Linac Design Status

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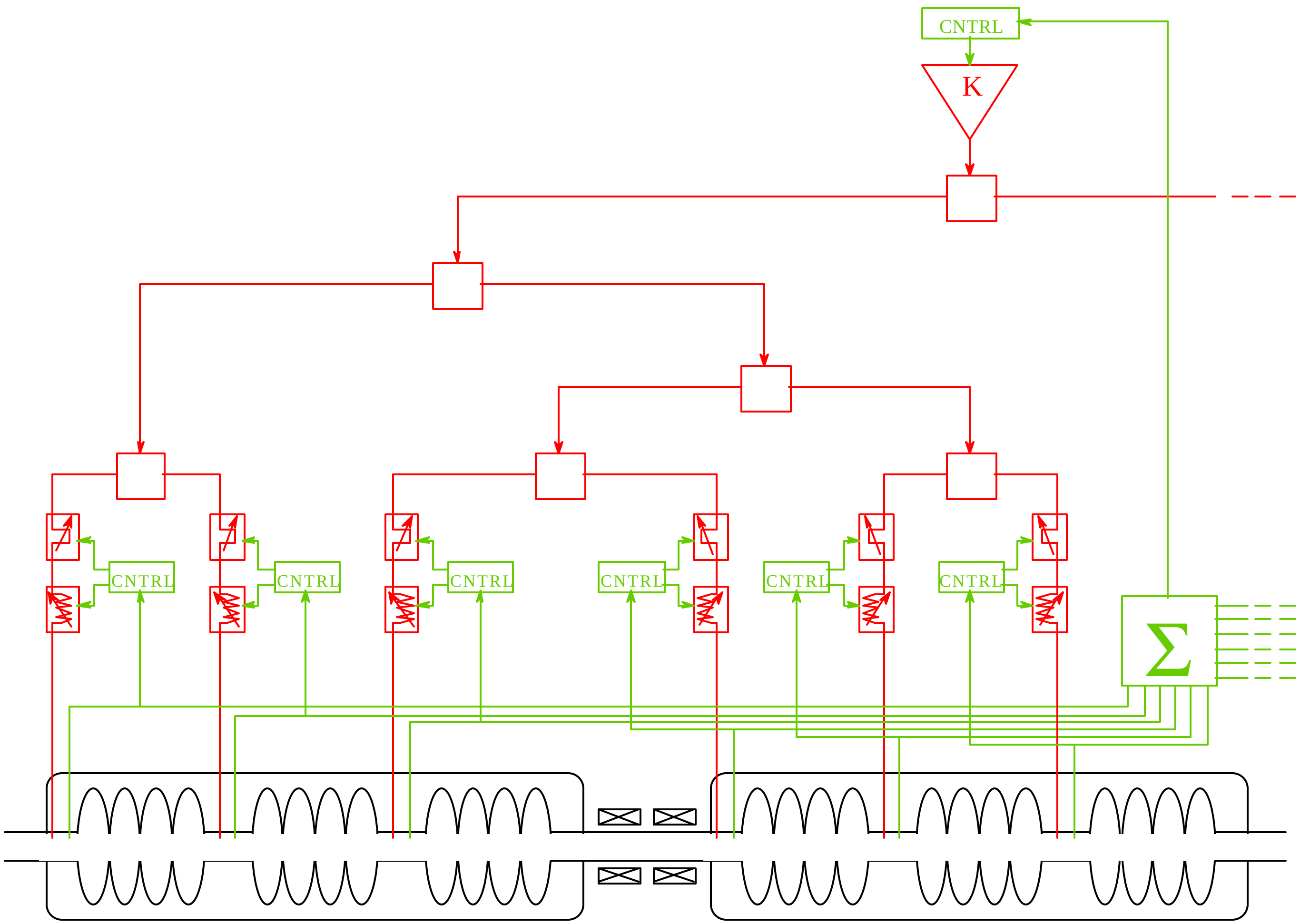
Outline

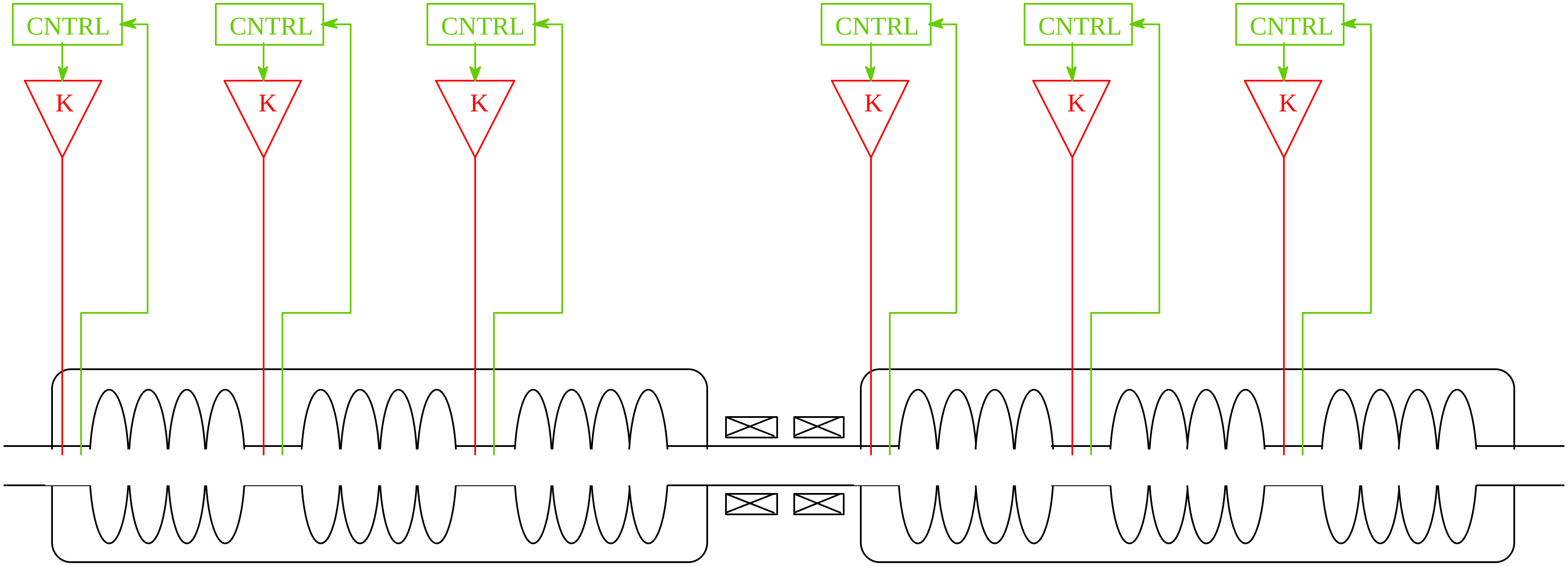
- SRF Linac design
- End-to-end beam dynamics simulations
- Cavity physics (Billen)
- SRF Beam commissioning (Young)

"March" Design, 12 Cavities/klystron
Individual + Collective Cavity Control



Reference Design

1 Cavity/Klystron Individual Control



Linac Architecture Summary

Structure	W_{final}	Total Length	Cells per Cavity	Cavities per Module	Modules	No of Klystrons	Structure Length
	MeV	m					m
DTL	86.8	36.6	60 to 21		6	6	36.6
CCL	185.6	91.9	8	12	4	4	55.4
SRF I	379.2	157.7	6	3	11	33	64.2
SRF II	948.7	276.0	6	4	15	59	118.4
SRF upgrade	1227.6	323.4	6	4	6	25	47.3

Structure	HVPS	HVPS Power	Transmitters	Klystrons	Klystron Power
		MW			MW
RFQ & DTL	3	10	7	7	2.5
CCL & HEBT	5	10	6	6	5.0
SRF I & II	8	10	16	92	0.55
SRF upgrade	3	10	5	25	0.60

Linac Design is Mature

- DTL Physics design is complete
  - Cavity cold-modeling underway
  - Field stabilization scheme demonstrated
- CCL Physics design is complete
  - Cavity cold-modeling underway
  - Cavity geometry finalized
    - details being incorporated into design
  - Bridge-coupler details under study
  - Hot-model in fabrication
- SRF Reference design is complete
  - Cavity layout is frozen
  - Investigating alternate phase & quad laws

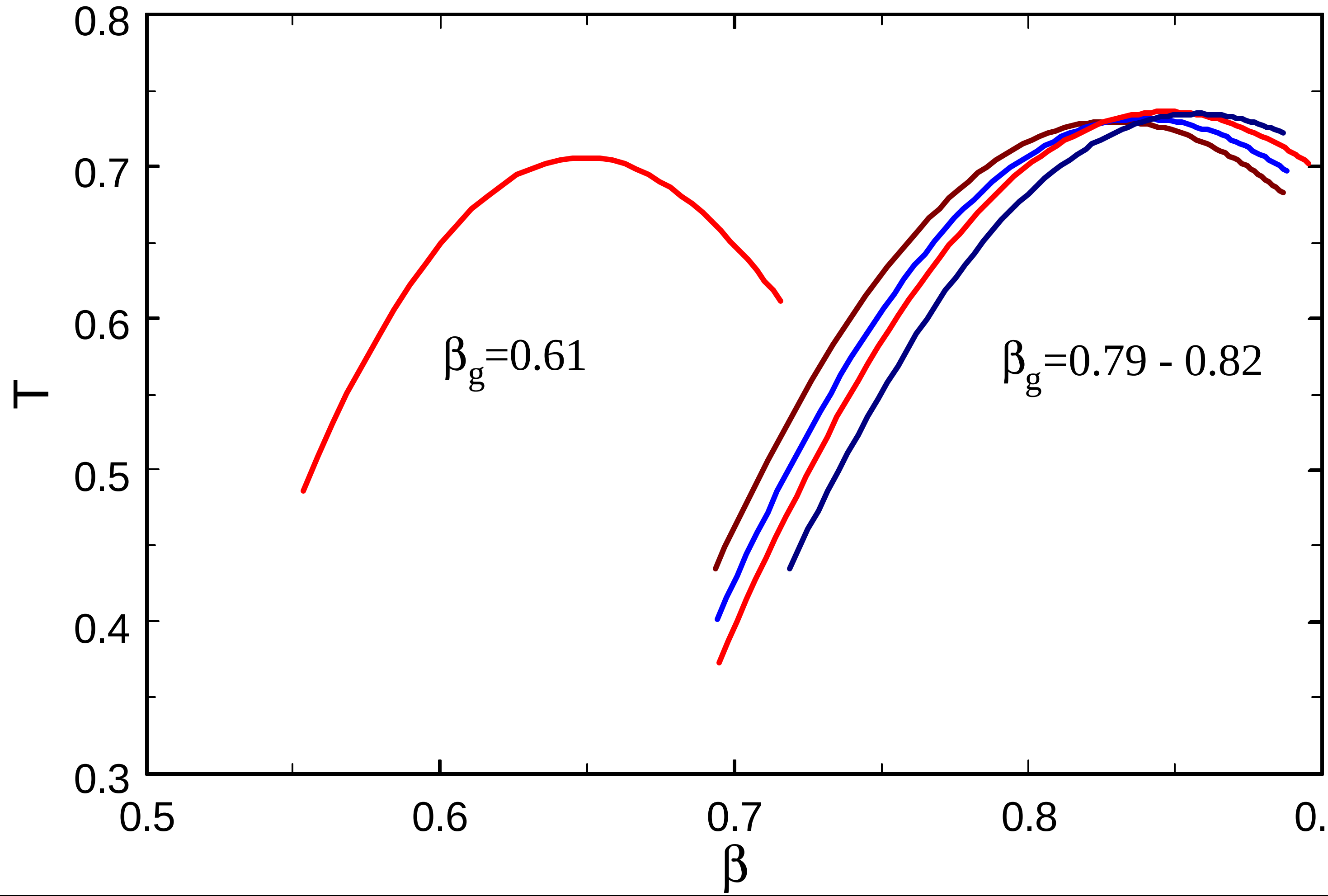
Linac Interfaces are Mature

- MEBT-DTL: dimensions are frozen, matching is complete
- DTL-CCL: dimensions are frozen, matching is complete
- CCL-SRF: dimensions are frozen, have a matched solution
- SRF β_1-β_2: have a matched solution
- SRF-HEBT: length frozen
  - end-to-end simulations underway
  - energy corrector/spreader cavity-physics design complete
  - HEPT interface workshop in Dec.

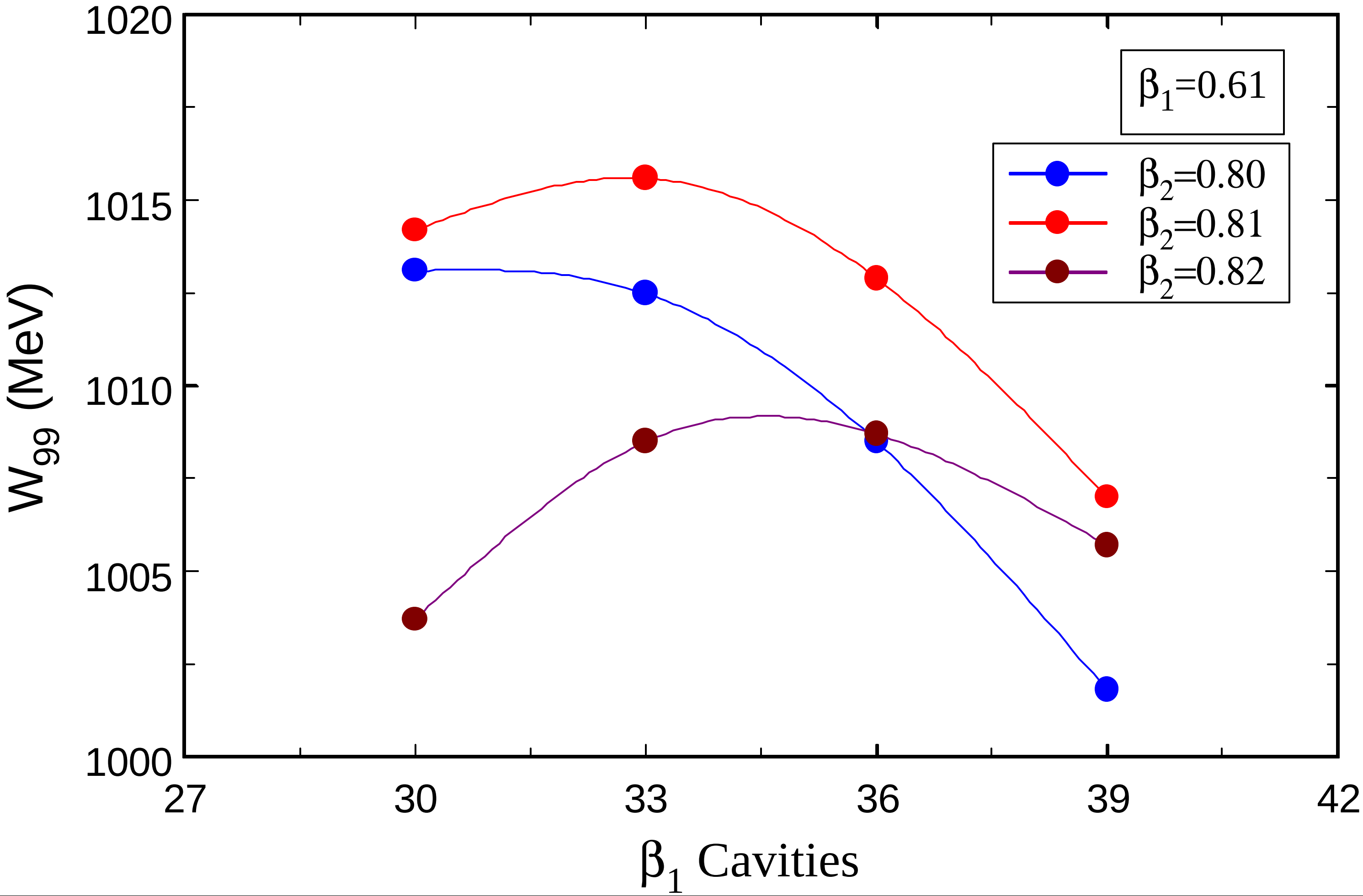
SRF Design is Based on 2 Cavity bs

- $E_{max} \leq 27.5$ MV/m
- Optimized for cost with 2 β cavities
  - a 3rd lower-β cavity would be too numerous & inefficient
- $\beta_1 \equiv 0.61$
  - based on earlier 2-cavity design studies
  - 5 MW CCL modules coarsely quantize initial energy
- $0.74 \leq \beta_2 \leq 0.82$
  - higher β provides more efficient acceleration
    - § i.e. higher E_0, T & L_{cav}
  - if $E_{max} > \langle E_{max} \rangle$, higher β supports a higher W_{final}
- Transition energy
  - maximized final energy for fixed cost machine

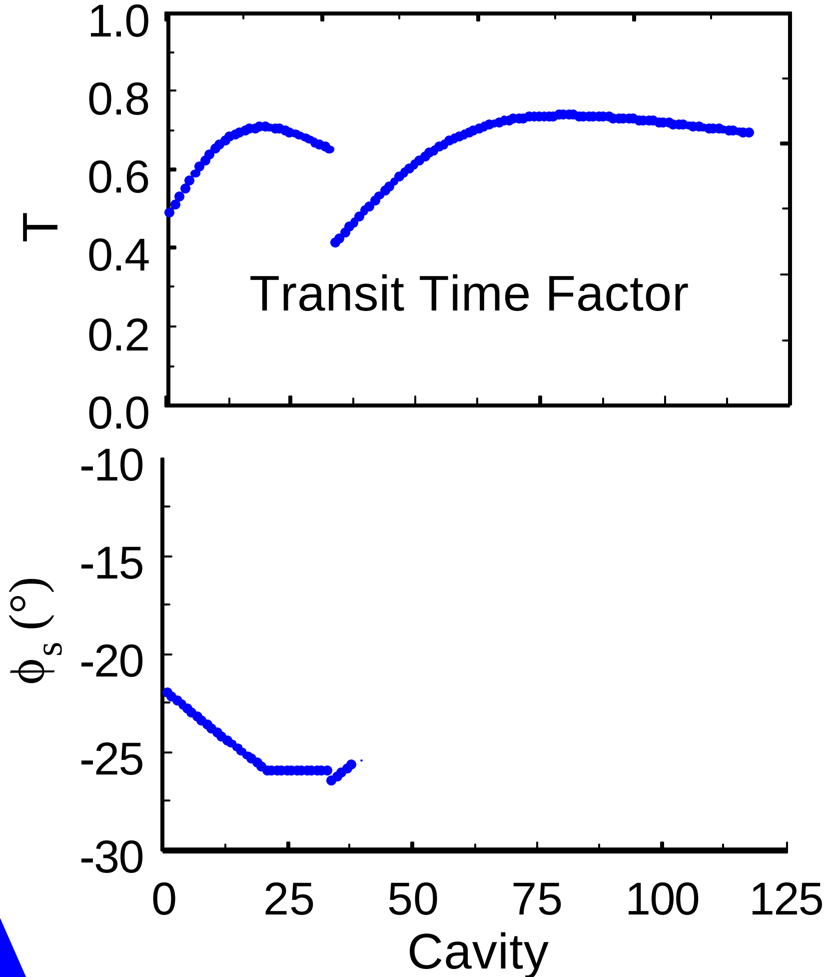
Transit Time Factors (T_{ave}) for Candidate Cavities Increase With b

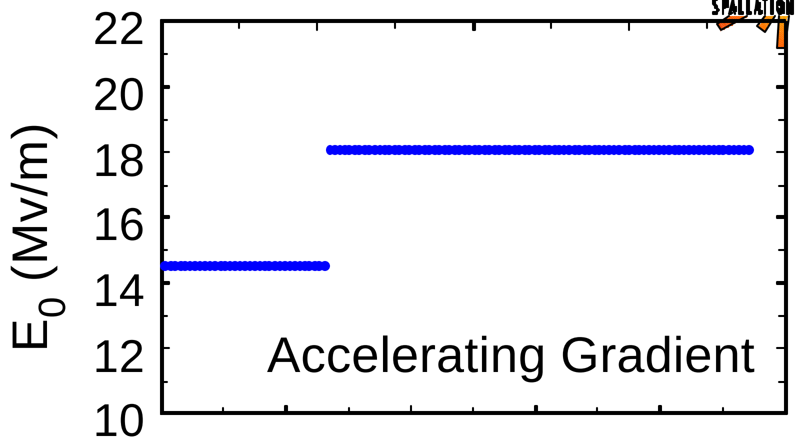


Cavity b & Transition Optimization for a Linac Having 99 Total Cavities

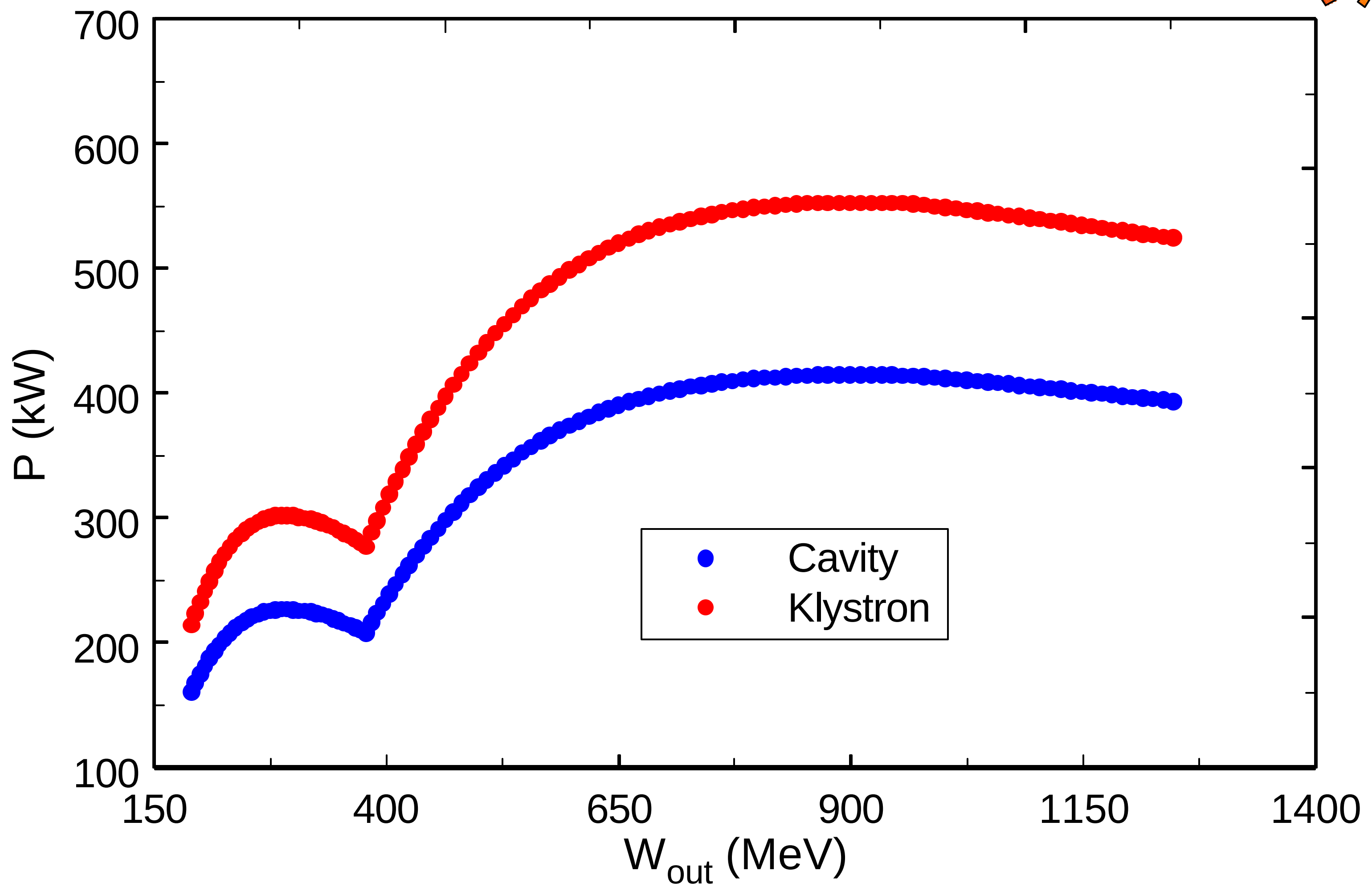


SRF Linac Design Assumes E_{max}=27.5 MV/m

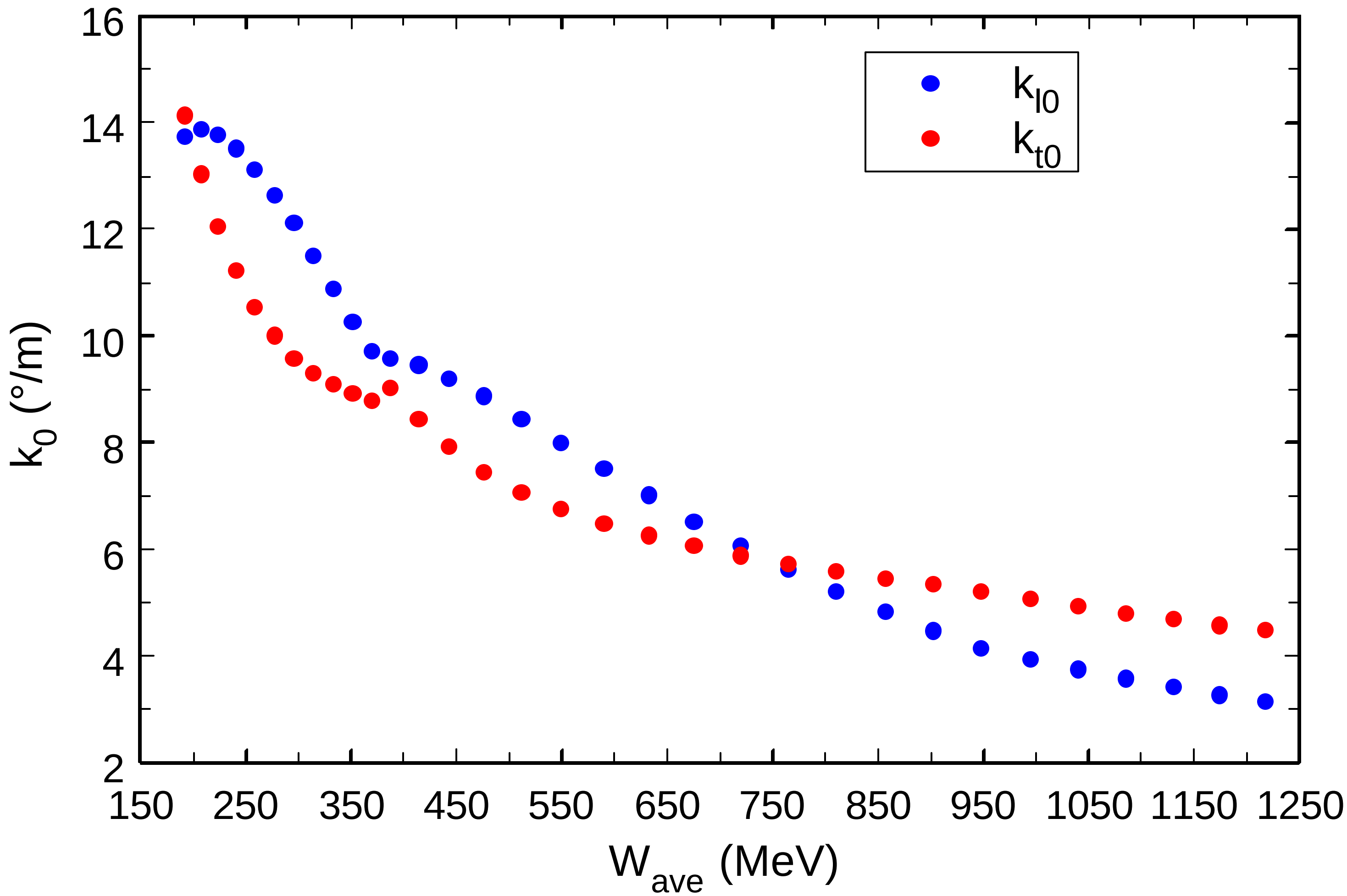




Beam Consumes 75% of Available rf Power



SRF Real-Estate Zero-Current Phase Advance is Smooth & Continuous



SRF Phase & Amplitude Set-Points Preserve Longitudinal Dynamics

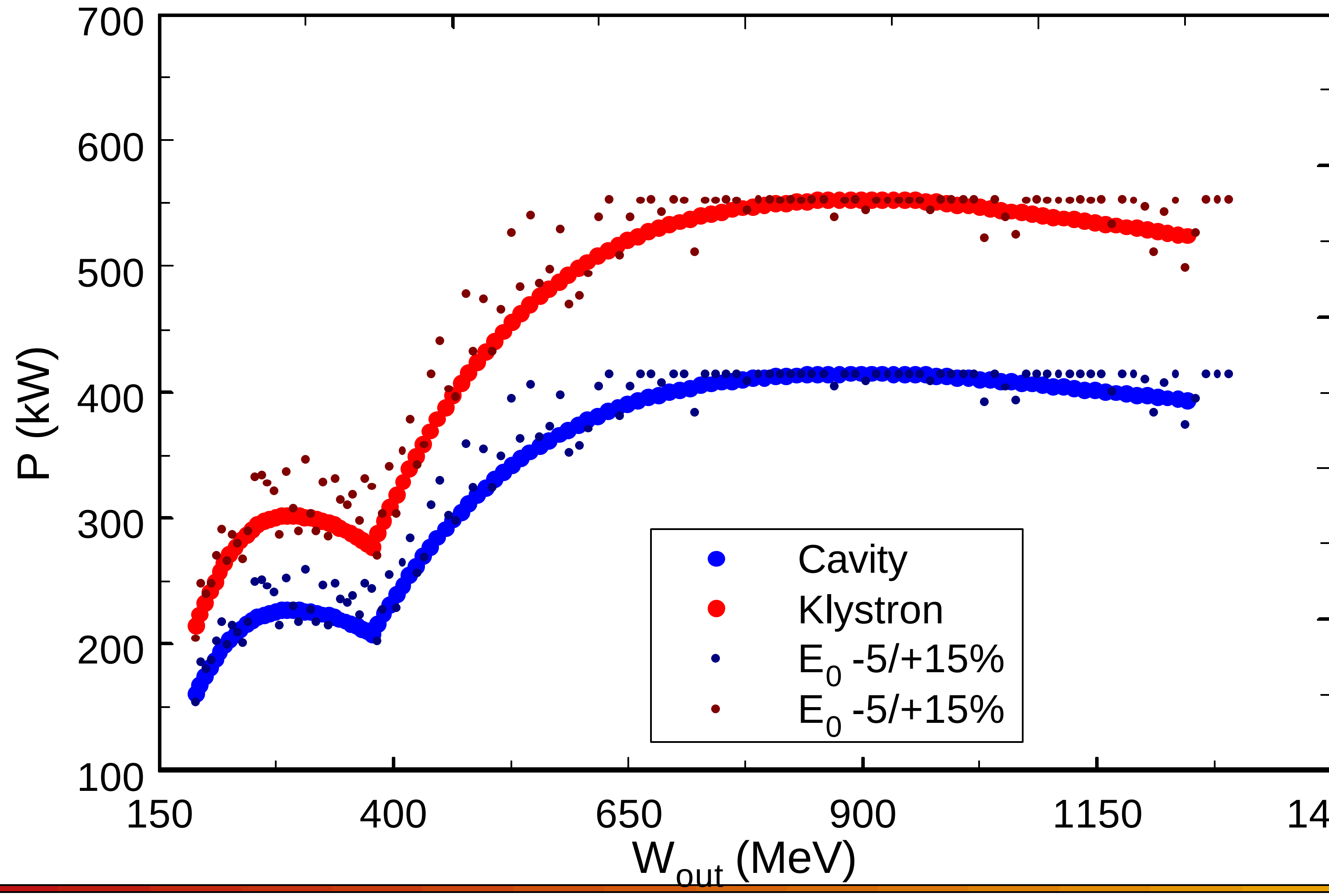
- E_{max} determined at acceptance for each cavity
  - $\langle E_0 \rangle \approx E_{dsn} \pm 10\%$
- Calibrate cavity field probes
  - using drifting beam to excite cavities
- $E_{0,operating}$ established for each cavity
- Corresponding $\phi_{operating}$ derived for each cavity
  - preserving longitudinal dynamics
  - holding $k_{0,l}$ constant
    - $k^2_{0,l} \equiv E_{0,design}\, T(\beta) \sin(\phi_{design} / \beta^3\gamma^3)$
  - $\phi_{operating} = \beta^3\gamma^3 \sin^{-1}(k^2/E_{0,operating}T)$

[redacted]

SRF Linac Will Have 184 Static Field Errors Effecting W_{final}

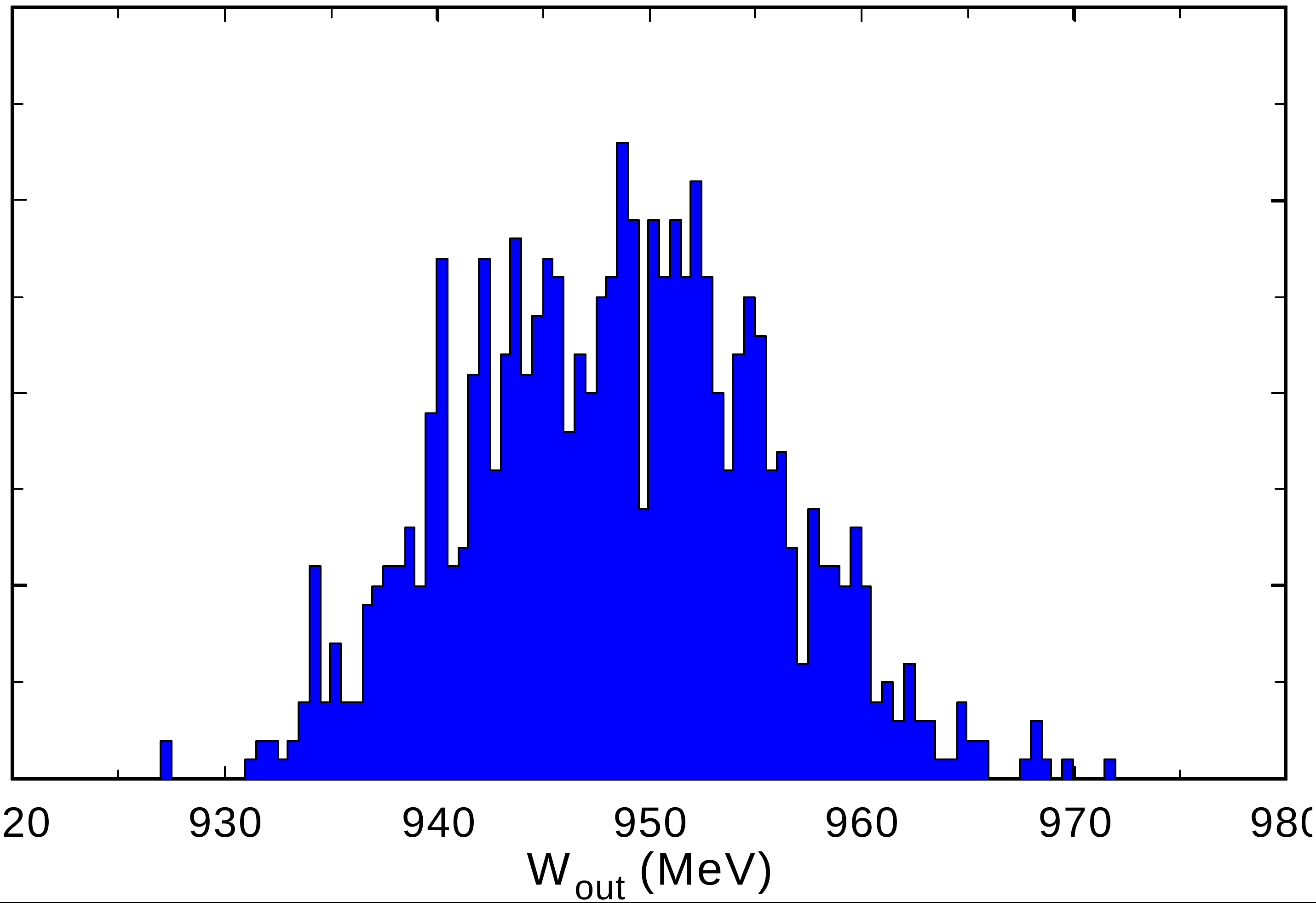
- Design cavity field: $E_{0,design}$
- Cavity performance varies: $E_{0,operating} = E_{0,design} \pm 10\%$ nom
- Field measurement error: $E_{0,measured} = E_{0,operating} \pm 5\%$ nom
- Design cavity phase: ϕ_{design}
- Phase set-point is derived: $\phi_{setpoint} = f(\phi_{design}, \beta, E_{0,measured})$
- Phase measurement error: $\delta\phi = \pm 2°$
- Actual cavity phase: $\phi_{operating} = \phi_{setpoint} + \delta\phi$

W_{final} is Limited by E_{max} & Installed rf Power

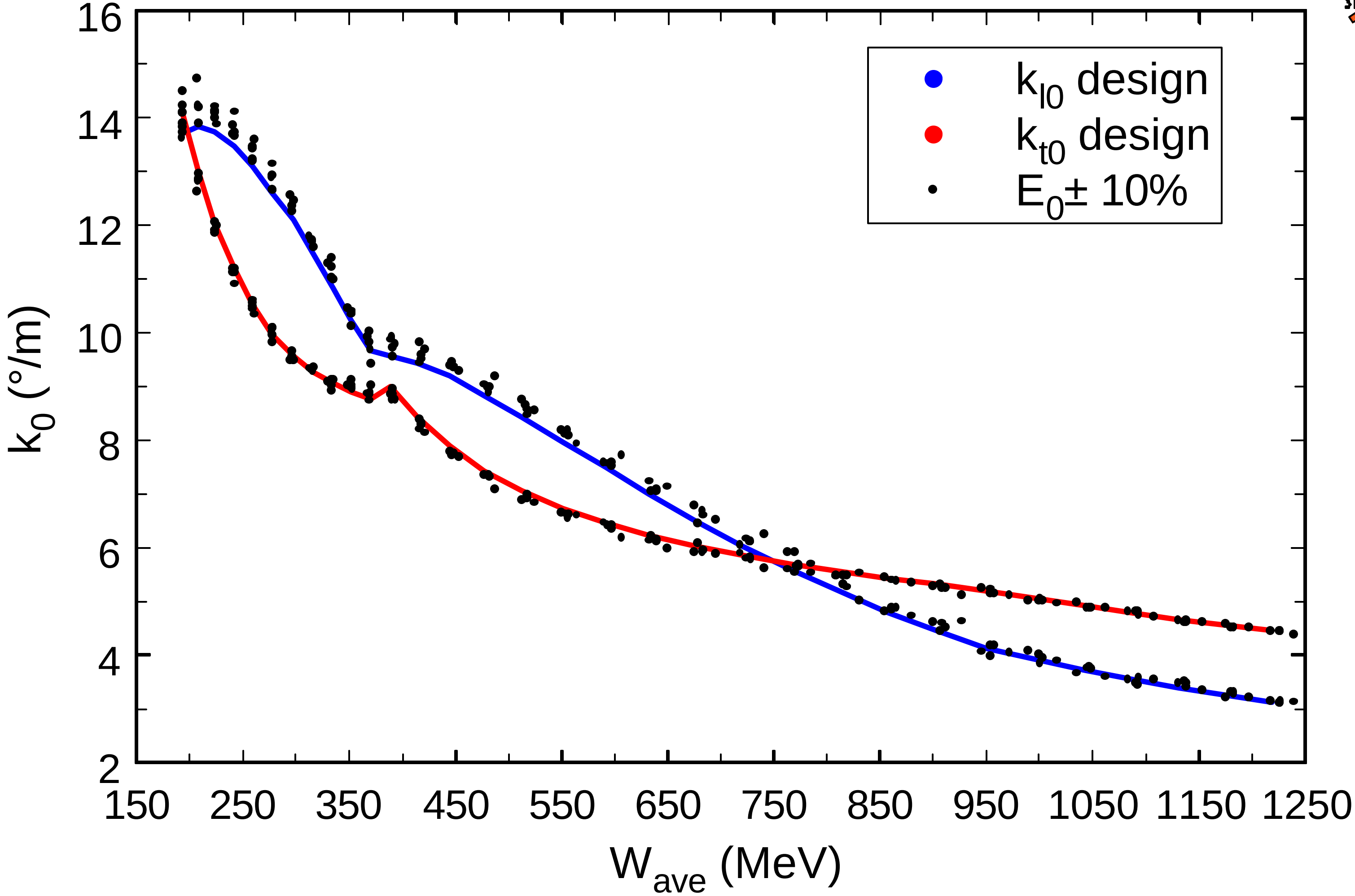


Expected Output Energy

E_{max}= 27.5 MV/m ± 10%



Tuning Philosophy ($k_{0,l}$=const) Preserves Beam Dynamics



End-to-End Beam Dynamics Simulations

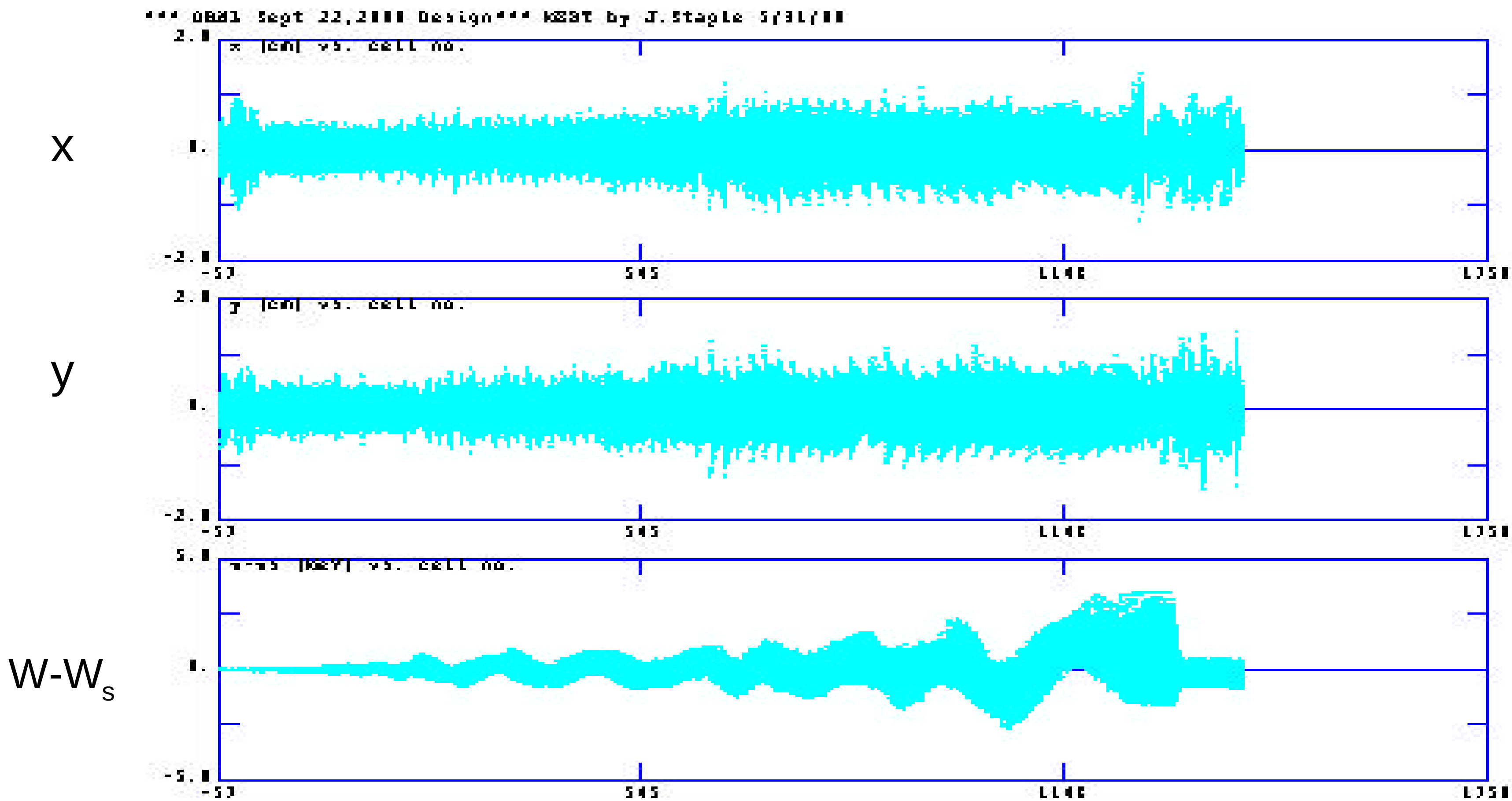
- 4-D “Waterbag” distribution enters the RFQ
- RFQ beam dynamics calculated by:
  - Parmteq: multiparticle space based
  - Toutatis: multiparticle time based
- Linac beam dynamics
  - MEBT, DTL, CCL, SRF & HEBT
  - Parmila is the design code
  - Parmila, Linac & Impact calculate multiparticle beam dynamics
  - LTrace calculates envelope dynamics

Error Budgets Included in Simulations to Date

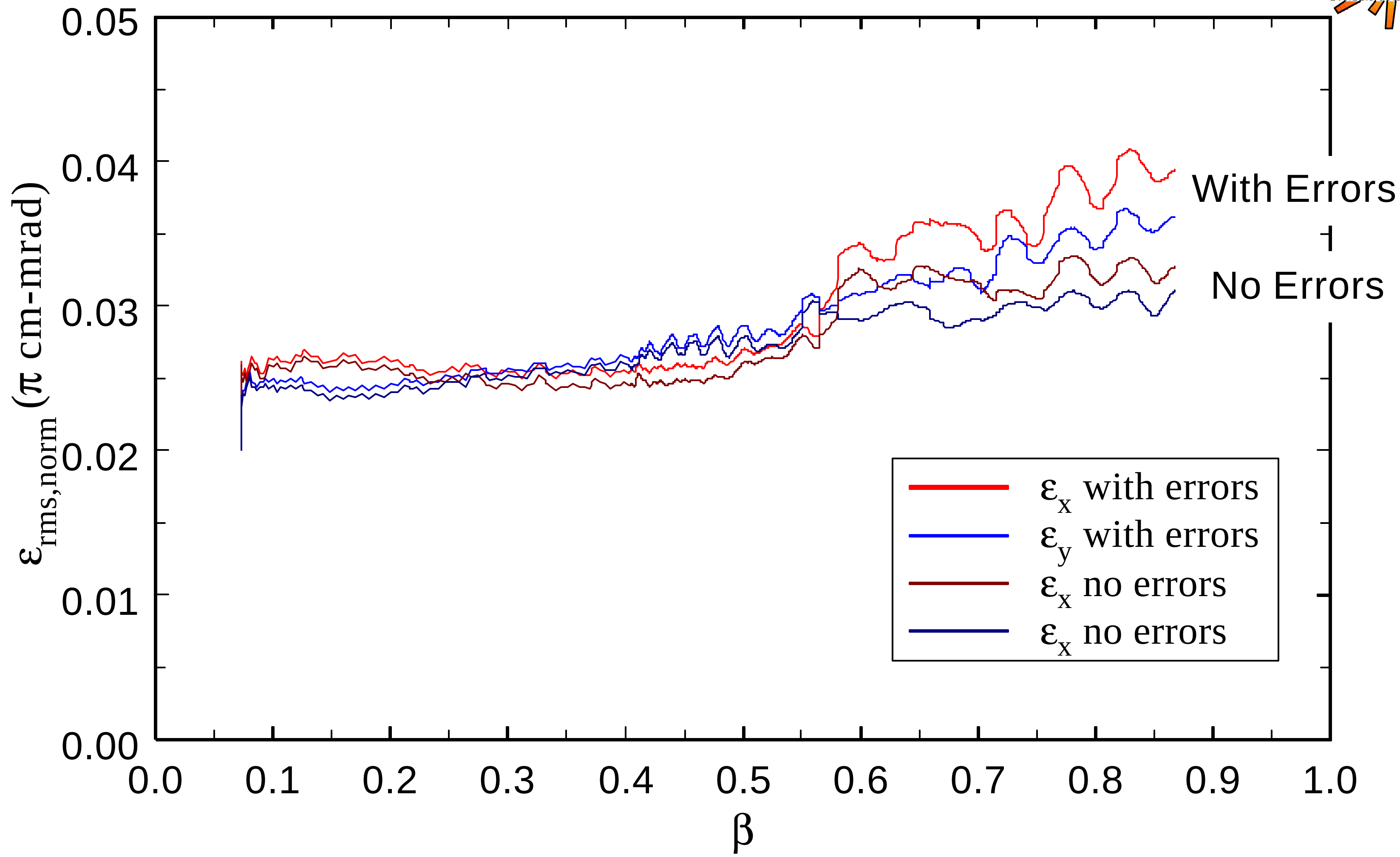
	Units	MEBT	DTL	CCL	SRF
Quad Errors:					
displacement	cm	--	--	--	--
Pitch & yaw	deg	0.57	0.57	0.57	0.57
Roll	deg	0.25	0.29	0.29	0.29
Gradient	%	1.73	0*	0.5	0.5
Cavity Errors, Static:		--	--	--	--
Cavity Errors, Dynamic:					
Phase	deg	0.5	0.5	0.5	0.5
Amplitude	%	0.5	0.5	0.5	0.5
Tilt	%	--	0.1	0.	0.

* Equivalent to 2% sorted.

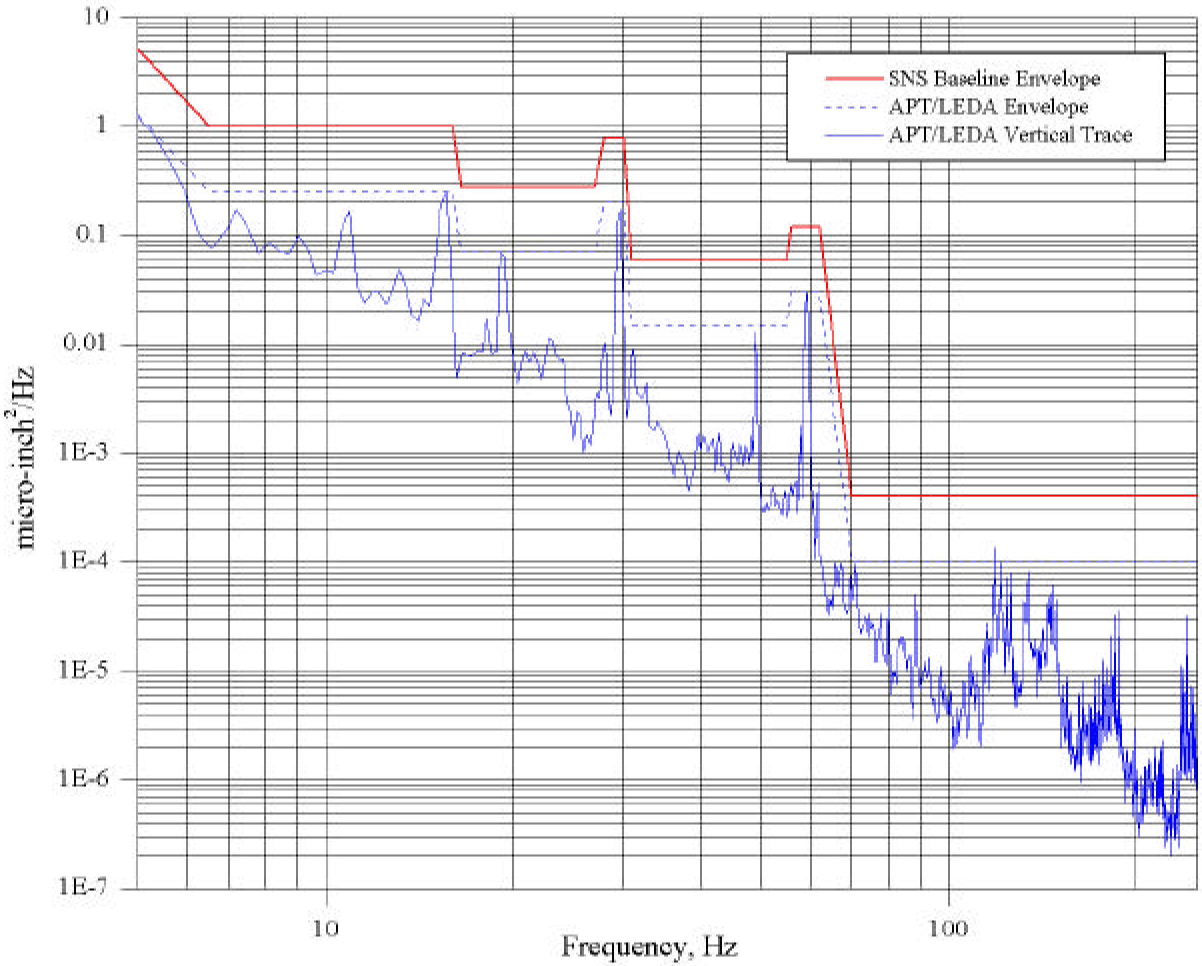
Beam Profiles for Reference Design With Errors



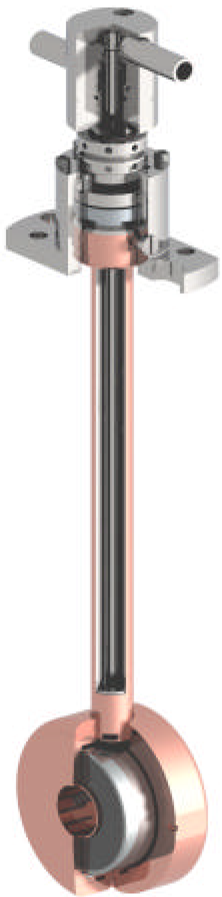
rms Emittance Profiles
With & Without Errors



Expected Vibration Spectrum in the Linac Tunnel

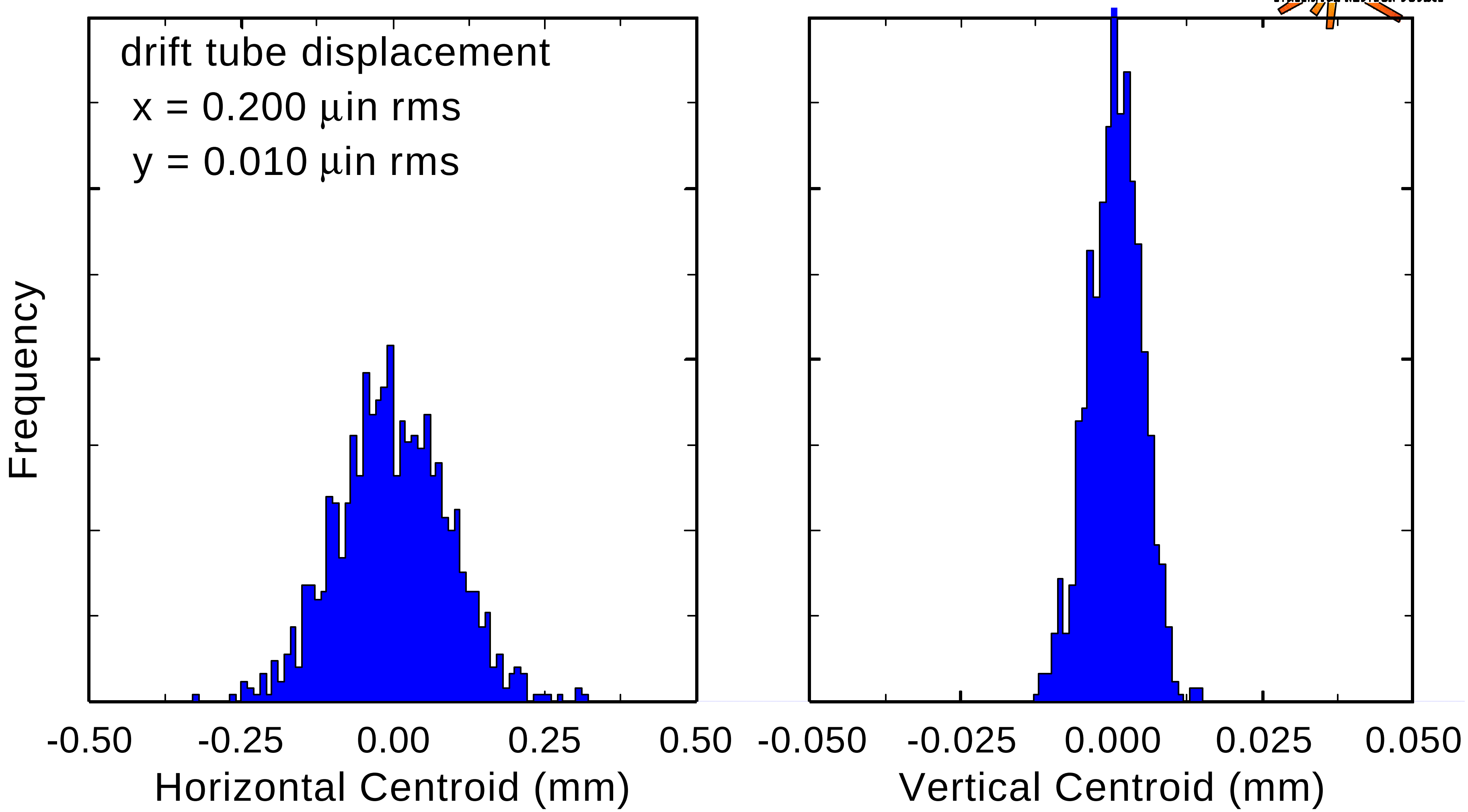


Vibration Amplitudes are Greatest in Tank 2

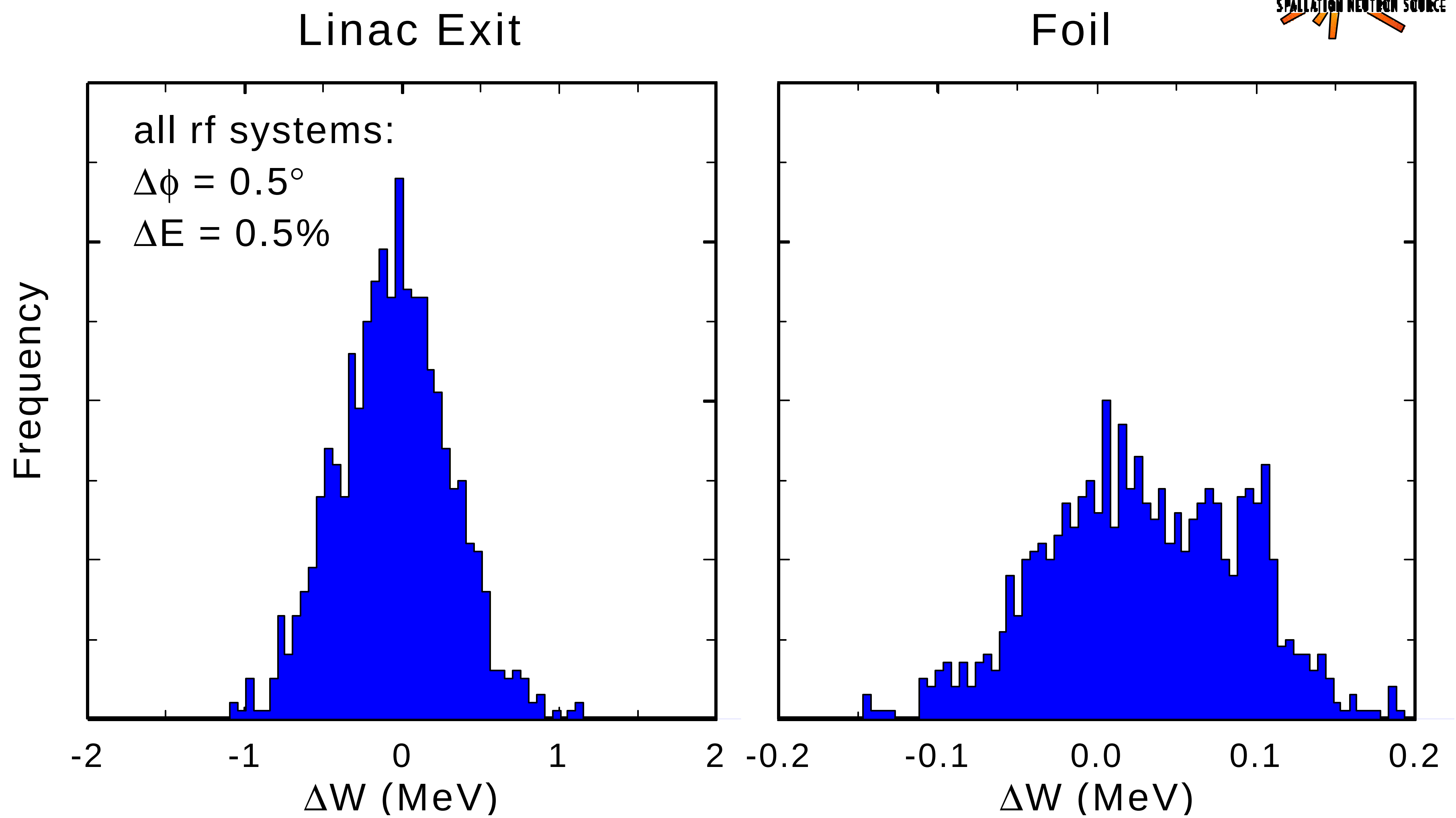


	RMS Displacement		
Drift tube	**x axis**	**y axis**	**z axis**
first	124 μ-in	24 μ-in	85 μ-in
~ middle	200 μ-in	10 μ-in	85 μ-in
end	148 μ-in	46 μ-in	86 μ-in

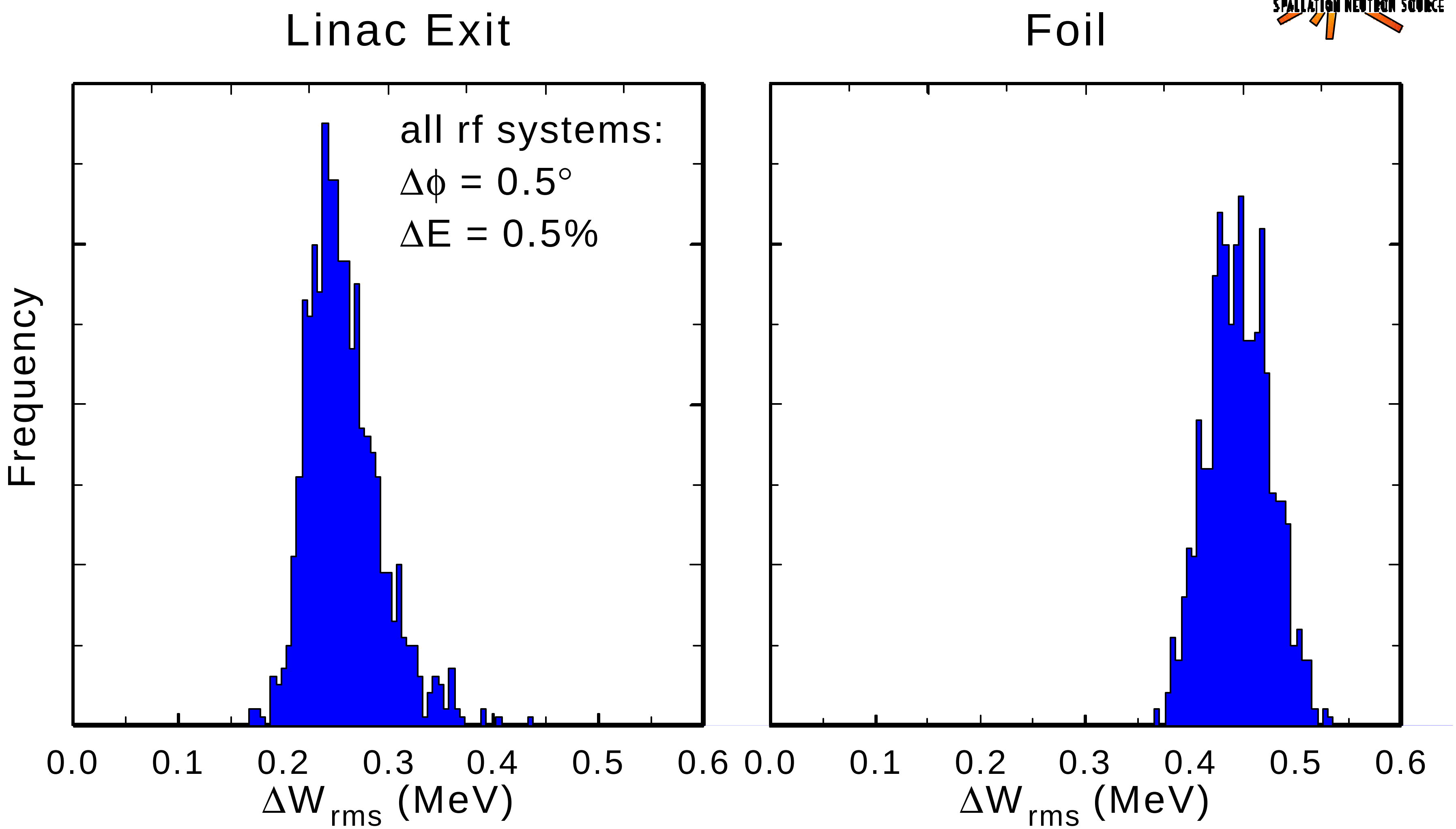
Transverse Jitter at the Foil is a Function of Quadrupole Vibrations



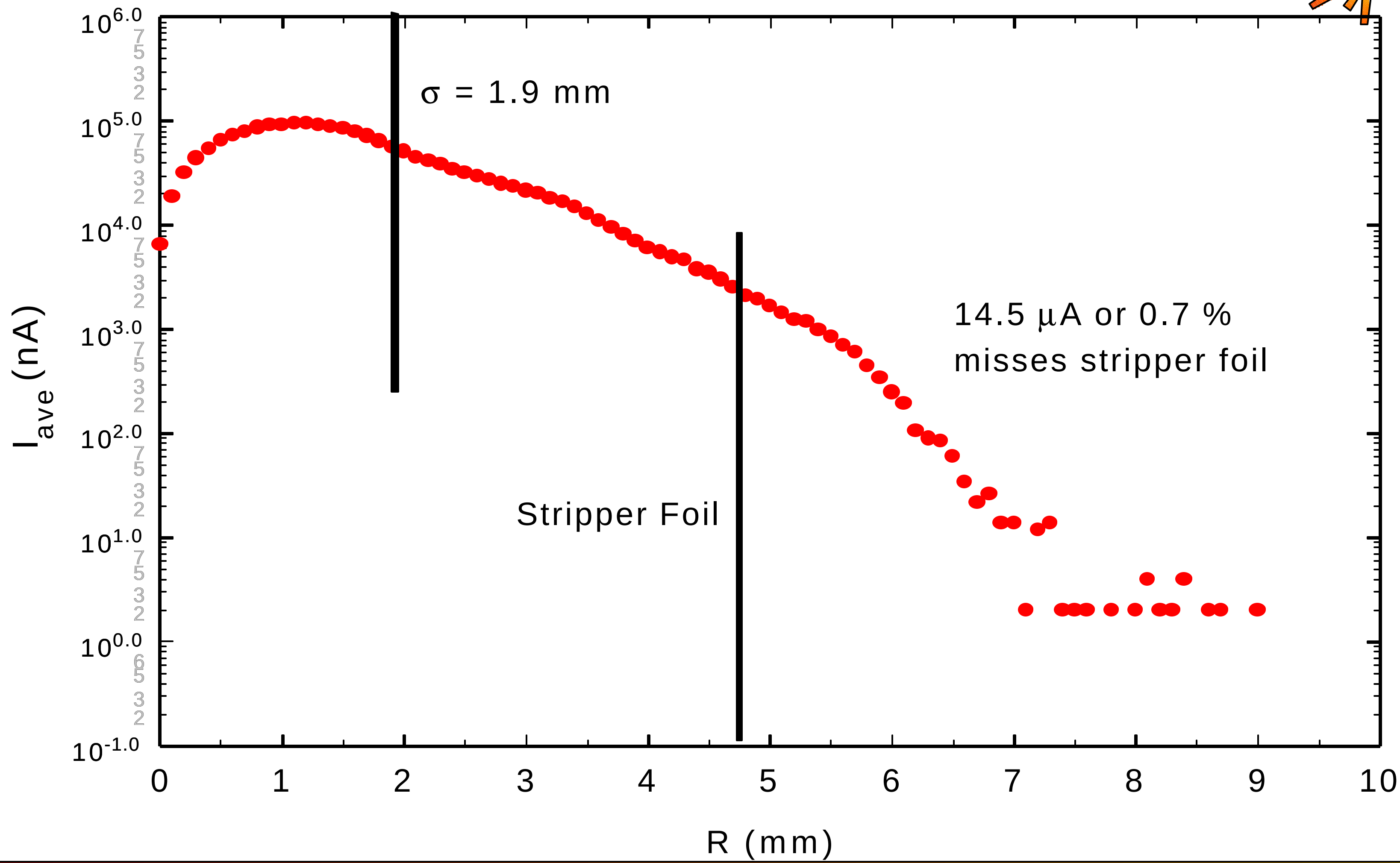
Energy Jitter is a Function of RF Control Tolerances



Energy Spread is a Function of Space Charge & Corrector Voltage



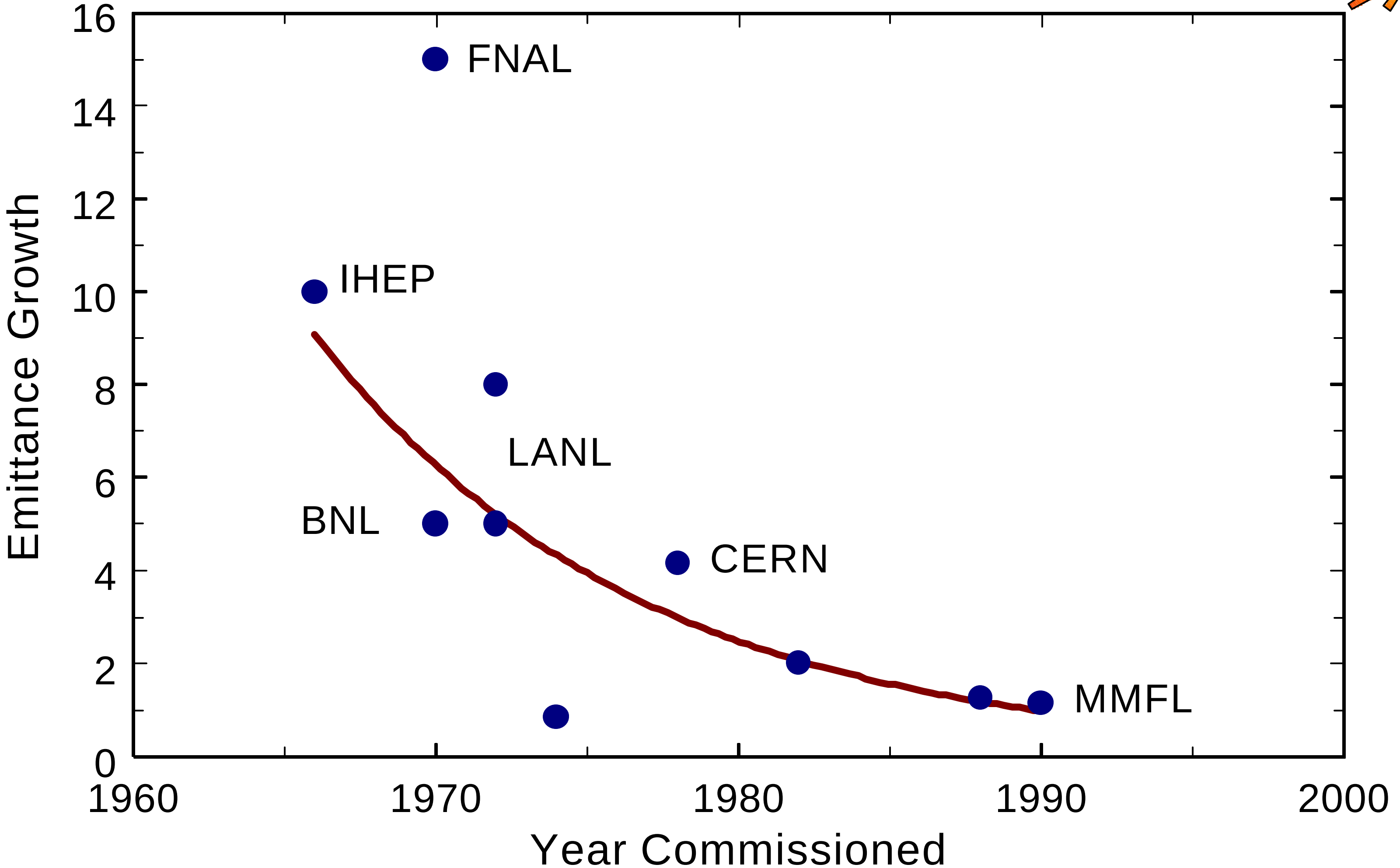
Radial Particle Distribution at the Foil with Errors



Emittance Growth is a Function of Many Variables

Linac	W_{in}	W_{out}	I_{out}	e_{in}	Growth	Vintage
	keV	MeV				
IHEP	700	103	100	0.2	10	66
FNAL	750	401	50	0.1	15	70/93
BNL	750	200	40	0.4	5	70
LANL	750	800	16	0.093	5	72
				0.09	8	
KEK-40	750	40	18	1.4	0.84	74/85
CERN	750	50	150	1.2	4.16	78
ISIS	665	70	25	--	----	83
Biejing	750	35.5	40	3.0	2	82/85
DESY	750	50	12	0.8	1.25	88
MMFL	750	423	20	0.7	1.14	90

Emittance Growth Improves With Youth



Status of Linac Design & Beam Simulation Studies

- Steering algorithms have been selected
- Dipole & BPM locations identified
- Algorithms incorporated into simulation codes
- Ready to include displacements
- DTL & CCL phase & amplitude set-point algorithms under study
- Code comparisons under study
- Missmatch studies pending
- Full error set pending
- Beam dynamics workshop in Nov.
- HEBT workshop in Dec.