7th International Workshop on Ring Imaging Cherenkov Detectors

RICH 2010

Cassis, Provence, France, 2-7 May 2010

A REPORT

S. Dalla Torre

A SUMMARY BY PICTURES

A SUMMARY BY FIGURES

PREVIOUS

RICH WORKSHOPS :

- Bari 1993
- Uppsala 1995
- Ein Gedi 1998
- Pylos 2002
- Playa del Carmen 2004
- Trieste 2007

- **IN TOTAL**
  - ~ 700 participants
  - ~ 400 talks and posters
  - ~ 60 Invited review talks
  - 6 NIM Volumes containing

RICH 2010

- ~120 participants
- 8 invited talks
- 41 contributed talks
- 37 posters
- 1 more NIM volume expected

After 17 years, the community and the interest are still growing !

→ Great vitality in this field

SCIENTIFIC PROGRAMME

Cherenkov imaging in particle and nuclear physics experiments (*)

Cherenkov detectors in astroparticle physics (*)

Novel Cherenkov imaging techniques (*)

Photon detection for Cherenkov counters (*)

Technological aspects of Cherenkov detectors

Pattern recognition and data analysis

Research & Development for future experiments (*)

in the following highlights from (*)

REFERENCES

All the RICH2010 scientific material is available at:

http://indico.in2p3.fr/conferenceTimeTable.py?confId=1697

- The individual speakers are not quoted in the following slides
- I thank for the great material I am making use of all the Colleagues who contributed to RICH2010

CHERENKOV IMAGING COUNTERS & PHYSICS

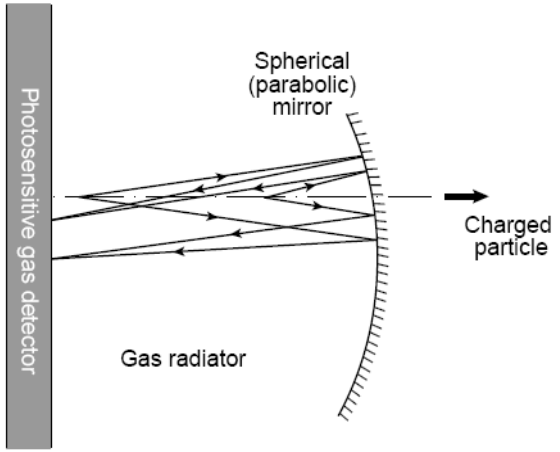
1. particle and nuclear physics

THE FAMILY OF RICH COUNTERS

an introductory slide

With focalization

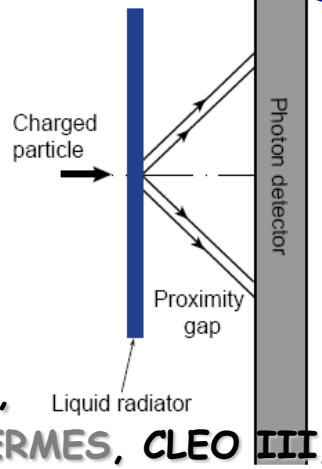
- Extended radiator (gas)
- the only approach at high momenta (p > 5 GeV/c)



- EXAMPLES: SELEX, OMEGA, DELPHI, SLD-CRID, HeraB, HERMES, COMPASS, LHCb RICH1 and RICH2

Proximity focusing

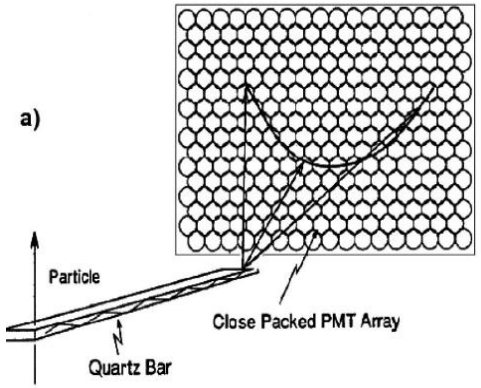
- thin radiator (liquid, solid)
- Effective
- at low momenta (p < 5 GeV/c)

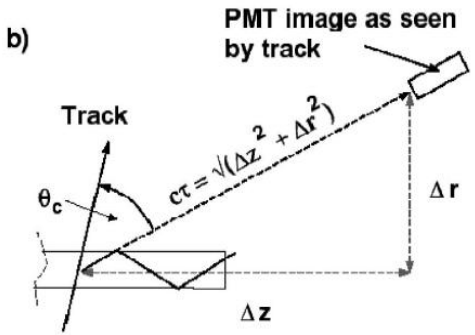


- EXAMPLES: STAR, ALICE HMPID, HERMES, CLEO III, LHCb RICH1

DIRC

- Quartz as radiator and as light guide
- Effective at low momenta (p < 5 GeV/c)



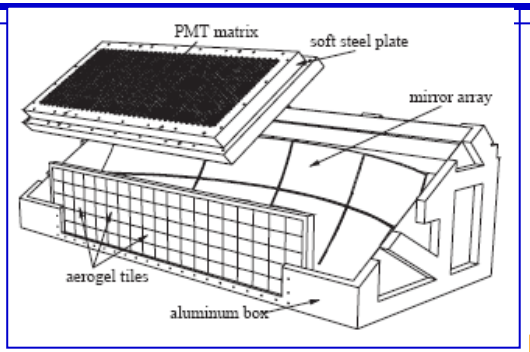


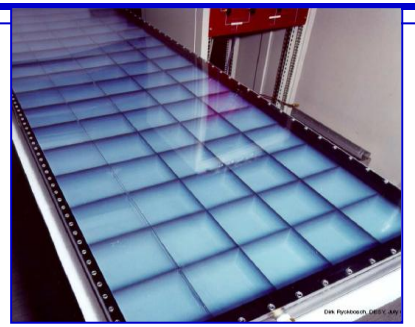
- The only DIRC ever used in an experiment is BABAR DIRC

RICHes recently RETIRED

HERMES dual RICH @ HERA, DESY

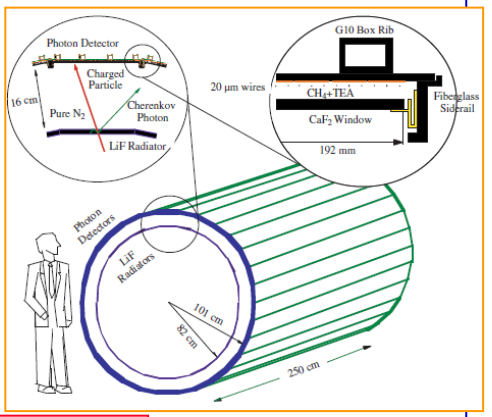
- 2 radiators (aerogel, C4F10), PMTs





CLEO III RICH @ CESR, Cornell

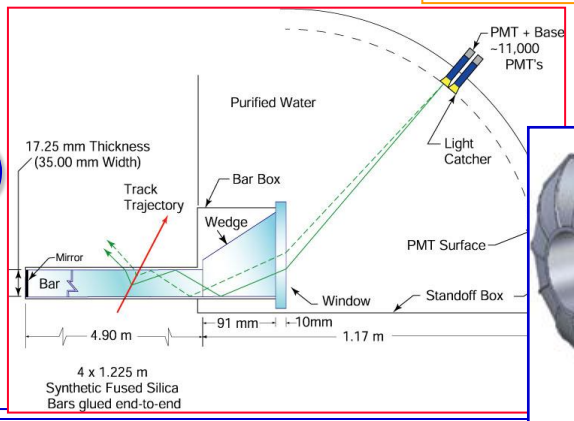
- Proximity focusing, LiF, MWPCs with TEA

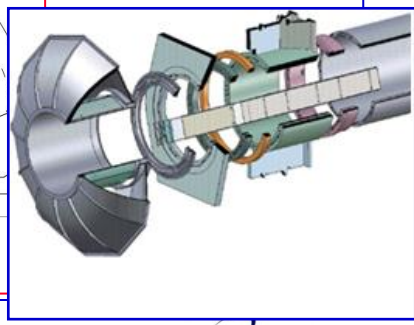


BaBar DIRC @ PEP-II, SLAC

- DIRC invention, quartz bars as radiator & guide light, PMTs (~11k !)

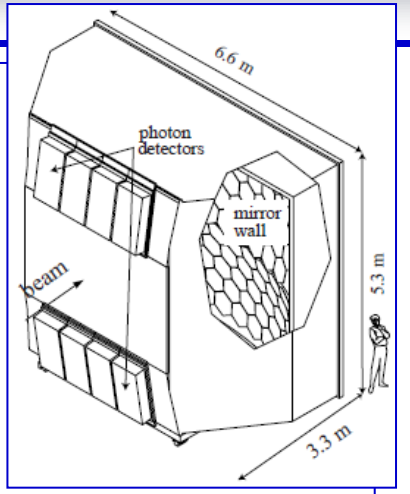
… <u>data analysis still on-going</u> …

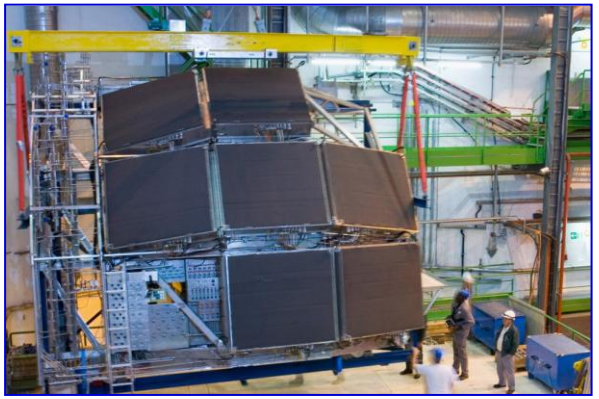




RICHes in OPERATION

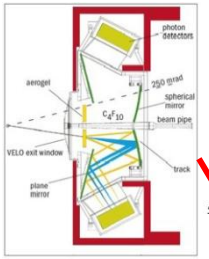
- **COMPASS RICH-1 @ SPS, CERN**
  - in operation since 2001, upgraded in 2006

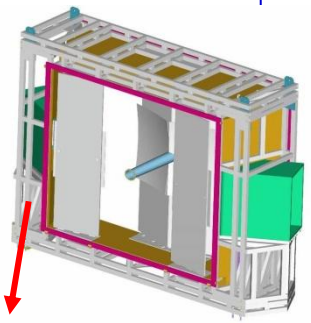


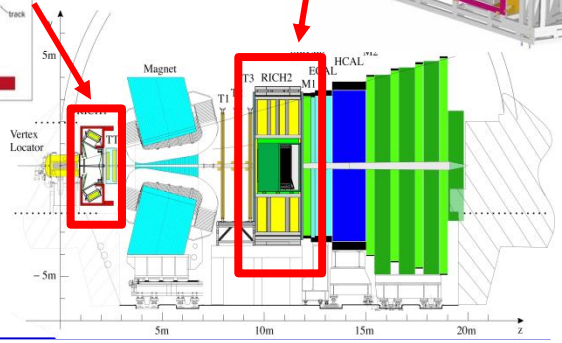


- **ALICE HMPID @ LHC, CERN**
  - starting operation

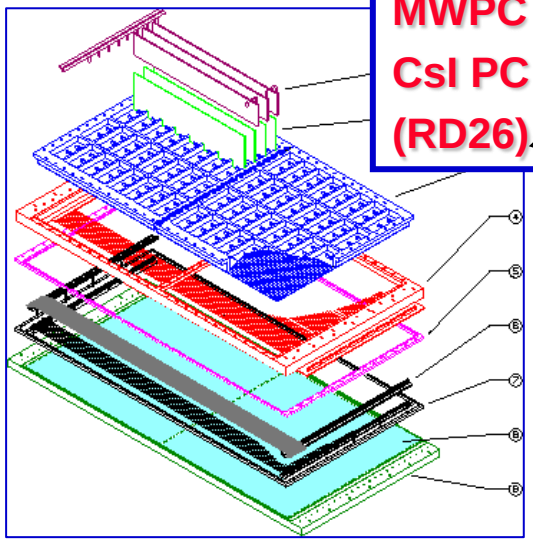
- **LHBb RICH1 and RICH2 @ LHC, CERN**
  - starting operation



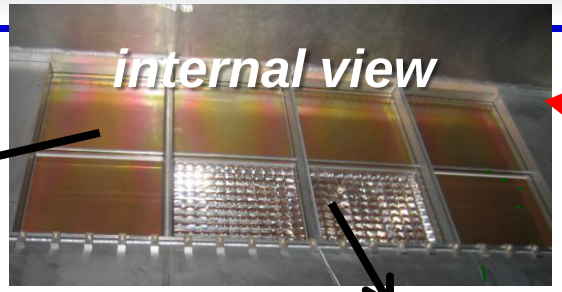


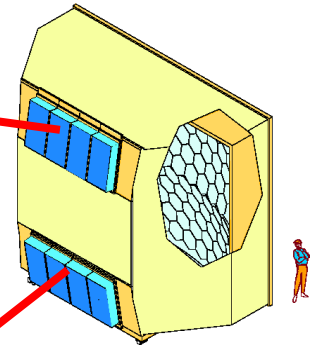


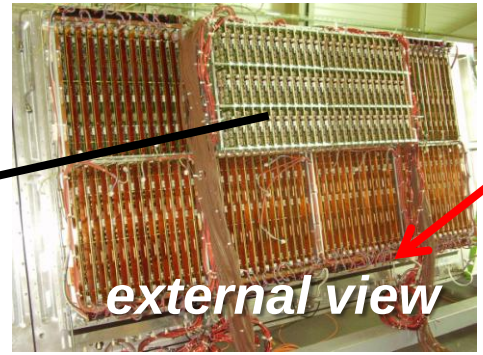
COMPASS RICH-1



MWPC
CsI PC
(RD26)

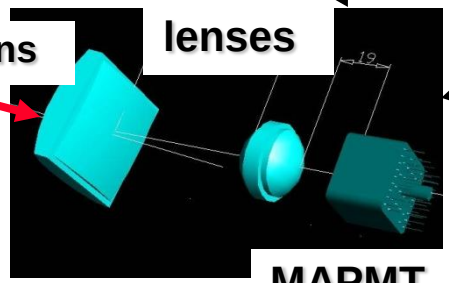






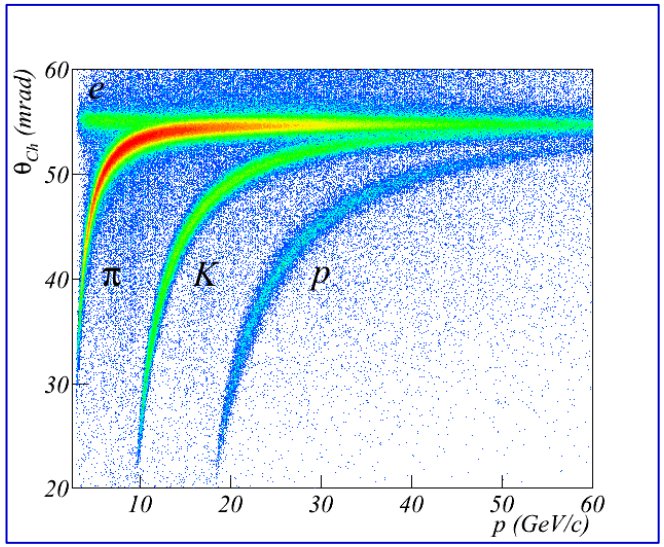
photons

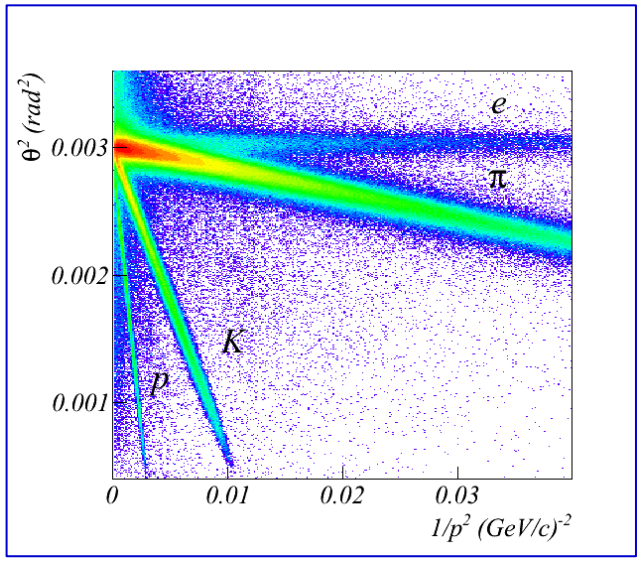
lenses



MAPMT

radiator gas: C_4F_{10}



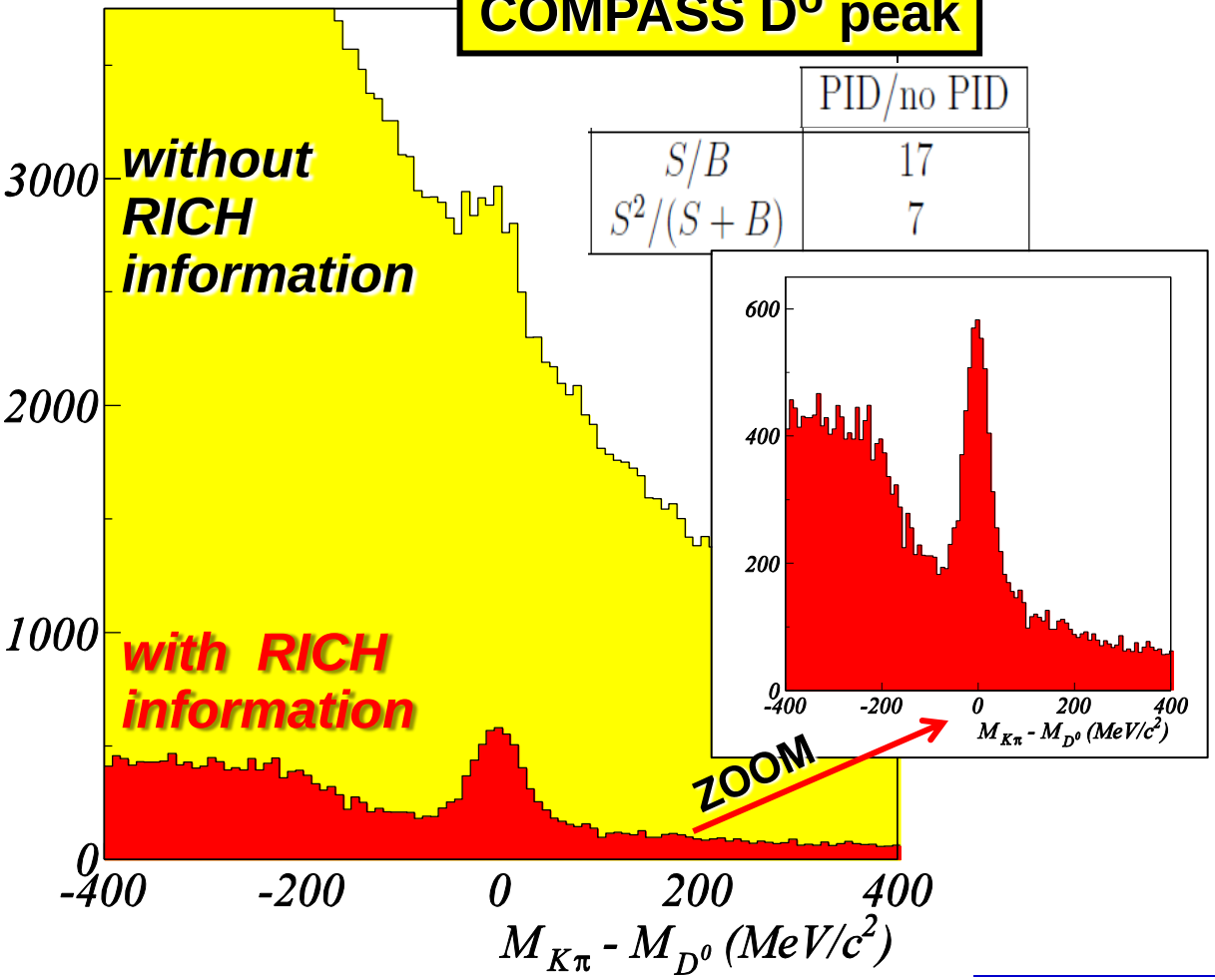


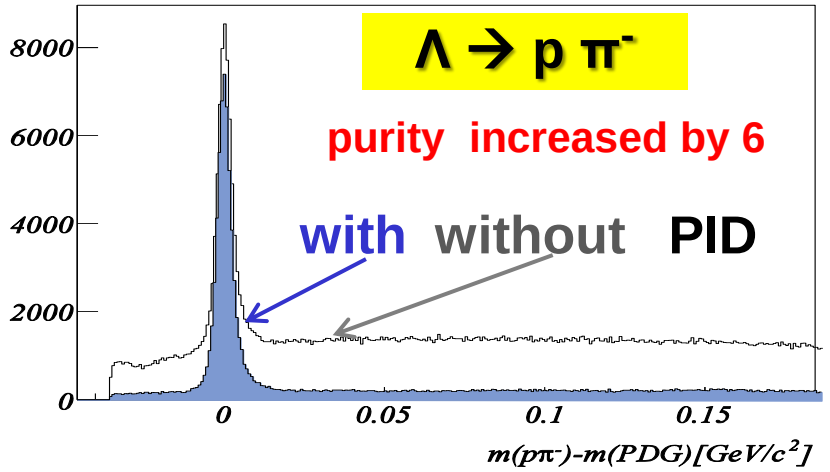
COMPASS RICH-1 FOR PHYSICS

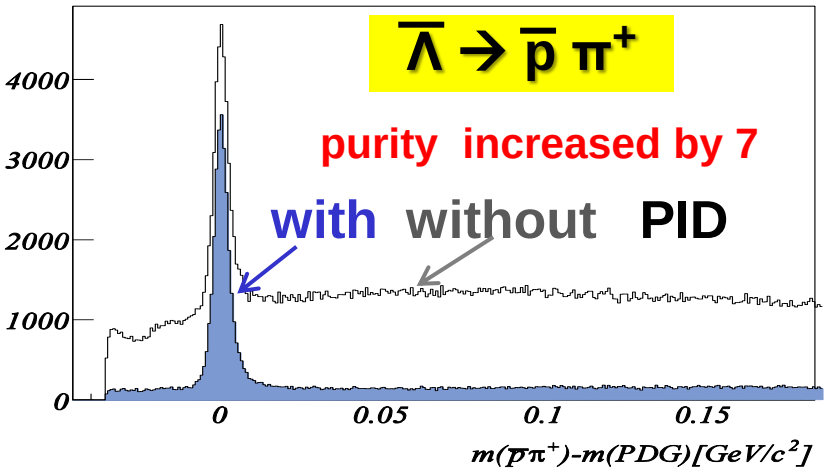
Recall : @ COMPASS no vertex information available (solid polarised target)

COMPASS D^0 peak

	PID/no PID
S/B	17
$S^2/(S+B)$	7

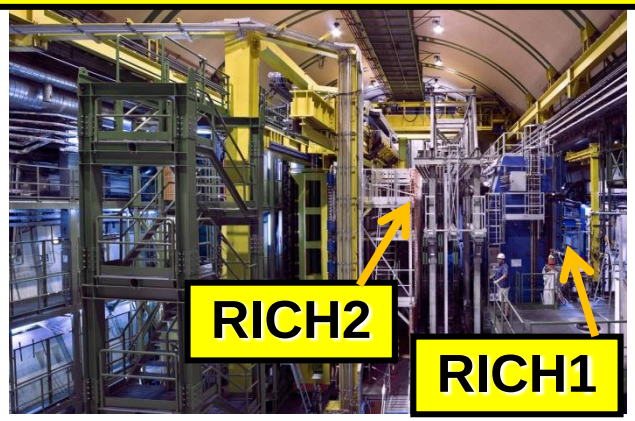


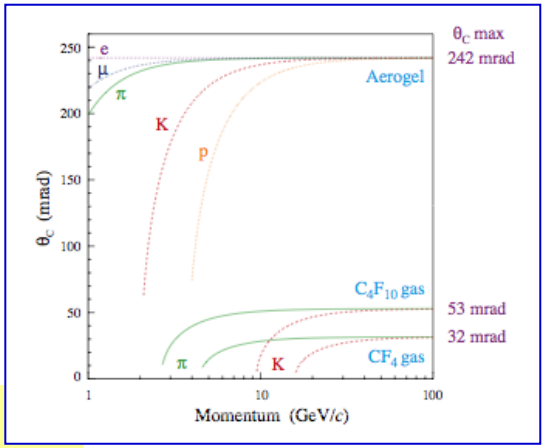


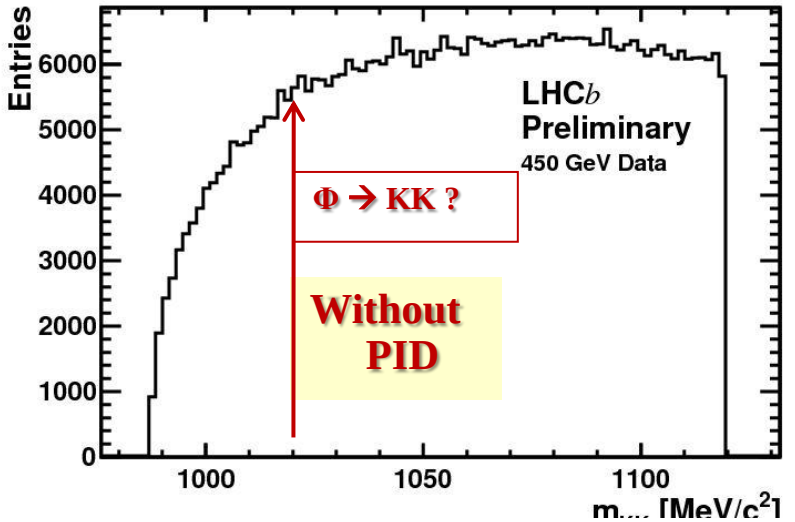


LHCb RICHes

3 radiators: Aerogel C_4F_{10} CF_4







Pixel HPDs

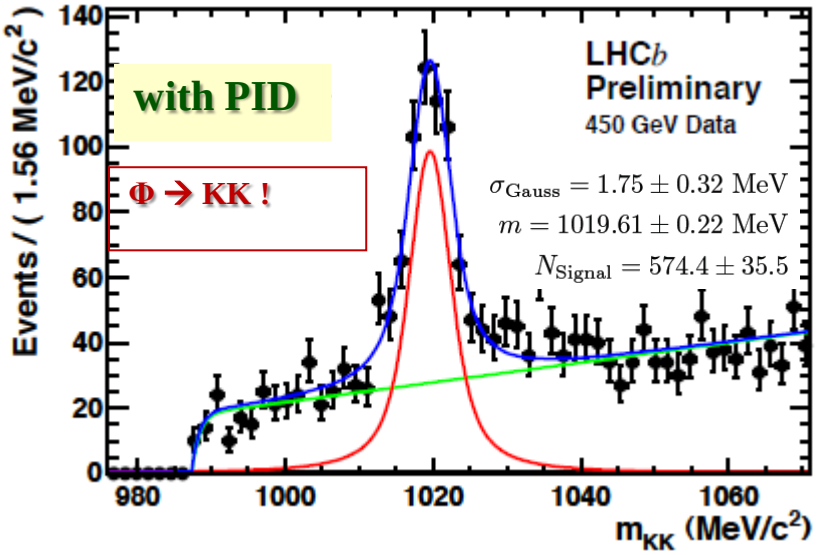
- 200-600 nm wavelength
- Factor 5 demagnification @ 20kV

LHCb RICH - 484 HPDs

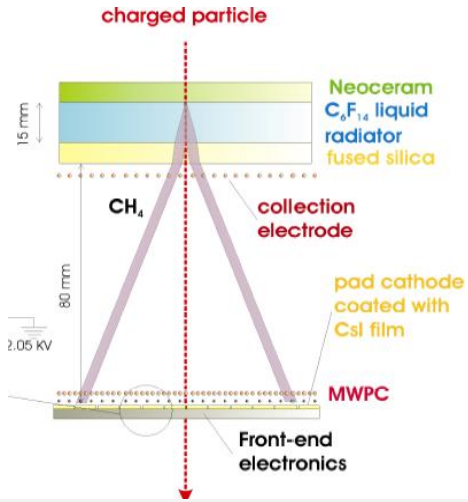
- total area of 3.3m²
- with 2.5 x 2.5 mm² granularity

Readout

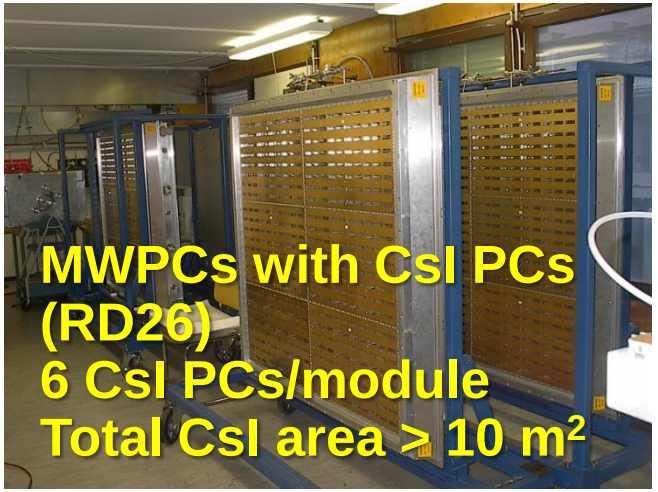
- Encapsulated 32x32 pixel silicon sensor

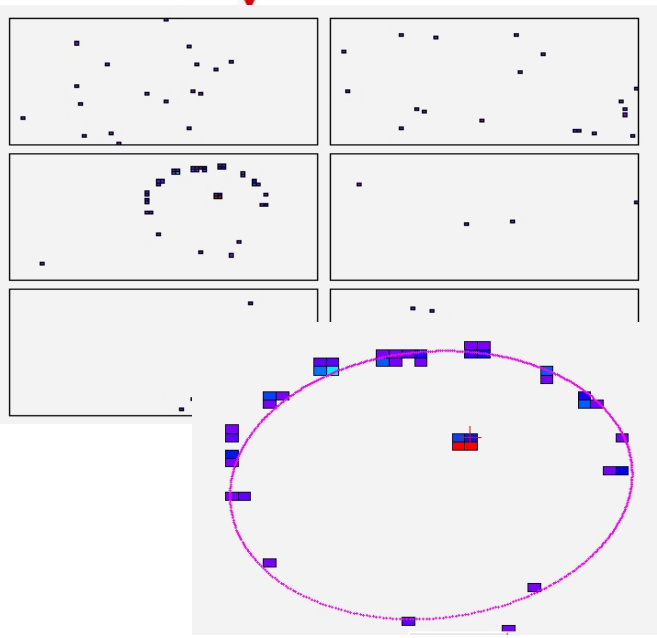


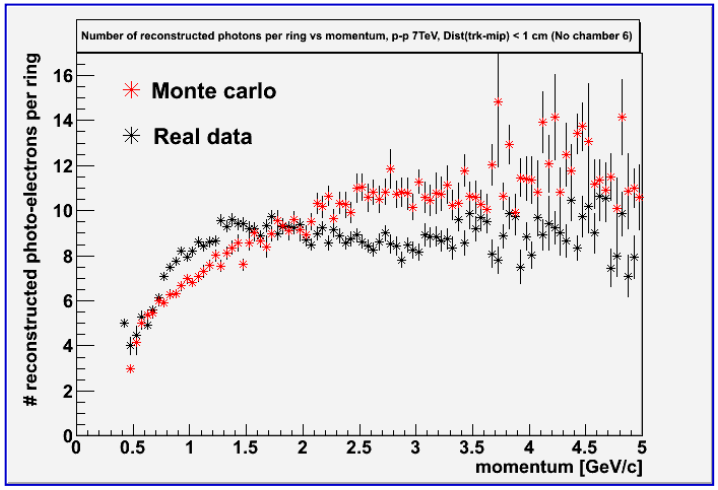
ALICE HMPID

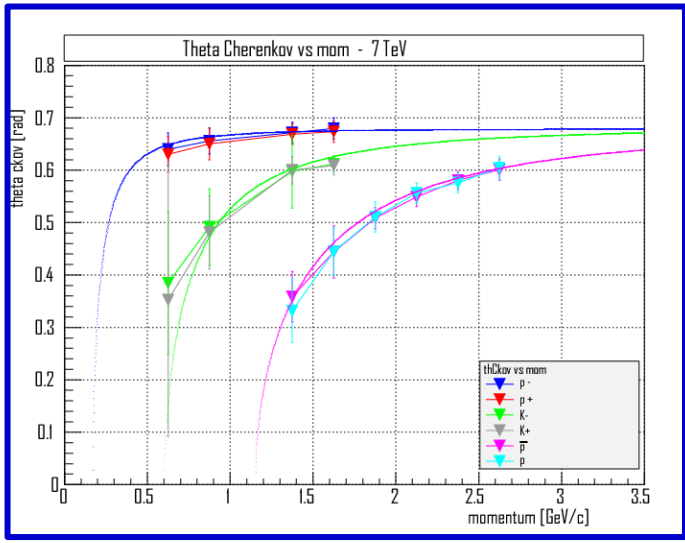

charged particle
15 mm
Neoceram
C_6F_{14} liquid
radiator
fused silica
CH_4
collection
electrode
80 mm
2.05 KV
pad cathode
coated with
CsI film
MWPC
Front-end
electronics


3 radiators/module,
8 l each


MWPCs with CsI PCs
(RD26)
6 CsI PCs/module
Total CsI area > 10 m²




Number of reconstructed photons per ring vs momentum, p-p 7TeV, Dist(trk-mip) < 1 cm (No chamber 6)
reconstructed photo-electrons per ring
Monte carlo
Real data
momentum [GeV/c]

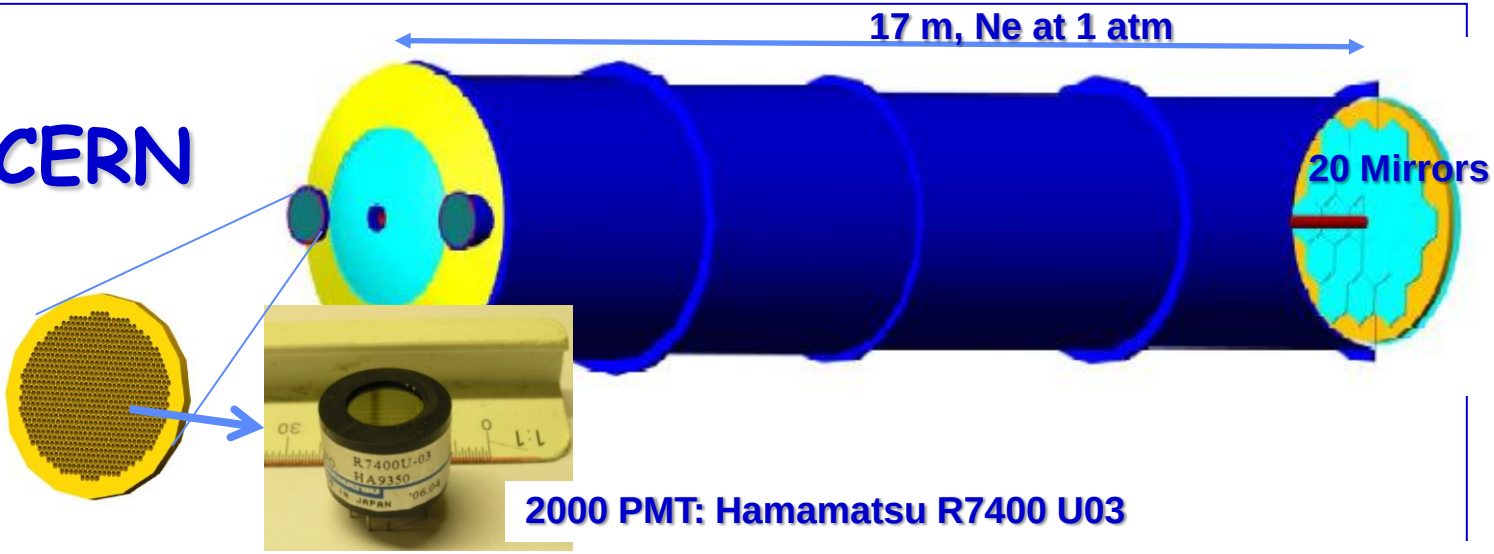

Theta Cherenkov vs mom - 7 TeV
theta ckov [rad]
thCkov vs mom
momentum [GeV/c]

A RICH in CONSTRUCTION

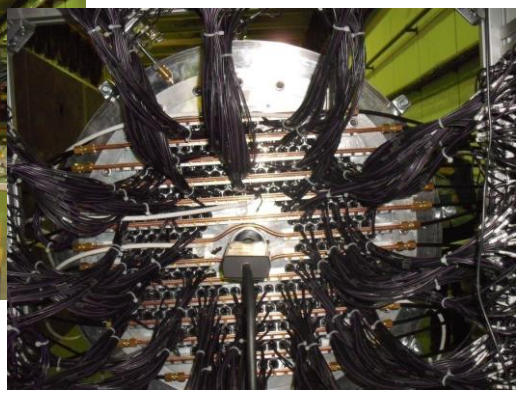
NA62 RICH @ SPS, CERN

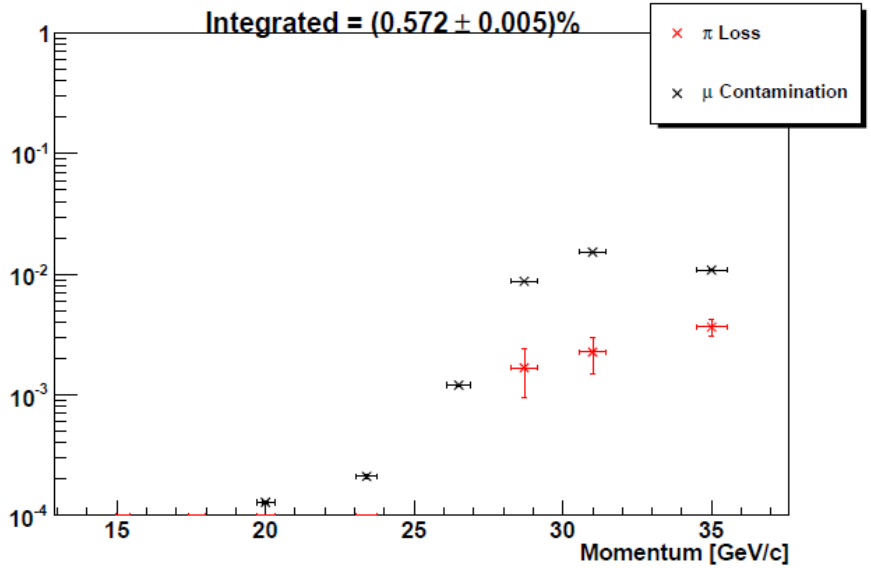
Mission:

3σ π–μ separation (15-35 GeV/c) with 100 ps global t resolution



prototype results



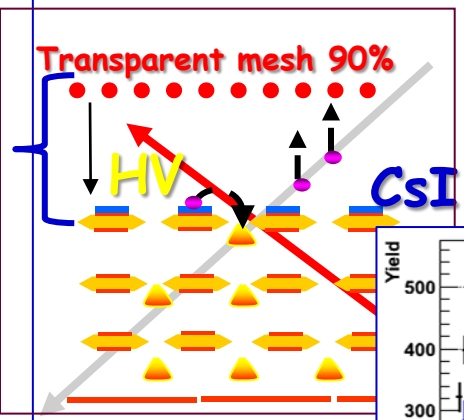


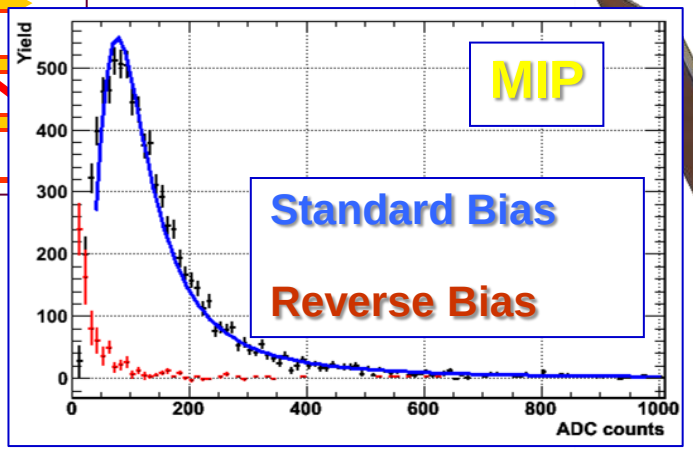
A NON-CONVENTIONAL CHERENKOV COUNTER

PHENIX HBD @ RHIC, BNL

(Hadron Blind Detector)

- Two identical arms
- Windowless: CF4 radiator & GEM gas





Aspects non exportable to imaging devices:

- detection of >> 1 ph. per pad: low gain (5000)
- non negligible noise level (~20% single e- signal)
- detect photons with λ down to ~110 nm: chromaticity !

NOVEL APPROACHES

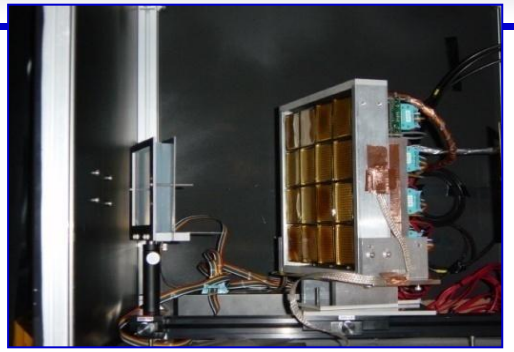
- Multiple refractive index Aerogel for proximity focusing RICH (FARICH, BELLE 2)

t resolution required: ~10 ps

- The new concepts of DIRC family
- COMPLEMENTARY or ALTERNATIVE possibilities with TOF
- Detectors exploiting the intrinsic fast response of the Cherenkov light

Multiple refractive index Aerogel

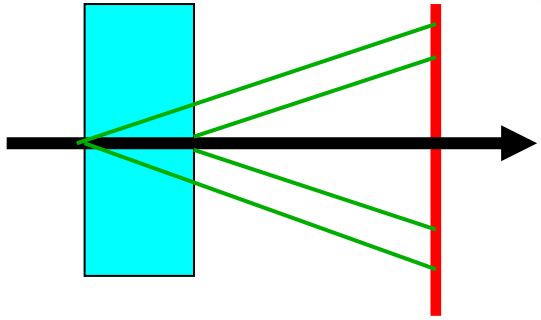
π/K separation with focusing configuration
~ 4.8σ @4GeV/c

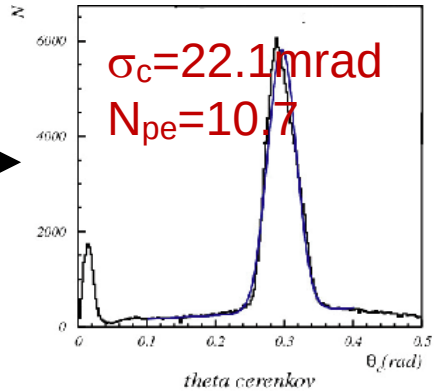


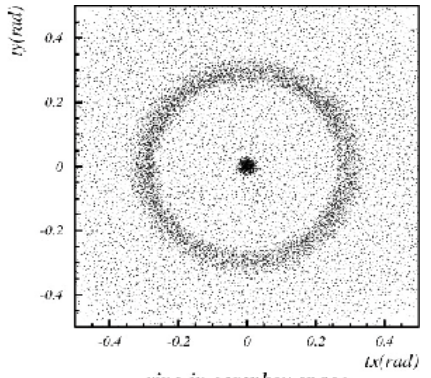
(Recall: $p^{max}_{n\sigma} \sim 1/\sqrt{\sigma_{ring}}$)

Conventional

4cm thick aerogel
n=1.047

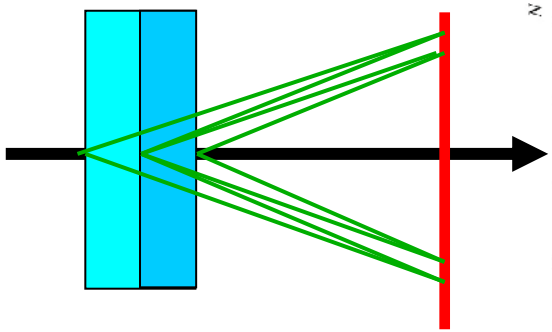


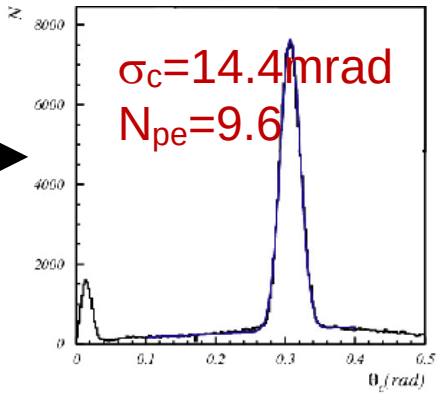


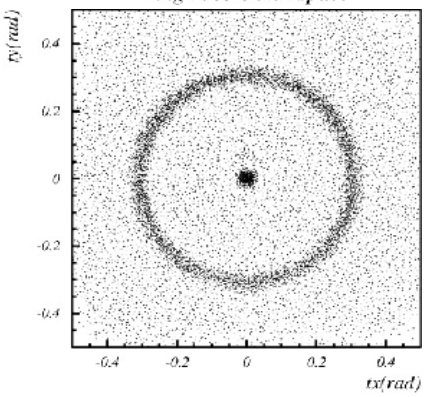


Multiple Radiators

2 layers of 2cm thick
n_1=1.047, n_2=1.057



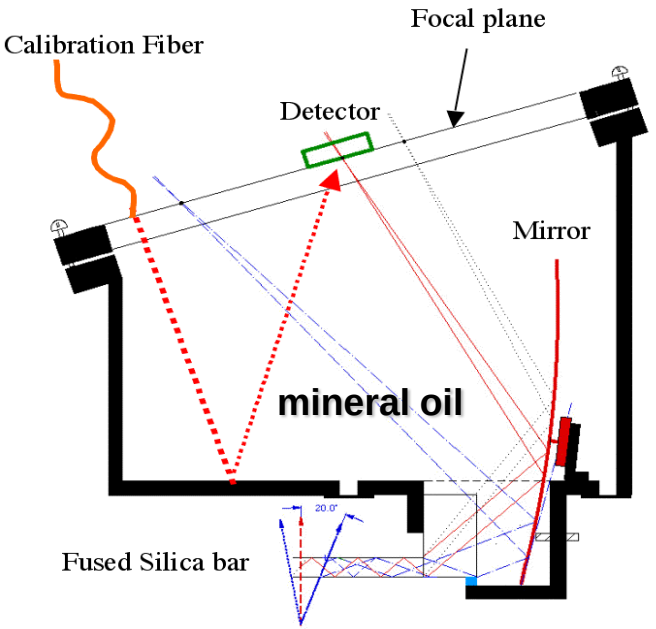




FOCUSING DIRC

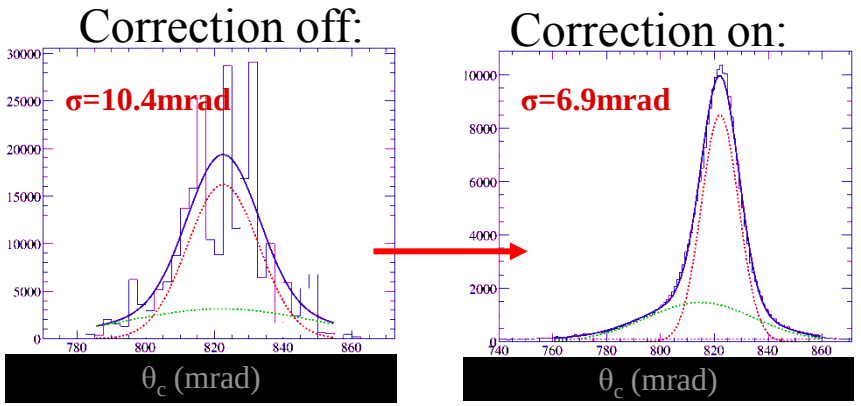
A general upgrade of the DIRC concept:
Future DIRC needs to be smaller and faster

- Focusing (to remove the bar thickness depende and smaller pixels can reduce the expansion volume by a factor of 7-10
- Faster PMTs to remove chramatic dependance and reduce sensitivity to background.

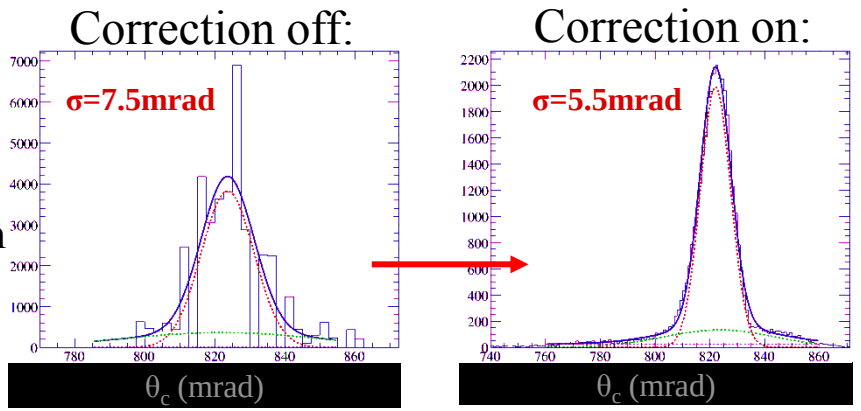


Photon detectors

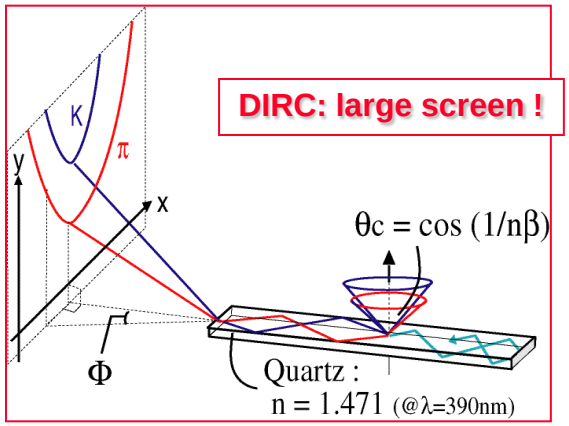
- Hamamatsu H-9500 MaPMTs
- Burle-Photonis MCP-PMT



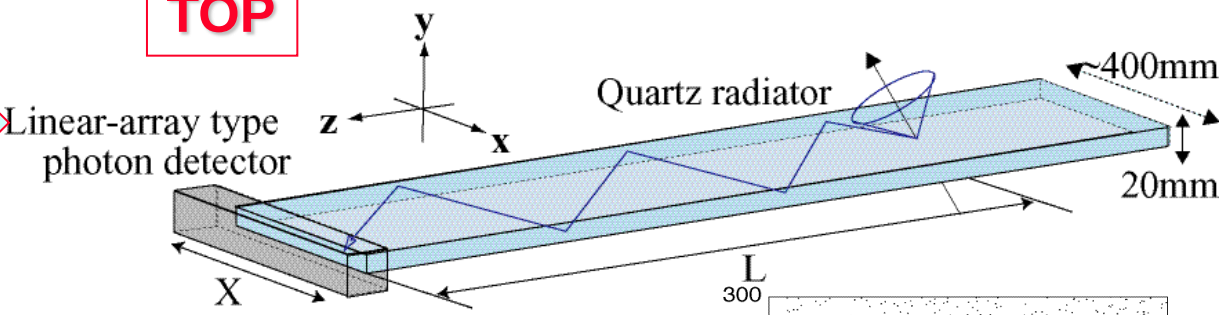
Position 1
Lpath≈10m



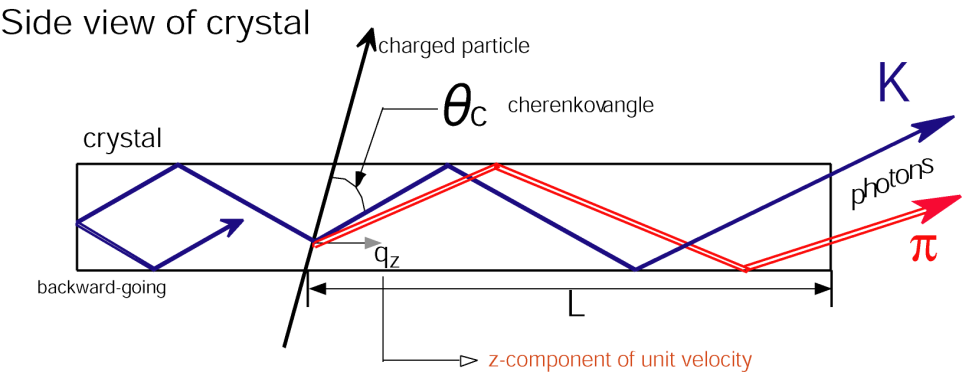
TOP CONCEPT

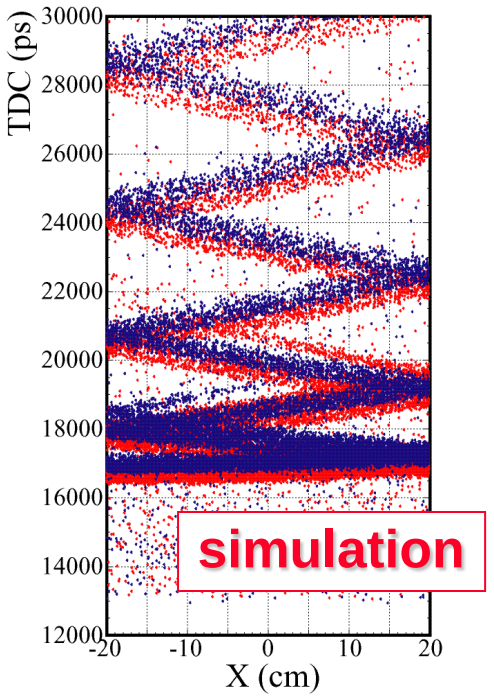


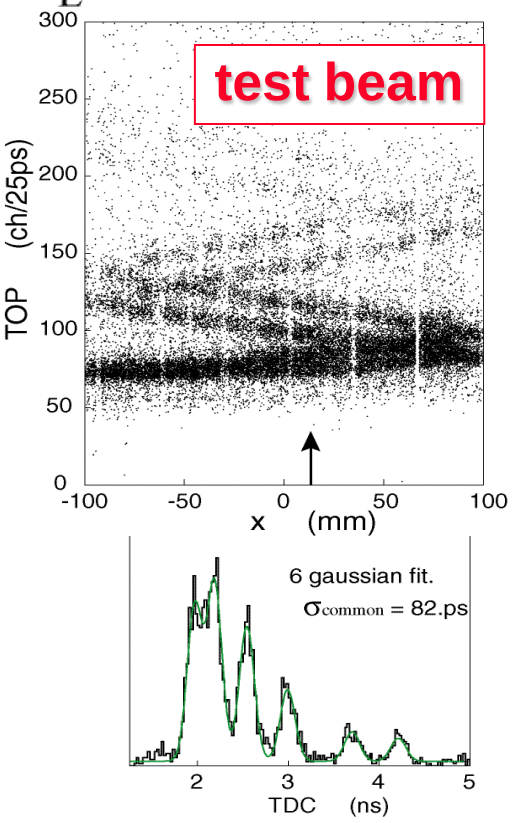
TOP



Second coordinate from time measurement: due to the different Cherenkov angle he light path has a different length

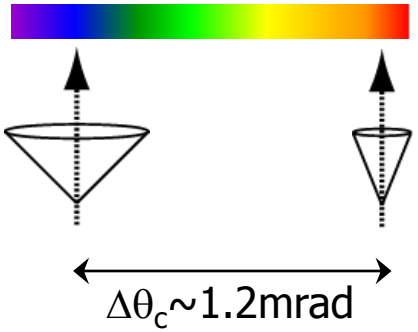




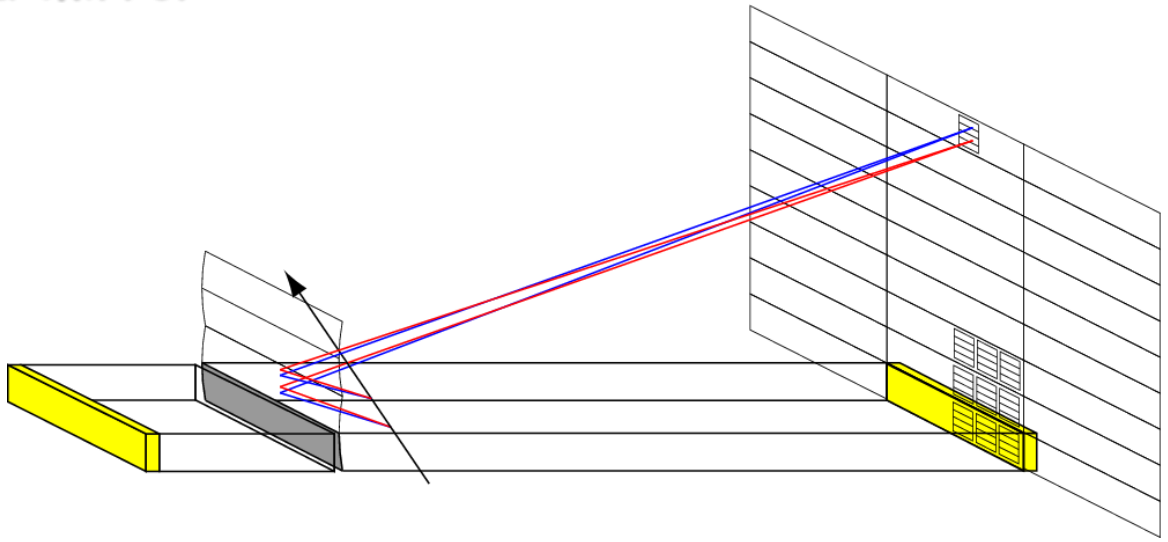


FOCUSING TOP

- **Chromatic effect:**
  - w/o chromaticity - time resolution ~ 35 ps
    (35 ps is given by the chosen photoin detectors)
  - Chromatic time dispersion: ~ 100 ps

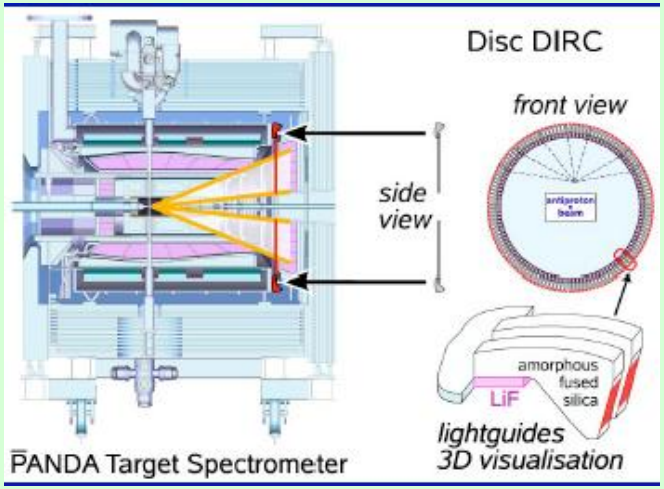


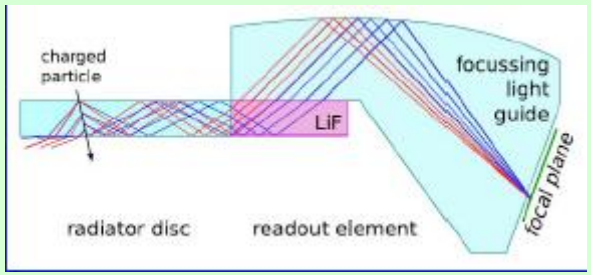
→ **Focalised TOP using a mirror**
  - Measure x, y, t
  - Work in progress



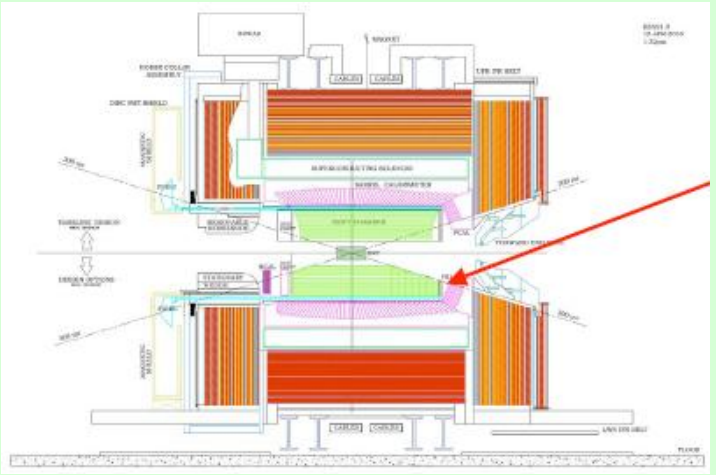
OTHER R&Ds for DIRC-like IMPLEMENTATIONs

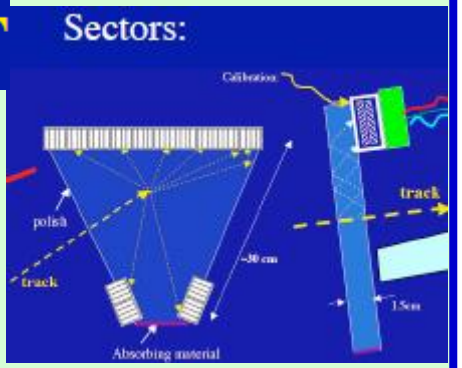
Panda Disc DIRC





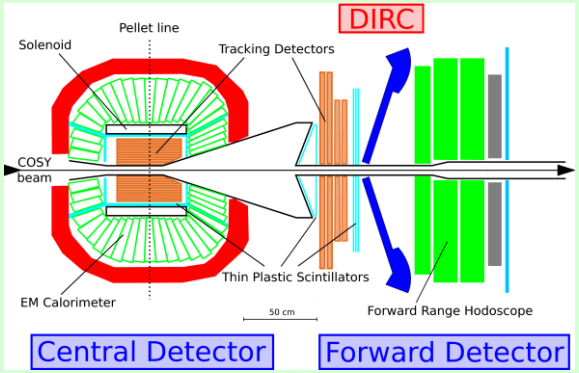
SuperB DIRC-like TOF



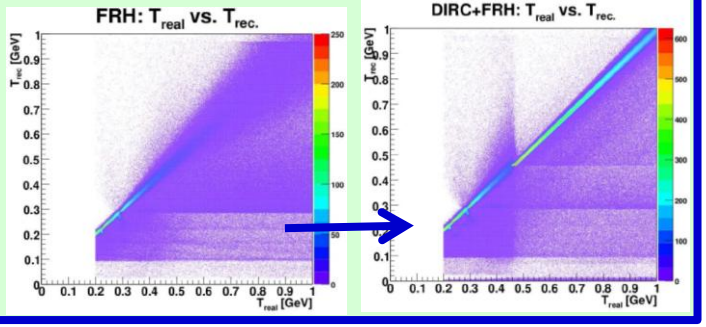


- Goal: σ ~ 40-50ps/track

The Wasa Detector (with DIRC)



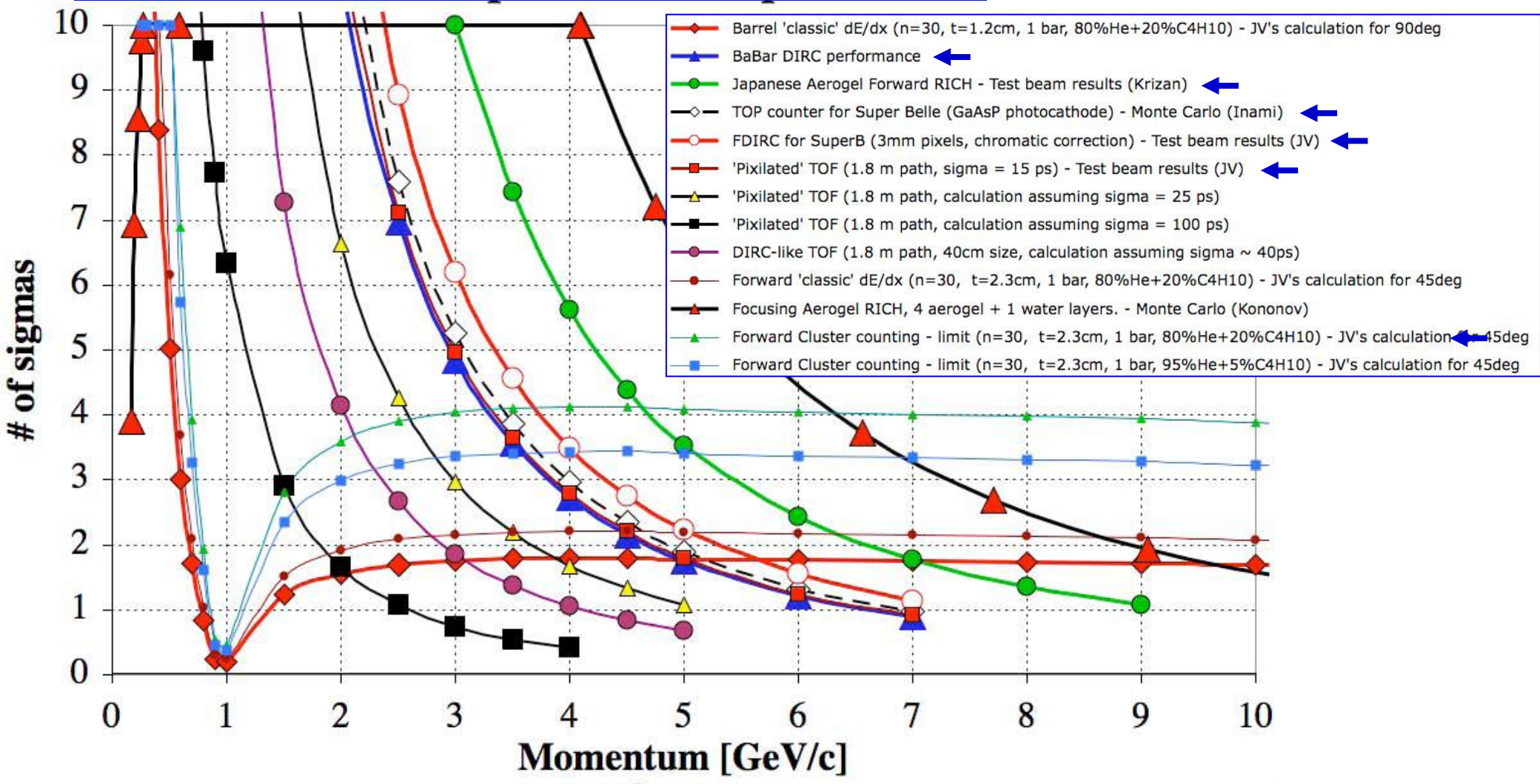
Energy resolution improves with DIRC (T>400MeV)



RICHes vs OTHER PID TECHNIQUES

J.V., 4.17.2010

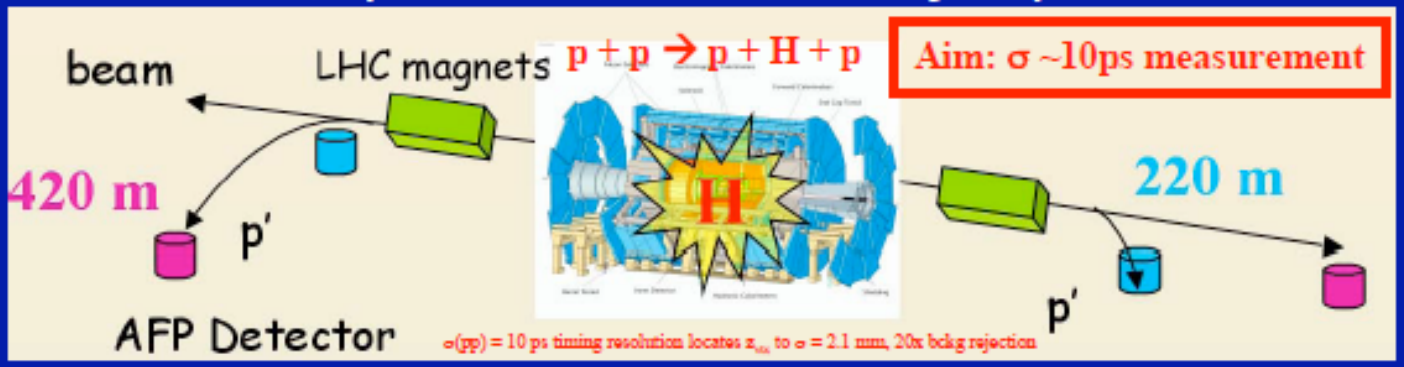
Example: π/K separation in SuperB forward endcap



EXPLOITING THE FAST CHERENKOV RESPONSE

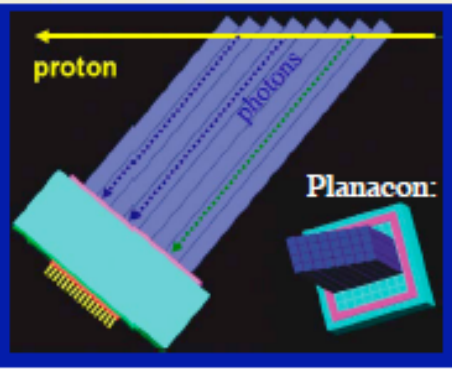
ATLAS & CMS: pp-diffraction scattering

Andrew Brandt, Krzysztof Piotrzkowski, Mike Albrow, Erik Ramberg, Anatoly Roznhin, and others

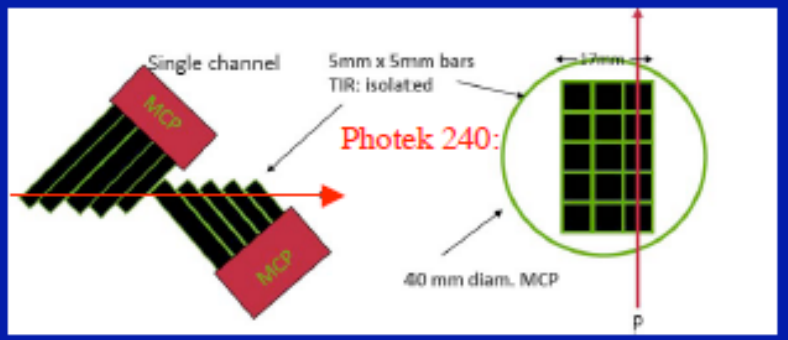


1)

Quartic:

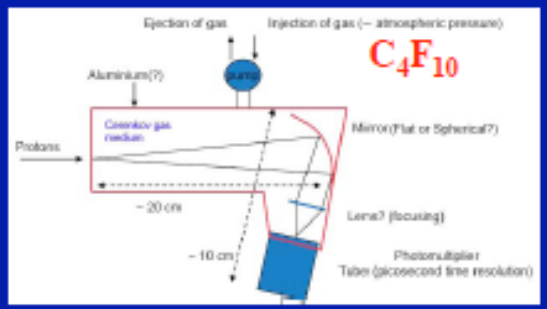


Qbar:



2)

Gastof:



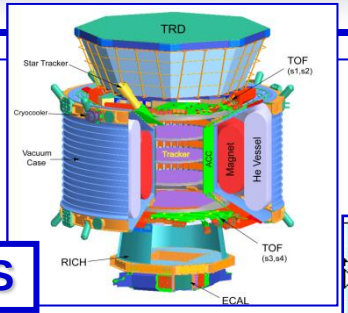
- **QUARTIC/Qbar** – multiple quartz bar detector (**single bar resolution 30-40 ps, resulting in total of ~10ps**).
- **GASTOF** – a gas Cerenkov detector (**single σ ~ 10 ps measurement**) (C_4F_{10}-based Cherenkov detector with very fast light (<1ps), limited by the detector presently !!).
- **Very challenging environment at LHC:**
  (a) High event rate, (b) Running MCP close to max anode current,
  (c) Large annual collected charge (~10C/cm²)

CHERENKOV (IMAGING) COUNTERS & PHYSICS

2. astroparticle physics

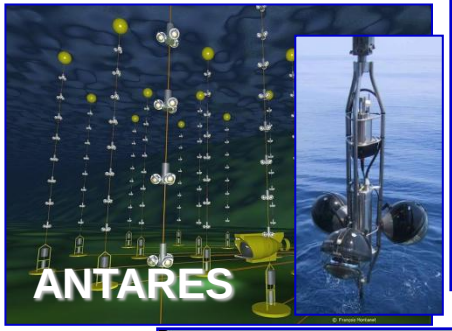
ASTROPARTICLE EXPERIMENTS @ RICH2010

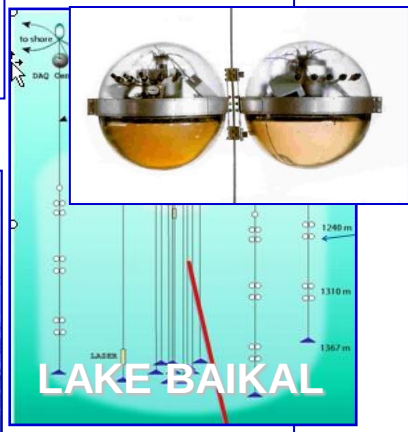
- **Flying spectrometers for CR detection**
  - AMS proximity focusing RICH



AMS

- **Huge volume ν telescopes**
  - ANTARES, Lake Baikal, KM3NET





These experiments are totally based on the detection of the Cherenkov radiation !

- **High energy γ ray spectroscopy**
  - HESS, MAGIC, CTA

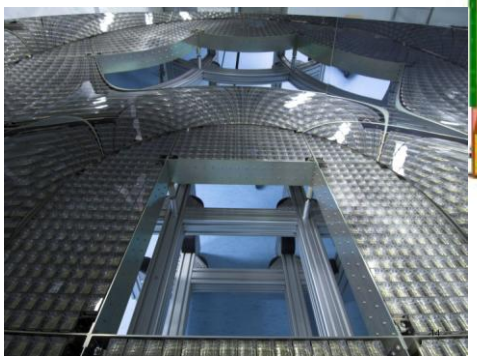
- **EAS Cherenkov array**
  - TUNKA, TUNKA-133

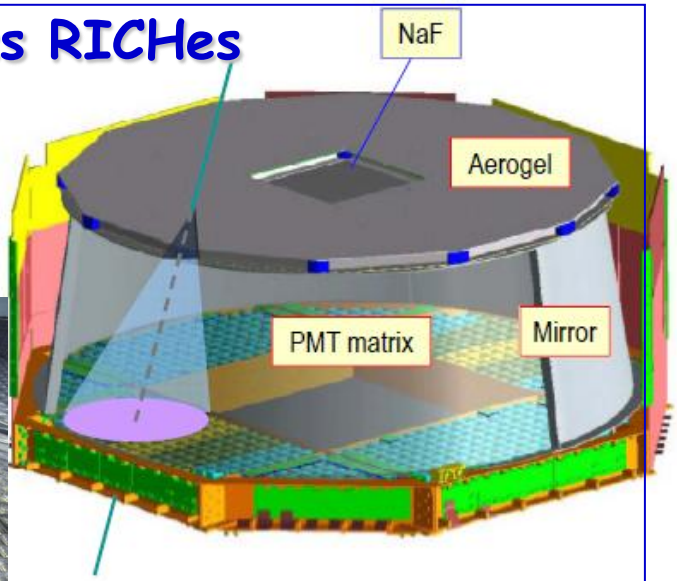
AMS-02 RICH

a proximity focusing RICH ~ nuclear/particle physics RICHes

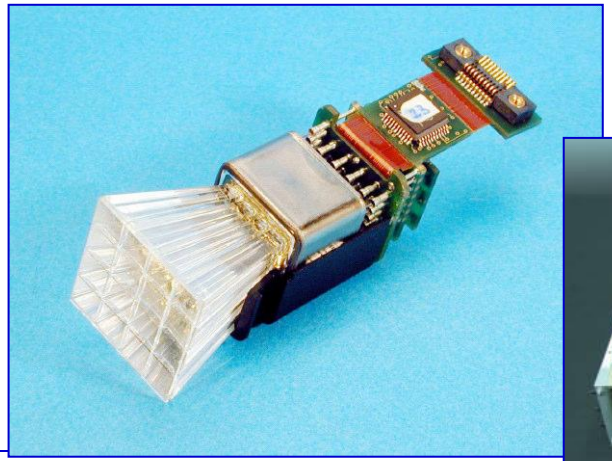
status: ready to fly

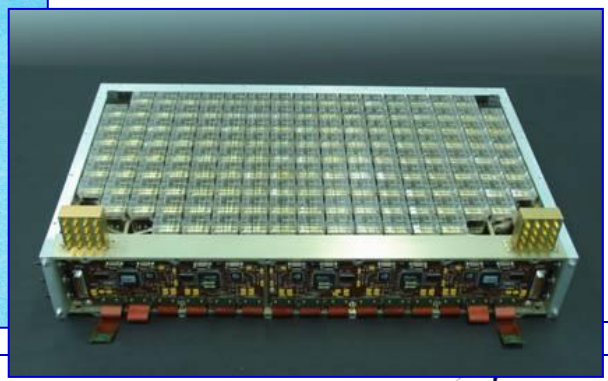
- Dual radiator configuration
  - Silica aerogel: outer region
  - NaF: central region





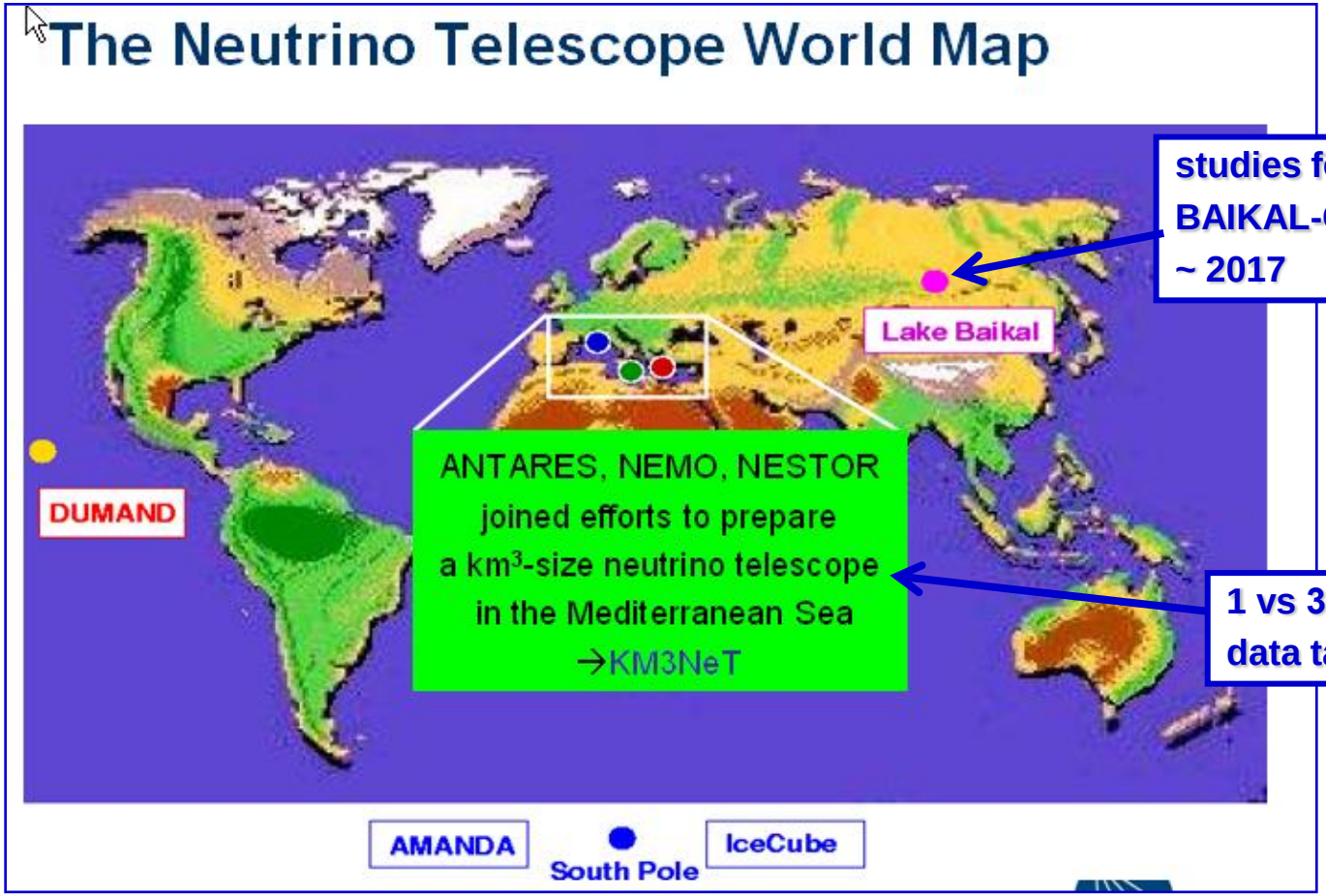
- PDs
  - 680 multianode MAPMTs (Hamamatsu R7900-MI6)
  - coupled to plexiglass light guides
  - pitch: 4.5 mm →8.5 mm





ν TELESCOPES - PERSPECTIVES

- **Operating well, but a clear need to be larger**
- **KM3NET (~ 220 M€ investment) goals: ν astronomy (1 to 100 TeV) complementing IceCube field of view, exceed IceCube sensitivity**

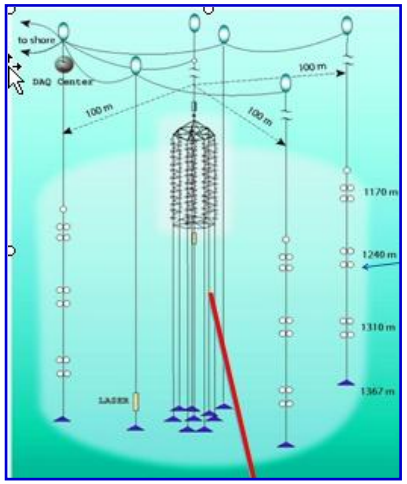


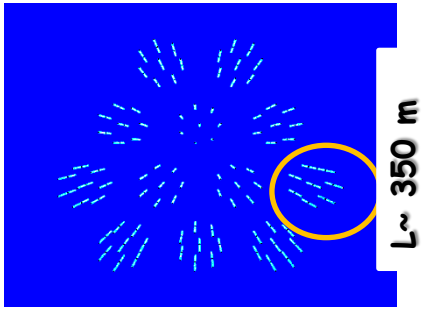
ν TELESCOPES - PDs

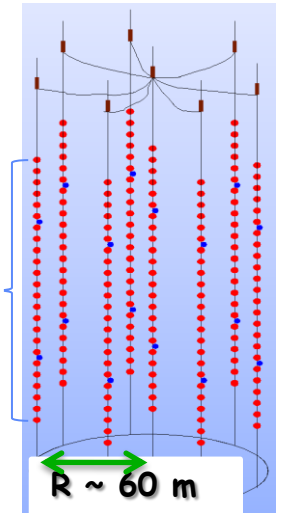
- **BAIKAL**

TODAY: NT 200+
NT200: 8 strings (192 optical modules)
Height x ∅ = 70m x 40m, $V_{inst}=10^5 m^3$
Effective area: 1 TeV~2000m^2
Eff. shower volume: 10 TeV~ 0.2 Mton

TOMORROW: NT 1000
NT200: 96 strings (~2300 optical modules)
Height x ∅ = 70m x 40m, $V_{inst}=10^5 m^3$
Eff. shower volume: 100 TeV





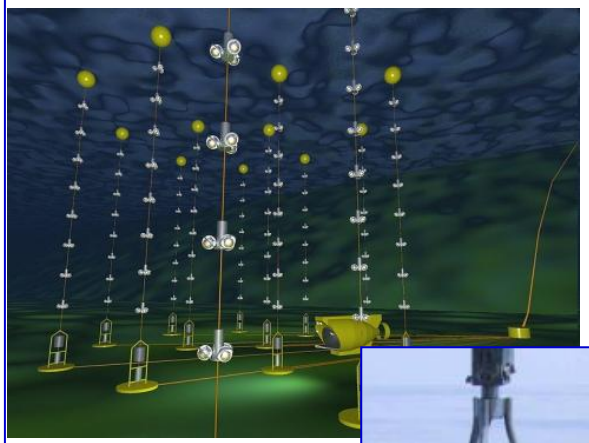


Quasar photodetector (∅=37cm)

ν TELESCOPES - PDs cont.

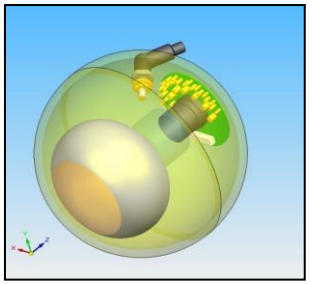
ANTARES

successfully in operation



Studies for KM3NET

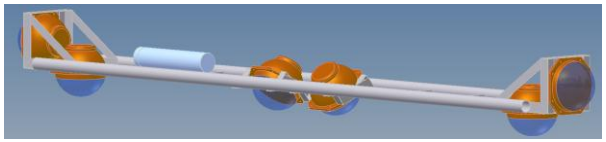
OM : classical vs small PMTs

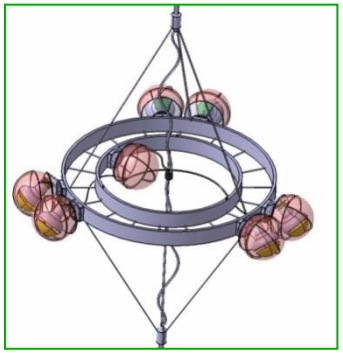


31 3-inch PMTs in 17-inch glass

OM arrangement:

bars vs triangles vs stringes





γ-RAY CHERENKOV TELESCOPES

MAGIC

2 x 17 m diameter
fast positioning (<17 s)
low energy threshold

MAGIC II

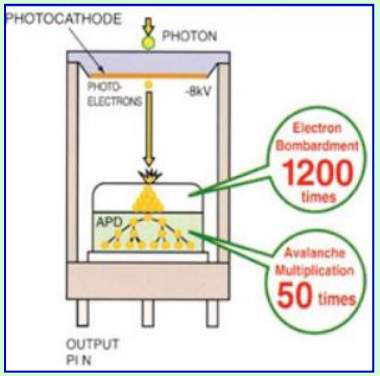
- 1039 identical 0.1° pixels

MAGIC I

- Different types of PMTs:
  396 x 0.1° in the center
  180 x 0.2° in the outer part
- Enhanced QE with special coating (25%)

MAGIC upgrade

HPDs?



Advantages:

- Good single photoelectron resolution
- High QE GaAsP Photocathode (QE>50%)
- High photoelectron collection efficiency (~100%)
- Low afterpulse rate (~300 times less than PMTs)

γ-RAY CHERENKOV TELESCOPES

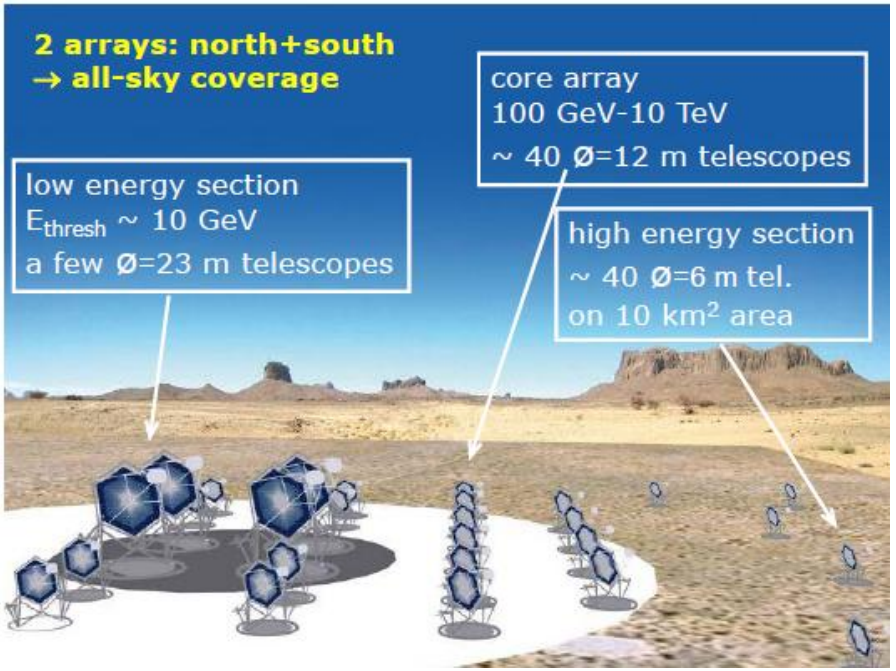
HESS → HESS II

improve sensitivity, lower en.threshold

adding a fifth larger telescope (2011)

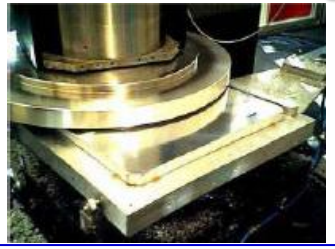
	HESSI	HESSII
#PMTs	960	2048
PMT FoV	0.16°	0.07°

CTA

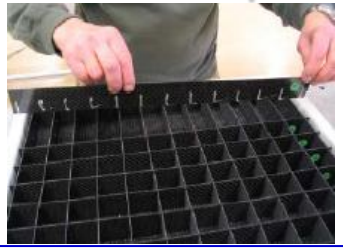


Mirror studies: they need to be light !

Al + diamont milling



C-fiber composite



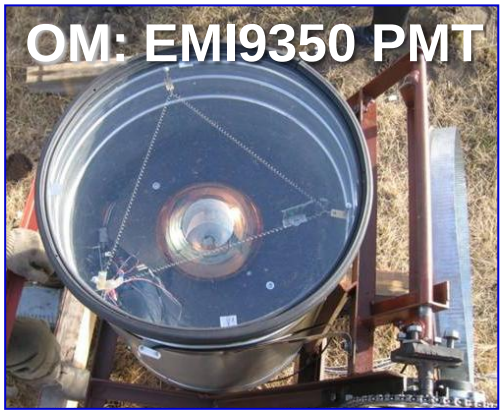
EAS ARRAY

TUNKA-25

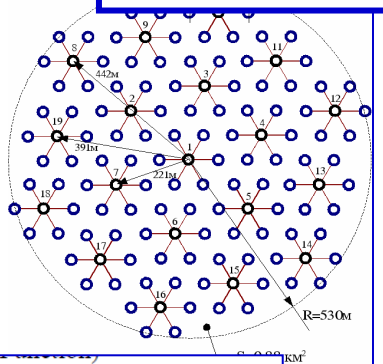
- 25 hybrid phototubes
  Quasar-370G (∅ 37cm)
- 400 x 400 m^2

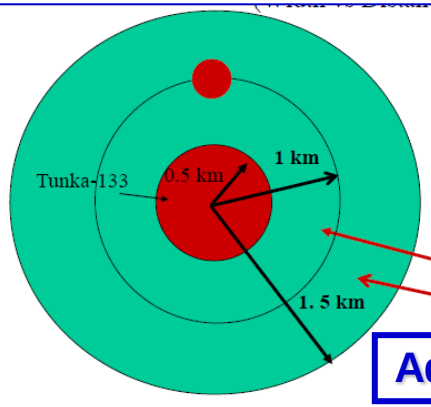
TUNKA-133

- Running since October 2009
- 133 8 inch EMI9350 PMT from MACRO



TUNKA-133





$E > 5 \cdot 10^{17}$ eV
Effective area will be increased by a factor of
4
9

Adding distant clusters

MESSAGES

from astroparticle experiments based on the detection of Cherenkov light

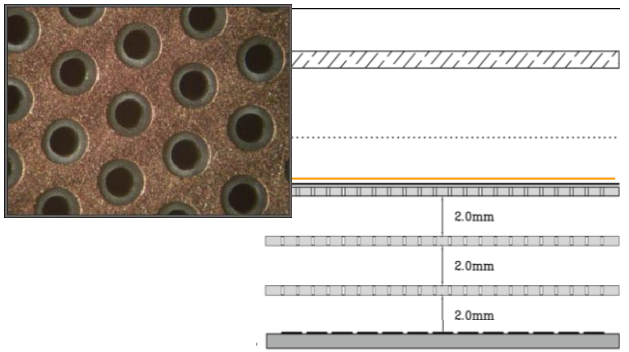
To improve sensitivity:

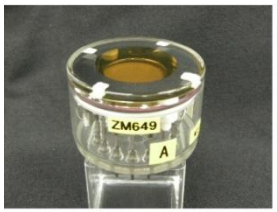
- the size has be increased,
- but it cannot grow unlimited
- improved photon detectors guarantee the progress in this field

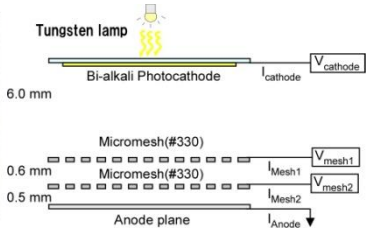
Single PHOTON DETECTION

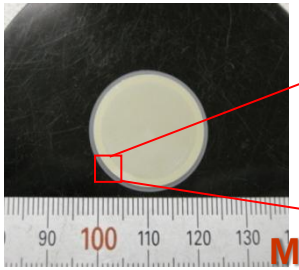
NOVEL GASEOUS PDs

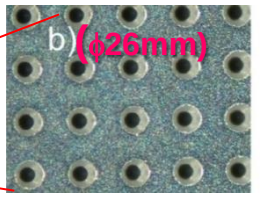
- **Important R&D efforts on going**
- **All based on MPGD → almost all included with the RD51 activity**
  - This community is informed well about
  - <u>These R&Ds are an essential ingredient in RD51</u>
- **At RICH2010:**
  - A. Breskin — THGEM/CsI: a potential UV-photon detector for RICH
  - S. Dalla Torre — Status and perspectives of gaseous photon detectors (review talk)
  - S. Levorato — Progress towards a THGEM-based detector of single photons
  - T. Sumiyoshi — Development of a gaseous PMT with micro-pattern gas detectors
  - J. Veloso — Thick-COBRA A New Thick-Hole Concept for Ion Back Flow Reduction
  - **A relevant invited talk:**
    L. Ropelewsky — Recent advances in the development of gaseous detectors and MPGDs











Material: Pyrex Glass
Electrodes : Al (1μm)

VACUUM-BASED PDs

Recent emphasis in vacuum-based PDs

Single photon counting with good

- Position sensitivity — O(mm)
- Efficiency (QE, gain, S/N) — >20%
- Timing — <100ps ⟸ **TOP/FDIRC**
- Magnetic field immunity — 1.5 T — **New trend**
- **Total area to cover — $O(1m^2)$-$O(10^5m^2)$**

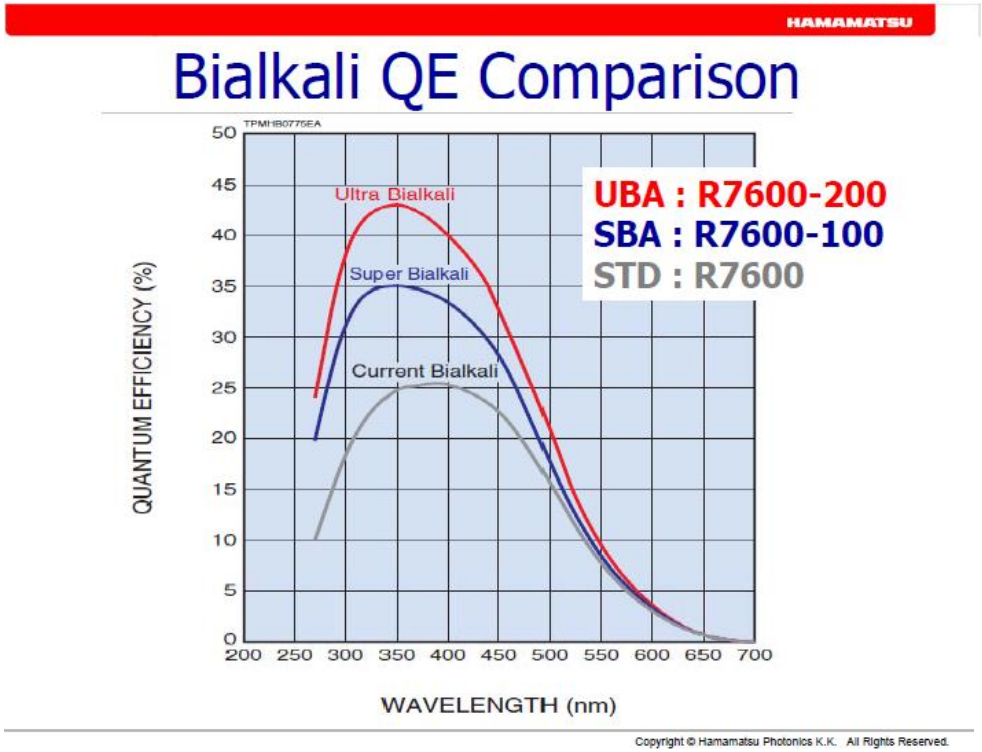
++ ASIC development to readout many channels. $O(10^5)$

DEVICES

- **Multi-anode PMTs (MaPMTs)**
- **Hybrid Photodetectors (HPD/HAPD)**
- **Micro-channel PMT (MCP-PMT)**
- **PD with luminescent anode (X-HPD etc.)**

VACUUM-BASED PDs: QE

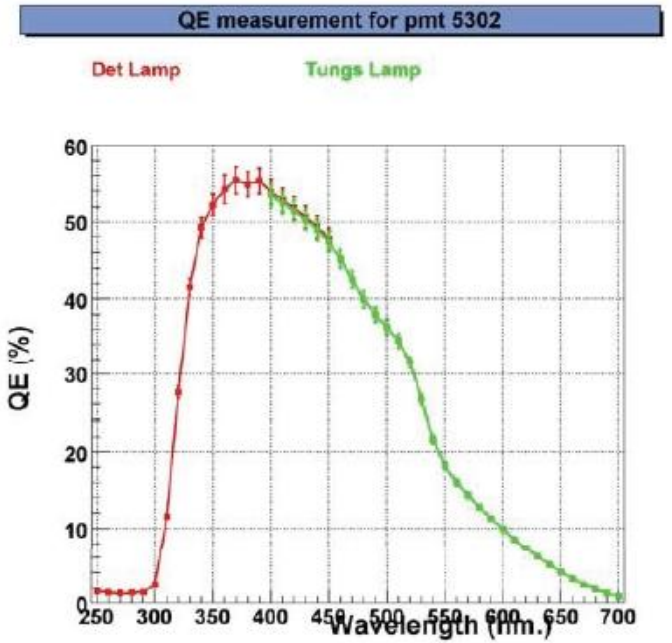
HAMAMATSU



PHOTONIS

Photonis PMT 5302

Measurements done at MPI Munich



D. Renker @ ICATPP 2009

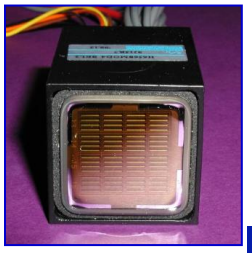
MAPMTs and HPDs

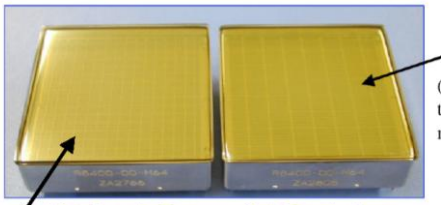
MAPMTs monopolized by Hamamatsu

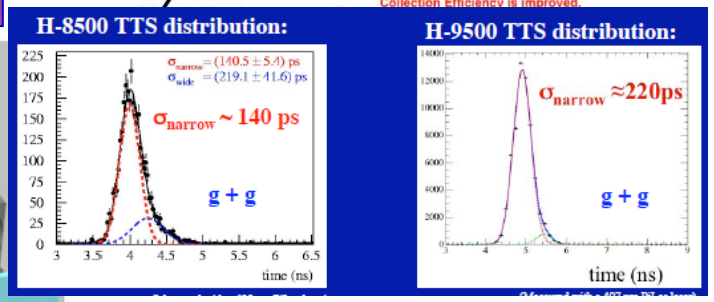
R7600-M16/M64 18x18mm^2/26x26mm^2 (48%)

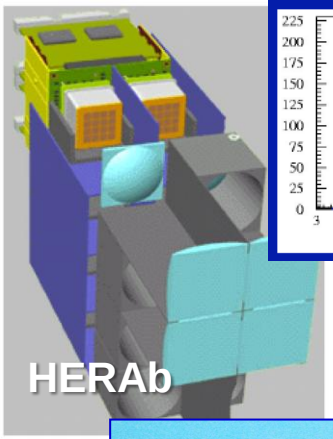
R8900-100-M16 23.5x23.5mm^2/26.2x26.2mm^2 (80%)

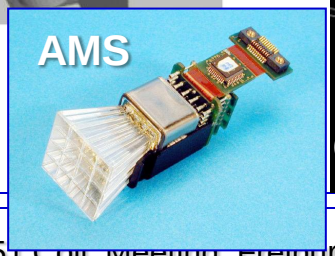
H8500C (8x8) / H9500 (16x16) 49x49mm^2/52x52mm^2 (89%)

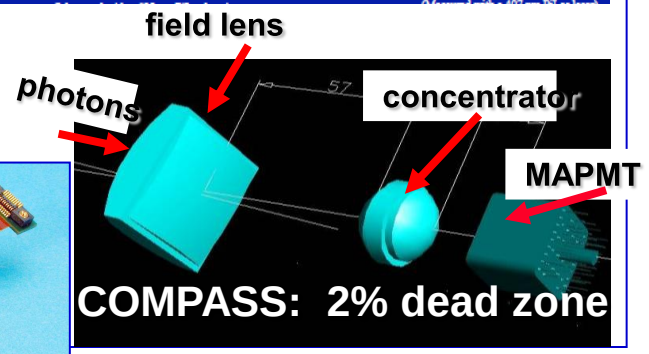




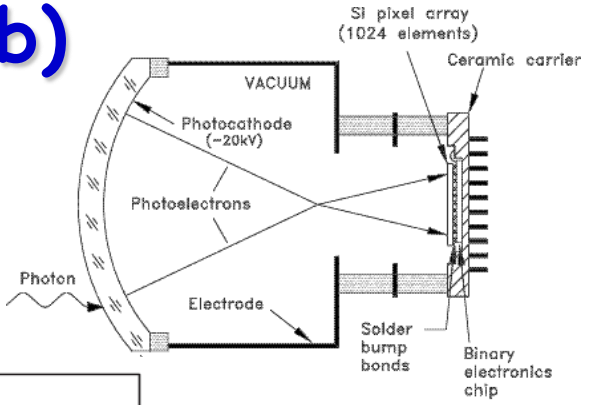


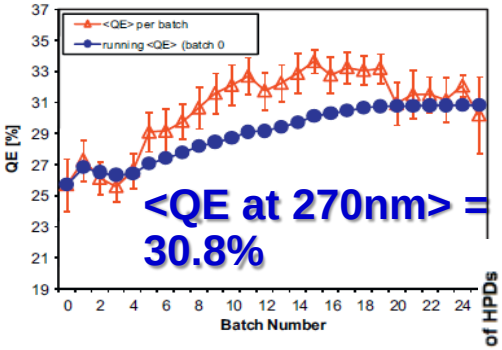


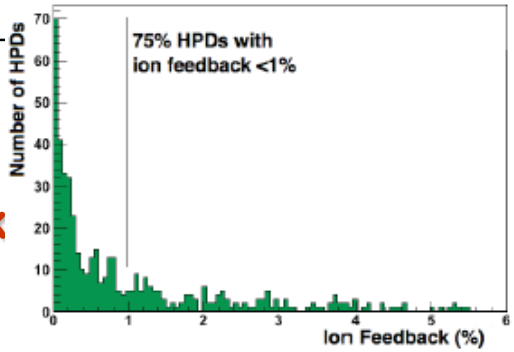




HPD (LHCb)





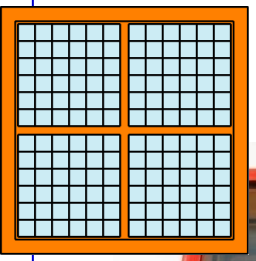


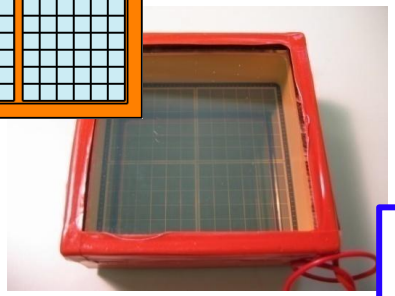
Vacuum/ion feedback and aging issues:

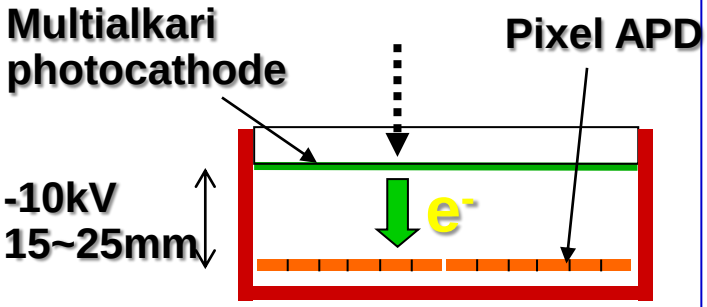
86/484 (18%) HPDs removed from RICHes so far

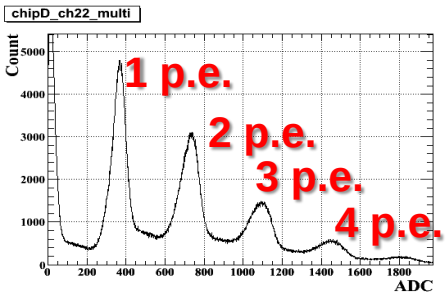
HAPDs

144 ch HAPD (baseline for Belle II RICH with aerogel)



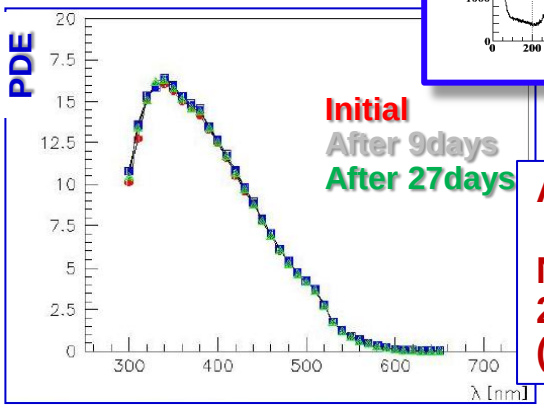






Total gain
~ 5×10^4

S/N = 8-15
for single p.e.

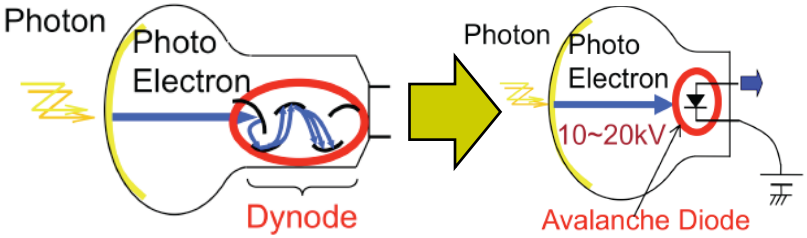


AGING

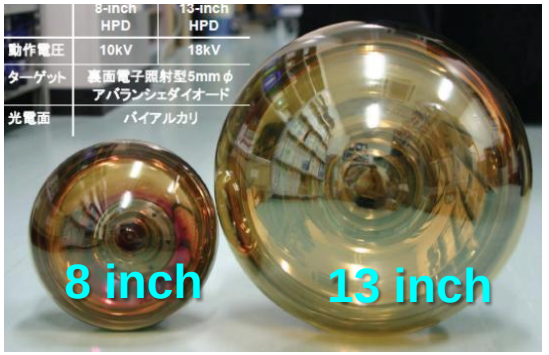
No degradation is seen after 27 days
(~25 Belle II RICH years)

Being developped in cooperation with Hamamatsu

Also large size !

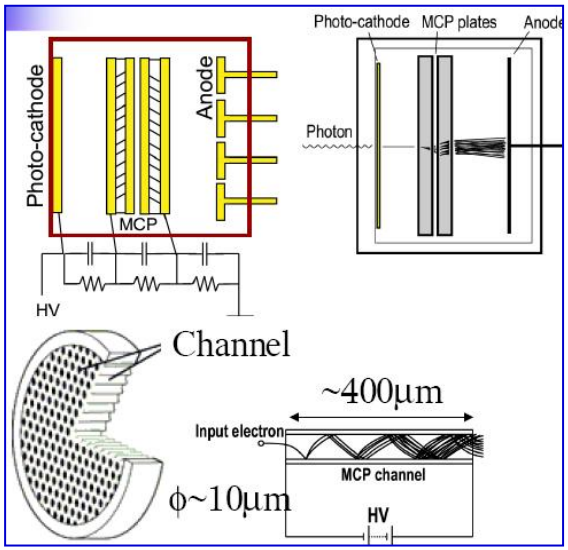


and digital



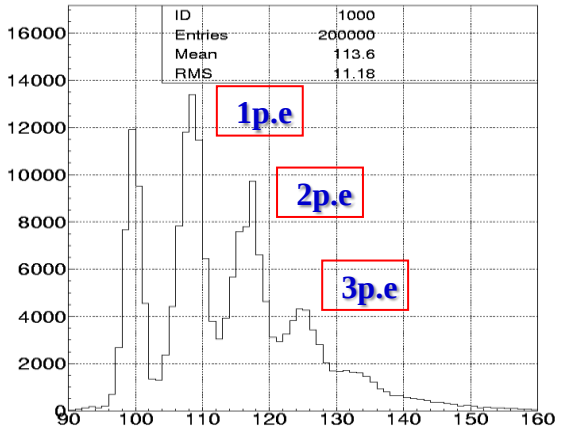
MCP DEVICES

Basic features

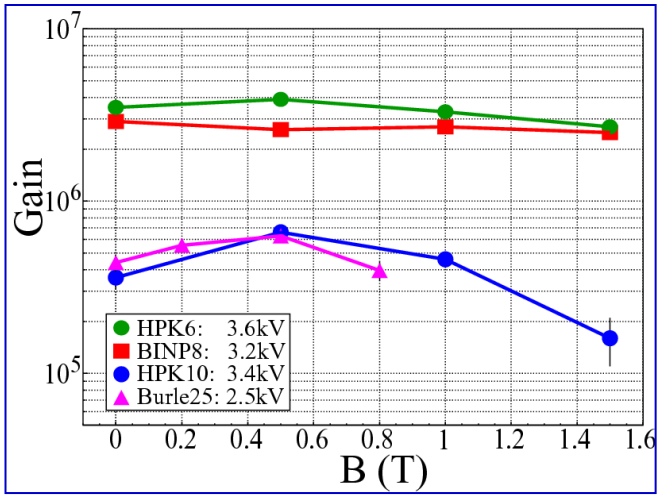


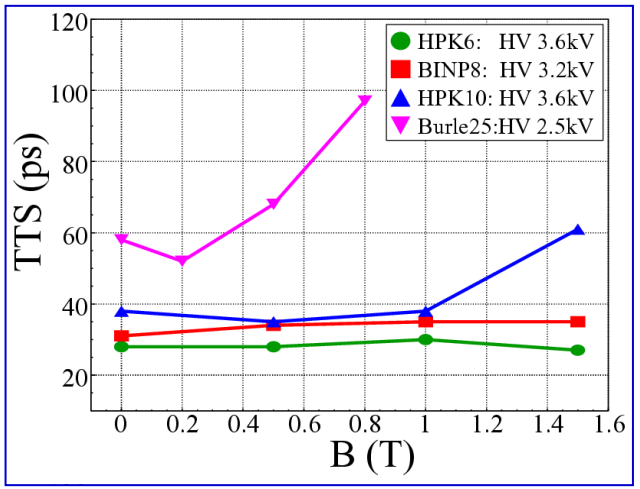
Gain ~O(10^6) w/ 2-3 stages

Photon counting In B=1.5T w/ 6μm MCP-PMT (HPK R3809-U50-11X, Nagoya R&D)



In B field





MCP DEVICES cont.

More about TTS

Parameters used:
- U = 200 V
- l = 6 mm (K-MCP)
- E_0 = 1 eV
- m_e = 511 keV/c²
- e_0 = 1.6 10^{-19} As

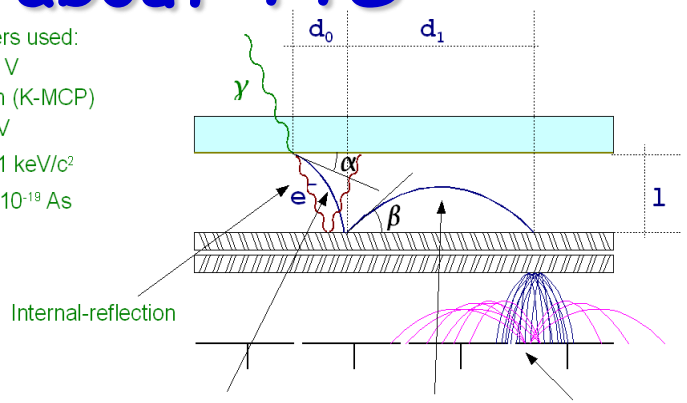
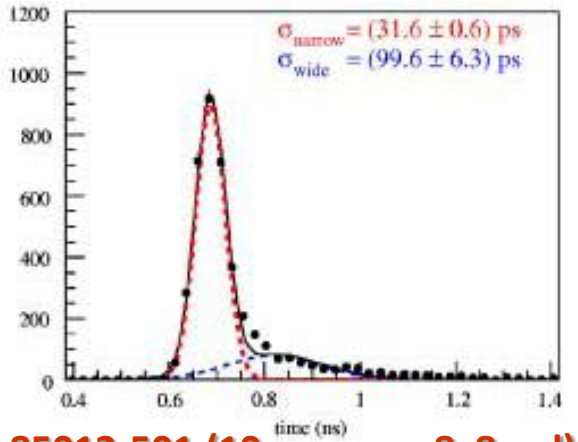


Photo-electron:
- $d_{0,max}$ ~ 0.8 mm
- t_0 ~ 1.4 ns
- Δt_0 ~ 100 ps

Backscattering:
- $d_{1,max}$ ~ 12 mm
- $t_{1,max}$ ~ 2.8 ns

Charge sharing

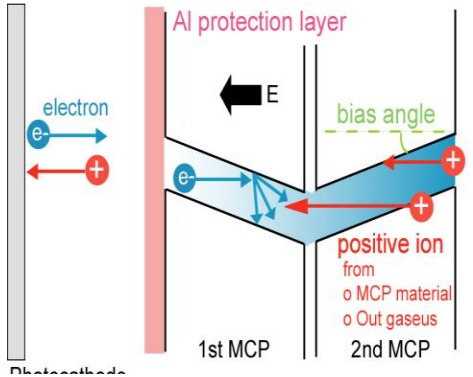


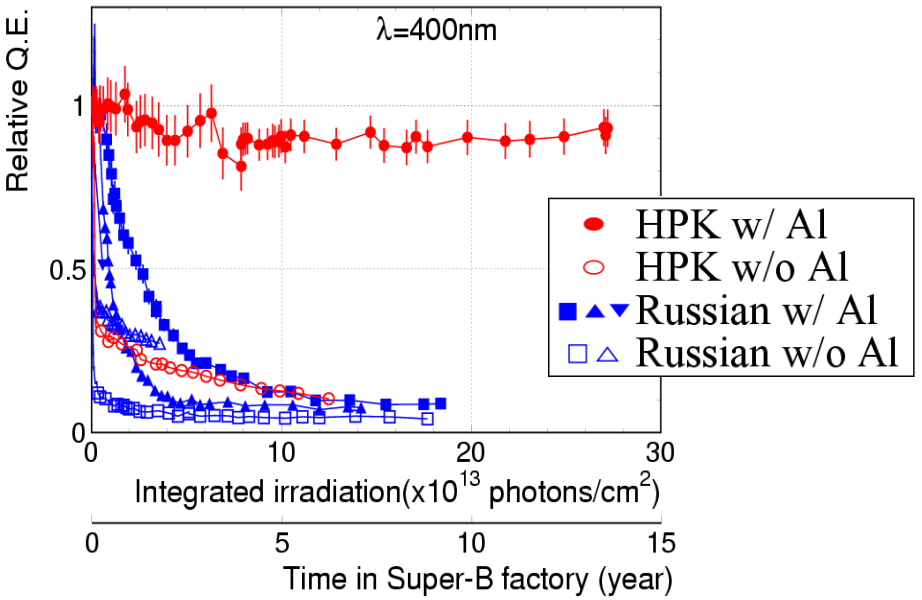
85012-501 (10µm pore, 8x8pad)

Note

σ= 54±4ps for 25µm pore sample

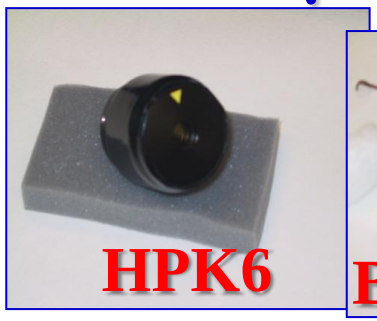
AGING



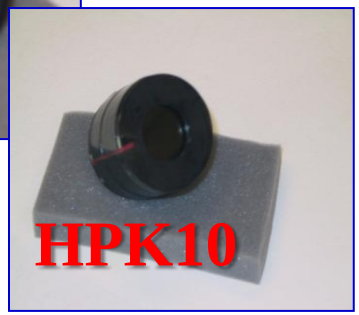


MCP DEVICES cont.

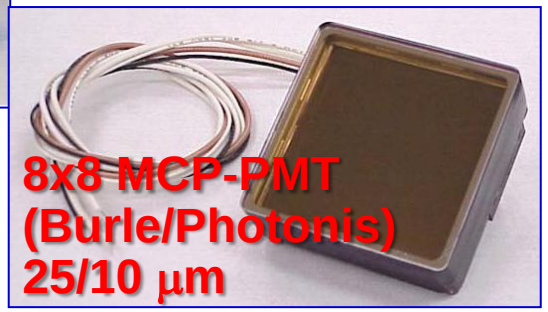
Some implementations

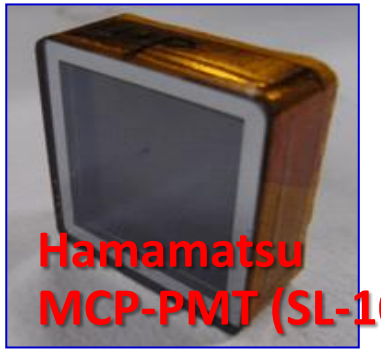

HPK6


BINP8


HPK10


Burle25


8x8 MCP-PMT (Burle/Photonis) 25/10 μm


Hamamatsu MCP-PMT (SL-10) 4 ch.s

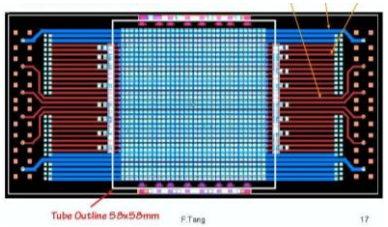
A relevant drawback:

the price

→ LAPPD:

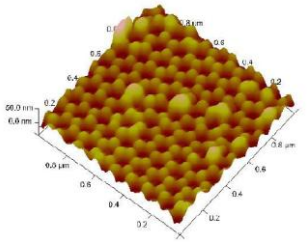
Large Area Picosecond PhotoDetectors Collaboration

Goal: ~ 10 x 10 cm²



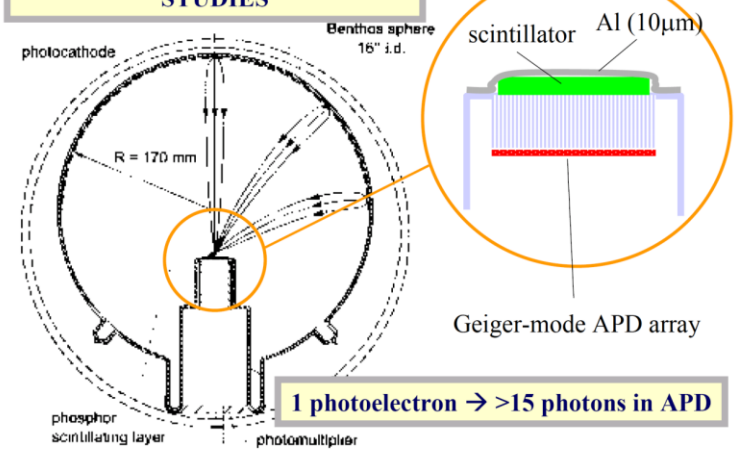
Transmission line readout to cover large area with reduced channel account.

MCPs via innovative approaches:
Atomic layer deposition (ALD) to form pore with active and pasivated layers
Anodic Aluminum Oxide (AA0) MCP's being developed



HYBRID PMTs

Spherical LIGHT AMPLIFIER STUDIES



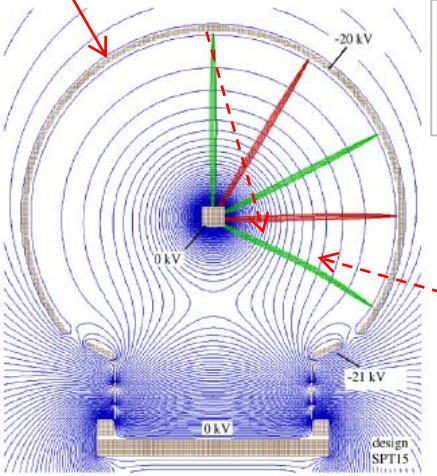
1 photoelectron → >15 photons in APD

SMART PMT, QUASAR

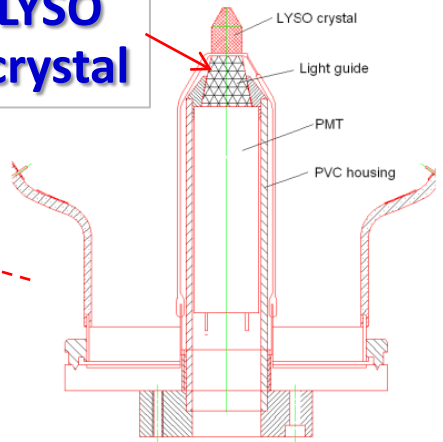
X-HPD

Double cathode effect

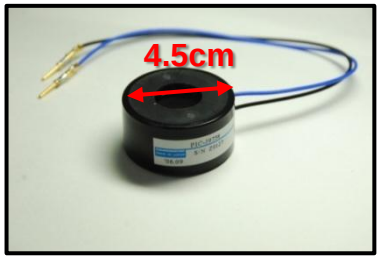
Large acceptance (3π)



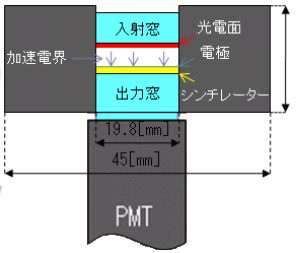
LYSO crystal



PIC = Proximity Image Converter

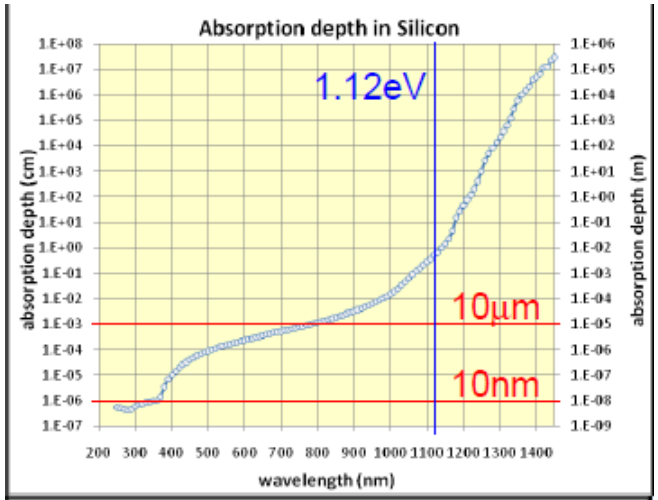


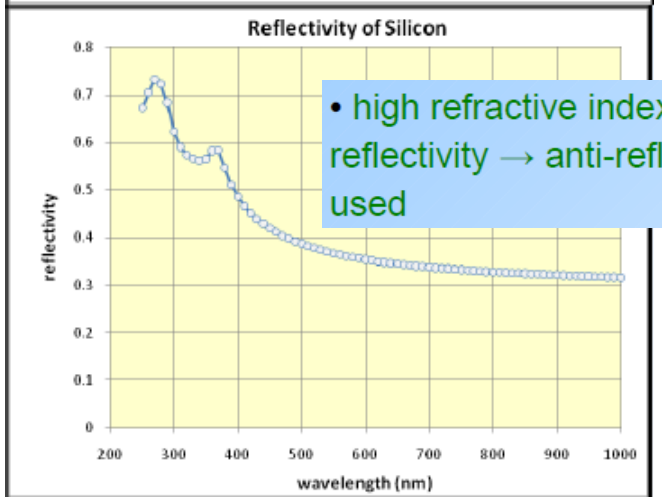
1"PMT (H6533) directly attched to PIC output window



Si-based PDs

Si optical properties





- high refractive index → high reflectivity → anti-reflecting coating is used

Devices

- Detection of light with solid state sensors
  - photo diode
  - avalanche photo diode (APD)
  - hybrid photo detectors (HPD, HAPD)
  - APD operated in Geiger mode
  - Silicon photomultiplier

Photodiodes

- no multiplication→ single photons

HPDs, HAPDs

- discussed within the vacuum-based detectors

APDs

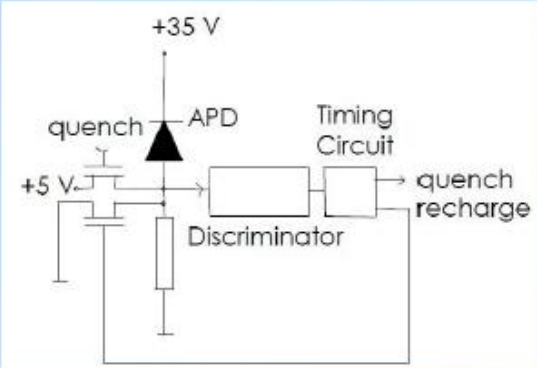
- Amplifications up to ~ 1000

APD in Geiger mode / Si PMs

APDs operated in Geiger mode

Another option is to operate the APD in Geiger mode.
Bias voltage is increased above the breakdown voltage and avalanche must be stopped by:

- active bias control or
- quenching resistor



Large are APD operating in Geiger mode would be most of the time in the recovery state due to the large number of dark counts.
Solution: localization of quenching, division of large area APD in an array of smaller ones → SiPM (1990's: Golovin, Sadygov)

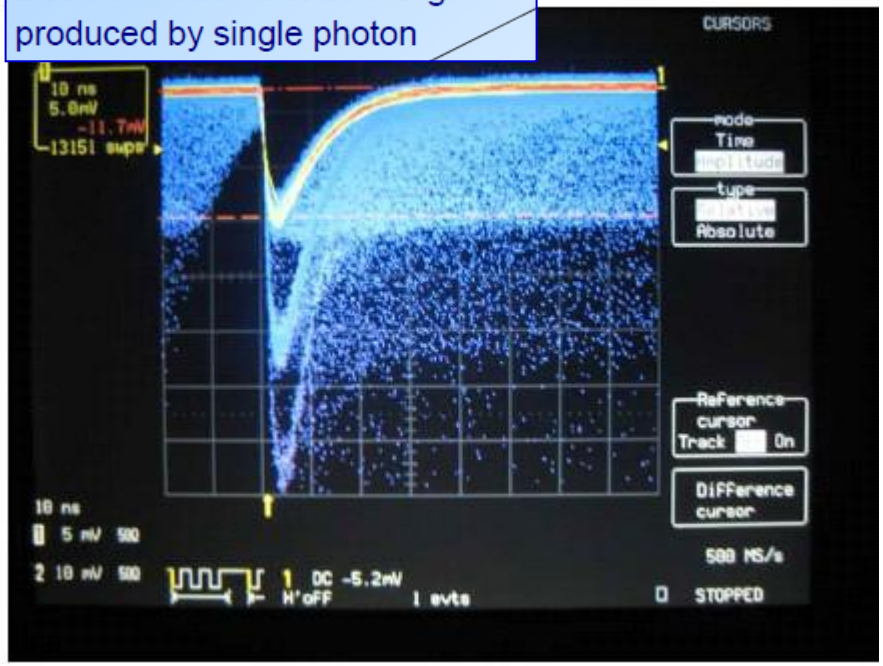
Many producers:
Photonique/CPTA
MEPhI/PULSAR
Hamamatsu
MPI
FBK-irst
STMicroelectronics
SensL
Philips (dSiPM)
Zecotec
...

Many different names:
SiPM
MRS APD
MAPD,
SPM
MPPC
PPD
...

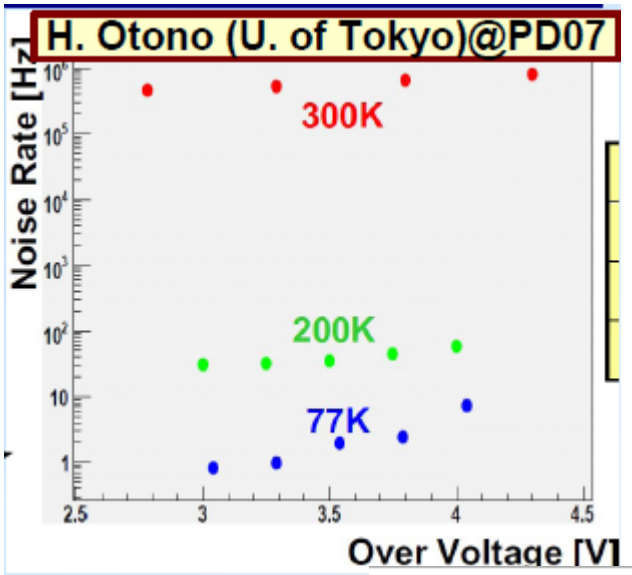
APD in Geiger mode / Si PMs cont.

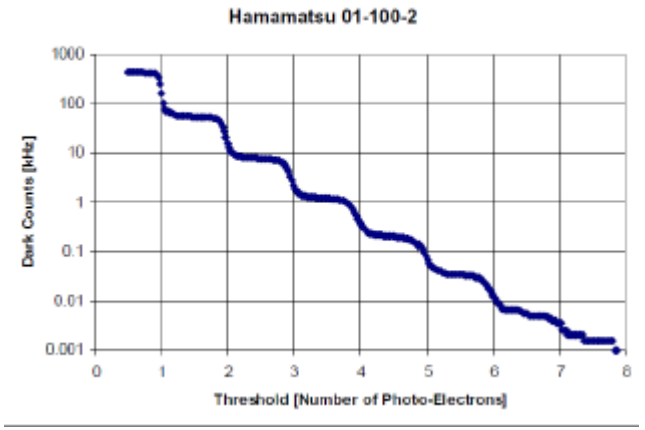
$$G = C_{m.c.} \times (V_{bias} - V_{breakdown}) / e_0$$

- large gains, typically 10^5 – 10^7
- short signals (~10 ns) produce several mV signals on 50 Ohm
- total signal is the sum of signals from individual micro cells
- afterpulses and optical crosstalk also contribute to total charge produced by single photon



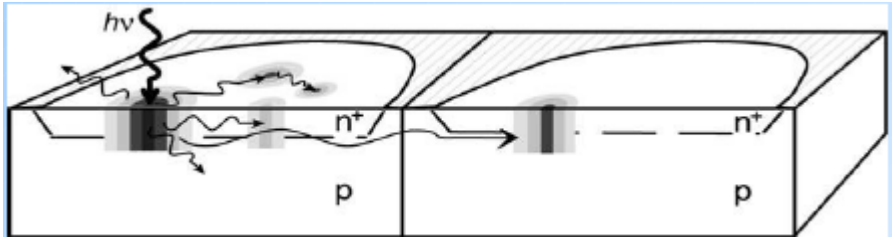
SiPM-Dark noise



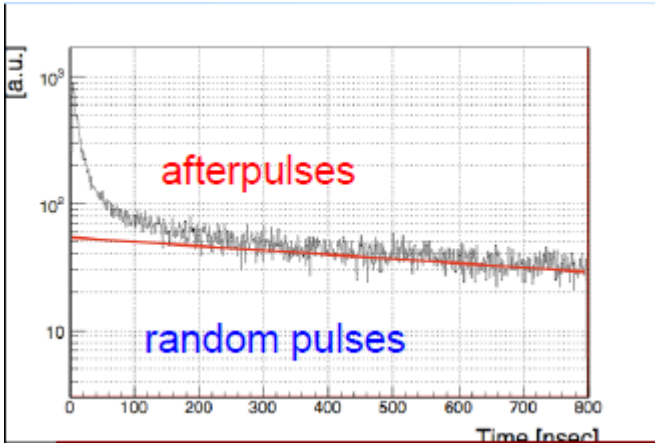


APD in Geiger mode / Si PMs cont.

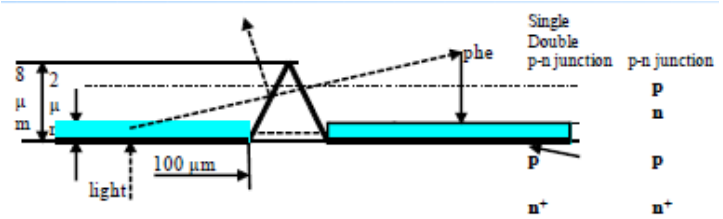
SiPM-Optical cross-talk



SiPM-Afterpulses

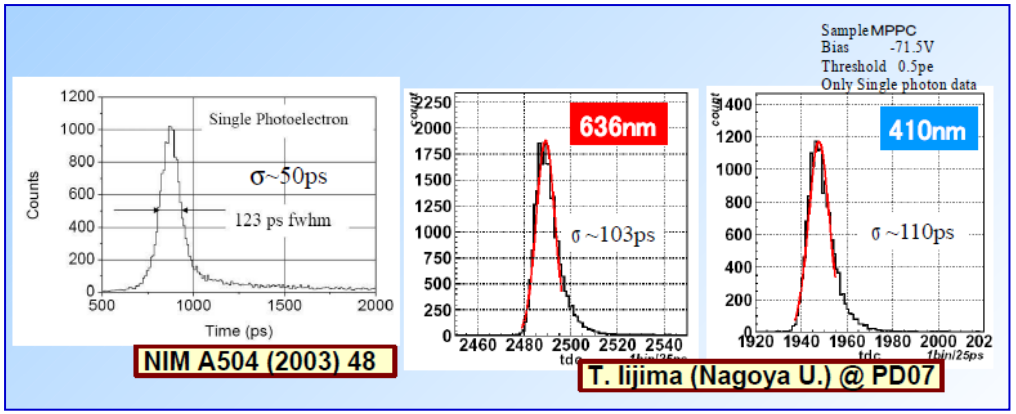


SiPM - Optical cross-talk suppresion



APD in Geiger mode / Si PMs cont.

SiPM-Timing



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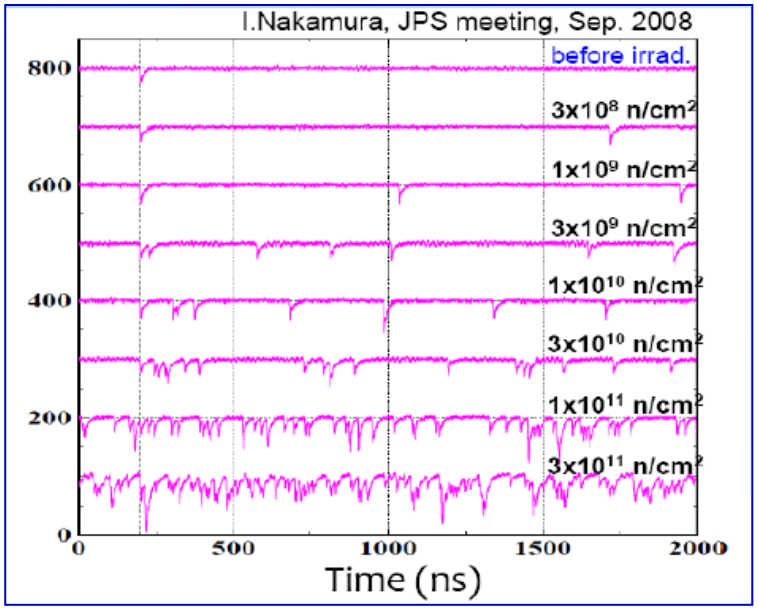
T. Iijima (Nagoya U.) @ PD07

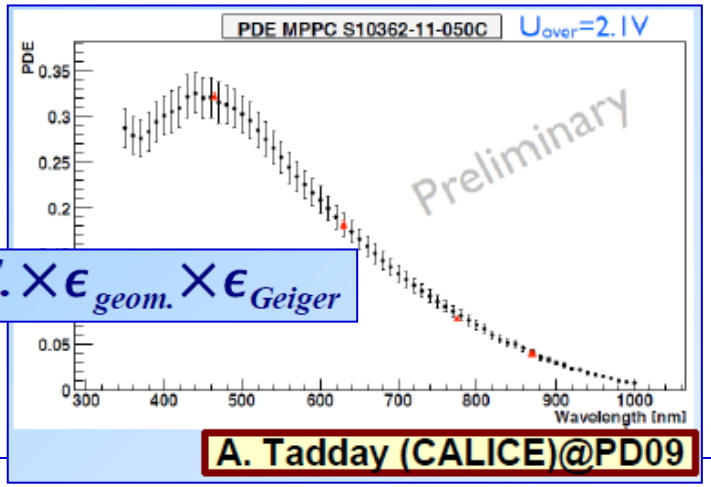
SiPM - p,n irradiation



→ Very hard to use present SiPMs as single photon detectors after fluence of 10^{11} n/cm² 1MeV neutrons

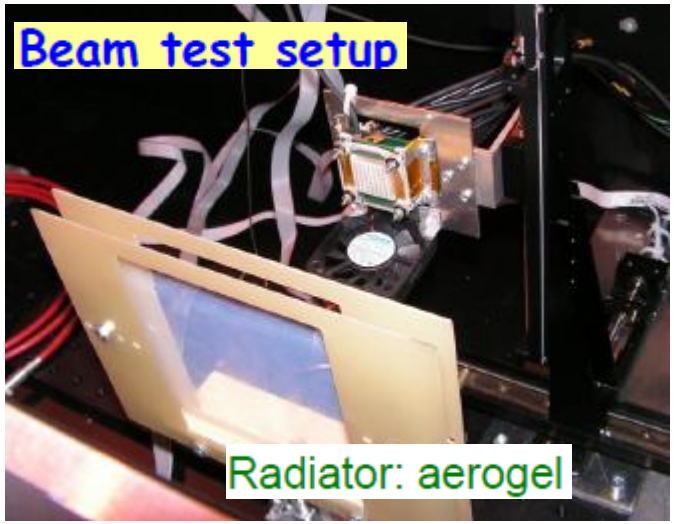
SiPM - Photon detection efficiency

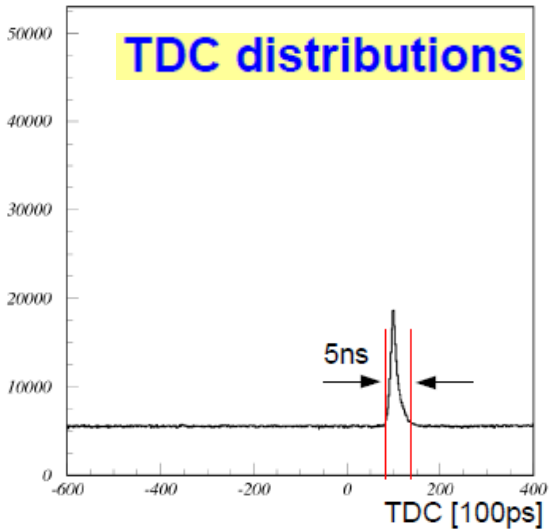
$$PDE = Q.E. \times \epsilon_{geom.} \times \epsilon_{Geiger}$$



A. Tadday (CALICE)@PD09

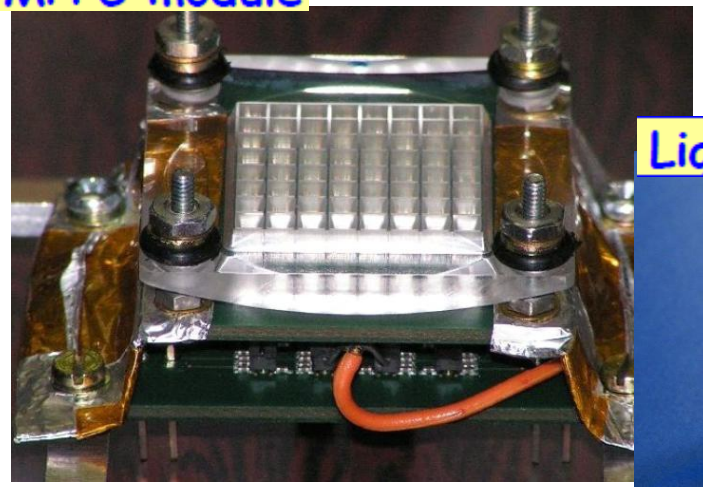
CAN a RICH w/ SiPMs WORK ?



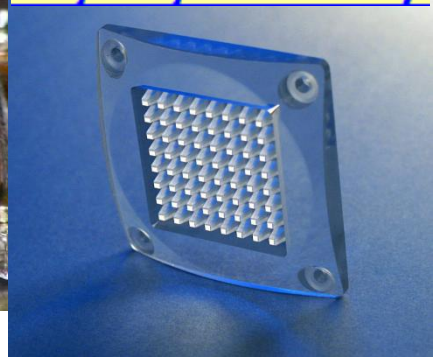


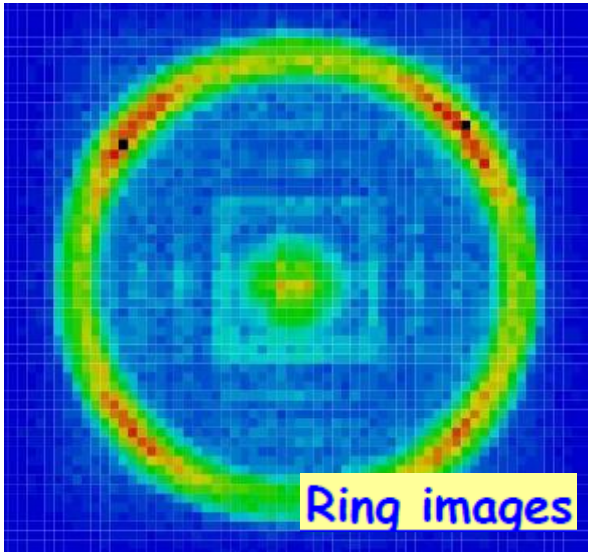
R&D for Belle II, Aerogel

MPPC module



Light guide array





3.7 detected ph.s / ring

CONCLUSIONS

Cherenkov imaging detectors represent
a field of great vitality and enthusiasm

These detectors are challenging, but established and novel techniques and technologies offer handles to overcome the difficulties

This community of detector practitioners certainly appreciates the challenge

RICH 2013

the next appointment with the community of RICH practitioners

RICH2013

Nov/Dec 2013
Kamakura (Japan)