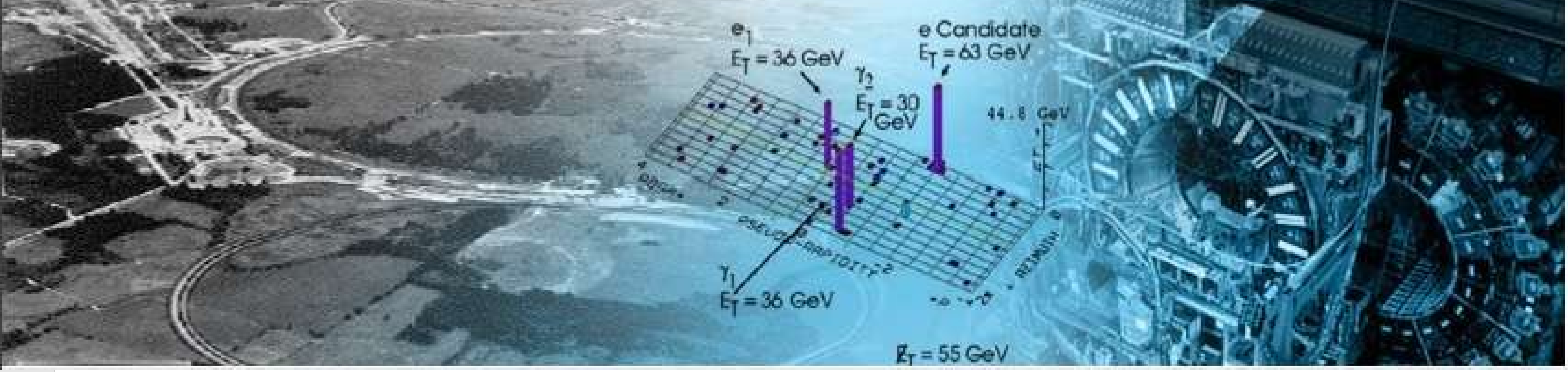


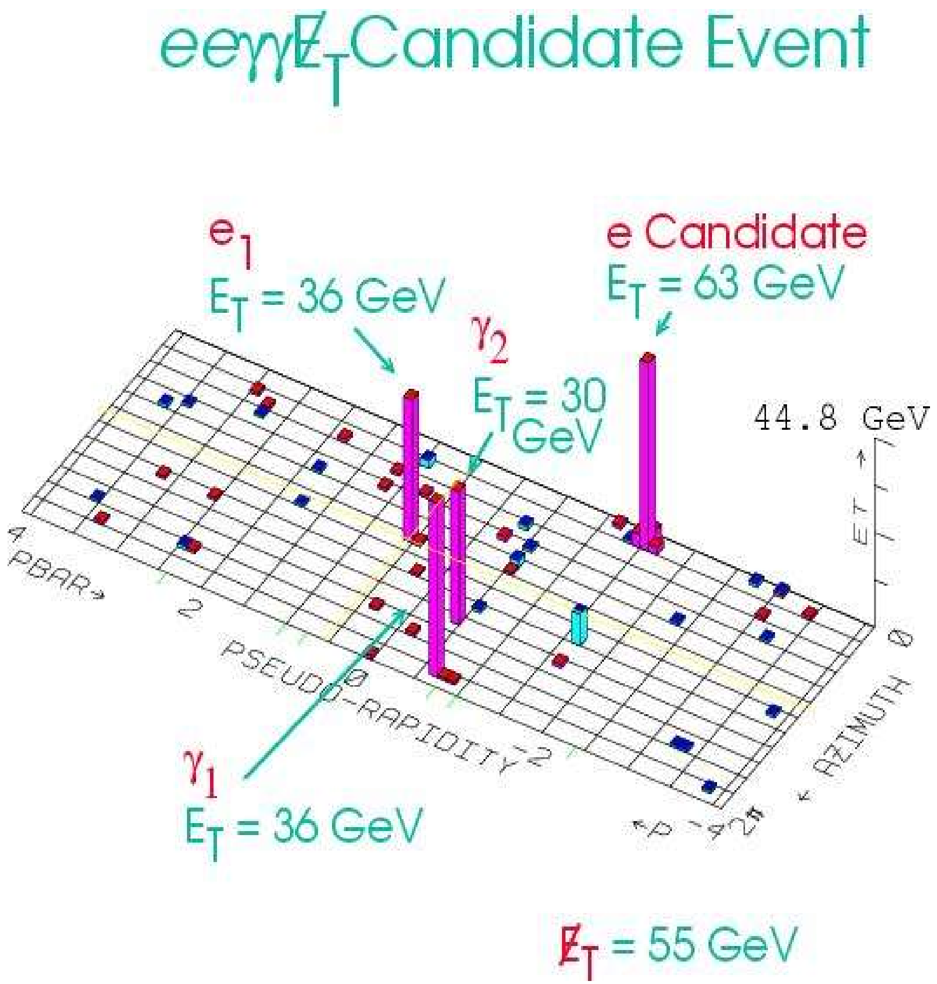
Calorimeter Timing System at CDF

Max Goncharov
Texas A&M University

In This Talk ...

- **Why we built the system**
  some history, motivations for building EMTiming system at CDF
- **System Design**
  specifications, design, testing, and installation
- **Performance**
  efficiency, noise levels
  calibrations, resolution
- **Things we did not expect to measure**
  beam width
  beam remnants,
- **Physics we expected to do**
  new exotic particles searches
  high luminosity effects on photons

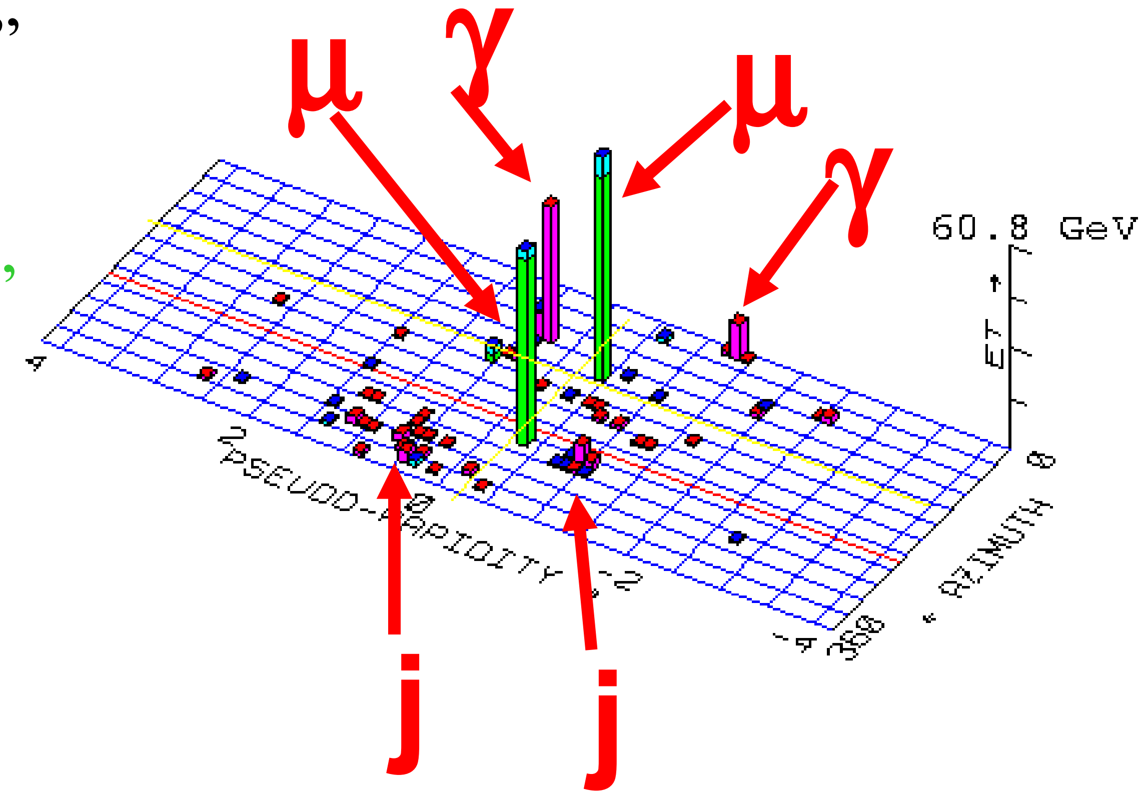
Exotic with Photons



- In addition to γγ+ Energy Imbalance this (famous) event has two high energy electron candidates
- Very unusual
- Good example of getting an answer which is far more interesting than what you asked for
- How unusual? Total: $(1 \pm 1) \times 10^{-6}$ Events

Exotic with Photons

- Another event in the data with properties “similar” to the eegg+Energy Imbalance candidate
- Not part of the “official” gg dataset
- No significant energy imbalance
- Not quite as interesting. Background only at the 10^{-4} level
  - 1 in 10 quadrillion
- Again, no good Standard Model explanation

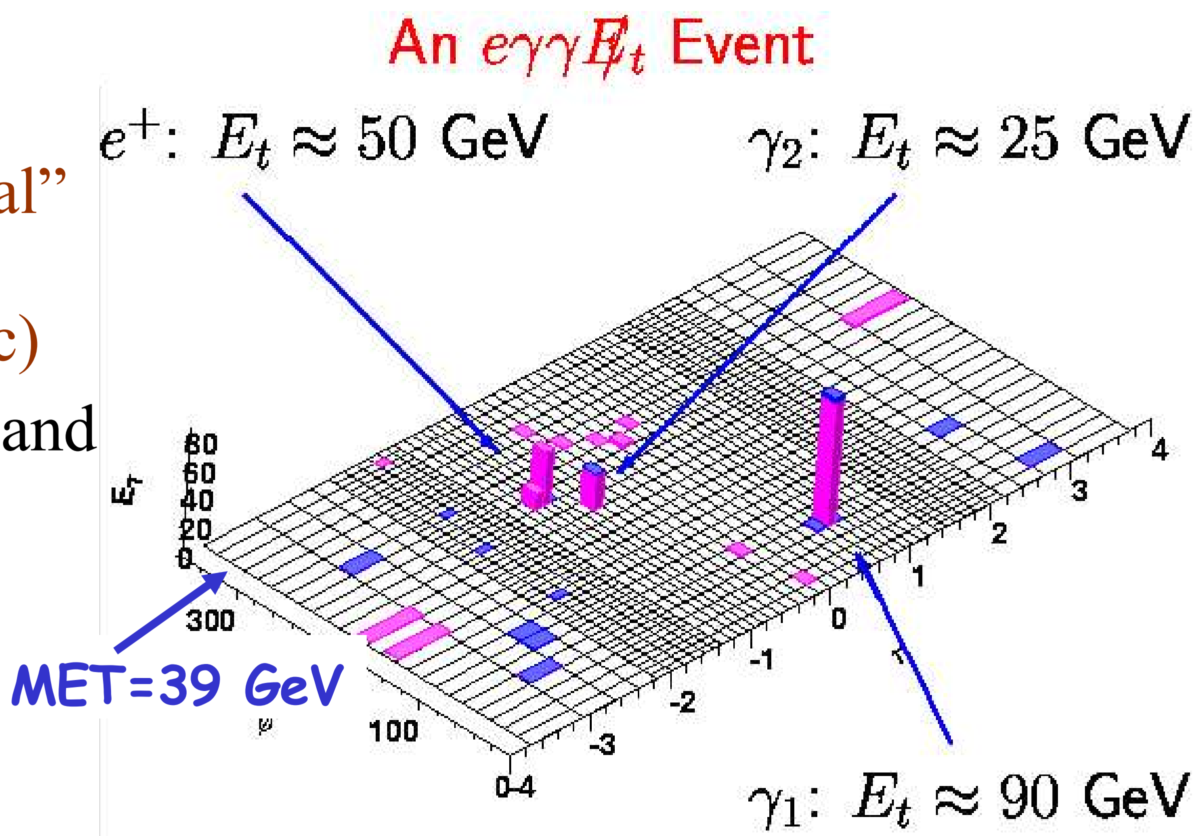


Unpublished confidential result

(CDF Internal 1996)

Exotic with Photons

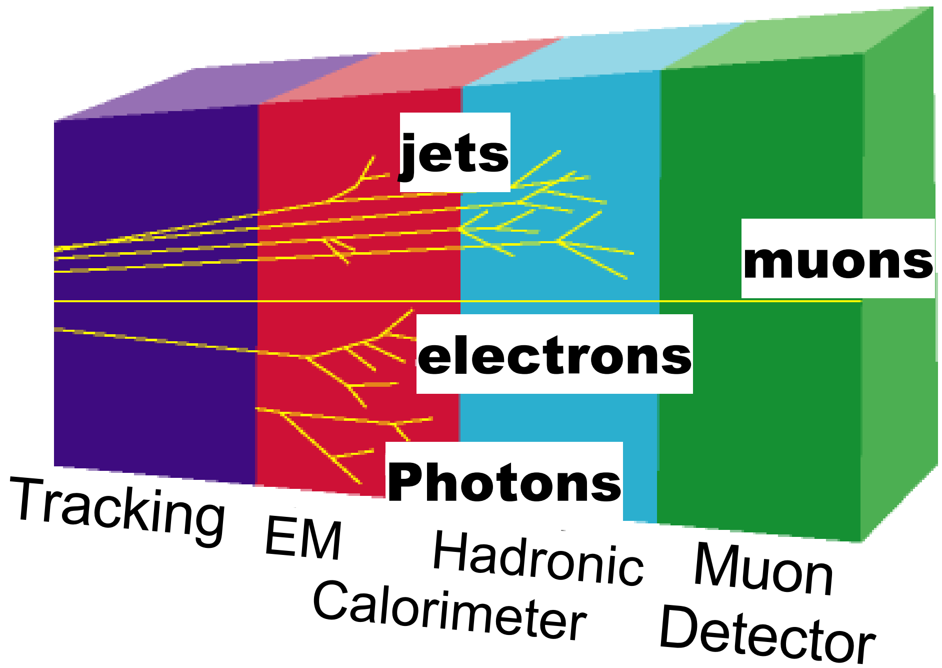
- And… another unofficial interesting event!!
- Came in <u>before</u> the “official” data taking period started (will never become public)
- Two photons, one electron and energy imbalance
- Preliminary background estimate at the
  3x10^{-3} level from Wgg
- Clearly similar to the other CDF anomalies



Unpublished confidential result

(CDF Internal 2002)

Why Timing?



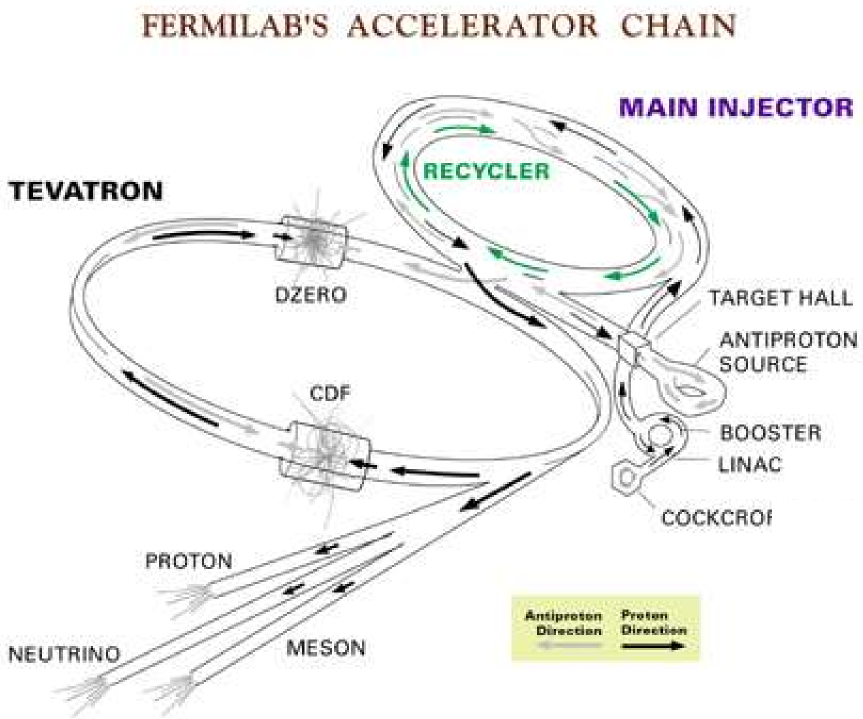
- If particle does not have track --> hard to say if it is really from collision or from accidents like cosmic rays or beam halo
- Accidents are not correlated in time with collision, hence timing becomes crucial

Reasons to Build

Adding timing on EM Calorimeter would help

- Photon handle: provide a vitally important handle that confirms or denies that all the photons in unusual events are from the primary collision.
- Met handle: for events with large EM energy, full calorimeter coverage reduces the cosmic ray and beam halo background sources and improves the sensitivity for high-P_T physics such as SUSY, LED, Anomalous Couplings etc.
- Search for long-live particles (More on this later)

CDF Detector

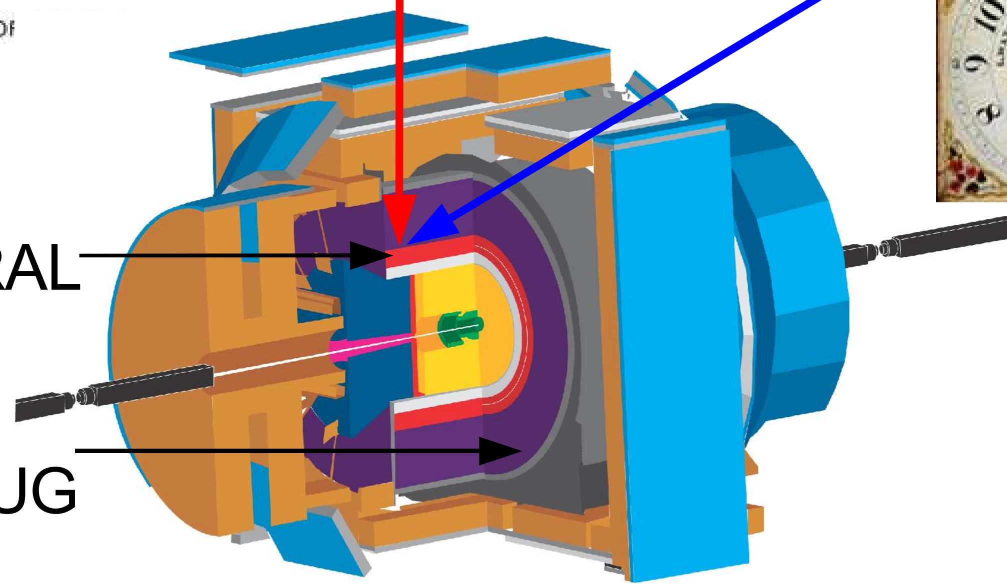


CDF Detector

Electromagnetic (EM) Calorimeter

EMTiming system

CENTRAL



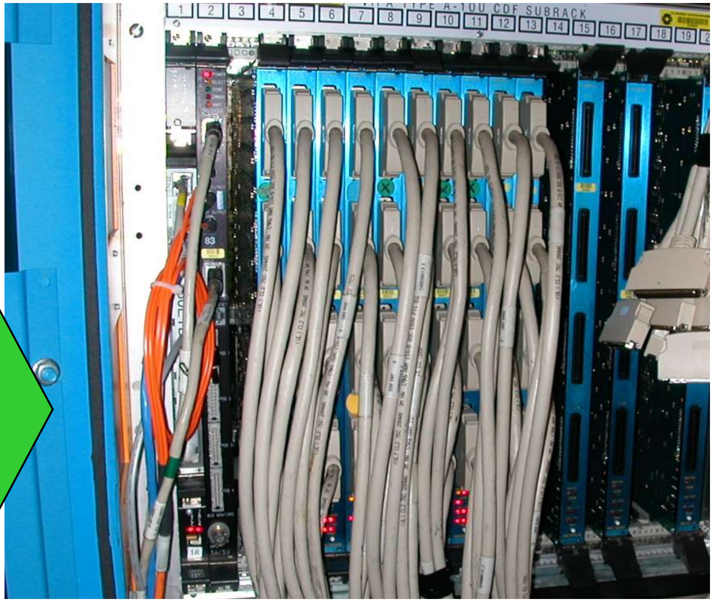
PLUG

http://hepr8.physics.tamu.edu/hep/emtiming/

EMTiming Project

~2000 Phototubes

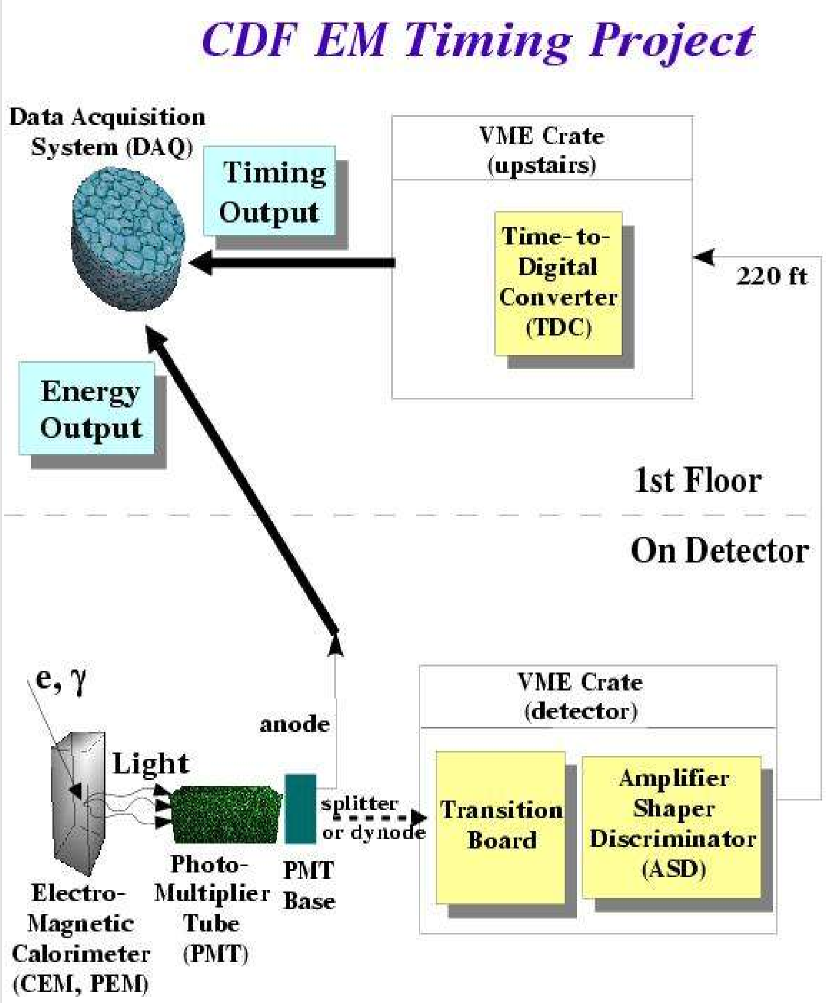
- Large system to add to existing (very large) detector
- Effectively put a TDC onto about 2000 phototubes at CDF
- International collaboration led by Texas A&M
  - INFN-Frascati*
  - Michigan*
  - Chicago*,**
  - Fermilab**
- ~$1M Run IIb project (parts and labor)
  - Project jointly funded by DOE and the INFN



Engineering support

** *Technician support*

Schematics



The calorimeter at CDF has two parts:
CEM ($|\eta|<1$) and PEM($1<|\eta|<2$)
We instrumented both with Time readout

ASD channel combines 2 PMT lines
In CEM one tower -> one TDC channel
In PEM 2 towers -> one TDC channel
(15^0 Phi segmentation)
CEM: 480 channels PEM: 384

Combining channels is dictated by crate space restrictions, but on the bright side – if PMT line breaks:

- threshold x 2
- channel still fully efficient

System Specs

Needed fully efficient system for all useful photon energies (above 5 GeV)

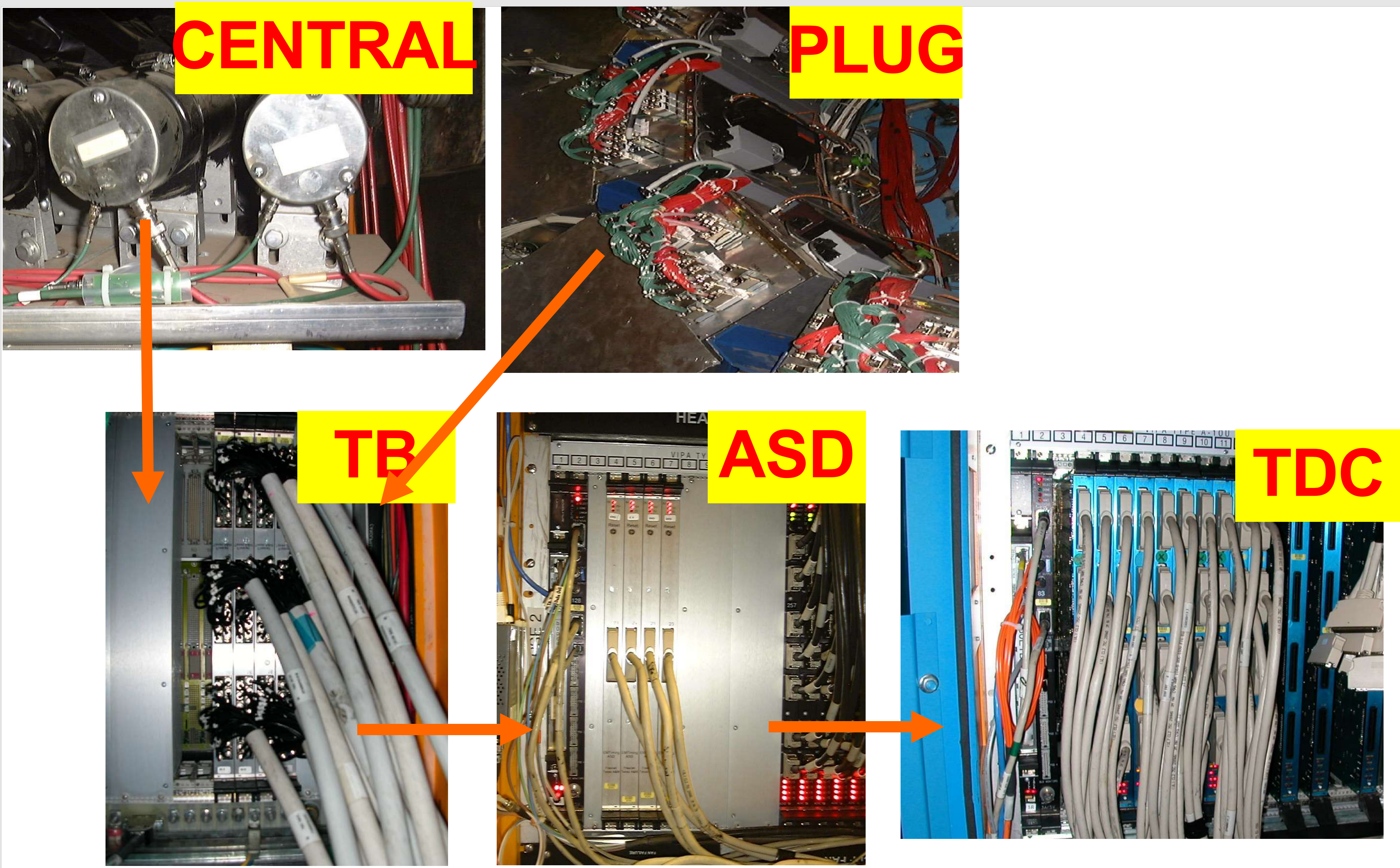
- Threshold should be as low as needed, but not lower in order to not trigger on noise

  photons normally above 20 GeV
- We wanted it low to be able to control missing energy

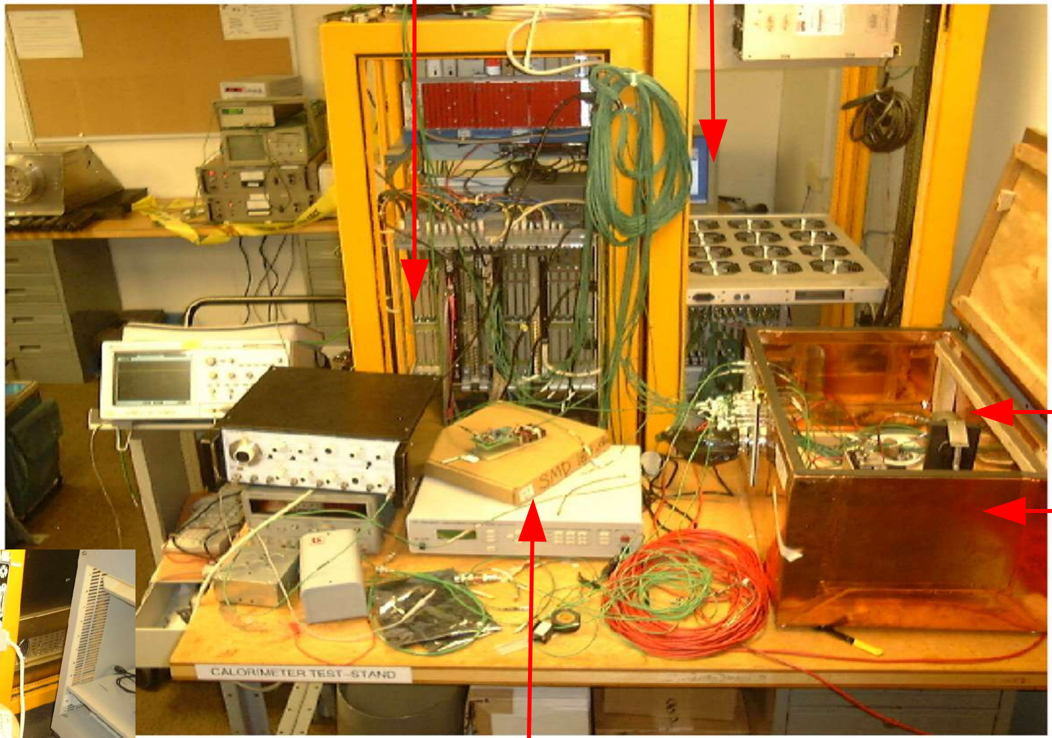
  for that we need the threshold as low as possible
- TDC bins information in 1 ns buckets

  the resolution lower limit is 0.28 ns

System in Pictures



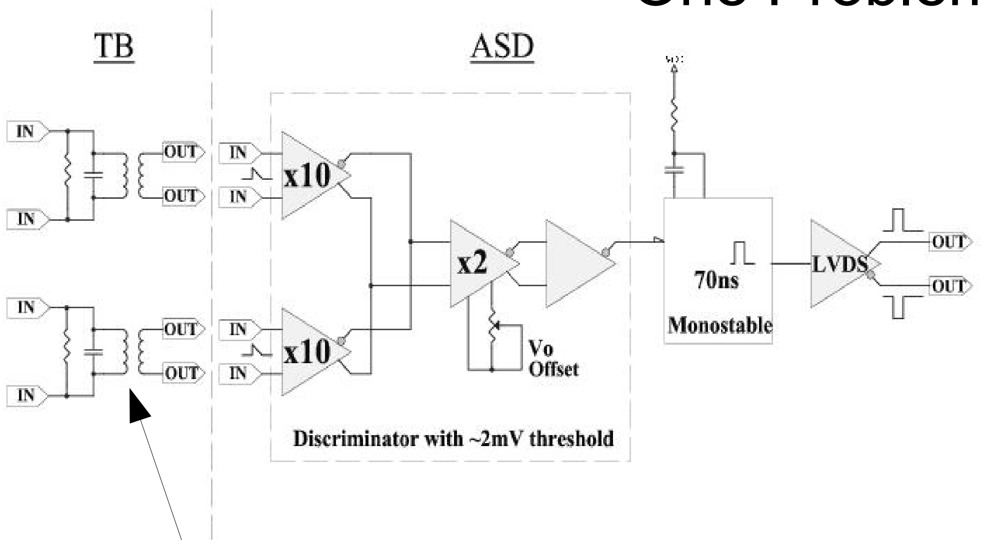
Test Stand



Tested by S. Chappa

Signal Path

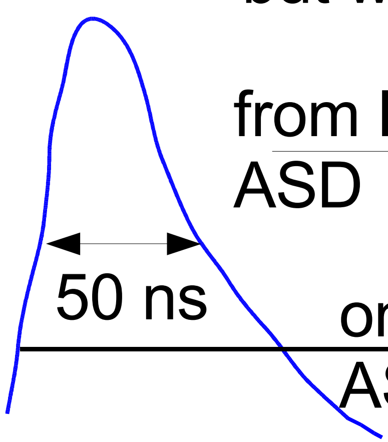
One Problem: CEM PMTs have only anods



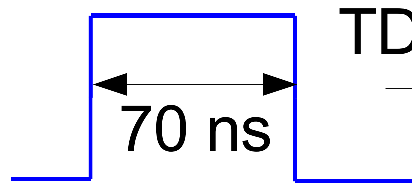
220 ft

TDC

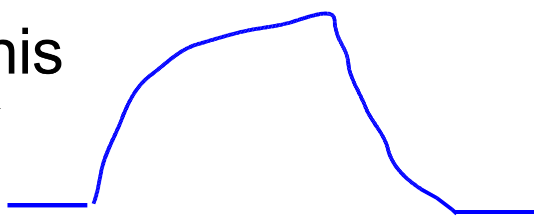
cuts noise,
but watch for reflections



from PMT to
ASD

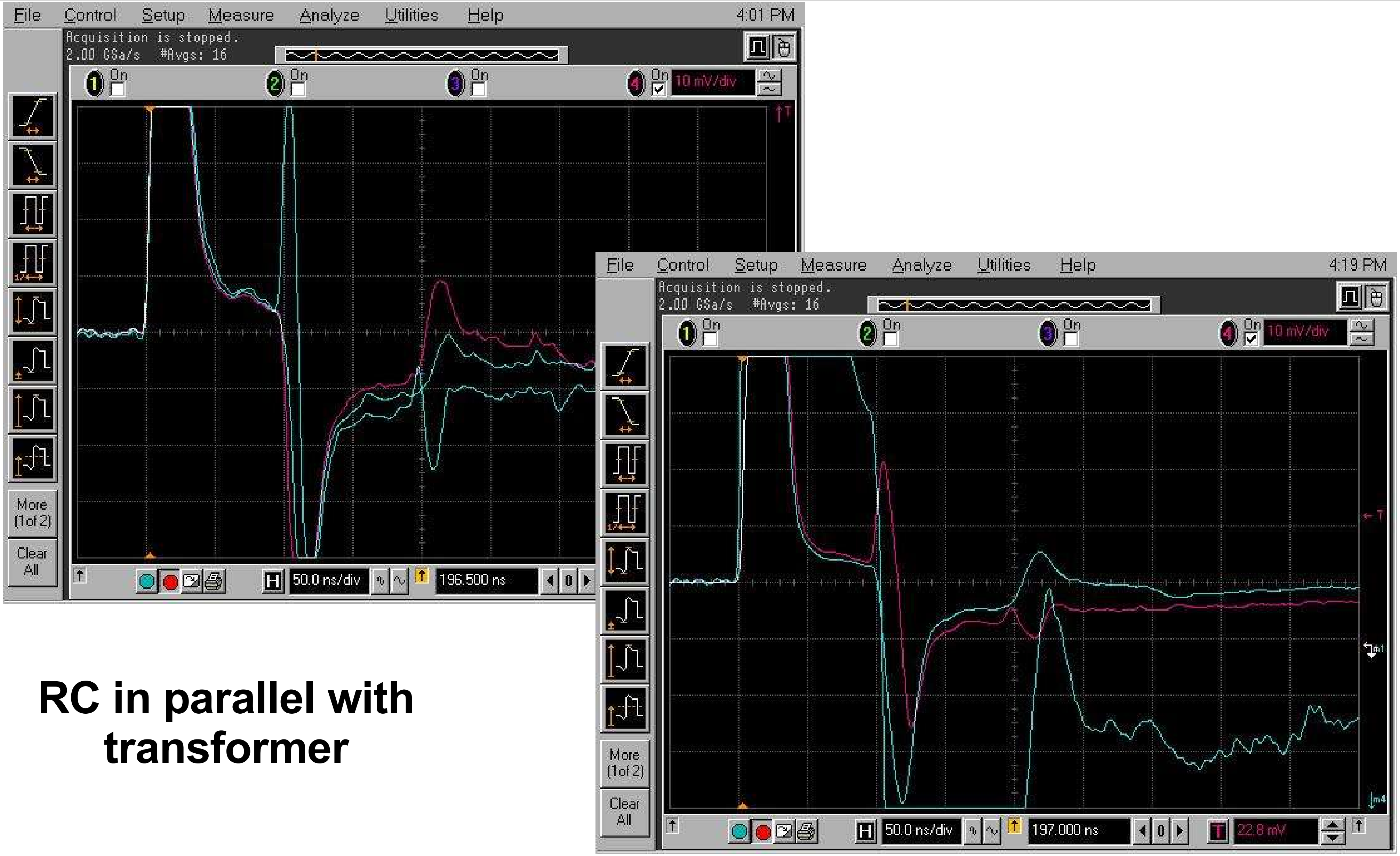


TDC sees this



once above ASD threshold
ASD sends LVDS to TDC

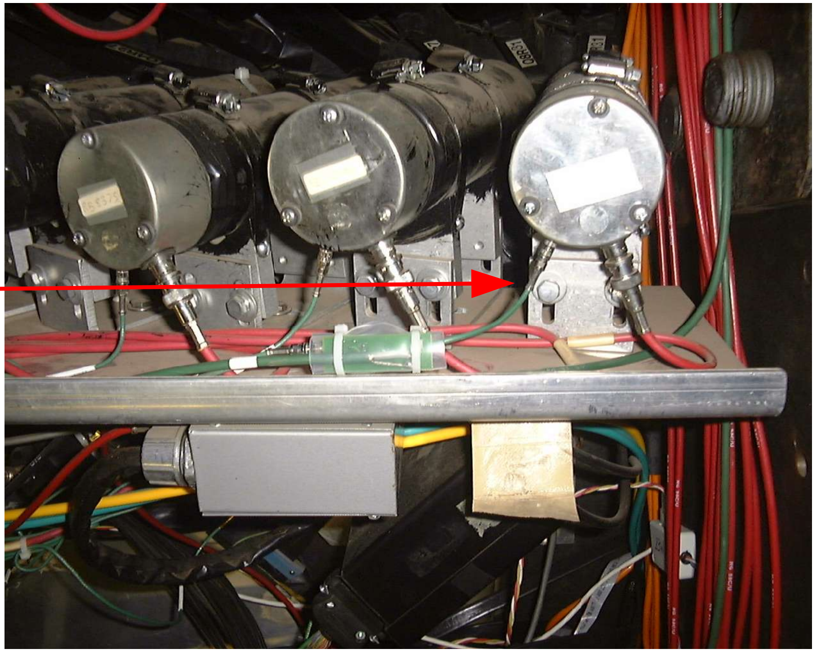
Fighting Reflections

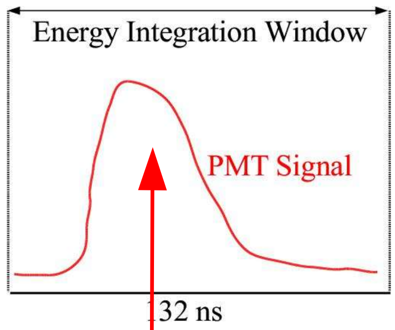


RC in parallel with transformer

Splitting the Signal

SOLUTION
anode provides energy readout
has no dynode readout ...
modify PMT base? ...
cut into the anode line? ...

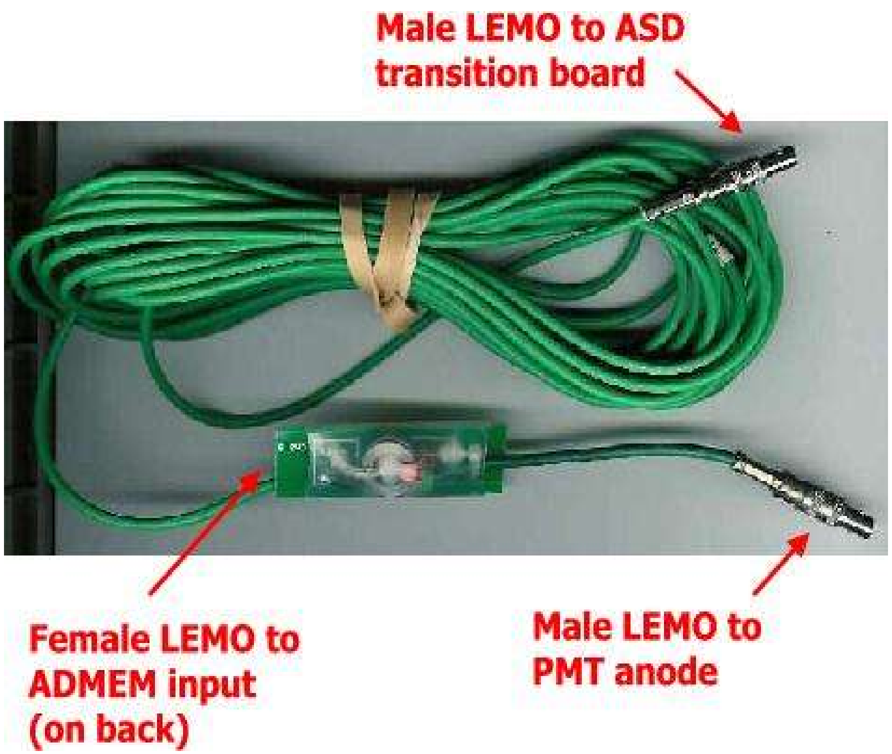


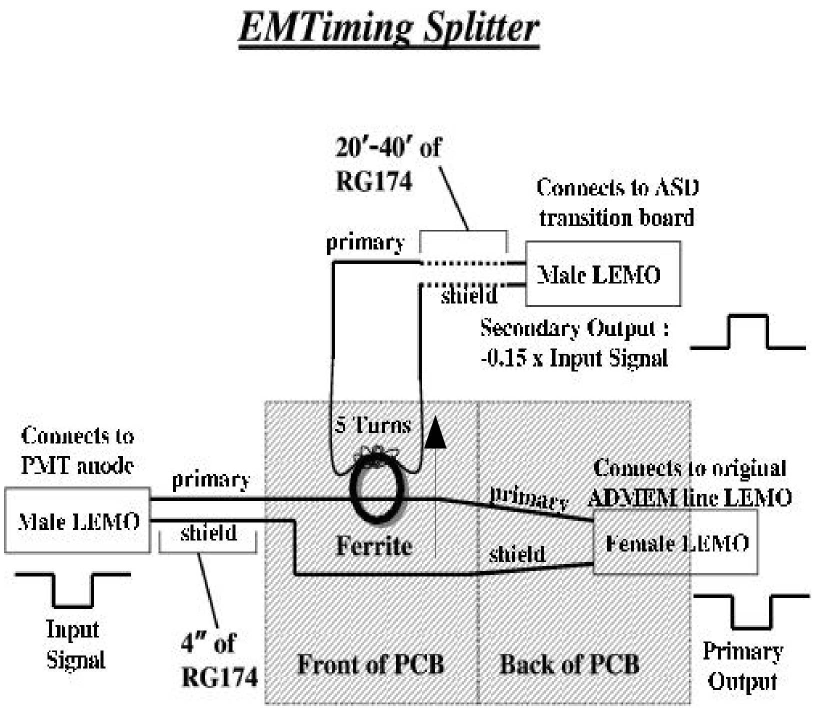


CAN DO NOT CHANGE
ENERGY READOUT,
OTHERWISE...

Splitting the Signal

Do not touch charge – do not change energy readout.

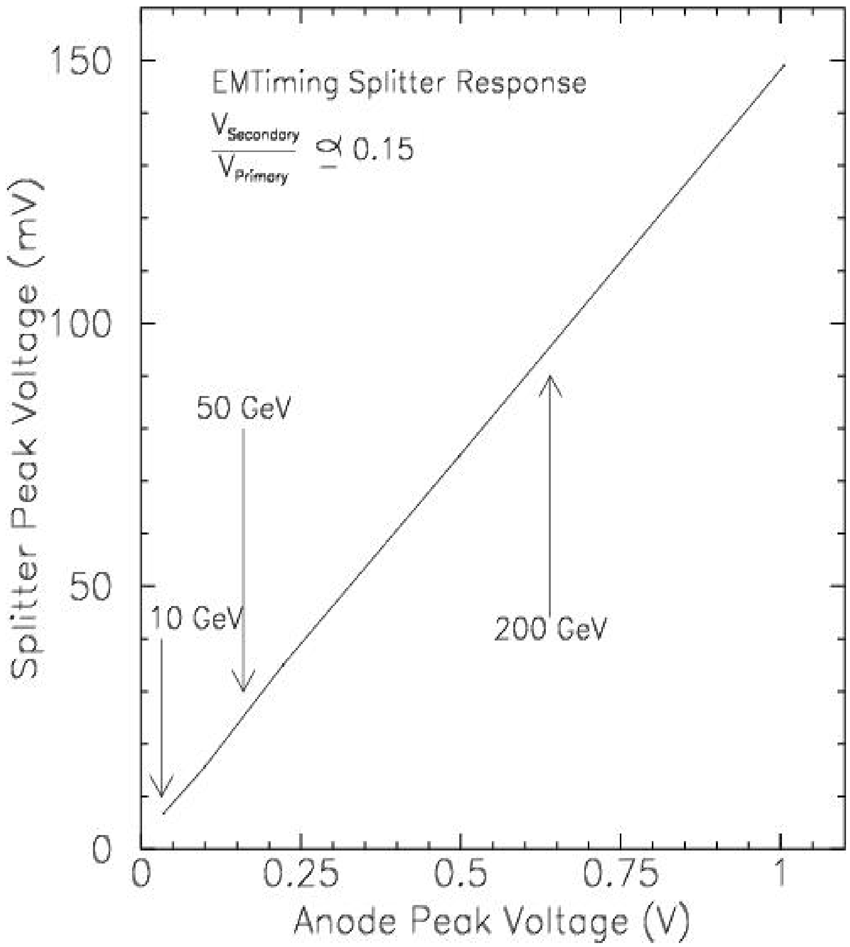


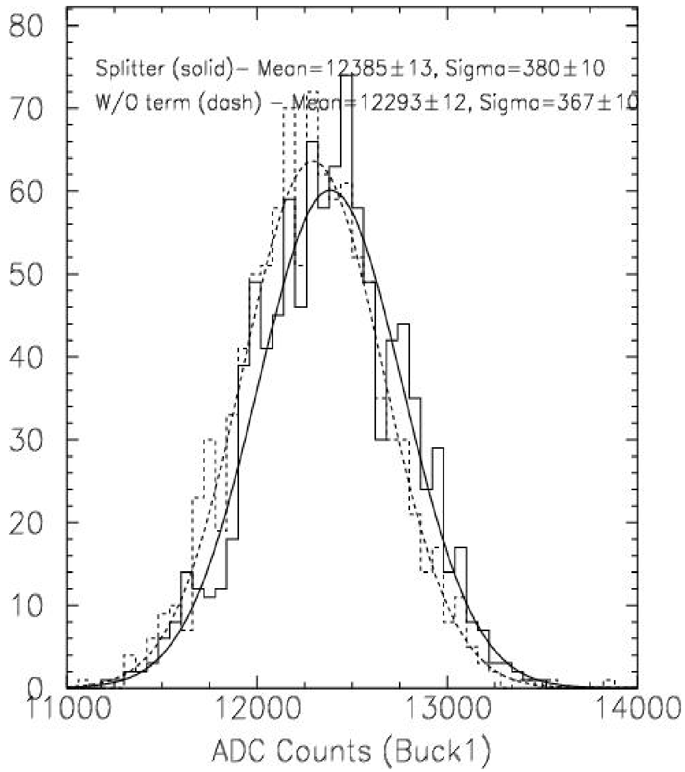


Idea, design, and production - University of Chicago (H. Frisch and H. Sanders)

Splitting the Signal

Signal transition coefficient ~0.15





- Linear in all reasonable energy range
- No change in PMT signal shape
- No change in pedestals
- No Change in E/P for electrons

Installation

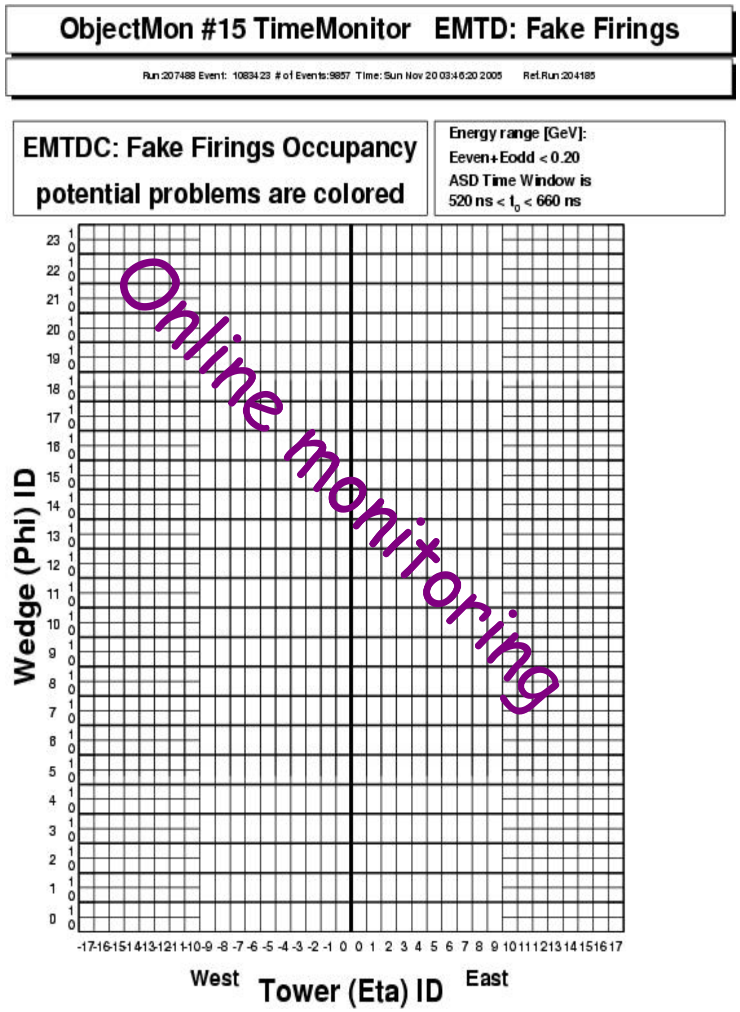
- ~100% Efficient above thresholds (CEM-5, PEM-2.5 GeV)
- System resolution is ~0.6 ns
- Very uniform
- No Noise
- Finished full installation this October (2 years ahead of original Run IIb schedule). Started taking data in January 2005 (1.4 fb^{-1} and counting)
  - <1% had problems right after installation (most are channel 6 and 9 mixes)
  - Lost only ~1 week of data to weed out all problems
  - Since then we do not have a single high P_T event without timing information

M. Goncharov, D. Toback *et al*, submitted to NIM in 2005

Noise – What is It?

Noise – no energy, but there is a TDC hit.

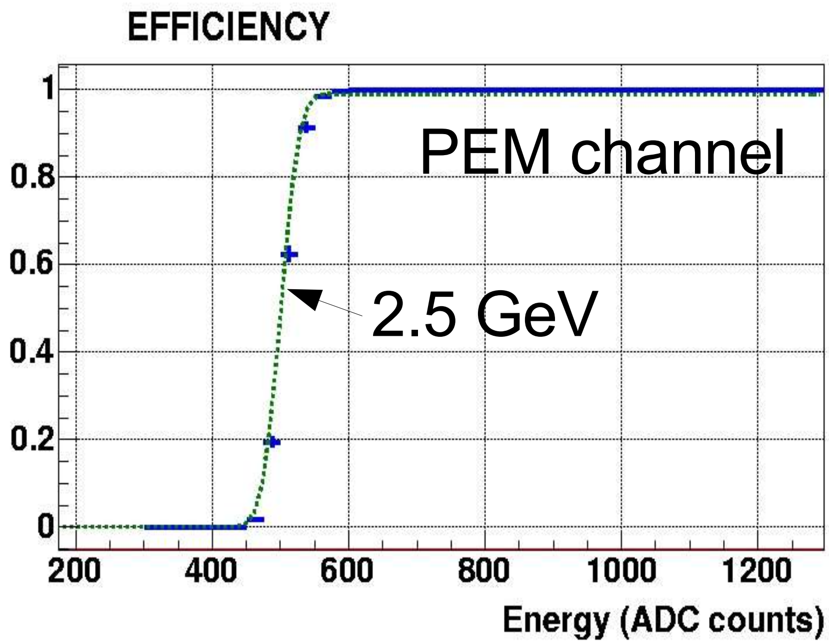
Looked at >10 M events, have yet to see a TDC hit from noise.

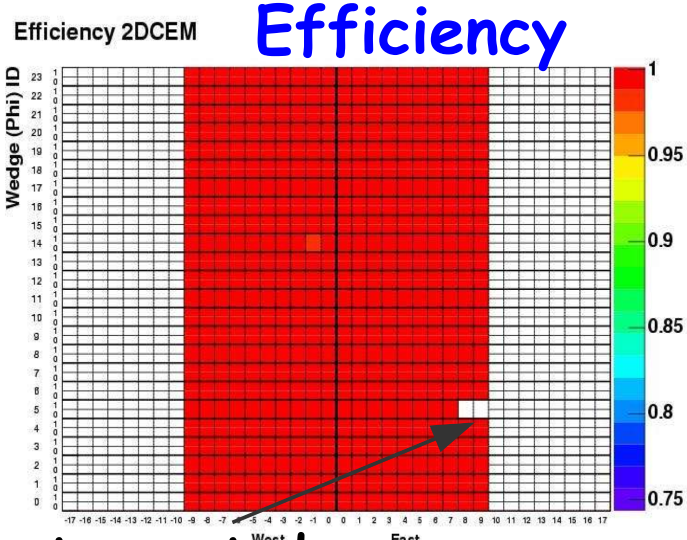


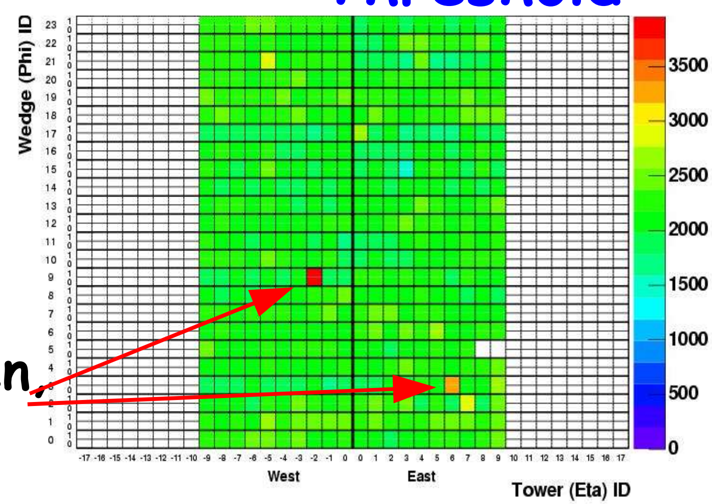
System Performance

No Data can be left behind – monitor online in real time

Efficiency curves show most problems right away



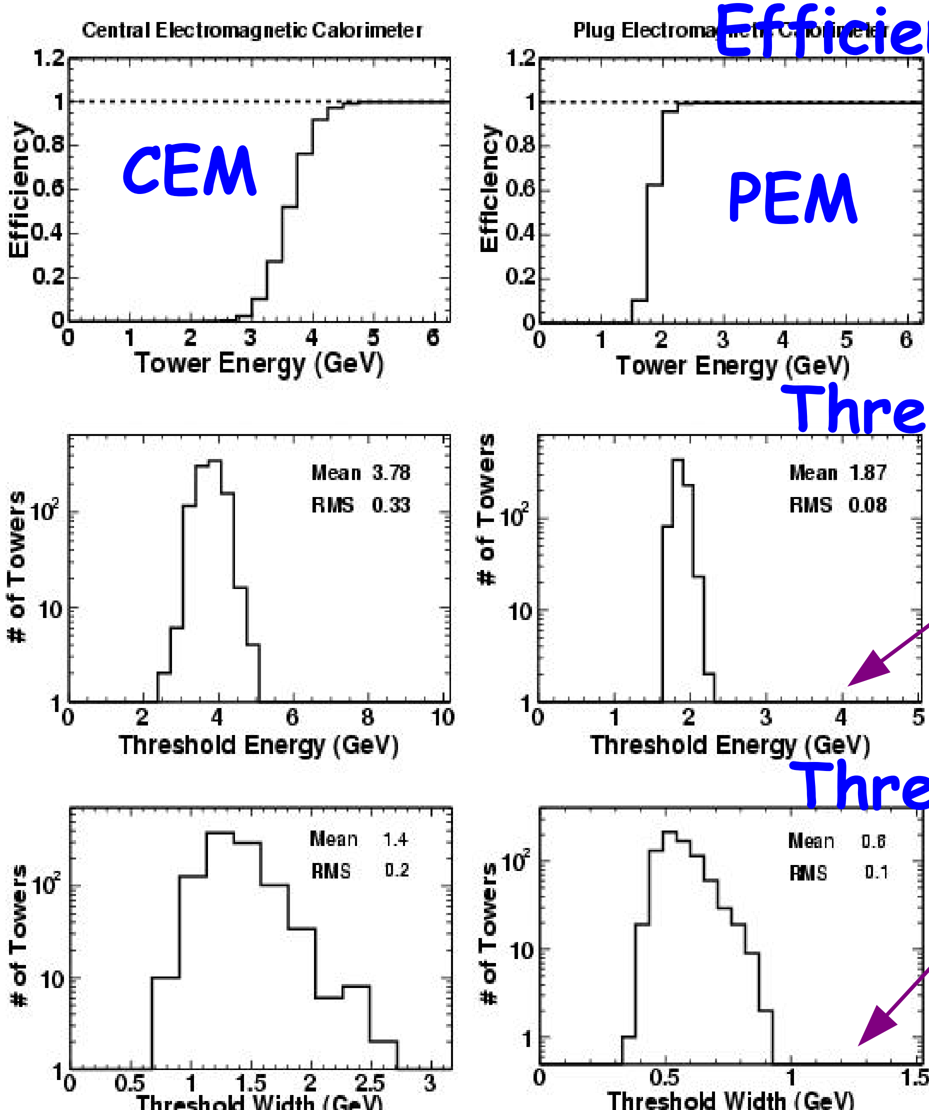




One line is broken, fixed right away

System Performance

No Data can be left behind – monitor online in real time



Efficiency

100 % above threshold

Threshold Energy

Uniform

Broken channel would be here

Threshold Width

... and here

Messaging the System

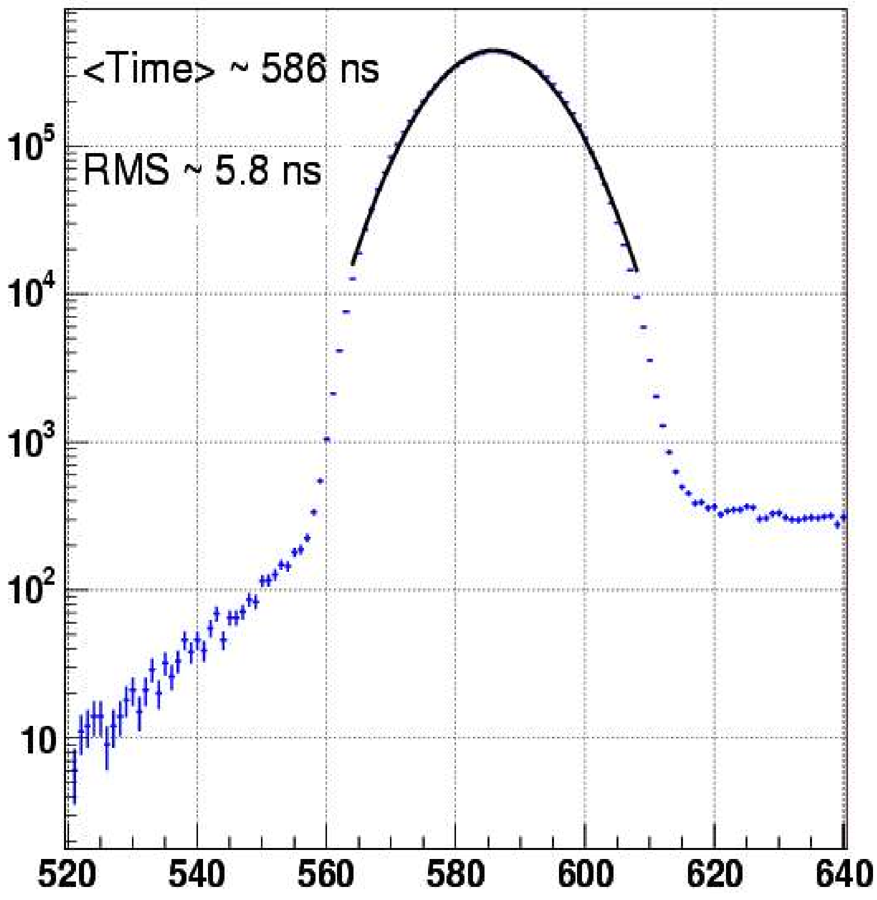
Can not use in the analysis data as it is

=> have to calibrate

Calibrations take out various effects

- channel to channel variations
- energy dependence (slewing)
- time variations

CEM

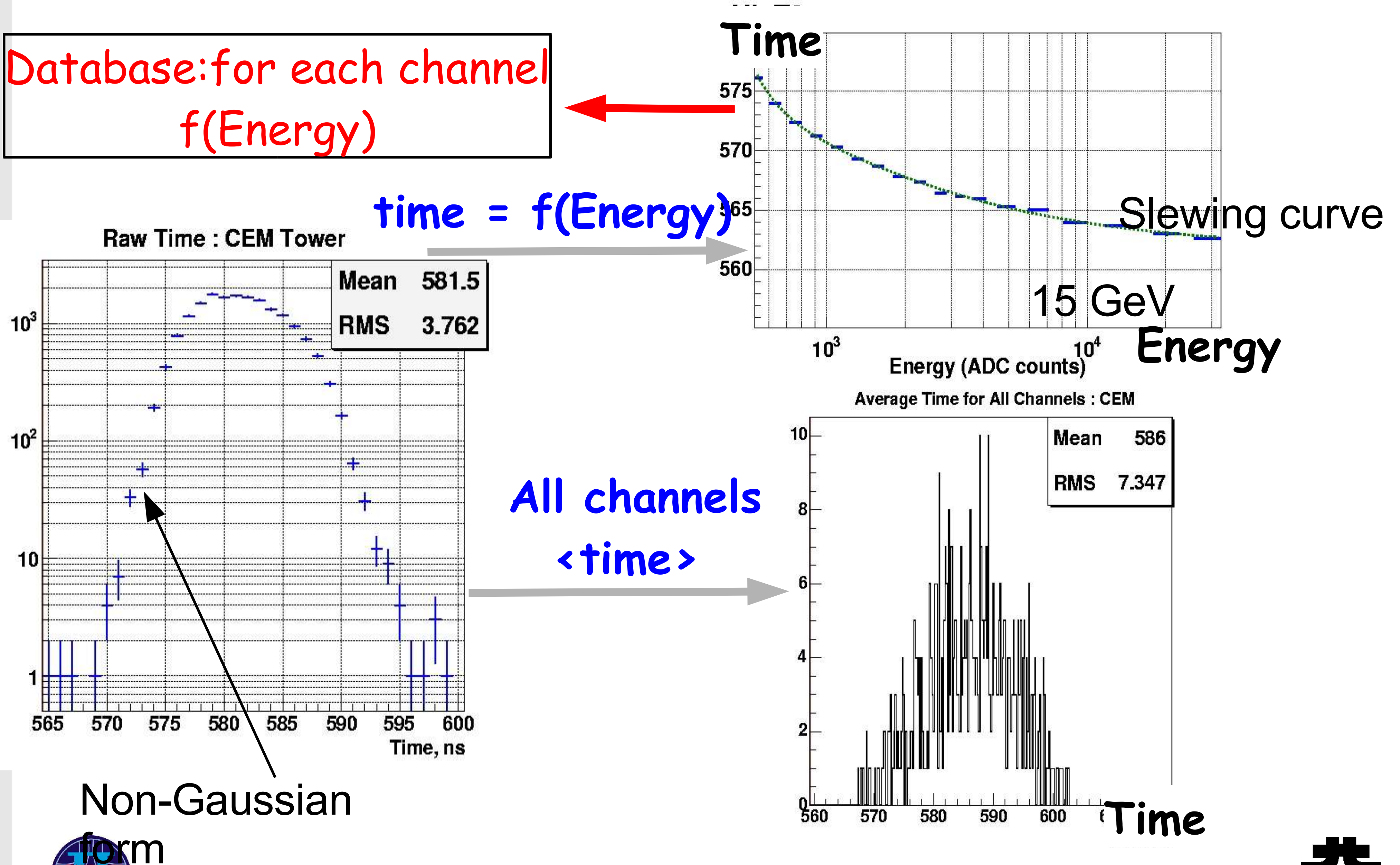


Time, ns

Calibrations

Database:for each channel f(Energy)

time = f(Energy)



All channels <time>

Energy Choice

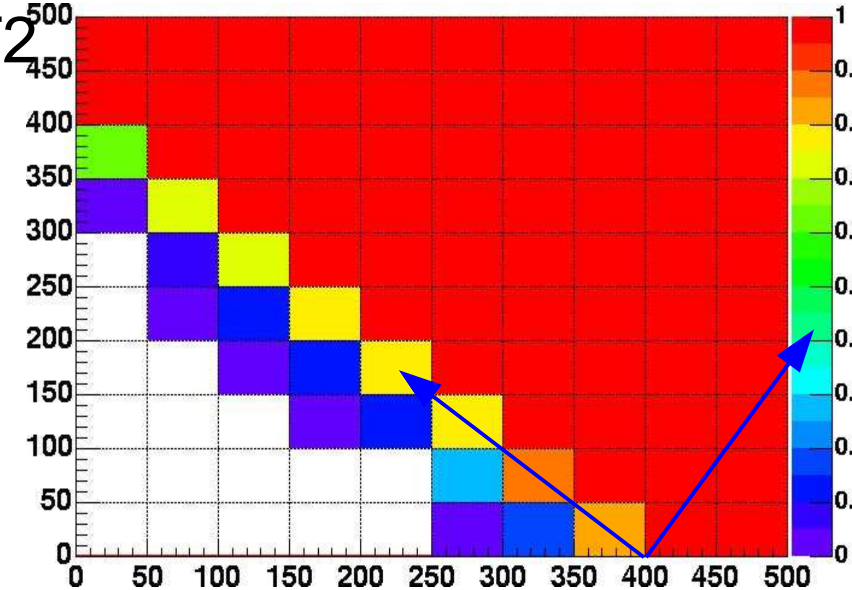
What to use for Calibrations
E = sqrt(PMT1*PMT2) ?

We use
• (PMT1-PMT2)/(PMT1+PMT2)
• PMT1+PMT2

makes CEM and PEM alike

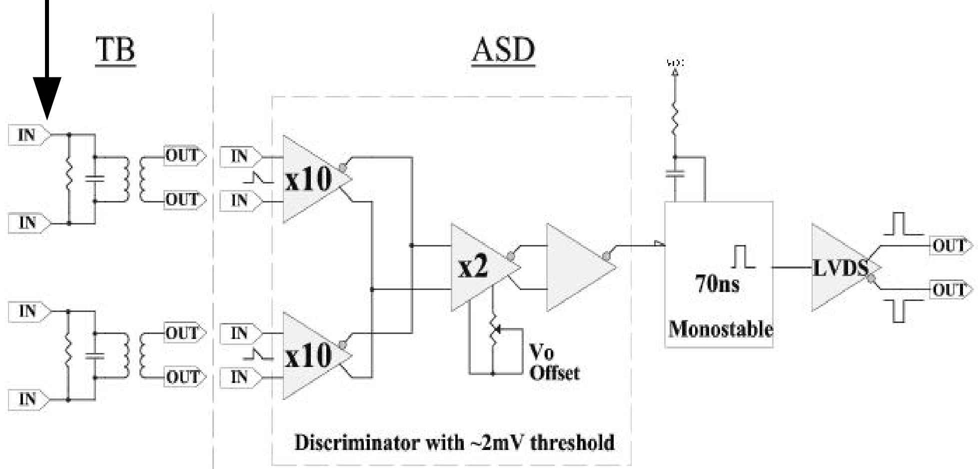
Threshold

PMT2



PMT1

All good ideas come late
Should have used



hardware sums PMT signals

Resolution

After slewing calibrations various effects remain:

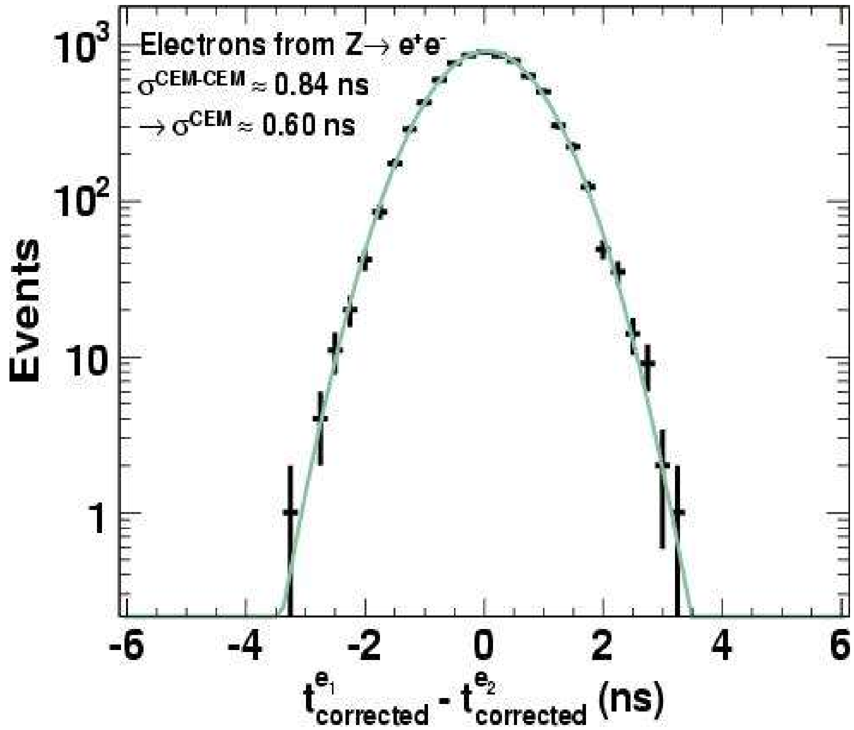
- when collision happens
- where it happens
- run by run dependence ...

Z->ee sample is perfect to find the resolution
Plot time(e1)-time(e2):
most of the external contributions cancel out

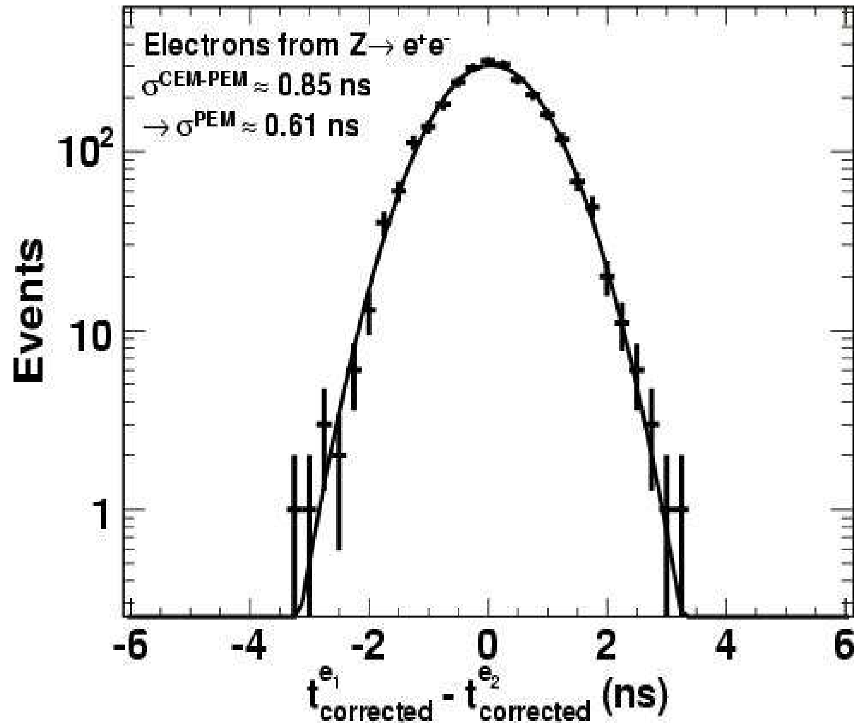
W->eν sample is good to check for tails

Resolution

CEM – 0.60 ns

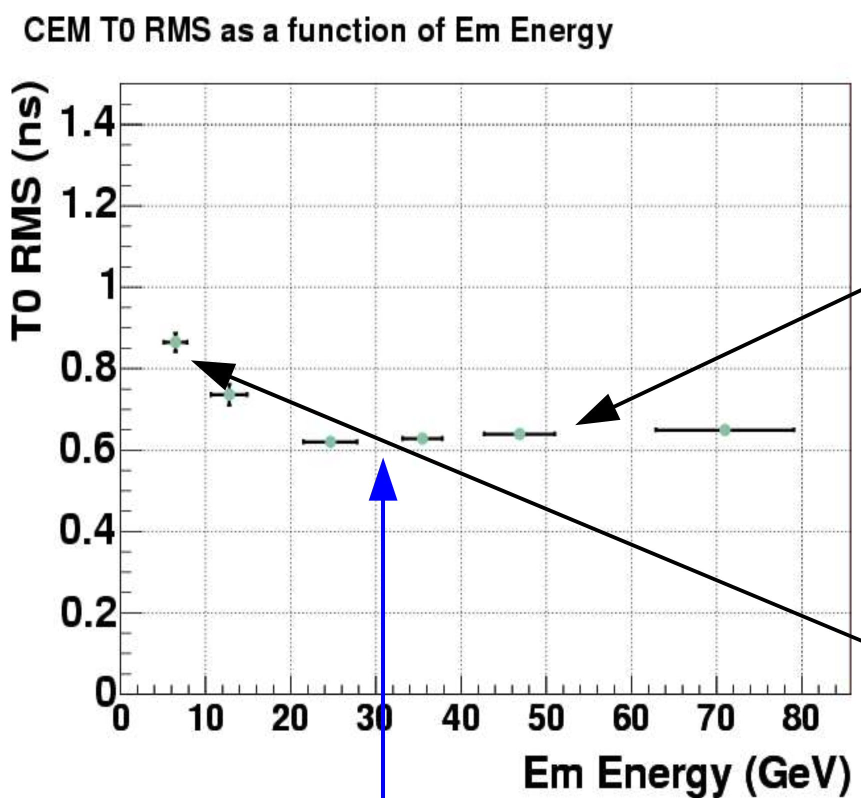


PEM – 0.61 ns

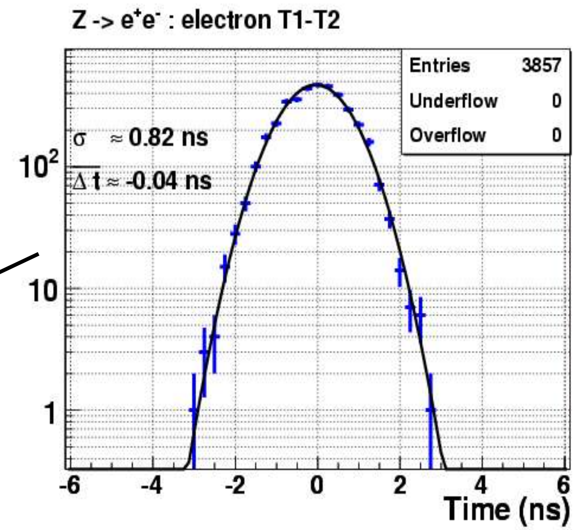


- Centered at zero, symmetric
- No non-Gaussian tails
- CEM and PEM are the same

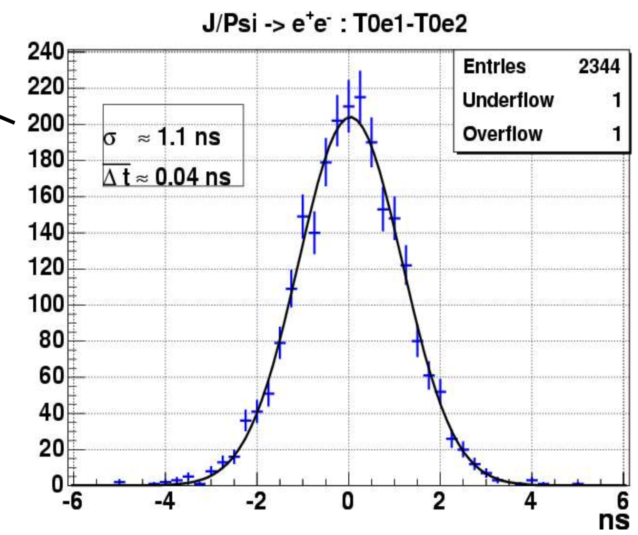
Resolution vs Energy



flat where it matters



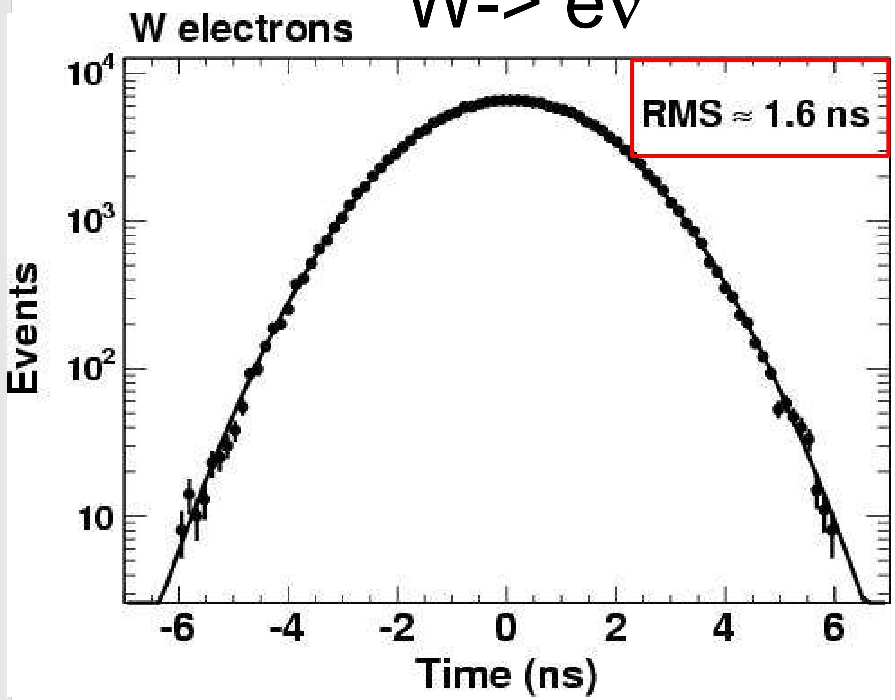
Z->ee



J/Psi->ee

Resolution, Tails

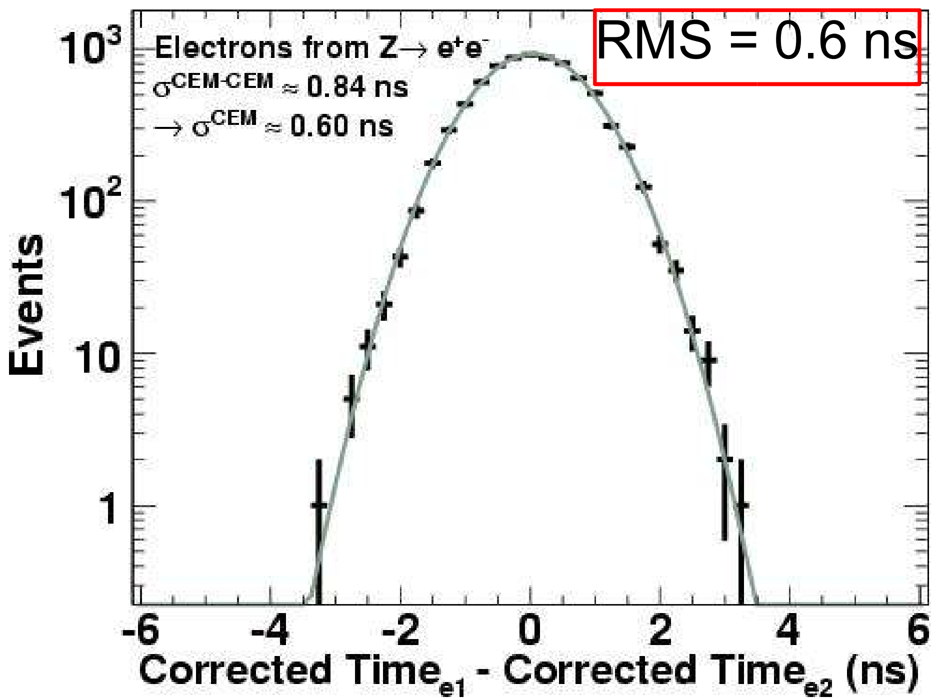
W-> eν



- Gaussian with no tails
- Symmetric around 0

This is how one normally measures true system resolution:

Z-> ee



WHEN interaction happens - must have RMS≈1.3 ns
It has to be subtracted from the photon time

Next Step ...

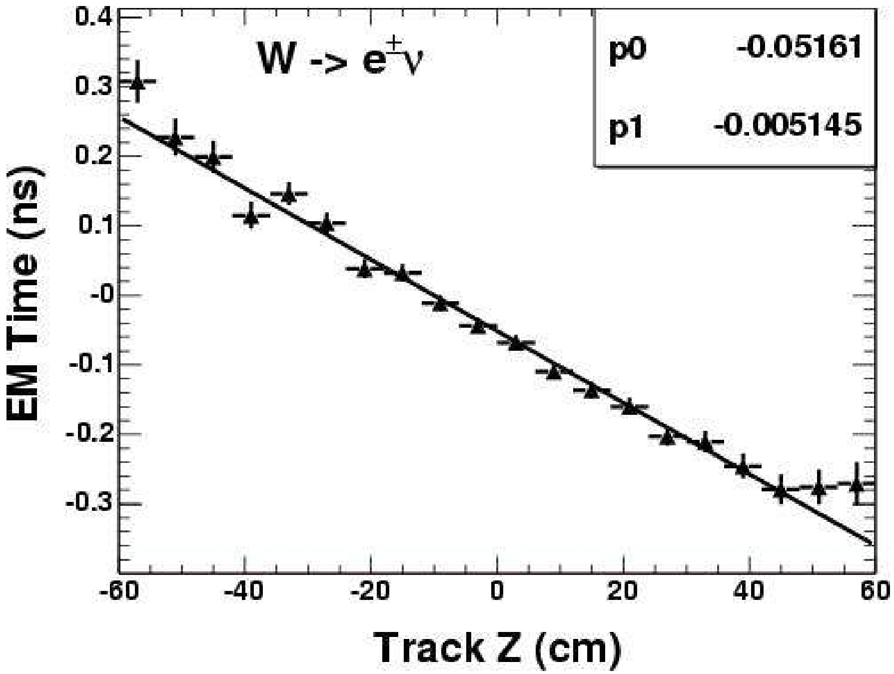
Ok, we have built the system and calibrated it

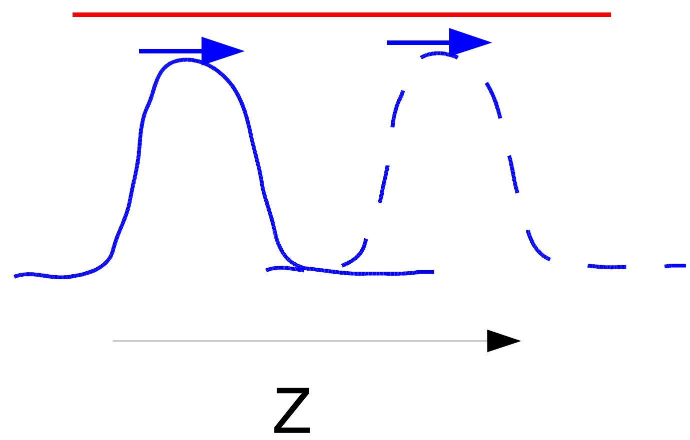
Gaussian Resolution - 0.6 ns
- No noise
- 100% efficient
- No non-Gaussian tails

Next I will show you how we
- measure beam width
- look at beam halo in CDF detector
- understand effects of hight Luminosity on photons
- **new type of physics**

Beam Width

p and p-bar bunches have different width =>
collision time is correlated with the collision location





Average z position of the interaction is given by

$Z = \exp(-(z-ct)^2/s^2(p))*\exp(-(z-ct)^2/s^2(pbar))$

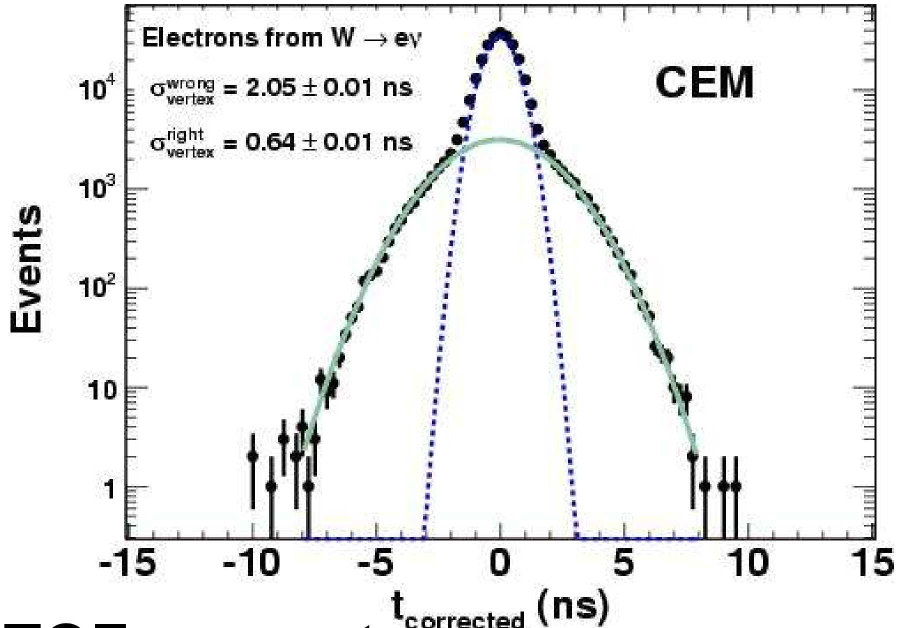
$s(p) = 55$ cm

$s(pbar) = 65$ cm

High Luminosity

Assigning the right vertex is a tricky business as L is high
We can measure how often mistake is made

Event T_0 1.28 ns
Vertex RMS 0.2 ns
TOF 0.4 ns
Run-by-Run 0.4 ns
EMTiming 0.6 ns



W electrons 1.6 ns :

- Right Vertex: Event T_0 and TOF - correct
- Wrong Vertex: Event T_0 and TOF - incorrect

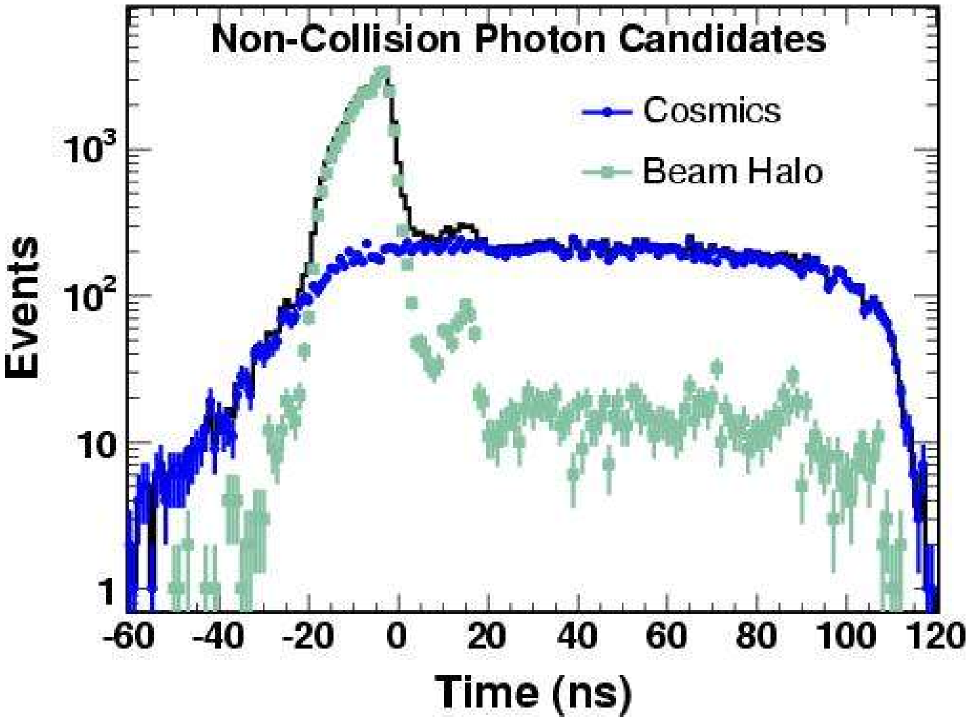
Right Vertex - RMS=0.64 ns
Wrong Vertex - RMS=2.05 ns

Photon Backgrounds

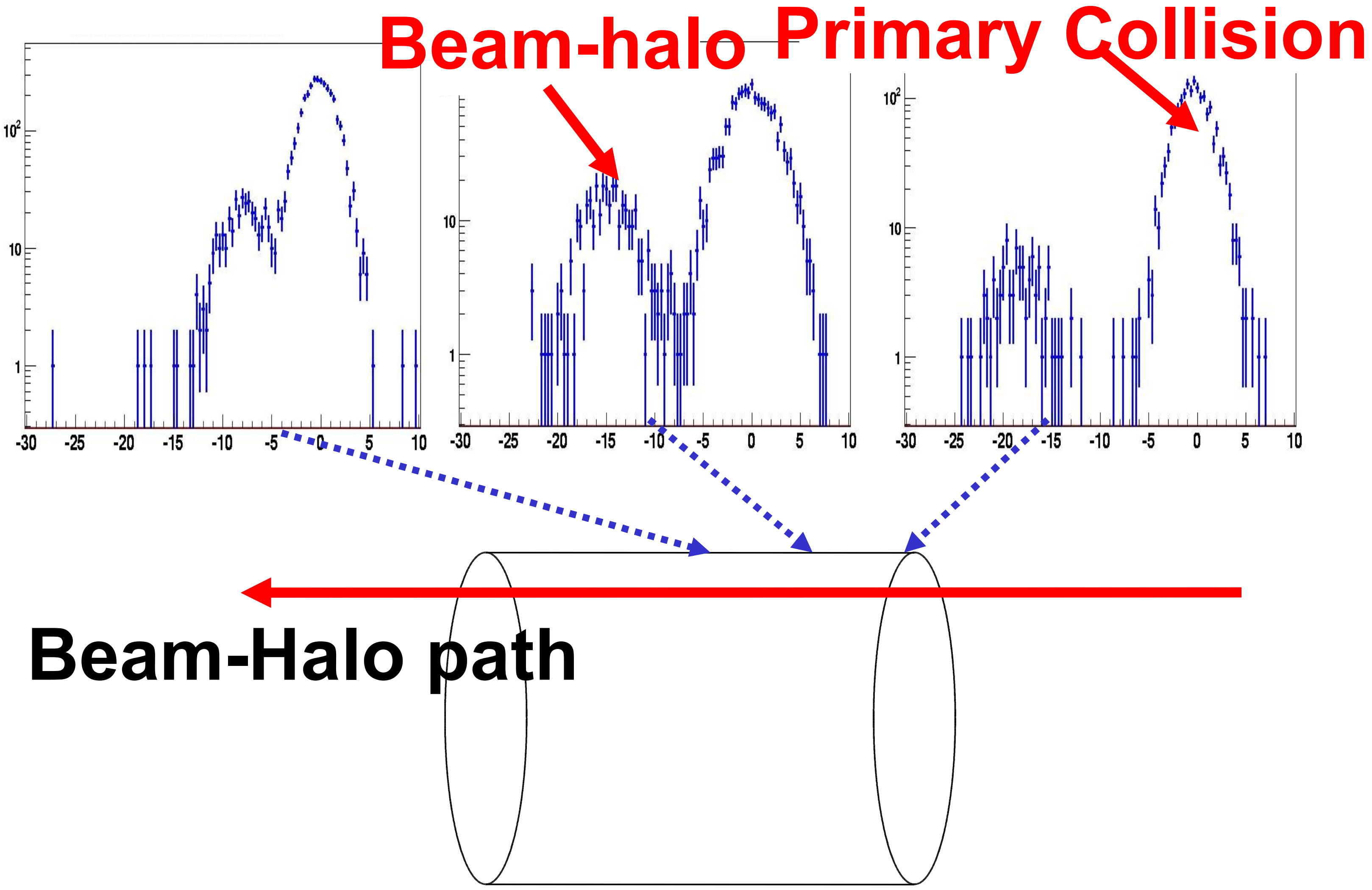
To study non-collision backgrounds:

- select Photon+MET events
- apply cut **tracks ΣP_T < 1 GeV**
- plot their timing distribution

We study non-collision photons and learn how to get rid of them

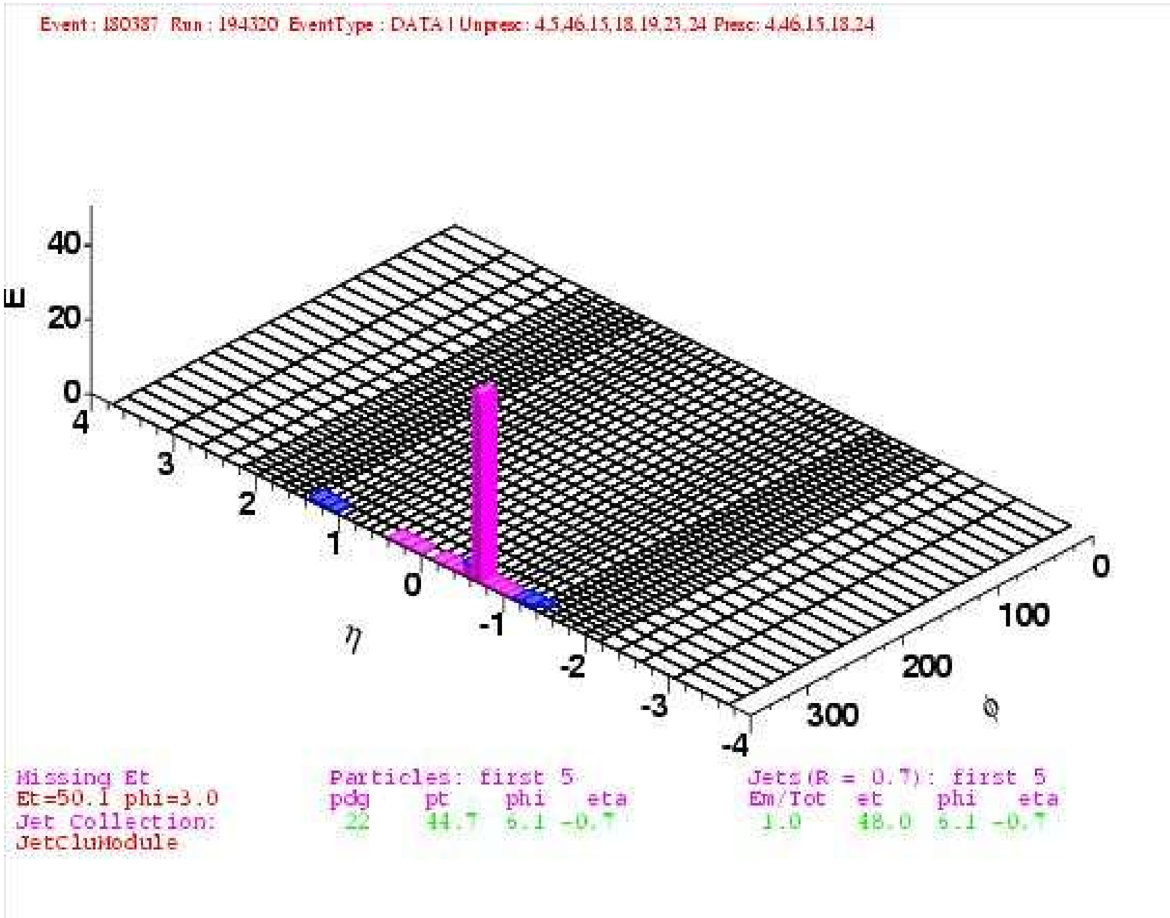


Beam Remnants

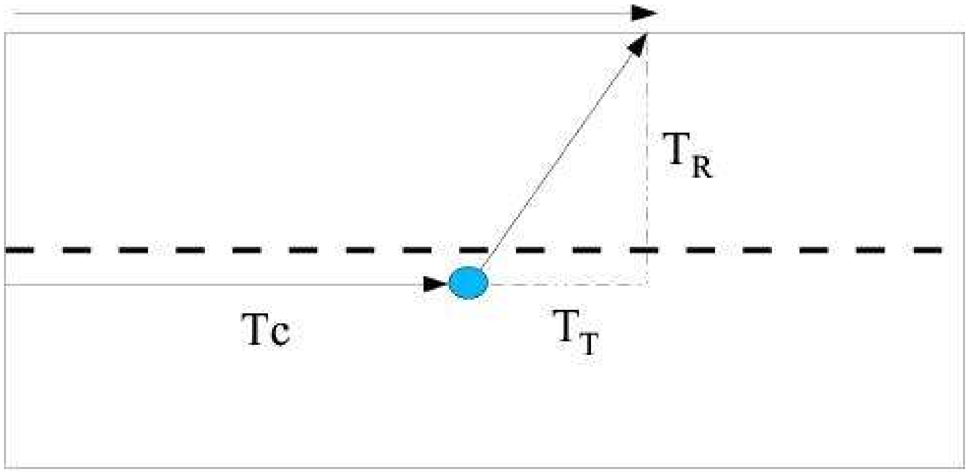


Measure speed of beam-halo to be $2*10^8$ m/s

Beam Remnants

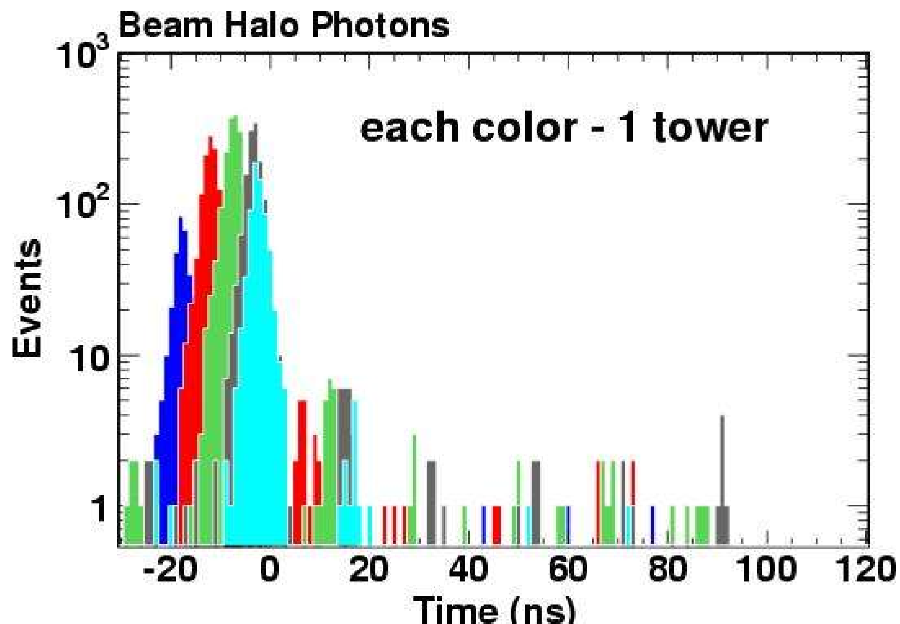


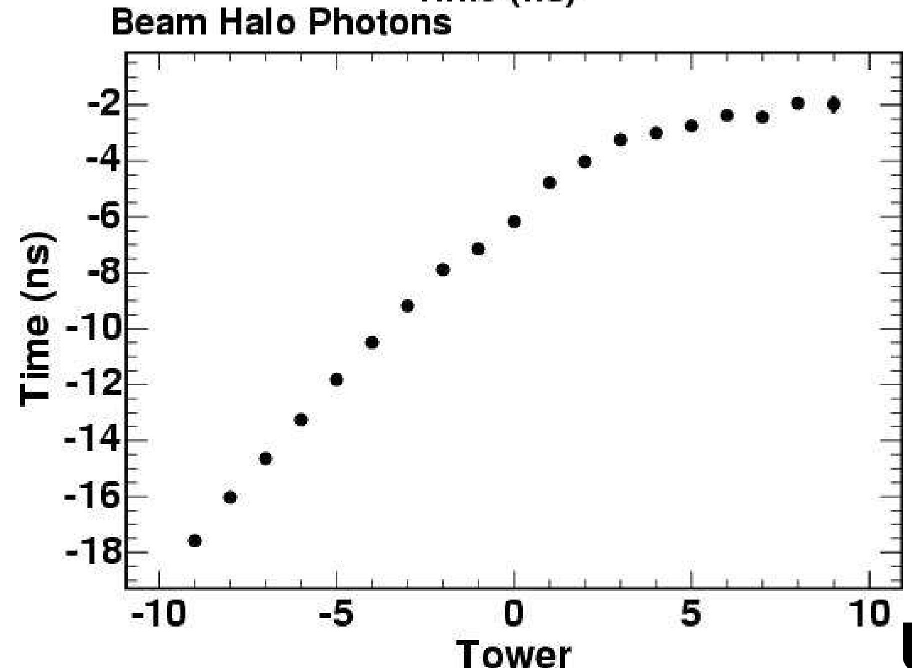
Beam Remnants



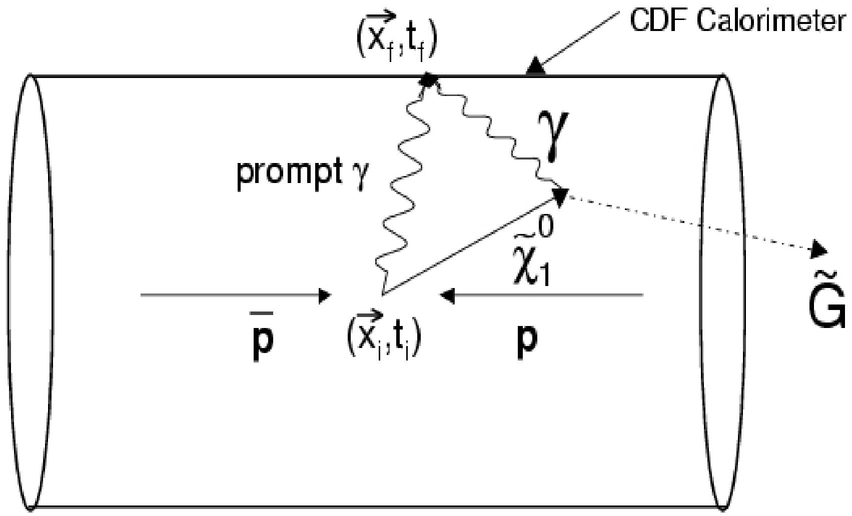
$$t(collision) = T_C + \sqrt{(T_T^2 + T_R^2)}$$
$$t(halo) = T_C + T_T$$
$$\delta t = T_T - \sqrt{(T_T^2 + T_R^2)}$$

$$Tower\,-9 : \delta t \approx -2T_T$$
$$Center : \delta t \approx -T_R + T_T$$
$$Tower\,9 : \delta t \approx -\frac{T_R^2}{2T_T}$$



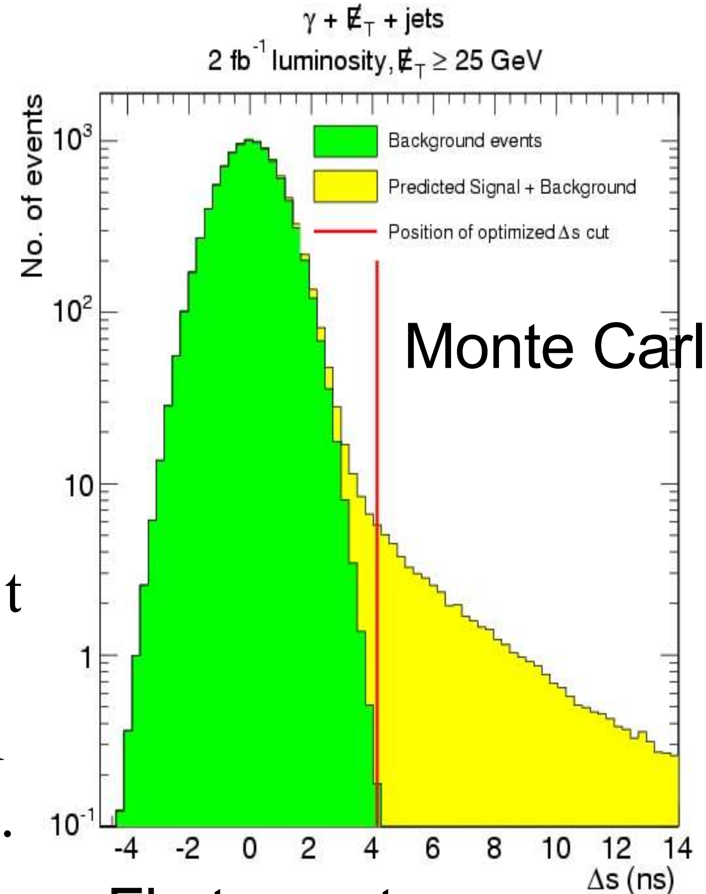


New Type of Physics



Look for non-prompt γ's that take longer t reach calorimeter.

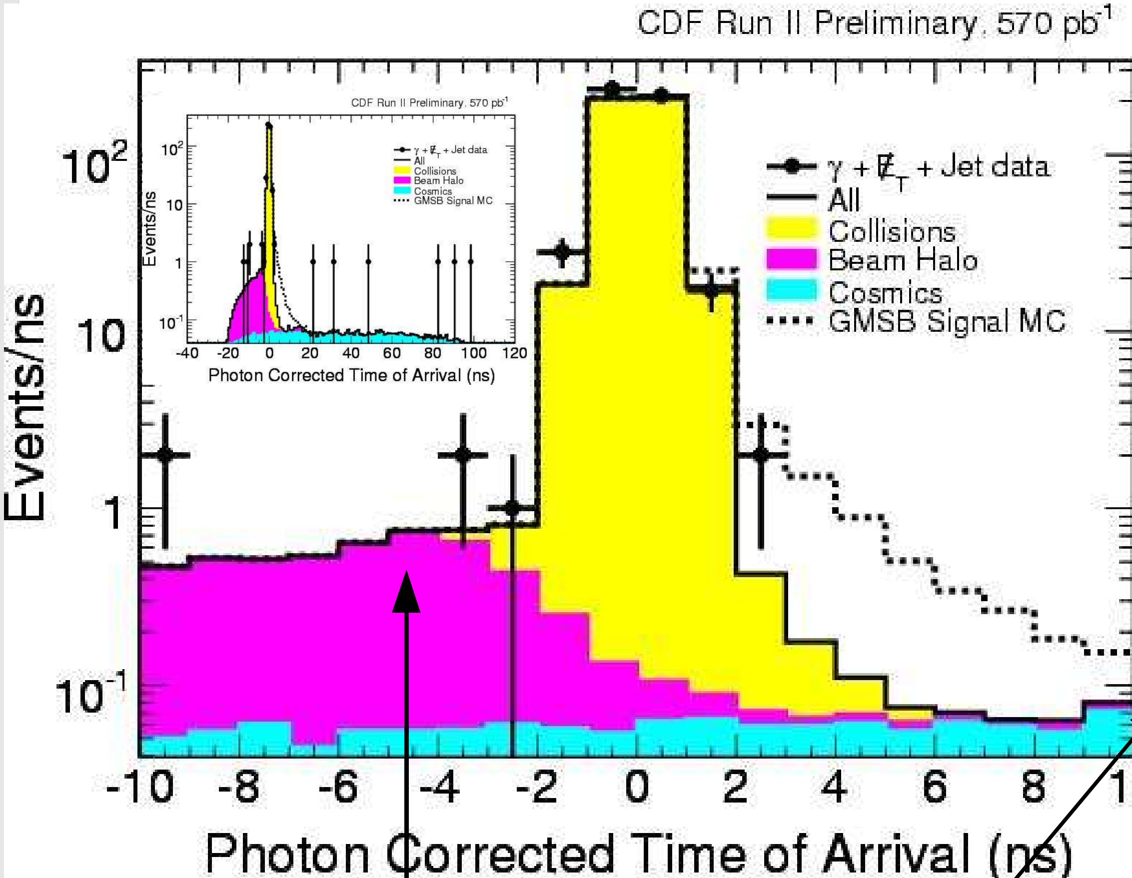
If the c has a significant lifetime, we can separate the signal from the backgrounds.

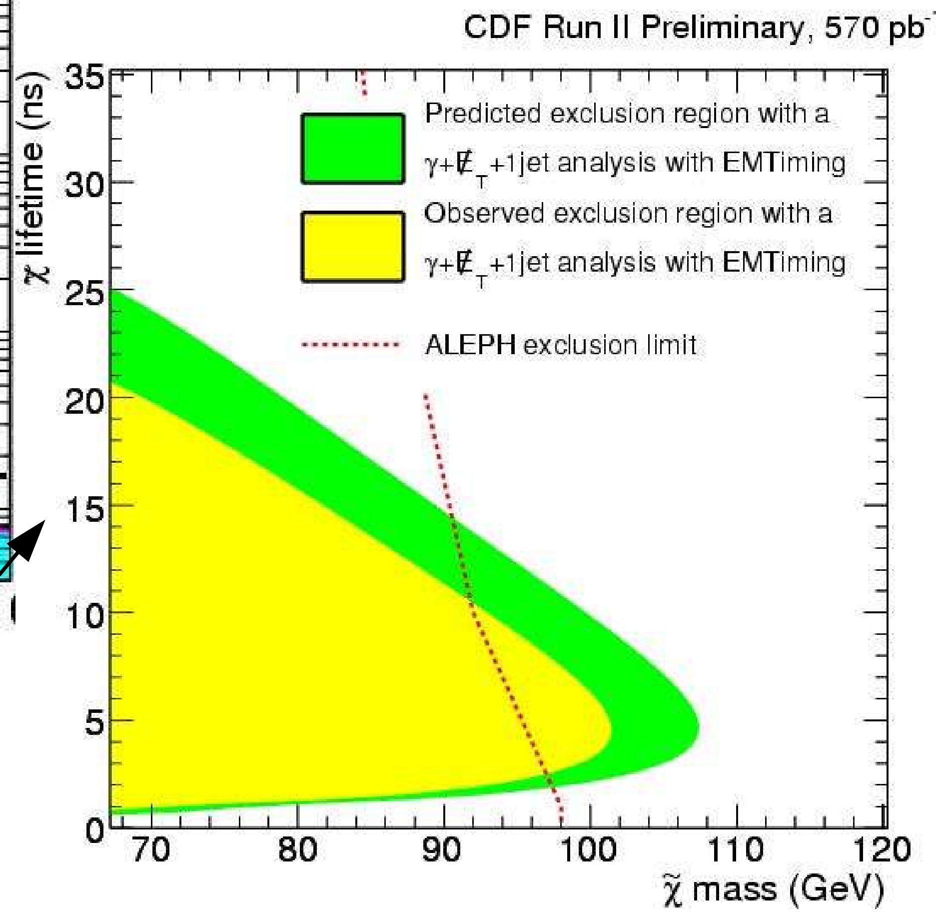


Monte Carlo

First count
Shape later

Delayed Photons





Use shapes, normalize to events

What is Next

We are still coming up with new uses of timing info

- MET model
- Highly Displaced Vertices
- ...

New era is coming – LHC ... ILC

New technologies are developed ...
U. of Chicago is developing picosecond resolution sys-tem

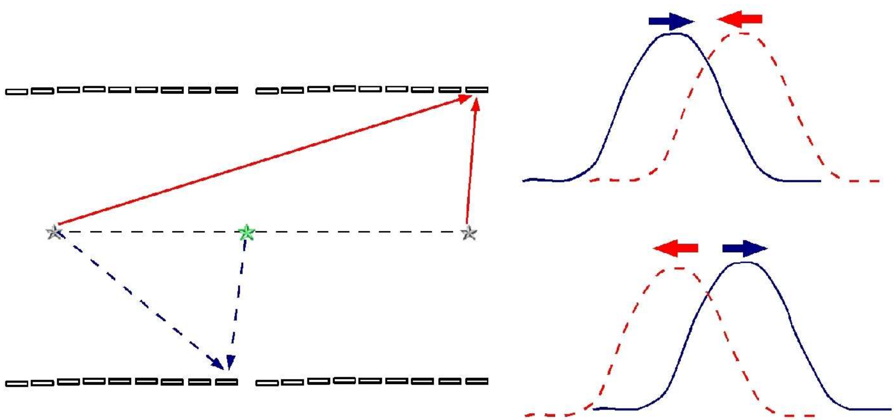
- next workshop is here, at Fermilab

Backup

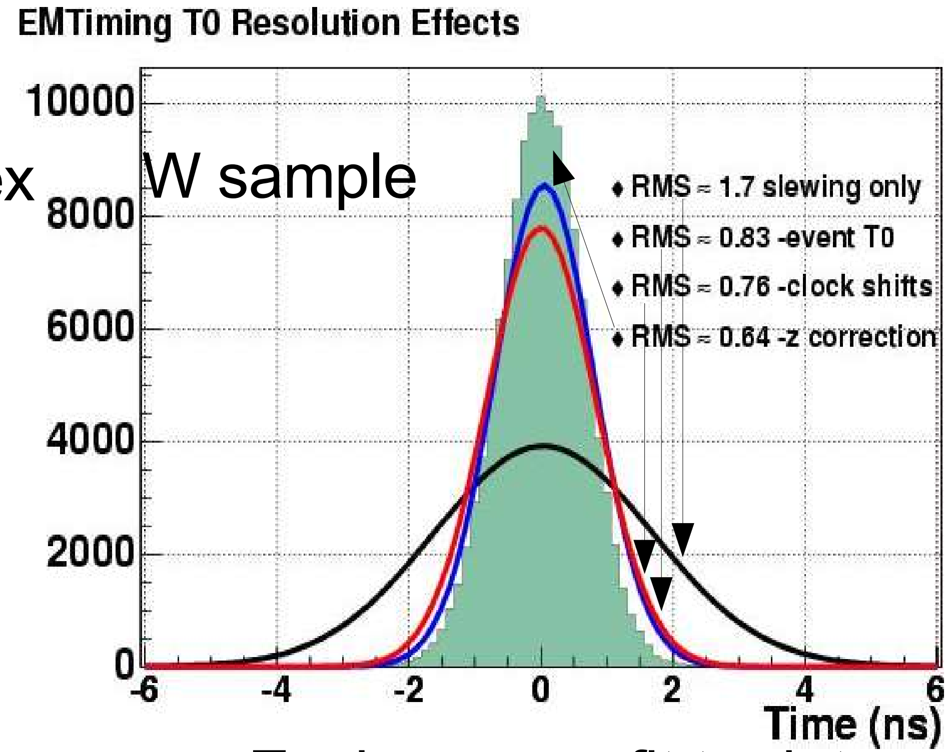
Resolution Effects

Calibrations and corrections:
- Energy slewing, applied at production level
- One calibration spans many runs --> need clock shifts
- Correct for Time of Flight (TOF)
- Event T0

TOF and Event T0 need vertex

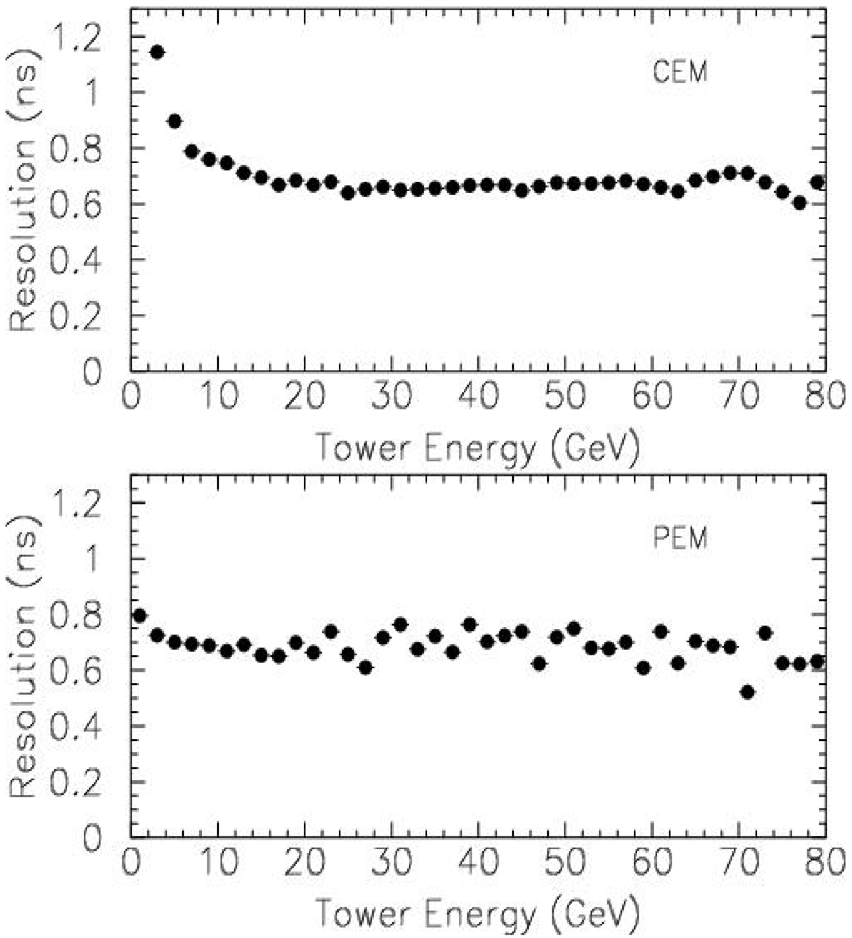


“Where” - Vertex

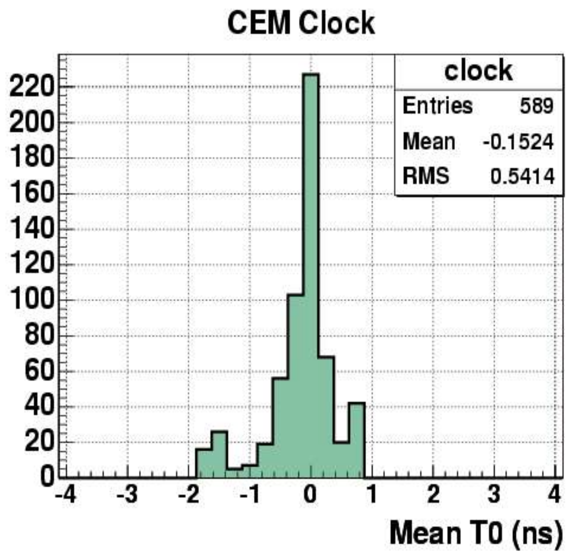


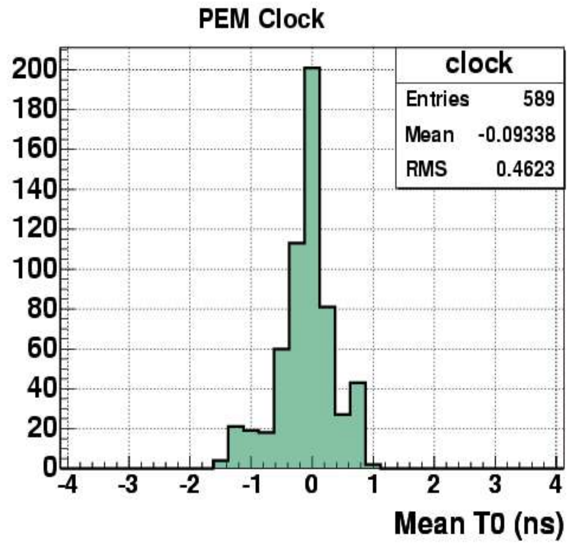
Each curve – fit to data

Resolution vs Energy

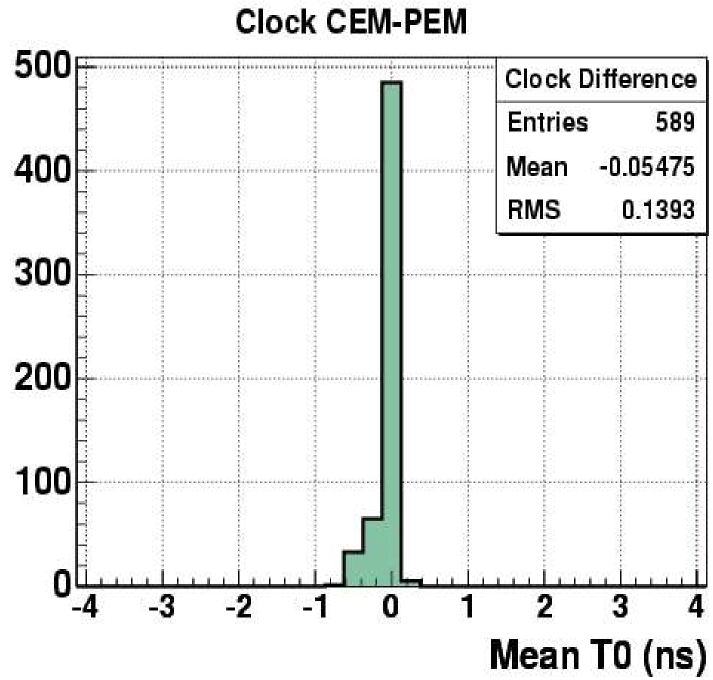


Clock Shifts



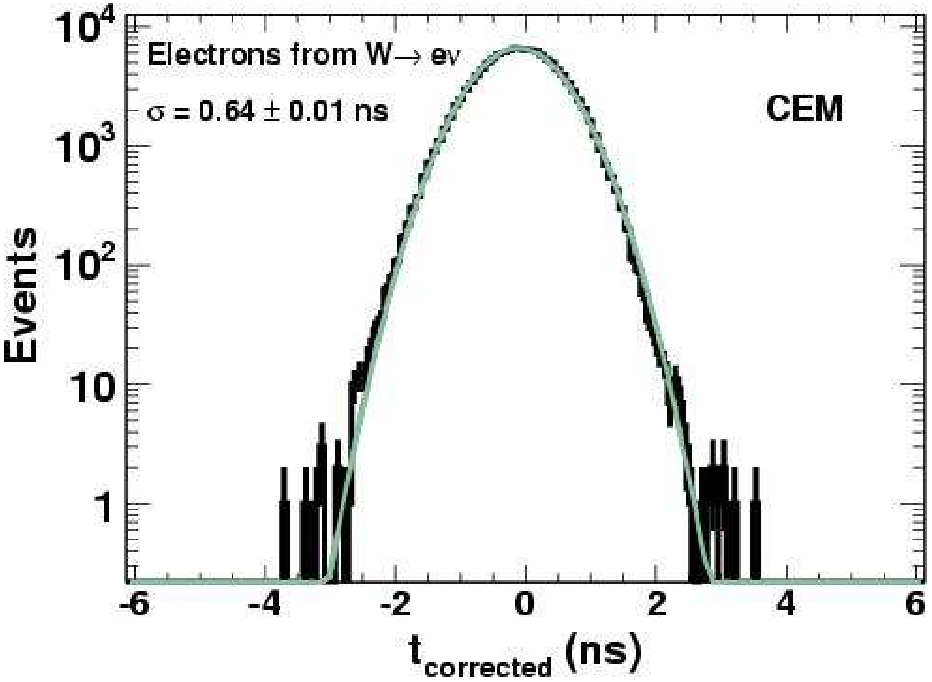


Calibrations average over multiple runs
CDF clock shifts (temperature, ...)
each run has to be corrected by a constant

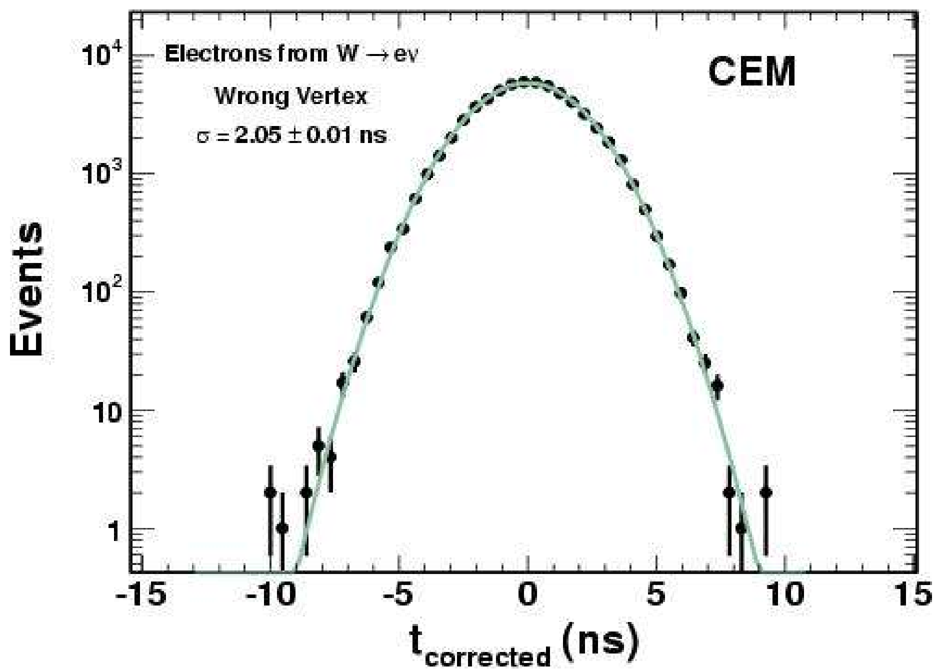


Use electron track to select configuration

$|Z_{e\ track} - Z_{Pr\ Vertex}| < 1$ cm



$|Z_{e\ track} - Z_{Pr\ Vertex}| > 2$ cm



Non-Collisions Backgrounds