Calorimeters in Future High Energy Physics

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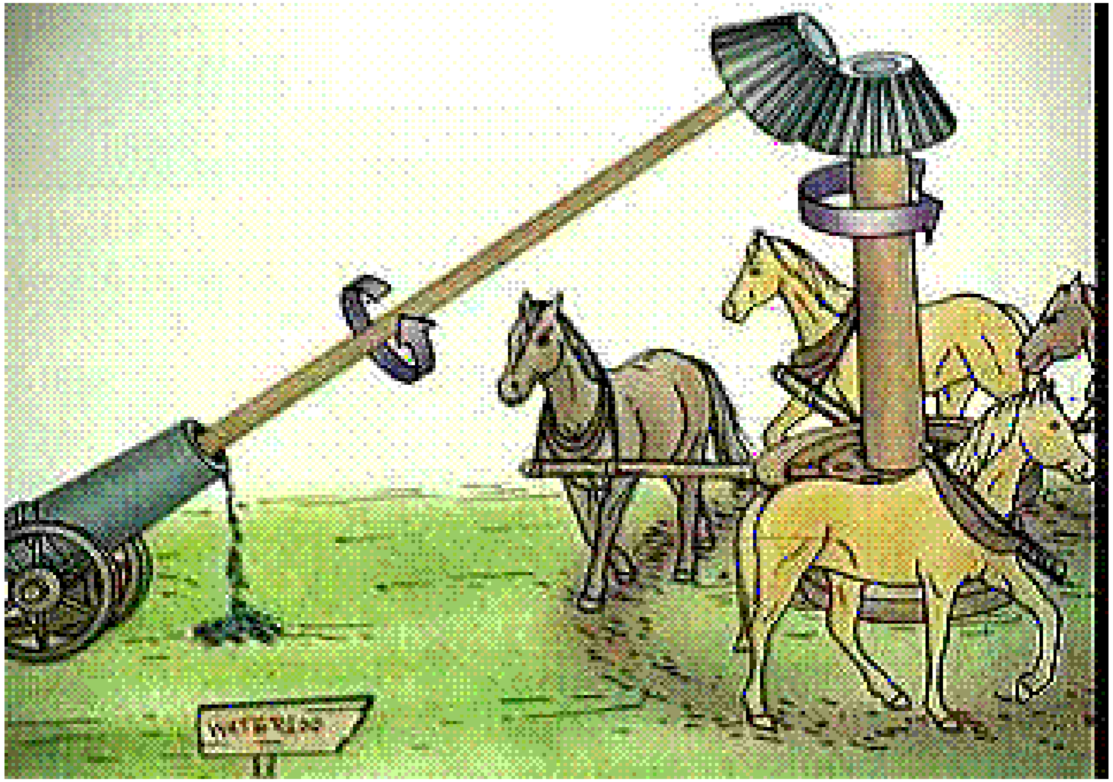
Calorimeters in Past and Future High Energy Physics

- **Generally, the Future means high energy, the Past, low energy. Of course the definition of these terms changes with time. Now the LHC is Present, and everyone knows about it since most of them are working on it, so it's not part of our talk. High energy means higher parton energies than the LHC, and then necessarily higher $\mathcal{L}$.**
- **Now, not in the Past, Future means high background environments. No more LEP environments!**

Energy → Heat

- **The first Calorimeter, from Benjamin Thompson, Count Rumford: Heat is produced as long as work is being put into the calorimeter material**



Signals,Substitutes for Heat

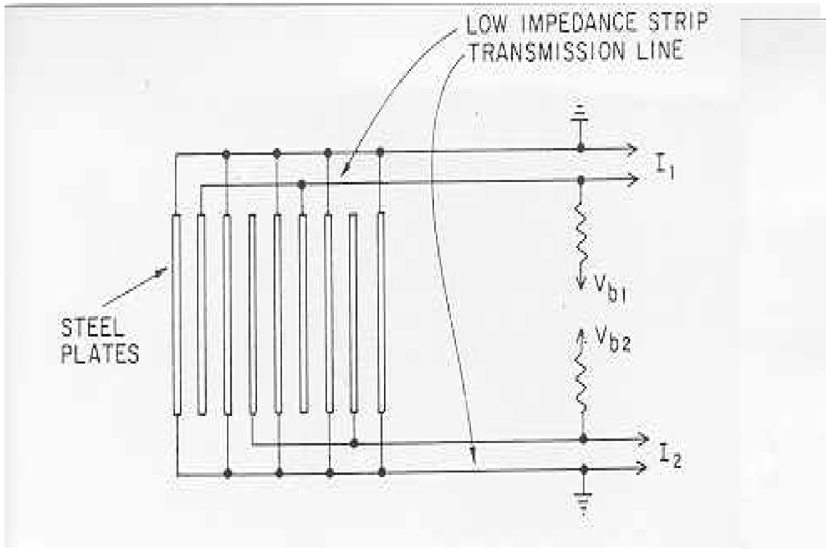
- **Ionization charge**
- **Scintillation light**
- **Cerenkov light**
- **Sound waves**
- **Phonons**
- **Radiation damage**
- **Activated halides**
- **Nuclear transmutation**
- **Neutron flux**
- **Shock wave**
- **Seismic waves**

Key Issues for Past Calorimeters

- **Spatial resolution (pi-zero rejection)**
- **Angular resolution (vertex position)**
- **Energy resolution**
- **Noise**
- **Sampling fluctuations**
- **Shower type dependent fluctuations**
- **Uniformity of response**
- **Calibration**
- **Radiation damage**
- **Pile up noise**

Sampling Fluctuations are Gaussian and Fall (relatively) with Energy

Many calorimeters sample the signal, the resulting fluctuation can be measured directly: e.g. Willis-Radeka Liquid Argon



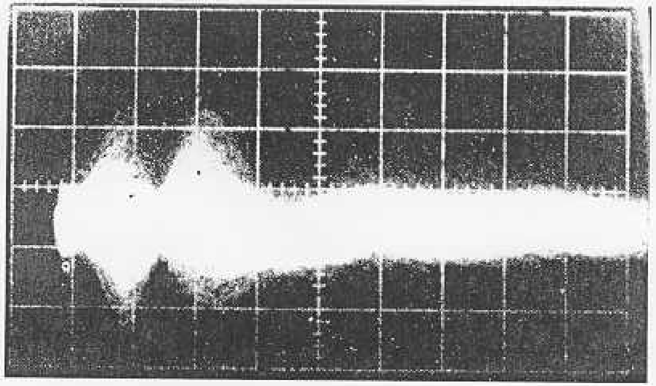
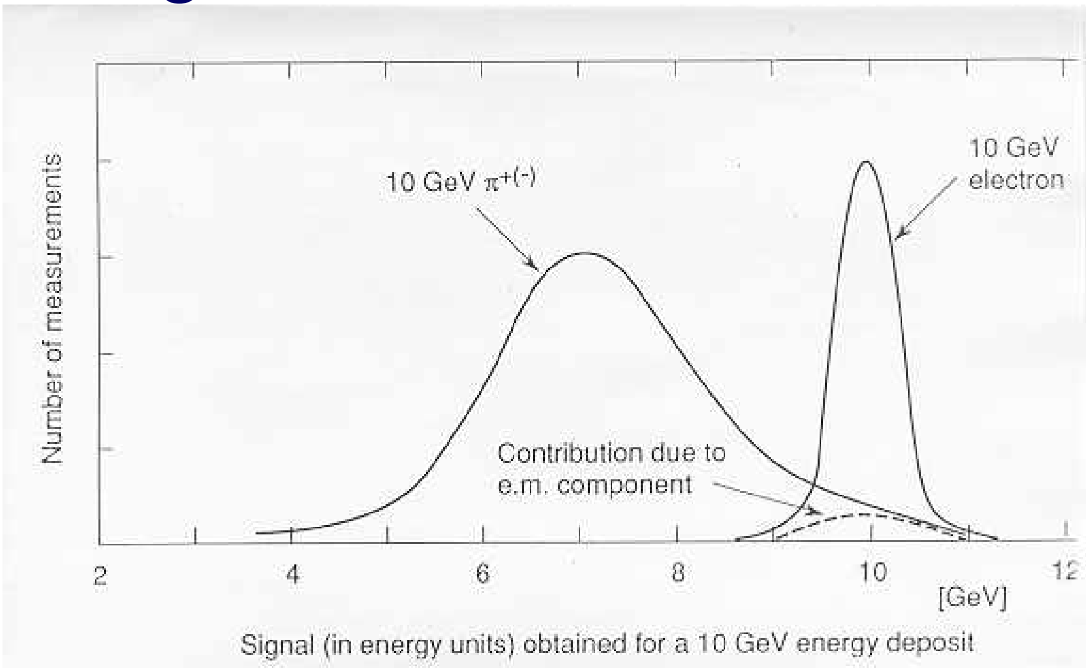


Fig. 15. Difference signals from two interleaved chambers for 7 GeV electrons (see text).

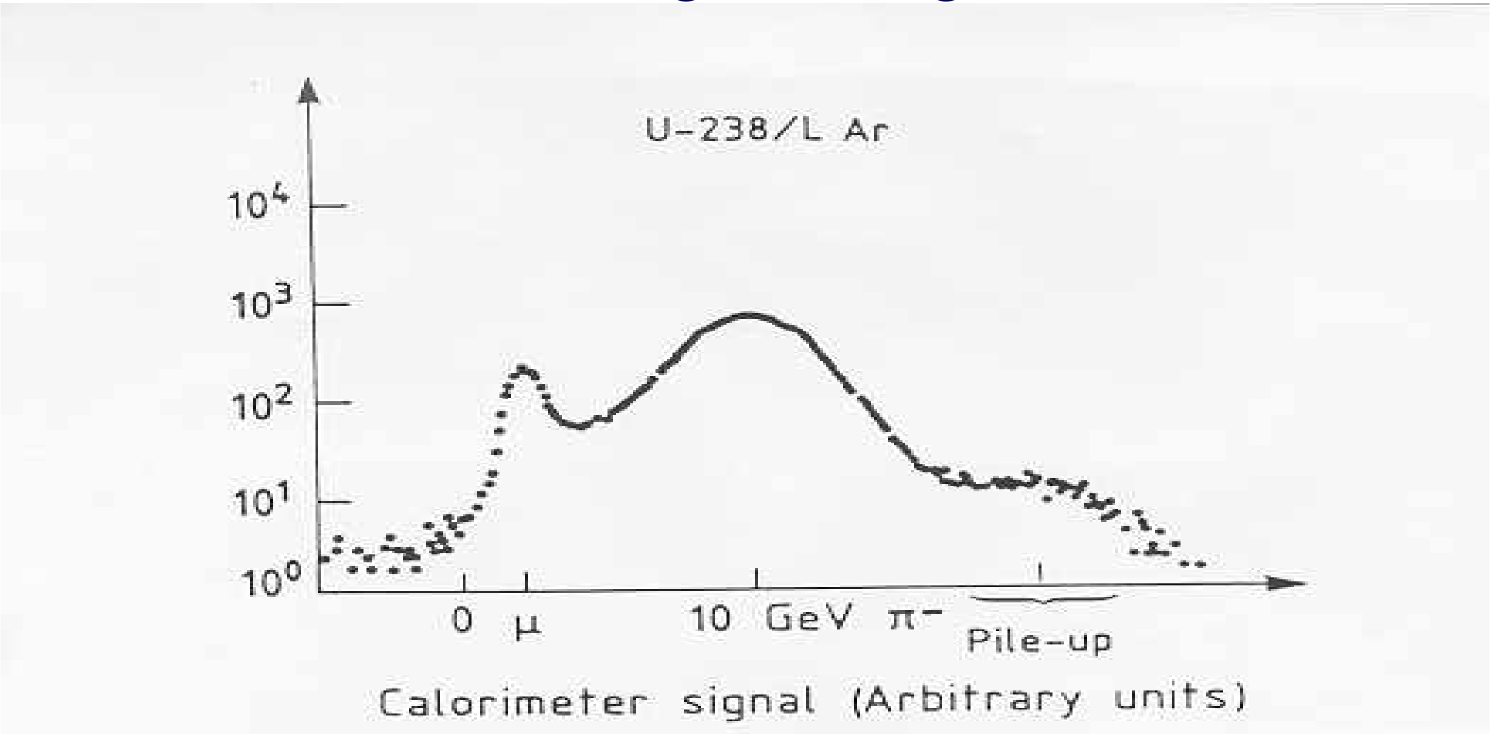
Shower Type Dependence

- **Each of the Signals mentioned, heat too, has a different relation between Signal and Energy deposit for different shower types, electromagnetic, hadronic…**

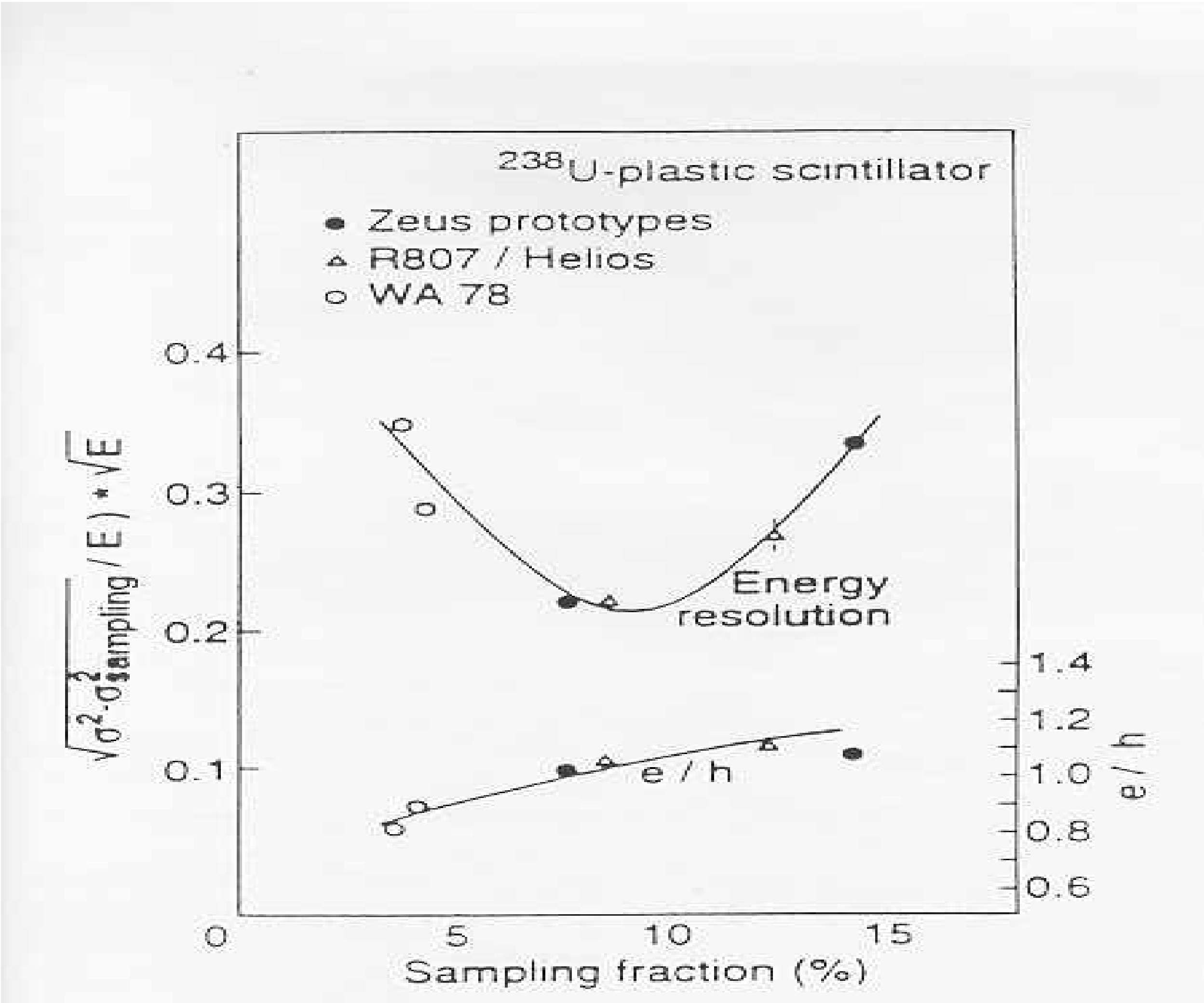


Solution: Amplify Nuclear Energy or Attenuate Electromagnetic Energy

- **Nuclear fission amplifies, high-Z sampling plates attenuate the electromagnetic signal**



Best Resolution is when Hadronic and Electromagnetic Response is Equal



IN PRESENT STATE OF THE ART, THESE ISSUES ARE UNDER CONTROL

- **In the LHC, B Factories HERA and KLOE... The electromagnetic calorimeter designs are adequate to the task**
- **In the LHC and HERA experiments, the hadronic calorimeters measure jets of quite high energy, and the uncertainties of jet definition mean that the shower-type dependence should not determine the precision**
- **Pile-up does limit the precision of the energy measurements for the lower end of the shower energy range, at the LHC but not in the "*natural* LHC range" around ~ 100 GeV.**
- **Shower "pointing," i.e. angle measurement, as well as shower position measurement, is important at the LHC because of the long interection region**

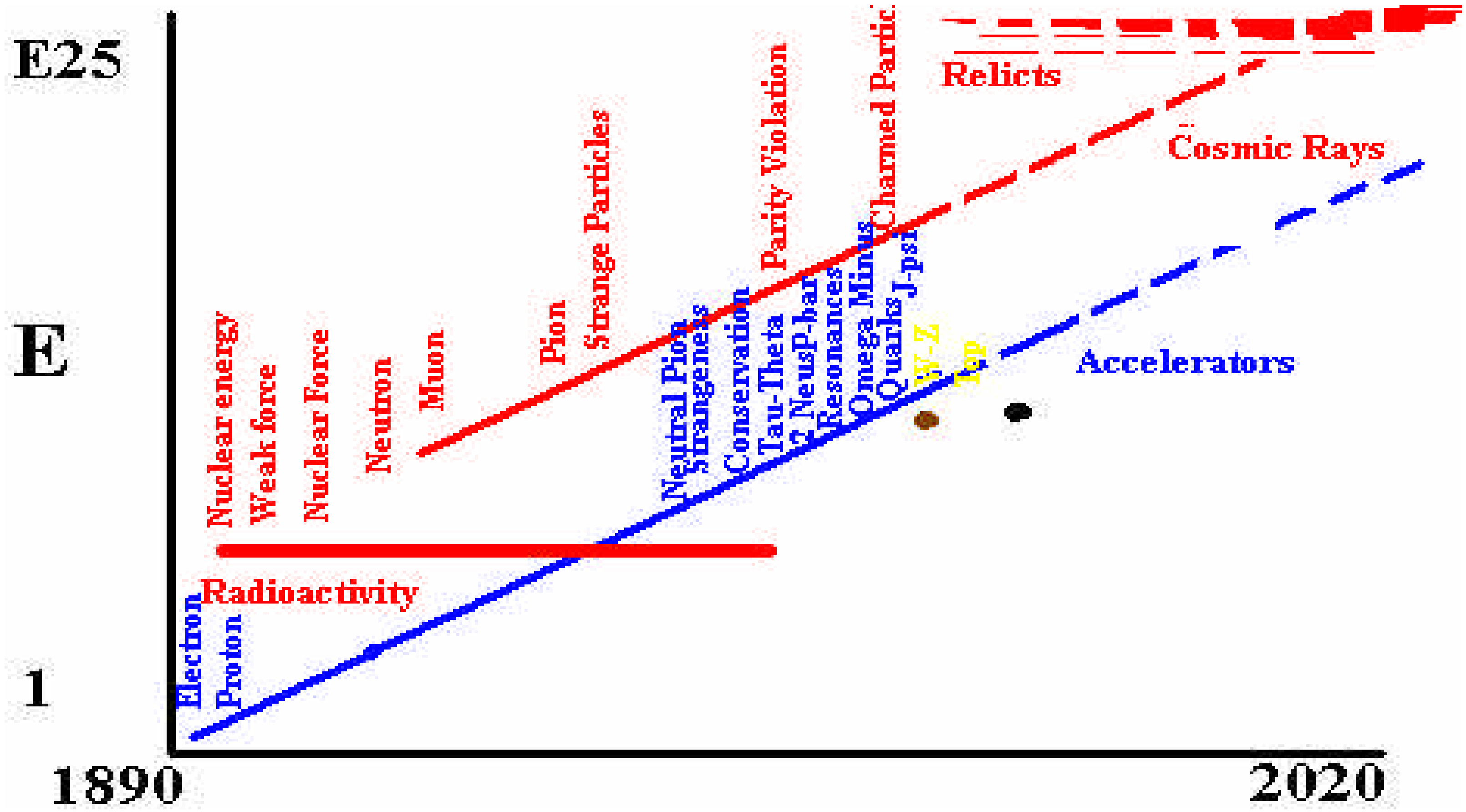
HISTORY AND PROPHESY

- **Prophesy based on History**
- **Here is a 1981 prophesy snapshot:**

- **Comments:**
  - **we are keeping on the “Auger curve”**
  - **we risk to get behind on the “Livingston curve”**
  - **have we started to see New Physics from cosmic rays?**
    - **Some people think so…**

Anyway, the moral applies that competition does not wait for you!

- Worse (or Better) News: Some new mass-scale particles may be stable. If so, find some; annihilate them: get energy 10^5-10^{16}GeV
- History:



Keeping on "Livingston curve"

- **Generally, discoveries come from more energy**
- **What is needed next to stay on the curve?**
- **LHC "reaches" to about 5 TeV.**
- **We usually increase by a factor of π**
- **The next lepton collider should be at 15 TeV or p-p about 50+50 TeV**
- **LHC should point the way**
- **(If there are no signposts at LHC, muti-$G may be had to sell)**

The Key Issues are Different in the <u>Future</u>

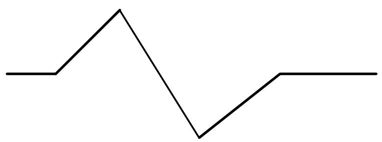
- They are somewhat distinct in a VLHC or a 10+10 Tev $\mu+\mu-$ Collider (see Montauk 99 Workshop). The muon collider must deal with a high level of very soft electromagnetic radiation from the shielding aperture near the collision point and a flux of high energy muons through the detector, particularly the end caps, parallel to the beams.
- The VLHC case is tougher in most respects, and we concentrate on it, specified by
- E =2x50 Tev
- $\mathcal{L}$ > 10^{36}/cm^2 s
- Bunch spacing = 5ns maximum

Scaling of Energy,
$\mathcal{L}$ uminosity and Pileup

- **We raise the energy of the pp collision to increase the parton collision energy, s**
- **The point-like cross sections that interest us fall, alas, with collision energy,**

ó $\propto$ 1/s

- **We need to keep the number of events, $\mathcal{L}$ ó, at least constant, so $\mathcal{L}$ $\propto$ s $\propto$ E^2, looks <u>scary!!</u>**
- **Pileup for bipolar shape of length τ:**



gives $\sigma_{pileup} = E_{low\ pt} \sqrt{(n\tau/3)}$, where n is rate of $E_{low\ pt}$

- **For $E_{low\ pt} << E$, n $\propto$ $\mathcal{L}$ log E $\propto$ E^2 log E for our conditions, so $\sigma_{pileup} \propto \sqrt{(E \log E)} = E \sqrt{\log E}$ for fixed τ, or σ_{pileup} /E = constant if we decrease τ slowly, like <u>$\tau \propto 1/ \sqrt{\log E}$: NOT SO BAD!</u>**

High Energy Machines for High Energy Physics!

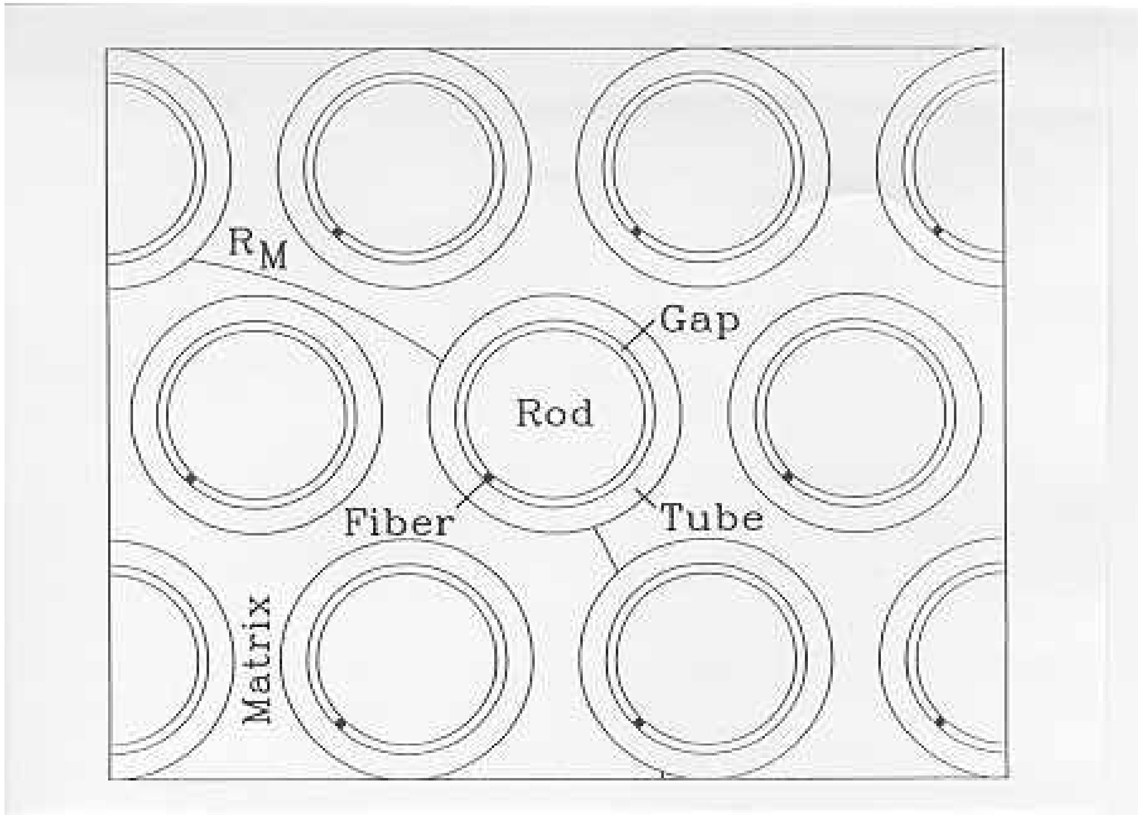
- This follows from the condition σ_{pileup}/E = constant, and sounds reasonable but is not the usual practice: we use the AGS to make stopping muons, the LHC to do b-physics, etc. profiting from log E in the rate. This is ok as long as we don't dip too far below the "normal range" of p_t
- That is, we can use the VLHC to make lots of Tops or Ws or SUSYs, but we have done enough for b-physics!!

But We Can Do Better Than $\tau \propto 1/\sqrt{\log E}$

- At least for the VLHC, perhaps not beyond
- The relevant $E_{low\ pt}$ is that in the angular cone in which the shower is measured, and this can be much reduced, keeping the detector radius fixed
- We have not exhausted the resources of density in the present electromagnetic calorimeters, or the granularity supported by the size of the core of the showers—their transverse form is not at all Gaussian
- We can also profit by the fact that a very high energy shower has much of its energy at depths where the low pt showers have died away

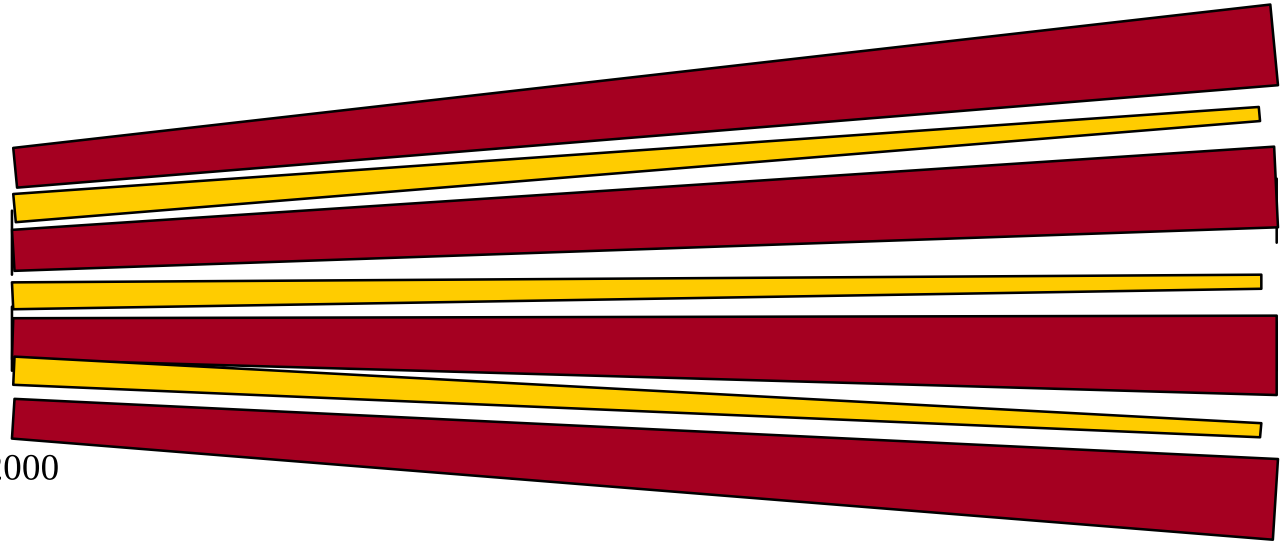
Dense and Fine Grained Calorimeters

- To bring the very forward calorimeter in GEM within the main body of the detector, I devised a structure with the ultimate density (adopted in ATLAS):
- LA only in a ~0.1 mm annular gap
- A coaxial signal path allows ns shaping, xformer couples to 50Ω cables out
- Gap small so can be projective without loss



Development for VLCH

- The core of the em show in first 10 rad. L. in high density metal is about 1mm radius; we want a 2mm granularity.
- We need a stereoscopic projective structure, with constant response along the radius. This can be achieved by cones with slightly different opening angles, to give appropriate variation of gap; exaggerated:

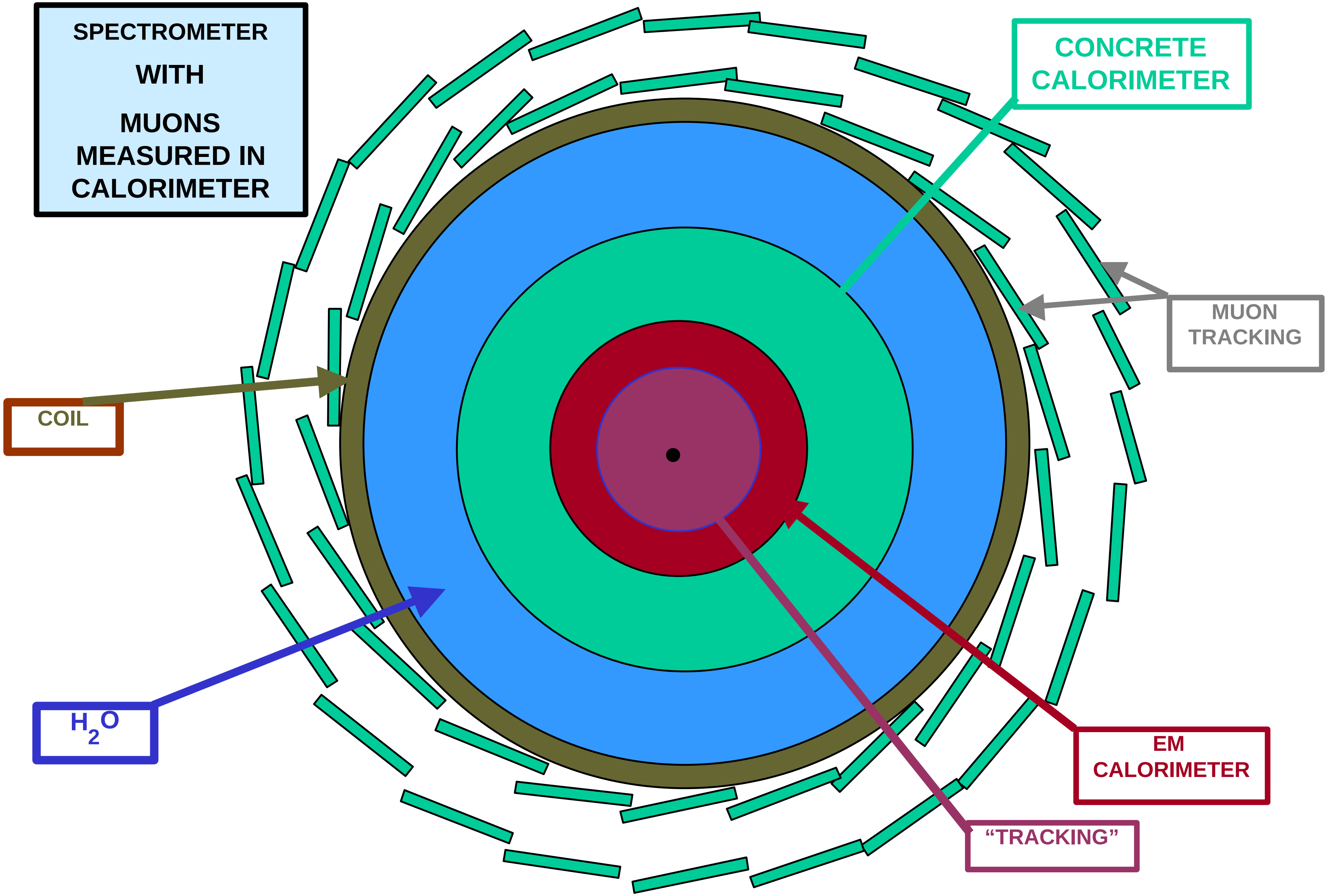


Spread $\mathcal{L}$ Over More Bunches

- **Perhaps ten times as many as in the LHC; the electronics in this future time should handle one ns resolution, ok for a few ns bunch spacing**
- **Compare number of background events in the solid angle of an electromagnetic shower in one bunch: $\mathcal{L}$ (x100) Area (1/10) events per bunch (1/10) log E (~4), about x4 LHC □ $\sigma_{low\ pt}$ ~ 2x LHC so there would be *much more* dynamic range relative to $\sqrt{s}$ than in LHC (or more $\mathcal{L}$). Clearly the problem is not in the em calorimeter!**

Jets in Hadron Calorimeter

- **A similar structure, with coarser cells, perhaps 20 mm, can be used for the hadronic calorimeter**
- **We could get the same increase in density compared to the standard iron calorimeter if we choose, but we do not have the dense inner core in a jet, so we will not gain a factor 10 in area, and the $\sigma_{\text{low pt}}/\sqrt{s}$ may end up about the same as in the LHC. Thresholds of 50 GeV for jets may be tolerable.**
- **Muon momentum measurement can get expensive as energy goes up, and we are led to examine other configurations, to better optimize the efficient use of magneti field in the spectrometer.**


SPECTROMETER
WITH
MUONS
MEASURED IN
CALORIMETER
CONCRETE
CALORIMETER
MUON
TRACKING
COIL
H_2O
EM
CALORIMETER
"TRACKING"

TRACKING
(NOT OUR SUBJECT, BUT…)

- **Tracking at ~ 1m radius, with this number of bunches, has lower track densities than inner layers at LHC.**
- **The precise location and pointing of the em calorimeter allows a match with the electron, and the electron bend gives an energy check, at least for electrons with less than a tev.**
- **Electron signs too!**
- **Everything, but b**

Summary

- **The calorimeters can do their job at the high luminosity required at a VLHC**
- **Some of the same tricks can be used at a muon collider to deal with the high backgrounds.**
- **The inner detector tracking needs a lot of R&D**