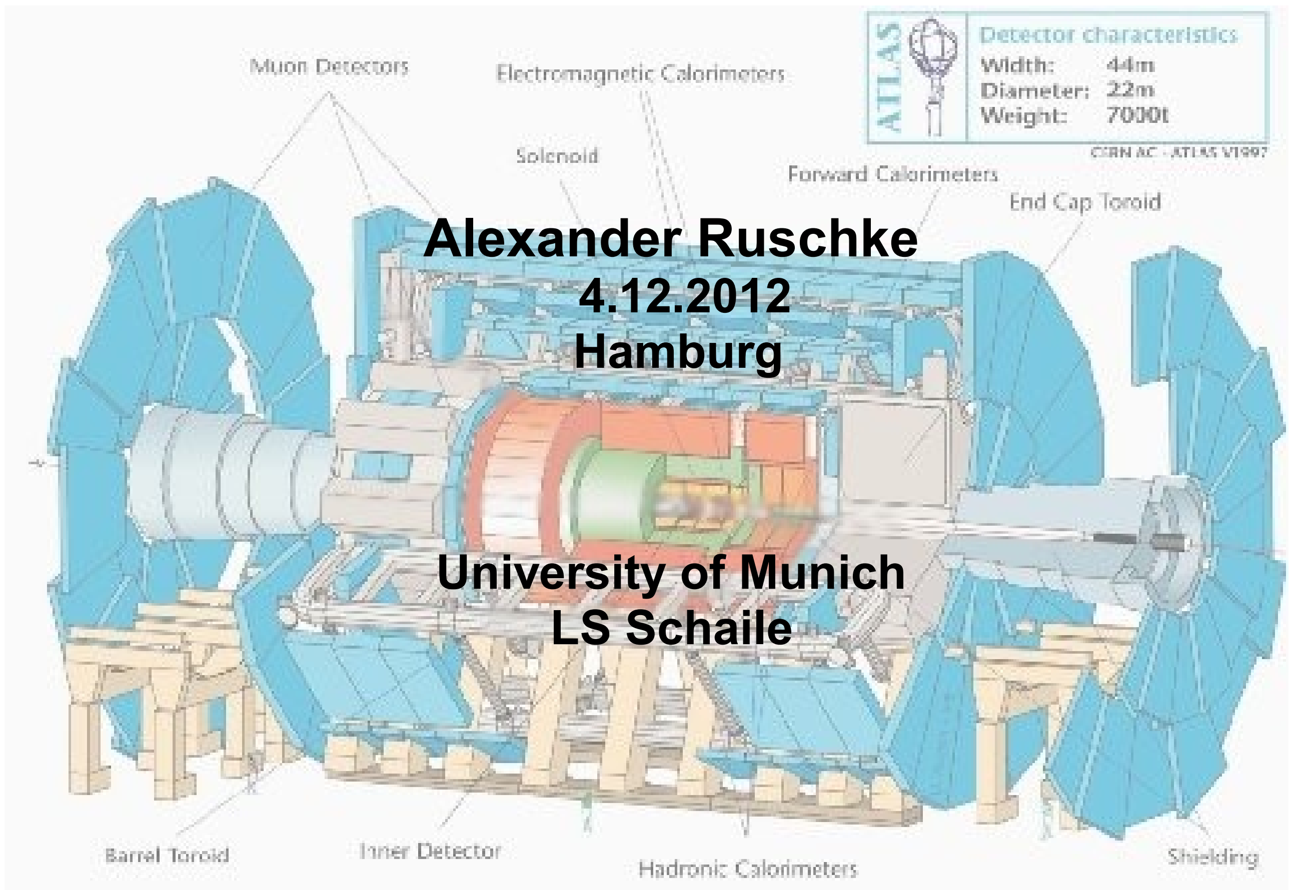
Ageing and Background Sensitivity of Particle Detectors



Alexander Ruschke
4.12.2012
Hamburg

University of Munich
LS Schaile

6th Annual Workshop of the Helmholtz Alliance “Physics at the Terascale”

Outline

Ageing and Background Studies:

- neutrons (10 MeV): large area irradiation
- protons (20 MeV): localized irradiation / ageing

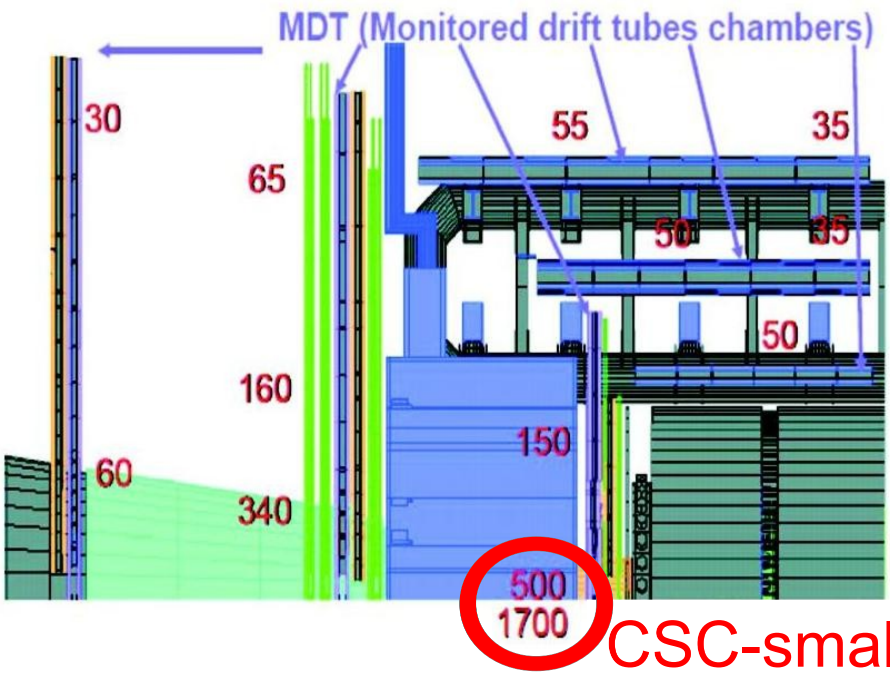
Spatial Resolving SiPM-Detector:

- idea and motivation of the SiPM-detector
- first results of H6-testbeam @ CERN october 2012

Background Rates of γ's and Neutrons @ LHC

simulation for LHC design luminosity with safety factor 2:

background: γ-particle and neutrons



CSC-small wheel

BOS-MDT
50 Hz/cm²

3 kHz / tube
(2m ◦ 3 cm)

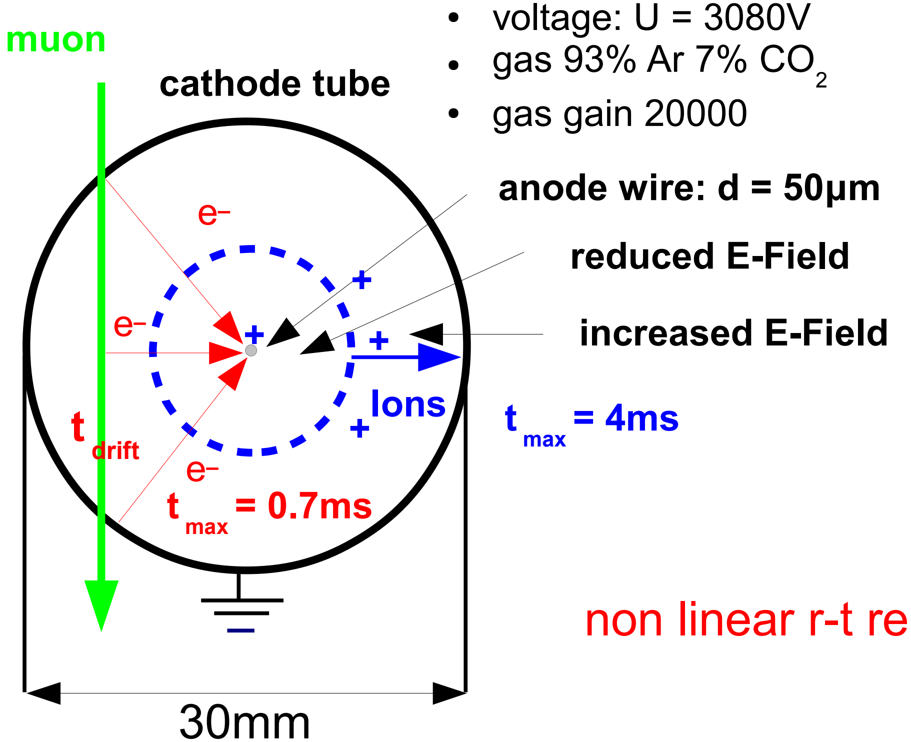
CSC – Detector
500–1700 Hz/cm²

300–1020 kHz/tube
(2m ◦ 3 cm)

Impact of γ-Background

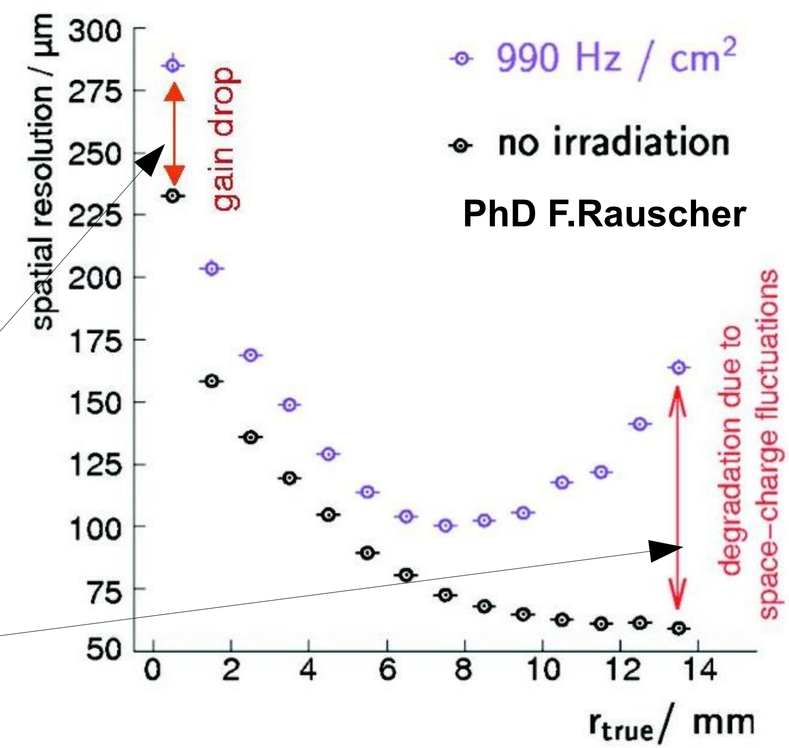
ATLAS drifttube:

- pressure 3 bar
- voltage: U = 3080V
- gas 93% Ar 7% CO_2
- gas gain 20000



Measurement :
100 GeV muons +^{137}Cs 550 GBq (662 keV γ)
X5 2005 at CERN:

non linear r-t relation



- slow ion-drift 4 ms:
  - reduction of gas gain → (gain drop)
  - degradation of resolution at large radii due to space charge fluctuation

Tandem Accelerator

Maier Leibnitz Laboratory Garching

- **10 MeV neutrons**
- **20 MeV protons**

Ageing and Background Studies

Neutron & Proton – Irradiation Facility @ Garching Tandem Laboratory

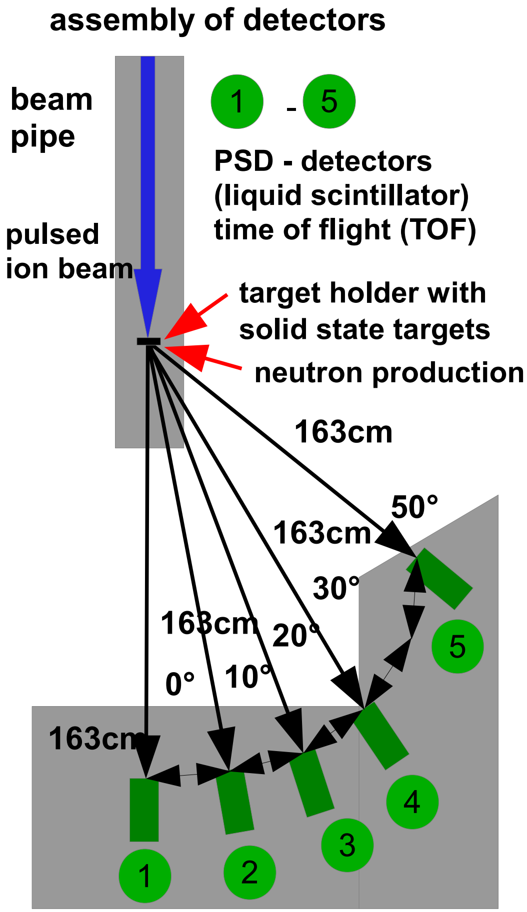
3 reactions: to study the impact of high-energy neutrons:

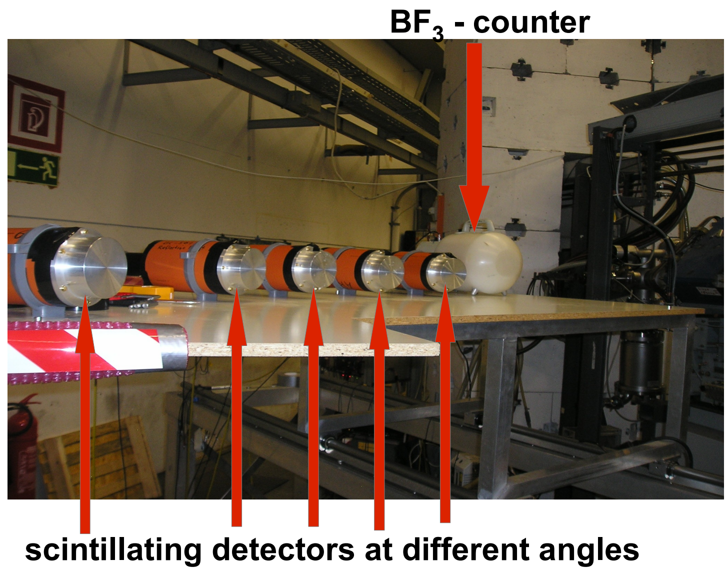
- $^{11}B + ^{1}H \rightarrow ^{11}C + n$ (60 MeV ^{11}B)
  E(n) = 11 MeV quasi-monoenergetic $2 \circ 10^{4}$ Hz/cm^{2}
- deuteron-breakup (20 MeV d)
  E(n) = 11 MeV (±5 MeV) $1 \circ 10^{7}$ Hz/cm^{2}
- α on Be (30 MeV α)
  E(n) = 7 MeV 1–18 MeV $1 \circ 10^{6}$ Hz/cm^{2}

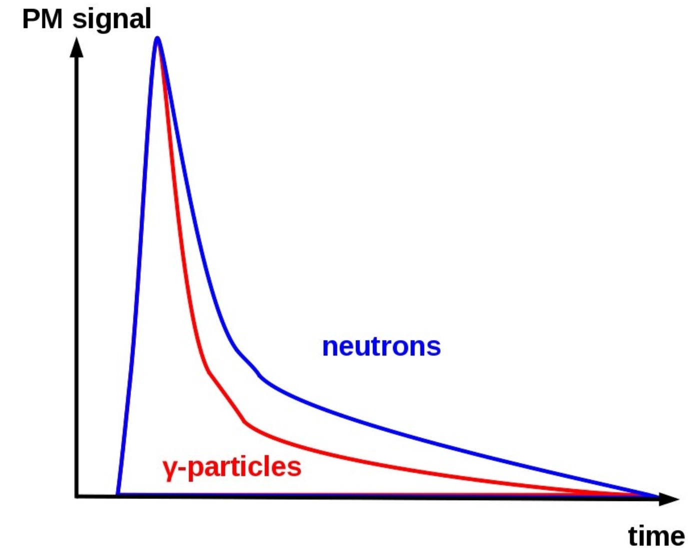
irradiations and aging studies with 20 MeV protons:

- well focused p-beams spot size 1 mm^{2}
- defocused p-beams spot-size up to 1 cm^{2}
- wobbled p-beams spot-size up to 7 cm ◦ 1 cm with max. 800 Hz

Neutron-Beam Monitoring

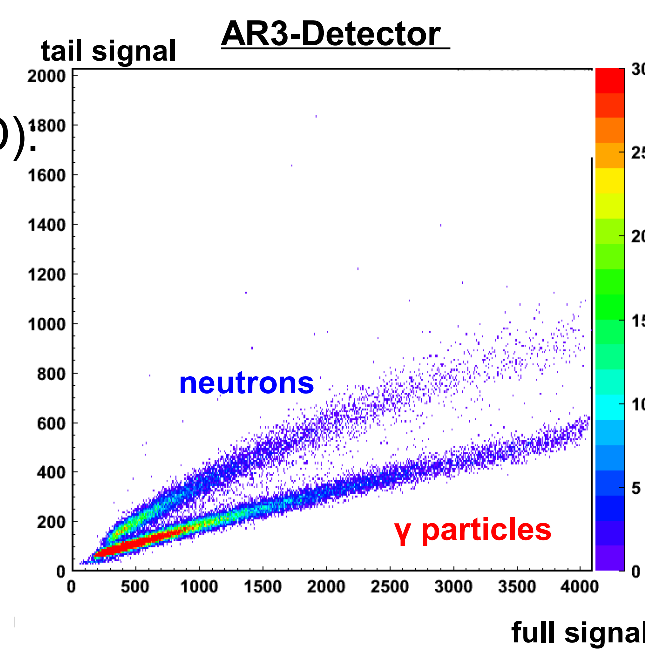






Pulse Shape-Dicrimination-Detectors (PSD):

- discrimination between γ-particles and neutrons
- angular distribution
- percentage of γ-particles
- calibrated BF_3 counter → n-flux-density



Neutron Energy: Time of Flight

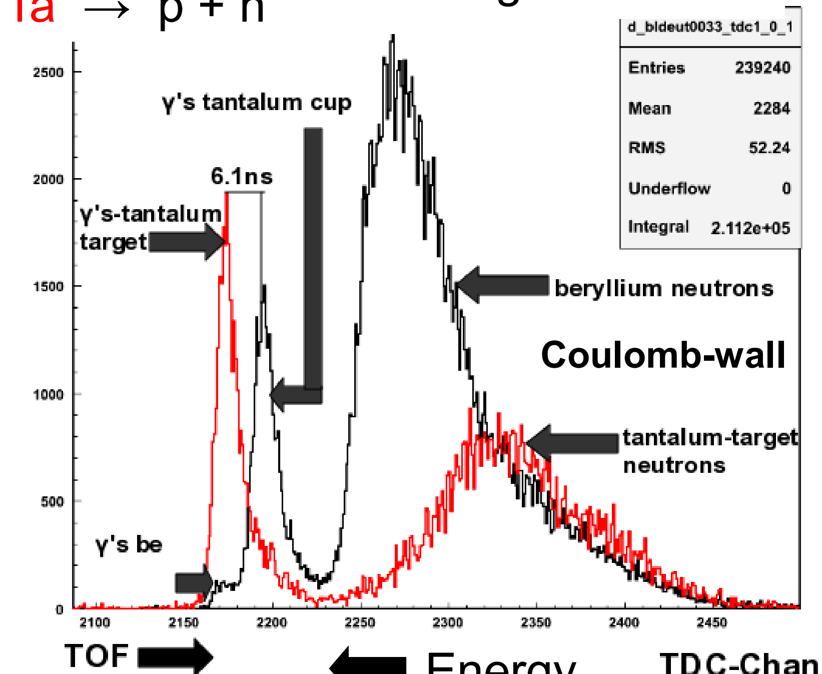
- d-breakup: 20 MeV deuteron on Be target 0.5 mm
  E(n) = 11 MeV (±5 MeV), $1 \circ 10^7$ Hz/cm^2 @ distance 30 cm

- (α,Be) 30 MeV α-ion on Be target 0.5 mm
  E(n) = 7 MeV (1-18 MeV), $1 \circ 10^6$ Hz/cm^2 @ distance 30 cm
  less γ's than d-breakup

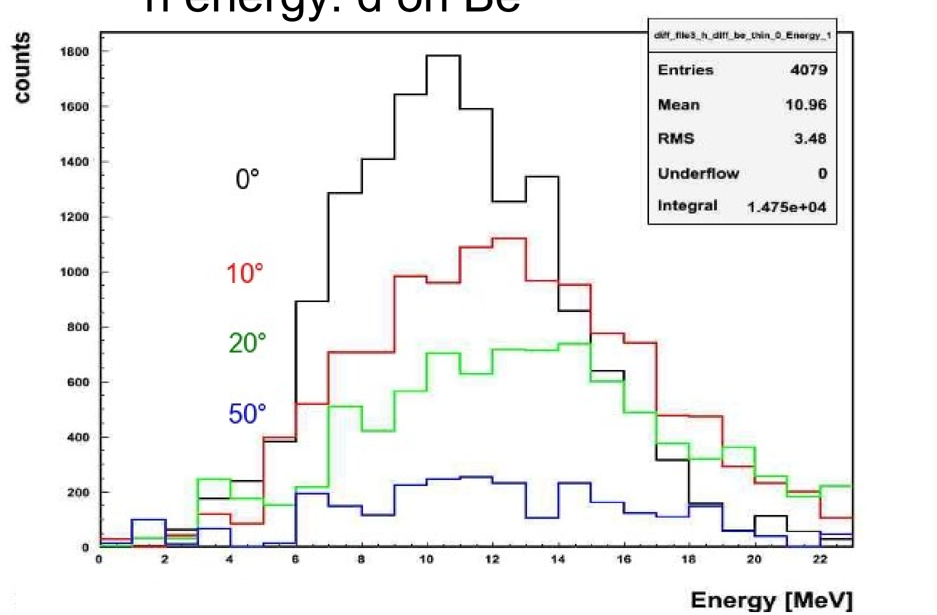
- angular distributions: constant within factor of 2 0 - 20 deg.

d on Be → p + n
d on Ta → p + n

time of flight



n energy: d on Be

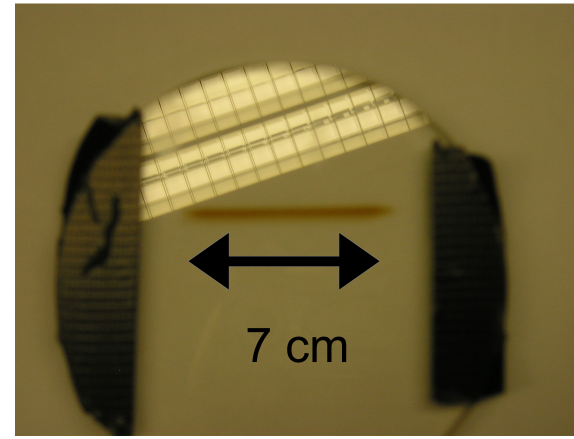


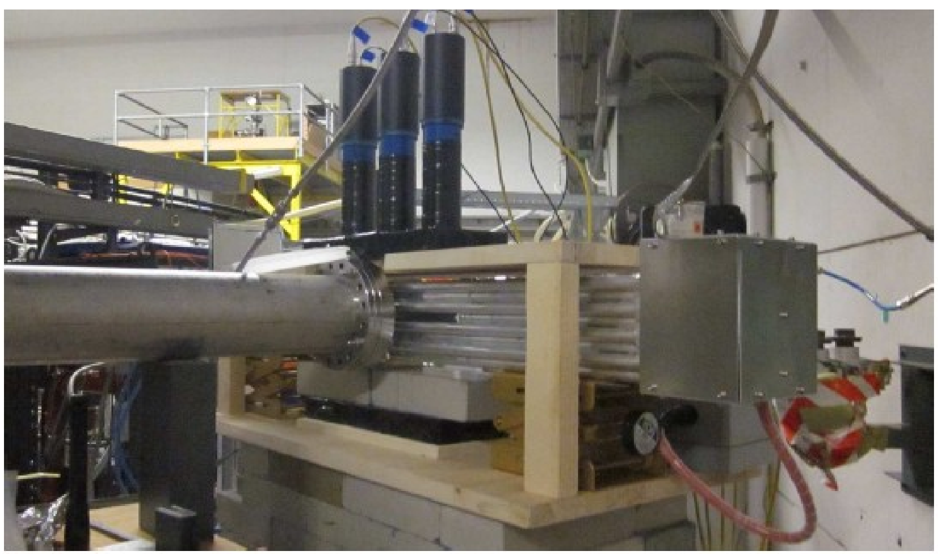
Localized Proton Beams

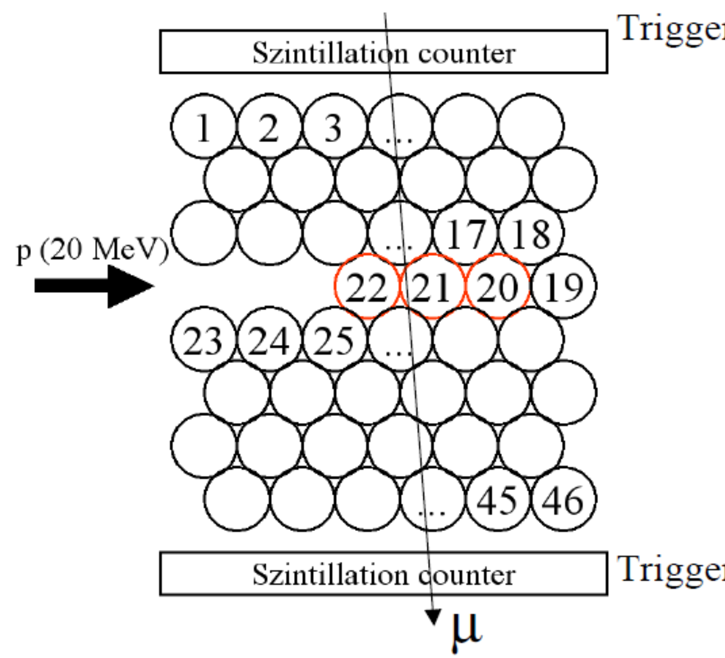
- goal: efficiency and resolution of cosmic muons under proton irradiation (strong space charge effects)
- beam spot 7 x 0.5 cm² @ 800 Hz (wobbler)
- $\Delta E_{proton} \equiv 200$ keV/tube $\longleftrightarrow$ $\Delta E_{muon} \equiv 15$ keV/tube
- rate_{proton} /tube = 0 Hz, ~ 200 kHz, ~1100kHz, 1400 kHz

HL-LHC

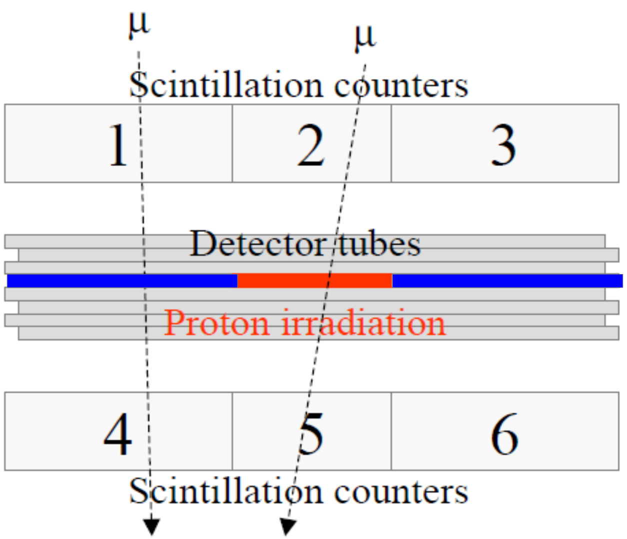
- $\text{Rate}_{proton} = 0\ \frac{\text{kHz}}{\text{cm}^2},\ 19\ \frac{\text{kHz}}{\text{cm}^2},\ 105\ \frac{\text{kHz}}{\text{cm}^2},\ 133\ \frac{\text{kHz}}{\text{cm}^2}$





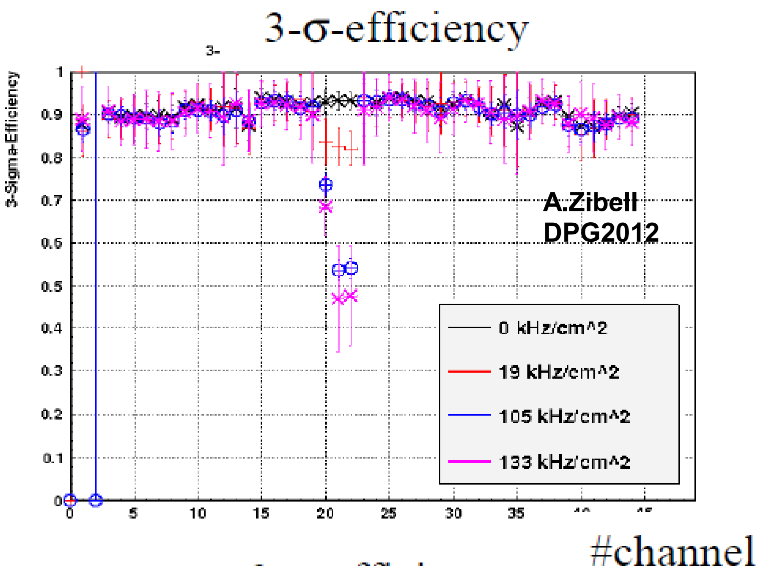


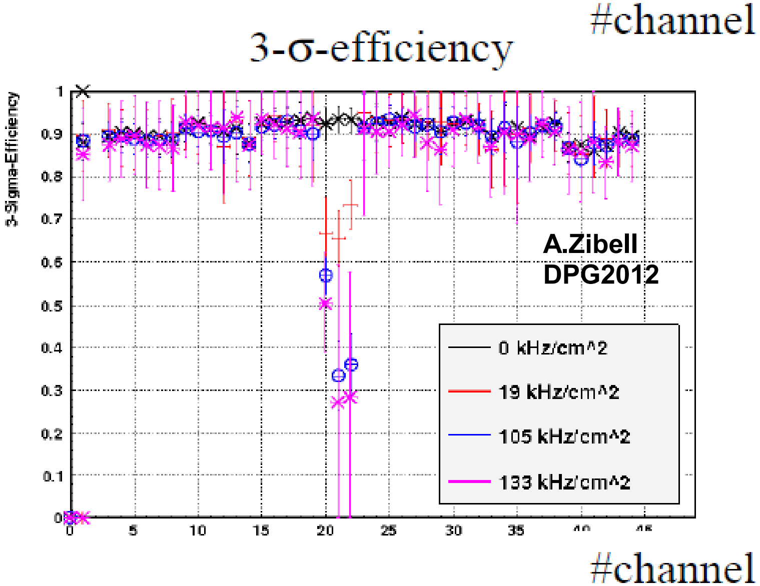
Track-Efficiency Measurement



non-irradiated part:

- drop in efficiency due to high channel occupancy
- electronic effect → new electronic development ongoing





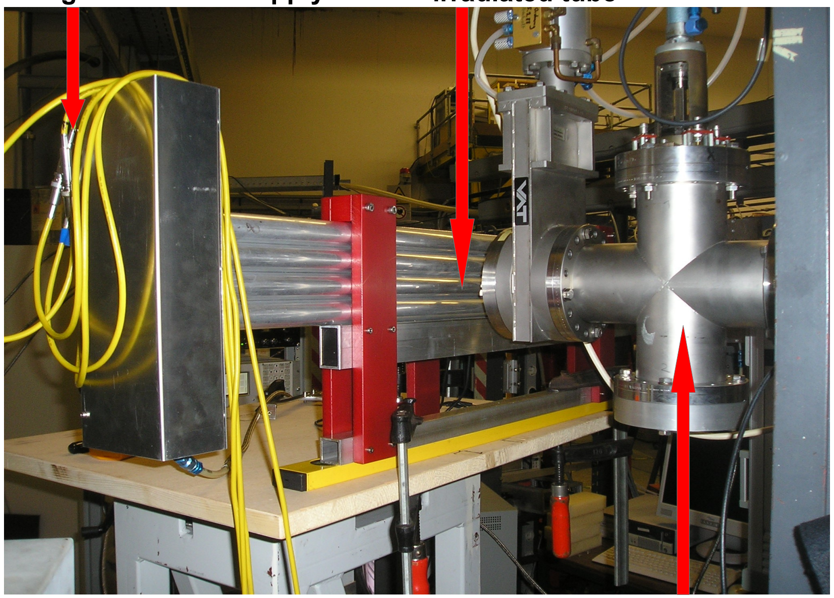
3 σ -efficiency:
percentage of μ-hits where measured position deviates less than 3 times spatial resolution from the track prediction
(P.Schwegler(MPP),A.Zibell (LMU))

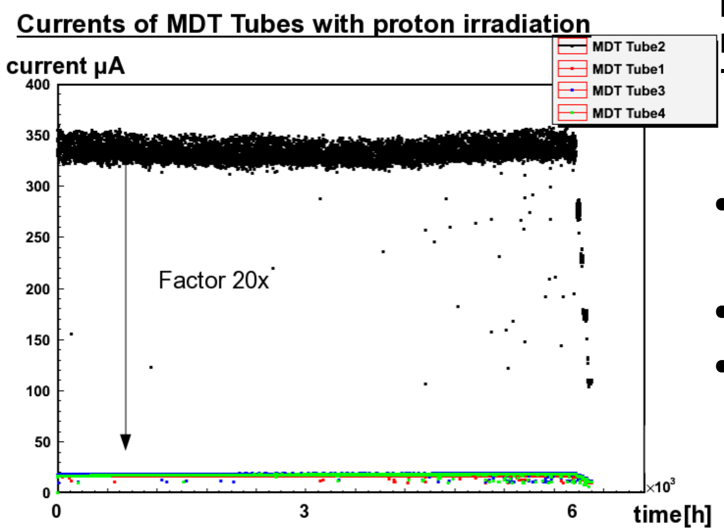
irradiated part:

- larger efficiency drop, space charge effects

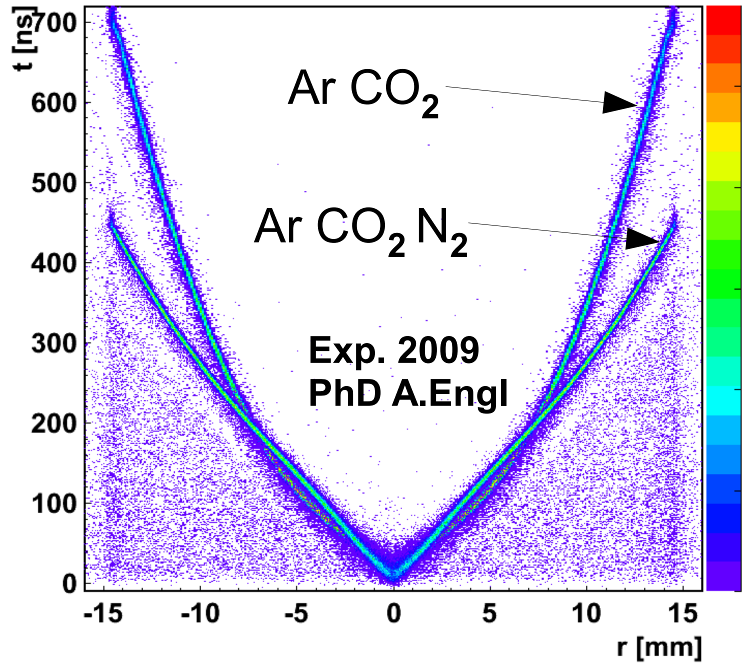
Ageing Study for ATLAS Drift-tubes

- beam spot : 7 ◦ 1 cm² at 8Hz





- Ar CO_2 N_2 96:3:1% promising drift gas
- almost linear, 35% faster than Ar CO_2



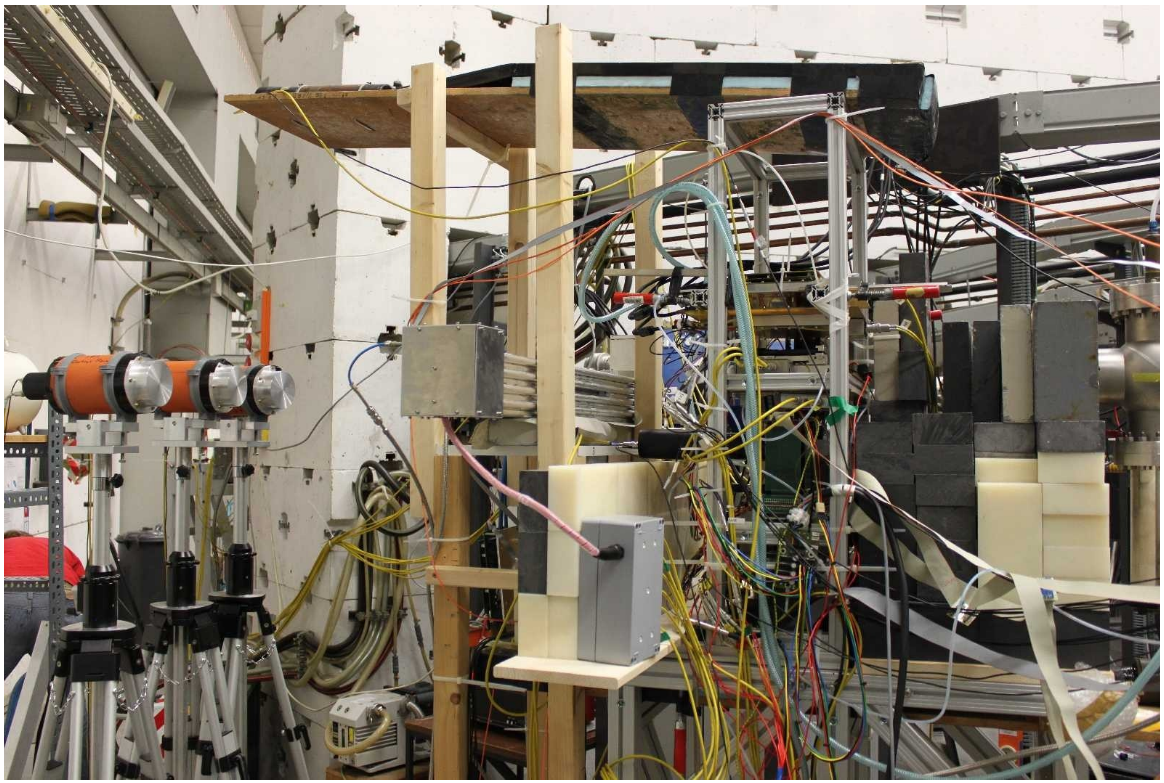
- 6 hour irradiation of ATLAS drift-tube with 20 MeV protons and beam current of 105 nA
- tube current 340µA ➡ 7As/7cm ≈ 1 lifetime of ATLAS
- **no ageing observed**

Summary of Ageing and Background Studies

- 3 reactions: to study the impact of high-energy neutrons:
  - $^{11}B + ^{1}H \rightarrow ^{11}C + n$ (60 MeV ^{11}B)
    E(n) = 11 MeV quasi-monoenergetic $2 \circ 10^4$ Hz/cm^2
  - deuteron-breakup (20 MeV d)
    E(n) = 10 MeV 1–20 MeV $1 \circ 10^7$ Hz/cm^2
  - α on Be (30 MeV α)
    E(n) = 7 MeV 1–18 MeV $1 \circ 10^6$ Hz/cm^2
- muon efficiency and track resolution in small drift-tubes (with Kroha MPP)
  high rates in chambers O(10^7Hz)
  decrease of efficiency and saturation effects observed
- aging studies of linear and fast drift-gas Ar CO_2 N_2 96:3:1%
  experiments finished no aging observed

- proton-irradiation of CVD diamond detectors (Ilgner, Spaan Uni-Do)
- SEU in control chips for the ATLAS pixel detector (Kersten,Zeitnitz Uni-Wu)
- light response of $LaBr_3$:Ce crystals with 30 MeV α-ions (A.Iuydin, Moscow State-Univ.)

Irradiation of Resistive Strip Micromegas by 11 MeV neutrons



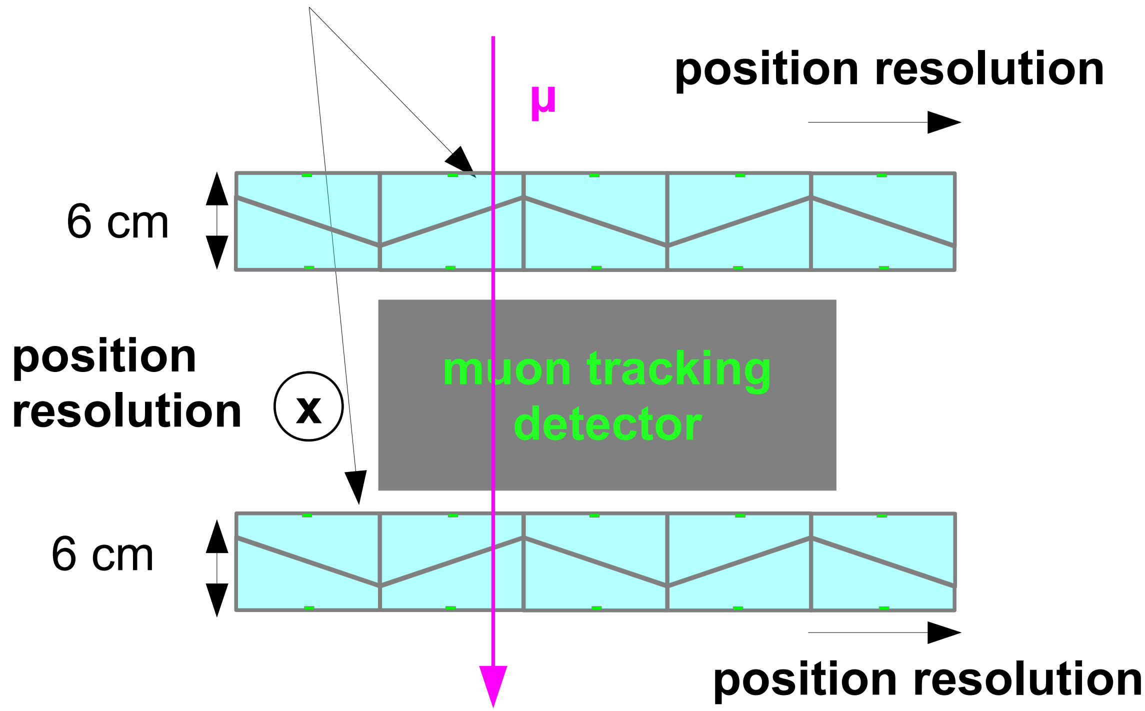
Neutron density of $10^7 \; \frac{n}{cm^2 \cdot s}$

detectors work reliably

In collaboration with Wotschak/ CERN

Spatial Resolving SiPM-Detector

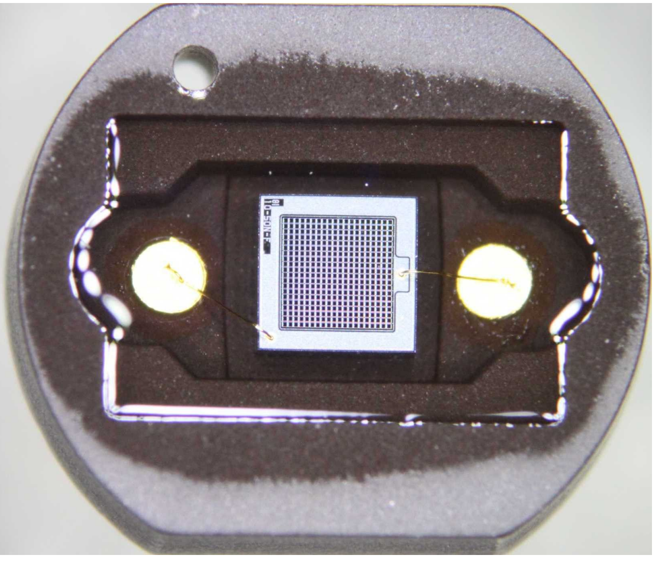
Spatial Resolving SiPM-Detector



SiPM based muon detector provides trigger information and a 2nd position coordinate

goal: spatial resolution of about 5 mm

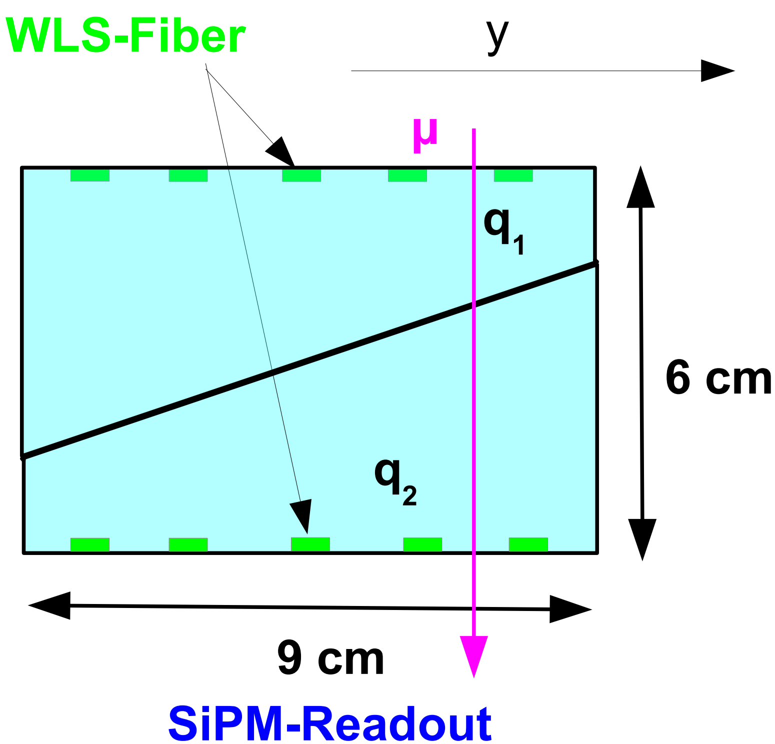
Silicon Photo-Multiplier:

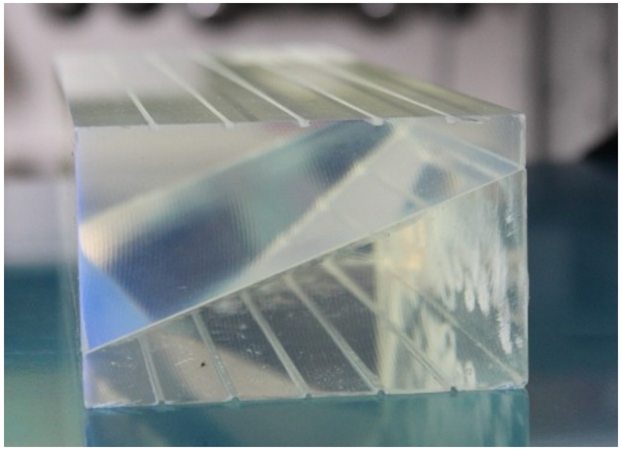


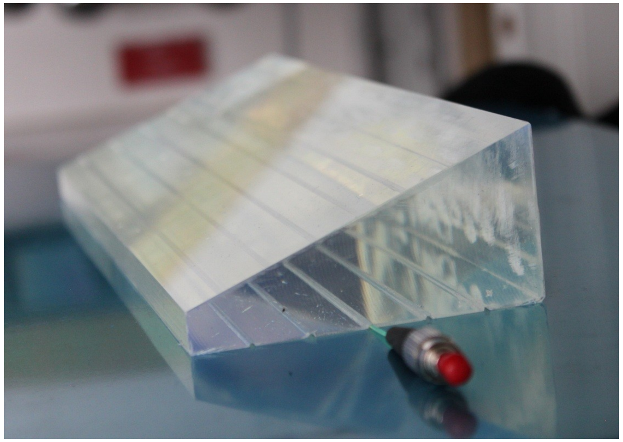
- Photon detection by Silicon Photo-multiplier (SiPM)
- 1x1 mm^2 SiPM consist of 400 pixel with a size of 50 μm (Hamamatsu)

Prototype Detector

Trapezoidal structure:







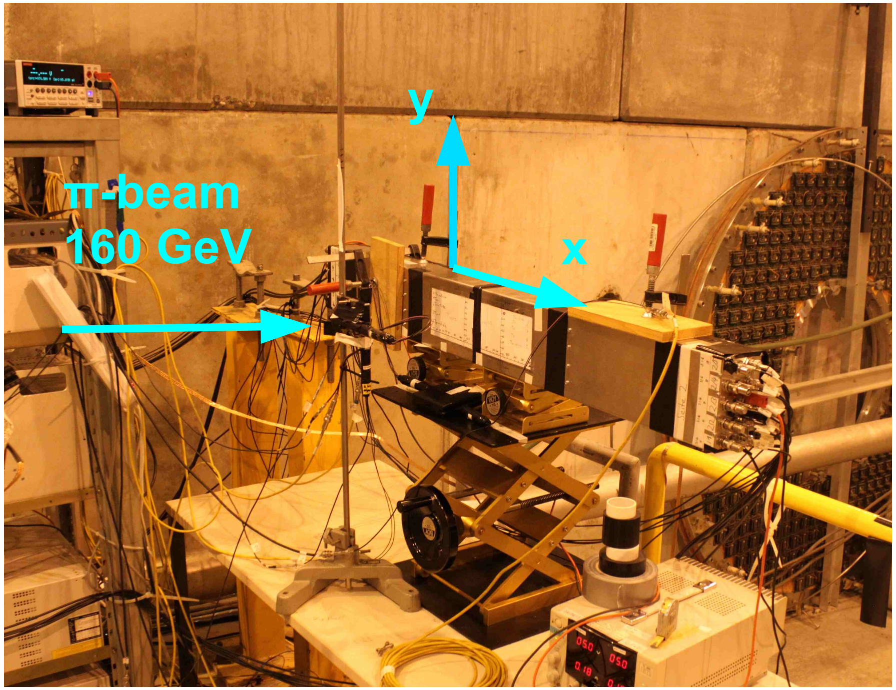
light yield: $q_{sum} = q_1 + q_2 = const$

$$y = \frac{q_1}{q_1 + q_2}$$

- light collection via wavelength-shifting-fiber WLS
- goal: spatial resolution of about 5 mm

- BC-400 plastic scintillator (area 300 x 88 mm²)
- BCF-92 Wave-Length-Shifting-Fiber (diameter 1 mm)
- scintillator wrapped with aluminum foil
- FC-Connectors used for coupling WLS-fibers to SiPM

160 GeV π-Test-Beam @ H6 CERN

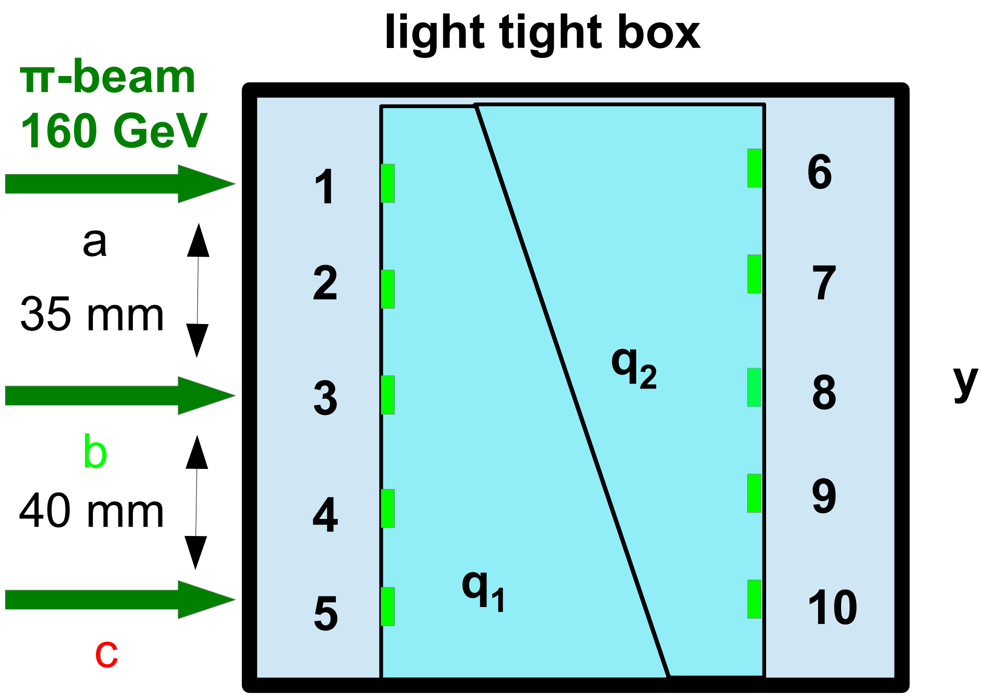


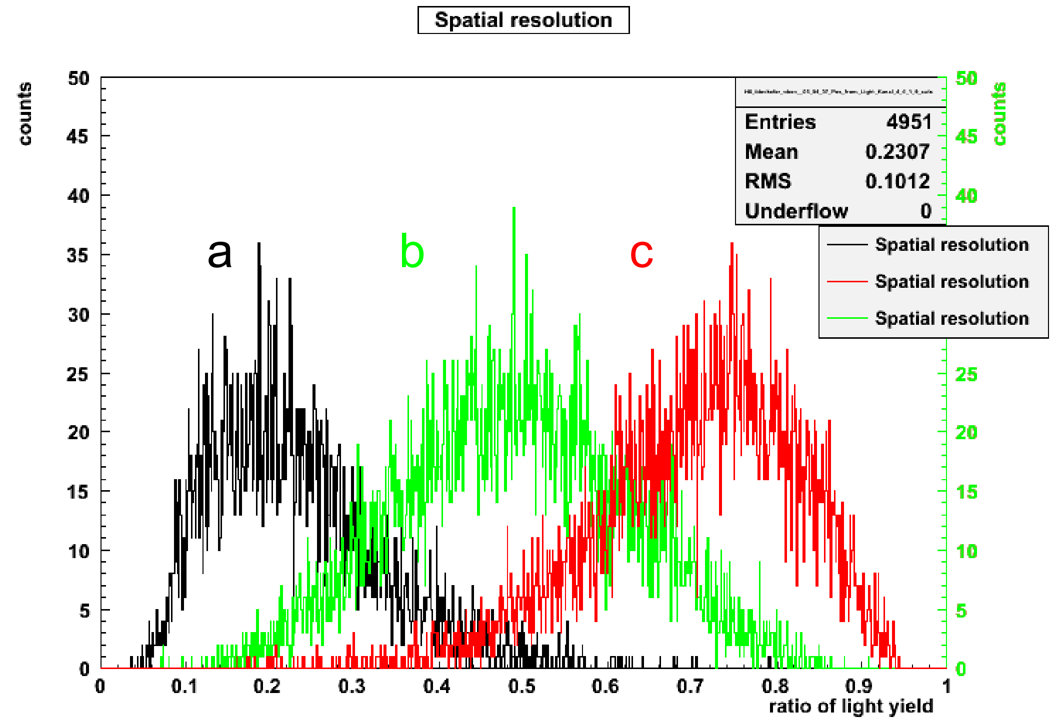
- prototype detector was mounted in a light tight box
- coincidence trigger (active area 5 mm^2)
- readout of 10 SiPM's via 1 GHz Flash ADC
- spatial resolution in y-direction is determined by light yield-ratio of the SiPM-signals
- spatial resolution in x-direction is determined by time difference of the SiPM-signals in each scintillator (propagation of light)

Measurements:

- vertical scan for position resolution in y-direction
- horizontal scan for position resolution in x- direction

Online Results of SiPM-Detector





$$y = \frac{q_1}{q_1 + q_2}$$

Experimental results of y-scan:

- channel 1-3 & 8-10 insensitive to π-beam-position
- channel 4,5 in $\mathbf{q_1}$ and channel 6,7 in $\mathbf{q_2}$ sensitive to π-beam-position
- maximum light output is in the order of 20 photons at each channel

- spatial resolution of FWHM = 30 mm

problems:

- global light yield of position sensitive fibers is too small (range 1-20 photons)

Summary

Results of Ageing and Background Studies:

- collaboration with 5 international groups and about a dozen experiments

- 3 reactions to produce ~10 MeV neutrons
  - deuteron-breakup (20 MeV d) highest intensity
    E(n) = 11 MeV (±5 MeV) $1 \circ 10^7$ Hz/cm^2
  - full neutron monitoring facility

- occupancy and efficiency studies in 15 mm drift-tubes
- ageing studies with protons → no ageing observed
- radiation hardness and high rate capability of resistive strip micromegas

Results of Spatial Resolving SiPM-Detector

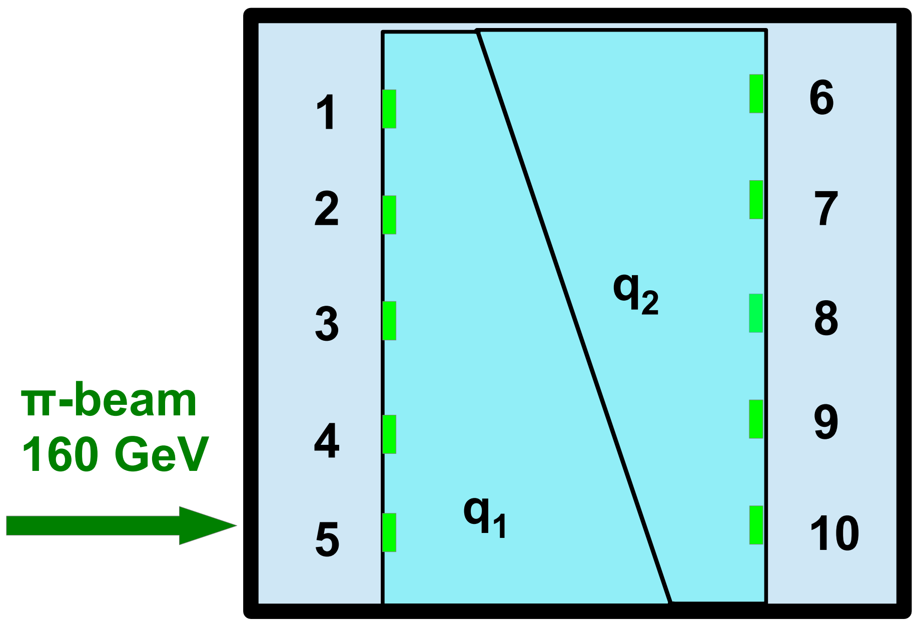
- trapezoidal geometry leads to spatial resolution
- spatial resolution in the order of 30 mm (analysis & improvement ongoing)
- channels insensitive to position resolution
- global light yield is to small,will be improved, studies of light propagation,better light coupling etc.

Thank you !

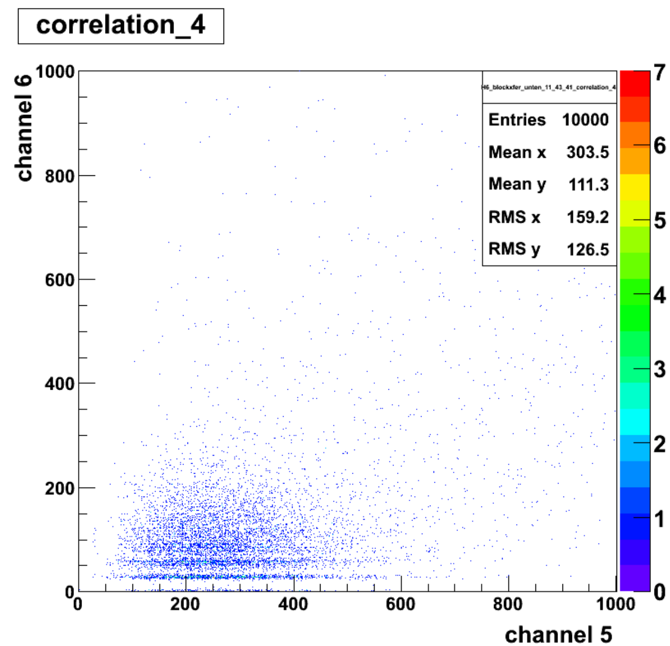
backup

Light - Correlation

light tight box



Light correlation of position sensitive Fibers

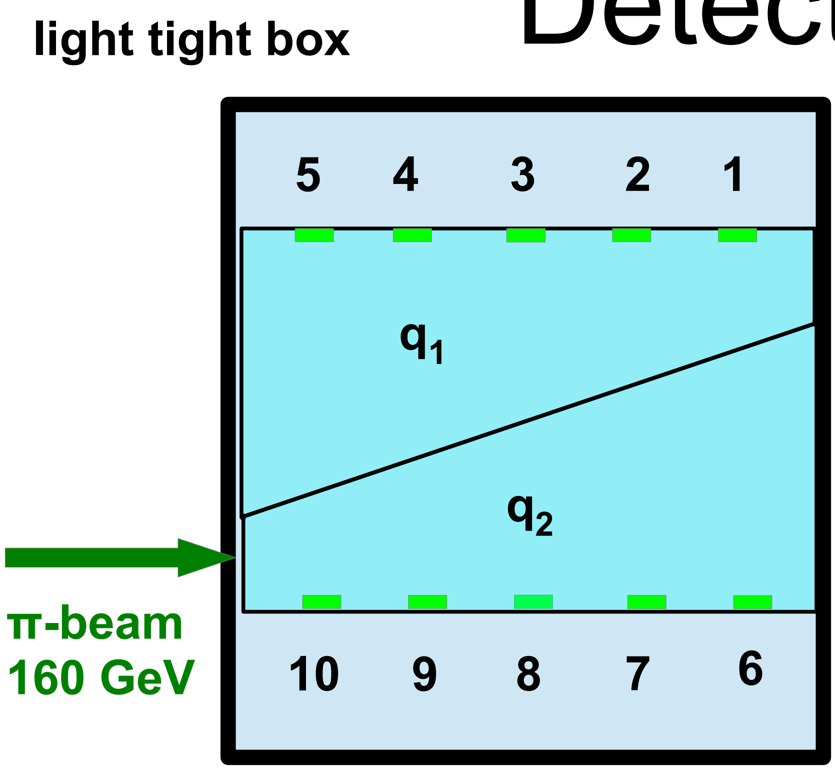


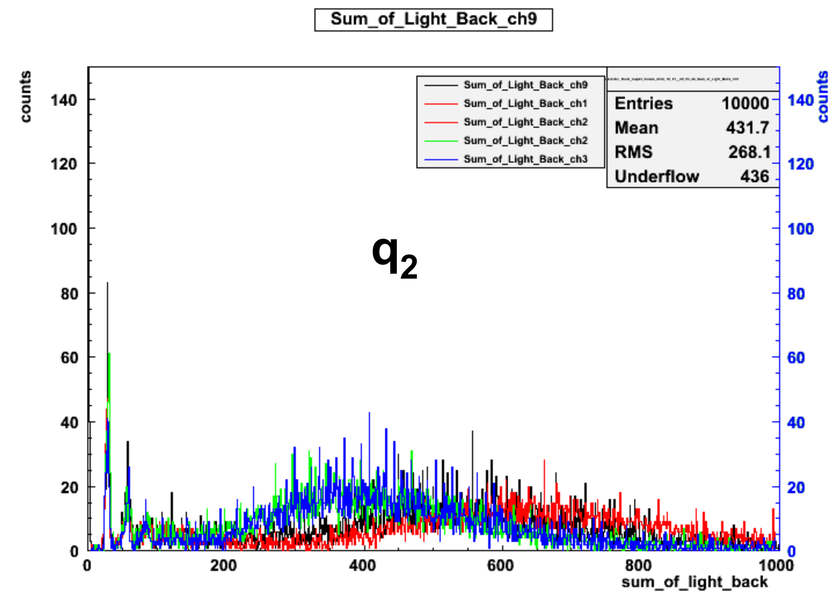
Expectation from π-beam:

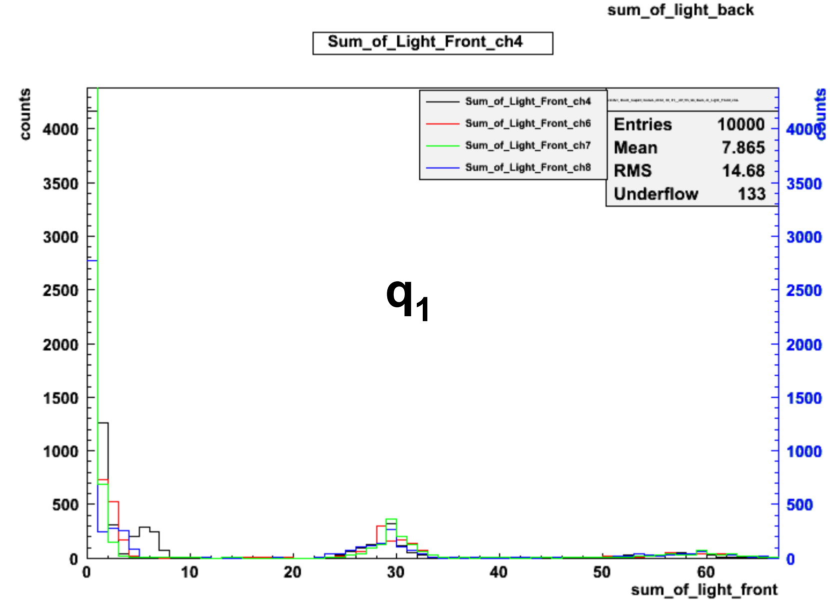
- High light yield in **q_1** , low light yield **q_2**

- Light output of position sensitive fiber with small light yield is in the range from 1-3 photons
- Light correlation between position sensitive fibers is broad → this corresponds to broad spatial resolution

Detector Calibration





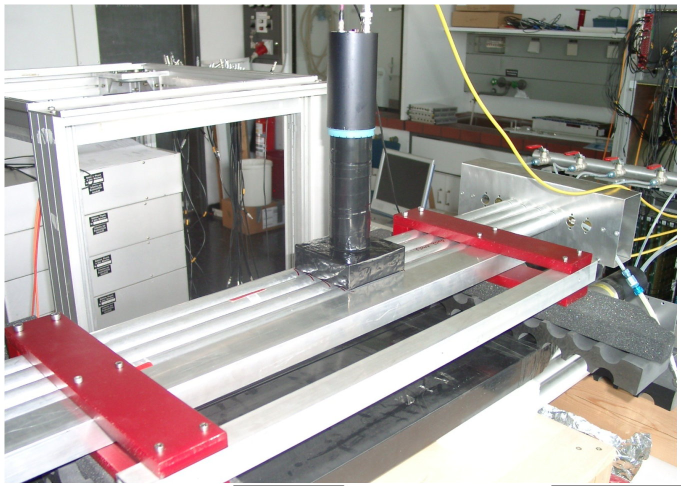


- gain of SiPM-channels are identical in $\mathbf{q_1}$
- collected light yield is different for SiPM-channel in $\mathbf{q_2}$,

Expectation:

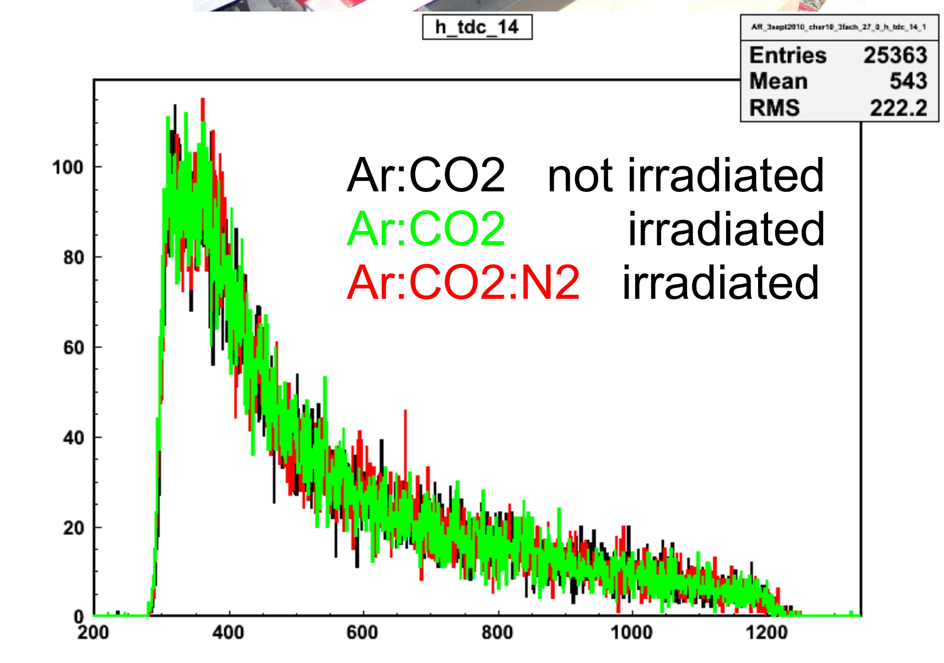
- All channels see same light-output in $\mathbf{q_2}$
- No light yield in q_1 → beam hits only one trapezoid

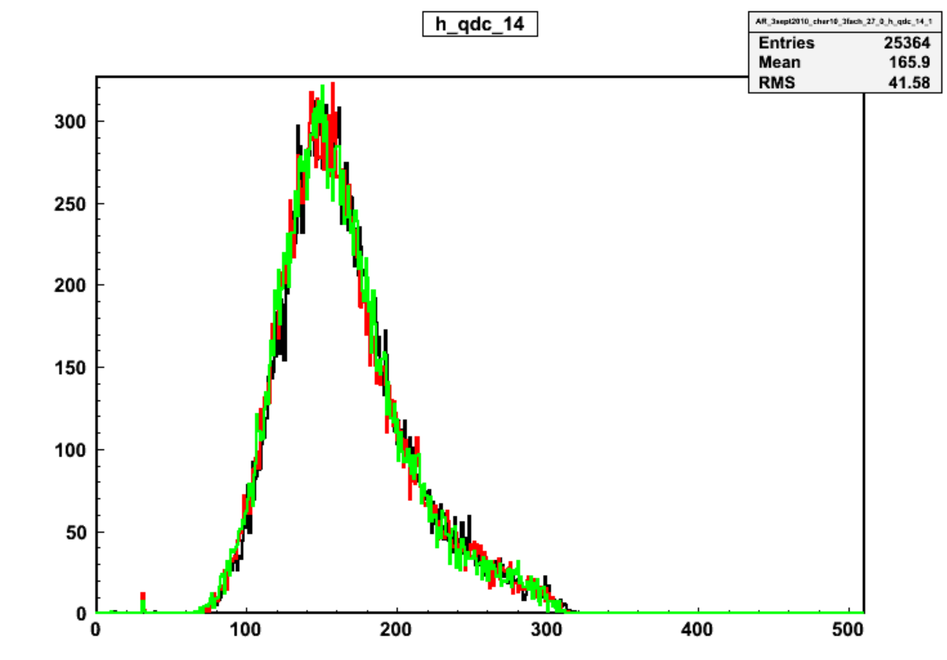
Aging studies
reference run in laboratory



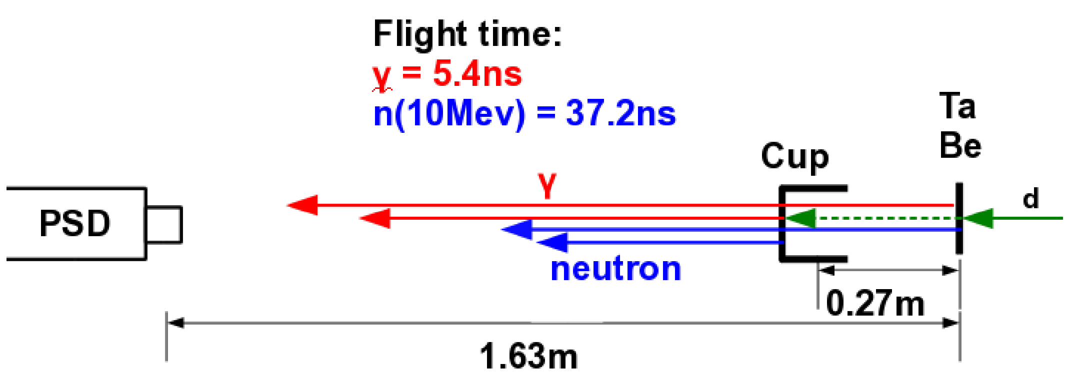
after irradiation:
control measurement in the lab
with Ar:CO2 and no aging:
=> identical spectra !

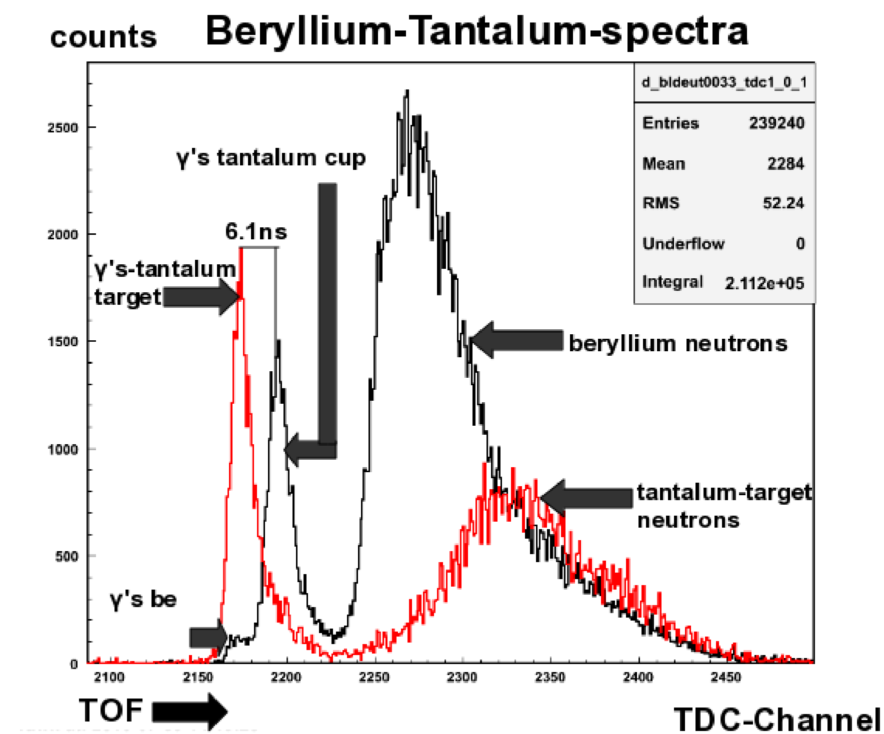
TDC spectra	identical
ADC spectra	identical
number of counts	identical





Neutron creation

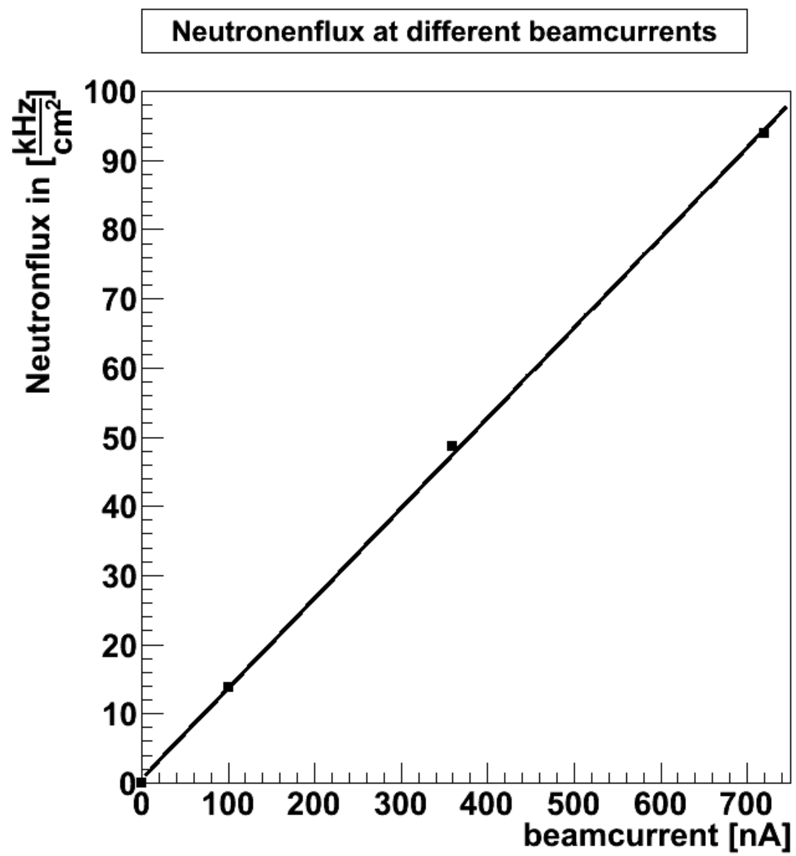


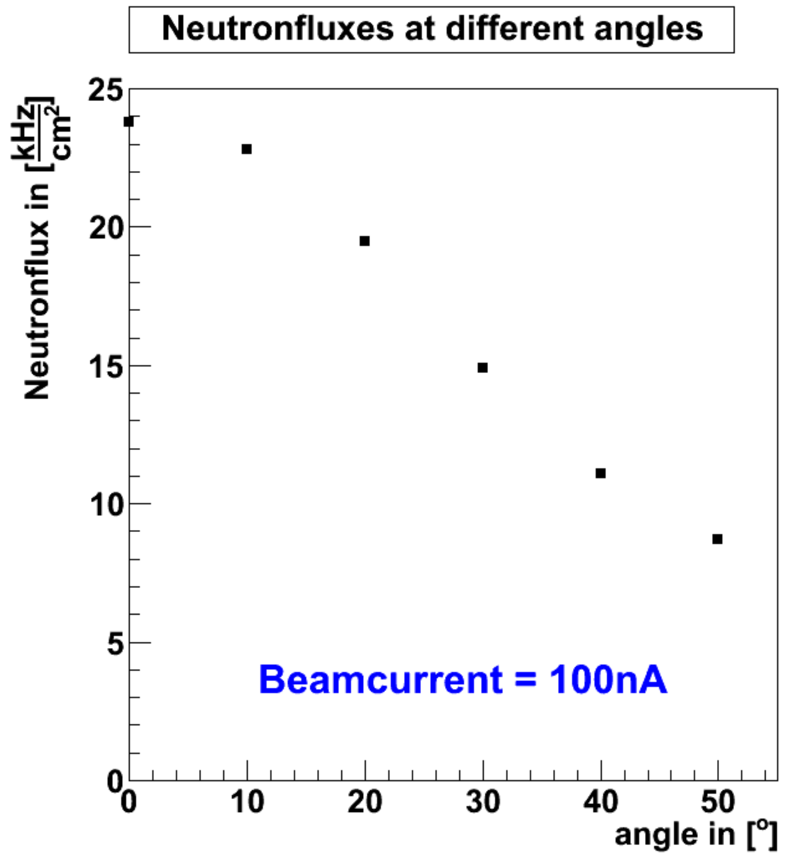


- **TDC = time to digital converter**
- **common start mode: start: bunch clock**
  stop: scintillator signal
- **beryllium creates high energy neutron, high yield**
- **tantalum creates low energy neutron, low yield**

different measure times (red and black)

Angle Distribution of Neutrons

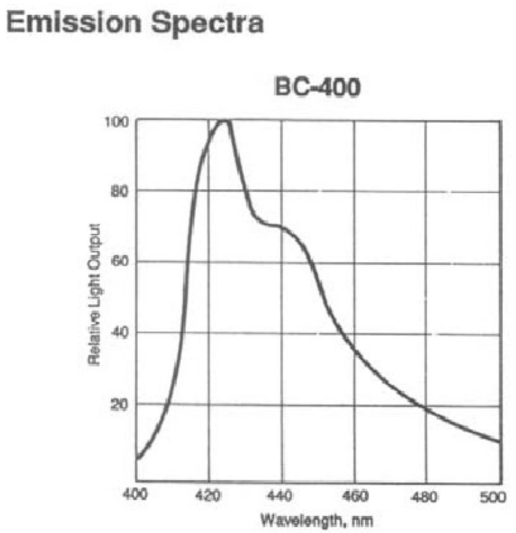




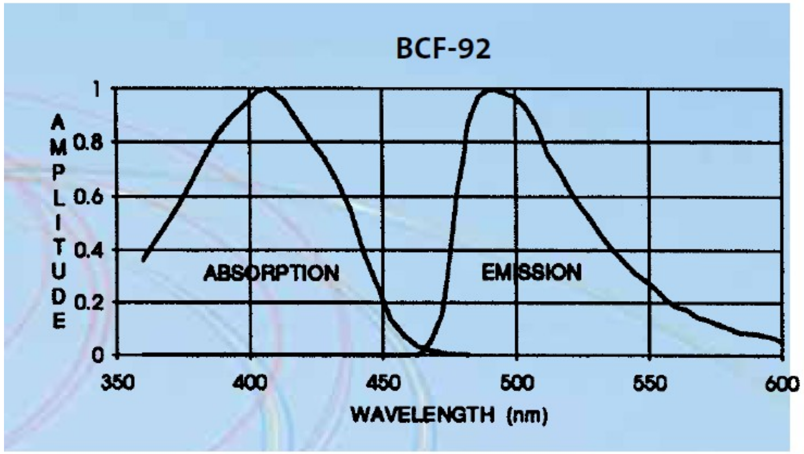
- α on Be (30 MeV α) flux increases linear with beam current
- Angular distribution of neutrons constant within a factor of 2 within angle of 20 º

Wavelength-Shifting-Fiber Readout

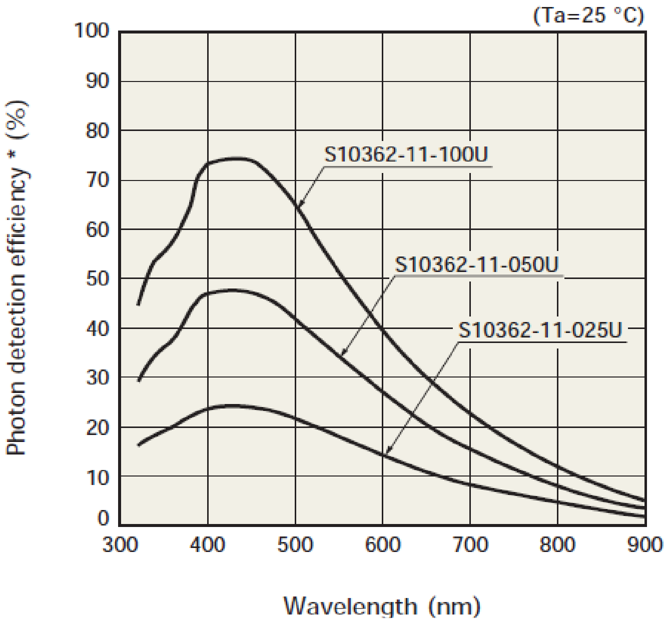
Scintillator light output of BC 400:



Absorption/ Emission spectrum of WLS Fiber BCF 92:



Light Sensitivity of SiPM:



- different component of WLS readout (Scintillator/Fiber/SiPM) are compatible
- cosmic muon creates light in scintillator → WLS-Fiber collects light and guide it to the SiPM