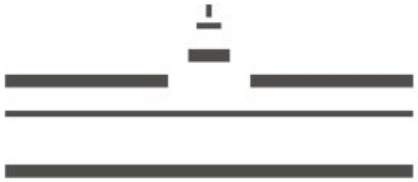
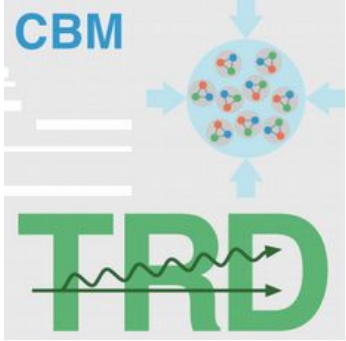




Test Beam Results

CBM-TRD TDR Review
2017, March 14th–15th

Philipp Kähler
WWU Münster, Germany
p.kaehler@uni-muenster.de

Westfälische Wilhelms-Universität Münster

Test Beam Overview

- CBM-TRD test beam measurements

Year	Beamline	Beam / Set-up	Prototypes	Read-out
2006	GSI-SIS18	p, e, π (up to 2 GeV), direct	dual-sided pre-types	ALICE-PASA *
2010	CERN-PS/T10	e, μ, π (up to 5 GeV) / direct	pre-types	SPADIC 0.3, Susibo *
2011	CERN-PS/T9	e, μ, π (up to 10 GeV) / direct	pre-types	SPADIC 0.3, Susibo *
2012	CERN-PS/T9	e, μ, π (up to 8 GeV) / direct	2012-style (57x57 cm^2)	SPADIC 0.3, Susibo *
2014	CERN-PS/T9	e, μ, π (up to 6 GeV) / direct	2012+2014-style (57x57 cm^2)	SPADIC 1.0, SysCore
2015	CERN-SPS/H4	^{208}Pb (30 *A*GeV) / Pb target	2012-style (57x57 cm^2)	SPADIC 1.0, SysCore
2016	CERN-SPS/H4	^{208}Pb (13, 30, 150 *A*GeV) / Pb target	Type 8 (95x95 cm^2)	SPADIC 1.1, SysCore

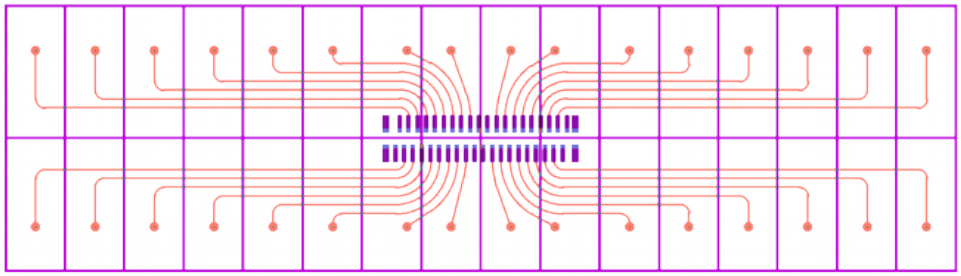
- Scheduled measurements

* triggered

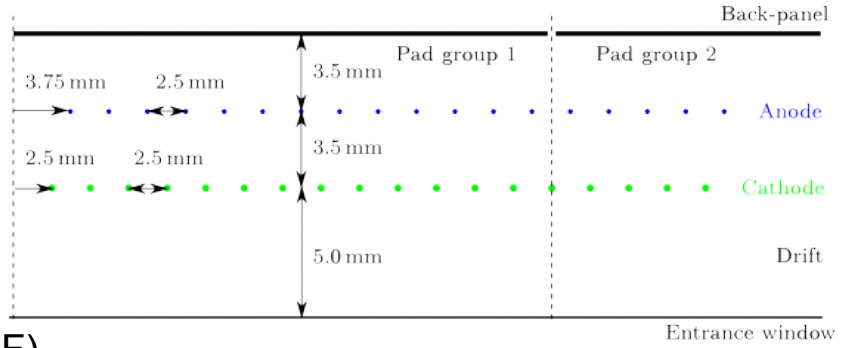
2017	DESY II/TB24	e (variable) / direct	Type 8	SPADIC 2.0, AFCK
2017	CERN-GIF++	γ from ^{137}Cs + μ beam	2012-style	SPADIC 2.0, AFCK

Prototype: 2012-style MWPC for CBM-TRD

- 2012-style prototype:
  - Used areas on pad-plane are each 32 pads in 2 rows
  - Pad sizes: 14 x 7.125 mm^2 and 75 x 7.125 mm^2



- Active volume spacing:
  - 3.5 / 3.5 / 5 mm
  - Nominal 1800 V on anode wires, -500 V on entrance window



- Charge distribution on pad-plane:
  - According to Pad-Response Function (PRF).

Altern. Position of 3-pad cluster:
(hyperbolic secant squared method)

$$d = \frac{a_3}{\pi} \tanh^{-1}\left(\frac{\sqrt{Q_i/Q_{i-1}} - \sqrt{Q_i/Q_{i+1}}}{2\sinh\left((\pi W)/a_3\right)}\right)$$

$$a_3 = \frac{\pi W}{\cosh^{-1}\left(0,5 \cdot \left(\sqrt{Q_i/Q_{i-1}} + \sqrt{Q_i/Q_{i+1}}\right)\right)}$$

$$\mathrm{PRF}(d/h) = \int_{d/h-W/2}^{d/h+W/2} \rho(d'/h)\; d(d'/h)\; \mathrm{d}d'$$

$$\Rightarrow \mathrm{PRF}(d/h) = -\frac{\arctan\left(\sqrt{K_3}\tanh\left(\pi\left(\sqrt{K_3}-2\right)\cdot\frac{W-2\cdot d}{8\cdot h}\right)\right)}{2\arctan\left(\sqrt{K_3}\right)} - \frac{\arctan\left(\sqrt{K_3}\tanh\left(\pi\left(\sqrt{K_3}-2\right)\cdot\frac{W+2\cdot d}{8\cdot h}\right)\right)}{2\arctan\left(\sqrt{K_3}\right)}$$

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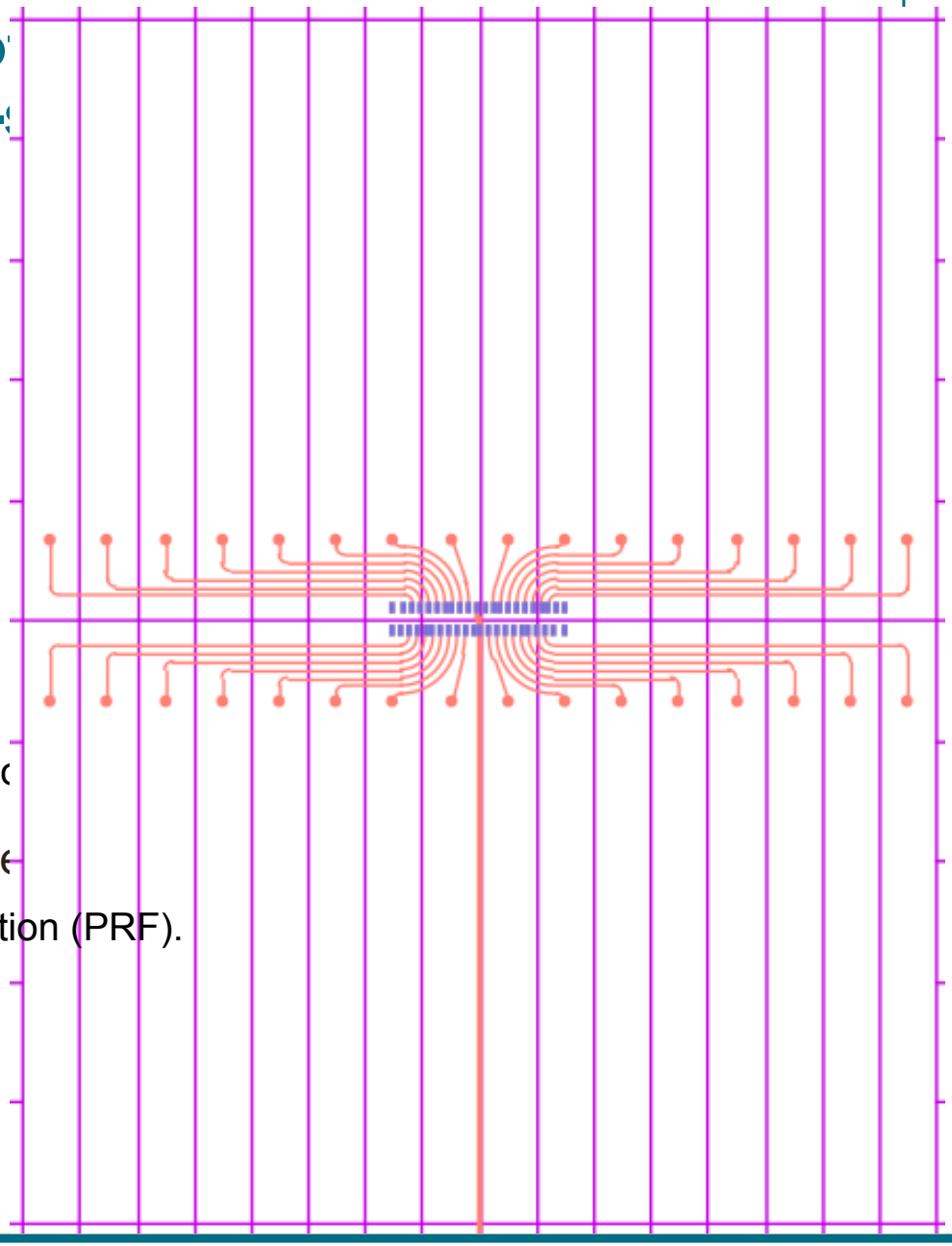
Proto
2012-



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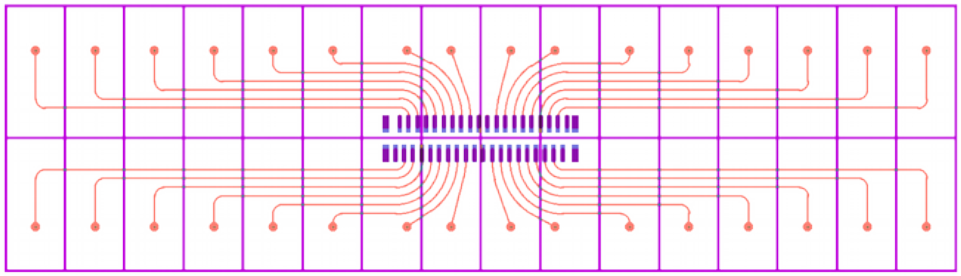

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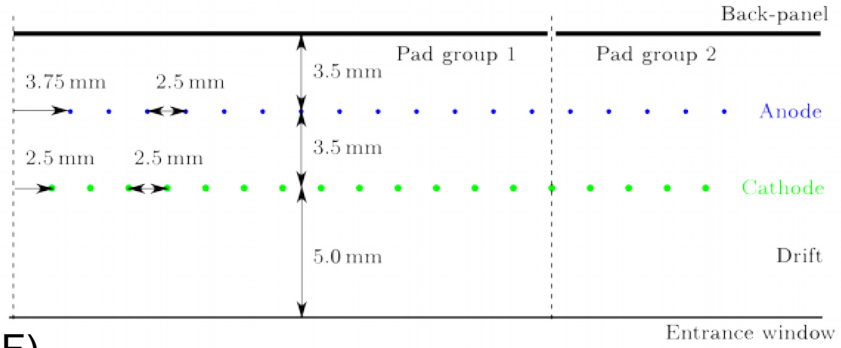

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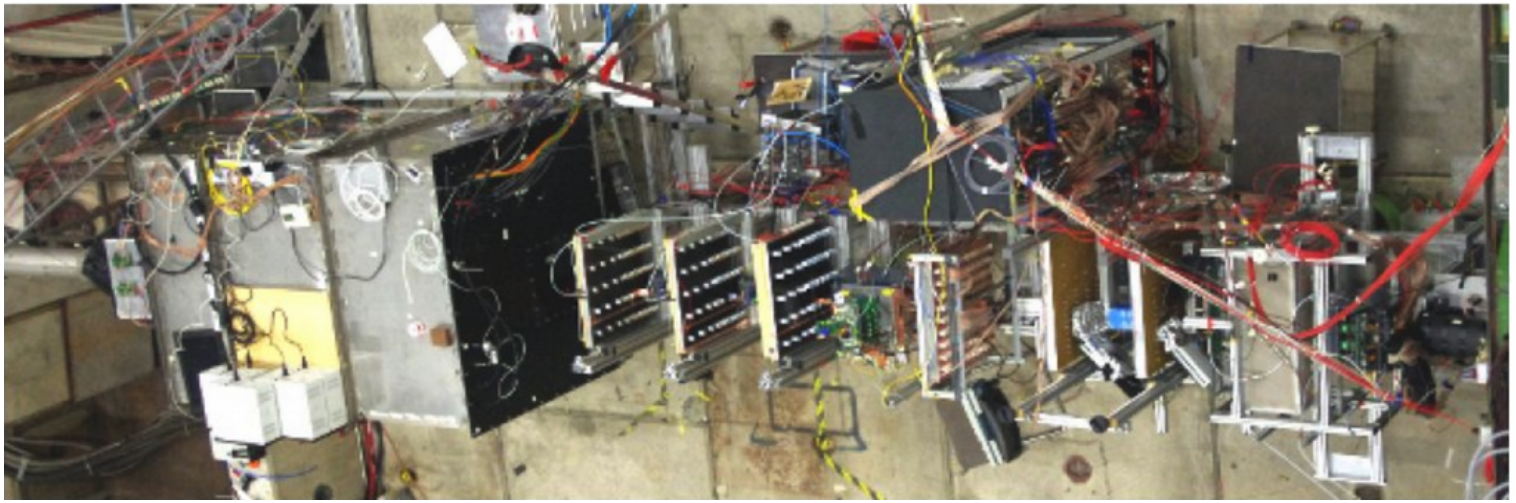
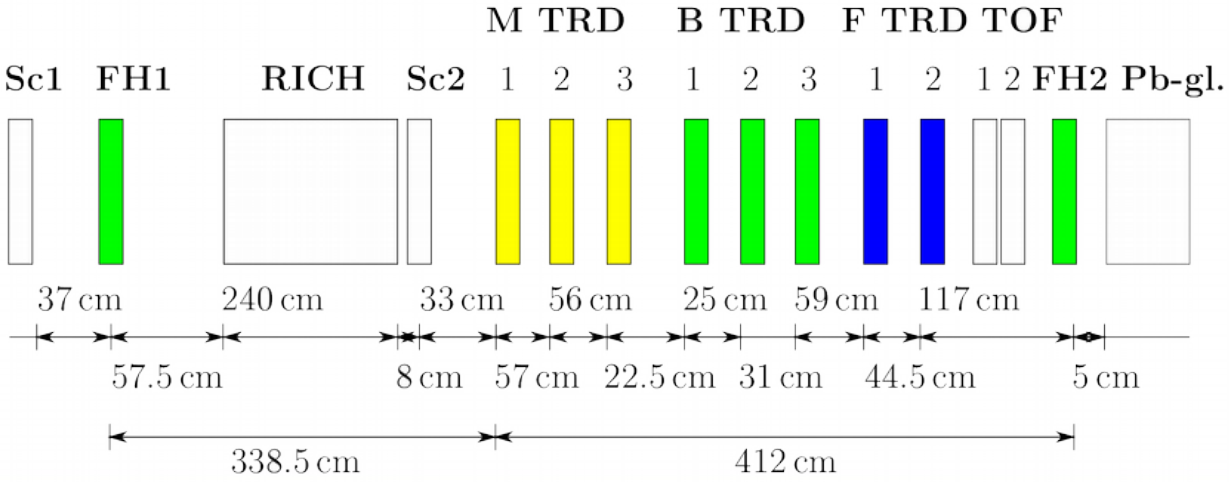
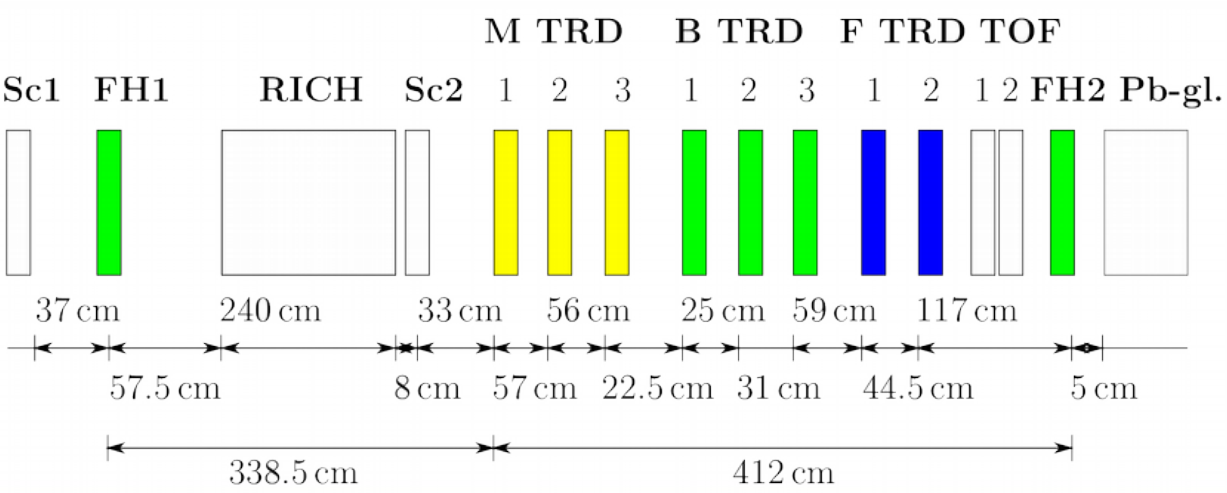
CERN-PS 2012 Campaign: Position Resolution





CERN-PS 2012 Campaign: Position Resolution

- CERN-PS/T9
- Mixed e, μ, π beam
  with particle momenta between 1 and 10 GeV
- Read-out with SPADIC 0.3 Rev3 and SUSIBO
- Triggered using the fibre hodoscopes
- Test radiators mounted also on MWPC used here
- Xenon/CO_2

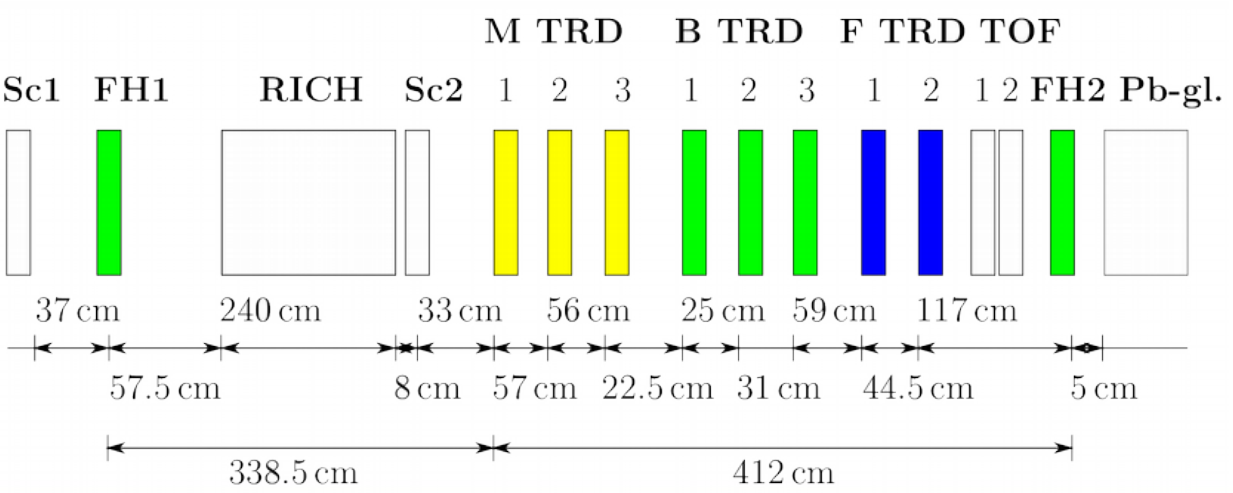


CERN-PS 2012 Campaign: Position Resolution

- Small-angle scattering assumed following Highland-Lynch-Dahl with Gaussian distribution for e, μ, π beam (1:1:1)

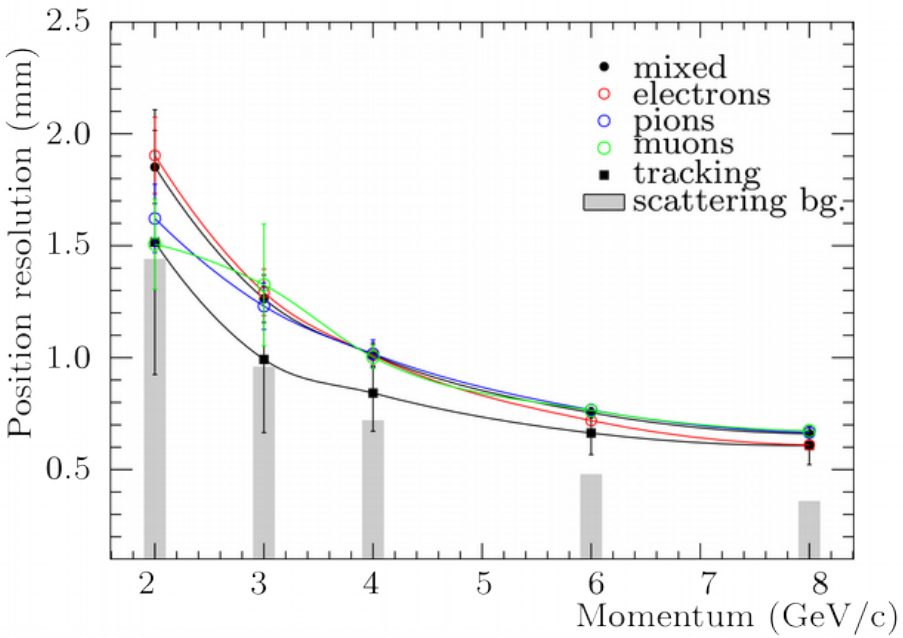
$$\theta_{proj}^{rms} = \frac{13.6\,\mathrm{MeV}}{\beta pc} z \sqrt{\frac{X}{X_0}} \left[1 + 0.038 \ln\left(\frac{X}{X_0}\right)\right]$$

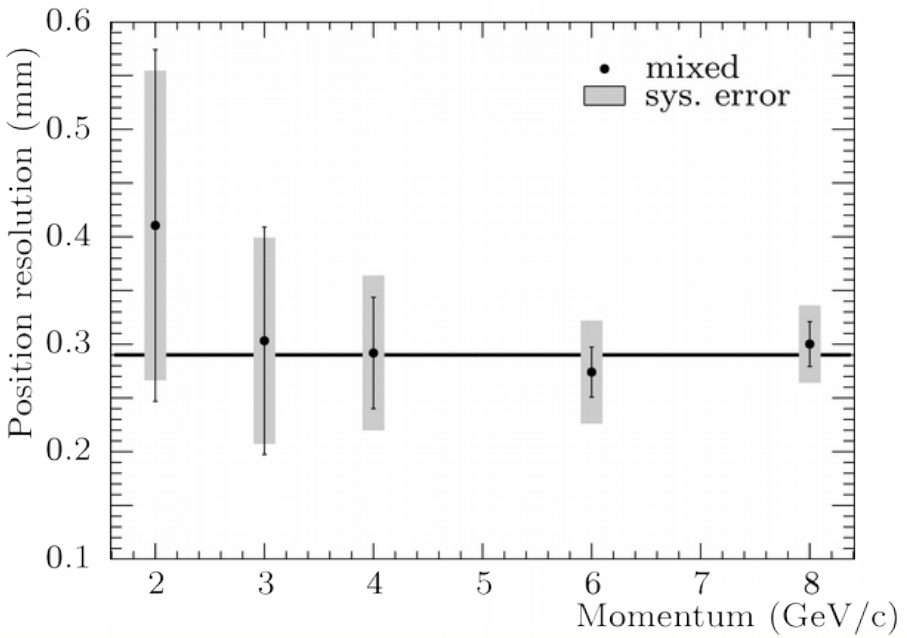
- **Material budget:** Scintillators (X/X_0 = 2x 3.0%), Fibre hodoscope 1 (X/X_0 = 2.0%), RICH 2 mm PMMA (X/X_0 = 2x 0.58%) and SIMAX (X/X_0 = 5.1%), TRD M1 (X/X_0 = 1.54%), Radiators (X/X_0 = 1.5% and 3.1%) – simulated each at the known position



CERN-PS 2012 Campaign: Position Resolution

- Misalignment compensation for parallel displacement along wire direction & rotation of the chambers
- Position determined by pad-response function fit
- Resolution as Gaussian fit to residual distributions: positions from detectors // checked by lin. tracks between hodoscopes





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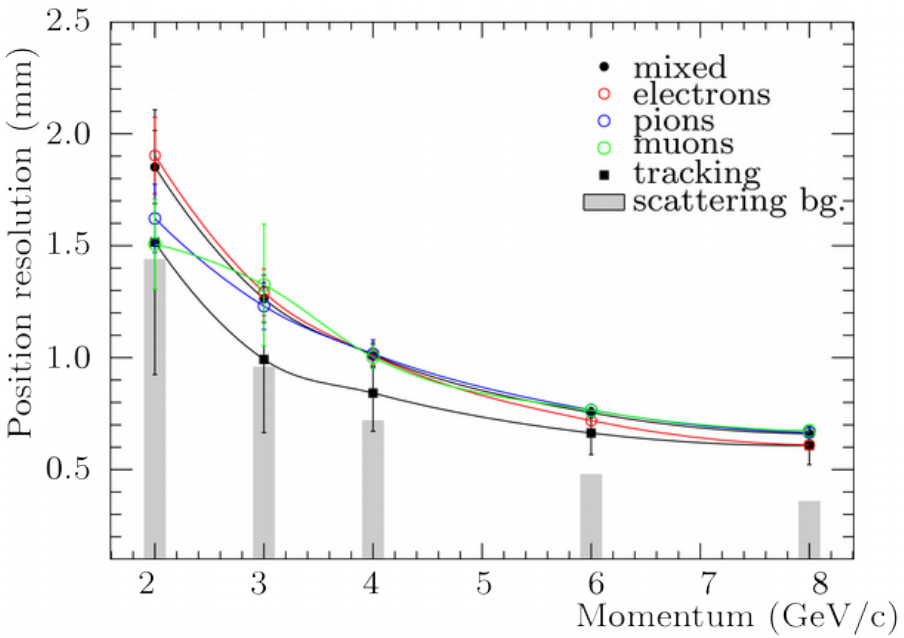
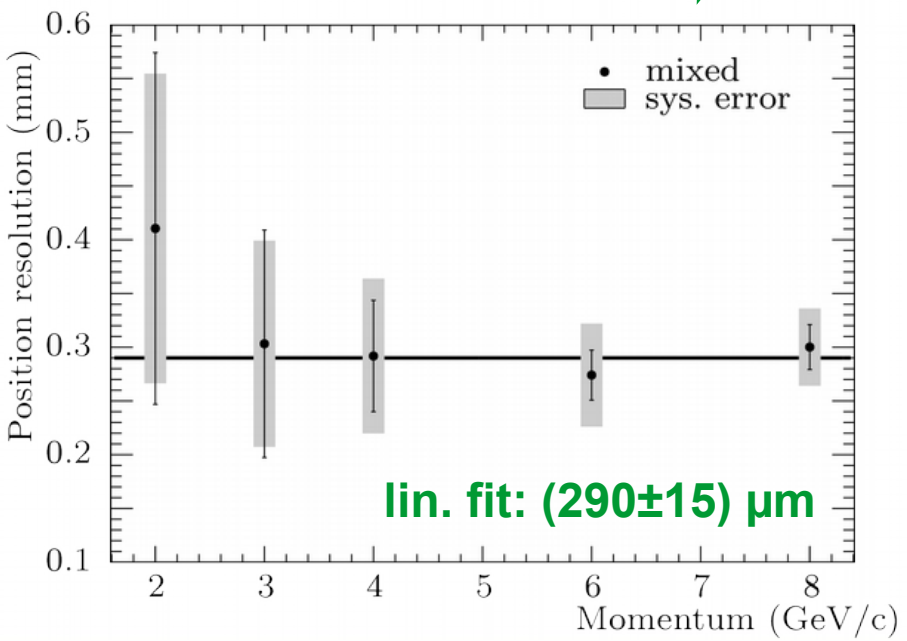
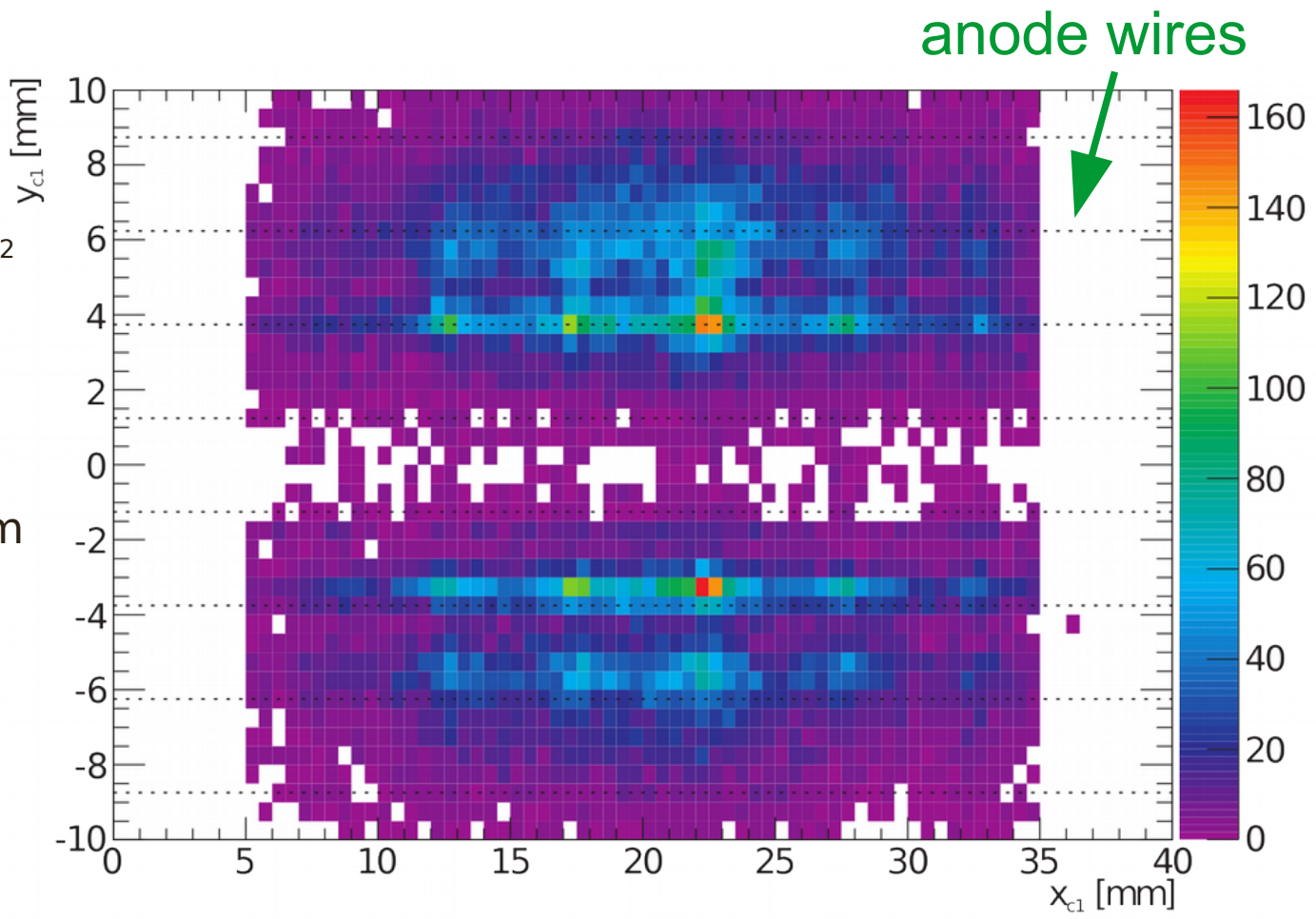
after scattering compensation



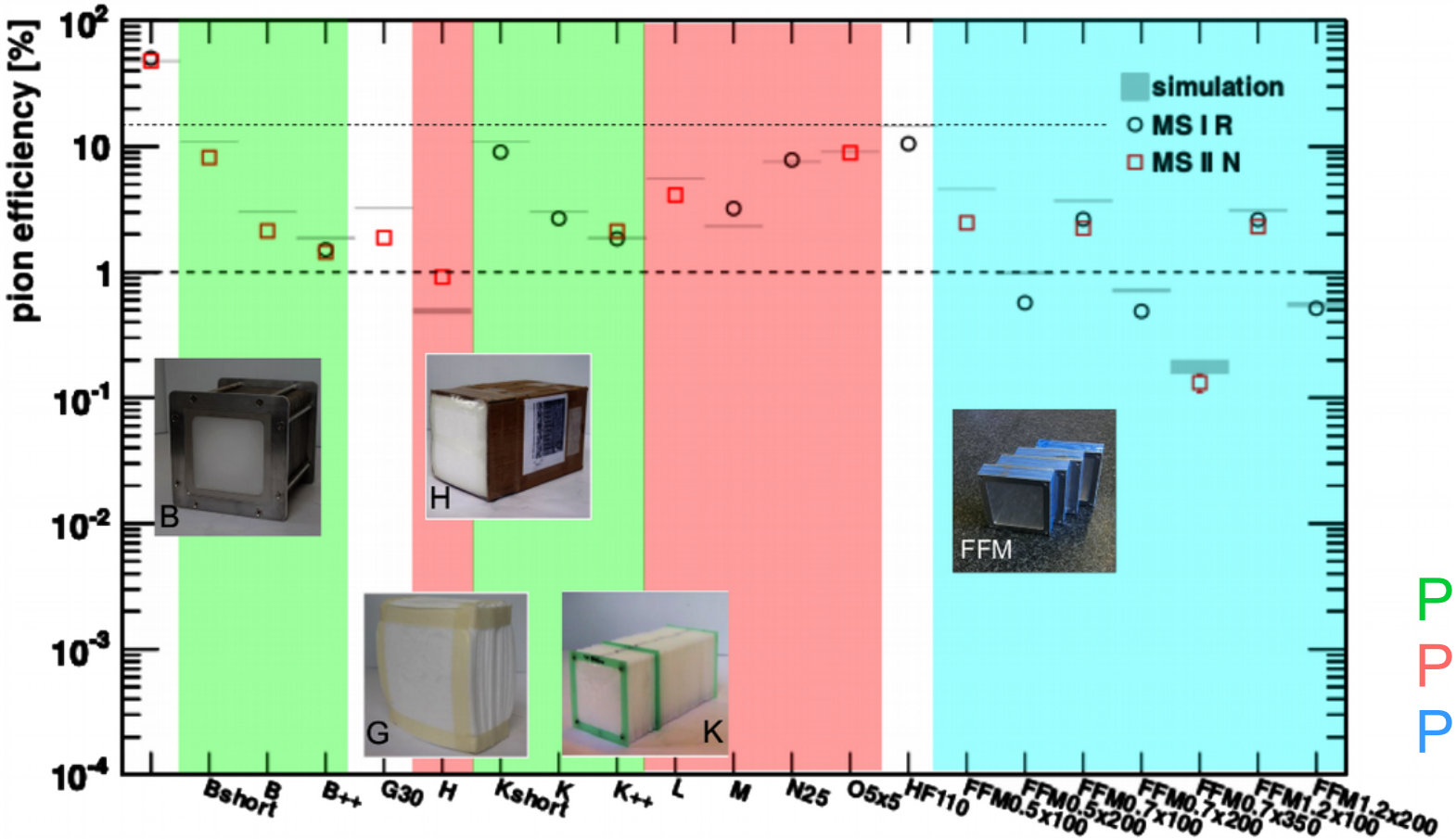


GSI-SIS18 2006 Campaign: 2-Dim. Position Reconstruction

- Data from SIS18, test beam 2006
- Dual-sided MWPC, pad size 5 x 10 mm^2 ($Xenon/CO_2$)
- Protons, positrons (2 GeV), direct beam
- Gaussian fit for *y*-position reconstr.
- Wire spacing: 2.5 mm



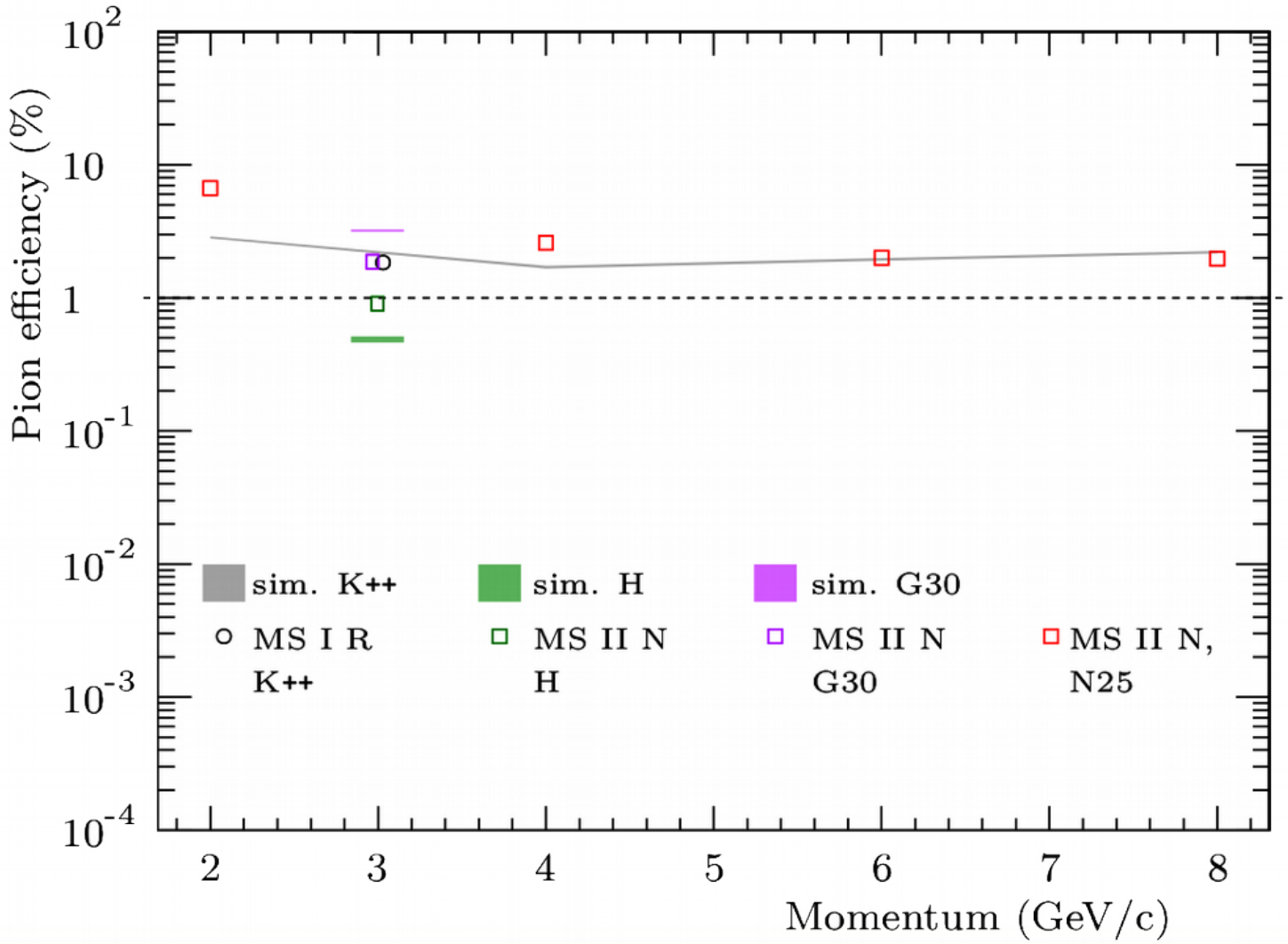
CERN-PS 2012 Campaign: Particle Identification



Pokalon
PE foam
PE foil

- Approximated pion efficiency with 4 detector hits per track (@ 90% electron efficiency)

CERN-PS 2012 Campaign: Particle Identification



CERN-SPS 2015 Campaign: Pad-Response Function

- CERN-SPS/H4
- Pb beam with 30 *A*Gev on Pb target, detectors exposed to secondaries
- Read-out with SPADIC 1.0 and SysCore 3.1
- Self-triggered and free-streaming
- Trigger rates of the order of 10^5 Hz/cm^2

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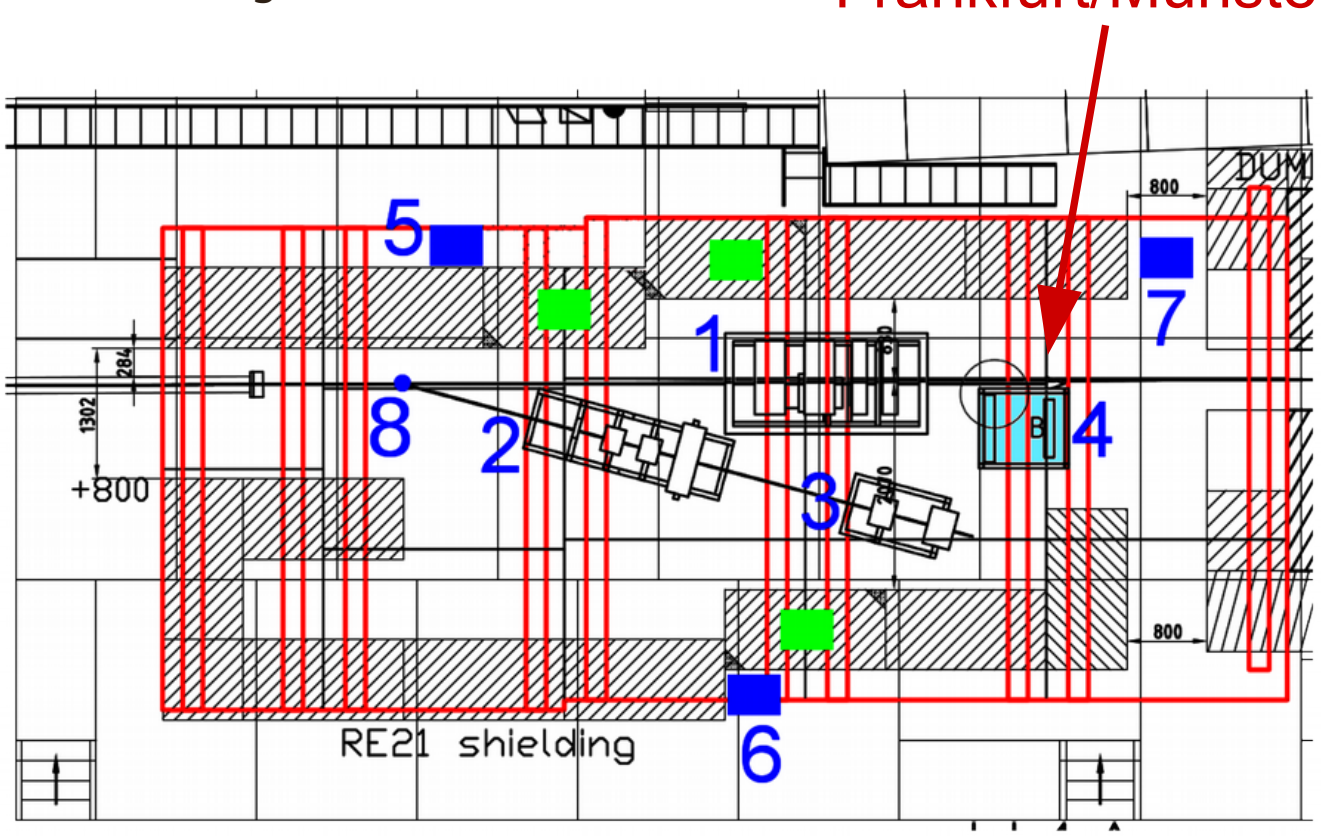

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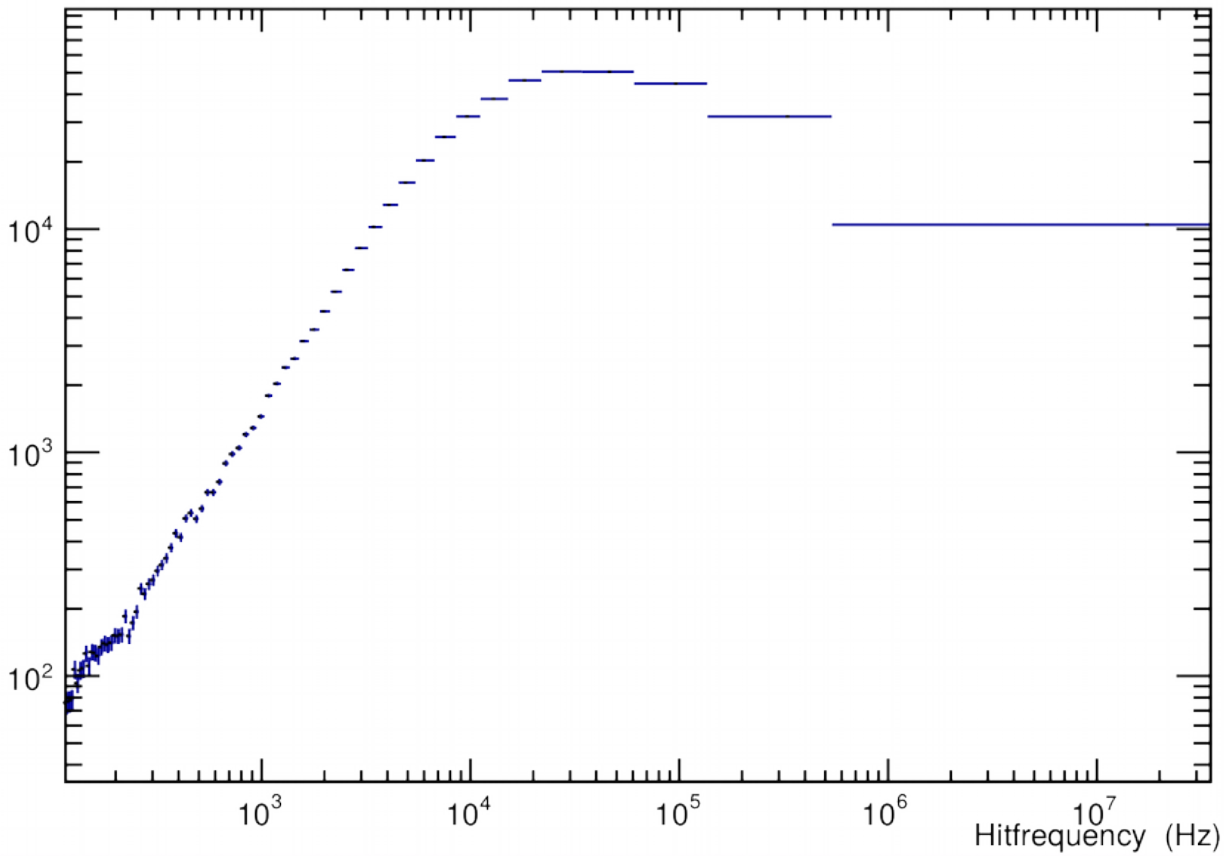

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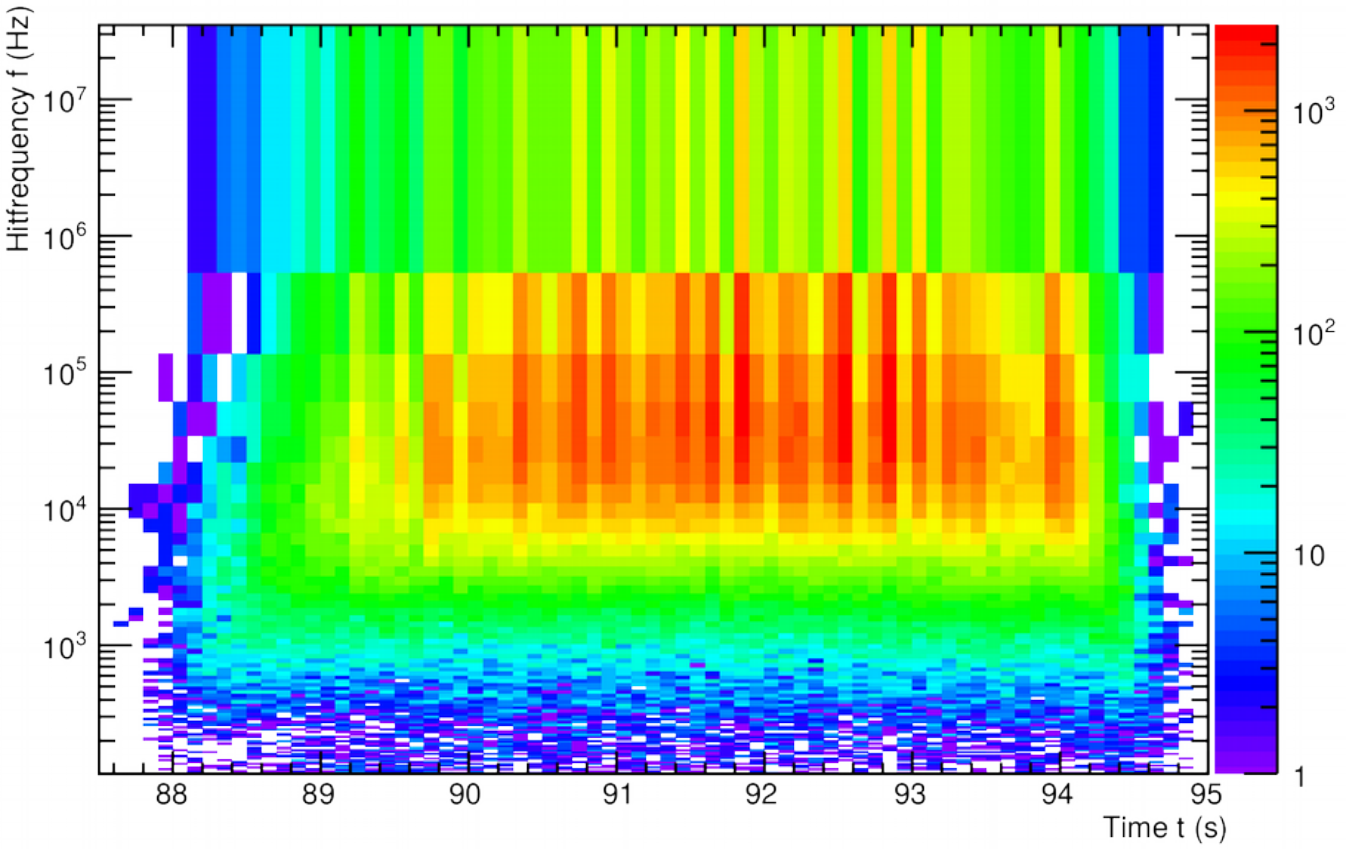
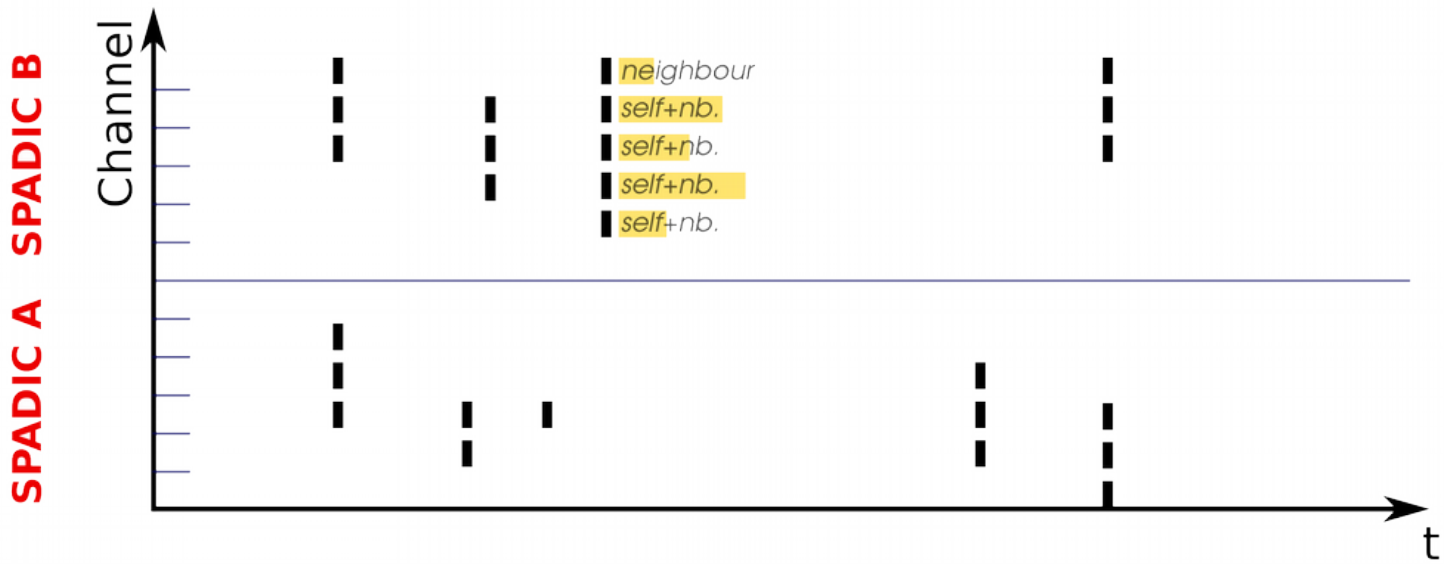
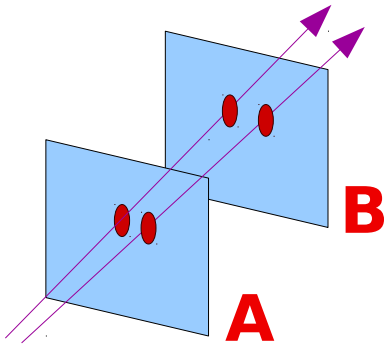


CERN-SPS 2015 Campaign: Pad-Response Function

- Offline event-building
  by reconstruction of charge-clusters
  from single hit messages

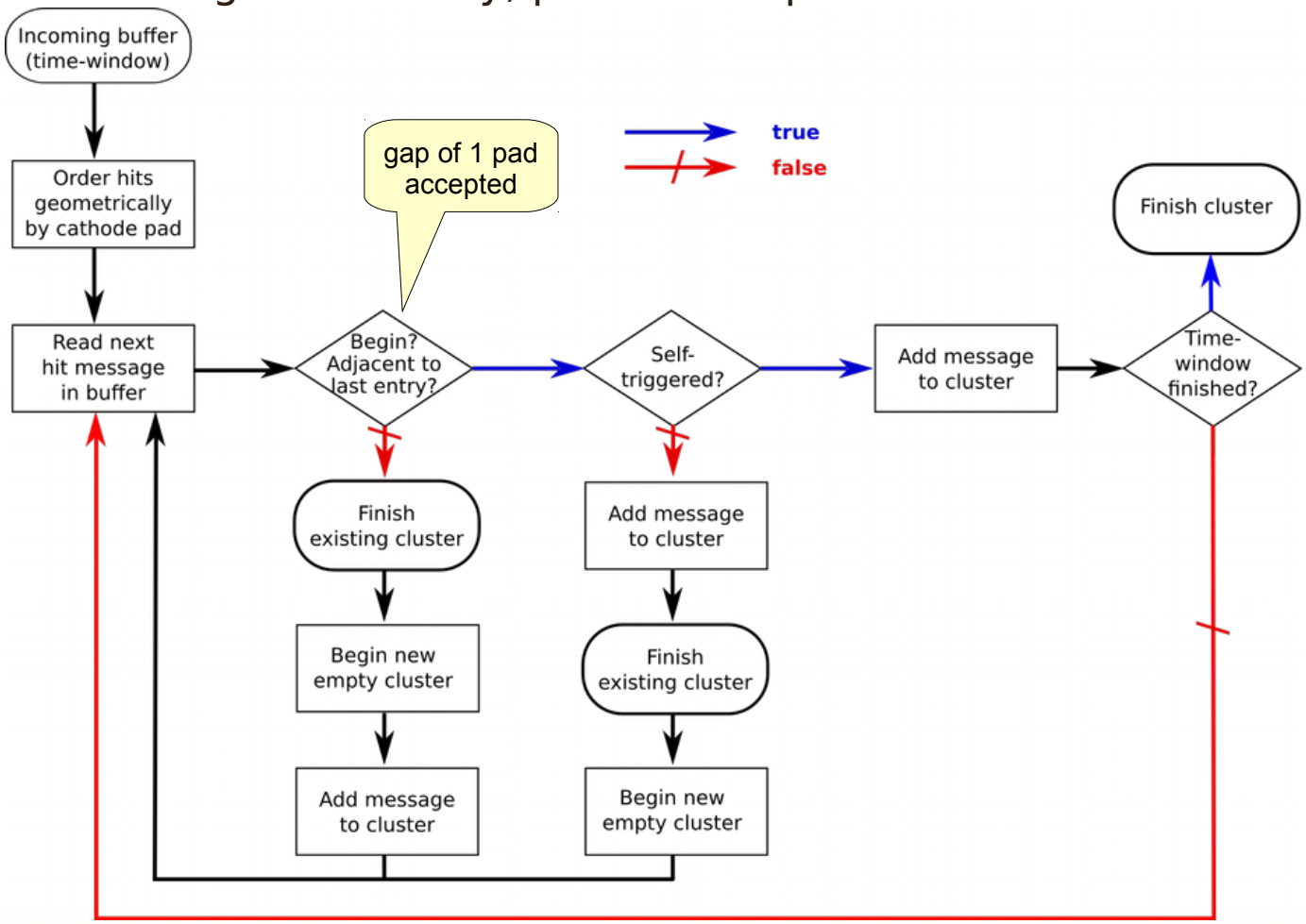




- Therefore, first: free-streamed hits to be sorted wrt. time
  (1 timestamp = 57 ns)

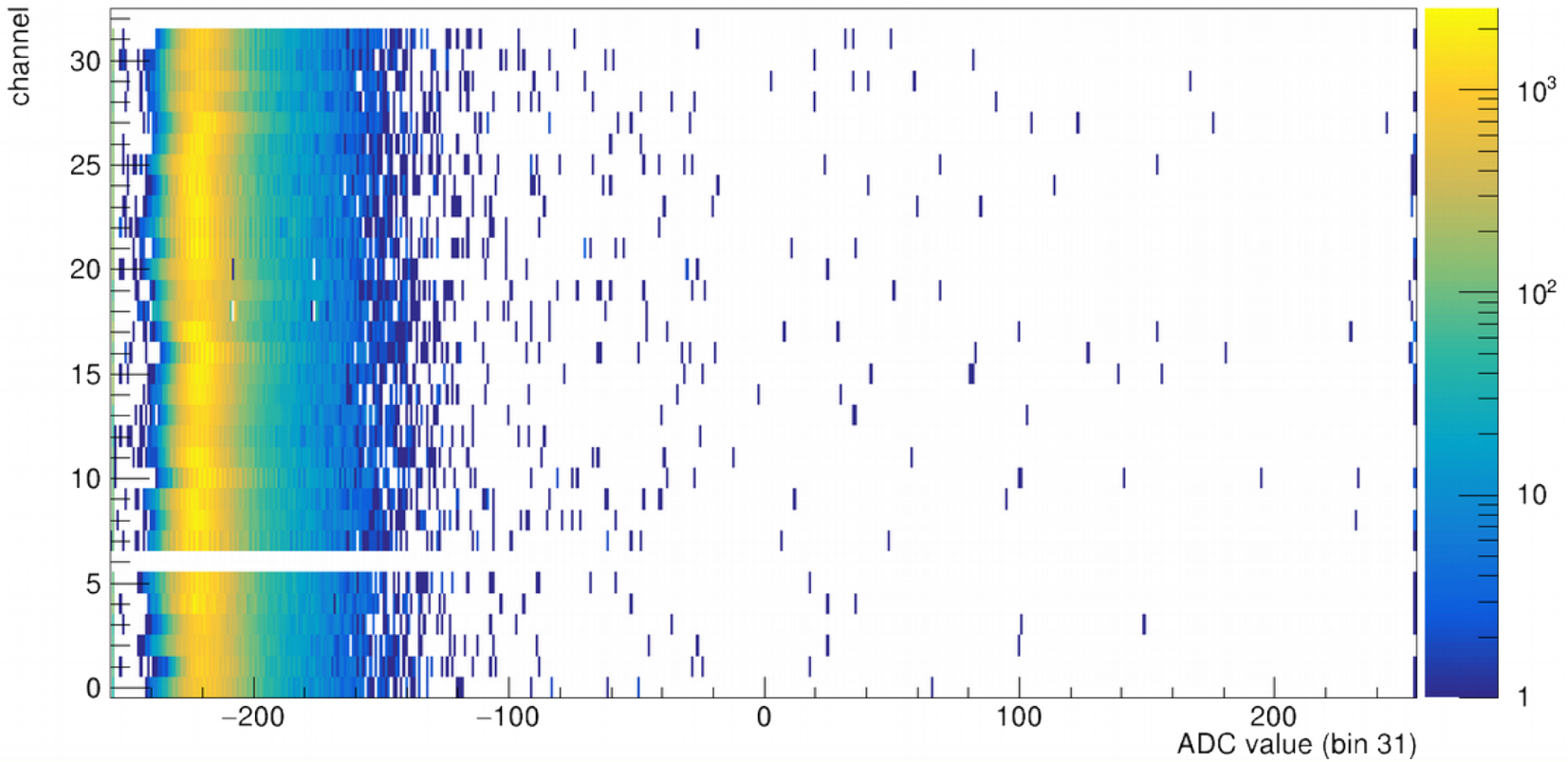
CERN-SPS 2015 Campaign: Pad-Response Function

- Second: order hits geometrically, process in spatial clusteriser



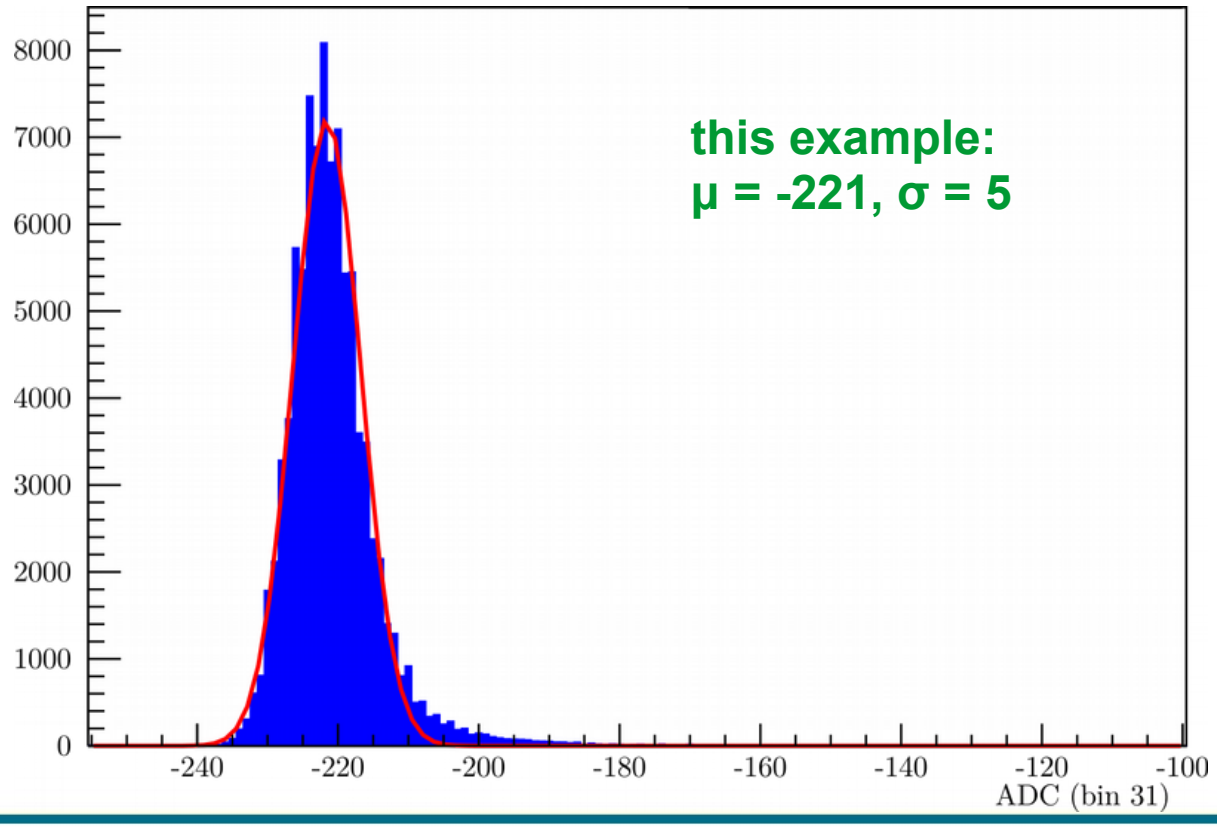
CERN-SPS 2015 Campaign: Pad-Response Function

- Determination of a channel-wise baseline
  - Use ADC value of last timebin from all complete, self-triggered hit messages
  - Collect this baseline distribution separately for every channel



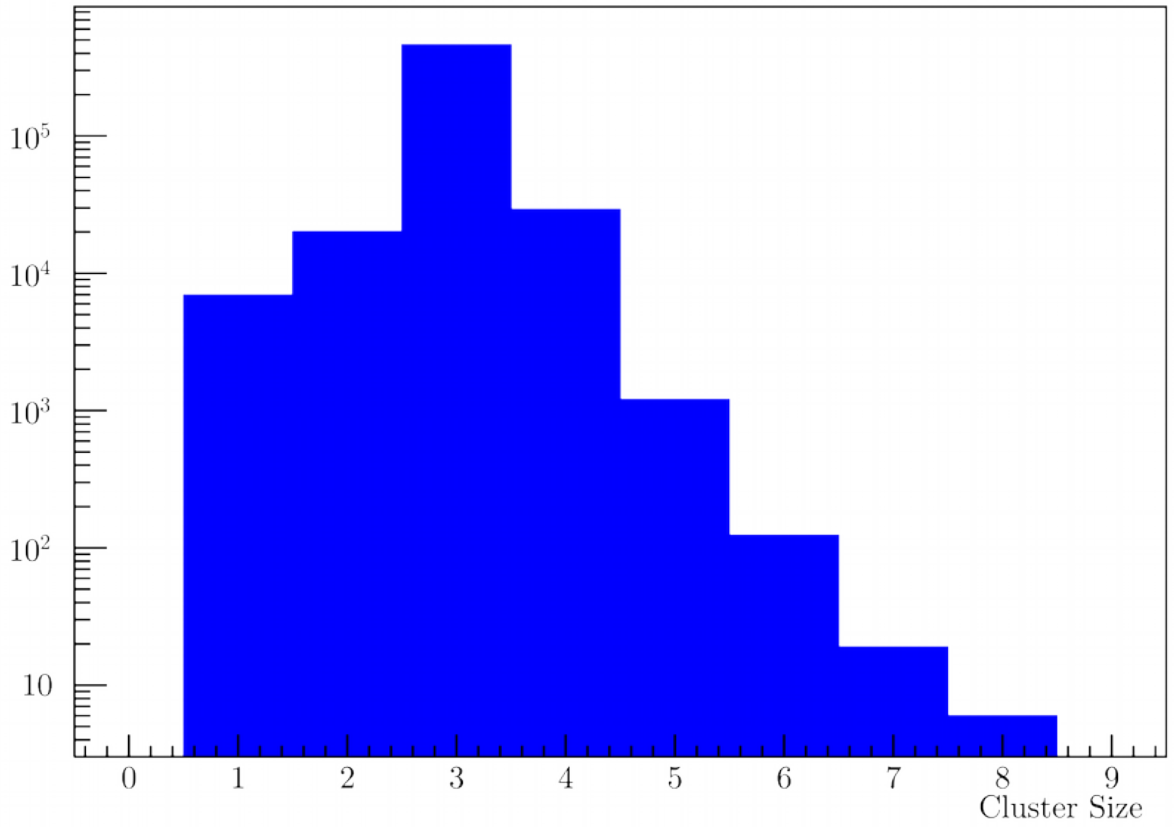
CERN-SPS 2015 Campaign: Pad-Response Function

- Determination of a channel-wise baseline
  - Use ADC value of last timebin from all complete, self-triggered hit messages
  - Extract baseline value for each channel by Gaussian fit



CERN-SPS 2015 Campaign: Pad-Response Function

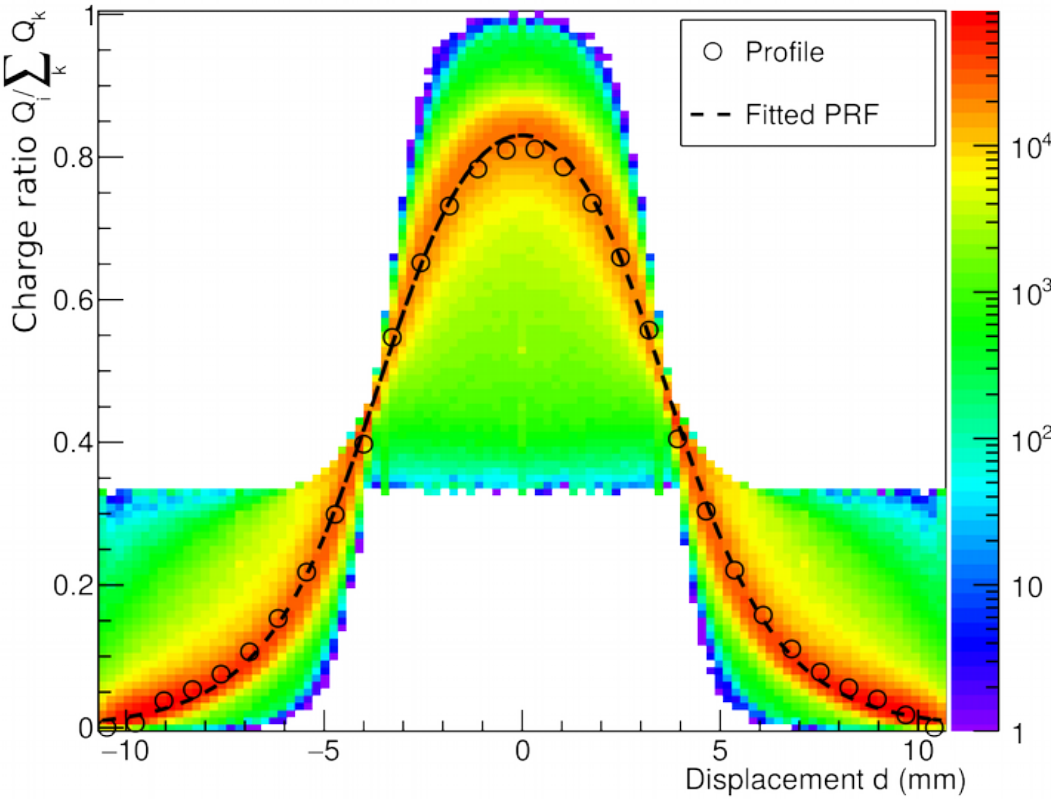
- Distribution of cluster sizes:



- Following: analysis of 3-pad clusters

CERN-SPS 2015 Campaign: Pad-Response Function

- Resulting Pad-Response Function from 3-pad clusters, type 0:



- From fitting: $K_3 = 0.388 \pm 0.008$ (expectation for this geometry: 0.38)

Outlook 1: CERN-SPS 2016 Campaign

- Successfully operated four type 8 chambers (95x95 cm)
- Operated multi-SPADIC setup, developed live-monitoring
- SPADIC 1.1 read-out: 48 x 2 pads p. chamber, 4 chambers projective on target (tracking)
- SPADIC 2.0 + AFCK commissioned

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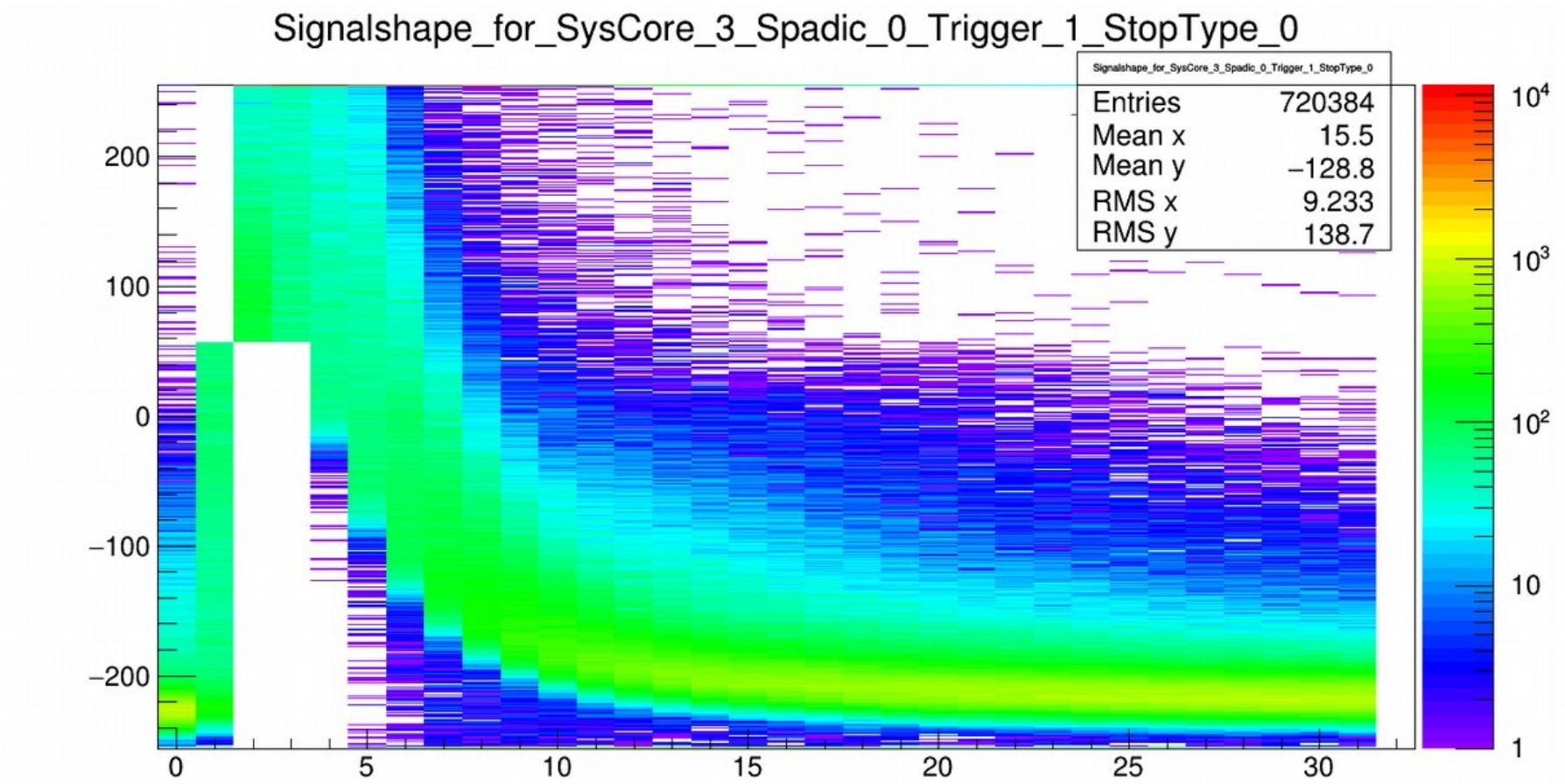

Outlook 2: DESY and GIF++

- DESY: Effiency and energy loss spectrum with electrons

  Radiators for full-size prototypes in preparation

- GIF++: High-rate environment (design rate of 100 kHz/cm²) and μ beam

  GEANT simulations in preparation

  Reference detector (Scintillator + PMT) currently in integration

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Conclusions

- Low-rate, mixed beam:
  - Position resolution of TRD prototype determined: (290±15) µm
  - Pion efficiency confirmed with preferred radiator
  - 2-dimensional position reconstruction demonstrated
- High-rate, secondaries behind fixed-target:
  - Charge distribution in chamber verified to follow the expected behaviour (Mathieson description)
- Read-out:
  - Gained experience in free-streaming, self-triggered SPADIC DAQ operation
- Thanks to all group members for the collaboration, support and discussions!

BACKUP

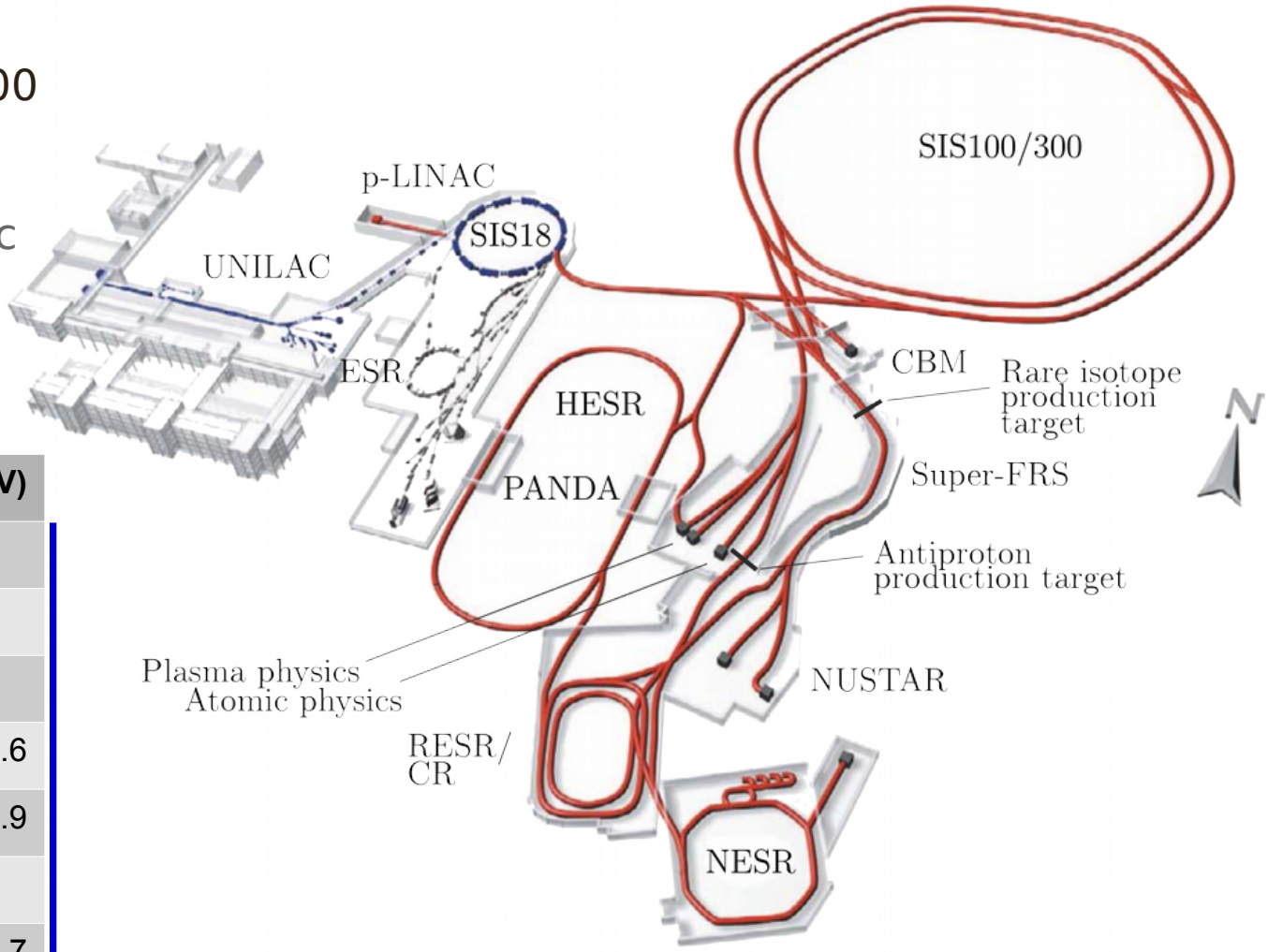
Westfälische Wilhelms-Universität Münster

The CBM-TRD in FAIR

- In construction: SIS100 (magnetic rigidity of 100 Tm)
- **C**ompressed **B**aryonic **M**atter as one of the four pillars of FAIR
- Upgradeable: SIS300

beam	Z	A	E (AGeV)
p	1	1	29
d	1	2	14
Ca	20	40	14
Ni	28	58	13.6
In	49	115	11.9
Au	79	197	11
U	92	238	10.7

SIS100 energies



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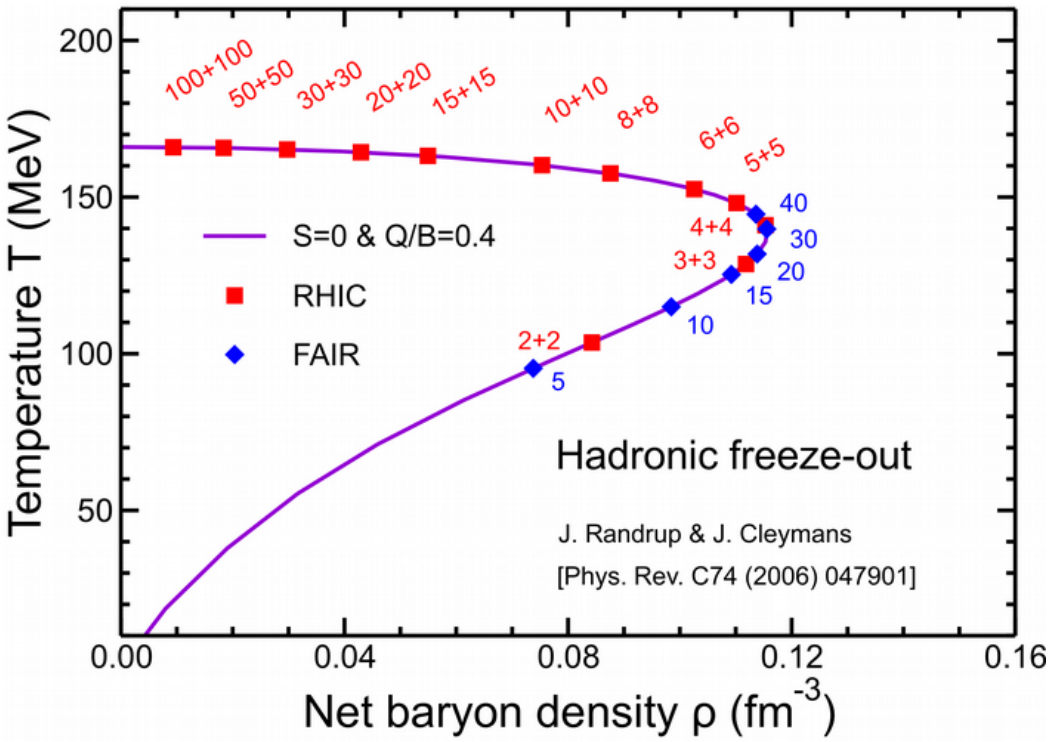

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The CBM-TRD in FAIR

- Physics objectives
  - Intermediate mass di-leptons … continuum from thermal sources (1…3 GeV)
  - Fragments … hyper- and anti-nuclei
  - Quarkonia … are probes for deconfined matter
  - Low mass vector mesons … medium-modified spectra
  - Direct Photons … inverse slope fits as thermometer
- Design considerations
  - Pion rejection capability … pion suppression up to 50 and 10^4 with RICH
  - (Charged) Particle identification … dE/dx resolution below 30%
  - Tracking capabilities … track resolution below 300 µm (pad granularity)
  - High interaction rates … optimised: 5 x 10^6 Hz & realistic multiplicities
  - Tracking of muons … high track matching with the MUCH

The CBM-TRD in FAIR

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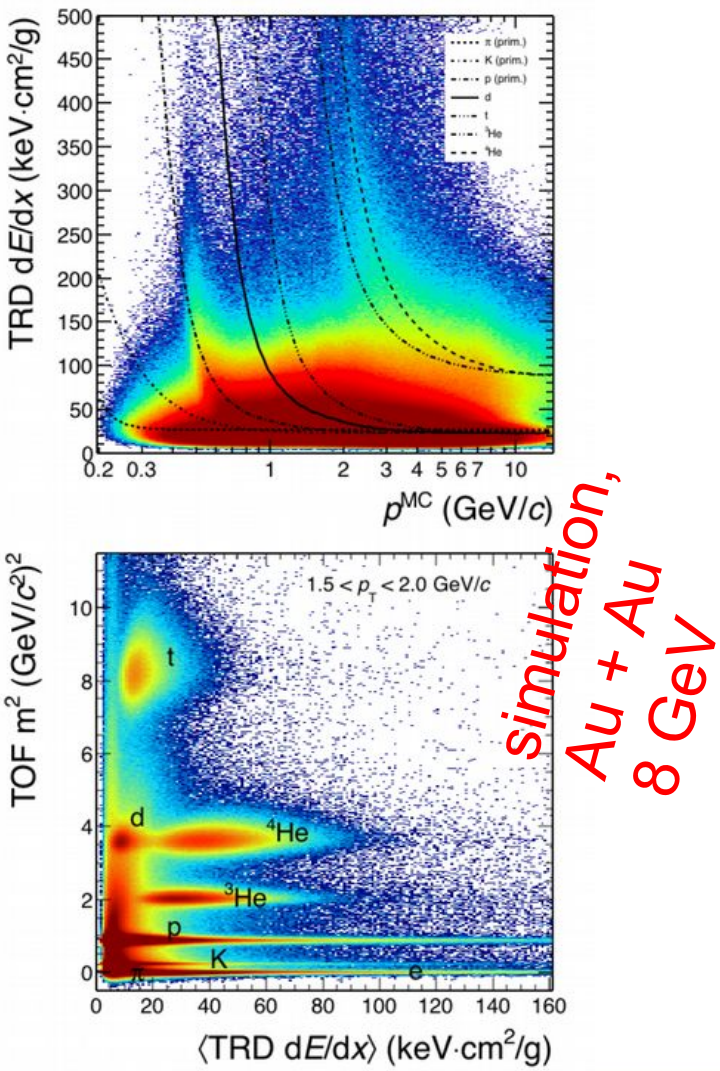
  - Tracking capabilities
  - High interaction rates
  - Tracking of muons

$^{\Lambda\Lambda}_{}{}^{6}\mathrm{He} \rightarrow {}^{\Lambda}_{}{}^{5}\mathrm{He} + p + \pi^-$

$^{\Lambda}_{}{}^{5}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + p + \pi^-$

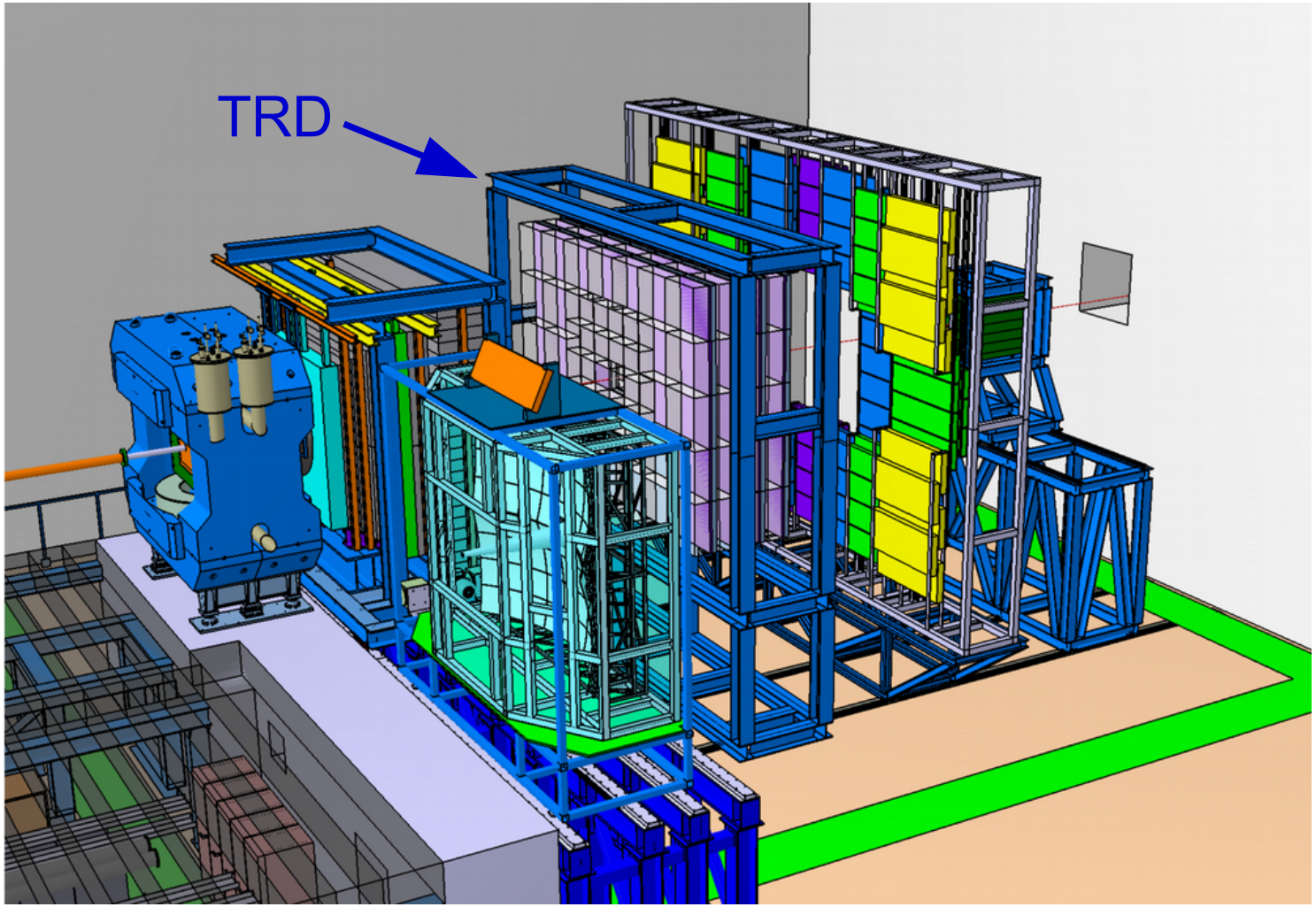
or

$^{\Lambda}_{}{}^{3}\mathrm{He} \rightarrow d + p + \pi^-$



The CBM-TRD in FAIR

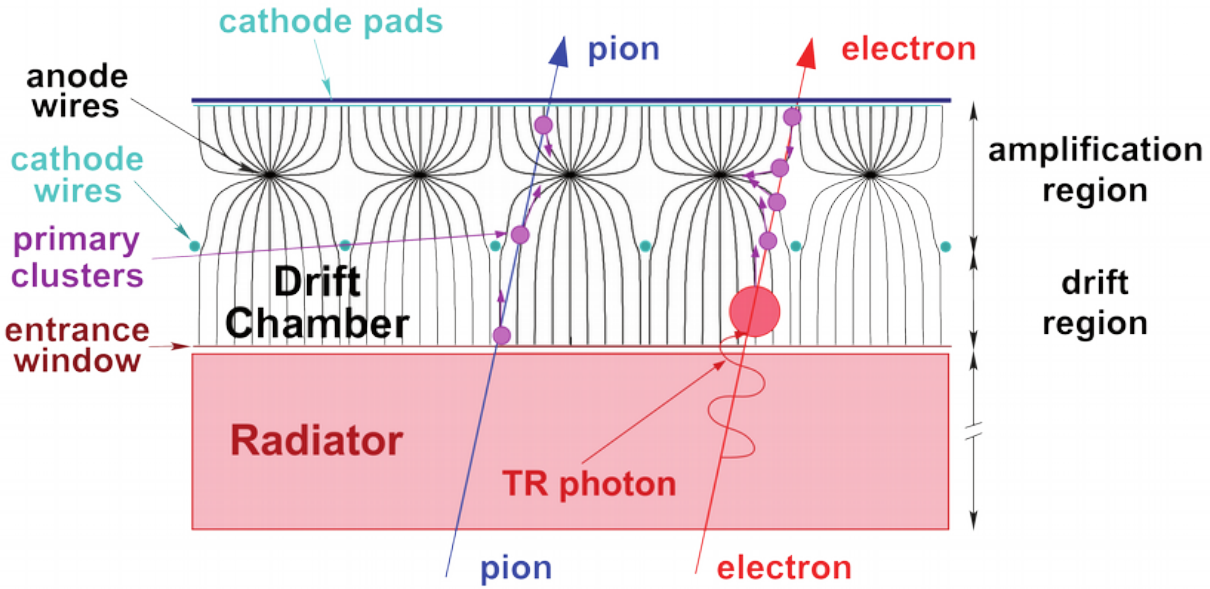
- MVD+STS
  Micro-Vertex Detector + Silicon Tracking Station
  magnetic field
- MUCH or RICH
  MuonChambers/ Ring imaging Cherenkov Detector
- TRD
  Transition Radiation Detector
- TOF
  Time Of Flight
- PSD
  Projectile Spectator Detector

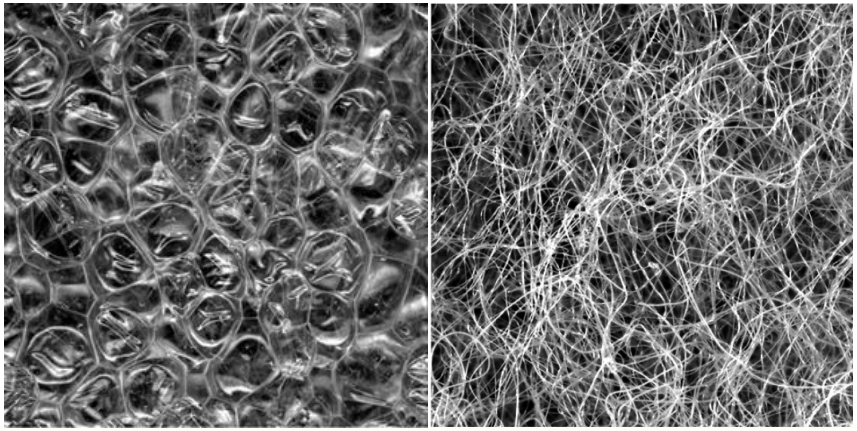


The TRD in CBM

Westfälische Wilhelms-Universität Münster

- TRD in principle:
  - Multi-wire proportional chamber-based
  - Transition radiation emitted at ε-transitions
  - Intensity of TR is ~ γ (idealised)
  - e/π-sep. e.g. by likelihood
- Regular and irregular radiators: foil, foam, fibers





Transition radiation at <u>one</u> ε-interface:

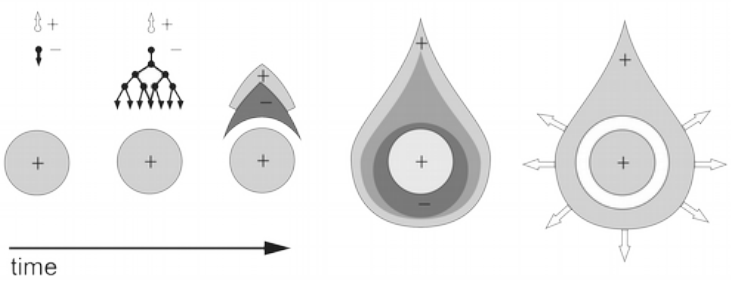
$$\left(\frac{\mathrm{d}^2 N}{\mathrm{d}\,\omega\,\mathrm{d}\,\vartheta}\right)_{\text{interface}} = \frac{\alpha}{\pi}\cdot\left(\frac{\vartheta}{\gamma^{-2}+\vartheta^2+\left(\omega_{P,1}/\ \omega\right)^2}-\frac{\vartheta}{\gamma^{-2}+\vartheta^2+\left(\omega_{P,2}/\ \omega\right)^2}\right)^2$$

ω: photon frequency
$\omega_{P,i}$: plasma frequency of material i
α: fine structur constant
ϑ: emission wrt. particle motion
γ: Lorentz factor

The TRD in CBM

Design principles

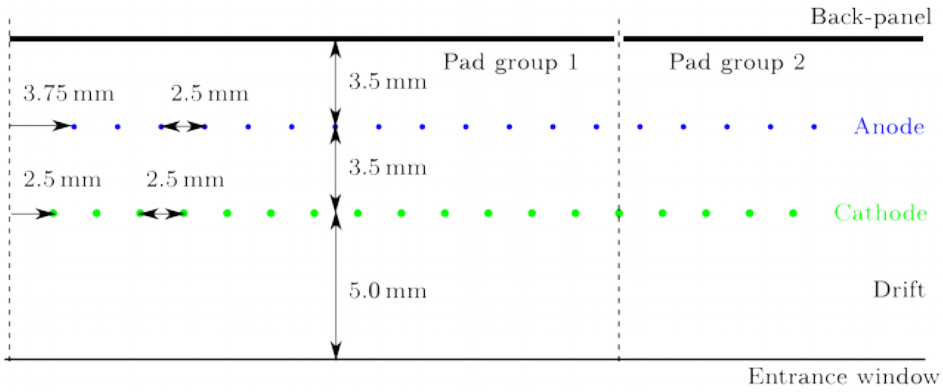
- High-voltage wire geometry: drift zone + two symmetrical amplication zones
- Proportional chamber: rate limits



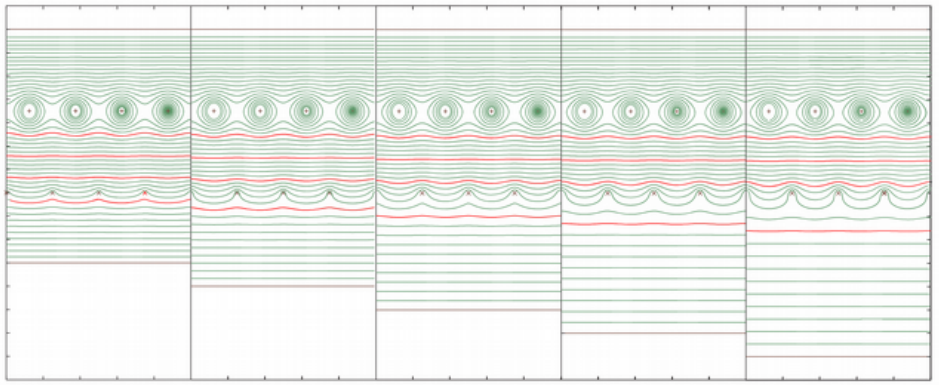
from F. Sauli, CERN lectures 1977

→ short ion drifts (3.5+5 mm)

- Special conditions: flexible cathode (entrance window)



Anode+Drift HV geometry

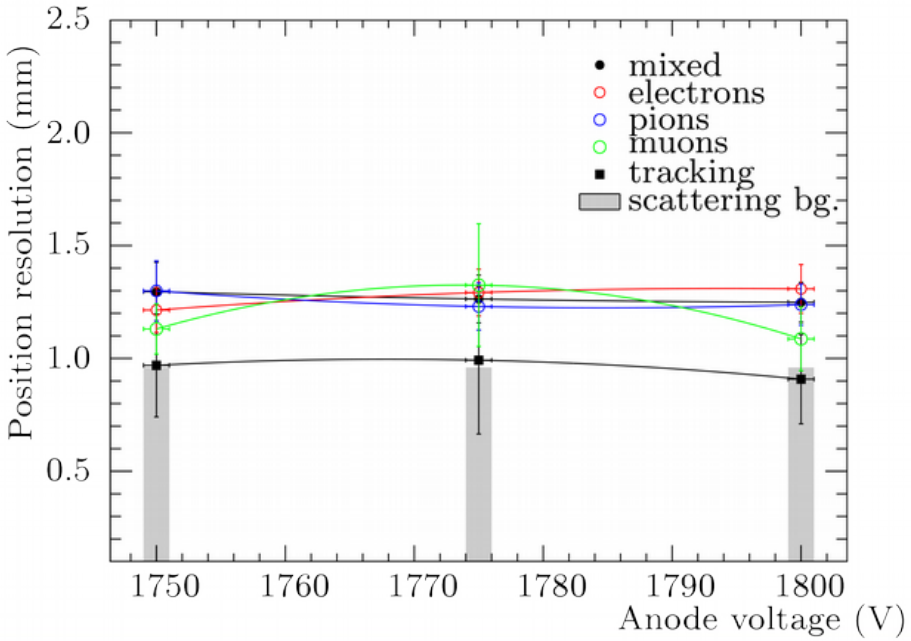


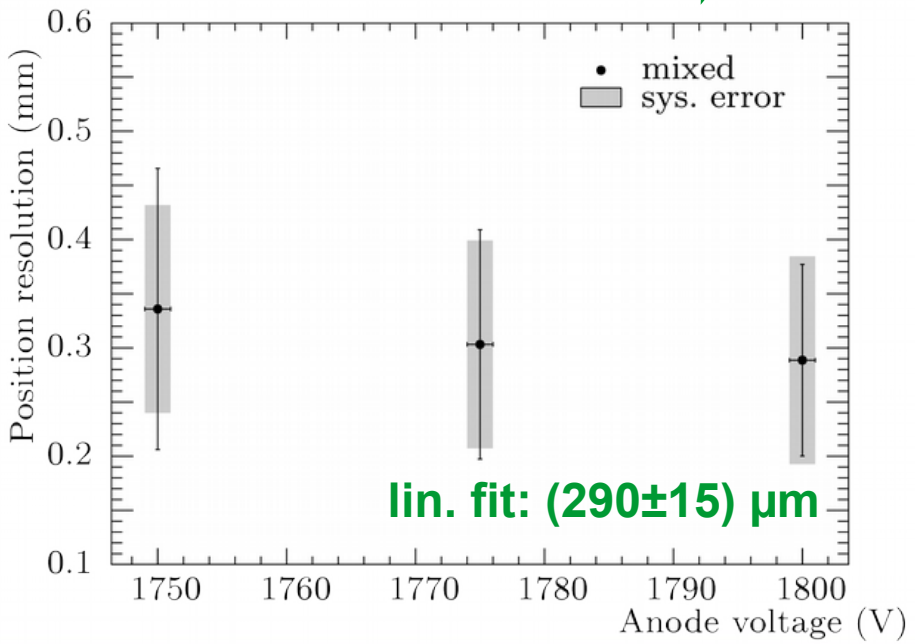
Example: Field distortion by entrance window stretching (Garfield sim.)

CERN-PS 2012 Campaign: Position Resolution

- Misalignment compensation for parallel displacement along wire direction & rotation of the chambers
- Position determined by pad-response function fit
- Resolution as Gaussian fit to residual distributions: positions from detectors // checked by lin. tracks between hodoscopes

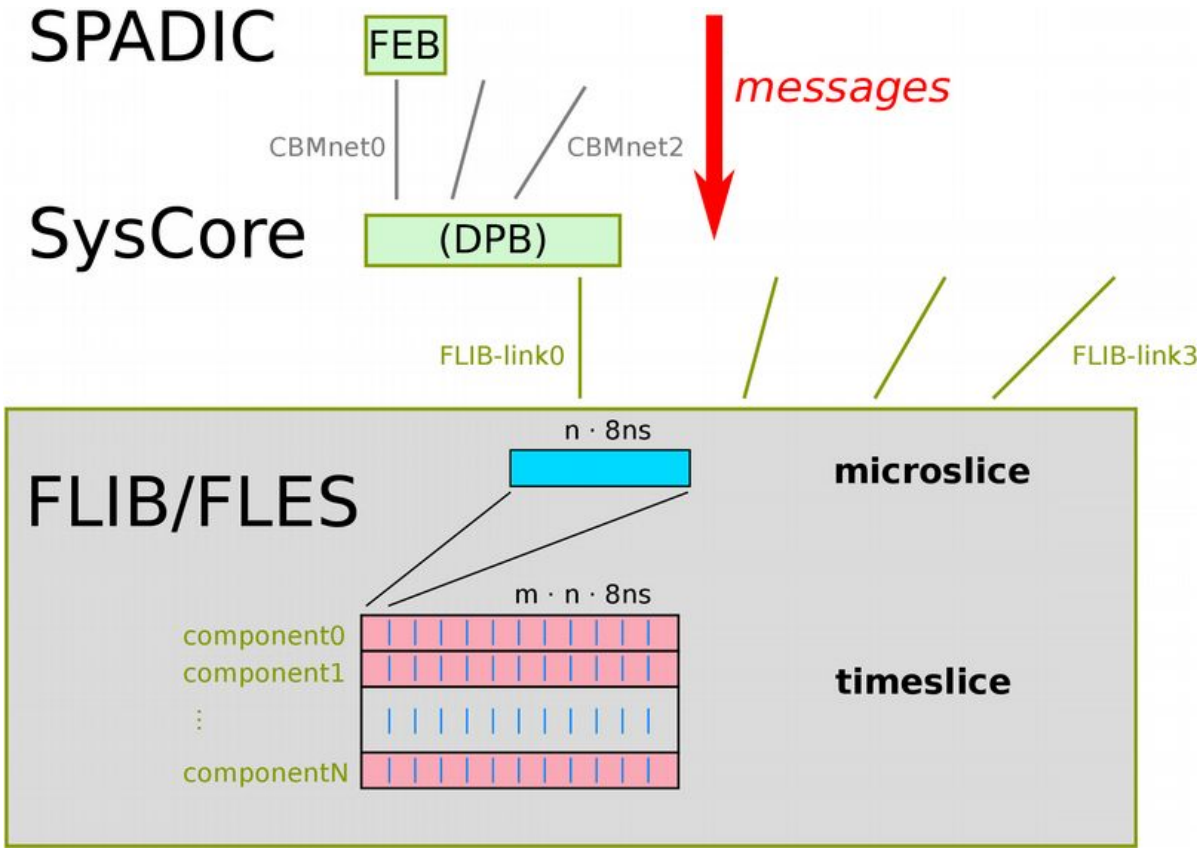
after scattering compensation





CERN-SPS 2015 Campaign: DAQ Chain

- Principle allows various microslice sources
- Ringbuffers minimize memory consumption, maximize throughput



CERN-SPS 2015 Campaign: DAQ Chain

free-streaming data recording

SPADIC

DPB

CLOCK

timestamp (12 bit) 57 ns x 4096 = 234 µs
overflows in
epoch (12 bit) x 4096 = 959 ms

FLIB/FLES

Storage

Towards event-building:

- The unpacker *extracts SPADIC messages* from container archives
- Full-time calculated on system-side

ofne/online analysis

Container Unpacking

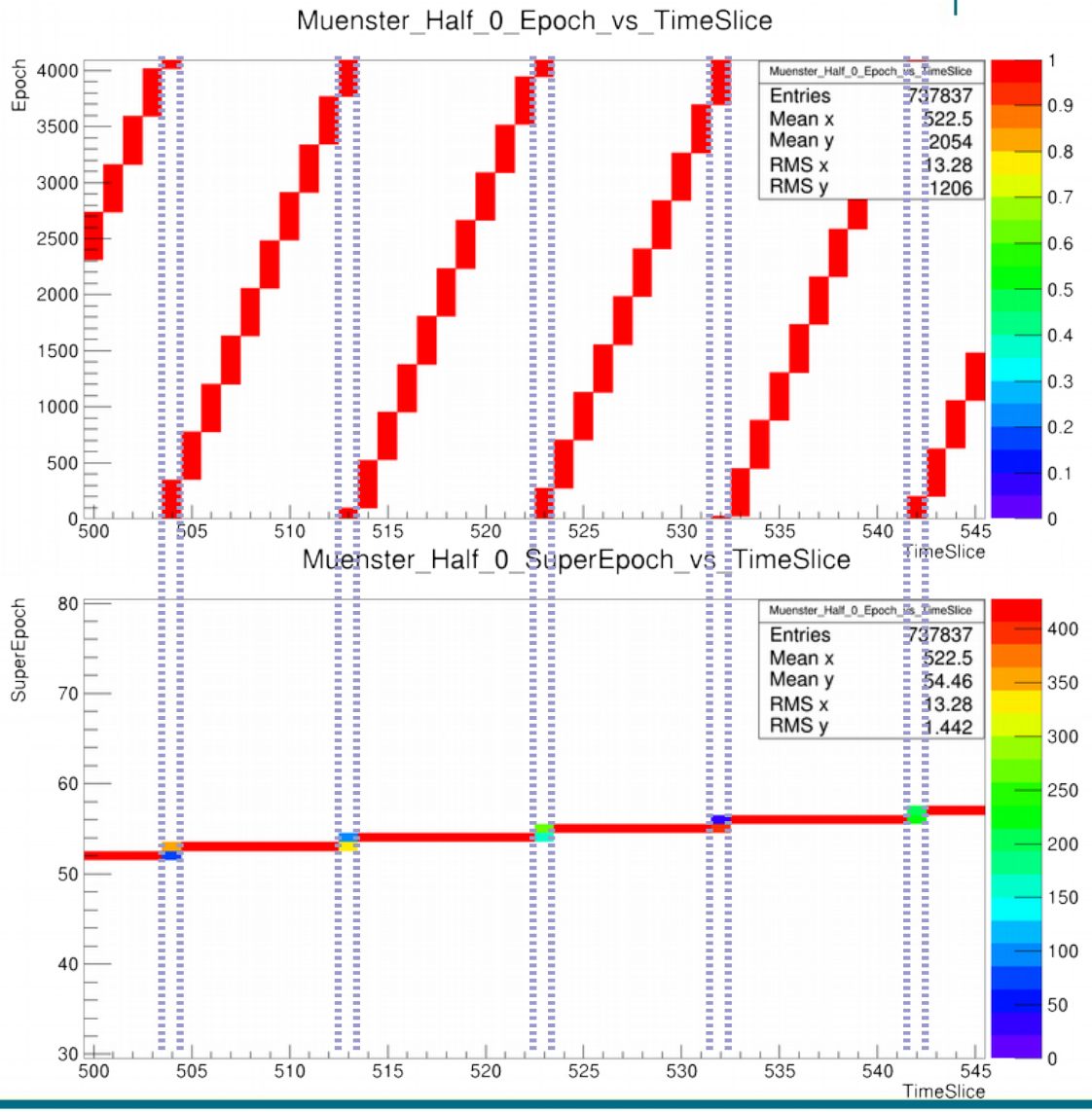
Message Extraction

overflows in
super-epoch (12 bit) x 4096 = 3927 s

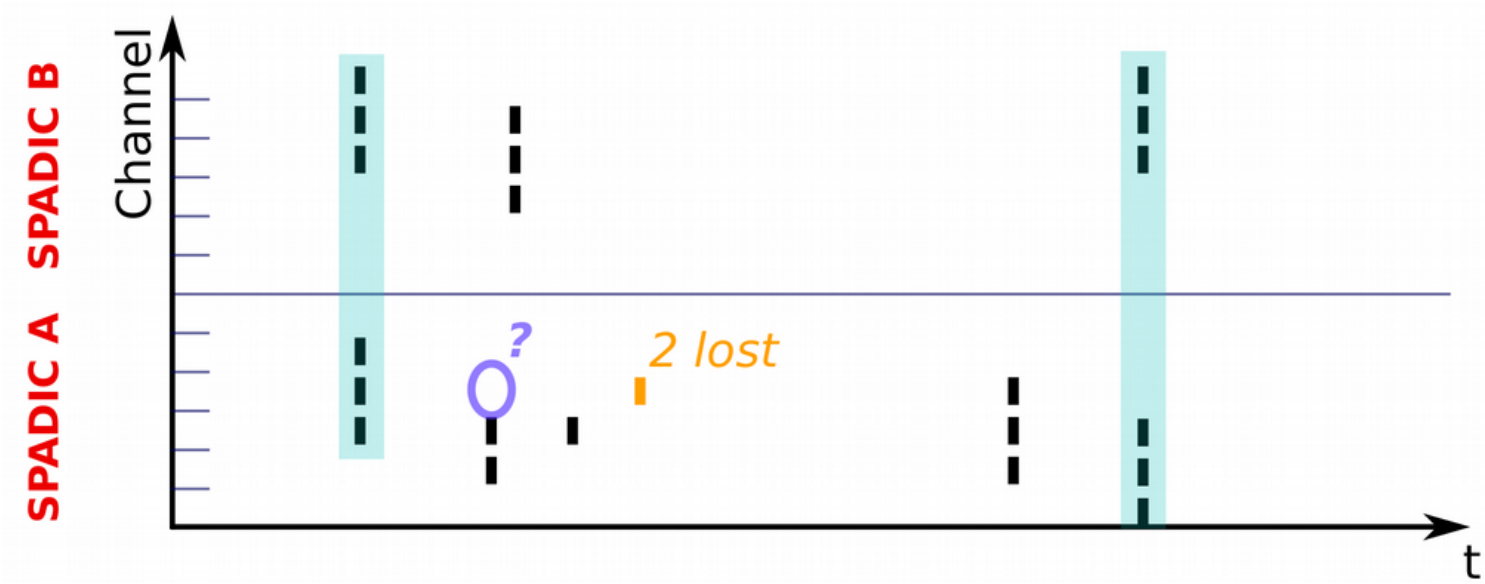
CERN-SPS 2015 Campaign: Time Record Validation

- Validation of time records in their three single layers

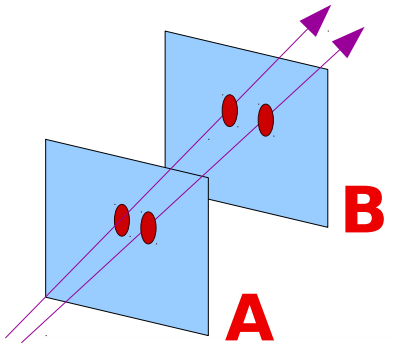
- *Super-epoch* and *epoch* are reconstructed dense, monotonously and synchronously as expected
- Last exceptions in *epoch* are currently under investigation



CERN-SPS 2015 Campaign: Spatial Clusterisation



- Let SPADIC A and SPADIC B be projective behind target
- Hits from one event to be correlated
- Needed: Routines for association in time
- Needed: Routines for message loss, e.g. caused by rate excess



CERN-SPS 2015 Campaign: Pad-Response Function

- Categorise clusters into classes, for 3-pad clusters:
  - 0 Complete and with central charge reconstruction - 55.8 %
  - 1 Outer neighbour-triggered message missing - 7.3 %
  - 2 Central self-triggered message missing - 1.5 %
  - 3 Reconstructed charge is negative - 0.001 %
  - 4 ADC negative or zero after baseline subtraction - 6.3 %
  - 5 Main charge not carried by central pad - 28.9 %

diff. reasons:
- comparator bug, which is resolved in SPADIC 1.1
- quick global baseline approach