ESS LINAC DESIGN OPTIONS

Mamad Eshraqi, Dave McGinnis

INTRODUCTION

- The ESS Linac is designed to provide:
  - 5 MW of average beam power
  - 125 MW of peak power
  - A repetition rate of 14 Hz
  - 95% availability
- The cost target for ESS linac is 497 M€
- The current cost estimate for the October 2012 baseline is 586 M€*

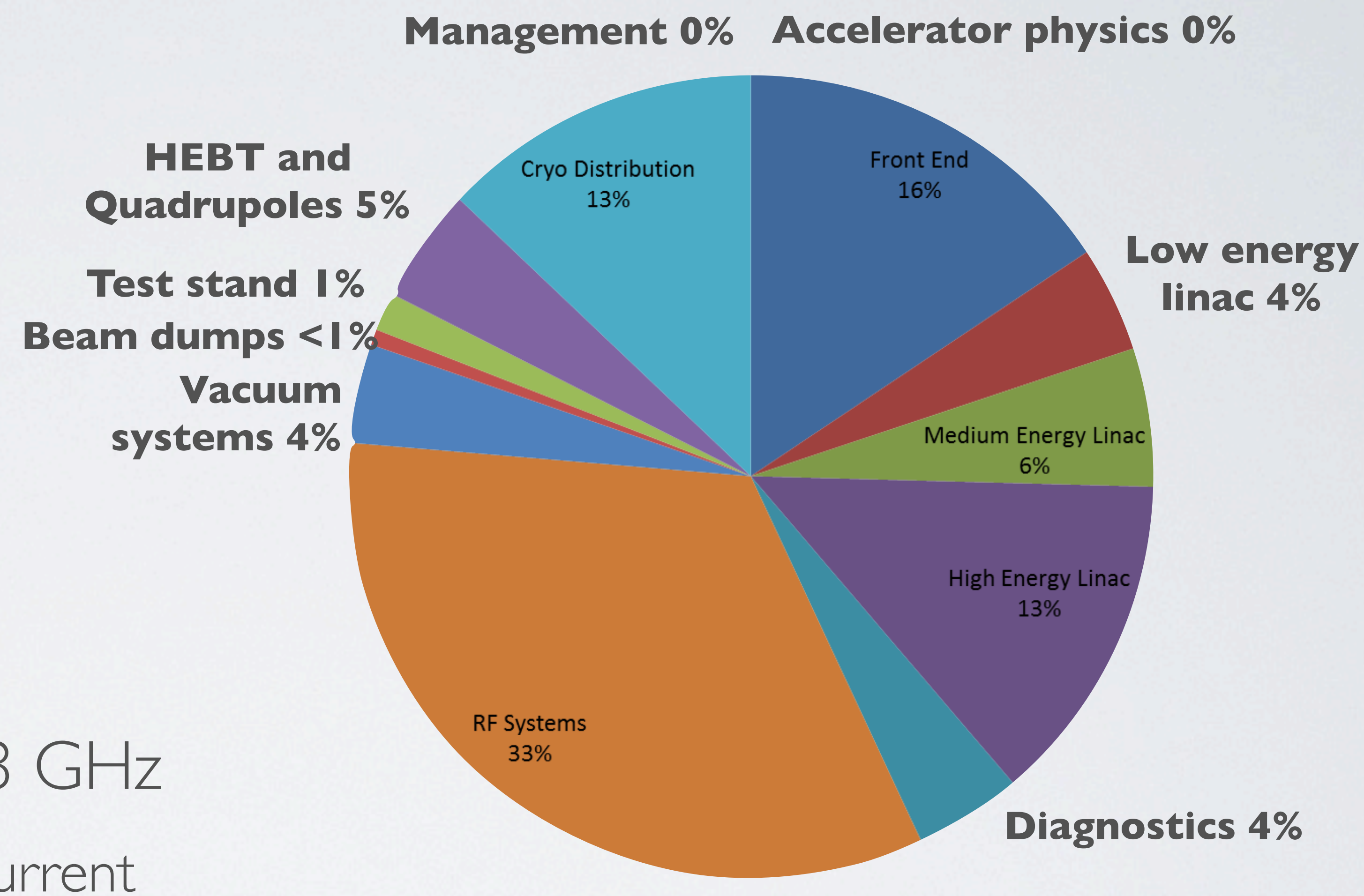
*Estimated cost in October 2012 was 550 M€. Since then, cost estimates have been updated.
The RF cost has increased by 17 M€
The Primavera rate change and the addition of the M-ECCTD increased the cost by another 6 M€
Although not final, the per unit cost of the cryomodules has increased by approximately 0.5 M€ giving a total increase of 23 M€.

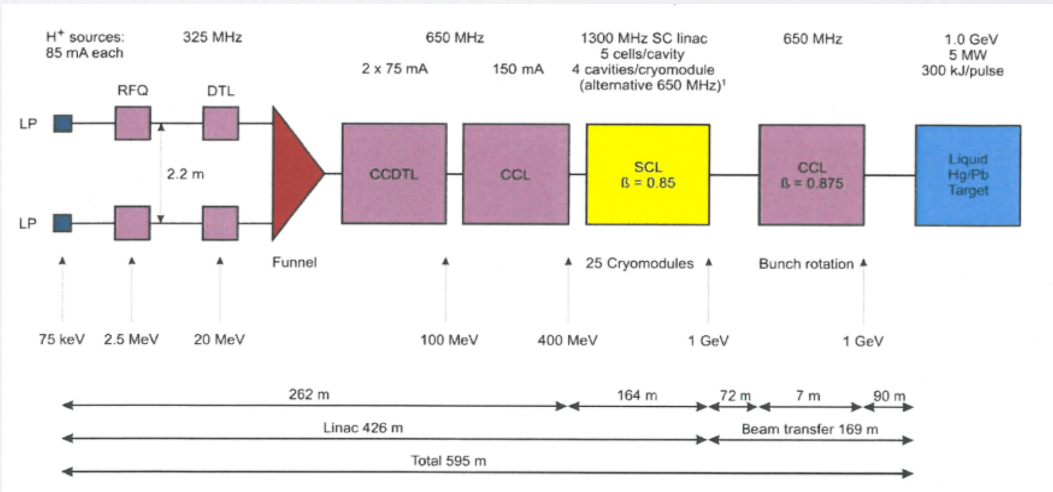
THE LONG PULSE CONCEPT

- Advantage - No compressor ring required
    - No space charge tune shift so peak beam current can be supplied at almost any energy
    - Relaxed constraints on beam emittance
        - This is especially true if the beam expansion system for the target is based on raster scanning of the beam on the target.
    - No H- and associated intra-beam stripping losses
    - Permits the implementation of target raster scanning
- Disadvantage - Experiment requirements "imprint" Linac pulse structure
    - Duty factor is large for a copper linac
    - Duty factor is small for a superconducting linac

2008 (2002) DESIGN

- Design Features
  - 1.0 GeV, 150mA
  - 2mS, 16.6 Hz
  - H- funnel
  - 40% in normal conducting
  - Superconducting linac at 1.3 GHz
    - 7cm bore compared to current 14cm
    - Low gradient – 12 MV/meter
    - Dynamic heat load 25%





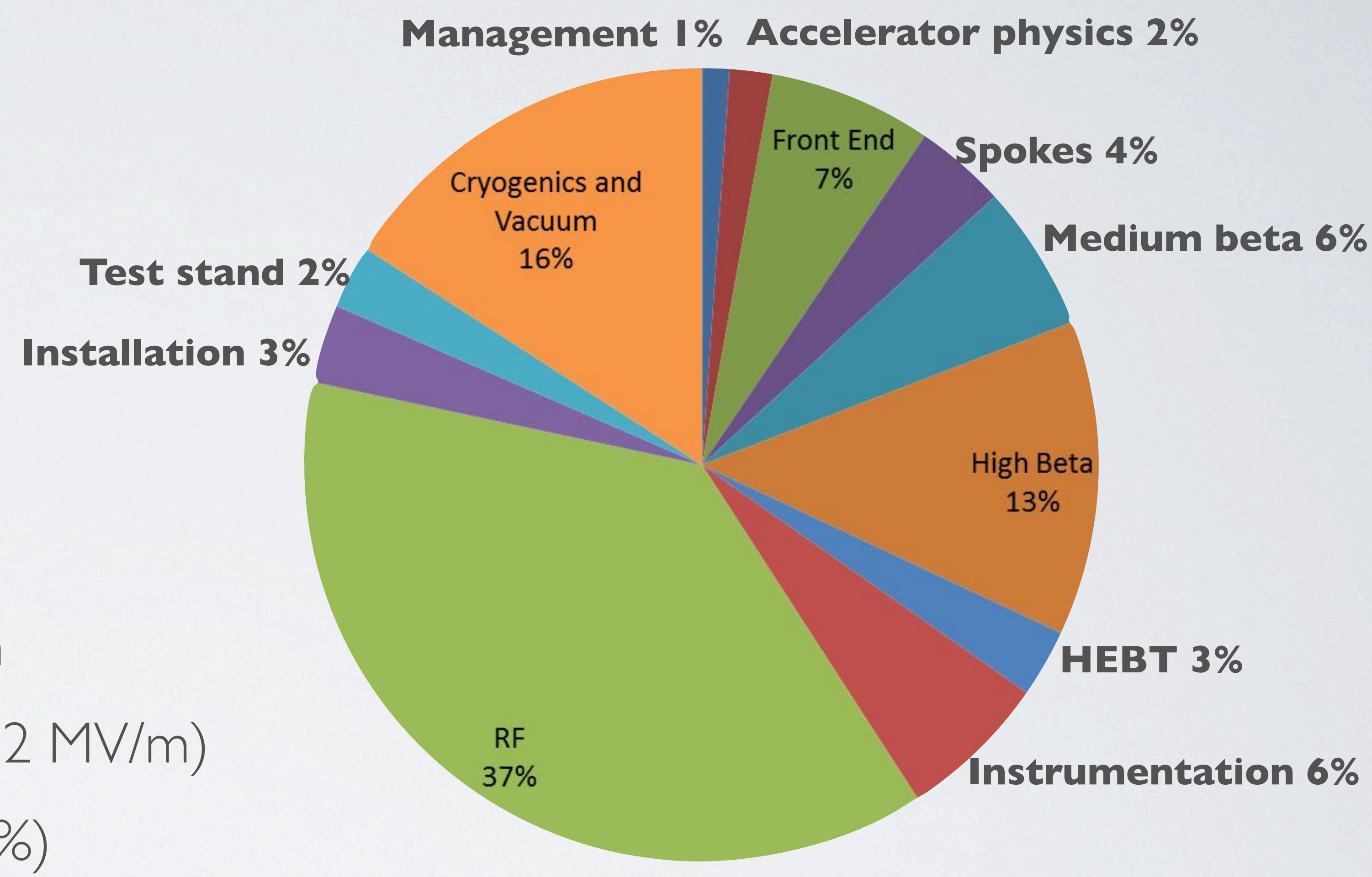
Pie charts courtesy of Suzanne Gysin

ACCELERATOR DESIGN UPDATE (ADU)

- At the beginning of the ADU, it was recognized that the beam current of 150 mA introduced considerable technical risk:
  - Beam Loss
  - Funnel concept
- In ADU, the beam current was reduced to 50 mA.
  - Linac energy increased by 2.5 x to compensate for most of the reduction
  - For this substantial increase in linac energy, superconducting RF is a more economical choice
    - Higher gradients, shorter linac
    - Lower operational costs
  - In addition superconducting RF has a much bigger aperture.

2012 DESIGN

- Design features
  - 2.5 GeV, 50mA
  - 2.86 mS, 14 Hz
  - 97% superconducting
  - SC linac at 352 & 704 MHz
    - ✳ 1/3 current in 4 x the aperture
    - ✳ 14 cm bore compared to 7 cm
    - ✳ High gradient – 18 MV/m (vs 12 MV/m)
    - ✳ Dynamic heat load 65% (vs 25%)



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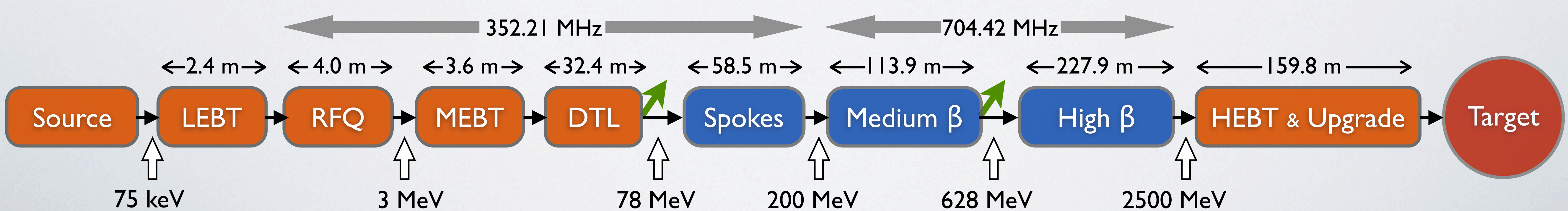
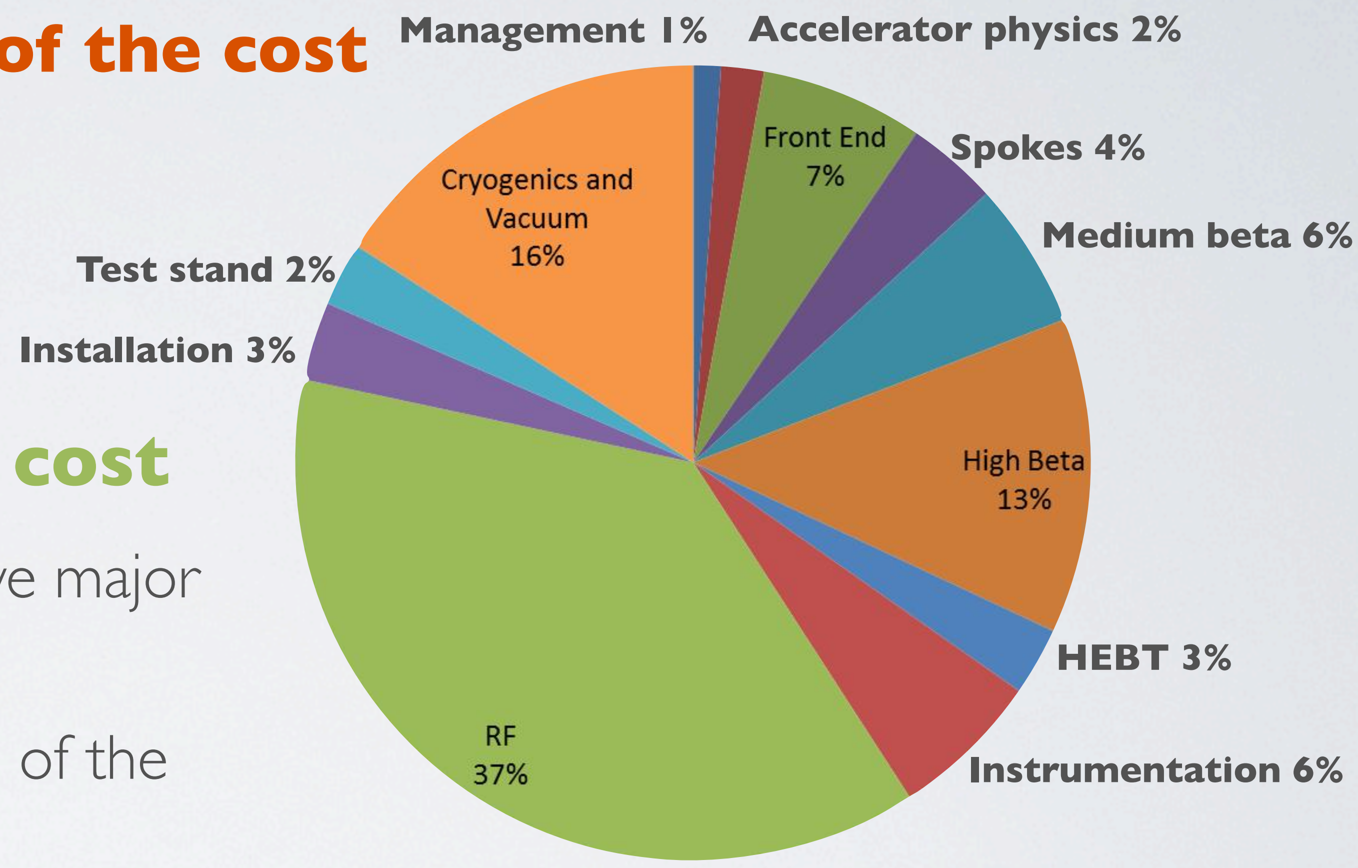


COST TARGET

- Although the 2008 design with 150 mA of beam current has higher technical risk, it has an inherently lower construction cost than the October 2012 baseline.
  - Large fraction of the 2008 linac consists of normal conducting structures which are significantly less expensive to build than superconducting structures
  - Lower energy (but higher beam current) requires a significantly shorter linac with less accelerating structures
- However, the current cost targets are based on the 2008 design even though the October 2012 design:
  - Has many more superconducting structures
  - And provides less technical risk
- The only way to close the gap between the cost estimate and cost target is
  - To modify the October 2012 baseline by adding technical risk
  - Adjusting the cost target

COST DRIVERS

- **Elliptical cryomodules occupy 19% of the cost**
  - ✳ There are 45 elliptical cryomodules
  - ✳ The cryogenic plant absorbs 14% of the total cost.
- **RF systems comprise 37% of the cost**
  - ✳ The RF costs are distributed over five major systems
  - ✳ The elliptical section comprises 82% of the RF system cost
- For the elliptical section
  - ✳ the klystrons and modulators comprise 80% of the RF system cost
  - ✳ **62% of the total cost of the linac**
  - ✳ 92% of the acceleration energy



Cost Distribution for the 2012 Linac

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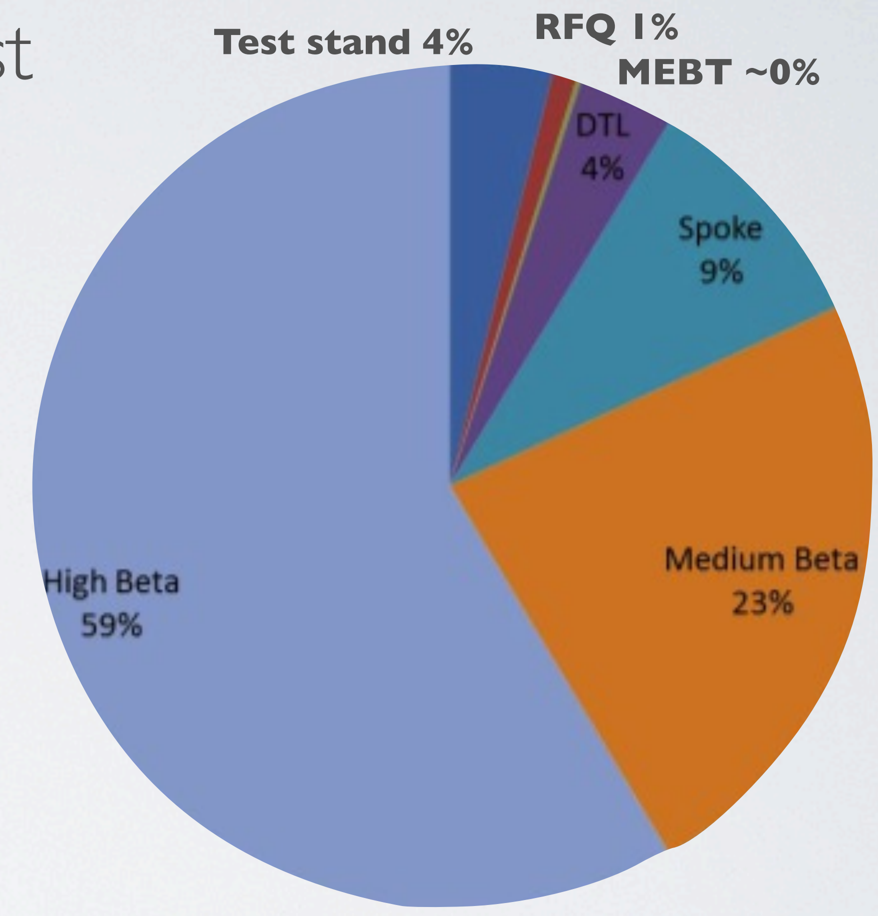

RF system cost distribution

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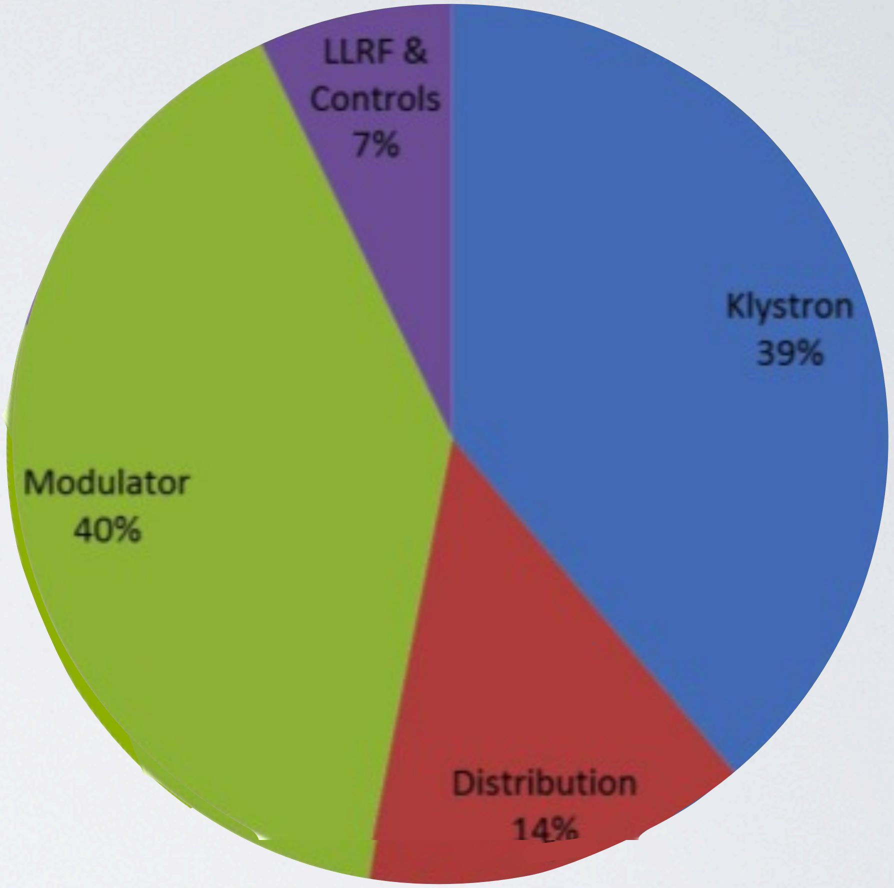

Cost breakdown for 704 MHz RF systems

COST DRIVERS

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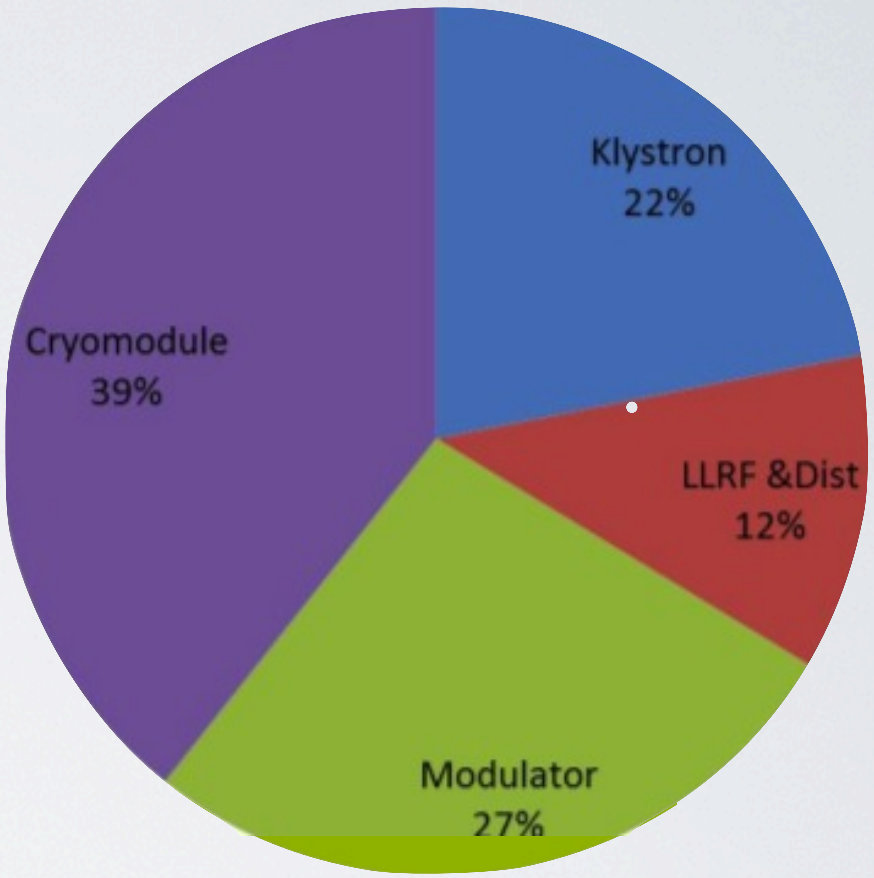


Cost breakdown for elliptical cryomodule system

COST REDUCTION STRATEGY

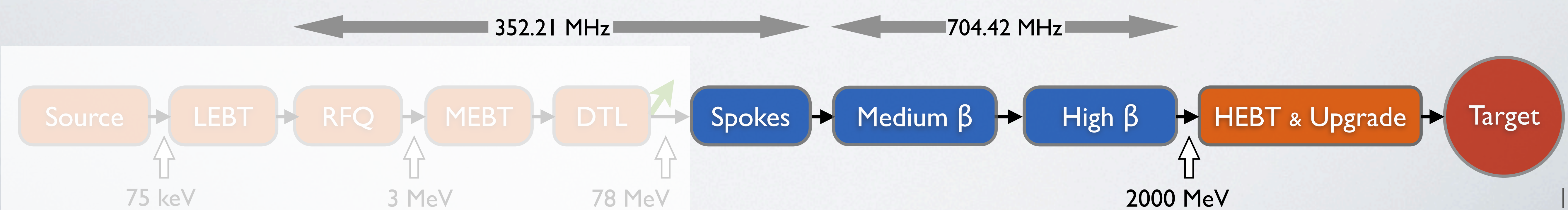
- The cost of the elliptical cryomodules and associated RF systems are the largest cost driver in the ESS Linac
  - Reducing the number of superconducting cavities will have the largest impact on cost and design contingency
    - Each cavity that is removed from the design not only removes the cost of the cavity
    - It also removes the need (and cost) for the RF power sources that feed the cavity.
- For any given strategy, as the number of cryomodules is reduced, the remaining cryomodules require more RF power to compensate.
- Simple models have been developed to predict the increased cost of more RF power

COST REDUCTION STRATEGIES

- Increase
  - ~~Duty factor, (Pulse length × Rep. rate)~~
  - Peak surface field, E_{peak}
  - Peak beam current, I_b
  - Average value of $E_{acc}T$ sum by adjusting the power profile
  - Ratio of $E_{acc}T/E_{peak}$ by appropriate choice of βg
  - Energy of the front end linac, E_{FE}

MUSTANG PARAMETERS

- Power: 5 MW
- L_{Pulse} × Rep. rate = Duty cycle : 2.86 ms × 14 Hz = 4%
- Peak surface field ⟶ 45 MV/m
- Energy ⟶ 2000 MeV ⇒ Current ⟶ 62.5 mA
- Max. Coupler power: 1.101 MW



SMART VS. MUSTANG

	Smart	Mustang	Unit
Current	61	62.5	**mA**
L_{pulse}	2.86	2.86	**ms**
Rep. rate	14	14	**Hz**
Energy	2077	2000	**MeV**
Power	5.07	5.00	**MW**
$N_{elliptical}$	30	30	**–**
N_{spoke}	14	14+1	**–**
Reliability	X	X + **α**	

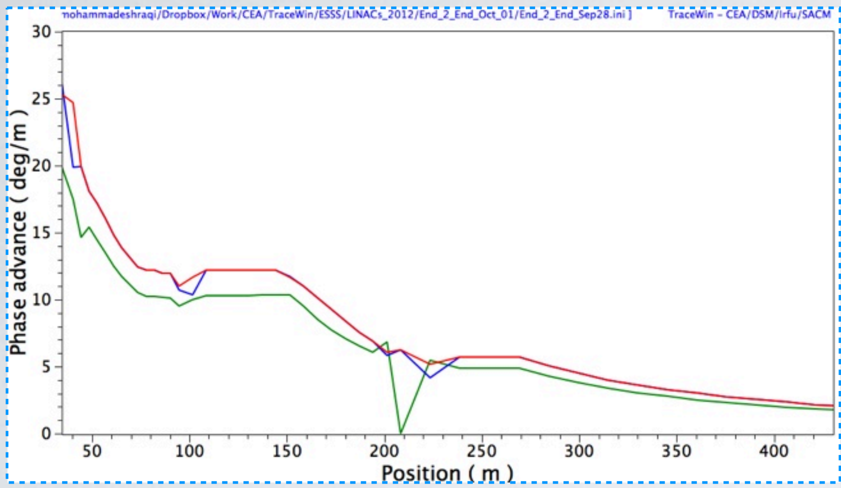
SMART VS. MUSTANG II

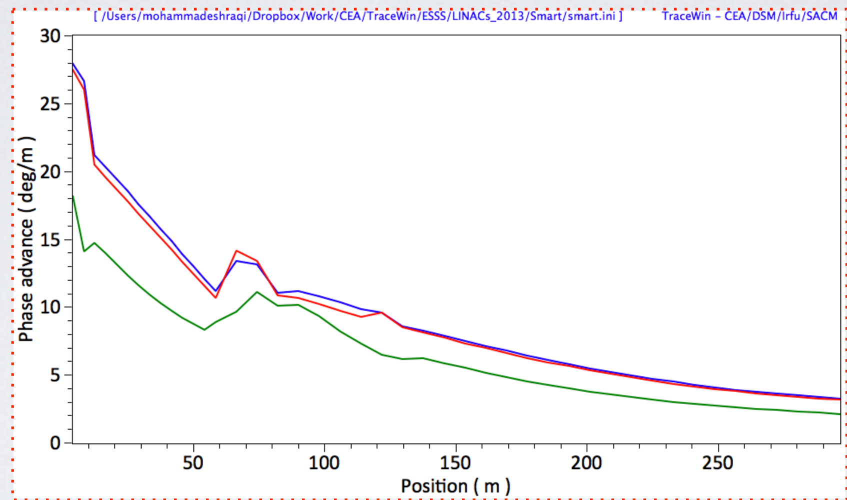
	Smart	Mustang	Unit
β_{in} / E_{in} Spoke	0.383 / 77.5	0.383 / 77.5	– / MeV
β_{geo} Spoke	0.50	0.50	–
N_{cell} Spoke	3 (dbl spoke)	3 (dbl spoke)	–
L_{period}	4.18	4.14	m
β_{in} / E_{in} Mβ	0.58 / ~210	0.59 / ~220	– / MeV
β_{geo} Mβ	0.67	**0.65**	–
N_{cell} Mβ	6	6	–
β_{in} / E_{in} Hβ	0.78 / ~500	0.78 / ~520	– / MeV
β_{geo} Hβ	0.86	0.86	–
N_{cell} Hβ	5	5	–
L_{period}	7.93	8.28	m

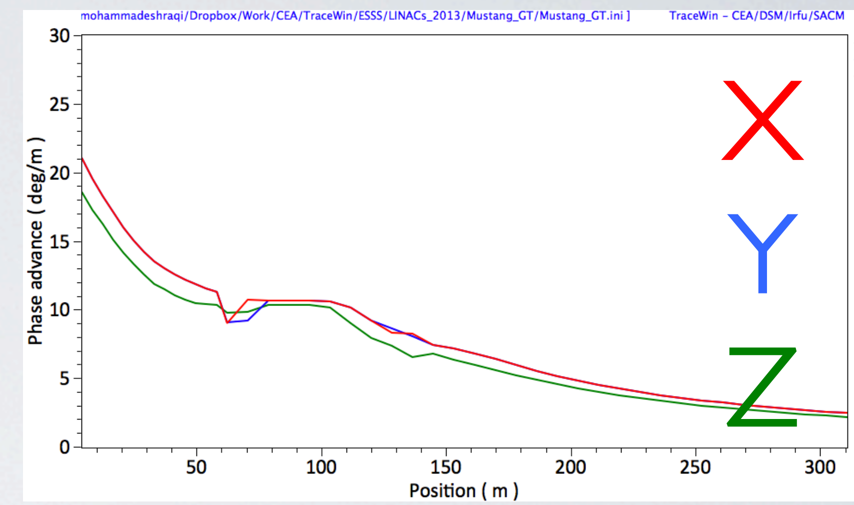
SMART VS. MUSTANG III

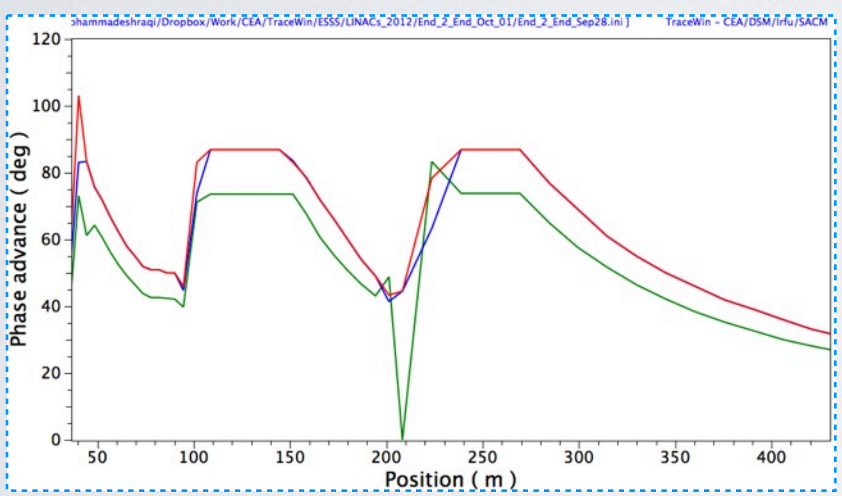
	Smart	Mustang	Unit
$E_{acc\ Spoke}$	8.8	9	MV/m
$P_{coupler\ Spoke}$	320	330	kW
$N_{Spoke\ modules}$	14	15	–
$B_{Quad.Max.Spoke}$	--	$0.14 \times L_{tot}/L_{mag}$	T
$E_{acc\ M\beta}$	16.8	16.4	MV/m
$P_{coupler\ M\beta}$	820	820	kW
$N_{M\beta\ modules}$	7	8	–
$E_{acc\ H\beta}$	19.7	19.9	MV/m
$P_{coupler\ H\beta}$	1060	1101	kW
$N_{H\beta\ modules}$	23	22	–
$B_{Quad.Max.Ellip.}$	--	$0.25 \times L_{tot}/L_{mag}$	T

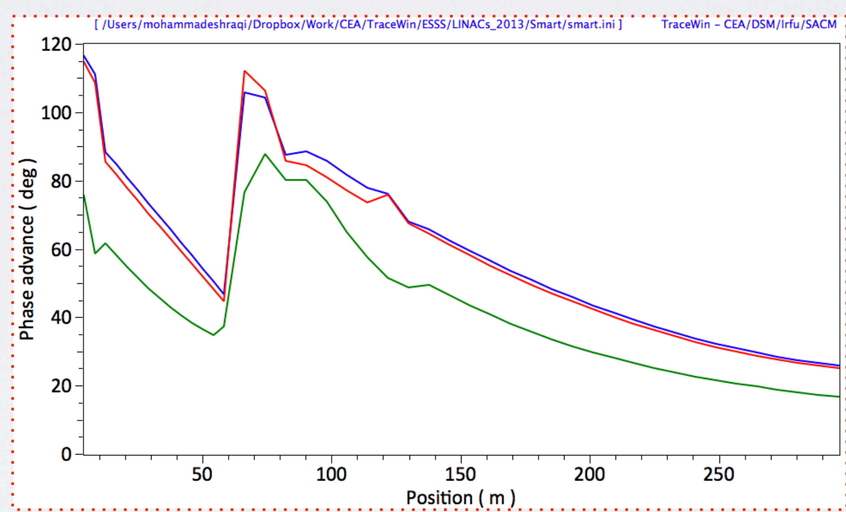
2012 BL vs. SMART vs. MUSTANG I

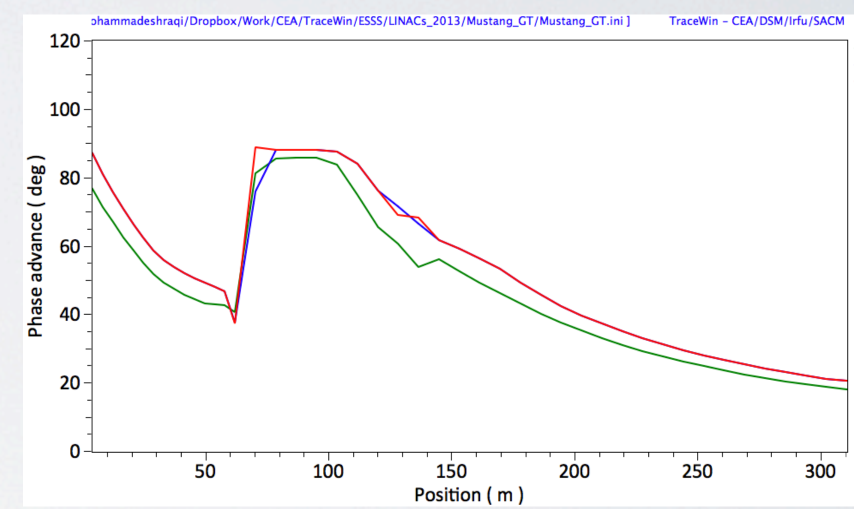


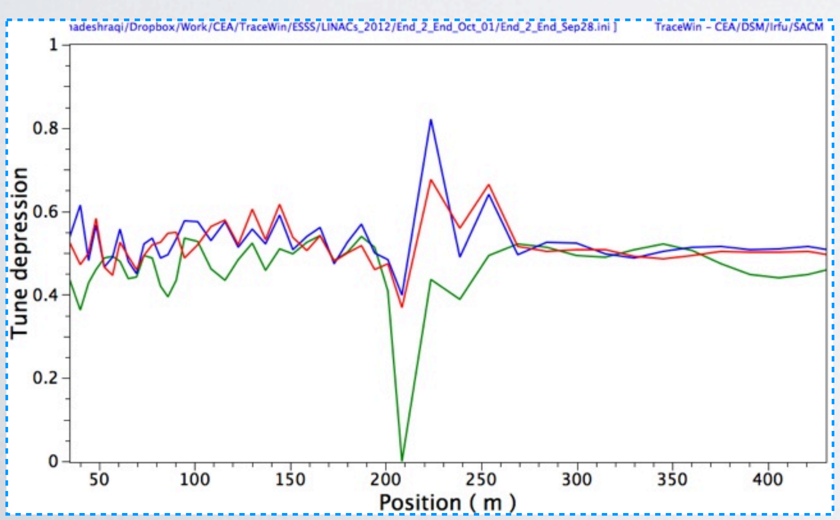


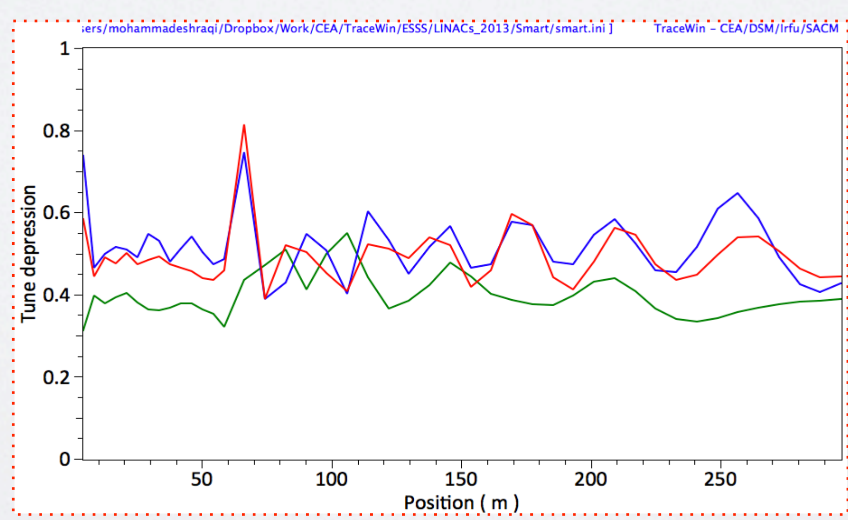


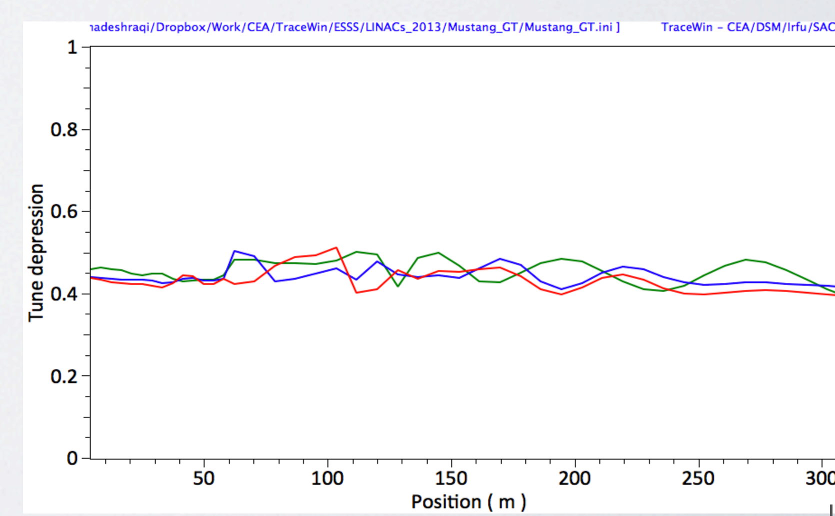




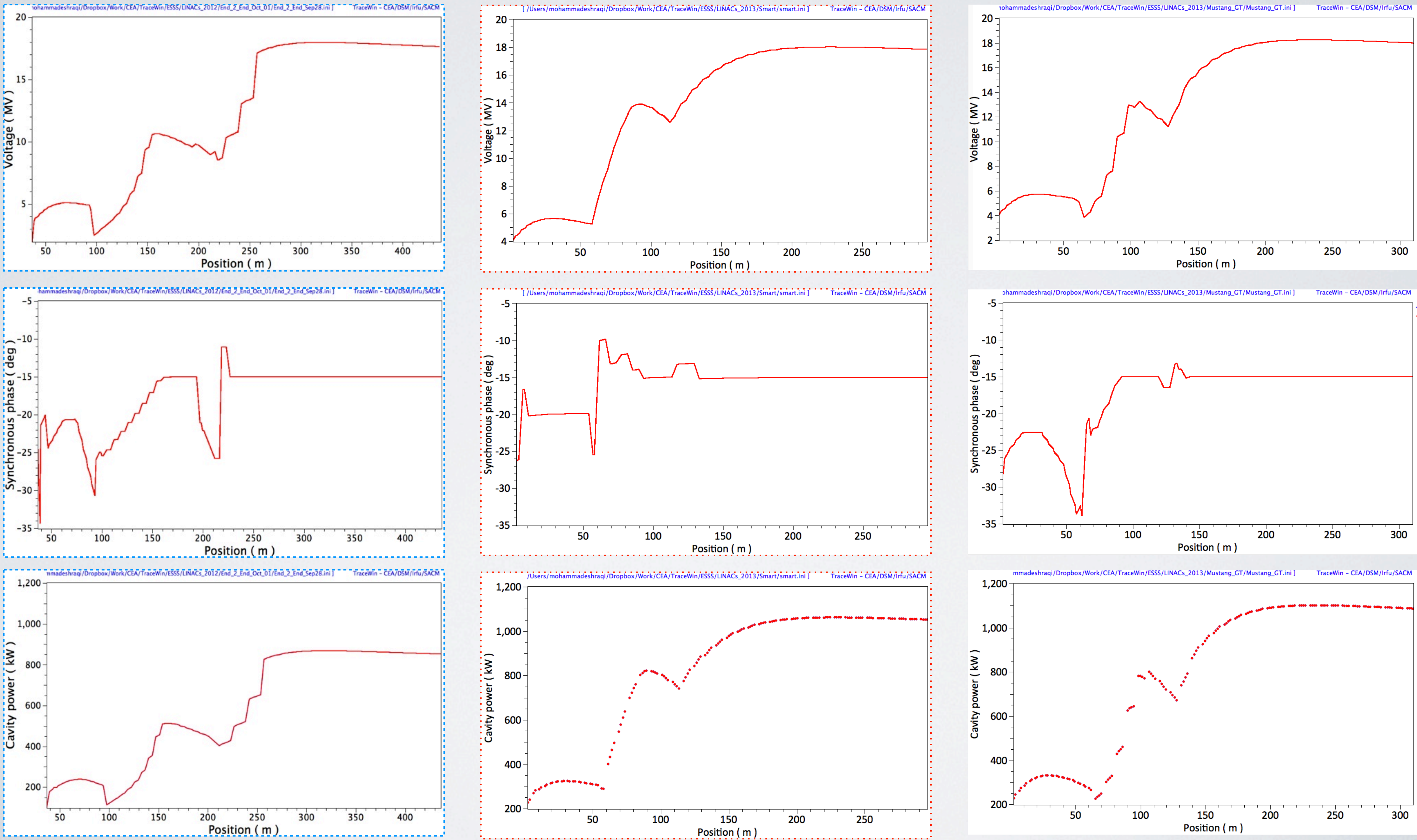






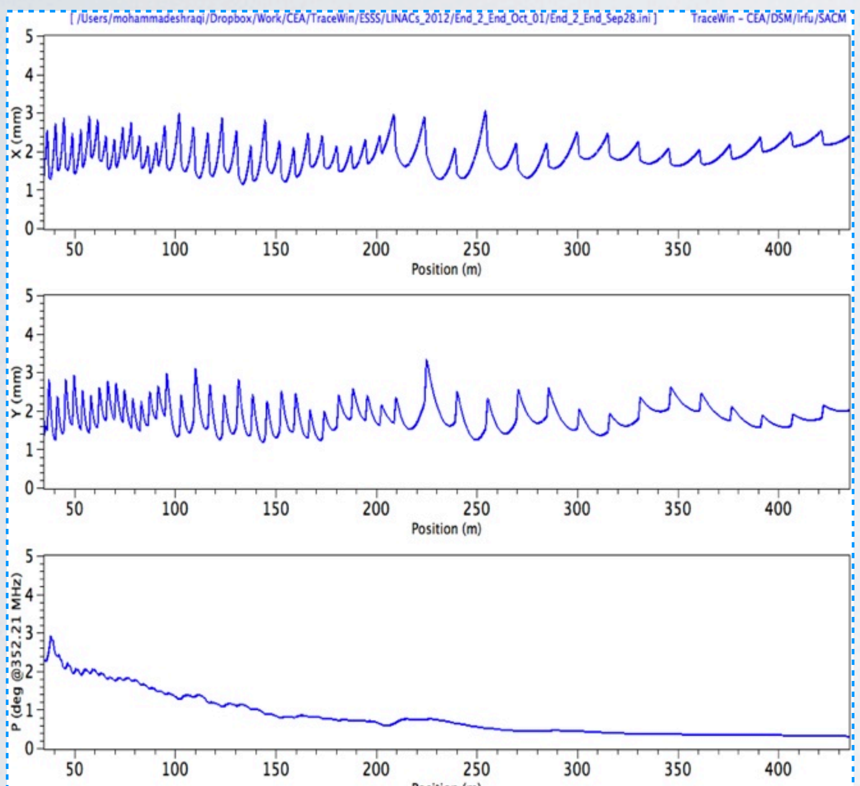


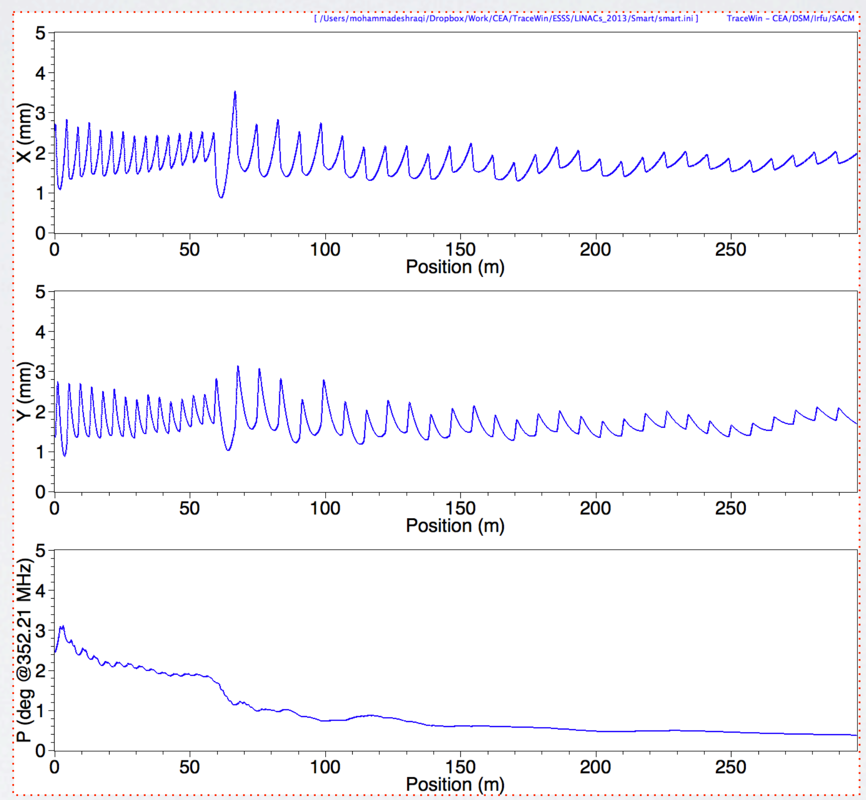
2012 BL vs. SMART vs. MUSTANG II

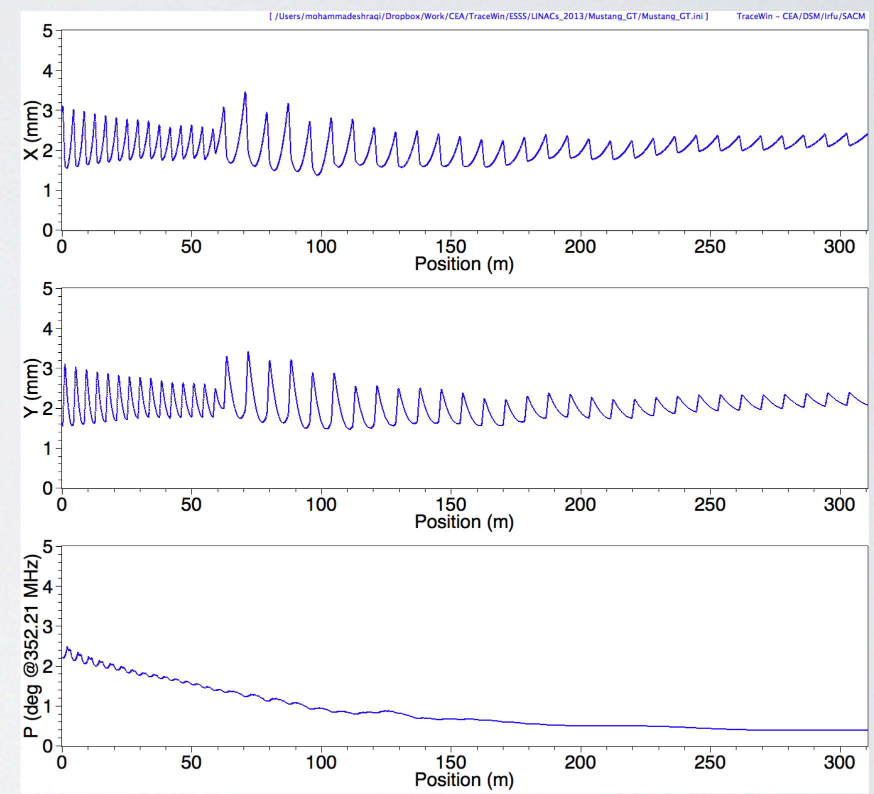


ENVELOPES

2012 BL vs. SMART vs. MUSTANG

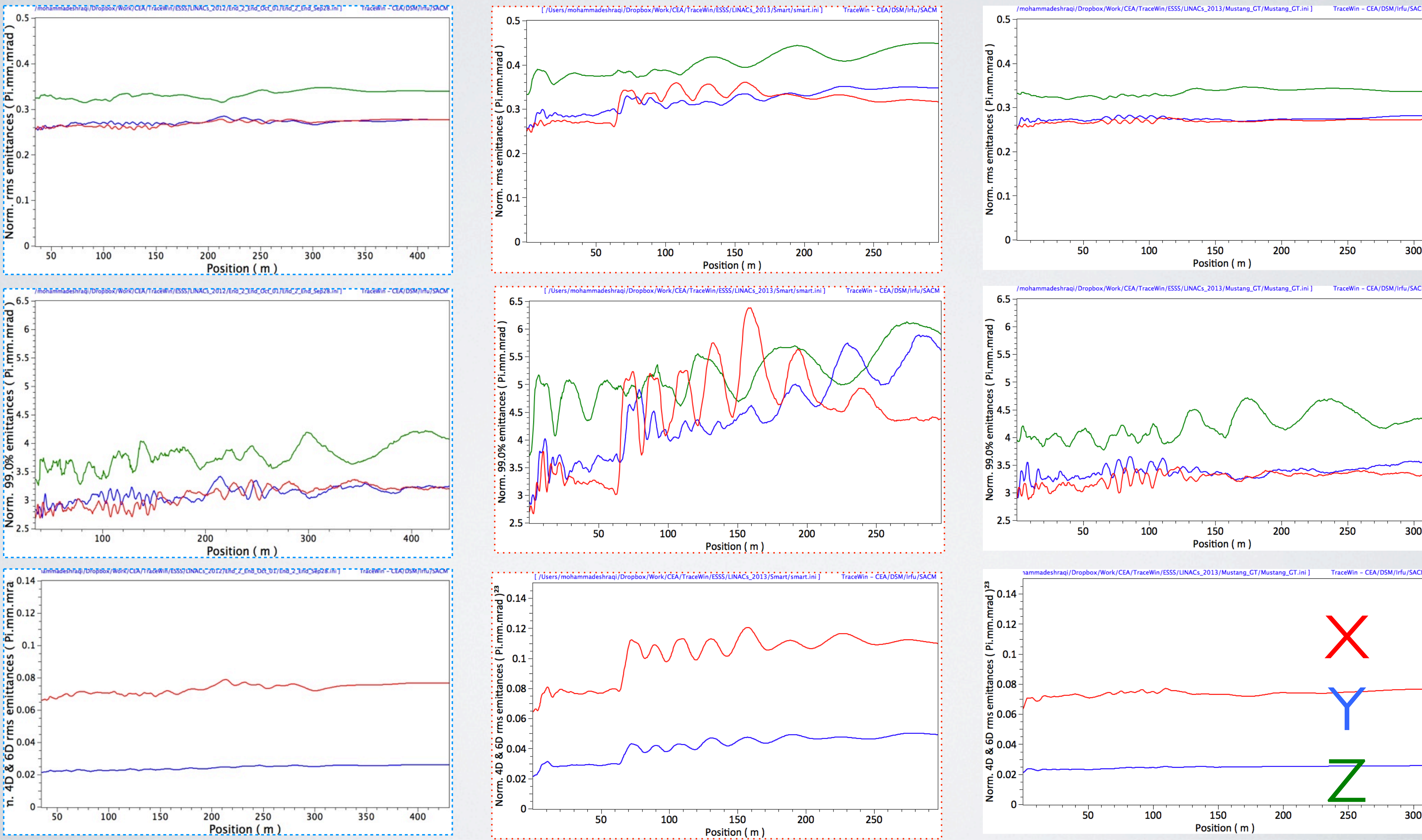




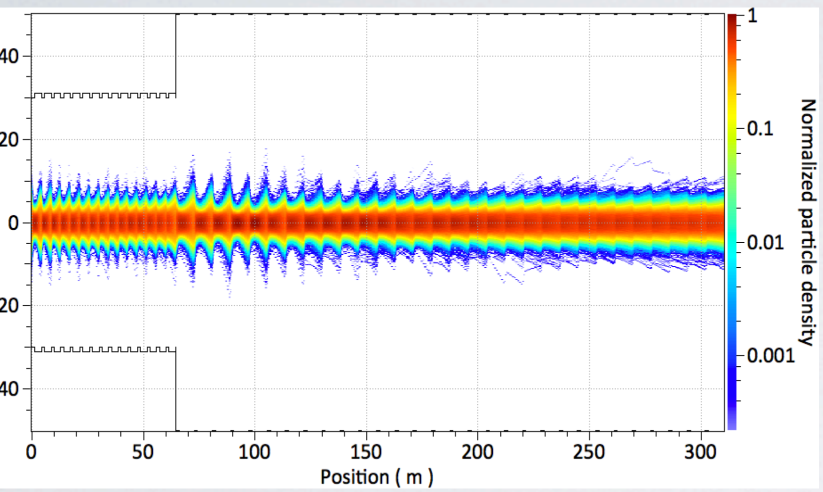


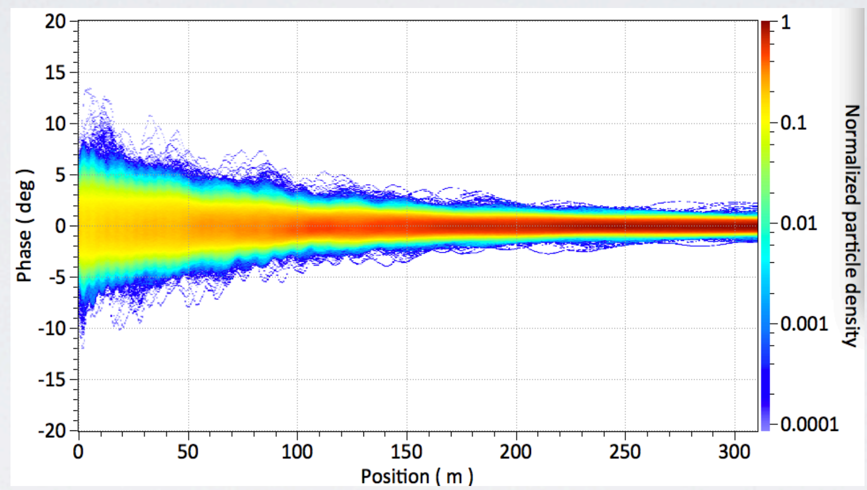
EMITTANCES

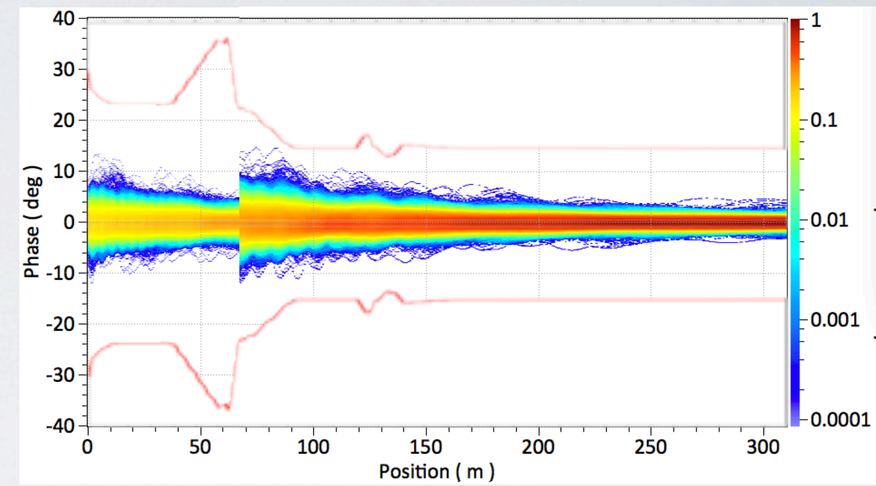
2012 BL vs. SMART vs. MUSTANG

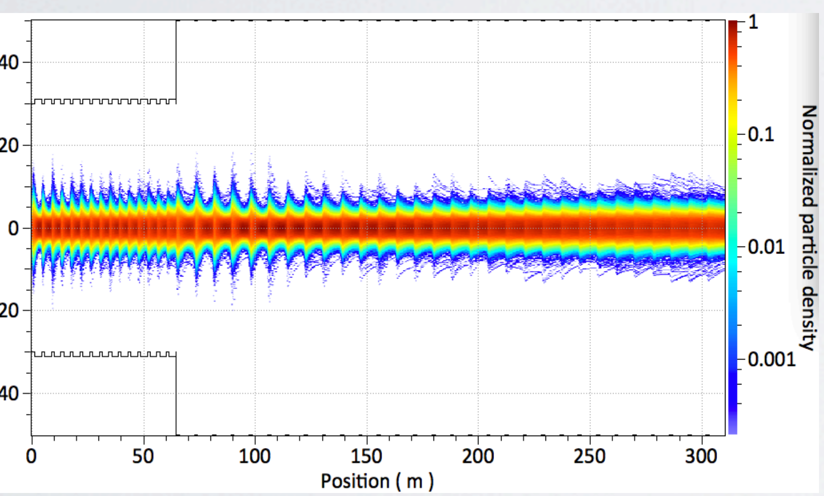


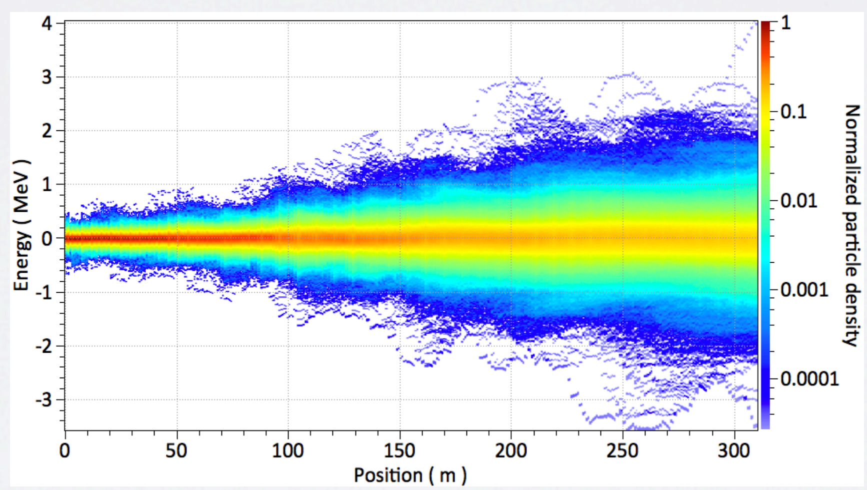
DENSITY (MUSTANG)

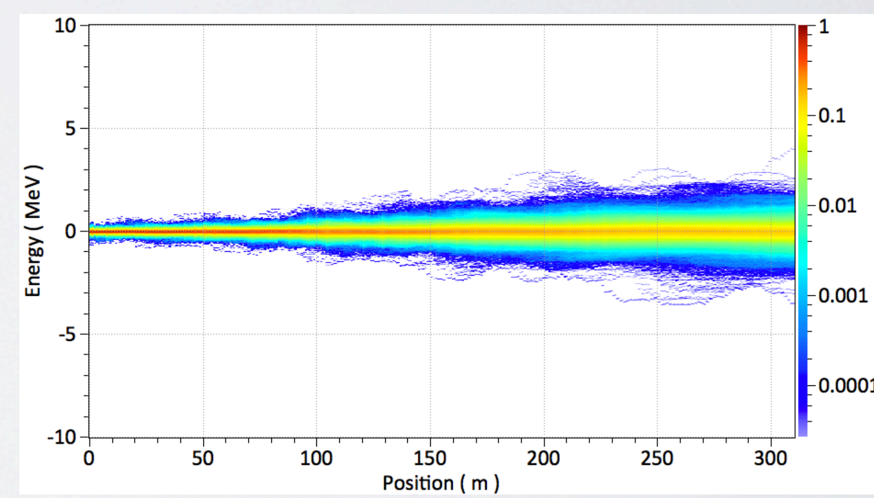












SUMMARY

- Mustang uses one more spoke cryomodule than Smart
- The βg of the medium reduced to avoid possible SOMs
- One Hβ is replaced with one Mβ, with no drawbacks
- Less emittance and halo growth plus a smooth lattice is achieved
- Increased energy out of DTL could reduce the spokes to original 14

RE-THINKING CONTINGENCY

- The major risk of Mustang vs. BL is 20% increase in current and 10% increase in gradient
- Mustang design is superior to BL
- In case of lower current or gradient, the linac would still work perfectly, but at a lower power
- The 100 m of real-estate gives us the "Design Contingency"

Thank you!