On the Status of the Longitudinal Emittance Measurement at the UNILAC

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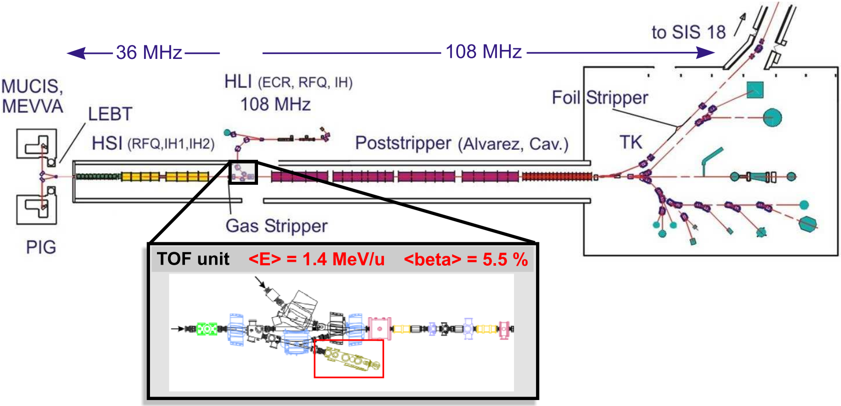
B/SD Group Seminar 02/11/10

February 15, 2010

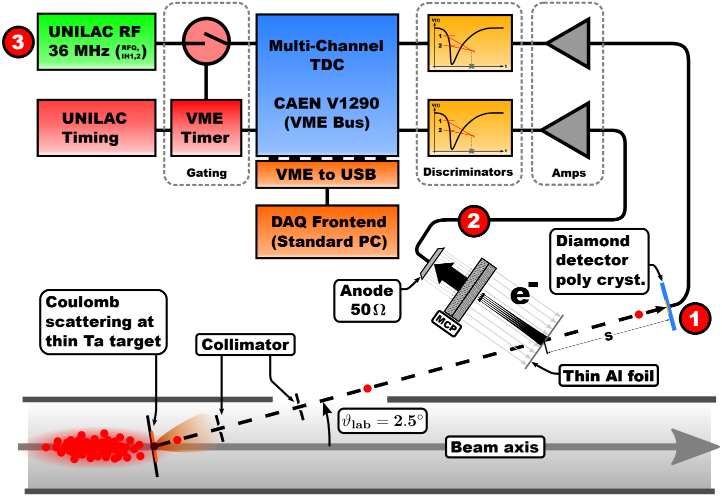
Outline

- Overview of the measurement setup
- Estimation of systematic errors
- Affect of a limited resolution on measured beam parameters
- Recent measurements
- SC Diamond and Post-Processing

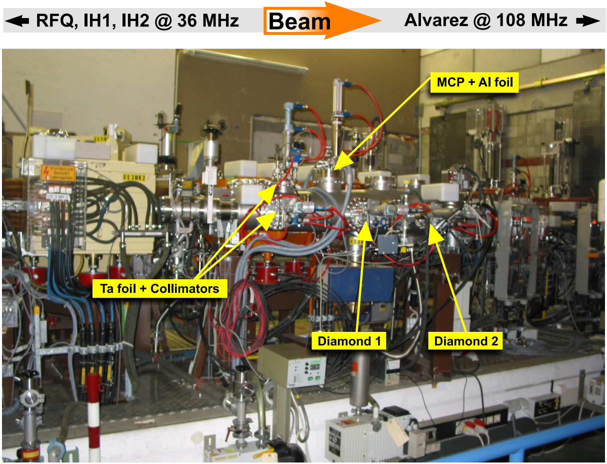
UNILAC Site


36 MHz
108 MHz
to SIS 18
MUCIS,
MEVVA
LEBT
HSI (RFQ,IH1,IH2)
HLI (ECR, RFQ, IH)
108 MHz
Foil Stripper
Poststripper (Alvarez, Cav.)
TK
Gas Stripper
PIG
TOF unit <E> = 1.4 MeV/u <beta> = 5.5 %

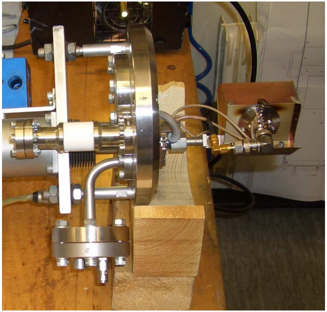
Schematic operation



Setup/Installation

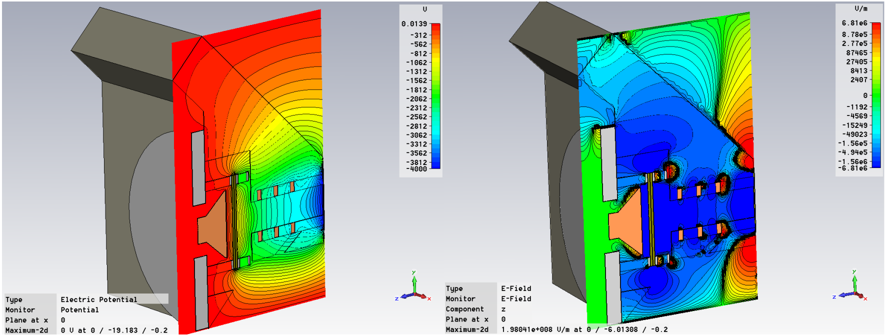


MCP (Multi Channel Plate)

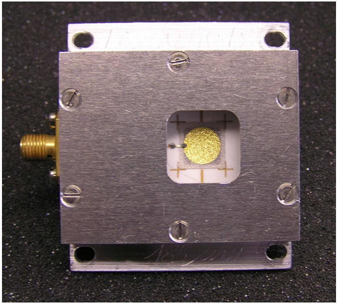


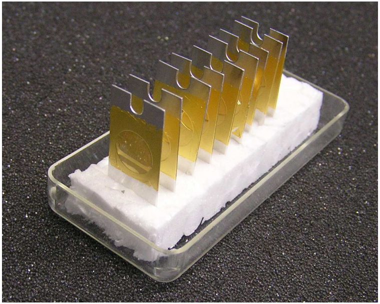
MCP (50 Ω setup) & assembled MCP actuator

MCP CST EM Field Simulation



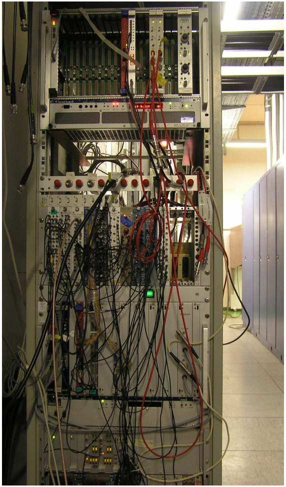
Foils & Diamond detector

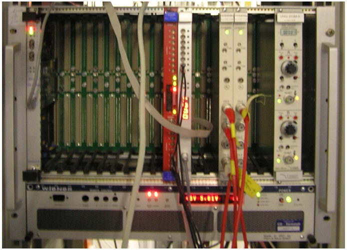




Diamond detector & Au foils (exemplar)

DAQ





Redesigned DAQ (2007)

- VME to USB interface, TDC (CAEN V1290), timing module, 3 HV supplies.

TDC Benchmark

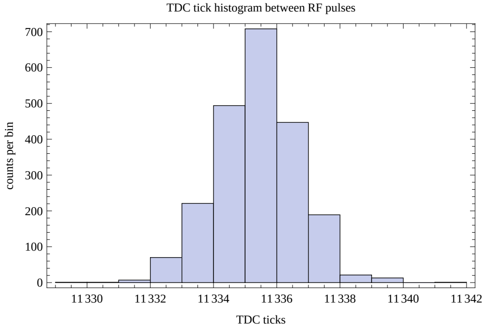
TDC (CAEN V1290):

- LSB of ≈25 ps.
- RMS resolution 35 ps typical.

Timing tests:

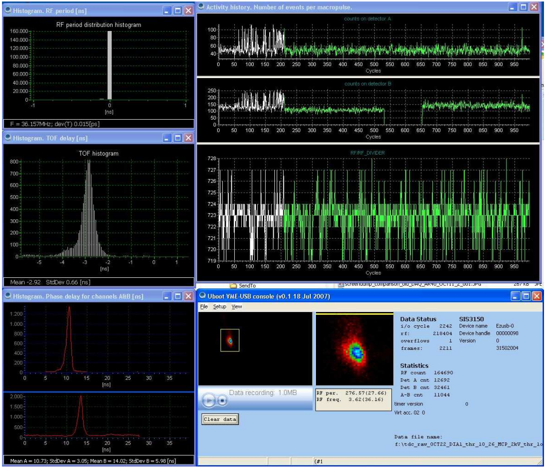
$\mu = 11334.9$ ticks $\widehat{=}10$ rf periods

$\sigma \simeq 1.32$ ticks $\widehat{=}32.25$ ps



Ticks during UNILAC rf periods (36.136 MHz, rf divider 10).

DAQ GUI


Histogram. RF period [ns]
RF period distribution histogram
F = 36.157MHz; dev(T) 0.015[ps]
Activity history. Number of events per macropulse.
counts on detector A
Cycles
counts on detector B
Cycles
RF/RF_DIVIDER
Cycles
Histogram. TOF delay [ns]
TOF histogram
Mean -2.92 StdDev 0.66 [ns]
Histogram. Phase delay for channels A&B [ns]
Mean A = 10.73; StdDev A = 3.05; Mean B = 14.02; StdDev B = 5.98 [ns]
Uboot VME-USB console (v0.1 18 Jul 2007)
File Setup View
Data recording: 1.0MB
Clear data
RF per. 276.57(27.66)
RF freq. 3.62(36.16)
Data Status
i/o cycle 2242
rf: 218404
overflows 1
frames: 2211
SIS3150
Device name Ezusb-0
Device handle 00000098
Version 0
31502004
Statistics
RF count 164690
Det A cnt 12692
Det B cnt 32461
A-B cnt 11044
timer version 0
Virt acc. 02 0
Data file name:

Primary Beam Attenuation Stage

Primary beam usually contains $> 10^9$ particles per bunch.
Beam attenuation is required due to

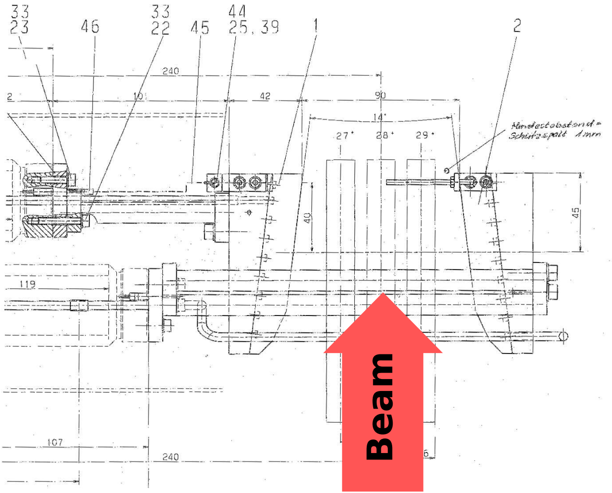
- sensitive foils (Ta 210 $\mu g\ cm^{-2}$, Al 9 $\mu g\ cm^{-2}$)
- required unambiguous coincidence condition, i.e. *rarely* more than one particle per micro pulse.

Primary Beam Attenuation Stage

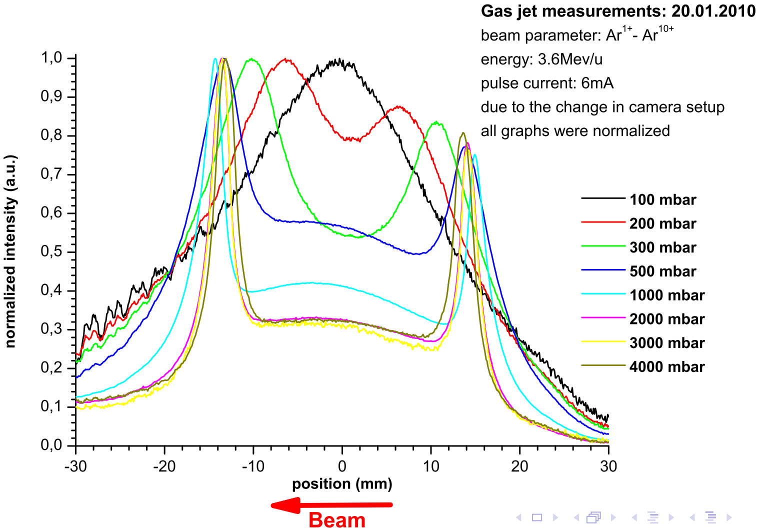
Current moderation down to several μA (20 μA typical):

- Low/Zero current:
  - Defocusing of the primary beam by quadrupole magnet in front of the RFQ section.
  - Selection of a suitable charge state after stripping.
- High current (space charge effects):
  - Adjustment of the gas pressure inside the stripper section.
  - Selection of a suitable charge state after stripping.
  - High current slits acting as horizontal scraper.

High Current Slits DS4, DS5 (horz. plane)



Stripper: Gas Jet Profile (BIF)

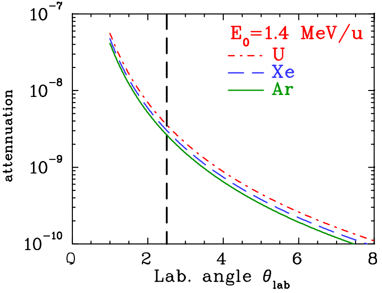


Secondary Beam Attenuation Stage: Particle attenuation via Coulomb scattering

- Coulomb scattering via Ta foil
- Two collimators mounted to satisfy a scattering angle of 2.5°.

- Rutherford cross section:
$$\sigma_{Lab} = \left(\frac{Z_1 Z_2 e^2}{4E_C}\right)^2 \cdot \frac{1}{sin^4 \frac{\theta_C}{2}}$$

- Attenuation:
$$\frac{N_{det}}{N_{bunch}} = \sigma_{Lab} \cdot d_{tar} \cdot \left(\frac{r_{col}}{r_{beam}}\right)^2 \cdot \delta\Omega$$



Constructing the Phase Space from Time Stamps

2-dim histogramming using time stamps from MCP, Diamond and UNILAC rf.

- Spatial phase information from arrival time at Diamond with respect to UNILAC rf.

$$\Delta t_i = t_i^{DIA} - t_{rf}$$

- Energy/Momentum information from TOF between MCP and Diamond (80 cm).

$$\Delta E_i \approx \frac{d}{dt} E(t)\Big|_{t_{\langle E \rangle}} \cdot \Delta t_i = -2 \frac{\langle E \rangle}{t_{\langle E \rangle}} \cdot \Delta t_i^{TOF}$$

$$\Rightarrow \frac{\Delta E}{\langle E \rangle}_i \approx -2 \frac{\Delta t_i^{TOF}}{t_{\langle E \rangle}} = -\frac{2\beta c}{d_{TOF}} \cdot \left(t_i^{DIA} - t_i^{MCP} \right)$$

Twiss Parameter - Short Overview

Integral statistic parameter to describe the beam.

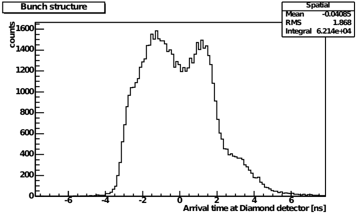
$$\varepsilon_{(rms)} = \sqrt{\langle x^2\rangle\langle y^2\rangle - \langle xy\rangle^2} \quad \text{RMS-Emittance}$$

$$\alpha = -\frac{\langle xy\rangle}{\varepsilon} = -\frac{cov(x,y)}{\varepsilon} \quad \text{Correlation}$$

$$\beta = \frac{\langle x^2\rangle}{\varepsilon} = \frac{\sigma_x^2}{\varepsilon}$$

$$\gamma = \frac{\langle y^2\rangle}{\varepsilon} = \frac{\sigma_y^2}{\varepsilon}$$

Typical Measurement Example



file name: hippia1_005.cor

<E>: 1.41 MeV/u β: 0.055

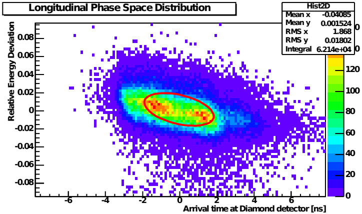
automatic Viewport boundaries
raw event data
integral count: 62960
bin size horizontal: 5 [LSB/TDC]
bin size vertical: 3 [LSB/TDC]

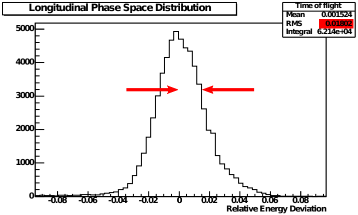
ε_{rms}: 42.96 keV ns
α: 0.467
β: 0.0812 ns / keV
γ: 15 keV / ns

Expected

$\alpha \approx 4$

$\sigma_E \approx 0.0092$

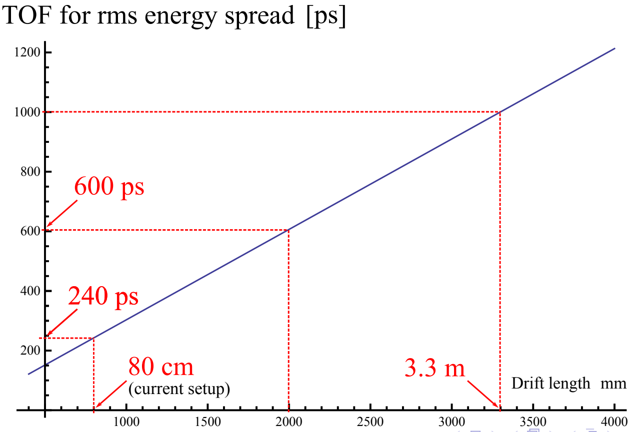




40AR 6.5 mA (60k events)

Getting a glance of the required Time Resolution

Difference in TOF between a *design* particle at 1.4 MeV/u and a particle that deviates 1% (expected RMS) vs. detector separation.



Systematic Errors

The systematic error can be coarsely grouped into two categories.

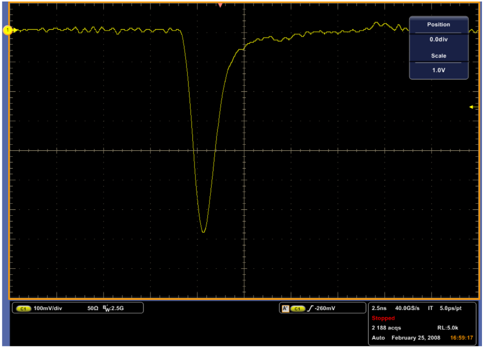
- Time resolution of detectors and electronic modules.
- *Physical* Phase Space distribution affected by the working principle of the device.

Systematic Contributions from Detectors and Electronics

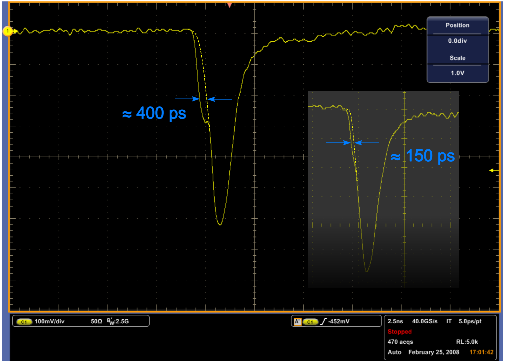
- TDC jitter per input link.
- Pulse shape discrimination jitter (walk, rise-time, edge distortions) from MCP and Diamond.
- Tilted Al-foil in front of MCP (37.5°) results in a spread in drift length which is used to determine the time-of-flight.
- Extension of Diamond electrode (8 mm) causes a jitter due to signal propagation depending on the location where a particle hits the electrode.
- Velocity distribution of emitted secondary e^- (MCP module).
- Anything major is missing?

MCP signal shape - The Beauty

- Expected sane shape of MCP signal.
- Height varies between 300mV to 1.2V.

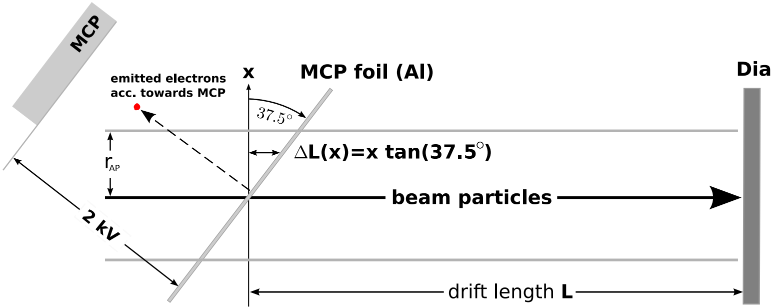


MCP signal shape - And the Beast(s)



RMS jitter is difficult to estimate since no monochromatic beam is available with $\frac{\Delta E}{\langle E \rangle} \ll 1\%$ that would allow a measurement of the pulse response.

Tilted Al Foil inside MCP Module



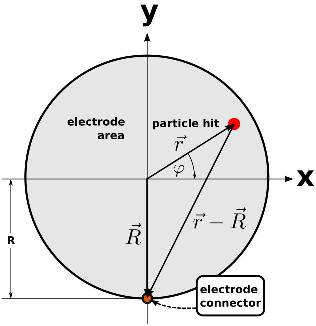
$\sigma_{\Delta L} = \frac{tan\varphi}{\sqrt{3}} r_{AP}$. r_{AP} is the effective aperture depending on the separation of the MCP and Diamond detector. For the current setup where the separation is 80 cm this contribution can be calculated as $\approx$ 25 ps.

Signal Propagation on Diamond Electrode

R=4 mm, Signal propagation ≈ c

$$\sigma_{|\vec{r}-\vec{R}|} = \frac{\int_0^R r dr \int_0^{2\pi} d\varphi \left(\langle|\vec{r}-\vec{R}|\rangle - r\sqrt{cos^2\varphi + \left(sin\varphi + \frac{R}{r}\right)^2} \right)^2}{\int_0^R r dr \int_0^{2\pi} d\varphi}$$

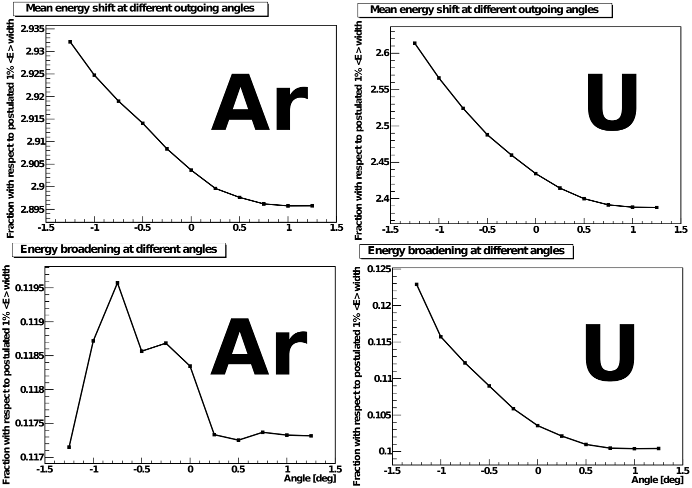
$$\Rightarrow t_{\sigma_{|\vec{r}-\vec{R}|}} = \frac{\sigma_{|\vec{r}-\vec{R}|}}{c} \approx 11 \text{ ps}$$



Systematic Contributions from affected Phase Space

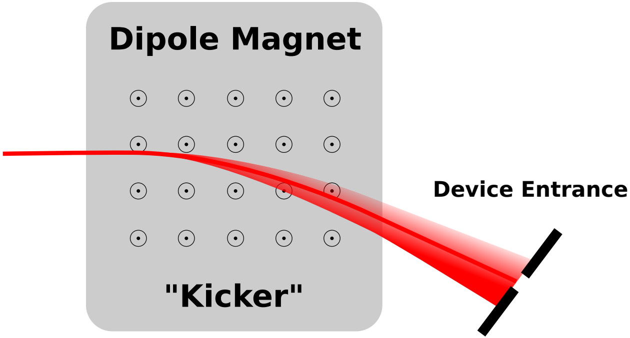
- Straggling contribution in Ta and Al foil (Electronic Stopping).
- Energy dependent scattering angle at Ta foil (finite solid angle).
- Attenuation via gas stripper and slits.
- T-L coupling in dispersive dipole section.
- Inhomogeneities in Ta and Al foil.
- Again, anything major is missing?

Electronic Stopping SRIM calculations (Ar, U)

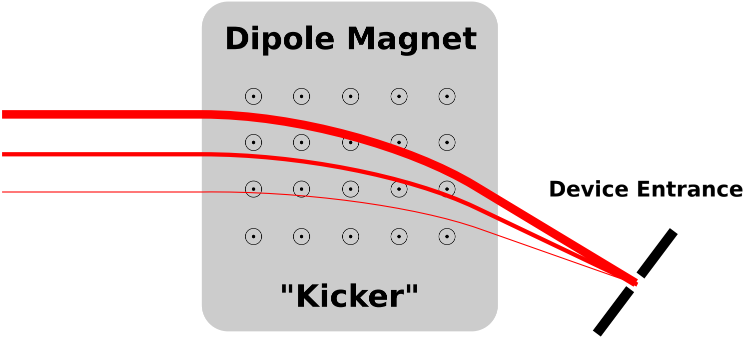


Dispersive Section - Dipole ("Kicker")

The Lorentz Force... $\vec{F}_L = q \cdot \left(\vec{E} + \vec{v} \times \vec{B} \right)$



Coupling of Transversal and Longitudinal Phase Space



Coupling of Transversal and Longitudinal Phase Space

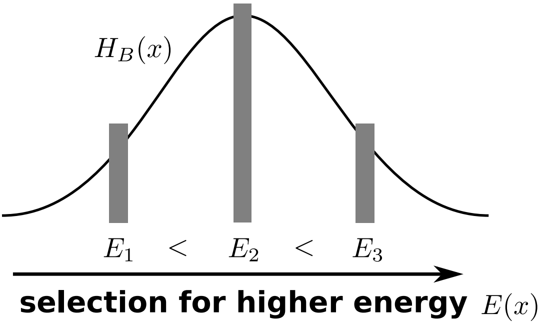
Can we treat the longitudinal and transversal Phase Space as decoupled degrees of freedom?

$$P(x, x', y, y', p, \varphi) \stackrel{?}{\approx} P(x, x', y, y') \otimes P(p, \varphi)$$

Even if we can - does that mean the dispersive section does *not* spoil the game?

T-L Decoupled Phase Space

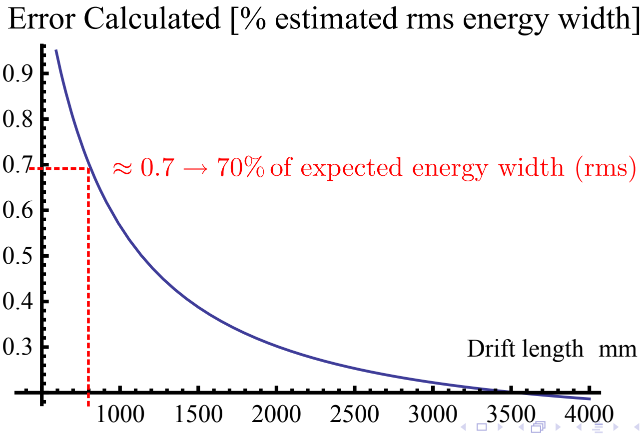
$H_B(x)$: Transversal, horizontal beam profile



$$I_m(E) = H_B(x(E)) \cdot I_{Long}(E)$$

Making an Estimate on Time Resolution from Systematic Effects

Taking into account all systematic effects that can be pinned down.



Limited Resolution in a Gaussian Model Space

- Consider a 2-dim Gaussian phase space distribution given by Twiss parameters $\{\alpha, \beta, \gamma, \varepsilon\}$

$$G(x, y; \alpha, \beta, \gamma, \varepsilon) = \frac{1}{2\pi\varepsilon} e^{-\frac{1}{2\varepsilon}\left(\gamma x^2 + 2\alpha xy + \beta y^2\right)}$$

- Assume a systematic *Gaussian pulse response* (for now y only)

$$g(y; \sigma_{res}) = \frac{1}{\sqrt{2\pi}\sigma_{res}} e^{-\frac{y^2}{2\sigma_{res}^2}}$$

Convolved Phase Space Distribution

- Allows qualitative analytic investigations on how *measured* Twiss parameters are affected by means of a convolution

$$(g * G)(x,y) = \int_{-\infty}^{+\infty} dz\, G(x,z;\alpha,\beta,\gamma,\varepsilon)\cdot g(y-z;\sigma_{res})$$

$$= \frac{1}{2\pi\varepsilon\kappa} e^{-\frac{1}{2\varepsilon\kappa}\left\{\left(\gamma\kappa - \frac{\sigma_{res}^2}{\varepsilon}\frac{\alpha^2}{\kappa}\right)x^2 + 2\frac{\alpha}{\kappa}xy + \frac{\beta}{\kappa}y^2\right\}}$$

$$\text{with } \kappa := \sqrt{\sigma_{res}^2\frac{\beta}{\varepsilon}+1} \quad \Rightarrow \quad (\kappa > 1) \text{ for } \sigma_{res} \neq 0$$

Transformation of Twiss parameters

- Invariant *form* of representation allows comparison of coefficients with undisturbed phase space and thus provides the transformation of the Twiss parameters depending on σ_{res}.

$$\begin{aligned}
\varepsilon' &= \varepsilon \cdot \sqrt{\sigma_{res}^2 \frac{\beta}{\varepsilon} + 1} = \varepsilon \cdot \kappa \\
\alpha' &= \frac{\alpha}{\kappa} = \alpha \cdot \frac{\varepsilon}{\varepsilon'} \\
\beta' &= \frac{\beta}{\kappa} = \beta \cdot \frac{\varepsilon}{\varepsilon'} \\
\gamma' &= \gamma \cdot \kappa - \frac{\sigma_{res}^2}{\varepsilon} \cdot \frac{\alpha^2}{\kappa} = \gamma \cdot \frac{1 + \frac{\kappa^2 - 1}{\alpha^2 + 1}}{\kappa}
\end{aligned}$$

$$\Rightarrow \beta' \cdot \gamma' - \alpha'^2 = 1 \qquad \checkmark$$

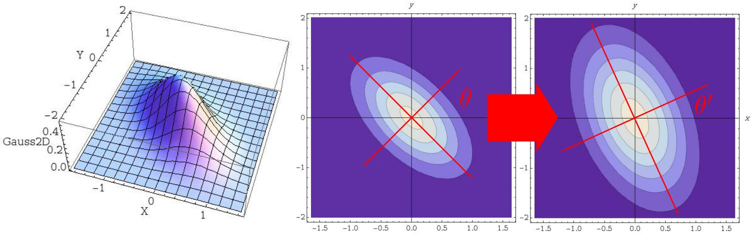
Transformation of Twiss parameters

- General tendency of Twiss parameters in case of vertical resolution limit.

$$
\begin{aligned}
\varepsilon' &> \varepsilon \\
\alpha' &< \alpha \\
\beta' &< \beta \\
\gamma' &= \begin{cases} \leq \gamma, & \kappa \leq \alpha^2 \text{ and } \alpha > 1 \\ > \gamma & \text{otherwise} \end{cases}
\end{aligned}
$$

2-dim Gaussian Sample Distribution with Vertical Gaussian Resolution Limit $\sigma_{res} = \sigma_y$

Original: $\varepsilon = 0.3$, $\alpha = 0.71$, $\beta = 1$, $\gamma = 1.5$, $\sigma_y = 0.67$, $\theta = 35.3^\circ$



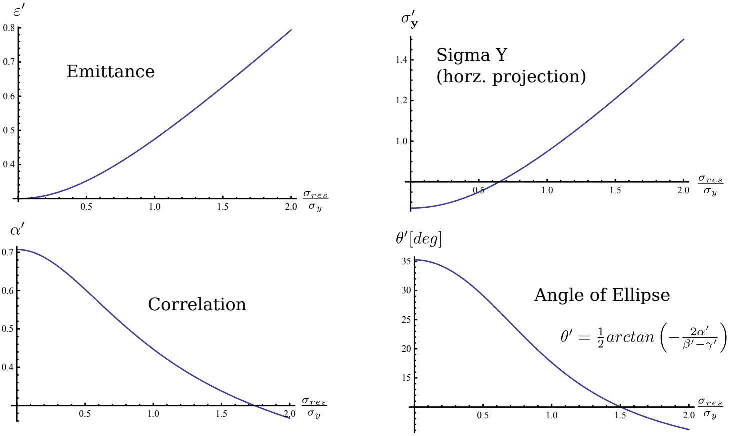
Original Original Convolved

Parameters after convolution:

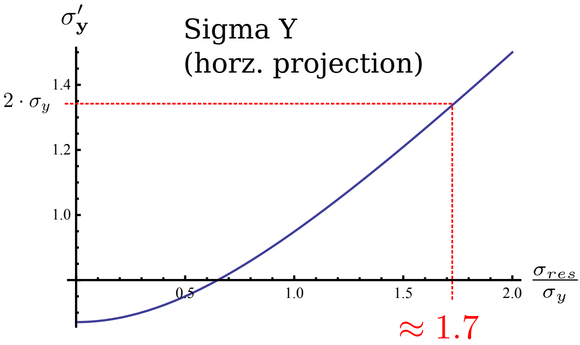
$\varepsilon' = 0.48$, $\alpha' = 0.45$, $\beta' = 0.63$, $\gamma' = 1.9$, $\sigma'_y = 0.95$, $\theta' = 17.6^\circ$

Beam Parameters vs. Vertical Resolution

Beam parameter: $\varepsilon = 0.3$, $\beta = 1$, $\gamma = 1.5$ $(\rightarrow \alpha = \frac{1}{\sqrt{2}})$



Estimation of Vertical Resolution



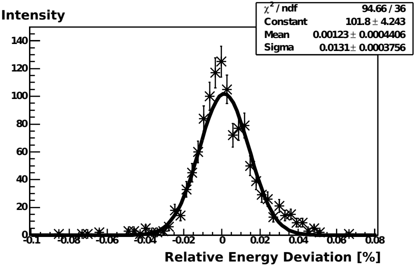
- Compared to our previous estimation (≈ 0.7) we might be missing something important.
- (Or) Do we underestimate some contribution?
- E.g. variation in thickness of primary scatter foil.

How about “common” Deconvolution then?

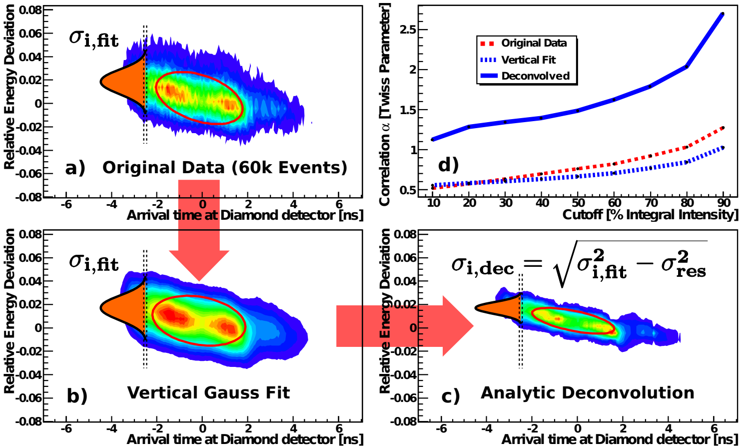
- Deconvolution is the attempt to reverse a convolution between to functions.
- Requires the precise knowledge of the pulse response (resolution property).
- *Very* sensitive to SNR.
- Difficult to find a consistent method to fit our needs with low statistics.

Analytic Deconvolution

- Fit vertical energy slice 'i' to a Gaussian parameterization ($\sigma^2_{i,fit}$).
- Pulse response σ_{res} deduced from error estimation is also considered Gaussian due to the different systematic contributions.
- Analytic deconvolution via Gaussian convolution theorem $\sigma_{i,dec} = \sqrt{\sigma^2_{i,fit} - \sigma^2_{res}}$
- Reconstruct Phase Space with $\{\sigma_{i,dec}\}$

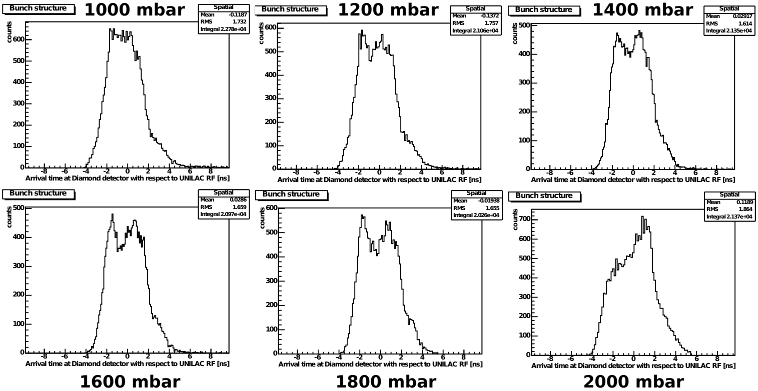


Analytic Deconvolution



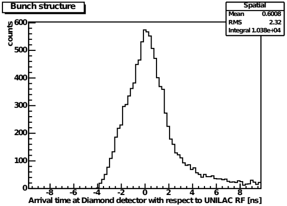
Variation of Stripper Gas Pressure

40Ar, high current setup, DS4 +/- 15 mm, DS5 +/- 6mm constant



500 mbar

40Ar, high current setup, DS4 +/- 15 mm, DS5 +/- 6mm constant

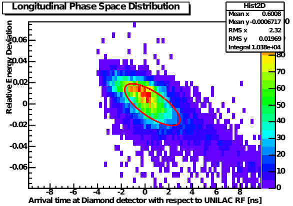


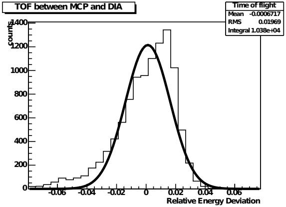
file name: AR14p_300mus_470mbar.cor

<E>: 1.41 MeV/u β: 0.055

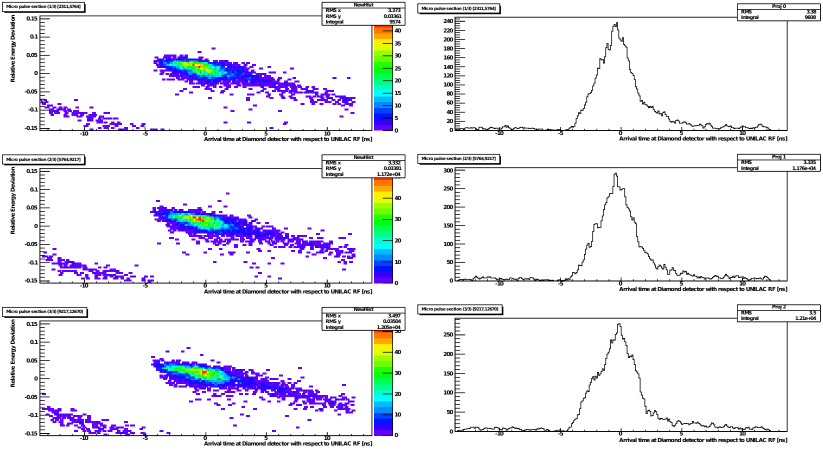
automatic Viewport boundaries
raw event data
integral count: 11240
bin size horizontal: 9 [LSB/TDC]
bin size vertical: 5 [LSB/TDC]

ε_{rms}: 44.20 keV ns
α: 1.06
β: 0.122 ns / keV
γ: 17.4 keV / ns



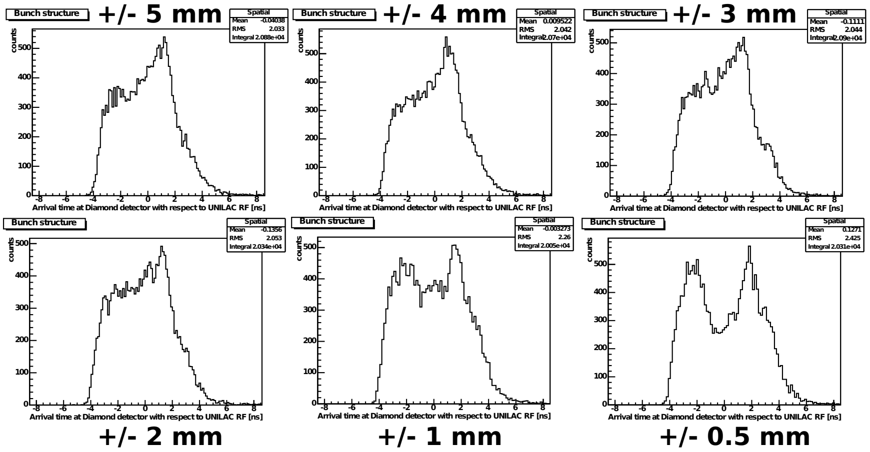


Micro Pulse Cuts (500 mbar)



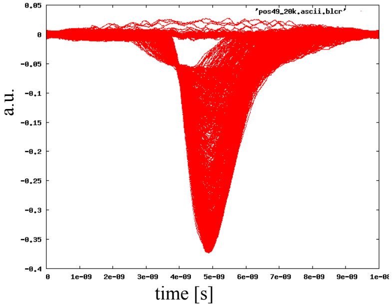
Variation of Slit DS5 (DS4 +/- 15 mm const.)

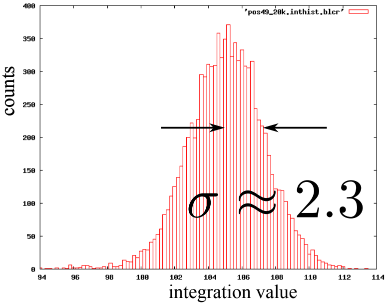
40Ar, high current setup, gas pressure 2000 mbar (constant)



Preliminary: Direct Calorimetric Measurement

Am-243 Source, vac 10^{-5} *mbar*





Tektronix DPO 7542 - 2.5 GHz BW, 20 GS/s (2 ch.)

Pre-Preliminary: Discrimination via Post-Processing

- Sample full data stream with Tek 7254 and discriminate afterwards.
- Can we perform better with this than the double threshold discriminators do yet?
- If so - does it improve the overall situation significantly?

Outlook

Thanks for your attention!
Questions?