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LABORATORI NAZIONALI DI LEGNARO



SAPIENZA
UNIVERSITÀ DI ROMA

Characterization of the Extraction System and LEBT Line of the LEGIS ECR Ion Source at INFN-LNL



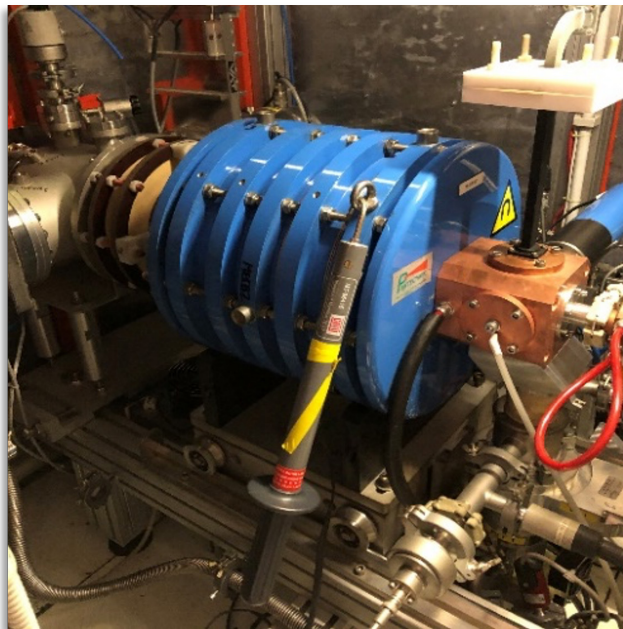
26th international Workshop on ECR Ion Source

Giada Rachele Mascali

Outline

- Description of the LEGIS (LEGnaro ecrlS) source and its beam line
- Description of the PIAVE-ALPI accelerators complex
- Case study: $^{208}\text{Pb}^{31+}$ beam extraction and its numerical simulation
- Results of beam transport calculation and analysis of the criticalities
- Summary and conclusions

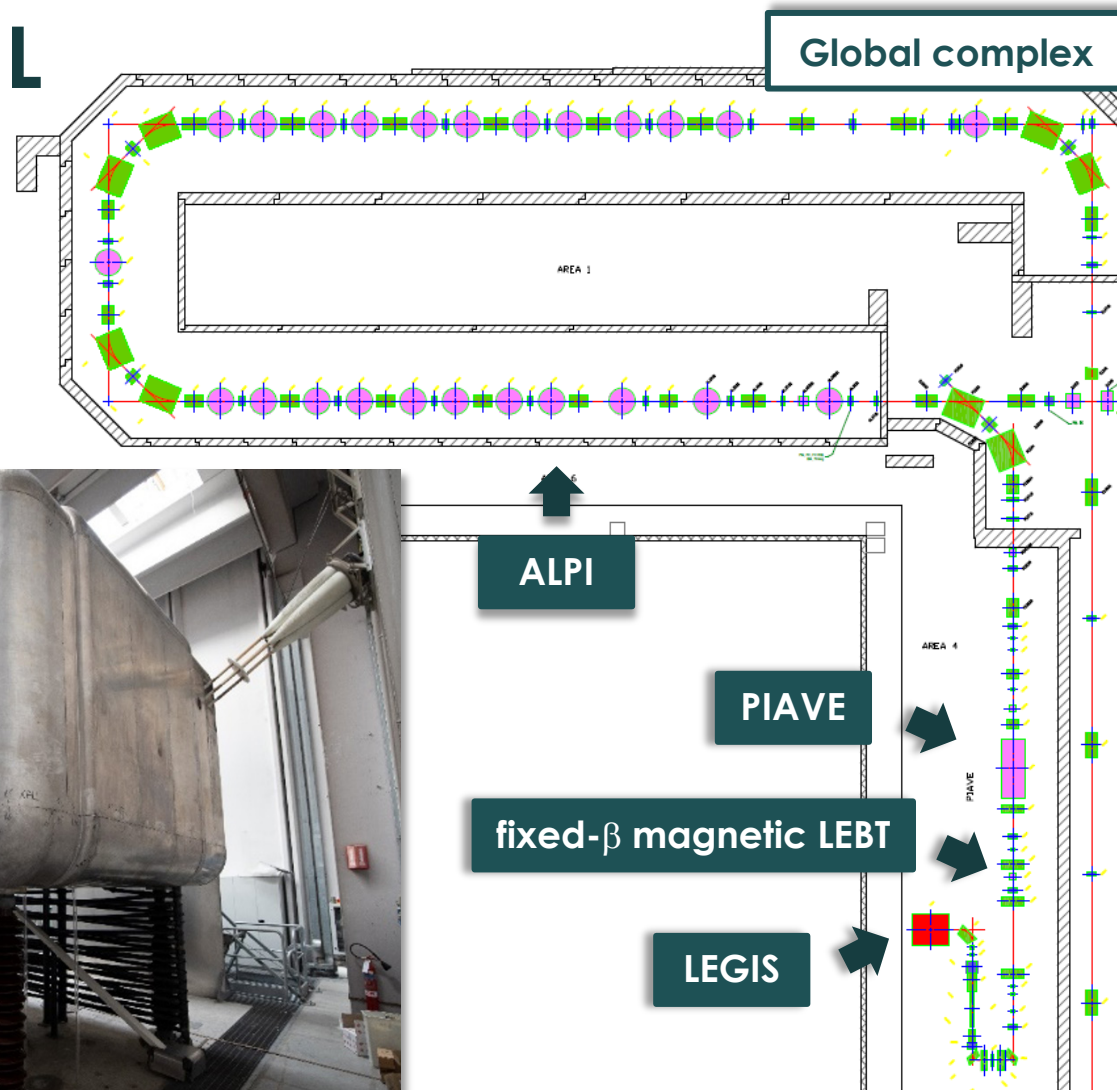
LEGIS and PIAVE-ALPI at LNL



LEGIS source

- ❖ Full permanent magnets
- ❖ **14 ÷ 14.5 GHz**
- ❖ extraction voltage **24 kV**
- ❖ magnetic field: **1.2 T, 0.45 T, 0.8 T, 0.8 T**

400 kV ECR platform



PIAVE-ALPI accelerators at LNL



ALPI cavities

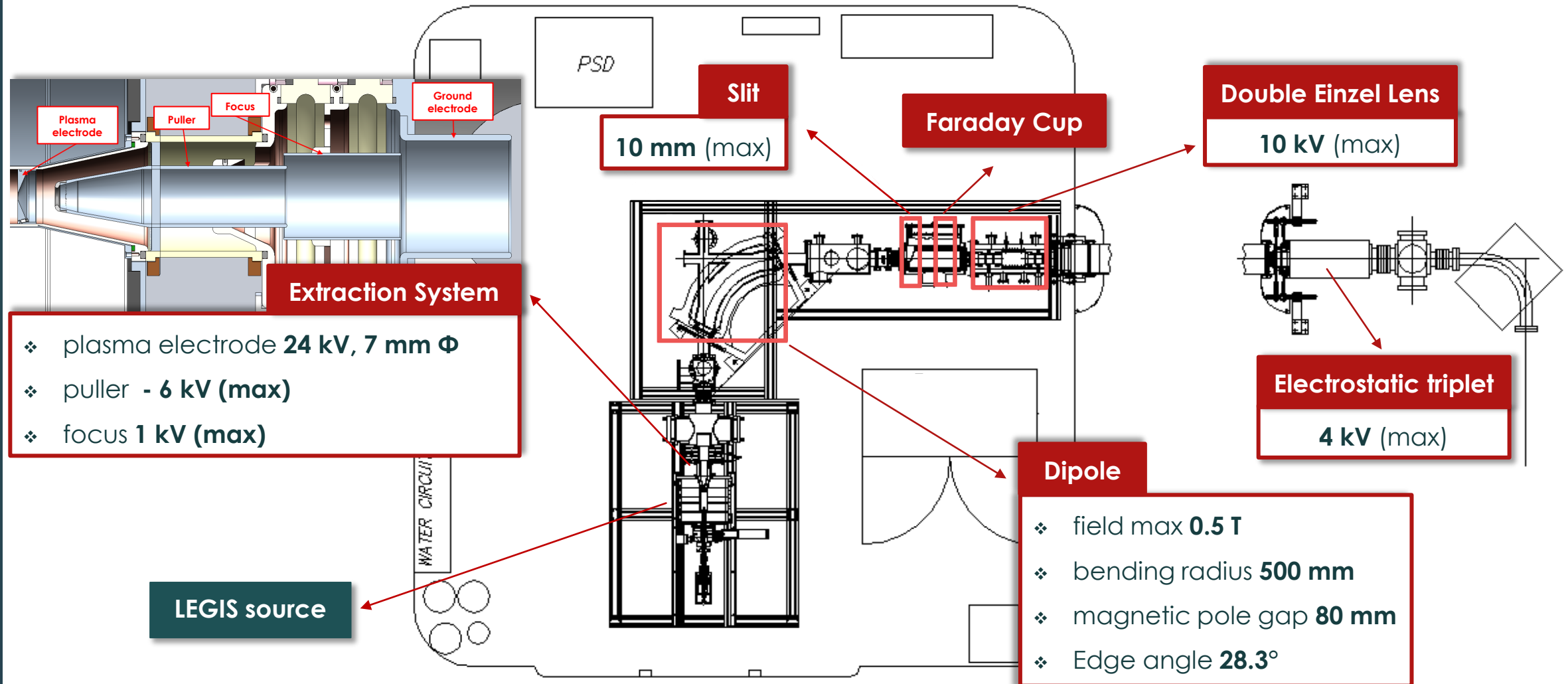
- ❖ 80 **sQWR** cavities (20 cryostats)
- ❖ 80 MHz (24 cavities), 160 MHz (56 cavities)
- ❖ 10 MeV/A energy for $A/q = 7$

PIAVE RFQ cryostat

- ❖ 2 **sRFQ**, 80 MHz, $\beta = 0.0089$ (input), $\beta = 0.0355$ (extr)
- ❖ acceptance 0.1 mm.mrad



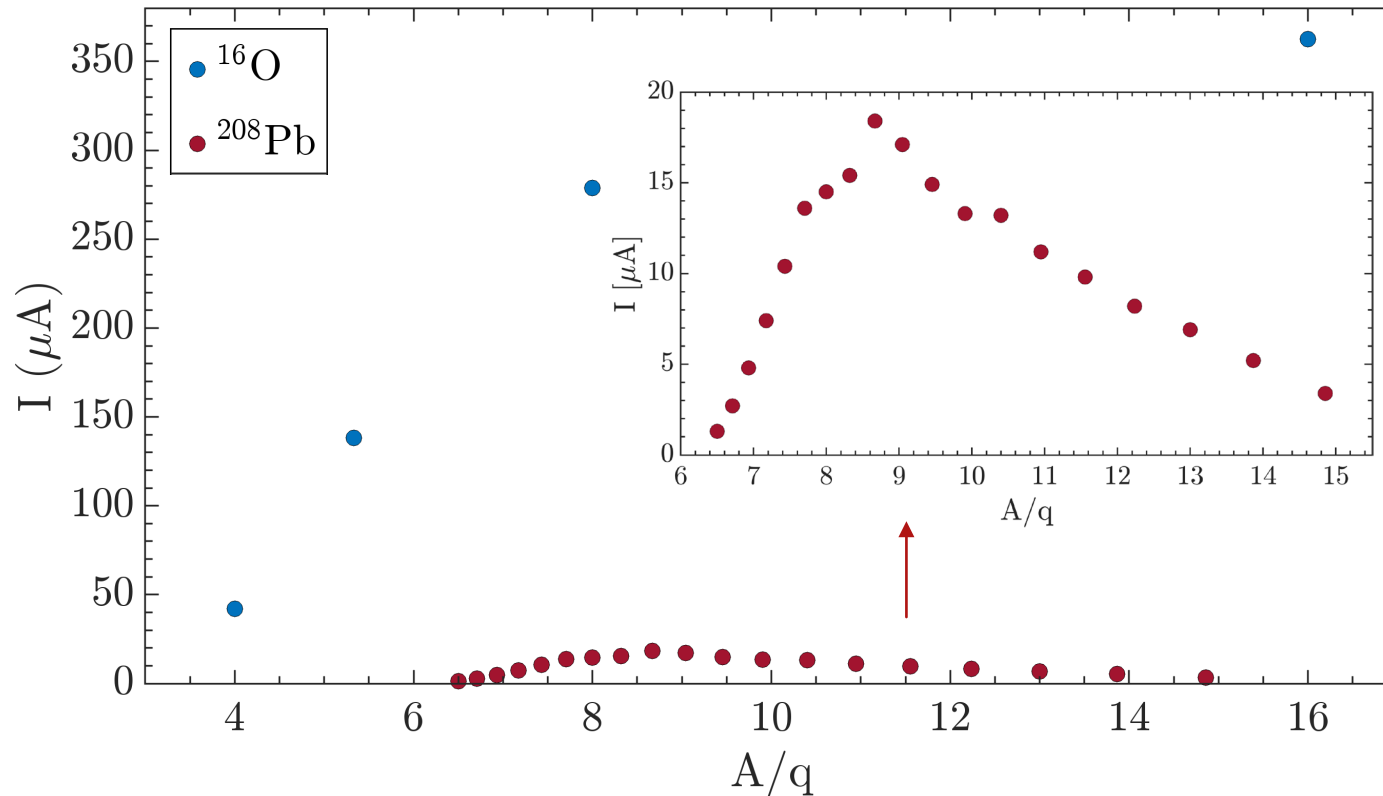
ECR platform transport line



$^{208}\text{Pb}^{31+}$ extraction and simulations

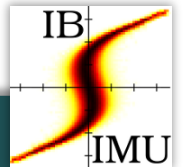
^{208}Pb ($14^+ \div 32^+$) and some ^{16}O ($1^+ \div 4^+$)
charge states distributions

P [W]	f [GHz]	I [μA]	$I_{\text{Pb}^{31+}}$ [μA]	V_{platform} [kV]
304	14.328	1013.3	2.7	224.68
V_{source} [kV]	V_{puller} [kV]	V_{focus} [kV]	V_{Einzel} [kV]	V_{triplet} [kV]
24	-1	1	6.4, 4	4



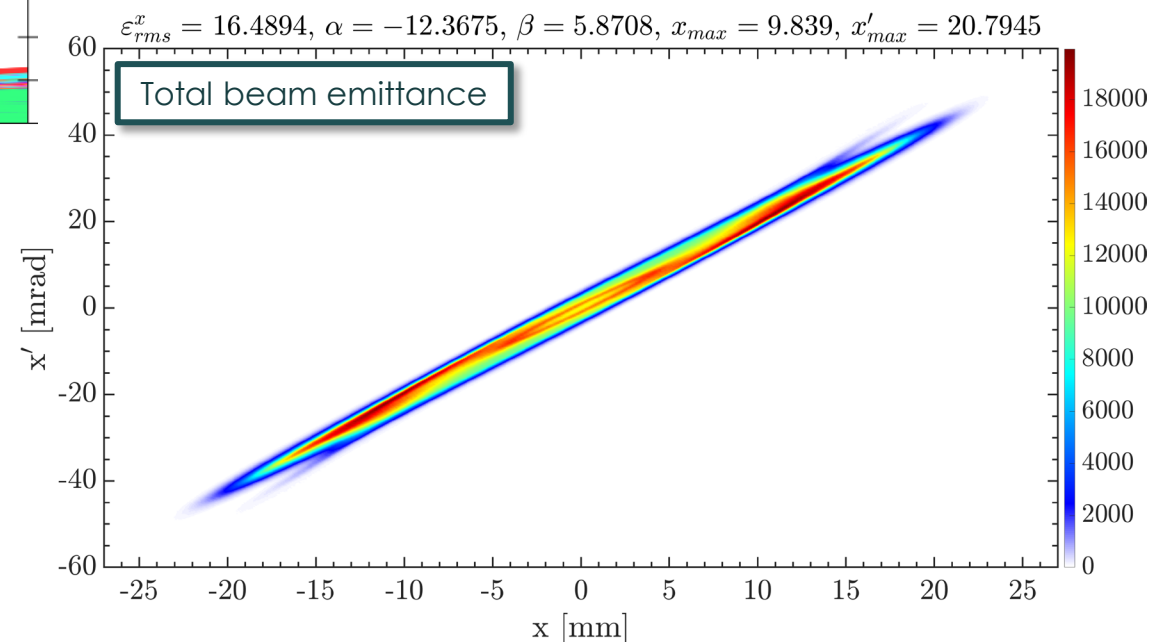
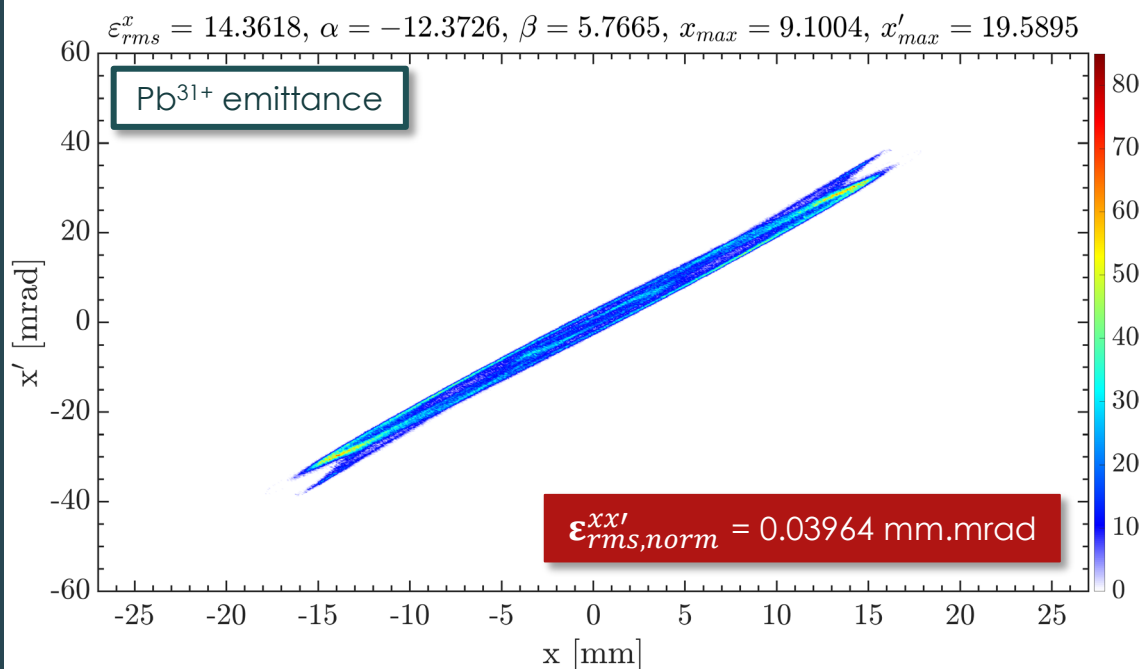
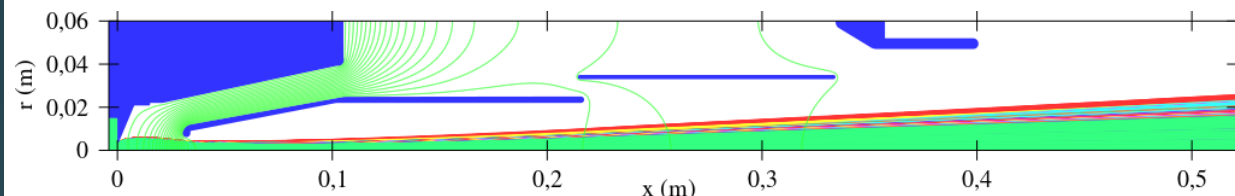
Optimization of $^{208}\text{Pb}^{31+}$ produced for
an experiment scheduled in fall 2022

Simulations with IBSimu
assuming **98% compensation**



simulated CSD = experimental CSD

$^{208}\text{Pb}^{31+}$ extraction and simulations



How well would the beam
be transported?



TraceWin
simulations



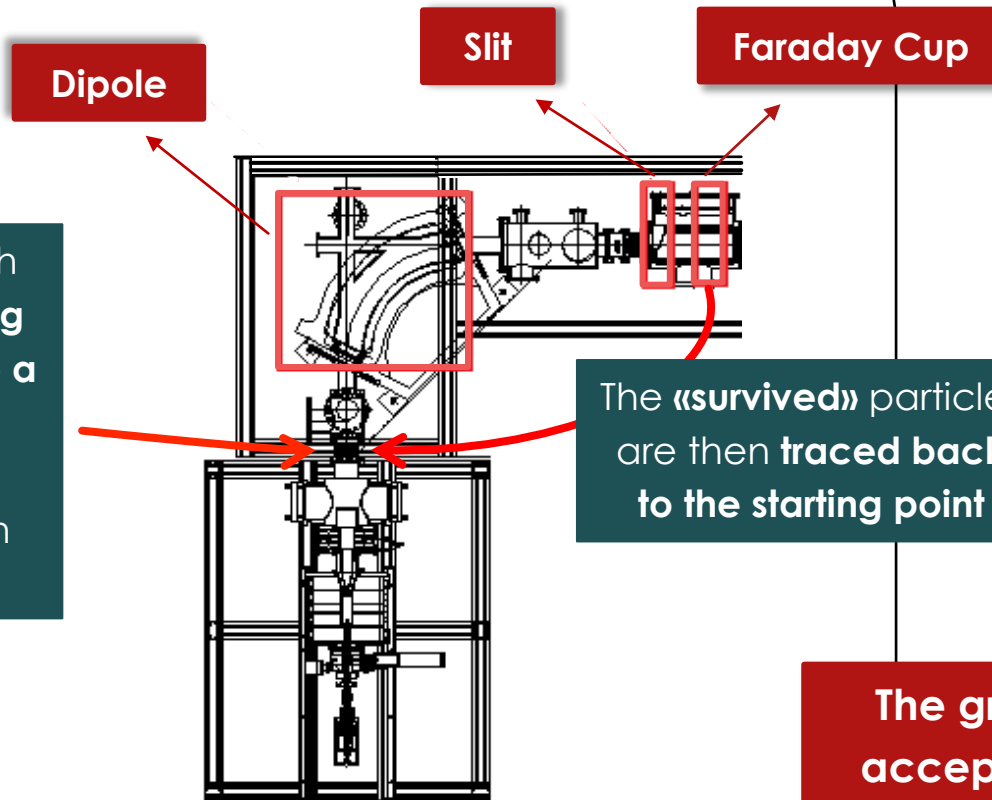
Explanation of the experimentally
observed criticalities:

- ❖ transmission of about 50% or less
- ❖ steerers in the fixed- β line downstream of the LEBT line do not scale with A/q

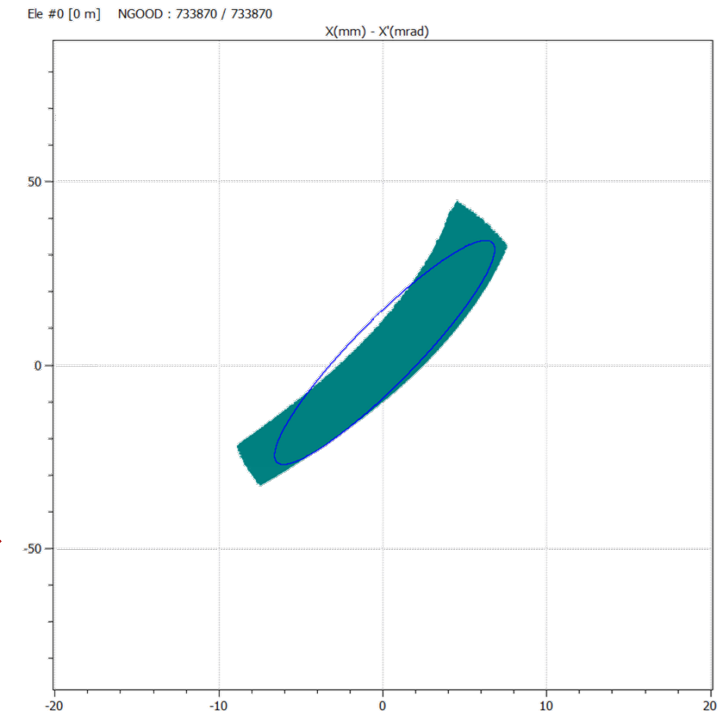
Beam transport calculations

Beam line acceptance calculation:

A uniform beam with an **artificially very big emittance** to explore a large area of the **phase space** is transported through the beam line



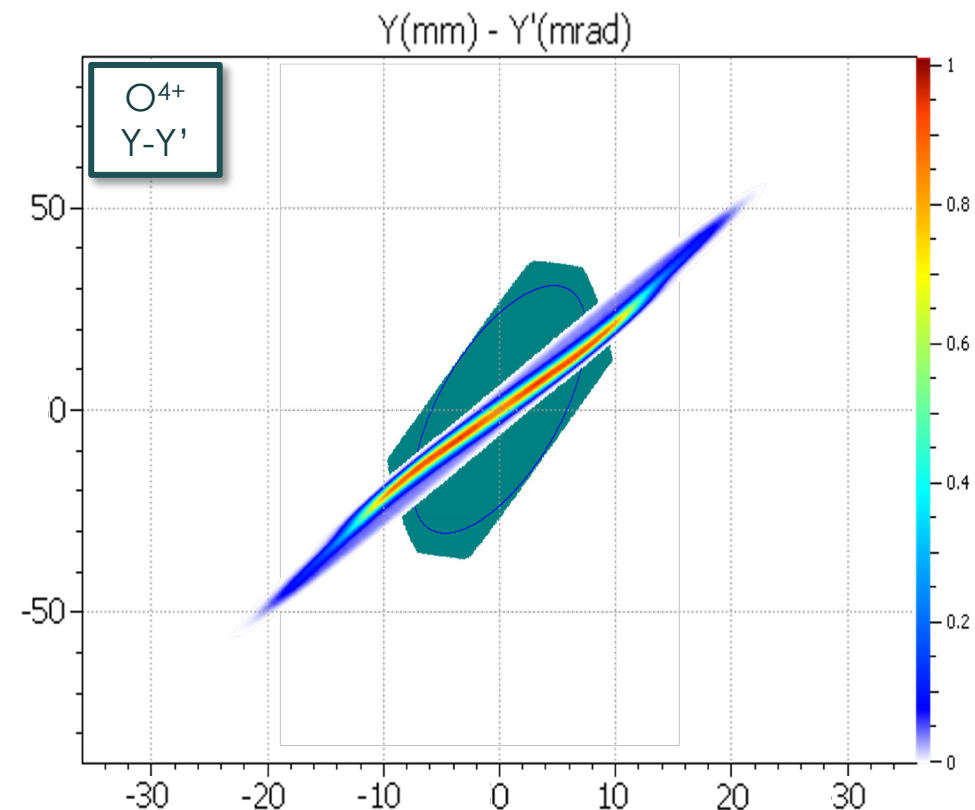
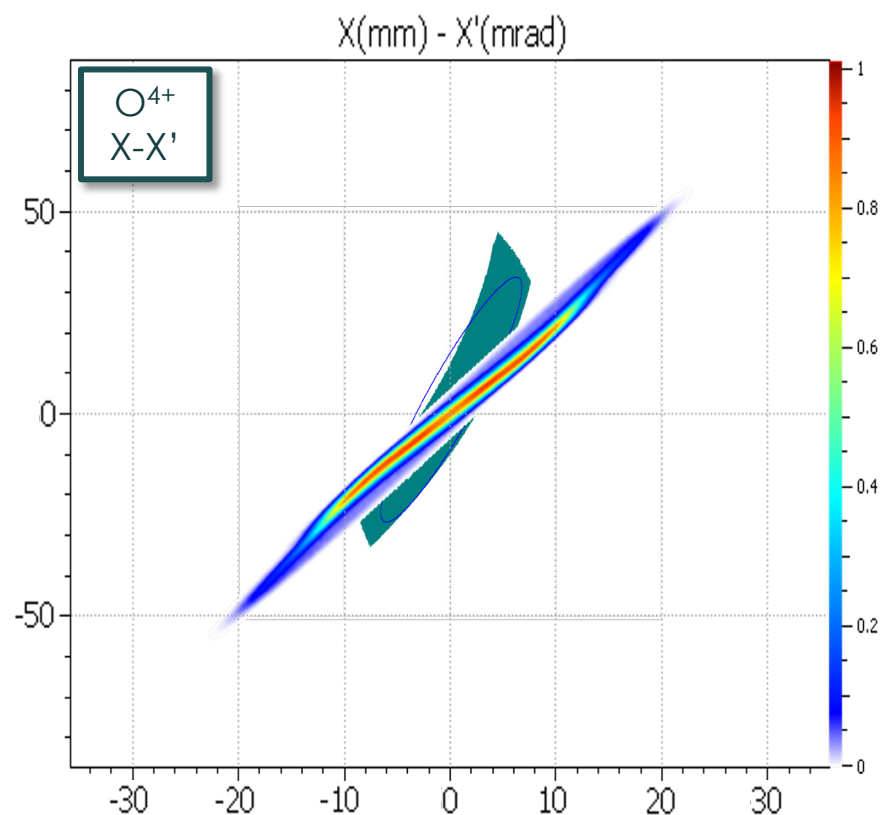
The «**survived**» particles are then **traced back** to the starting point



The green area shows the $x-x'$ phase space accepted by the beam line together with the biggest ellipse enclosed in the distribution

Beam transport calculations

Line acceptance - beam emittance mismatch
evaluated at the entrance of the LEBT line



**Same behaviour for
all charge state**

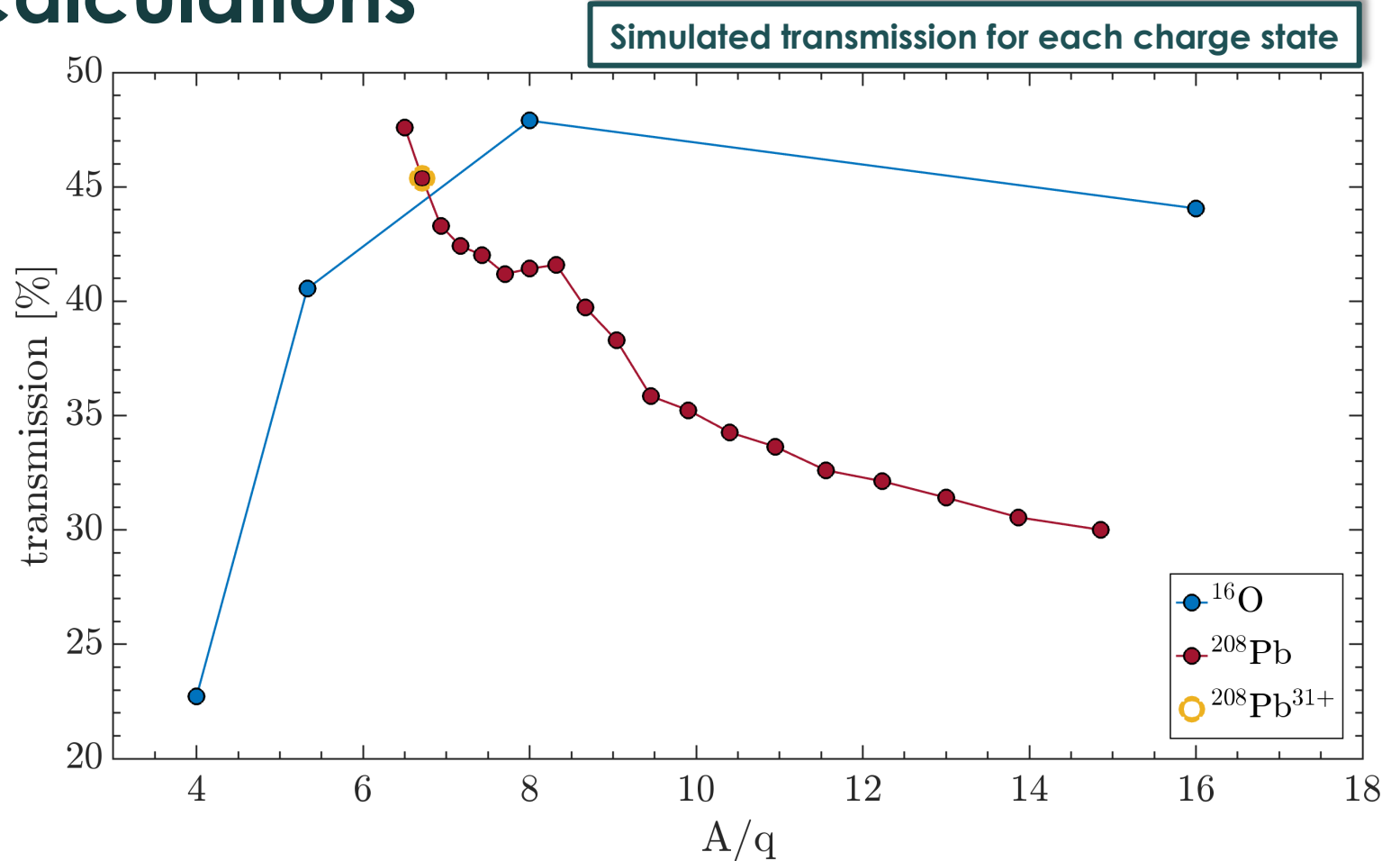


**Problems related
to transport
clear cause of
beam losses**

Beam transport calculations

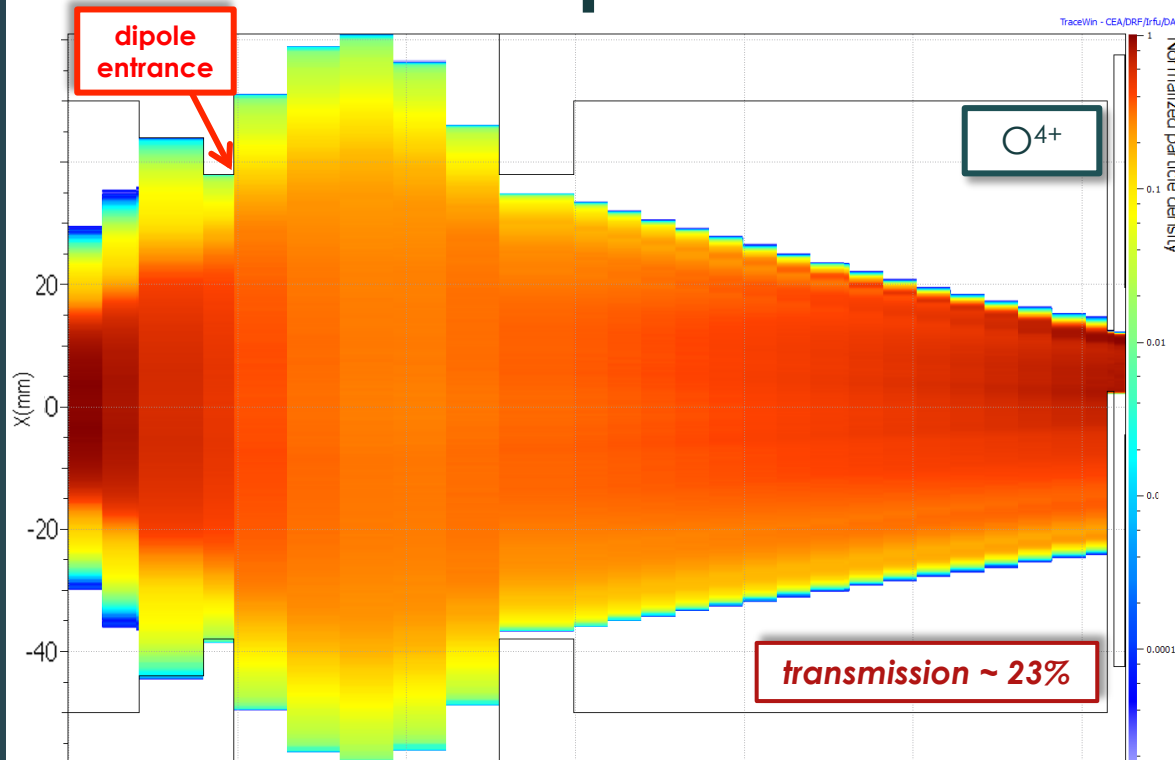
O^{4+} confirmed as the beam
with the **lowest transmission**

Numerical and
measured global
beam transmission are
in good agreement



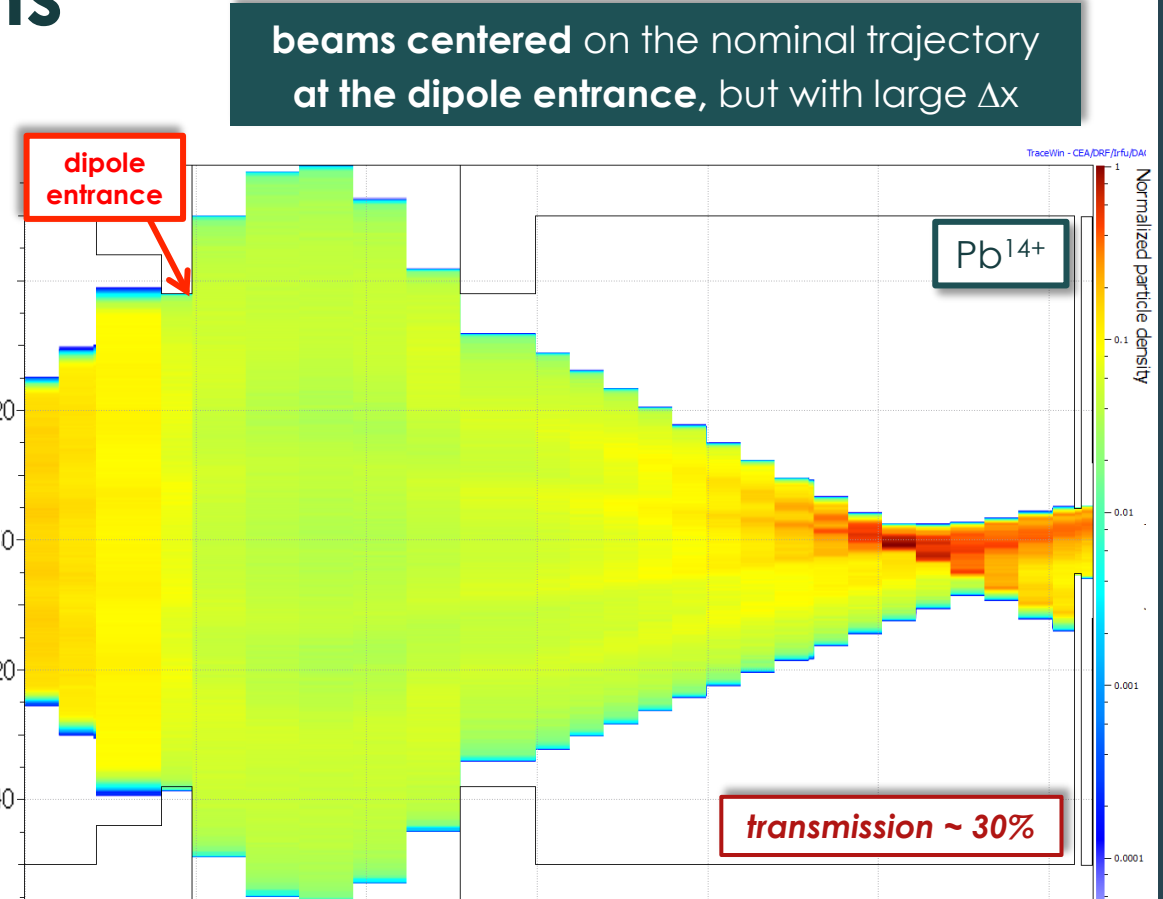
Confirmation: losses can be traced back to criticalities in the transport process

Beam transport calculations



different optic for each charge state, all off-centered in position and distribution at the LEBT line exit

Aberrations due to the non-linear effects induced by the dipole



beams centered on the nominal trajectory at the dipole entrance, but with large Δx

Distorsion of the distribution and beam losses

Beam transport calculations

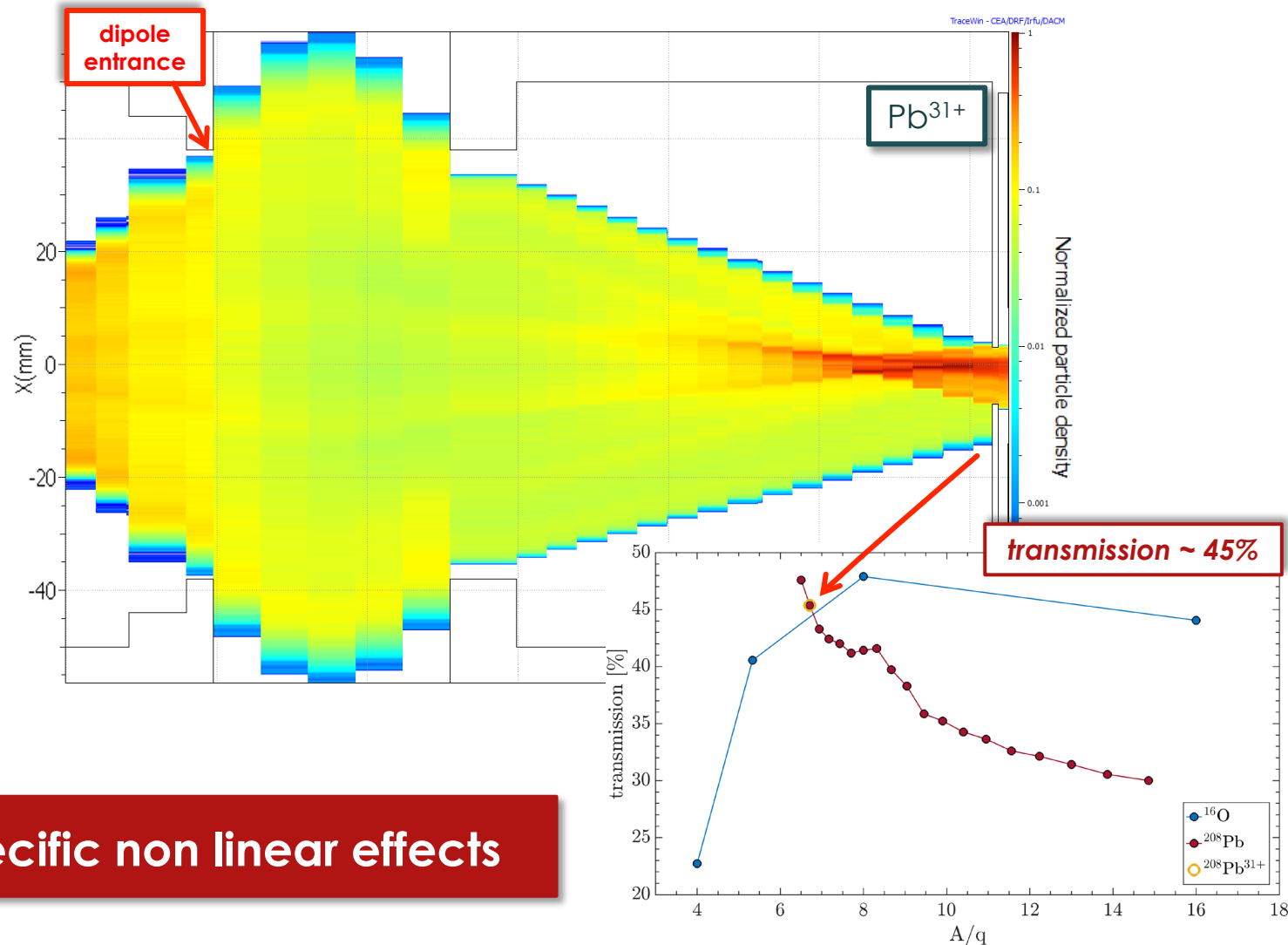
beam splitted closer to the slit
→ a larger portion of the beam passes

slightly smaller Δx at the dipole entrance
→ less aberrations
→ dynamics closer to the nominal one

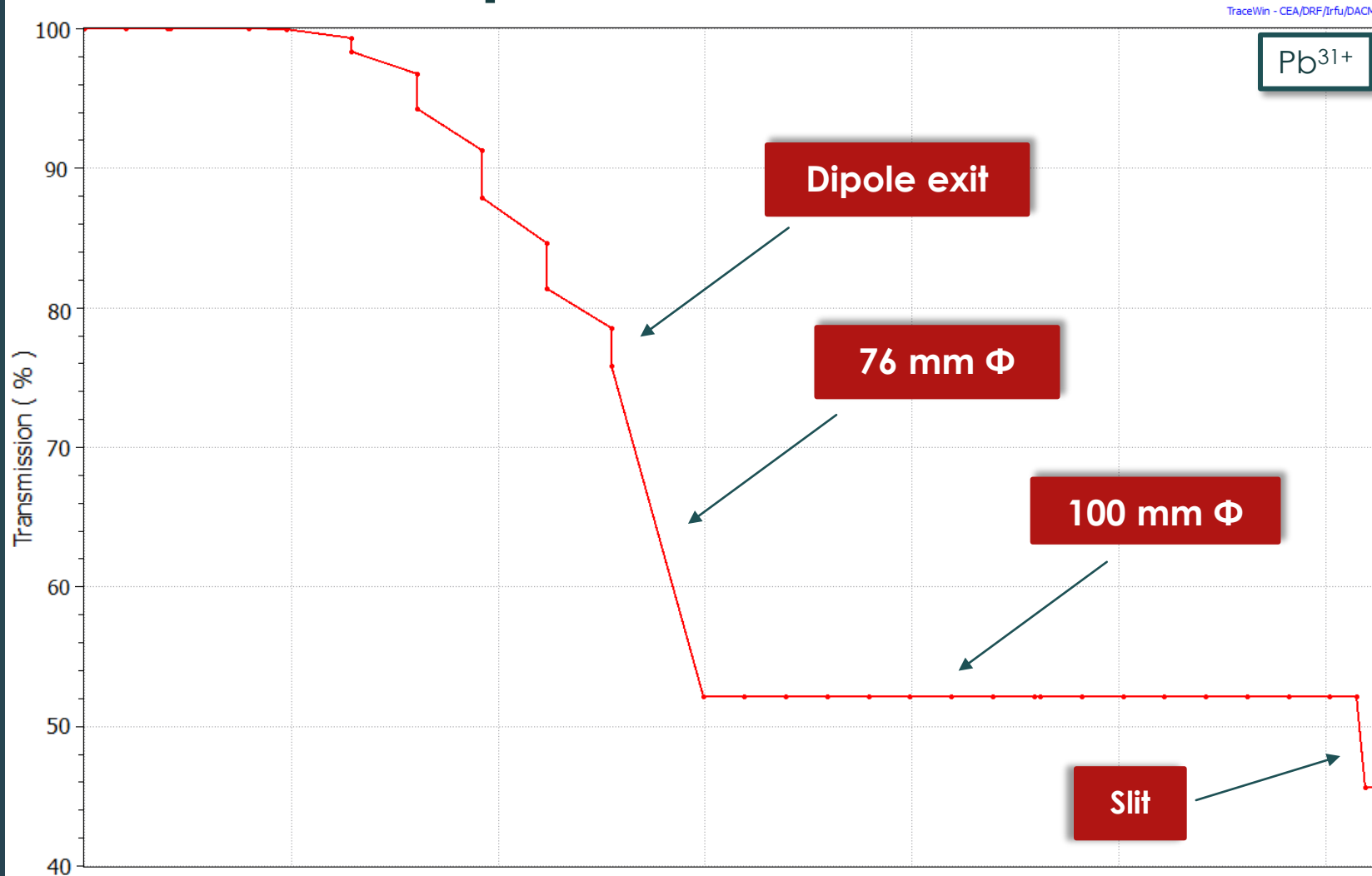


Pb^{31+} is one of the best transmitted charge state, contrary to O^{4+} and Pb^{14+}

Each beam is affected by specific non linear effects



Beam transport calculations

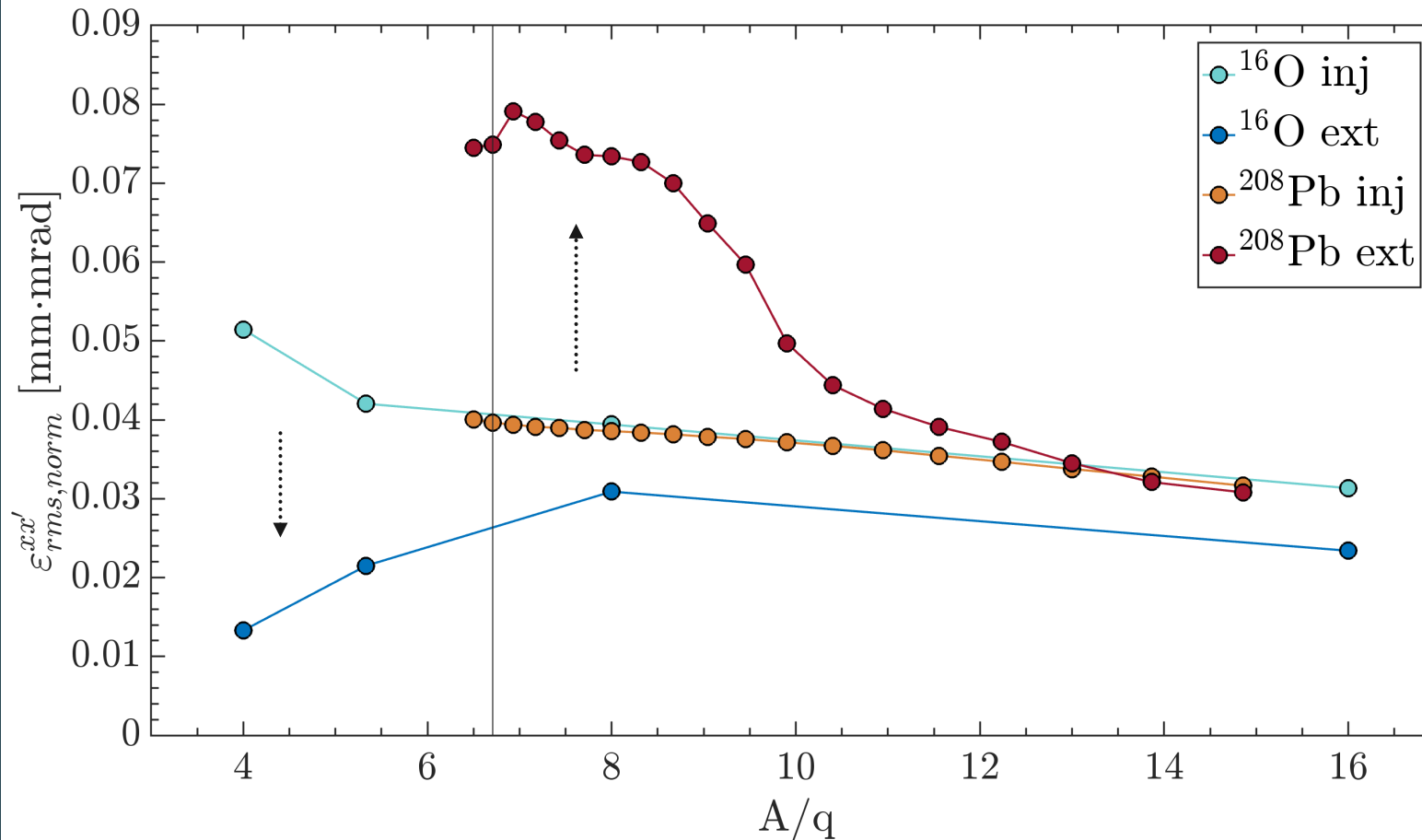


Pb 31+ transmission
along the LEBT line

Very large cuts even
in elements other
than the slit

only a 10% loss
at the slit

Beam transport calculations



normalized rms emittance of
transmitted beam
vs.
input beam from IBSimu



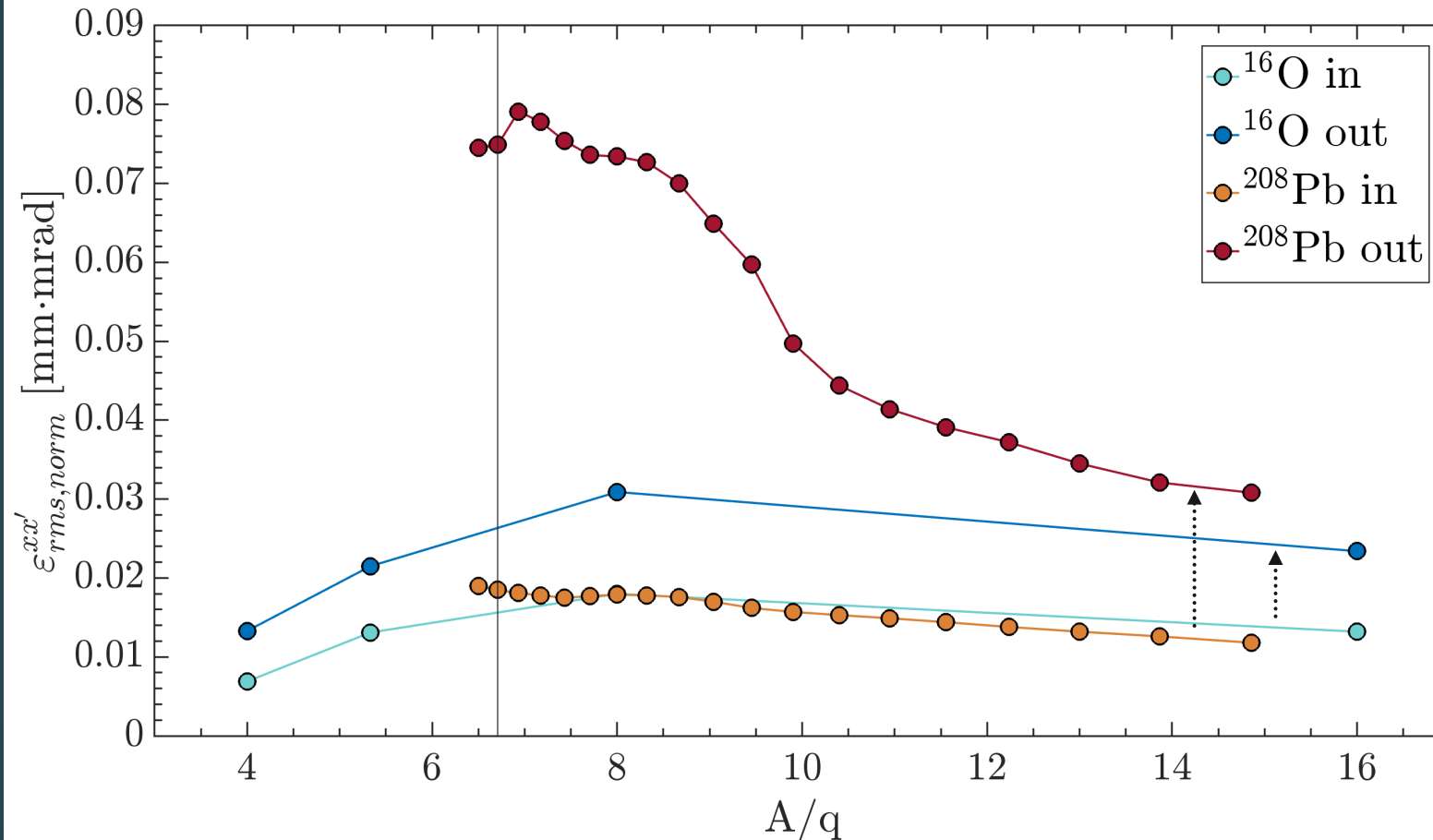
O beams emittances **decrease**, while
 Pb emittances show an **increase**

**Deteriorated
emittances are still
within the acceptance
limit expected
for PIAVE**

Transmission through PIAVE is close to the nominal one



Beam transport calculations



normalized rms emittance of
transmitted beam
vs.
same % in the input beam

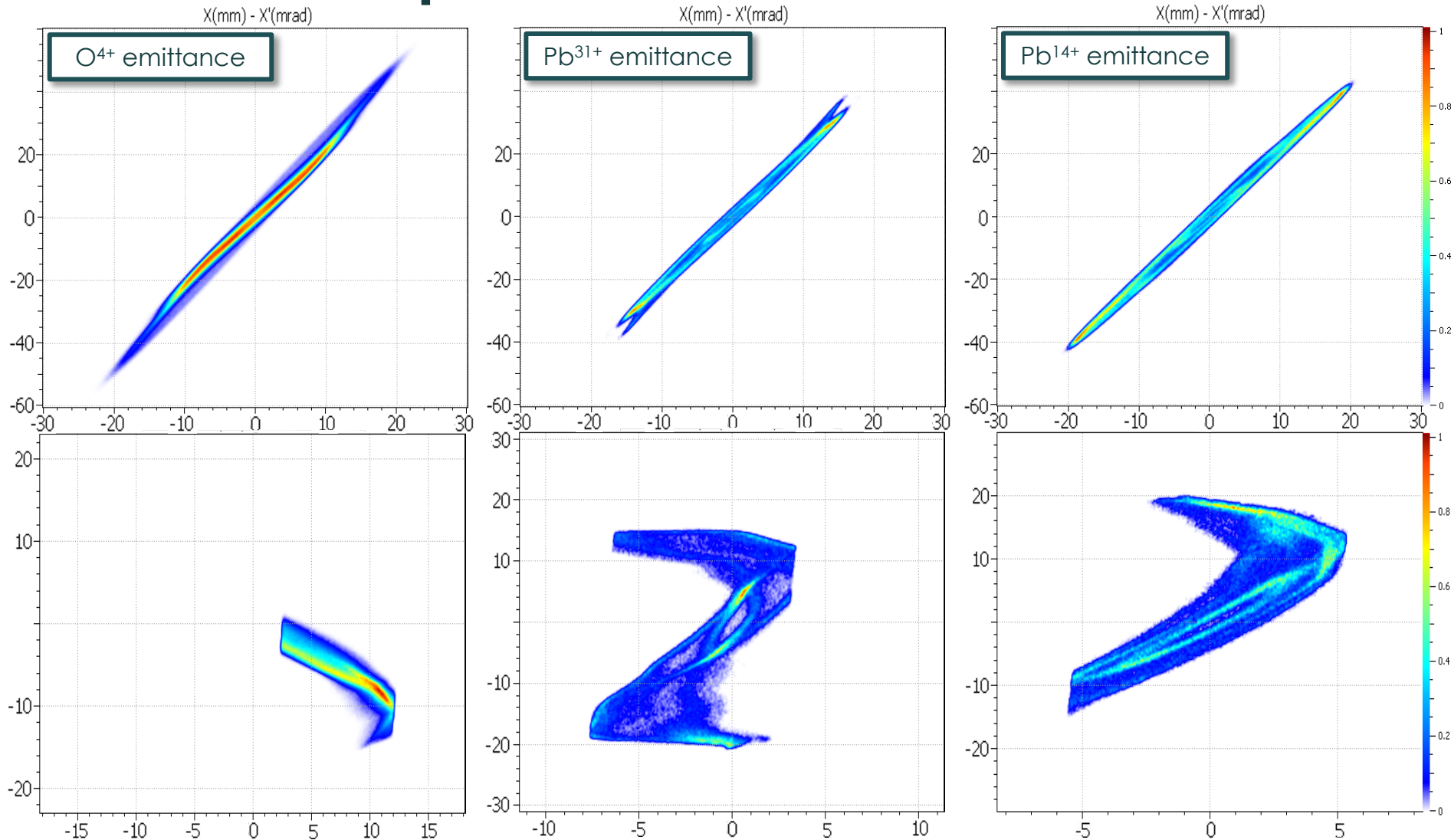


All beams show increasing
emittances

Emittance is not
conserved for the
same percentage of
the transmitted beam

Confirmation: non-linear forces are present in the dipole

Beam transport calculations



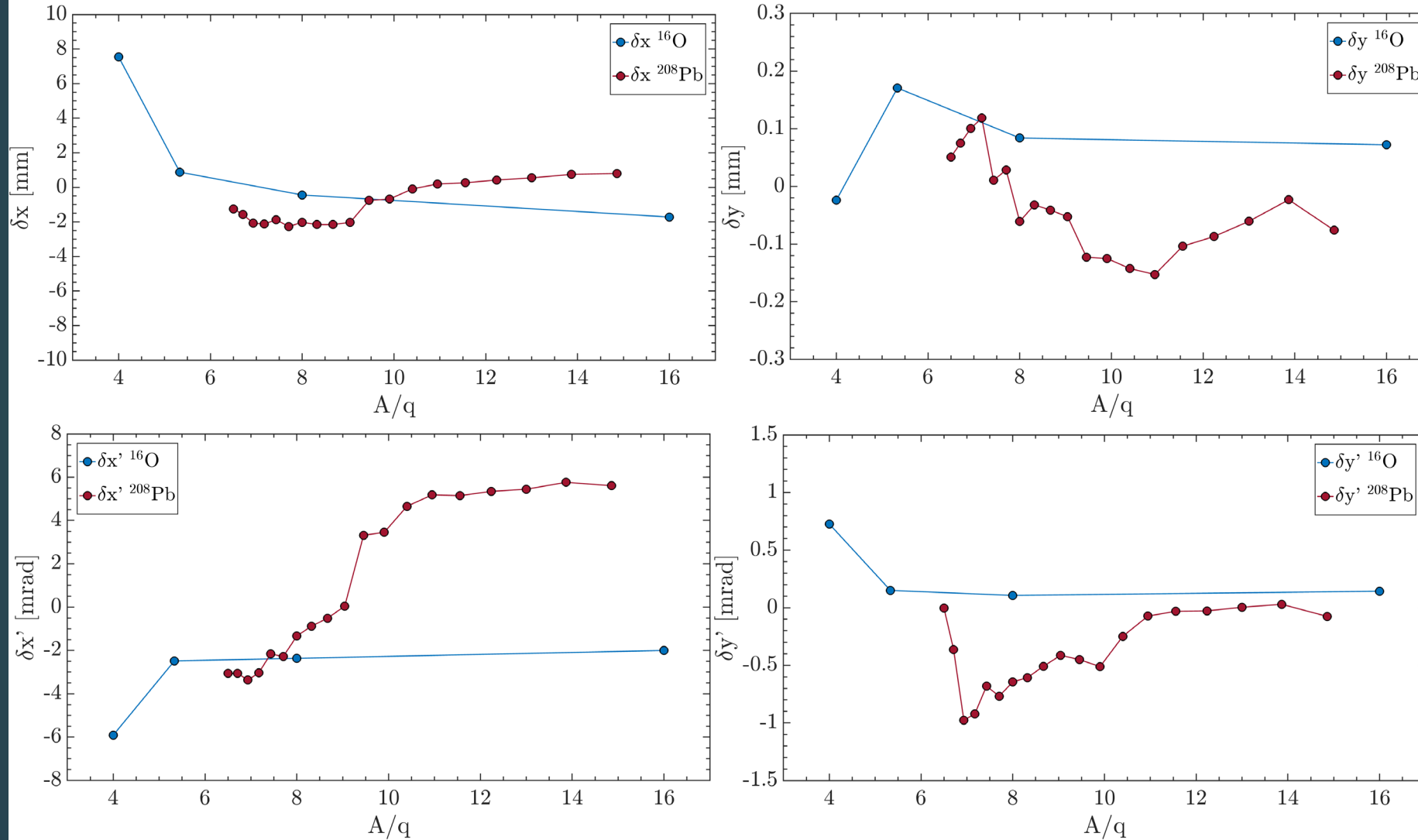
LEBT
entrance



LEBT
exit

**Phase space
deformation
→ emittance
deterioration**

Beam transport calculations



$\delta x, \delta x', \delta y, \delta y'$
differ for every beam



Transport induced
misalignment in
addition to the
mechanical ones

**Steerer values
cannot be scaled
following A/q**

Summary and Conclusions

- Thanks to IBSimu we simulated the beam extracted from LEGIS for the first time
- Transport simulations shed light on the reasons for the observed criticalities:
 - acceptance-emittance mismatch with the LEBT under study
 - main reason for the losses
 - optics not suitable for transport through the dipole
 - beam quality deterioration due to non linear effects induced by the dipole
 - irregular variation of position and divergence of the beam centroid with A/q
 - impossibility of a steerer scaling following the A/q

Possible solutions are under study:

modification of the LEBT layout and/or the design of a new extraction system

THANK YOU
FOR YOUR
ATTENTION!