

# *Recent results from the DREAM\* project*

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## *Outline:*

- The DREAM approach to precision hadron calorimetry
- Recent results
- Future plans
- Conclusions

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\* DREAM is a collaboration of US and Italian institutions  
TTU, UCSD, ISU (USA), PV, RM1, CS, CG, PI (I)

*An attractive option for improving the quality of hadron calorimetry:*

*Use Čerenkov light!! Why?*

Hadron showers  $\left\langle \begin{array}{l} \text{em component } (\pi^0) \\ \text{non-em component (mainly soft } p) \end{array} \right.$

Calorimeter response to these components not the same ( $e/h \neq 1$ )

$\langle f_{em} \rangle$  energy dependent  $\rightarrow$  *hadronic signal non-linearity*

Fluctuations in  $f_{em}$  large, non-Gaussian  $\rightarrow$  *poor resolution, etc.*

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Čerenkov light almost exclusively produced by em component \*  
(~80% of non-em energy deposited by non-relativistic particles)

$\rightarrow$  **DREAM (Dual REAdout Method) principle:**

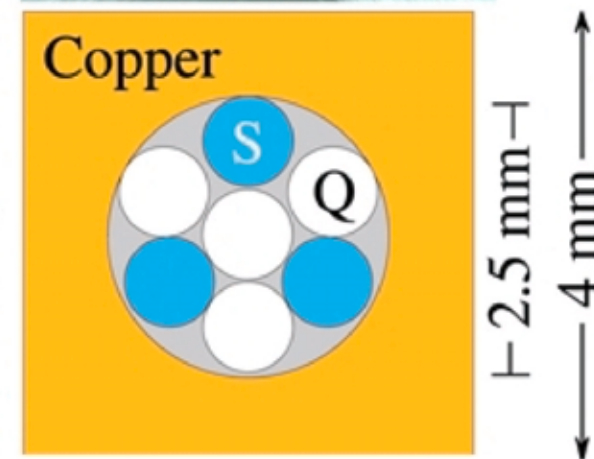
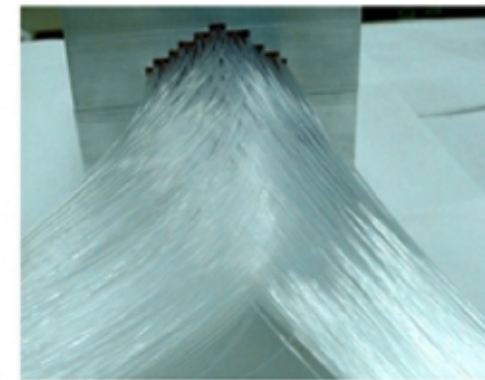
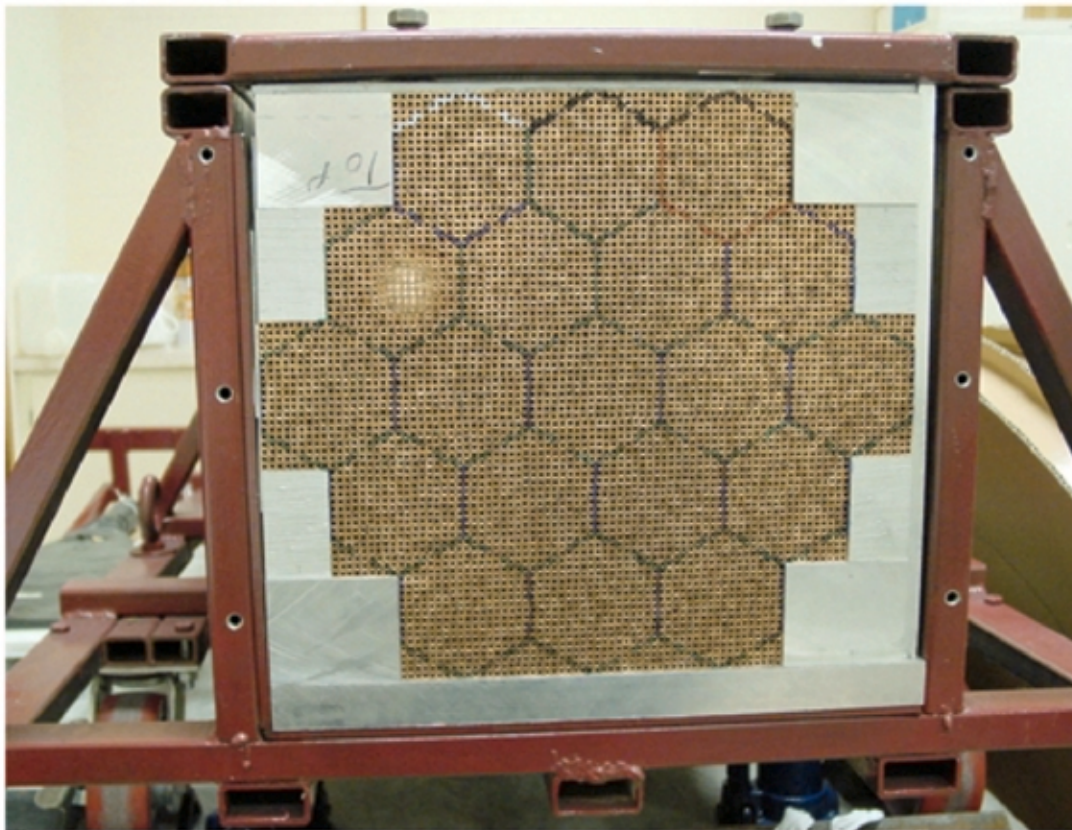
*Measure  $f_{em}$  event by event by comparing Č and  $dE/dx$  signals*

\* How do we know this?

- CMS HF:  $e/h \sim 5$

- Lateral profiles of hadronic showers

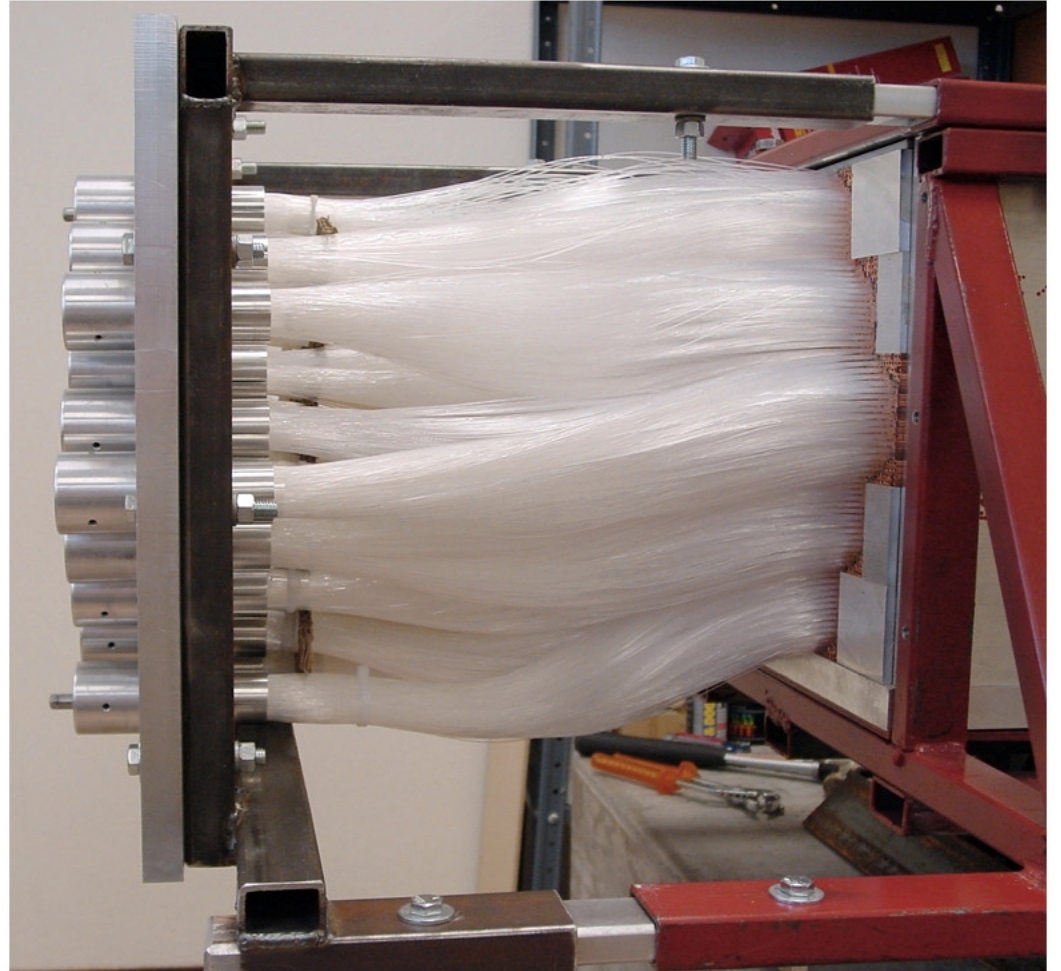
## DREAM: Structure



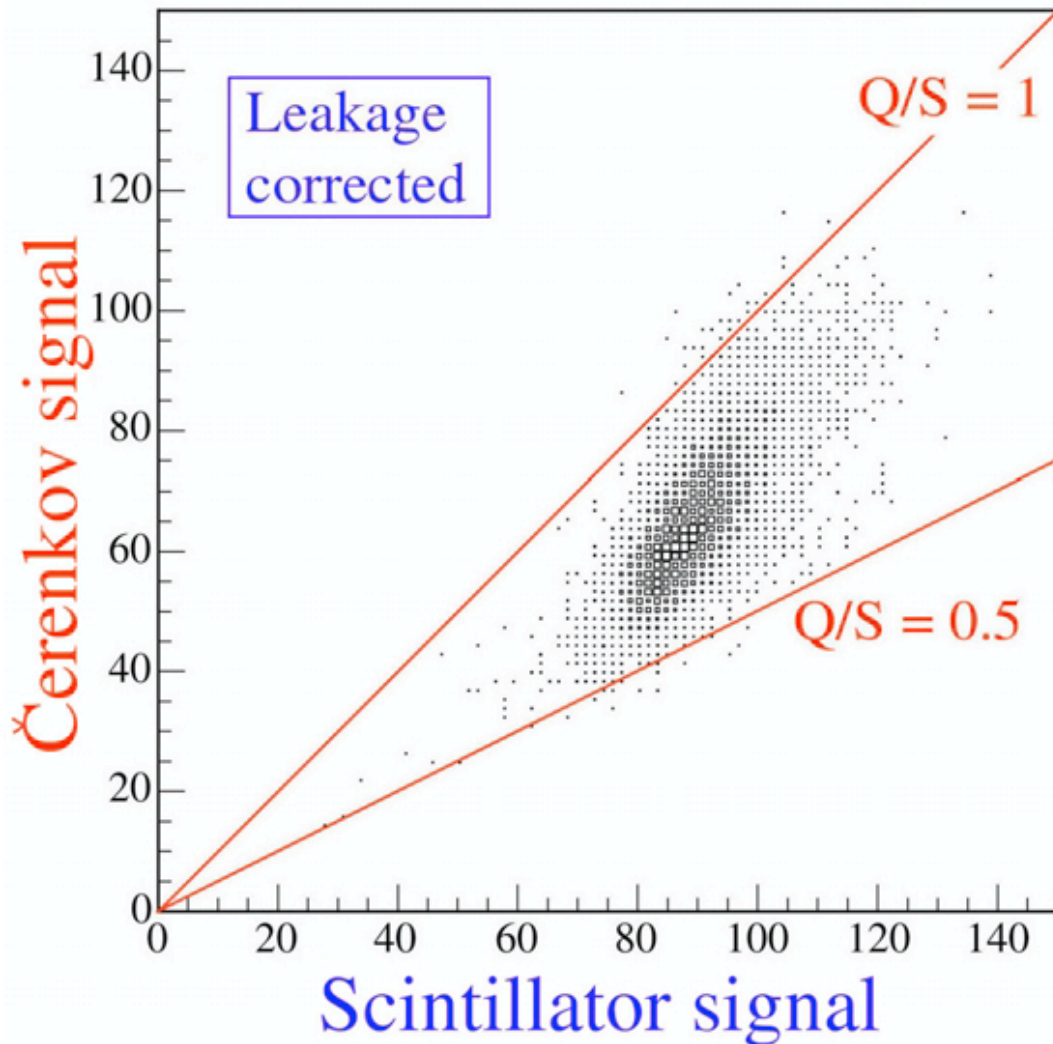
- *Some characteristics of the DREAM detector*

- **Depth** 200 cm ( $10.0 \lambda_{\text{int}}$ )
- Effective **radius** 16.2 cm ( $0.81 \lambda_{\text{int}}$ ,  $8.0 \rho_M$ )
- **Mass** instrumented volume 1030 kg
- Number of **fibers** 35910, diameter 0.8 mm, total length  $\approx 90$  km
- Hexagonal **towers** (19), each read out by 2 PMTs

# DREAM readout



# DREAM: How to determine $f_{em}$ and $E$ ?



$$S = E \left[ f_{em} + \frac{1}{(e/h)_S} (1 - f_{em}) \right]$$

$$Q = E \left[ f_{em} + \frac{1}{(e/h)_Q} (1 - f_{em}) \right]$$

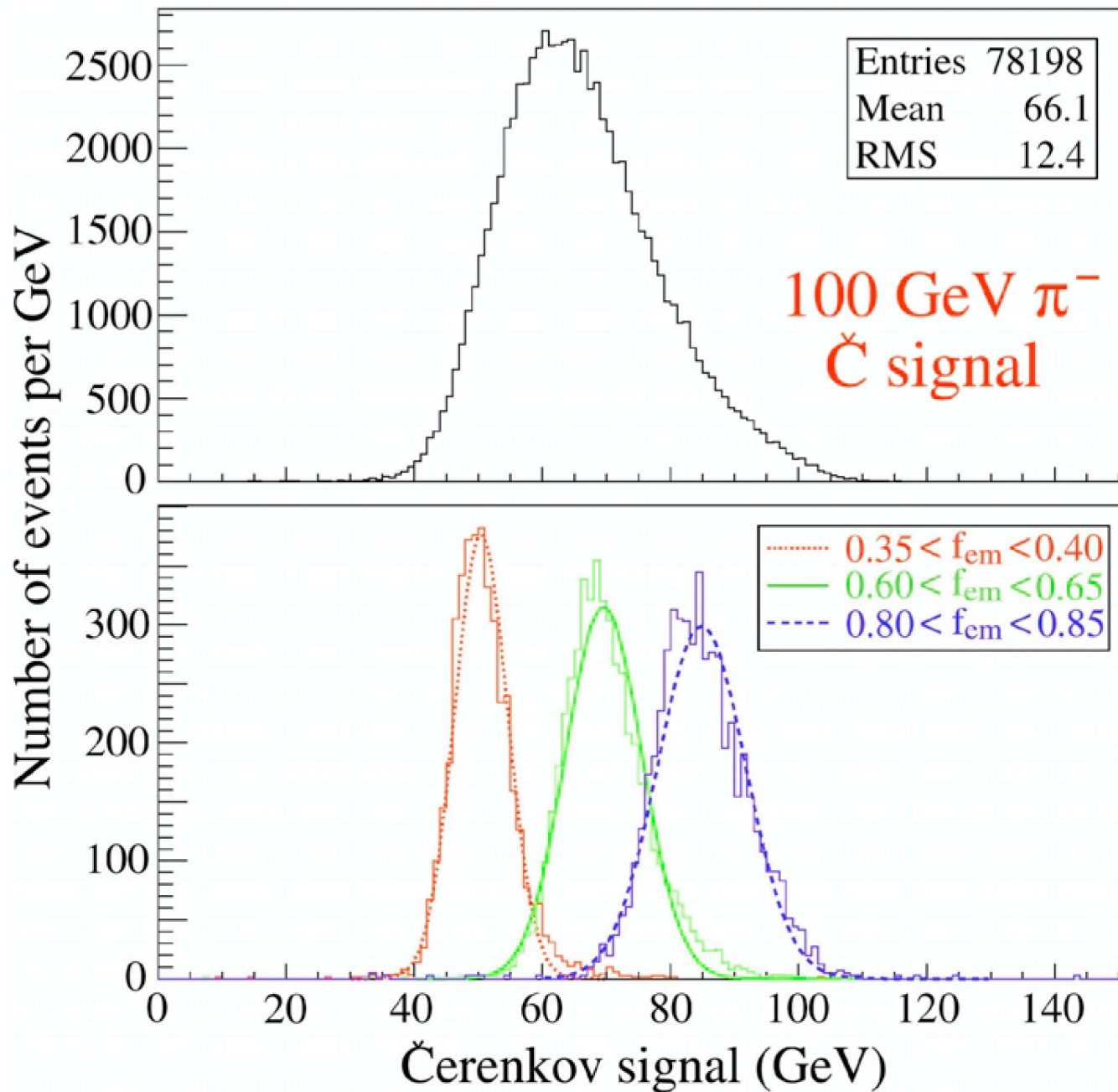
e.g. If  $e/h = 1.3$  (S),  $4.7$  (Q)

$$\frac{Q}{S} = \frac{f_{em} + 0.21 (1 - f_{em})}{f_{em} + 0.77 (1 - f_{em})}$$

$$E = \frac{S - \chi Q}{1 - \chi}$$

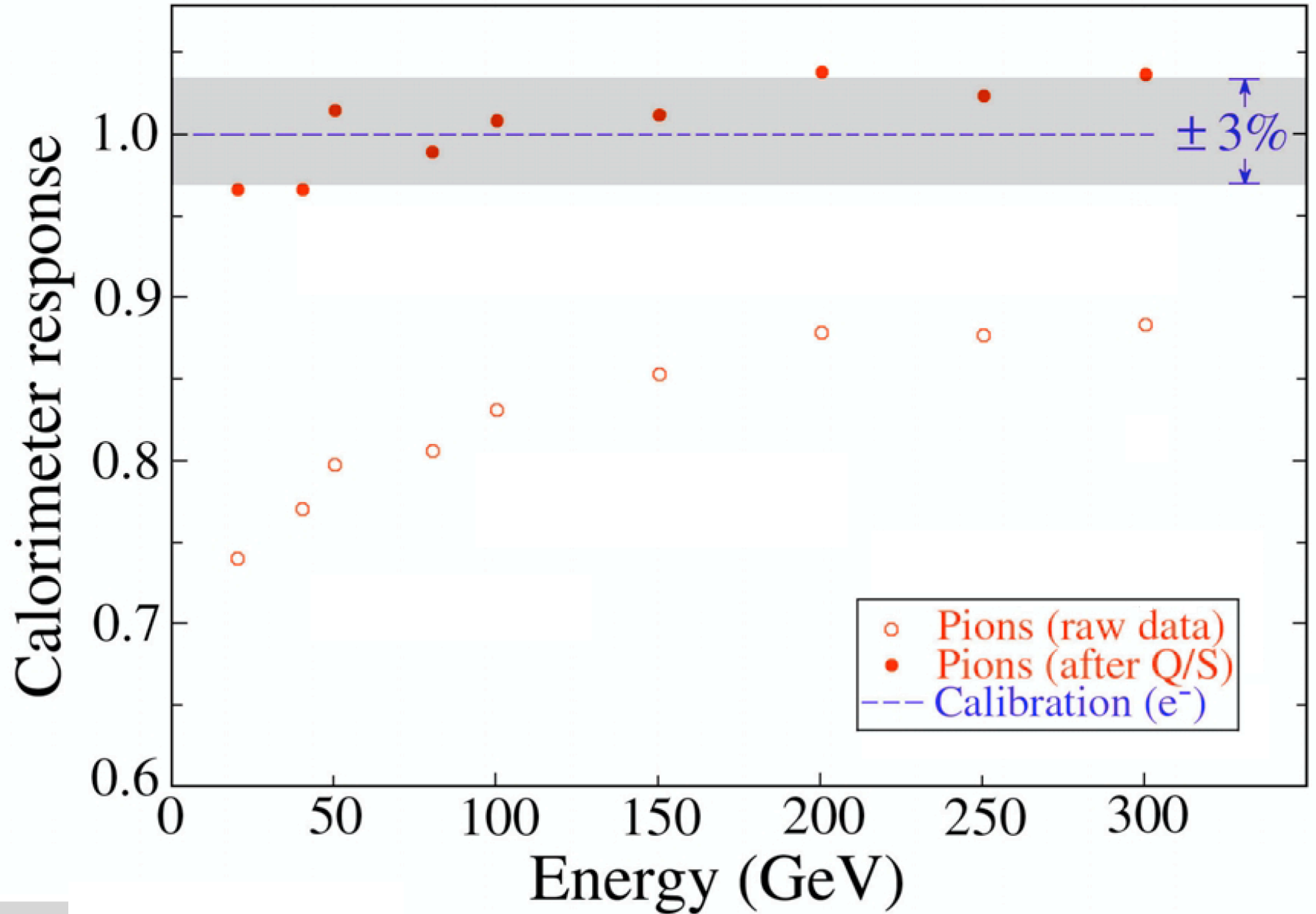
with  $\chi = \frac{1 - (h/e)_S}{1 - (h/e)_Q} \sim 0.3$

# DREAM: Effect of event selection based on $f_{em}$



*From:*  
NIM A537 (2005) 537

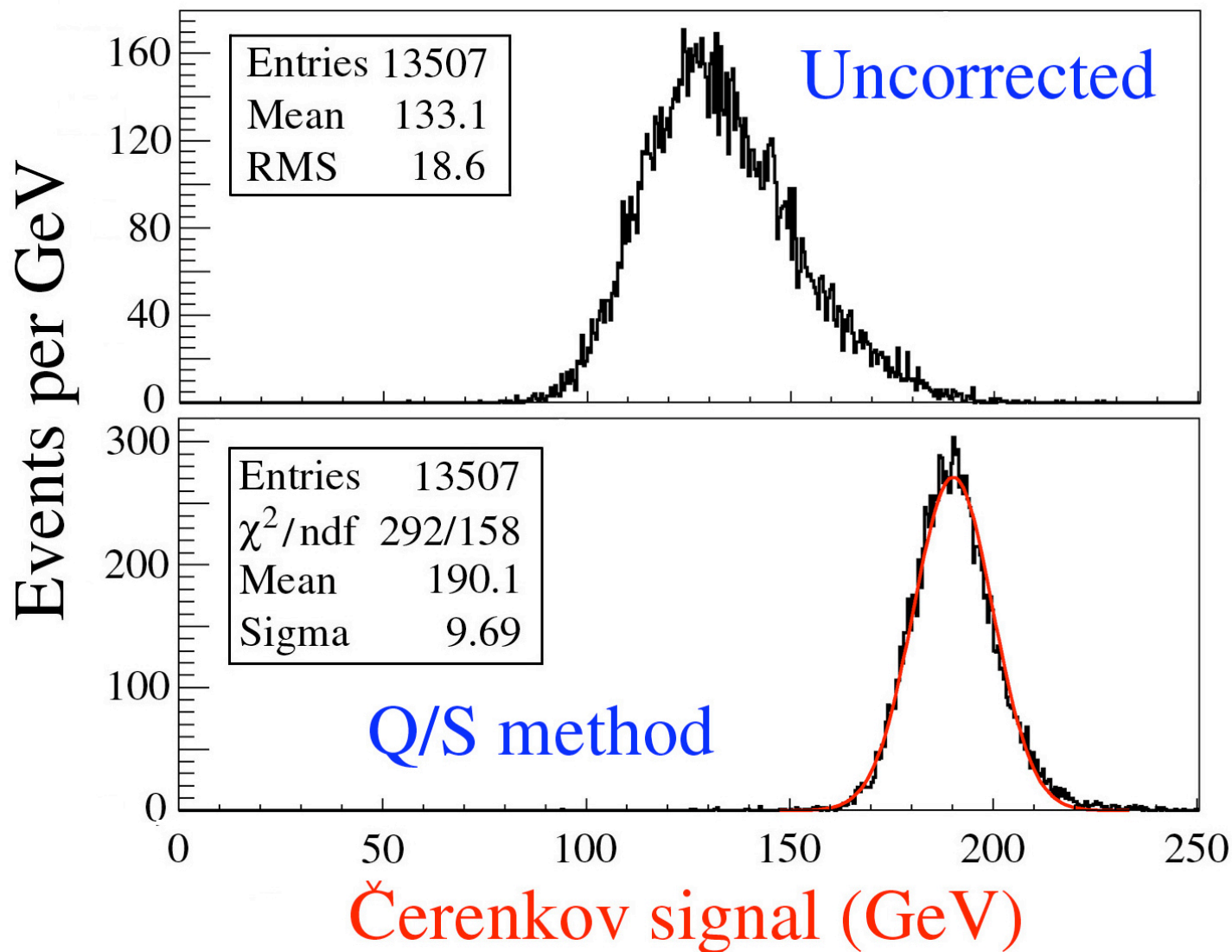
# DREAM: *Reconstructed hadronic energy*



*From:*

NIM A537 (2005) 537

# DREAM: Effect of corrections (200 GeV "jets")



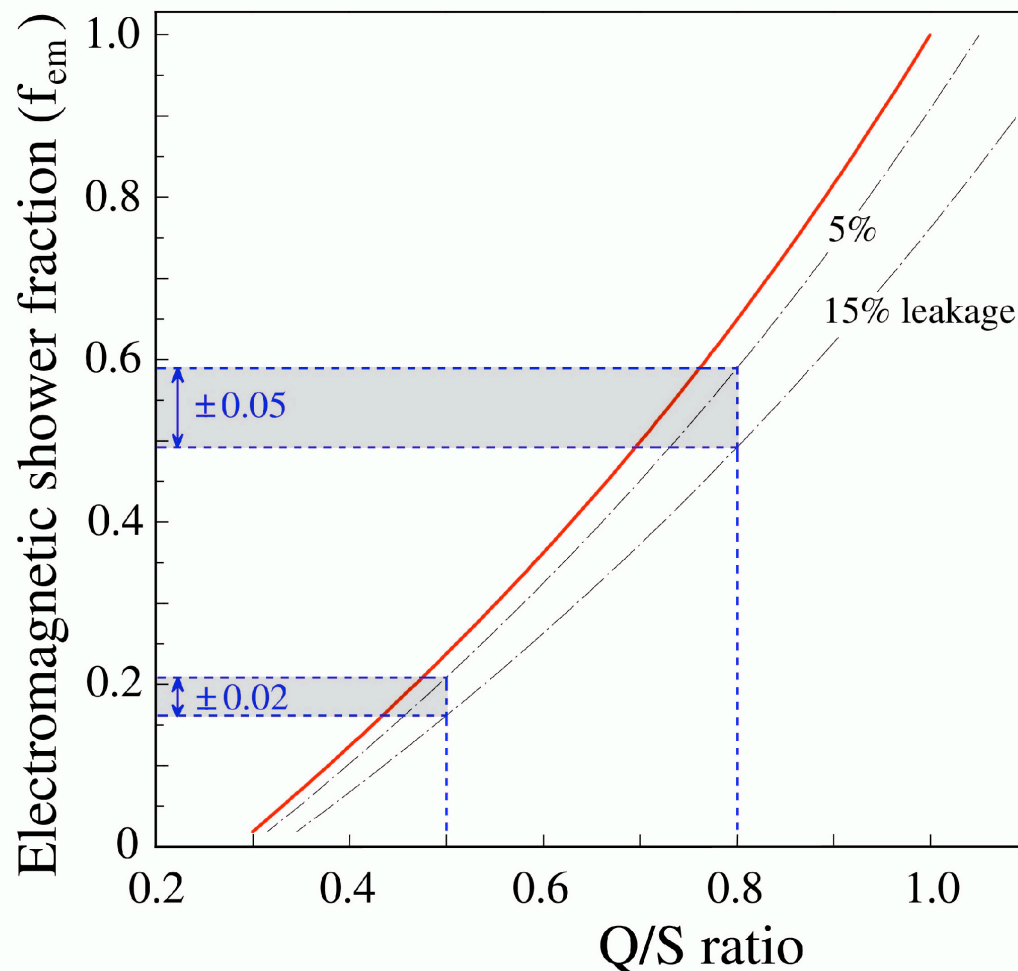
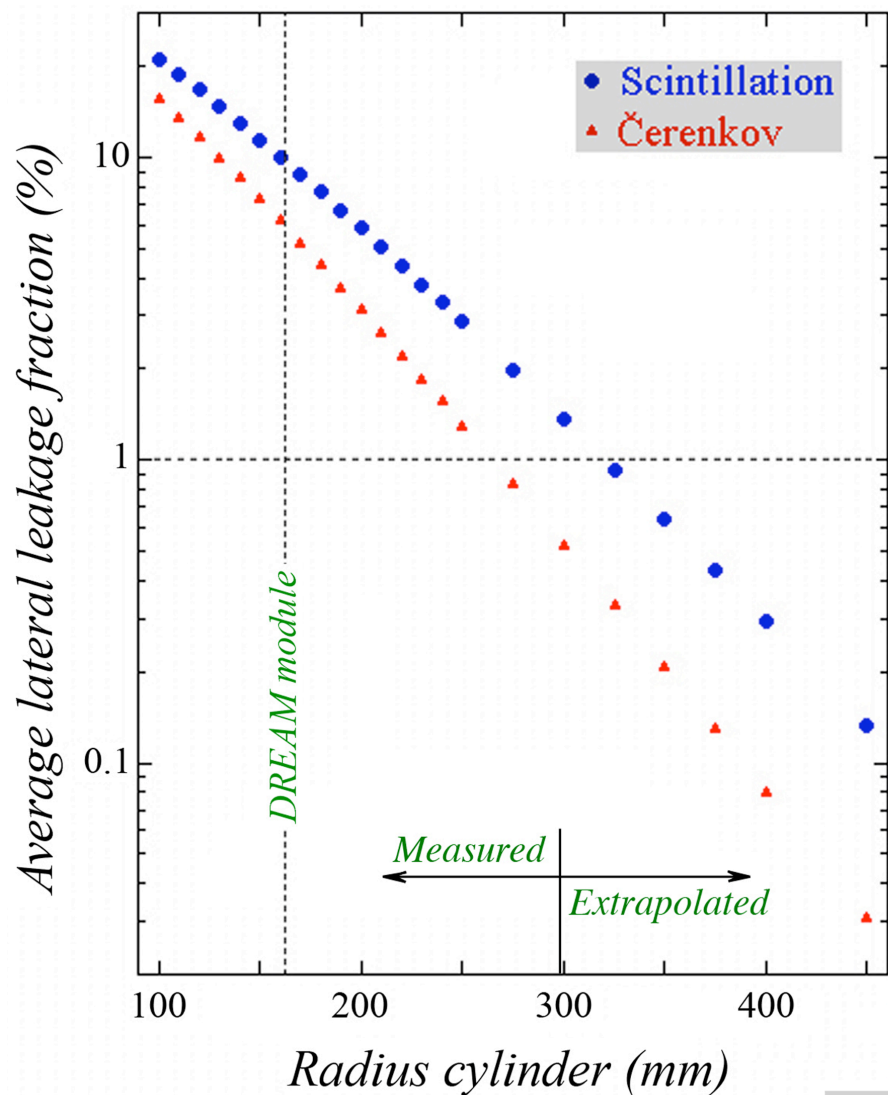


## *How to improve DREAM performance*

- Build a larger detector → *reduce effects side leakage*

# DREAM: The importance of leakage and its fluctuations

## Lateral shower containment ( $\pi$ )



From:  
NIM A584 (2008) 273

## *How to improve DREAM performance?*

- Build a larger detector  $\longrightarrow$  *reduce effects side leakage*
- *Increase Čerenkov light yield*  
DREAM: 8 p.e./GeV  $\longrightarrow$  fluctuations contribute 35%/ $\sqrt{E}$   
No reason why DREAM principle is limited to fiber calorimeters

*Homogeneous detector ?!*

$\longrightarrow$  *Need to separate the light into its Č, S components*

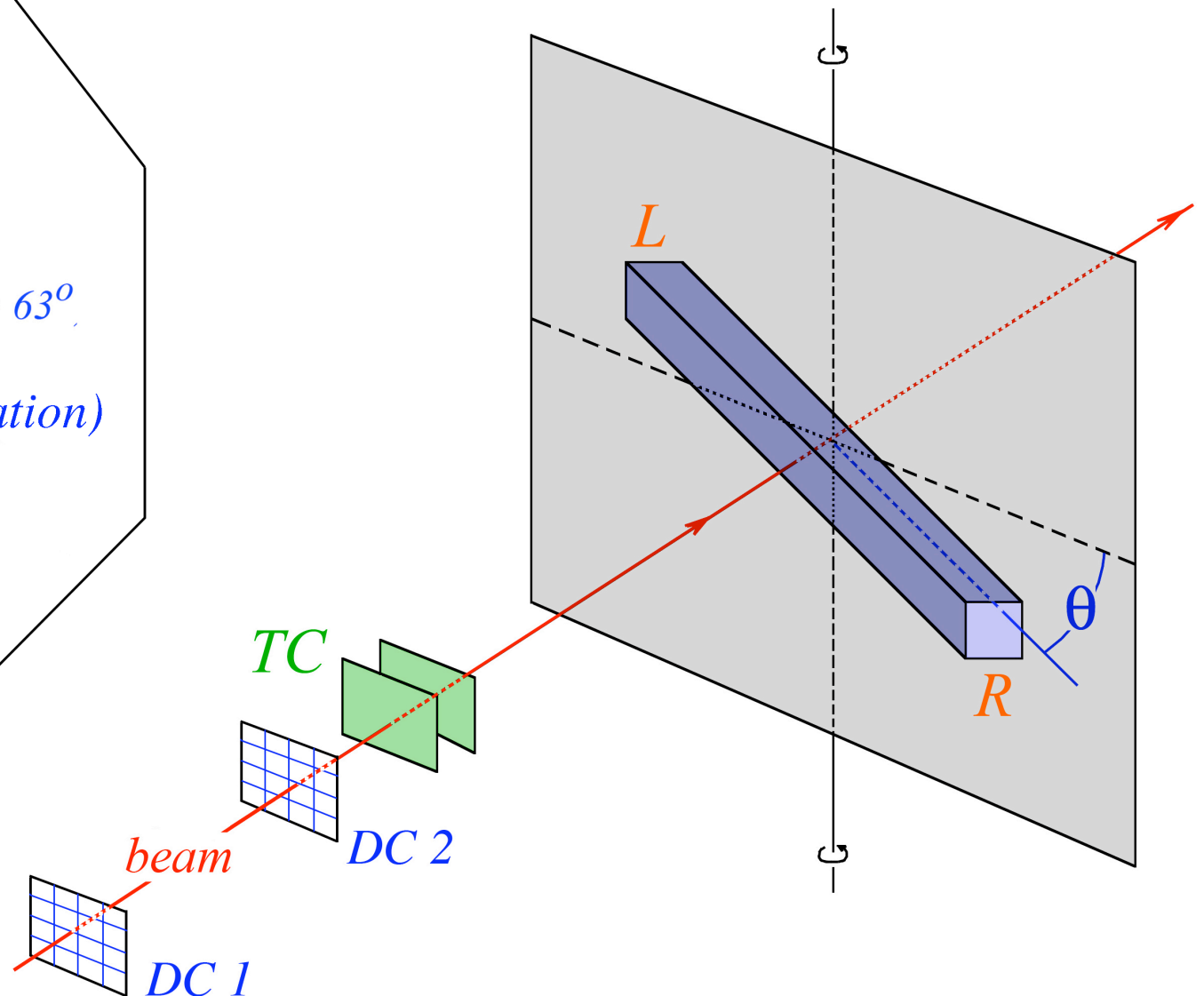
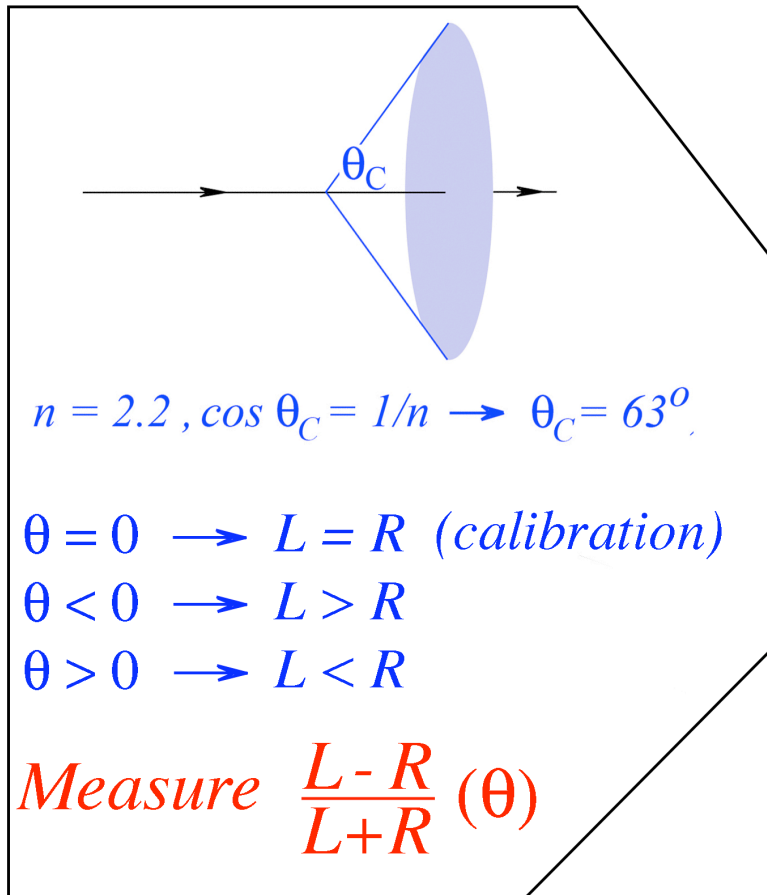
# *Čerenkov component in light from PbWO<sub>4</sub> crystals?*

- Light yield typically  $\sim 10$  p.e./MeV (dependent on T, readout)
- Lead glass: 500 - 1000 p.e./GeV from Čerenkov effect (3 - 5%/ $\sqrt{E}$ )  
—→ *Expect substantial Č component in PbWO<sub>4</sub> signals*
- *How to detect / isolate Čerenkov component?*
  - *Directionality of Čerenkov component*
  - *Time structure of the signals*
  - *Spectral differences*

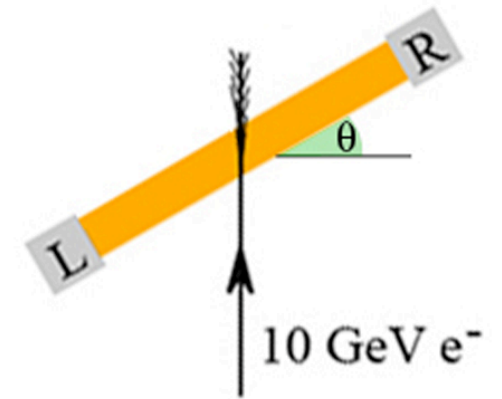
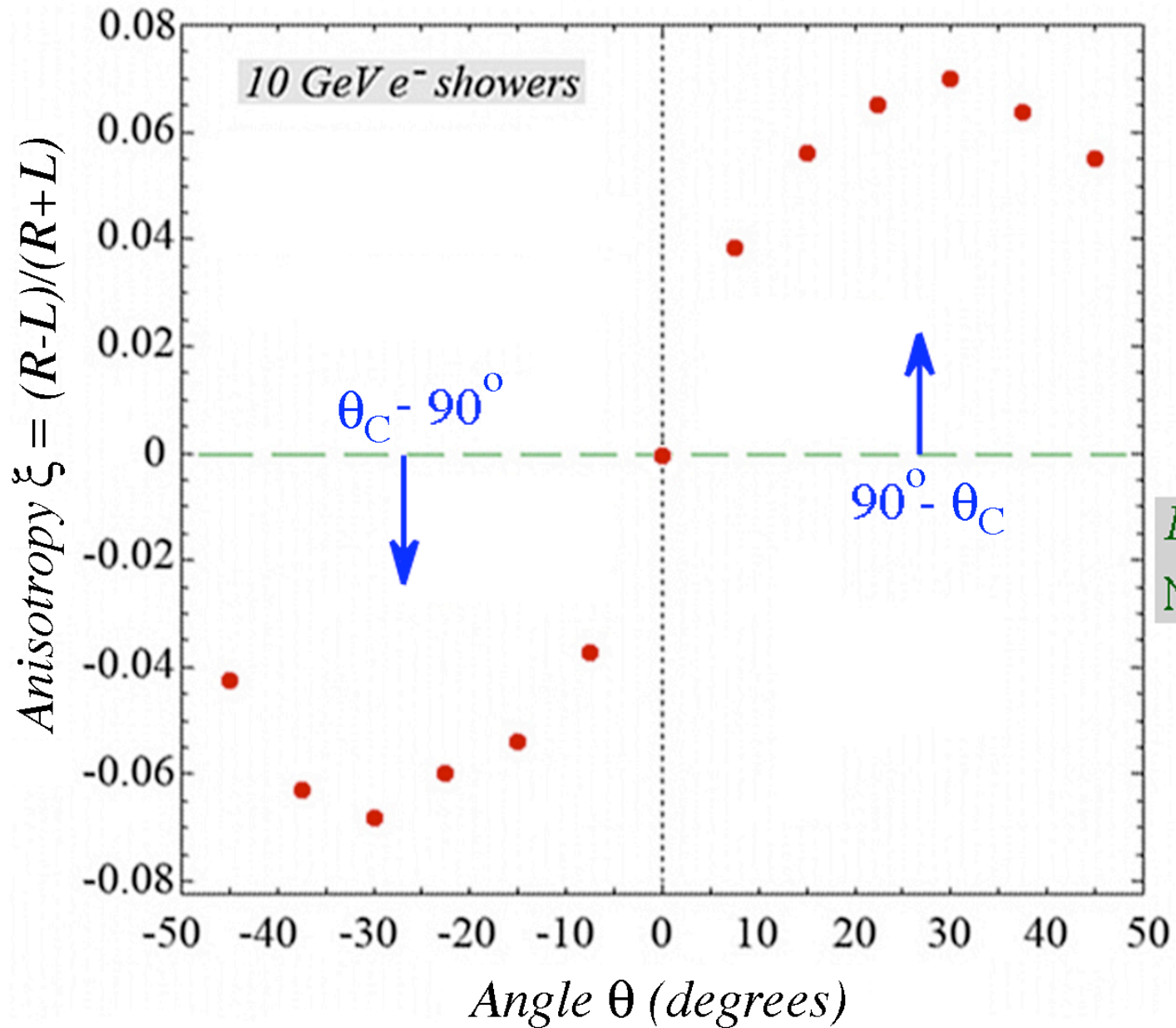
We have performed dedicated beam tests with PbWO<sub>4</sub>  
We tested both single crystals (22X<sub>0</sub> long, 2.2X<sub>0</sub> across)  
and an ECAL made of 19 such crystals\*

\* *courtesy ALICE*

# Experimental setup Čerenkov measurements (directionality)



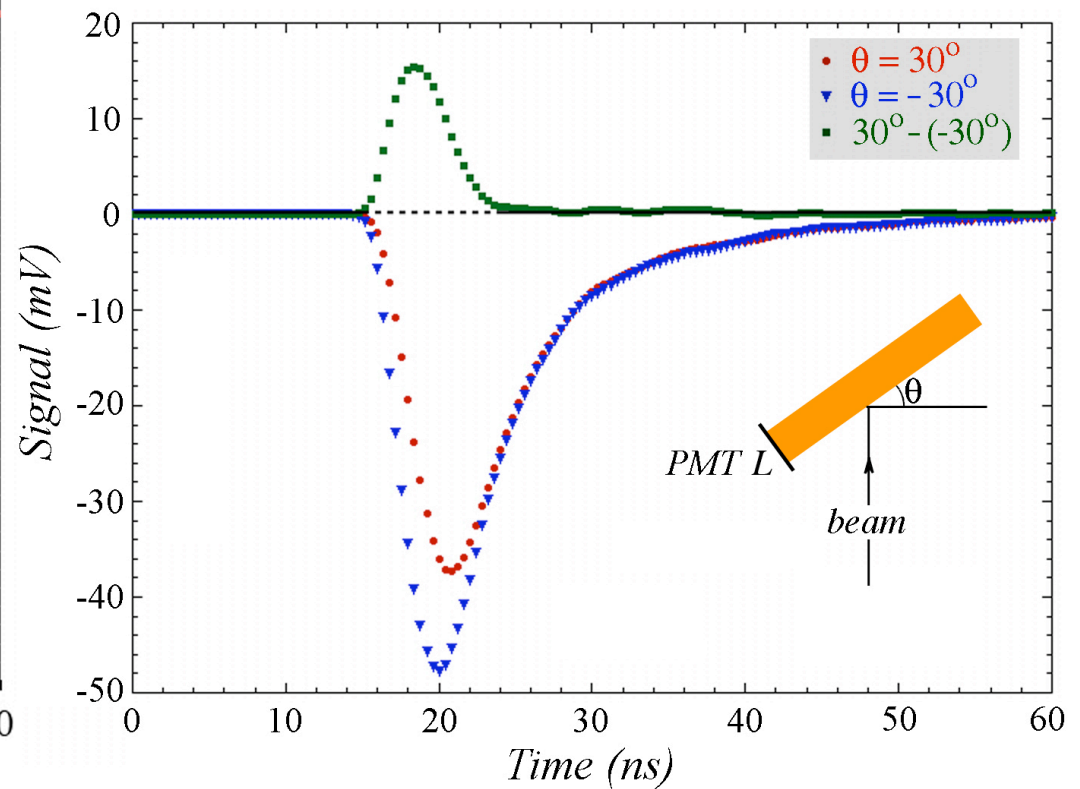
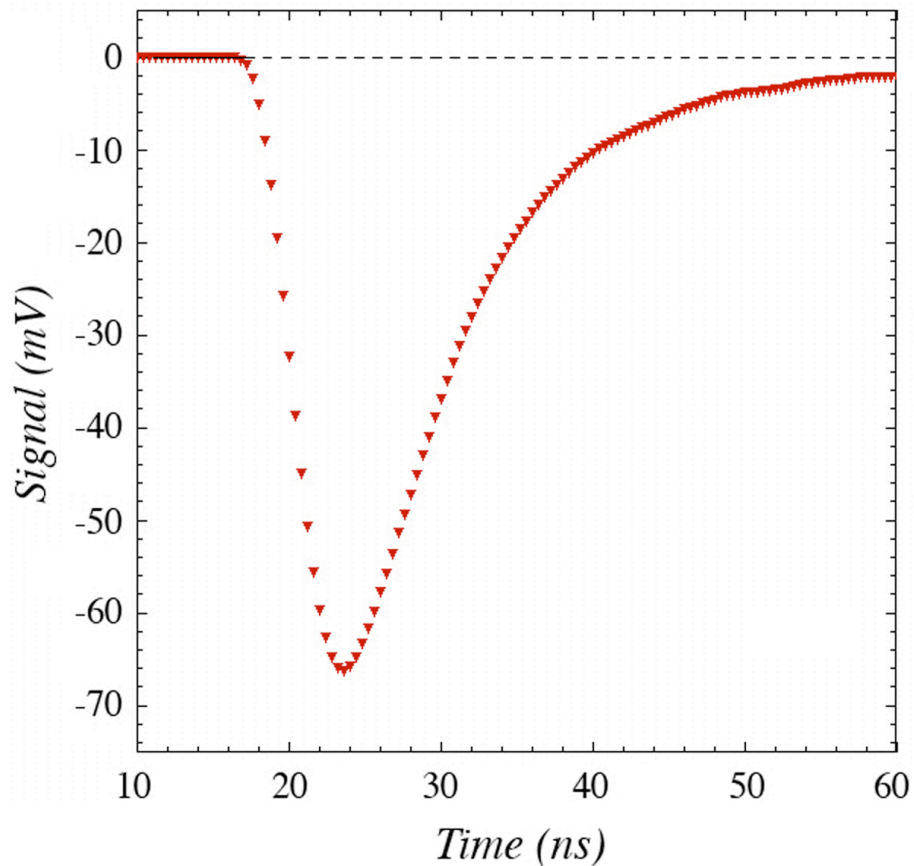
## Experimental results $PbWO_4$ : Directionality



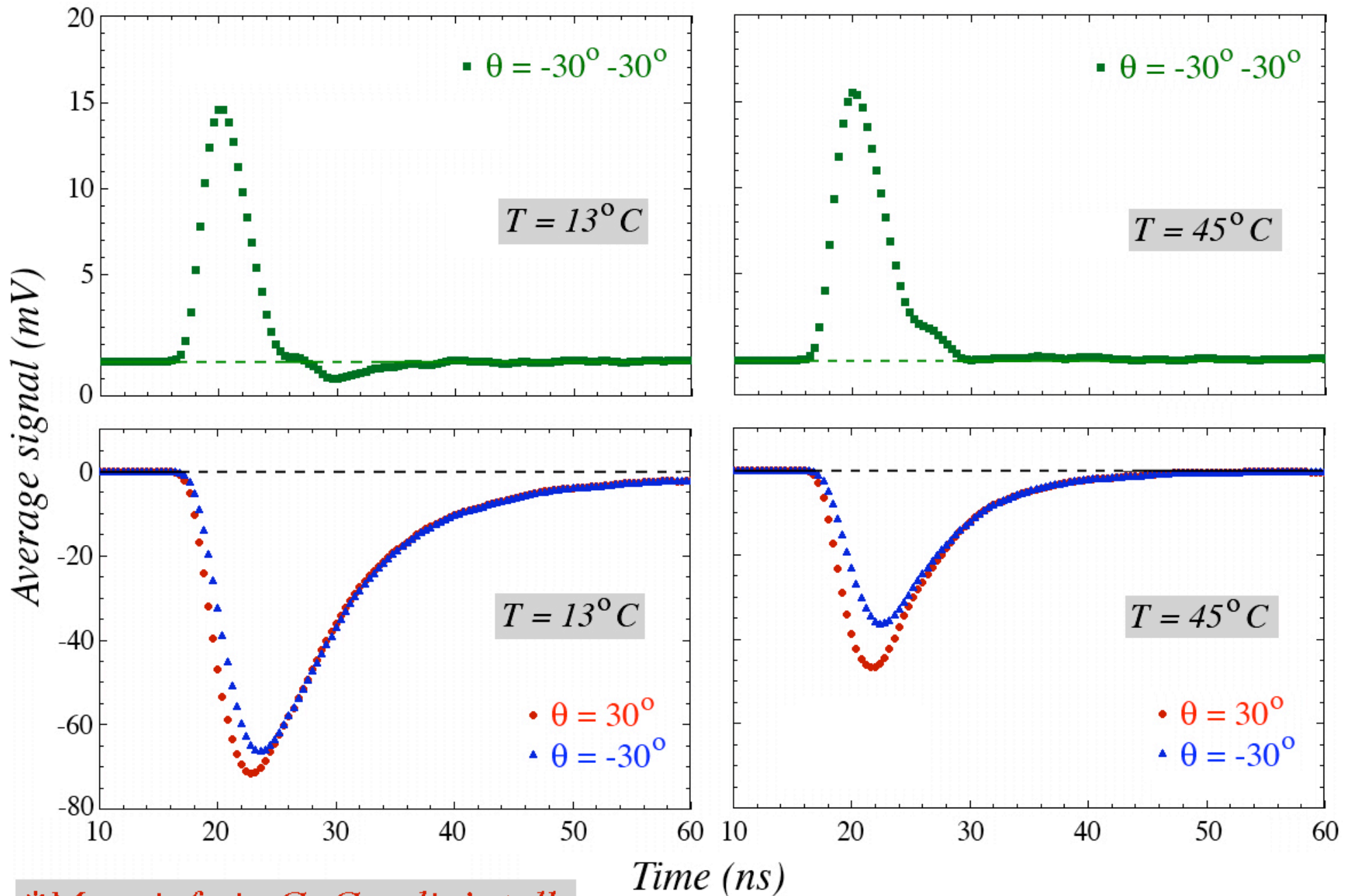
From:  
NIM A582 (2007) 474

# Experimental results $\text{PbWO}_4$ : *Time structure of the signals*

*The importance of time resolution for the  $\text{PbWO}_4$  signals  
(0.4 ns sampling oscilloscope)*



# Temperature effects on the $PbWO_4$ signals



\*More info in G. Gaudio's talk



# *A new crystal: BGO!!*

Disadvantage compared to  $\text{PbWO}_4$ :

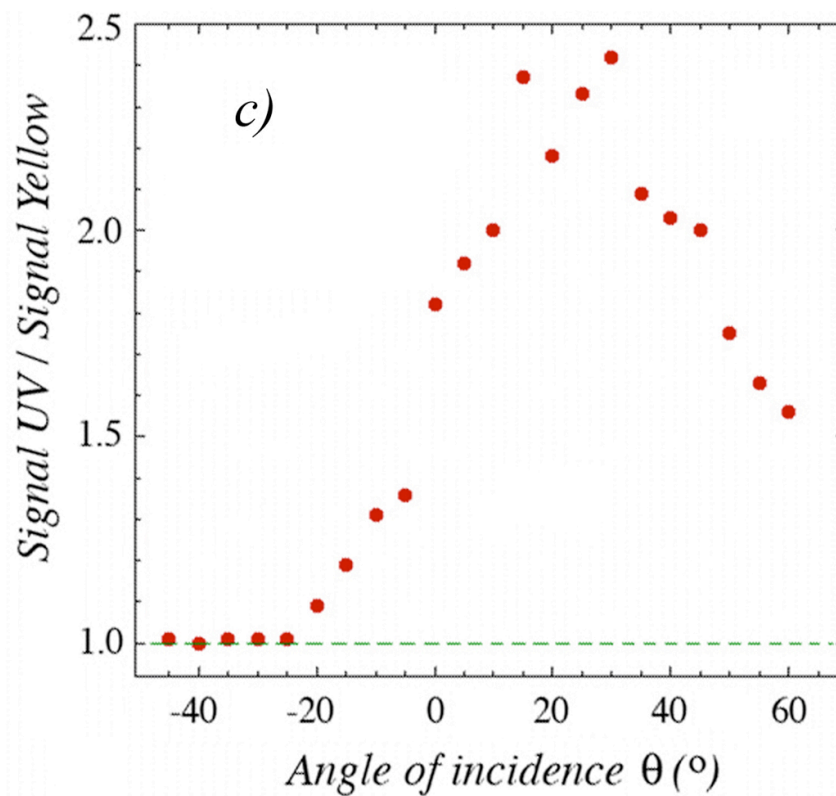
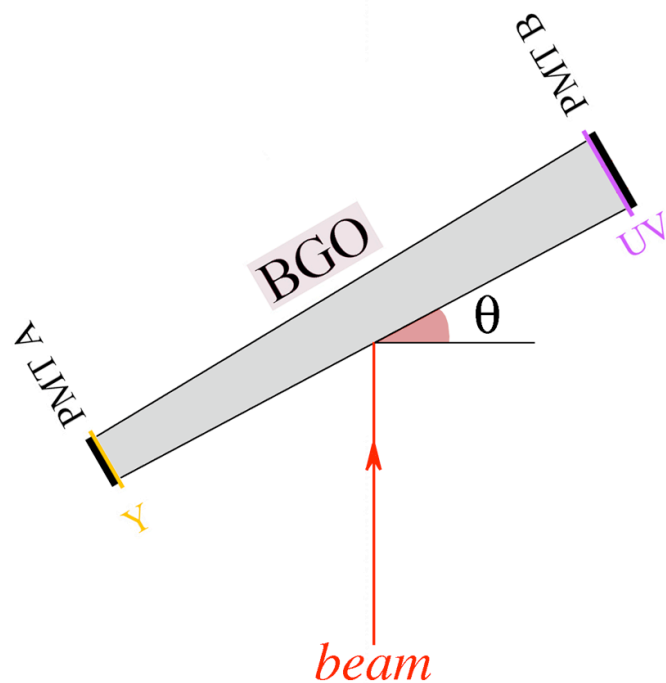
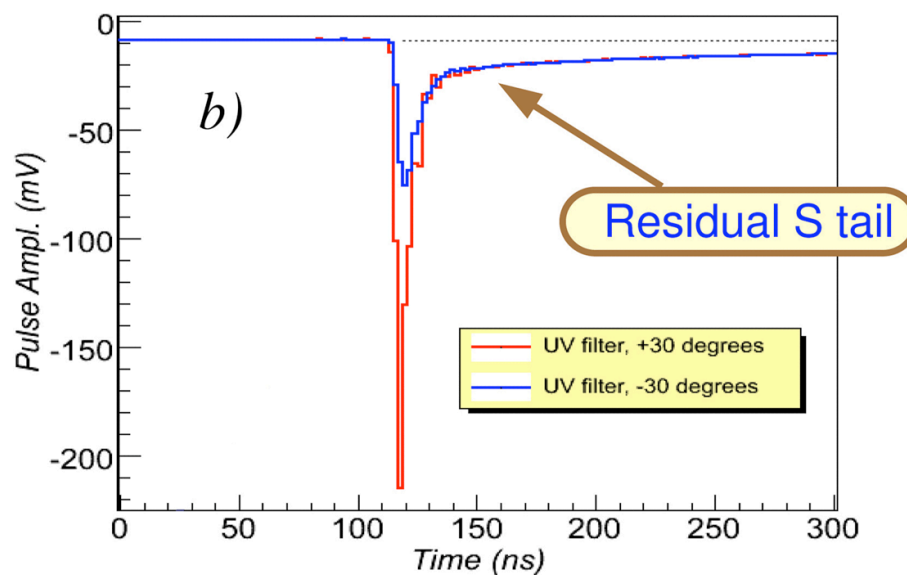
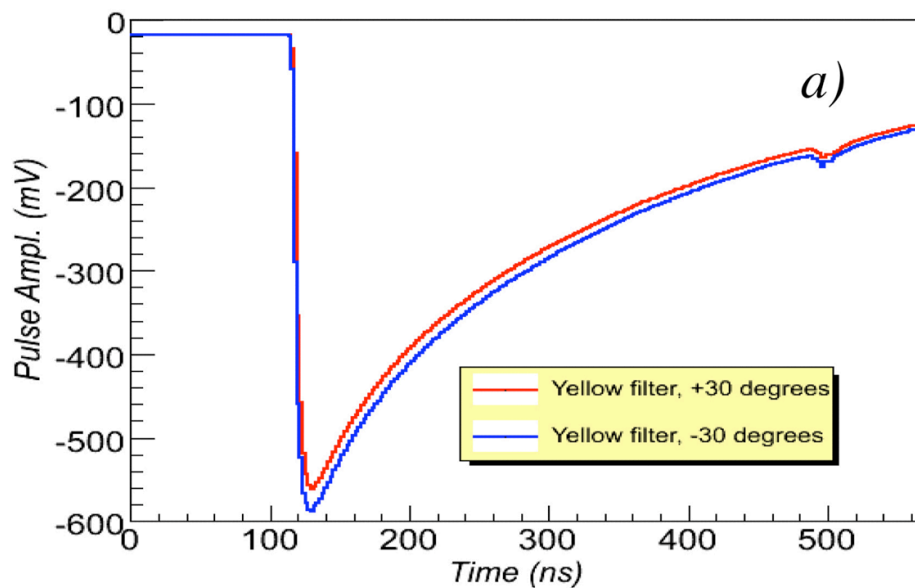
*A much brighter scintillator, Č/S factor 100 smaller*

Advantages:

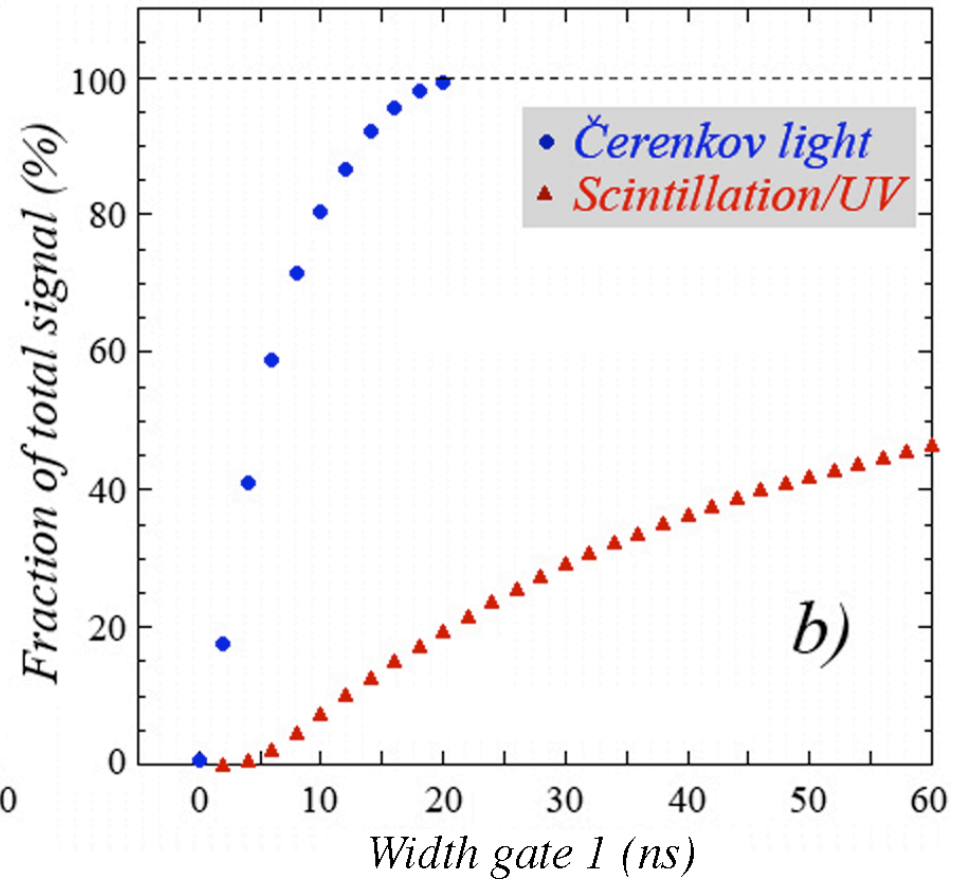
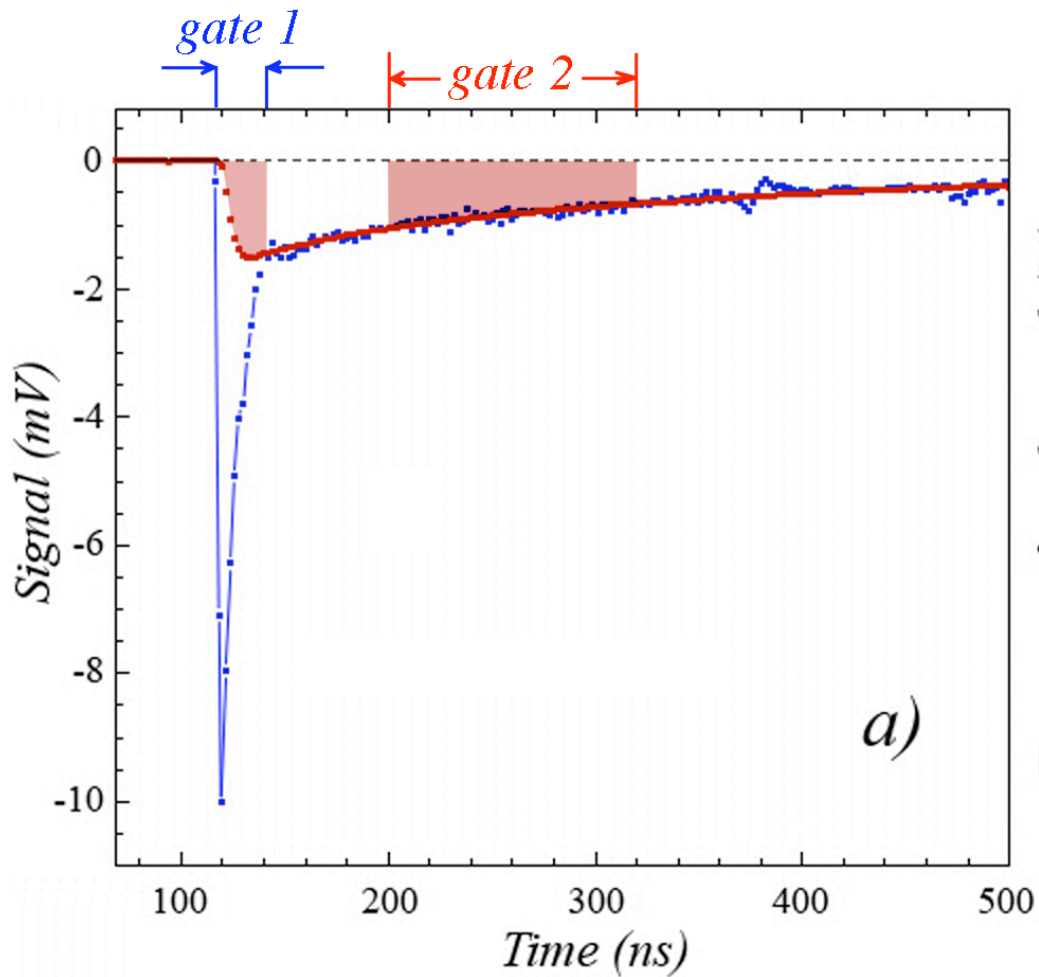
- *Scintillation spectrum peaks at 480 nm → use filters*
- *Decay time scintillation 300 ns (very different from prompt)*

*→ More (and better) options to isolate Čerenkov signal*

# The Čerenkov component in BGO signals

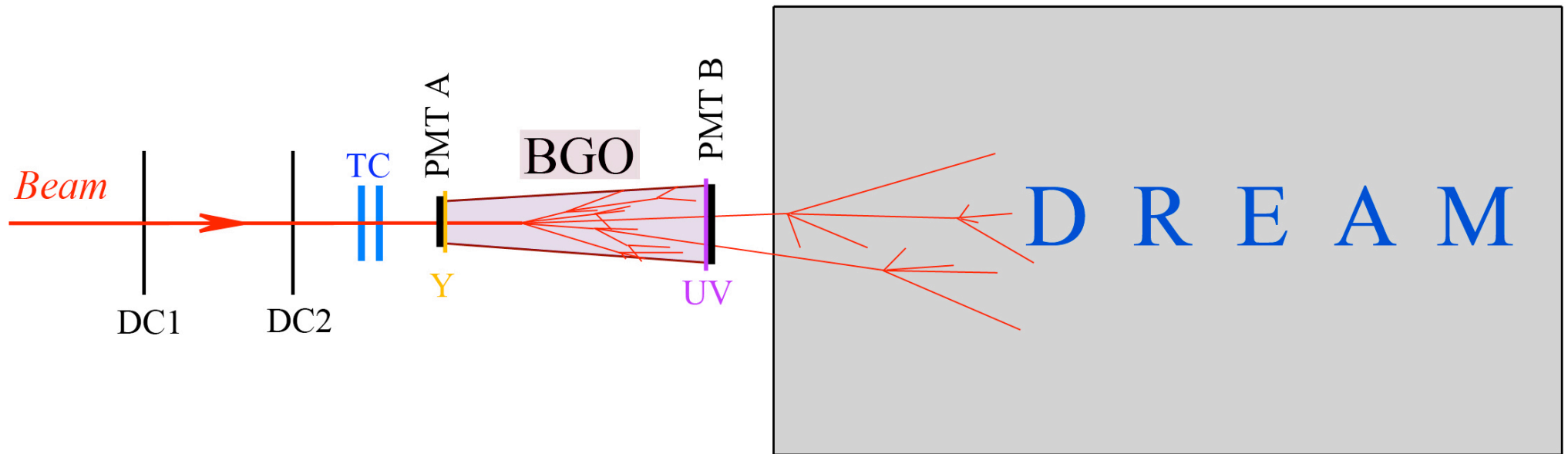


# Čerenkov and Scintillator information from one signal !

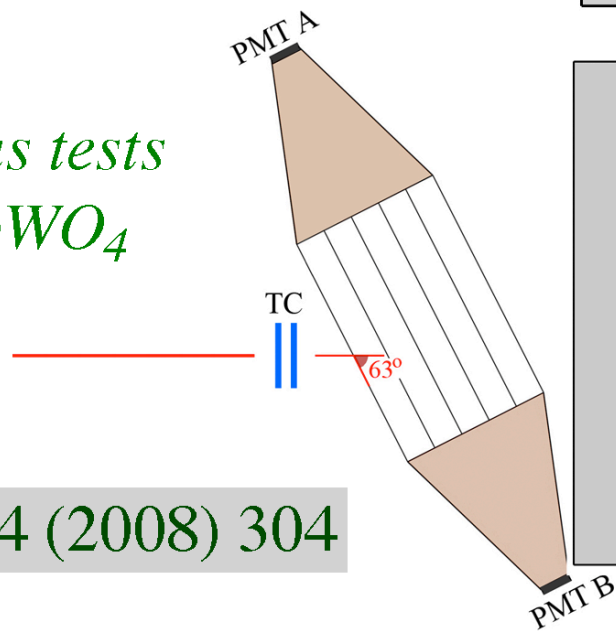


\*More information in C. Voena's talk

# Experimental setup for the BGO + DREAM tests



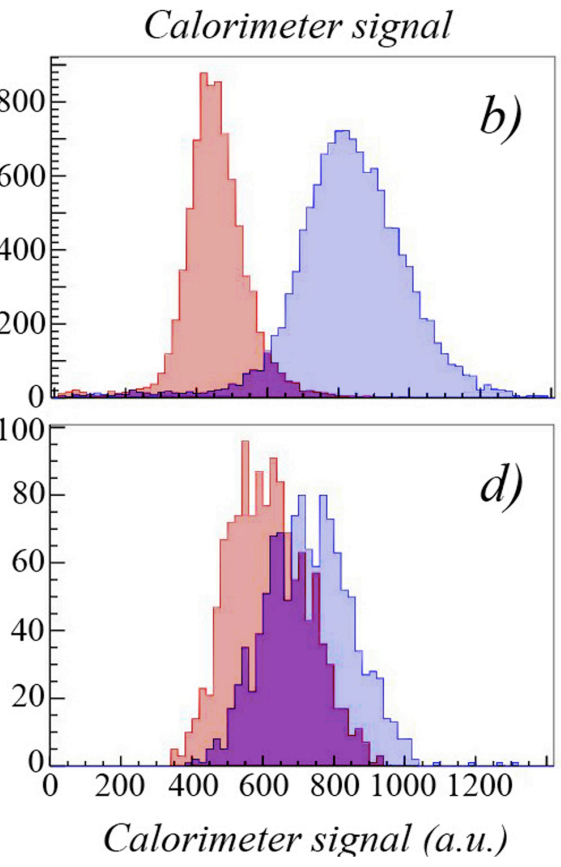
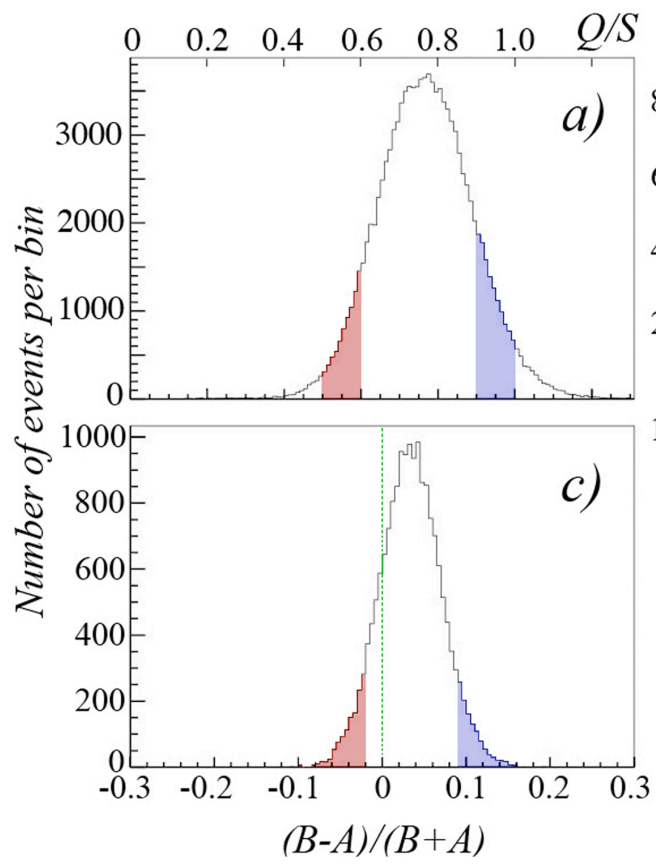
Previous tests  
with  $PbWO_4$   
matrix



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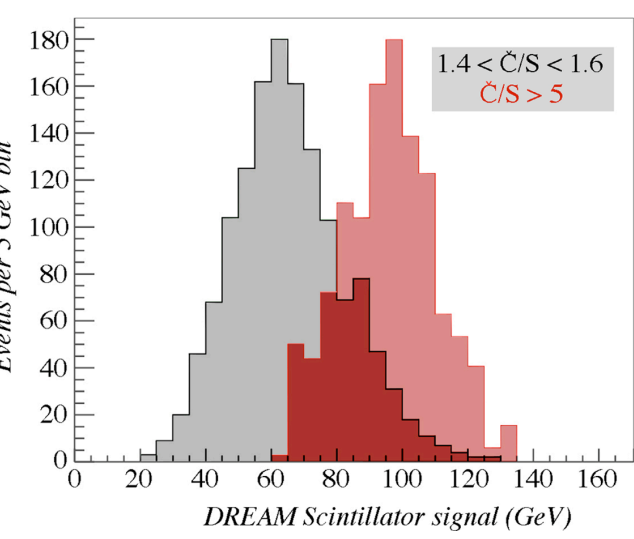
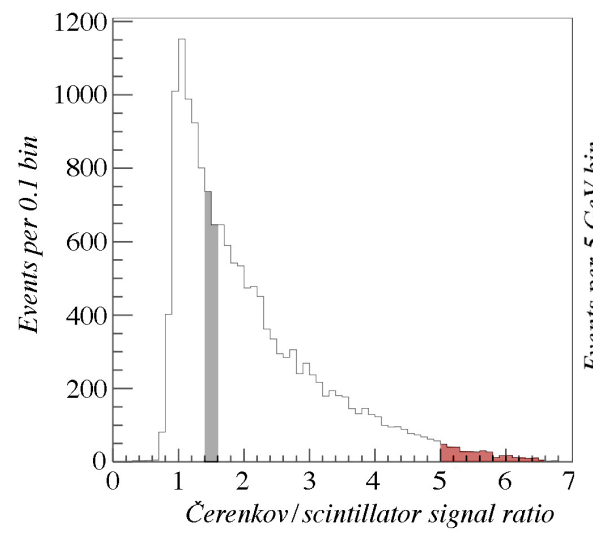
*\*See D. Pinci's talk*

# Selective power of the measured Cerenkov component



*DREAM  
stand-alone  
(2 separate media)*

*$PbWO_4$  matrix  
(directionality)*

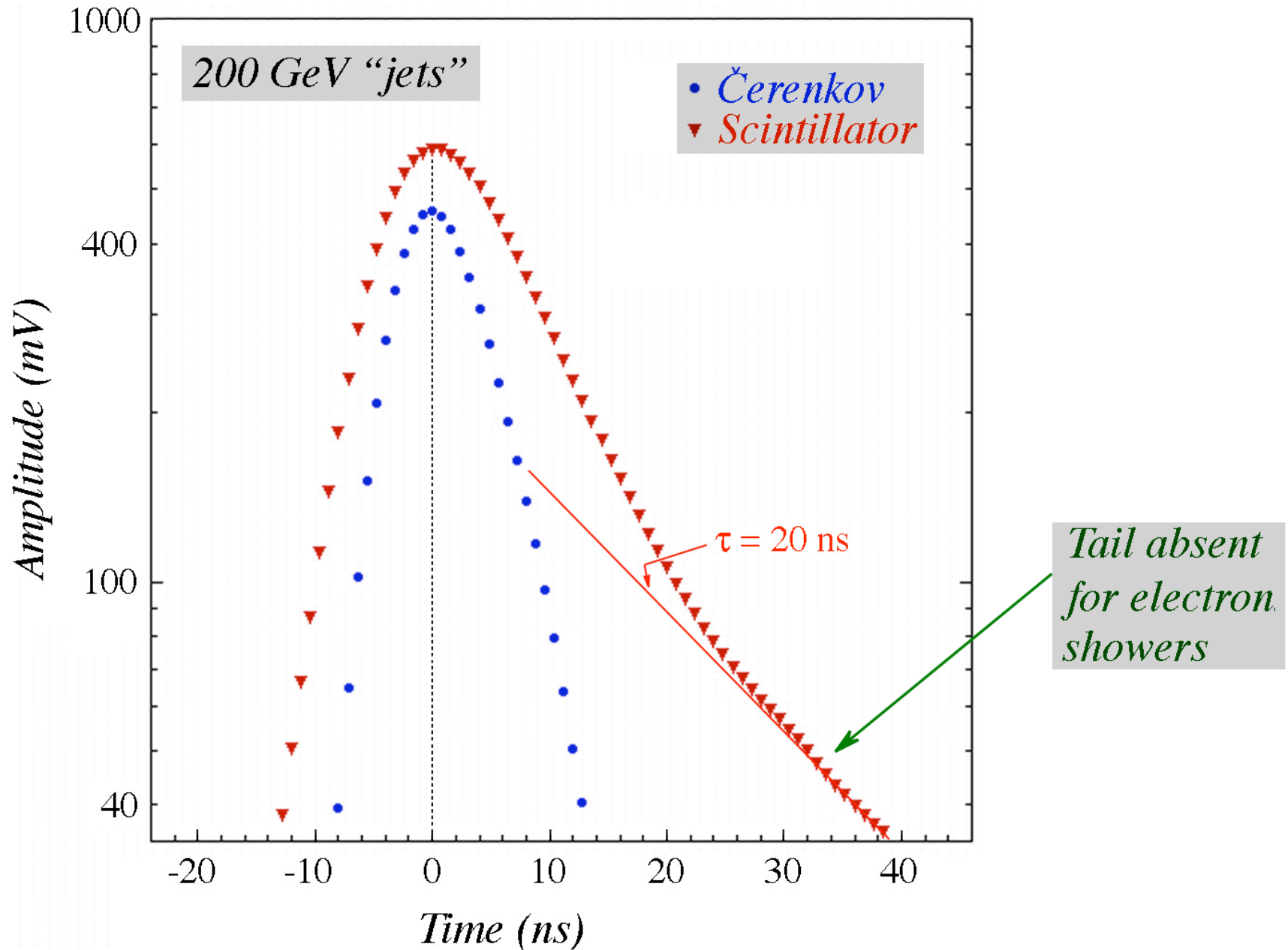


*$BGO_{UV}$  (1 crystal)  
(time structure  
+ spectrum)*

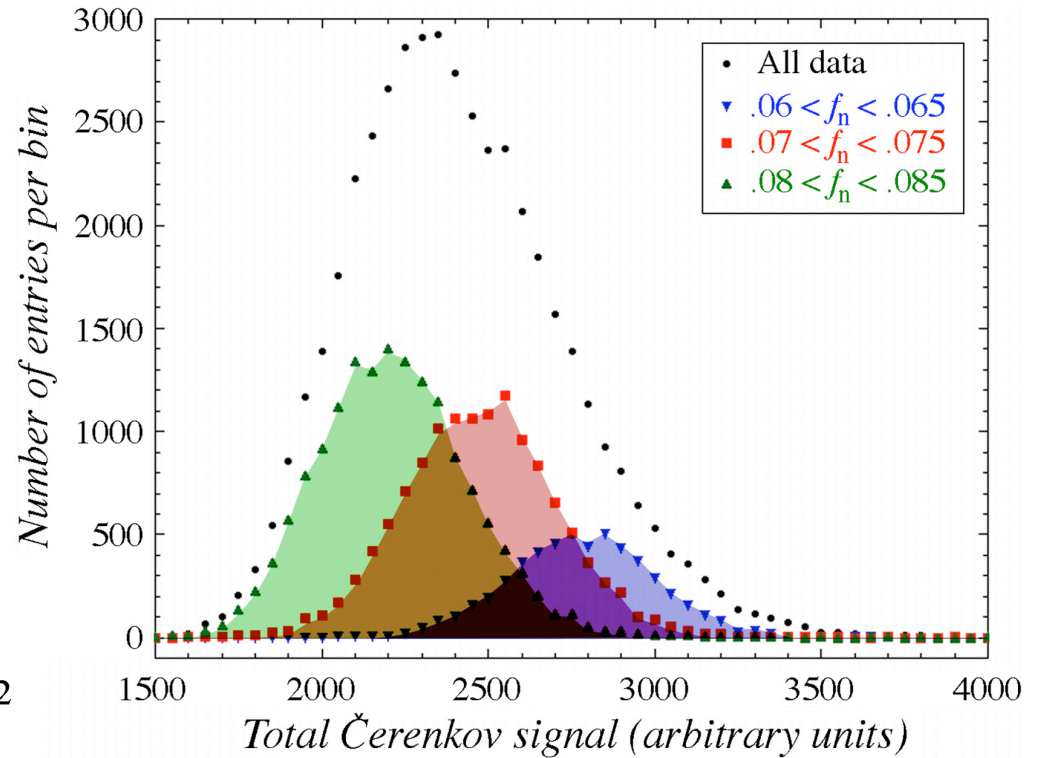
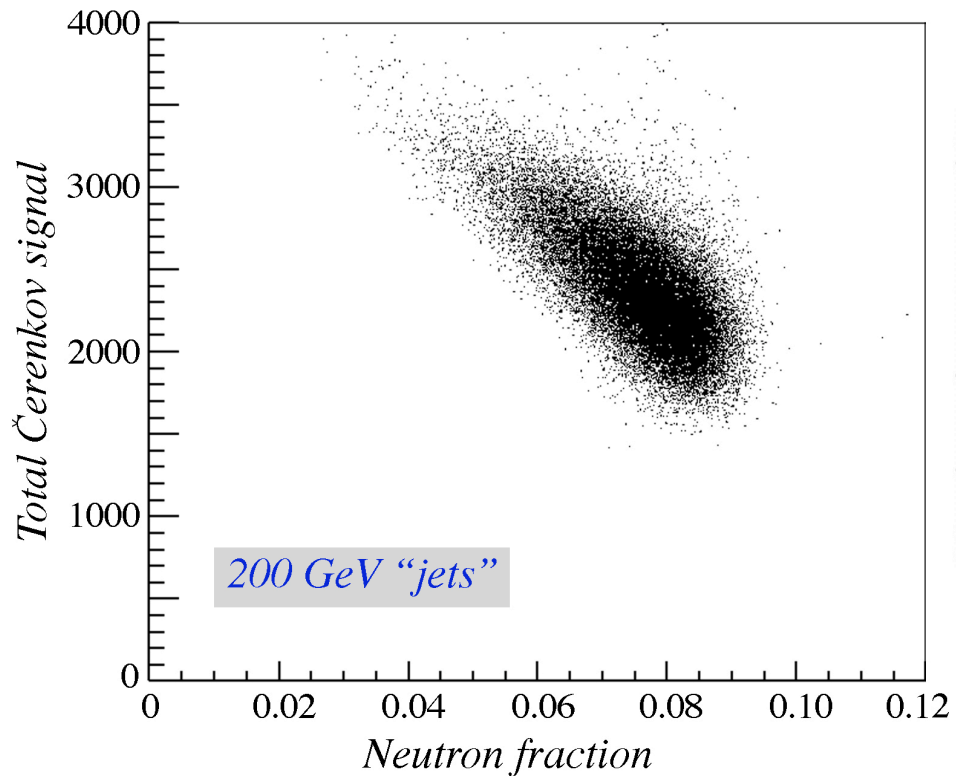
# *How to improve DREAM performance*

- Build a larger detector  $\longrightarrow$  *reduce effects side leakage*
- *Increase Čerenkov light yield*  
DREAM: 8 p.e./GeV  $\longrightarrow$  fluctuations contribute  $35\%/\sqrt{E}$   
No reason why DREAM principle is limited to fiber calorimeters  
*Homogeneous detector ?!*  
 $\longrightarrow$  *Need to separate the light into its Č, S components*
- For ultimate hadron calorimetry ( $15\%/\sqrt{E}$ ): *Measure  $E_{kin}$  (neutrons)*  
Is correlated to nuclear binding energy loss (invisible energy)  
Can be measured with third type of fiber: **TREAM**  
*Or inferred from the time structure of the signals*

# *Time structure of the DREAM signals: the neutron tail*

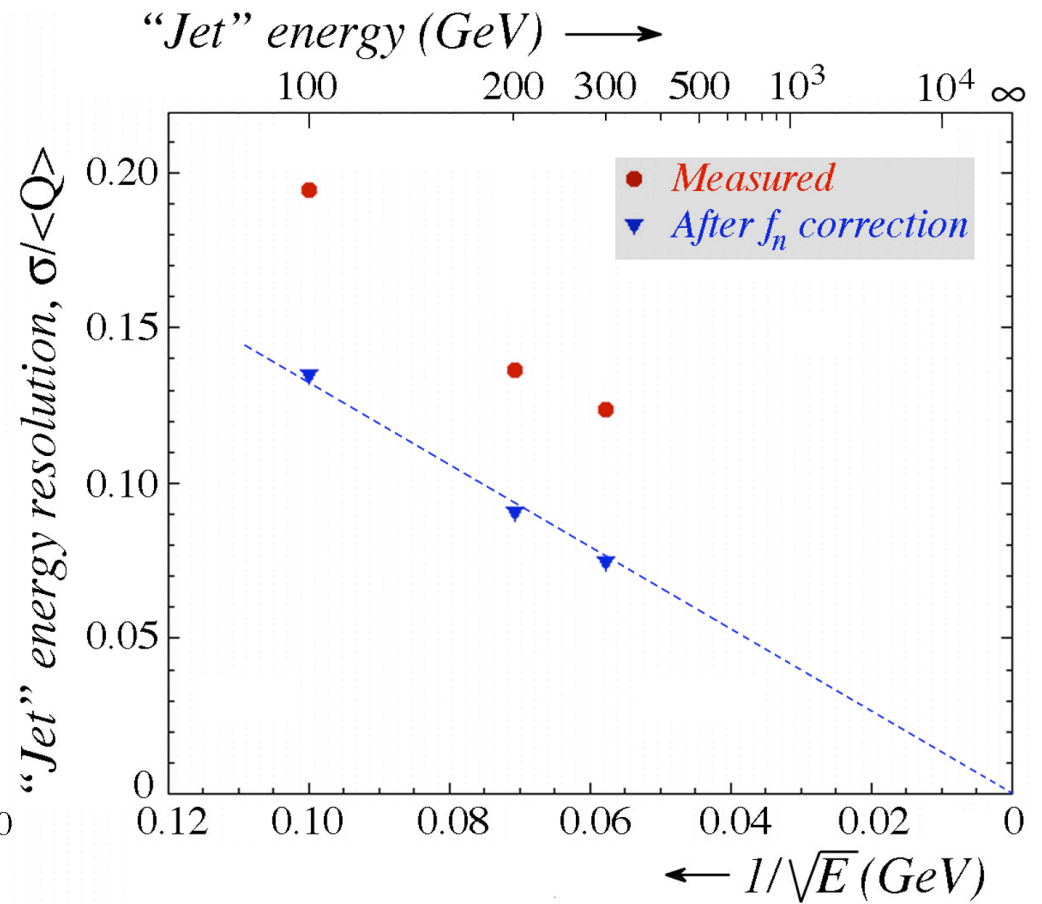
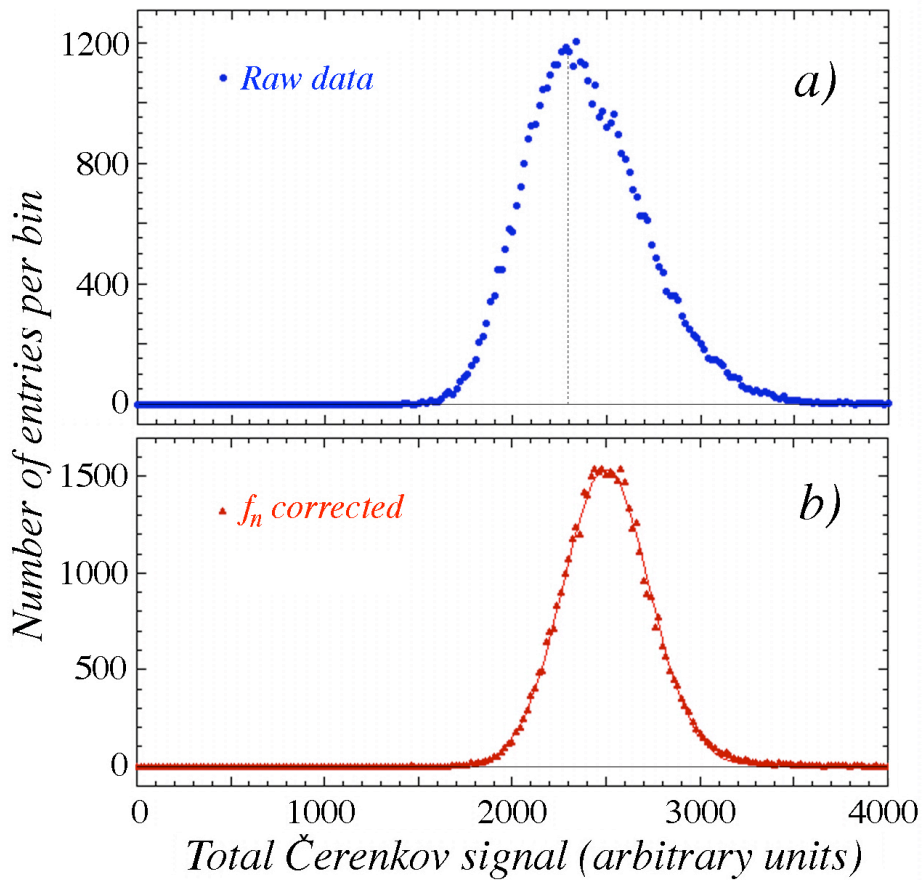


# Probing the signal distribution on the basis of the neutron fraction

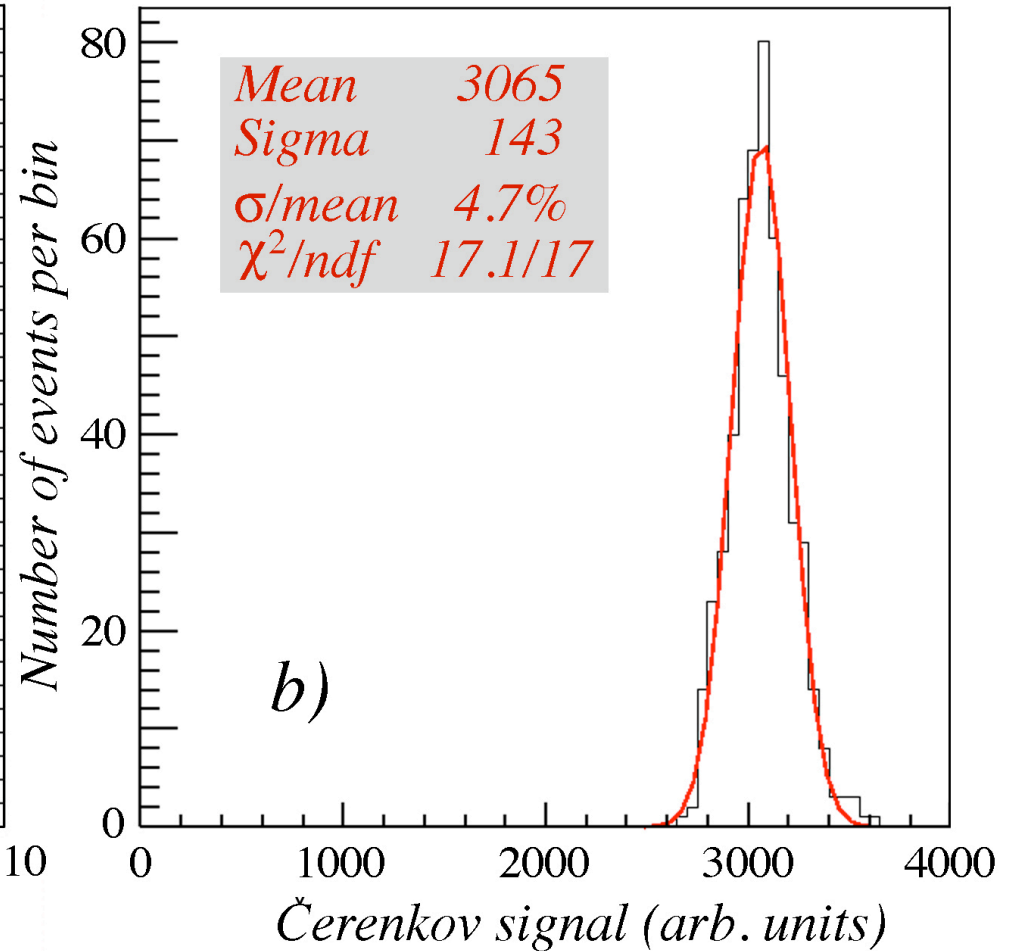
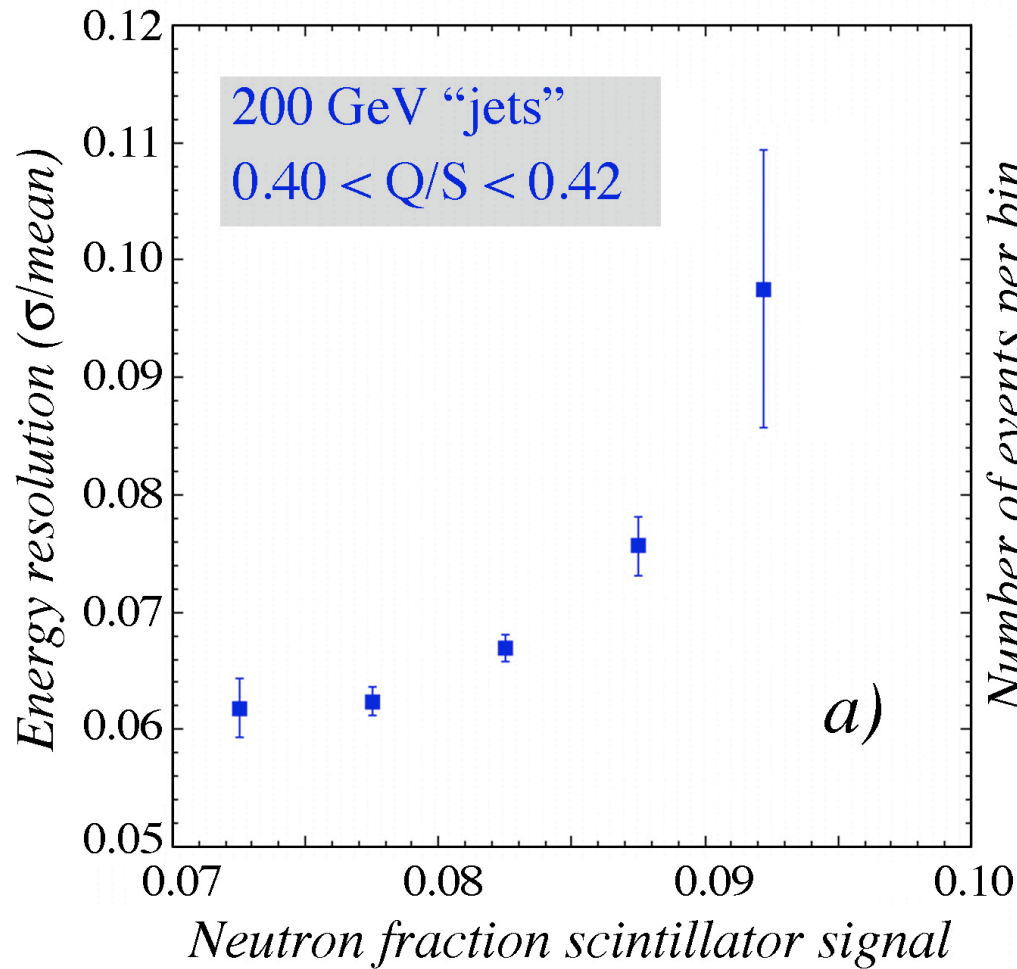




# Improvement of the response function with neutron info



# Neutron information is complementary to $f_{em}$



\*More information in J. Hauptman's talk

# *Plans for the Future*

## *DREAM road map:*

*Eliminate the dominating sources of fluctuations one after the other*

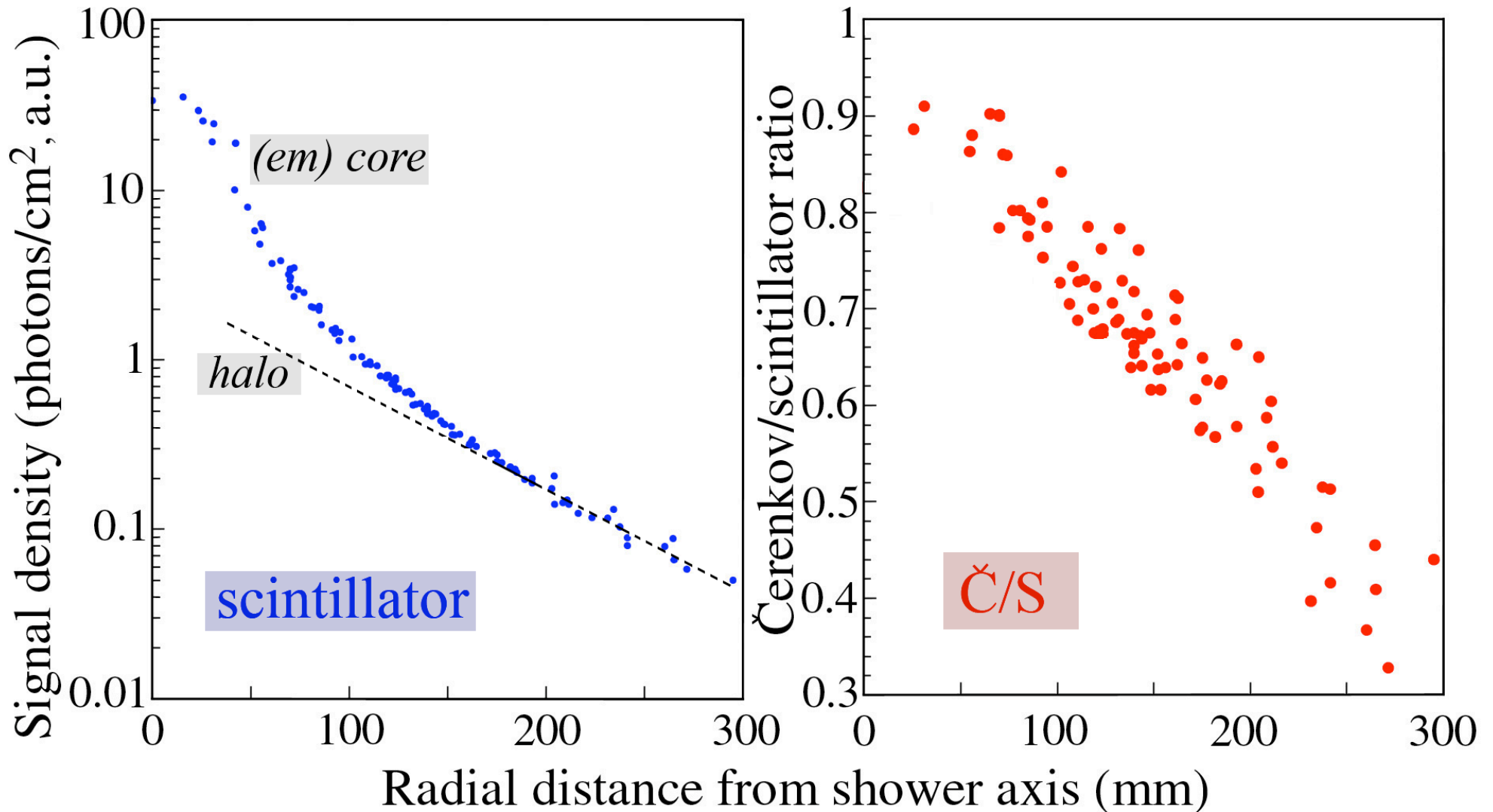
- Fluctuations in the em shower fraction
  - Fluctuations in Čerenkov light yield
  - Sampling fluctuations
  - Fluctuations in invisible energy
- > Develop dedicated crystal(s)  
(Pavia group)*
- see talk R. Carosi*

*Then build a full-scale prototype calorimeter*

## *Conclusions*

- The DREAM approach combines the advantages of compensating calorimetry with a reasonable amount of design flexibility
- The dominating factors that limited the hadronic resolution of compensating calorimeters (ZEUS, SPACAL) to  $30 - 35\%/\sqrt{E}$  can be eliminated
- The theoretical resolution limit for hadron calorimeters ( $15\%/\sqrt{E}$ ) seems within reach
- The DREAM project holds the promise of high-quality calorimetry for *all* types of particles, with an instrument that can be calibrated with electrons

# Radial hadron shower profiles (DREAM)



*From:*

NIM A584 (2008) 273