Aerogel counter with a Fresnel lens

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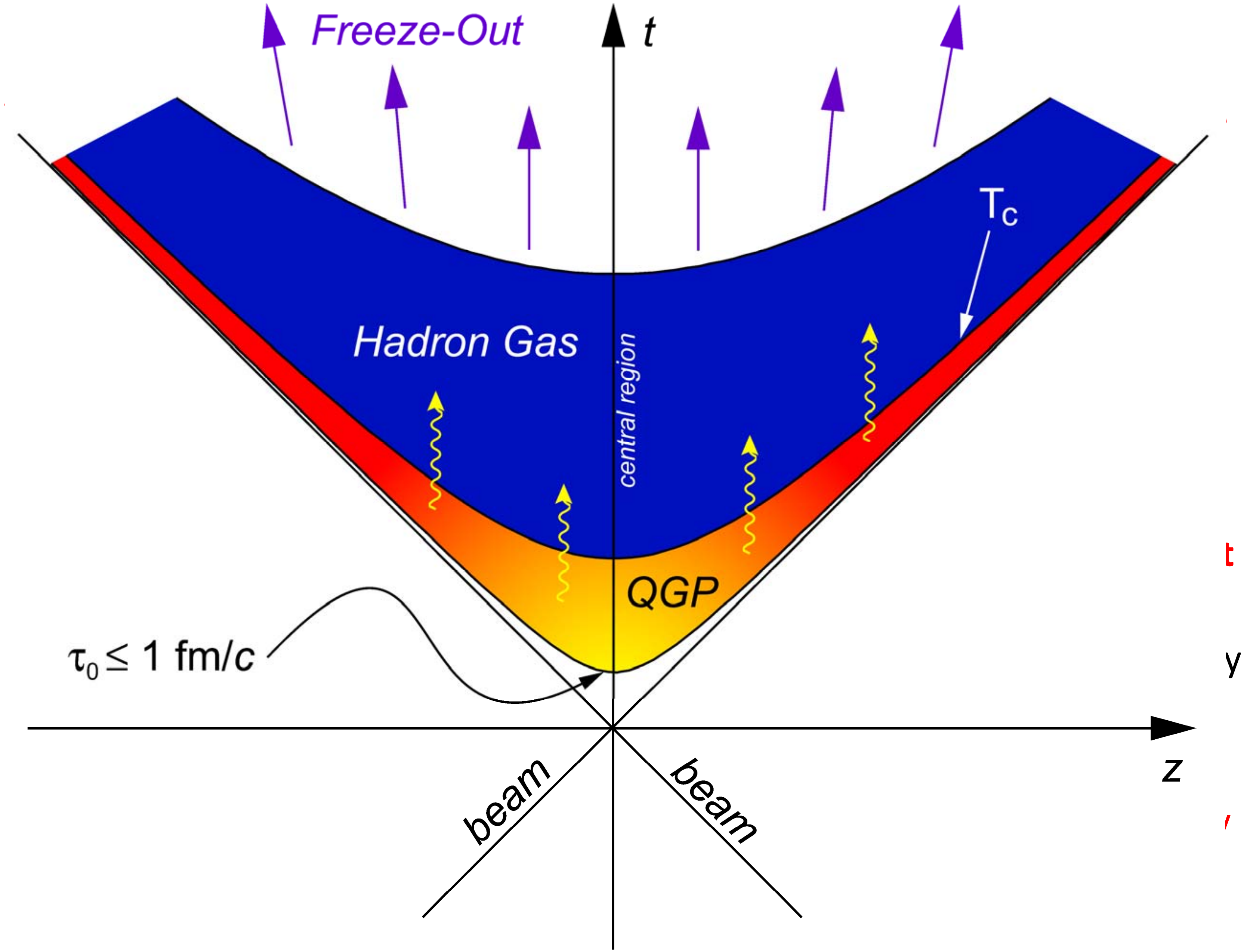
outline

- The physics case
- The constraint on the detector
- The principle of propagation and focalisation
- Results of prototypes with cosmics
- Results at the PS beam
- conclusions


Freeze-Out
t
T_c
Hadron Gas
central region
QGP
$\tau_0 \leq 1$ fm/c
z
beam
beam

The hadronisation scenarios

- The hadronisation of the thermal part happens according to the statistical model
- The hadrons issued from jets bear another way of hadronisation.
  - the hadronisation is assumed to occur outside the volume belonging to the thermal part. This is due to the fact the hadronisation length is given by E
  - Production independent of entourage
- The baryon puzzle at RHIC contradicts in the intermediate momentum range (2-6 GeV/c)

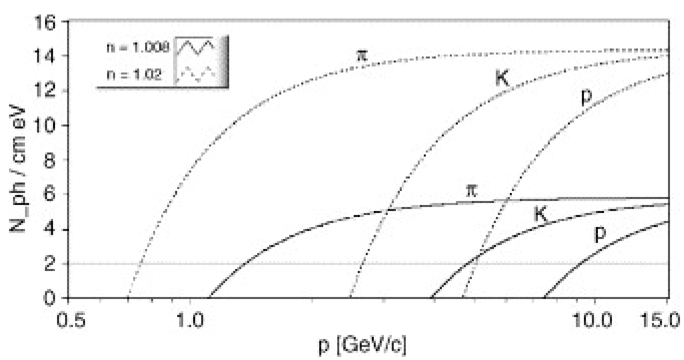
Predictions at LHC energies

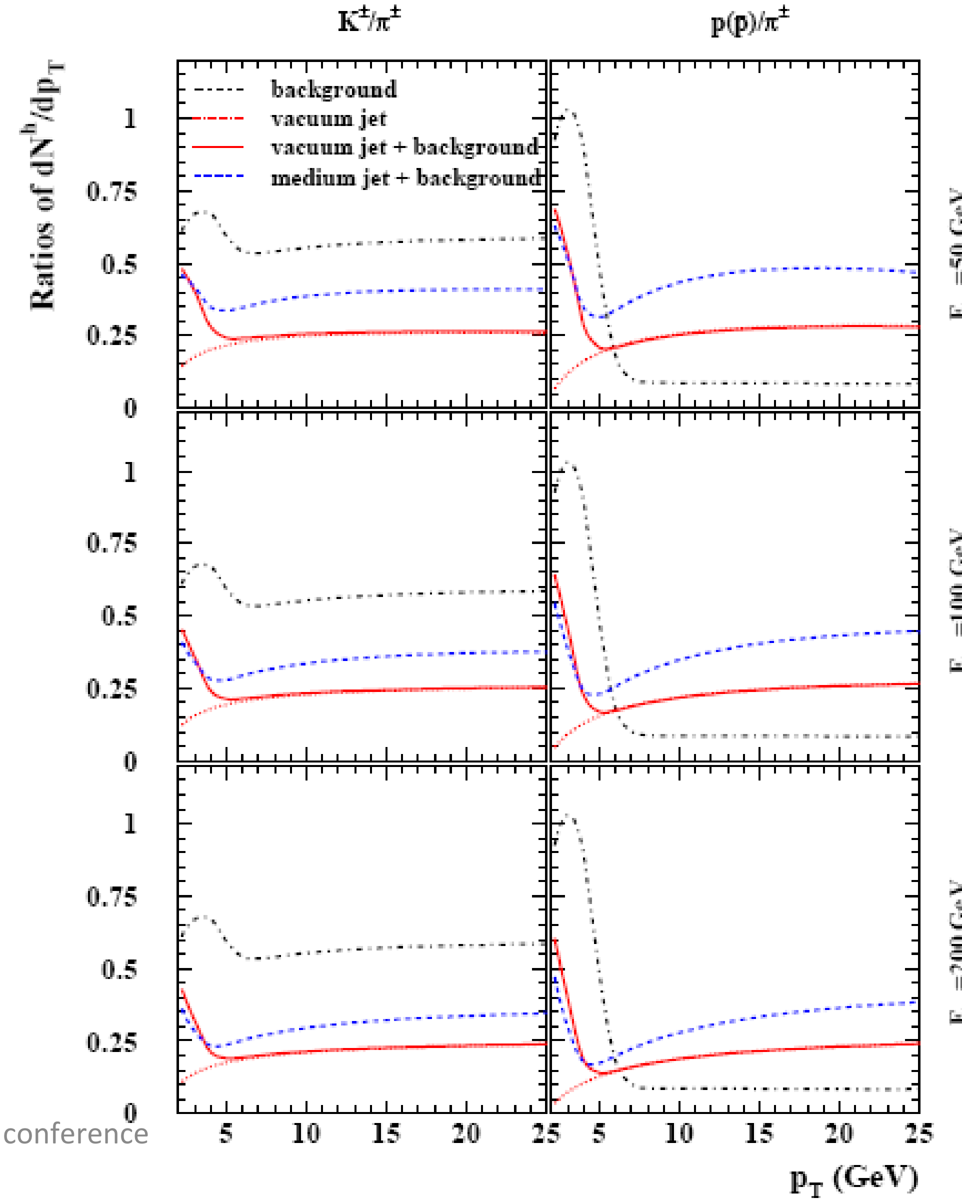
- Many models – not necessarily in agreement!

Change in hadrochemistry

Jet quenching can leave signatures not only in the longitudinal and transverse jet energy and multiplicity distributions, but also in the hadrochemical composition of the
jet fragments.

S. Sapeta and U. A. Wiedemann, arXiv:0707.3494 [hep-ph], July 2007.





Requirement on the detector

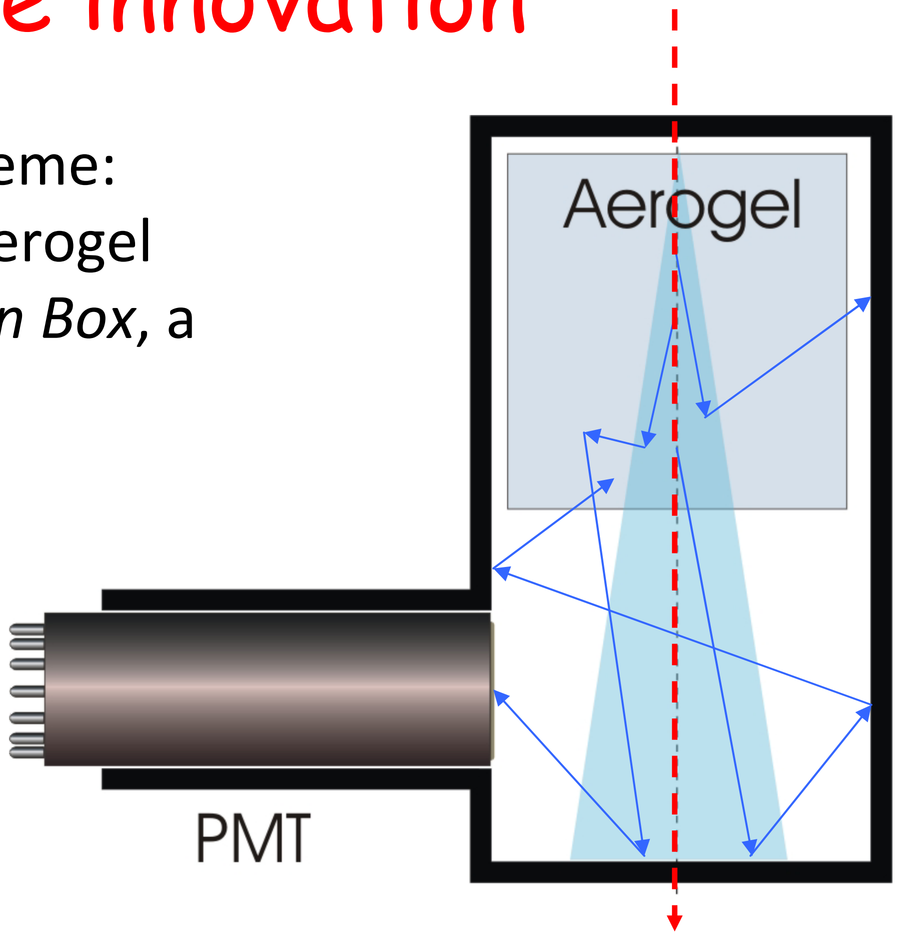
- *a silica aerogel radiator of a very small refraction index, n~1.01.*
- *operation Inside magnet*
  - The Fine-Mesh photomultipliers (FM-PMT) that can work in a magnetic field
- The challenge: minimize the number and size of the PMT while ensuring a good uniformity of acceptance over the aerogel surface.
-

Where is the innovation

- Traditional light collection scheme: Cherenkov light produced in aerogel scatters in the *Light Integration Box*, a fraction of light reaches the photomultiplier (PMT).
- Efficiency:

$$E_{int} = \frac{\epsilon}{1 - M(1-\epsilon)}$$

M – wall reflectivity (≈90% for teflon)
ϵ – PMT window relative area



3.0 inch PMT: Eff=22%
1.5 inch PMT: Eff=8%

} shows drastical dependence on the PMT size!

About photon production in aerogel

- The number of photons emitted by a charged particle of Z = 1 per unit path per unit wavelength depends on the particle velocity and the refraction index n(λ) of the medium and is given by:

$$\frac{\partial N^2}{\partial l \partial \lambda} = 2\pi\alpha \left(1 - \frac{1}{n^2(\lambda)\beta^2}\right) \frac{1}{\lambda^2}$$

the transparency of an aerogel is given by Rayleigh scattering, the cross-section of which scales as the 4th power of the photon energy.

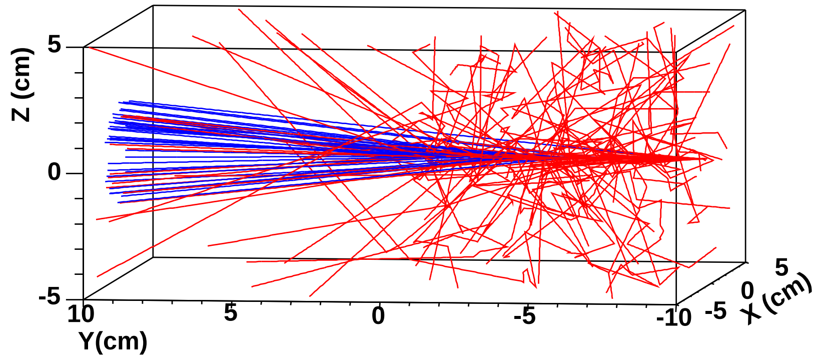
- It is usual to characterize the transparency of an aerogel by the photon mean free path at λ_0 = 400 nm.

$$L_{\mathrm{Ray}}(\lambda) = L_{\mathrm{Ray}}(\lambda_0)\left(\frac{\lambda}{\lambda_0}\right)^4$$

Good quality aerogel $L_{\mathrm{Ray}}(\lambda_0) = 4.5$ cm

Production of cherenkov photons

Two kinds of photons:



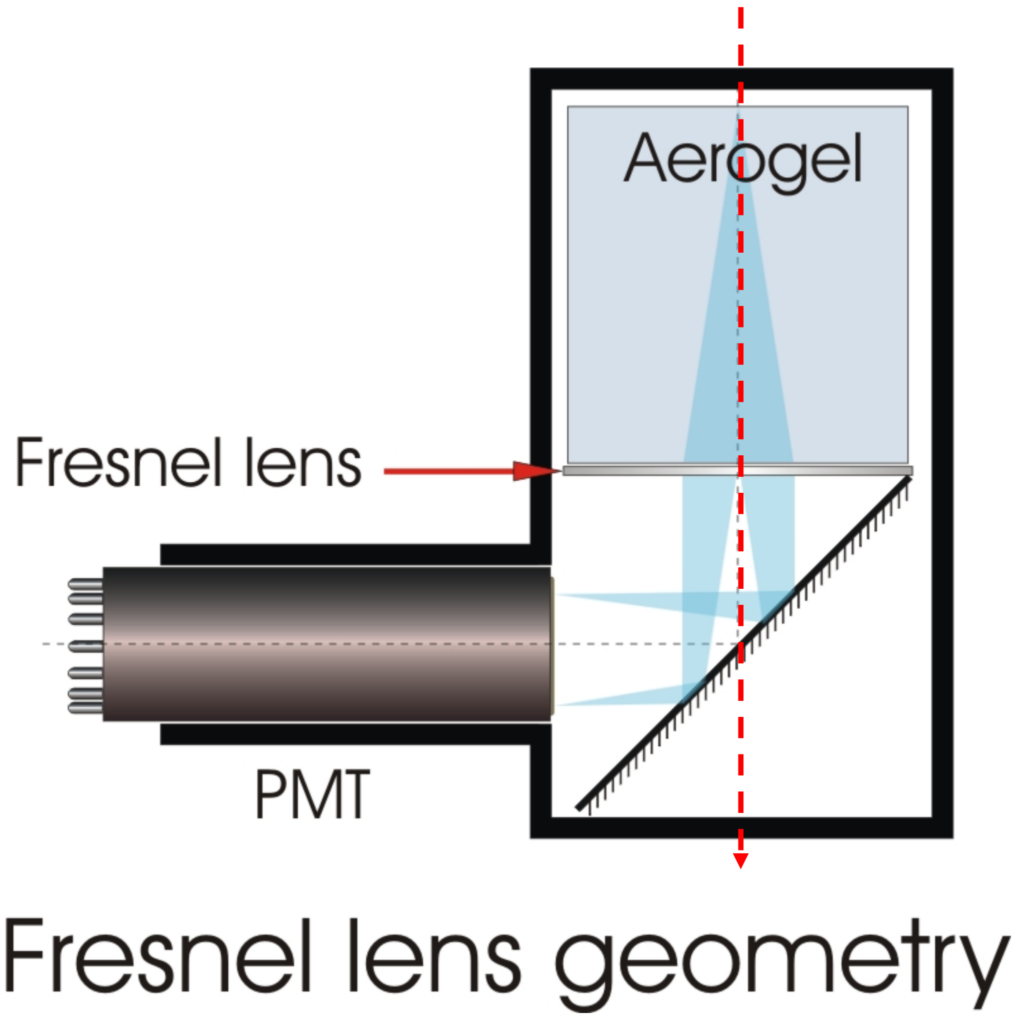
The number of photons in the wavelength interval *dλ* that escapes the aerogel directly without scattering is:

$$\frac{dN_{\mathrm{dir}}(\lambda)}{d\lambda} = \frac{\partial N^2}{\partial l \partial \lambda} \cdot \frac{L_{\mathrm{Ray}}(\lambda)}{n} \left[1 - \exp(-nL/L_{\mathrm{Ray}}(\lambda))\right]$$

Integrating:

$$N_{\mathrm{pe}} = \int_{\lambda_{\mathrm{min}}}^{\lambda_{\mathrm{max}}} \frac{dN_{\mathrm{dir}}(\lambda)}{d\lambda} \cdot \mathrm{QE}(\lambda) \cdot \mathscr{E}_{\mathrm{opt}} \cdot d\lambda$$

Light collection scheme with a Fresnel lens.



- The Fresnel lens is placed right under the aerogel block
- The focal length equals to the optical path between the lens and the PMT
- The lens focuses the unscattered photons on to the PMT window

Cherenkov light emission and passage through the aerogel (absorption)

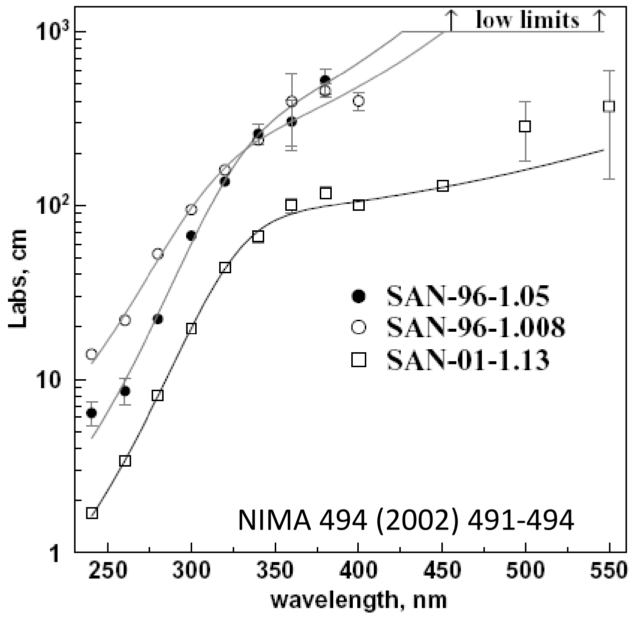
Light emission spectrum

$$\frac{dN}{dl} = 2\pi\alpha\left(1 - \frac{1}{n^2(\lambda)\beta^2}\right)\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

The spectral density goes as ~$1/\lambda^2$, the majority are short-wavelength photons.

Light absorption

- L_{abs}>1m for λ>350 nm
  ➔ is quite small.



Cherenkov light emission and passage through the aerogel (scattering)

Light scattering is dominated by

- Rayleigh scattering, $L_{scat} \sim \lambda^4$

➔ Short-wavelength photons scatter more

Flat aerogel block transmission : $T \sim \exp(-1/\lambda^4)$

Average transmission factor for the photons emitted along the particle path in the aerogel:

$$T = \int_0^d \exp\left(-\frac{n \cdot x}{L_{scat}(\lambda)}\right) dx = \frac{L_{scat}(\lambda)}{d \cdot n}\left(1 - \exp\left(-\frac{n \cdot d}{L_{scat}(\lambda)}\right)\right)$$

d – aerogel block thickness,

n – refraction index

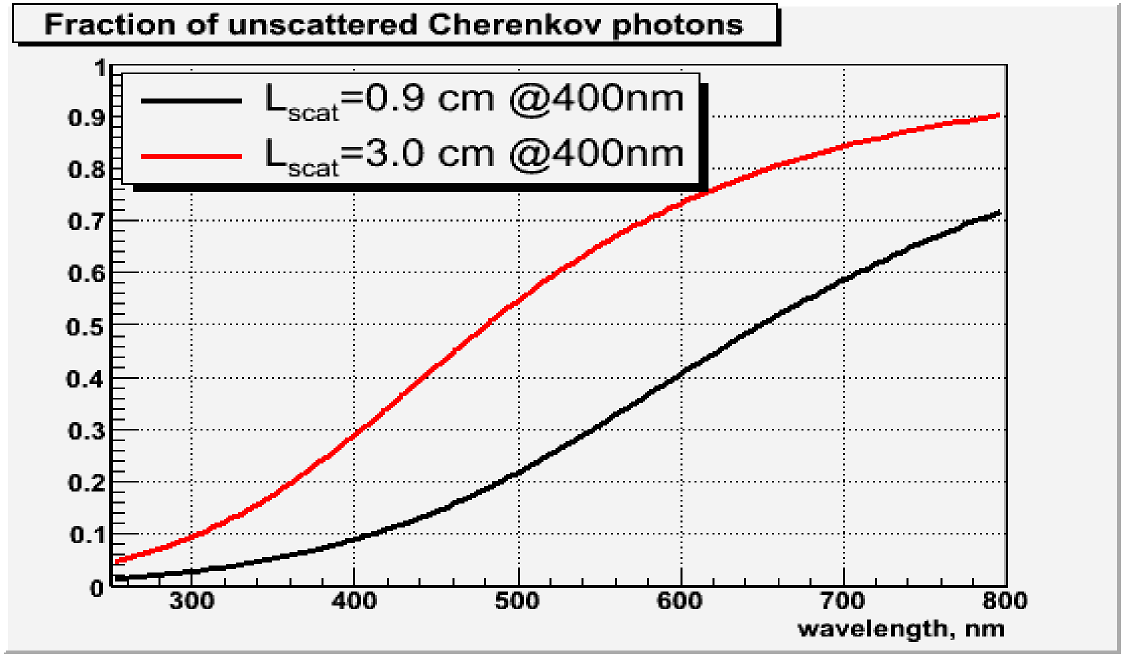
Cherenkov light transmission

Available Matsushita Electric Works aerogel sample “SP-30”, produced in 2003.

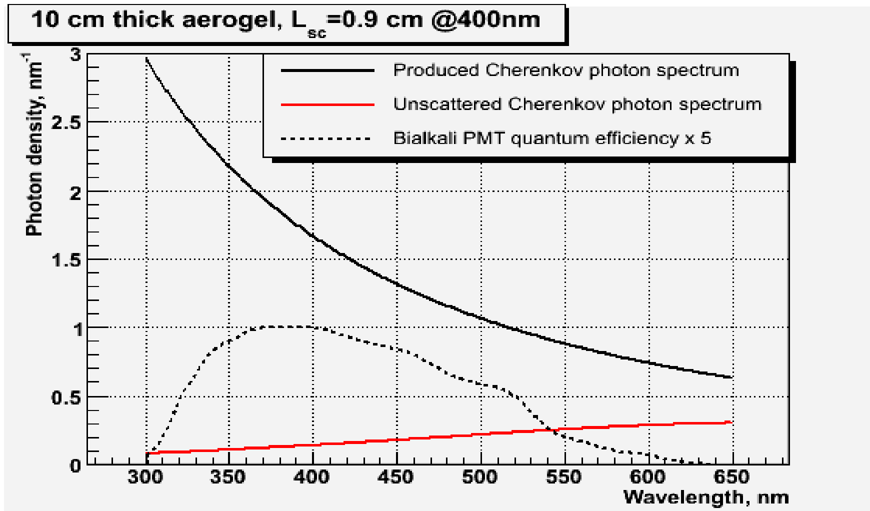
n=1.030, L_{scat}=0.9 cm @400nm, it is not very transparent.

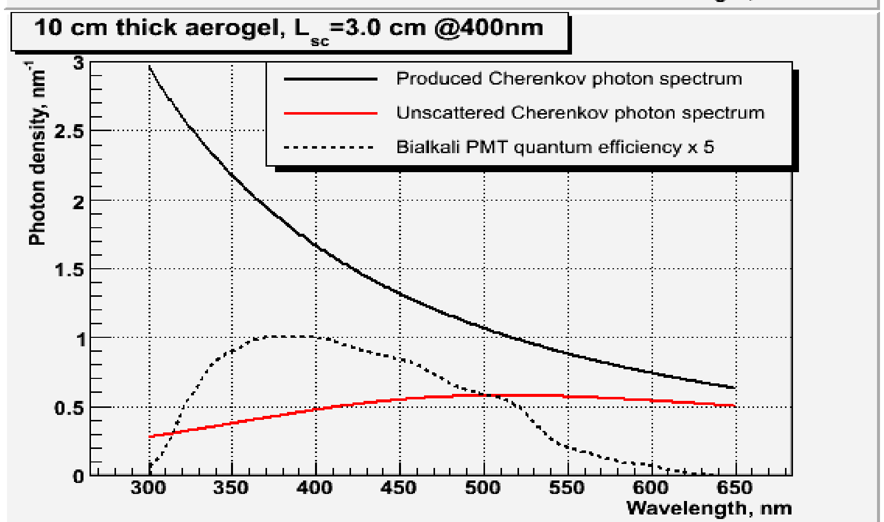
Nowadays produced SP-30 has a better optical quality:

L_{scat}>3.0 cm @400nm



Transmitted photon spectrum





Available aerogel sample, L_{scat}=0.9 cm @400nm;

6 photoelectrons (due to unscattered photons), expected with a PMT with bialkali photocathode.

Aerogel of higher transparency, L_{scat}=3.0 cm @400nm;

18 photoelectrons (due to unscattered photons),
➔3 times as much!

prototype

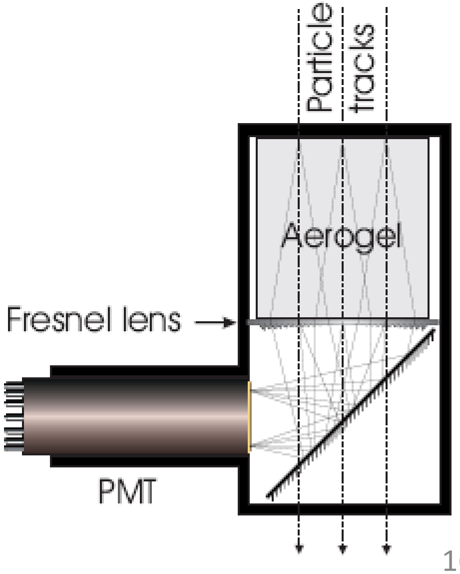
- the Cherenkov light emitted in a cone is focused by a Fresnel lens into a ring that fits into a PMT window.
    - For vertical particle tracks, the location of the ring does not depend on the impact point of the track.
- The PMT window is located in the focal plane of the lens
- The Fresnel lens was produced by Edmund Optics (part number NT32-684)

and has F=5 inch focal distance and 10 cm diameter.

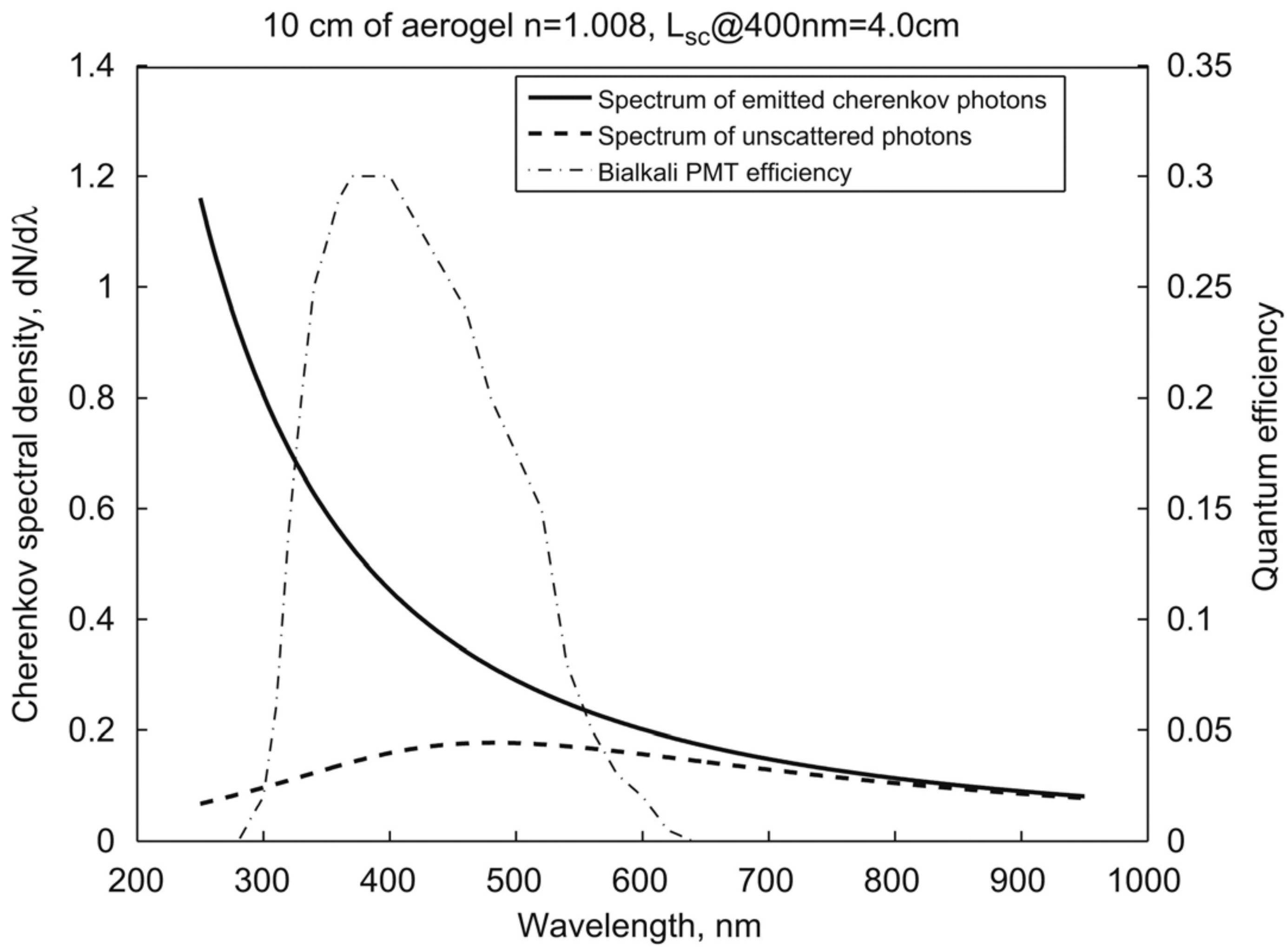
Note:

the lens material has refraction index *n = 1:49, the Cherenkov threshold in the lens is much lower than in the* aerogel, and this may produce a background signal.

The walls were covered by black paper to absorb these photons

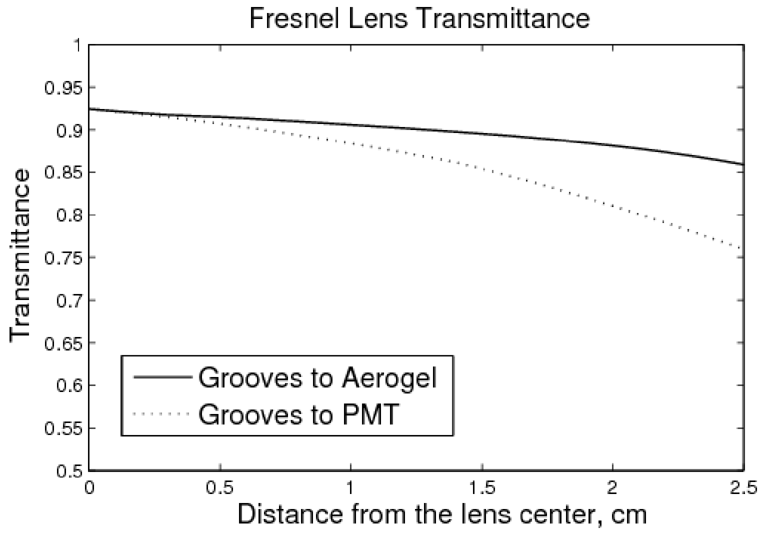


Spectrum of photons & PMT



Light transmittance through the Fresnel lens

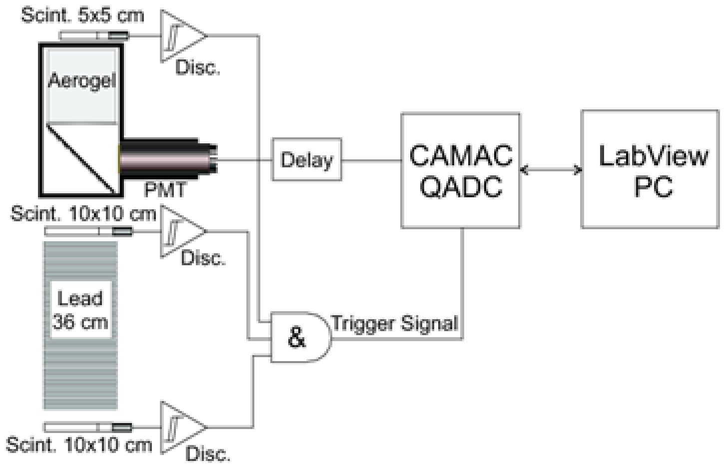
- losses of the Cherenkov light in the Fresnel lens:
  - absorption light in the lens,
  - light reflection at the lens surface and a multiple refraction of photons on the lens grooves.
    - the lens - optical grade acrylic, transparent in the visible and near-infrared region and has a short-wavelength cut-off at 350 nm.

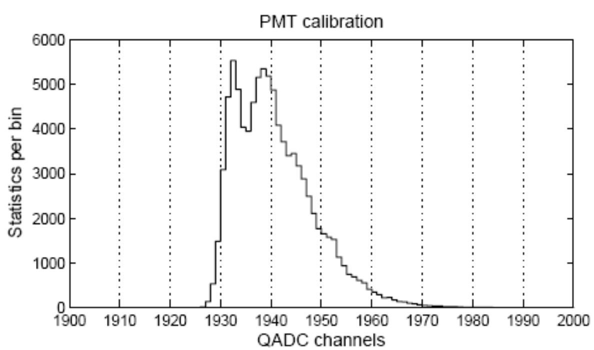


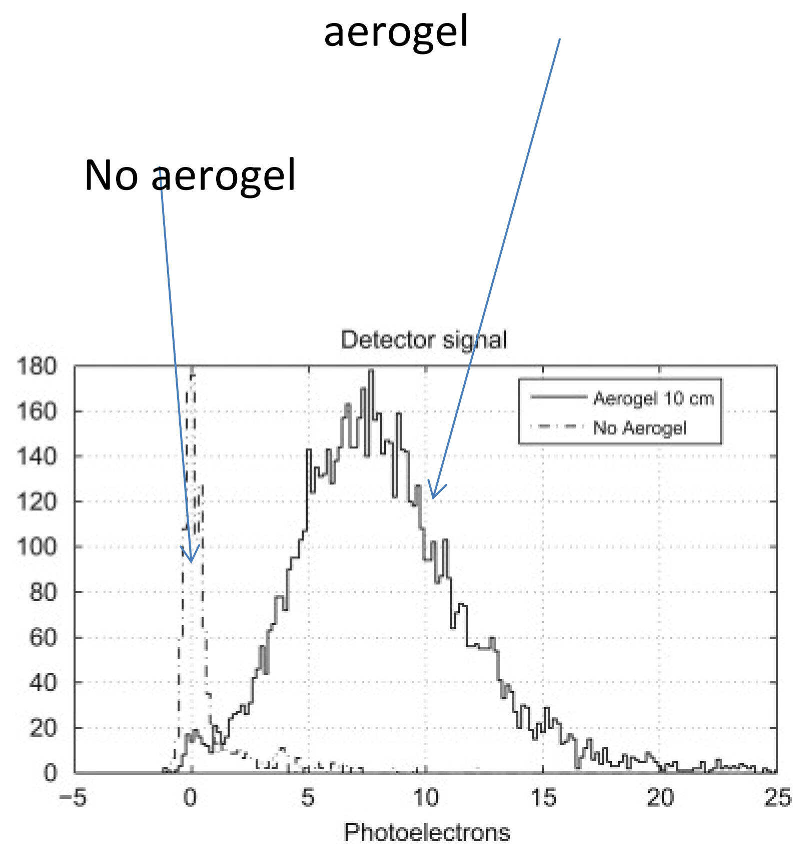
The ring diameter and the PMT

- **Aerogel n=1.03**
- Cherenkov cone half-opening angle θ for particles of β~*1 : 0.24 rad,*
- F=5" Fresnel lens -
  - Ring diameter d=61 mm at the PMT window, fitting the 3" PMT
- **Aerogel *n = 1:008***, *the opening angle θ = 0.126 rad*
  - *Ring diameter would be around 32 mm, which* fits into a 1.5" Fine-Mesh PMT window.

Cosmic muon setup and results

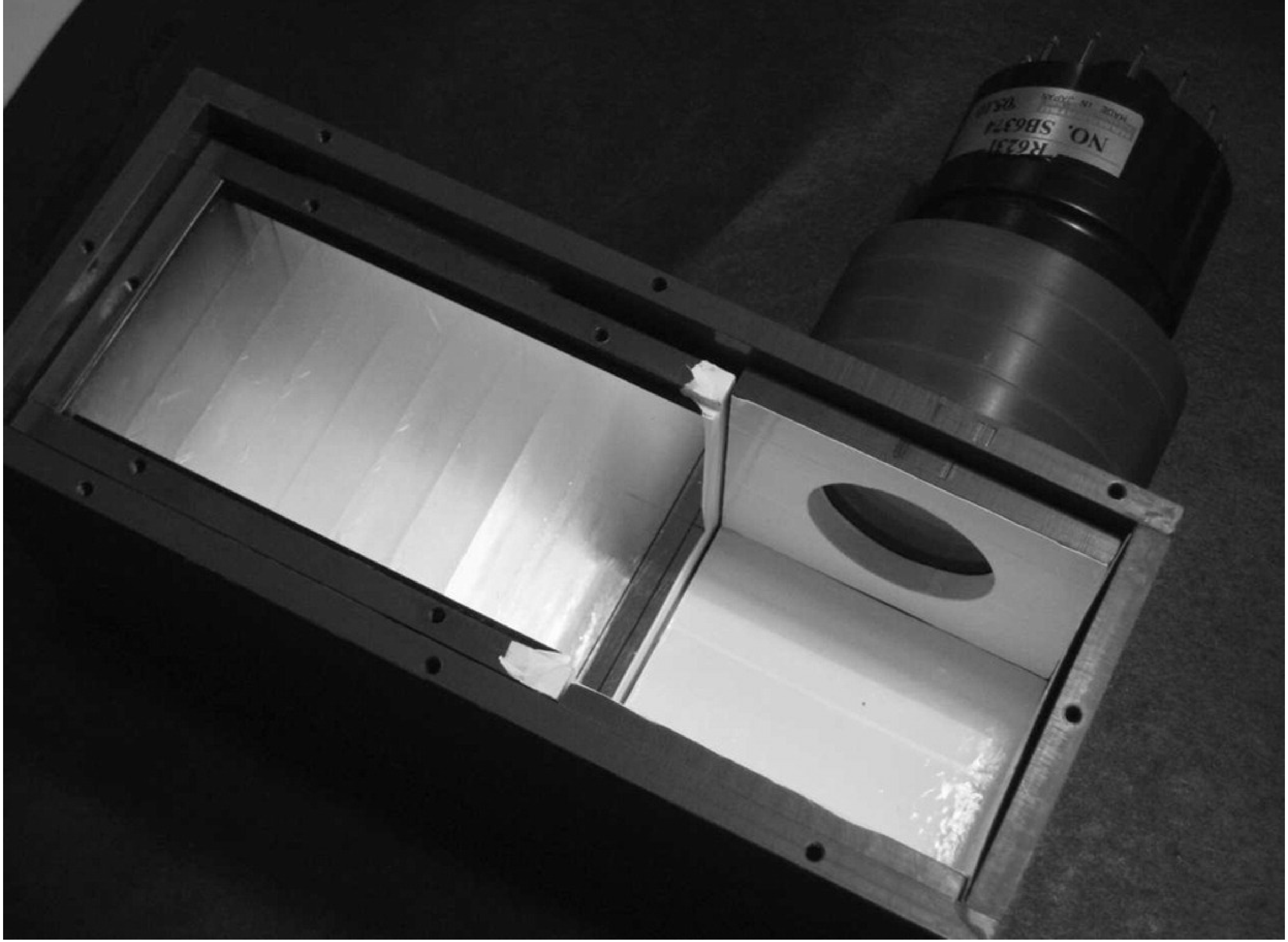




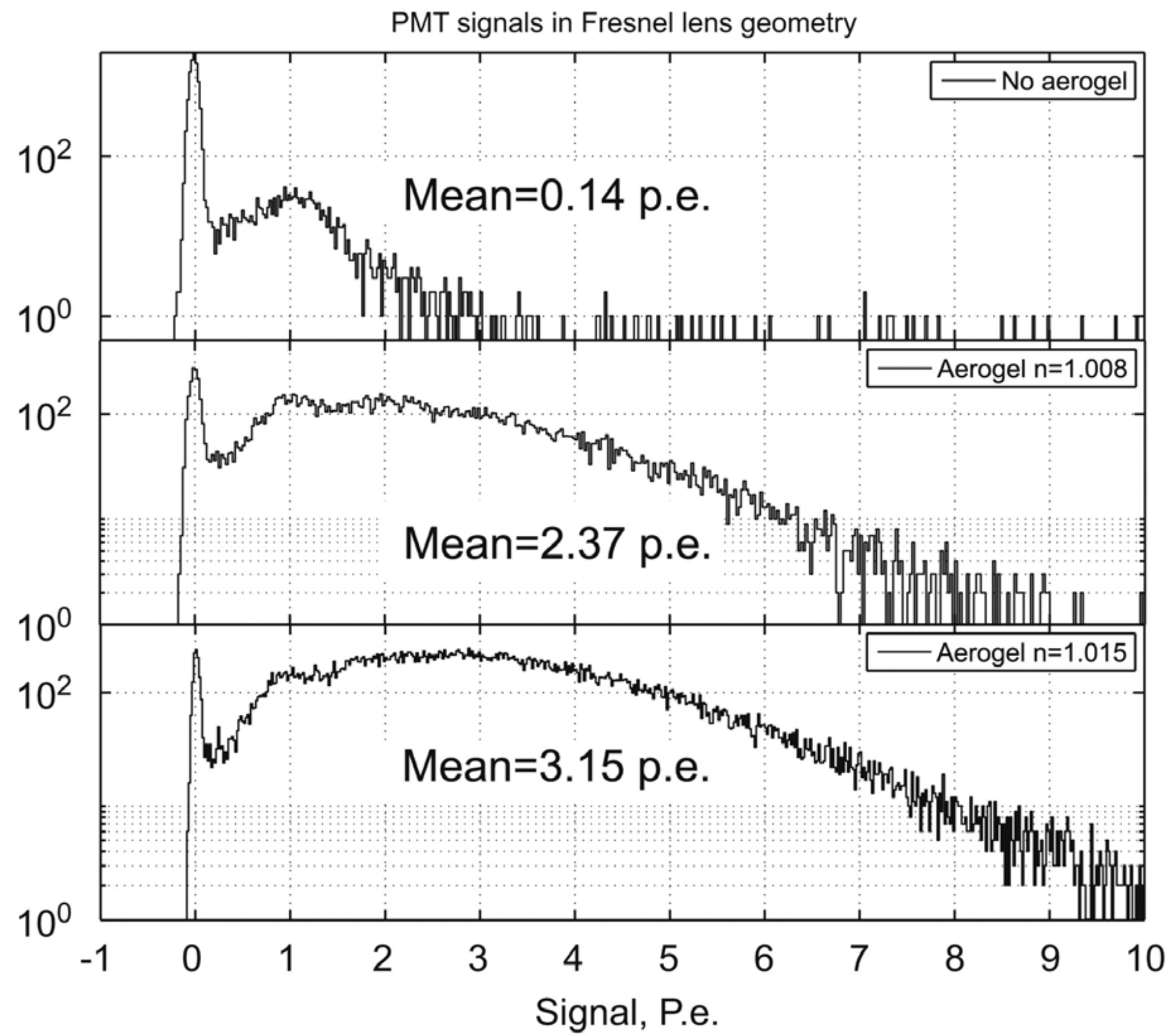


Results with aerogel 1.015 and 1.008

- Particle tests at PS accelerator aerogel samples of n=1.015 and 1.008.
- For both aerogels we used a Fresnel lens with focal length and a 2-in. PMT.
- The diameters of the Cherenkov rings are 25 and 18 mm for n=1.015and 1.008, respectively. The active diameter of the PMT photocathode was 52 mm. We were using masks of various diameters put in front of the PMT window to measure the efficiency of the light collection as a function of the PMT effective diameter.

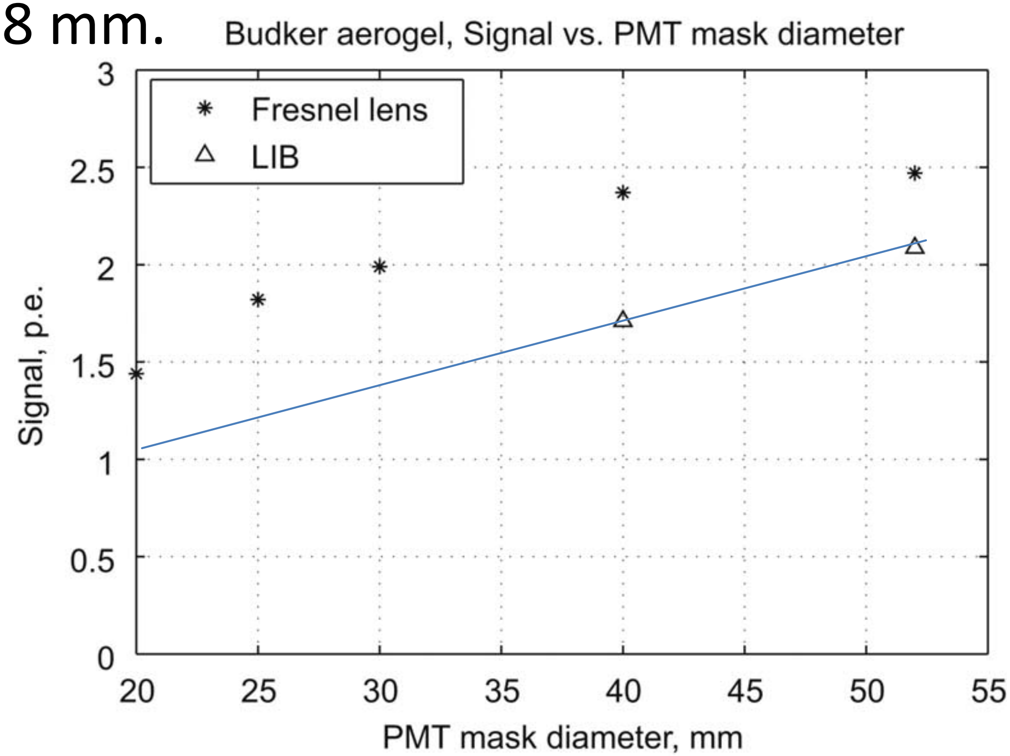


Results for 6 GeV pions @ PS

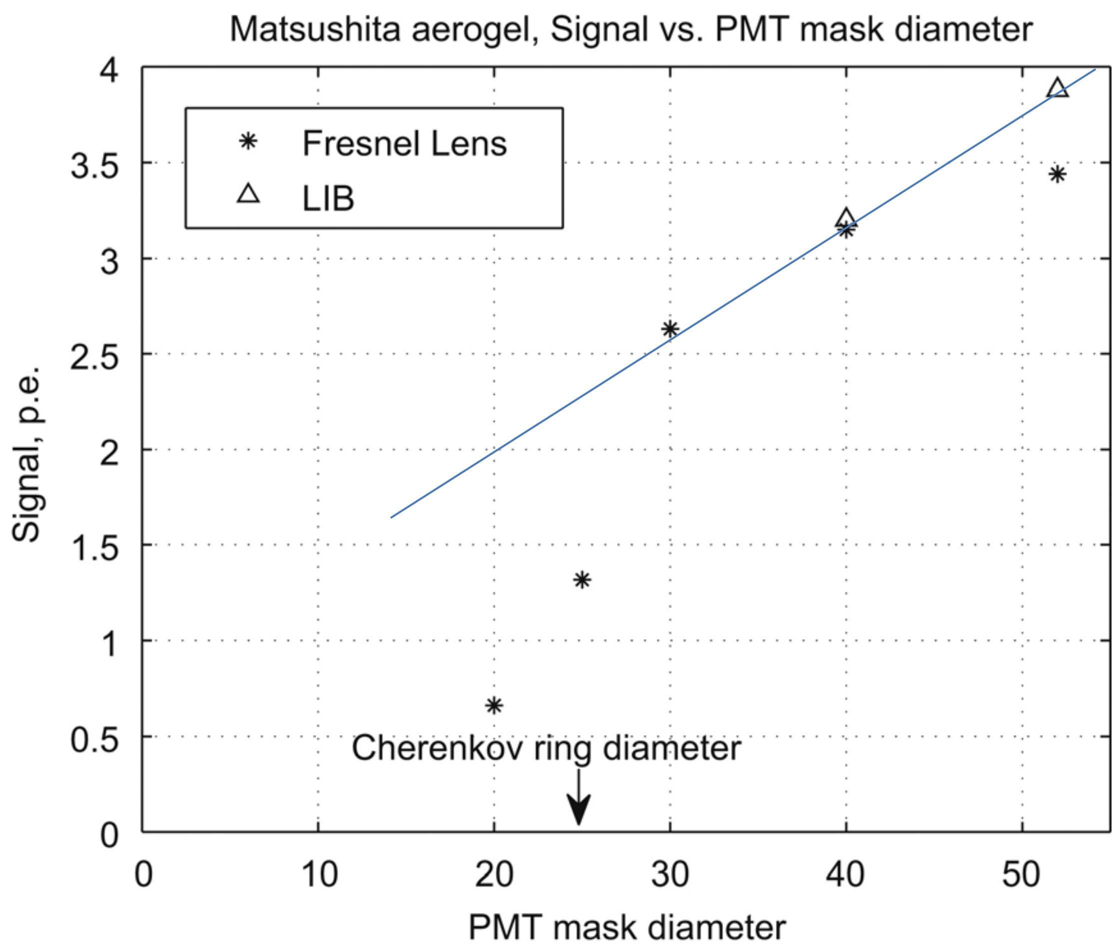


Signal vs. the PMT mask diameter

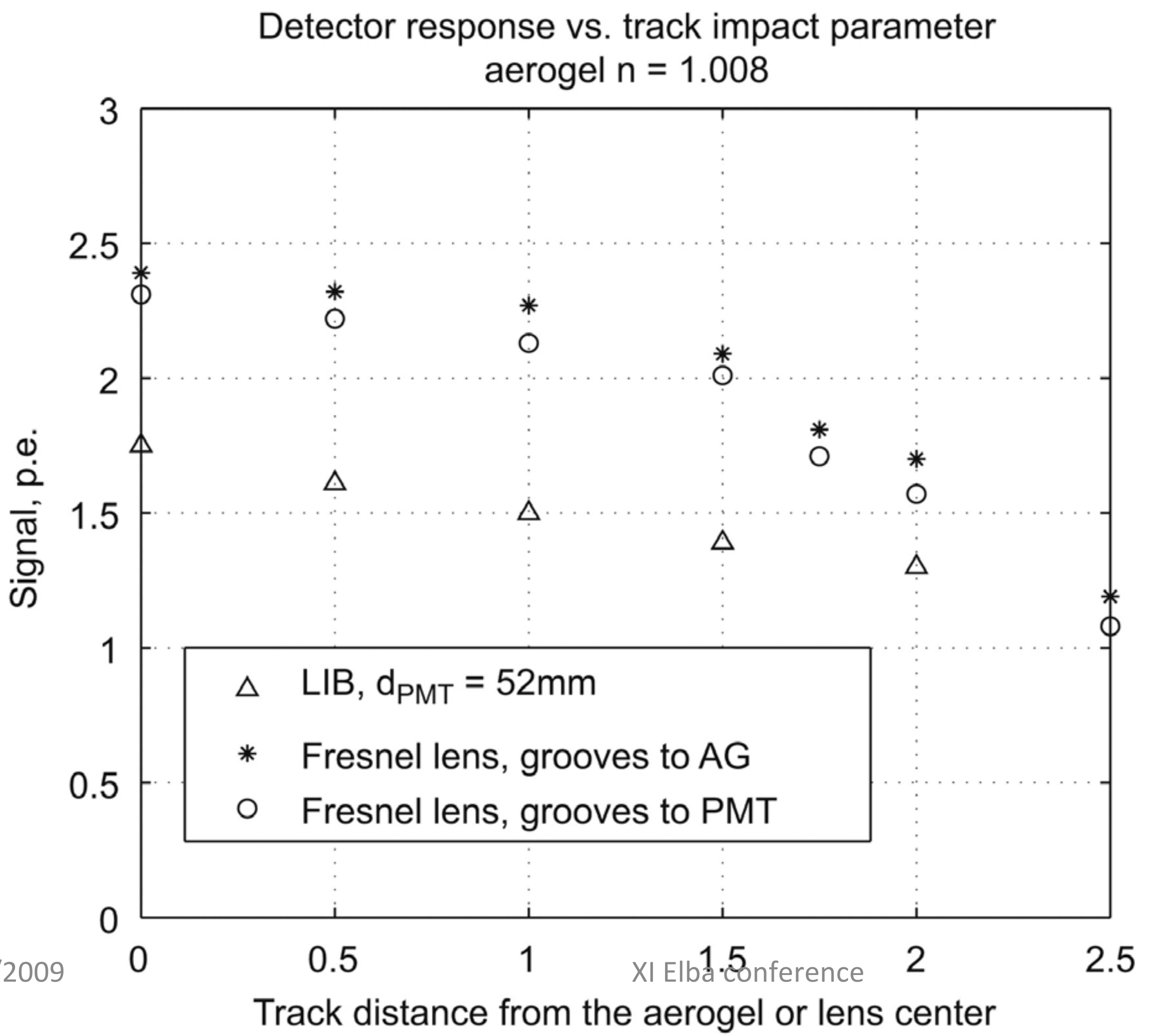
Signal collected with Fresnel lens and LIB, aerogel *n*=1.008, as a function of the PMT effective diameter. The size of the Cherenkov ring for this aerogel is 18 mm.

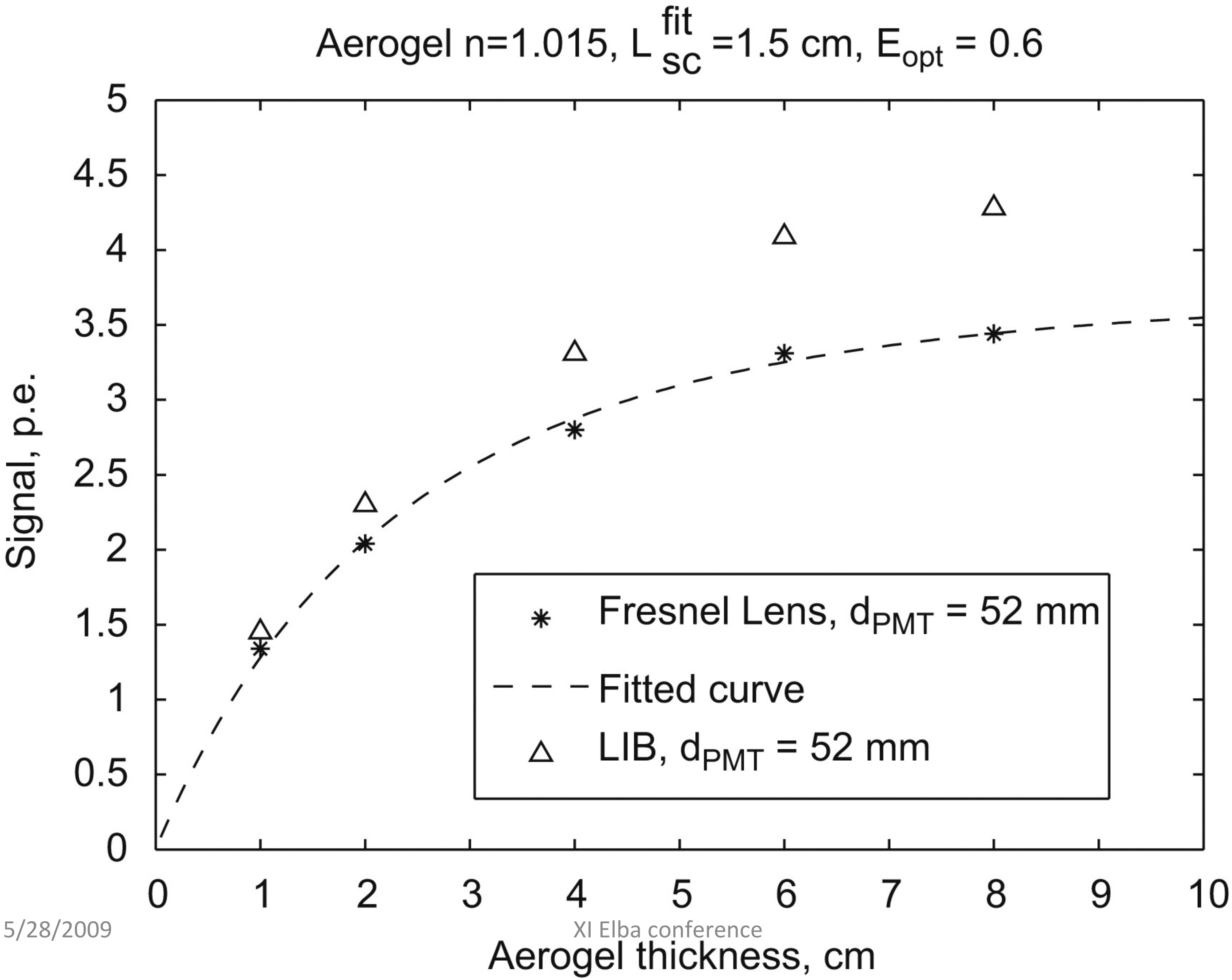


Signal collected with Fresnel lens and LIB, aerogel *n*=1.015, as a function of the PMT effective diameter. The size of the Cherenkov ring for this aerogel is 25 mm.



Position dependence of the output signal




Aerogel n=1.015, L fit sc =1.5 cm, E opt = 0.6
Signal, p.e.
Aerogel thickness, cm
Fresnel Lens, d PMT = 52 mm
Fitted curve
LIB, d PMT = 52 mm
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10

Possible improvements

- Better quality aerogel.
  - With state of the art aerogels of 1.015 we would get twice better signal
- Fresnel lens made of UV-transparent acrylic, increasingthe photon yield by ~ 20 %.
- Machine the flat part of the lens to reduce the background
- multialkali photocathode instead of the bialkali.
  - The multialkali photocathode has a wide spectral sensitivity range, from ultraviolet to near infrared region around 850 nm, which is particulary beneficial because long-wavelength Cherenkov photons undergo much less scattering in the aerogel,

Conclusion

- The use of aerogel in conjunction with Fresnel lenses has been studied.
- The results show that for n< 1.015 one may get satisfactory results focusing onto a small PMT
- With better aerogel and Fresnel lenses promising results could be achieved.