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Design of a Two-Stage Light Gas Gun for Muzzle Velocities of 10 – 11 km/s

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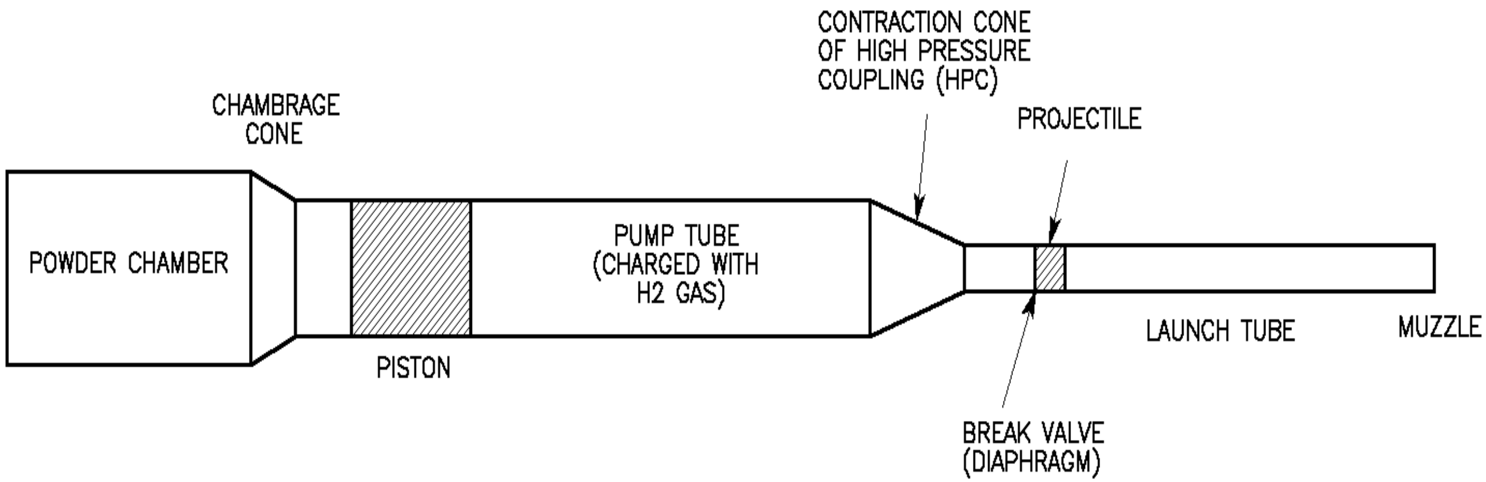
Overview

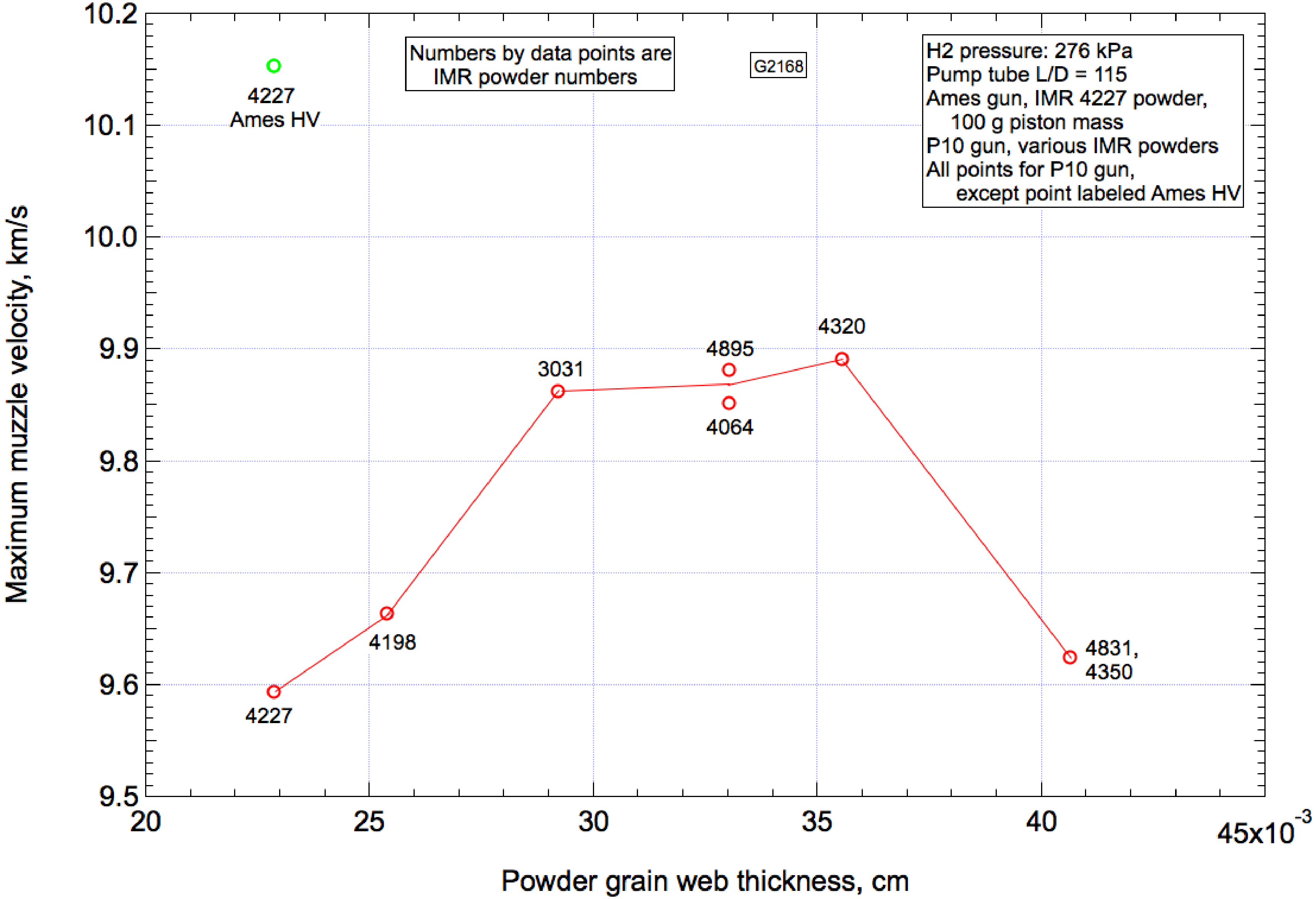
- Need for higher muzzle velocities
- Select best known existing gun to start with, scale up, optimize powder type
- Optimize pump tube L/D, hydrogen pressure, piston mass
- Study effect of high pressure coupling cone angle, break valve rupture pressure
- Increase muzzle velocity by decreasing launch mass, increasing powder mass
- Increase muzzle velocity by using refractory metal liner
- Conclusions



Schematic sketch of representative two-stage light gas gun

Need for higher muzzle velocities

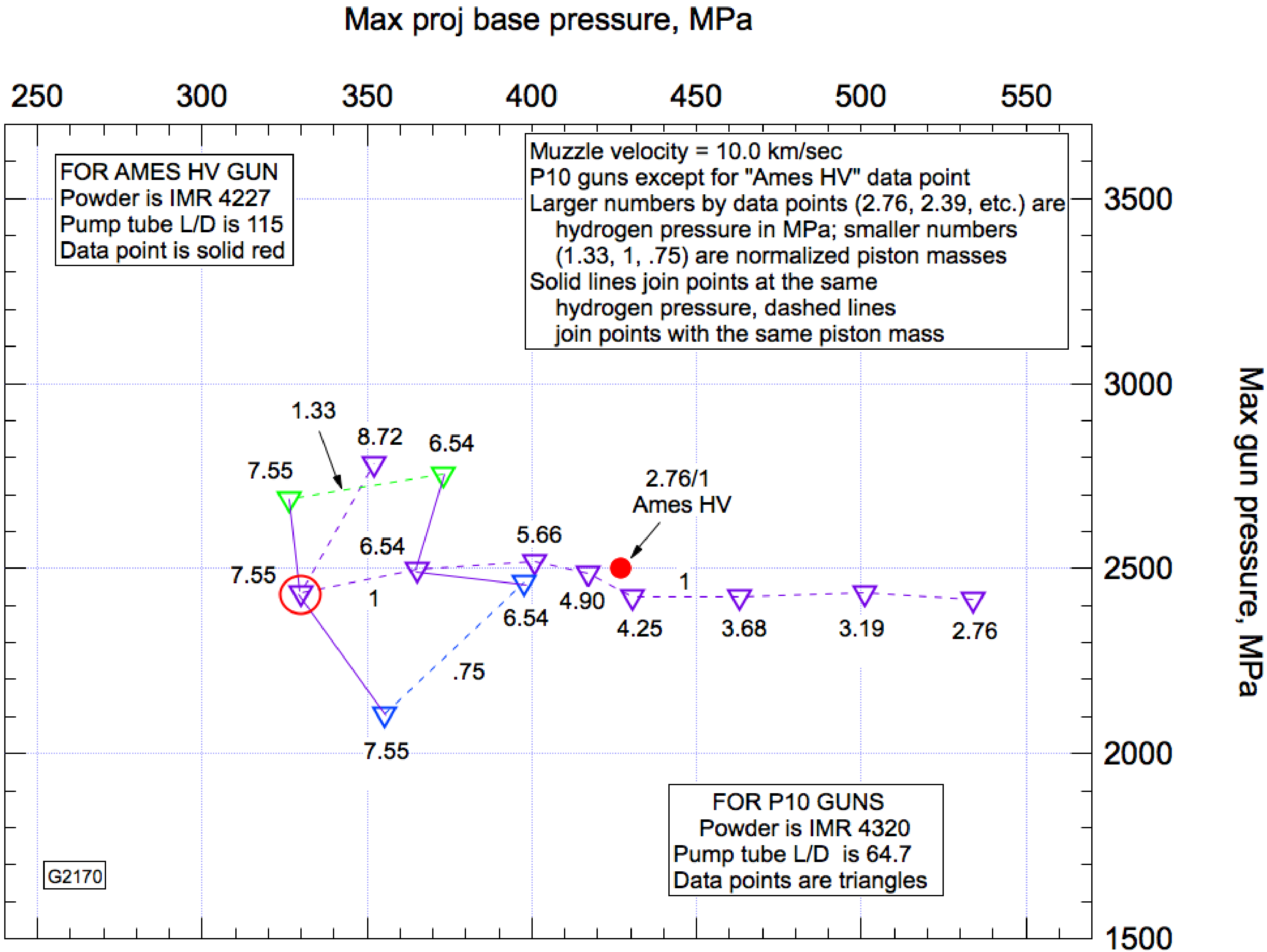
- Space debris impacts can be at 10 – 11 km/s (crossed orbits) up to 15 km/s (directly opposed orbits); need to achieve these velocities for the design of debris shields; a first step would be to achieve velocities of 10 – 11 km/s
- Max velocity for saboted spheres for Ames stable of standard guns with pump tube L/Ds of 208 to 273 is 8.2 km/s
- Start with design based on Ames 32.5 mm/5.59 mm gun (Ames HV gun), which has achieved 10 – 11.3 km/s, but is no longer available
- Scale up to 7.95 mm launch tube, optimize powder type. (The new design guns are denoted by “P10”.)



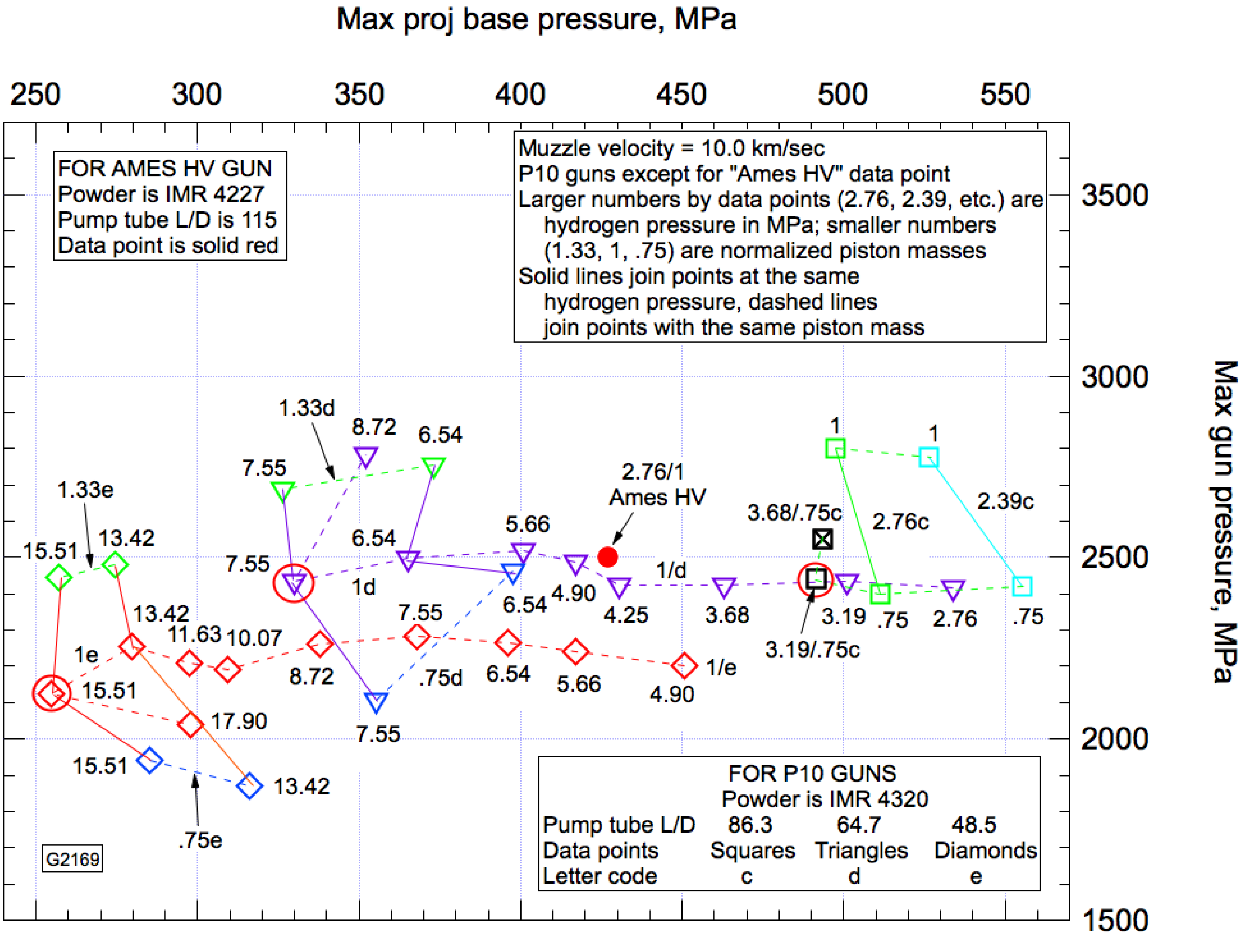
Maximum muzzle velocities for Ames HV and P10 guns versus powder grain web size for IMR powders.

Optimization of P10 gun

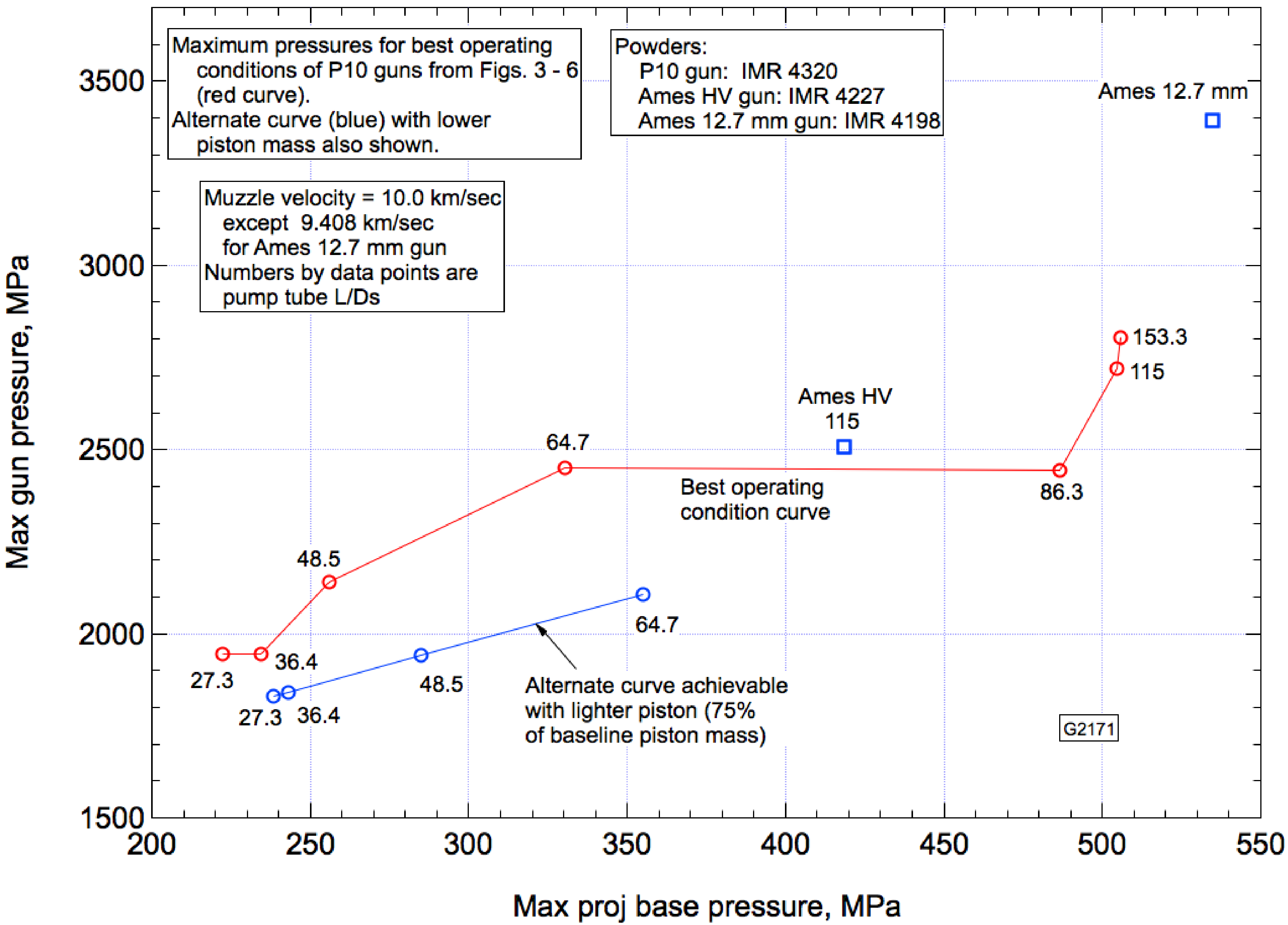
- **Optimization with respect to pump tube L/D, hydrogen pressure and piston mass**
- **Seven pump tube L/D values – 153.3, 115, 86.3, 64.7, 48.5, 36.4, 27.3 (L/D of Ames HV gun is 115)**
- **For each pump tube L/D, vary $p(H_2)$ and m_{pis} to move towards lowest max proj base pressure without a substantial increase in max gun pressure**



Maximum pressures for P10 guns with a pump tube L/D of 64.7



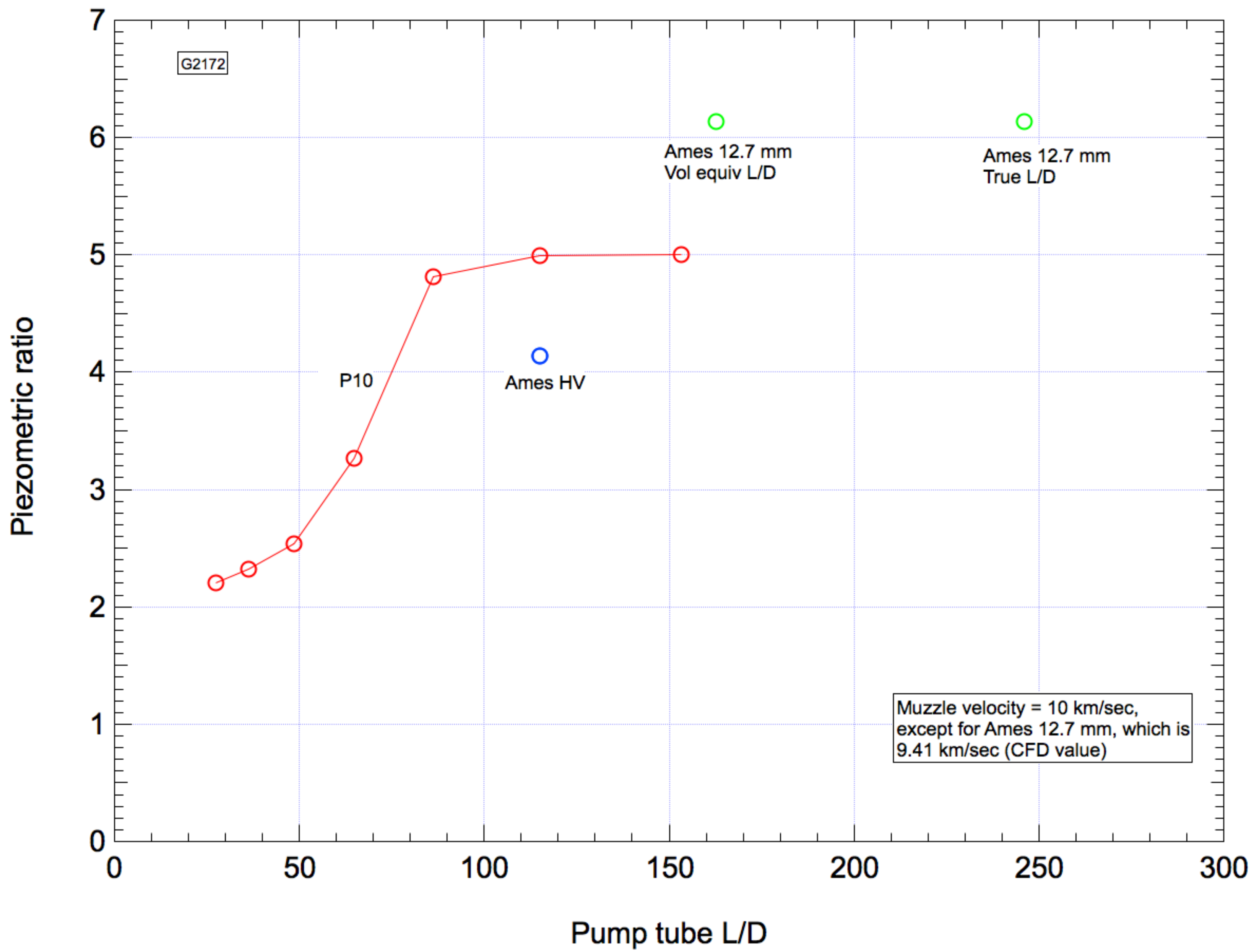
Maximum pressures for P10 guns with pump tube L/Ds of 86.3, 64.7 and 48.5



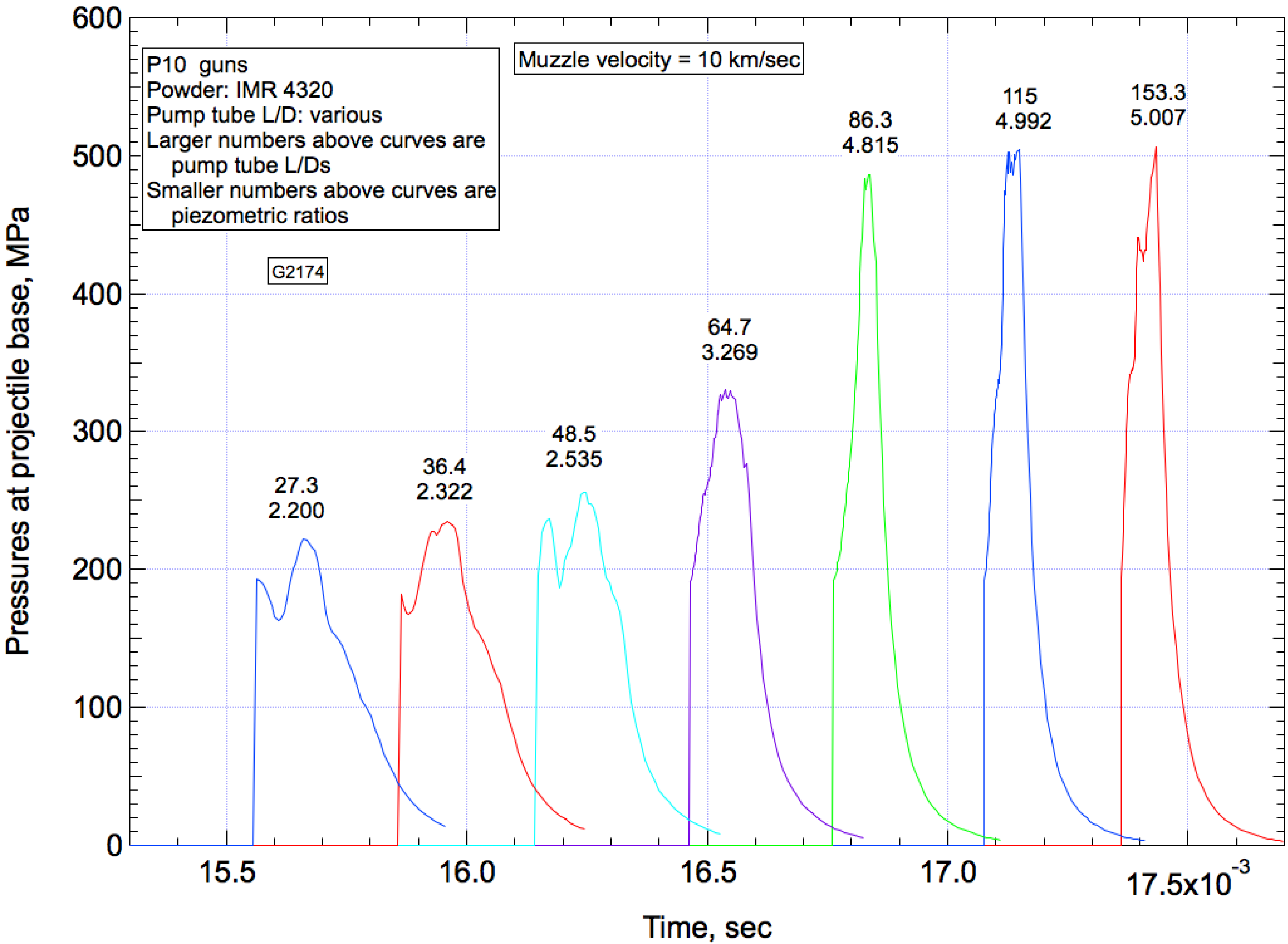
Maximum pressures for P10 guns with all pump tube L/Ds

Optimization of P10 gun

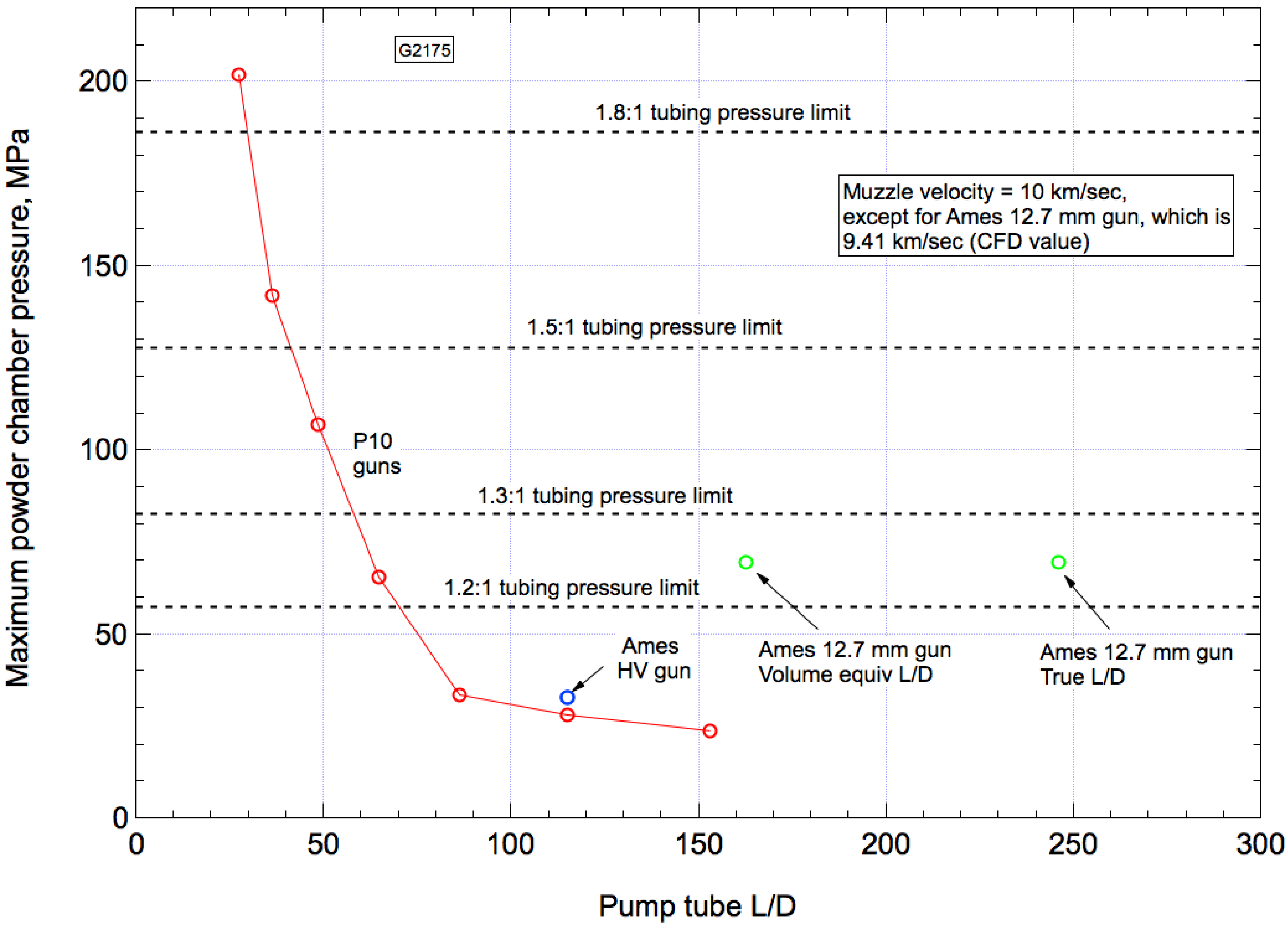
- **Ames HV gun much superior to Ames 12.7 mm gun**
- **Best P10 guns much superior to Ames HV gun**
- **Note alternate curve with lower max gun pressures but higher max proj base pressures, but do not study these conditions further herein**



Piezometric ratios for P10 guns and Ames 12.7 mm and Ames HV gun plotted versus pump tube L/Ds



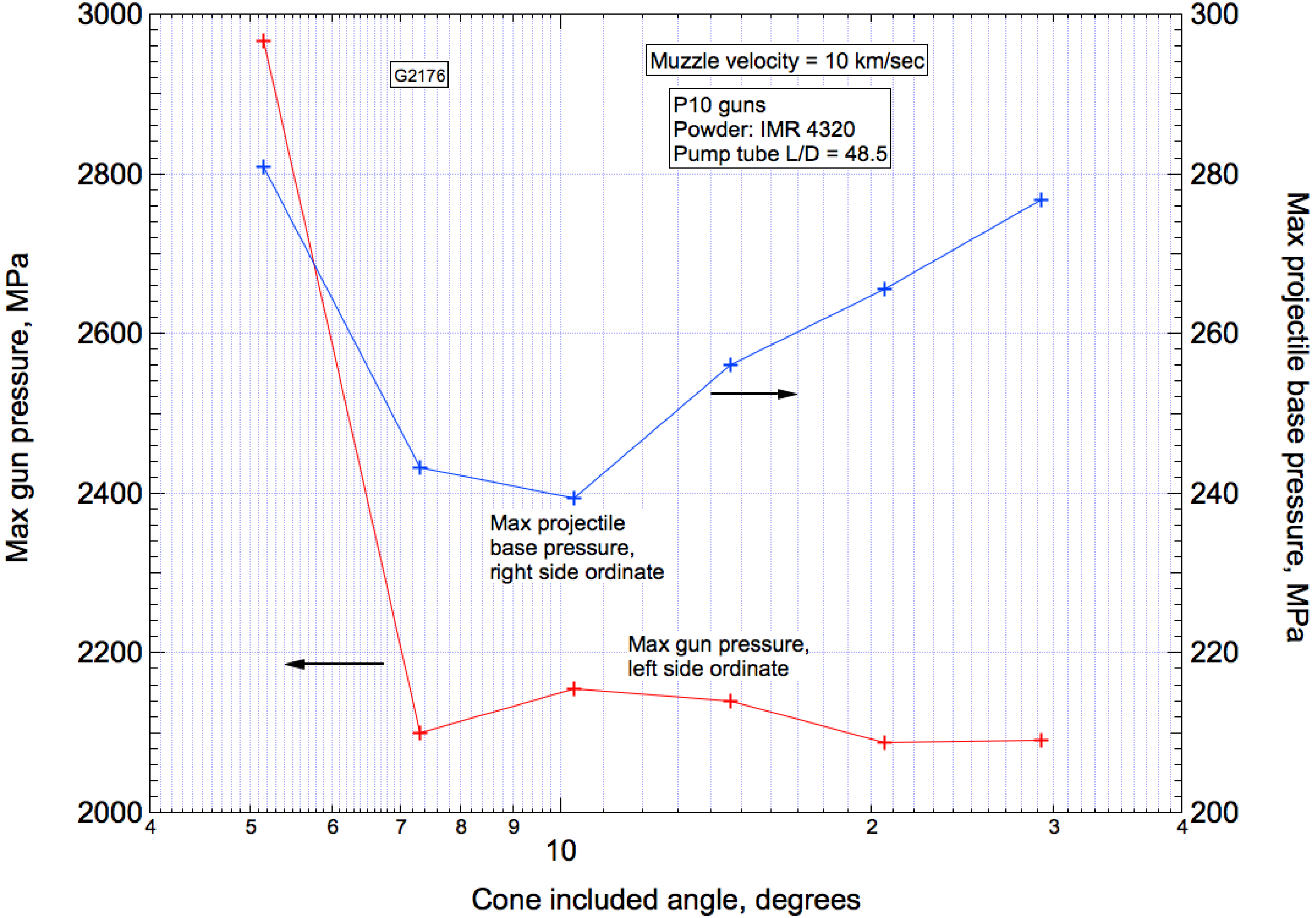
Projectile base pressure histories for all P10 guns



Maximum powder chamber pressures for P10 guns and Ames HV gun and Ames 12.7 mm gun

Notes on preceding graph

- For pump tube L/D = 27.3, max powder breech pressure is 202 MPa
- For pump tube L/D = 36.4, max powder breech pressure is 142 MPa
- Choose L/D = 36.4 for further study to have lower powder breech pressures



Maximum pressures versus high pressure coupling cone angle for P10 gun with pump tube L/D = 48.5

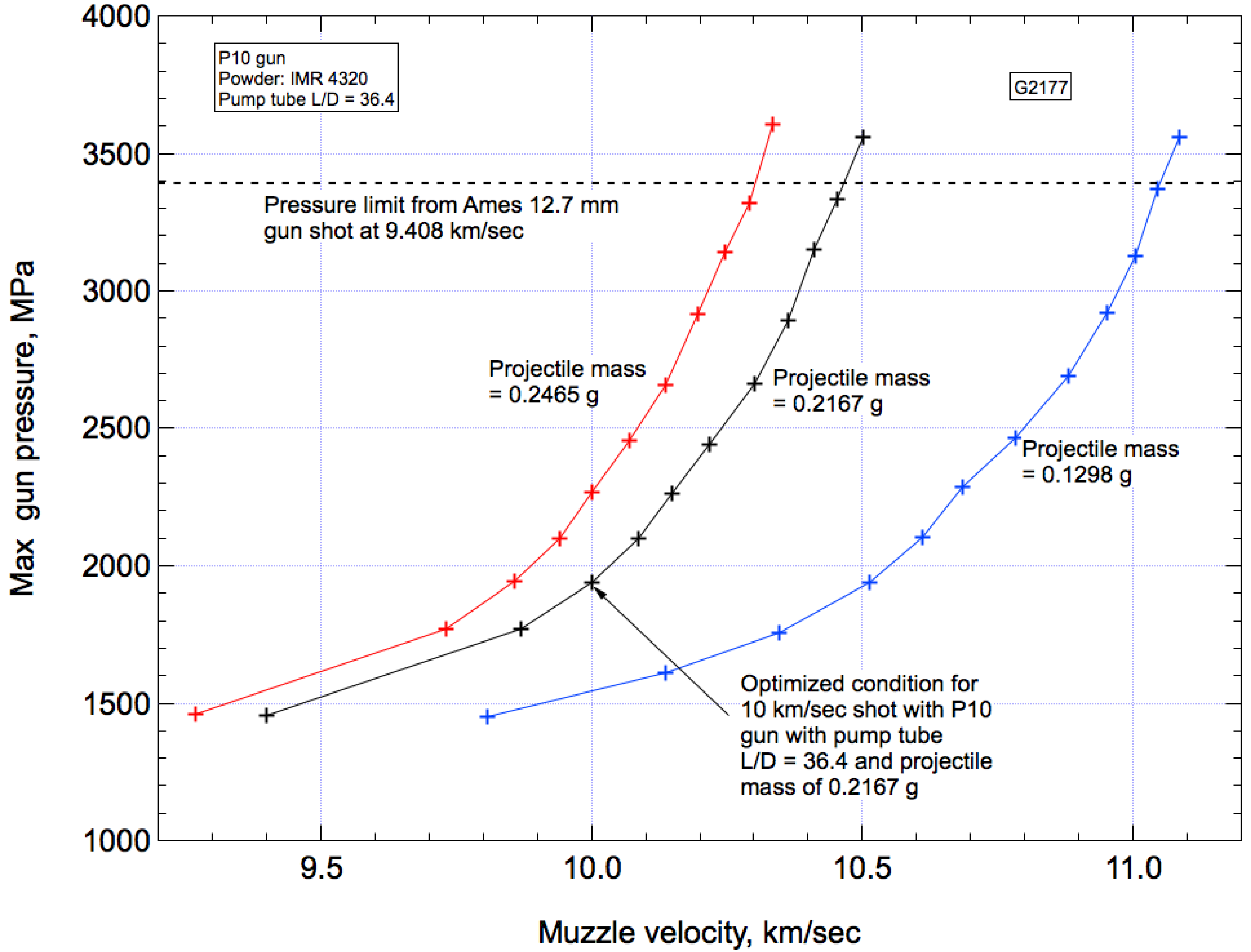
Notes on preceding graph

- Sweet spot of HPC cone angles from 7.3 to 14.6 degrees (for pump tube L/D = 48.5)
- Current study used HPC cone angle of 14.6 degrees
- By switching from 14.6 to 10.3 degrees, could reduce max proj base pressures by about 6%

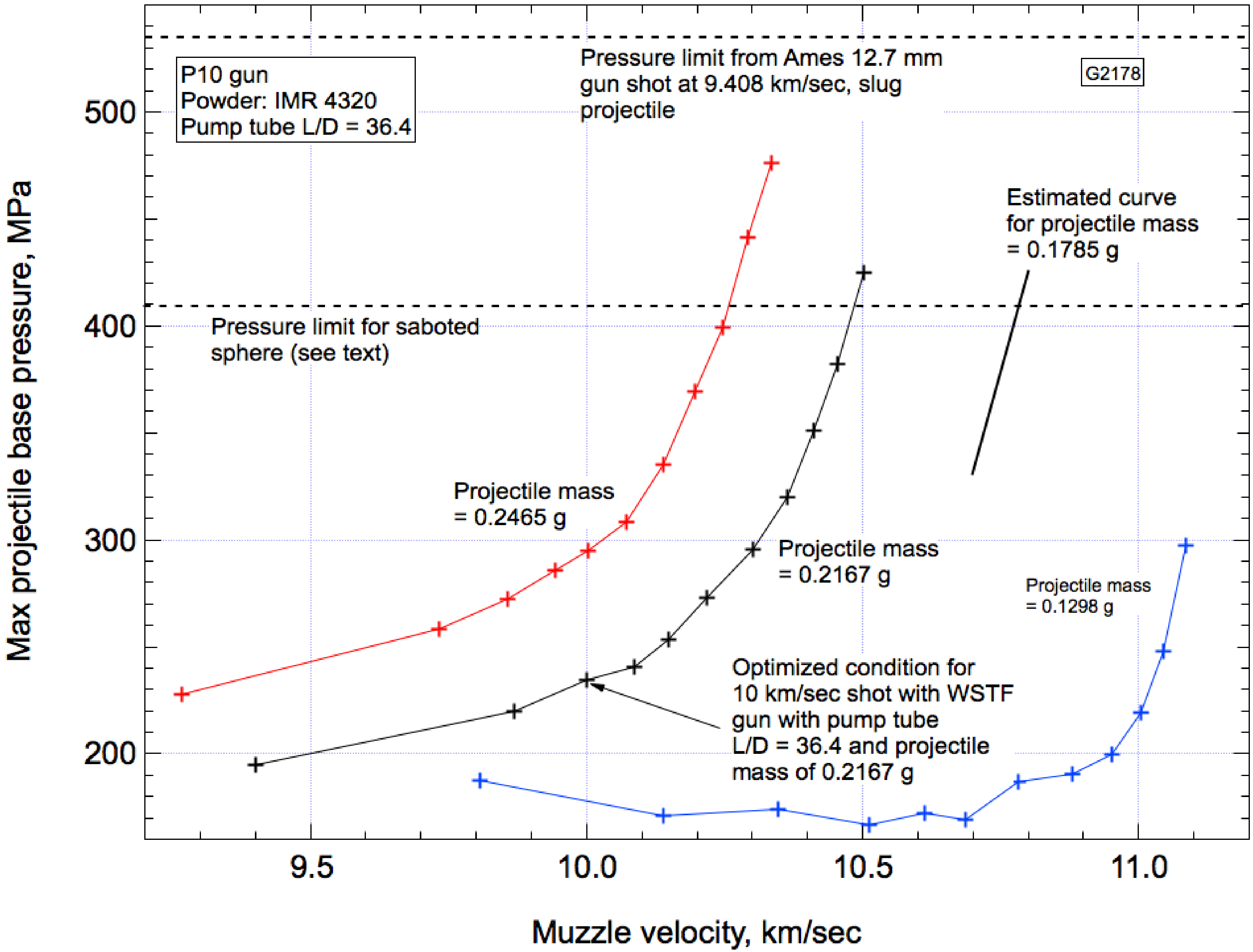
Optimization of P10 gun

- Wide range of (pump tube volume)/(launch tube diameter)^3 studied – 4230 to 23,750

- Since a wide range of normalized pump tube volumes has been studied, it seems likely that varying the ratio (pump tube diameter)/(launch tube diameter) would not provide further significant performance gains, but this has not been studied to date



Maximum gun pressures versus muzzle velocity. Projectile mass and powder load are varied. Pressure limit shown.



Maximum proj base pressures versus muzzle velocity. Projectile mass and powder load are varied. Pressure limits shown.

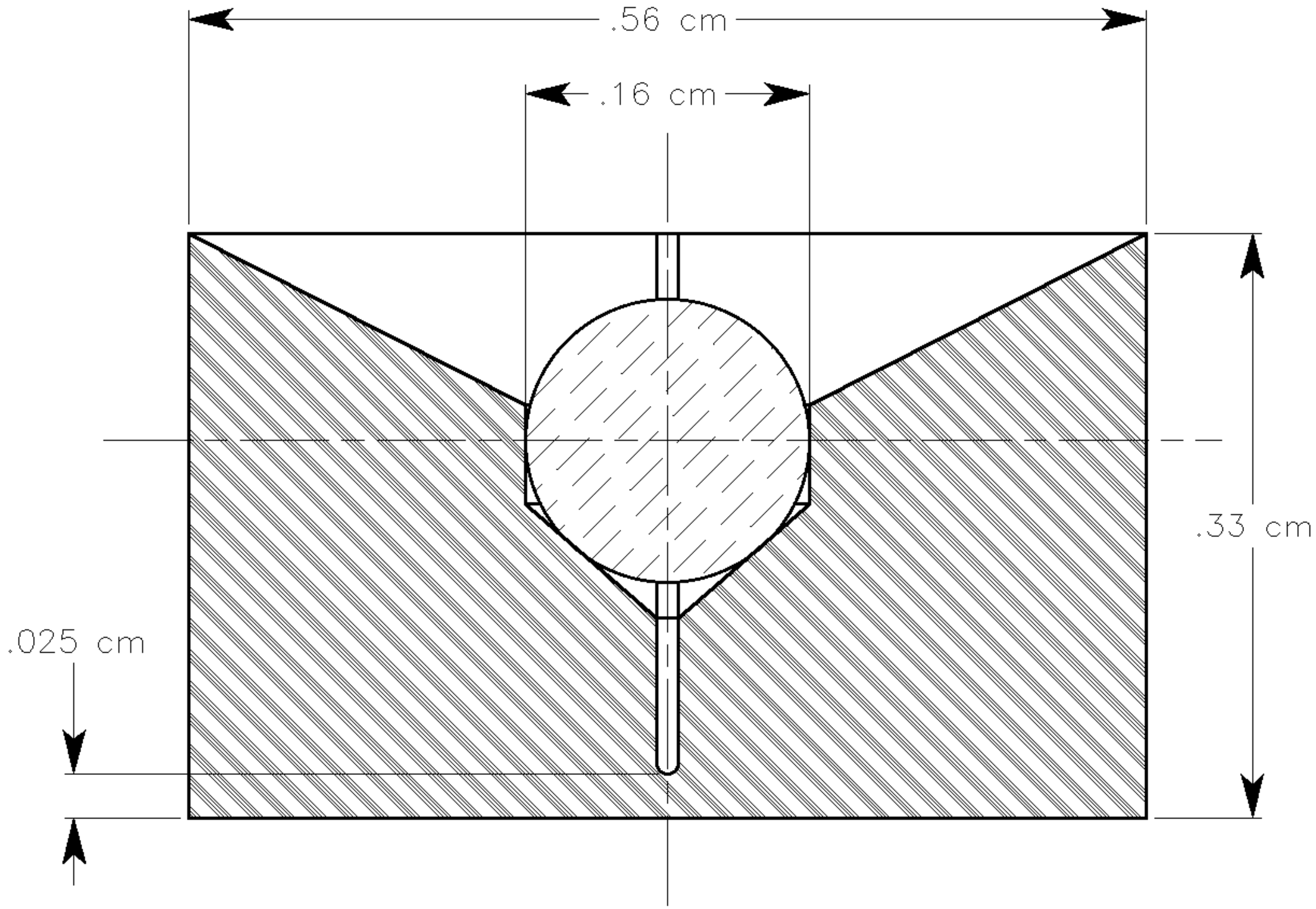
Maximum velocities

- For slug projectiles, max gun pressure is limiting:

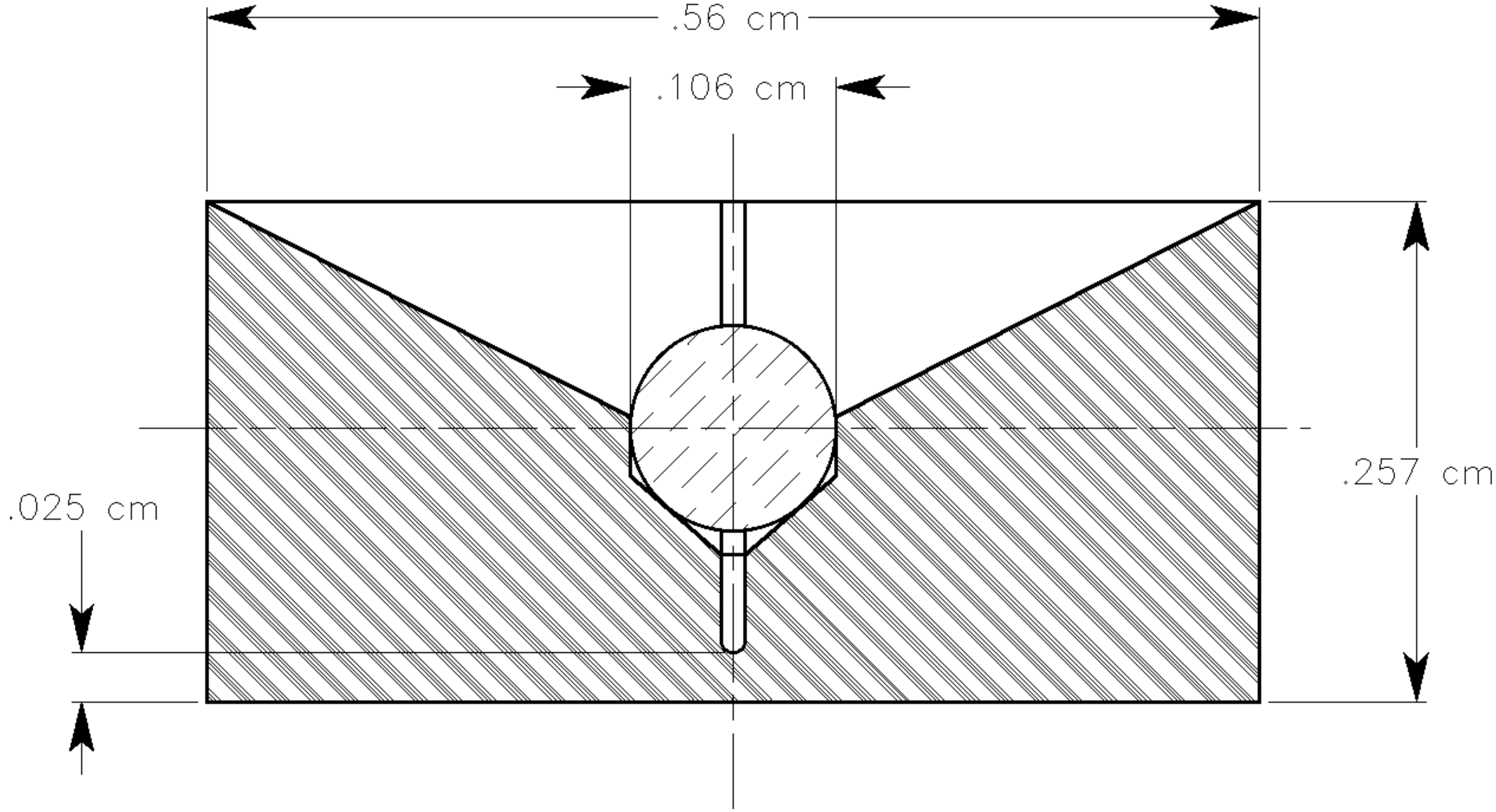
  - for 0.2465 g launch mass, max v_{muz} = 10.30 km/s
  - for 0.2167 g launch mass, max v_{muz} = 10.47 km/s
  - for 0.1296 g launch mass, max v_{muz} = 11.05 km/s

- For saboted sphere projectiles, max base pressure is limiting:

  - for 0.2465 g launch mass, max v_{muz} = 10.25 km/s ($D_{sphere}/D_{launch\ tube}$ = 0.286)
  - for 0.1785 g launch mass, max v_{muz} = 10.80 km/s ($D_{sphere}/D_{launch\ tube}$ = 0.188)



Sphere in sabot ($D_{sphere}/D_{launch\ tube}$ = 0.286). Launched at 9.4 km/s. Based on max allowable base pressures, could be launched by P10 gun at 10.25 km/s.



Sphere in sabot ($D_{sphere}/D_{launch\ tube}$ = 0.188). Based on max allowable base pressures, could be launched by P10 gun at 10.80 km/s.

Refractory metal launch tube liners

- **Refractory metal liners provide large reduction in the loading down of hydrogen working gas with eroded tube wall material > v_{muz} increases of 2 to 4 km/s**
- **Re has slightly higher thermal properties than Ta, <u>but</u>**
- **Ta has much better mechanical properties (modulus, elongation) and has been used successfully in military gun systems**
- **CFD calculations show that Ta is almost as good as Re regarding muzzle velocity increases**
- **Ta is the liner material of choice**
- **CFD calculations show muzzle velocities of as high as 12 – 13 km/s with a Ta liner**

Summary and conclusions - 1

- Need for higher launch velocities stated
- Gun designed for muzzle velocities of 10 – 11 km/s
- Start with Ames 32.5 mm/5.59 mm gun
- Scale up to 7.95 mm launch tube, optimize powder type
- Optimize with respect to pump tube L/D (shorten pump tube), hydrogen pressure, piston mass
- Best new guns have piezometric ratios of ~2.3, versus 4 to 6 for guns with pump tube L/Ds of 210 - 270

Summary and conclusions - 2

- Select pump tube L/D of 36.4 for further study
- Effect of varying cone angle of high pressure coupling studied, “sweet spot” found (7.3 – 14.6 degrees)
- Studied effect of break valve rupture pressure - lowering rupture pressure lowers max projectile base pressure, but increases max gun pressure
- For velocities above 10 km/s, decrease projectile mass, increase powder mass
- For slug launches, max gun pressure limiting, light slugs can be launched at up to 11.05 km/s

Summary and conclusions - 3

- **For saboted sphere launches, projectile base pressure limiting**

  - for $D_{sphere}/D_{launch\ tube}$ = 0.286, can launch at 10.25 km/s

  - for $D_{sphere}/D_{launch\ tube}$ = 0.188, can launch at 10.80 km/s

- **Refractory metal liners, Ta is material of choice**

- **CFD calculations with Ta liner predict muzzle velocities up to 12 – 13 km/s**