Simulation of electron transport within electron cooler and hollow e. lenses using Warp – Status report

Technical Student: Ondrej Sedlacek
Supervisor: Adriana Rossi

Outline

Introduction

- My project & goal
- Warp and its features

Current state of work

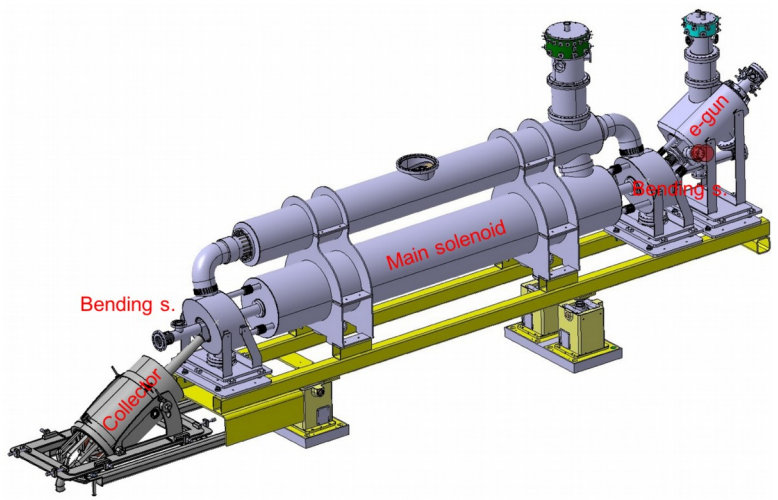
Next steps

Summary

Project

Simulation of an electron beam transport with Warp

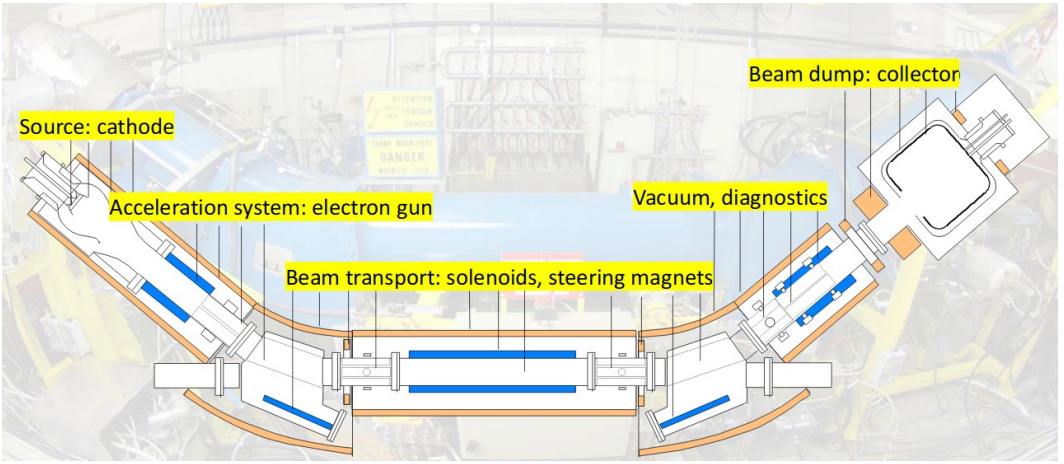
Hollow electron lenses



I	5A	R	1.6/0.8cm	Ekin	10keV
Gun	0.2T	Bend	3.-3.5T	Main	4T

D.Perini, C.Zanoni, CERN-ACC-NOTE-2017-0004

Electron cooler

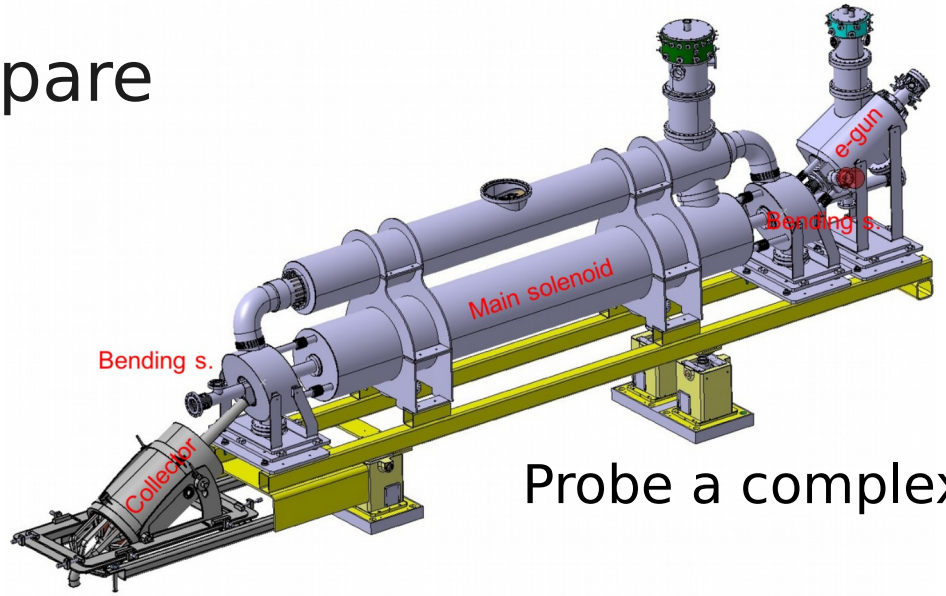


Current:						
	I	2.5A	R	5cm	Ekin	26.5keV
	Gun	0.058T	Main	0.058T		
Proposed						
	I	3.5A	R	1.25cm	Ekin	68.1keV
	Gun	0.24T	Main	0.06T		

L. Joergensen, G.Tranquille, Design Par. Of the new AD E. Cooler, CERN-AD Electron Cooler Consolidation Review

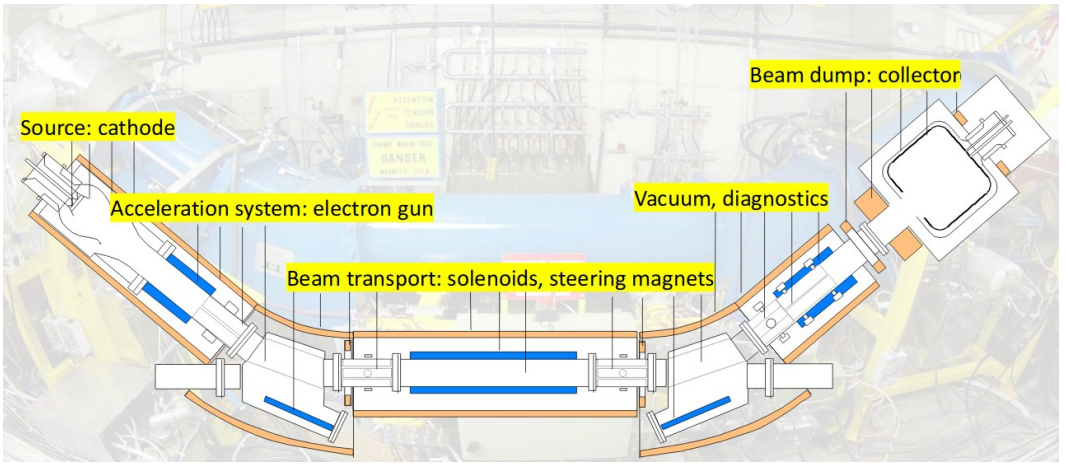
Goal of the project

Simulate and compare



D.Perini, et. al.,
CERN-IPAC2019
doi:10.18429/JACoW-IPAC2019-MOPTS099

Probe a complex part

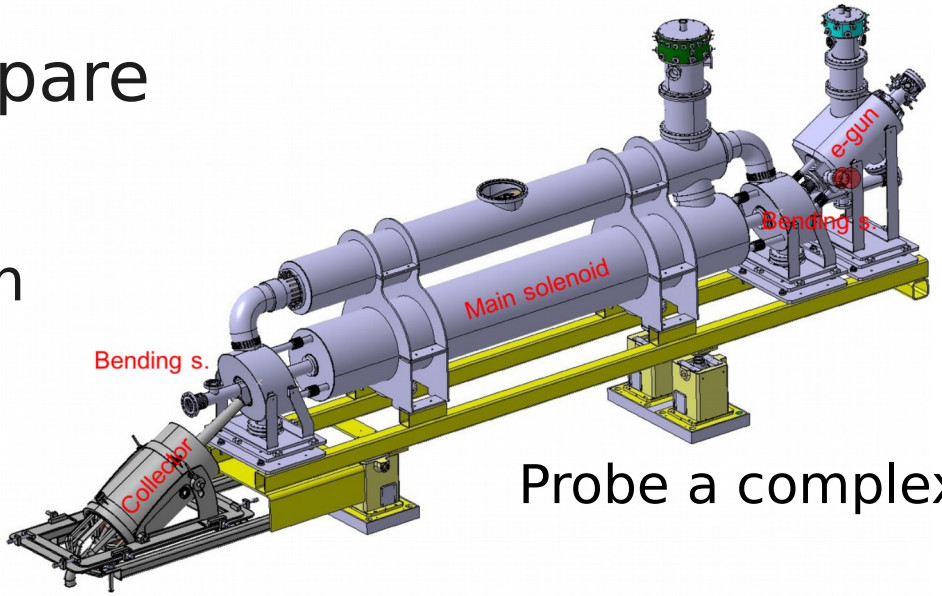


G.Tranquille et al., AD e. cooler, CERN –
AD Electron Cooler Consolidation Review

Goal of the project

Simulate and compare

- Solenoid transport
- Bending of the beam
- Electron gun



D.Perini, et. al.,
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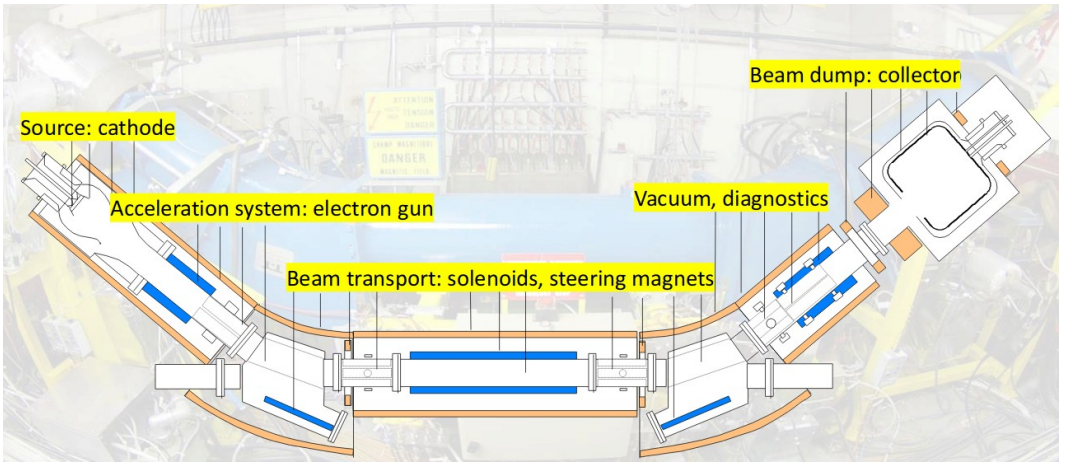

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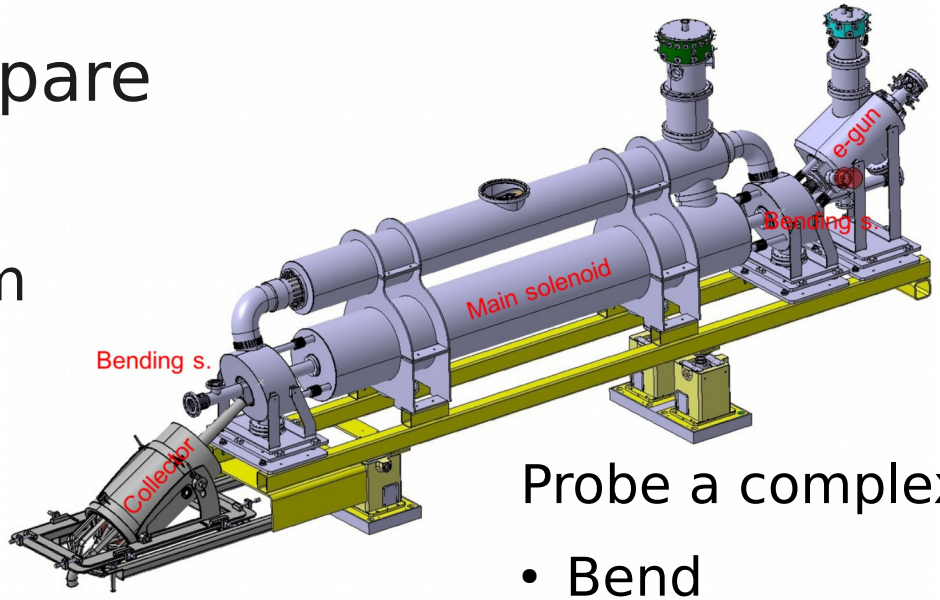
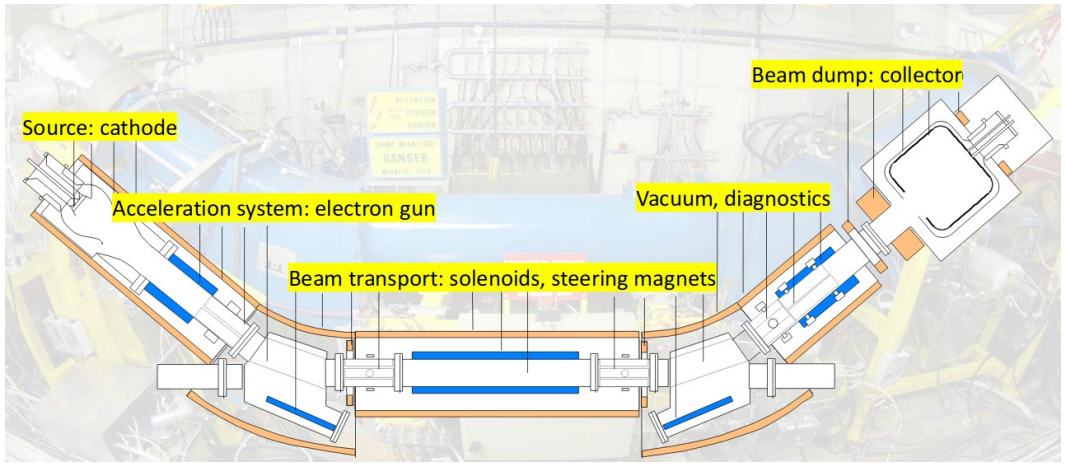


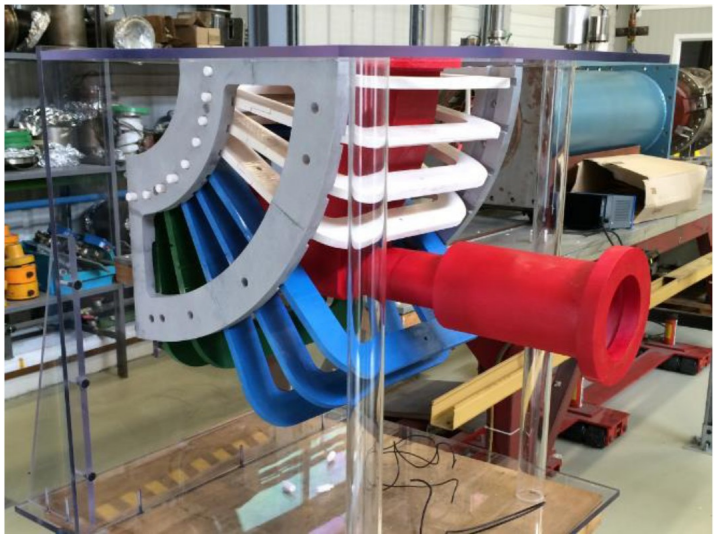
D.Perini, et. al., CERN-IPAC2019 doi:10.18429/JACoW-IPAC2019-MOPTS099

Probe a complex part

- Bend



G.Tranquille et al., AD e. cooler, CERN – AD Electron Cooler Consolidation Review



G.Tranquille et al., ELENA, CERN, IPAC2016

Examples of currently used simulations

Electron gun:			
	Electron Cooler	Comsol	Gerard A. Tranquille,... (CERN)
	Electron Cooler	Trak	Alexander Pikin (BNL/CERN)
	Hollow E. Lenses	Warp	Guillio Stancari (FNAL)
	Hollow E. Lenses	ULTRASAM	Danila Nikiforov et al.(BINP)
	Hollow E. Lenses	CST	D. Nikiforov & S. Sadovich (BINP & CERN)
	...		
Bend:			
	IOTA	BENDER	Daniel Noll (JWGU)
	Hollow E. Lenses	CST	Danila Nikiforov et al.(BINP)
	HEL & E. Cooler	Warp	Ondrej Sedlacek (CERN)
	...		
(future)	Hollow E. Lenses	SMILEI	Sergey Sadovich (CERN)
	...		

Warp

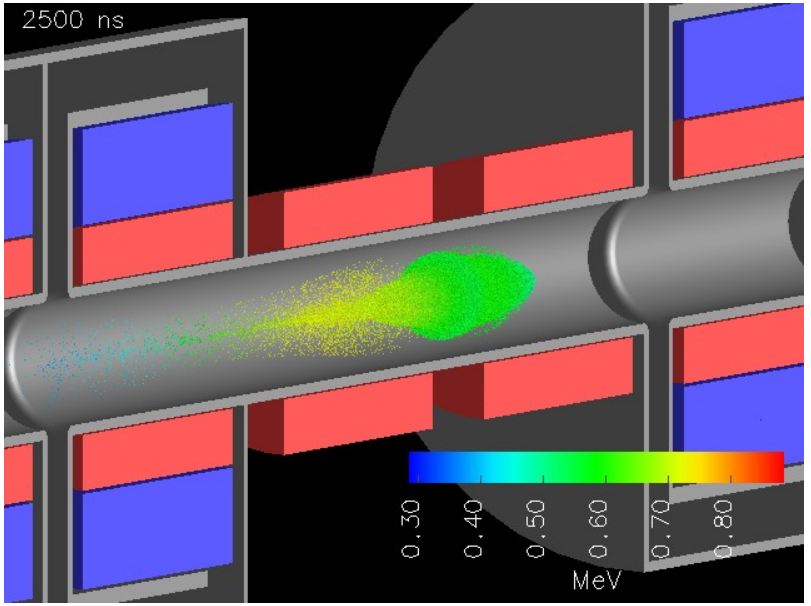
Designed for

- Plasma & high current density particle beams
- Space-charge effects in bent accelerator lattices

Main properties

- Particle-in-cell (PIC)
- Open-source
- Python code (Fortran partly inside)
  - Possible MAD-style lattice input
- Intensely developed & used
- Supports parallel computation

Beam simulation tool



D. P. Grote et al, IEEE 2014, DOI: 10.1109/TPS.2014.2308546

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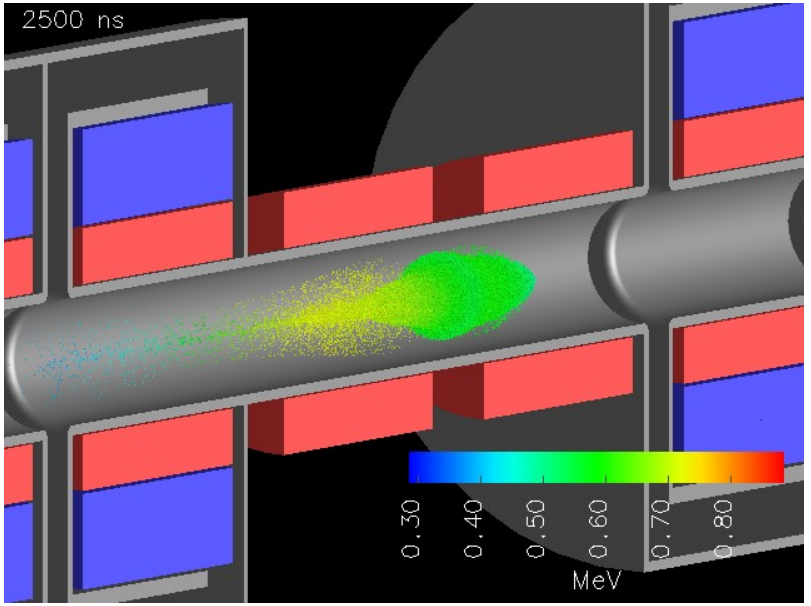
Why Warp?

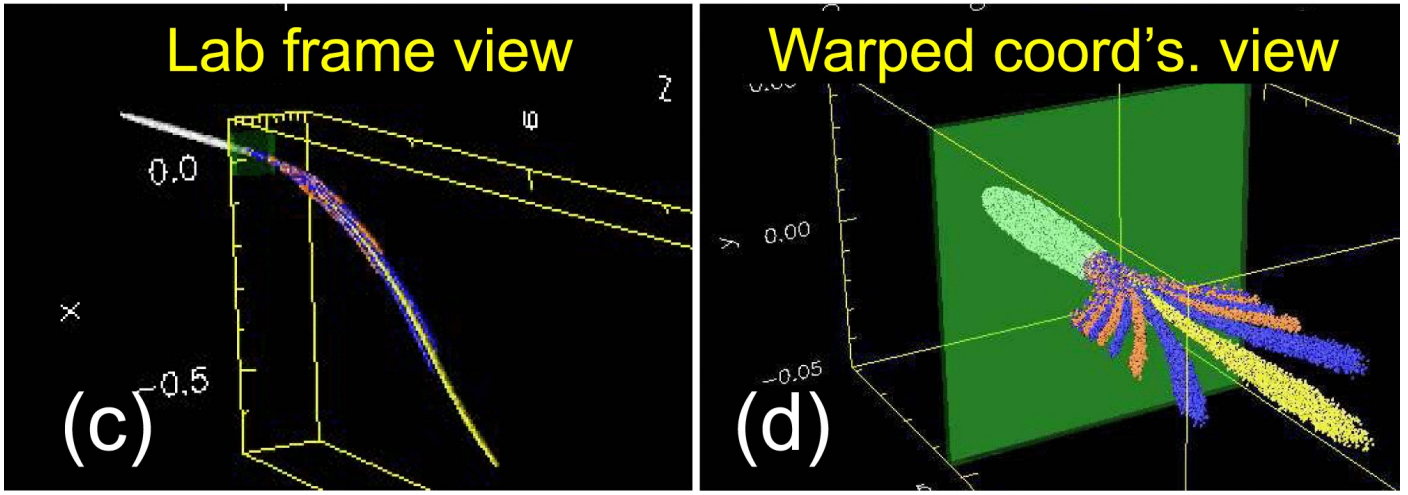
Beam simulation tool



D. P. Grote et al, IEEE 2014, DOI: 10.1109/TPS.2014.2308546

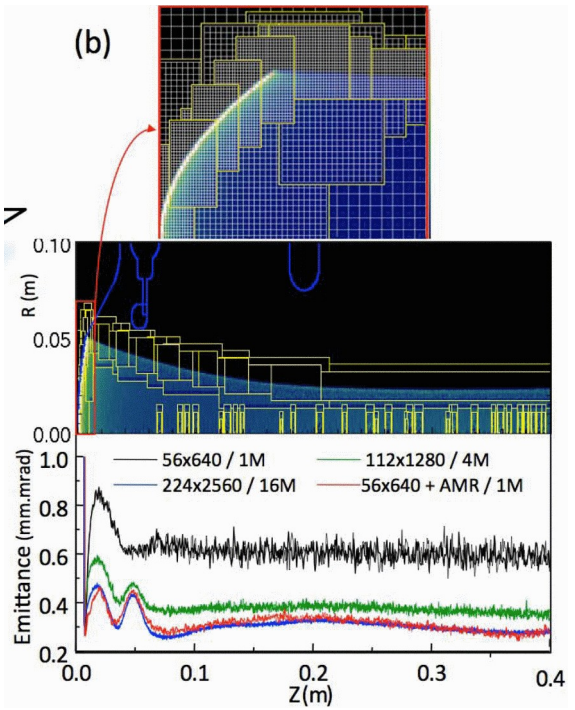
Warp features./[-]

Cartesian and Warped-Cartesian coordinates



Cylindrical coordinates – longitudinal coordinate replaced by angle

Adaptive mesh refinement



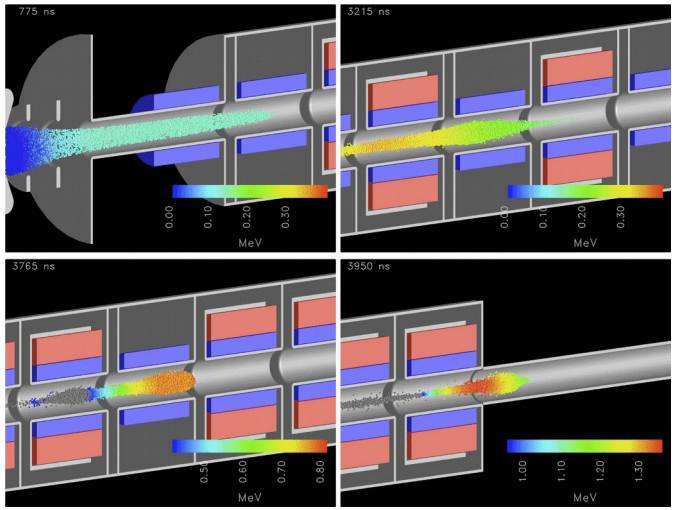
Subgrid (Submesh) conductor edge resolution

- Important for the boundary position dependent field

D. P. Grote et al, IEEE 2014, DOI: 10.1109/TPS.2014.2308546

Warp - example of use cases

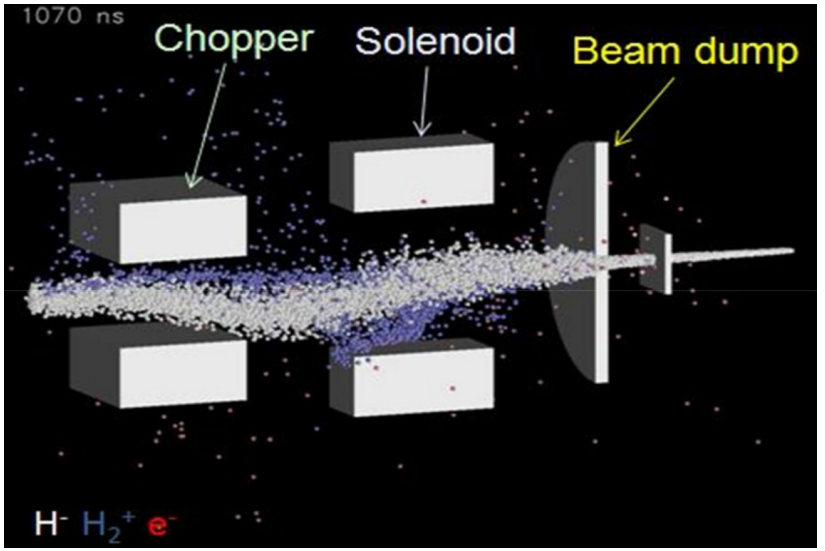
Evolution of space-charge dominated beam



D. P. Grote et al, IEEE 2014, DOI: 10.1109/TPS.2014.2308546

NDCX-II - LBNL

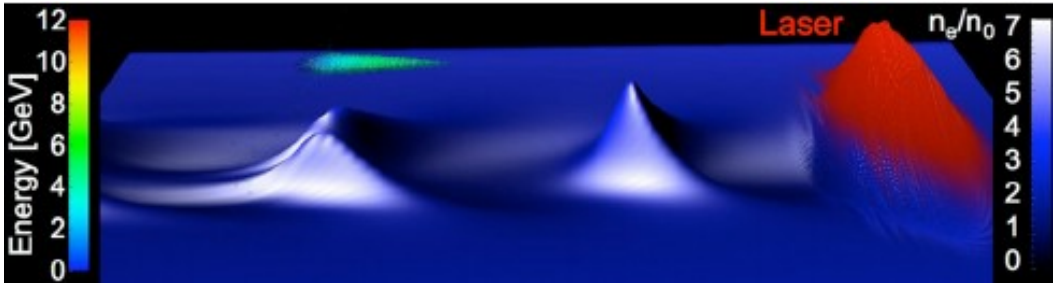
Multi-charge state beams



Project-X - Fermilab

D. P. Grote et al, HB2012, THO3B04

Plasma acceleration



D. P. Grote et al, Phys. Plasmas 2011, DOI: 10.1063/1.3663841

BELLA - Berkley

Current state of work

Timeline

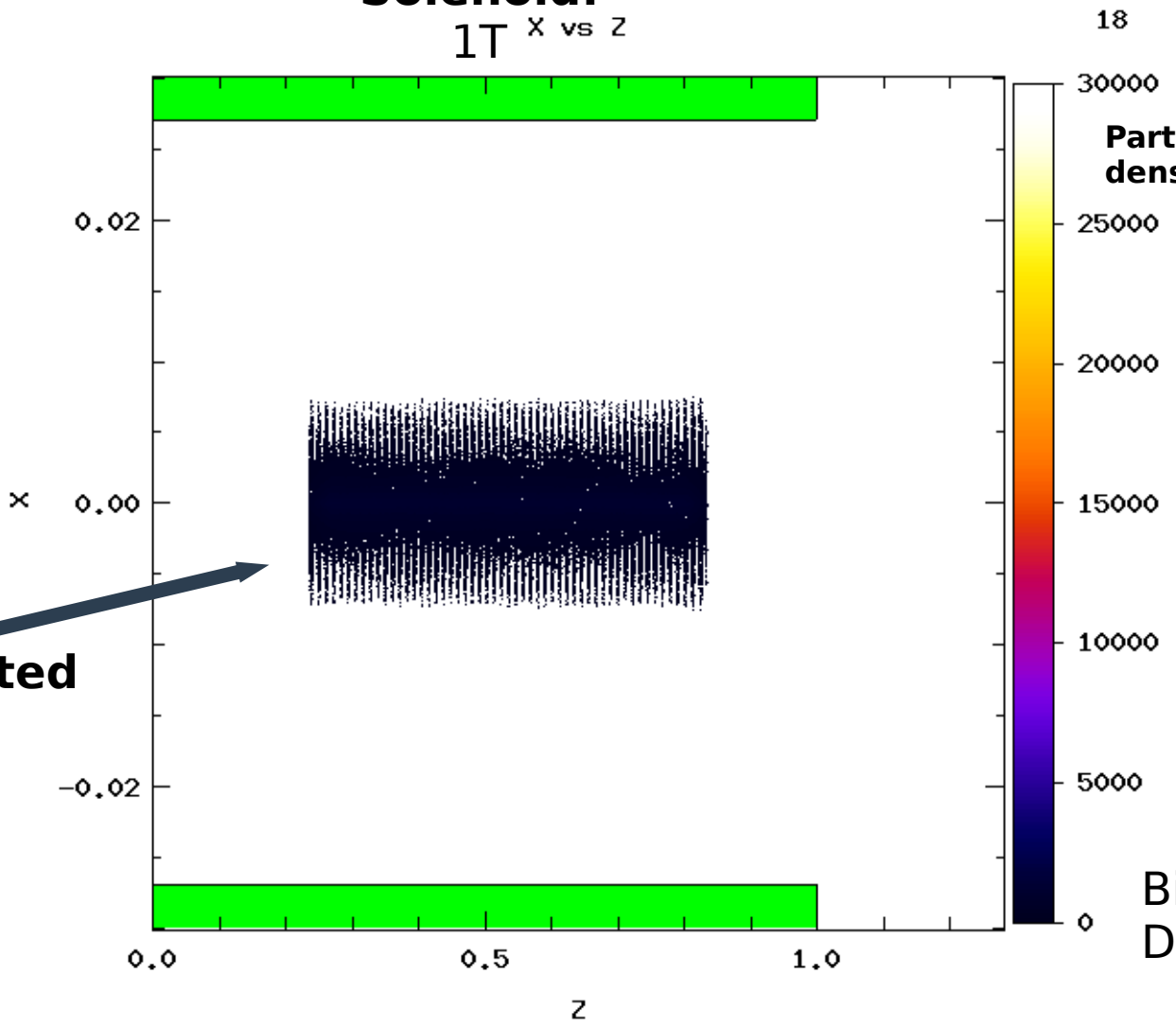
Solenoid transport	Electron gun	**Bending**

Timeline

Transport in single solenoid

Transport in single solenoid

Solenoid:
1T



Beam created in space

Initial parameters:

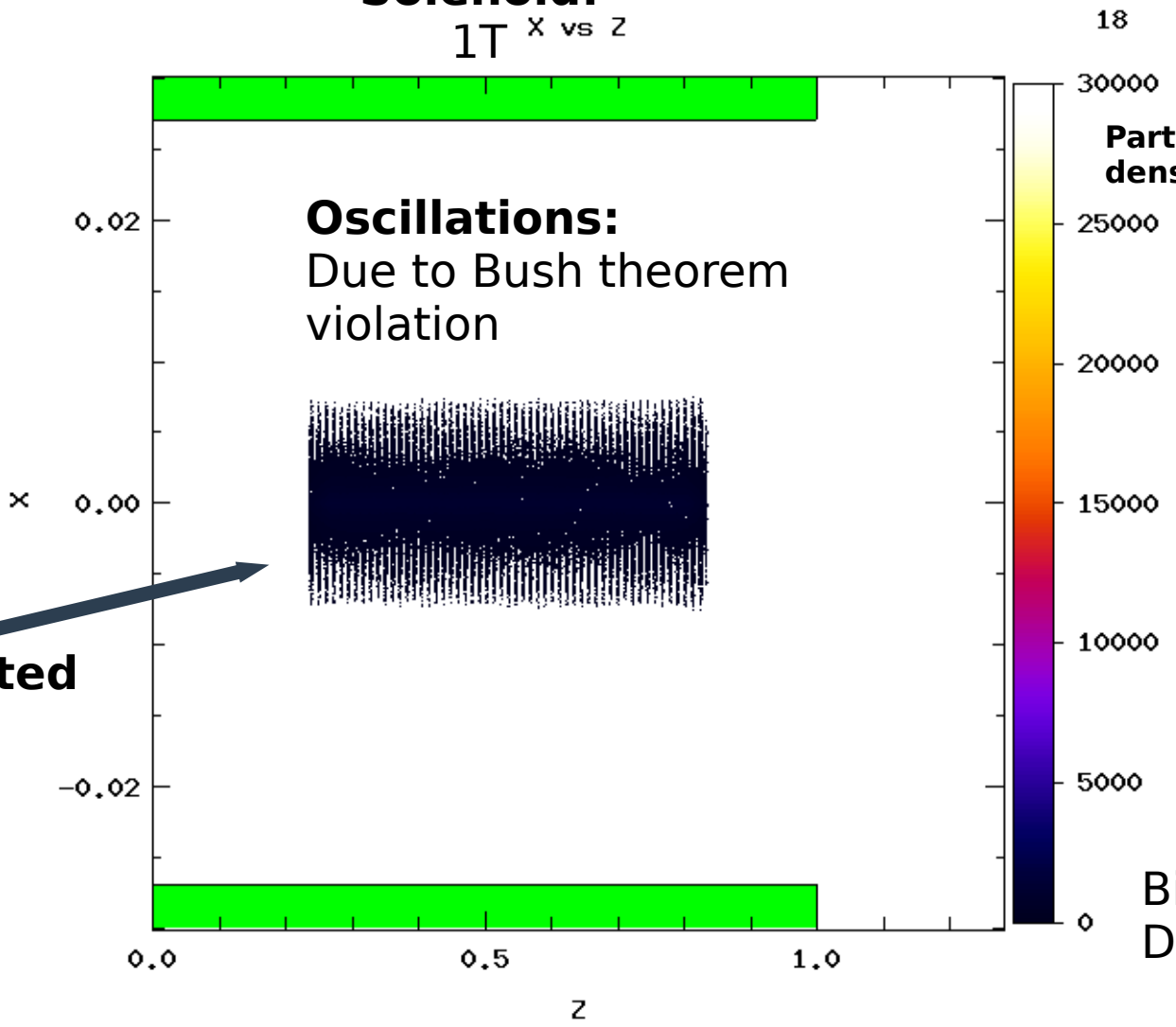
Beam:

I	1 A
R	1 cm
Ekin	10keV

Big help from:
Danila Nikiforov

Transport in single solenoid

Solenoid:
1T



Oscillations:
Due to Bush theorem violation

Beam created in space

Initial parameters:

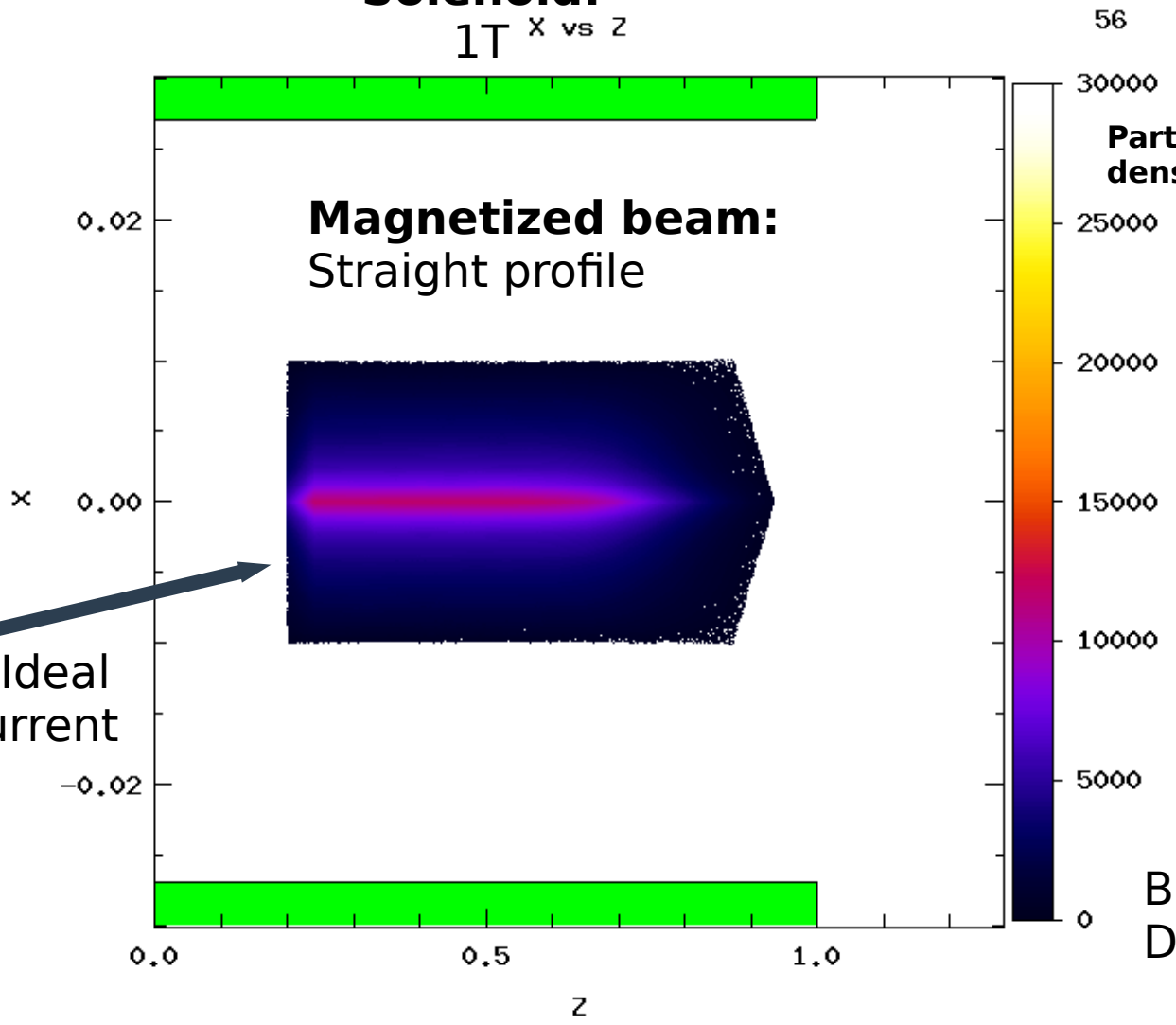
Beam:

I	1 A
R	1 cm
Ekin	10keV

Big help from:
Danila Nikiforov

Transport in single solenoid

Solenoid:
1T



Magnetized beam:
Straight profile

Injection: Ideal constant current

Initial parameters:

Beam:

I	1 A
R	1 cm
Ekin	10keV

Big help from:
Danila Nikiforov

Timeline

Add a pipe

Transport in single solenoid

Timeline

Add a pipe

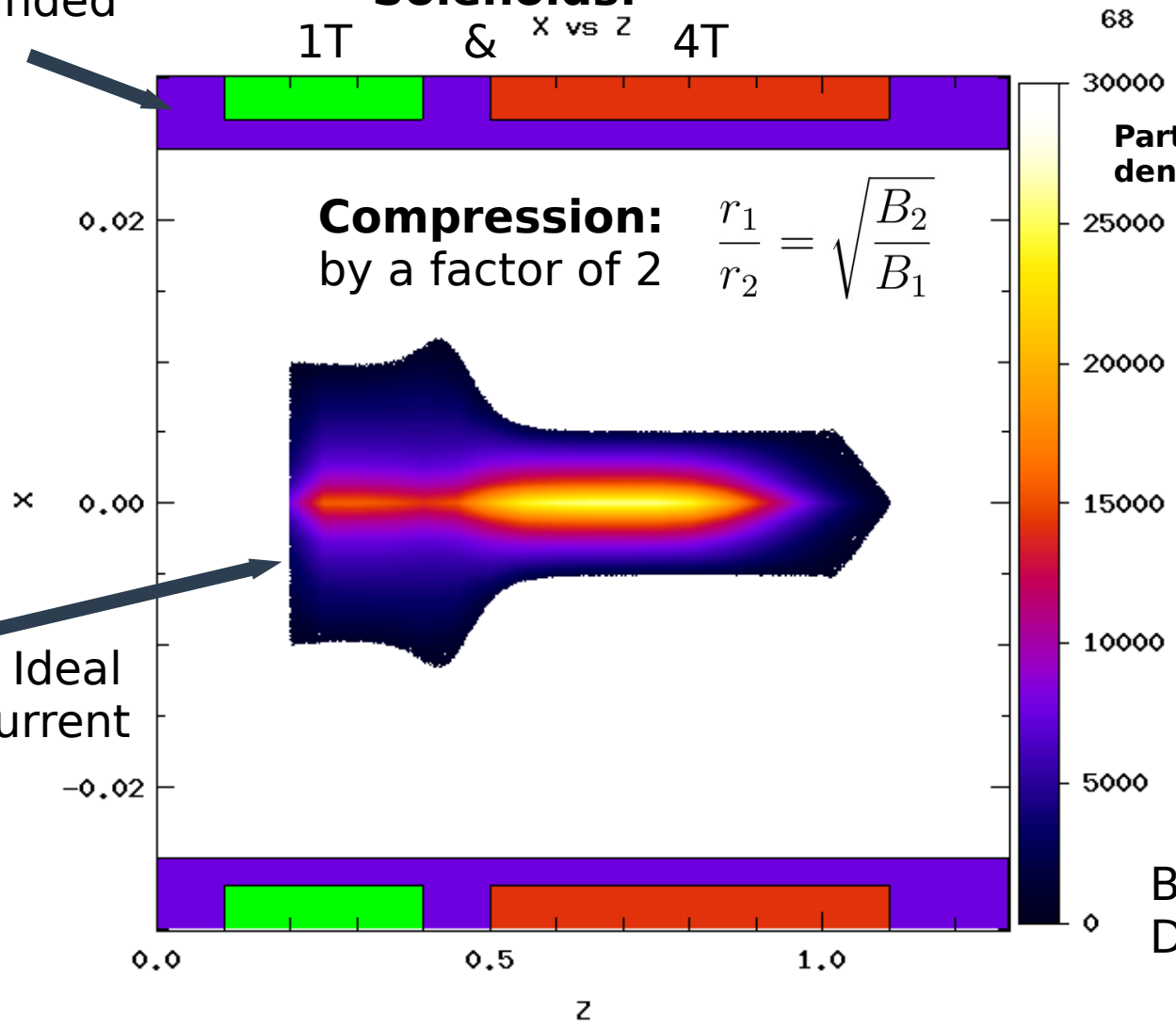
Transport in single solenoid

Add second solenoid

Current state of work

Pipe: grounded conductor

Solenoids: 1T & 4T



Compression: by a factor of 2 $\frac{r_1}{r_2} = \sqrt{\frac{B_2}{B_1}}$

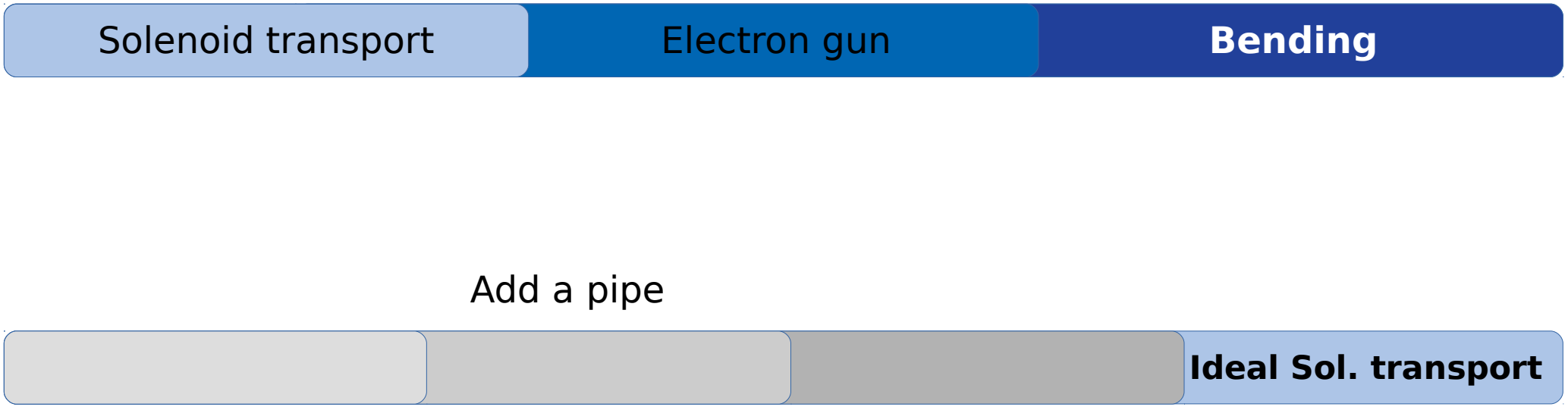
Injection: Ideal constant current

Initial parameters:

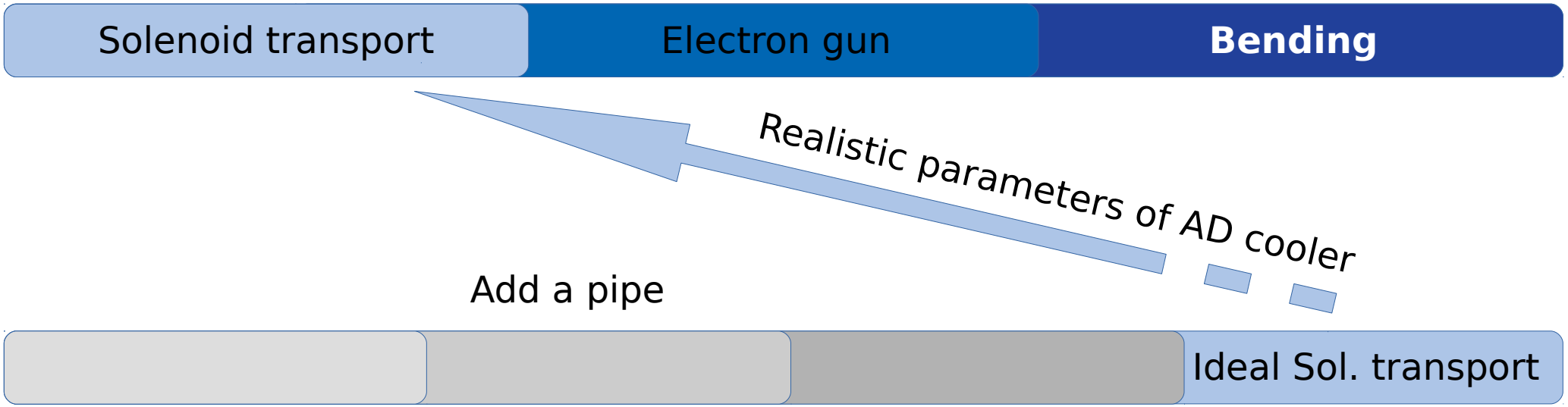
Beam:		
	I	1 A
	R	1 cm
	Ekin	10keV
Pipe:		
	R	2.5 cm
	Length	1.28m

Big help from:
Danila Nikiforov

Timeline


Solenoid transport
Electron gun
Bending
Add a pipe
Ideal Sol. transport
Transport in single solenoid
Add second solenoid

Next steps


Solenoid transport
Electron gun
Bending
Realistic parameters of AD cooler
Add a pipe
Ideal Sol. transport
Transport in single solenoid
Add second solenoid

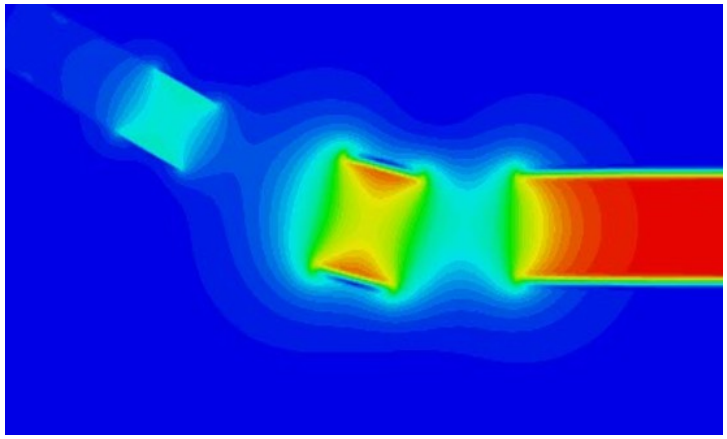
Summary

- **Simulate** the Electron Cooler and Hollow electron lenses with Warp
  - **Compare** the results with other simulations and measurements if possible
- **Probe and focus** on the bending

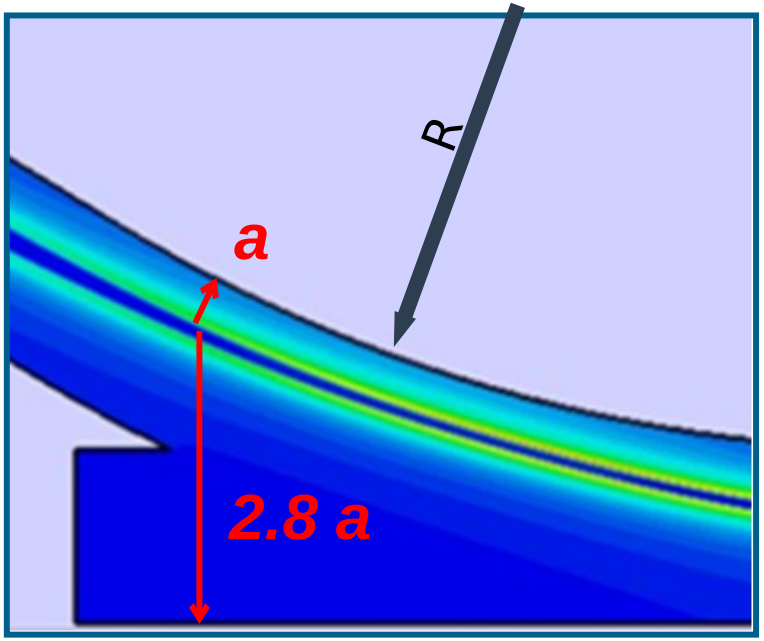
- Constructed simulation of **Double solenoid transport** with ideal parameters
  - **Inject** arbitrary distribution
  - Constructed a grounded pipe – **Conductor**
  - **Added Solenoids**
  - **Tested** the simulation against compression formula

- Next Steps will include: Include **real parameters** of AD cooler, construct an **Electron gun,** construct & prob the **Bending**.
  - After finishing the AD cooler move Hollow electron lenses

Nonuniform forces in the bend



Asymmetric forces due to the B field gradient



Centrifugal forces

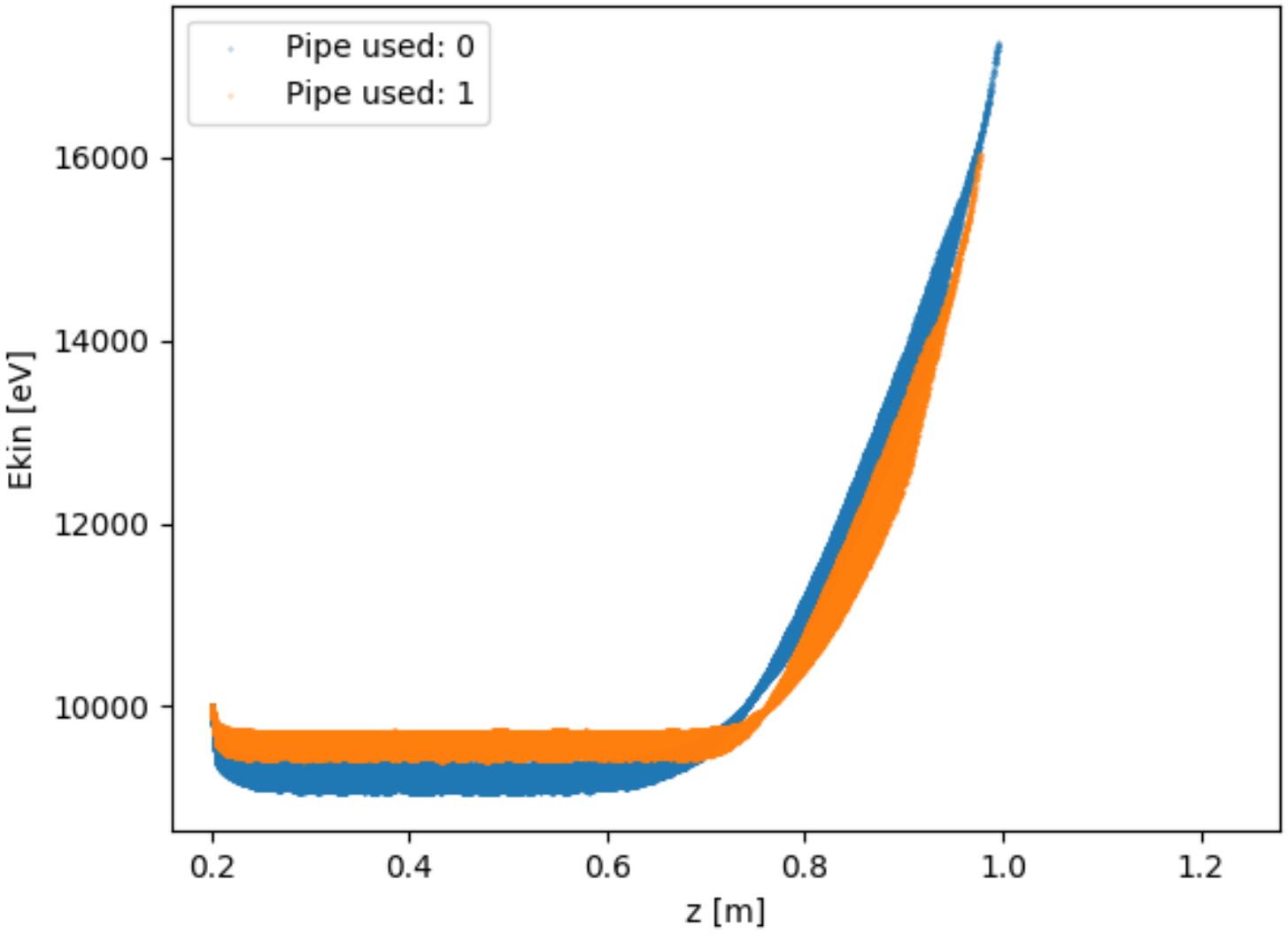
Asymmetric electric field due to the decentering of the beam inside the grounded vacuum chamber

Displacement of beam in the pipe
- grounded pipe → external e-field
- beam tries to compensate →

beam potential becomes asymmetric

A. Barnyakov, D. Nikiforov, M. Arsentyava, A. Levichev, 8th HL-LHC Collaboration Meeting

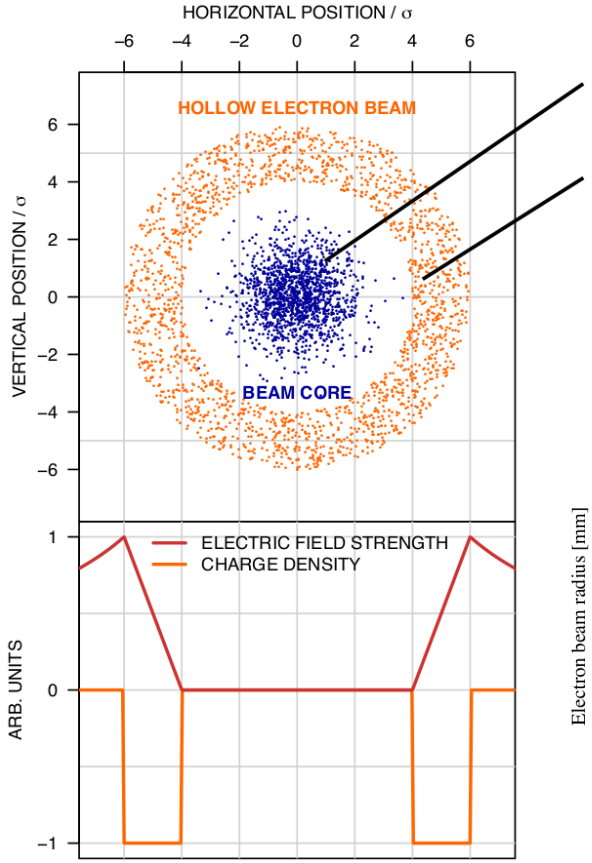
Kinetic energy with vs without pipe



Beam:		
	I	1 A
	R	1 cm
	Ekin	10keV
Pipe:		
	R	2.5 cm
	Length	1.28m

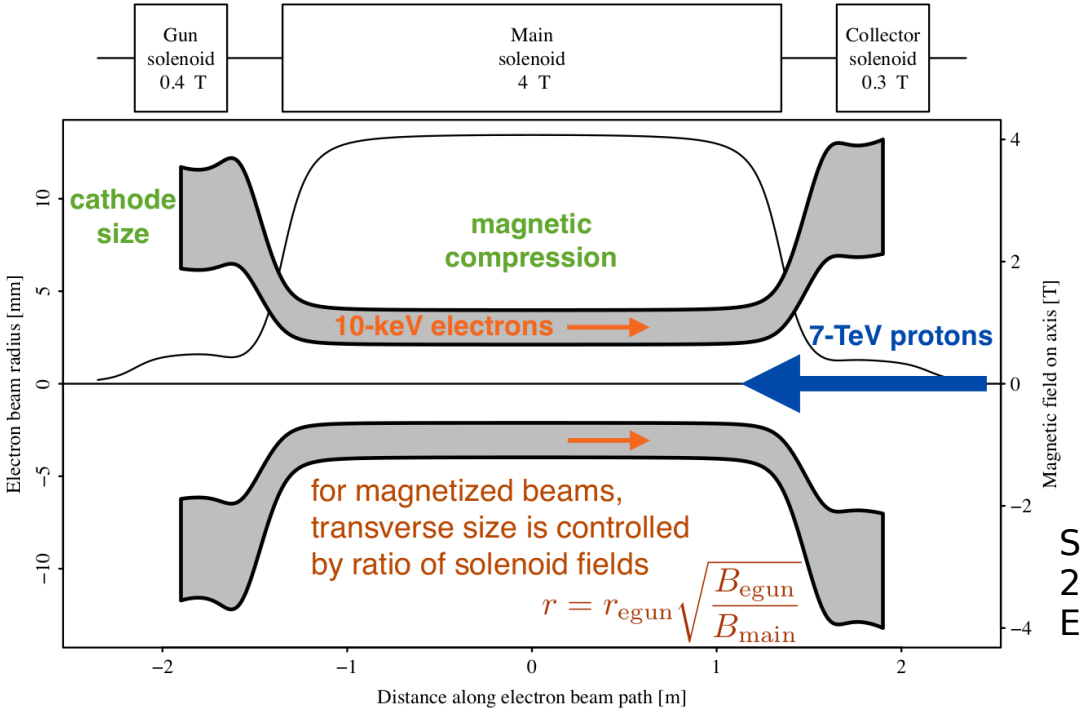
Hollow electron lenses - back

- Beam scrapping of protons
  - Part of the colimator system for HL-LHC



Beam core experiences no field

Beam halo experiences nonlinear transverse kicks



Shiltsev, BEAM06,CERN-2007-002 Shiltsev et al., EPAC08