Polarization as a Tool in Calorimetry

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(DREAM)

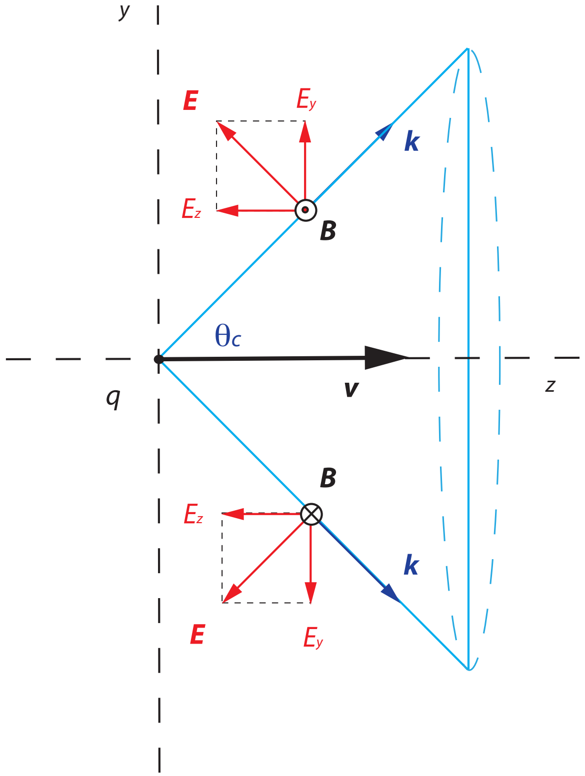
Cherenkov Radiation in Calorimetry

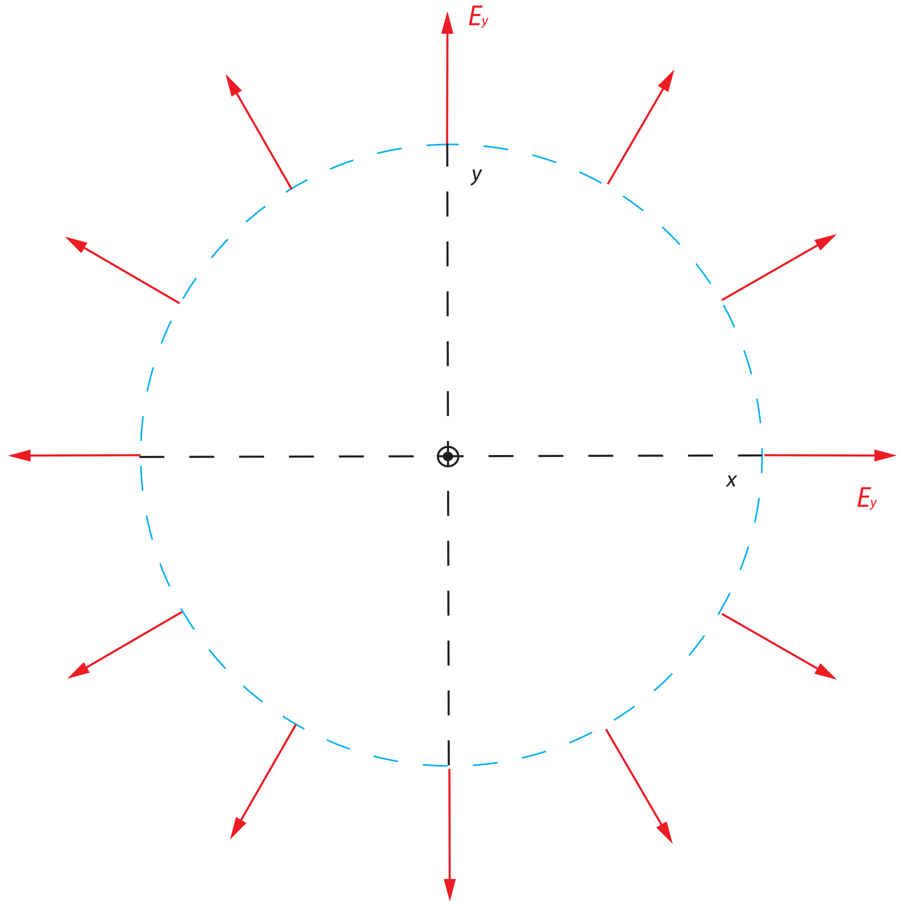
Cherenkov light is produced by charged particles above the Cherenkov threshold (~200 keV for electrons and ~400 MeV for protons in quartz). In calorimetry, this is essentially the electromagnetic core of showers.

Separation of Cherenkov light from scintillation light is possible by exploiting its unique features in different ways as done in dual readout schemes:

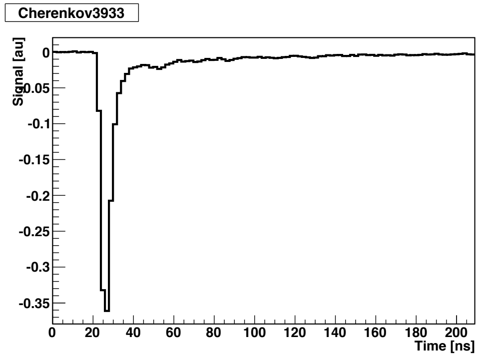
1. Directionality: Cherenkov light is directional *vs* scintillation light is isotropic
2. Temporal signal structure: Cherenkov light is nearly prompt *vs* scintillation light is a result of molecular transitions in 1-100's ns
3. Spectral signal structure: Cherenkov light is continuous ($1/\lambda^2$) *vs* scintillation properties depend on material
4. Polarization: Cherenkov light is polarized *vs* scintillation light is unpolarized

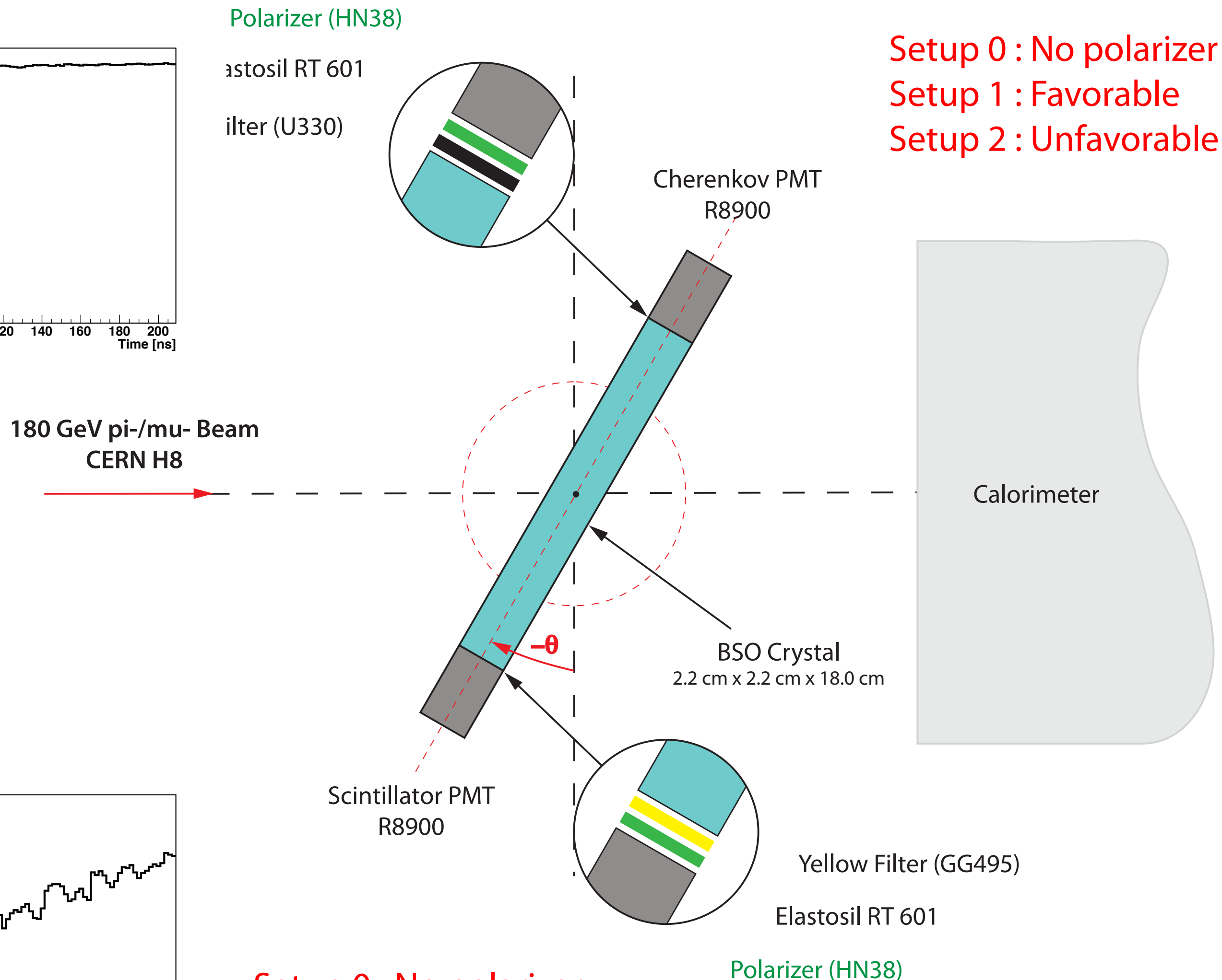
Cherenkov Radiation and Polarization - I



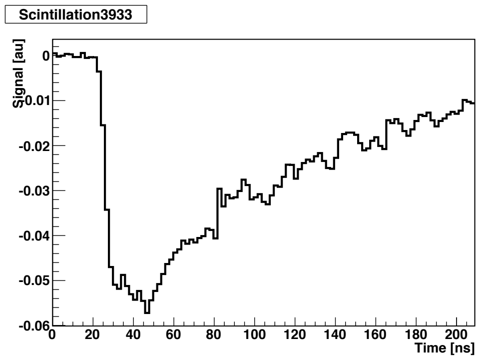


Measuring Cherenkov Polarization in Three Steps





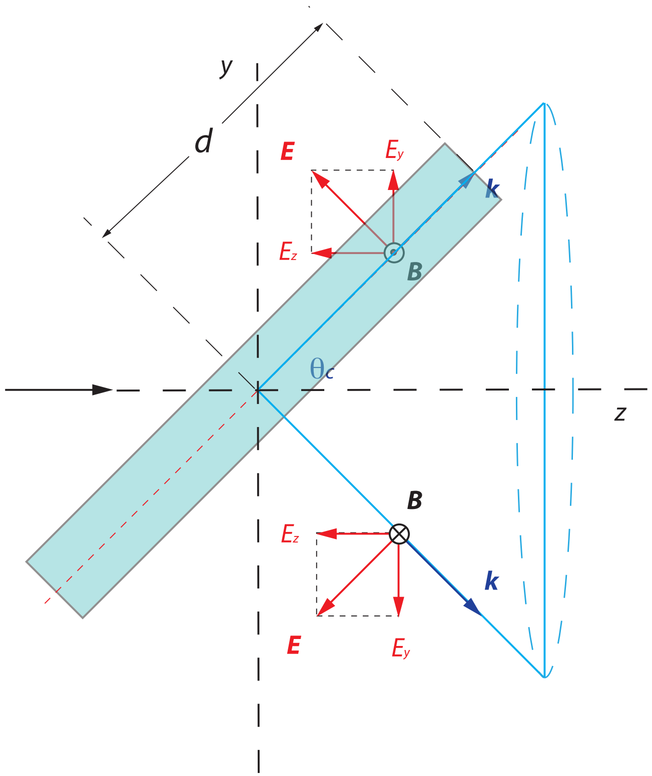
Setup 0 : No polarizer
Setup 1 : Favorable
Setup 2 : Unfavorable



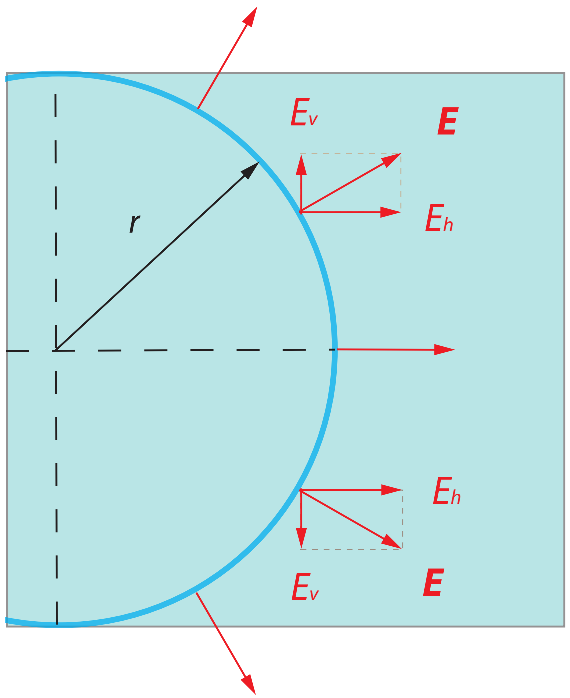
Setup 0 : No polarizer
Setup 1 : Favorable
Setup 2 : Favorable

Cherenkov Radiation and Polarization - II

$$r = d \sin \theta_C$$



TOP VIEW



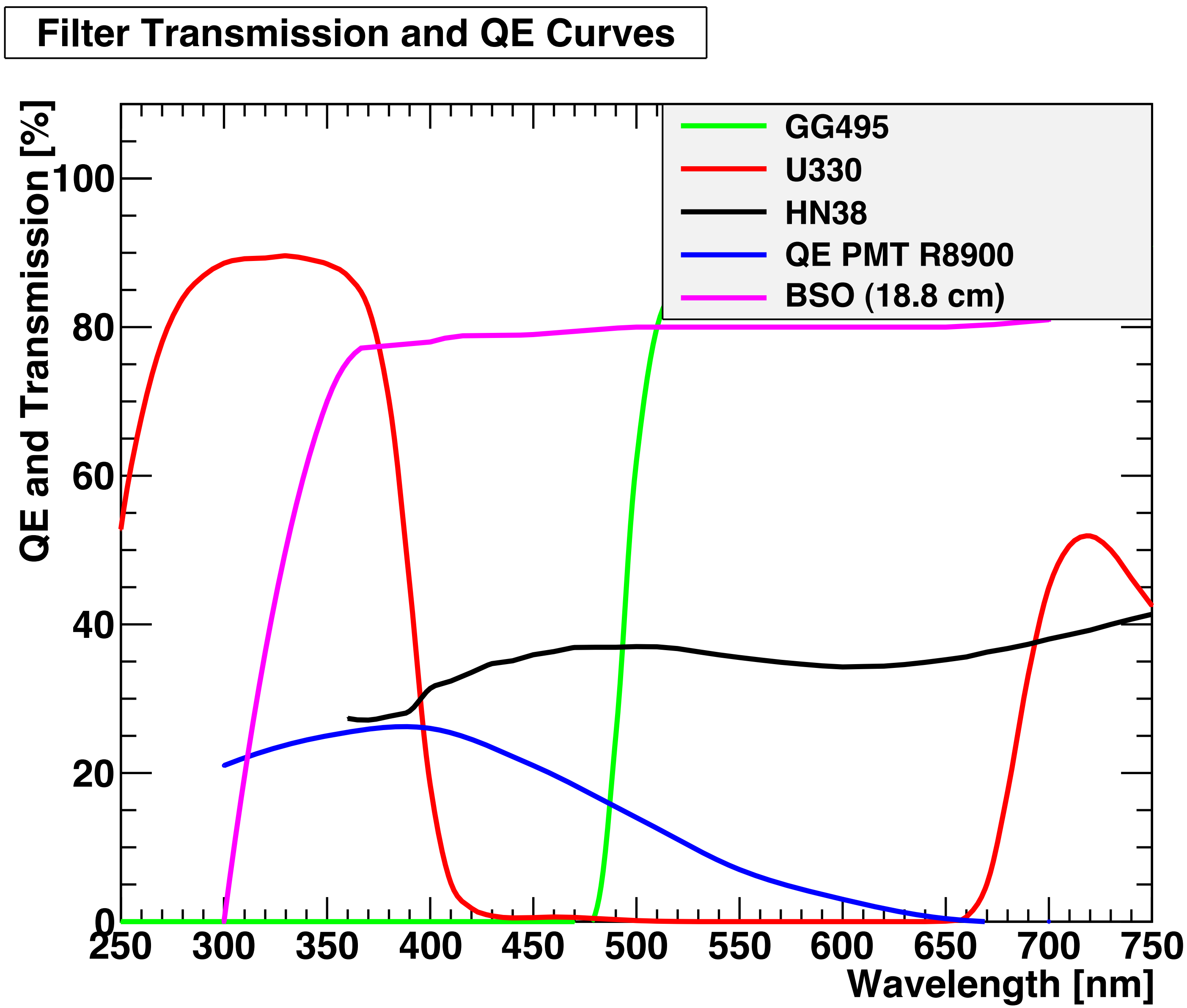
END VIEW
"As PMT views it"

BSO ($Bi_4Si_3O_{12}$) Crystal - I

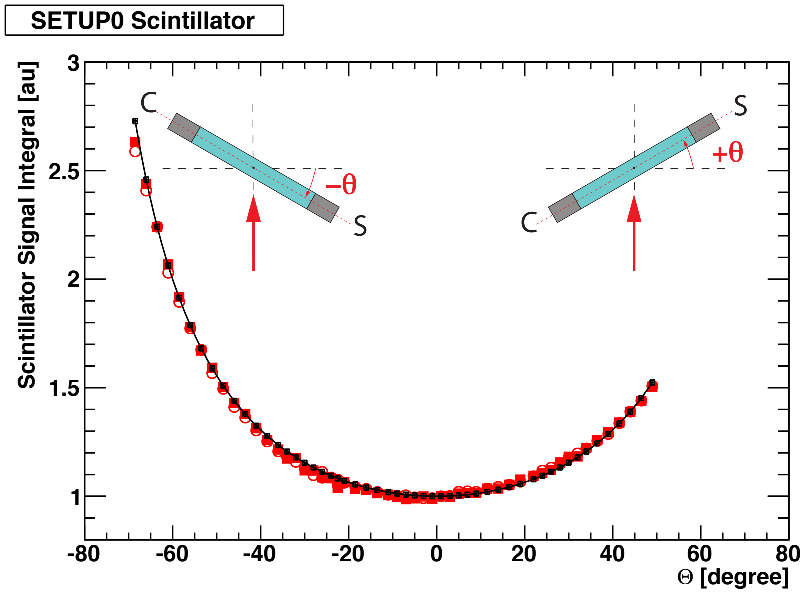
	BSO	BGO	PWO
Density (g/cm^3)	6.80	7.13	8.28
Radiation length (mm)	11.5	11.2	8.9
Decay time (ns)	~100	~300	~10
Peak emission (nm)	480	480	410-500
Relative light output	0.04	0.1	0.01
Refractive index	2.06	2.15	2.20
Cherenkov angle (^{o})	61	62	63

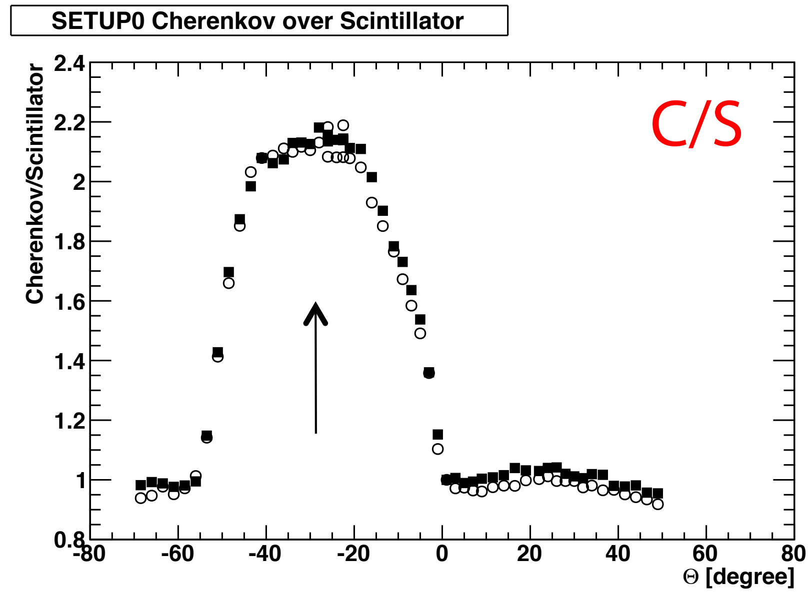
Any transparent medium with a refractive index will generate Cherenkov light when a relativistic charged particle traverses it. In this study, a BSO crystal is used as an example because the spectral characteristics proved convenient.

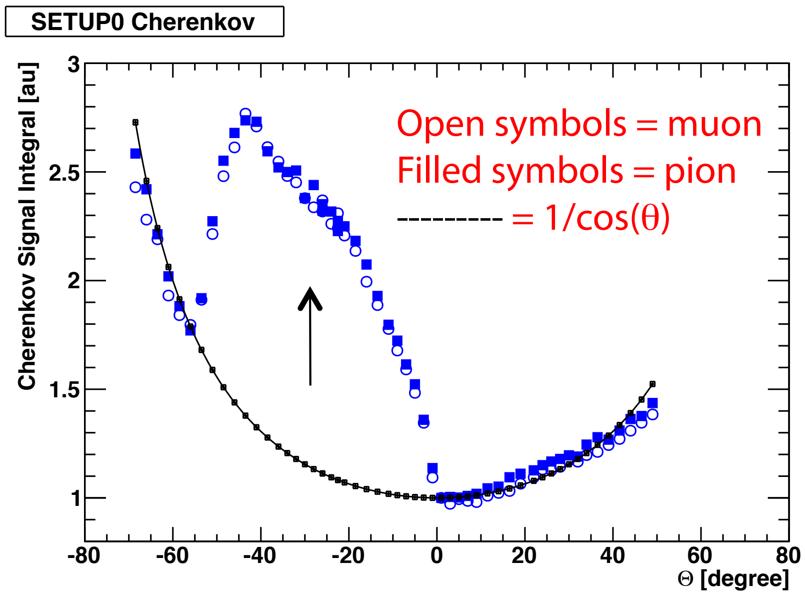
BSO ($Bi_4Si_3O_{12}$) Crystal - II

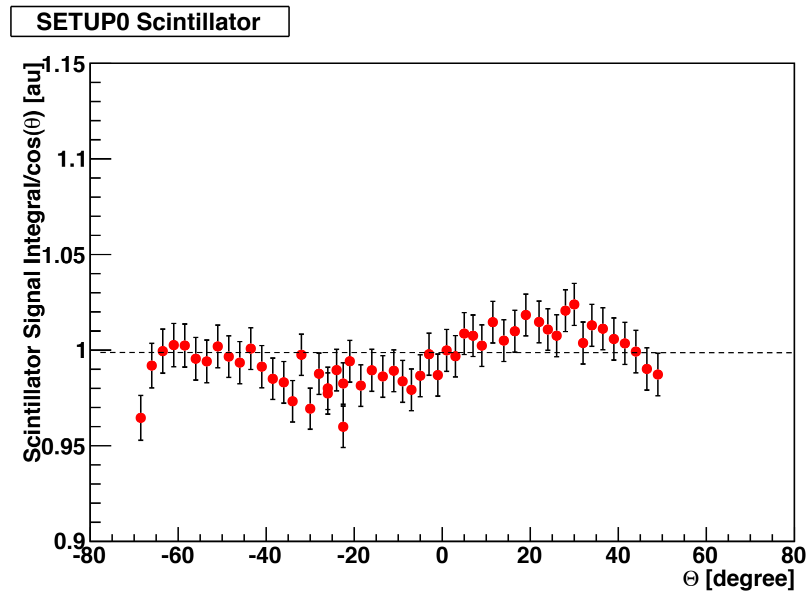


Setup 0 : No Polarizers





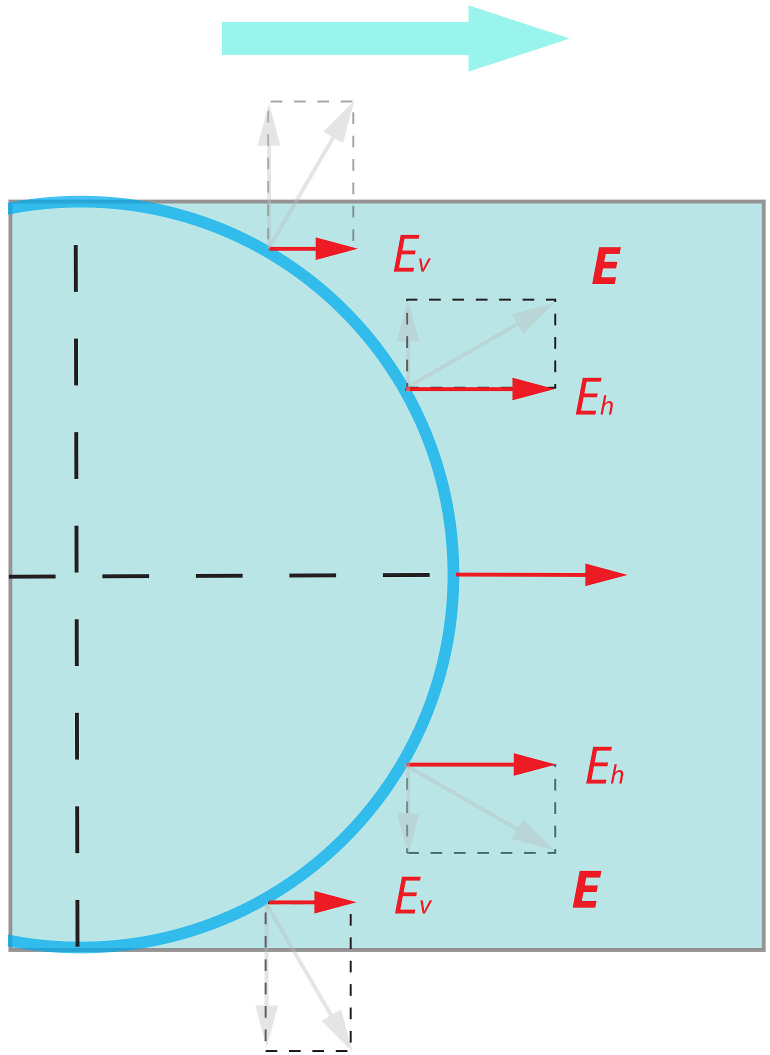




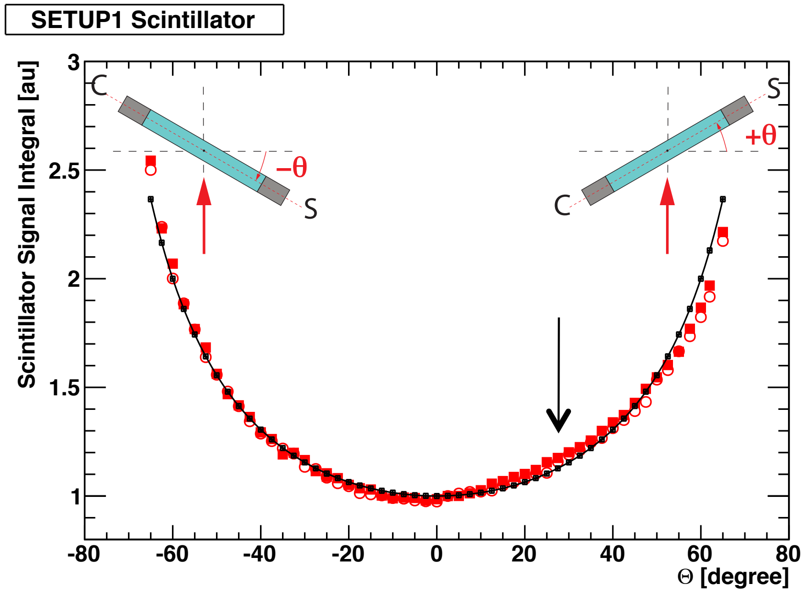
Setup 1 : Favorable Polarization Selection

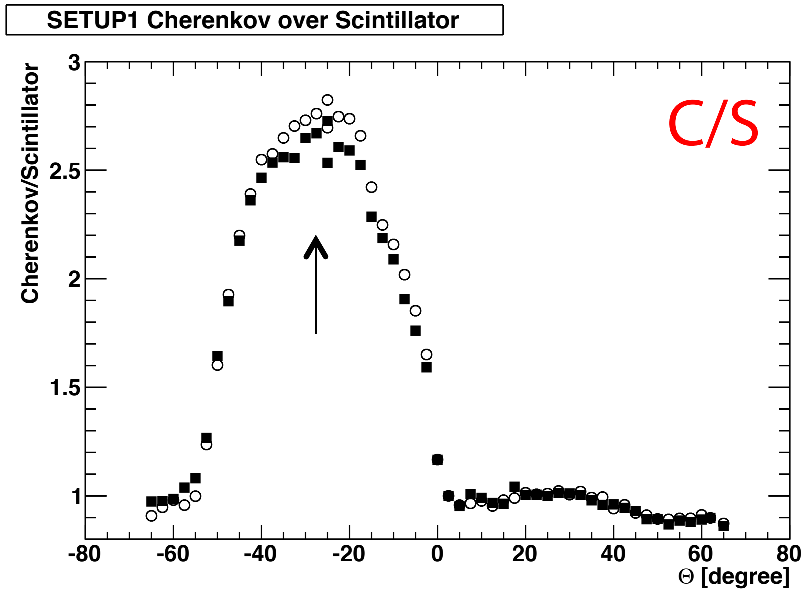
The polarizers at both Cherenkov and scintillation side are oriented such that the horizontal components are transmitted as shown on the right.

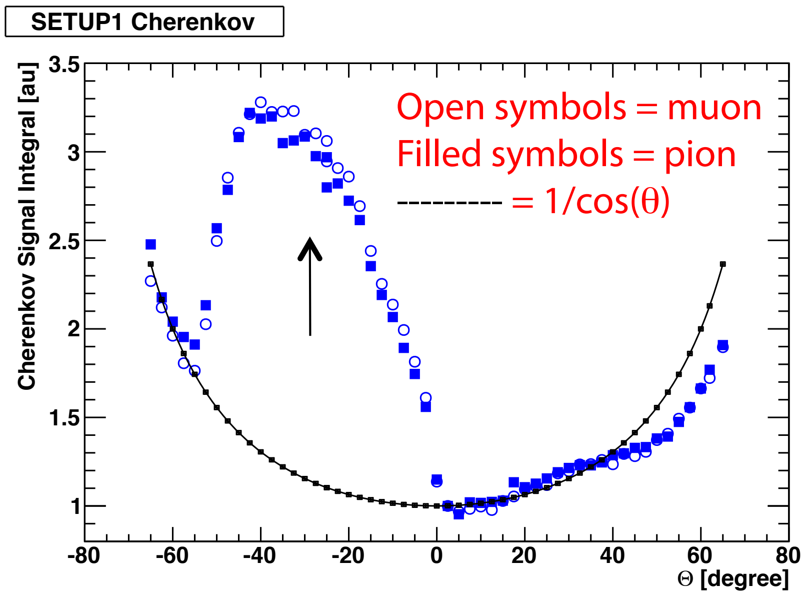
The vertical components are blocked.

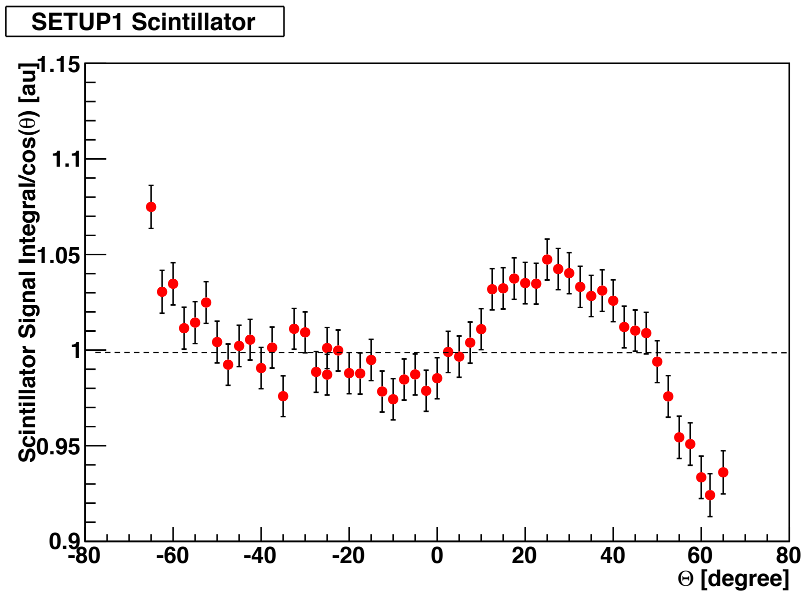


Setup 1 : C (Favorable) & S (Favorable)





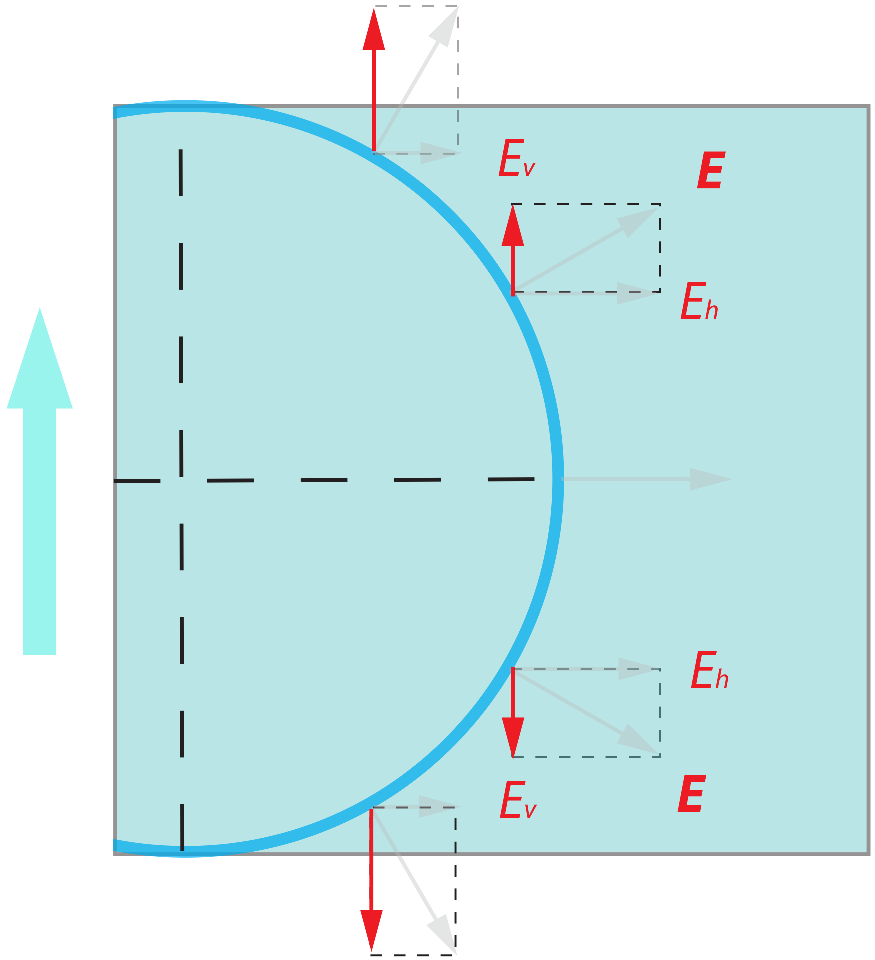




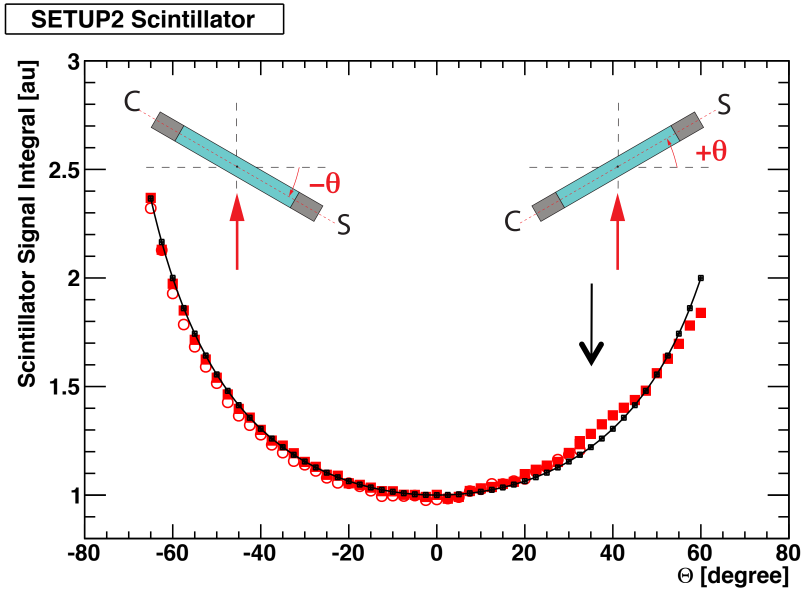
Setup 2 : Unfavorable Polarization Selection

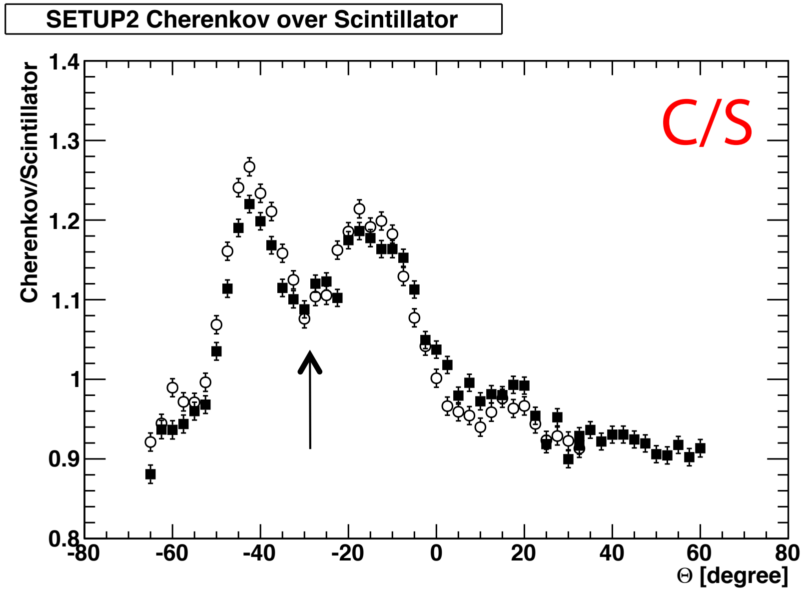
The polarizer at Cherenkov side is oriented such that the vertical components are transmitted which on average add to zero as shown on the right.

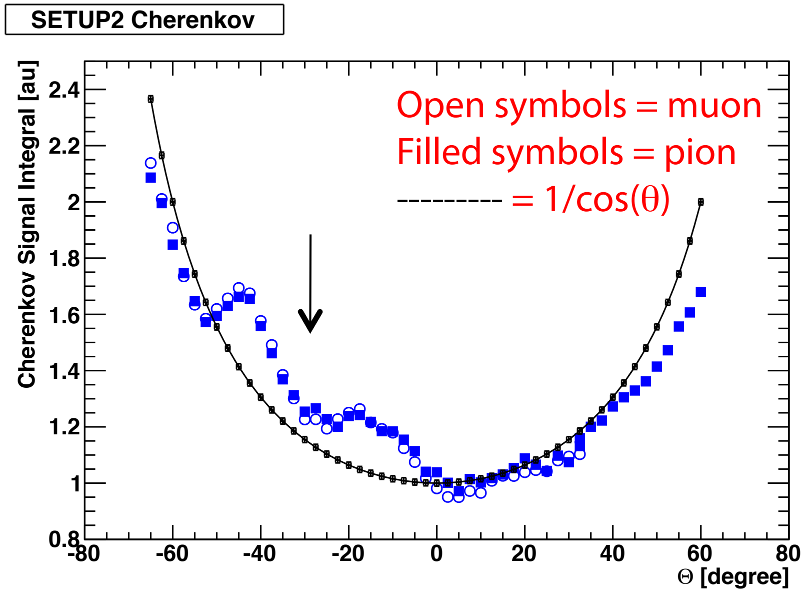
The horizontal components are blocked.

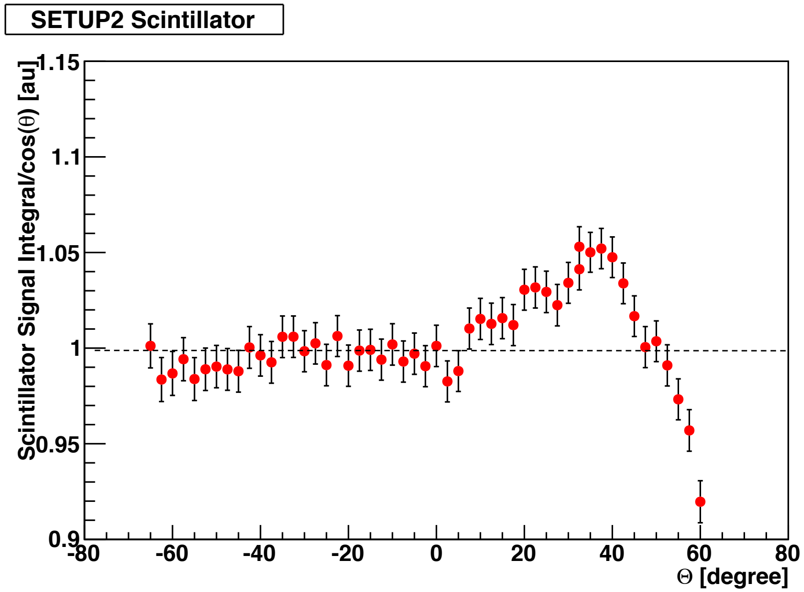


Setup 2 : C (Unfavorable) & S (Favorable)

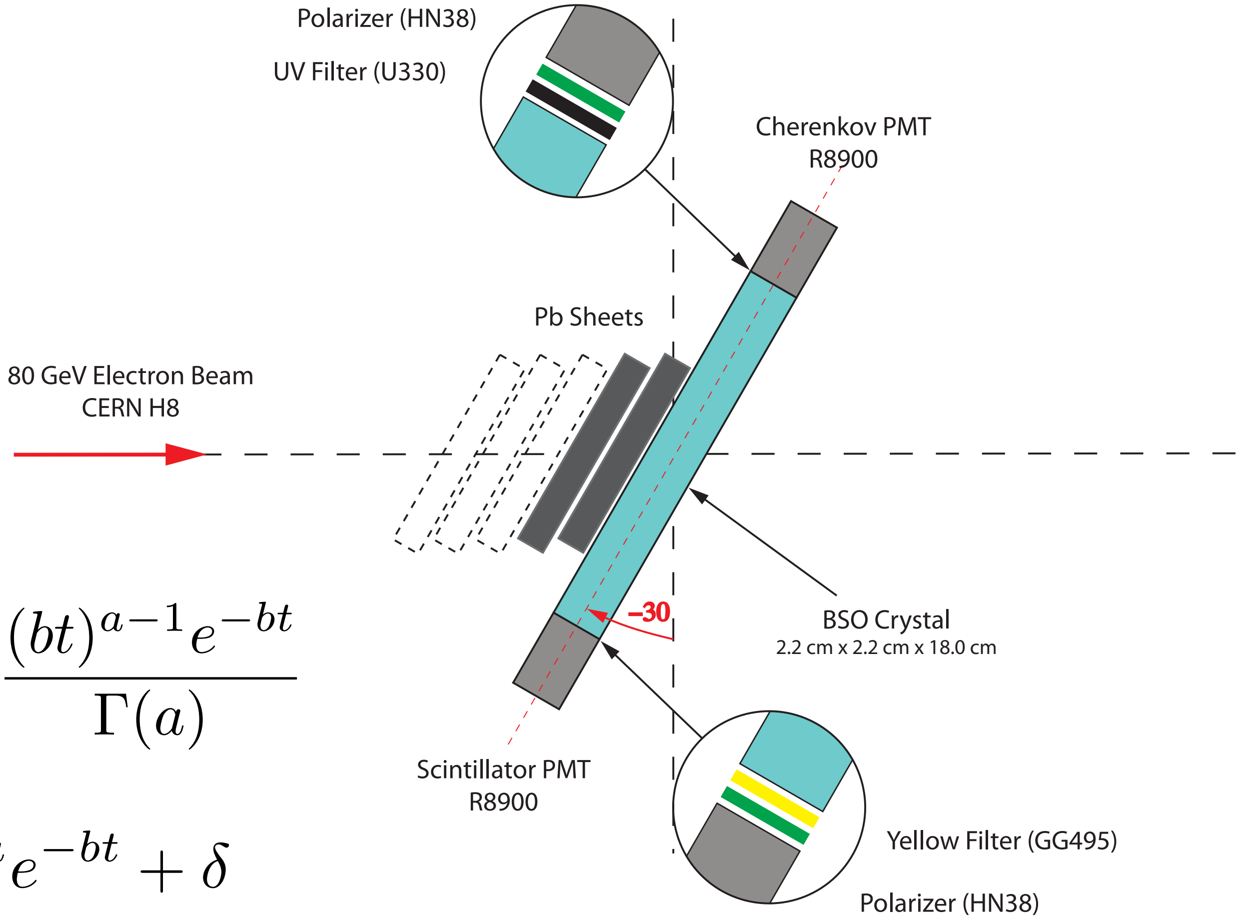








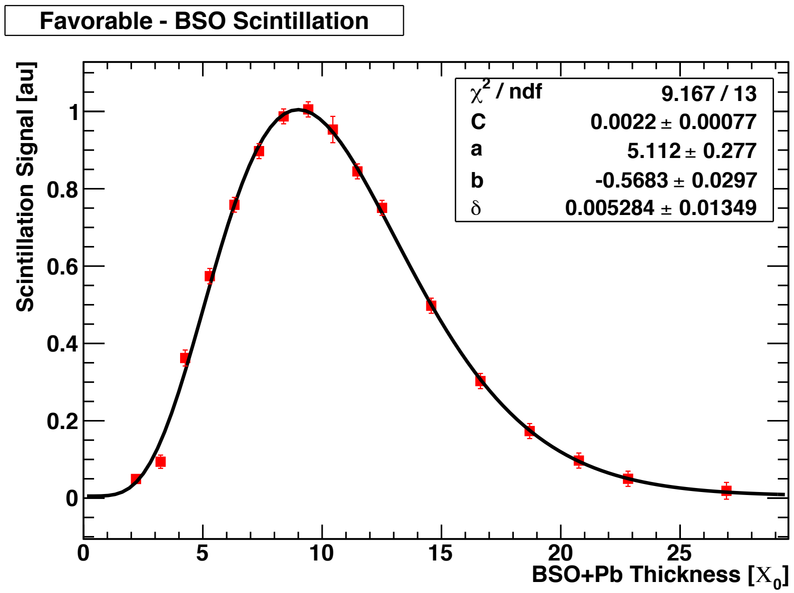
Polarization Profile in EM Showers

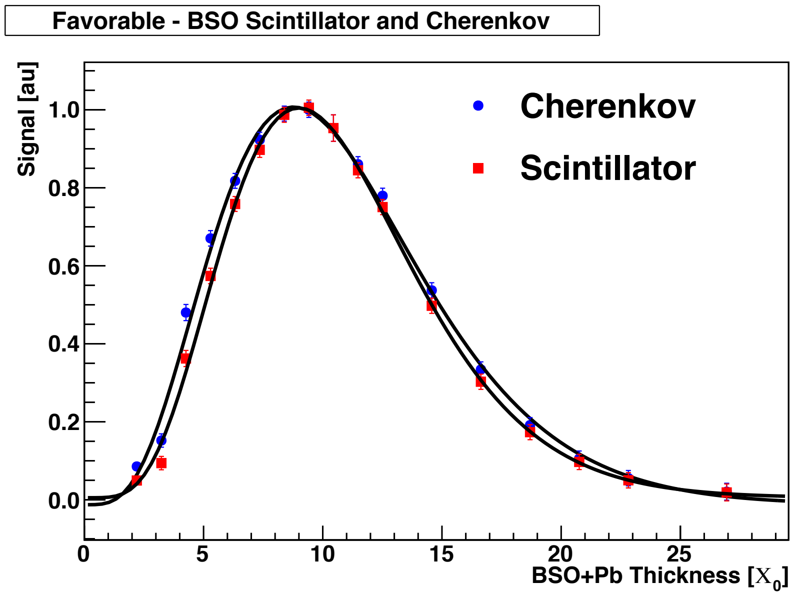


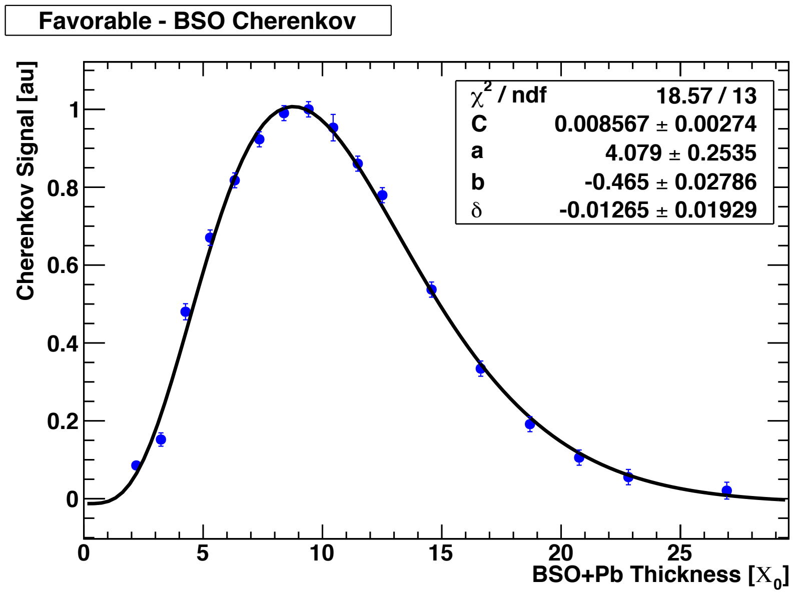
$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

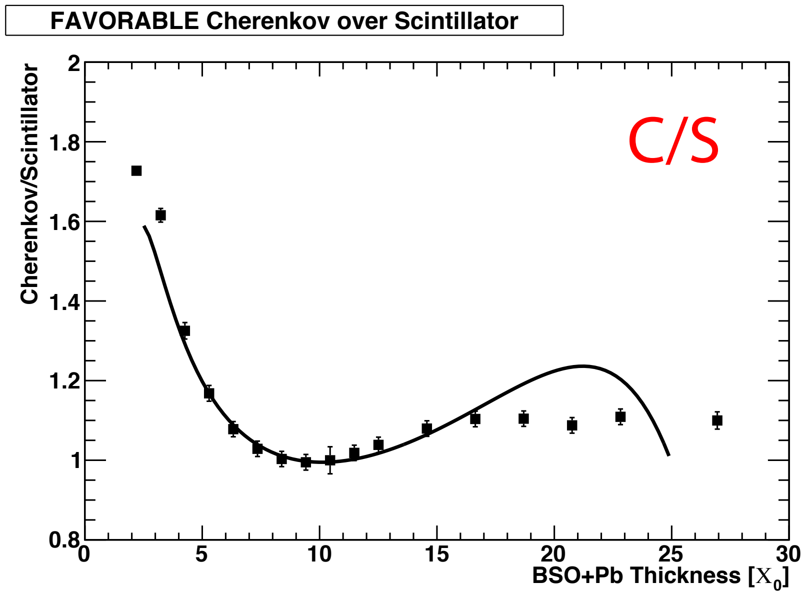
$$\frac{dE}{dt} = C t^a e^{-bt} + \delta$$

Favorable Polarizer Orientation

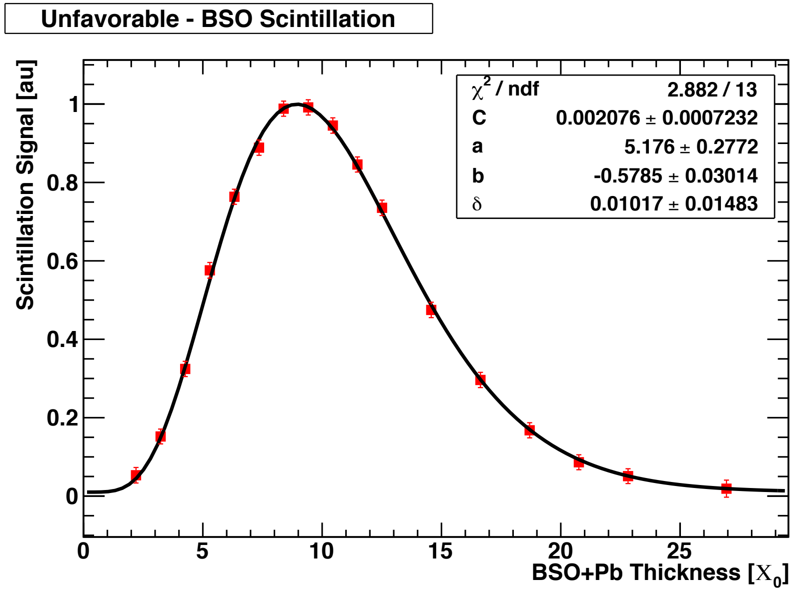


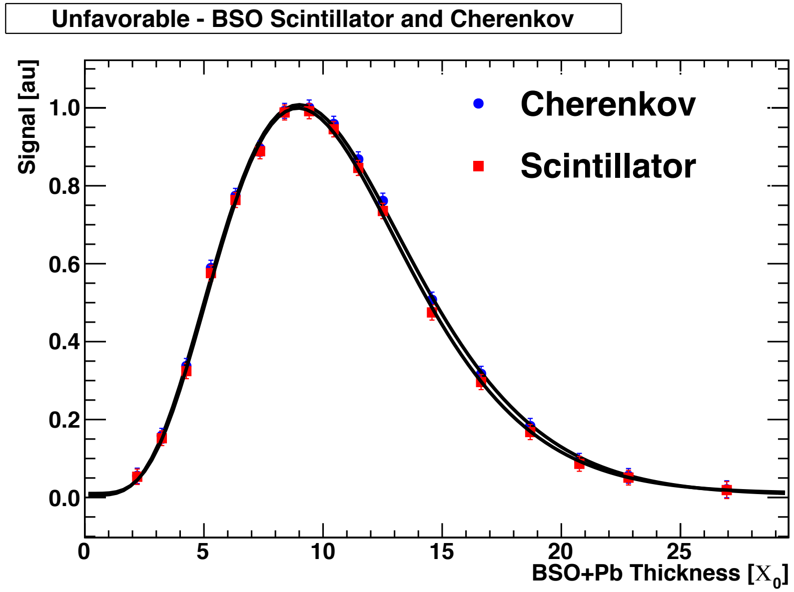


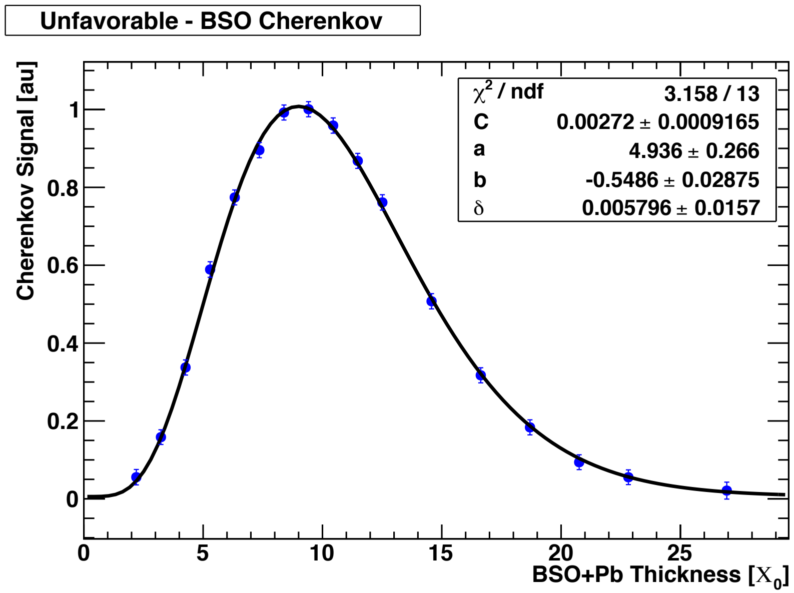


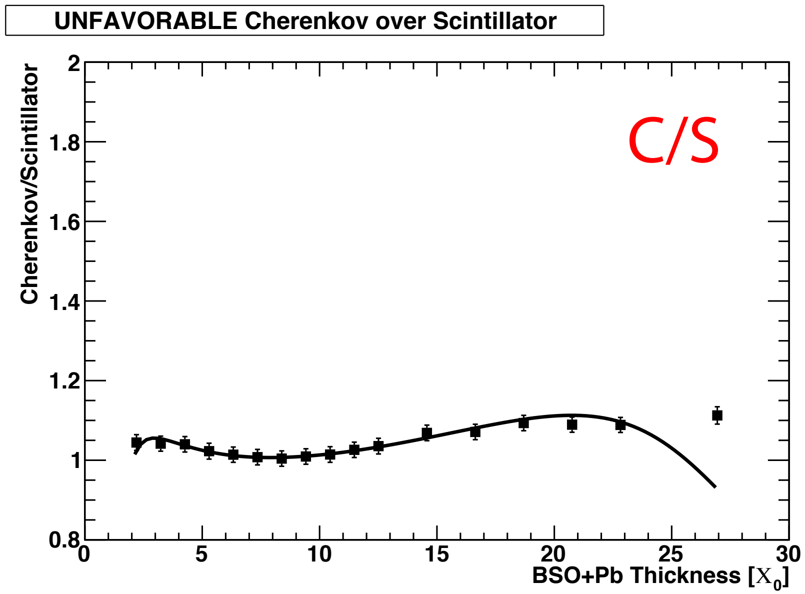


Unfavorable Polarizer Orientation







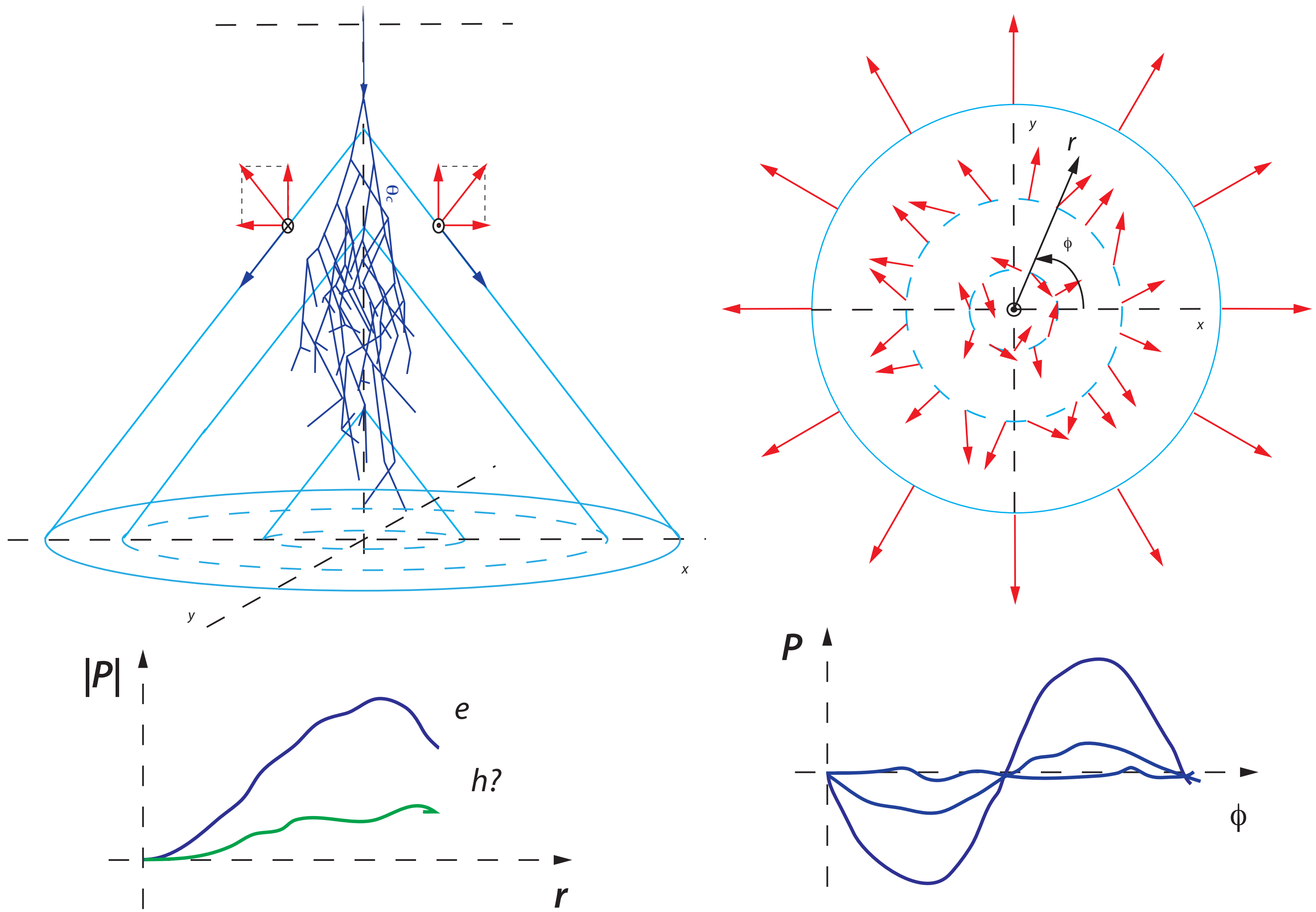


Longitudinal Cherenkov Polarization Profile

	a	*b*
Favorable (Sci)	5.11 ± 0.28	0.568 ± 0.029
Favorable (Che)	4.08 ± 0.25	0.465 ± 0.028
Unfavorable (Sci)	5.18 ± 0.28	0.579 ± 0.030
Unfavorable (Che)	4.94 ± 0.27	0.549 ± 0.029

- Polarization of Cherenkov light in the earlier stages of the em shower development ($<7\ X_o$) is preserved and the effect is relatively large
- After the shower maximum, as expected Cherenkov polarization has no unique orientation
- This aspect of Cherenkov radiation maybe useful in different applications in calorimetry such as to study the structure of air showers, tagging neutral pions in hadronic showers, *etc*.

A Possible Application in Air Showers – an Example



It may be possible to perform a dual-readout method for air showers (or fully sampling large media *e.g.* air, ice). The polarization component of Cherenkov light adds another aspect that we are now exploring/simulating. This approach will enable us to measure the early part of the shower, effectively longitudinally segment the shower and perform particle ID.

Conclusions and Remarks

Polarization of Cherenkov light adds another interesting aspect in the study of shower development.

The polarization feature of the Cherenkov light might be exploited in dual-readout schemes but probably not as easily as timing and spectral discriminants.

In the early part of the em showers, the polarization direction is largely preserved because particles tend more forward. In the exponential tail, the average polarization is zero.

Applications in astrophysics seem promising as we further explore possibilities that might be afforded by this phenomenon.