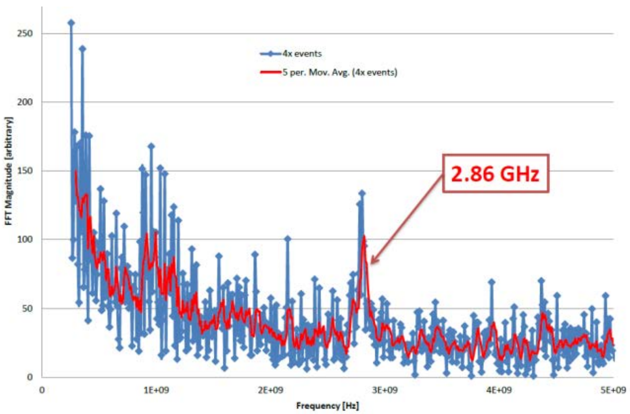
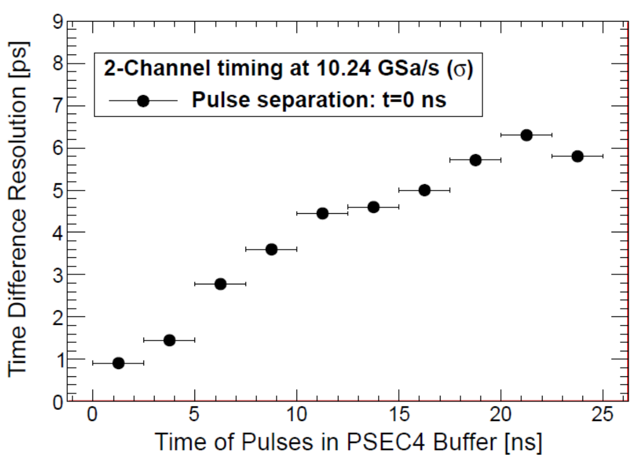
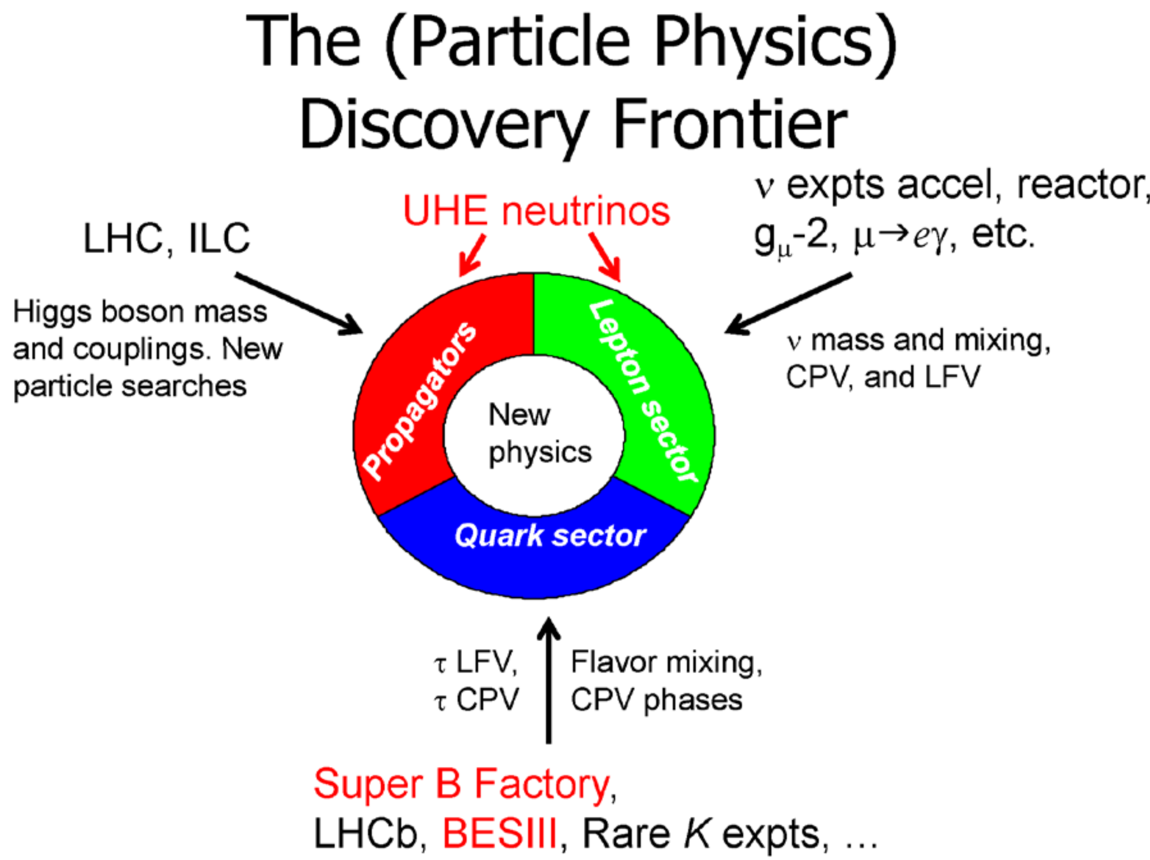
Fast Detectors and Electronics for Future Experiments







G. Varner, University of Hawai'i

A. Apresyan, A. Brandt, K. Nishimura, M. Wetstein, S. White

Speed!

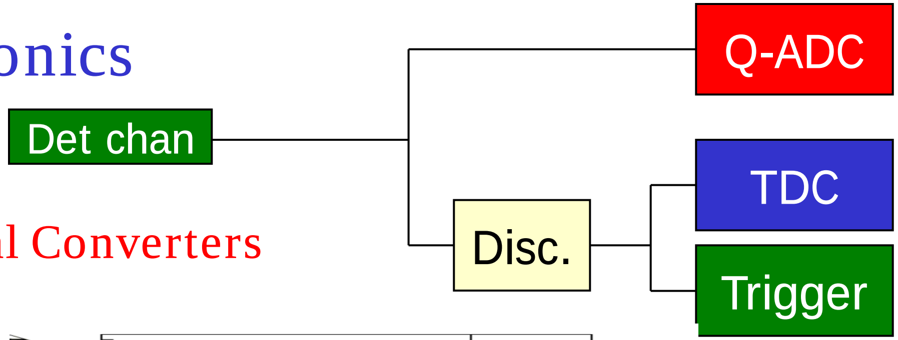
- Fast timing increasingly important
- Don’t have to crash and burn

Overview

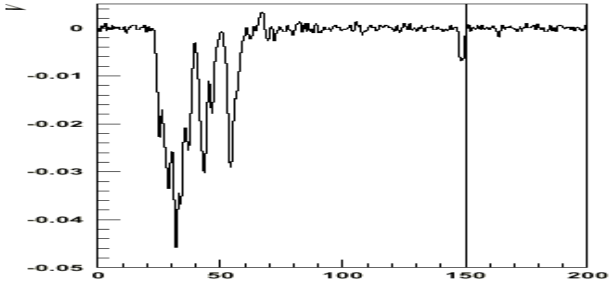
- Fast Timing traditionally
  - Particle Identification
  - Difficult, expensive, low-density, …
- Next generation experiments
  - Rare processes → background suppression
  - High statistics → high event rates
  - High event rates → pile-up, loss of signal purity
- Some examples:
  1. Next generation Particle ID
  2. Reinvigorating older techniques
  3. VH-LHC event pile-up
  4. Even at trigger level

Fast Timing Instrumentation Evolution

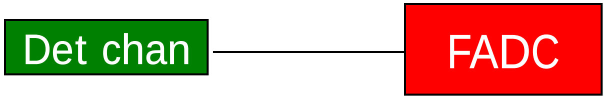
- Traditional "crate based" electronics
  - Gated Analog-to-Digital Converters
  - Referenced "triggered" Time-to-Digital Converters



- High-rate applications
  - "pipelined operation"
  - Low-speed, low-resolution sampling



- High channel counts
  - Motivation to reduce cabling
  - Integrate electronics onto detector elements



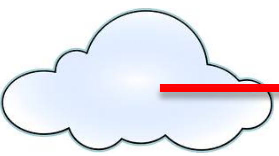
Triggerless DAQ pushing envelope

Underlying (intrinsic) Fast Timing

2. 100's of **Giga**flops per Field-Programmable Gate Array

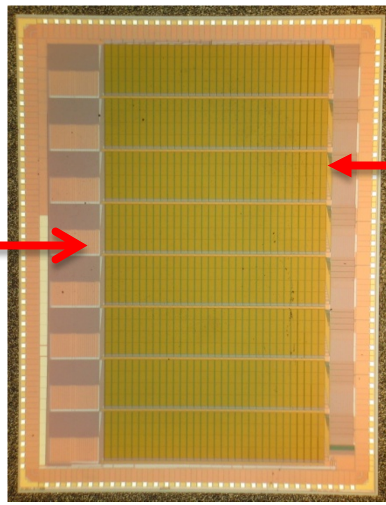
4. Commodity Servers running at **Giga**-Hz rates, 1000's of **Giga**flops

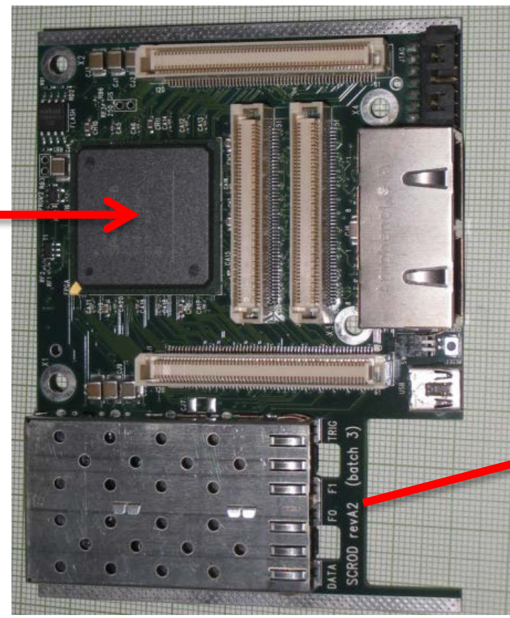
Physical

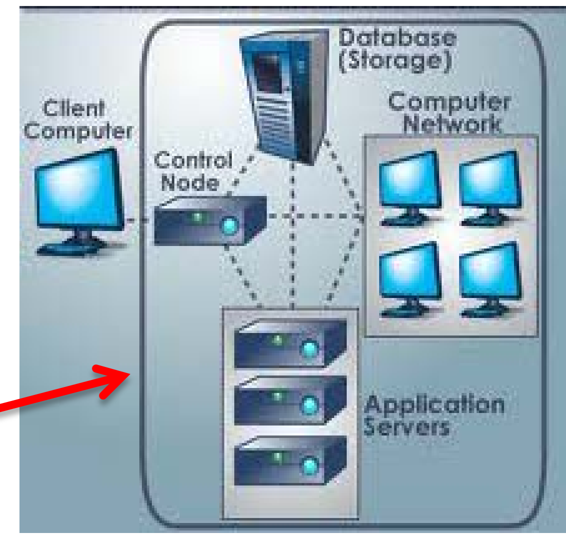


Measurement

3mm → 10ps





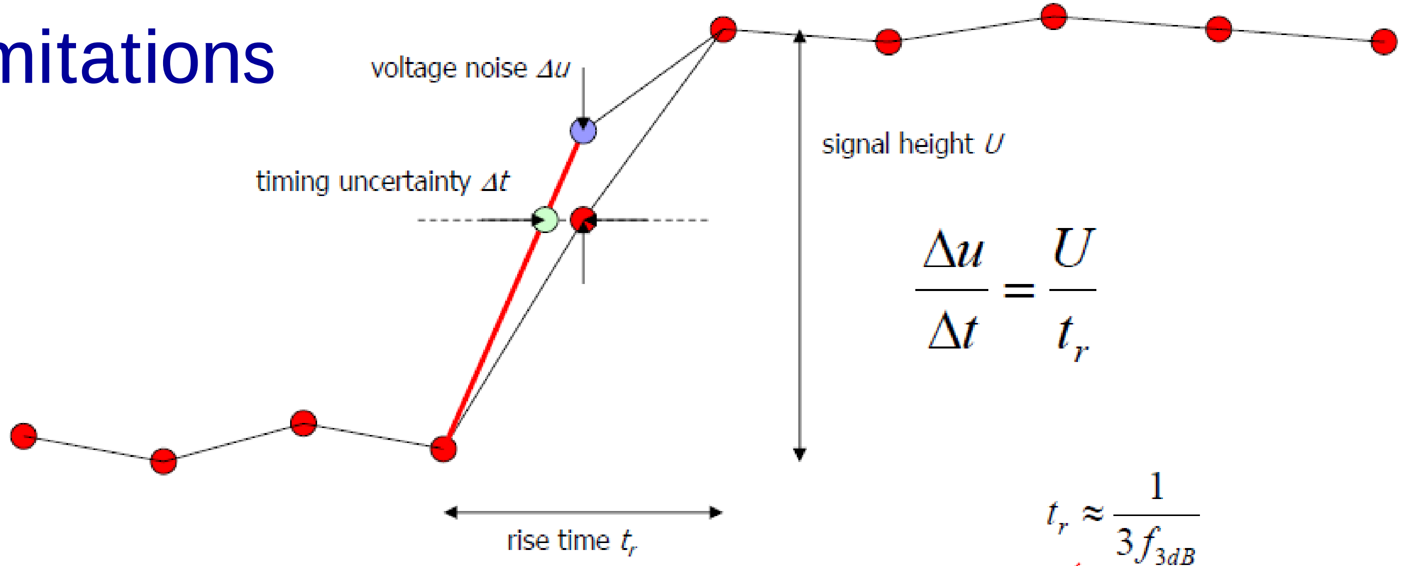


1. **Giga**sample/s "digital oscilloscope on a chip"

3. Inexpensive **Giga**-bit/s fiber link interconnect; **Giga**-bit ethernet

As Giga-Hz → Tera-Hz, good timing implicit

Limitations



$$\frac{\Delta u}{\Delta t} = \frac{U}{t_r}$$

$$t_r \approx \frac{1}{3 f_{3dB}}$$

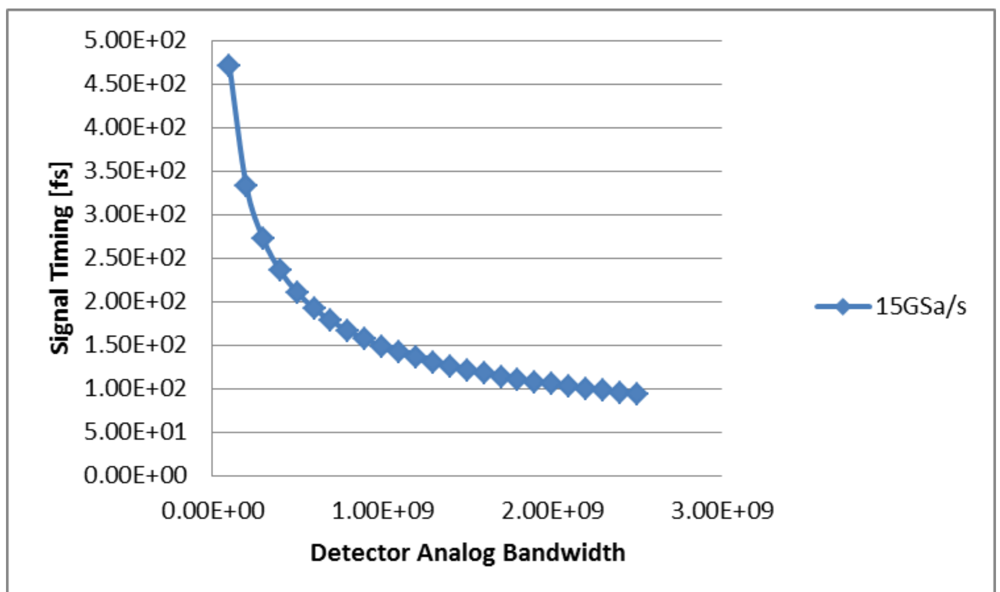
$$\Delta t = \frac{\Delta u}{U}\cdot t_r = \frac{\Delta u}{U\sqrt{n}}\cdot t_r = \frac{\Delta u}{U}\cdot\frac{t_r}{\sqrt{t_r\cdot f_s}} = \frac{\Delta u}{U}\cdot\frac{\sqrt{t_r}}{\sqrt{f_s}} = \frac{\Delta u}{U}\cdot\frac{1}{\sqrt{3 f_s\cdot f_{3dB}}}$$

*Diagram, formulas from Stefan Ritt

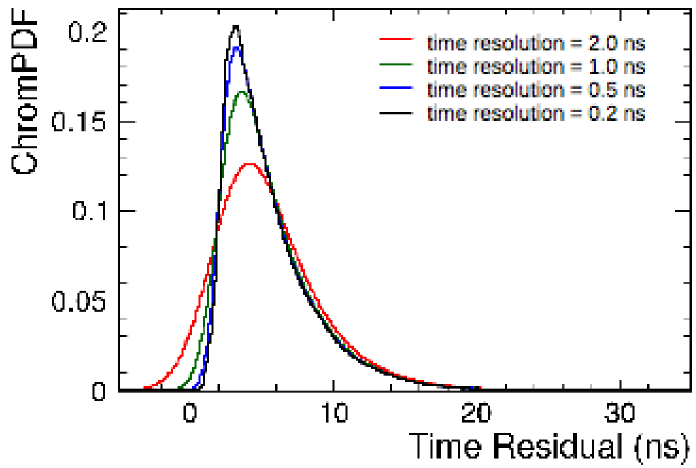
For $\Delta u/U = 10^{-3}$

$f_s = 15\text{GSa/s}$

(CF PSEC4)

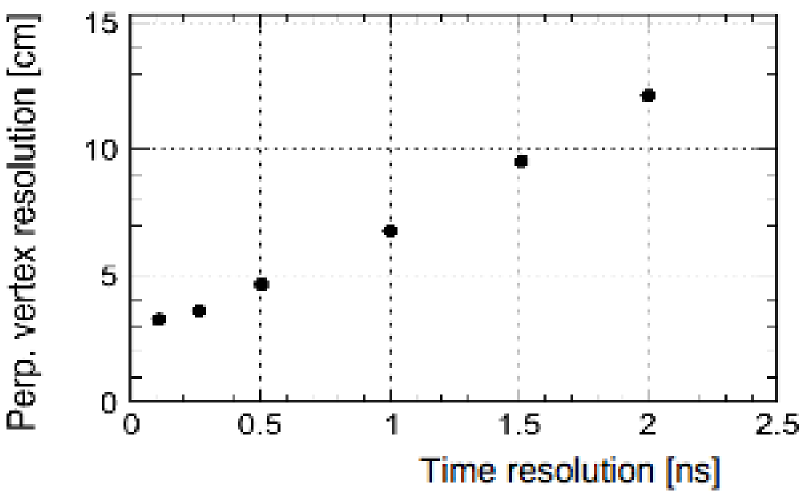


"Simple Vertex" Reconstruction



improved time resolution (<500 ps) combined with the ability to resolve individual photons makes it possible to resolve the effects of chromatic dispersion.

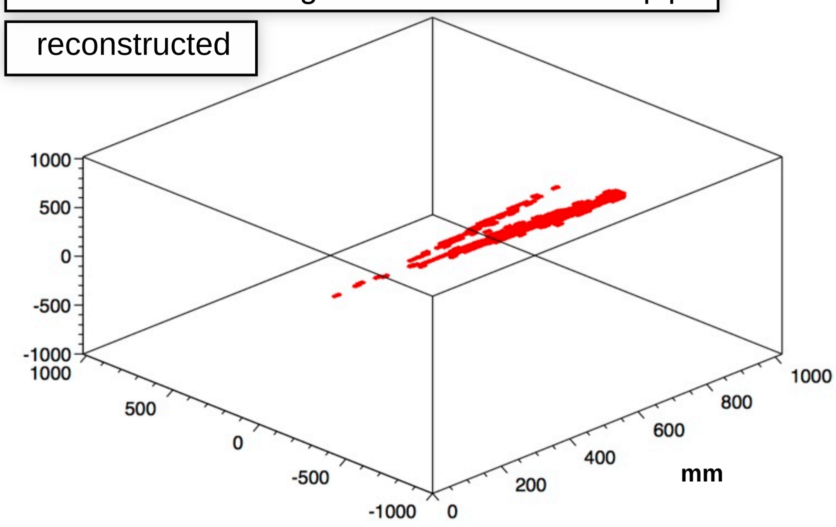
fits to the transverse component of the vertex wrt to the track (or shower) direction are very sensitive to timing. It may be possible to build large water Cherenkov detectors with the ability to resolve event topologies on cm scales.



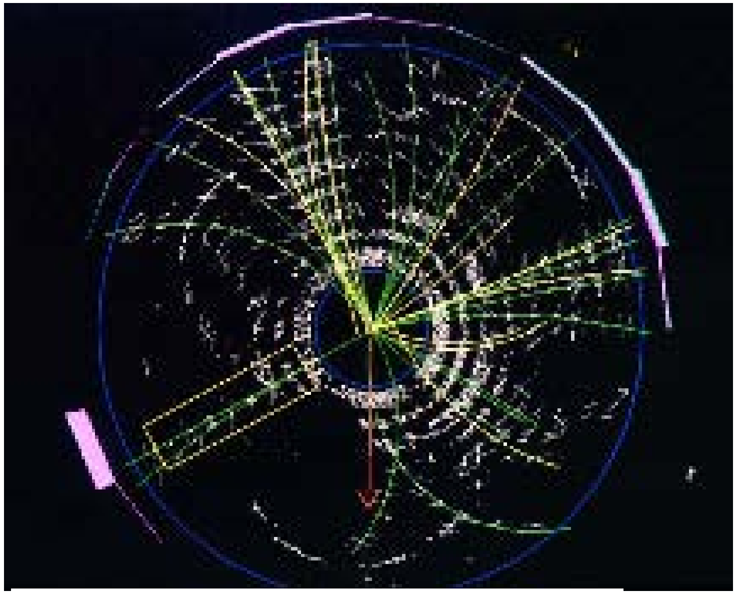
Work by I. Anghel, M. Sanchez, M Wetstein, T. Xin

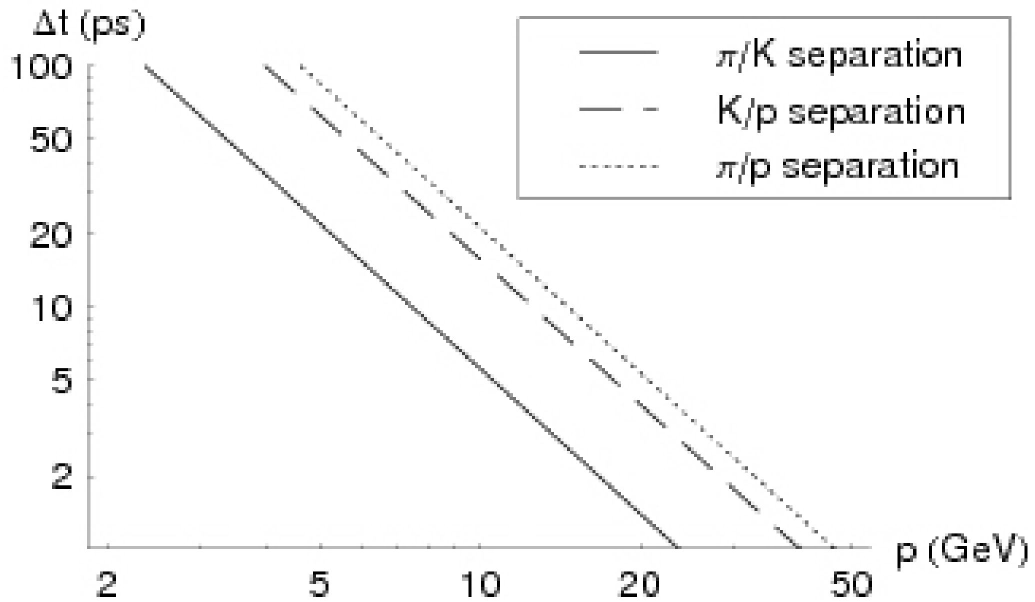
first 2 radiation lengths of a 1.5 GeV $\pi^0 \rightarrow \gamma\,\gamma$

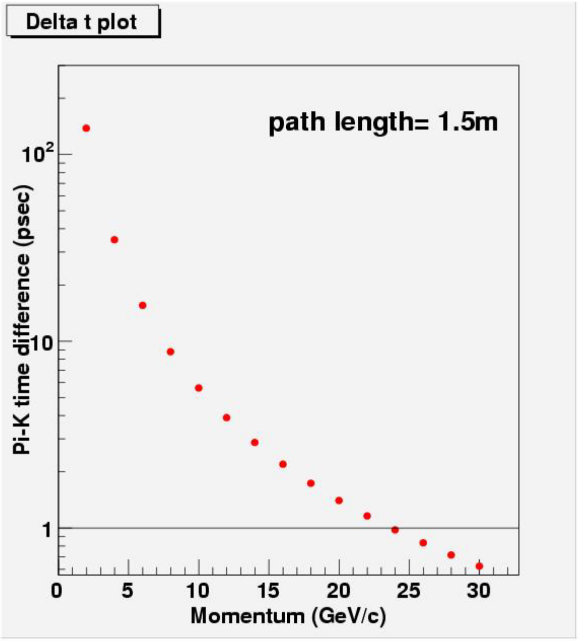
reconstructed



Even in a Hadron Collider Environment





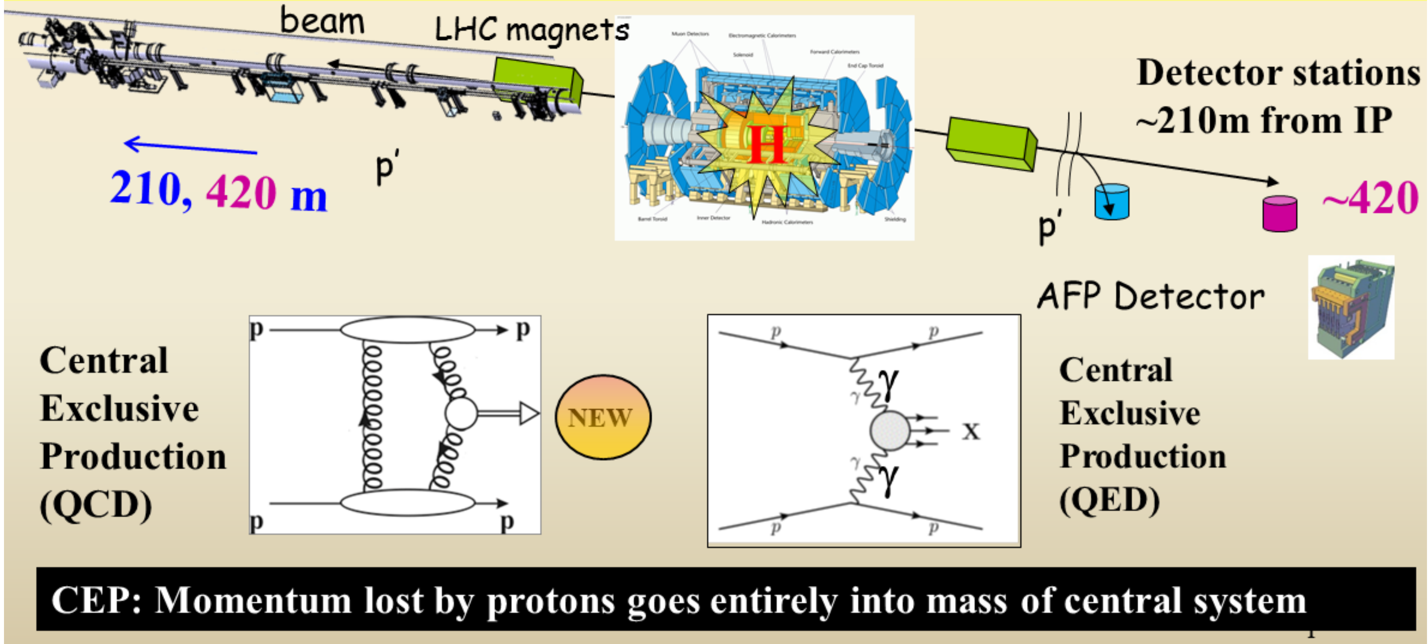


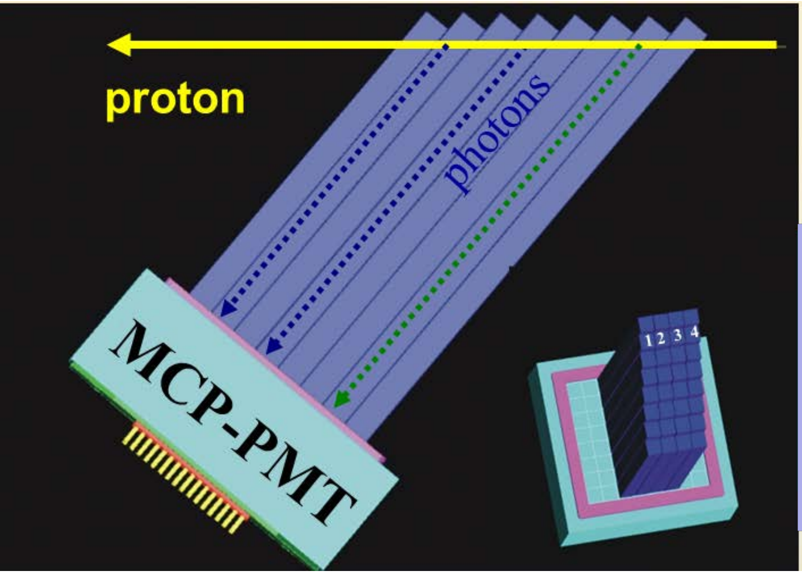
- While single-track timing difficult, differentially can do PID
- For good gamma conversion timing, can match to vertex

Whitepaper by H Frisch: A Differential Time-of-Flight Technique for Collider Detectors

LHC Timing Example – shorter-term

A. Brandt

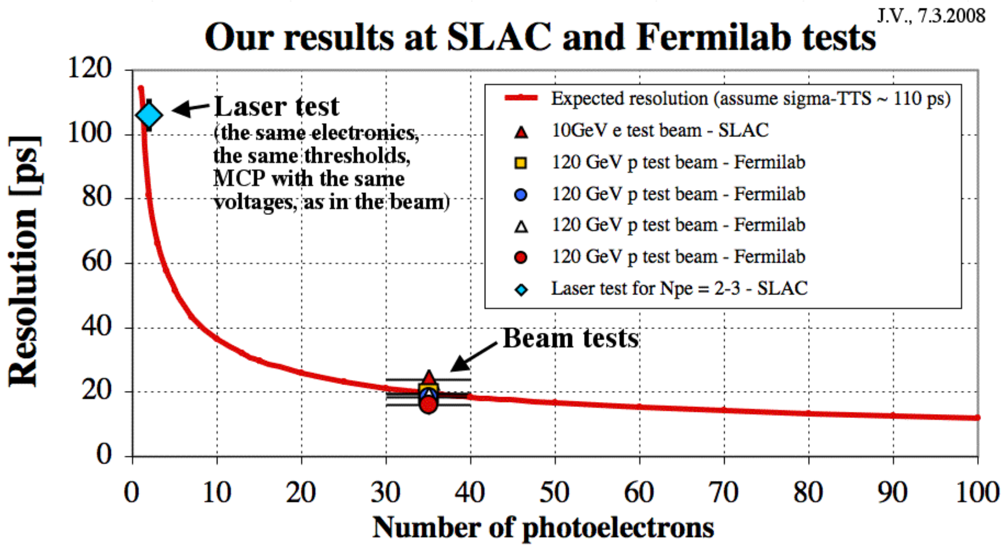




QUARTIC concept: Mike Albrow for FP420 (joint ATLAS/ CMS effort) 2004 based on Nagoya Detector.

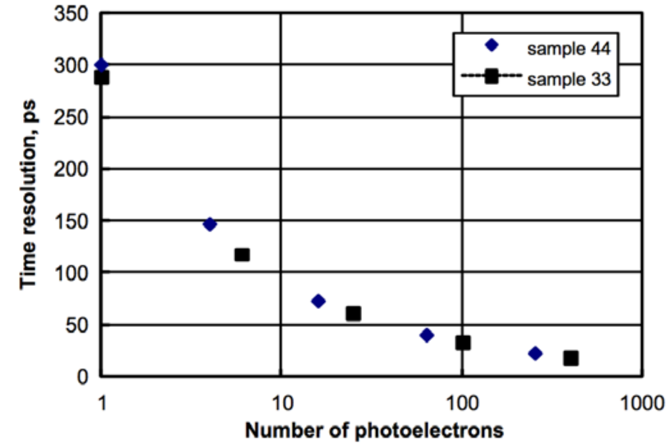
10 ps or better resolution (including electronics)
High efficiency and acceptance
High rate capability (~5 MHz/pixel)
Segmentation for multi-proton timing
L1 trigger capability
Robust operation in high radiation environment

Photo-sensors

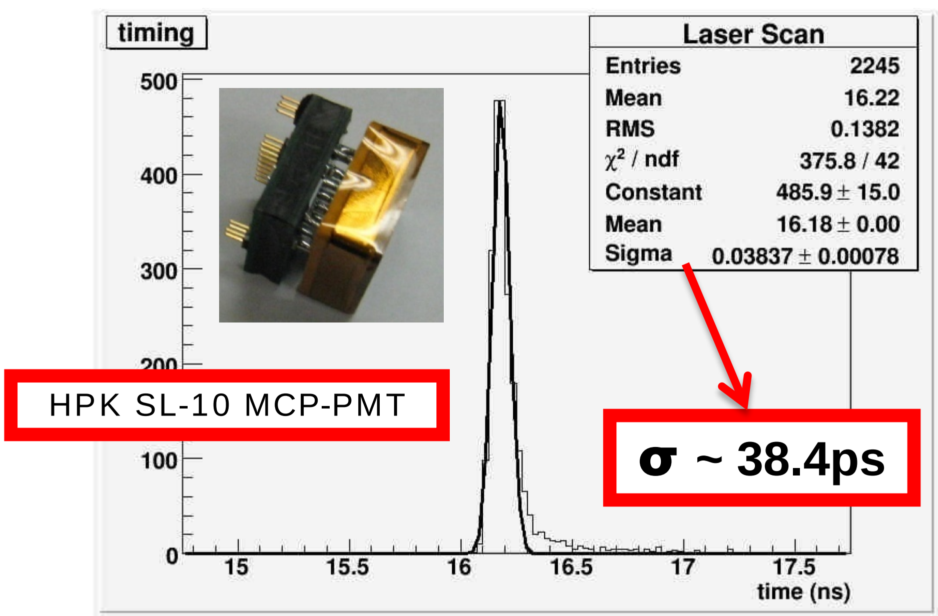


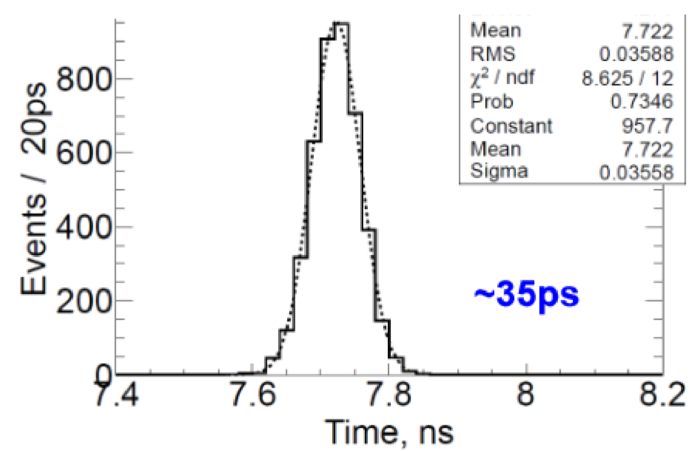
Jerry Va'vra – subsequent points filled in

A.Ronzhin et al, NIM A 616



MPPCs

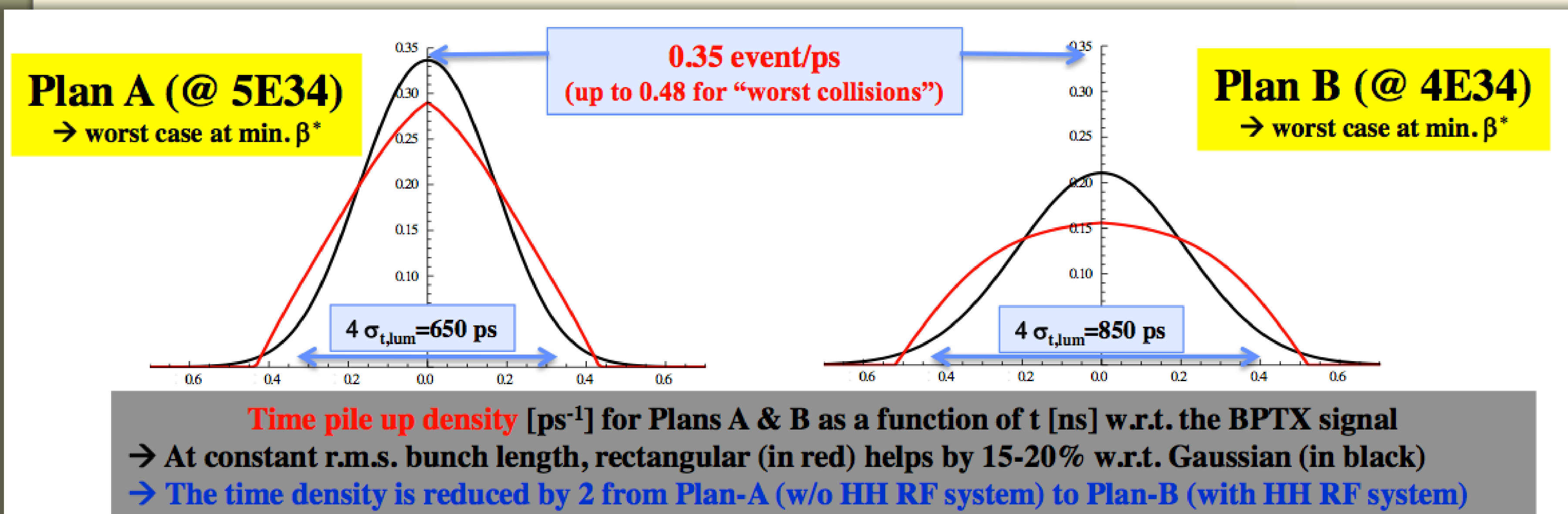




LAPPD

US-CMS Precision Timing Proposal for Phase II upgrades

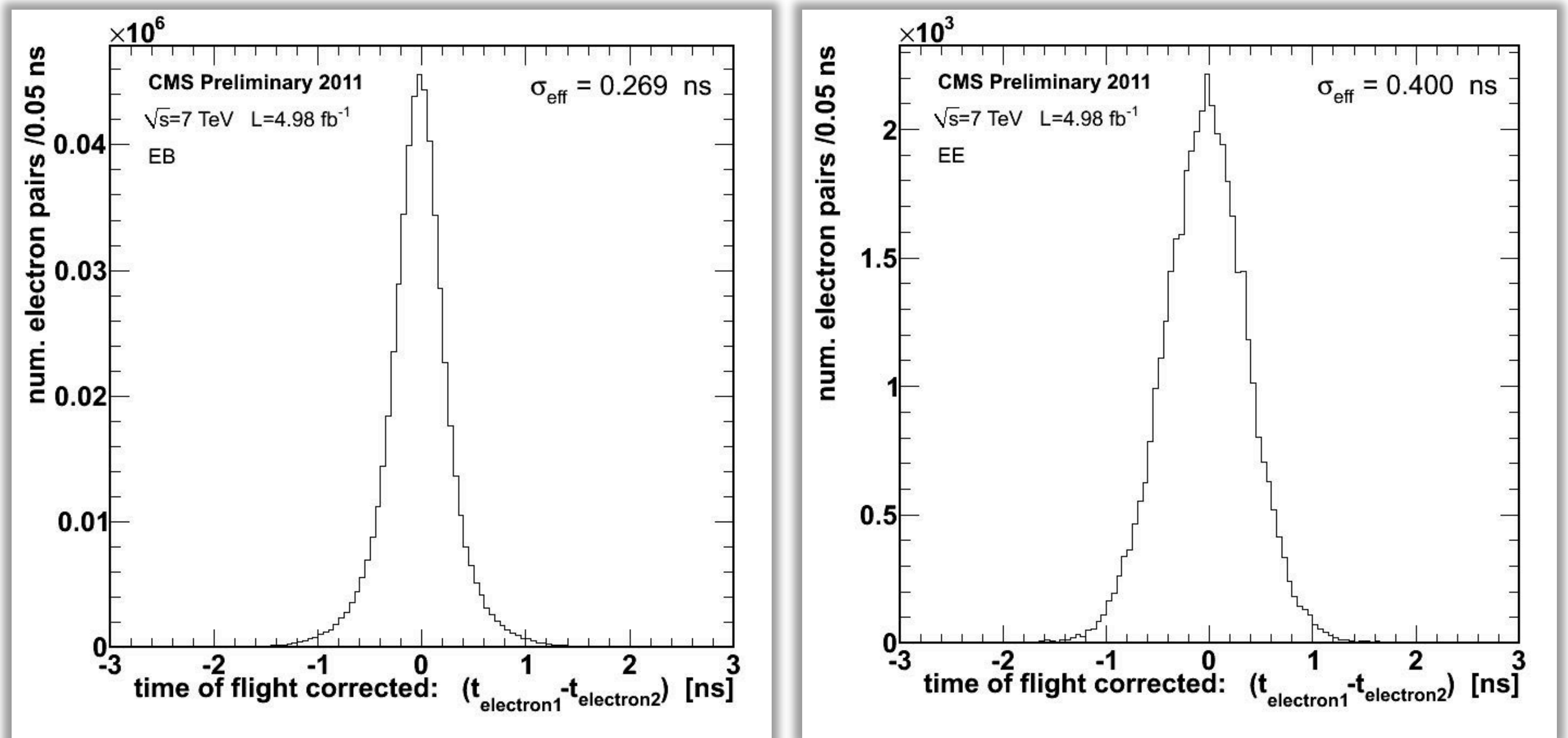
- Multiple collisions overlapping: 1.0-1.5 events/mm in each crossing
  - Degraded event reconstruction (ele, γ, jets, MET); object identification (pileup jets)
- Need ability to identify particles coming from hard scatter vertex
  - Precision timing measurements could provide such information
  - Even with extended coverage in rapidity of trackers, neutral particles still an issue
- Considering an option to implement precision timing device in Phase 2



S. Fartoukh: http://indico.cern.ch/conferenceDisplay.py?confId=263083

CMS ECAL

- Test beam resolution for average rechit energy: 80 psec ~20 GeV
- Measurement performed in situ with events from Z→ee
  - Found to be **190/280 psec** in ECAL barrel/ECAL endcap
- Need to improve an ~order magnitude to resolve different vertices



CMS DP-2012/007

Fast Semiconductor Tracker Timing

Ultra-fast Silicon Detectors (4D-UFSD)
Contribution of Hartmut Sadrozinski (UC Santa Cruz)

From the values shown in Table 1, pixel sensors offer very attractive combinations of moderate gain, small capacitance, and short collection time. Due to the high value of backplane capacitance, strip sensors cannot be made as fast as pixel sensors; however, a "mini-strip" of 1-2 mm long offers a quite fast collection time, 50-100 ps, with a moderate value of capacitance (~1 pF).

Thickness [um]	BackPlane Capacitance Pixels [fF]	BackPlane Capacitance Strips [pF/mm]	Signal [# of e-]	Coll. Time [ps]	Gain required for 2000 e	Gain required for 12000 e
2	125	2.5	80	25	25	149
5	50	1.0	235	63	8.5	51
10	25	0.50	523	125	3.8	23
20	13	0.25	1149	250	1.7	10.4
100	3	0.05	6954	1250	0.29	1.7
300	1	0.02	23334	3750	0.09	0.5

Table 1 Silicon sensor characteristics for various thicknesses of the active area.

Does require gain, highly integrated readout, but very interesting

Precision Timing @ L1 Trigger?

R&D Topics: Trigger
(mostly ATLAS & CMS)

CSS 2013

THE UNIVERSITY of WISCONSIN MADISON

W. Smith

Increase of rate from Level-0 to HLT to read out
- Absolute rate & balance between levels

L1 complexity vs. HLT input rates
- Study the trade-offs

L1 Trigger Latency
- How much is needed & consequences on electronics

L1 Track Triggers
- Associative Memories
- Study techniques: sharpen p_T threshold, e- & μ- ID, Isolation, primary vertex for jets, multi-object triggers, possibility of pixel b-tag.
- Interplay with tracker design

Improvements to L1 Calo. & Muon Triggers
- Processing of much finer-grain, higher bandwidth information

Impact of higher bandwidth links & denser optical interconnects

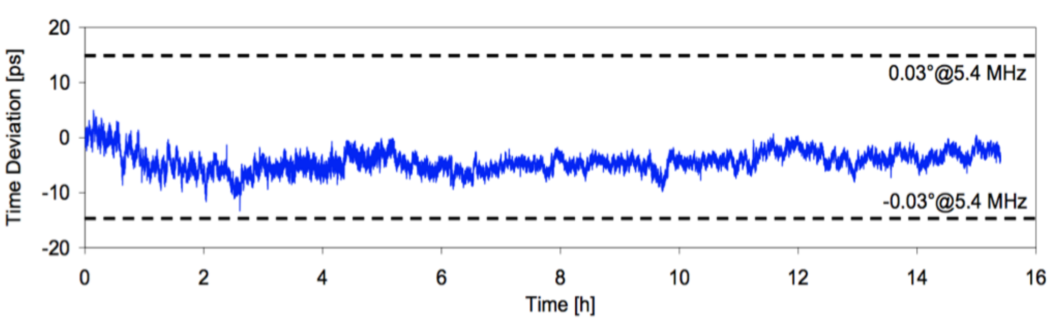
New packaging & interconnect technologies
- ATCA, μTCA, RCE

Use of FPGAs in L1 Trigger

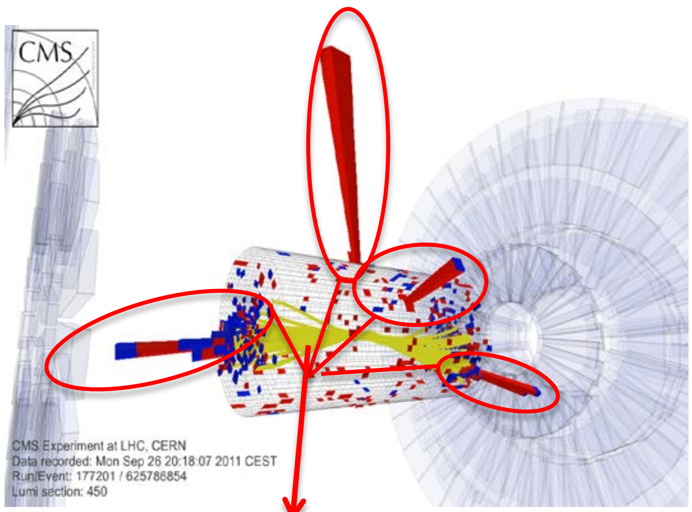
Impact of detector timing improvements (~100 ps)
- e.g. crystal calorimeters (CMS: $PbWO_3$ has ~ 150 ps, LYSO < 100 ps)

Detector Synchronization

- Detector Synchronization necessary to achieve physics goal
  - Need to keep the large area detector well synced
  - Synchronization needs to be stable over long period of time
- Possible alternatives:
  - Technology for full synchronization with in-situ techniques
- Universal psec timing system for FAIR, White Rabbit
  - Reference signal generation jitter ~8psec
  - Send several independent clocks via DWDM
  - WR: sub-nsec accuracy for >1000 nodes
  - WR: Up to 10 km of length.



FAIR, PH-ESE seminar, CERN, 02.06.2013



Synchronize different parts of CMS

Open Questions/Discussion Items

- What limits timing in future detectors?
  - Space-time (300um → 1ps)
  - Extrapolations → 100fs
- What technologies would be transformative?
  - Fast sensors? [LAPPD++, Semicond, ???]
  - Integral electronics?
- Areas for future exploration?
  1. Sub-ps distributed timing standards
  2. Detector segmentation, fast signal collection
  3. New techniques: e.g. radio (Askaryan) calorimetry
  4. THz/mm-wave active interrogation of passive detectors
  5. …

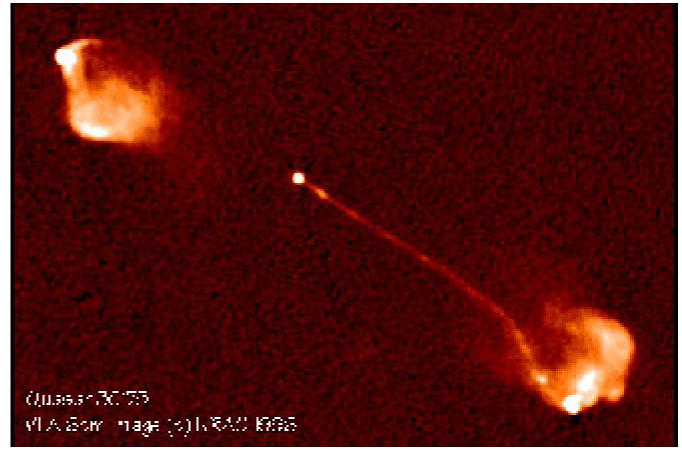
Field test example

Ultrawide-band Interferometry

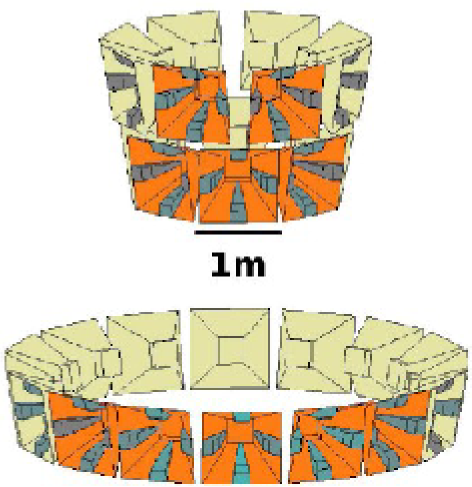
-Interferometric technique applied by radio astronomers.

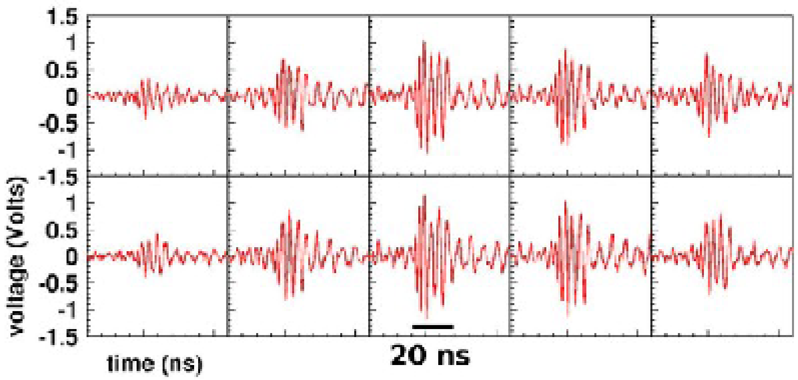
-They use single narrow band frequency.

-More interested in source imaging rather than point source direction reconstruction.



Produce Ultrawide-band Interferometric Images with ANITA



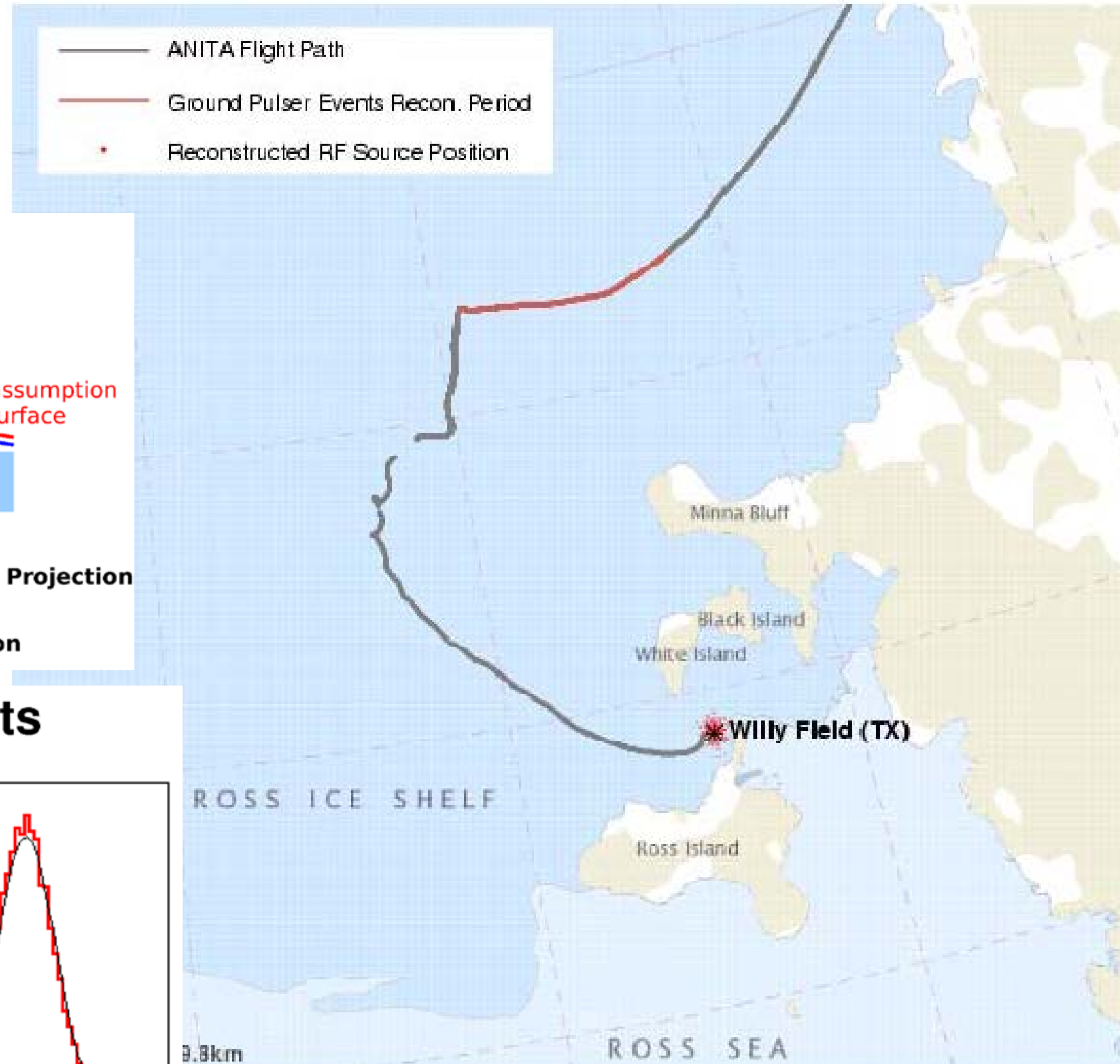


With distributed clock → **~30ps (16ps) resolution between channels**

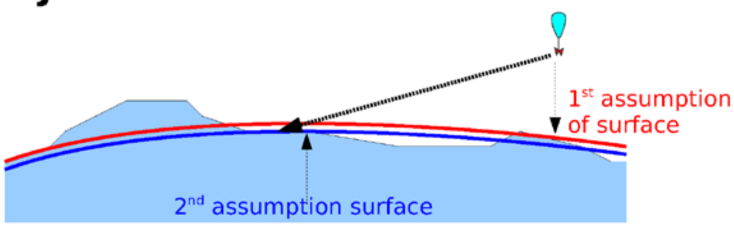
Not just on the bench – in the field

After full calibration – 100's km

<30ps timing



RF Projection onto the surface



Fast Algorithm: Line Sphere intersection

- **1st R_{earth}=Geoid + Surface @ Ballon position -> Rough Projection**
- **2nd R_{earth} = Geoid + Surface @ (position from 1st)**
- **3rd: one more iteration -> converged after 2nd iteration**

V-pol results

Borehole Data (used for calibrations)