Prototyping the PANDA Barrel DIRC

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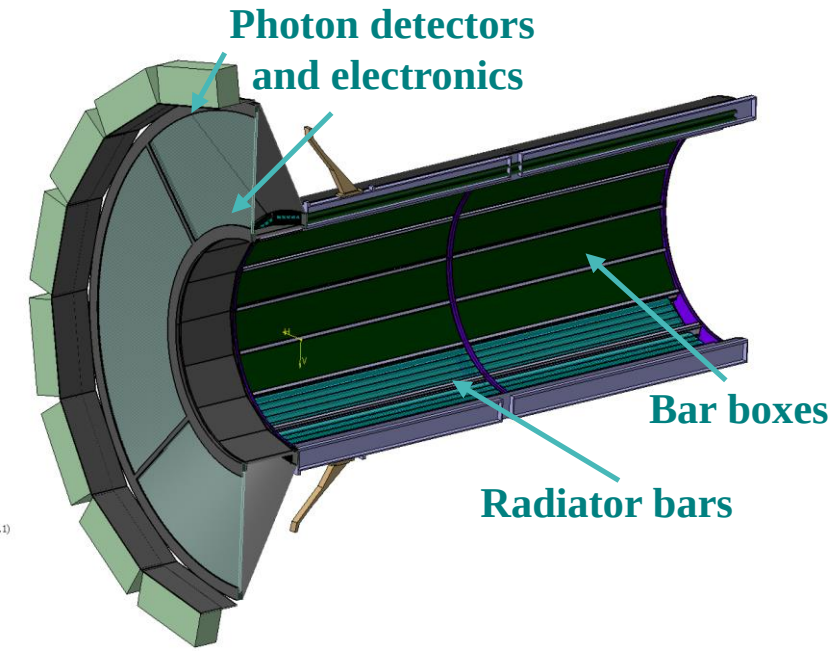
for the PANDA Cherenkov Group

DIRC Focusing DIRC with fast timing

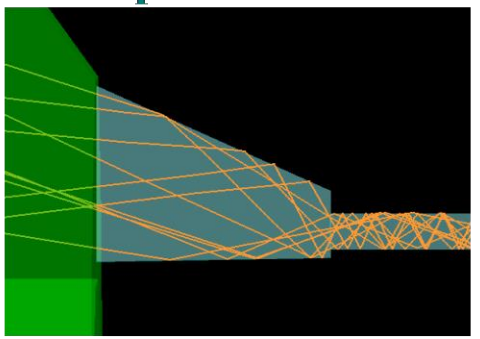


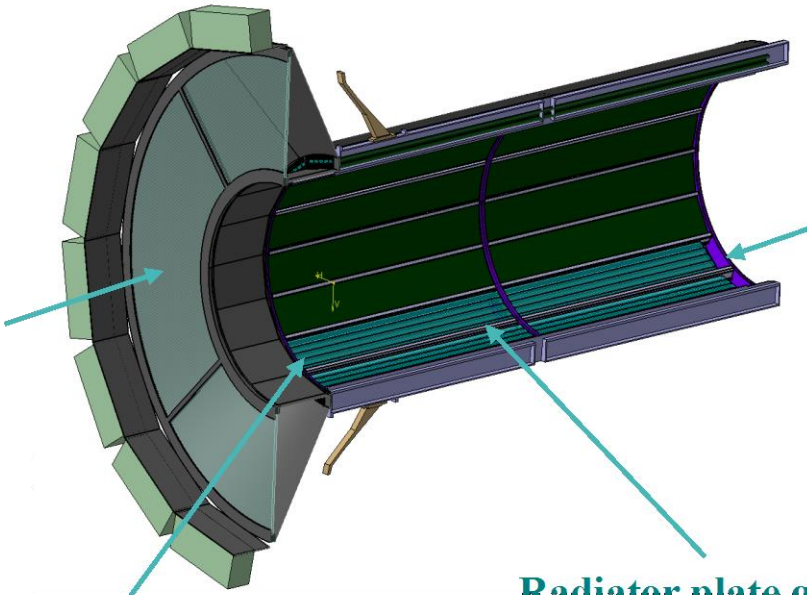
- Barrel radius ~48 cm.
- 80 radiator bars, synthetic fused silica 17mm (T), 32mm (W), 2400mm (L).
- 30 cm depth expansion volume.
- 10,000 - 15,000 channels of MCP-PMTs.

- **Inspired by BABAR-DIRC** with important improvements.
- **Focusing optics:**
  Doublet lens system – better Cherenkov angle resolution.
- **New compact photon detectors:**
  Array of Microchannel Plate PMTs – smaller expansion region, easier detector integration.
- **Fast photon detection:**
  Sensors and electronics – less sensitivity to the background.
- **Still considering several design options**

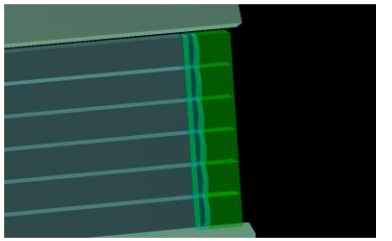
DIRC Design options

Compact fused silica prism as expansion volume

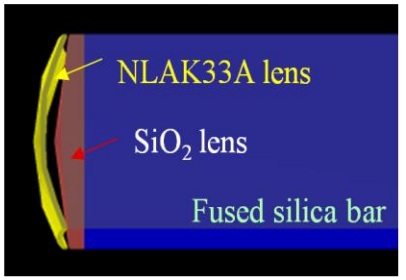




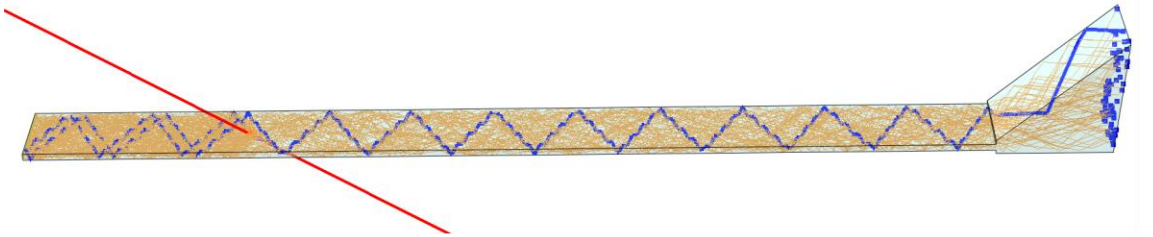
Focusing mirror



Lens



Radiator plate geometry



Barrel DIRC Prototyping

- **Full System Prototypes in Particle Beams:**
  - **2008, 2009 – GSI**
  - **2011 – GSI, CERN**
  - **2012 – CERN**
  - **2013 – Mainz**

- **Prototype Component Lab Tests:**
  - **Radiators**
  - **Photon Detectors**

    (see "Lifetime measurements of MCP-PMTs" Albert Lehmann, Erlangen)
  - **Readout Electronics**

    (see "The TRB Readout system" Michael Traxler, GSI)

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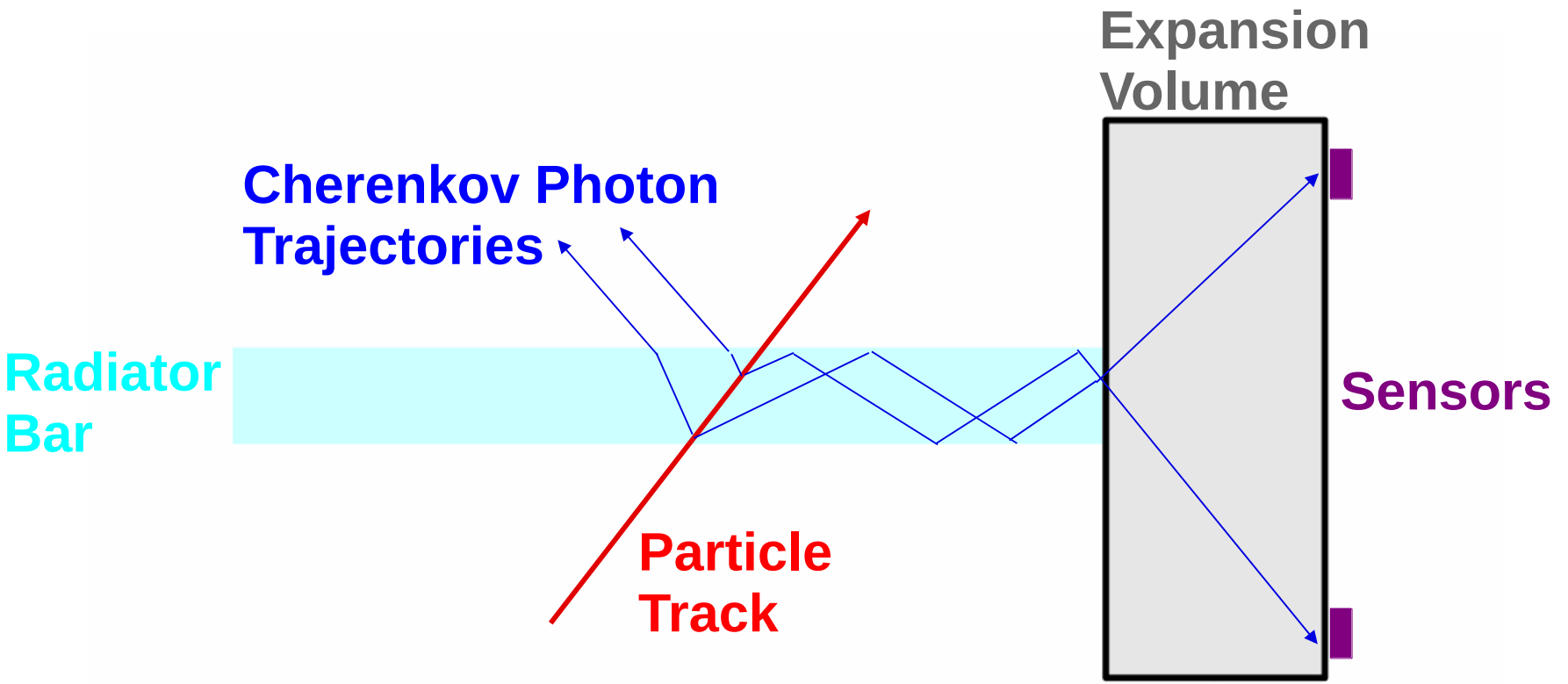
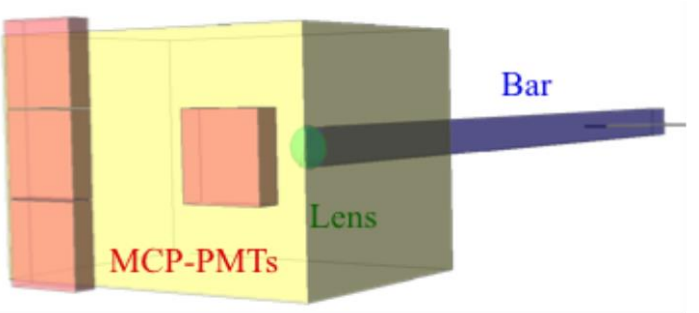
Barrel DIRC Prototype Basic components

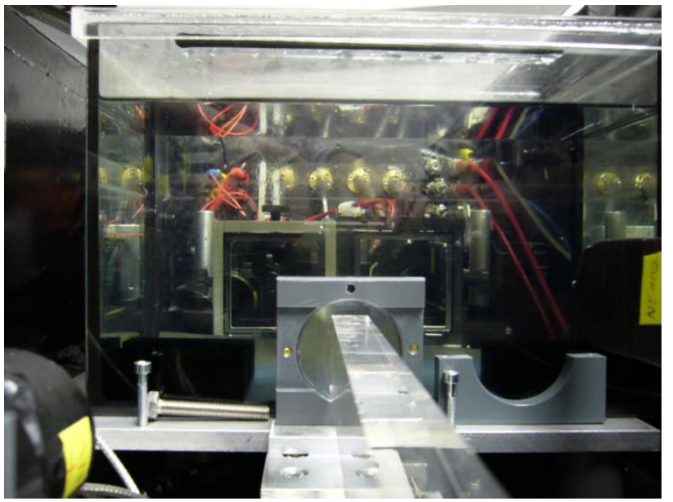


Barrel DIRC Prototype Evolution of the prototype



- **2008, 2009 – GSI:**
- Schott Lithotec bar, spherical lens.
- Expansion volume: small oil tank.
- MCP-PMTs with pre-amplifiers.

→ **First clear Cherenkov ring observed.**



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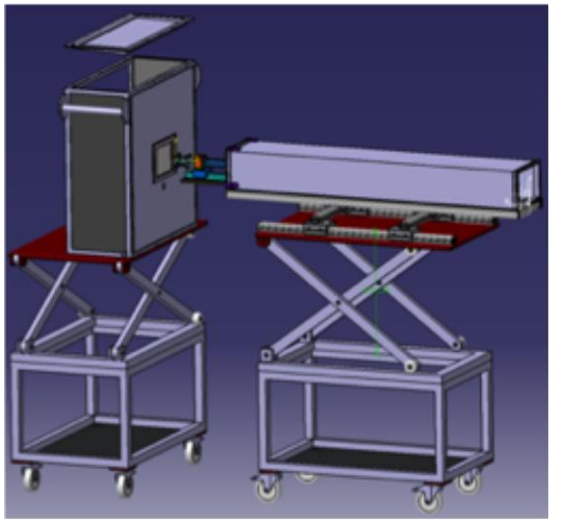
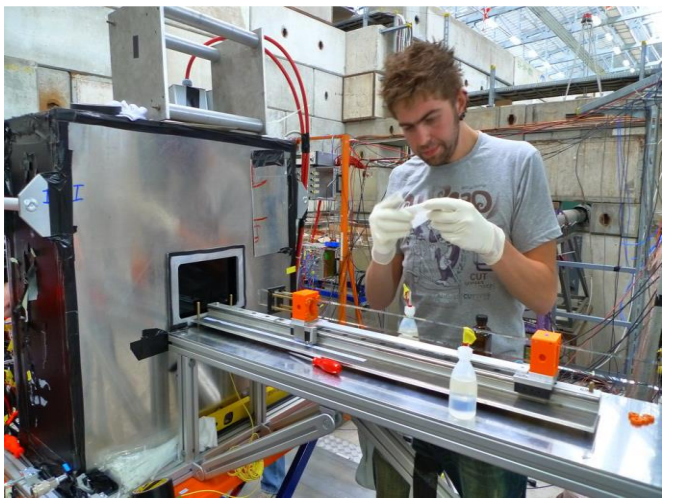


- **2011 – GSI, CERN:**

- Larger, deeper expansion volume filled with mineral oil.
- Movable and rotatable prototype support.
- Larger detector plane, space for more, different type sensors (MCP – PMTs, SiPM, Multi Anode PMT).
- 640 electronics channels (HADES TRB/NINO) some optimized for use without amplifiers.
- Focusing lenses with different AR coatings.



→ **First determination of angular resolution ($\sigma_{\Theta c}$= 9 mrad) and number of photons per track (N_{ph} = 3).**

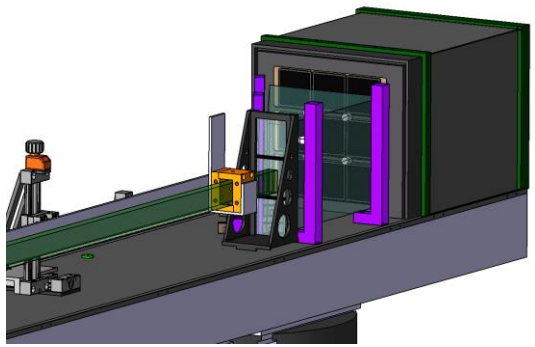
Barrel DIRC Prototype Test beam Aug 10 – Sep 3, 2012

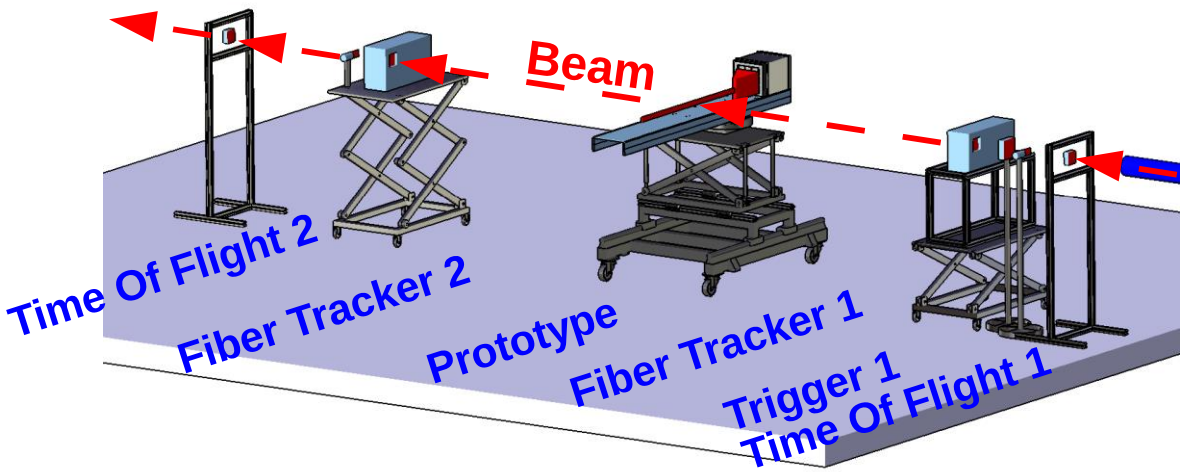
4 weeks of beam time at CERN PS (T9)

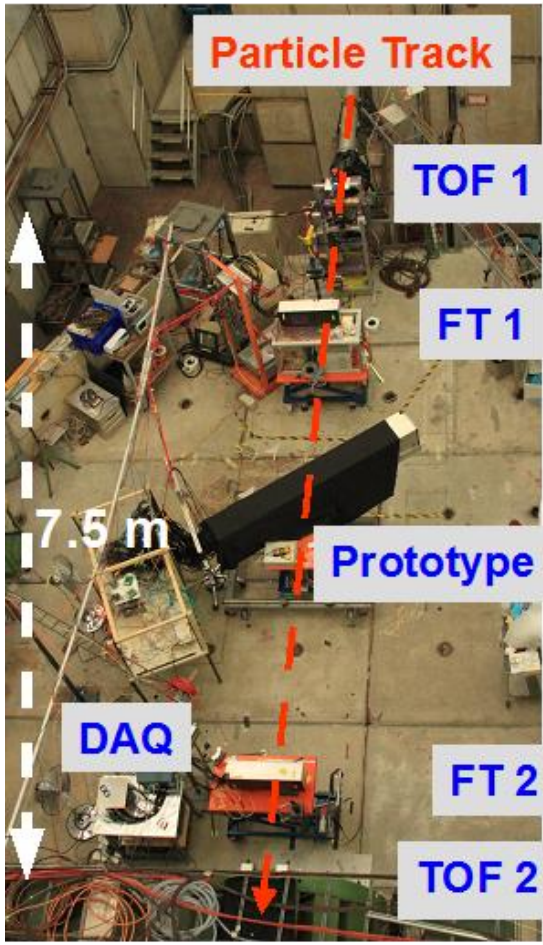
- Wide range of beam-bar angles and beam positions, similar to PANDA phase space.

- First experience with:
  - → Prism as expansion volume.
  - → Plate as radiator.
  - → Lens w/o air gap.

- 220M triggers recorded.







Test Beam 2012 Varied parameters

- **Bar prototypes**

  InSync, Zeiss, Lithotec, LZOS, Röhm (acrylic glass)

- **Focusing**

  different lenses, no lens - w/ and w/o air gap

- **Coupling MCP–PMT/prism/bar**

  matching liquid, optical grease,

  silicone sheet

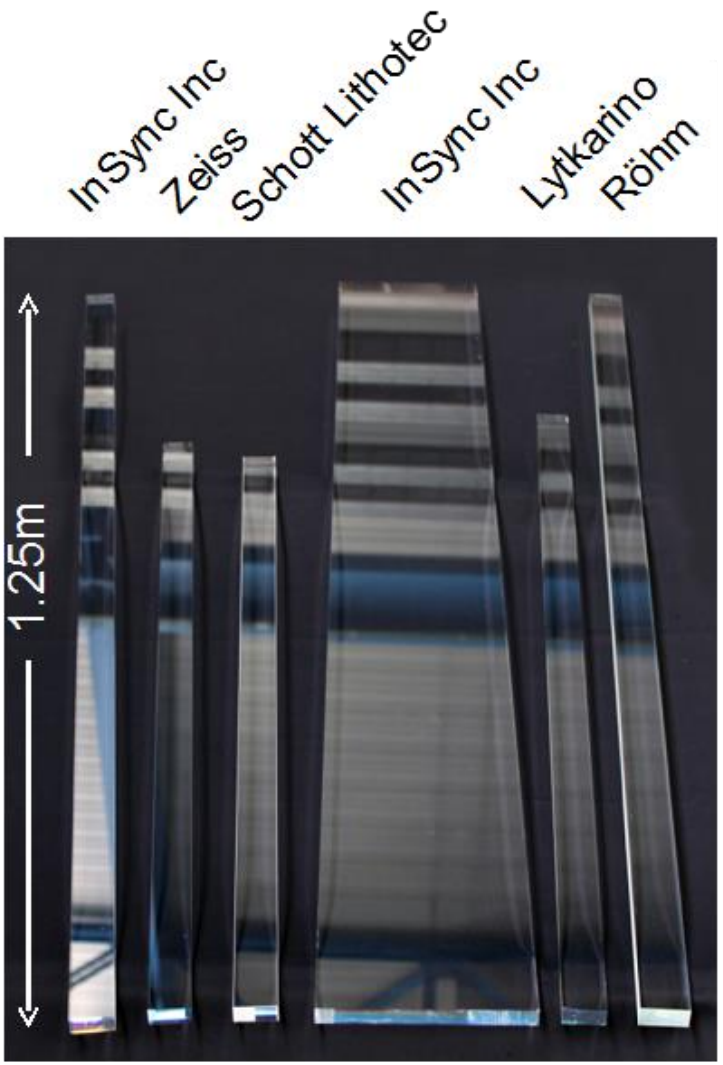
- **Beam momentum (1.5 – 10 GeV/c)**

  Allows to study of PID performance.

- **Polar/azimuth angle of beam to bar**

  Fine and coarse step polar angle scans.

- **Beam position on bar**



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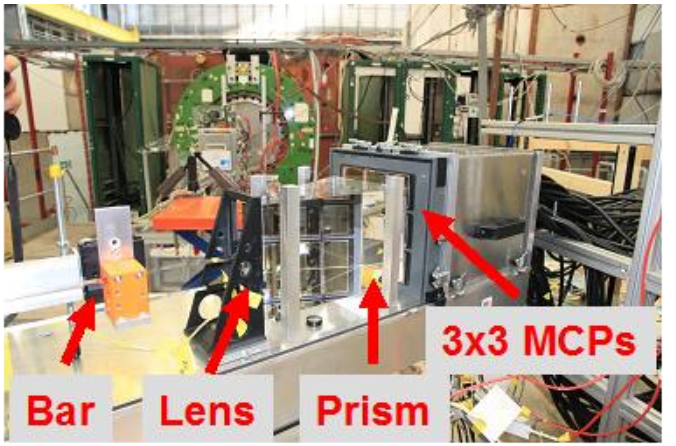

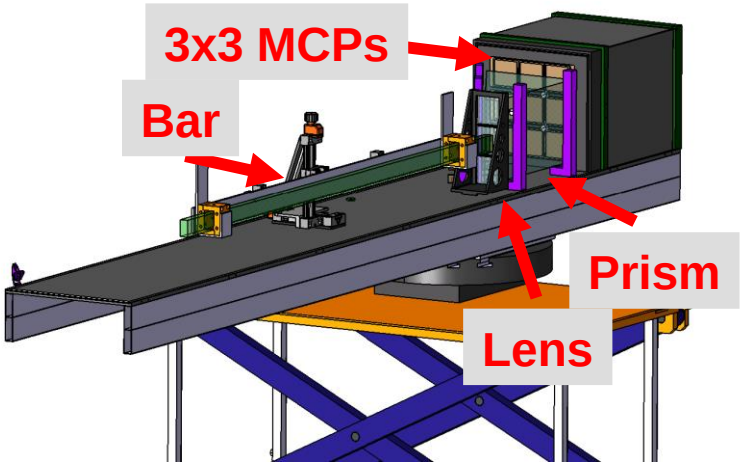

Test Beam 2012 Event selection

- **Single event**
  Coincidence of two trigger counters.

- **Elimination of the double hits and beam halo effects.**
  (99% hits selected)

- **Two stage time cut:**

  - Raw hit time.
    (~86% hits selected)
  - Trigger corrected hit time.
    (~75% hits selected)

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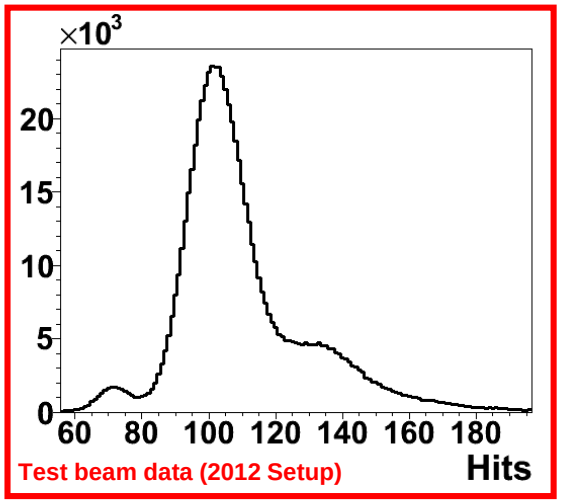
Total number of hits:



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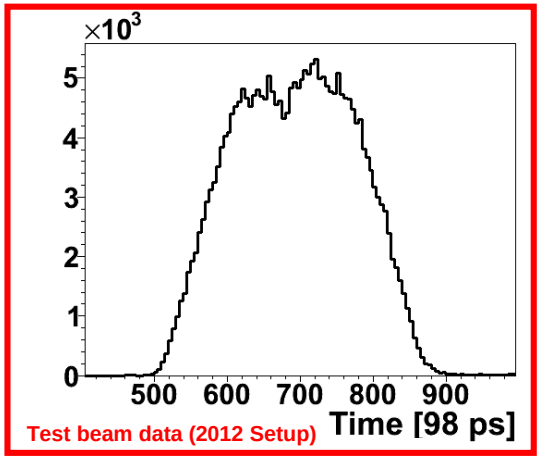
Raw hit time distribution
(for single MCP-PMT)



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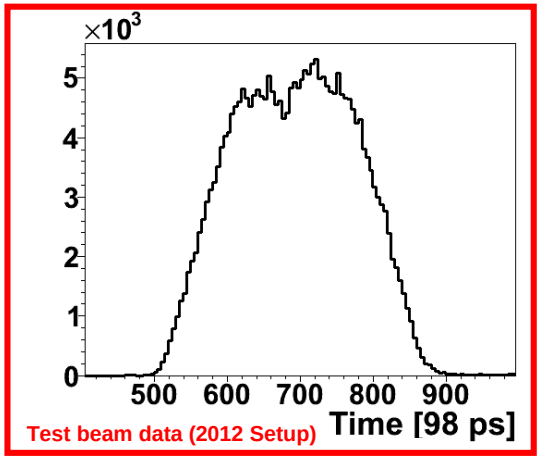

Trigger corrected hit time distribution
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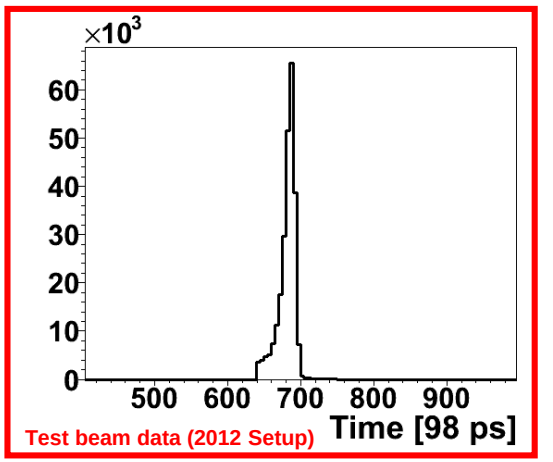
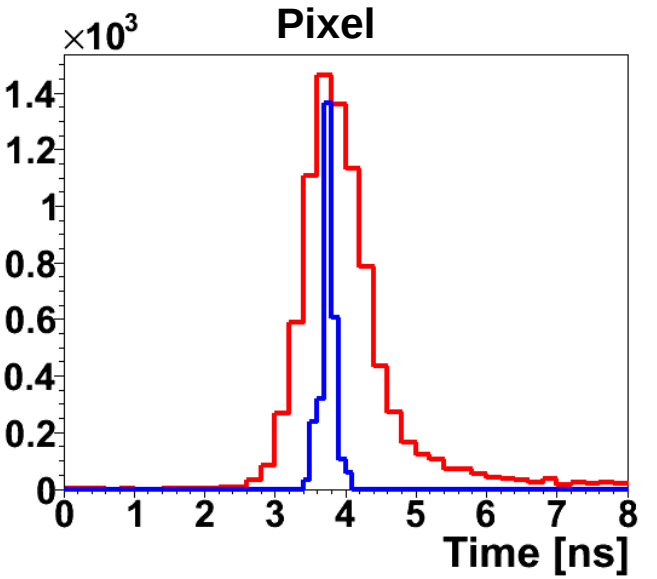


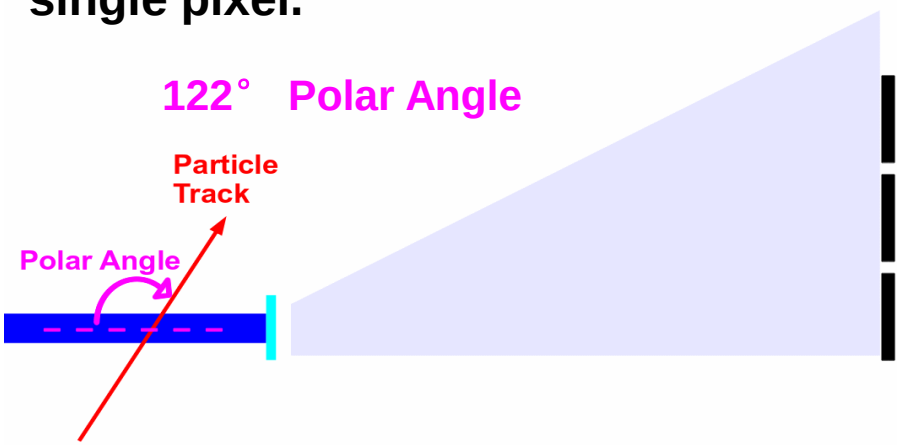
Test Beam 2012 Time resolution

- **Irreducible time spread**
  Different path lengths and chromatic smearing (described by Monte Carlo).

- **Additional effects in test beam data:**
  - Start counter timing resolution (slow scintillator)
  - Pixel-TRB cable length variation (calibration data issues)
  - Signal charge effects (no pre-amplification)



- **Reasonable time cuts possible only for single pixel.**



Time resolution (RMS) [ns]

	Test beam	Monte Carlo
Pixel	0.75	0.10
MCP	1.12	0.11
System	1.13	0.36

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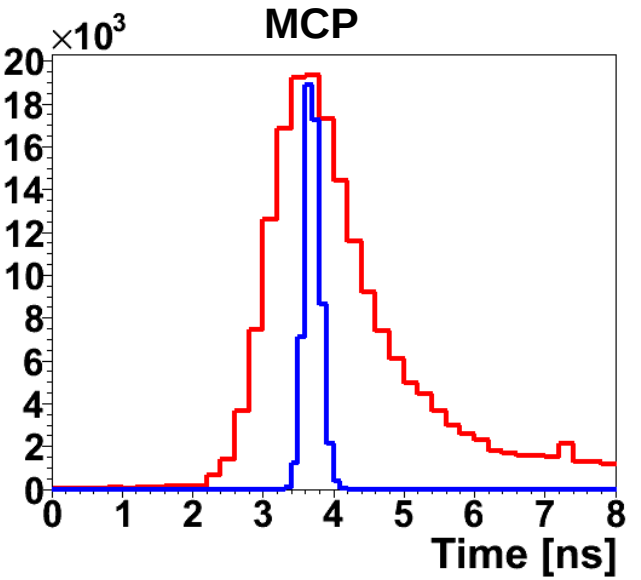

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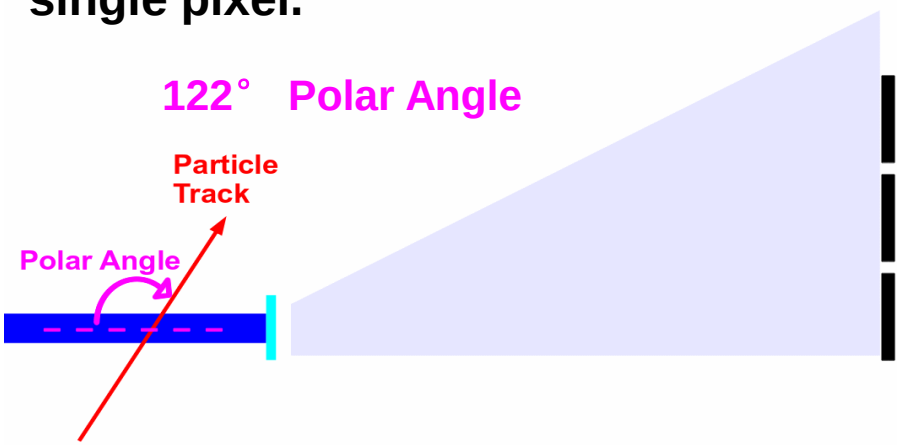

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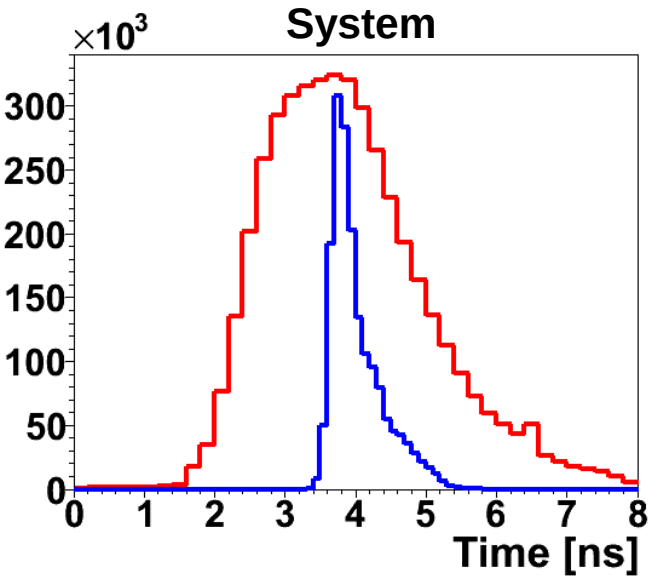

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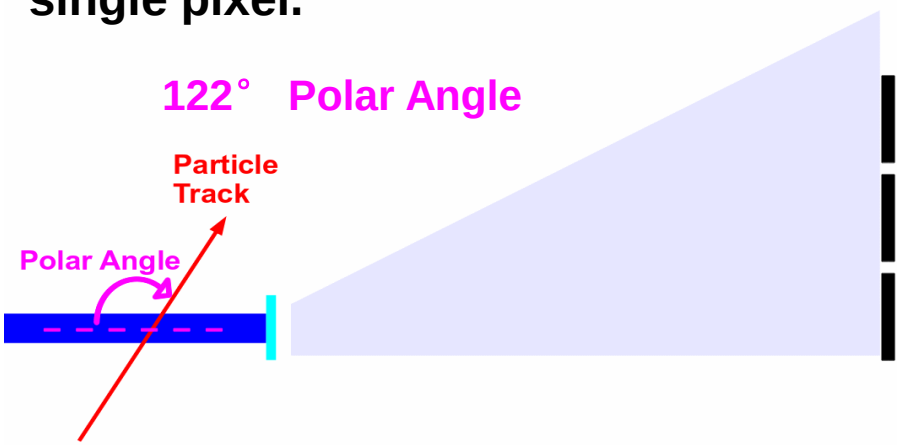

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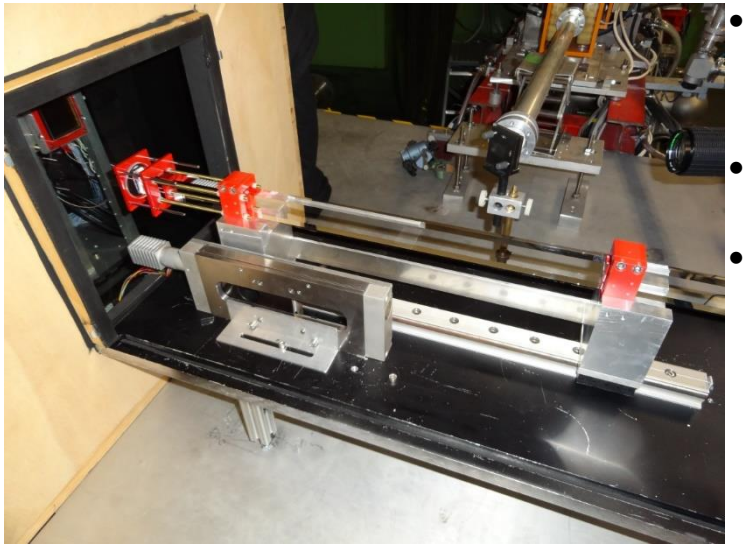
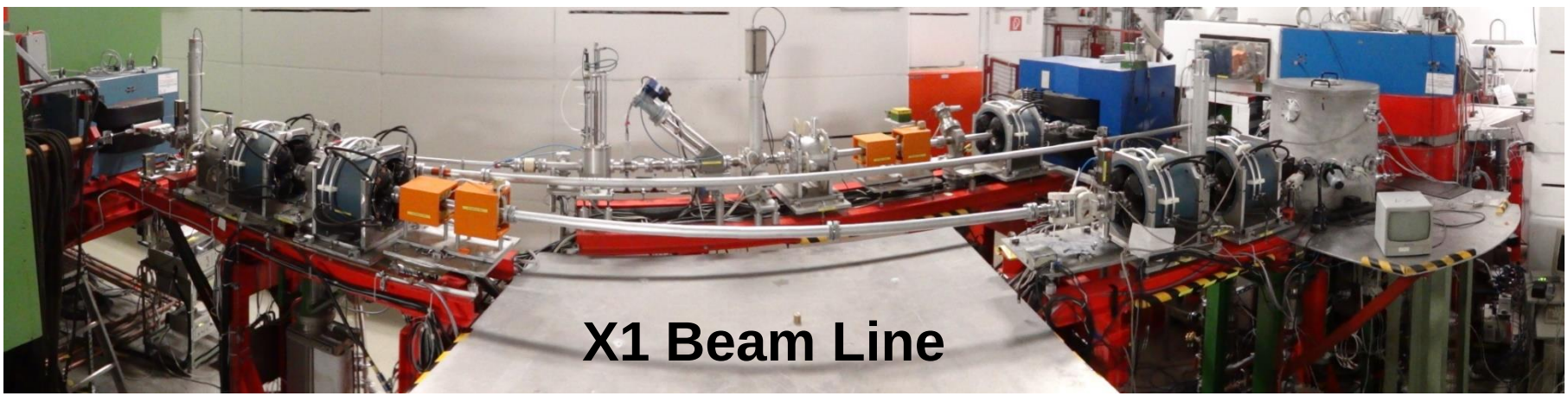
Prototype components Barrel DIRC FEE test at MAMI



- Main focus on different **FrontEnd Electronics (FEE)** timing properties study.
- Up to **855 MeV/c e^- beam** (CW)
- **Setup:**
  - Radiator bar w focussing lens
  - Up to 6 MCP-PMT Planacon XP85012
  - Mixed TRBv3 readout
    - 3 MCPs w NINO FEE
    - 3 MCPs w PADIWA FEE



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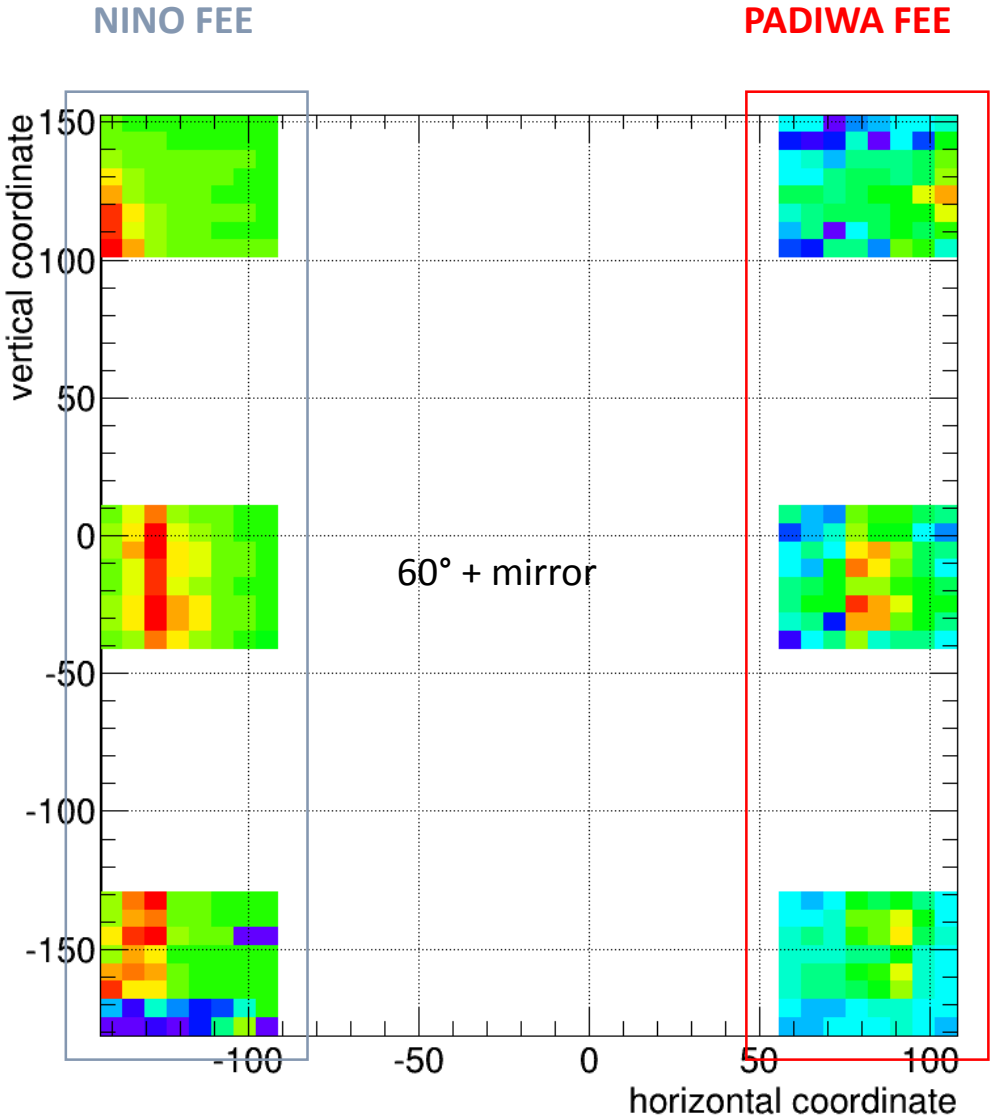
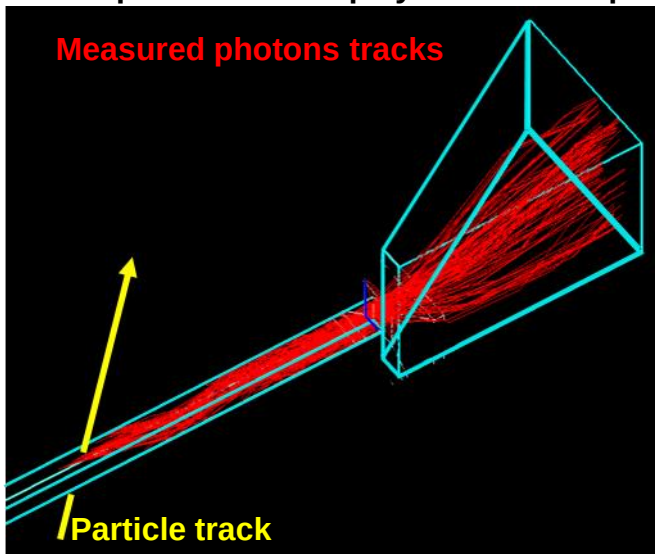


- **Tests include:**
  - HV scans
  - Threshold studies
  - Rate variations
- **Analysis is underway**

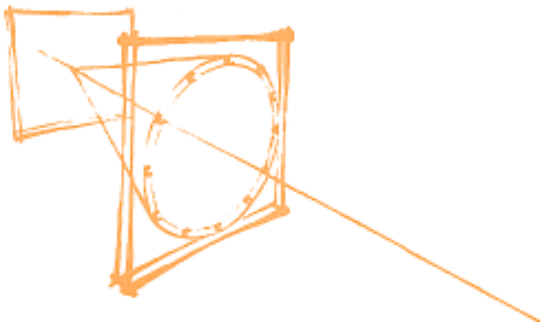
Test Beam 2012 Monte Carlo Simulations

- **DrcProp: stand-alone package for ray tracing simulations includes:**
  - Prototype geometries
  - Beam properties
- **Producing occupancies and timing spectra**
  - Optimizing the final design of the prototype (bar, lens and sensor placement).
  - Predictions and setting goals for the test beam.
  - Reproduction of the conditions and changes from the test beam.
  - Important input to data analysis.

Example of event display from DrcProp



Test Beam 2012 Hit pattern



- DIRC hit patterns do not look like typical RICH detector.

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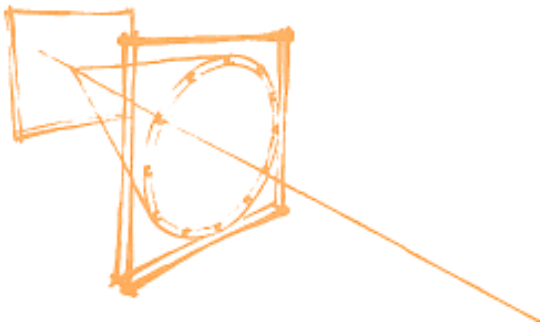

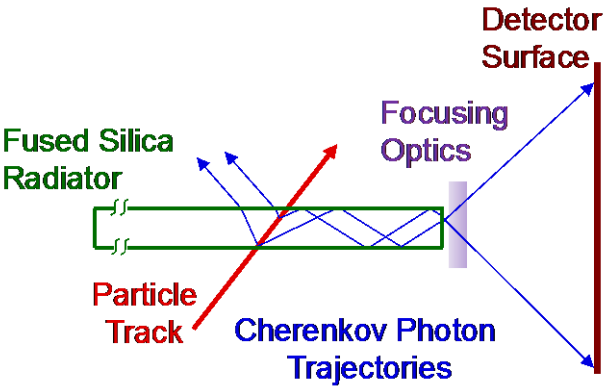

- DIRC hit patterns do not look like typical RICH detector.

- Part of the ring escapes, not totally internally reflected.
- Ring image gets folded due to propagation in bar/plate.

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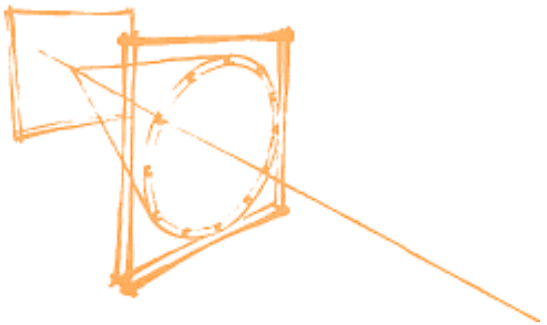

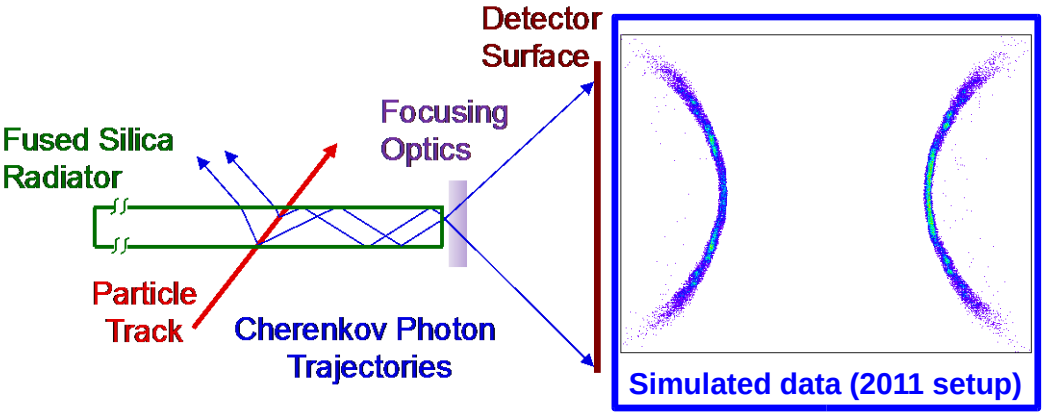

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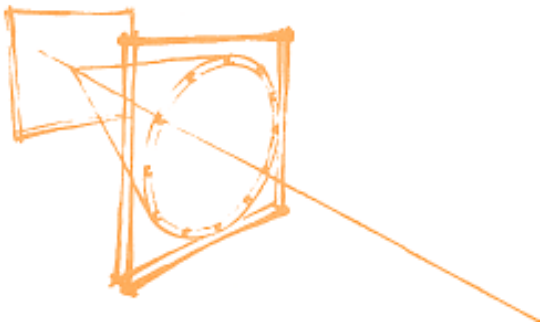

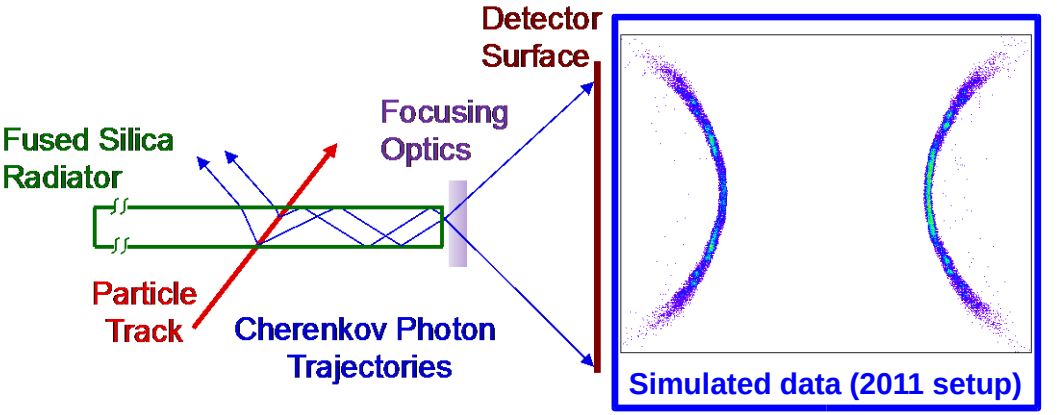

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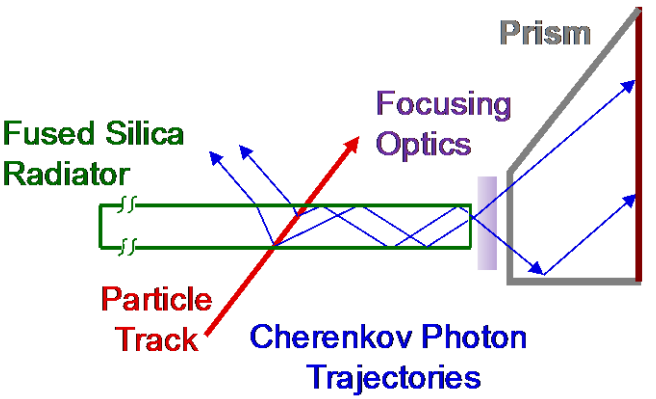

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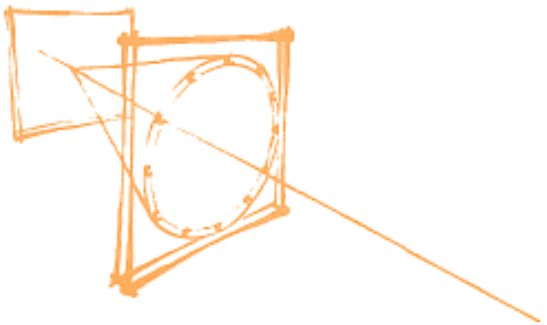

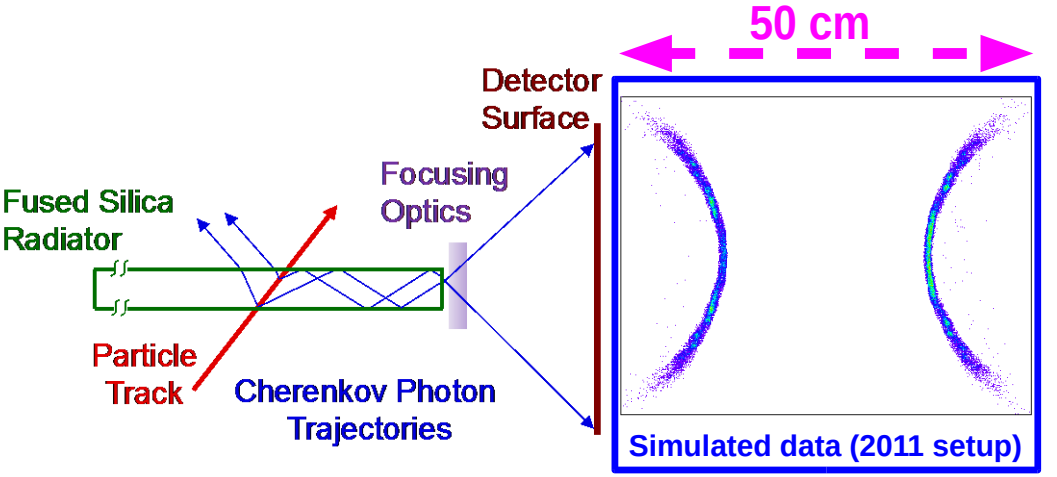

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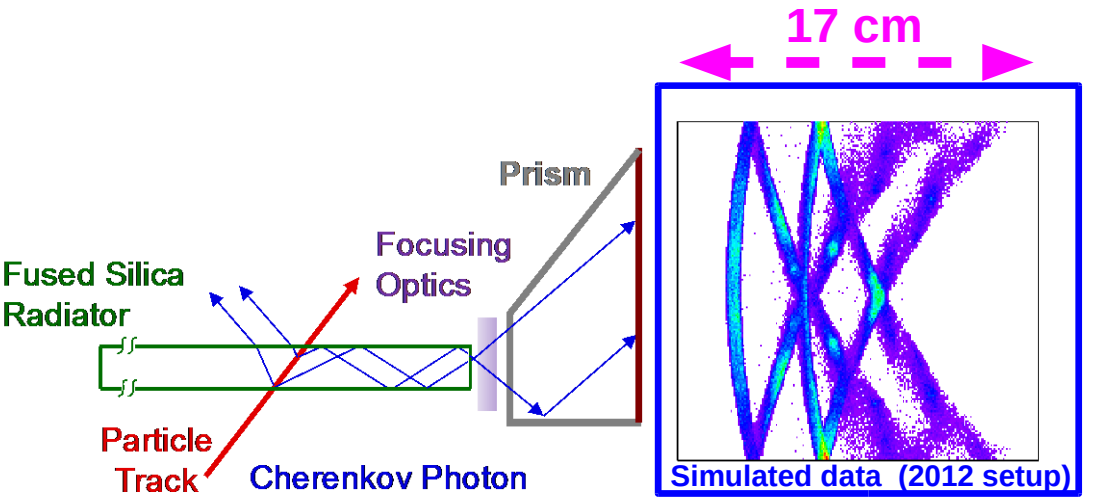
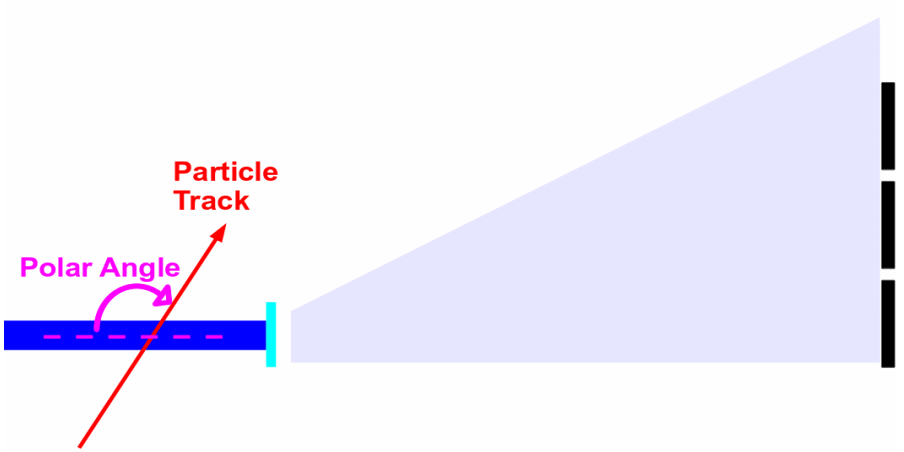
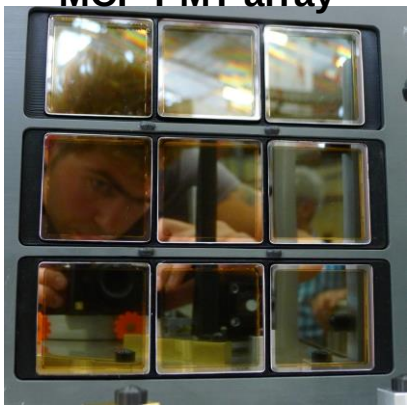
- Ring image gets folded due to propagation in bar/plate.
- Additional folding in the prism expansion volume.



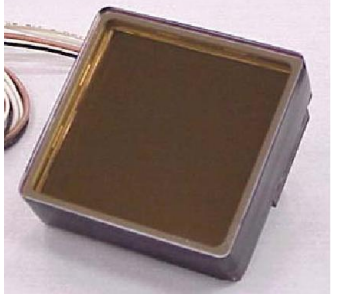
Test Beam 2012 Occupancy plots



MCP-PMT array

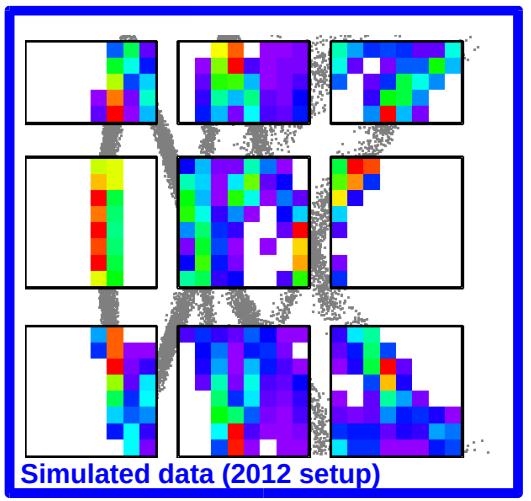


Photonis Planacon
XP85012 (8 x 8 pixels)

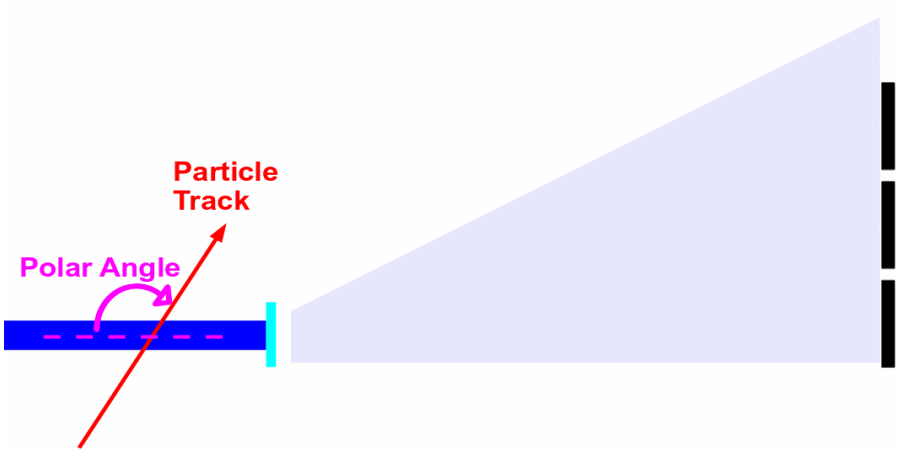


122° polar angle

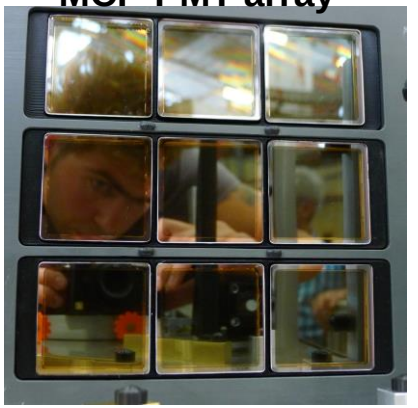
- **Pixelized simulated data** for different polar angle of the particle track.
- Grey dots in the background are true hit positions from the simulation.



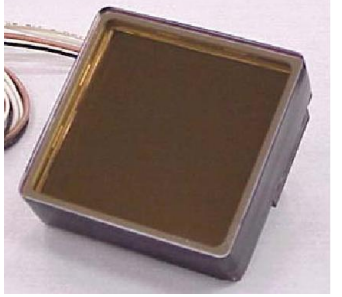
Test Beam 2012 Occupancy plots



MCP-PMT array

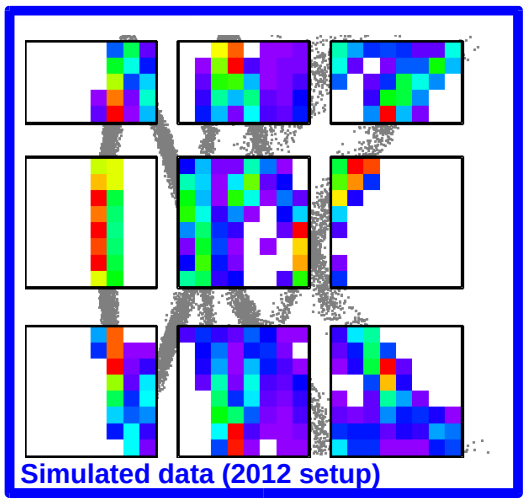


Photonis Planacon
XP85012 (8 x 8 pixels)

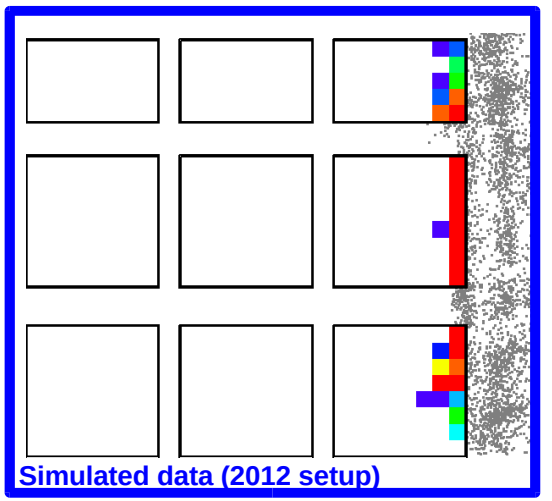


- **Pixelized simulated data** for different polar angle of the particle track.
- Grey dots in the background are true hit positions from the simulation.

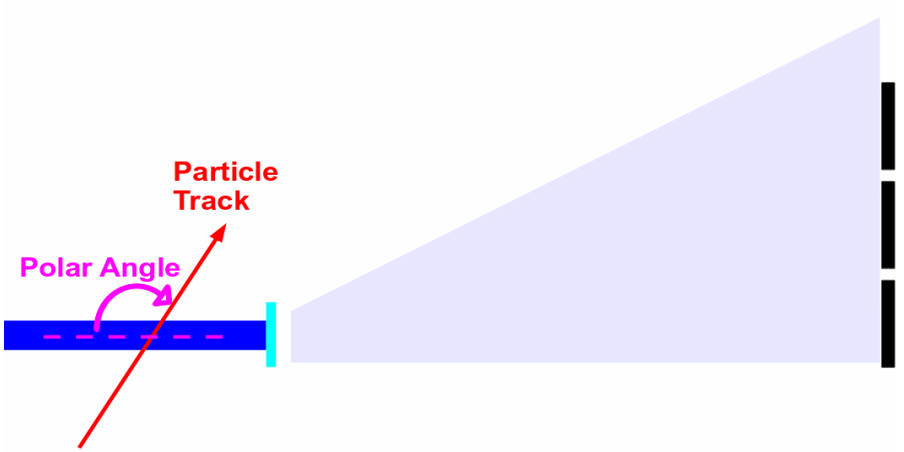
122° polar angle



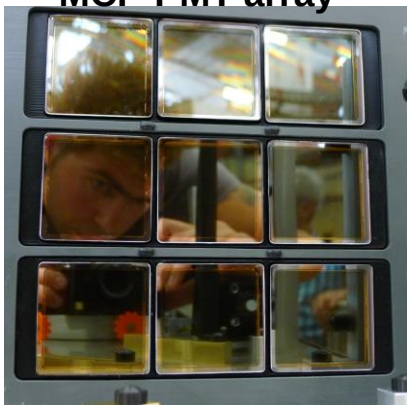
100° -160° polar angle



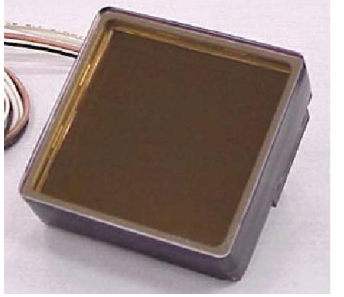
Test Beam 2012 Occupancy plots



MCP-PMT array

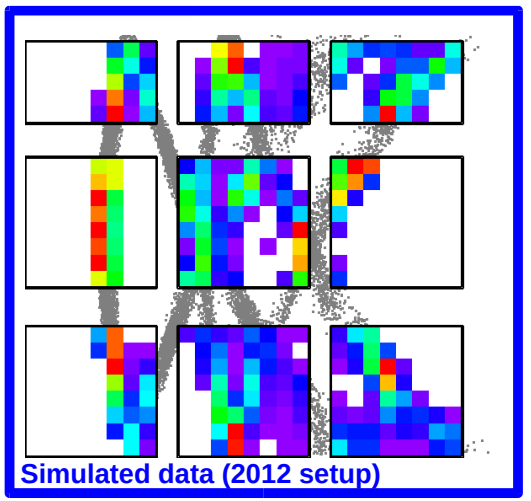


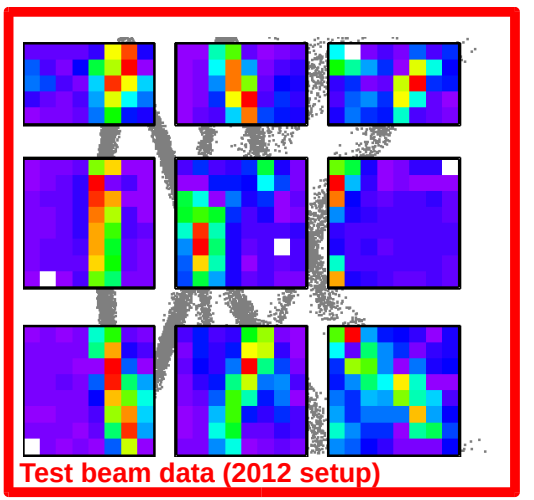
Photonis Planacon
XP85012 (8 x 8 pixels)



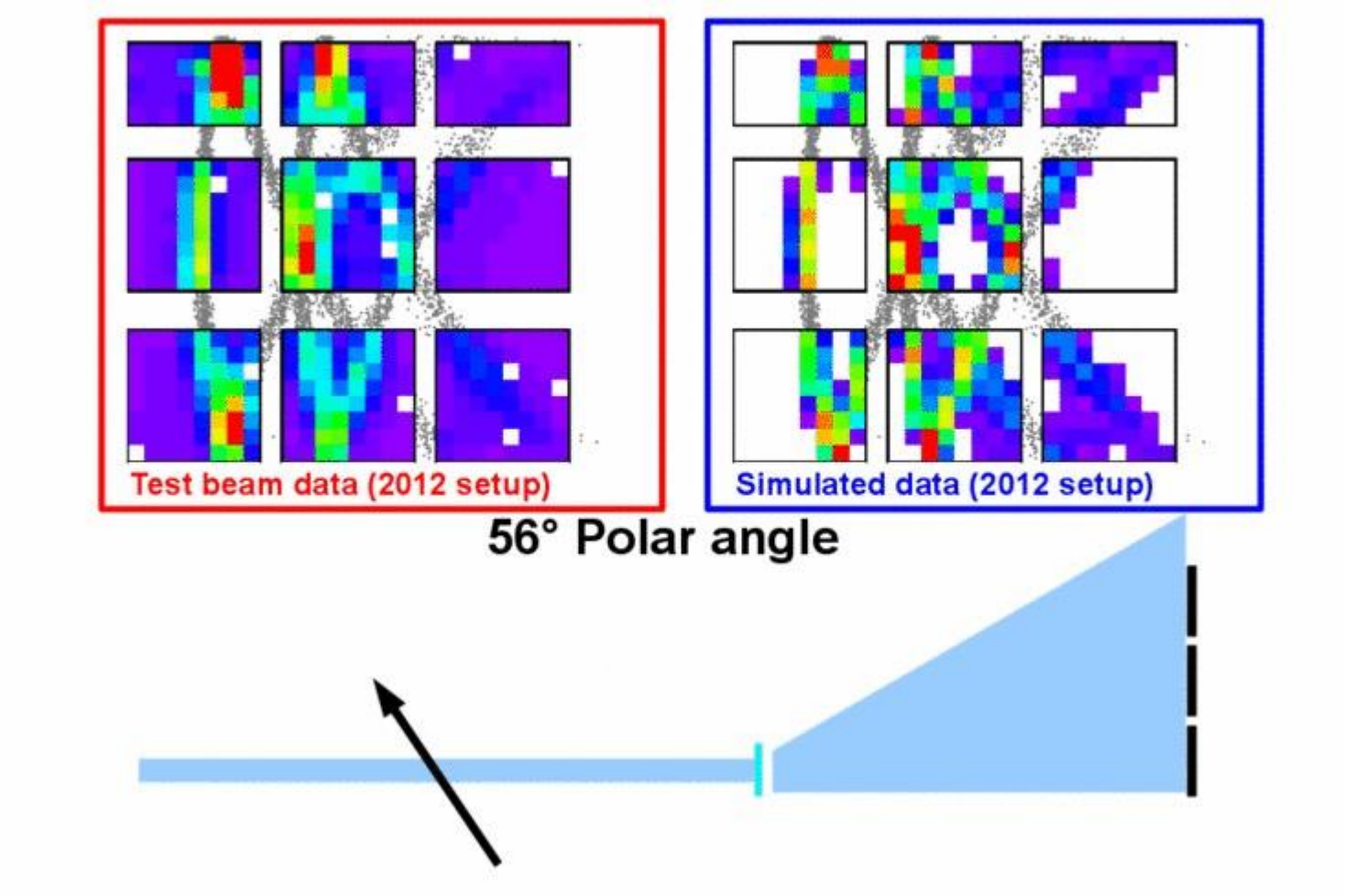
122° polar angle

- Comparison of the **pixelized simulated data** to **test beam data.**
- Grey dots in the background are true hit positions from the simulation.

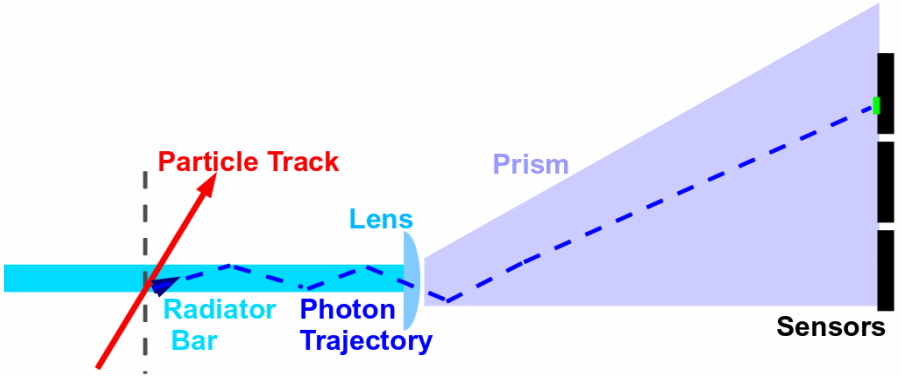




Test Beam 2012 Occupancy plots



Data Analysis Cherenkov angle reconstruction method

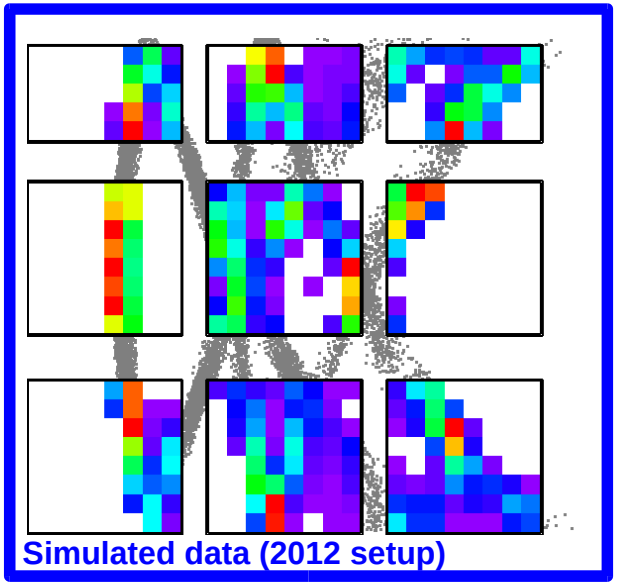


Method similar to BaBar-DIRC:

Pixel position + bar location define photon direction at bar end, stored in Look-up table, combined with particle track to calculate Θ_C.

- **Path pixel – bar not unique**
  combinatorial background in Θ_C requires carful treatment.

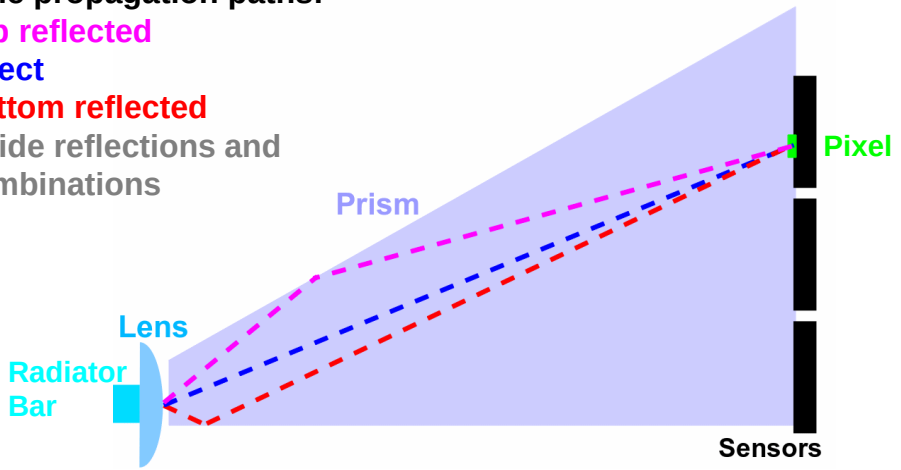
- **Time cut**
  ($t_{measured} - t_{expected}$) improves resolution in simulation.
  Timing resolution in test beam data not sufficiently good.

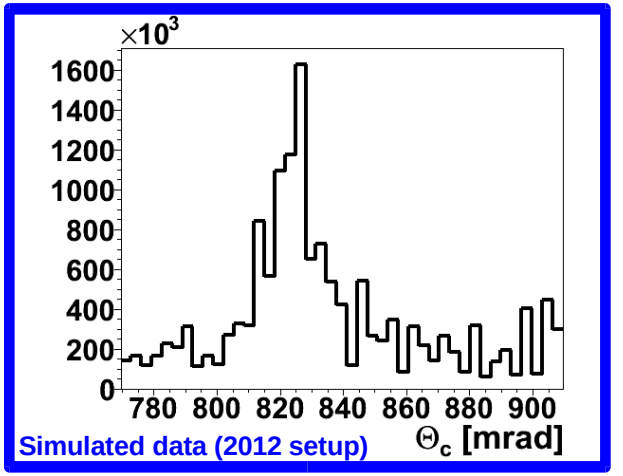


Data Analysis Cherenkov angle reconstruction method

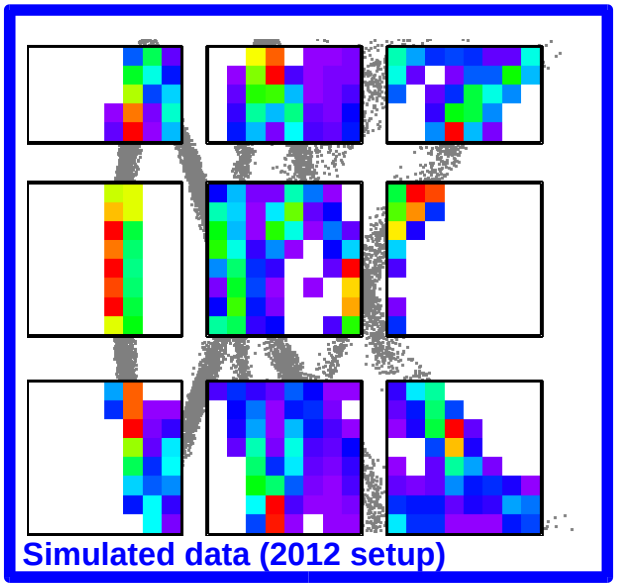
Possible propagation paths:

- Top reflected
- Direct
- Bottom reflected
- + side reflections and combinations





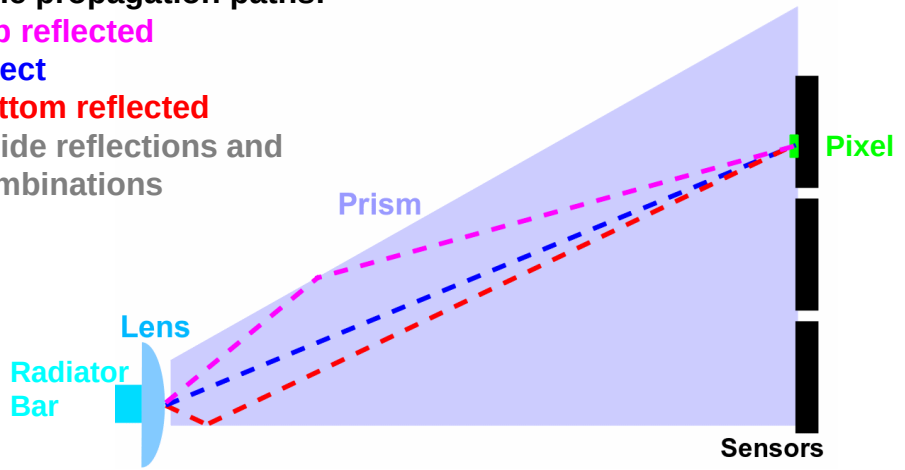
- **Path pixel – bar not unique**
  combinatorial background in Θ_C requires carful treatment.
- **Time cut**
  $(t_{measured} - t_{expected})$ improves resolution in simulation.
  Timing resolution in test beam data not sufficiently good.



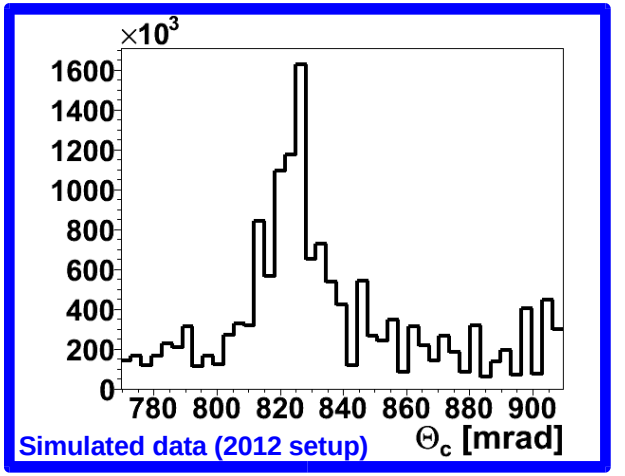
Data Analysis Single photon Cherenkov angle reconstruction

Possible propagation paths:

- Top reflected
- Direct
- Bottom reflected
- + side reflections and combinations

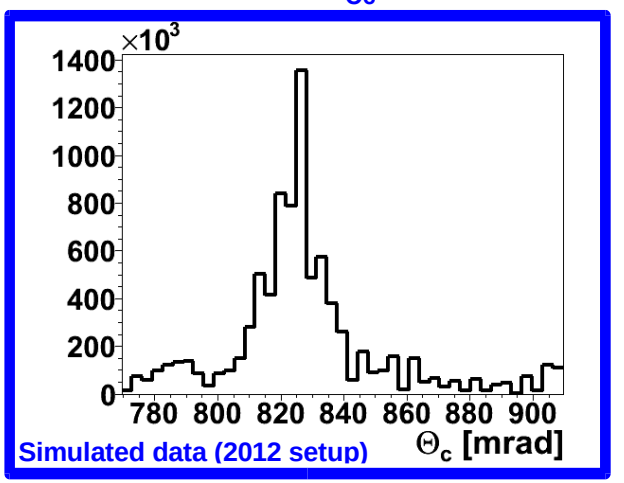


Θ_C = 823.2 mrad
$\sigma_{\Theta c}$ = 9.5 mrad

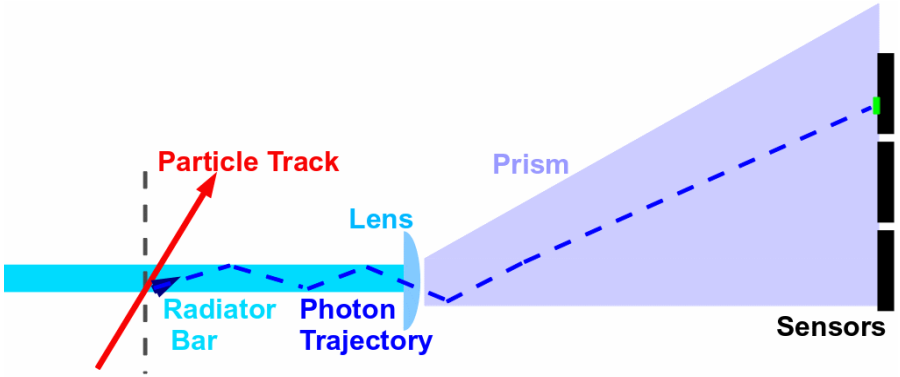


- **Path pixel – bar not unique**
  combinatorial background in Θ_C requires carful treatment.
- **Time cut**
  ($t_{measured} - t_{expected}$) improves resolution in simulation.
  Timing resolution in test beam data not sufficiently good.

Time cut ↓ Θ_C = 823.5 mrad
$\sigma_{\Theta c}$ = 8.8 mrad

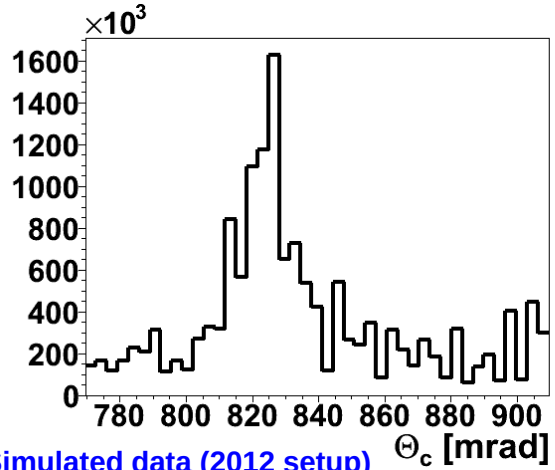


Data Analysis Combinatorial background in Θ_C



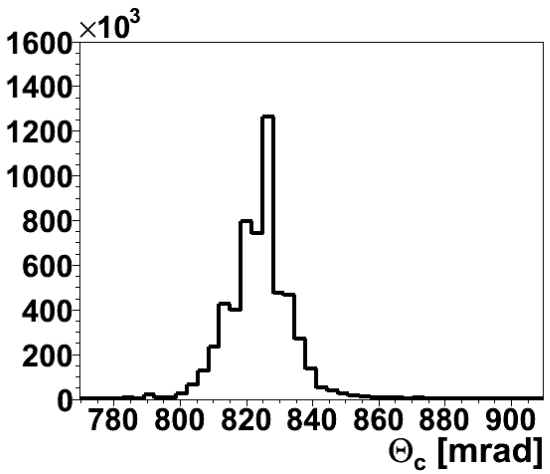
- **Possible photon paths:**
  - → Bar ambiguities
  - → Prism ambiguities
- **Tuned Monte Carlo simulation match test beam data**

Cherenkov angle (bar & prism ambiguities)

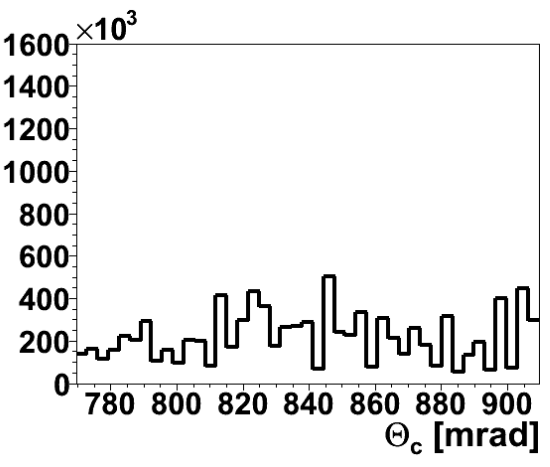


Simulated data (2012 setup)

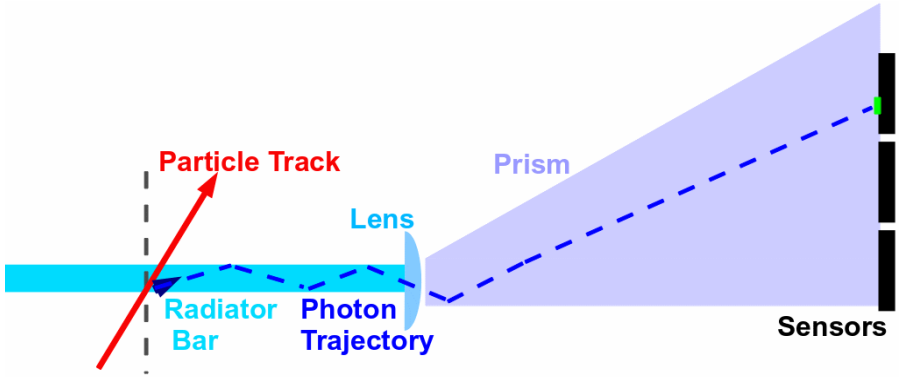
Cherenkov angle (bar ambiguities)



Prism ambiguities background

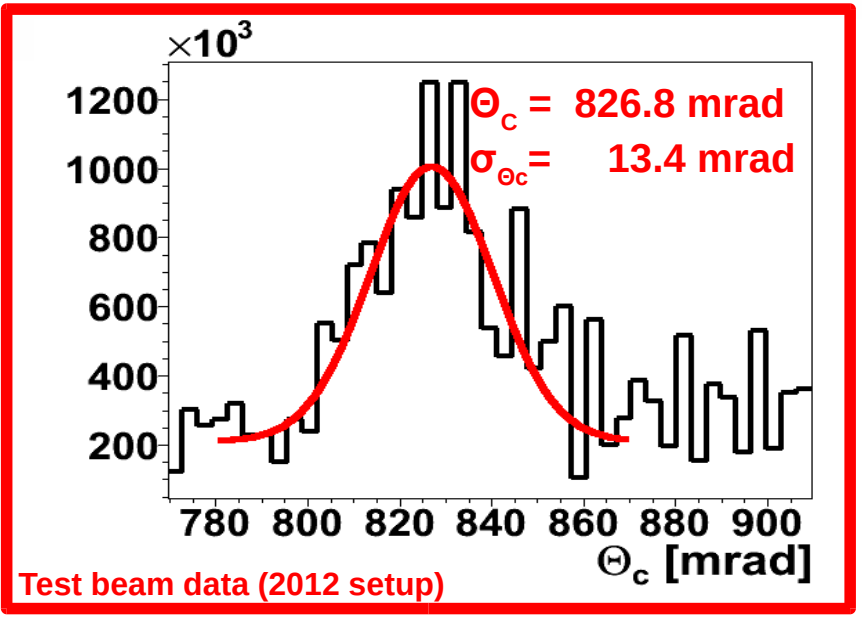


Data Analysis Combinatorial background in Θ_C

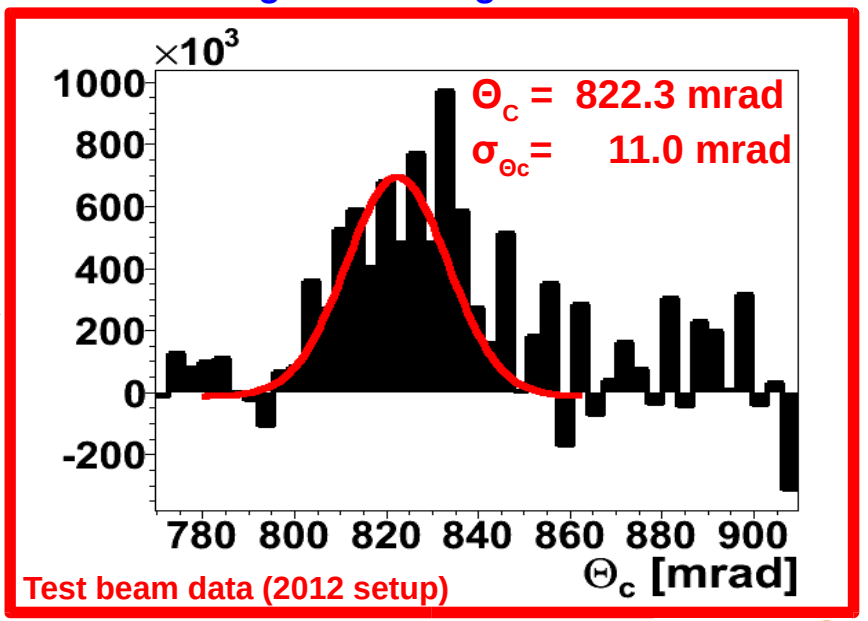


- **Subtraction of the background in test beam data:** Tuned Monte Carlo simulation match test beam data.
- **Expected:** Θ_C = 823.6 mrad
  $\sigma_{\Theta c} \approx$ 8.5 mrad

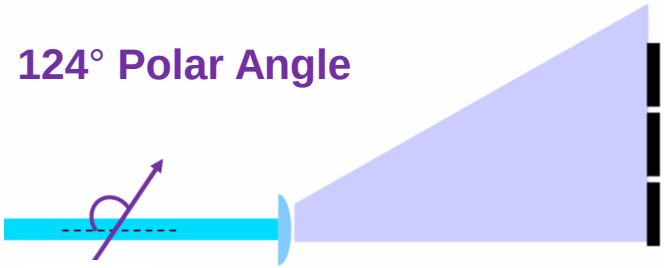
Reconstructed test beam data



Reconstructed test beam data with simulated Prism ambiguities background subtracted.



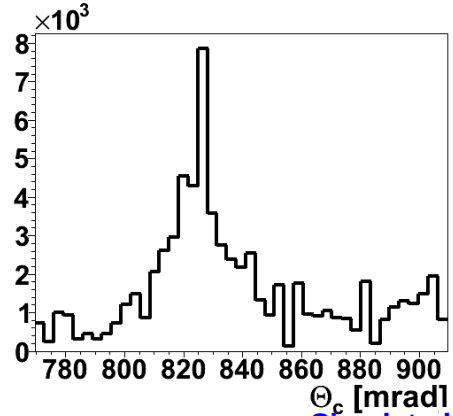
Data Analysis Single photon Cherenkov angle reconstruction



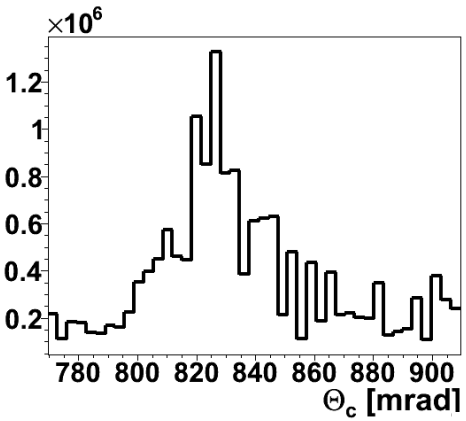
- Θ_C value varies for different polar angle of the track

(see H.Kumawat talk at 11:30).

124°

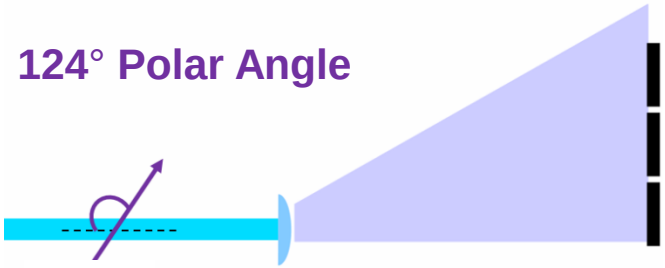


Simulated data (2012 Setup)

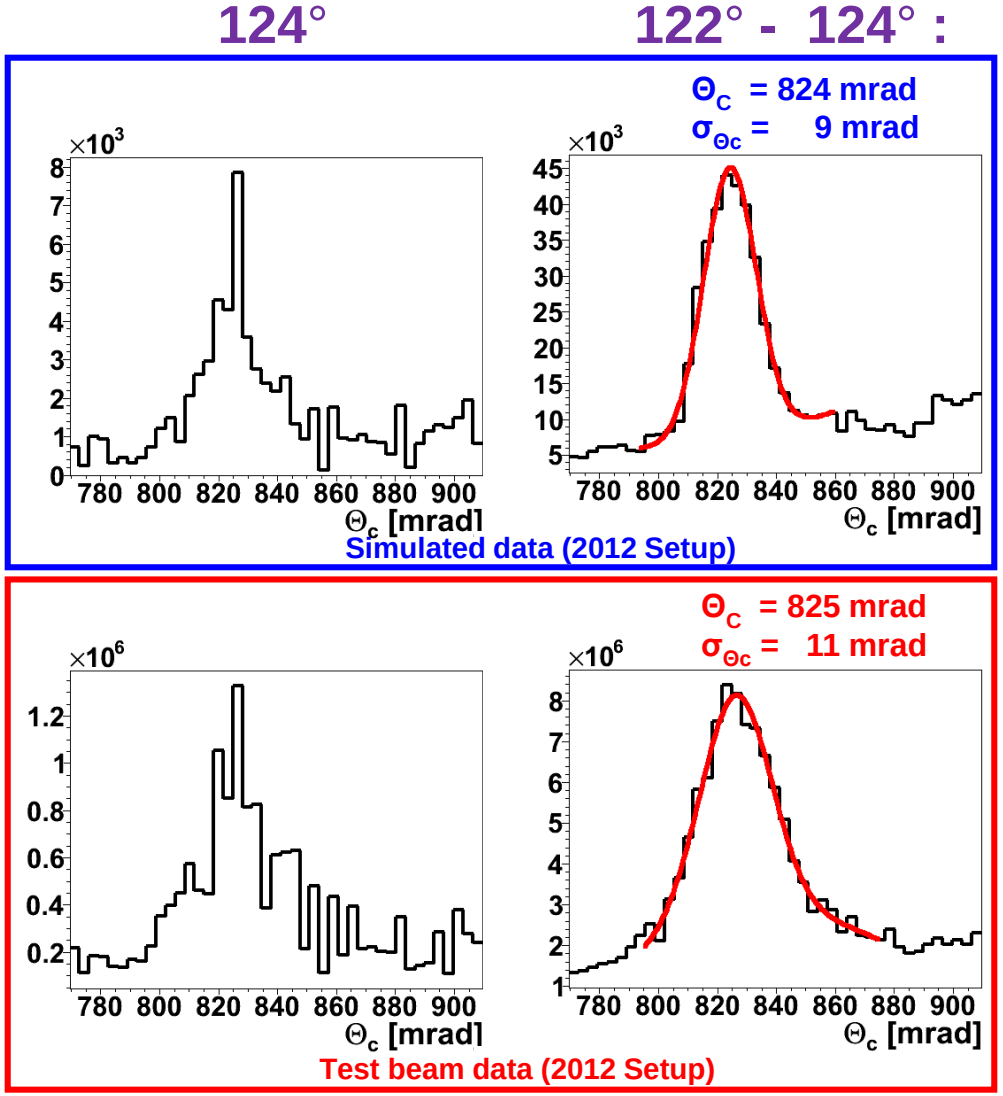


Test beam data (2012 Setup)

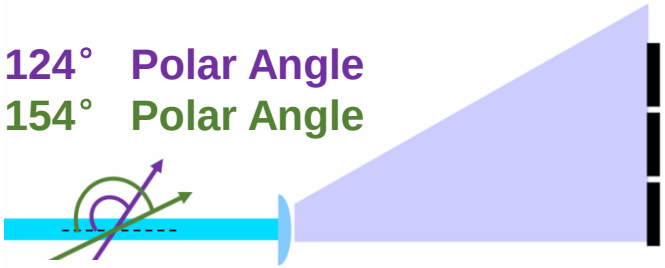
Data Analysis Single photon Cherenkov angle reconstruction



- **Θ_C value varies for different polar angle of the track** *(see H.Kumawat talk at 11:30)*.
- **Fine angular scan study** 2° range with 0.25° steps to avoid pixelization effect.
- **Expected Θ_C = 824 mrad**
  $\sigma_{\Theta c} \approx$ 8 mrad
- Θ_C consistent with expectations.
- Differences in σ comes from beam divergence.



Data Analysis Single photon Cherenkov angle reconstruction



- **Θ_C value varies for different polar angle of the track** *(see H.Kumawat talk at 11:30)*.

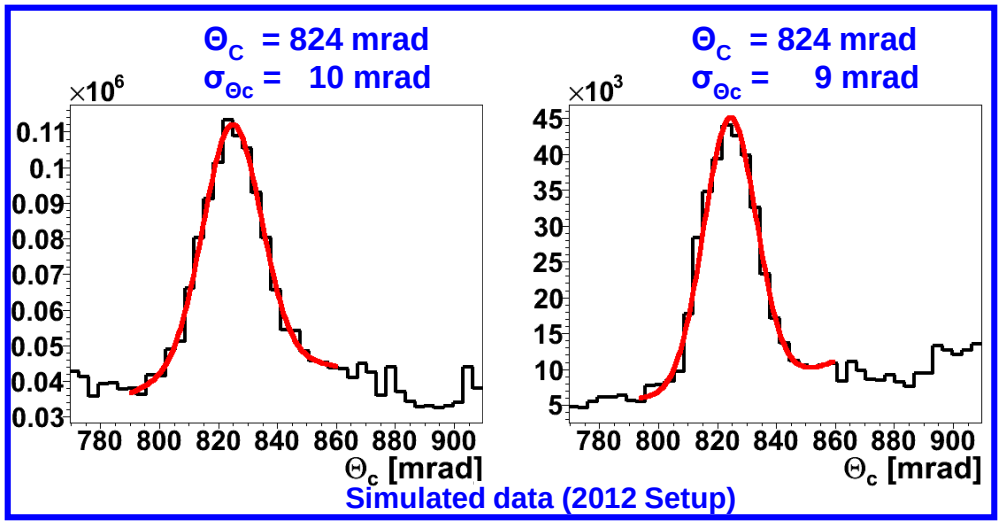
- **Fine angular scan study** 2° range with 0.25° steps to avoid pixelization effect.

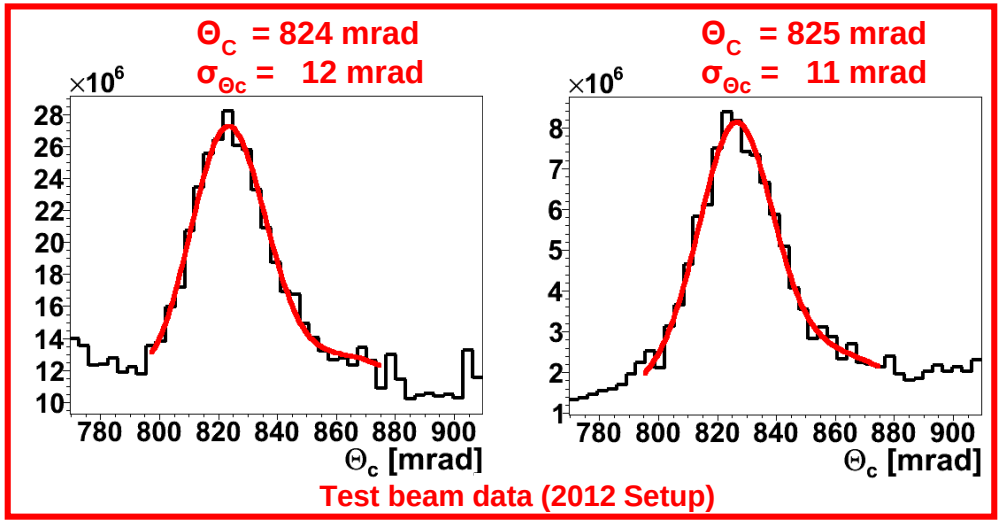
- **Expected Θ_C = 824 mrad**
  $\sigma_{\Theta c} \approx$ 8 mrad

- Θ_C for **different polar angle ranges** consistent with expectations.

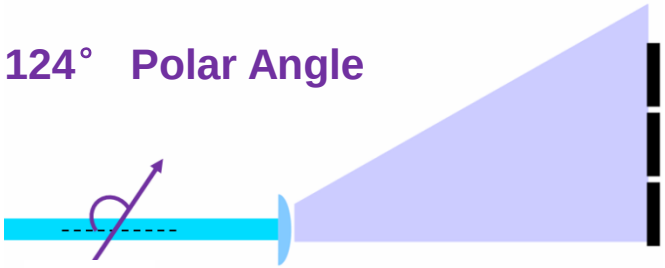
- Differences in σ comes from beam divergence.

154° - 156° : **122° - 124° :**



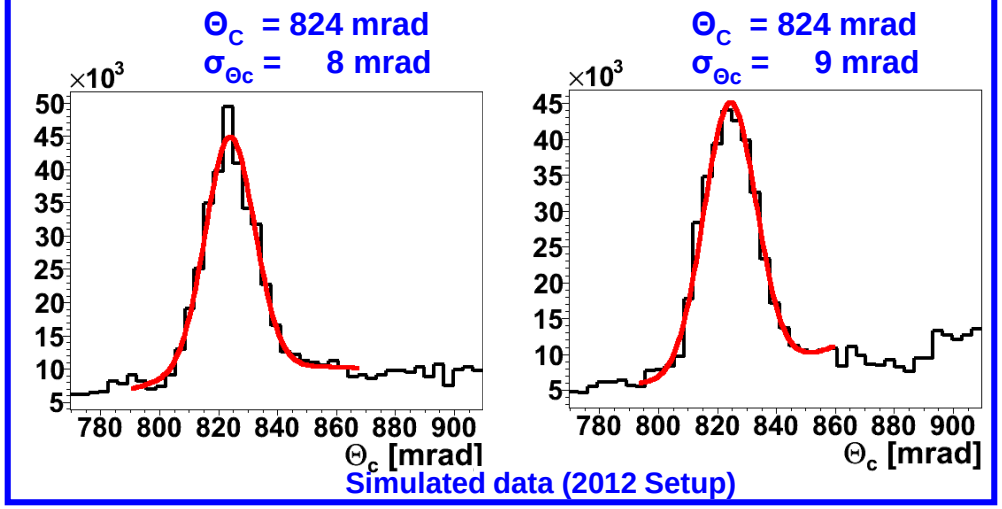


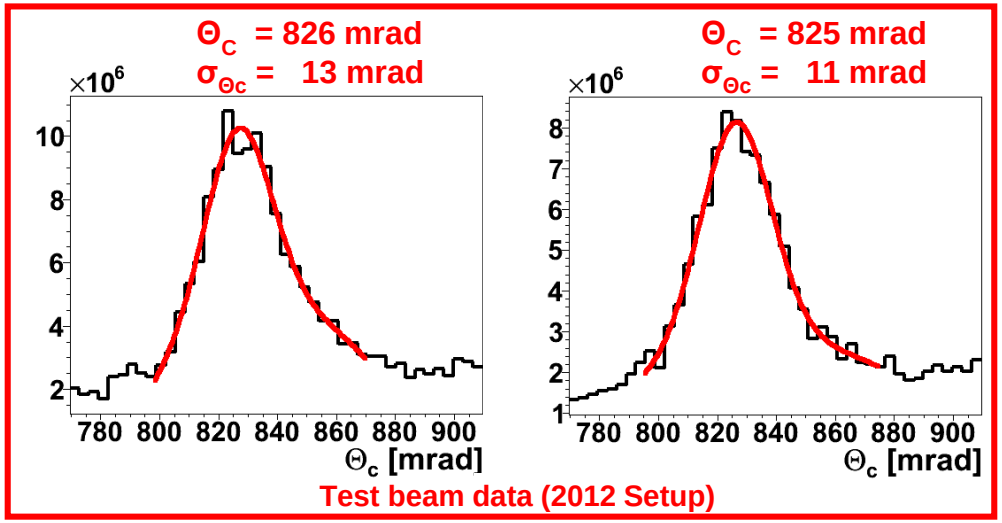
Data Analysis Single photon Cherenkov angle reconstruction



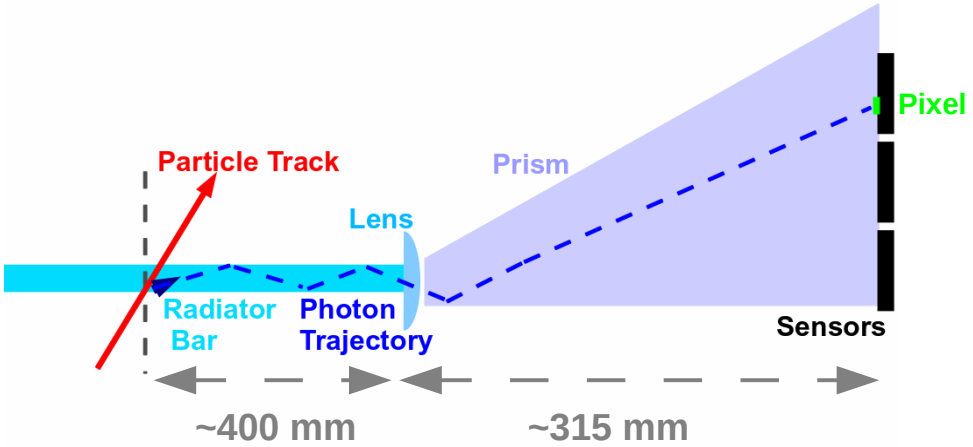
- **Θ_C value varies for different polar angle of the track** *(see H.Kumawat talk at 11:30)*.
- **Fine angular scan study** 2° range with 0.25° steps to avoid pixelization effect.
- **Expected Θ_C = 824 mrad**
  $\sigma_{\Theta c} \approx$ 8 mrad
- Θ_C for **different prototype bars** consistent with expectations.
- Differences in σ comes from beam divergence.

Zeiss bar: **InSync bar:**

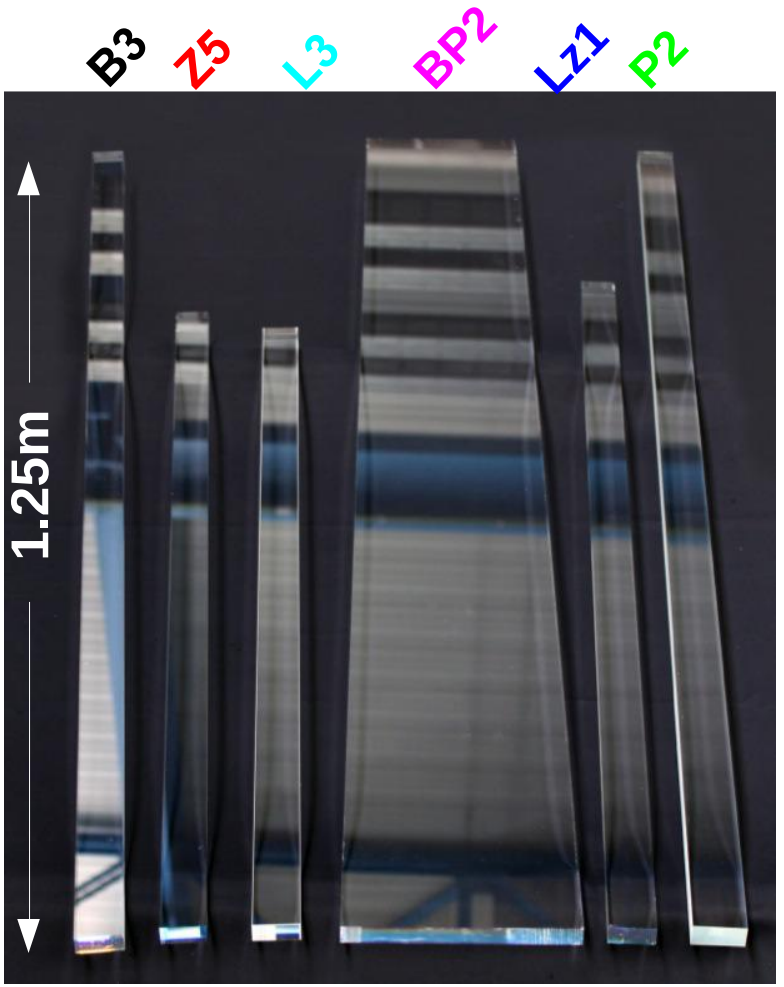




Data Analysis Different radiator bars

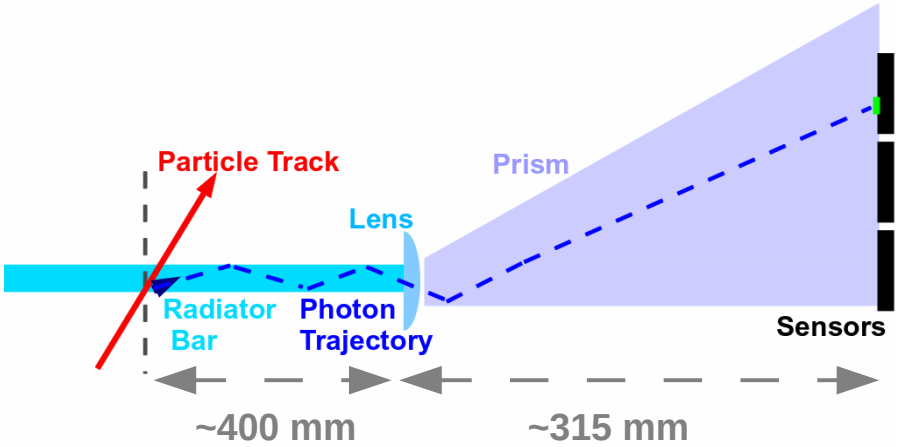


- B3 – InSync Inc
- Z5 – Zeiss
- L3 – Shott Lithotec
- BP2 – InSync Inc
- Lz1 – Lytkarino
- P2 – Röhm (Acrylic glass)



Radiators used in 2012 test beam

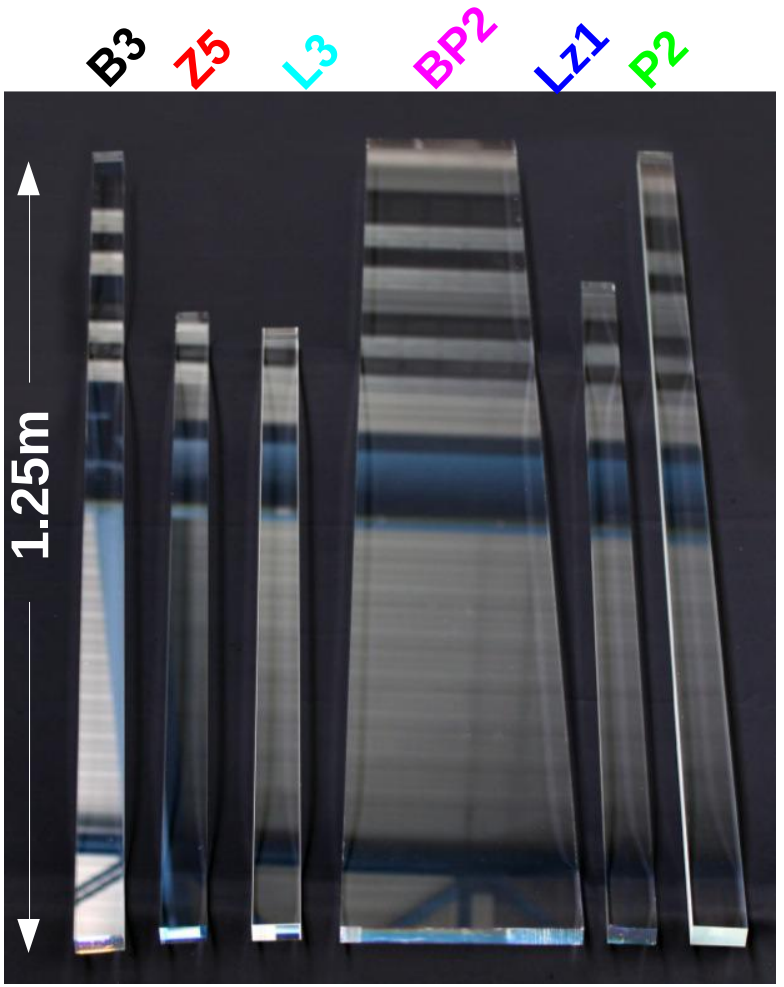
Data Analysis Number of hits per track



Number of hits per track:

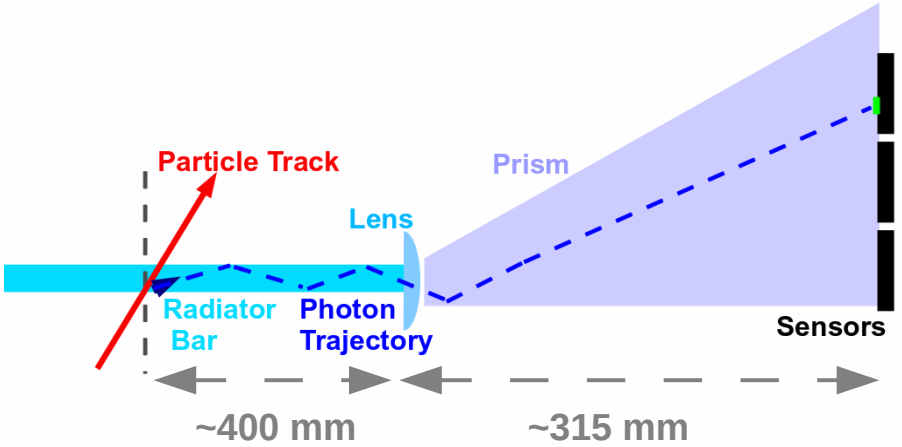
Bar	Monte Carlo
B3	18.7
Z5	19.3
L3	18.9
Lz1	18.0
P2	21.9

(Simulation assumes fused silica)



Radiators used in 2012 test beam

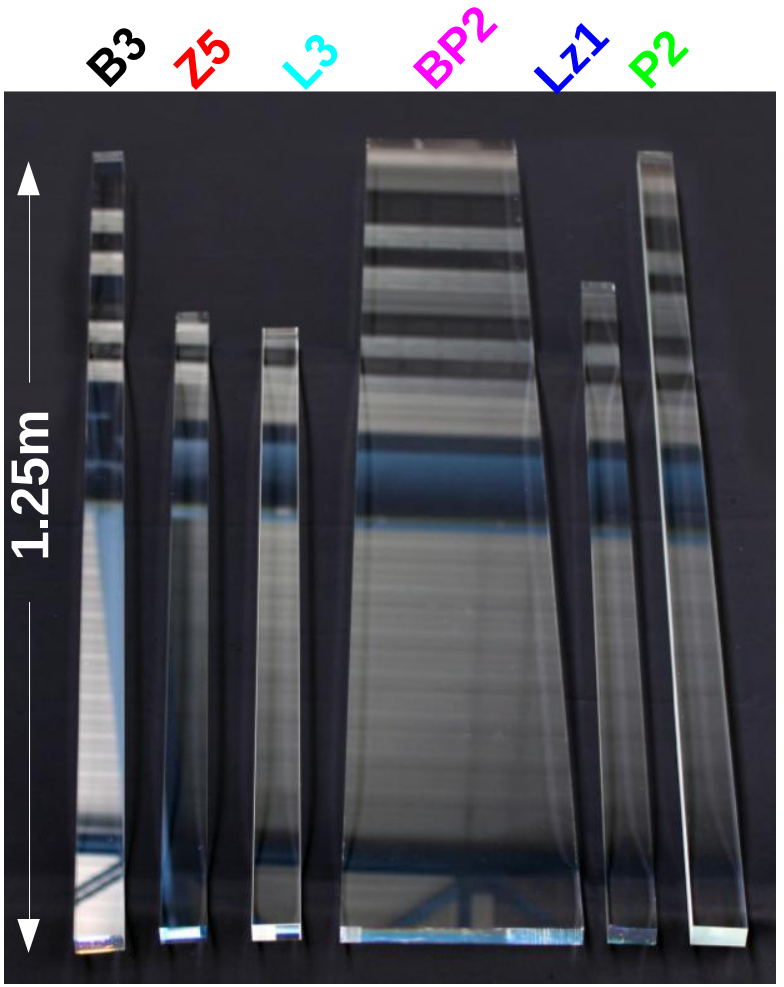
Data Analysis Number of hits per track



Number of hits per track:

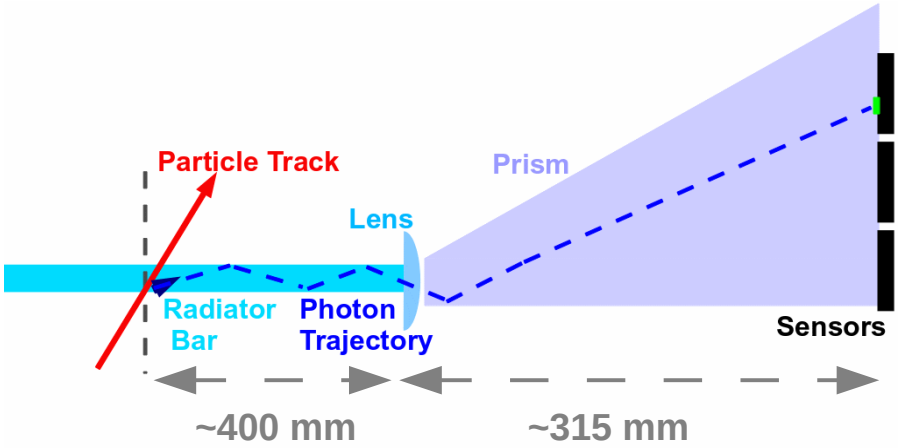
Bar	Monte Carlo	Test beam
B3	18.7	23.7
Z5	19.3	21.0
L3	18.9	20.7
Lz1	18.0	20.2
P2	21.9	6.9

(Simulation assumes fused silica)
(Test beam data includes cross talk effects)



Radiators used in 2012 test beam

Data Analysis Number of hits per track



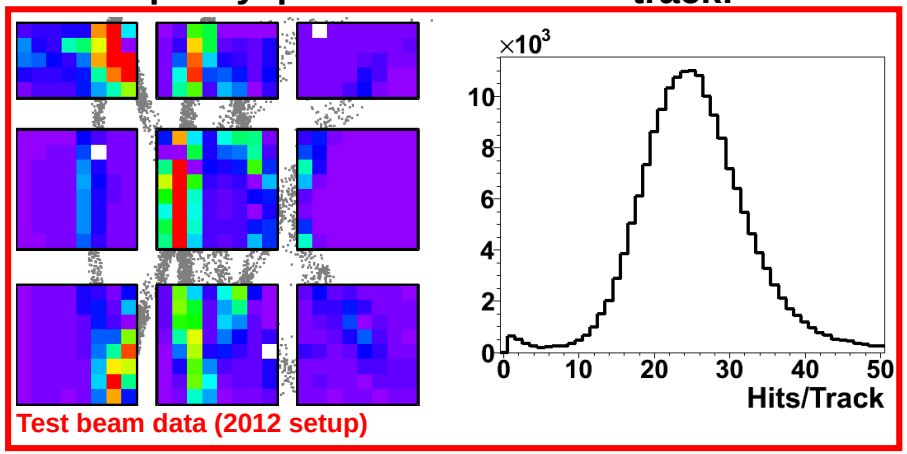
Number of hits per track:

Bar	Monte Carlo	Test beam
B3	18.7	23.7
Z5	19.3	21.0
L3	18.9	20.7
Lz1	18.0	20.2
P2	21.9	6.9

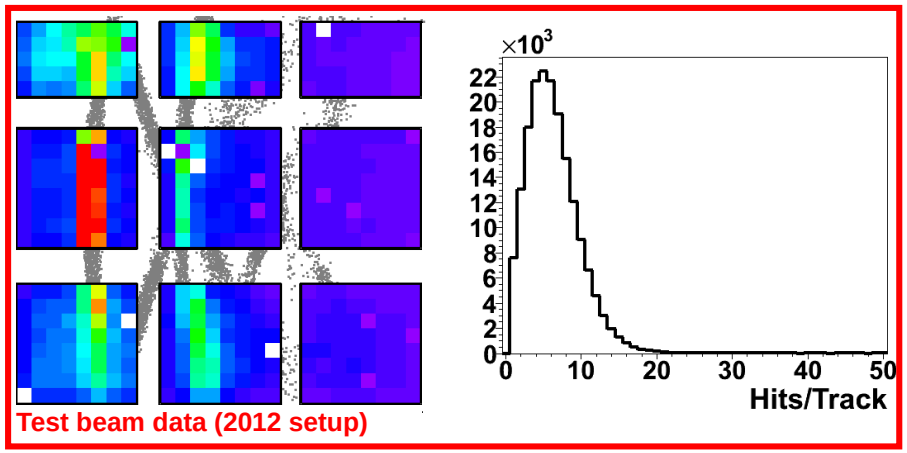
(Simulation assumes fused silica)
(Test beam data includes cross talk effects)

Occupancy plots:

Number of hits per track:



B3 (Quartz)

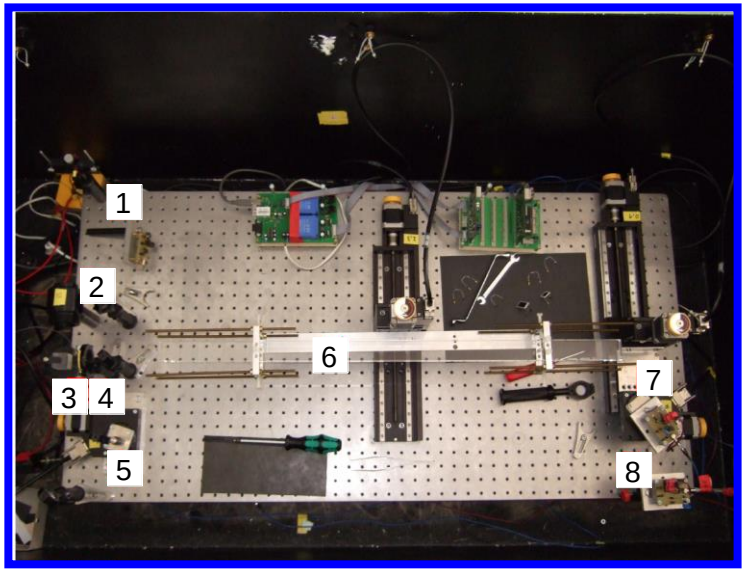


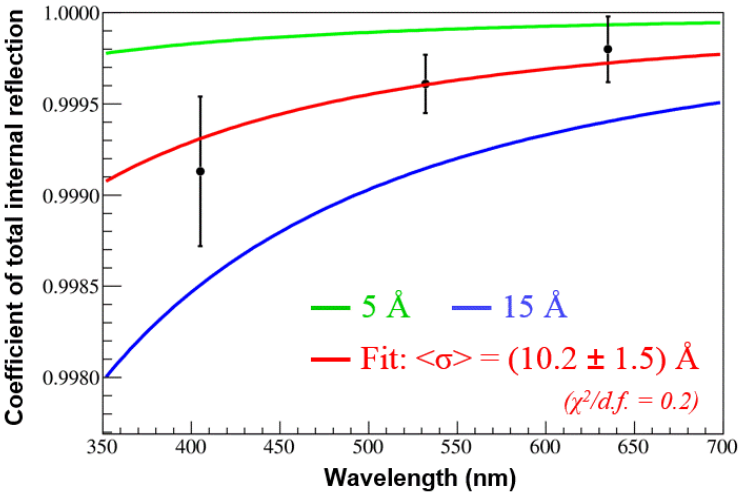
P2 (Acrylic glass)

Prototype Components Radiator tests

Photon transport

- Setup to measure bulk transmission and coefficient of total internal reflection using 3 lasers.
- Sensitive to **surface roughness and subsurface damage**, indirect measurement of rms roughness with **1-2Å precision**.
- **Previous version of setup** (only short bars).

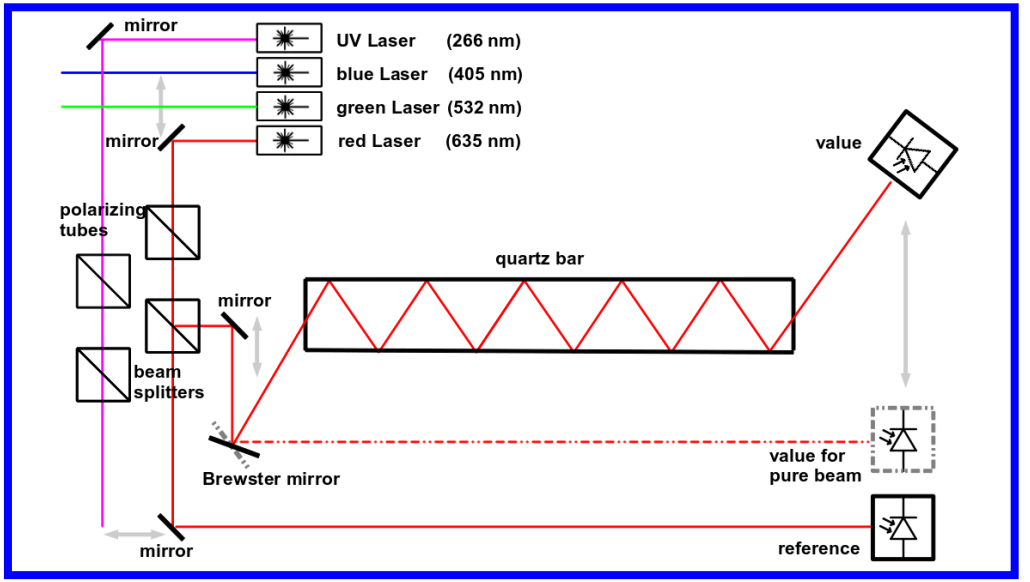


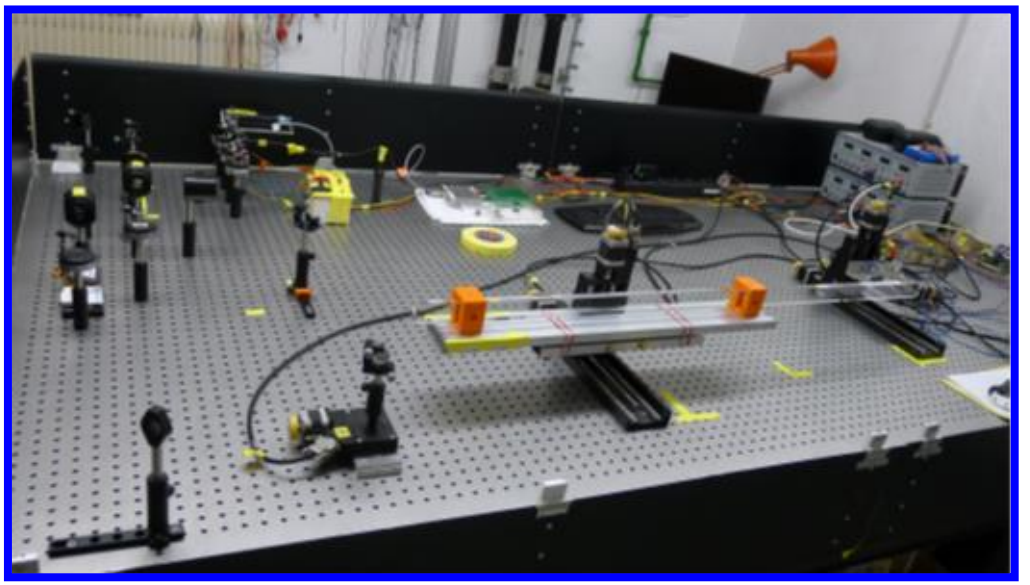


Prototype Components Radiator tests

Photon transport

- Setup to measure bulk transmission and coefficient of total internal reflection using 4 lasers.
- Sensitive to **surface roughness and subsurface damage**, indirect measurement of rms roughness with **1-2Å precision**.
- Previous version of setup (only short bars).
- **Current version of setup:**
  - Improved stability.
  - Capable of measuring longer bars.
  - Expand wavelength range using a UV-laser.





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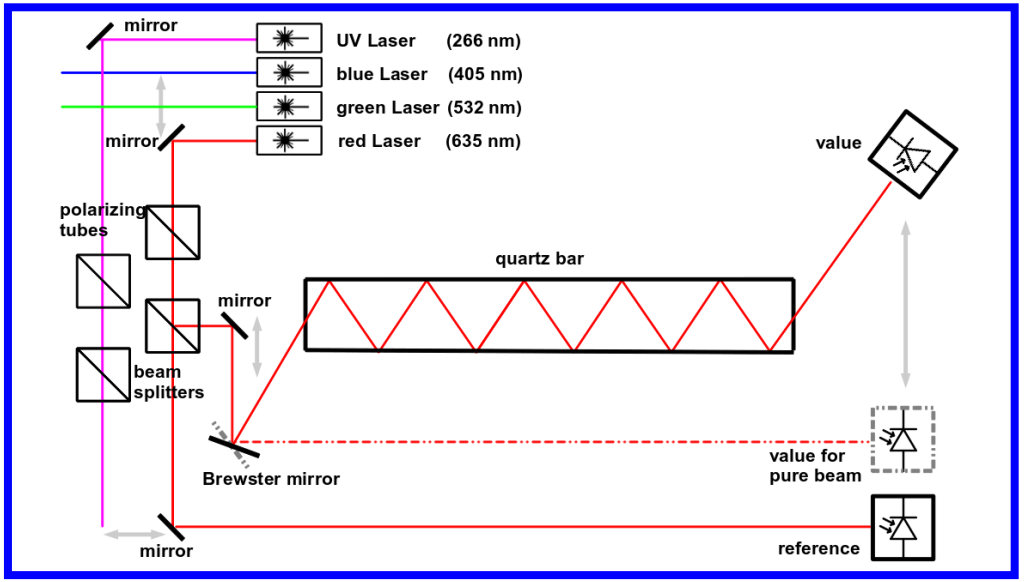
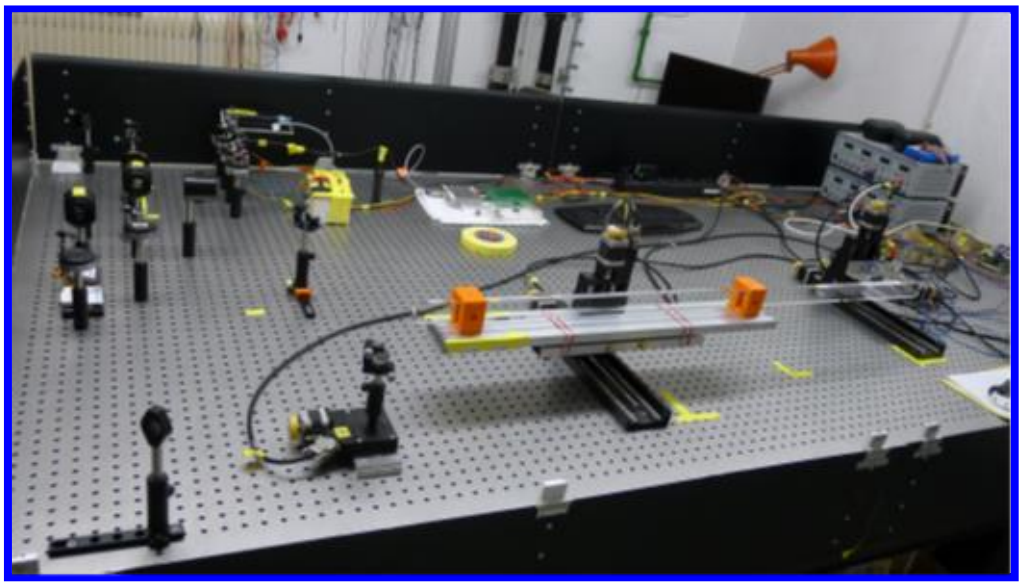
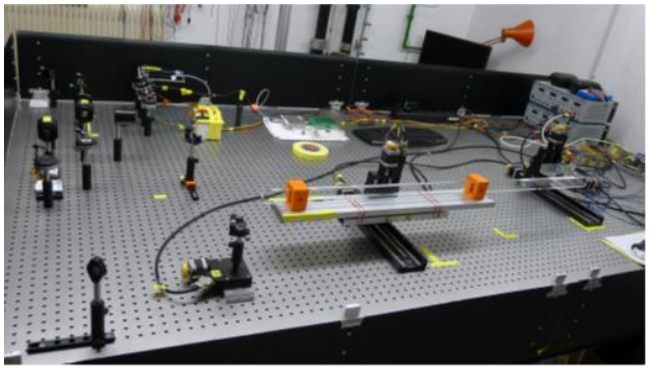


Shape of the bar

- Setup to measure **bar angles** (parallelism and squareness) with **<0.1 mrad precision** (lasers, autocollimator).



Summary and Outlook



- **Prototype components tests in progress**
  Radiators, photon sensors, and readout boards.
- **Progression of increasingly complex system prototypes -** validating technology and design choices using particle beams.
- **Prototype 2012 in CERN test beam**

→ Advanced data analysis.
→ Crucial numbers for different bar prototypes and wide range of beam-bar angles determined.
→ Still a lot of studies to process.
→ Study to find alternative reconstruction method for Prism and Plate geometries in progress.

- **2014 May/August – beam time in GSI.**

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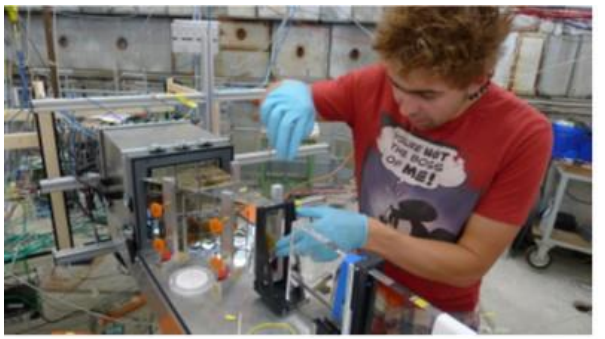

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BACKUP

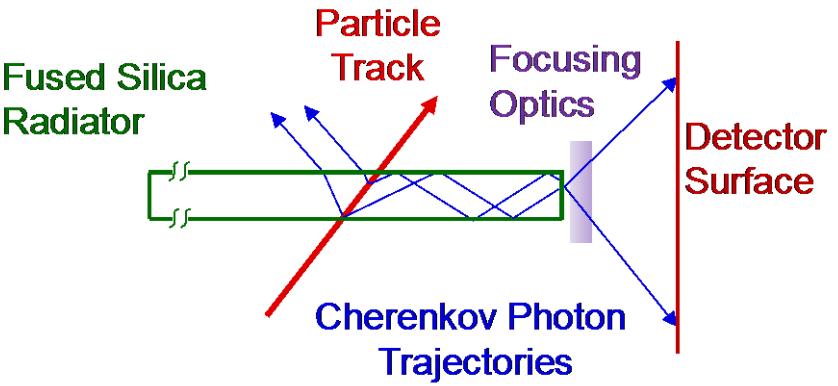
DIRC Detection of Internally Reflected Cherenkov Light

- Charged particle traversing radiator (with refractive index n) with velocity $\beta = \frac{v}{c}$ emits Cherenkov photons on cone with half opening angle: $cos\theta = \frac{1}{\beta n}$

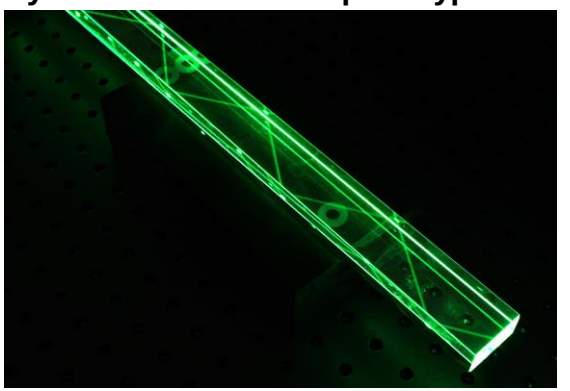
- Cherenkov angle conserved during internal reflections of propagating photons.

- Photons exit radiator bars through focusing elements into expansion volume and are imaged on photon detector array.

- Photon detector array measures **x, y and time** of photons that exit radiator and defines **θ_c, φ_c and time of propagation of individual Cherenkov photons.**

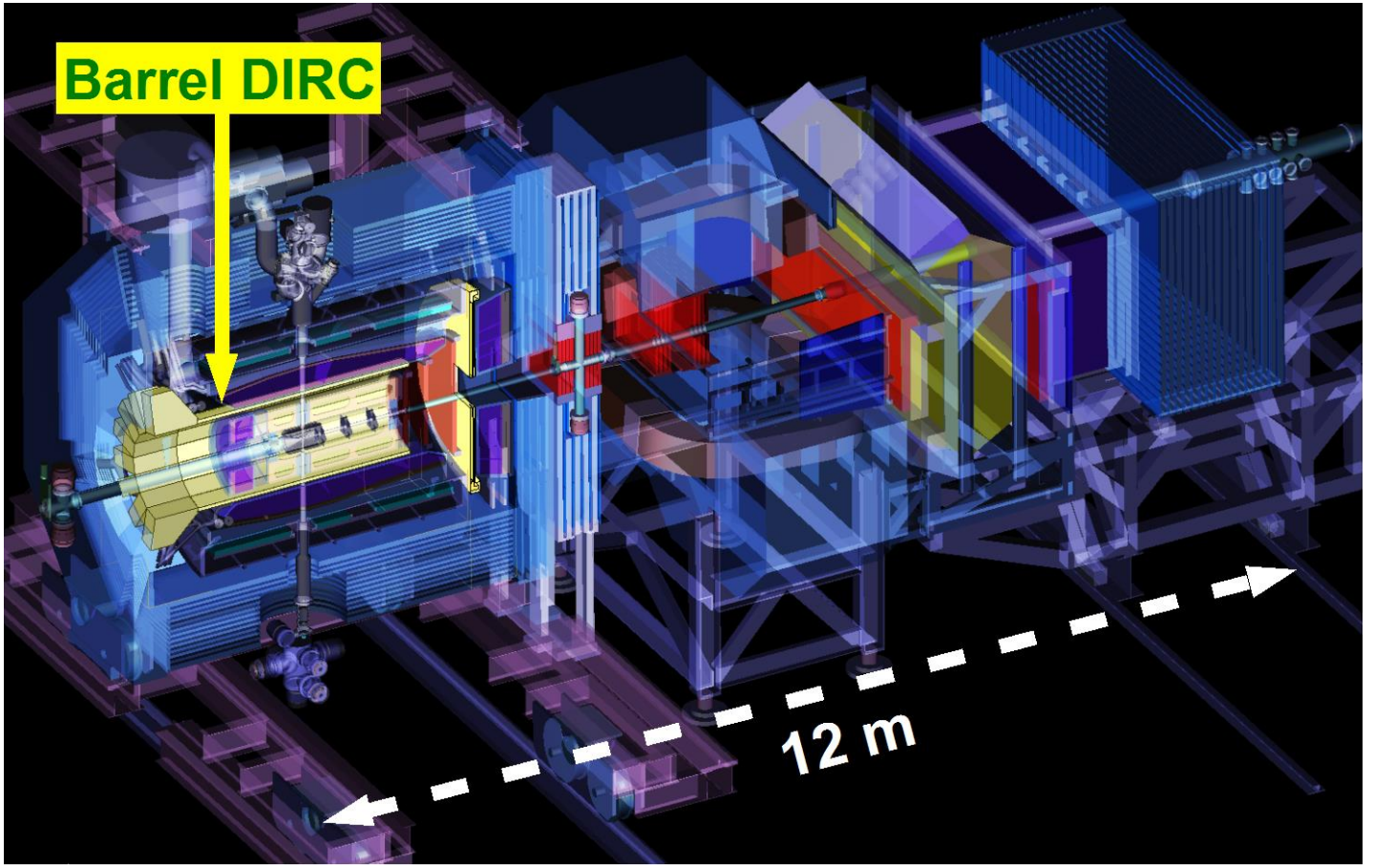


Synthetic fused silica prototype bar



PANDA antiProton ANihilations at DArmstadt

PANDA: Rich program of QCD studies using anti-proton beam with unique intensity and precision.



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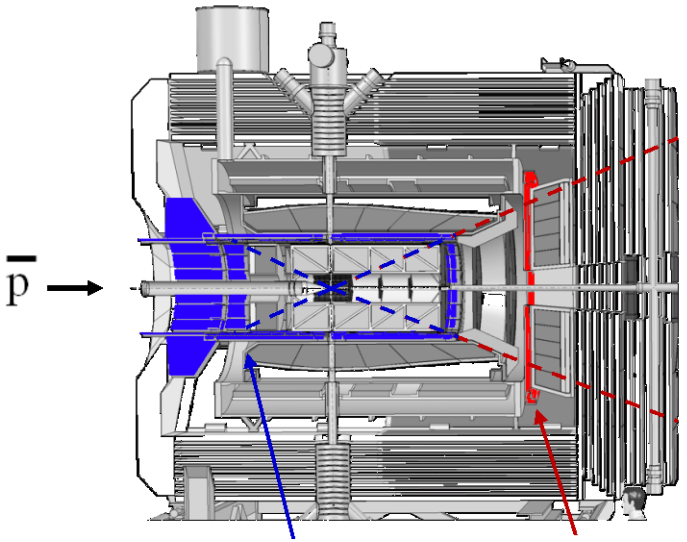

Target Spectrometer
PANDA Detector
HESR/FAIR

- **Requirements**:

→ Good Particle Identification (PID).
→ Excellent energy and angular resolution.
→ Nearly full solid angle coverage.
→ High rate capability (~20 MHz).
→ Efficient event selection.

- **Particle Identification coverage of the two DIRC detectors:**

→ **Barrel DIRC:**
3σ π/K separation for momentum range 0.5 – 3.5 GeV/c.

→ Endcap Disc DIRC:
3σ π/K separation for momentum up to 4 GeV/c.

Prototype Components Radiators

- Retrain/qualify vendors more then 10 years after BaBar production.
- Difficult to produce large fused silica bars and plates polished to 10-20 Å rms with non-squareness < 0.5 mrad.
- Tight requirements – fabrication expensive andpossible only for few vendors world wide (mechanical tolerances on flatness, squareness, and parallelism with optical finishand long sharp edges).

Working with potential vendors in Europe and USA, obtained/ordered prototype bars and plates from several companies, verifying surfaces and angles.