High Rate Performance of Drift Tube Detectors

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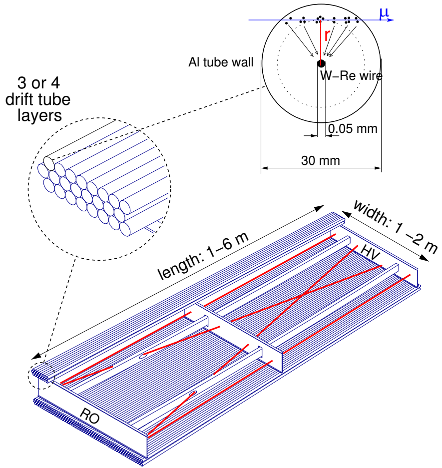
ATLAS Monitored Drift Tube (MDT) Chambers



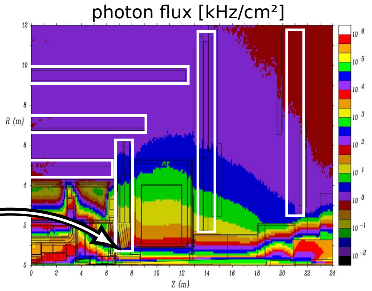
- 30 mm tube diameter
- gas mixture: $\mathrm{Ar}/\mathrm{CO_2}$ (93/7) bei 3 bar absolutem Druck
- max. drift time: $\approx$ 700 ns

without radiation background:

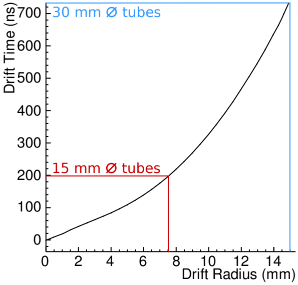
- tube resolution: 80 µm
- chamber tracking resolution: $\approx$ 40 µm

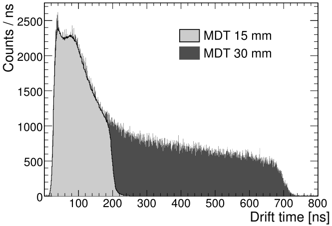
Challenge:

- High photon and neutron background
- Max. expected rate at HL-LHC: 14 kHz/cm^2



High Rate Effects
Occupancy





Drift gas Ar/CO_2 (93/7):

- no ageing effects
- non-linear $r(t)$ relationship

in the following:
Comparison of ⌀30 mm MDT with ⌀15 mm sMDT

Occupancy:

occupancy = counting rate × max. drift time

- maximum drift time:
  - 30 mm MDT: 700 ns
  - 15 mm sMDT: 185 ns

⇒ gain a factor 3.8

- counting rate:

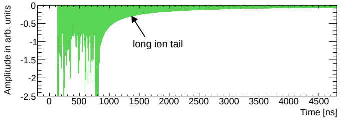
⇒ gain a factor 2 due to tube cross section

Space-drift time relationship $r(t)$ for drift tubes with 15 mm ⌀almost linear!

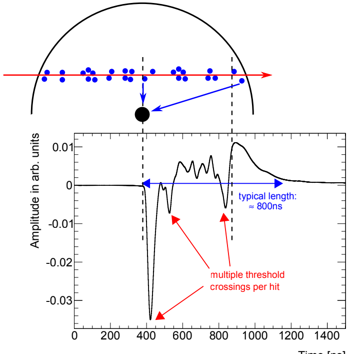
High Rate Effects

Deadtime

- Slowly drifting ions cause long pulse tail



- Use bipolar signal shaping for fast baseline restoration



- One hit can cause multiple threshold crossings

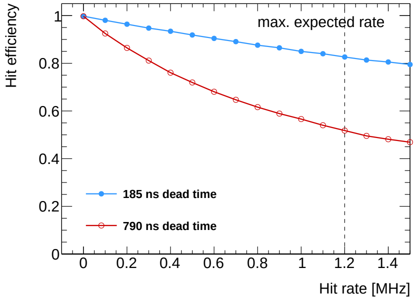
$\Rightarrow$ adjustable dead time in front-end electronics

$\Rightarrow$ dead time masks consecutive hits

- pulse length $\sim$ tube diameter

$\Rightarrow$ smaller tube diameter $\rightarrow$ shorter dead time

$\Rightarrow$ less efficiency loss

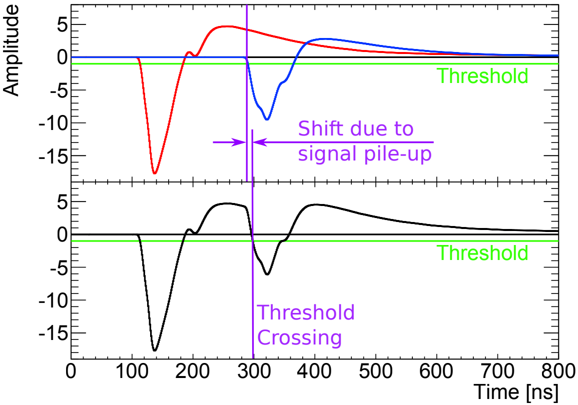


High Rate Effects

Signal Pile-up

- good efficiency requires short dead time

but: signal pulses are affected by preceding background pulses



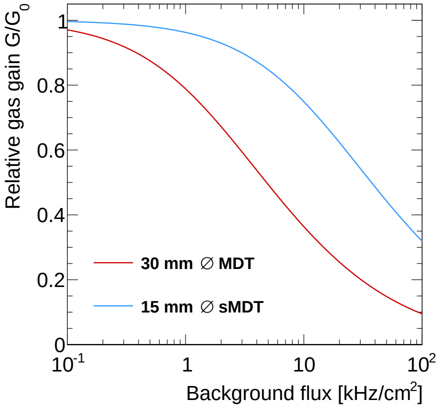
⇒ systematic shift depending on pulse shape and time difference

- can be partially corrected. better: optimized signal shaping
- for large signal amplitude variations, hits can go missing

High Rate Effects

Drop of the Gas Amplification

The ions drifting outwards attenuate the electric field needed for the gas amplification



Iterative calculation of the gas amplification with Diethorn formula:

$$G = \left[\frac{E_{\mathrm{wire}}}{3E_{\mathrm{min}}}\right]^{\frac{r_{\mathrm{wire}} E_{\mathrm{wire}} \ln 2}{\Delta V}}$$

E_{wire}: electric field on the wire surface, depending on the space charge and thus on the background flux.

G_0 = nominal amplification = 20000

- Space charge effects $\sim R^3$ for photons, $\sim R^4$ for charged hadrons
- In ATLAS photons dominant background

$\Rightarrow$ gain a factor 8 in rate capability

High Rate Effects

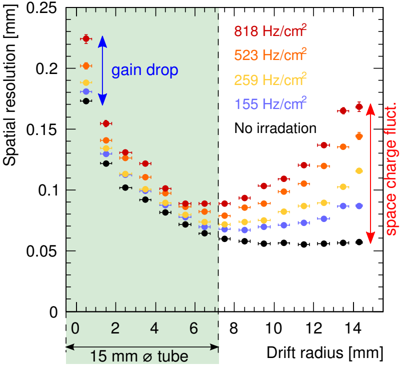
Space Charge Fluctuations

a further effect due to space charge

- space charge fluctuates in time

⇒ drift properties vary while drifting

⇒ degradation of the resolution ∼ drift time/radius



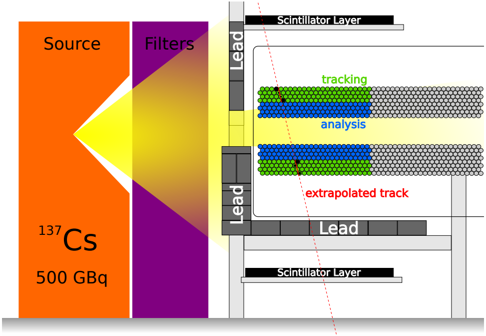
Effect is virtually eliminated for tubes with 15 mm diameter.

Measurements in the Gamma Irradiation Facility (CERN)

Method of Measurement

No muon beam in the GIF:

- shielded tubes for precise tracking of cosmic ray muons
- extrapolate muon tracks to irradiated tubes



Resolution and efficiency from off-track residuals:

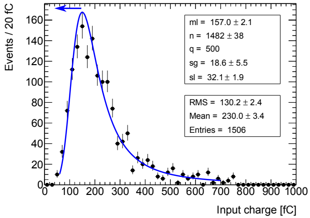
- correct for tracking resolution and multiple scattering $\Rightarrow$ single tube resolution σ
- determine the 3σ single tube efficiency.

Measurement Results

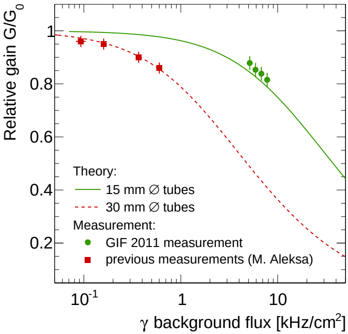
Gas Amplification

2 methods to measure the amplification:

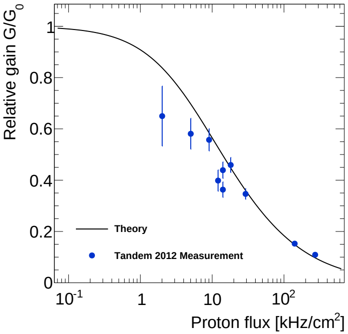
1. from current $I = R \cdot Q \cdot G$, with R: counting rate, Q: ionisation charge, G: amplification
2. from ADC measurement (relative): drop of amplification $\Rightarrow$ shift of the charge spectrum $\frac{Q}{Q_0} \sim \frac{G}{G_0}$



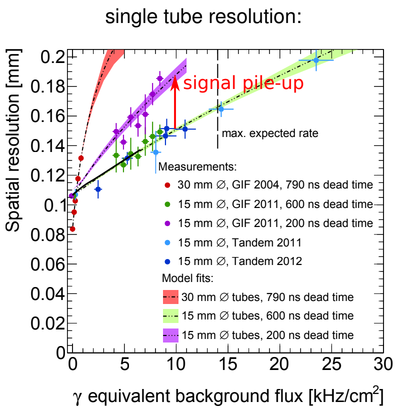
gamma irradiation:

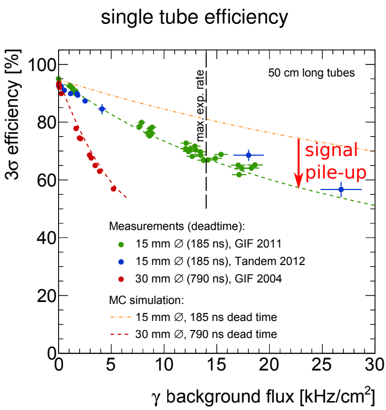


proton irradiation:



Measurement Results



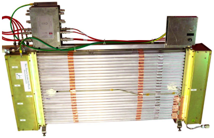


- Reducing the tube diameter brings huge improvement
- Further improvement possible with optimized signal shaping

Additional improvement due to smaller tube diameter:
more tube layers fit into the same volume
⇒ more robust pattern recognition, better tracking resolution

Rate Measurement for Upgrade Plans

Two sMDT chambers installed in ATLAS in the winter shutdown 2011/12

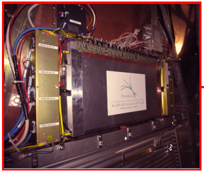


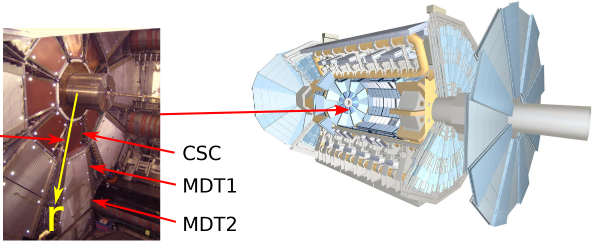
Predicting the background rates is difficult because of uncertainties in:

- detector sensitivities to radiation background and
- composition of the background radiation.

Therefore, a sMDT chamber was installed in the hottest region to directly measure the predominant background.

- 1 multilayer consisting of 4 tube layers
- 96 tubes in total
- 4 high voltage segments for segmented rate measurement





Rate Measurement Methods

Two independent methods:

Hit counting method:

- Count number of hits n_{hits} in a time window of length t_{window} in individual tubes
- n_{events}: total number of events/triggers, l_{tube}: tube length, d_{tube}: tube diameter

$$\Rightarrow \boxed{\text{Hitrate}[\text{Hz}/\text{cm}^2] = \frac{n_{\text{hits}}}{t_{\text{window}} \cdot n_{\text{events}}} \cdot \frac{1}{l_{\text{tube}} \cdot d_{\text{tube}}}}$$

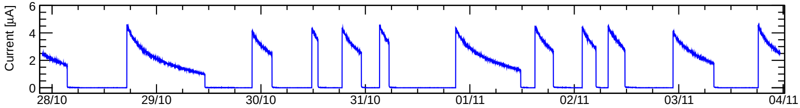
High voltage current method:

- The current drawn by n_{tubes} tubes is: $I = n_{\text{tubes}} \cdot R \cdot q_{\text{prim}} \cdot G$
- R: hit rate, q_{prim}: primary ionization charge, G: gas gain

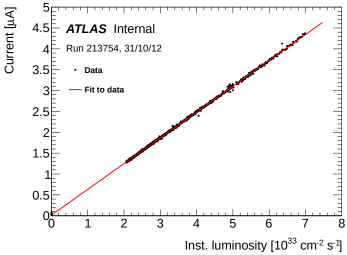
$$\Rightarrow \boxed{\text{Hitrate}[\text{Hz}/\text{cm}^2] = \frac{n_{\text{tubes}} \cdot I}{q_{\text{prim}} \cdot G} \cdot \frac{1}{l_{\text{tube}} \cdot d_{\text{tube}}}}$$

Rate Measurement

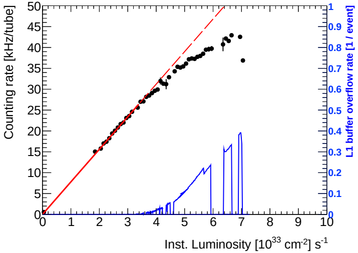
Example of HV current in tubes experiencing the highest rates:



HV current:



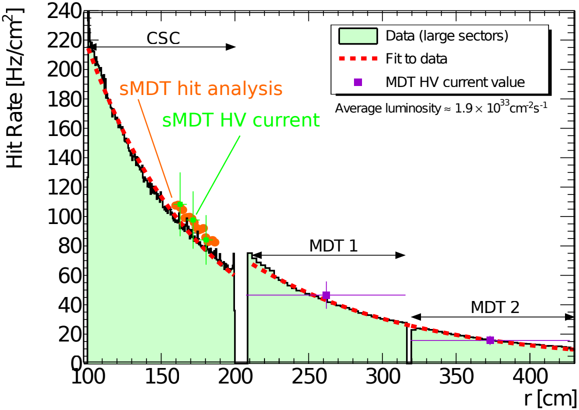
Counting rate:

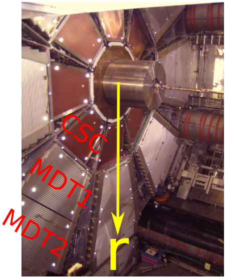


For better comparison: Convert both measurements to the background flux (next slide).

Rate Analysis for Upgrade Considerations

Background rates in the Small Wheels (hottest regions)





- The two measurement methods agree perfectly
- sMDT rate follows CSC rate and is slightly higher (due to higher background sensitivity) . . .
- . . . however not as much as it was expected from the MDT

Afterglow measurement

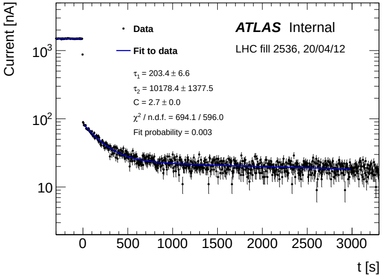
Measurement of the decay constant(s) of the cavern background

Fit the current before and after the beam dump ($t = 0$):

$t < 0$: with a 1st order polynomial $I_{\text{before}}(t)$ and

$t \geq 0$: with two exponential decay functions and constant dark current:
$I_{\text{after}}(t) = A \cdot \exp(-t/\tau_1) + B \cdot \exp(-t/\tau_2) + C$

Did this for several runs with the high voltage kept at its operating value for up to four hours after the beam dump.



Results:

$\langle \tau_1 \rangle = (204 \pm 3)\,\text{s}$

$\langle \tau_2 \rangle = (13755 \pm 577)\,\text{s}$

Afterglow rate $= \frac{I_{\text{before}}(0)}{I_{\text{afer}}(0)} = (5.5 \pm 0.1)\%$

Possible isotopes are $^{13}_{28}$Al ($\tau = 194\,\text{s}$) and $^{56}_{25}$Mn ($\tau = 13392\,\text{s}$). Both can be produced in fast and thermal neutron activation and occur in the detectors and the mounting and shielding material.

Summary

- Resolution and efficiency of drift tube chambers deteriorate at high radiation background due to:
  - signal pile-up of consecutive hits
  - drop of the gas amplification due to space charge
  - space charge fluctuations
  - masking of hits due to the dead time
- Reducing the tube diameter from 30 to 15 mm very effective:
  - shorter dead time possible (790 ns $\rightarrow$ 185 ns)
  - factor 8 less drop of gas amplification
  - effects of space charge fluctuations virtually eliminated
- Further improvement possible with optimized signal shaping
  - new front-end chip development started
- Successful operation of a sMDT chamber in the ATLAS cavern for several months.
  - background rate measurements for upgrades with two methods
  - determined life-times of the cavern afterglow which could be identified with two possible isotops.

Thank you!