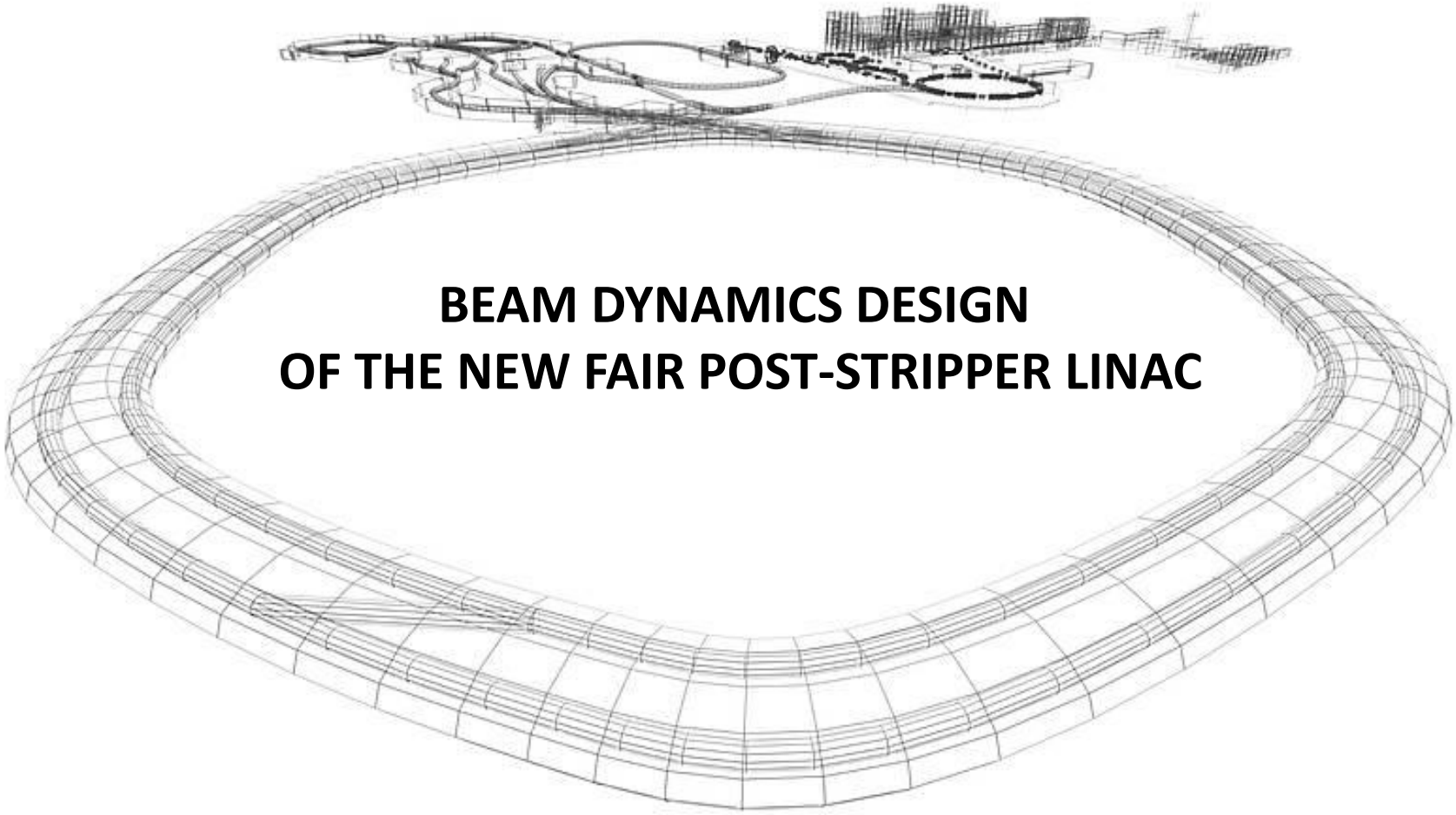
GSI Helmholtzzentrum für Schwerionenforschung GmbH



BEAM DYNAMICS DESIGN OF THE NEW FAIR POST-STRIPPER LINAC

Anna Rubin, 14.06.17

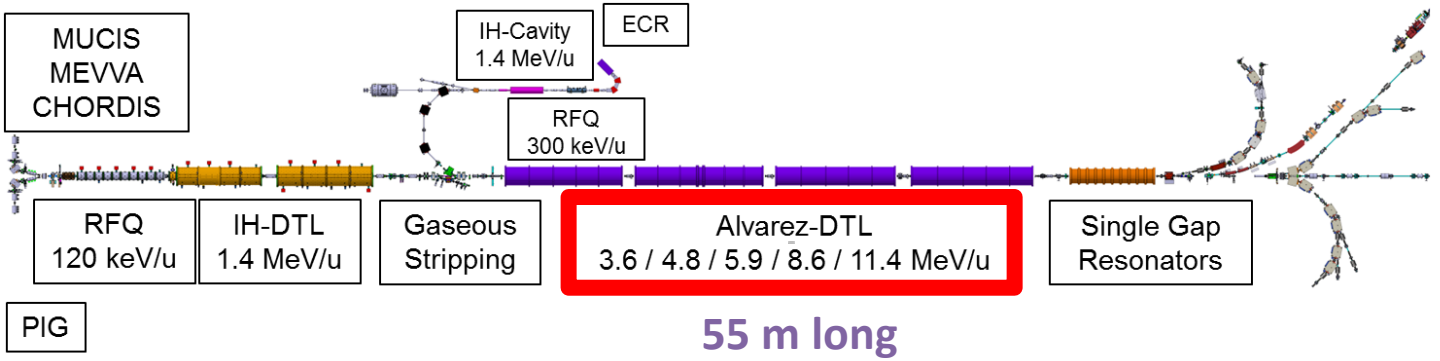
THANKS TO MY COLLEAGUES

Lars Groening
Sascha Mickat
Xiaonan Du

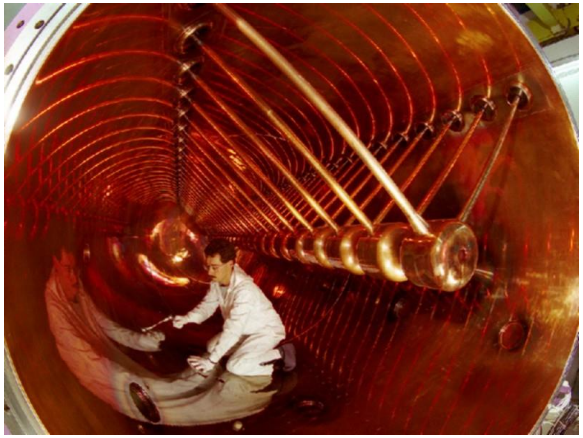
Michael Kaiser
Peter Gerhard
David Daehn

Udo Weinrich
Sabrina Appel
Oksana Geithner

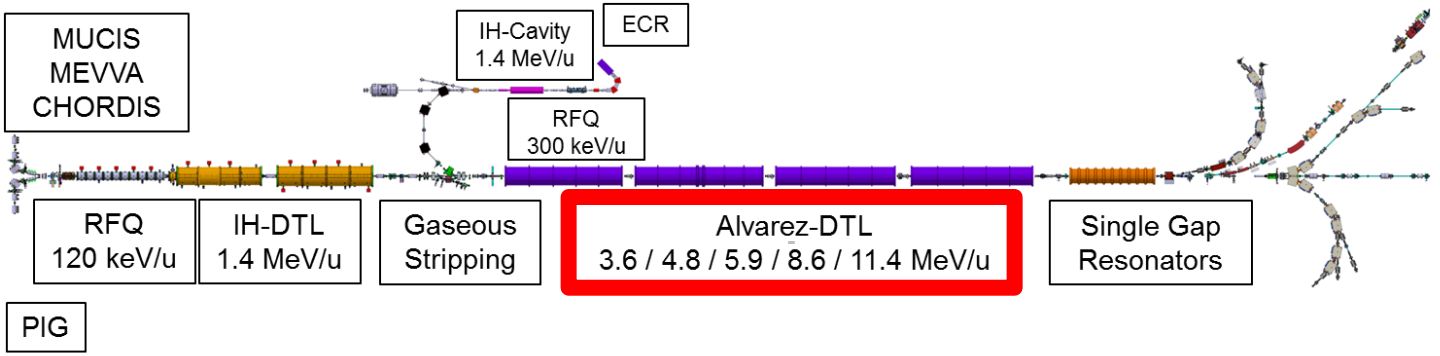
- Introduction
- Beam dynamics simulations
- Error study
- Beam brilliance study at SIS 18 input



55 m long

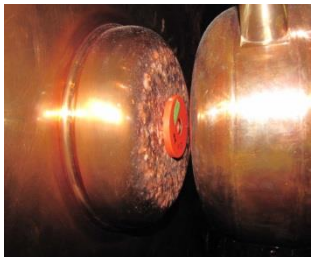


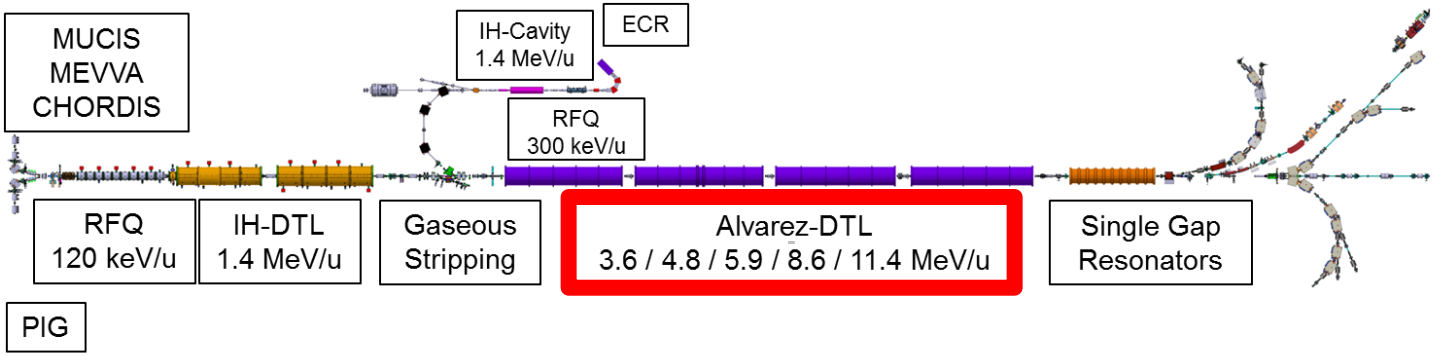
Acceleration of all ion species from protons to U^{28+}
Frequency 108 MHz



Alvarez DTL is more than 40 years in operation

- It has suffered from material fatigue (sparking, beam induced defects, water leaks, iron oxide deposits, bubbles and scars on the inner-tank surface)



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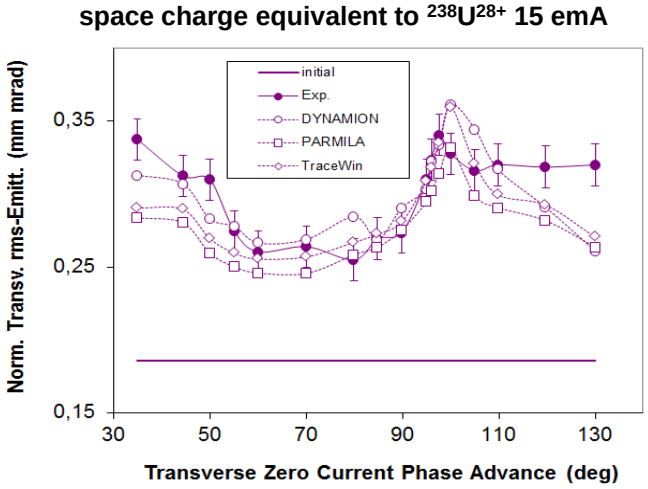
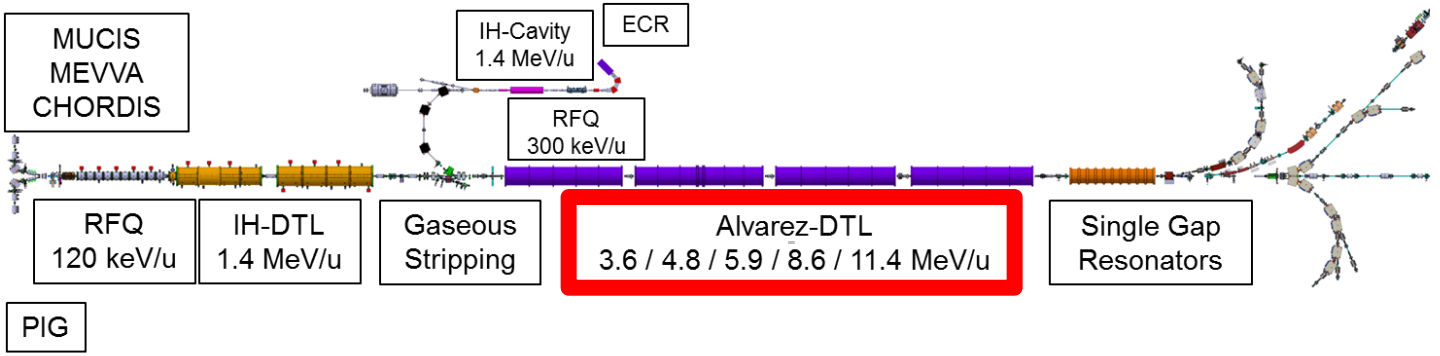
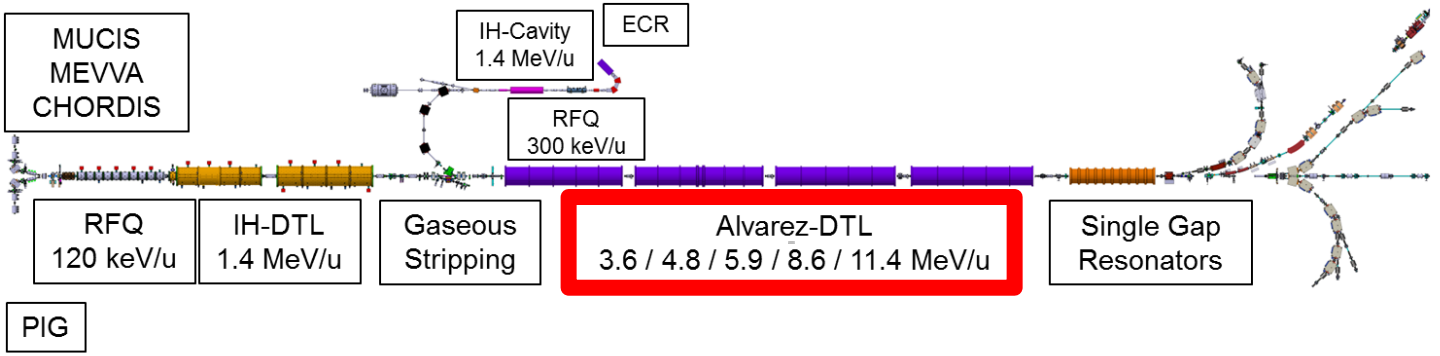
- Higher phase advance through stronger quadrupole gradients is needed to minimize the emittance growth due to the space charge (zero current phase advance 60º or higher instead of current limit for U^{28+} of 55º)





Alvarez DTL is more than 40 years in operation

- It has suffered from material fatigue (sparking, beam induced defects, water leaks, iron oxide deposits, bubbles and scars on the inner-tank surface)
- Higher phase advance through stronger quadrupole gradients is needed to minimize the emittance growth due to the space charge (zero current phase advance 60^{o} or higher instead of current limit for U^{28+} of 55^{o})
- Non-pulsed operation limits todays flexibility and efficiency for providing adequate beam to an increased number of users (multi-ion operation)



Refurbished vs new Alvarez

- A refurbished Alvarez would be strongly limited in beam dynamics with respect to FAIR, new DTL is designed to meet FAIR requirements

- Economically the refurbishment can not compete with a new DTL

New Alvarez DTL layout

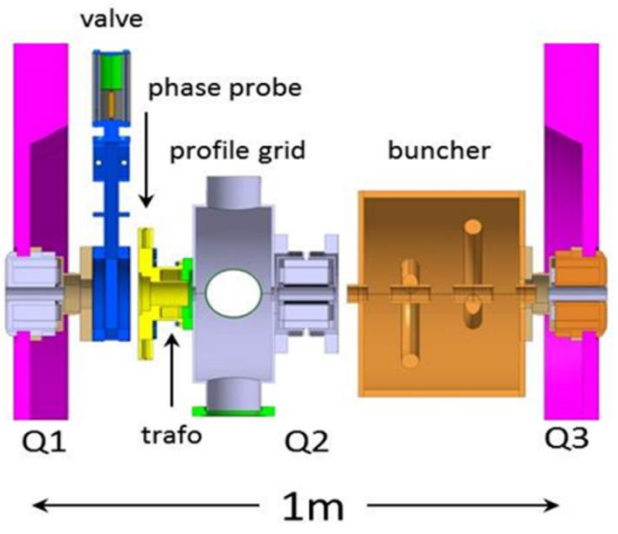
5 rf-cavities for acceleration, 184 cells

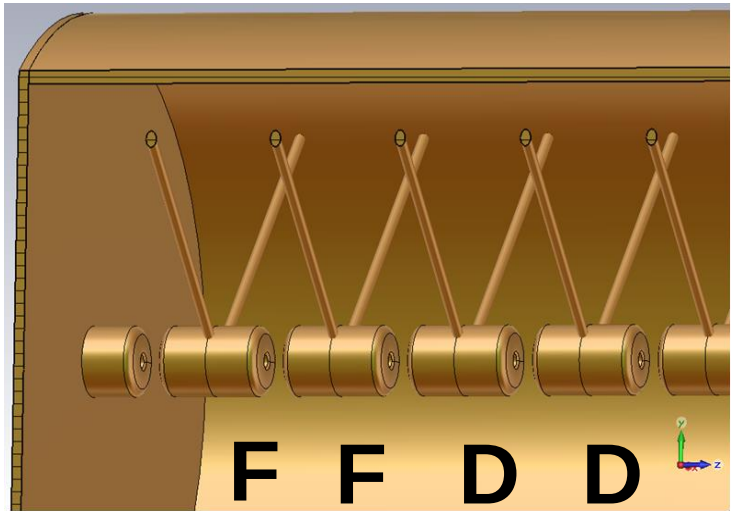
4 intertank sections

189 pulsed quadrupoles

4 intertank re-bunchers

INTERTANK





FFDD – quadrupoles focusing

zero current phase advance: 65 ^{o}

max pole tip field ≤ 0.8 T

RF design phases: -30^{o}, -30^{o}, -30^{o}, -25^{o}, -25^{o}

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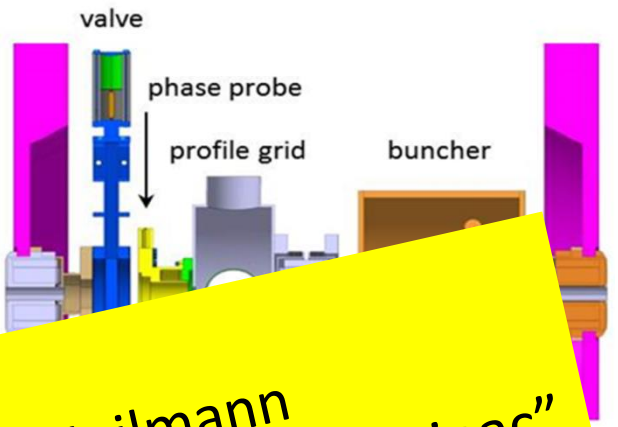
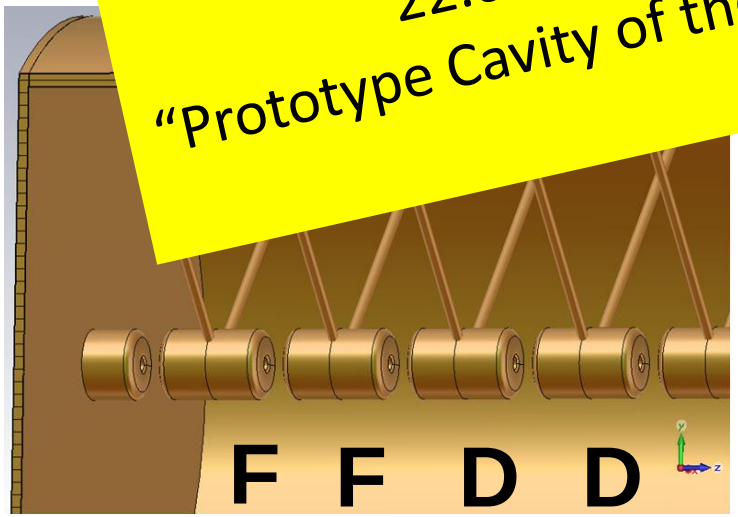
INTERTANK



22.06.2017: Dr. Manuel Heilmann
"Prototype Cavity of the new FAIR post-Stripper Linac"



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RF design phases: -30°, -30°, -30°, -25°, -25°

TRACEWIN

D. Uriot, N. Pichoff

CEA Saclay
DSM/Irfu/SACM/LEDA
CEN Saclay 91191 Gif sur Yvette cedex

TRACEWIN

“hard edge” model
DTL description

TRACEWIN

“hard edge” model
DTL description

3D field mapping

X. Du

D. Daehn

Studied models (A1):

- "hard edge" model for E-field and B-field with identical quadrupoles in each drift tube (effective length of 96mm)
- 3D field maps for E-field, analytical field model for B-field with identical quadrupoles
- 3D field maps for E-field and B-field with identical quadrupoles
- "hard edge" model for E-field and B-field with three groups of quadrupoles (effective lengths of 96 mm, 122 mm and 140 mm)
- 3D field maps for E-field, analytical field model for B-field with three groups of quadrupoles as above

DELIVER ALMOST IDENTICAL RESULTS !

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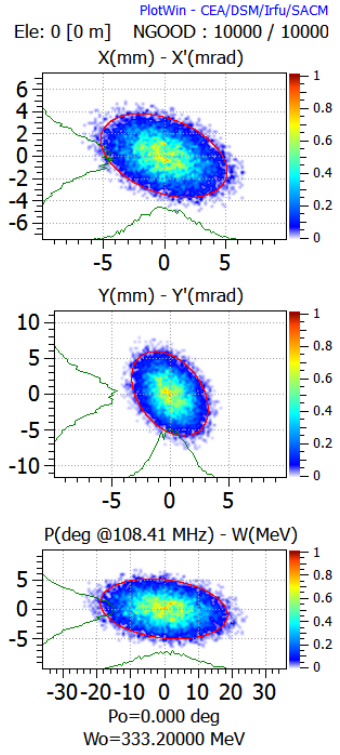
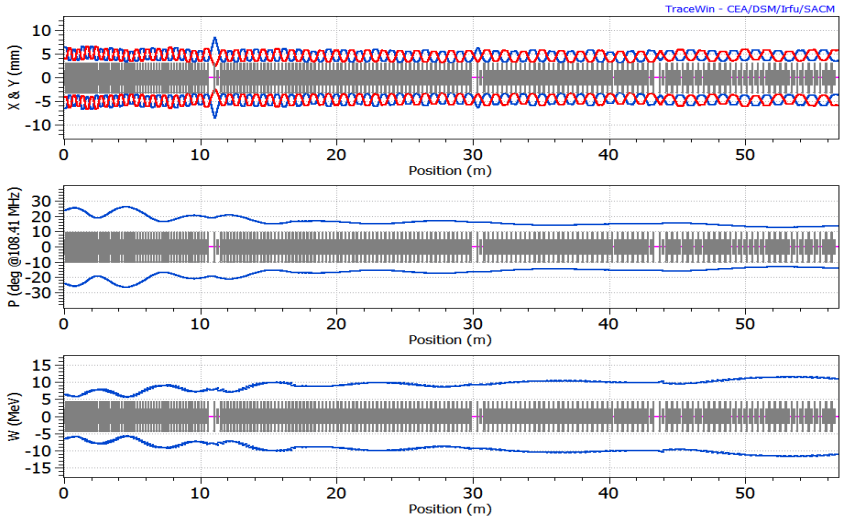
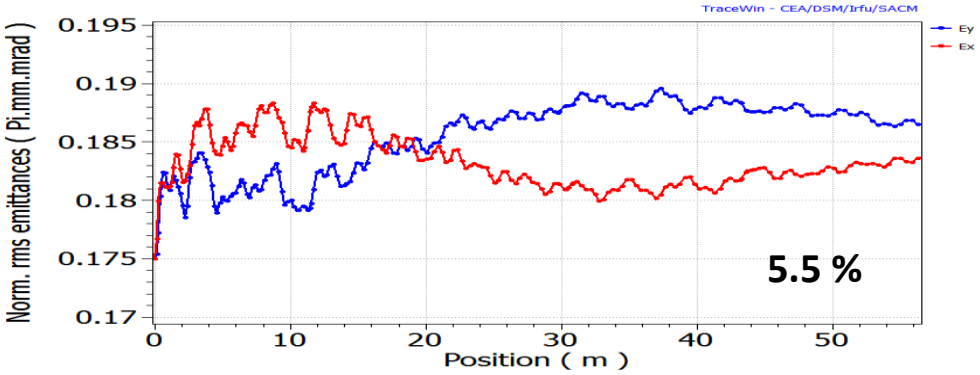
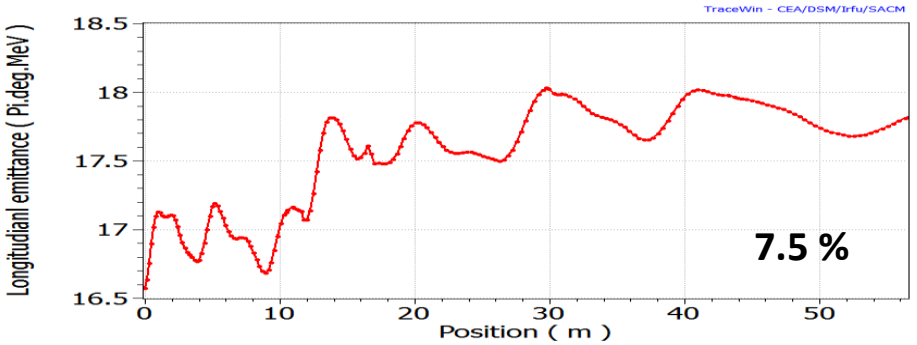
DELIVER ALMOST IDENTICAL RESULTS !

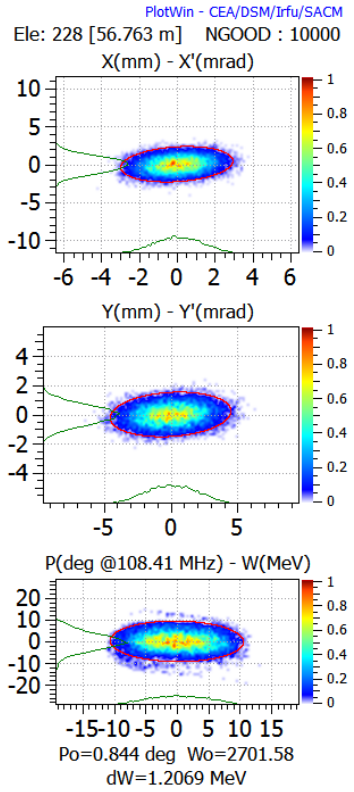
NOMINAL FAIR CASE











X-X'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9878 Pi.mm.mrad [Norm.]
Beta = 1.4800 mm/Pi.mrad
Alpha = 0.4100
Y-Y'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9861 Pi.mm.mrad [Norm.]
Beta = 0.6000 mm/Pi.mrad
Alpha = 0.4000
Phase-Energy
Emit [rms] = 16.5700 Pi.deg.MeV [Norm.]
Emit [95.00%] = 93.0913 Pi.deg.MeV [Norm.]
Beta = 3.8082 deg/Pi.MeV
Alpha = 0.2100

X-X'
Emit [rms] = 0.1838 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0690 Pi.mm.mrad [Norm.]
Beta = 1.2879 mm/Pi.mrad
Alpha = -0.1881
Y-Y'
Emit [rms] = 0.1865 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0702 Pi.mm.mrad [Norm.]
Beta = 2.9929 mm/Pi.mrad
Alpha = -0.1522
Phase-Energy
Emit [rms] = 17.8232 Pi.deg.MeV [Norm.]
Emit [95.00%] = 99.0856 Pi.deg.MeV [Norm.]
Beta = 1.1308 deg/Pi.MeV
Alpha = 0.0265

INPUT

	1 FAIR	2 Zero Current	3 Low Energy	4 Larger Long. Emit.	5 Smaller Long. Emit.	6 Transv. Flat Input
I, mA	16.5	**0**	**0**	16.5	16.5	16.5
E_x (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.0875**
E_y (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.35**
E_z (rms), MeV/u deg	0.07	0.07	0.07	**0.14**	**0.035**	0.07
Energy (out), MeV/u	11.4	11.4	**3.3**	11.4	11.4	11.4

INPUT

	1 FAIR	2 Zero Current	3 Low Energy	4 Larger Long. Emit.	5 Smaller Long. Emit.	6 Transv. Flat Input
I, mA	16.5	0	0	16.5	16.5	16.5
E_x (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	0.0875
E_y (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	0.35
E_z (rms), MeV/u deg	0.07	0.07	0.07	0.14	0.035	0.07
Energy (out), MeV/u	11.4	11.4	3.3	11.4	11.4	11.4

OUTPUT

	1 FAIR	2 Zero Current	3 Low Energy	4 Larger Long. Emit.	5 Smaller Long. Emit.	6 Transvers. Flat Input
Transmission	100%	100%	100%	100%	100%	100%
ΔEx, total for 95%	7%	0%	0%	7%	8%	16%
ΔEy, total for 95%	7%	0%	0%	10%	7%	3%
ΔEz, total for 95%	10%	0.7%	1.7%	5%	11%	4%
Bunch Length, 95%	±16 deg	±11 deg	±33 deg	±21 deg	±14 deg	±17 deg

ERROR STUDY FOR THE NEW ALVAREZ (TraceWin, FAIR nominal case):

machine errors + **beam errors**

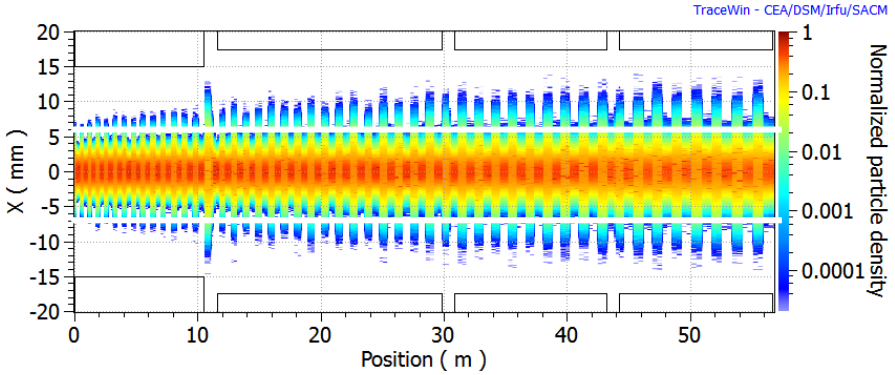
ERROR STUDY FOR THE NEW ALVAREZ (TraceWin, FAIR nominal case):

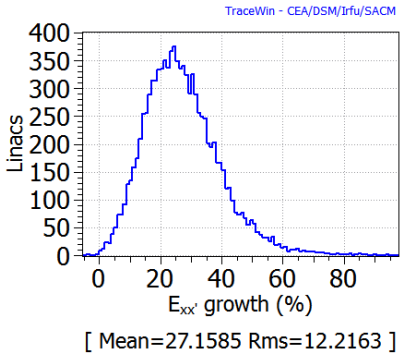
machine errors + **beam errors**

Quadrupole displacement x,y: ± 0.15 mm each
Quadrupole rotation around each of the three axis: ± 1°
Gap voltage : ± 1%
Gap phase: ± 1°

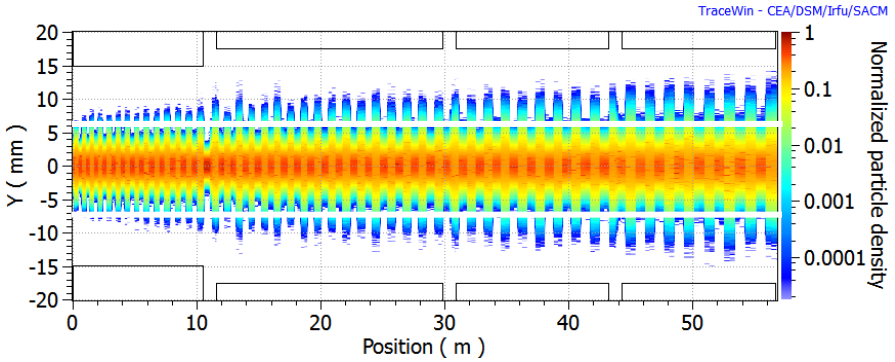
Initial energy: ± 0.5%
All three initial emittances: ± 15%
Mismatches: ± 10%
Current: ± 15%

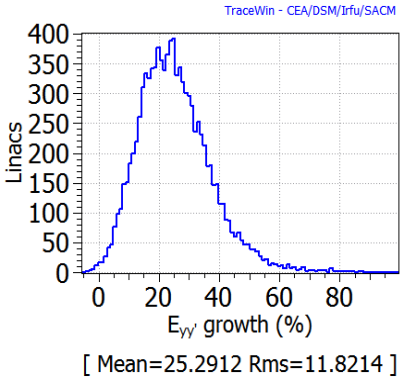
all errors are independently and uniformly distributed on the interval [-max, +max]





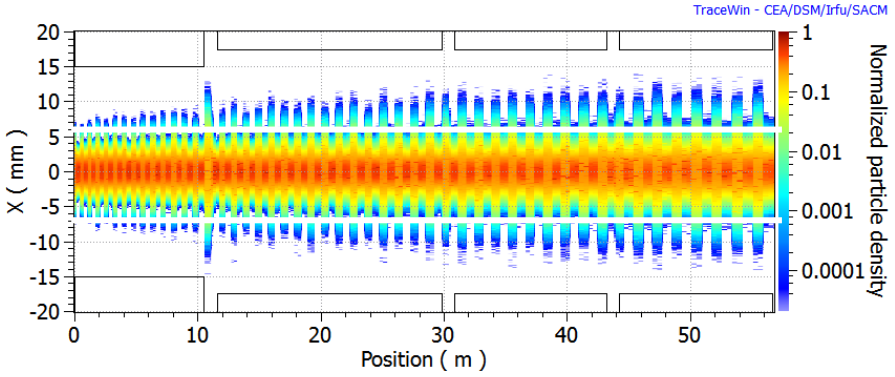
10 000 runs,
10 000 particles

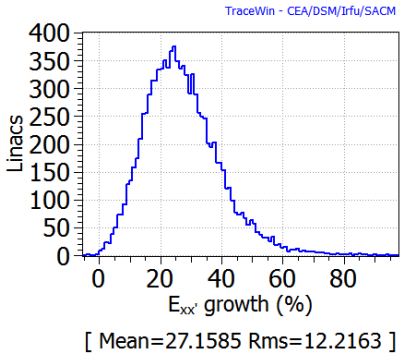




mean additional
Ɛ growth is 26%

(rms = 12%)





10 000 runs,
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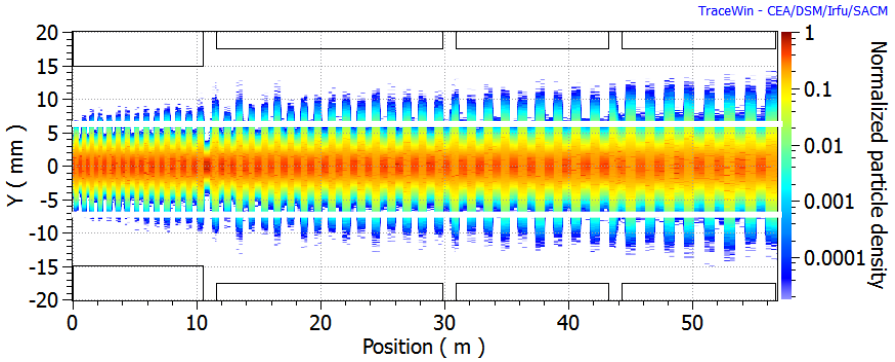

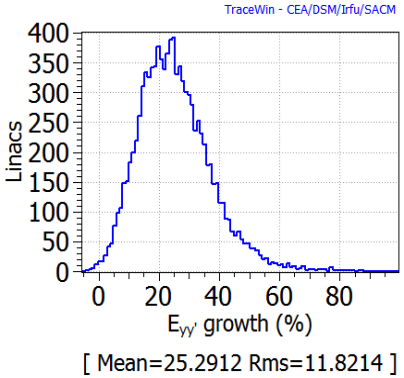

mean additional
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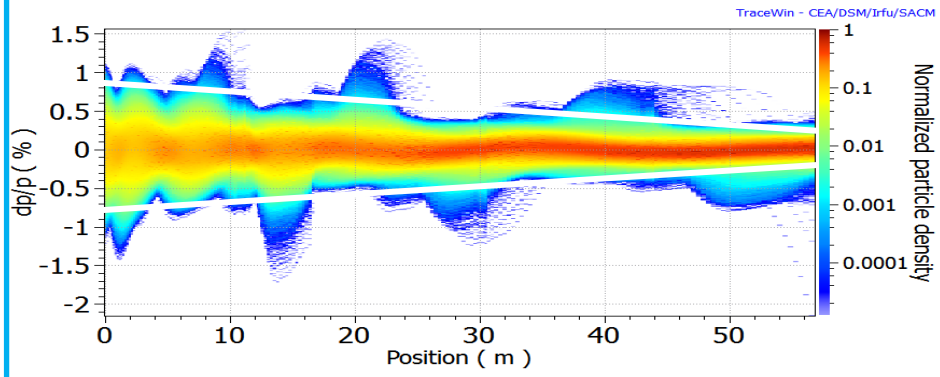
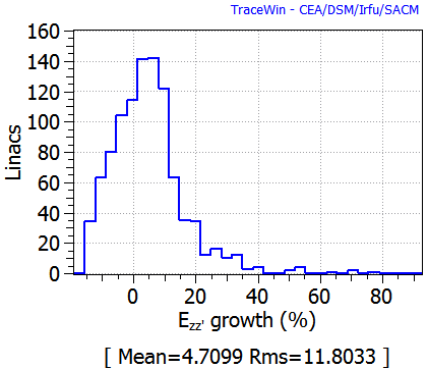
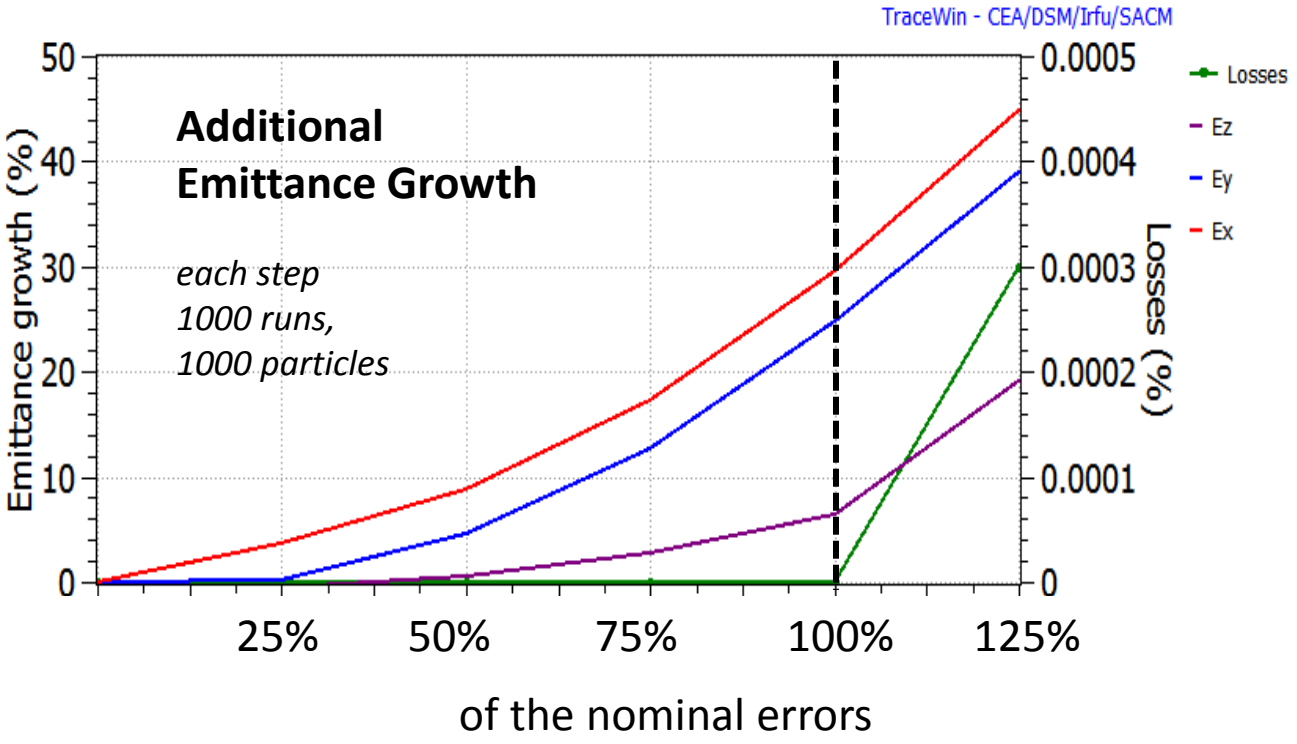
(rms = 12%)





mean additional
Ɛ growth is 5%

(rms = 12%)

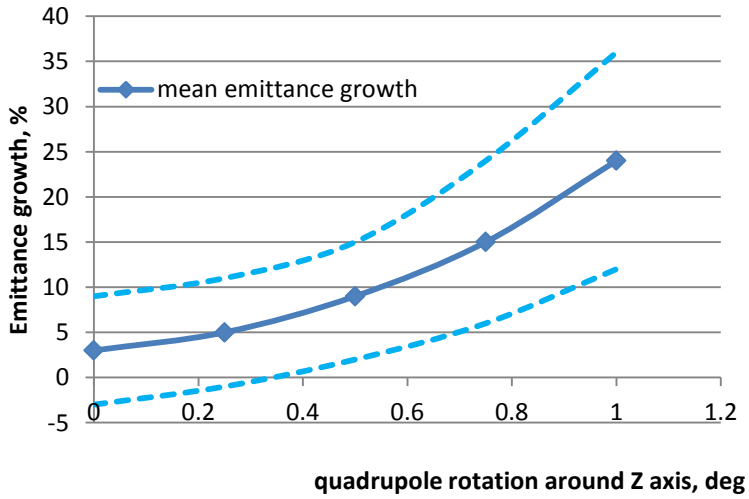

TraceWin - CEA/DSM/Irfu/SACM
Additional
Emittance Growth
each step
1000 runs,
1000 particles
Emittance growth (%)
Losses (%)
Losses
Ez
Ey
Ex
0
10
20
30
40
50
0
0.0001
0.0002
0.0003
0.0004
0.0005
25%
50%
75%
100%
125%
of the nominal errors

WHO IS GUILTY?

WHO IS GUILTY?

Transversally

quadrupole rotation
around Z axis

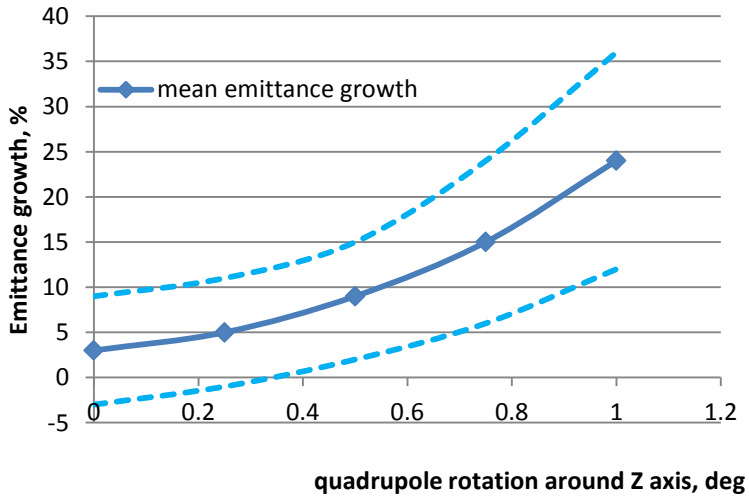


100 runs, 10 000 particles

WHO IS GUILTY?

Transversally

quadrupole rotation
around Z axis



A1: 0.5°
A2-A5: 1.0°

=> 20 % of emit. growth

A1-A5: 0.5°

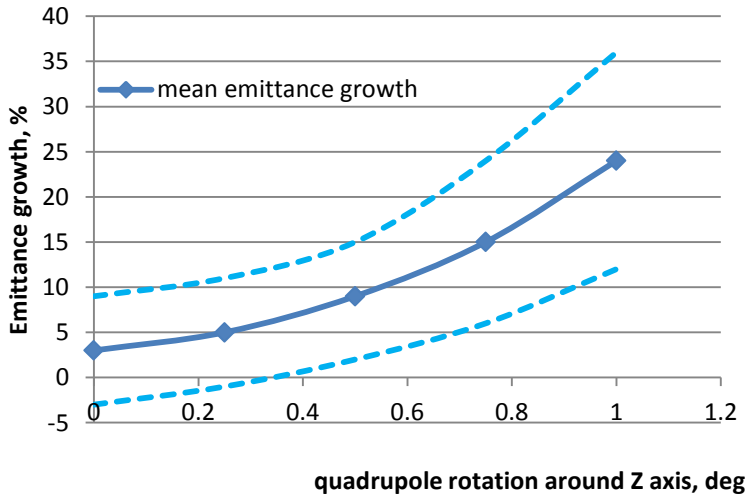
=> 10 % of emit. growth

100 runs, 10 000 particles

WHO IS GUILTY?

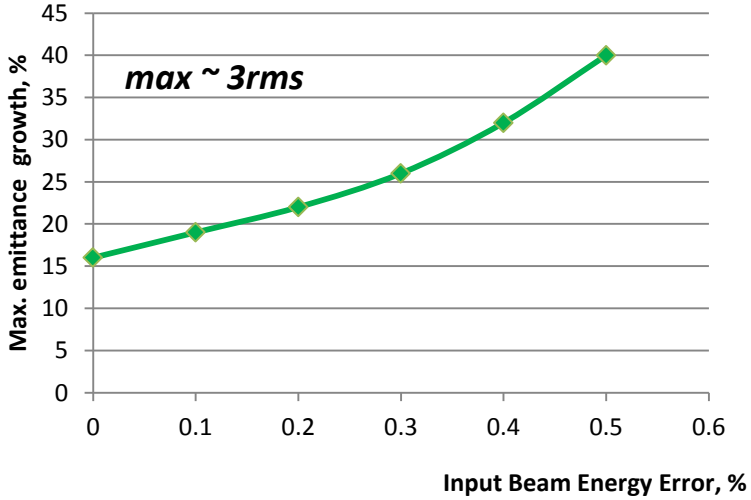
Transversally

quadrupole rotation
around Z axis



Longitudinally

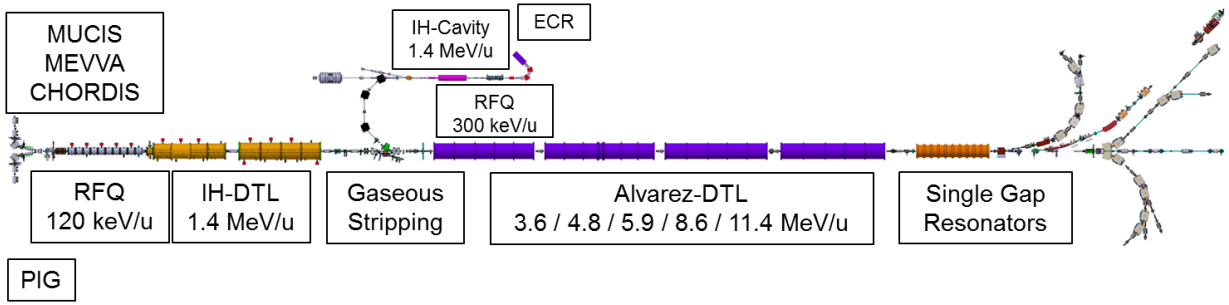
energy error
of the input beam



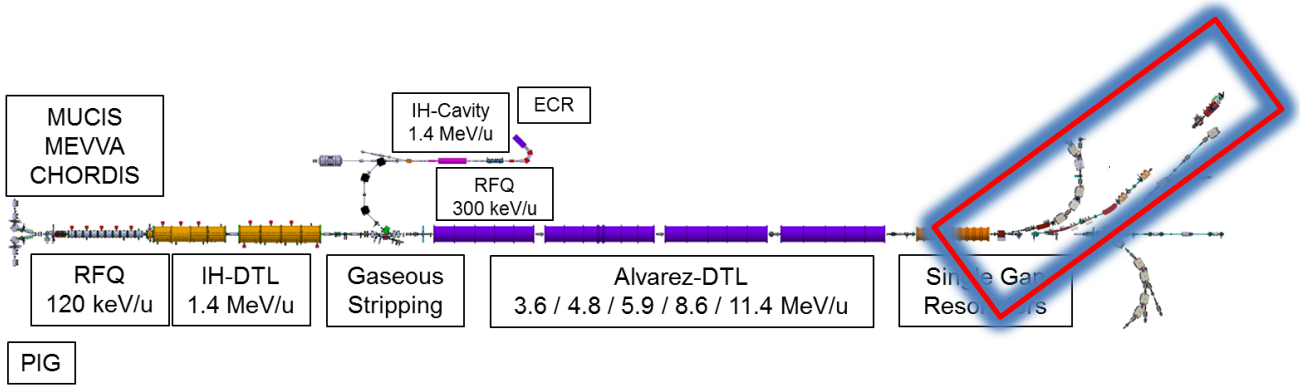
100 runs, 10 000 particles

SIS18 Acceptance / Beam Brilliance Study

Total normalized emittance at SIS 18 is ε_x = 0.8 mm mrad



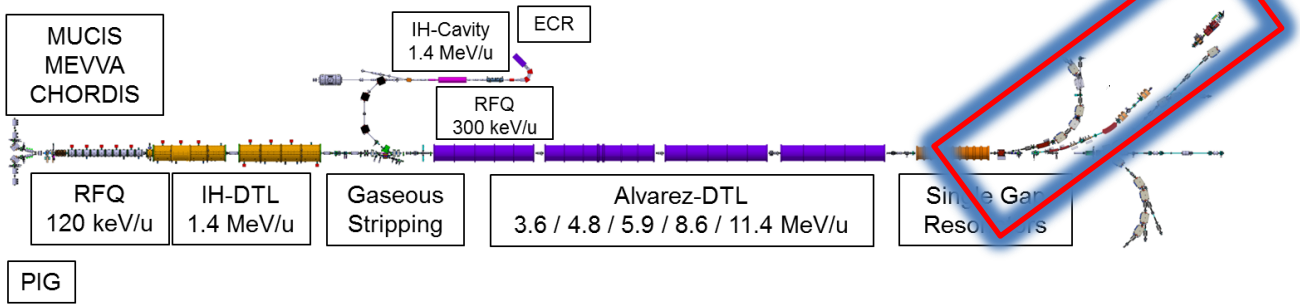
SIS18 Acceptance / Beam Brilliance Study



Total normalized emittance at SIS 18 is ε_x = 0.8 mm mrad

Emittance growth in TK

SIS18 Acceptance / Beam Brilliance Study

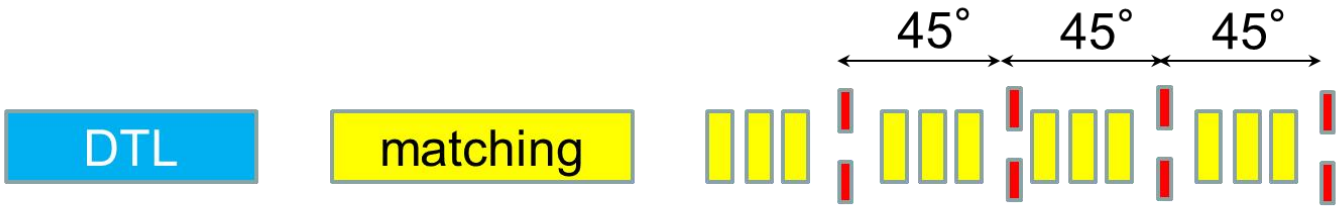


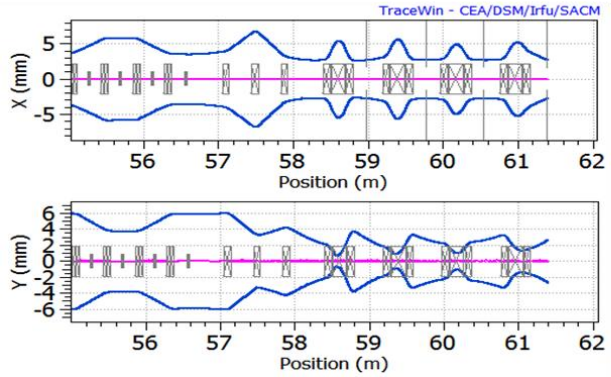
Total normalized emittance at SIS 18 is ε_x = 0.8 mm mrad

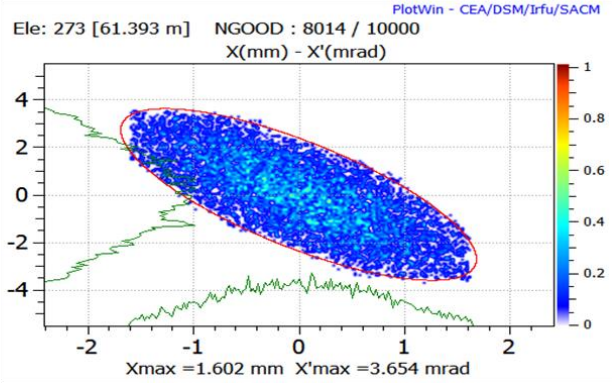
Emittance growth in TK

Total normalized emittance at the DTL Alvarez exit

Virtual Collimators Line



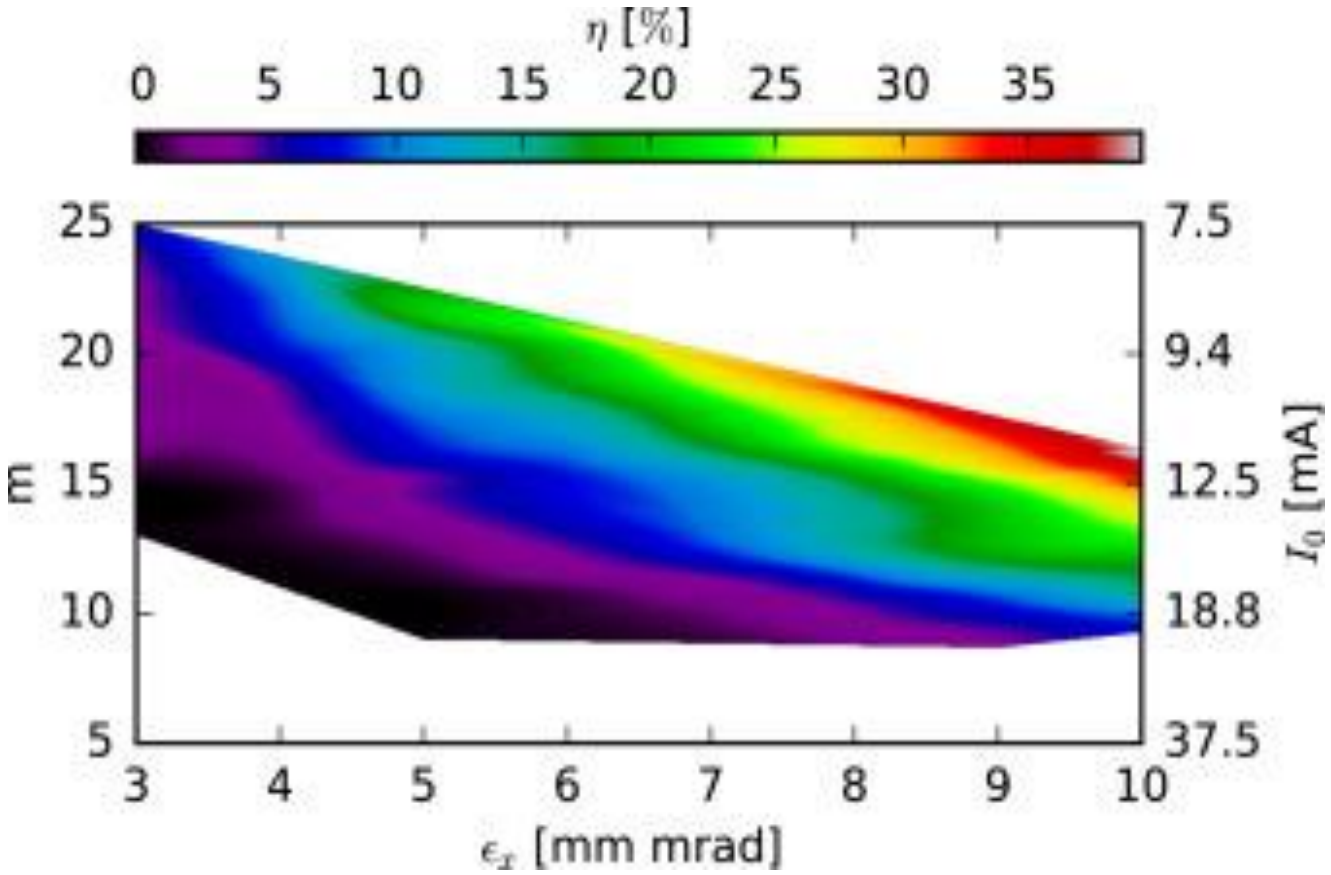




Emittance growth from DTL to SIS18	SIS18 Input Without errors	SIS18 Input With errors in DTL (aver.)
30%	13.2 mA	12.2 mA
10%	14.2 mA	13.2 mA

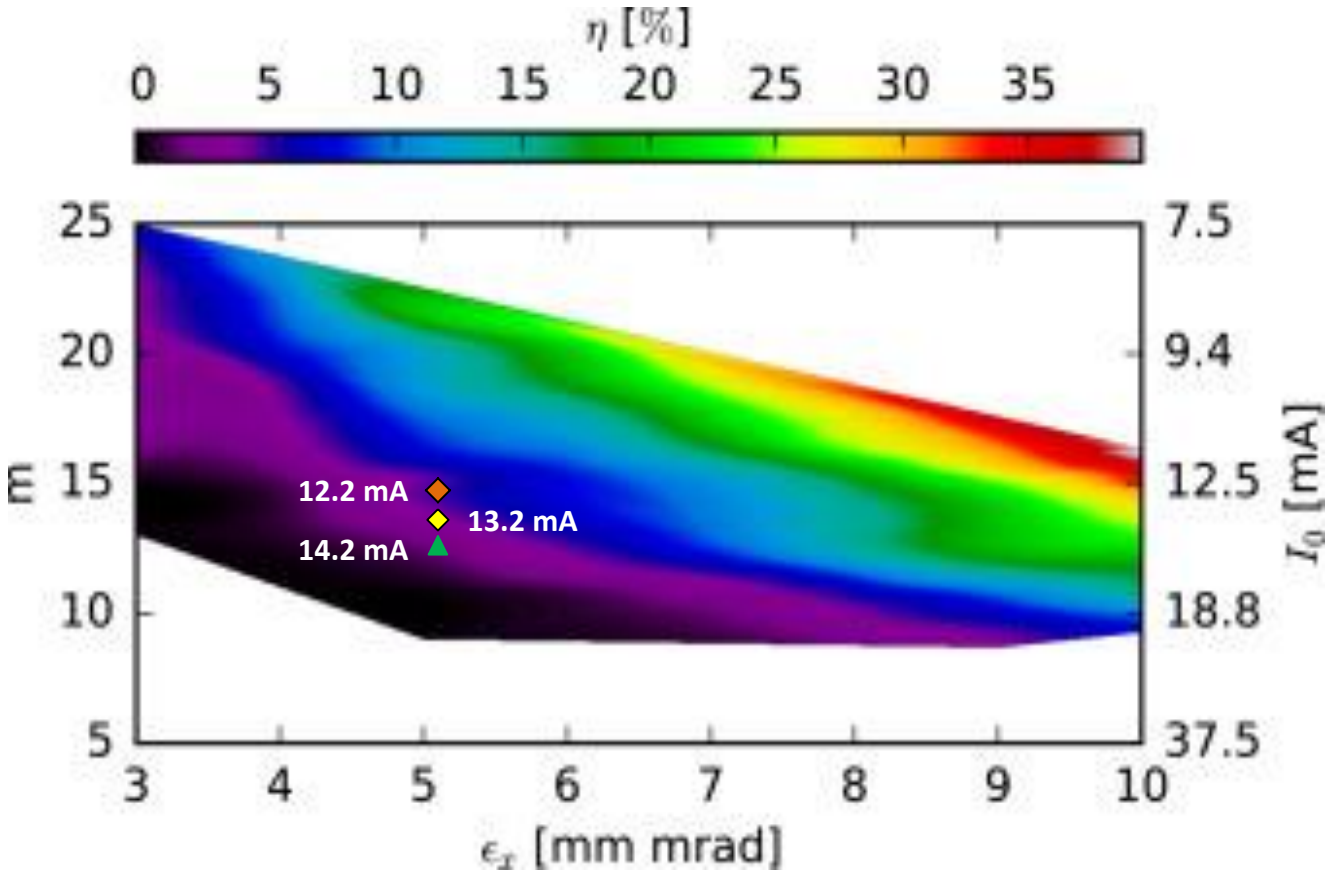
Emittance growth from DTL to SIS18	SIS18 Input Without errors	SIS18 Input With errors in DTL (aver.)
30%	13.2 mA	12.2 mA
10%	14.2 mA	13.2 mA

S. Appel - The 3D Pareto front for a simultaneous optimization of multiplication factor, loss and emittance



Emittance growth from DTL to SIS18	SIS18 Input Without errors	SIS18 Input With errors in DTL (aver.)
30%	13.2 mA	12.2 mA
10%	14.2 mA	13.2 mA

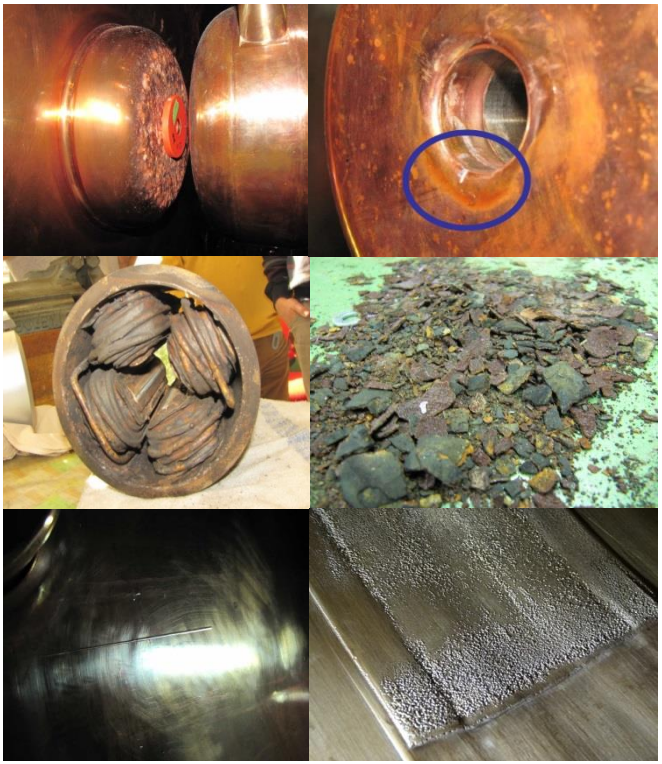
S. Appel - The 3D Pareto front for a simultaneous optimization of multiplication factor, loss and emittance



CONCLUSION:

- The new Alvarez DTL is robust machine with a small emittance growth
- Error study shows the mean rms emittance growth of ~ 30%, taking into account nominal emittance growth and large machine and beam errors
- The quadrupole rotation around Z axis (especially in A1) is a critical point for the transverse emittance growth, input energy error – for longitudinal
- Small emittance growth in TK will provide the beam brilliance, which satisfies the FAIR requirements

Thank you for your attention!

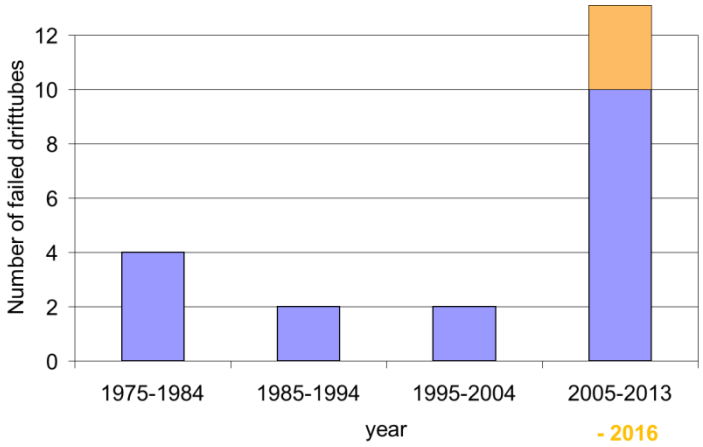


- HV sparking
- beam induced defects

- ground fault
- water leaks
- deposits (iron oxide)

- inner-tank surface (bubbles, scars)

S. Mickat, oct. 2016

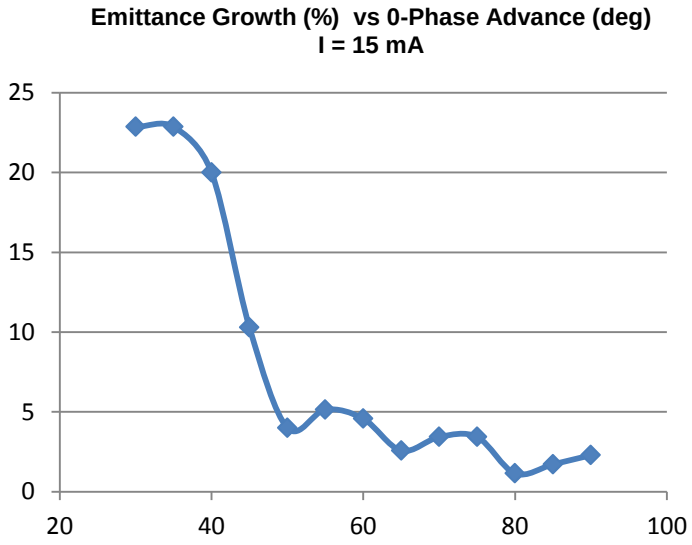


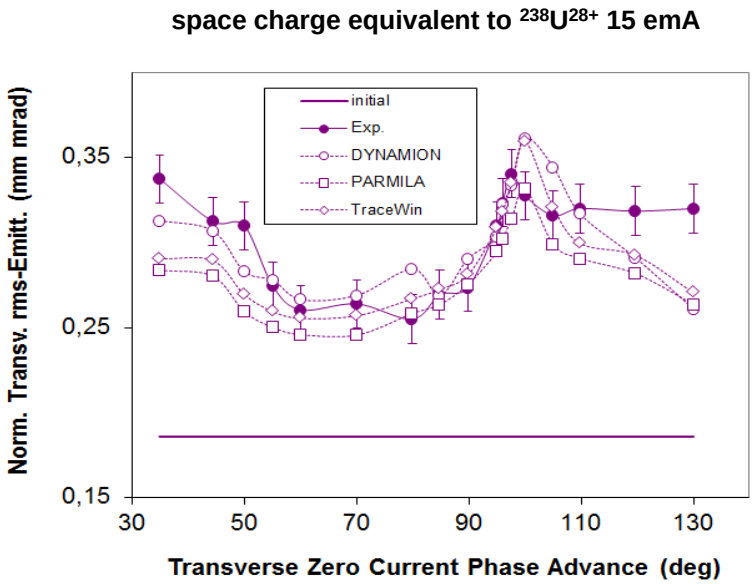
1.st TANK

Transverse emittance growth for different initial phase advance

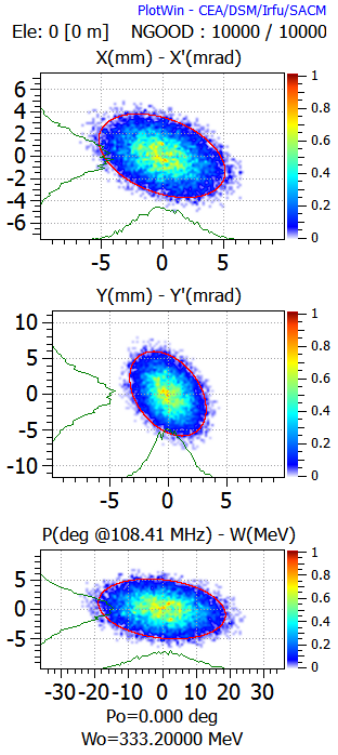
matched solution, box model

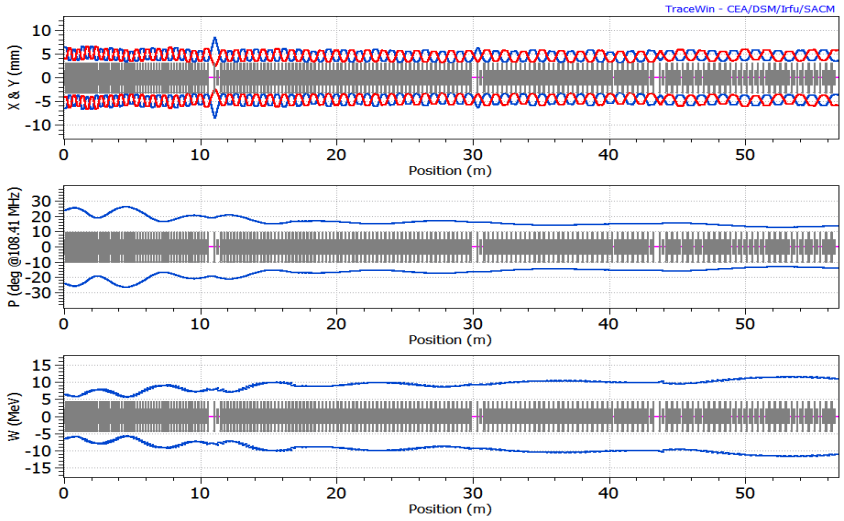
$E_{x,y}$ (rms, norm) = 0.175 mm mrad, E_z = 70 deg keV/u

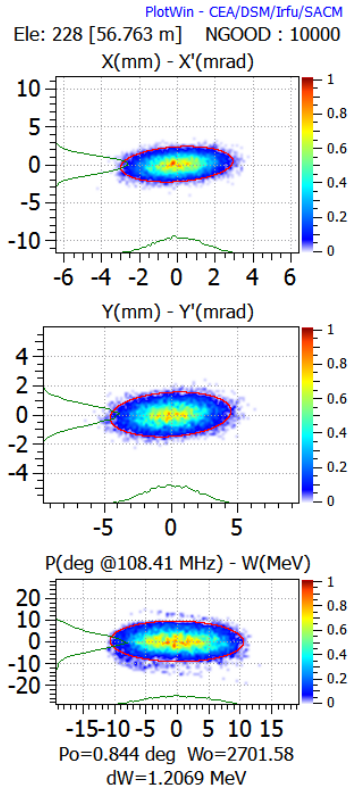


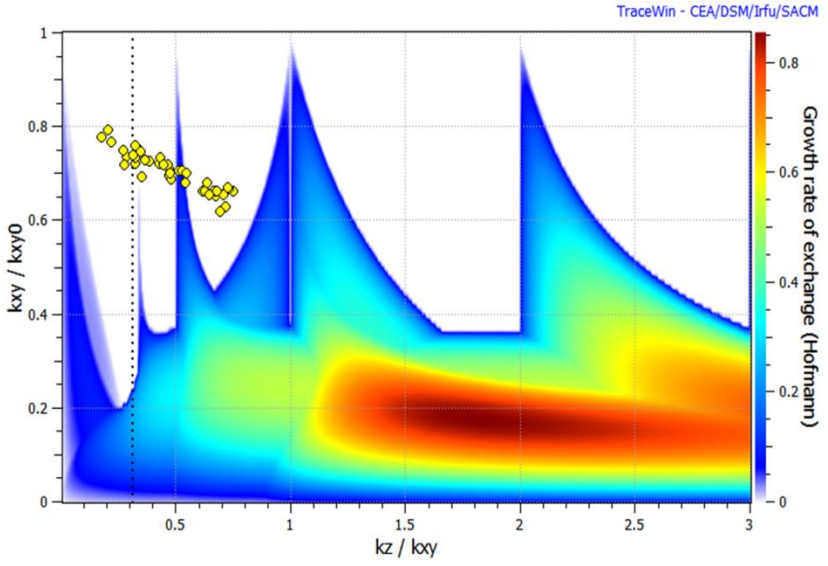


NOMINAL FAIR CASE









X-X'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9878 Pi.mm.mrad [Norm.]
Beta = 1.4800 mm/Pi.mrad
Alpha = 0.4100
Y-Y'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9861 Pi.mm.mrad [Norm.]
Beta = 0.6000 mm/Pi.mrad
Alpha = 0.4000
Phase-Energy
Emit [rms] = 16.5700 Pi.deg.MeV [Norm.]
Emit [95.00%] = 93.0913 Pi.deg.MeV [Norm.]
Beta = 3.8082 deg/Pi.MeV
Alpha = 0.2100

X-X'
Emit [rms] = 0.1838 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0690 Pi.mm.mrad [Norm.]
Beta = 1.2879 mm/Pi.mrad
Alpha = -0.1881
Y-Y'
Emit [rms] = 0.1865 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0702 Pi.mm.mrad [Norm.]
Beta = 2.9929 mm/Pi.mrad
Alpha = -0.1522
Phase-Energy
Emit [rms] = 17.8232 Pi.deg.MeV [Norm.]
Emit [95.00%] = 99.0856 Pi.deg.MeV [Norm.]
Beta = 1.1308 deg/Pi.MeV
Alpha = 0.0265

30% total emittance growth behind DTL

DTL Input rms emittance	SIS18 Input Without errors	SIS18 Input With errors in DTL (aver.)
0.175 mm mrad	13.2 mA	12.2 mA
0.150 mm mrad	14.0 mA	12.9 mA (*)
0.125 mm mrad	14.6 mA	13.4 mA (*)

(*) very preliminary estimations

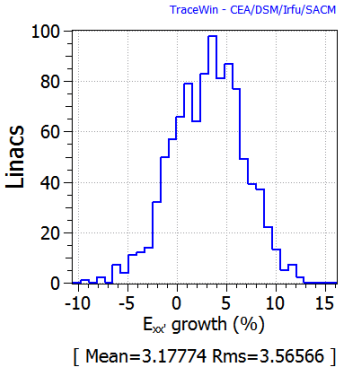
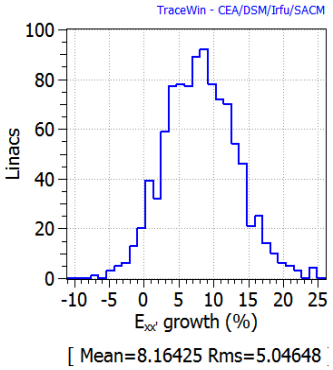
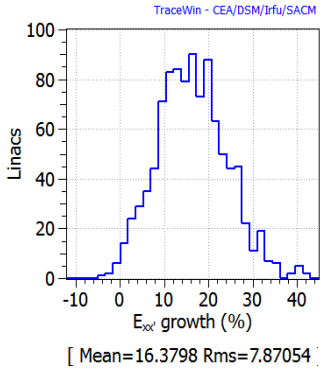
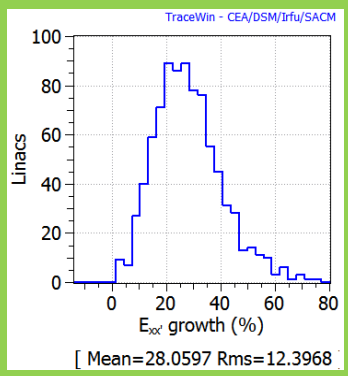
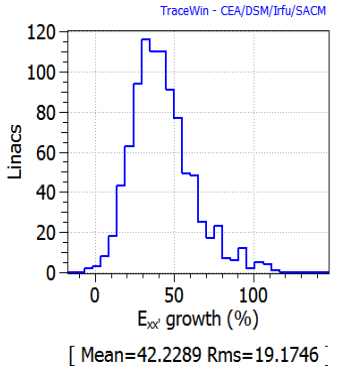
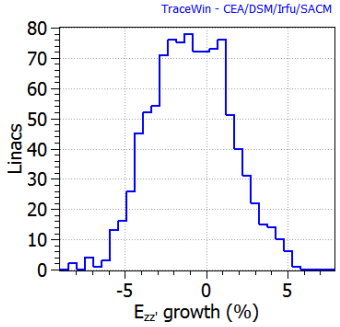
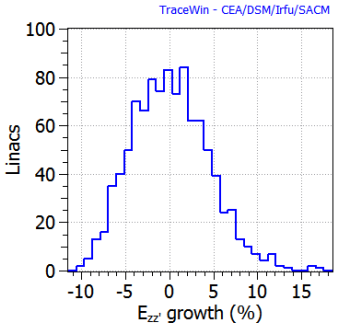
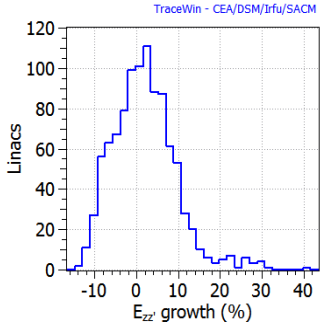
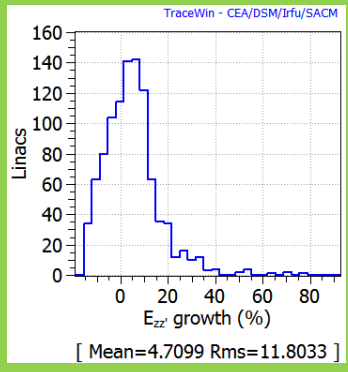
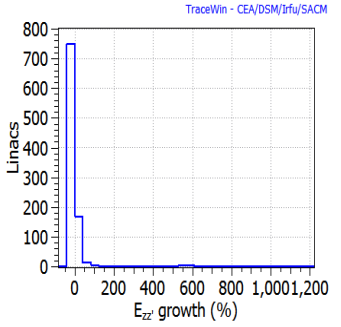
10% total emittance growth behind DTL

DTL Input rms emittance	SIS18 Input Without errors	SIS18 Input With errors in DTL (aver.)
0.175 mm mrad	14.2 mA	13.2 mA
0.150 mm mrad	14.6 mA	13.6 mA (*)
0.125 mm mrad	15.3 mA	14.5 mA (*)

FOR TOTAL EMITTANCE 0.8 MM MRAD AT SIS INPUT

preliminary, from Sabrina's data

MTI losses 5% and less - more than 13.0 mA
MTI losses 4% and less - more than 13.5 mA
MTI losses 3% and less - more than 14.3 mA
MTI losses 2% and less - more than 15.0 mA

25 %	50 %	75 %	100 %	125%
				
[Mean=3.17774 Rms=3.56566]	[Mean=8.16425 Rms=5.04648]	[Mean=16.3798 Rms=7.87054]	[Mean=28.0597 Rms=12.3968]	[Mean=42.2289 Rms=19.1746]
				
[Mean=-0.896381 Rms=2.41135]	[Mean=0.124504 Rms=4.36621]	[Mean=1.89622 Rms=7.55969]	[Mean=4.7099 Rms=11.8033]	[Mean=-3.69473 Rms=72.9623]