Aerogel studies for the dRICH detector

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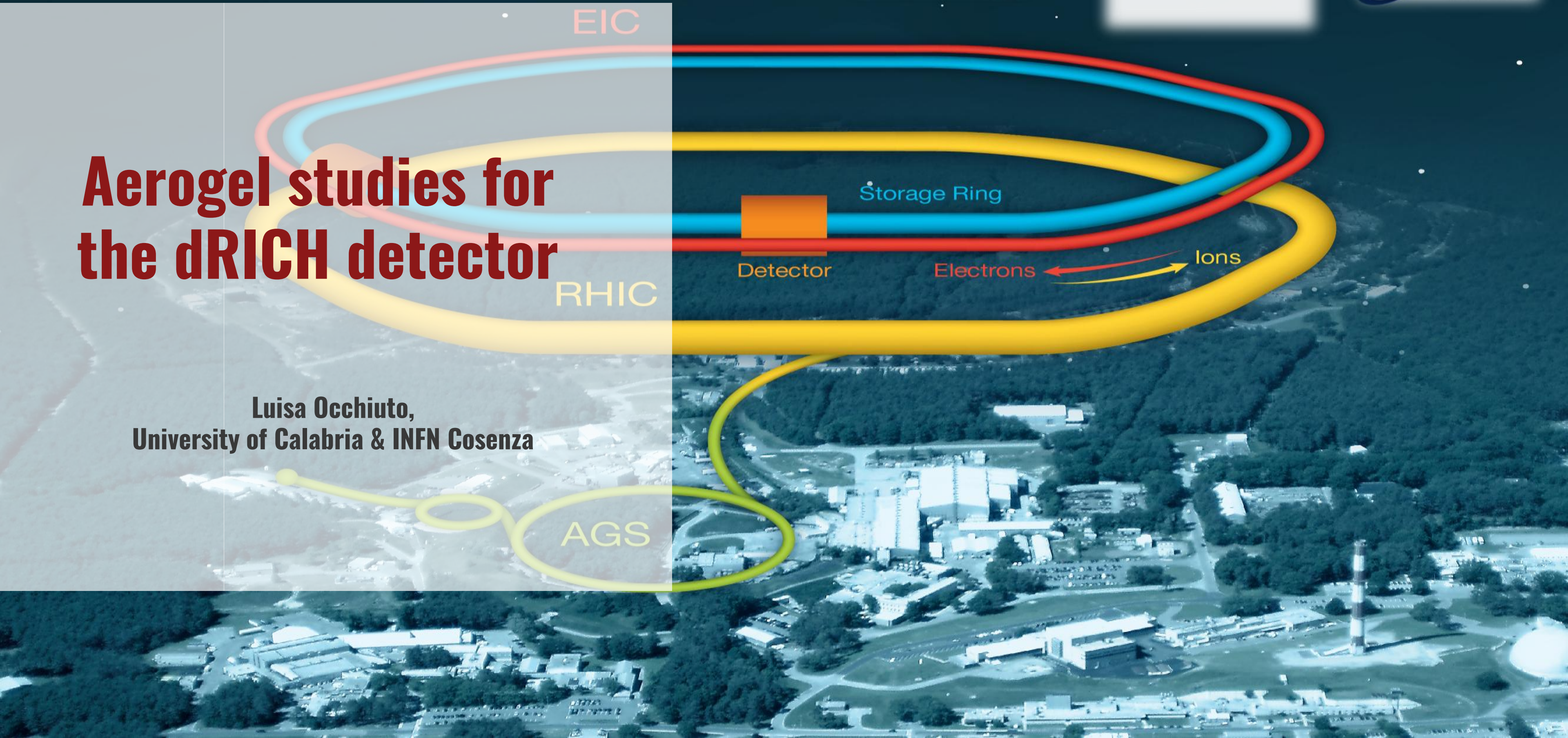
University of Calabria & INFN Cosenza



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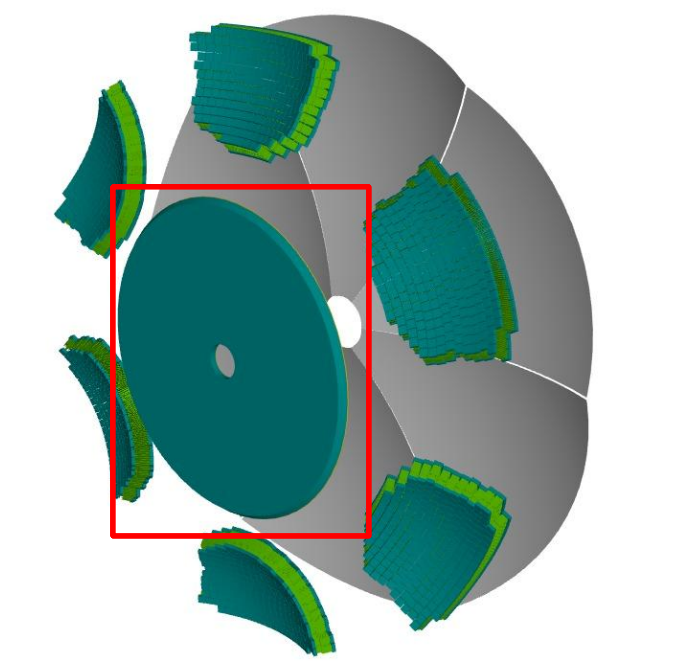
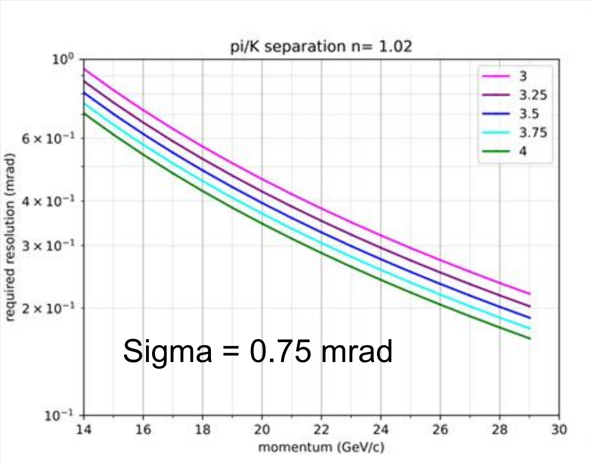
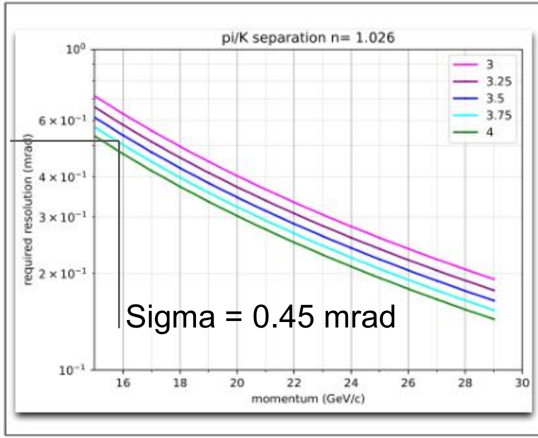
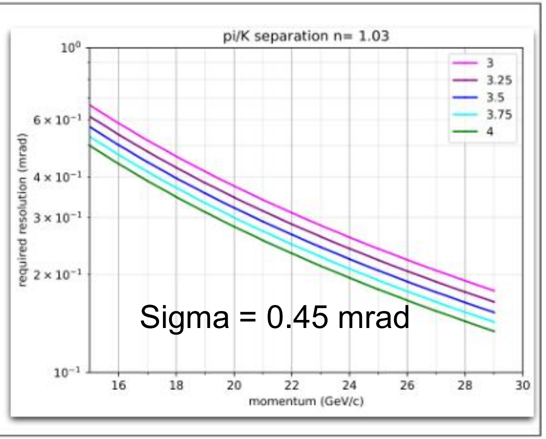


REQUIREMENTS FOR AEROGEL AND FOR THE GAS







Baseline

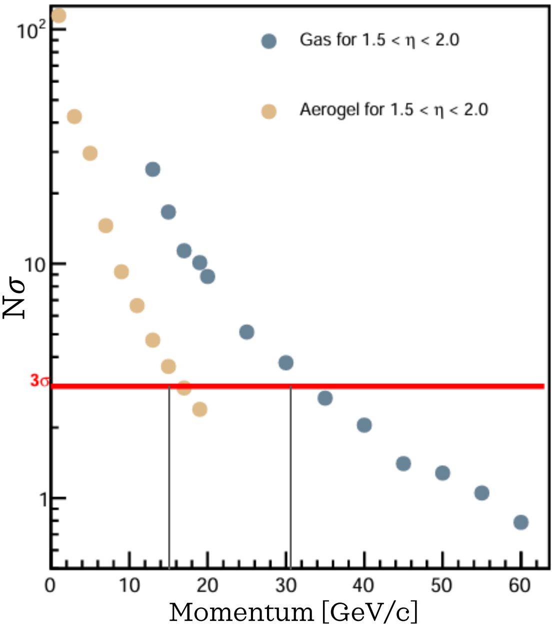
Type-1 (n=1.026)

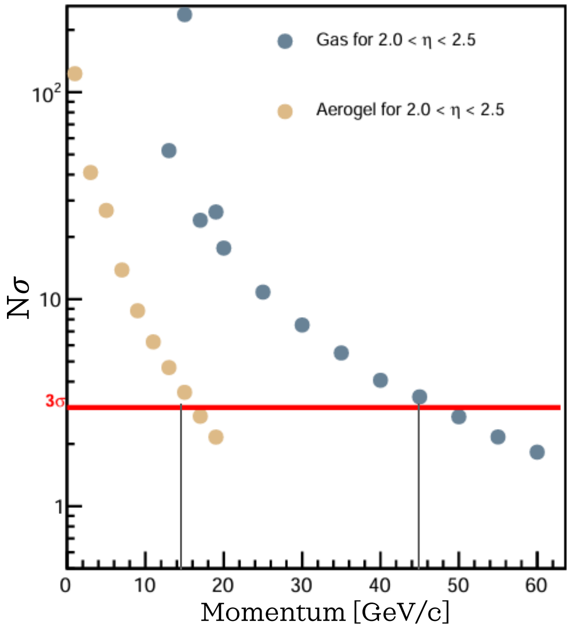
Type-2 (n=1.03)

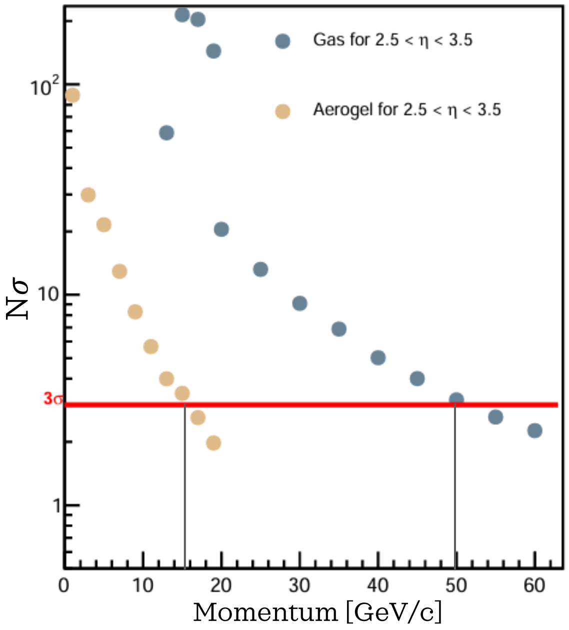
Higher refractive index = higher photon yield

Performance for Aerogel (n=1.019)

Nσ separation in function of momentum

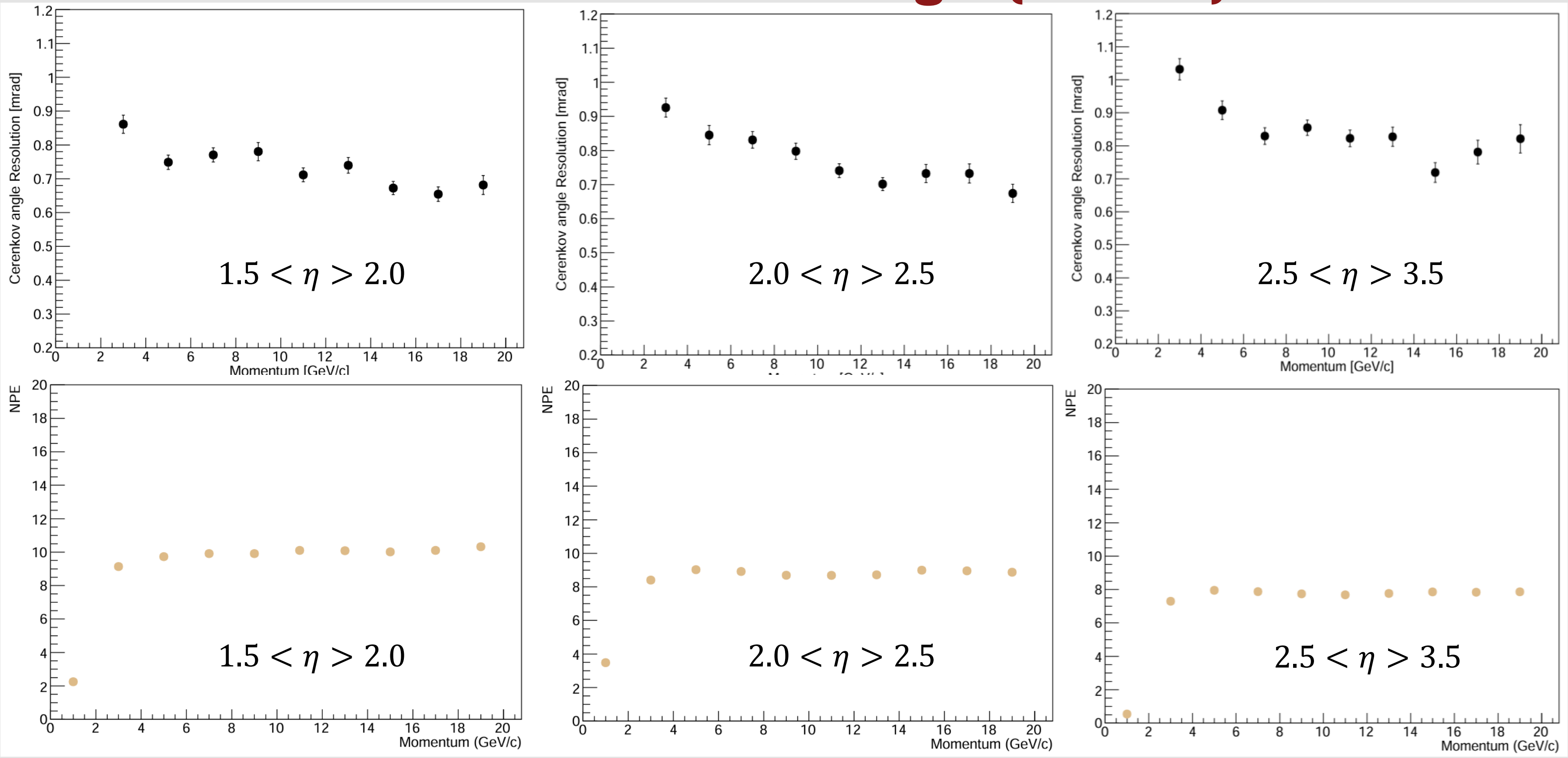






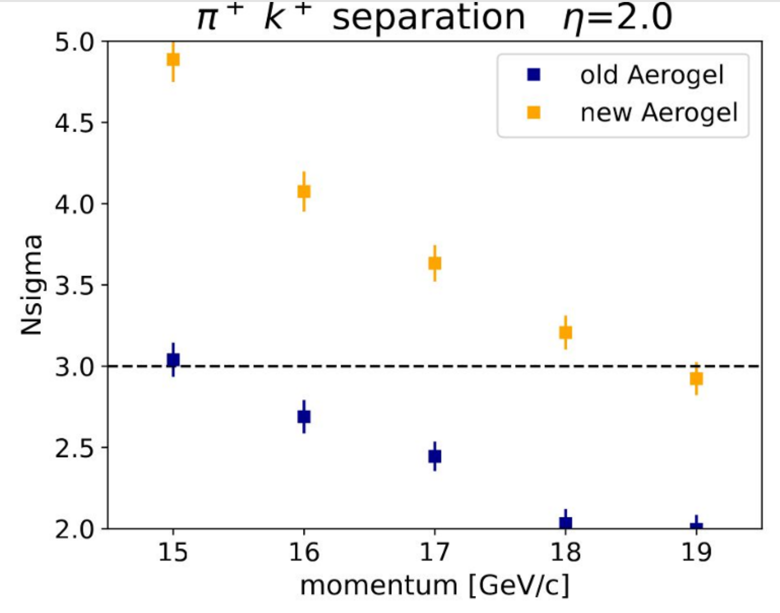
@ η>2.5 we achieve 3σ with ~ 15 GeV/c of momentum for the aerogel and ~ 50 GeV/c for the gas.

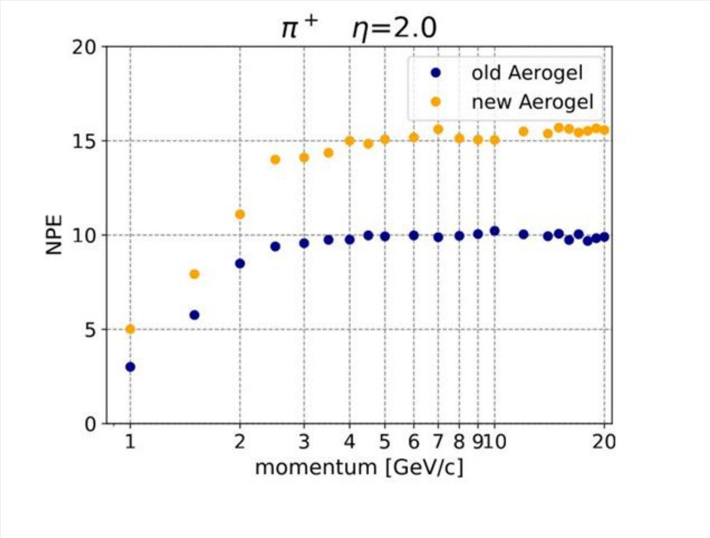
Performance for Aerogel (n=1.019)



Performance Comparison of Aerogel Type-1 (n=1.026)

Gain in performance (wrt baseline), 3.5-4 GeV/c more!



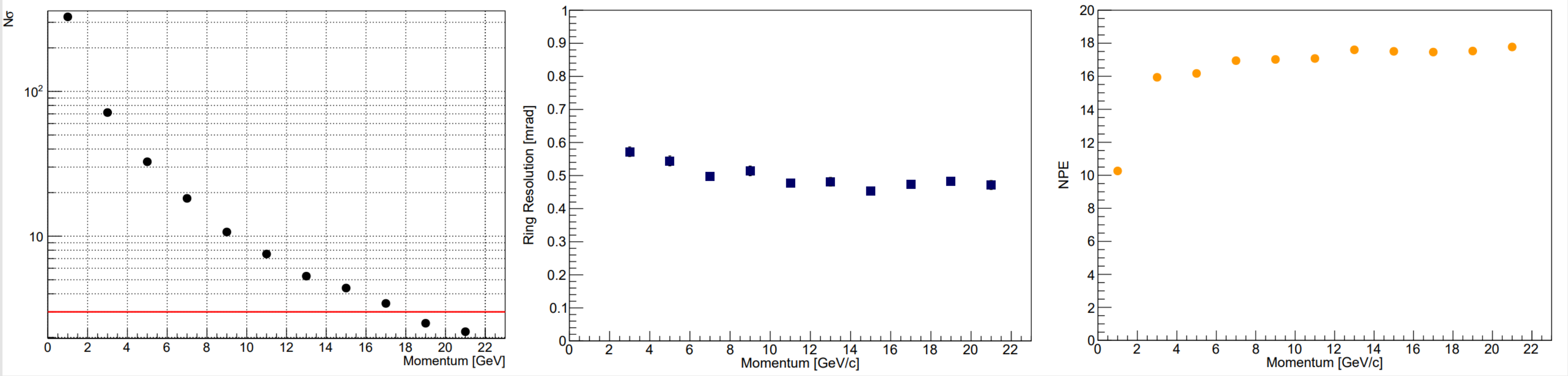


Significantly larger number of photons, ~1.5 times more Nph!

Performance Comparison of Aerogel Type-2 (n=1.03)

- ✓ Better optical properties
- ✓ Higher refractive index
- ✓ Improved separation

π+, φ=0, **η=2.0**

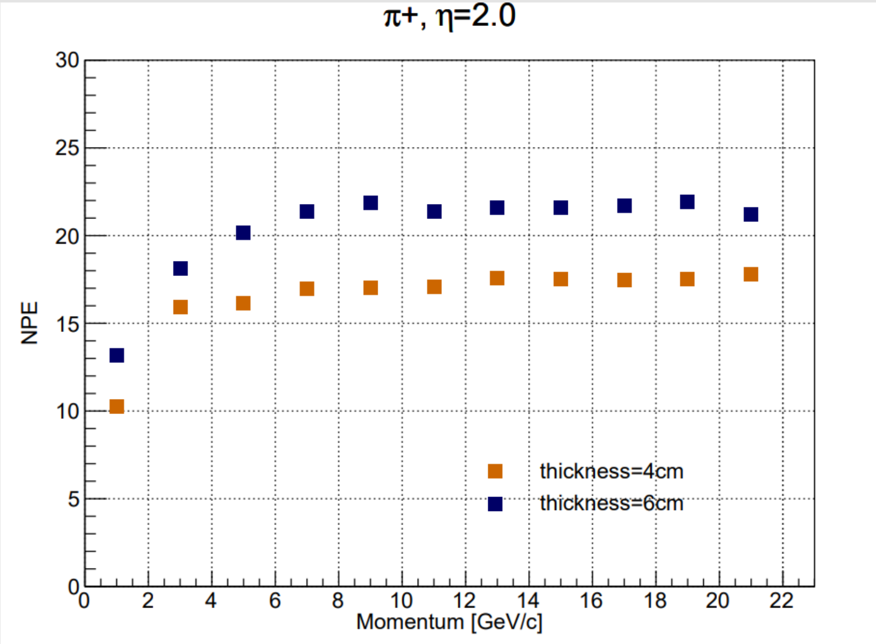


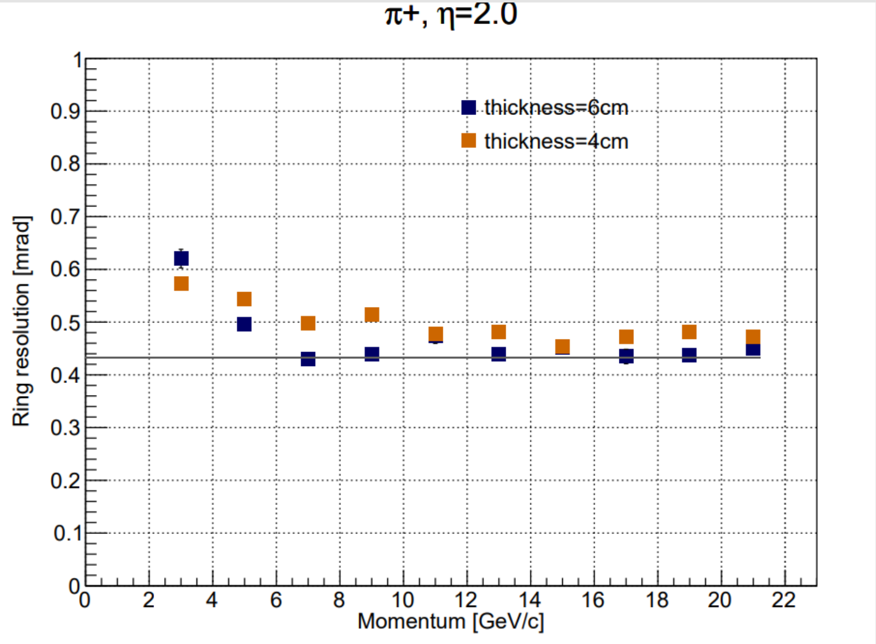
@ η=2.0 we achieve 3σ with ~ 17 GeV/c of momentum for the aerogel.

Performance: NPE and Resolution vs η of Aerogel Type-2 (n=1.03)

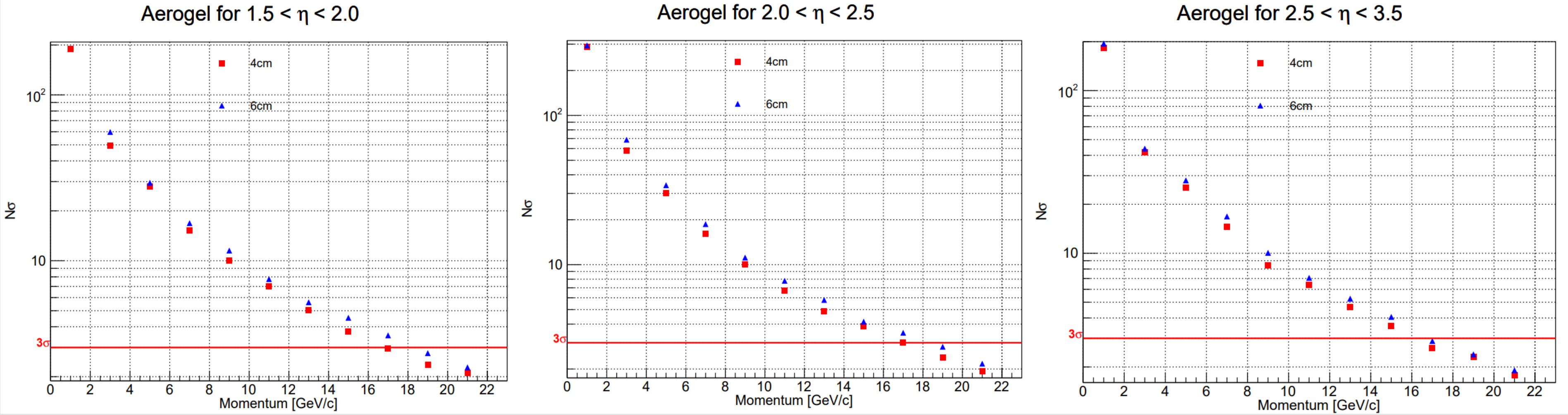
Two aerogel thickness studied:

- ✓ **4 cm**
- ✓ **6 cm**





Performance: Nσ Separation of Aerogel Type-2 (n=1.03)



Two aerogel thickness studied:

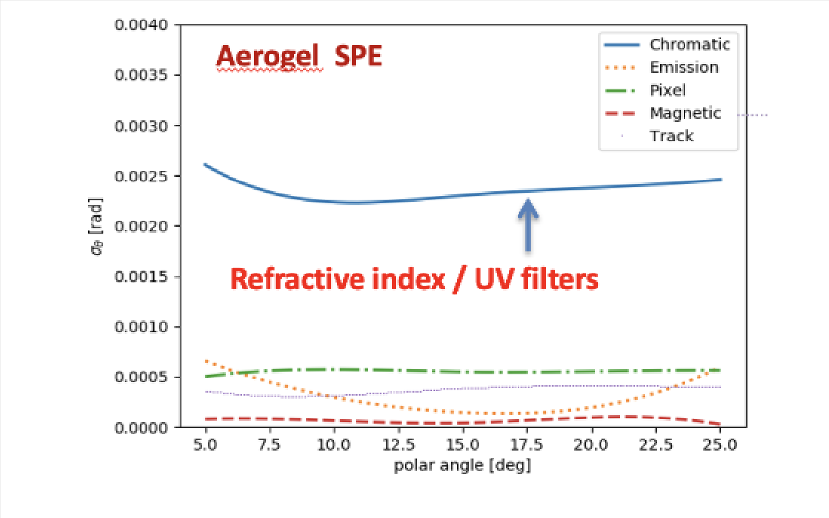
- ✓ **4 cm**
- ✓ **6 cm**

Chromatic aberration

Chromatic aberration is an optical effect that limits the precision of Cherenkov angle measurements.

It occurs because the medium's refractive index (aerogel or gas) depends on the photon's wavelength.

Chromatic aberration is identified as the primary source of angular resolution degradation per photon.



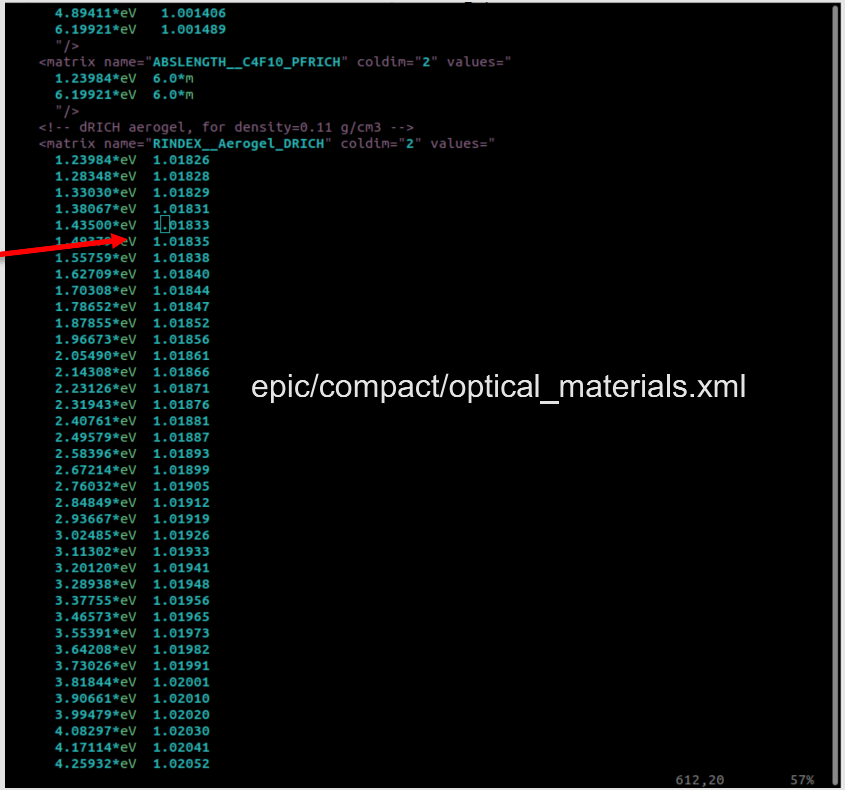
https://zenodo.org/records/14328280

Chromatic aberration

To calculate the contribution of chromatic aberration

- ✓ Simulation -> both with the refractive index fixed and with the lambda dependency.
- ✓ 1000 events.
- ✓ PID: 211
- ✓ Momentum fixed @ 15 GeV/c.
- ✓ Different bins of η.

Its effect has been studied at different refractive index



```
  4.89411*eV   1.001406
  6.19921*eV   1.001489
  "/>
<matrix name="ABSLENGTH__C4F10_PFRICH" coldim="2" values="
  1.23984*eV  6.0*m
  6.19921*eV  6.0*m
  "/>
<!-- dRICH aerogel, for density=0.11 g/cm3 -->
<matrix name="RINDEX__Aerogel_DRICH" coldim="2" values="
  1.23984*eV  1.01826
  1.28348*eV  1.01828
  1.33030*eV  1.01829
  1.38067*eV  1.01831
  1.43500*eV  1.01833
  1.49[illegible]eV  1.01835
  1.55759*eV  1.01838
  1.62709*eV  1.01840
  1.70308*eV  1.01844
  1.78652*eV  1.01847
  1.87855*eV  1.01852
  1.96673*eV  1.01856
  2.05490*eV  1.01861
  2.14308*eV  1.01866
  2.23126*eV  1.01871
  2.31943*eV  1.01876
  2.40761*eV  1.01881
  2.49579*eV  1.01887
  2.58396*eV  1.01893
  2.67214*eV  1.01899
  2.76032*eV  1.01905
  2.84849*eV  1.01912
  2.93667*eV  1.01919
  3.02485*eV  1.01926
  3.11302*eV  1.01933
  3.20120*eV  1.01941
  3.28938*eV  1.01948
  3.37755*eV  1.01956
  3.46573*eV  1.01965
  3.55391*eV  1.01973
  3.64208*eV  1.01982
  3.73026*eV  1.01991
  3.81844*eV  1.02001
  3.90661*eV  1.02010
  3.99479*eV  1.02020
  4.08297*eV  1.02030
  4.17114*eV  1.02041
  4.25932*eV  1.02052
                                         612,20        57%
```

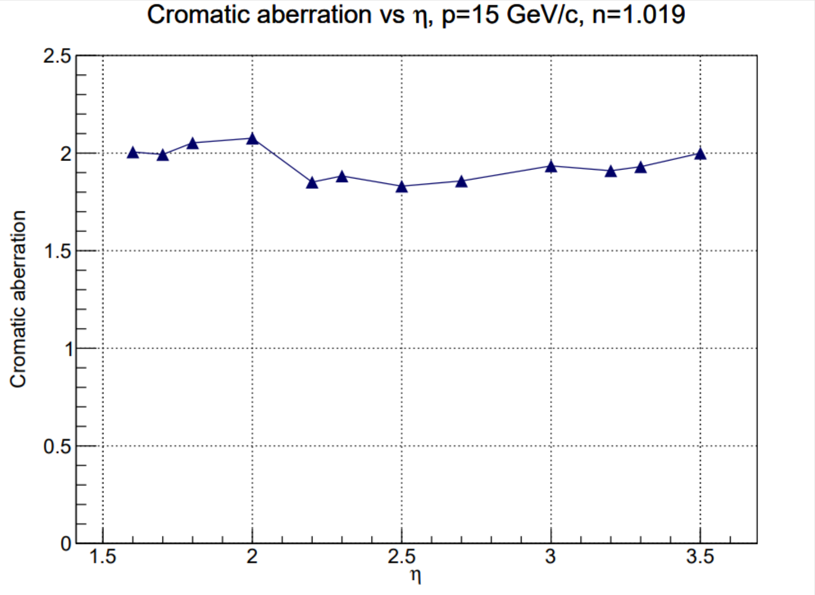
epic/compact/optical_materials.xml

Chromatic aberration

Chromatic aberration as a function of η, fixing momentum @ 15 GeV/c and n = 1.019

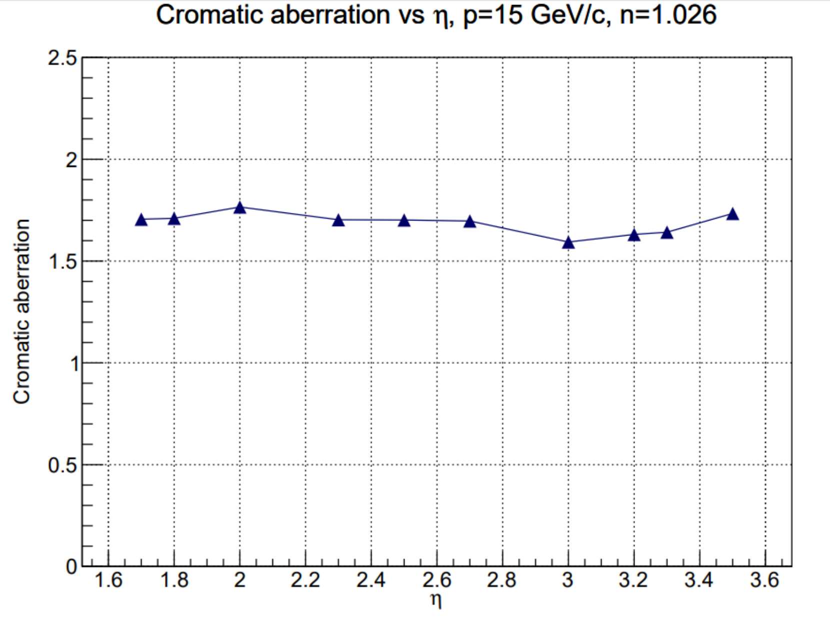
$$\sigma_{\{cromatic\ aberration\}} = \sqrt{\sigma_{tot}^2 - \sigma_{w/o\ \lambda\ dep.}^2}$$

Where σ_{tot}^2 is σ with λ dependency and $\sigma_{w/o\ \lambda\ dep}^2$ is σ with n fixed (w/o λ dependency).



Chromatic aberration

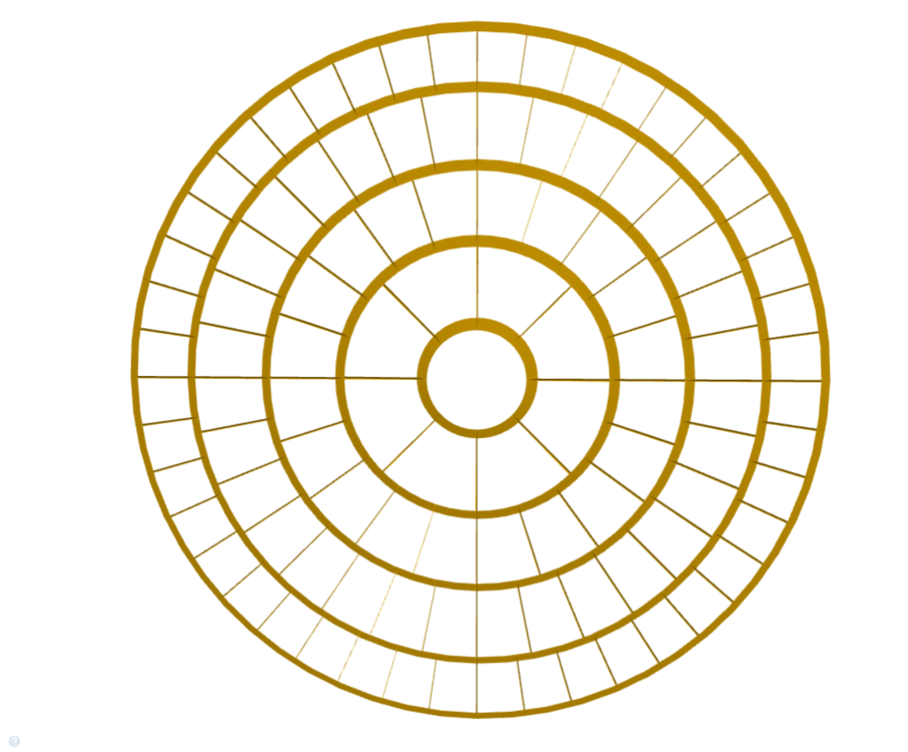
Chromatic aberration as a function of η, fixing momentum @ 15 GeV/c and n = 1.026



$$\sigma_{\{cromatic\ aberration\}} = \sqrt{\sigma_{tot}^2 - \sigma_{w/o\ \lambda\ dep.}^2}$$

Where σ_{tot}^2 is σ with λ dependency and $\sigma_{w/o\ \lambda\ dep}^2$ is σ with n fixed (w/o λ dependency).

Aerogel tiling: 1 structure (4 cm)



Parameters	
Thickness (crowns and segments)	1 mm
# Crowns	5
# radial segments	{8, 20, 32, 44}
square's dimension	20 cm

Structure in carbon fiber similar to the one we will later insert into the experiment!

Aerogel tiling: How does this code work?

1. **Crowns**: Calculated the radius for each crown
2. **Sectors**: Created sectors between each pair of crowns
3. **Union**: Merged crowns and sectors into a single solid
4. **Subtraction**: Subtracted this solid from the aerogel to avoid overlapping materials
5. **Insertion**: Placed the carbon fiber structure into the resulting "hole"

```
<constant name="DRICH_corona_thickness" value="1*mm"/>
<constant name="DRICH_num_coronas" value="5"/>
<constant name="DRICH_d_square" value="200*mm"/>
```

From drich.xml

```
<aerogel
  material="Aerogel_DRICH"
  vis="DRICH_aerogel_vis"
  thickness="DRICH_aerogel_thickness"
  />
<coronas
  thickness="DRICH_corona_thickness"
  num="DRICH_num_coronas"
  material="CarbonFiber_15percent"
  vis="DRICH_filter_vis"
  d= "DRICH_d_square"
```

Aerogel tiling: No overlaps (checked)!

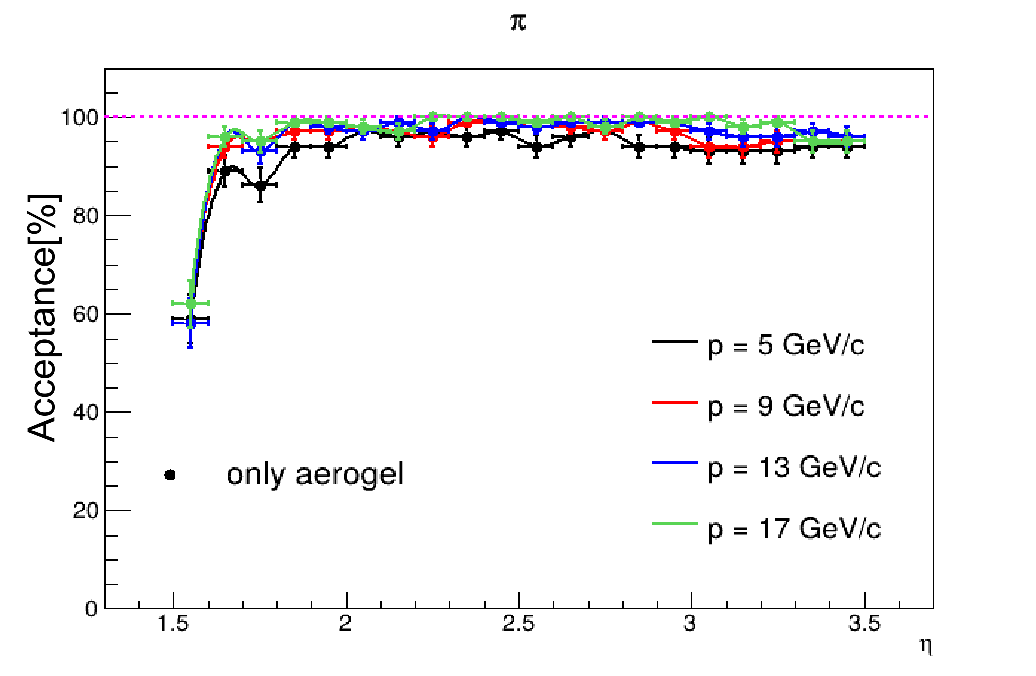
I have also calculated the overlaps, and since there are none, the structure seems solid!

```
Geant4UI          INFO  +++ Geant4RunManager> Install Geant4 control directory:/ddg4/Geant4RunManager/
Geant4RunManager WARN  +++ Configured run manager of type: G4RunManager.
Geant4Kernel     WARN  +++ Multi-threaded mode requested, but not supported by this compilation of Geant4.
Geant4Kernel     WARN  +++ Falling back to single threaded mode.
Geant4Exec       WARN  +++ Only 1 subdetectors present. You sure you loaded the geometry properly?
Geant4UI         INFO  +++ DetectorConstructionAction> Install Geant4 control directory:/ddg4/DetectorConstructionAction/
Geant4Exec       WARN  +++ Building default Geant4DetectorConstruction for single threaded compatibility.
Geant4UI         INFO  +++ PhysicsList> Install Geant4 control directory:/ddg4/PhysicsList/
G4PhysListFactory::GetReferencePhysList <QGSP_BERT>  EMoption= 0
<<< Geant4 Physics List simulation engine: QGSP_BERT


UserInitialization INFO  +++ Executing Geant4UserActionInitialization::Build. Context:0x560009d37510 Kernel:0x560009cddef0 [-1]
Geant4Converter  INFO  +++  Successfully converted geometry to Geant4. [  0.267 seconds]
Geant4UI         INFO  +++ ConstructGeometry> Install Geant4 control directory:/ddg4/ConstructGeometry/

 hInelastic QGSP_BERT  Thresholds:
    1) between BERT  and FTF/P over the interval 3 to 6 GeV.
    2) between FTF/P and QGS/P over the interval 12 to 25 GeV.
  -- quasiElastic: 1 for QGS  and 0 for FTF
### Adding tracking cuts for neutron  TimeCut(ns)= 10000  KinEnergyCut(MeV)= 0
UI               INFO  ++ Executing pre-run statement: /geometry/test/resolution 10000
UI               INFO  ++ Executing pre-run statement: /geometry/test/tolerance 0.1
UI               INFO  ++ Executing pre-run statement: /geometry/test/verbosity 0
UI               INFO  ++ Executing pre-run statement: /geometry/test/run
Running geometry overlaps check...
Geometry overlaps check completed !

Geant4Kernel     INFO  ++ Terminate Geant4 and delete associated actions
```

Aerogel tiling: Test acceptance without structure

Some simulations test with A. De Caro (SA)!

- ✓ 100 events
- ✓ η fixed
- ✓ Differents momentum

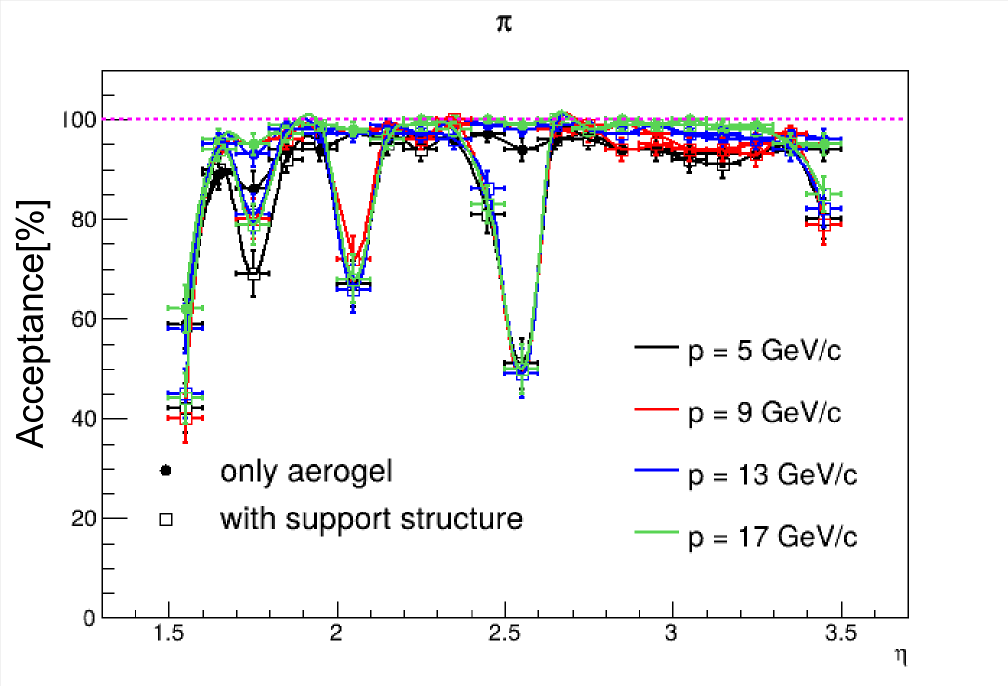


Aerogel tiling: 1 structure (4 cm)

Some simulations test with A. De Caro (SA)!

- ✓ 100 events
- ✓ η fixed
- ✓ Differents momentum

The drops you see here are due to an overestimation of the structure's thickness. **But no worries, this has already been fixed**. ☺



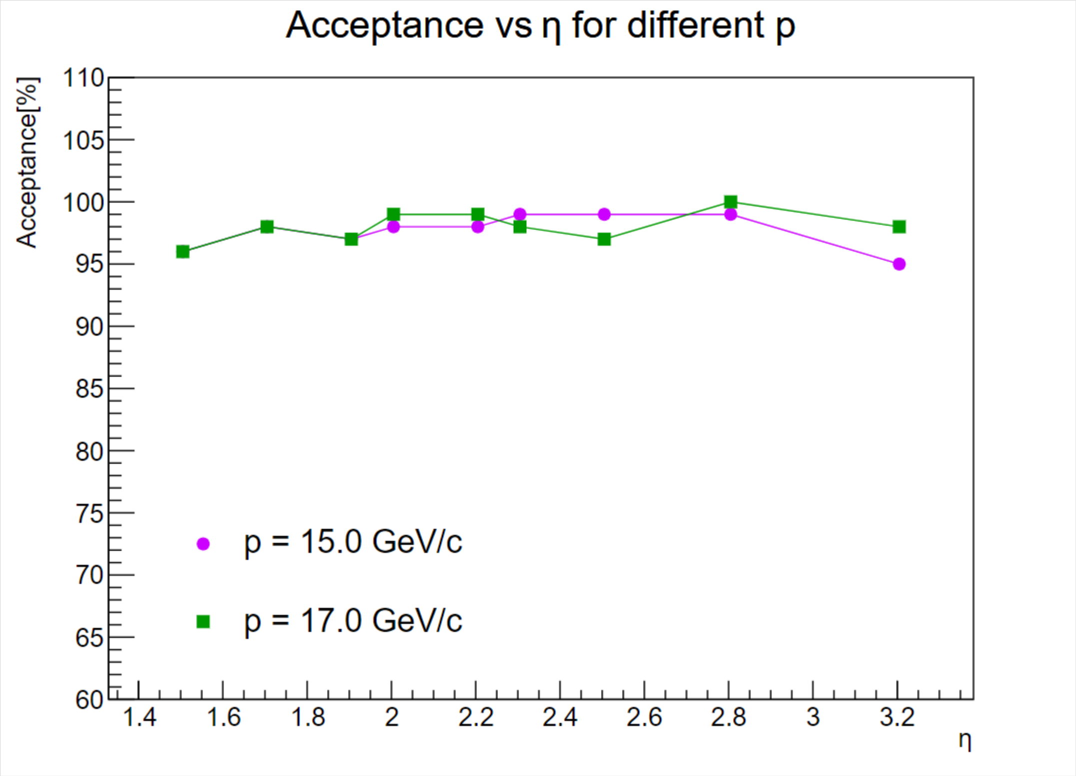
Aerogel tiling: 1 structure (4 cm)

n=1.019

Some simulations test with A. De Caro (SA)!

- ✓ 100 events
- ✓ η fixed
- ✓ Differents momentum

WORK IN PROGRESS



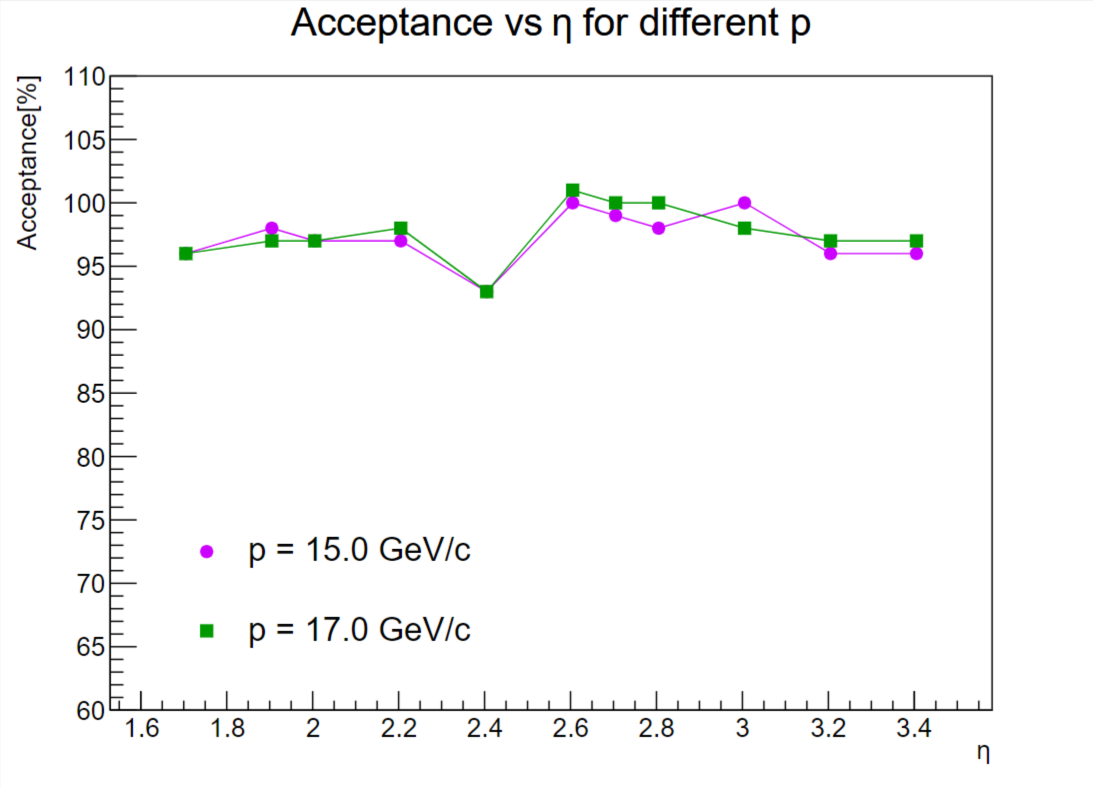
Aerogel tiling: 2 structure (2 cm each)

n=1.019

Some simulations test with A. De Caro(SA)!

- ✓ 100 events
- ✓ η fixed
- ✓ Differents momentum

WORK IN PROGRESS



SUMMARY

1. The aerogel with a refractive index of **n=1.026** produces a greater NPE compared to the aerogel with n=1.02 and provides better resolution at 3σ.
2. Chromatic aberration is identified as the primary source of angular resolution degradation per photon.
3. Robust code for implementing a carbon fiber structure to efficiently model the segmentation of the aerogel, with good acceptance.

This work was carried out under the supervision of Chandra, A. De Caro(SA), and Salvatore.

Studies ongoing:

a. Several studies on the optimization and automatization of the code for the aerogel tiling
b. Implementing multiple layers of aerogel
c. Taking the right parameters, introduce some surface impurity (curvature) so that multiple layers don't match perfectly

THANKS!

Backup

Aerogel tiling

Chandradoy Chatterjee
a Salvatore, me, Annalisa

Traduci in italiano

Hi Salvatore,
actually Luisa can do the following studies with her trapezoidal aerogel tiles:

1) Optimal tile size both radially outward and along phi direction
   - -a) Number of optimal tiles
   - -b) Number of optimal ribs
2) Optimal thickness of the ribs.
   - - a) Do we improve anything if the ribs are partially covering the edges of the aerogel?
3) Implementing multiple layers of aergel
   - -a) Flat aerogel surfaces.
   - -b) Implementing needed changes into the reconstruction to account multiple layers of aerogel
   - -c) Optimal staggering.
   - -d) Taking the parameters from Marco, introduce some surface impurity (curvature)
     so that multiple layers don't match perfectly.

Then, to repeat the same exercise with different refractive index of the aerogels to account for the dead-areas, photon absorption so on.
This can be her task.

Goal: Create a structure with user-tunable parameters, mainly from the drich.xml file

Chromatic aberration

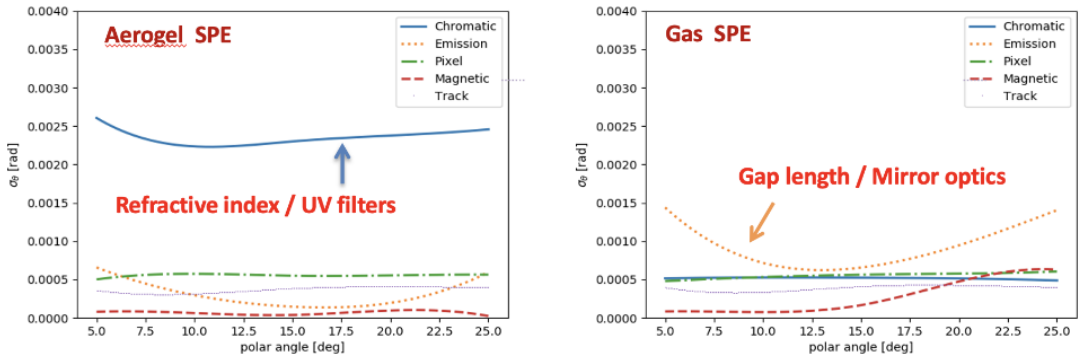
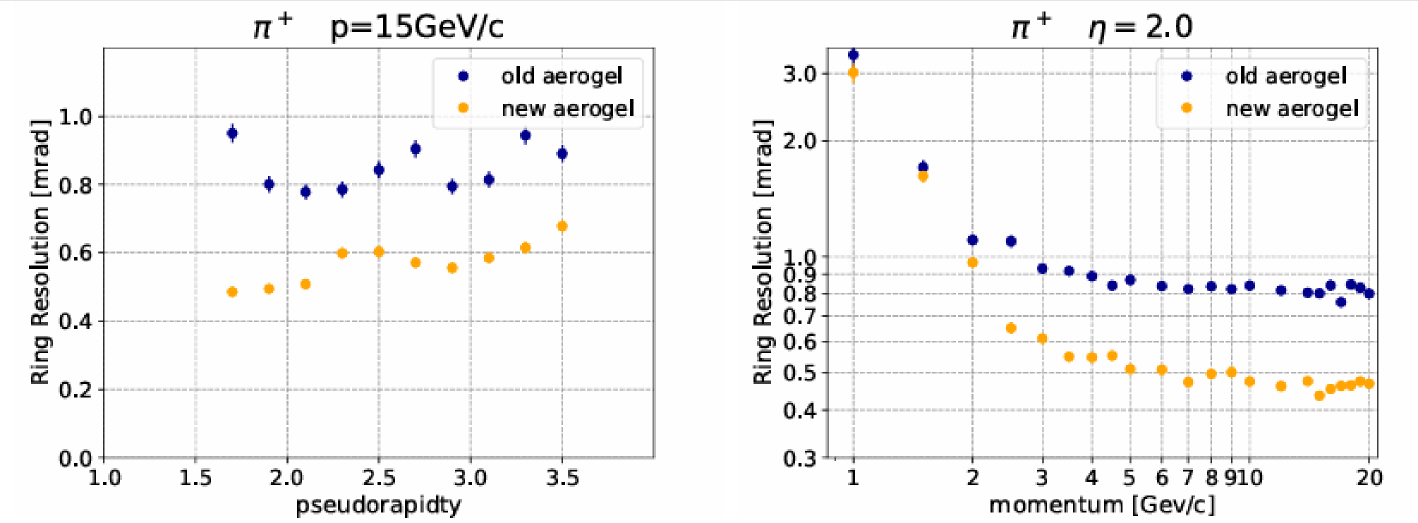


Figure 8.103: (Left) Contributions to the single-photon angular resolution for aerogel. (Right) Contributions to the single-photon angular resolution for radiator gas.

The chromatic dispersion is expected to provide the largest contribution to the single-photon angular resolution of the aerogel.

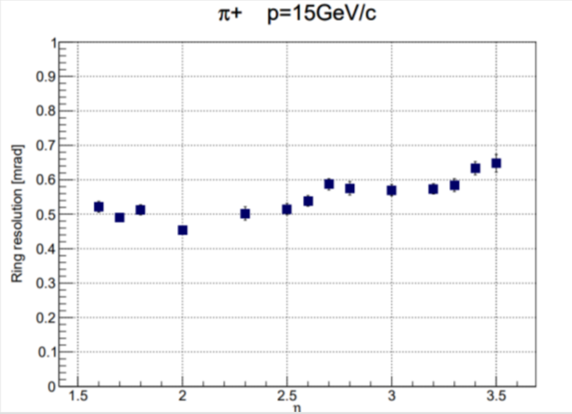
Its effect has been studied at different refractive index,

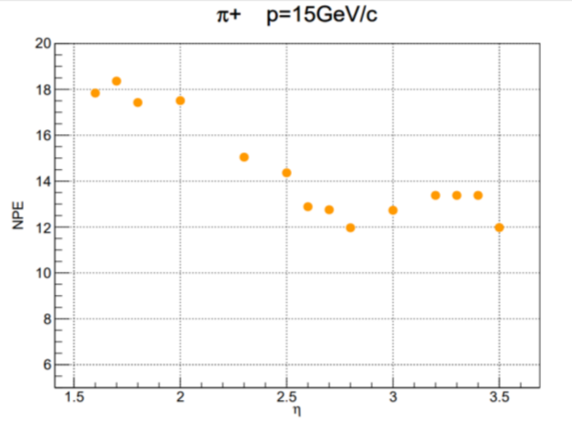
Performance Comparison of new Aerogel Type-1 (n=1.026)



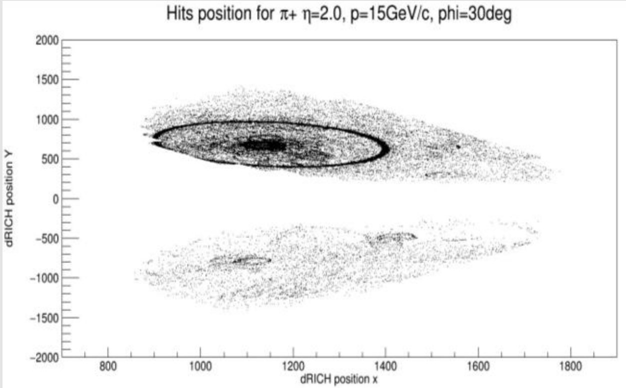
New type-1 Aerogel provides ring resolution capable to perform PID ~ 18-19 GeV (@eta=2.0), baseline aerogel is limited only upto 15-16 GeV

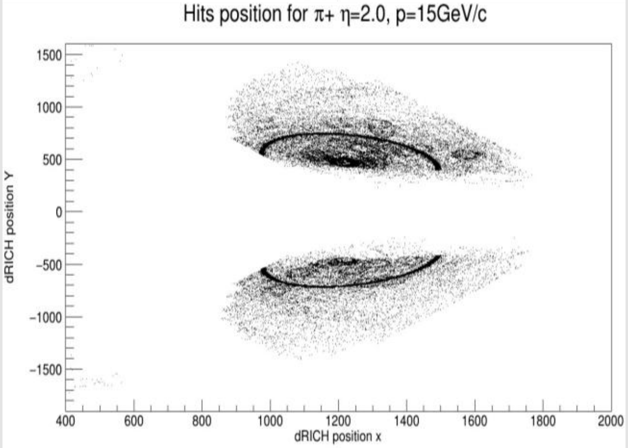
Performance Comparison of Aerogel Type-2 (n=1.03)



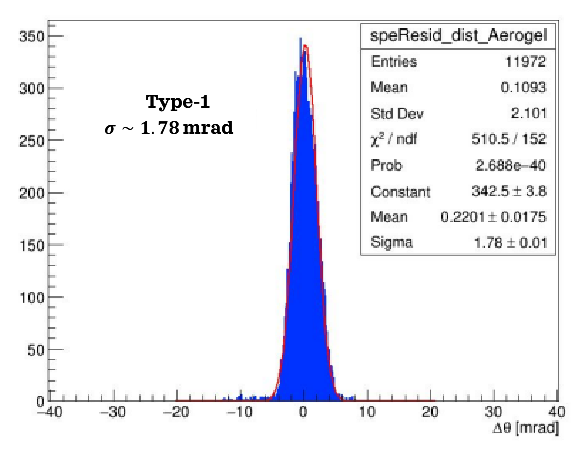


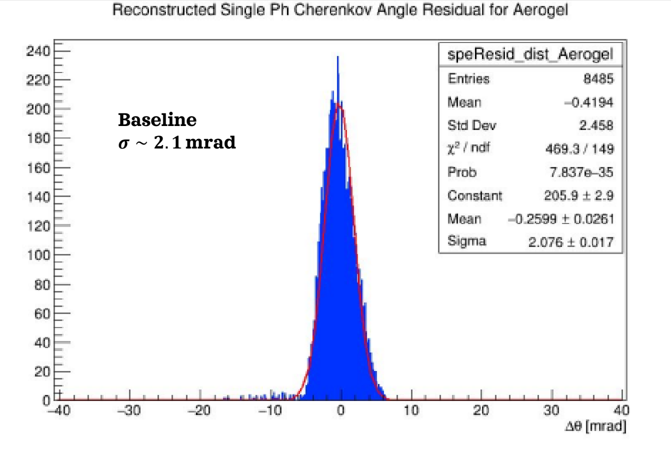
Pseudorapidity dependency is seen also for type-2 aerogel for fixed azimuthal angle

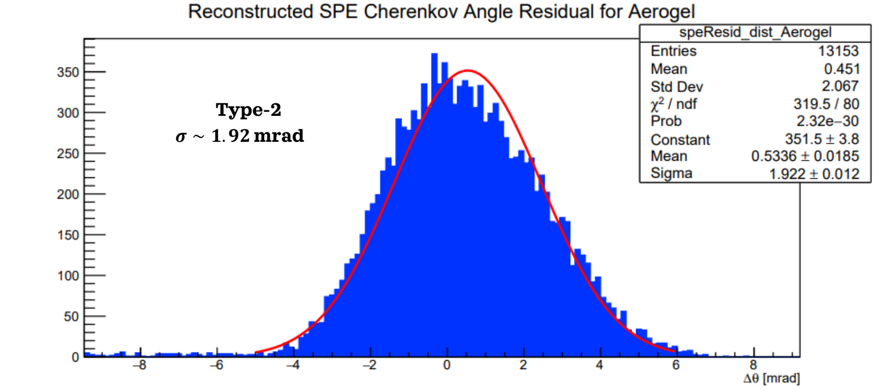




COMPARISON SPE TYPE-1 vs TYPE-2







Known Visualization issue in Geant4

Due to the well known Geant4 display issues with Boolean operations, the subtraction of the two solids operation cannot be visualized.

Boolean operation - subtract volumes
Geometry, Fields and Transportation

3.5k views 1 link

evc Sep 2019

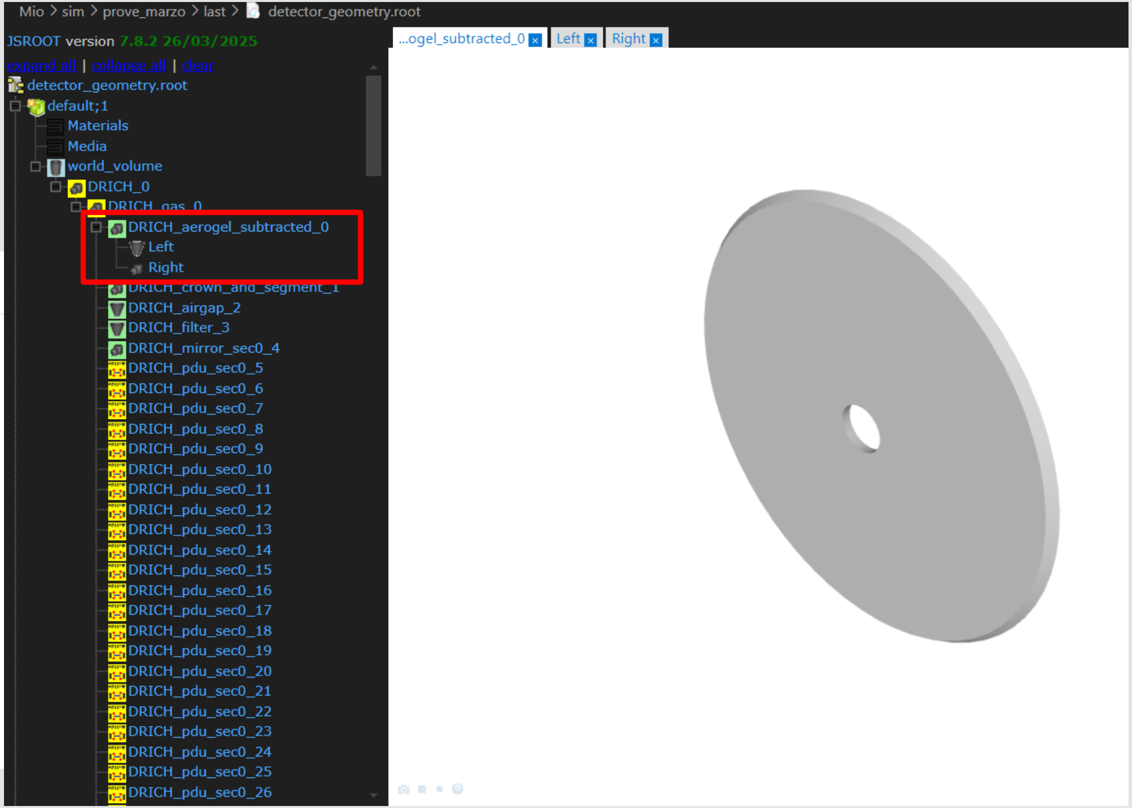
Dear Manuel,

It is a known problem in Geant4 visualization. You can get a correct image by using the RayTracer, which is based on the tracking algorithms of Geant4. For details please see the Geant4 Book for Application Developers, section Visualization.

However, it should be noted that a better way to define such kind of geometry is to define the smaller box (the hole) as a daughter volumes of the bigger box, instead of a Boolean subtraction.

Alternatively, in this particular case, you can also use G4Polyhedra.

Regards,
Evgueni



Known Visualization issue in Geant4

However, the RayTracer viewer is able to display this!!!!!!

So, NO PROBLEM here!