Review of relevant Cherenkov imaging devices in particle/nuclear experiments currently running, under construction and planned

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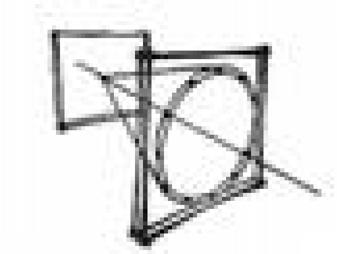
6th International Workshop on Ring Imaging Cherenkov Counters (RICH2007)
Stazione Marittima, Trieste, Italy
15 - 20 October 2007



Outline of this talk

Review of *relevant* Cherenkov imaging devices in particle/nuclear experiments currently running, under construction and planned

What is included ?

Detectors of focused Cherenkov radiation in accelerator/collider experiments

Why is the RICH needed ?

Physics motivation

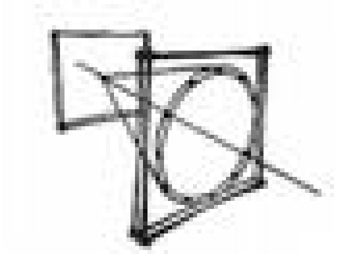
How is the RICH detector used ?

highlighting specific features of current/planned experimental devices

"Review" → "Preview" a pointer to contributed papers presented here

Apologies for omissions does not mean *irrelevant* !

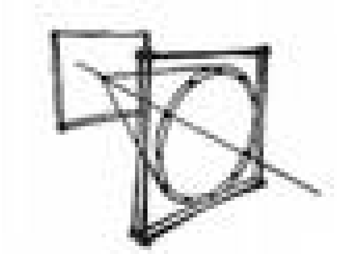
Acknowledgements to experiment websites for presentation material



Outline of this talk

What ? Types of RICH detector in use/proposed

- Image focused by lens/mirror
  Classic RICH detector (Seguinot, Ypsilantis)
- Proximity focusing
  “thin” solid/liquid radiator
- Pin-hole focusing
  DIRC (Detector of Internally Reflected Cherenkov light)
- Imaging using timing
  Water Cherenkov
  TOP – time of propagation



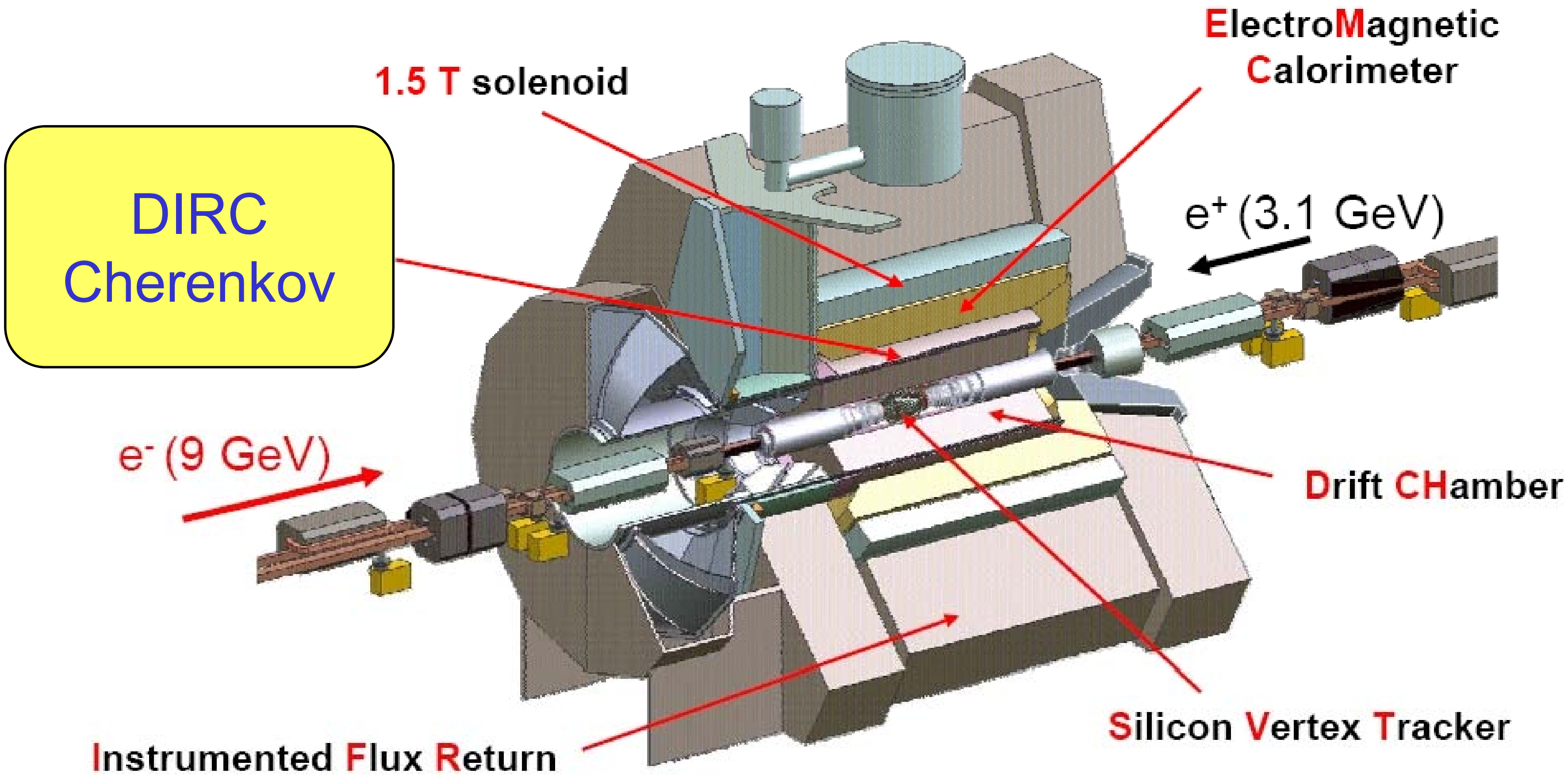
Why are RICH detectors used ?

Physics motivation — Reported at RICH2007

- Flavour physics and CP violation — LHCb, BELLE, BABAR, NA62
  Hadron ID: to identify quark flavours in decays
- Hadron (low p_T) physics — PANDA, MIPP, COMPASS
  Hadron ID: to identify final states, particle production, spectroscopy
- Nucleon structure — COMPASS, HERMES
  Hadron ID: charmed hadrons as probe of gluons in nucleons
- Heavy Ion physics and QGP — ALICE, JLAB, CBM, PHENIX
  Electron ID: nuclear matter transparent to leptons so probe interior
- Neutrino physics — T2K (MIPP)
  Event reconstruction for oscillation studies

Flavour physics – BABAR DIRC

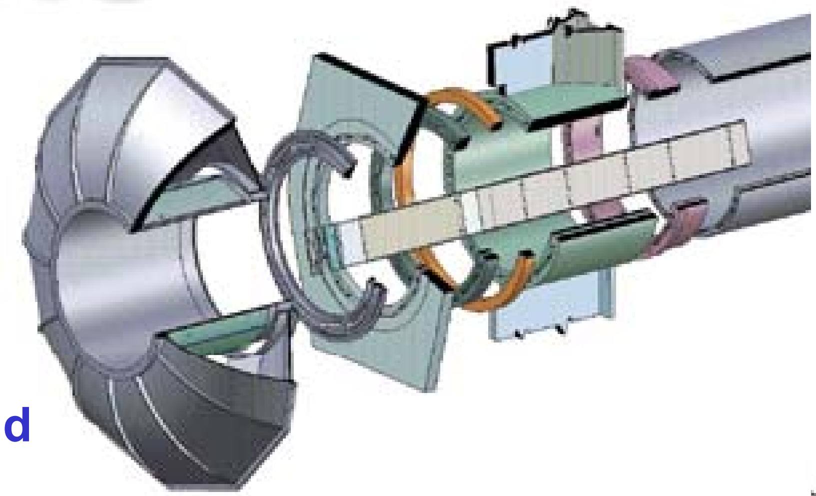
Babar detector at PEPII electron-positron collider
$b\bar{b}$ factory – CP violation in decay of $B_{u,d}$ mesons

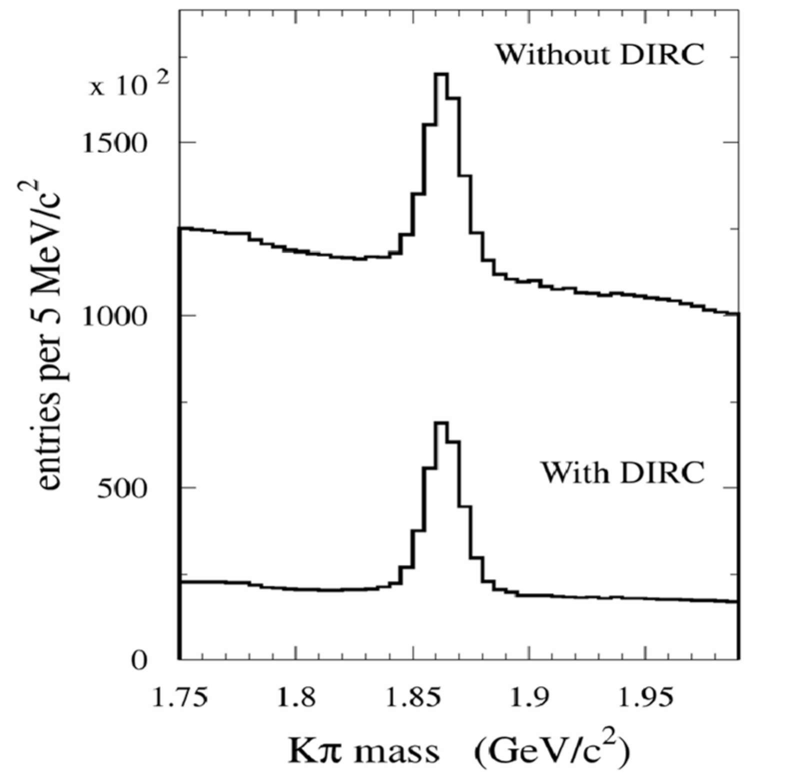


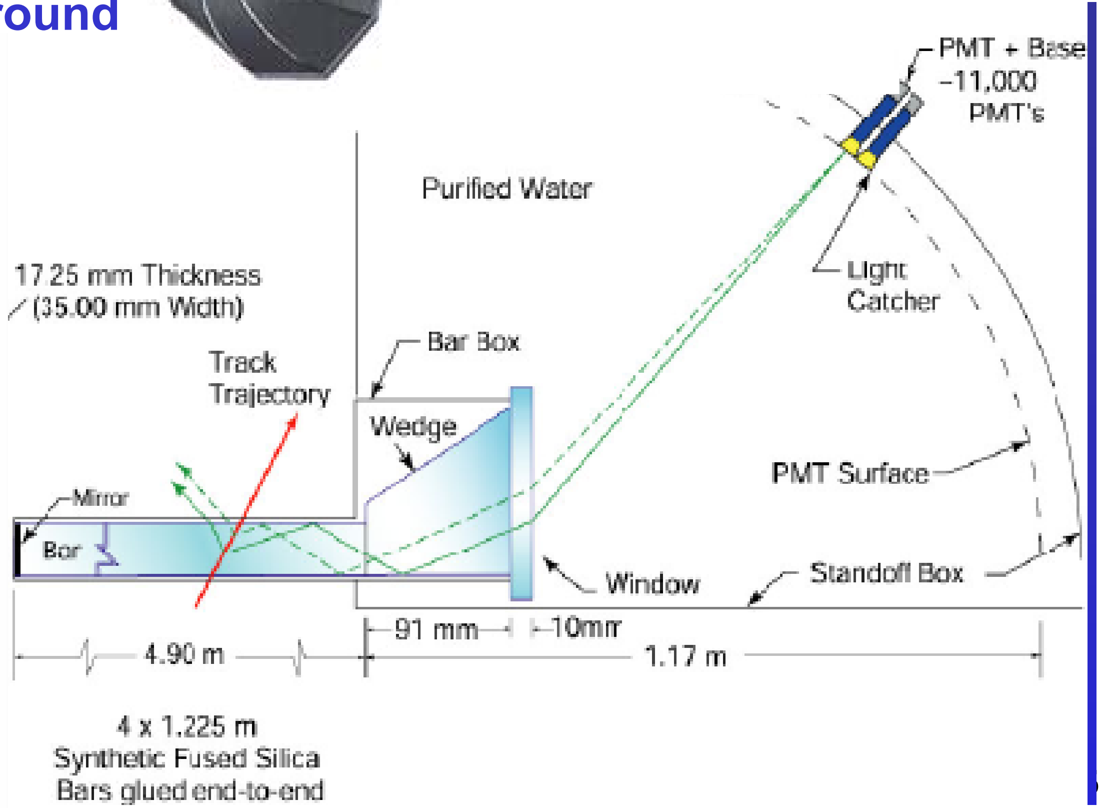
Flavour physics – BABAR DIRC

11,000 PMTs: 29mm diameter
π / K separation: 0.5 - 4 GeV/c

N_photons detected > 30 / track
σ_θ < 10 mrad
x 6 reduction in $D^0 \rightarrow K\pi$ background



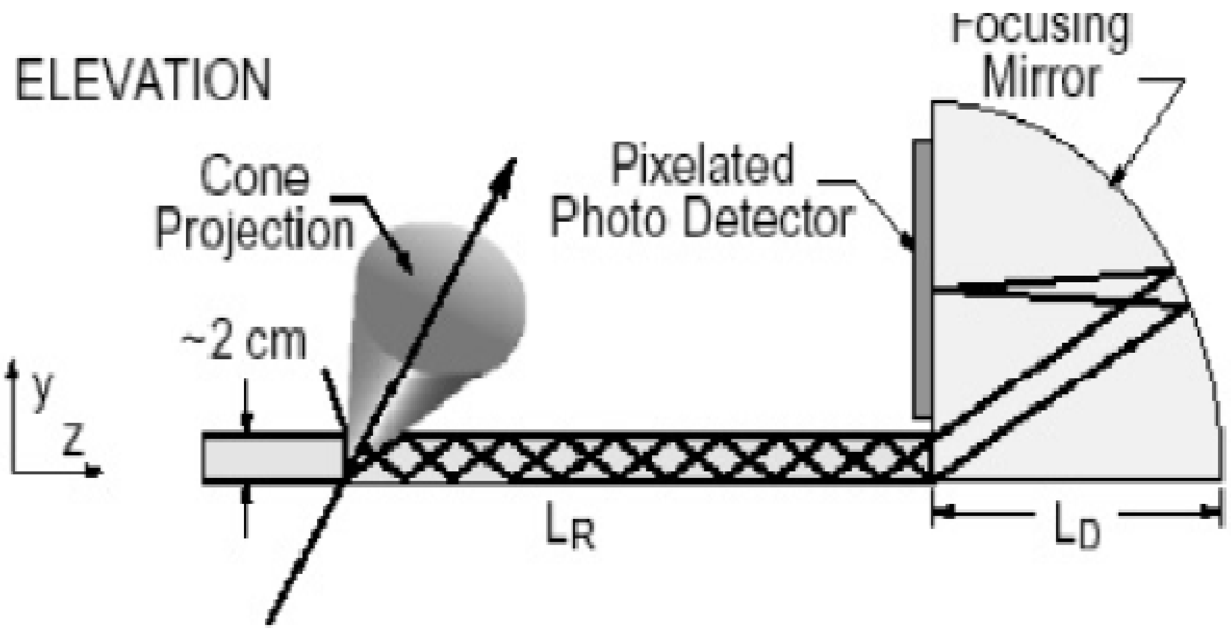




Flavour physics – BABAR DIRC

DIRC (SuperB) Upgrade – to handle x 100 luminosity

Focusing DIRC
Reduced photon detector pixel size → ~ 5mm
Improved timing resolution (e.g. MCP) → ~100ps
Determine colour of photon and correct chromatic error on θ_C



See talk by:
J.Schwiening

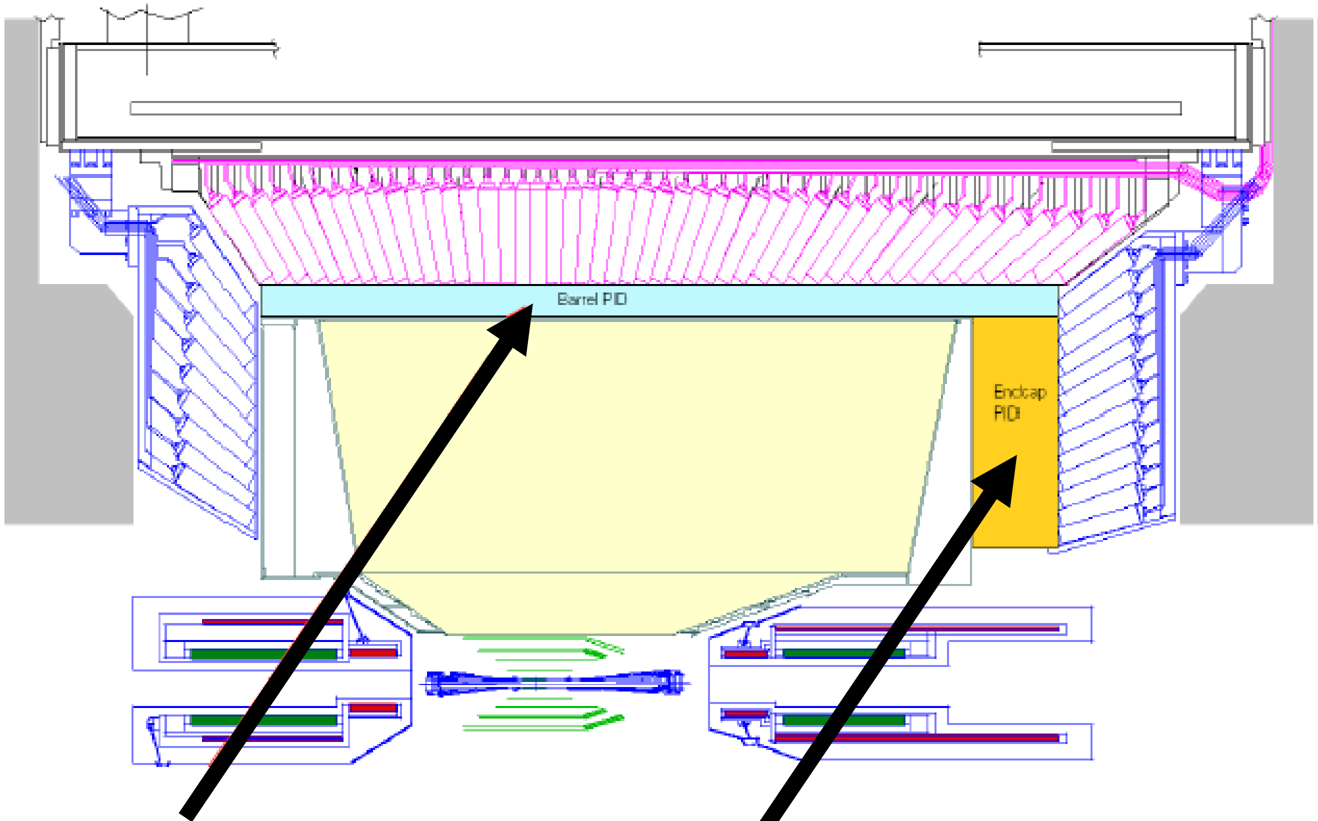
Flavour physics – BELLE upgrade

BELLE detector at KEK electron-positron collider
b$\bar{b}$ factory – CP violation in decay of $B_{u,d}$ mesons

Currently uses
aerogel threshold

Upgrade proposed
for super B factory
x 100 luminosity

π / K separation:
0.5 - 4 GeV/c



Focusing / Time of Propagation (TOP) DIRC

Proximity focusing aerogel RICH

Flavour physics – BELLE upgrade

TOP barrel DIRC:

MultichannelPlate PMTs with time resolution ~ 40ps

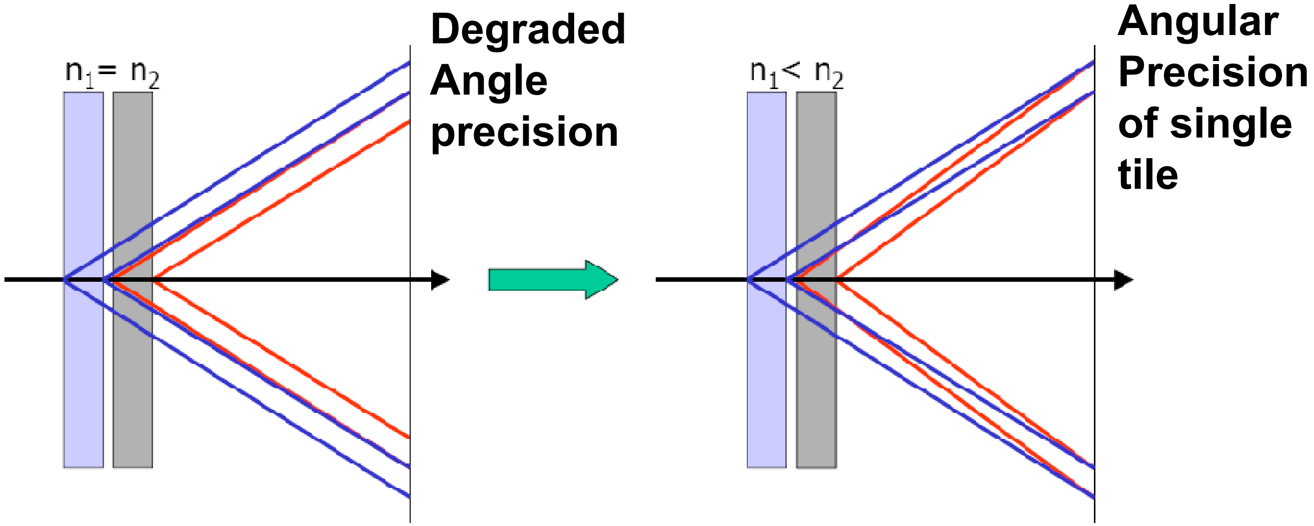
End Cap proximity focused aerogel

20mm-thick Aerogel tiles to limit emission-point error

FlatPanel (H8500) PMTs → σ_θ ~ 14 mrad

N_detected photons ~ 6

Increase N_ph by using graded-n aerogel tiles (FARICH)



See talks by:

K.Inami

T.Iijima

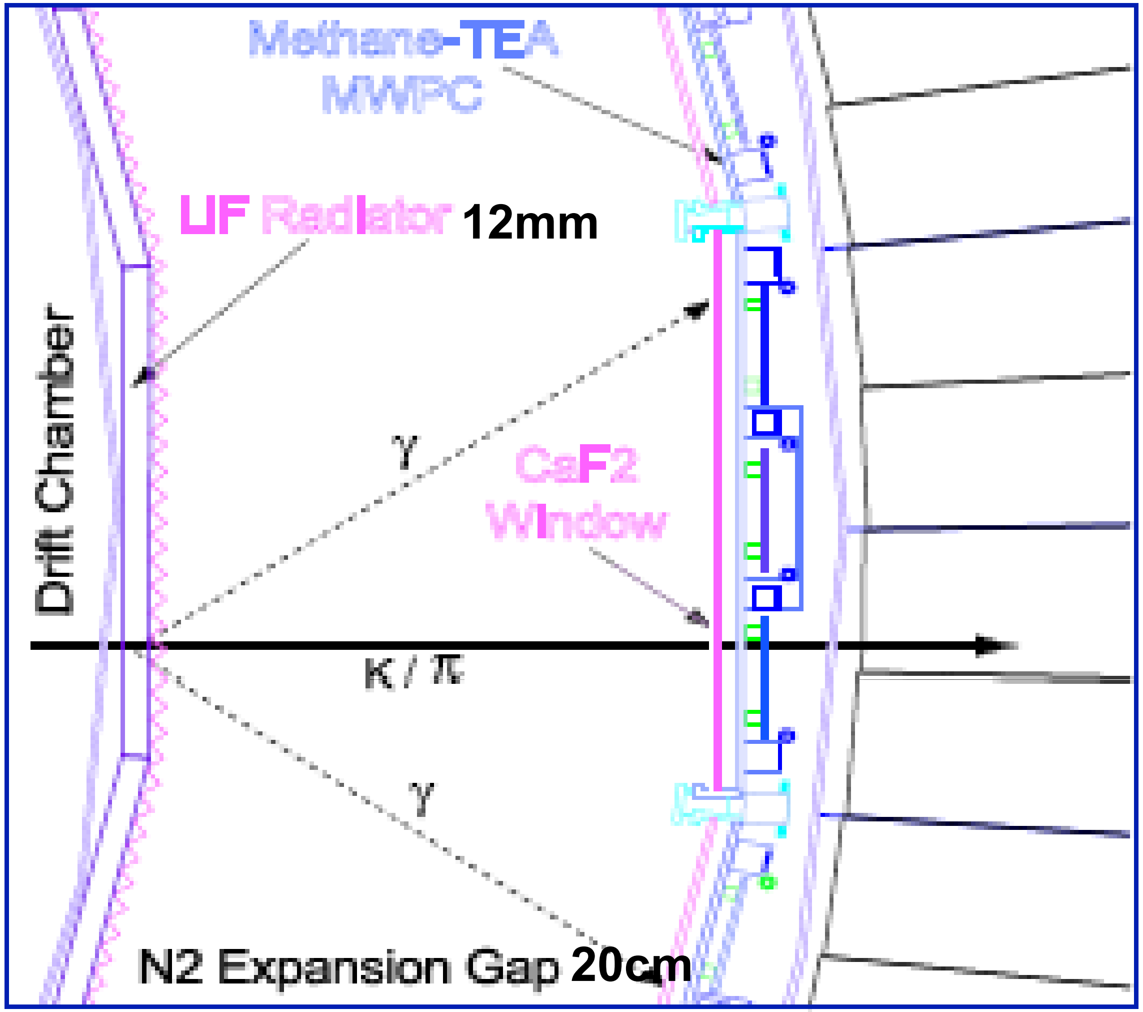
E.Kravchenko

P.Krizan

S.Nishida

Flavour physics – CLEOc

Beauty and Charm physics at CESR electron-positron collider



Proximity focused LiF RICH

π/K separation up to 3 GeV/c

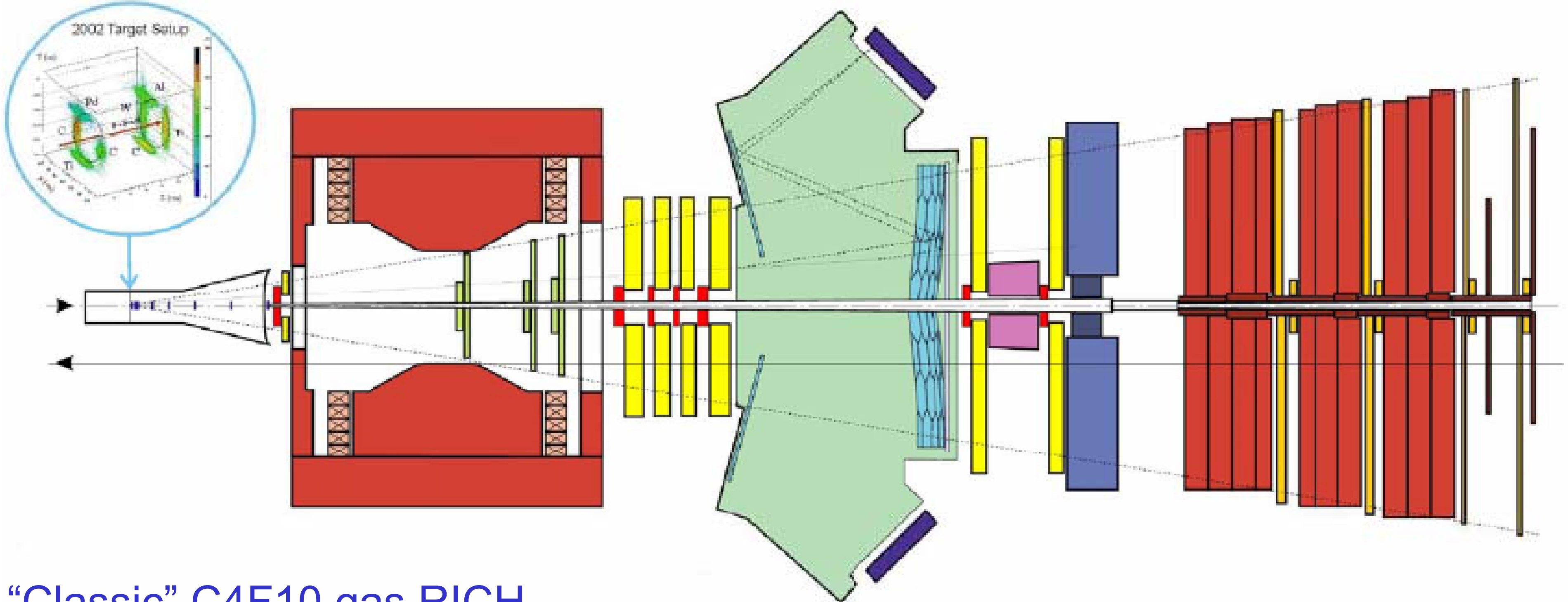
CH_4-TEA gas photo detector
20m² (biggest out there)

230k pixels: 8mm x 8mm

N_detected photons ~ 12
σ_θ ~ 14 mrad

Flavour physics – HERA-B

Beauty and Charm physics with fixed target at HERA proton ring



“Classic” C4F10 gas RICH

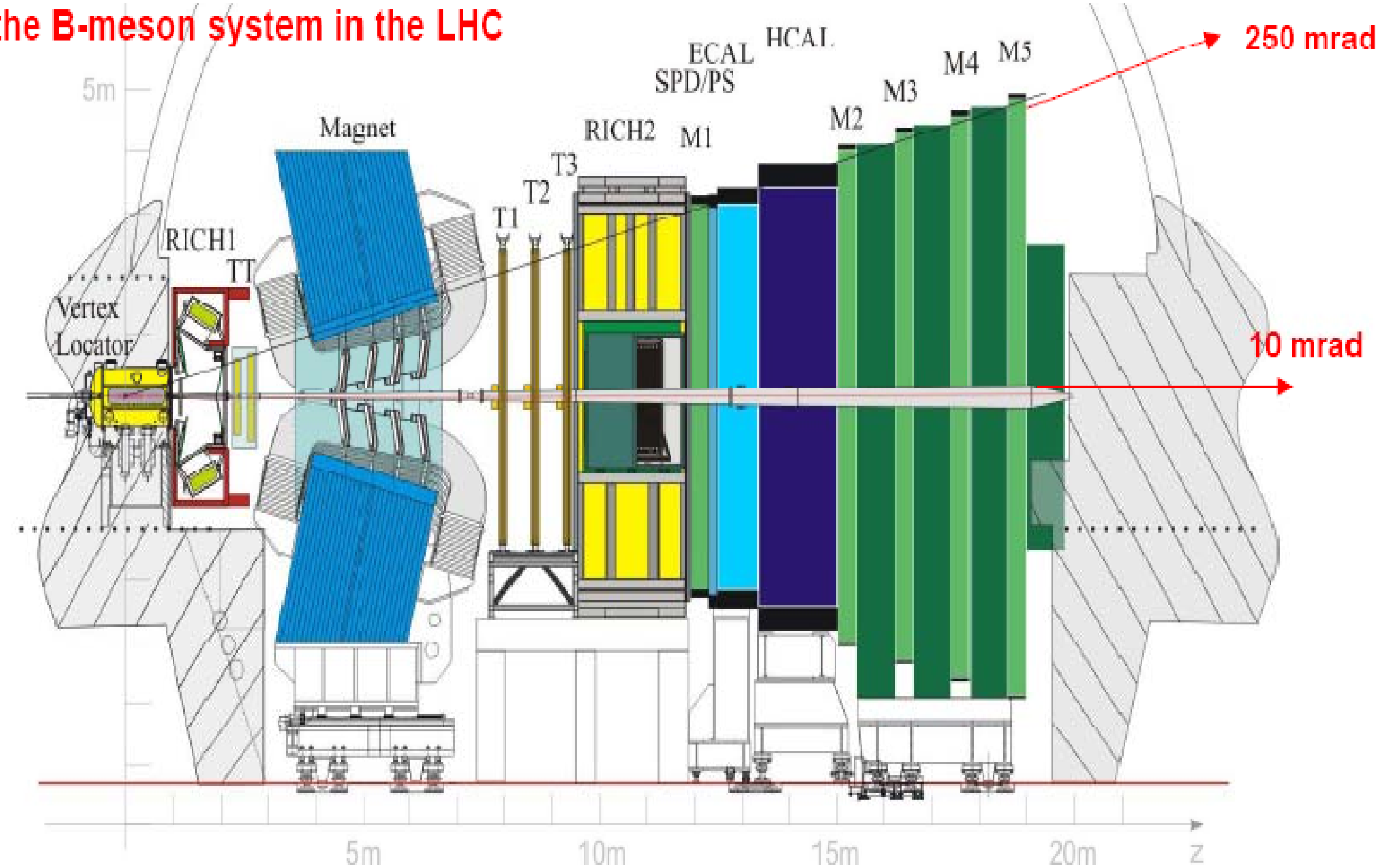
5 yrs stable good performance

Pioneered use of MultiAnode PMTs
Hamamatsu M4, M16 equipped with lenses

N_detected photons ~ 30
σ_θ ~ 1 mrad

Flavour physics – LHCb

Single arm spectrometer for precise CP Violation measurements and rare decays in the B-meson system in the LHC



Vertex reconstruction:	Trigger:	PID:	Kinematics:
VELO	Muon Chambers	RICHes	Magnet
	Calorimeters	Calorimeters	Tracker
	Tracker	Muon Chambers	Calorimeters

See talks by:
N.Harnew
C.D'Ambrosio
S.Eisenhardt
S.Brisbane
C.Buszello
T.Bellunato
A.Papanestis
F.Metlica
M.Sannino
D.Wiedner
F.Muheim

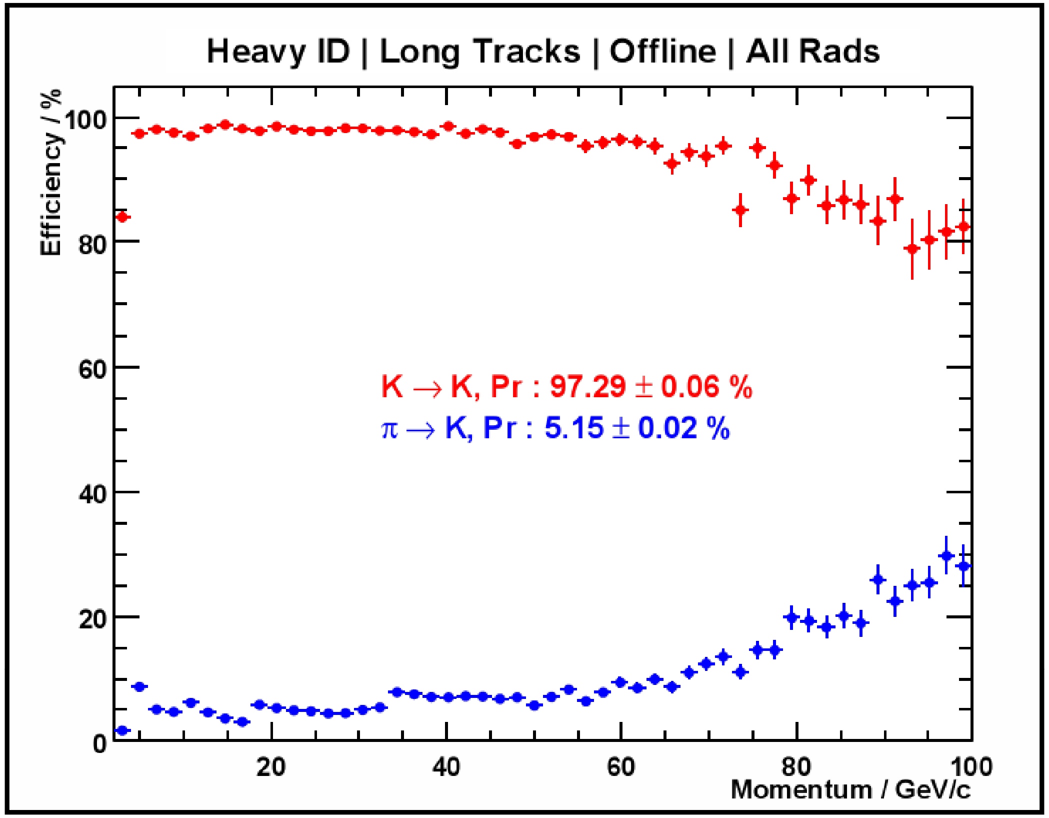
Flavour physics – LHCb

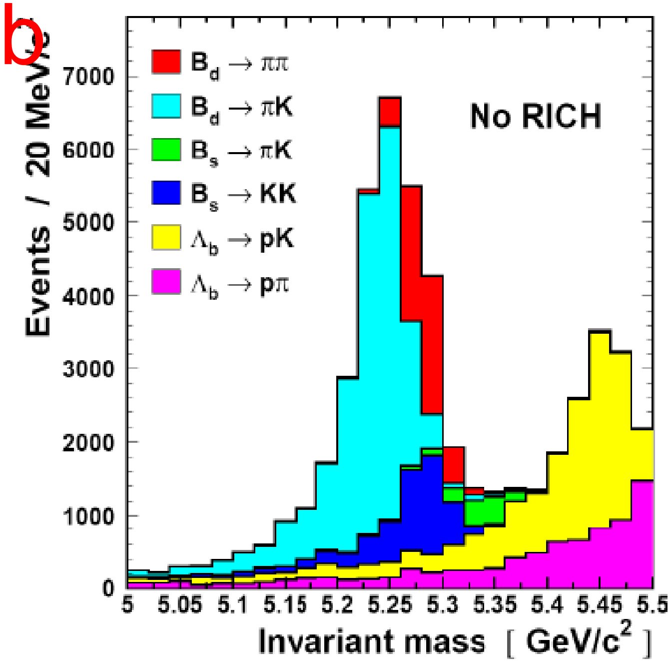
Hadron ID from 1-100GeV/c

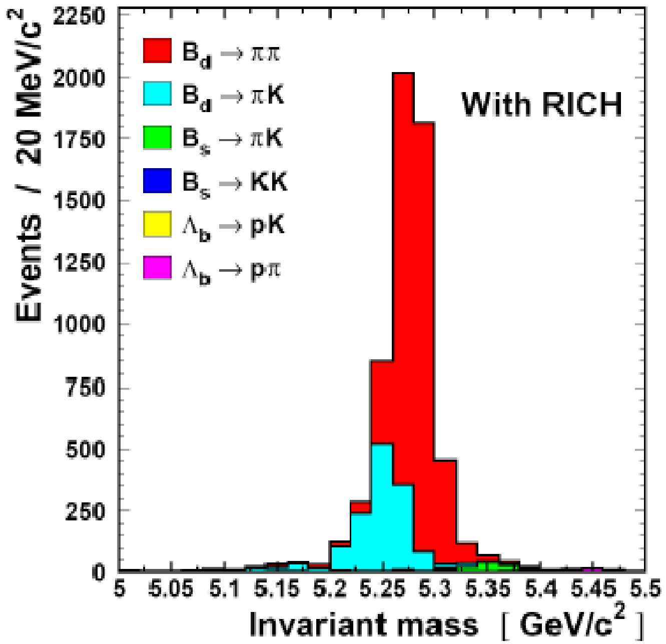
3 radiators: Aerogel, C_4F_{10}, CF_4

484 HPDs: 2.8m^2 with 2.5 x 2.5mm^2 pixels

Allows rare B-decay to be cleanly identified



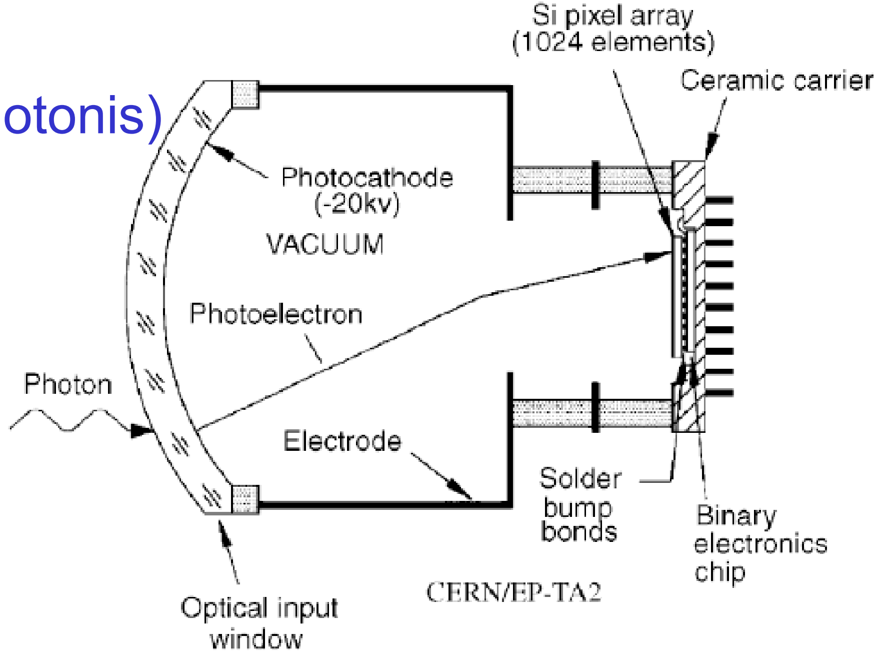


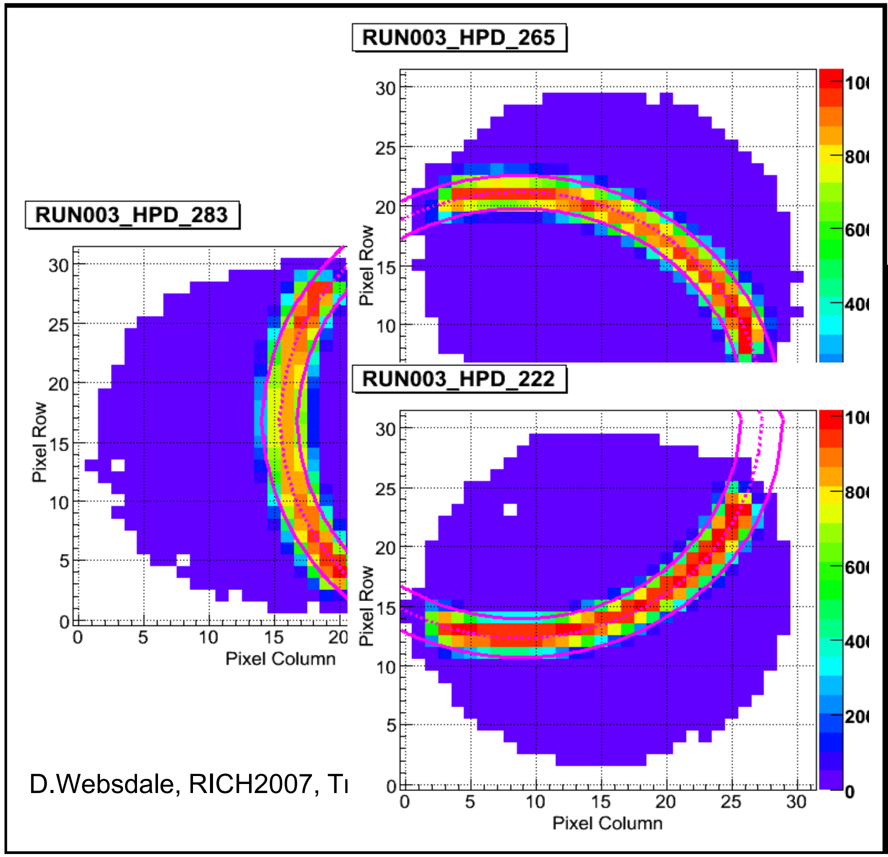


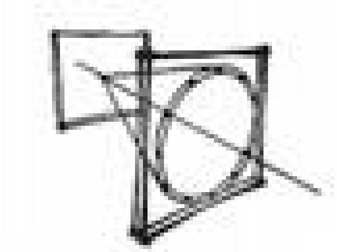
Hybrid Photon Detectors in LHCb RICH

LHCb has pioneered use of HPD (DEP-Photonis)

1000 pixels per tube: readout chip bump-bonded to sensor and encapsulated in vacuum tube







Flavour physics – NA62 at CERN

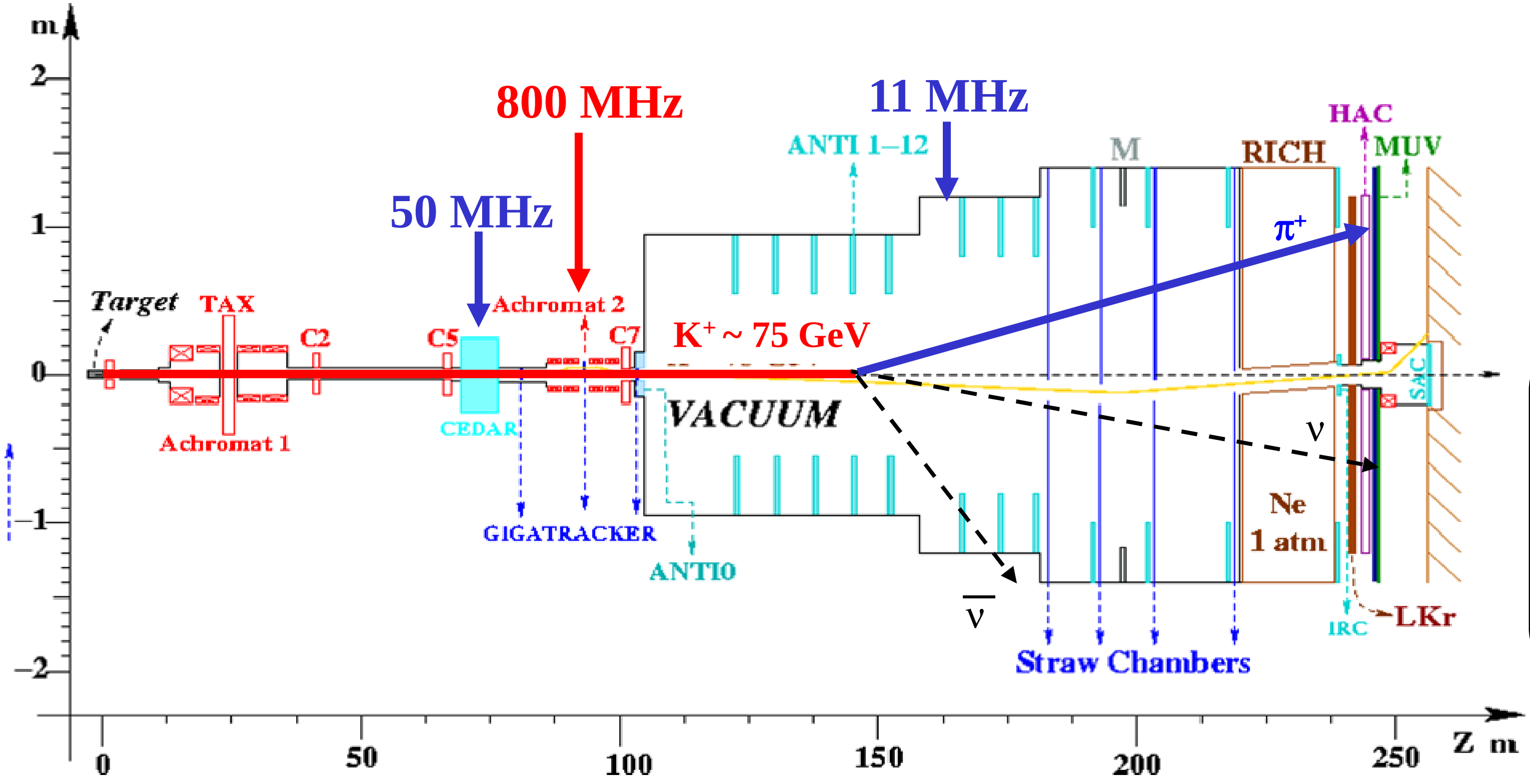
Measure $K^+ \to \pi^+ \nu \nu$ branching fraction to extract V_{td}

SM prediction: 0.8 x 10^{-11}

See talk by:
F.Bucci

$K^+ \to \mu^+ \nu$ background: x 10^{12} rejection required (RICH x μ-veto x kinematics)

18m Ne radiator "classic" RICH with 16mm PMTs will deliver σ_θ < 0.1 mrad
e- μ- π separation over 10 – 70 GeV/c



CKM (kTeV2)
Similar expt
Was planned
for FNAL
Main injector

Nucleon structure physics - HERMES

See talk by:
R.De Leo

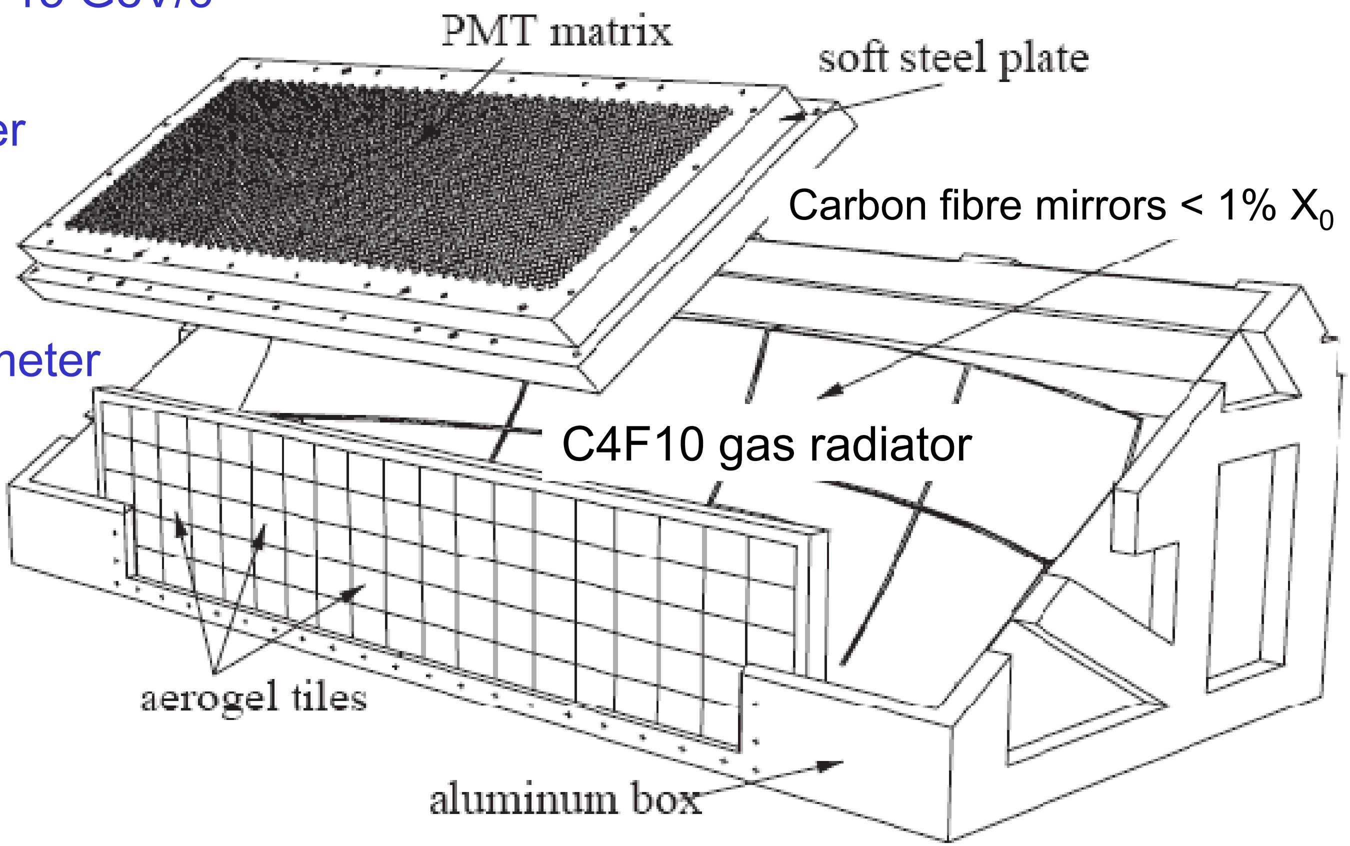
HERA electron beam on polarized gas-jet target

Probe spin structure of nucleon

C_4F_{10} gas + Aerogel radiators (Pioneered Aerogel RICH)
Hadron ID in range 2 – 15 GeV/c

Completed in 2007 after
7 years stable running

2000 PMTs 23mm diameter
N_photon hits ~12
σ_θ ~ 7mrad



Nucleon structure physics - COMPASS

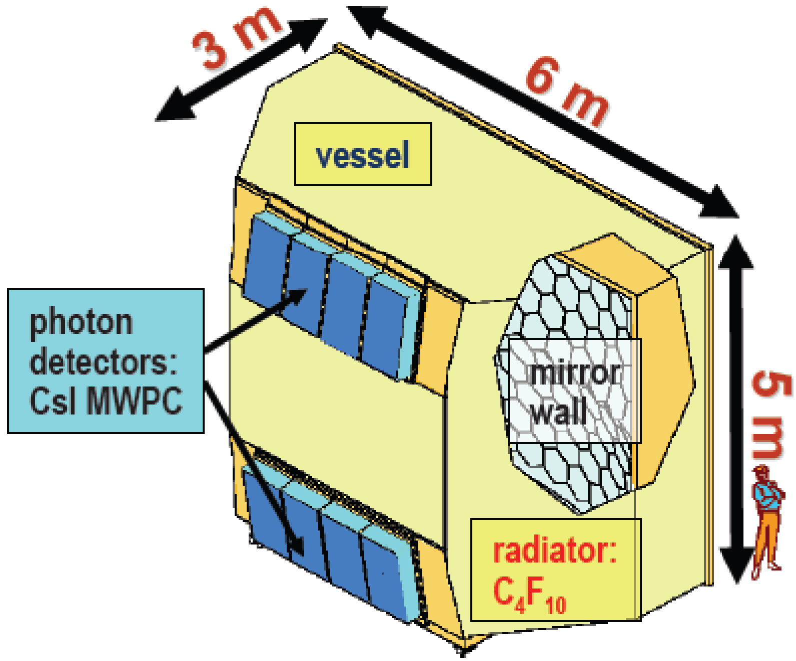
160 GeV polarized muons on polarized target at CERN SPS

Probe of gluon structure function and spin of nucleon

Charm is signature of gluon (no vertex detector so hadron ID is crucial)

RICH: C_4F_{10} gas radiator, mirror ($20m^2$) focused RICH

$5m^2$ CsI photocathode + MWPC ($1cm^2$ pixel)



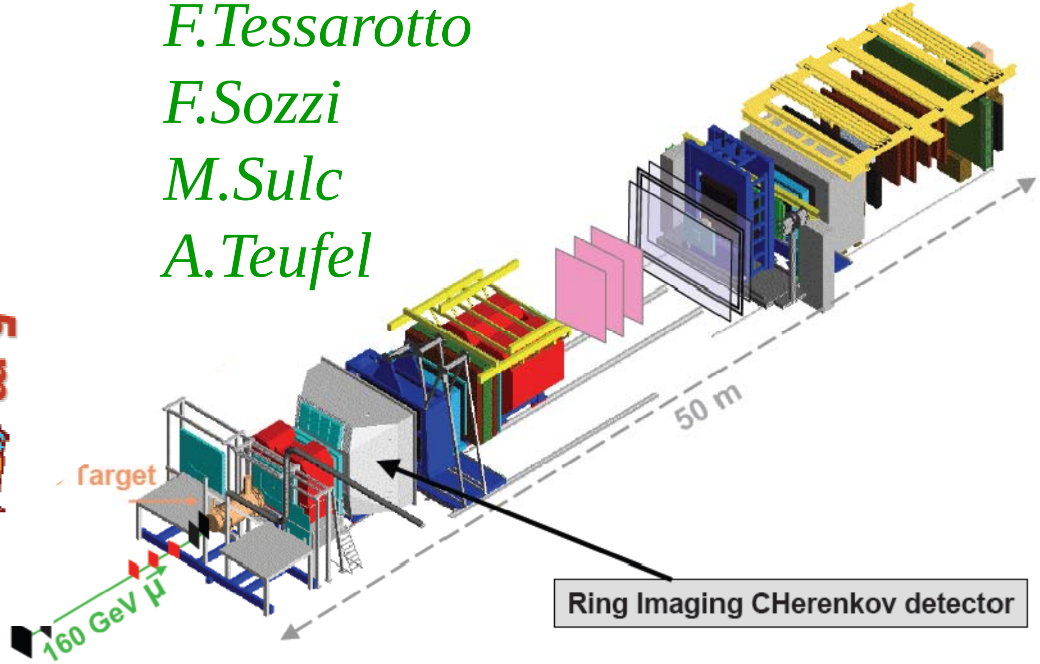
See talk by:

F.Tessarotto

F.Sozzi

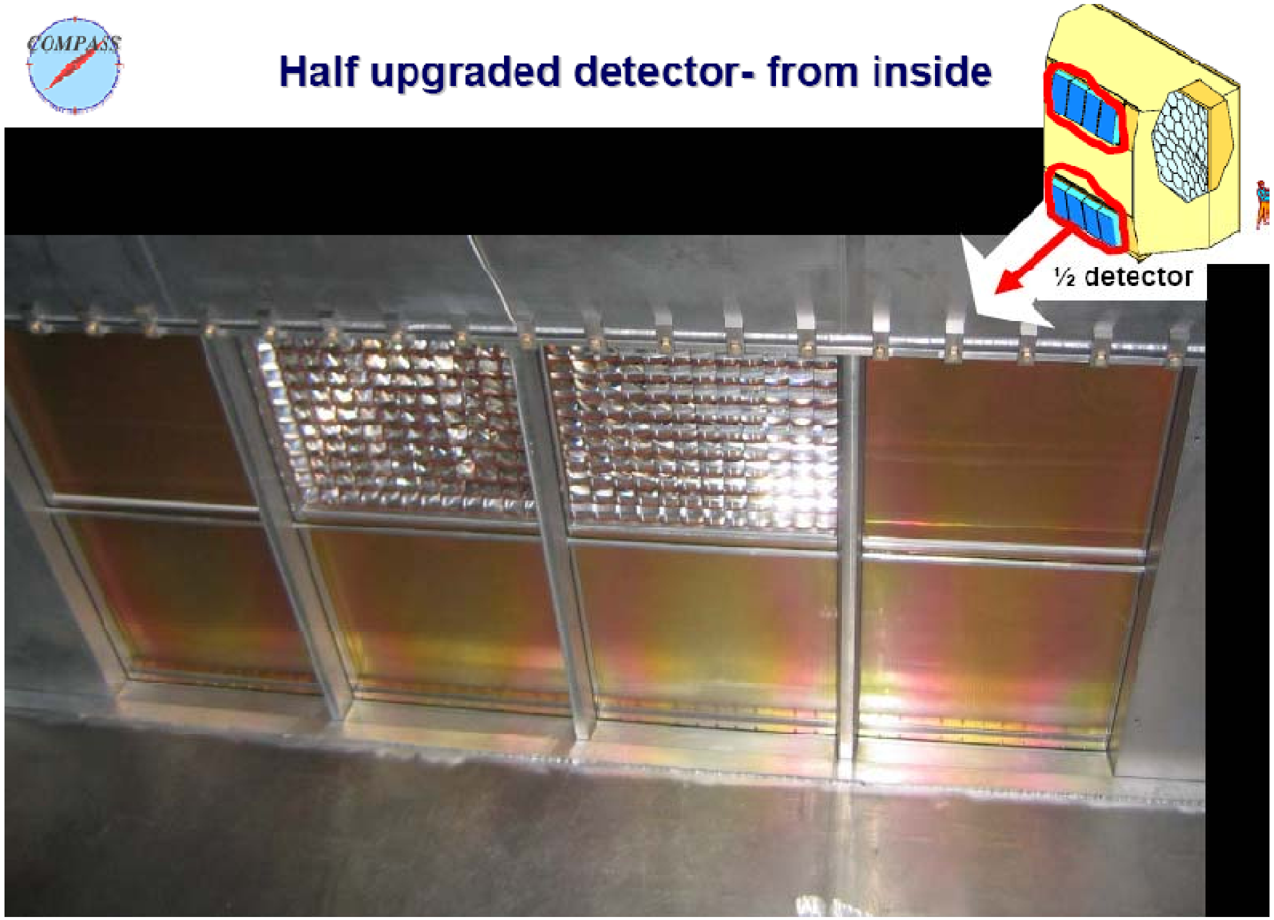
M.Sulc

A.Teufel



Nucleon structure physics - COMPASS

Compass operation stable after 2 years running in
2006 upgrade: Replaced central CsI photon detectors by M16 MaPMTs



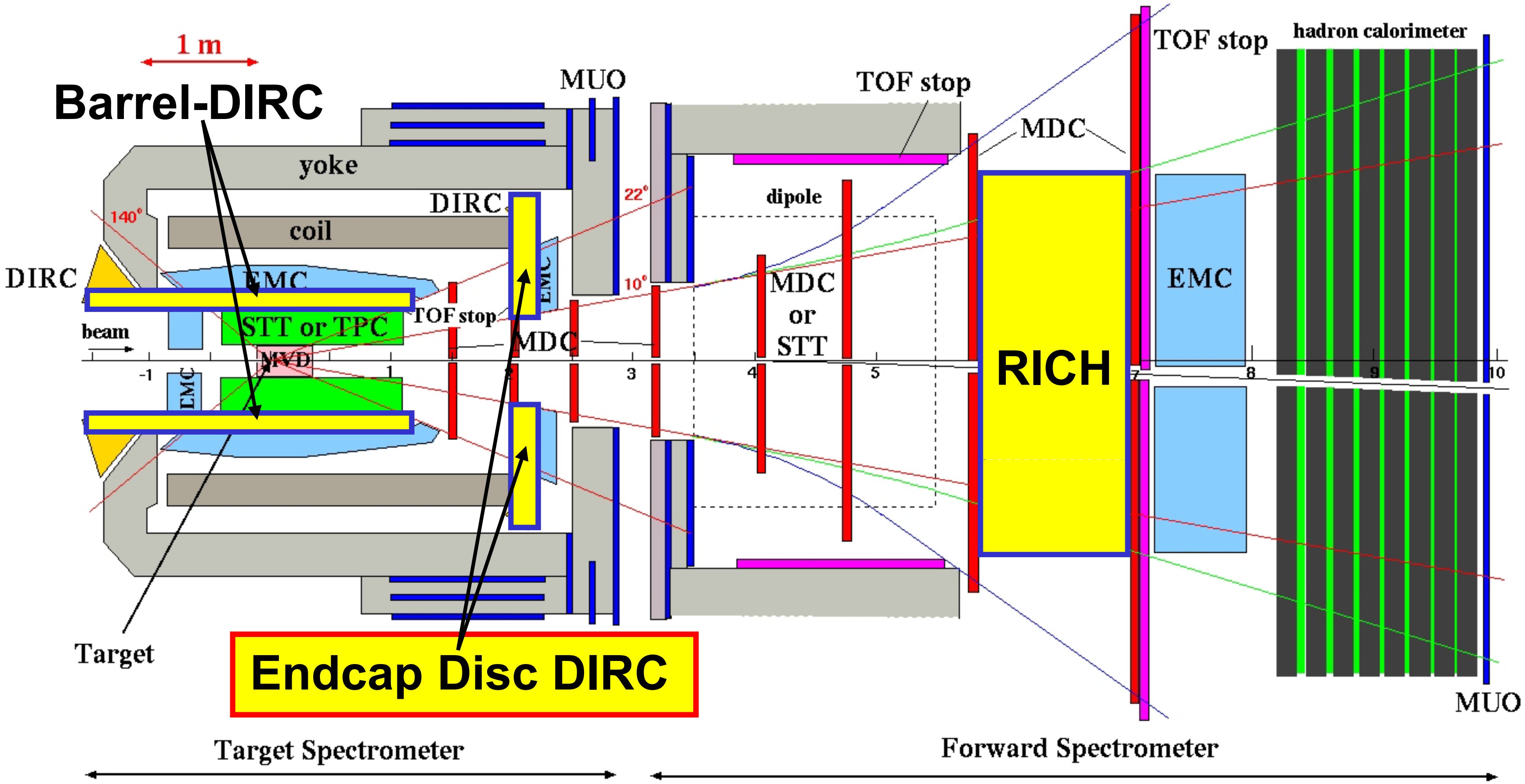
Big improvement

$N\gamma$ ~ 60 (cf 14)
σ_{ring} ~ 0.3mrad(0.6)
PID up to 55 GeV (43)
Δt ~ 1ns (3μs)

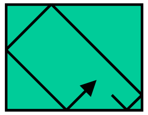
Hadron physics (low p_T) - PANDA

PANDA: AntiProton ANihilations at Darmstadt (~2013)
100% acceptance fixed target spectrometer at **FAIR**
(**F**acility for **A**ntiproton and **I**on **R**esearch at GSI)

Exotic hadron spectroscopy – glueballs, quark molecules, hybrids



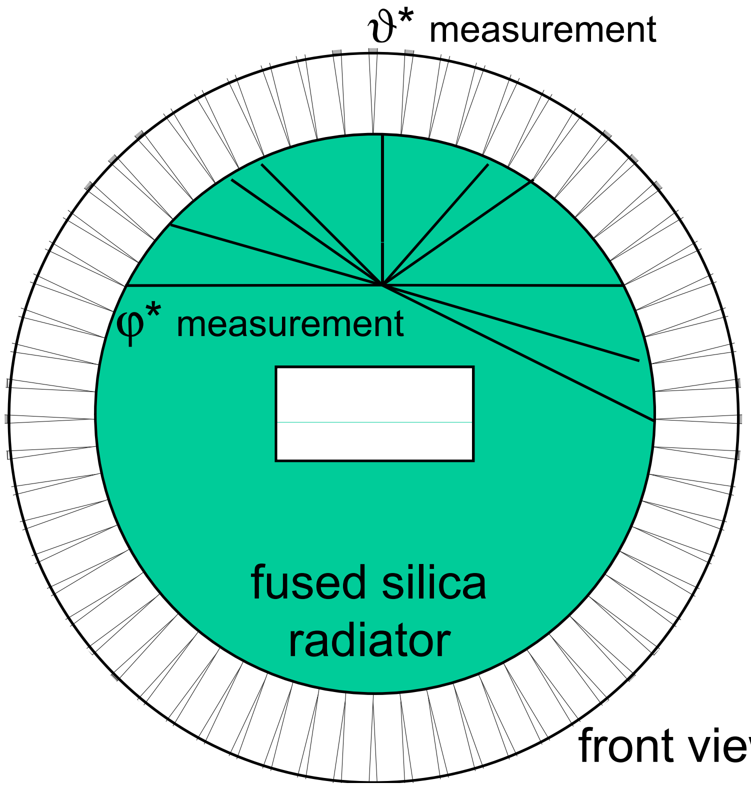
Cherenkov Detectors in PANDA

- HERMES-style RICH
- BaBar-style DIRC — 2-dimensional imaging type 
- **Disc focussing DIRC**

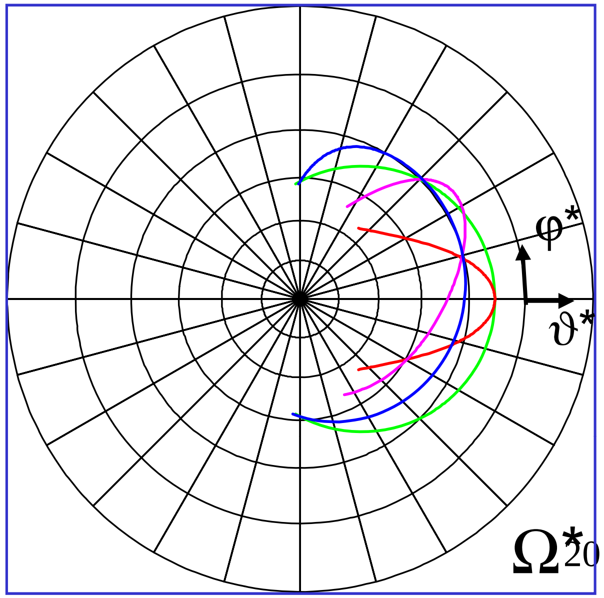
See talk by:
K.Föhl
C.Schwarz
P.Schönmeier

one-dimensional imaging DIRC type


side view



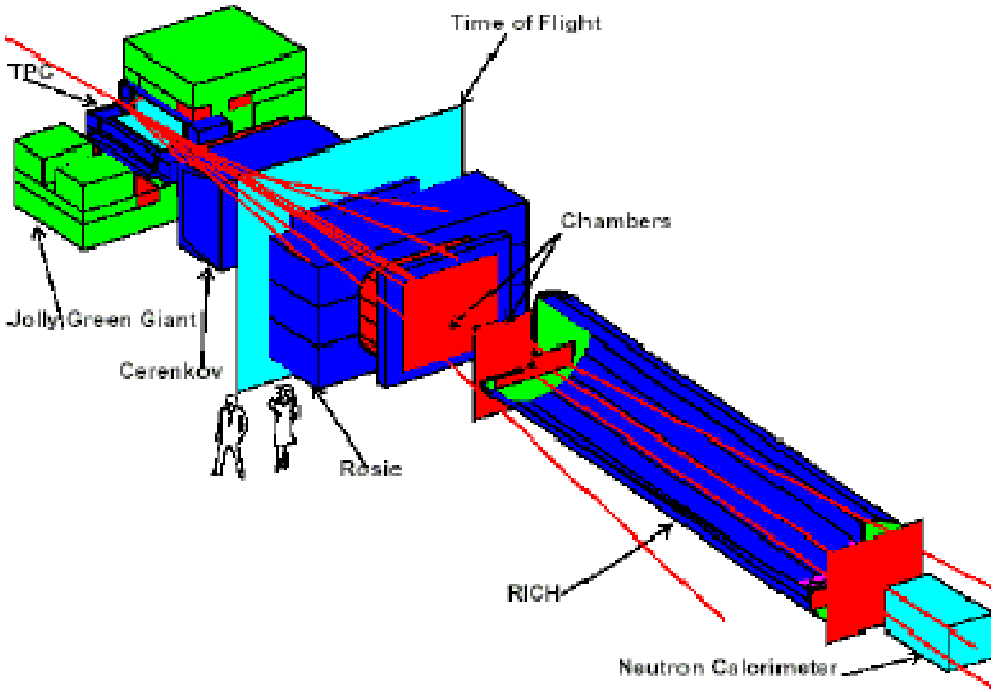
front view



Hadron physics (low p_T) – MIPP

MIPP

Main Injector Particle Production Experiment (FNAL-E907)



See talk by:
N.Graf

100% acceptance spectrometer
π,K,p beam from FNAL Main Injector

CO_2 classic RICH, 3000 PMTs
3σ π / K separation up to 90 GeV

Planned upgrade for neutrino beam and ILC studies (verification of Hadron interaction simulation codes)

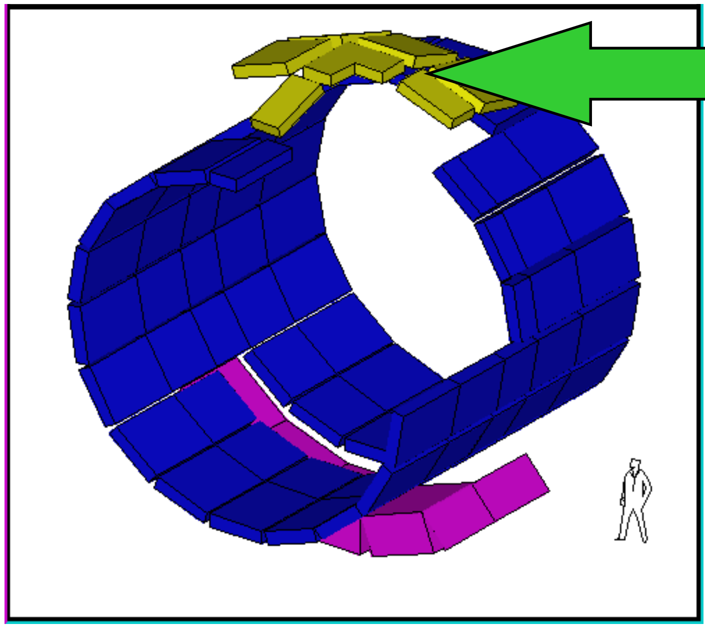
COMPASS also moves on to its hadron spectroscopy programme

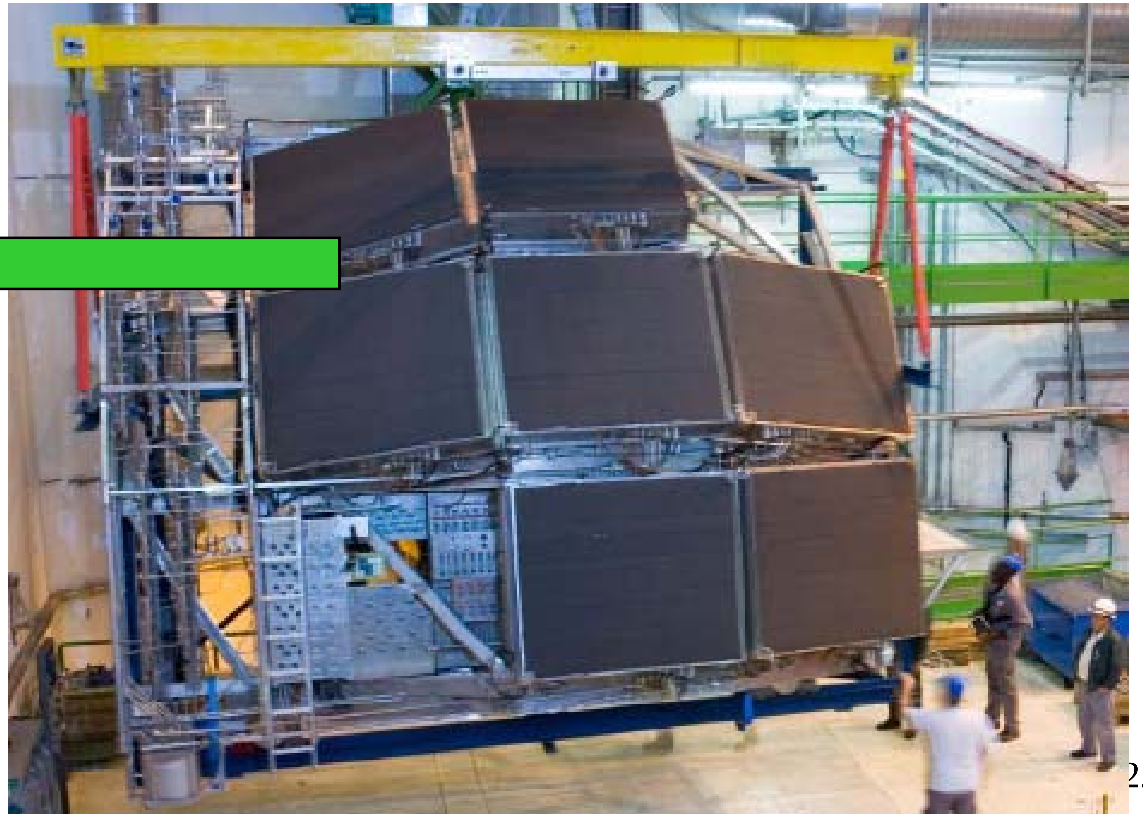
Heavy Ion physics - ALICE

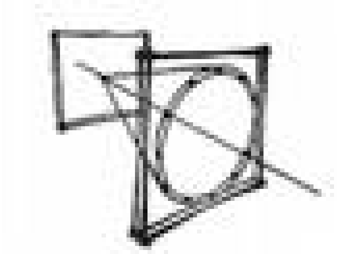
See talk by:
A.Di Mauro
G.Volpe
D.Di Bari

ALICE studies the physics of strongly interacting matter and the quark-gluon plasma (QGP) in nucleus-nucleus collisions at the LHC.

The HMPID RICH identifies hadrons π/K/p in the range 1/3/5 GeV/c







Heavy Ion physics - ALICE

Measurement of particle ratios over a wide momentum range
dE/dx, TOF, RICH, TRD are used

The HMPID RICH covers the range 1-5GeV/c

7 modules of 1.5m x 1.5m (5% of barrel)
C_6F_{14} liquid radiator, proximity focused → CsI + MWPC (8mm x 8mm pixels)

VHMPID: upgrade planned to extend PID to 30 GeV/c.

C_5F_{12} gas radiator (1m) mirror-focused RICH
CsI photocathode + GEM photon detector

See talk by:
G.Volpi

Heavy Ion physics - JLAB

JLAB: fixed target High Resolution Spectrometer

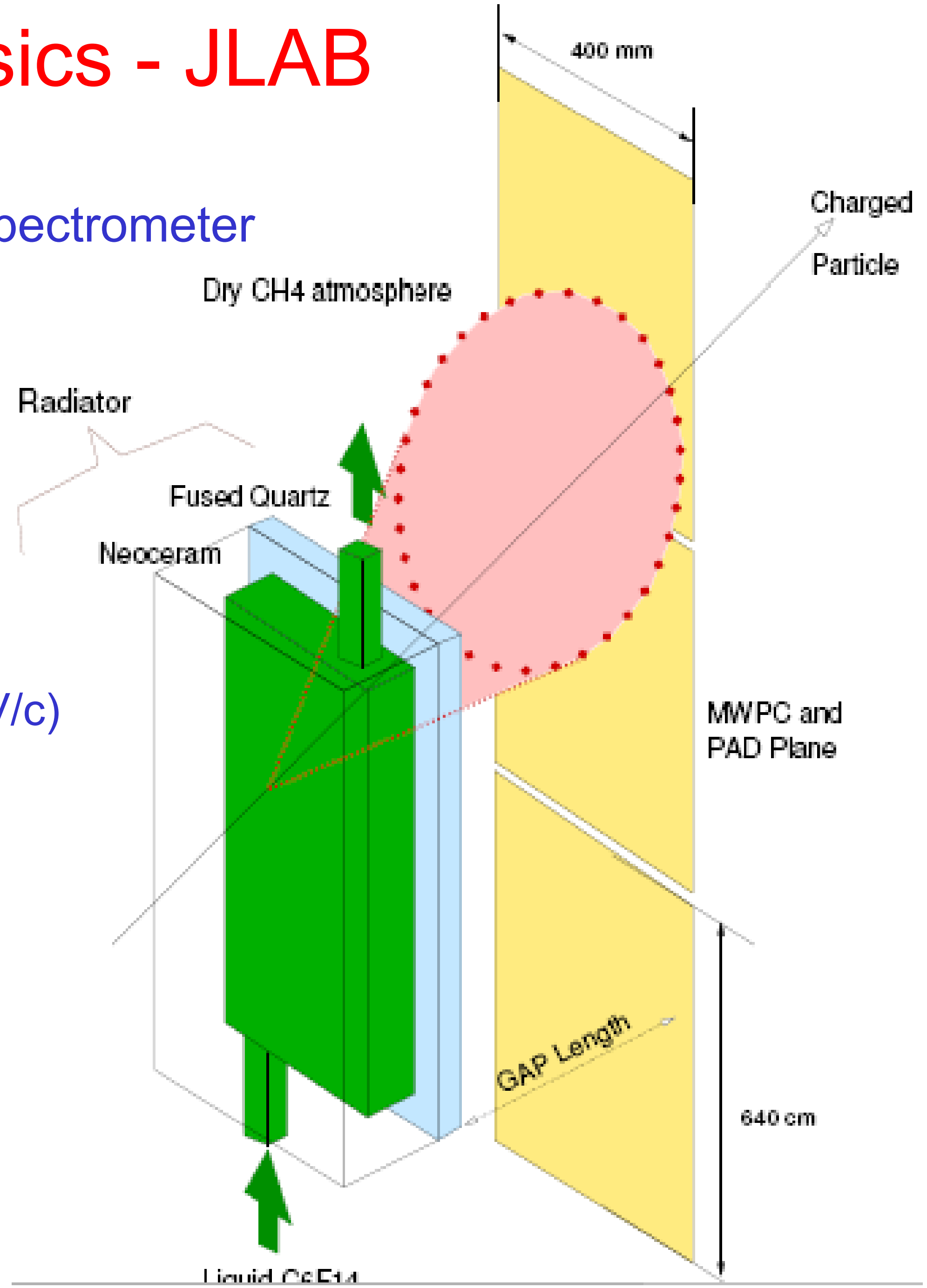
RICH for K physics
Same technology as ALICE HMPID

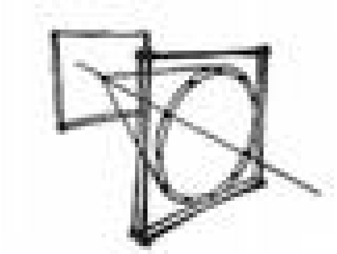
Electron scatter from nuclei
(ee'K) reaction creates hypernuclei
important to physics of neutron stars

Pion rejection factor ~ 1000 (0.8 – 3 GeV/c)

Upgrade foreseen for 2008 running

See talk by:
E.Cisbani

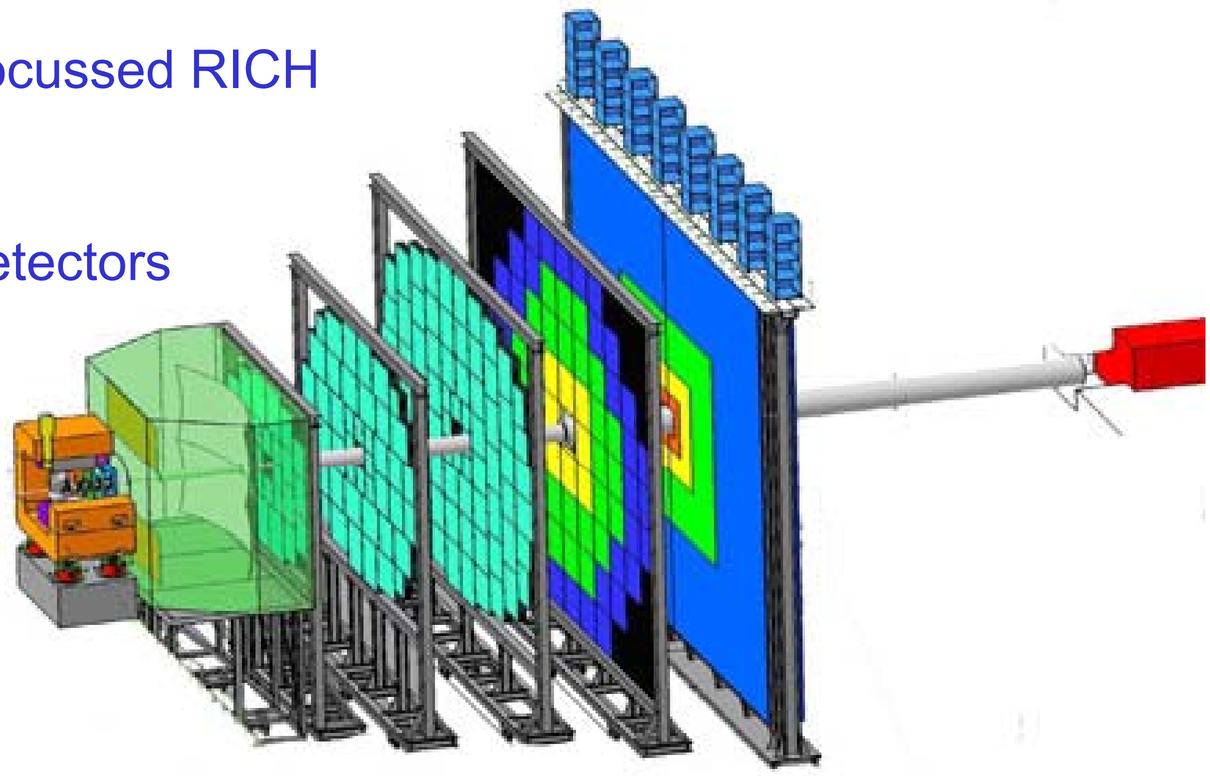




Heavy Ion physics - CBM

CBM: **C**ompressed **B**aryonic **M**atter at FAIR, GSI (2013)
Fixed target: 15-35 AGeV, 10MHz rate
Detect low-mass vector mesons → leptons
PID up to 10GeV/c with excellent electron ID

RICH: "Classic" mirror-focussed RICH
2.2m gas radiator
Be-glass mirrors
MaPMT photon detectors



See talk by:
C.Höhne

Heavy Ion physics - RHIC

Relativistic Heavy Ion Collider: E_{CM} = 200 AGeV

Physics requirements

- Compare hadron ratios: e.g. meson/baryon in p-p vs A-A
- Identify electron pairs: nuclear matter is transparent so probe interior

Three of the experiments use RICH for PID

BRAHMS

C_4F_{10}/C_5F_{14} gas: M4 MaPMTs: hadron ID up to 30GeV

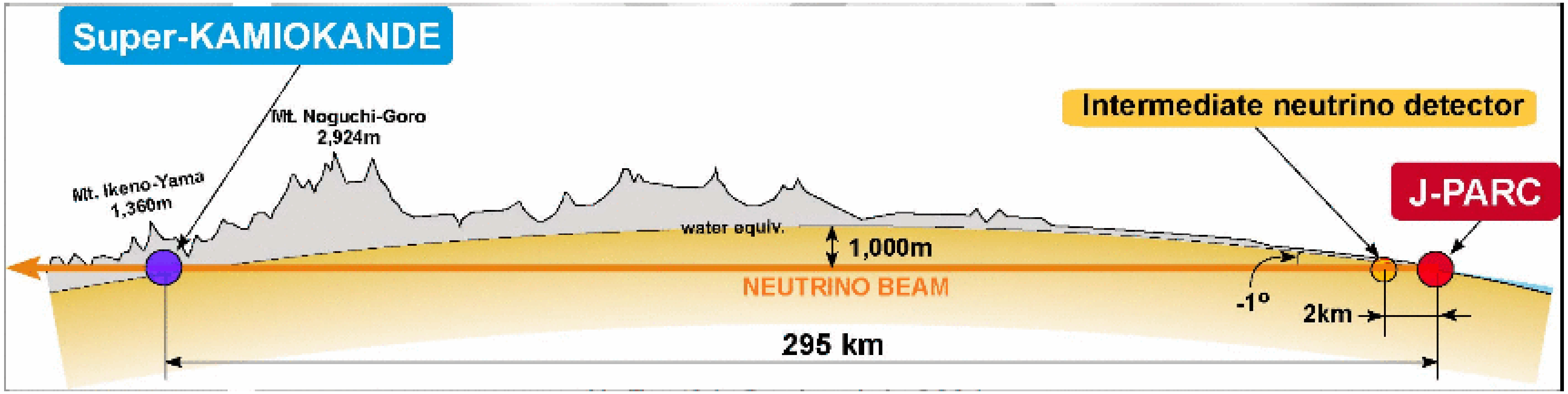
PHENIX

CF_4 gas: CsI photocathode: hadron blind electron ID

STAR (ALICE-like RICH)

C_6F_{14} liquid: proximity focused: π/K/p ID from 1/3/5GeV/c

Neutrino physics – T2K (2009)



Super Kamiokande

The largest Cherenkov in use at an accelerator-based experiment will soon be fully repaired, operational with upgraded DAQ
50ktonnes water viewed by 13,000 20" PMTs

Upgrade : deadtime-less acquisition and enhanced DAQ allow refined trigger and lower (~2MeV) threshold
Aim is to measure mixing angle θ_{13}

Summary - 1

Many accelerator/collider experiments use or plan to use RICH detectors

Flavour physics and CP violation	**BELLE, BABAR,** HERA-B, **LHCb, NA62**
Nucleon structure	**HERMES, COMPASS**
Hadron (low p_T) physics	**PANDA, MIPP, COMPASS**
Heavy Ion physics, QGP	**ALICE, JLAB, CBM,** STAR, BRAHMS, **PHENIX**
Neutrino oscillations	T2K (**MIPP**)

Bold type = reporting at RICH 2007

NB: Not in high p_T collider detectors – Tevatron, LHC GPDs

Summary - 2

Personal observations and interpretations

Ubiquity of the RICH detector

Diversity of RICH detector types – choice informed by:

- physics requirements
- space constraints
- cost

Current trends

- Classic mirror-focused gas RICH for high energies
- Use of vacuum tube photon detectors where feasible
- Proximity focused + CsI+MWPC/GEM photon detectors for large areas
- Emergence of DIRC as favoured technique for barrel configuration

Future trends

- Exploring benefits of precise timing (TOP)
- Development of solid state photon detectors