Beam quality requirements for HADES and CBM @ SIS100

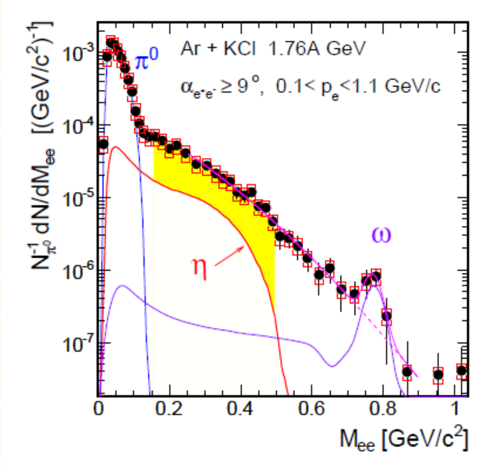
- Introduction and motivation - requirements driven by physics program.
- What has to be avoided/provided at SIS100 - lessons from SIS18 and consequences
  - Beam focus, emittance – slow extraction, 10 s spill.
  - In-spill beam position stability
  - Time structure of the beam
  - Fast beam abort system
- CBM/HADES at SIS100
  - Experimental setup
  - Beam requirements summary table
- HADES @ SIS 18 experiments (details on Friday)
- Beam quality requirements for CBM/HADES - summary

Jerzy Pietraszko for the CBM/HADES

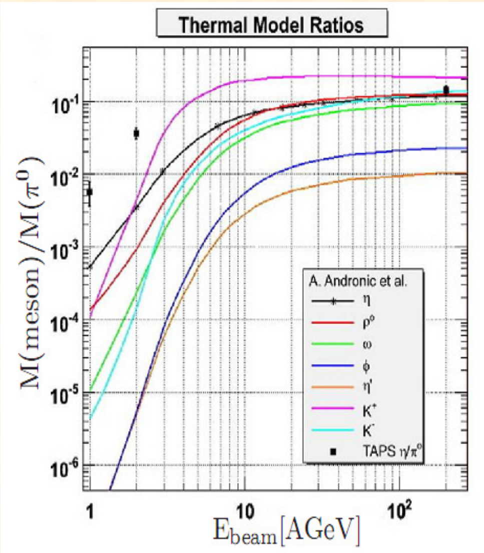
Experimental challenges (di-lepton spectroscopy)

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)
$\pi^+\pi^-\pi^0$	(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}

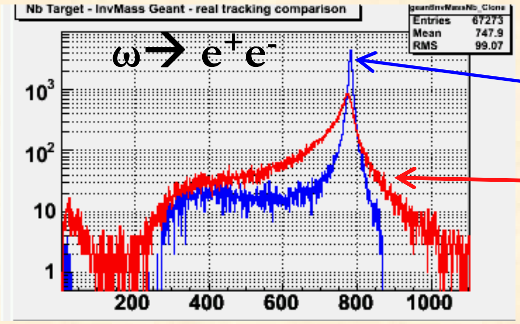
Key issues:

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

→ for more details see Friday talk

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

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



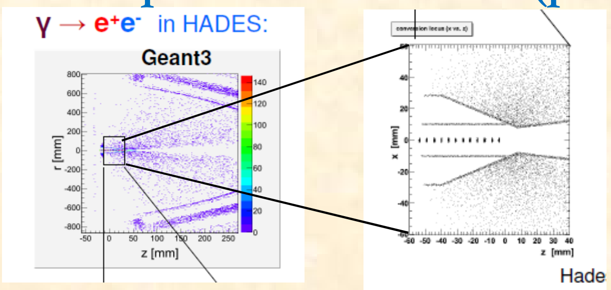
Inv. mass [MeV]

ideal (Geant)

reconstructed in the spectrometer
(bremsstrahlung, energy loss)

bremsstrahlung:
electromagnetic radiation

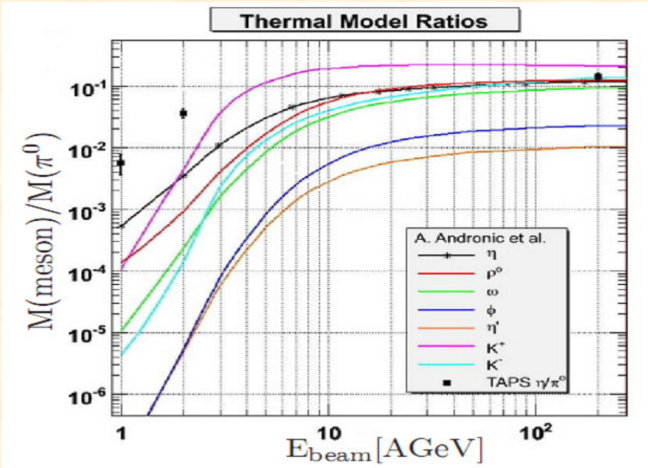
photon conversion (p+Nb)



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%)

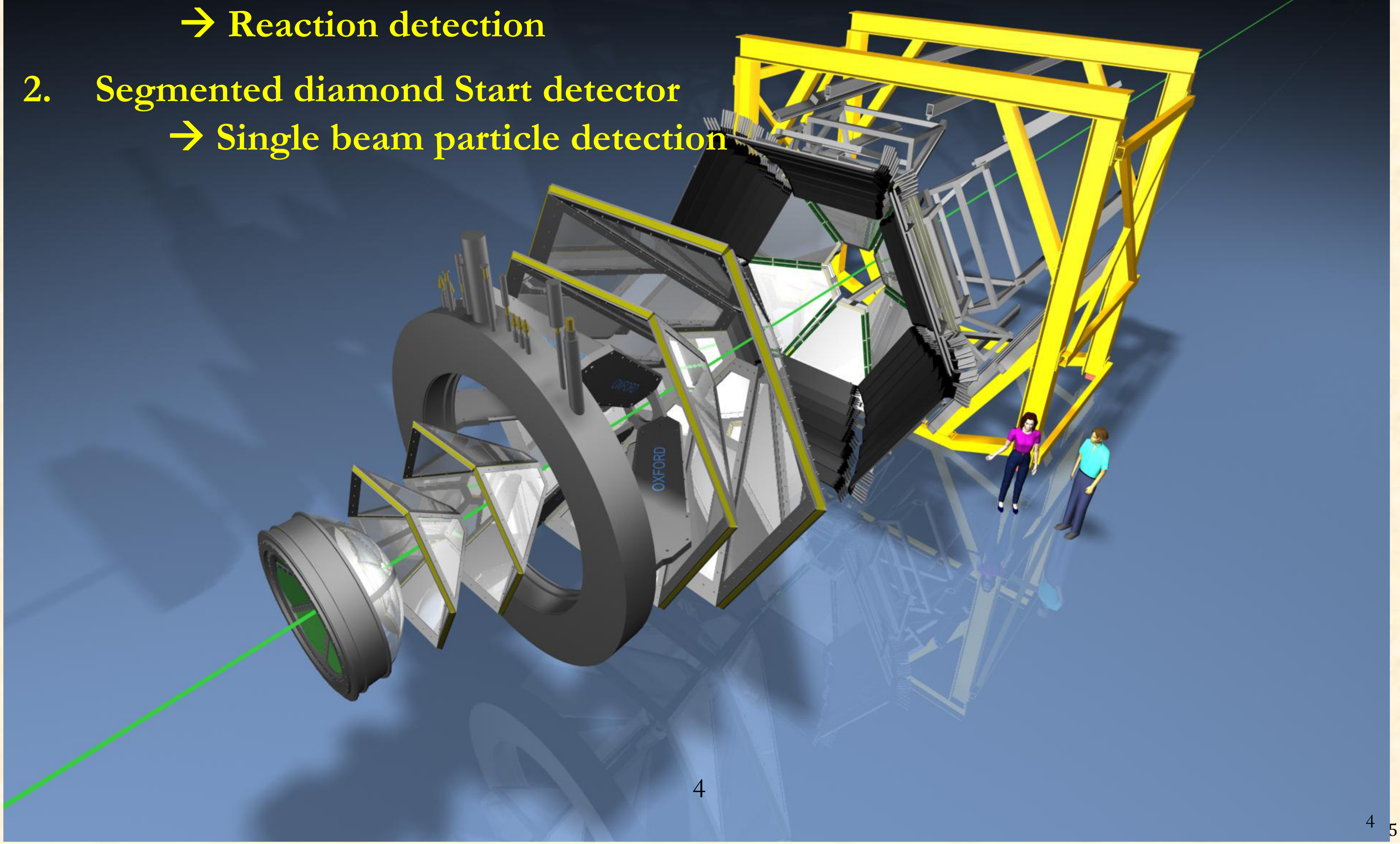
$\gamma \rightarrow e^+e^-$ - conversion

Keep bremsstrahlung and photon conversion on the lowest possible level → reduce X/X_0

Target for Au beam: 2.2 mm diameter , segmented target

Beam monitoring at HADES/CBM @ SIS100
Prototype device tested @ SIS18

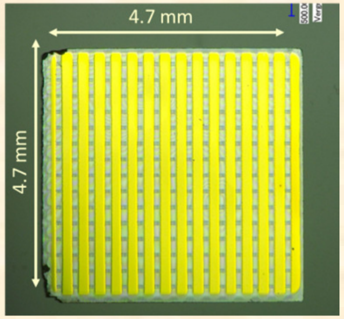
1. Multiplicity in the Spectrometer
   → Reaction detection
2. Segmented diamond Start detector
   → Single beam particle detection

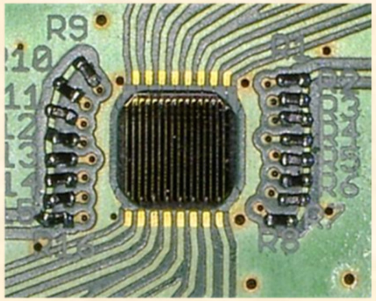


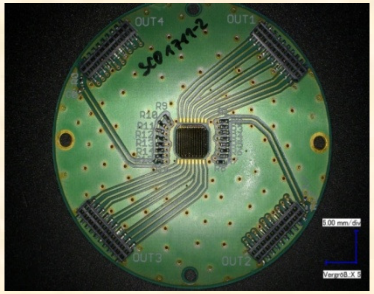
Start detector for CBM/HADES @ SIS100 prototype tested at Au+Au (Apr12)

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







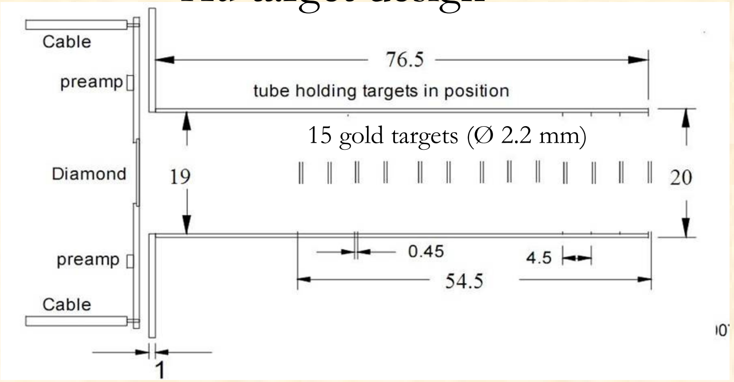
- 16 stripes on each side
- **strip width: 200µm**
- **gap: 90 µm**
- **det. thickness about 60 µm**
- **dedicated electronics:**

  Multihit TDC (17ps)

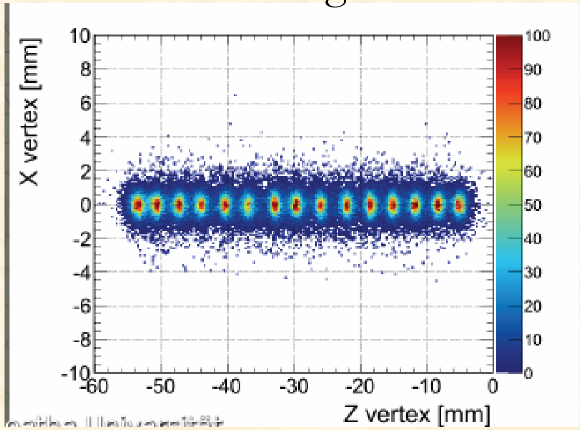
  Det. resolution : 50 ps

Keep bremsstrahlung and photon conversion on the lowest possible level → reduce X/X_0

Au target design

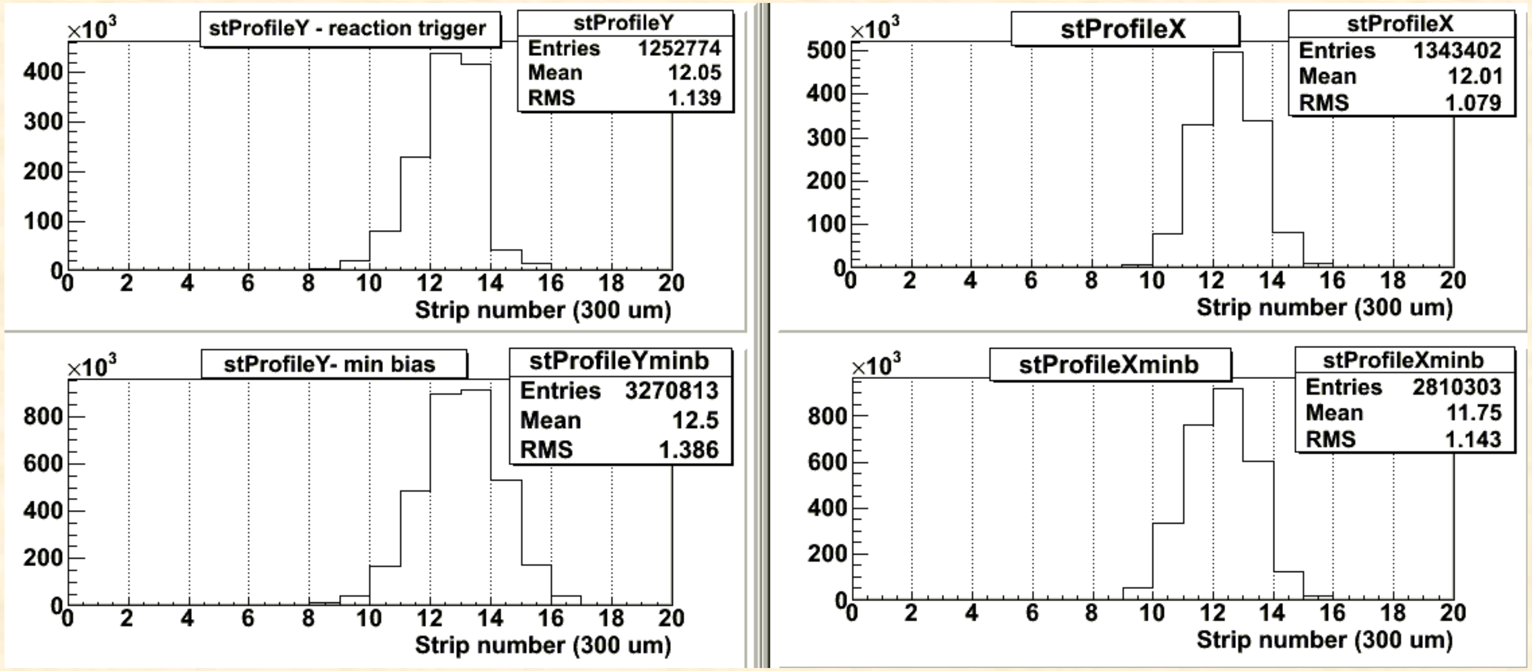


reconstructed target elements



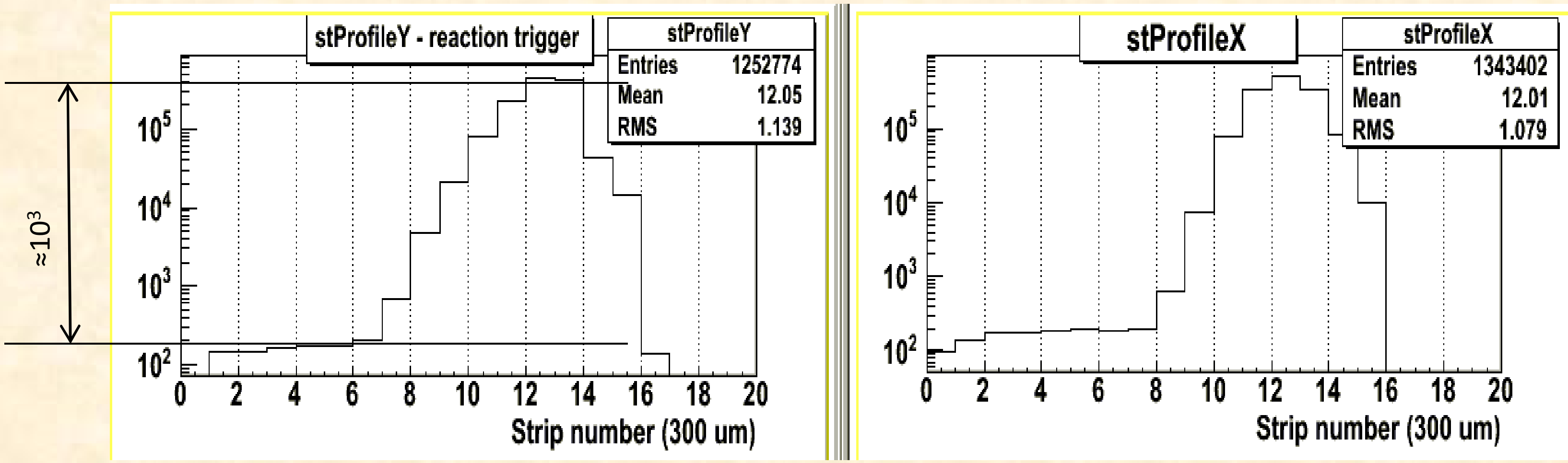
Required size of the beam spot at CBM/HADES @ SIS100 at least as small as at SIS18

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



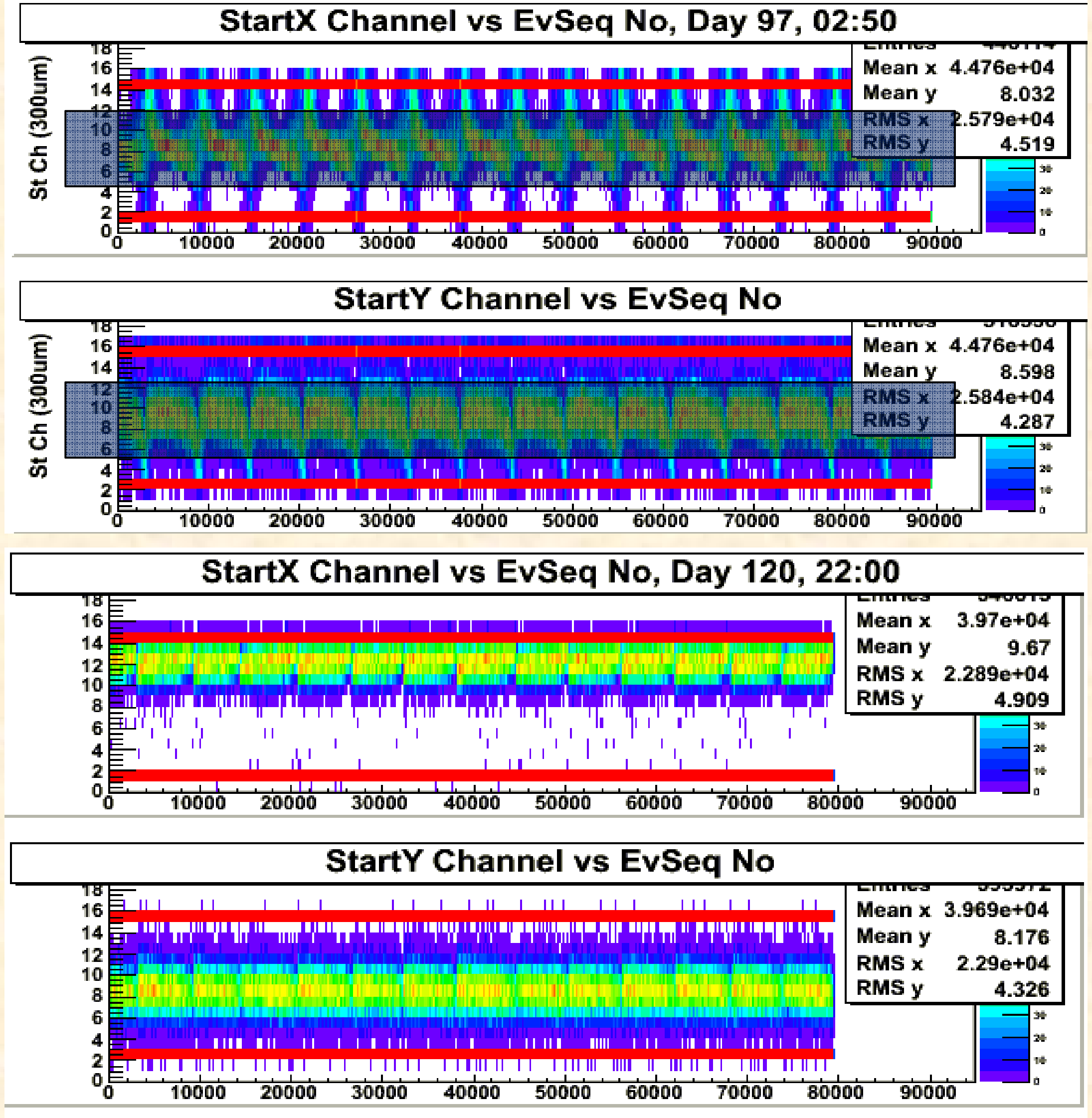
Required beam halo at CBM/HADES @ SIS100 should be lower than at SIS18 (below 10^{-5} at 5 mm away from beam axis)

Beam halo at SIS18 - Au beam Apr12



Requirement for beam position stability during spill – variations smaller than 0.5mm

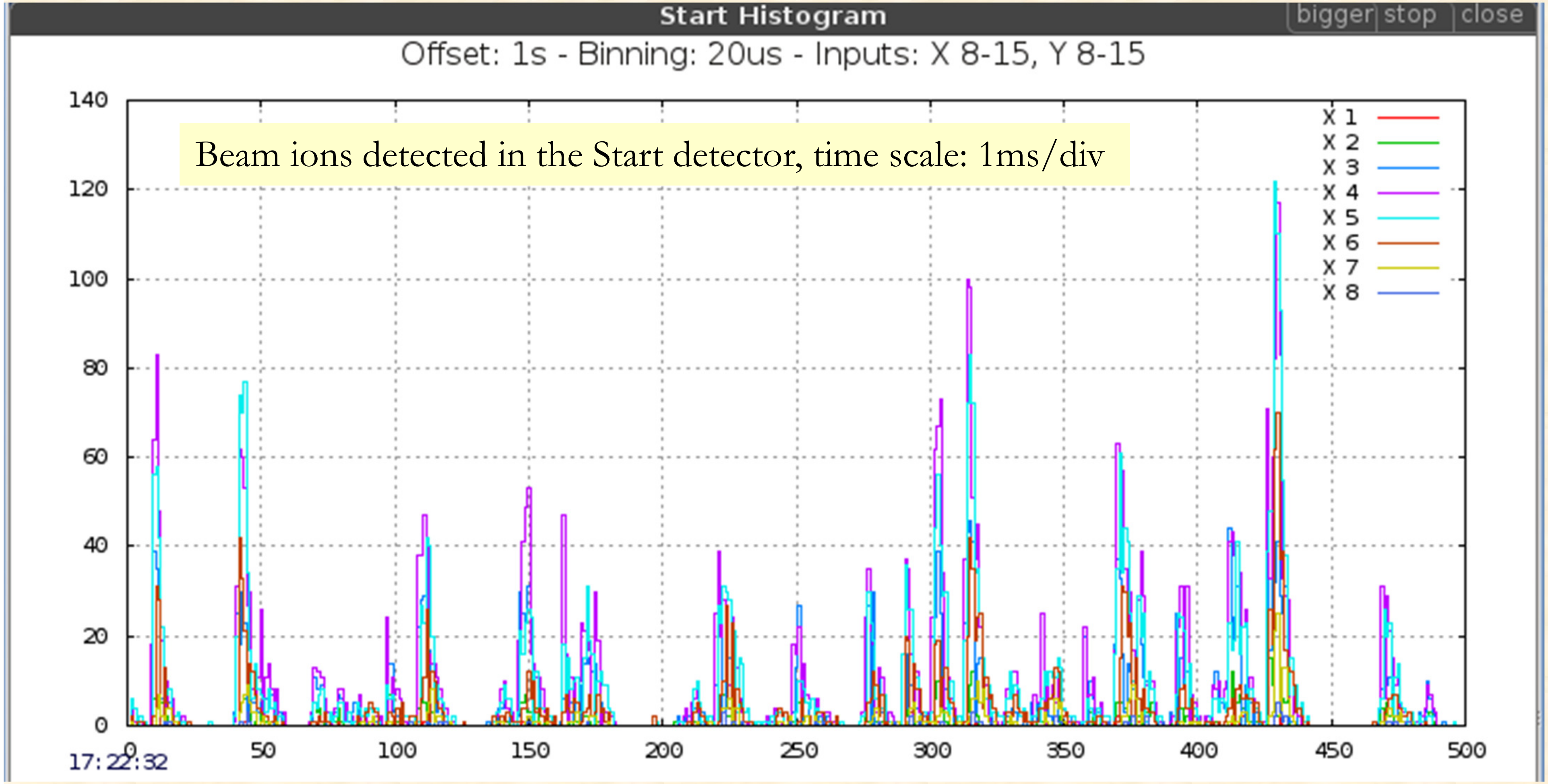
should be much better than at SIS18 – Au beam - Apr12



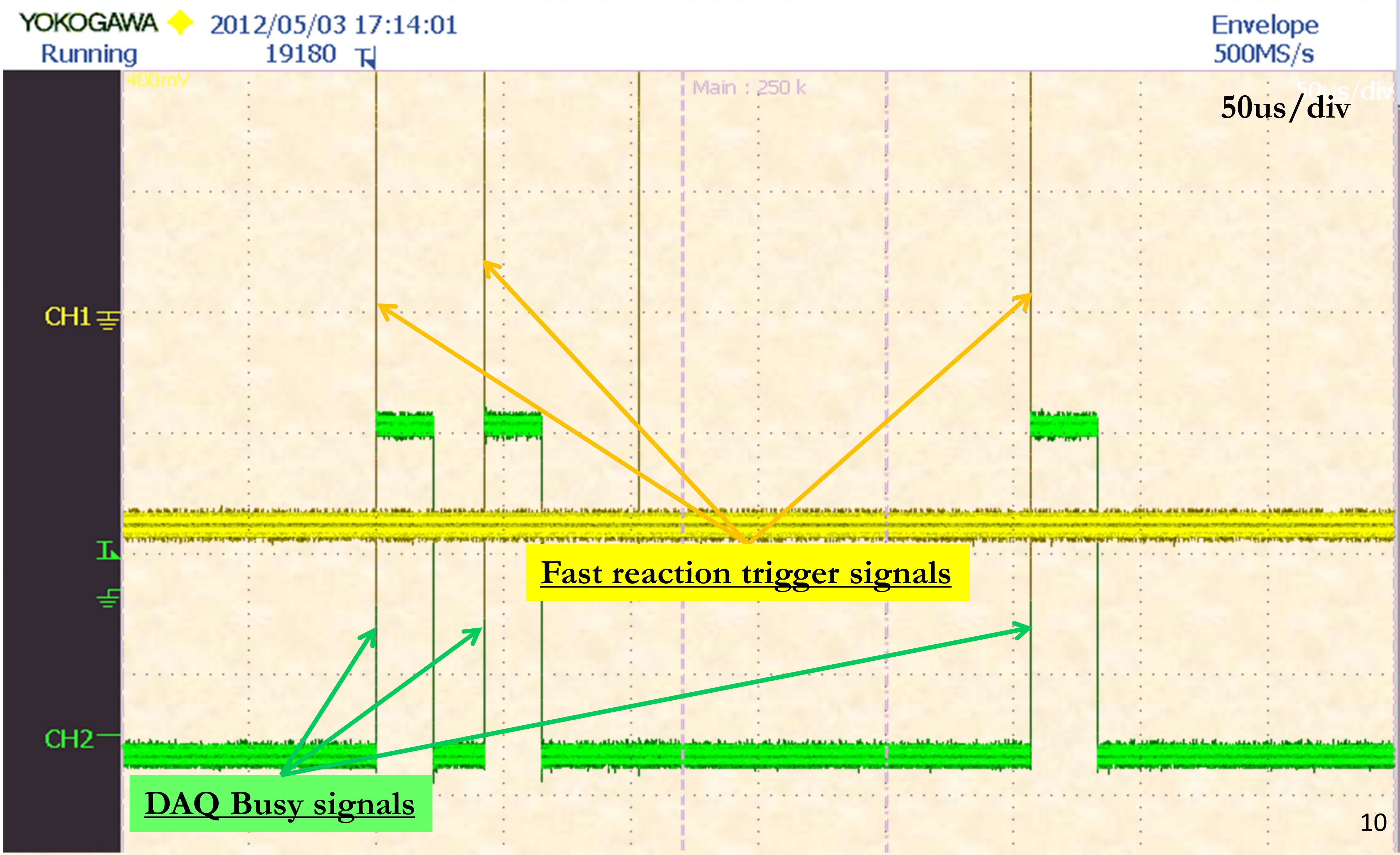
- Significant instability of the beam position in X and Y direction at the target point.
  Mean position change:
  X: ch14-ch4 ($\Delta X \approx 3.0$mm !)
  Y: ch12-ch4 ($\Delta Y \approx 2.4$mm !)

- Several days later - improved beam spot position stability

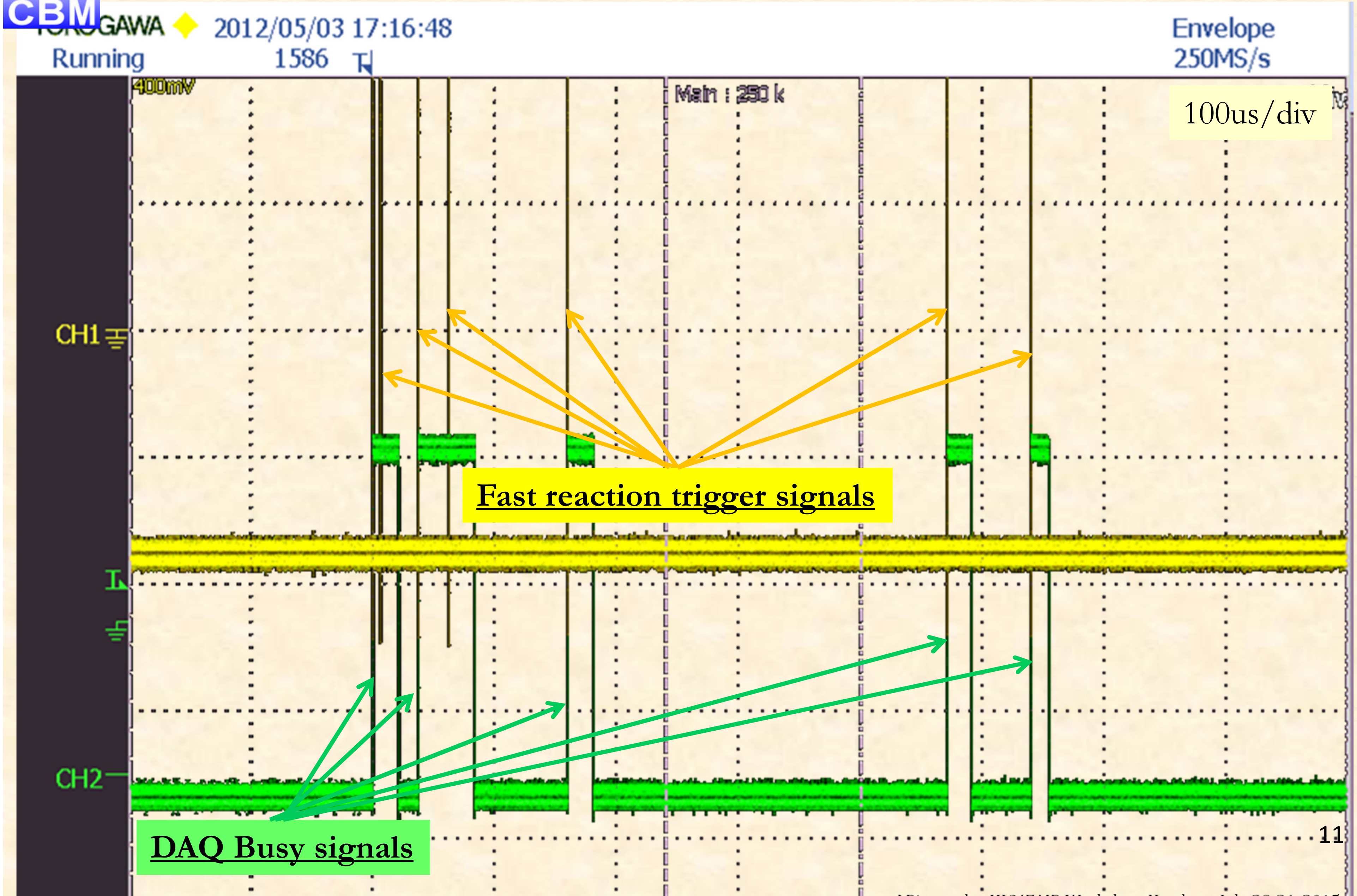
Requirement for time structure of the beam at SIS100 – has to be significantly better than at SIS18



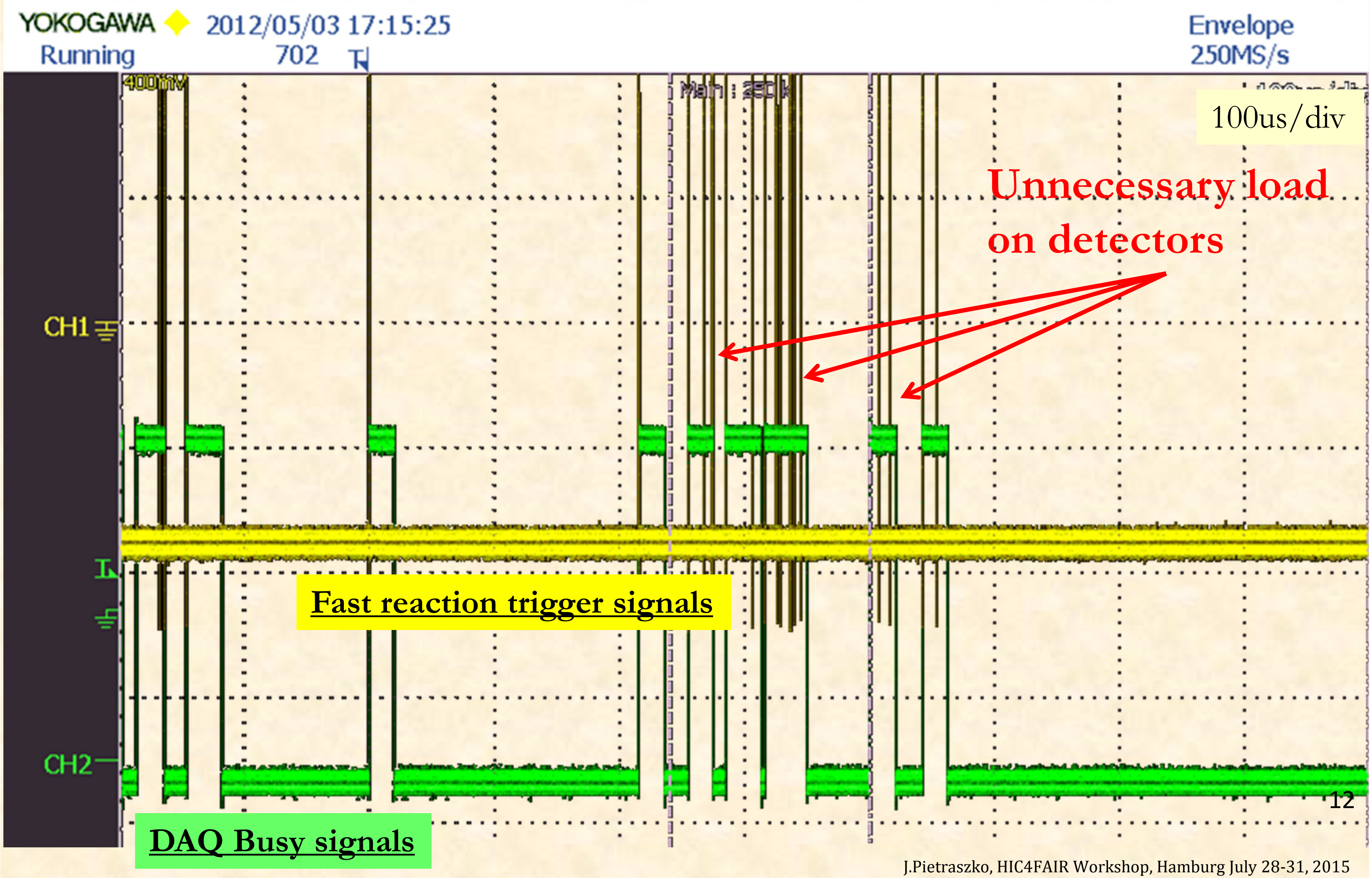
DAQ busy and reaction trigger at 50µs scale



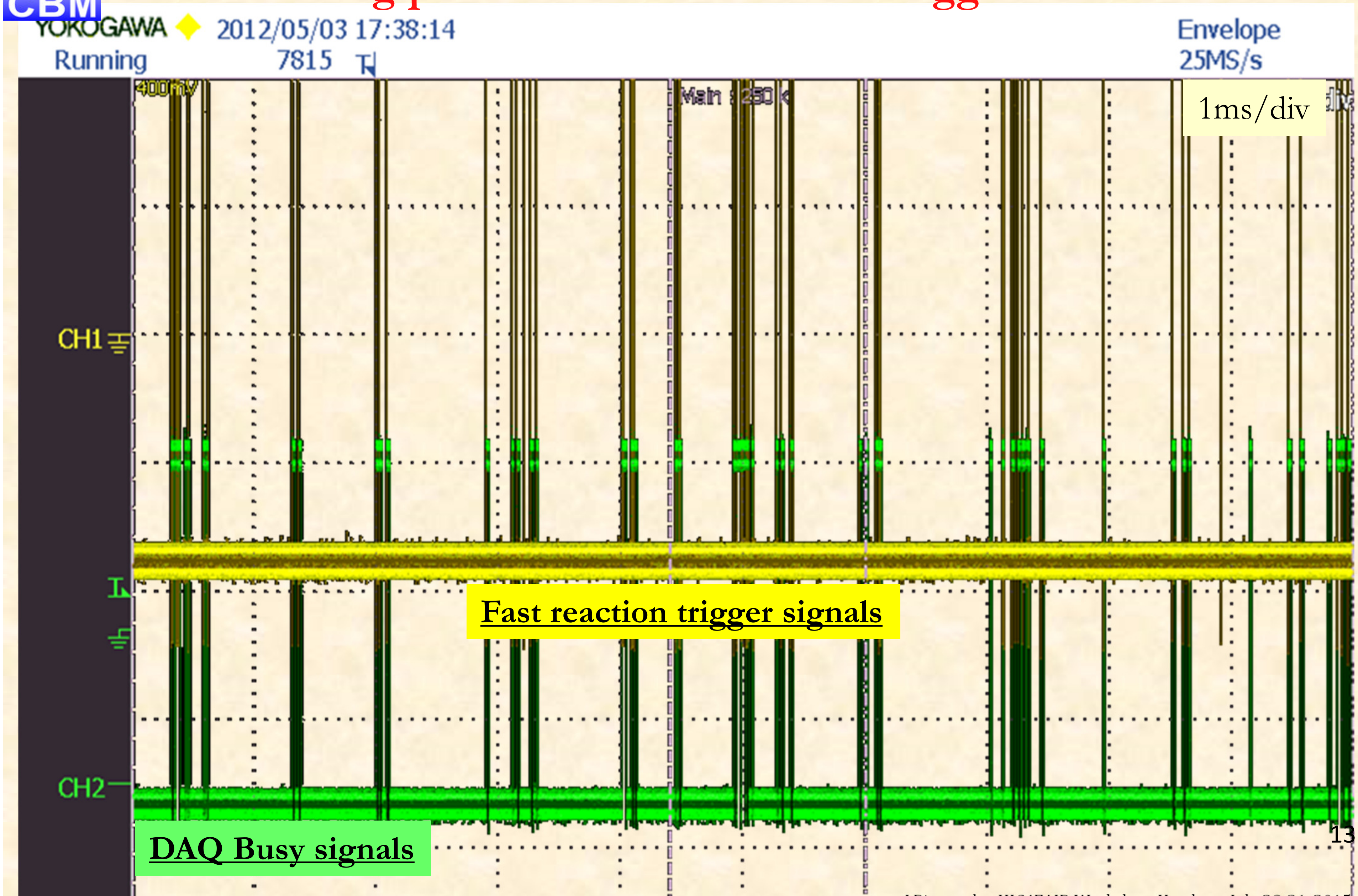
DAQ busy and reaction trigger at 100µs scale



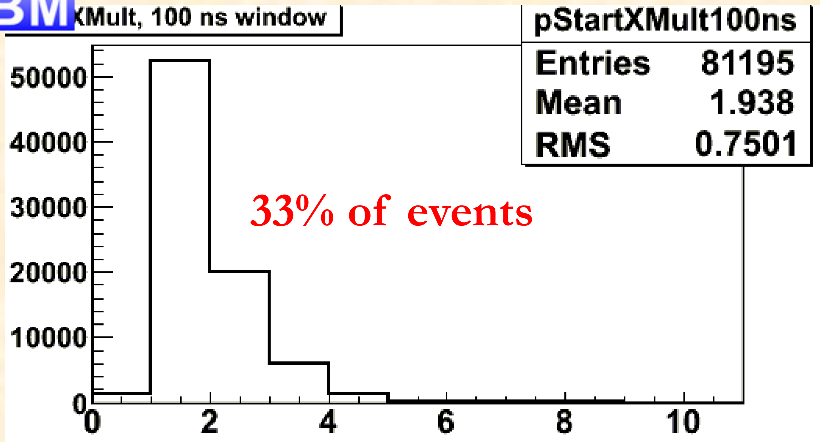
DAQ busy and reaction trigger at 100µs scale
→ long periods without reaction trigger

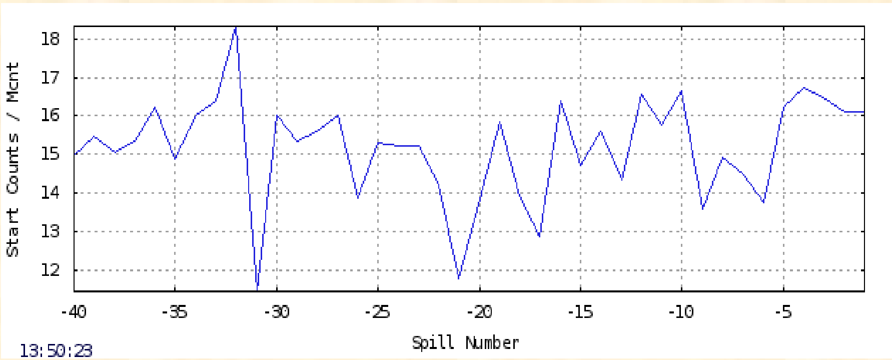


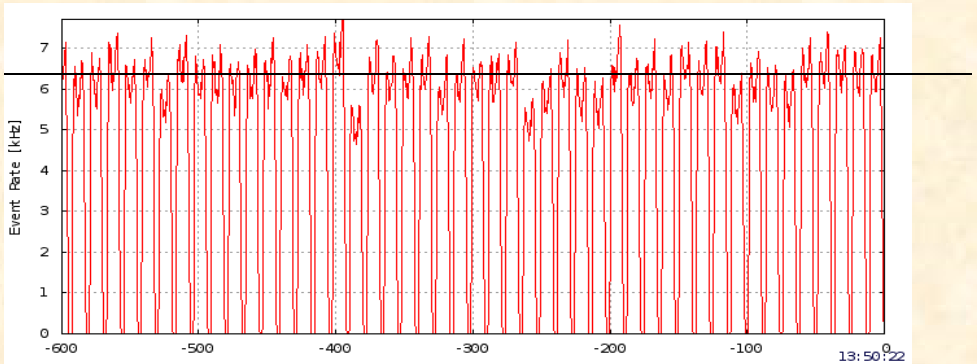
DAQ busy and reaction trigger at 1ms scale
→ long periods without reaction trigger



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

The time structure of the beam – bunched extraction

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

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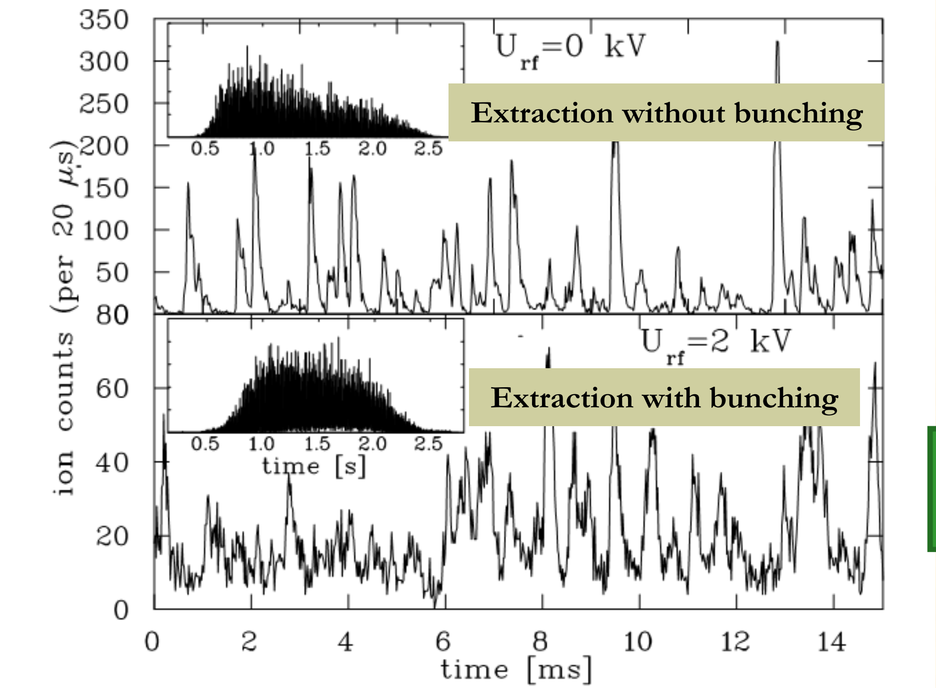
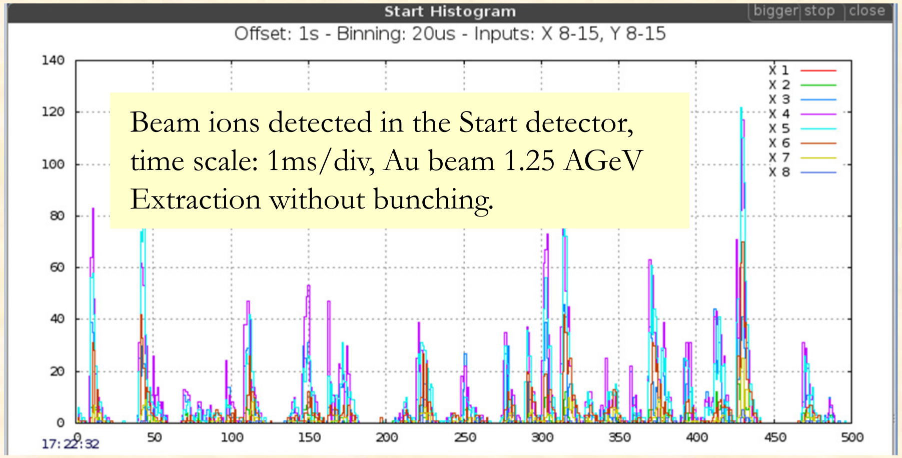
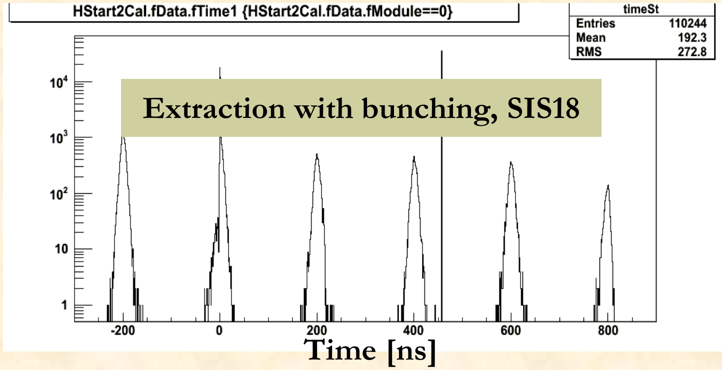
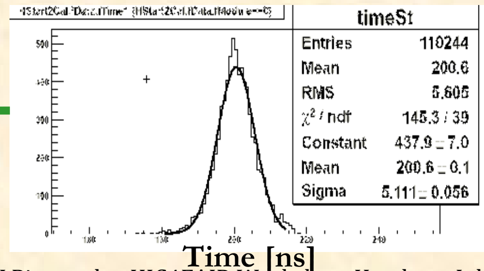
e-mail: p.forck@gsi.de



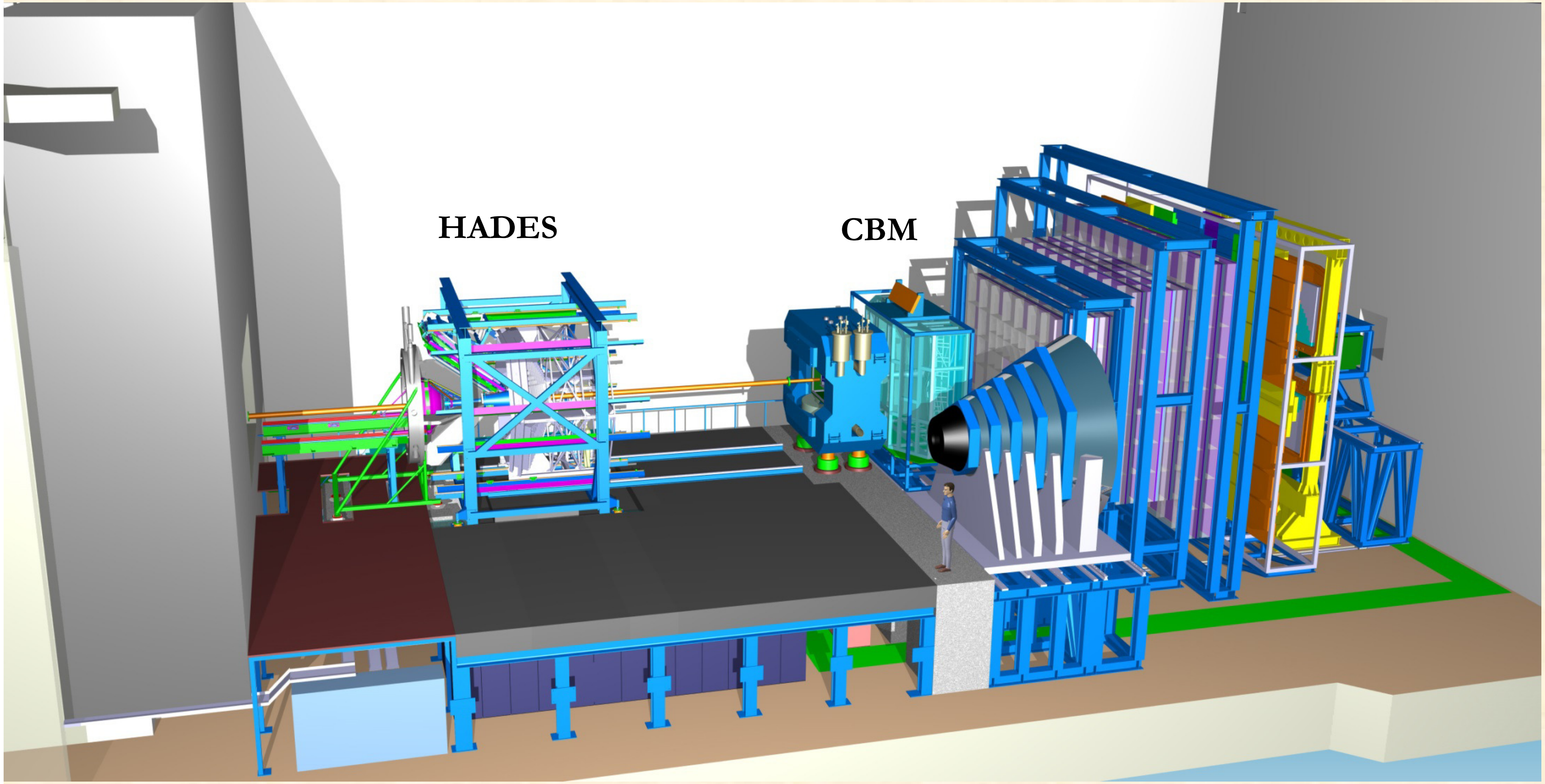




Resonator frequency: 5 MHz
→ Deadly for CBM !!!!
→ we would need more than 40 MHz



CBM/HADES @ SIS100 – experimental area



CBM/HADES @ SIS100 – beam line aperture

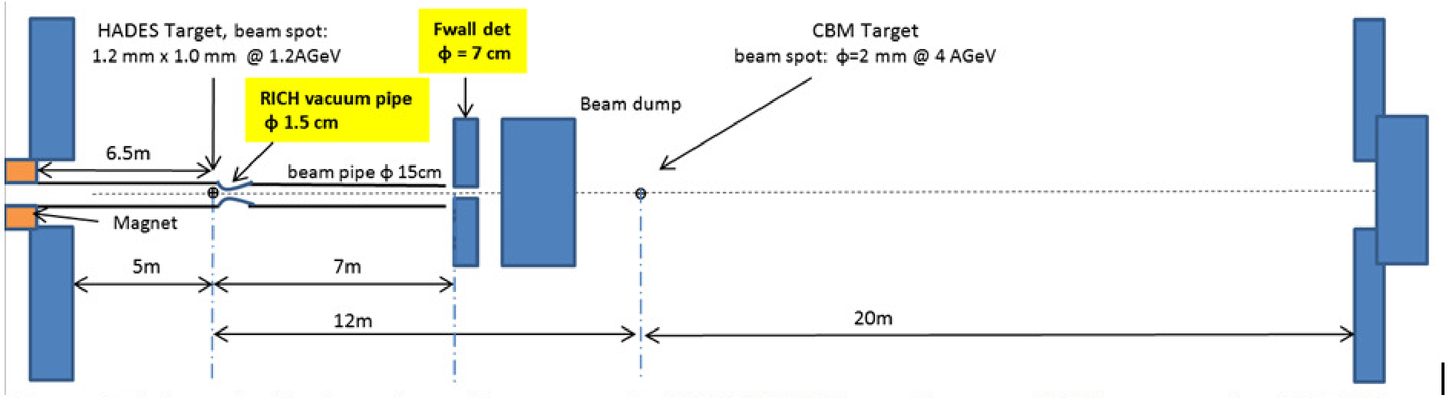


Figure 2. Schematically drawn beam line aperture in HADES/CBM cave (not to scale) for a case when HADES conducts an experiment. The emittance limiting openings are the RICH vacuum pipe and the beam opening in the Forward detector with diameter of about 7 cm.

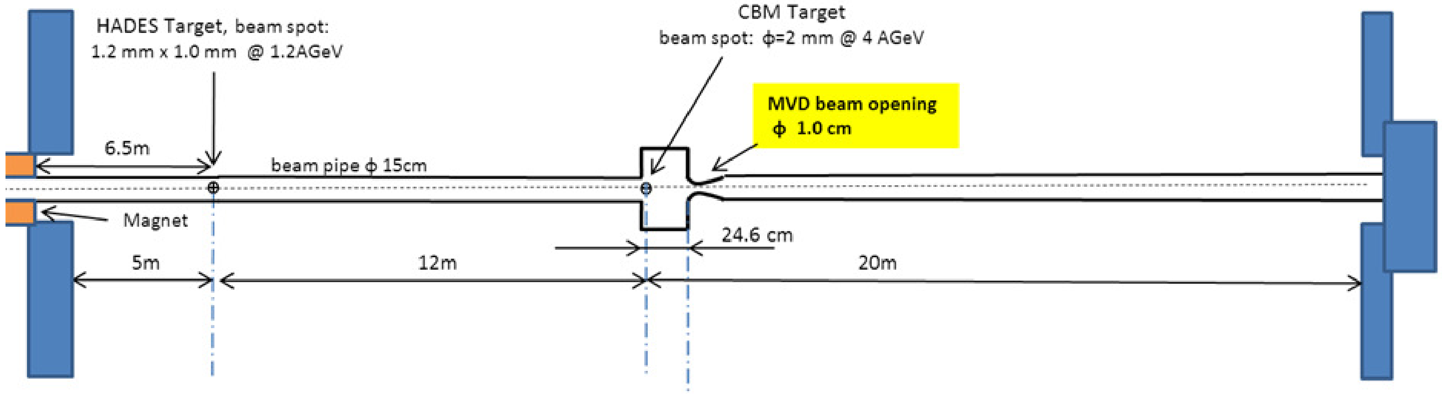


Figure 3. Schematically drawn beam line aperture in HADES/CBM cave (not to scale) for a case when CBM conducts experiments. The requested emittance is constrained by a long distance between the last magnet and a small beam spot on the CBM target.

CBM @ SIS100 – beam emittance requirements

1. Requested **beam spot** at the CBM target point should be smaller than **2 mm** in diameter in both directions (99.73 % of the beam) for beam energies above 4 AGeV.
2. **CBM beam divergence:**
   The beam divergence in case of the CBM experiment is fixed and constrained by a long distance between the last focusing magnet and the focal point which is 17 meters. Only 70% of the beam line aperture will be filled. Based on fixed geometrical constrain the beam divergence can not be larger than 6 mrad.
3. **The CBM beam line aperture**: the smallest opening in the CBM beam line is located at the first MVD plane, at the distance of 10.0 cm from the focal point, and is 1.0 cm in diameter. The beam line aperture in front of CBM target is fixed and is 15 cm.
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.

Emittance conventions used in this document:

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 @ 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.

Emittance conventions used in this document:

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 $(1/\beta\gamma)$.

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

Beam energies requested for HADES at SIS100

Isotope	Energies [AGeV] min-max	beam intensity in spill / s
p	5 – 15	10^8 /s
^{12}C	3 – 14	$2 * 10^7$ /s
^{40}Ca	3 – 14	10^7 /s
^{58}Ni	2[1] – 13	10^7 /s
^{107}Ag	2[1] – 6	$8 * 10^6$ /s
^{197}Au	2[1] – 4	$4 * 10^6$ /s

Table 1. A list of proposed beam isotopes, energies and requested beam intensities for HADES at SIS100 experiments. Other spherical or nearly spherical isotopes can be considered for experiments as well.

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

Examples 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 abort system in included in the SIS100 design

Summary

- ✓ Precise beam diagnostic at the experimental focal point:

  at SIS18 – exist, at SIS100 will be provided

- ✓ Significant data quality loses because of micro-spill structure and beam instability should be avoided at SIS100

  → reduced data quality and rate capability !

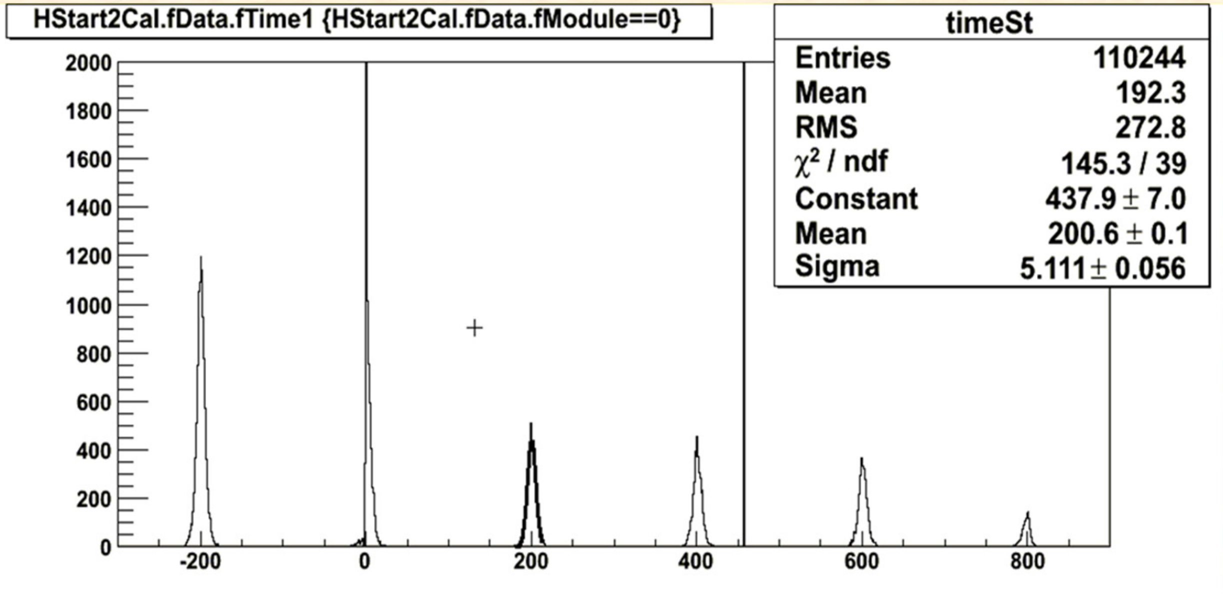
  → load on detectors !

  → Not acceptable for CBM (10^7 interactions/s)

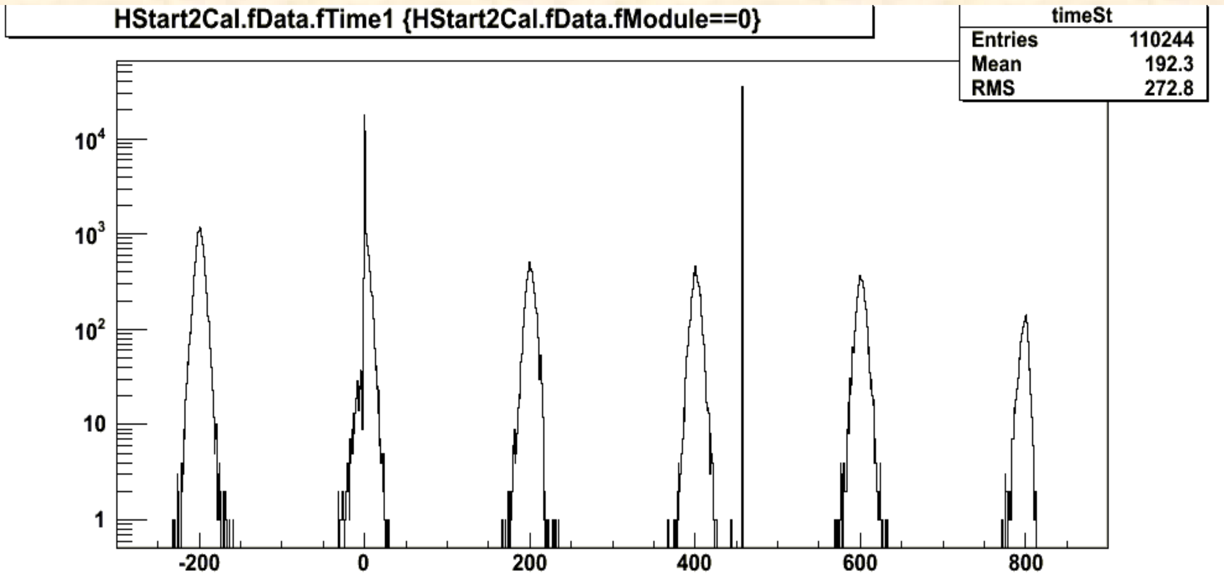
  → Consequences for HADES@SIS18 will be shown on Friday

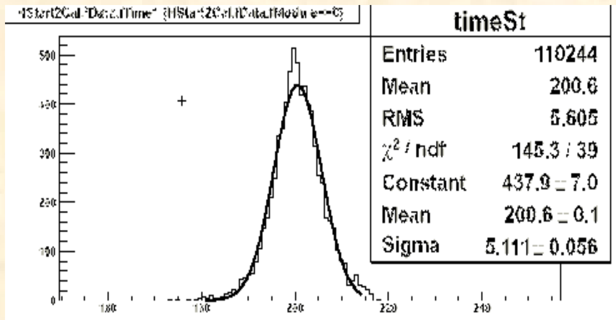
- ✓ Beam requirements for CBM@SIS100 based on realistic SIS18 results.
- ✓ Beam abort system essential for safe detector operation at SIS100.
- ✓ FAIR document summarizing experiment requirements proven by accelerator experts:

"FAIR Operation Modes - Reference Modes for the Modularized Start Version (MSV)" - status ?

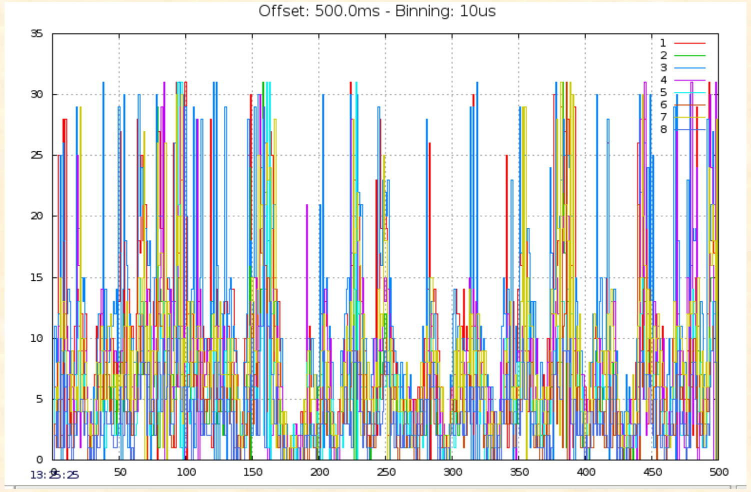


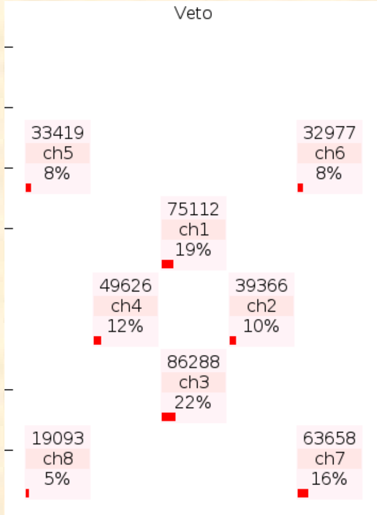
Start Cal level, everything in ns.



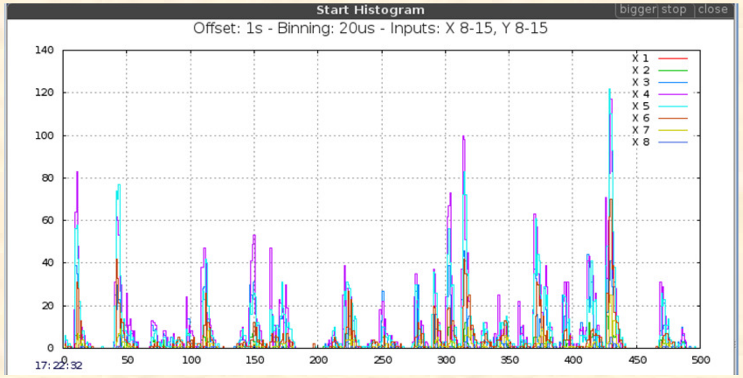


Bunched beam





Standard beam extraction



HADES@SIS18 (before SIS100 era) – experimental strategy

- **Request one run per year with a minimum of four weeks beam on target** for production, high statistics and precision measurements
    - Rare probes (strangeness, dileptons)
    - Excitation functions (beam energy scans)
- **Long set-up times of the experiment**, mainly beam transport and optimization
    - how this can be reduced ?
- **Major statistics and data quality losses due to**:
    - parasitic users
    - changes in UNILAC settings seem to influence extraction efficiencies
    - ion source changes during a run

- **No production experiment request before second half of 2018**
    - Upgrades not finished before

HADES@SIS18 – pion beam in 2014

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.

HADES@SIS18 – feature goals for pion beam at SIS18

Goal: maximize π - flux on the HADES target

Current limitations come from radiation issues, therefore:

- optimize extraction efficiency - what can be done to substantially increase this efficiency?
- optimize transfer line efficiency
- enlarge aperture where necessary
- reduce activation of magnets in front of the pion production target
- improve on shielding of magnets in NE5
- improve substantially on the shielding of the NE5 roof (includes redoing the water cooling solder joints of the magnets in the pion production cave)
- better and more granular monitoring of the radiation level
- better beam line monitoring
- diagnostic of beam profile near the production target
- improve predictions from Mirco to calculate the beam line settings

Stable running conditions with respect to radiation safety alarms

Dual harmonics, More bunches in SIS at space charge limit

HADES beam line controllable with new control software

Is there successor of MIRCO ?

HADES@SIS18 – primary beams in HADES: p/HI

Proton case:
Highest proton beam momentum which can be used for stable runs
In theory it should be $0.3 \times 18 = 5.4$ GeV/c corresponding to 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
but with the requirement of a 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 (without using HADES-detectors).
- More/better beam diagnostic elements in our beam line → reliable and fast beam line setting (without the best experts around)