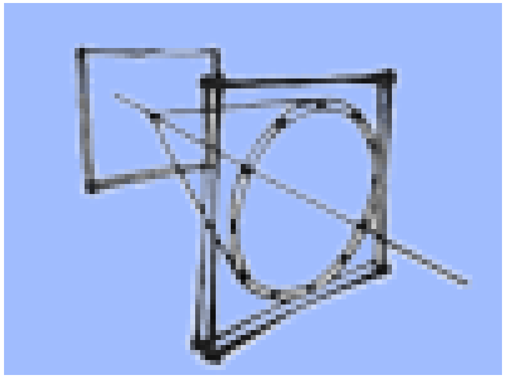
RICH detectors and alternative/complementary options for PID at colliders

Thank you to

all the colleagues who kindly provided information

all the colleagues whose material (paper, slides) I used

Of course, all the mistakes and biases are mine !



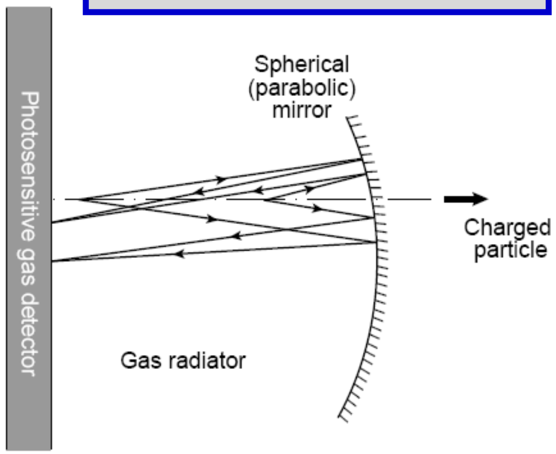
INTRODUCTION

ABOUT RICHes, A QUICK REMINDER

HIGH MOMENTA

With focalization

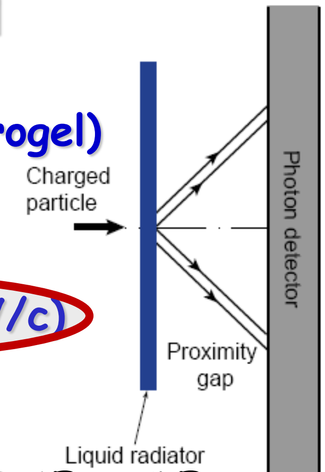
- Extended radiator (gas)
- the only approach at high momenta (p > 3-4 GeV/c)



- EXAMPLES: SELEX, OMEGA, DELPHI, SLD-CRID, HeraB, HERMES, COMPASS, LHCb, NA62, EIC

Proximity focusing

- thin radiator (liquid, solid, aerogel)
- Effective at low momenta (p < 5-6-8? GeV/c)

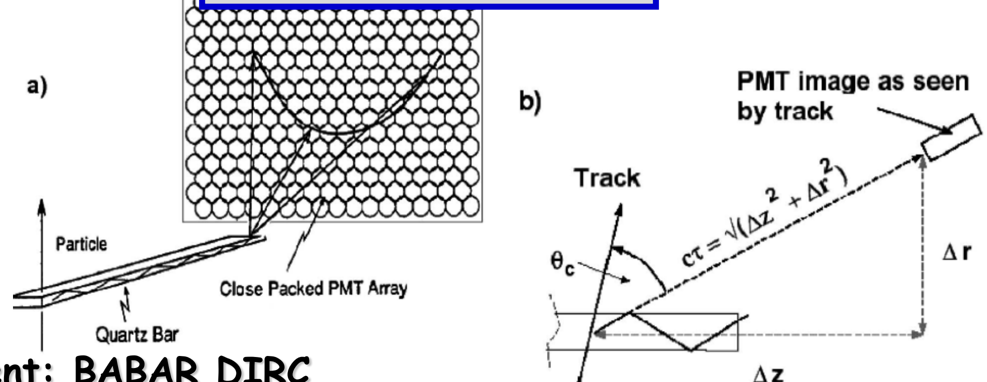


- EXAMPLES: STAR, ALICE HMPID, HERMES, CLEO III, CLAS12, BelleII A-RICH, EIC

LOW MOMENTA

DIRC

- Quartz as radiator and as light guide
- Effective at low momenta (p < 5-6 GeV/c)



- The only existing DIRC operated in an experiment: BABAR DIRC
- NEW: DIRC-derived architectures in BELLE II (TOP), Panda & EIC (focusing DIRC)

ABOUT RICHes @ COLLIDERs

HIGH MOMENTA

With focalization

- **LHCb** – not a classical collider setup: forward angles one arm spectrometer
- **DELPHI, SLD-CRID** – the only examples in contexts of much lower $\mathscr{L}$ than what expected in the next generation colliders
- **EIC**

Proximity focusing

- **ALICE HMPID**
- **Belle II A-RICH**
- **EIC**

LOW MOMENTA

DIRC

- **BABAR DIRC**
- **BELLE II (TOP)**
- **Panda (focusing DIRC)**
- **EIC (high performance DIRC)**

From this quick analysis

- **Up-to-date options for low momenta available *(DIRC-like, aerogel)* ↔ limited space required**
- **Problematic approach for high momenta ↔ space demanding: the development of a *compact RICH concept* required**

Addressing the photon detector issues

(common to high and low momenta)

ABOUT SINGLE PHOTON DETECTORS

3 families (grouping by technologies)

Vacuum based PDs

- **PMTS** (SELEX, Hermes, BaBar DIRC, NA62)
- **MAPMTs** (HeraB, COMPASS RICH-1 forward region, LHCb upgrade, GlueX, CLASS12, Panda forward-RICH)
- **Hybride PMTs** (LHCb)
- **HAPD** (BELLE II aerogel-RICH)
- **MCP-PMT** (BELLE II barrel: TOP detector)
- **LAPPDs – large size MCP-PMTs, development ongoing**

Gaseous PDs

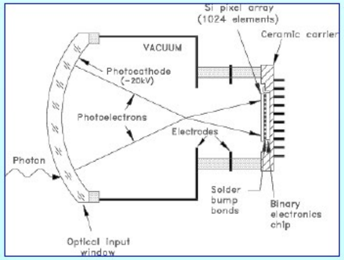
- **Organic vapours - in practice only TMAE and TEA** (Delphi, OMEGA, SLD CRID, CLEO III, …)
- **CsI and open geometry** (HADES, COMPASS, ALICE, STAR, JLAB-HALL A)
- **CsI and MPGDs** (PHENIX HBD, no imaging, NEW: COMPASS RICH-1 2016-17 upgrade)

SiPMs

- **Silicon PMs** (not used so far in any experiment)
  - radiation hardness , intrinsic noise
  - cooling to moderate them → more material, complexity

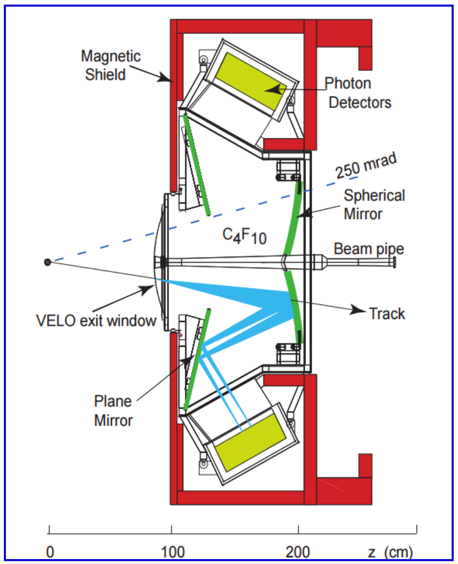
PMTs & MAGNETIC FIELD

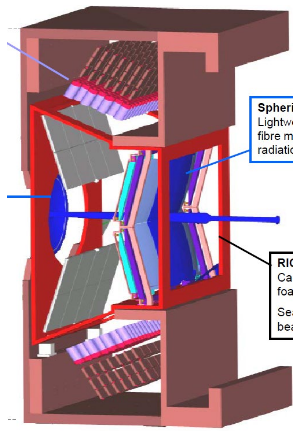
LHCb



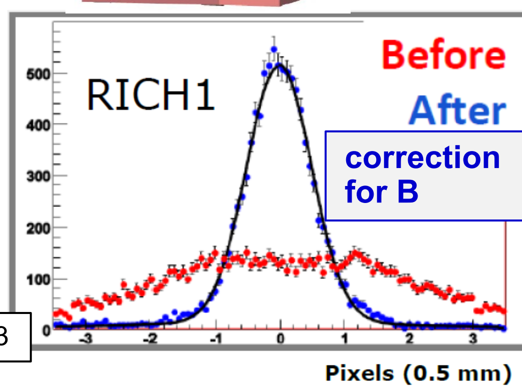
HPM, LHCb custom
1024 anods

Impressive mag. shielding





Nevertheless:

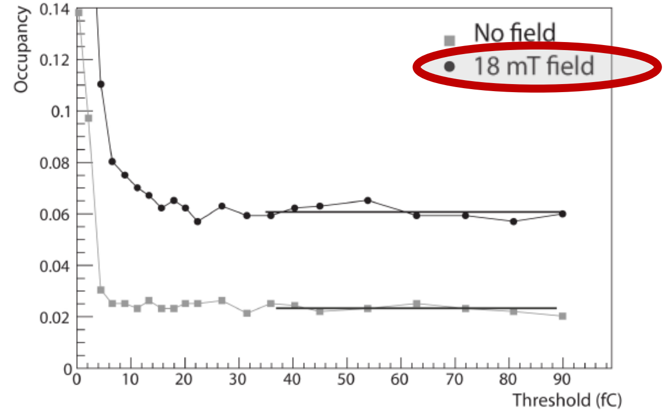


correction for B

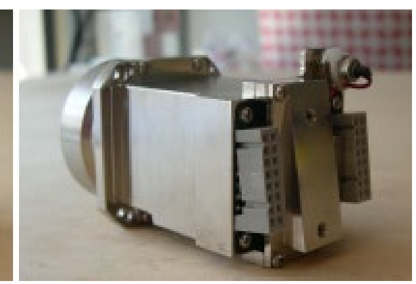
A. Papanestic, RICH 2013

COMPASS

P. Abbon et al., NIMA 616 (2010) 21



MAPMT type R7600-03-M16 by Hamamatsu



Individual soft iron shielding → B < 2 mT (external B ~ 20 mT)

A FEW WORDS ABOUT SINGLE PHOTON DETECTORS
cont.

Time resolution (σ)

- PMTs, MAPMTs >/~ 0.3 ns
- MCP-PMT <100 ps
- SiPM <100 ps
- MWPCs >/~ 20 - 400 ns
  - FE dependent, ballistic deficit implications (*)
- MPGDs ~ 7-10 ns (INTRINSIC)

(*) COMPASS – Gassiplex 400 ns, ballistic def. 50%
APV25 20ns, ballistic def. 25%

Effective QE range

- Vacuum-based devices:
  λ > 300, 250, 200 nm
  [also solar-blind]
- Gaseous devices (CsI):
  λ < 205 nm

Operation in magnetic field

- PMTs, MAPMTs, HPMTs NO
- MCP-PMT ~YES
- MWPCs, MPGDs YES
- SiPM YES

COSTS

- Gaseous (*) - $ (0.2-0.4 M / m^2)
- MAPMTs - $$ (0.5-1 M / m^2)
- SiPM - $$ (0.8-1 M / m^2)
- MCP-PMT - $$$ (???)
  - LAPPD - $$ (0.8-1 M / m^2)

(*) UV: gas system, mirrors more DEMANDING → expensive

MORE ABOUT SINGLE PHOTON DETECTORS cont.

Any source of noise compromises PID efficiency and purity

- **Here shown making use of LHCb experience**

LHCb

RICH 1

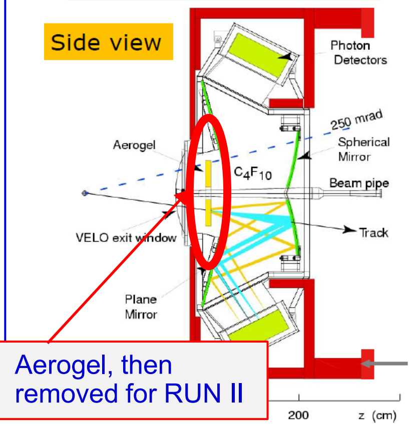
Acceptance 25-300 mrad

2 Detectors
3 Radiators

RICH 2

Acceptance 15-120 mrad

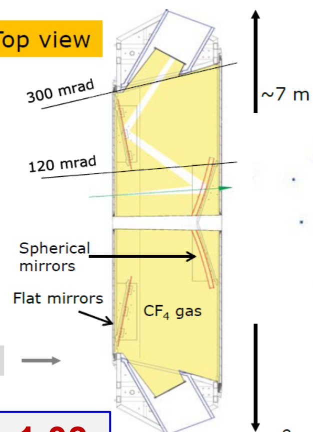
Side view



Aerogel, then removed for RUN II

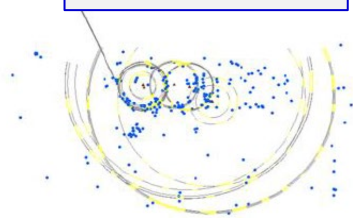
Note Scale Difference

Top view



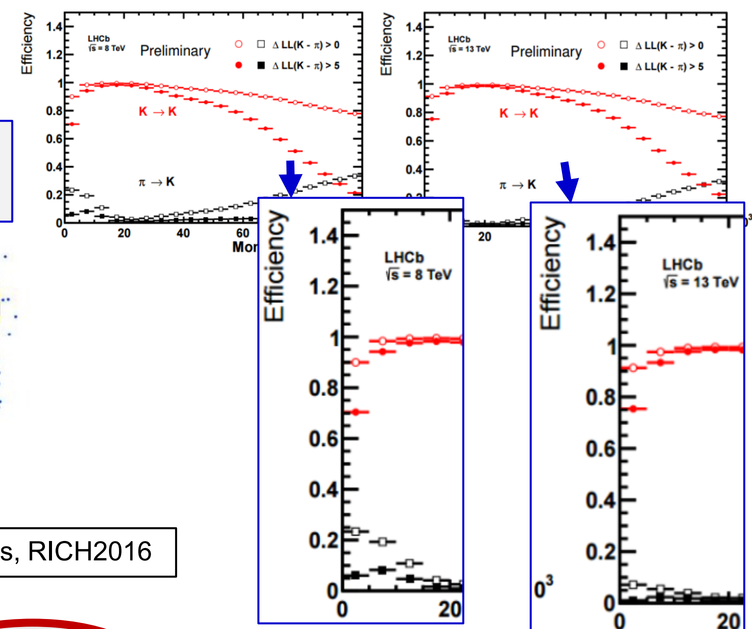
n = 1.03

Image RICH1 In RUN I



Run I

Run II (2015)



A. Papanestis, RICH2016

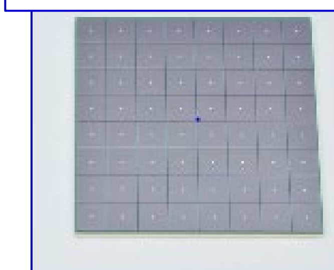
Aerogel rings very big

- Many photons, many track/photon combinations

Intrinsic noise rate, hits per m² in a time window of 10 ns

- **MAPMTs (cut to reject cross talk with only 5% photoelectron loss): ~0.1** (information source: COMPASS)
- **Gaseous (cut at 3 σ noise) : < 20** (information source: COMPASS)
- **SiPM (S13361-3050-08, room temperature, no ageing): 500** (information source: Hamamatsu data sheet)

MCCPs by Hamamatsu, 70% active area



MAPMT : Gaseous : SiPM = 1 : 200 : 5000

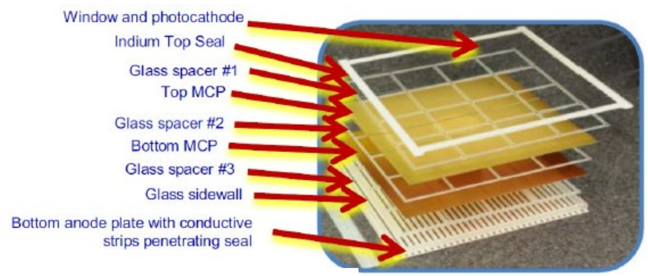
LAPPD, an OPTION ?

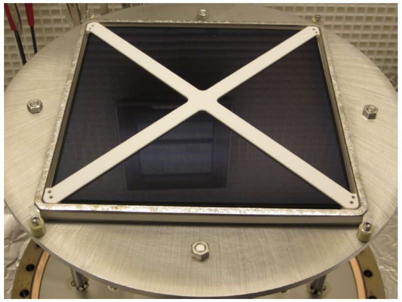
MINOT, Pisa Meeting 2018

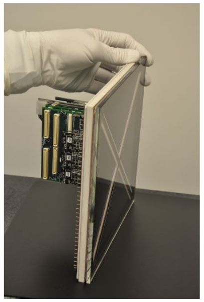
B.W. Adams et al., arXiv:1603.01843

LAPPD

(20x20 cm^2) MCP-PMTs







LAPPD #25 Performance Summary

GEN I Strip r-o

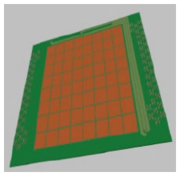
Parameter	LAPPD 25
MCP resistance (Entry/Exit; MΩ)	10.7 / 14.2 MΩ at 875 V
QE	@365 nm: Max: 10%, Mean: 7.1%, s = 0.8% @455 nm: Mean: 10.2%
Gain	7.5 x10^6 @ 850/950 V (entry/exit)
Dark rate (Single 13.5 cm2 strip)	9.5 Cts/s cm2 @ 50 volts on the P/C, 850 V/MCP, and Threshold of 7.6x105 gain
After pulses	Typical for MCP PMT – about 3.5%
Along-strip **Spatial Resolution** Cross-strip	2.8 mm RMS (measured as 33.4 psec) 1.3 mm RMS
Time Resolution	64 psec resolution TTS MCP Pulse Rise time: 850 psec, FWHM: 1.1 nsec

Table 1 - LAPPD Pricing Schedule (05-18-2019)

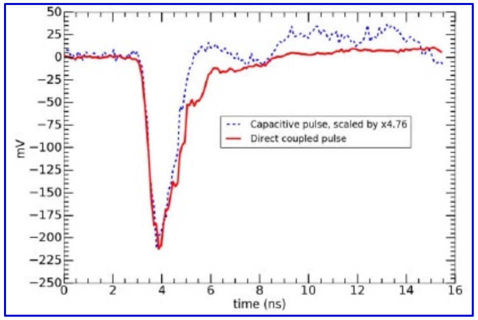
# Sold	Unit Price	Sales
1	$ 50,000	$ 50,000
2	$ 47,044	$ 94,088
3	$ 43,440	$ 130,319
4	$ 41,461	$ 165,842
5	$ 40,111	$ 200,557
6	$ 39,095	$ 234,571
7	$ 38,284	$ 267,988
8	$ 37,611	$ 300,890
9	$ 37,038	$ 333,343
10	$ 36,540	$ 365,398
20	$ 36,100	$ 721,995
50	$ 33,334	$ 1,666,694
75	$ 30,000	$ 2,250,007
100	$ 28,633	$ 2,863,335
300	$ 27,702	$ 8,310,468
500	$ 24,414	$ 12,206,898
750	$ 23,021	$ 17,265,691
1000	$ 21,972	$ 21,972,132

GEN II Capacitive Coupling

A thin metal DC ground plane is deposited onto the inside of the detector.



User-designed read-out elements



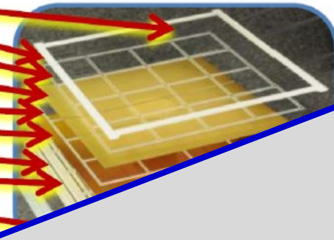
LAPPD, an OPTION ?

MINOT, Pisa Meeting 2018

B.W. Adams et al., arXiv:1603.01843

LAPPD

(20x20 cm^2) MCP-PMTs



LAPPD #25 Performance Sum…

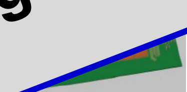
Parameter	
MCP resistance (Entry/Exit; MΩ)	
QE	

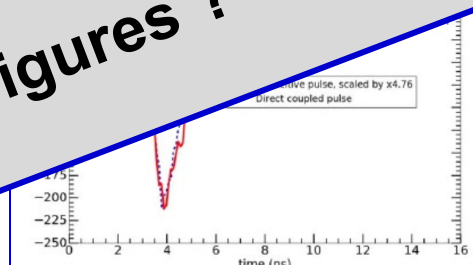
GEN I Strip-o…

GEN …

A thin m… plane is dep… inside of t…

User-designe… out elements





		…88
		$ 300,890
		$ 333,343
	$ …6,540	$ 365,398
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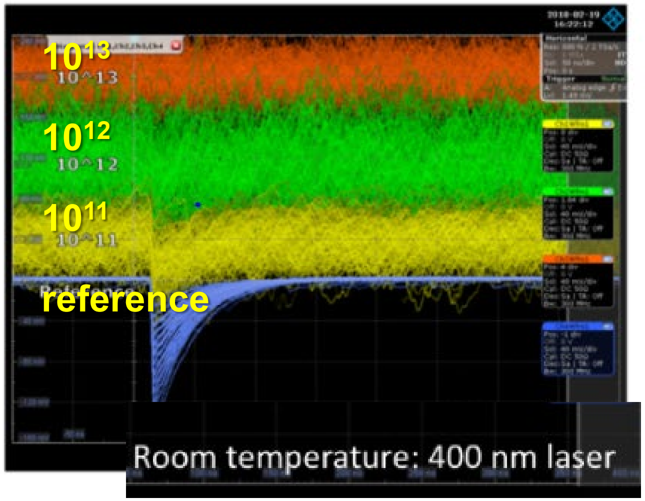
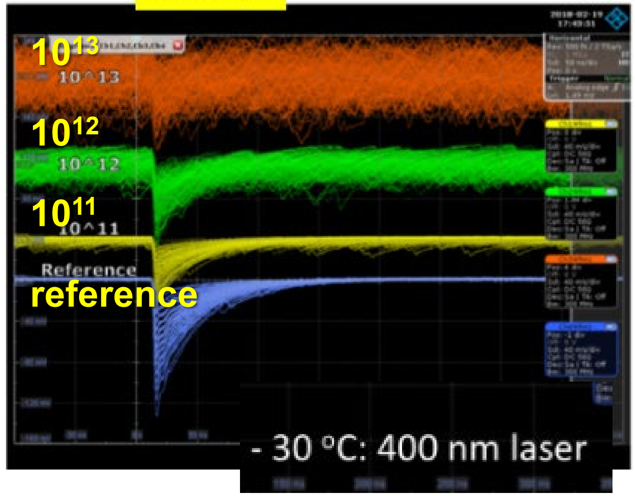
OPEN QUESTIONS

1. **Will the development be continued up to full maturity?**
2. **What about the rate capability in the generation-2, namely the LAPPDs with resistive anode?**
3. **Cross-talk level with small pads ?**
4. **Ageing figures ?**

A FEW MORE WORDS ABOUT SiPMs 1/2

From recent literature

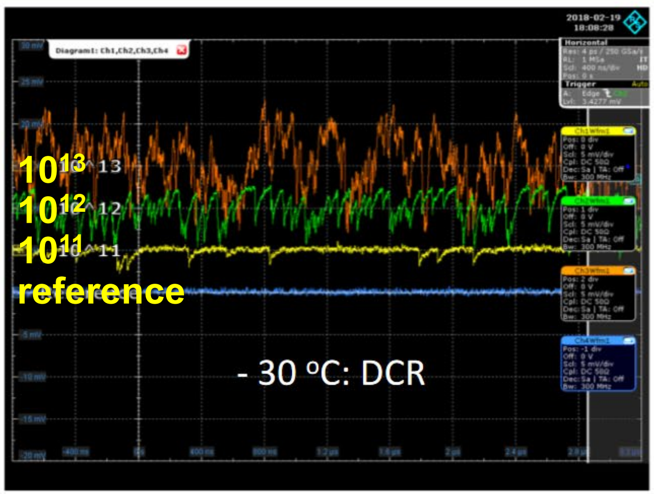


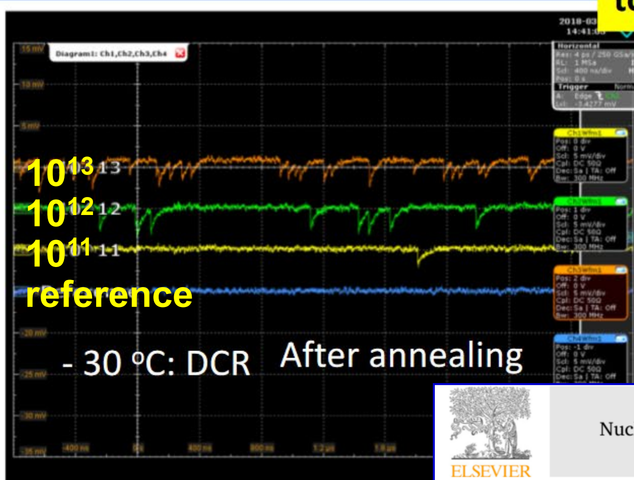


Room temperature NOT an option !

Radiation damages and recovering via annealing (@175 °C)

Radiation tolerance





SiPMs

- **@ – 30 °C**
- **With annealing**

Compatible with integrated fluence ~ 10^{11}neq/cm^2 ?

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

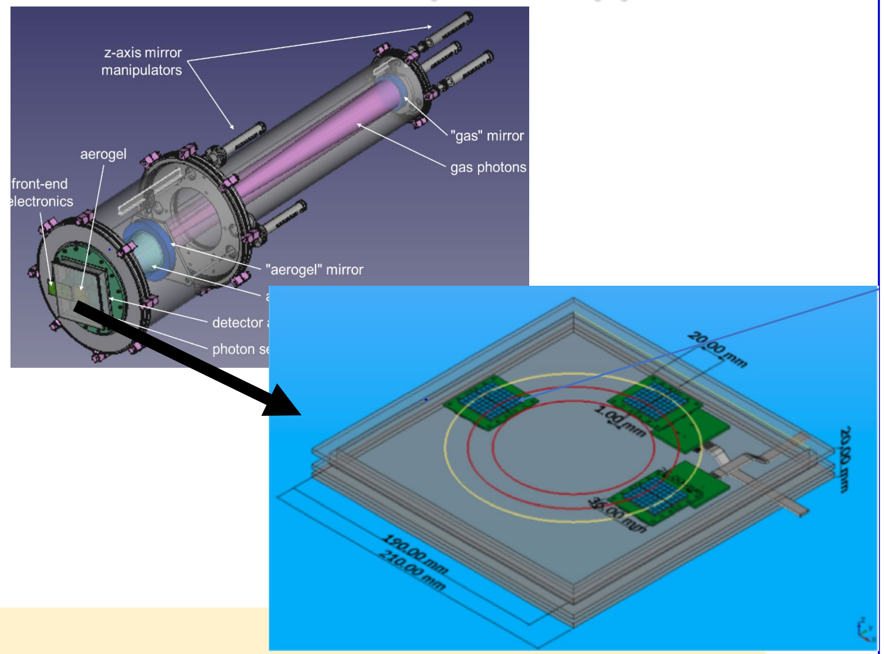
Single photon detection with SiPMs irradiated up to 10^{14} cm^{-2} 1-MeV-equivalent neutron fluence

M. Calvi [a,b], P. Carniti [a,b,*], C. Gotti [a,b,*], C. Matteuzzi [a], G. Pessina [a]

A FEW MORE WORDS ABOUT SiPMs 2/2

A dedicated effort for application at EIC by a cluster of INFN groups

- **SiPMs from different producers mounted on a RICH prototype**
  - Part as received
  - Part irradiated
  - Part irradiated and annealing cycle
- → **Performance in a test beam**
- **Coupled to specific FE r-o:**
  - ALCOR, developed for DarkSide



multiple manufacturers

differences in architecture, V_{bd} and electric fields

keep Hamamatsu, leading producer of photosensors

keep Broadcom, possible future R&D within FBK-INFN collaboration agreement

choose between Ketek (25/15 µm, cheaper) and SensL (30/20 µm, timing)

RICHes

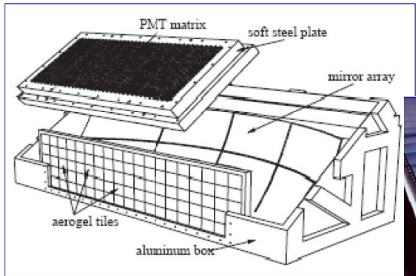
The low momentum sector

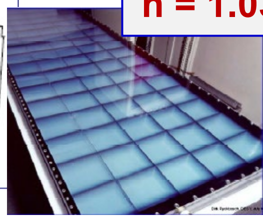
AEROGEL

AEROGEL in CHERENKOV IMAGING, so far 1/2

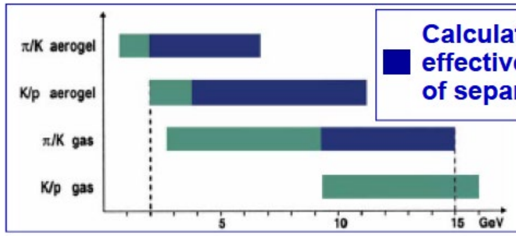
HERMES

2 identical RICHes
Dual radiator:
Aerogel & C4F10

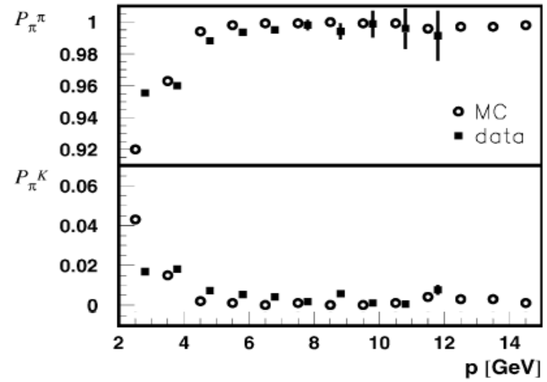




n = 1.03



Calculation: effective range of separation



N. Akopovet al.,
NIMA 479 (2002) 215

LHCb

RICH 1

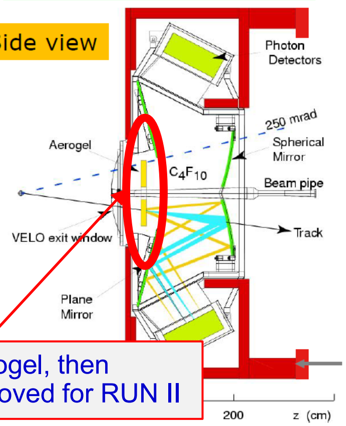
Acceptance 25-300 mrad

2 Detectors
3 Radiators

RICH 2

Acceptance 15-120 mrad

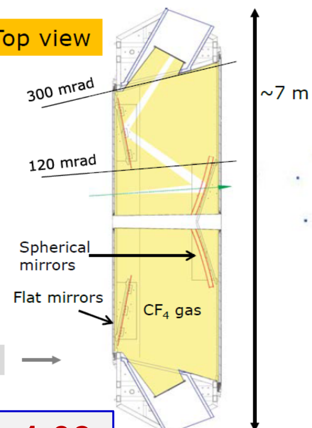
Side view



Aerogel, then removed for RUN II

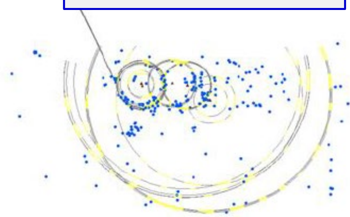
Note Scale Difference

Top view

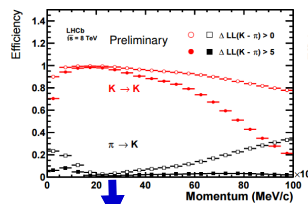


n = 1.03

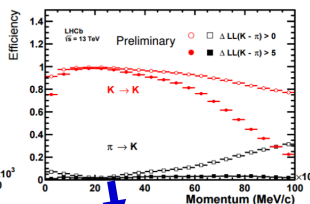
Image RICH1 In RUN I

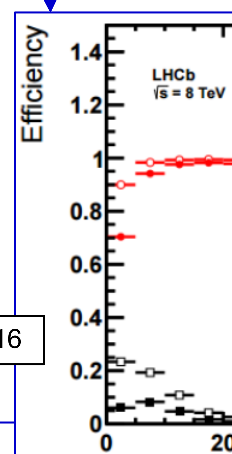


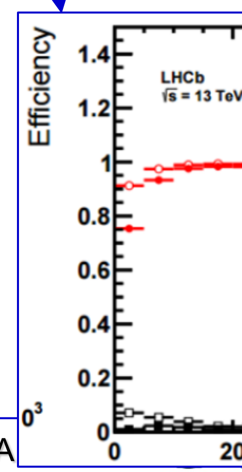
Run I



Run II (2015)







A. Papanestis, RICH2016

Aerogel rings very big

- Many photons, many track/photon combinations

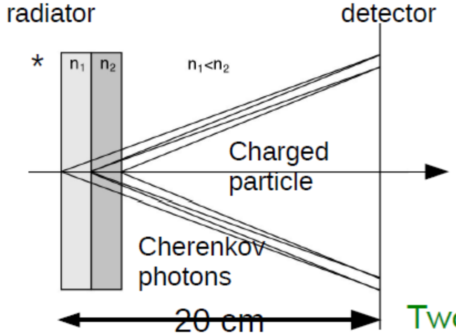
AREOGEL in CHERENKOV IMAGING, so far 2/2

BELLE II - ARICH

Goals and constraints:

- > 4 σ K/π separation @ 1-3.5 GeV/c
- operation in magnetic field 1.5T
- limited available space ~280 mm
- radiation tolerance (n,γ)

proximity focusing aerogel RICH

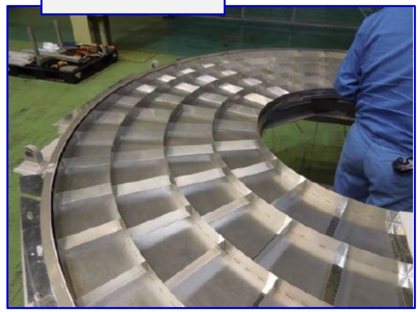


Two 2cm thick layers

n_1= 1.045 n_2= 1.055

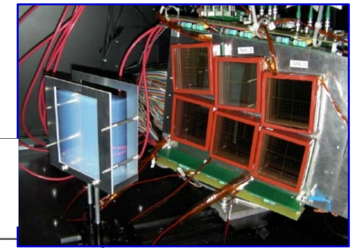
HAMAMATSU HAPD
Selected because of Radiation tolerance

ASSEMBLY



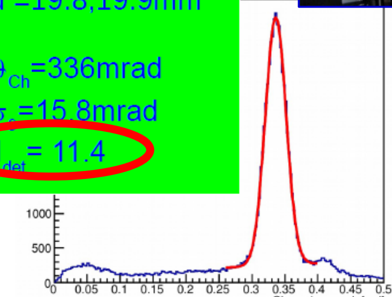
R. Pestotnik, RICH2016

TEST BEAM



double aerogel
- n_0=1.050,1.065
- d =19.8,19.9mm

ϑ_{Ch}=336mrad
σ_0=15.8mrad
N_{det} = 11.4



>5.5 σ K / π separation at 4 GeV/c

CLAS12, prelimiunary results

RICH goal: π/K/p identification from 3 up to 8 GeV/c and 25 degrees

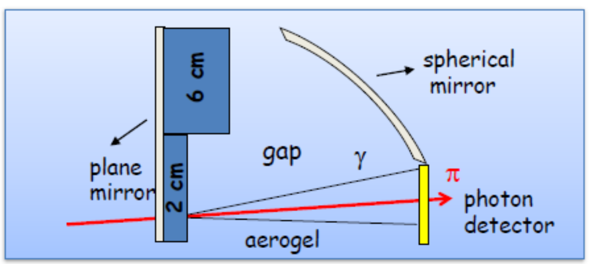
~4σ pion-kaon separation for a pion rejection factor ~ 1:500

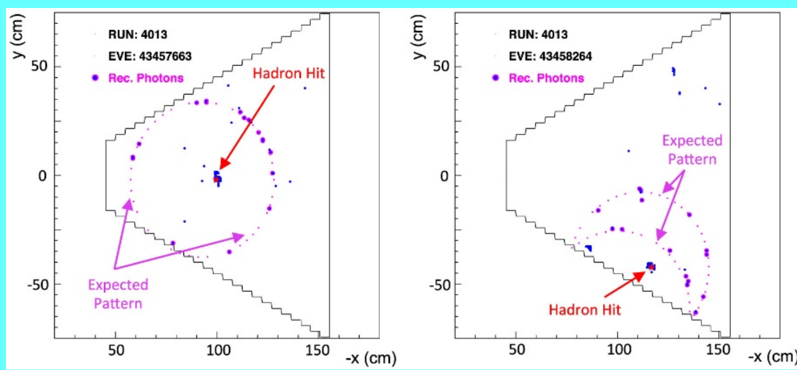
Implemented so far

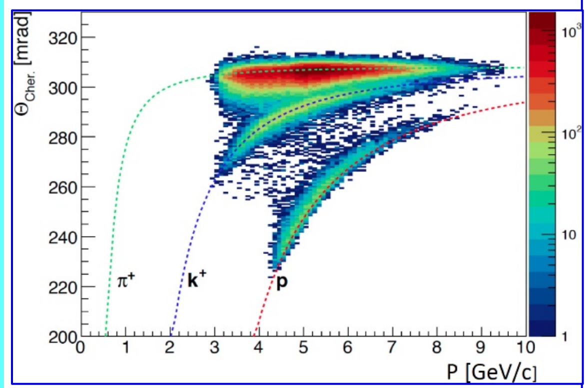
n = 1.05

from test beam, 12 ph.s/ring expected for 2 cm-long tiles (TDR)

Direct rings and best performance for high momentum particles







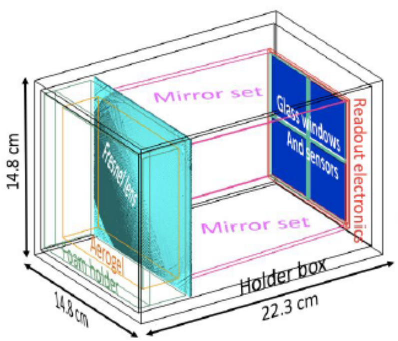
M. Contalbrigpo et al., NIMA 994 (2020) 163791

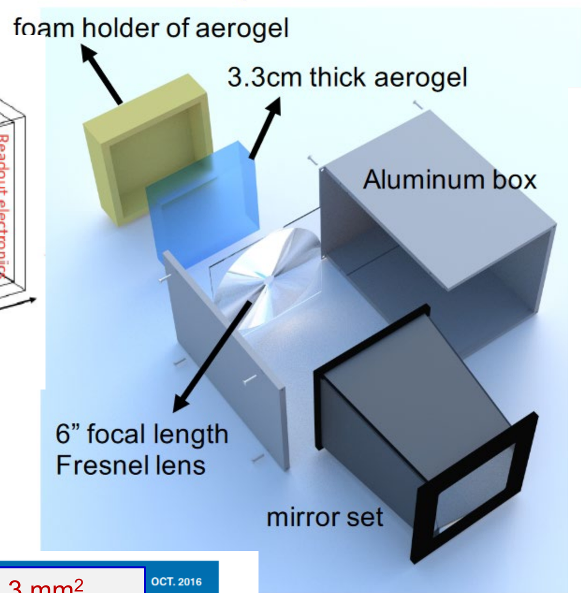
On going R&D for EIC

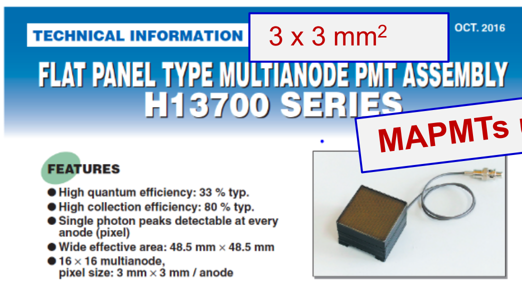
Modular RICH

- An important ingredient: The Fresnel lens

Goal: rise 3σ π/K separation to 10 GeV /c thanks to focalization with Fresnel lens

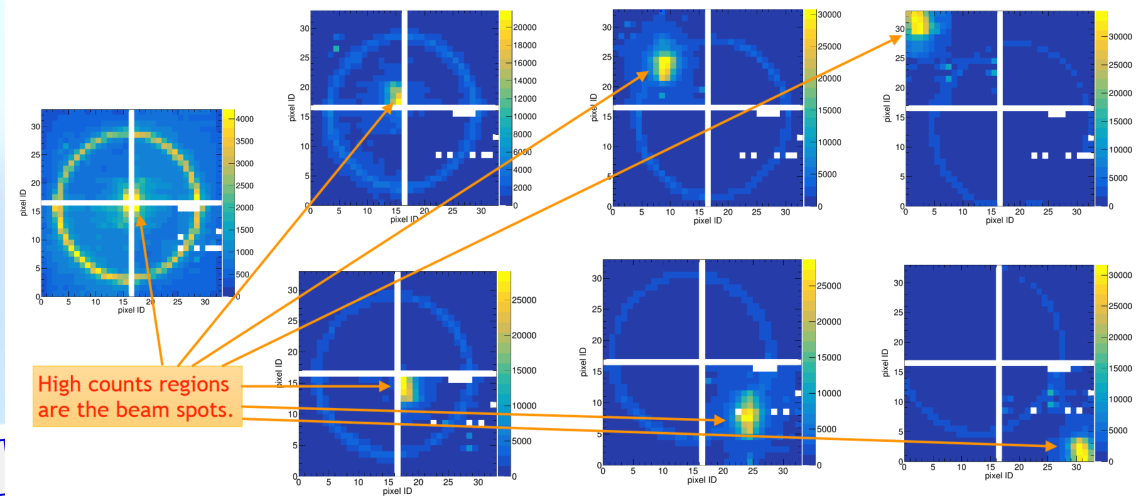






MAPMTs used at the moment !

Position scans with 120 GeV/c proton beam



Xiaochun He

EIC PID mRICH Yellow Report

ABOUT AEROGEL ITSELF

Producers:

HERMES - Matsushita Electric Works, Japan (*no longer available*)

LHCb, AMS, CLAS12 – Bunker and Boreskov Institutes in Novosibirsk, Russia

BELLE II ARICH -

Mass Production

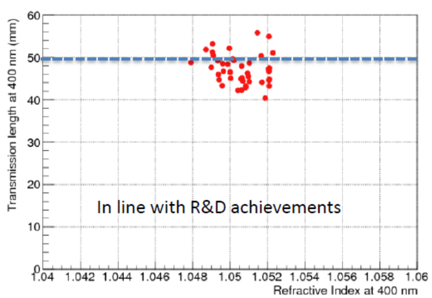
- **Japan Fine Ceramics Center (JFCC) for mass production.**
  - Panasonic no longer accepts new aerogel production.
  - Technology transfer by joint effort with us.
  - Recipe was provided from our side.

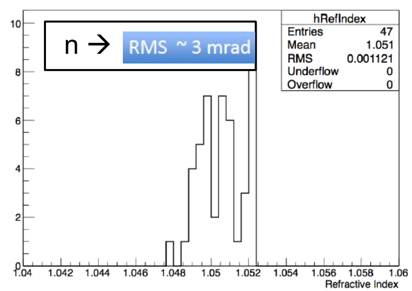
I.Adachi, RICH2016

Aerogel for CLAS12

M. Contalbrigo, RICH2016

Hygroscopic aerogel



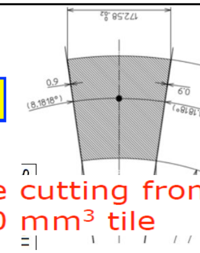


Aerogel for BELLE II

I.Adachi, RICH2016

Hydrophobic treatment

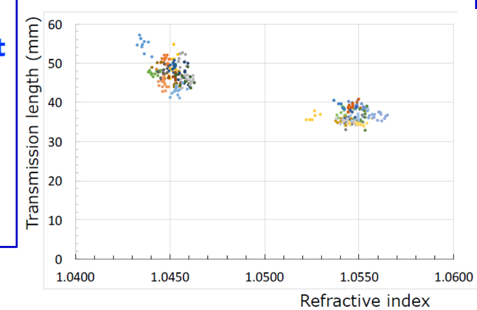
Provide long-term stability in optical property



Total 124 tiles for each refractive index
production over 13 months

Wedge shape cutting from 180×180×20 mm³ tile

- **Visual inspection**
  - **Crack/Chip/Milky area**
- **Dimensions/weight measurement**
- **Refractive index measurement**
  - **Fraunhofer technique**
- **Transparency measurement**
  - **Using a spectro-photometer**



Yield ~74%

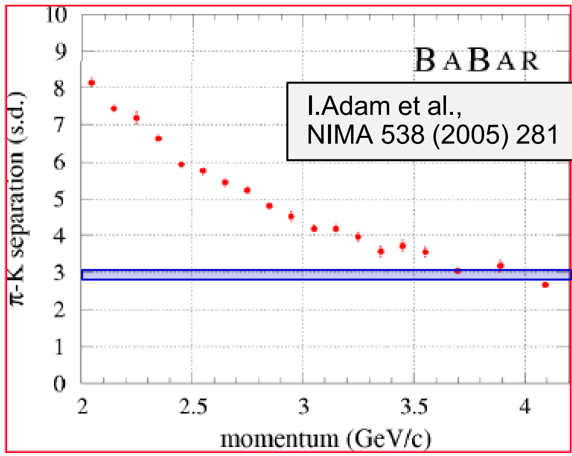
DIRC
& RELATED DETECTORS

DIRC

The only DIRC operated so far:

Babar

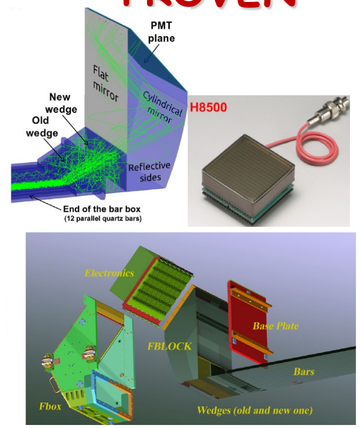
π/K separation power:

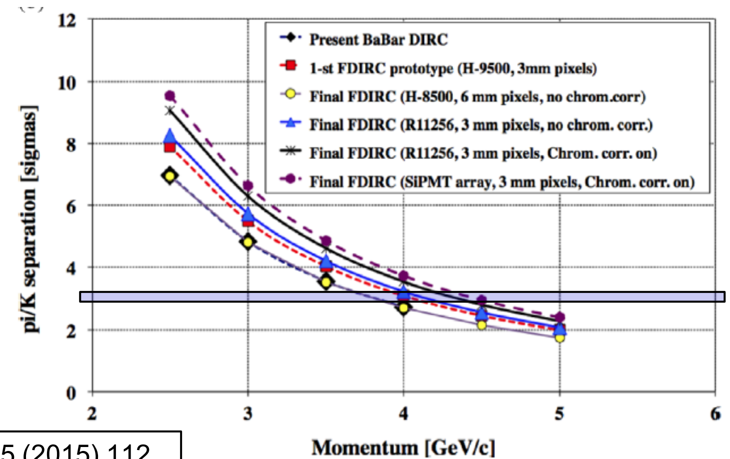


I.Adam et al.,
NIMA 538 (2005) 281

The concept of the focusing DIRC

- fine timing allowing for Chromatic Correction, PROVEN



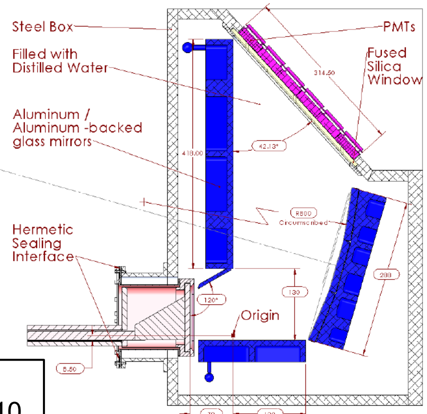


B. Deyet al., NIMA 775 (2015) 112

a FDIRC in Glue-X

GOAL:

3σ @ 4 GeV/c



J. Stevens et al.,
JINST 11 (2016) C07010

More exotic configuration: PANDA DISC-DIRC

- Barrel DIRC

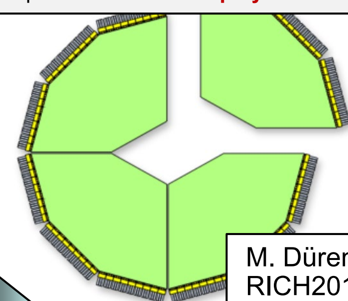
  Goal: 3 s.d. π/K separation up to 3.5 GeV/c

- Endcap Disc DIRC

  Goal: 4 s.d. π/K separation up to 4 GeV/c

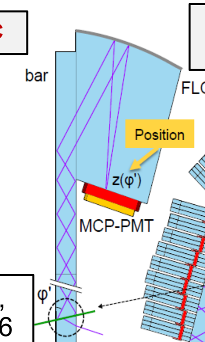
J. Schwiening.,
RICH2016

Concepts tested in **WASA polymer DIRC**



M. Düren,
RICH2016

Focusing light guide: **LiF**

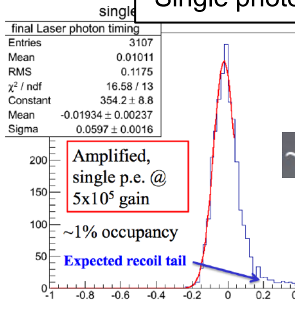


MORE WITH FINE TIME RESOLUTION PDs

BELLE II - TOP

- First Cherenkov device using MCP-PMTs in an experiment

Single photon (laser)



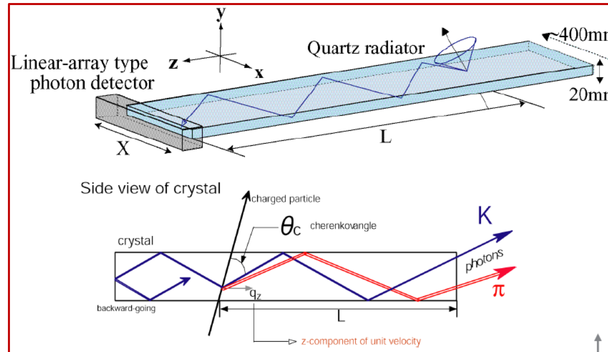
Preliminary: systematics of using reference time marker needs study

~50-60 ps single hit

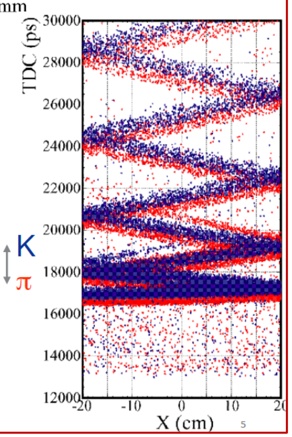
Consistent results in channels tested

Working to automate

HAMAMATSU R10754-07 M16(N)



Simulation 2GeV/c, θ=90 deg.



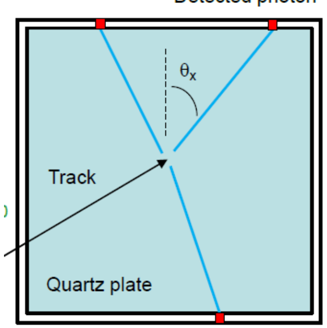
Different opening angles for the same momentum

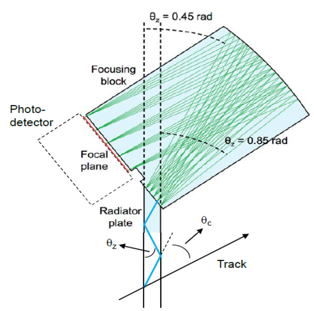
- Measure x-y position (5 mm) of photons (imaging)
- Measure precise (40 ps) time of arrival of photons (time-of-propagation); TOF from IP works additively

J. Fast, RICH 2016

TORCH (LHCb upgrade): a DIRC for TOF measurements using MCP-PMTs

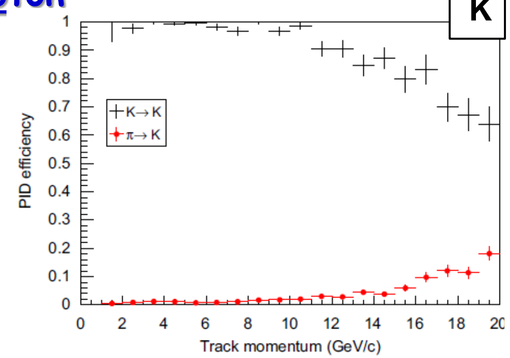
- Overcoming:
  - the upper limit from θ_C saturation
  - the time-resolution limit from single photon

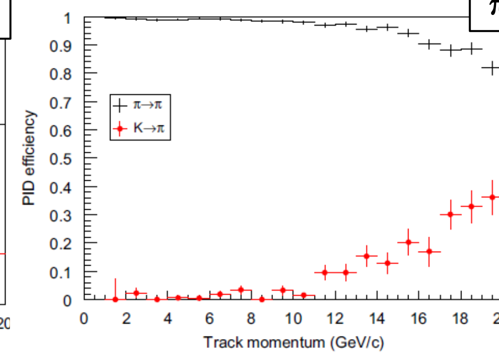




MC
10 m
σ_t = 12.5 ps

M.J.Charles, R. Forty, NIMA 639 (2011) 173



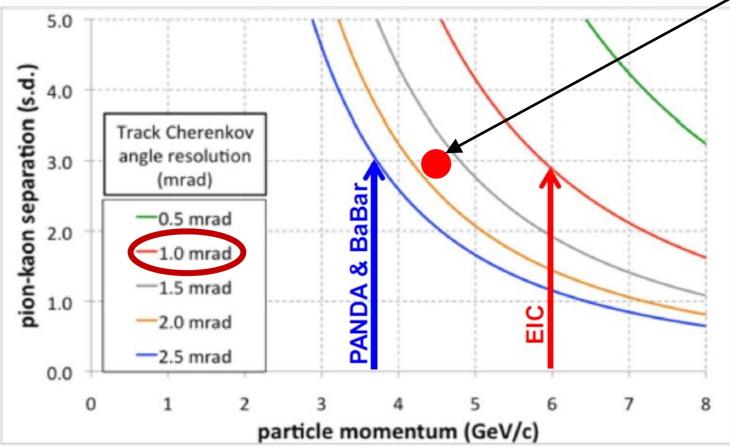


EIC DIRC

On going R&D for EIC

- **R&D including FDIRC & TOP concepts**
- **Goal**
  - p/K up to 10 GeV/c
  - π/K up to 6 GeV/c
  - e/π up to 1.8 GeV/c
- **Therefore needed:**

π/K identification as a function of the θ_c resolution

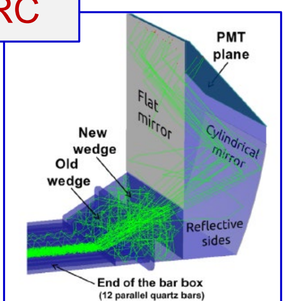


FDIRC
B. Deyet al., NIMA 775 (2015) 112

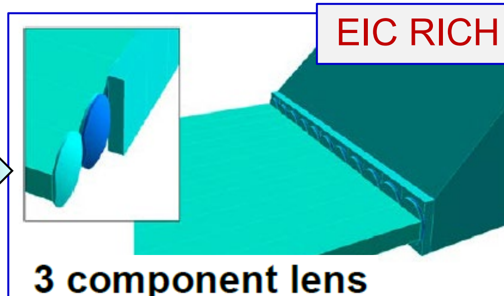
Majority of the material provided by G. Kalicy

- **Handles:**
  - New focusing element
  - Better timing (electronics limits in FDIRC)

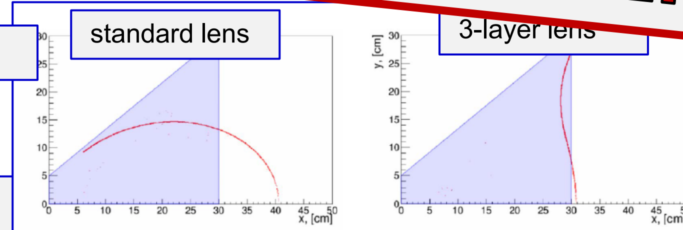
FDIRC



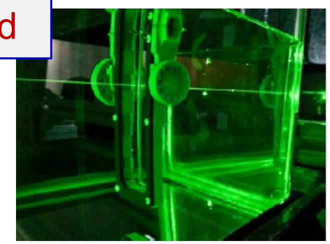
EIC RICH



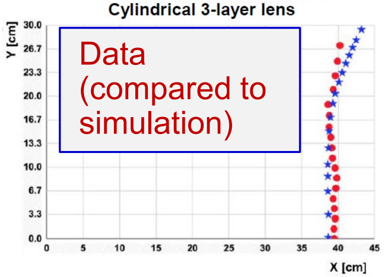
simulation



Promising & confirmed

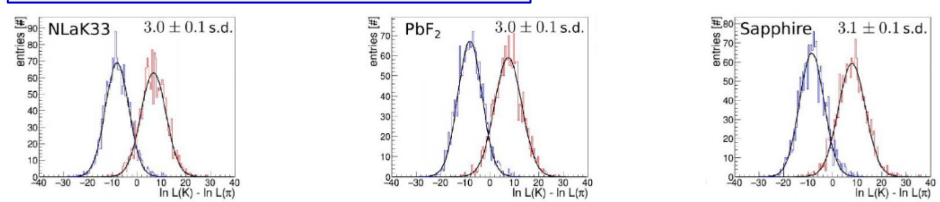


Measured and simulated focal plane: Cylindrical 3-layer lens

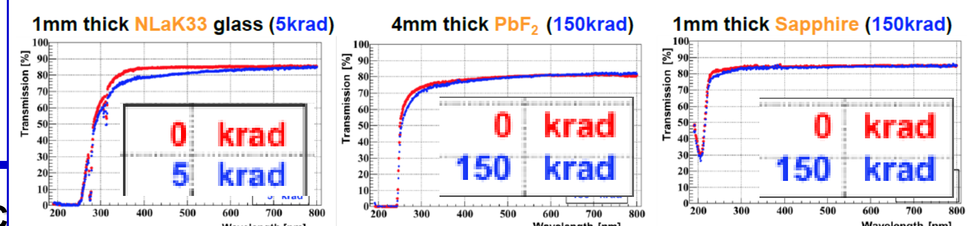


3-layer lens material: performance & radiation hardness

π-K separation at 6 GeV/c (MC)



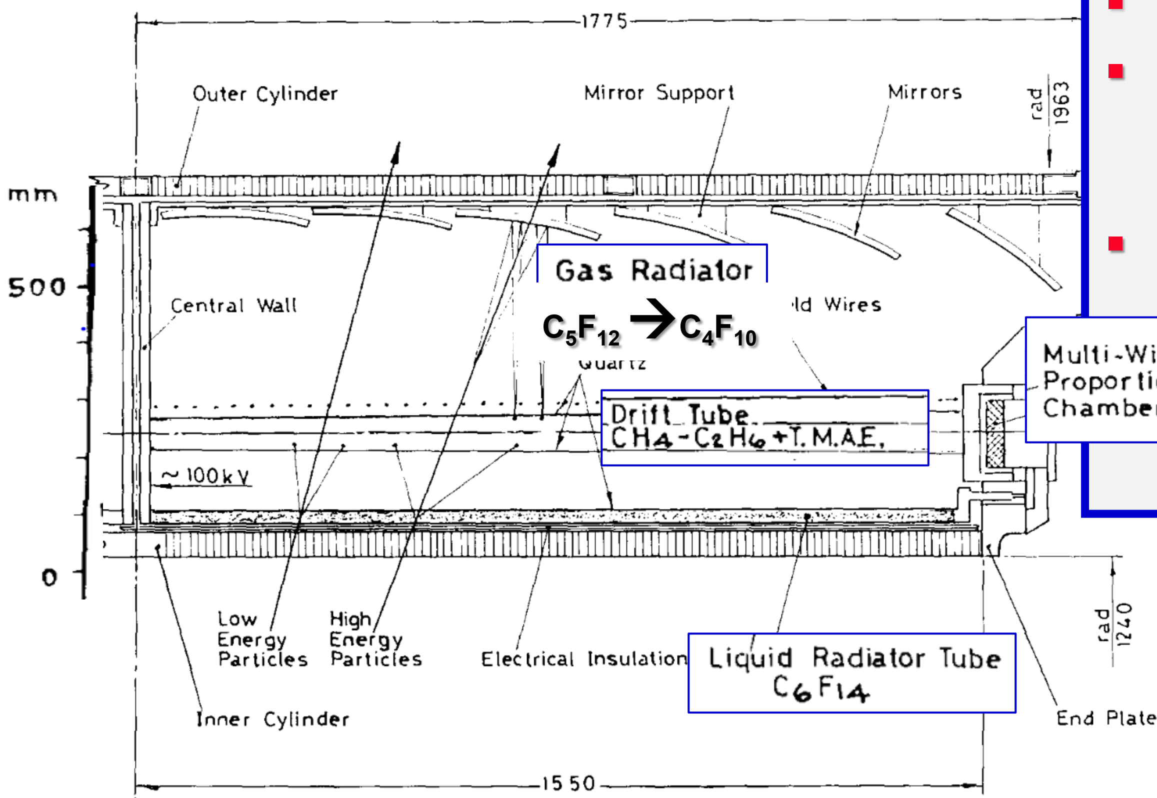
NLaK33 | Pb F2 | SAPPHIRE



RICHes for high momenta

DELPHI BARREL RICH

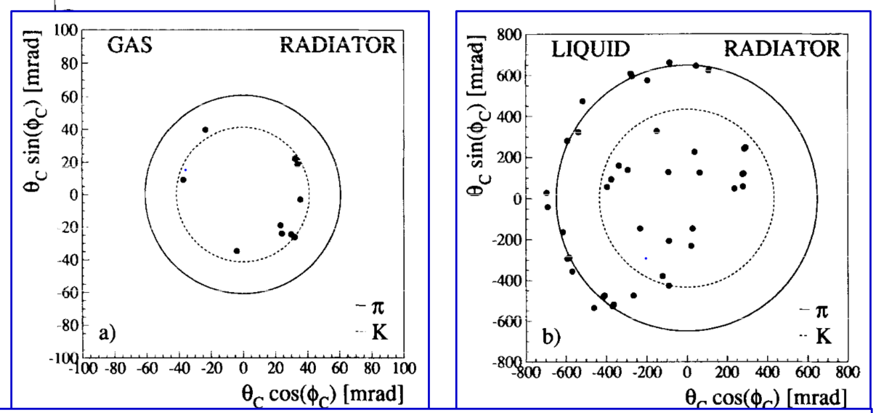
E.G. Anassontzis et al. / BRICH counter of DELPHI



Layout of the Barrel RICH; $\frac{1}{4}$ of cut along axis.

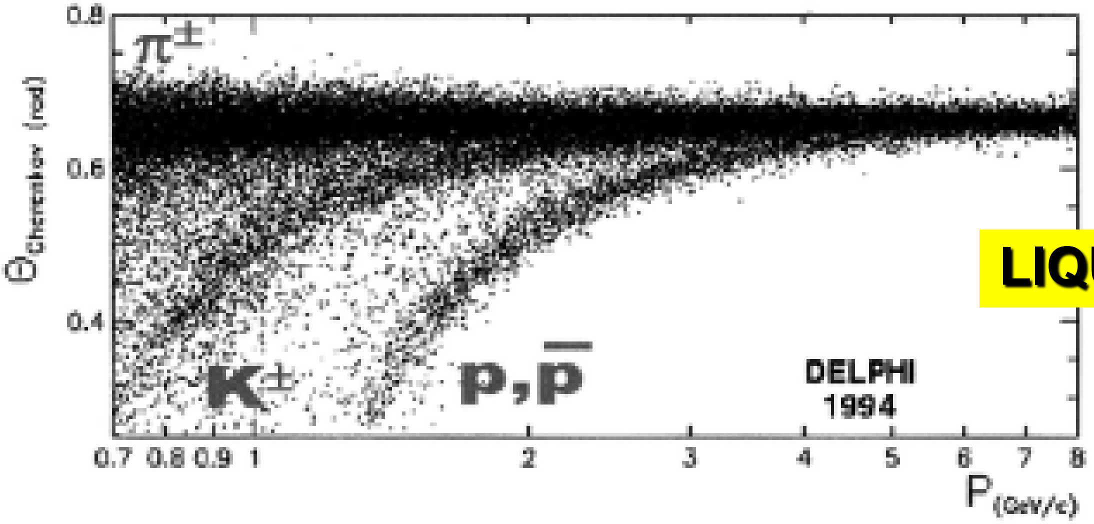
some DATA

- LEP max $\mathscr{L}$ = 10^{32} cm^{-2} s^{-1}
- Max photoelectron drift time: 25 µs
- Thickness of the conversion gap: 5 cm (parallax error → limiting momentum range for PID)
- Thickness of the gas radiator: 38-42 cm
  - Initially designed for C_5F_{12} at 40 °C and 1.3 bar, than operated with C_4F_{10} at 1.03 bar

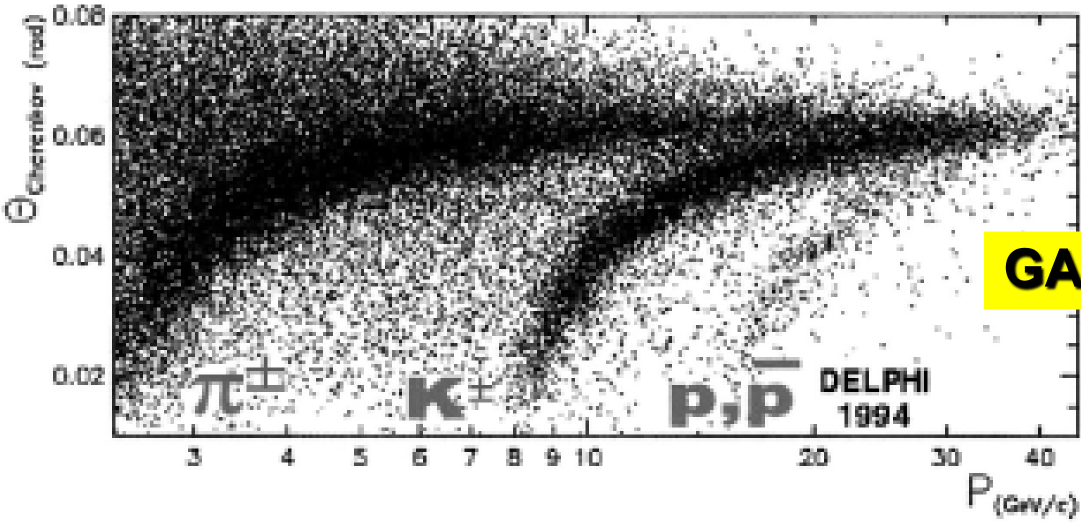


Nuclear Instruments and Methods in Physics Research A 371 (1996) 240–242

DELPHI BARREL RICH



LIQUID RADIATOR



GASEOUS RADIATOR

High-p RICH & beyond at colliders, WHICH CHALLENGES ?

- **What is needed & related challenges:**

- Gaseous radiator ……………………. Short radiator length in spite of limited Ch. photon yield → the COMPACT RICH concept
- Focusing system (mirrors) .... Light support and substrate
- Wide phase space acceptance …. Extended systems complemented by low-p RICH & beyond
- Detector in B-field region ……….. Photon detectors effectively operating in B-field

- **Limited number of active RICHES for high p RICH & beyond world-wide**

  - COMPASS
  - LHCb (2-counter system)
  - NA62

  (COMPASS, LHCb:) Wide phase space acceptance

  (NA62:) small phase space acceptance

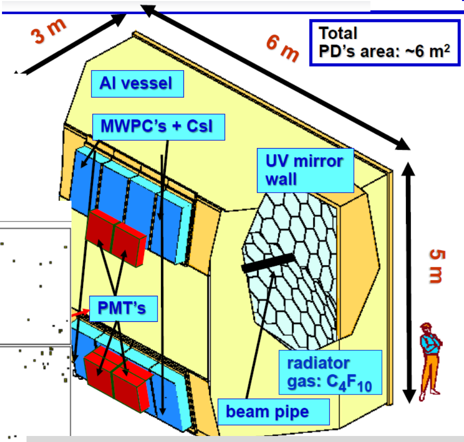
- **WHERE NEEDED?**

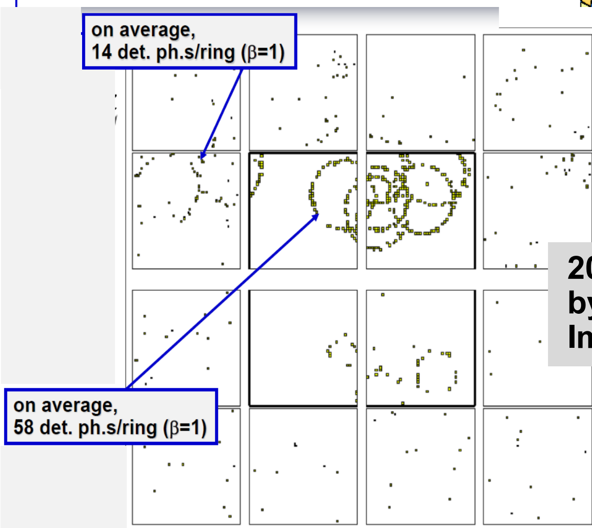
  - An absolute must at the EIC, now an approved project
  - A desired option in circular e+e- colliders

LESSONS FROM HIGH p RICHes IN OPERATION

COMPASS

C_4F_{10} - 3 m
(n = 1.0015)



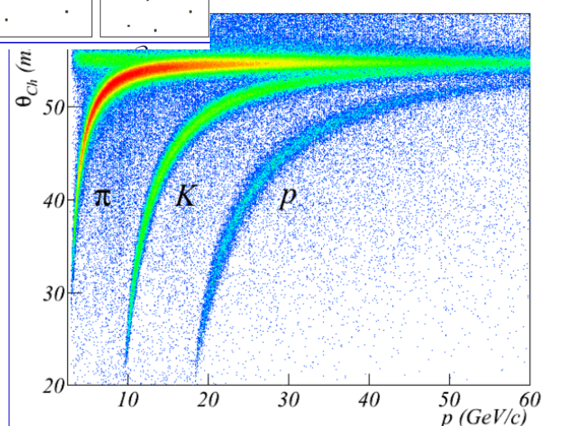


2016-2017: novel PDs by MPGD technologies: Improved detector stability

Effective QE range

CsI : 165-205 nm

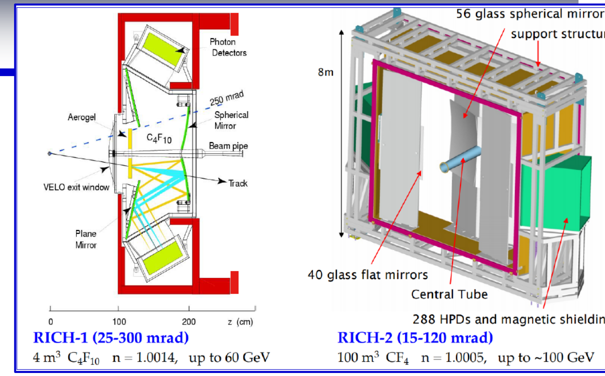
MAPMTs (UV extended window) : 200-650 nm



P. Abbon et al., NIMA 616 (2010) 21

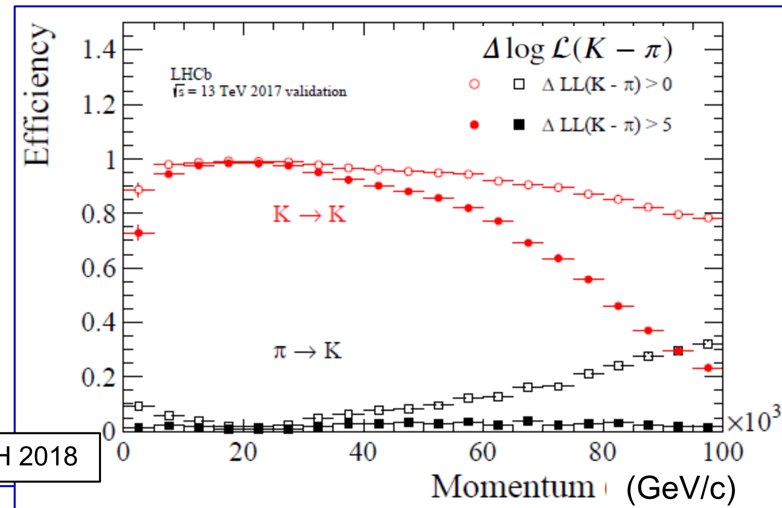
π-K separation, CL > 95% up to 45 GeV/c
π-K separation, CL > 90% up to 60 GeV/c

LHCb



NIMA, 766 (2014) 245

Radiator	N_{pe} from data		N_{pe} from simulation	
	Tagged $D^0 \to K^- \pi^+$	$pp \to pp\mu^+\mu^-$	Calculated N_{pe}	True N_{pe}
Aerogel	5.0 ± 3.0	4.3 ± 0.9	8.0 ± 0.6	6.8 ± 0.3
C_4F_{10}	20.4 ± 0.1	24.5 ± 0.3	28.3 ± 0.6	29.5 ± 0.5
CF_4	15.8 ± 0.1	17.6 ± 0.2	22.7 ± 0.6	23.3 ± 0.5

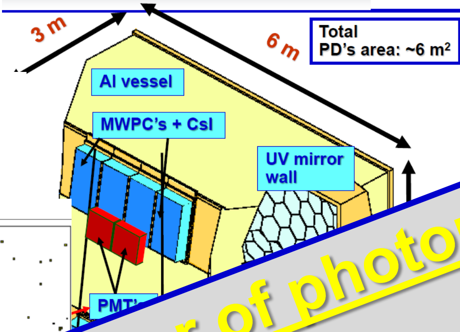


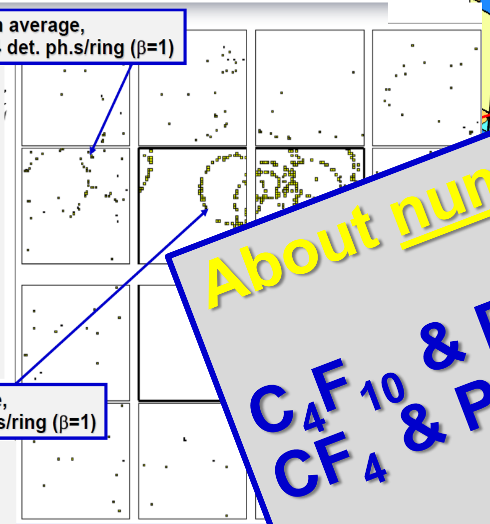
S. Gambetta, RICH 2018

LESSONS FROM HIGH p RICHes IN OPERATION

COMPASS

C_4F_{10} - 3 m (n = 1.0015)

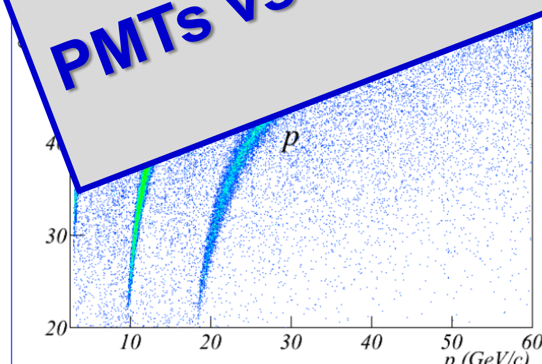




Effective QE range

CsI : 165-205 nm

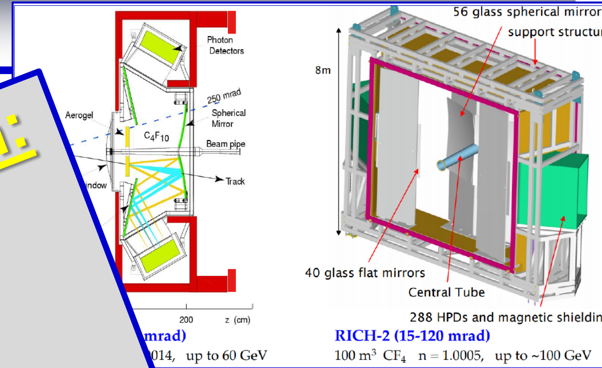
MAPMTs (UV extended window) : 200-650 nm



π-K separation, CL > 95% up to 45 GeV/c
π-K separation, CL > 90% up to 60 GeV/c

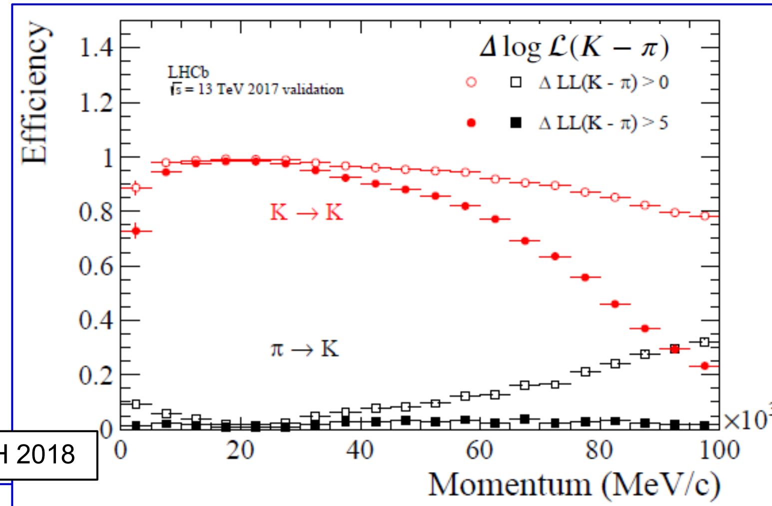
P. Abbon et al., NIMA 616 (2010) 21

LHCb



N_{pe} from simulation

	Calculated N_{pe}	True N_{pe}
[illegible]	8.0 ± 0.6	6.8 ± 0.3
24.5 ± 0.3	28.3 ± 0.6	29.5 ± 0.5
17.6 ± 0.2	22.7 ± 0.6	23.3 ± 0.5



S. Gambetta, RICH 2018

About number of photons at saturation:

C_4F_{10} & PMTs : ~ 20 / m

CF_4 & PMTs : ~ 10 / m

PMTs vs CsI (cut at 165 nm) = 4 : 1

Options for RICH at high p in classical collider setups

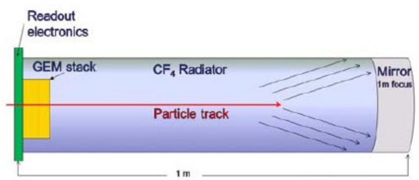
“STANDARD” APPROCH

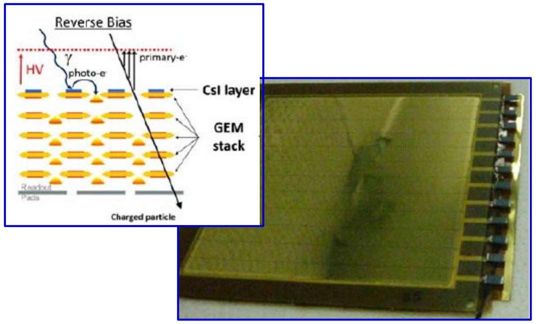
- 1 m-long radiator and visible light PDs
- *PDs: LAPPDs or SiPMs*
- C_4F_{10} (n = 1.0015, θ_max: 55 mrad)
  - π threshold : 2.5 GeV/c
  - K threshold : 9.0 GeV/c
  - n_det.ph.s (β=1) / 1m : ~ 20
  - To exploit PID up to 50 GeV/c : σ_C_ph < 1.5 mrad (vis. range)
- CF_4 (n = 1.0005, θ_max: 32 mrad)
  - π threshold : 4.4 GeV/c
  - K threshold : 15.6 GeV/c
  - n_det.ph.s (β=1) / 1m : ~ 10
  - to exploit PID up > 60 GeV/c : σ_C_ph < 0.7 mrad

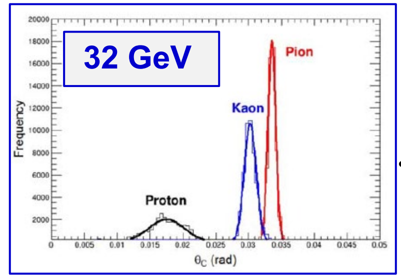
"WINDOWLESS" RICH

CF_4 windowless RICH concept, test-beam results

M. Blatnik et al., IEEE NS 62 (2015) 3256

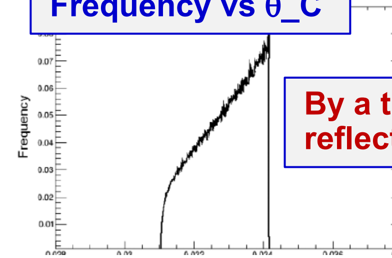






- Pad-size ~ 5 mm
- n_det_ph.s : 10

Frequency vs θ_C



By a thin-film reflecting mirror

- 1 m-long radiator and gaseous PD
- Increased n. of detected photons with a wavelength range around 120 nm
  - 10 photons (as with visible PDs !)
- CF_4 (n = 1.0005, θ_max: 32 mrad)
  - π threshold : 4.4 GeV/c
  - K threshold : 15.6 GeV/c
  - n_det.ph.s (β=1) / 1m : ~ 10
  - to exploit PID up > 60 GeV/c : σ_C_ph < 0.7 mrad
- *High-tech, expensive mirrors, gas transparency issues at 120 nm*

"HIGH PRESSURE" RICH

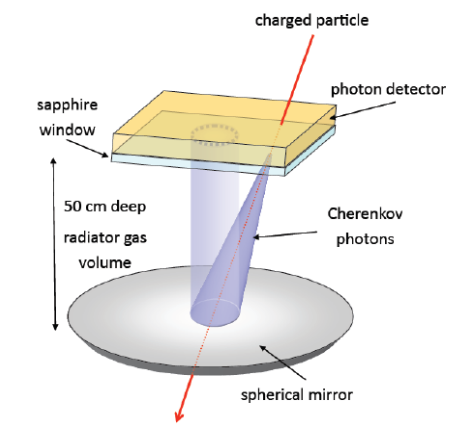
An option for ALICE HMPID upgrade (later abandoned)

M. Weber at RICH2013

Goals:

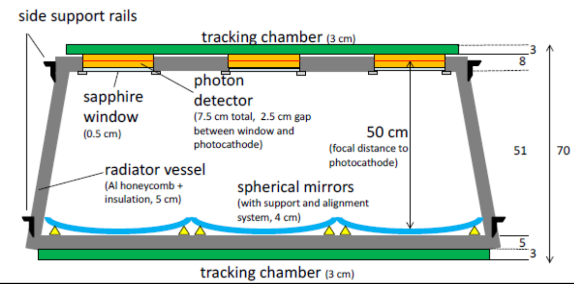
- 1.5 mrad resolution
- p/K 3 σ sep. up to 25 GeV/c
- π/K sep. from 5 GeV/c
- π/K 3 σ sep. up to 16 GeV/c

A. Agocs et al. NIM A 732 (2013), 361-365

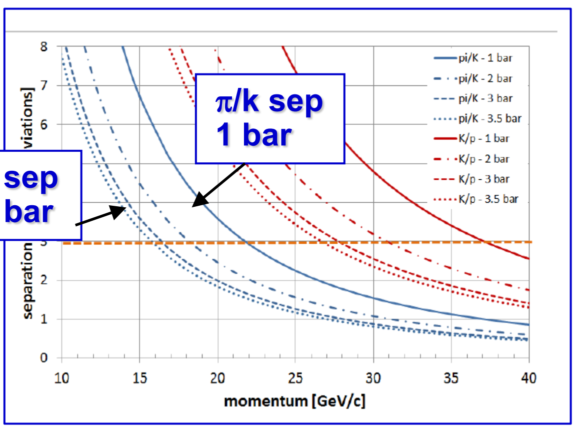


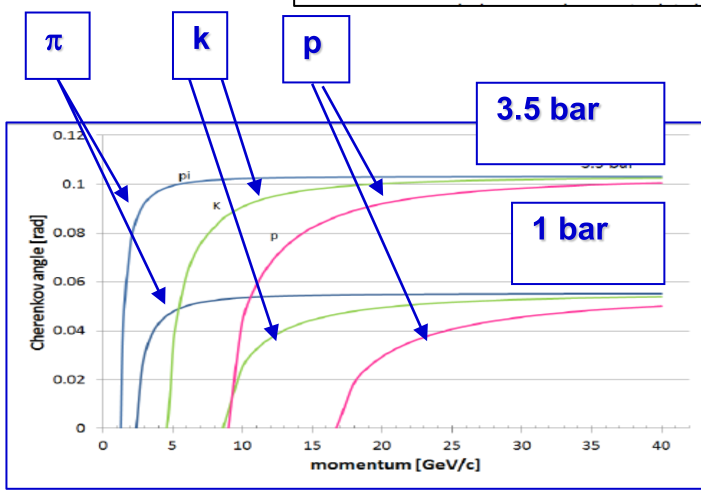
Details:

- Focusing RICH
- Radiator: 3.5 bar C_4F_8O (50 cm)
- Photon detector: CsI-MWPC (CH_4)
- Window: Sapphire
- Mirrors: 3x3



Expected (simulations):





Test-beam :

n. of ph.s: 10 (saturation)

→ 20 ph.s per m

Reminder:
at 1 bar with MWPCs +CsI:
~ 5 ph.s per m

ONE MORE ISSUE

- The current model are based on the use of fluorocarbons
  - Limited chromaticity
  - High Cherenkov photon yield
- These gasses are not eco-friendly
  - They attack O_3
- They have high Global Warming Potential (GWP) values (100 y)
  - C_4F_{10}: 4800
  - CF_4 : 6500
- Can satisfactory gas system/operation w/o fluorocarbons went-out in the open air be realized ?
- Procurent ?
- Other gas options?
  - A first proposal in the context of the design of PID for EIC

REPLACING C-F GASES BY PRESSURIZED Ar

C-F, 1 bar

Chromatic dispersion

gas	P (bar)	VISIBLE (bialkali with ext. UV glass window) (n-1) *10⁶	σ (n-1) *10⁶	θ_max (mbar)	σ_θ (mbar)	σ_θ / θ_max (chrom. only) (%)	n_ph/m (β = 1)
CF_4	1	497	11.5	31.5	0.4	1.2	10.0
C_4F_{10}	1	1367	46	52.3	0.9	1.7	27.5
Ar	1	294	10	24.2	0.4	1.7	5.9
Ar	1.5	441	15	29.7	0.5	1.7	8.9
Ar	2	588	19.5	34.3	0.6	1.7	11.8
Ar	3	882	29.5	42.0	0.7	1.7	17.7
Ar	3.5	1029	34.5	45.3	0.8	1.7	20.7

HIGH PRESSURE- RICH:
Eco-friendly alternative to C-F-gasses

- **Ar @ 3. 5 bar ↔ C_4F_{10}**
- **Ar @ 2 bar ↔ CF_4**

Ar, P > 1 bar

Number of detected photons at β = 1 (scaling from yellow box, LHCb figure)

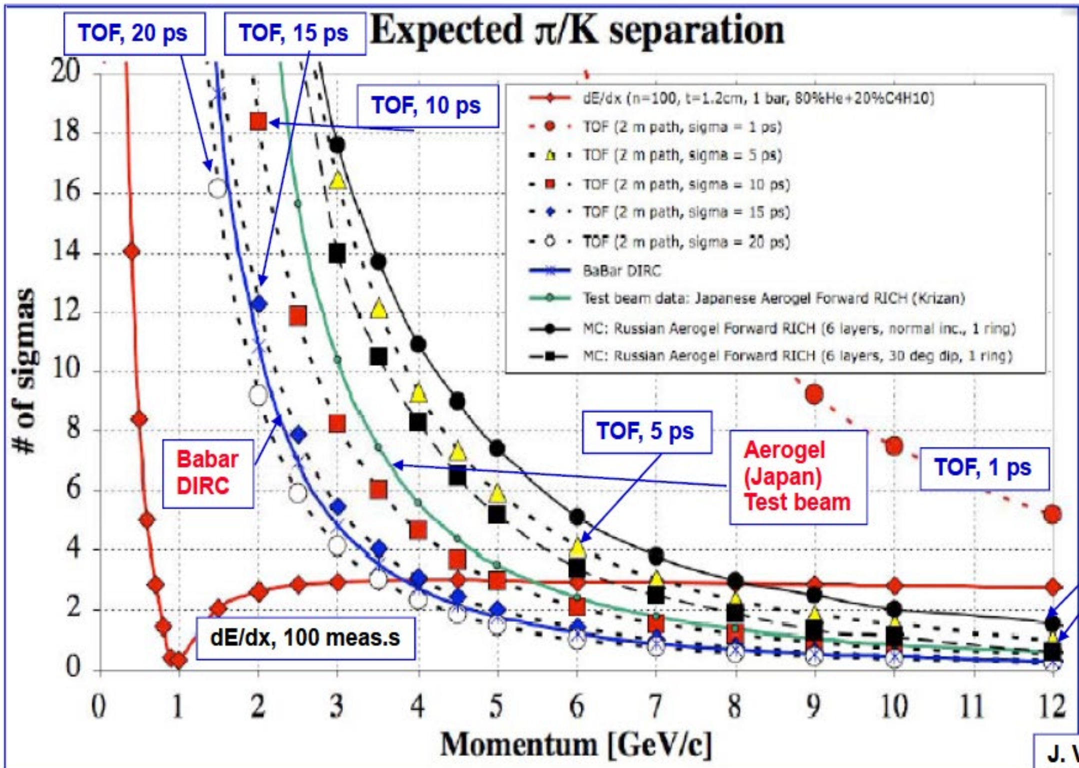
S. Dalla Torre, High Momentum PID at EIC (in 10 years from now), 1st EIC Yellow Report Workshop, Temple University, Philadelphia, 19-21 March 2020, https://indico.bnl.gov/event/7449/.

ALTERNATIVE/COMPLEMENTARY OPTIONS

ARE THERE ALTERNSATIVE OPTIONS? 1/2

TOF

2m lever arm assumed

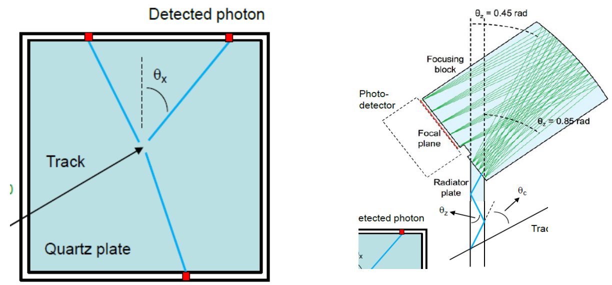


J. Va'vra @ RICH2007

TORCH : a DIRC for TOF

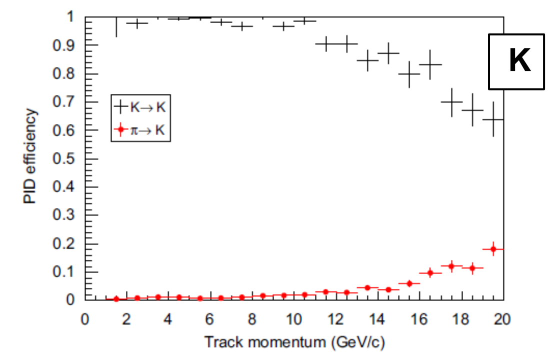
Overcoming:

- the upper limit from θ_C saturation
- the time-resolution limit from single photon



MC
10 m
σ_t = 12.5 ps

M.J.Charles, R. Forty, NIMA 639 (2011) 173

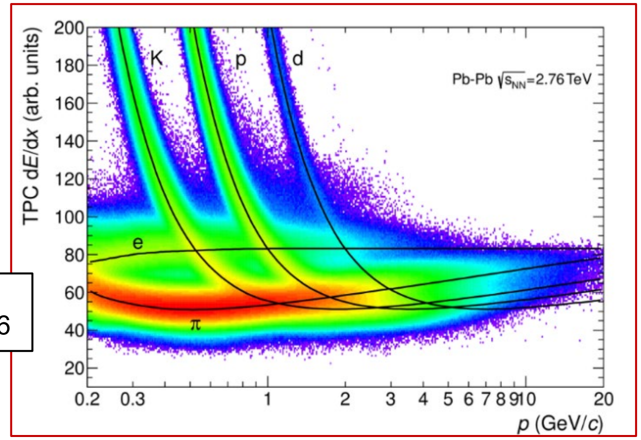


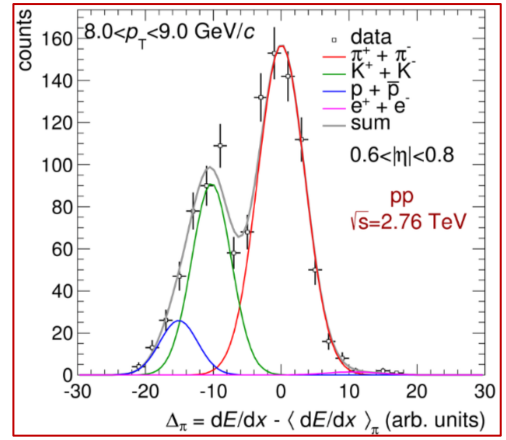
ARE THERE ALTERNSATIVE OPTIONS? 2/2

dE/dx

ALICE TPC
(before upgrade)

J. Alme et al., NIMA 622 (2010) 316



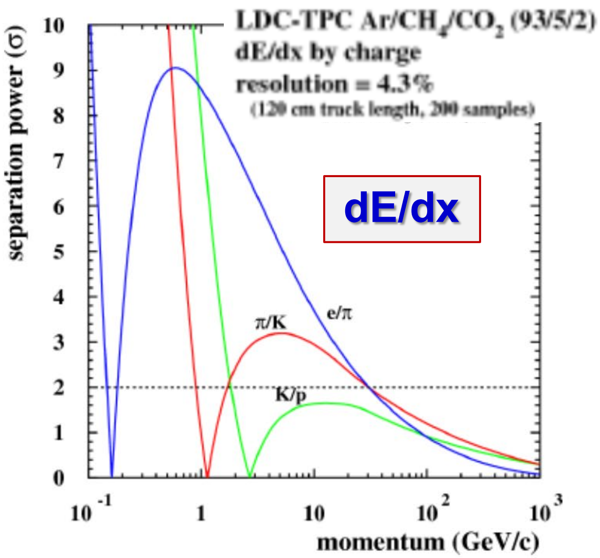


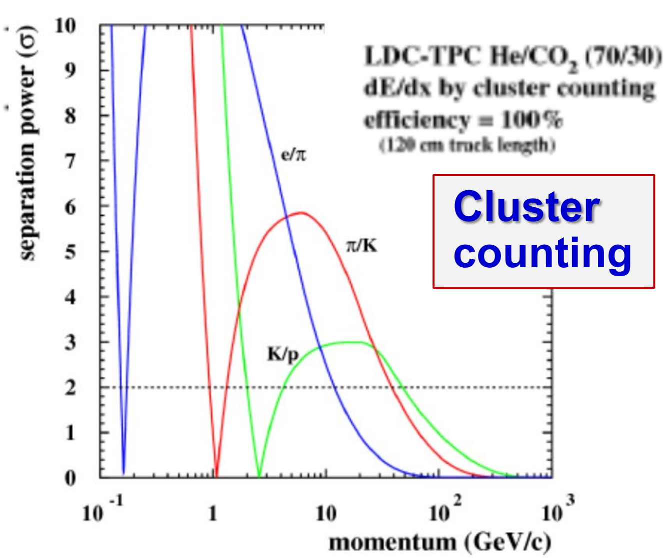
Cluster counting ?

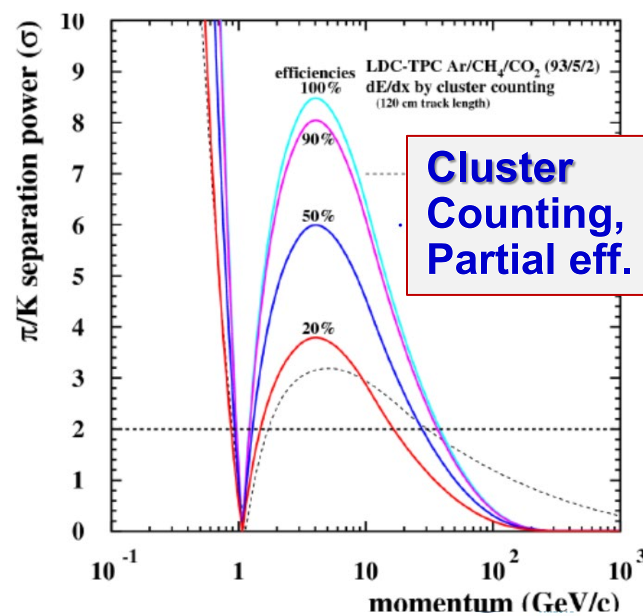
MC studies in the EIC context

Proposal for Generic Detector R&D for an Electron Ion Collider
A novel TPC readout system based on readout chips for Si-pixel detectors

Ties Behnke[1], Klaus Dehmelt[3*], Klaus Desch[2], Ralf Diener[1], Ulrich Einhaus[1], Prakhar Garg[3], Jochen Kaminski[2], Thomas K. Hemmick[3]





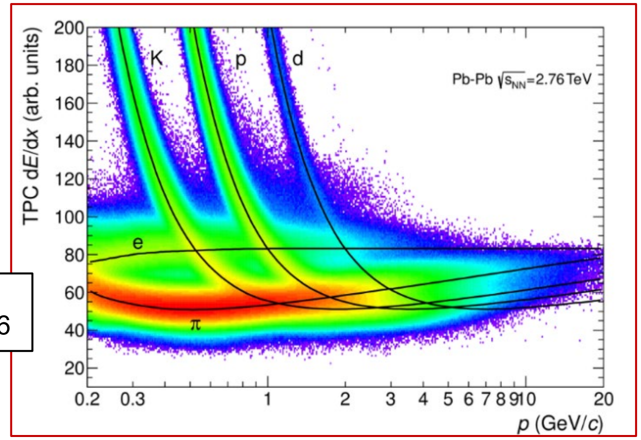


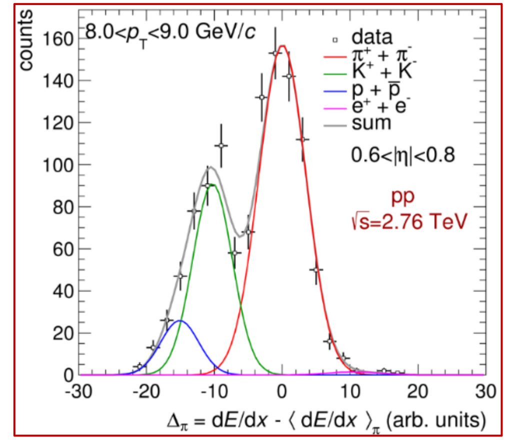
ARE THERE ALTERNSATIVE OPTIONS? 2/2

dE/dx

ALICE TPC (before upgrade)

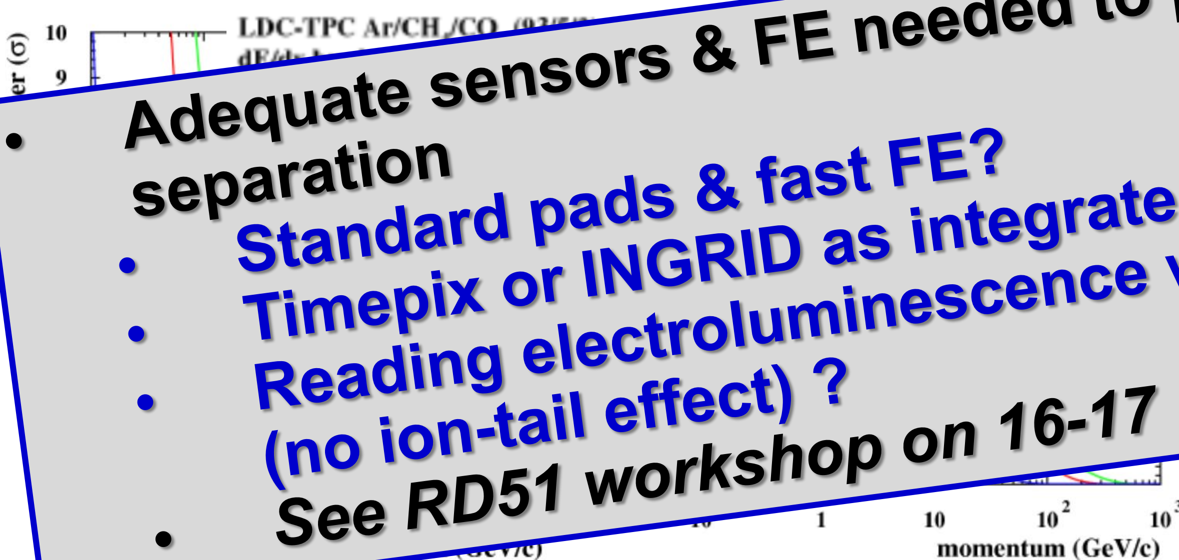
J. Alme et al., NIMA 622 (2010) 316

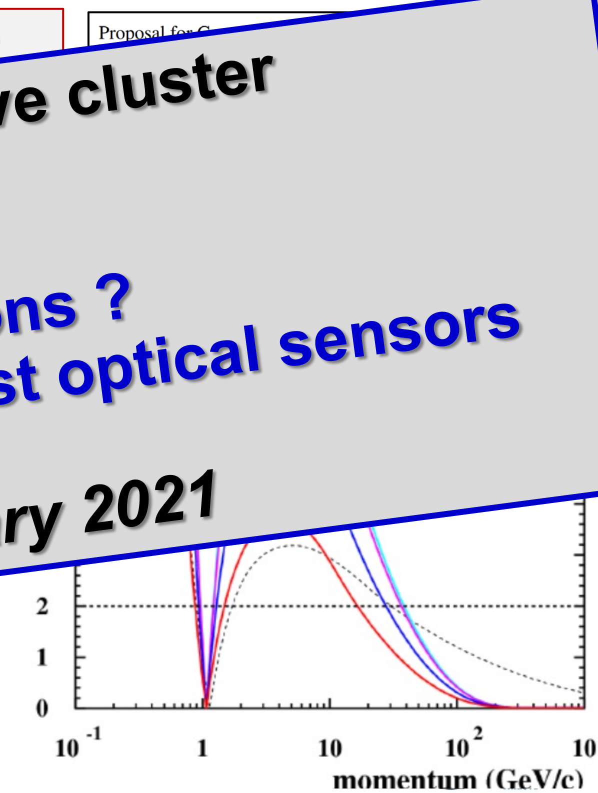




Cluster counting ?

MC studies in the EIC context

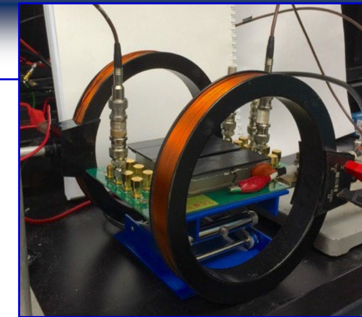




- **Adequate sensors & FE needed to preserve cluster separation**
  - **Standard pads & fast FE?**
  - **Timepix or INGRID as integrated options ?**
  - **Reading electroluminescence with fast optical sensors (no ion-tail effect) ?**
- ***See RD51 workshop on 16-17 February 2021***

Dedicated R&D

Dedicated R&D

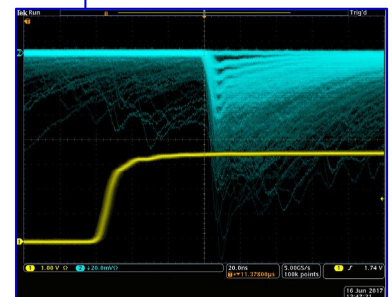


LAPPD studies

G.A.Cowan et al, NIMA 876 (2017) 80

- Ongoing within LHCb
  - particular attention to B-field behaviour (LHCb environment)
  - time resolution performance (as a handle to overcome the high rate occupancy at HiLumi LHC)
- Ongoing within eRD14 (generic R&D for EIC)
  - For low-p RICH & beyond applications
- in one task within AIDAinnova
  - Focus on high-p RICH & beyond applications

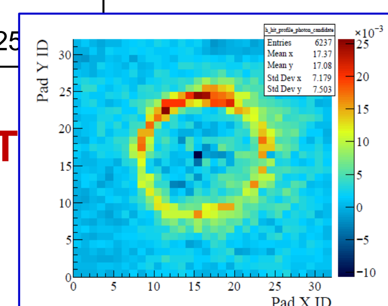
Reports in
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D



SiPM studies

- Ongoing within LHCb
  - time resolution performance (as a handle to overcome the high rate occupancy at HiLumi LHC)
- in one task within AIDAinnova
  - Operational parameters and ageing for low- and high-p applications
- Within INFN EIC_NET

Reports in
https://wiki.bnl.gov/conferences/index.php/EIC_R%25



MPGD-based photon detectors

- Initial studies within eRD6 (generic R&D for EIC) and INFN program EIC_NET
- Study continuation in one Expression of Interest for AIDAinnova
- Within INFN EIC_NET

SUMMARIZING

SUMMARY

- **For PID at both low and high momenta**
  - **a new generation of photon detectors NEEDED**
  - **no PD option without open questions**
    - **Gaseous PDs : number of detected photons**
    - **LAPPD: development still on-going**
    - **SiPM: noise rates and ageing**
- **RICH & beyond at high-p in classical collider setups**

  needed at EIC, desired for e+e- colliders
  - **Challenges: "short" radiator, light material, PDs operated in B-field**
  - **A few active high-p counters (RICHes in LHCb, COMPASS)**
- **No completely consistent RICH model existing yet**
- **Principle approaches**
  - **Standard with visible light PDs**
  - **Windowless RICH with MPGDs**
  - **High-pressure RICH**
- **FLUOROCARBON RADIATOR issues: high P-Ar approach, to be validated**

SUMMARY

- **For PID at both low and high momenta**
  - **a new generation of photon detectors NEED**
  - **no PD option without open questio**
    - Gaseous PDs : number of
    - LAPPD: developm
    - SiPM: noi
- **RICH &**
- **No**
- **Princ**
  - **St**
  - **Wi PGDs**
  - **High ICH**
- **FLUORO RBON RADIATOR issues: high P-Ar approach, to be validated**

PID @ colliders:

THE CHALLENGE IS THERE,

JOIN THE EFFORT !

Thank you !