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Investigations of the longitudinal phase space at a photo injector for the X-FEL

Contents

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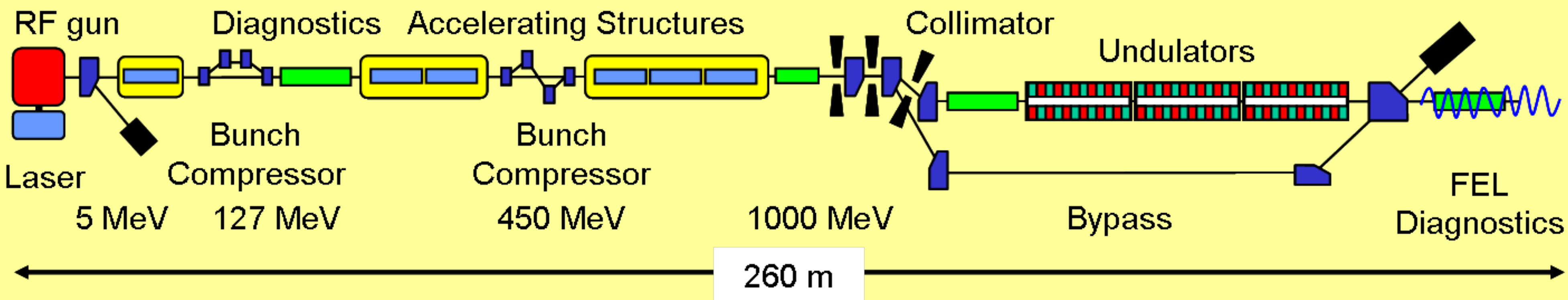
- Introduction
- PITZ
- Longitudinal phase space of a photoinjector
- **Devices of longitudinal phase space measurement at PITZ**
- **Measurements and simulations of longitudinal phase space at PITZ**
- Summery and outlook

Introduction



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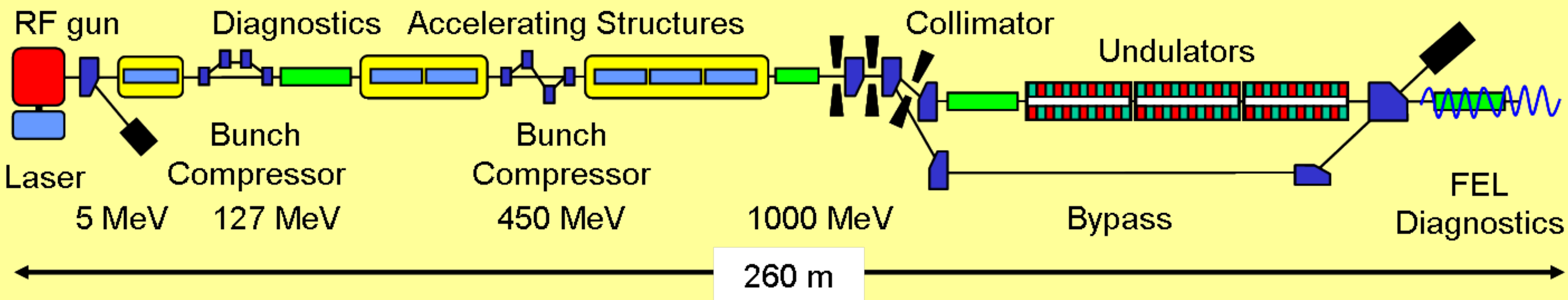


gun: - beam of a few MeV

-> space charge forces play a major role on emittance growth

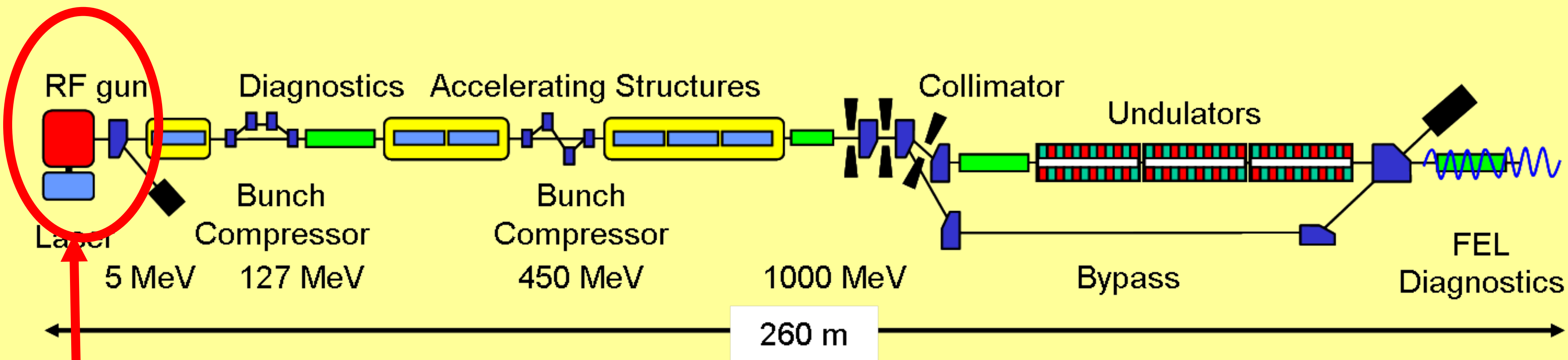
-> the initial electron bunch length: 20ps -> peak current: about 50 A

bunch compressor:
- energy is high enough to neglect space charge forces
- bunch compression increases peak current
- optimum compression: only for a linear long. phase space

-> 3^{rd} harmonic

-> knowledge of longitudinal phase space is of particular interest

Introduction



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ELECTRON GUN

→crucial element of a Free Electron Laser !

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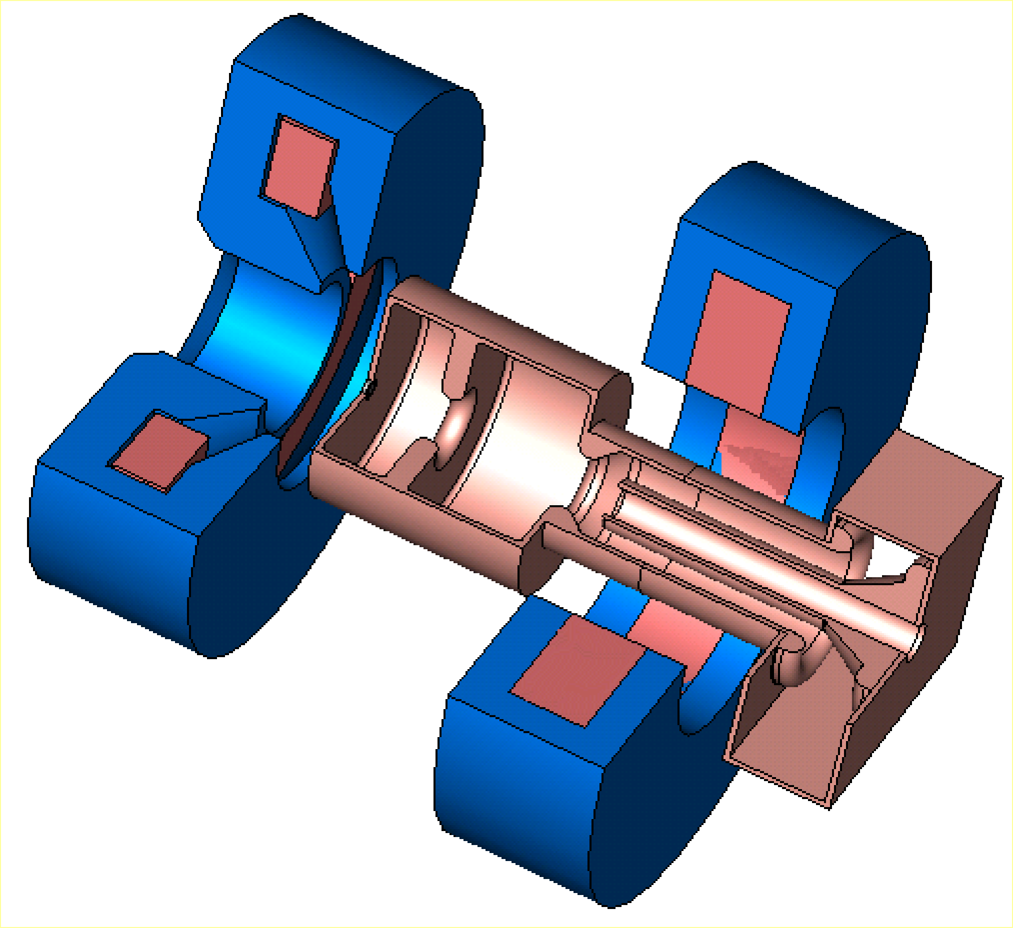
PITZ



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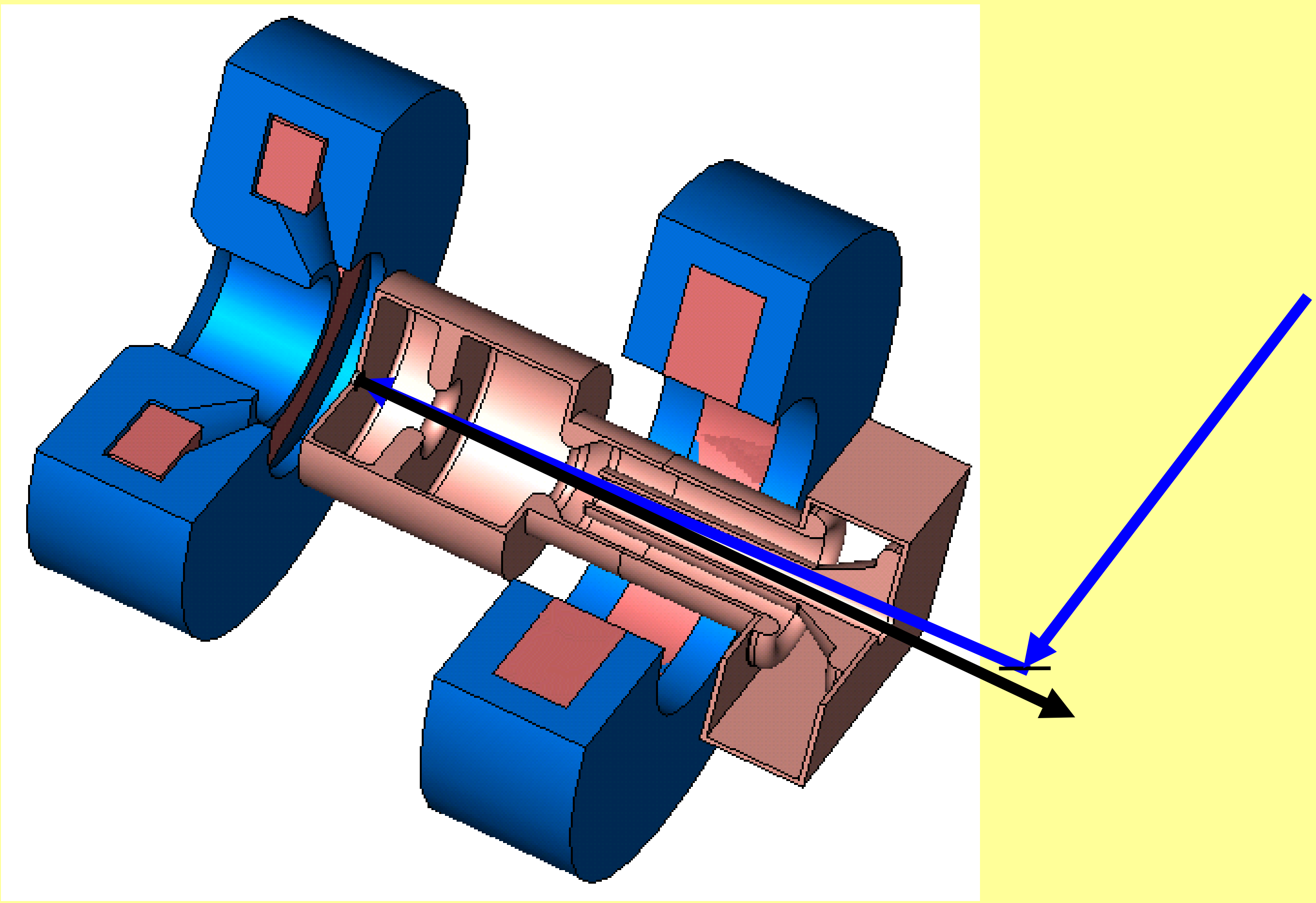

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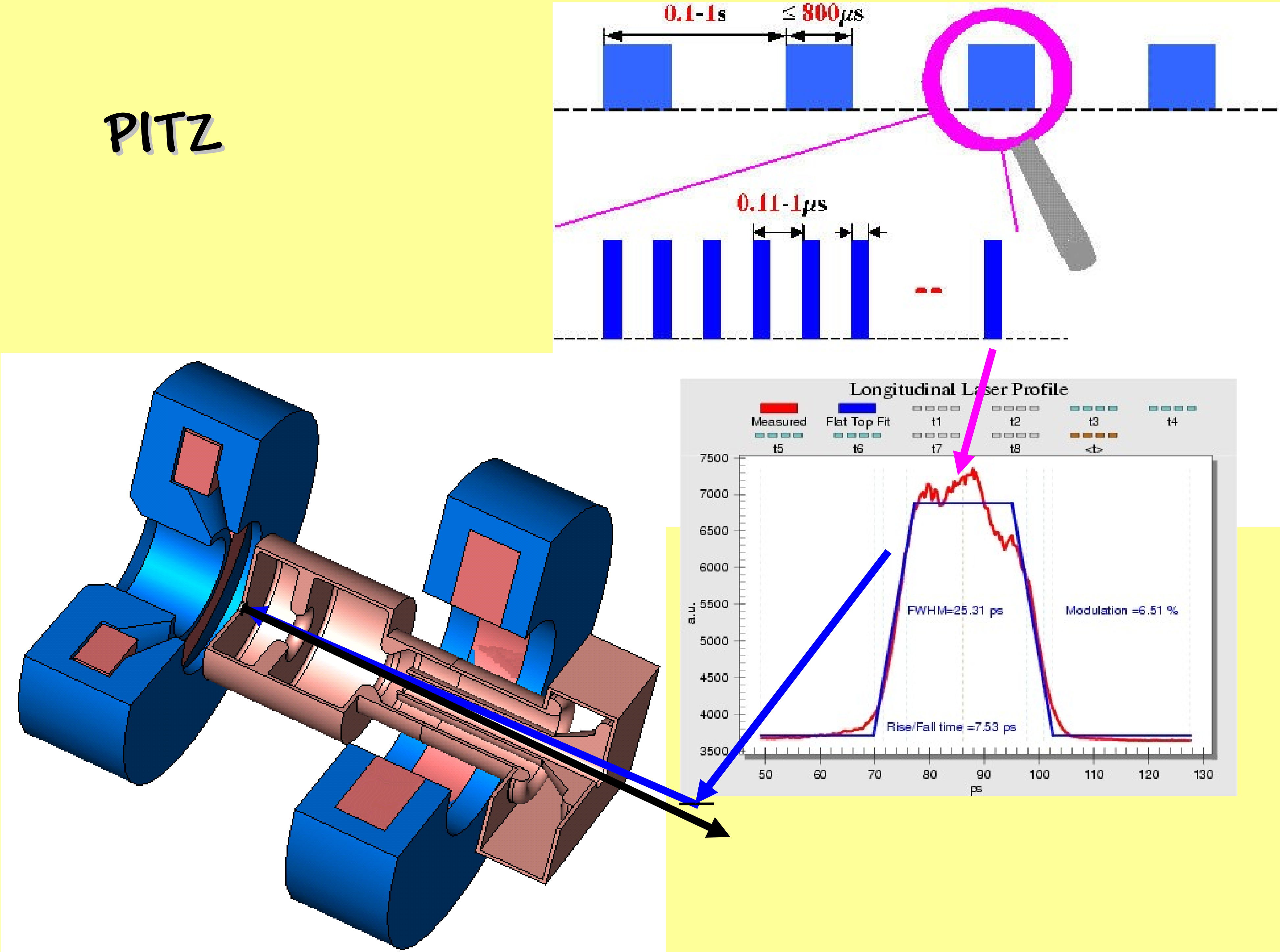
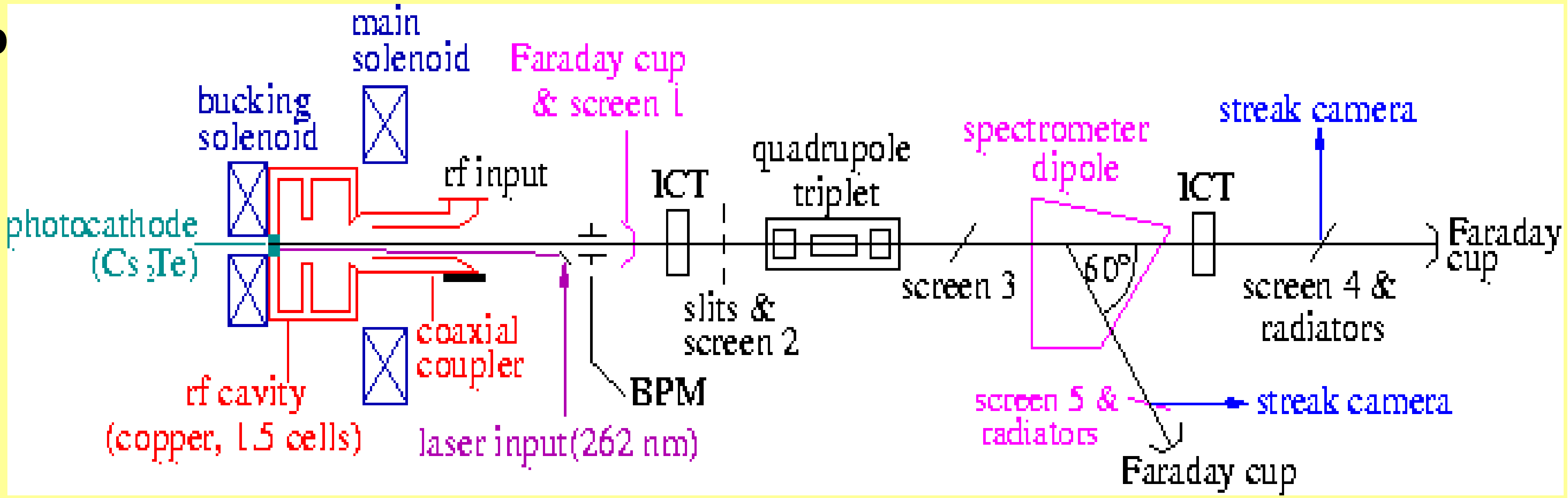


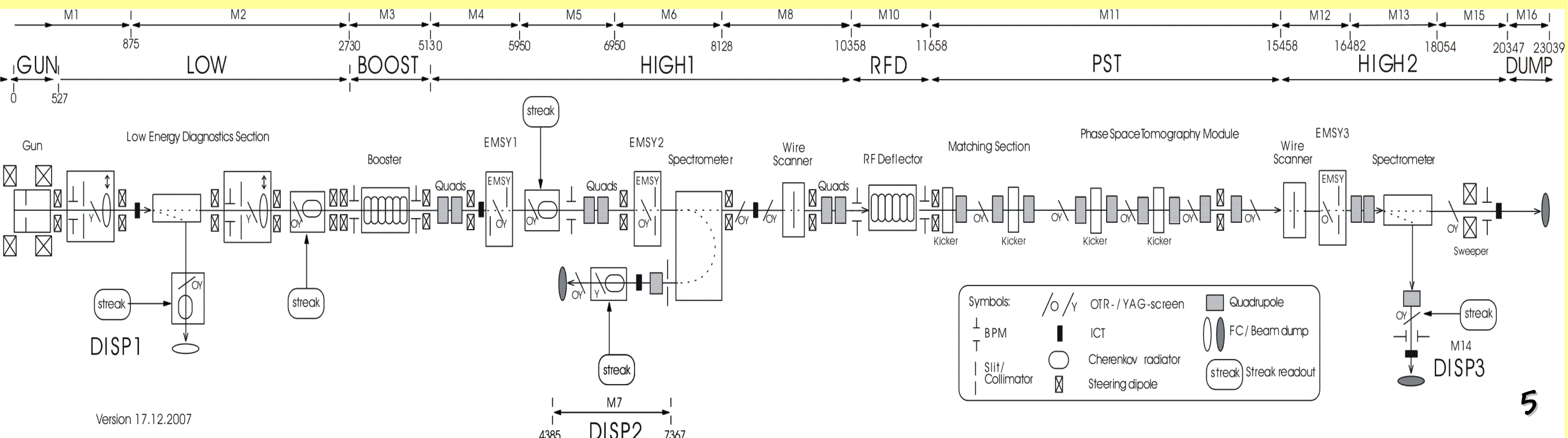
0.1-1s
≤ 800μs
0.11-1μs
Longitudinal Laser Profile
Measured
Flat Top Fit
t1
t2
t3
t4
t5
t6
t7
t8
<t>
7500
7000
6500
6000
5500
5000
4500
4000
3500
a.u.
50
60
70
80
90
100
110
120
130
ps
FWHM=25.31 ps
Modulation =6.51 %
Rise/Fall time =7.53 ps

PITZ

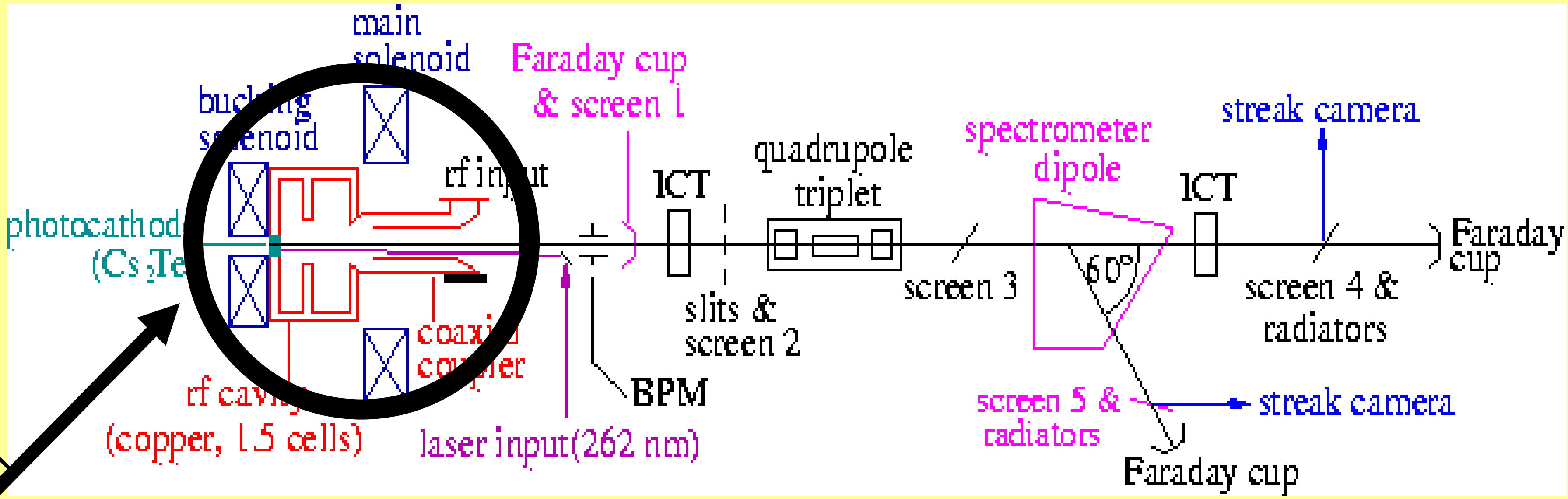
PITZ1 setup



PITZ2 setup

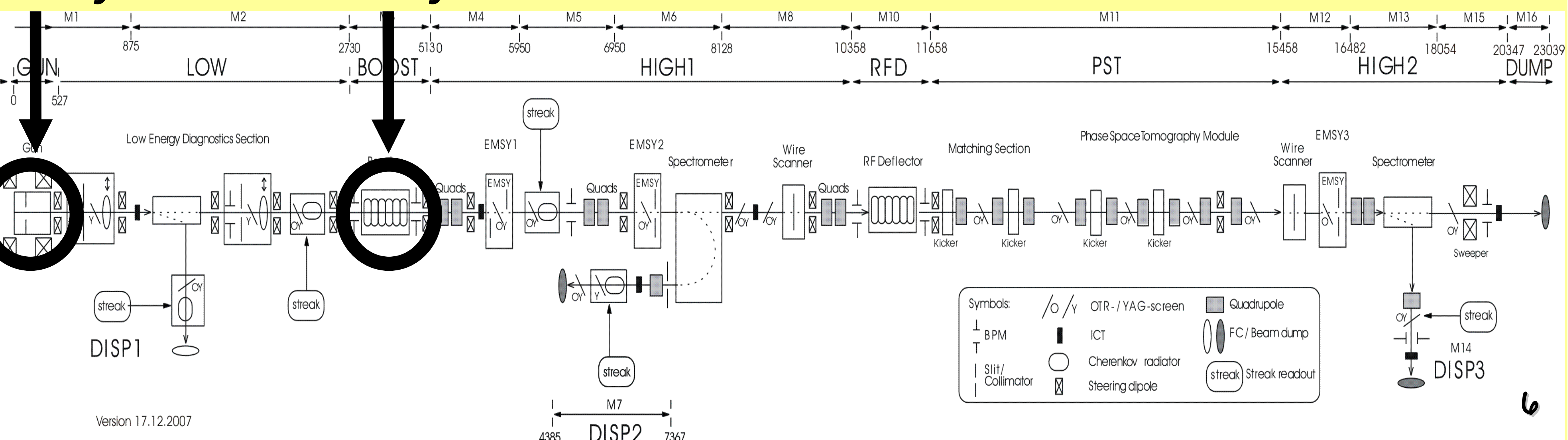


Setup of PITZ

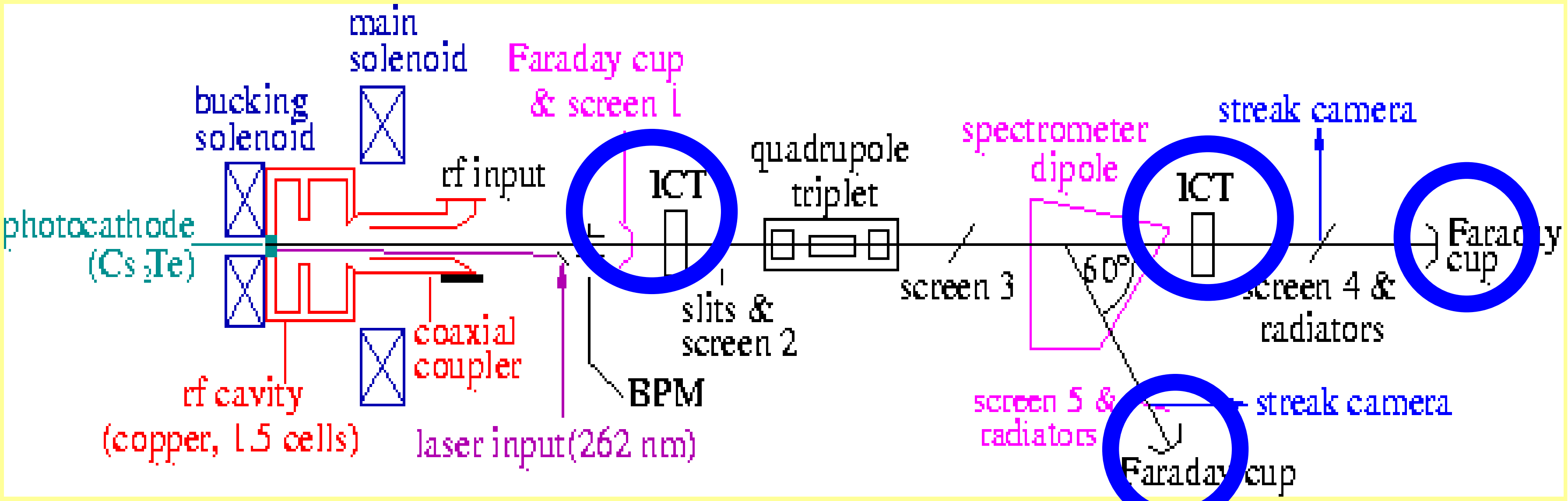


GUN cavity

BOOSTER cavity

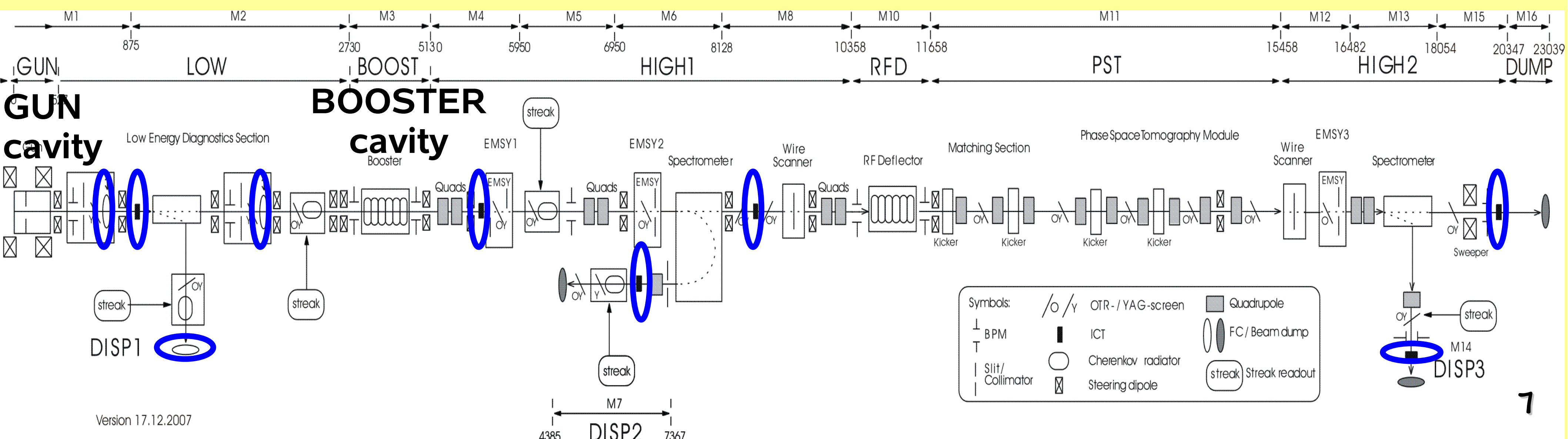


Setup of PITZ



charge measurement:

- faraday cup
- ICT



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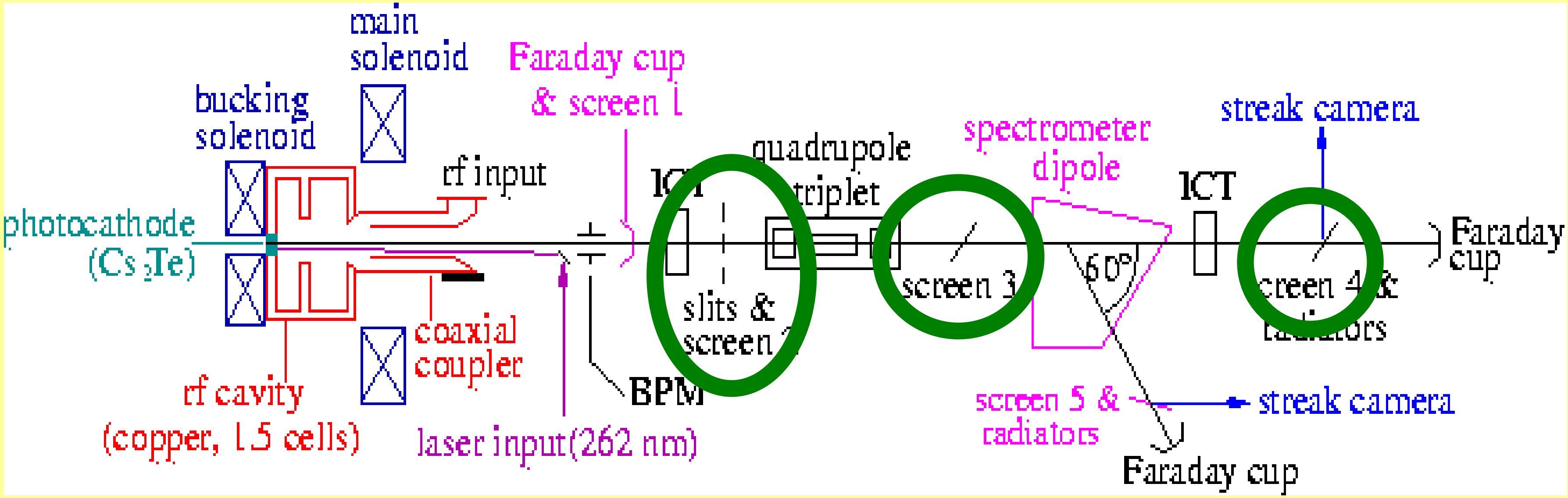
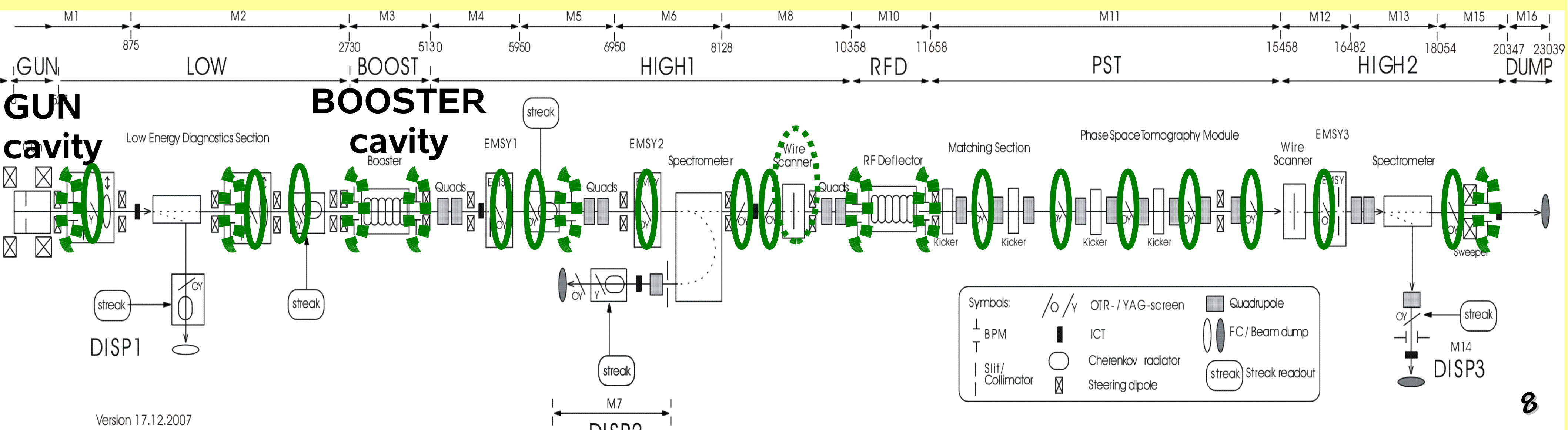


beam size measurement:

- view screens combined with CCD Cameras
- wire scanners
- BPMs



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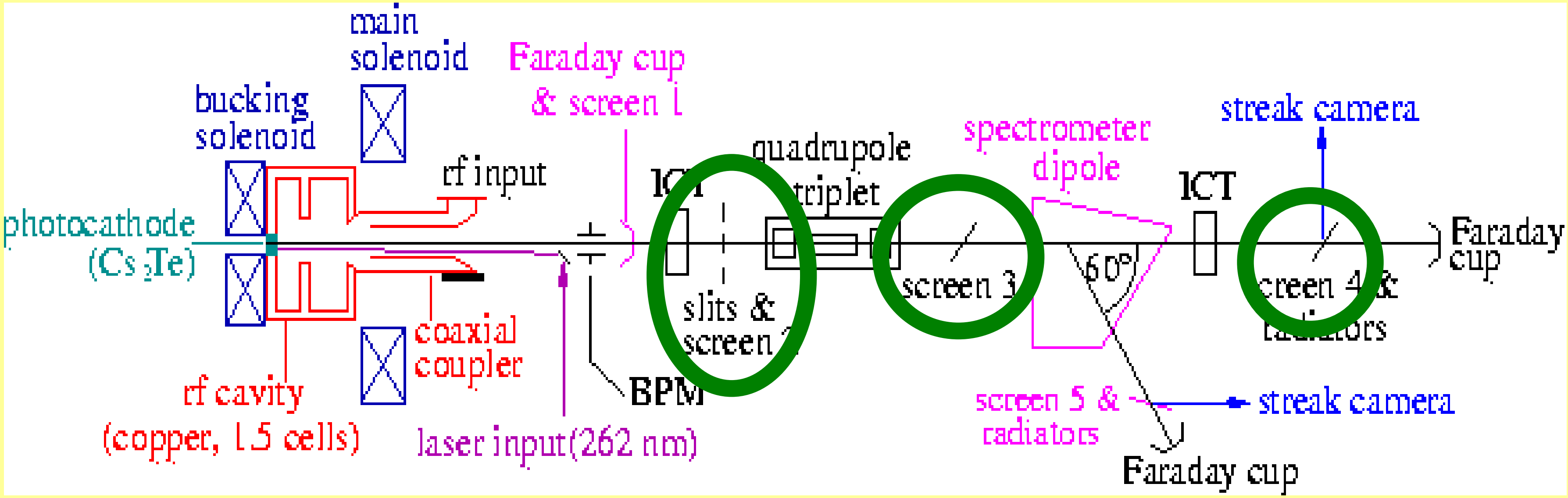
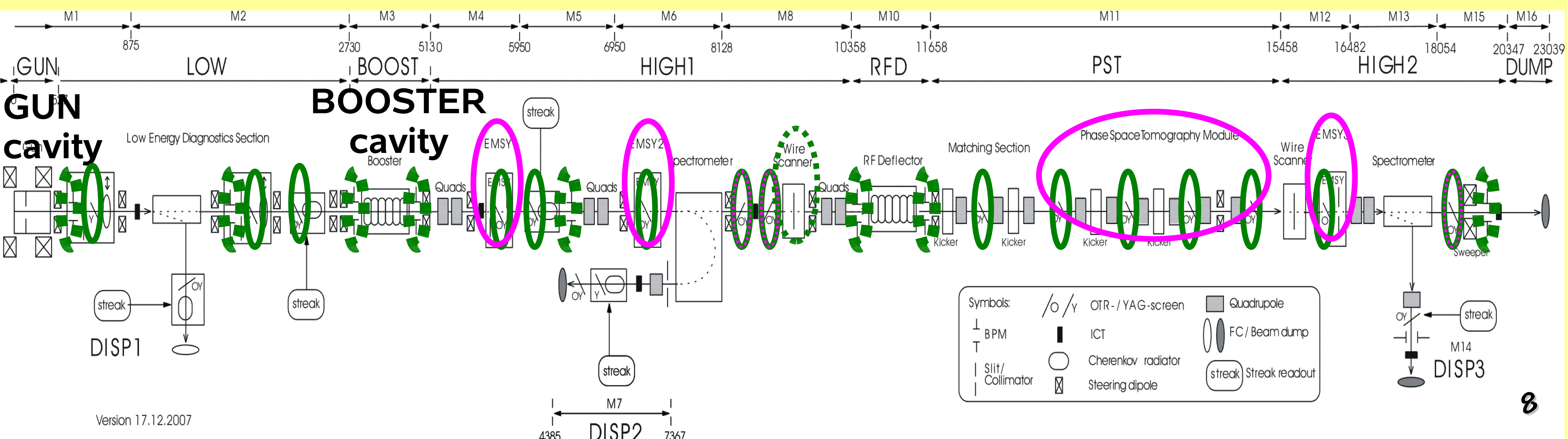


beam size measurement:

- view screens combined with CCD Cameras
- wire scanners
- BPMs

transverse emittance measurement:

- EMSYs: slit scan method
- tomography module



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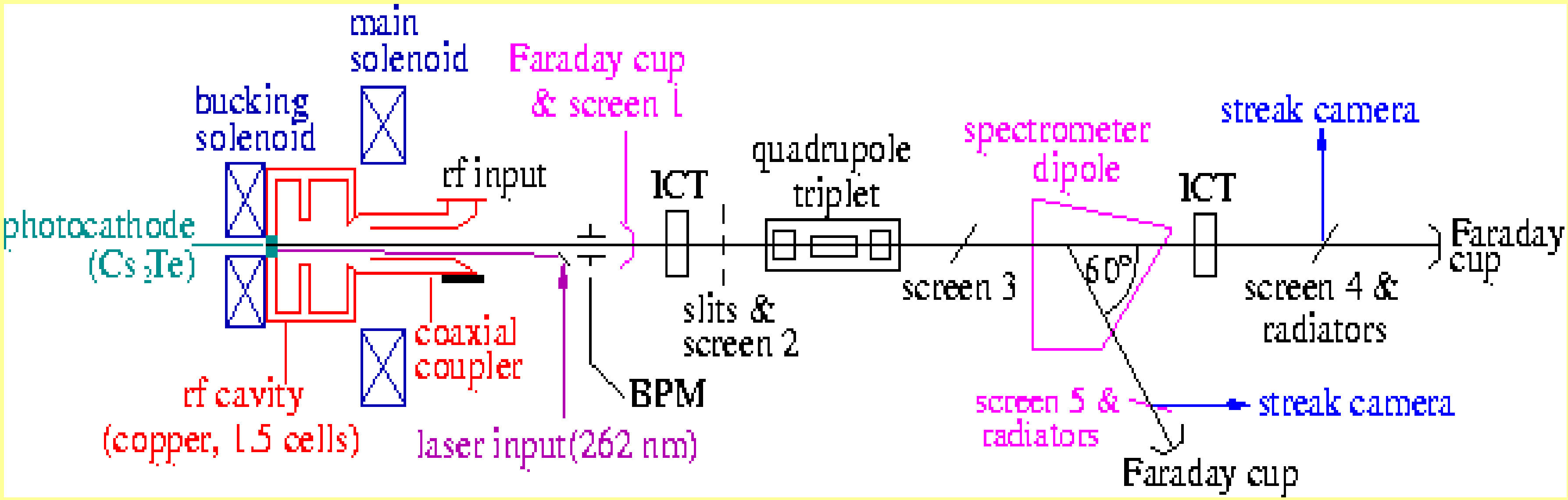
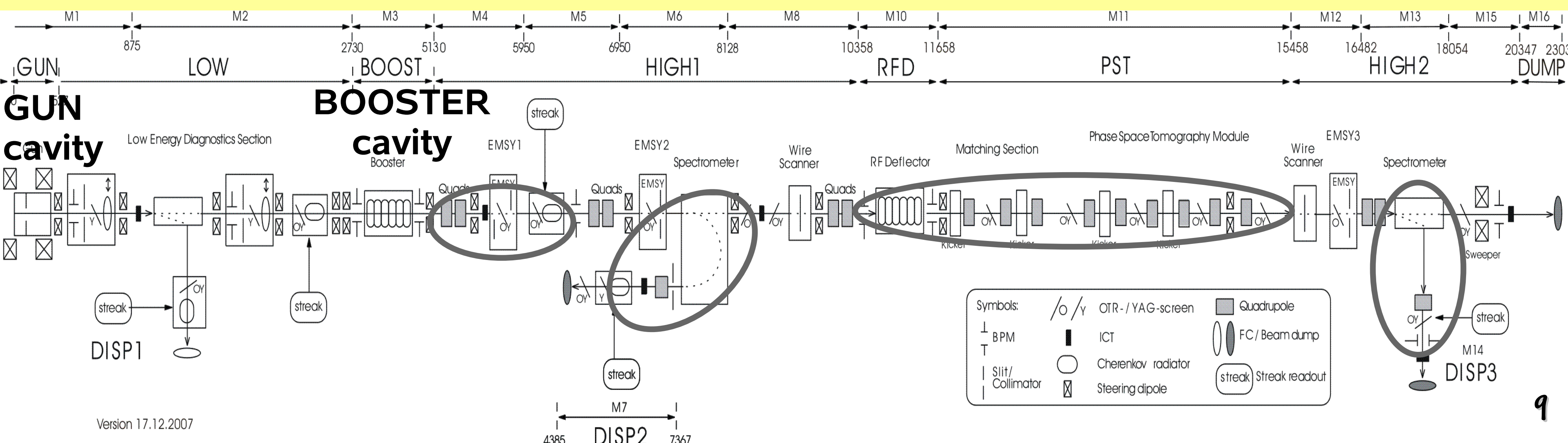
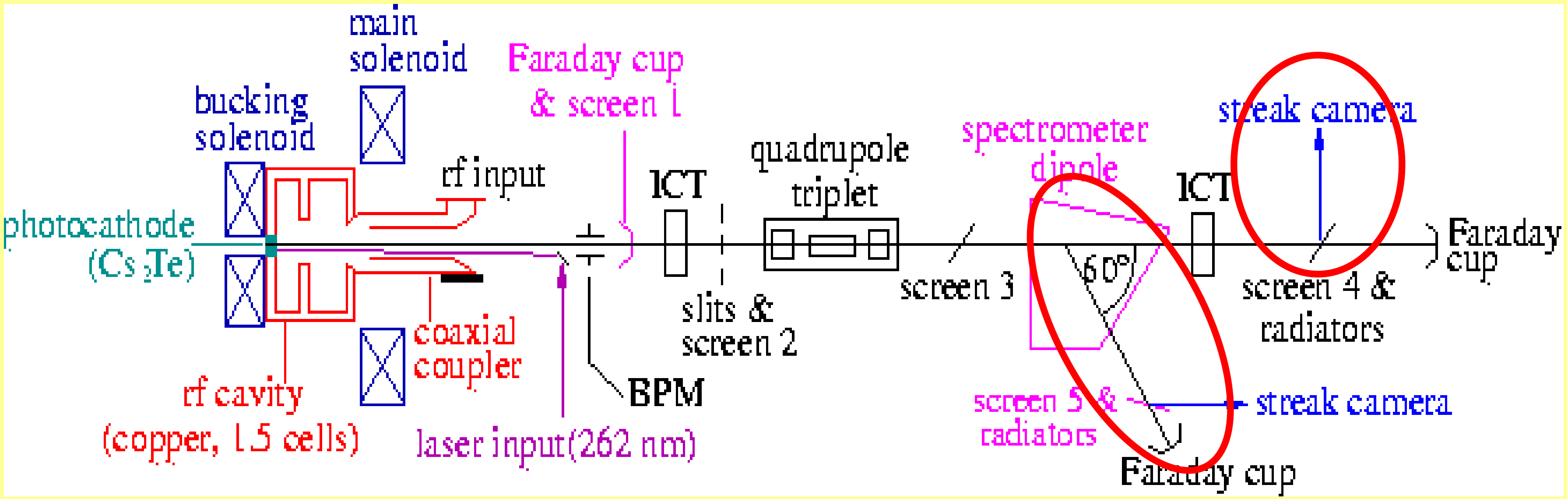


slice emittance measurement:

- RF-deflector and tomography module
- dipole, slit and quadrupole
- quadrupole, aerogel and streak camera

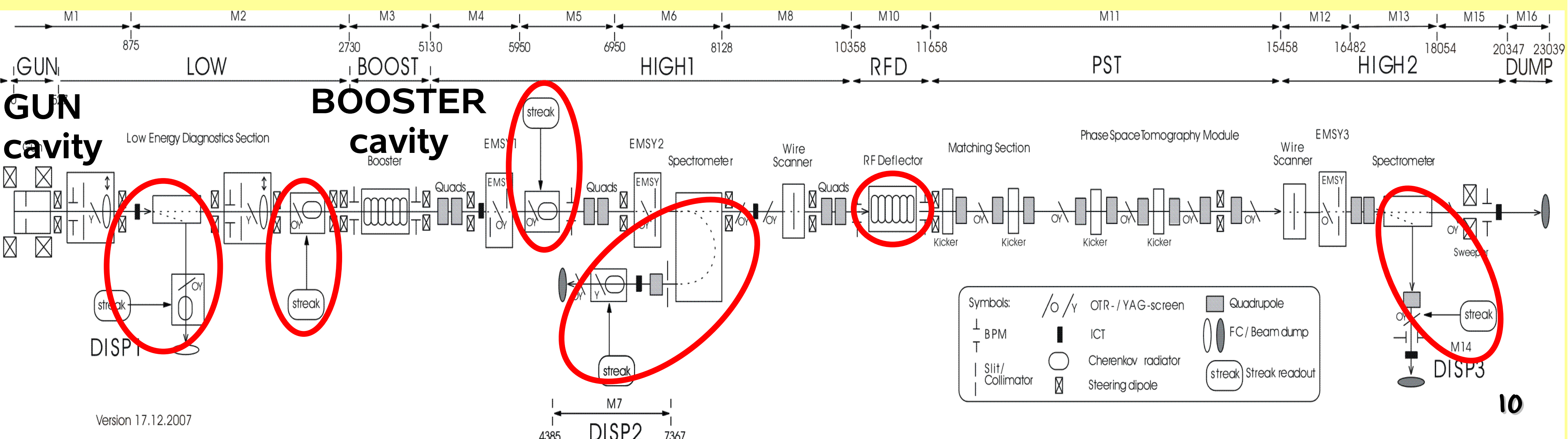


Setup of PITZ



longitudinal phase space measurement:

- Beam momentum distribution
- longitudinal distribution
- longitudinal phase space



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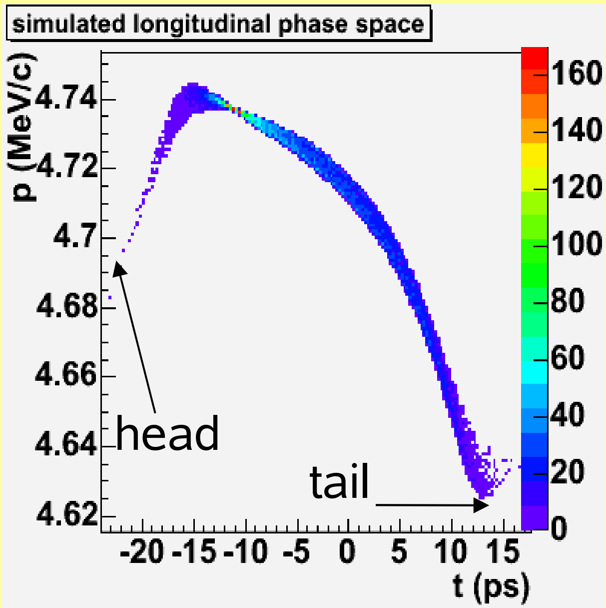
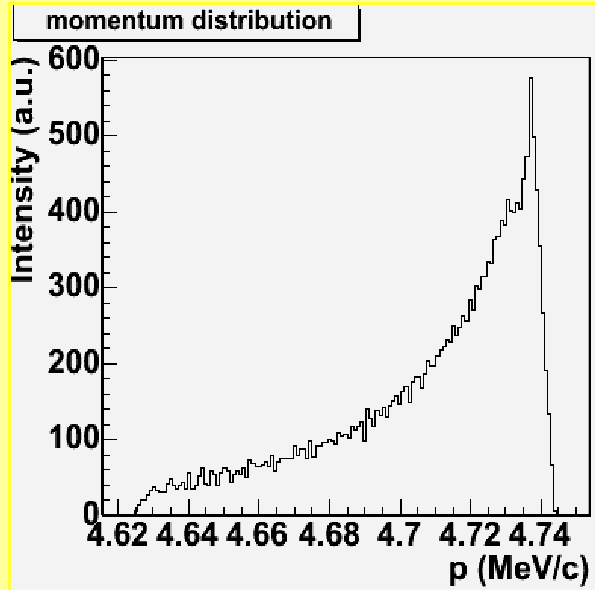
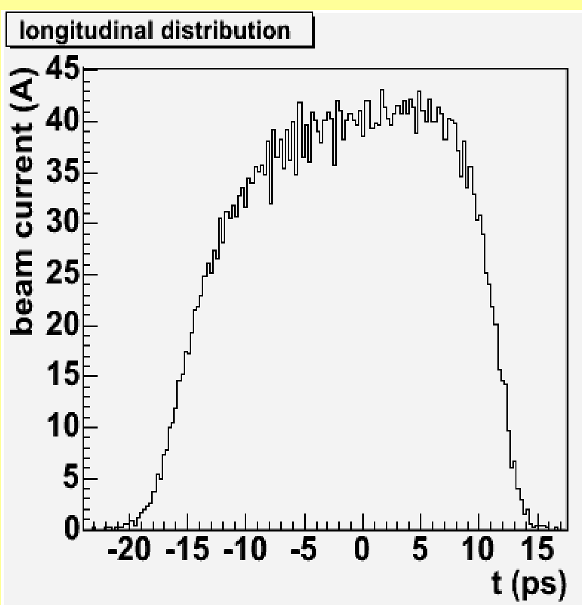
Longitudinal phase space of a photoinjector





- 1 nC
- 40 MeV/m
- 0.5m after the cathode
- laser:
  - long.: flat-top
    FWHM : 20 ps
    risetime : 7 ps
  - transv.: flat-top
    Ø : 2 mm



projections of longitudinal phase space:

- momentum distribution
- longitudinal distribution

area of longitudinal phase space:
emittance ε_z

$$\varepsilon_z = \sqrt{<(\Delta p_z)^2> <(\Delta z)^2> - <\Delta p_z \Delta z>^2}$$

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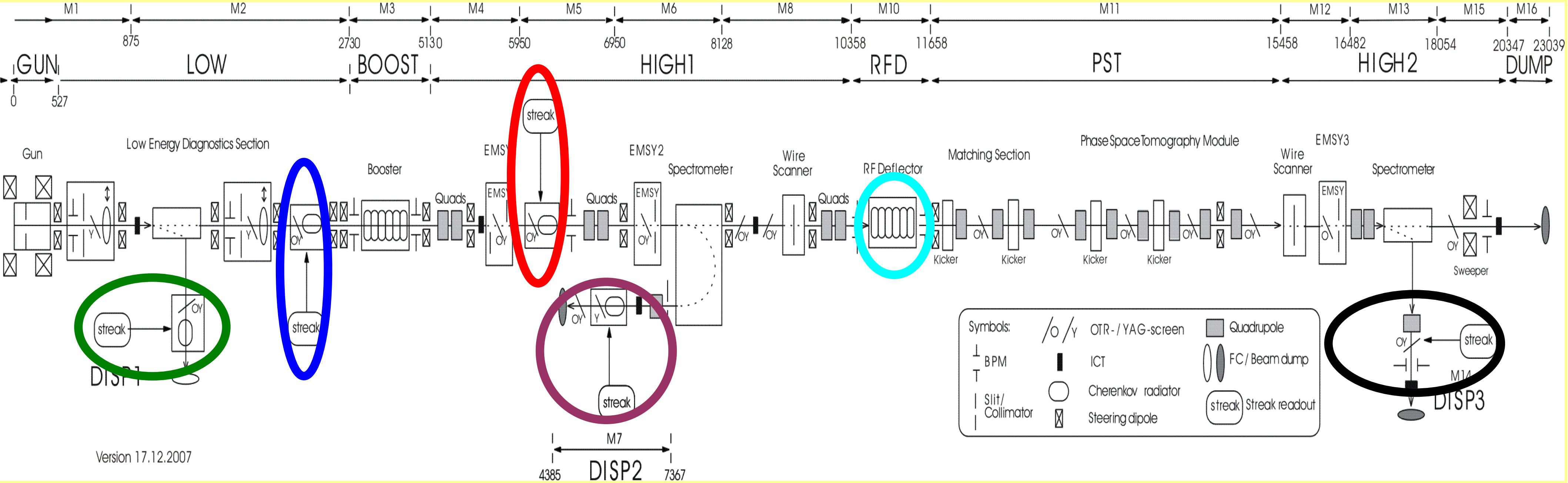
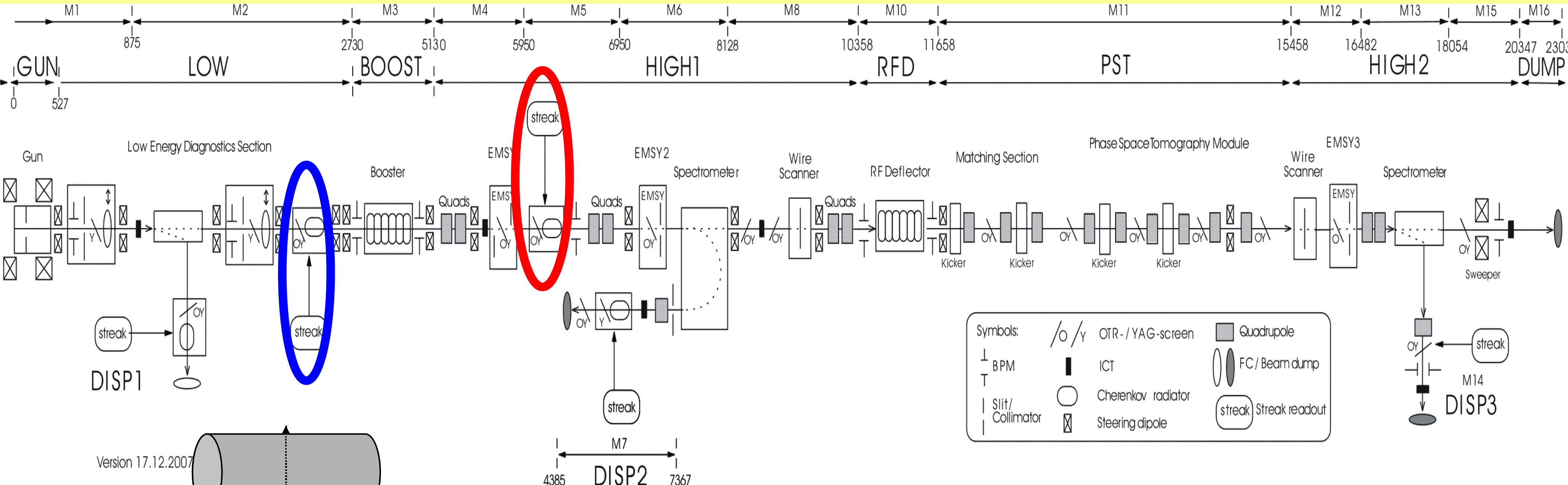
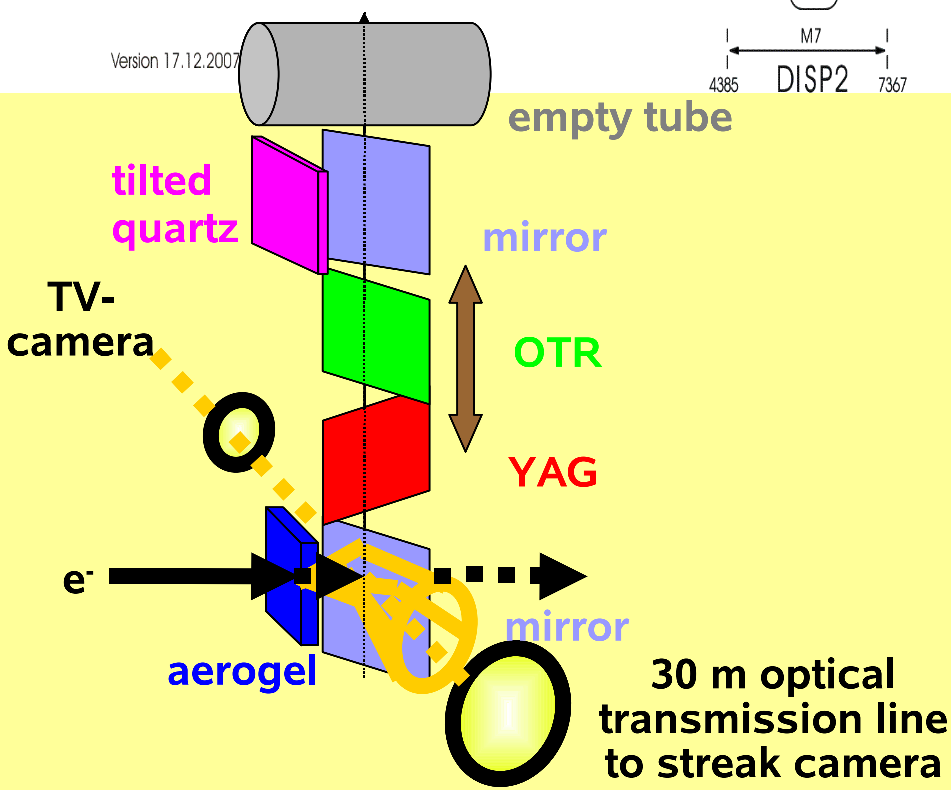
Devices of longitudinal phase space measurement at PITZ



- Beam momentum distribution: dipole magnet and a view screen
- Bunch length: - aerogel or OTR as radiators and a streak camera
  - RF deflector
- Longitudinal phase space: - dipole magnet, radiator and streak camera
  - RF deflector and dipole magnet

measurement of longitudinal distribution using streak camera





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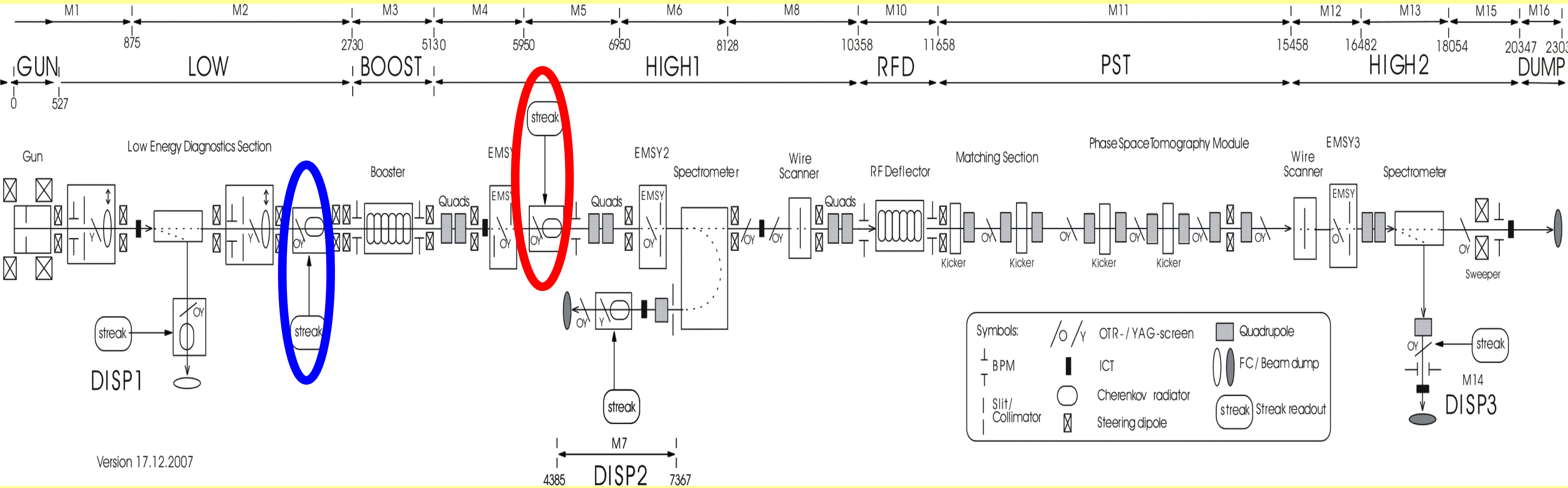
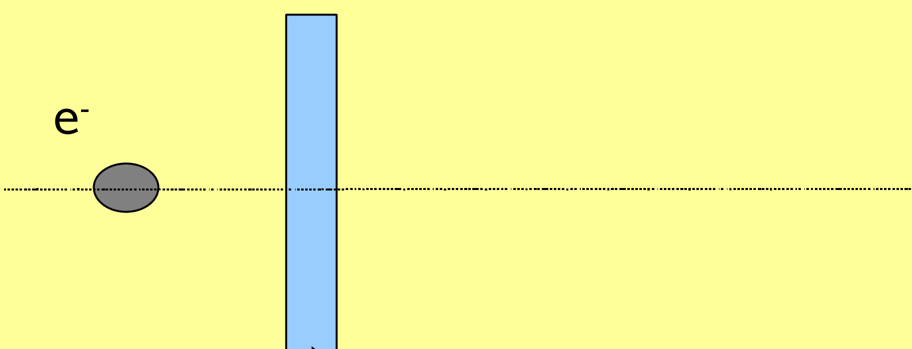
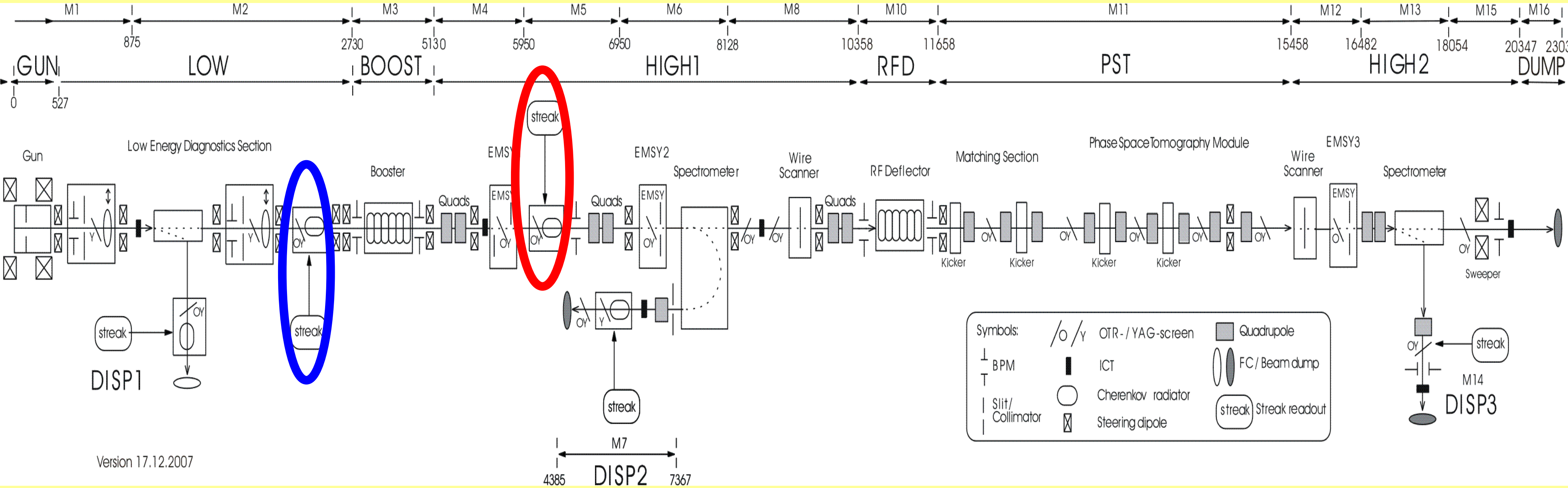


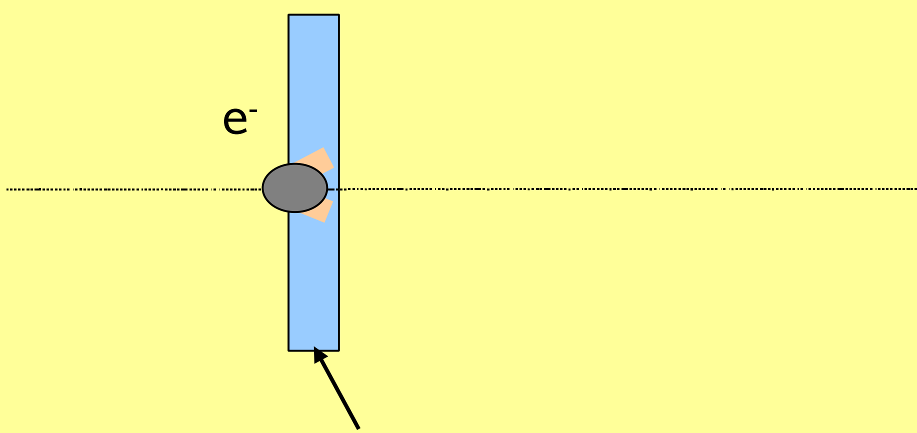


Silica aerogel
n = 1.008 - 1.05

measurement of longitudinal distribution using streak camera



- electron bunch is transformed into a light pulse with approximately the same temporal distribution by the Cherenkov effect



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Cherenkov radiator

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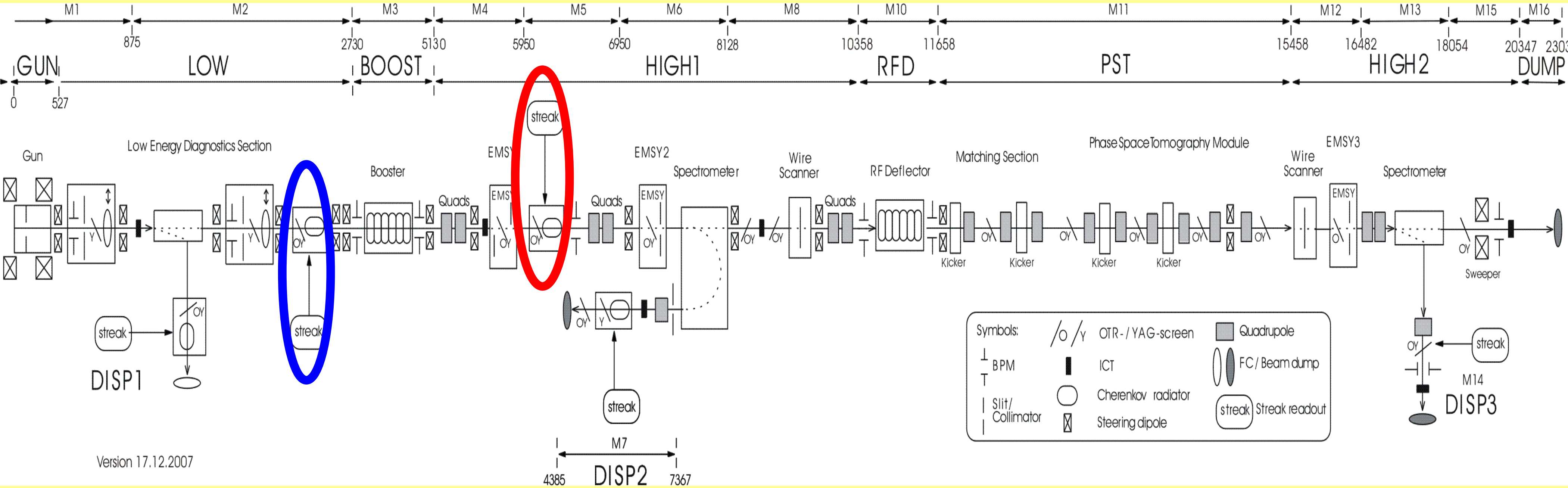

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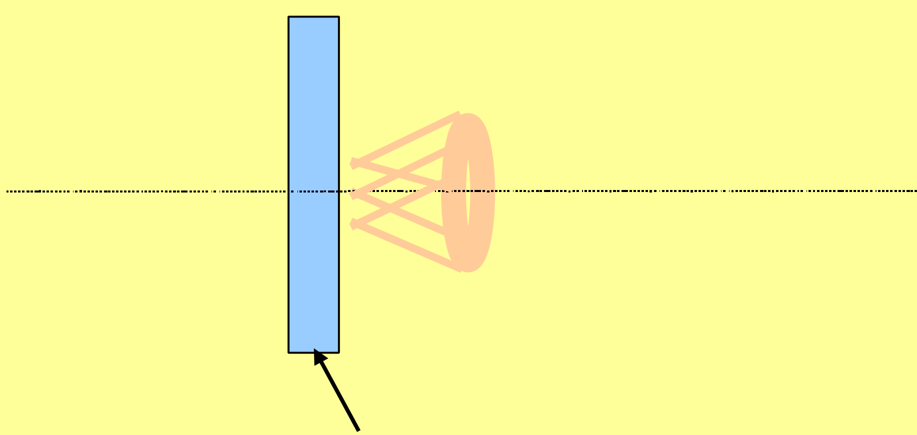

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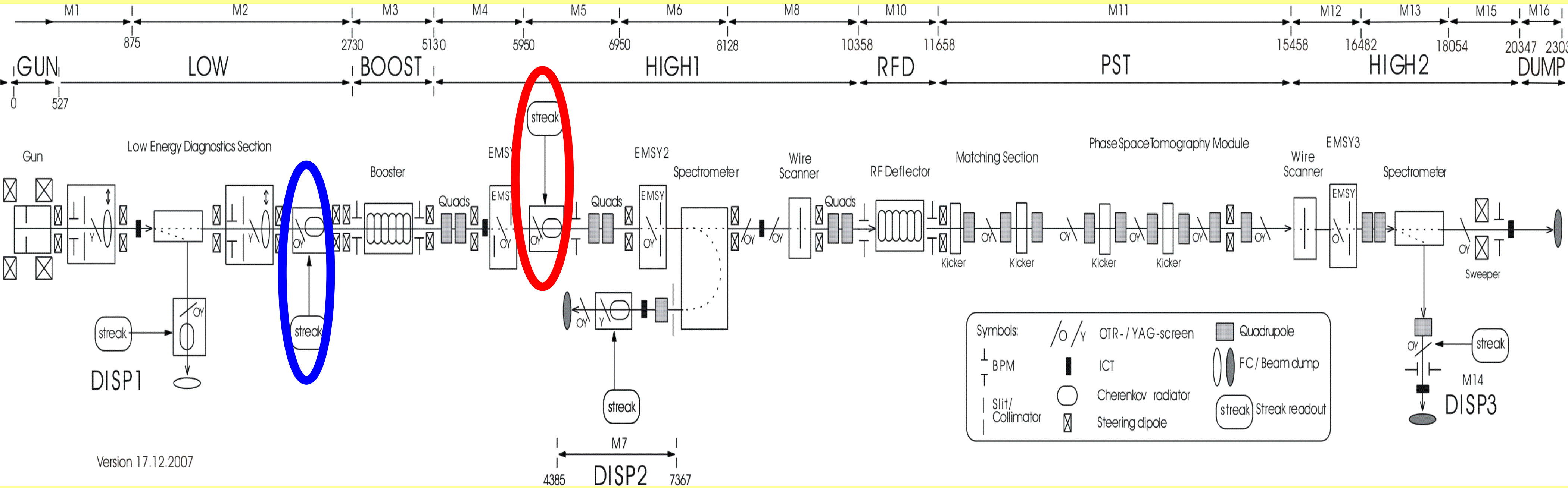

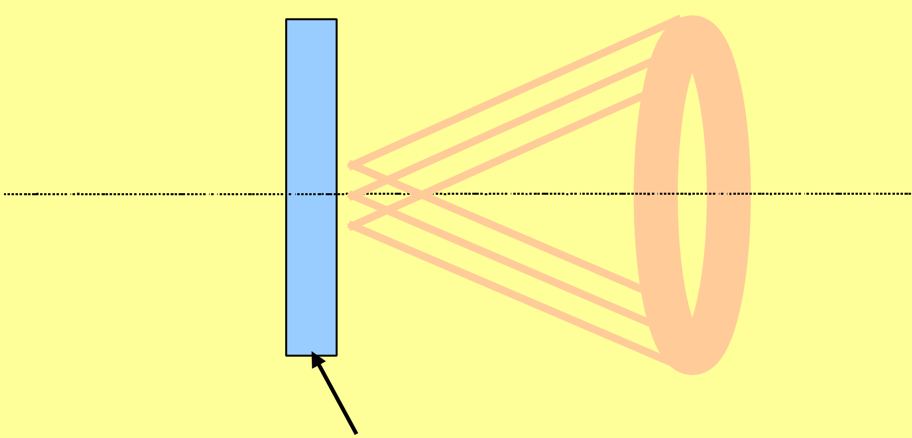

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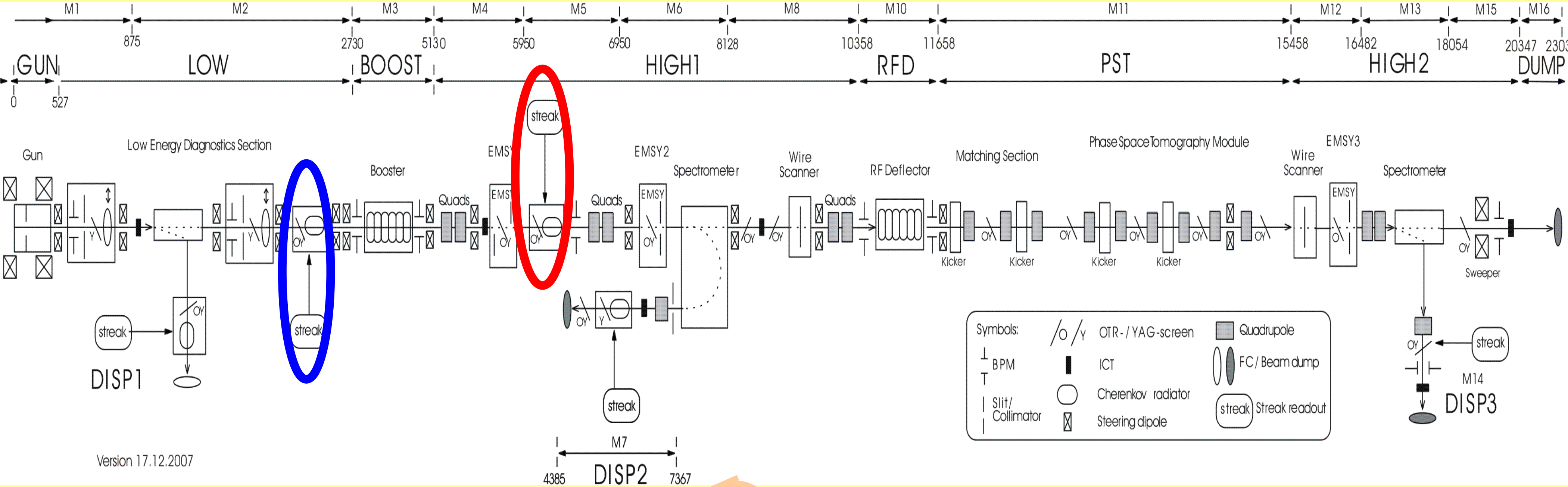

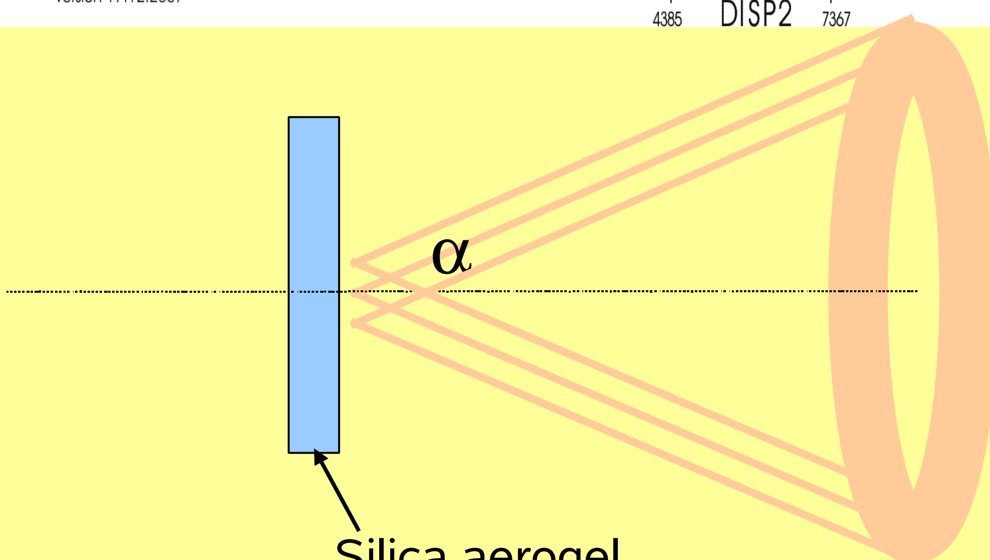

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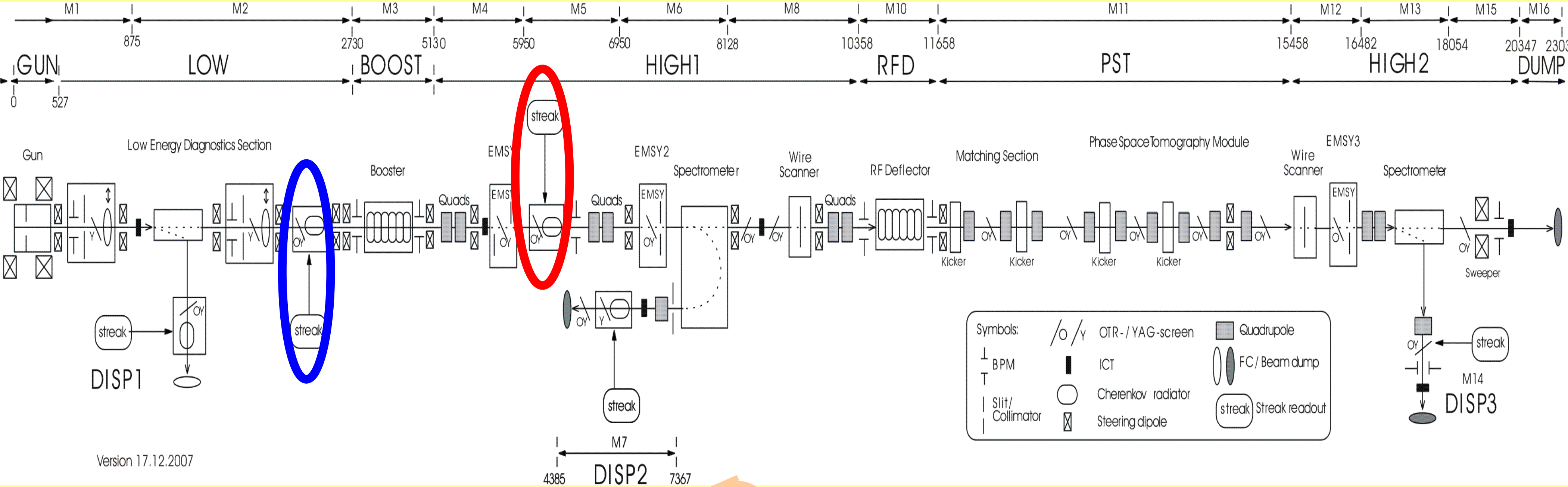
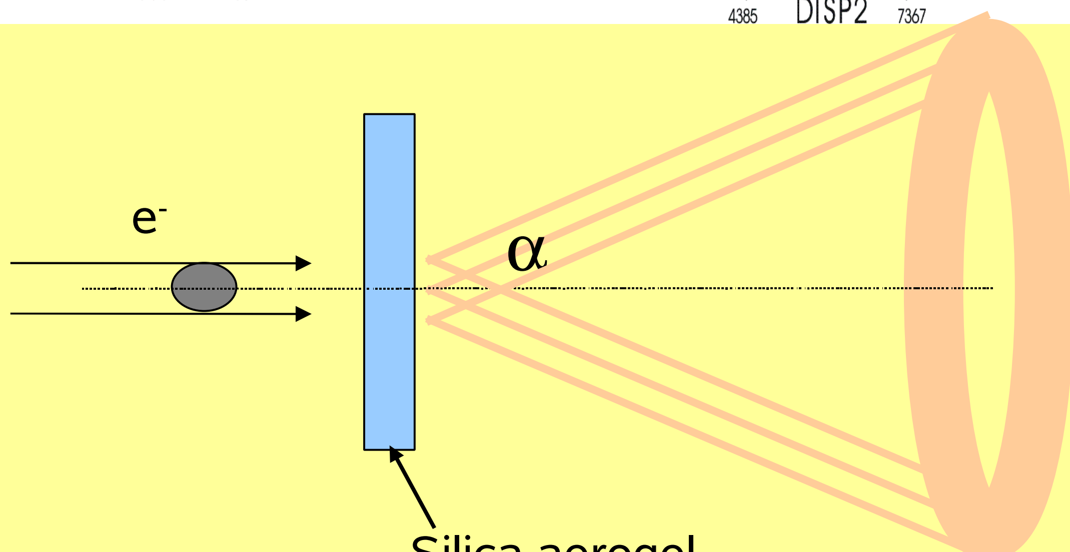
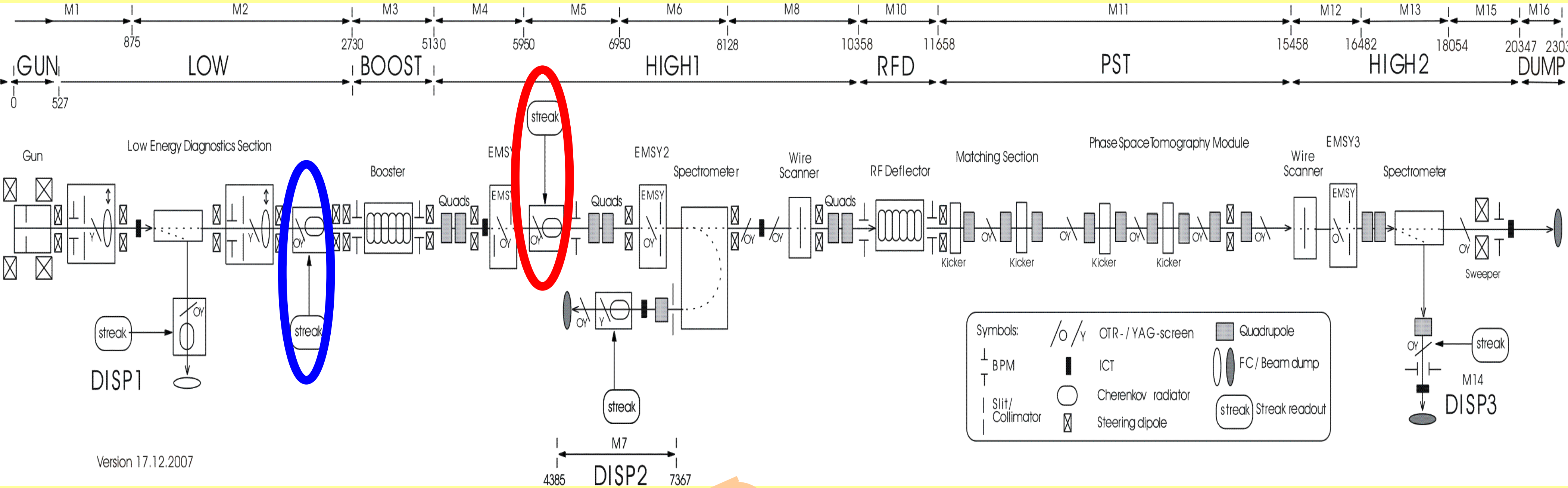


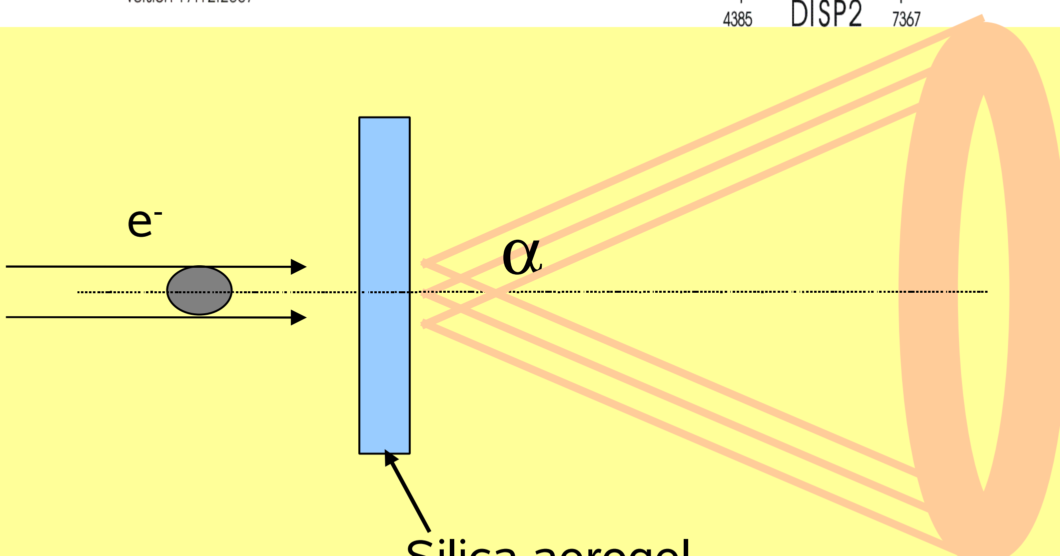


Silica aerogel
n = 1.008 – 1.05
Cherenkov radiator

- electron bunch is transformed into a light pulse with approximately the same temporal distribution by the Cherenkov effect
- light transport
- streak camera measurement

measurement of longitudinal distribution using streak camera



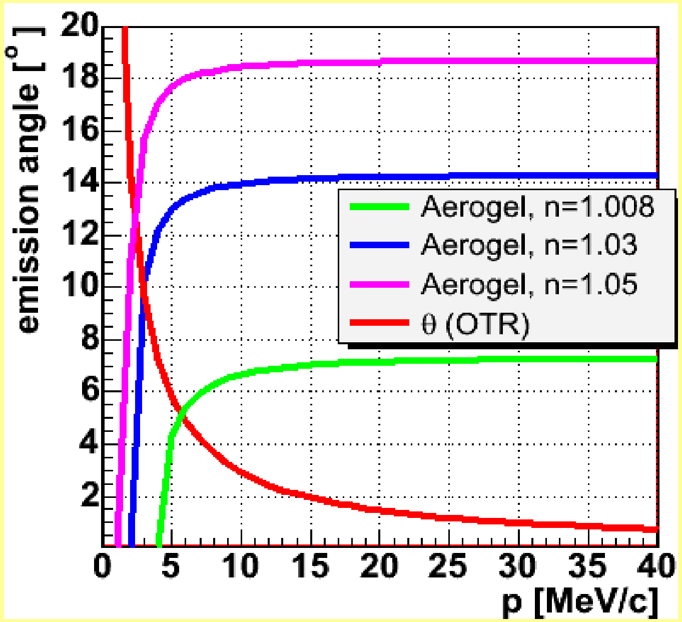


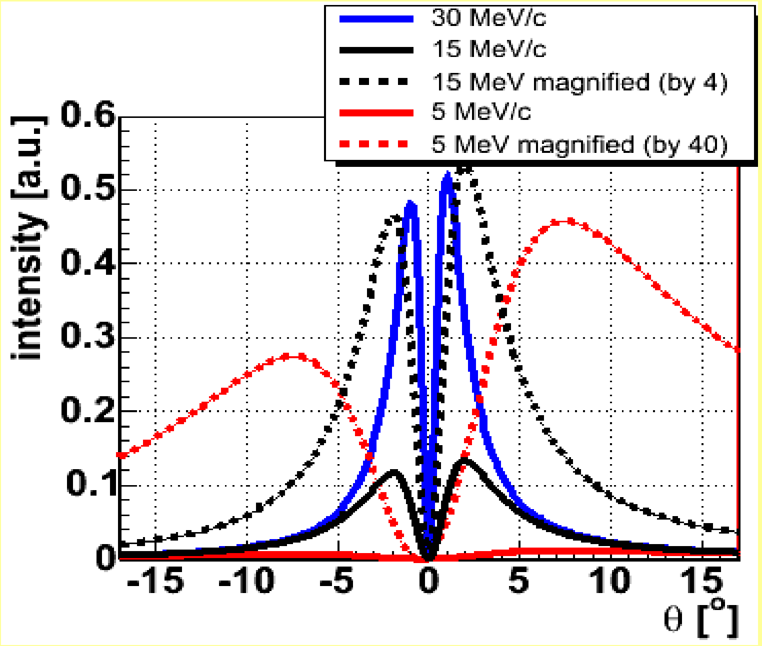
Silica aerogel
n = 1.008 – 1.05
Cherenkov radiator

- electron bunch is transformed into a light pulse with approximately the same temporal distribution by the Cherenkov effect
- light transport
- streak camera measurement

- advantage compared to RF-deflector: measurement at several positions along the beamline
- disadvantage compared to RF-deflector: poor resolution

measurement of longitudinal distribution using streak camera





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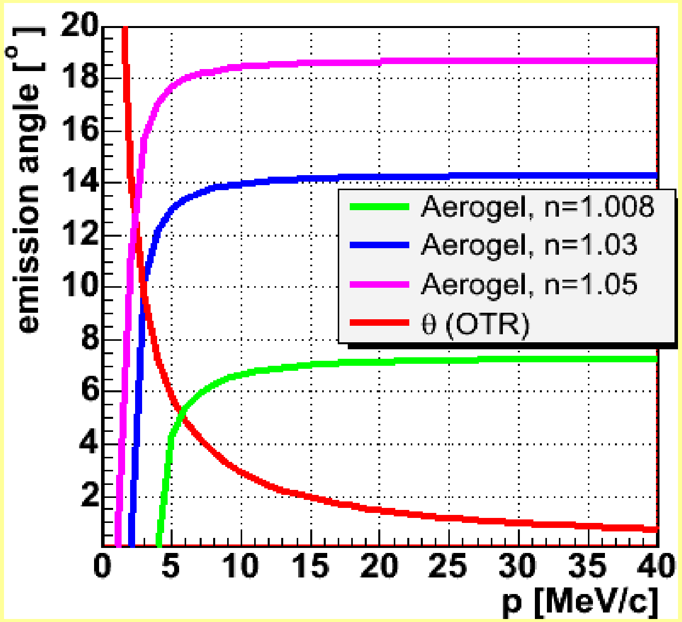
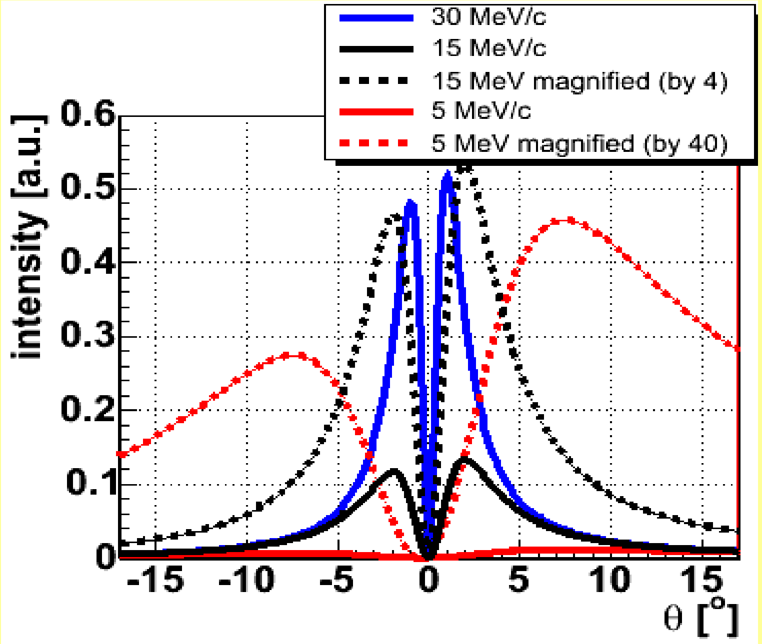
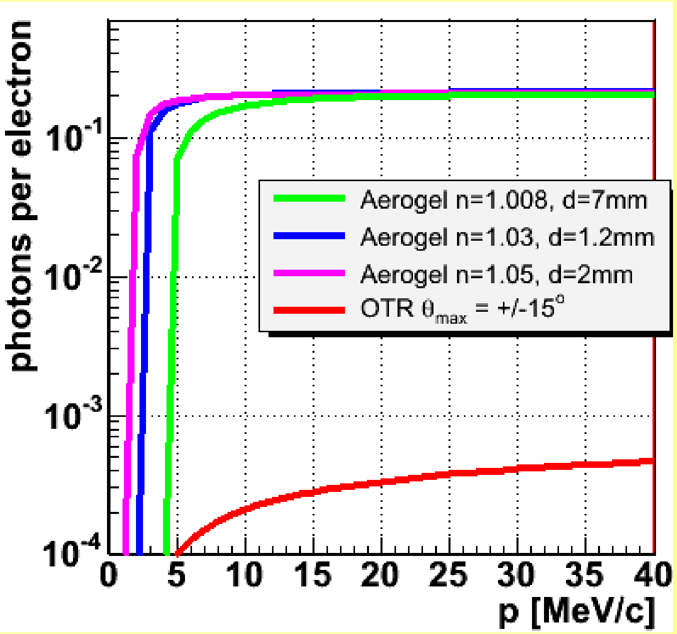




The amount of light produced by silica aerogel is several order of magnitude higher than the the one of an OTR-screen.



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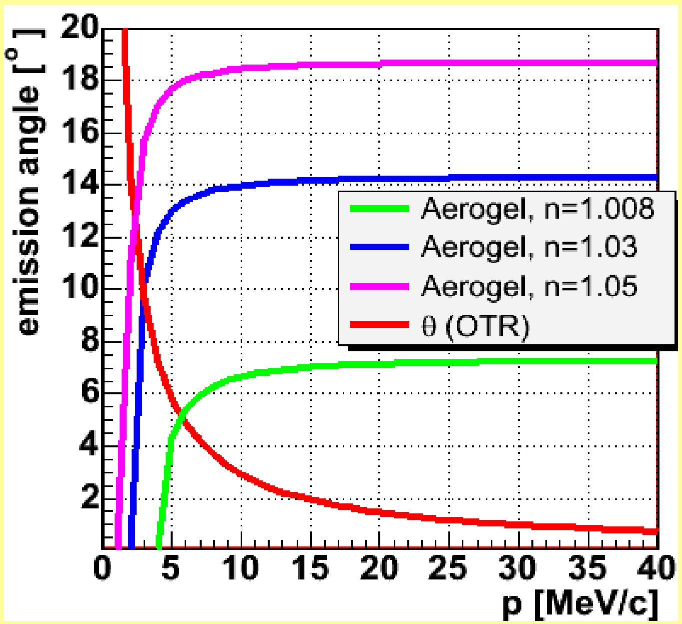

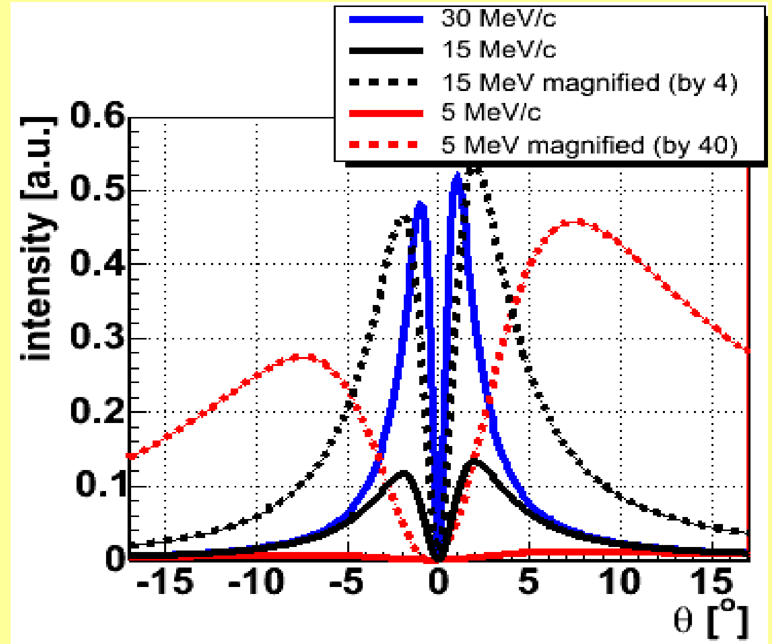

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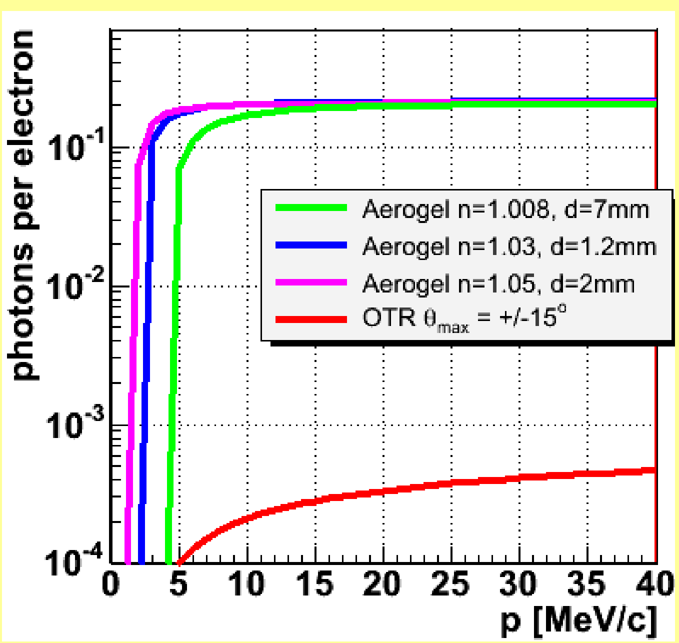
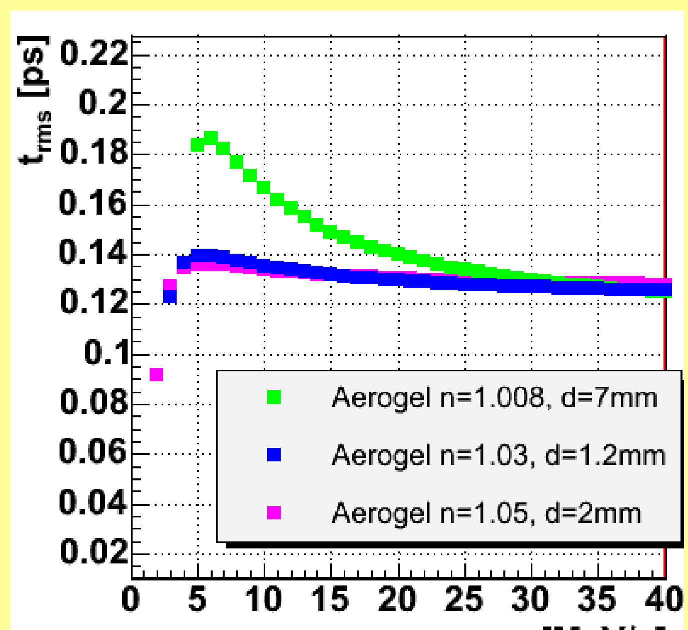
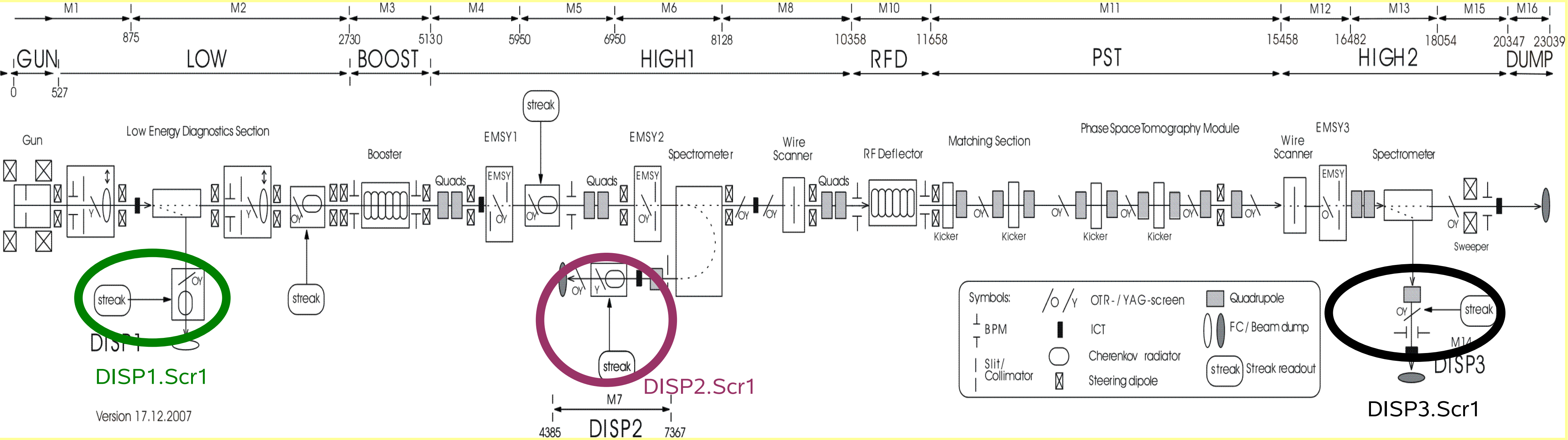
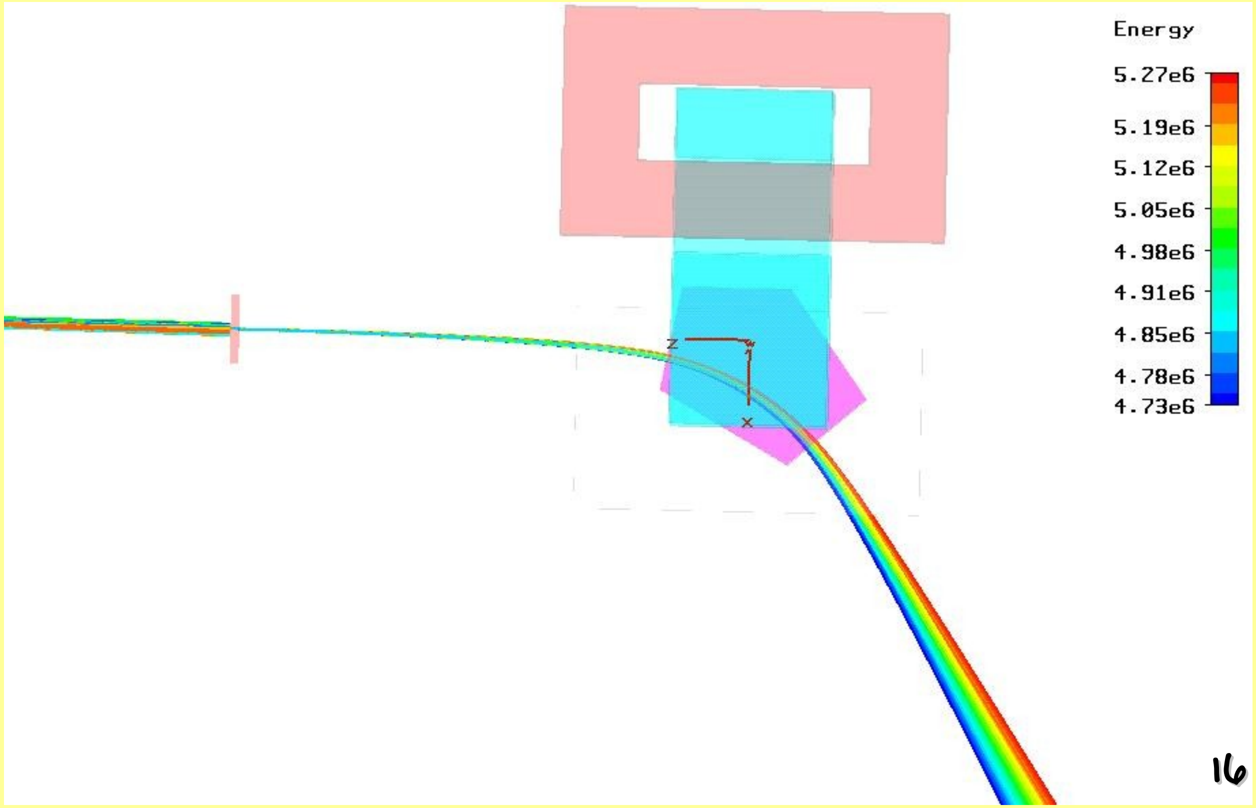




momentum measurement





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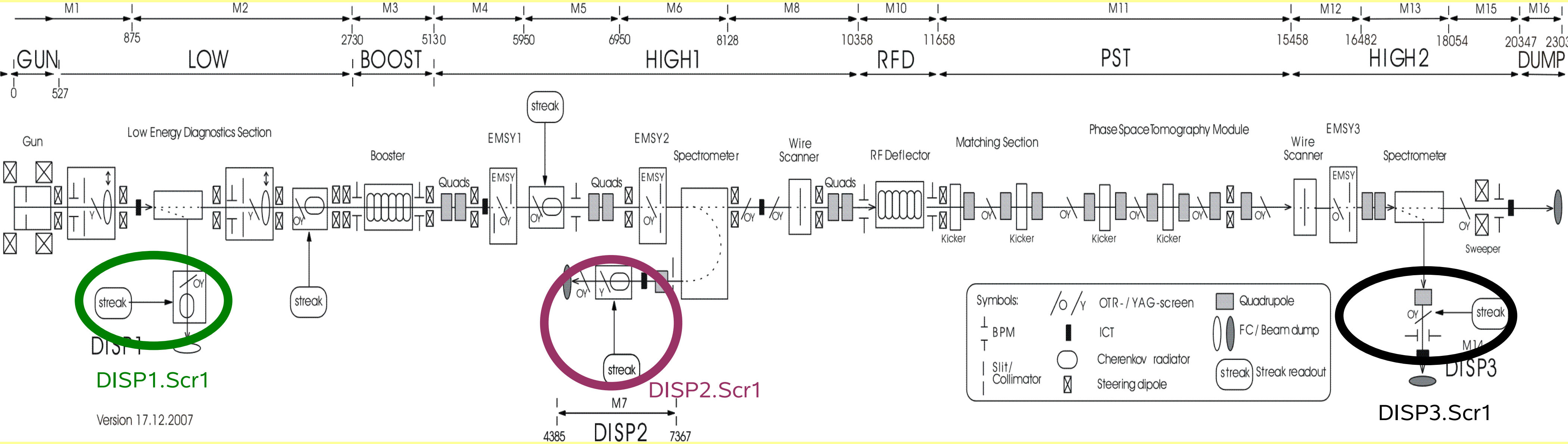
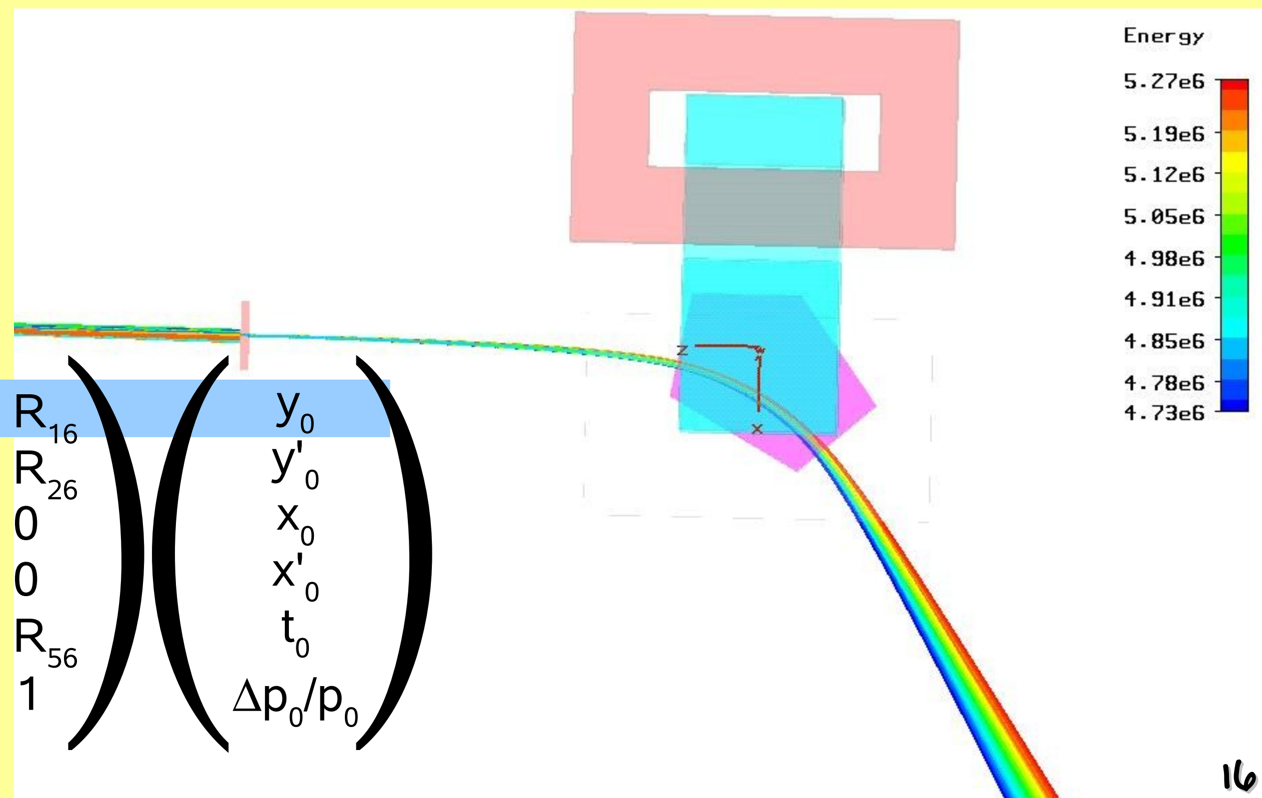
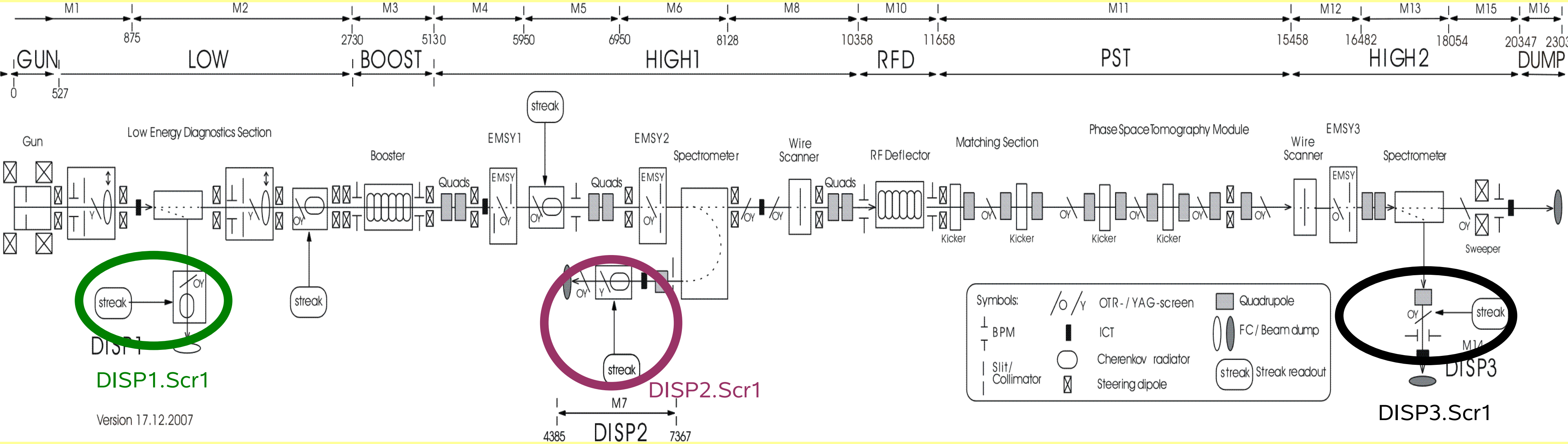




$$
\begin{pmatrix} y \\ y' \\ x \\ x' \\ t \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} & 0 & 0 & 0 & R_{16} \\ R_{21} & R_{22} & 0 & 0 & 0 & R_{26} \\ 0 & 0 & R_{33} & R_{34} & 0 & 0 \\ 0 & 0 & R_{43} & R_{44} & 0 & 0 \\ R_{51} & R_{52} & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} y_0 \\ y'_0 \\ x_0 \\ x'_0 \\ t_0 \\ \Delta p_0/p_0 \end{pmatrix}
$$

momentum measurement



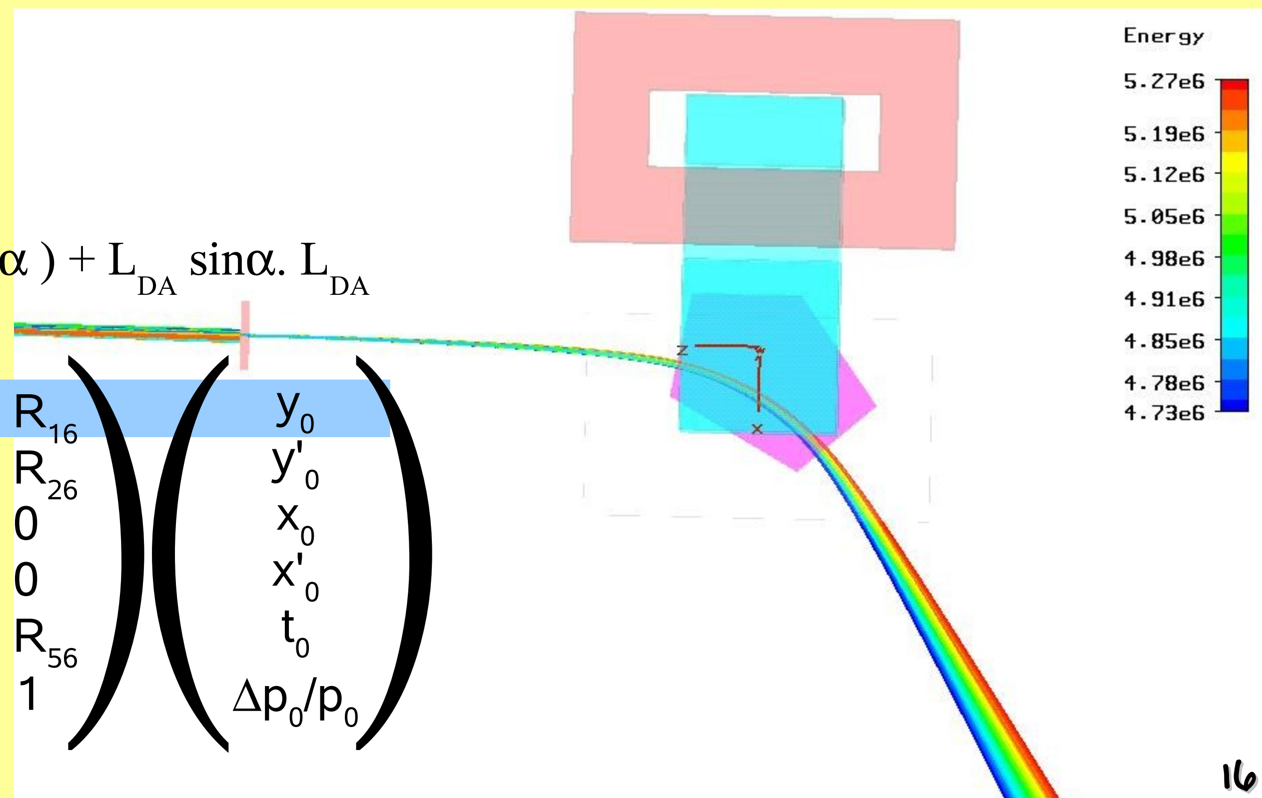
$$p = e / \alpha \int B_{dipole}(l)\, dl$$

$$p_c = |e B_{dipole}\, l_{eff} / \alpha|$$

$$\Delta p = p_c \,\Delta y / R_{16}$$

$$R_{16} = (l_{eff}/\alpha + L_{DA} \tan\beta_{out})(1-\cos\alpha) + L_{DA} \sin\alpha .\, L_{DA}$$

$$\begin{pmatrix} y \\ y' \\ x \\ x' \\ t \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} & 0 & 0 & 0 & R_{16} \\ R_{21} & R_{22} & 0 & 0 & 0 & R_{26} \\ 0 & 0 & R_{33} & R_{34} & 0 & 0 \\ 0 & 0 & R_{43} & R_{44} & 0 & 0 \\ R_{51} & R_{52} & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} y_0 \\ y'_0 \\ x_0 \\ x'_0 \\ t_0 \\ \Delta p_0/p_0 \end{pmatrix}$$



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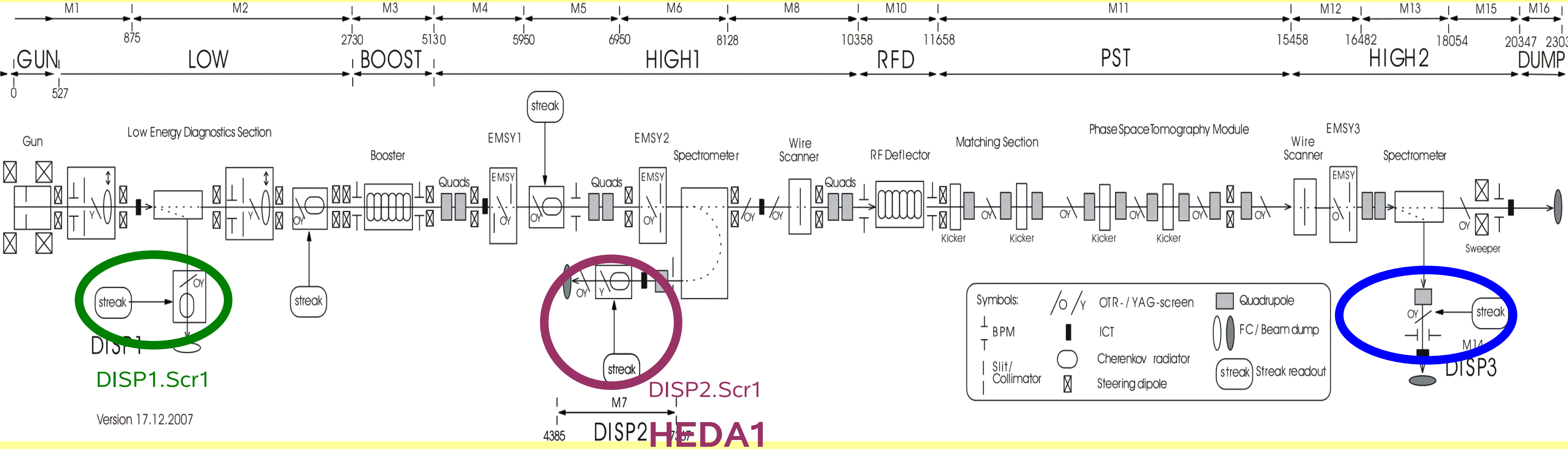
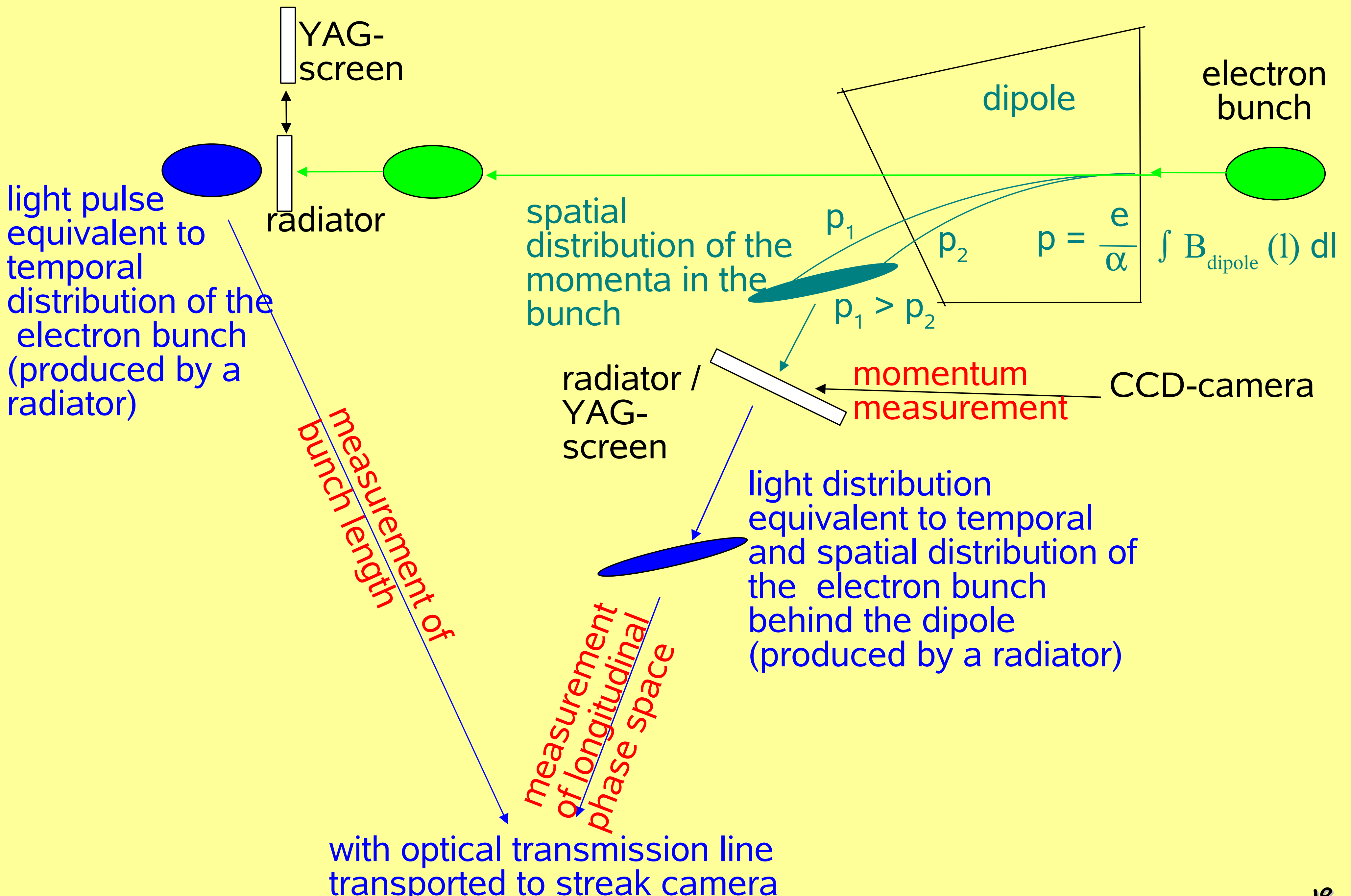
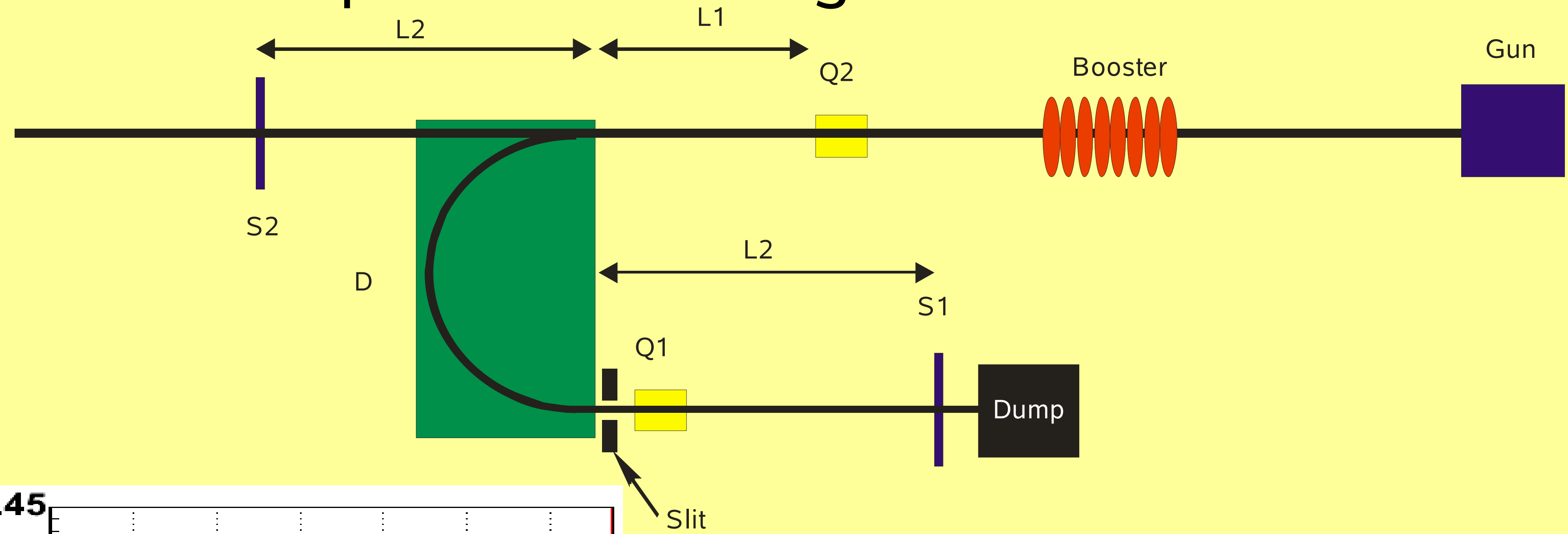


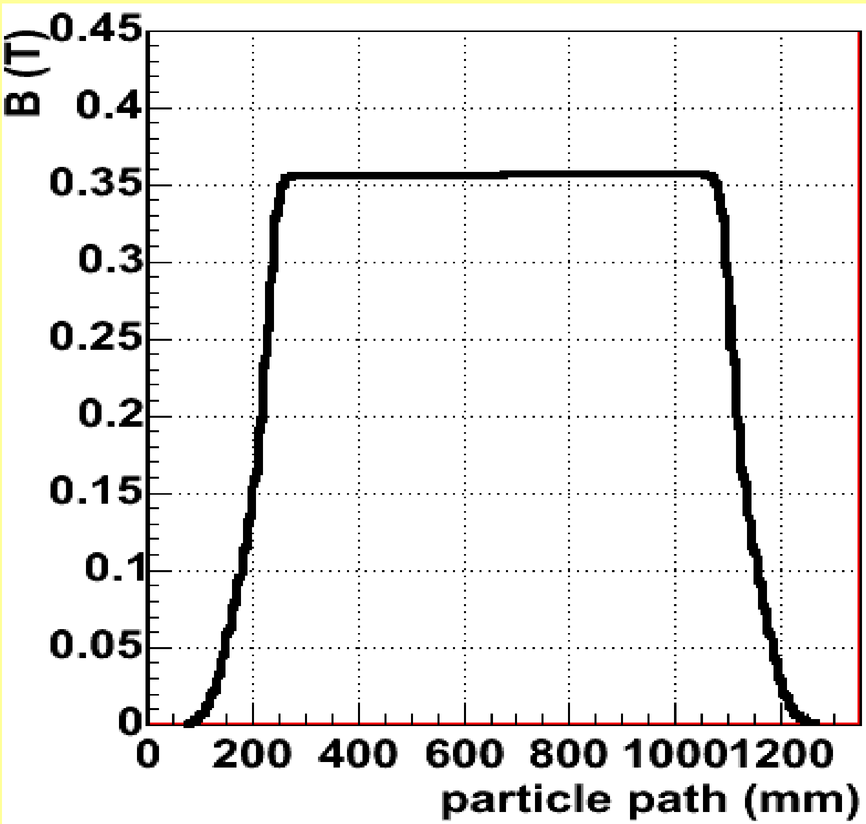
	Disp1.Scr1	Disp2.Scr1/2	Disp3.Scr1	spare dipole
deflection angle α	60°	180°	60°	60°
β_{in}	11° -> 0°	0°	*to be defined*	31.7°
β_{out}	11° -> 25°	0°	*to be defined*	2°
r (mm)	~105 -> 150	300	*to be defined*	~350
L_{DA} (mm)	568.4 ->~525	1411.5 / 1958.5	*to be defined*	507.6
l_{eff} (mm)	141.2 ->~160	941.65	*to be defined*	365.5
gap width (mm)	**20 -> 35**	40	43	50

Measurement of longitudinal phase space



spectrometer magnet HEDA1

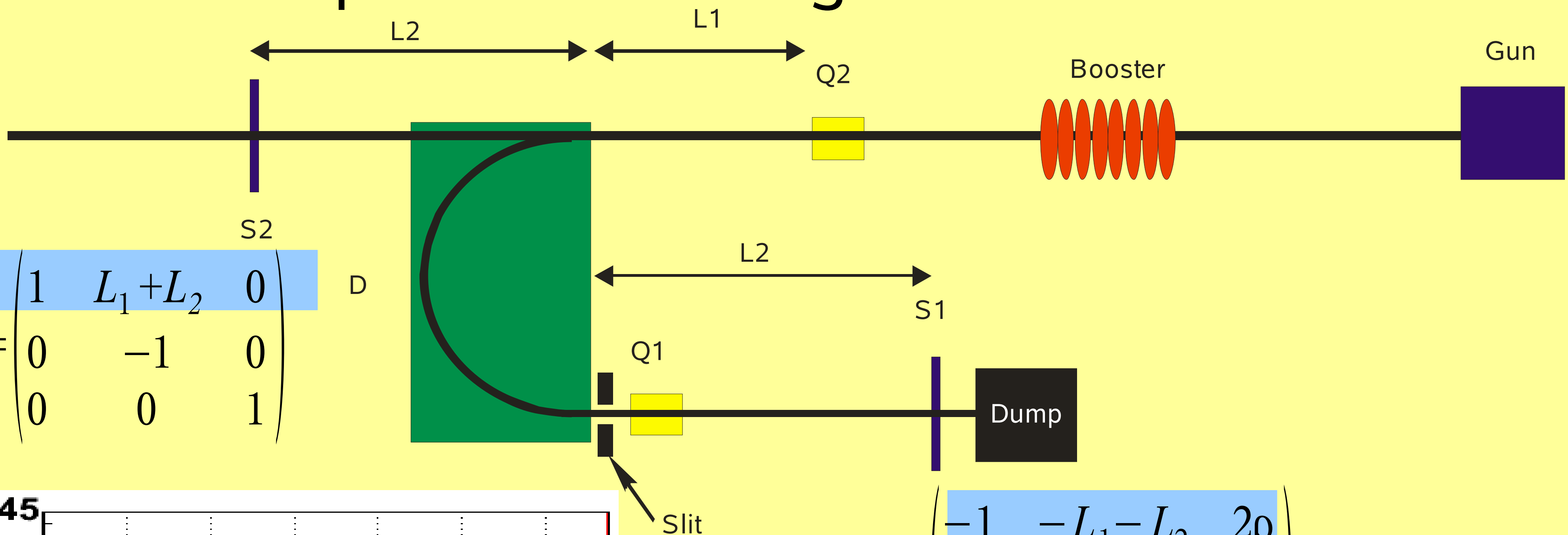




deflecting angle: 180°
deflecting radius: 300 mm

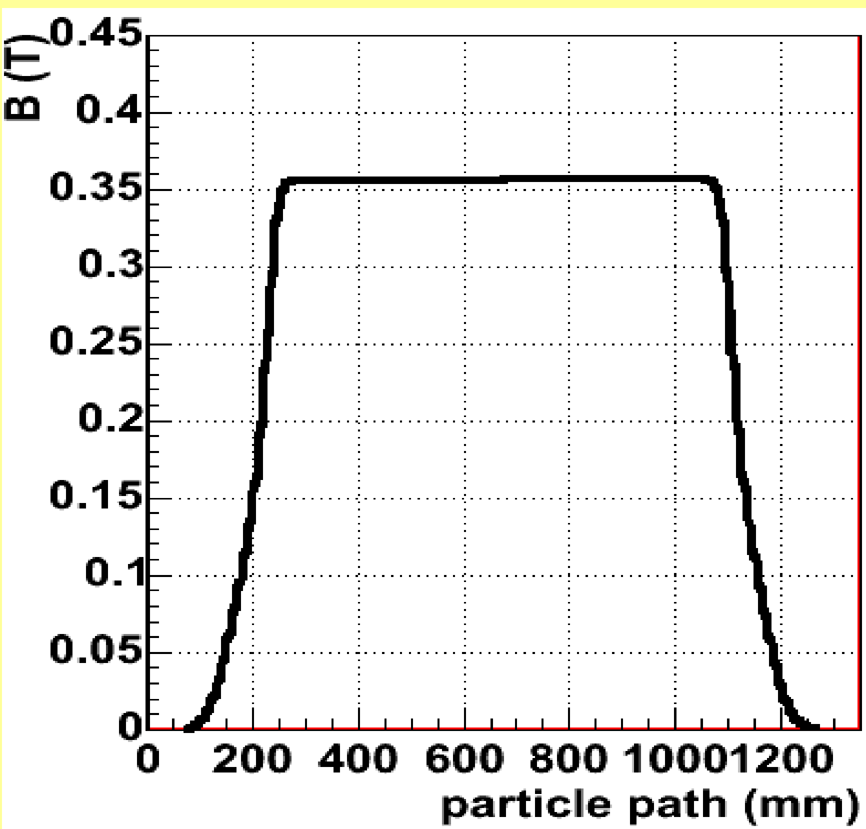
$L_{eff} = 1/B_0 \int B_x \, dz$
$L_{eff} = 941.6$ mm
geometrical length: $L_{geom} = 942.5$ mm

spectrometer magnet HEDA1



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$M_D = \begin{pmatrix} -1 & -L_1 - L_2 & 2\rho \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



deflecting angle: 180°
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$L_{eff} = 1/B_0 \int B_x\, dz$
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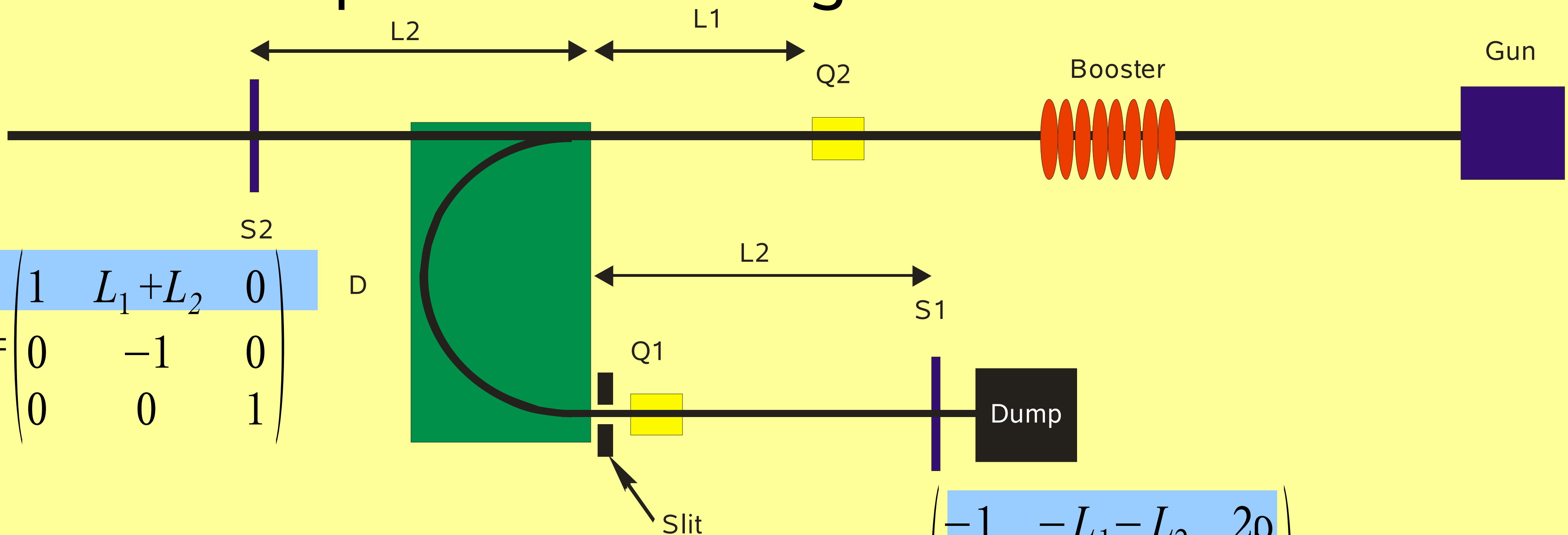
spectrometer magnet HEDA1



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

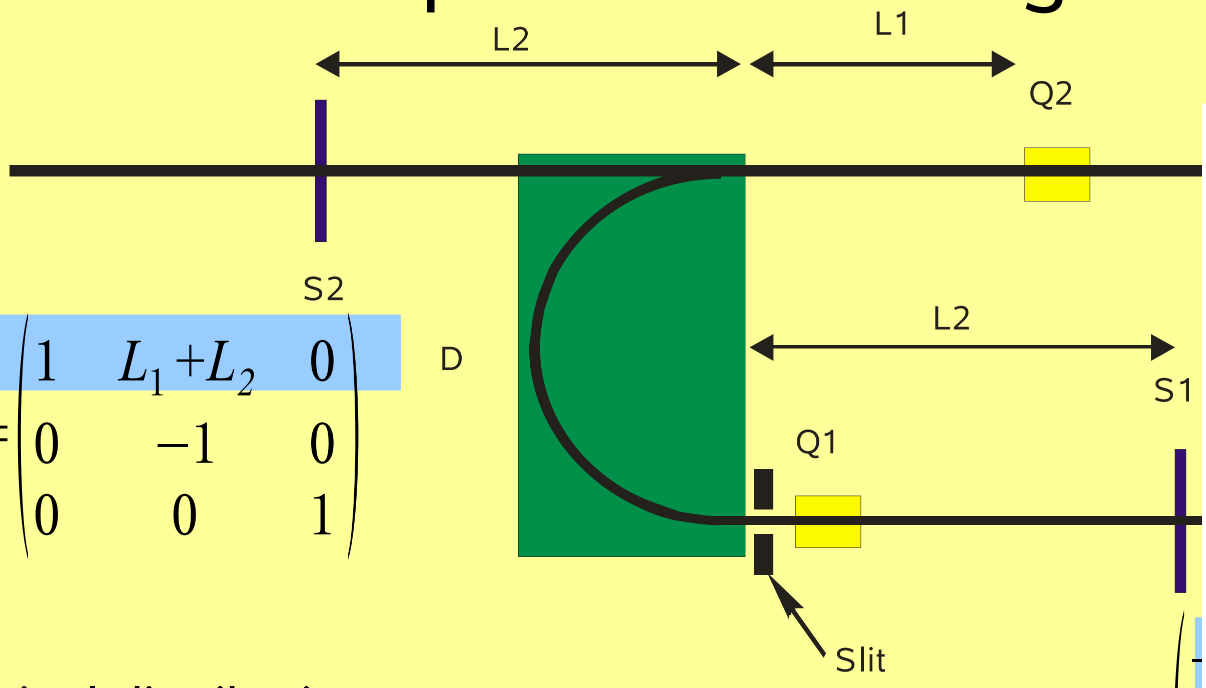
$$M_D = \begin{pmatrix} -1 & -L_1 - L_2 & 2\rho \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

vertical distribution

$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0 / p_0$

$\Rightarrow R_{16}\, dp_0 / p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$

spectrometer magnet HEDA1



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

vertical distribution

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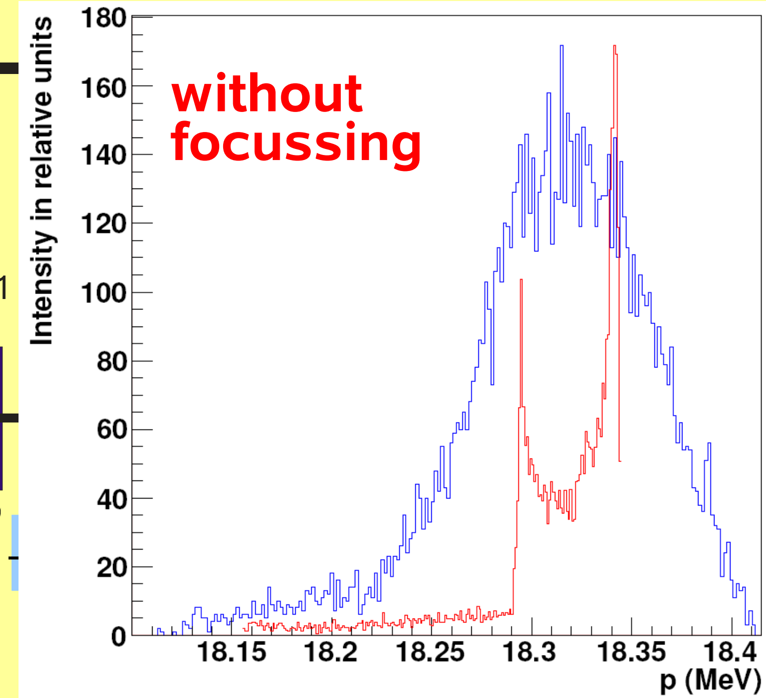
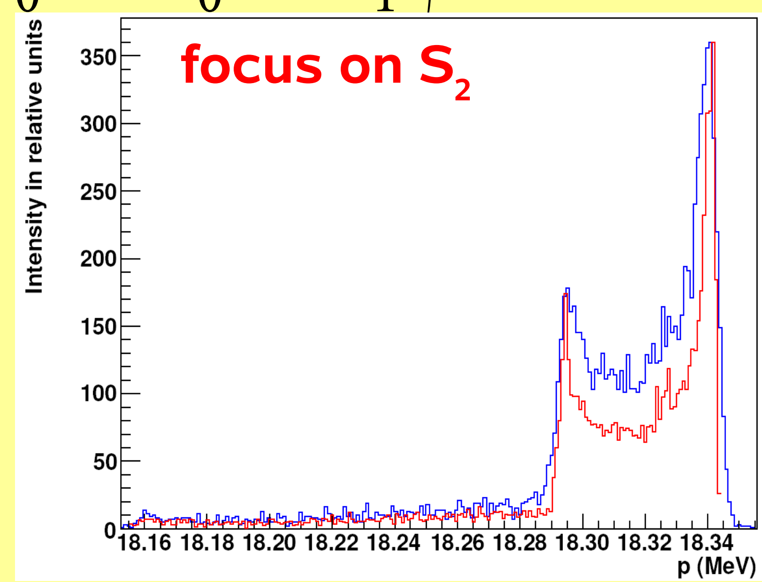
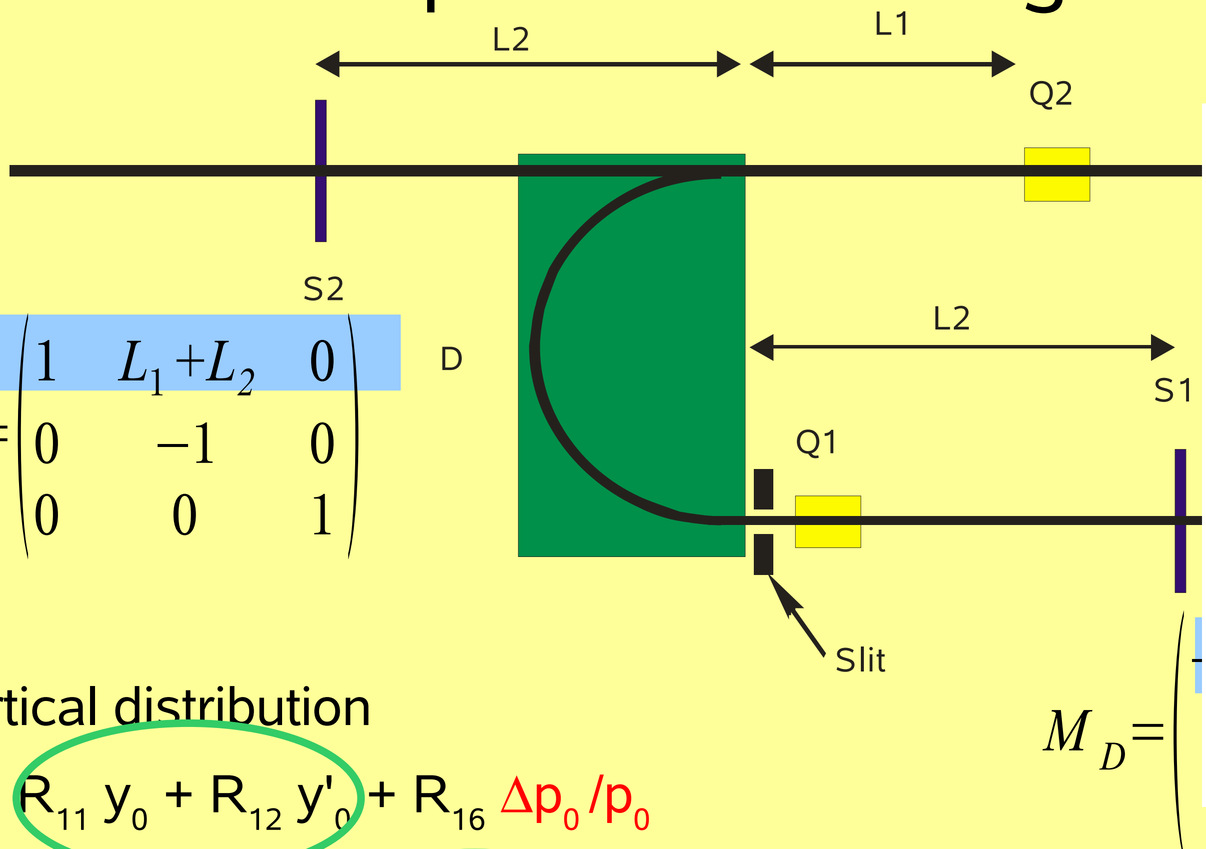




spectrometer magnet HEDA1



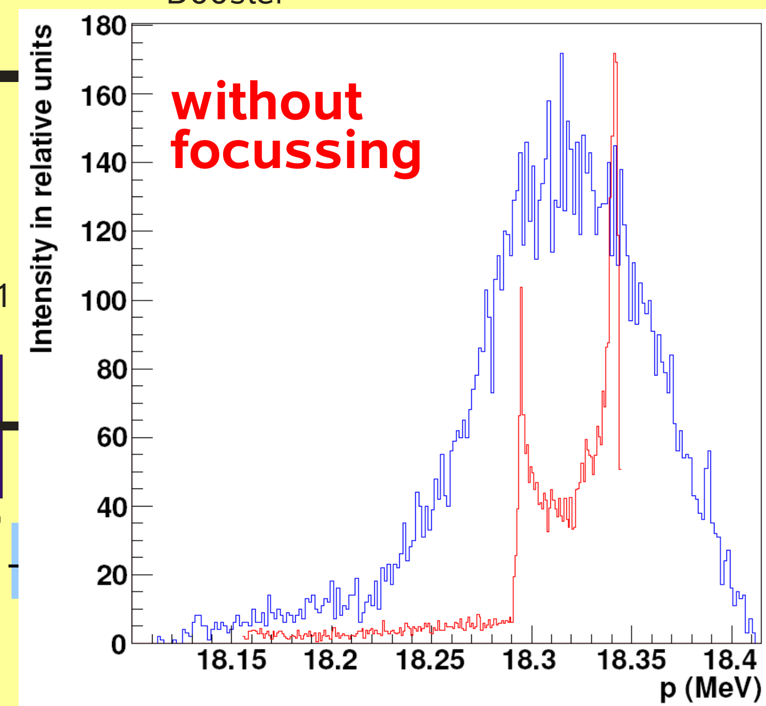
$$M_S = \begin{pmatrix} 1 & L_1+L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

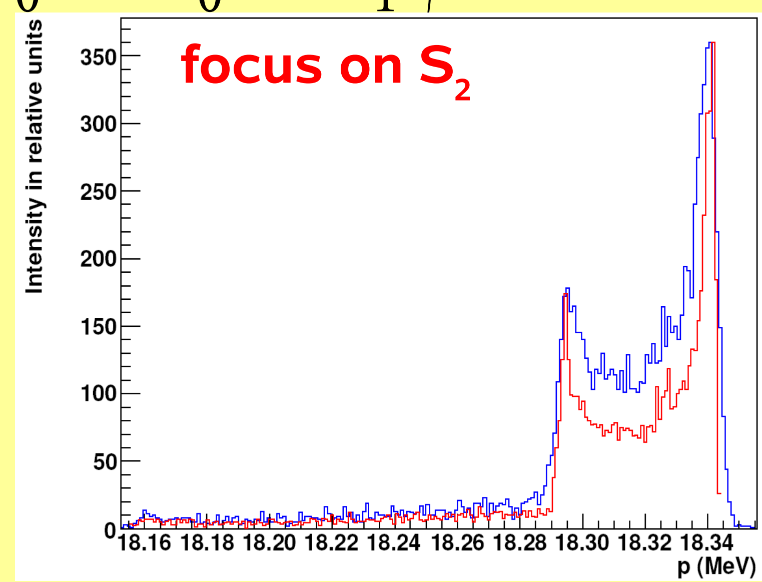
vertical distribution

$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0 / p_0$

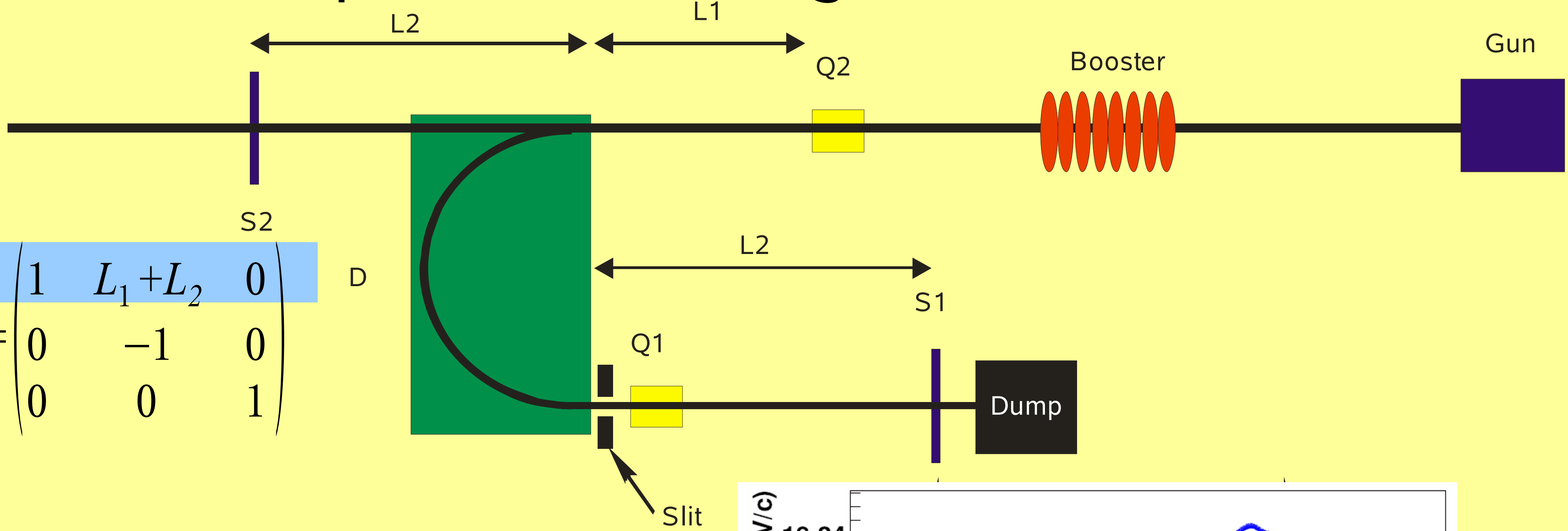
$\Rightarrow R_{16}\, dp_0 / p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$

correction by deconvolution





spectrometer magnet HEDA1



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

vertical distribution

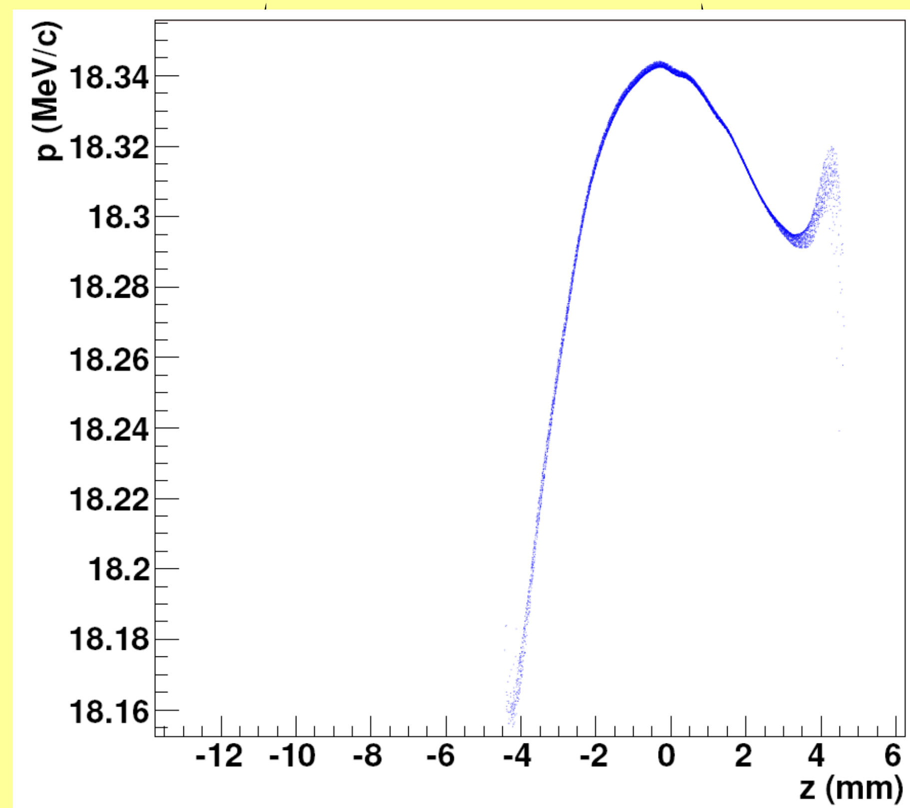
$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0 / p_0$

$\Rightarrow R_{16}\, dp_0 / p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$

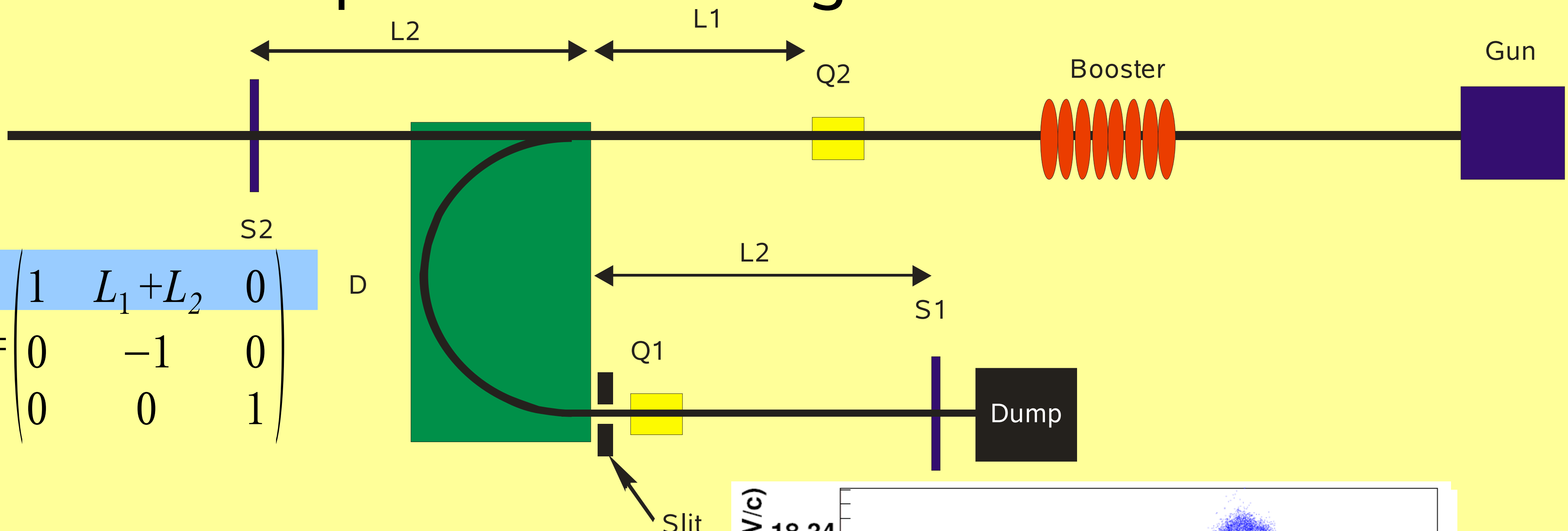
temporal distribution:

$t = R_{51}\, y_0 + R_{52}\, y'_0 + t_0 + R_{56}\, \Delta p_0 / p_0$

correction by deconvolution



spectrometer magnet HEDA1



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

vertical distribution

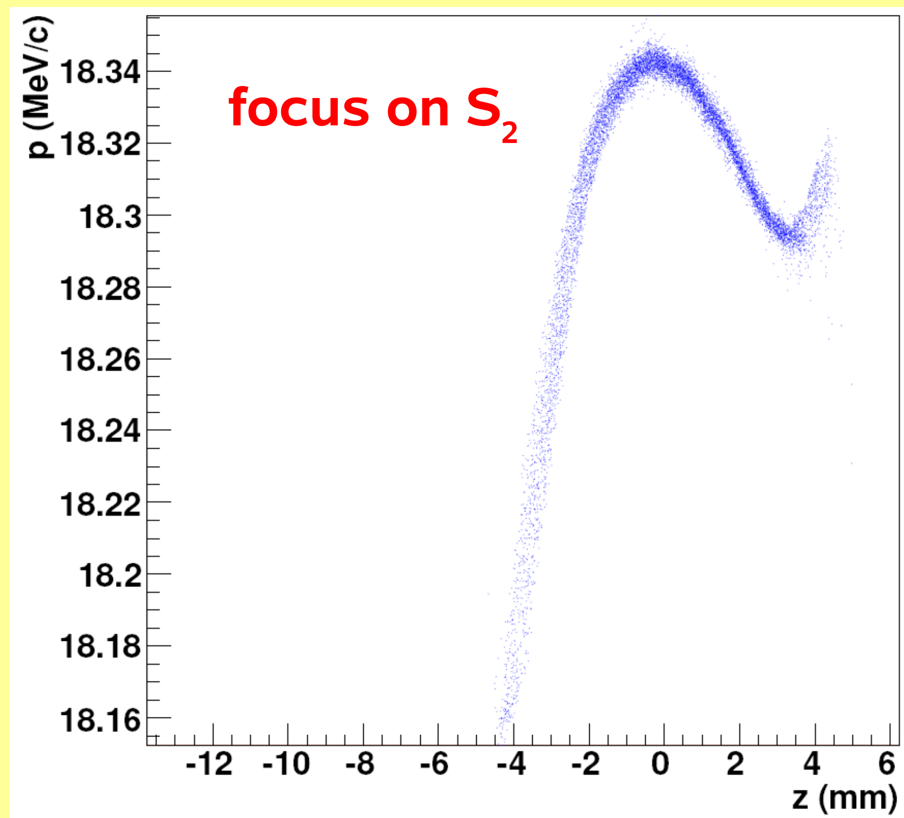
$$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0 / p_0$$

$$\Rightarrow R_{16}\, dp_0 / p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$$

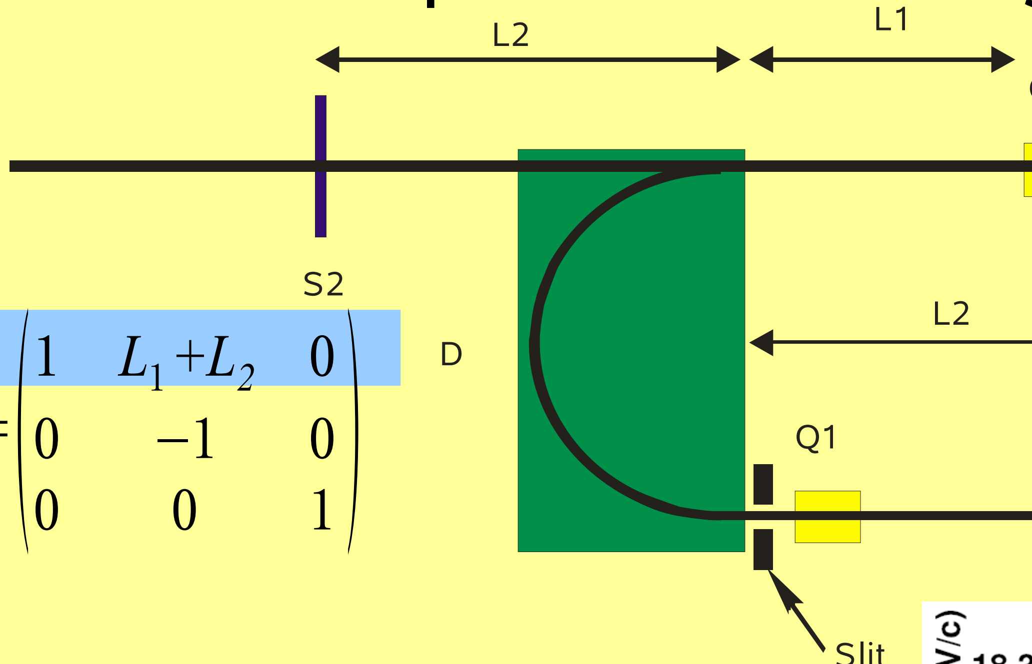
temporal distribution:

$$t = R_{51}\, y_0 + R_{52}\, y'_0 + t_0 + R_{56}\, \Delta p_0 / p_0$$

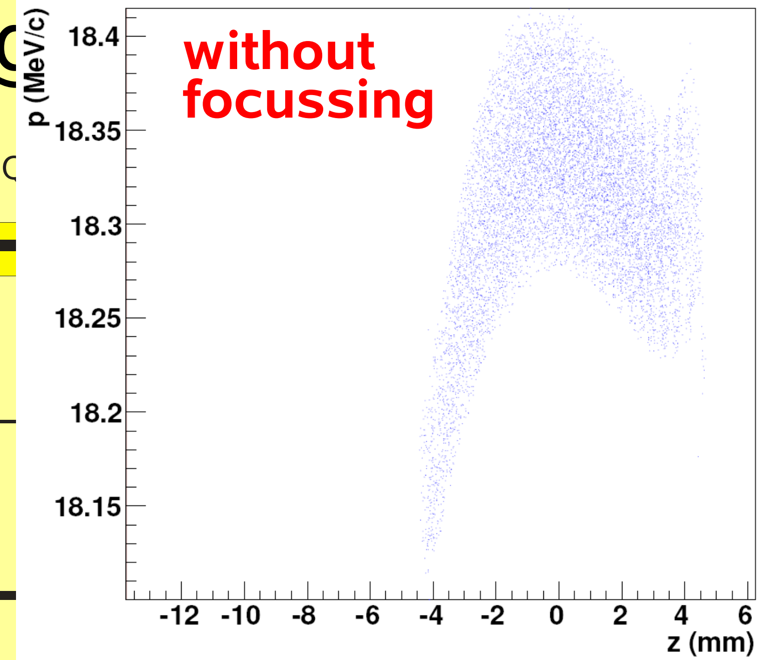
correction by deconvolution

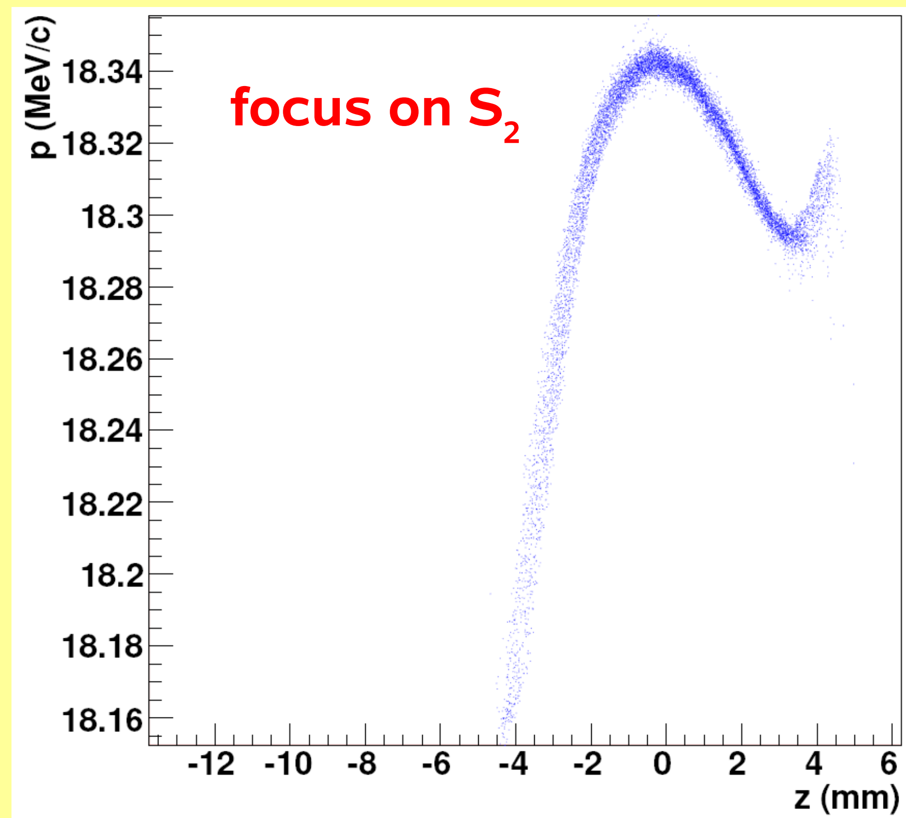


spectrometer mag



$$M_S = \begin{pmatrix} 1 & L_1 + L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$





vertical distribution

$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0 / p_0$

$\Rightarrow R_{16}\, dp_0 / p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$

temporal distribution:

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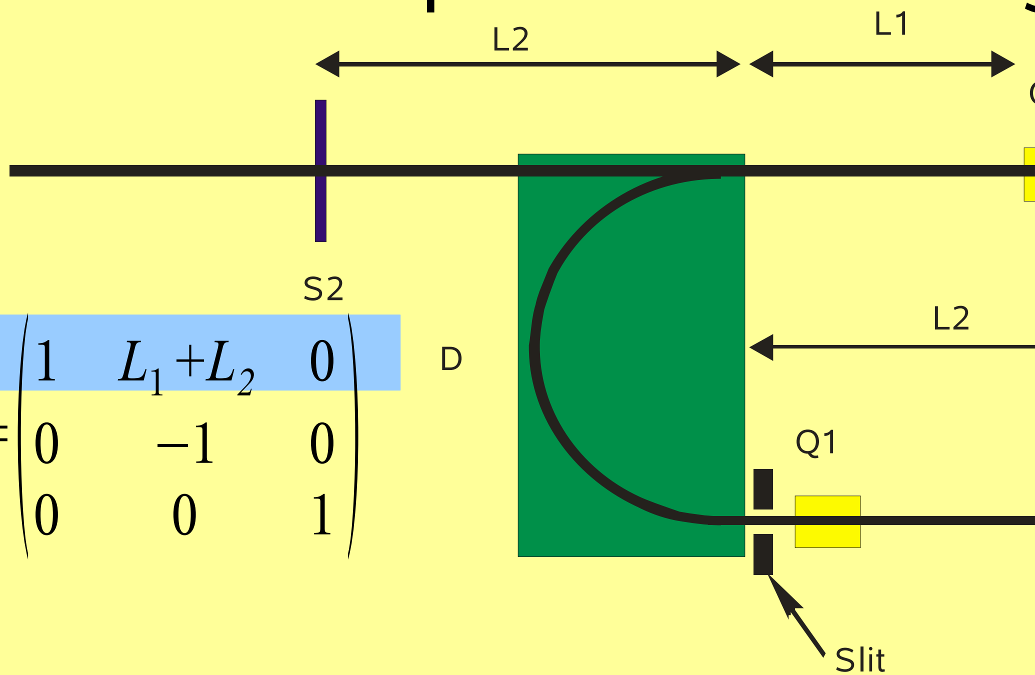
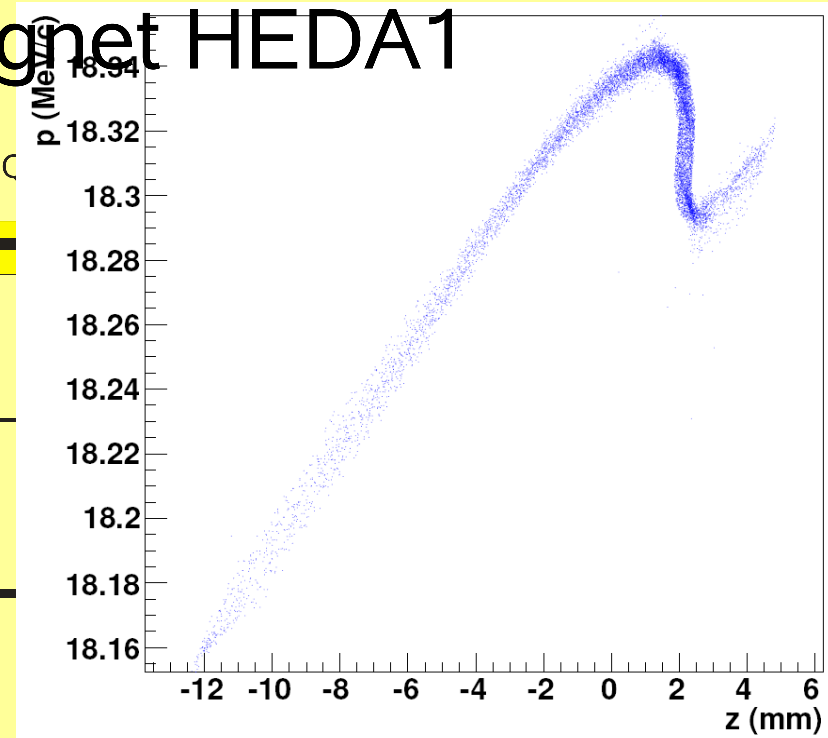
correction by deconvolution

spectrometer magnet HEDA1



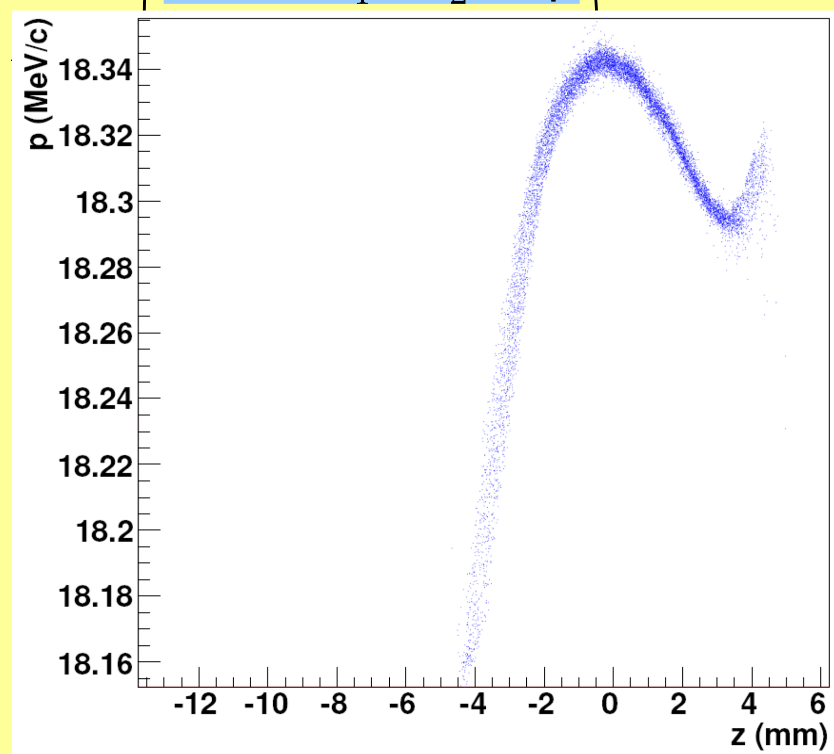
$$M_S = \begin{pmatrix} 1 & L_1+L_2 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



vertical distribution

$y = R_{11}\, y_0 + R_{12}\, y'_0 + R_{16}\, \Delta p_0/p_0$

$\Rightarrow R_{16}\, dp_0/p_0 \gg R_{11}\, y_0 + R_{12}\, y'_0$



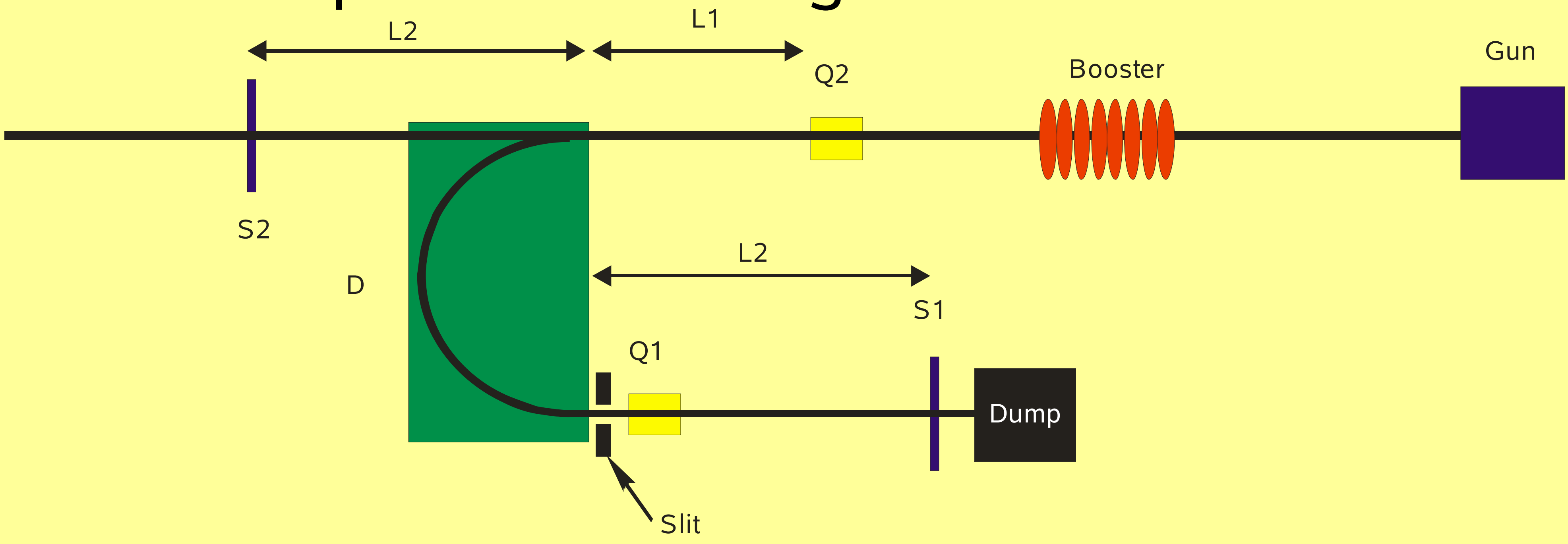
temporal distribution:

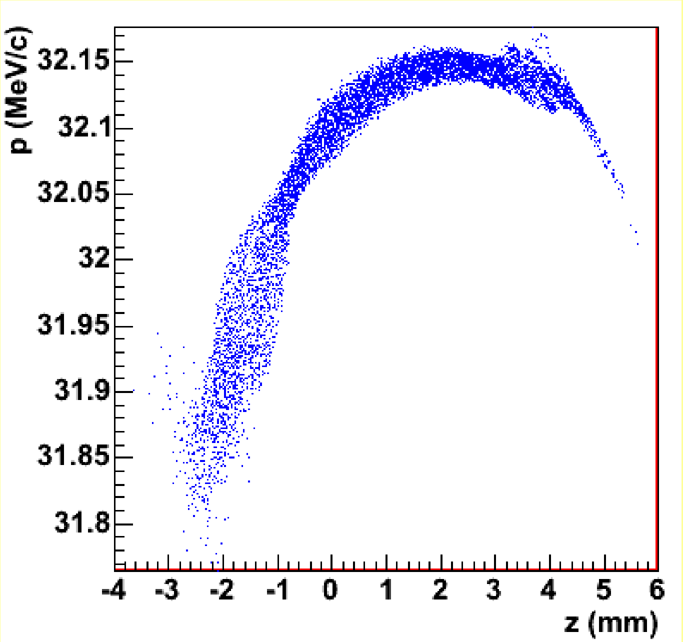
$t = R_{51}\, y_0 + R_{52}\, y'_0 + t_0 + R_{56}\, \Delta p_0/p_0$

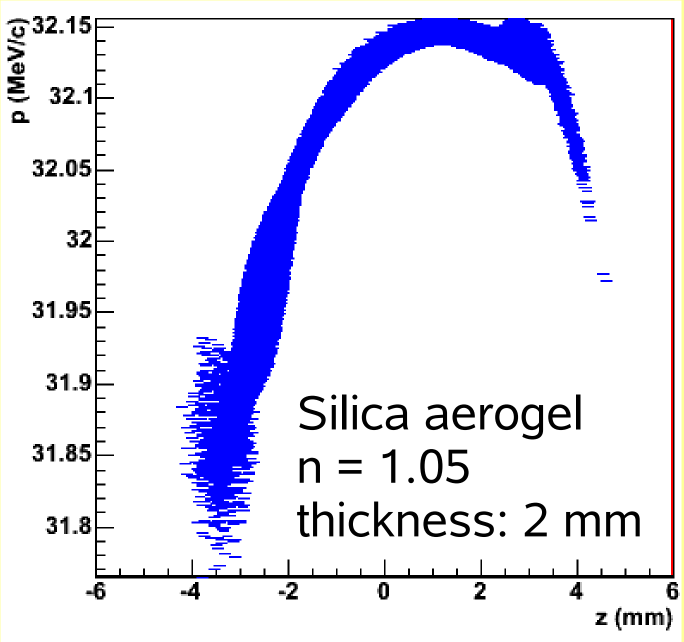
correction by deconvolution

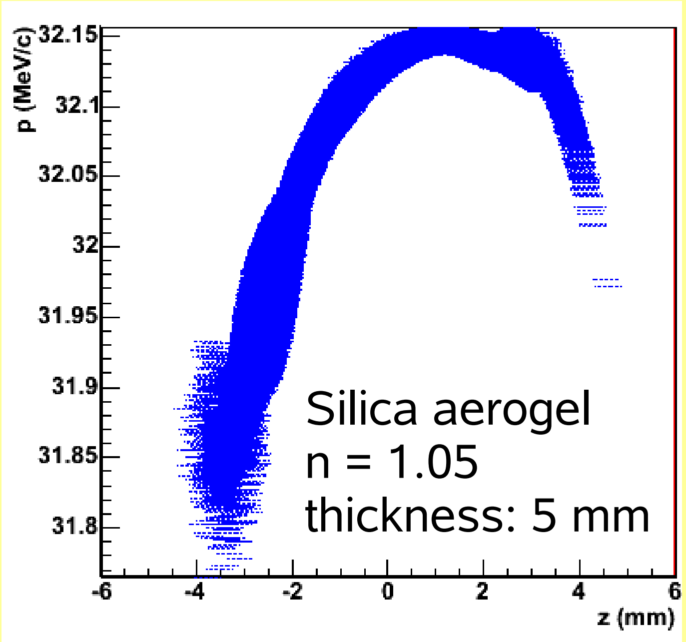
correction by shearing the image

spectrometer magnet HEDA1

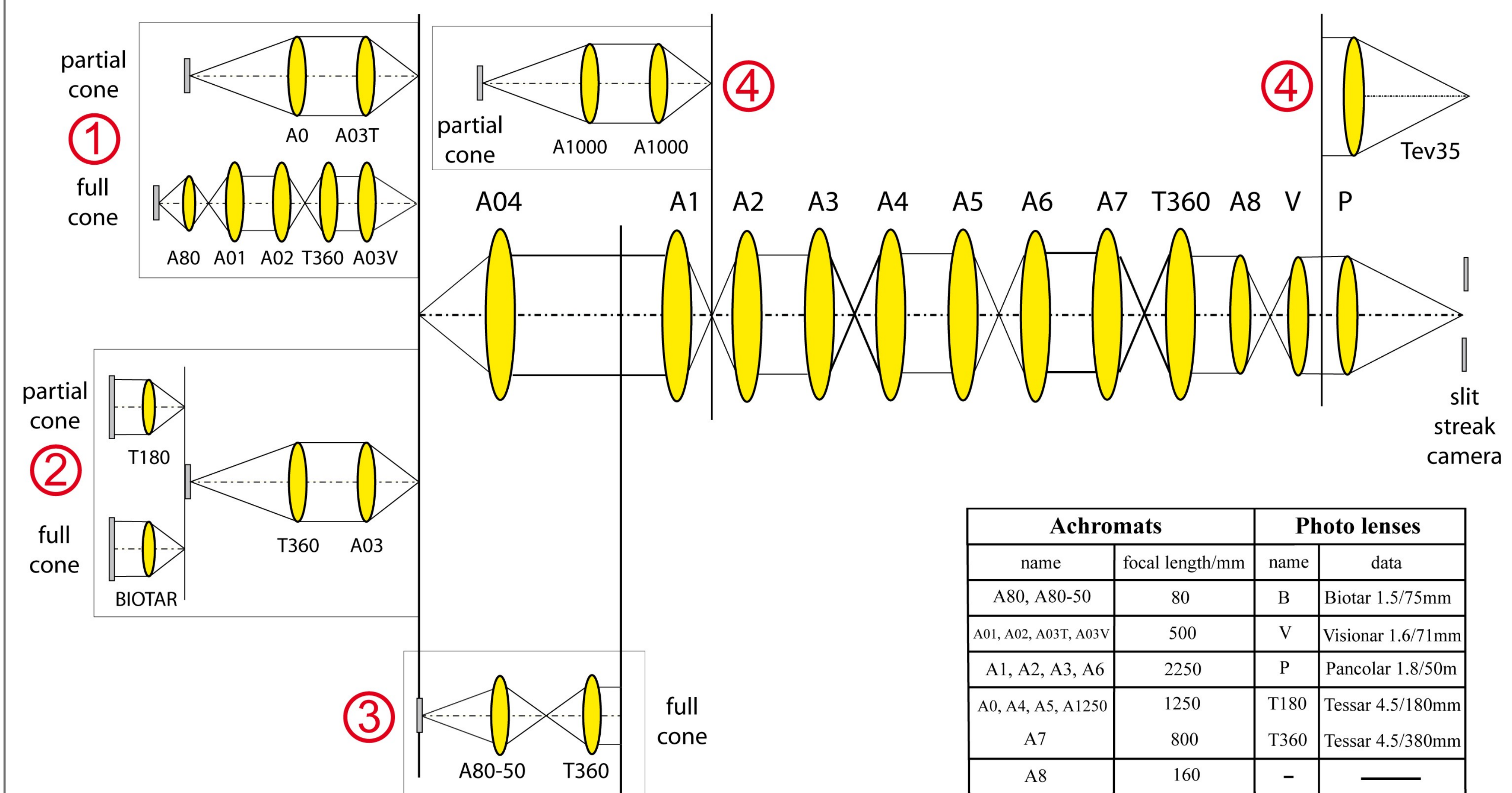






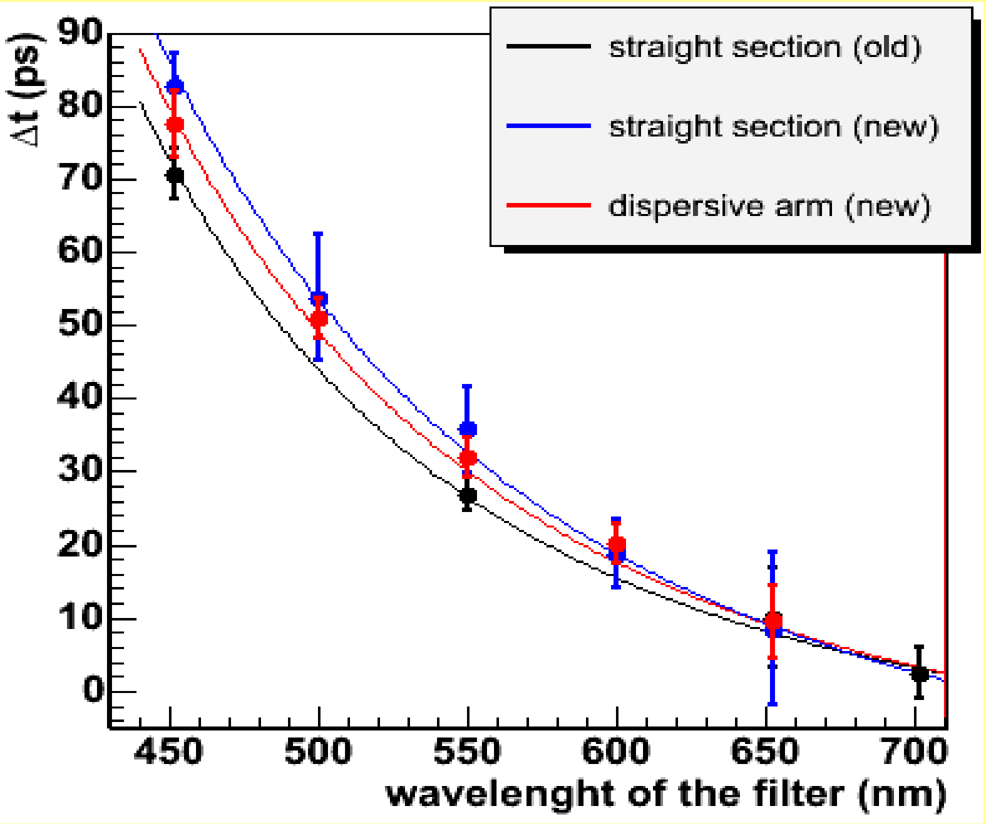


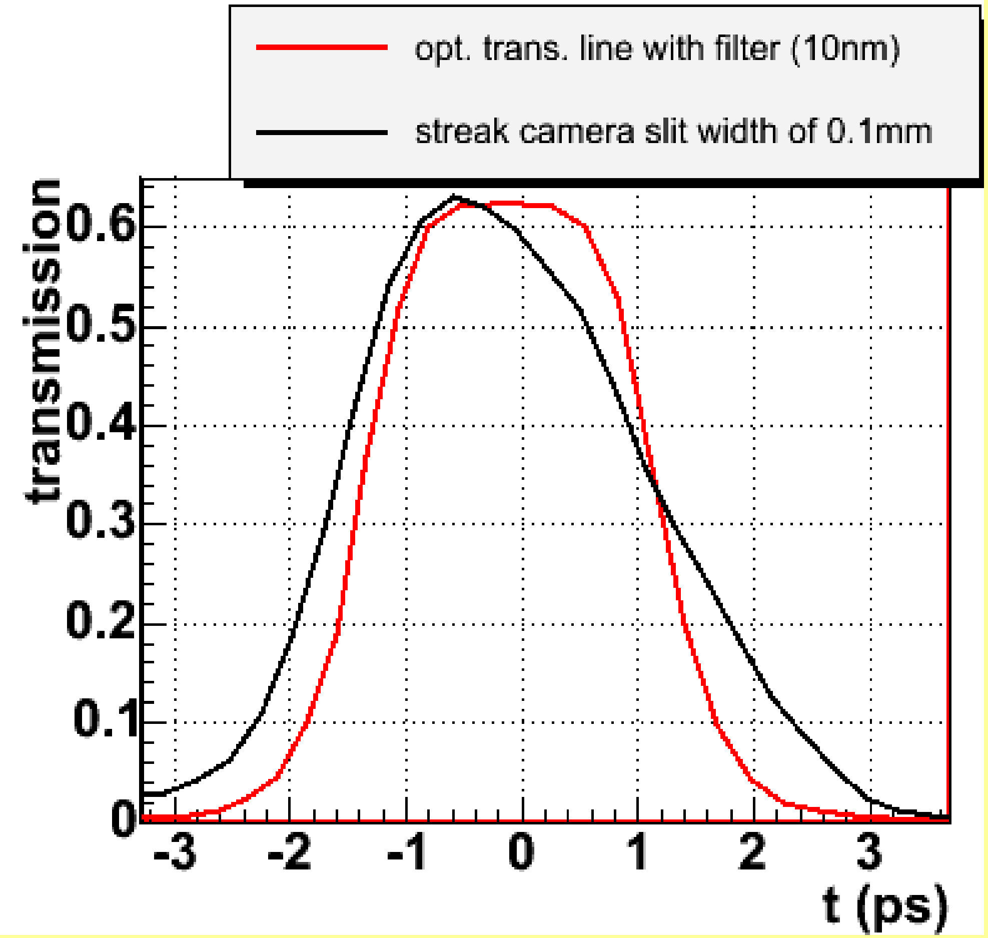
optical transmission line



Achromats		Photo lenses	
name	focal length/mm	name	data
A80, A80-50	80	B	Biotar 1.5/75mm
A01, A02, A03T, A03V	500	V	Visionar 1.6/71mm
A1, A2, A3, A6	2250	P	Pancolar 1.8/50m
A0, A4, A5, A1250	1250	T180	Tessar 4.5/180mm
A7	800	T360	Tessar 4.5/380mm
A8	160	–	———
A1000	1000	Tev35	Tevidon 19/35mm

optical transmission line





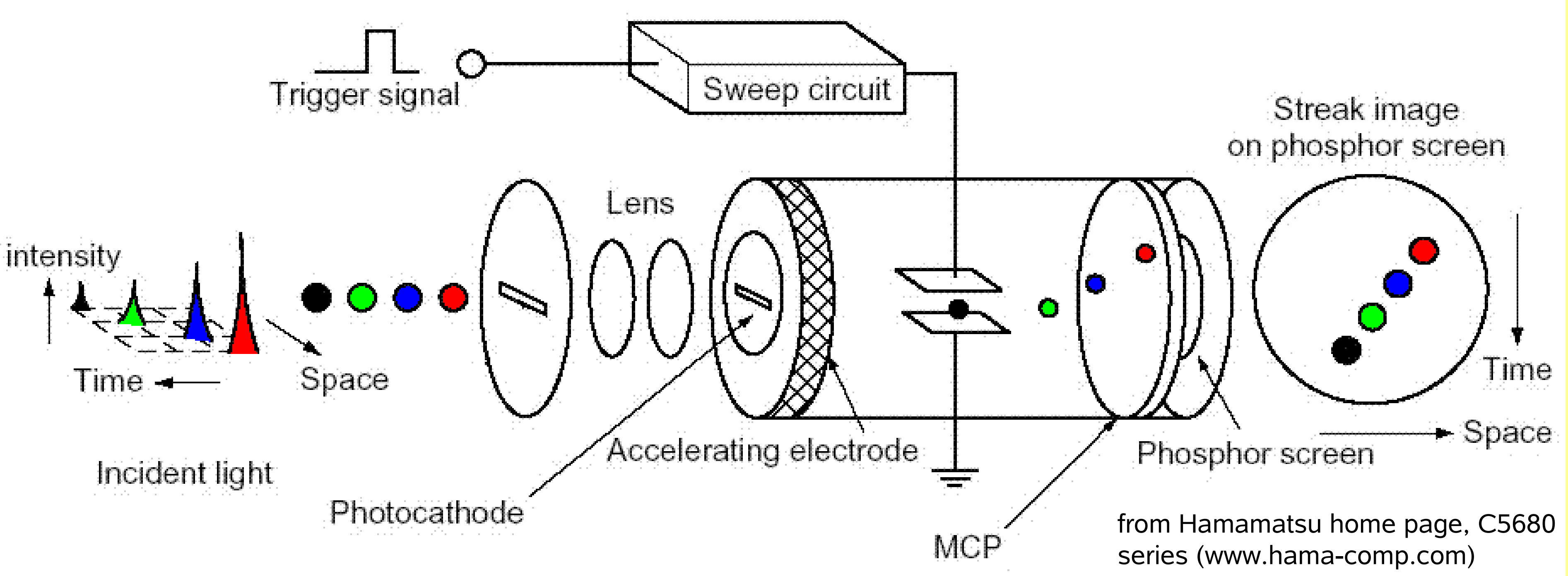
the optical system is the major limitation of resolution,

a system consisting of reflective optics is under development

Influence of the streak camera (C5680)

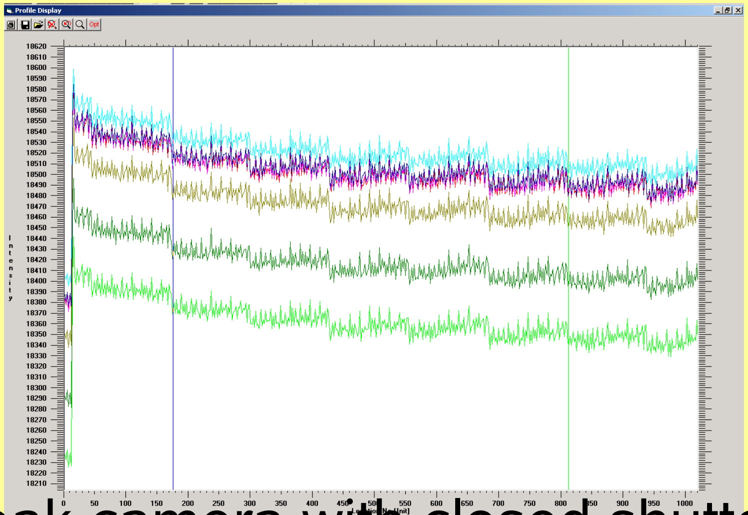
resolution is limited by:

- **streak camera slit width and space charge**
  - **slit width of 100 μm: δt = 1.75 ps**
  - correction: deconvolution (signal without RF-field)
- **RF and laser jitter: 100 pulses: δt = 0.99 ps**
- **diff. momentum of photo electrons for diff. wavelength**
  - with 10 nm: δt = 0.16 ps, without filter: δt = 0.55 ps

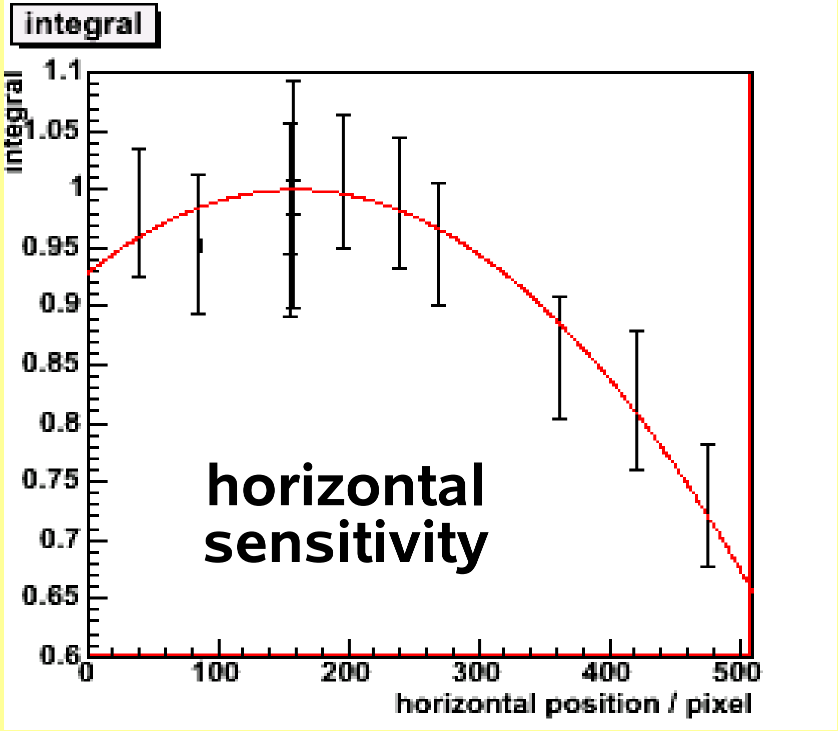


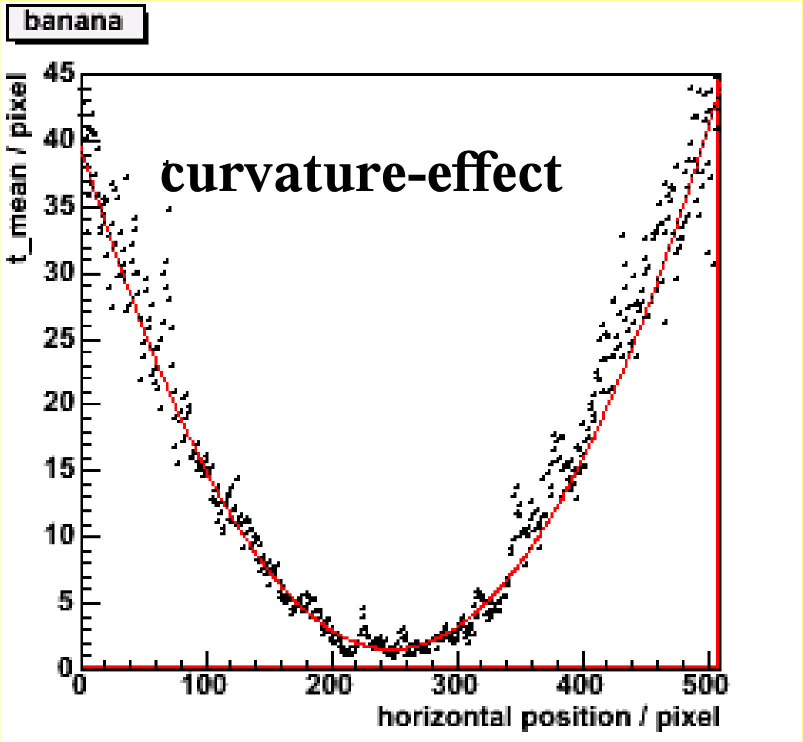
from Hamamatsu home page, C5680 series (www.hama-comp.com)

Influence of the streak camera (C5680)



Background of the streak camera with closed shutter

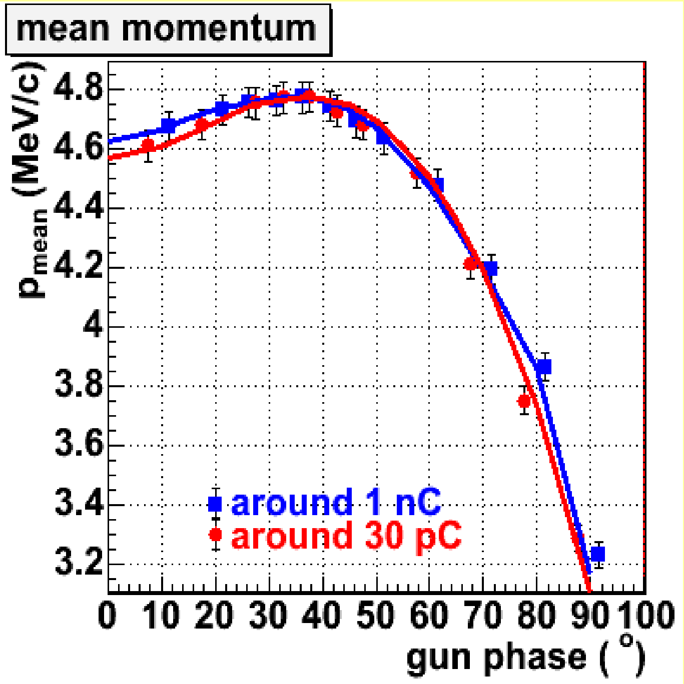




Contents

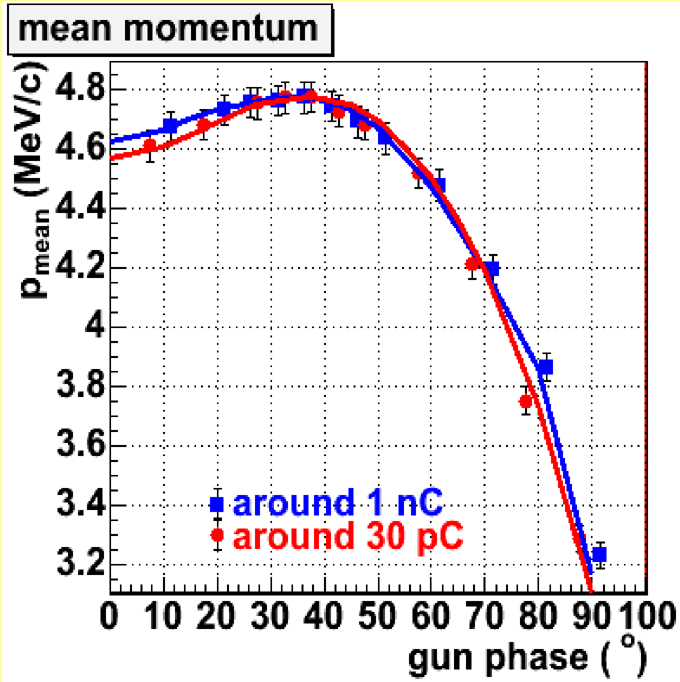
- Introduction
- PITZ
- Longitudinal phase space of a photoinjector
- **Devices of longitudinal phase space measurement at PITZ**
- **Measurements and simulations of longitudinal phase space at PITZ**
- Summery and outlook

momentum measurement



- Gradient: ~40MV/m
- mean momenta are similar for different charge
  - highest mean momentum: 4.8 MeV/c
    lunch phase: 35°

momentum measurement



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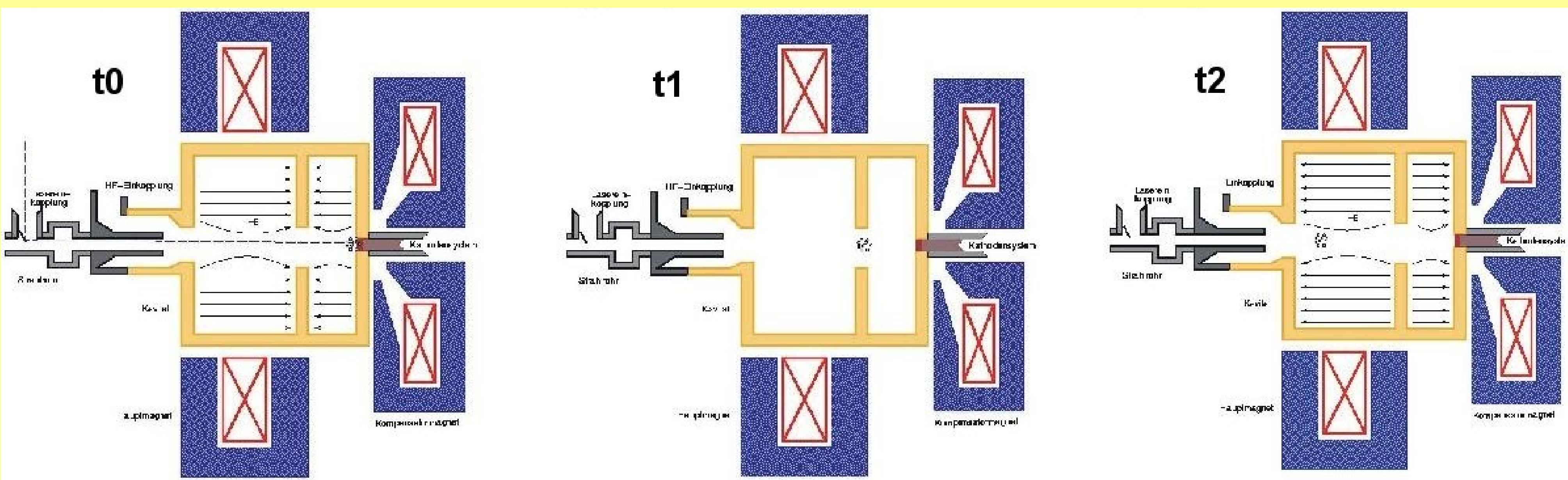
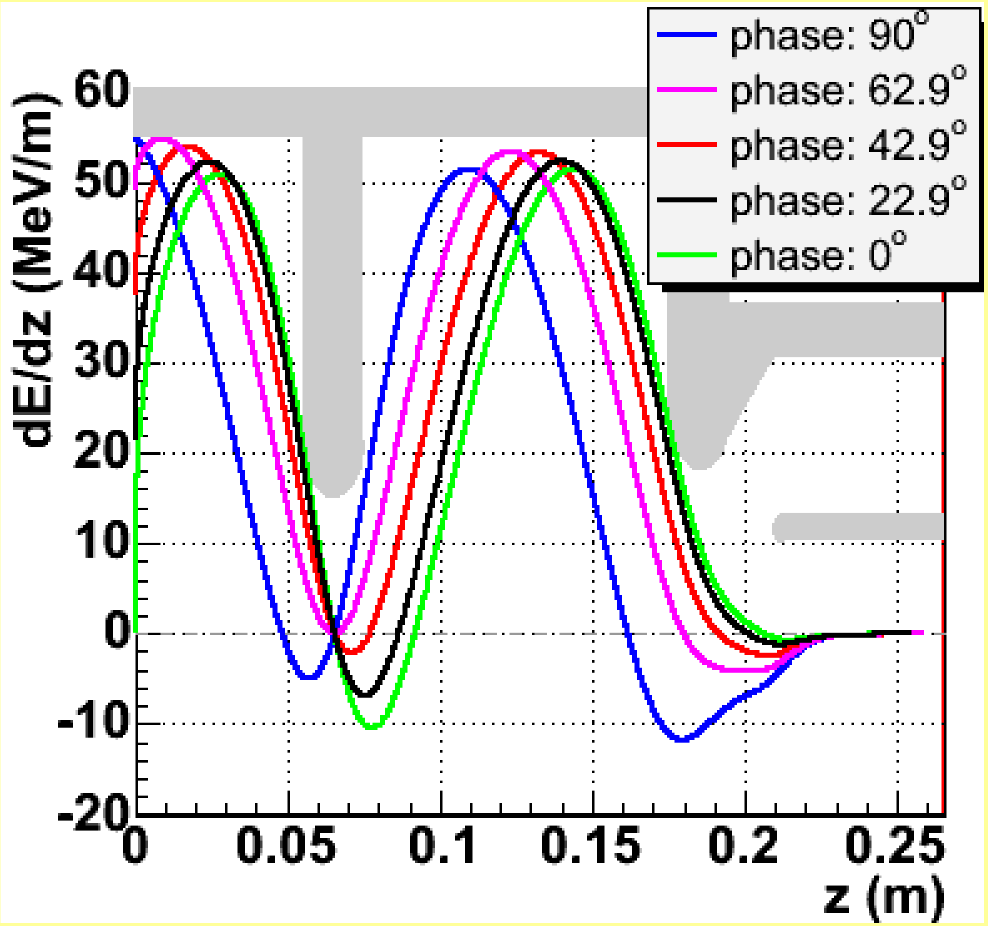
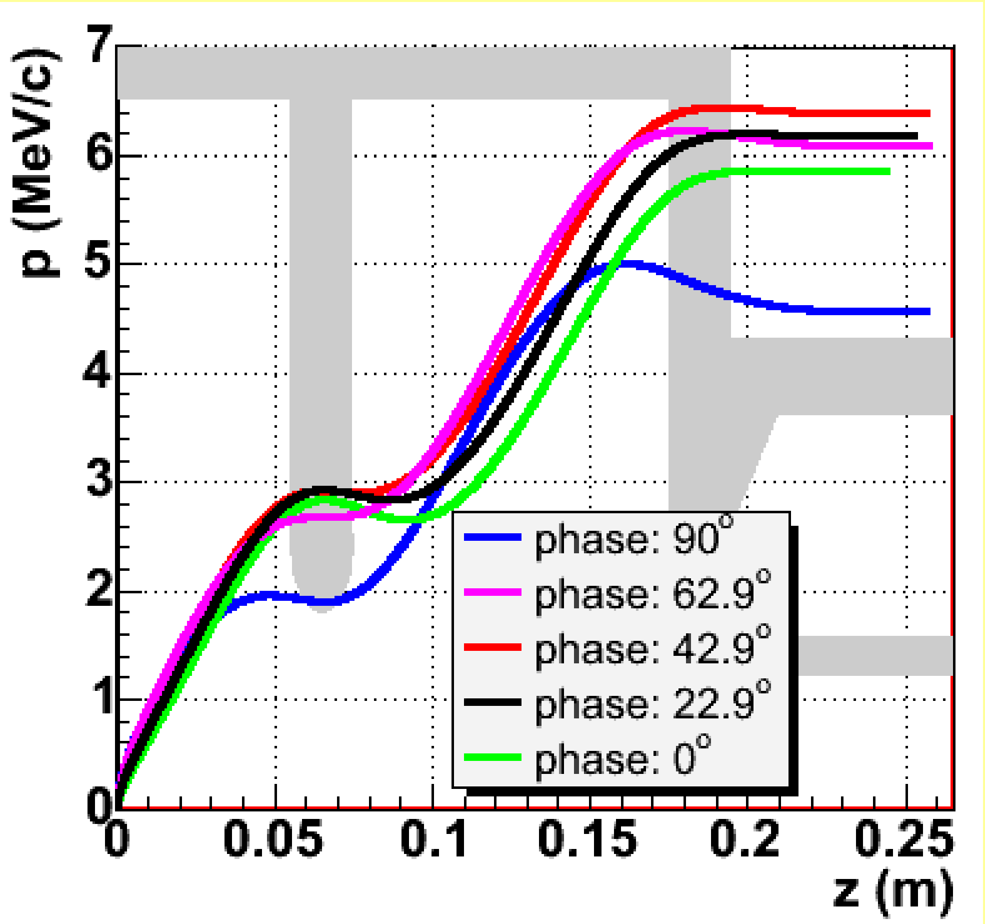
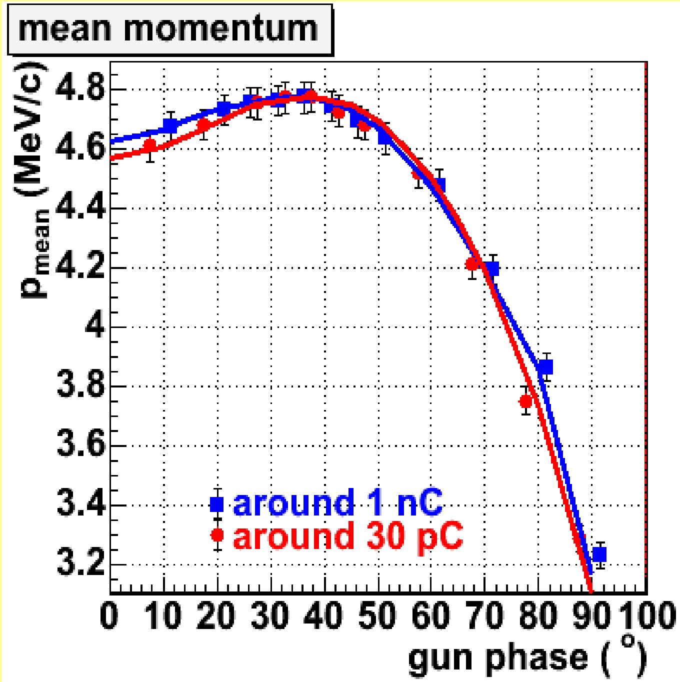


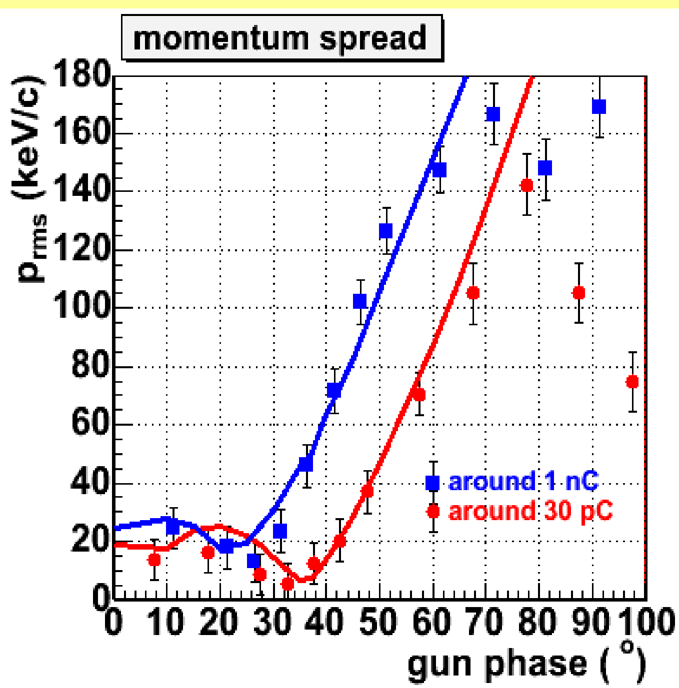
momentum gain





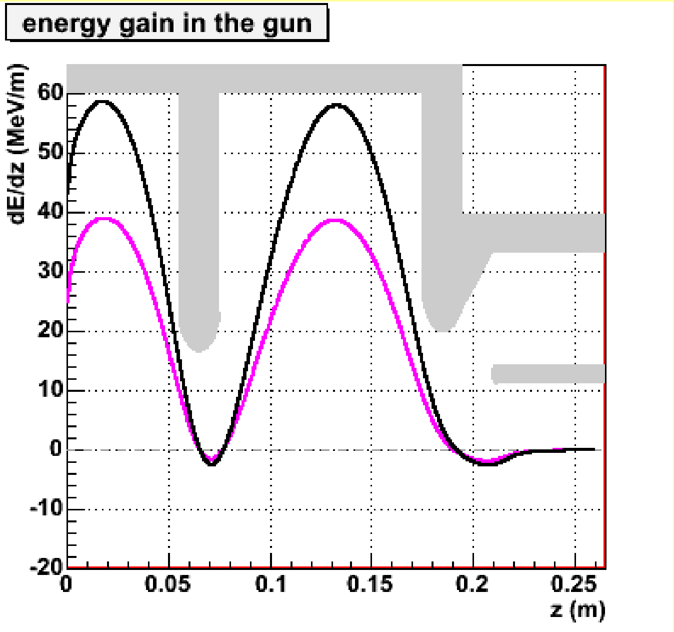
influence of charge
momentum measurement

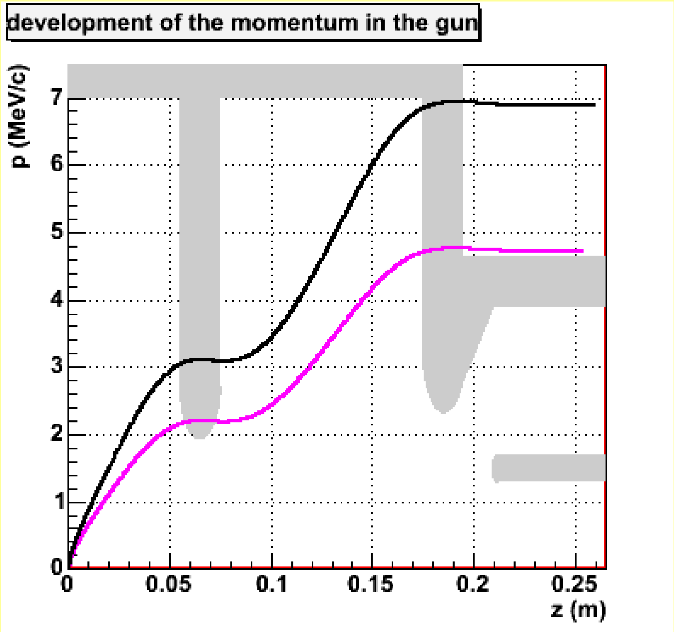


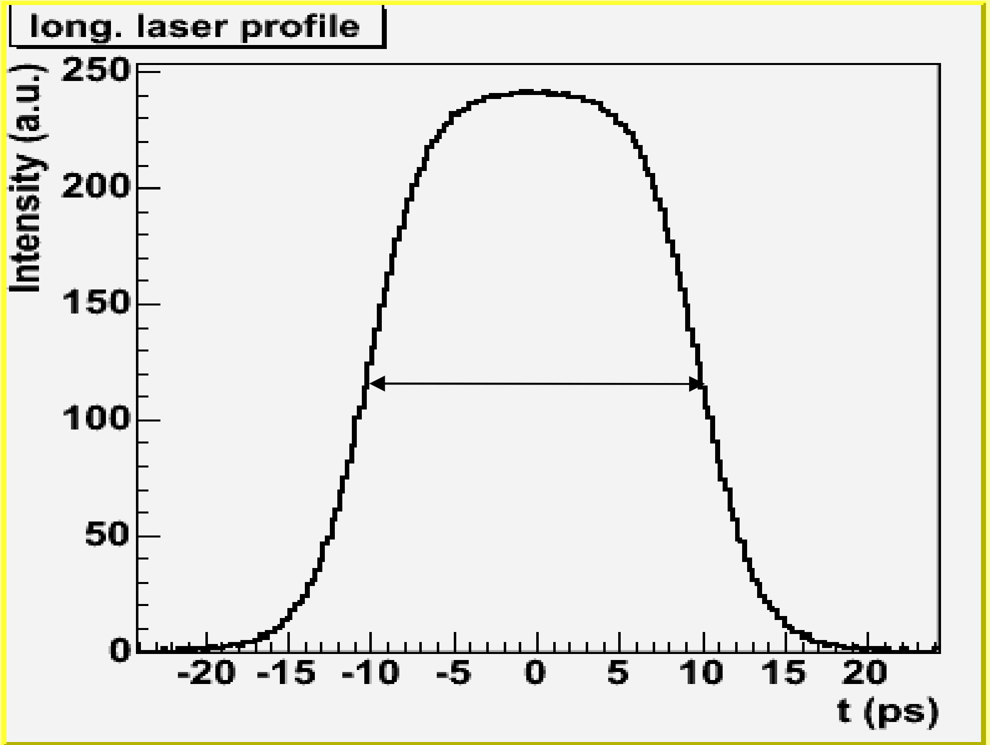


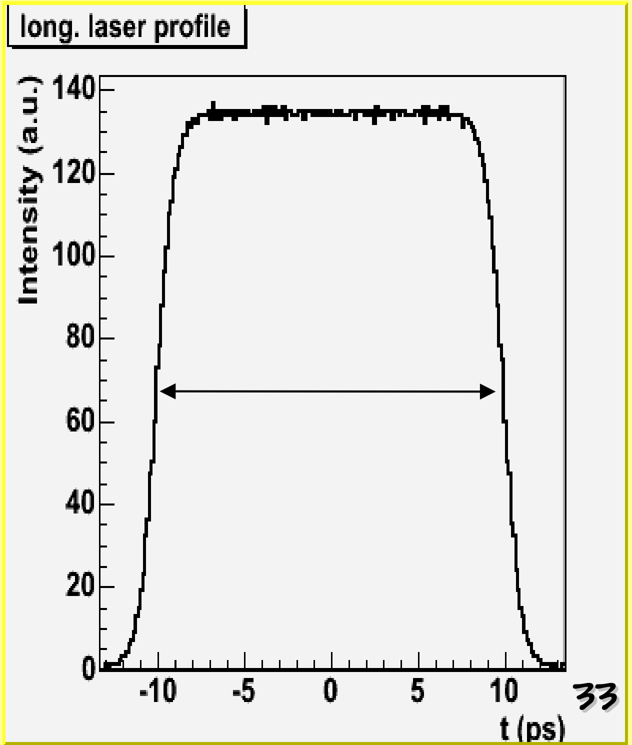
- Gradient: ~40MV/m
- mean momenta are similar for different charge
  - highest mean momentum: 4.8 MeV/c
    lunch phase: 35°
- minimum momentum spread:
  30 pC: 5 keV/c at lunch phase: 35°
  1 nC: 13 keV/c at lunch phase: 30°
- for high phase the momentum distribution is cut by the screen
- at 1nC space charge effects increase momentum spread
- at 30 pC phase of maximum momentum gain is equal to phase of minimum momentum spread
  -> space charge forces small

longitudinal phase space simulations

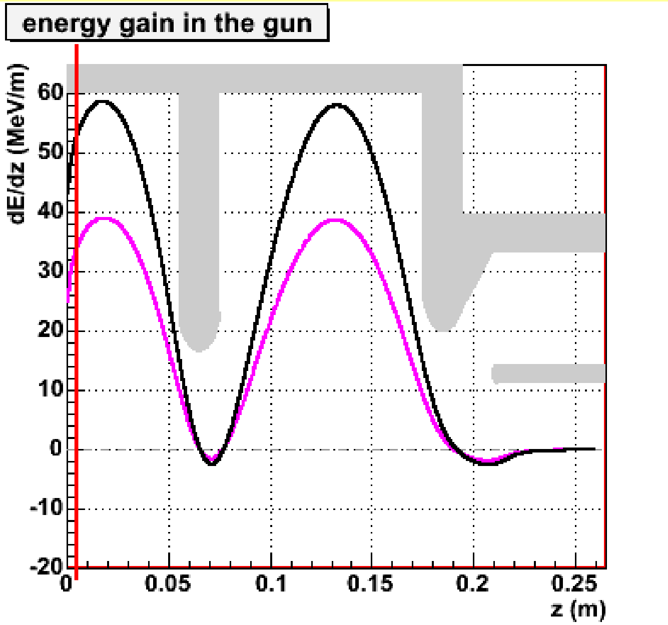


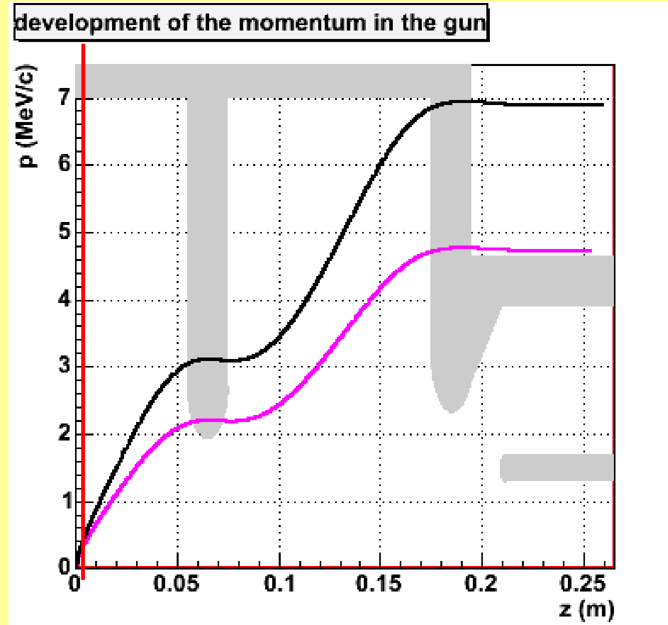






longitudinal phase space simulations

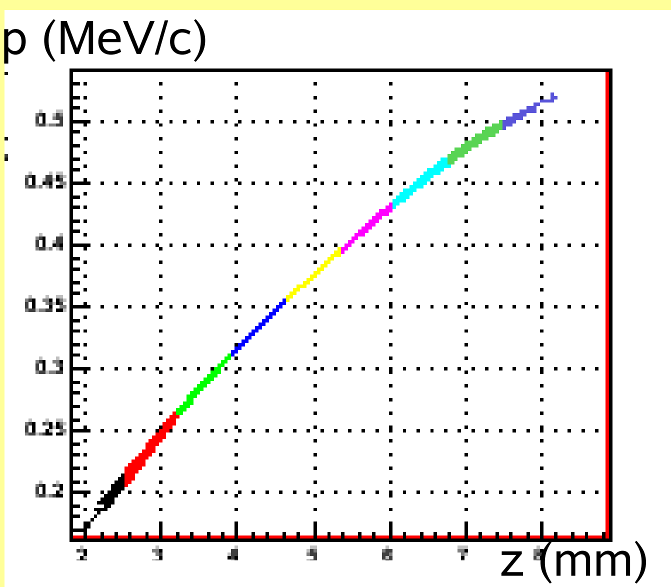


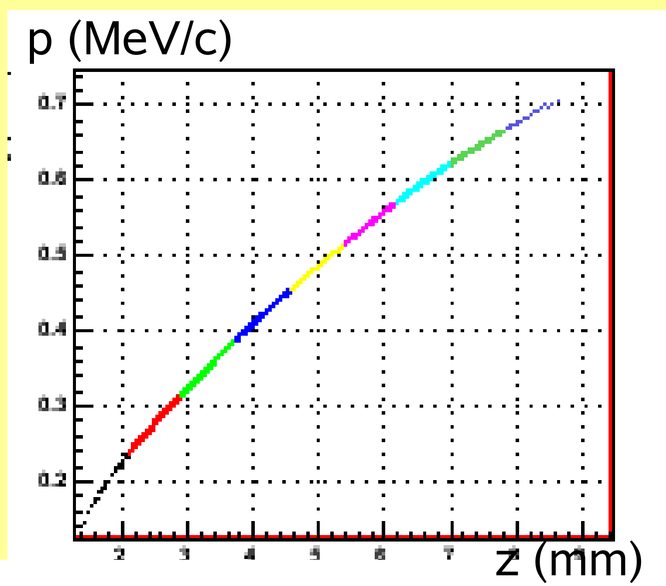


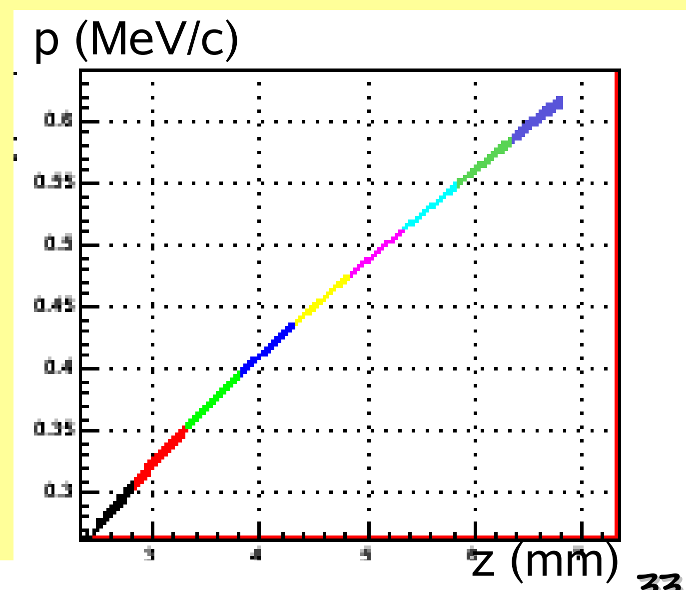
40MV/m
rise time = 7ps

60MV/m
rise time = 7ps

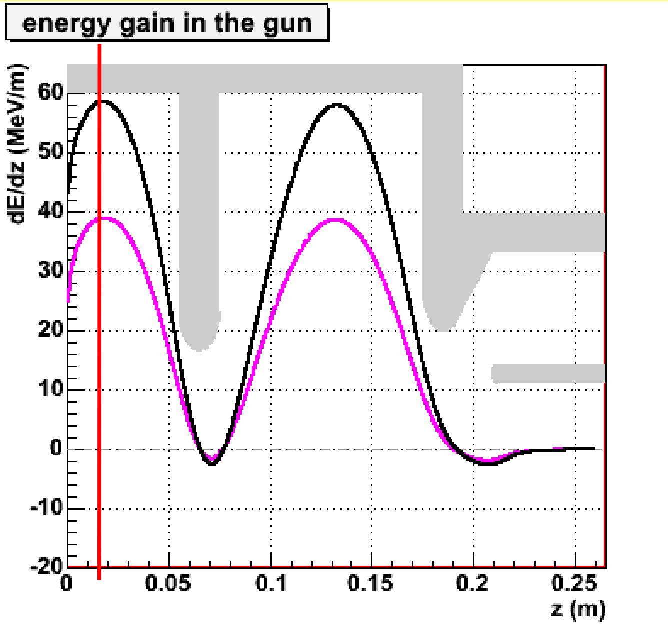
60MV/m
rise time = 2ps

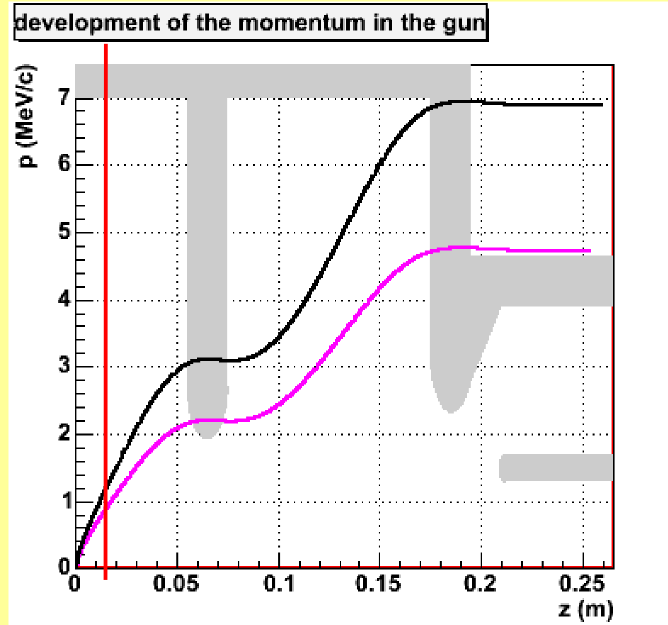




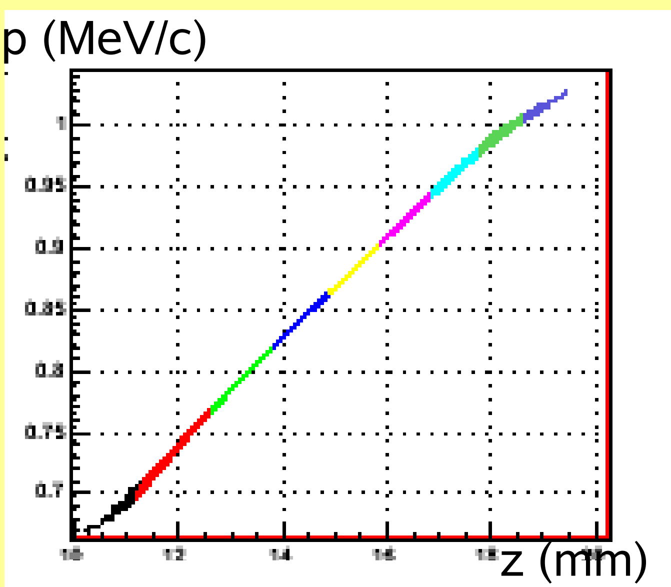


longitudinal phase space simulations

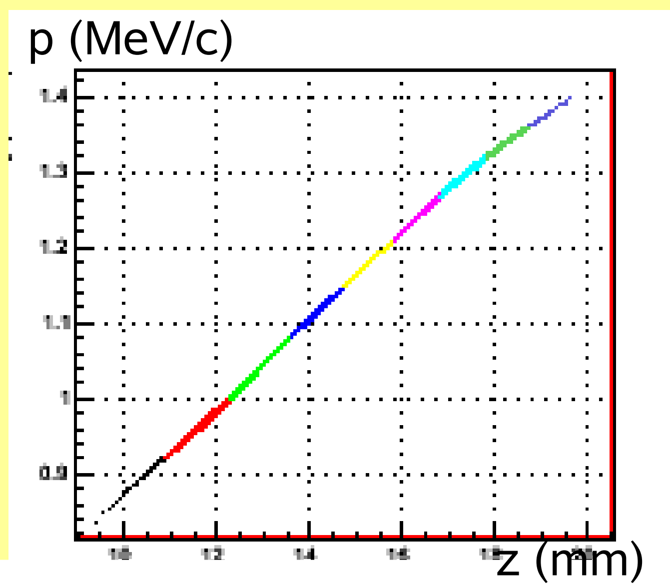




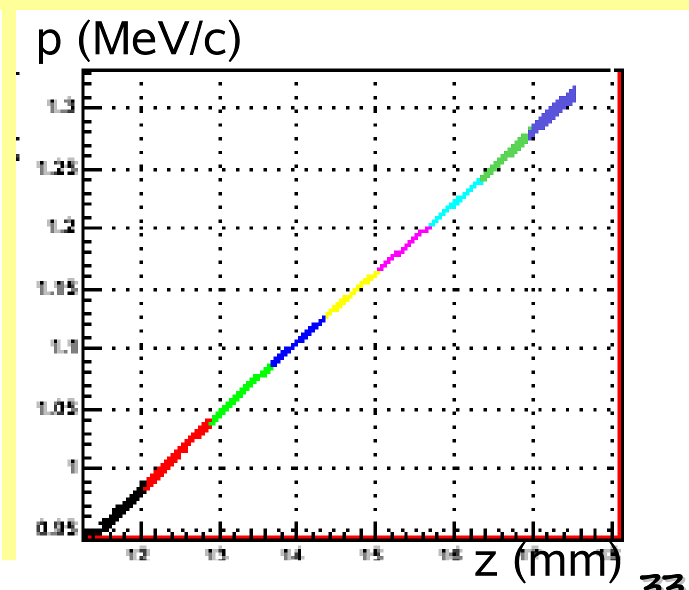
40MV/m
rise time = 7ps



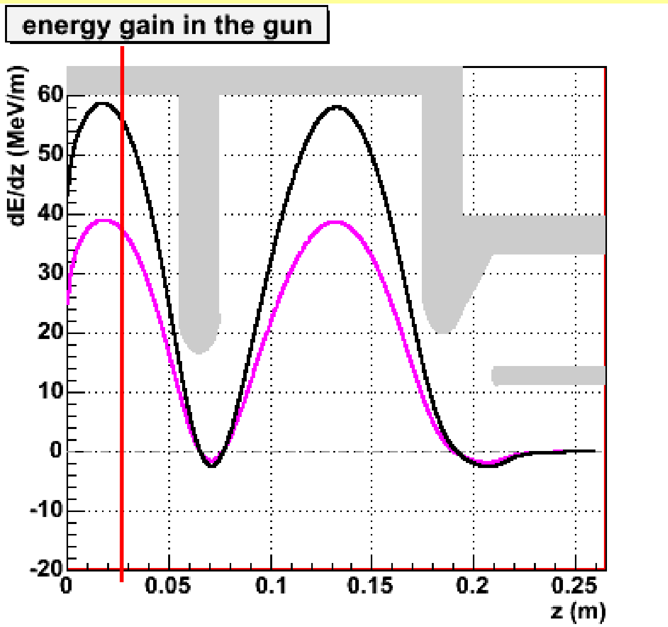
60MV/m
rise time = 7ps

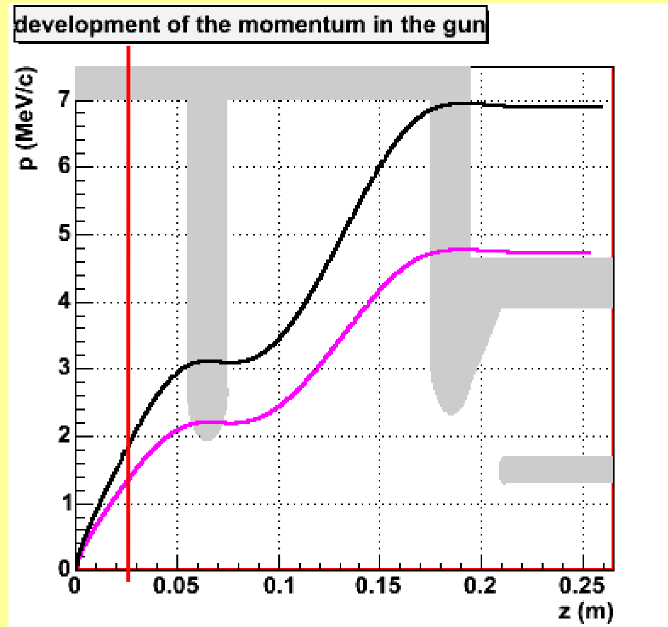


60MV/m
rise time = 2ps

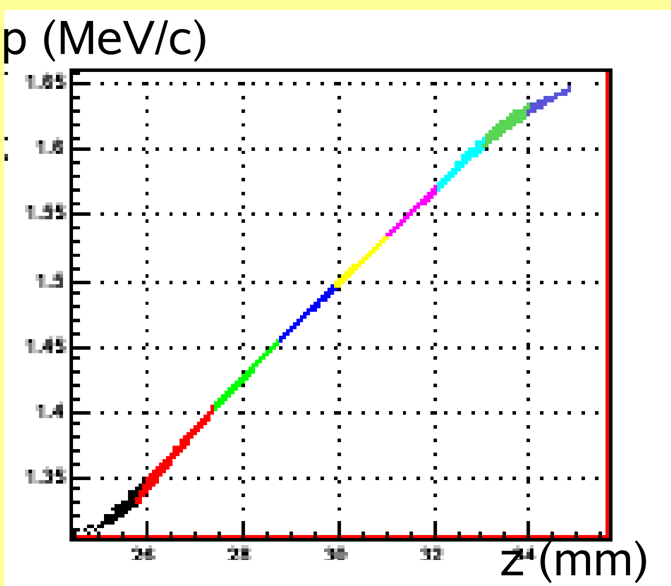


longitudinal phase space simulations





40MV/m
rise time = 7ps



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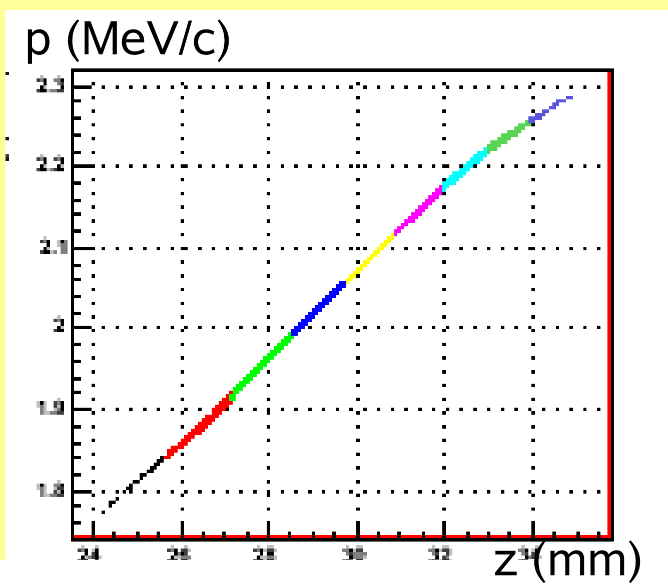
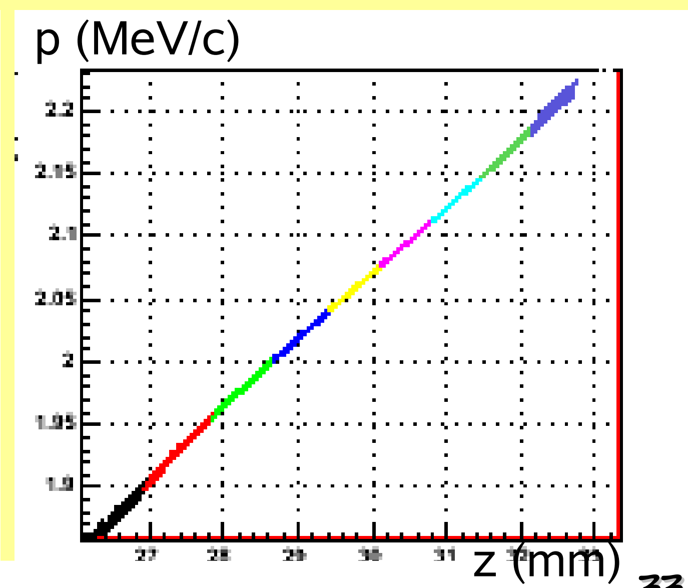
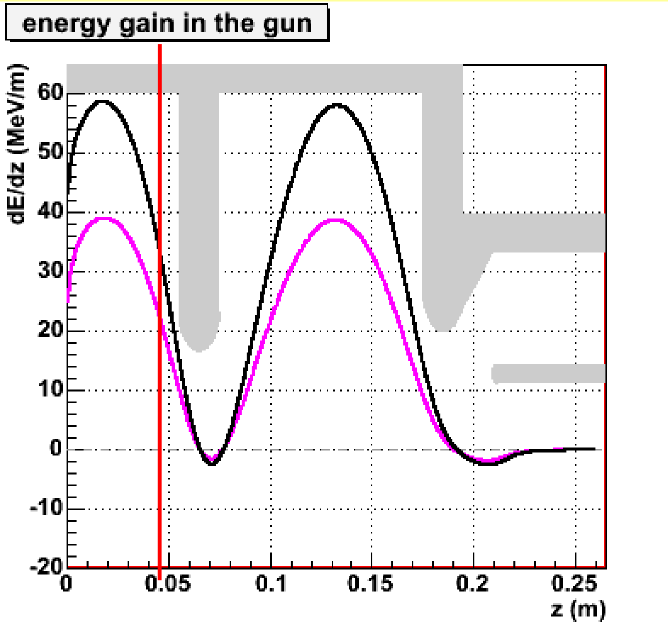
rise time = 7ps

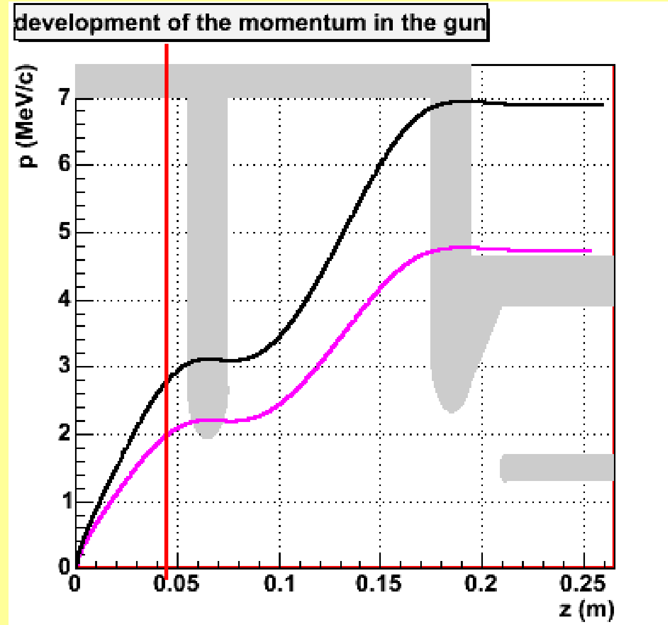


60MV/m
rise time = 2ps



longitudinal phase space simulations





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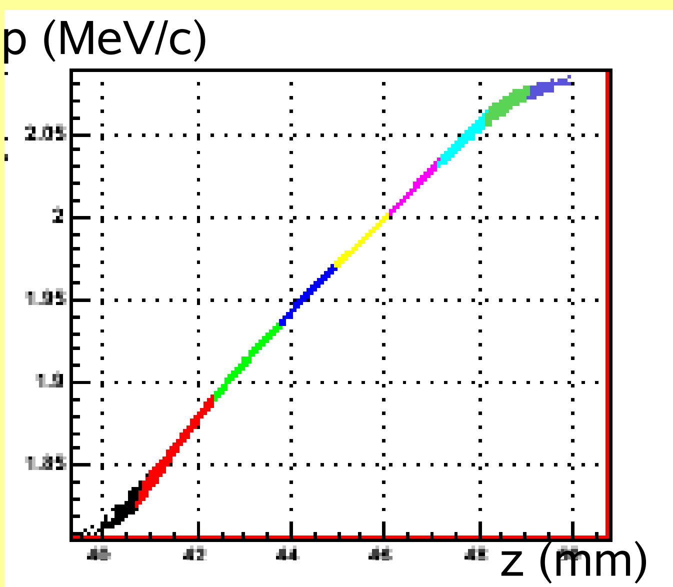
rise time = 7ps



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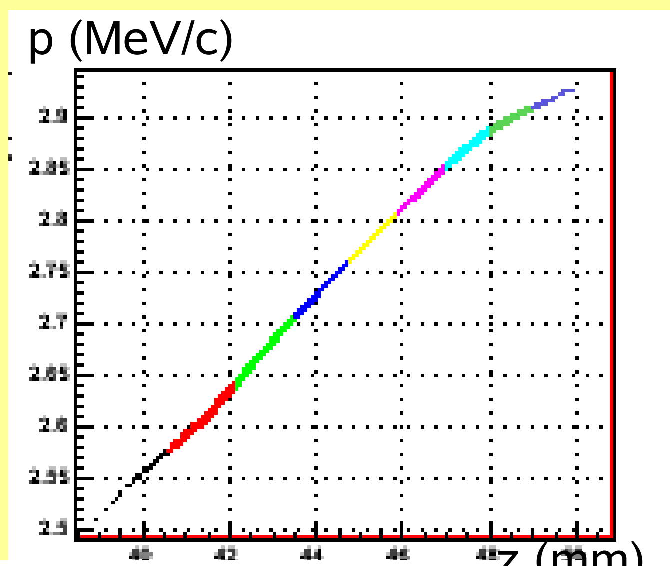
rise time = 7ps



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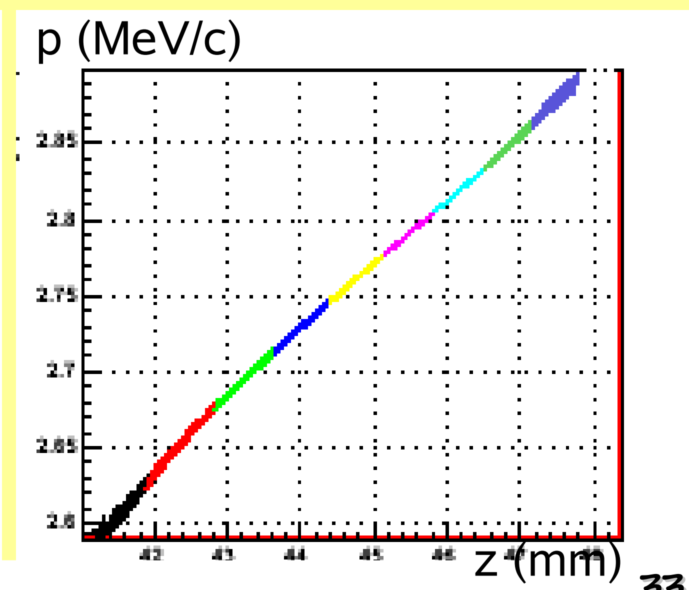
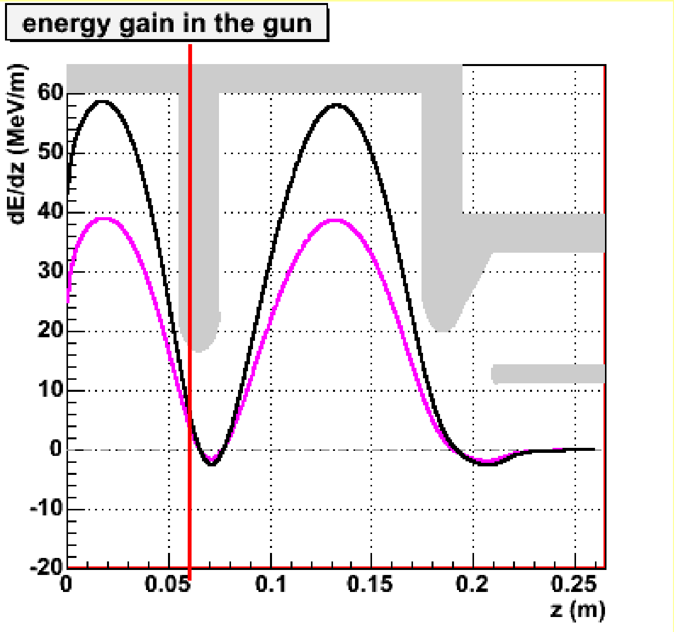
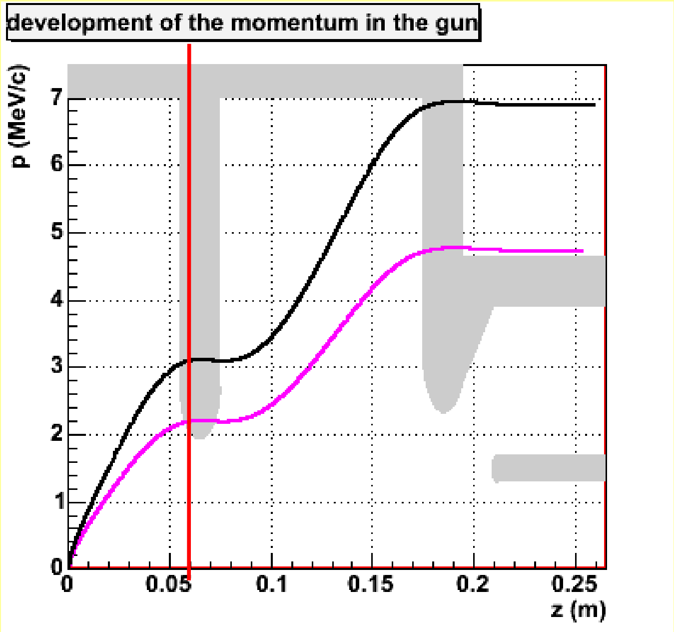
rise time = 2ps



longitudinal phase space simulations





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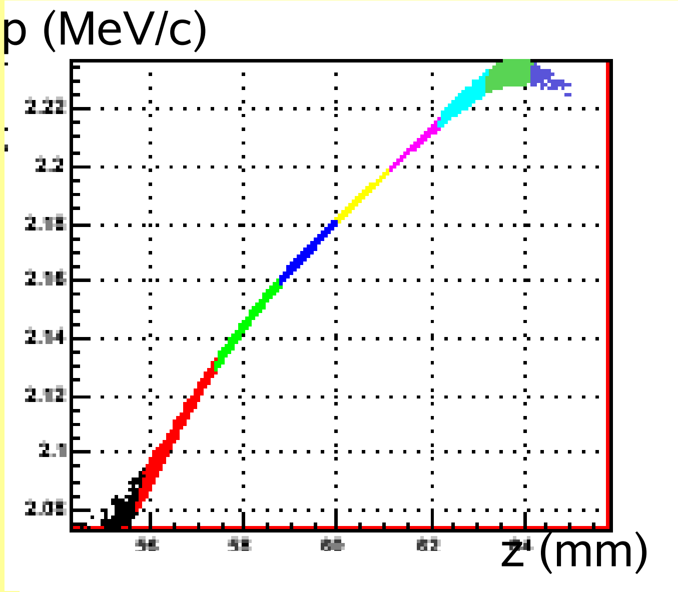

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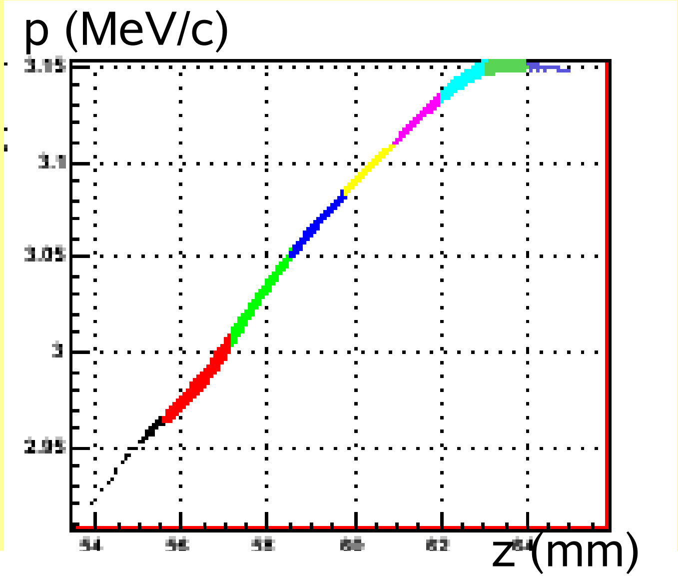

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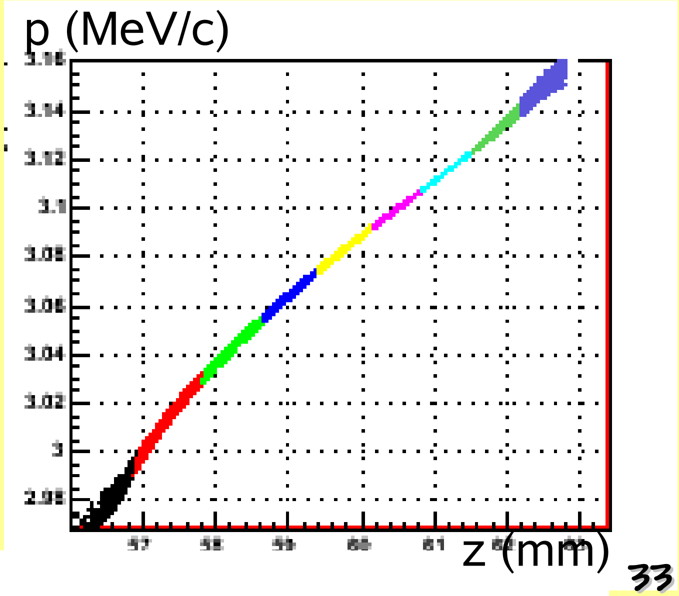
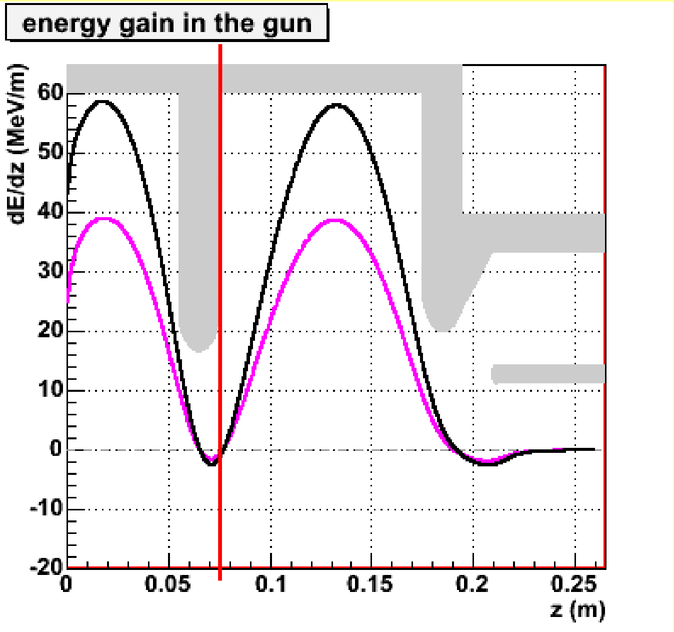
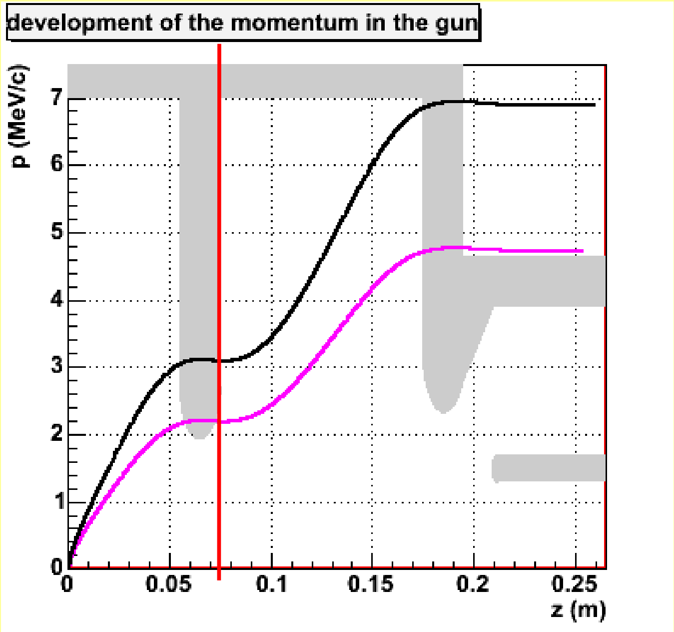


longitudinal phase space simulations





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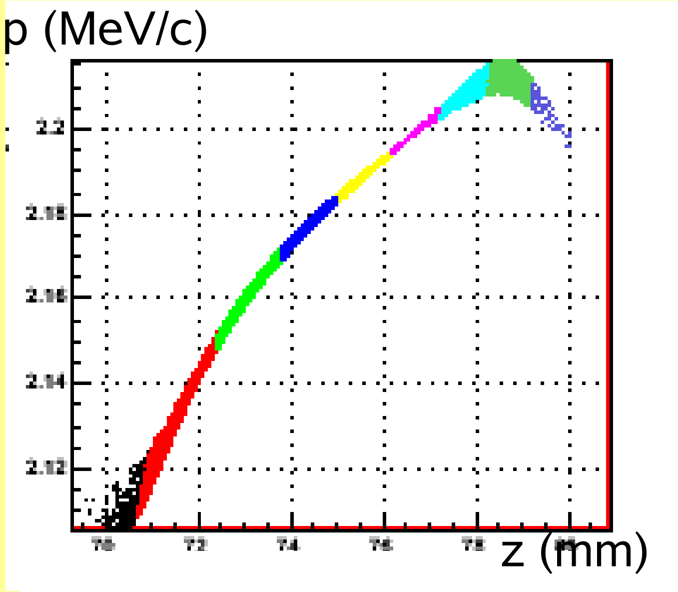
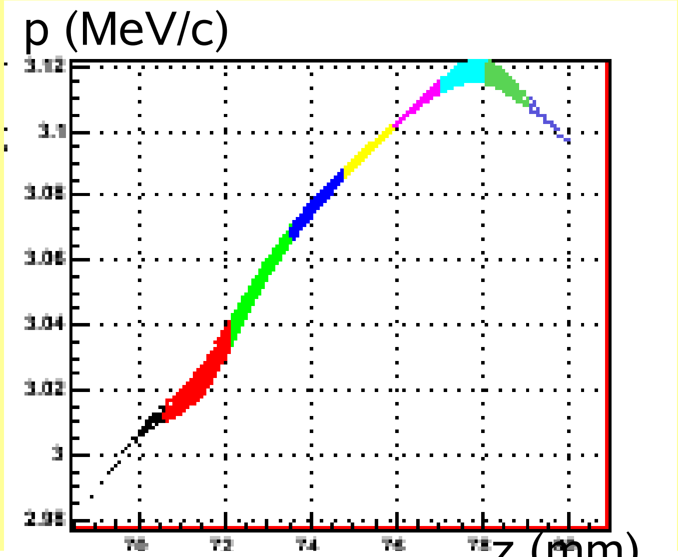
rise time = 7ps



60MV/m
rise time = 7ps



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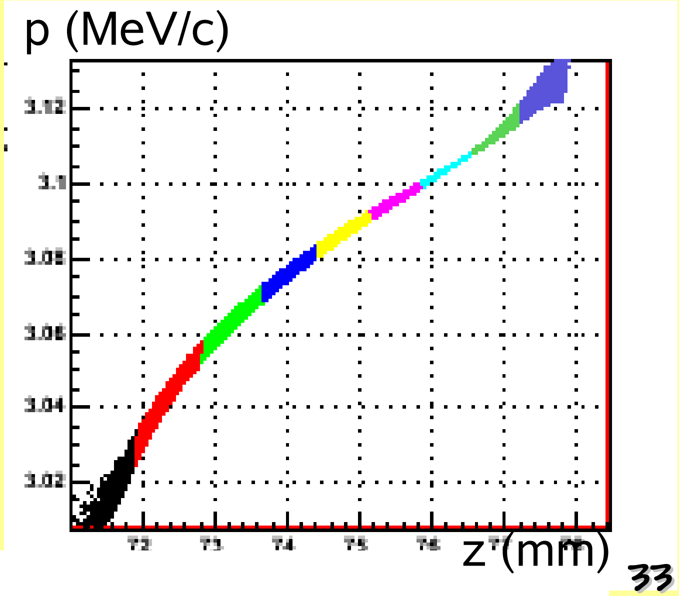
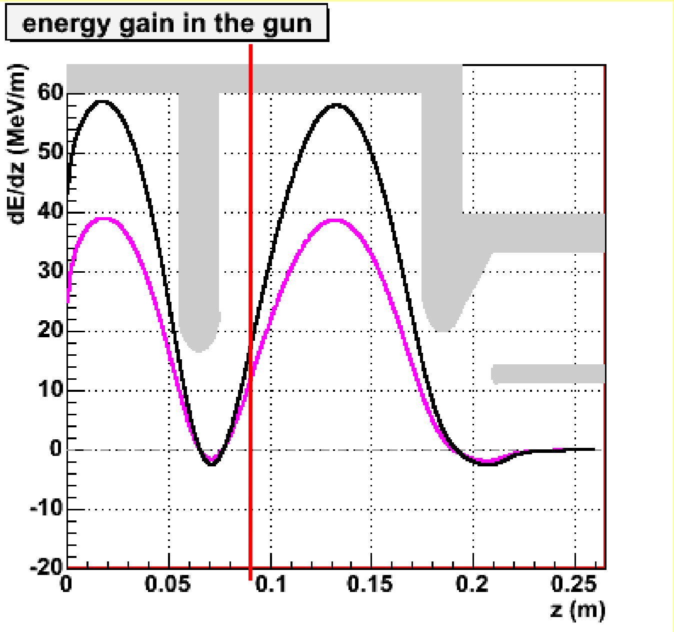
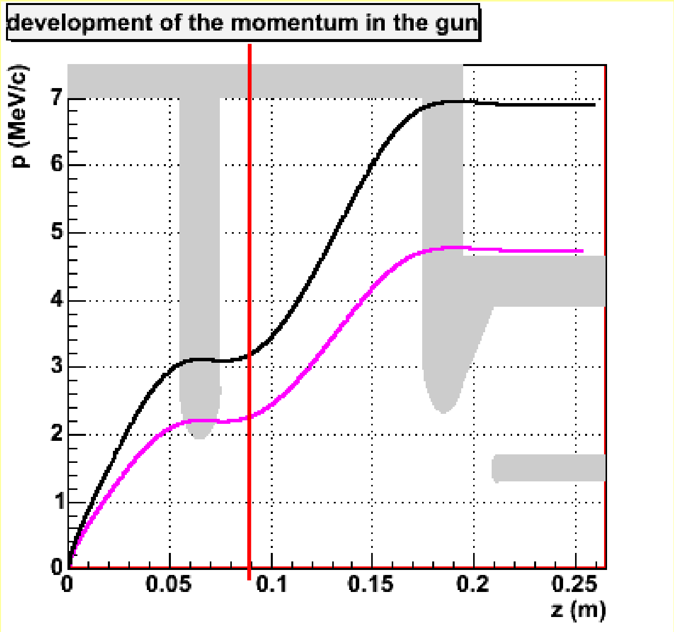


longitudinal phase space simulations





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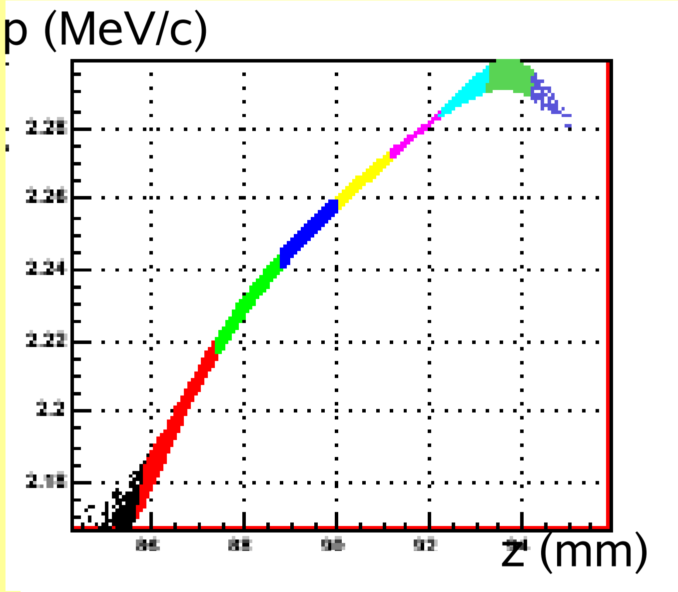
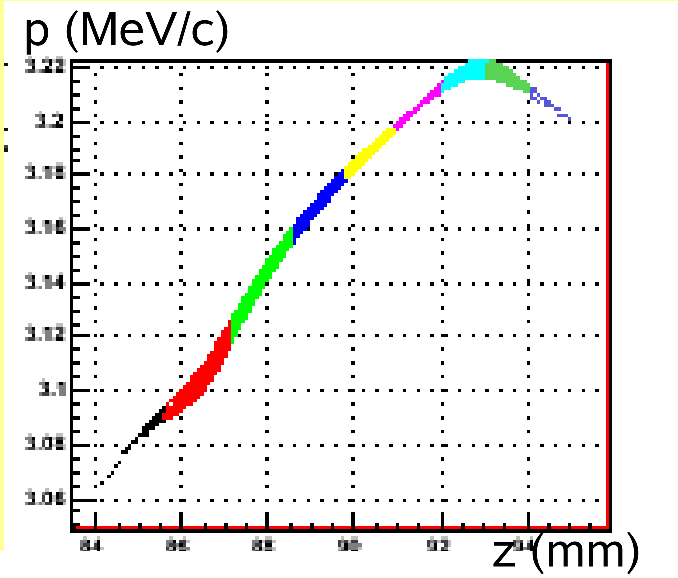
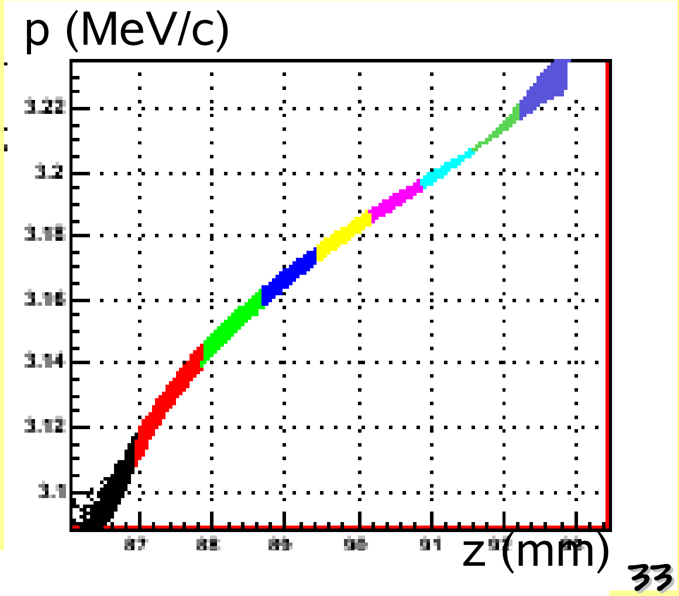
rise time = 7ps



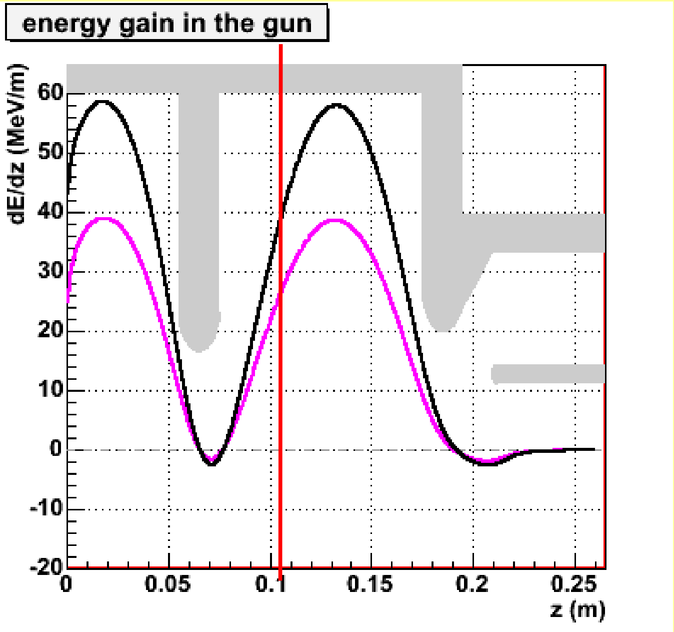
60MV/m
rise time = 7ps

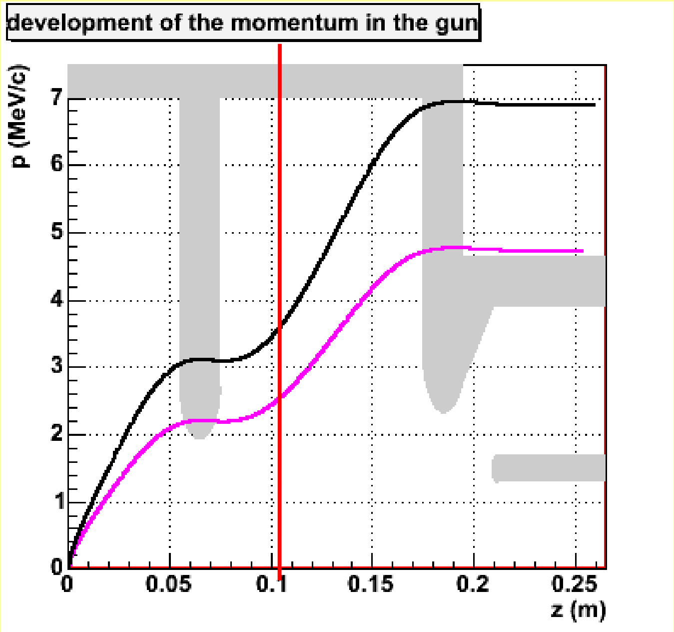


60MV/m
rise time = 2ps

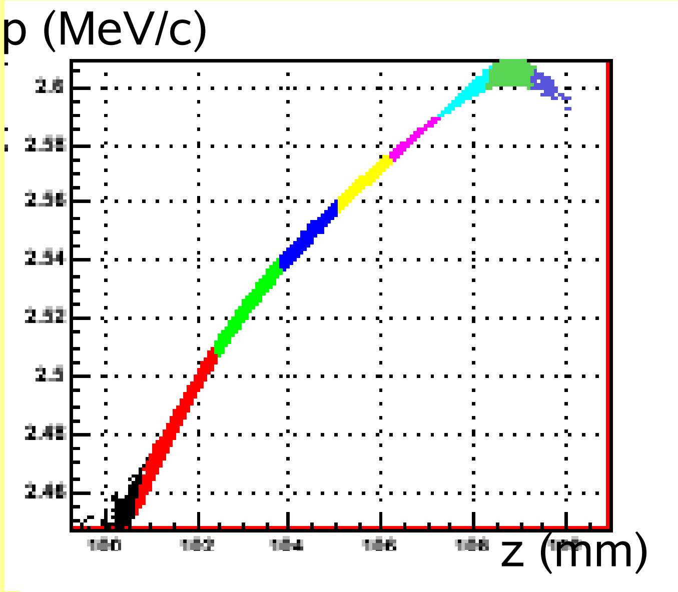


longitudinal phase space simulations

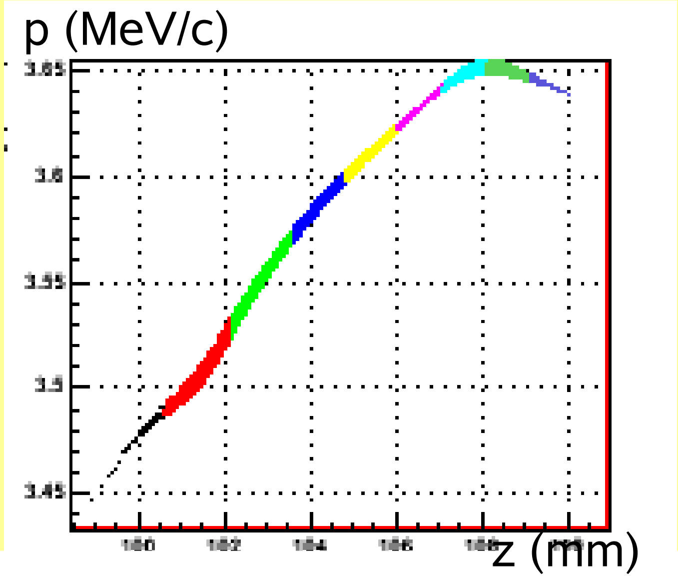




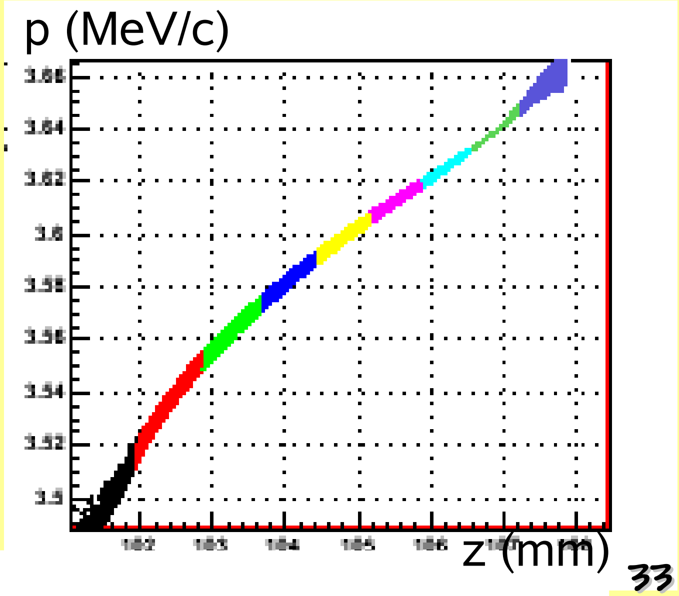
40MV/m
rise time = 7ps



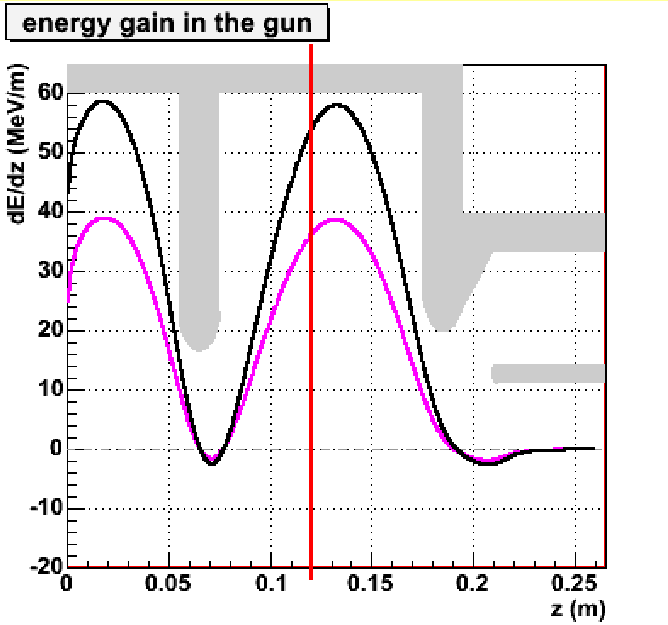
60MV/m
rise time = 7ps

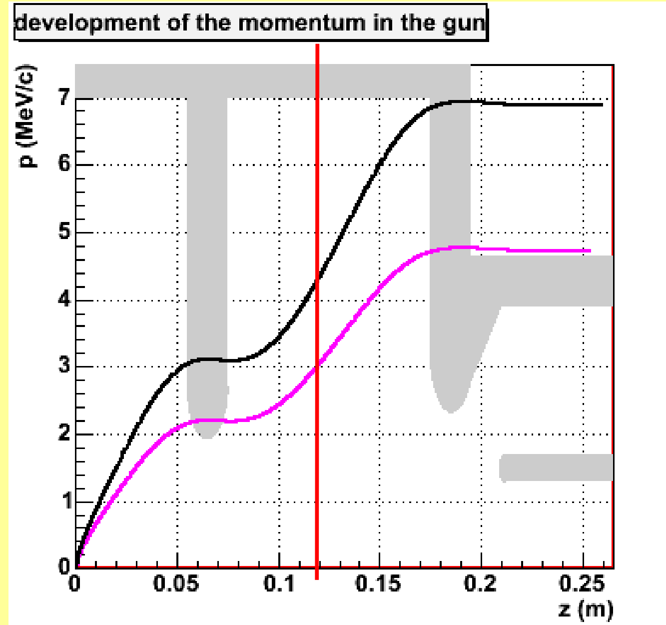


60MV/m
rise time = 2ps

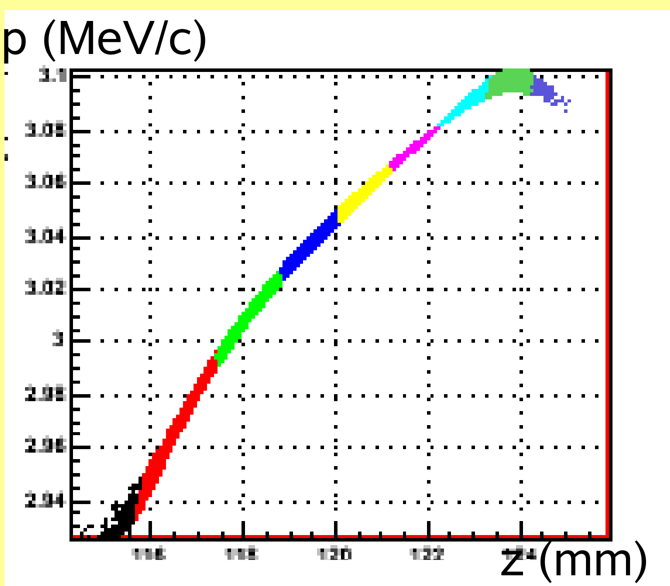


longitudinal phase space simulations

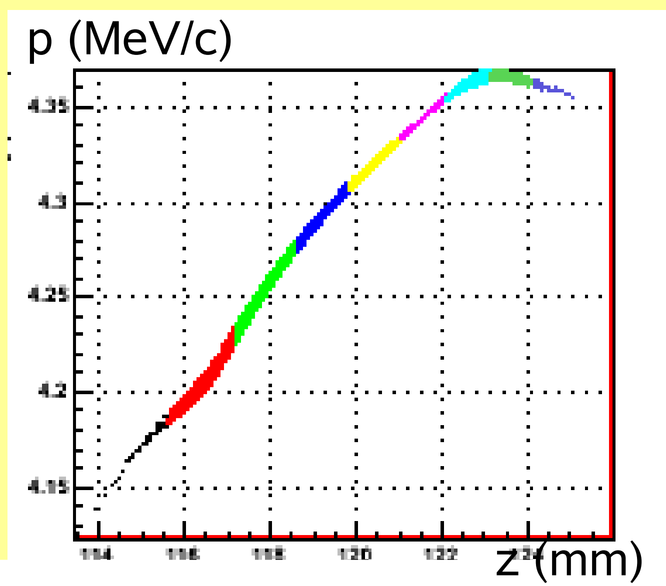




40MV/m
rise time = 7ps



60MV/m
rise time = 7ps



60MV/m
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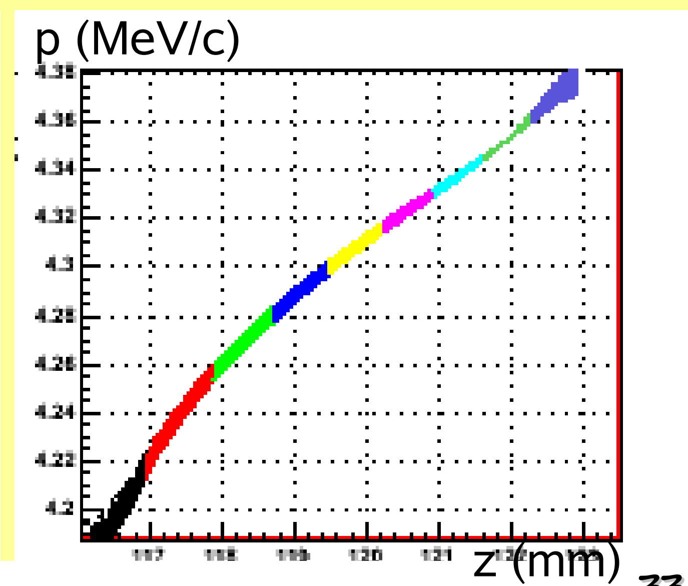
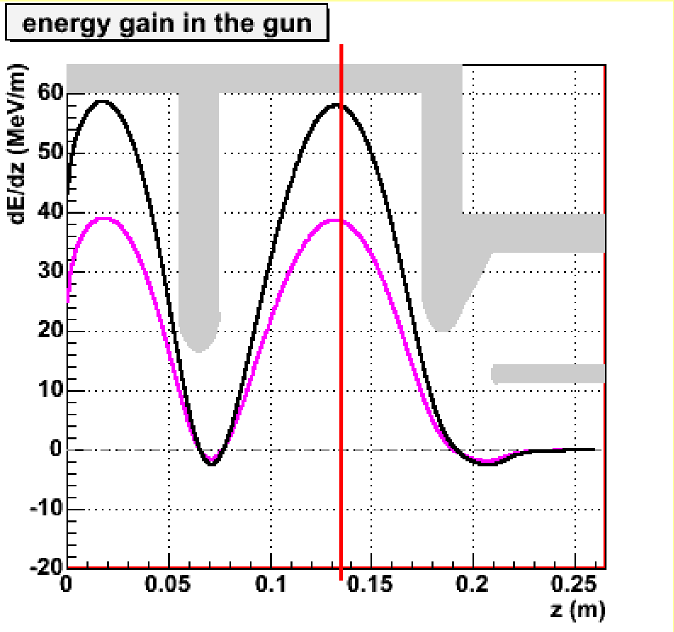
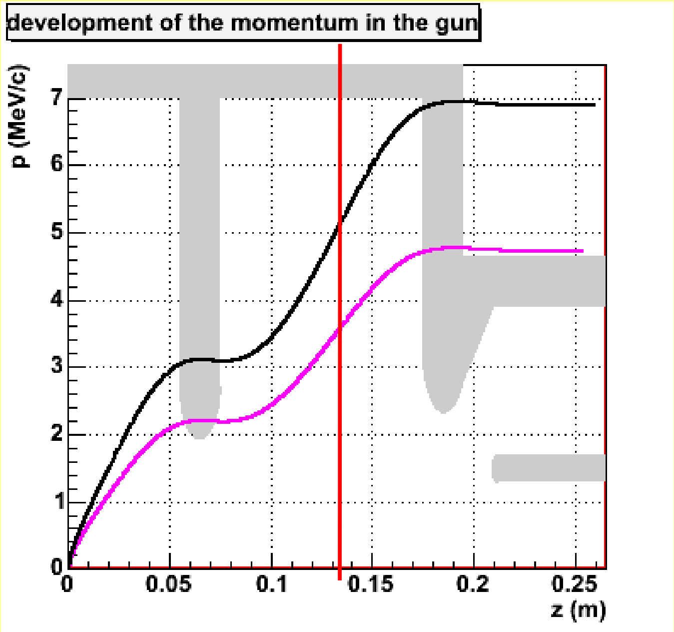
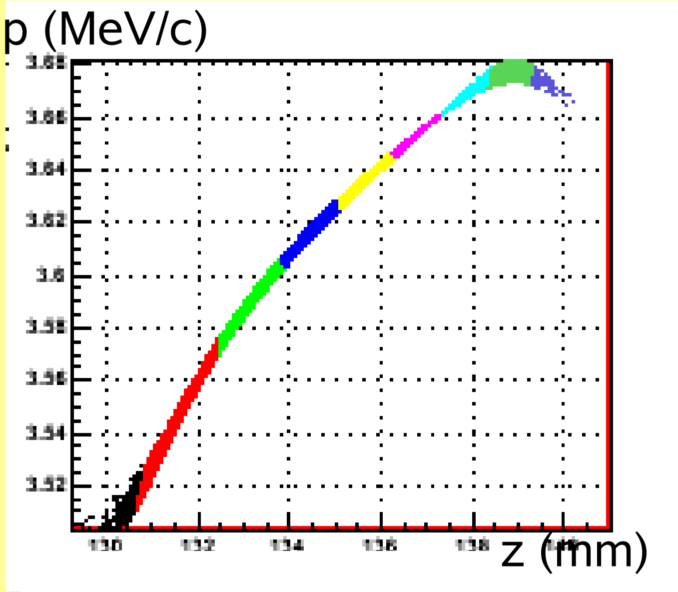


longitudinal phase space simulations





40MV/m
rise time = 7ps



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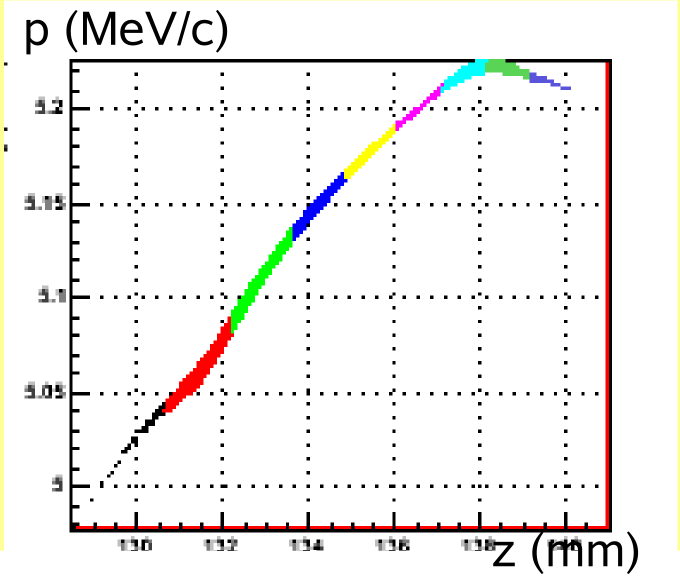
rise time = 7ps



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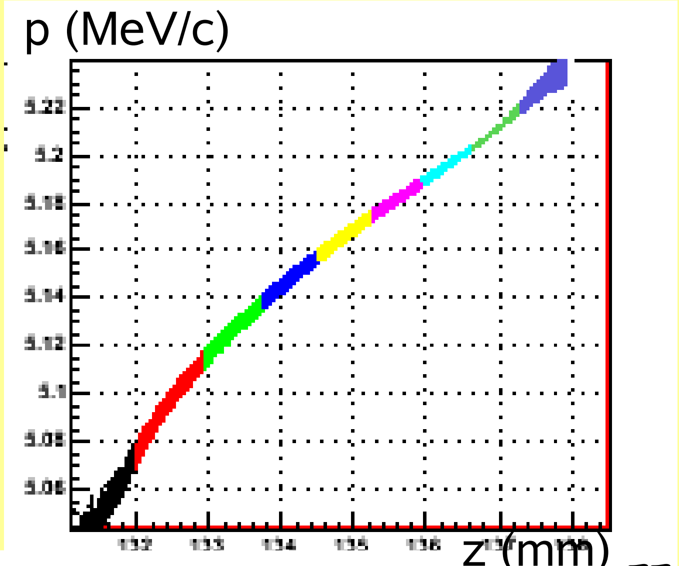
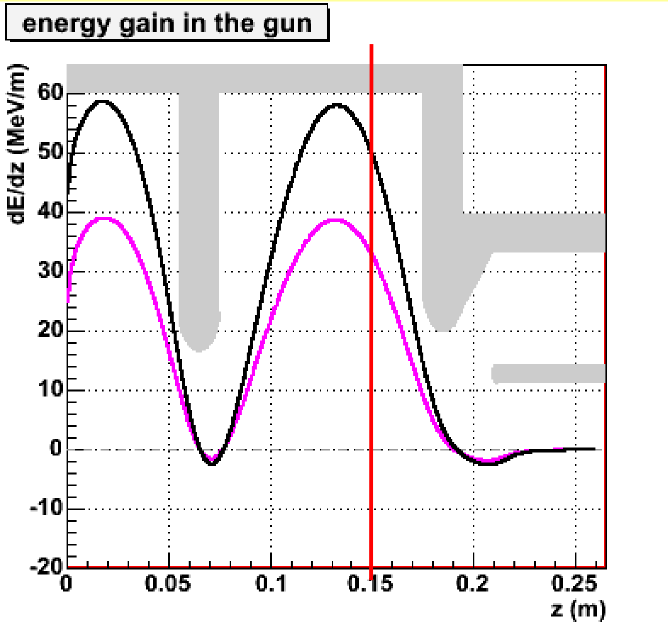
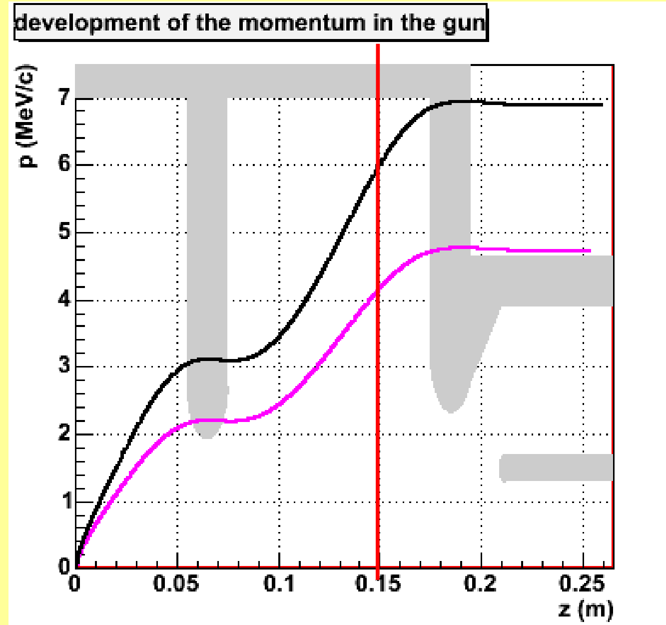
rise time = 2ps



longitudinal phase space simulations





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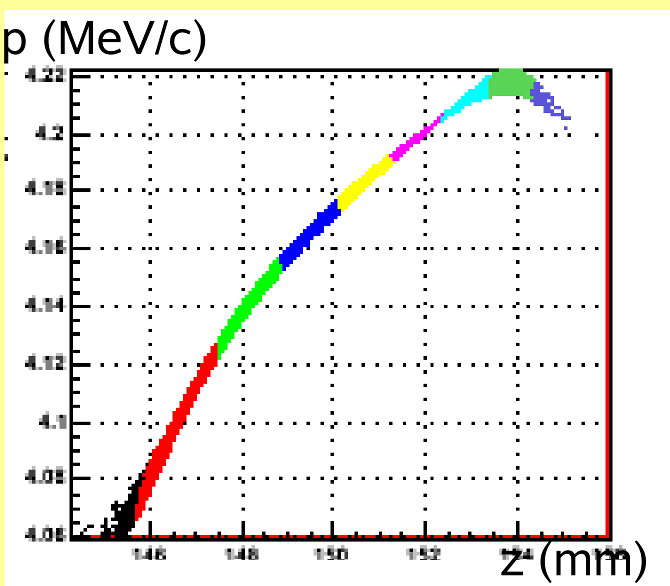

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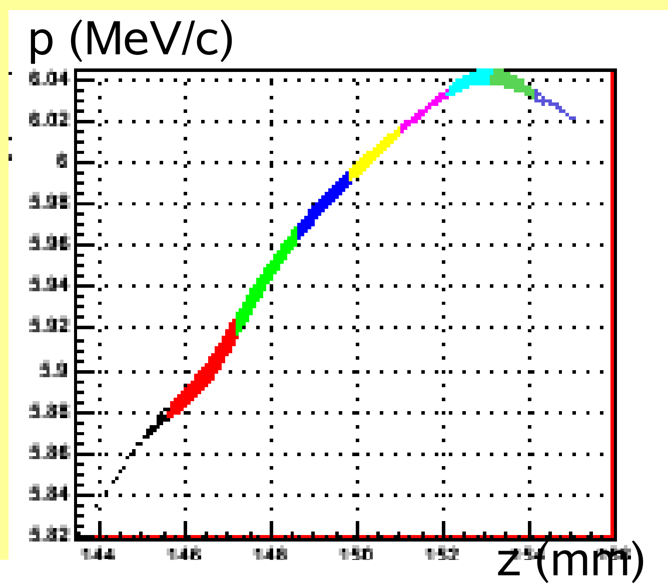

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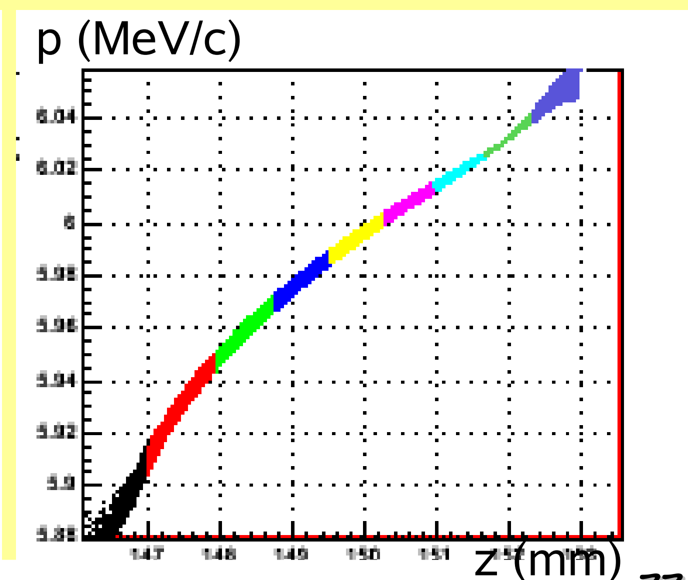
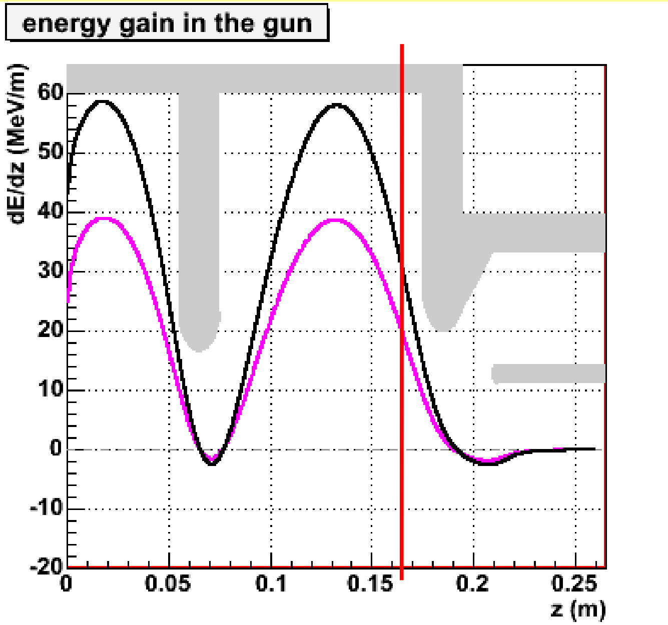
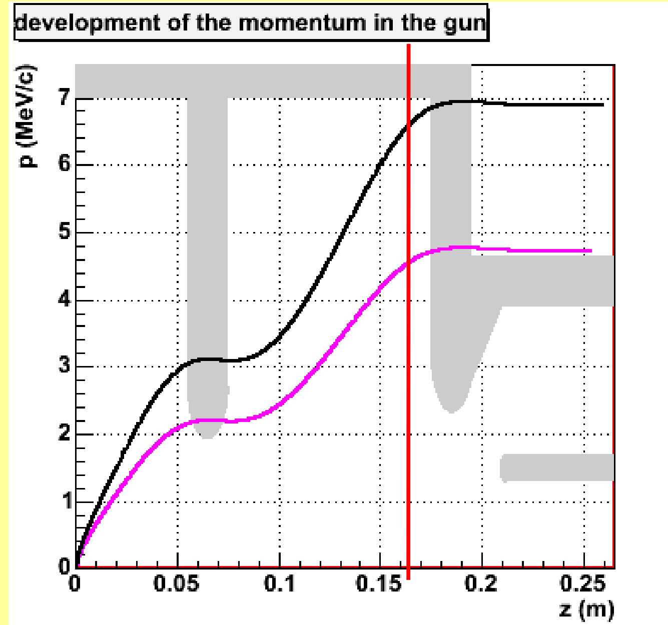


longitudinal phase space simulations





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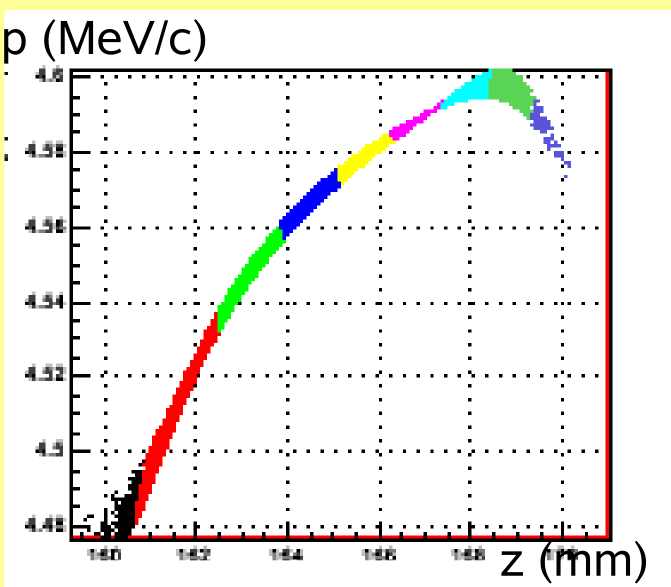

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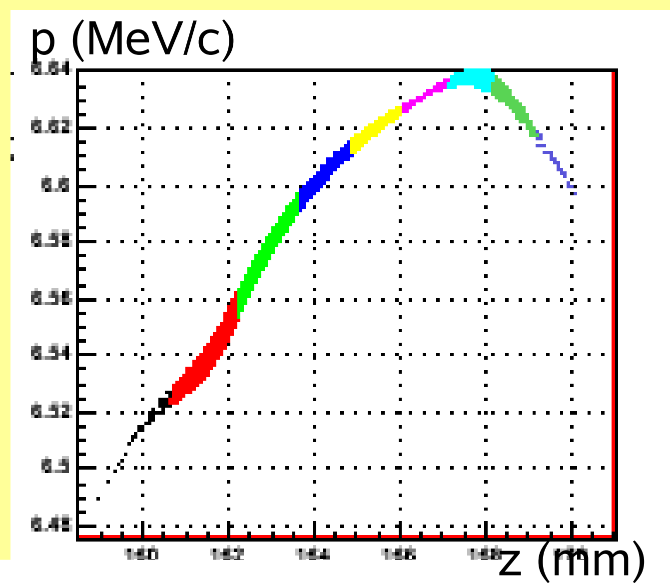

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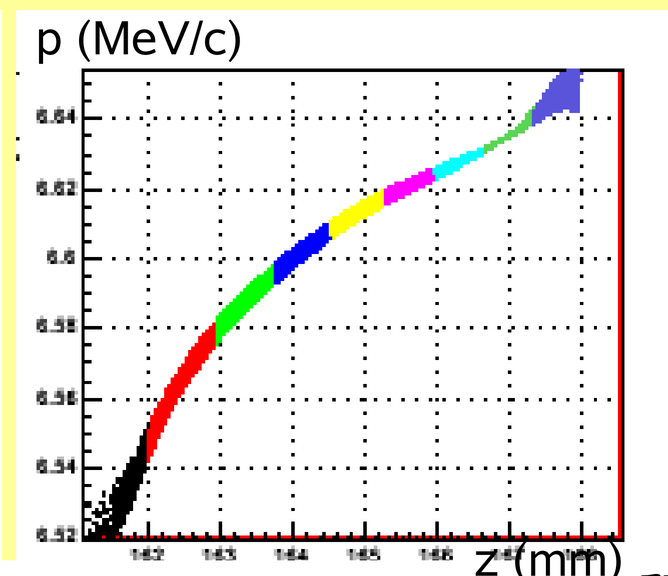
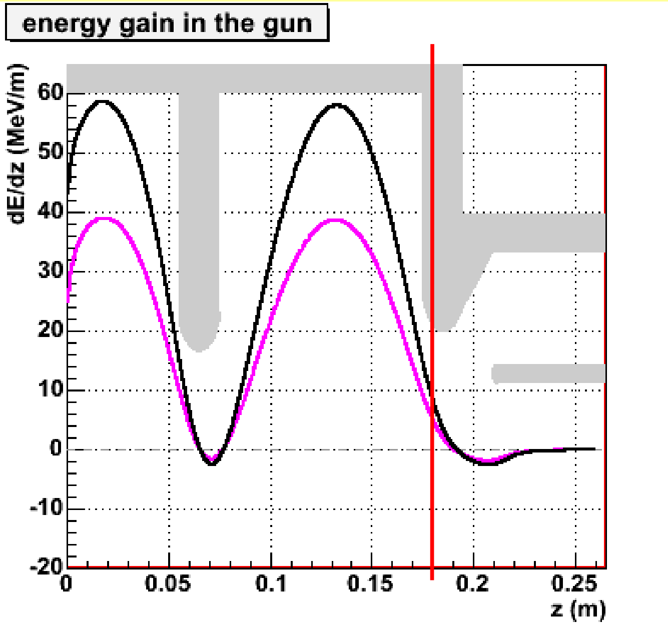
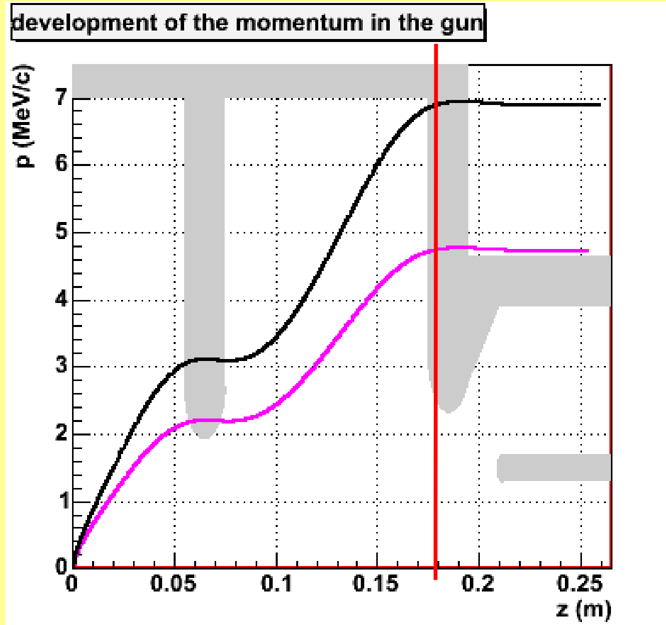


longitudinal phase space simulations





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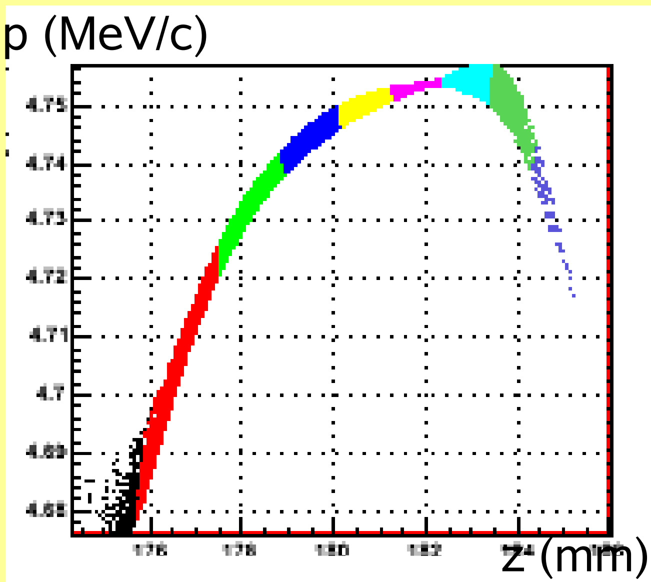

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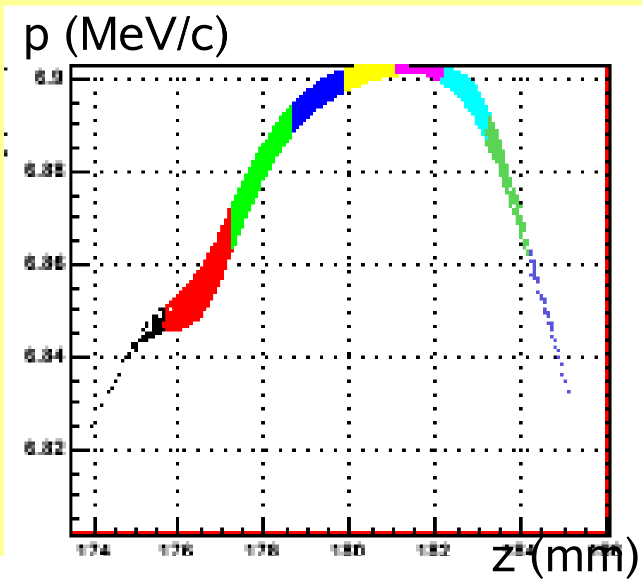

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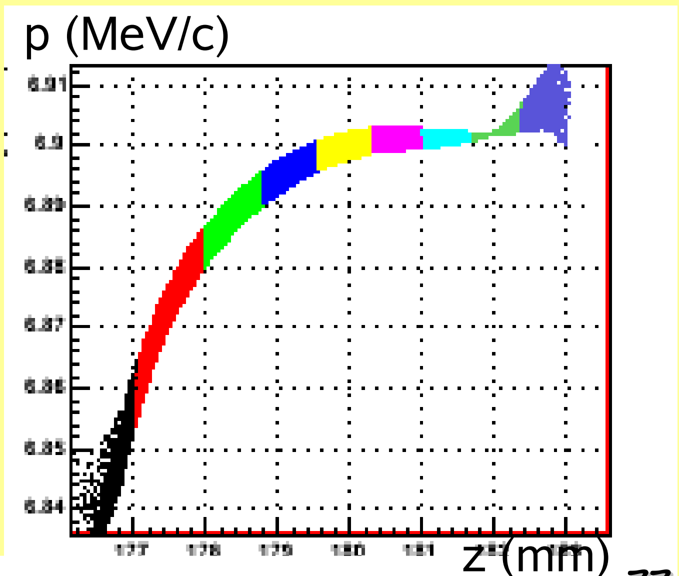
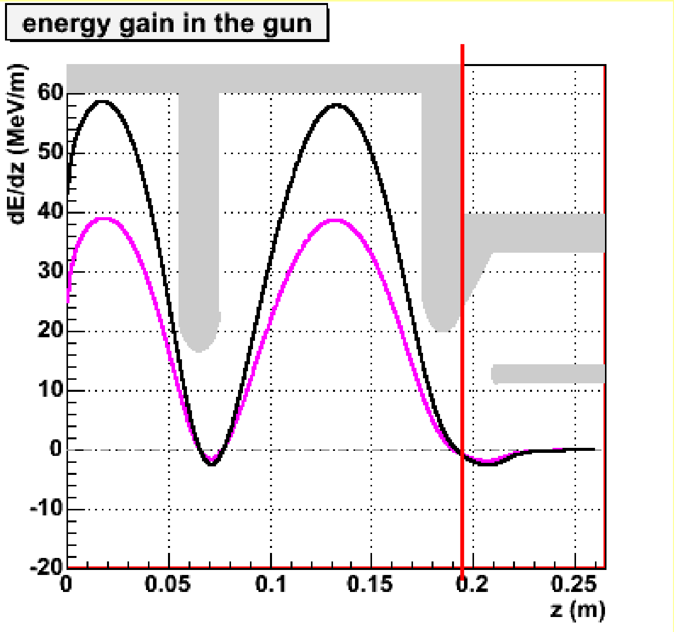
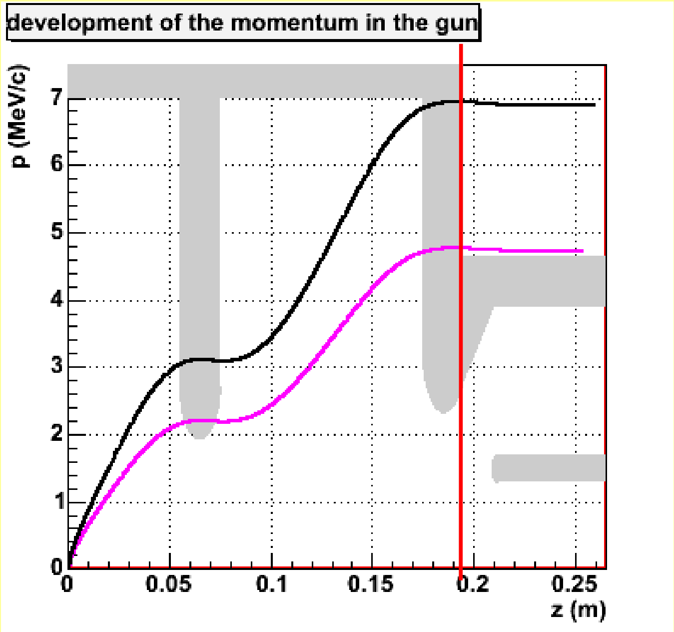


longitudinal phase space simulations





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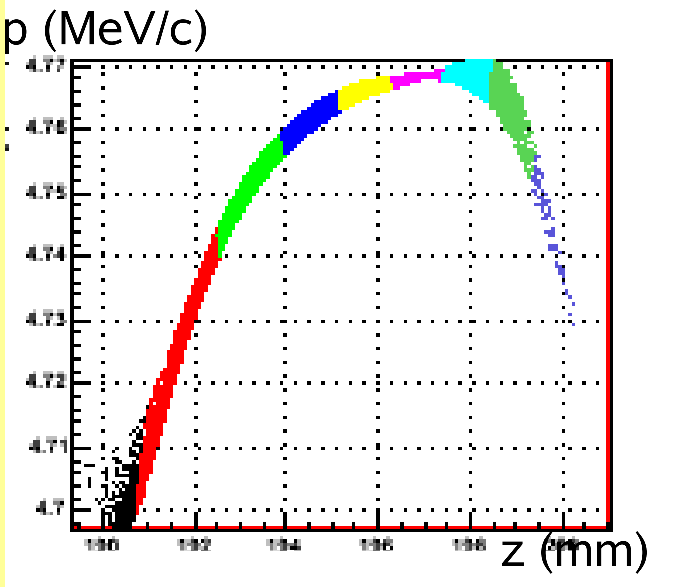

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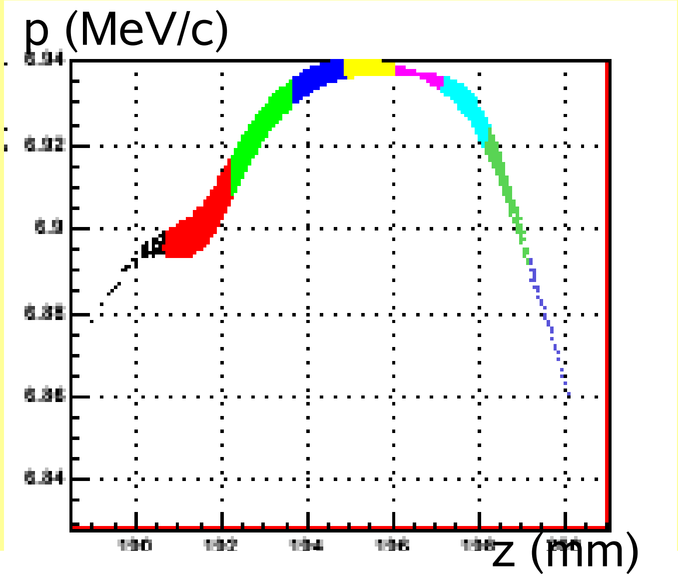

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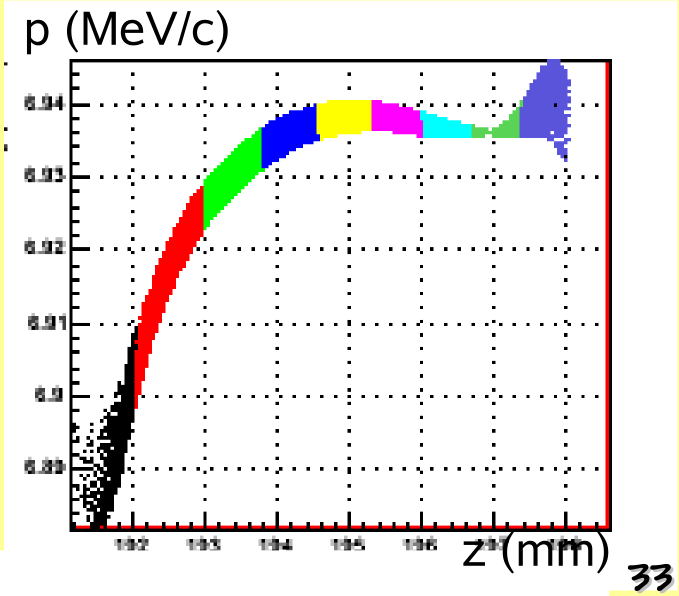
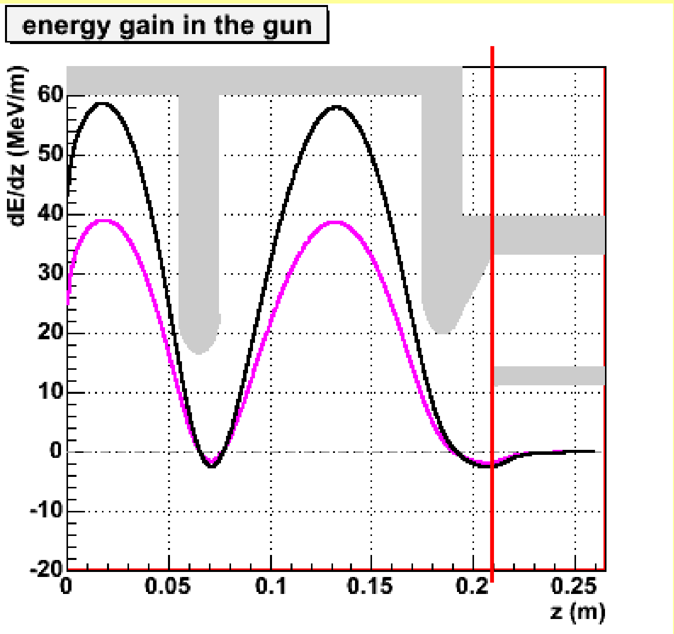
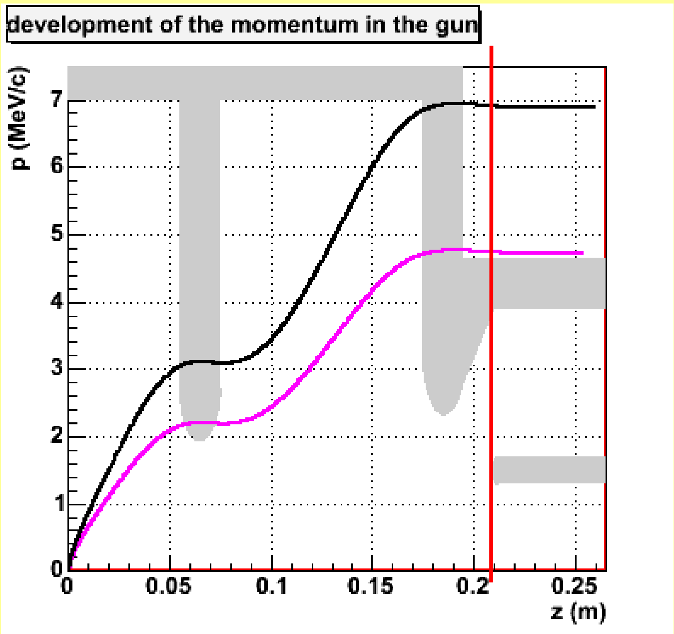
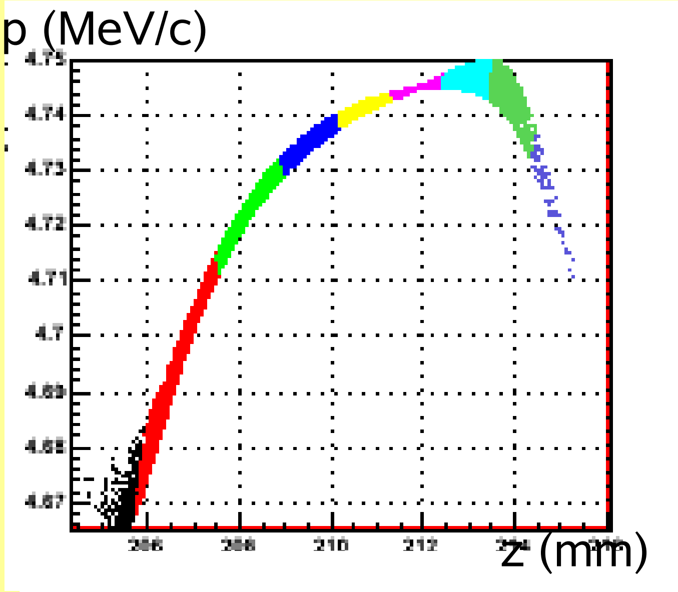


longitudinal phase space simulations

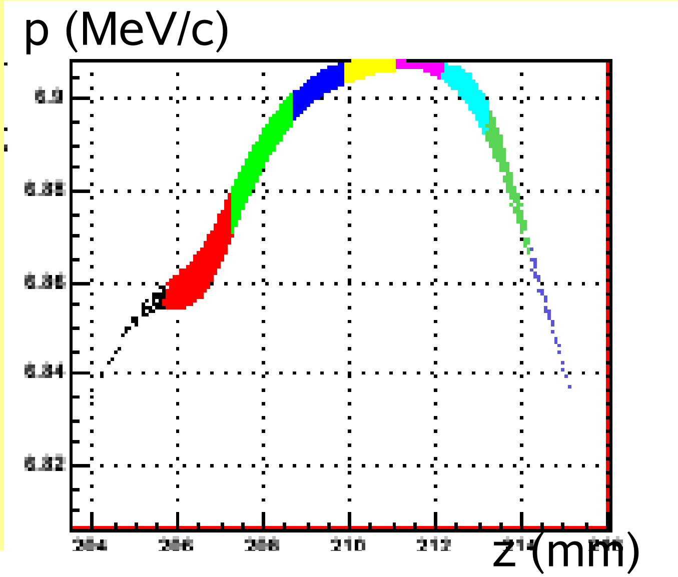




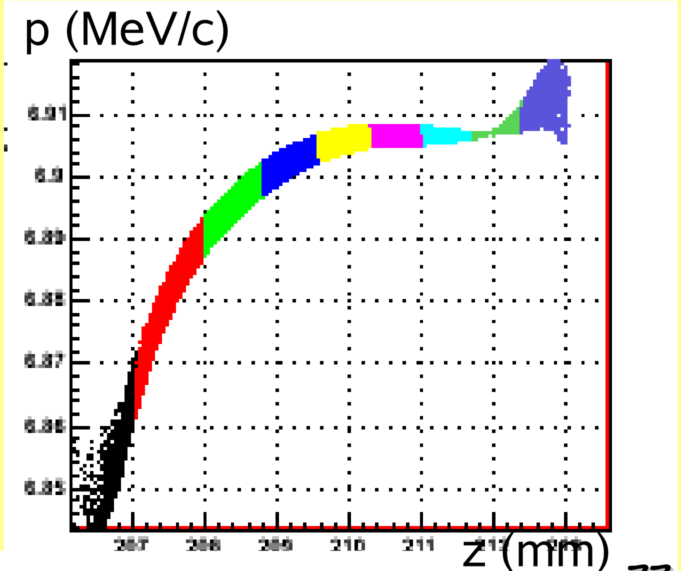
40MV/m
rise time = 7ps



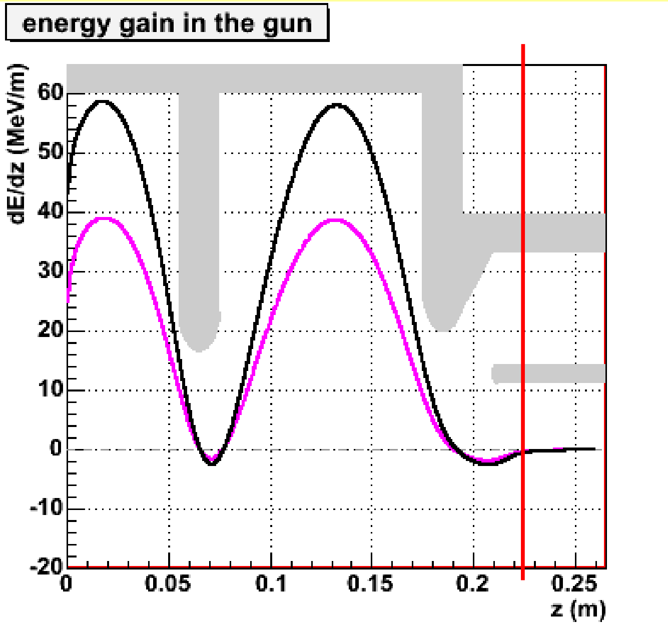
60MV/m
rise time = 7ps

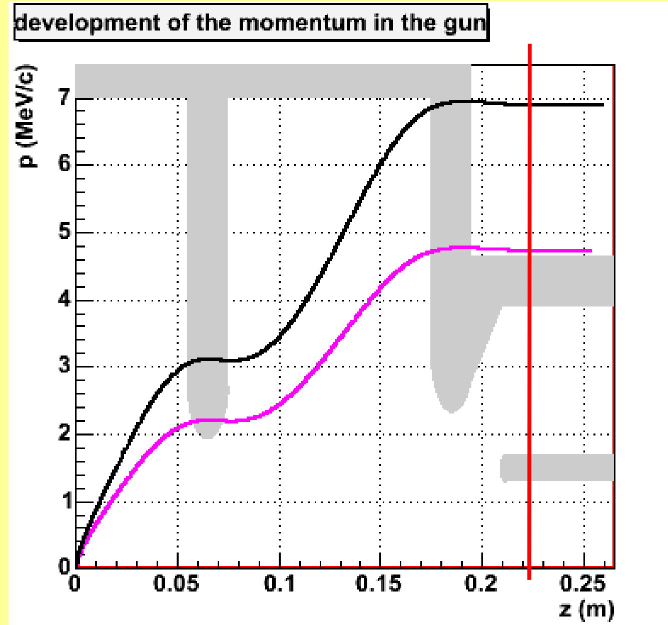


60MV/m
rise time = 2ps



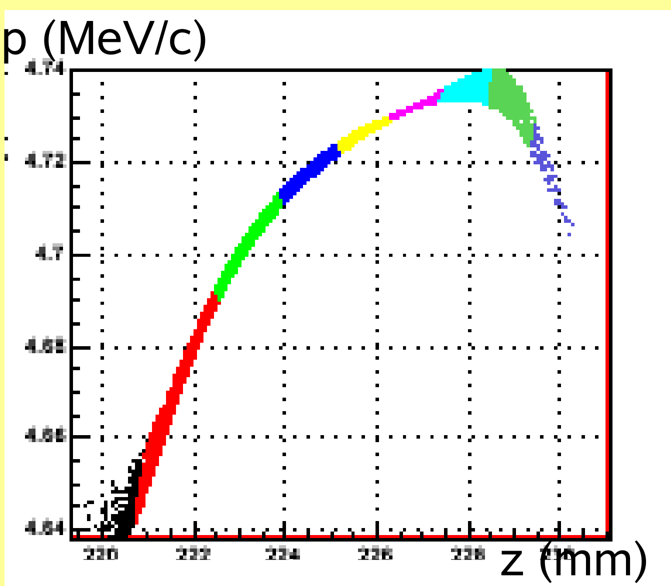
longitudinal phase space simulations



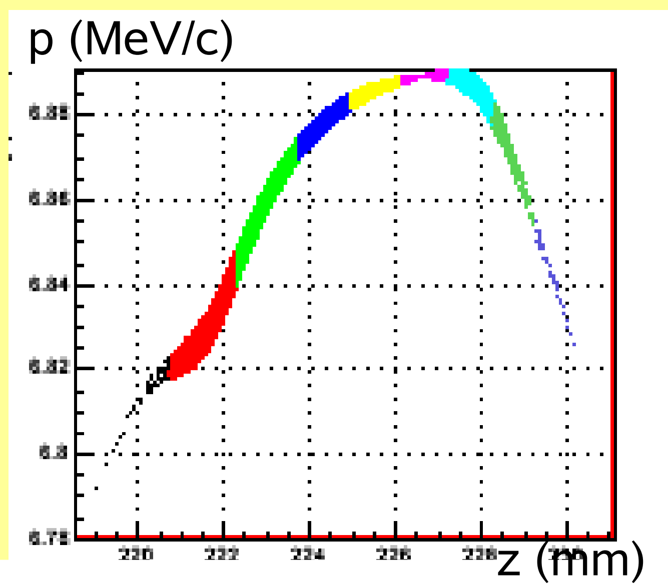


- Beam density distribution for:
- 1 nC
- transv. laser diameter = 2mm
- Flat-top laser
- opt. gun phase

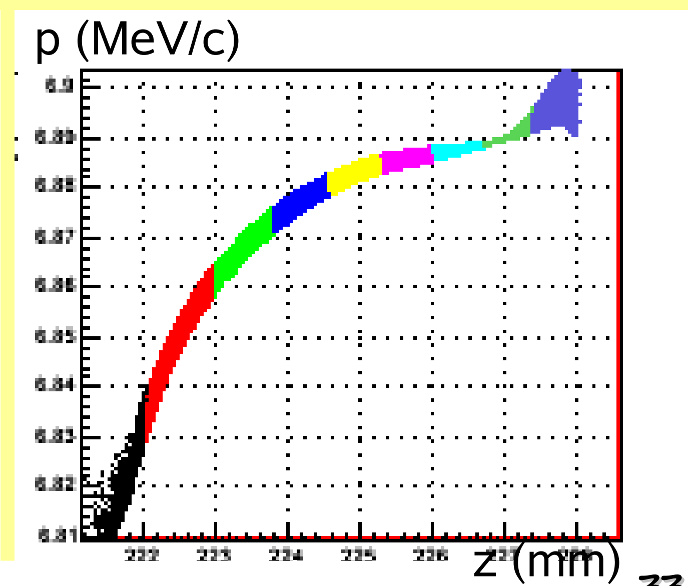
40MV/m
rise time = 7ps



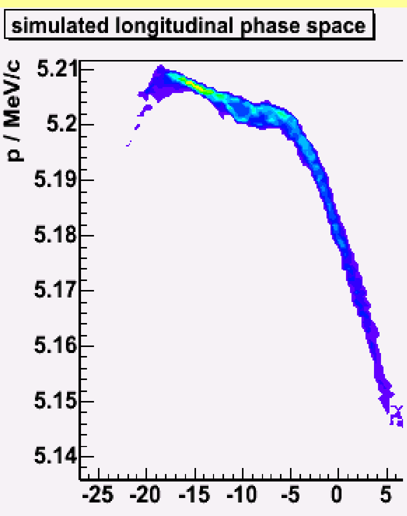
60MV/m
rise time = 7ps



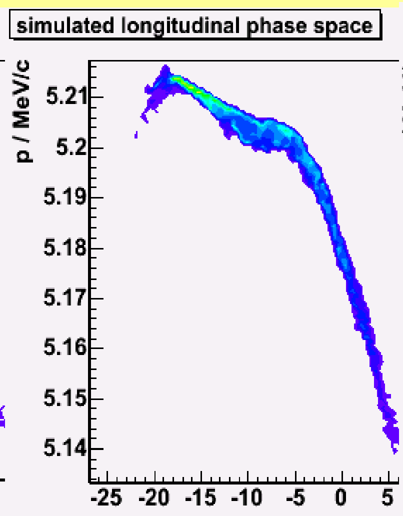
60MV/m
rise time = 2ps



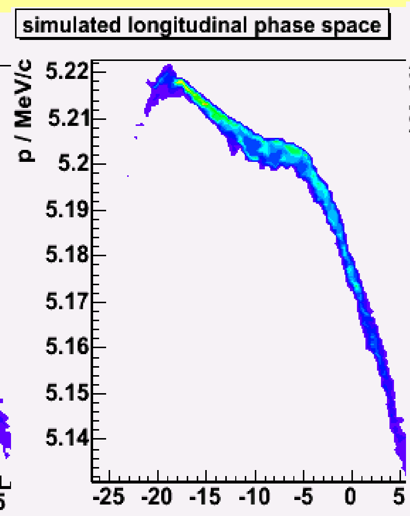
simulations for optimum phase, 1 nC, flat-top laser distribution at different positions (~40MV/m)



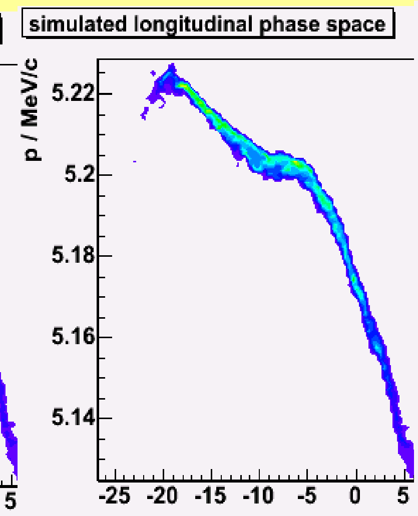
0.31 m



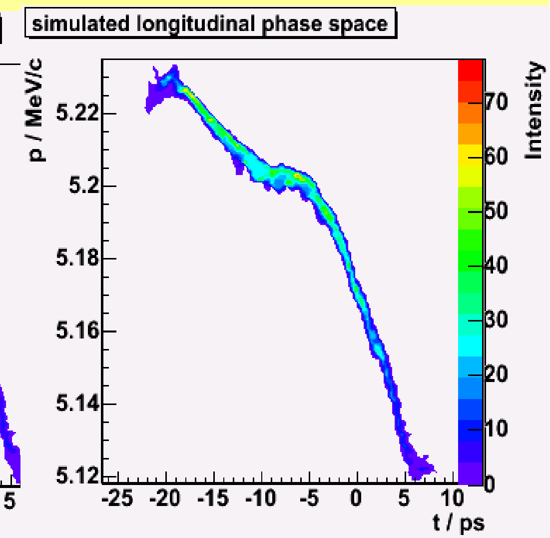
0.66m



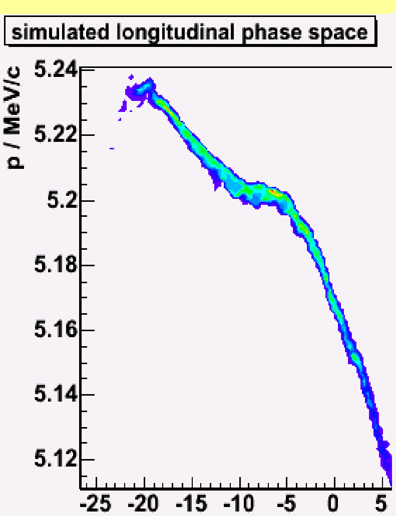
1.01m



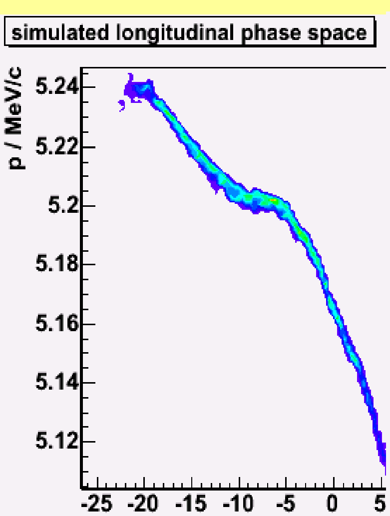
1.36m



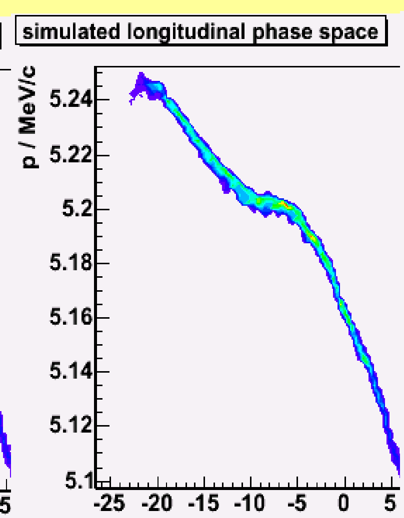
1.71m



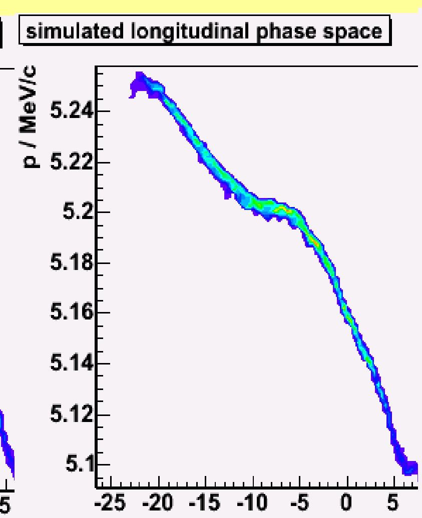
2.05 m



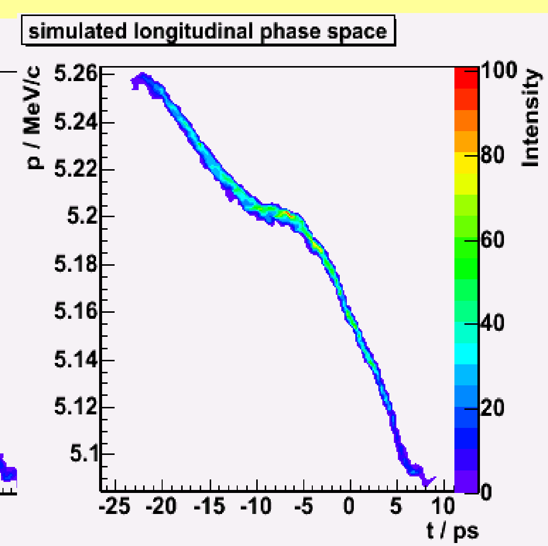
2.40m



2.75m

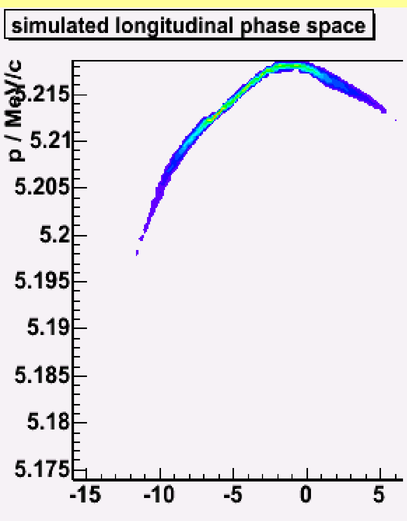


3.10m

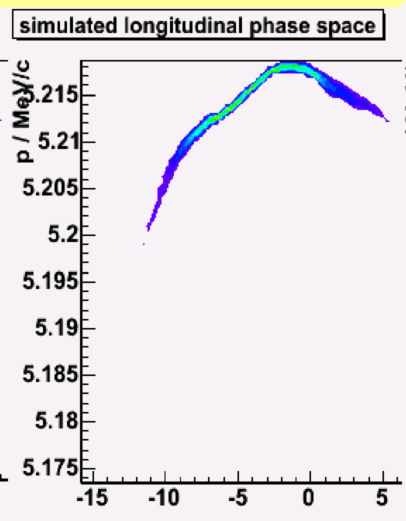


3.45m

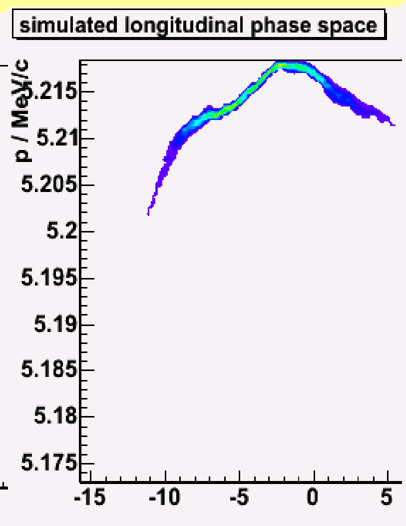
simulations for optimum phase, 30 pC, flat-top laser distribution at different positions (~40MV/m)



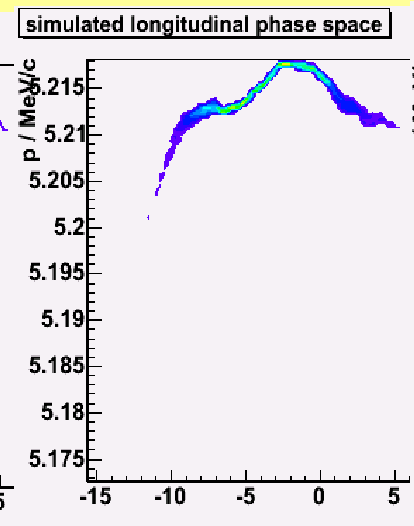
0.31 m



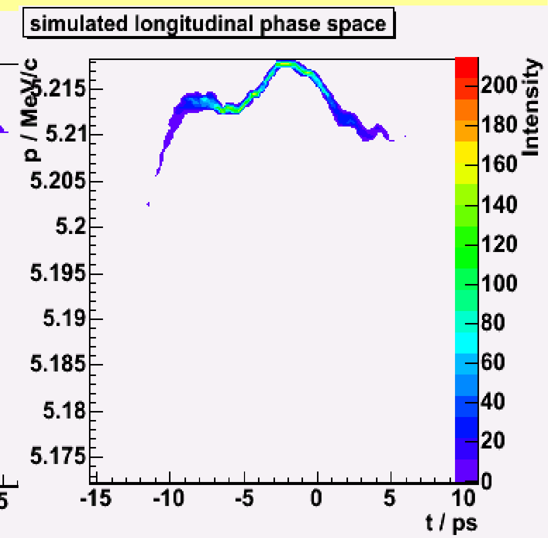
0.66m



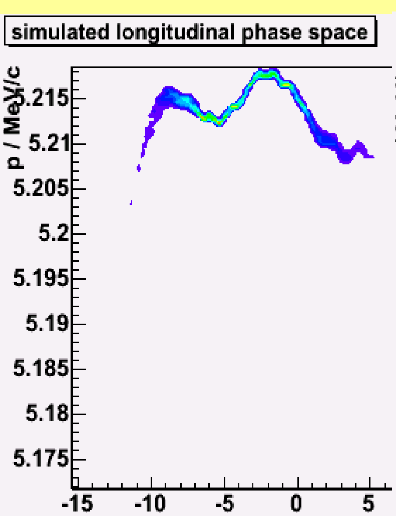
1.01m



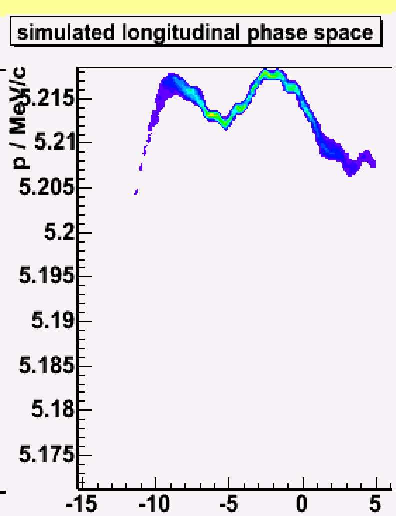
1.36m



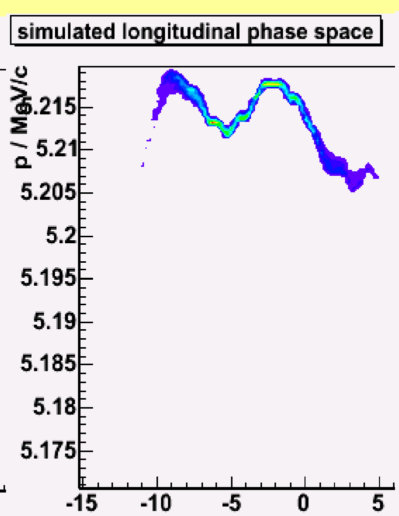
1.71m



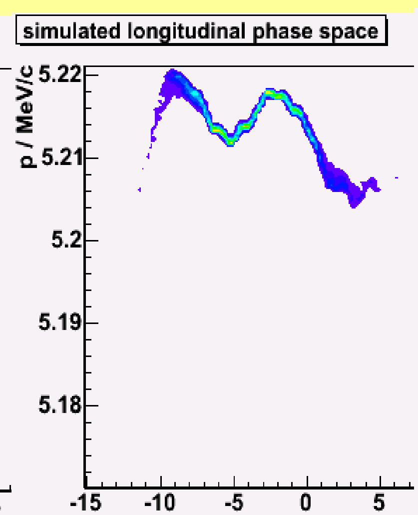
2.05 m



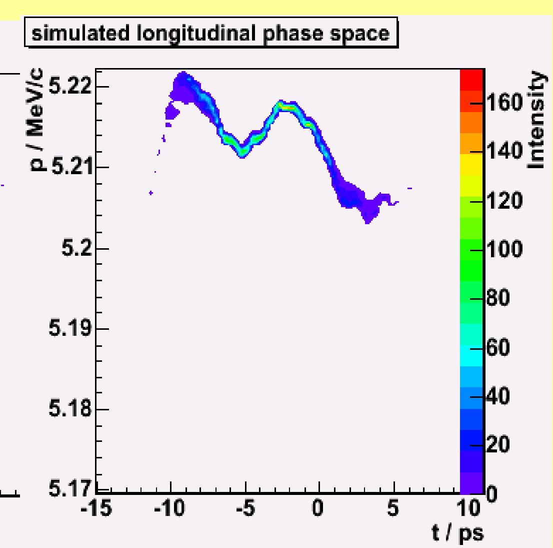
2.40m



2.75m

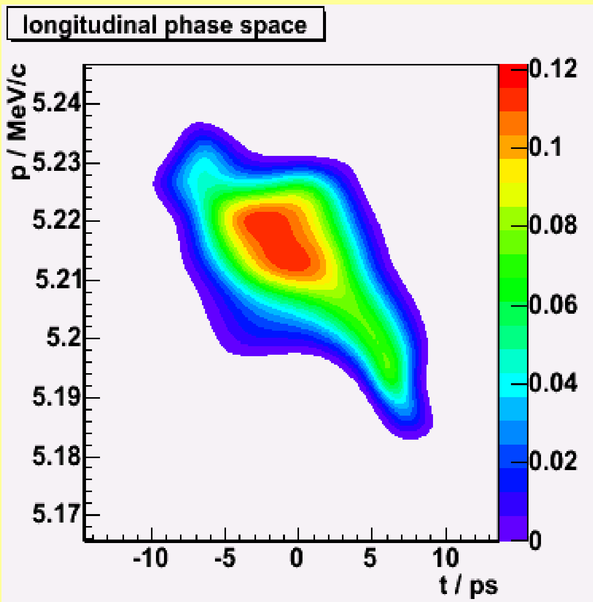


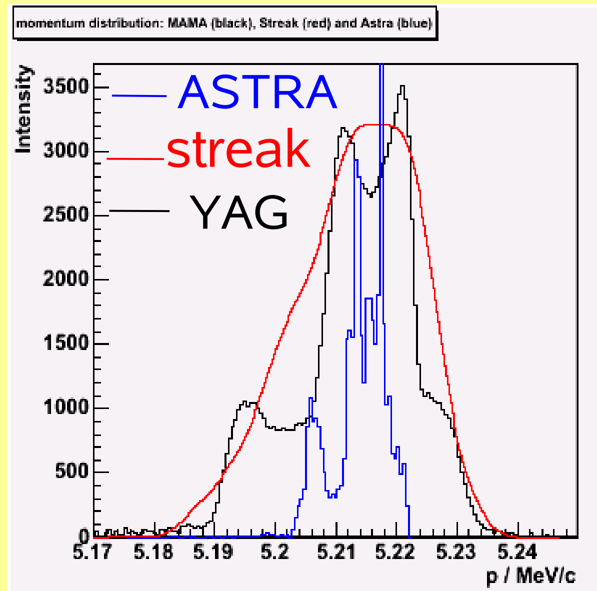
3.10m

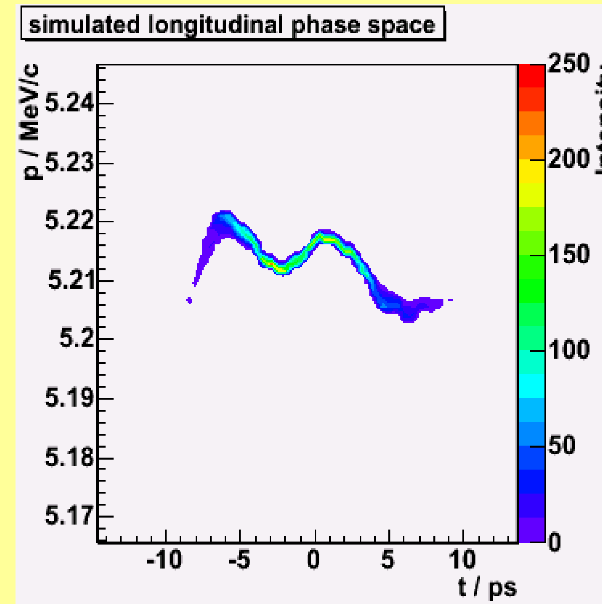


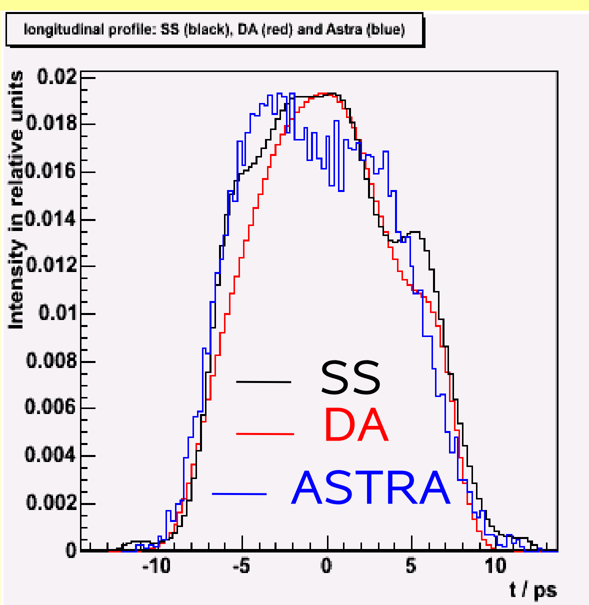
3.45m

optimum phase, 30 pC, flat-top laser distribution

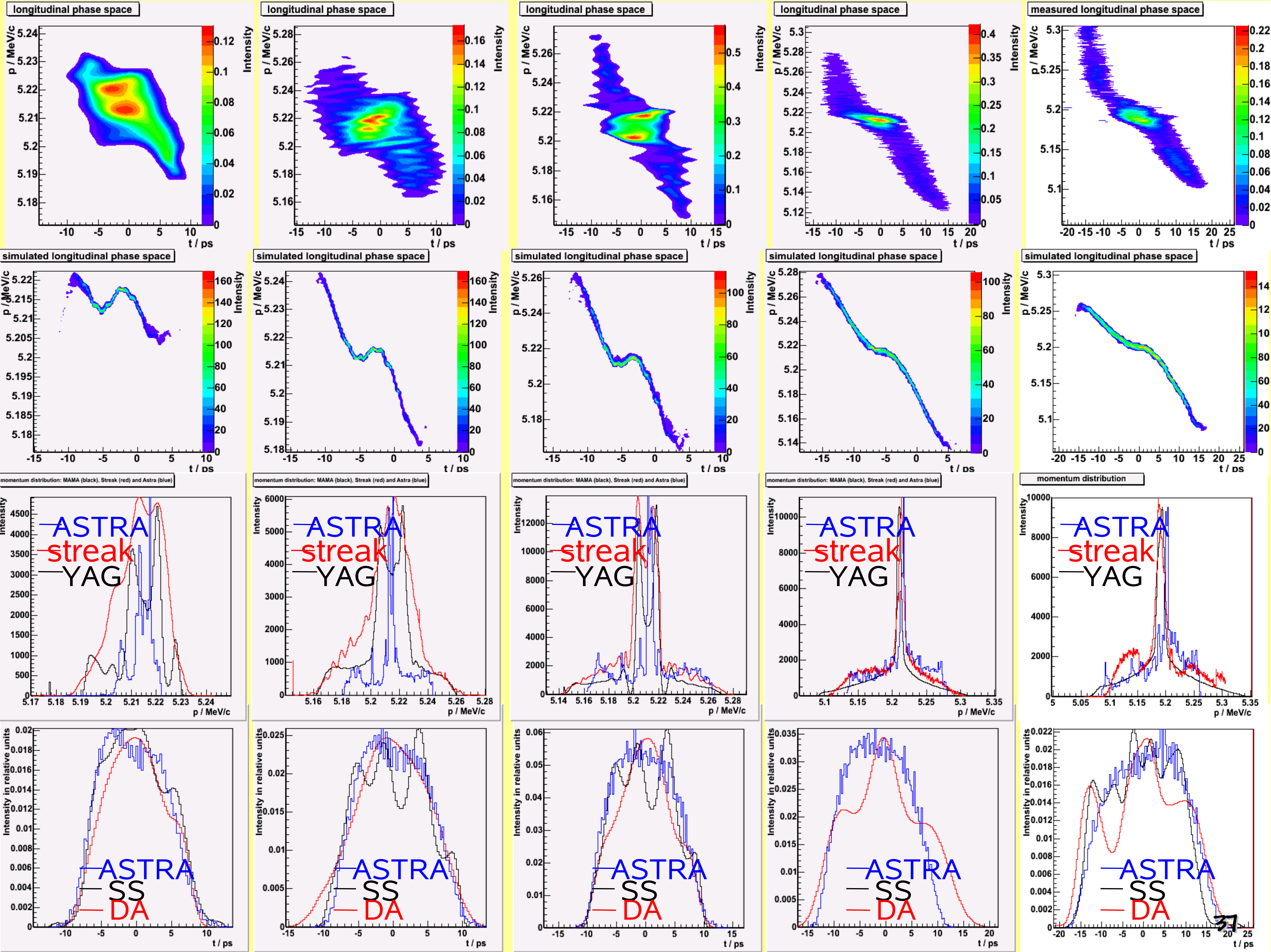


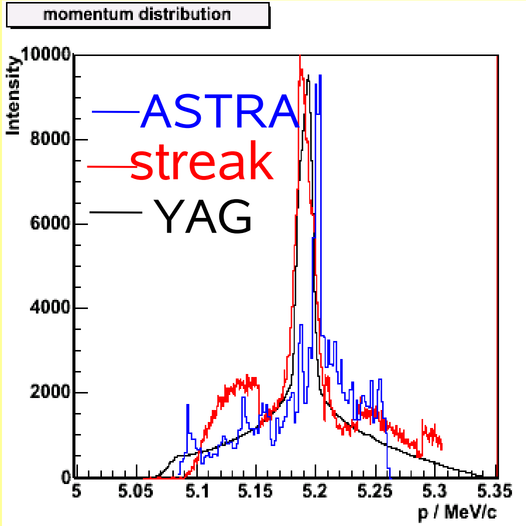




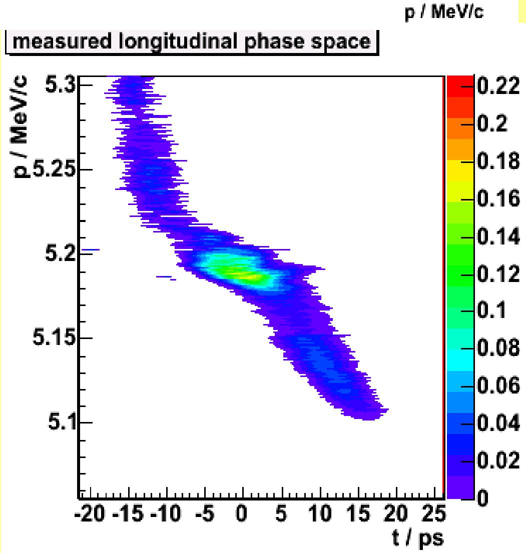


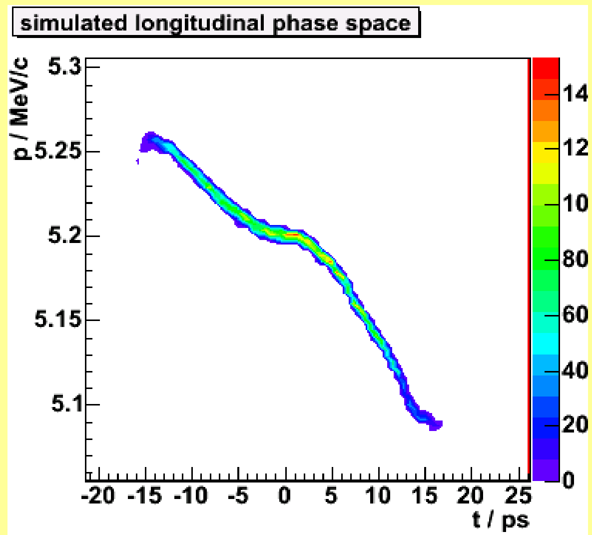
- for optimum phase accelerating field reaches its maximum during emission time this means electrons emitted in the middle of the bunch receive the highest acceleration due to the field
- due to space charge effects the particles in the beginning of the bunch become accelerated and the ones in the end decelerated

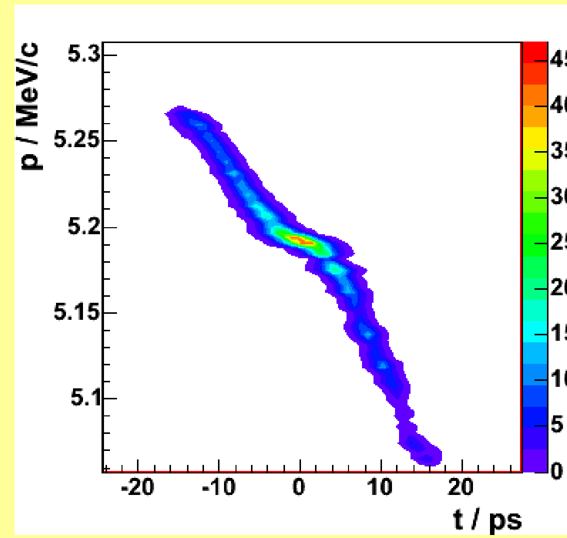

longitudinal phase space
measured longitudinal phase space
simulated longitudinal phase space
p / MeV/c
t / ps
Intensity
momentum distribution: MAMA (black), Streak (red) and Astra (blue)
momentum distribution
ASTRA
streak
YAG
Intensity in relative units
ASTRA
SS
DA
37

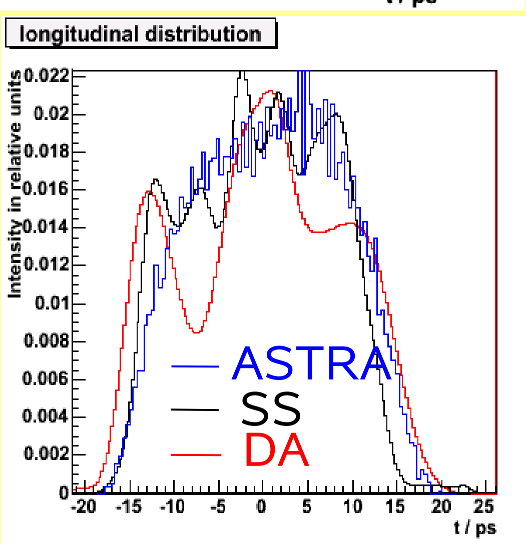


optimum phase, 1 nC, flat-top laser distribution



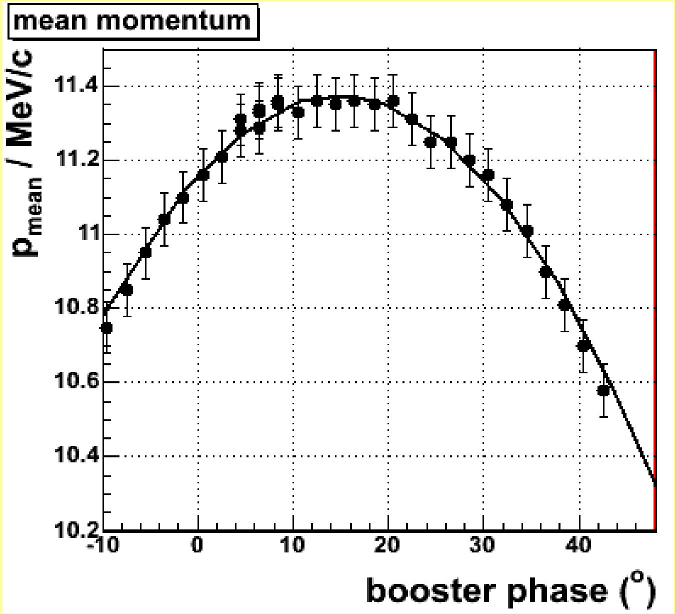


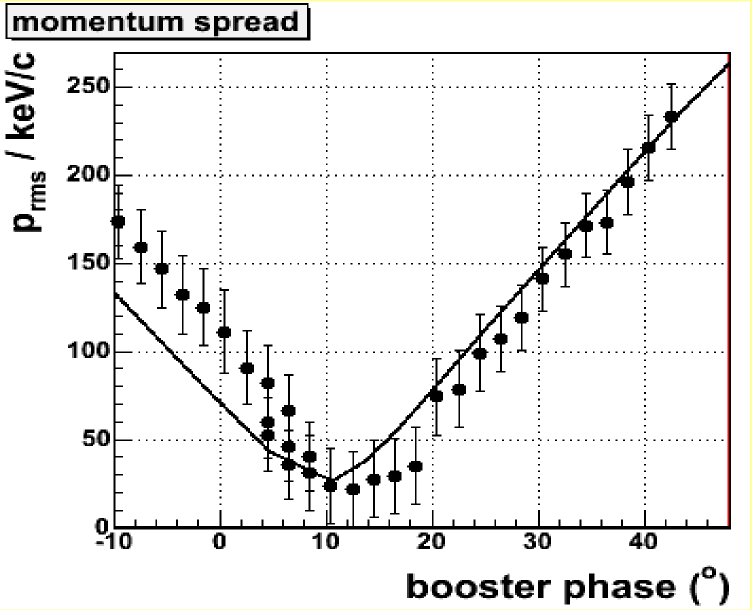


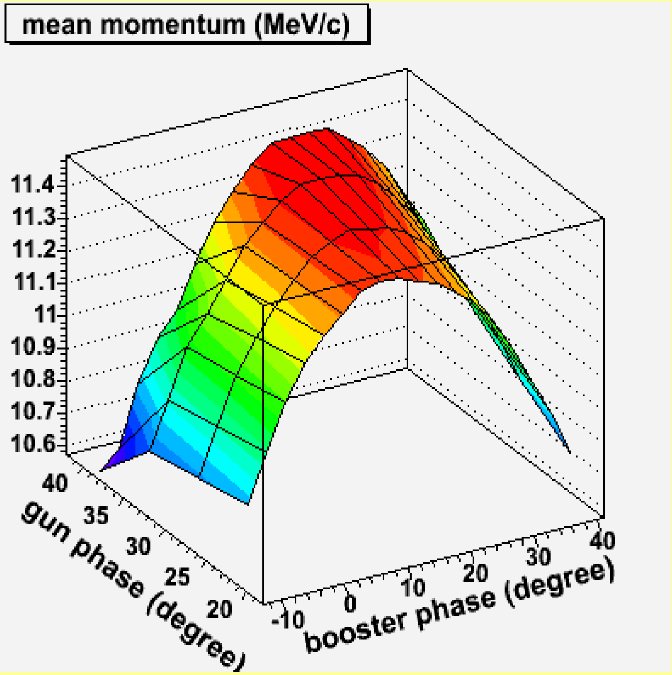


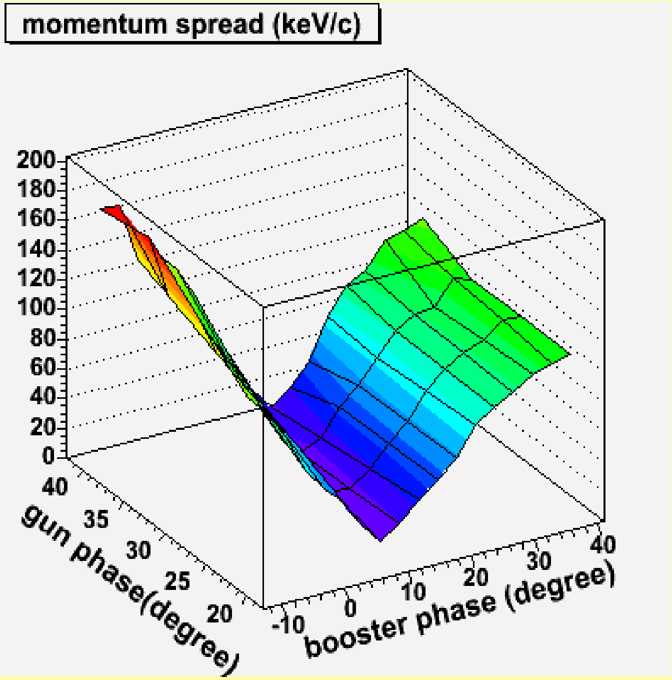
	measured	Astra
FWHM / ps	StSe: 25.2 +/- 1.3; DA: 28.5 +/- 3.3	25
long. emittance / π keV mm	32.7 +/-6.8	26,6
momentum / MeV	5.19 +/- 0.06	5,19
momentum spread / keV	46.0 +/- 5.1	42,2

momentum measurement after the booster cavity



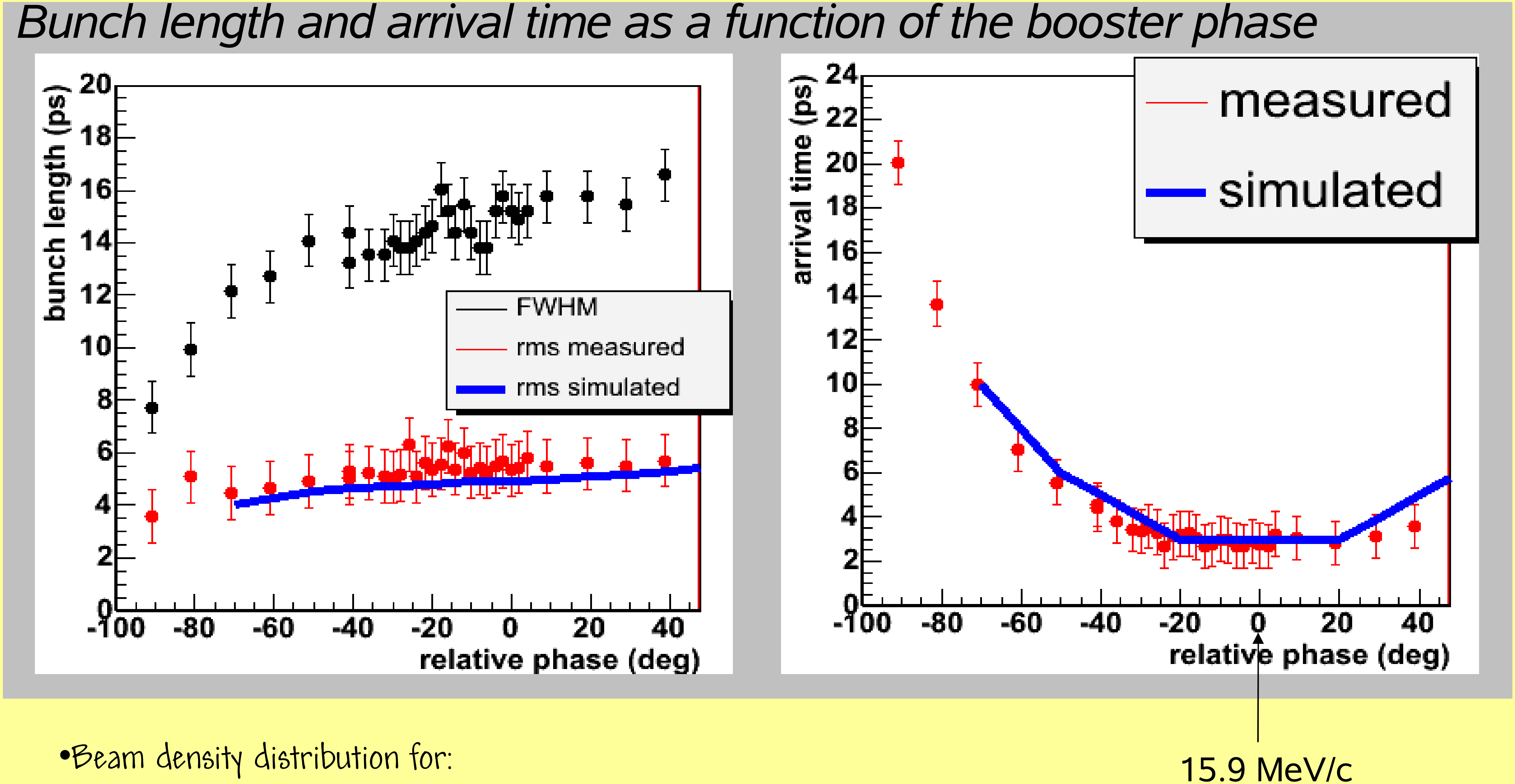






bunch length after the booster cavity

Bunch length and arrival time as a function of the booster phase

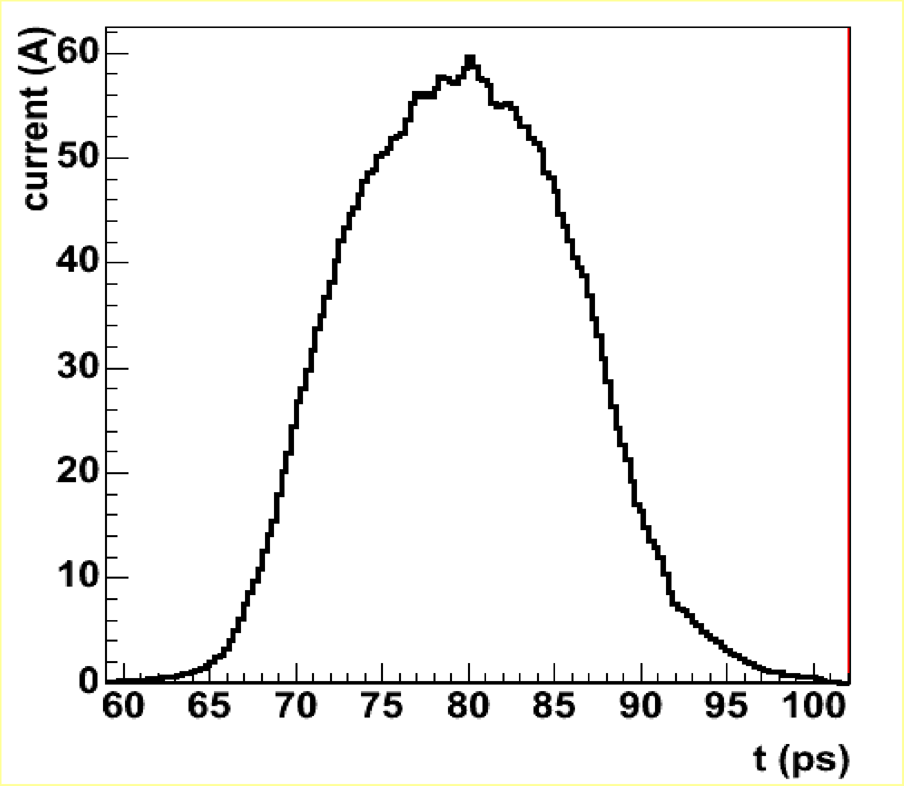


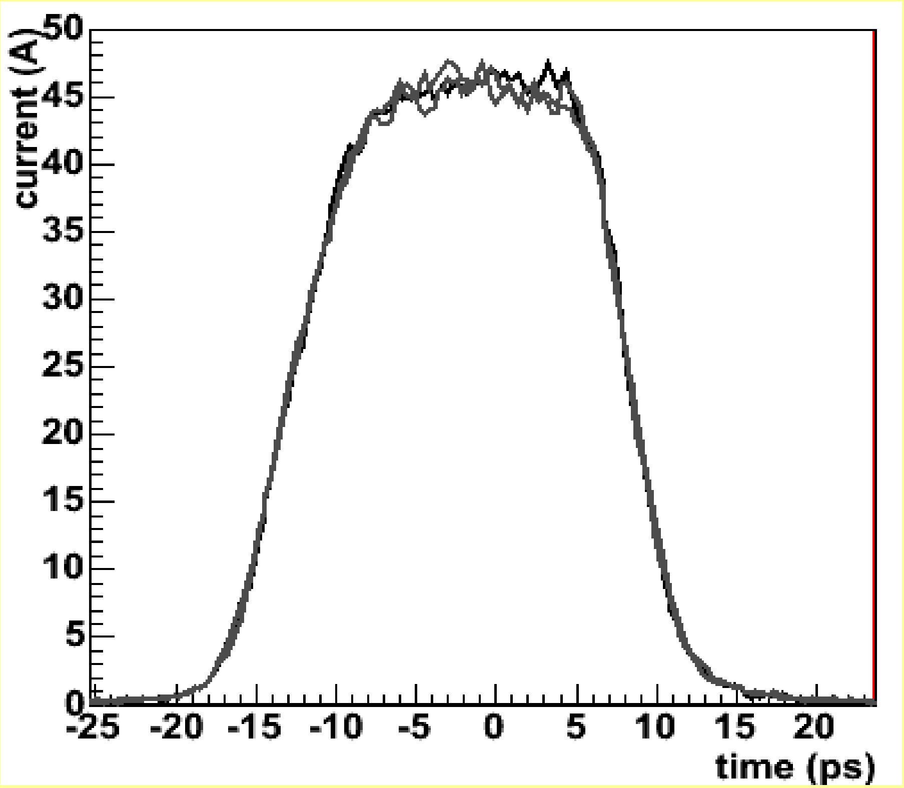
- Beam density distribution for:
- 800 pC
- transv. laser diameter = 1.5mm
- Flat-top laser
- opt. Gun phase

momentum measurement after the booster cavity

- Beam density distribution for:
- 1 nC
- transv. laser diameter = 2mm
- Flat-top laser
- opt. Gun phase

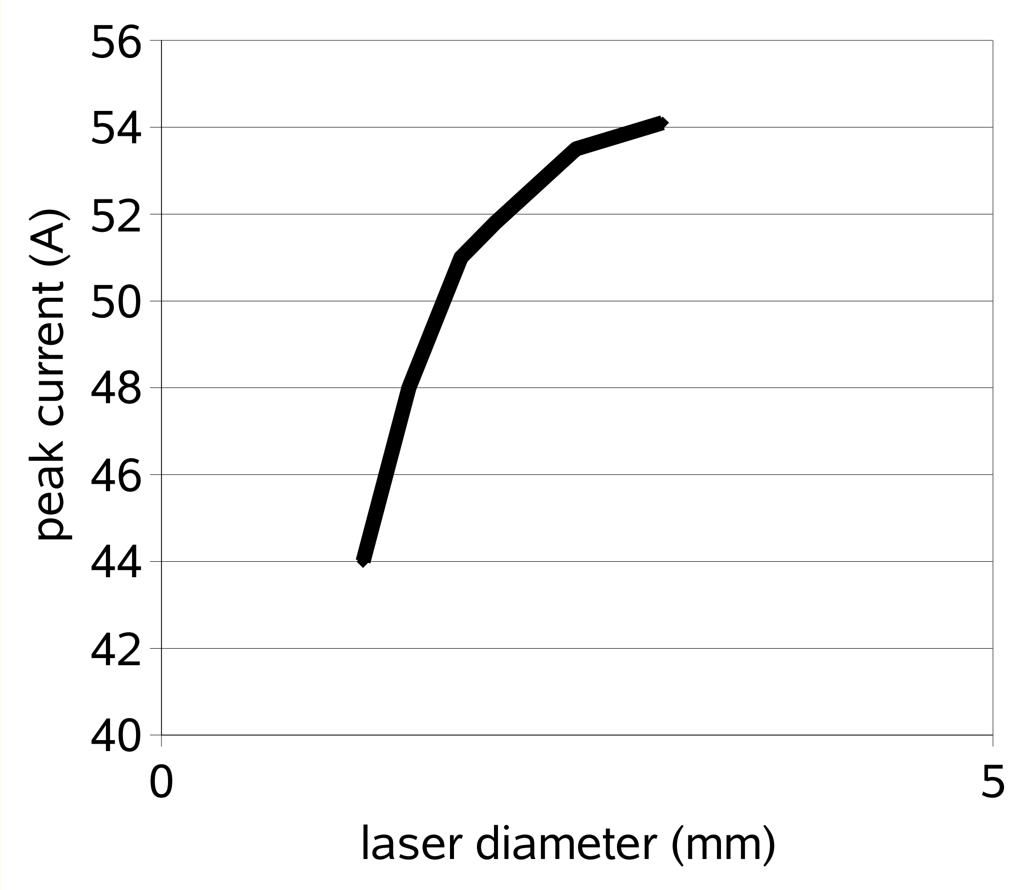
- Beam density distribution for:
- 1 nC
- transv. laser diameter = 1.5mm
- Flat-top laser
- opt. gun and booster phase

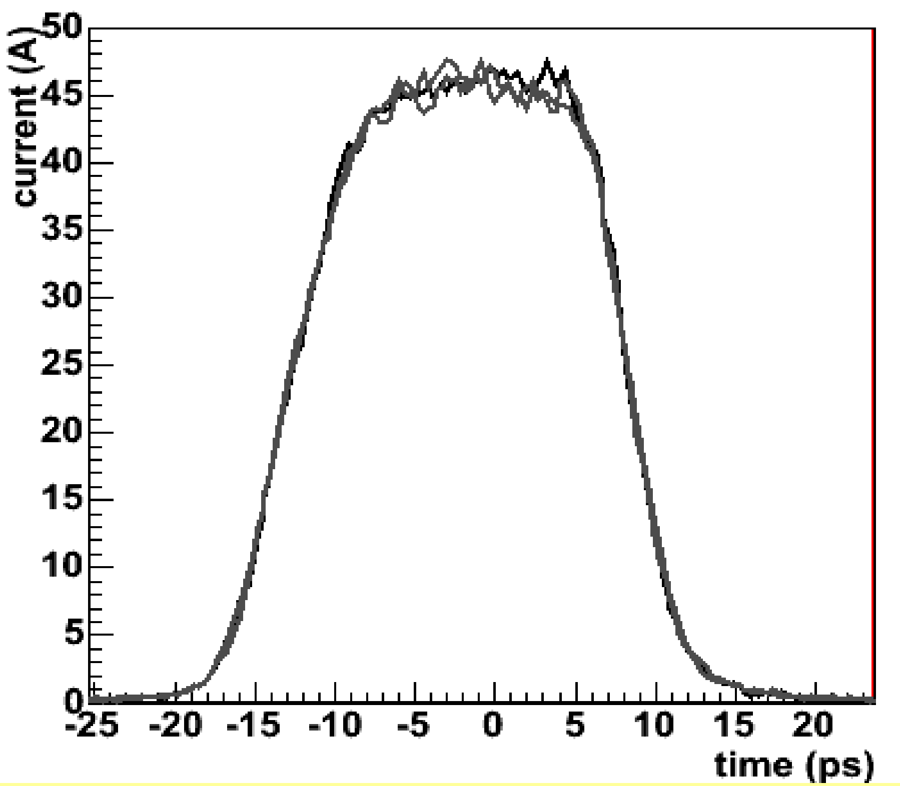




momentum measurement after the booster cavity

- Beam density distribution for:
- 1 nC
- transv. laser diameter = 1.5mm
- Flat-top laser
- opt. gun and booster phase





Summery and outlook

- The PITZ setup and its diagnostics was presented
- A method to measure the longitudinal phase space and its projection used at PITZ was presented
- Resolution of this method was analysed, the major limitation of the temporal resolution is the optical transmission, an replacement by reflective optics is ongoing
- Examples of longitudinal phase space, bunch length and momentum measurement at PITZ and simulations were presented

Thanks

for your attention