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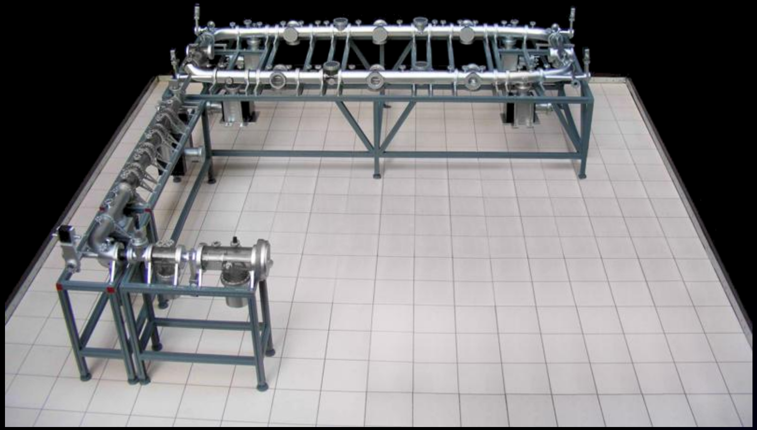
Development of a Low-energy Heavy-ion Storage Ring Facility at KACST



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King Abdulaziz City for Science and Technology (KACST)

IPAC`13, Shanghai , May 12-17 , 2013

Outline

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- Structure of the future facility at KACST
- Layouts and lattices of Electrostatic Ion Storage Rings
- Design of the KACST Electrostatic Storage Ring
- Status of the project
- An ion injector for the ring
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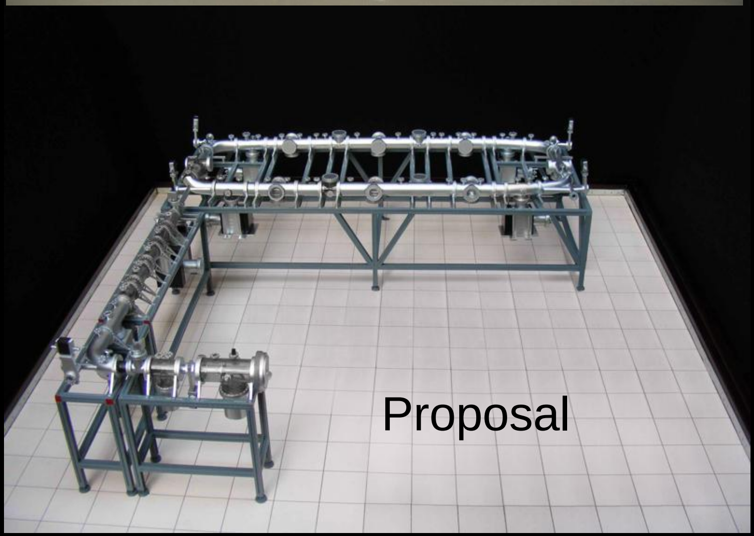

Introduction

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To build a laboratory for atomic and molecular collisions at KACST

Research program focused on the processes that occur when an electron or a laser interacts with a gas-phase ion e.g.:

$e^- + AB^+$ (cation) $\xrightarrow{AB^*}$ $A^+ + B^-$ Resonant Ion pair Formation (RIP)

$A^+ + B + e^-$ Resonant Dissociative Excitation (RDE)

$\longrightarrow$ $A^+ + B + e^-$ Dissociative Excitation (DE)

$\longrightarrow$ $A^+ + B + 2e^-$ Dissociative Ionisation (DI)

$e^- + AB^-$ (anion) $\xrightarrow{AB^{-2*}}$ $A + B^- + e^-$ Resonant Electron Attachment (EA)

$\longrightarrow$ $A + B^- + 2e^-$ Electron Detachment (ED)

➡ Absolute measurements of the cross-section of the reactions

Introduction

a multi-purpose facility for interdisciplinary applications e.g. in astrophysics, biophysics, biochemistry, clusters...

- A facility built around an electrostatic storage ring combined with a single-pass setup, with a common experimental section

With the standard but complementary ion -beam techniques such as e.g. merged-beams and crossed beams

Motivation for an Electrostatic Storage Ring

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- Electrostatic storage rings (ESR) is a field where the technology is not too difficult

- The field is new and presents a large potential, in particular towards biological sciences

- ESRs have several advantages over magnetic rings:
  - no magnetic hysteresis
  - low power consumption (no water cooling)
  - no limitation to the mass of stored ions

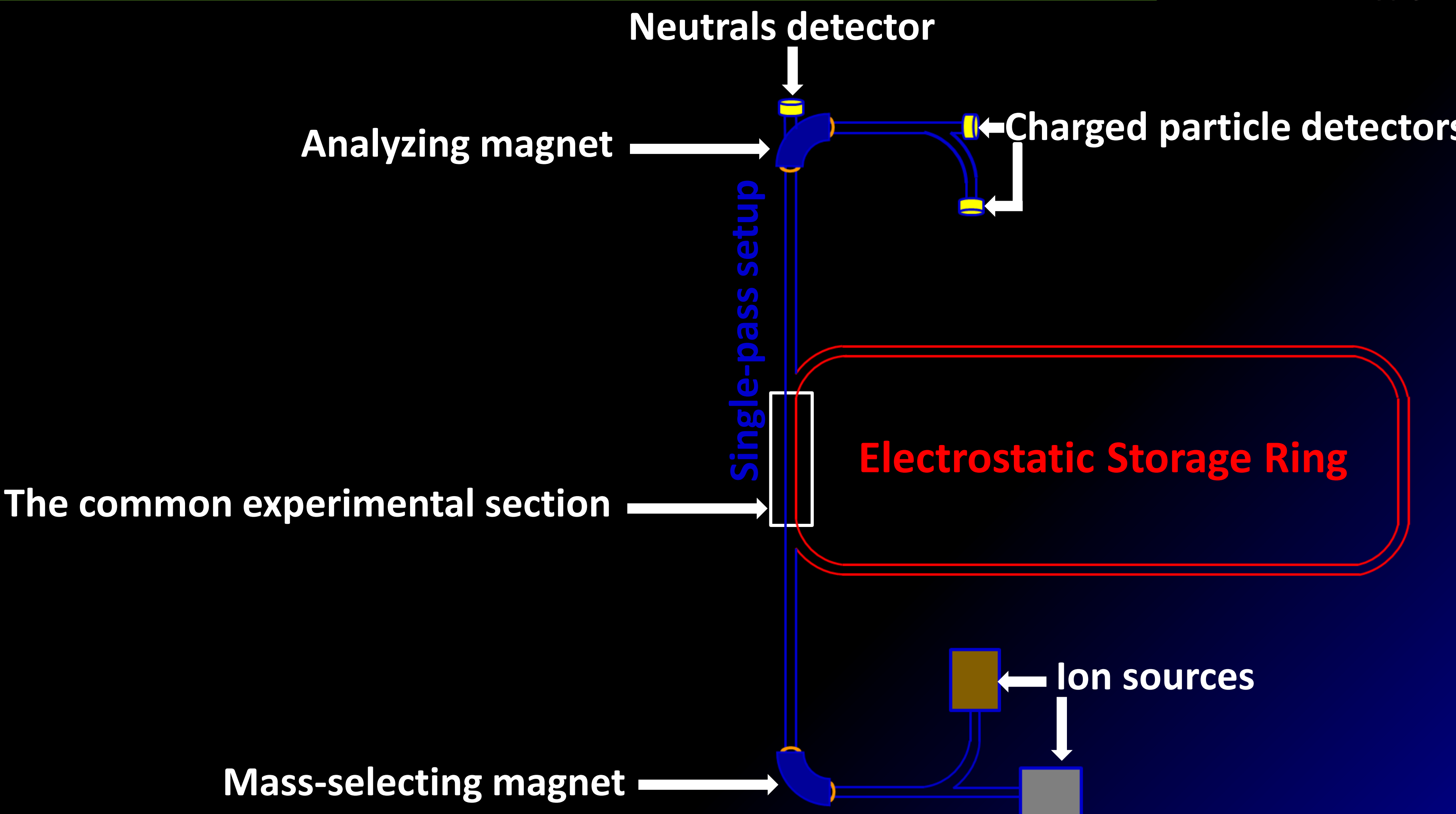
ESRs are usually smaller and consequently easier to operate and cheaper to build

Motivation for an Electrostatic Storage Ring

- **Limitations of an Electrostatic Storage Ring:**
  - **Difficult to separate the different neutral products**
  - **No absolute measurement of the cross-section is yet possible**

Combining the features of an electrostatic storage with those of a single-pass setup

Structure of the future facility at KACST



Structure of the future facility at KACST

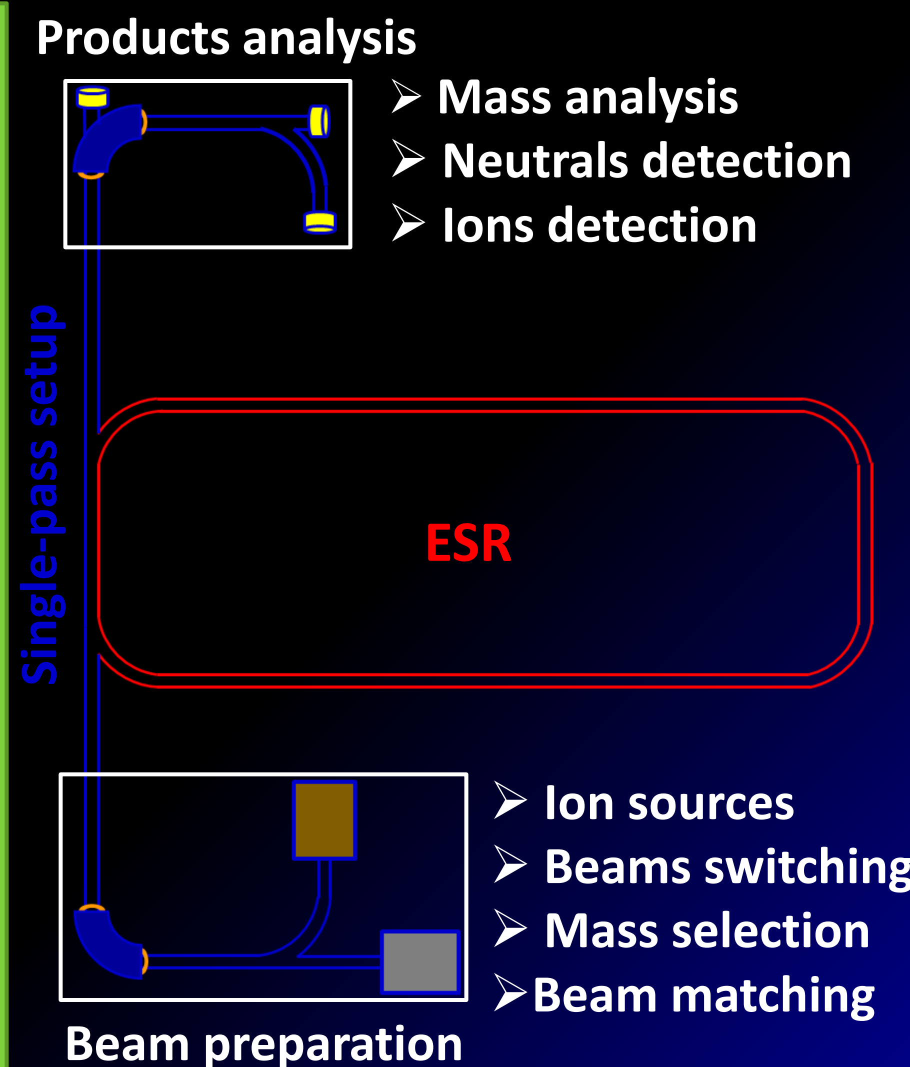
KACST

- All the advantages associated with the use of single-pass and storage ring:
  - ➡ High luminosity, high statistic /SR
  - ➡ Mass spectrometry/SP
  - ➡ Absolute measurements/SP
  - ➡ The same initial conditions

- Highly flexible design:

➢ Construction in a staged approach:

- ➡ Beam preparation setup + ESR
- ➡ Analyzing setup



Layouts and lattices of Electrostatic Ion Storage Ring

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FIRST: ELISA, Aarhus, Denmark, 1998

- Original
- Room temperature
- Cooling: liquid nitrogen

Second: KEK-ring KEK, Japan, 2002

- an improved version of ELISA
- Room temperature
- Electron cooler/target

Third: TMU E-ring TMU, Japan, 2004

- Different vacuum and cooling concept: electrodes and shields are kept at liquid nitrogen temperature

Layouts and lattices of Electrostatic Ion Storage Ring

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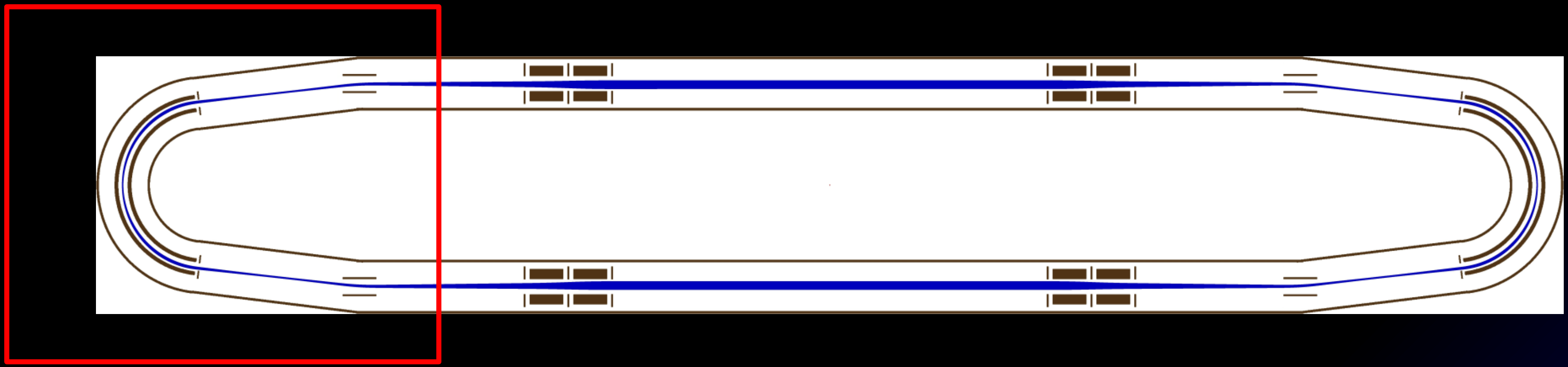
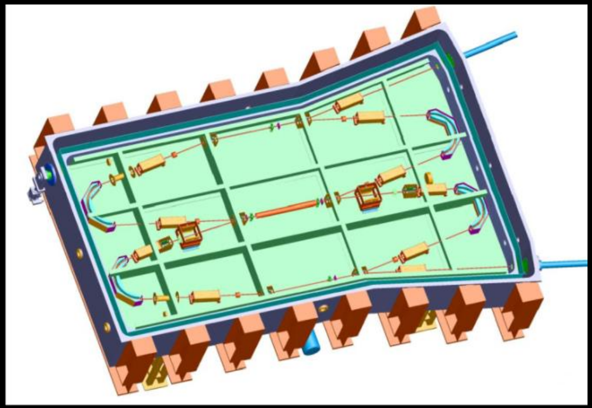
- Single-bend racetrack shape



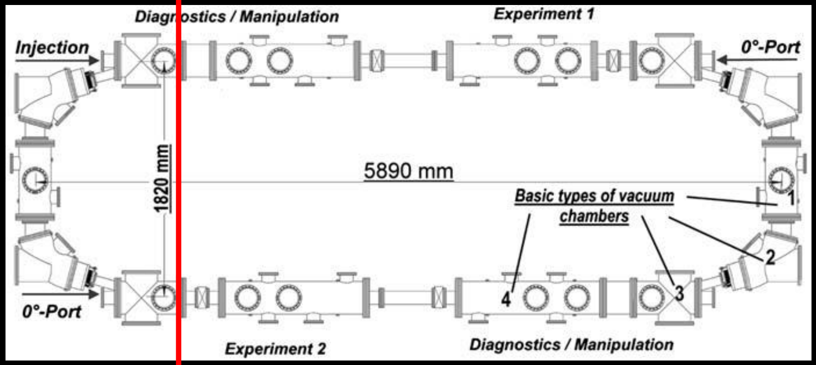
U-turn of particles: a single-bend inserted in between 2 Deflectors



Single-bend racetrack shape in a double ring: **DESIREE**

Layouts and lattices of Electrostatic Ion Storage Rings

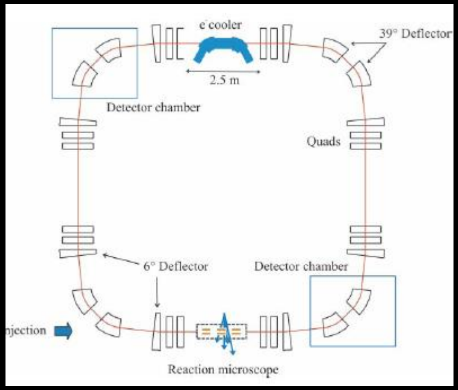
- Split-bend racetrack shape



FLSR

U-turn of particles: 2 split-bends are inserted in between 2 Deflectors

- Split-bend quadratic shape



U-turn made of two 90° split-bending corners: CSR and USR at FLAIR

Layouts and lattices of Electrostatic Ion Storage Rings

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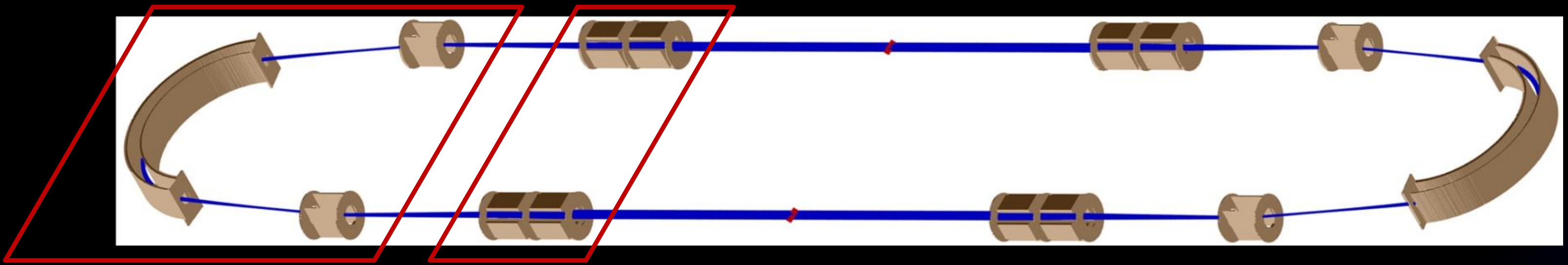
- An identical optics that makes up the ring



U-turn Deflectors → $E \sim \frac{1}{R}$ ← Dipole

Quadrupole double → $E \sim kx$ ← Quadrupole

→ linear field components

Only two multi-pole fields; a dipole for beam bending and a Quadrupole for beam focusing: ***linear beam optics***

Layouts and lattices of Electrostatic Ion Storage Rings

Non-linear fields

$$E_x(x,z,s) = \frac{2T_0}{q}\left[\frac{1}{R} + kx + \frac{1}{2!}mx^2 + \frac{1}{3!}Ox^3 + \cdots\right]$$

Sextupole Octupole

non-linear multi-pole components

Dipole Quadrupole

In higher energy storage rings:

Sextupole → Chromaticity compensation

Octupole → Field error or field compensation

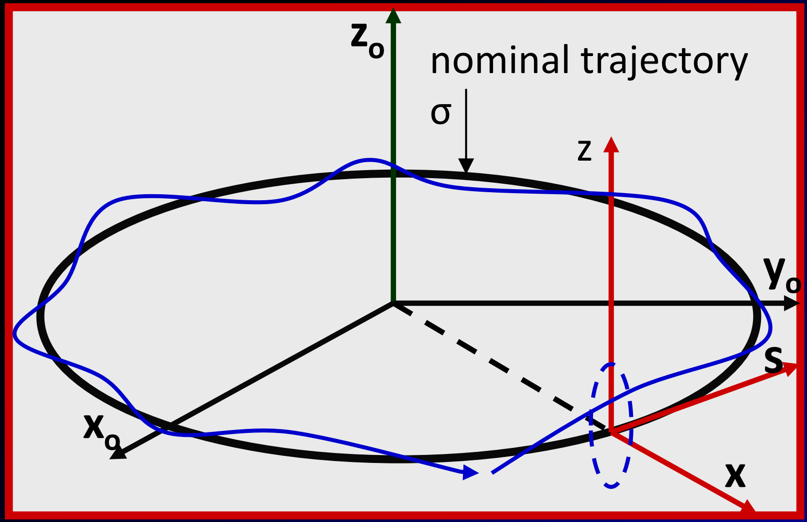


Figure: Frenet-Serret coordinate system

Layouts and lattices of Electrostatic Ion Storage Ring

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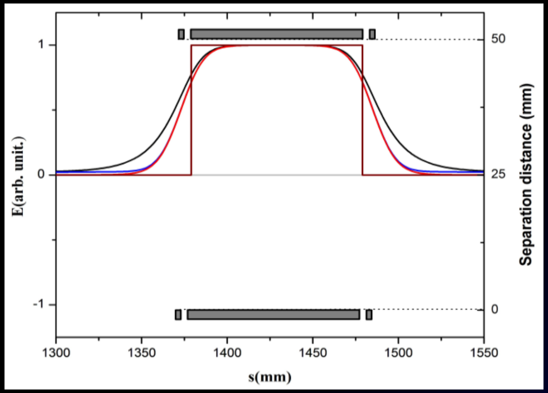
Non-linear fields

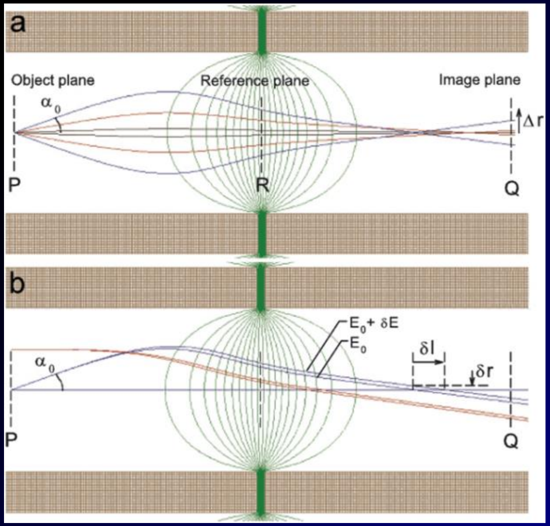
- **Non-linear multi-poles are due to fringing fields and beam aberrations**
  - electrostatic bends cause a change in the energy of the particles, which in return get focused at different image points: **chromatic aberrations**.
  - **Spherical aberrations** are facts of the geometry of the lens field.

- **Fringe fields and aberrations can cause dramatic limitations in beam lifetime and acceptance of the ring**

Fringe field in a Parallel-Plate deflector



Spherical and chromatic aberrations



Sise et *al*., Nucl. Instr. & Meth. A 573 (2007) 329

Layouts and lattices of Electrostatic Ion Storage Ring

Non-linear fields

Aberrations induced by the quadruples as they are the main focusing lenses in an electrostatic ring:

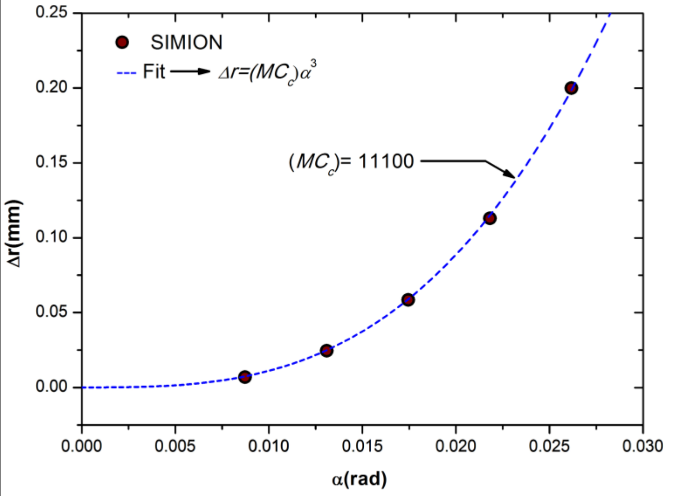
Spherical aberrations:

- A parabolic growth: $\Delta r = -MC_s\alpha^3$
- An aberration disc radius of *Δr=200µm* for *α=1.5°*

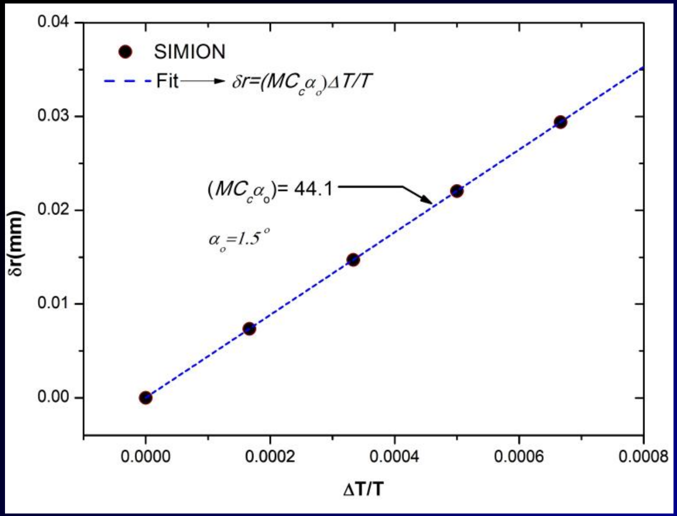
Chromatic aberrations:

- Linear growth: $\delta r = -MC_c\alpha\frac{\Delta T}{T}$
- Aberration disc radius of δr =30µm for T=20 eV

Spherical aberrations



Chromatic aberrations



Layouts and lattices of Electrostatic Ion Storage Ring

Non-linear fields

The effective field boundaries have been calculated to evaluate the fringe fields effects and optimize the effective length of deflectors:

- **Extension of the bending angle (Wollnik):**

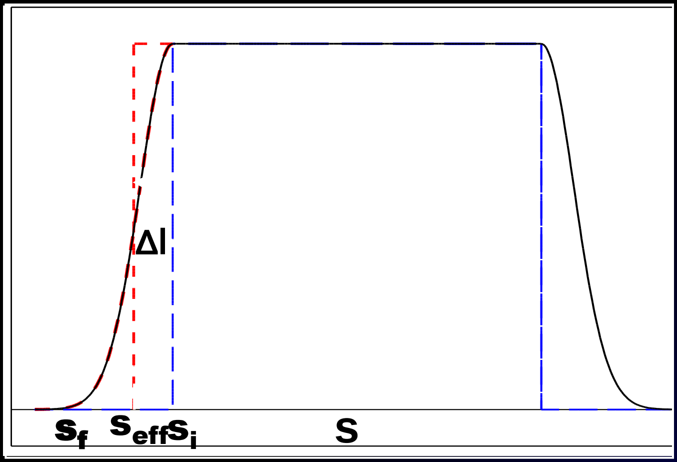
$$\Delta\beta = \frac{G_o}{\pi\rho}\left[ln\left[\frac{4}{(x^2+4)}\right] - 2x\,arcos\left[\frac{x}{\sqrt{(x^2+4)}}\right]\right]$$

- G_o is the electrodes gap
- ρ is the nominal radius of deflector
- D is the Deflector- Shield gap

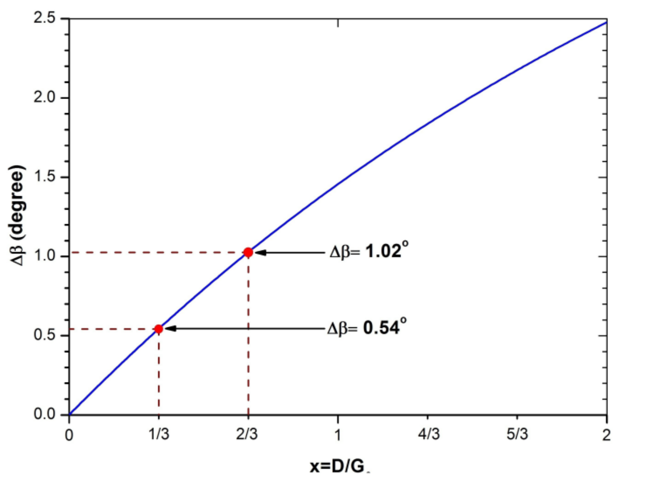
For D=10mm and G_o =15mm → $\Delta\beta=1.02^o$

If D is reduced to $5\ mm$ → $\Delta\beta\sim0.54^o$

The effective boundaries of the field



$\Delta\beta$ caused by the fringe field as a function of $x=D/G_0$



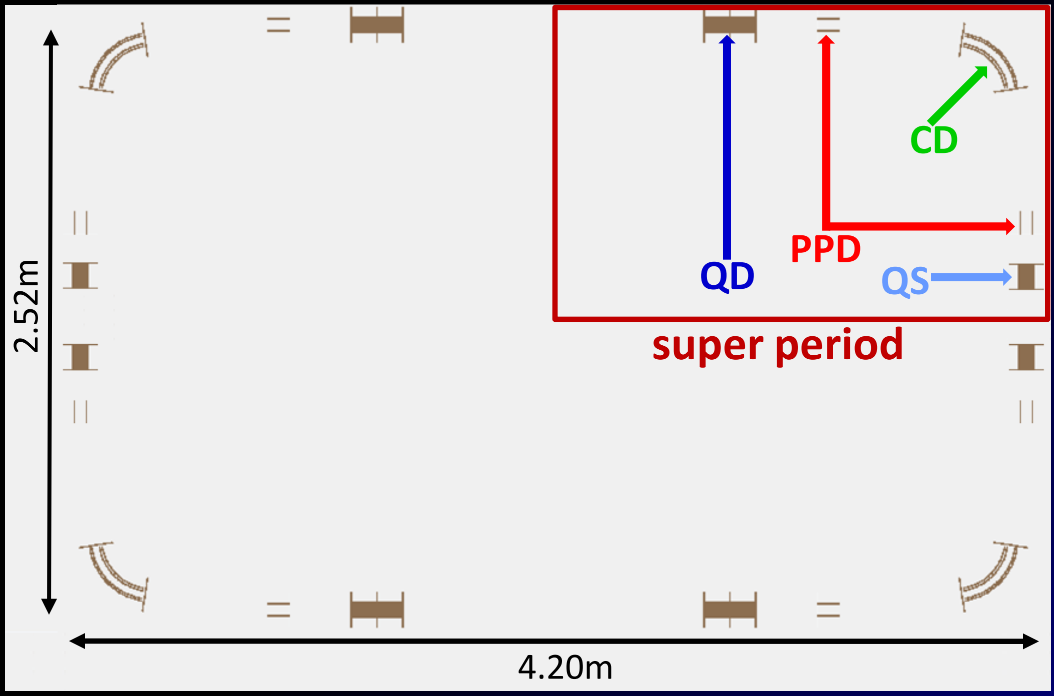
Design of the KACST Electrostatic Storage Ring

- Split-bend design of 4 super periods with double-mirror symmetry

➡ Each period consists of a 90° corner bend, connected on one side to a QD and on the other side to a QS

➡ The 90° corner bend consists of a CD, inserted between two PPD

In this design the beam is bent back before traversing any quadrupole



Split-bend design: CD: Cylinder Deflector, PPD: Parallel-Plate Deflector, QS: Quadrupole Singlet, QD: Quarupole Doublet

Design of the KACST Electrostatic Storage Ring

- 4 straight sections interconnected by 4 identical 90° bending corners

  - ➡ More experimental regions
    - - Long arm: Merged beams
    - - Short arm: Crossed beams
  - ➡ 8 beam inlets/outlets
  - ➡ Upgrade to a double-ring

Double-ring

Design of the KACST Electrostatic Storage Ring

- 4 straight sections interconnected by 4 identical 90º bending corners

➡ More experimental regions

- Long arm: Merged beams
- Short arm: Crossed beams

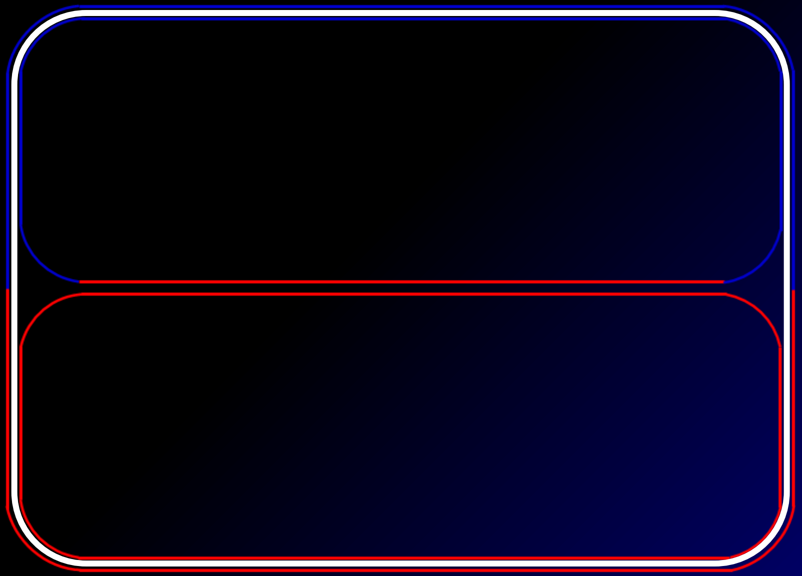
➡ 8 beam inlets/outlets

➡ Upgrade to a double-ring

Double-ring

↕

Long mode single-ring



Cannot be done in single-bend layout!

Design of the KACST Electrostatic Storage Ring

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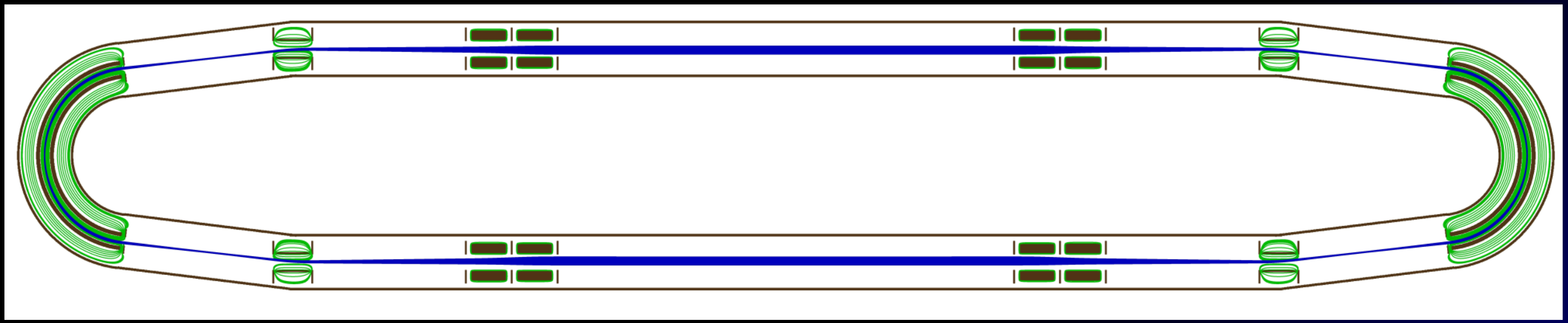
- **Single-bend racetrack-shaped ring**
  - Priority was given to a quick realization of the ring, with a single-bend adaptation of the ring.
  - This ring can then be upgraded to the ultimate split-bend version



Beam stored in the simulated ring for tens of thousands of turns

A complete SIMION`s study has been performed and shows that an electrostatic storage ring can store low-energy beams in spite of existing fringing fields.
→ limitations in ring acceptance and dynamic aperture were clearly observed

Design of the KACST Electrostatic Storage Ring

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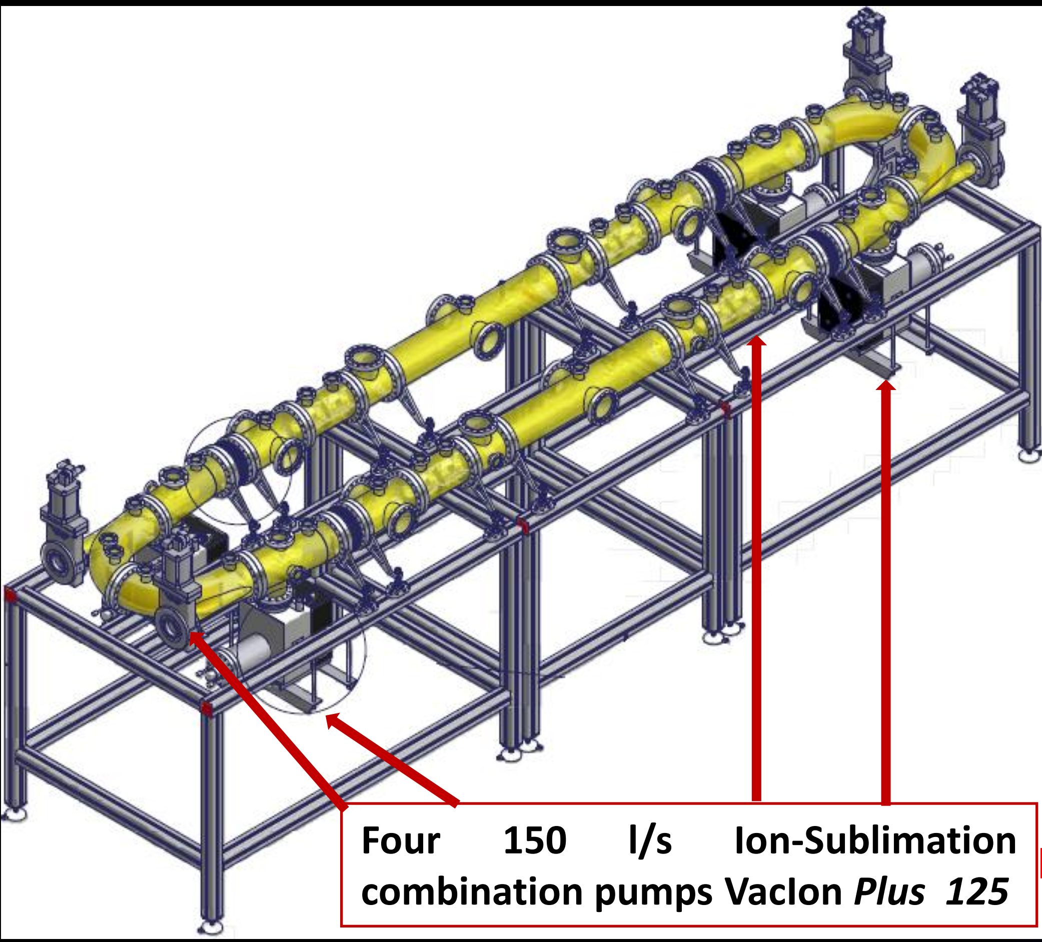

- Similar to the well-tested rings
- Flexible layout → future upgrades
- Flexible frame from BLOCAN profile assembly system

→ Vacuum: 10^{-10} -10^{-11} mbar

El Ghazaly et *al*. Nucl. Instr. Meth. A 709 (2013) 76–84

Components of the ring

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Components of the ring

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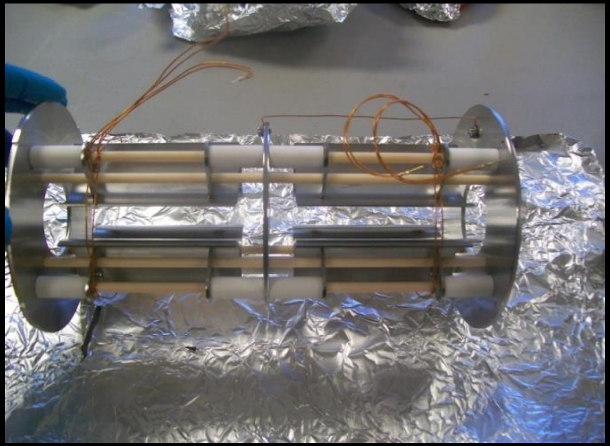
Single-bend in the chamber



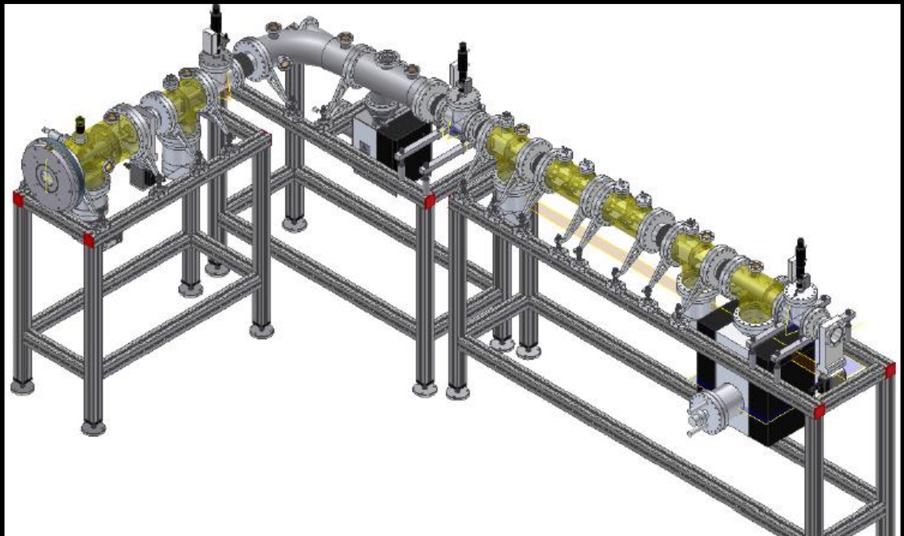
Quadrupole doublet

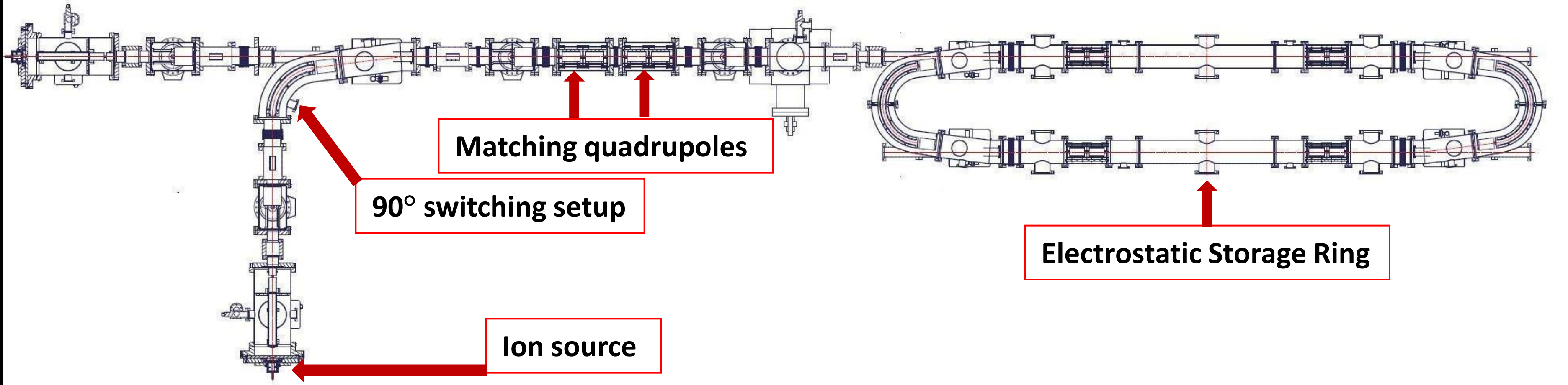
Single-bend & frame

Status of the project

Work-packages	Status
Injector beam line	Operating- Ongoing upgrade
High Voltage platform	Built and in use
Racetrack adaptation	Under manufacturing
The ultimate/Split-Deflector layout	Manufacturing on stand-by
Diagnostics (BPM/P, Pickup, Faraday cups)	Under investigation
Control system (lab view)	Operating injector – under upgrade
Mounting and operation of Racetrack adaptation	Later in 2013
Construction of the analysis setup	Future upgrade

An ion injector for the ring


The injector without the magnet

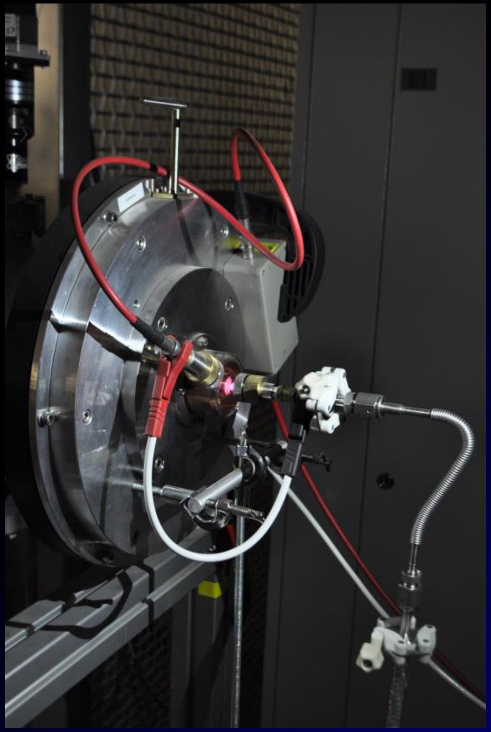


El Ghazaly et *al*. AIP Conf. Proc. 1370, 272 (2011)

Achievements

The ion injector at KACST

Non-heated cathode ion source KACST in-house development



- The ions produced by an in-house cold-cathode ion source: air is injected
- In a first run, a 25 KeV ion beam of 0.532 μA at the exit of the beam-line

Achievements

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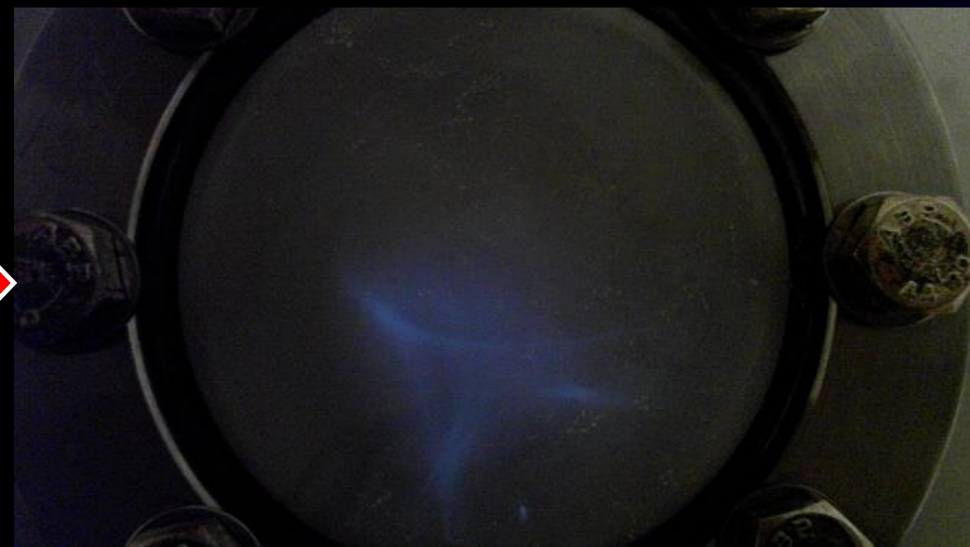
'Rome has not been built in one day'



Beam sport seeing from the first accelerator developed in Saudi Arabia, seeing Riyadh, 16 May 2012

Thanks to:

Members:

- Suliman Alshammari
- Hamed Alamer

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- Hartmut Reich-Sprenger, GSI
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- Henrik Juul
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Thank you