Straw-detectors

Outline:

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- ❖ **High Pressure Straw**
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- ❖ **Transient Operation mode**

Introduction

Transition Radiation Detectors (TRD);

Trackers (ST);

Transition Radiation Detector/tracker(TRT)

Straw detectors were used:

TRD: DELPFI (barrel 5 x 192 straws 2м; ⌀ 0,9);

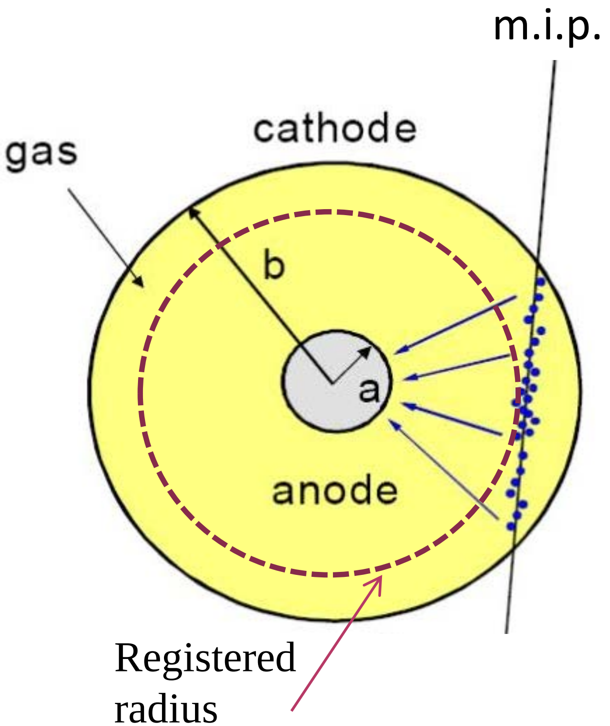
NOMAD {pion rejection factor ~1000);

AMS (lepton-hadron separation ≥100; 5 248 straws)

ST: COMPASS; MECO/Mu2e; LHCb;

SVD2, OKA (Protvino); COSY\TOF); PANDA; …..

TRT: ATLAS

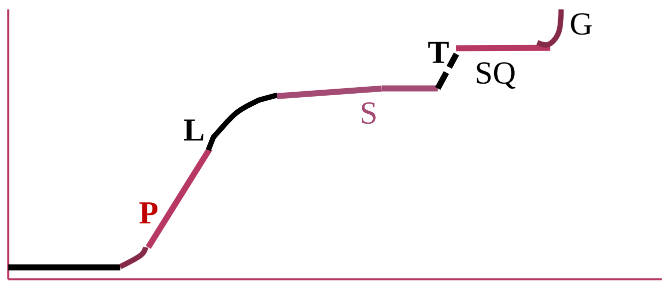


Cylindrical electrical field.
Anode ⌀ (a): 20-50 μm
and catode (b): 4-15 mm

Straw operate :
- in vacuum
- at a filling gas mixture ≤ 5 bar

All elements consists of low-Z materials

Operation modes:



- **Proportional : gas gain (G) < $4*10^4$**
- **Limited Proportional: G $4*10^4 – 10^5$**
- **Saturated (G - near 10^5)**

and

- **Transient mode to Self Quenched Streamer mode**
- **SQSM (is not used)**

Main difference of straws in comparison with other detector type:

- Least material budget
- Good straightness and diameter uniformity independent on straw length
- Small aging
- Independent operation of the individual drift cells
- .Little operating problems
- Straws are operated in vacuum (MECO/Mu2e, COSY\TOF, balloon flight experiments….)
- Straws are operated with HP gas filling (up to 5 bar)

Detecting Elements

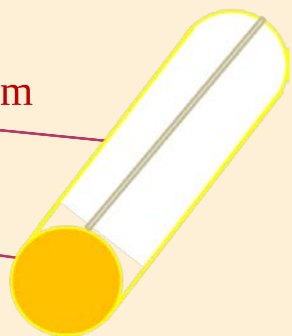
Two design of the straw production:

1. Asymmetric
2. Symmetric

Metalized maylar tape are lapweld by ultrasound

Longitudinal stream

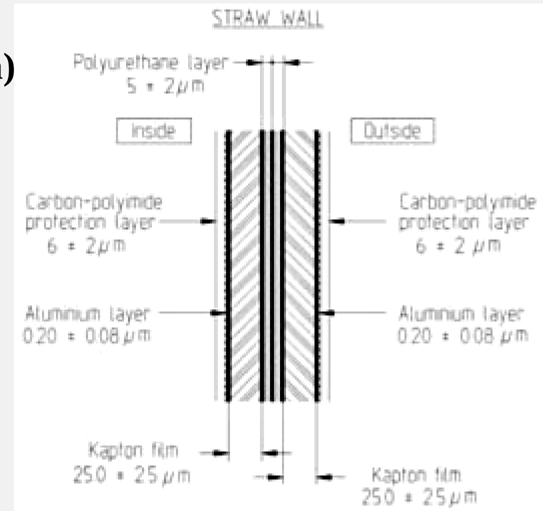
cathode

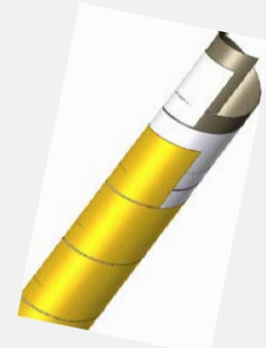


Film thickness: 30-100 µm. Asymmetric design.

Two kapton film strips are wound around of mandrel. Inner conducting film trip can be loated or coated by carbon.

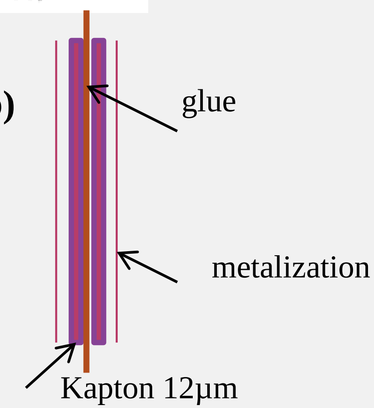
(a)





Wall thickness: 25-70 µm. Symmetric design

(b)



The straws can be composed of carbon loaded PEEK extruded through a die (seamless, Osaka Wall thickness - 30 um, Length < 80 cm. (MECO)

Gas mixtures:

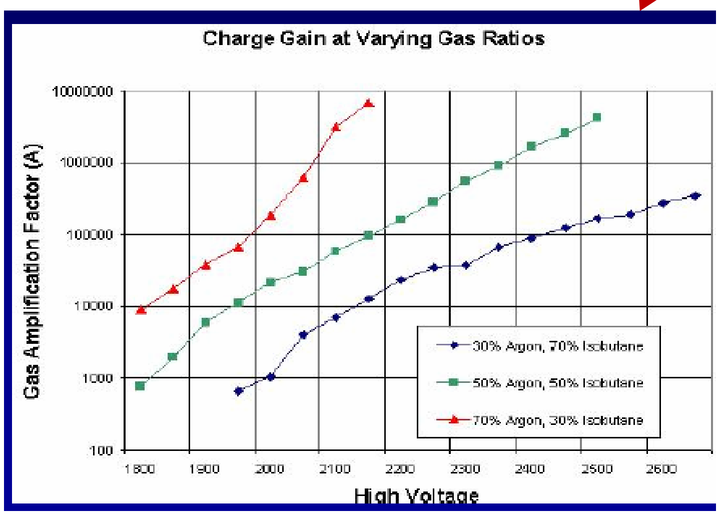
Typical gas mixtures:

- *$ArCO_2$*
- *$XeCO_2$*
- *$ArCO_2CF_4$*
- *$XeCO_2CF_4$*

To increase the signal values:

- *Ar/C_4H_{10}*
- *Xe/C_4H_{10}*

or other - *CF_4/C_4H_{10}*
(but inflammable gas)

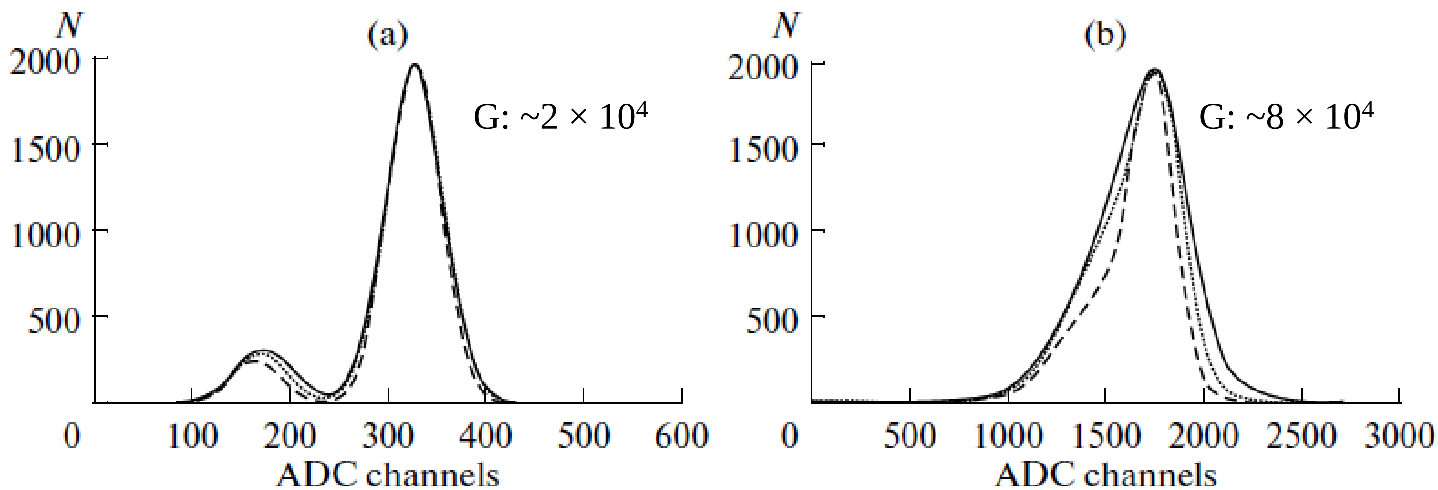


For various gases at NTP: (a) yield of ionization encounters for m.i.p., (b) t99: thickness of the gas layer for 99% efficiency, and (c) the average number of free electrons produced by a m.i.p. (L.G. Christophorou).

	Encounters/cm	t_{99}(mm)	Free electrons/cm
He	5	9.2	16
Ne	12	3.8	42
Ar	25	1.8	103
Xe	46	1.0	340
CO_2	35	1.3	107

For the MECO/Mu2e

Energy resolution



Energy resolution (FWHM) Straw diameters: 4, 6 and 9.56 mm.
a- (HV are 1.39, 1.52 and 1.665 kV;
b - 1.57, 1.72 and 1.85 kV, respectively

Gas mixture - ArCO_2 (80/20). ΔE/E -18% and ~30% for (a) and (b). The ΔE/E at the same gas gain are very equal. Deterioration is observed for straws of lesser diameter, which is likely due to the worsening of the ratio between the accuracy of the technological assembly of straws and their diameters.

PANDA Experiment:

studying annihilation reactions of antiprotons with protons (pp) and in nuclear matter (pA).

The STT in solenoidal magnet:

- 27 layers of the straws (L=1.5 m, d= 10 mm) around the beam-target.
- Straws with axial and incline directions.

The tasks:

o The measurement of the particle momentum by the reconstruction of the helical trajectory.

$(\sigma_z = \sigma_r/\sin(\beta))$

σ_r – radial resolution and β angle of the skewed layers (2.9°)
for z- coordinate: 3mm single hits.

.

o PI to separate protons, kaons and pions by the measurement of the energy-loss (dE/dx) in straws..

Prototype tests - **8% (σ of the $\Delta E/E$)**

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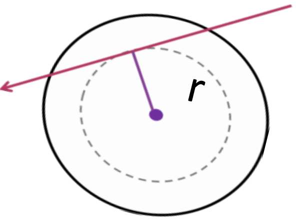
Radial Spatial Resolution



Drift time measurement of the of 1-st e^- determines the radial coordinate **r**.

Straw tubes of the LHCb tracker:
Inner diameter - 5 mm
Ar–CF4–CO2 gas mixture

Maximum drift time

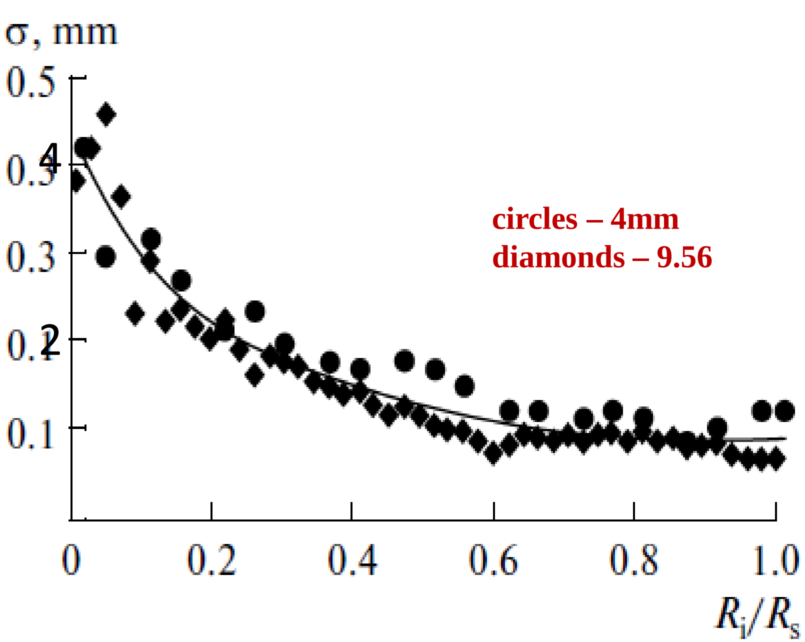
	Diameter of straws (d), mm		
Gas mixture	**4**	**6**	**9.56**
$ArCO_2$ (70/30)	38	68.4	129
$ArCO_2 CF_4$ (63/32/5)	36.5	66.7	144
$ArCO_2 CF_4$ (63/27/10)	36	60	119
$ArCO_2 CF_4$ (63/17/20)	34	45	99

$Ar/CF_4/CO_2$	$B = 0$ T	$B = 0.72$ T	$B = 1.00$ T	$B = 1.37$ T
65/30/5	30 ns 230 μm	31 ns 220 μm	34 ns 215 μm	38 ns 205 μm
75/20/5	33 ns 210 μm	34 ns 205 μm	38 ns 205 μm	42 ns 190 μm
65/5/30	39 ns 155 μm	41 ns 150 μm	43 ns 145 μm	46 ns 140 μm

Maximum drift times (upper entry) and resolution (lower entry) of straw drift tubes operated with three different gas mixtures and various magnetic fields (B) parallel to the wire.

Spatial resolution measurements on the SPS test beam:.

Ø, mm	Gas gain	σ, μm	efficienty, %	Gas mixture
4	~$7x10^4$	~190	~85	•$ArCO_2$ •(80/20).
9.56	~$8x10^4$	~180	99	the same

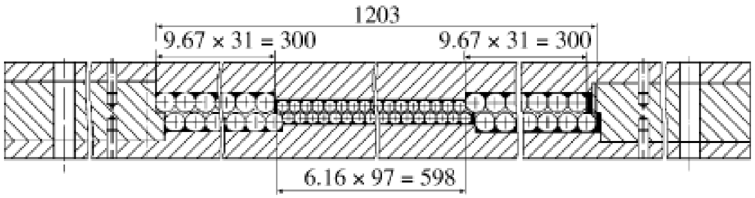


The distribution of the resolution (σ) along straw radius are very close.
These distributions take account of a drift velocity changing along the radius and can be used in track reconstruction.

Double layer chambers allow a search of the hit by 2 straws and definition the coordinate by one only.

For long straws:
Passing of signals along 1m of anode wire take 3.48ns

Detector Modularity



Cross section of COMPASS double layer. Max full straw length is 3.6 m.

Each chamber consists of two layers straws. One layer is shifted by a straw radius with respect to the other I n order to resolve left–right ambiguities.

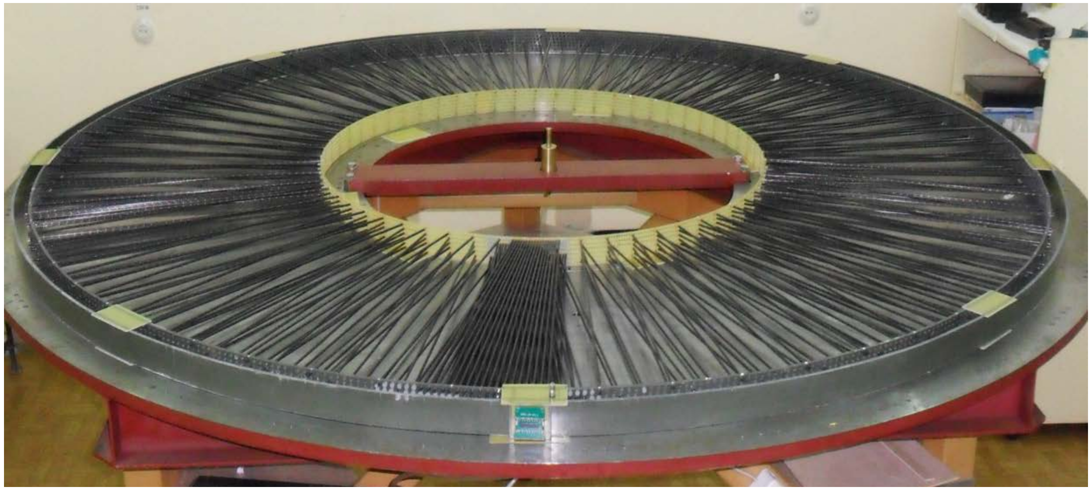
The straws of one layer can be glued together to one plane. The plane can contains the straw with different diameters.

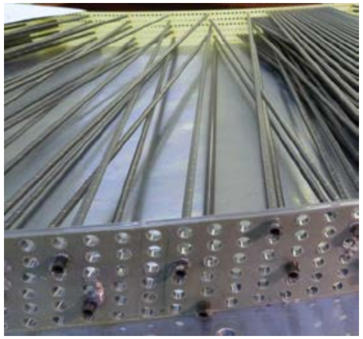
Such plane has a much higher mechanical stability compared to individual straws. This improves the ruggedness and the mechanical achieved precision, and much reduces the tighting force to the frame.

6-layers
3600

Three chambers are grouped together in a module. Each module contains vertical and inclined straws and measures one space point.

2-layers
1300

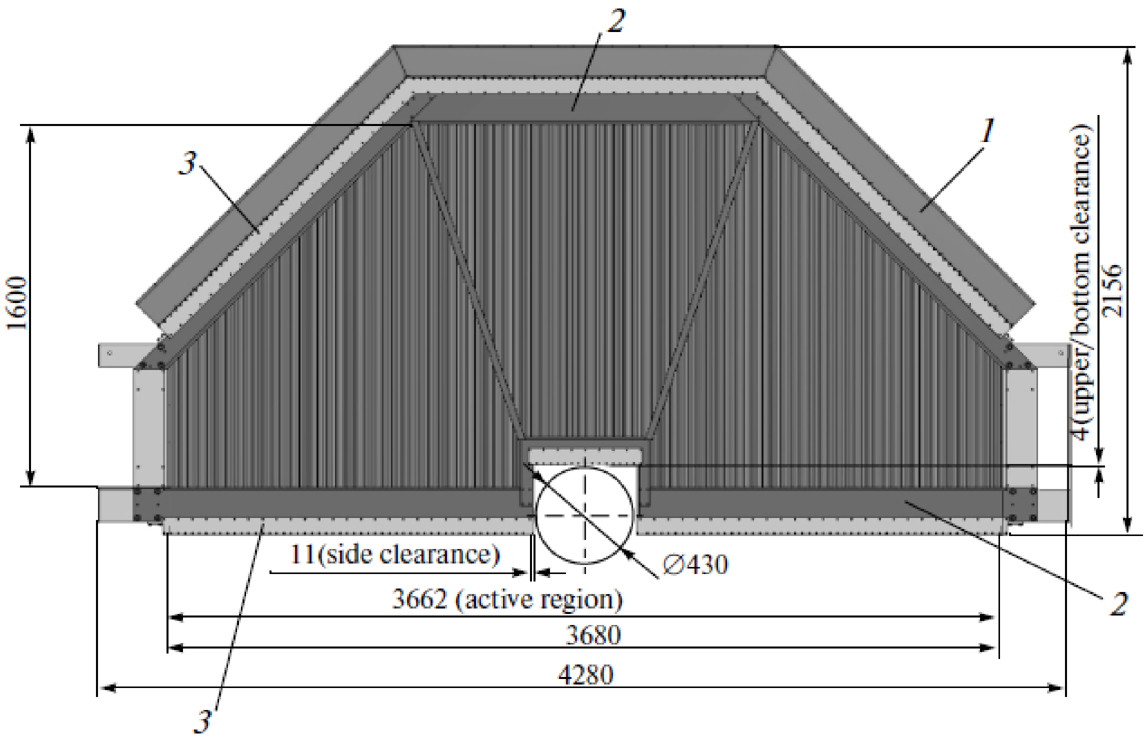




Engineering prototype of the six-layer.

Orientation: R, +7d. -7d, R, +7d. -7d

Straw length – 602 mm



Engineering prototype of the CBM (FAIR)

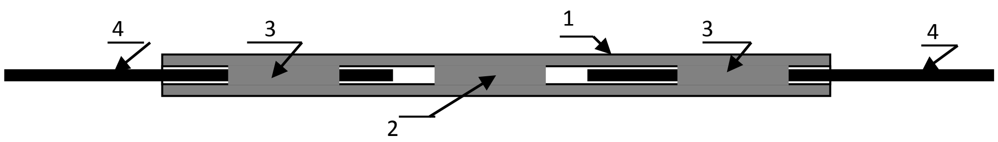
HISTORY (~2000)

COMPASS straw – activity

Granularity of Straws

Straw rate capability: **up to 4.5 Mhz/cm²**. Sensitive area per one FEE channel is: 2RL.

The chosen straws are a compromise between minimizing the collection time in straw (R) and its length while keeping the occupancy in each straw below (5-15)% at maximum beam rates.

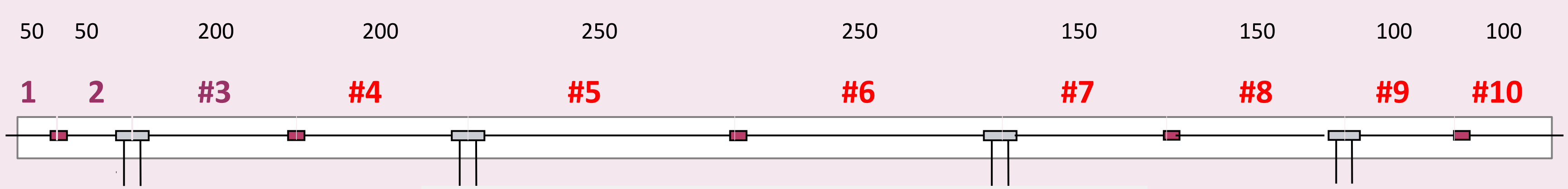


Capillary tube -(1), isolation gap - (2), (3)- molten fixing of the anode wire.

Some straws of the ATLAS Barrel TRT contain the anode divided by the glass capillary tube to three electrical independence parts.

AFTER: technique of multi-segment anodes
segment anode wires outlet outside through the straw wall
low-mass readout/HV flat cable with length up to 1 m

were developed

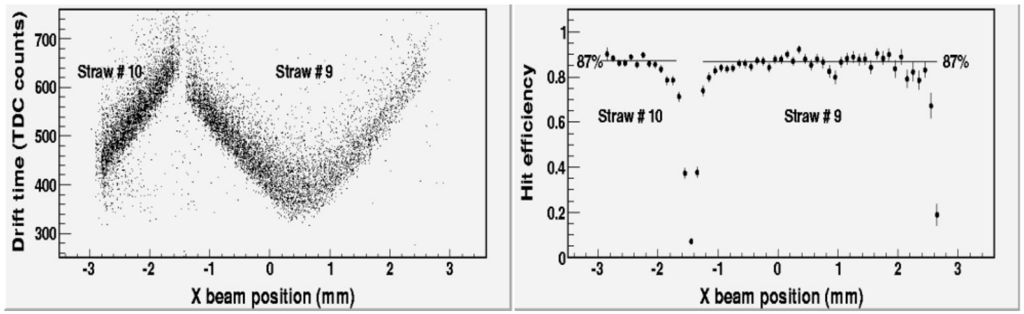


10-segments anode L eangth -1600 mm

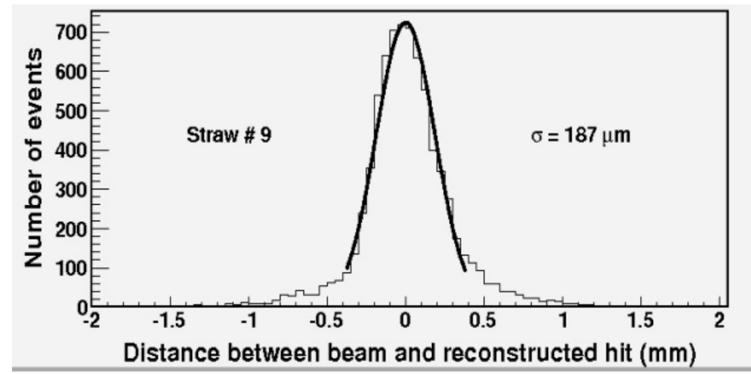
A prototype based on segmented straws had been studied at SPS.

Individual readout from each segment.

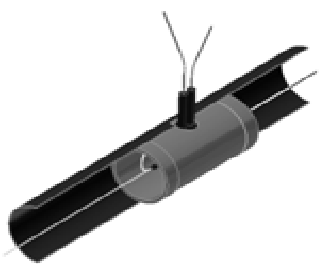
Straw diameter - 4 mm, 360 registration channels. The prototype' granularity - 4 cm^2.

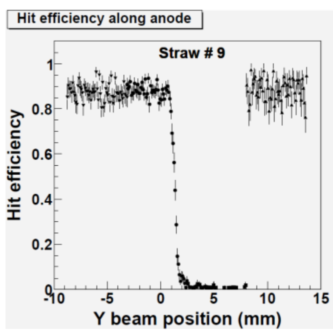


RT dependence and efficiency for two straws along their radius (X, mm).



spatial resolution (σ) of the straw





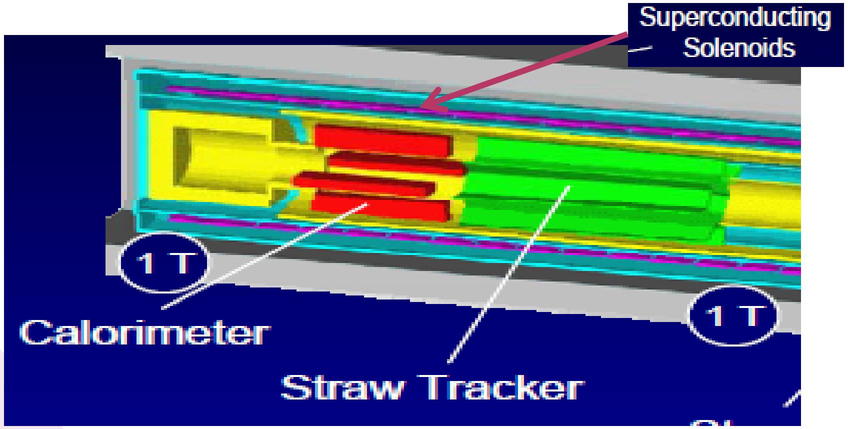
View of the plastic spacer and its insensitive length

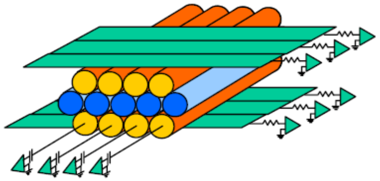
length of insensitive region due to straw internal elements is less than 5% of full sensitive area.

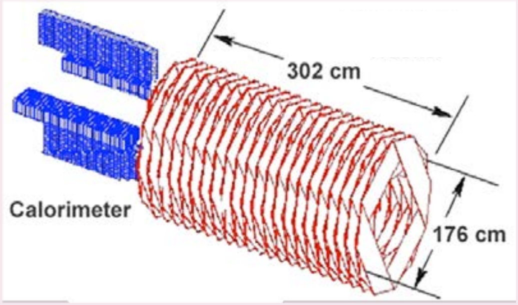
The time and spatial parameters of the detector do not differ from those of conventional tracking detectors based on drift tubes.

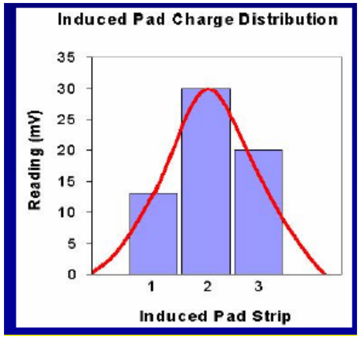
Two-Dimensional Readout (MECO/Mu2e)

Capability of the cathode readout for the straws was shown in beginning of 90 y. (V. Bychkov et al., NIM A325, 1993). Large R@D was done by prof. Molzon after.
Two straw trackers (L and T) will be used for the Drift Time Measurement, Charge-Division Technique and the Cathode Pad readout.









T-Tracker:
12960 straws:70–30 cm length, ∅ 5 mm, 25μm wall. All straws conducting. Resolution: 0.2 mm (x,y). Length of the resistive anodes – not more1m. Helical pattern recognition, 2 full helical turns of the electron trajectories

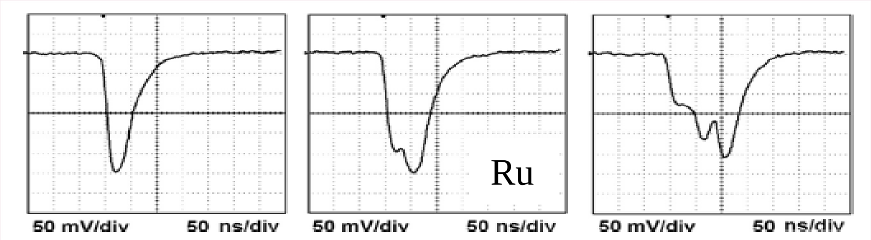
Two-Dimensional readout of the L-tracker.
2800 sraws: 2.9 m, ∅ 5 mm, 25 μm wall. 3 layers of straws per plane, outer 2 – resistive cathodes, inner-conducting. 16640 pads.
Resolution: 0.2 mm (r,φ) × 1.5 mm (z).

In-depth study of the Direct Timing Method (Radeka in 1988).

Determination of longitudinal coordinates - by the measurements the difference in pulse arrival time at the two straw ends.

Main disadvantage of the charge-division technique is fast degradation of the resolution with the anode length growth.

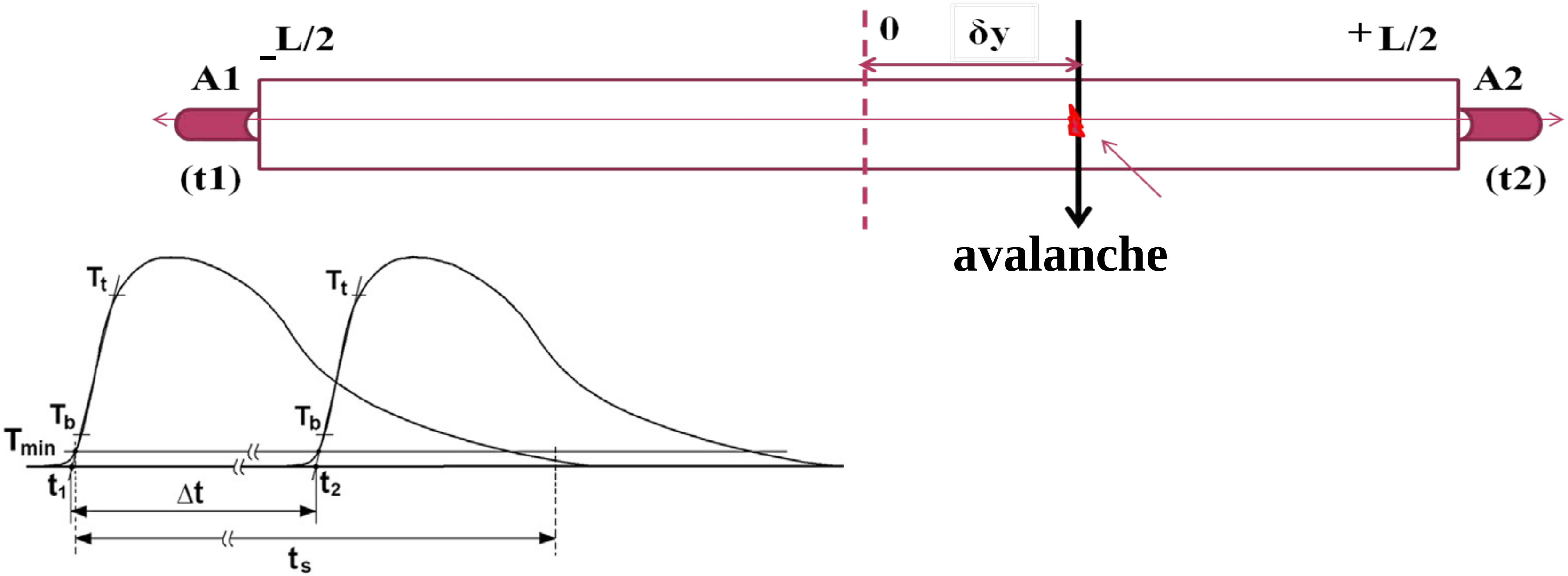
The prototype with 2 m long straws was used for i study of the DTM.
The transmission line impedance of the straw - 360 Ohm.
Gas: Ar/CO_2 (80/20). Source: Fe-55 or Ru-106 (3.55 MeV electrons)
Amplifiers: typical for the drift time measurements.



Fe-55 – fix amplitude and signal shape

A wide dynamic range of the signals produced by MIPs and ionized electrons clustering lead to greater distortions of the pulse waveform:

The pulses from the outputs of the amplifiers were led Into two channels of a DRS4 ADC which can digitize an input signals and store an amplitude and a pulse shape.



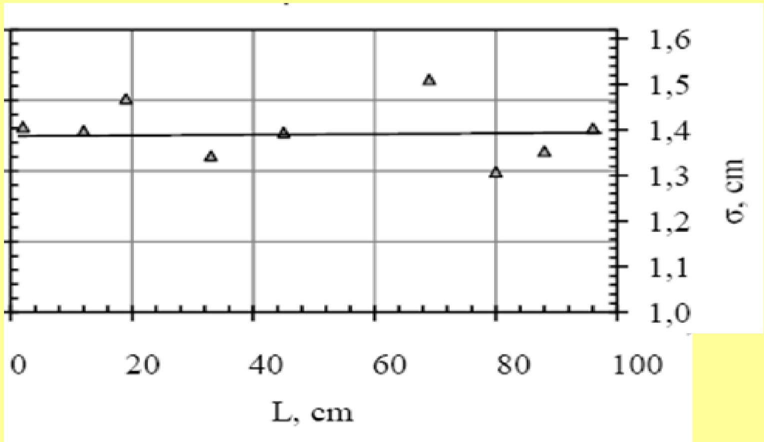
The point of the avalanche is δy from anode center. Signals arriving at amplifiers pass the distance L/2 ± δy, where L is the anode length. So, **Δt=2δy/v**, where v is the signal propagation velocity along the anode wire, and the direction from the straw center is determined by the sign. The v = 3.49 ns/m. 1 cm distance corresponds to the difference in the time delay = 69.8 ps.

Algorithm of determination the values of difference δt was developed. (nima. A735, 649-654)

The slope of the leading edge of signals are changed depend on passed way.
Signals from two ends pass different ways, and had different changing of slops.

The developed algorithm takes in account all effects.

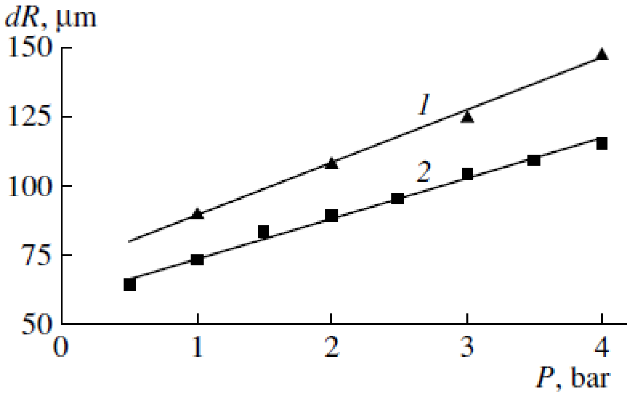
maximum permissible limit of the resolution:

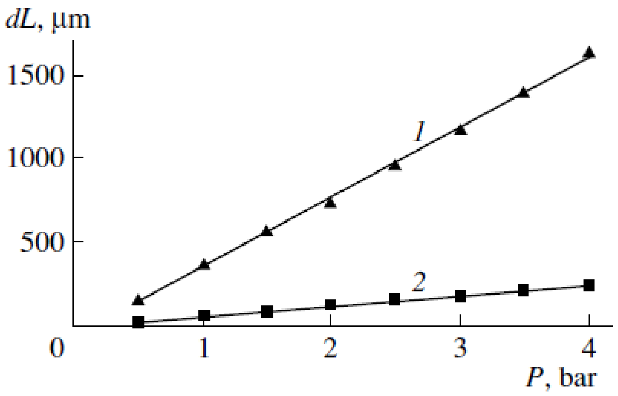


Resolution of DTM is almost the same at registration of MIP and gamma from 55Fe

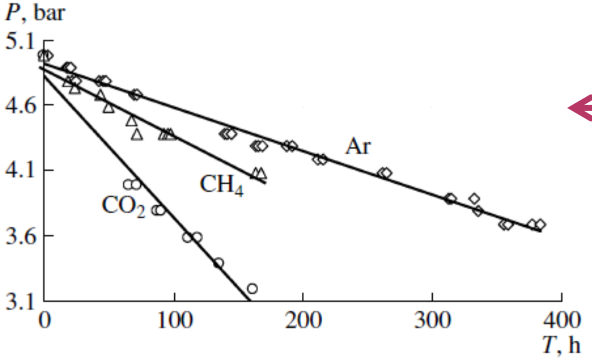
High Pressure Straw

Mechanical properties of the kapton 10 mm in diameter traws were checked for the differential pressure of the tube-filling gas up to 4 bar. Wall - ~60um. (2) – for the reinforcing straws.





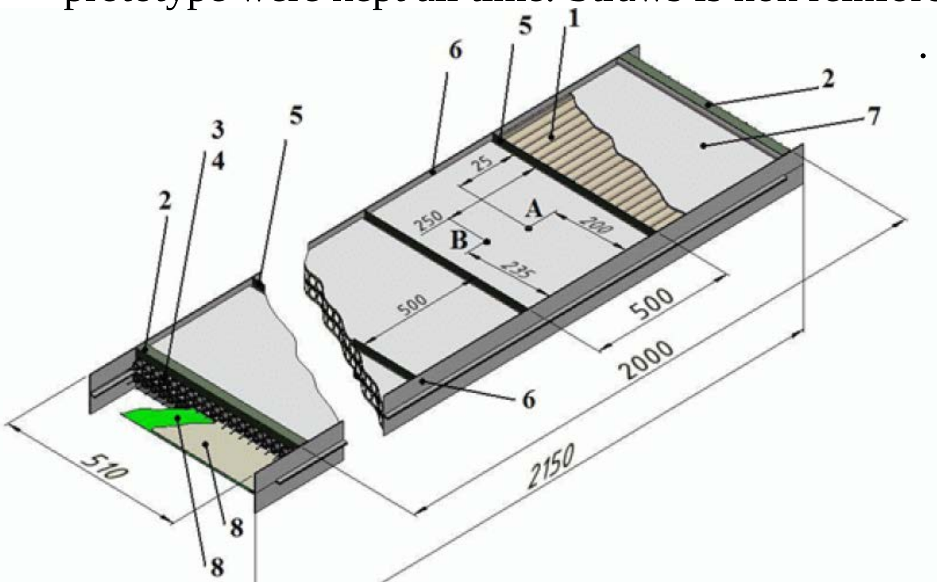
The increasing of the diameter is up to 0.3 mm and 0,25 for non- and reinforcing straws
The elongation was ~400 and ~60 µm/(m bar) for the non- and reinforcing straws.



Gas leakes of straws with such design exist alwas by the gas permeability of different components of mixture..

Thus, for a two-layer detector with 1 m.sq. sensitive area the Ar loss through the wall at an absolute pressure of 5 bar is 0.8 l/day.

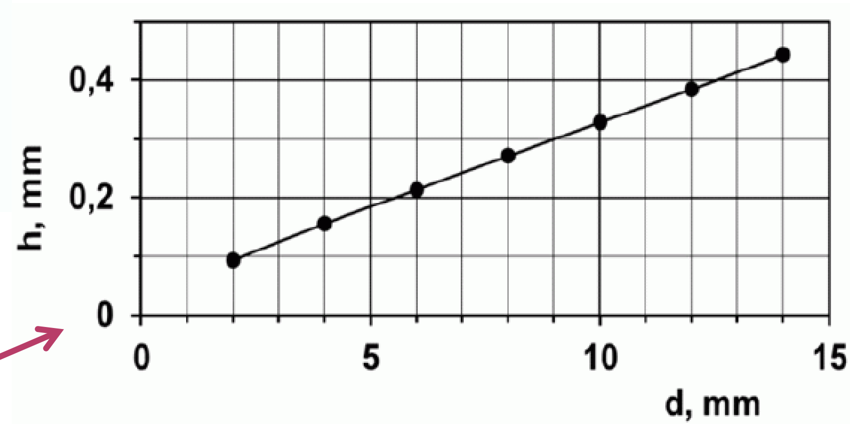
A prototype module with sensitive area of 2 x 0.5 m^2 based on 2 m long straws. The parameters of the prototype were kept all time. Straws is non reinforcing, - 10 mm.



1 - straw, 2 - gas manifolds covered by epoxy resin, 3, 4 - end-plugs with crimping pins, 5 - supporting strips, 6 - thin-walled profiles, 7 - metallized film, 8 - mother boards.

Operating pressure: -1 - +5 bar. Very small gas loss.

The radiation thickness of similar detectors for one layer straws of different diameters is compared with the drift aluminum tubes, where, h- thickness of tube wall; d – straw diameter (wall – 70um)::

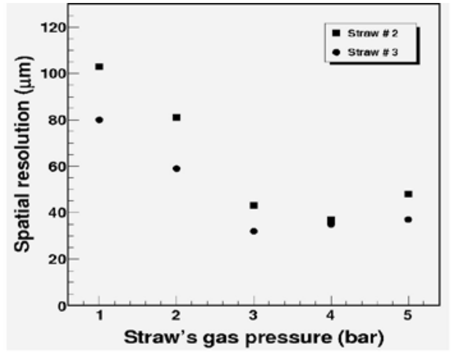


Double layer modules can be used as assembly units for large size muon detector .

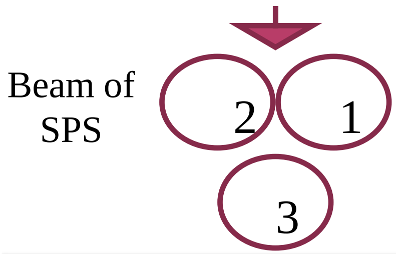
Spatial Resolution

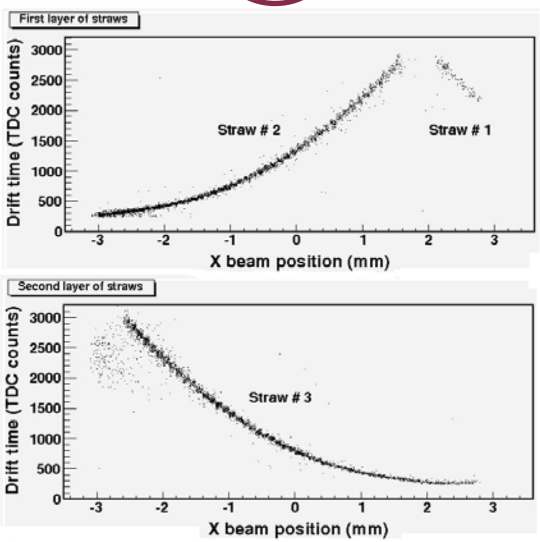
The two layers prototype contained the reinforcing straws in 115 mm length.
The inner diameter was 9.53 mm for 1 bar pressure. The straws were similar to the COMPASS straws,
The prototype was blown with Ar/CO_2 (80/20) mixture, the absolute pressure of the gas varied from 1 to 5 bar.

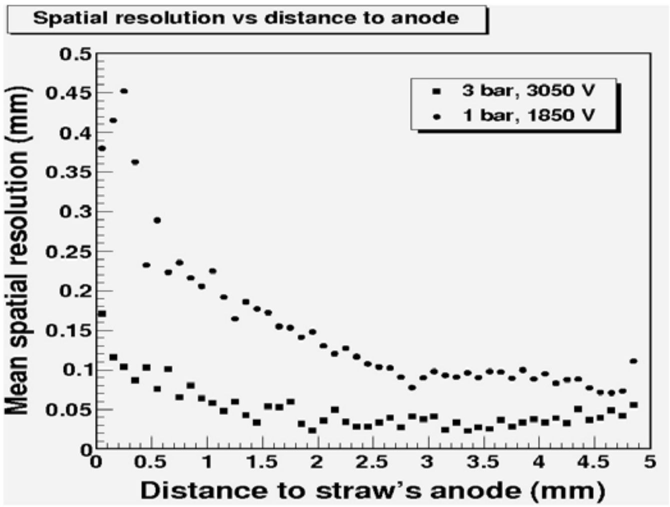
Best average resolution

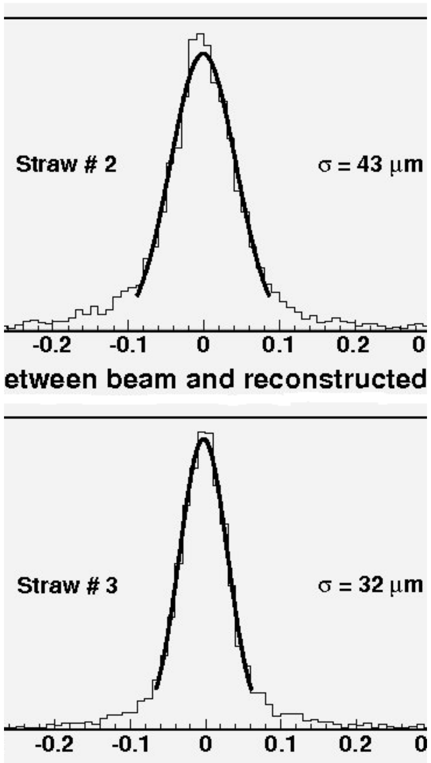


Rate of the beam along the straw radius

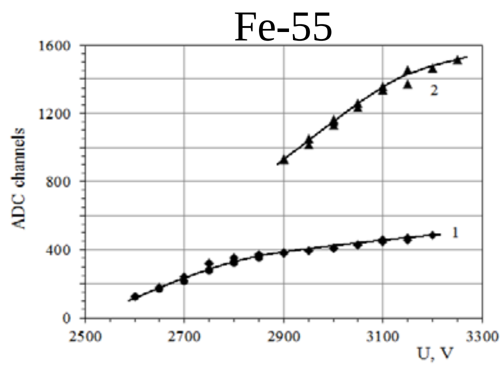








Transient Operation mode of the high pressure straws



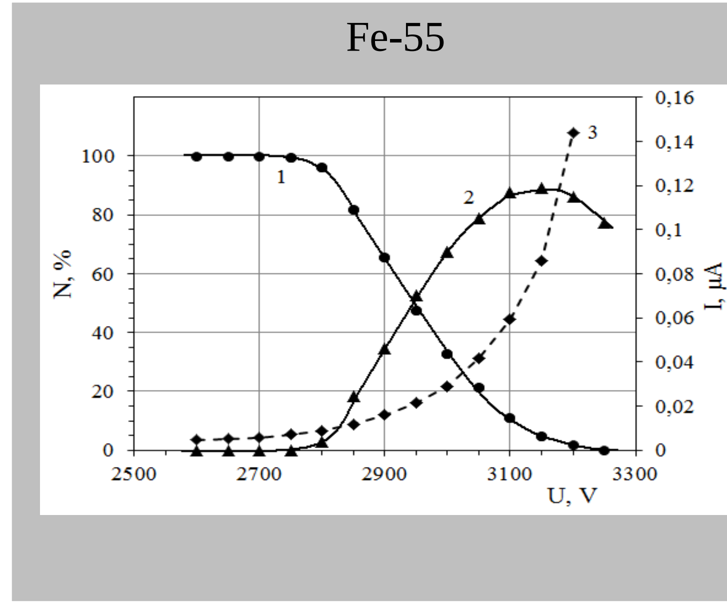
Signal values vs HV; P=3 bar

Similar curves for the Ru-106; electrons 3.55 MeV.

HV from ~2.9 to ~3.15 kV; high stability transient mode (TOM) from limited/saturated mode to high current.

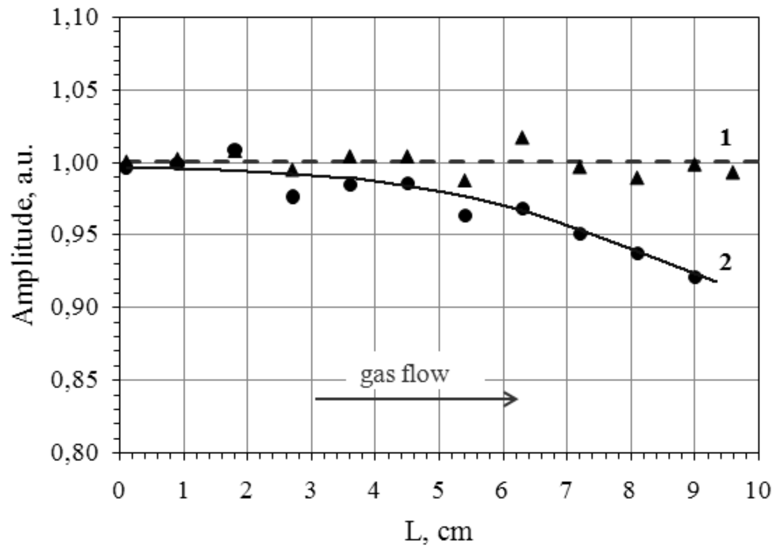
Ratio of the current of is not more than 10.

SQS mode is begun from 3.15 kV.



Operation modes vs on HV. Number of the signals: 1- with small current, 2 – high current. 3- value of current

Aging test: irradiation of full length of straw by Fe-55, ~2600 hours, the average charge is 4.2 C/cm. Aging is absent.



Signal amplitudes along the length of the monitor straw (curve 1) and the irradiated straw (curve 2).
MC - Pressure is 1 bar, gas gain is ~2×10^4 .

Aging test:

Pressure was 3 bar, high voltage – 3.05kV. Average accumulated charge per 1 cm of the straw length is ~ 4.2 C. The arrow points the gas flow direction.

SUMMARY

All capability of the straws are not used yet.

Good examples of the straw activity are TRT ATLAS, AMS, MECO et al.

Any detectors need very high assembly technology,
Some advantages of the based on the straw detectors (small material budget, mechanical properties, cost, best resolution) exist , and can be developed and used.

Thanks for the attention