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A Differential Time-of-Flight Technique for Collider Detectors

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The growth of capabilities of large particle detectors at high-energy collider accelerators is truly remarkable- the contrast in capabilities between ATLAS and CMS, and UA1, UA2, or Mark-I, for example, is a testament to the technical and managerial strengths of the field of HEP. However, while the development of the measurement of particle 3-vectors has been the subject of a large investment, the measurement of 4-vectors has languished. These big detectors are precision tools, and are capable of reconstructing invariant masses at great precision from combinations of tracks. The particle mass for a given track is the only information other than spin that remains to be measured. To get our money's worth we should extract all the information available from each and every collision.

In addition, for hadron colliders, as the achievable luminosity rises the problem of the association of particles with the correct one of many vertices becomes severe, and can limit the precision as well as lead to errors in track and event reconstruction. Associating photons with vertices, as one might want to in events with high P_T photons in possible Higgs, KK, or gauge-mediated SUSY signatures, has been even more difficult. Psec-resolution timing adds another, strong, constraint on the vertex position for both charged particles and photons.

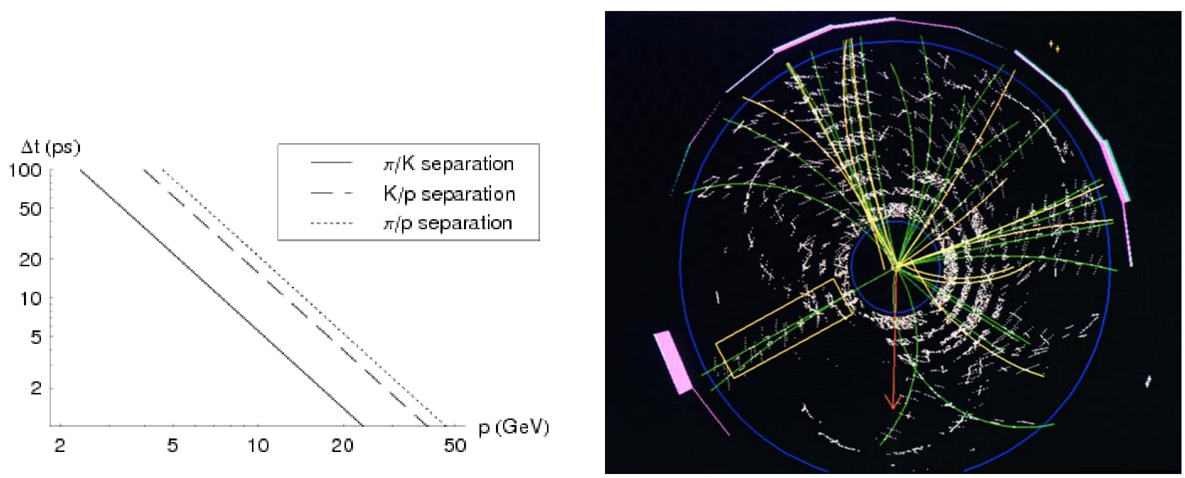

Figure 1: Left: The delay in arrival in psec of pions, kaons, and protons compared to the photon arrival time, vs the log of the transverse momentum. Right: A top event from CDF showing the tracks and photons arriving at the outer radius of the solenoid coil. The differential timing proposal for a collider detector would implement fast timing 'tiles', with the local (space and time) calibration being given by the difference in arrival times of charged particles and the nearby photons or electrons used for calibration for a given vertex.

In addition to precision reconstruction and parton flavor-tracking, precise timing allows searches for new heavy or metastable particles that arise in the many models of new physics.

The recent work on psec or sub-psec timing opens the possibility of large-area TOF systems for colliders [1, 2, 3, 4]. A resolution of 1 psec gives 1-σ separation of pions and kaons at $P_T = 21$ GeV, as shown in Figure 1.

With large signals, such as one would expect from a Cherenkov radiator faceplate traversed by a charged particle at a collider, the LAPPD Collaboration has achieved a resolution of ≤ 5 psec on the difference of pulse arrival times at opposite ends of an 8" 'frugal' glass anode [5], driven by a pair of MCP plates with 20μ pores [6]. Improvements in pulse fitting and noise reduction in the present setup should reduce this to a few psec or less.

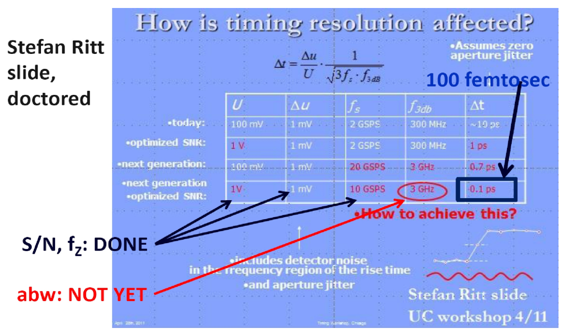

Figure 2: A simple but intuitive parameterization by Ritt [7] of the time-of-flight precision versus the analog bandwidth, signal-to-noise, and waveform sampling rate.

Figure 2 shows a simple but well-motivated parameterization by Ritt [7] of the time-of-flight precision versus the analog bandwidth, signal-to-noise, and waveform sampling rate. If one holds the number of samples constant, this 'rule-of-thumb' translates into the resolution depending linearly on the risetime and inversely on the S/N-ratio. Risetimes of 60 psec have been achieved [8], and signal-to-noise ratios appreciably greater than 100 have been measured with sampling rates exceeding 10 GS/sec [9]. Looking at the bottom row of the table in Figure 2, the extrapolated timing resolution is significantly less than 1 psec [10]

Beyond this, we have now a good understanding of the determining factors for better time resolution [11, 12]. Higher-bandwidth anodes [13], faster rise-times (i.e. higher band-widths) from smaller pores [8], and customized secondary-emitting structures [14] have the potential of moving solidly into the regime of sub-picosecond TOF resolution.

However, even if this can be achieved locally, it will be very difficult to build a large TOF system that has a precision of 1 psec or better over long times and large detector subsystems. The proposal here is 'differential TOF', in which the time-of-arrival of particles is measured relative to the first particles from the same vertex to arrive nearby at the TOF counters. Thus the first particles should be photons and electrons, followed by muons, pions, kaons, protons, etc., depending on momentum. The differences in timing are small, as shown in Figure 1; the goal is to measure them directly. This reduces both the requirements on stability vs time of the clock reference and of the cross-calibration over the detector, as the former are short, and the latter are local and involve only a local, shared, clock.

The first step in testing the concept will be in a test beam, with several stations of LAPPD or equivalent counters in close proximity. The next step, presumably, would be to test several LAPPD tiles in either a test beam with a target to measure TOF with multiple particles from a common vertex, or as a test in an active experiment [15].

I thank all my LAPPD collaborators for their essential contributions on which the

idea of differential TOF at colliders rests.

References

[1] *Visions of Experimental Particle Physics - Where Are We Going?* (Invited Summary Talk, Aspen Winter Conference; January 26, 2003).

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[3] K. Inami, N. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima; Nucl. Instr. Meth. A560, p.303, 2006

[4] The original LAPPD institutions include ANL, Arradiance Inc., the Univ. of Chicago, Fermilab, the Univ. of Hawaii, Muons,Inc, SLAC, SSL/UCB, and Synkera Corporation. More detail can be found at http://psec.uchicago.edu/.

[5] *RF strip-line anodes for Psec large-area MCP-based photodetectors*; H. Grabas, R. Obaid, E. Oberla, H. Frisch, J.-F. Genat, R. Northrop, F.Tang, D. McGinnis, B. Adams, M. Wetstein; Nucl. Instr. Meth, Feb., 2013

[6] The glass capillary substrates are produced by Incom Inc. Charlton Mass. See http://www.incomusa.com/.

[7] S. Ritt, in *The Factors that Limit Time Resolution in Photodetectors*; Workshop, Univ. of Chicago, Chicago, IL; 28-29 April 2011. See http://psec.uchicago.edu/workshops/ Note that of the values needed of the four parameters to achieve a time resolution of 100 fsec (the bottom row of the table of extrapolations), we have achieved or exceeded three: sampling rate, noise, and signal size. Only the analog bandwidth falls short at present.

[8] J. Milnes and J. Howorth (Photek Ltd.), "Advances in Time Response Characteristics of Micro-channel Plate PMT Detectors". See http://www.photek.com/support/technical_papers.htm (website says: 'Ref. not yet available').

[9] E. Oberla, *A Fast Waveform-Digitizing ASIC-based DAQ for a Position & Time Sensing Large-Area Photo-Detector System*; Photodet2012, LAL Orsay, France; June, 2012

[10] At the predicted level of 100 fsec many new system factors will come into play; the point is that the intrinsic resolution of the detector itself will be very small, and substantial effort should be devoted to the other limiting factors.

[11] J.-F. Genat, G. S. Varner, F. Tang, H. Frisch; *Signal Processing for Pico-second Resolution Timing Measurements*, Nucl. Instr. Meth. A607, p387, Oct. 2009; e-Print: arXiv:0810.5590

[12] For a discussion of the factors that determine time and space resolution in MCP-based detectors, see the talks at: *The Factors that Limit Time Resolution in Photodetectors*; Workshop, Univ. of Chicago, Chicago, IL; 28-29 April 2011. See http://psec.uchicago.edu/workshops/

[13] L. Sadwick, R. J. Hwu, H. Frisch; *A High Bandwidth LAPPD Anode*; 2012 DOE STTR.

[14] J.W. Elam, J. A. Libera, M.J. Pellin, and P.C. Stair, "Spatially Controlled Atomic Layer Deposition in Porous Materials", Applied Physics Lett., 2007 **91** (24)

[15] A short test measuring TOF of converted photons to reconstruct pizero decays at KOTO at JPARC would be very interesting, as the photons would give large signals and hence large S/N.