Plannar Active Absorber Calorimeter

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Outline

- Principle
- Implementation
- Key advantages
- Geant4 Studies

Motivation of Our Stuty

Using cherenkov photons generated in hadron showers to achieve compensation for high energy jets in a calorimeter with a conventional analog readout and planar geometry

- **Single hadron and jet energy resolution**

$$\frac{\sigma_E}{E} \leq \frac{30\%}{\sqrt{E}} + ?\%$$

- **Resolution of the EM section**

$$\frac{\sigma_E}{E} = \frac{5\% - 10\%}{\sqrt{E}}$$

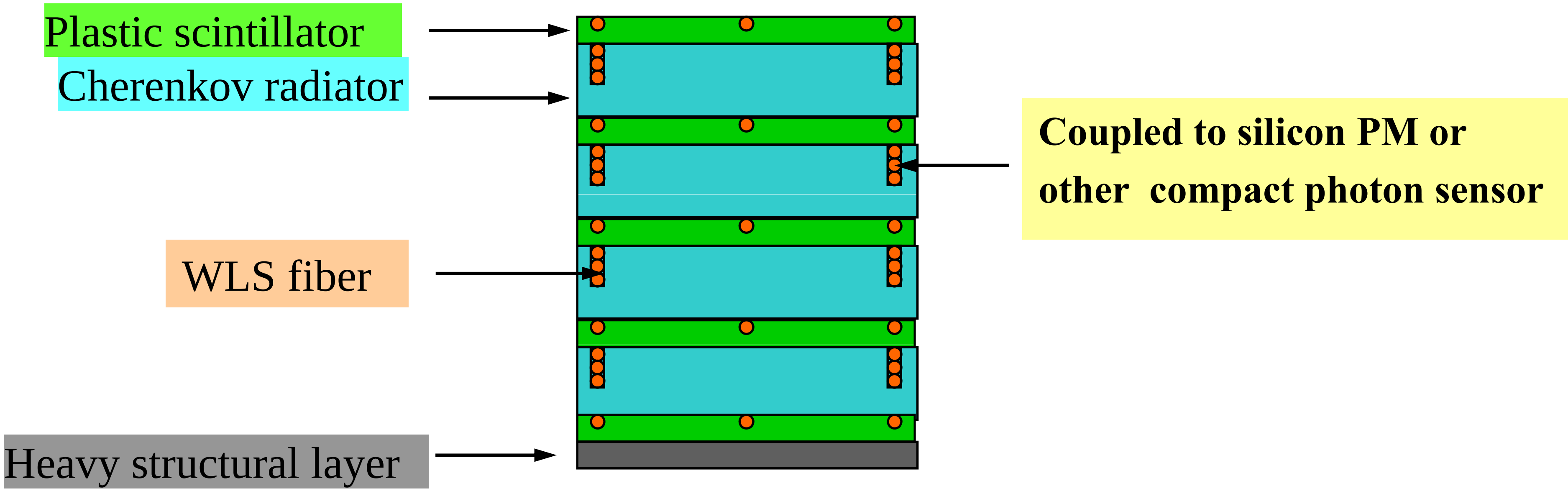
Limit the readout channels to << 10^6 with an analog approach

Basic Detector Configuration (1)

- **Thin plastic scintillator plates**

- **Thicker heavy lead glass plates as Cherenkov radiator**
  "Low cost hot pressed glass plates!"

- **Analog readout (WLS fiber and imbedded silicon PMT)**



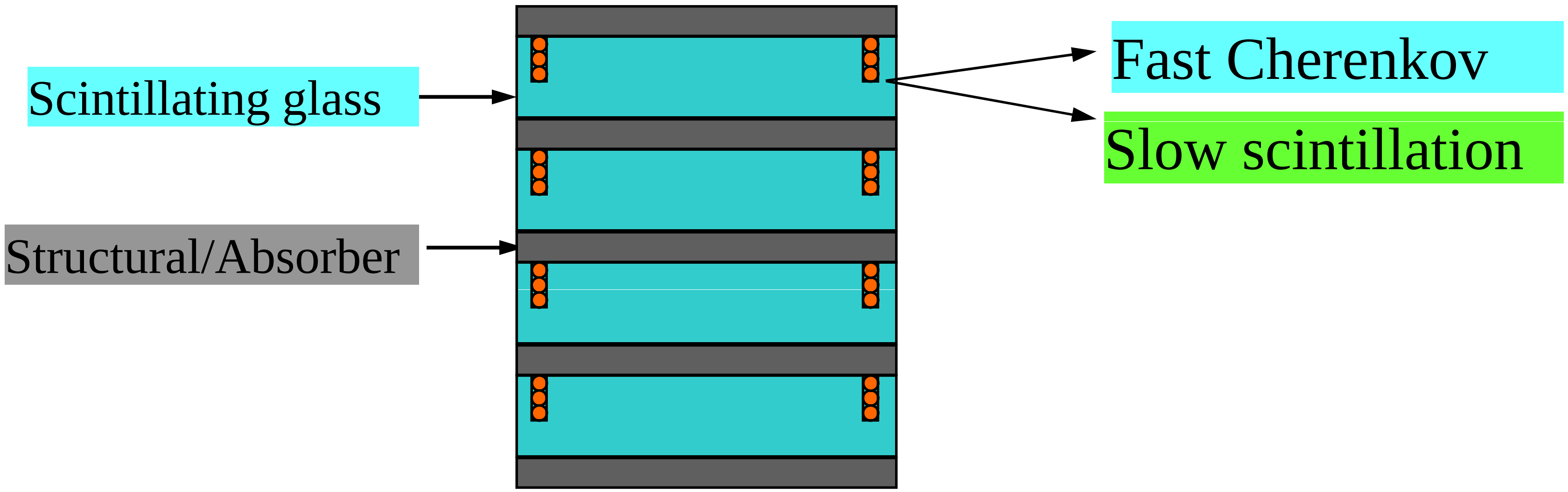
- **Use large plates to reduce the readout channel**

Basic Detector Configuration (2)

- **Scintillating glass plates as active layers for both scintillation and Cherenkov light generation**

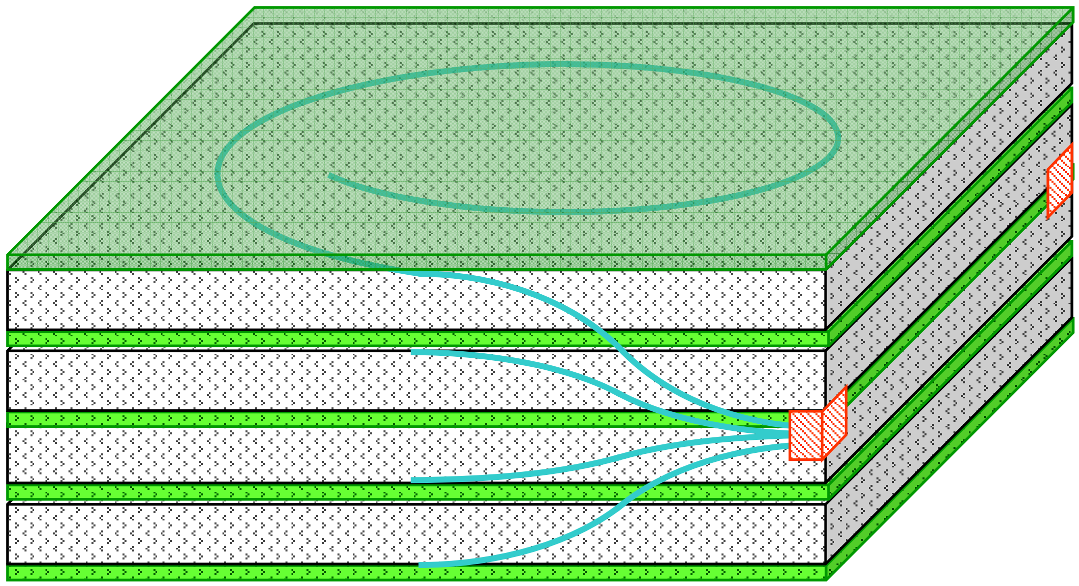
Eg. SCGI-C scintillating glass with ~ 15% cherenkov light
(Ohara Optical Glass. Manufacturing Company, Ltd)

- **Readout both Cherenkov light and scintillation light**



Construction and Readout Possibilities

- **Both scintillation and the Cherenkov rediator plates are coupled to a WLS fibers**
- **Silicon PMT readout**
- **May be able to combine fibers to reduce the number of Readout channels**



A possible way to combine WLS fibers

Key Advantages of This Approach

- **Potential of achieving good energy resolution for both hadrons and EM showers**
- **The Cherenkov plates are nearly a total absorption calorimeter and the EM energy resolution is not limited by the sampling fluctuations**
- **Can use conventional photon sensors**

  eg. Hybrid PMT in CMS HCal
- **Can be be segmented transversely and longitudinally allowing e/π separations, muon tracking and localized e/h energy correction, etc.**

Compare Digital and Analog Approaches

Digital

- **Number of readout channels: ~ 50 Million**
- **Plus W/Si calorimeter readout channels: 10 – 30 Million**
- **Total thickness: 5 – 6 interaction length ?**

Analog Approach

- **Number of readout channels: ~ 1M**
- **Total thickness: Need > 8 interaction length**

Past and Recent work on Dual Readout Calorimeter

A beam test organized by Albert Erwin of Wisconsin was done in 1980 at BNL with a small (~60 cm long) detector made of Pb/Lucite and Pb/plastic Scintillator plates. The plates were 1 cm thick with WLS bars glued to the sides.
PMTs were used for readout.
No conclusive results, not published.

More recent work:

See the 4th Detector Concept talks

Properties of Cherenkov Radiators

OPAL EM Calorimeter material (SF57)

Material	Pb	F5	SF5	SF57	Heavy	PbF2
PbO content (%)	-	40	51	75	85	-
Density (g/cm^3)	11.3	3.47	4.07	5.57	6.2	7.8
Index of refraction	_	1.6	1.6	1.85	-	1.82
UV absorption edge (nm)	0.5	370	380	380	450	300
Radiation length (cm)	0.5	2	1.6	1.5	1.4	0.93
Interaction length (g/cm2)	193	104	108	120	120	156
Interaction length (cm)	18	29.9*	26.5*	21.4*	20**	20

* GEANT4 results

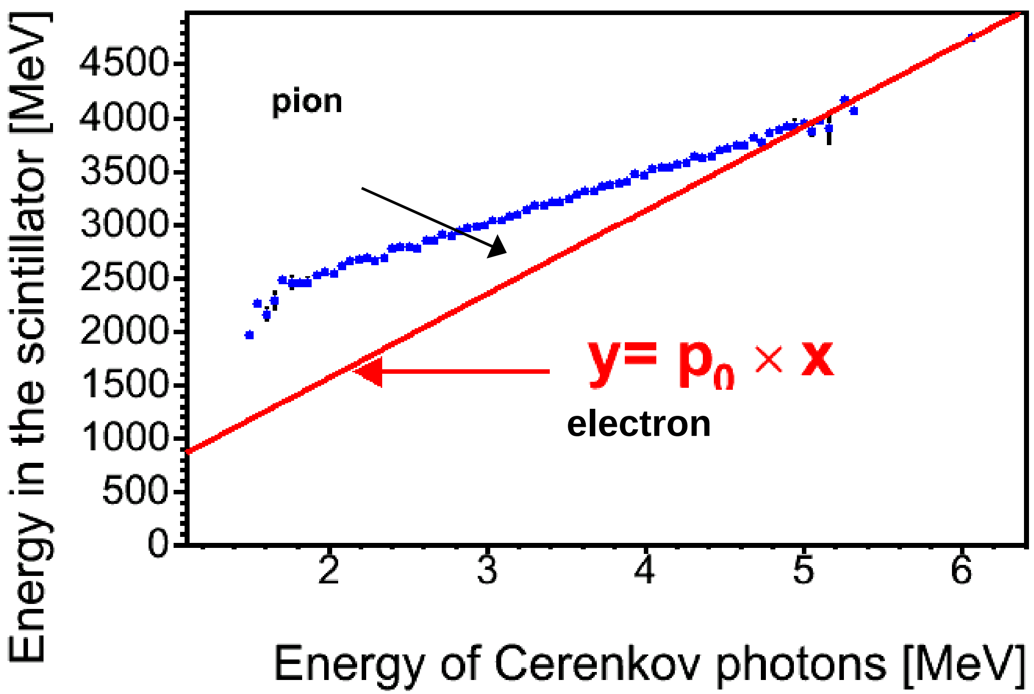
** Estimate

Response of electrons and pions (GEANT4)

Take an arbitrarily large block of lead glass and generate e's and π's

E_{π}^{ion} → π ionization energy E_{π}^{ch} → π cherenkov photon energy

E_{e}^{ion} → e ionization energy E_{e}^{ch} → e cherenkov photon energy



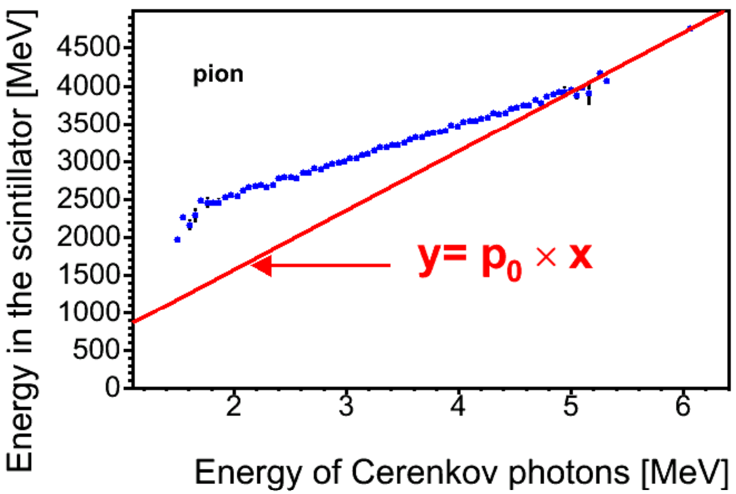
- 20 GeV pions create 3.5 MeV cherenkov photon energy or about 1 million photons on average

  (no wavelength cut)
- Linear correlation between ionization energy and Cherenkov photon energy

Hadron Shower Energy Corrections

EM fraction in a hadron shower: $$f_{em} = \frac{\alpha E_\pi^{ch}}{\alpha E_\pi^{ch} + E_\pi^{ion}}$$

The "calibration" constant α is obtained by adjusting the response of the cherenkov photon generation by pions and electrons.

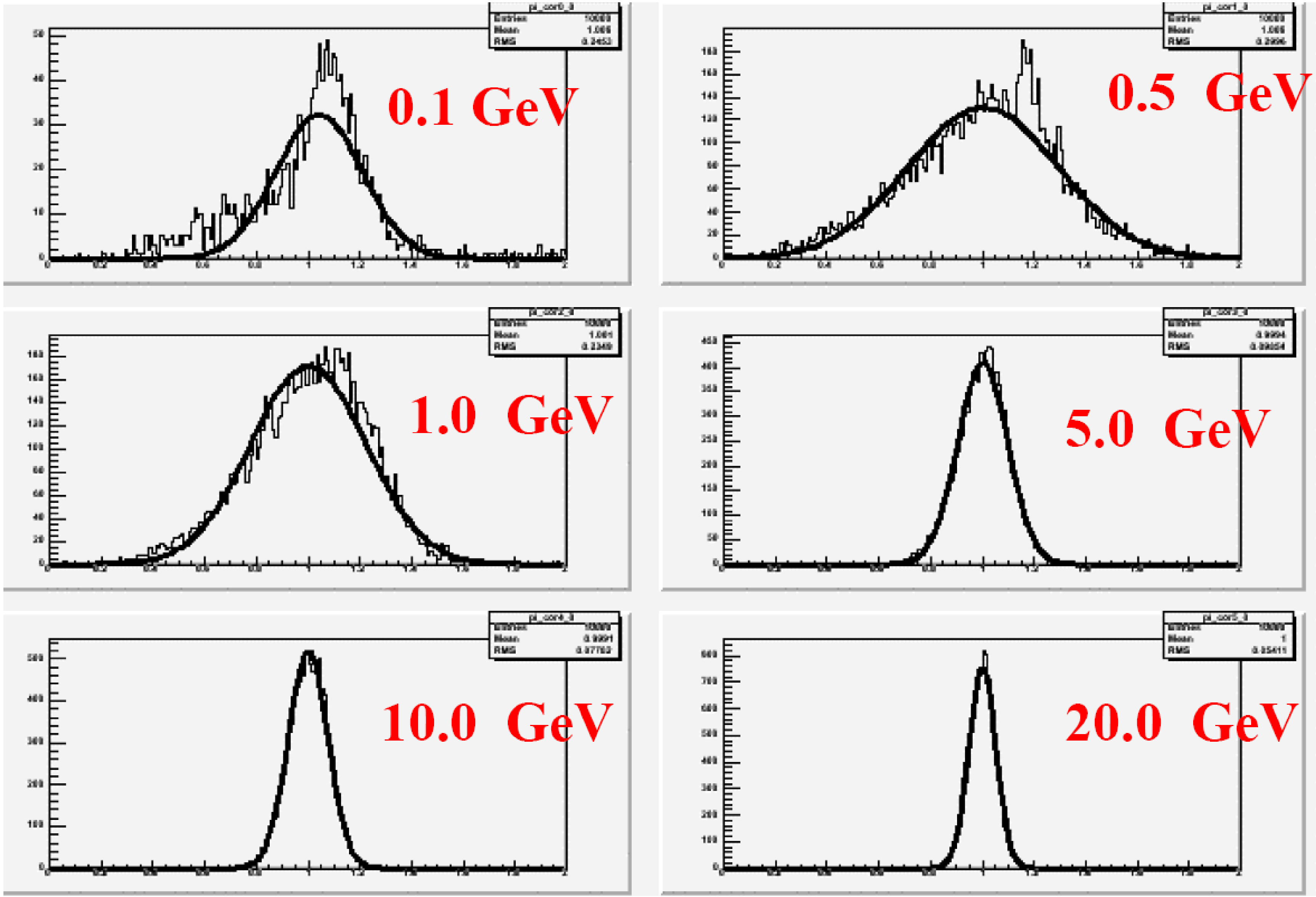


Make final adjustment for the f_{em} based on the calibration factor α

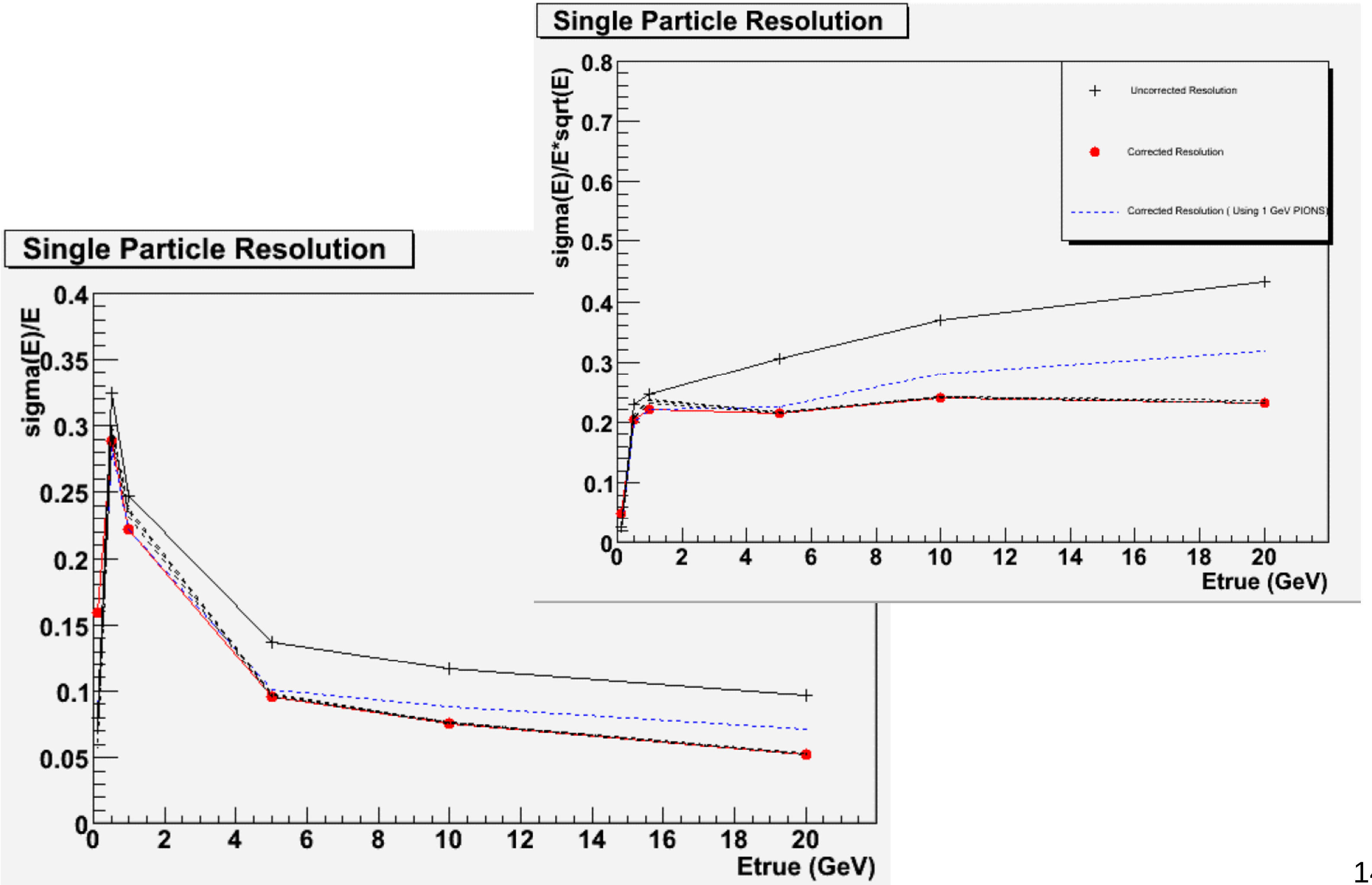
Remark:

On average, we get ~5×10⁴ cherenkov photons per GeV hadronic energy.
We can get 100 γ's/GeV even if the capture efficiency is only 0.2%. This should be sufficient to perform the energy correction for compensation.

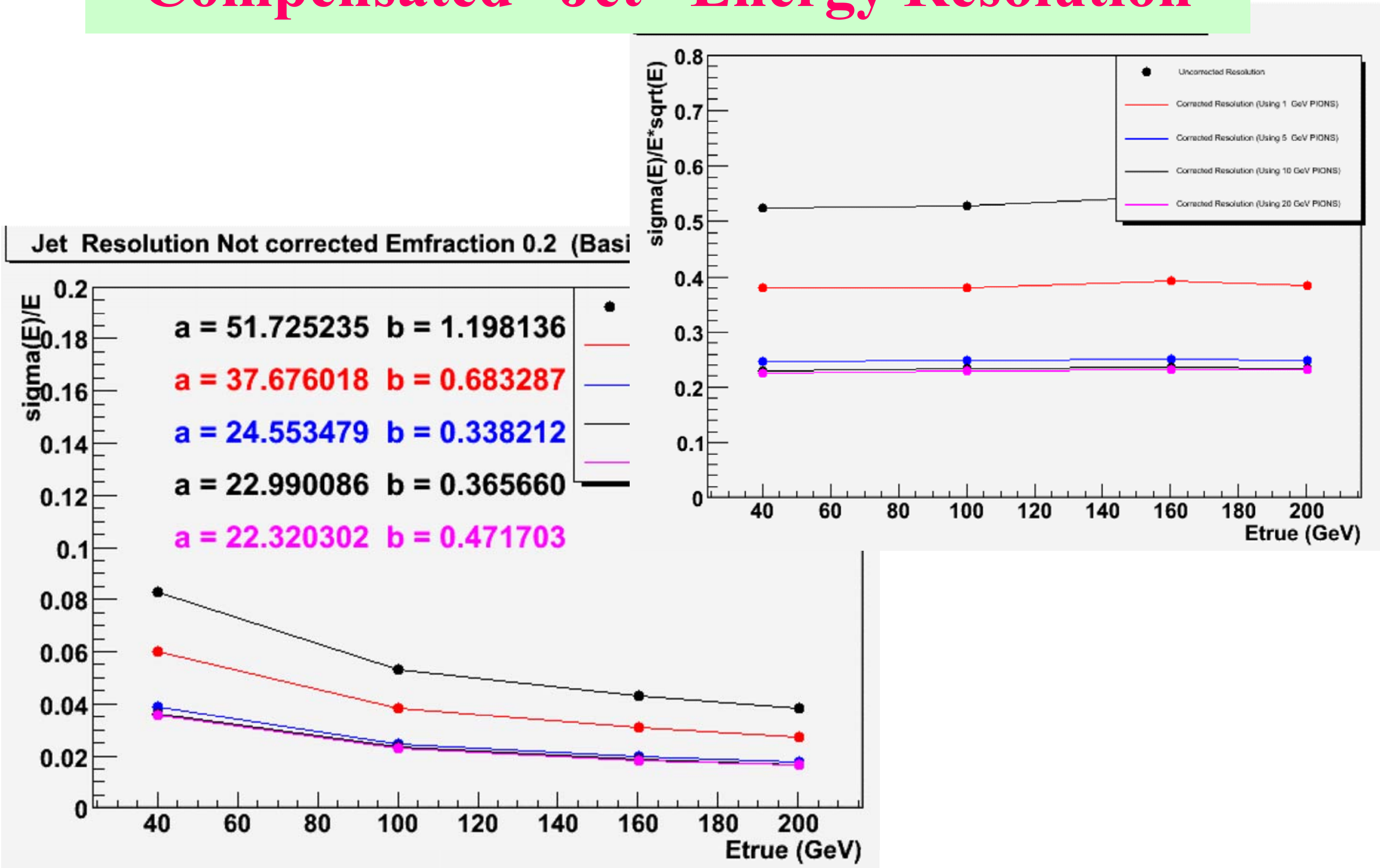
Corrected E_{out} vs E_{true}



Corrected Energy Resolution Function



Compensated “Jet” Energy Resolution



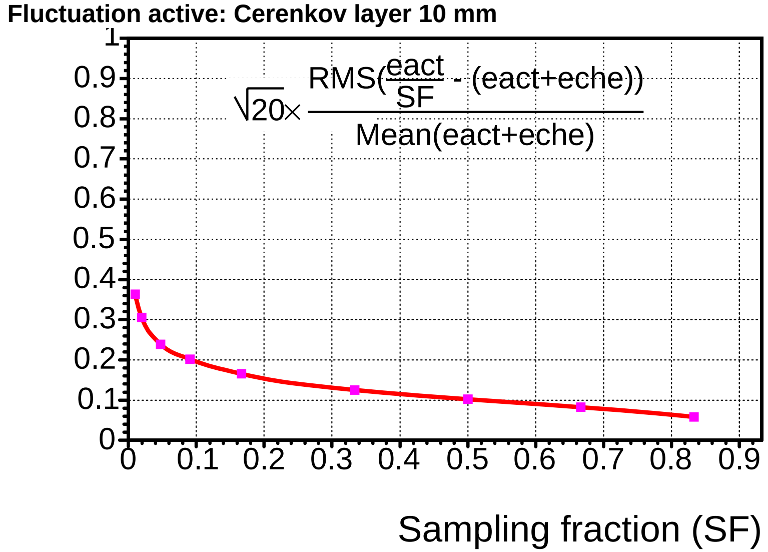
“Jet” defined as a mixture of hadrons and 20% of photons

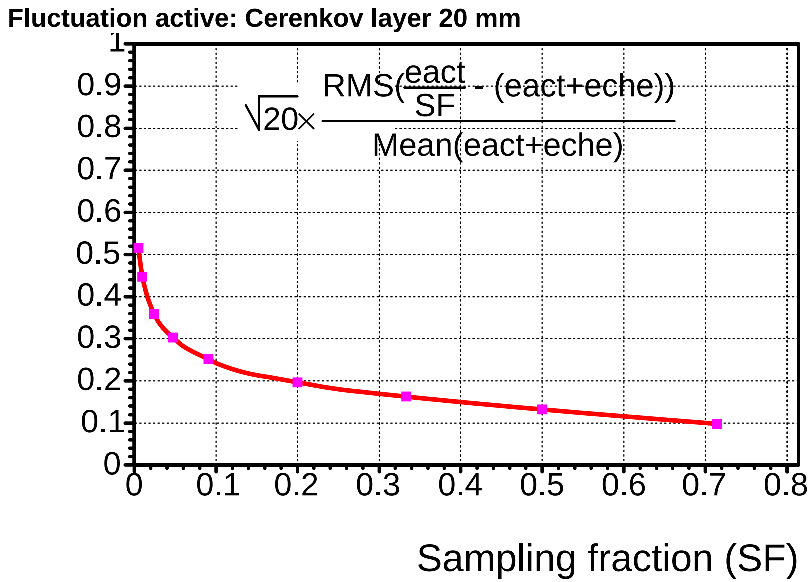
Sampling Fluctuations: 20 GeV pions

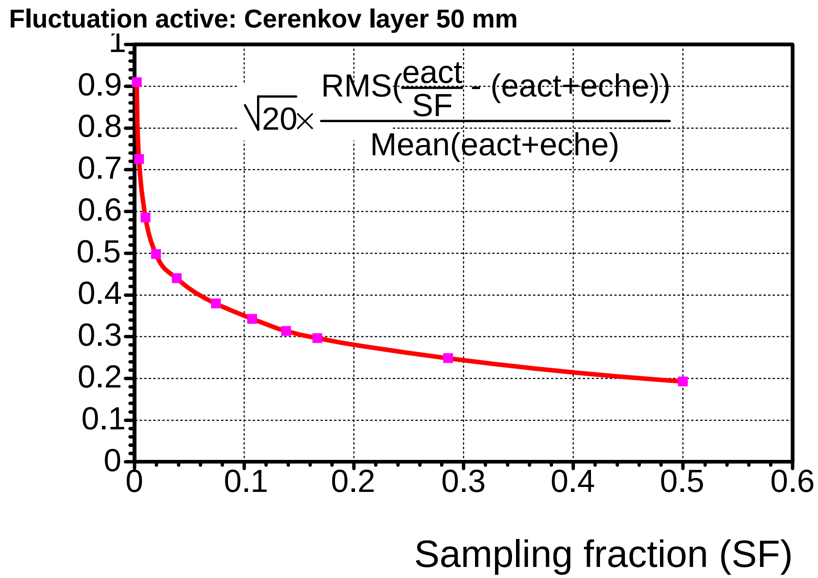
Fix cherenkov radiator thickness to 10, 20, 50 mm

Plot $a = \frac{\Delta E}{E}\sqrt{E}$ **against SF**

SF: ratio of ionization energies in two types of plates



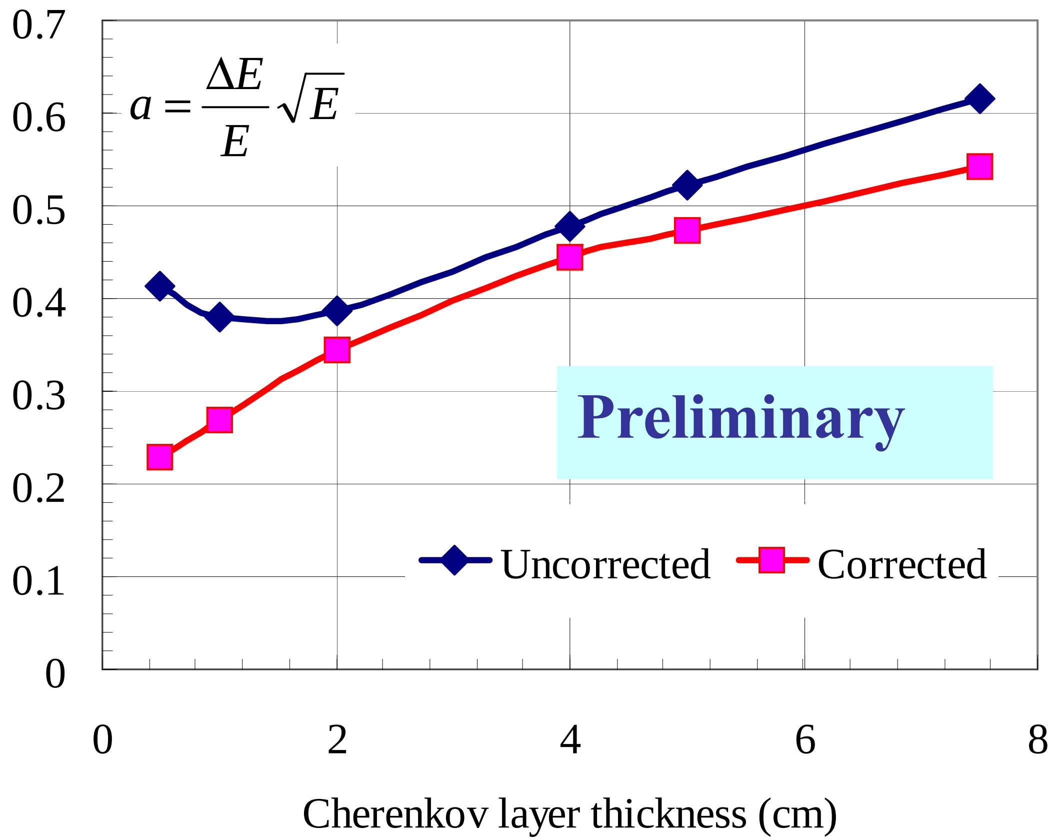




Sampling calorimeter with a planar geometry

- **Lead glass plates as cherenkov radiator**
- **Plastic scintillator plates sample the ionization energy**
- **Studied 20 GeV pions**

Energy resolution vs Lead Glass Thickness (5 mm scintillator plates)



Comments on Prompt Photon Measurements

Prompt photons are measured twice by scintillator plates and by Cherenkov plates

Cherenkov plates can be a nearly total absorption EM calorimeter with energy resolution not limited by the sampling fluctuations

Can consider PbF_2 crystal (ρ = 7.7, R_M= 2.2 cm**) for the first 15 r.l. of EM section**

Conclusions

- **Based on the limited GEANT studies we have done, it**

  appears the goal for achieving $\frac{\sigma_E}{E} < \frac{30\%}{\sqrt{E}}$

  is possible by the dual readout concept with a planar geometry
- **More simulation studies are needed**
- **Hardware implementation is very challenging**

  - Measure the weak Cherenkov light

  - Achieving high average density of the calorimeter

  - Calibration

  - Dynamic range of the readout channels in EM section if silicon PMs are used

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