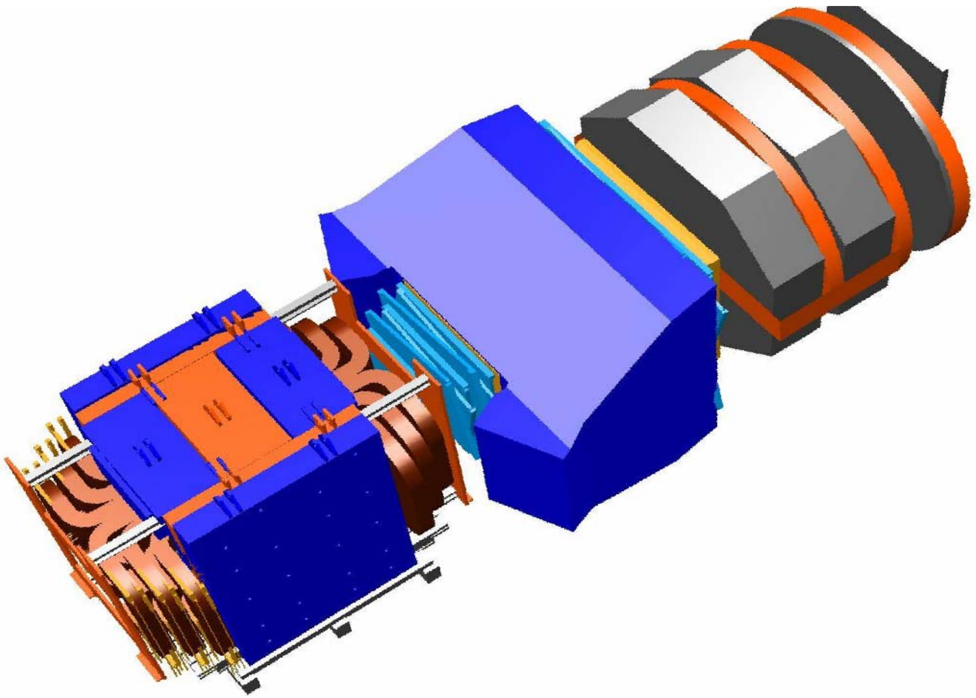
A novel Cherenkov detector

Raja Nandakumar

- Introduction to BTeV
- The BTeV-RICH design
  - Salient features
  - Validation
- RICH Testbeam
  - Design
  - Results
  - Summary



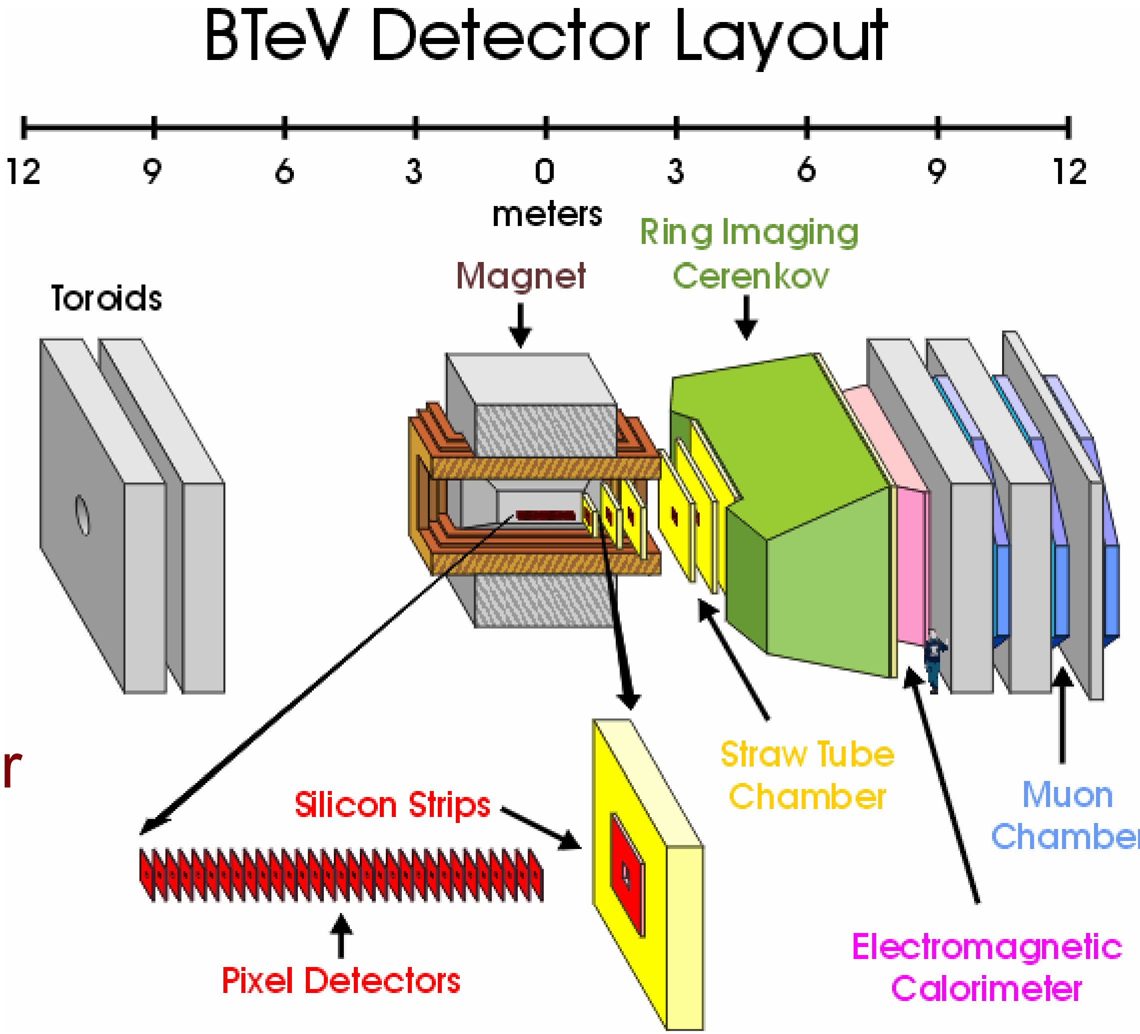
The BTeV experiment

- Forward experiment on $p - \bar{p}$ collider at tevatron
- First proposed in 1996
  - Originally 2-arm experiment
  - Reduced to 1-arm in 2002 due to budget constraints
- Optimised primarily for b & c physics
  - Mixing, CP violation and rare decays
    - → Good particle ID is crucial!
  - Precision SM measurements
    - → Test for inconsistencies
- Beamtests of all detector systems in the last 2 years
- BTeV ended in February 2005 (end of funding in November 2005)

The BTeV detector

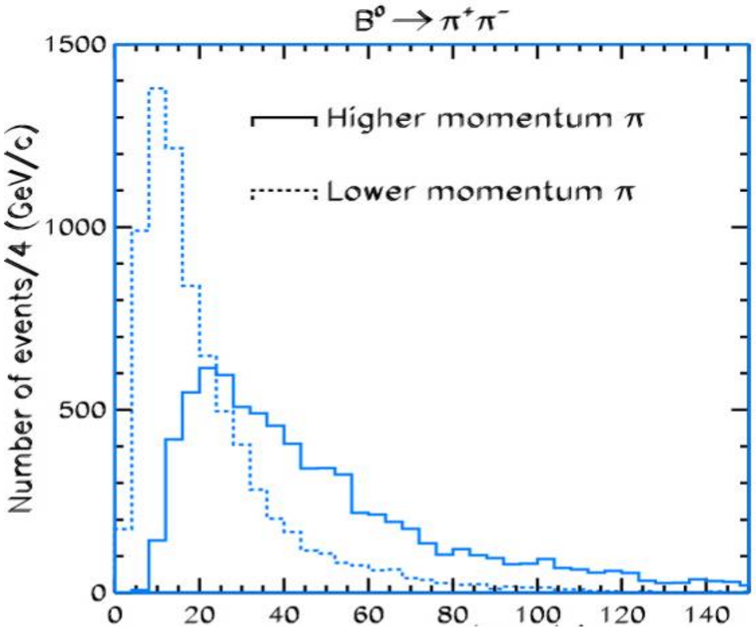
➢Features :

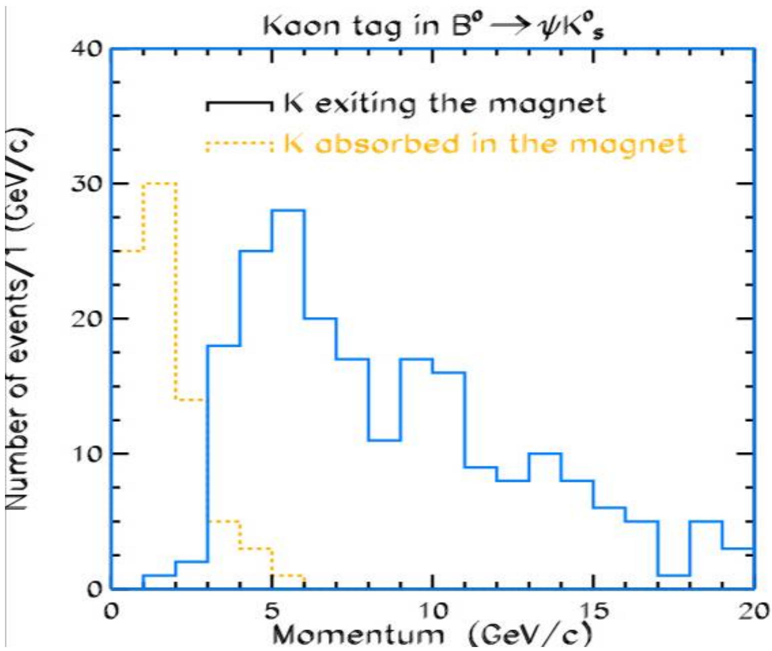
- 10 – 300 mrad
- High speed DAQ
- L1 Vertex trigger
- Unique RICH
- $PbWO_4$ Calorimeter
- 20°C environment



RICH design parameters

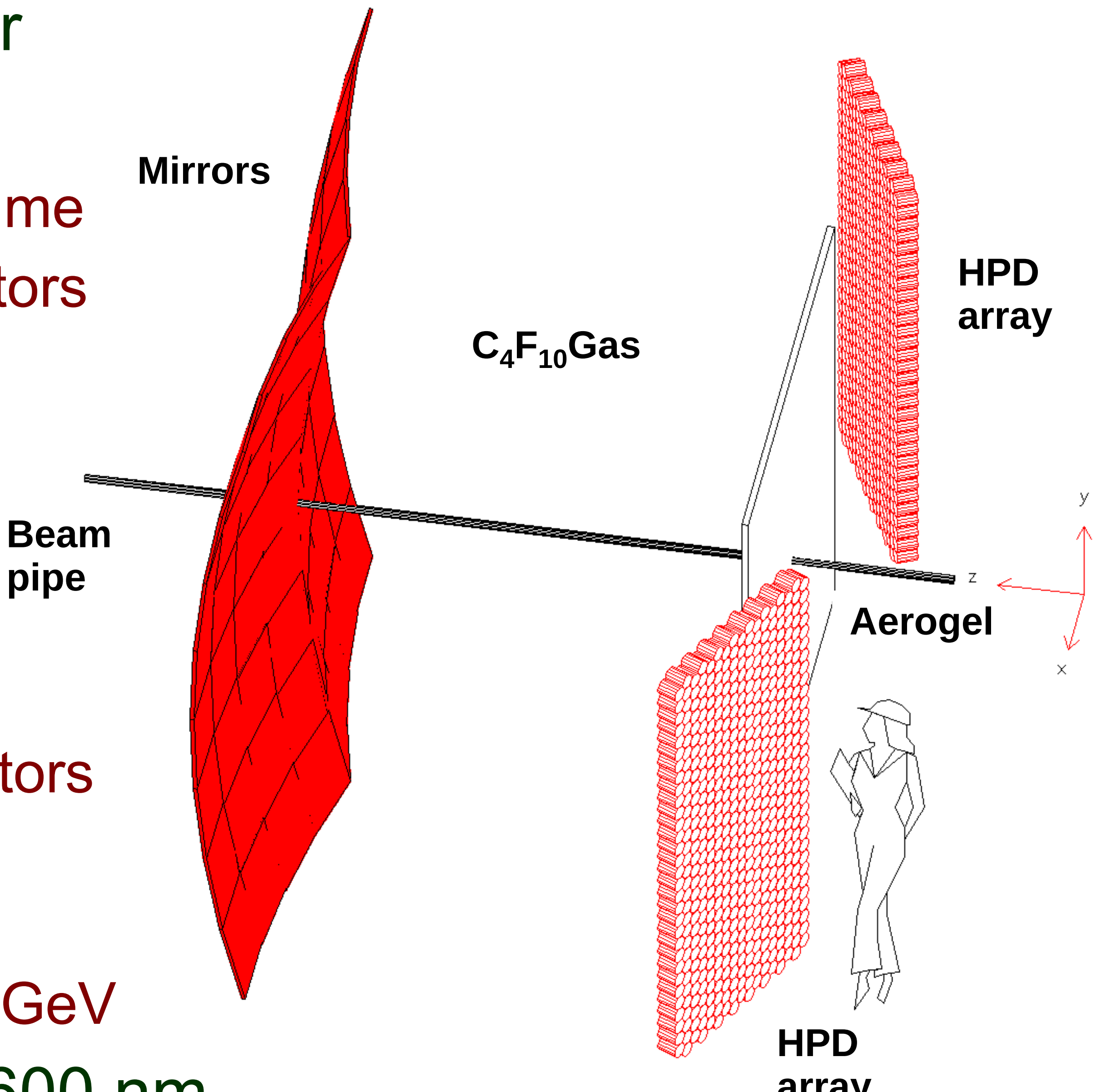
- ➢Lower momentum cutoff (~3 GeV) from magnet
- ➢Upper limit (~70 GeV) from two-body B decay kinematics
  - 4σ separation at 70 GeV requires -
    - ➔$\sigma_\theta^{ch} / \gamma \leq 0.83$ mRad
    - ➔σ_θ^{ch} / track ≤ 0.115 mRad



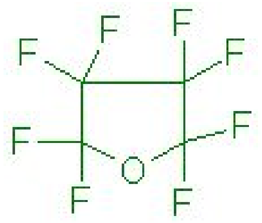


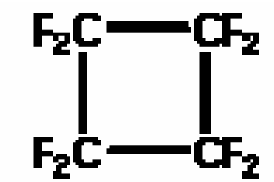
Original RICH design

- ➢ Two stage detector
- ➢ Gas detector
  - 3m long C_4F_{10} volume
  - HPD photon detectors
  - n=1.001380
  - π-p separation 3-70 GeV
- ➢ **Aerogel**
  - 4 cm thick aerogel
  - HPD Photon detectors
    - ➔Share with Gas
  - n=1.03
  - k-p separation 3-9 GeV
- ➢ Photon λ ~ 280 – 600 nm



First : RICH gas

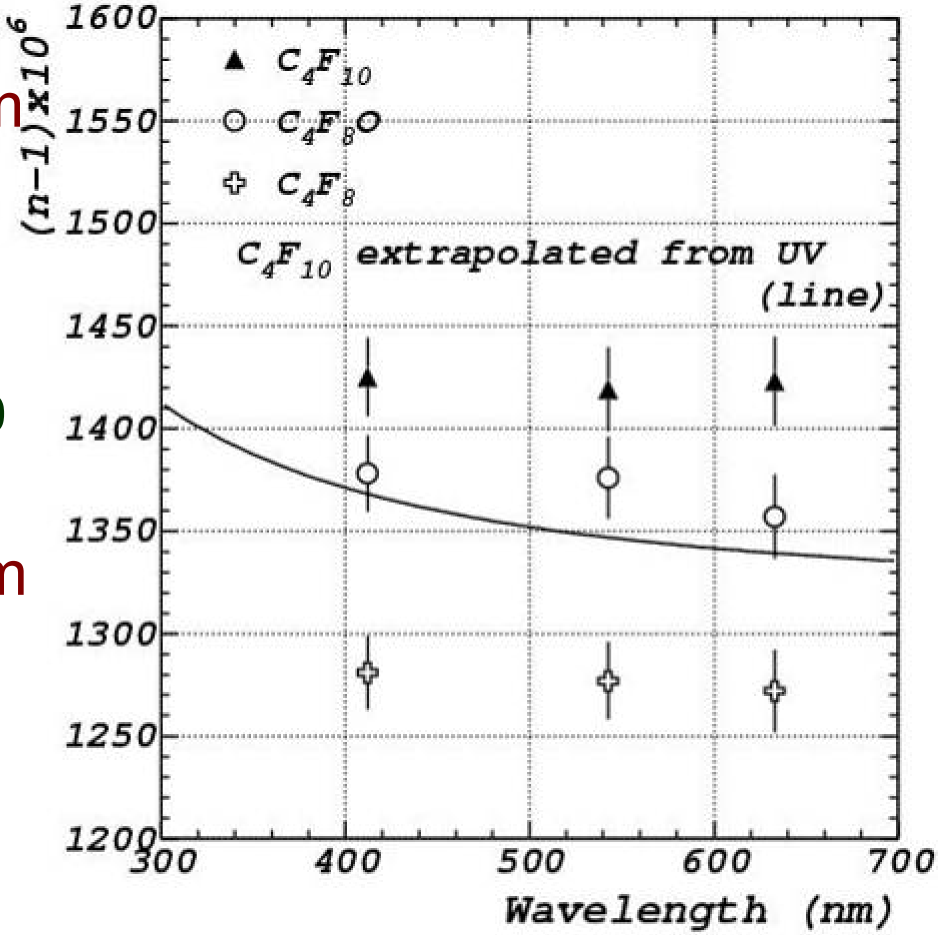
- Original gas : C_4F_{10}
  - Widely used in RICH detectors
  - 3M stopped taking new orders for it in 2001
    - ➜Other suppliers are much costlier, unreliable
- Possibility : C_4F_8O
  

  - Unknown / new molecule
  - Easily available : Widely used in semiconductor industry
- Backup option : C_4F_8
  

  - Used before in RICH detectors
- Need to study as a function of wavelength
  - Refractive index
  - Transmission
- Material compatibility tests

Refractive index measurements

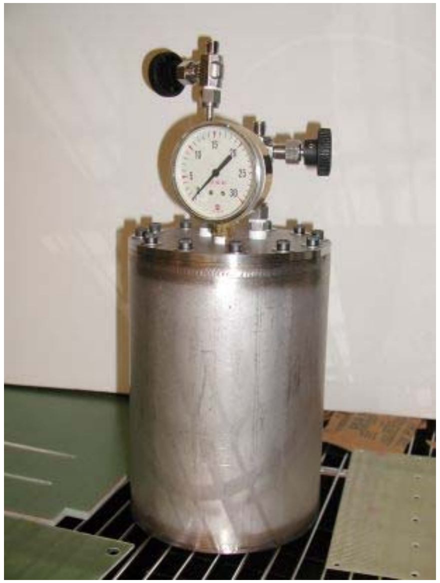
- Michelson interferometer
  - Two identical vessels in beam paths
  - Three laser light sources
- First measurement of C_4F_{10} in visible range
  - Solid line is extrapolation from UV measurements
    - ➔Used in simulations
- C_4F_8O is best alternative
    - ➔Also, closest to simulations!



C_4F_8O compatibility tests : 1

- Never before used in HEP
  - ✓ C_4F_{10} substitute : Montreal protocol, EPA
  - Earliest use : 1999 (3M), 1985 (CAS)
  - Stable, non toxic, non explosive
    - ➔ Does not destroy atmospheric ozone
    - ➔ High global warming potential
- Compatibility with materials in RICH
  - 10 year equivalent exposure
  - Variety of materials

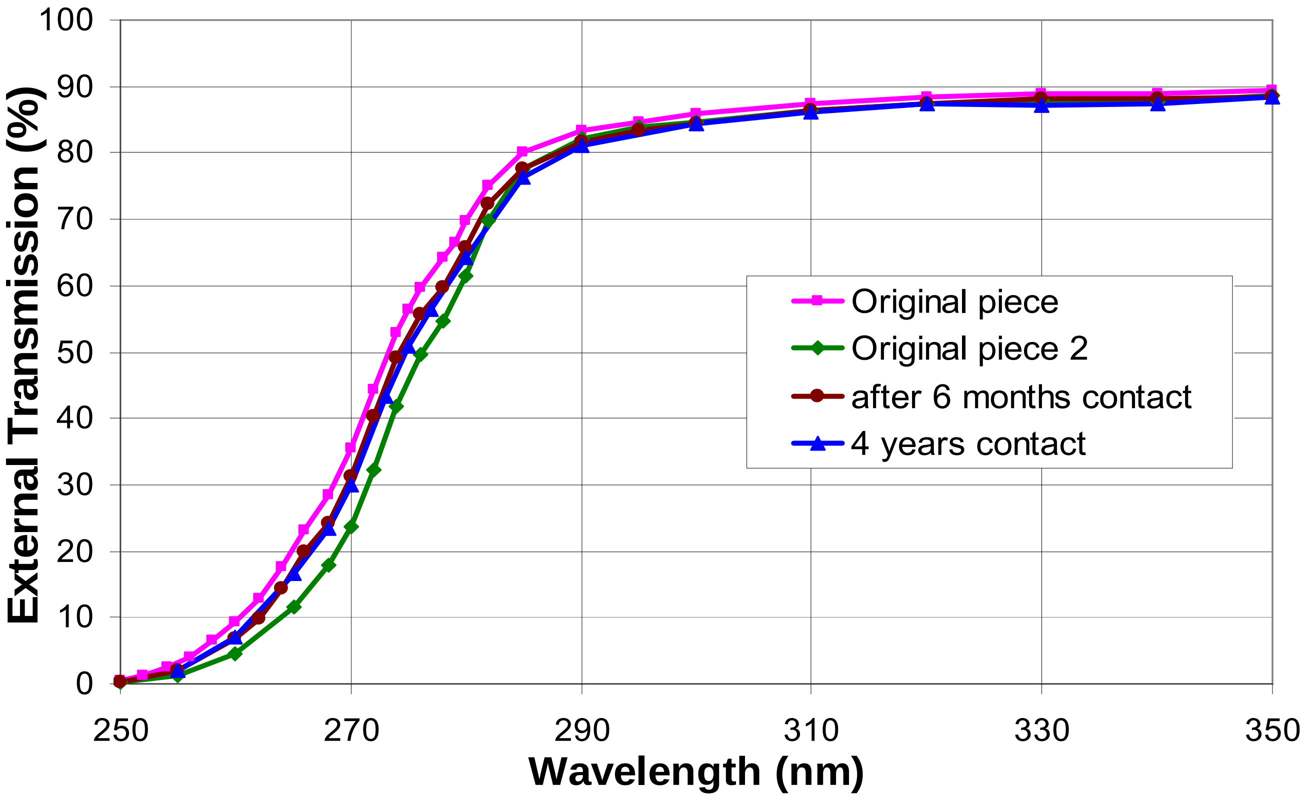
    Plastics, metals, epoxies, composites, mirror, mirror material, water, etc



C_4F_8O compatibility tests : 2

- 6 gas tight stainless steel volumes (teflon o-rings)
  - 1 : water + C_4F_8O
  - 4 : C_4F_8O + solid samples (various time durations, mirror separately)
  - 1 : N_2 + solid samples
- Oven at stable 80°C
  - 64x reaction rate at room temperature (20°C)
- Tests :
  - Gas – proton NMR, gas chromatography
  - Water : pH, proton NMR
  - Solids : as needed
    - ➔ **All : Weight, colour, dimensions**
    - ➔ **Epoxies : Strength**
    - ➔ **UVT : Transmission**
    - ➔ **Mirror : Reflectivity, spot size**

C_4F_8O compatibility tests : 3



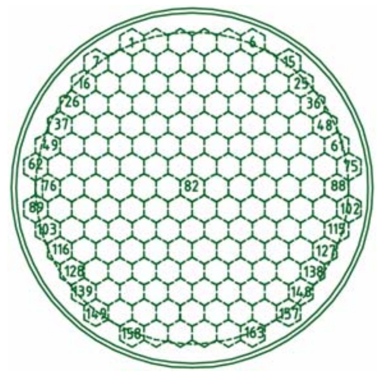
- No measurable material changes seen
  - 13.5 years equivalent exposure for water
  - Upto 9.6 years equivalent for solid samples
- Temperature effect on Cu

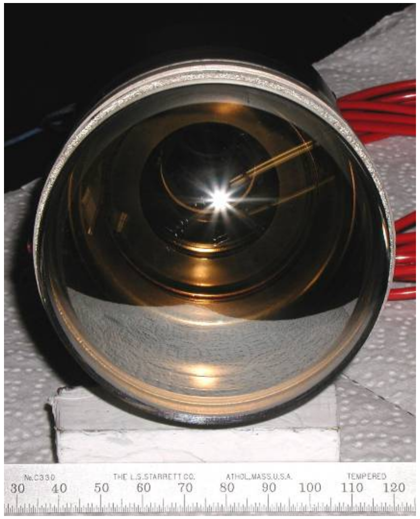
Next : Photon detectors

- ~45% cost of the RICH
- Pixel size needed ~ 6 mm
- Original proposal : HPD (PP0380AT)
  - From DEP
  - Then the best available technology
- Later development : MAPMT (R8900-M16)
  - Hamamatsu, Redesign of R5900 in 2002
- Others : MCP (Burle), Flat Panel MAPMTs (Hamamatsu)
- Need to study
  - Plateau, cross talk, ...
  - Gain, sensitivity to magnetic field, ...
  - Quantum efficiency
- Can study many details only in beam test

RICH Gas photon detectors

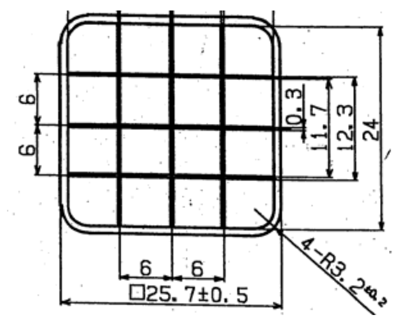
➢ Hybrid Photon Diode (HPD)





- DEP Holland, PP0380AT
- 163 pixels/tube, ~5.5mm pixel
- Quartz window
- 20 KV power supply, gain ~ 5000
- 944 tubes, \$6353/tube, total 5997K\$ (Dec 04)

➢ Multi-Anode PhotoMultiplier Tubes (MAPMT)



- Hamamatsu, R8900-M16
- 16 pixels/tube, ~6mm pixel size
- Borosilicate / UV glass window
- 1KV power supply, gain ~ 10^6
- 9016 tubes, \$529/tube, total 4769K\$ (Dec 04)

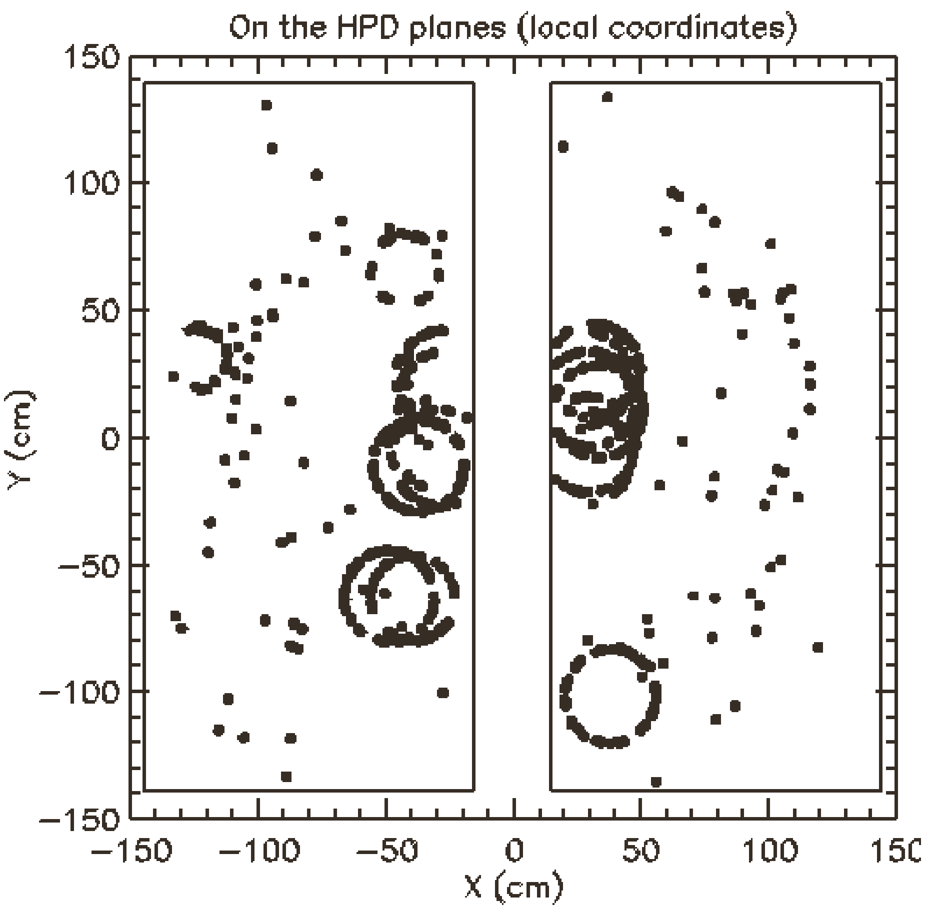
Comparison of Photon Detectors (simulation)

Photon detector	MAPMT	HPD
Emission point error	0.49 mrad	
Segmentation error	0.51 mrad	0.45 mrad
Chromatic error	0.44 mrad	0.52 mrad
Total σ_θ per photon	**0.83 mrad**	**0.84 mrad**
Quantum Eefficiency @ 400nm	~0.24	~0.21
Collection Efficiency	~0.7	~0.95
Geometrical Eff. with magnetic shield	~0.79	~0.62
QE*CE*GE	**~0.133**	**~0.124**
$N\gamma$ per track (simulated)	**52.0**	**50.3**
Total σ_θ per track	**0.115 mrad**	**0.118 mrad**

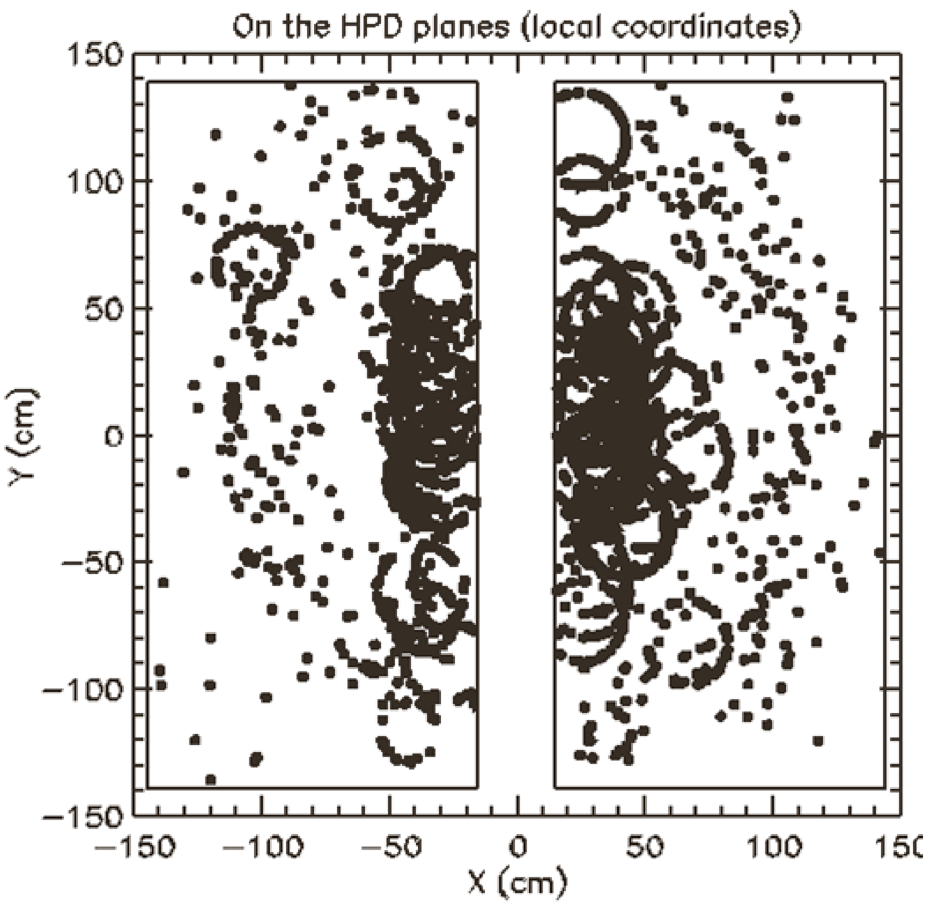
- Expect similar resolution in both systems
- MAPMT chosen as baseline option in 2004 (cost)
  - → MAPMTs separated from gas by UV acrylic window

Finally : Aerogel rings

Low multiplicity event

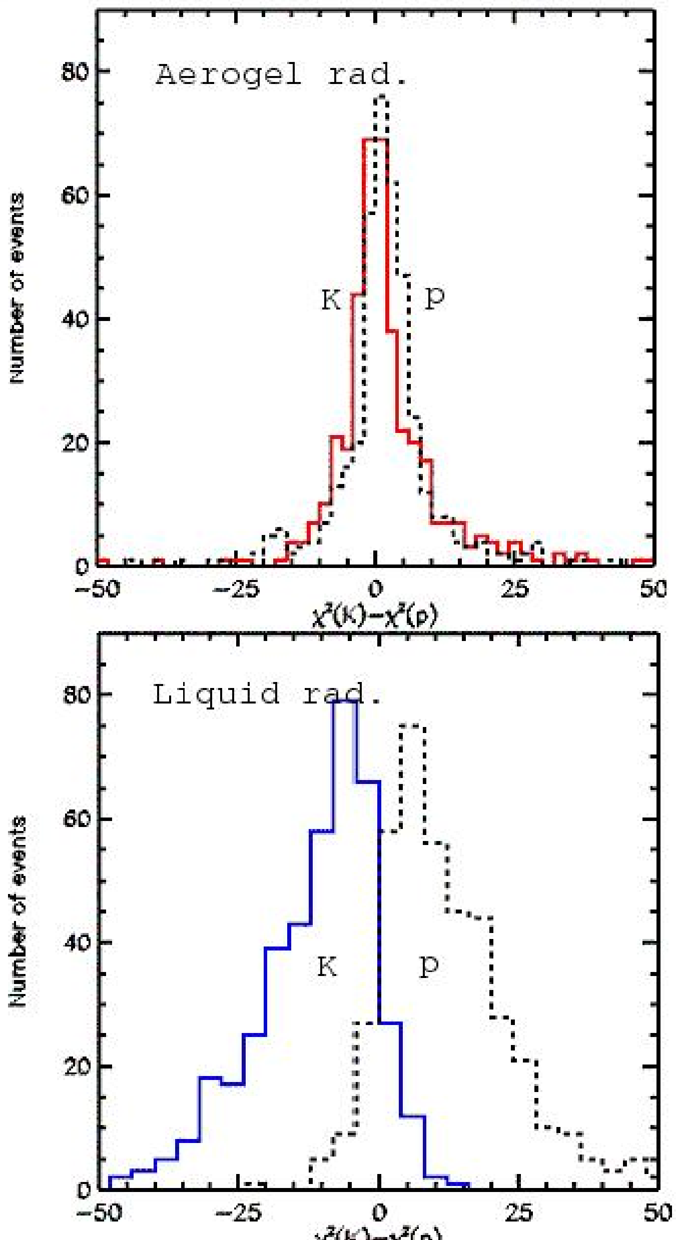


High multiplicity event



- Overlapping rings difficult to separate in reconstruction for aerogel

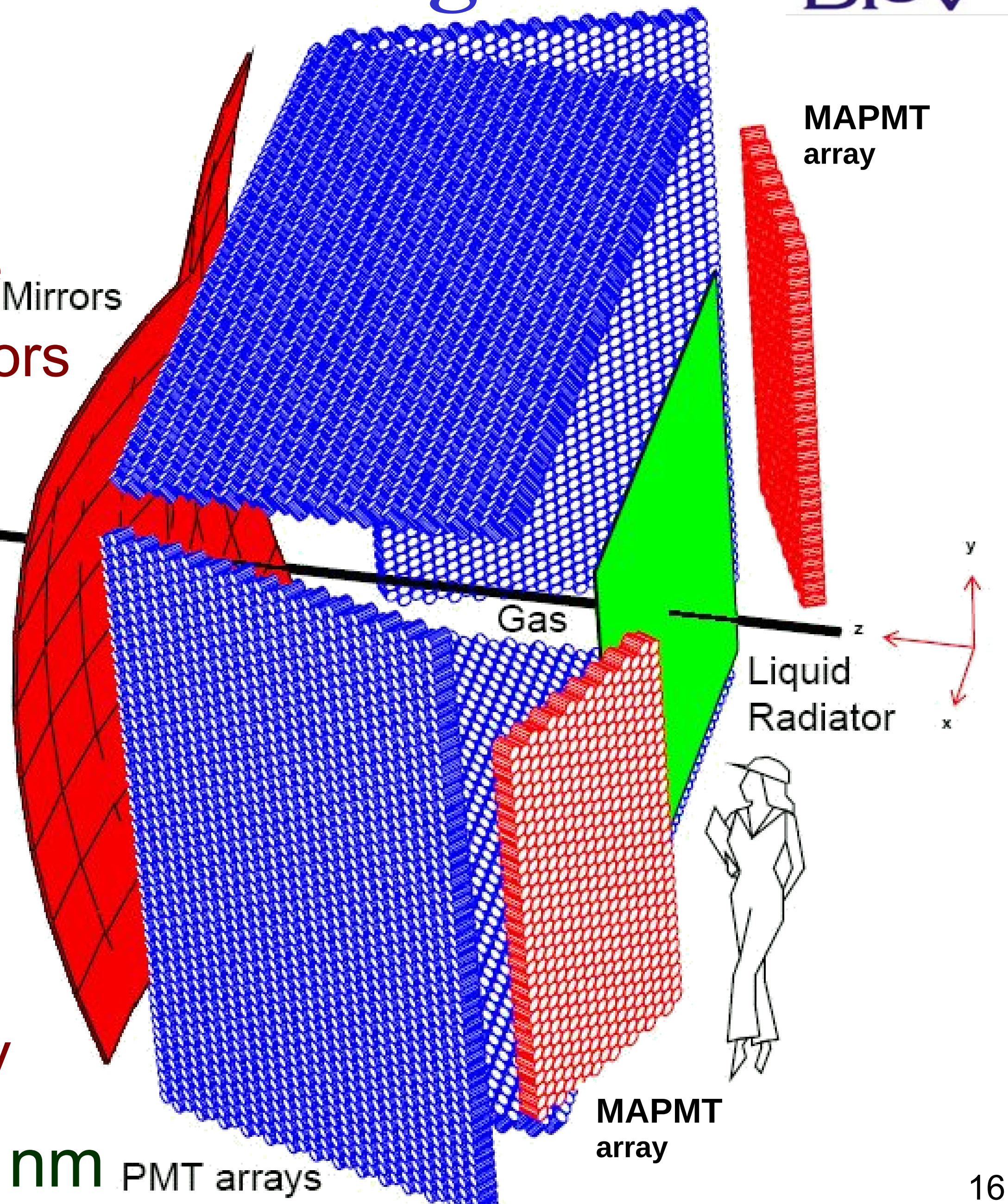
Aerogel replacement



- Aerogel (n=1.03)
  - Shares photon detectors with gas
  - Works for low multiplicities
    - ➔HERMES multiplicity 1-2
  - No ID power in higher multiplicities
    - ➔Faint rings : Limit of 10 γ/track
    - ➔γ lost in reconstruction due to gas ring overlap
- Liquid (C_5F_{12}, n=1.24) system
  - Separate γ detectors for gas, liquid
  - Increase thickness for photon yield
- Further improvement from ring finding

Final RICH design

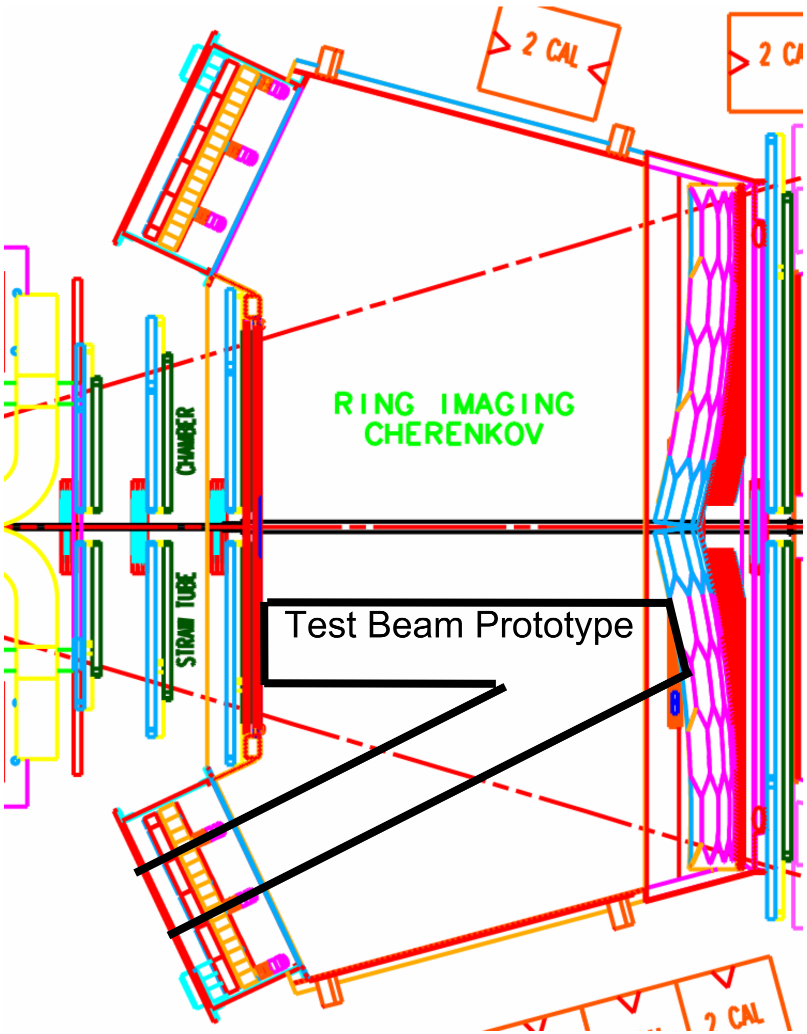
- Two stage detector
- Gas detector
  - 3m long C_4F_8O volume
  - MAPMT photon detectors
  - n=1.001380
  - π-p separation 3-70 GeV
- Liquid detector
  - 1cm thick C_5F_{12}
  - 3" PMTs
  - n=1.24
  - k-p separation 3-9 GeV
- Photon λ ~ 280 – 600 nm



Beamtest goals

- ➢Full test of RICH design
- ➢Primary aim :
  - Test MAPMT system with C_4F_8O gas
    - ➔BTeV-RICH baseline option
    - ➔Cherenkov angle resolution, photon yield
- ➢Secondary aims :
  - Evaluate mechanical and gas system design
  - Test backup systems (if possible ...)
    - ➔HPDs, Gas (C_4F_8)
  - Support systems – HV, LV, Cooling, etc.
  - Fine tune simulation (cross talk, etc.)

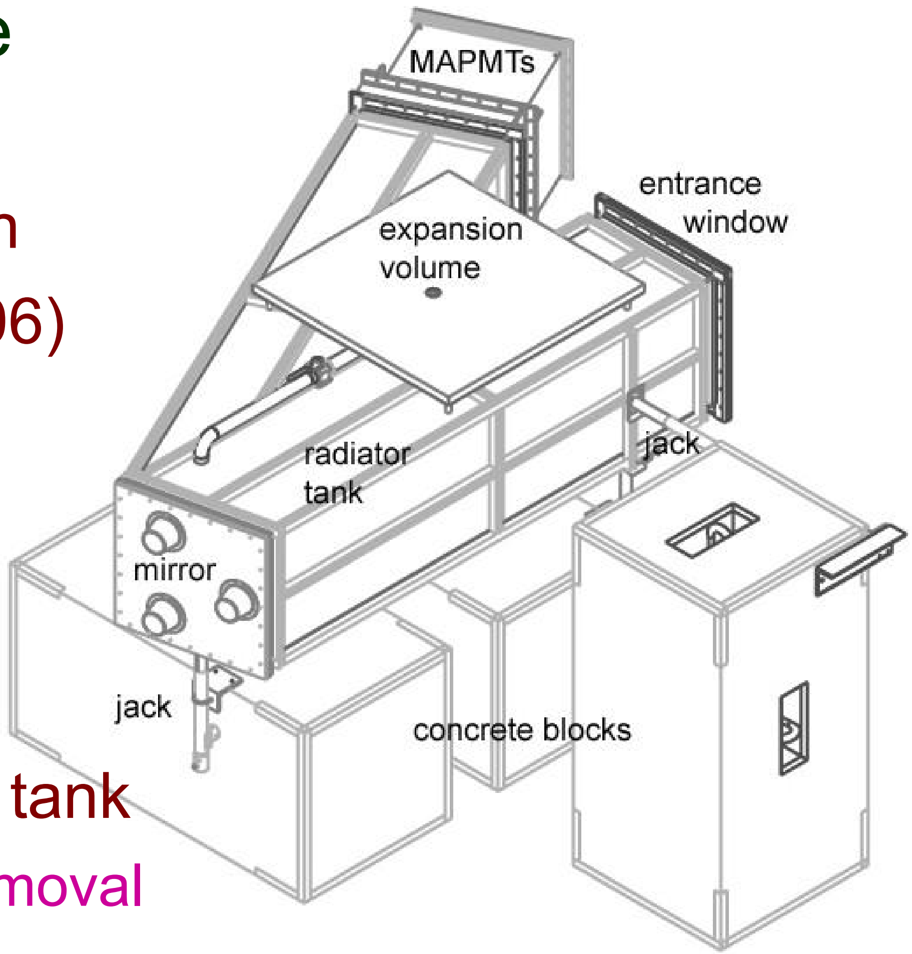
RICH Testbeam



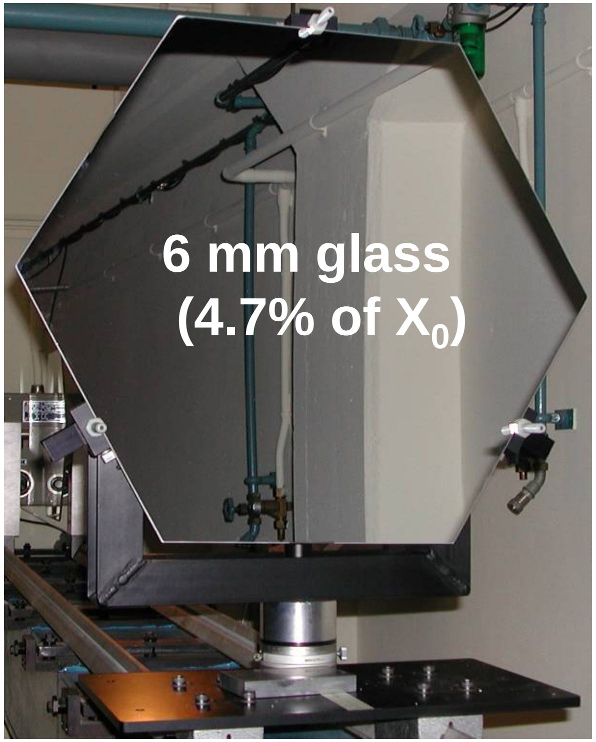
- One section of BTeV RICH
  - 3m long gas radiator
  - Mirror
  - MAPMT + electronics
- 120 GeV proton beam
  - ➔~10mm radius beam spot
- Two stages
  - 1 : Gas system, basic readout (June 2004)
  - 2 : Full electronics + trigger (Jan 2005)

RICH testbeam system

- Aluminium sides and frame
  - Minimize weight
  - Leak rate < 1 volume / month
  - Black interior (aeroglaze Z306)
    - ➔Reduce stray light
- Gas system
  - 1 atm pressure inside vessel
    - ➔Expansion volume
  - Compressor + condensation tank
    - ➔Recirculation, air / argon removal
  - Filter pack for gas purification
    - ➔Particulate, water vapour removal
    - ➔94 ± 2 % purity by wt. achieved asymptotically

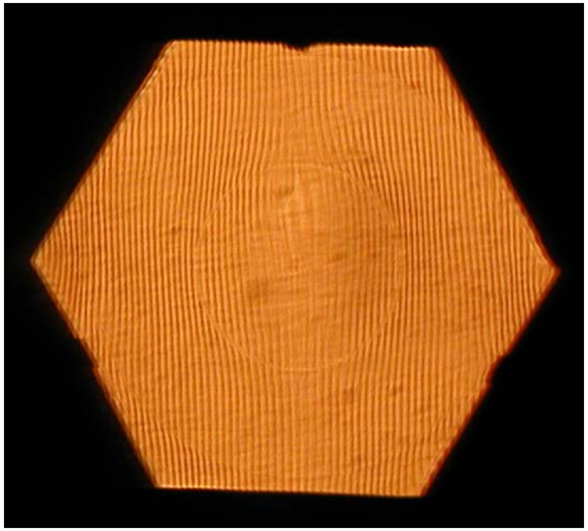


Mirror



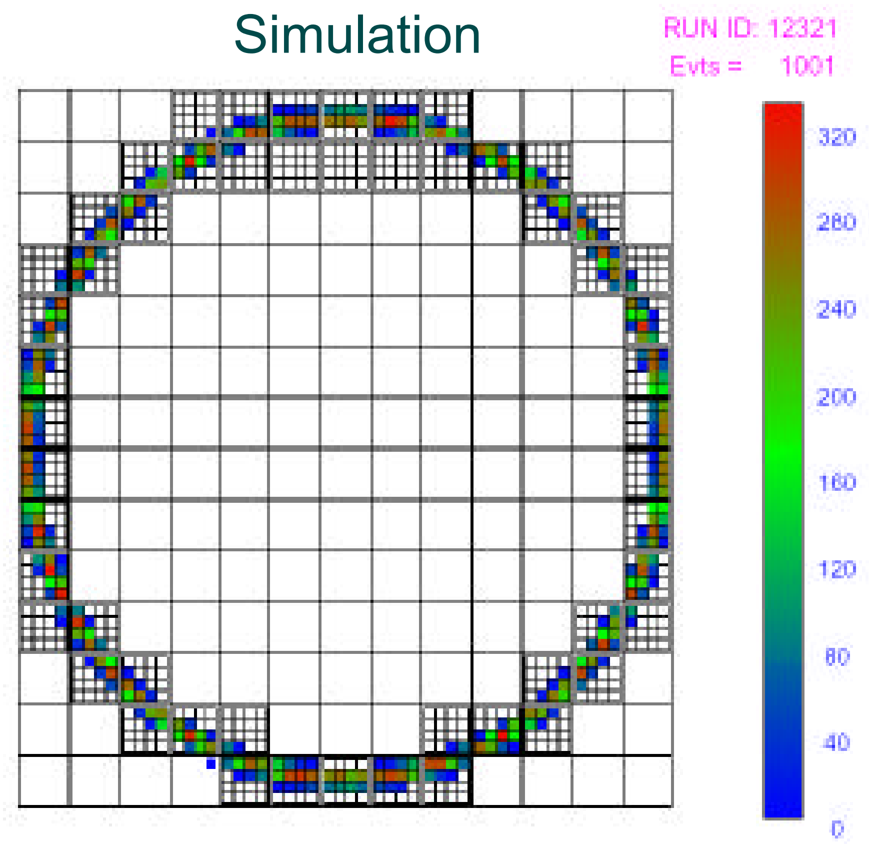
Spot size = 2.97 mm
Radius = 659 cm

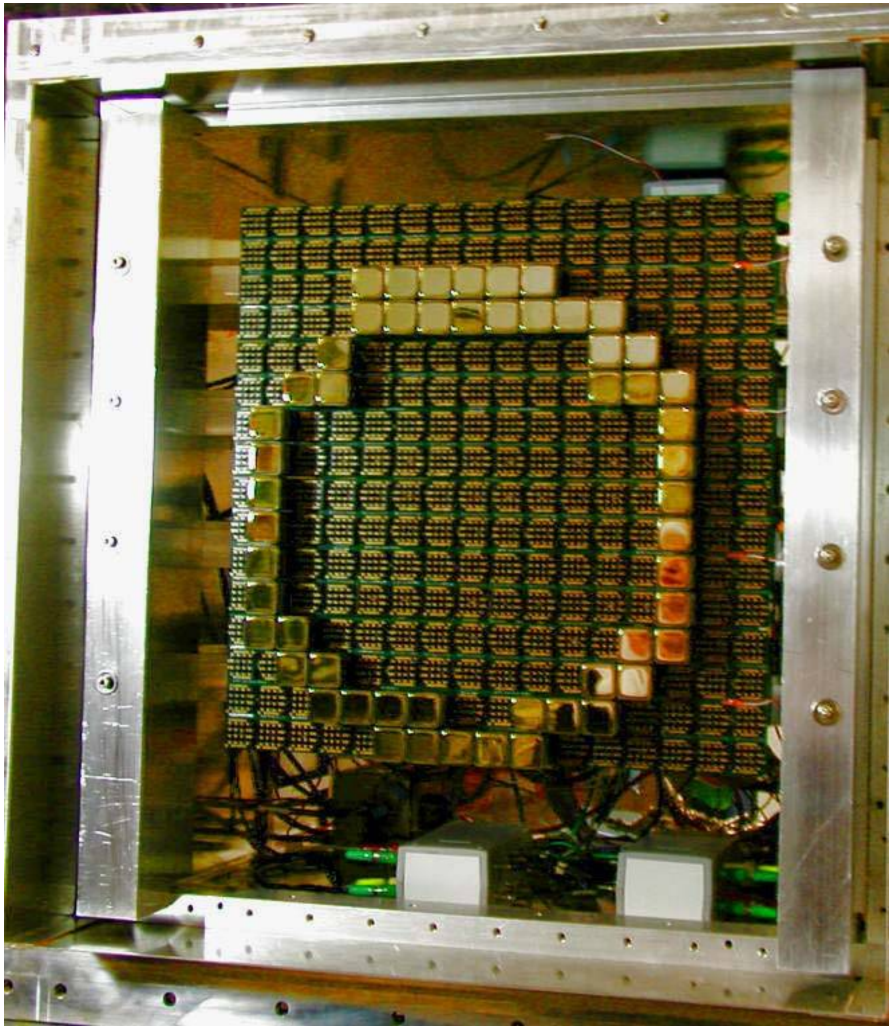
- Manufactured by COMPAS
  - Reflectivity ~ 90% (>85%)
- 3 point kinetic mount
- Laser alignment system



Ronchi-gram of the mirror

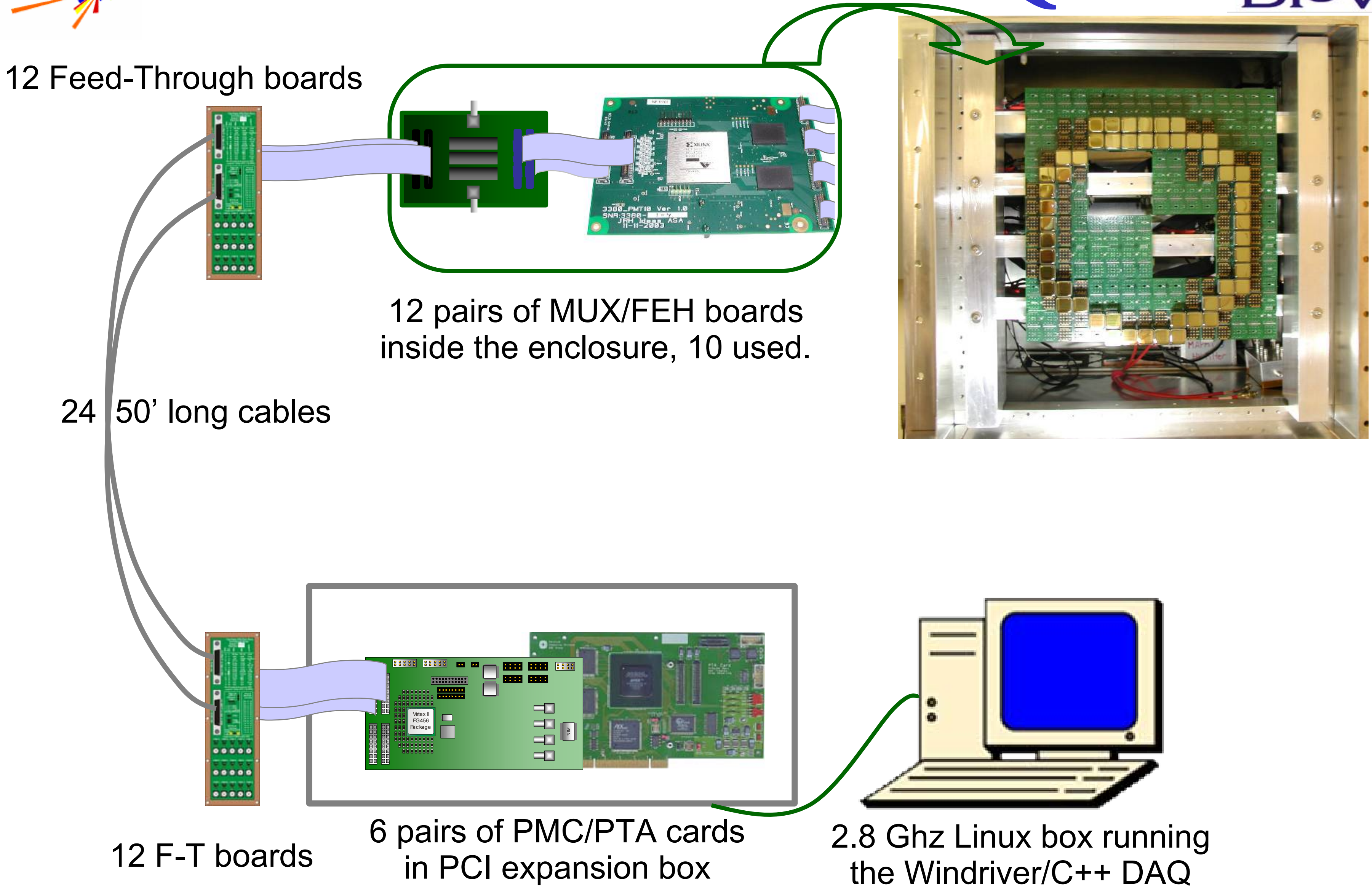
Photon detector array





- 48 MAPMTs along expected ring (93.6% coverage)
  - 5 Extra MAPMTs for noise measurement

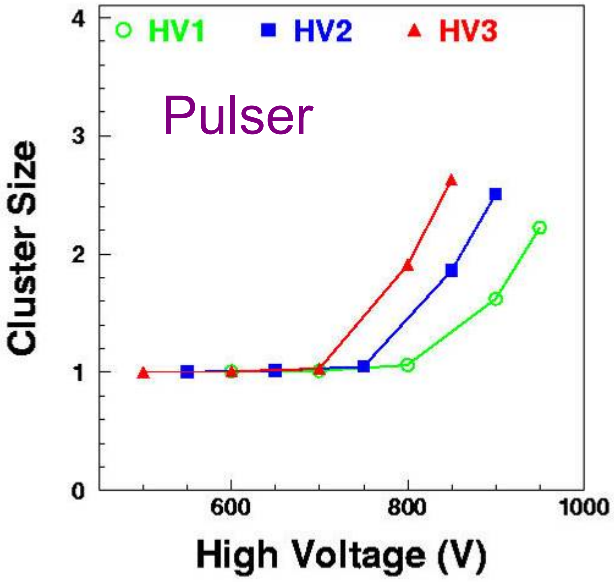
Electronics and DAQ

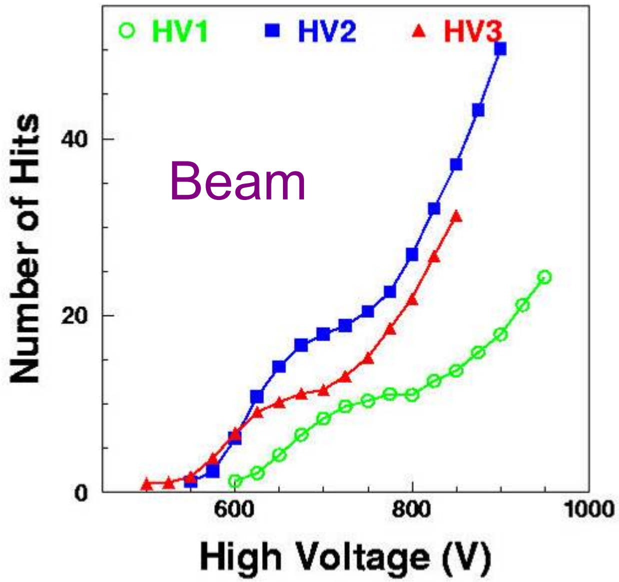


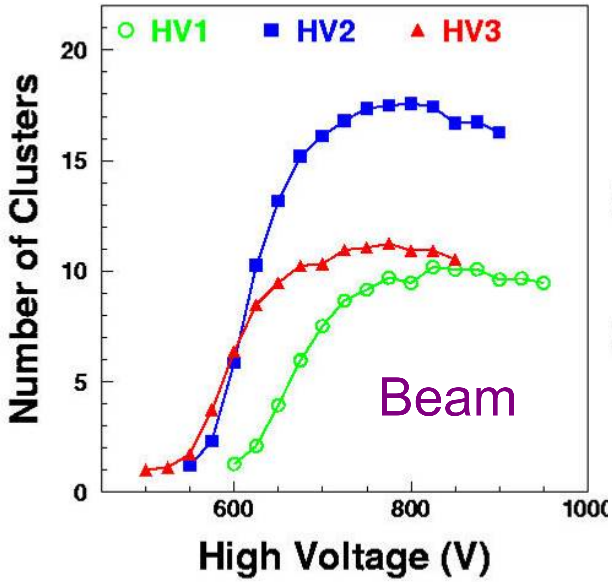
H.V. Setting

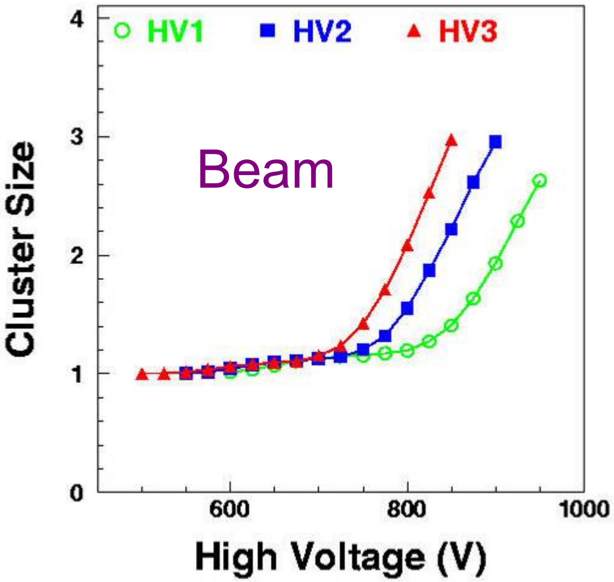
3 different HV groups based on gain

- ➔X, X+50, X+100 V
- ➔Calibrated with pulser, data
  - ✔Cluster : Adjacent electronic channels
  - ✔Look at #hits, #clusters, <cluster size>
- ➔Choose X=700V
  - ➢~5% hits due to cross talk

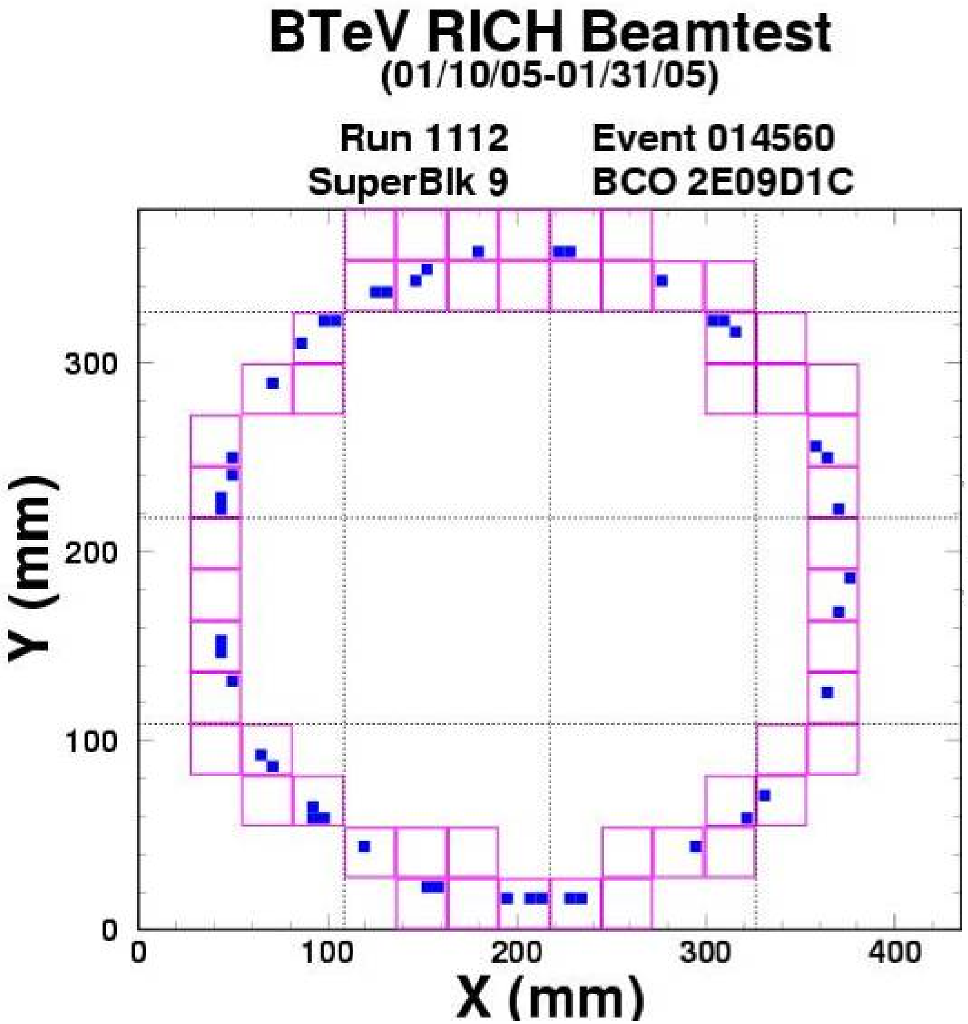


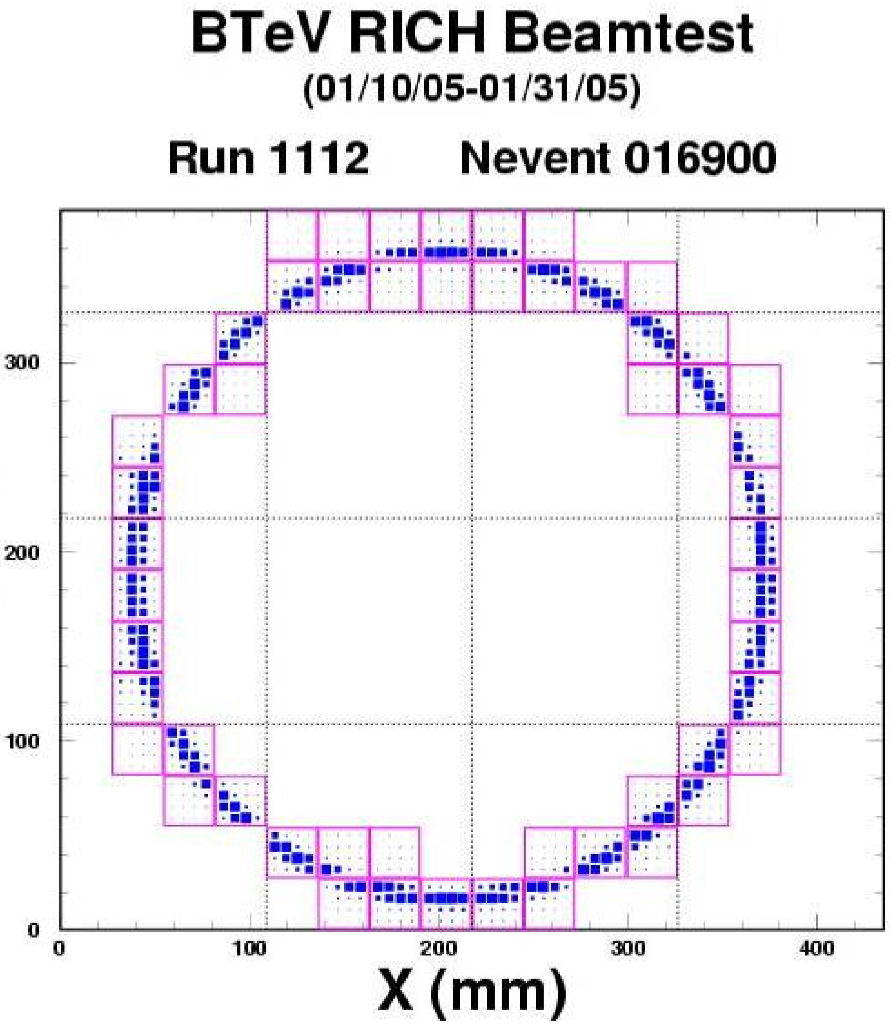






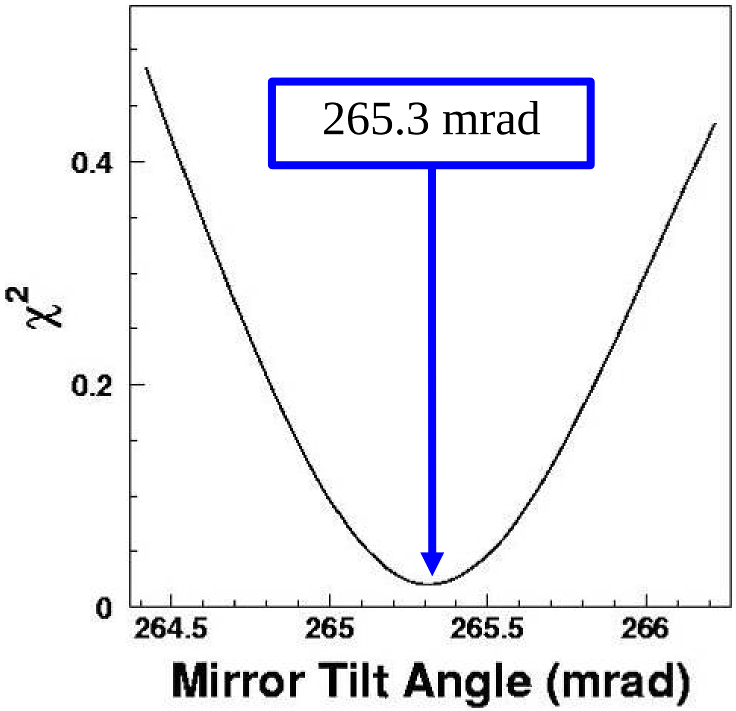
Complete Cherenkov ring

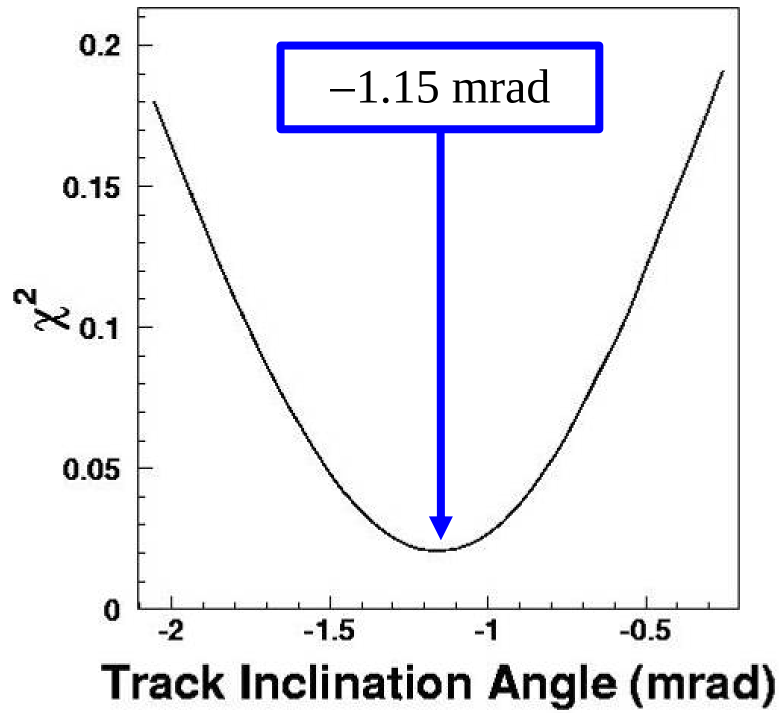




44 hits, 36 clusters

Detector alignment





$$\chi^2 = \sum_{Pix} (Pix_{data} - Pix_{MC})^2$$

Fit for :

- Mirror tilt
- Track inclination
- Gas refractive index

Gas refractive index

$$n_{expt}-1=\frac{PT_0}{TP_0}\left\{(n_{C_4F_8O}-1)(1-f_{air})+(n_{air}-1)f_{air}\right\}$$

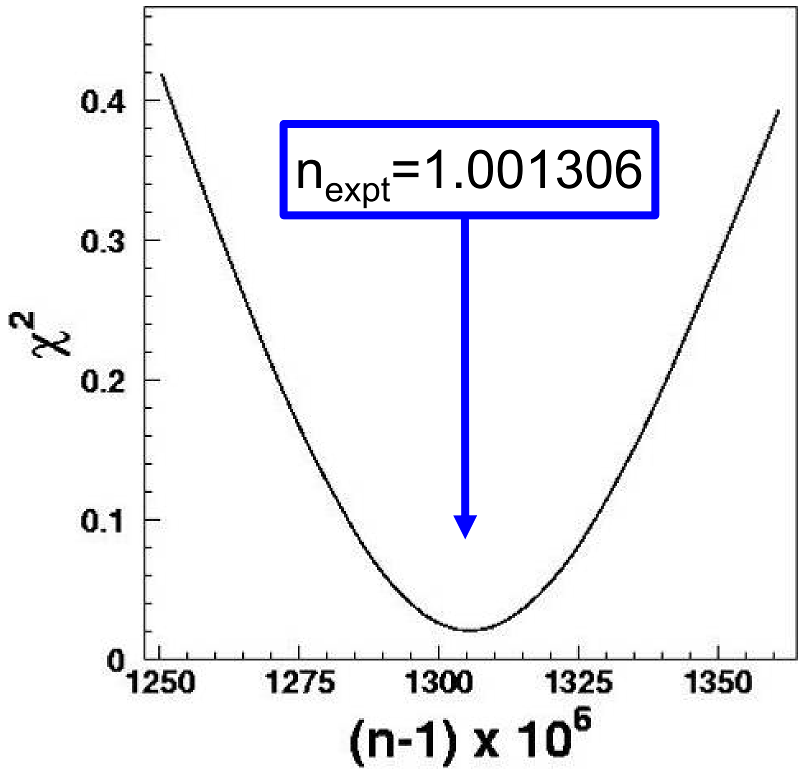
6±2%

98±1%

$$n_{C_4F_8O}=1.001396\pm0.000030$$

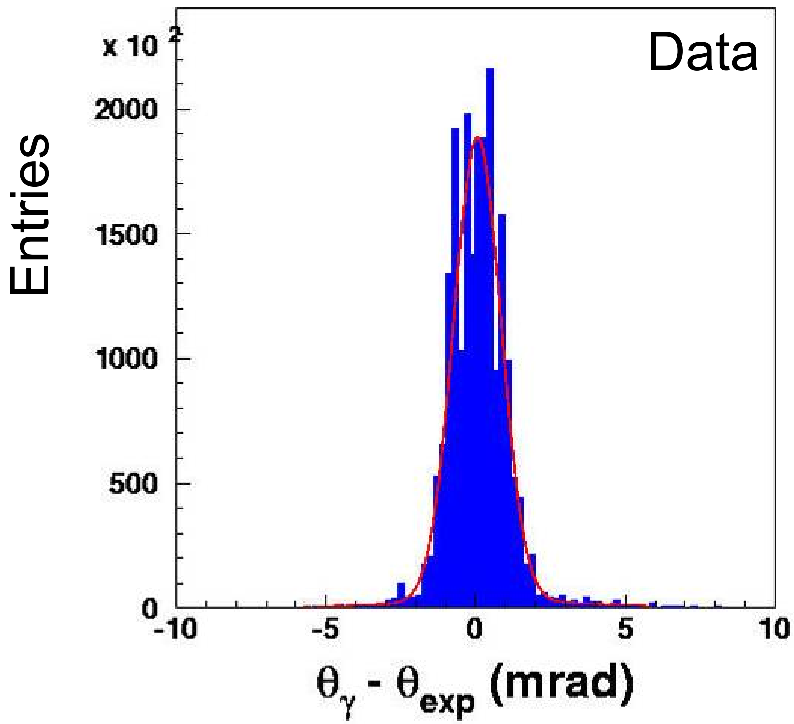
$$(n_{C_4F_8O}=1.001378)$$

Measurement at 412 nm using
Michelson interferometry

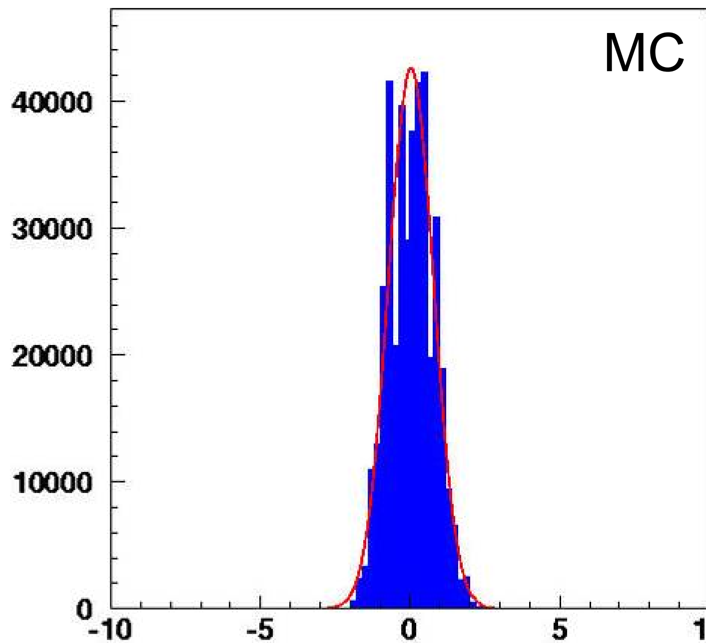


Cherenkov angle resolution / γ

σ ~ 0.79 mrad

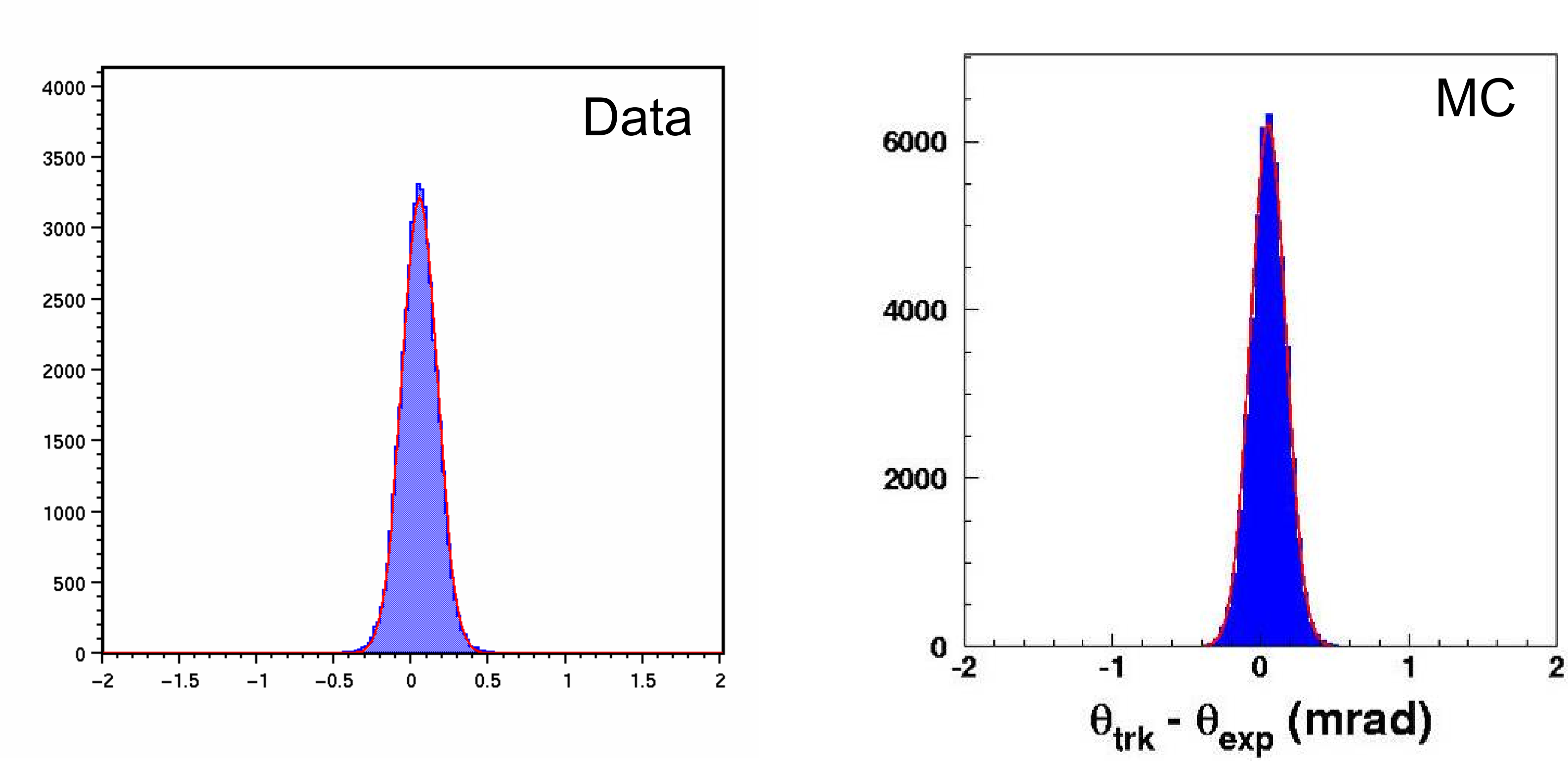


σ ~ 0.75 mrad



Difference ~ 5% (consistent with cross talk)

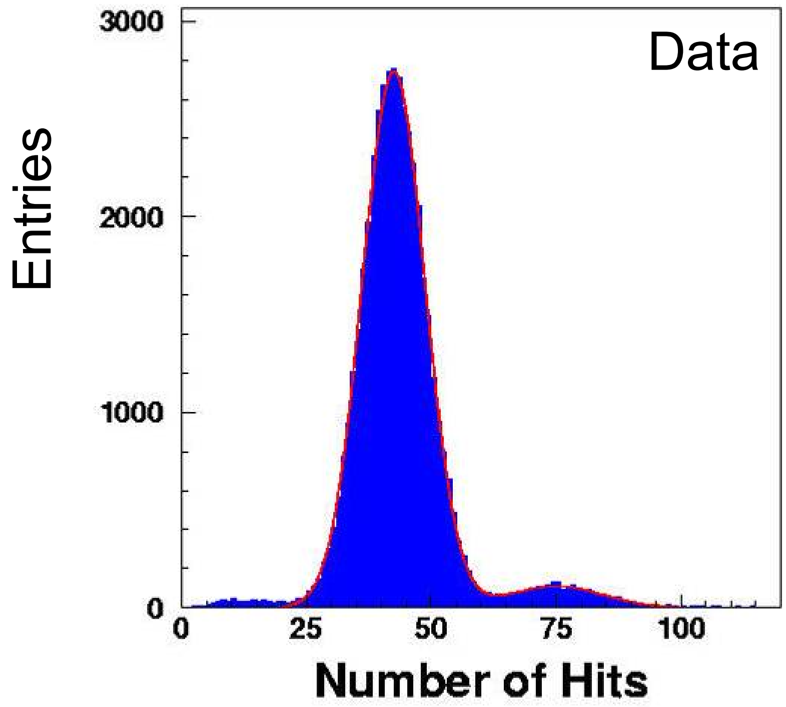
Cherenkov angle resolution / track

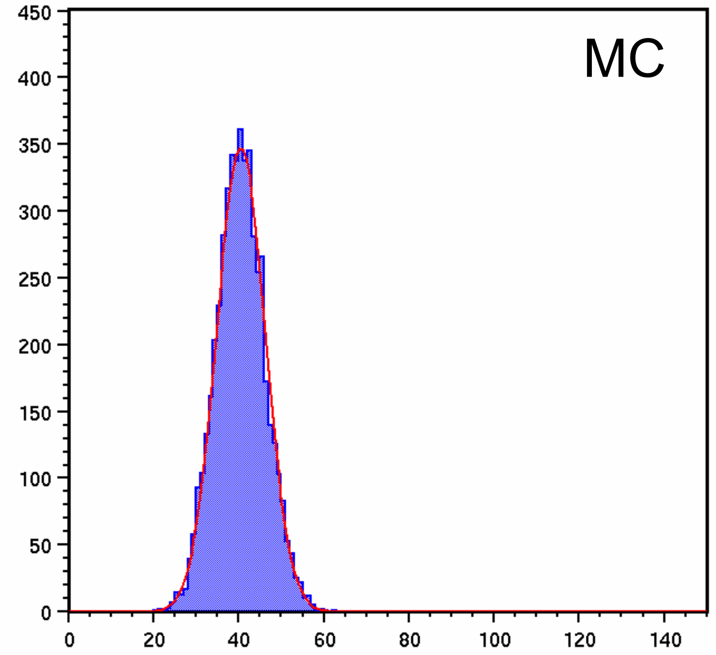


σ_{Data} = 0.116 mrad

σ_{MC} = 0.111 mrad

Photon yield





Single track peak

$\langle N \rangle_{Data} = 43.1$

$\langle N \rangle_{MC} = 40.5$

Results

- C_4F_8O performs well as a cherenkov radiator
  - Good replacement for C_4F_{10}
- First results using new MAPMTs (R8900-M16)
  - Good performance, crosstalk problem
- Data is consistent with Monte Carlo expectation
  - Typically ~5% difference, can be explained with crosstalk
  - Simulation of crosstalk reproduced these differences
    - ➔Does not mean we fully understand the effect
- Numbers from beamtest data for BTeV RICH :
  - $N_g = 43.1$
  - $\sigma(\theta_{ch})/\gamma = 0.8$ mrad
  - $\sigma(\theta_{ch})$/track = 0.116 mrad

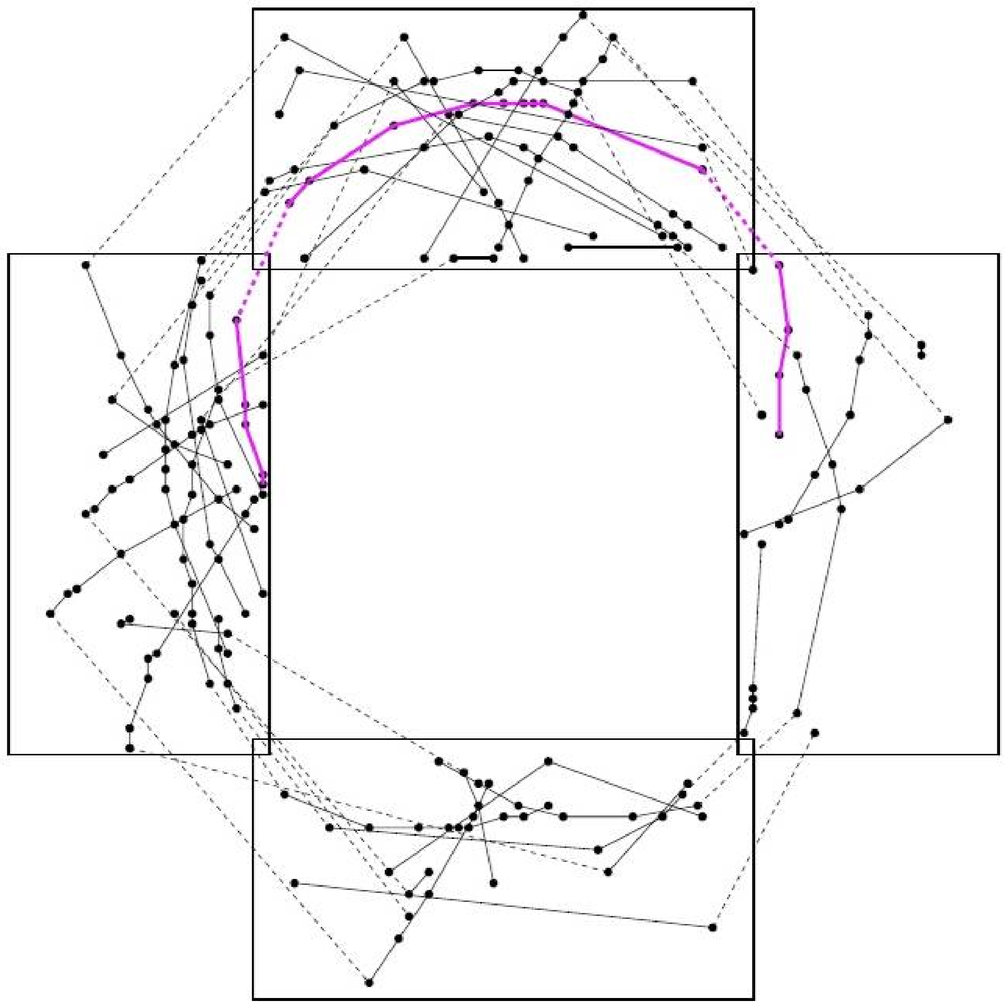
Points to keep in mind

- MAPMTs
  - Crosstalk problem : two sources
    - ➔ Signal from neighbouring wire in readout cable

      Change cable design. Optimise ASIC gain to MAPMT.
    - ➔ Photoelectron going into neighbouring dynode

      Error from this is negligible.
  - MAPMT High Voltage optimisation
- Gas system
  - Prefer active system for pressure maintainance
    - ➔ Bellows : wastage, slow response time
- Mechanical support for various elements
  - Fixes were needed to original design

Rings from Liquid radiator



- Photons from the same track are connected by a line
- Tagging kaon with magenta colour

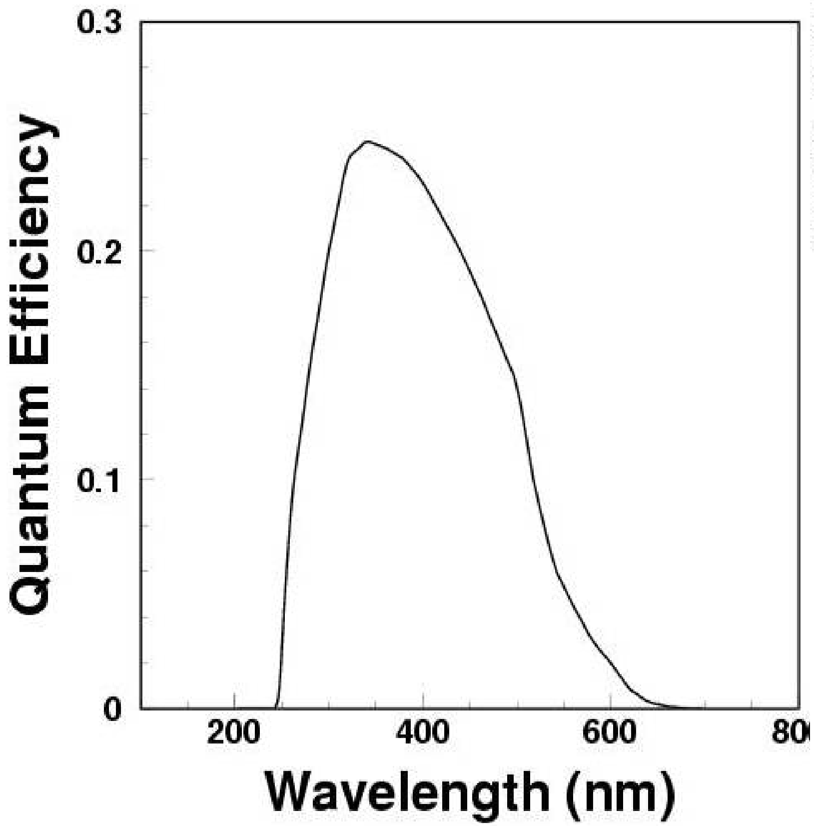
$B_s \rightarrow J/\psi\ K^*$

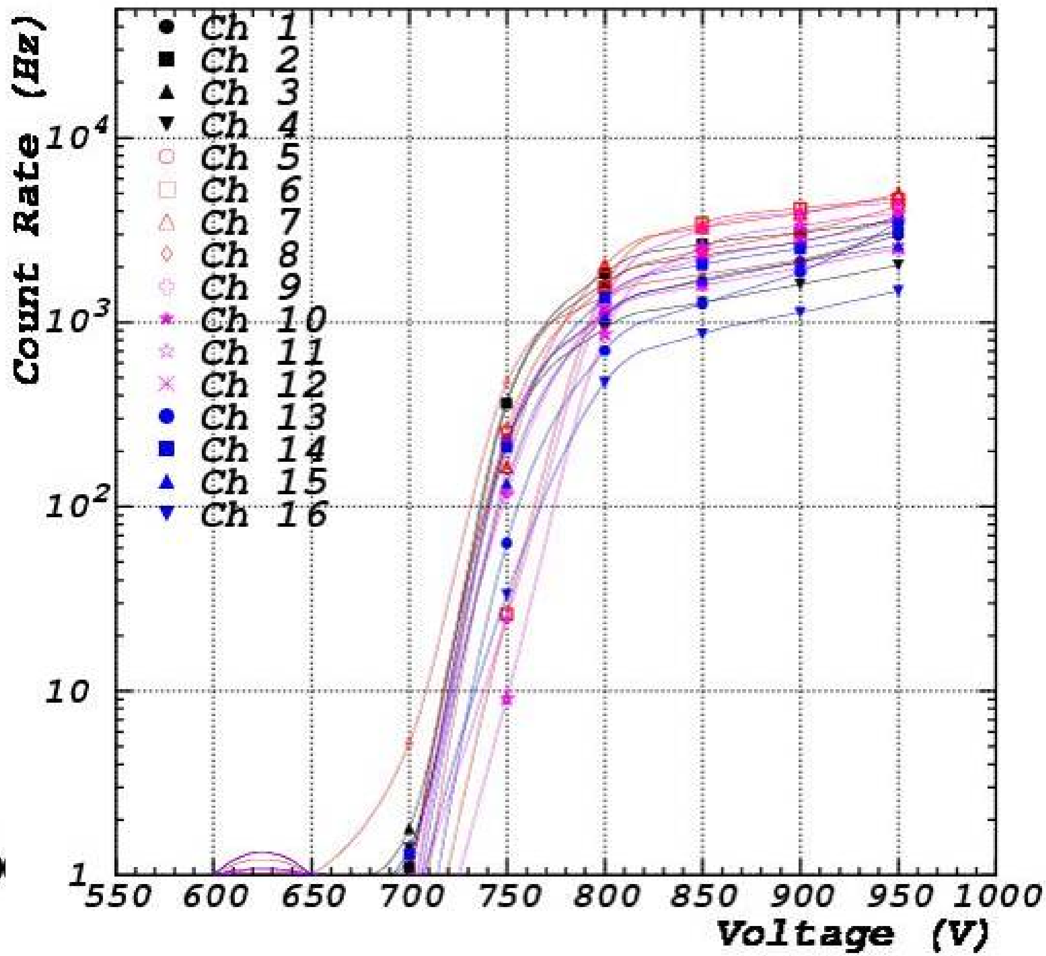
$K^* \rightarrow K^- \pi^+$

MAPMT performance - 1

Borosilicate glass

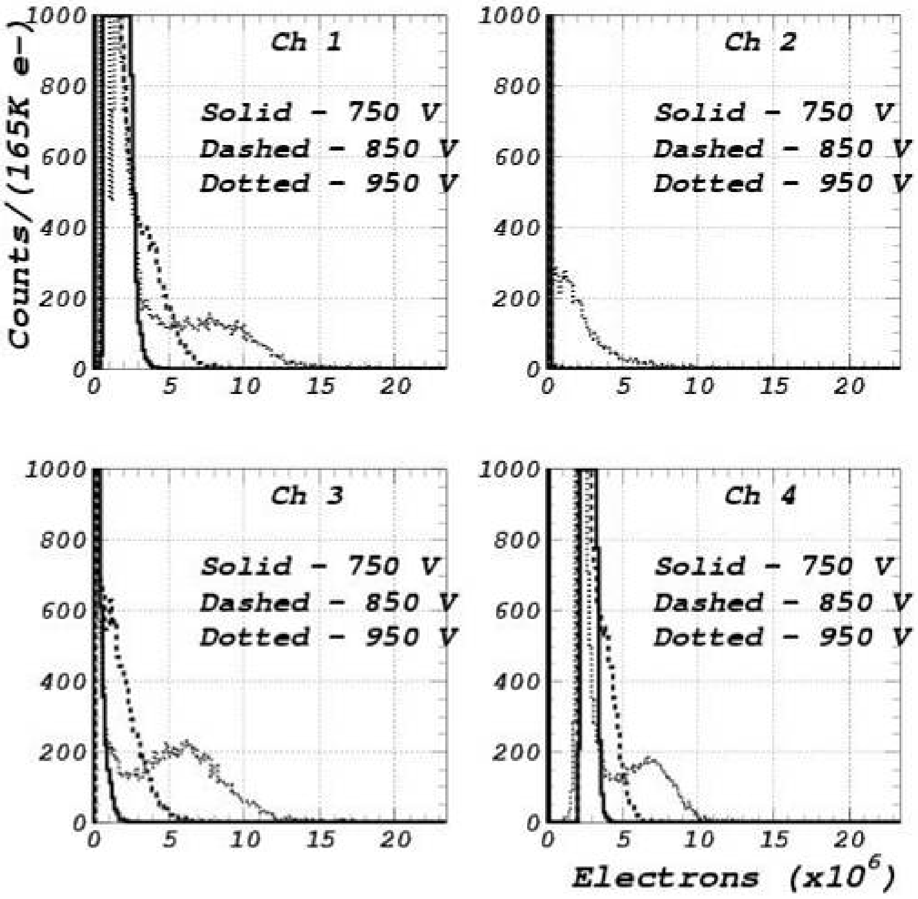
Hamamatsu



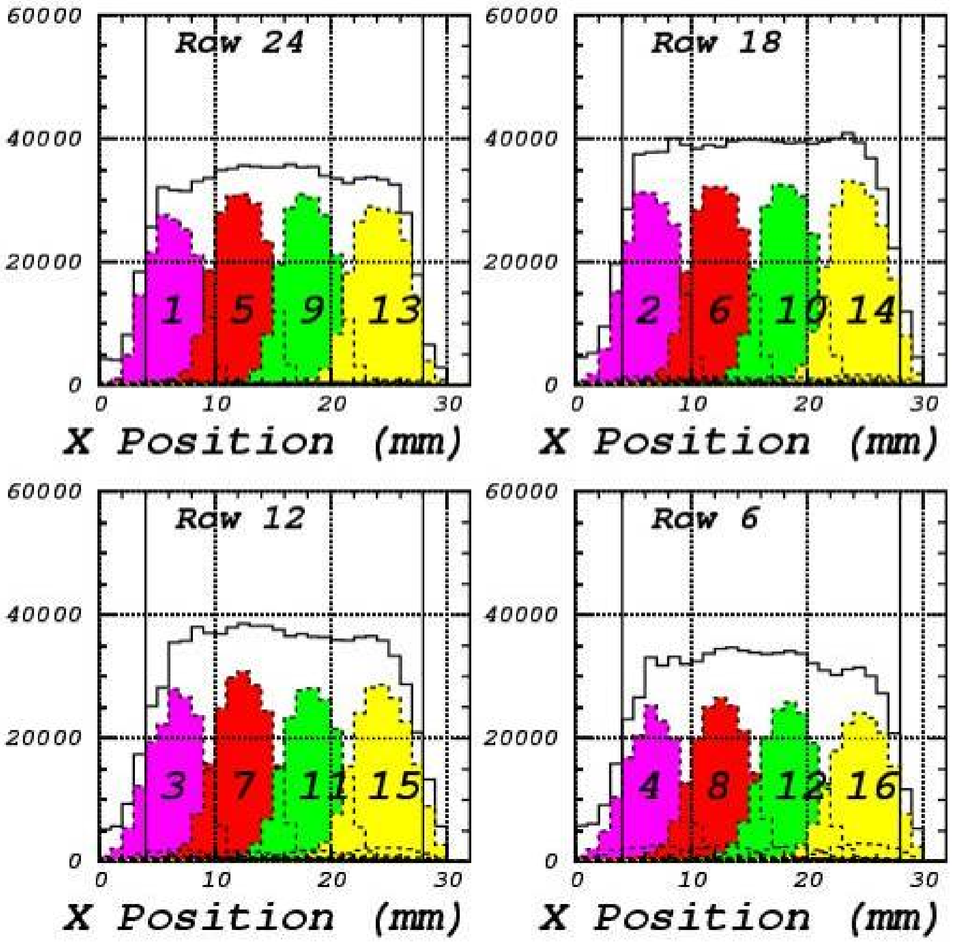


MAPMT performance - 2

Pedestals

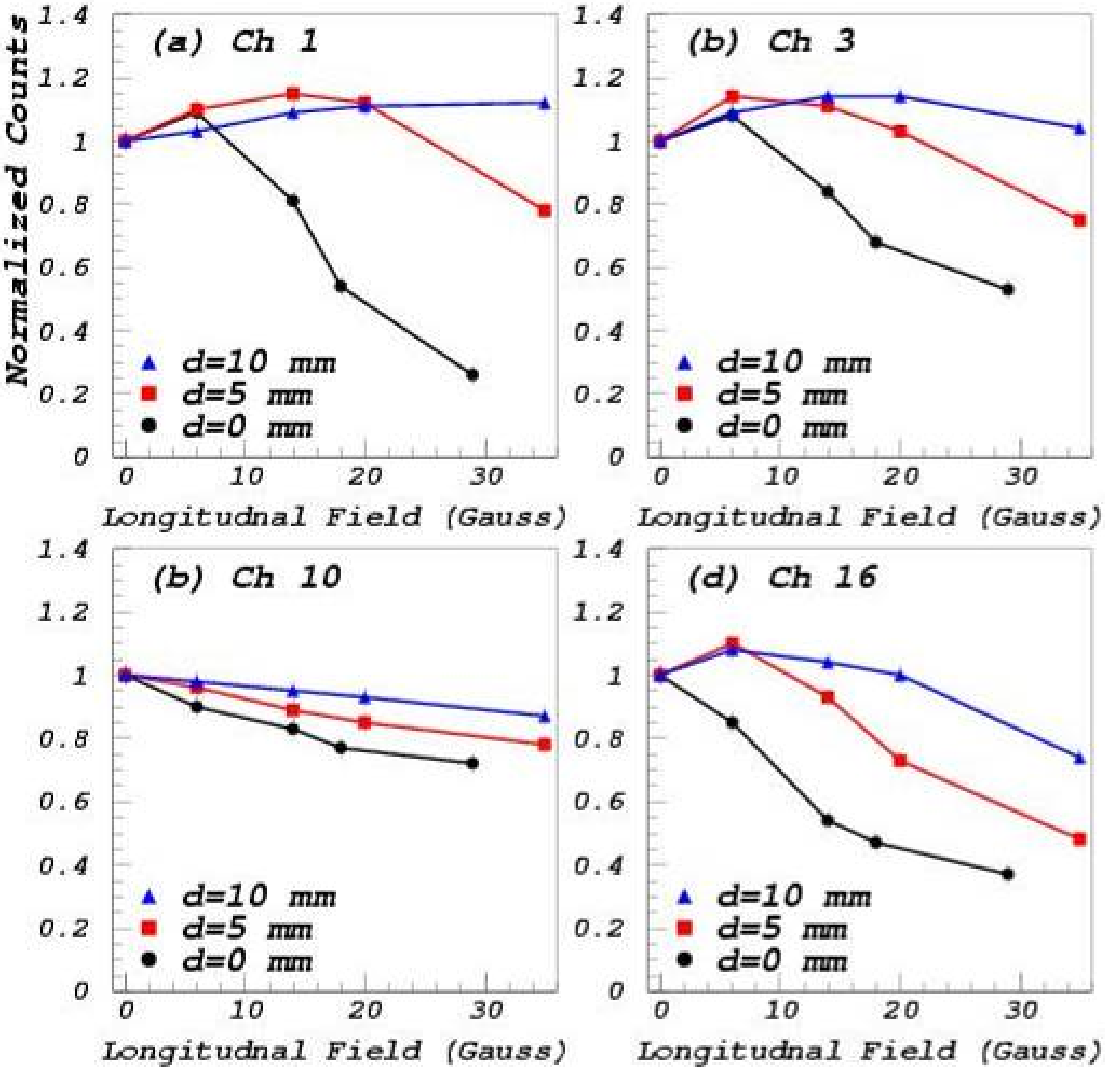


Cross talk



MAPMT performance - 3

Magnetic field sensitivity



System may have to operate in magnetic fields of upto 10G

Tubes shielded with 0.25mm mu-metal shield extending distance “d” in front of tube

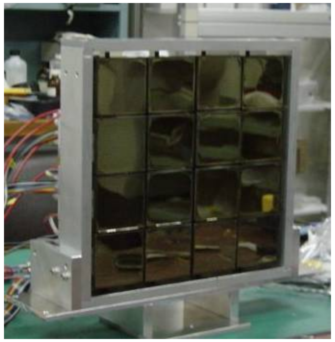
✓With shield, system not sensitive to transverse field

►Sensitivity to longitudinal field d=10mm, average loss < 5%

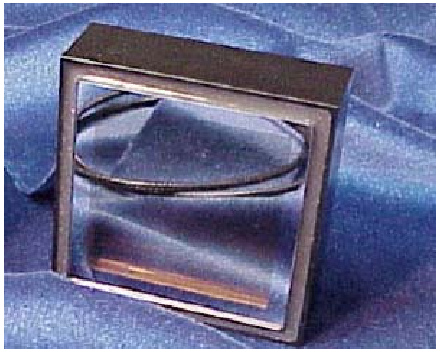
✓As shield is extended, losses are reduced

MAPMT alternatives

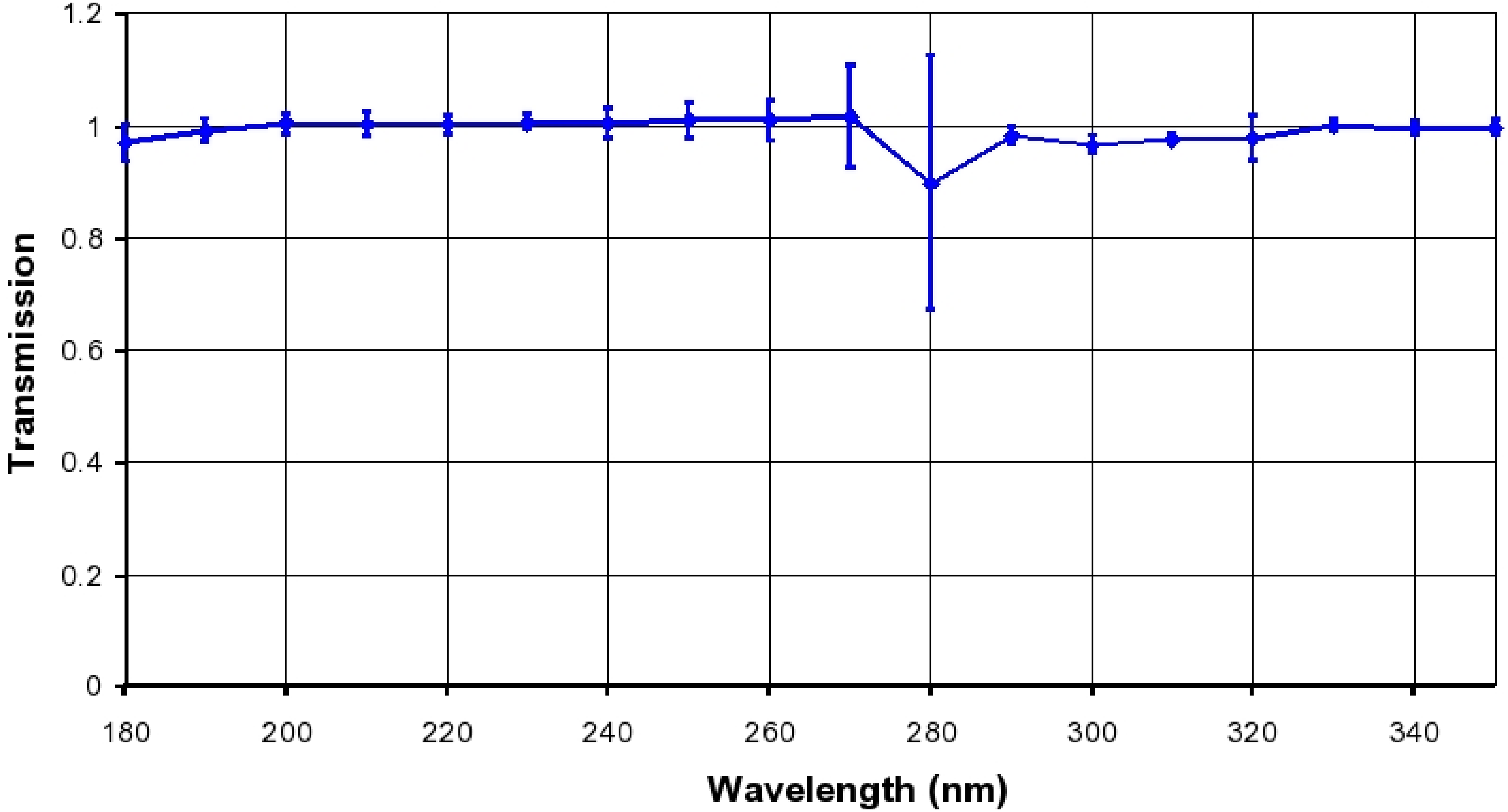
- ➢Status ~ Feb 05
- ➢Flat Panel MAPMTs (Hamamatsu)
  - QE ~25% lower than the R8900-M16
  - QE*CE ~35% lower in aerogel testbeam
    - ➜T.Matsumato et.al. NIMA251,367(2004), Belle R&D
  - Single photo-electron peak not yet clean



- ➢Micro Channel Plate (Burle)
  - Low active area - 67% (87% for R8900-M16)
  - 6.4mmx6.4mm pixel size
  - Early stages of development



Transmission of C_4F_8O



- Transmission ~100% in wavelengths surveyed

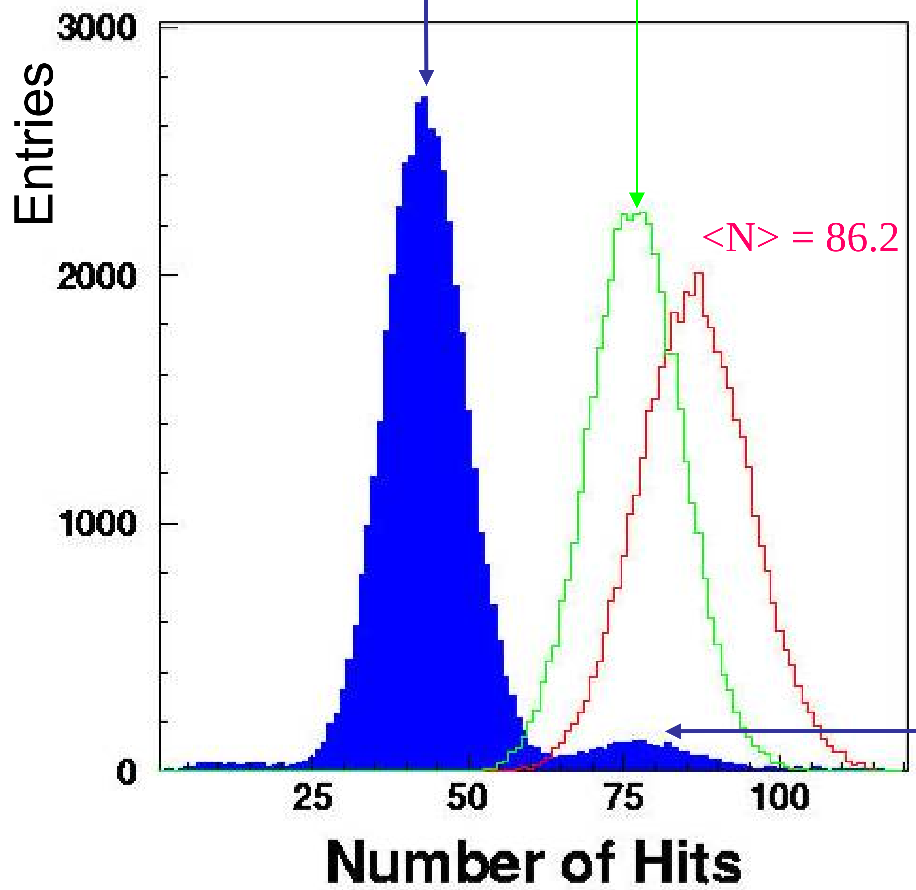
Inputs to MC simulation

- No loss in front-end electronics
- QE curve from Hamamatsu
  - Max of 25% at 340 nm
- Transmission curves measured at SU
- Dynode collection efficiency = 70%
  - Hamamatsu projection
- Reflectivity of mirror = 90%
  - Manufacturer : > 85%
  - HERA-B : 90%
  - Calculations : 90%

The second peak in N^{γ}_{hit}

Single track peak in data
<N> = 43.1
σ = 6.5

Double track peak in MC
<N> = 76.9

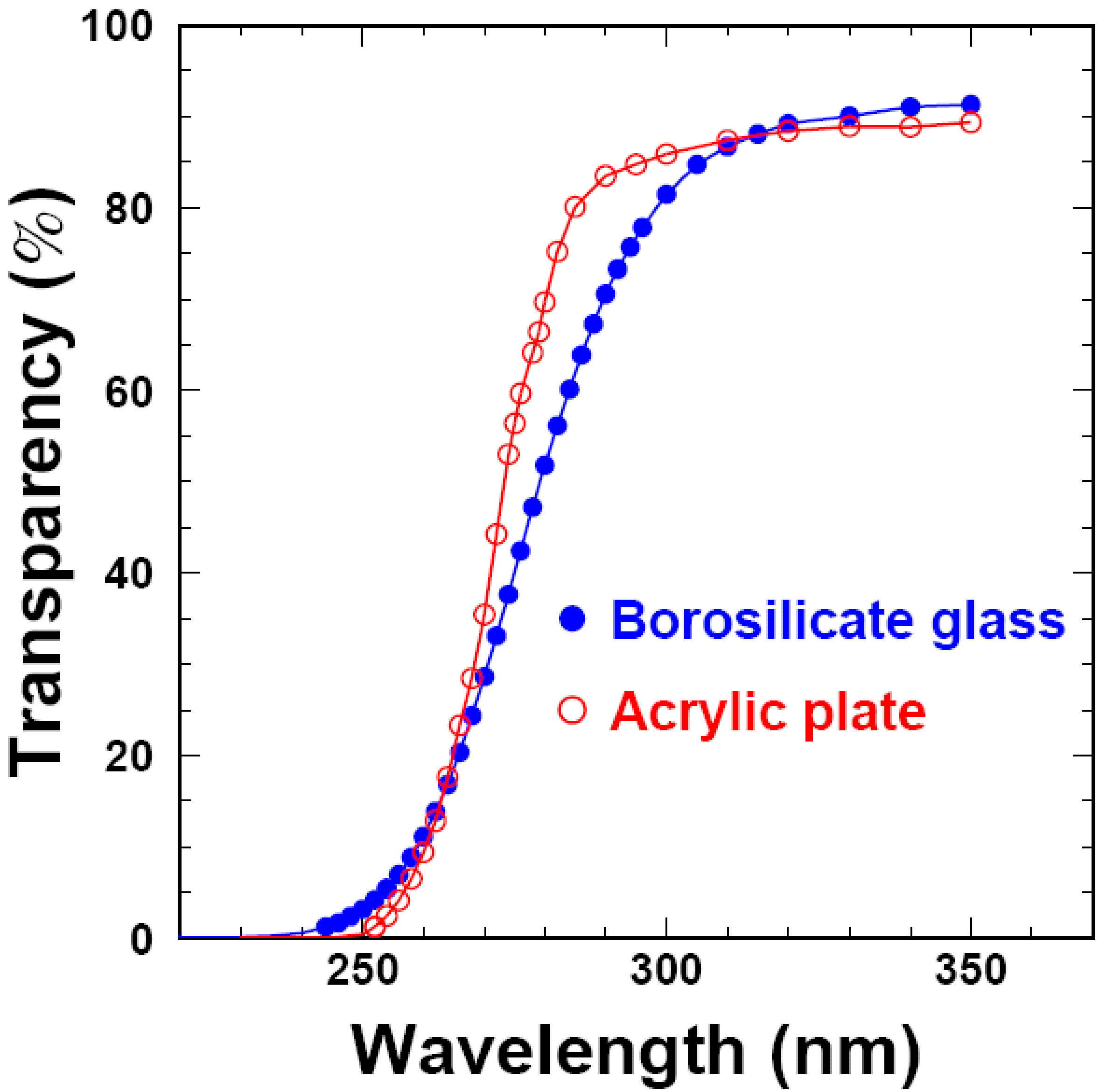


- Number of hits in double track events ~ 10% < 2*N_{hit} **/ track**
- Deficit is due to photon overlap effect (seldom happens in real experiment)
  - ➔Tracks rarely have exactly same angle

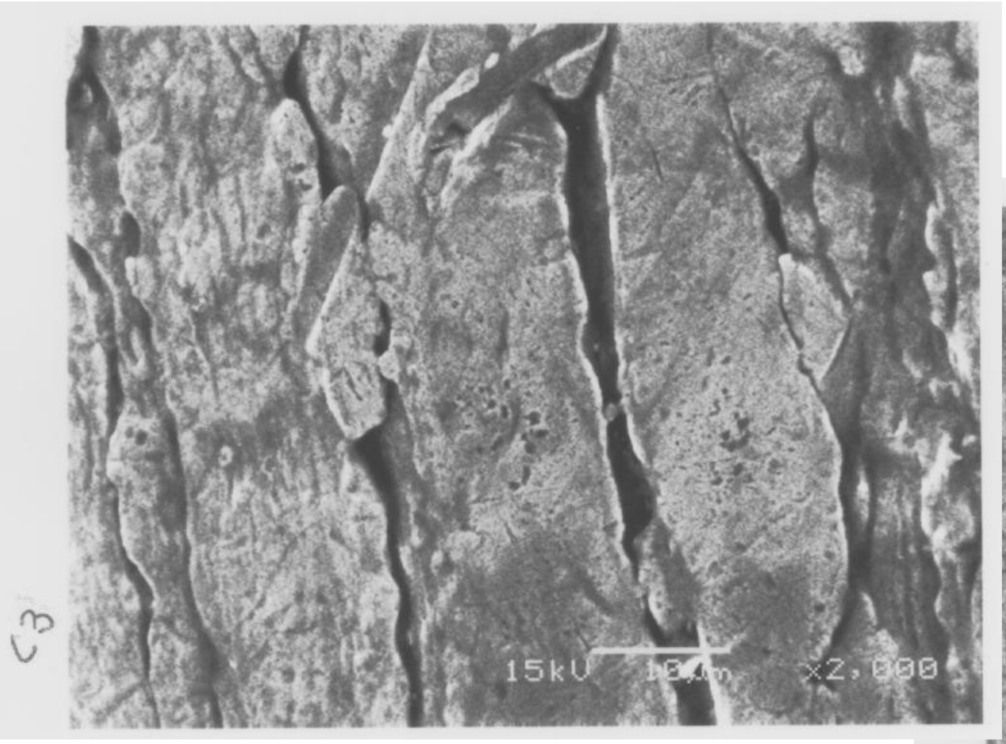
Fraction of double track events = 5.9%

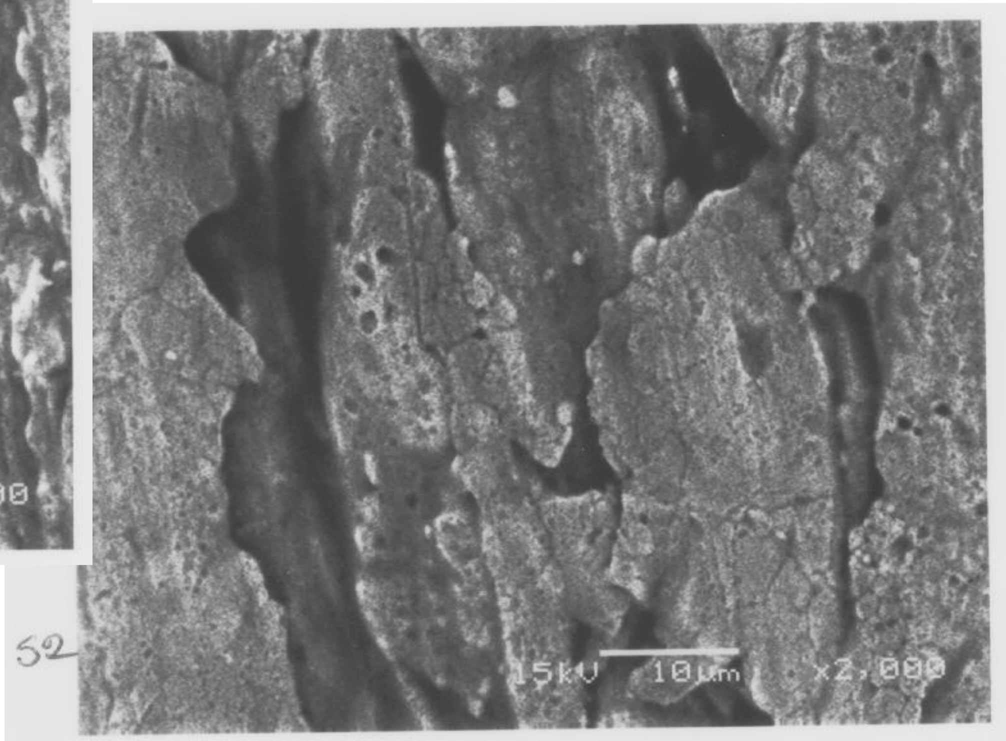
Double track peak in data
<N> = 76.8
σ = 10.2

Borosilicate glass vs UVT acrylic



EDXAnalysis of Copper samples






SYRACU
1 2 3 4 5 6 7 8 9 10 11