

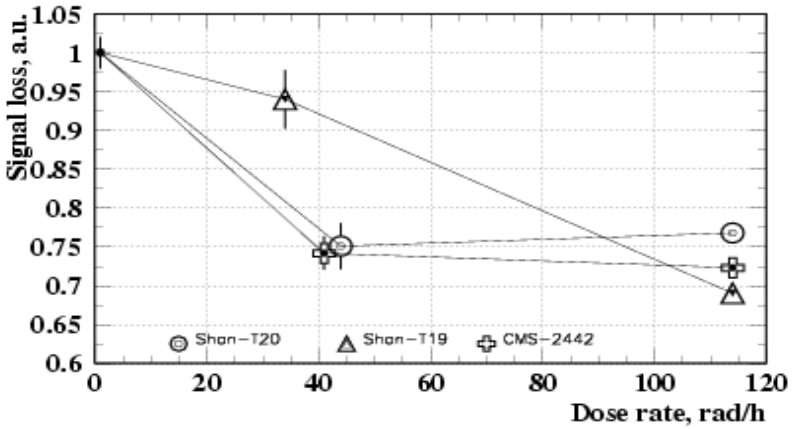
Good news : even after very intensive irradiation $PbWO_4$ still produce light and are able to recover afterward

Steps towards quality control

- Cs-137 source (E=0.661MeV)
- Dose rates 30-60rad/hr, 114rad/hr
- Special lead screen to emulate dose longitudinal profile similar to that of π- irradiation

Results are preliminary





Under similar irrad. conditions crystals behavior under γ irrad. scales well to that under π- irrad. (in state of saturation)

For ``good'' crystals light output stabilizes under irradiation so that increasing the irradiation intensity does not induce additional damage

BTeV/ECAL Calibration : General

Light output changes due to radiation => needs monitoring
PMT's gain varies with intensity => needs monitor
Calibration precision 0.2% to maintain expected performance in reconstructing γ's, π^0's, B's

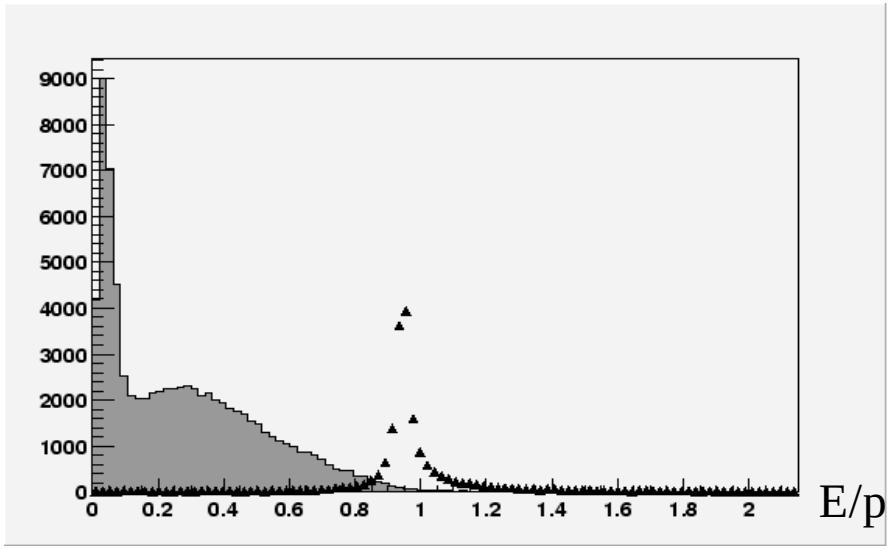
Scenario :

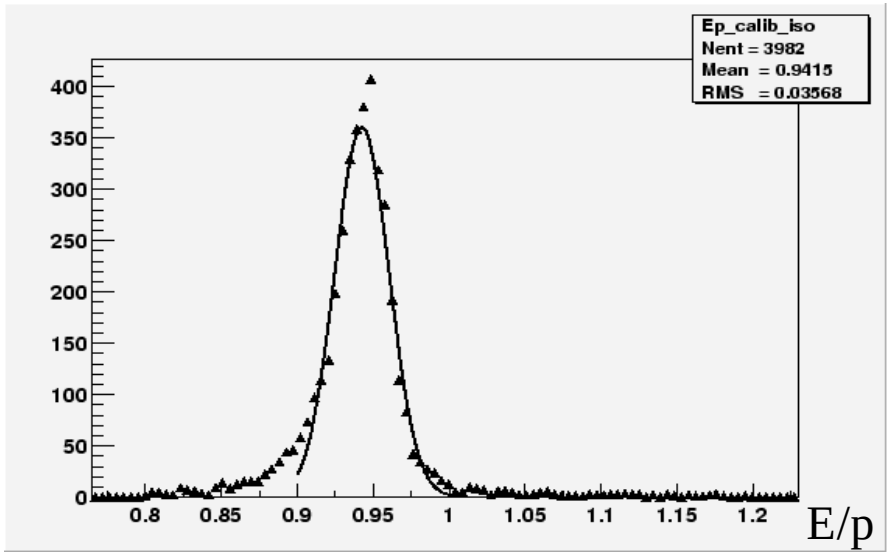
Light Pulser System (short-term variations, entire readout chain during assembly, crytals recovery during shutdowns, rapid survey after shutdowns)

+

In Situ **calibration (long-term variations of energy scale of each crystal)**

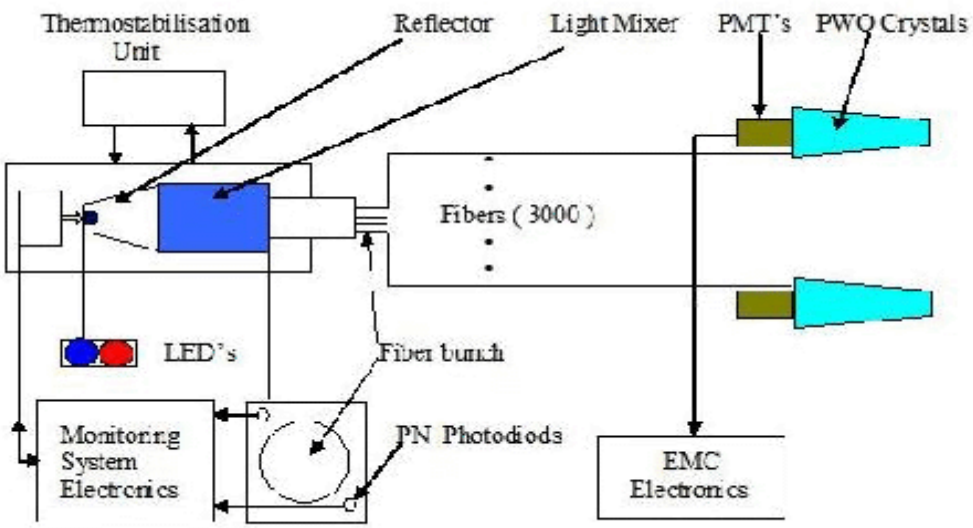
BTeV/ECAL Calibration : *In Situ*





- **Use e's produced in events**
- **Rely on E/p selection criteria**
- **Calib.precision ~1/sqrt(N_e), σ(E/p)~1.9% => 100e's/xtal to achieve 0.2% precision**
- **Rates : (1-17)x10^{-5} e's/xtal/evt**
- **In the worst care scenario need ~10^7 events - several hours of running**

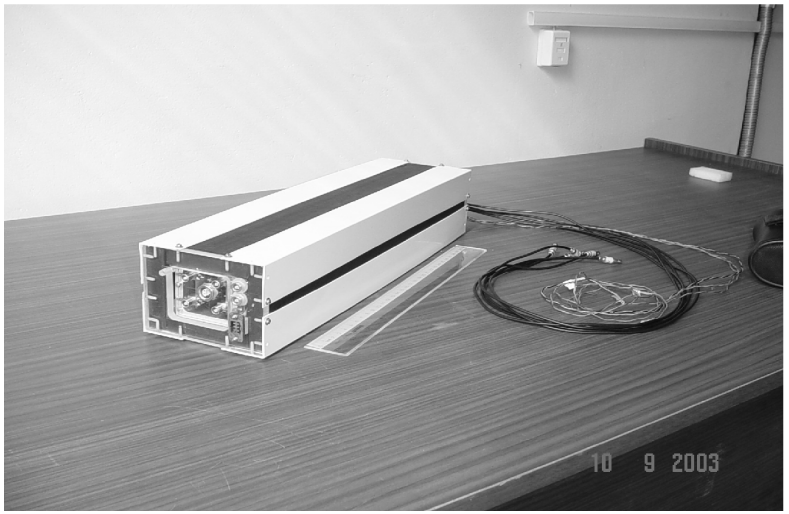
BTeV/ECAL Light Pulser System

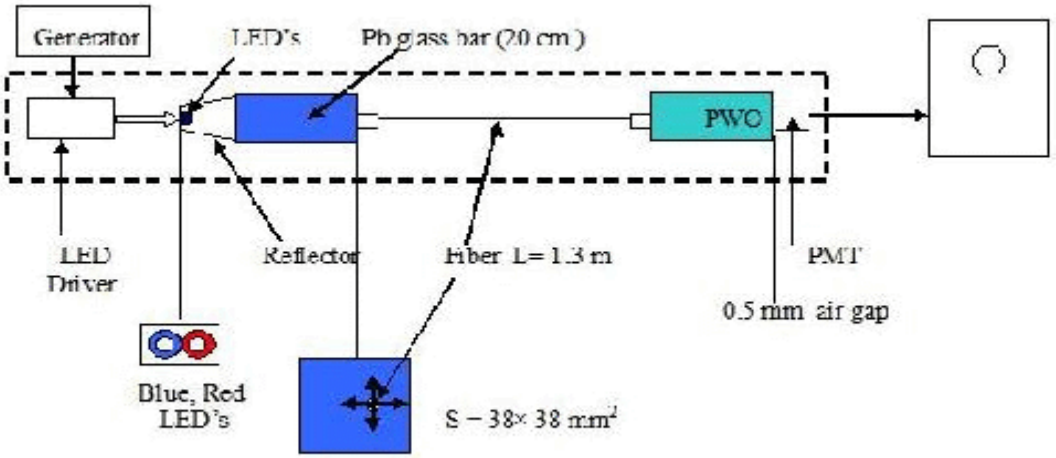


4 such boxes to be mounted at the outer radius of the ECAL mechanical support structure

- **Required stability of 0.2% over several days is realistic**
- **Each pulser feeds via fibers 2,500 PbWO4 crystal with equivalent of scint.light produced by 20GeV photon (per crystal)**
- **Light distribution must be very uniform over 38x38mm^2 area**
- **Luxeon blue, red LED's (exceptional luminous flux, long operating life, temp.dep. of light output <0.1%/C)**
- **Reference PN silicon photodiodes**
- **Silica optical fibers - rad.hardness**

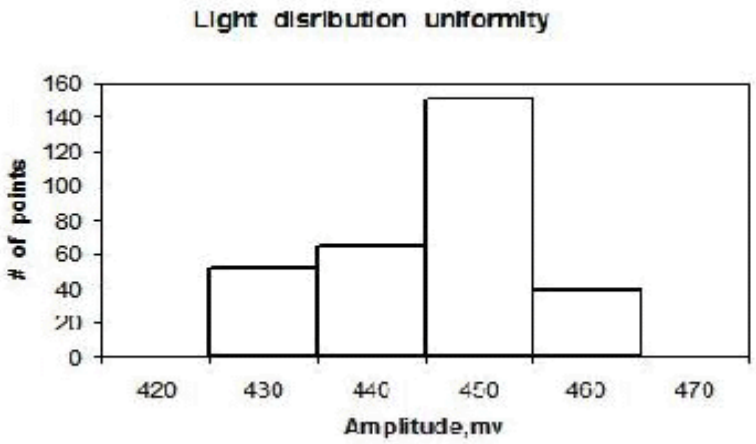
Light Pulser : Test of Prototype





Inside : LED's+driver, light mixer, temp.stabilization unit, reference PN
Cables for test only; will be fibers

Light uniformity over 34x34mm^2 :
FWHM=2%, full width 8%
Stability :
0.05%- 1 day, 0.1% -20 days



Summary

- **Expected energy/position resolutions proved experimentally**
- **BTeV pioneered in studying the $PbWO_4$ radiation hardness in the particle environment similar to expected at hadron colliders**
- **$PbWO_4$ crystals sustain radiation damage but are able to recover naturally, thus the loss of light output is limited**
- **Changes will be constantly monitored; calibration precision of 0.2% is realistic**
- **BTeV ECAL is capable of CLEO/BaBar/Belle-like performance in both efficiency and energy resolution - unprecedented in hadron machine**