Recent results from the DREAM project*

Richard WIGMANS (TTU)

CALOR 08, Pavia, March 27, 2008

Outline :

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

---

* 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 < *em* component (π^0) / *non-em* component (mainly soft *p*)

Calorimeter response to these components not the same *(e/h ≠ 1)*

$< f_{em} >$ energy dependent → *hadronic signal non-linearity*

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

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

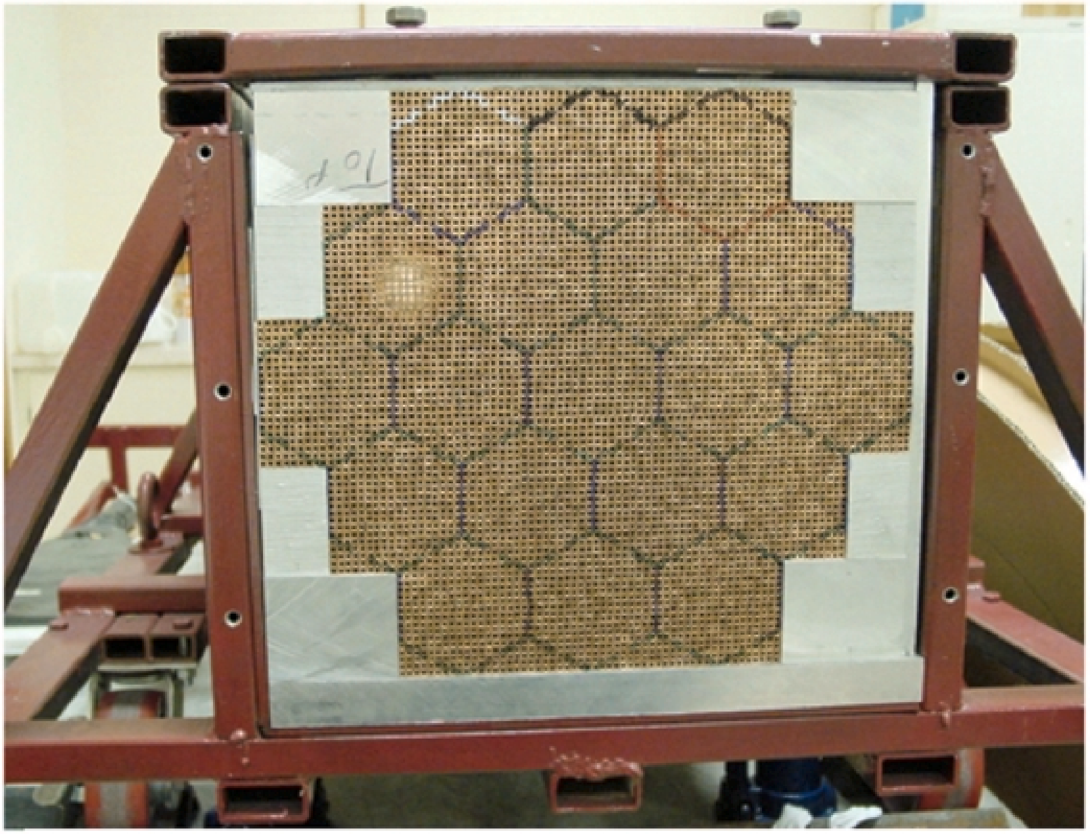
➡ DREAM (Dual REAdout Method) principle:

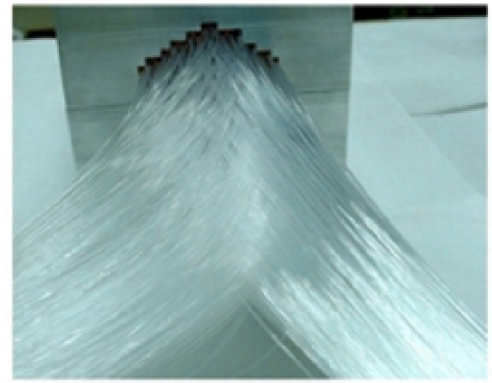
Measure f_{em} event by event by comparing Č and dE/dx signals

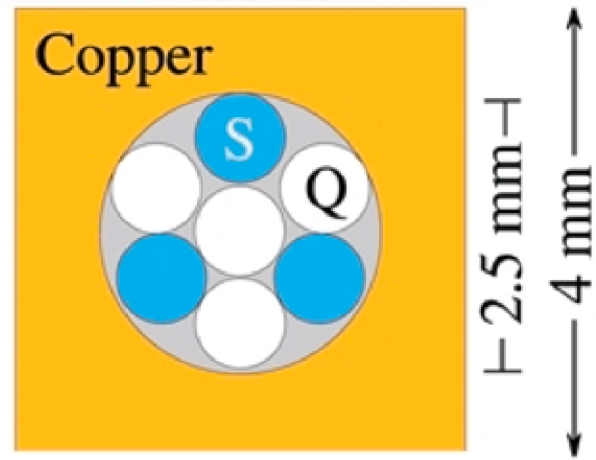
* How do we know this?

- CMS HF: *e/h* ~ 5
- Lateral profiles of hadronic showers

DREAM: Structure

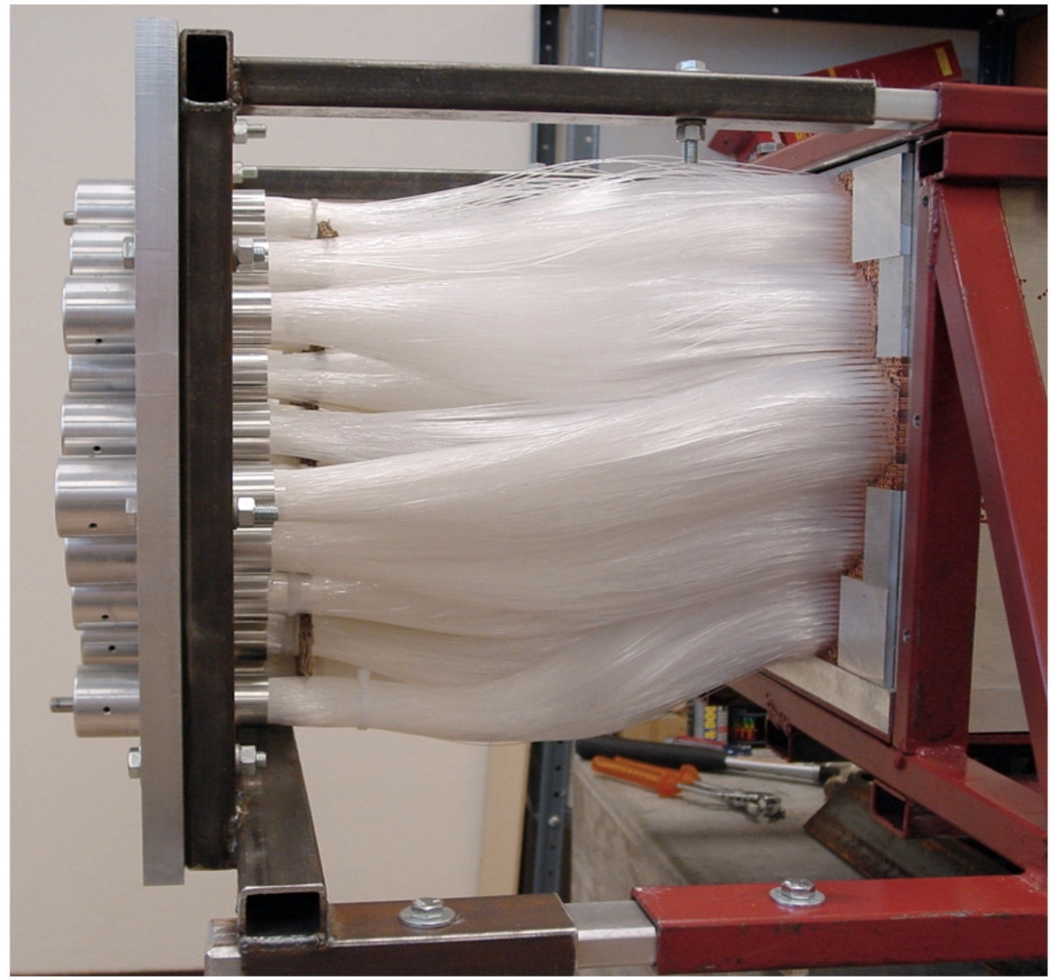




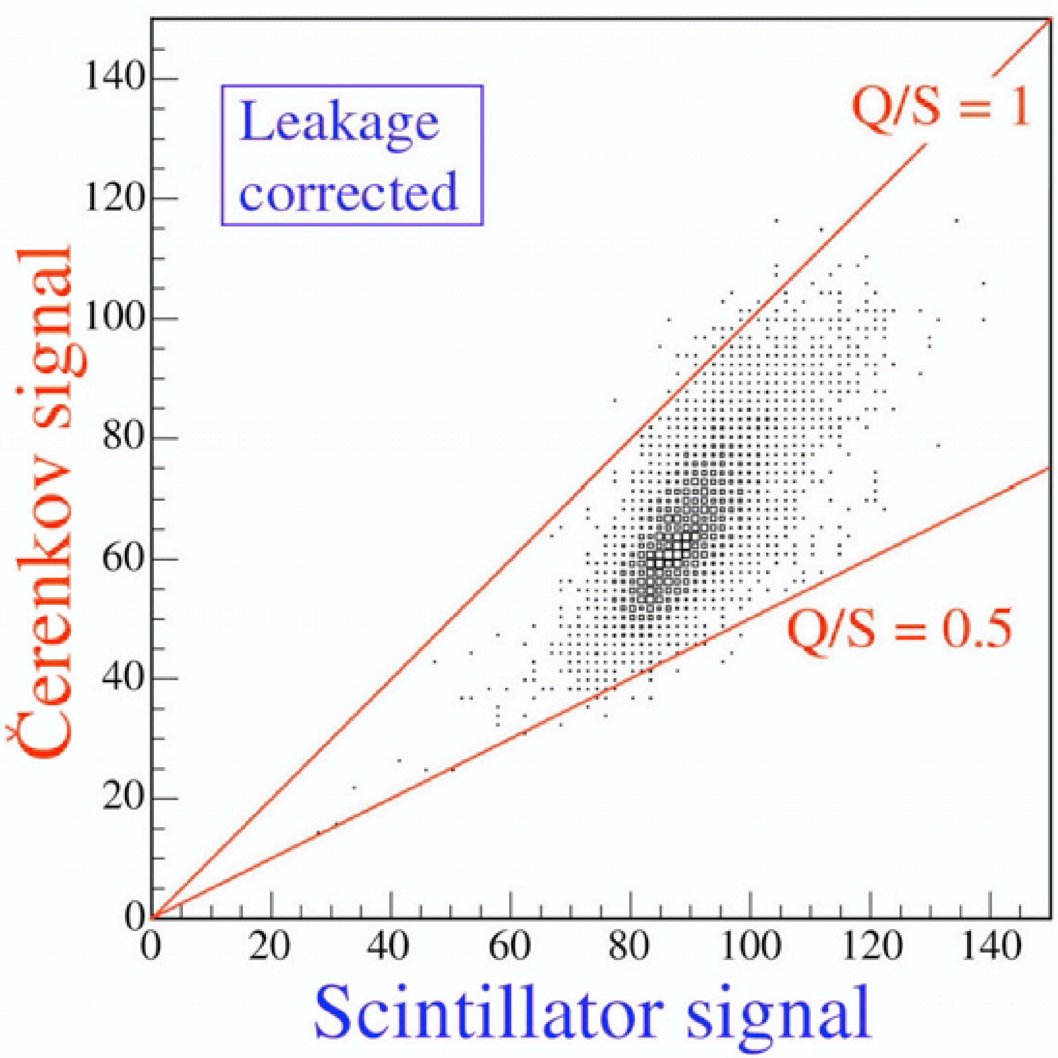


- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

DREAM readout



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



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

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

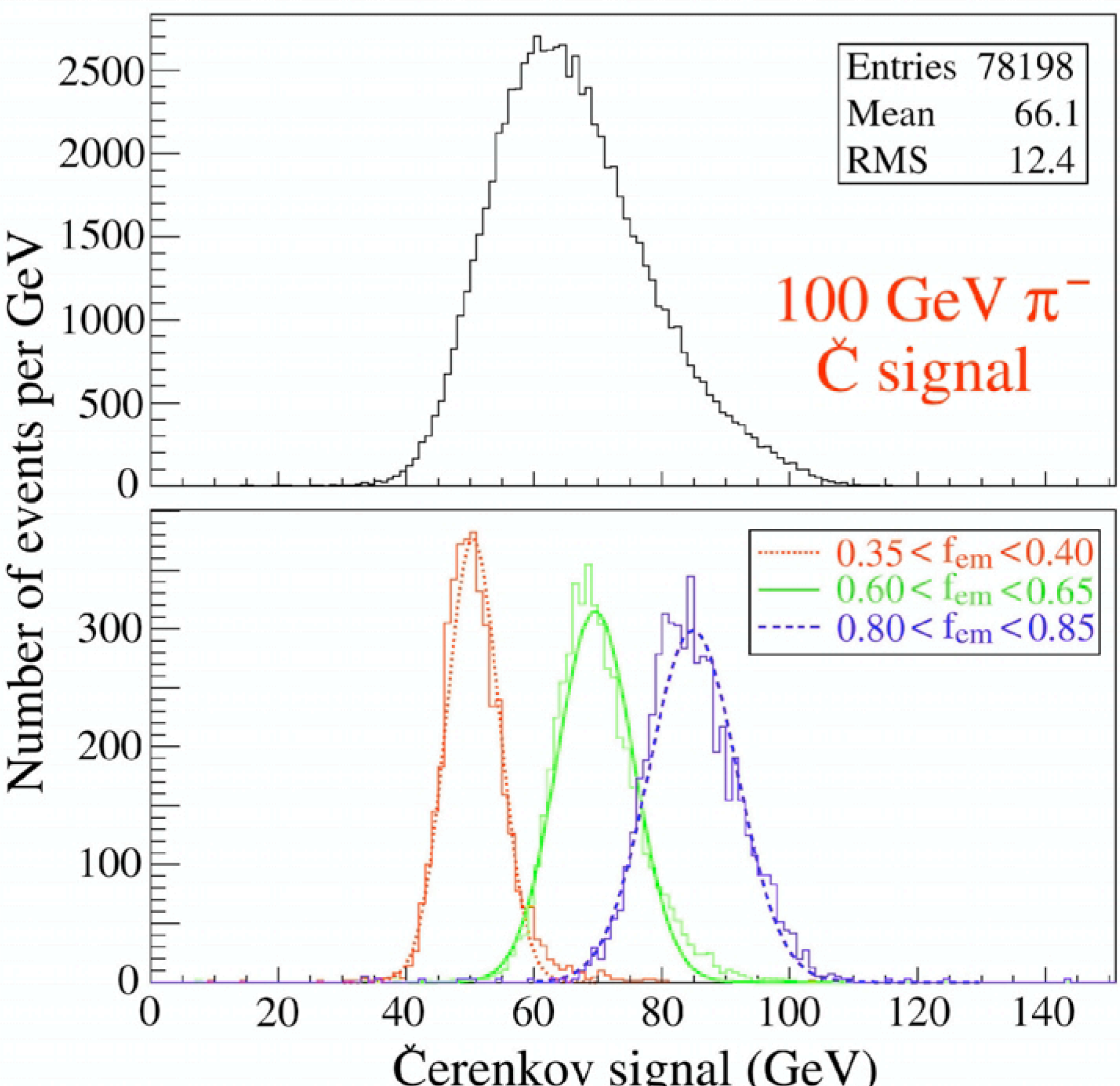
e.g. If $e/h = 1.3$ (S), 4.7 (Q)

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

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

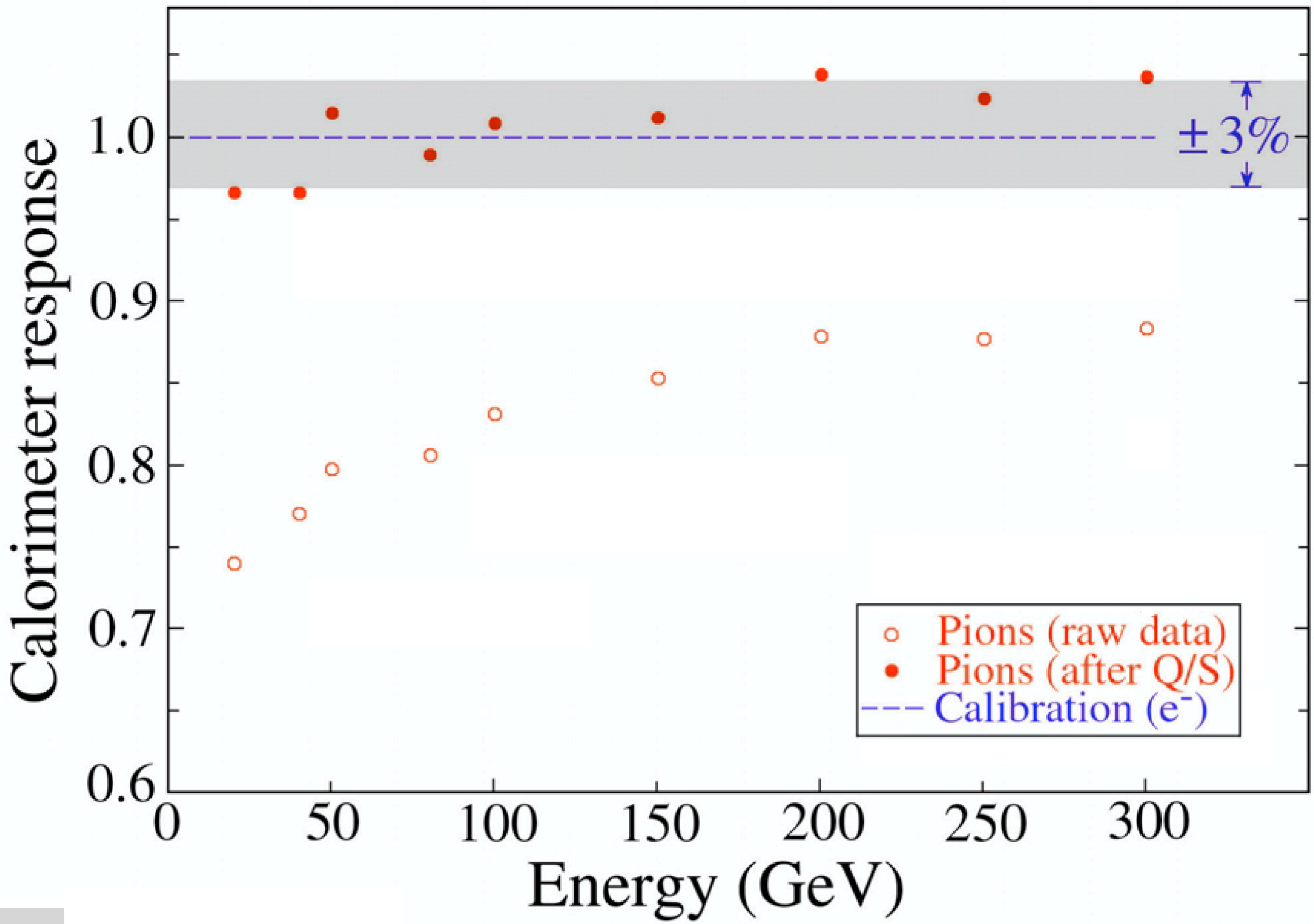
with $\chi = \dfrac{1 - (h/e)_S}{1 - (h/e)_Q} \sim 0.3$

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



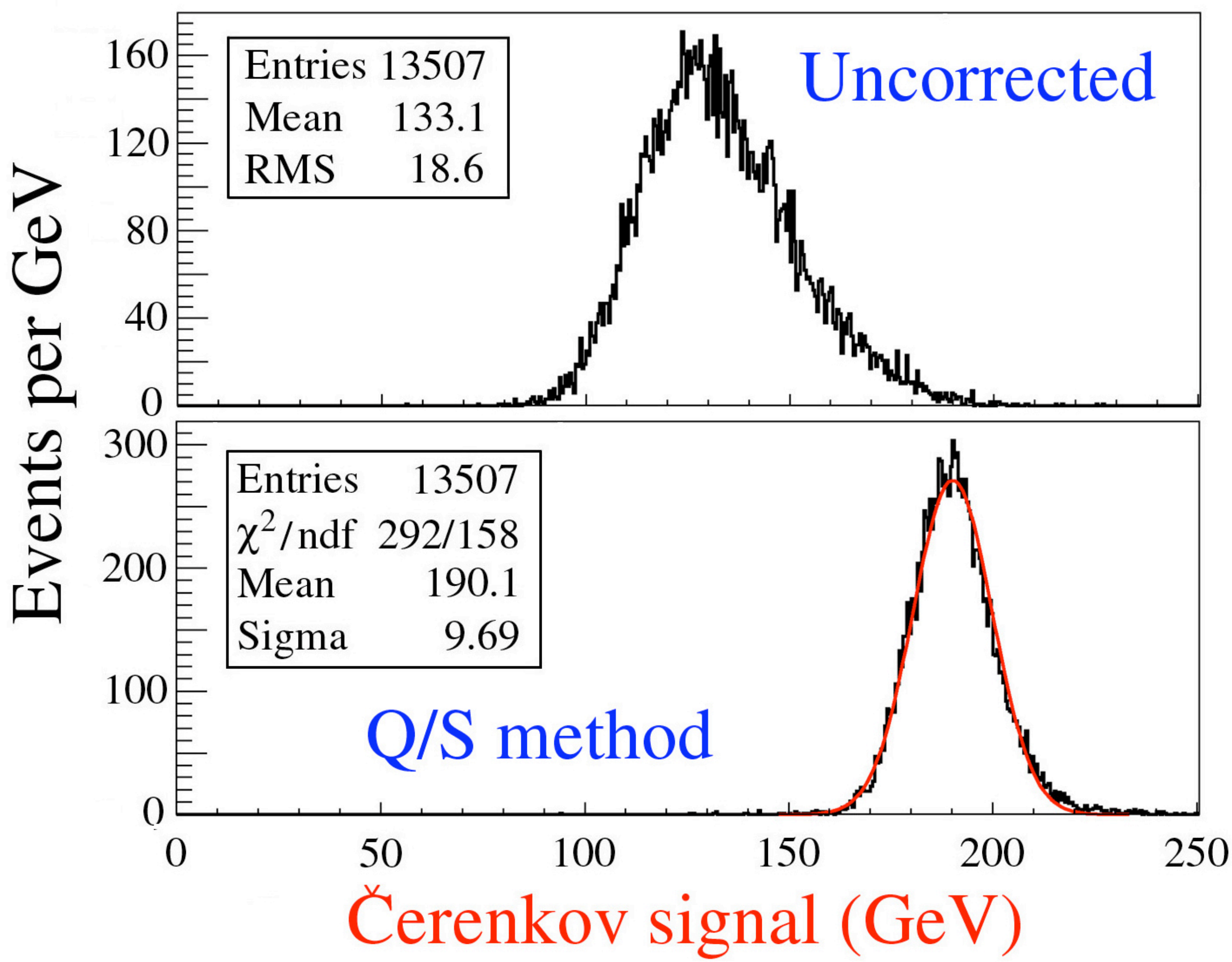
From:
NIM A537 (2005) 537

DREAM: *Reconstructed hadronic energy*



From:
NIM A537 (2005) 537

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

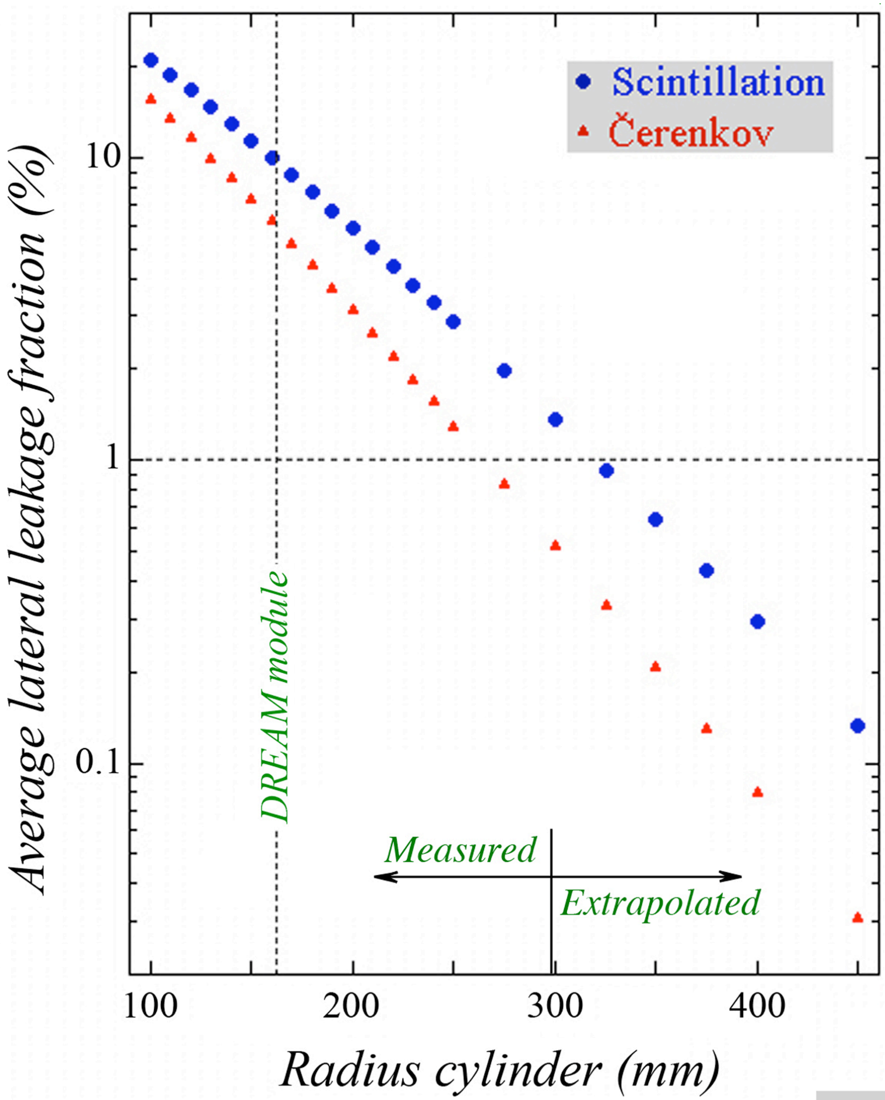


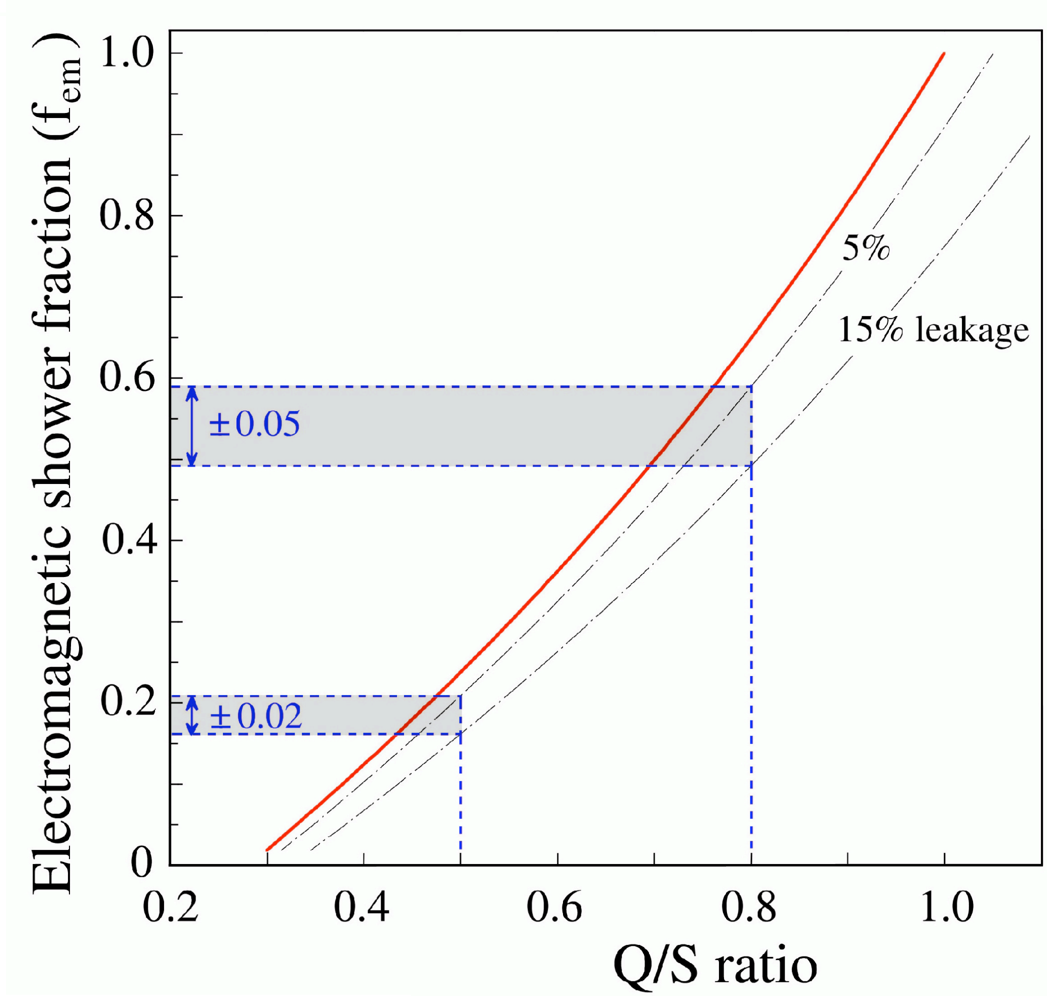
How to improve DREAM performance

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

DREAM: The importance of leakage and its fluctuations

Lateral shower containment (π)





From:
NIM A584 (2008) 273

How to improve DREAM performance?

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

- *Increase Čerenkov light yield*

DREAM: 8 p.e./GeV ⟶ fluctuations contribute $35\%/\sqrt{E}$

No reason why DREAM principle is limited to fiber calorimeters

Homogeneous detector ?!

⟶ *Need to separate the light into its Č, S components*

Čerenkov component in light from $PbWO_4$ crystals?

- Light yield typically ~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 $PbWO_4$ signals*

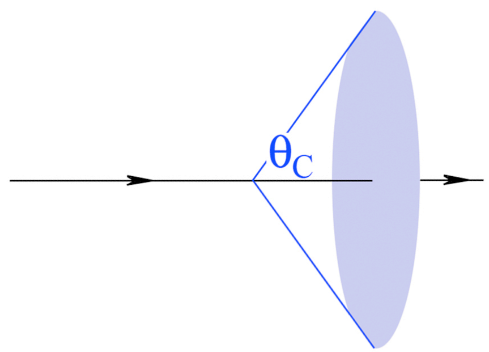
- *How to detect / isolate Čerenkov component?*

  - *Directionality of Čerenkov component*
  - *Time structure of the signals*
  - *Spectral differences*

We have performed dedicated beam tests with $PbWO_4$
We tested both single crystals ($22X_0$ long, $2.2X_0$ across)
and an ECAL made of 19 such crystals*

** courtesy ALICE*

Experimental setup Čerenkov measurements
(directionality)



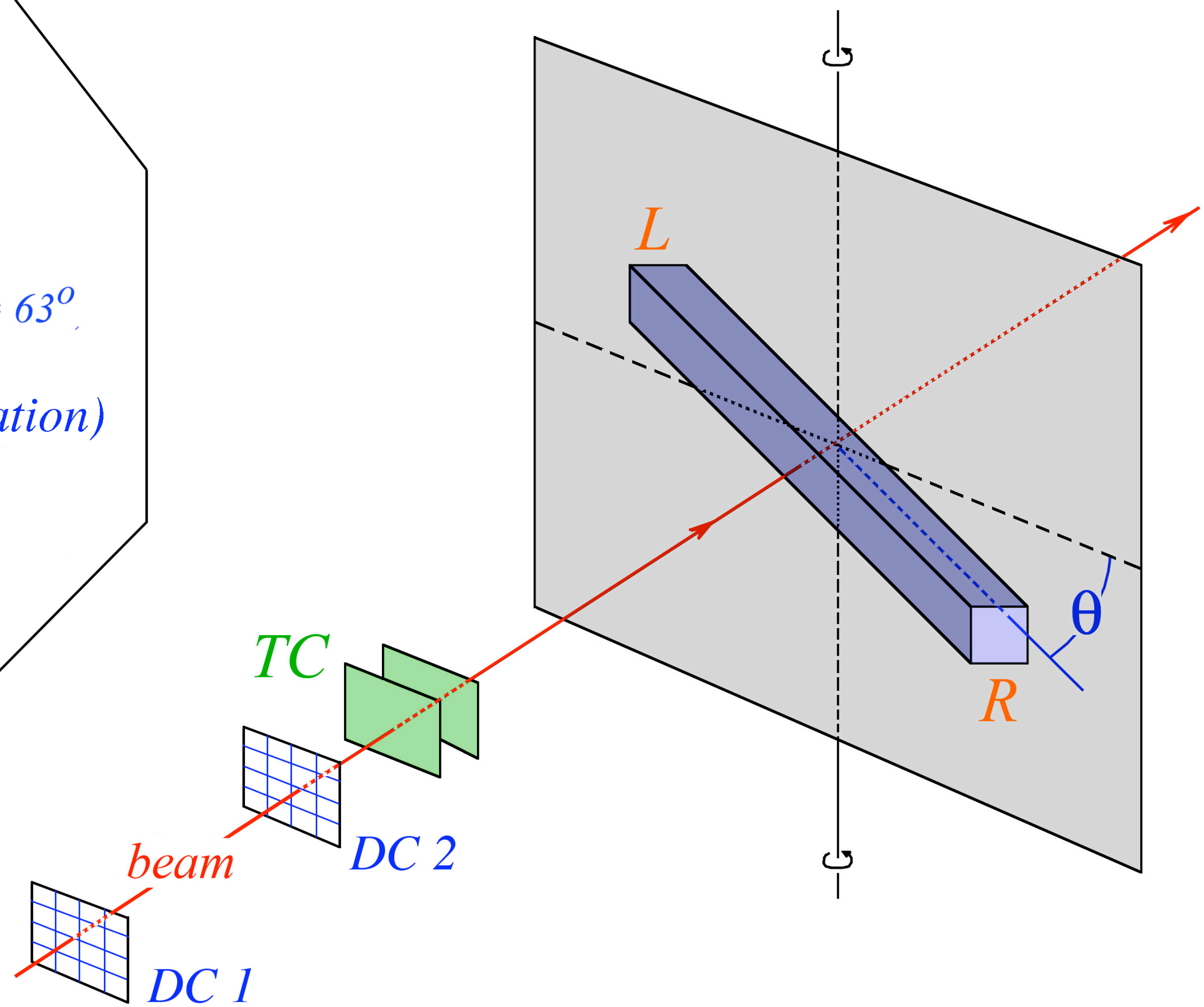
$n = 2.2$, $\cos\theta_C = 1/n \longrightarrow \theta_C = 63^o$

$\theta = 0 \longrightarrow L = R$ *(calibration)*

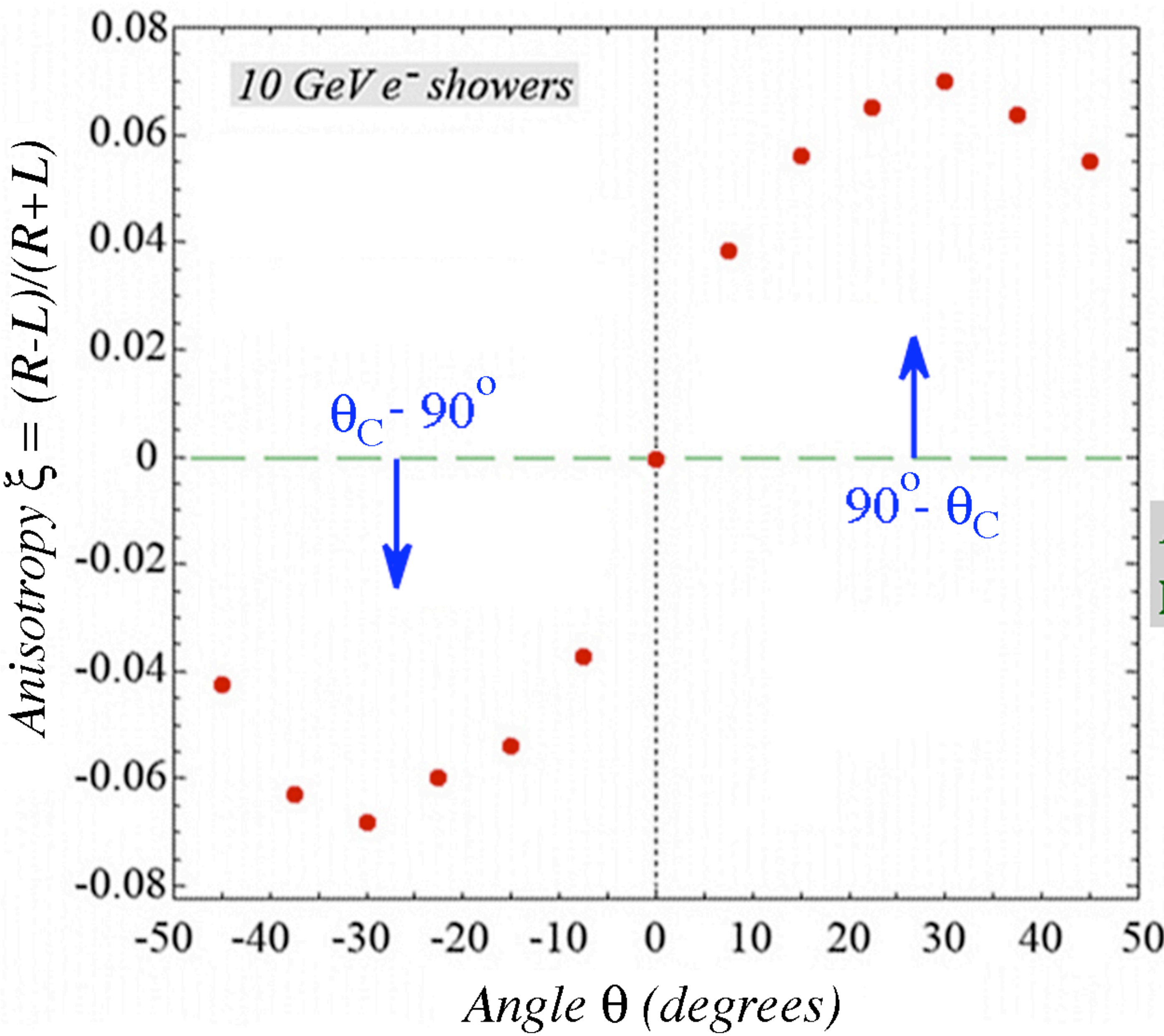
$\theta < 0 \longrightarrow L > R$

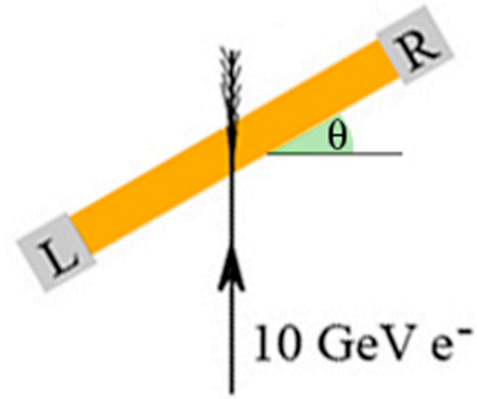
$\theta > 0 \longrightarrow L < R$

Measure $\frac{L - R}{L + R}\,(\theta)$



Experimental results $PbWO_4$: Directionality

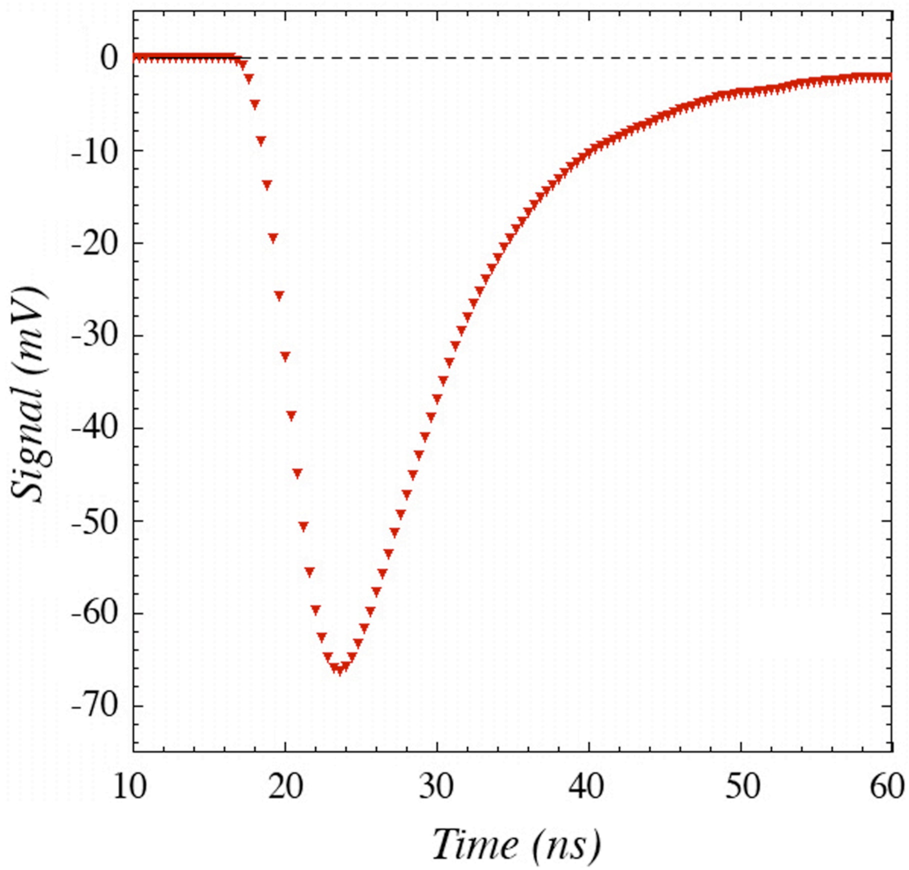


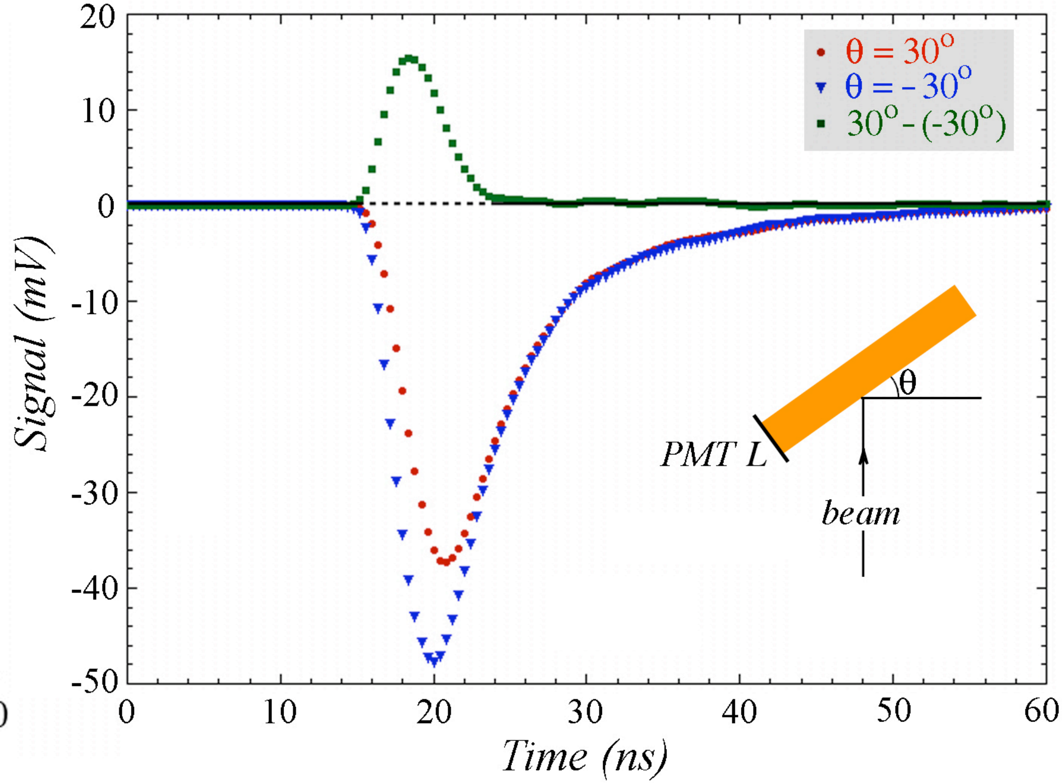


From:
NIM A582 (2007) 474

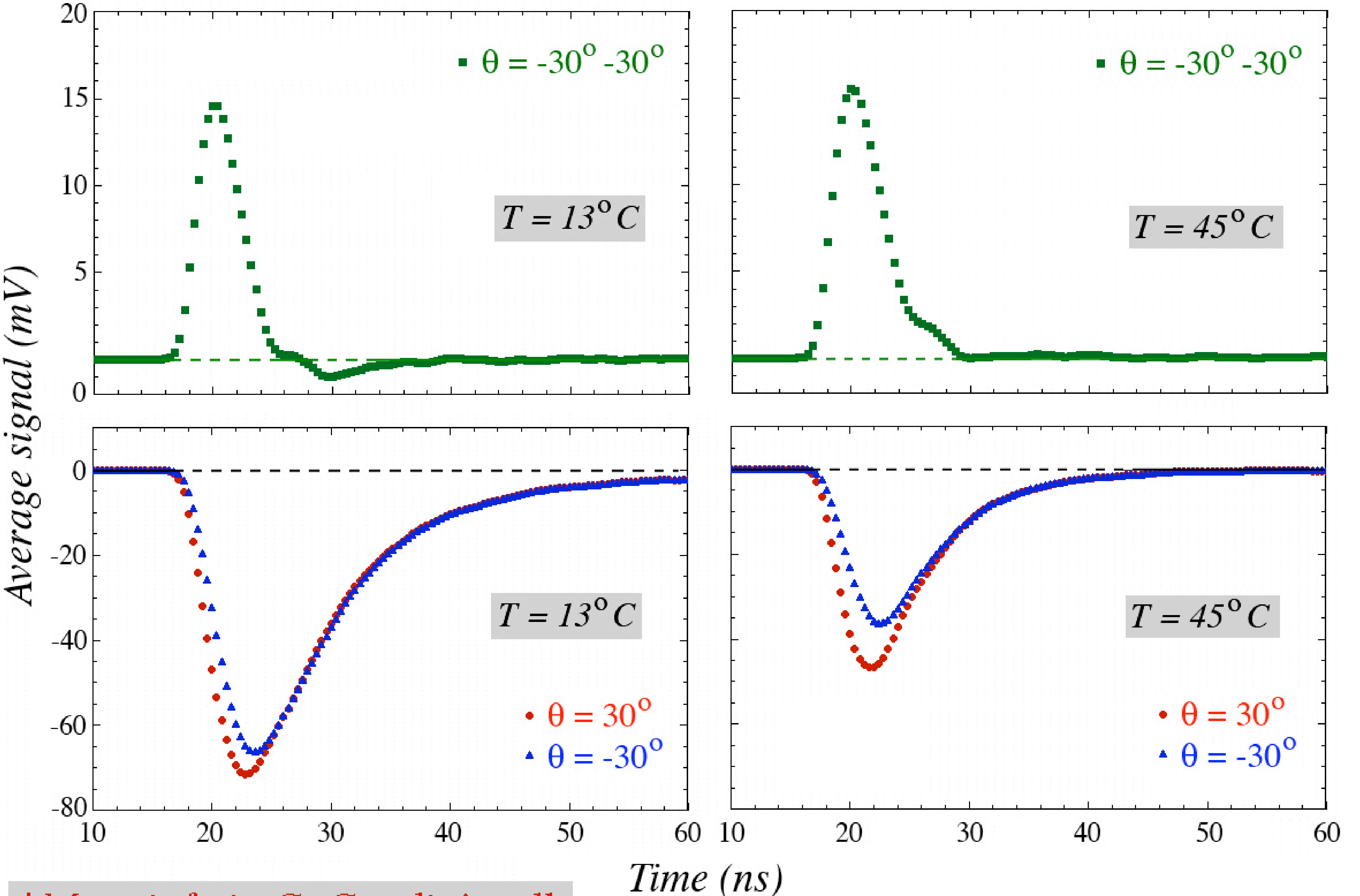
Experimental results $PbWO_4$: *Time structure of the signals*

The importance of time resolution for the $PbWO_4$ 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 $PbWO_4$:

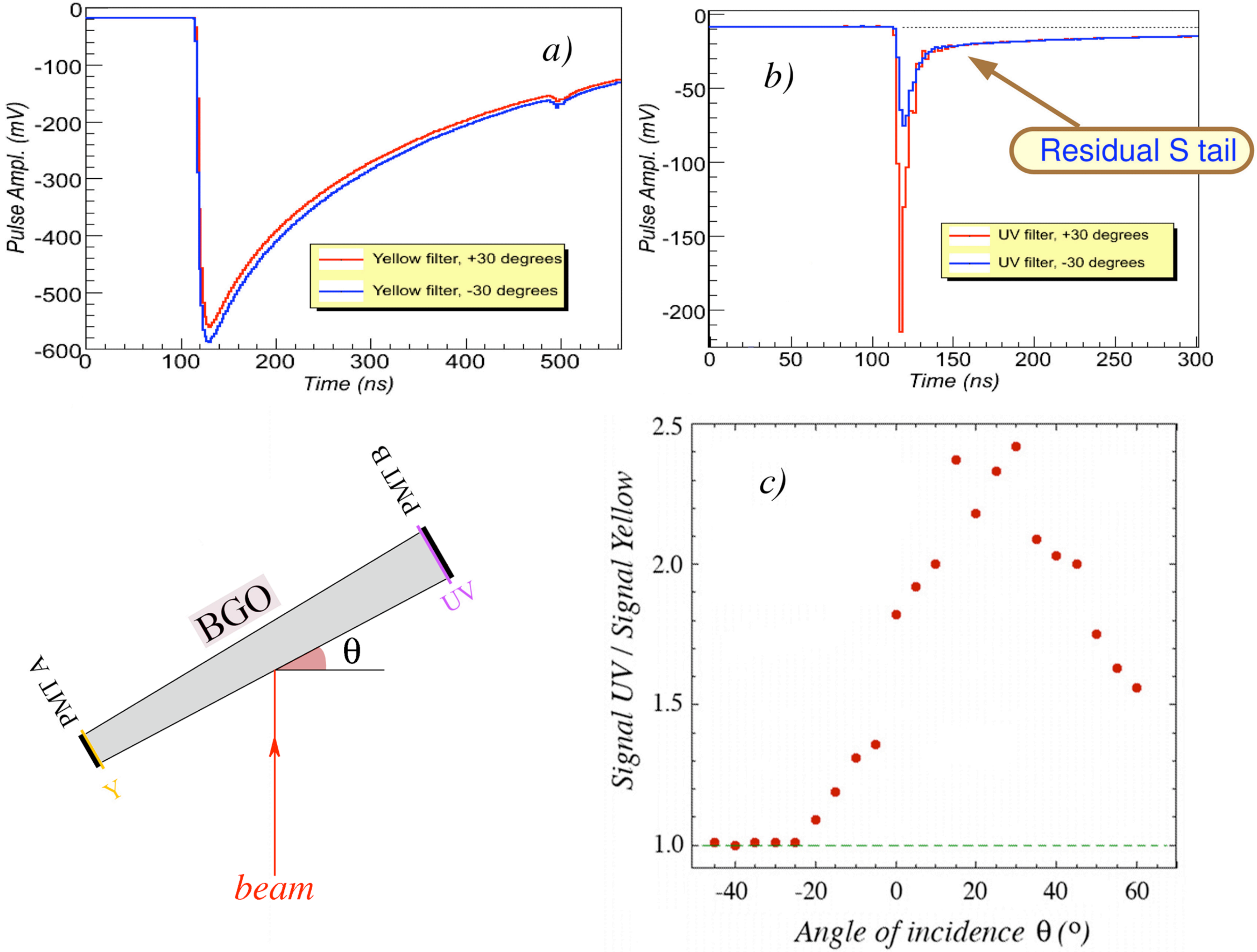
A much brighter scintillator, Č/S factor 100 smaller

Advantages:

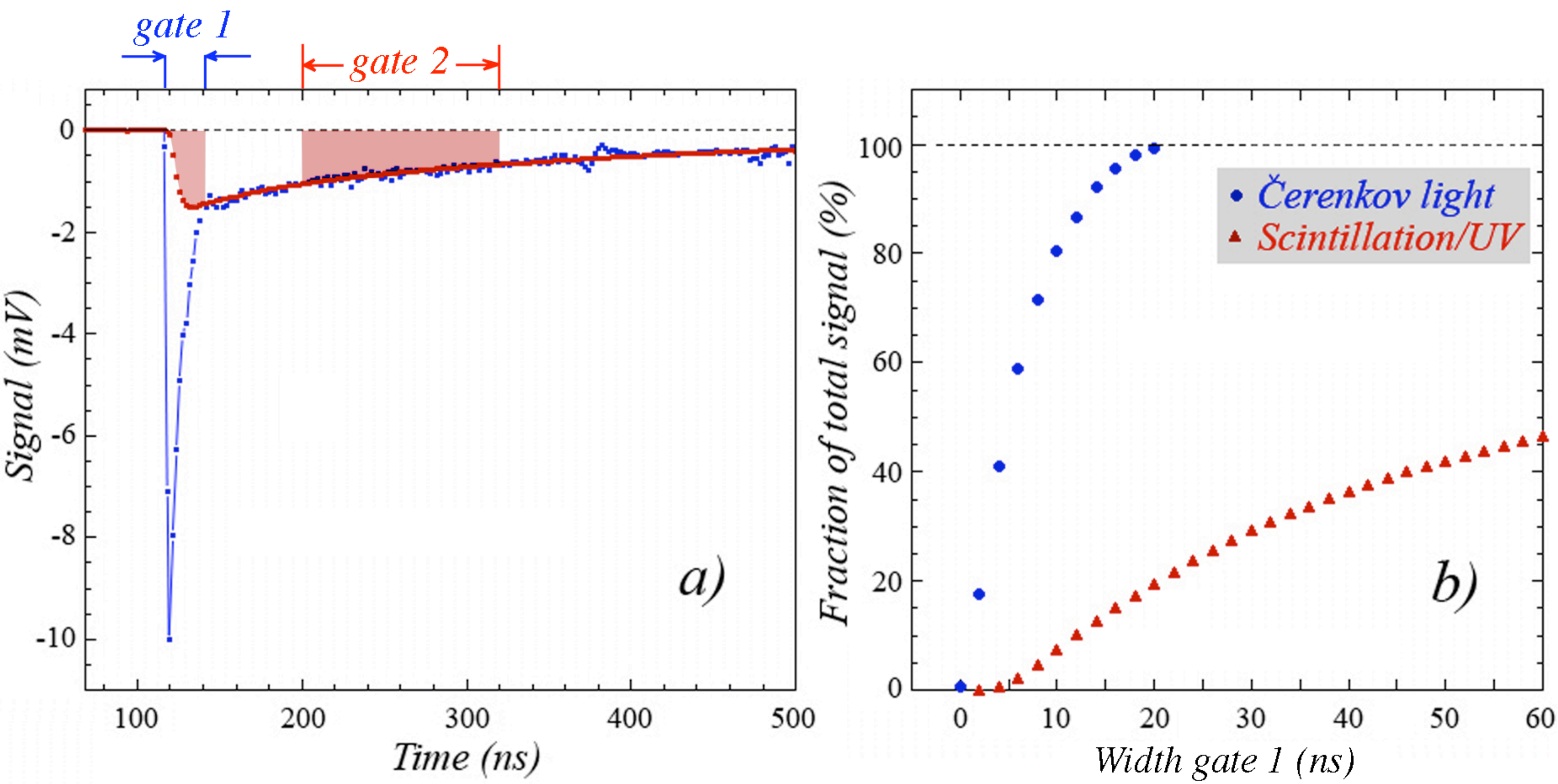
- *Scintillation spectrum peaks at 480 nm* → *use filters*
- *Decay time scintillaton 300 ns (very different from prompt)*

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

The Čerenkov component in BGO signals

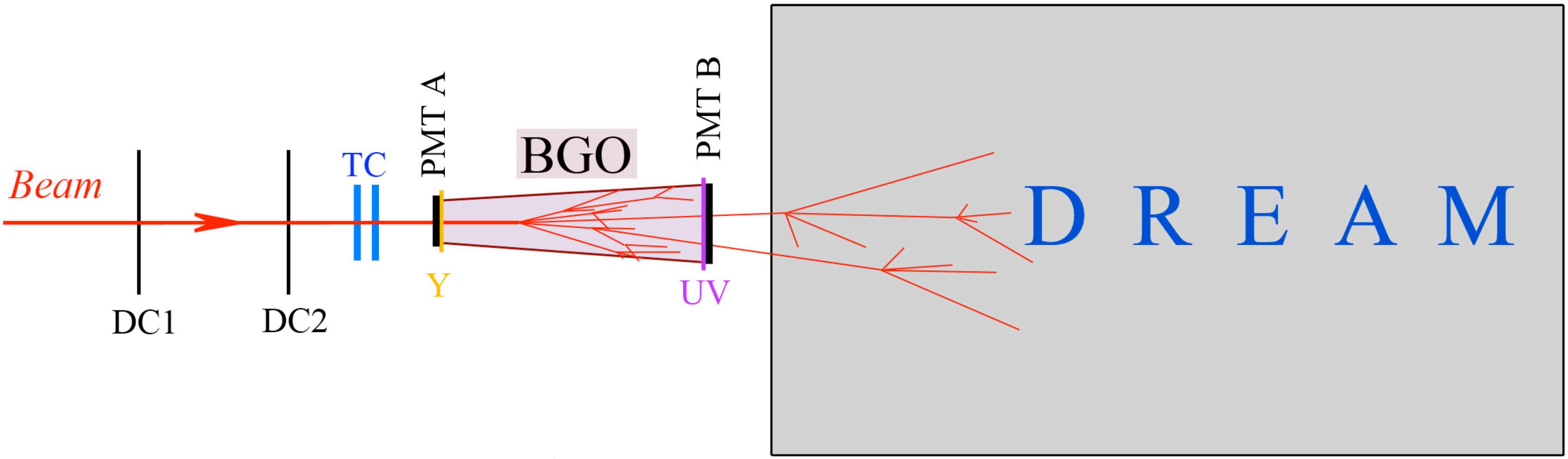


Čerenkov and Scintillator information from one signal !

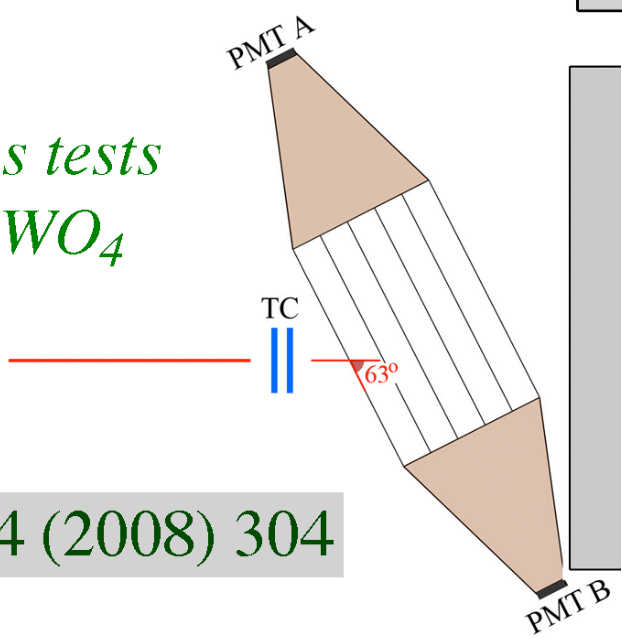


*More information in C. Voena's talk

Experimental setup for the BGO + DREAM tests



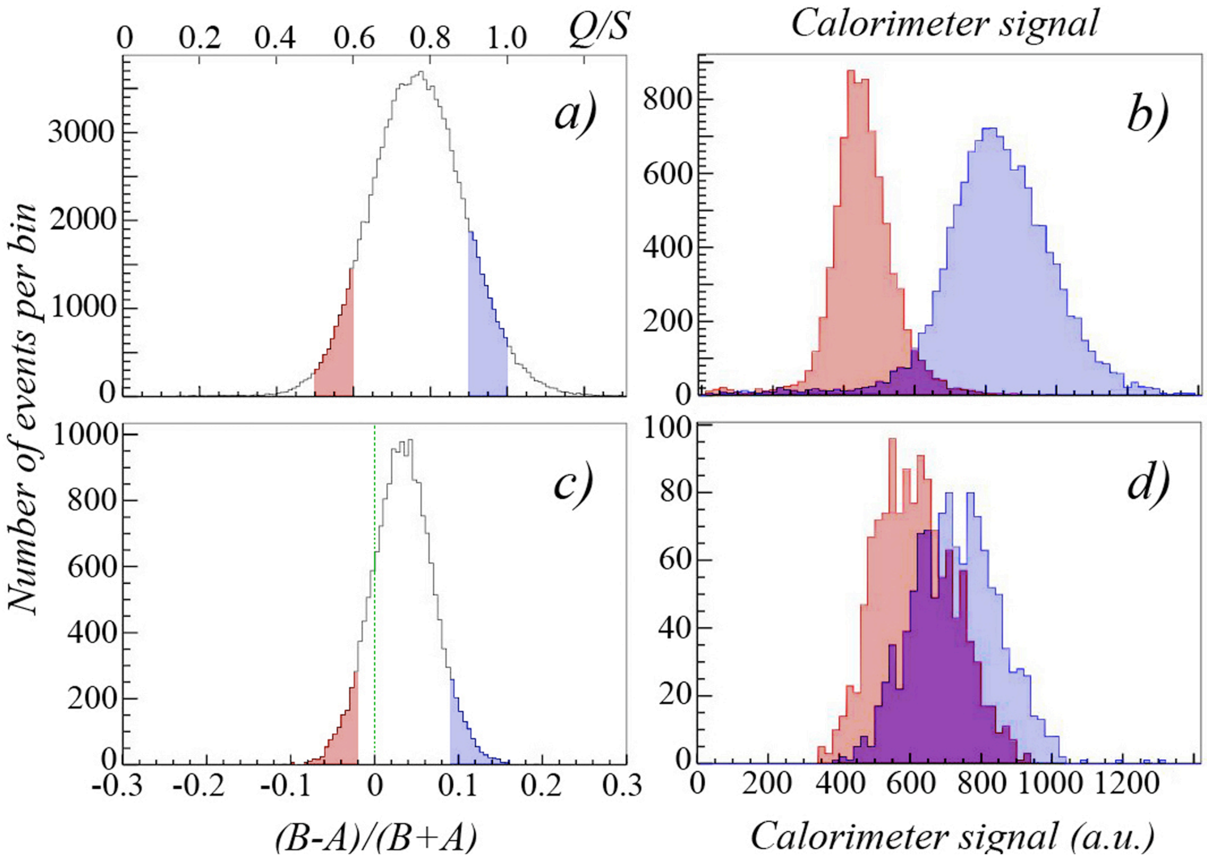
Previous tests with $PbWO_4$ matrix



NIM A584 (2008) 304

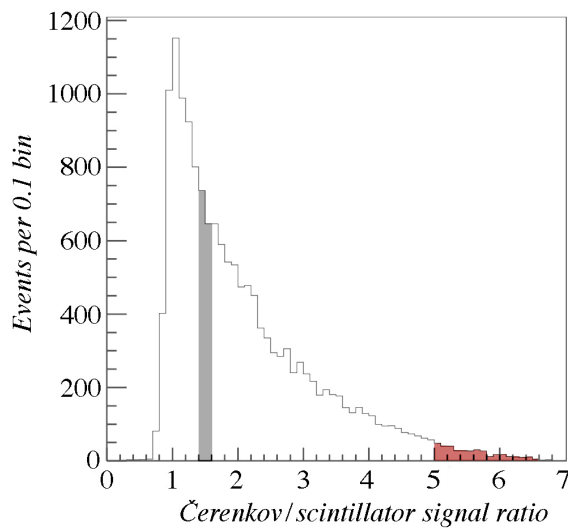
**See D. Pinci's talk*

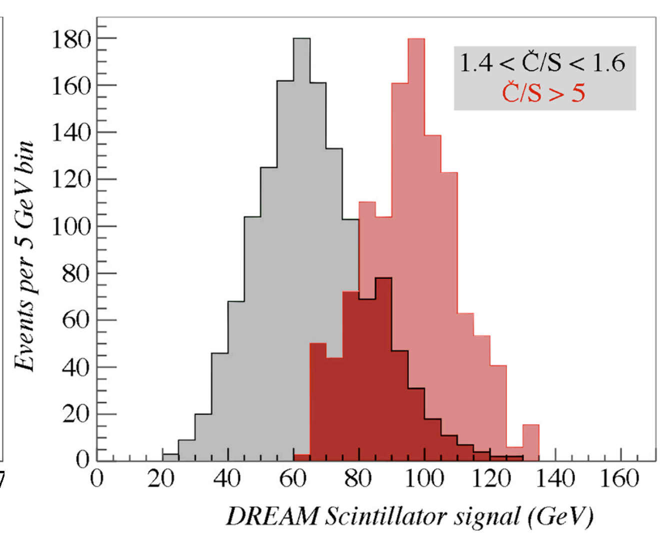
Selective power of the measured Cerenkov component



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 ⟶ *reduce effects side leakage*

- *Increase Čerenkov light yield*

  DREAM: 8 p.e./GeV ⟶ fluctuations contribute $35\%/\sqrt{E}$

  No reason why DREAM principle is limited to fiber calorimeters

  Homogeneous detector ?!

  ⟶ *Need to separate the light into its Č, S components*

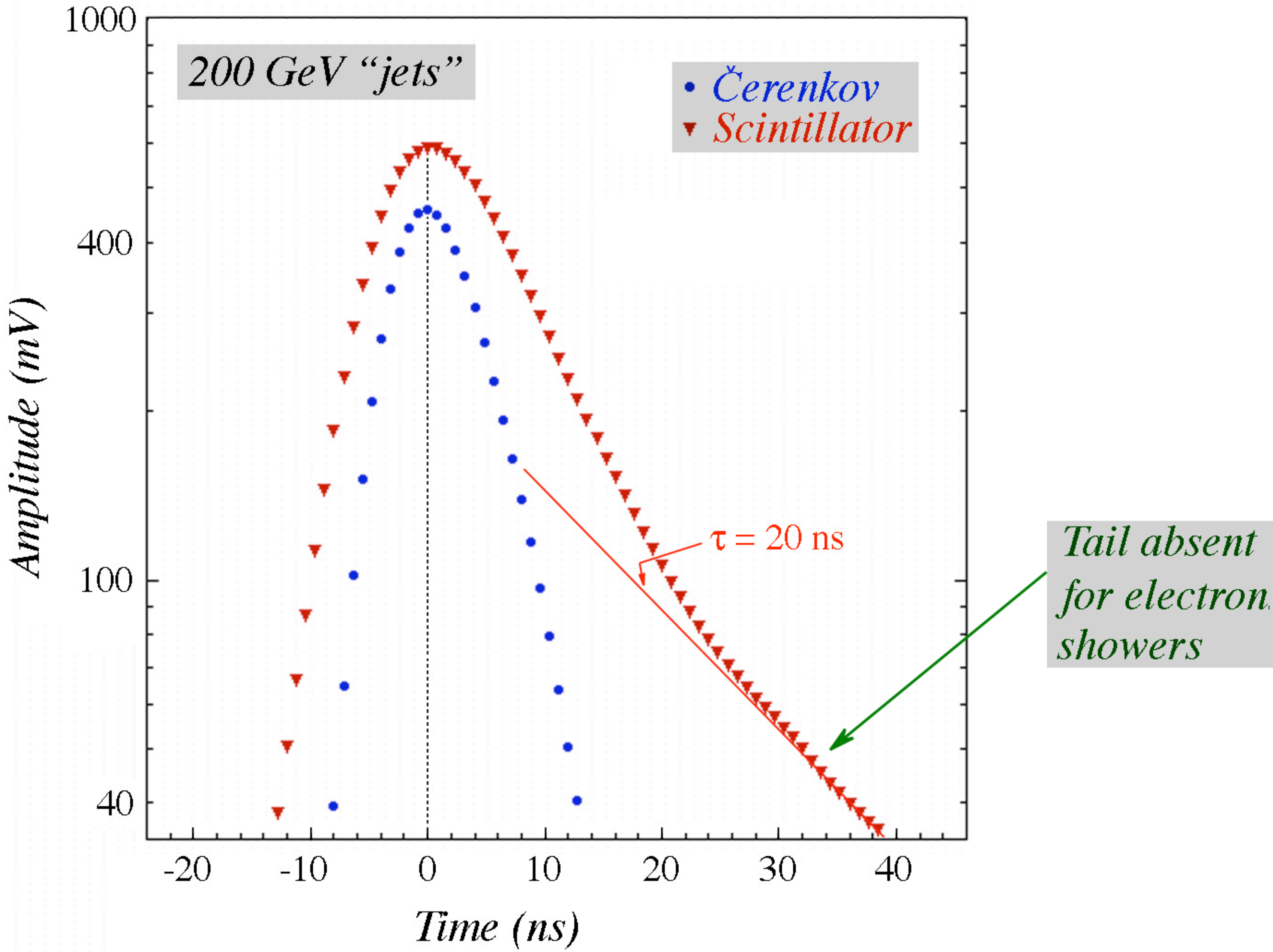
- For ultimate hadron calorimetry ($15\%/\sqrt{E}$): *Measure E_{kin} (neutrons)*

  Is correlated to nuclear binding energy loss (invisible energy)

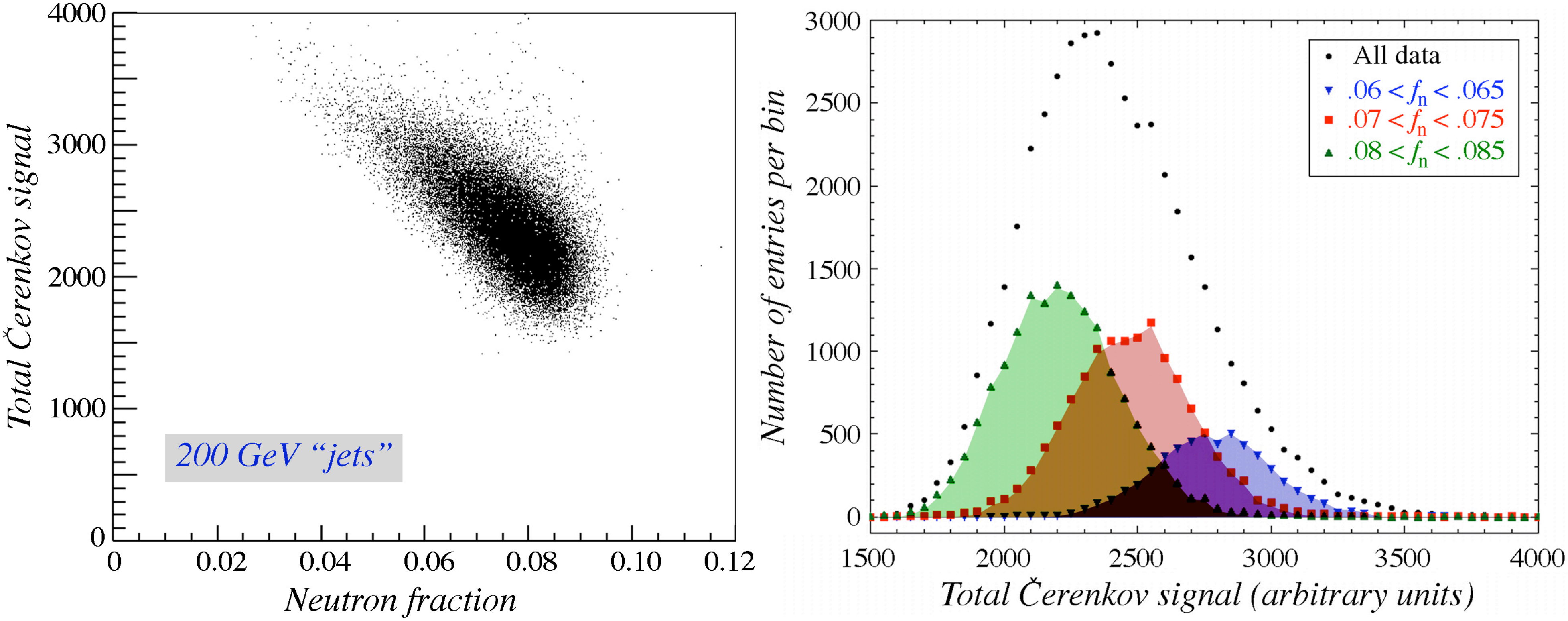
  Can be measured with third type of fiber : TREAM

Or inferred from the time structure of the signals

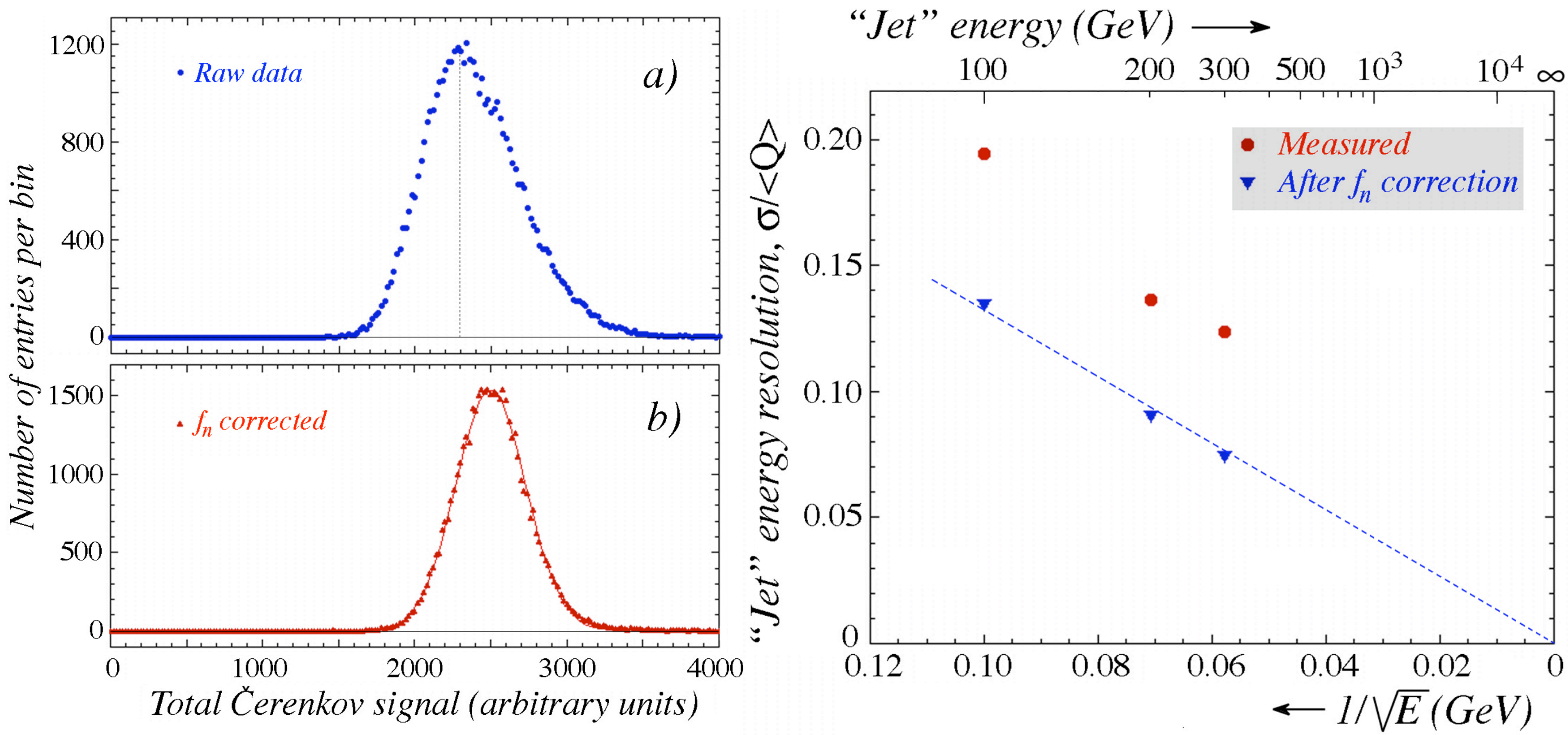
Time structure of the DREAM signals: the neutron tail



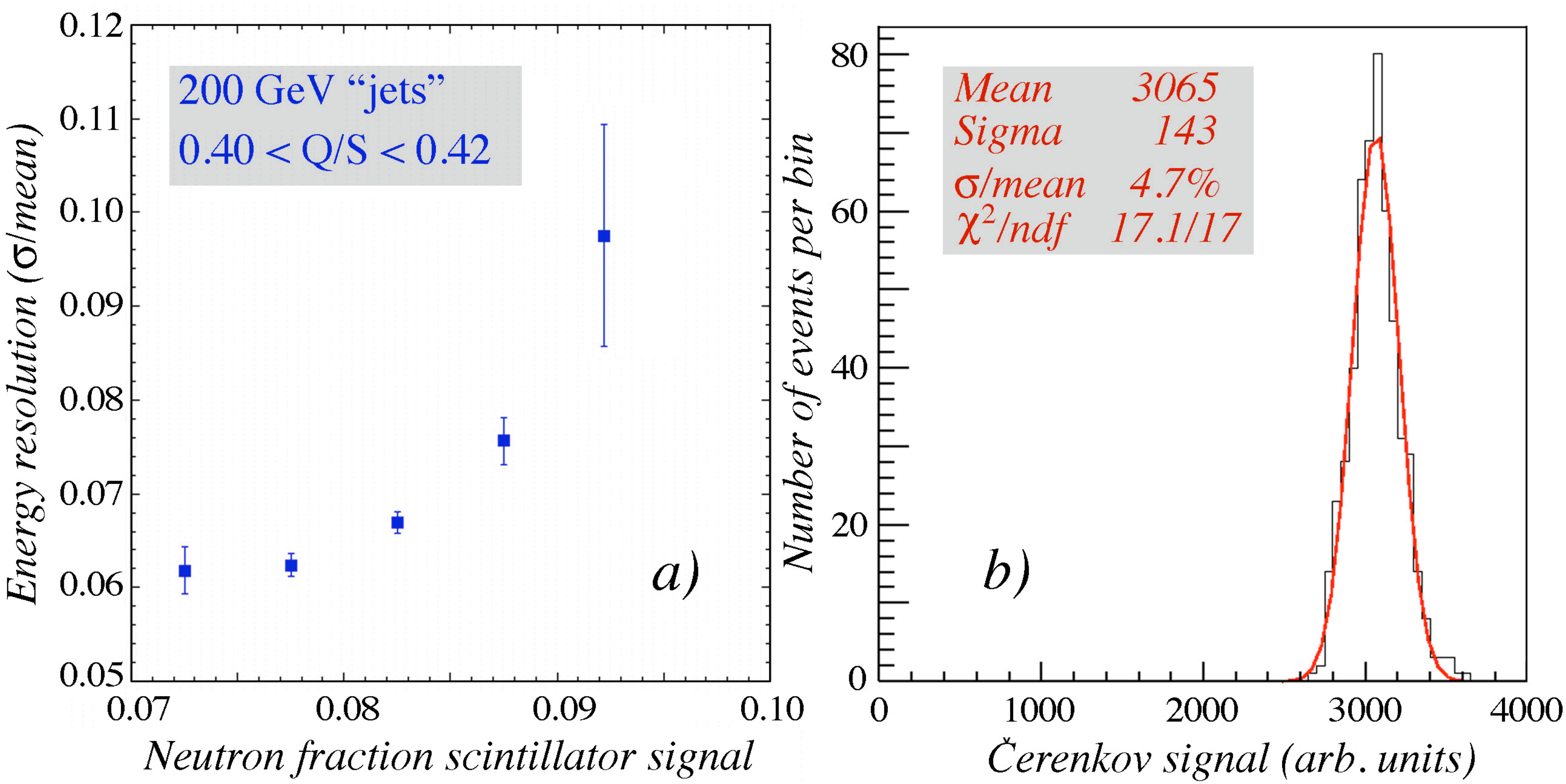
Probing the signal distribution on the basis of the neutron fraction



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)* — applies to: Fluctuations in Čerenkov light yield; Sampling fluctuations

— *see talk R. Carosi* — applies to: Fluctuations in invisible energy

Then build a full-scale prototype calorimeter

Conclusions

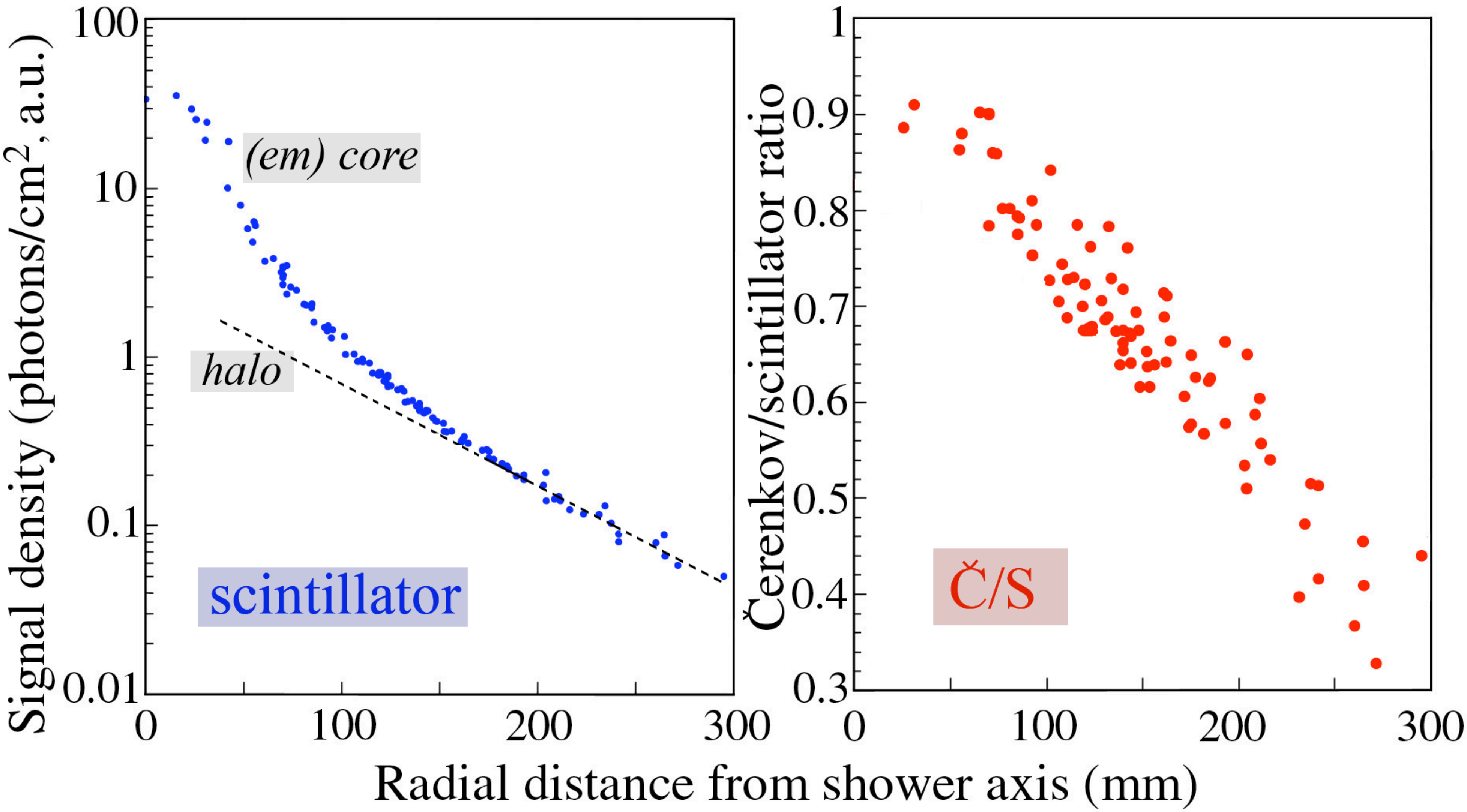
- The DREAM approach combines the advantages of compensating calorimetry with a reasonable amount of design flexibility

- 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