Beam Dynamics Layout of the FAIR Proton Injector

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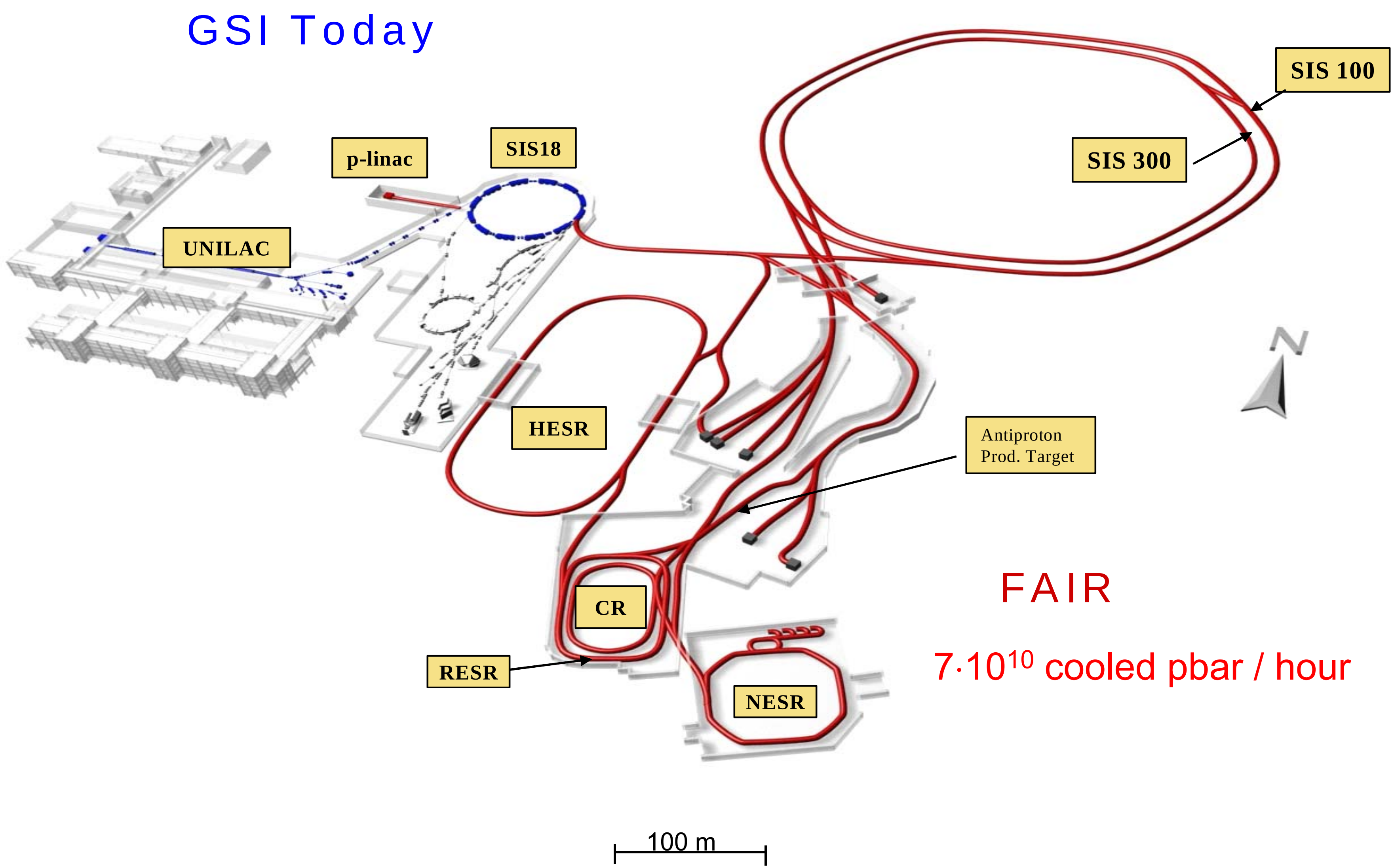
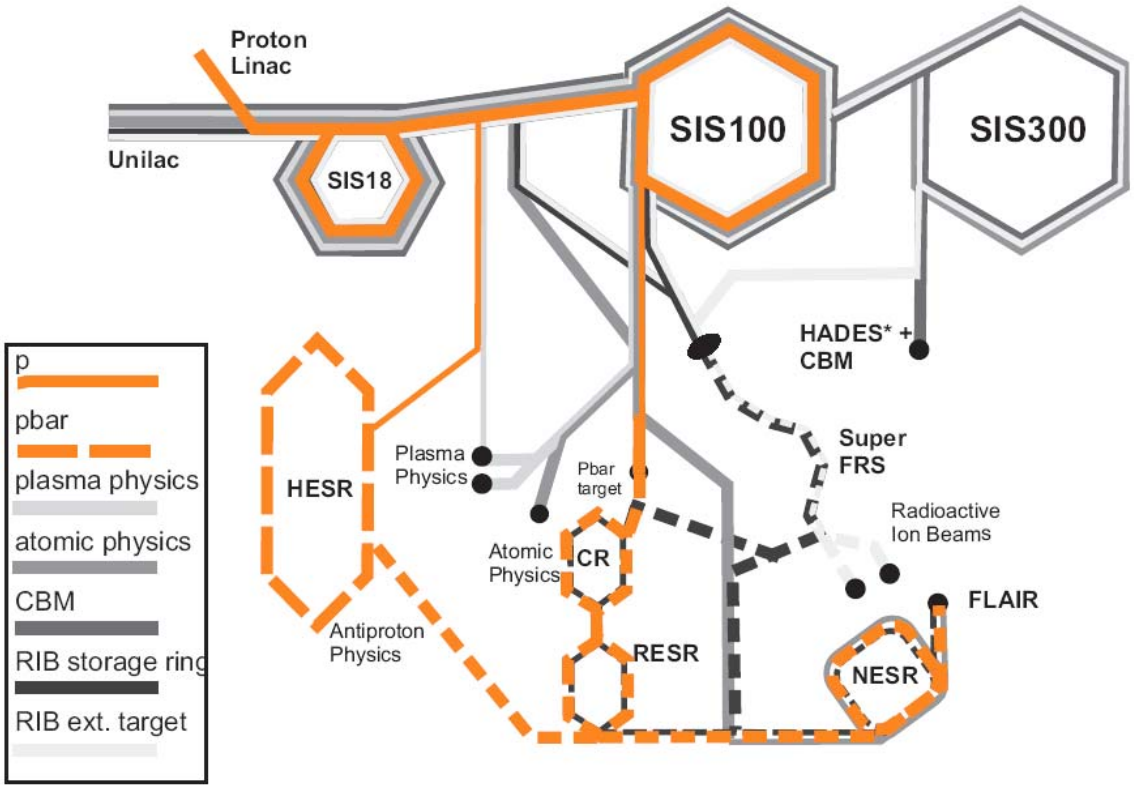
TOPIC

- The FAIR Proton Injector: Overview and Requirements
- Comparison between different currents
- Alternative solutions for the beam dynamics layout
- Loss and Random Error Studies
- Conclusions & Milestones
- People

FAIR: Facility for Antiproton and Ion Research



Accelerator Chain for Cooled Antiprotons



<=100 x :

4 x :
Injection of protons into SIS18
Acceleration to 2 GeV
Injection into SIS100

Acceleration to 29 GeV
Impact on target → hot pbars
Stoch. pbar cooling in CR
Injection into in RESR

Injection into HESR
Acceleration to 14.5 GeV

or

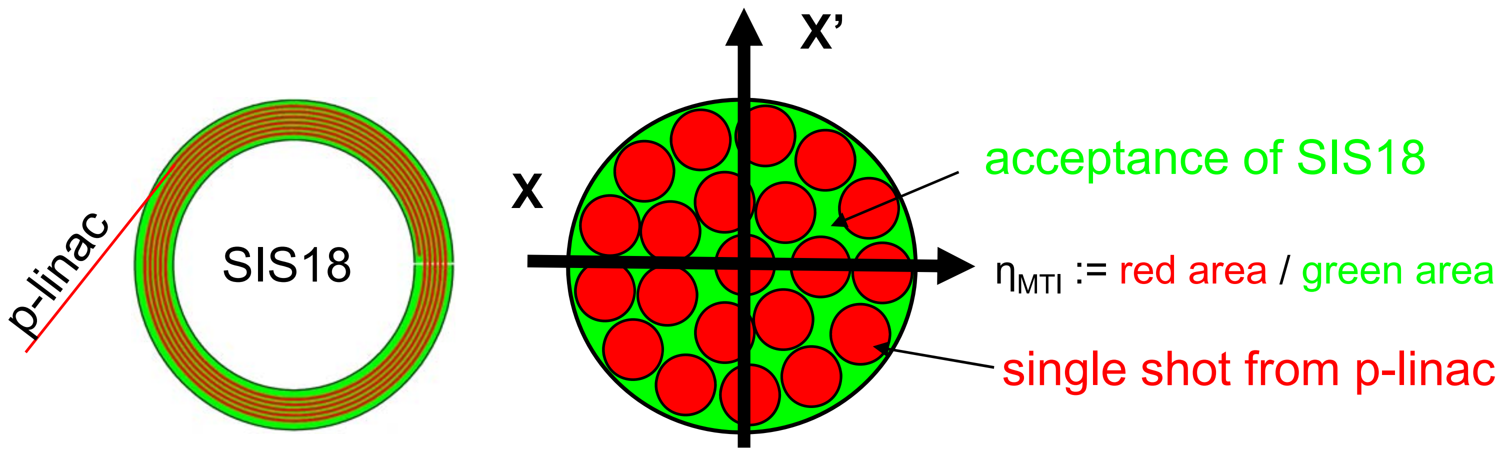
Deceleration in NESR to 30 MeV
Extraction to low energy pbar experiments

Injection into SIS18

- The client of the p-linac is SIS18
- Number of protons that can be put into SIS18 limited to

$N_{SIS} = 4.305 \cdot 10^{13} \cdot \beta^2\gamma^3$, i.e. depends on energy

- Number of SIS18 turns during injection depends on phase space areas



- Injection energy → duration → current → emittance ε are coupled by

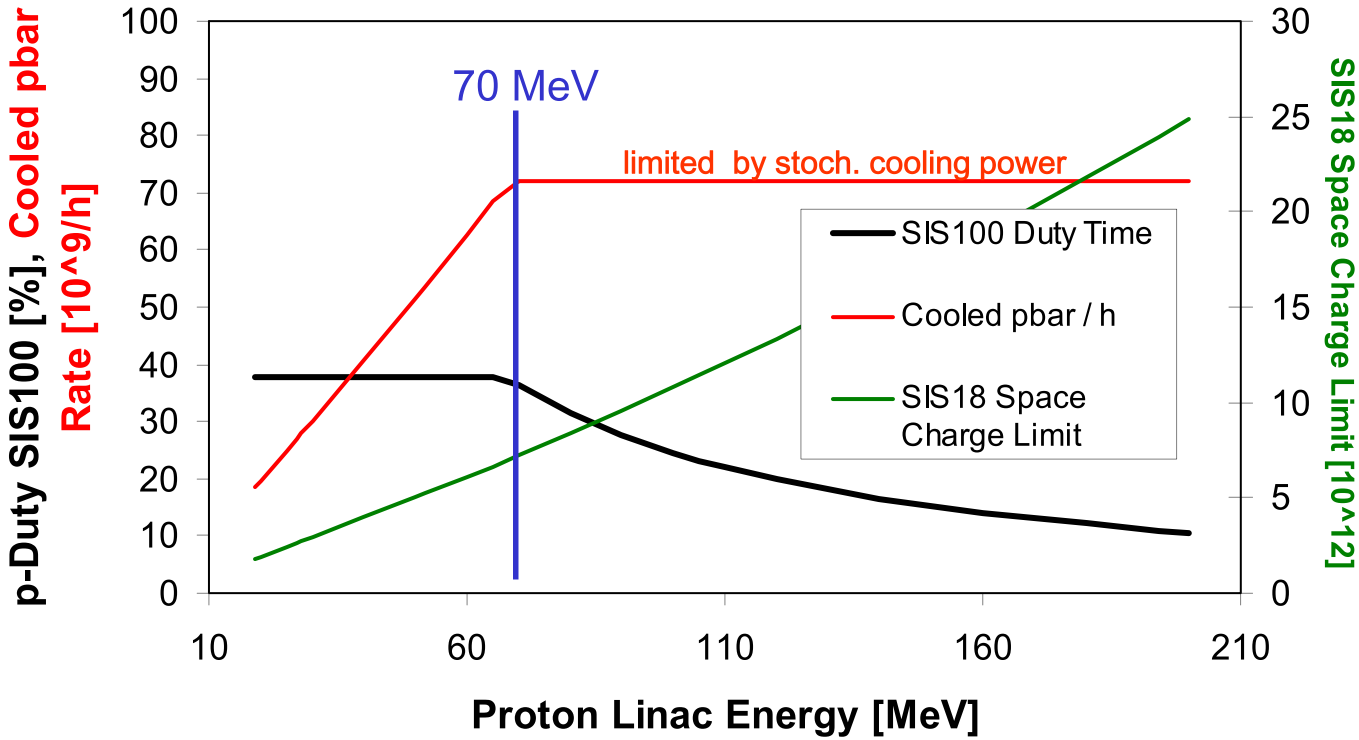
$$B_n := \frac{I}{(\beta\gamma)\epsilon_{tot}} = 63.6\,\frac{\mathrm{mA}}{\mu\mathrm{m}} \cdot \frac{(\beta\gamma)^2}{\eta_{MTI}}$$

- η_{MTI} → 60% (good empiric value)

Energy remains to be chosen

Parameters for Proton Linac

final rate of cooled pbar depends on injector energy:



$$B_n := 63.6 \frac{\mathrm{mA}}{\mu\mathrm{m}} \cdot \frac{(\beta\gamma)^2}{\eta_{MTI}}$$ → 16.5 mA / µm →

- I = 35 mA Required for Operation — RF Cavity DESIGN up to 70 mA
- $\beta\gamma\varepsilon_x$ = 2.1 µm — RFQ Optimised for 45 mA

Frequency

The choice of the operating frequency is a compromise between the demands of

- High frequency in order to optimize the RF Efficiency

$$ZT^2 \propto \sqrt{f}$$

- Low frequency to minimize the RF defocusing effect on the beam at low energy

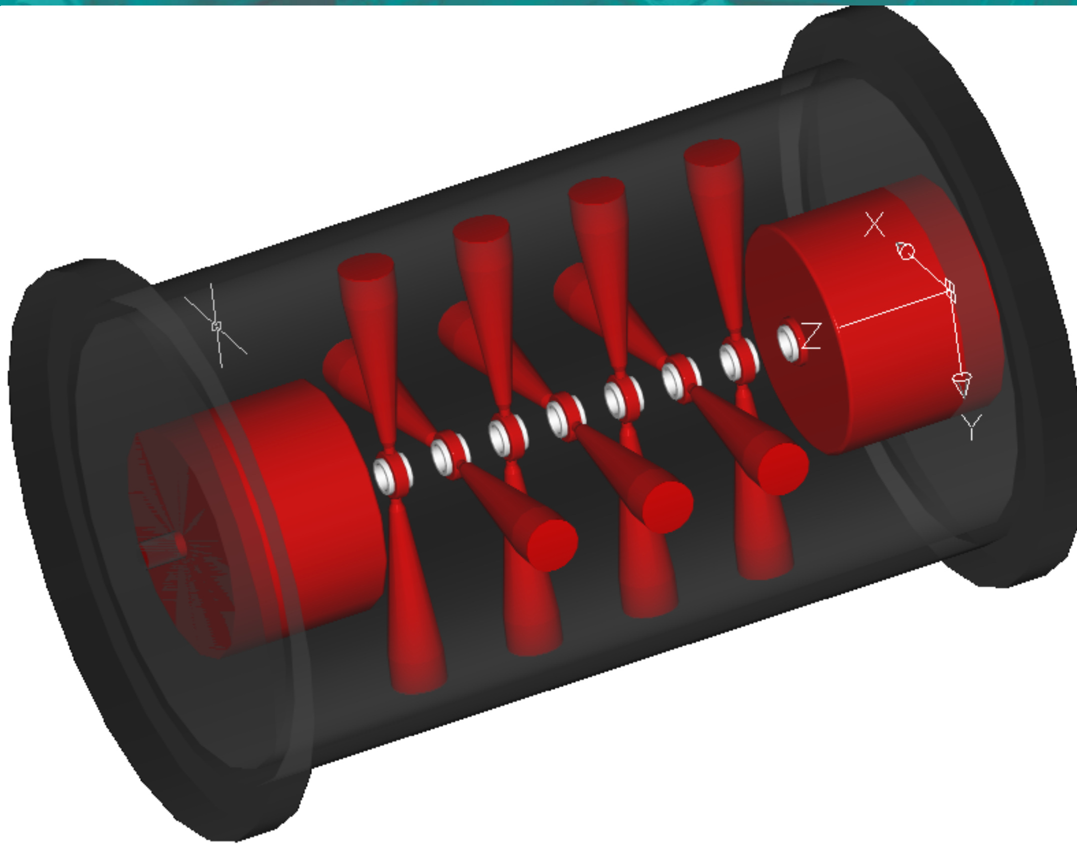
$$\Delta p_r \propto \frac{f}{(\beta\gamma)^2}$$

and the avaibility of commercial RF feeder (klystrons, tubes, IOT's.....)

For a Multi MeV machine the best choice is to base the machine in the 300-400 MHz range which satisfies all those requirements

F = 325,244 MHz , i.e 9 x 36.13 MhZ (GSI HSI-Unilac)

The CH-DTL



H_{211}

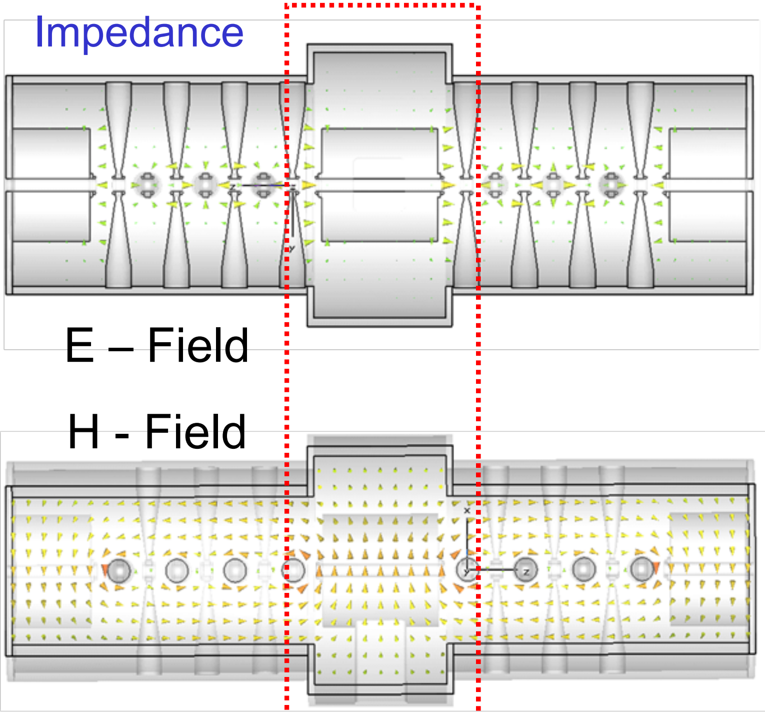
R.T and S.C. CH

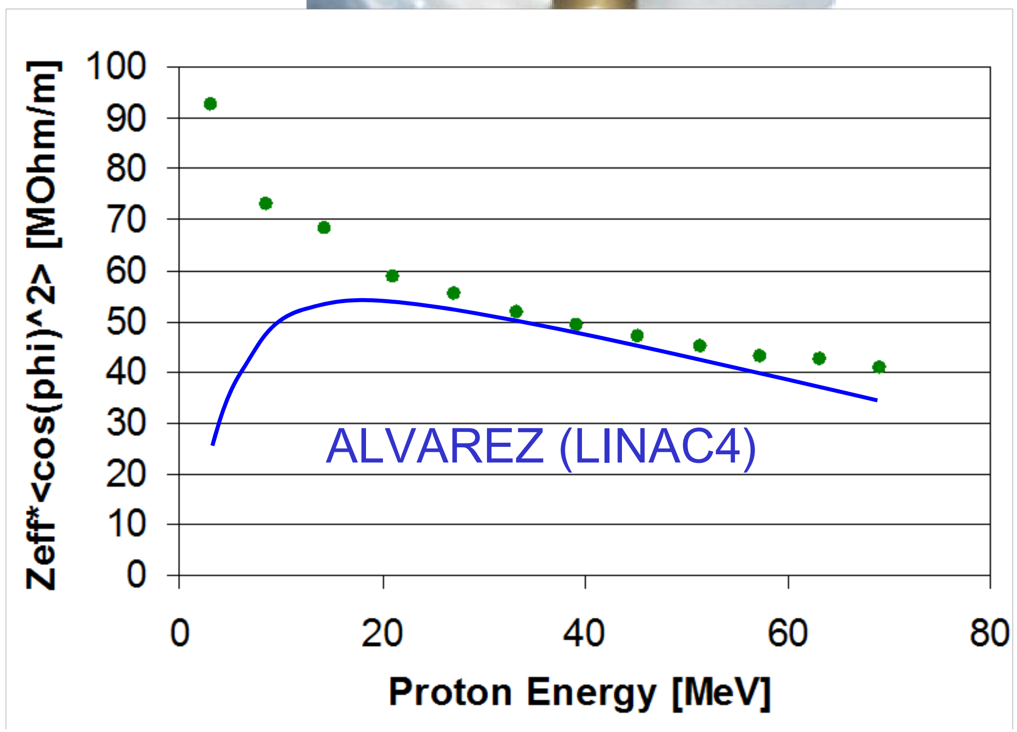
E< 150 AMeV
150<f<3000 MHz

Cross-Bar H-mode DTL (CH-DTL) represents the extension of well established Interdigital Linac for low-medium β velocity profile. It s geometry it' s particulary suited for efficient cooling and allows the construction of high duty cicle and superconductiong linacs

DTL: Rf-coupled Crossed-bar H-Cavities

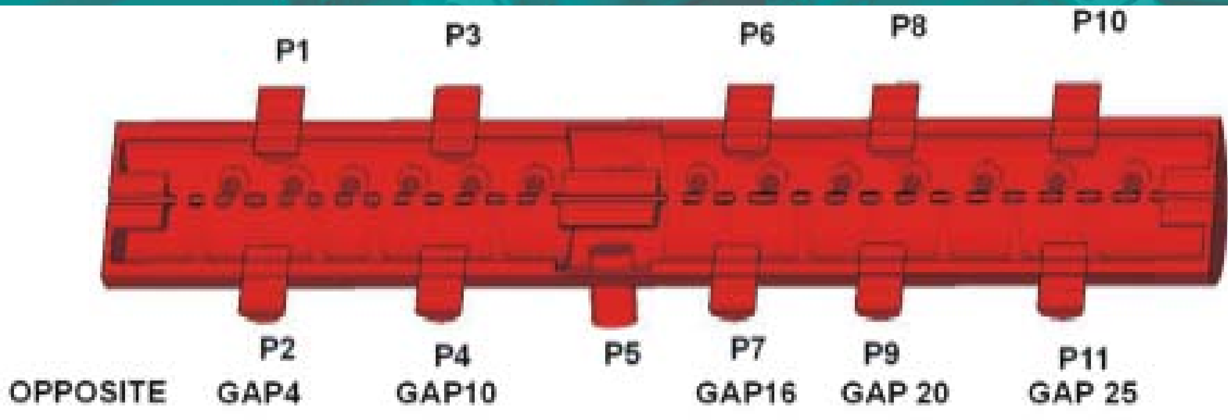
H-Mode cavities in combination with the KONUS Beam Dynamics ⇒ Highest Shunt Impedance



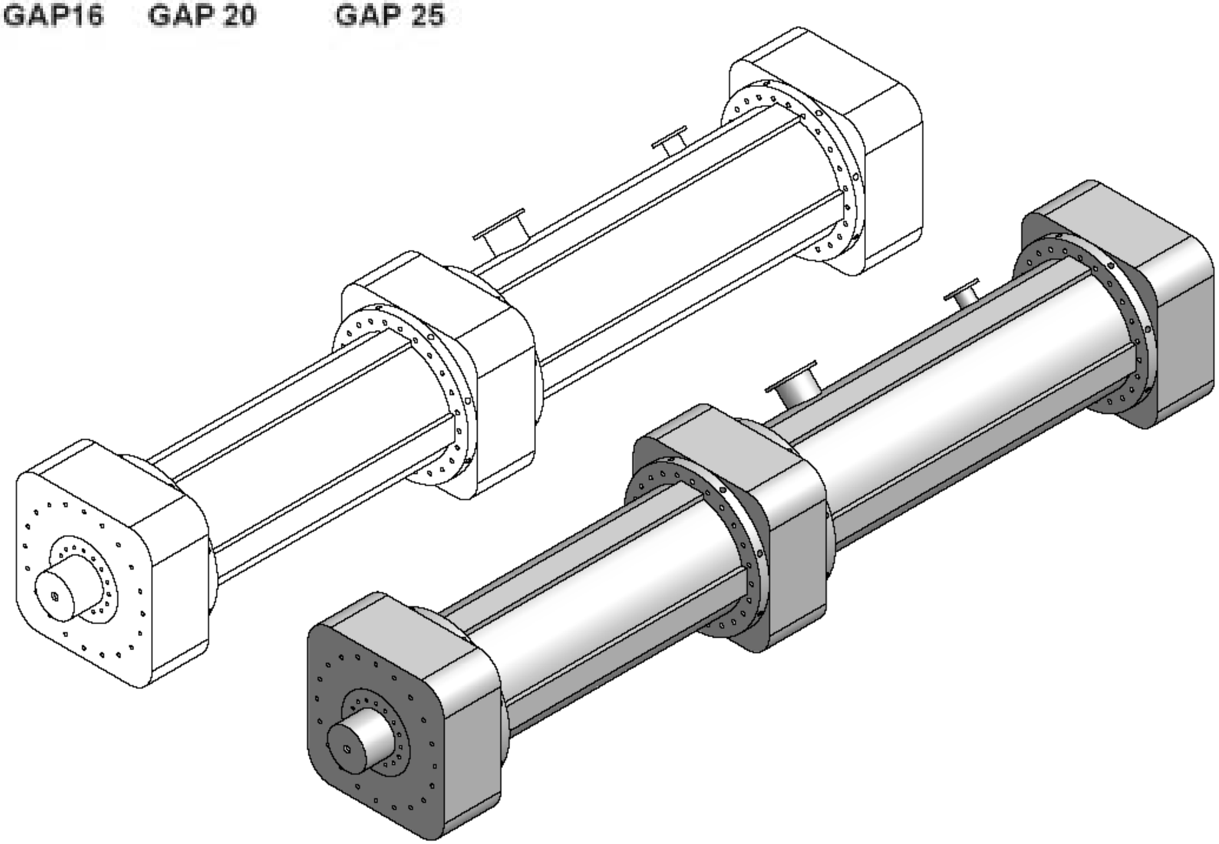


- reduce number of klystrons
- reduce place requirements
- profit from 3 MW klystron development
- avoid use of magic T's
- reduce cost for rf-equipment

Technical Drawing

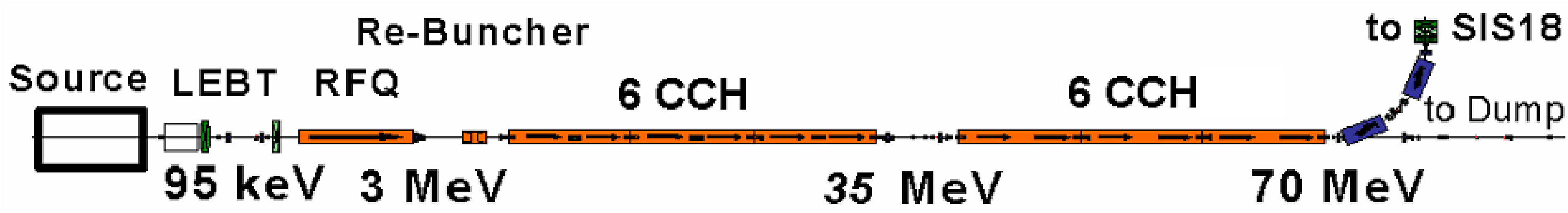


Position of mobile tuners



Linac will be mounted on rails and each module is directly connected with the next one

General Overview

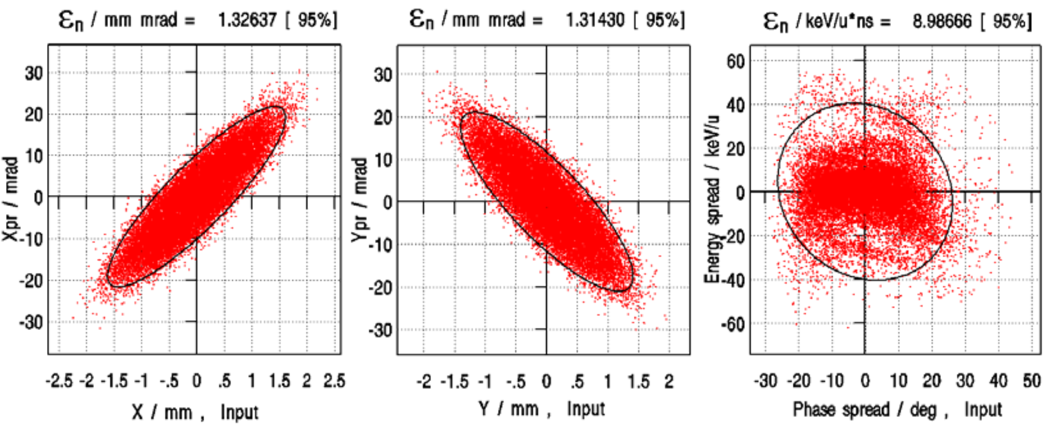


Beam energy	70 MeV
Beam current (op.)	35 mA
Beam current (des.)	*70 mA*
Beam pulse length	36 µs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Tot. hor emit (norm.)	2.1 / *4.2* µm
Tot. mom. spread	$\leq \pm 10^{-3}$
Linac length	≈ 35 m

- **ECR proton source & LEBT**
- **RFQ (4-rod)**
- **6 Pairs of Coupled CH-DTL**
- **2 Bunchers**
- **14 Magnetic Triplet**
- **4.9 MW of beam loading (peak), 710 W (average)**
- **11 MW of total rf-power (peak), 1600 W (average)**
- **41 beam diagnostic devices**

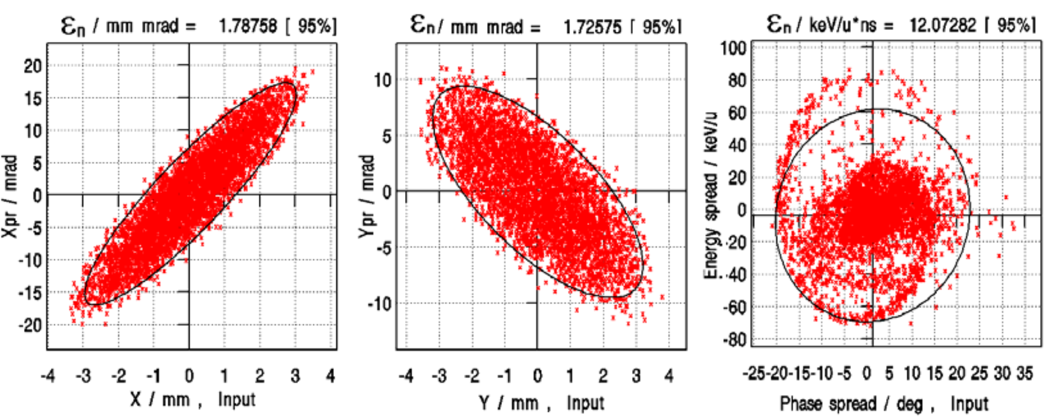
RFQ-Output distributions

- 45 mA



RMS ε_{norm}X-X' mm mrad	0.262
RMS ε_{norm}Y-Y' mm mrad	0.26
RMS $\varepsilon_{norm}\Delta\Phi$- ΔW keV/ ns	1.292

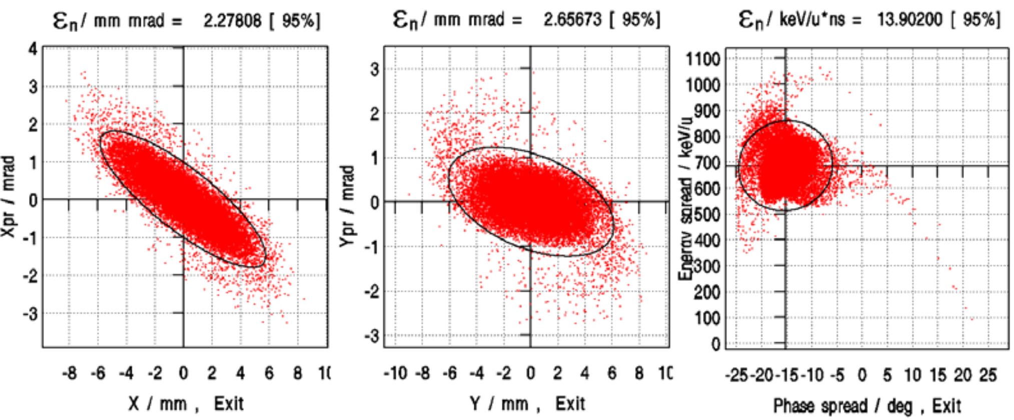
- 70 mA



RMS ε_{norm}X-X' mm mrad	0.362
RMS ε_{norm}Y-Y' mm mrad	0.357
RMS $\varepsilon_{norm}\Delta\Phi$- ΔW keV/ ns	1.58

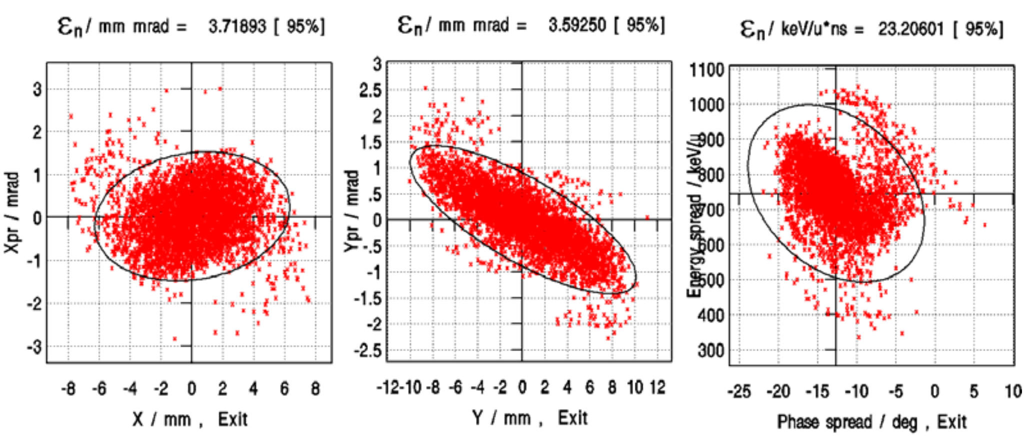
Output

- 45 mA



RMS ε_{norm}X-X' mm mrad	0.383
RMS ε_{norm}Y-Y' mm mrad	0.409
RMS $\varepsilon_{norm}\Delta\Phi$- ΔW keV/ ns	2.09

- 70 mA

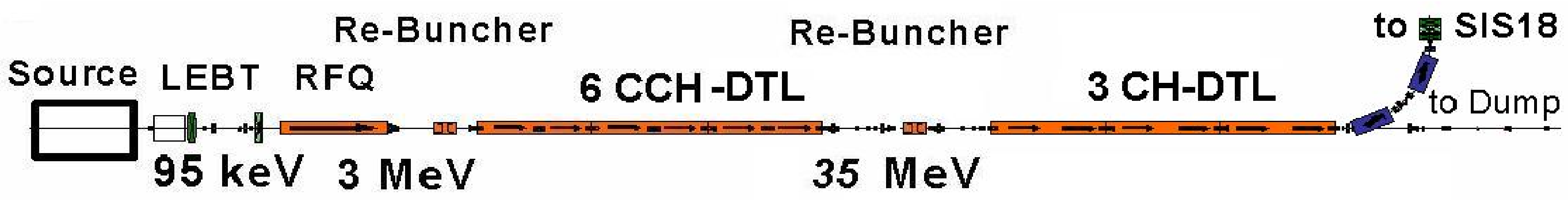


RMS ε_{norm}X-X' mm mrad	0.657
RMS ε_{norm}Y-Y' mm mrad	0.650
RMS $\varepsilon_{norm}\Delta\Phi$- ΔW keV/ ns	2.82

Relative RMS Increase doesn t depend on the input current!

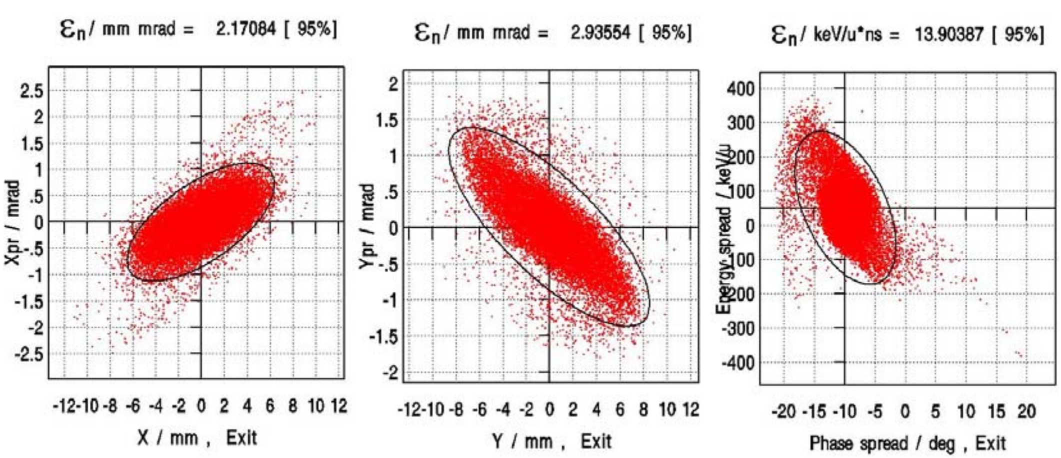
Alternative Layout

USE of KONUS ⇒ Long section without triplet



- 3 Pairs of Coupled CH-DTL's followed by 3 longer standard CH-DTL's
  - 11 magnetic triplet required instead of 14
  - Simplified RF and Mechanical Design
  - A rebuncher needed after the diagnostics section

OUTPUT for I= 45 mA



RMS ε_{norm}X-X' mm mrad	0.41
RMS ε_{norm}Y-Y' mm mrad	0.45
RMS $\varepsilon_{norm}\Delta\Phi$- ΔW keV/ ns	1.95

Loss and Random Errors Studies

1. Singles errors are applied to fix the tolerances for fabrication errors and power oscillation. Single errors includes

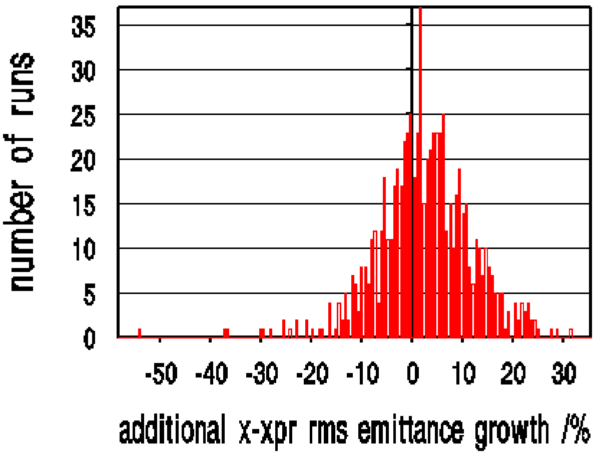
- Transversal Quadrupole translations : ΔX, $\Delta Y \leq \pm$ ***0.1 mm***
- 3D Quadrupole Translations : $\Delta\Phi_X$, $\Delta\Phi_Y \leq \pm 1$ ***mrad***, $\Delta\Phi_Z \leq 5$ ***mrad***
- Single Gap Voltage Errors : **± *1%***
- Phase Oscillations : **≤ ± *1°***
- Voltage Oscillations : **≤ ± *1%***
- Errors follow a gaussian distributions cut at 2 σ

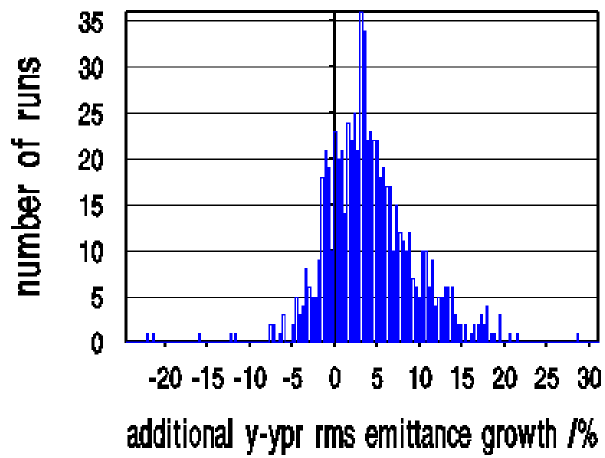
Single error tolerancies doesn' t depend on the current

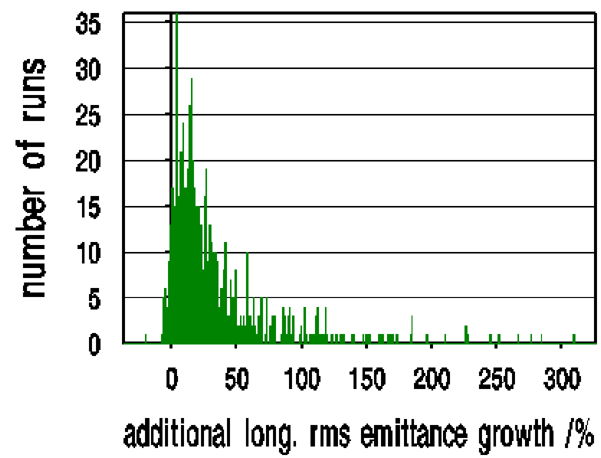
2. All the sources of error are combined to evaluate the effect in terms of beam losses and RMS emittance degradation
3. In case 1 and 2, 1000 runs are performed with a 100 000 particles RFQ-Output Distribution

RMS Degradation 45 mA

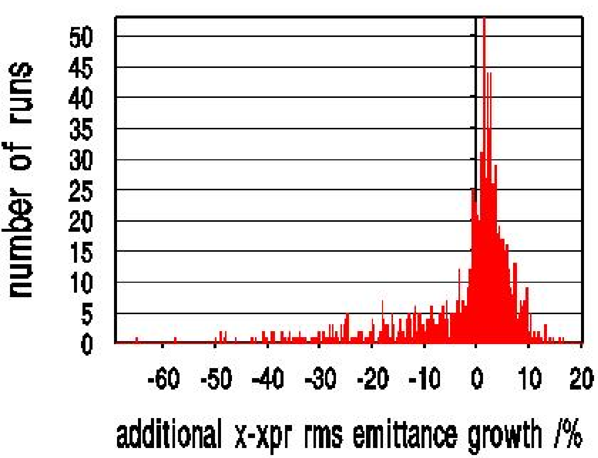
12 CCH

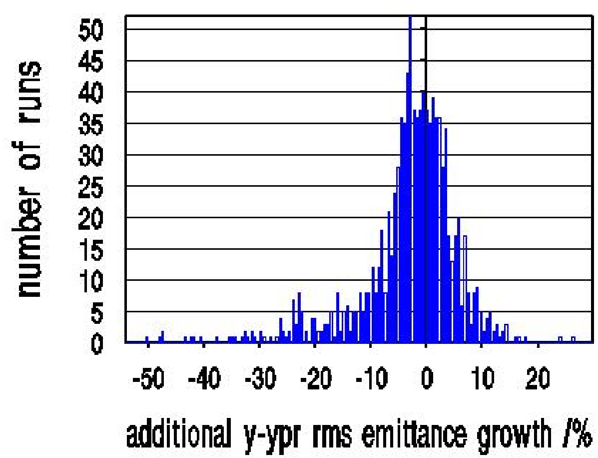


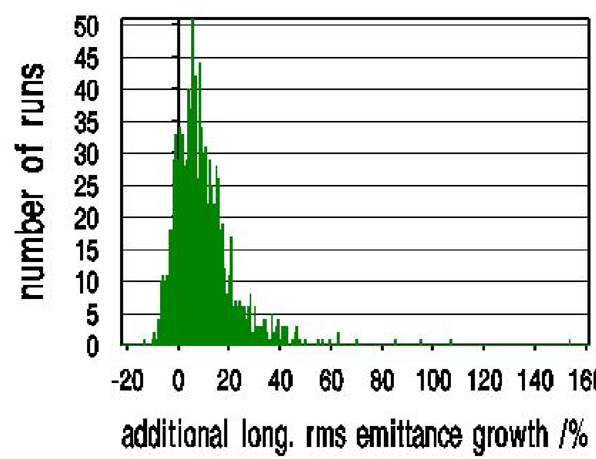




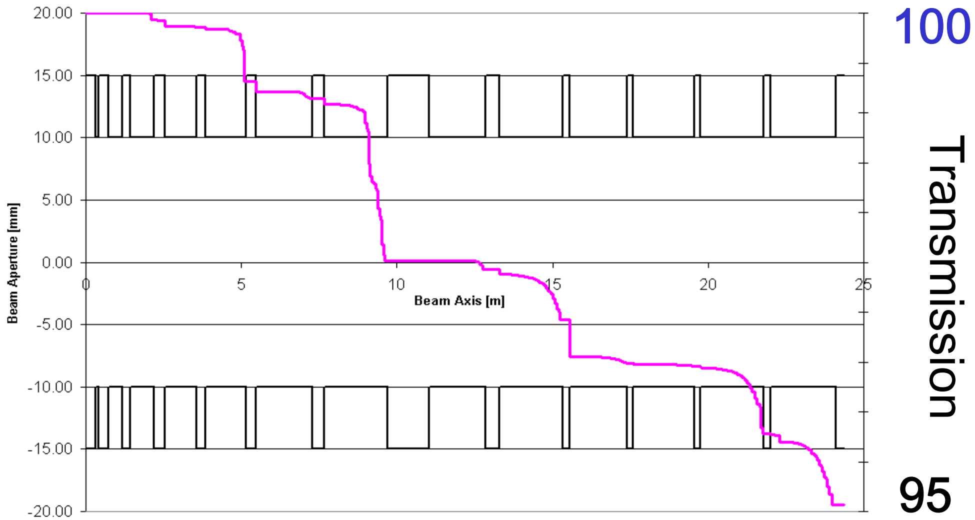
6 CCH + 3 CH-DTL







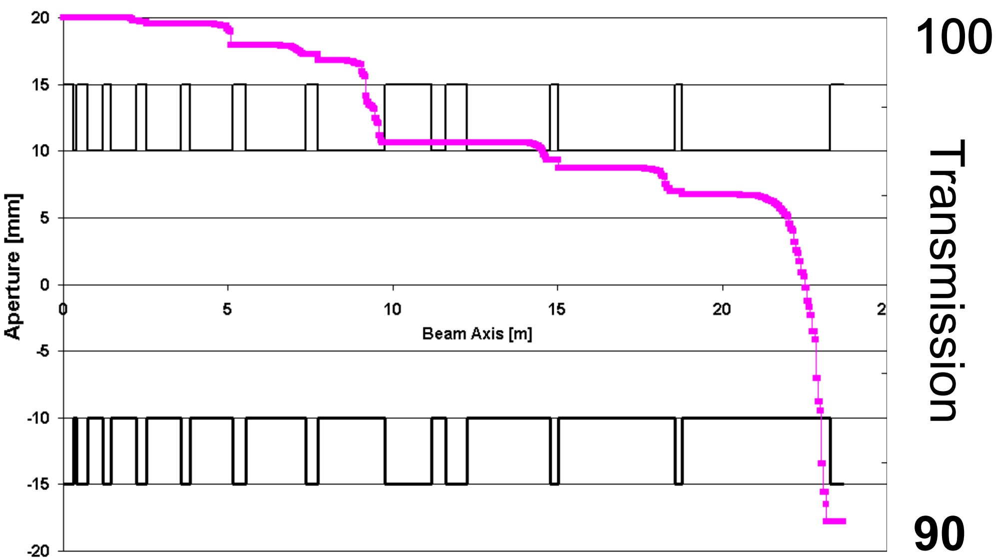
Average Transmission



Minor Losses distributed

all along the machine

Steering correction not included



Critical point is represented by the last long CH-DTL

CONCLUSIONS & Milestones

- The GSI Proton injector will be the first linac basedon coupled H-Mode cavities in combination with the KONUS Beam Dynamics
- Two designs are under discussions and they are comparable in terms of beam quality
- Error Studies indicated that both designs are robust enough against fabrication errors and power supplies oscillations
- Tolerances are comparable with the ones of other High Intensity linacs such as LINAC 4 or SNS
- Fabrication of the first RF Cavity (Coupled CH 3 and 4) in preparation
- Express of Interest declared by Germany, France, Russia and India
- Construction starts in 2010
- Commissioning in 2013

Partners and People

University of Frankfurt, GSI

- CH-cavity design
- RFQ design
- DTL beam dynamics

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R. Tiede, G. Clemente, R.Brodhage

CEA/Saclay

- Proton source & LEBT

R. Gobin et al.

GSI Darmstadt

- Magnets, Power converters, Rf-sources
- Proton source, Diagnostics, UHV, Civil constr.,
- Controls, Coordination

G. Aberin-Wolters, R.Bär,
W.Barth, P.Forck, L.Groening,
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H.Ramakers, H.Reich,
W.Vinzenz, S.Yaramyshev