Project X Physics Study: Time-of-Flight Group Study Summary

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I. Topics

During the workshop the Time-of-Flight group had talks and discussions covering the following topics:

1. Timing needs for rare decays: $\mu \to e\gamma$, $\mu \to eee$, $K_L^0 \to \pi^0 \nu\bar{\nu}$, $K^+ \to \pi^+ \nu\bar{\nu}$
2. Timing needs for n-nbar oscillation search
3. Timing detectors for forward physics: QUARTIC (CMS), AFP (ATLAS)
4. Precision timing detector development: Large Area MCPs (LAPPD), Gigatracker (hybrid silicon pixel detector)
5. Test beam timing capabilities
6. Timing for accelerator development: ultra-fast lasers, MCP timing for muon cooling

II. Timing for Rare Decays

The high beam fluxes that Project X will make available will provide opportunities to push the limits on many rare or forbidden decay processes. Typically rare decay experiments demand high rate capability for all detectors with timing detectors being no exception. Fritz DeJongh covered timing possibilities for $\mu \to e\gamma$ which aims to reach 10^{-16} sensitivity. A low mass pixel detector could be used to make multiple measurements of helix trajectories in a solenoidal B field for the decay products from a stopped muon beam. Time-of-flight resolution of ~20ps would be required to separate ambiguities in path length differences. Gammas would be converted in an inner cylindrical layer allowing identification and measurement of the e^+e^- pair. Low mass and high rate are critical requirements.

Laurie Littenberg covered the search for $K_L^0 \to \pi^0$ nu nubar. This requires identification of the decay π^0 with high rejection of backgrounds that produce π^0's. Precision measurement of energy, position, direction and time are all necessary; again in the presence of very high beam rates. Mike Albrow discussed a possible scheme for an EM calorimeter that might have application for a KOPIO type experiment using a Shashlik design for energy measurement and large area MCP-PMTs for good timing.

The Gigatracker (Bob Velghe) is aimed at the measurement of $K^+ \to \pi^+$ nu nubar. The tracker will provide momentum ($\delta p/p$~0.2%), timing (σ~200 ps) and direction for the beam ($\sigma(\theta_K)$~16μrad). The tracker is required to be thin to reduce inelastic scatterings and, hence, employs a hybrid silicon pixel detector of 200μm thickness with 18k 300×300μm^2 pixels. The total material in the beam for each tracker is <0.5% X_0. Micro-channel cooling of the detector is being considered as an option. A prototype has been studied in the CERN test beam and achieved a resolution of 175ps. Having met the specifications with the prototype, a full scale detector is now being built.

III. Timing for n-nbar Oscillations

Yuri Kamyshkov discussed timing needs for an n-nbar oscillation search. The experiment relies on nbar + C $\rightarrow 5\pi$ and uses a backgroundless detection. A tracker is used to reconstruct the vertex in a thin carbon target. The timing precision is not stringent and measures time-of-flight before and after the tracker to remove vertices of particles coming from outside. Scintillation counters with conventional PMTs give δt~900ps which is considered adequate.

IV. Timing Detectors for Forward Physics

Andrew Brandt and Mike Albrow discussed their respective detectors for forward physics for ATLAS and CMS. The detectors are used to determine the beam interaction longitudinal coordinate ("z") requiring a timing resolution of ~10ps giving δz~2mm. Rejection of pile-up background is also provided. Operation close to the beam (4mm) requires radiation hardness and high rate capability. The QUARTIC (Quartz Timing Cherenkov) detector uses quartz bars oriented at the nominal Cherenkov angle for beam protons (48°) giving an approximately isochronous wavefront. The Cherenkov light is detected using a commercial micro-channel plate photomultiplier. Timing resolution of 27ps/bar is obtained with 8 bars provided the required 10ps resolution. For the AFP (ATLAS Forward Proton) detector, SiPMs are used coupled to an "L"-bar quartz radiator. This allows the SiPMs which are not rad-hard to be far from the beam. Single bar resolution of ~35ps has been measured.

V. Precision Timing Detector Development

In addition to the Gigatracker which provides high precision timing with high rate capability for small areas, the development of large active area (20cm×20cm) micro-channel plate detectors was discussed by Andrey Elagin. The innovation that allows for fabrication of large MCPs is production of the substrate using inexpensive hollow core borosilicate glass capillary arrays which are subsequently functionalized via atomic layer deposition (ALD). Gains of up to 10^7 have been demonstrated recently by the LAPPD collaboration. A working sealed large area tube is expected to be produced by the end of the year. Since larger scale production is expected to be several years in the future, the detectors would be suitable for incorporation into experiments planned for initiation on a 5 year time scale. This may fit well with some proposed experiments at Project X.

VI. Test Beam Timing Capabilities

Erik Ramberg nicely summarized the timing studies and capabilities at the Fermilab test beam. Photek MCP photomultiplier have been used for studies of both quartz bars and aerogels. Time resolution of 24ps was obtained with the quartz; 45 ps single pe resolution. In addition, silicon photomultipliers (SiPM) have been characterized in the test beam with 15ps intrinsic resolution. Work on a 3D ASIC for SiPM is ongoing with a promise of using the SiPM as the digital photon counting device that it actually is.

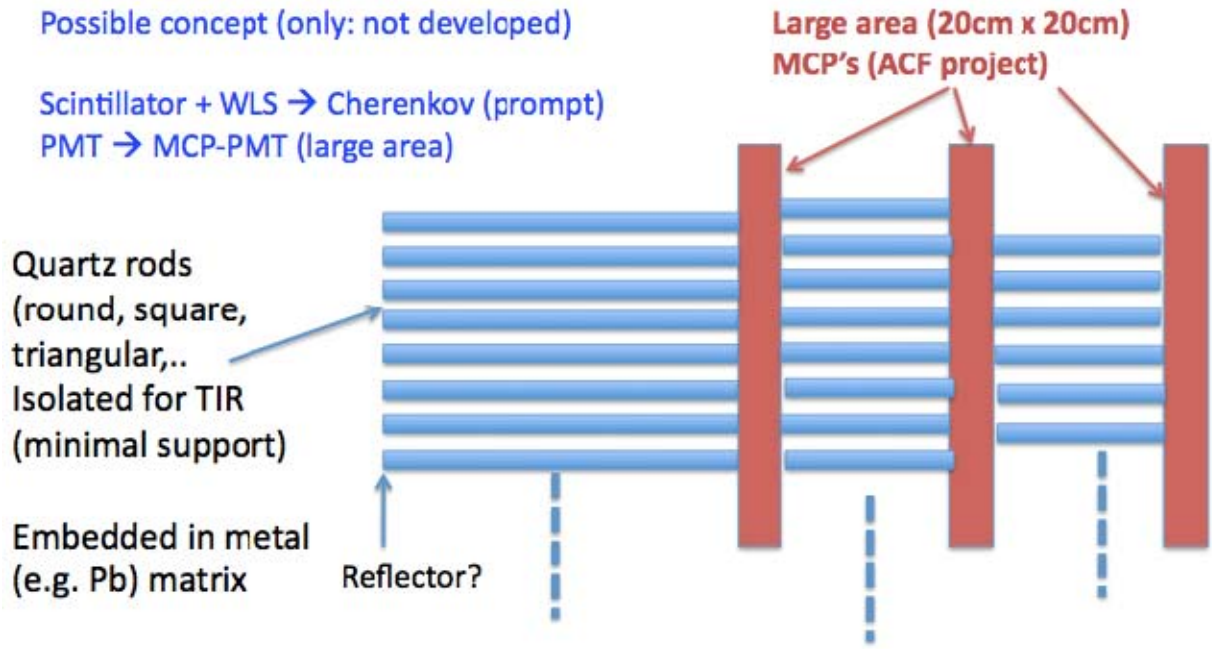
VII. Timing for Accelerator Development

Muon cooling experiments aimmed at an eventual muon collider use timing to determine the phase space and emittance, e.g. MICE. Time resolutions of 50-60ps and spatial resolution of a few centimeters have been obtained with fast scintillator and PMTs. This is an area where the Large Area MCP Photodetector could improve capabilities. Vic Scarpine discussed accelerator timing applications for ultrafast lasers. The goals are stable timing and synchronization, and high precision time-of-flight. Pulses of tens of femtoseconds in width are now possible. Vic outlined the scheme for doing bunch arrival time monitoring with such lasers. If the need arose for Project X, it might be possible to time events with ~10fs precision.

Roadmap for Time-of-Flight for Project X

The most relevant use of time-of-flight detection for Project X experiments appears to be for rare decay experiments and, in particular, rare kaon decays. Since Gigatracker as described by Bob Velghe is something that is already in construction for $K^+ \rightarrow \pi^+$ nu nubar, time-of-flight for K_L^0 -> π^0 is the main area needing development. For pi zero identification and rejection of the large background for alternative pi zero sources, it is necessary to have complete precision reconstruction of the pi zero (energy, position, direction, and time-of-flight). An obvious choice for precision timing would the use of the large area picosecond MCP photodetector. Since the timing is best done with the MCP operating in saturation mode, this is not a useful device for calormetric energy measurement. A hybrid of a scintillation calorimetry readout by conventional photomultipliers integrated with MCP time-of-flight measurement is a possibility and a possible concept was outlined by Mike Albrow (see accompanying figure). Dual readout crystal calorimetry with PMTs providing energy measurement and MCP giving timing via the Cherenkov light seems a possibility. Timing development of large area MCPs will proceed independent of the Project-X schedule. Rate capabilities are a limitation

Shashlik design: absorber plates alternating with scintillator plates,
read with longitudinal WLS fibers to conventional PMTs $\sigma(t) = 90ps$ claime
For $K^0 \rightarrow \pi^0 \upsilon\upsilon$ need to reconstruct photons and so π^0 as well as possible.

Possible concept (only: not developed)

Scintillator + WLS → Cherenkov (prompt)
PMT → MCP-PMT (large area)