A Focussing Disc DIRC for Particle Identification in $\bar{\text{P}}$ANDA

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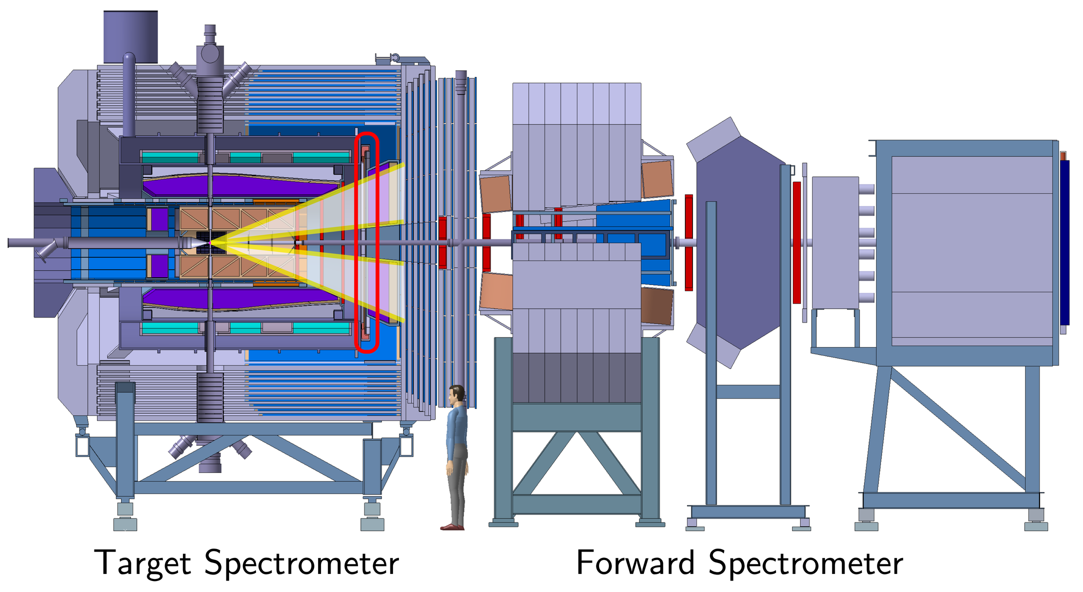
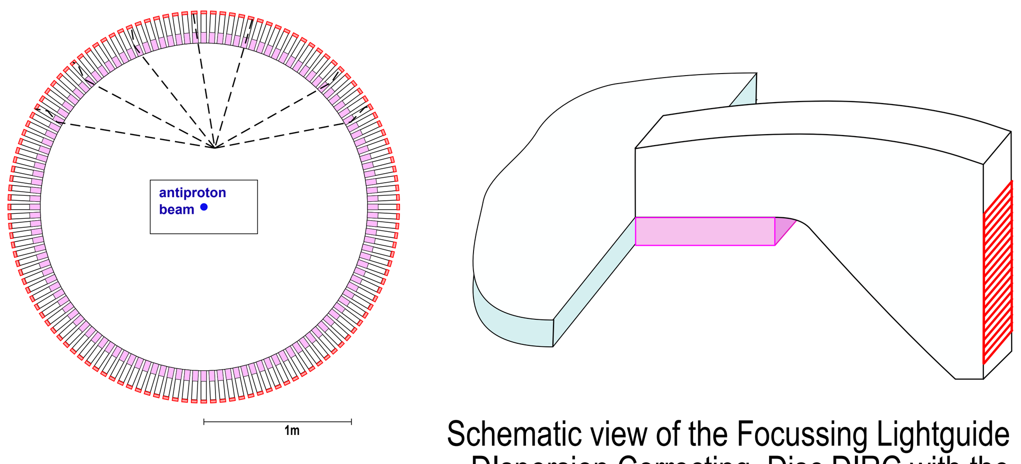


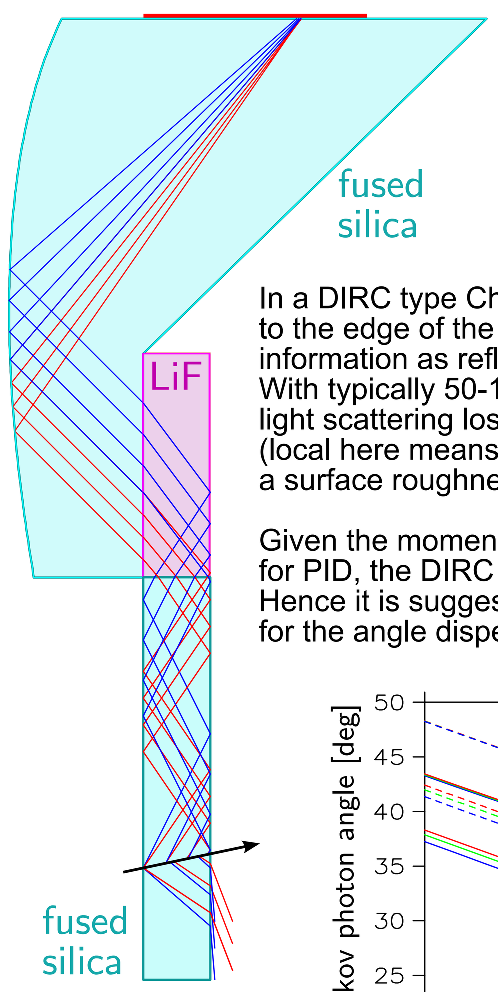
Side view of the PANDA detector, with the relevant angular range coverage for the proposed disc DIRC in the Target Spectrometer being highlighted.

For the PANDA antiproton experiment at the future FAIR laboratory, investigating the charmed quark sector with high luminosity and high precision, the detectors that provide particle identification (PID) are a crucial element.

The PANDA target spectrometer is almost hermetically sealed to avoid solid angle gaps, and to keep material volume low, there is little spare space inside. The prospect of using thin radiator sheets and placing the readout elements outside of the acceptance (and potentially outside the magnet return yoke) favours the use of DIRC designs as Cherenkov imaging detectors for PID.

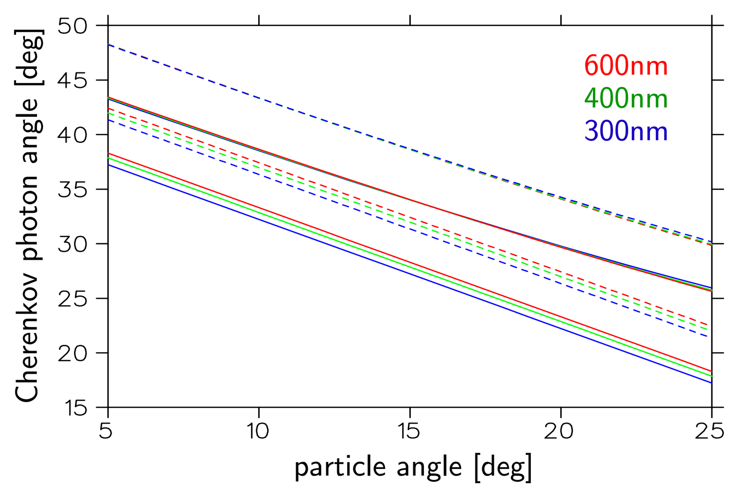


Schematic view of the Focussing Lightguide DIspersion Correcting Disc DIRC with the Cherenkov radiator plate in the middle and the optical readout element circling around the rim. Each element starts with a lithium fluoride plate for dispersion correction, then an amorphous fused silica lightguide with curved top surface to focus the light on a readout plane to the right.

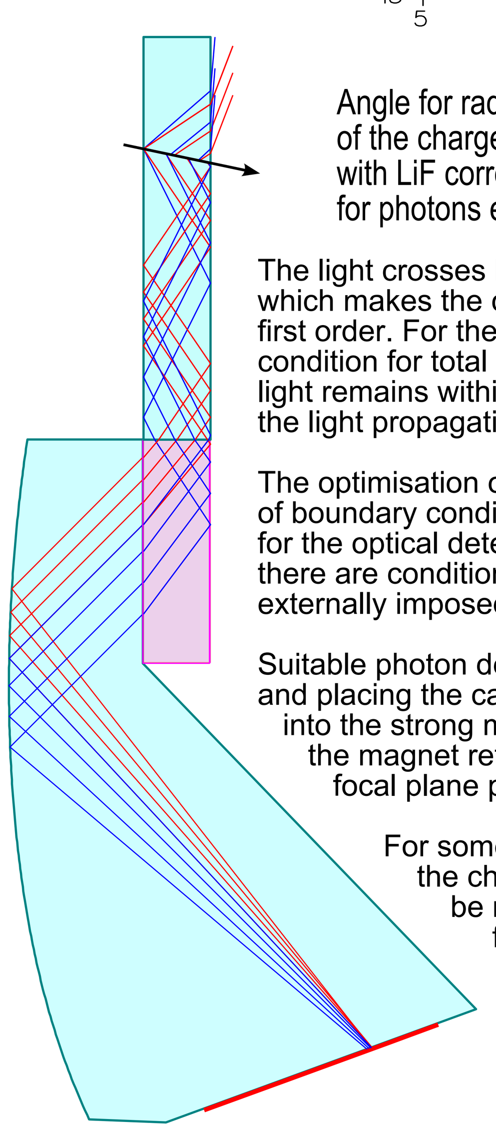


In a DIRC type Cherenkov detector, the photons are transported to the edge of the radiator volume while preserving the angle information as reflections occur between parallel surfaces. With typically 50-100 reflections one needs to avoid too much light scattering loss per surface reflections which locally requires (local here means any randomly selected millimetre-sized area) a surface roughness not exceeding several nanometres RMS.

Given the momentum range that need to be covered in PANDA for PID, the DIRC design has to improve over current detectors. Hence it is suggested to include a focussing property and correct for the angle dispersion of the Cherenkov light.



Angle for radially forward emitted photons as a function of the charged particle angle, below without and above with LiF correction. Dashed lines are projected angles for photons emitted at 30 deg on the Cherenkov cone.

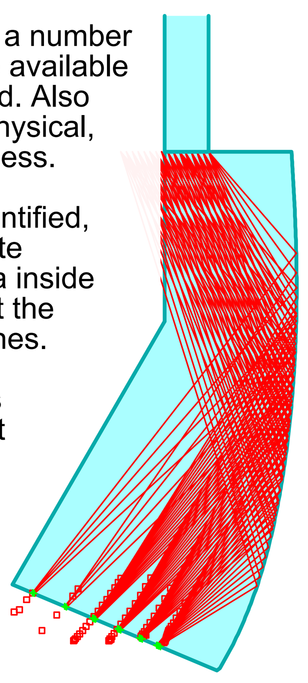


The light crosses LiF-amorphous fused silica boundaries twice, which makes the chromatic correction angle-independent to first order. For the reflection on the focussing surface the condition for total internal reflection is being fulfilled,and as the light remains within dense optical medium,the phase space for the light propagation is not reduced.

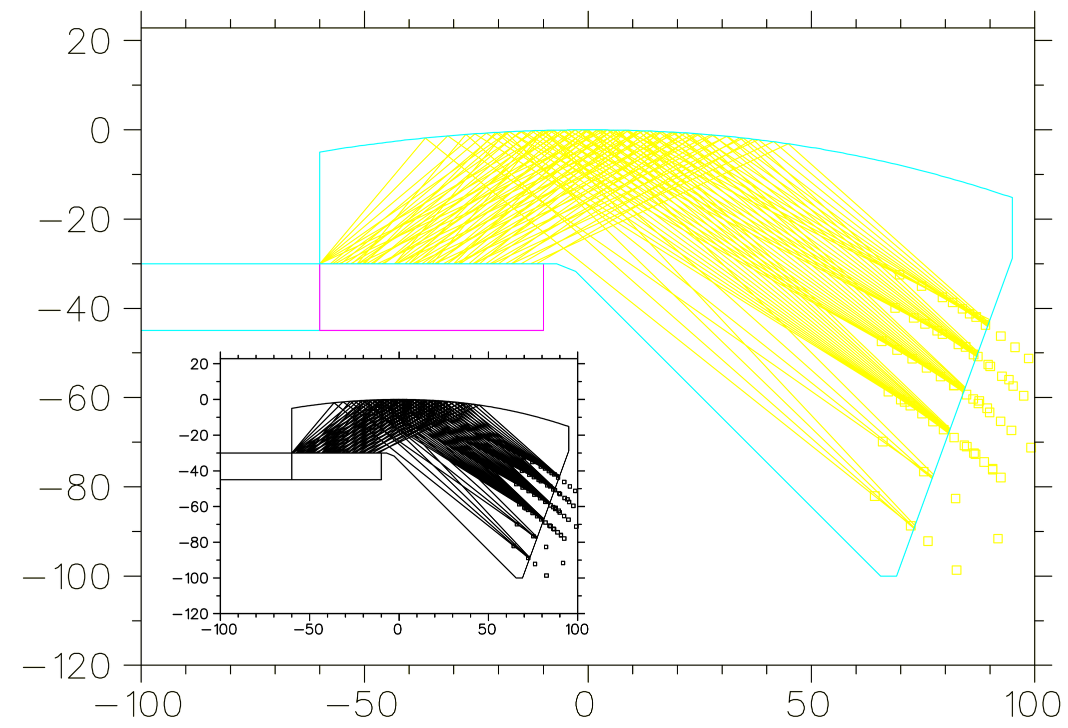
The optimisation of the detector has to obey a number of boundary conditions. Obviously the space available for the optical detector components is limited. Also there are conditions, both mechanical and physical, externally imposed on the the radiator thickness.

Suitable photon detectors have still to be identified, and placing the candidate Multi Channel Plate into the strong magnetic field of B1-2 Tesla inside the magnet return yoke requires to orient the focal plane perpendicular to the field lines.

For some non-PANDA applications the chromatic correction may not be required. A different shape for the lightguides, shown to the right, should be considered in such a different case.



For the optimisation of the focussing surface with cylindrical shape the curvature has been parametrised with a polynomial of fifth order. Quantities like lightguide length, orientation of the focal plane, and radiator disc thickness are fixed during optimisation, which determines an overall minimum for the focus spot sizes of the different angles on the focal plane, for a disc thickness of 15mm the individual standard deviations being well below 1mm for the instrumented area.



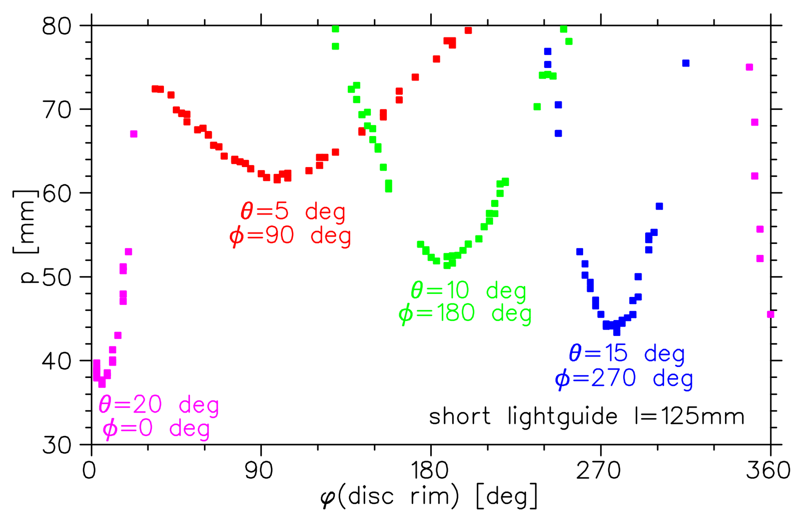
Side view of a lightguide, adapting to 15mm radiator thickness, 70 degrees focal plane inclination, and imaging onto a 50mm focal plane length.

Sigma errors for this Focussing Lightguide design:

3.1 to 6.2 mrad	1.5mm pixel size - granularity (theta component only)
1.1 to 4.6 mrad	imaging error of curved lightguide, 15mm radiator
1.4 mrad	angular straggling of saturated particle 2GeV/c
0.4 mrad	tracking precision upstream of DIRC radiator 2GeV/c
0.1 mrad	track curvature in B field, 2GeV/c and theta=18deg
5 mrad	chromatic error uncorrected (QE box response 2eV-4eV)
<1.5 mrad	chromatic effects LiF-corrected lambda=600nm-300nm

Charged particles emitting Cherenkov radiation and photon propagation have been simulated for the Focussing Lightguide design, and the detector resolving power derived in analysing the photon hit patterns. Results here are shown for the separation of pions and kaons, the particle pair of most interest.

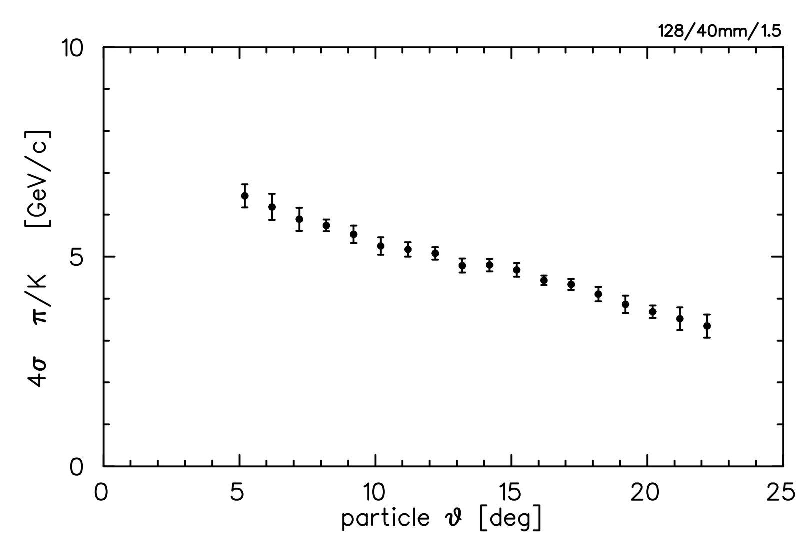
The charged particle trajectory includes angular straggling, and the wavelength dependence of the refractive indices is parametrised with Sellmeier coefficients. Examples of idealisations in the current status of the optical simulations are for instance the assumption of perfectly parallel disc surfaces, no bulk light absorption, and 100% reflectivity for total internal reflection. These effects can be investigated separately and largely factored in into the results from these simulations.



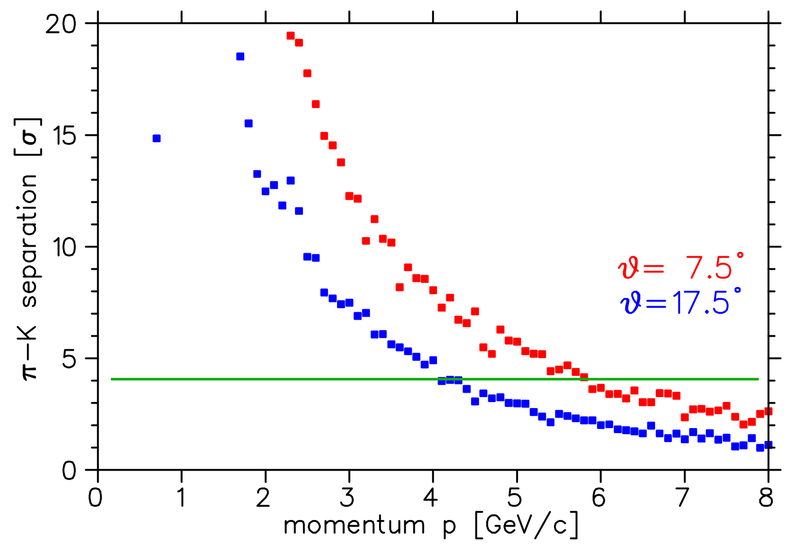
Photon hit pattern showing photons from four particles.

The photon pattern analysis is seeded with particle vertex information, smeared to the resolution of the upstream tracking detectors. Differential response vectors are computed, one tracking parameter offset at a time, with high photon statistics using the simulation code.The photon parameters are varied in a deterministic way instead of using randomly generated values to ensure the difference vectors are not governed by noise. Particle vertex parameters and velocity are then fitted simultaneously.

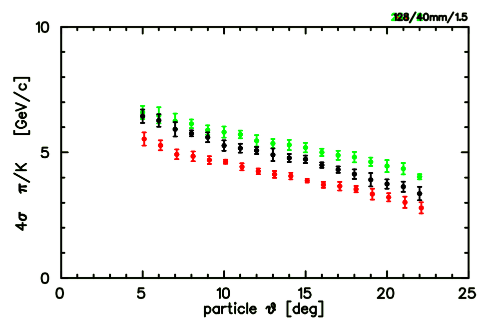
Event sets are recorded for two different particle types A and B of same momentum. The detector resolving power is then derived from the mean m and standard deviation sigma values of the beta=v/c distributions ot the two particle types.



Angle-dependent upper momentum limit for 4 sigma pion-kaon separation within the acceptance theta=5-22 degrees for an Endcap DIRC detector with 128 lightguides and 4096 detector pixels that fits inside the available space of the target spectrometer return yoke,

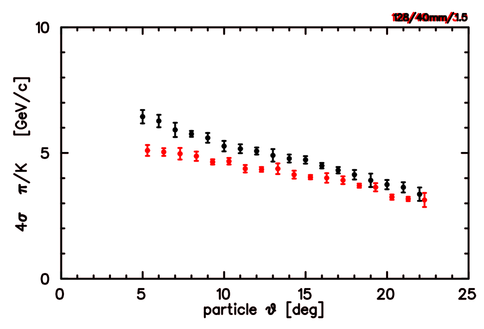


Detector separation power as a function of momentum, shown for two angles.



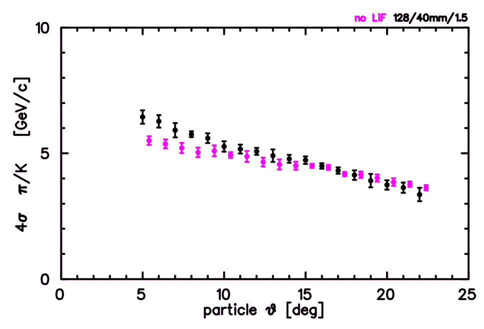
Some detector design numbers need to be reviewed as well, for instance the number of lightguides. Here we compare the performance with 64, the nominal 128, and 256 lightguides. One needs to note that the vertical scale is rather non-linear, and scales as the 4th root of the detected photon number.

The increase in performance for 64-128 is more pronounced than for the 128-256 case.



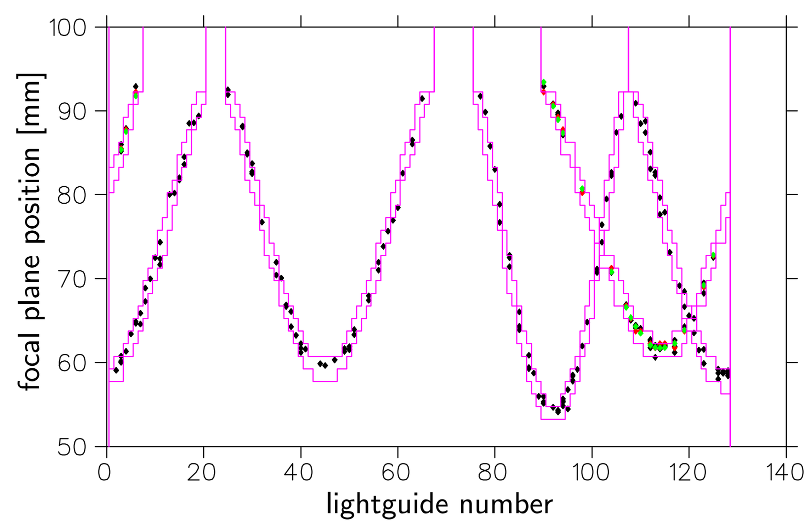
The number of pixels per lightguide can also be changed, for comparison the pixel number is halved (red points) from 4096 down to 2048, with the pixel size increasing from 1.5 to 3mm.

The performance at large angles is similar, but at small angles like 5 deg the performance is markedly different.



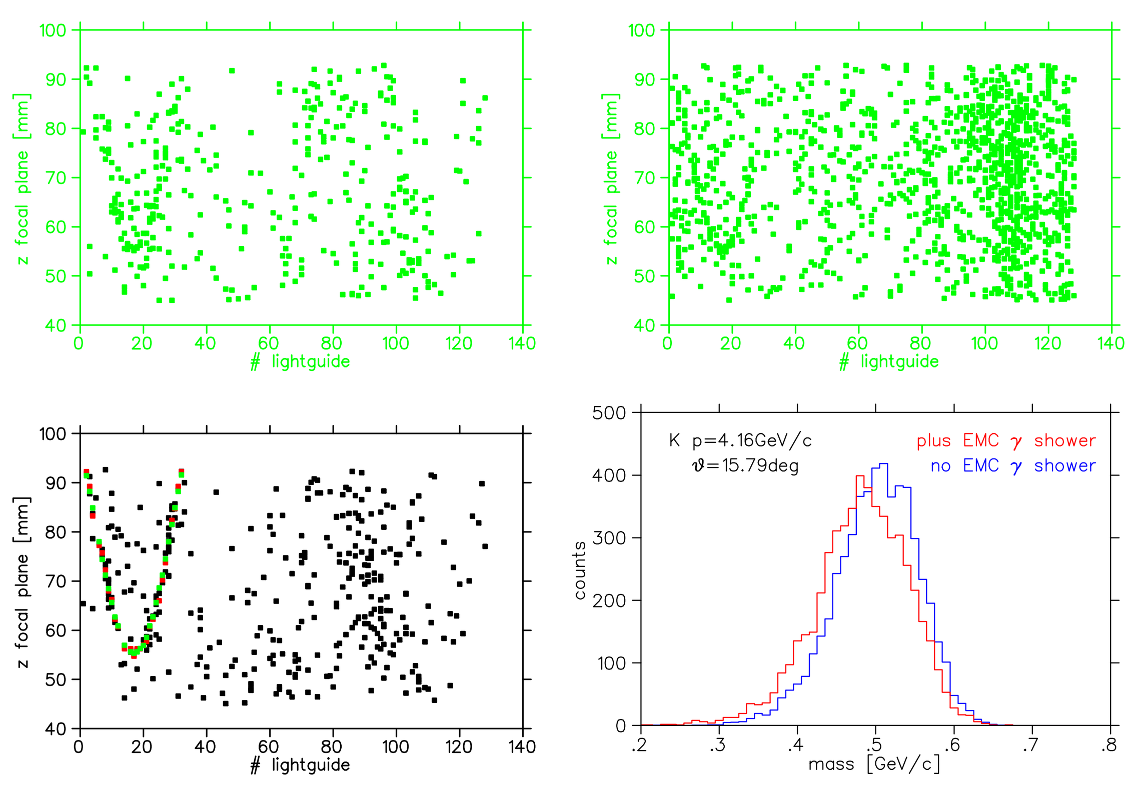
Comparison of two similar designs, one using LiF for dispersion dispersion (black), one with amorphous fused silica optical elements only.

Due to a compromise in the choise of the LiF plate aspect ratio, causing some photon loss, the design without LiF performs marginally better at large angles. Dispersion correction still has the edge at small particle angles.



Photon hit pattern from a Dual Parton Model generated event with photons from four particle in the Endcap reagion. Violet lines show the selection roads for photon selection prior to single particle pattern analysis.

In a first stage, the pattern analysis was geared for single partilces only and no presence of background photons or noise signals in the photon detectors. The figure above shows the stage of photon selection, based on tracking info to be provided from the upstream PANDA tracking detectors, which allows to narrow down the area where Cherenkov photons can be expected, even before the particle identification step which usually means a rather precise detemination of the vertical position of the parabola-like patterns. Photons outside these roads, or being contained in multiple roads, are not used for analysis in this scheme.



Background study with Cherenkov light from Calorimeter shower leakage into the disc superimposing a seeded kaon pattern. As the shower particle have no tracking, only the kaon road can be used. For the reconstructed kaon mass the distribution width increases by 10-15%. No timing info has been used here. The coma effect in the lightguide imaging biases the roads computing, hence the kaon mass shift.