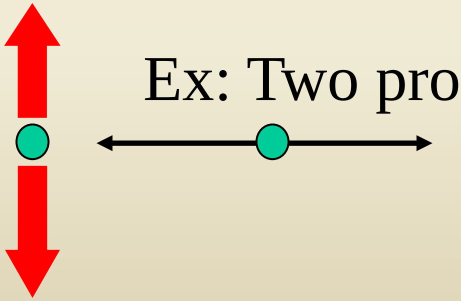
LHC Fast Timing Detector R&D

Andrew Brandt, University of Texas at Arlington
(for North America fast timing group:Alberta, New Mexico, Oklahoma State, Stony Brook, UTA)

Purpose: Pileup background rejection/signal confirmation

Use arrival time difference between protons to measure z-vertex compared with the central tracking primary vertex

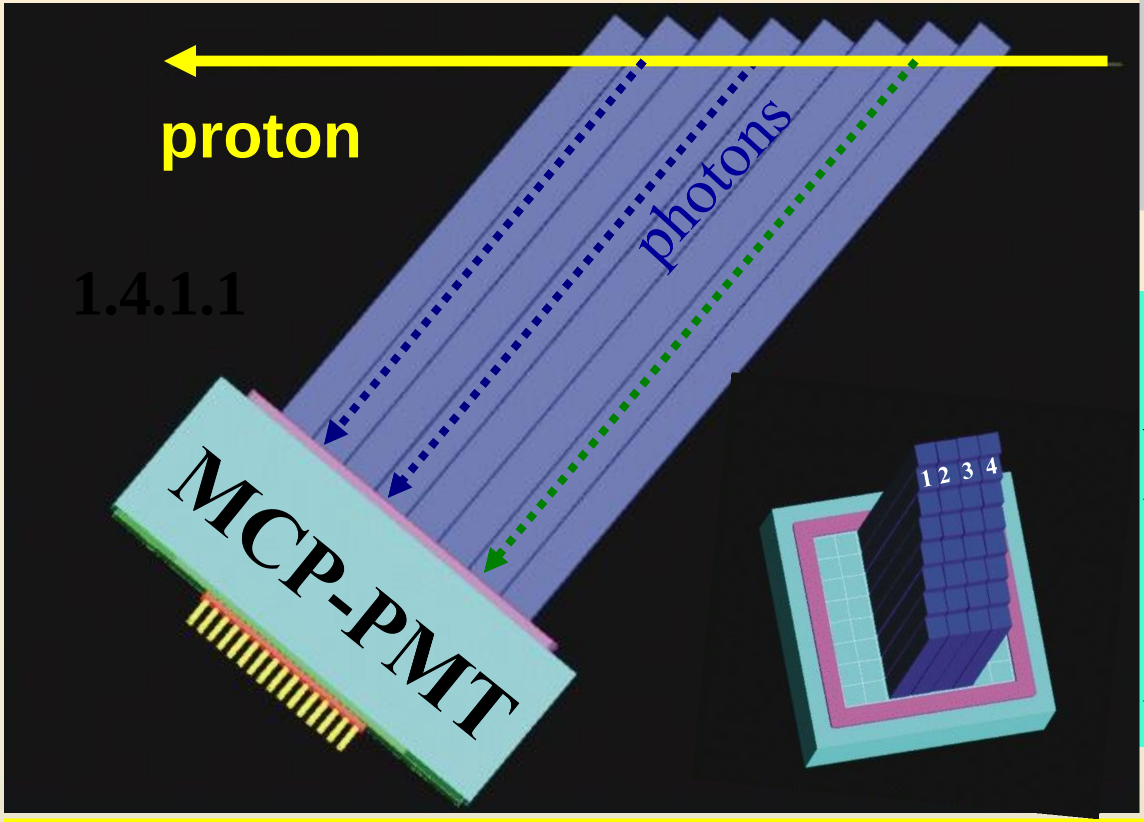


Ex: Two protons from one interaction and two jets from another

1) **Intro/overview**
2) **PMT lifetime including new approach**
3) **New detector development**

QUARTIC Concept (an oldie but a goodie)

Quartz bars at Cherenkov angle read out by MCP-PMT



Idea of Mike Albrow for FP420 (joint ATLAS/ CMS effort) 2004 based on Nagoya detector

Initial design: **4x8** array of 6x6 mm^2 ~10 cm long quartz (fused silica) bars, not coincidentally well-matched to then Burle now Photonis Planacon

Isochronous—by mounting detector at Cherenkov angle, all light reaches tube at ~same time

Proton is deflected into one of the rows and measured by eight different bars/detector with a micro-channel plate PMT.

If δt= 40 ps/bar need 16 measurements/row for 10 ps

If δt= 28 ps/bar need 8 measurements/row for 10 ps

Increase #rows to avoid multi-proton and rate effects (pixelation)

An R&D Success Story

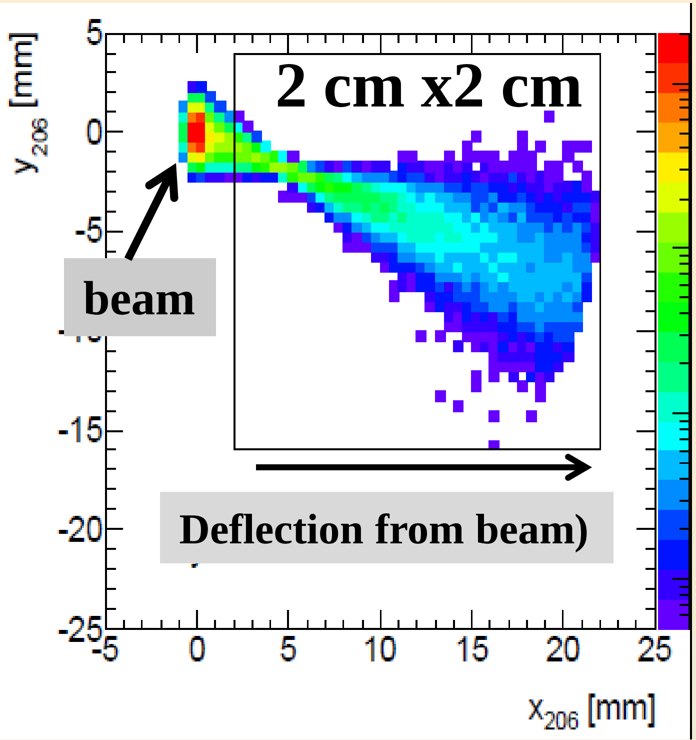
- **Led by UTA/Brandt raised ~400k$ in Generic R&D funds from Texas ARP (2006) , DOE ADR (2007 w/ Burle/Photonis), NSF SBIR (2011 w/ Arradiance Inc.) , DOE ADR (2011 w/Stony Brook), and in-kind from Universities**

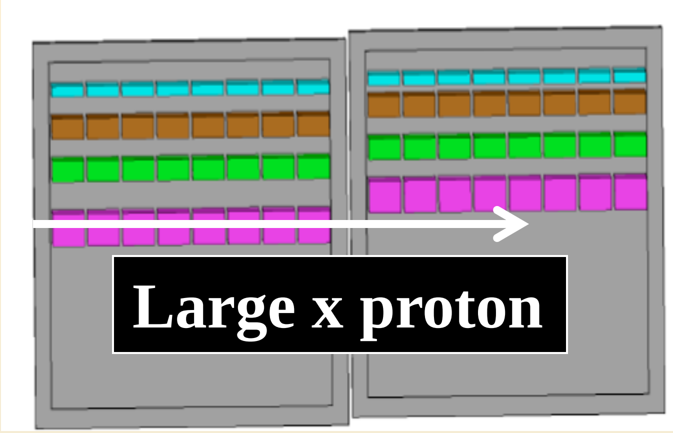
- **From first test beam in 2006 to last one in 2012 improved the resolution:**
  - by a factor 5 from 100 ps/bar to 19 ps/bar (for PMT/MCP-PMT/CFD)
  - by a factor 4 (24 ps/bar) if you include the HPTDC

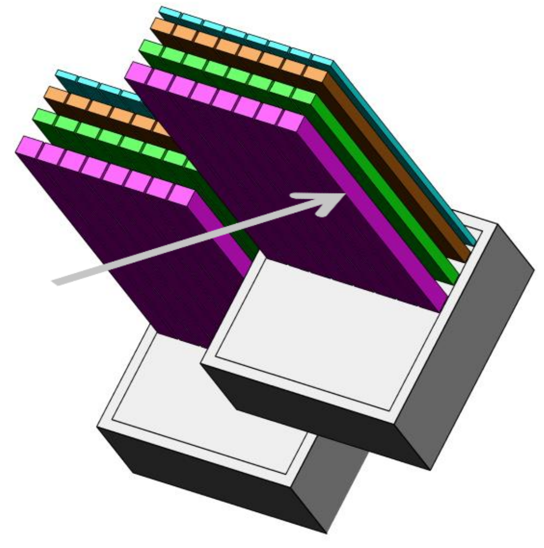
- **The improvement was due to a combination of many factors:**
  - coupling of q-bar to MCP-PMT
  - MCP-PMT pore size (25 µm to 10 µm) and optimized gain/HV
  - improved amplifier and CFD (based on Louvain design with modest improvements from Alberta + Stony Brook) . Note: a low noise, well-shielded amplifier is really a crucial, rarely discussed aspect of fast timing (electronics discussed in M. Rij talk)

- **Designed and built prototypes for a full system including all electronics**

We Developed a 10 ps TOF System for use with a Hamburg Pipe







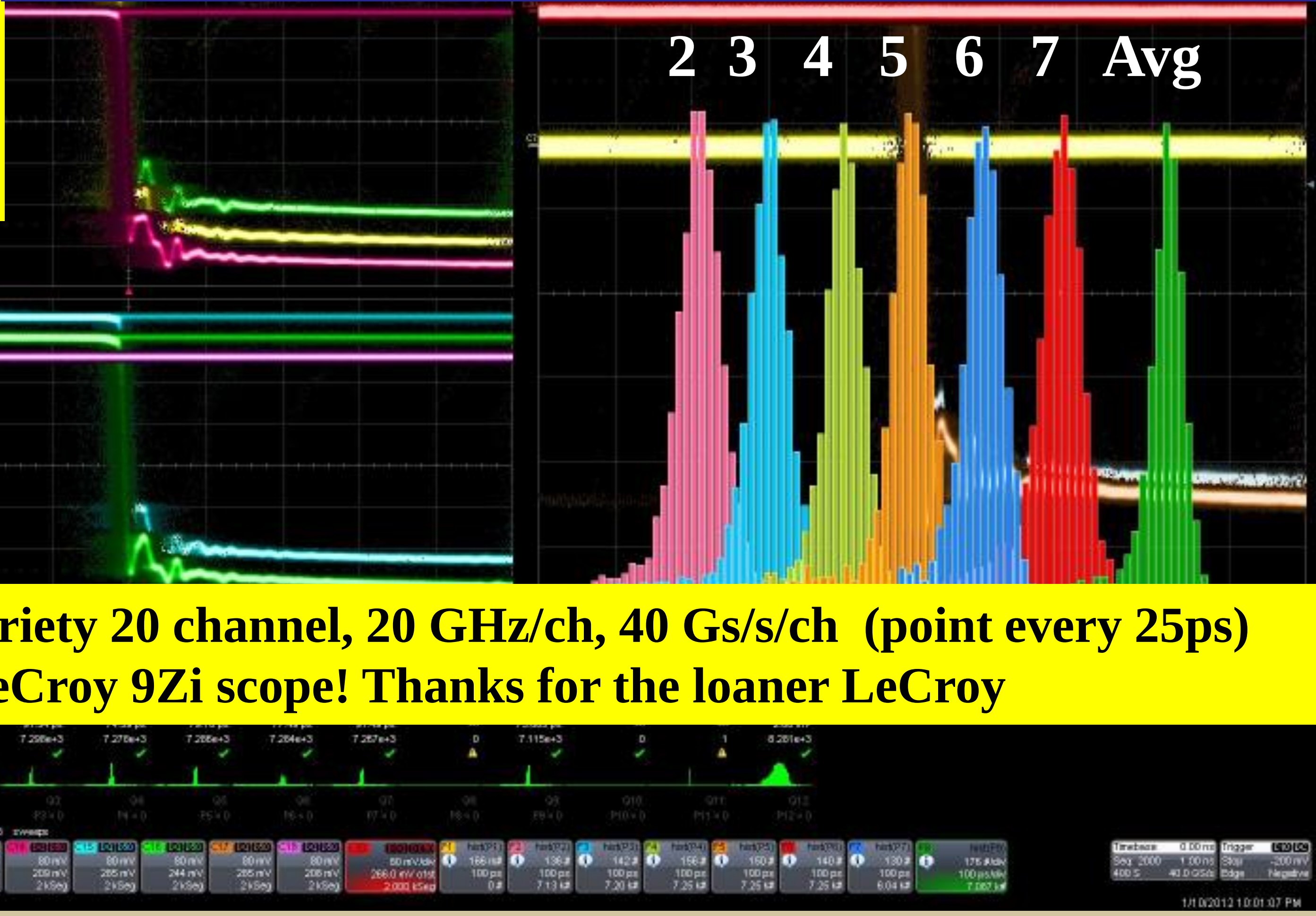
Validated the components of this design in test beam and at UTA Picosecond Test Facility with laser and "undergrad army"

Design considerations:

1) full acceptance, excellent timing expected <10 ps
2) 8 rows with Δx =1.5 to 3 mm (x=distance of proton from beam) to minimize multi-proton effects (>90% efficient) and keep rate/pixel under 5 MHz to help control current/lifetime issues
3) gaps between rows to reduce cross talk
4) capable of operating beyond 50 interactions/crossing (where <N>=1/det/BC)

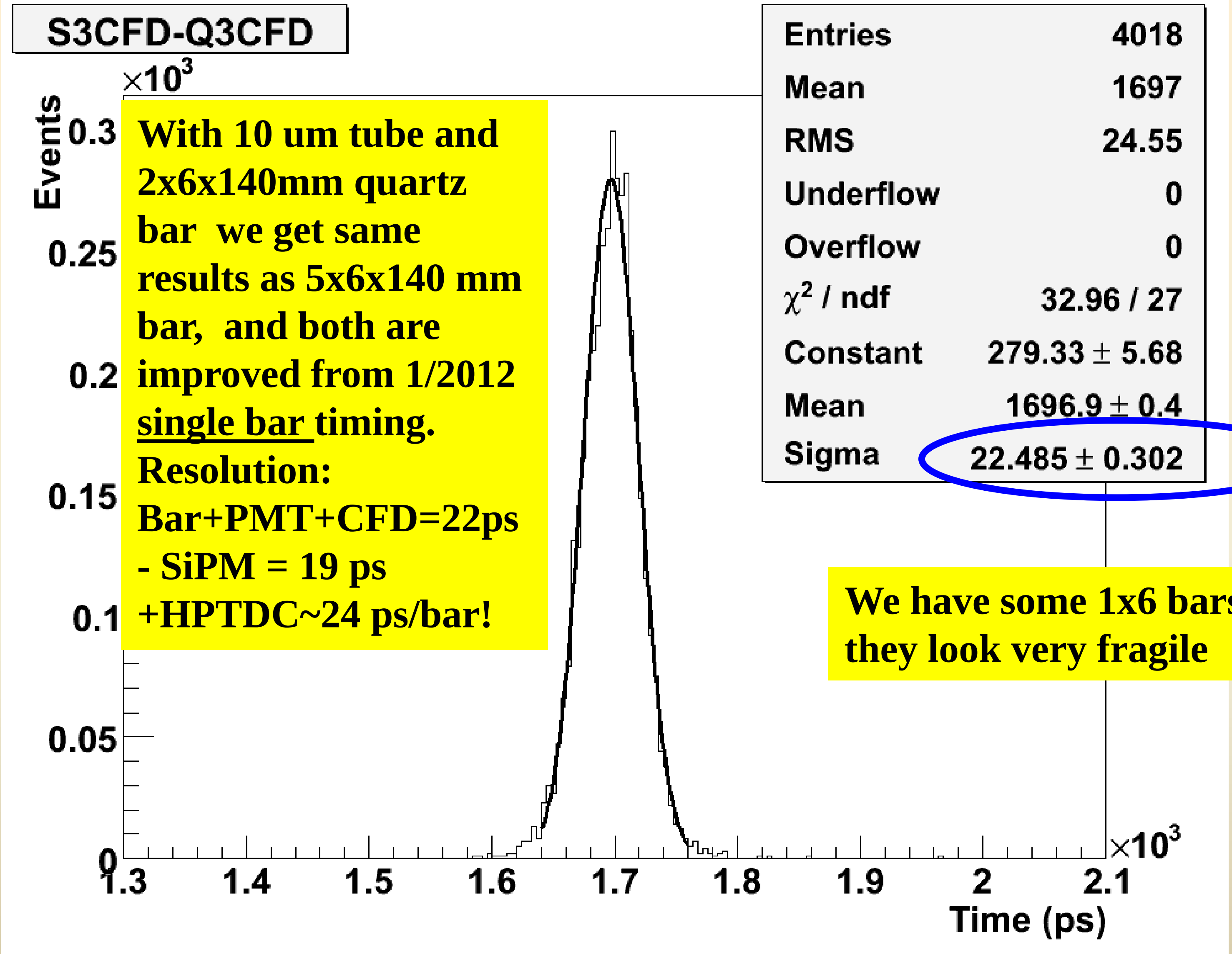
T958 DAQ (FNAL 1/2012)

Time difference between reference detector (FNAL SiPM in Nagoya mode courtesy of Albrow +Ronzhin) and 6 –bar Quartic average gives online FWHM=47 ps (σ=20 ps), removing SiPM resolution gives δQavg=14-15 ps


2 3 4 5 6 7 Avg

Just your garden variety 20 channel, 20 GHz/ch, 40 Gs/s/ch (point every 25ps) 500k$ LeCroy 9Zi scope! Thanks for the loaner LeCroy

Validate Thin Bar



With 10 um tube and 2x6x140mm quartz bar we get same results as 5x6x140 mm bar, and both are improved from 1/2012 single bar timing. Resolution: Bar+PMT+CFD=22ps - SiPM = 19 ps +HPTDC~24 ps/bar!

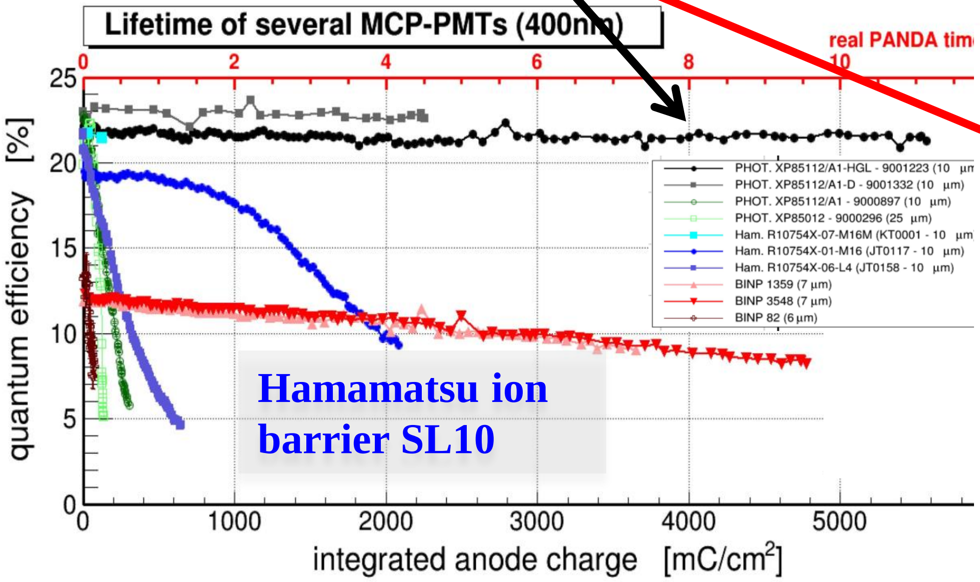
We have some 1x6 bars, but they look very fragile

Rate and Lifetime Issues

- Historically MCP-PMT’s have **not** been extremely robust, their performance (QE) degrades from positive ion feedback (“an unsolvable problem”) Challenge accepted!
- **Formed a collaboration between UTA, Arradiance Inc. , and Photonis in 2009 to help address this [phone call with Emile, Bruce Leprade, Paul Hink, Neal Sullivan and me] (2011 SBIR funds important for ALD development including refining process leading to Lehman Super tube)**

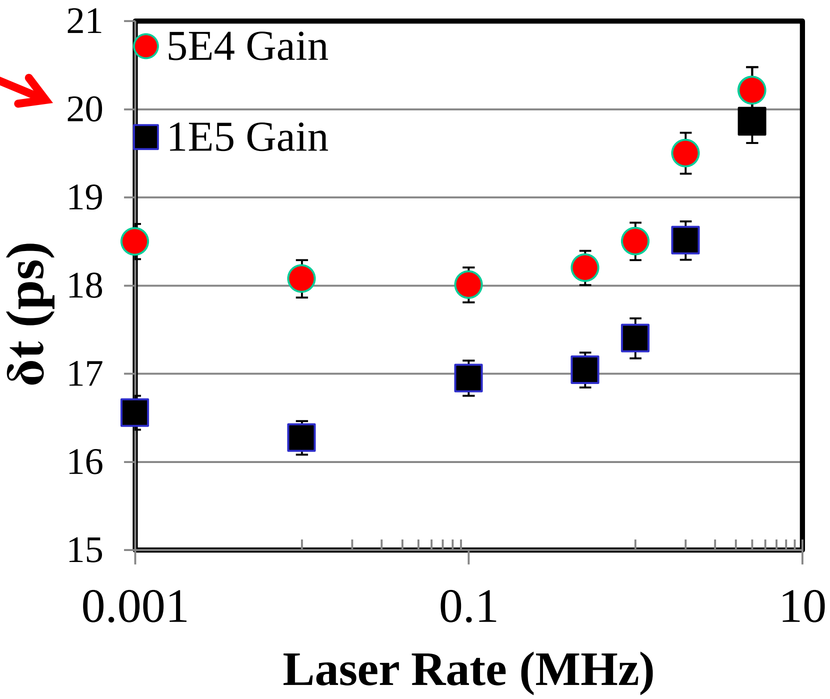
Photonis Planacon with Arradiance ALD-coated 10 (25) μm pores

<20 ps single bar resolution at 5 MHz rep rate (10 pe per event) even at low gain for EDR MCP (11 MΩ); 10 μm pore would improve resol. and rate capability



Hamamatsu ion barrier SL10

Lehman et al. (Panda conditions) No loss in QE with ∫Q>6 C/cm^2 >10x improvement over non-ALD tube For LHC 1C~10 fb^{-1}



Lifetime Solutions (NEW!)

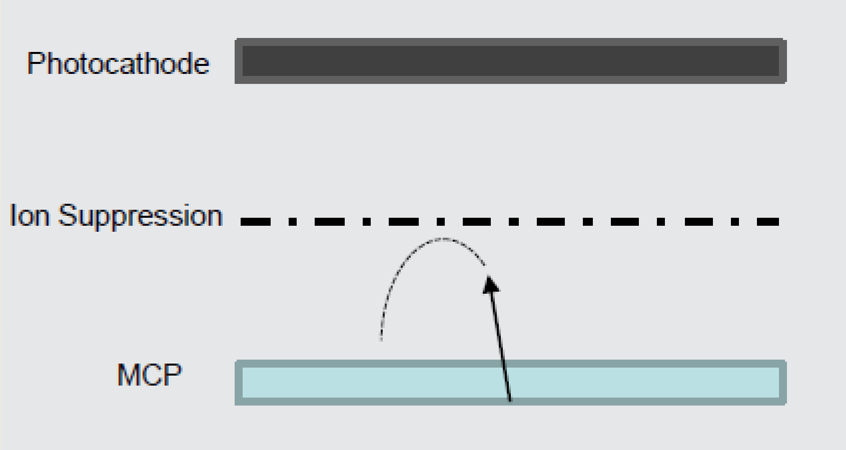
Photonis Parallel Development Effort (patent pending)

Could be used instead of, or as acomplement to, ALD coating of MCP's

-Features an electrostatic ion suppression grid (basically an energized ion barrier)

-Grid between MCP and photocathode to reduce/prevent + ions from reaching and damaging photocathode

-Complete suppression requires grid bias to be energetically higher than the highest bias source of + ions (MCP-out)

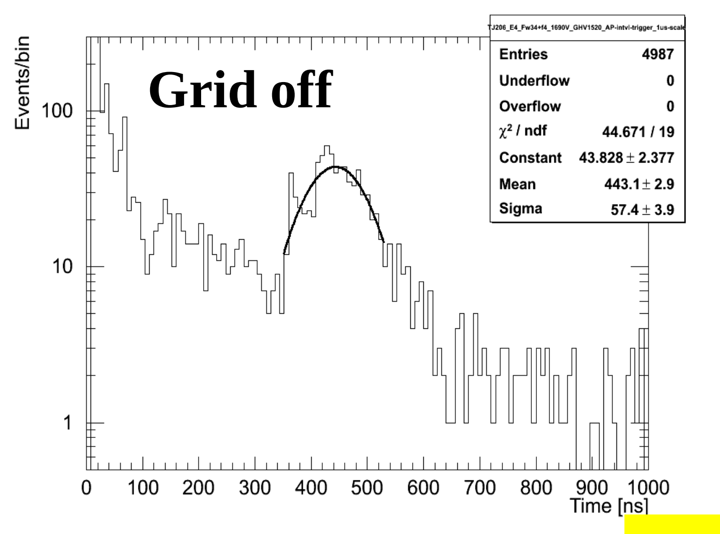


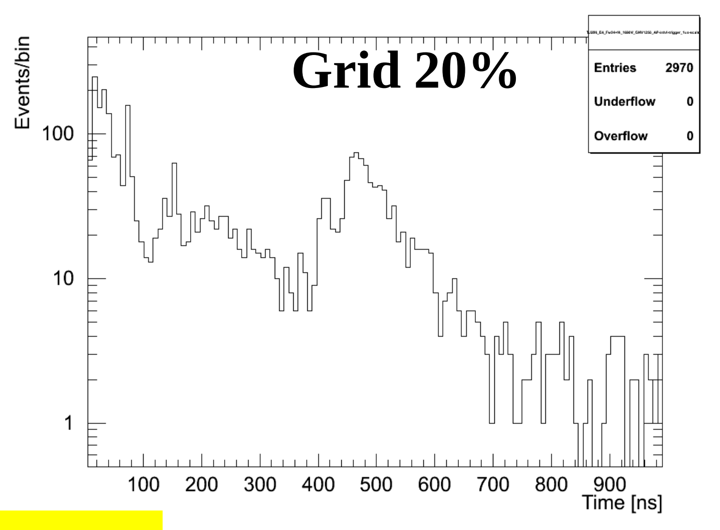
-Time delay (ion TOF aka afterpulsing) increases as the ions are decelerated and eventually suppressed from reaching the photocathode

-Coulds still get some level of afterpulsing from ions on surface of MCP or from energetic neutrals

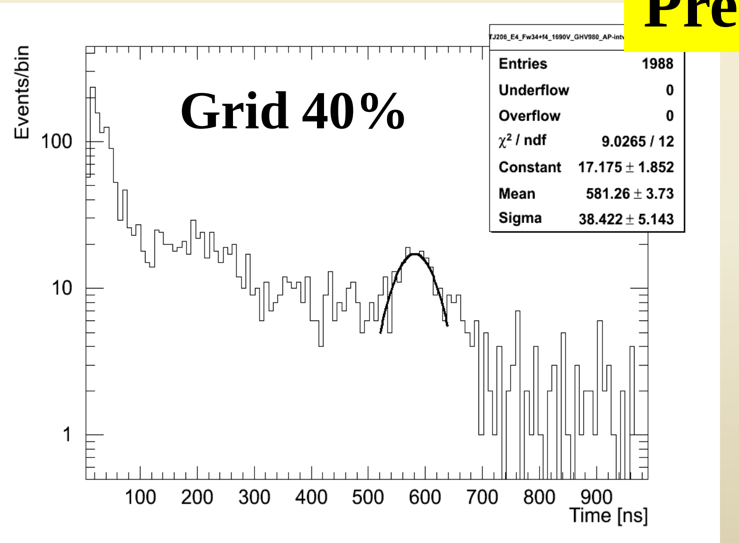
Afterpulsing as a f(GridVoltage)

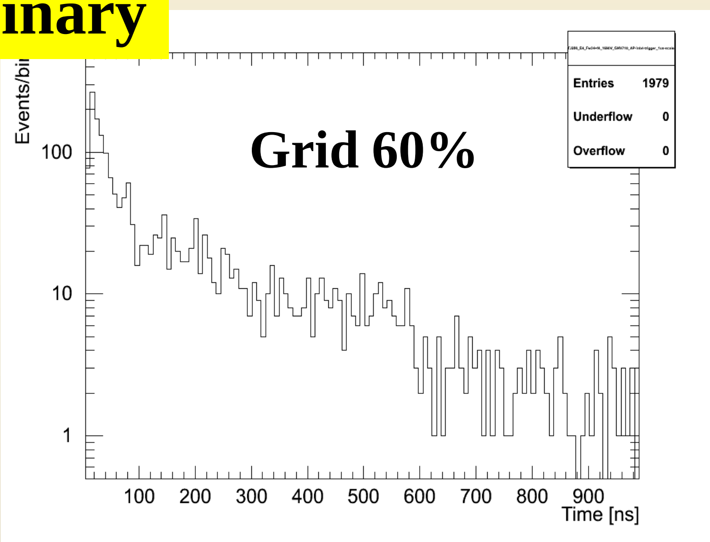
Tests
Done
In
Secret
At
UTA
PTF





Preliminary

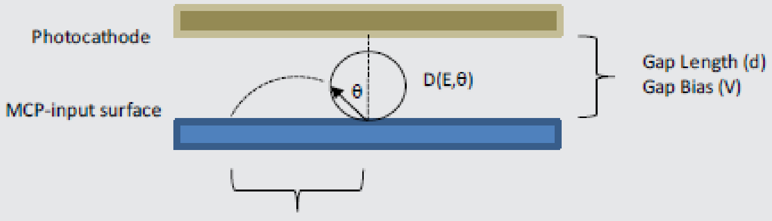




Large suppression in “heavy metals” as grid is activated;
generic positive ion suppresion factor (#AP grid on/grid off) is about 4x

MCP-PMT 101 Courtesy of J. Defazio , Photonis USA

MCP-PMT: Secondary Electrons and TTS

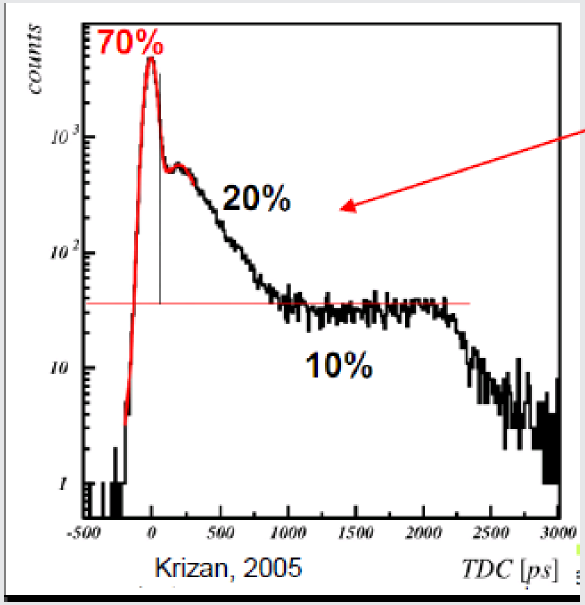


-Secondary electrons produced at the MCP input return to the MCP and can be detected at later times (t) and different positions (r) from the primary event.

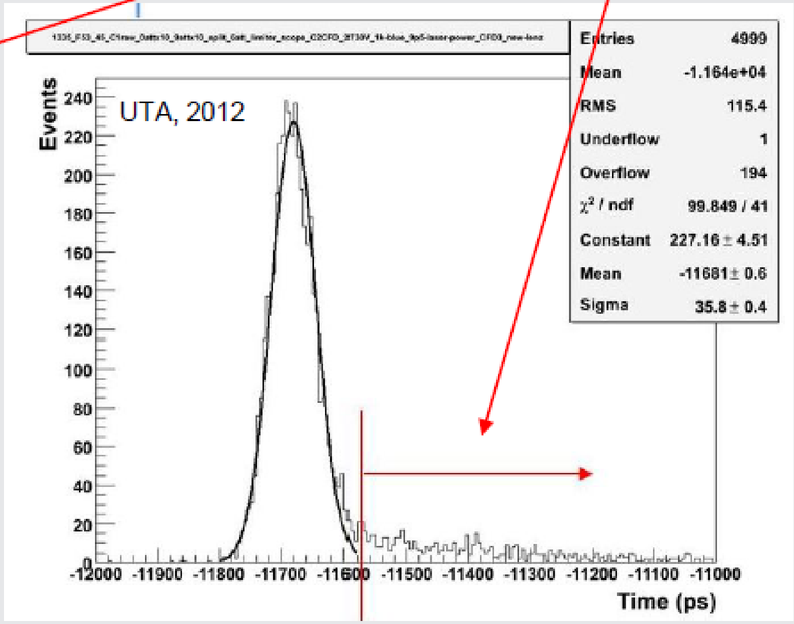
- Assume a constant MCP detection efficiency to estimate the contribution of these electrons to the TTS based only on the electron ballistics

Displacement r ~ E,d, 1/V

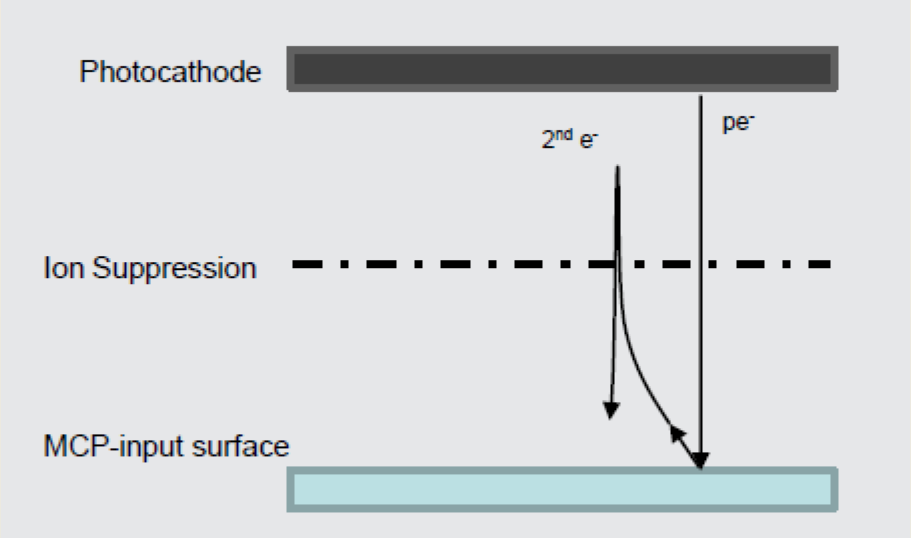
Flight time t ~ d, 1/V, $E^{1/2}$



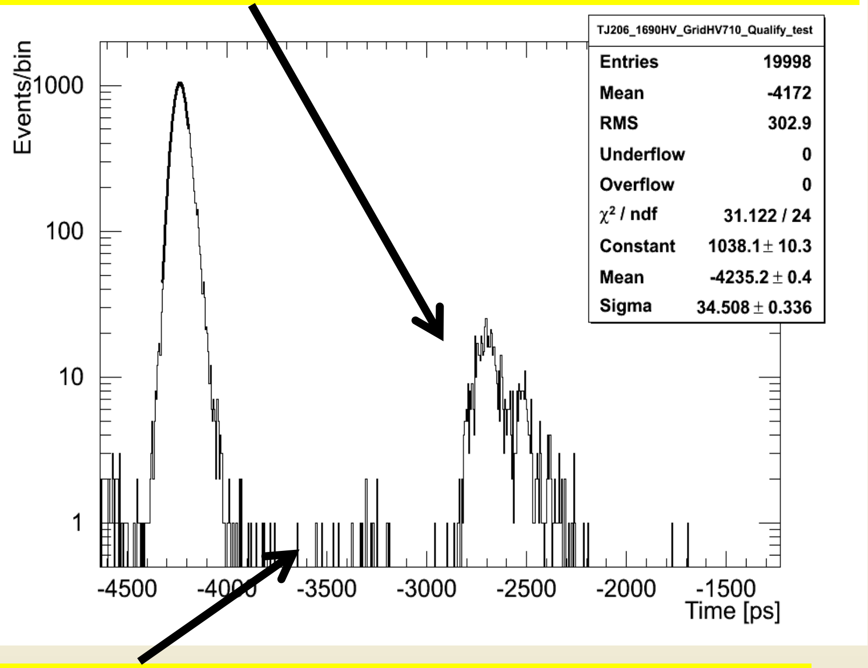
Krizan, 2005



Active Ion Barrier Improves TTS



Scattered electrons are organized and delayed (separated from main peak)



Tail of TTS distribution is suppressed

Seconday electron peak is focussed a couple ns later, results in improved TTS by 10-20% (we obtained 34 ps for 25 um tube)

Active Ion Suppression Conclusions

Promising new development effort by Photonis

We obtained a 4x suppression in positive ion acceptance, this potentially implies a 4x improvement in lifetime (lifetime testing in progress at Photonis) which should be orthogonal to ALD improvement (suppress +ion creation with better MCP'S, then coat them with ALD to further suppress, and if they do escape inhibit them — life is getting tough for positive ions).

Seconday electron peak is focussed a couple ns later, results in improved TTS by 10-20%!

Still have a loss in collection efficiency, not quite as bad as an inactive ion barrier, but leads one (me) to conclude that this active ion barrier approach is probably most useful for multiple PE detectors (and in conjunction with ALD)

MCP-PMT Lifetime Summary

Over past several years the difficult problem of PMT lifetime has been attacked on several fronts leading to significant improvements in the prospects of using MCP-PMTs in a high rate environment

1) Multiple PE's allows running tube at lower gain x10-20

2) ALD suppresses creation of +ions x10-100

3) Further suppression possible with more ALD tuning, R2D2 at least x2-3

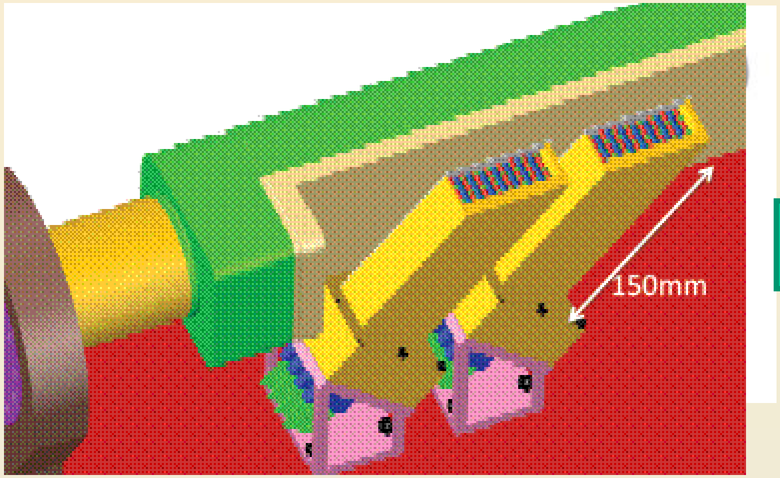
4) Electrostatic ion barrier to deter the rest x4- xlarge

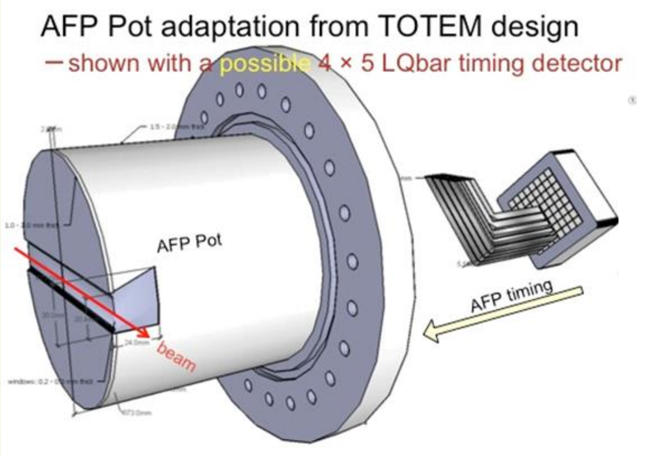
*The net effect of these gains is O(1000) improvement over initial calculations that led some to abandon the technology.

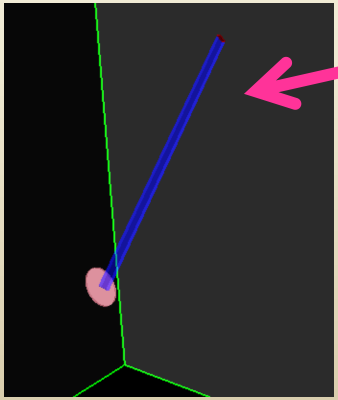
HOWEVER, too early to declare victory! Development effort is not complete! More R&D funds required to finish optimization and make "long-life" a standard product option

New Challenge: Adapt Timing Detector to be compatible with Roman Pot instead of HBP…

1) Arggh! **2) Challenge Accepted**



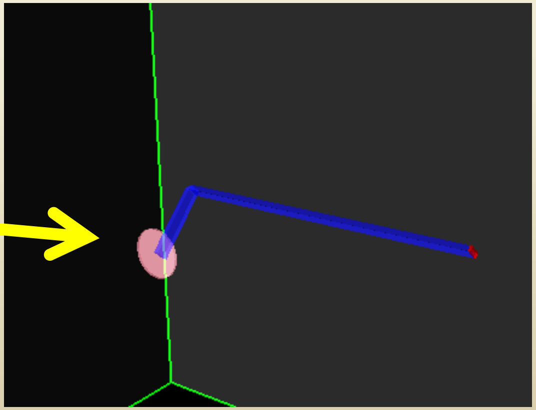

AFP Pot adaptation from TOTEM design
– shown with a possible 4 × 5 LQbar timing detector



Q-Bar straight bar at Cherenkov angle

LQBar still at Cherenkov angle but take light out at 90 degrees

(Albrow Lbar parallel to beam takes light out at 90)



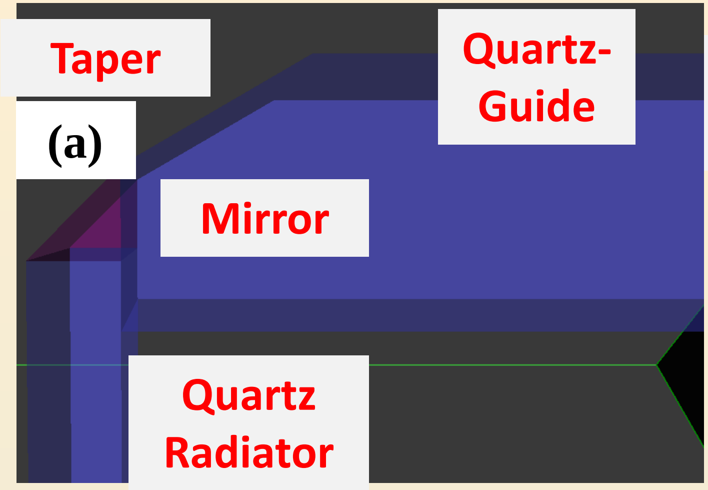
New GEANT4 Simulation Effort

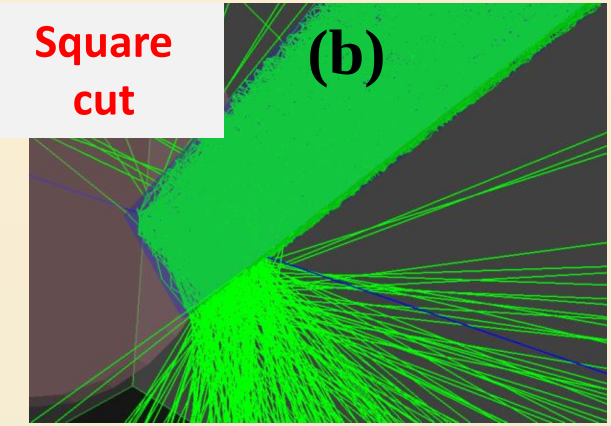
Led by Tom Sykora’s group at Palacký University, Olomouc Czech Republic (Libor Nozka, Leszek Adamczyk et al with UTA UG Tim Hoffman)

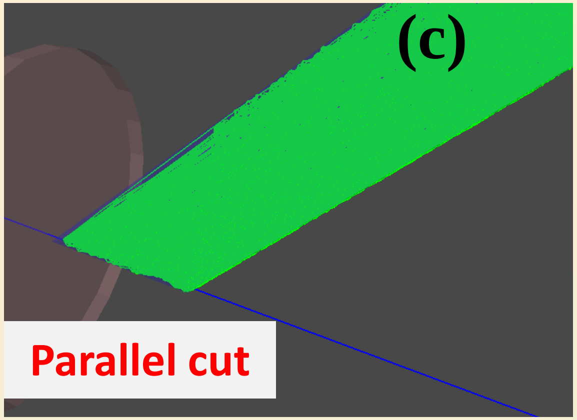
Start with straight Qbar (θ_c ~48°) (2mm x 6mm x 150 mm), since we have test beam data for this we can normalize simulation of LQbars and other geometries (heh heh) to Qbar

We also are undergoing detailed studies of how MCP-PMT treats different photon arrival time distributions , as correlations between photon arrival times exist are a f(TTS, gain, rise time, etc.) and are generally not well modelled.

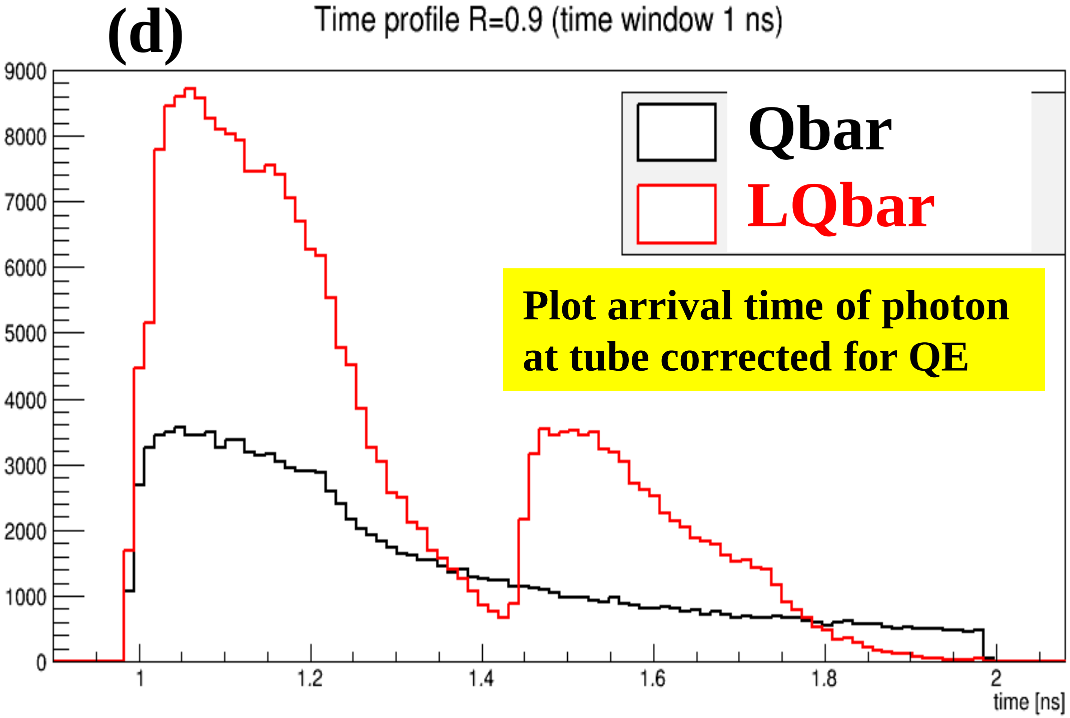
LQbar Design Conclusions







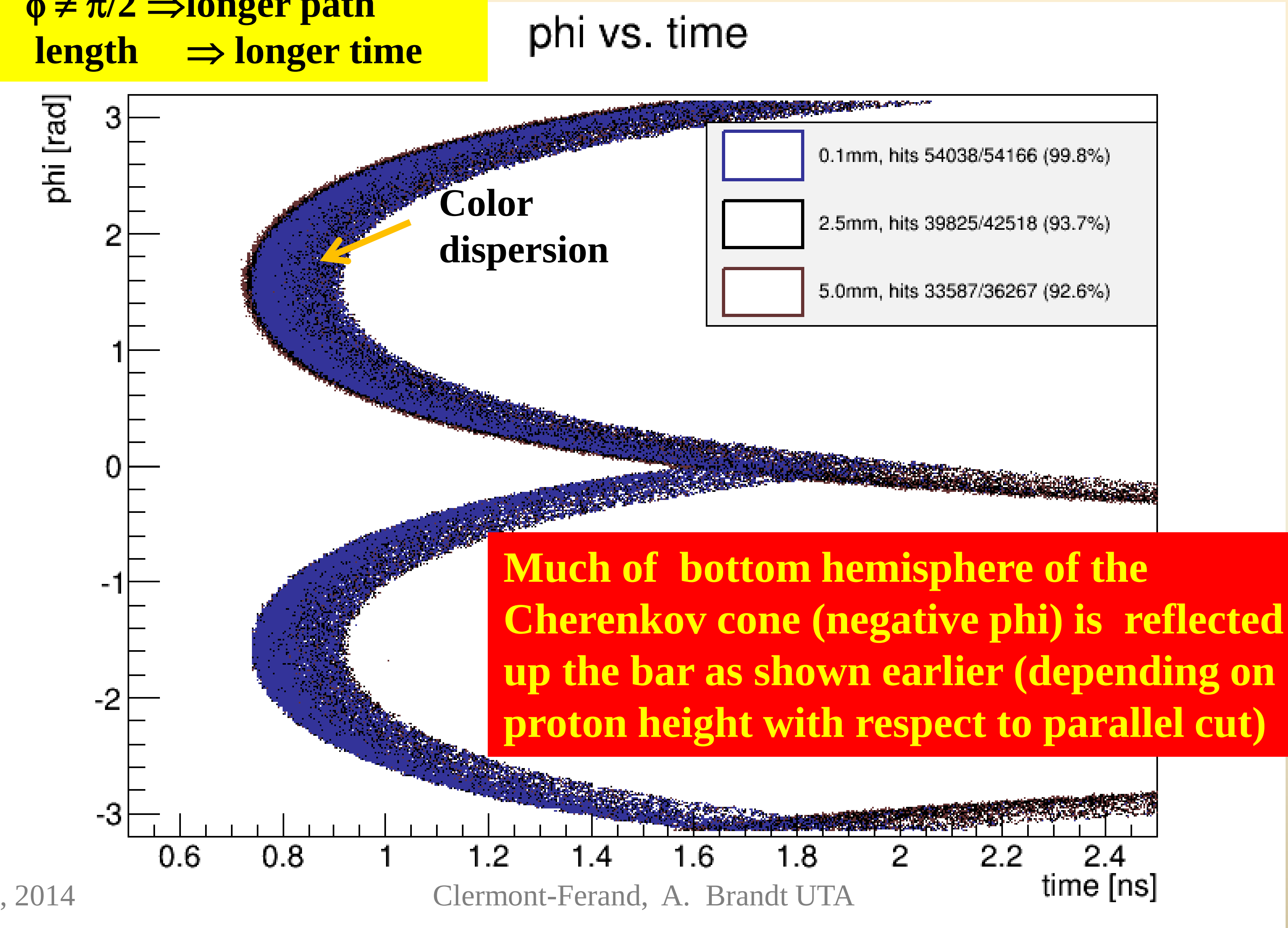
The expectation was that the LQbar would be inferior to the Qbar, due to light lost at the elbow, but a taper (a) to focus the slower wide angle light and replacing a square cut (b) with a parallel cut at the bottom end of the bar (c) actually gives an improved distribution (d) from which we can infer that the bent bar will actually have superior performance



Plot arrival time of photon at tube corrected for QE

Phi vs Time for Parallel Cut on Qbar

$\phi = \pi/2$ straight down bar
$\phi \neq \pi/2 \Rightarrow$ longer path length $\Rightarrow$ longer time

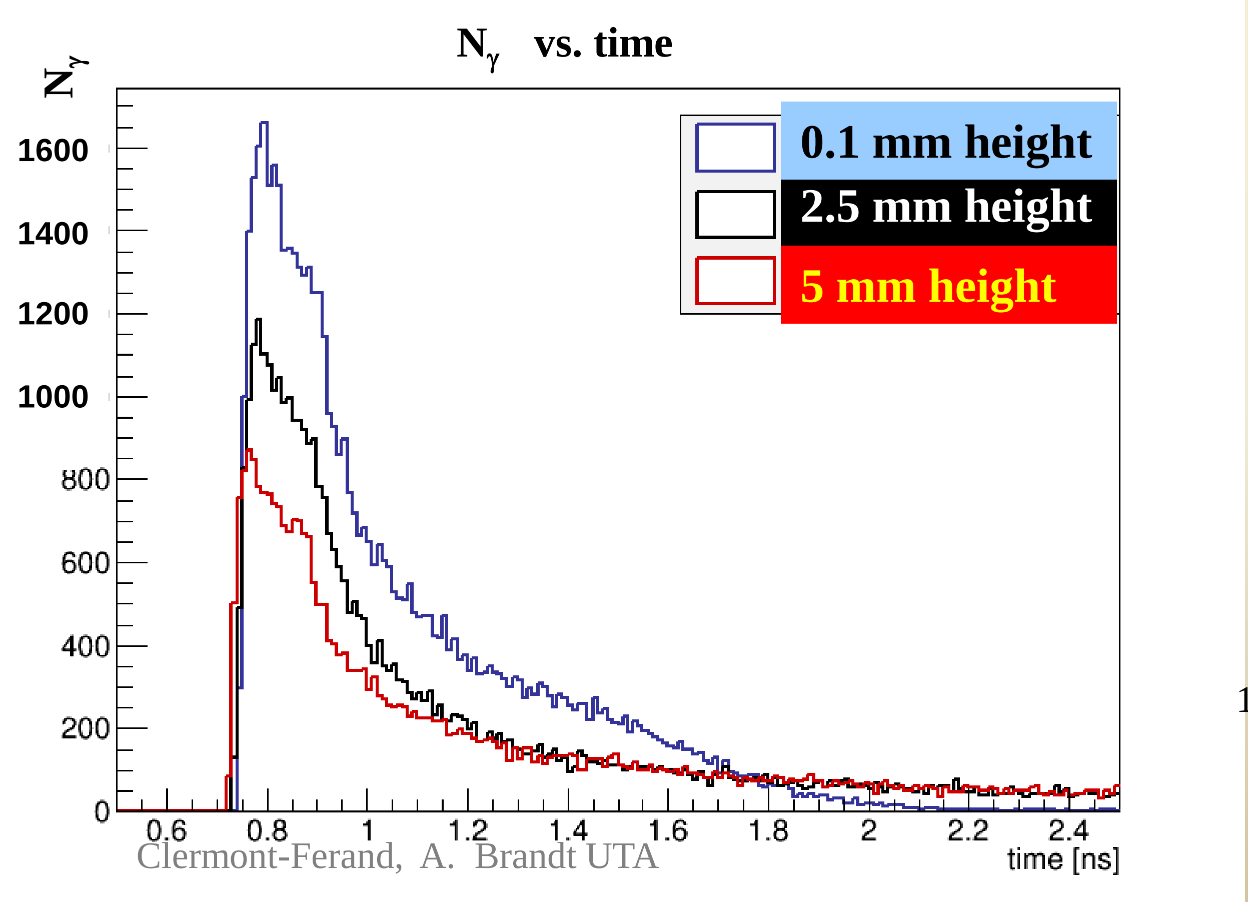


Color dispersion

Much of bottom hemisphere of the Cherenkov cone (negative phi) is reflected up the bar as shown earlier (depending on proton height with respect to parallel cut)

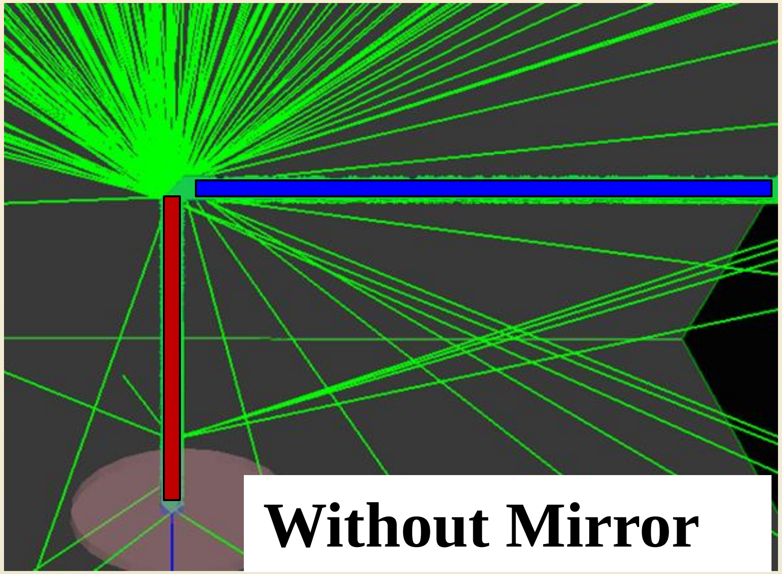
N_γ vs. time for Qbar with Parallel Cut as f(y)

- Protons close to the parallel cut (y~0) give the biggest gain in photon acceptance (if we stayed with Q-bars we would use this feature)
- For y>5 mm there is no gain from the parallel cut
- Test beam data uses rectangular bars, so will use this as baseline for comparison with simulation



LQbar* (radiator bar at θ_c +light guide bar)

2x6x(30+120)mm



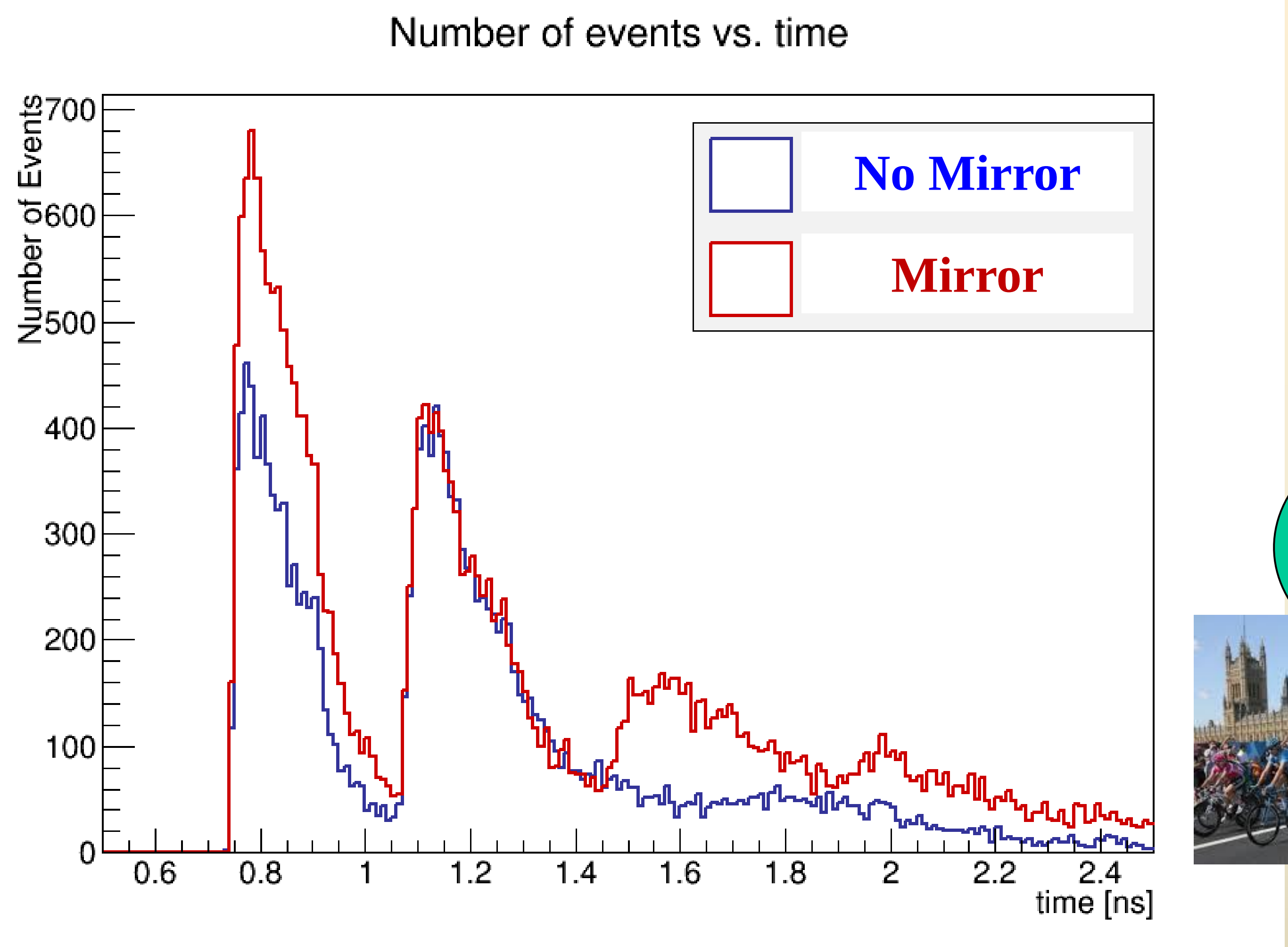
Without Mirror

With Mirror

***Not to be confused with Albrow’s Lbar which is oriented parallel to beam and has no elbow**

- 45 degree bend to route light from radiator to perpendicular light guide bar, lose some light at elbow
- Aluminizing helps but light ~⊥ tp mirror lost oopposite to elbow.still lost at elbow

LQbar: what's with all the peaks?



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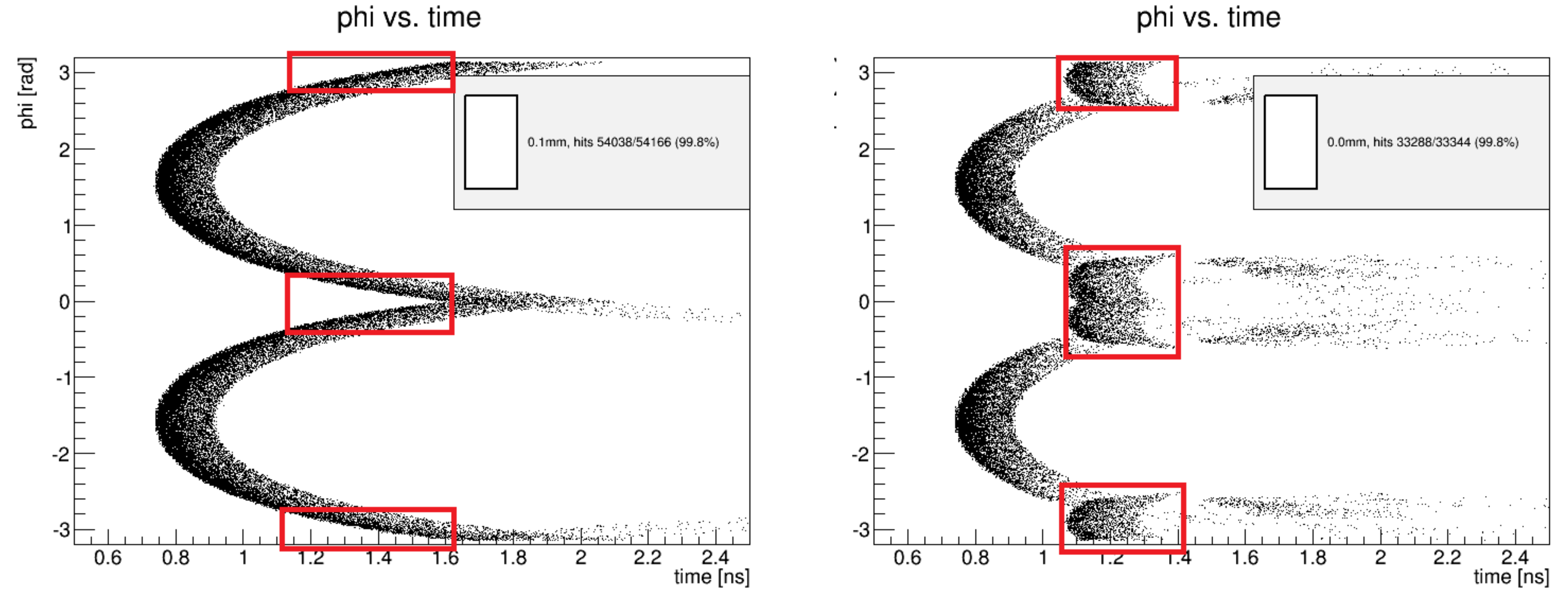
Mirror adds ~30% more good light (1st peak) and some bad (late) light (3rd +4th peak) 2nd peak is unchanged, so this light is missing the mirror region

“Wings”

- Taking the Cherenkov cone around the 90° degree bend leads to “wings” that are relatively faster (shorter path length) compared to the prompt light then for the straight bar case.

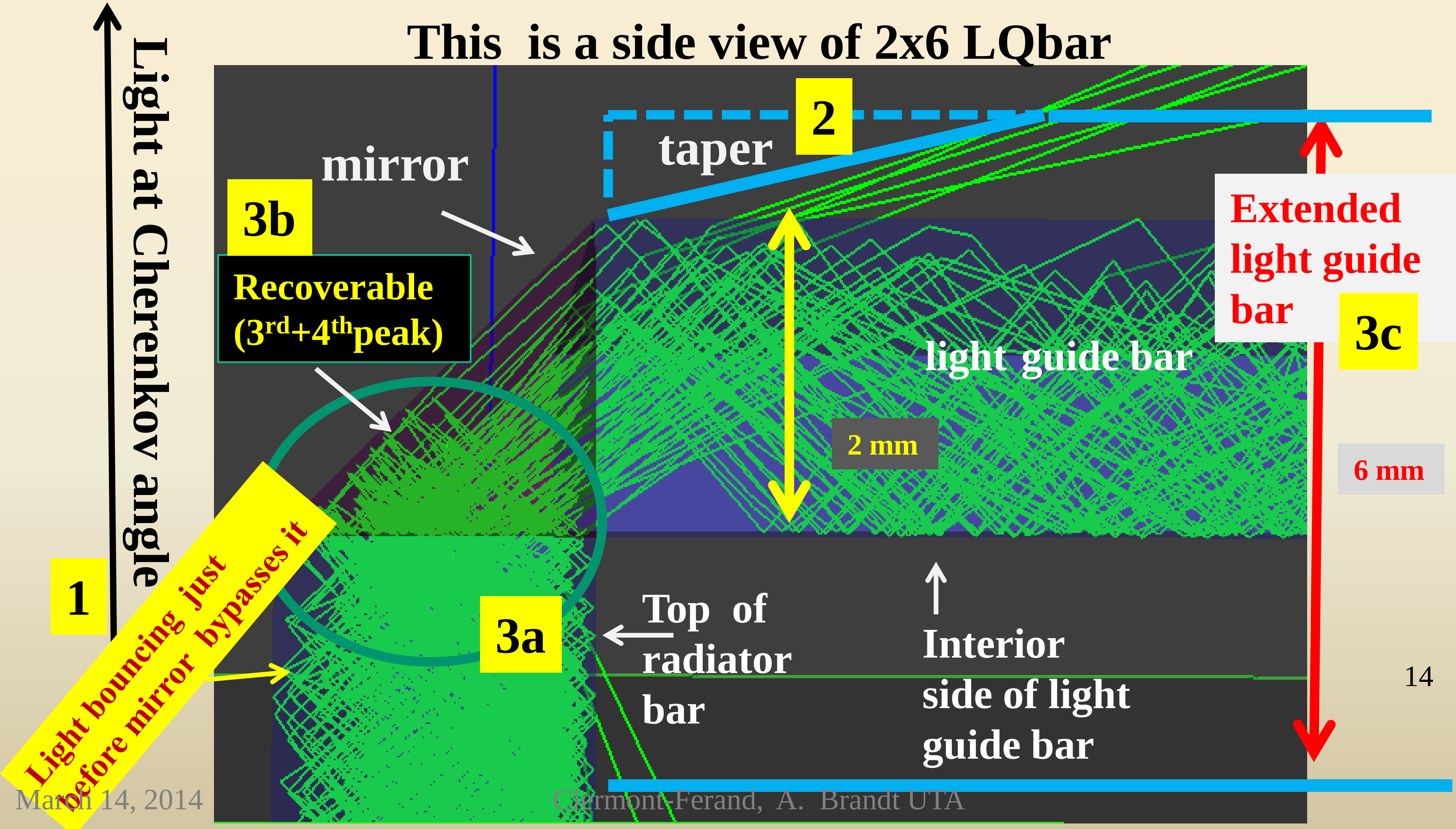


Qbar **Lqbar (unoptimized)**

Harnessing the “Wings”

- Can we optimize the light guide design to speed up the wings?
- Study adding a taper (angle +length) and a wider light guide bar

This is a side view of 2x6 LQbar



Recoverable (3^{rd}+4^{th}peak)

Extended light guide bar

Light bouncing just before mirror bypasses it

New Nuclear Interaction Study

- At 14 TeV find about 2% chance per bar (8 mm of quartz) of an interaction
- These interactions have a high multiplicity

  O(tens) particles, which would typically saturate amps and cause that bar timing to be mismeasured (but the event could be salvaged with somewhat degraded resolution almost all of the time).
- **Significant Implications on timing detector optimization: Ex. Filling a pot or pipe w/quartz is a good fixed target experiment, may not be so great as timing detector**

UPTOP: Detector

Low lum
Baseline:
16 ch/side
4 layers in x
2 layer in y (+/-)
2 meas. each

Latest drawing censored Only showing cartoons today

shared RP with silicon detector