Considerations on Proton Driver Parameters for a Neutrino Factory

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International Scoping Study

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Collaborators

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Outline

1. Motivation of this study
2. Examples of parameter dependence
3. Possible design parameter phase space
4. Comparative merit of various approaches
5. Future R&D
6. Summary and Conclusions

Motivations for This Study

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- Understand the impacts and constraints imposed by downstream sub-systems
- Identify possible design parameter phase space of the Proton Driver
- Comparison of Linac, RCS, FFAG, and LAR configurations

This is a progress report to be completed in May

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Considerations of parameters - I

To deliver 4 MW beam power on target,

we consider the effects of

1. Energy
2. Repetition Rate
3. Intensity
4. Bunch Length

Of the Proton Driver

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Consideration of Parameters - II

We evaluate their impacts on

1. Target
2. Muon Collections and Conditioning
3. Muon Acceleration
4. Muon Decay Rings

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Proton per pulse required for 4 MW

$$\overline{P}_{arc}(w) = E[eV] \times N \times e \times f_{rep}\,[Hz]$$

	10 Hz	25 Hz	50 Hz
10 GeV	250×10^{12}	100×10^{12}	50×10^{12}
20 GeV	125×10^{12}	50×10^{12}	25×10^{12}

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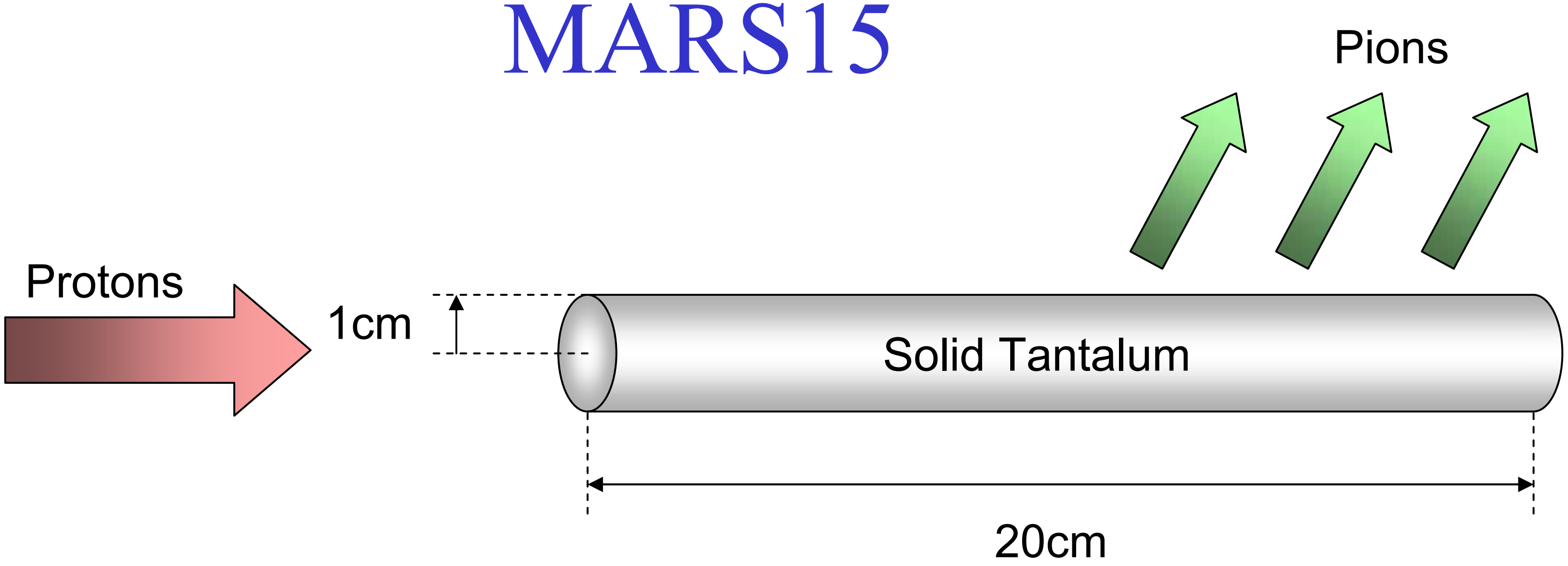
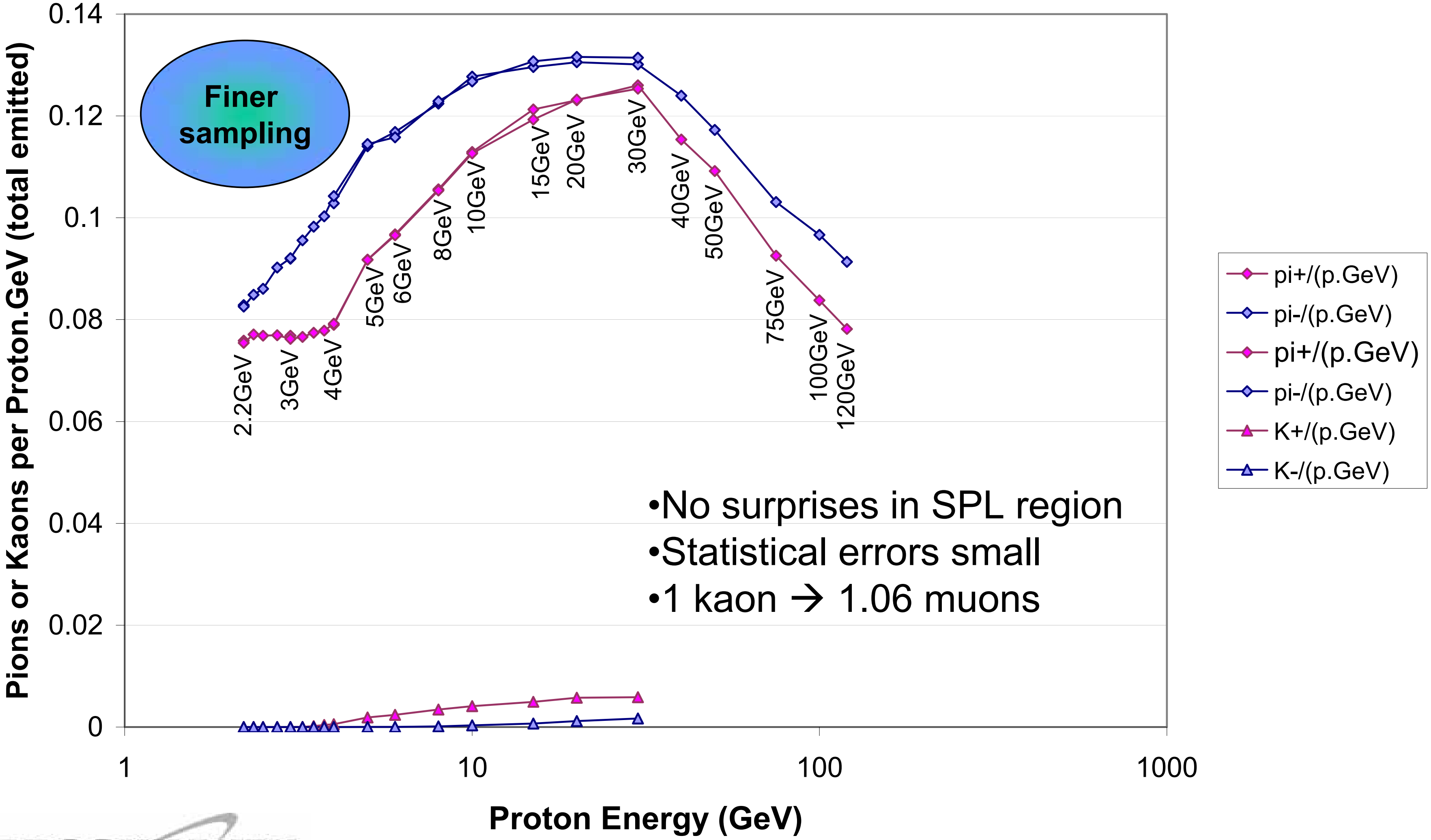
Stephen Brooks' Analysis with MARS15



- Pions counted at rod surface
- **B**-field ignored within rod (negligible effect)
- Proton beam assumed parallel
  - Circular parabolic distribution, rod radius

Yield of $\pi^{\pm}$ and $K^{\pm}$ in MARS



Phase Rotator Transmission

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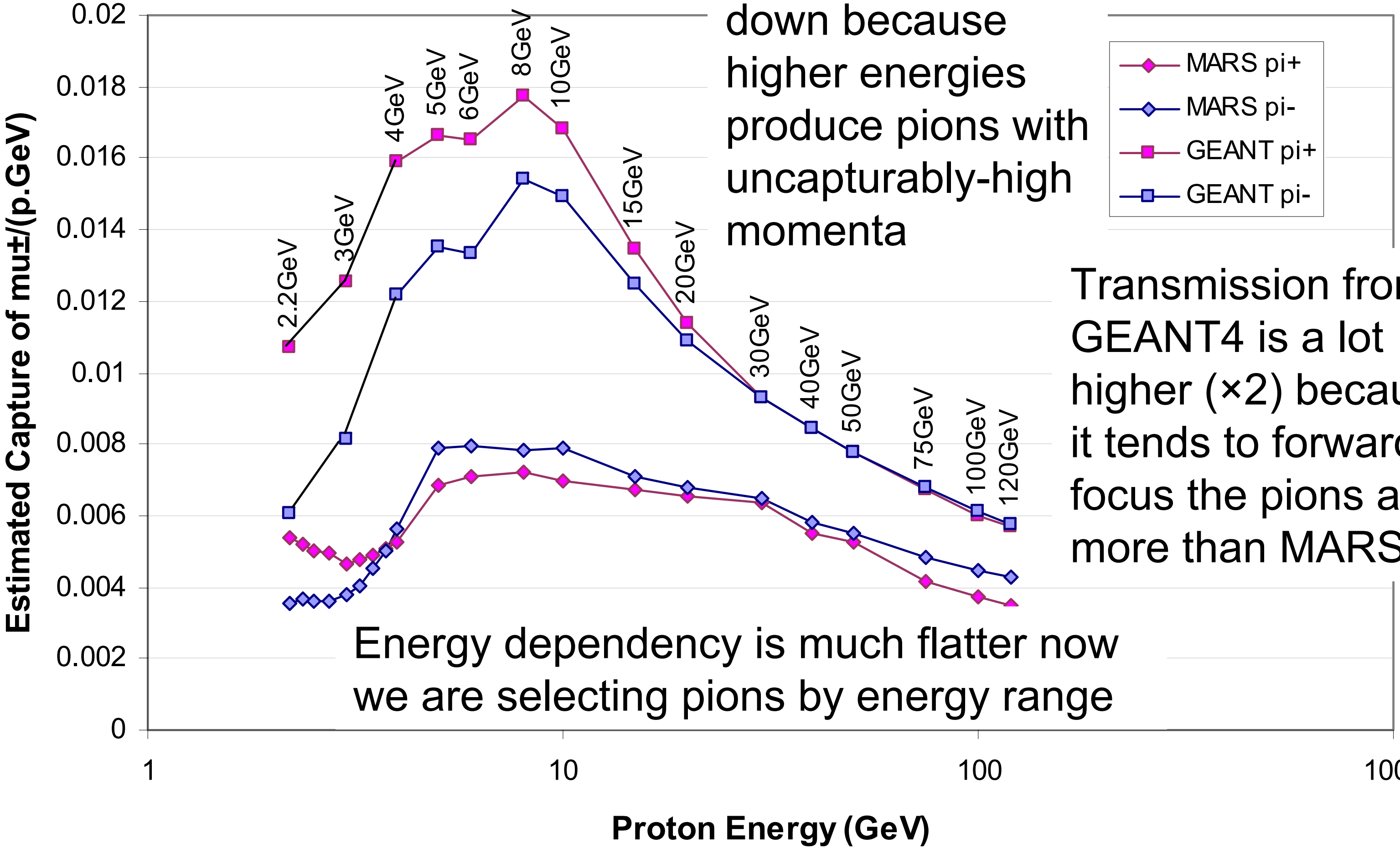

Optimum moves down because higher energies produce pions with uncapturably-high momenta

Transmission from GEANT4 is a lot higher (×2) because it tends to forward-focus the pions a lot more than MARS15

Energy dependency is much flatter now we are selecting pions by energy range

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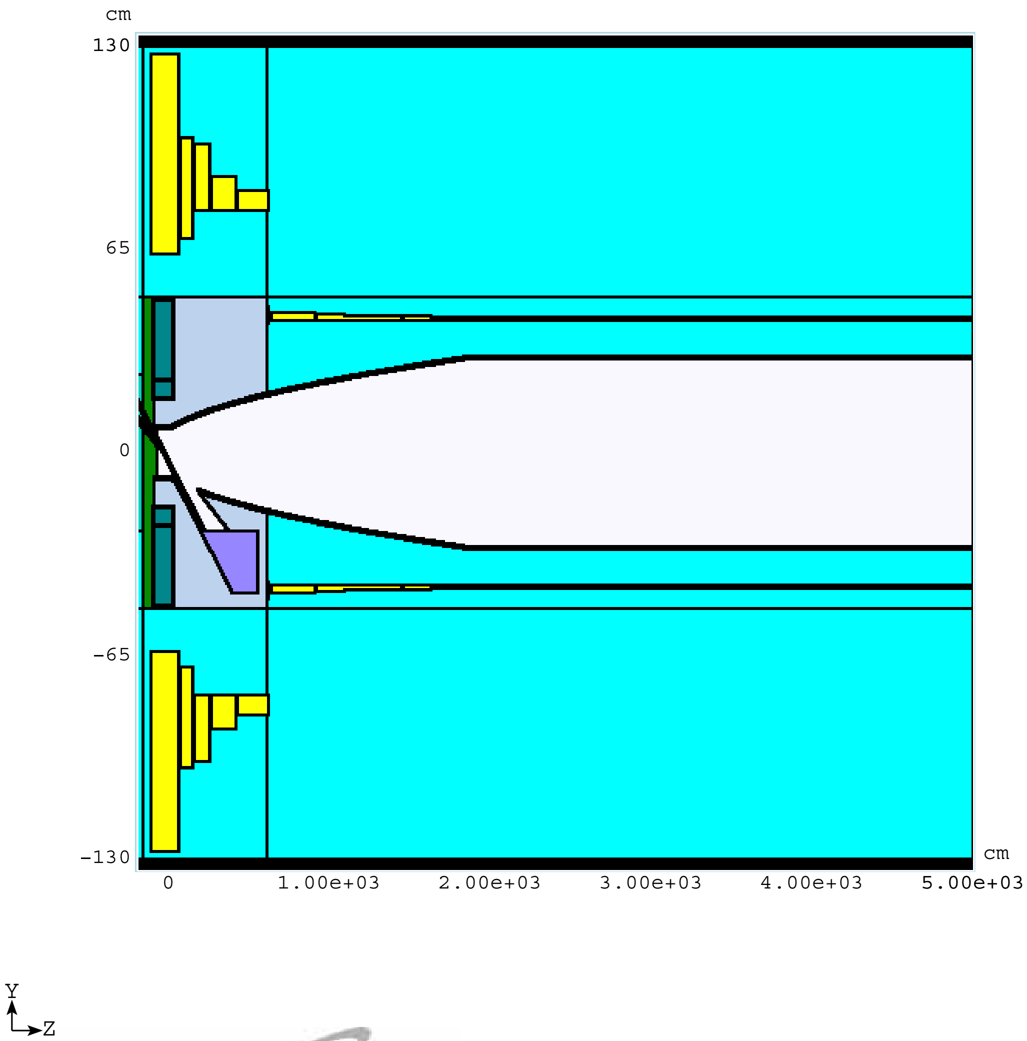
The Study2 Target System



- Analysis I

- Count all the pions and muons that cross the transverse plane at z=50m.

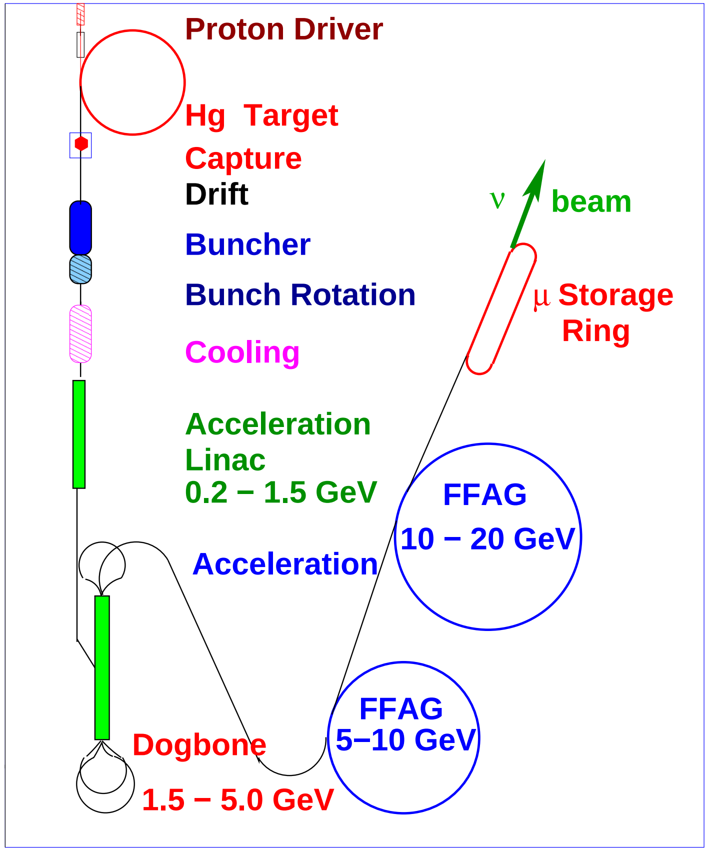
- For this analysis we select all pions and muons with KE< 0.35 GeV.

Process mesons through Cooling

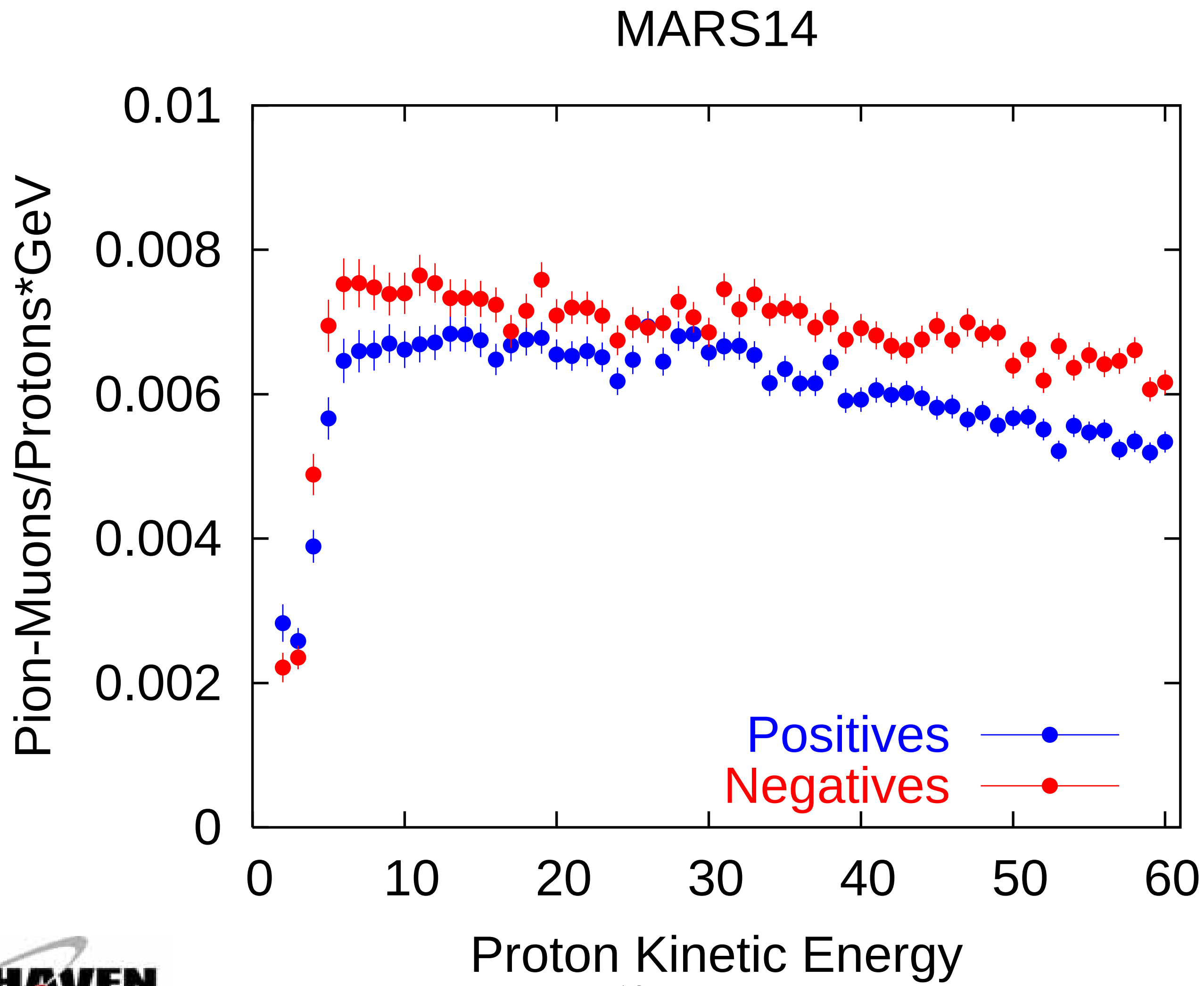
Analysis II

Post Cooling

Count mesons within acceptance of 30π mm



Post-cooling 30π Acceptance



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Summary

- For Negatives the peak occurs for

  6 Gev < Proton KE < 11 GeV

- For Positives the peak occurs for

  9 Gev < Proton KE < 19 GeV

- **Consensus: 10 GeV is a good place to be**

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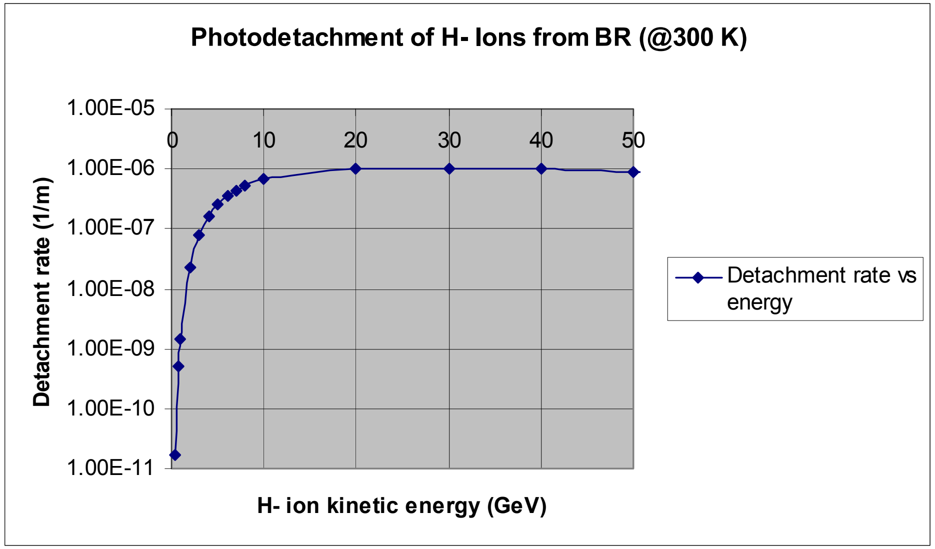
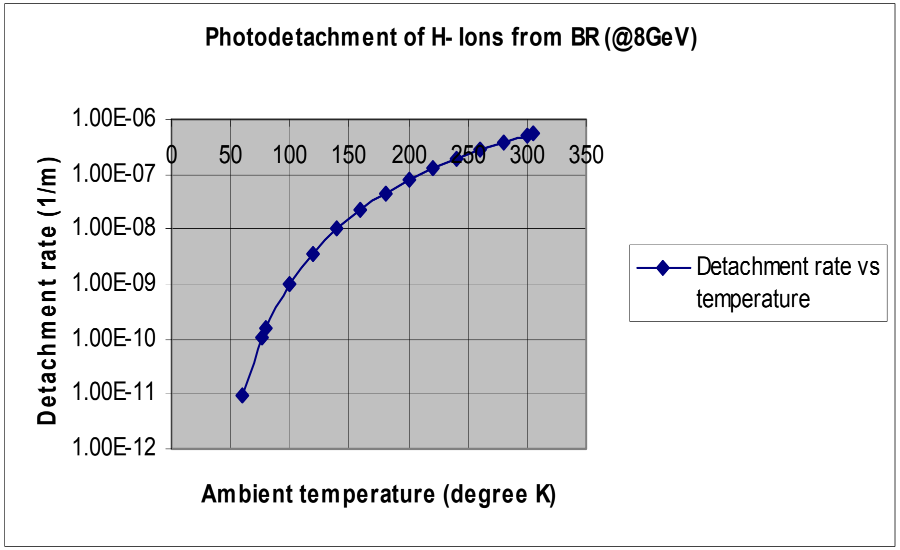
Blackbody Radiation Stripping

Energy Dependence



Temperature Dependence



At 305 K (90 F) and 8 GeV, H^- loss rate = 0.8×10^{-6} m^{-1}

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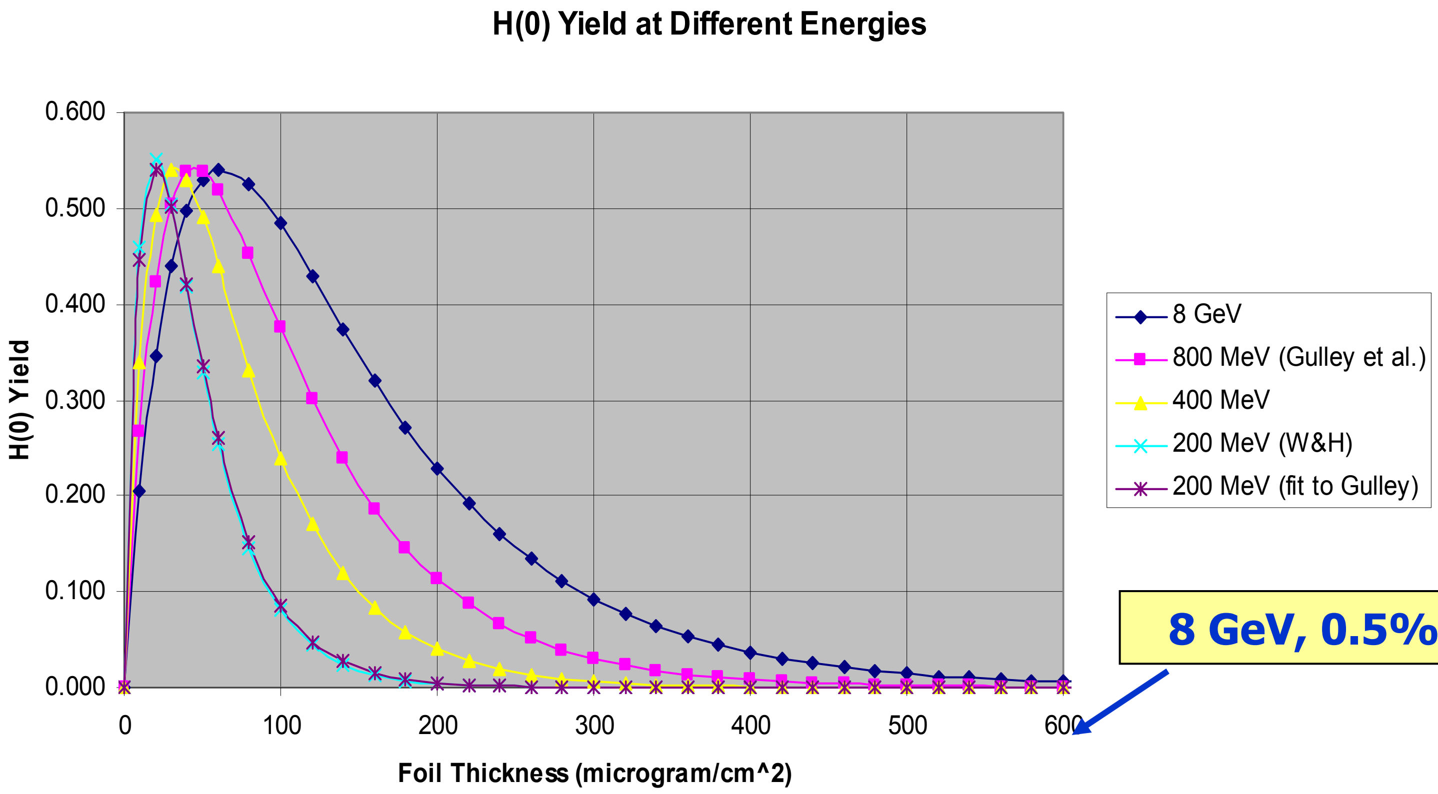
Summary of H^- Stripping Losses

Blackbody (305 K)	0.8×10^{-6} m^{-1}
Magnetic field	10^{-9} m^{-1}
Residual gas	0.1×10^{-6} m^{-1}
Total	$\mathbf{0.9 \times 10^{-6}}$ **m^{-1}**

- Transport line ~ 1 km $\Rightarrow$ Loss on the beam line ~ 10^{-3}
- H^- Beam intensity = 1×10^{14} s^{-1} $\Rightarrow$ Loss rate ~ 10^{8} m^{-1}s^{-1}
- At 8 GeV $\Rightarrow$ 0.13 W/m
- When MI operates at lower energy *E* with same beam power, loss will increase:

$$\text{Loss} = 0.13\ \text{W/m} \times \frac{120}{E\ (\text{GeV})}$$

Energy Dependence of H(0) Yield



8 GeV, 0.5% H^0

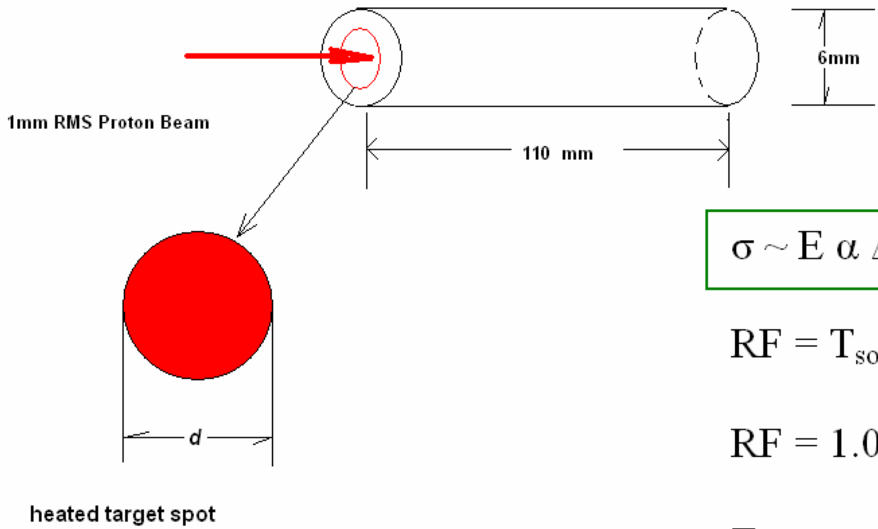
Pulse Length Effects on Solid Targets

Of interest is the pulse length assessment for the following power, rep-rate and consequently pulse intensity combinations

1 MW/50 Hz 12.0 e+12 ppp	**4 MW/50 Hz** 48.0 e+12 ppp
1 MW/200 Hz 3.0 e+12 ppp	**4 MW/200 Hz** 12.0 e+12 ppp

Target/Beam Baseline used for:

24 GeV Protons on Copper Target



$$\sigma \sim E\,\alpha\,\Delta T/\,(1 - 2\nu) \cdot RF$$

$RF = T_{sound}/T_{pulse}$ (if $T_{sound} < T_{pulse}$)

$RF = 1.0$ (if $T_{sound} > T_{pulse}$)

$T_{sound} = d/V_s$

V_s = sound velocity in material

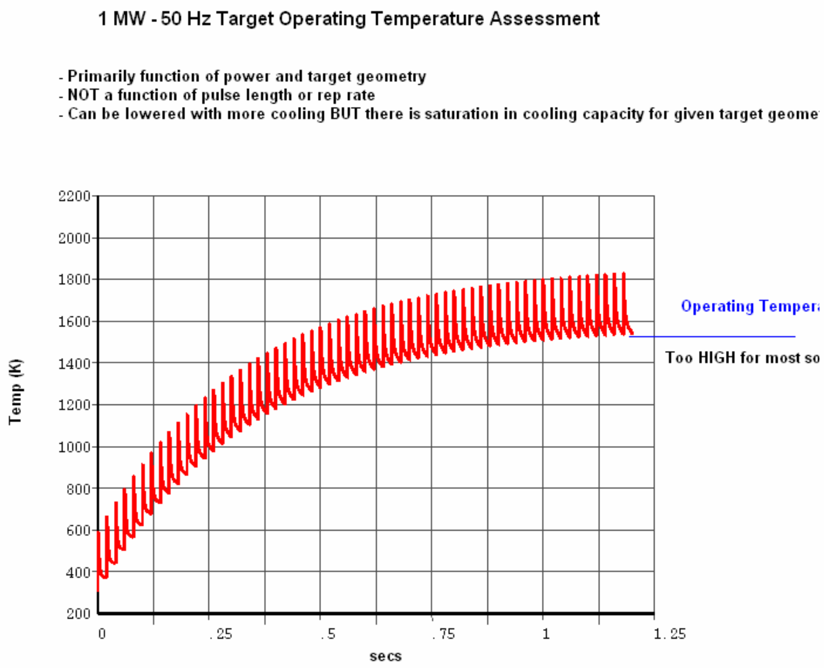
Parameters Affecting Shock Level in Solid Target

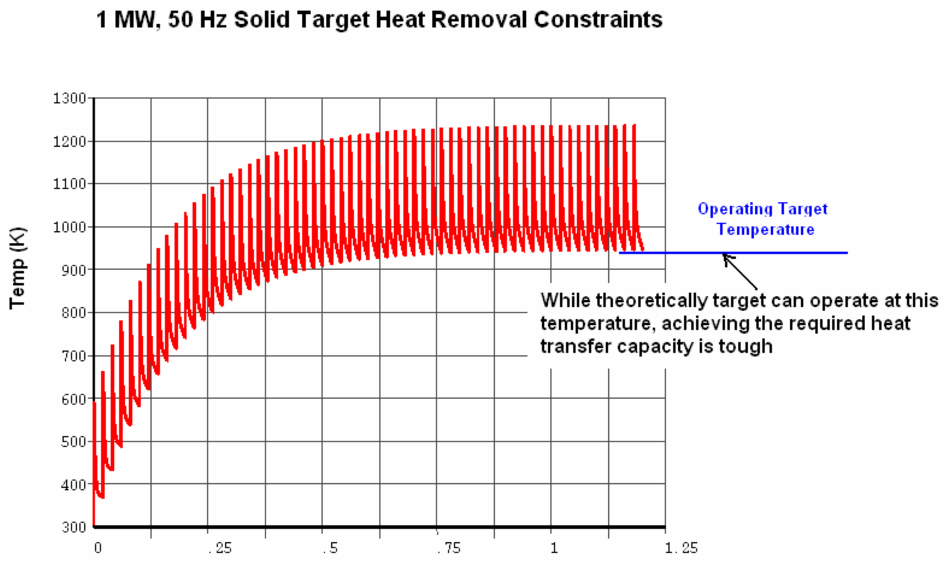
- Heat capacity (controlling temperature spike)
- Speed of sound in the material
- pulse length
- coeff. of thermal expansion
- Young's modulus

NOTE: If pulse is too short NO reduction in peak stress can be realized since heated zone does not have time to relax during deposition

1 MW Proton Driver - Temperature Issues

Power and Heat removal capacity from target go hand-in-hand





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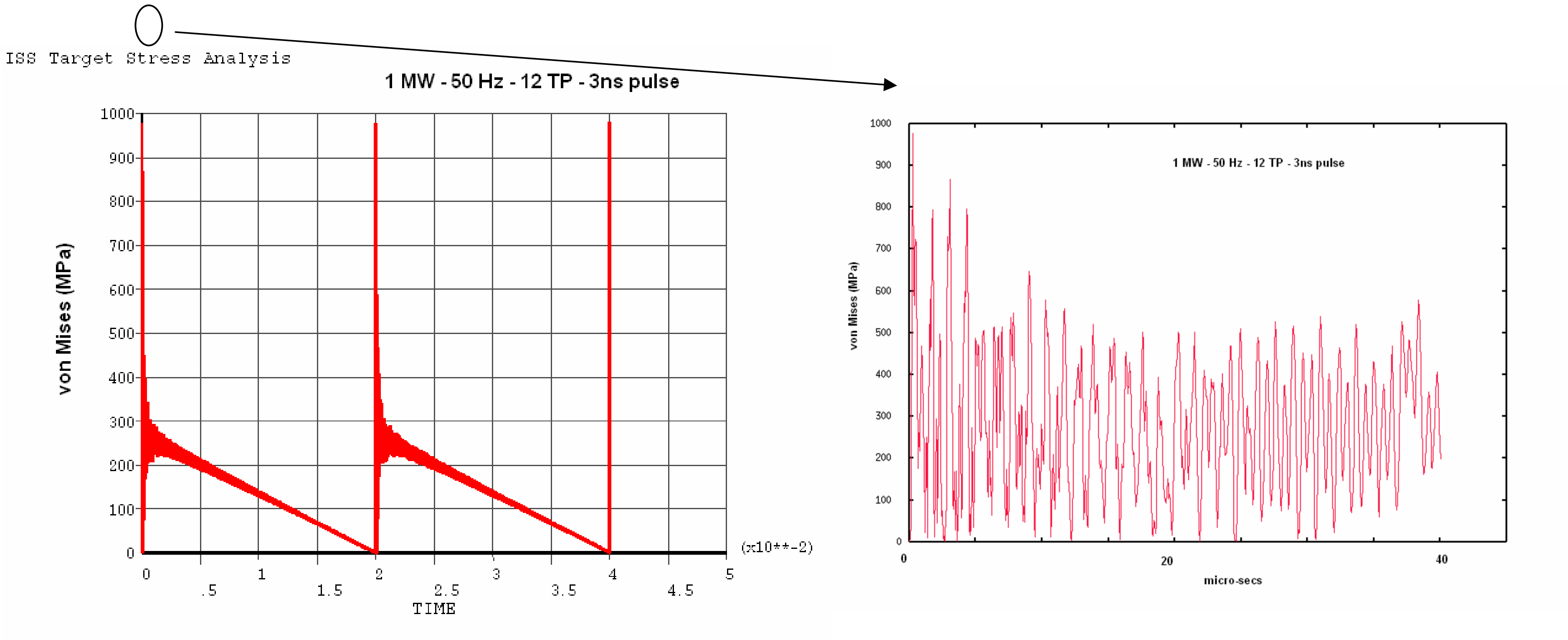
1 MW/50 Hz PD – Shock Stress Effects



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1 MW/50 Hz PD – target peak stresses
3ns – 30ns – 300ns – 600ns

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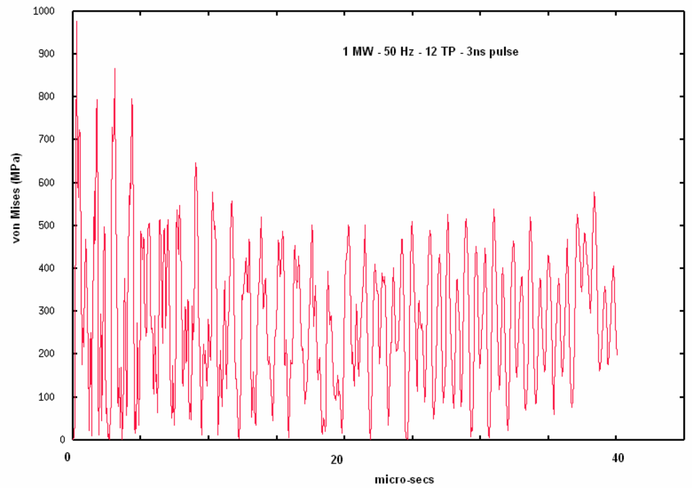

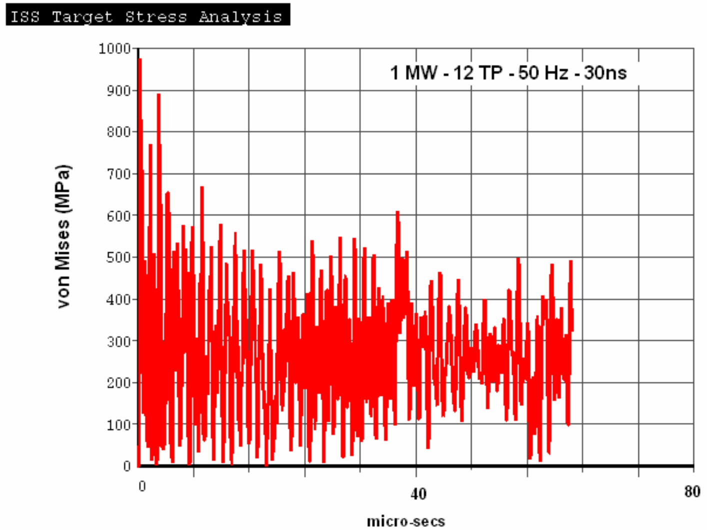

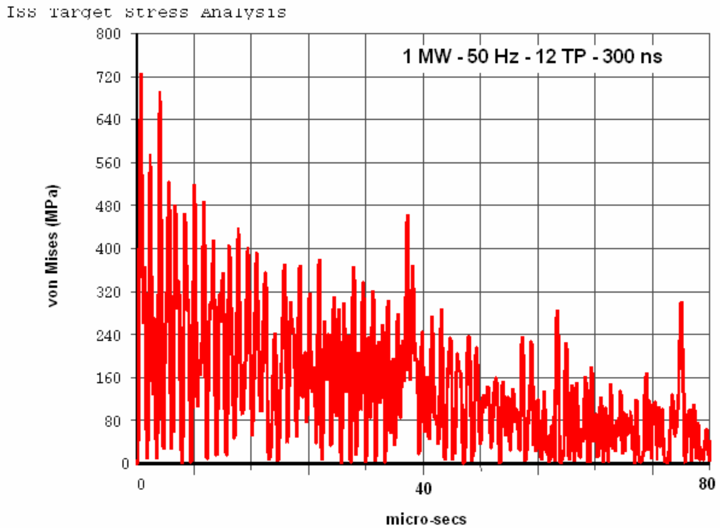

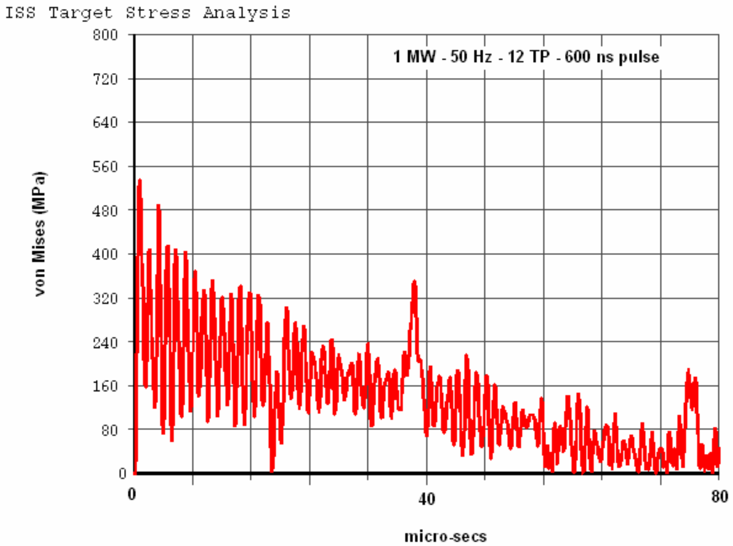

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4MW/50 Hz Proton Driver – Effect of pulse length on target peak stresses [3ns – 30ns – 300ns – 600ns]

1. **Solid target CAN support a proton driver operating at 1MW with 50 Hz rep-rate**
2. **Solid target CAN operate at 1MW at all pulse length**
3. **Solid target CANNOT operate at 4MW/50Hz, even with 600ns.**
4. **Liquid target has fewer such constraints(P, L, F) Modified solid Target design(non-stationary,..)**

SUMMARY of Performance

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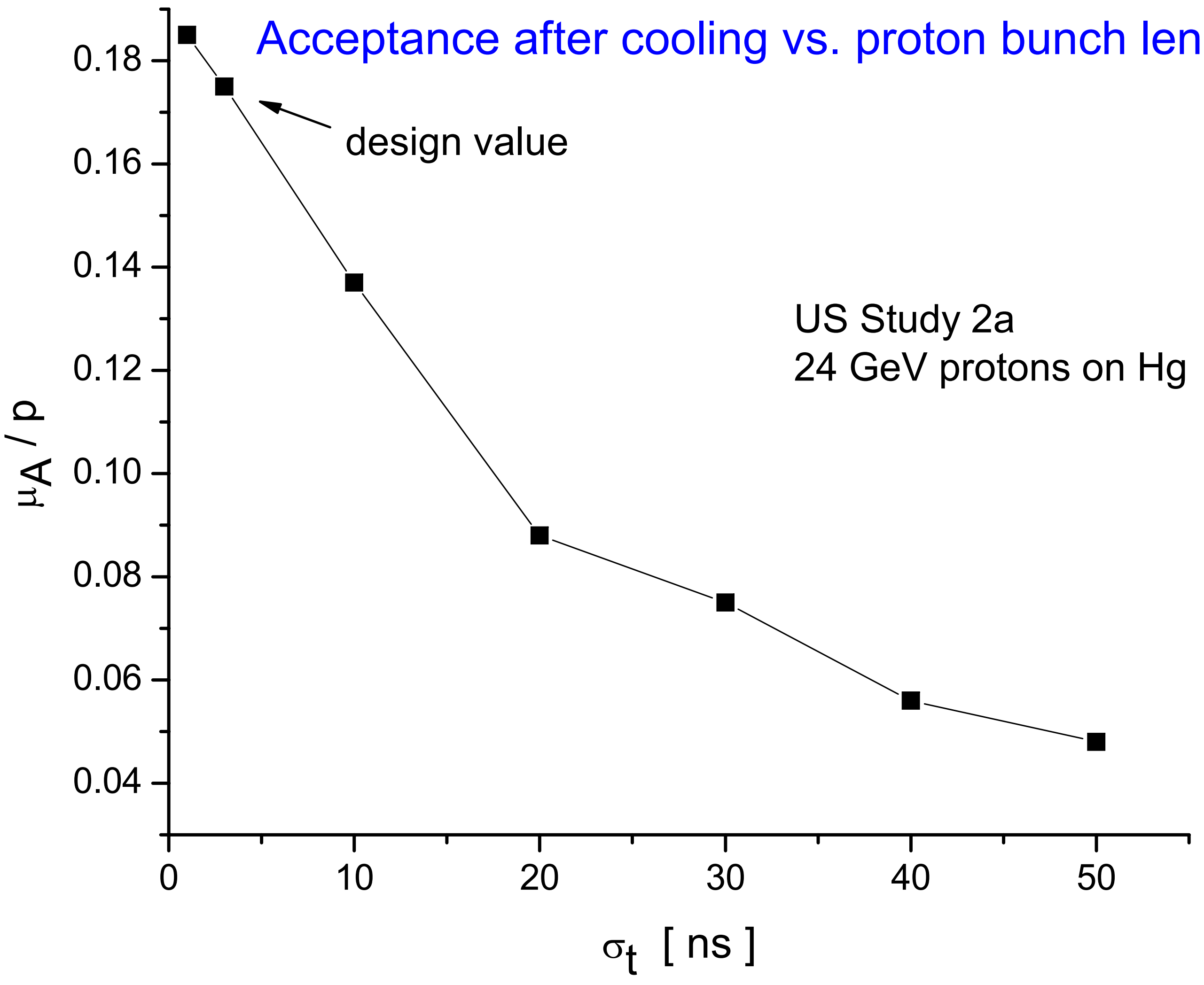
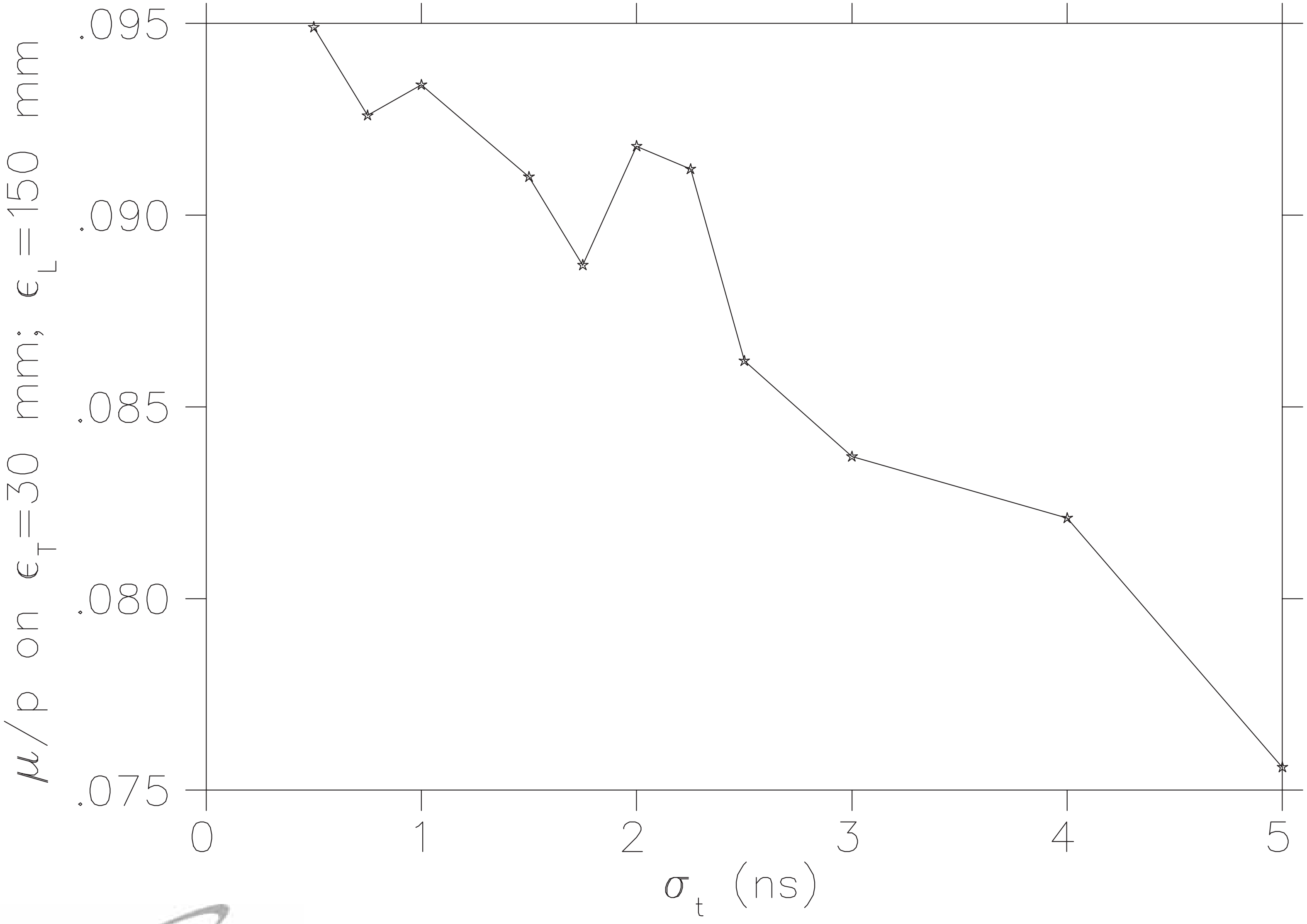
1 MW/50 Hz 12.0 e+12 ppp **YES**	**4 MW/50 Hz** 48.0 e+12 ppp **NO**
1 MW/200 Hz 3.0 e+12 ppp **YES**	**4 MW/200 Hz** 12.0 e+12 ppp **MAYBE**

Acceptance after cooling vs. proton bunch length




.095
.090
.085
.080
.075
0
1
2
3
4
5
σ_t (ns)
μ/p on ϵ_T=30 mm; ϵ_L=150 mm

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Design Parameter Phase Space

1. 8.0 GeV < Energy < 20.0 GeV
2. Rep Rate ~ 50(25) Hz
3. Intensity 50*10**(12) ppp, at 10(20) GeV
   (very difficulty with solid target)
4. Bunch Length < 3 ns, for longitudinal acceptance
5. Cost ???

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Technology Matrix*
(Picture will change after R&D)

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	Linac	RCS	FFAG	LAR
Energy	B	A	A	A
Rep Rate	A	A	A	A
Intensity	A	A	B_	A
Bunch L	C	B	B_	B
Cost	B_	B	B+	B_

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Accelerator/Target R&D Needed

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- Generation of intense short bunch
- Optimal design of a proton linac
- Development of liquid target
- More study of the production of Pions and Muons
- Better understanding of impact on cost by the parameter choice

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Summary and Conclusions

- We have presented the parameter constraint for the Proton Driver
- A preferred parameter phase space has been identified and relative merit of each technology has been evaluated
- Further study is need to complete the search and more R&D is needed for a reference design