NNP
Non Neutral Plasma Physics Group

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Institut für Angewandte Physik Frankfurt am Main

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Gabor-Lenses

for

NA61/SHINE

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Goethe-University Frankfurt

NA61 / SHINE at Low Energy

December 2020

Motivation

- Accelerator Physics

  How can we preserve the brightness of hadron beams passing very long transfer lines?

  Can we combine smooth focussing and a phase space compression to anhance the luminosity for fixed target experiments?

- Non-neutral plasma physics

  Can we measure the collective interaction of relativistic hadron beams with pure electron plasmas?

  What can we learn to mitigate the electron cloud effect in synchrotrons like SPS or LHC?

- Advanced electron targets

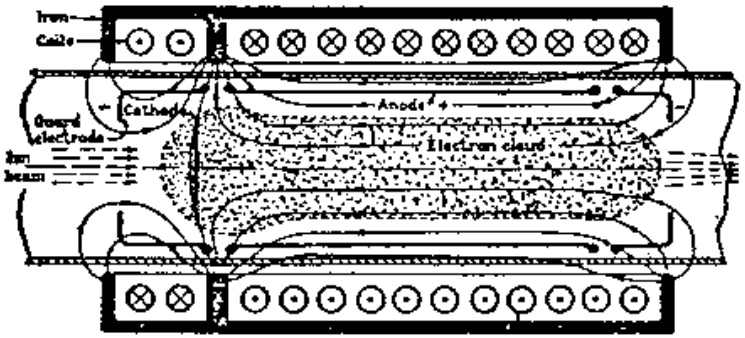
  Is there any deep inelastic reaction between hadrons and electrons measurable by the use of Gabor-Lenses?

Brief Description

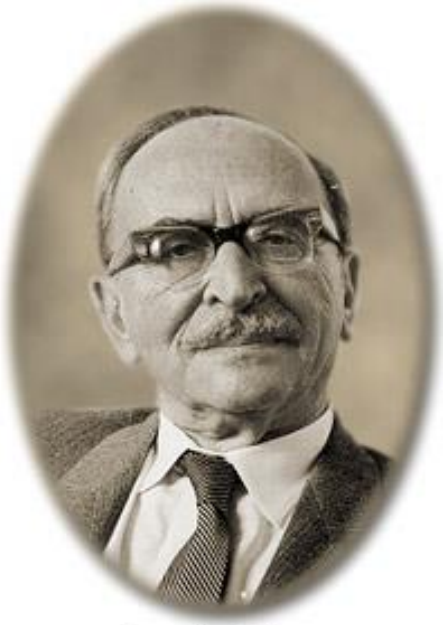
No. 4055 July 19, 1947 NATURE 89

A Space-Charge Lens for the Focusing of Ion Beams

SOME time ago I proposed a magnetron of special design as a divergent lens for electron beams[1]. It now appears that the same device may become useful as a very powerful concentrating lens for positive ions, particularly for ion beams of extreme energy.



MAGNETRON LENS FOR ION BEAMS

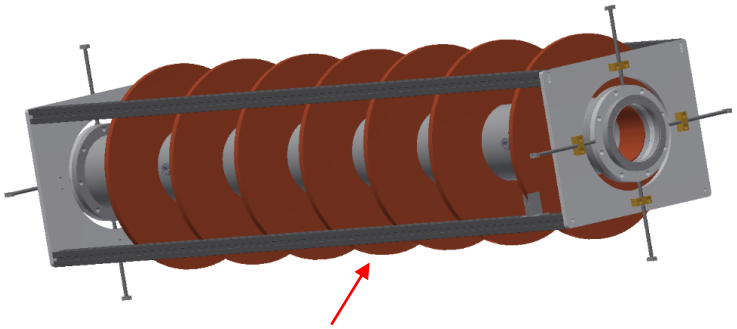


Dennis Gabor
(1900-1979)

Proposal of a Space-Charge Lens by Gabor, July 1947

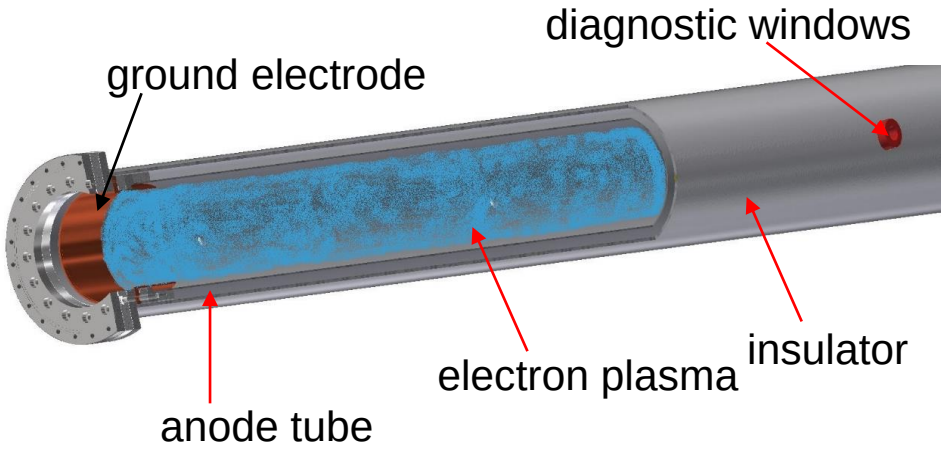
A Gabor-Lens is a trap for a pure electron plasma

Transvers confinement



coils for axial magnetic field

Longitudinal confinement



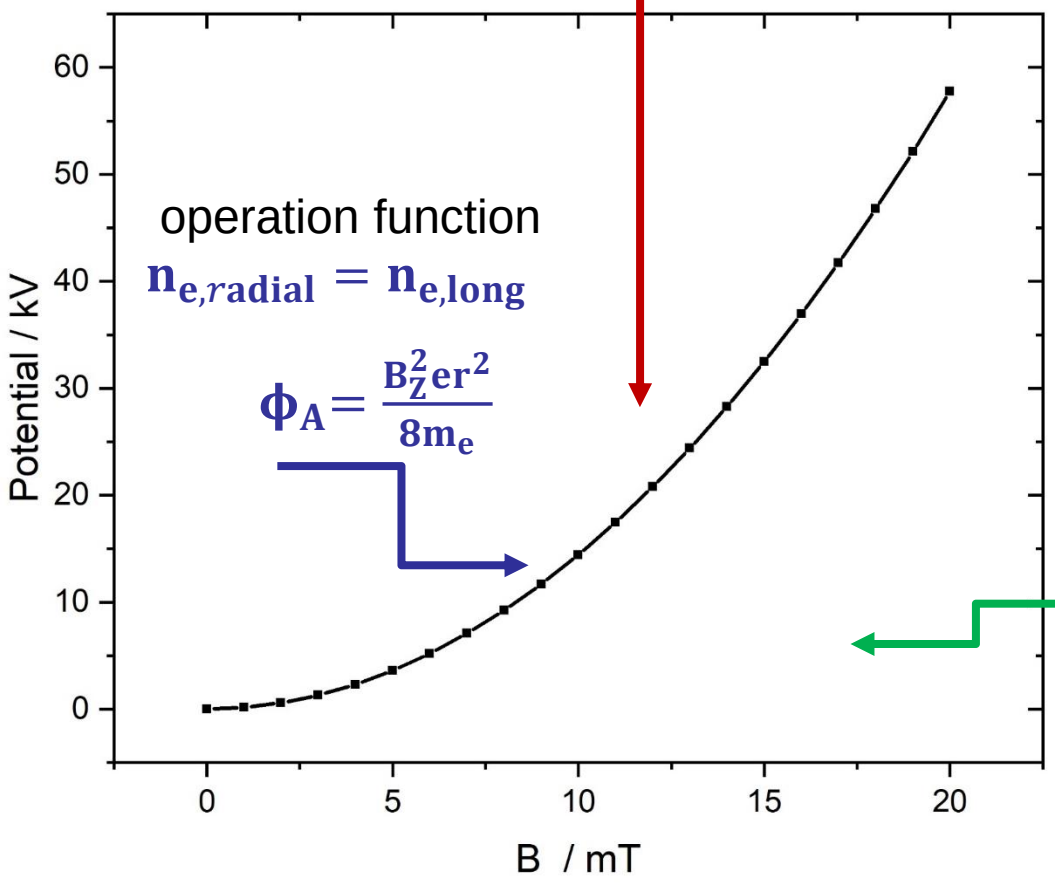
$$n_{e,r} = \frac{\varepsilon_0 B_z^2}{2m_e}$$

$$n_{e,l} = \frac{4\varepsilon_0 \phi_A}{er^2}$$

$$n_{e,radial} = n_{e,long}$$

$$\phi_A = \frac{B_Z^2 e r^2}{8m_e}$$

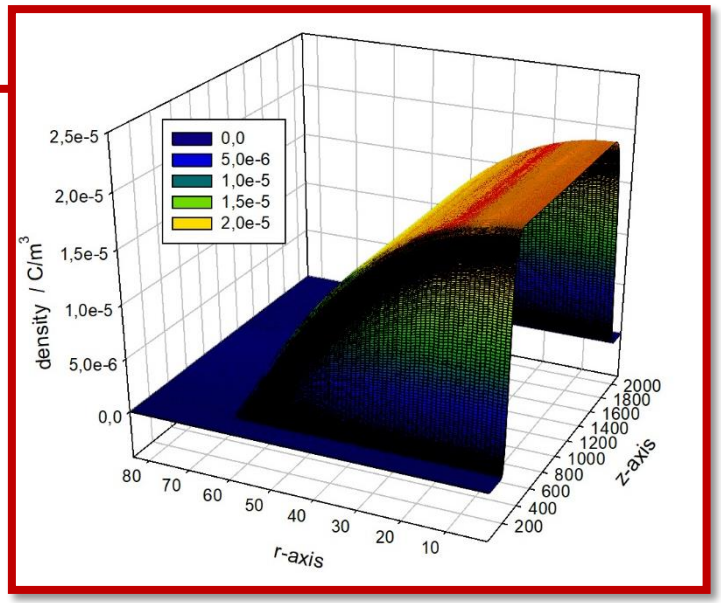
Electron Density

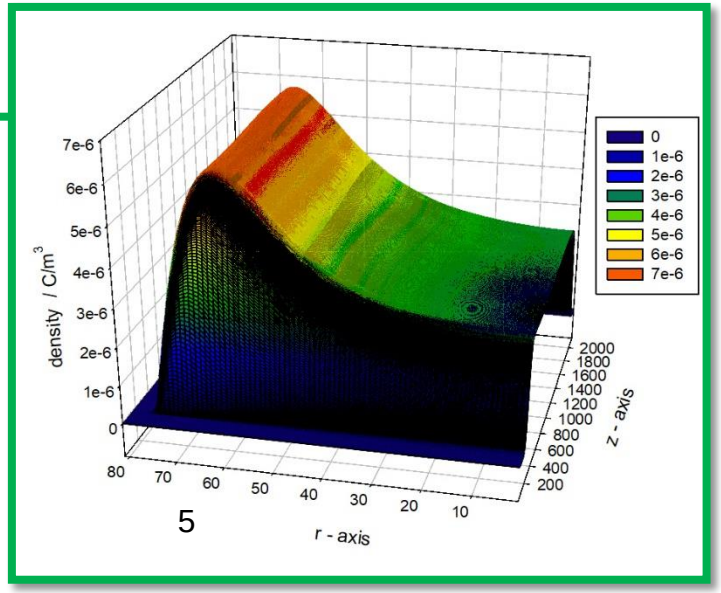


operation function

$$n_{e,radial} = n_{e,long}$$

$$\phi_A = \frac{B_Z^2 e r^2}{8 m_e}$$





Adjustment of density and/or density distribution

Collective Response

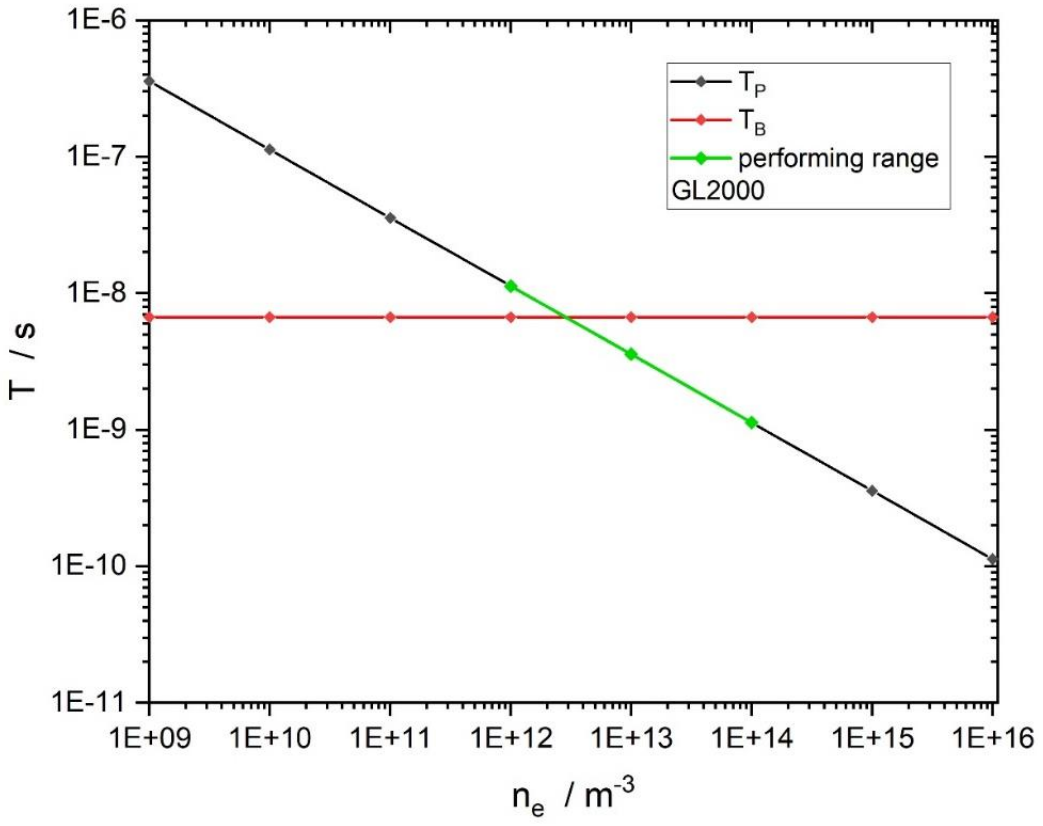
- Transit time T_B of a beam through a two meter long electron column with

$$v_{beam} \approx c$$

- Plasma frequency of the electrion plasma

$$\omega_{PE} = 2\pi f = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

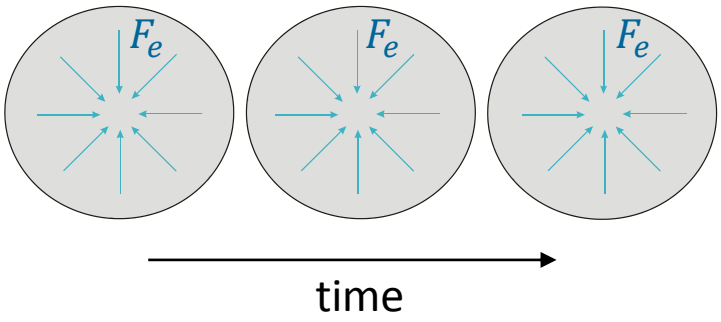
$$\Rightarrow \quad T_P = 1/\mathrm{f}$$

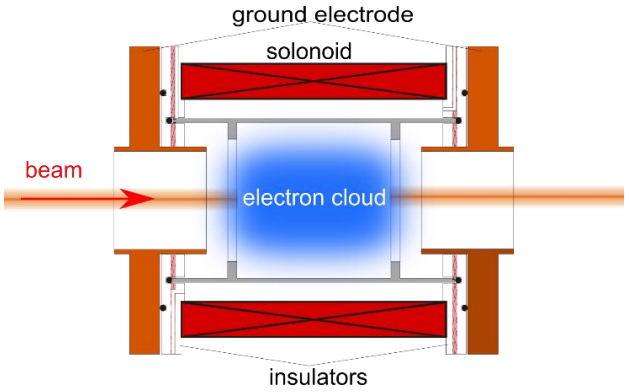


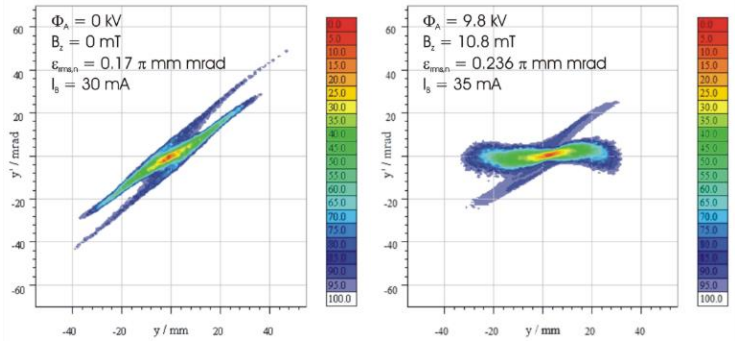
Advantage of Gabor-Lenses

- Space charge compensation
- Linear focussing preserve beam emittance (no abberations)
- Radial symmetric focussing

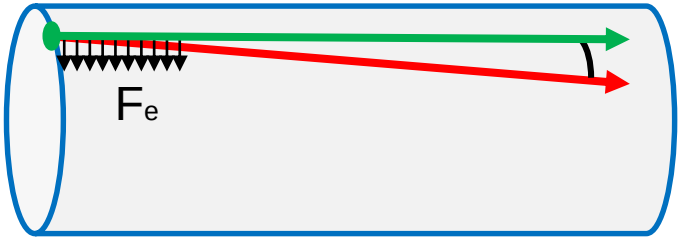
$$\frac{1}{f} = \frac{n_e e L}{2\varepsilon_0} \frac{q}{\gamma \beta^2 m_0 c^2}$$







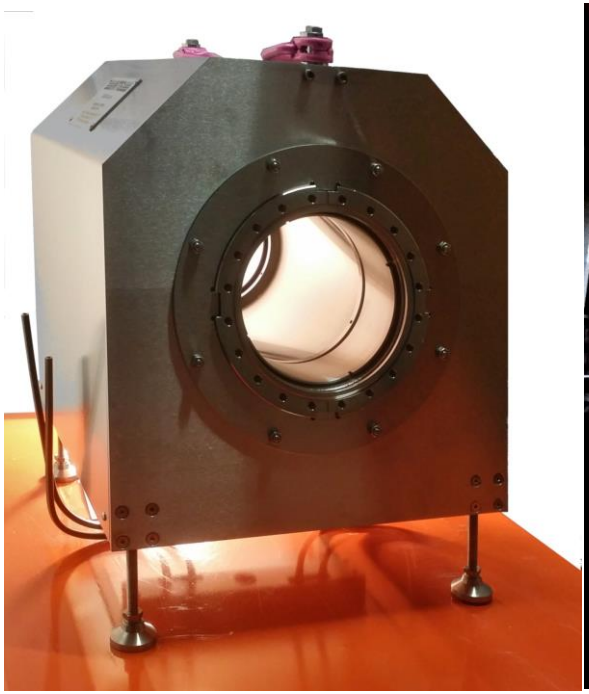
Kathrin Schulte

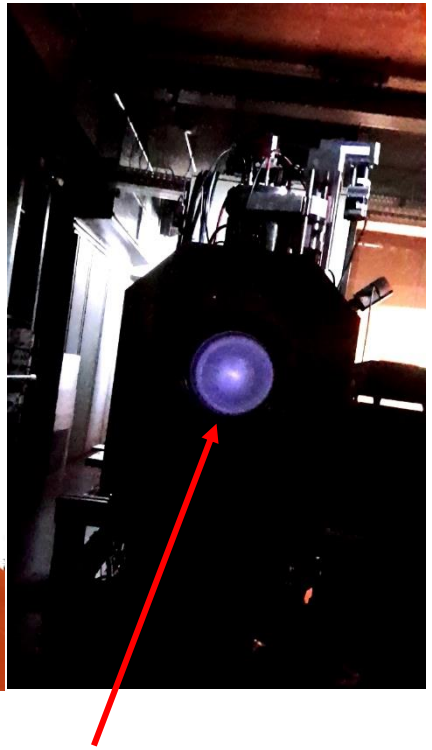


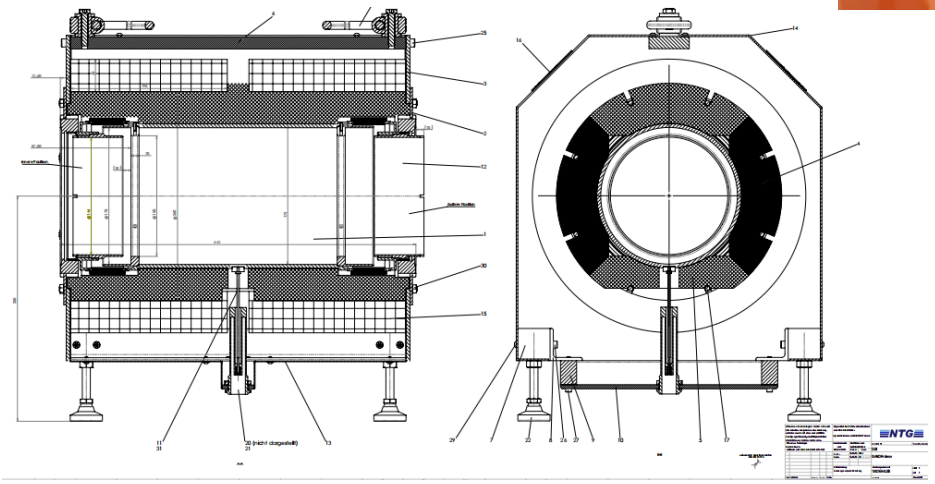
Example of a Gabor-Lenses

short L=0.4m GL prototyping

- reliable industry partners
- compact design
- estimation of costs
- production process optimization
- fast processing



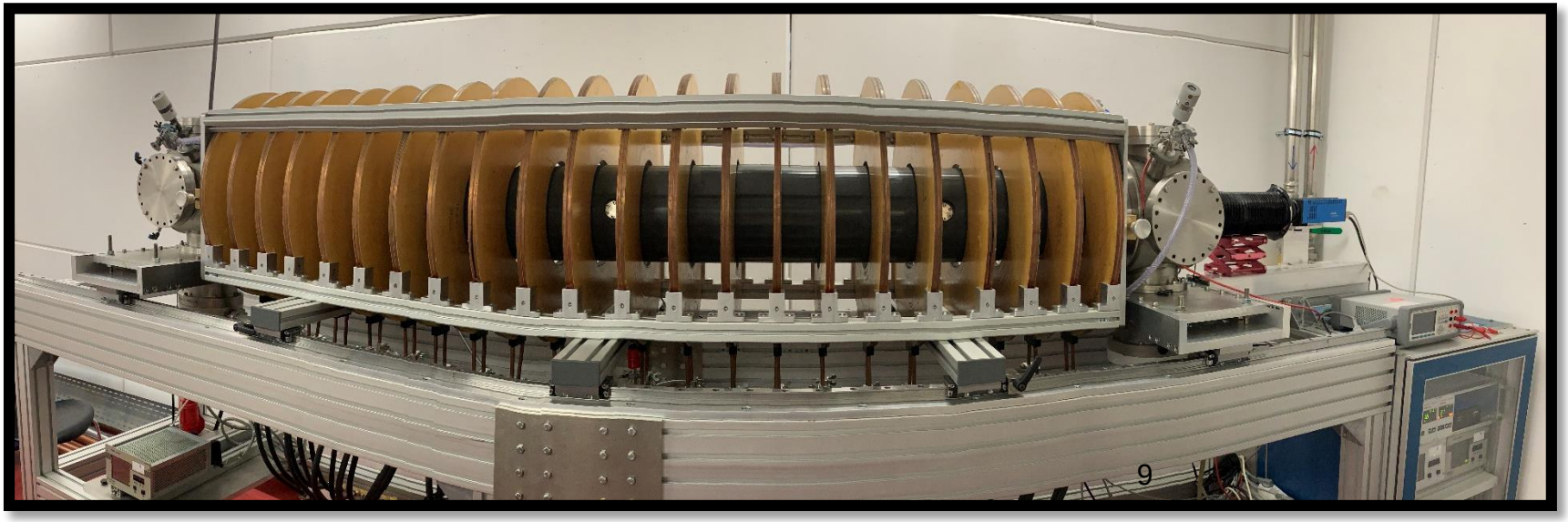




confined electron plasma
with $n_e = 2 \cdot 10^{15} m^{-3}$

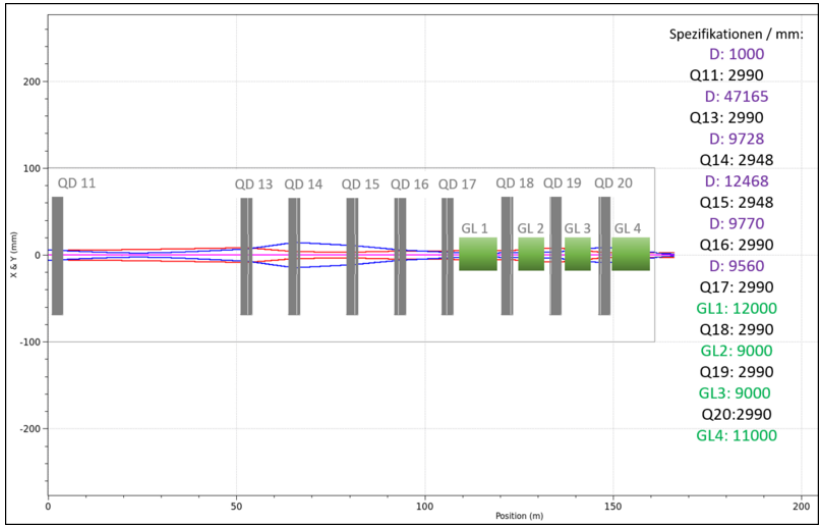
Gabor-Lenses

- r/l ratio of: 0.0375
- up to 30 kV potential
- 2 m long stainless steel anode and 75 mm radius copper electrodes for longitudinal confinement
- 22 coils in pancake configuration for radial confinement



Gabor-Lenses at NA61/Shine

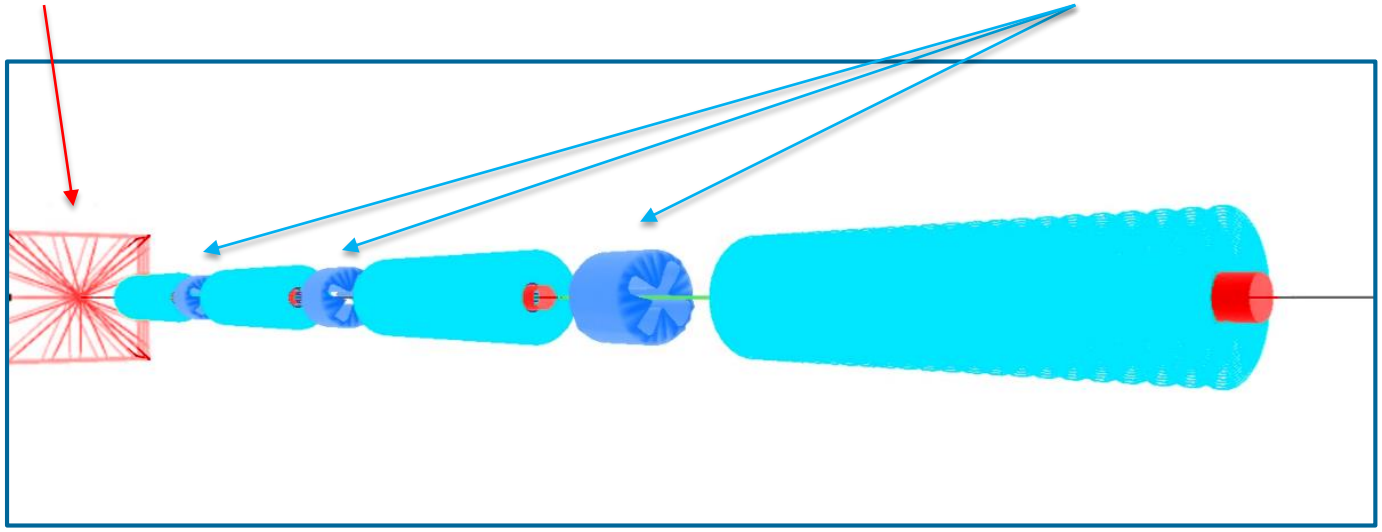
- A possible way of introducing an 8m chain of four 2m long GLs
- Integration into existing beam optics (Beach-Files)
- If GLs are switched off, they act like drift sections.



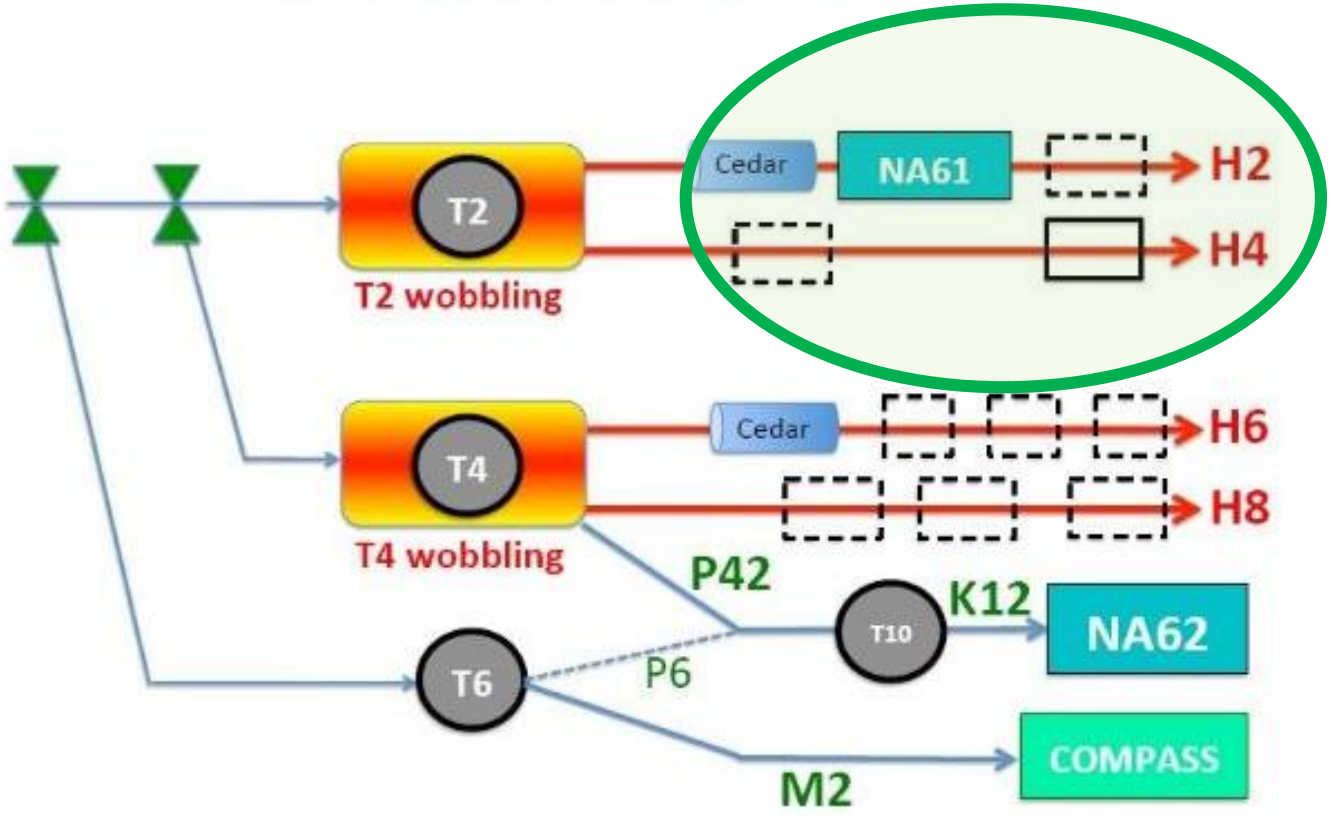
Target

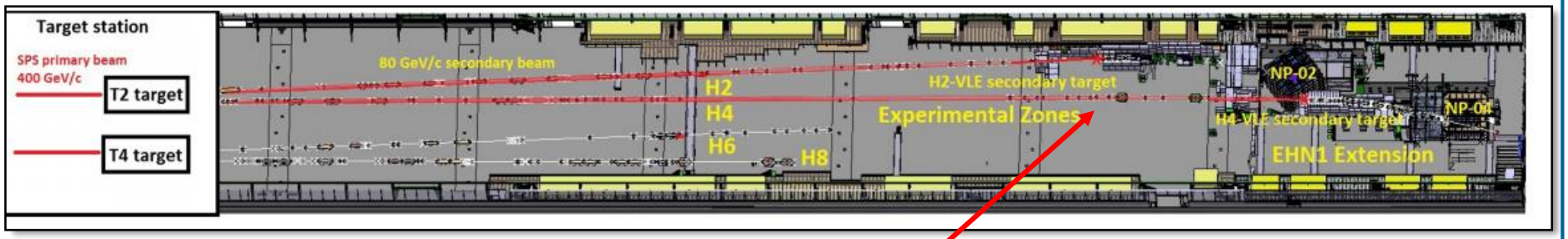
Gabor-Lenses

Existing Beam Optic



Proposal for H4-Beamline as a test bench for implementation of Gabor Lenses in NA61/SHINE





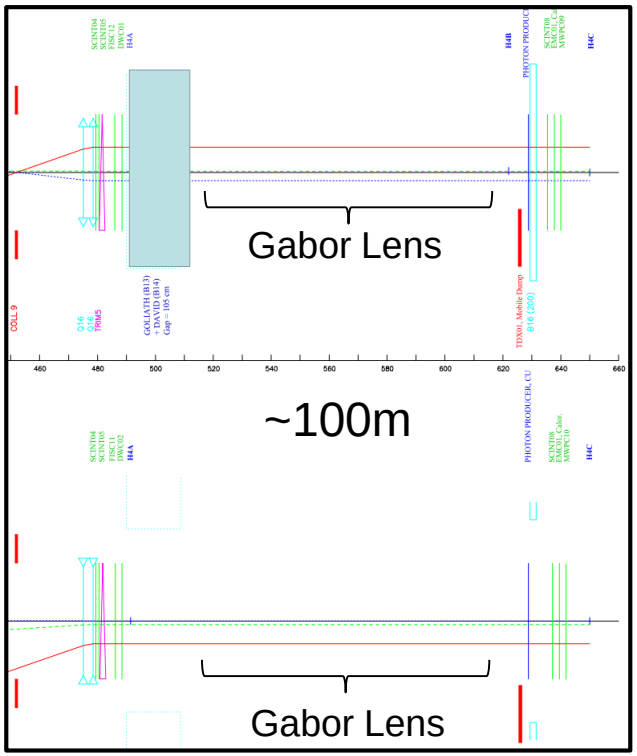
A. C. BOOTH et al., PHYS. REV. ACCEL. BEAMS 22, 061003 (2019)

possible placement of 4x2m H4-GL

- H4-GL is fully beam transparent when switched off
- no influence on existing elements

- desired species 20GeV/c protons with focal length of f=276m

→equivalent to 7.874 AGeV/c $^{208}Pb^{82+}$



H4-Beamline

Study of Beam Dynamics

Trace Win

- beam dynamic to evaluate the implementation of GL in existing beamlines

AcceleratorConstructionSet2

- AI (genetic) – optimal GL position, best settings for integration between existing beam optics

GabLensM3

- (Monte Carlo) to evaluate the interaction of relativistic proton beams and confined electron column

Gabor-Lens Focal Length

Proposal of 4 x 2m Gabor Lenses as pilot experiment

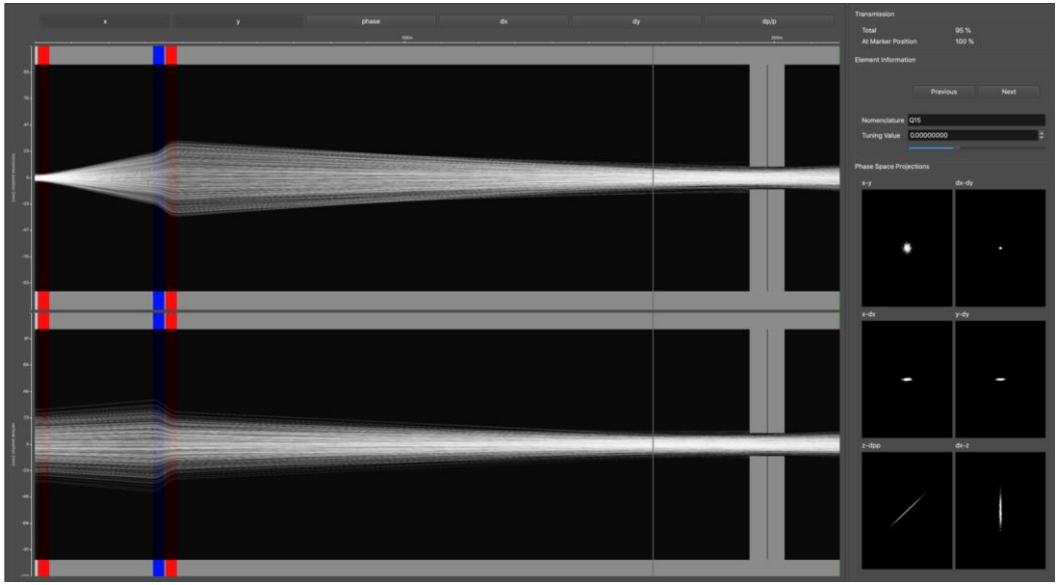
$$\frac{1}{f} = \frac{n_e e L}{2\varepsilon_0} \frac{q}{\gamma \beta^2 m_0 c^2}$$

Momentum	Energy	β	γ	focal length
5 GeV c^{-1}	4.149 GeV	0.982845	5.42196	68 m
10 GeV c^{-1}	9.106 GeV	0.995627	10.7047	138 m
20 GeV c^{-1}	19.08 GeV	0.998901	21.3392	276 m
80 GeV c^{-1}	79.07 GeV	0.999931	85.2690	1105 m
140 GeV c^{-1}	139.1 GeV	0.999978	149.214	1934 m

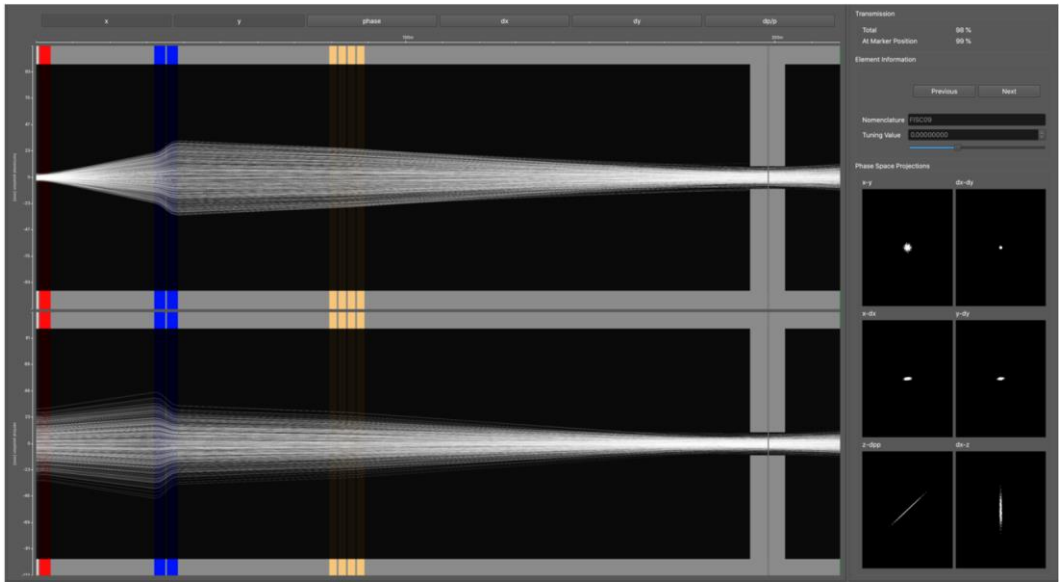
Stephan Reimann 09.2020

Initial proposal: 200m GLs → longer GL → shorter f
increased transit time to improve beam quality
very low energies are possible

Without GLs



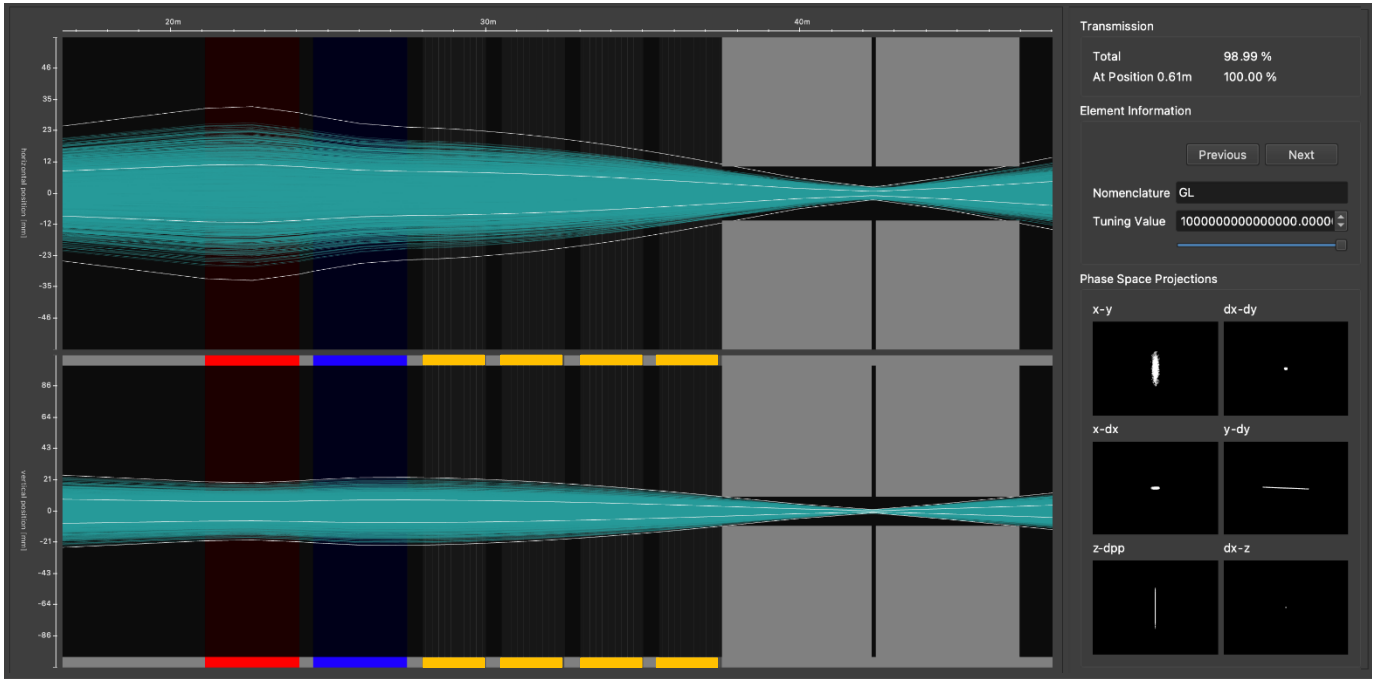
With 4 GLs



started simulations with ACSet2

… and for VLE

Simulations with 1GeV/c p-beam started and the very first sets looking promising.



existing Quadrupole

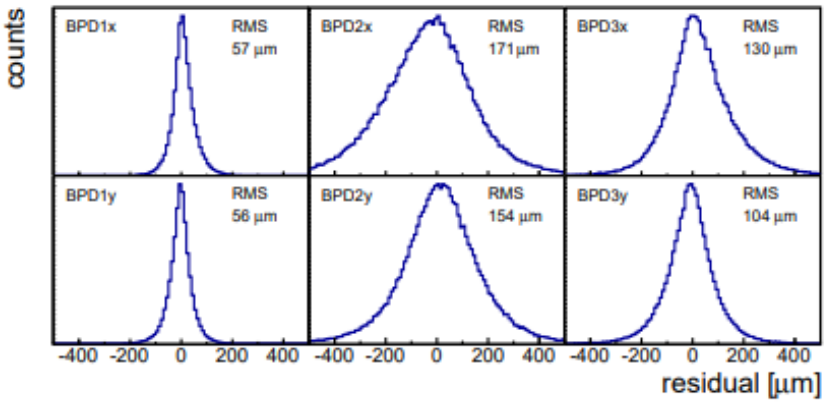
4 Gabor-Lenses

Aperture / Collimator

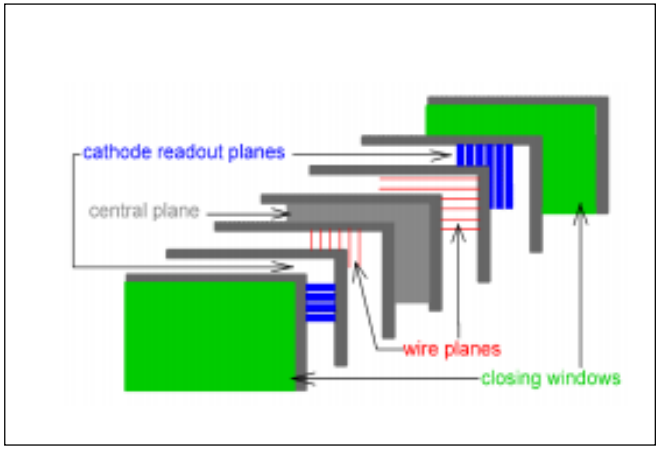
Beam Instrumentation

We don‘t have any beam instrumentation.

Beam Position Detectors are suitable for the evaluation of beam focussing.



NA61/SHINE facility at the CERN SPS: beams and detector system



taken from:
arXiv:1401.4699v1 [physics.ins-det] 19 Jan 2014

Thank you for your attention!

on behalf of the Frankfurt NNP-physics group