“Laundry list” of possible detectors to be used in (future) eRHIC setup, and detector response simulation status

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Some (obvious) but constraints

- Request / Challenge for eRHIC Detector

  -- the best possible electron momentum (energy) measurement in: (0.1 – 30.) GeV/c → (good tracking and EMCAL, low mass set-up, not "very strong" Bz-field (~2. T); R of SC solenoid ~1.5 m)

  -- PiD performance: ~90% electron efficiency / ~1000 hadron rejection. K/π/p PiD for ~(0.5 – 20. GeV/c)

  -- primary and secondary vertexes reconstruction

  -- "special" set-ups for |η| > 3. (both e- and H- directions)

  -- but: no occupancy, rate(?!), and (possible) no TPC space charge problem

  -- "high level" trigger possibilities (!?).

Charge particle tracking detectors

- "Natural" classification: Si , Gas --

  as an ionization matter (and drift, amplification)

- Stand alone possible tracking detectors:

  -- high precision space hit detector – MCP (hope for progress)

  -- TRD, Fibers, drift (straw) tubes (may be not for eA detector setup)

Si detectors

- There are a lot of nice reviews

  (example: D. Christian report on EDIT 2012)
- Main properties:

  -- average energy / e-h pair: 3.62 eV

  -- large number of e-h pair “production”: ~80 / μm; good energy resolution and small thickness (20 – 500 μm)

  -- reasonable fast (~ 1 μs)

  -- “no” diffusion (high stopping power) and “not so strong” magnetic field distortion {Bz=2.T tan(ϕ_{lor})=0.15}

  -- high space resolution (4 – 30 μm)

  -- Si IC technology: photolithography, doping, ion implantation, passivation:

  1D (strips), 2D (double sided, pads, drift) → space points

  -- ionization and FEE – the same wafer; e-collection and FEE – the same wafer.
- Main problem: radiation damage (cooling, cost)

Types of Si detectors

- Strip detectors (SSD)
- CCDs
- Hybrid Pixel detectors (ATLAS, CMC, ALICE, …)

sensor (SSD with very short strips) + bump bonding + readout IC

- (Monolithic) Active Pixel Sensor

MAPS (sensitive layer thickness ~ 10 ϻm, read-out pad with IC ~25x25 ϻm^2 and options: FADC, Memory,…), needs > 25 ϻs for "frame read-out"; "active" during read-out time (STAR)

DEPFET: (sensitive layer thickness ~ 50 ϻm, read-out pad with IC ~50x50 ϻm^2; (SuperB ?)

- 3D: TSV (Through Si Via) Etching, Laser drilling holes (cylinders) (1 - 10) ϻm radius x (50-70) ϻm length electrodes to "organize" cell or connect sensor to IC
- TimePix (needs "special" discussion, but 25x25 ϻm^2 pad readout)

Si detectors and eRHIC

- Most probable it is "only" solution for Vertex Detector: two low mass, high hit position resolution (~4 мm) layers + two fast strip (double sided) layers as a "pointer".

- Most probable it is "only" solution for tracking η > 3.

Crucial point – background conditions and radiation hardness.
3D detector option is a most "stable" from this point of view (LHC upgrade option).

- Plus 3 more Si-layers in Barrel can be considered as "full" tracking setup with
  BdL = 2.T x 100 cm
  Quality of dE/dX data (number of hits/track), and cost are "factors"

But to-day LHC experiments → >100 m^2 of Si; > 7.5e7 channels (CMS only)

"Fast" and "Slow" detector response simulation is working nice
{ H. Bichsel, http://faculty.washington.edu/hbichsel/ ;
F. Sikler, NIM 691 (2012), 16;
F. Hartmann and J. Kaminski; Ann. Rev. Nucl. Part. Sci. 2011.61:197 }

Gas Detectors

- Practical any new gas detector construction, proposal, R&D, … relay on Micro-Pattern technology for a gas amplification (GEM, MMEGAS, …) with low mass 1d- 2d- 3d- strips and pads read-out (different size and shape)
- Main types of tracking detectors: “planar”, “cylinder”, “short drift”, TPC;

  and some combinations with PiD.

PiDetectors

- dE/dX (gas and Si; detector response can be simulated reasonable well)

- Cherenkov and RICH detectors; Gas radiator + CsI based readout; AeroGel or Quartz + "photo-detector" (DIRC) { SuperB, Belle II, PANDA}.

  (for simulation GEANT has all needed tools;

  scintillation light "production" (gases) and scattering, absorption steps (AiroGel) were added)

- EMCAL + tracking (momentum reconstruction, ɣ)

- Muon Detectors

- ToF + tracking (L) + T0

  { MCP-PMTs, Multi-gap RPCs, G-APDs (or SiPM);

  T0 problem for eA and ee collisions;

  SuperB and Belle II solutions and experience. }

Charge particle energy losses simulation (gas detectors)

-- FVP (or PAI) approach *)

-- Monte-Carlo program was prepared to simulate number of interactions (and position along the particle track), and a transfer energy in each interaction as a function of a gas mixture parameters and particle momentum ($\beta\gamma$).

-- It allows to simulate number and position of "ionization" electrons, including so-called δ-electrons.

*) All details can be found:

-- H. Bichsel, NIM A562 (2006) 154

-- http://faculty.washington.edu/hbichsel/

Detector response simulation
STAR TPC as an example; MWPC with pad read-out .

- For each electron:

-- drift, absorption, diffusion, anode wire selection steps were simulated.

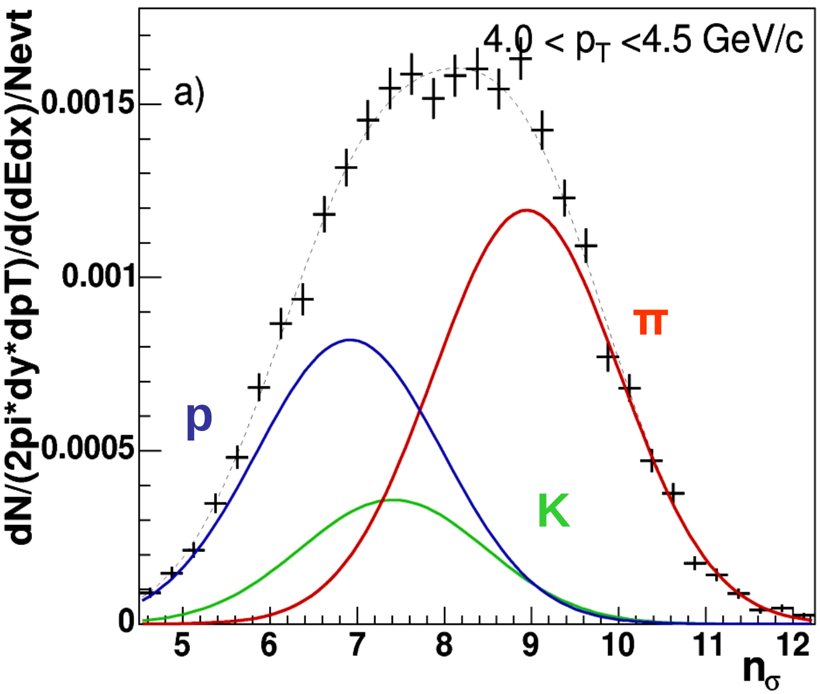
-- Gas amplification (Polya distribution).

-- An induction charge on read-out pads was calculated.

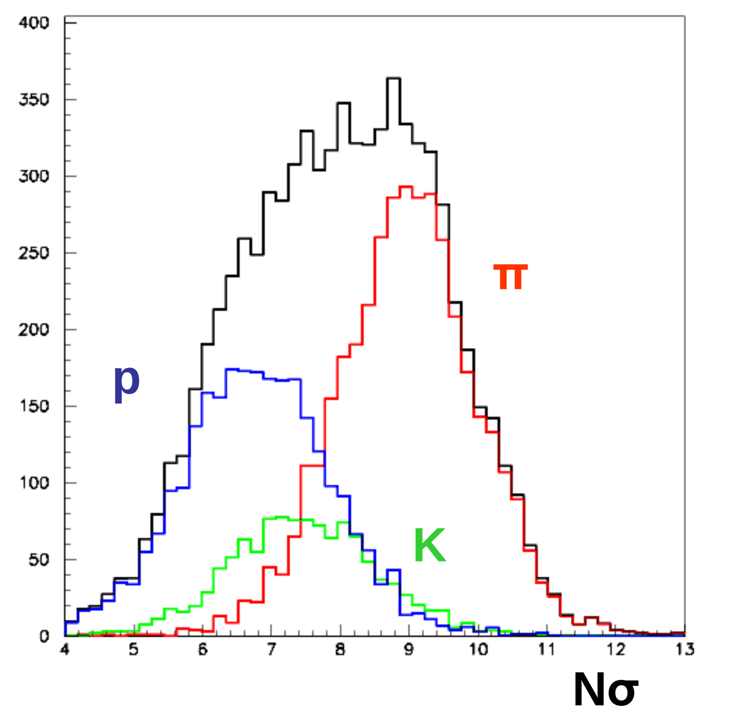
- FEE response using an “arrival” time for each electron, “noise” and “cross-talk” parameters.
- Cluster finding (“voxel”); coordinate reconstruction; q in a cluster.
- Track finding.
- Truncated procedure.
- dE/dX and PID analysis – in “N_σ“ for {log(q / <q>)/σ+9}.

STAR TPC; experiment – simulation comparison

Data from O. Barannikova,
Proc. 21st Winter Workshop on Nuclear Dynamics (2005).



Simulation:
***Try to be ACAP with number of Hits / track; and use the same Truncated approach*.**



STAR TPC; experiment – simulation comparison

Pt, GeV/c	(Nσ, K - Nσ, π)	(Nσ, p - Nσ, π)
	{ experiment *) / simulation }	
3.125	-1.68 / -1.68	-2.03 / -2.08
4.25	-1.67 / -1.72	-2.35 / -2.45
6.25	-1.61 / -1.69	-2.51 / -2.59
11.0	-1.44 / -1.44	-2.27 / -2.35

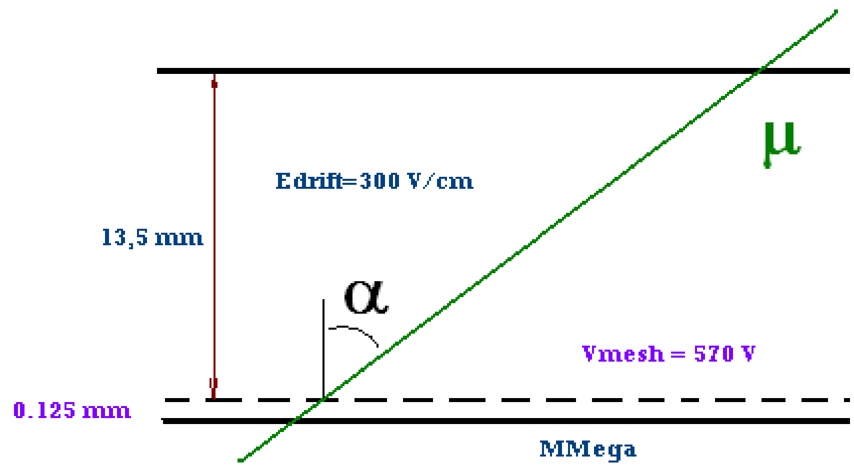
- ***Conclusion:*** Simulation approach reproduced experimental data (STAR, P10).

*) Yichun Xu, … arXiv:0807.4303v1, 27 July 2008

"MicroTPC" (or "Shot drift") Operation of mMegas Detector
ATLAS muon detector upgrade

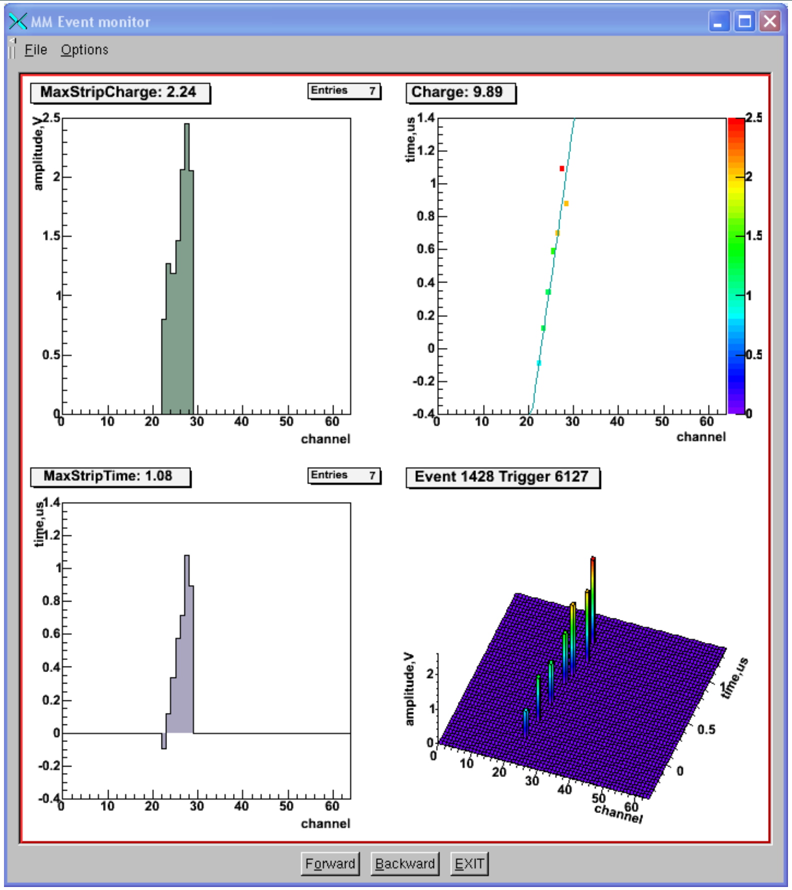
Detector was instrumented with new "BNL" chip
For each strip – Q and T (in q-max) signals

E_{drift} 300V/cm V_{drift} ~2cm/μs
V_{mesh} 570 V



Ar+CO2(15%);   Strip pitch – 250 мm; Gain $4 \cdot 10^3$

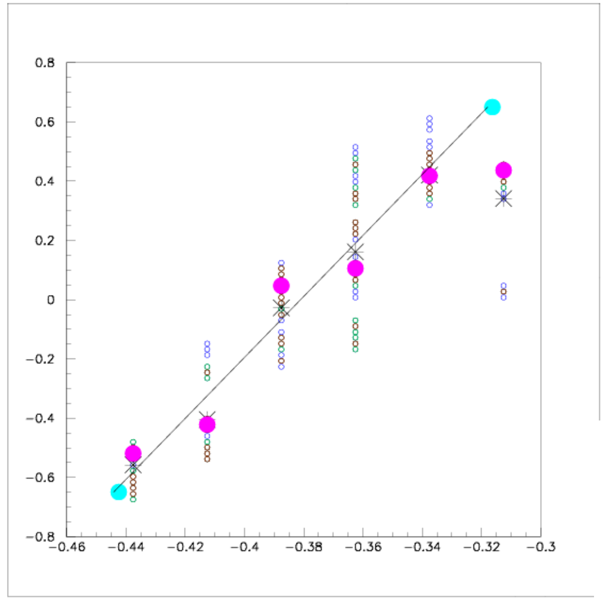
Event Display



Y, cm drift

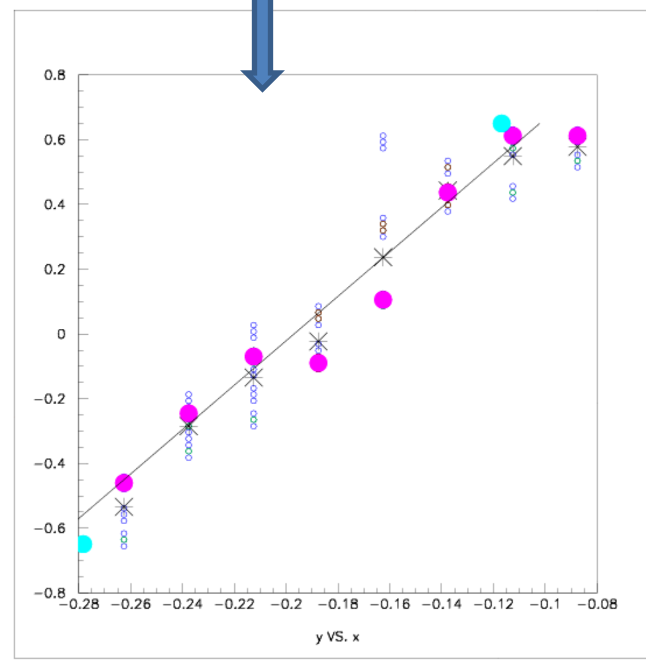
X, cm strip

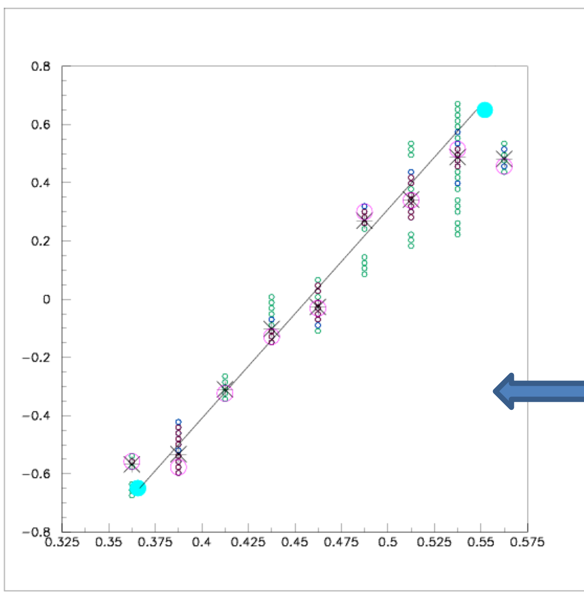
	slope	alpha	offset
Simul.	10.3097	5.3 deg	-0.4424
Reco.	10.296	5.55 deg	-0.4441
Diff.		0.25 deg	0.0017



Simulation: "Event display"

	slope	alpha	offset
Simul.	8.0518	7.1 deg	-0.2782
Reco.	6.864	8.29 deg	-0.2915
Diff.		1.18 deg	0.0133





	slope	alpha	offset
Simul.	6.975	8.06 deg	0.366
Reco.	7.187	7.93 deg	0.367
Diff.		0.13 deg	0.001

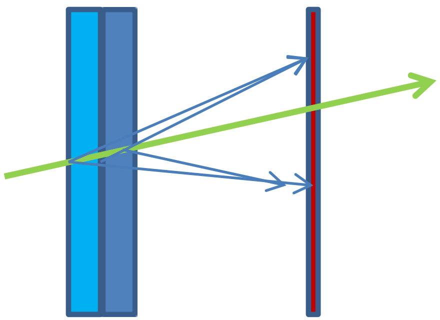
Cherenkov UV radiators

Material	n	π_{thr} (GeV/c)	K_{thr} (GeV/c)	P_{thr} (GeV/c)	Θ_{max} (β=1) deg
Fused silica	1.474	0.13	0.45	0.85	47.
C6F14	1.29	0.17	0.60	1.13	39.
AeroGel*)	1.05 – 1.01	0.4 – 1.	1.5 – 3.5	3. – 7.	18 - 8
C4F10	1.0014	2.6	9.	17.	3.
Isobutane	1.00127	3.	10.	18.	2.9
Argon	1.00059	4.	14.	27.	2.
CF4	1.00050	5.	16.	30.	1.8
Methane	1.00051	5.	16.	30.	1.8

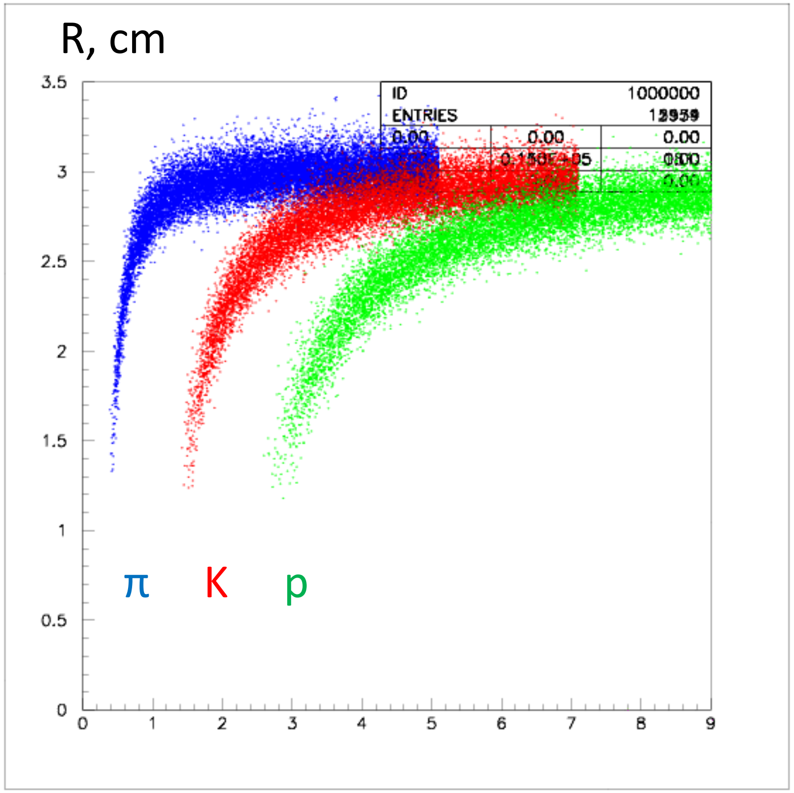
*) last publication from Japan team; NIM 668 (2012) 64
n = (1.006 – 1.14) ; Methanol → DMF: transmission length increased x2.
Size: 26 x 18 x 2 cm^3.

Aerogel detector response simulation, “projective” blocks 15x15 cm^2.
(two layers, proximity focusing)
UV light “production”, transport (scattering, absorption), MCP QE,
hits position (MiP, UV) reconstruction

Circle fit with some kind of
hits truncated procedure



This “combination” can be very good tracking and ToF detector also, but a lot of ???



Momentum, GeV/c

GEM detector (with CsI option) response. Some details, how simulation was done

Input parameters: geometry, n-index, gas (ionization, diffusion), E-field, Average Gas Amplification, FEE parameters,…

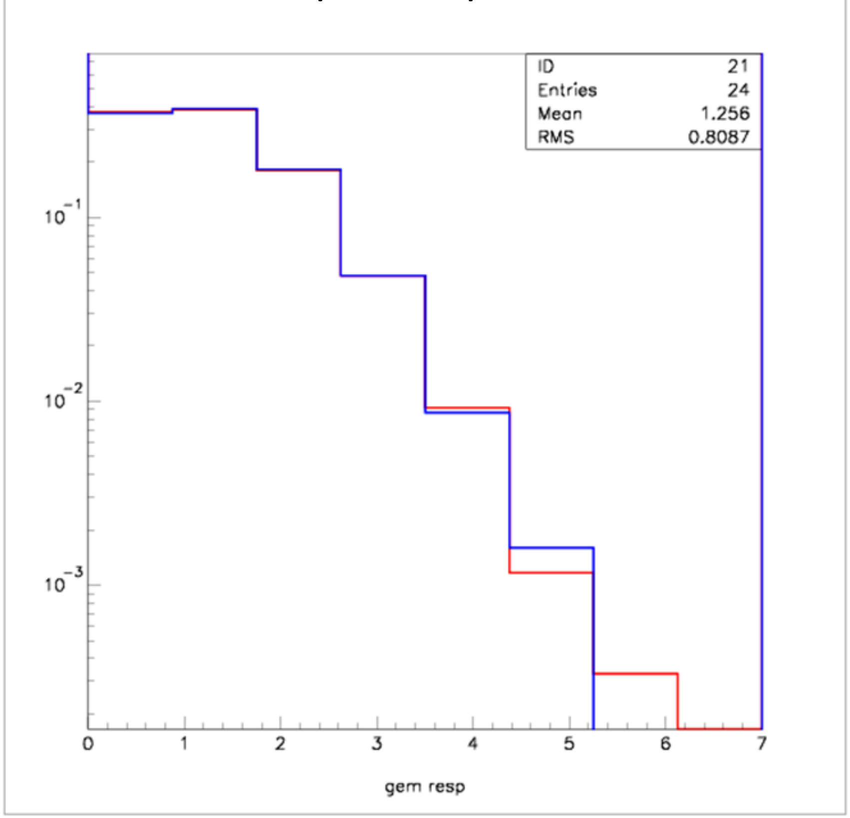
- Primary ionization*): track; Fe55 (position in a space of each e-); single photo-electron from CsI on a top of a first foil (GEANT-3 for UV production, transport and CsI QE)
- Transport of each e- to nearest hole in first foil (probability and position in a hole)
- Gas amplification; Polya distribution and "some special parameters".
- Transfer of each e- after gas amplification step to next foil (hole selection)
- Repeat GA and Transport steps for second and third foil.
- Collect electrons on pad (strip) structure
- Add FEE noise and t-response for each ("active") pad (strip)
- Select "active" pads (pedestal, threshold) .
- Cluster finding and reconstruction.

- NO Background (for the moment)

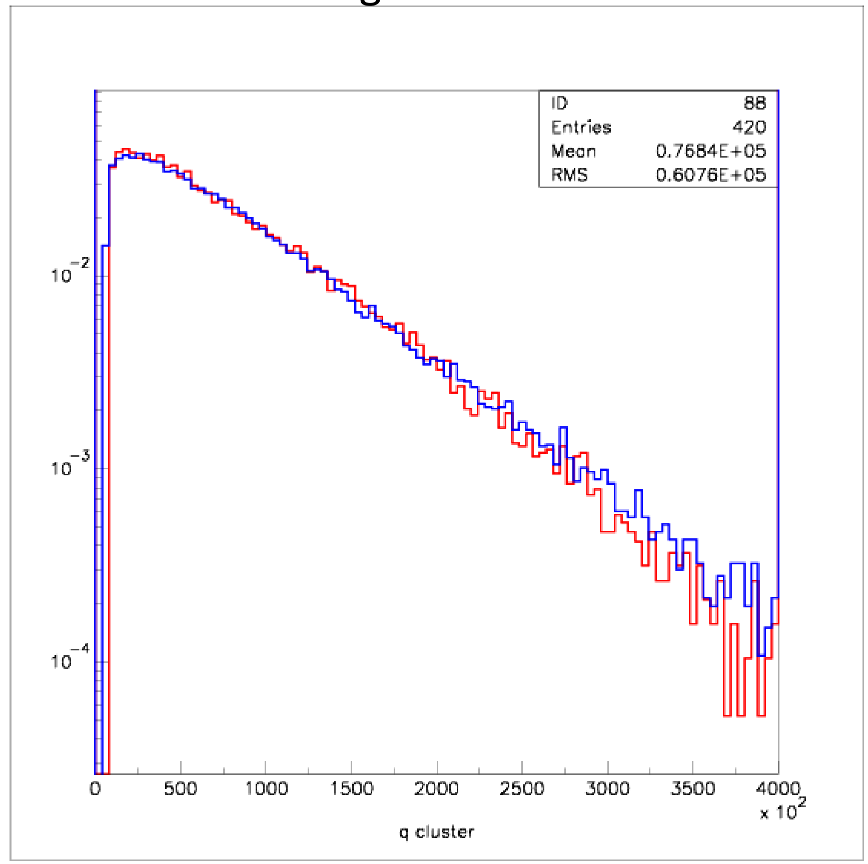
*) All details can be found:
-- H. Bichsel, NIM A562 (2006) 154
-- http://faculty.washington.edu/hbichsel/

Test-beam CERN PS, triple TGEM with CsI; C6F14 UV photons radiator;
5 10x10 cm^2 detectors in "circle hits expected position".
Red – experiment; Blue -- simulation results

Number of reconstructed UV-hits / event / detector



UV Cluster charge in number of electrons



Tracking + PiD setup (as option for eRHIC detector)
NO RICH inside Magnet !! No huge RICH + EMCAL in EndCaps

- **Vertex**

-- 2 layers of pixel Si detectors (CMOS technology), $\sigma_{x,z}$ = 4 μm
-- 2 layers of Si-strips (double sided), σ_x = 20 μm, σ_z = 20 μm

- **Barrel**

-- Small (~40-50 cm drift), fast (~5. μs drift time), low mass TPC with "GEMs + pad Si- read-out": best track finding (> 25 pad-rows); possibility to "combine" with an additional PiD (Cherenkov Detector with pad read-out); low Pt tracks and decay products reconstruction; dE/dX measurements; (single hit space resolution: $\sigma_{r\phi}$ < 150. μm, σ_z = ~300. μm)

-- 2 – 3 layers of μ–pattern gas detectors with 2d- readout
(single hit space resolution: $\sigma_{r\phi,\,z}$ < 100. μm)

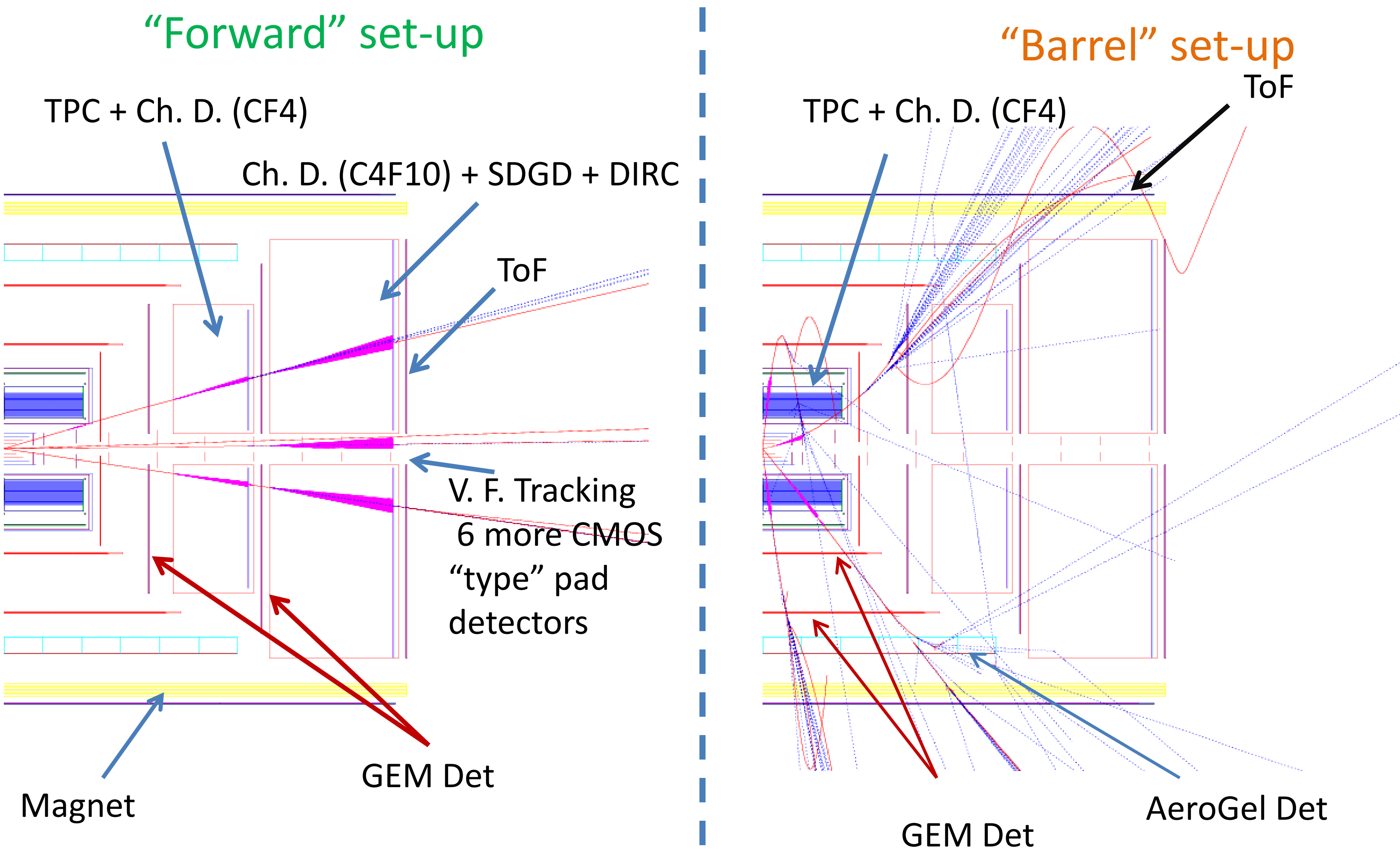
- **Forward**

-- 3 - 4 layers of "planer" or/and "short drift" (3 – 30 cm) μ–pattern gas detectors with 2d- readout ; can be used in a combination with quartz and gas Cherenkov detectors

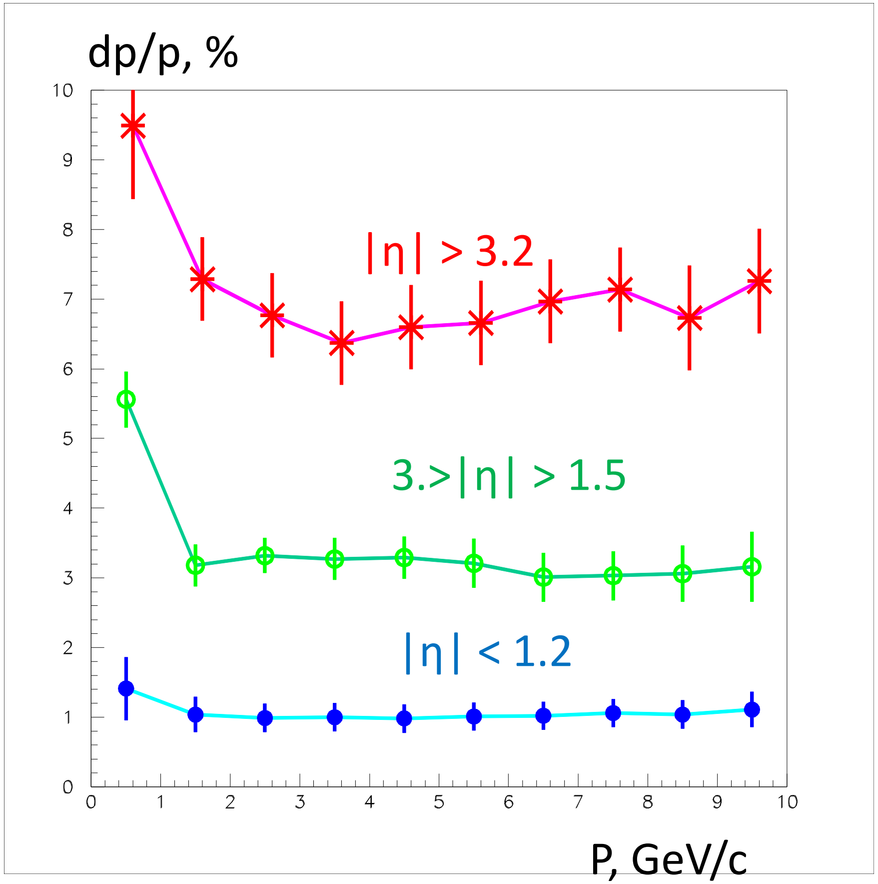
- **"very Forward"**

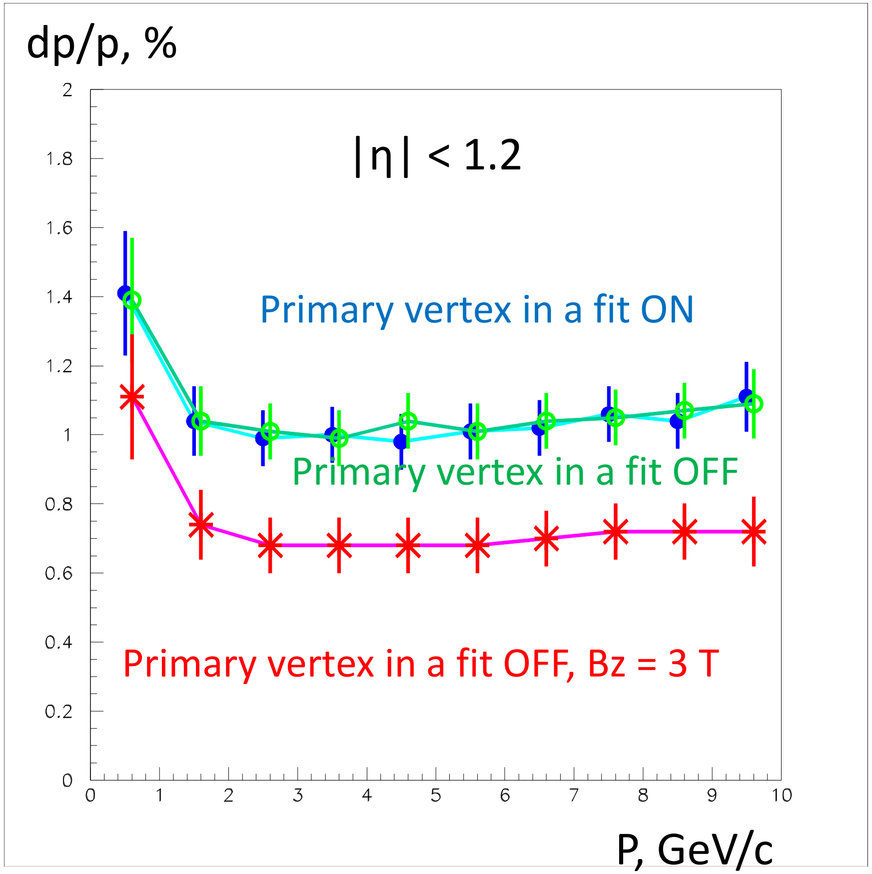
-- Si detectors, CMOS, TimePix and strip technology

Set-up in simulation; SC magnet Bz=2. T, R=1.5 m, dZ=2.5 m; (EMCALs not shown)

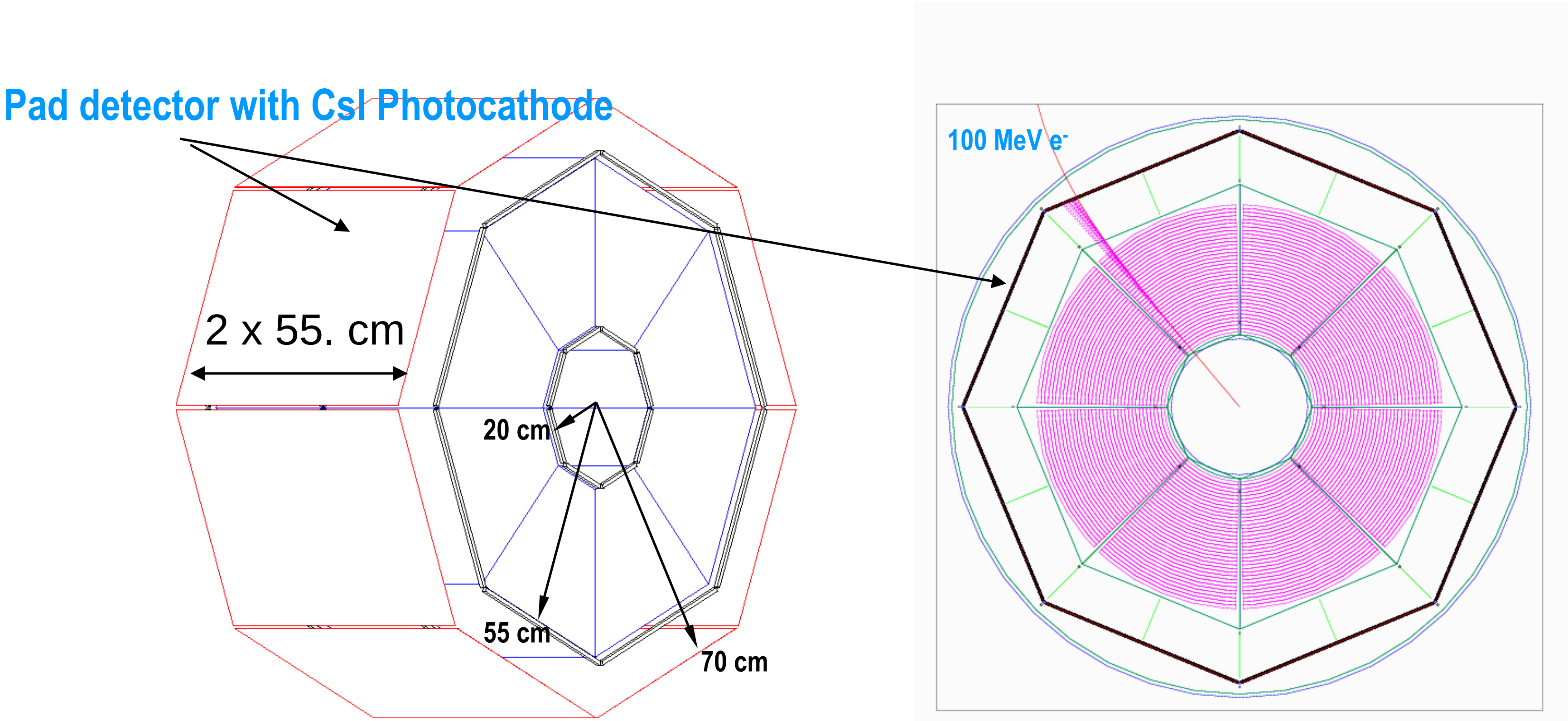


dP/P performance (%); one π^- / event; Bz = 2. T





Fast, Compact TPC with enhanced electron ID capabilities (it was proposed as STAR upgrade option, 2001; simulation results for central Au+Au events were reported, RICH conference, Cancun, 2004)



16 identical modules with 35 pad-rows,
GEM readout with pad size: 0.2x1. cm². Maximum drift: 40-45 cm. “Working” gas: fast, low diffusion, good UV transparency .

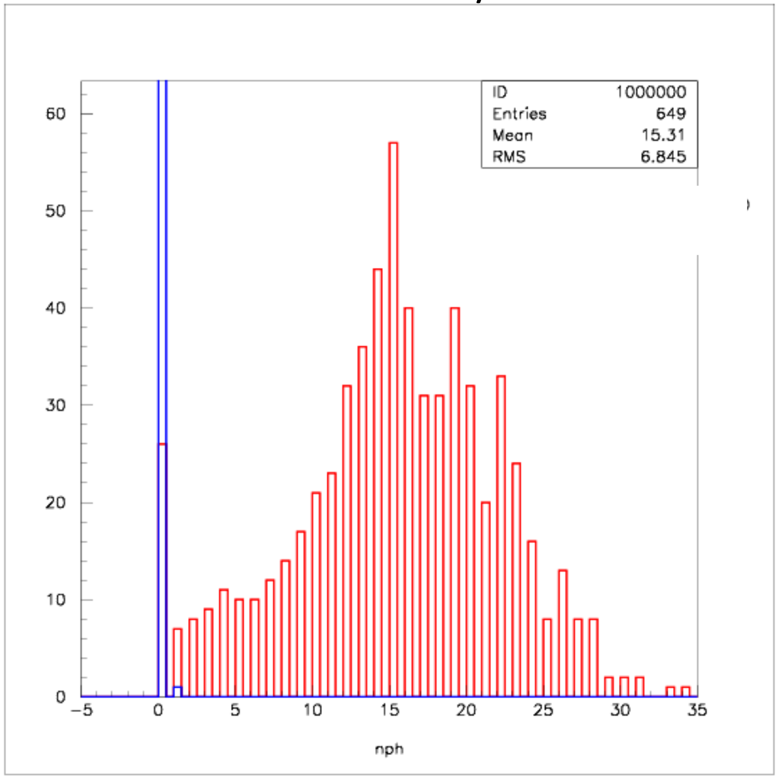
It is possible to combine: tracking, dE/dX, Cherenkov detectors in one low mass setup;
needs some kind of T0 (“beam clock”)

Hadron PiD performance; TPC + Cherenkov Det. in barrel

|η| < 1.2

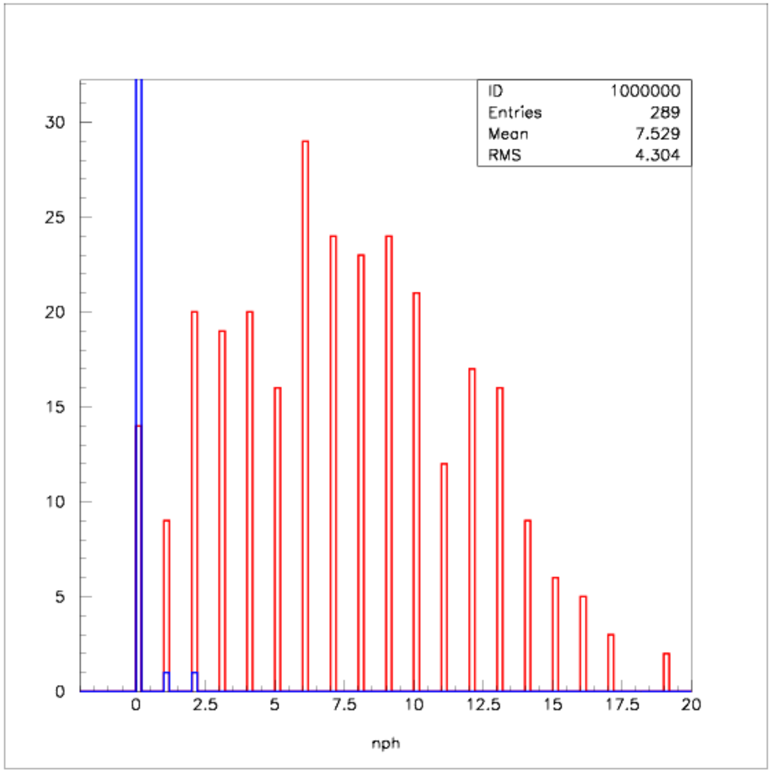
CF4 gas, GEM + CsI as UV Detector

π, Prec > 4.2 GeV/c – Red
Prec < 4.2 GeV/c – Blue



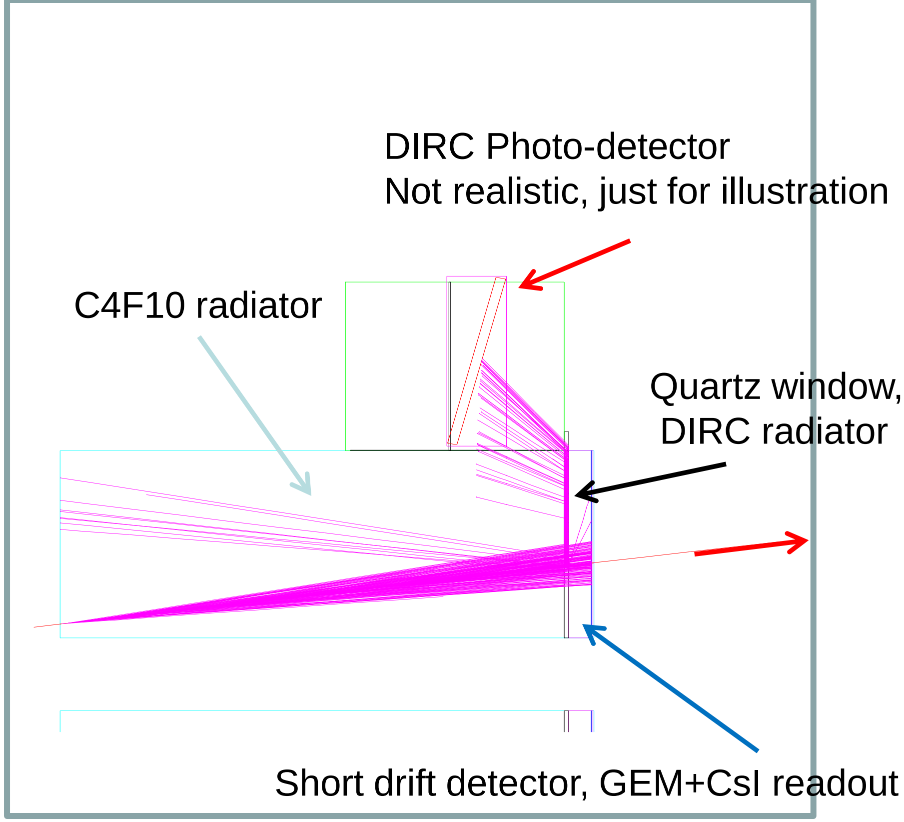
Number Ph. Electrons / event

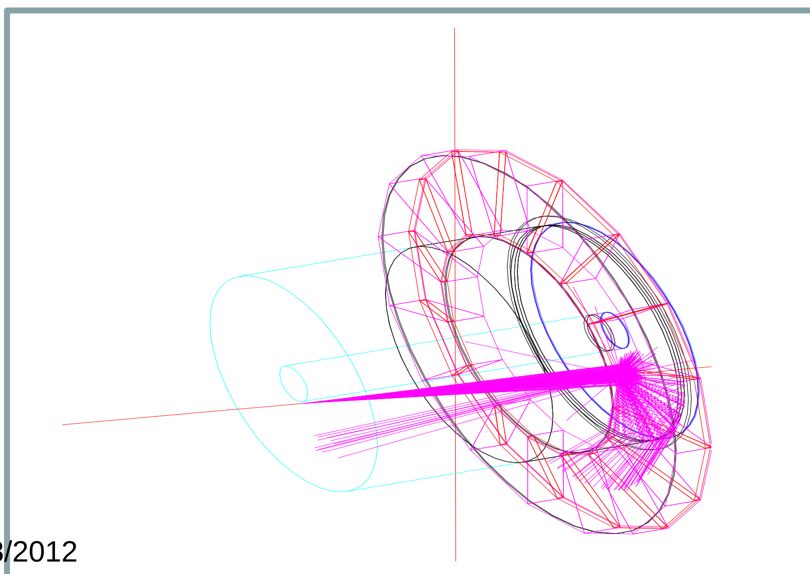
K, Prec > 14.9 GeV/c – Red
Prec < 14.9 GeV/c – Blue

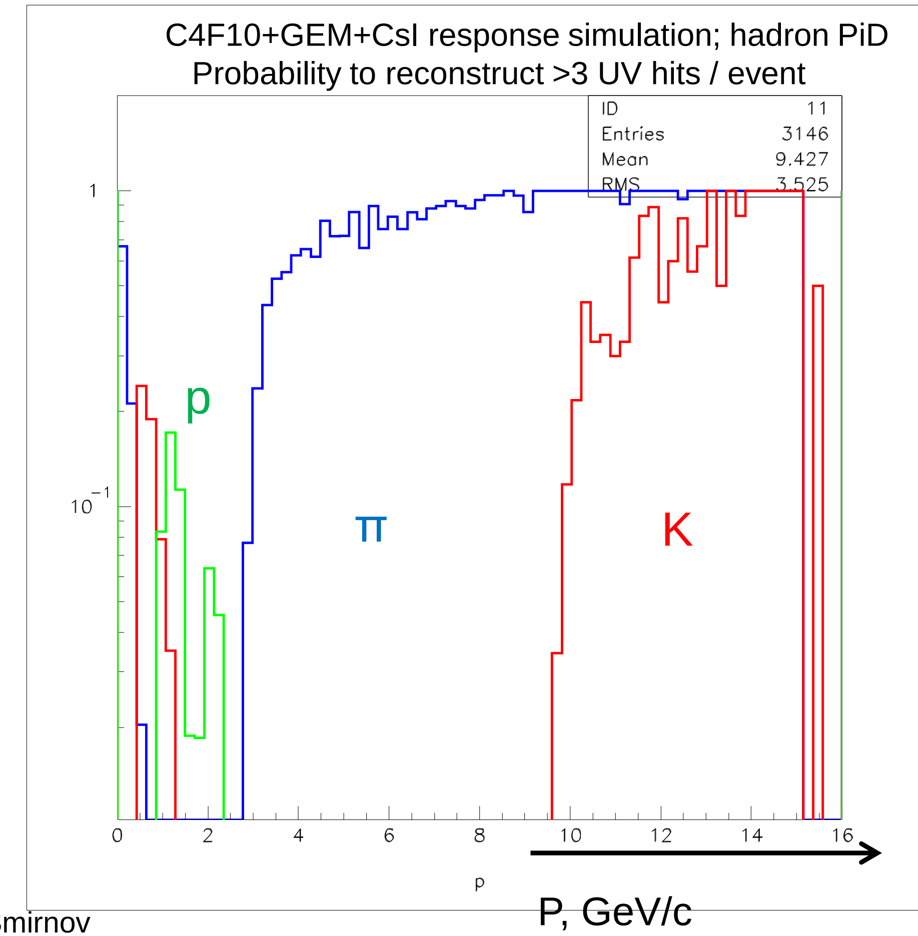


Number Ph. Electrons / event

Where is DIRC (in “Forward”);
or “three-in-one” Detector;
needs some kind of T0 (“beam clock”)

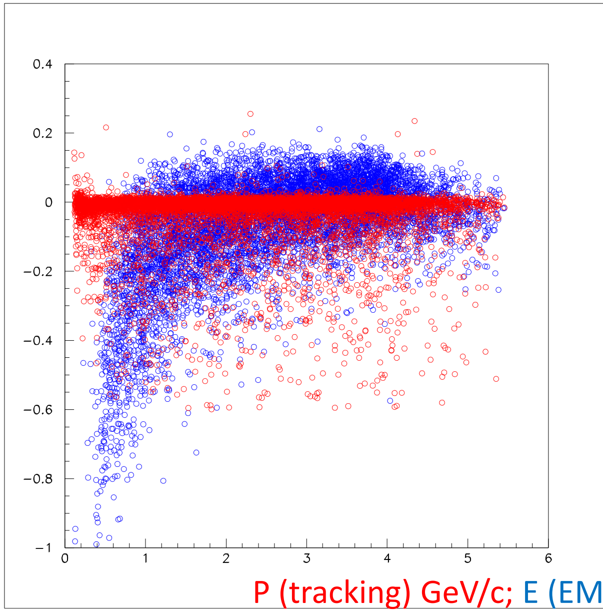




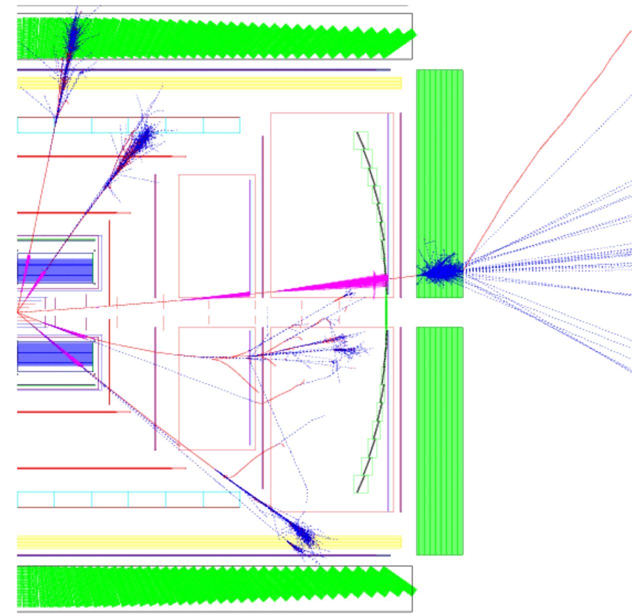


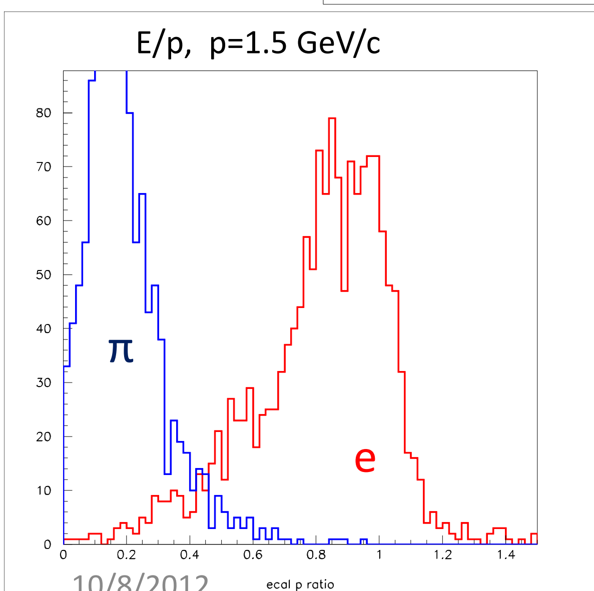
Response to electrons (tracking –EMCAL)

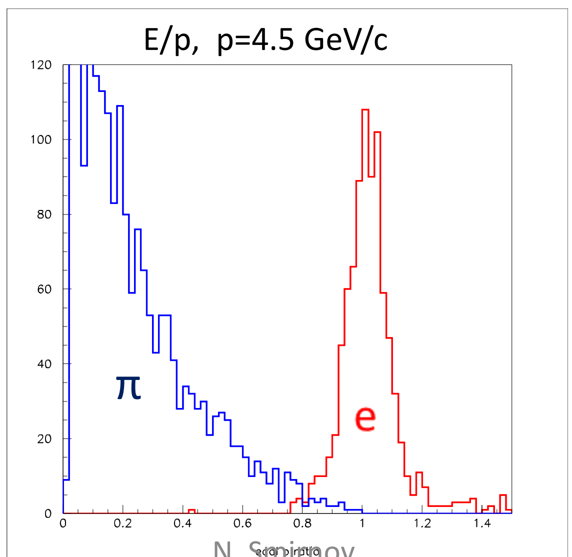
dp/p; dE/E



P (tracking) GeV/c; E (EMCAL); GeV





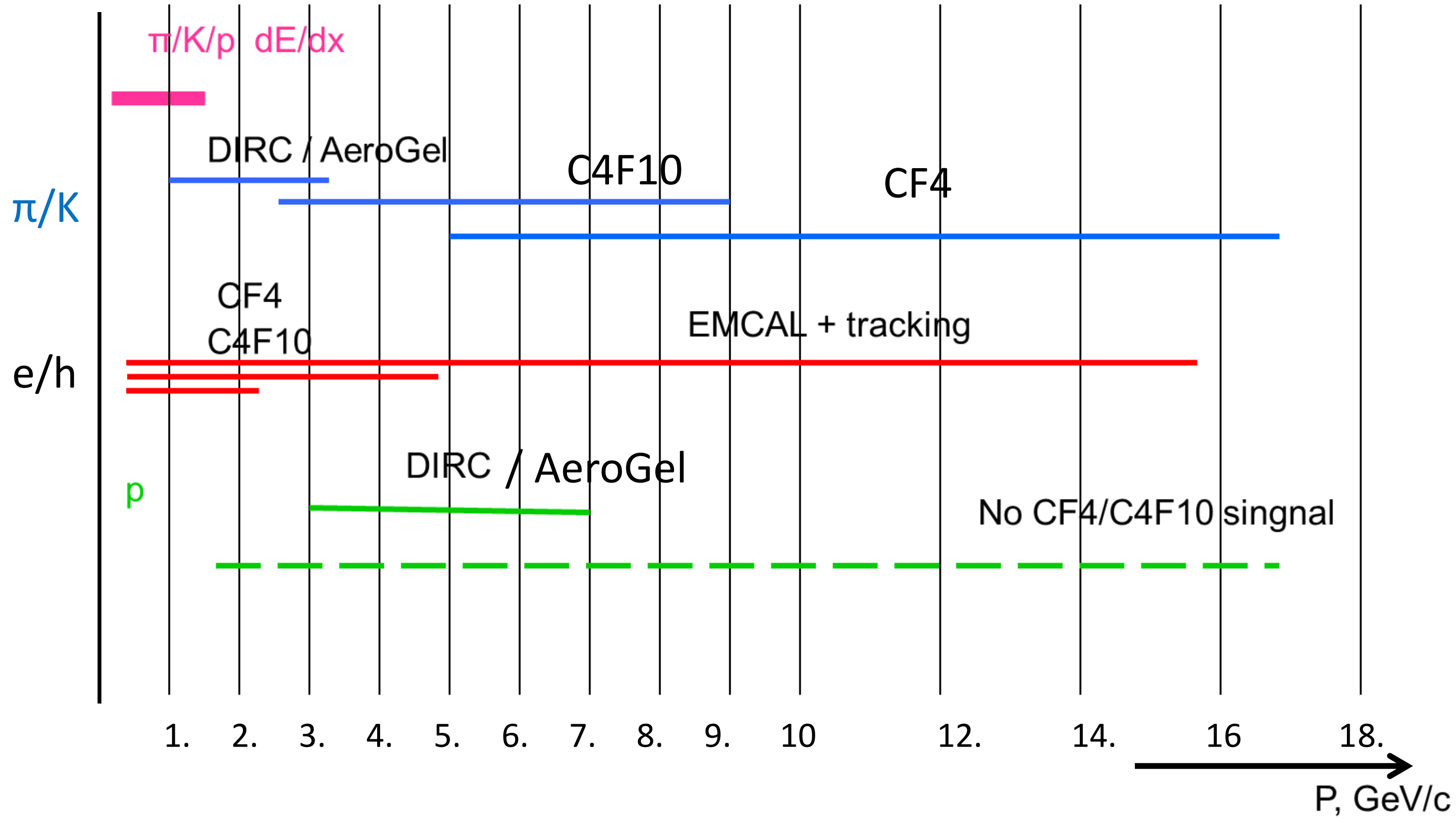


PiD performance for particle P (GeV/c)

	dE/dX	DIRC/Aerogel	C4F10*)	CF4	EMCAL
π/K	0-1. (1.5)	1-3 (1-4)	2.5-9	5 – 17	
e/h	0-0.2	< 0.5	<2.5	< 5.	> 0.5
p	0-1.5	3-7	< 17. (no signal)	<30 (no signal)	

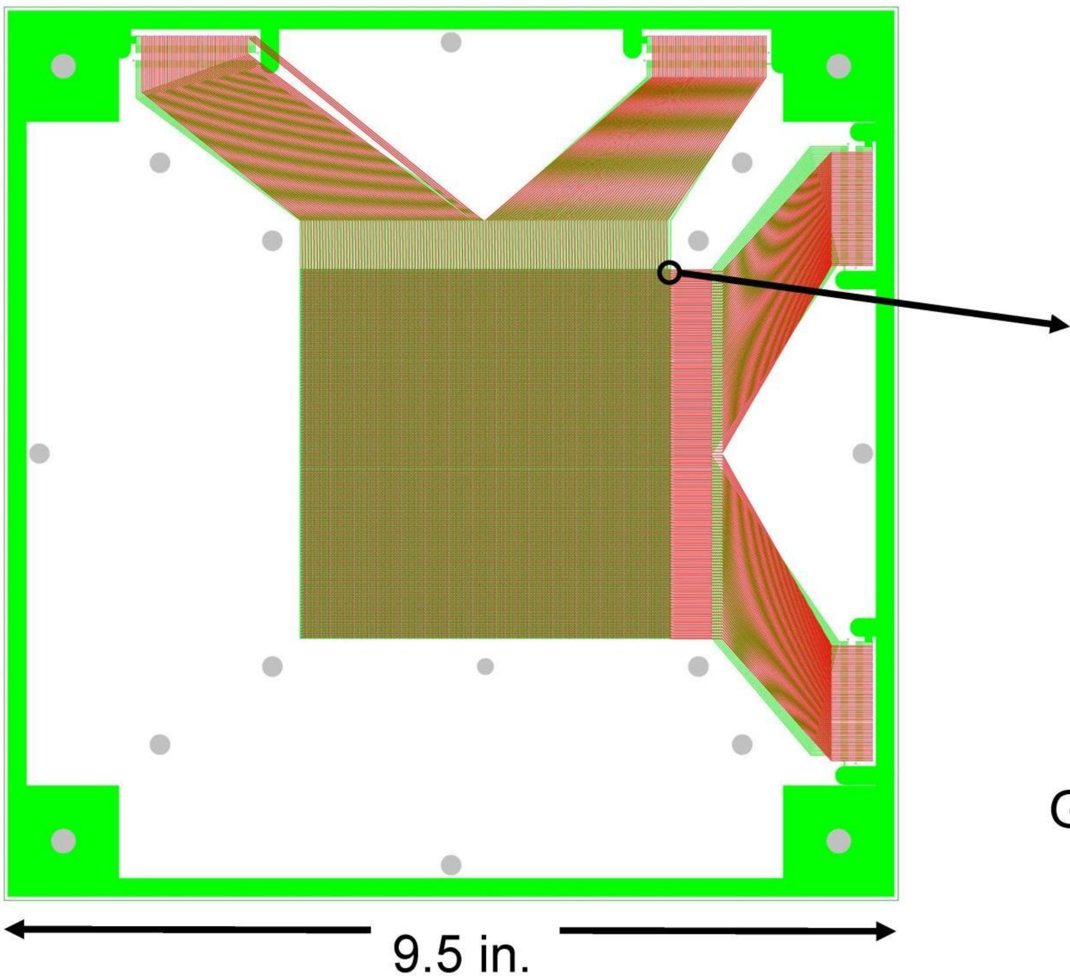
*) Forward only

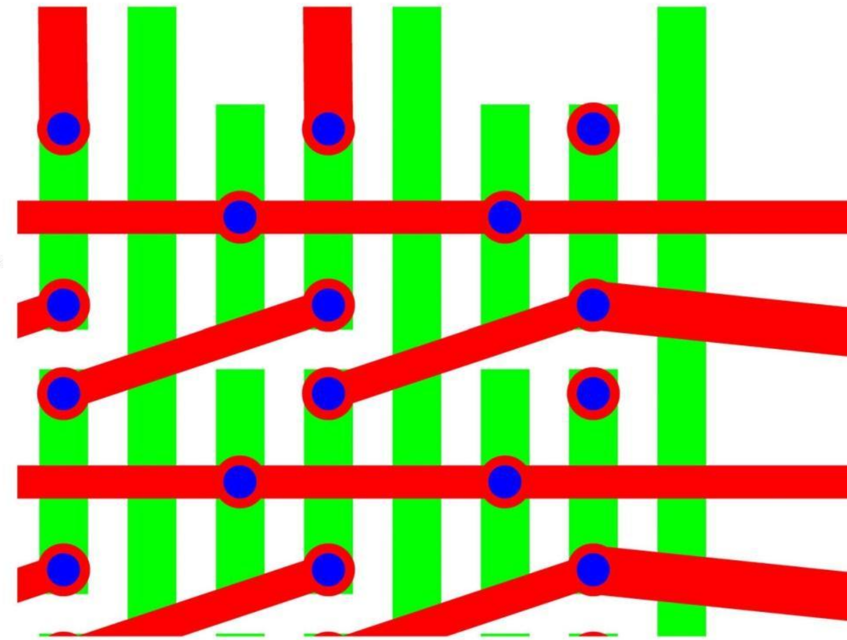
Electron and Hadron PID



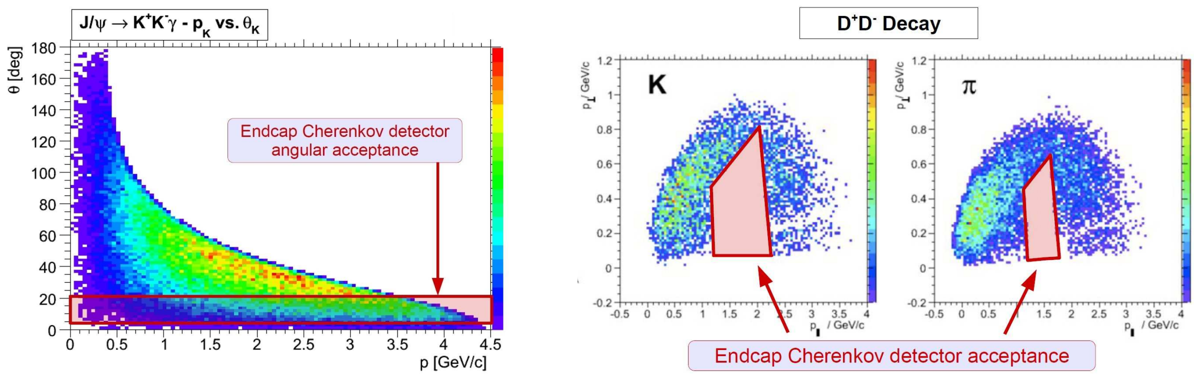
Conclusion (personal opinion, can be wrong)

- Our next (more-less urgent) job is to put in simulation some options for eRHIC Detector setup with as realistic as possible tracking, PiD and EMCAL detectors position, size and response, including B-field (Coil) and background conditions (and beam structure).
- It looks like we have all needed “tools” to start “Physics” simulation as soon as tomorrow.
- We don’t need any special / fixed frame-work on this step. Any can (should) be used if good explanation from authors and the SAME event generator(s) and background.
- All last (today) experiments were “designed” using different frame-forks but GEANT3, and it was “not so bad” job !? (+ L3 and AMS examples).
- Of course, during experimental data analysis MC simulation approach should be fixed.



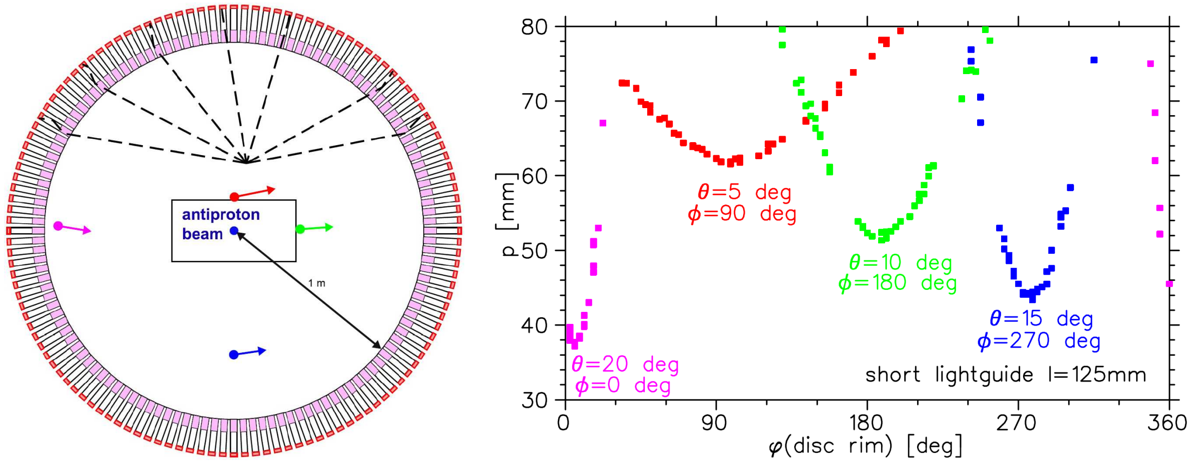


Green = top side, red = bottom side



(a) (b)

Figure 2. Acceptance for an Endcap Cherenkov detector. (a) Particle polar angle acceptance from 5 deg to 22 deg for decays like J/Ψ. (b) Longitudinal versus perpendicular momentum of the particles for the D^+D^- decay.



(a) (b)

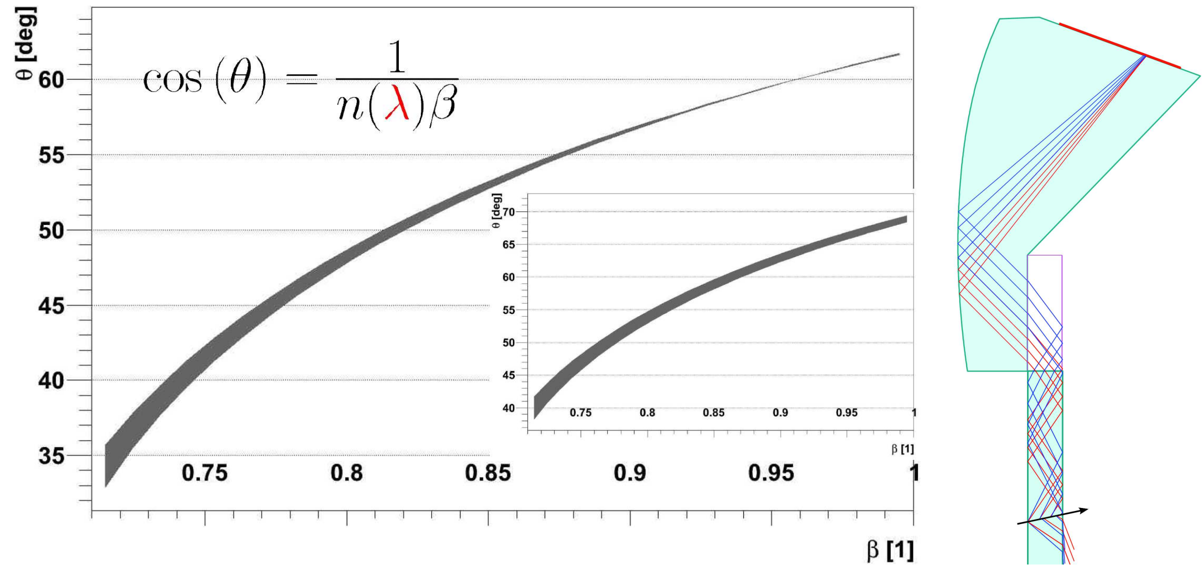
Figure 3. (a) Novel disc geometry as radiator for a DIRC based detector. Arrows indicate the corresponding 2D-hit pattern on the right side (b) 2D-hit pattern for different particle impact position.

relevant properties of the Cherenkov photons. The resulting patterns for reconstruction are illustrated in Fig. 3(b). Additional timing information (1t) with a moderate timing resolution of around 300 ps can be used for background suppression and event separation [8].

The produced Cherenkov light has a wide range of wavelengths (λ). This causes a smearing of the opening Cherenkov light cone angle as indicated by

$$\cos(\theta) = \frac{1}{n(\lambda)\,\beta},$$

where the opening angle of the Cherenkov light cone θ depends on the refractive index $n(\lambda)$ and particle velocity β=v/c. Therefore dispersion correction is necessary to minimize the uncertainty in the angular measurement. Active chromatic correction by straight Time-of-Propagation



(a) (b)

Figure 4. Novel techniques (a) Polar angle spread due to dispersion (inset) and passive chromatic correction with LiF bars. (b) Translation of the polar angle into spatial position by total-internally-reflection parallel-to-point optics.

measurement requires very challenging timing resolution below a few tens of ps. Directing the Cherenkov light through an optical element acting as a prism, made of a different material with an appropriate refractive index mitigates the effects of dispersion in the fused silica radiator (see fig. 4(a)). For the FDD , the crystal tiles are made of LiF and have the dimensions 15 mm × 50 mm × 50 mm. Focusing lightguides are foreseen to map the polar angle of the propagating Cherenkov light onto spatial positions on the surface of photon detection devices (see fig. 4(b)).

The requirements for photon detection are various and several options are available. Potential photon detection devices have to detect single photons in a 1.5 T magnetic field with a large number of channels for position measurements, must have uniform gain of around 10^6 and must be capable for high hit rates of around 2 MHz/cm^2. Currently Microchannel-Plate PMTs and Geiger-mode APDs are under investigation [9], [10].

The PANDA experiment will not feature a hardware first level trigger as signal and background have similar signatures. The readout electronics therefore have to work without a central trigger. Instead a timestamping system with 20 ps timing resolution [11] will be used to generate virtual high level triggers for event preselection in a massive parallel computing network [12]. Various options for the frontend electronics are under investigation [13]. A conventional setup with preamplifier, shaper and Time-to-Digital-Converter would fit the requirements. An extended readout with analog and time measurement by sampling technique allows calibration in situ. In total there are 128 LiF bars and focusing lightguides with around 4000 readout channels.

4. Performance

For the design requirements various simulations were carried out to ensure the desired performance. Figure 5 shows the required π-K-separation as a function of the particle momentum and for two representative particle polar angles.

Various test beam experiments are carried out to verify the simulations against experimental

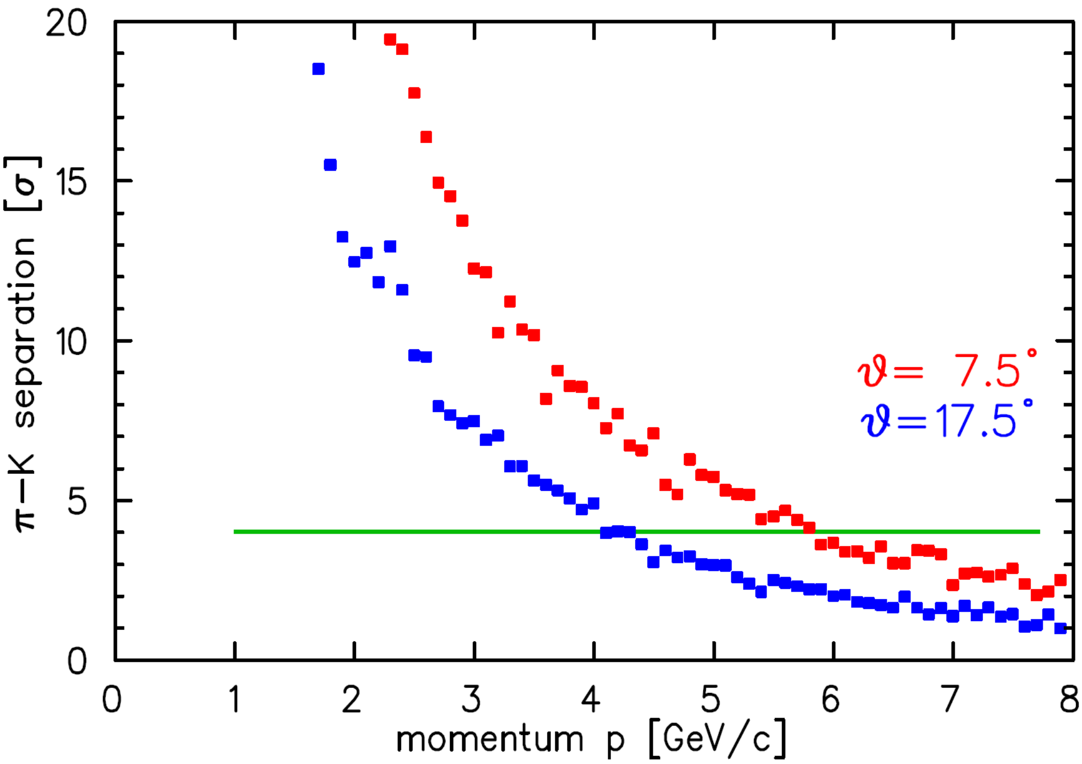


Figure 5. Simulated π-K-separation as function of particle momentum for two polar angles. The green line shows the required separation.

data. During a recent test experiment a primary proton beam with 2 GeV kinetic energy was used, impinging on a fused silica bar under various angles and various positions (see fig. 6(a)). One of the aims of this experiment was the validation of simulations for light generation, transportation and detection of Cherenkov photons. In addition as the integral absorption coefficient η for the selected wrapping being unknown several simulations within the range $0.5 \leq \eta \leq 1.0$ were carried out.

The result shown in figure 6(b) indicates good agreement of the simulation with experimental data since the points follow same shape. Another result shows that the selected wrapping has an integral absorption coefficient of $\eta \approx 0.6$. These results can be used to improve further simulations and to remove ambiguity.

5. Conclusion

For the wide range of its scientific program the general purpose PANDA detector at FAIR will require an excellent particle identification system. By using several new techniques in this field the FDD is designed to assist in providing the necessary particle identification capabilities. A thin synthetic silica disc is foreseen as radiator to generate Cherenkov photons. LiF crystal bars will be used to correct passively for dispersion. Focusing elements will map propagating photon angles to spatial positions by using total-internally-reflecting parallel-to-point optics.

Despite the integral absorption coefficient η of the wrapping was unknown, first tests show good agreement between simulations and experimental data as the points follow the same shape. The integral absorption coefficient η for the selected wrapping was determined to be around 0.6.

Further test experiments will be carried out to verify the planned optical imaging system.