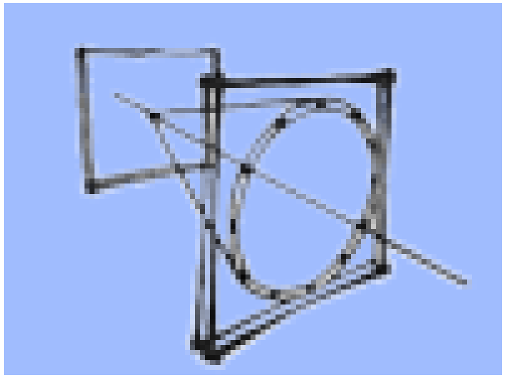
Charge particle identification for hadrons

Thank you to

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

In particular to the contributors to PID in the EICUG YR

Of course, all the mistakes and biases are mine !



OUTLOOK

« Charge particle identification for hadrons »

the title is very comprehensive;

I will shape it according to the EIC needs

- A QUICK INTRODUCTION
- WHAT CONSIDERED TECHNOLOGIES CAN OFFER TO EIC
- SINGLE PHOTONS IN CHERENKOV IMAGING DEVICES, AN OPEN QUESTION AT EIC

IMPORTANT: in this talk, the PID device contribution to e identification is NOT mentioned; nevertheless, it must be considered in a global optimization framework

DETERCTOR TECHNOLOGIES

h-PID = determine m from equation $E^2 = (mc^2)^2 + (pc)^2$, namely: $m = \frac{p}{c\beta\gamma}$

- **2 measurements are needed**

p (deflection in B)	&	β	standard approach for h
E (range)	&	β	low energy or μ
p (deflection in B)	&	γ (TR)	e-PID
p (deflection in B)	&	E (range)	low energy or μ

→h-PID obtained measuring β by

→Very fine measurement is a must:

$$\left(\frac{dm}{m}\right)^2 = \left(\gamma^2\frac{d\beta}{\beta}\right)^2 + \left(\frac{dp}{p}\right)^2$$

Approaches to measure β:

- TOF
- Energy loss
- Cherenkov imaging

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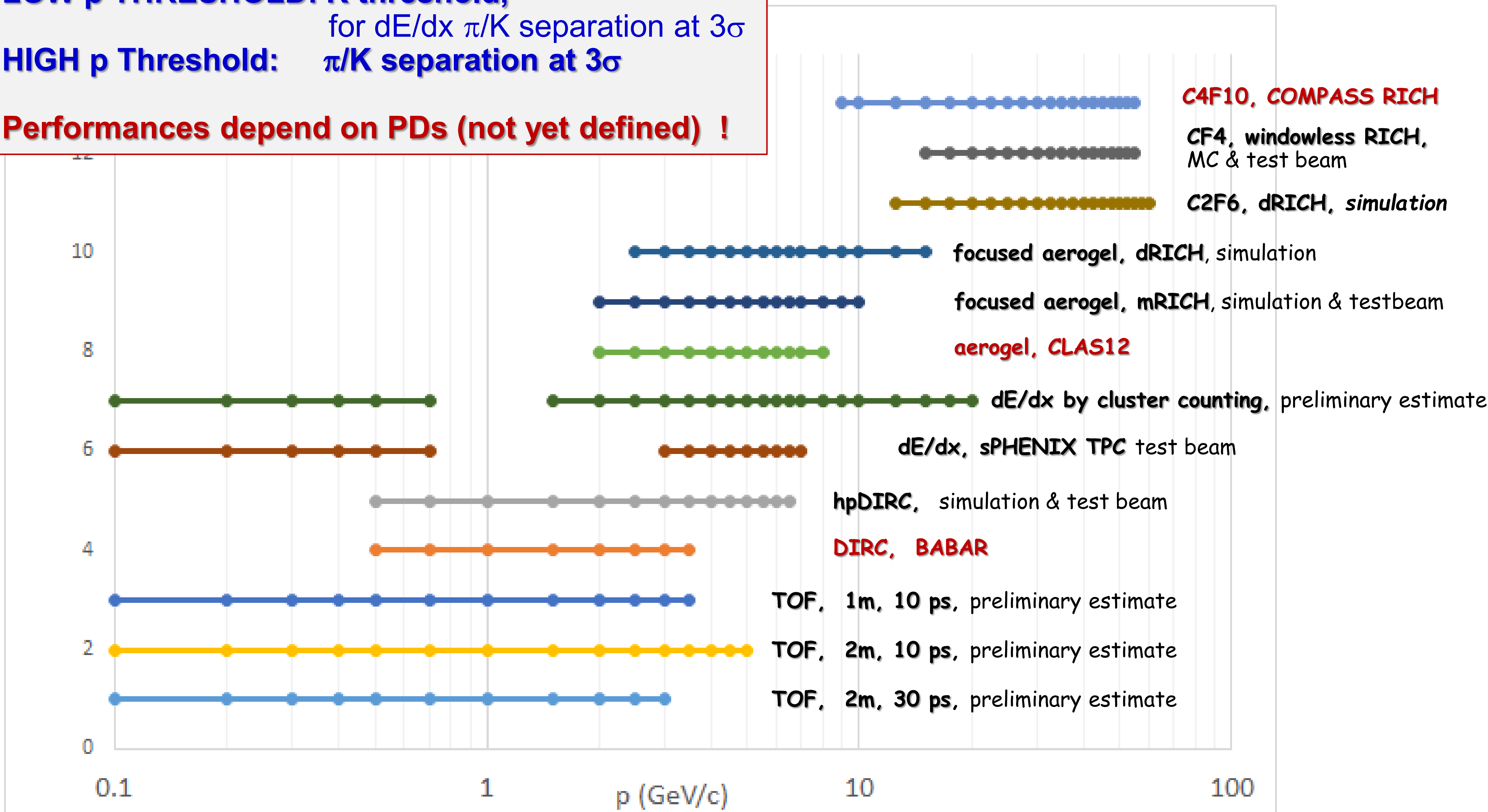
WHAT TECHNOLOGIES CAN OFFER

LOW p THRESHOLD: K threshold,
for dE/dx π/K separation at 3σ
HIGH p Threshold: π/K separation at 3σ

Performances depend on PDs (not yet defined) !



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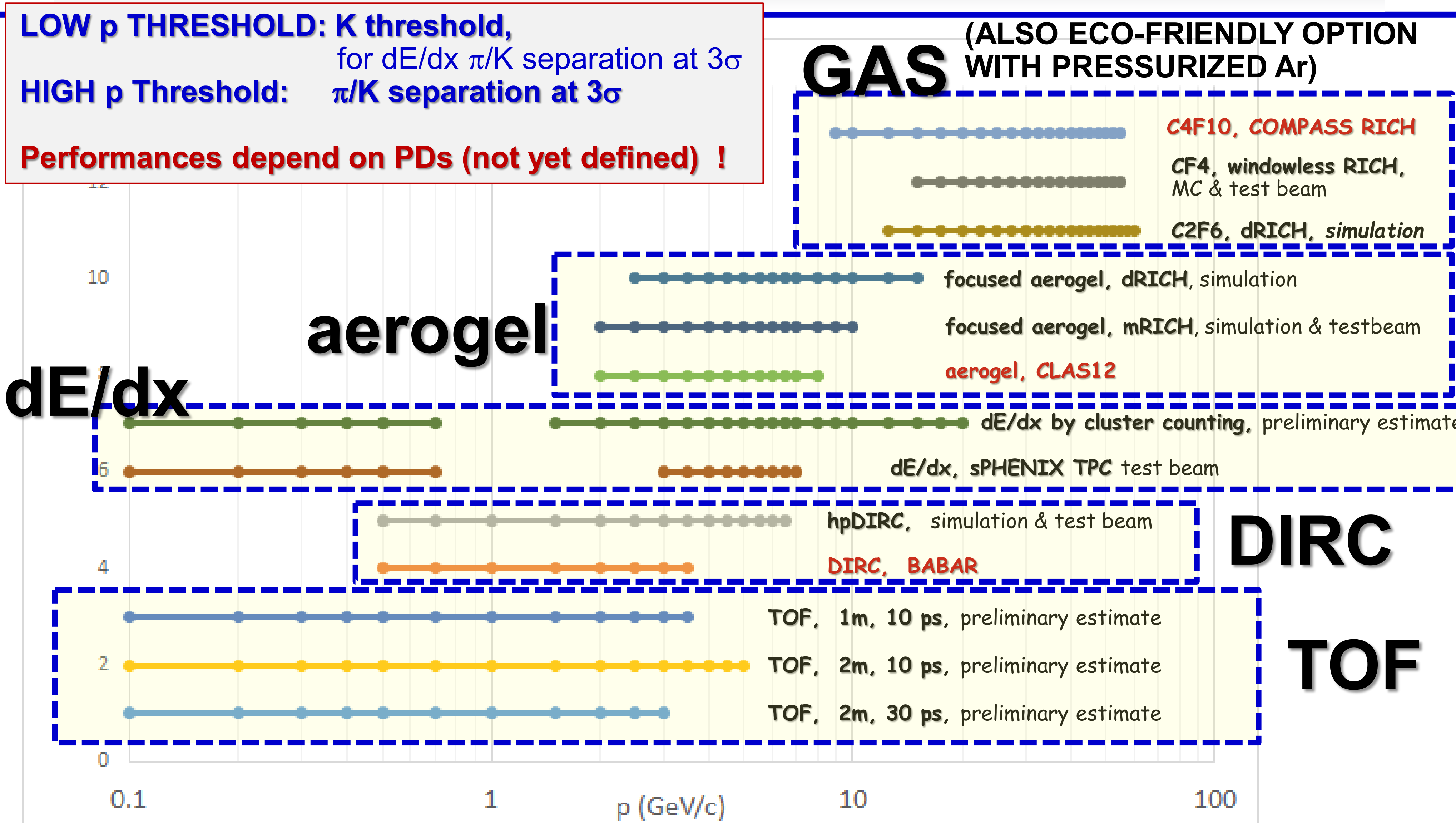
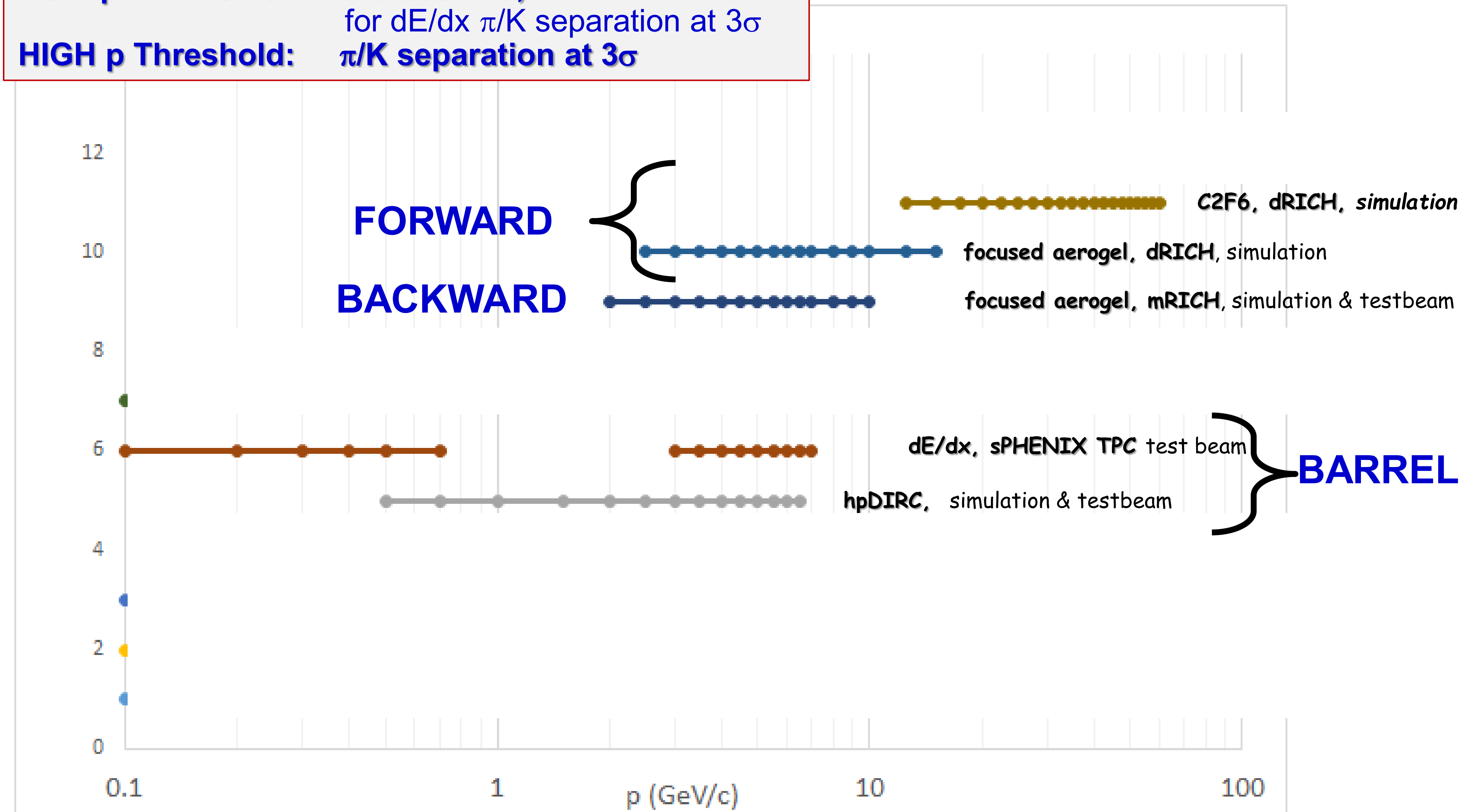


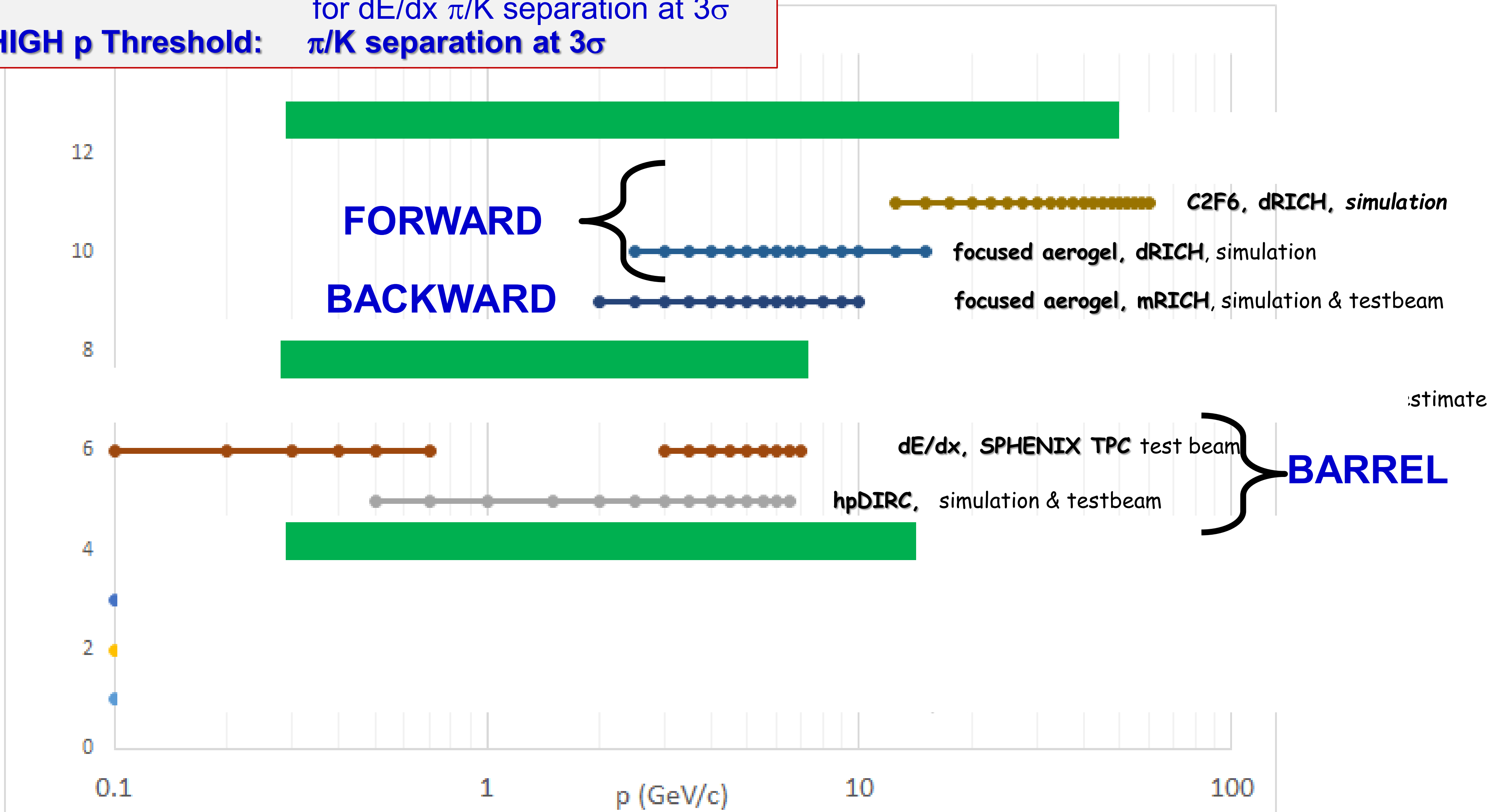
WHAT IS ASSUMED IN THE REFERENCE DETECTOR

LOW p THRESHOLD: K threshold,
for dE/dx π/K separation at 3σ
HIGH p Threshold: π/K separation at 3σ



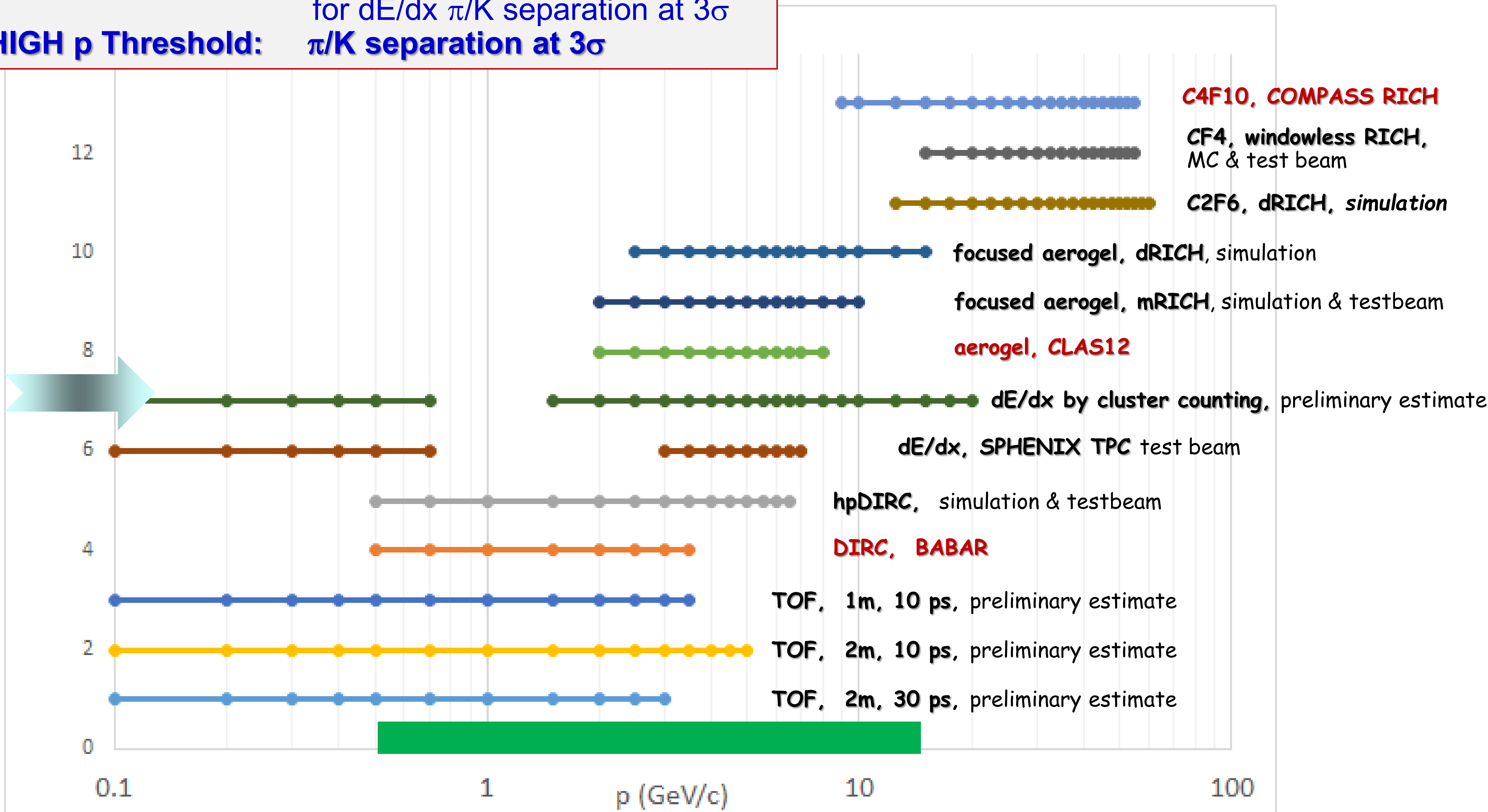
WHAT IS REQUESTED BY THE PHYSICS PROGRAM

LOW p THRESHOLD: K threshold,
for dE/dx π/K separation at 3σ
HIGH p Threshold: π/K separation at 3σ



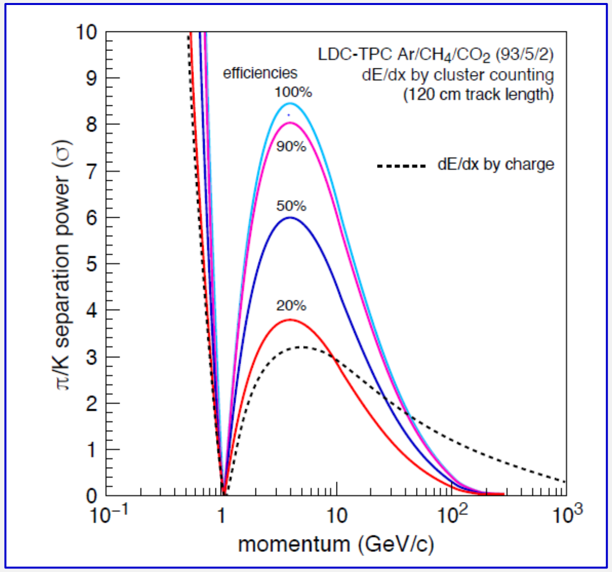
A WAYOUT FOR THE BARREL ?

LOW p THRESHOLD: K threshold,
for dE/dx π/K separation at 3σ
HIGH p Threshold: π/K separation at 3σ



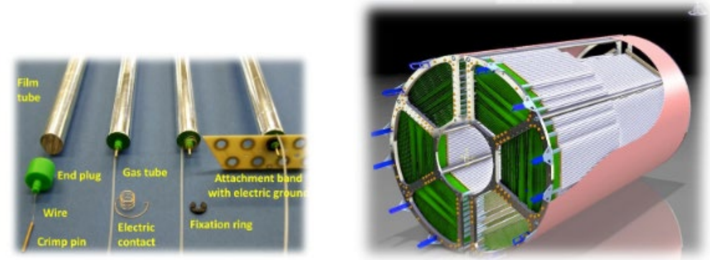
CLUSTER COUNTING OPTIONS

dE/dx by cluster counting



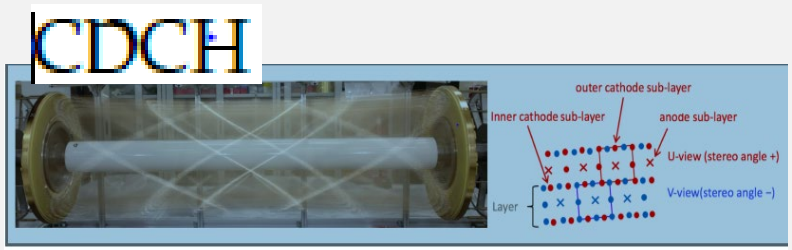
An example from literature of what dE/dx by cluster counting can provide

- Straw tracker (PANDA)

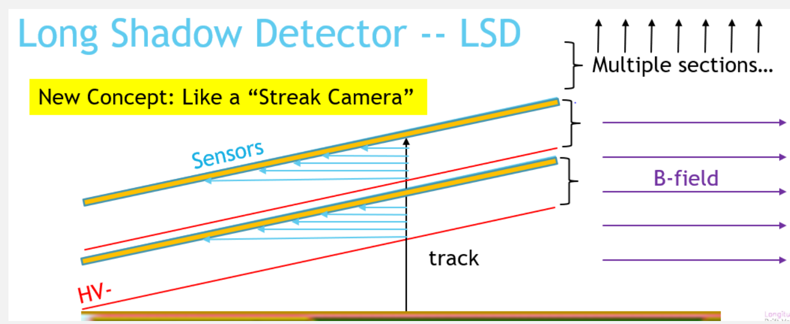


- as light-weight as the other EIC options
- can provide dE/dx (over pressure by design)

Development for PANDA well advanced



MEG experiment at PSI (w/o cluster counting); proposed with cluster counting for CepC (concept: IDEA)



LSD: Novel idea proposed within the YR initiative;

at very initial state

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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

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 & SiPMs
  λ > 300, 250, 200 nm
- Gaseous devices (CsI):
  λ < 205 nm
- On-going studies with H-ND
  λ < 200 nm, still preliminary stage

Operation in magnetic field

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

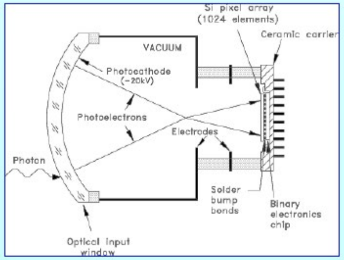
COSTS

- 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

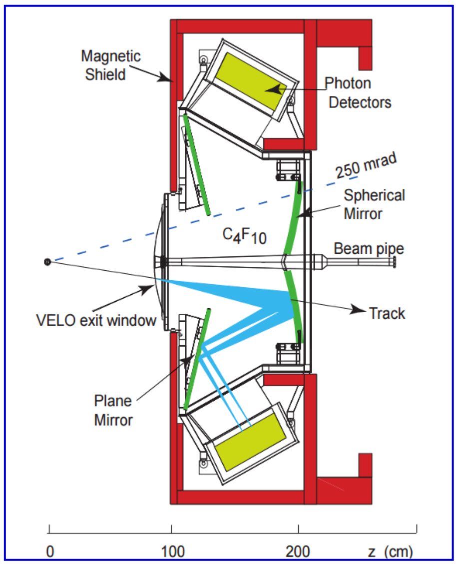
PMTs & MAGNETIC FIELD

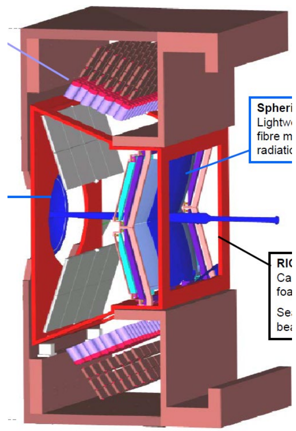
LHCb

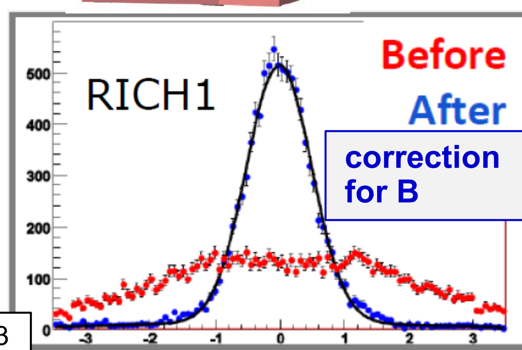


HPM, LHCb custom 1024 anods

Impressive mag. shielding







correction for B

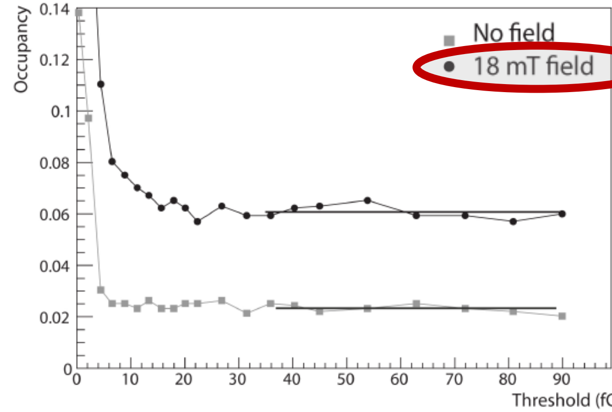
Pixels (0.5 mm)

Nevertheless:

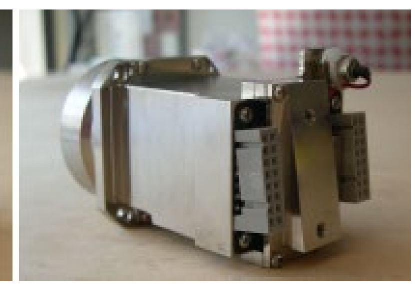
A. Papanestic, RICH 2013

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)

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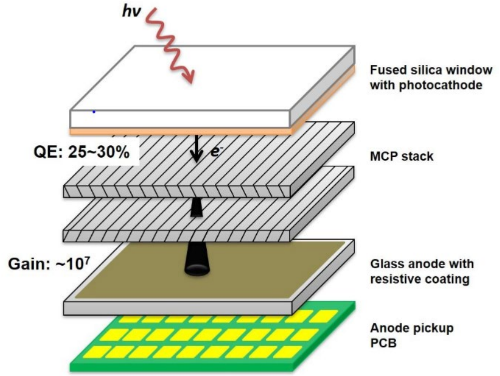
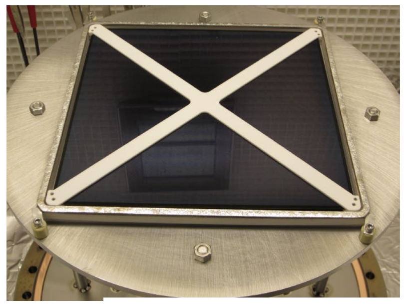
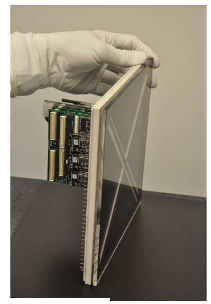
1st EIC YR workshop,
March 2020

LAPPD, an interesting OPTION

LAPPD







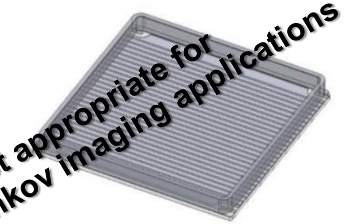
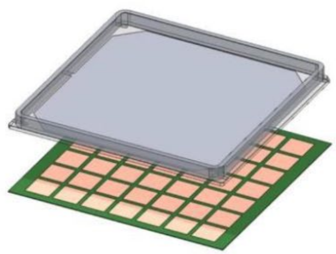
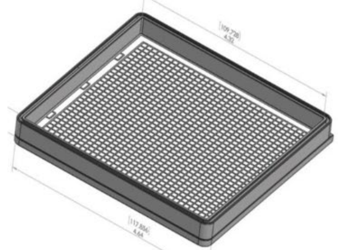
(20x20 cm^2) MCP-PMTs

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

From M. Minot, INCOM.

Different readout schemes

Gen I	Gen II	Gen III
		
Stripline readout	Capacitive coupling	Low temperature co-fire ceramic
Products Available	**Prototypes Available**	**Under development**

Strip not appropriate for Cherenkov imaging applications

LAPPD, an interesting OPTION

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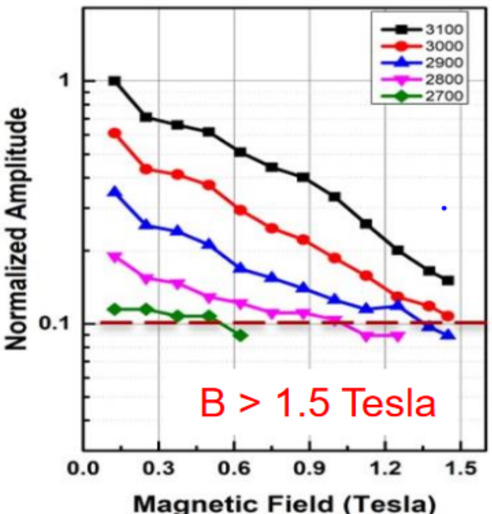
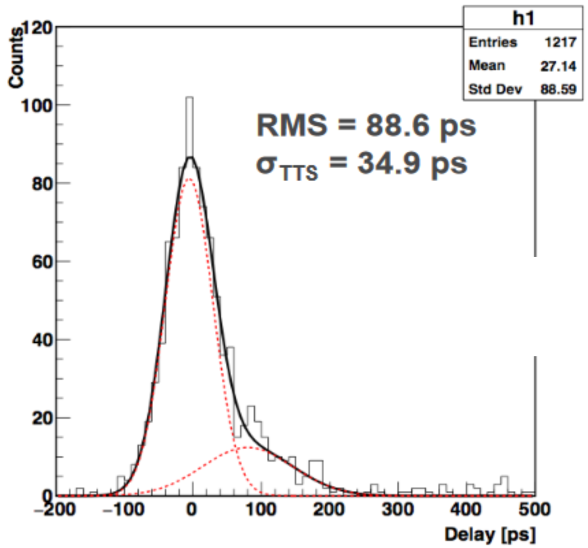
March 2020

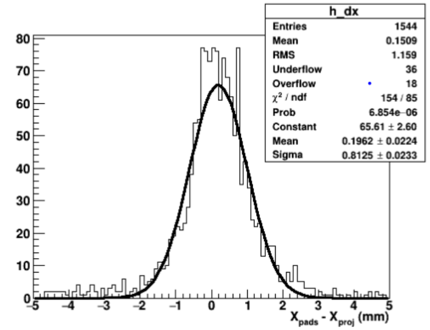
LAPPD, recent measured performance

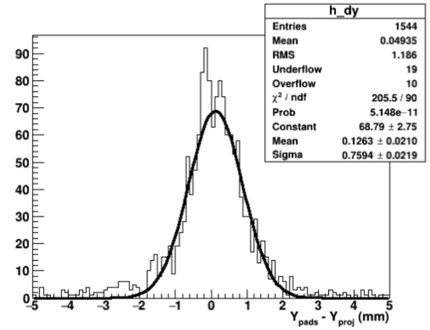




X res (mm)	Y res (mm)
0.81	0.76

4 mm x 4 mm pixel as example





ANL version 4
IBD design 10 µm MCP
reduced spacing

Further improvement if needed:

Smaller pore size: 6 µm, version 4 -> 5 (future)

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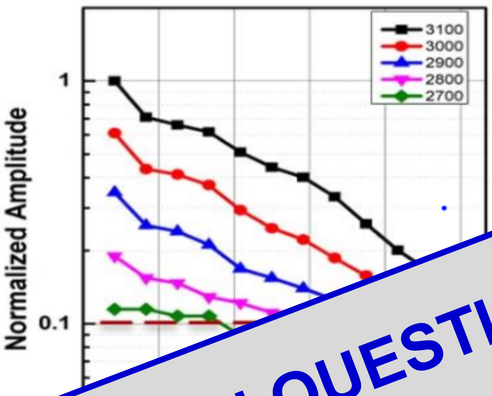
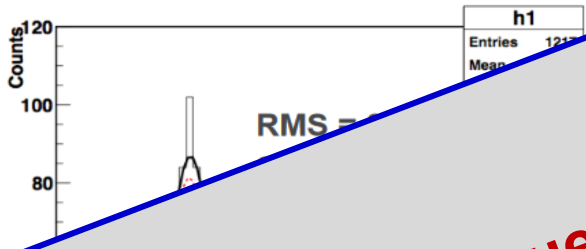
LAPPD, an interesting OPTION

LAPPD, recent measured performance



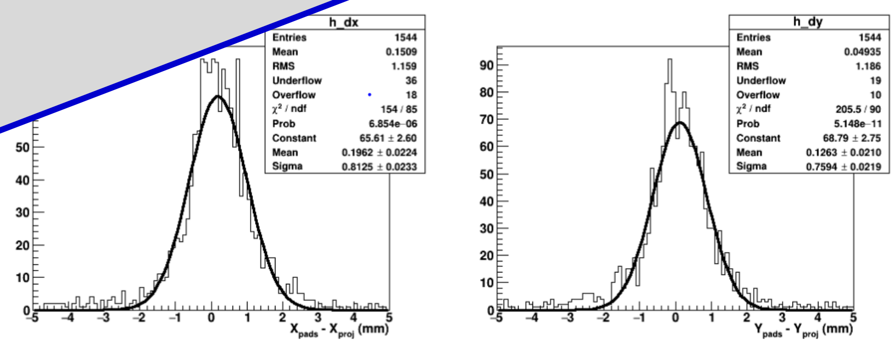


IBD
r

Further im
Sma
4 -> 5 (future)

0.76

pixel as example

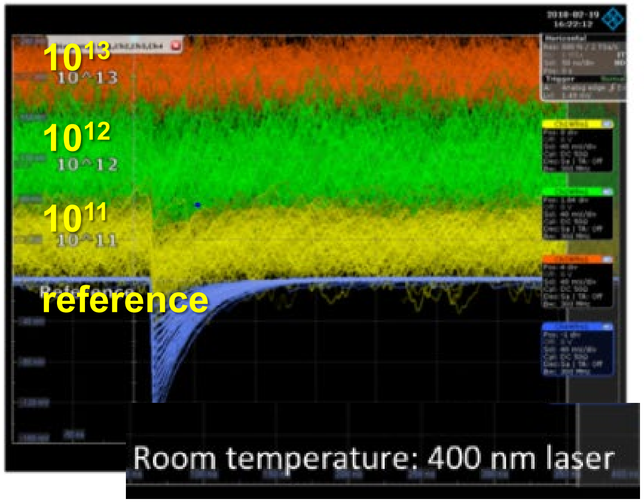


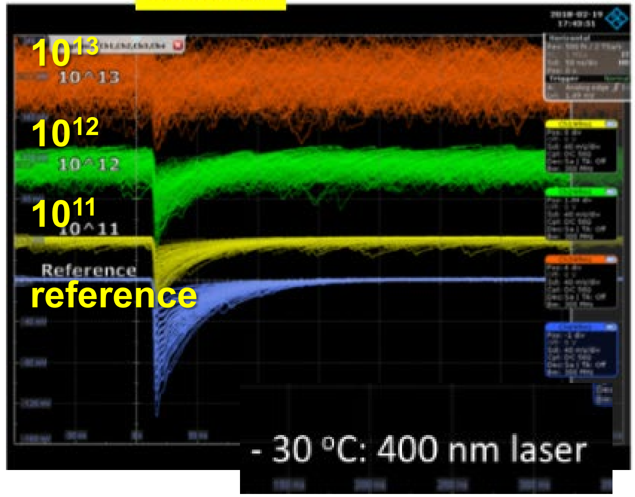
OPEN QUESTIONS

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 WORDS ABOUT SiPMs 1/2

From recent literature

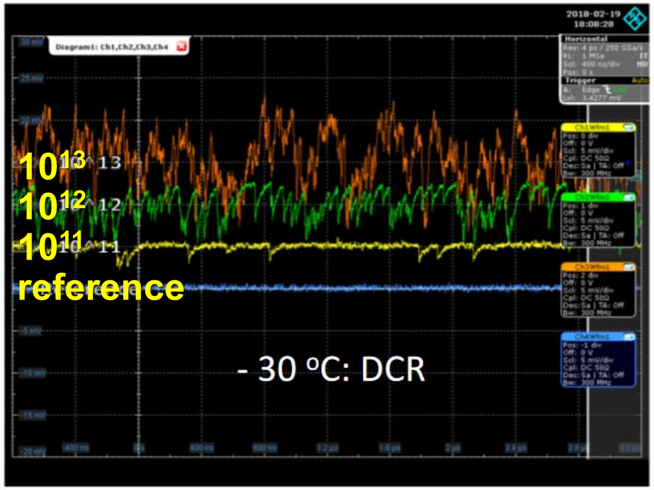


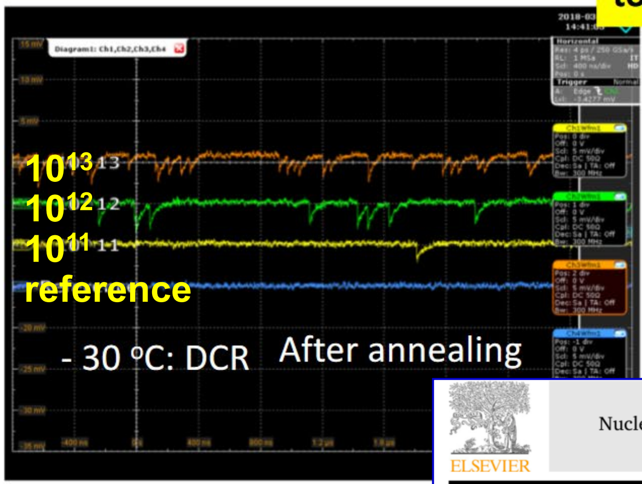


Room temperature NOT an option !

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

Radiation tolerance

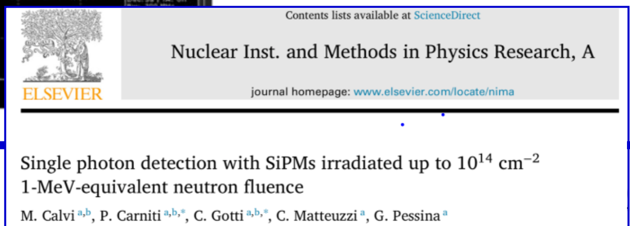




SiPMs

- **@ – 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

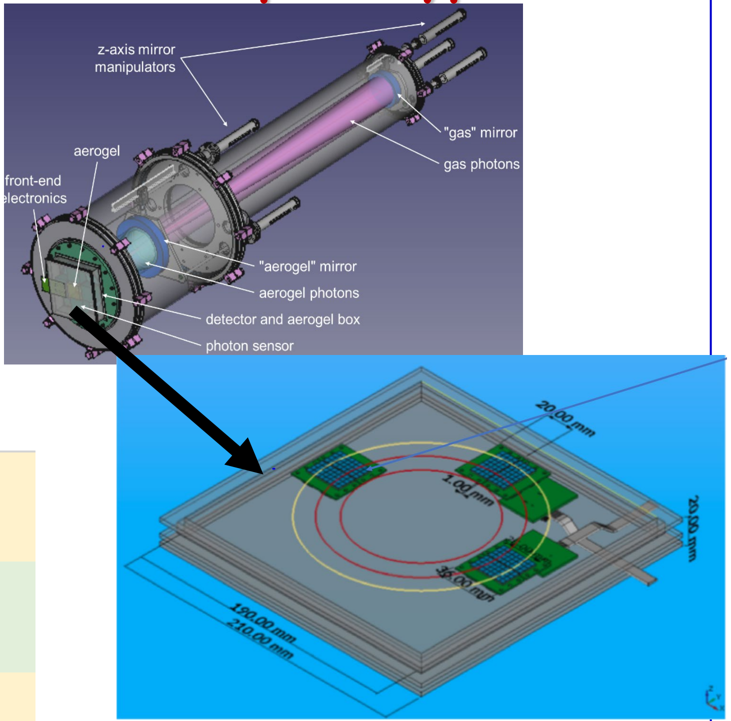
Single photon detection with SiPMs irradiated up to 10^{14} cm^{-2} 1-MeV-equivalent neutron fluence

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

A FEW 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 thermal annealing cycle
- → Performance in a test beam
- Coupled to specific FE r-o:
  - ALCOR, developed for DarkSide



MULTIUPLE MANIFACTURES	
SENSEL (OnSemiconductors)	microFJ-30020-TSV
	microFJ-30035-TSV
Broadcom	AFBR-SAN33C013
Hamamatsu Photonics	S13360-3050VS
	S13360-3025VS
	S14160-3015HS
	S14160-3050HS
FBK, Fondazione Bruno Kessler	custom SiPM

WHICH SINGLE PHOTON DETECTORS FOR THE EIC

To be considered (after obvious exclusions)

Vacuum based PDs

- **MCP-PMT, commercial**
  - Deeply studies for DIRC
  - Some magnetic field issue still in place
  - The most expensive option, therefore NOT extendable to the whole needs of PID at EIC

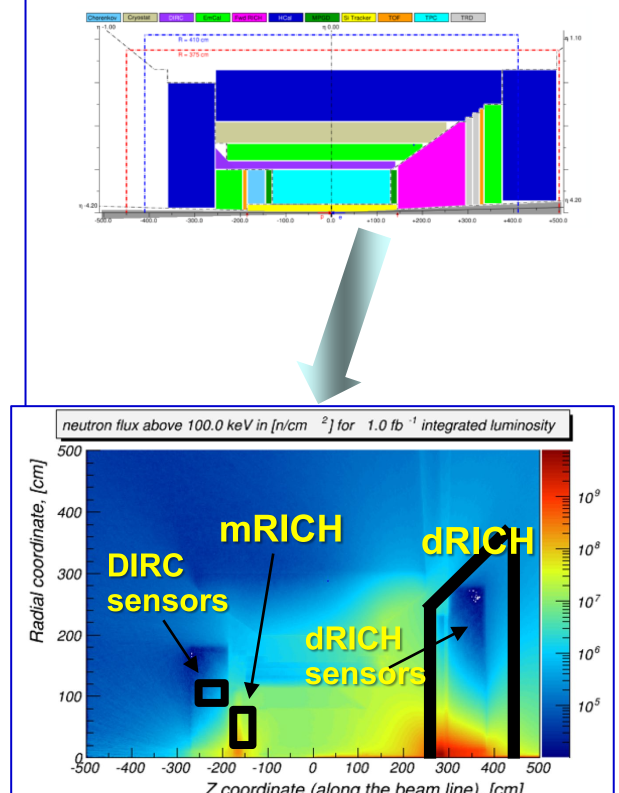
- **LAPPDs – large size MCP-PMTs, development ongoing**
  - Potentially interesting even for the whole needs of PID at EIC
  - Synergies with TOF and other precise time needs
  - magnetic field issues still open
  - rate capabilities to be established
  - Will they be developed up to the end ?

Gaseous PDs

- **CsI and MPGDs**
  - Only adequate for windowless gaseous RICH (short-radiator required in a collider setup)
  - The optimization for EIC still ongoing
  - Very demanding mirrors: λ O(120 nm)

SiPMs

- **Silicon PMs**
  - Capatility to operate up to integrated n flux O(10^{11}neq/cm^2) to be demonstrated
  - IF YES, it is not possible to use them every where: the n-flux map defines the applicability



THANK YOU