QUARTIC Front-end Readout – Initial Steps

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For the QUARTIC Working Group

The QUARTIC Working Group

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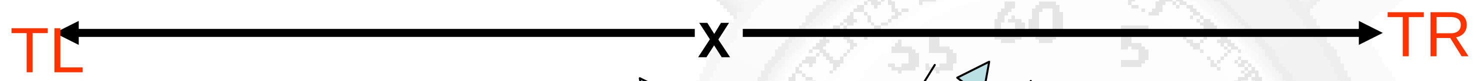
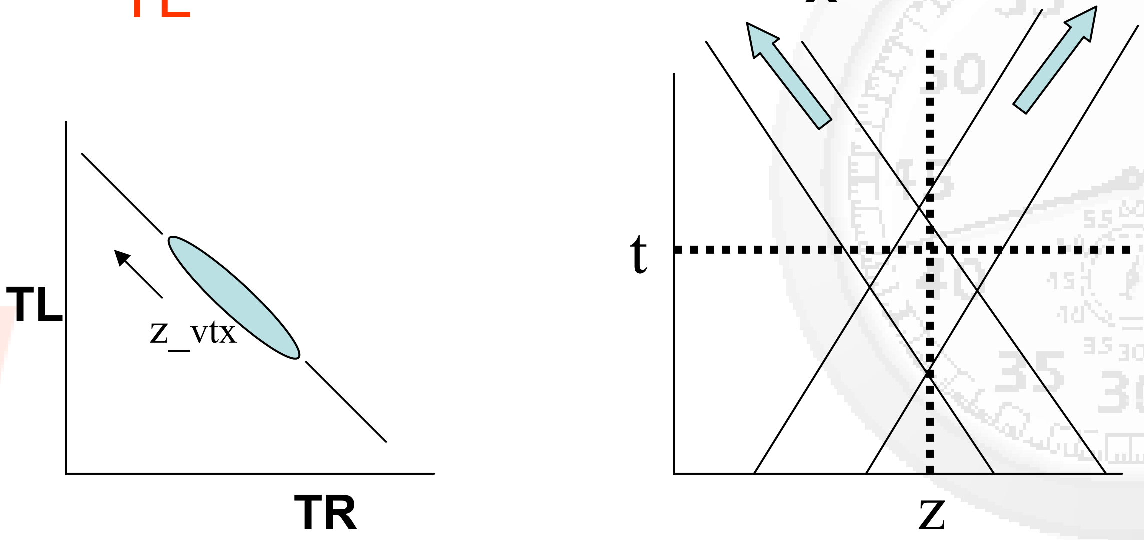
Associated Group

- University of Louvain: Krzysztof Piotrzkowski

Initial Conception of Quartic

- AIM: Use a precise ToF Cerenkov detector to match z(vertex) with central track vertex and thus reduce backgrounds to, for example, exclusive diffractive Higgs production
- Z of interaction = c(TR-TL)/2 where TR(TL) is the time measured in the RHS(LHS) QUARTIC detectors (420m from IP) -

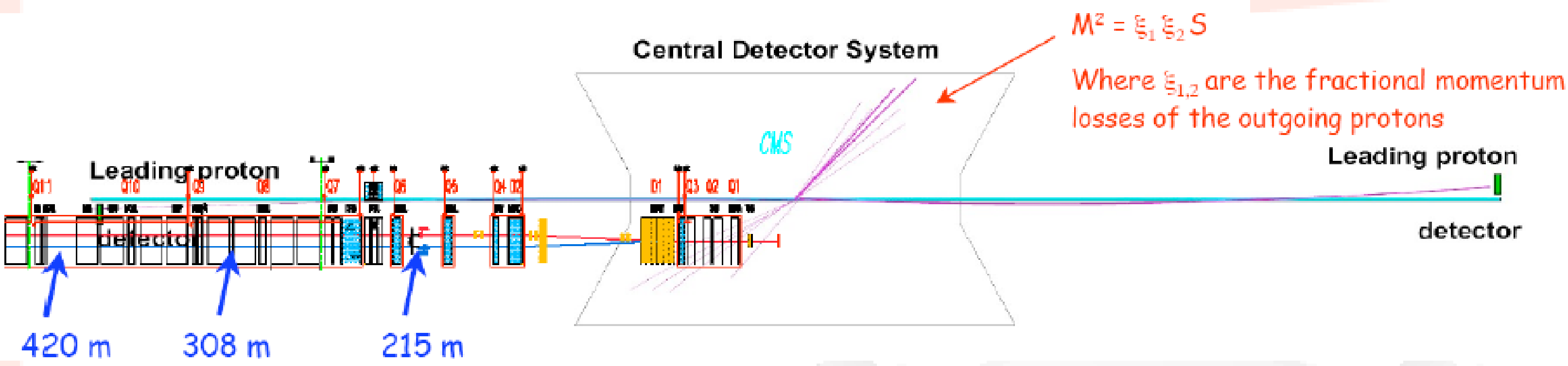


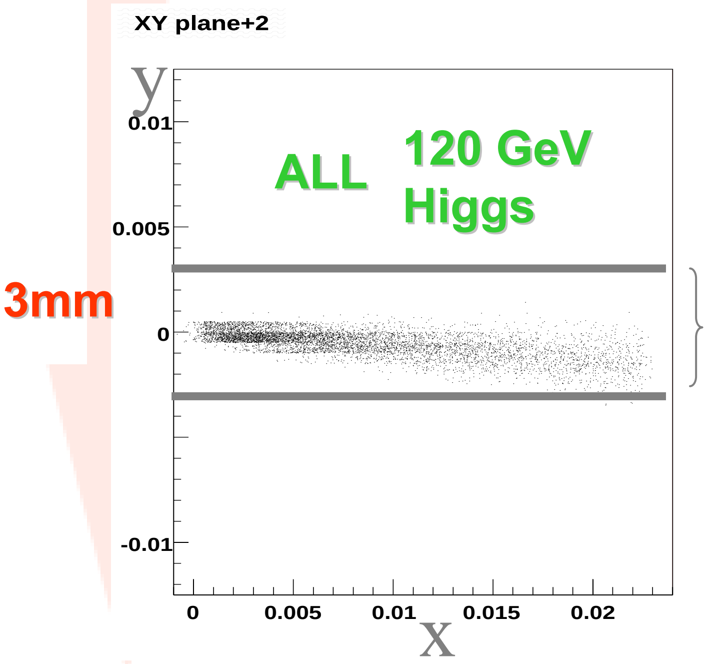


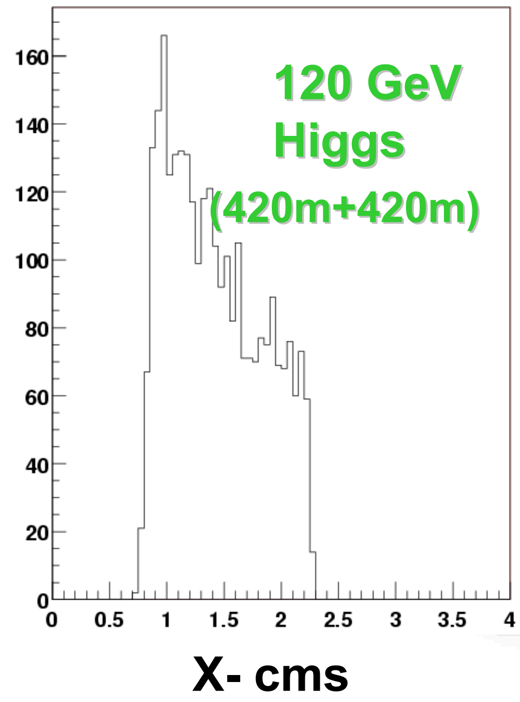
We are aiming for ~10ps resolution (3mm at the speed of light)

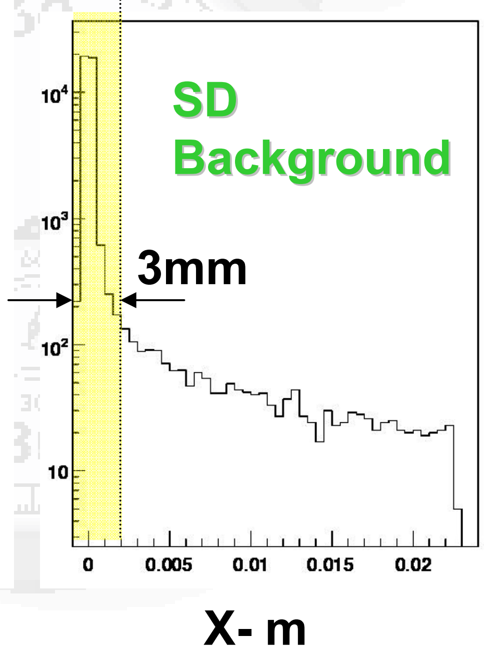
- **We have Δz (mm) =0.21 Δt (psec) (2.1 mm for Δt=10 ps [$c\Delta t/\sqrt{2}$])**

Where do the Protons Go?









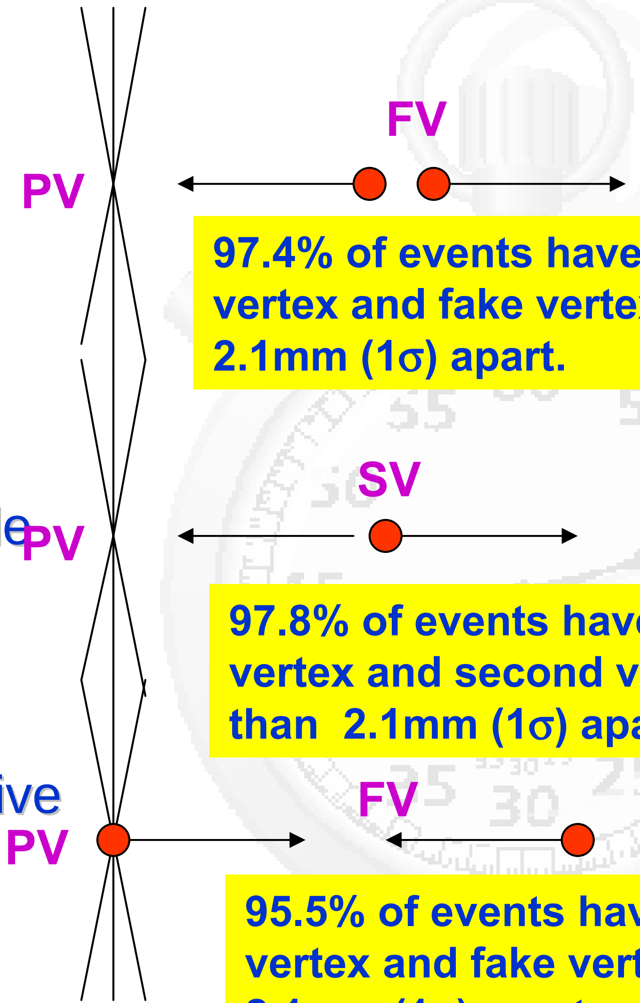
QUARTIC Background Rejection (1)

Rule of thumb: ~1% of interactions have a proton at 420m

A. 2 single diffractive protons overlapping a hard scatter

B. A hard scatter with an overlapping double pomeron event

C. A hard single diffractive event overlapping a soft diffractive event



97.4% of events have primary (PV) vertex and fake vertex (FV) more than 2.1mm (1σ) apart.

97.8% of events have primary (PV) vertex and second vertex (SV) more than 2.1mm (1σ) apart.

95.5% of events have primary (PV) vertex and fake vertex (FV) more than 2.1mm (1σ) apart.

Background Rejection (2)

δt	A	B	C
10ps	97.76%	97.42%	95.52%
20ps	95.52%	94.83%	91.06%
30ps	93.29%	92.25%	86.62%
40ps	91.06%	89.68%	82.22%
50ps	88.84%	87.12%	77.88%
100ps	77.88%	74.57%	57.43%

Background rejection

A. Two single diffractive protons overlapping a hard scatter
B. A hard scatter with an overlapping double pomeron event
C. A hard single diffractive event overlapping a soft diffractive event

Achieved – a 10ps Timing Resolution

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MCP-PMT timing property for single photons

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Abstract

We have measured the performance, especially the timing properties, of micro-channel plate photo-multiplier tubes (MCP-PMTs) by irradiating with single photons with/without a magnetic field. A time resolution of $\sigma = 30$–35 ps was obtained for single photons under 1.5 T. With an MCP-PMT, a small time-of-flight counter, by means of Cherenkov light radiation instead of scintillation light has been prepared, and a time resolution $\sigma \sim 10$ ps was attained for a high-energy π-beam by multiple photons.

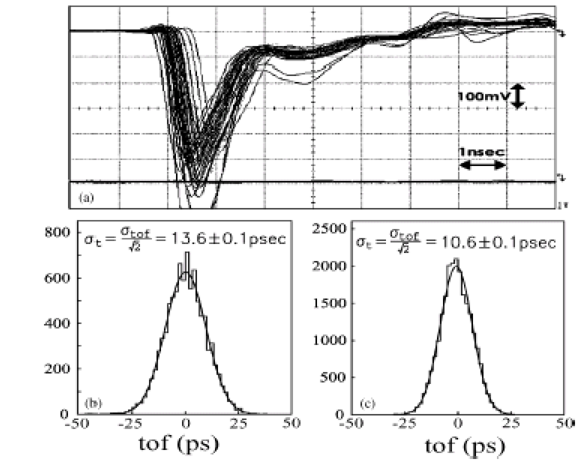


Fig. 13. (a) shows HPK 10s output signal for 3 GeV/c pion beam; (b) and (c) are the distributions of the time difference between two test counters without and with a quartz radiator, respectively. Their resulting time resolutions of the single counter are obtained as $\sigma_t = \sigma_{tof}/\sqrt{2} = 13.6\pm0.1$ ps and 10.6 ± 0.1 ps.

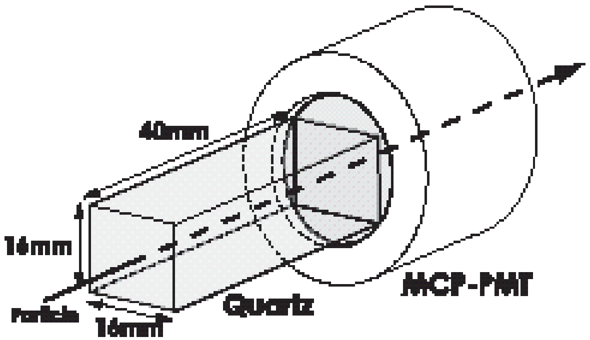


Fig. 12. Schematic drawing of the test TOF counter. HPK10 is used as the MCP-PMT.

The problem is we cannot put a PMT in a 7 TeV beam.

Frontend Readout With the HPTDC

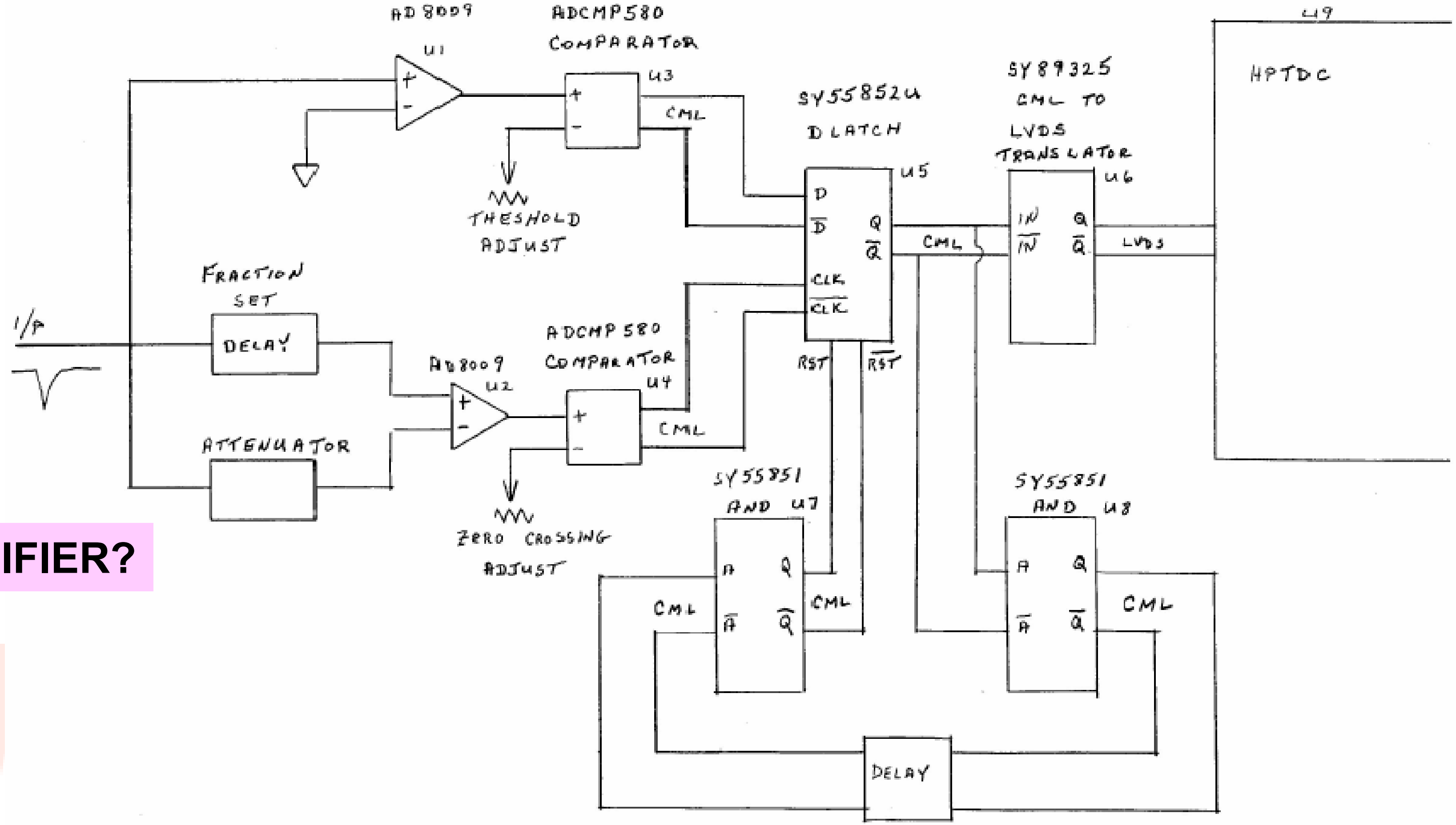
- High precision Alberta-GlueX CFD Aiming for 20-ps resolution.
- Using CERN HP-TDC as key component
- Initially we are assuming we have enough pe's so an ampplifier is not required
- Technical specification of HP-TDC
  - **32 → channels/chip。 Size～2.7×2.7 cm^2 。**
  - **External clock：40MHz。Synchronized to bunches.**
  - **Internal clock: 40MHz / 160 MHz / 320 MHz internal**
  - **Time Bin Size:**
    - **781 ps low resolution mode + 195 ps medium resolution mode**
    - **98ps high resolution mode**
    - **24 ps very high resolution mode (8 channels)**
  - **Time resolution: Typical values**
    - **0.34 bin RMS (265 ps) low resolution mode + 0.44 bin RMS (86ps) medium resolution mode**
    - **0.65 bin RMS (64ps) high resolution mode**
    - **2.4 bin RMS (58ps) very high resolution mode**
    - **0.72 bin RMS (17 ps) very high resolution mode (8 channels)**

HP-TDC Tech. Specs (continued)

- Crosstalk caused by logic core running at 40MHz. This can be corrected for using a simple table correction in the following data processing
- Variation with temperature: Maximum 100ps change with 10 Deg. change of IC temperature.
- Cross talk: Maximum 150 ps from concurrent 31 channels to one channel.
- Dynamic range:
  - **12 + 5 = 17 bit low resolution mode**
  - **12 + 7 = 19 bit medium resolution mode**
  - **12 + 8 = 20 bit (19) high resolution mode**
  - **12 + 8 + 2 = 22 bit (21) very high resolution mode.**
- Double pulse resolution: Typical 5 ns. Guaranteed 10ns
- Max. recommended Hit rate: Core logic at 40 MHz
  - **2 MHz per channel, all 32 channels used**
  - **4 MHz per channel, 16 channels used.**
  - **2 MHz per channel in very high resolution mode**

Readout Electronics (1st take)

Discrimination **Shaping** **HPTDC**



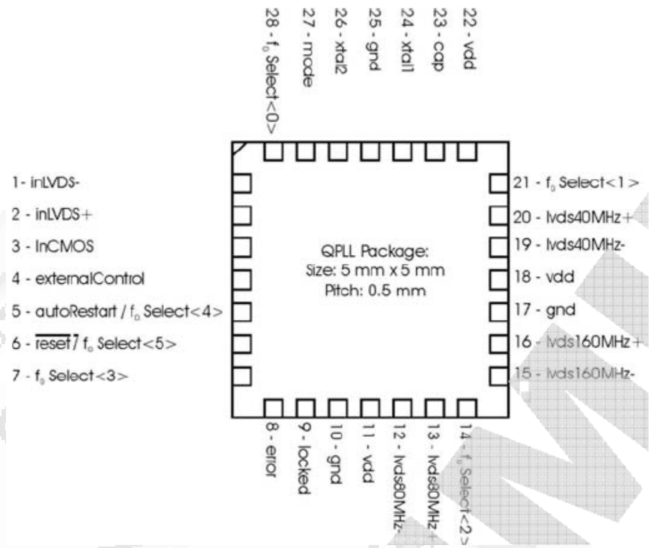
AMPLIFIER?

First Meeting on HPTDC

- Krzysztof Piotrzkowski and I met with the designer of the HPTDC chip - Alessandro Marchioro - in February 2006.
- He expressed the opinion that we (using the HPTDC) we should be able to get down to 20 ps with some work, 15ps with a lot more work, but he thought 10 ps would be extremely "challenging"
- We also discussed the problem of the time jitter on the LHC bunch crossing time (T0). He told us about the QPLL chip- containing a Quartz crystal based Phase-Locked Loop. Its function is to act as a jitter-filter for clock signals operating at the LHC clock frequency.
- He also stressed the need for fibre optic transmission of signals to FP420/QUARTIC
- *Alessandro expressed a willingness to work with us to update his chip based on new and interesting user requirements*
- Last but not least we walked away with 6 sample HPTDC chips!

The QPLL Chip

- The QPLL is a Quartz crystal based Phase-Locked Loop that act as a jitter-filter for clock signals operating at the LHC clock frequency. Features:
  - **Quartz crystal based PLL Operation frequency: f(LHC)=40.0786 MHz•**
  - **Two frequency multiplication modes(×4, ×2 and ×1•×3, ×1.5 and ×1)**
  - **Locking range: ..±4KHz**
  - **Loop bandwidth: < 7KHz**
  - **Output jitter: < 50 ps peak-to-peak for input signal jitter less than 120 ps RMS.**
  - **Power supply voltage: 2.5V**
  - **Power consumption: 100 mW**
  - **Reference clock inputs: LVDS & Single-ended 5V compatible**
  - **Three LVDS clock outputs**
  - **Radiation tolerant**
  - **0.25 µm CMOS technology**



Package: LPCC-28(5mm x 5mm, 0.5mm pitch)

One Approach to sub-20ps Timing

- One can tackle by developing the relevant technology to get down to ~10ps Δt resolution – which won't be easy.
- Another approach that might work is to make a number of independent measurements with resolutions of ~20 ps and average them
- This should be possible with the rather compact QUARTIC approach.
- This approach would require us to eliminate important sources of coherent noise – "or correlated influence" on the independent measurements.
- If this can be done it would seem to be the easiest approach to sub-20ps timing resolution.

Future Work

- Ascertain whether or not we can use signal direct from MCPMT
- If not identify a suitable amplifier
- Construct a prototype readout board
- Construct a test setup capable of measuring time resolutions down to the ~20 ps level
- Test the readout board and iterate
- PROBLEMS:
  - **The Centre for Subatomic Research has recently moved to a "decant" building – to await a new building**
  - **We lost 2-3 months packing up to move and we will likely be much less efficient during the unpacking phase (1-2 months)**
- However, we should be able to finalize the design of the first prototype board based on the HPTDC in the next few weeks
- The board layout will take around a month with board delivery another two weeks.
- Thus we could have the first FE readout boards by as early as the end of June 06.

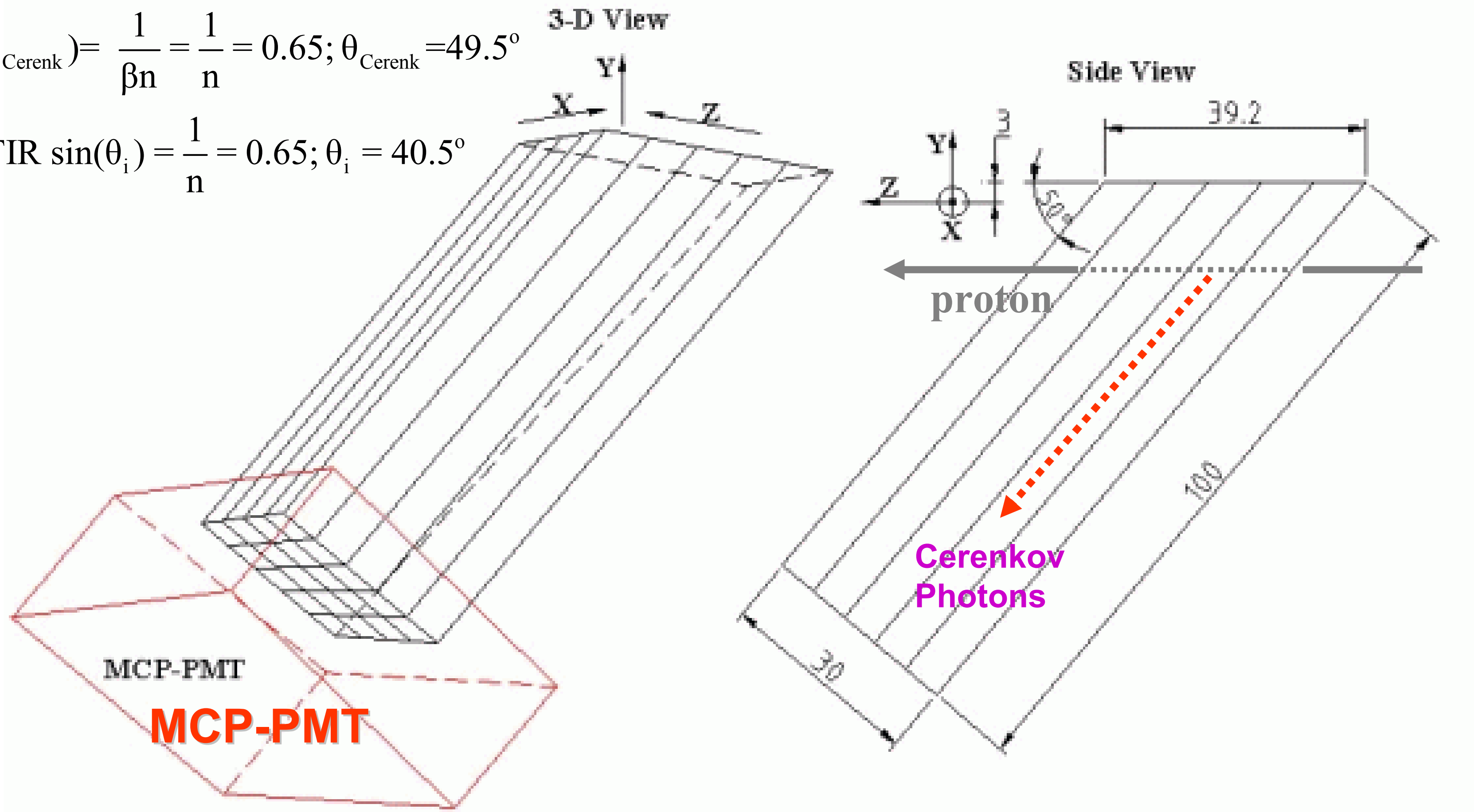
EXTRA SLIDES

Initial Geometry for QUARTIC

For quartz n(λ)~1.54

$$\cos(\theta_{Cerenk}) = \frac{1}{\beta n} = \frac{1}{n} = 0.65;\ \theta_{Cerenk} = 49.5^{o}$$

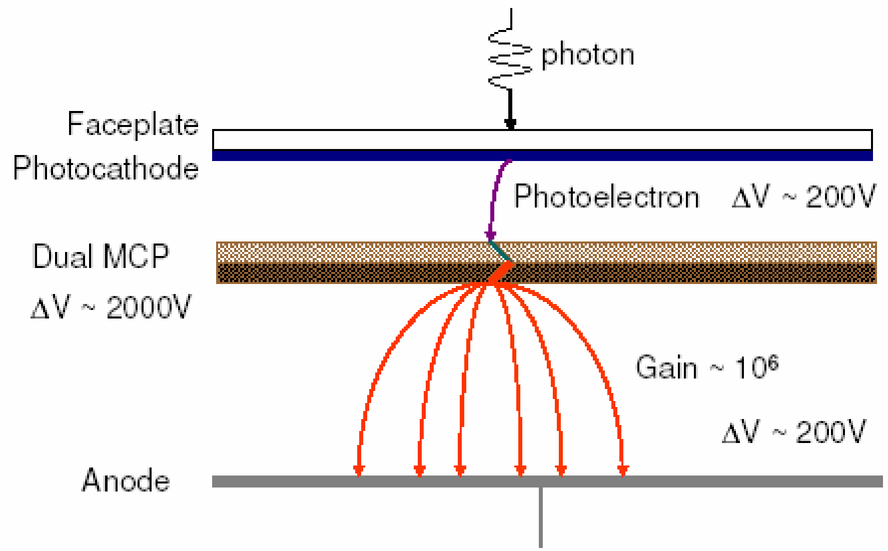
$$\text{For TIR } \sin(\theta_i) = \frac{1}{n} = 0.65;\ \theta_i = 40.5^{o}$$



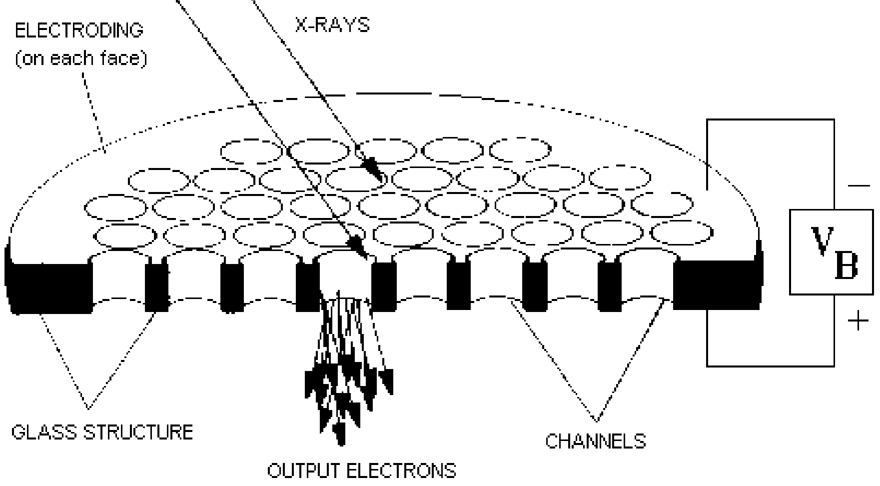
20 fused silica bars 6mm² x 100 mm

NB fused silica is rad-hard

What is a MCP-PMT?

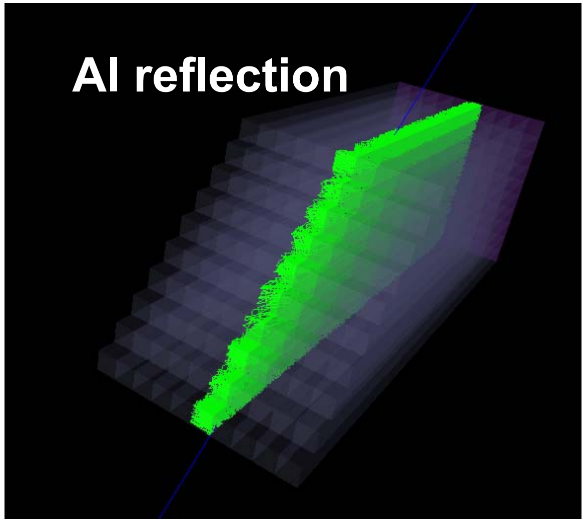


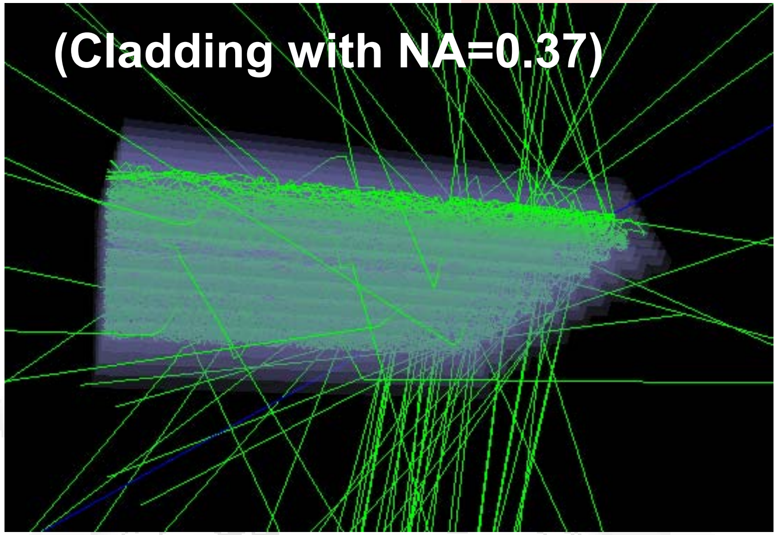
The MCP-PMT is a micro channel plate equipped with a photocathode & (usually) a multi-anode readout



Burle 2" MCP-PMT

Geant4 Simulation





- The detector simulation includes:
  - –**Tracking and timing of Cerenkov photons to the MCP-PMT**
  - –**Wavelength dependent refractive index, attenuation & reflectivity**
  - –**Ability to study cladding (eg air) or a reflective layer (with a possibility of including diffuse reflection)**
  - –**The effects of coupling grease (if necessary)**

Simulating the MCP-PMT

- Arrival time at the face of the MCP-PMT recorded
- Simulate geometrical acceptance
- Implement wavelength dependence of the photo-cathode QE.
- Simulate PMT transit-time jitter by adding a normally distributed random time jitter with the appropriate standard deviation
- Simulate the layout of the anode pad readout of the MCP-PMT.
- Assume that when the MCP-PMT o/p voltage reaches a certain level it triggers the discriminator – this level corresponds to a certain number of photons having arrived.

Cerenkov Light in Fused Silica*

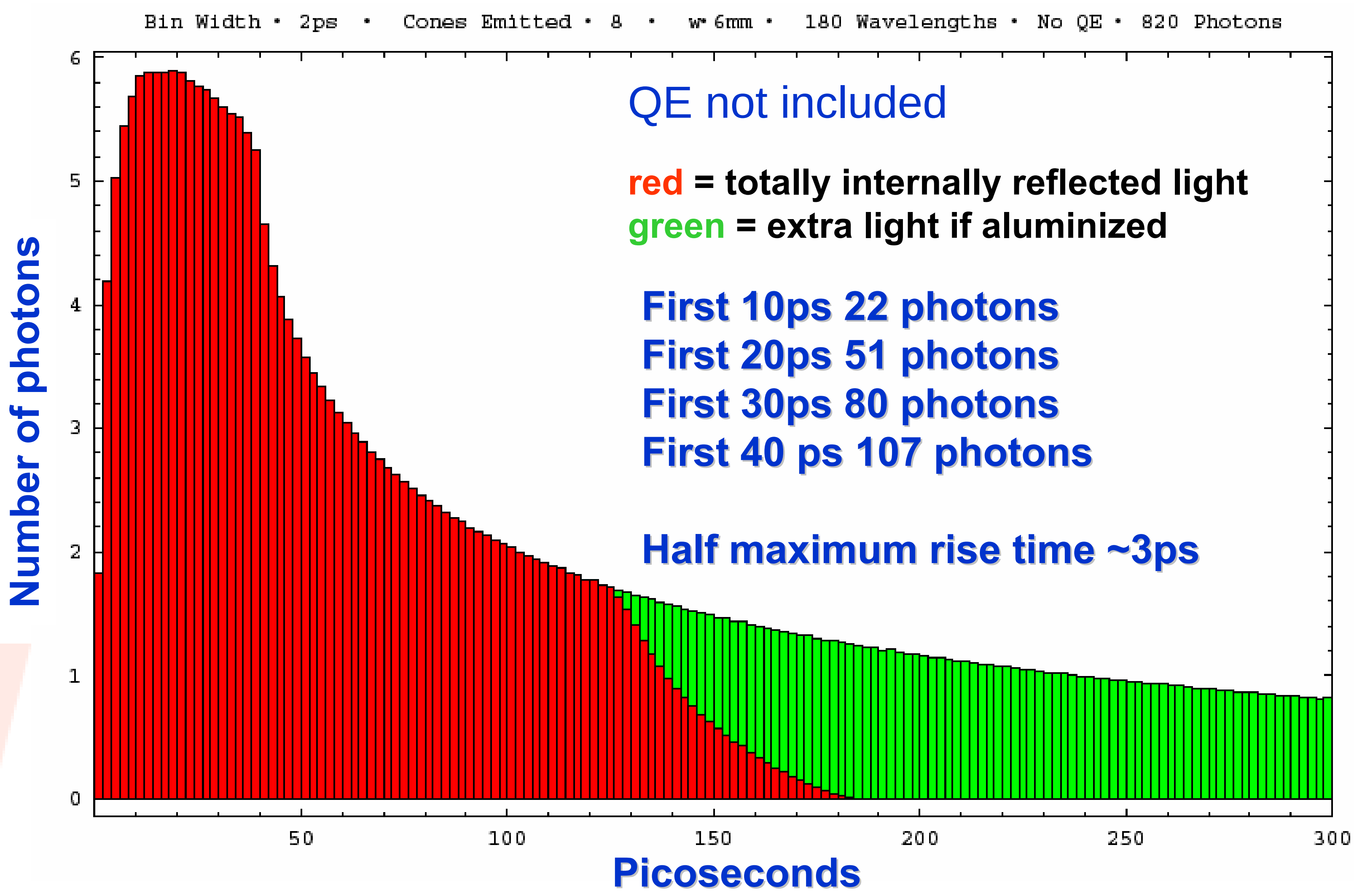
$$\# ph. = 2\pi\alpha L \sin(\theta c)^2 \int_{\lambda 1}^{\lambda 2} 1/\lambda^2 d\lambda$$

λ	#PH	QE	#PH*Q E	Θc	n
180-250	1652.6	15.70%	259.5	49.6	1.544
250-350	1148.7	18.00%	206.8	47.8	1.490
350-450	624.7	19.90%	124.3	47.2	1.471
450-550	394.3	11%	43.4	46.9	1.464
550-650	271.1	1.50%	4.1	46.7	1.458
total	4100		638.0		

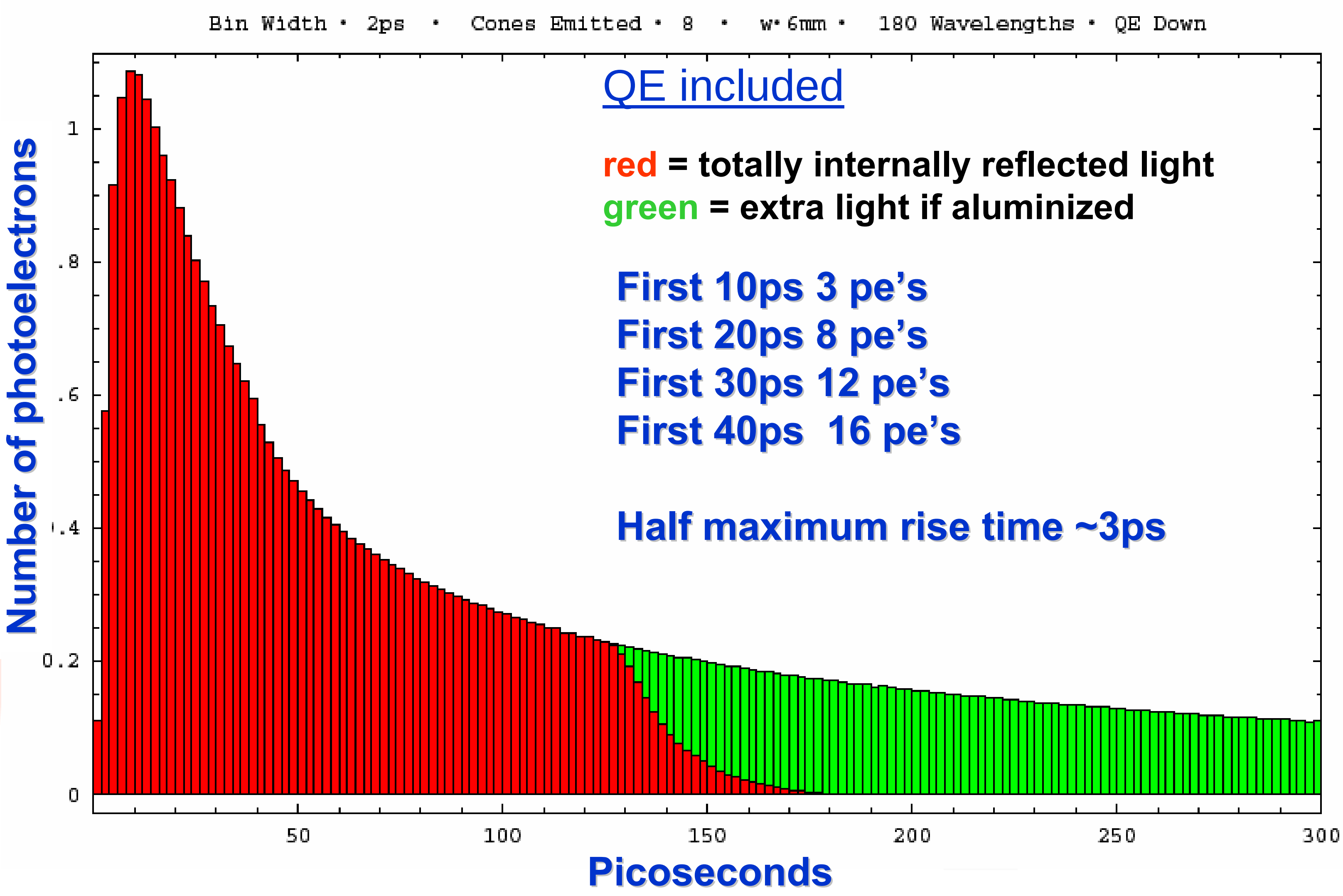
UV is important! 640 total pe's : ~130 pe's/6mm rod
(collection efficiency reduces this number to ~80 pe's/bar)

*UTA simulation

Photon Arrival Times (1)



Photon Arrival Times (2)



Test-beam at Fermilab

- Planned for summer of 2006 (beam starts in mid-June)
- Test-beam manned by UTA and Alberta
- Online/DAQ development required for QUARTIC prototype readout.
- Optical pulser & scope (TDS6804) will be used to validate electronics prior to test-beam
- Constant Fraction Discriminator+ HPTDC will be used to readout the detector
- Full sized prototype of detector available – but not all channels readout

Funding Initiatives

UTA (with UofA collaboration):

Texas ARP $100K/2 years, TOF and Mechanics; passed University pre-proposal stage (12/79); proposal due Feb. 14, award May 15

DOE ADR $130k/2 years, TOF only, proposal due Dec. 15! Award date June. Burle is contributing MCP-PMT's 25μm pore (60 psec TTS), 10μm pore (~30 psec expected), 10um, dropped face plate (removes tail from recoil electrons), and high current capability version

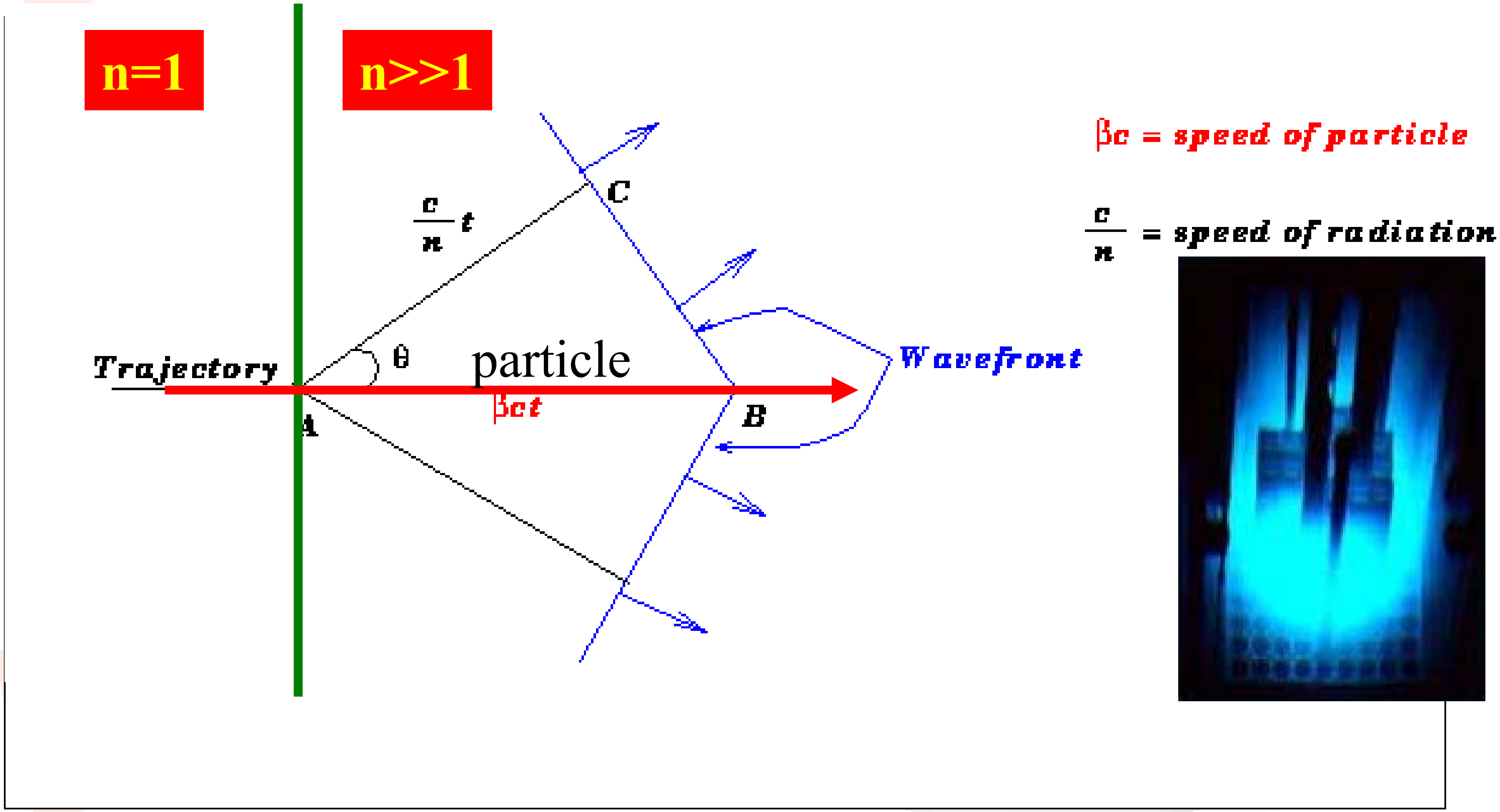
Alberta

A small amount of initial funding is available (~$15K) plus electronics engineer time (at $5/hr!)

Conclusion

- The QUARTIC precision ToF detector offers the possibility of reducing physics backgrounds to exclusive central Higgs production at ATLAS
- ToF detector resolutions of ~10ps have been achieved previously and initial simulation studies indicate that we should be able to deploy a detector with resolution of better than 30ps at the LHC
- This resolution will allow us to reduce the background from events contributing central “activity” and two protons at 420m (hard scatters + diffractive & double pomeron events) by more than 90%.
- The R&D effort to develop QUARTIC is well underway with the first beam-test to take place in the summer of 2006.

Cerenkov Effect



Use this property of prompt radiation to develop a fast timing counter