Measurement of momentum spread and bunch length at the Photo Injector Test facility at DESY Zeuthen, PITZ

- Goal and setup
- Operation principle of the photo injector
- Longitudinal laser beam property
- Momentum measurement
- Beam longitudinal distribution
- Summary

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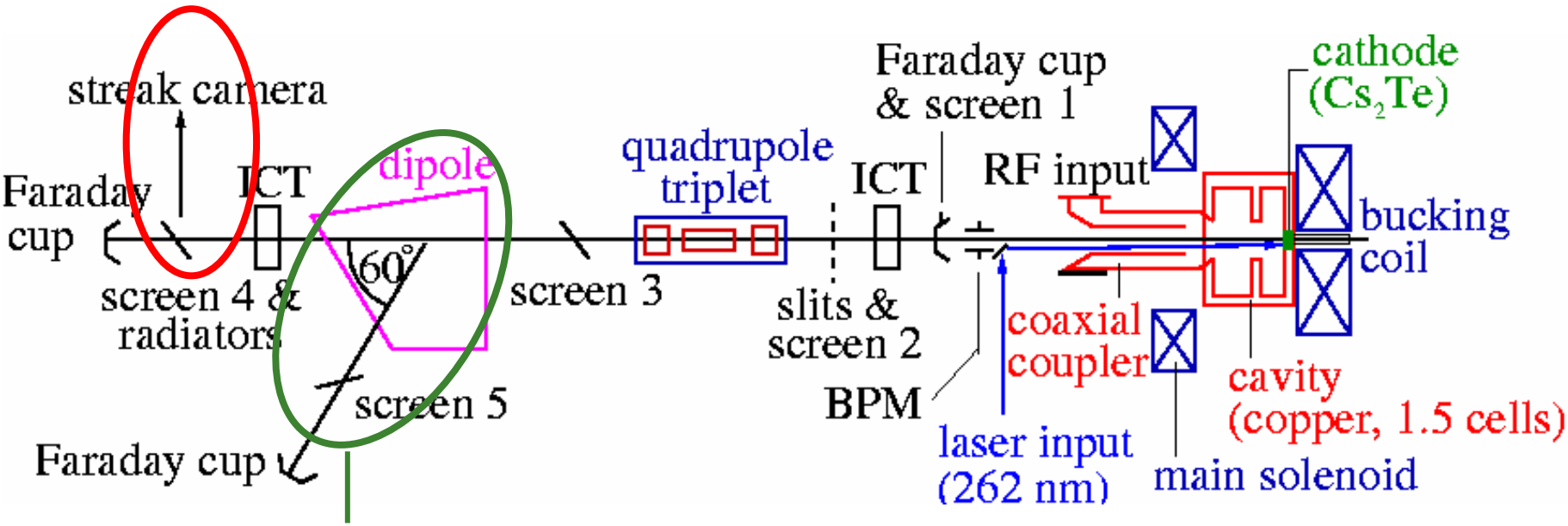
Goal and setup

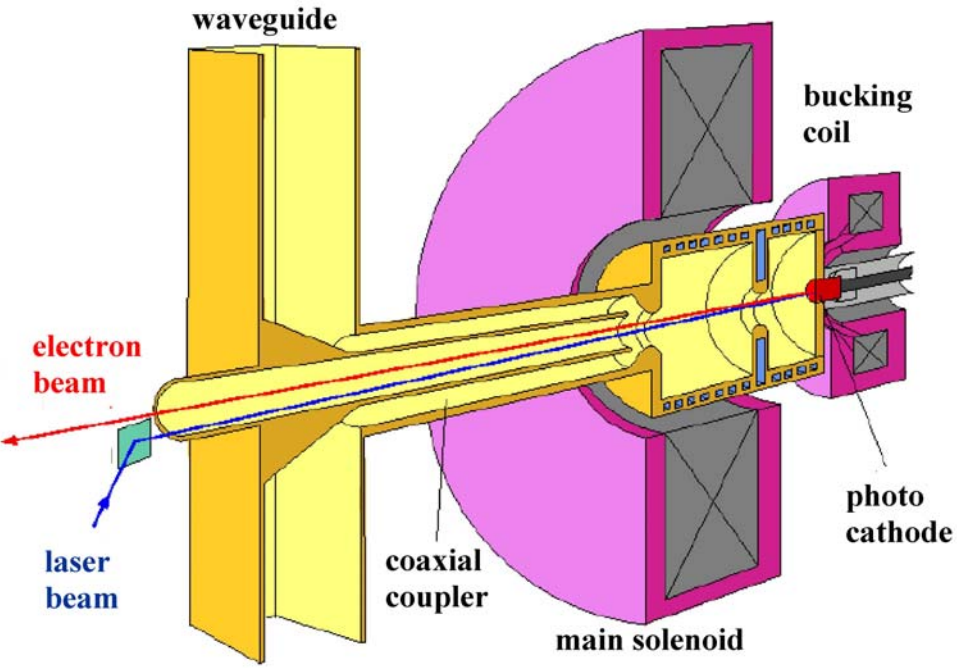
Optimizing: momentum spread and bunch length
of the electron bunch from the photo injector

Bunch length measurement setup

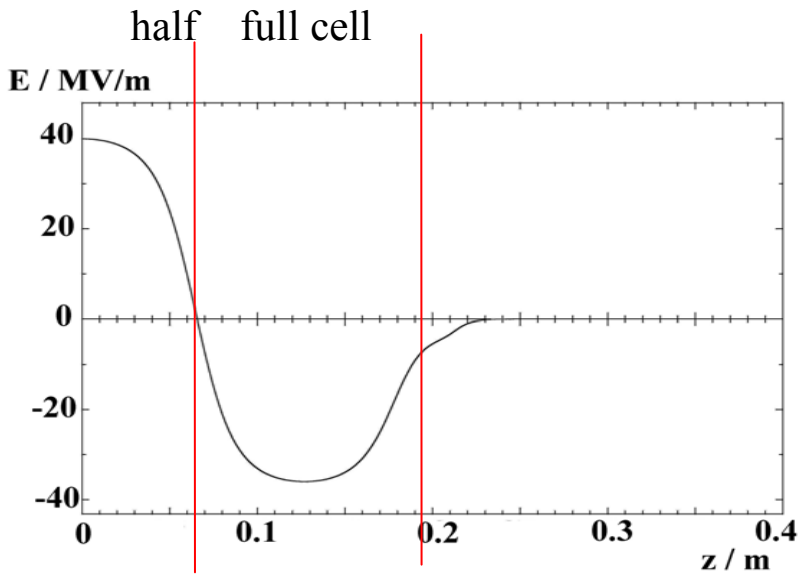


Momentum measurement setup

Operation principle



Accelerating field:



Parameters:

- electron bunch charge: 1 nC
- resonance frequency: 1.3 GHz
- cathode material: Cs_2Te
- laser wavelength: 262 nm
- energy at exit of gun: ~5 MeV

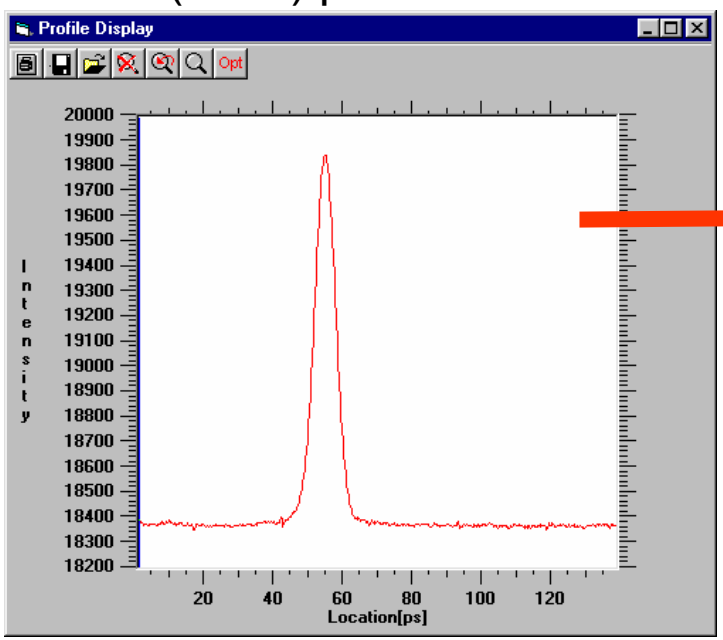
$$E_z = E_0 \, f\left(\cos\left(k\,z\right)\right)\sin\left(\omega\,t+\phi_0\right)$$

Longitudinal laser pulse property

An important component of the photo injector: photo cathode laser for the production of the electron bunch at the photo cathode

The longitudinal shape of laser beam is changed:

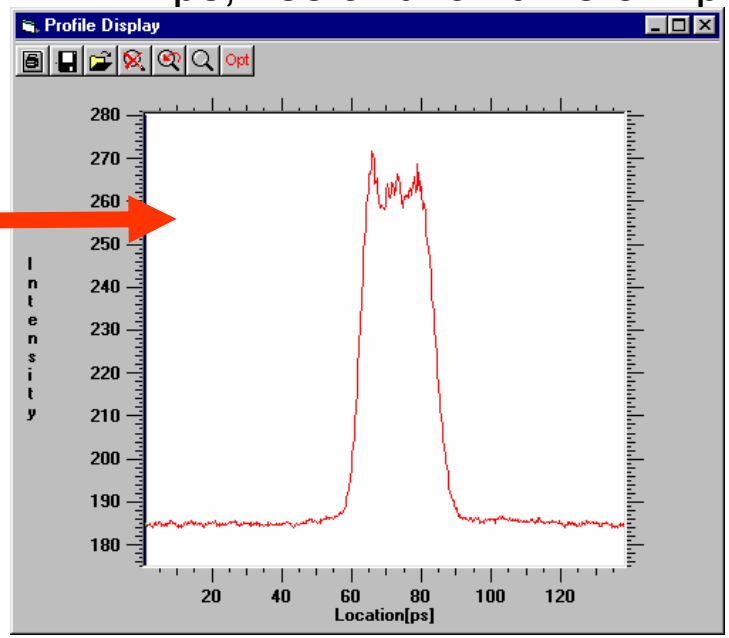
Gaussian shape
FWHM = (7 ± 1) ps



Inhomogeneous space charge

Measured by using a Streak-camera

changed to flat top
FWHM ~ 24 ps, rise and fall time 5-7 ps



homogeneous space charge density

Momentum measurement: Gauss

Measurement conditions:

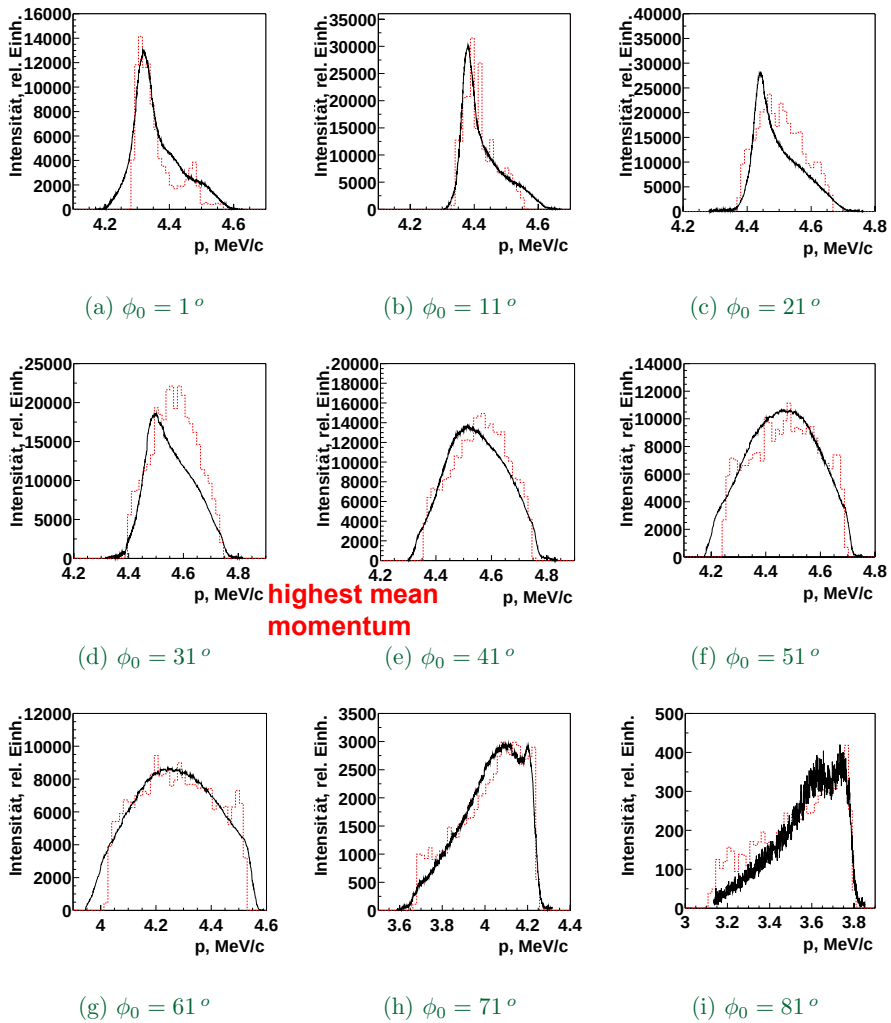
Laser shape: Gaussian

Maximum charge 1.1 nC at cavity exit

Solenoid current 270 A (B_{max} = 159 mT)

- Low ϕ_0: field low at t = 0 → space charge determines momentum spread
- High ϕ_0: variation of RF determines momentum spread

Measurement compared to simulation for different ϕ_0



(a) $\phi_0 = 1^o$ (b) $\phi_0 = 11^o$ (c) $\phi_0 = 21^o$

(d) $\phi_0 = 31^o$ (e) $\phi_0 = 41^o$ (f) $\phi_0 = 51^o$

(g) $\phi_0 = 61^o$ (h) $\phi_0 = 71^o$ (i) $\phi_0 = 81^o$

Momentum measurement: flat-top

Measurement conditions:

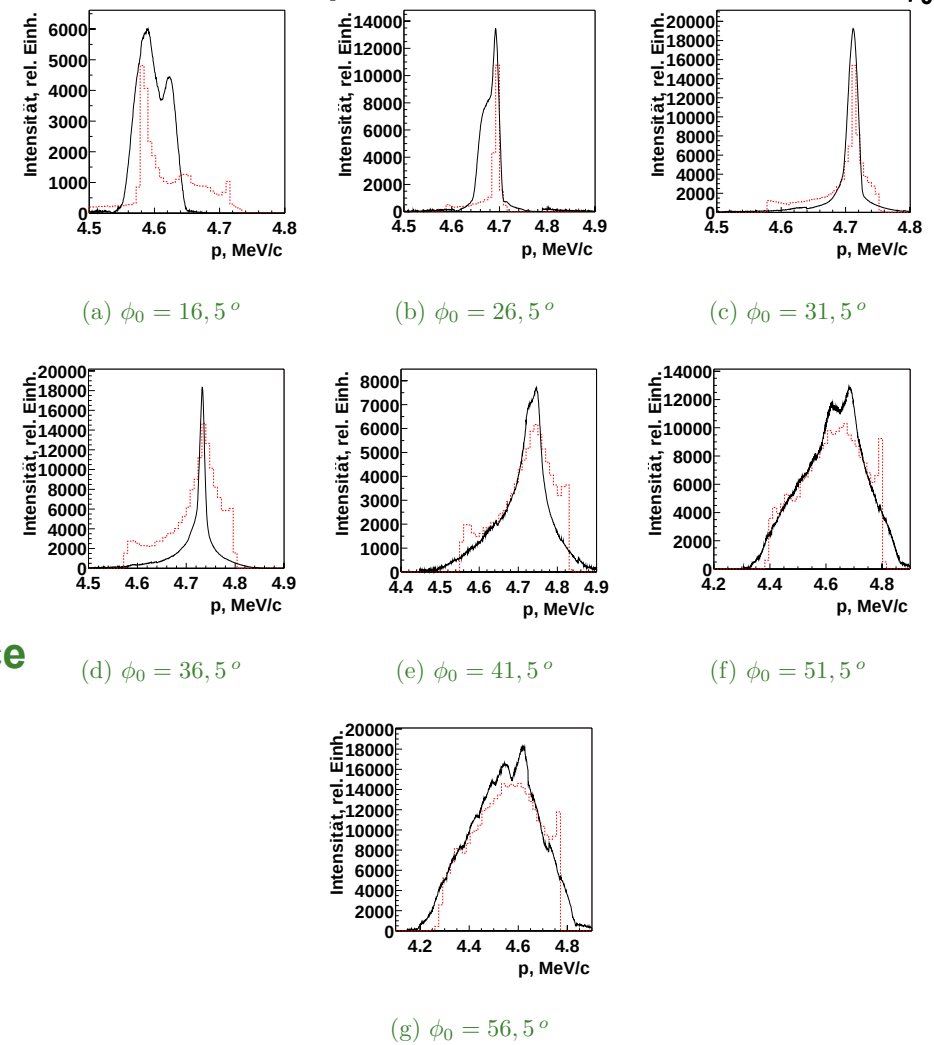
Laser shape: flat-top

Solenoid current 280 A (B_{max} = 165 mT)

charge 1.0 nC

highest mean momentum

Measurement compared to simulation for different ϕ_0



(a) $\phi_0 = 16,5^o$ (b) $\phi_0 = 26,5^o$ (c) $\phi_0 = 31,5^o$

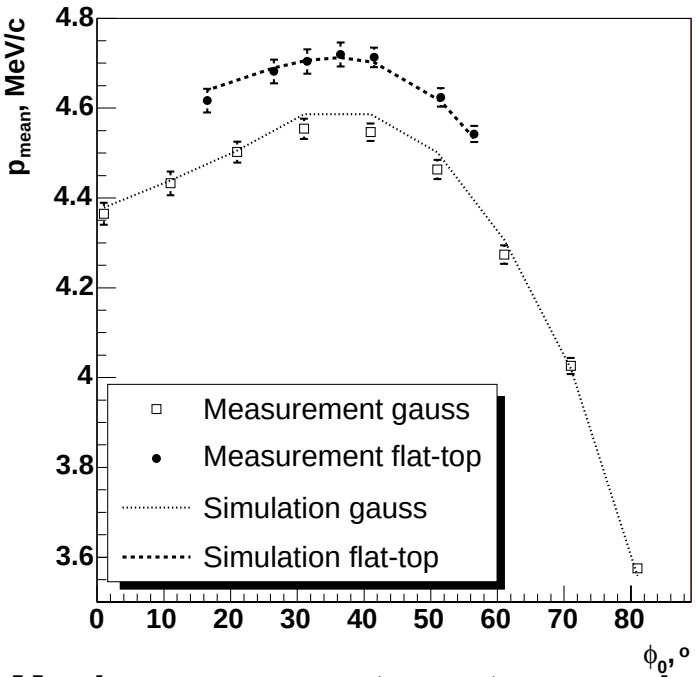
(d) $\phi_0 = 36,5^o$ (e) $\phi_0 = 41,5^o$ (f) $\phi_0 = 51,5^o$

(g) $\phi_0 = 56,5^o$

- Low ϕ_0:
  - **simulation: cylinder symmetric space charge**
  - **data: not cylinder symmetric space charge**
- Higher ϕ_0: **simulation reasonable agreement with data**

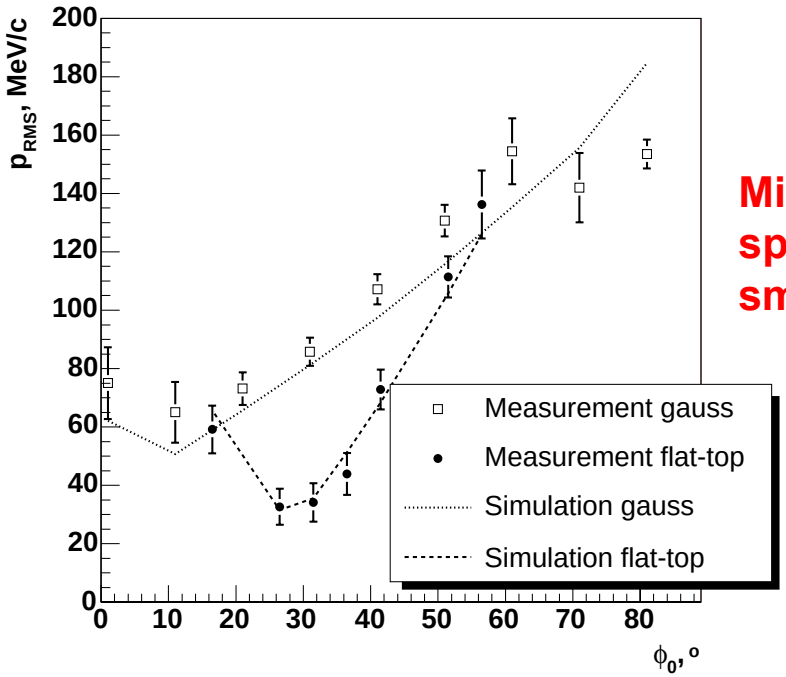
Momentum measurement: comparison

Mean momentum



Maximum momentum at same phase

Momentum spread



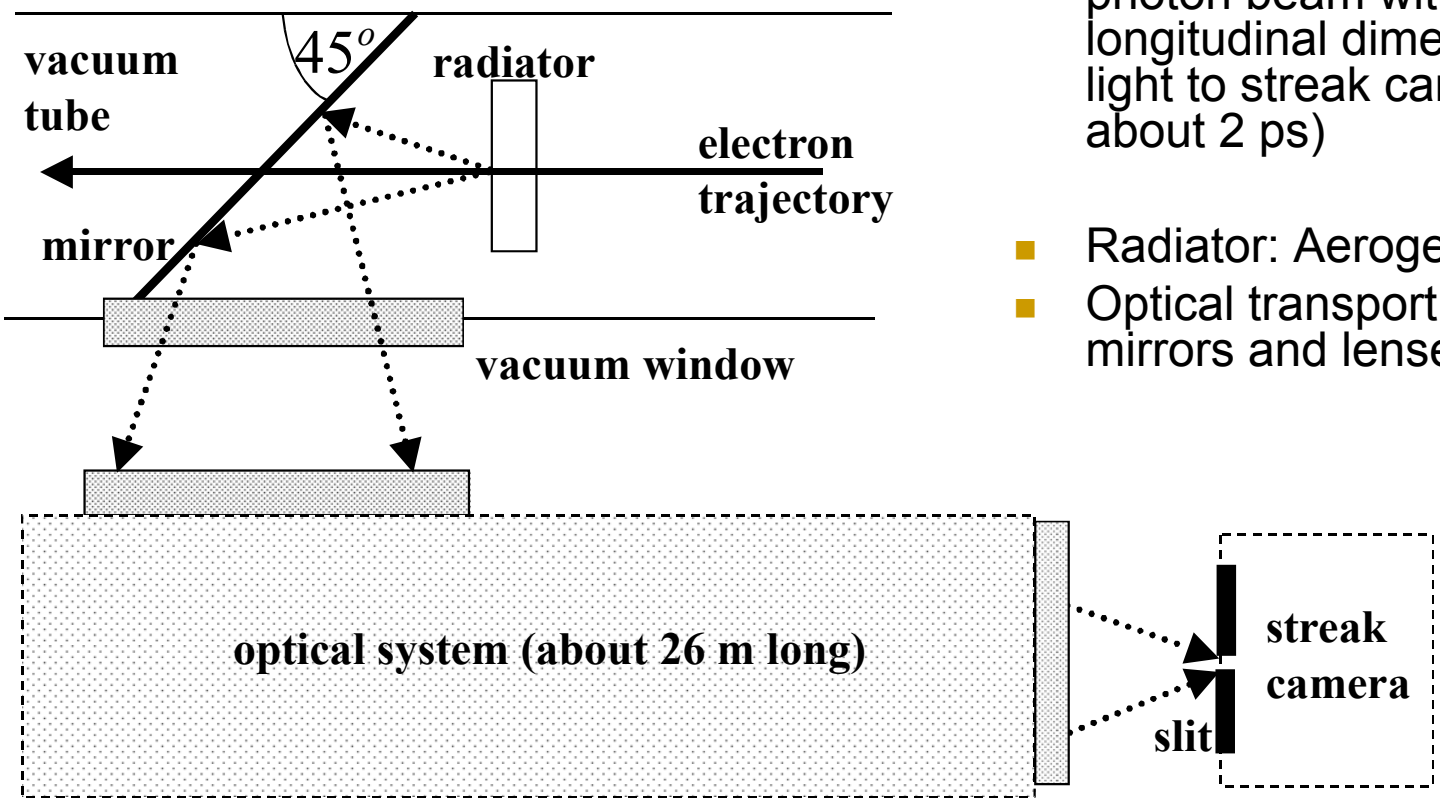
Minimum momentum spread with flat-top smaller by a factor 2

Phase with smallest momentum spread with flat top laser pulse nearer to phase with highest momentum

Field amplitude and maximum phase chosen such that simulation matches the measurement

Beam longitudinal distribution

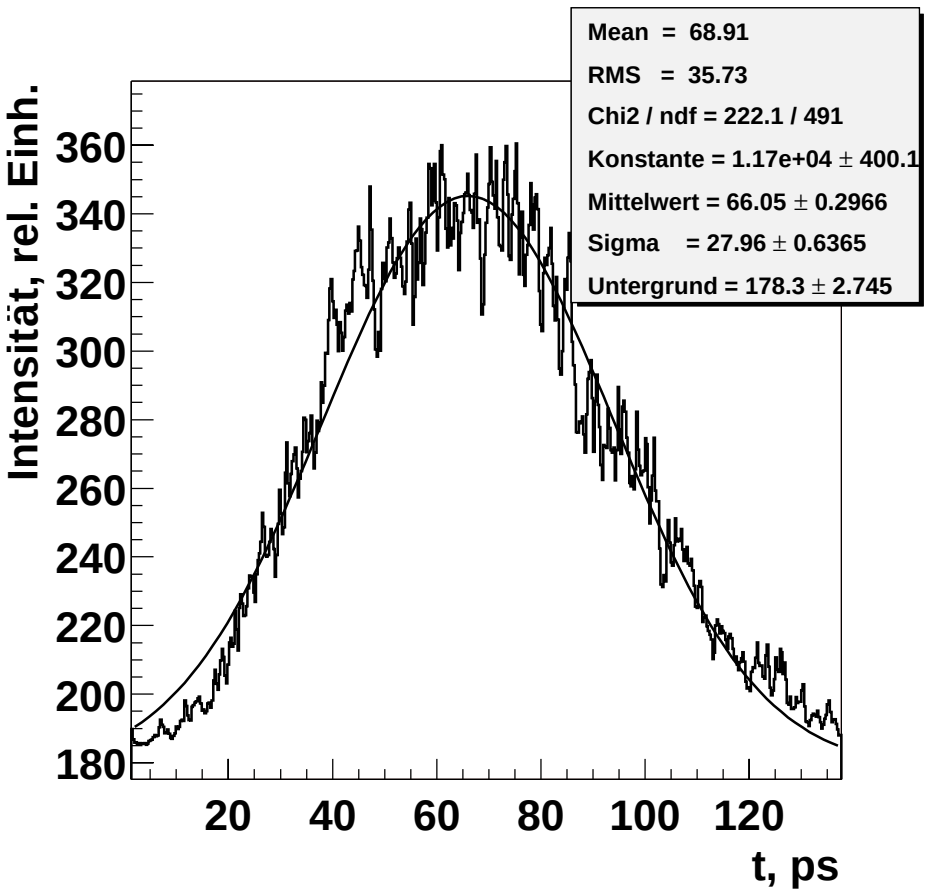
Experimental setup



- Conversion of electron beam in photon beam with same longitudinal dimensions, transport light to streak camera (resolution about 2 ps)
- Radiator: Aerogel with n = 1.03
- Optical transport system consist of mirrors and lenses

Beam longitudinal distribution

Longitudinal distribution of photon beam

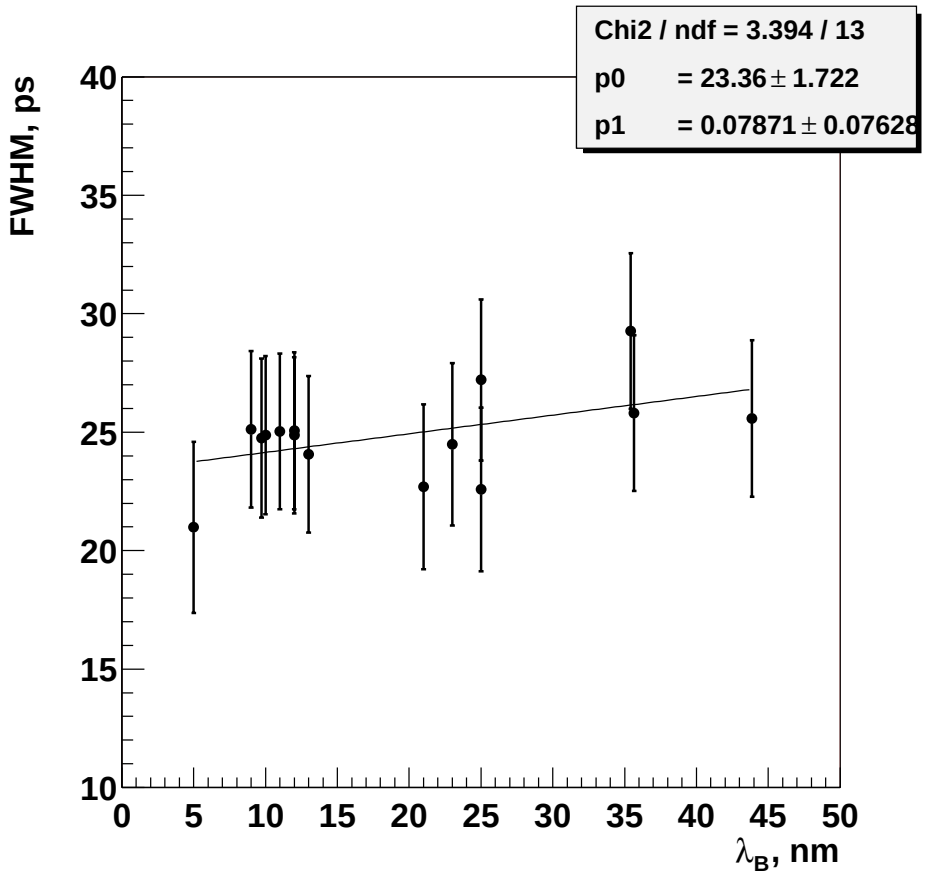


- One photon pulse has low intensity: superimpose pulses
- Check: jitter
- 100 single bunches:
  - RMS of mean 0.99 ps
  - streak camera resolution 1.8 ps
  - bunch length σ = 27.9 ps

Beam longitudinal distribution

Dispersion: elongation of photon beam

Transmission filters with different bandwidth λ_B



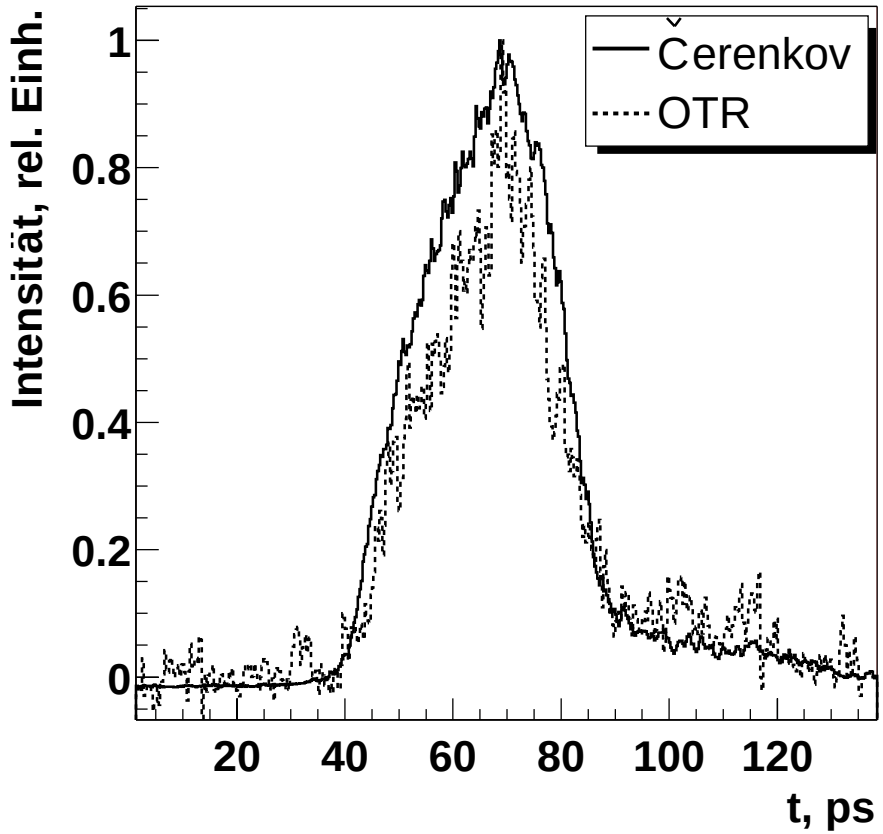
- Use FWHM (longitudinal distribution is not gaussian)
- Error bars contain statistical and systematic uncertainties:
  - 1.38 ps Streak camera
  - 0.99 ps jitter
  - 0.11 ps aerogel
- Fit: overestimation of bunch length due to dispersion of 0.079 ps per bandwidth in nm

Beam longitudinal distribution

Time resolution of different radiators:
Compare Cherenkov effect in aerogel with optical transition radiation (OTR)

- Cherenkov effect: radiator thickness influences time resolution
- OTR: photons are produced on surface, no contribution to time resolution
- Plot: tail due to second transmission peak (420 nm) of the interference filter

- Intensity differs by a factor of 1000
- Both distributions show same shape → small time resolution from aerogel



(normalized by maximum)

Beam longitudinal distribution

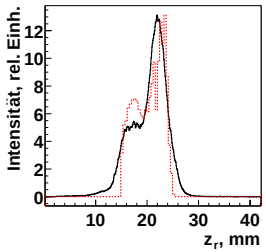
Measurement conditions:

- same as for the momentum distributions: 1 nC charge fixed, flat-top laser pulse
- main solenoid, quadrupole triplett and steerers used to obtain highest light intensity

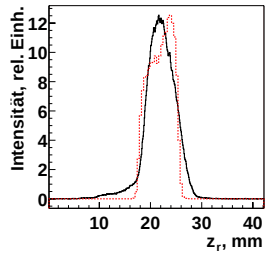
Low ϕ_0: focusing not successful

High ϕ_0: beam can not be focused (large beam momentum spread)

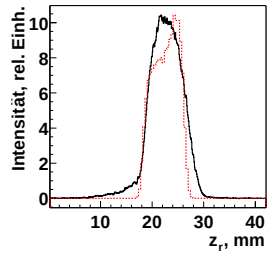
Measurement compared to simulation for different ϕ_0



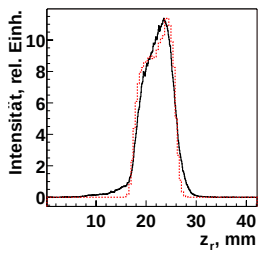
(a) $\phi_0 = 16,5^o$



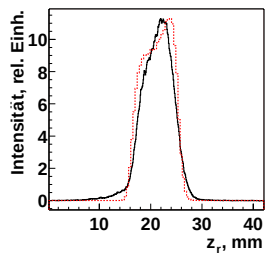
(b) $\phi_0 = 26,5^o$



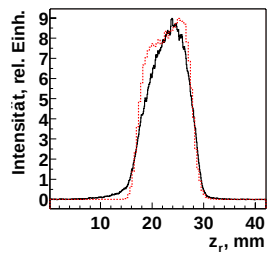
(c) $\phi_0 = 31,5^o$



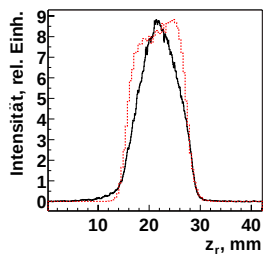
(d) $\phi_0 = 36,5^o$



(e) $\phi_0 = 41,5^o$



(f) $\phi_0 = 51,5^o$

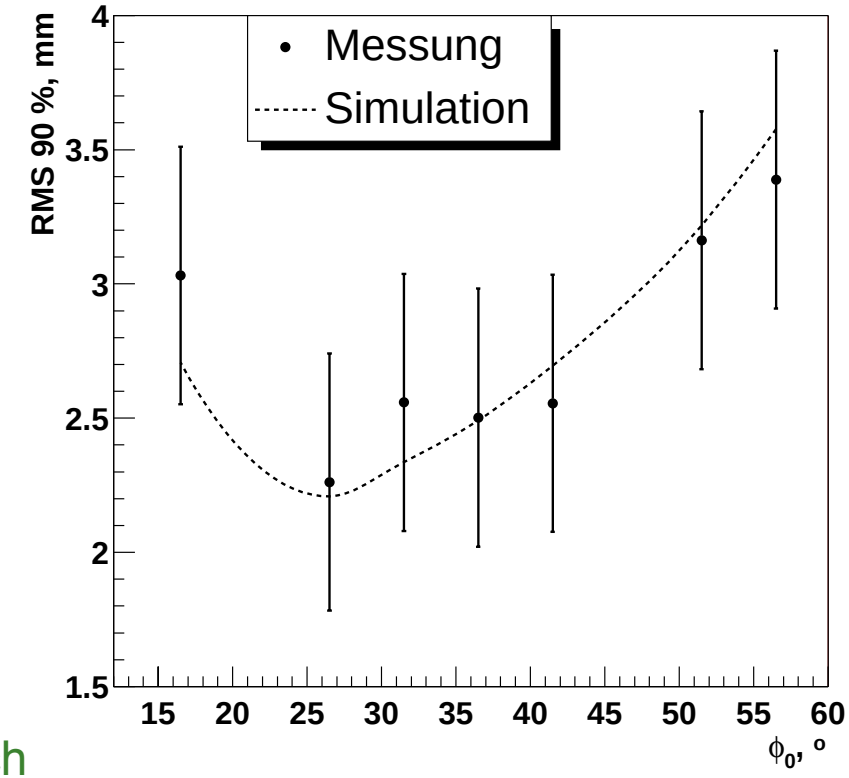


(g) $\phi_0 = 56,5^o$

Beam longitudinal distribution

Bunch length

Bunch length in RMS 90 %:
cut out the tails with < 10 % max. intensity



- Low ϕ_0: higher space charge
- High ϕ_0: variation of RF elongates the bunch
- Minimum bunch length: FWHM = (21.04 ± 0.45stat ± 4.14syst) ps
  = (6.31 ± 0.14stat ± 1.24syst) mm
  at same phase of 26.5 deg. where the minimum momentum spread is obtained

Summary

Momentum spread and bunch length are important issues for the optimization of a photo injector

Study them has been done at PITZ:

- Longitudinal laser shape changed from Gaussian to flat-top
- Measurement of momentum distributions for different phases (flat-top pulse):
  - **momentum spread decreases by a factor of 2**
  - **phase with smallest momentum spread is closer to the phase with highest energy gain**
- Used aerogel to measure the longitudinal distributions of electron beam
- Small jitter of the injector and experimental setup measured
- Dispersion between radiator and streak camera obtained → use of transmission filters is necessary
- Compared longitudinal distribution from Cherenkov-effect (Aerogel) with OTR-effect successful
- Bunch length for different phases is measured
- Minimum bunch length and minimum energy spread at the same phase

Outlook

- Dispersion elongates photon bunch between radiator and streak camera, to avoid dispersion use of reflective optics for the optical transport system including streak camera input optics
- Measurement system for the measurement of correlation between momentum and longitudinal position of electrons in bunch in production (complete longitudinal phase space)
- PITZ will be extended by a booster → electron energy up to 30 MeV, makes it possible to use OTR-screens as radiator for measurements of the longitudinal distributions of electron bunches