DETECTOR MATRIX
BARREL PID

S. Dalla Torre

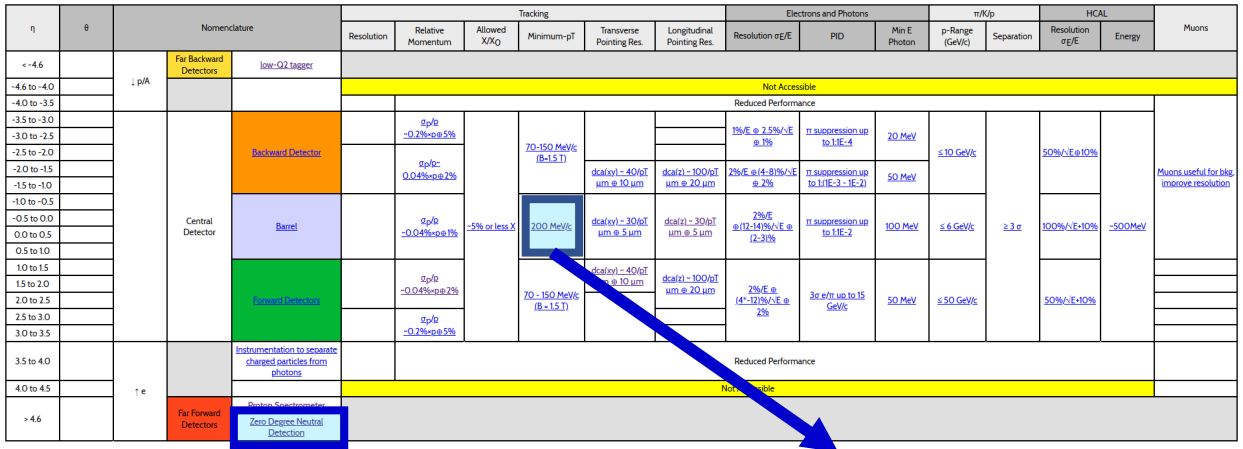
credits: Material by the EICUG Yellow Report Initiative, Physics WG & Detector WG

INTRODUCTION: ABOUT THE DETECTOR MATRIX

2 main points:

- The figures in the matrix are the expected detector performance for the *reference detector*
  - *Reference detector*: the more advanced option, so far
- The matrix is truly interactive !
  - *See the examples of "clicking" in this slide*

https://physdiv.jlab.org/DetectorMatrix/



Detector Information for η from > 4.6

Zero Degree Neutral Detection

title: Zero-Degree Neutron Detection

abstract: Neutrons + photons are accepted in the ZDC. We are considering additional photon detection in the B0 as well.

notes: ZDC: size ~~60x60x200cm~~
HCAL resolution 50%/√E⊕5% (quadrature sum).
Angular resolution 3 mrad/√E
~~uniform~~ acceptance for 0<θ<4.5 mrad
ECAL ~~in front~~ not detailed requirements for ECAL resolution yet.

references: Zero-Degree High Precision Hadronic Calorimetry
Detectors Far Forward

Details for 200 MeV/c

Abstract:

latest tracking performance numbers as provided recently to DWG conveners (also circulated directly to the PWG conveners).

Referenced Files

1 Tracking characteristics
Latest version of tracking from EICUG YR Tracking WG Wiki

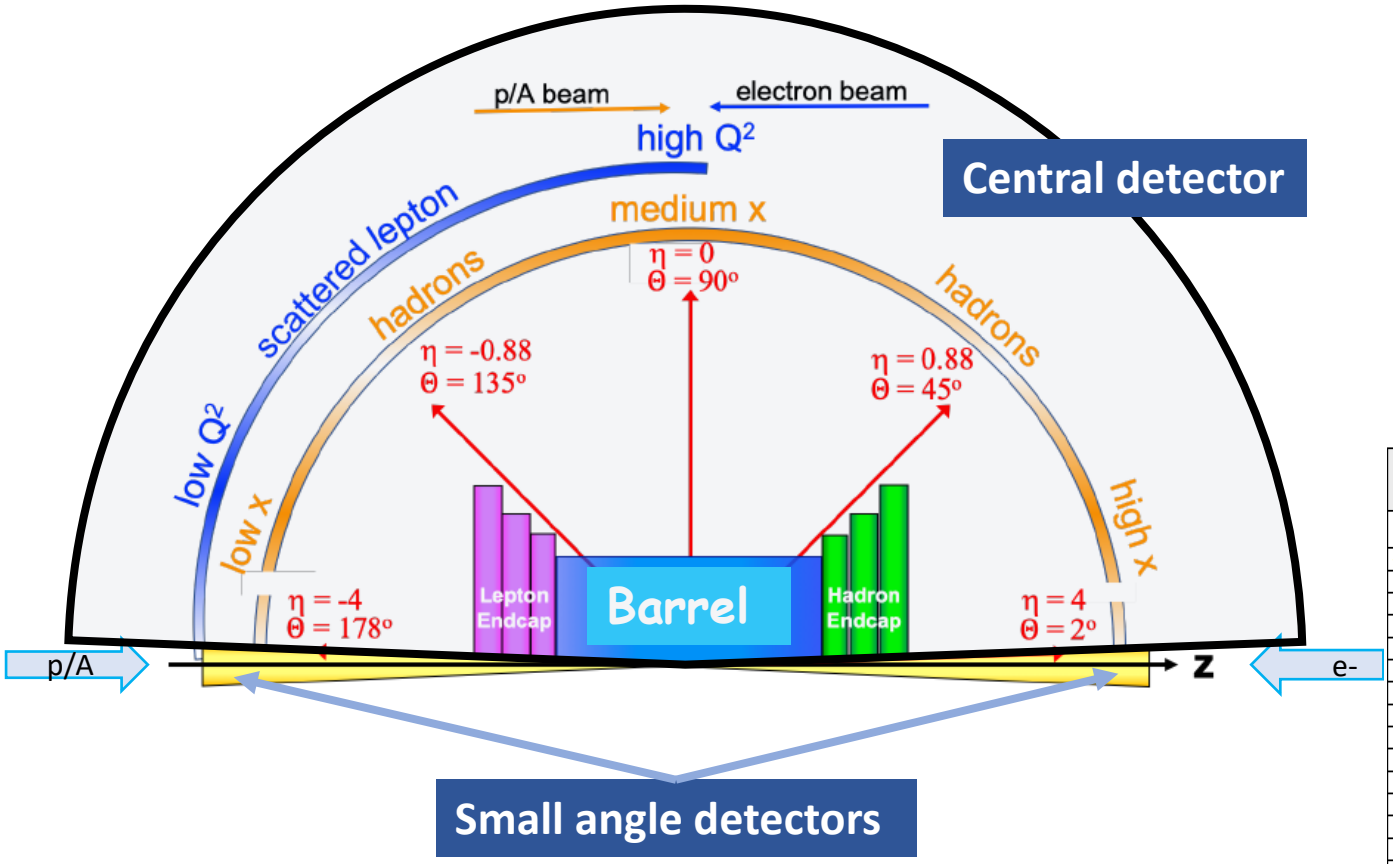
Notes:

for B=1.5 T; with 90% acceptance (similar for pi and K)

(For B = 3T: minimum pT = 400 MeV/c with 90% acceptance (similar for pi and K))

INTRODUCTION: ABOUT THE DETECTOR MATRIX

The detector matrix takes care of the whole EIC phase space !



η	Nomenclature		Tracking: Resolution	Tracking: Relative Momentum	Tracking: Allowed X/X_0	Tracking: Minimum-pT	Tracking: Transverse Pointing Res.	Tracking: Longitudinal Pointing Res.	Electrons and Photons: Resolution σE/E	Electrons and Photons: PID	Electrons and Photons: Min E Photon	π/K/p: p-Range (GeV/c)	π/K/p: Separation	HCAL: Resolution σE/E	HCAL: Energy	Muons
< -4.6	Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0			Not Accessible													
-4.0 to -3.5				Reduced Performance												
-3.5 to -3.0	Small angle detectors															
-3.0 to -2.5																
-2.5 to -2.0				σp/p ~0.2%×p⊕5%												
-2.0 to -1.5		Backward Detector				70-150 MeV/c (B=1.5 T)			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV	≤ 10 GeV/c		50%/√E⊕10%		Muons useful for bkg improve resolution
-1.5 to -1.0				σp/p= 0.04%×p⊕2%			dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1/(1E-3 - 1E-2)	50 MeV					
-1.0 to -0.5		Barrel		σp/p ~0.04%×p⊕1%	~5% or less X	200 MeV/c	dca(xy) ~ 30/pT μm ⊕ 5 μm	dca(z) ~ 30/pT μm ⊕ 5 μm	2%/E ⊕(12-14)%/√E ⊕ /2-3)%	π suppression up to 1:1E-2	100 MeV	≤ 6 GeV/c	≥ 3 σ	100%/√E⊕10%	~500MeV	
-0.5 to 0.0	Central detector															
0.0 to 0.5																
0.5 to 1.0																
1.0 to 1.5		Forward Detectors		σp/p ~0.04%×p⊕2%		70 - 150 MeV/c (B = 1.5 T)	dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/√E⊕10%		
1.5 to 2.0																
2.0 to 2.5				σp/p ~0.2%×p⊕5%												
2.5 to 3.0																
3.0 to 3.5																
3.5 to 4.0		Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5			Not Accessible													
> 4.6	Small angle detectors	Proton Spectrometer														
	Far Forward Detectors	Zero Degree Neutral Detection														

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THE NEW RELEASE OF THE DETECTOR MATRIX

https://physdiv.jlab.org/DetectorMatrix/

Previous version: 0.1

Present version: 0.2

η	θ	Nomenclature			Tracking						Electrons and Photons			π/K/p		HCAL		Muons
					Resolution	Relative Momentum	Allowed X/X_0	Minimum-pT	Transverse Pointing Res.	Longitudinal Pointing Res.	Resolution σE/E	PID	Min E Photon	p-Range (GeV/c)	Separation	Resolution σE/E	Energy	
< -4.6		↓ p/A	Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0					Not Accessible													
-4.0 to -3.5						Reduced Performance												
-3.5 to -3.0						σp/p ~0.2%•p⊕5%												
-3.0 to -2.5																		
-2.5 to -2.0																		
-2.0 to -1.5			Central Detector	Backward Detector				70-150 MeV/c (B=1.5 T)			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV	≤ 10 GeV/c		50%/√E⊕10%		Muons useful for bkg improve resolution
-1.5 to -1.0						σp/p= 0.04%•p⊕ 2%			dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1:(1E-3 - 1E-2)	50 MeV					
-1.0 to -0.5																		
-0.5 to 0.0				Barrel		σp/p ~0.04%•p⊕1%	~5% or less X	200 MeV/c	dca(xy) ~ 30/pT μm ⊕ 5 μm	dca(z) ~ 30/pT μm ⊕ 5 μm	2%/E ⊕(12-14)%/√E ⊕ (2-3)%	π suppression up to 1:1E-2	100 MeV	≤ 6 GeV/c	≥ 3 σ	100%/√E+10%	~500MeV	
0.0 to 0.5																		
0.5 to 1.0																		
1.0 to 1.5				Forward Detectors		σp/p ~0.04%•p⊕2%		70 - 150 MeV/c (B = 1.5 T)	dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/√E+10%		
1.5 to 2.0																		
2.0 to 2.5																		
2.5 to 3.0						σp/p ~0.2%•p⊕5%												
3.0 to 3.5																		
3.5 to 4.0		↑ e		Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5					Not Accessible													
> 4.6			Far Forward Detectors	Proton Spectrometer														
				Zero Degree Neutral Detection														

Based on the information in the new release of the Detector Matrix, parameterizations for fast simulations are available:

the parameterizations are available for both **eic-smear** and **Delphes** and for versions 0.1 and 0.2.

Thanks to the Software WG for preparing the parametrization !

INTRODUCTION: ABOUT TALKS IN THIS SECTION

- The requirements by physics have been summarized in a complete matrix elaborated by the PWG and released on September 1st
- Comparing the Detector Matrix (about detector performance) and Requirement Matrix some points of tension have been punt in evidence
- Here and in the following talks, we illustrate these points of tension to open the discussion about
  - In this talk we start with PID in the barrel
    - This talk is NOT meant to provide complete information about PID in the YR, which will be provided in the dedicated talk tomorrow

BARREL PID in the YR : WHERE ARE WE?

η	θ	Nomenclature			Tracking						Electrons and Photons			π/K/p		HCAL		Muons
					Resolution	Relative Momentum	Allowed X/X_0	Minimum-pT	Transverse Pointing Res.	Longitudinal Pointing Res.	Resolution σ_E/E	PID	Min E Photon	p-Range (GeV/c)	Separation	Resolution σ_E/E	Energy	
< -4.6		↓ p/A	Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0					Not Accessible													
-4.0 to -3.5						Reduced Performance												
-3.5 to -3.0			Central Detector	Backward Detector		σ_p/p ~0.2%×p⊕5%	~5% or less X	70-150 MeV/c (B=1.5 T)			1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV	≤ 10 GeV/c		50%/√E⊕10%	~500MeV	Muons useful for bkg. improve resolution
-3.0 to -2.5																		
-2.5 to -2.0																		
-2.0 to -1.5						σ_p/p~ 0.04%×p⊕2%			dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1:(1E-3 - 1E-2)	50 MeV					
-1.5 to -1.0																		
-1.0 to -0.5				Barrel		σ_p/p ~0.04%×p⊕1%		200 MeV/c	dca(xy) ~ 30/pT μm ⊕ 5 μm	dca(z) ~ 30/pT μm ⊕ 5 μm	2%/E ⊕(12-14)%/√E ⊕ (2-3)%	π suppression up to 1:1E-2	100 MeV	≤ 6 GeV/c	≥ 3 σ	100%/√E+10%		
-0.5 to 0.0																		
0.0 to 0.5																		
0.5 to 1.0																		
1.0 to 1.5				Forward Detectors		σ_p/p ~0.04%×p⊕2%		70 - 150 MeV/c (B = 1.5 T)	dca(xy) ~ 40/pT μm ⊕ 10 μm	dca(z) ~ 100/pT μm ⊕ 20 μm	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/√E+10%		
1.5 to 2.0																		
2.0 to 2.5																		
2.5 to 3.0						σ_p/p ~0.2%×p⊕5%												
3.0 to 3.5																		
3.5 to 4.0				Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		↑ e			Not Accessible													
> 4.6			Far Forward Detectors	Proton Spectrometer														
				Zero Degree Neutral Detection														

e/π separation

h-PID

https://physdiv.jlab.org/DetectorMatrix/

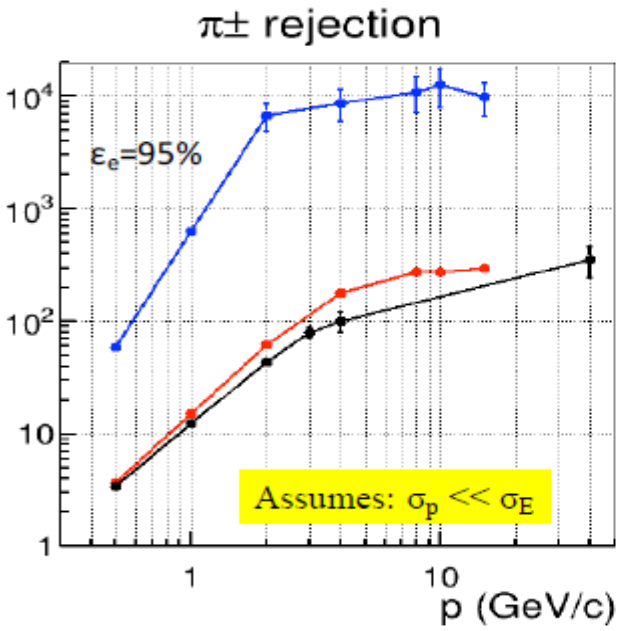
PID in the YR : WHY DEALING WITH e/π SEPARATION?

REFERENCE

- ECal as main actor
- Complemented by Cherenkov detectors
  - Backward, mRICH : e/π separation 3 σ up to 2 GeV/c
  - Forward, dRICH: e/π separation 3 σ up to 15 GeV/c
  - **Barrel, DIRC: e/π separation 3 σ up to *at least* 1.3 GeV/c**

ECal studies

π± rejection with E/p cut



E/p > 1 - 1.6 · σ_{EMC} to keep ε_e=95%

Ideal case:
- No material on the way to EMCal
- Perfect EMCal (no gaps/cracks)
- Gaussian response to electron

	$PbWO_4$ Crystal	W/SciFi	PbSc
Depth, X_0	20	~20	18
$\frac{\sigma_E}{E}$	$\frac{2.5\%}{\sqrt{E}} \oplus 1\%$	$\frac{13\%}{\sqrt{E}} \oplus 3\%$	$\frac{8\%}{\sqrt{E}} \oplus 2\%$
Depth, λ_I	0.87	~0.83	0.85
e/h	>2		<1.3

Barrel reference option

https://physdiv.jlab.org/DetectorMatrix/

BARREL PID REQUIREMENTS

η	Nomenclature			Tracking				Electrons and Photons			π/K/p		HCAL		Muons
				Resolution	Allowed	minimum-pT	Si-Vertex	Resolution σ_E/E	PID	min E	p-Range	Separati	Resolution σ_E/E	Energy	
-6.9 to -5.8	↓ p/A	Auxiliary Detectors	low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5															
-4.5 to -4.0			Instrumentation to separate charged particles from photons							50 Me					
-4.0 to -3.5						<100MeV pions, 135MeV				50 MeV			~50%/√E + 6%		
-3.5 to -3.0		Central Detector	Backward Detector	σp/p ~ 0.1%⊕0.5%	~5% or less X	<100MeV pions, 135MeV				50 MeV	≤ 7 GeV/c		~45%/√E+6%	~500 MeV	muons useful for bkg, improve resolution
-3.0 to -2.5						<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT μm + 40 μm			50 MeV					
-2.5 to -2.0				σp/p 0.1%⊕0.5%		<100MeV pions, 135MeV	σ_xy ~ 30/pT μm + 20 μm	2%/√E(+1-3%)	ττ suppression up to 1:1E-4	50 MeV					
-2.0 to -1.5				σp/p 0.05%⊕0.5%		<100MeV pions, 135MeV		7%/√E(+1-3%)		50 MeV					
-1.5 to -1.0						<100MeV pions, 135MeV		7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5			Barrel	σp/p ~0.05%×p+0.5%		<100MeV pions, 135MeV kaons	σxyz ~ 20 μm, d0(z) ~d0(rΦ) ~ 20/pTGeV μm + 5 μm			50 MeV	≤ 10 GeV/c	≥ 3 σ	~85%/√E+7%		
-0.5 to 0.0						<100MeV pions, 135MeV				50 MeV			~85%/√E+7%		
0.0 to 0.5						<100MeV pions, 135MeV				50 MeV			~85%/√E+7%		
0.5 to 1.0						<100MeV pions, 135MeV				50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5			Forward Detectors	σp/p ~0.05%×p+1.0%		<100MeV pions, 135MeV	σ_xy ~ 30/pT μm + 20 μm			50 MeV	≤ 30 GeV/c				
1.5 to 2.0						<100MeV pions, 135MeV				50 MeV	≤ 50 GeV/c				
2.0 to 2.5						<100MeV pions, 135MeV				50 MeV					
2.5 to 3.0				σp/p ~ 0.1%×p+2.0%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT μm + 40 μm	(10-12)%/√E(+1-3%)	3σ e/ττ	50 MeV	≤ 30 GeV/c		35%/√E		
3.0 to 3.5						<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT μm + 60 μm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0		Auxiliary Detectors	Instrumentation to separate charged particles from photons			<100MeV pions, 135MeV kaons				50 MeV					
4.0 to 4.5	↑ e					300 MeV pions				50 MeV					
4.5 to 5.0			Neutron Detection			300 MeV pions		4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)		
>6.2			Proton Spectrometer	σintrinsic(|t|)/|t| < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

Required: $1 : 10^{-4}$
- from inclusive

Reference detector: $\sim 1 : 10^{-2}$

Required: <10/15 GeV/c
- Semi-inclusive up to 8 GeV/c
- Jets & HQ: 10/15 GeV/c

Reference detector : <6 GeV/c

BARREL PID REQUIREMENTS, DEEPER UNDERSTANDING

h-PID in barrel

Required: <10/15 GeV/c

- Semi-inclusive up to 8 GeV/c
- Jets & HQ up to 10 GeV/c(η: -1 – 0.5)
  15 GeV/c (η: 0.5 – 1)

Reference detector : <6 GeV/c

JETS & HQ

- Talk by Miguel Arratia 8/28 at the PID bi-weekly meetings on 8/28
- Brian Page invited to a meeting with the DWG conveners, 10/13
  - *In short:* covering the phase space for the whole jet program would require the indicated prescription, in particular for TMD's from jets; the impact on physics of reduced performance still requires a deeper assessment

SEMI-INCLUSIVE

- Conversation between Anselm Vossen and one of the DWG convener on 10/22
- Talk by Anselm Vossen at the Complementary meeting on 11/11
  - *In short:* part of the phase space at mid-x, high Q^2 will loose PID for the higher CME options; the current TMD extraction framework studies indicate that the impact of this loss is not severe.

π suppression in the barrel

Required: $1 : 10^{-4}$

- from inclusive

Reference detector: ~$1 : 10^{-2}$

INCLUSIVE

- Renee Fatemi invited to a meeting with the DWG conveners, 10/13
- Talk by Renee Fatemi at the Complementary meeting on 11/11
  - *In short:* the most demanding physics channel is A_{PV}; π/e at the 10^{-3} at least needed to the systematic error from the π background to 10% of the statistical errors
  - *Comment:* this requirement means more then requiring π suppression at the 10^{-4} level; <u>technologically possible?</u>

ABOUT π SUPPRESSION REQUIREMENTS

Estimated π/e ratios

Here a π suppression at the 10^{-4} level is applied

$E^{e^-}_{beam}$ (GeV)	η bin	$p^{e^-}_{min}$ (GeV)	Max π^-/e^-	final π^-/e^- ratio
18	(-3.5,-2)	0.9	200	0.02
18	(-2,-1)	0.9	800	0.08
18	(-1, 0)	1.0	1000	0.1
18	(0, 1)	1.8	100	0.01
10	(-3.5,-2)	1.4	10	0.001
10	(-2,-1)	0.5	400	0.04
10	(-1, 0)	0.6	800	0.08
10	(0, 1)	1.0	1000	0.1
5	(-3.5,-2)	2.8	0.1	0.00001
5	(-2,-1)	0.4	100	0.01
5	(-1, 0)	0.3	500	0.05
5	(0, 1)	0.5	1000	0.1

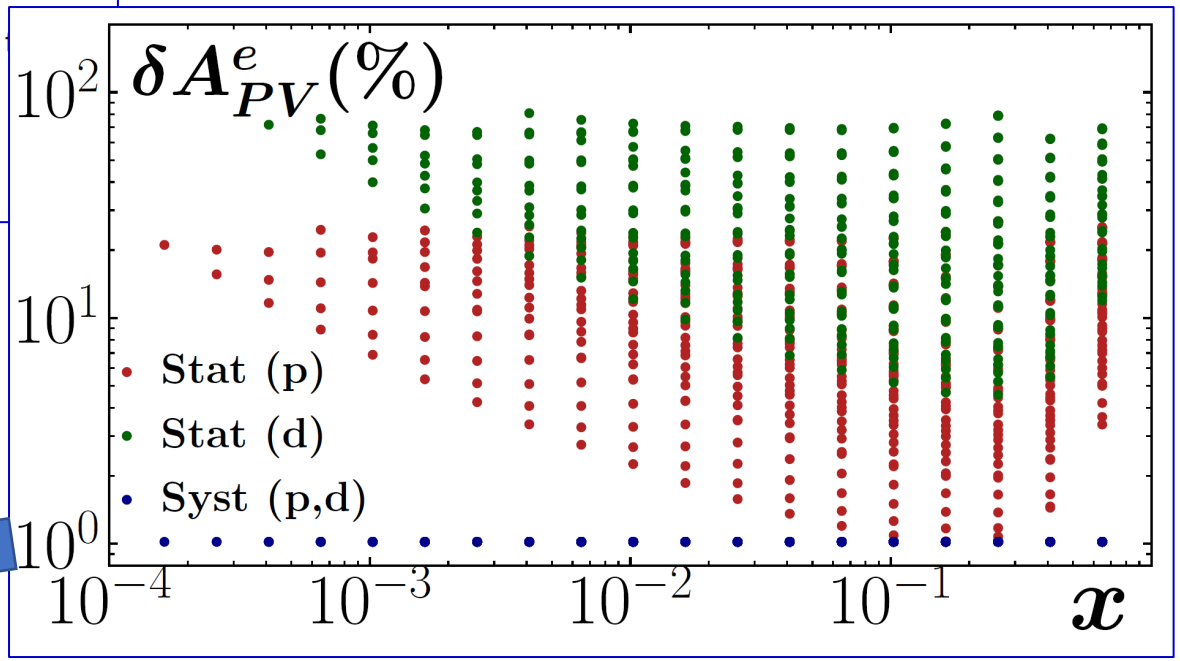
Pion contamination

1) Inflates statistical errors because it is typically treated as a dilution

2) Incurs ~1% systematic error

Tightest constraints come from electron parity violating asymmetries $A_{PV}^{e^-}$

Despite, the sever π rejection applied, the condition: "π/e at the 10^{-3} level" is satisfied only here



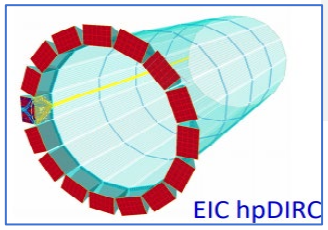
2 slides by Renee Fatemi, 12 Nov. 2020

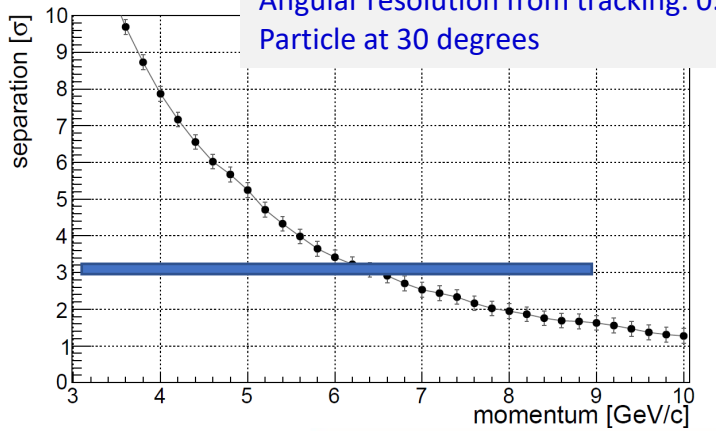
the impact study of the detector performance is being repeated (Chris Concuzza)

BARREL PID: WHERE THE FIGURES COME FROM ?

REFERENCE

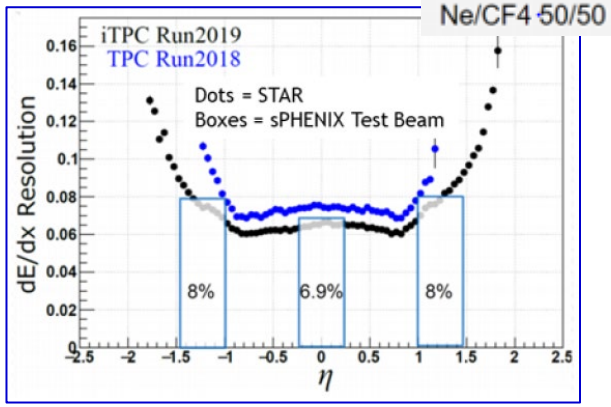
- hpDIRC (High Performance DIRC)
  - Quartz bar radiator, light detection with MCP-PMTs
  - Fully focused
  - π/K separation: 0.6 GeV/c (0.2 GeV/c in veto mode) - 6 GeV/c (3σ)
  - e/π separation: < at least 1.3 GeV/c



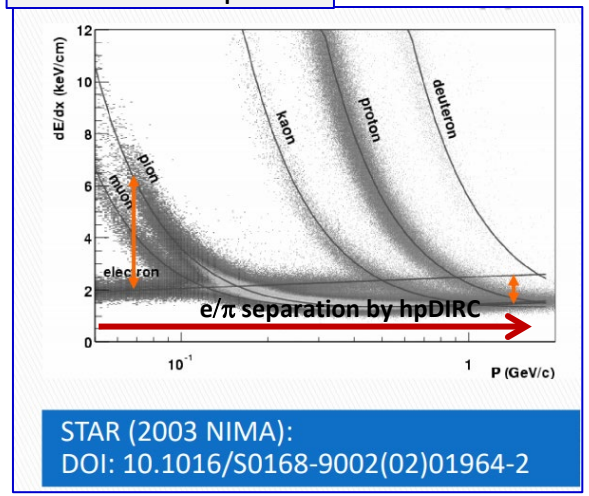


Angular resolution from tracking: 0.5 mrad;
Particle at 30 degrees

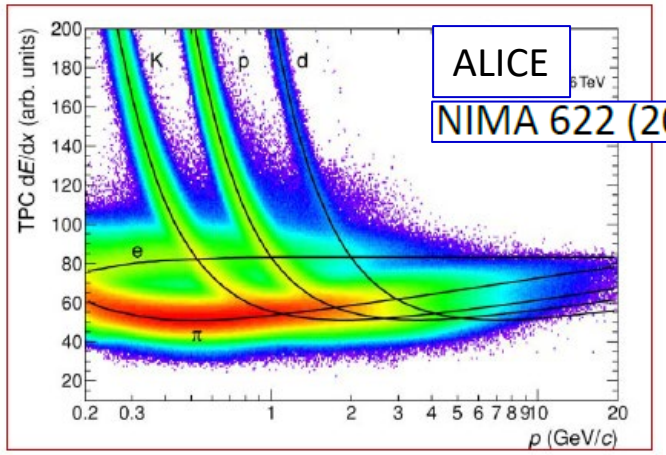
complemented with dE/dx by TPC



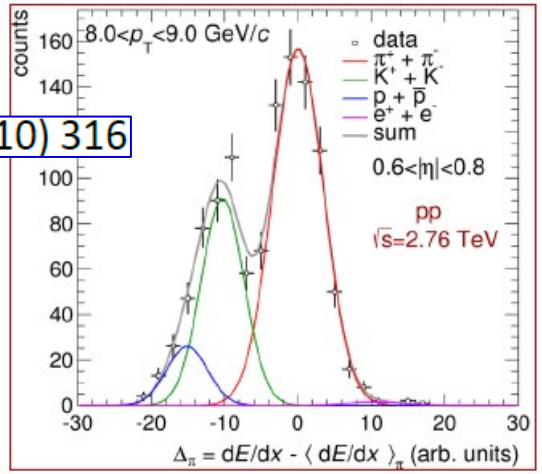
STAR,
~ similar
resolution expected



STAR (2003 NIMA):
DOI: 10.1016/S0168-9002(02)01964-2



ALICE
NIMA 622 (2010) 316

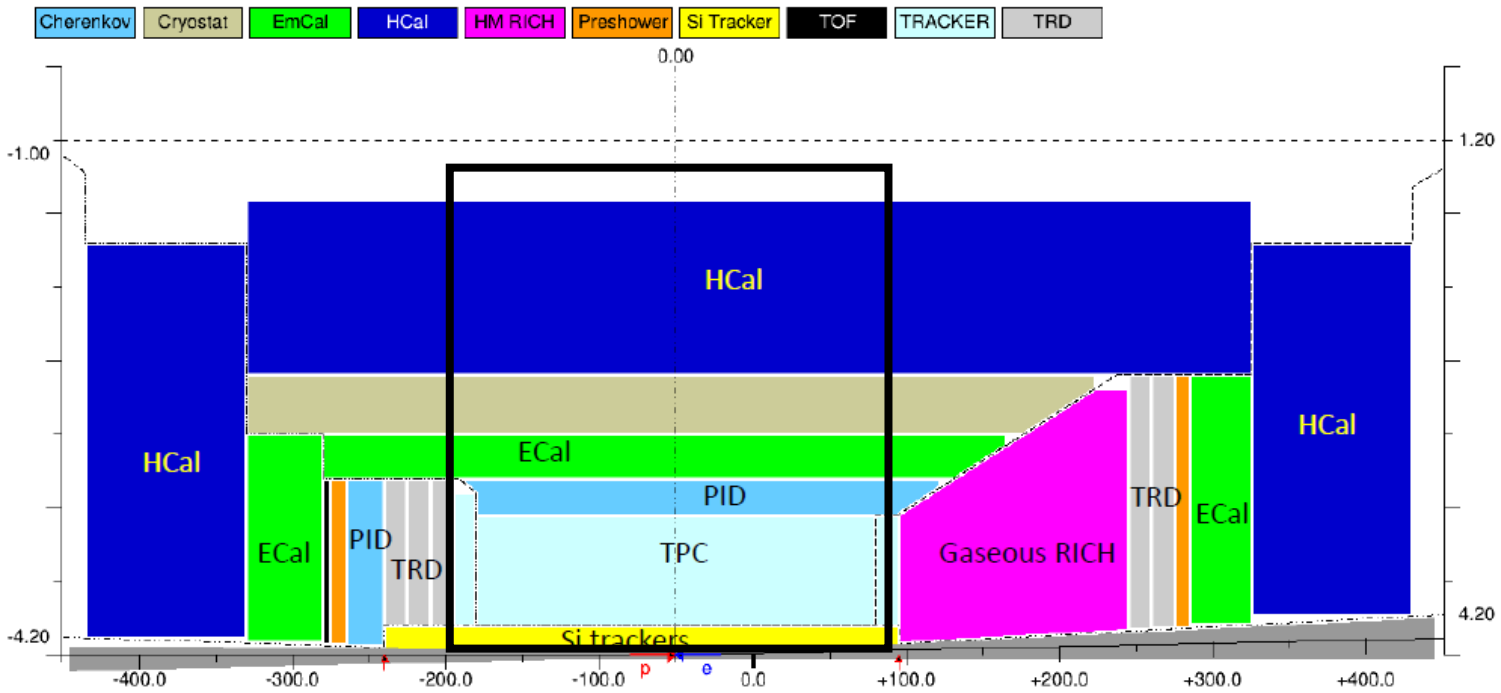


Combining hpDIRC & TPC

- **π/K separation – globally <6 GeV/c** [dE/dx: < ~0.5 GeV/c; hpDIRC: 0.6 - 6 GeV/c (3σ)]
- **e/π separation - globally < ~ 1.7 GeV/c** [dE/dx contributing up to ~ 0.2 GeV/c] < ~ 1.7 GeV/c

BARREL PID: CONSTRAINS

SPACE CONSTRAINS



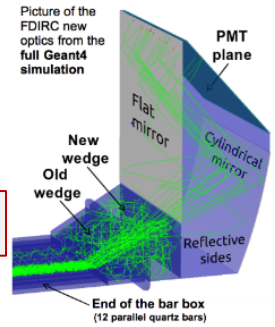
A possible "option"

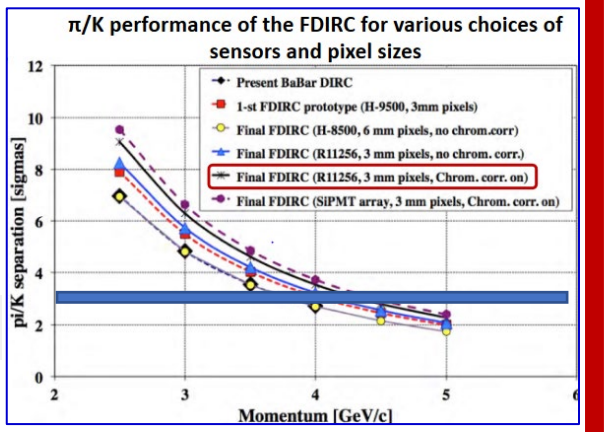
- radially, ~30 cm more if TPC→ full Si tracking
- What for? Alternative possibilities:
  - h-PID
  - e/π sep.
  - Improved Ecal

BARREL PID: ALTERNATIVE OPTIONS

alternatives

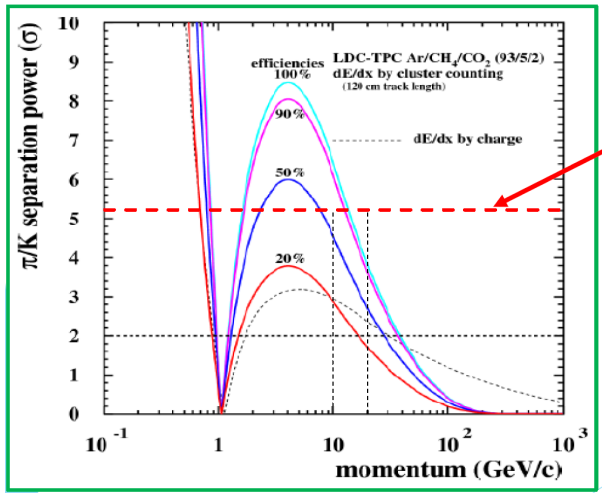
F-DIRC (super B)

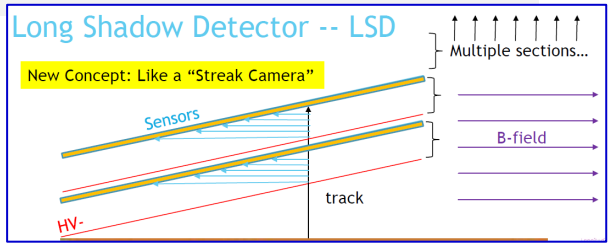




π/K separation: 4.5 GeV/c (3σ)

dE/dx → cluster counting





Assuming 40 cm available and scaling results from literature

- If ~ 90% efficiency, 3σ at ~ 10 GeV/c

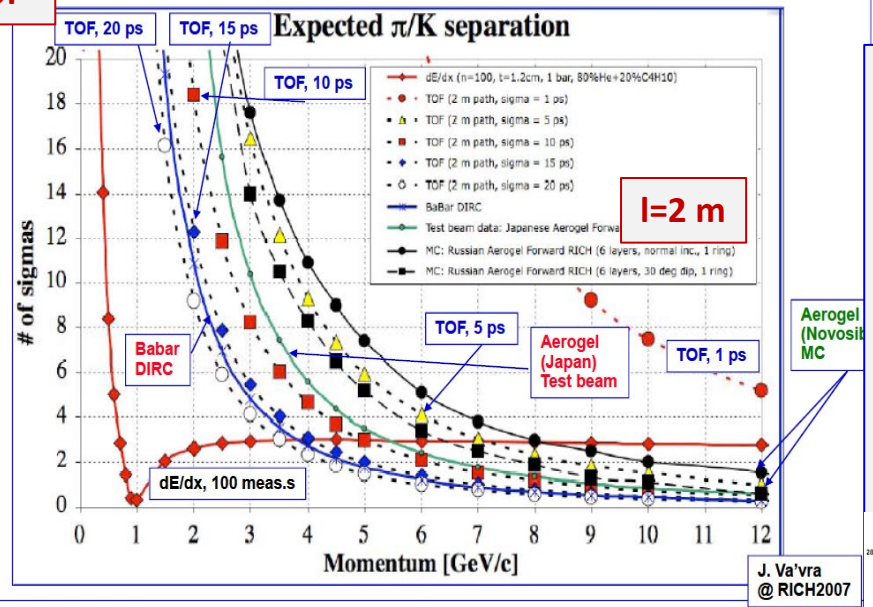
BUT

Complement of DIRC/TOF needed at small p

Which cluster detectors?

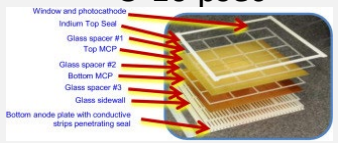
All this only speculative so far

TOF

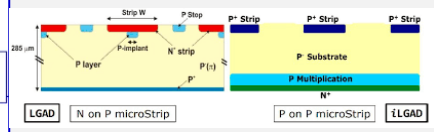


TOF, 2 options

- LAPPD, Cherenkov in window
  - 5-10 psec



- LGAD, Silicon Avalanche
  - 20-35 psec



For π rejection only: **empowered HBD**

- By decreasing the MIP signal with minimum gas gap between multiplication stages (HBD ++)
- By 2 HBDs, each one with half length; reduced probability to have MIP signal in both!

BUT

- **No test so far**