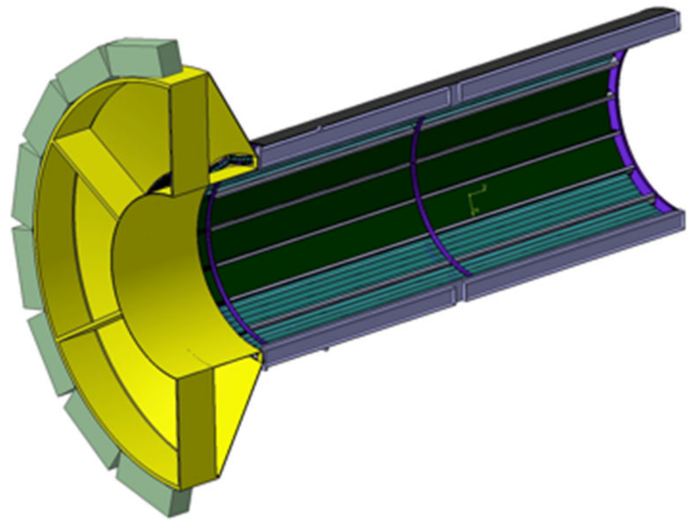
THE PANDA BARREL DIRC

Jochen Schwiening

GSI

for the PANDA Cherenkov Group



PANDA Cherenkov Group:

JINR Dubna, FAU Erlangen-Nürnberg, JLU Gießen, U. Glasgow, GSI Darmstadt, HIM Mainz, JGU Mainz, SMI OeAW Vienna.

DIRC2013, Schloss Rauischholzhausen, Sept. 5, 2013

PANDA BARREL DIRC OVERVIEW

PID REQUIREMENT, BASELINE DESIGN

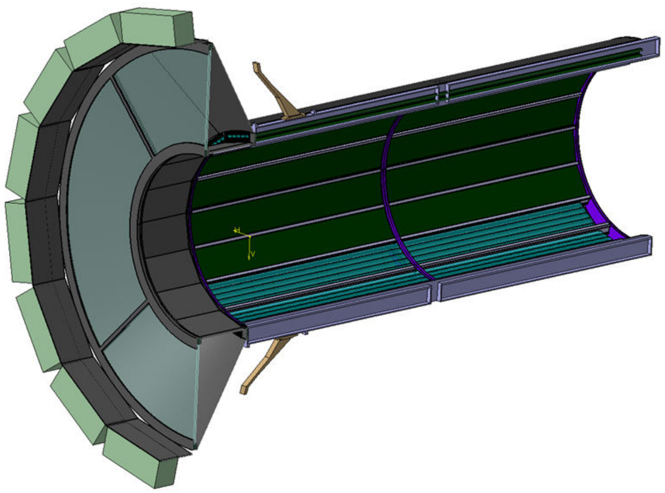
EVOLUTION OF THE DESIGN

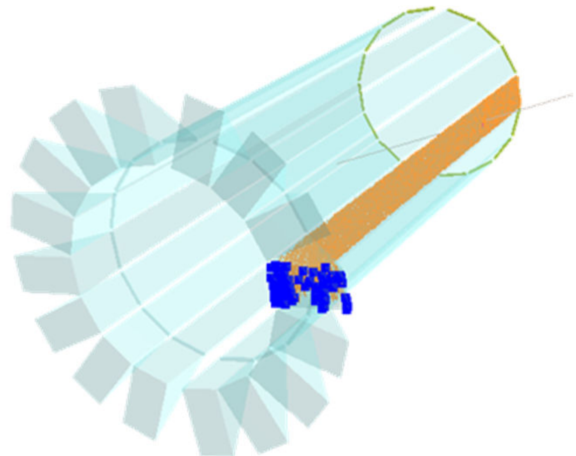
CURRENT CHALLENGES

RADIATORS, GEOMETRY, RECONSTRUCTION

THE ROAD AHEAD

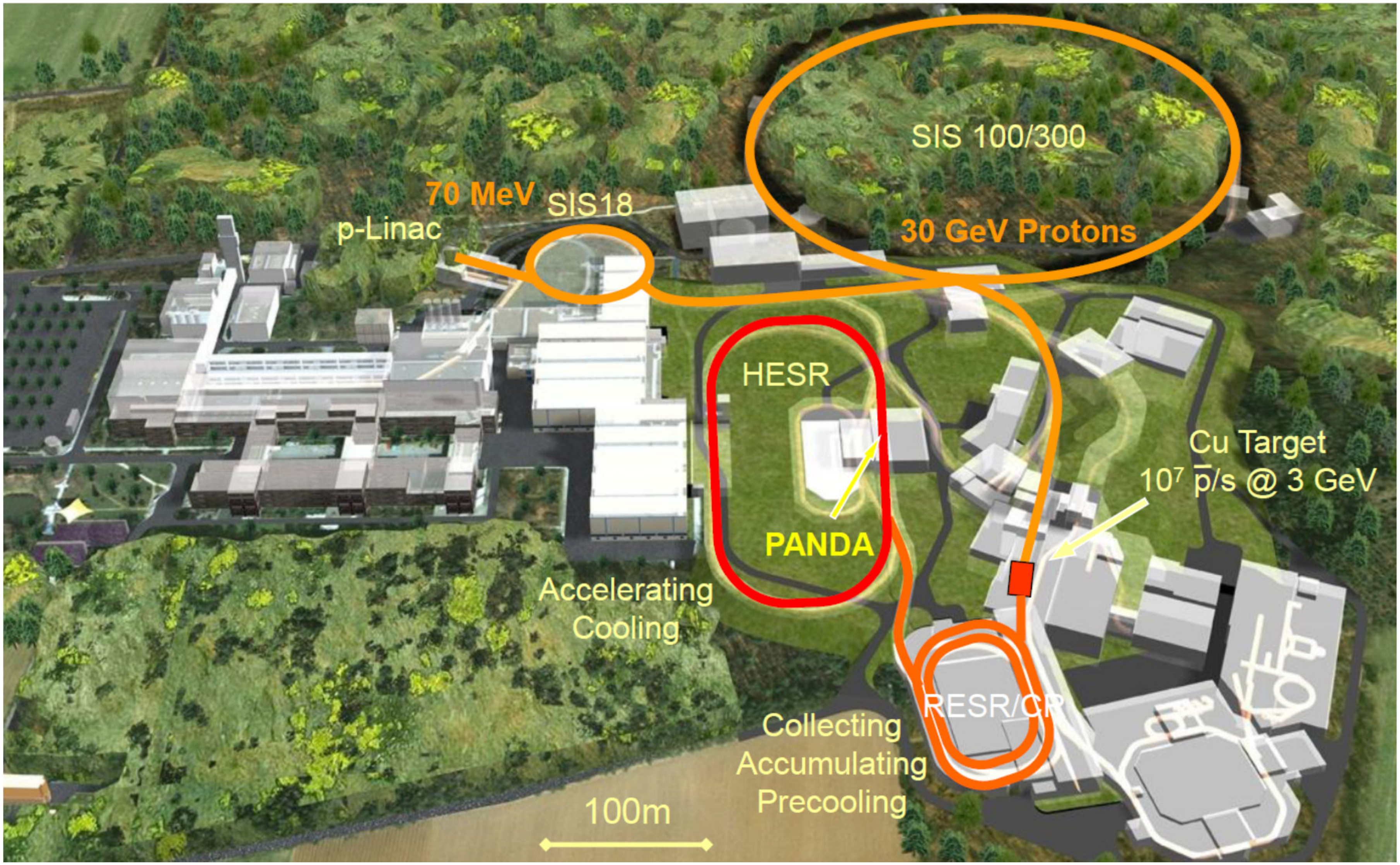
DESIGN DECISIONS, PROTOTYPING, SCHEDULE





FAIR

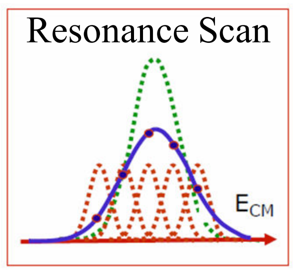
Facility for Antiproton and Ion Research at GSI near Darmstadt, Germany



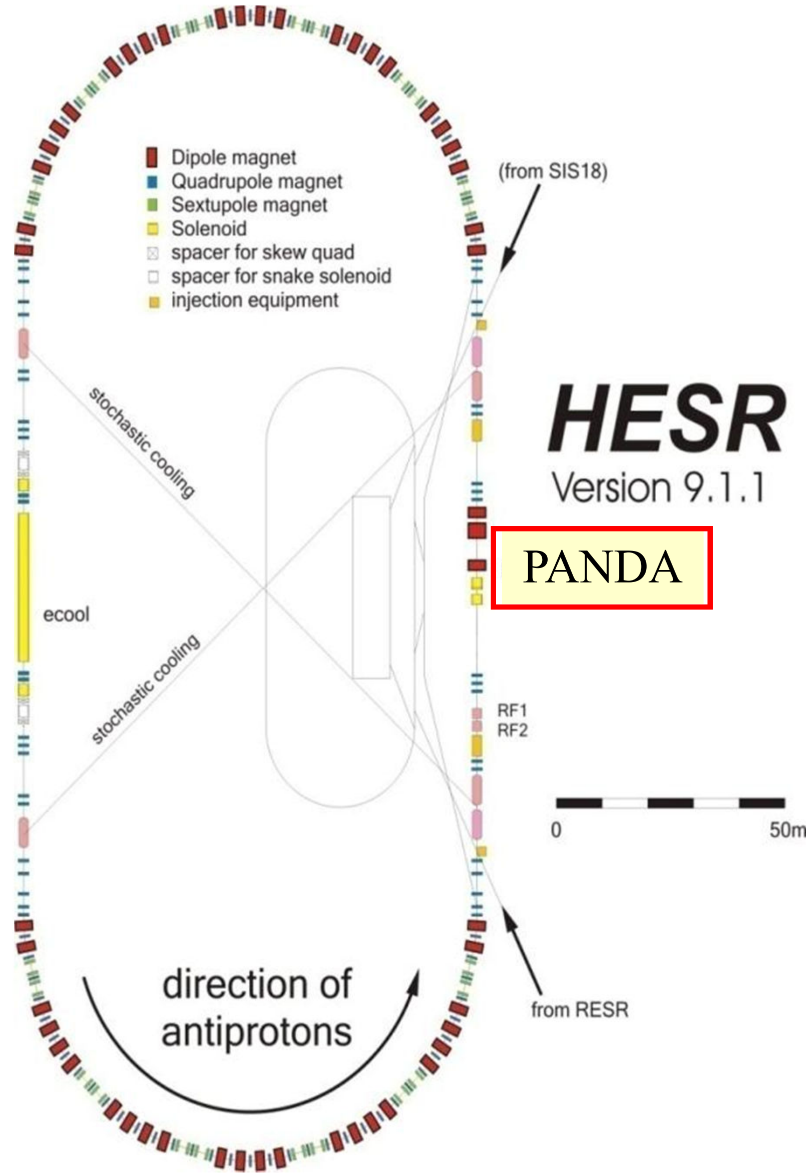
- Average production rate: 2×10^7/sec
- p_{beam} = 1.5 ... 15 GeV/c
- N_{stored} = up to 1×10^{11} $\overline{p}$

- Internal Target
- Beam Cooling (Electron & Stochastic)

- High Resolution Mode
  (up to 8.9 GeV/c)
  - $\delta p/p \approx 10^{-5}$
  - $L = 10^{31}$ $cm^{-2}s^{-1}$



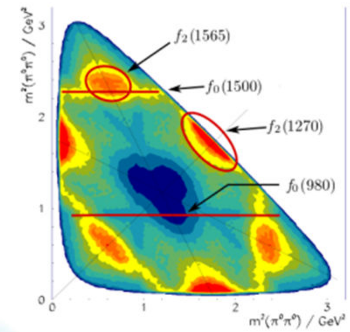
- High Luminosity Mode
  - $\delta p/p \approx 10^{-4}$
  - $L = 2 \times 10^{32}$ $cm^{-2}s^{-1}$

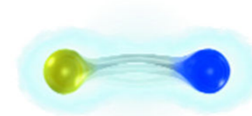


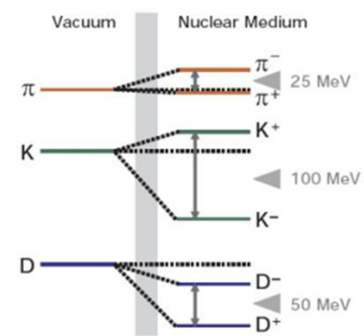
Study of QCD with Antiprotons

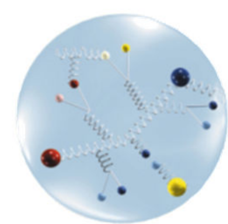
- Charmonium Spectroscopy
  - Precision Spectroscopy
  - Study of Confinement Potential
  - Access to all these puzzling X, Y and Z
- Search for Exotics
  - Look for Glueballs and Hybrids
  - Gluon rich environment → high discovery potential
  - Disentangle Mixing via PWA
- Hadrons in Medium
  - Study in-medium modification of Hadrons
- Nucleon Structure
  - Generalized Parton Distribution
  - Timelike Form Factor of the Proton
  - Drell-Yan Process
- Hypernuclear Physics *... and more*

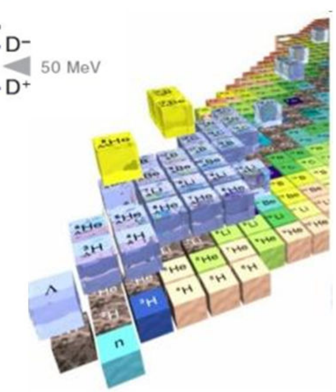
→ excellent particle identification required











PANDA: two DIRC detectors

- Barrel DIRC

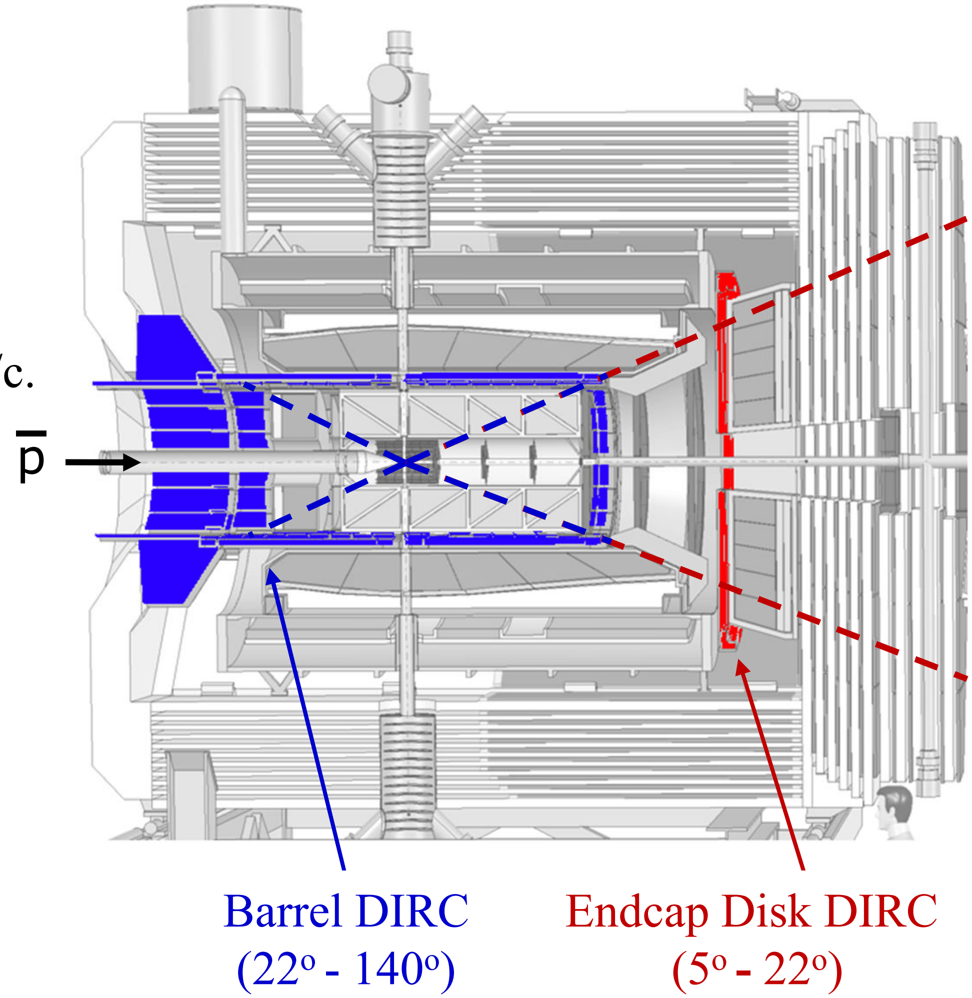
  German in-kind contribution to PANDA

  PID goal: 3σ π/K separation for p<3.5 GeV/c.

- Novel Endcap Disk DIRC

  PID goal: 3σ π/K separation for p<4 GeV/c.

See talk by O. Merle



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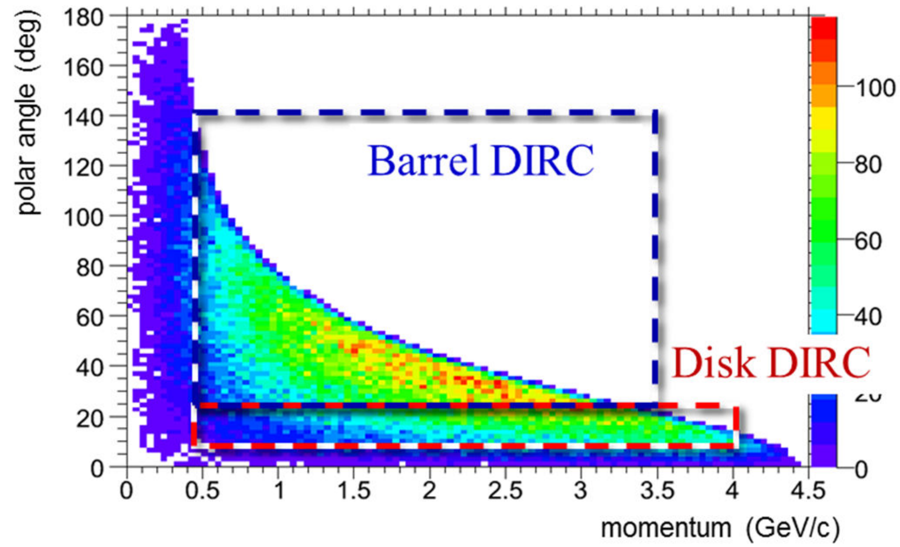


Kaon distribution of the radiative decay

$J/\psi \to K^+K^-\gamma$

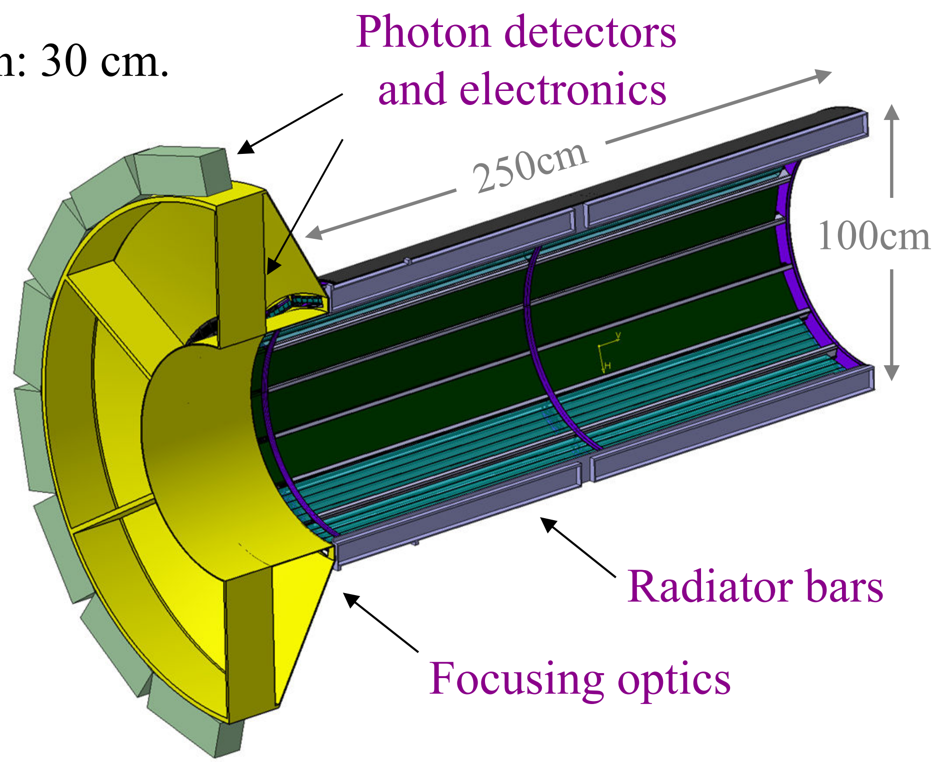
(search of glue balls)

Best barrel DIRC performance required at steep forward angles (highest momenta for most physics channels of interest).

Good match to DIRC technology: larger photon yield at steep angles (longer path in fused silica).

π/K Cherenkov angle difference in fused silica at 3.5 GeV/c: 8.5 mrad

Baseline design: based on BABAR DIRC with key improvements

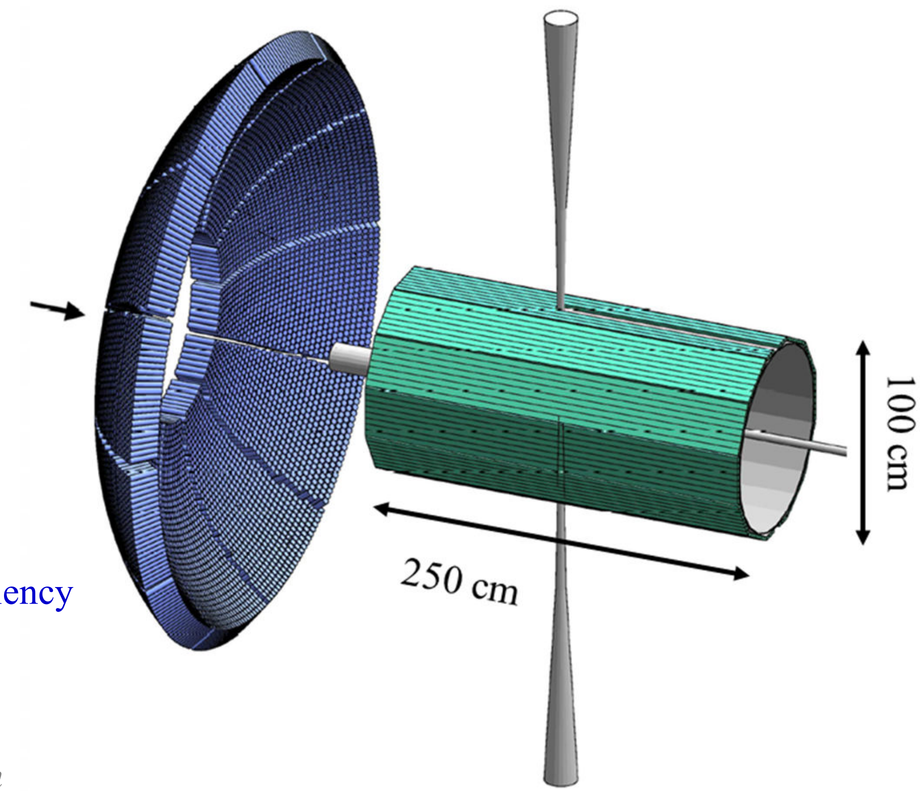


- Barrel radius ~48 cm; expansion volume depth: 30 cm.
- 80 narrow radiator bars, synthetic fused silica
  17mm (T) × 32mm (W) × 2400mm (L).
- Focusing optics: lens system.
- Compact photon detector:
  30 cm oil-filled expansion volume
  ~15,000 channels of MCP-PMTs.
- Fast photon detection:
  fast TDC plus ADC (or ToT) electronics.
- Expected performance:
  Single photon Cherenkov angle resolution: 8-10 mrad.
  Number of photoelectrons for $\beta \approx 1$ track: at least 20.

See talks by
A. Lehmann on MCP-PMTs
and
M. Traxler on readout electronics

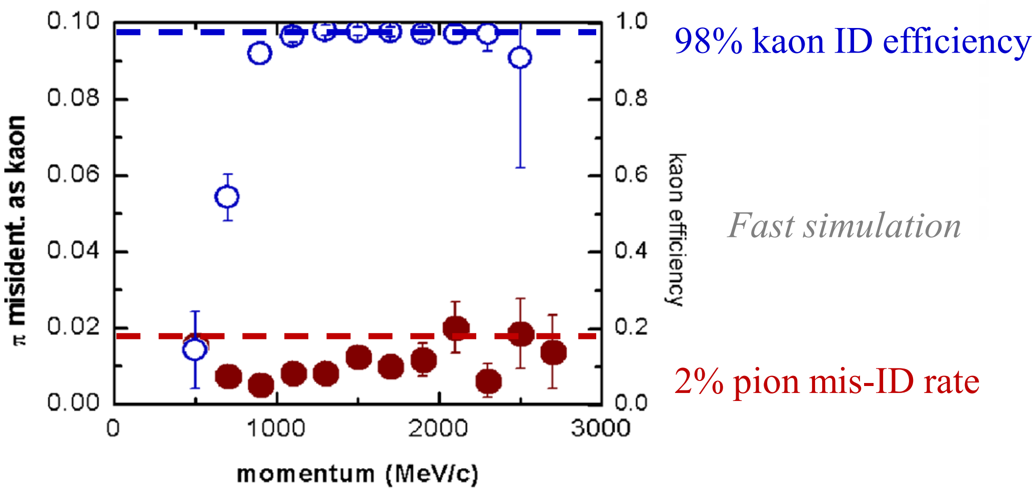
Initial approach (before 2007): scaled version of BABAR DIRC

- 96 narrow fused silica bars, 2.5m length
- Expansion volume: water tank
- ~ 7,000 conventional PMTs



Fast simulation:

performance good match to PANDA



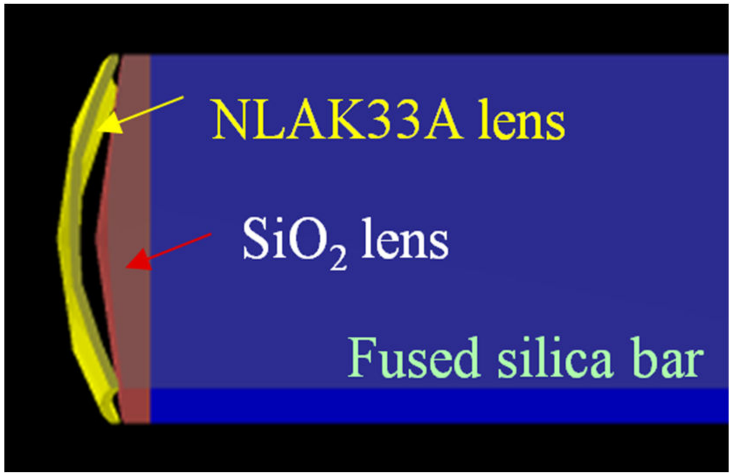
PANDA Barrel DIRC Design

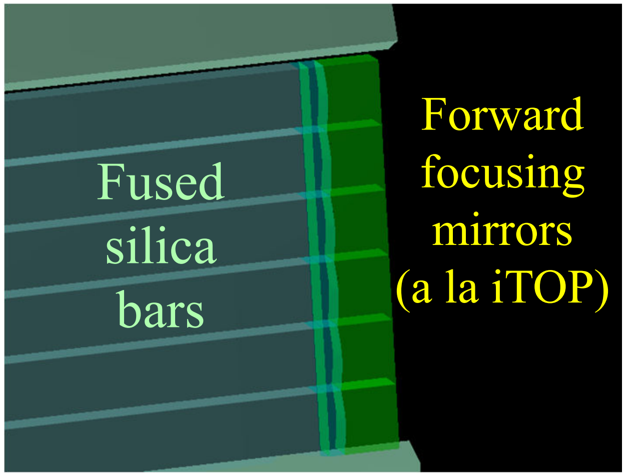
Next iteration: place small expansion volume inside yoke

- profit from SLAC fDIRC R&D, new MCP/MaPMT advances,
  fast timing, small pixels, possible chromatic correction
- shorter bars, avoid space conflicts in crowded backward region of PANDA

But: bar size dominates Cherenkov angle resolution (17mm thickness, 300mm depth: $\sigma \approx 16$ mrad)

→ small expansion volume requires focusing to achieve required PID performance.
Considering mirror system or lenses; many materials and designs considered.





Optics optimized using ZEMAX, ray-tracing, Geant

Air gap between lens and bar/expansion volume causes massive photon loss - only 2-5 photons per track around 90º polar angle

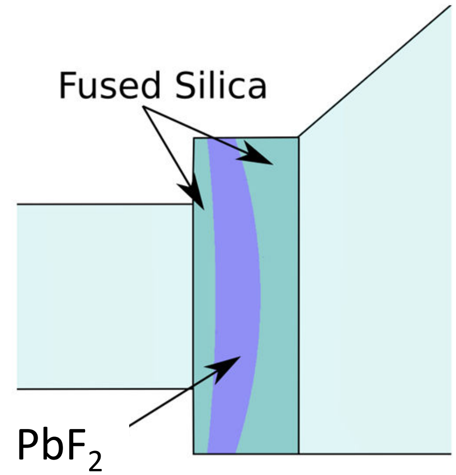
Idea: high-refractive index lens

refraction between SiO_2 and high-n material: NLAK, PbF_2, etc

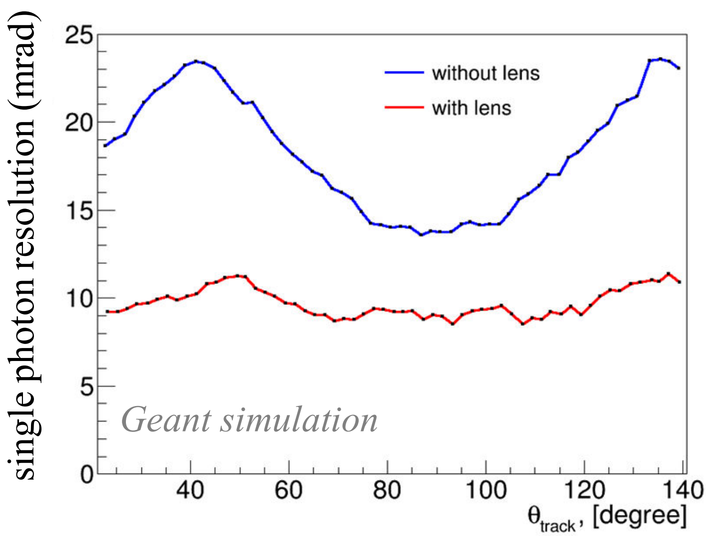
Tested prototype (SiO_2, NLAK33, SiO_2) cyl. lens at CERN in 2012.

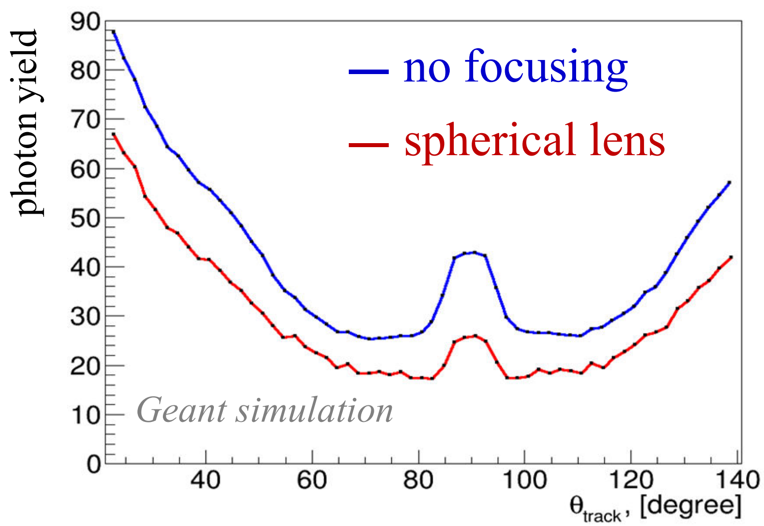
Simulation example: spherical lens (SiO_2, PbF_2, SiO_2) → promising results.

But: exotic optical materials → polishability, UV transmission, radiation hardness, etc?

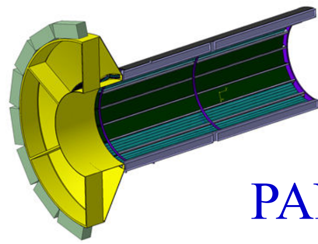


See talk by H. Kumawat

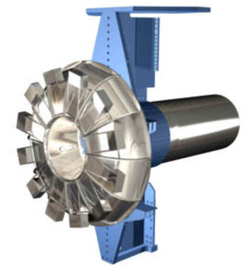




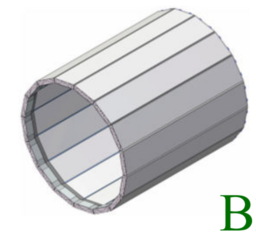
Barrel DIRC Landscape



PANDA
Barrel DIRC



BaBar
DIRC



Belle II
iTOP

Radiator geometry	Narrow bars *(32mm)*	Narrow bars *(35mm)*	Wide plates *(450mm)*
Barrel radius	48cm	85cm	115cm
Bar length	240cm *(2×120cm)*	490cm *(4×122.5cm)*	250cm *(2×125cm)*
Number of long bars	80 *(16×5 bars)*	144 *(12×12 bars)*	16 *(16×1 plates)*
Expansion volume	30cm, mineral oil	110cm, ultrapure water	10cm, fused silica
Focusing	Lens system	None (pinhole)	Mirror
Photodetector	~15k MCP-PMT pixels	~11k PMTs	~8k MCP-PMT pixels
Timing resolution	~0.1ns	~1.5ns	<0.1ns
Pixel size	6.5mm×6.5mm	25mm diameter	3.2mm×3.2mm
PID goal	3 s.d. π/K to 3.5 GeV/c	3 s.d. π/K to 4 GeV/c	3 s.d. π/K to 4 GeV/c
Timeline	Installation 2017	1999 - 2008	Installation 2015

PANDA Barrel DIRC Options

Investigating several design options:

Segmented optical expansion volume, "camera"

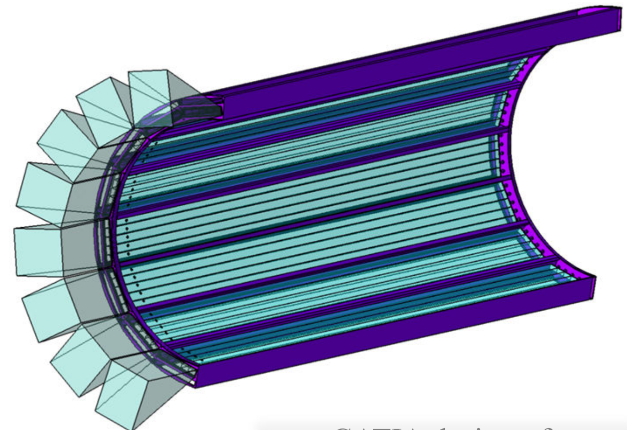
one solid fused silica prism per sector instead of oil tank

→ better optical and operational properties,

good match to possible geometry with wide plates.

but: reflections in prism complicate reconstruction for

baseline design with narrow bars, add background.



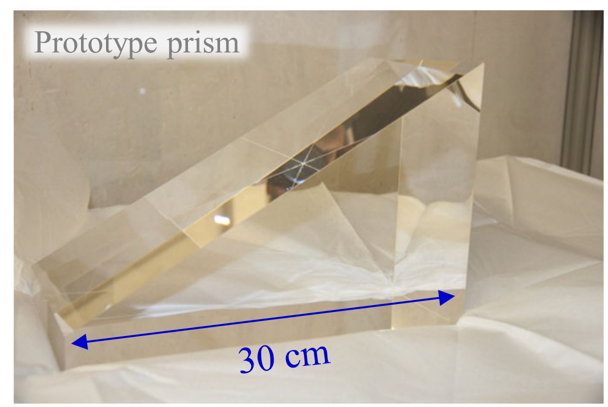
CATIA design of
Barrel DIRC geometry with
narrow bars and prisms

Purchased prototype prism in 2012,

tested combination at CERN T9 test beam,

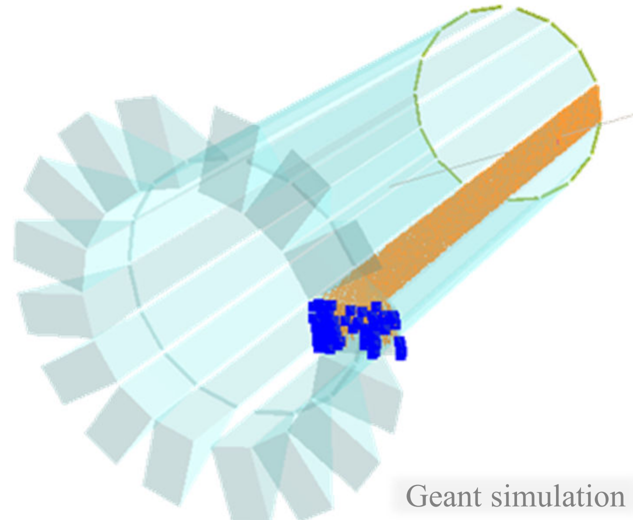
software development and data analysis ongoing,

additional beam test in 2014 required for decision.



Investigating several design options:

Use of one wide fused silica plate (16cm) per sector
instead of 5 narrow (3.2cm) bars



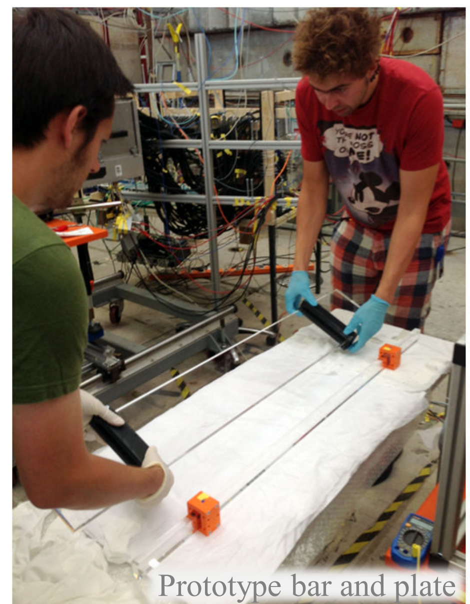
Geant simulation

Belle II iTOP is leading the way with plate fabrication, prototyping, and software development.

Smaller number of pieces would drastically reduce the radiator fabrication cost (1.5 – 2M€ savings possible).

Our Barrel DIRC would still be keep large number of pixels, more robust operation, timing less critical.

Purchased prototype plate and tested at CERN T9 test beam 2012, software development and data analysis ongoing, additional beam test in 2014 required for decision.



Prototype bar and plate

PANDA BARREL DIRC OPTIONS

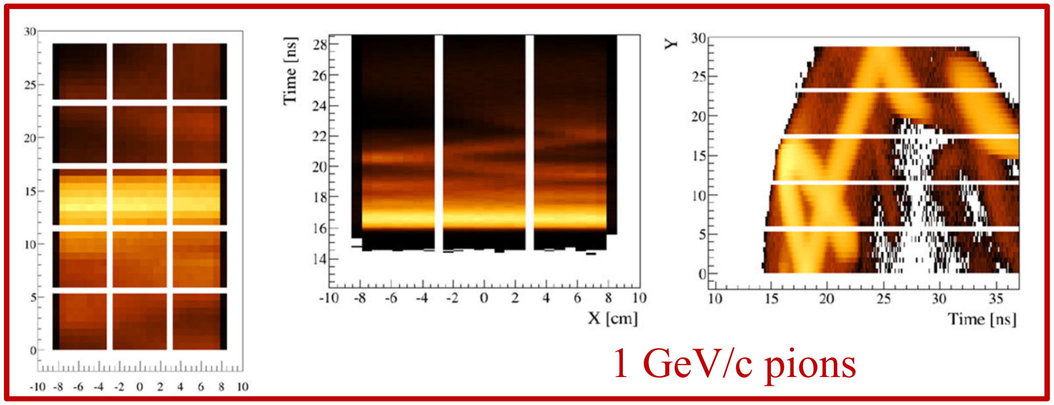
See talk by H. Kumawat

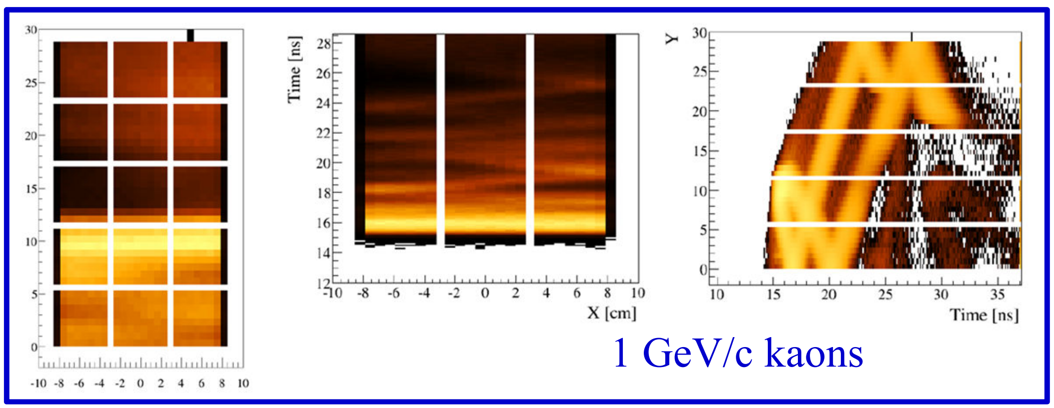
BABAR-like reconstruction no longer works, new approach required.

Promising initial results from a Belle II-like time imaging approach.

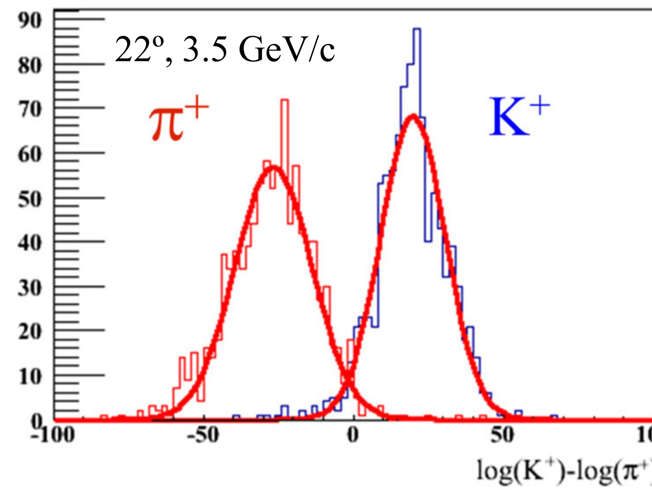
Generate probability density functions of photon hit time per pixel from simulation.

Example: hit patterns in X/Y, X/T, T/Y for 1GeV/c particles





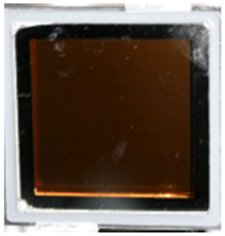
Geant simulation



Log-likelihood analysis shows
clean π/K separation at 3.5 GeV/c
even without focusing optics

More studies and analytic pdfs needed.

Photon Detector Challenges

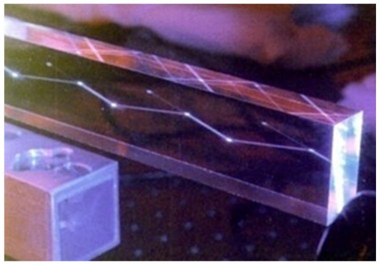


- Compact multi-pixel sensor with single photon sensitivity in 1T magnetic field.
- Few mm position resolution with ~100ps timing.
- High rates up to 0.2 MHz/cm^2, long lifetime: 0.5 C/cm^2 per year at 10^6 gain.

Recent lifetime advances make MCP-PMTs an excellent sensor candidate.

See talk by A. Lehmann

Radiator Challenges



- Production of large fused silica bars or plates (lesson learned from BABAR).
- Require mechanical tolerances on flatness, squareness, and parallelism with optical finish and long sharp edges.
  → difficult, potentially expensive, few qualified vendors worldwide.
- BABAR-DIRC used bars polished to 5 Å rms, non-squareness < 0.25 mrad; successfully done for BABAR, need to qualify/retrain vendors 10+ years later.

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

Goal: qualify vendors, quality assurance

Obtained ~30 prototype bars and plates from several vendors including actual BABAR DIRC bars.

Current prototype production with Aperture Optical Sciences/Okamoto Optics, due next week.

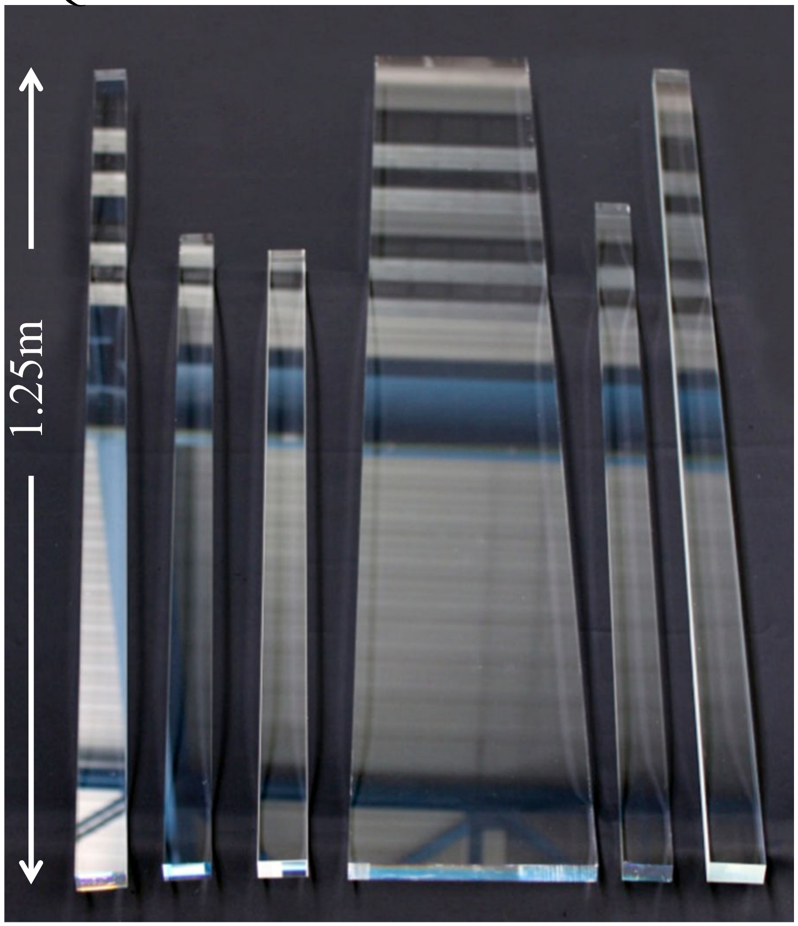
Different fabrication processes and bulk materials.

One setup to measure internal angles user lasers, recently added autocollimator.

Another 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.

InSync Inc (BABAR DIRC)
Zeiss
Schott Lithotec
InSync Inc
Lytkarino
Röhm



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See talk by G. Kalicy

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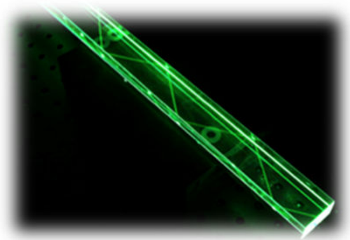

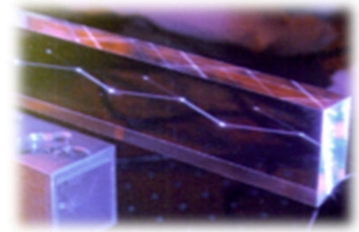

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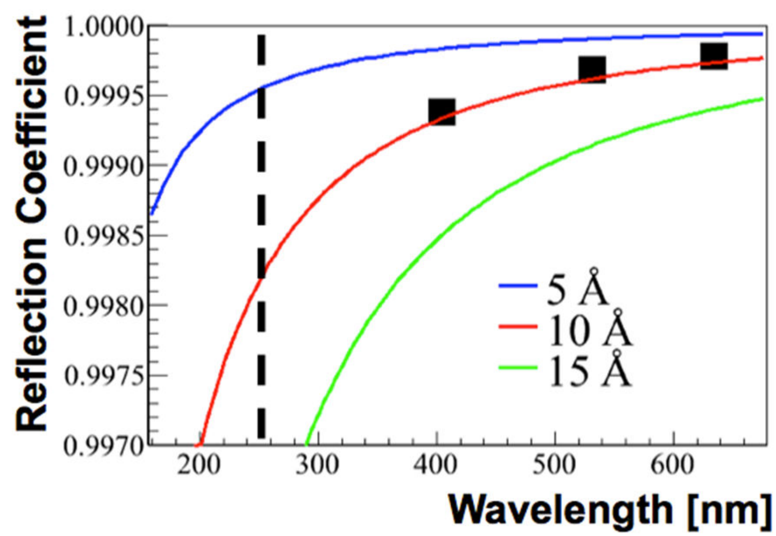


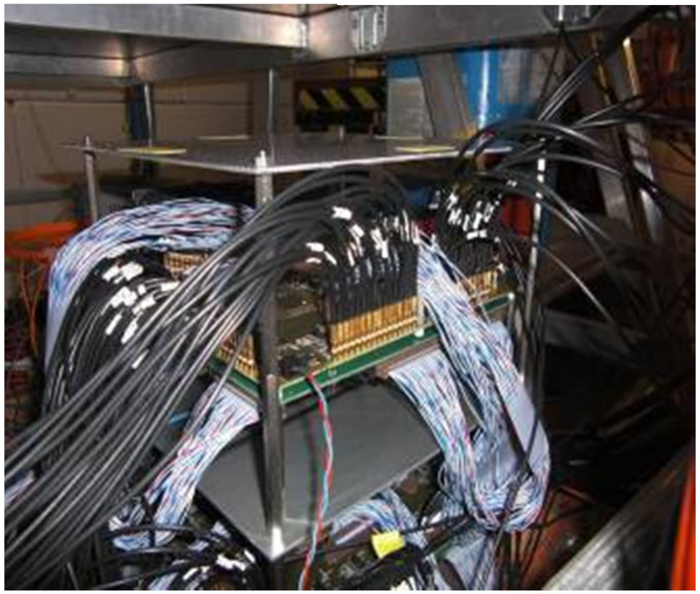
First impression: InSync, Zeiss, Zygo all capable of producing high quality DIRC bars (angles, corners).

Electronics Challenges

See talk by M. Traxler

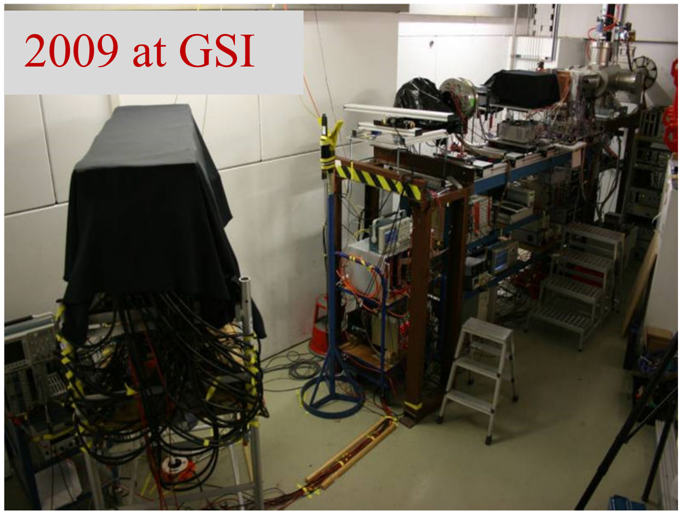
- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifier usually needed.
- High bandwidth 500MHz – few GHz (optimum bandwidth not obvious).
- Pulse height/charge information required for < 100 ps timing (time walk correction),
  and desirable for 100-200 ps timing (ADC / time over threshold / waveform sampling / ...)
- PANDA will run trigger-less.
- Radiation hardness may be an issue (FPGA).
- Large data volume (to disk: up to 200 Gb/s).
- Current approach:
  HADES TRBv3 board with amplifier/discriminator front-end card mounted on MCP-PMT.
  FEE cards developed at Mainz and at GSI.
- Verify electronics performance with fast laser pulsers
  and several dedicated beam times at MAMI B, X1.

HADES TRB2 w/ NINO

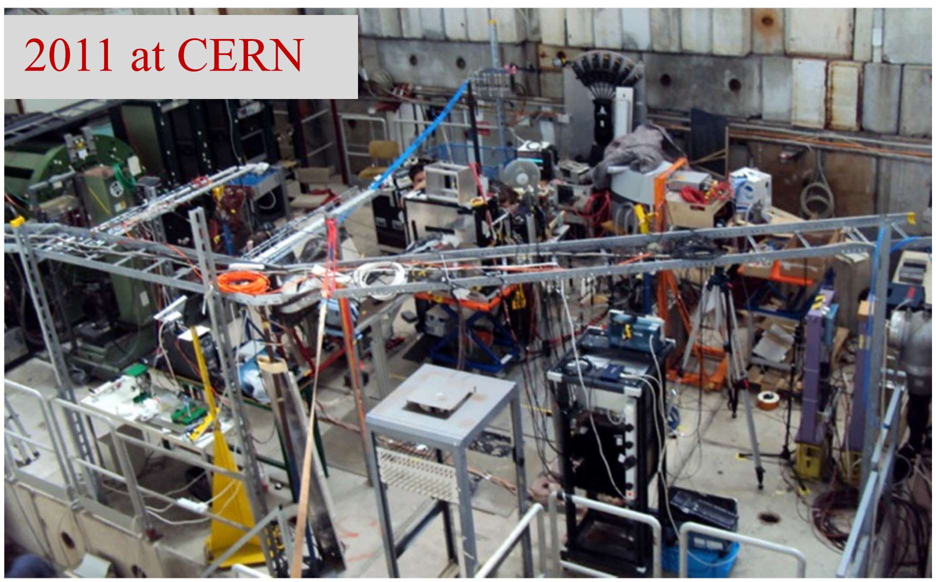


PROTOTYPES IN PARTICLE BEAMS

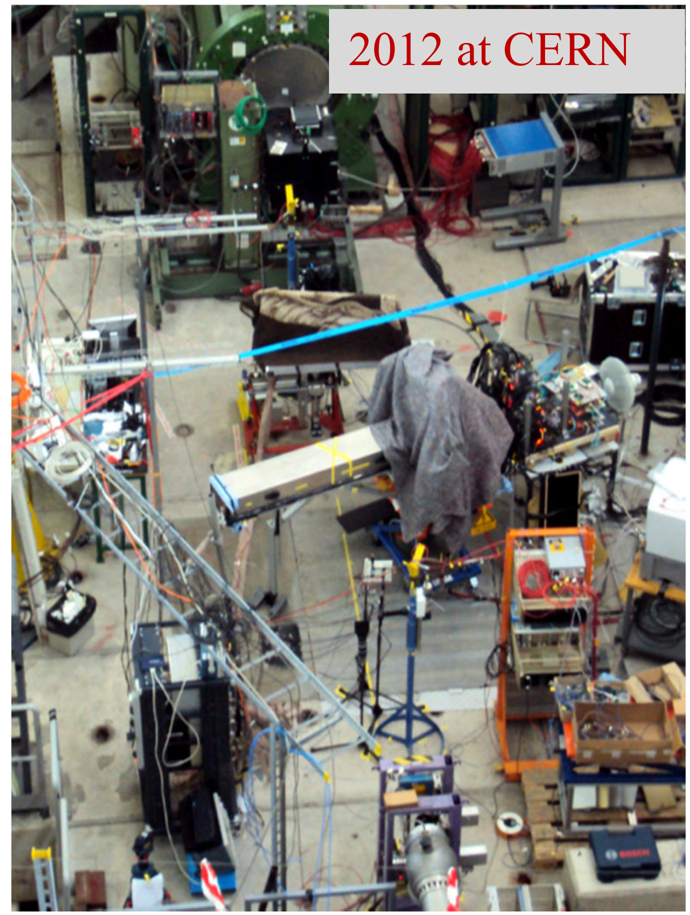
Barrel DIRC system prototype
test beam campaigns



2009 at GSI



2011 at CERN

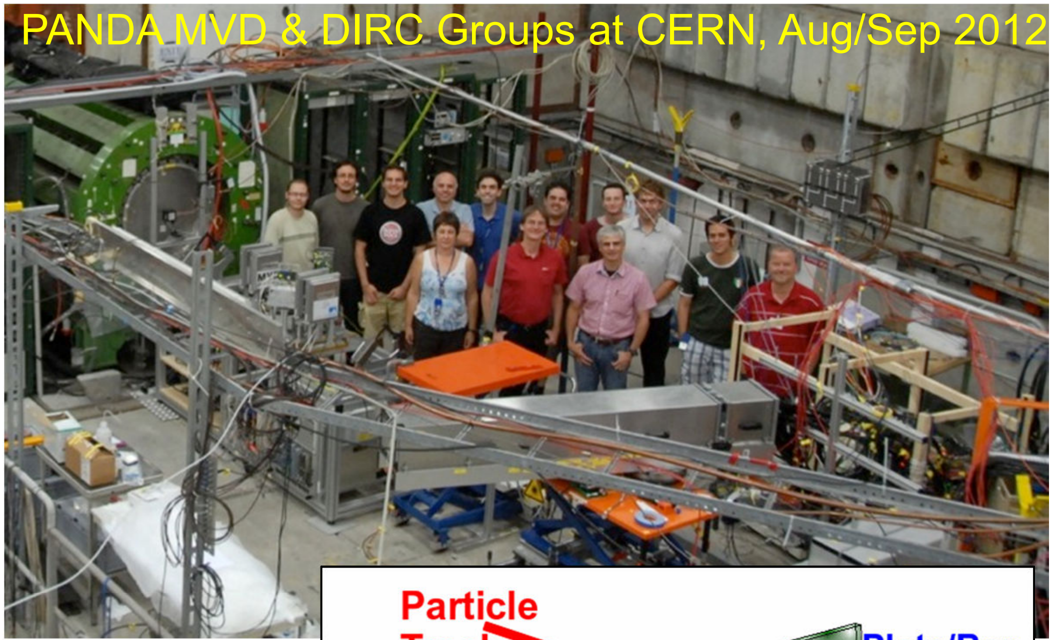


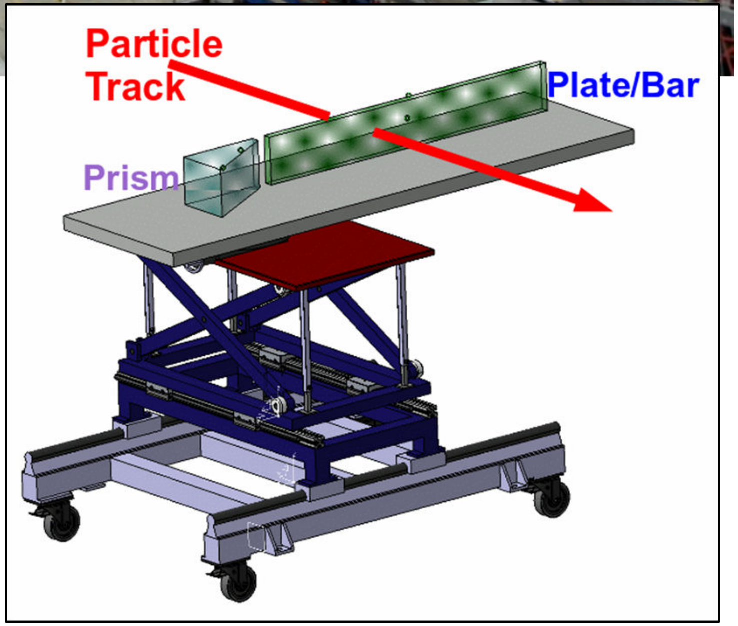
2012 at CERN

PROTOTYPES IN PARTICLE BEAMS

2012: π/p beam at CERN PS

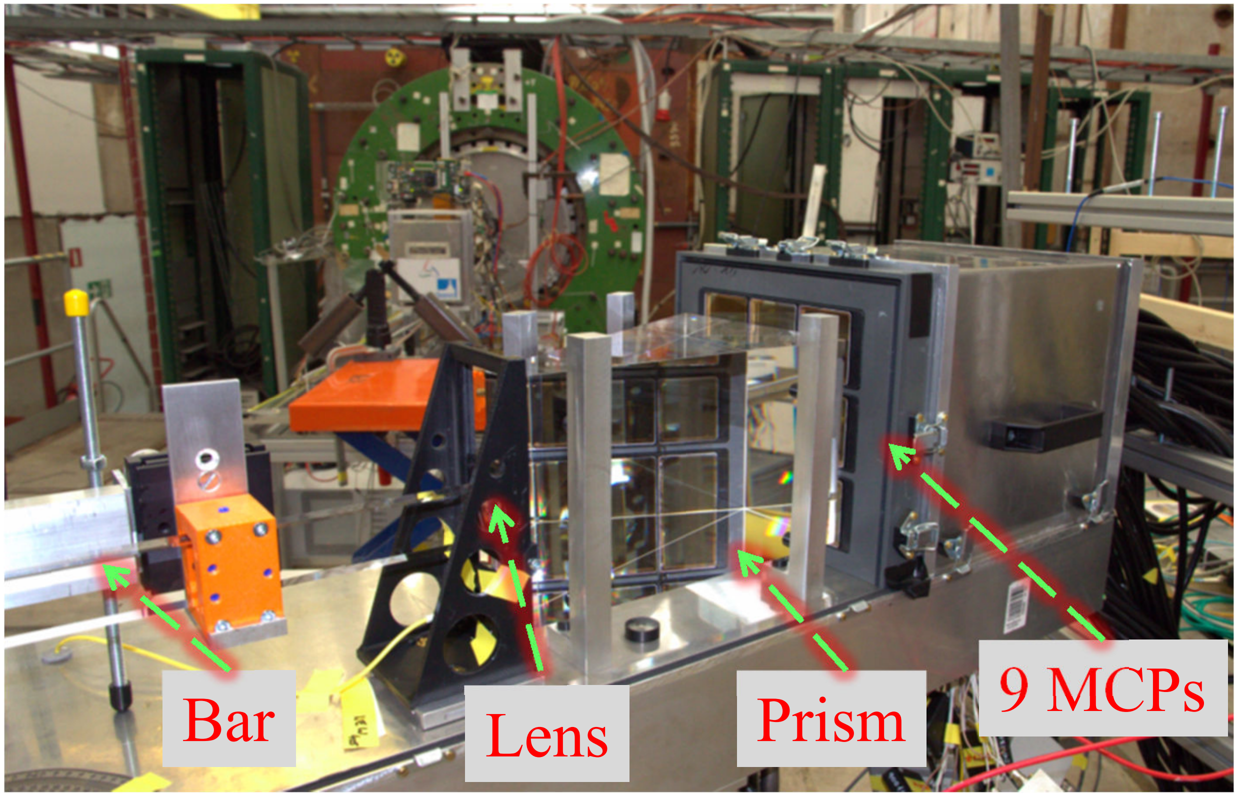
- Compact solid fused silica expansion volume (prism) instead of oil tank.
- Wide fused silica plate in addition to narrow bars.
- Focal plane almost fully covered by array of 3x3 Photonis Planacon MCP-PMTs, 896 channel DAQ.

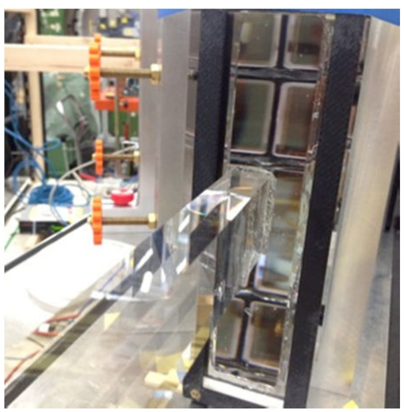


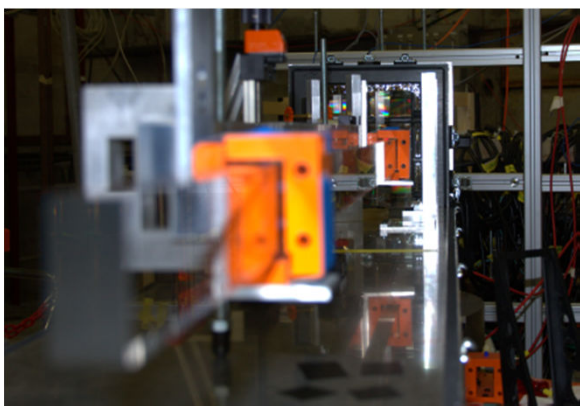


- *Capability to position, rotate, exchange bars/plates easily to compare radiator performance in beam.*
- *Different lenses w/ and w/o air gap, A/R coatings.*
- *Choice of coupling media between MCP/prism/radiator (matching liquid, optical grease, silicone sheet).*
- *Tracking stations to define track direction to ~1mrad.*
- *Time of flight system to enhance pion/proton sample.*

PROTOTYPES IN PARTICLE BEAMS







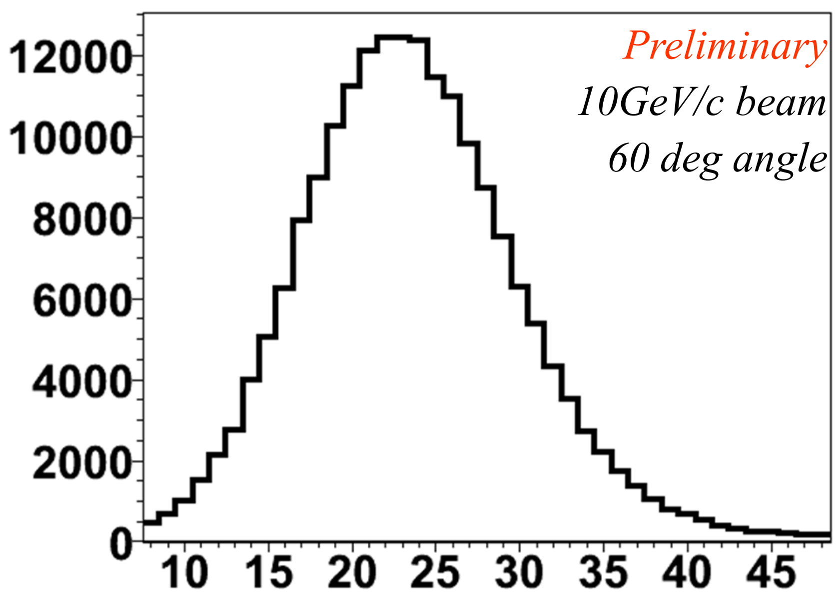
Detailed analysis of 2012 CERN data continuing, still preparing 3D tracking and improved timing/position calibration, plate reconstruction still in preparation.

Preliminary performance example:

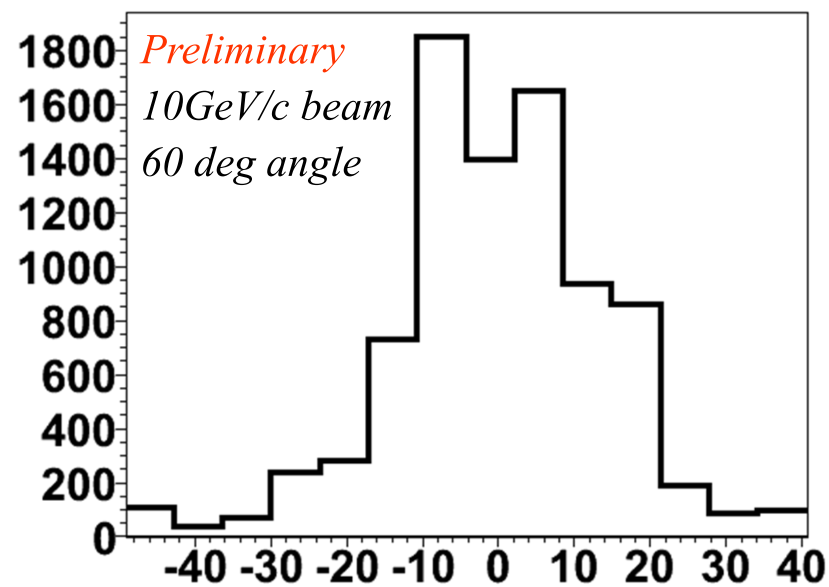
InSync bar, spherical lens with UV A/R coating and 2.2mm air gap.

→ Clear Cherenkov signal with reasonable single photon resolution.

See talk by G. Kalicy



Number of detected photons per trigger



θ_C per photon – average θ_C [mrad]

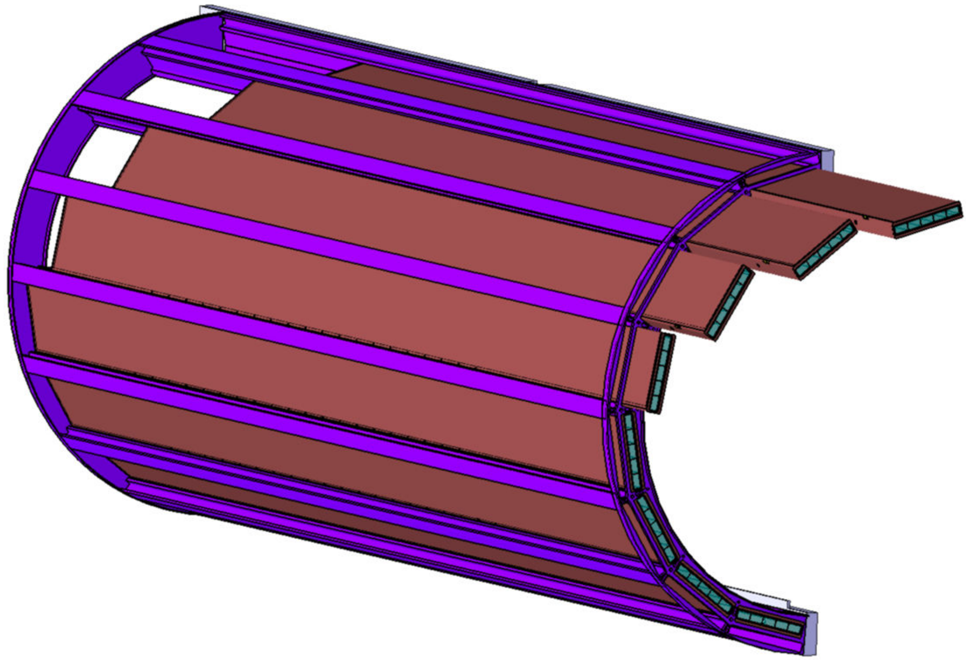
MECHANICAL DESIGN

Mechanical design concept based on BABAR DIRC detector experience.

→ Bar boxes slide on wheels into slots.

→ Staged installation simplified if component fabrication should be delayed.

- bar boxes themselves provide much of the required mechanical stability
- rings in 2 locations in Z couple DIRC mechanics to support beam
- slots in rings for bar box and SciTil modules
- ribs along the length of the barrel provide required stiffness
- wheels mounted on bar box run on rails attached to the ribs



- carbon fiber sheet attached to ribs provide additional strength
- expansion volume/camera support separate for access to detector

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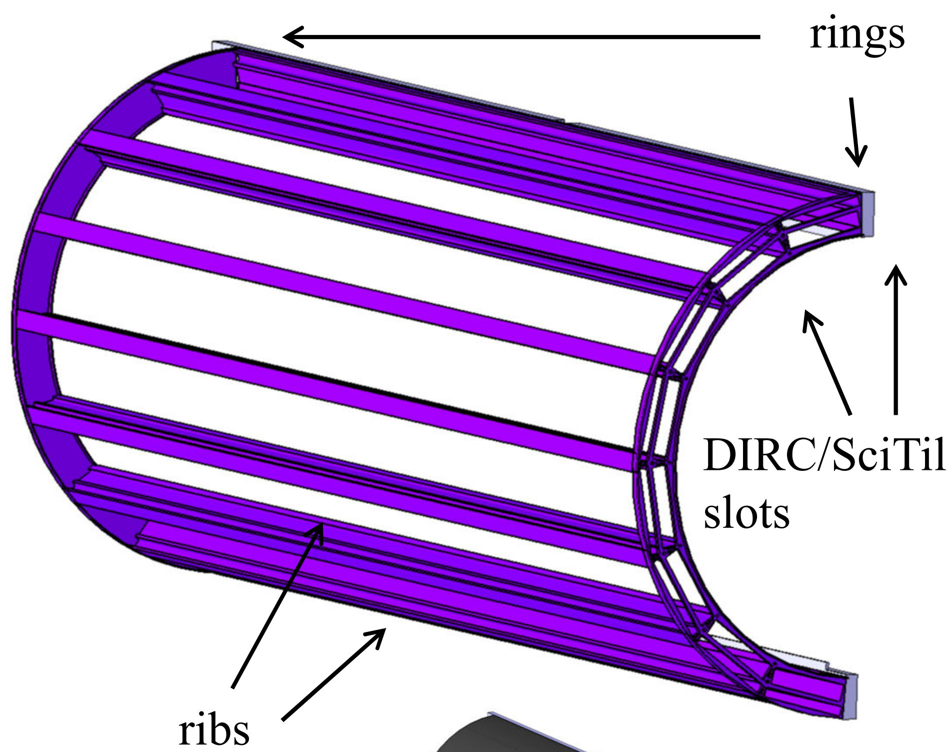
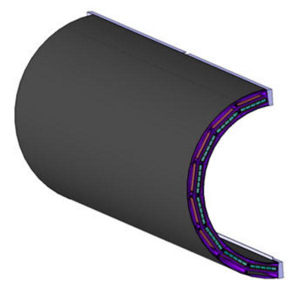
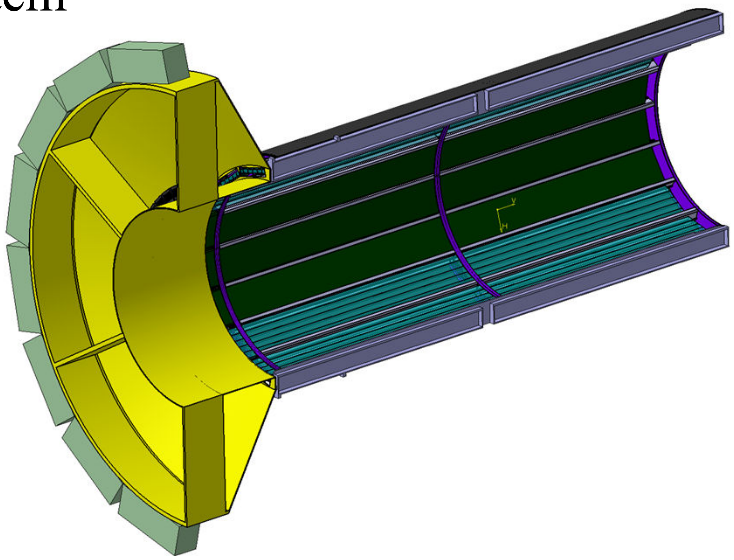




The PANDA Barrel DIRC design evolved from scaled-down BABAR DIRC to a compact fast focusing DIRC.

Baseline design with narrow bars and high-n lens system appears to meet PANDA PID goals.



Recent lifetime advances make MCP-PMTs an excellent sensor choice.

Ongoing prototype program has identified several potential vendors for radiator fabrication.

Decision on wide radiator plates and solid fused silica prisms as Cherenkov cameras due 2014.

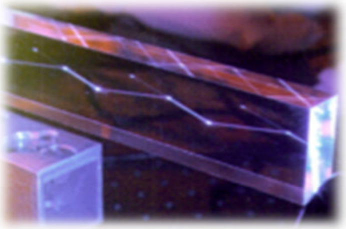
Progression of increasingly complex system prototypes to validate design choices and PID performance using particle beams.

Leading edge technologies, benefit from delayed technology decision → system still in R&D phase, Technical Design Report planned for late 2014.

PANDA BARREL DIRC OUTLOOK

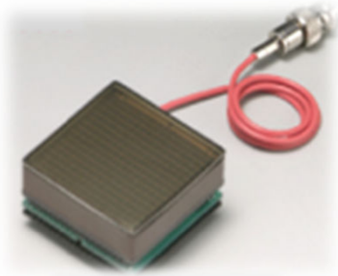
2013-2014: Continue R&D, test designs in particle beams, write TDR.

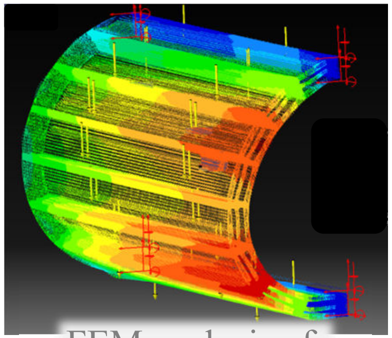
- Summer 2014: beam tests at GSI, basis for design decisions and TDR
  bars vs. plates, tank expansion volume vs. prisms


DIRC bar with laser

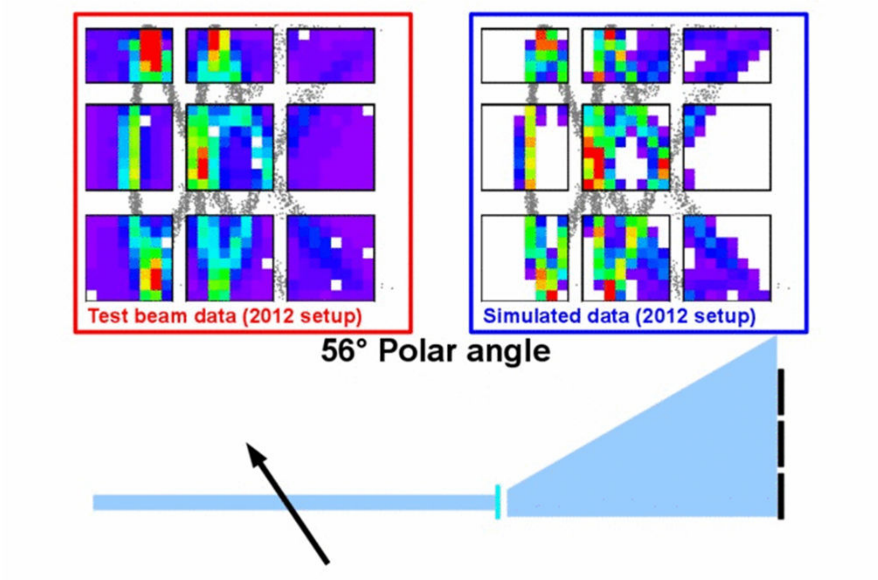
2015-2017: Component Fabrication, Assembly, Installation

- 2015-2017: Industrial production of radiators, prisms, photon sensors.
- 2015-2016: Production and QA of readout electronics.
- 2016-2017: Fabrication of bar containers and mechanical support frame, gluing of bars, construction of complete bar boxes.
- 2016-2017: Detailed scans of all sensors, assembly of readout modules.
- 2017: Installation of mechanical support frame in PANDA
  insert bar boxes, mount readout modules.
  Ready for commissioning in 2018.


Photon sensor


FEM analysis of DIRC mechanics

THANK YOU



Hit patterns for 2012 prototype with narrow bars and fused silica prism

Geant simulation of hit pattern for narrow bars and oil tank geometry