“On the Correlation of sub-events”

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Forward Calorimetry Task Force meeting, Sept. 20, 2012

- title from 2007 paper: arXiv:0707.1500
- our activity will address general problem of resolving event fragments in presence of pileup
- very little focus on timing in CMS and ATLAS designs. Main large scale expertise is in Alice-TOF.
- event timing is not a new idea-see C.T.R. Wilson
- my background is: managed design and construction of 2 large calorimeter systems that achieved <100 psec time resolution
- we are currently involved in a DOE ADR&D funded project to develop tools for 10 picosec timing at rates in hi-lum LHC (Kirk McDonald and I are co-PI's, Iouri Musienko and Crispin Williams in)

today's talk:

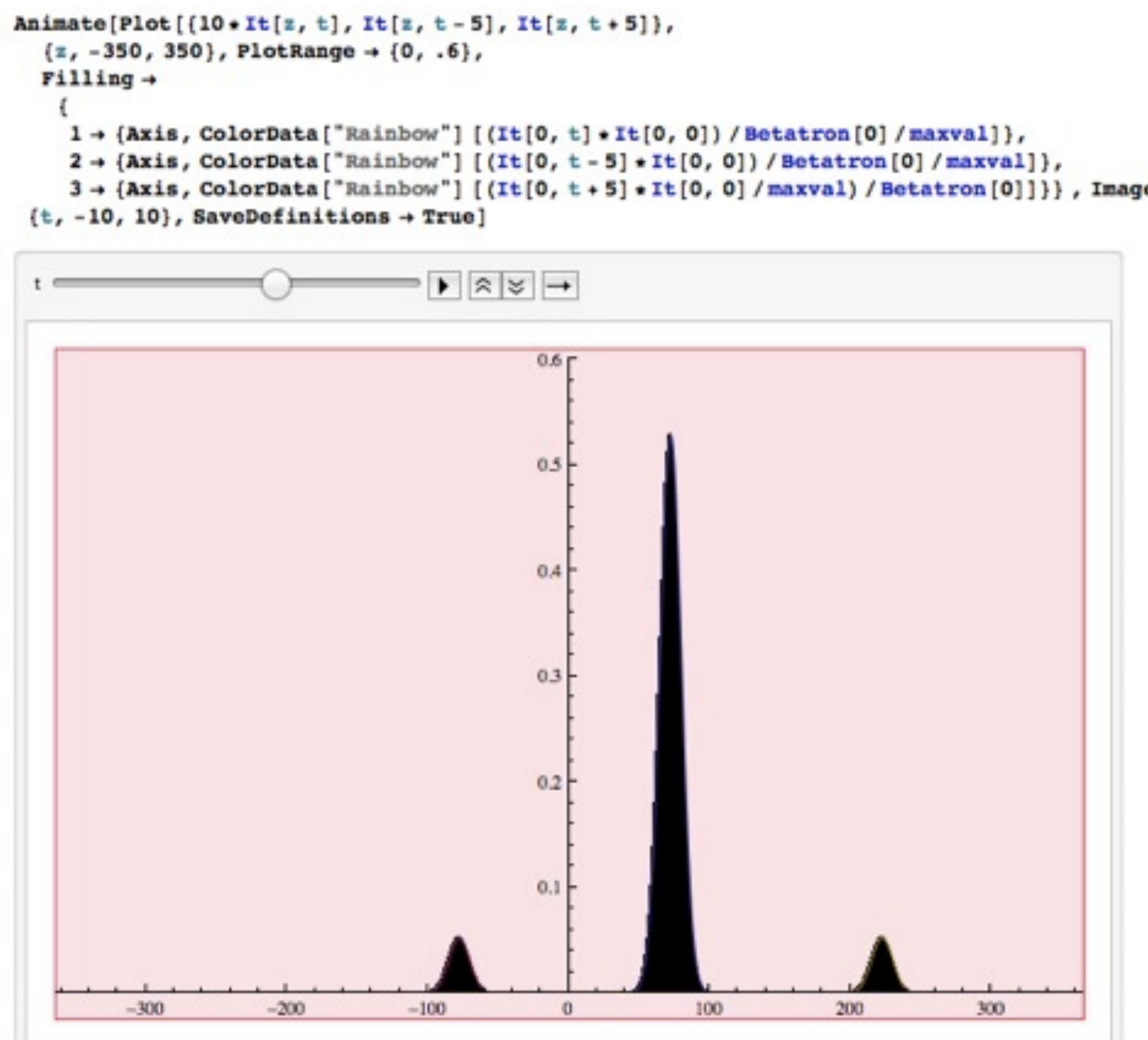
- modeling pileup in LHC
- past experience in large systems at LHC
- technologies for push to <<100 picosec

  (should hear more from Matt Wetstein, HADES, Crispin, Va'vra, etc)

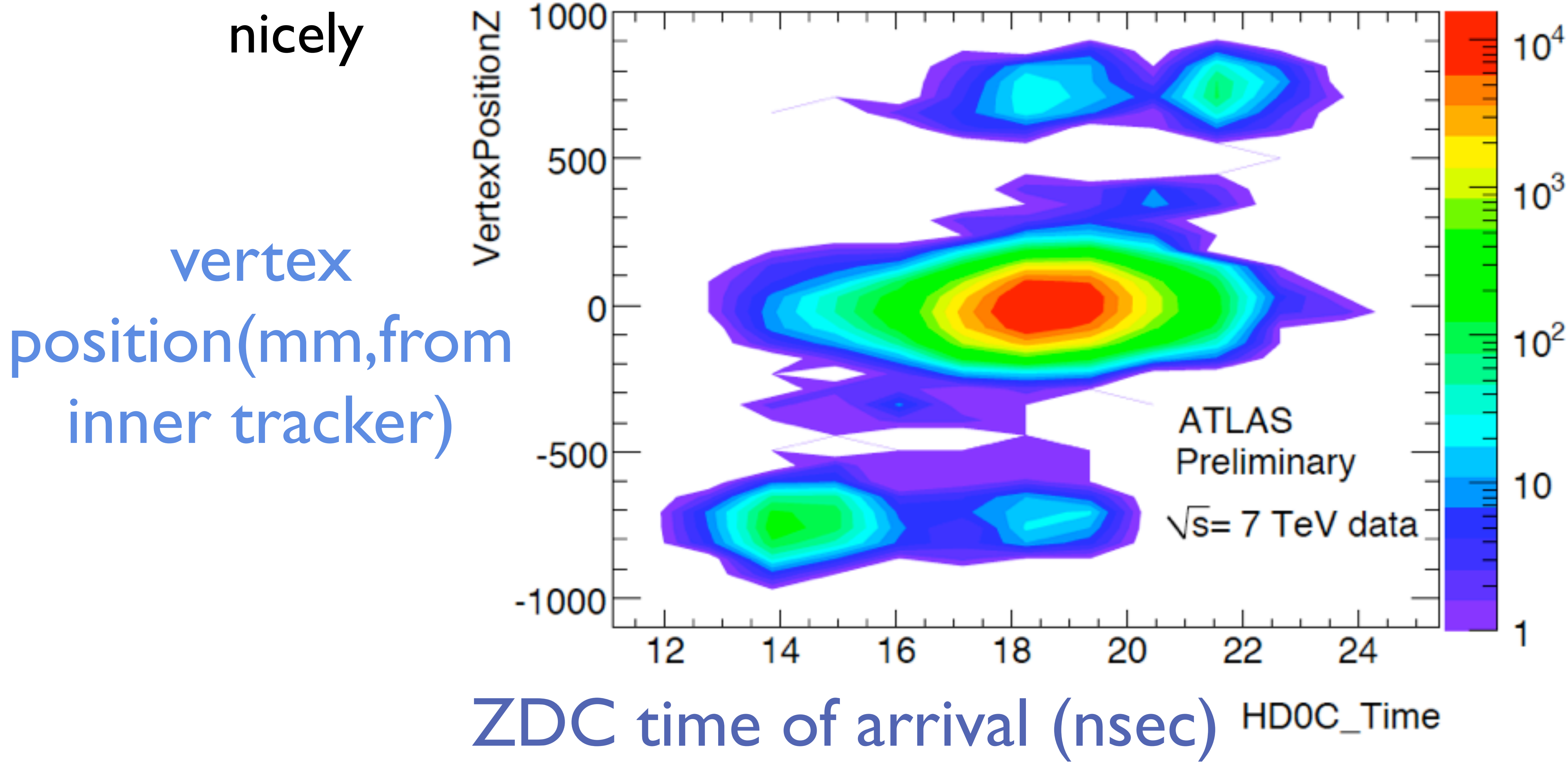
- brief status on our R&D project
- short intro to timing performance of ATLAS ZDC tungsten/quartz shashlik

Resolving event times.

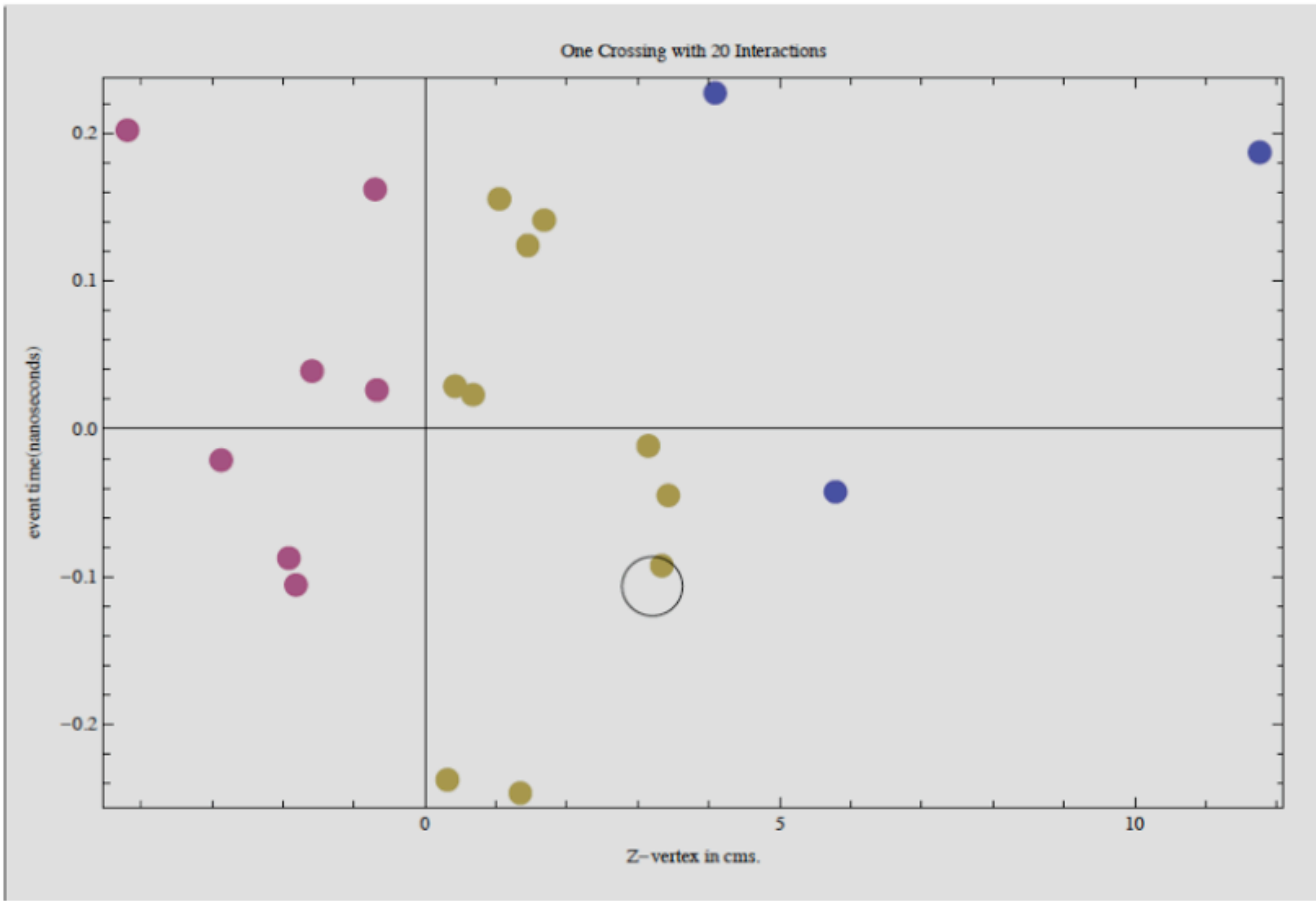
- (see also Ledovskoy's presentation last week)
- LHC simulation originally in 2007 paper:**On the Correlation of Subevents in the ATLAS and CMS/Totem Experiments**White, Sebastian N.eprint arXiv: 0707.1500
- animations also posted to Wolfram library:http://library.wolfram.com/infocenter/Articles/7716/

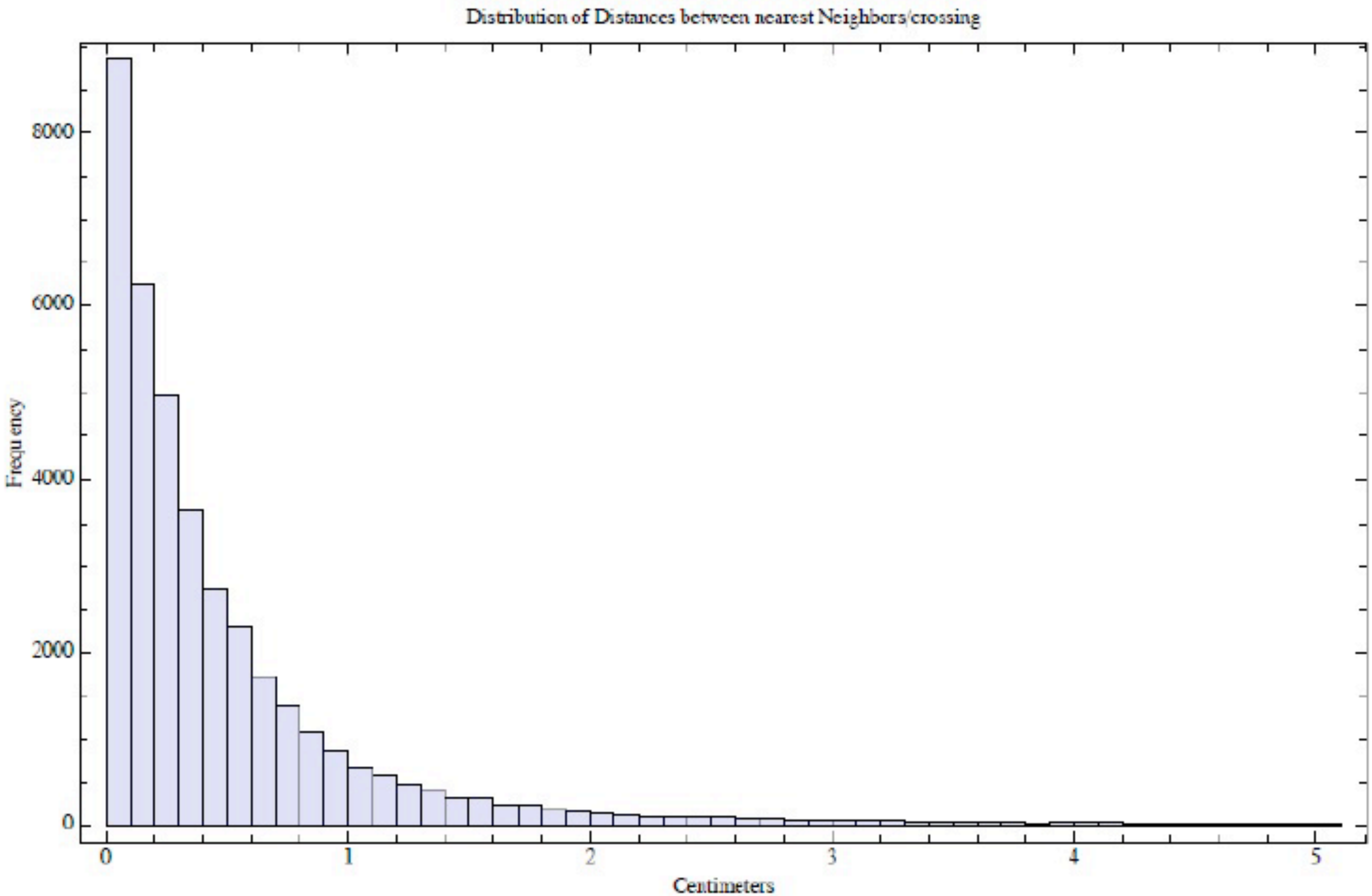


- on experiment side, in ATLAS and CMS, main emphasis on identifying crossing
- in Summer of 2010 there was an interest in experimentally more difficult problem of resolving small satellites from 400 MHz SPS rf
- combined effort of ATLAS ZDC and IT resolved this nicely



resolving event fragments within the same bunch crossing: (colored dots represent actual event time, vertex& error ellipse is assumed resolution from a fragment pair)





Exponential due to Poisson distributed population

see eg. p 362 Papoulis: Probability, random variables and stochastic processes (1991 ed)

prior LHC experience

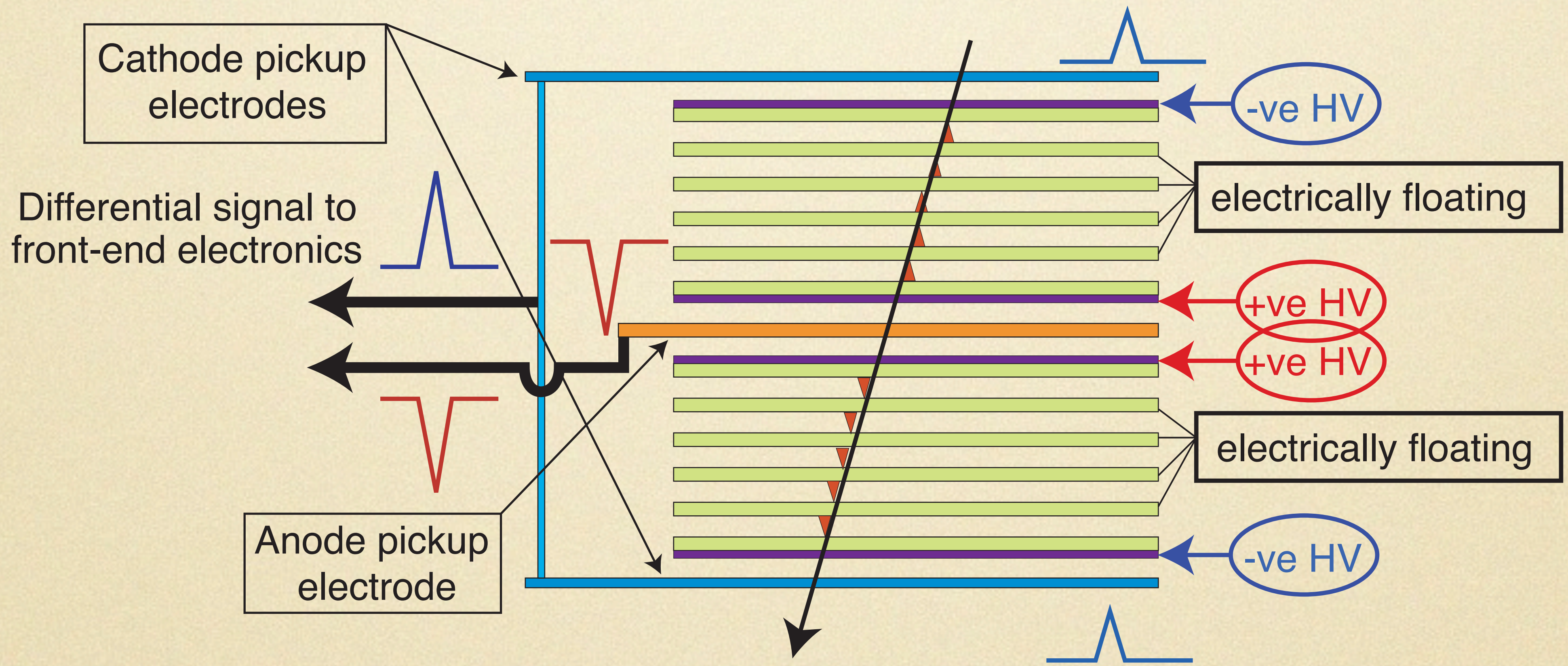
- ALICE TOF 160k channels, 150 m^2
    - (slides from Crispin)
- ATLAS ZDC (more details next time)
- CVD diamond, etc. (mostly HADES)
- experience with CMS ECAL and ATAS LAr timing (future talks?)

ALICE MRPC for TOF

schematic view

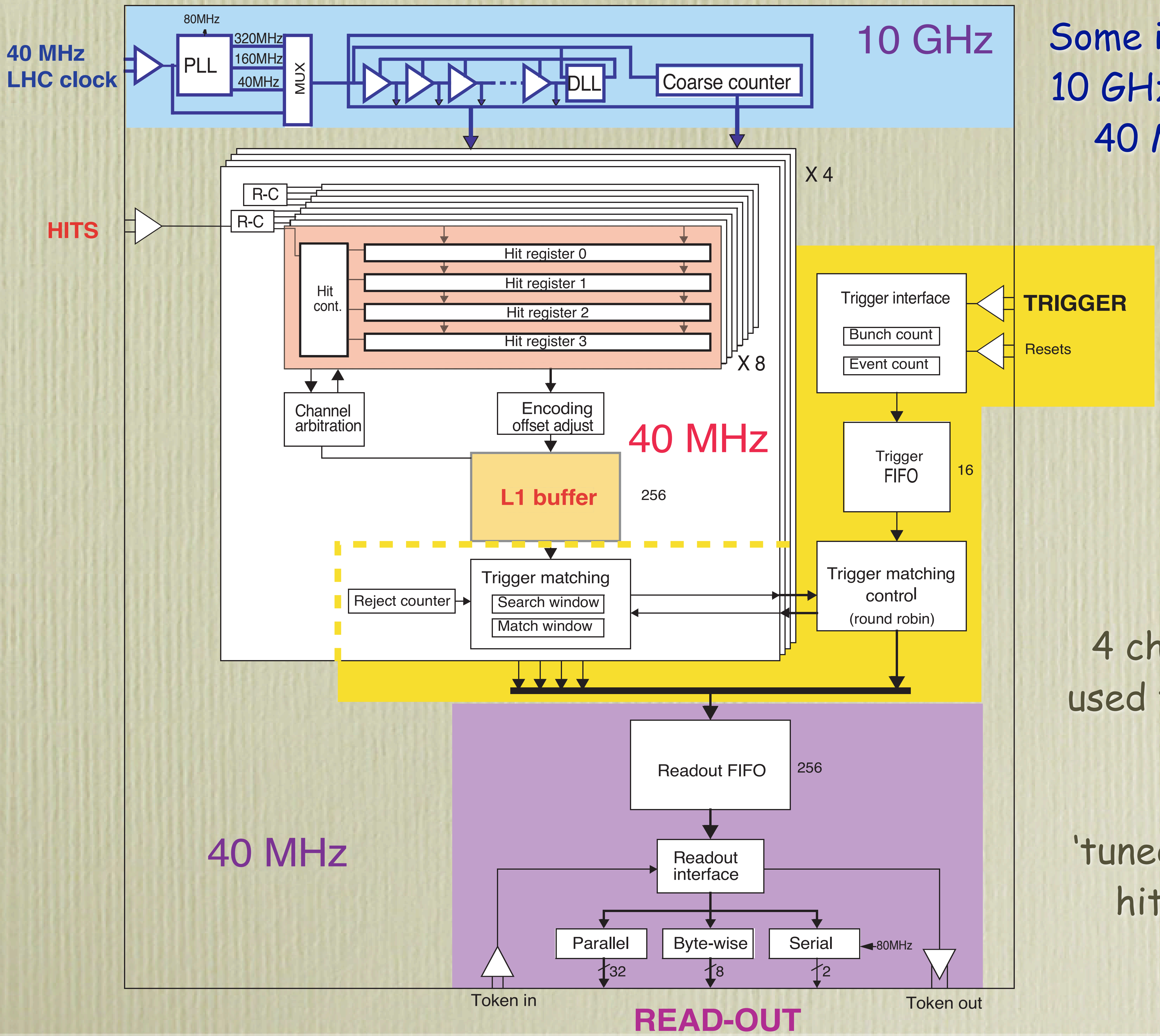
ALICE-TOF has 10 gas gaps (two stacks of 5 gas gaps) each gap is 250 micron wide

Built in the form of strips, each with an active area of 120 x 7.2 cm^2, readout by 96 pads



Note : HV only applied to outer surfaces of each stack of glass (internal glass sheets electrically floating) this makes it very easy to build.

HPTDC



Some interference between 10 GHz clock for timing and 40 MHz clock for data control

4 channels (100 ps) are used to get down to 25 ps bin size

'tuned' RC circuit offsets hits signals by 25 ps

Time jitter - ALICE TOF

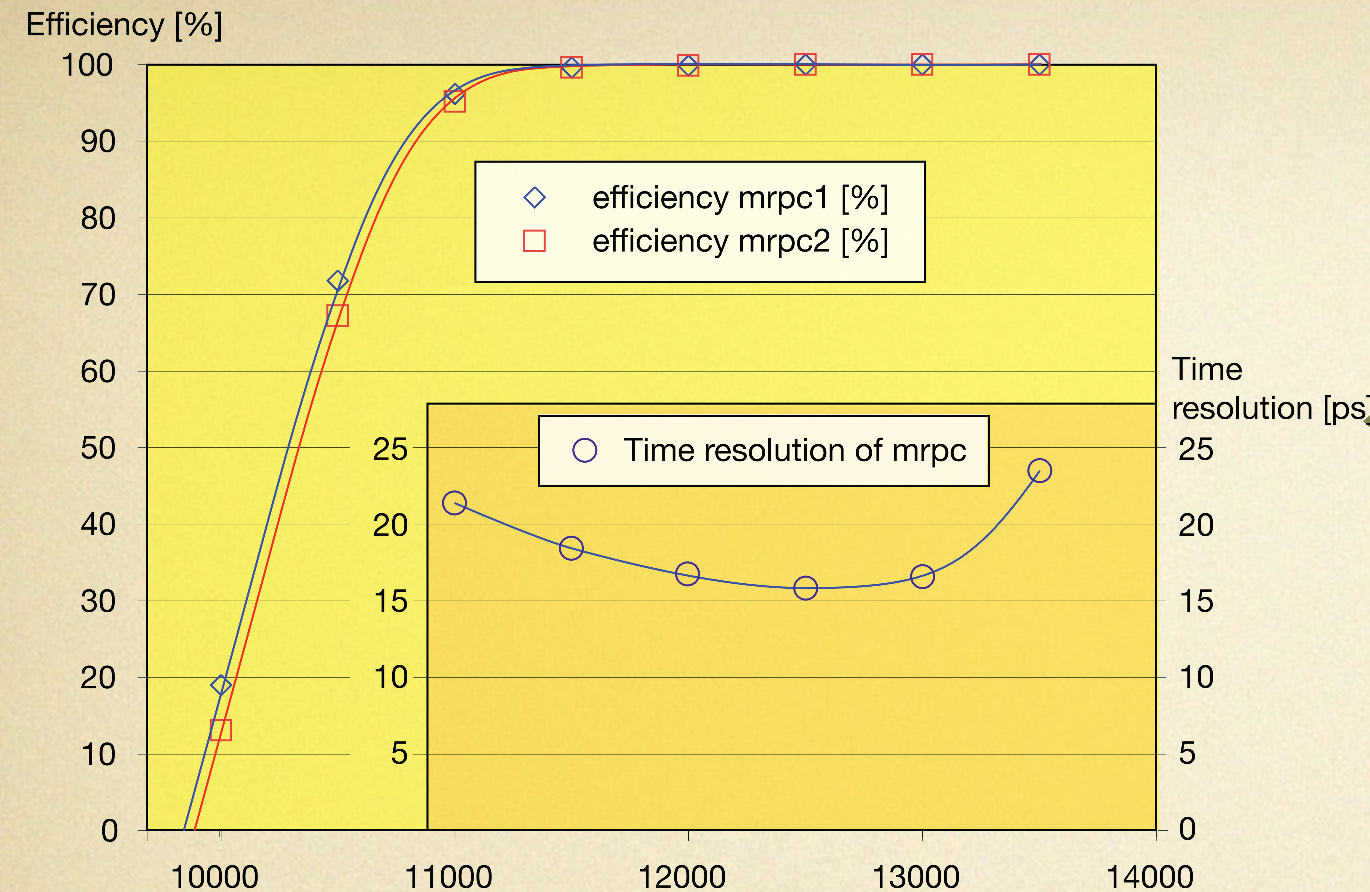
- tdc time resolution (time difference between two channels) 30 ps
- beam spot 1 cm in size (50 ps/√12) 14 ps
- NINO ASIC + cables + interface card 21 ps
- intrinsic MRPC time resolution 20 ps
- **total $\sqrt{(30^2 + 14^2 + 21^2 + 20^2)}$ = 44 ps**

given this : can we hope to build a detector with, for example, 10 ps time resolution?

44 ps time resolution of 10 gap ALICE TOF detector

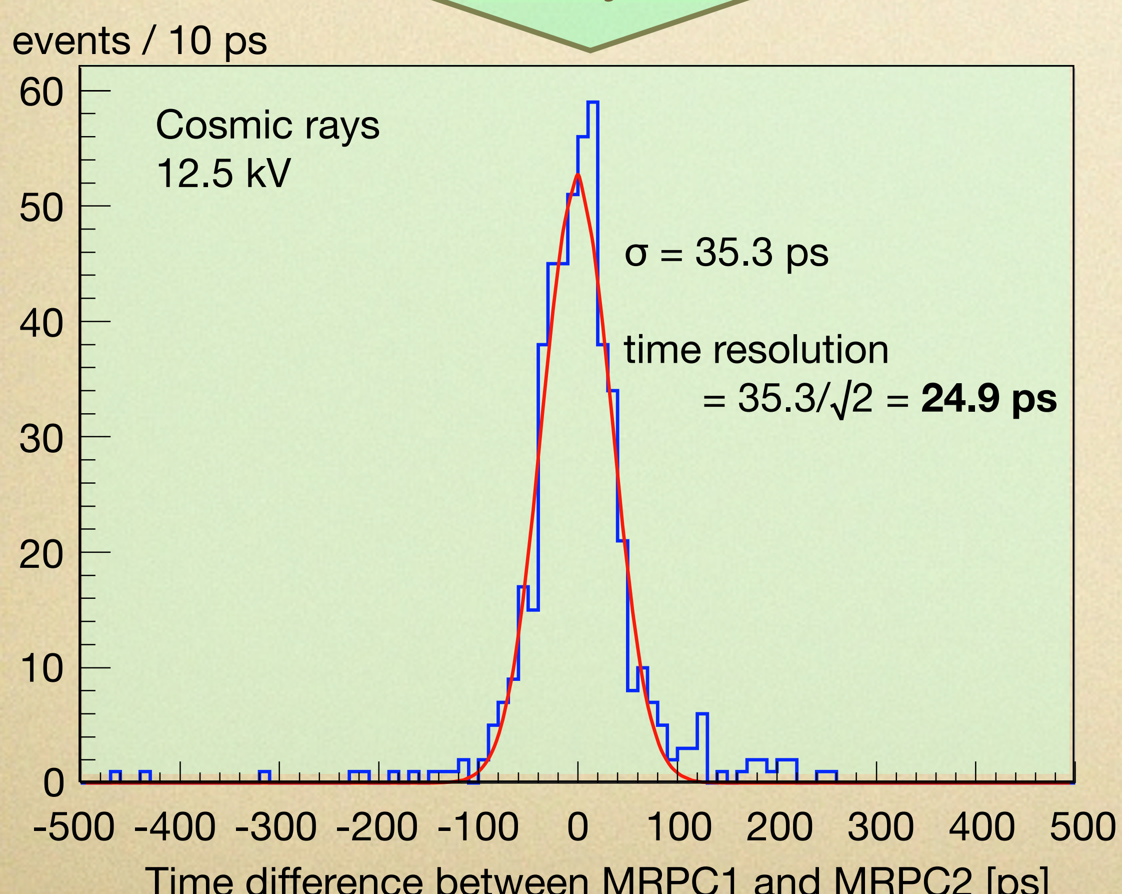
- tdc time resolution (time difference between two channels) ~~30 ps~~
  use oscilloscope (4 ch tdc) 5 ps
- beam spot 1 cm in size (50 ps/√12) ~~14 ps~~
  read out both sides of pad 5 ps
- NINO ASIC + cables + interface card ~~21 ps~~
  mount NINO on mrpc (also faster rise time) 5 ps
- intrinsic MRPC time resolution ~~20 ps~~
  24 gaps of 160 micron 9 ps

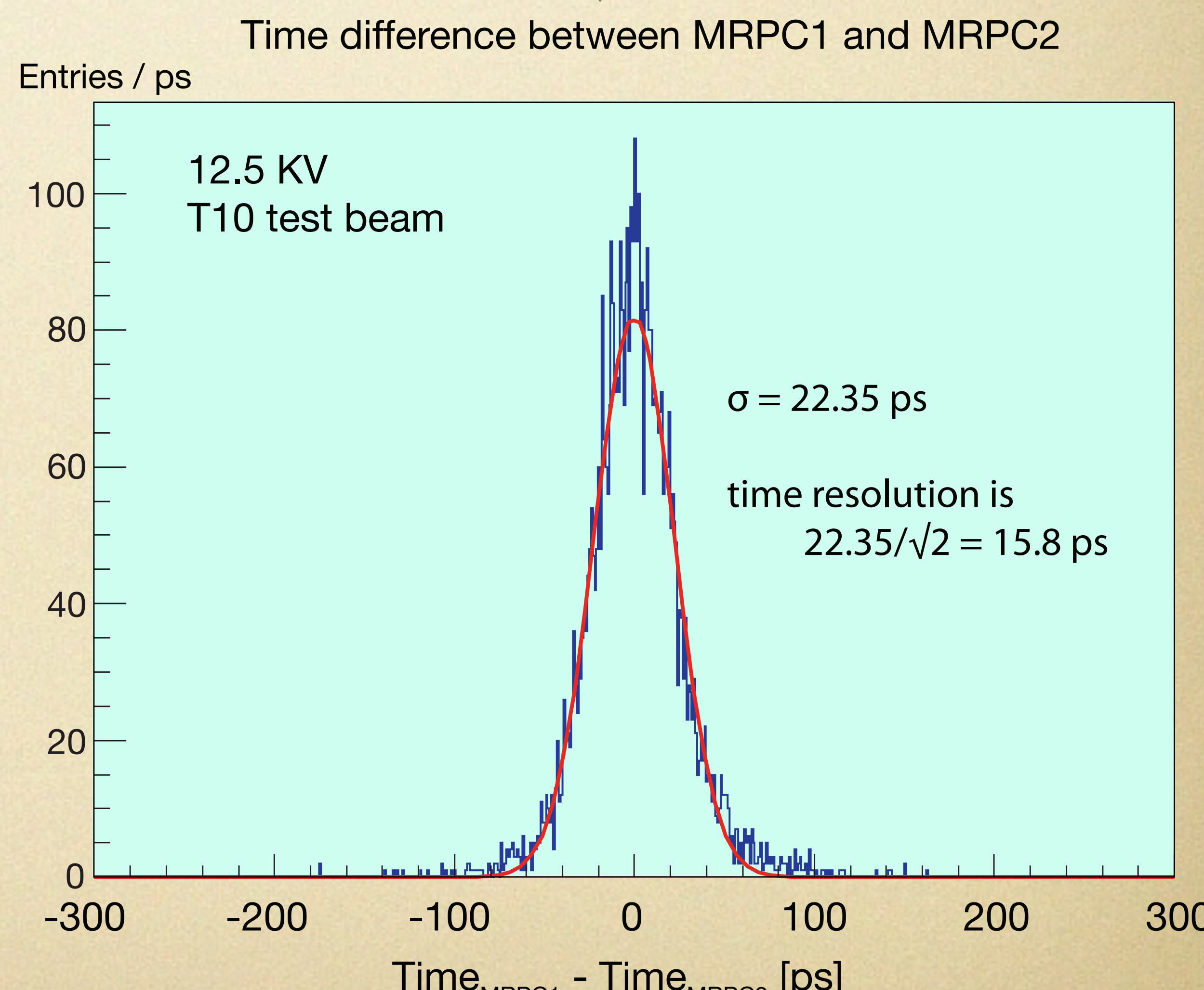
- total $\sqrt{(5^2 + 5^2 + 5^2 + 9^2)}$ = 12.5 ps expected from 24 gaps of 160 micron



T10 test beam

Cosmic ray





issues concerning gas detectors for CMS timing:

- good timing achieved using many gaps
- resistivity of glass in RPC an issue for high rates. Crispin works with known technology for optimizing timing (limited to ~kHz/cm^2). New glasses could ("comfortably") achieve 100 kHz/cm^2
- maybe should also hear from Giomataris(micro-megas)
- in any case, much useful experience on large systems

photodetectors

- limited work on isochronous optics
- MCP PMT has gotten a lot of attention but:
  - no experience in large collider systems (most R&D with few channels, in PET mostly single Na^22 source and 2 channels)
  - notorously expensive and limited, by PMT lifetime issues, to low rate
  - should hear more from Matt/Henry about status at Chicago

alternative photodetectors

- SiPM:
  - Up to now, not comparable in single photon time response(SPTR) (~100-300 picosec)
  - but incremental improvements in trace variations and time uniformity within pixel (should hear from Yamamoto and Sensl)
- HAPD:
  - our group worked with Hamamatsu on a device and obtained 11 picosec SPTR with >240 Coulomb lifetime (3 orders of magnitude better than standard MCP PMT)

What about direct charged particle timing?

- Some LHC work (ATLAS, CMS) on CVD diamond for BCM.
- In principle rad hard and fast
- nothing written yet in ATLAS but some results from HADES (Heavy Ions) who obtained 120 picosec with 0.5mm CVD and SNR for protons of 27:1. They project an ultimate time resoluion of 65 picosec rms
- other candidates: GaAs, SiC, etc

Are there viable silicon candidates?

- our group has focused on deep-depleted APD (RMD)which, in principle, have ultimate time resolution
  - radiation tolerance calculated using CMS APD scaling rules, test in October
  - 6,000 e-h pairs for 1 MIP, internal gain of 100s, risetime ~0.5 nsec

calculations

Design of a 10 picosecond Time of Flight Detector using Avalanche Photodiodes

Sebastian White, Mickey Chiu, Milind Diwan, Grigor Atoian, Vladimir Issakov

(Submitted on 16 Jan 2009)

We describe a detector for measuring the time of flight of forward protons at the Large Hadron Collider (LHC) up to and beyond the full instantaneous design luminosity of 1034 cm−2 s−1. Our design is based on deep diffused, high gain avalanche photodiodes (APDs) which give a signal of ~6000 e when traversed by 7 Teravolt protons. We observe pulse risetimes of 650 psec and a pulse width of 5 nsec and calculate a time resolution of ~10 psec and a maximum count rate of >100 Mhz.

Comments: 6 Pages, 3 figures
Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)
Cite as: **arXiv:0901.2530 [physics.ins-det]**
(or **arXiv:0901.2530v1 [physics.ins-det]** for this version)

Submission history

From: Sebastian N. White [view email]
[v1] Fri, 16 Jan 2009 17:22:21 GMT (205kb)

assuming annual dose of
5*10^13/cm^2 hadrons(or ~8.5 10^13 n/cm^2)==>

Pulse width	5 nsec
f (excess noise factor)	2.2
$I_{surface}$	1,700 pA/mm^2
I_{Bulk}	7 pA/mm^2
$I_{bulk}(-30^\circ C)/I_{bulk}(22^\circ C)$	1/200

With leading edge timing the noise jitter is [1]

$$\delta t=\sigma(e)/(d(\text{Amplitude})/dt)$$

where $d(\text{Amplitude})/dt = N_{e\text{-}h}/\tau_R$

and τ_R is the signal risetime. In our case the dominant noise contribution is from leakage current:

$$\sigma_{leakage}^2(e)=(I_{surface}/G^2+I_{bulk}*f)*\tau_{shaping}/q_e$$

so the noise limit to the time jitter at –30°C and after 10 years of irradiation is

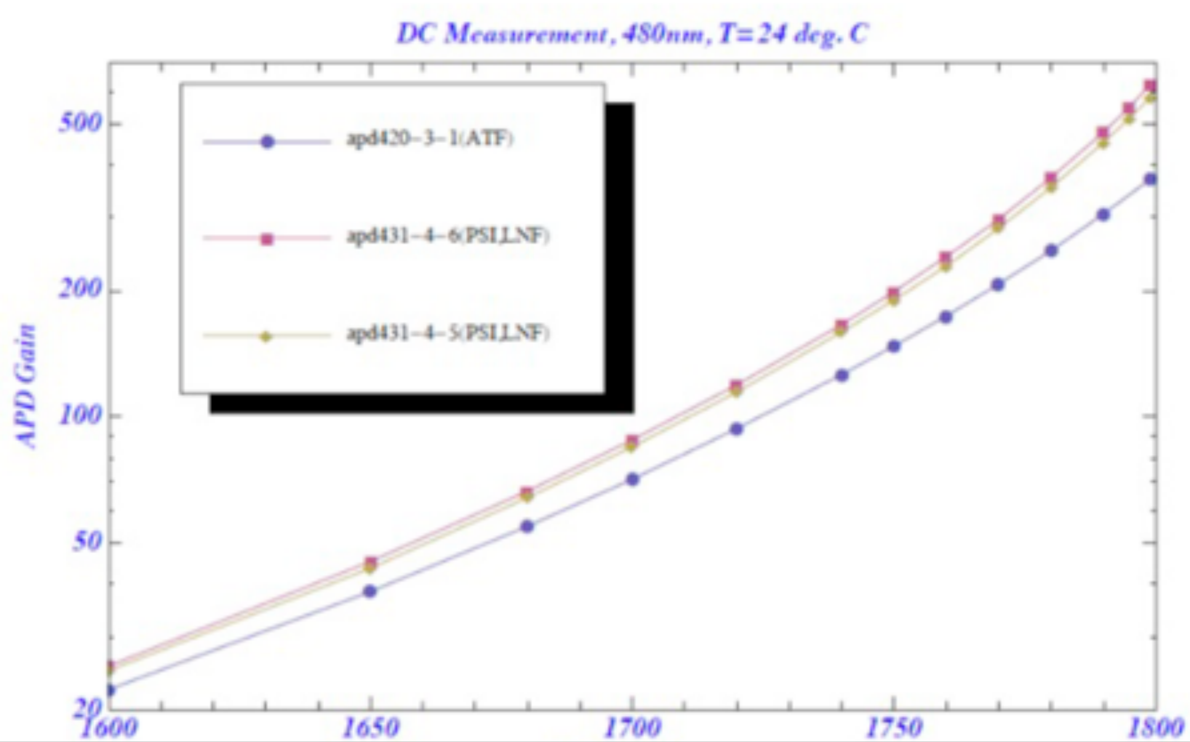
$$\delta t=48e/6000e*\ \tau_R= 5.2 \text{ psec}$$

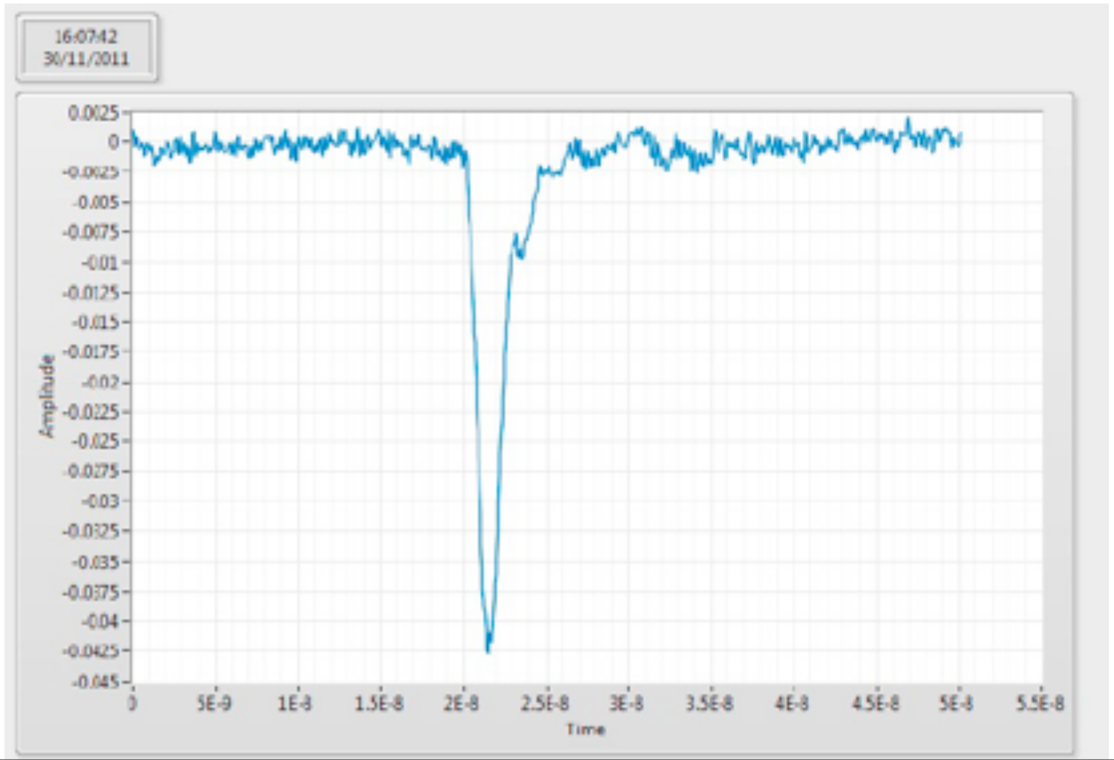
As mentioned before, the amplitude jitter, which has contributions from gain nonuniformity(<3%), excess noise factor (<2%) and the Landau distributed fluctuation of energy loss (18%) totals 18%. We therefore need to correct for walk to a level of 0.18*650 psec/10 psec or ~11. This is roughly what was achieved in ref. [3].

measurements:

Test Beam:

- 2009-2010- Accelerator Test Facility
- fall 2011:CERN PS, PSI, Frascati
- 2012: beta source data at CERN and Princeton
- last month: femtosecond laser tuned to signal size and depth profile (1000nm) of 1 MIP





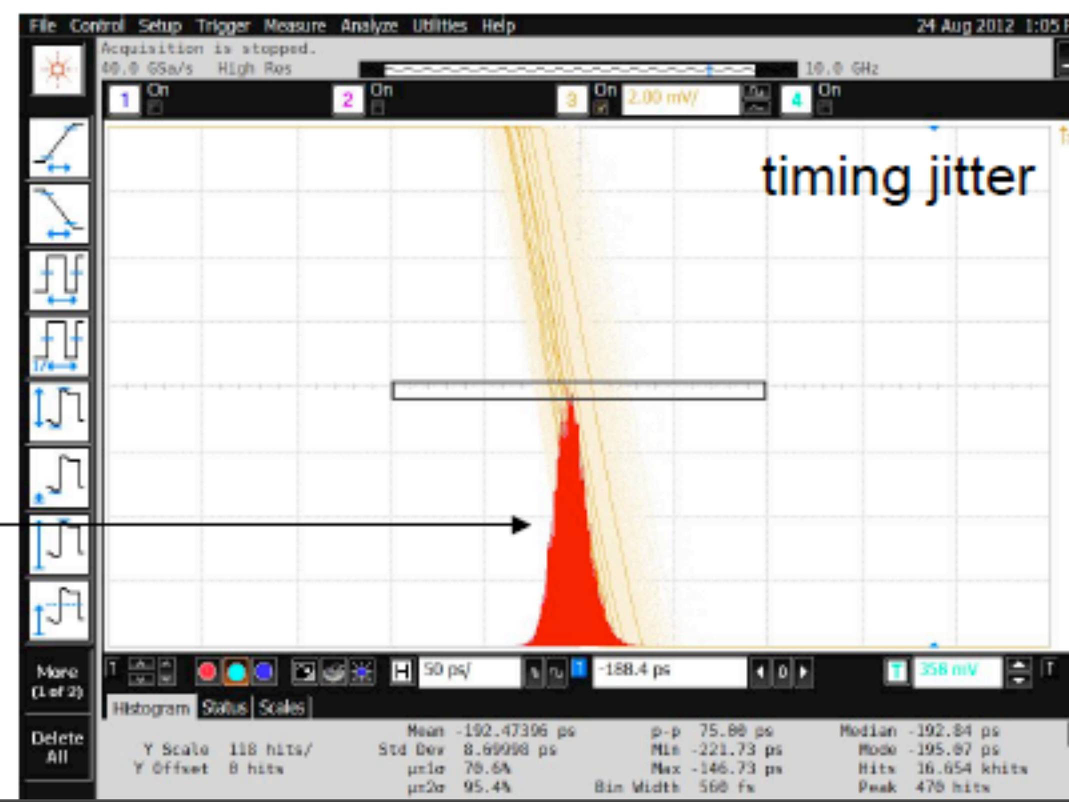
August 24, 2012 APD timimg jitter on Agilent DSO91304A 13 GHz oscilloscope

Laser: **1000 nm, ~ 2 μW, 1.3x10^5 photons/pulse**

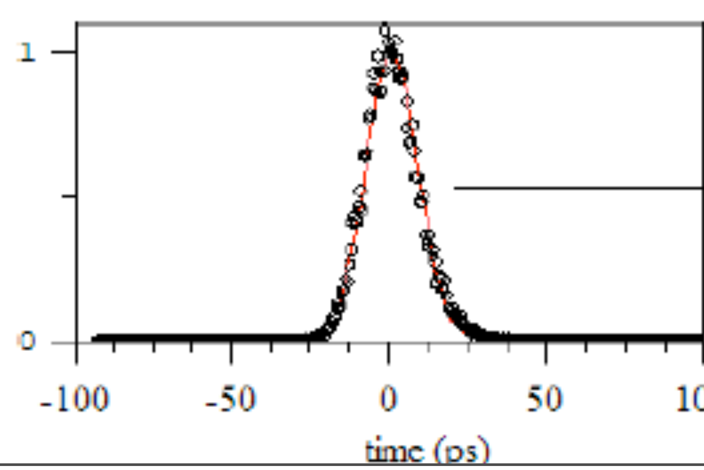
Trigger: ET2010 photodiode, t_r=120 ps

Signal: RMD APD + Ortec 9306 preamp

HV bias on APD -1.85 kV



timing jitter t_{rms}=8.28 ps



near term plans

- continued laser work to characterize current APD structures for uniformity of time response
- test beam at CERN with Saclay and TOTEM
- radiation damage test by Iouri up to few 10^12
- battle test in LHC before LS1
- collaborative work with RMD to optimize sensors
- discussions on other candidate technologies