Status of synchronization study

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Introduction

Motivation

- In the previous meeting [link], we have seen a significant difference between the simulation of two groups.
- The origin of this difference was not well-understood, since the difference turns out to be still exist even after synchronizing χ factor to 0.291.
- To understand the difference, we performed a routine of estimating single hadron energy resolution using the simulation package of INFN, including calibration, EM energy measurement and single pion energy measurement.

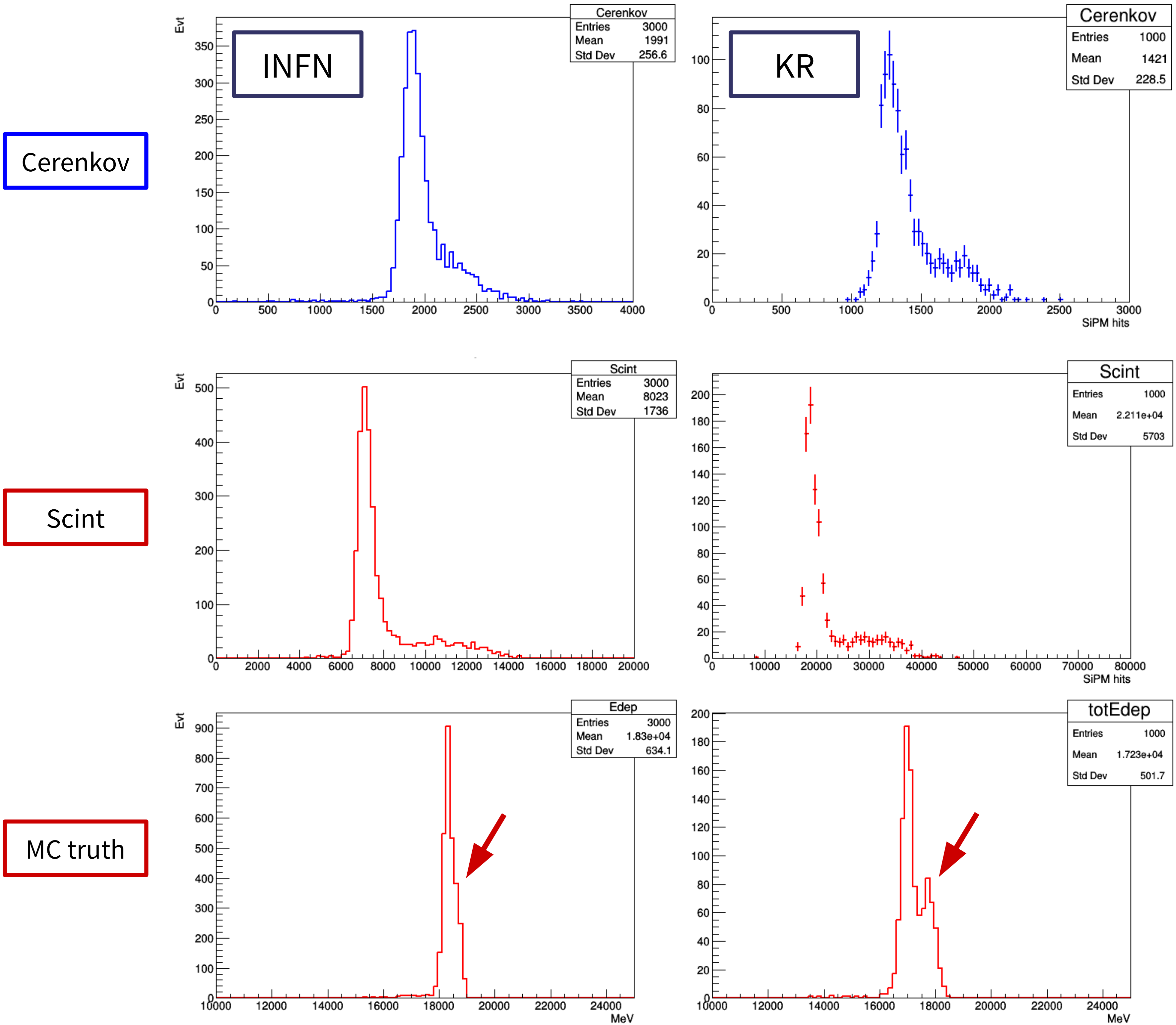
Notes on the following slides

- Plots from INFN simulation package are shown on the left side, while Korean package are shown on the right.
- The χ factor is fixed to 0.291 in the following study for both simulations.
- For INFN simulation, calibration is done up to first 10 towers. Note that this is enough to contain full hadronic shower (see backups).

Calibration

Calibration procedure

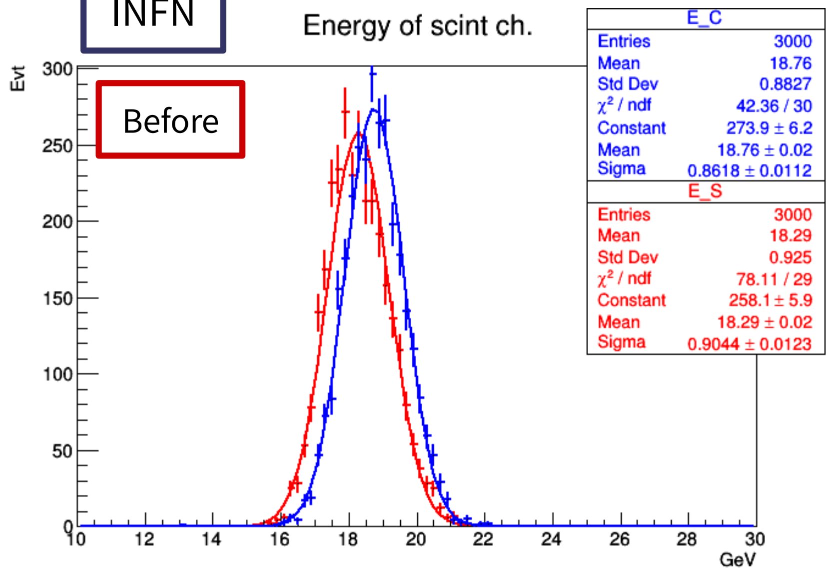
- Used 1cm x 1cm 20 GeV electron beam parallel to the target tower
  - For INFN package: Direction of the beam & the tower is identical up to 9 digits.
  - For Korean package: Direction of the beam & the tower is exactly identical.
- Extracting equalization constants
  - Eq. constant = # of p.e. counted in the channel / MC truth energy deposited in the target tower
- Applying scale factor
  - Using equalization constants solely does not provide correct energy measurement for whole shower.
  - Uniform scale factor is applied to equalization constants to correct energy, using 20 GeV electron events.
  - Beam setup used for estimating scale factor is different from the that used for calibration.
    - Used 1cm x 1cm 20 GeV electron beam, with $(\theta, \phi) = (1.5°, 1.0°)$ inclination regarding to the axis of the 1^{st} tower in the right.
    - This beam setup is maintained for energy measurements for electrons and pions after the calibration.

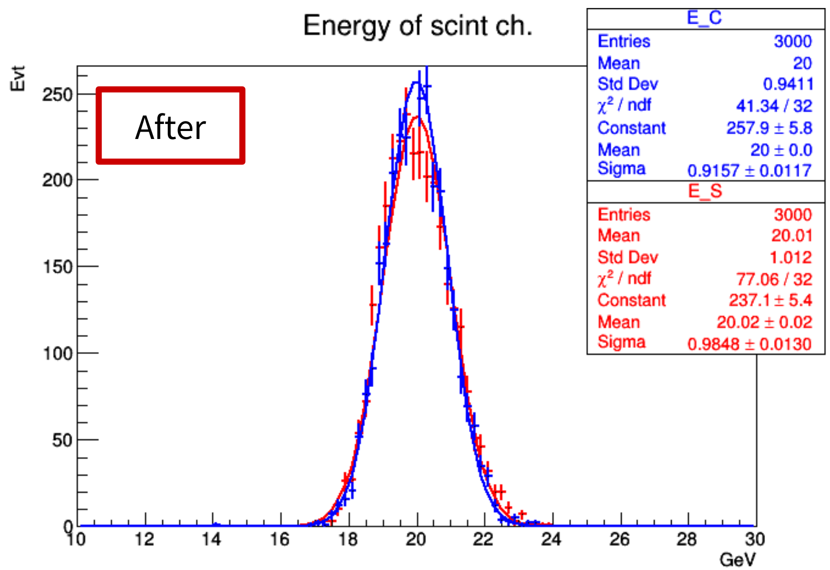


Cerenkov
Scint
MC truth
INFN
KR
Cerenkov Entries 3000 Mean 1991 Std Dev 256.6
Cerenkov Entries 1000 Mean 1421 Std Dev 228.5
Scint Entries 3000 Mean 8023 Std Dev 1736
Scint Entries 1000 Mean 2.211e+04 Std Dev 5703
Edep Entries 3000 Mean 1.83e+04 Std Dev 634.1
totEdep Entries 1000 Mean 1.723e+04 Std Dev 501.7
Evt
SiPM hits
MeV

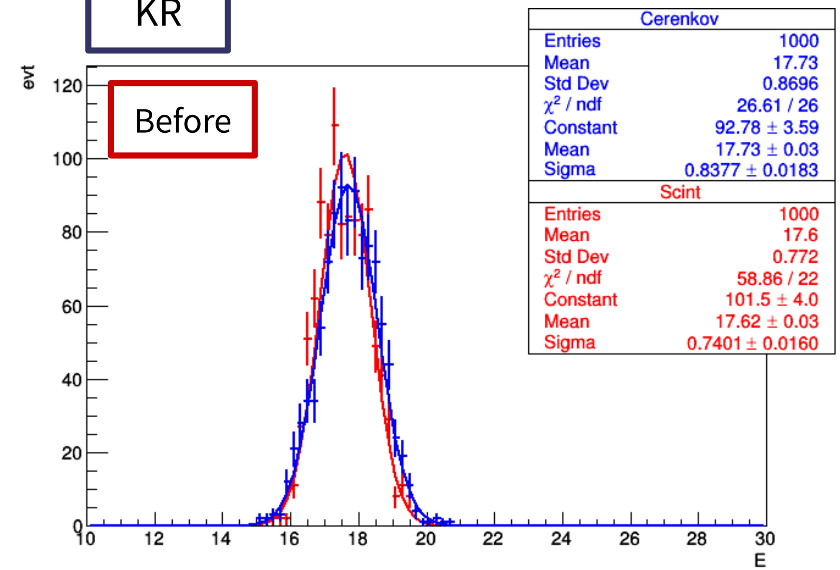
Estimating scale factor using 20 GeV electrons

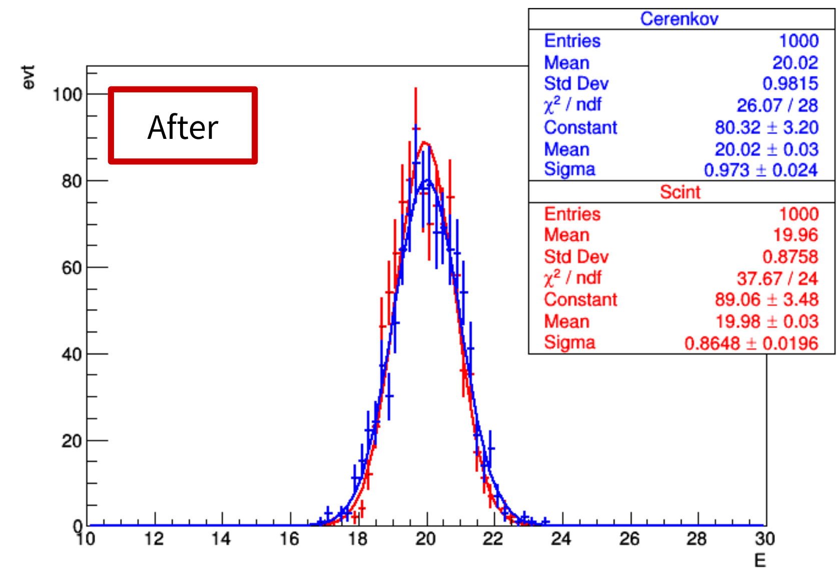
INFN





KR





Calibration constants

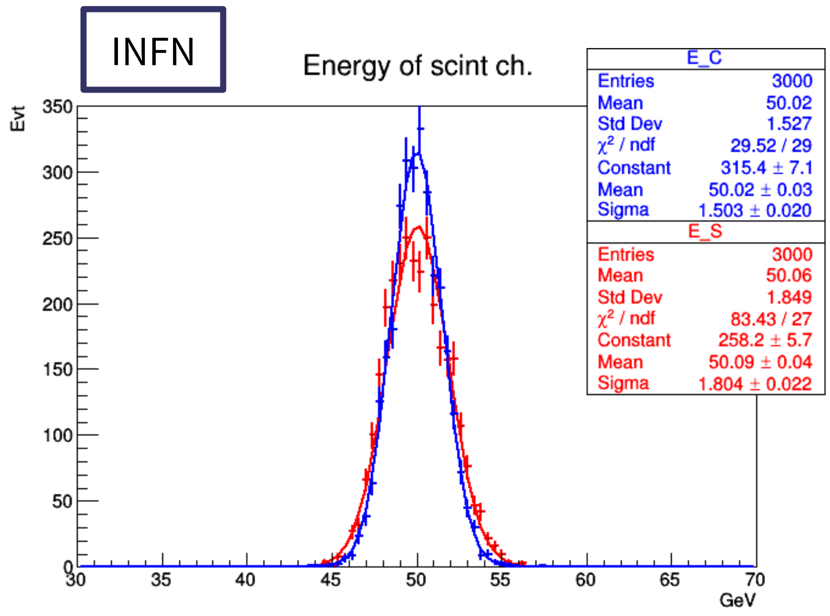
Estimated calibration constants after applying scale factor

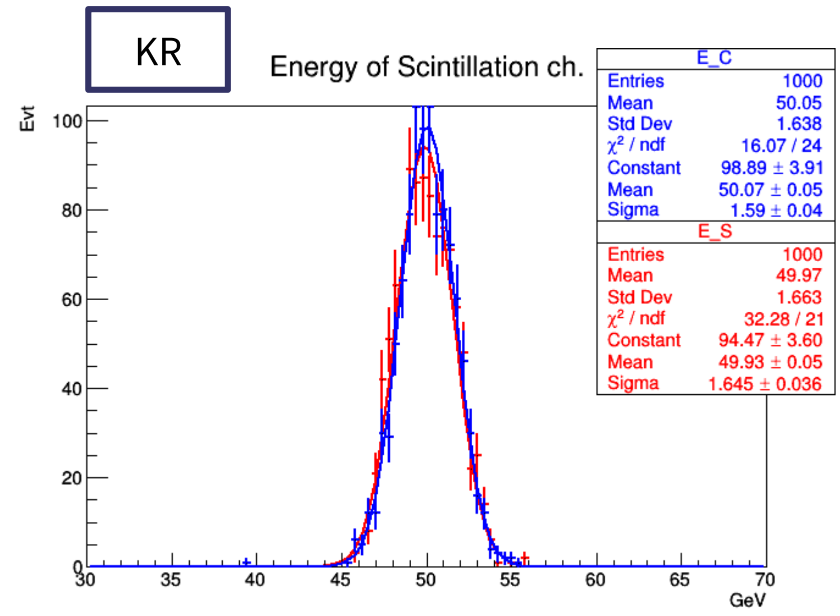
		1	2	3	4	5	6	7	8	9	10
KR	Scint	1131.16	1128.69	1129.40	1137.81	1133.72	1128.75	1129.48	1135.76	1130.36	1098.79
	Ceren	73.0705	73.4569	72.9496	73.6362	73.3276	73.3702	73.1823	73.3276	73.2939	73.1464
INFN	Scint	401.369	400.112	400.761	399.881	399.500	401.441	400.672	400.411	401.741	400.074
	Ceren	102.219	102.206	102.052	101.903	101.907	102.047	102.503	101.744	102.281	102.145
INFN (ref)	Scint	398.584	399.254	398.484	396.961	395.388	394.207	393.698	394.323	…	…

- Large (also obvious) difference in the value itself due to the different optical physics of two simulations.
- Meanwhile, the trend remains similar when using the same calibration procedure, which is somewhat different between the calibration constants that I & Lorenzo estimated.

- Possible candidate for the difference between two simulations.

Energy response for 50 GeV electrons



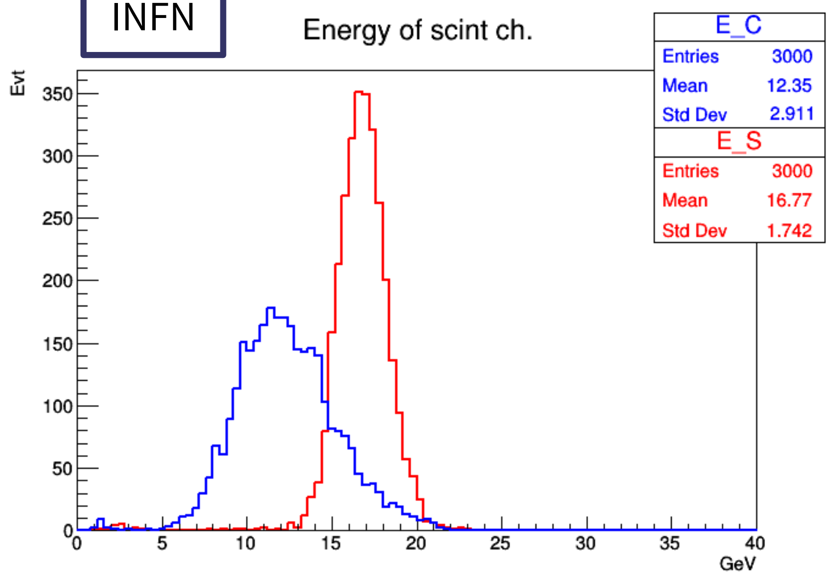


- Sanity check
- Both simulation show good linearity to EM showers.

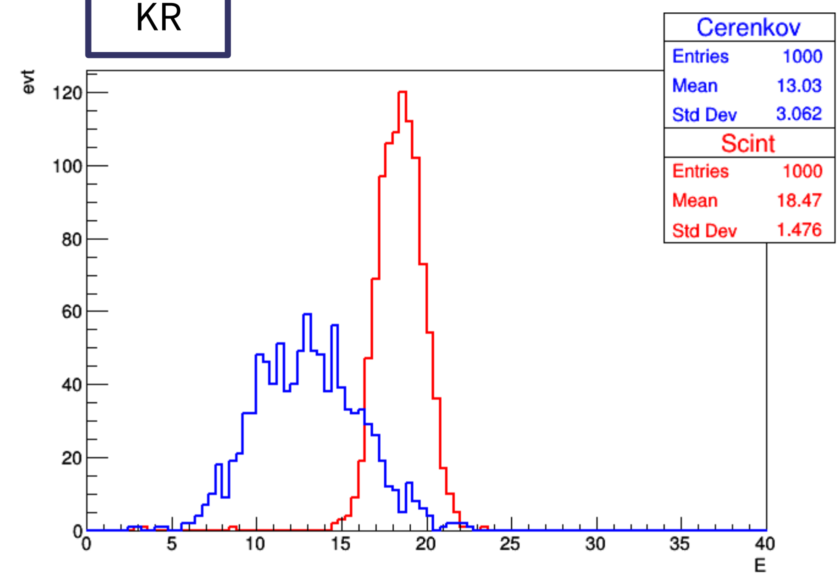
Energy response to 20 GeV π+

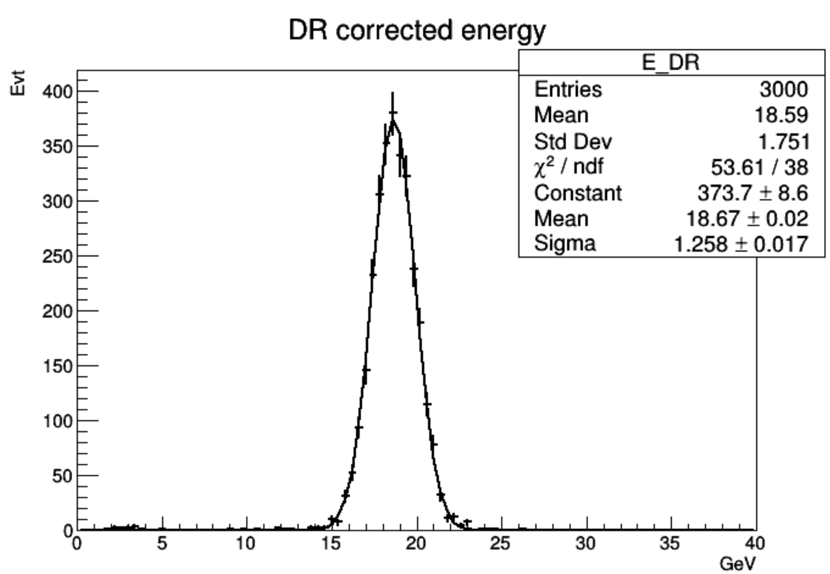
Energy response to 20 GeV π+ for INFN & KR package (w/o light attenuation correction)

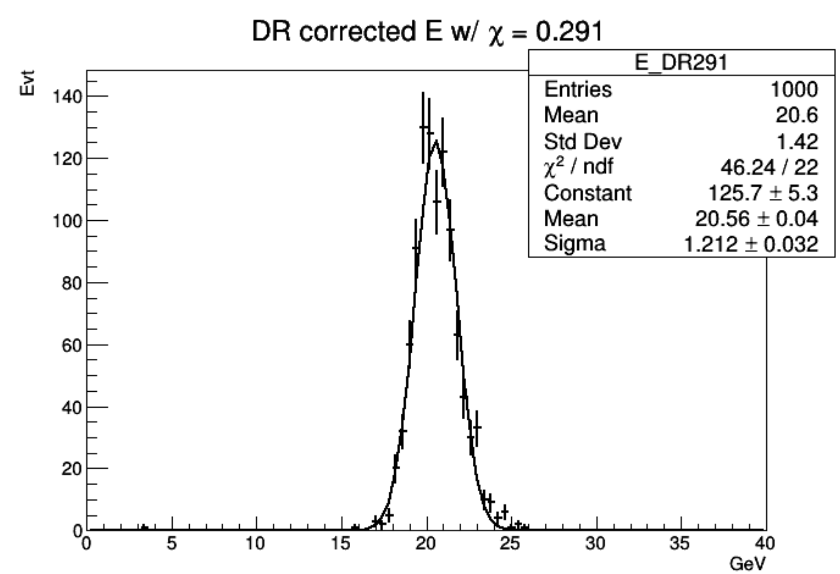
INFN



KR



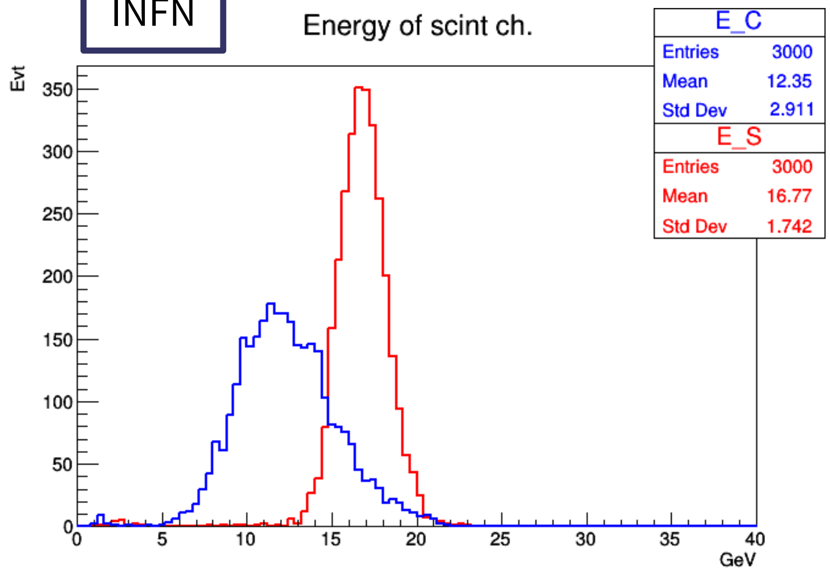




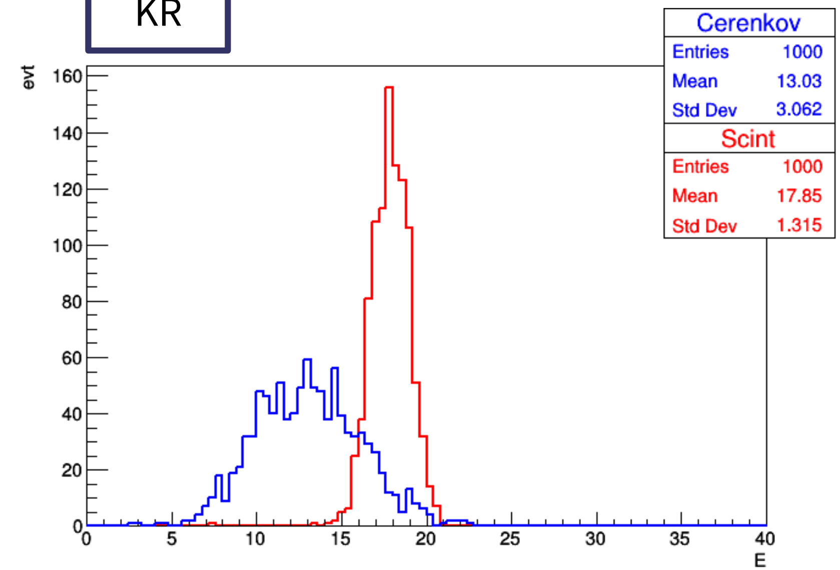
Energy response to 20 GeV π+

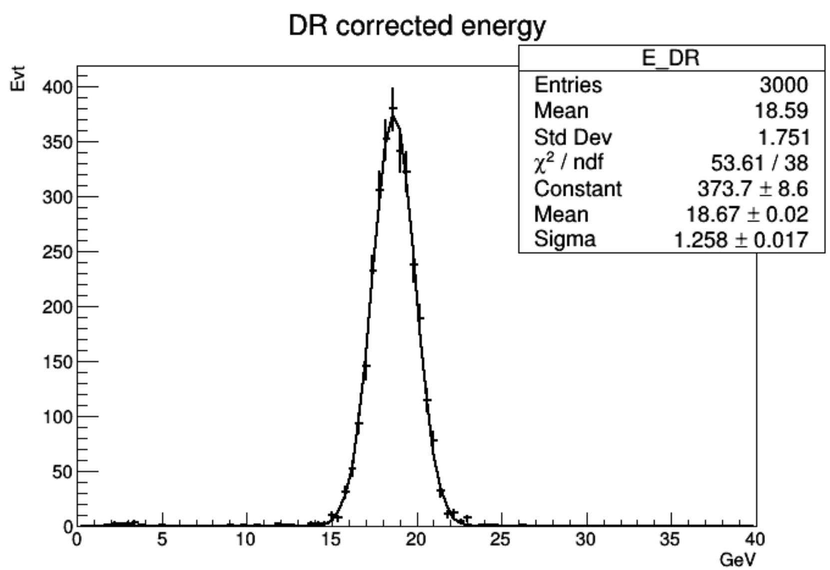
Energy response to 20 GeV π+ for INFN & KR package (w/ light attenuation correction)

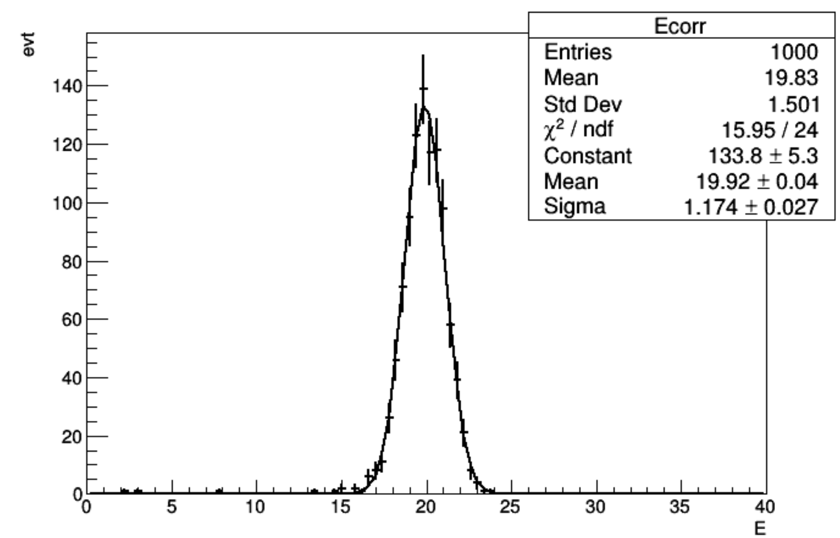
INFN



KR

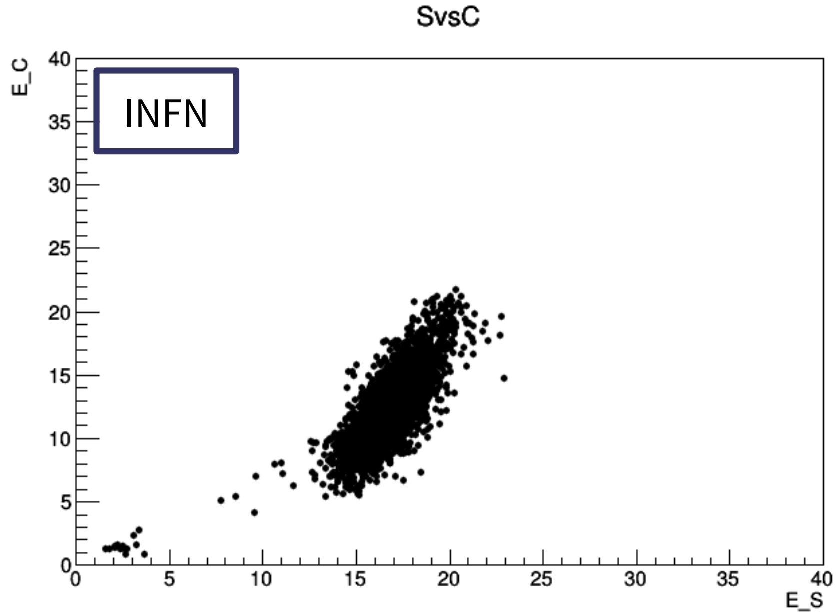


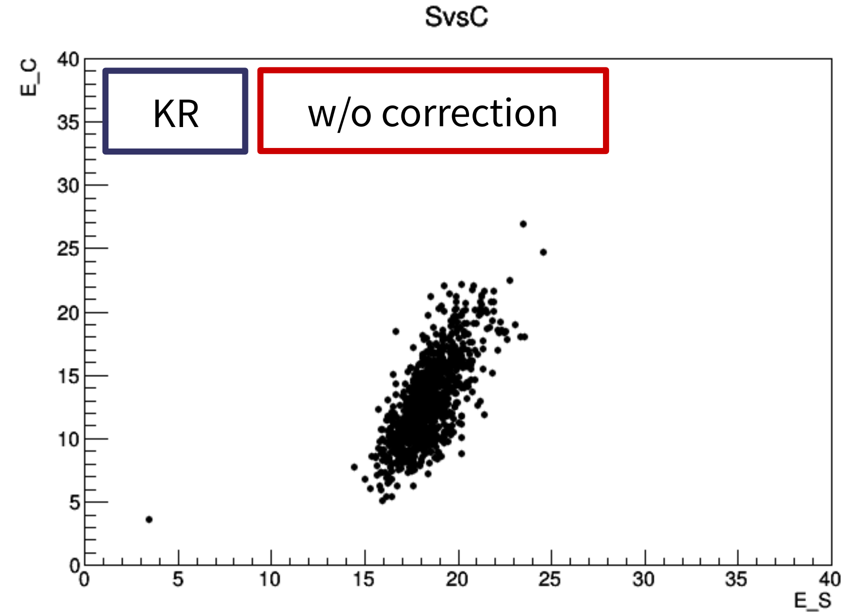




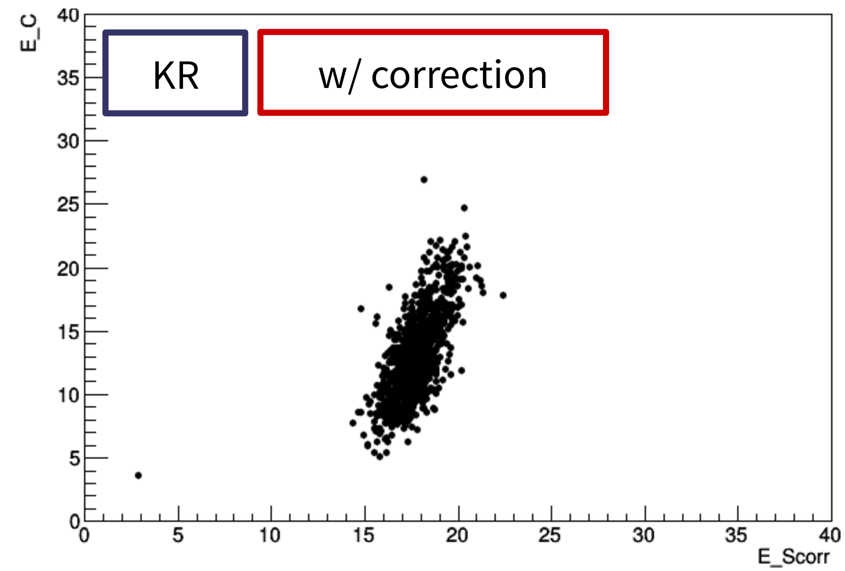
Energy response to 20 GeV π^+

Scintillation channel energy vs Cerenkov channel energy



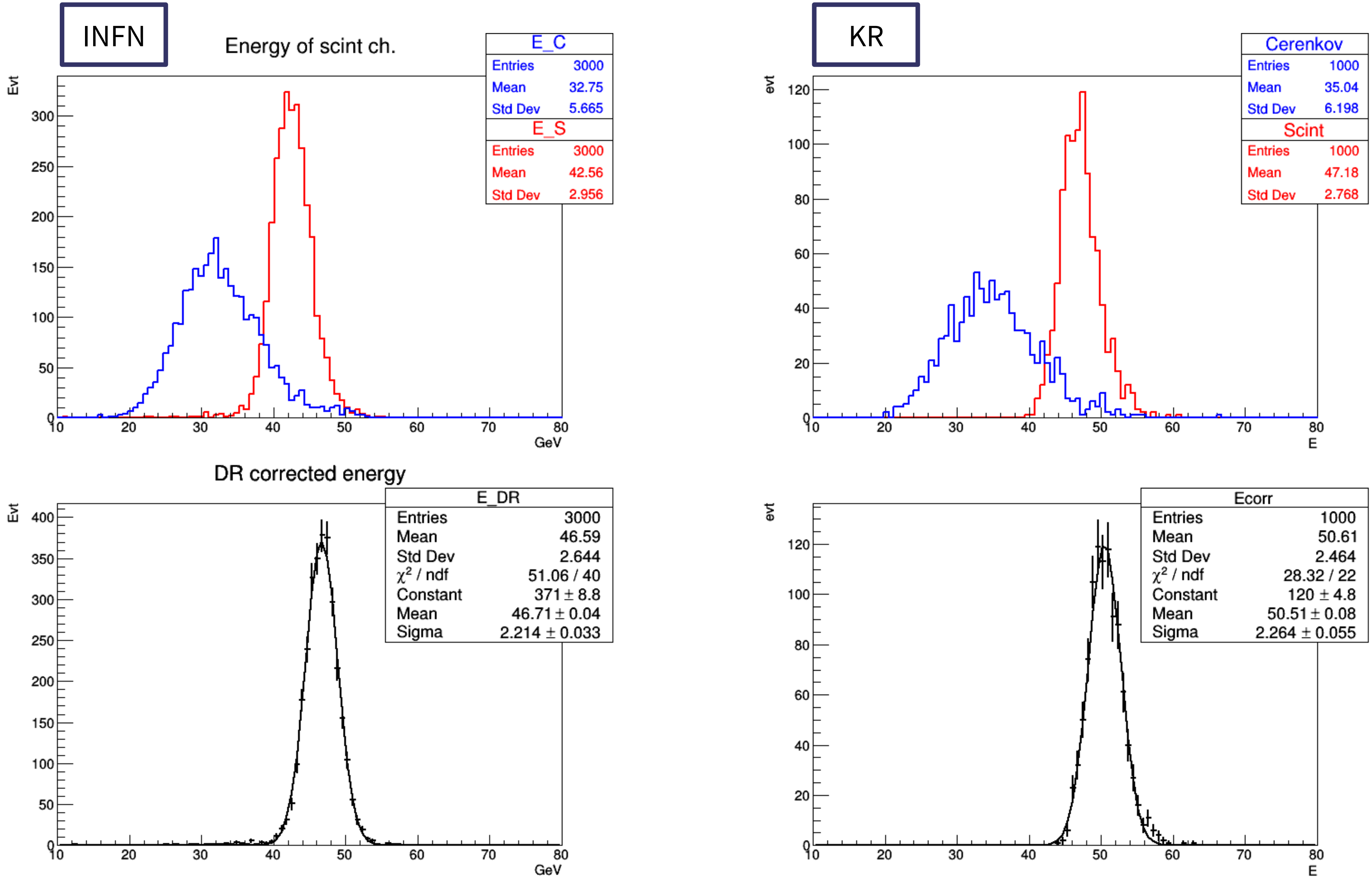


- Two simulations may have different intrinsic χ value according to the slope.
- For KR package, not applying light attenuation correction may overestimate energy response of scintillation channel for hadrons.
- Difference in dispersion mainly caused by light yield difference.



Energy response to 50 GeV π+

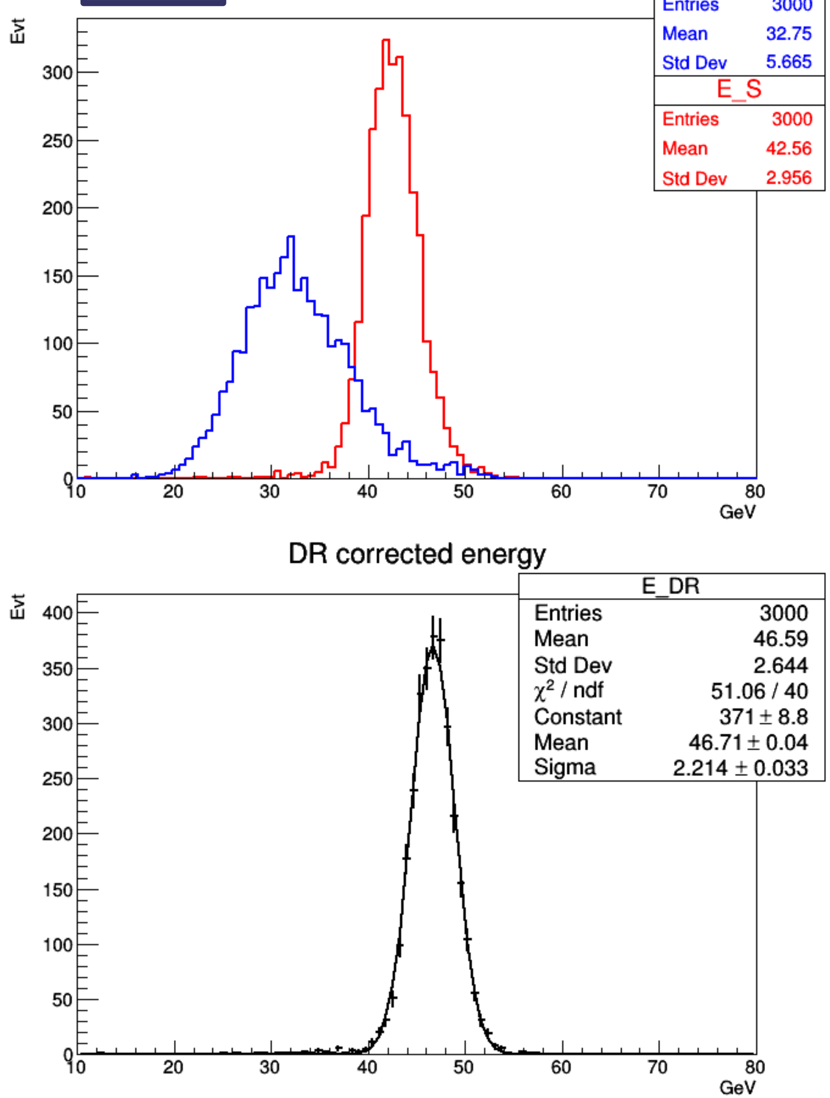
Energy response to 50 GeV π+ for INFN & KR package (w/o light attenuation correction)



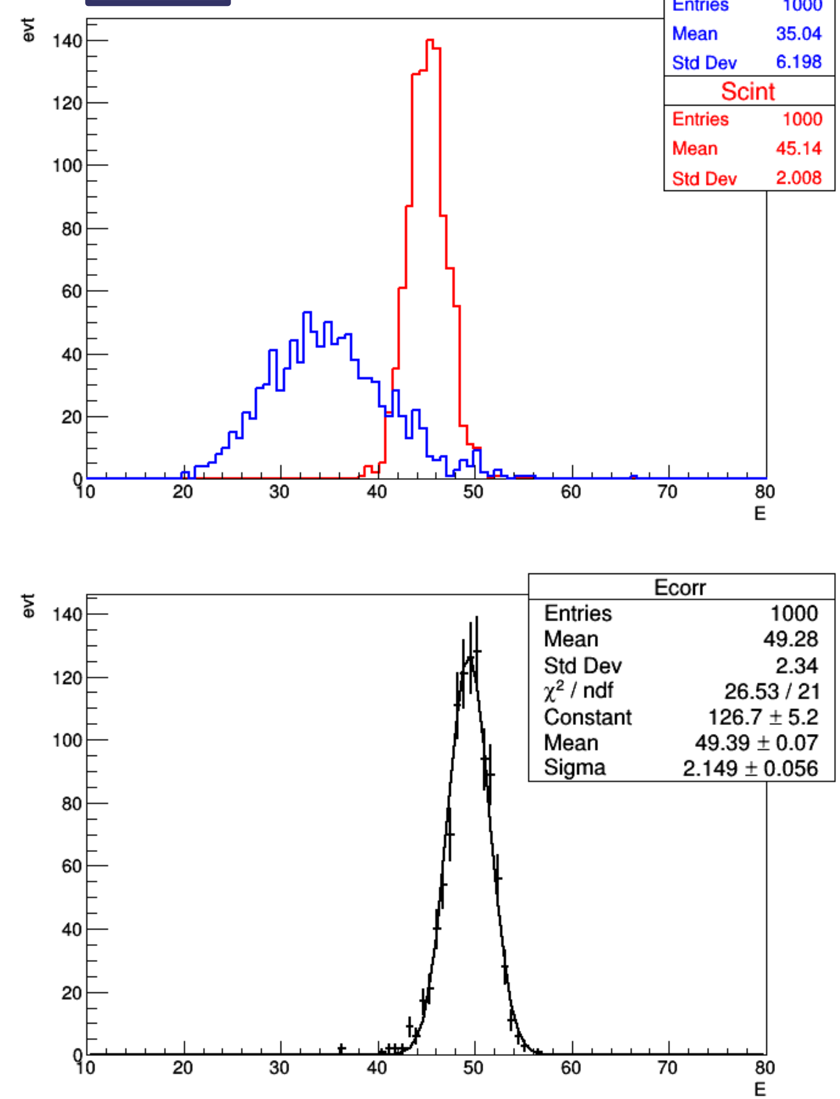
Energy response to 50 GeV π+

Energy response to 50 GeV π+ for INFN & KR package (w/ light attenuation correction)

INFN

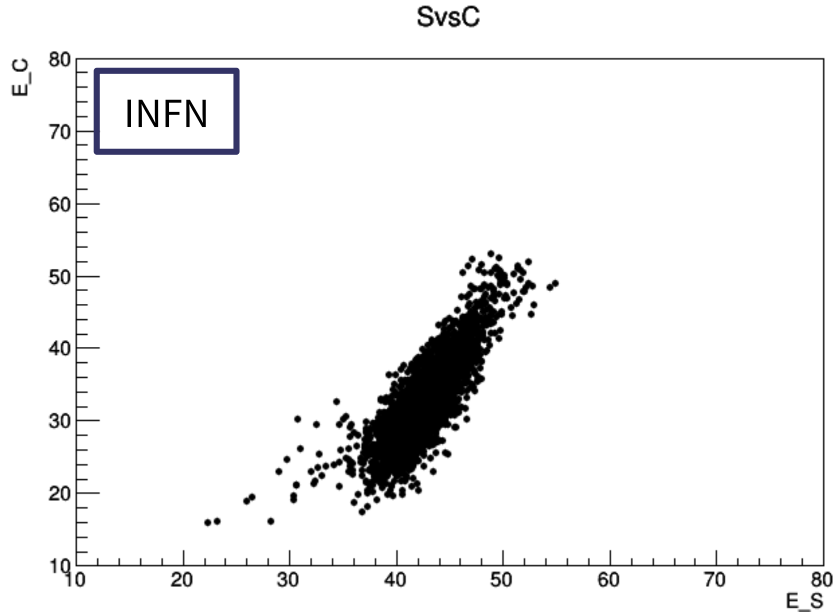


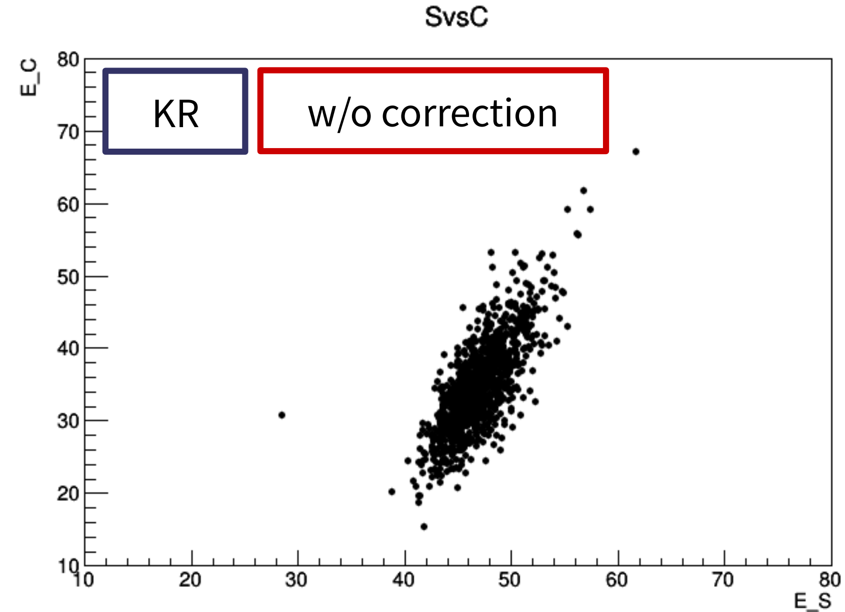
KR



Energy response to 50 GeV π+

Scintillation channel energy vs Cerenkov channel energy





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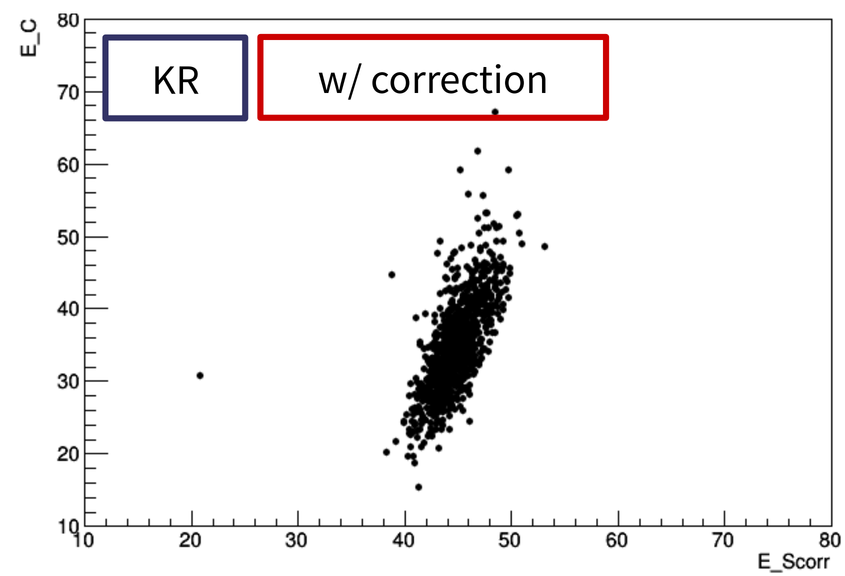
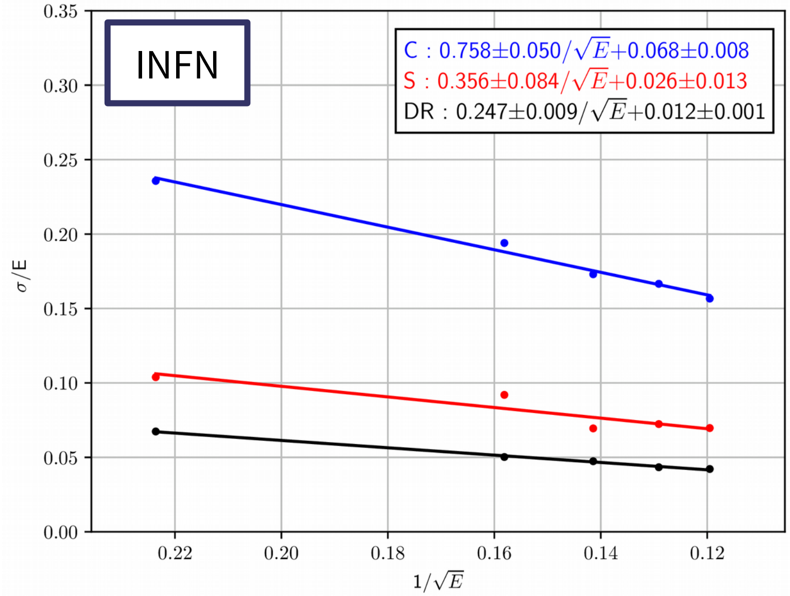
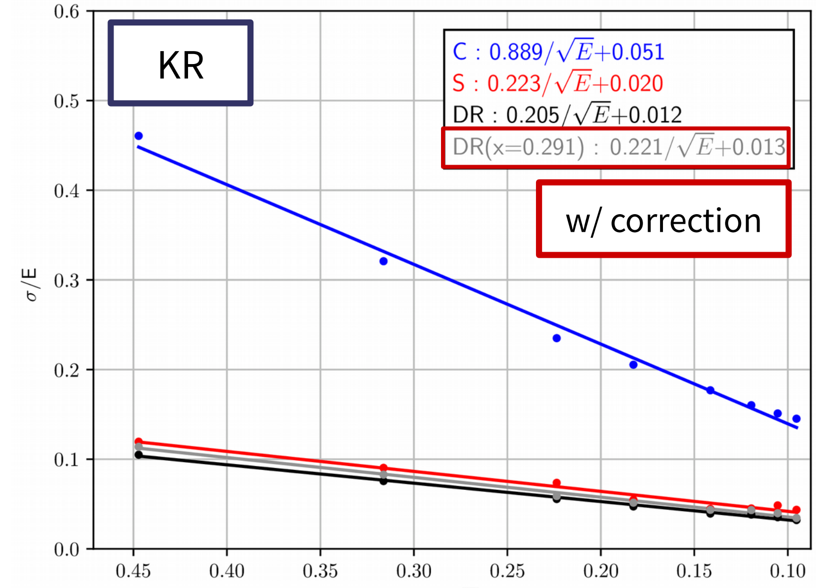
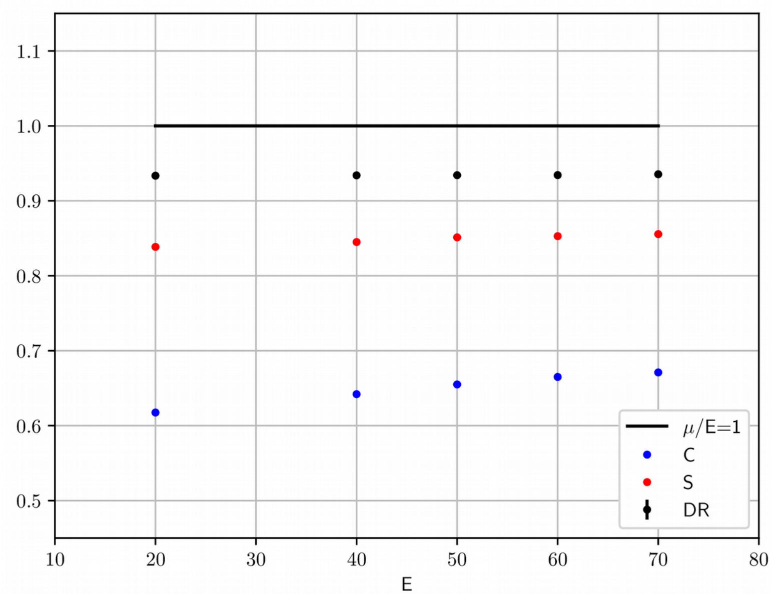


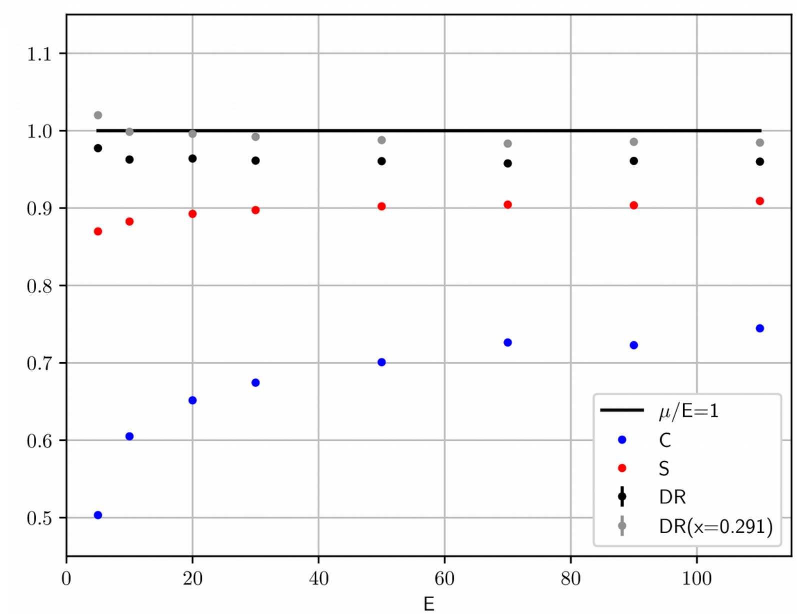
Single hadron energy resolution

Expected single hadron energy resolution & linearity using π+









Summary

Differences between two simulation

- With synchronized beam setup and calibration procedure, expected single hadron energy resolution of INFN package has no big difference with that of light-attenuation corrected KR package, using $\chi = 0.291$.
- This may indicate the difference is caused by either the beam setup, or the calibration procedure (or both).

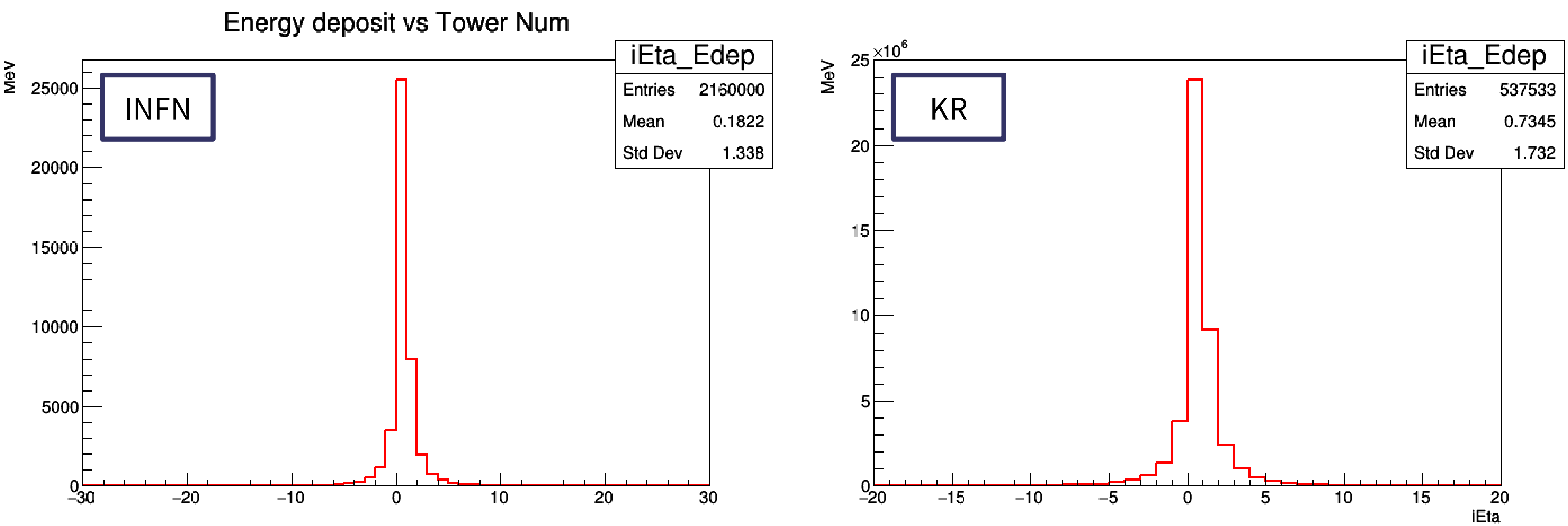
Future plans

- Estimate calibration constants with different beam setup (with inclination).
- Estimate scale factor for each tower, by calculating the ratio between the response of the target tower & neighboring 3x3 tower.
- Testing 2.0m length tower for KR package.

Backups

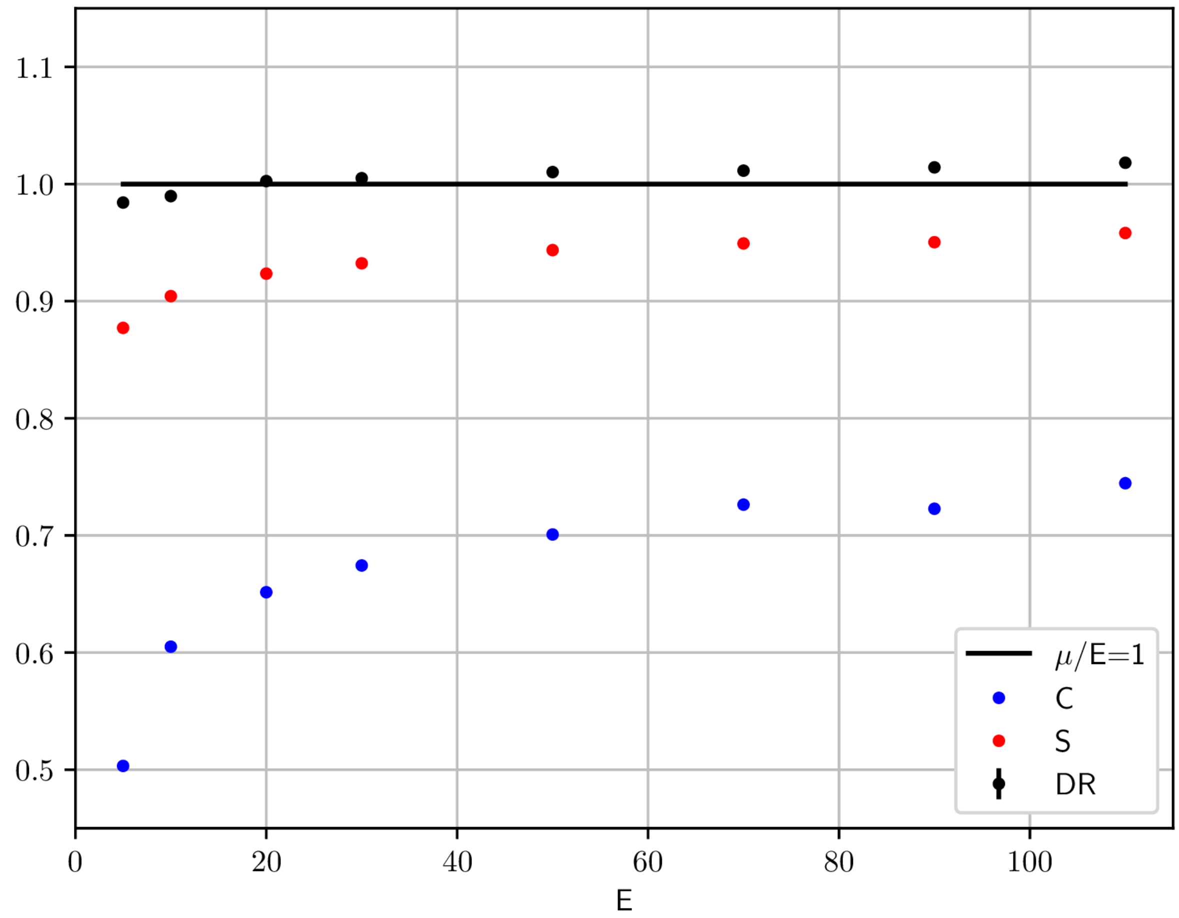
Averaged energy deposit vs tower # for 50 GeV π+

- To check calibration of the first 10 towers is enough to contain shower from pions.



Linearity w/o light att. correction

Linearity without light attenuation correction



Macro used for calibration for n-th tower

```
/run/numberOfThreads 1
#
# Initialize kernel
/run/initialize
#
# Kinematics:
#
/gps/particle e-
/gps/energy 20 GeV
/gps/position 0 0 0 cm
/gps/pos/type Plane
/gps/pos/shape Square
/gps/pos/rot1 0 0 1
/gps/pos/halfx 0.5 cm
/gps/pos/halfy 0.5 cm
/gps/ang/type beam1d
/gps/direction 0.9995663085 0 0.029448173248
#
/run/beamOn 3000
```

sin((1/2+n)*(π/4)/40)

cos((1/2+n)*(π/4)/40)

Macro used for measuring energy of electrons & pions

```
/run/numberOfThreads 1
#
# Initialize kernel
/run/initialize
#
# Kinematics:
#
/gps/particle pi+
/gps/energy 50 GeV
/gps/position 0 -4.363766 -6.546 cm
/gps/pos/type Plane
/gps/pos/shape Square
/gps/pos/rot1 0 0 1
/gps/pos/halfx 0.5 cm
/gps/pos/halfy 0.5 cm
/gps/ang/type beam1d
/gps/direction 0.999199957 0.0174524 0.03598416
#
/run/beamOn 3000
```

- -4.363766: 250cm*tan(1.0°)
- -6.546: 250cm*tan(1.5°)
- 0.03598416: sin(1.5°+1/2*(π/4)/40)
- 0.0174524: cos(1.5°+1/2*(π/4)/40)*sin(1.0°)
- 0.999199957: cos(1.5°+1/2*(π/4)/40)*cos(1.0°)

Light attenuation correction (1)

Light attenuation correction

- π+ can go deep inside tower compared to e-.
- Although filters are applied to S channel to mitigate the light attenuation, energy measured from S channel should be corrected to take into account of attenuation properly.
- Can be corrected by measuring the shower depth event-by-event, using time structure of the scintillation signal.

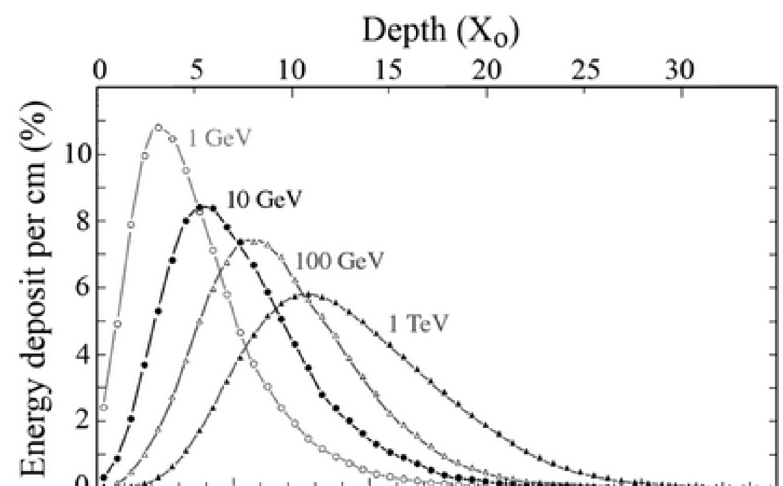
Shower depth as a function of time

- Shower depth x can be represented as a function of detection time

$$t_c = \frac{1}{0.3\,m/ns}x + \frac{1.8\,m}{0.3\,m/ns}$$ TOF of π+ in vacuum/tower

$$t_v = \frac{2.5\,m - x}{v}$$ Propagation time of optical photons

$$t_{max} = t_v + t_c = \frac{2.5 - x}{v} + \frac{x}{0.3\,m/ns} + \frac{1.8\,m}{0.3\,m/ns}$$ Detection time



Longitudinal profile of EM shower (EGS4)

Estimation of average optical photon velocity

- The average velocity of optical photons (v) can be estimated by calculating effective radiation length of the tower & exploiting well-known longitudinal profile of EM showers.

	Cu	PS	PMMA
Volume (%)	65.1	17.45	17.45
X0 (cm)	1.436	41.31	34.07
X0_eff (cm)		2.1613	

Light attenuation correction (2)

Light attenuation correction

- Estimated avg velocity of optical photons using 20GeV e- evts.

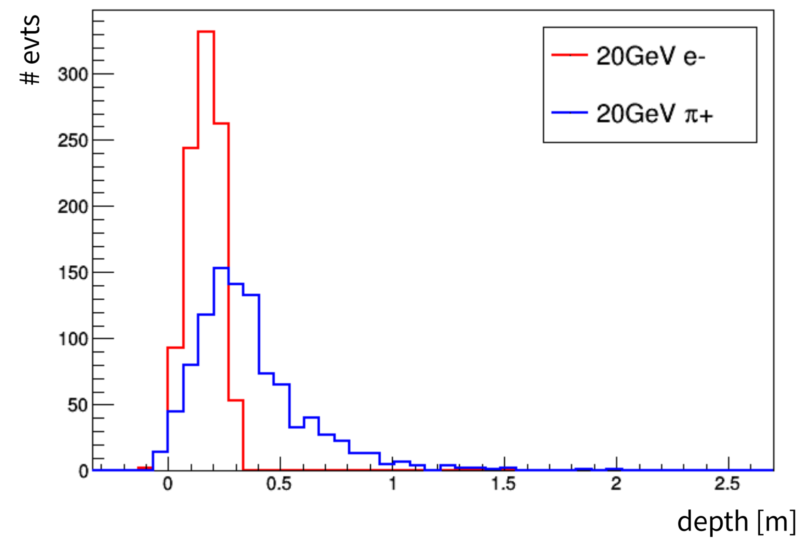
$$v = \frac{2.5\,m - 0.1368\,m}{t_{max} - \frac{0.1368\,m}{0.3\,m/ns} - \frac{1.8\,m}{0.3\,m/ns}}$$

- Shower depth can be estimated event-by-event.
- Average measured energy shows exponential dependency on the depth of a shower.

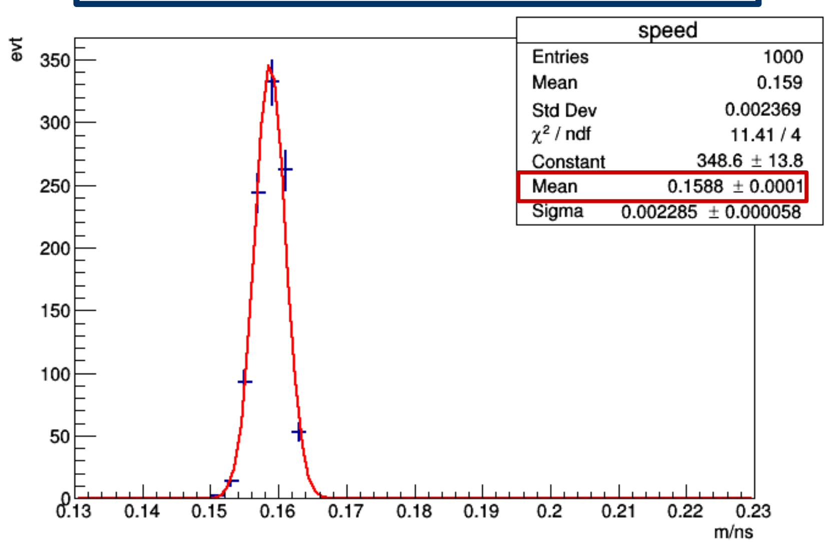
$$E = E_{6.33\,X_0} \exp\frac{x - 6.33\,X_0}{\lambda_{eff}}$$

- Removing the exponential term corrects the attenuation loss.

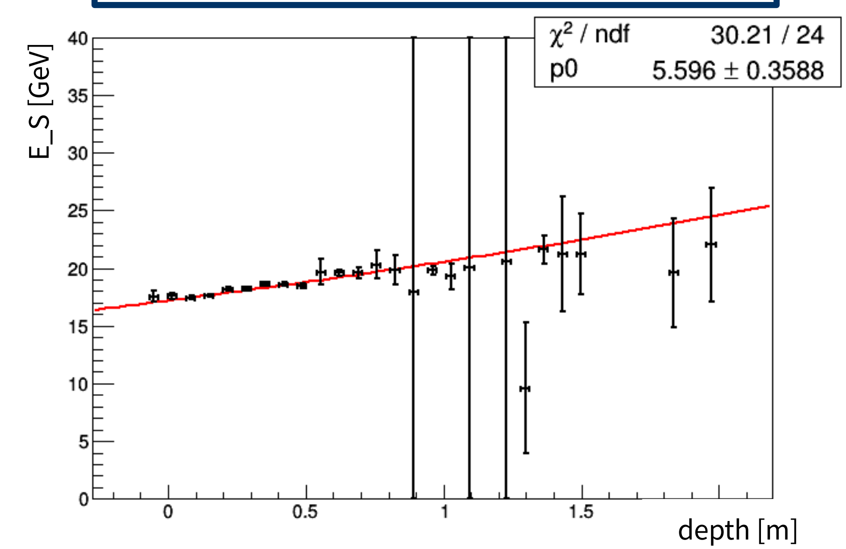
Shower depth of 20 GeV e- & π+



Velocity of optical photon v within fibers



Avg E_S vs shower depth for 20GeV π+



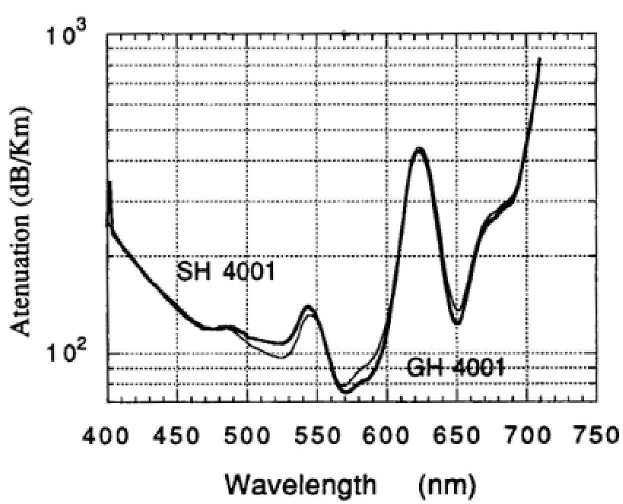
Material properties

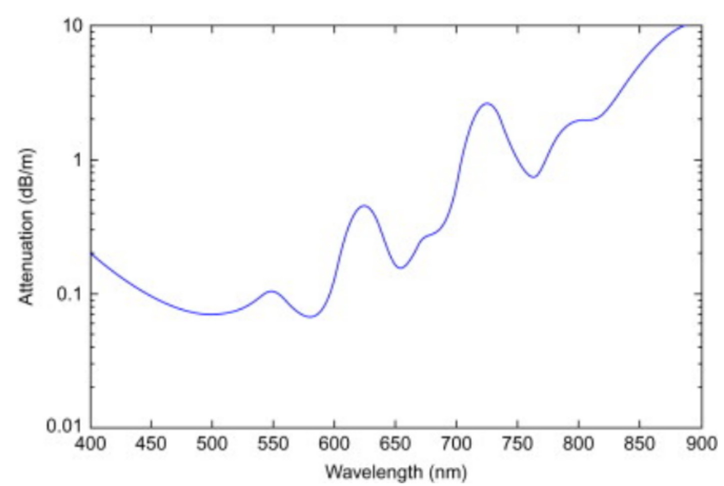
Photon energy

- The energy window of optical photons is set to 900-300 nm (1.37760-4.13281 eV) with 25 nm step.

PMMA

- RI
  - refractiveindex.info (G. Beadie, M. Brindza, R. A. Flynn, A. Rosenberg, and J. S. Shirk. Refractive index measurements of poly(methyl methacrylate) (PMMA) from 0.4-1.6μm, Appl. Opt. 54, F139-F143 (2015))
- Attenuation
  - sciencedirect (Silvio Abrate, Handbook of Fiber Optic Data Communication (4th Ed.), 2013)
  - Eska POF manufacturer





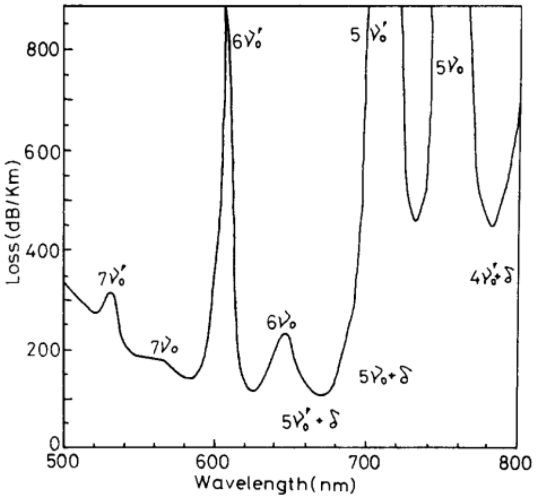
Material properties

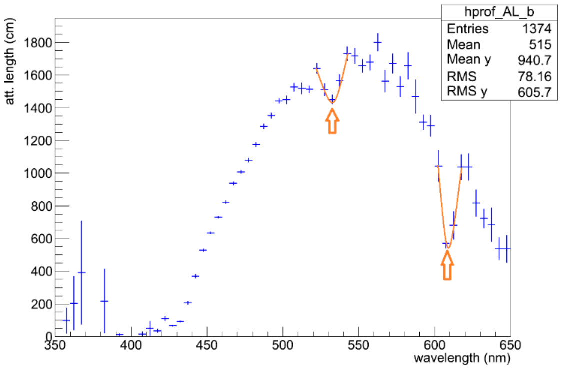
Fluorinated polymer

- RI
  - RD52 paper (N. Akchurin, et al., Nuclear Instruments and Methods in Physics Research, A762 (2014), pp. 100-118.)
  - Set to single value (1.42).

Polystyrene

- RI
  - refractiveindex.info (N. Sultanova, S. Kasarova and I. Nikolov. Dispersion properties of optical polymers, Acta Physica Polonica A 116, 585-587 (2009))
- Attenuation
  - J. Applied Physics (T. Kaino, M. Fujiki, and S. Nara, Low-loss polystyrene core-optical fibers, Journal of Applied Physics 52, 7061 (1981))
  - LHCb-PUB-2015-011, 012 (SCSF-78 LHCb Sci-Fi tracker R&D TDR)
  - kuraray scintillating fiber manufacturer (SCSF-78)

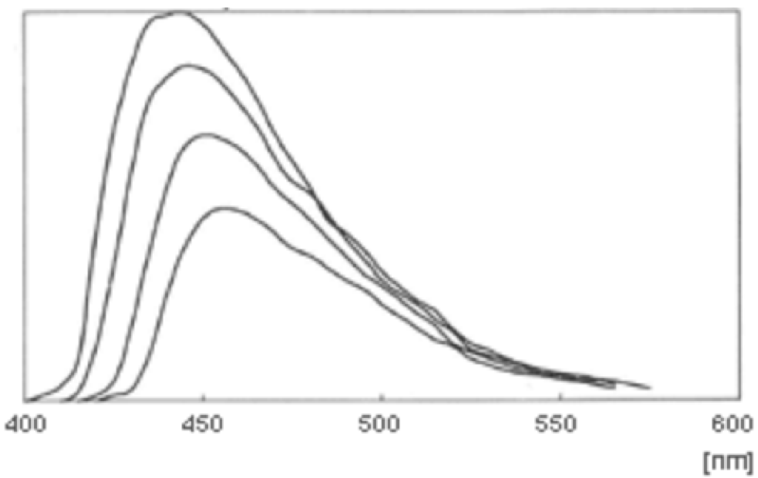




Material properties

Polystyrene

- Emission spectrum, decay constant
  - kuraray scintillating fiber manufacturer (SCSF-78)
  - Decay constant = 2.8 ns
- Birks constant
  - k_B = 0.126 mm/MeV

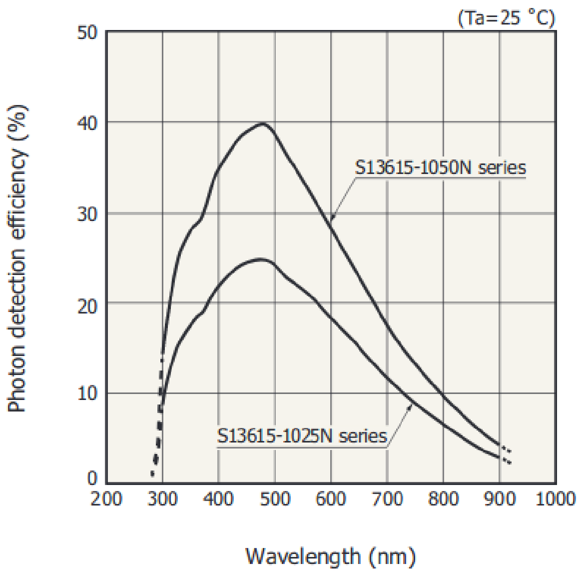


Glass, Air

- RI
  - 1.52, 1.0
- Attenuation
  - 420 cm, N/A

PDE (Photon Detection Efficiency)

- Hamamatsu S13615-1025N series



Title

Text

$$formula$$