First measurement of Z-Stack LAPPD Gen II in magnetic field

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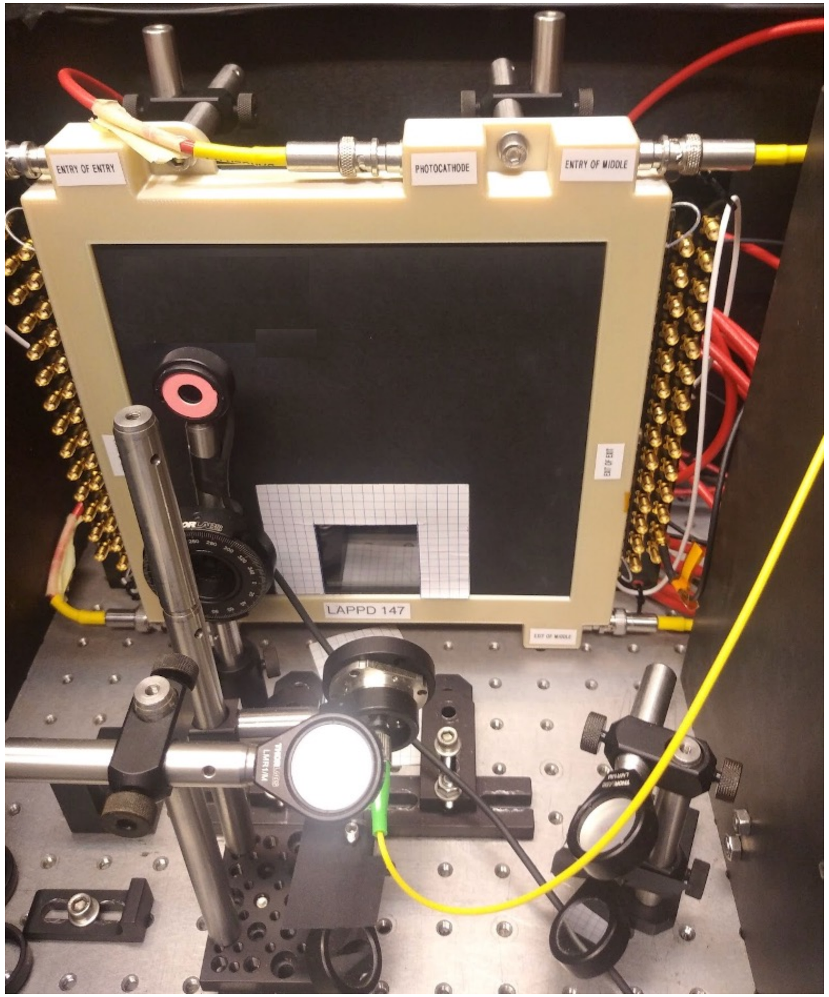
Aims of the measurements

- Measure amplitude and time resolution of single photoelectrons from LAPPD Gen II (built ad-hoc with Z-Stack) in strong magnetic field
- Varying B field strength from 0 to 3T with field perpendicular to the LAPPD window, and rotating LAPPD at fixed field strength (1T)
- Measurements performed in one day using MRI scanner at a hospital in Padova, Italy
  - Ospedale Giustinianeo, Azienda Ospedale Università Padova

LAPPD under test

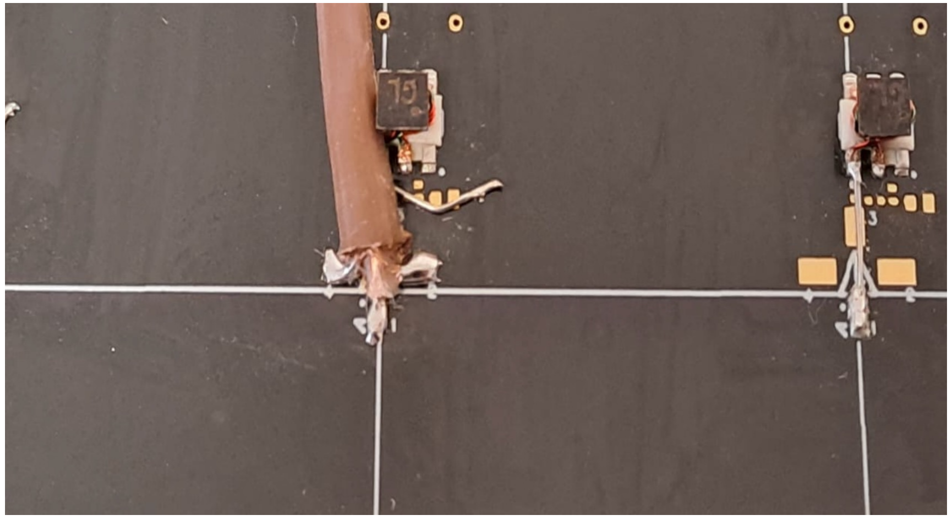
- Gen II LAPPD (#147) with 64 capacitively coupled pixels (2.5 cm pitch) on external PCB
- Three 10 μm MCPs in a Z-Stack with independent voltage inputs

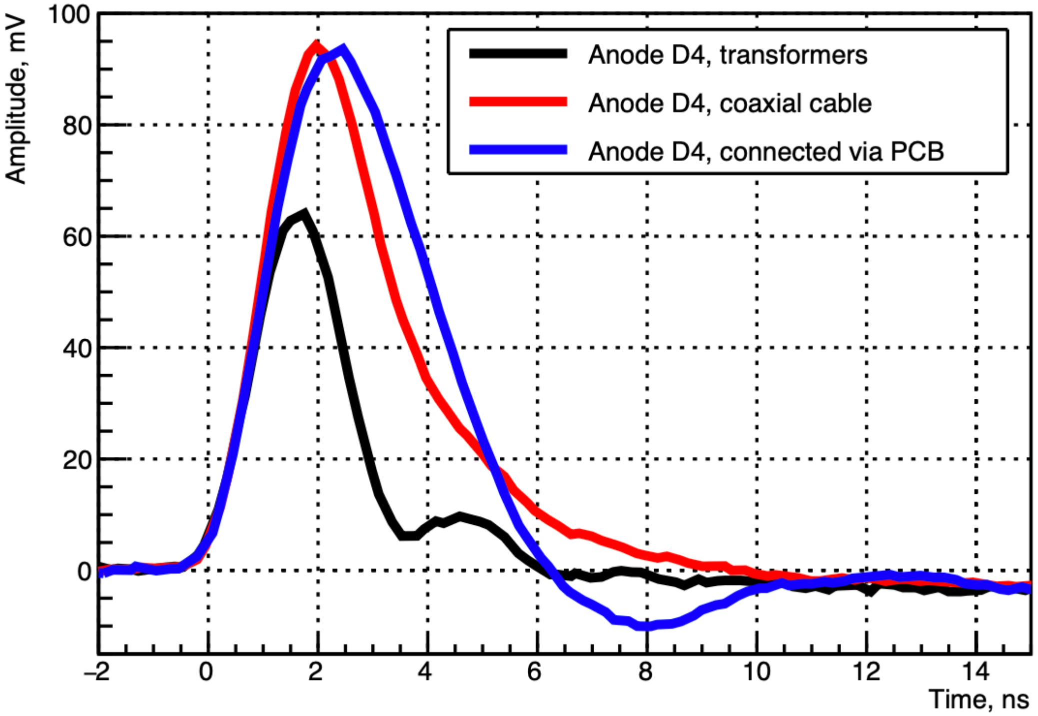
MCPs	Three Arranged in a Z-Stack
Dimensions	203 mm x 203 mm X 0.6 mm
MCP Substrate	Incom C5 Glass
Capillary Pore Diameter (μm)	10
Center to Center Pitch (μm)	13
Channel Length / diameter	60:1
Substrate Thickness (mm)	0.6
Bias Angle	13
Capillary Open Area Ratio	≥ 72%



LAPPD backplane modifications

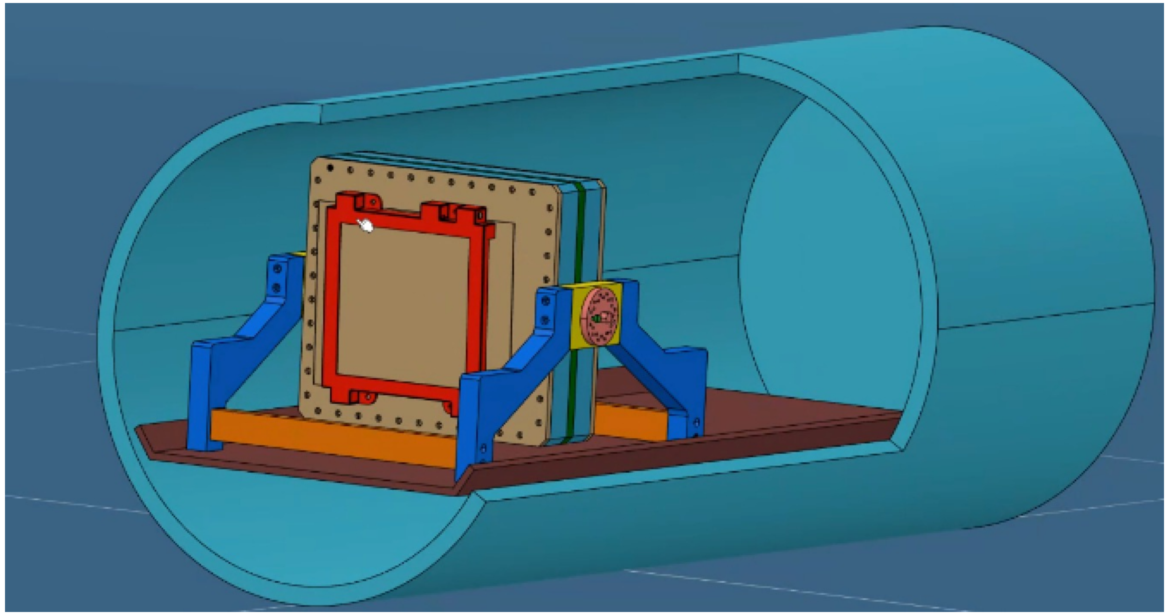
- To operate a LAPPD with capacitively coupled pixels in a magnetic field it is necessary to bypass the balun transformers in the backplane, as they saturate very quickly
- This was made by soldering coaxial cables directly to the pixels
- Incidentally, we noticed that (in absense of magnetic field) bypassing the tranformers, either with a coaxial cable or with a jumper on the PCB, the signal amplitude increases, along with the duration of the rising front

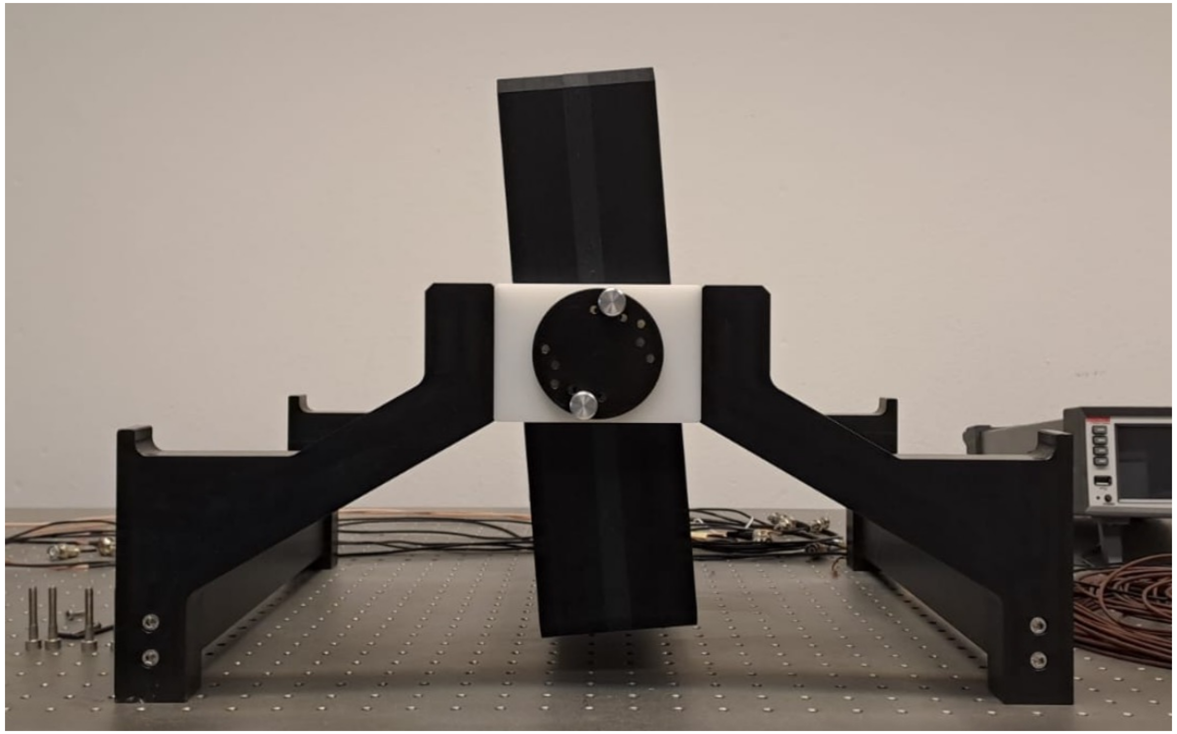




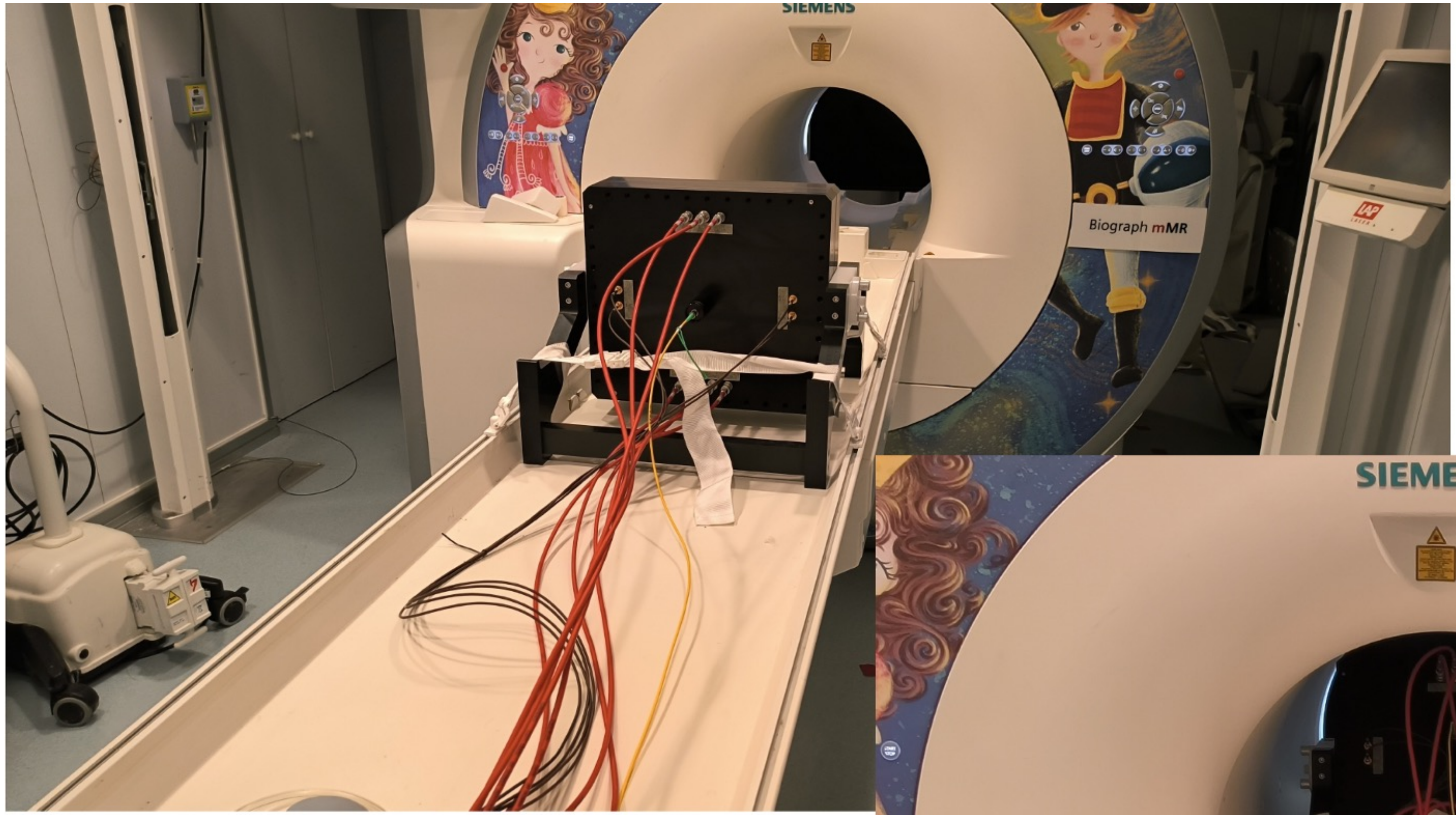
Tools in use

- LAPPD enclosed in light-tight plastic box, which can be rotated in fixed steps around central axis, built on purposed to be used on MRI scanner table
- Laser pulse (ALPHALAS, 405 nm) brought to the LAPPD via 10m long fiber (all electronics equiments must reside outside MRI room) and attenuated to single photoelectron regime using ND filters
- Signals read out using DRS4 digitizer (CAEN v1742)

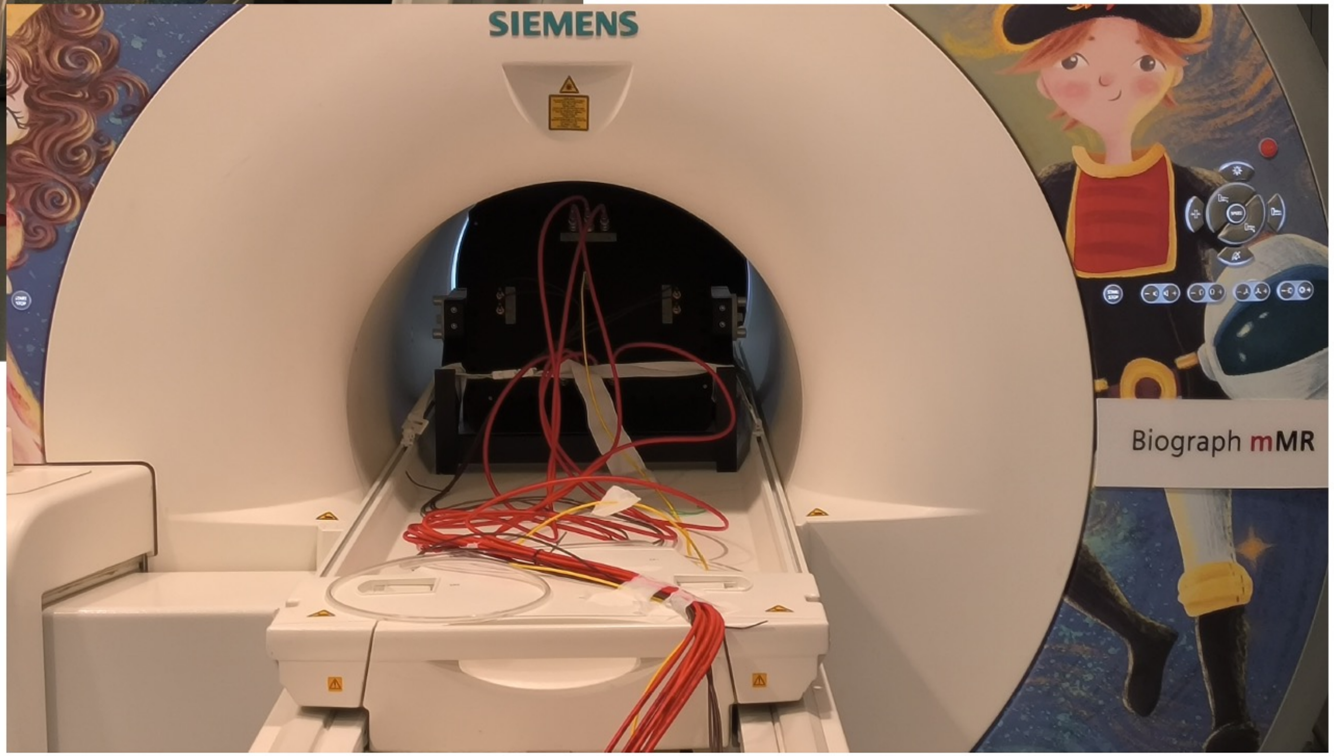




Tools in use



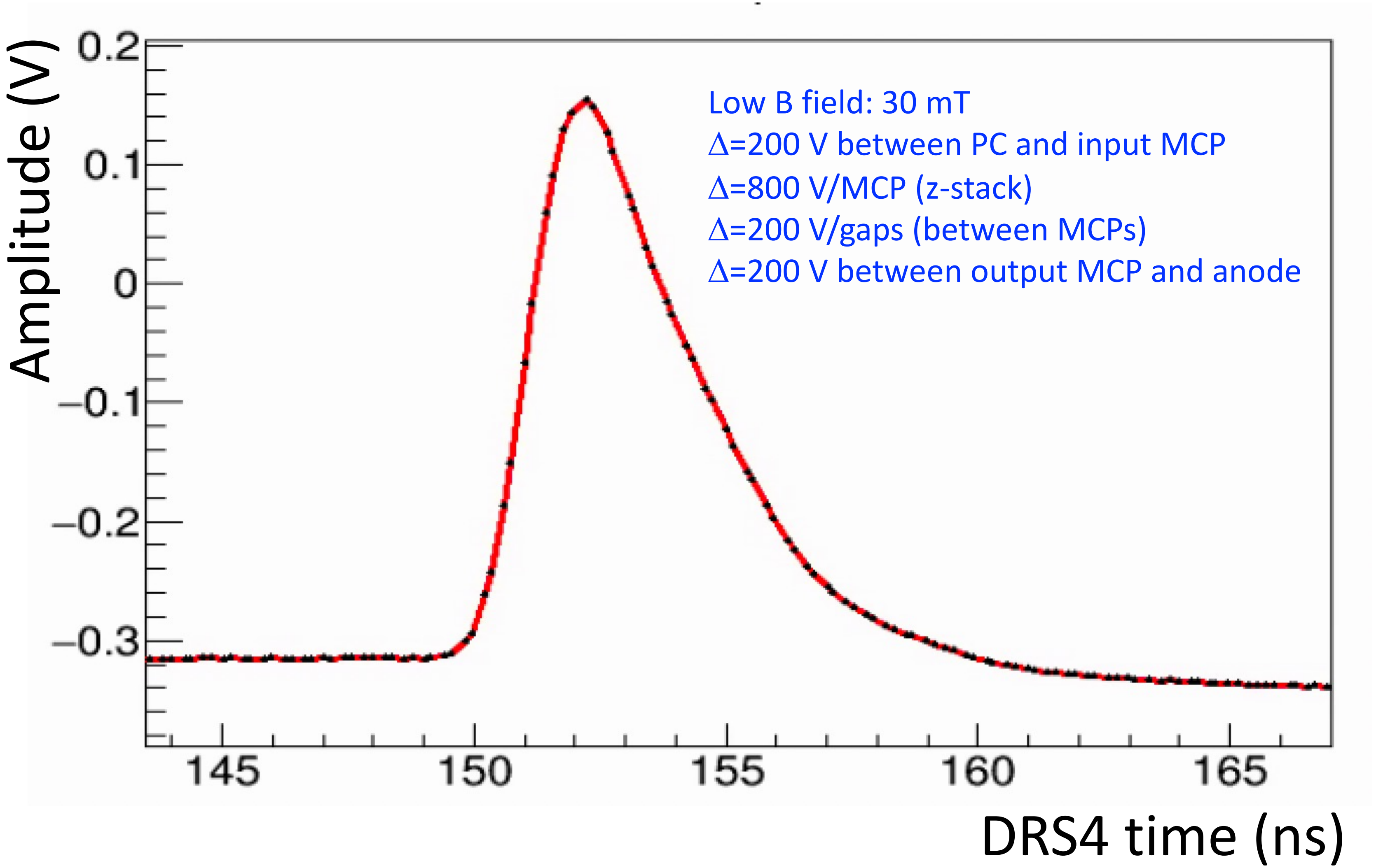
- Magnetic field measured as a function of position using Gauss meter with sensor placed aside the laser fiber connector
  - Correction for small distance between sensor and LAPPD accounted for



- PET/MRI Biograph mMR (Siemens Healthineers), normally used for patients, with 3T B field
- Bore size just right to host the equipment

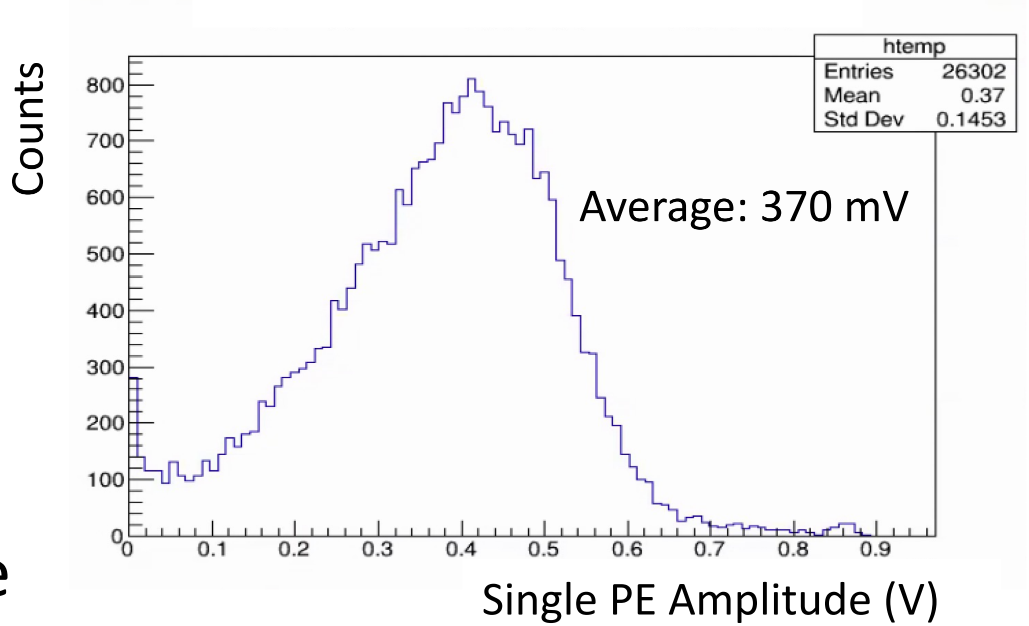
LAPPD signal characteristics

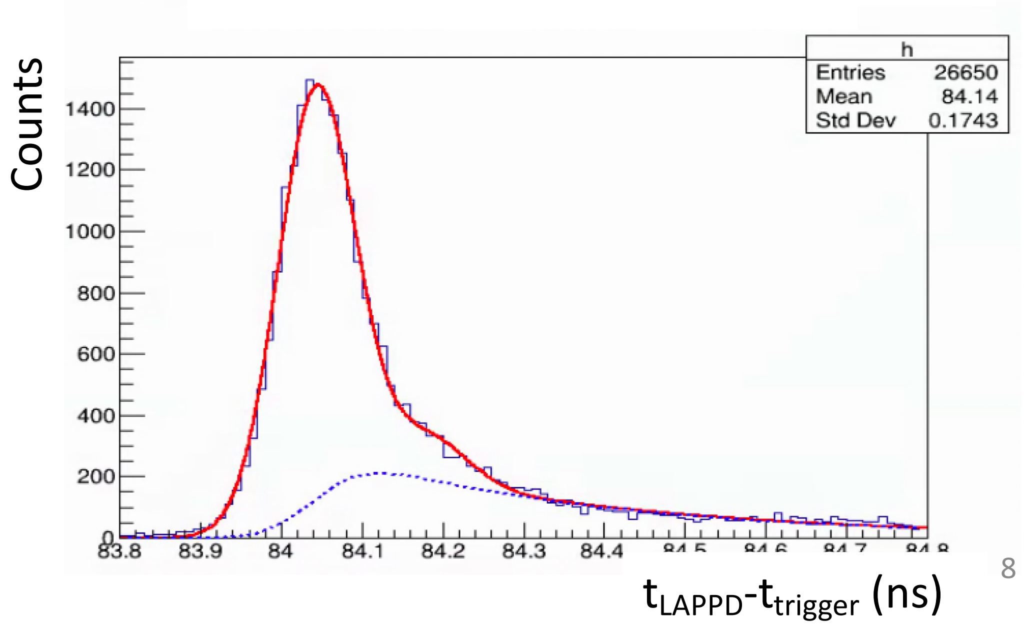
- Typical signal from coaxial cables soldered on the backplane, as read out by the DRS4 digitizer
- Measured rising front has a duration of about 1.45 ns from 10% to 90%



Typical amplitudes and time distributions

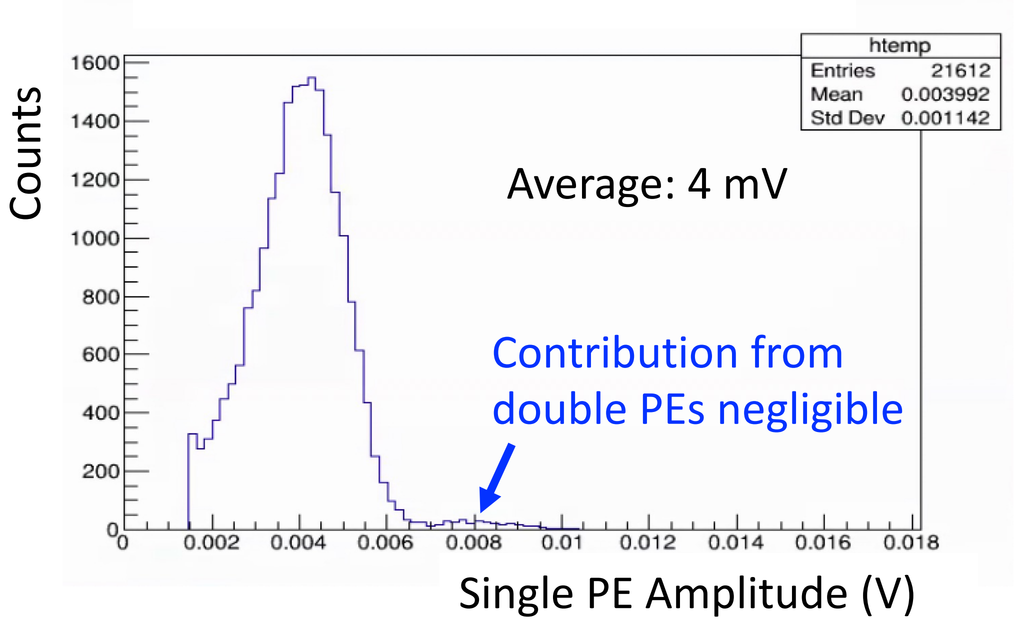
- Example at low B field: 30 mT
- Voltage settings
  - Δ=200 V between PC and input MCP
  - Δ=800 V/MCP (z-stack)
  - Δ=200 V/gaps (between MCPs)
  - Δ=200 V between output MCP and anode
- Fit model for time resolution
  - Single Gaussian for main laser pulse
  - Single Guassian for laser afterpulse
  - Exponential convolved with Gaussian for backscattering tail

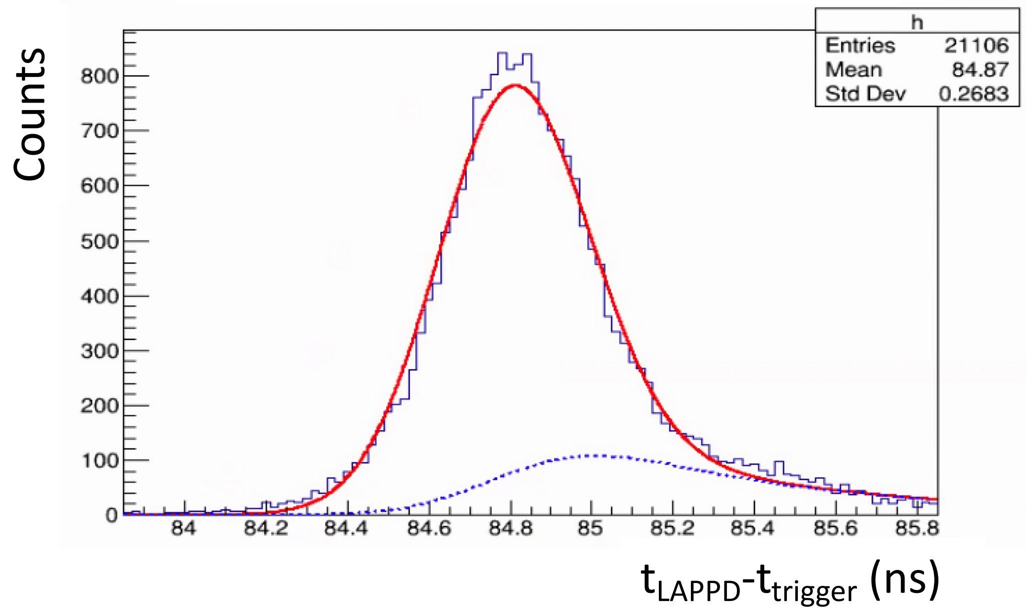




Typical amplitudes and time distributions

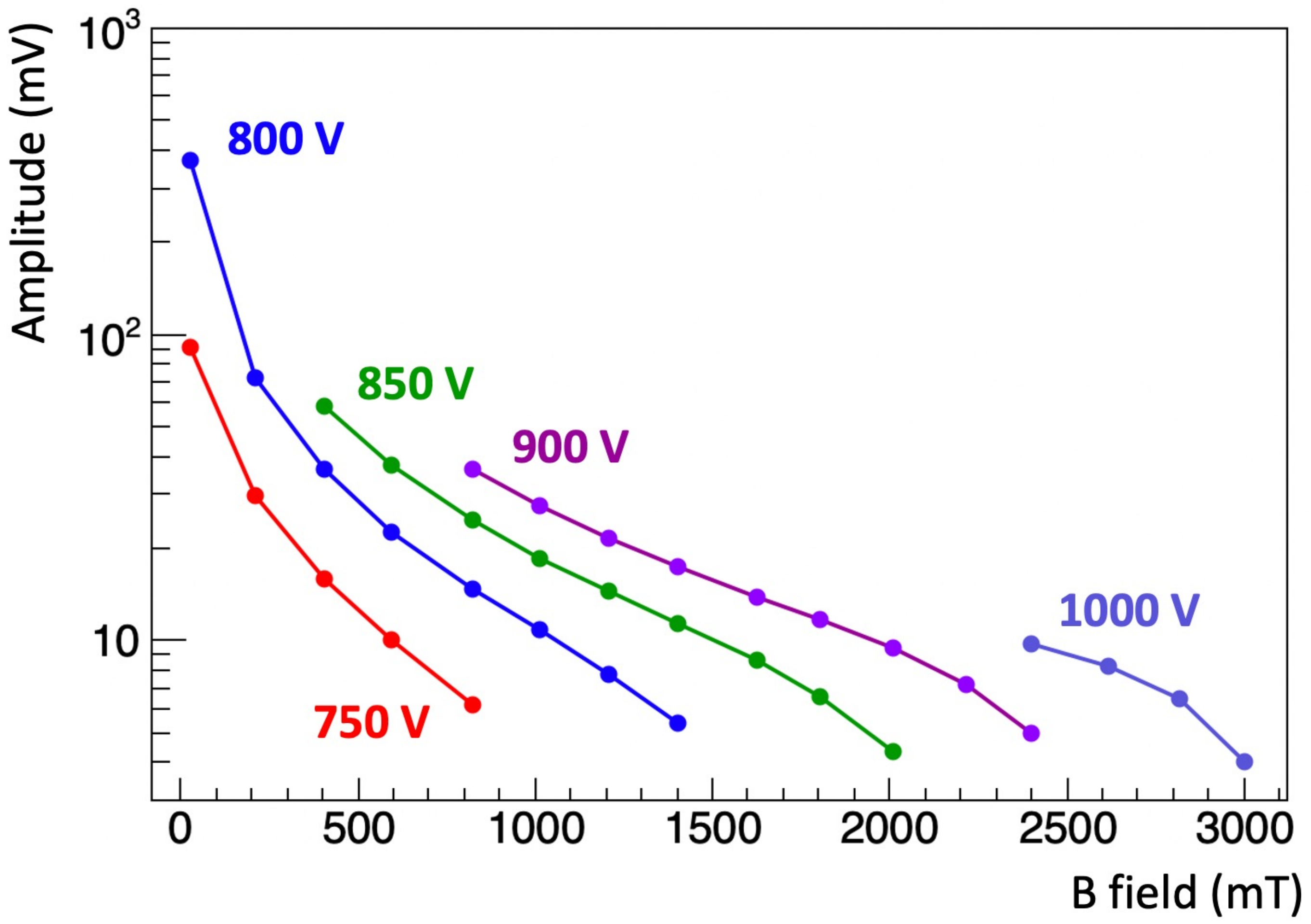
- Example at high B field: 3000 mT
- Voltage settings (power supplier limited to 3.5 kV)
  - Δ=200 V between PC and input MCP
  - Δ=1000 V/MCP (z-stack)
  - Δ=100 V/gaps (between MCPs)
  - Δ=100 V between output MCP and anode
- Same fit model for time resolution
- In all of the following, when citing time resolutions, it will be intended as the RMS of the Gaussian corresponding to the main laser pulse





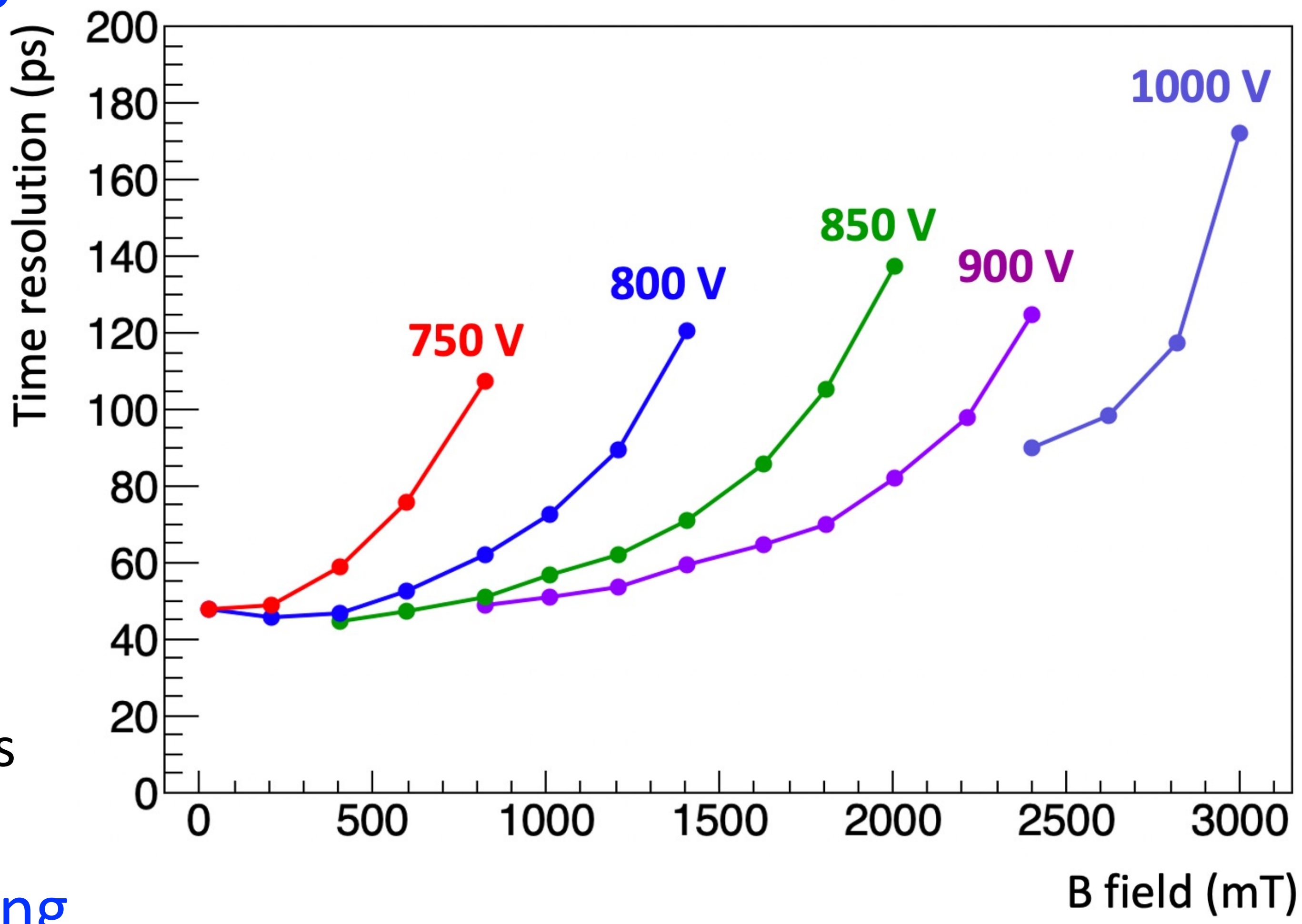
Amplitude as a function of B field intensity

- B field perpendicular to LAPPD
- At each step, about 500k events taken, containing mostly empty events and about 20-25k single PE events
- Could raise the voltage of the three MCPs to 1000 V each only in high-intensity B field
- Couldn't go beyond 1000 V due to the limit of the power supply



Time resolution as a function of B field intensity

- Same conditions as in previous slide
- Timestamps measured at 20% CFD
  - Found optimal for large amplitudes but sub-optimal for small ones
- Time resolution for single photoelectrons with low magnetic field is about 45 ps at best
  - I.e., this is the asymptotic time resolution of this LAPPD model, dominated by transit time spread when signal amplitude overwhelmes electronic noise
- Then it can be noted that the scaling is dominated by S/N (see next slide)



Time resolution as a function of B field intensity

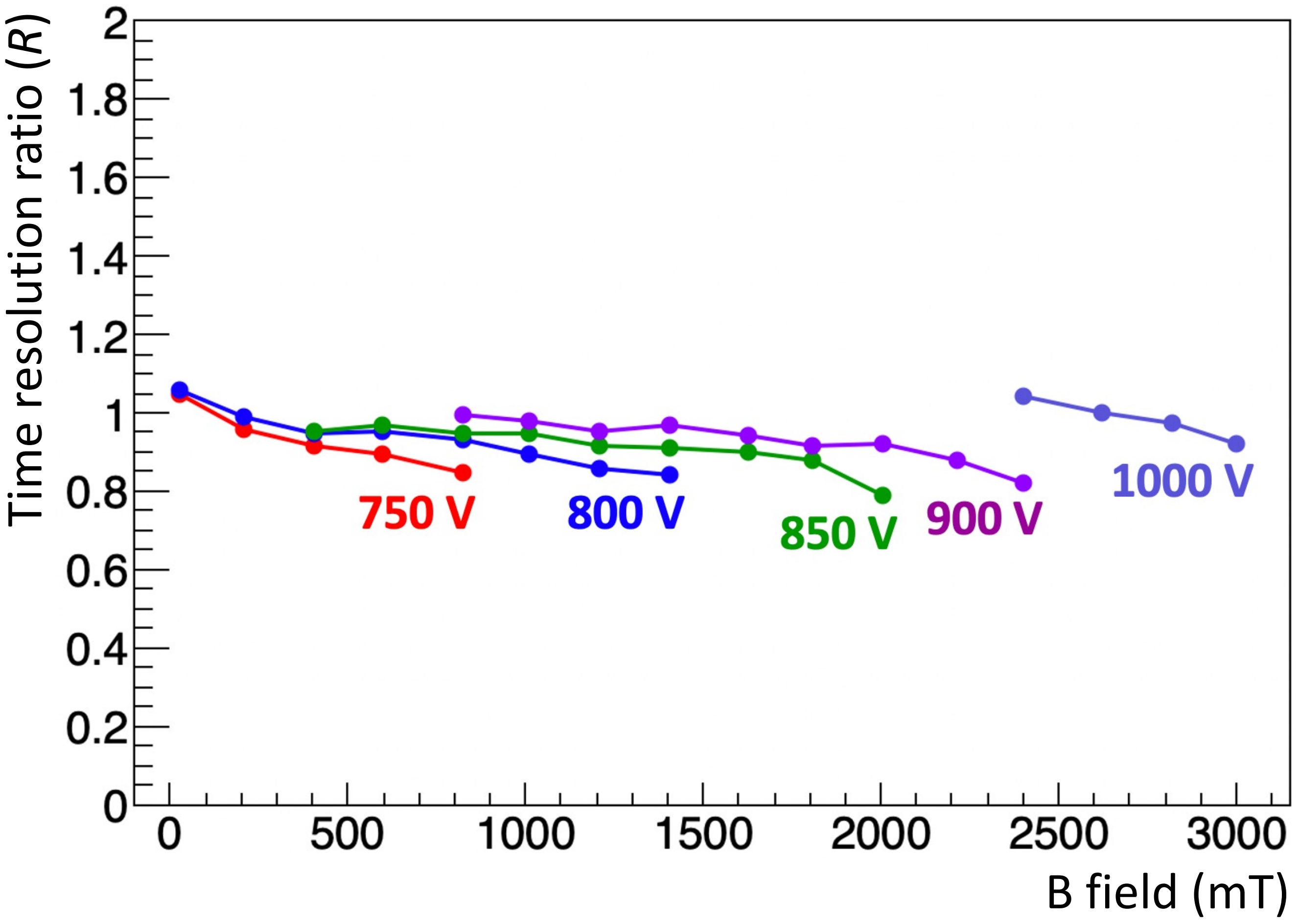
- Considering
  - The intrinsic TTS measured for this LAPPD: δt_{TTS} = 45 ps
  - The DRS4 average noise: N = 0.5 mV
  - The measured 10-90% signal rising front: δt_{rise} = 1.45 ns

  we can build the ratio

$$R = \frac{measured\ time\ resolution}{\sqrt{\delta t_{TTS}^2 + \left(\delta t_{rise}\ \frac{N}{S}\right)^2}}$$

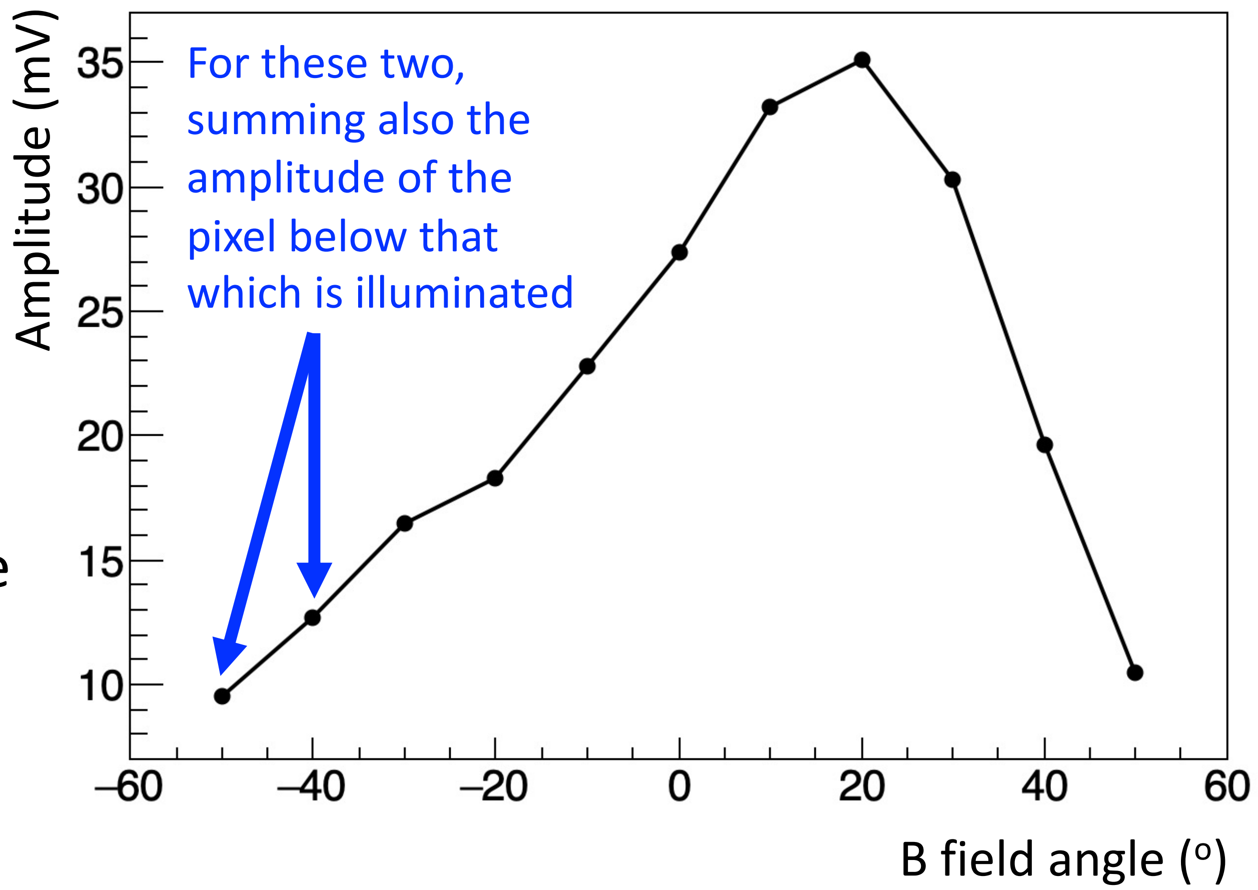
  where S is the signal amplitude

- This ratio should be about 1 if the scaling is only due to S/N, as it is actually found to be the case



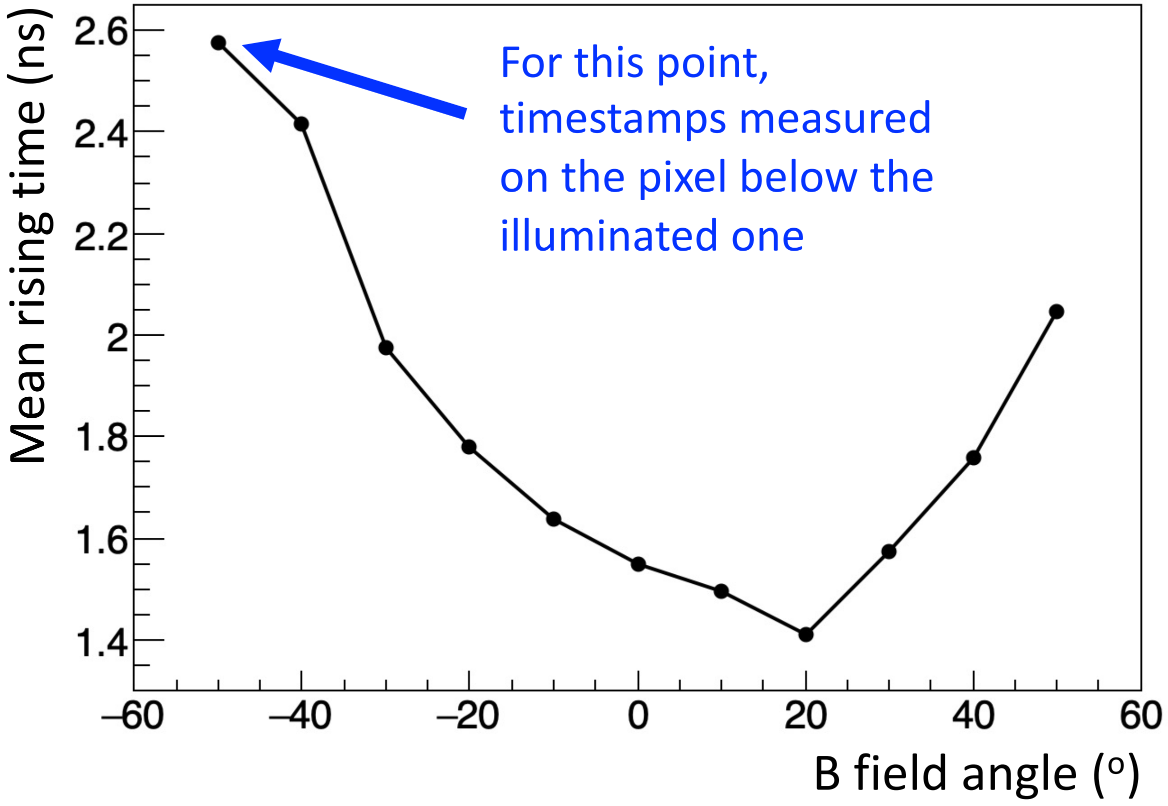
Signal amplitude as a function of B field angle

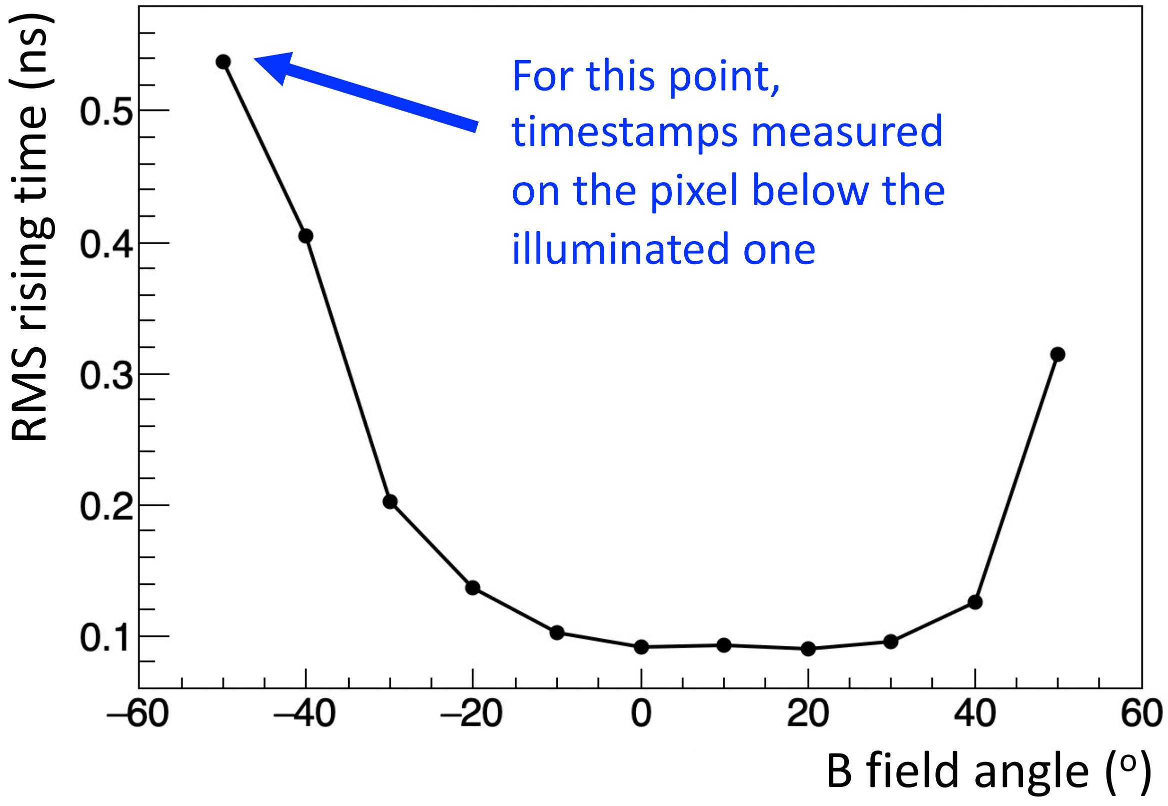
- Data taken at a fixed B field of 1T and variable angles
- Voltage settings
  - Δ=200 V between PC and input MCP
  - Δ=900 V/MCP (z-stack)
  - Δ=200 V/gaps (between MCPs)
  - Δ=200 V between output MCP and anode
- As expected, maximum reached when the B field angle is around the bias angle of the pores of the input MCP
- At -40^o sizeable amplitude found in the pixel below the illuminated one, and at -50^o most of the amplitude in that pixel



Signal rising time as a function of B field angle

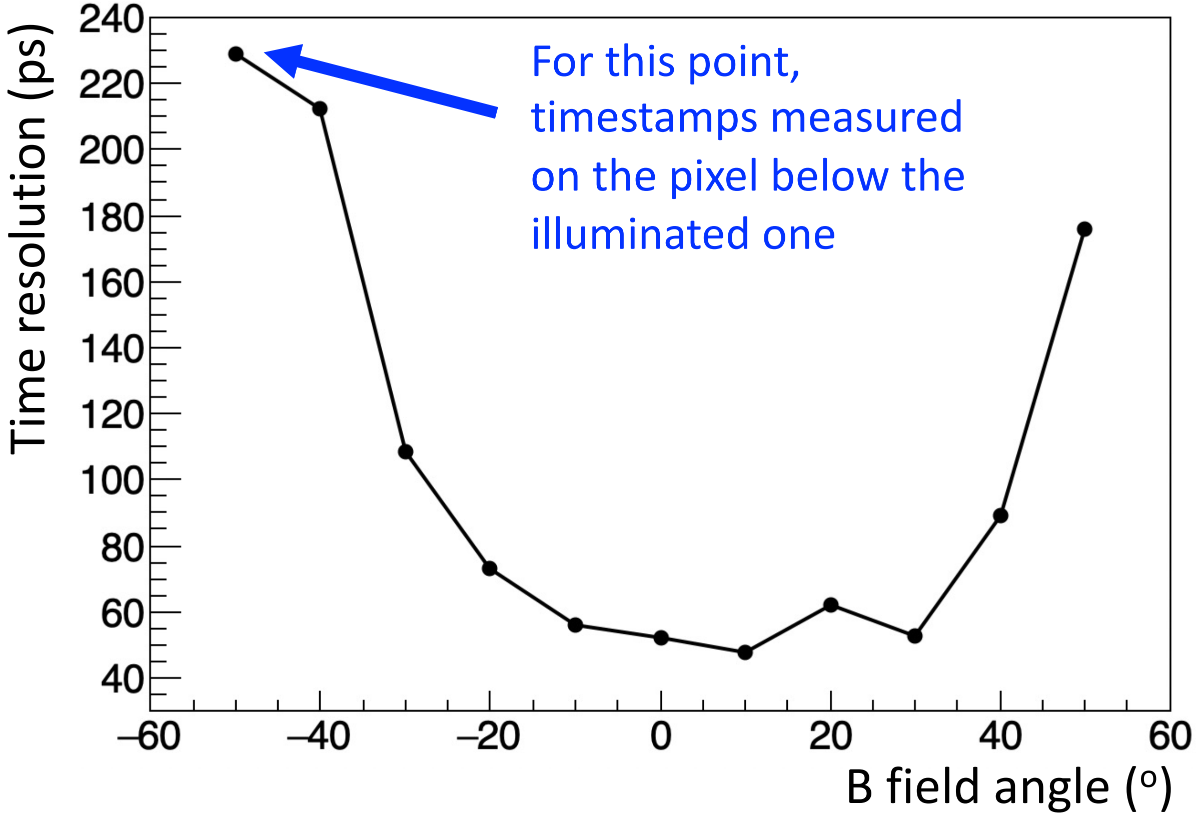
- Same conditions as in previous slide
- Strong dependence of the 10-90% rising time observed both in average and RMS

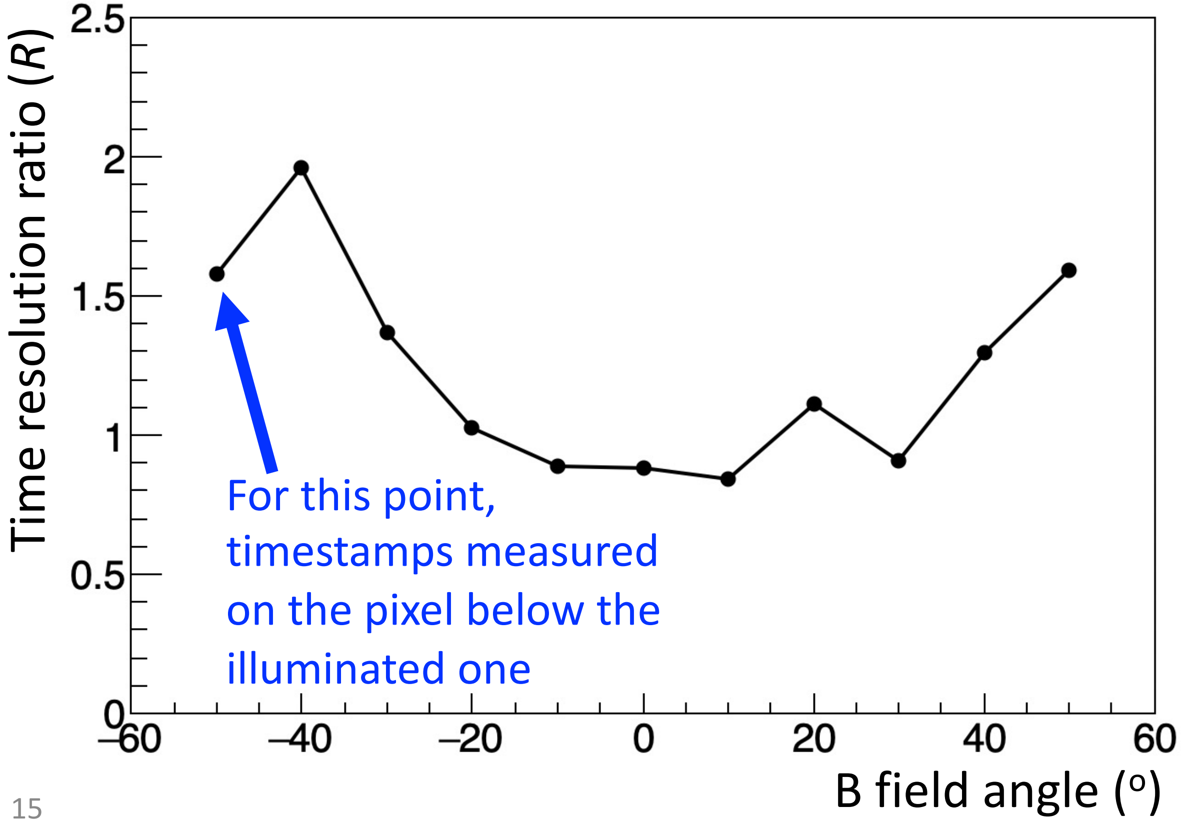




Time resolution as a function of B field angle

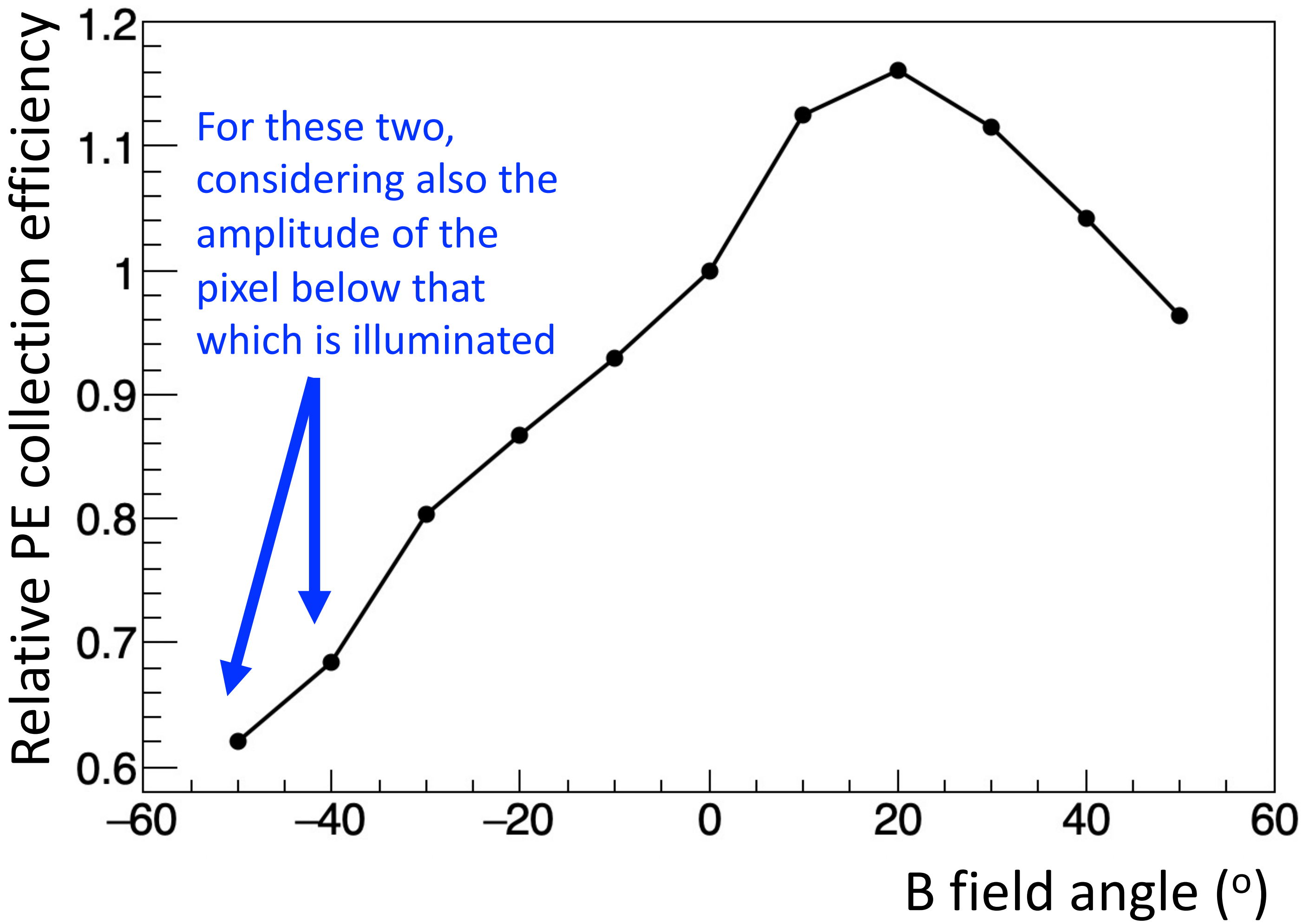
- Same conditions as in previous slide
- Strong dependence of time resolution found, with no simple scaling on *S/N*





Photoelectron collection efficiency as a function of B field angle

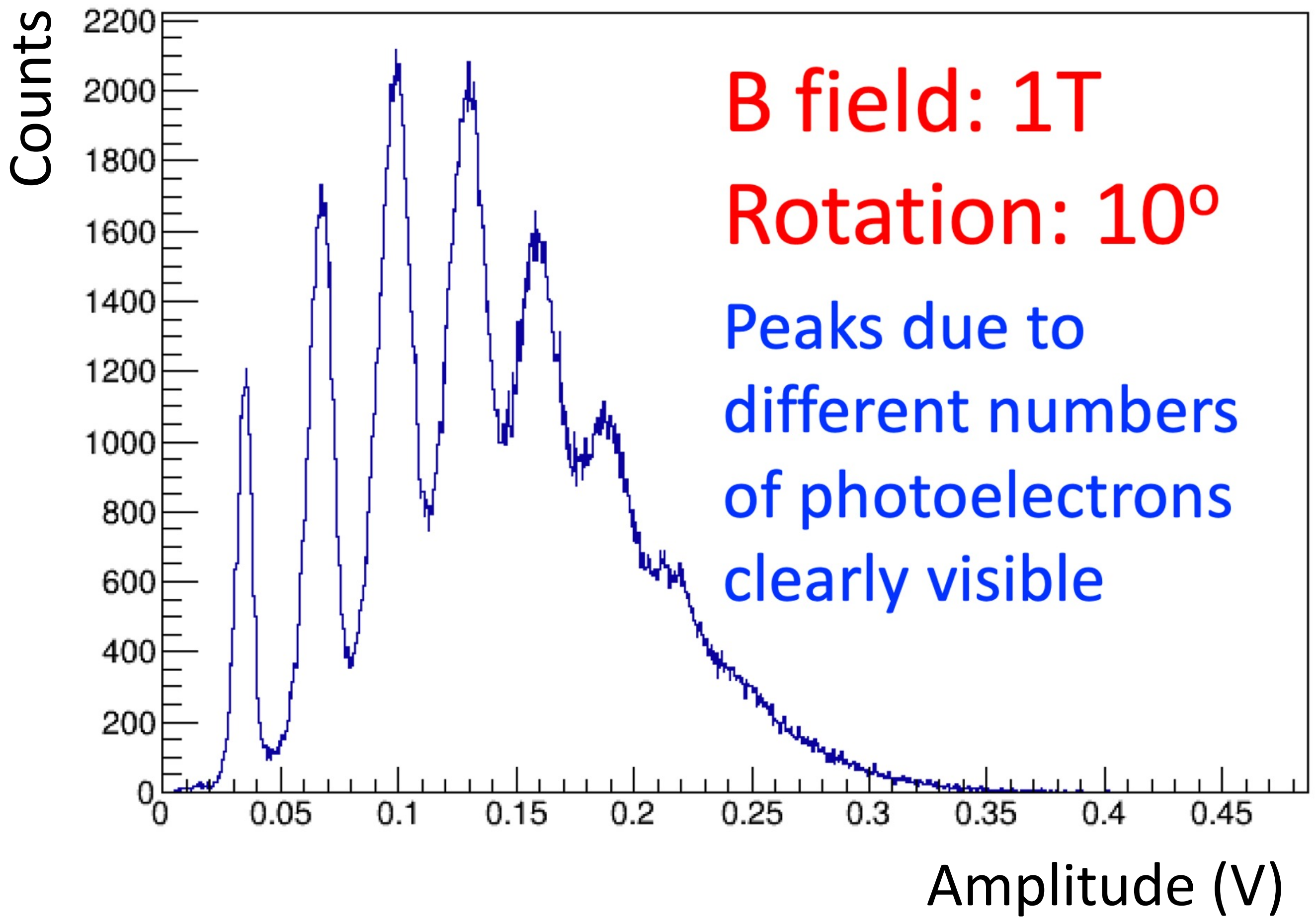
- Same conditions as in previous slide
- Counting fraction of detectables photoelectrons, relative to the point at 0°, as a function of the B field angle
- Collection efficiency increases towards positive angles up to a maximum, and then starts to decrease, whereas it constantly decreases at negative angles



A curious plot

- As the magnetic field has the effect of reducing the spread of the amplitude distribution for single photoelectrons, by reducing the attenuation of the laser it becomes possible to distinguish peaks due to multiple photoelectrons

This is a LAPPD and not a SiPM!



Summary

- A LAPPD Gen II with three MCPs arranged in a Z-Stack has been measured for the first time in a strong magnetic field, up to 3T
  - Siemens MRI scanner made available by Ospedale Giustinianeo, Azienda Ospedale Università Padova
- Response to single photoelectrons, also including timing performances, has been studied as a function of the B-field strenght and at different B-field angles
- Many thanks to the Padova hospital and to the Incom R&D team for their support!