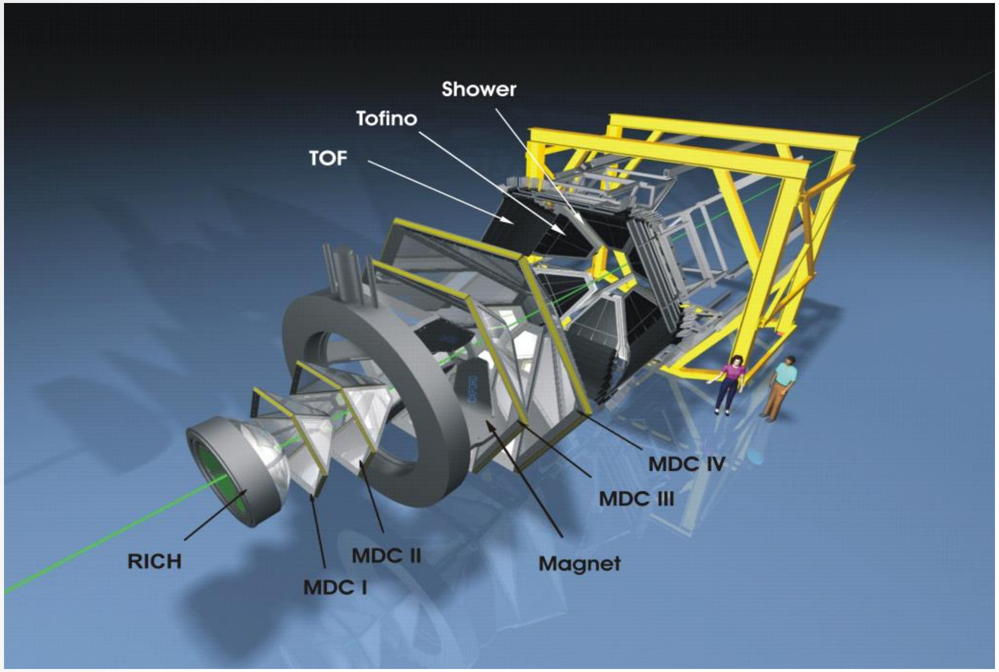
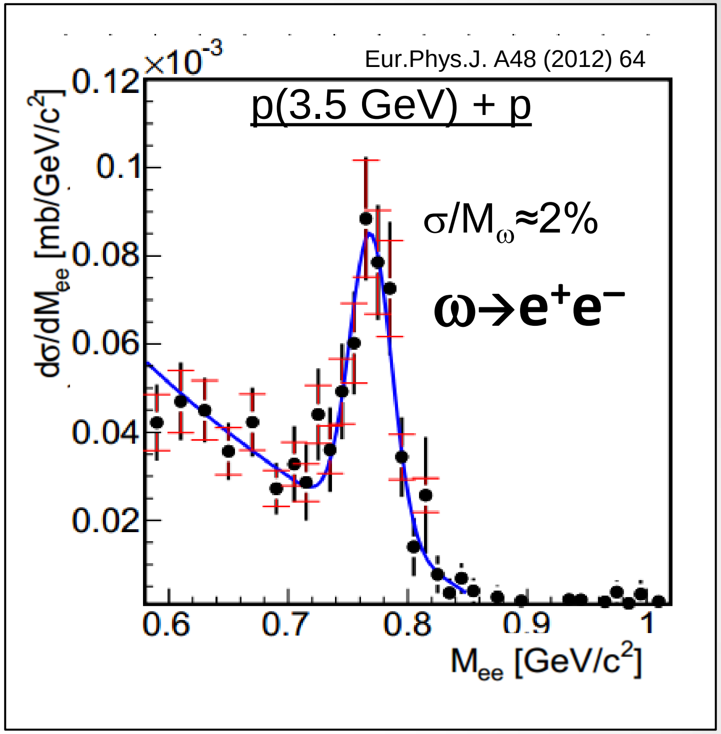
The HADES/CBM physics case requirements

Jerzy Pietraszko for the CBM/HADES

- Introduction and motivation - requirements driven by physics program
- Beam properties measured at HADES focal point
  - T0 and beam monitoring detector in HADES
  - Beam focus
  - In-spill beam position stability
  - Time structure of the beam
- HADES @ SIS 18 future experiments
  - Pion, proton and HI induced reactions
- CBM/HADES at SIS100 - setup
- Beam quality requirements for CBM/HADES @ SIS100

Experimental apparatus: HADES
(The High-Acceptance Di-Electron Spectrometer)





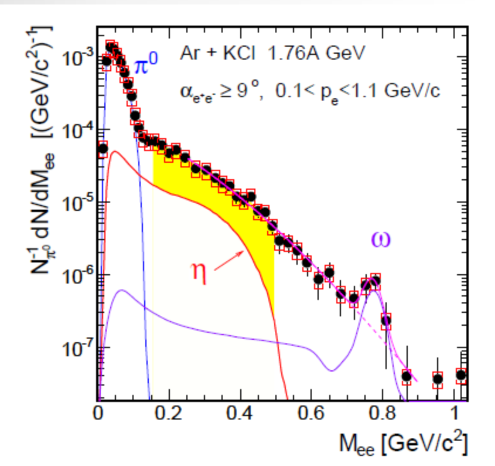
- ✓ Geometrical acceptance: 2π in φ; $18^{0} < \theta < 85^{0}$
- ✓ Di-electron pair acceptance ≈ 35 %
- ✓ low mass spectrometer
  - RICH: $X/X_0 < 1\%$
  - MDC: $X/X_0 \approx 0.42\%$
- ✓ $\sigma_M(\omega) \cong 2.0\%$

Systematic di-electron and strangeness measurements in heavy ion, proton and pion induced reactions. Beams from SIS18 and SIS100 at FAIR.

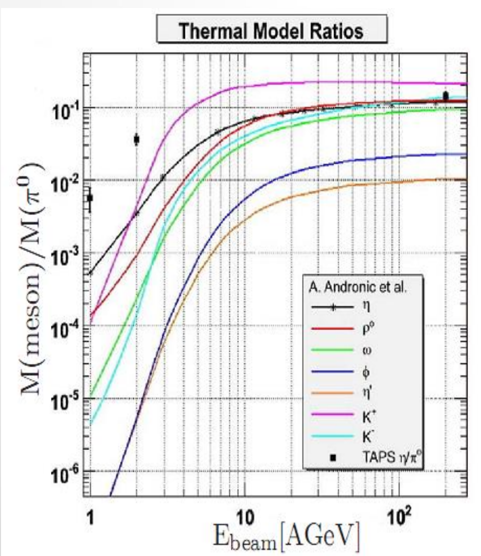
Experimental challenges (di-lepton spectroscopy)

Benchmark; ω measurement via e^+e^- channel ($\omega \rightarrow e^+e^-$)

✓ Di-leptons do not undergo strong interaction → carry undisturbed information about meson



ω(782) DECAY MODES	Fraction (Γ_i/Γ)	Sc Confi
$\pi^+\pi^-\pi^0$	(89.2 ± 0.7) %	
$\pi^0\gamma$	(8.28 ± 0.28) %	
$\pi^+\pi^-$	$(1.53^{+0.11}_{-0.13})$ %	
neutrals (excluding $\pi^0\gamma$)	$(8\ ^{+8}_{-5}) \times 10^{-3}$	
$\eta\gamma$	$(4.6 \pm 0.4) \times 10^{-4}$	
$\pi^0 e^+ e^-$	$(7.7 \pm 0.6) \times 10^{-4}$	
$\pi^0 \mu^+ \mu^-$	$(1.3 \pm 0.4) \times 10^{-4}$	
$e^+ e^-$	$(7.28 \pm 0.14) \times 10^{-5}$	



For ω (subthreshold production):

- 10^{-3} – production probability
- 10^{-4} – e^+e^- channel
- 10^{-1} – acceptance, det efficiency, ...

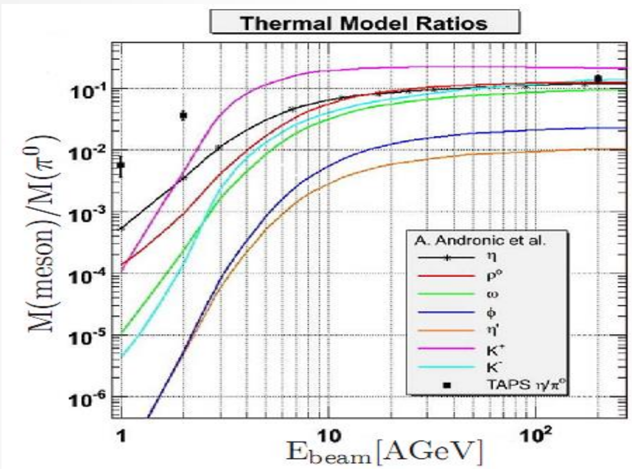
→probability to measure one ω about 10^{-8}

Key issues:

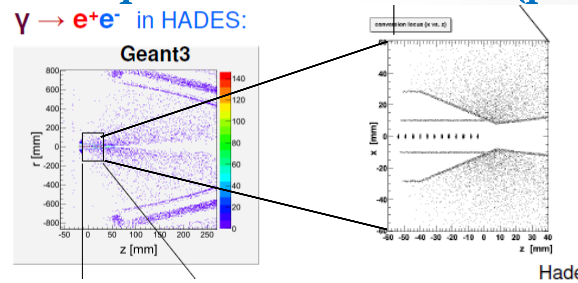
1. High statistic measurements
2. Very clean data → low fake contributions

Experimental challenges
example for p+Nb bremsstrahlung and background processes
→ low mass detection system

Benchmark; ω measurement via e^+e^- channel (ω→ e^+e^-)



photon conversion (p+Nb)



Conversion probabilities from Geant:

- Nb target 2.54%
- target holder 0.14%
- beam pipe 0.51%
- RICH radiator 0.96%
- RICH mirror 0.50%

4.1% effective (for η photons)

$M(\omega)/M(\pi^0)$: 10^{-3}

$\pi^0 \rightarrow \gamma\gamma$ (100%)

$\gamma \rightarrow e^+ e^-$ - conversion

Keep bremsstrahlung and photon conversion on the lowest possible level

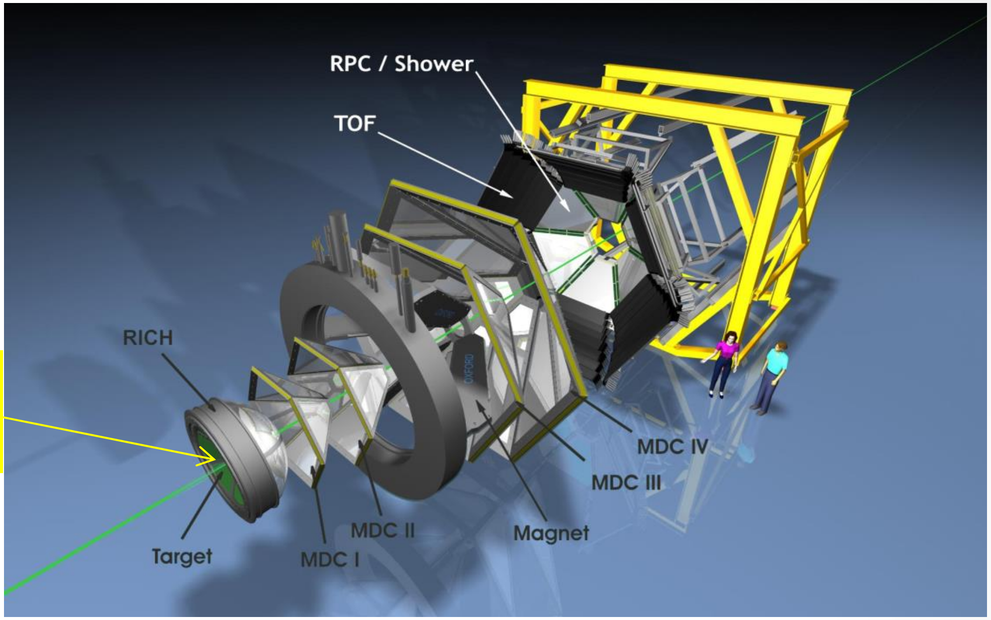
→ reduce X/X_0 , segmented, small target

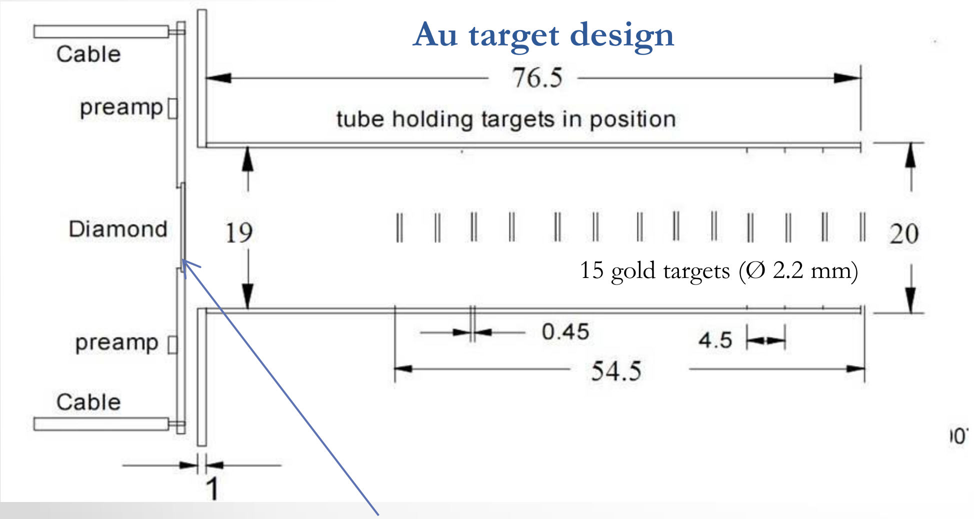
Target for Au beam: 2.2 mm diameter , 15 segments

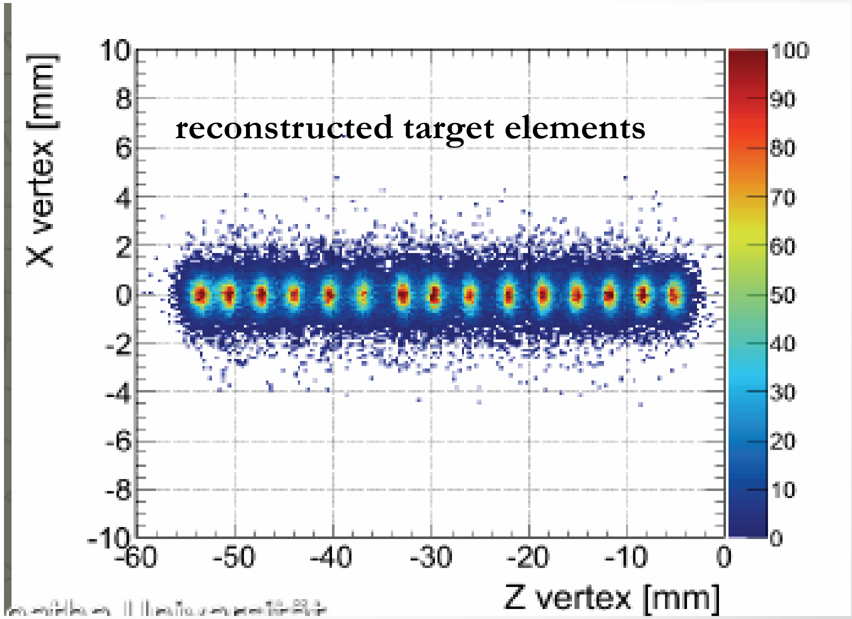
→ perfect beam focus, stable beam position !

HADES Spectrometer

Segmented diamond Start detector
→ Single beam particle detection







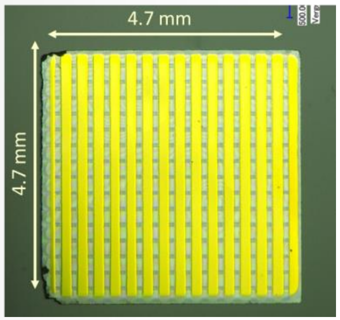
- Start detector (scCVD diamond) 5

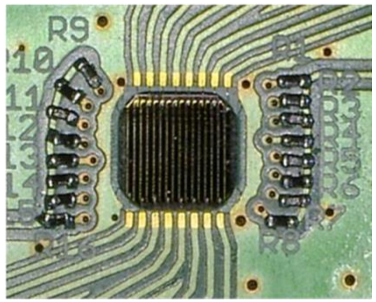
Start detector for CBM/HADES @ SIS100
Performance at Au+Au (Apr12)

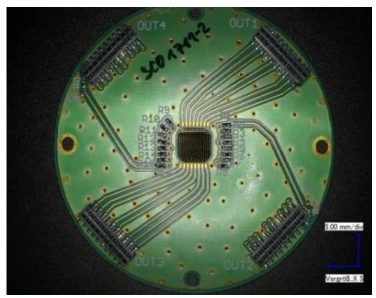
The key features:

✓ Double-sided multi-strip diamond based sensor for HI (16 channels on each side)

✓ fast, high rate readout electronics, up to 10MHz/channel

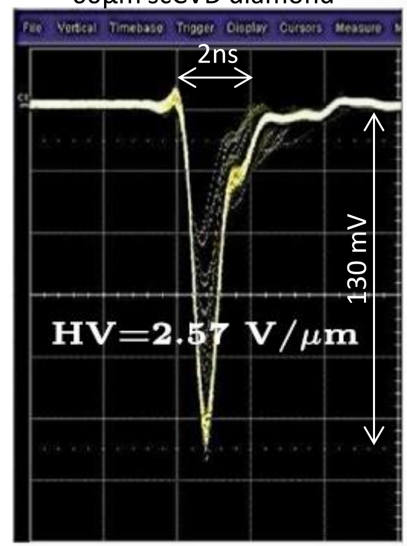






- 16 stripes on each side
- strip width: 200µm
- gap: 90 µm
- det. thickness about 60 µm

30 waveforms from Au ions on 60µm scCVD diamond



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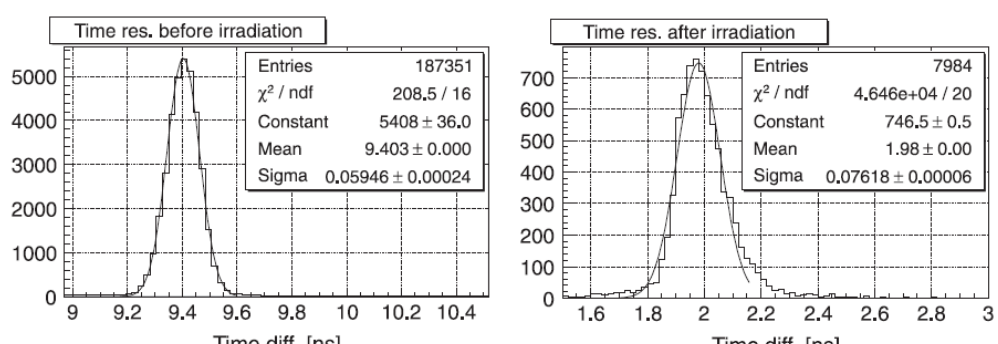

- dedicated electronics:
  - Multihit TDC (17ps)
  - Det. resolution : 50 ps

→ Main limitation:
TDC speed 10^6/channel/s

scCVD diamond start detector for MIPs

The key features:

- ✓ 4.5 mm x 4.5 mm x 0.5mm scCVD high purity diamond material
- ✓ Segmentation, time resolution < 100 ps

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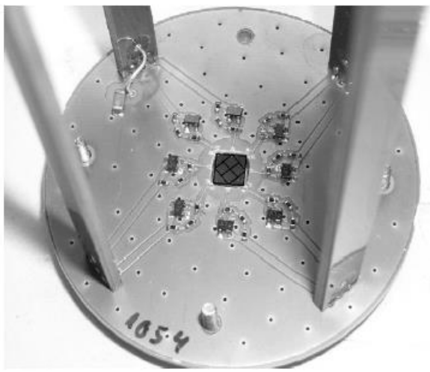


Fig. 1. PC board ($\phi = 50$ mm) with the diamond ($4.7 \times 4.7\,\mathrm{mm}^2$) in the centre surrounded by eight amplifiers (1st stage of amplification).

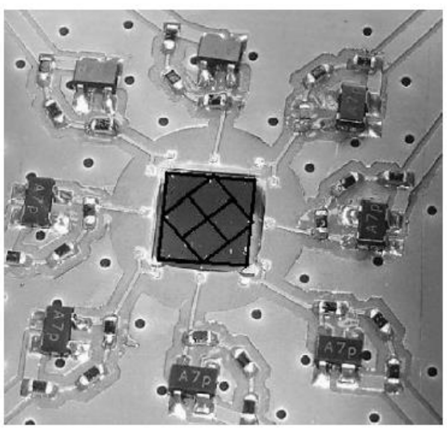
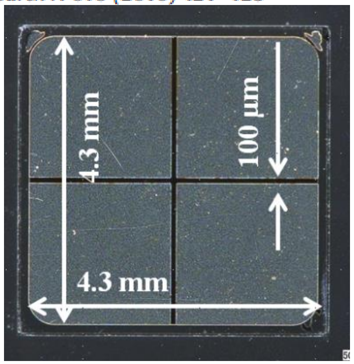
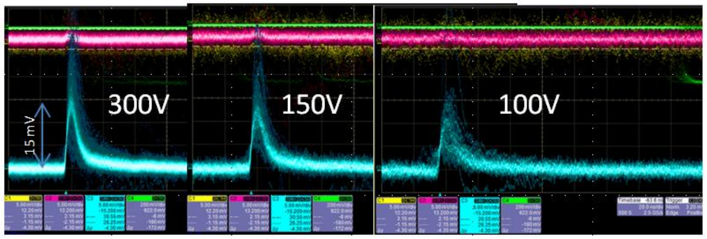


Fig. 2. Segmentation of the metal surface on the diamond detector. Eight diamond segments connected with the amplifiers located on the PCB. The bonding wires used to provide electrical contact are not visible in the photo.

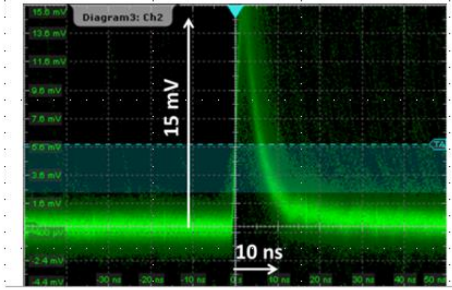


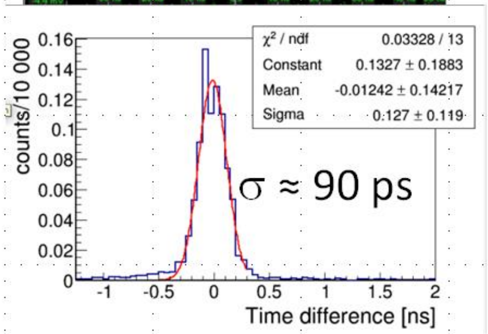
Jülich (COSY), p@2.95 GeV

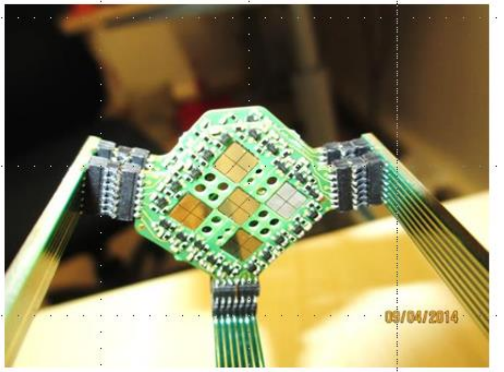


Two key conditions to achieve time resolution σ below 100 ps:

- ➢ bias voltage above 1 V / µm
- ➢ signal to RMS noise ratio > 40







Radiation damage – systematic study for Au beam

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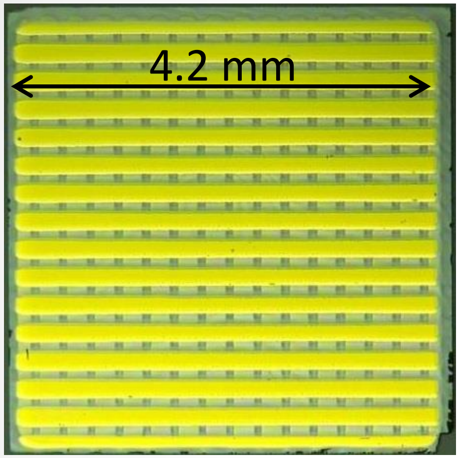
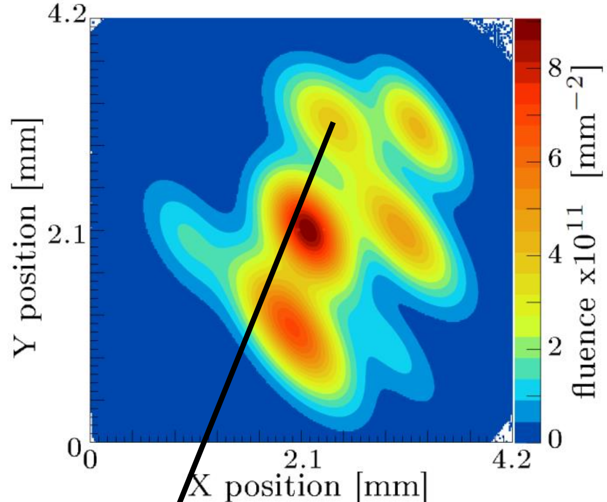
[c] Ruder Bošković Institute, Zagreb
d Technische Universität Darmstadt, Darmstadt, Germany

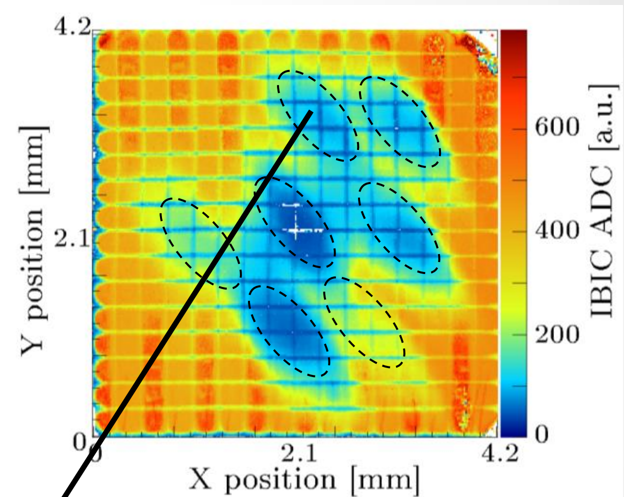
Photo of the metallized sensor before mounting on the PCB

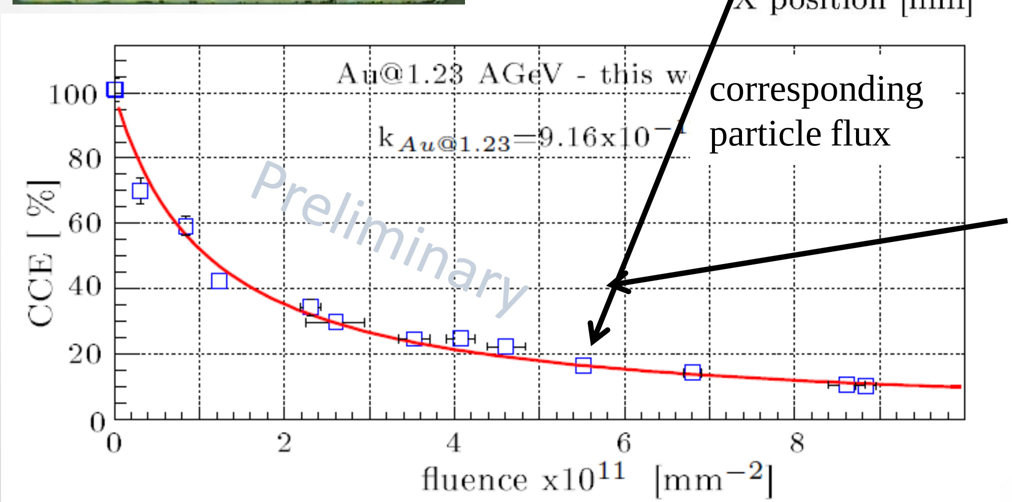


Fit **result** to the fluence: seven 2-dim functions.

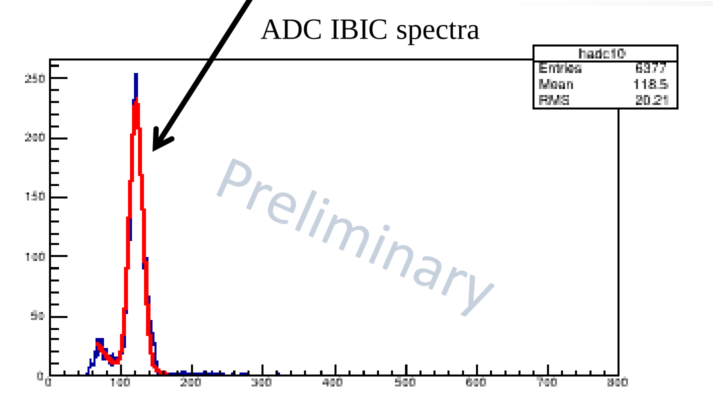


IBIC - μBeam scan, Zagreb,
Whole detecotr measuered



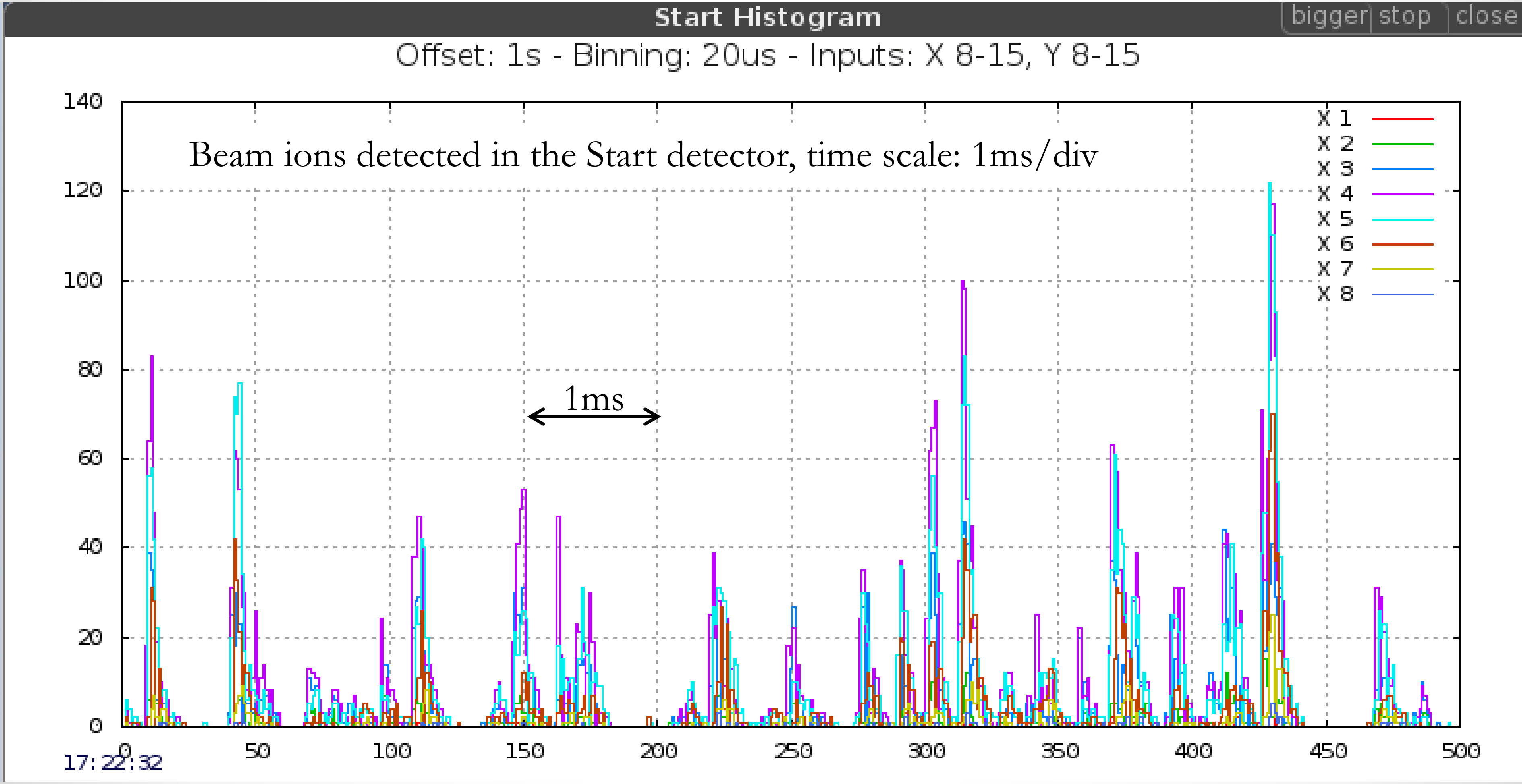


ADC IBIC spectra

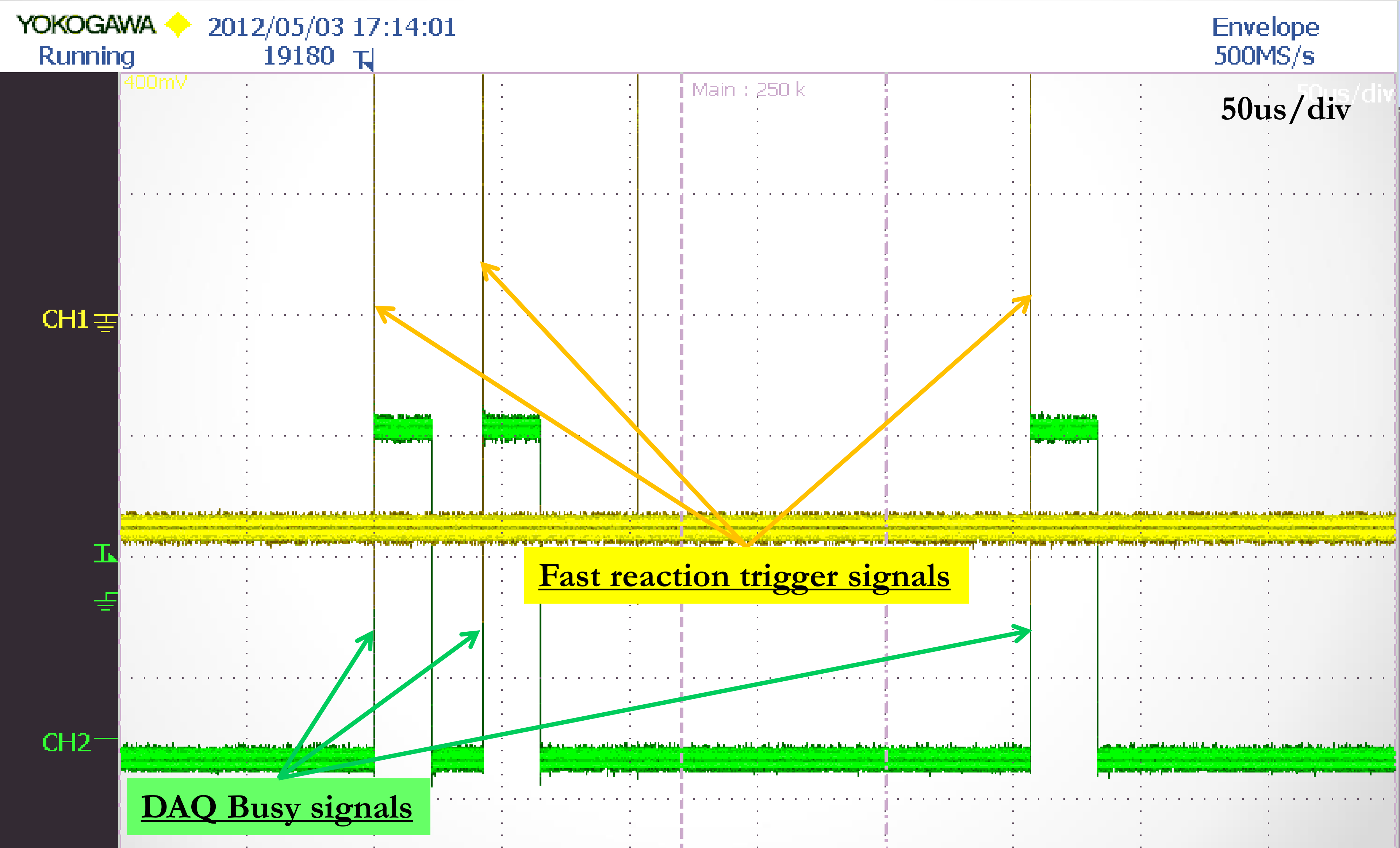


→ $k_{Au} = 300 * k_{MIPs}$

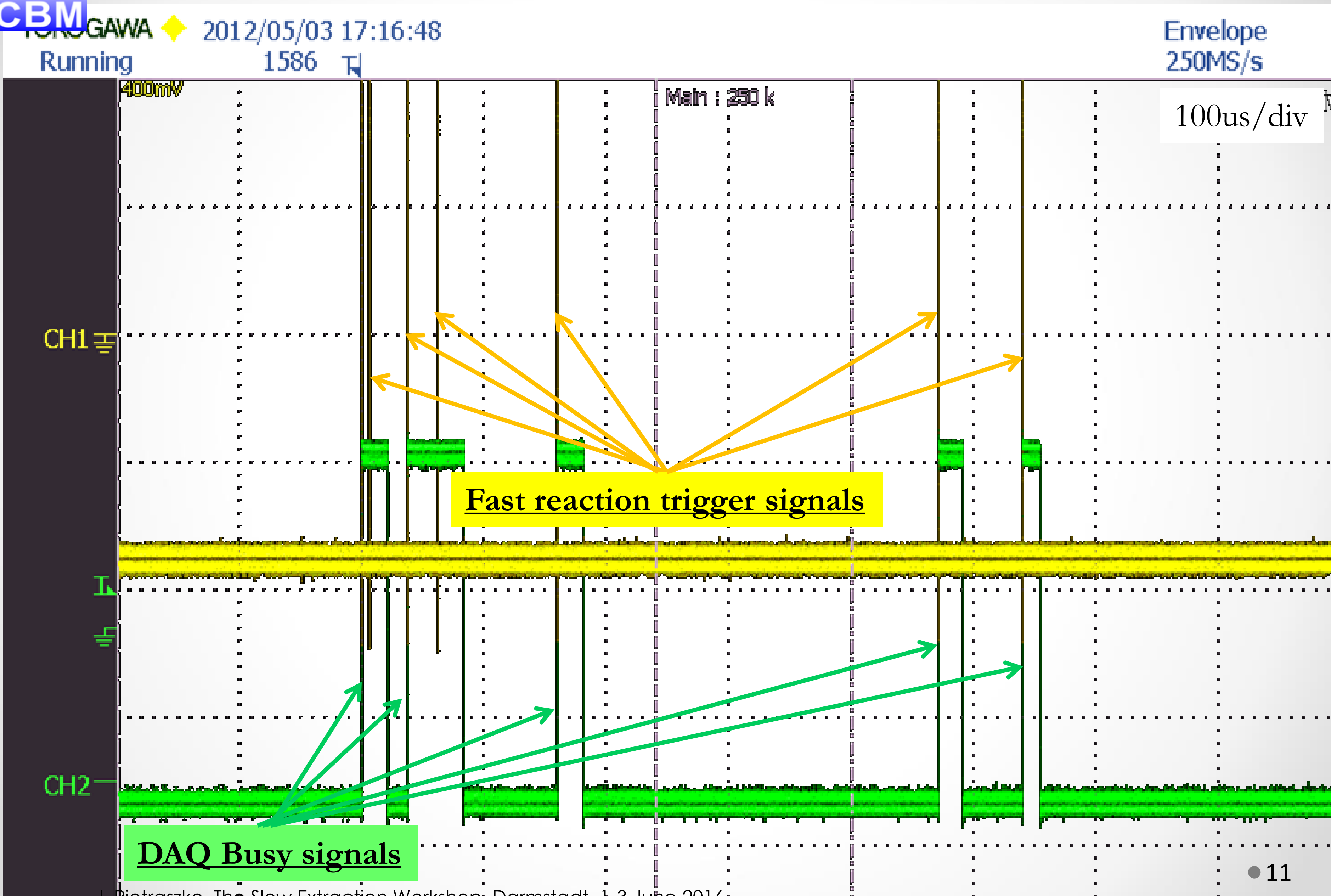
Time structure of the beam at SIS18



DAQ busy and reaction trigger at 50μs scale

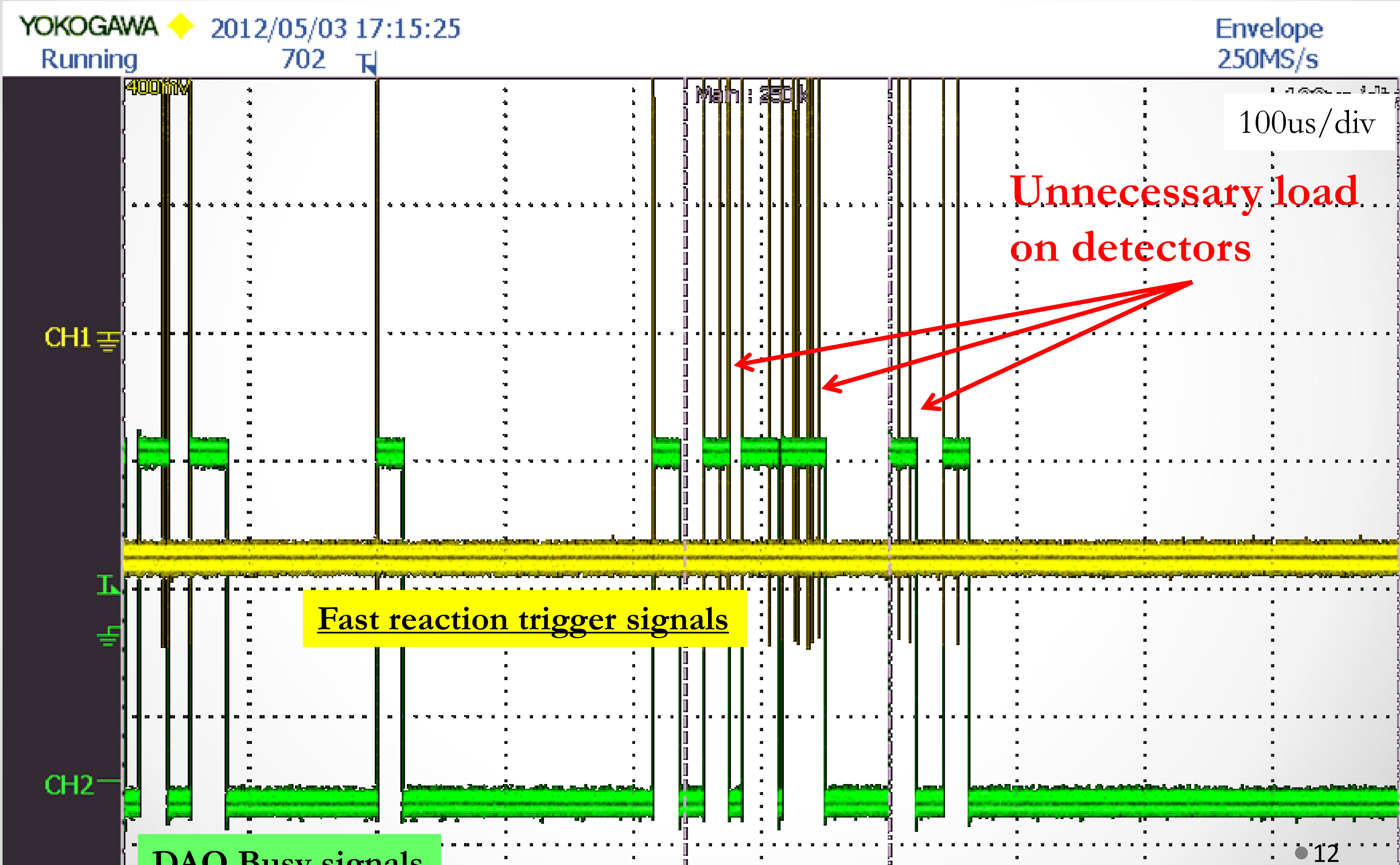


DAQ busy and reaction trigger at 100µs scale



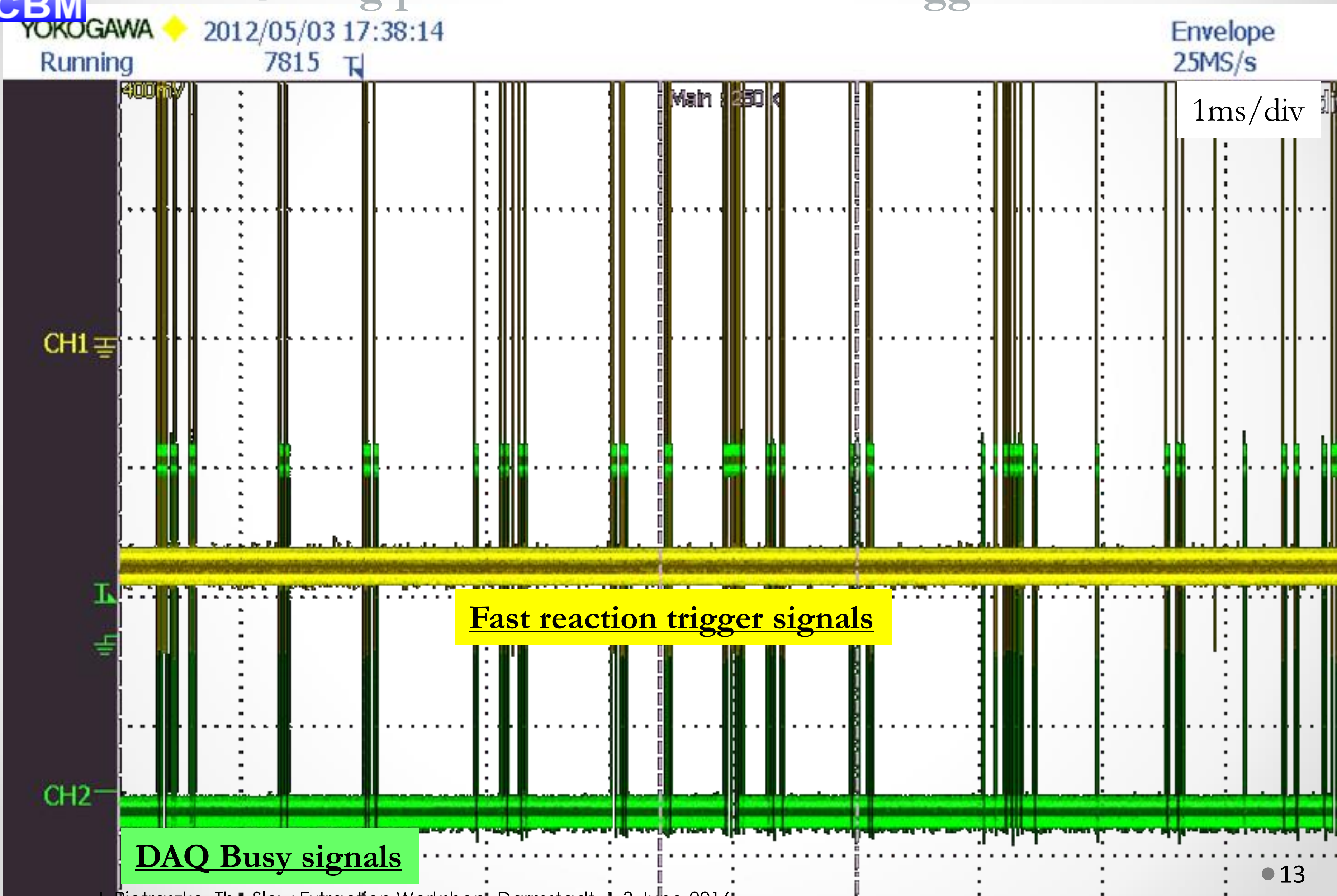
DAQ busy and reaction trigger at 100µs scale

→ long periods without reaction trigger

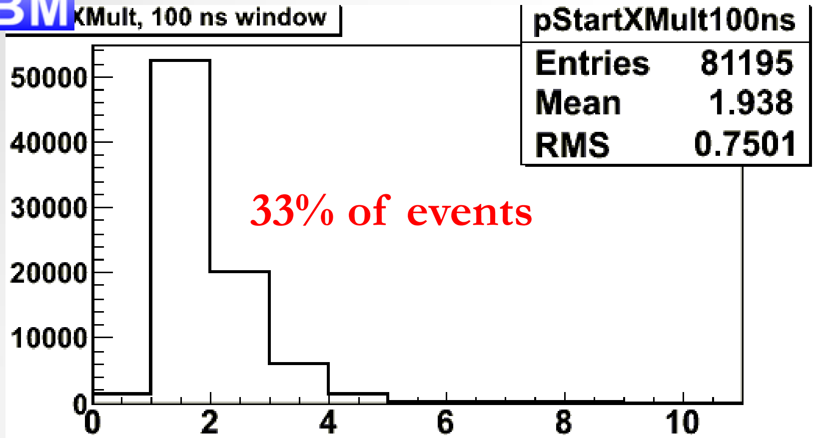


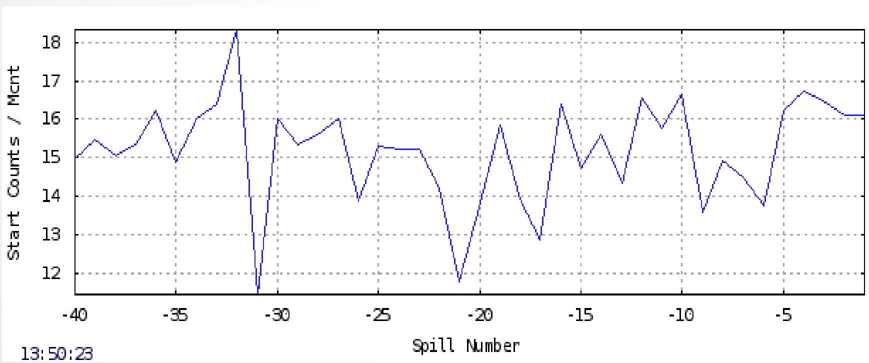
DAQ busy and reaction trigger at 1ms scale

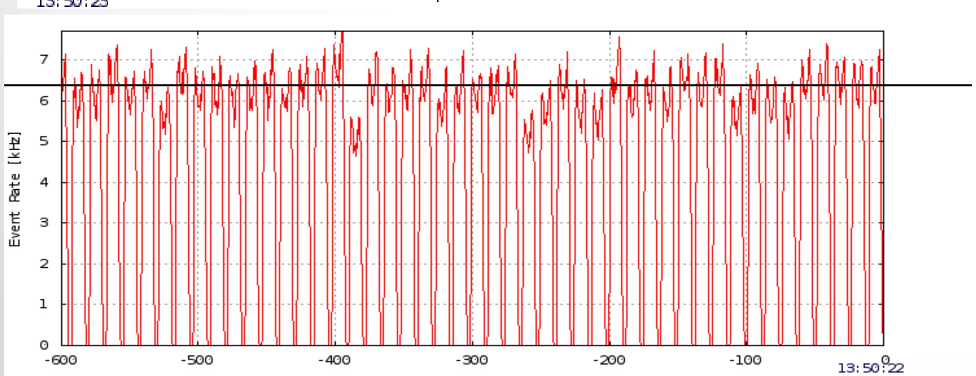
→ long periods without reaction trigger



Experimental consequences for Au beam







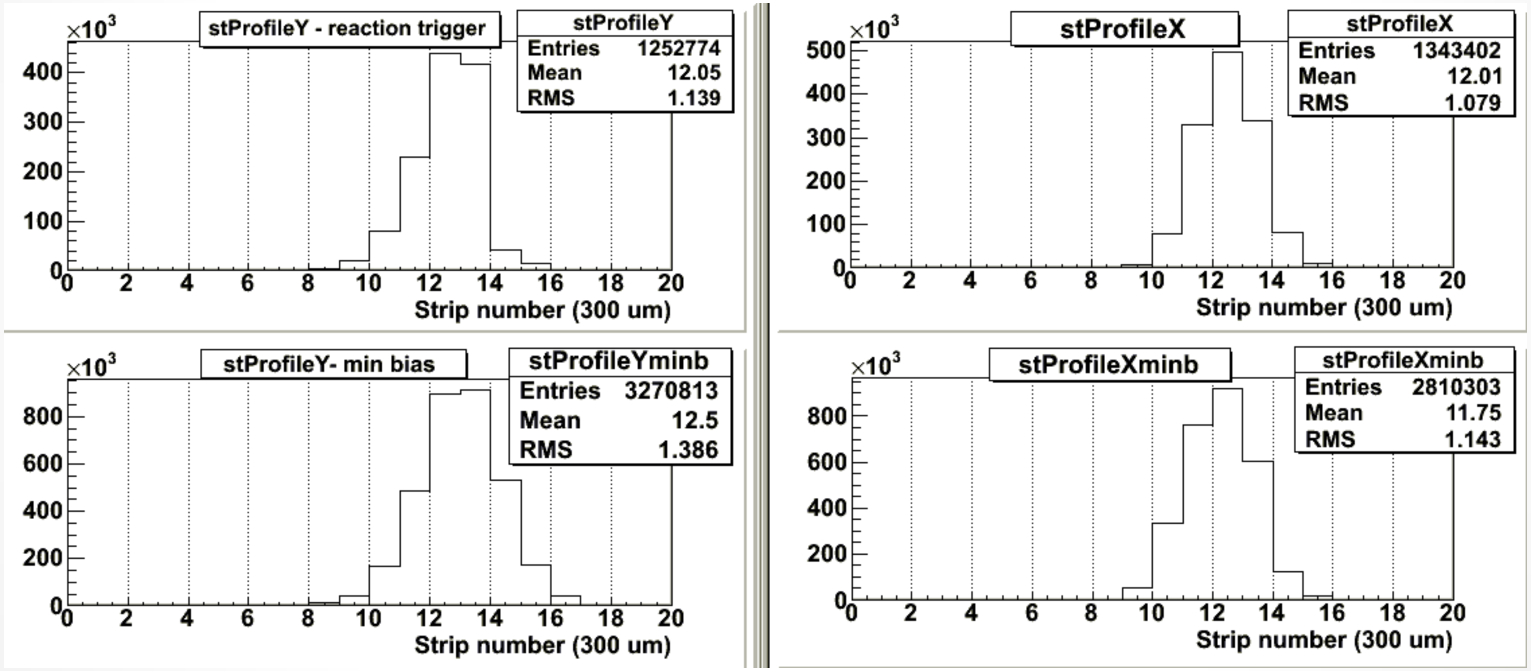
- δ-electrons within the detector integration time (140ns)
- unknown T0 (reaction time) → background !!

- Reduced performance od the system,
- Event rate reduced more than a factor of 3 !!!

- Unnecessary load on detectors – radiation damage → lifetime reduced

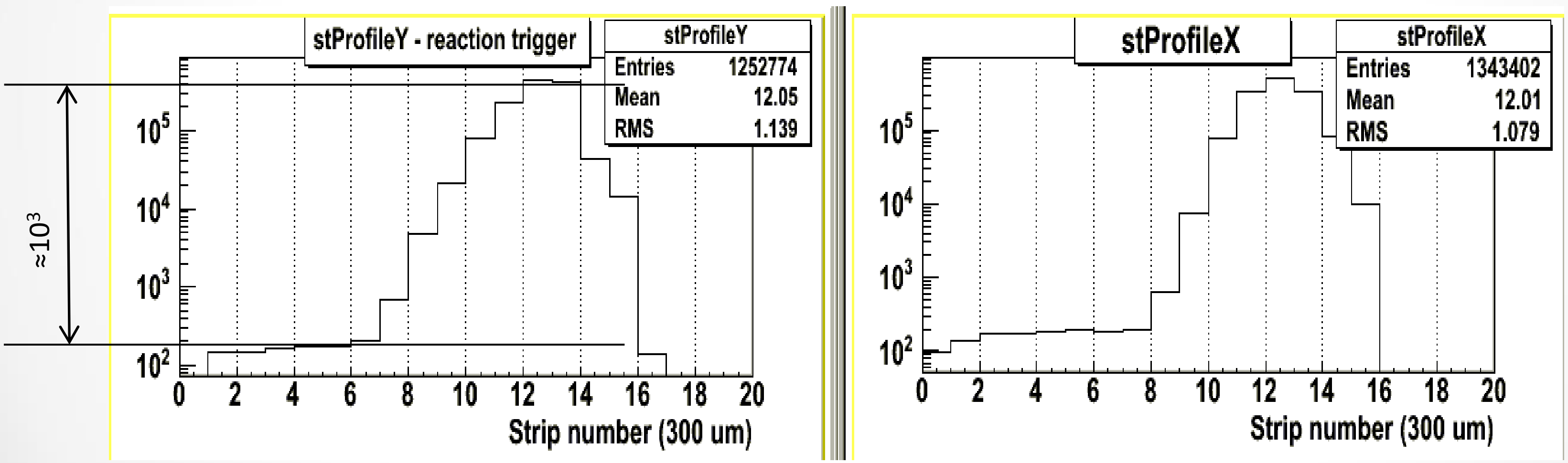
Required size of the beam spot at CBM/HADES @ SIS100 at least as small as at SIS18

→ 2.5 mm (Y) x 1.9mm (X) - (6σ ! - 99,7%)



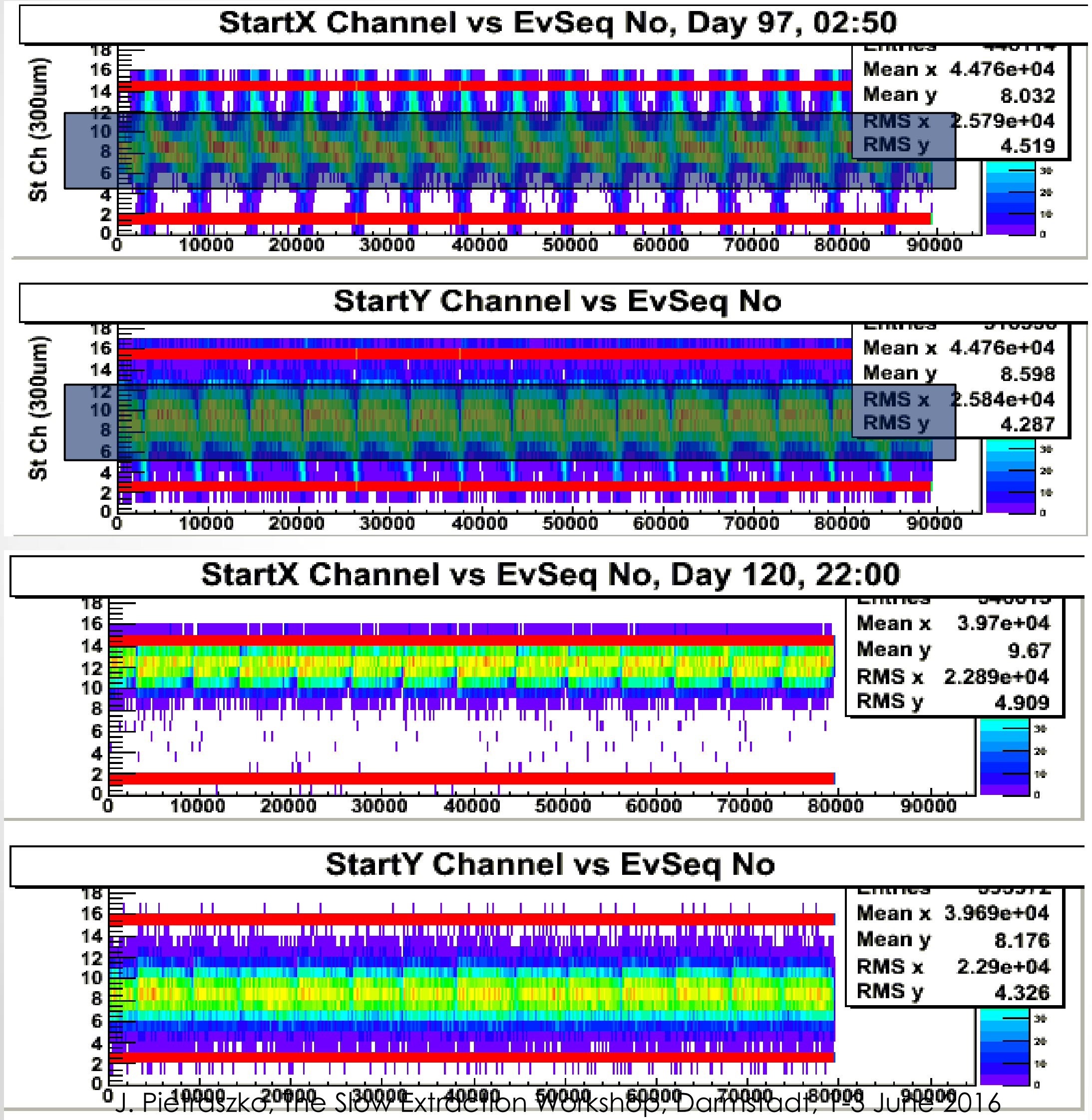
Beam halo at HADES @ SIS18

Beam halo at SIS18 - Au beam Apr12



For CBM at SIS100 we need below 10^{-5} at 5 mm away from beam axis very sensitive detectors in forward region (MVD/STS)

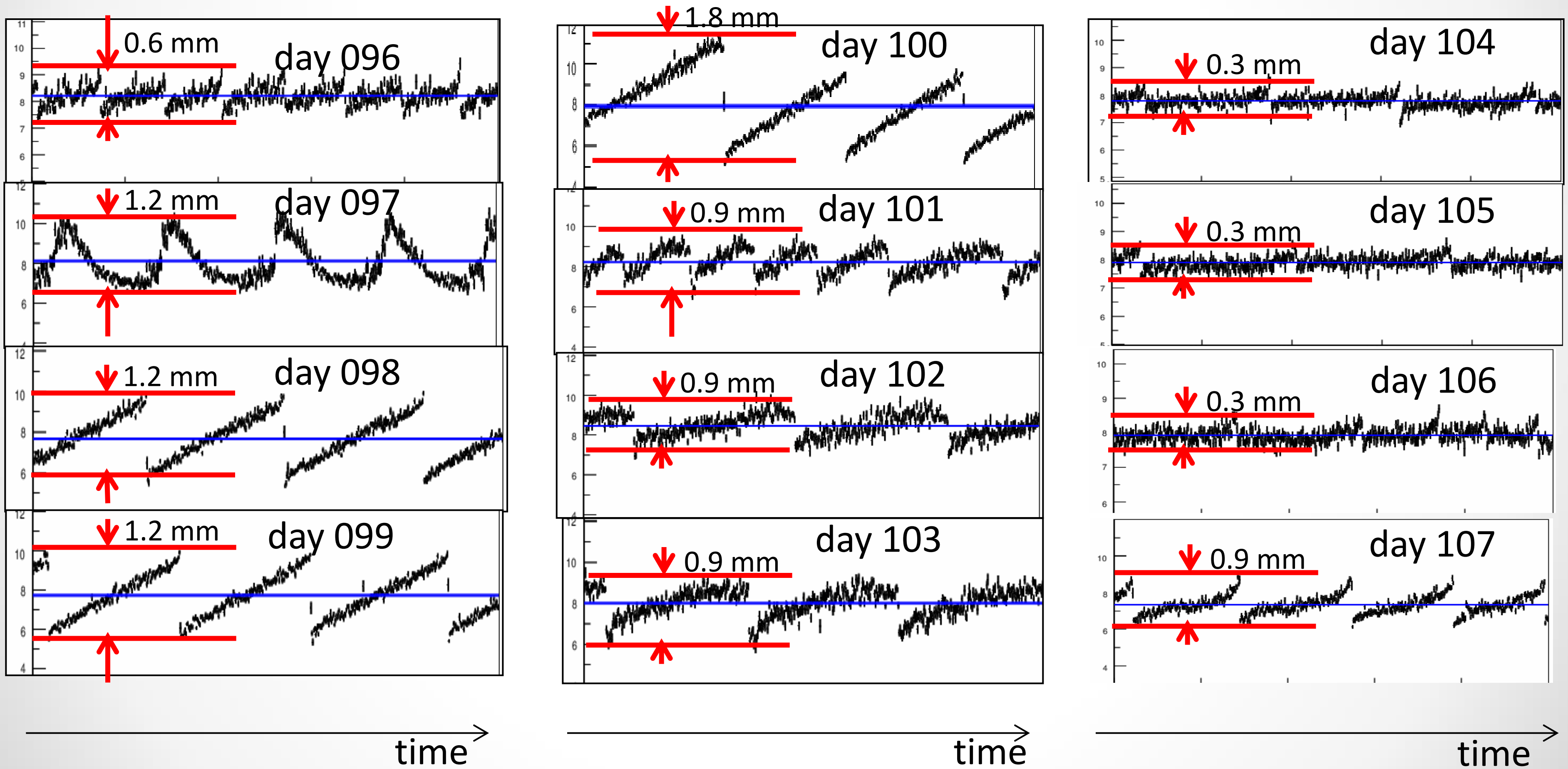
Beam position stability during spill



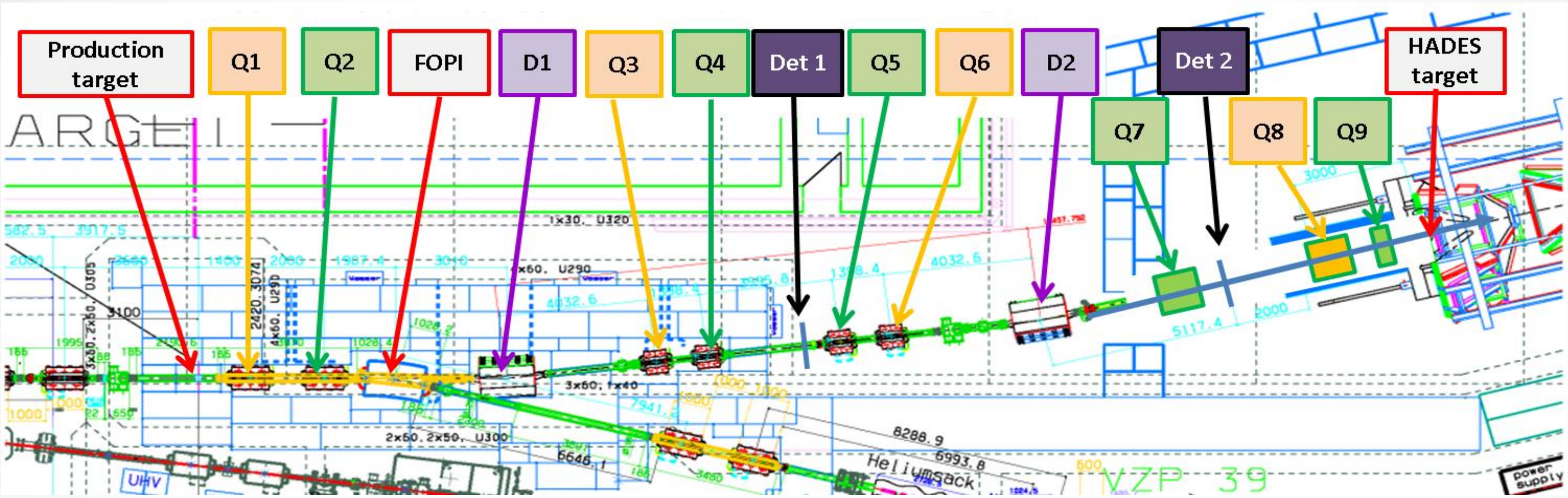
- Significant instability of the beam position in X and Y direction at the target point.
  Mean position change:
  X: ch14-ch4 (ΔX ≈ 3.0mm !)
  Y: ch12-ch4 (ΔY ≈ 2.4mm !)

- Several days later - improved beam spot position stability

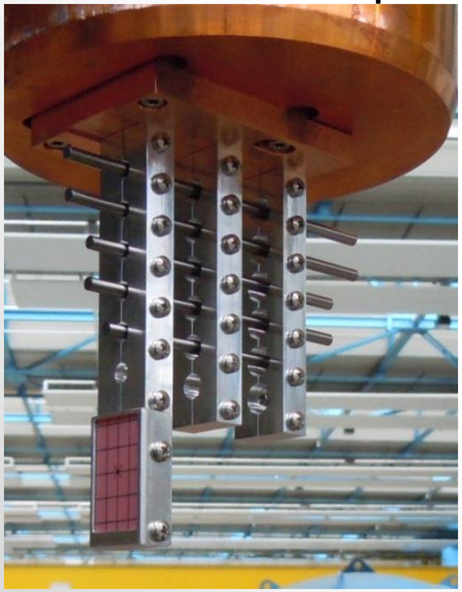
Beam position stability – day-wise

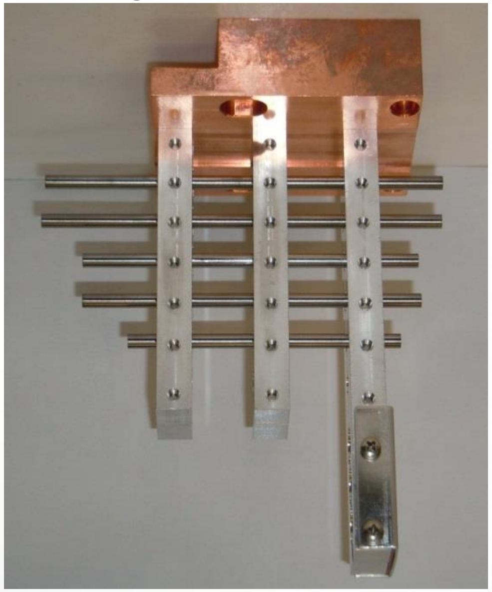


Beam position instability – consequences for pion beam (secondary beam)



Pion production target





- maximal SIS intensity (N beam),
- Be target diameter 4 mm

→ losses if the beam is not stable

→ plan to install Be target of 2.3 mm diameter !?

HADES@SIS18 – slow extraction of high current beam (pion beam in 2014)

HADES

High current experiment in July/August 2014

- In 2014, 400.000 π /spill at 0.7 GeV/c on HADES target were reached with approx. $0.9*10^{11}$ N_2 ions/spill.
- Too high radiation level in NE5 and SIS tunnel

(Intensity had to be reduced to150.000 π /spill):

Hottest areas:

- extraction area – mSv/h

- first quadrupole after the septum

1.5mSv/h (6 weeks after the high int. run)

(4 times higher than ever measured at this point)

- TH3MU1 – in Jan. 2015 - 60 μSv/h

- air activation - for the first time at GSI

– more than 1000 Bq/m^3 of Ar-41 outside controlled areas !

40 days of high current N-beam – 90% of total annual dose in halls TR and EX

Dose Measurements at SIS18 and connected experimental halls TR, EX, TH. T. Radon et al. to be published in GSI annual report.

Pion beam planned in HADES in 2018 - .....

→ improvements needed !

HADES@SIS18 future experiments with π/p/heavy ion beams

Pion case:

Highest primary beam intensity,
Improved extraction quality (efficiency)
Improved primary beam monitoring

Proton case:

Highest proton beam momentum which can be used for stable runs ?
4.5 GeV kinetic beam energy ($\sqrt{s}$ =3.47 GeV) ?
→ Can be used for strangeness production, i.e. Cascade

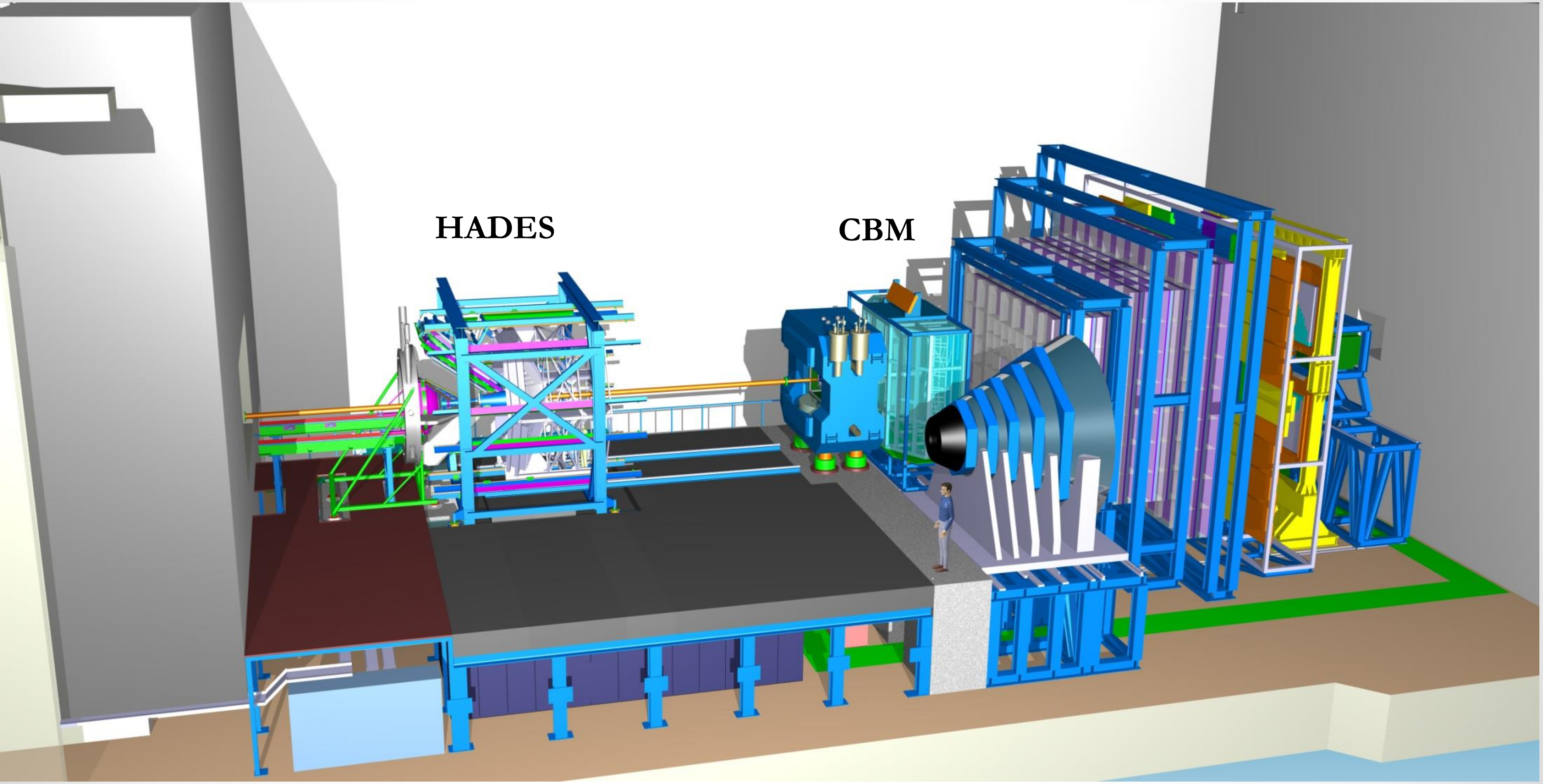
HI case:

Moderate primary beam intensities
- slow extraction, as long as possible, i.e. around 10 seconds
- minimum of rate fluctuations in spill (micro spill structure)

- beam intensity: < 10^7 Ag or Au ions per second in flat top
- Very stable beam spot (< 0,5 mm spread during spill)
- Fast micro spill structure monitoring in the beam line
- More/better beam diagnostic elements in our beam line → reliable and fast beam line setting (without the best experts around)

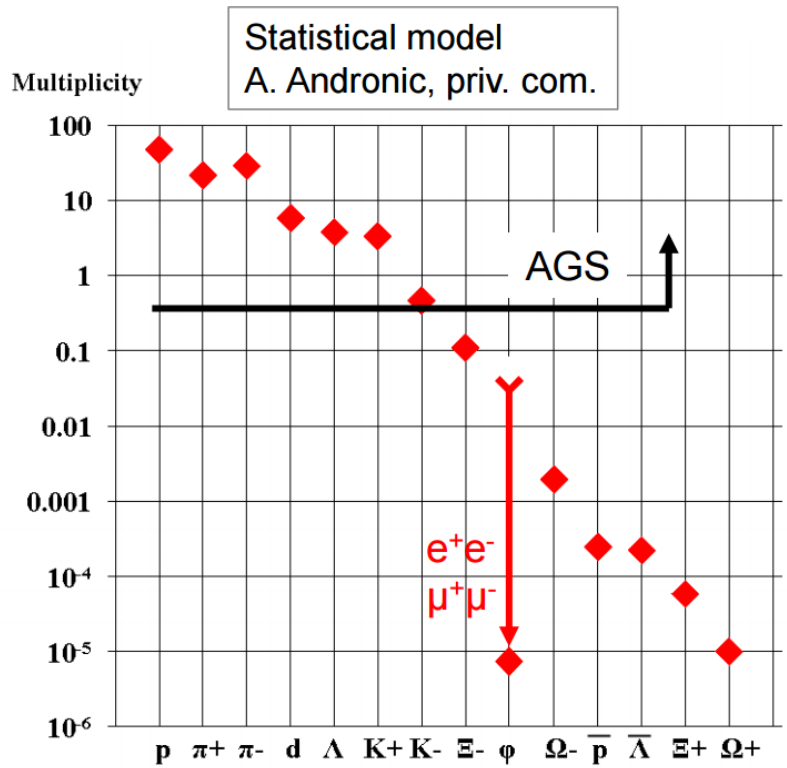
→ Need for improvements in reduction of fluctuations in spill (micro spill structure)

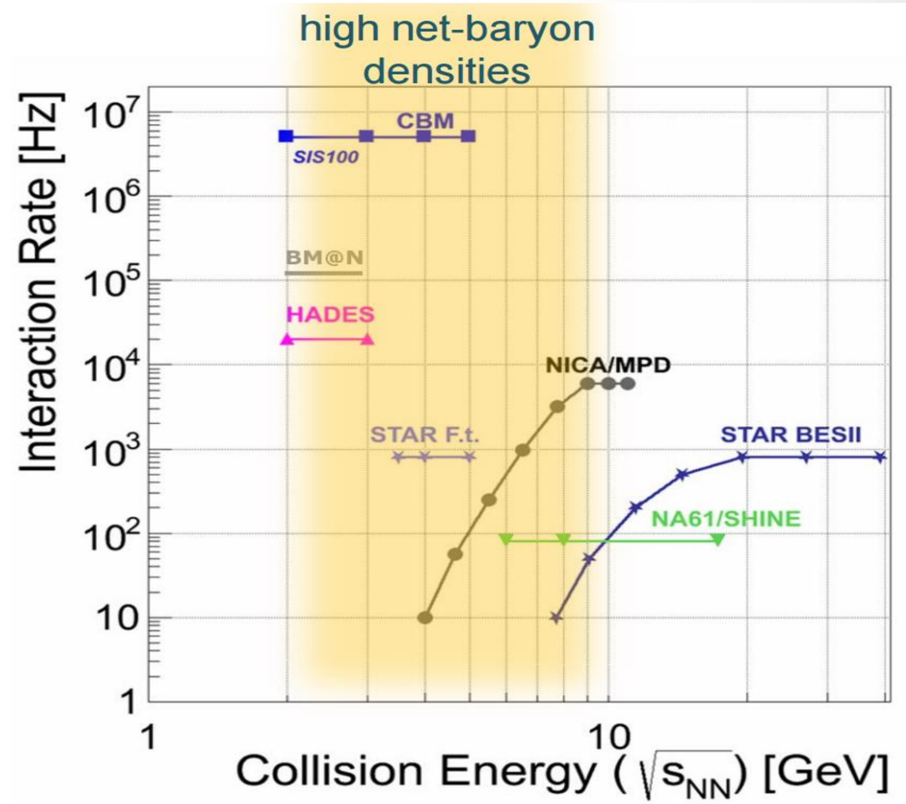
CBM/HADES @ SIS100 – experimental area



CBM @ SIS100 – experimental challenges

Particle yields in central Au+Au 4 A GeV



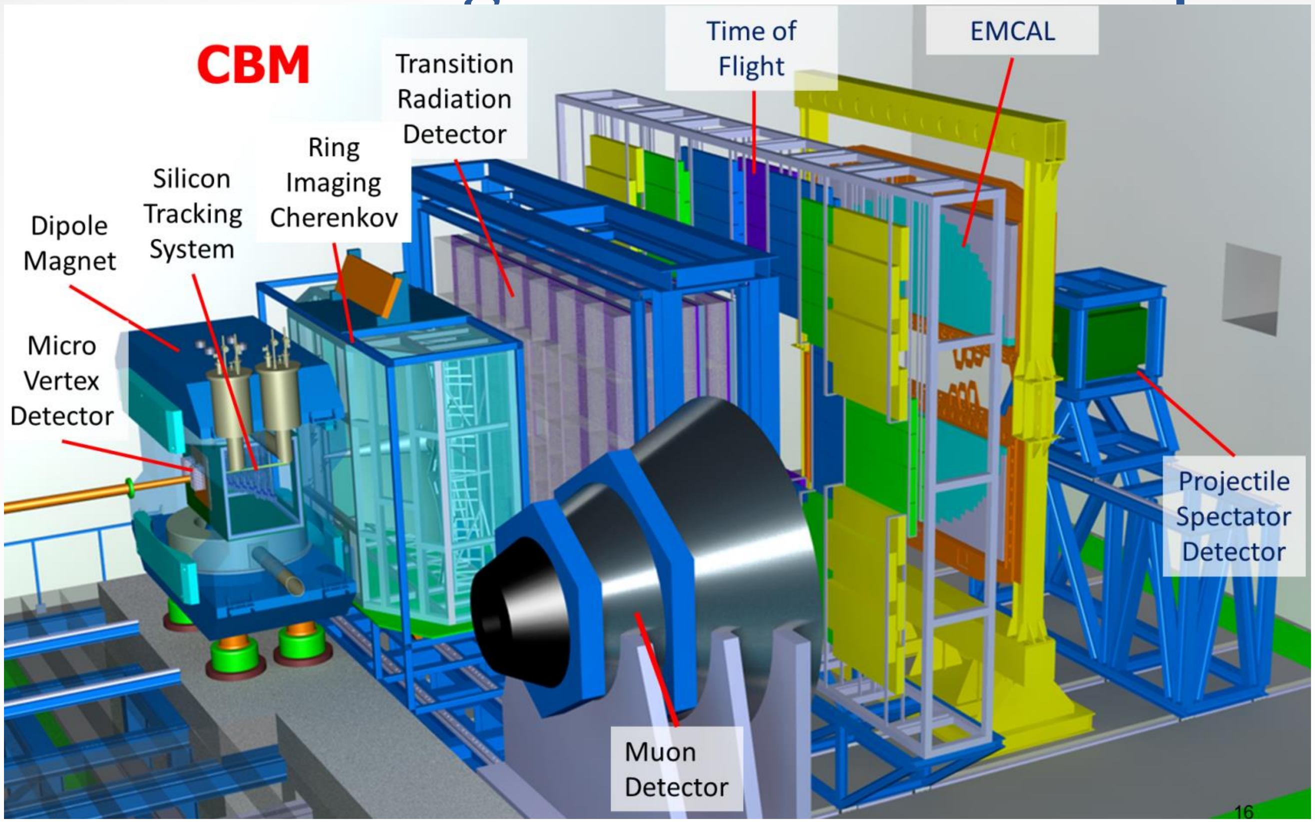


Rare probes:

→ **vey high interaction rates required**

→ **high quality/purity data, excellent beam quality**

CBM SIS100 configuration – beam line aperture



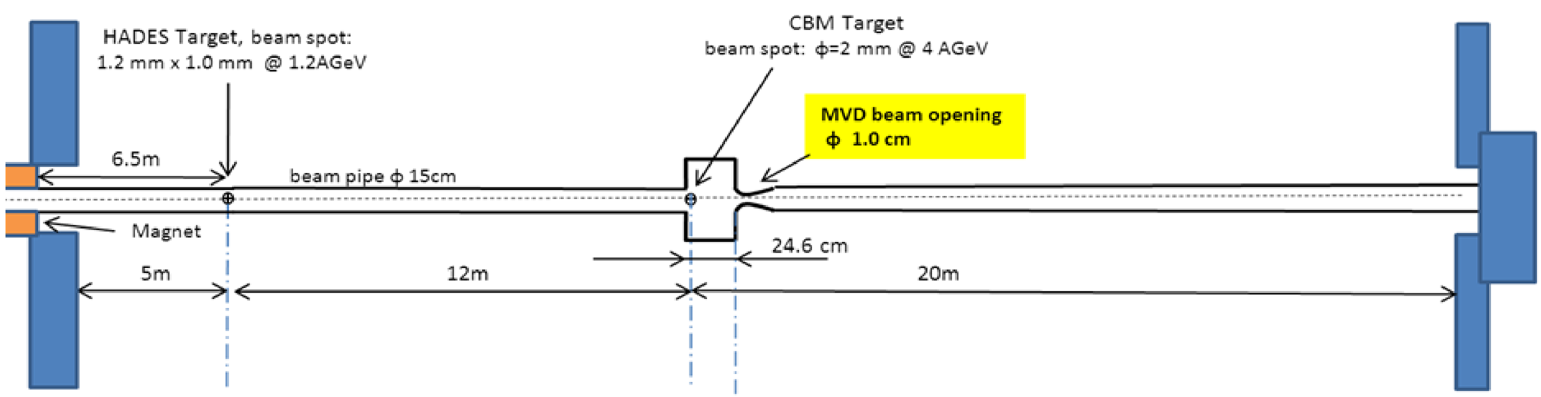


Figure 3. Schematically drawn beam line aperture in HADES/CBM cave (not to scale) for a case when CBM conducts experiments. The requested emittance is constrained by a long distance between the last magnet and a small beam spot on the CBM target.

CBM @ SIS100 – beam emittance requirements

1. **Beam spot** smaller than **2 mm** in diameter in both directions (99.73 % of the beam) for beam energies above 4 AGeV.
2. **CBM beam divergence** smaller than 6 mrad.

   (17 meters distance between the last focusing magnet and target point

   and only 70% of the beam line aperture will be filled)
3. **The CBM beam line aperture**: the smallest opening is 10 mm

   (MVD detector, 10.0 cm from the focal point)
4. **The requested beam emittance** is constrained by the beam divergence (6 mrad) and small beam diameter at the target point, 2 mm at 4 AGeV. Thus, the beam emittance should be 3 mrad * 1 mm = **3.0 mm mrad** at **4 AGeV.**
5. **The BEAM HALO** around the CBM focal point should be reduced **below 10^{-5}** of the total beam intensity at a distance greater than 5 mm away the beam symmetry axis.

<u>Emittance conventions used in this document:</u>

1. Transverse emittance. In these considerations the emittance definition is as follows: Emittance = delta(x) * delta(x') where x – displacement and x' – angular divergence. For ellipse with semiaxes delta(x) and delta(x') the Emittance is defined as area/π.
2. The emittance quoted below is the emittance containing 99.73 % of the beam (three sigma) assuming Gaussian beam.
3. To estimate the beam spot at focal points of both experiments for different beam kinetic energies the adiabatic cooling is taken into account where beam emittance scales with (1/βγ).

CBM @ SIS100 – ion intensities/energies
(slow extraction, 10 s long spill)

Beam energies requested for CBM at SIS100

Isotope	Energies [A GeV] min-max	beam intensity in spill / s
p	5 – 29	10^{11} /s
^{12}C	3 – 14	10^{10} /s
^{40}Ca	3 – 14	$4*10^{9}$ /s
^{58}Ni	2[1] – 13	$4*10^{9}$ /s
^{107}Ag	2[1] – 12	$2*10^{9}$ /s
^{197}Au [2]	2[1] – 11	10^{9} /s

Table 2. A list of proposed beam isotopes, energies and requested beam intensities for CBM at SIS100 experiments. Other spherical or nearly spherical isotopes can be considered for experiments as well.

CBM/HADES @ SIS100 – beam abort system - missing part of the SIS18 system

Motivation:

dE/dx ~ Z^2 of the particle charge

Example for Au ion @ 1.2 A GeV, dE/dx is 4.46 MeV/μm in diamond.

for proton @ 1.2 GeV, dE/dx is 0.00056 MeV/μm

→ Almost four orders of magnitudes difference !!!!

→ Any accidental irradiation by direct beam ions can damage the detection system components and has to be avoided.

→ A fast, fail-safe, beam abort system is requested for the SIS100/300 accelerator. Block the beam transport to the HADES/CBM experimental area within 100-200μs time and should be triggered by the beam abort signal delivered by a dedicated detection system from the experiments.

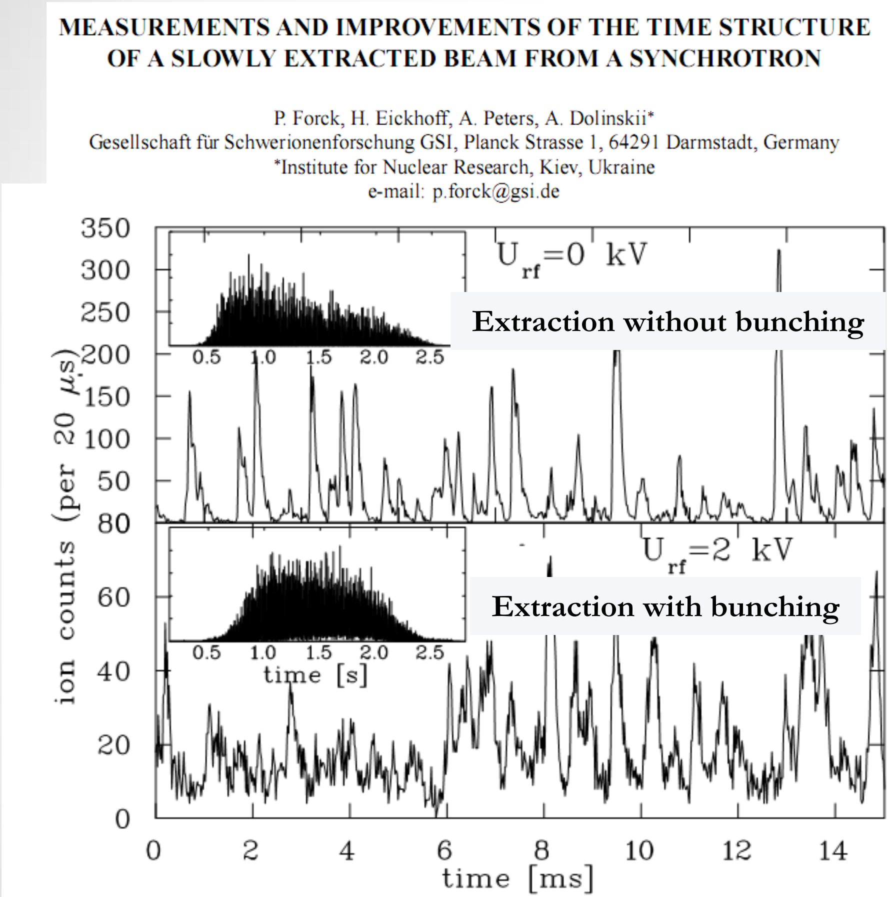
→ the beam abort system is included in the SIS100

Summary

- ✓ **Precise beam diagnostic at the experimental focal points of HADES/CBM is essential:**
  - → based on scCVD/pcCVD diamonds
- ✓ **Significant data quality losses due to micro-spill structure and beam instability**
  - → Needs improvements at SIS18 for planned HADES experiments !
  - → Should be significantly improved at SIS100
    - → Reduced data quality and rate capability !
    - → Load on detectors !
    - → Impossible to run CBM @ 10^7 interactions/s (10^9 ions/s) !
- ✓ **Beam requirements for CBM@SIS100 based on realistic SIS18 results.**
- ✓ **Beam abort system essential for safe detector operation at SIS100**

Thank you

The time structure of the beam – bunched extraction at SS18 not suited for high rate experiments


MEASUREMENTS AND IMPROVEMENTS OF THE TIME STRUCTURE OF A SLOWLY EXTRACTED BEAM FROM A SYNCHROTRON

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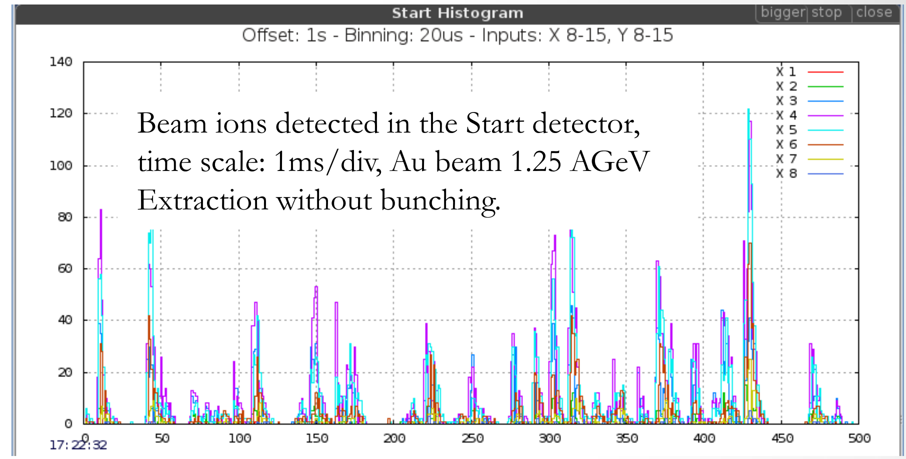

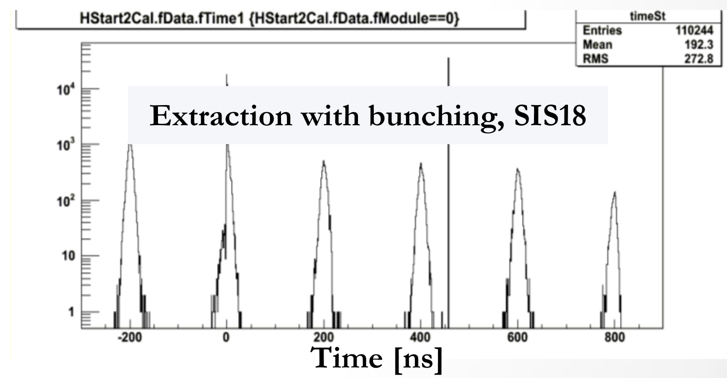

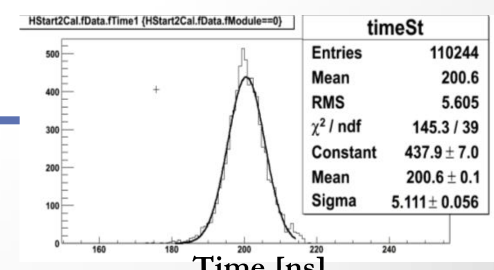

Resonator frequency: 5 MHz

→ not usable for CBM at SIS100 !!!!

→ we would need more than 40 MHz

The time structure of the beam – spill feedback

Ripple Measurements on Synchrotron Spill-Signals in the Time- and Frequency-Domain

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At SIS, we obtained a delay of roughly 50µS. This value is equivalent to about 50 revolutions of the particles. The delay sets an upper limit for the feedback bandwidth of a spill regulator.

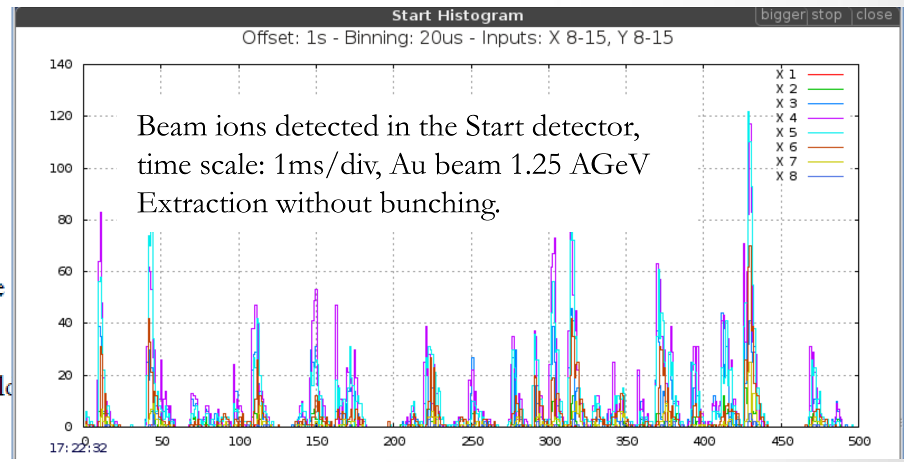
RF.-K.O.-Extraktion

S 07 BO 1E

8.1 Analogeingänge

Die Elektronikkarte hat folgende Analogeingänge:

- *HF-Masterfrequenz Ext Clk*, aus der sich mit Angabe der Harmonischenzahl H die momentane Umlauffrequenz f(rev) = f(hf)/H ergibt.
  (benutzt bei externem Betrieb)
- *HF-Aux-Eingang RF Ext in*, der bei statischen Q-Wert-Messungen und allg. Strahl... den Exciterverstärker direkt mit einem HF-Signal versorgt.
  (benutzt bei Q-Messung statisch)
- *Funktionsgeneratoreingang FG*, der die Amplitude des Extraktionssignals bestimmt.
- *VCA-Auxeingang Aux*, der alternativ zum Funktionsgeneratoreingang die Amplitude des Extraktionssignals bestimmt.
- *Feedback – Regelsignaleingang FB*(wird aus Spillform aus Detektor abgeleitet) (benutzt bei KO-Extraktion mit Spillregelung), der additiv zugeschaltet werden kann.
- *Aux-Regelsignaleingang Aux*
  (alternativer Analogeingang zur Amplitudensteuerung des VCA)



HADES @ SIS100 – beam emittance requirements

1. **Beam spot** at the focal point of HADES should be **smaller than 2 mm** in diameter in vertical and in horizontal directions. The beam spot should contain 99.73 % of the beam.
2. FWall detector is located 7 meters downstream of the target. The beam line hole in this detector is 7 cm in diameter.
3. The beam aperture in front of the HADES target is 15 cm in diameter.
4. **The beam emittance,** constrained by the beam hole in the FWall detector and small beam spot, should be 5 mrad * 1 mm = **5 mrad mm** at 2 AGeV.
5. Presence of HALO particles around the HADES focal point should be kept below 10^{-5} of the total beam intensity at a distance greater than 5 mm away the beam symmetry axis.

<u>Emittance conventions used in this document:</u>

1. Transverse emittance. In these considerations the emittance definition is as follows: Emittance = delta(x) * delta(x') where x – displacement and x' – angular divergence. For ellipse with semiaxes delta(x) and delta(x') the Emittance is defined as area/π.
2. The emittance quoted below is the emittance containing 99.73 % of the beam (three sigma) assuming Gaussian beam.
3. To estimate the beam spot at focal points of both experiments for different beam kinetic energies the adiabatic cooling is taken into account where beam emittance scales with ($1/\beta\gamma$).

HADES & CBM: Complementary Setups