dRICH in ATHENA: results and Lesson learned

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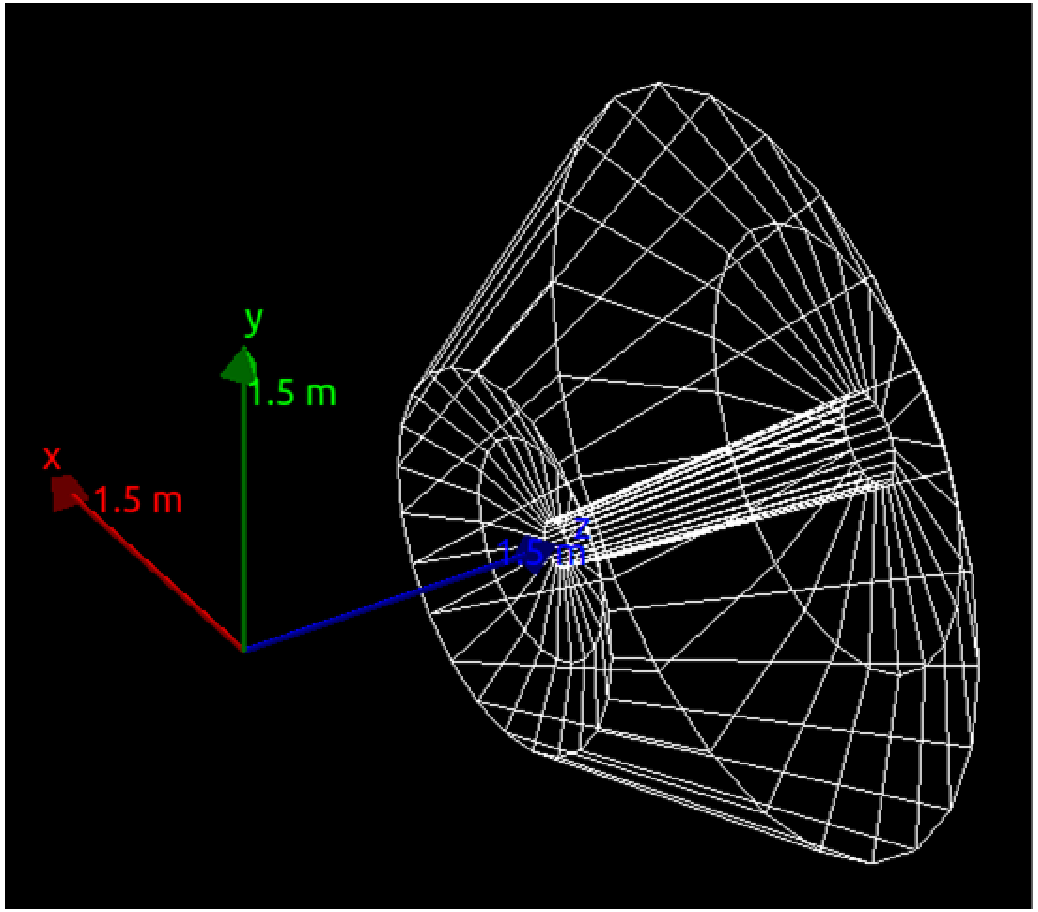
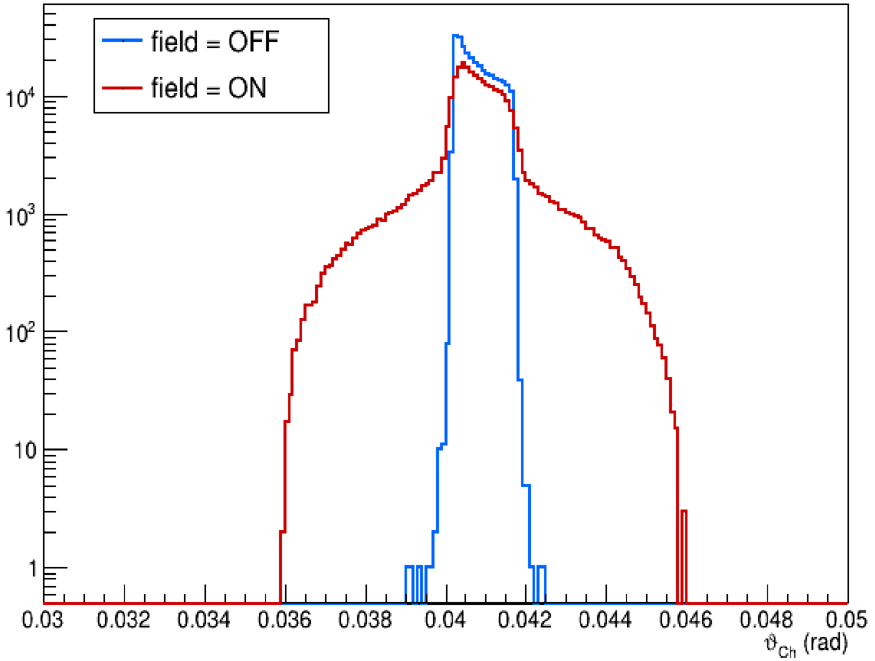
The beginning days: selection of location and size

- The location of the dRICH has been optimized following the impact of magnetic field in single Cherenkov photon resolution at different position of the detector.
- The radial size → Large to have larger acceptance.
- Length→ Made larger to keep the aspect ratio→ Improvement in focusing→ Bonus→ Larger number of photons

Stand alone Geant4 model : Optimisation of position

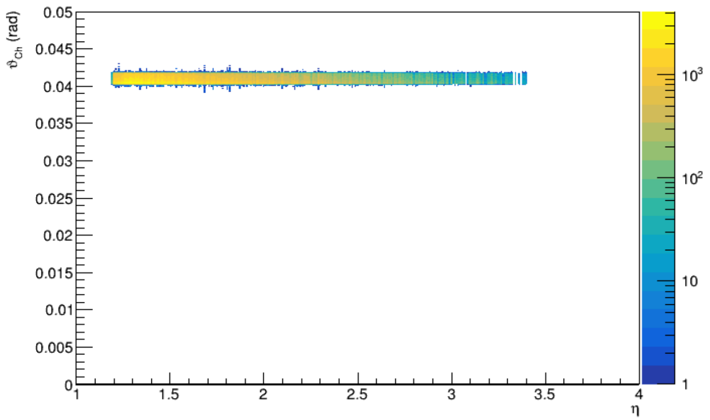
- **C2F6 refractive index for the radiator**
  - with chromatic dispersion
  - realistic C_2F_6 material
- **spherical mirror with perfect reflection**
  - R = 300 cm
- **spherical sensor surface**
  - R = 150 cm
- **basically an ideal RICH detector**
- **inverse ray-tracing reconstruction**
  - from HERMES papers
  - fix emission at mid-point of the radiator
  - assumes perfect tracking information
    - namely the actual track position / direction at the emission point

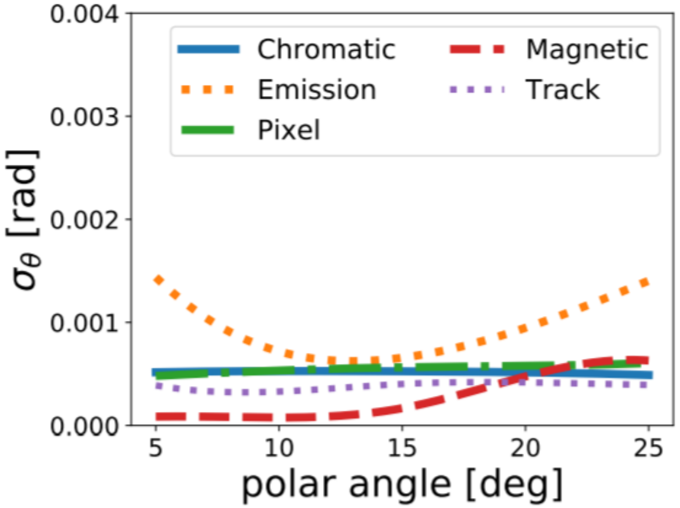




fixed particle direction / energy
η = 1.5 (ϑ = 25 deg)
E = 30 GeV
muons

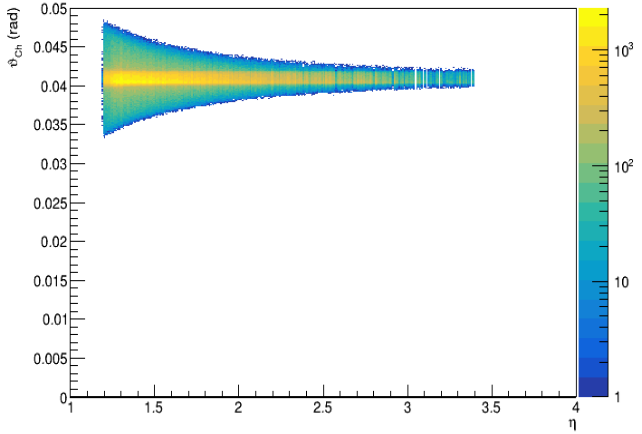
single-photon Cherenkov angle distribution measured via inverse ray-tracing algorithm

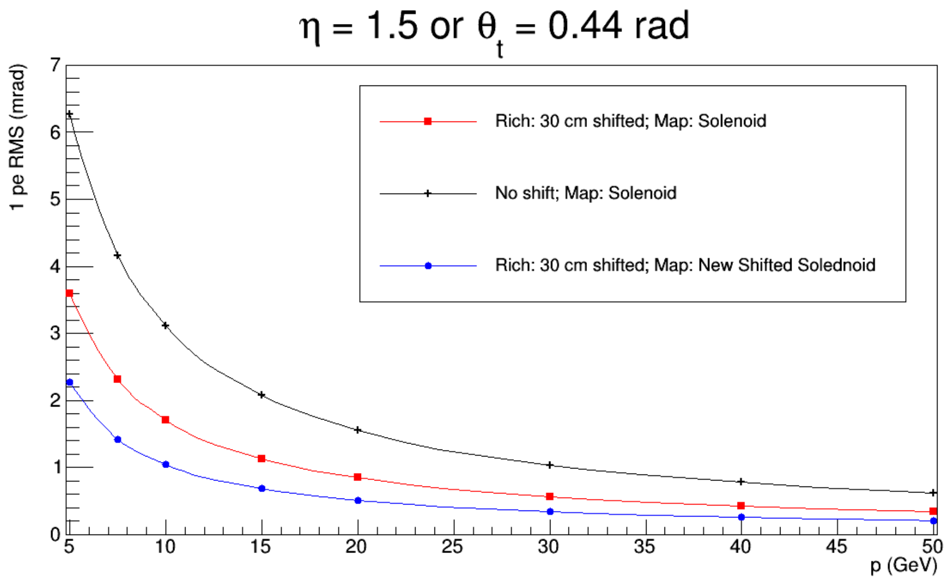




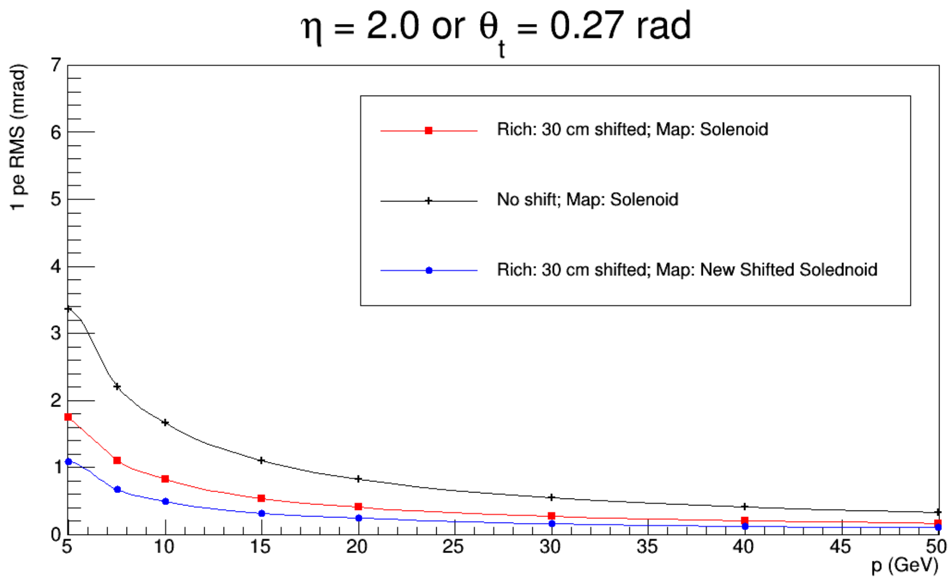
ingle-photon Cherenkov angle
listribution measured via
nverse ray-tracing algorithm

3 field increases StdDev
o 1.1 mrad
- 1 mrad contribution





η = 1.5 or θt = 0.44 rad
1 pe RMS (mrad)
p (GeV)
Rich: 30 cm shifted; Map: Solenoid
No shift; Map: Solenoid
Rich: 30 cm shifted; Map: New Shifted Soledniod



η = 2.0 or θt = 0.27 rad
1 pe RMS (mrad)
p (GeV)
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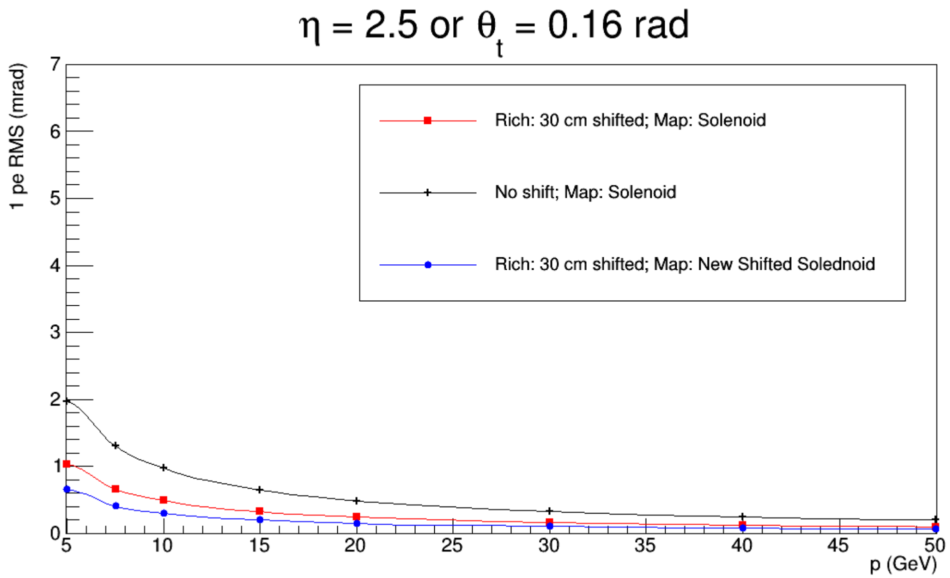
No shift; Map: Solenoid
Rich: 30 cm shifted; Map: New Shifted Soledniod



η = 2.5 or θt = 0.16 rad
1 pe RMS (mrad)
p (GeV)
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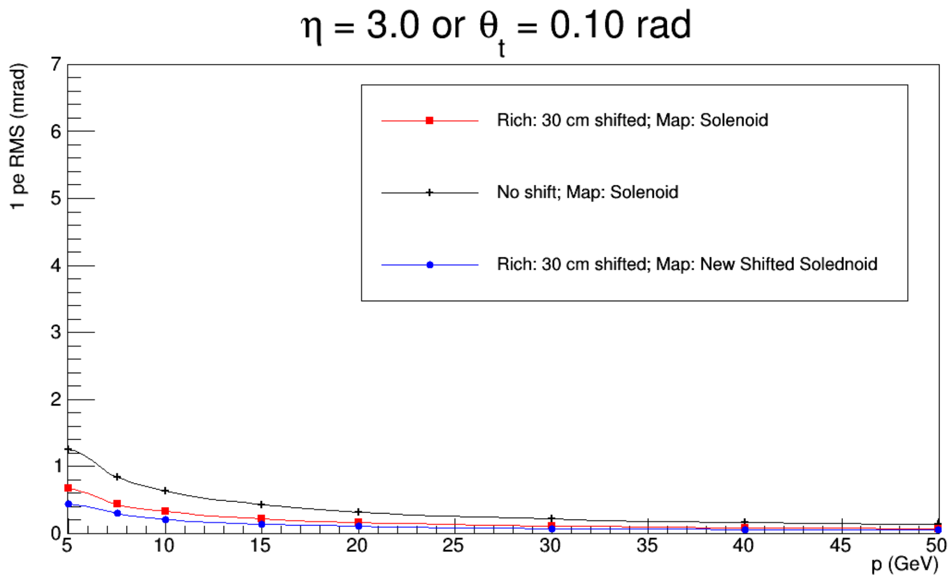
No shift; Map: Solenoid
Rich: 30 cm shifted; Map: New Shifted Soledniod



η = 3.0 or θt = 0.10 rad
1 pe RMS (mrad)
p (GeV)
Rich: 30 cm shifted; Map: Solenoid
No shift; Map: Solenoid
Rich: 30 cm shifted; Map: New Shifted Soledniod

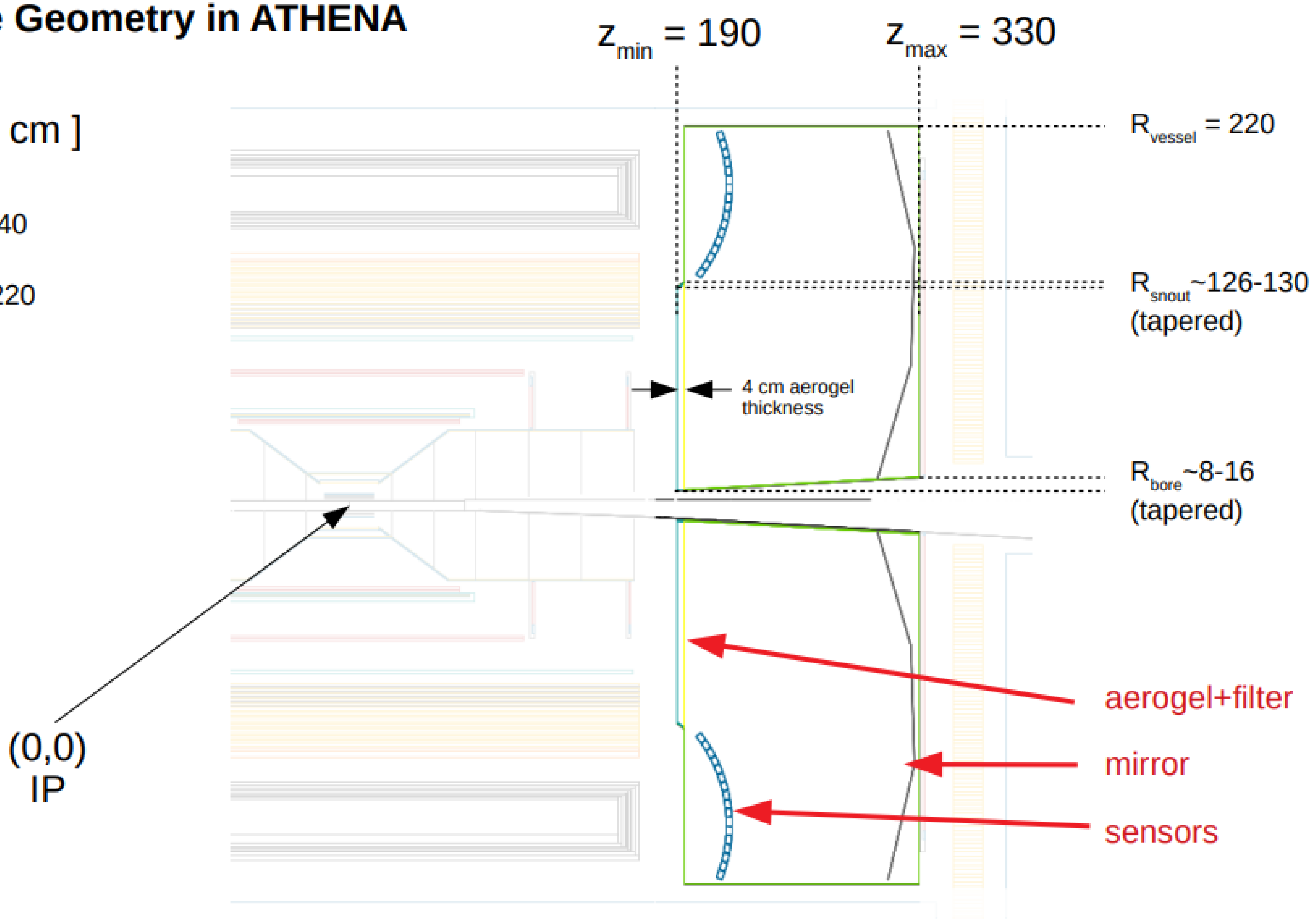
Geometrical and material properties

Envelope Geometry in ATHENA

[units = cm]

$z_{length} = 140$

$R_{vessel} = 220$



C. Dilks

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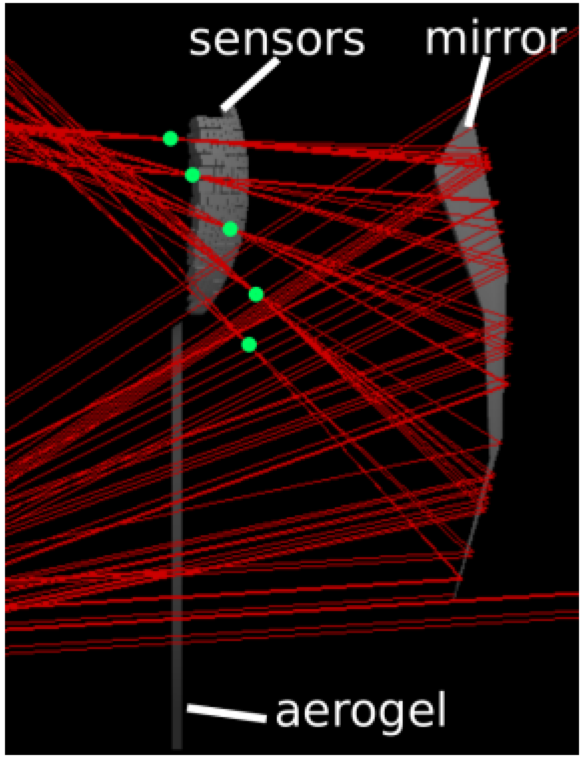
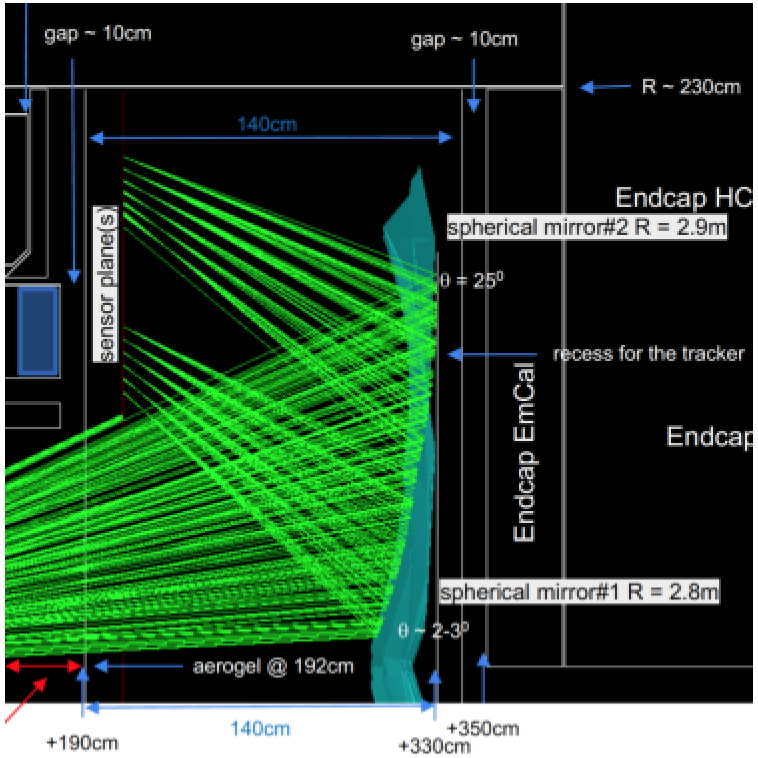
dRICH Dual Mirrors

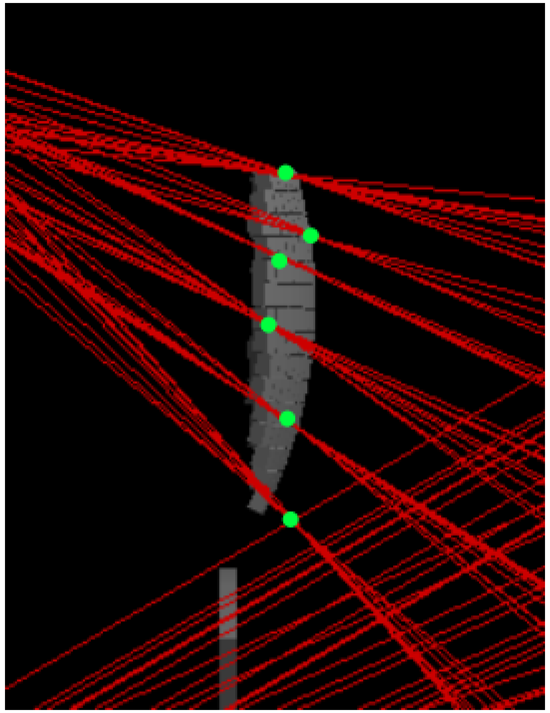
single-mirror config, 5 collimated photon beams; this was the configuration for the ATHENA proposal performance studies



Alexander’s dual mirror configuration, in standalone Geant4 sandbox



current status of dual mirror configuration in DD4hep:



still plenty of room for improvement!!

Sensors tiled on a sphere may not be ideal... 10

Sensor surface definition fixation

Message from Alexander during the proposal studies:

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"…(I believe) the non-negligible gas-to-resin (numerically <5%) and resin-
to-silicon (~15%) reflections must be effectively
accounted in the quoted PDEs. At all incident angles of interest
for us (up to 30 degree or so) there numbers get shared between
the polarization states, but average stays more or less the same.
 So I temporarily changed the material to AirOptical, and added
a benign surface to the optical_metarials.xml database, and we are
back at ~10 npe. And "Chandra's number" for 350..650nm integral is
now ~72 or so.
…I think the correct way to account Cherenkov photon polarization is
to create a resin volume, and perhaps even a silicon volume inside it,
but renormalize the PDE, accounting for the normal incident losses.
In the future perhaps.

  At present the ERICH has all of the geometry restored. I only left
the gap between the sensors at 100um."
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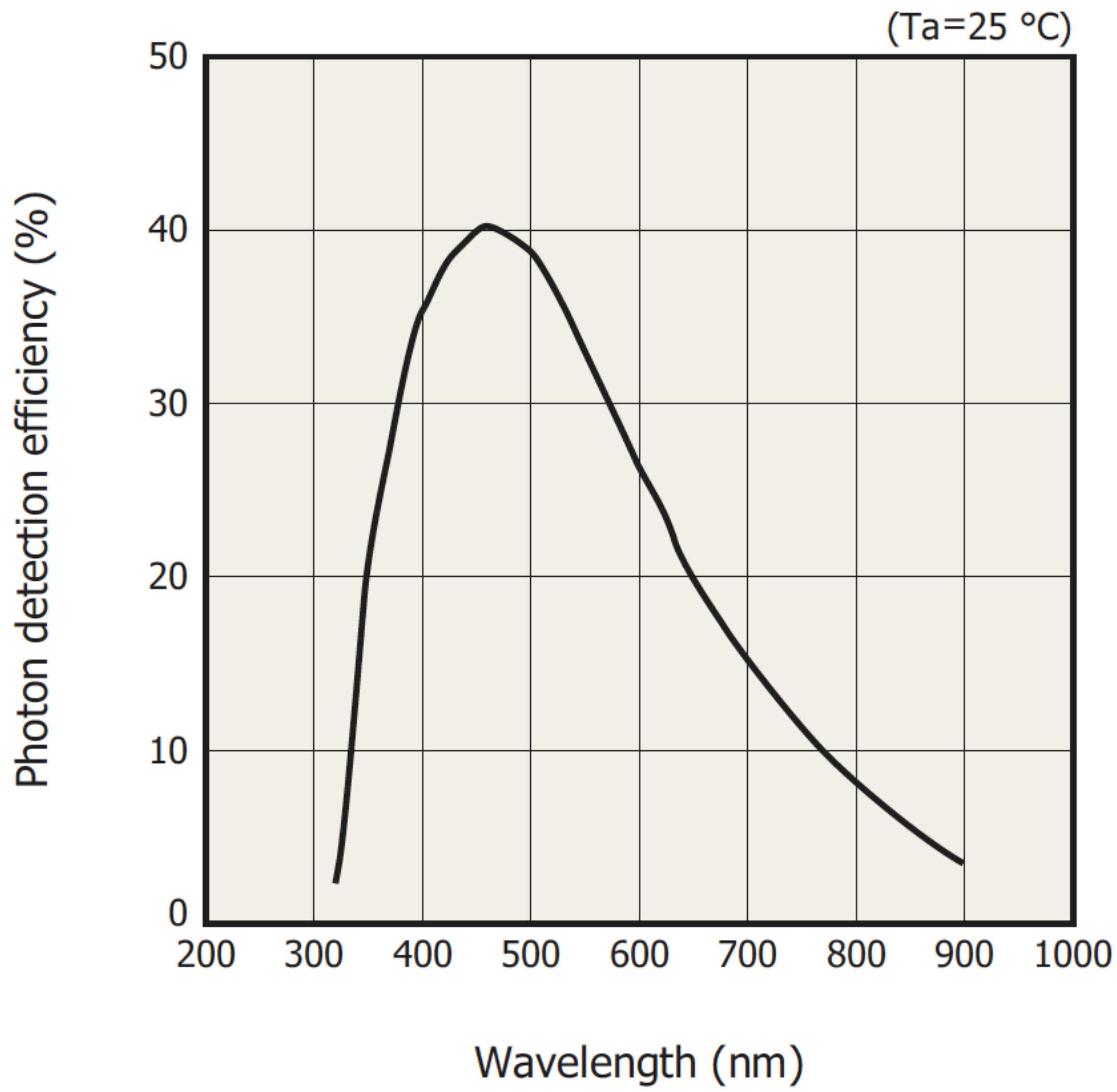
<u>Correct definition of the sensor surface is in pipeline to get fixed.</u>



Sensors:

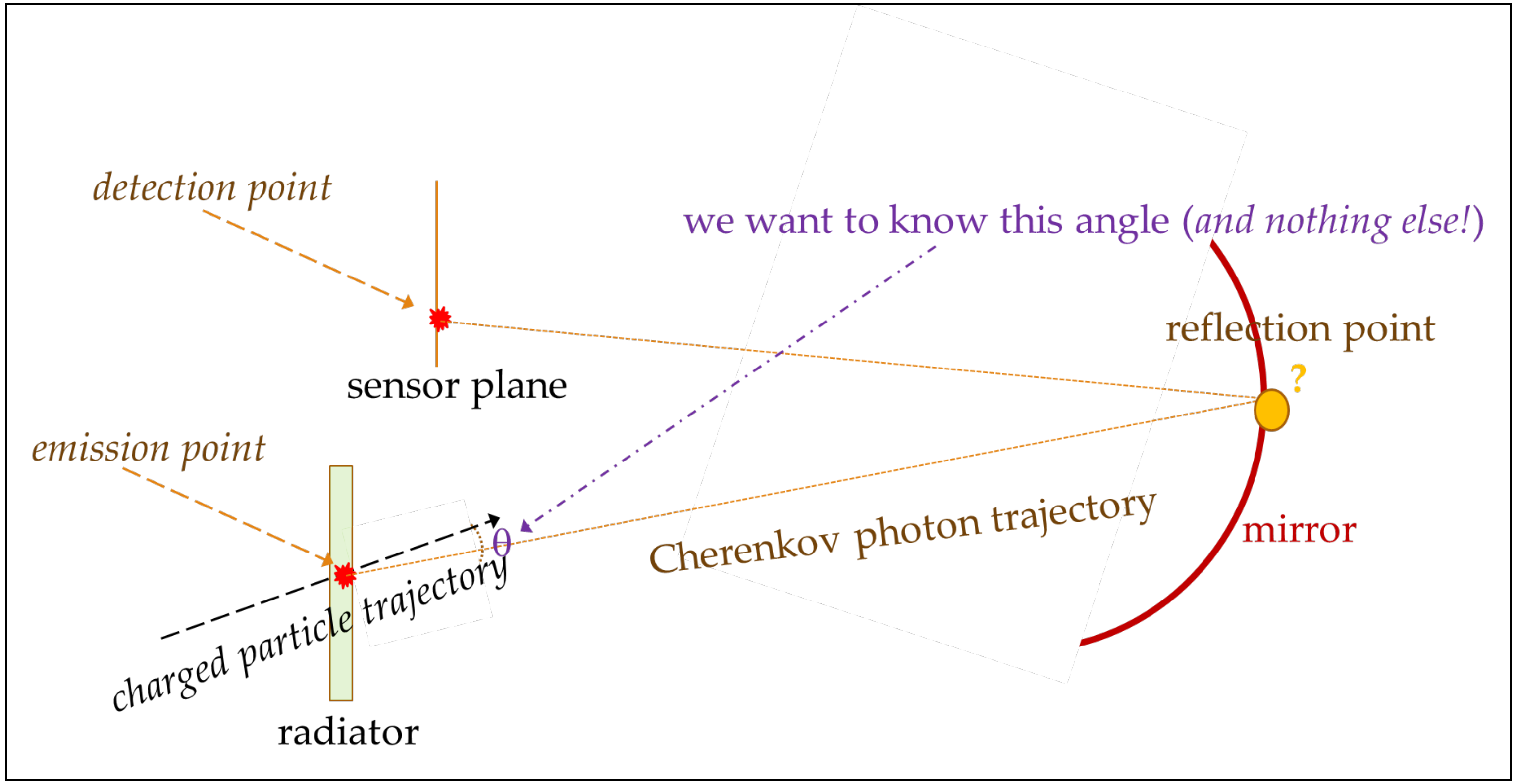
a) Hamamatsu S13361-3050AE-08 8x8 SiPM panels (https://www.hamamatsu.com/us/en/product/type/S13361-3050AE-08/index.html)

b) 3 mm X 3 mm single SiPM with 8X8 pixels in each sensor. Sensor full size = 25.8 mm X 25.8 mm. → 0.85 geometric efficiency.

c) Additional safety factor of 0.7 on top of Photo Detection Efficiency provided by Hamamatsu.

Inverse ray tracing

Inverse Ray Tracing: concept



- ❖ Standalone implementation by Alexander Kiselev. HERMES approach. Solution obtained by 2D Newton method.
- ❖ Can be extended to more sophisticated cases→ Dual mirror configuration.
- ❖ Framework independent.
- ❖ Adopted in ATHENA framework. In principle can be used in any chosen framework.
- ❖ Provides Cherenkov polar and azimuthal angle information.

Inverse Ray Tracing: machinery

- In case of a single (unknown!) reflection point the task is reduced to a 2D case, a quartic equation follows, can be solved iteratively (e.g. using the Newton method)
- The math can be extended to a case with a second (flat!) mirror
- For dRICH the refraction on aerogel boundary can be accounted in a more or less consistent way a posteriori

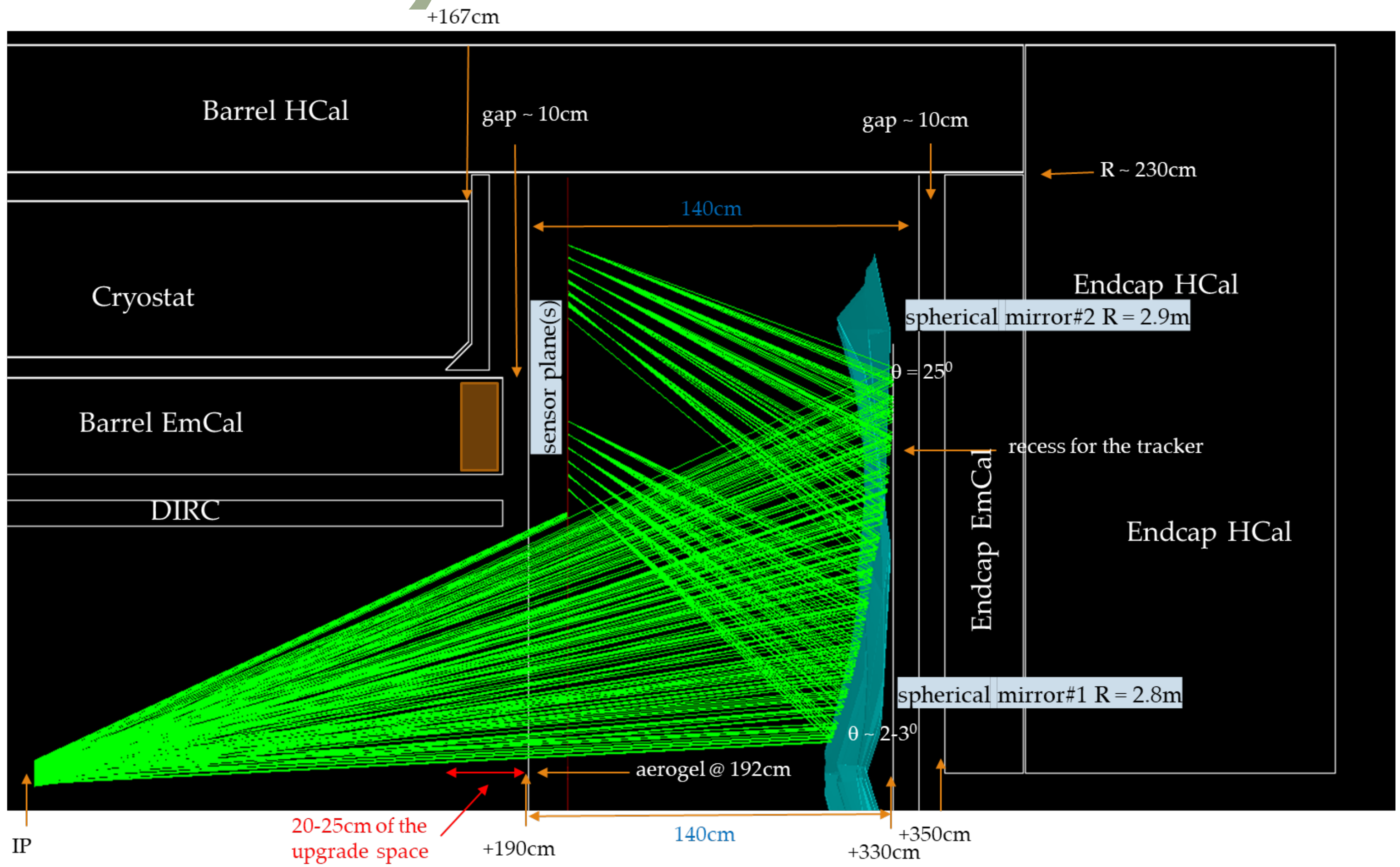
- More complicated cases (tilted aerogel tiles, acrylic layer, 2-d spherical mirror) require generalization into 3D space
- Some sort of bookkeeping is required when
  - a single charged particle produces Cherenkov photons detected in different sectors
  - a pair of [emission, detection] 3D points allows for more than one optical path (like in a dual mirror configuration)
- Very important: GEANT geometry should be consistent with the optical setup!

Inverse Ray Tracing: implementation

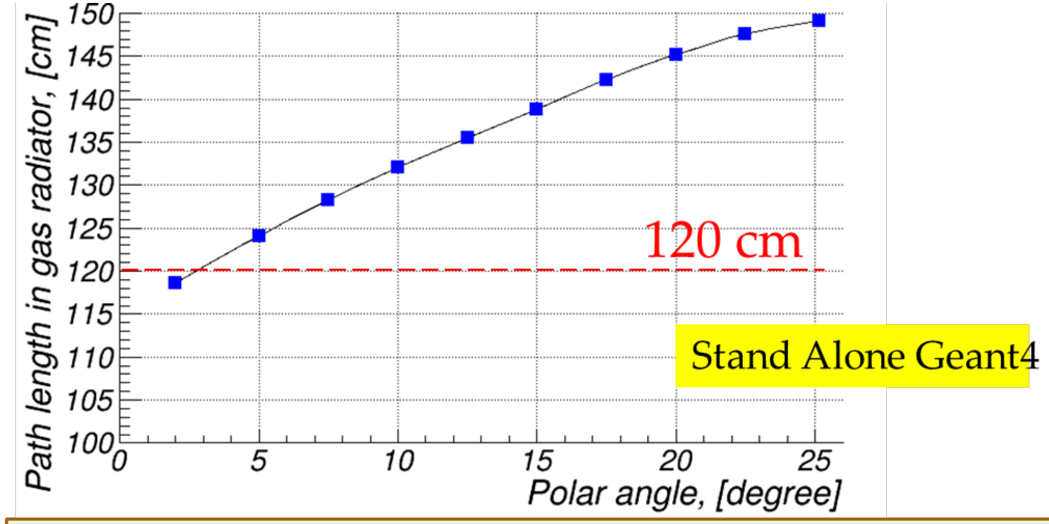
Repository (as of Dec 15, 2021) : https://eicweb.phy.anl.gov/EIC/irt/-/tree/irt-init-v02

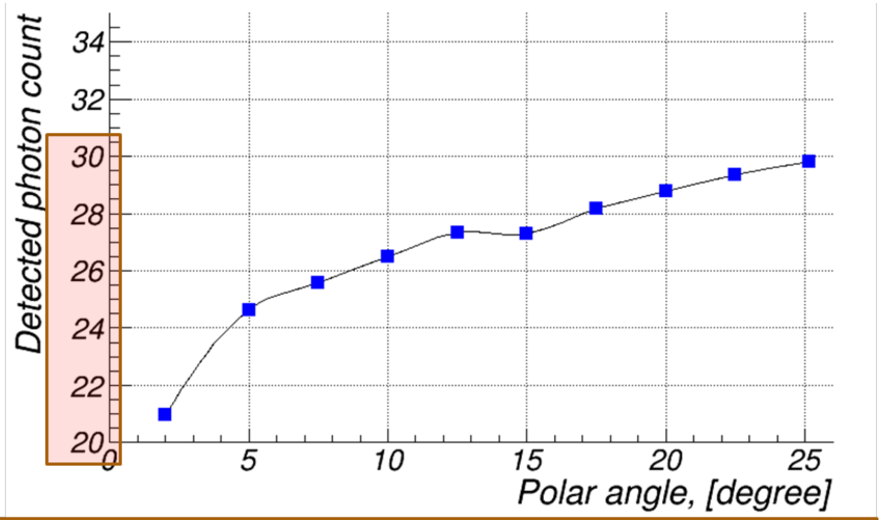
- A compact C++ library
  - Can be used in a standalone GEANT code as well as in the ATHENA environment
  - Optical geometry ROOT class instance is created *in the same code, which creates RICH detector* (therefore simulation-vs-reconstruction consistency is guaranteed)
  - Persistency model: optical setup dump in ROOT format
  - Newton-Gauss iterative solver for optical path defined by arbitrary sequence of refractive and reflective surfaces in 3D (presently flat and spherical boundaries only)
  - Absorbtion length accounting (azimuthally-asymmetric shift of emission point)
  - Emission angle uncertainly calculation (it does depend on the azimuthal angle!)
  - A wrapper for sampling along the charged particle trajectory (magnetic field case, etc.)

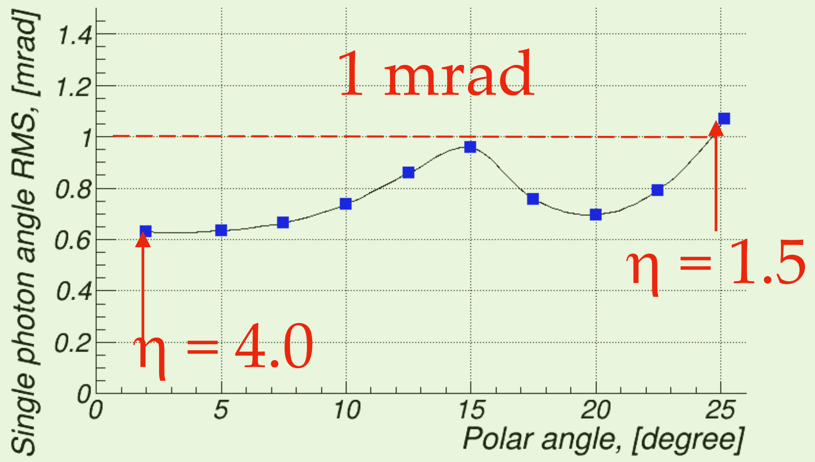
Inverse Ray Tracing: application (standalone GEANT4)

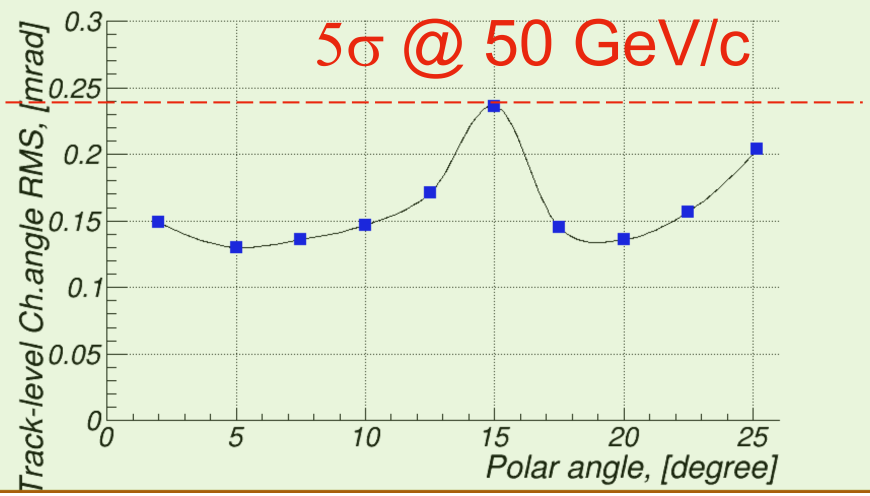


Inverse Ray Tracing: performance plots (C_2F_6, 50 GeV/c π^+)



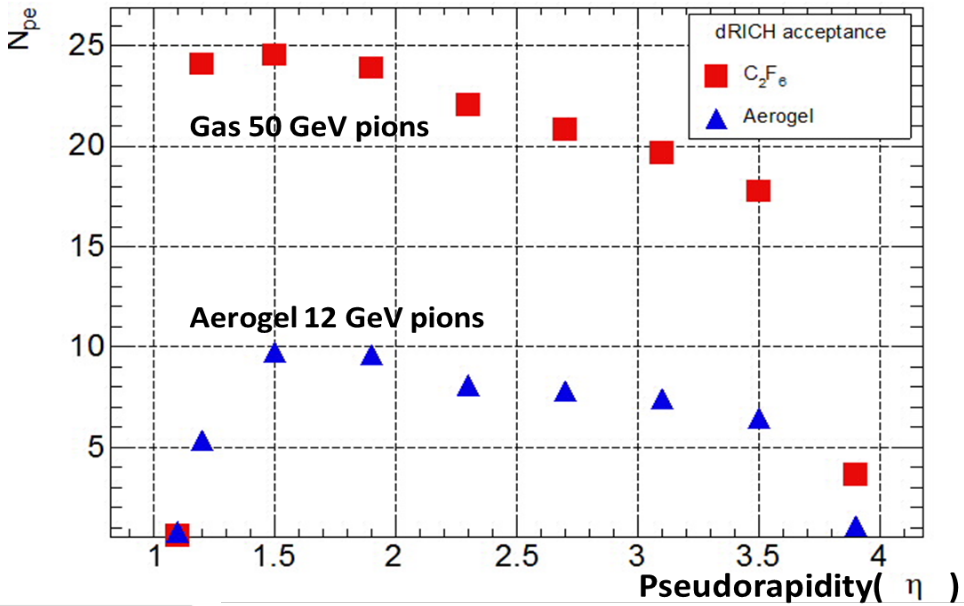


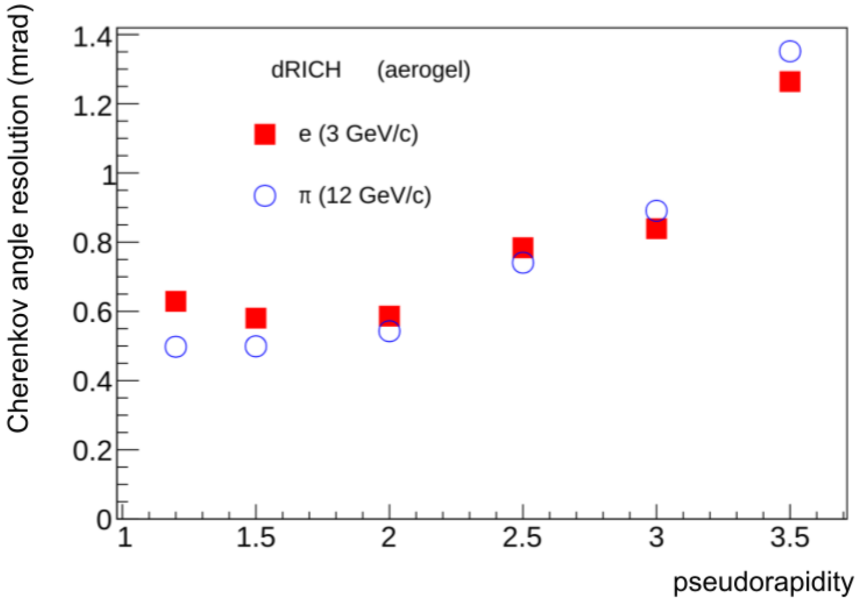


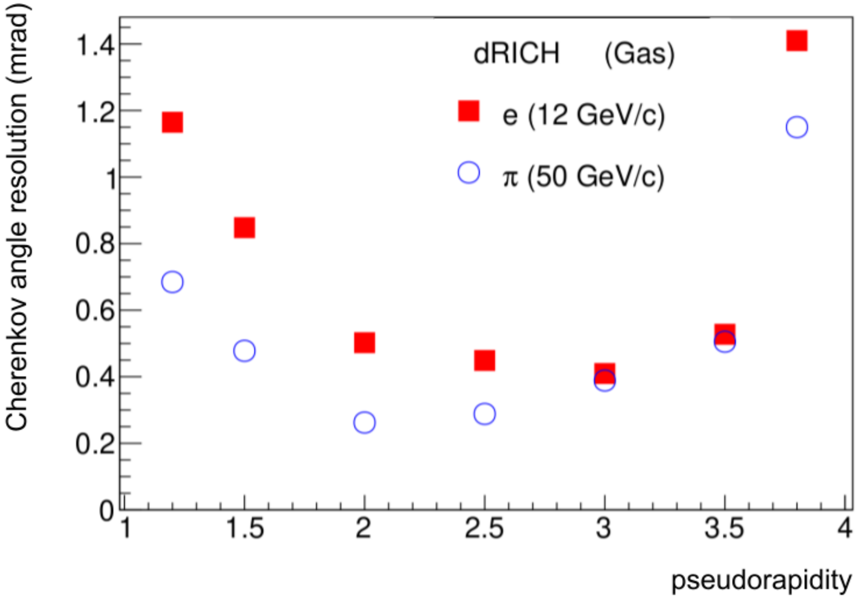


Simulation outcome

dRICH acceptance and resolution as a function of pseudorapidity

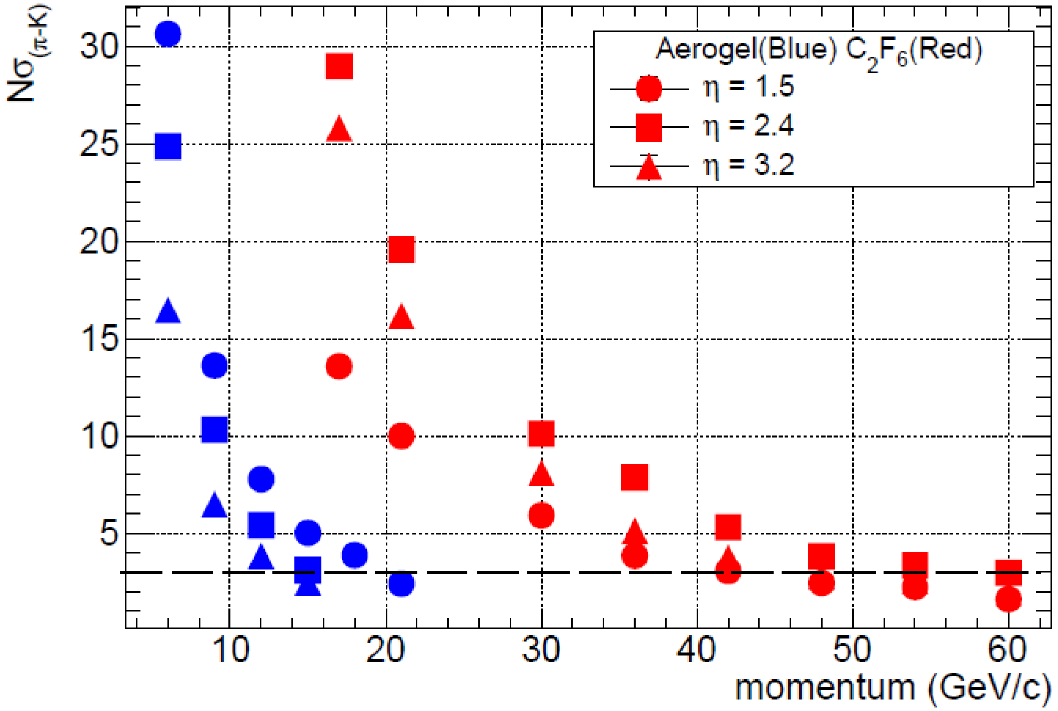


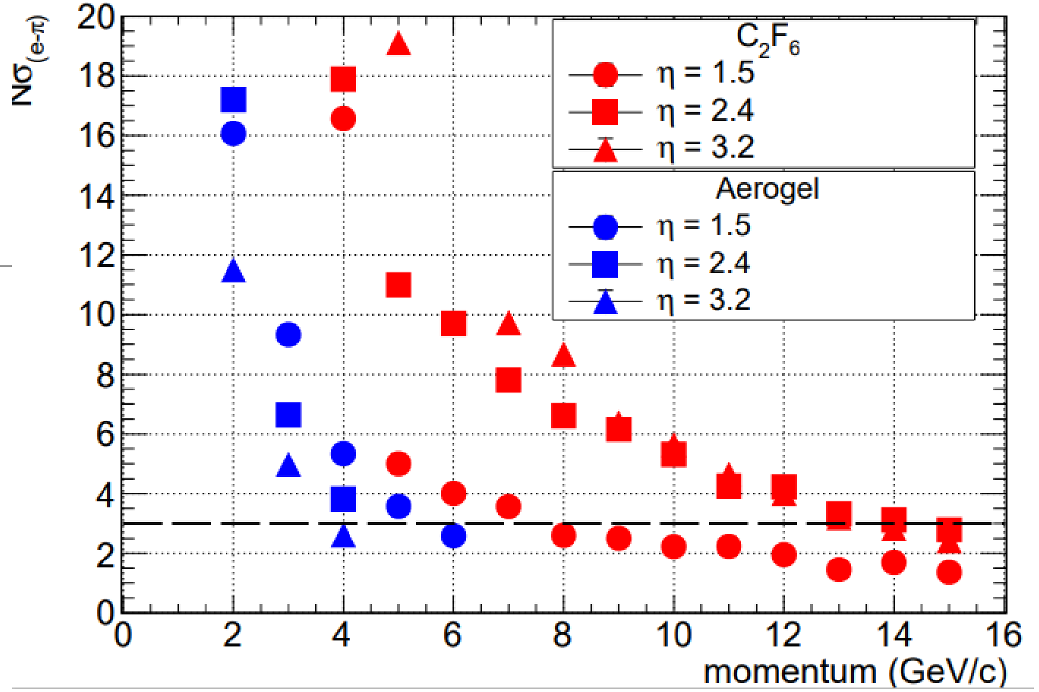




YR requirement: acceptance for the dRICH is 1.0 ≤ η ≤ 3.5. These reference numbers were taken as a guidance for the ATHENA implementation.

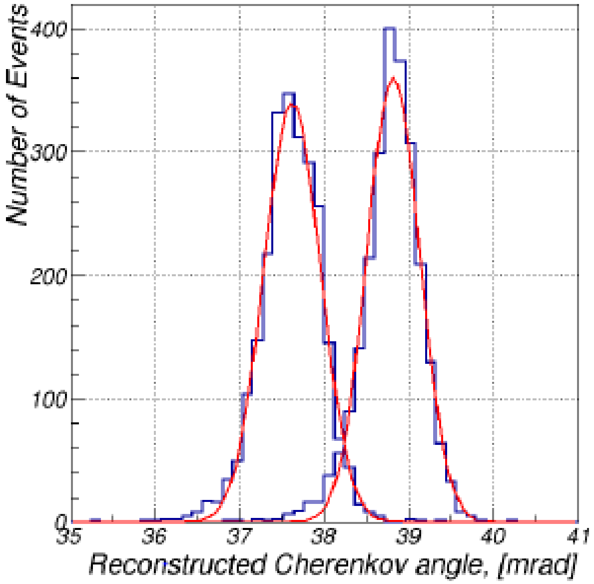
N Sigma Separation

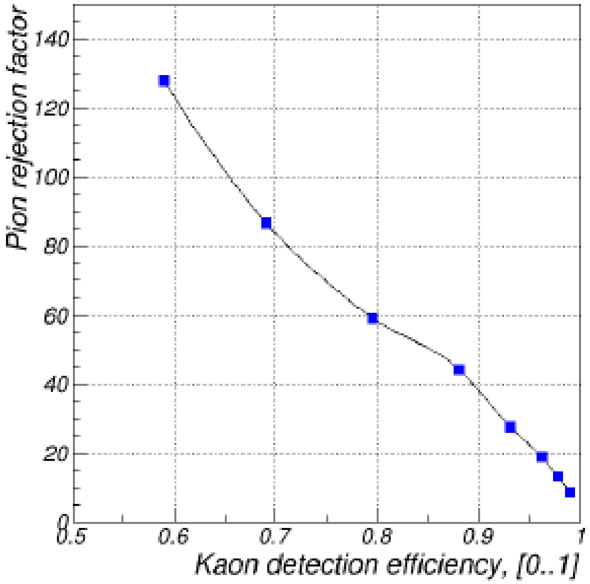




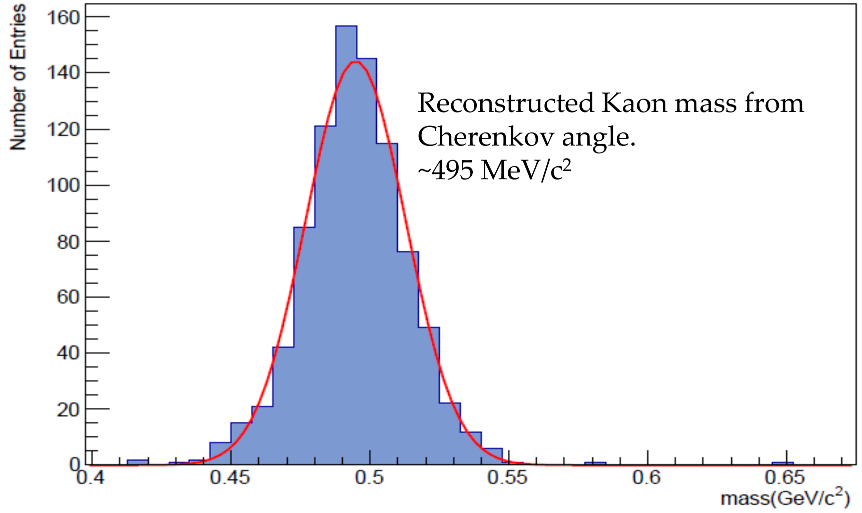
YR prescription achievable.

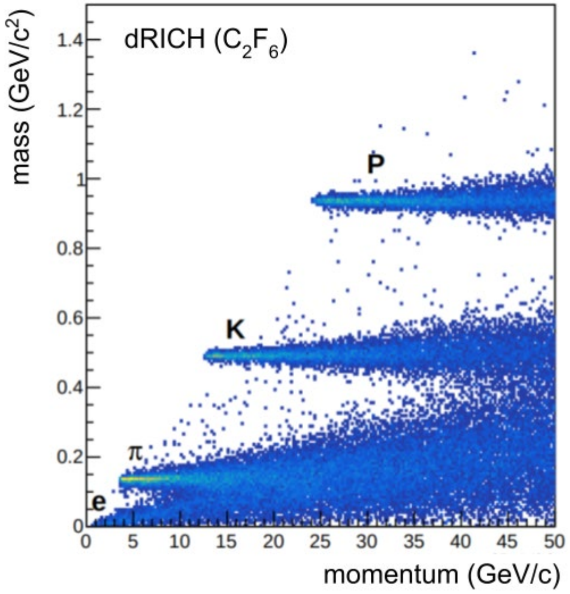
Performance plots





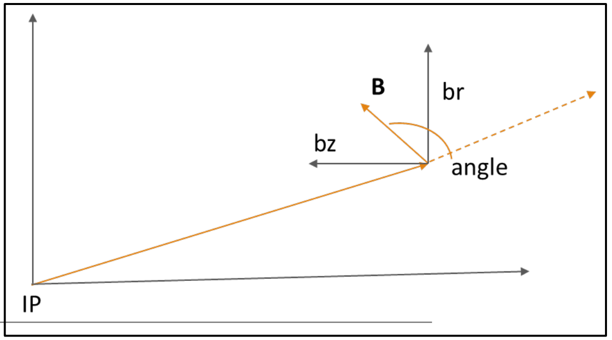
- Left: reconstructed Cherenkov angle peaks for a 50:50 mix of 50 GeV/c kaon and pion tracks at η = 2.4 are ~3σ apart (C2F6 radiator). Right: dependency of pion rejection factor on kaon detection efficiency with the selection cu varying between 37.6 mrad and 38.4 mrad applied to the left hand side plot.



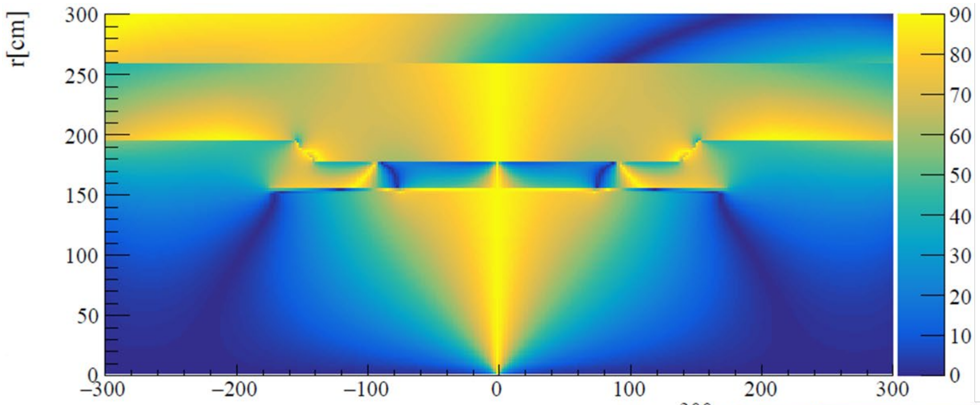


Particle Mass as a function of momentum retrieved from reconstructed Cherenkov angle

Work initiated and progress



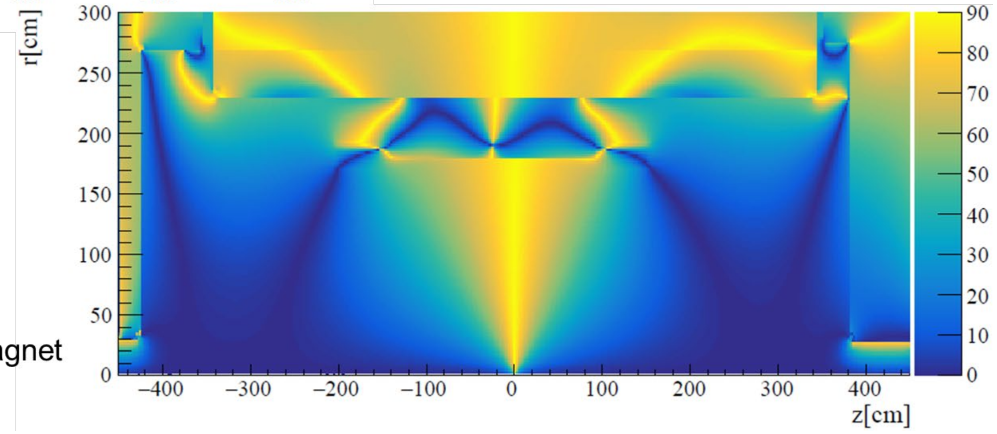
- Discussion with Jin Huang on the possibility to study the ring smearing in presence of magnetic field.
- We found good level of consistency in the ATHENA and ECCE ring smearing due to magnetic field, multi scattering etc.
- We plan to study in coming days the PID performance in dd4Hep with the scaled geometry and the studies related to geometric acceptance.



Babar Magnet

No apparent large difference in the projective nature of the field lines

ATHENA Magnet



Rescaling the dRICH to ecce configuration in dd4HEP

- The dRICH is rescaled and merged to ecce description in dd4hep.
- We can see rings → The simulation part is revived; we are doing some first order tuning and overlapping checks.
- Next step is to revive the IRT algorithm and Juggler reconstruction.
- The next study will be done to create the performance plots and to study the effect of magnetic field in single photon resolution in different phase space.