Performance Studies of Microchannel Plate PMTs in High Magnetic Fields

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on behalf of the PANDA Cherenkov group

- Introduction
- Performance in magnetic fields
- Time resolution measurements
- Summary

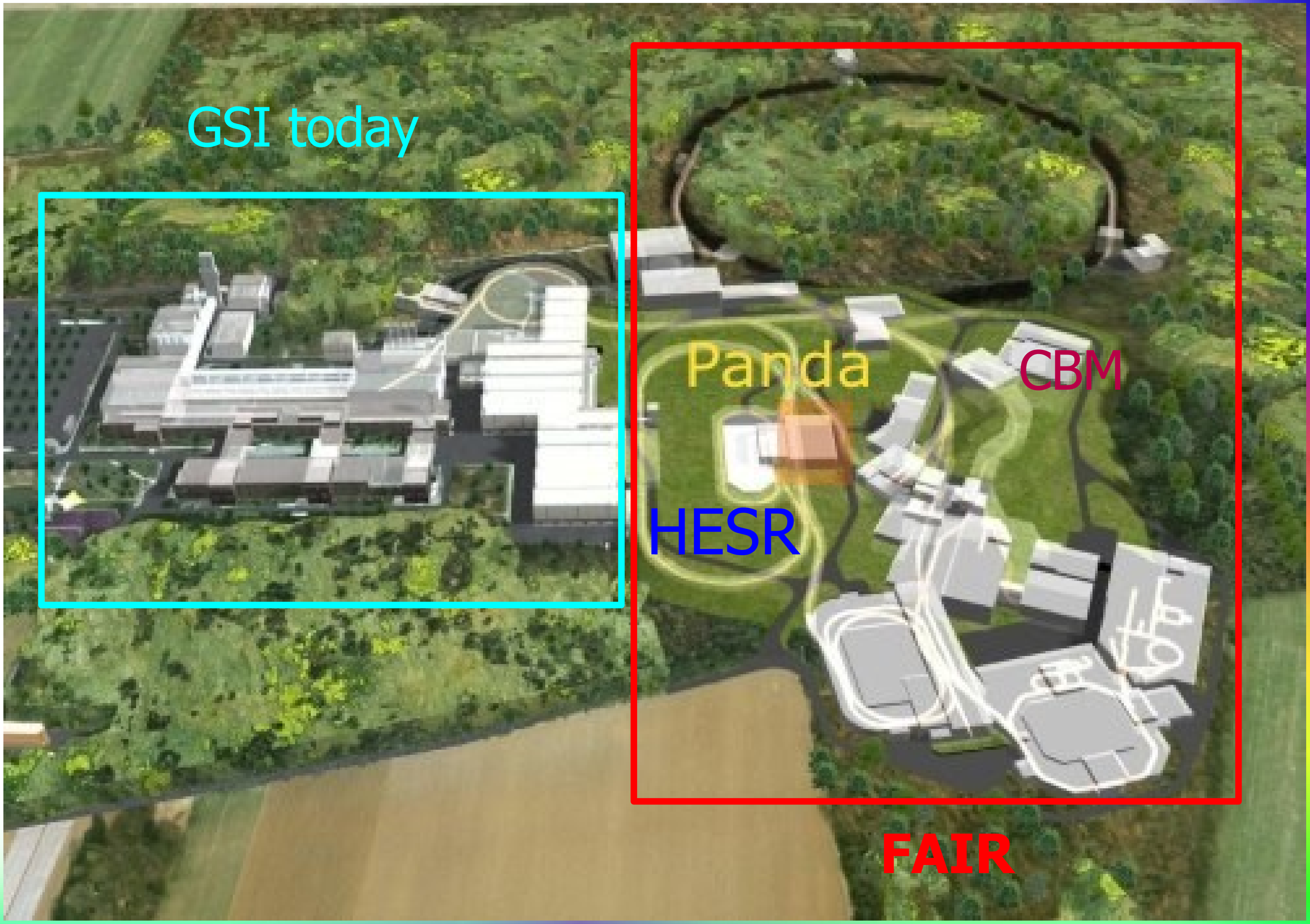
supported by BMBF and GSI

New Accelerator Facility FAIR at GSI

FAIR = Facility for Antiproton and Ion Research

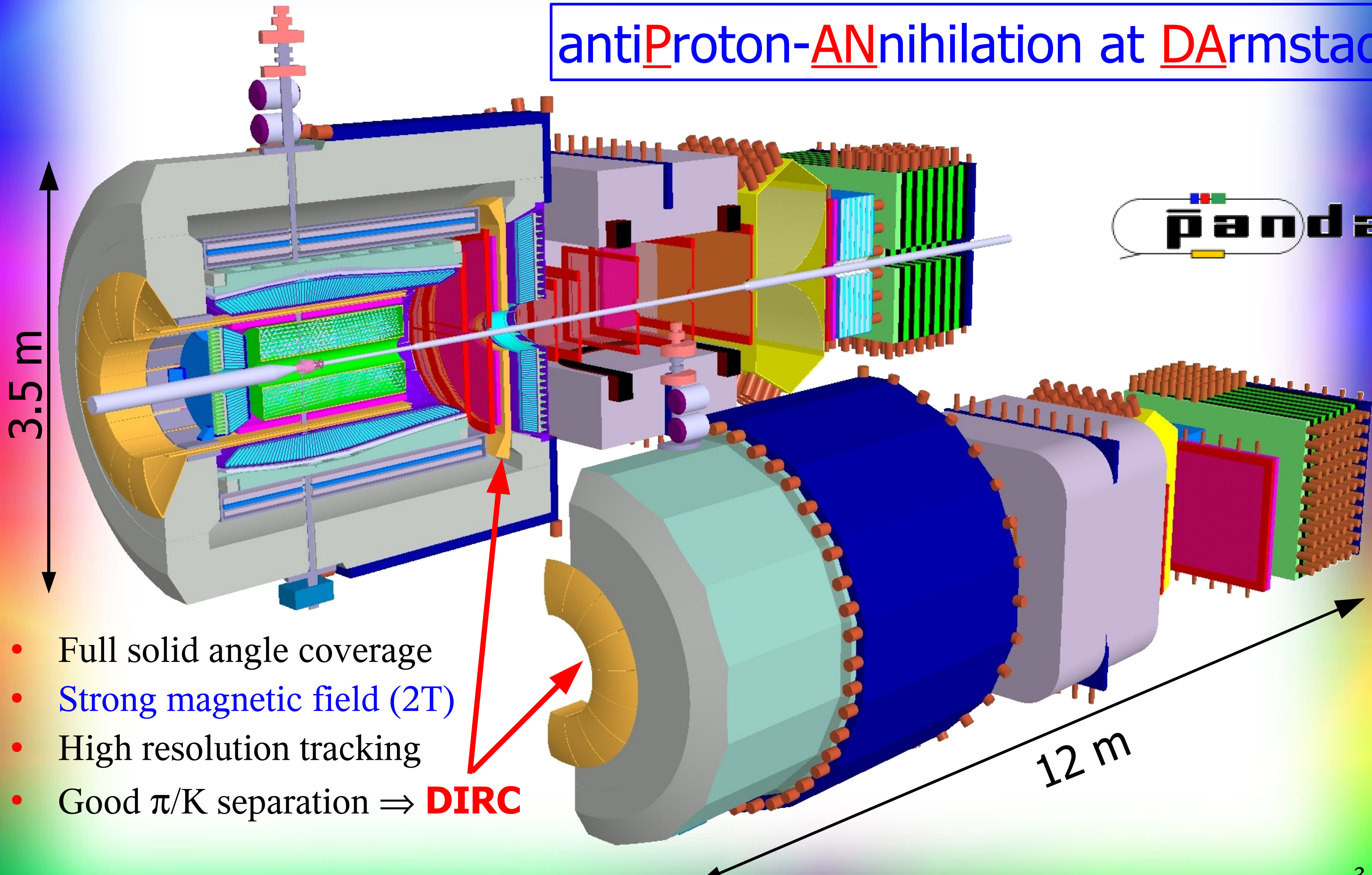
HESR =
High Energy
Storage Ring

- 1 - 15 GeV/c cooled antiprotons
- momentum resolution up to $\delta p/p \sim 10^{-5}$
- annihilation rate 10^7 Hz
- **PANDA**



PANDA Detector

antiProton-ANnihilation at DArmstadt



- Full solid angle coverage
- Strong magnetic field (2T)
- High resolution tracking
- Good π/K separation $\Rightarrow$ **DIRC**

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PANDA – DIRC Versions

→ overview talk of K. Föhl

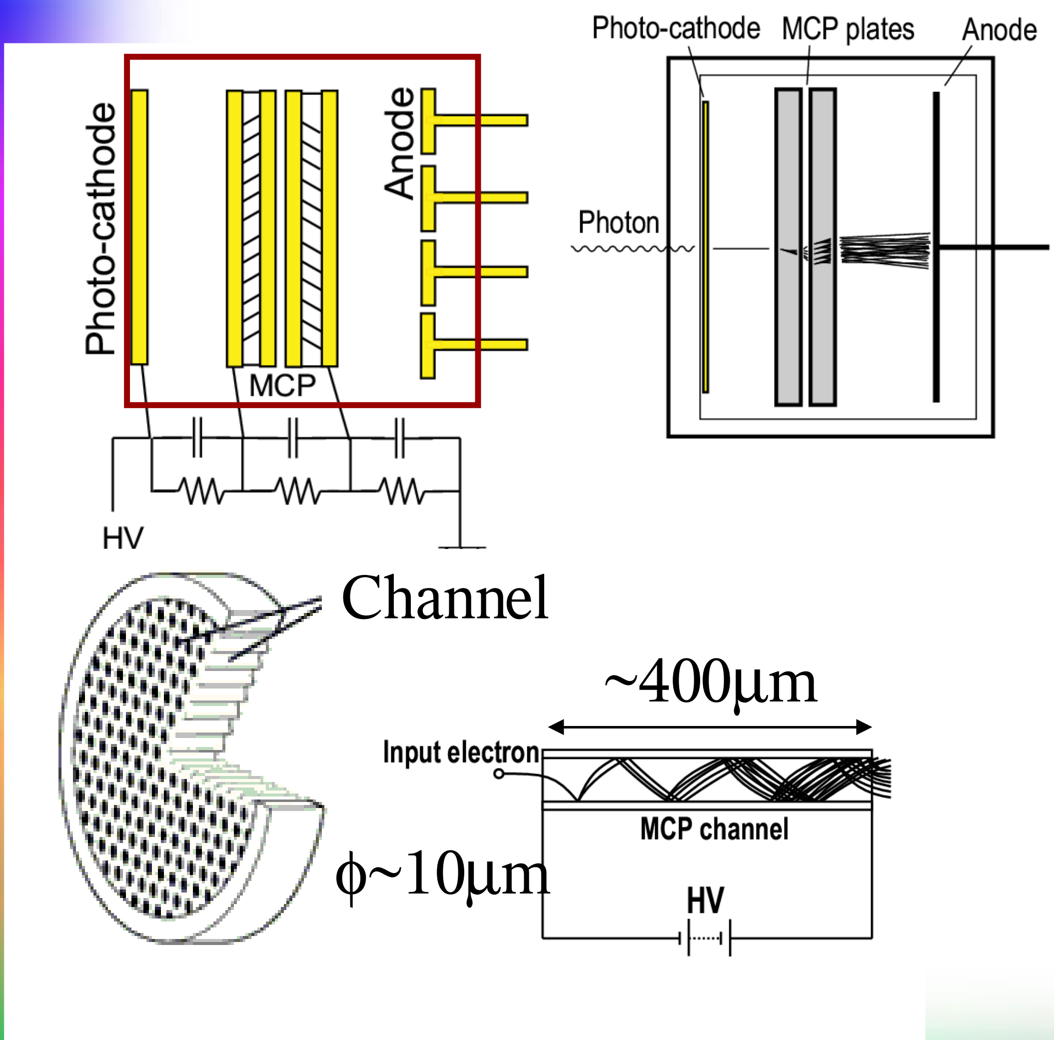
- Barrel-DIRC → poster of C. Schwarz
  - time-of-propagation (TOP) version
    - measure TOP of Cherenkov photons from creation to the photosensor
    - 2-dim. readout: X and TOP
  - 3D version
    - TOP information used to correct for dispersion effects
    - 3-dim. readout: X, Y and TOP
- Endcap Disc-DIRC → poster of P. Schönmeier
  - TOP version
    - prolongation of TOP and dispersion correction by using dichroic filters
    - 2-dim. readout: φ and TOP
  - version with focussing light guides
    - dispersion correction and focussing with LiF plate and light guide
    - 3-dim. readout: θ, φ and TOP

Technical Challenges to Photon Sensors

- Photon rates in the MHz regime
  - high rate stability (rates of several MHz/cm^2)
  - very short pulses (< 10 ns) to avoid pile-up
  - long lifetime
- Few photons per track
  - high detection efficiency $\eta = QE * CE * GE$
    [QE = quantum efficiency; CE = collection efficiency; GE = geometrical efficiency]
  - low dark count rate
- Single photon detection in high B-field
  - high gain (> $5*10^5$) even in a 2 Tesla magnetic field
- Time resolution to separate π/K with TOP
  - very good single photon transit time resolution of < 50 ps

Microchannel Plate PMT

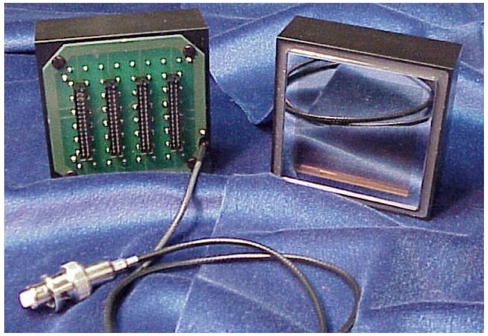
electron multiplication in glass capillaries (∅ ≈ 10 μm)

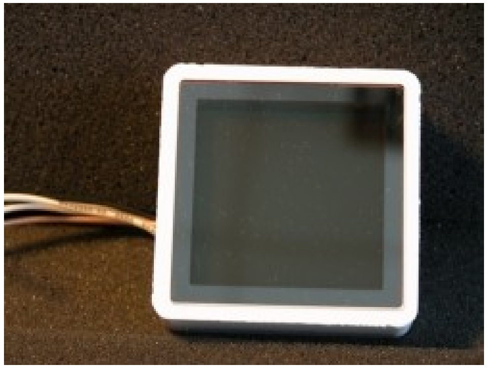


- very fast time response:
  - signal rise time = 0.5 – 1.5 ns
  - TTS < 50 ps
- high gain:
  - $>10^6$ with 2 MCP stages
  - single photon sensitivity
- usable in high magnetic fields
- low dark count rate
- quantum efficiency comparable to that of standard vacuum PMTs
- multi-anode PMTs possible
- caveats:
  - life time
  - price

Studied MCP-PMTs

Burle 85011 | **Burle Prototype** | **BINP #73**





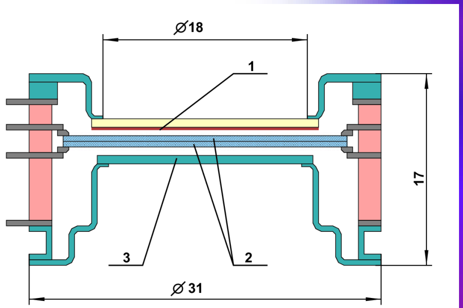
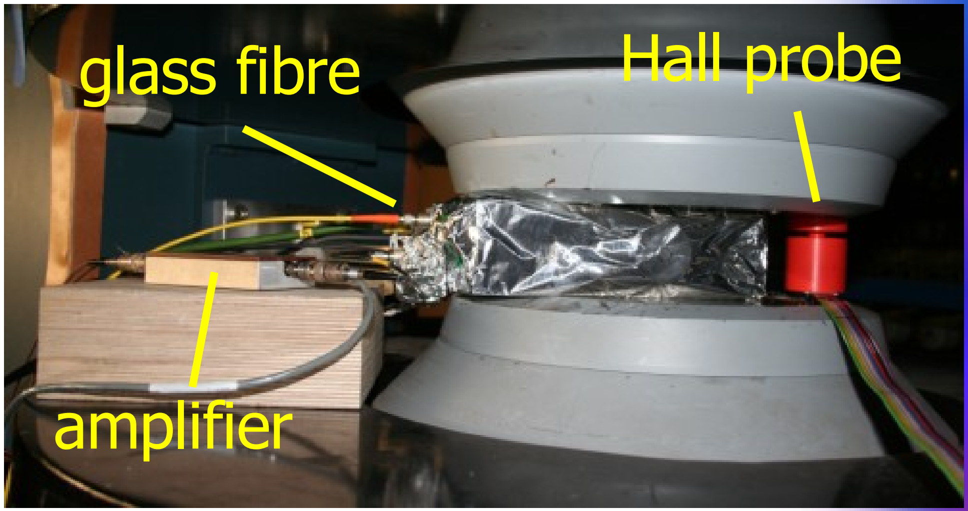


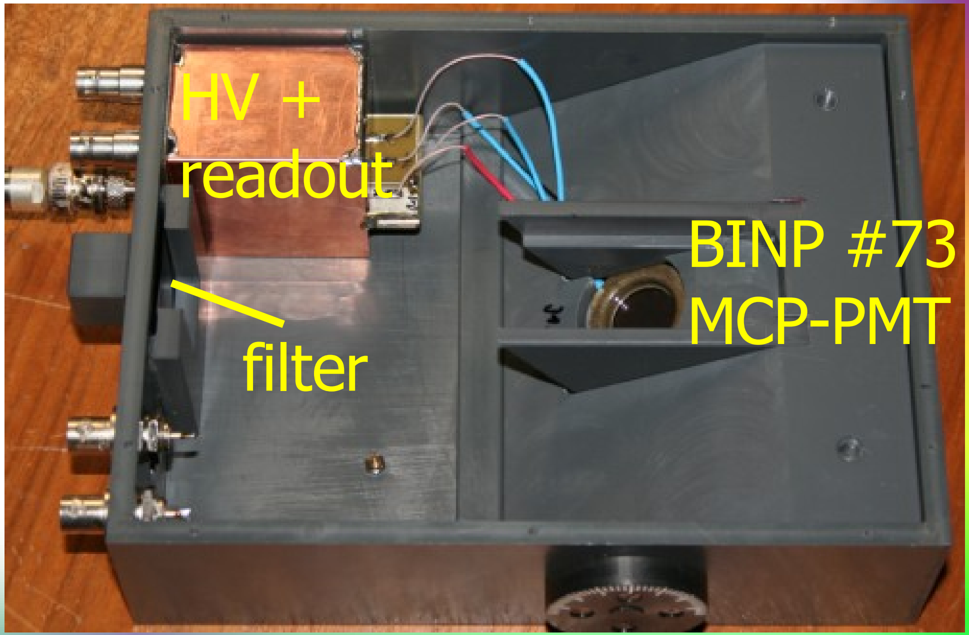
Fig. 1. The MCP PMT layout. 1—photocathode, 2—MCPs, 3—anode. Sizes are in millimeters.

	Burle 85011	Burle Prototype	BINP #73
MCP channel diameter (µm)	25	10	6
Peak wavelength (nm)	400	400(?)	500
Active area (mm x mm)	51 x 51	51 x 51	Ø 18
Number of pixels	64 (8 x 8)	64 (8 x 8)	1
Pixel size (mm x mm)	5.9 x 5.9	5.9 x 5.9	Ø 18
Protection of photo cathode	No	No	5-9 nm Al2O3

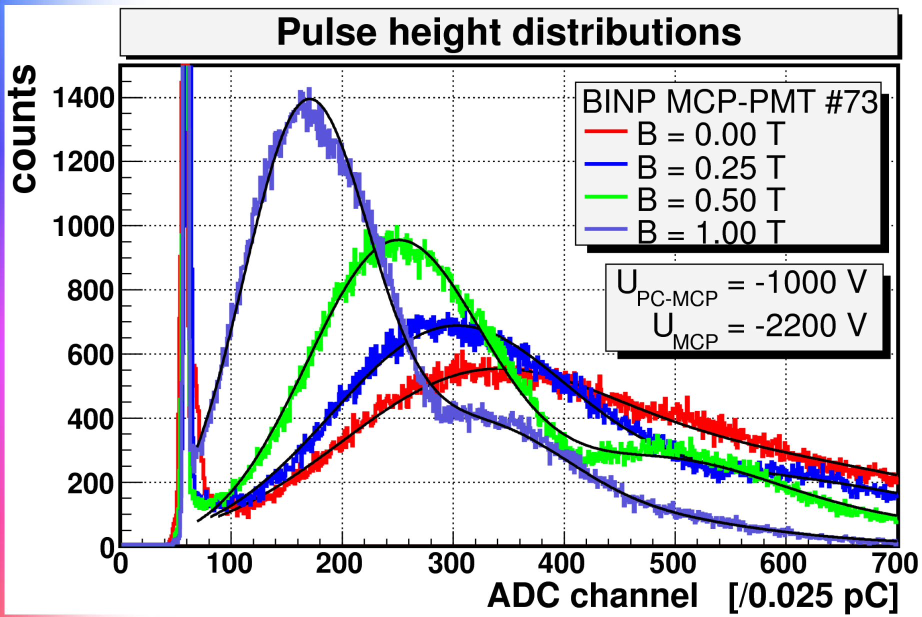
Setup at Juelich Dipole Magnet

- Dipole magnet
  - homogeneous field up to 2.05 T
  - 6 cm pole shoe gap
  - field measured with Hall probe
- PiLas light pulser
  - pulse width 14 ps (σ); λ = 372 nm
  - glass fibre and micro lenses
  - gray filters
- MCP-PMTs
  - mounted in shielded box
  - BINP #73 with $\phi = 15^{\circ}$ steps betw. field direction and MCP-axis
  - different amplifiers
    - Ortec VT120A (350 MHz, x200)
    - Ortec 9306 (1.0 GHz, x100)
    - Hamamatsu C5594 (1.5 GHz, x63)





Analysis of Gain and Time Resolution

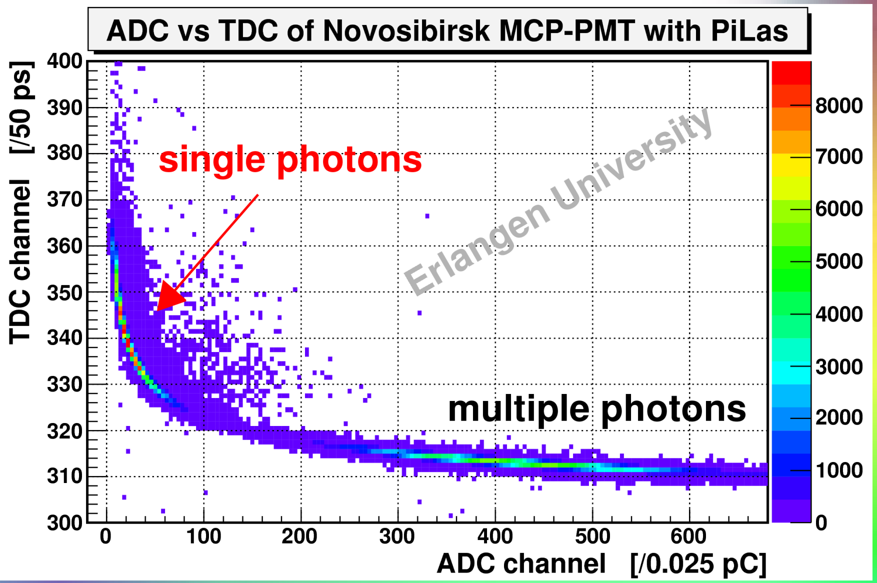


- Analysis of gain
  - fitted with a discrete Poissonian distribution convoluted with k Gauss distributions

$$f(x, N, \sigma) = C \sum_{k>0} \left[\frac{e^{-N} N^k}{k!} \cdot \frac{1}{\sigma \sqrt{2\pi k}} \exp\left\{ -\frac{(x - k x_0)^2}{2 k \sigma^2} \right\} \right]$$

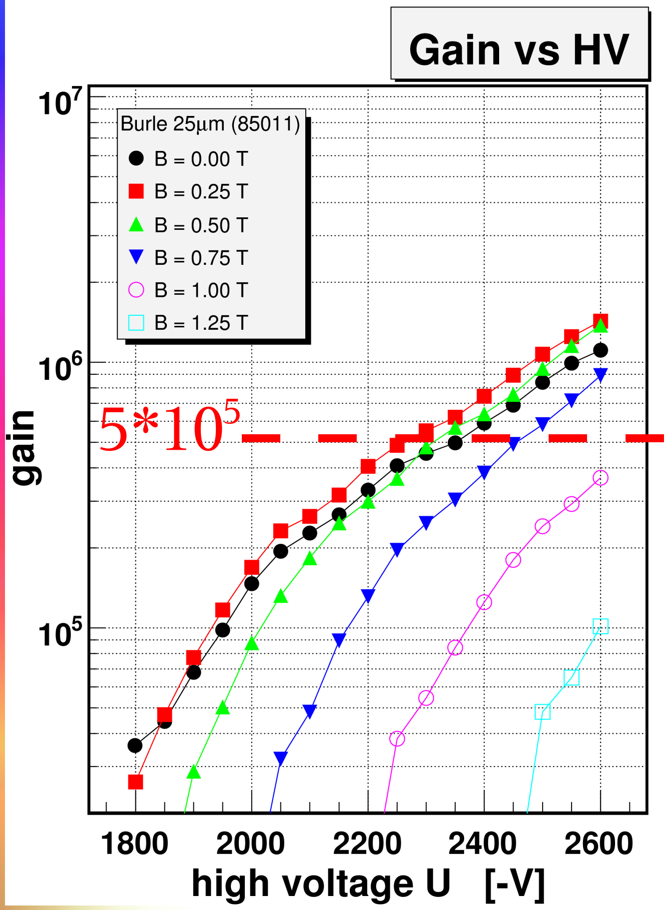
with x_0 := ***position of SEP*** (Poisson scale)

- Analysis of time resolution
  - measure time walk (charge vs delay)
  - slices along charge axis (ADC) and Gaussian fits to TDC distribution ⇒ σ_t

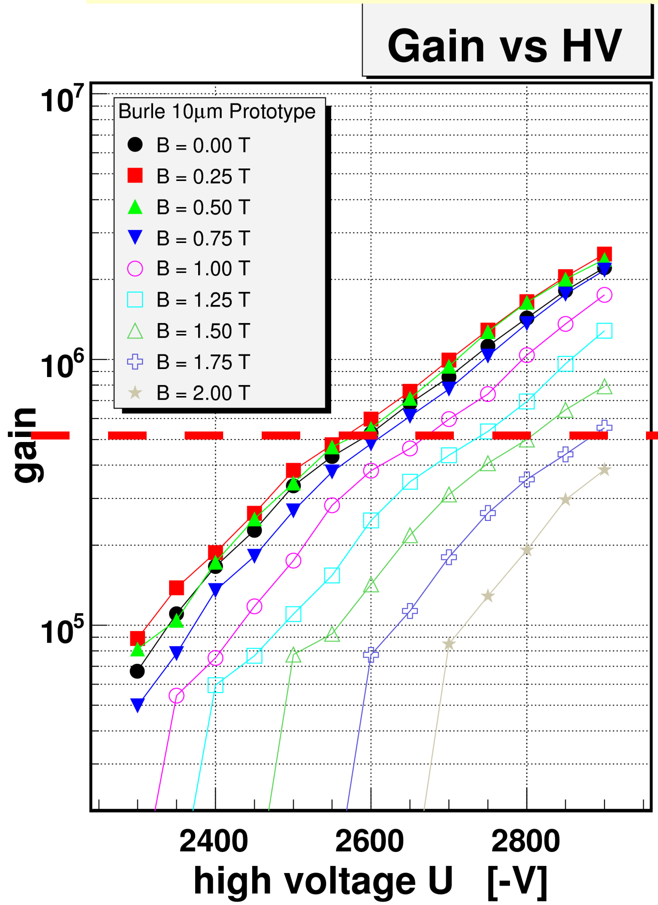


Gain in Magnetic Field (I)

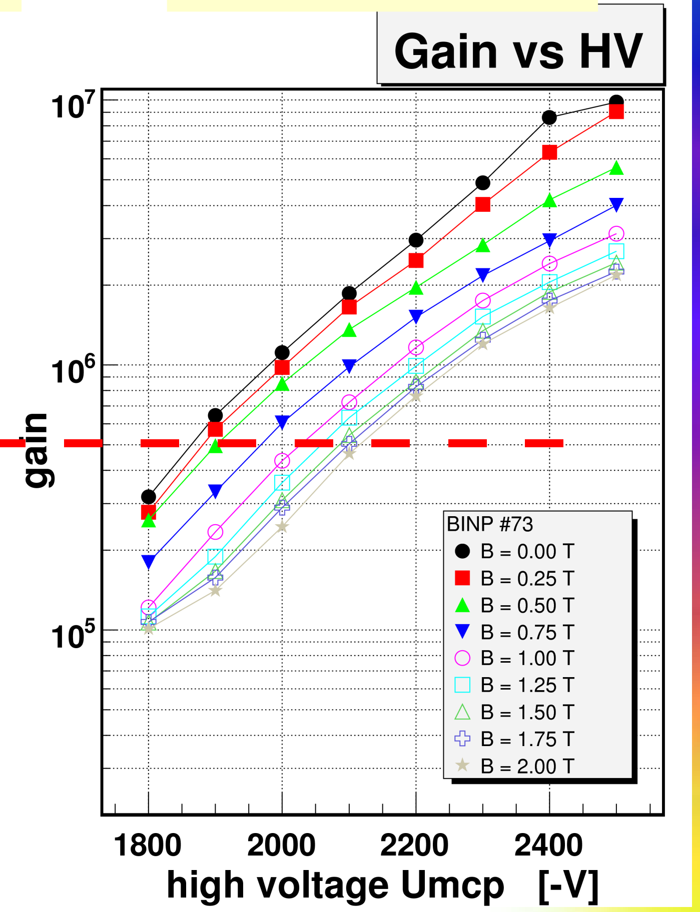
Burle 85011 (25µm)



Burle Prototype (10µm)

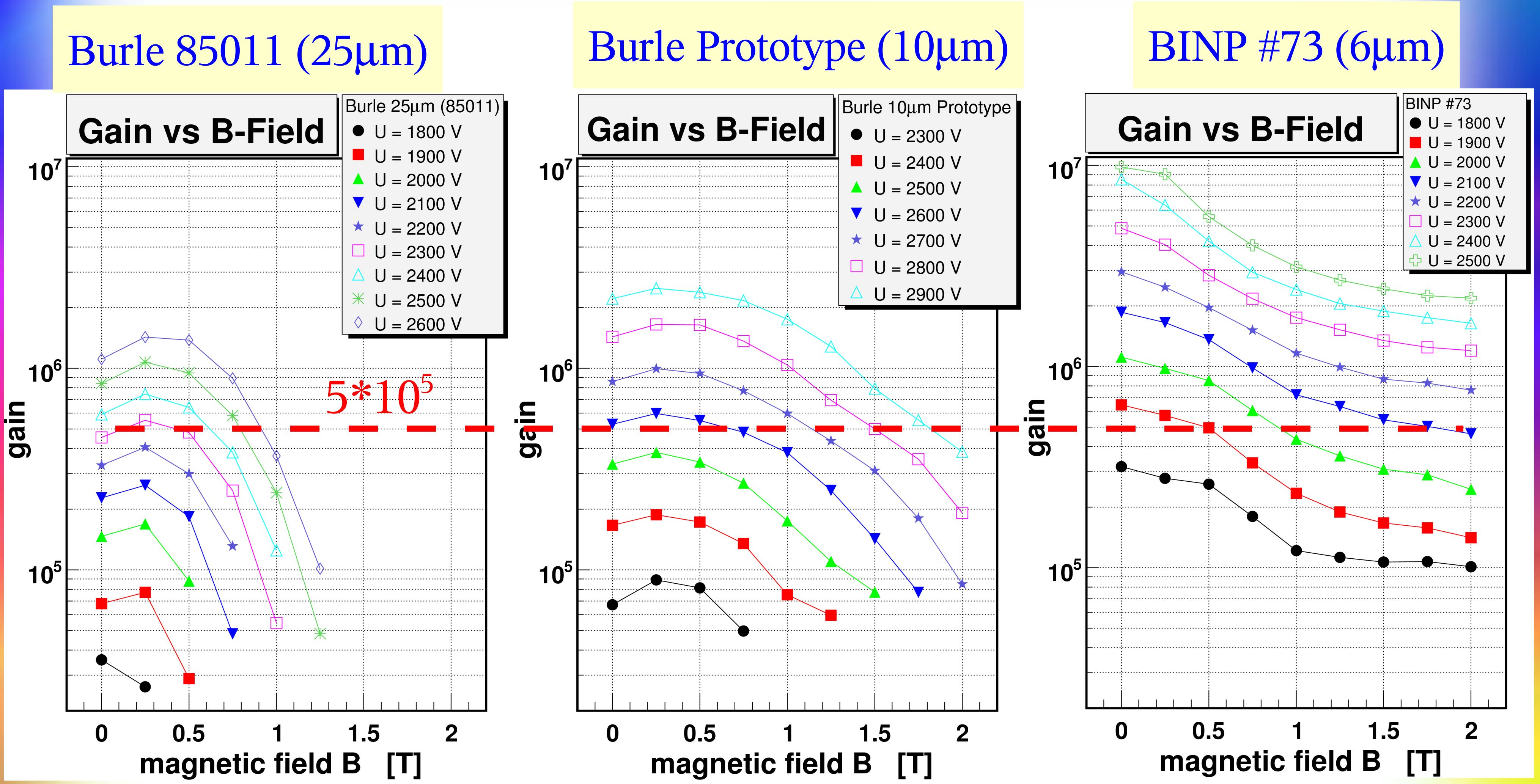


BINP #73 (6µm)



- gain improves significantly with smaller MCP channel diameter
- gain of Burle 85011 not enough for single photon detection with PANDA

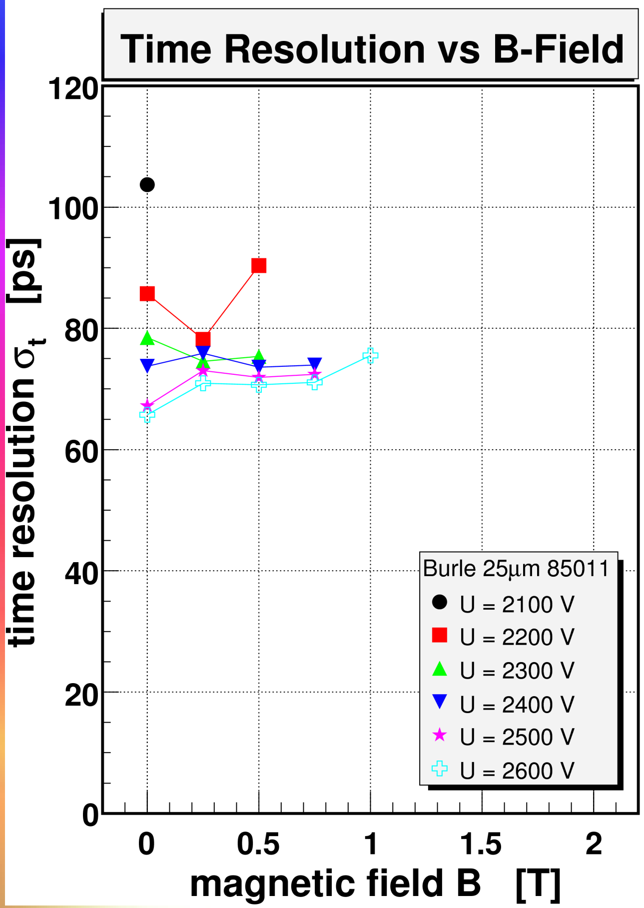
Gain in Magnetic Field (II)



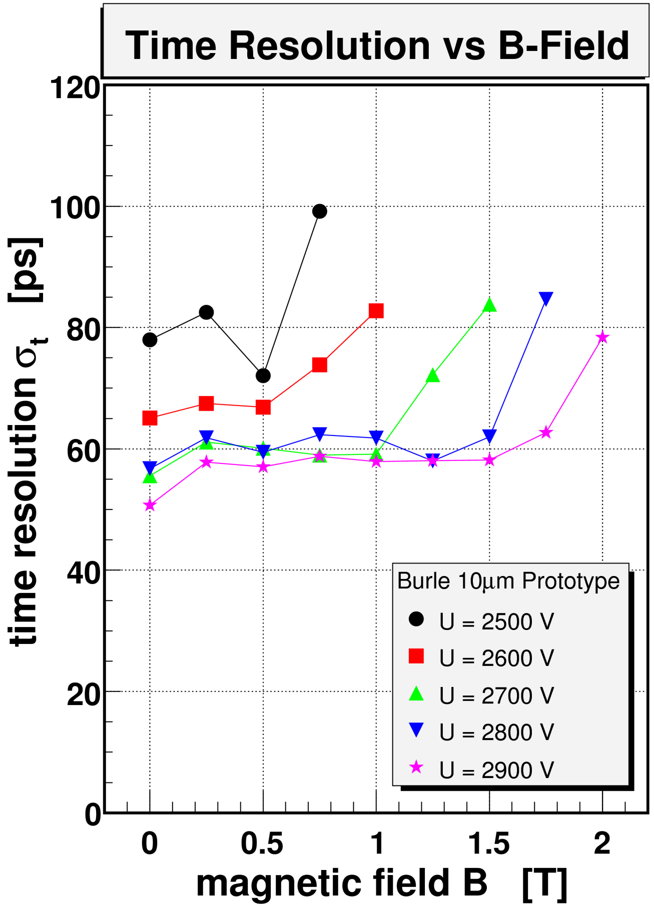
- gain of Burle 85011 collapses above 1 Tesla field
- Burle 10 µm prototype can be used for single photon detection up to 2 Tesla
- moderate voltages enough for single photon detection with BINP #73

Time Resolution in Magnetic Field

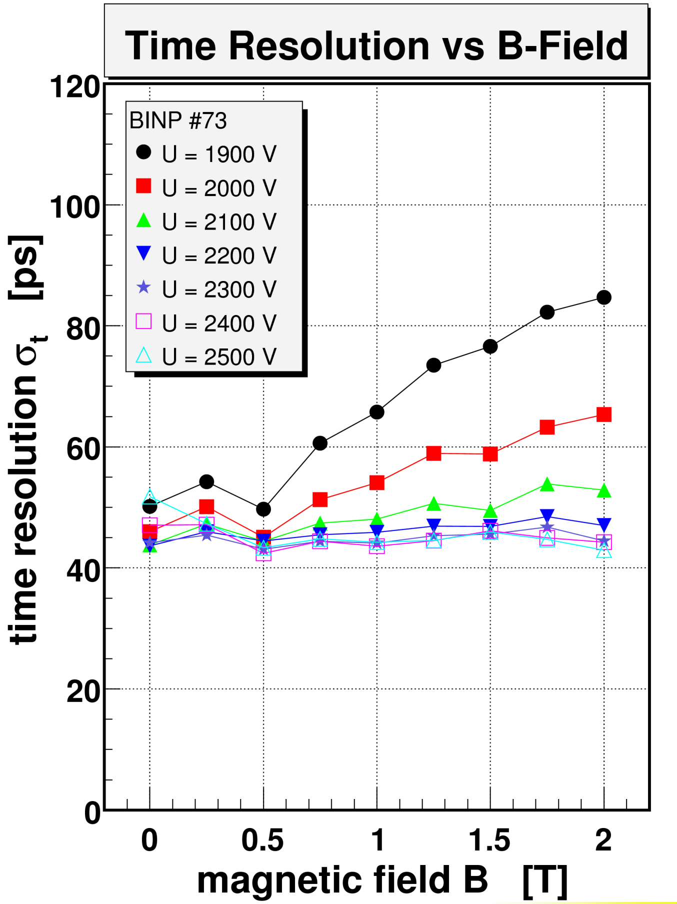
Burle 85011 (25µm)



Burle Prototype (10µm)



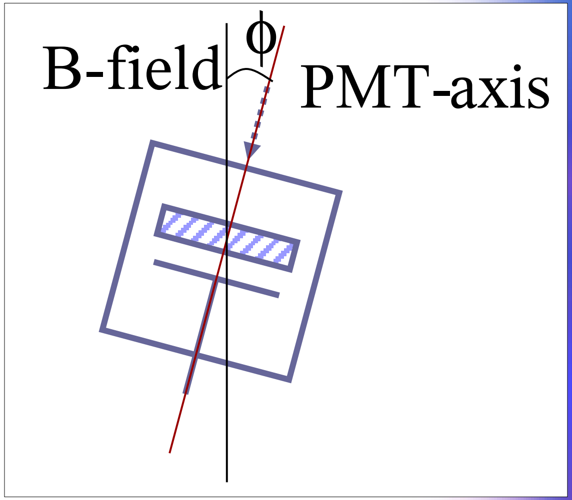
BINP #73 (6µm)

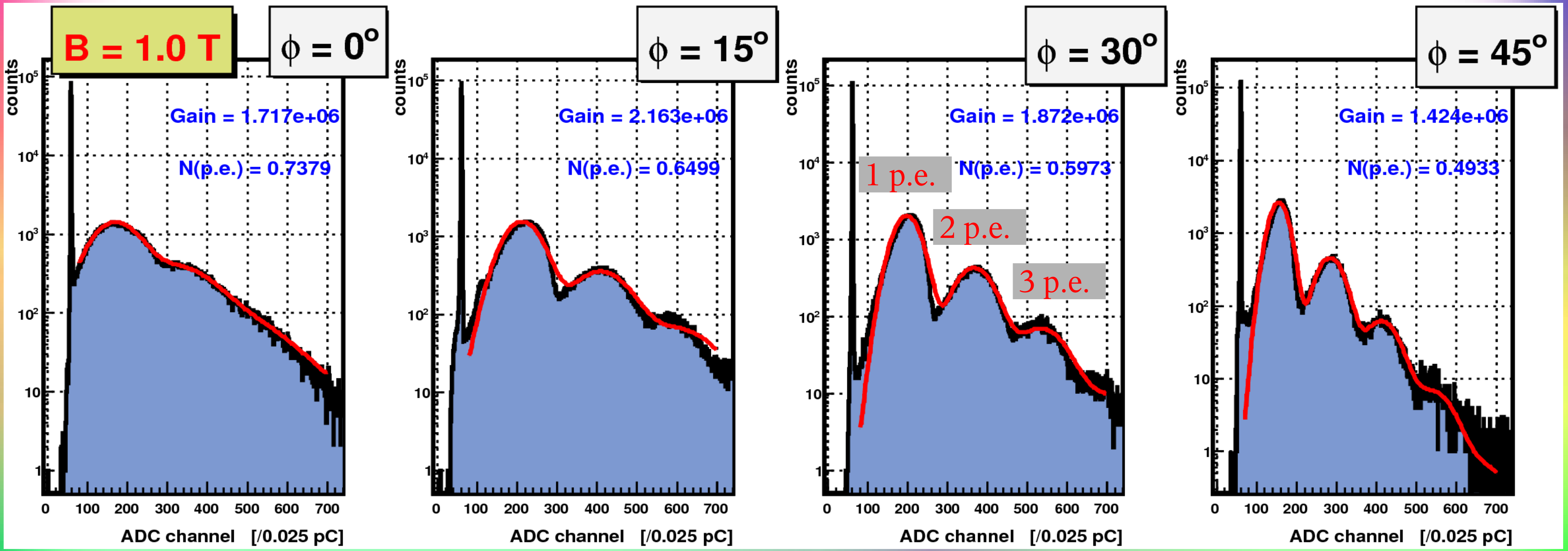


- all given time resolutions show upper limits (< 80 ps)
- time resolution improves with MCP channel diameter
- time resolution appears to be almost independent of B-field

Variation of the Field Axis

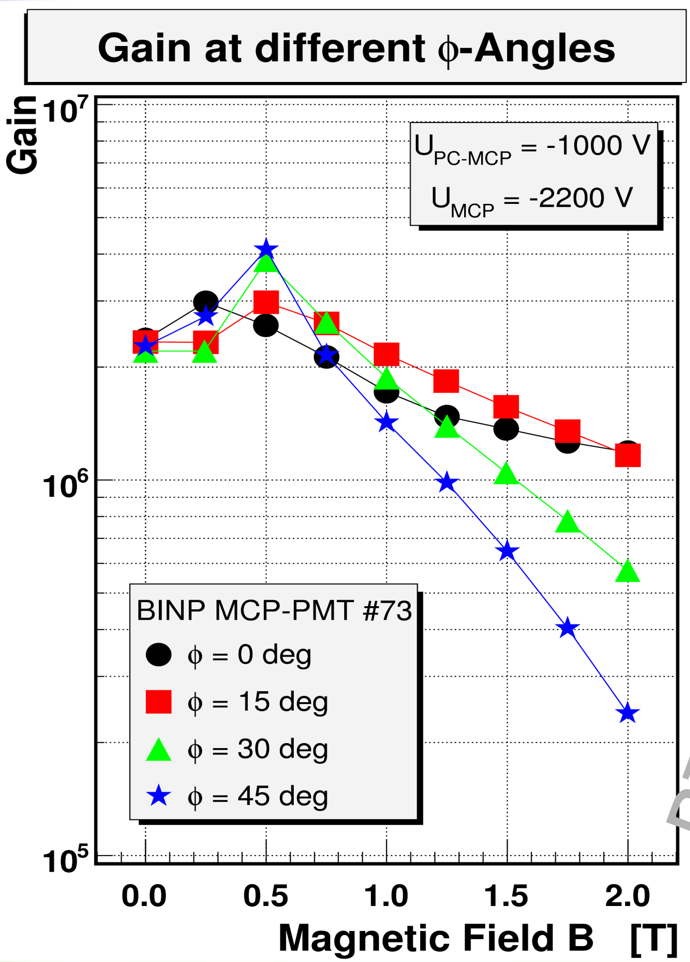
- ϕ = angle between field direction and PMT axis
- Photo electron peaks become asymmetric
- Photo electron peaks become narrower and more clearly separated at larger ϕ-angles
  - probably the electrons after the first MCP hit less capillaries of the second MCP ⇒ less spread



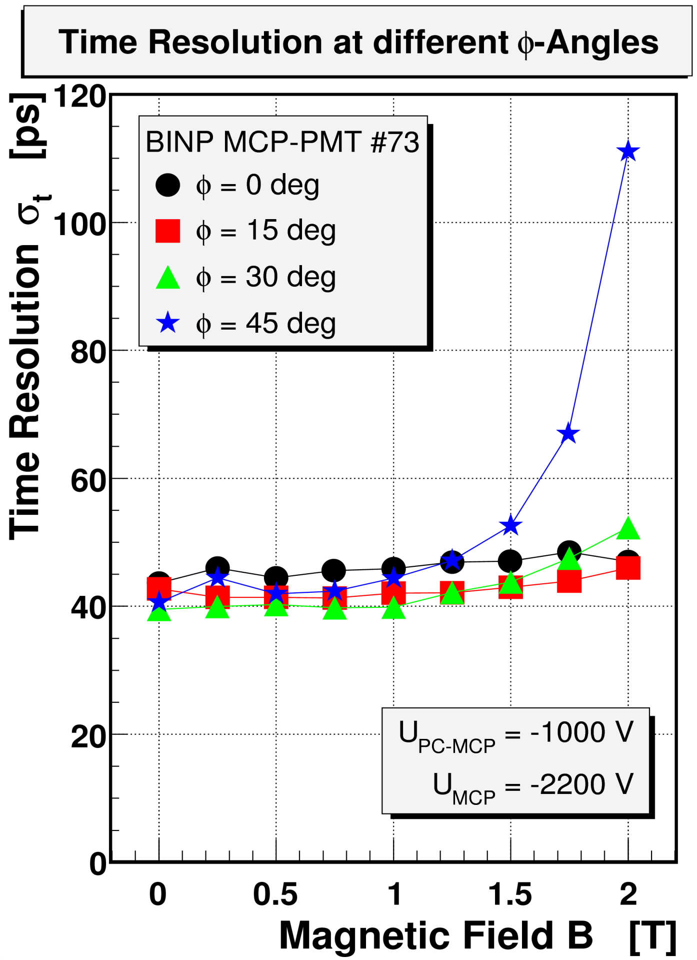


Performance at Different Field Axes

- gain



- time resolution (measured)

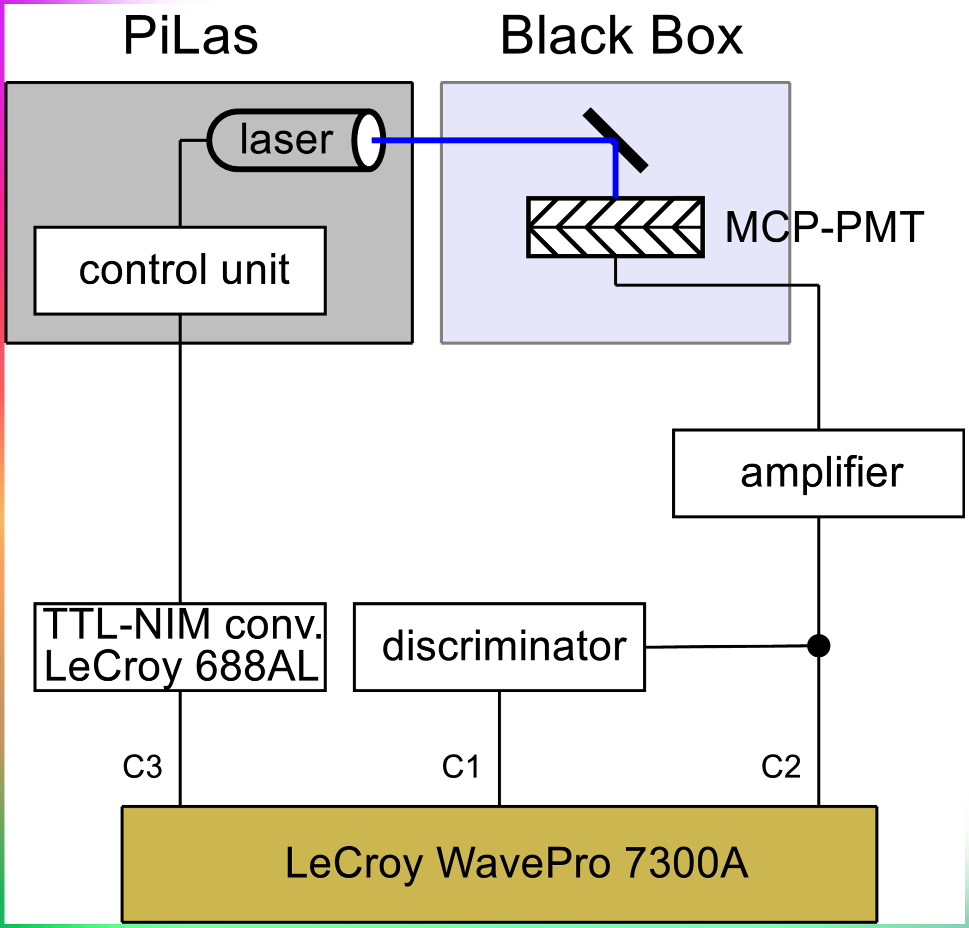


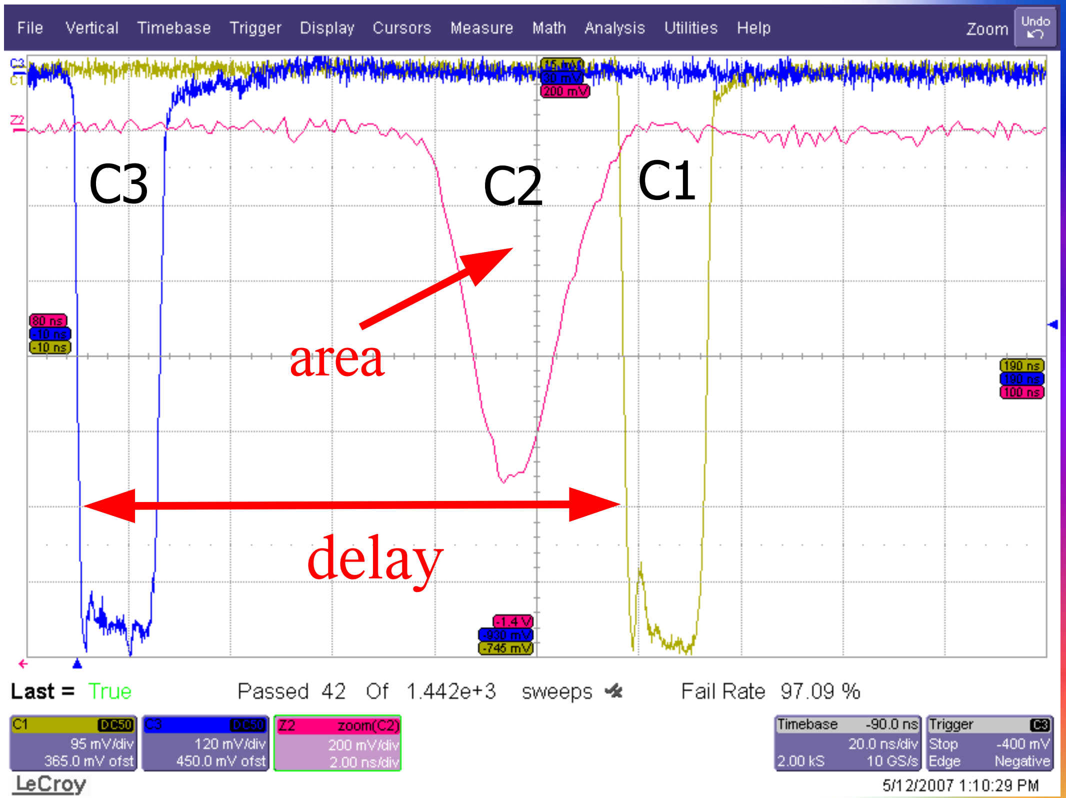
BINP MCP-PMT #73

Good gain and excellent time resolution even in 2 Tesla B-field

Timing Measurements with Oscilloscope

- 3 GHz / 20 Gs oscilloscope
- various amplifiers and discriminators tested



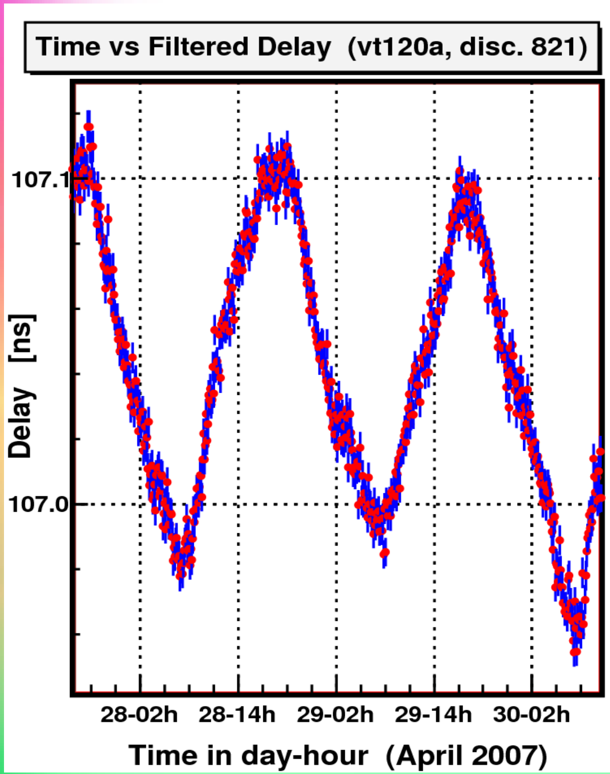


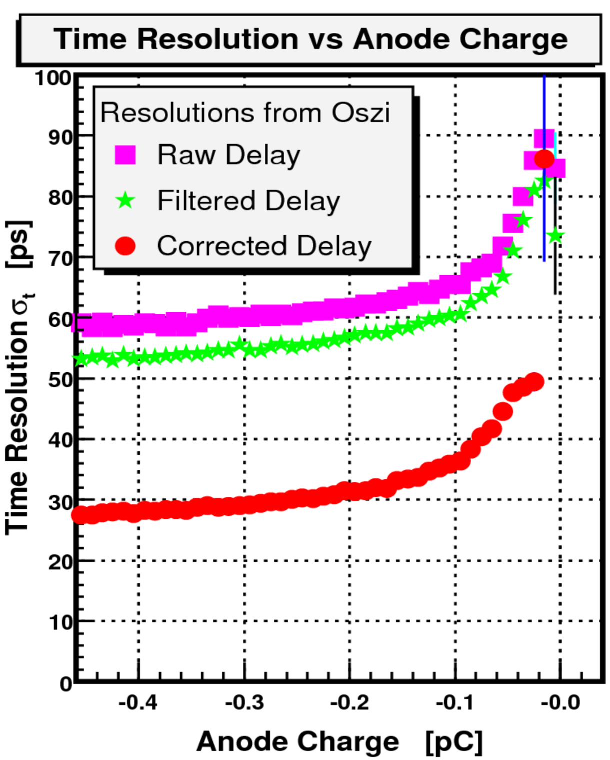
- no magnetic field
- measure area (C2)
- measure delay of PiLas reference pulse C3 to MCP pulse C1

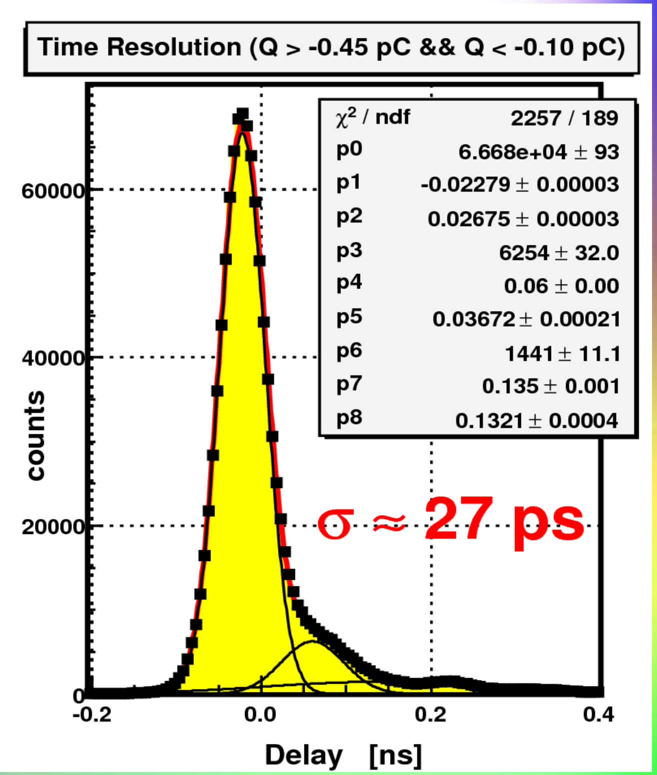
  ⇒ jitter ≡ time resolution

Time Resolution with Oscilloscope

- True MCP time resolution blurred
  - sampling noise of oscilloscope
  - long term drifts (e.g., temperature)
  - electronics
  - cables (??)
  - width of laser pulses
- Resolution of electronics
  - scope (after noise filter): < 6 ps/ch
  - LeCroy 821 discr.: ~ 6 ps
  - TTL-NIM converter: < 6 ps
- PiLas laser
  - pulse width: ~ 14 ps







Amplifier and Discriminator Comparison

Time Resolutions in ps (at a gain of 2.5*10^6)

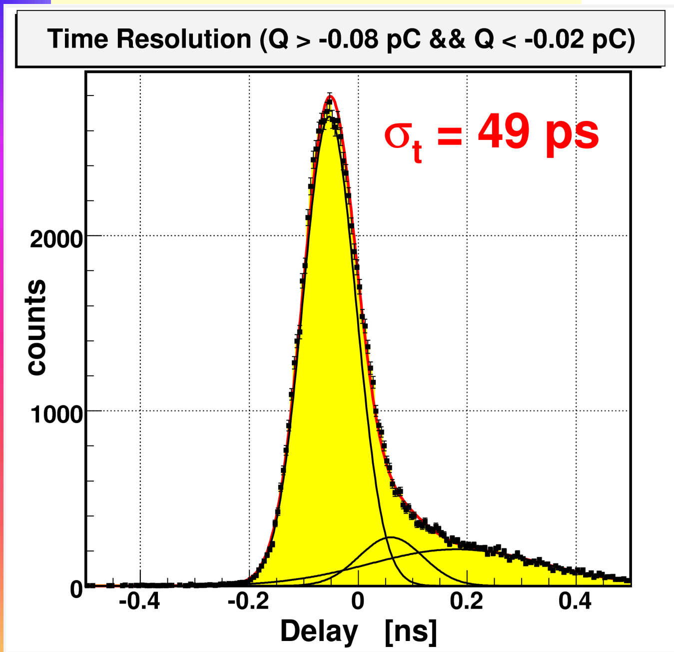
Amplifier		Leading Edge Discriminators: LC 821	LC 620CLR	Constant Fraction Discriminators: CF4000	Ortec 934	Average
Fixed Pulse Height						
	Area in nVs					
Ham. C5594	[-1.2,-0.4]	27.7	33.1	25.9	27.9	**28.7**
Ort. 9306	[-1.2,-0.4]	29.8	34.9	27.9	31.4	**31.0**
Ort. VT120A	[-1.2,-0.4]	30.4	37.7	29.8	31.6	**32.4**
Average		**29.3**	**35.2**	**27.9**	**30.3**	
Single Photons						
	Q in pC					
Ham. C5594	[-0.45,-0.10]	30.5	37.7	27.7	30.7	**31.7**
Ort. 9306	[-0.45,-0.10]	30.2	35.4	27.8	31.2	**31.2**
Ort. VT120A	[-0.45,-0.10]	26.8	33.2	26.5	29.0	**28.9**
Average		**29.2**	**35.4**	**27.3**	**30.3**	

- Best amplifier at fixed pulse height: C5594
- Best amplifier for single photons: VT120A
- Best discriminator: EG&G ESN CF4000

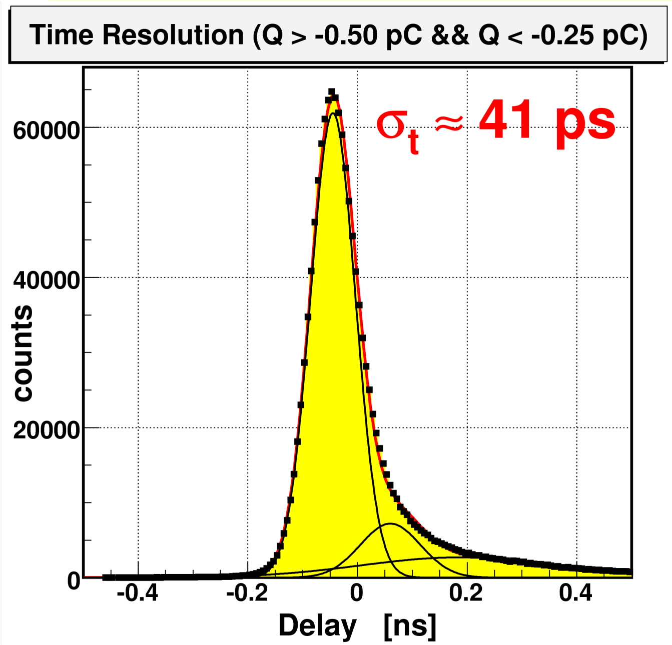
Time Resolution without Magnetic Field

Amplifier Ortec VT120A (x200; 350 Mhz) --- Discriminator LeCroy 821

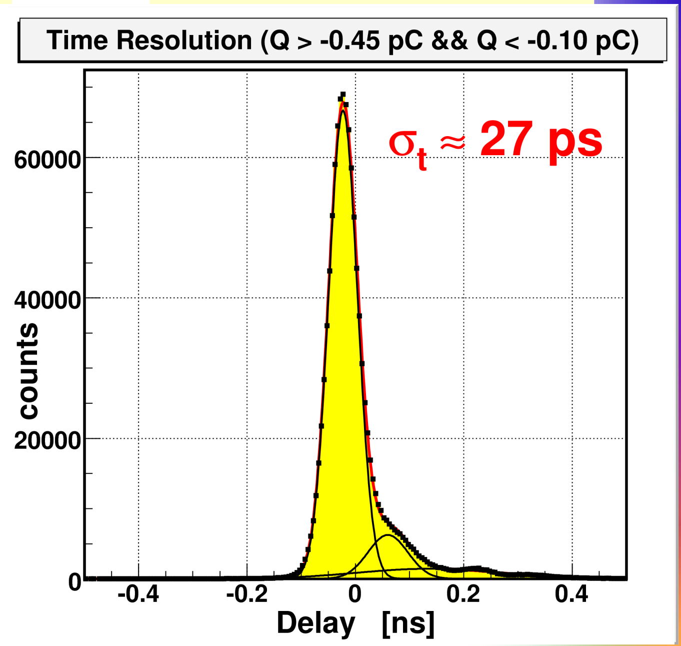
Burle 85011 (25µm)



Burle Prototype (10µm)



BINP #73 (6µm)



- Resolutions corrected for electronics effects and laser pulse width
  - Burle 85011 (25 µm) **45 ps**
  - Burle Prototype (10 µm) **37 ps**
  - BINP #73 (6 µm) **20 ps**
- Single photon time resolution of BINP #73 is by far the best !

Summary

- Single photon gain
  - 25 μm Burle MCP-PMT only usable up to ~ 1T (without tilt)
  - 10 μm Burle MCP-PMT usable for single photon detection up to 2 Tesla at high operation voltage, but will presumably be problematic at larger tilt angles
  - BINP #73 MCP-PMT well usable for single photon detection at 2 Tesla and at 45° tilt angle
- Single photon time resolution
  - inside B-field all studied MCP-PMTs better than ~80 ps
  - oscilloscope measurements without B-field:
Burle MCP-PMTs <50 ps and BINP #73 MCP-PMT <30 ps
  - best resolution of ~20 ps obtained for BINP #73
- BINP #73 MCP-PMT shows the best performance