FACET-II Emittance Measurements

Facility for Advanced Accelerator Experimental Tests

FACET-II SCIENCE WORKSHOP 2017
Kavli Auditorium, SLAC

Christine Clarke
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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

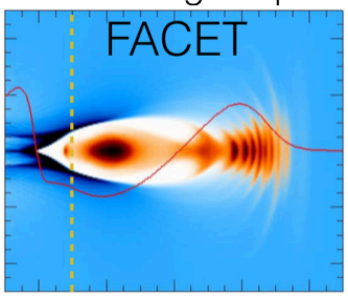
PWFA Research Priorities at FACET-II

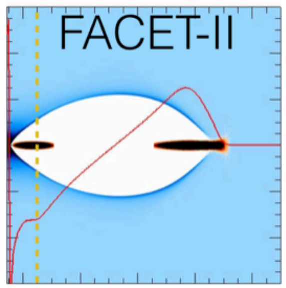
Emittance Preservation with Efficient Acceleration

FY19-21

- High-gradient high-efficiency (instantaneous) acceleration has been demonstrated @ FACET

  - Full pump depletion and preservation of emittance at μm level is planned as the first high impact experiment

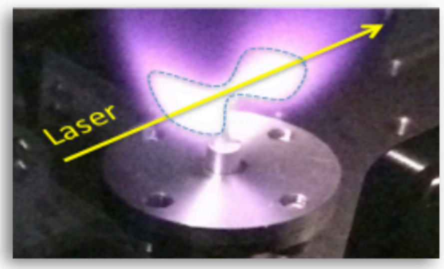


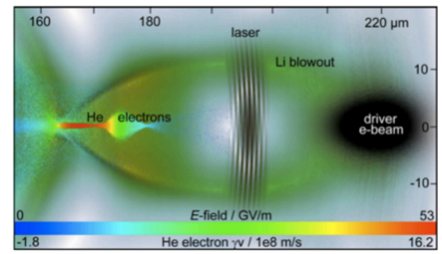


High Brightness Beam Generation & Characterization

FY20-22

- 10’s nm emittance preservation is necessary for collider applications
- Ultra-high brightness plasma injectors may lead to first applications of PWFA technology

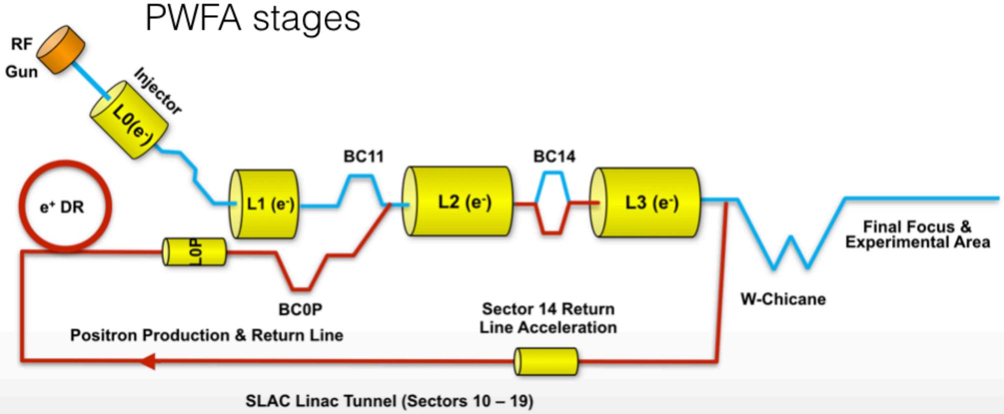




Positron Acceleration

FY21-24

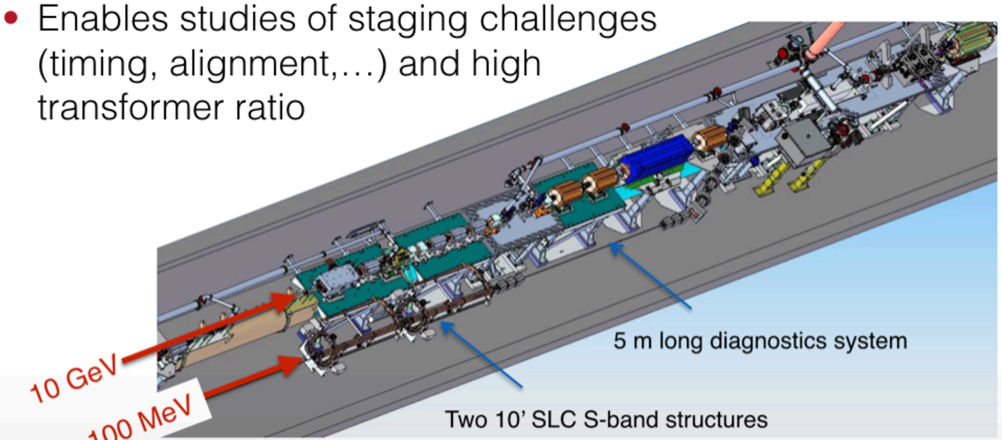
- Only positron capability in the world for PWFA research will be enabled by Phase II
  - Develop techniques for positron acceleration in PWFA stages



Staging Studies

FY22-25

- Independent witness injector planned to be added to FACET-II as an AIP project
- Enables studies of staging challenges (timing, alignment,…) and high transformer ratio



FACET Experiments use different Plasmas: Laser or Beam Field Ionization, "Heat pipe oven" or Gas

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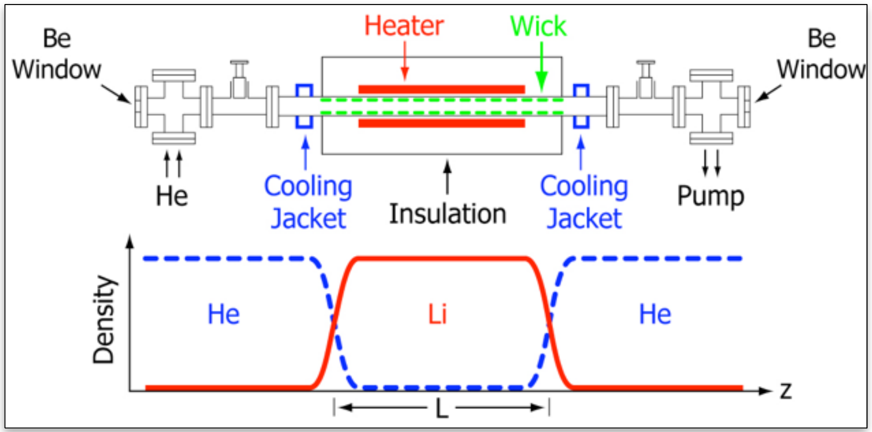
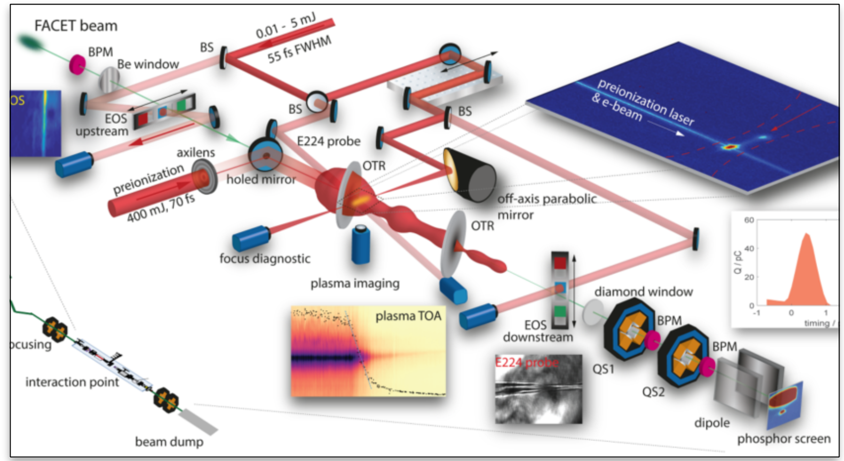
Heat Pipe Oven: Li/He or Rb/Ar Vapor/buffer gas (at same pressure):

- $n_0 = 10^{14}$-10^{17} e^-/cm^3, L = 20-200 cm



Hydrogen, Argon or Mixed Gas Cells:

- $n_0 = 10^{16}$-10^{18} e^-/cm^3, L = 10-100 cm



Enabled Many Advances in PWFA Physics:

• 42 GeV E-gain in one meter – ***Nature 2007***	***(2.7E17, 35 Torr)***
• High efficiency acceleration – ***Nature 2014***	***(5E16, 5.8 Torr)***
• Multi-GeV e+ PWFA – ***Nature 2015***	***(8E16, 9.6 Torr)***
• Hollow Channel e+ PWFA – ***Nature Communications 2016***	***(8E16, 9.6 Torr)***
• Wakefield Mapping – ***Nature Communications 2016***	***(2.5E17, 32.5 Torr)***
• Ionization Injection – ***PRL 2014***	***(2.7E17 Rb, 16 Torr)***
• High-field Acceleration – ***Nature Communications 2016***	***(1E18 Ar, 32 Torr)***
• Trojan-horse Injection – *in preparation*	***(1E17, 3.2 Torr H/He mix)***

2016 FACET-II Workshop:

10 GeV driver

Pump depletion

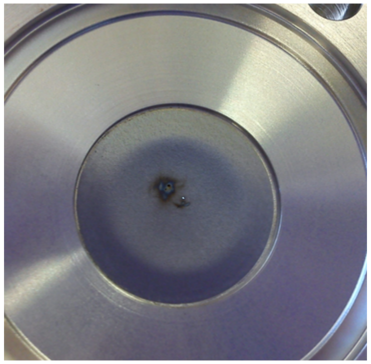
Emittance preservation

4E16, 4.6 Torr

Goals of Differential Pumping System

- No windows in beam path at FACET-II:
  - damage by beam
  - spoiled emittance

- Design requirements:
  - 5 Torr He pressure for experiments
  - 10^{-8} Torr before xTCAV
  - Compatible with laser ionization
  - Requirements for downstream of experiment not yet defined



Leaky window due to beam burn-through

Theory of Differential Pumping

Viscous flow: mean free path is similar to or smaller than size of object

- number of molecules that pass through a hole is proportional to the pressure of the gas and inversely proportional to its molecular mass
- 760 Torr - ~10 Torr

Transition flow: a mix between the two

- Empirically derived formulae or MC simulation
- 10 Torr - ~ 10^{-3} Torr

Free molecular flow: mean free path of the molecules is larger than the size of the chamber/object under test

- For objects of the size of several cm, this means pressures well below 10^{-3} Torr
- Good vacuum regime

Pinhole $C = 2.7\left(\frac{T}{M}\right)^{\frac{1}{2}} D^2$

Capillary $C = 3.81\left(\frac{T}{M}\right)^{\frac{1}{2}}\left(\frac{D^3}{L}\right)$

Temperature T = 293
Molecular Mass of Hydrogen M = 2

Pump speed: S = C(P0/P1 -1)

FACET-II will operate in transition and free molecular flow regimes

Beam Stay Clear

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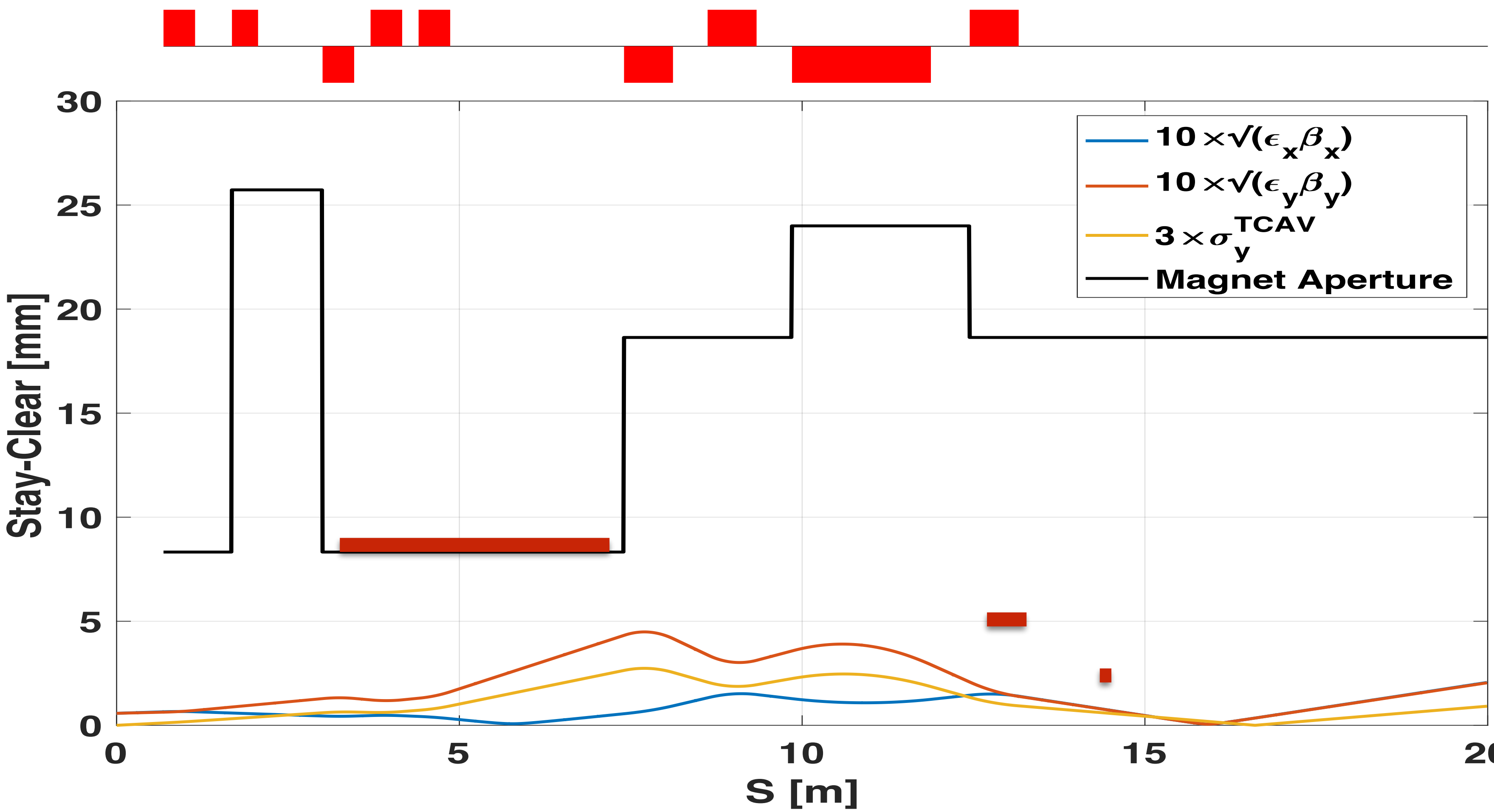
- Stay Clear definitions:
- $SC(\beta) = 10^{*}\sqrt{\varepsilon\beta}$
- SC(TCAV) = $3*\sigma\_z$ V_rf k_p R_34^(TCAV→ele), k_p=2πf / cp

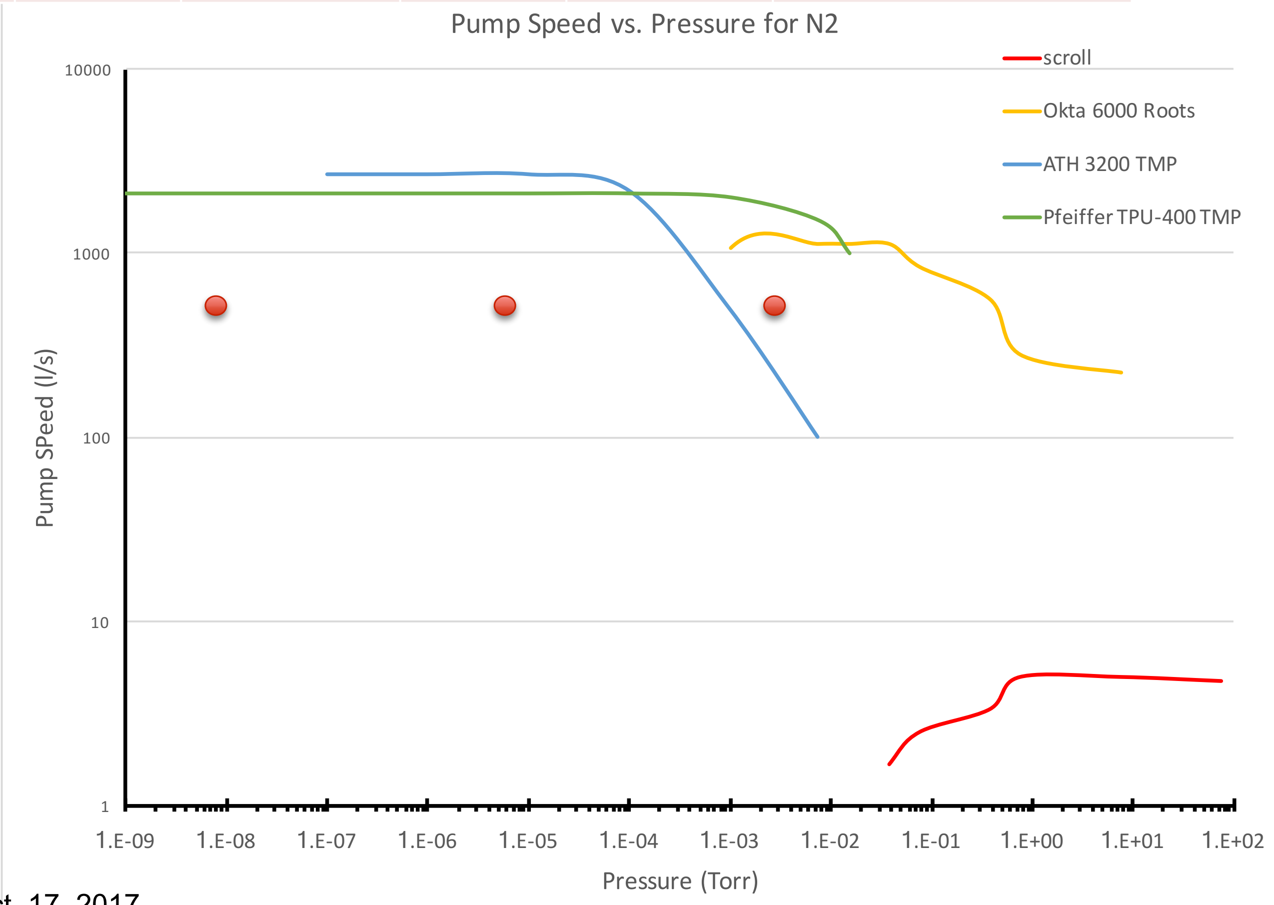
- $\beta^{*}_{x,y} = 0.1$ m
- $\sigma_z = 100$ μm
- $\gamma\varepsilon_{x,y} = 5$ μm-rad
- TCAV $V_{rf} = 23$ MV



Real time calculations

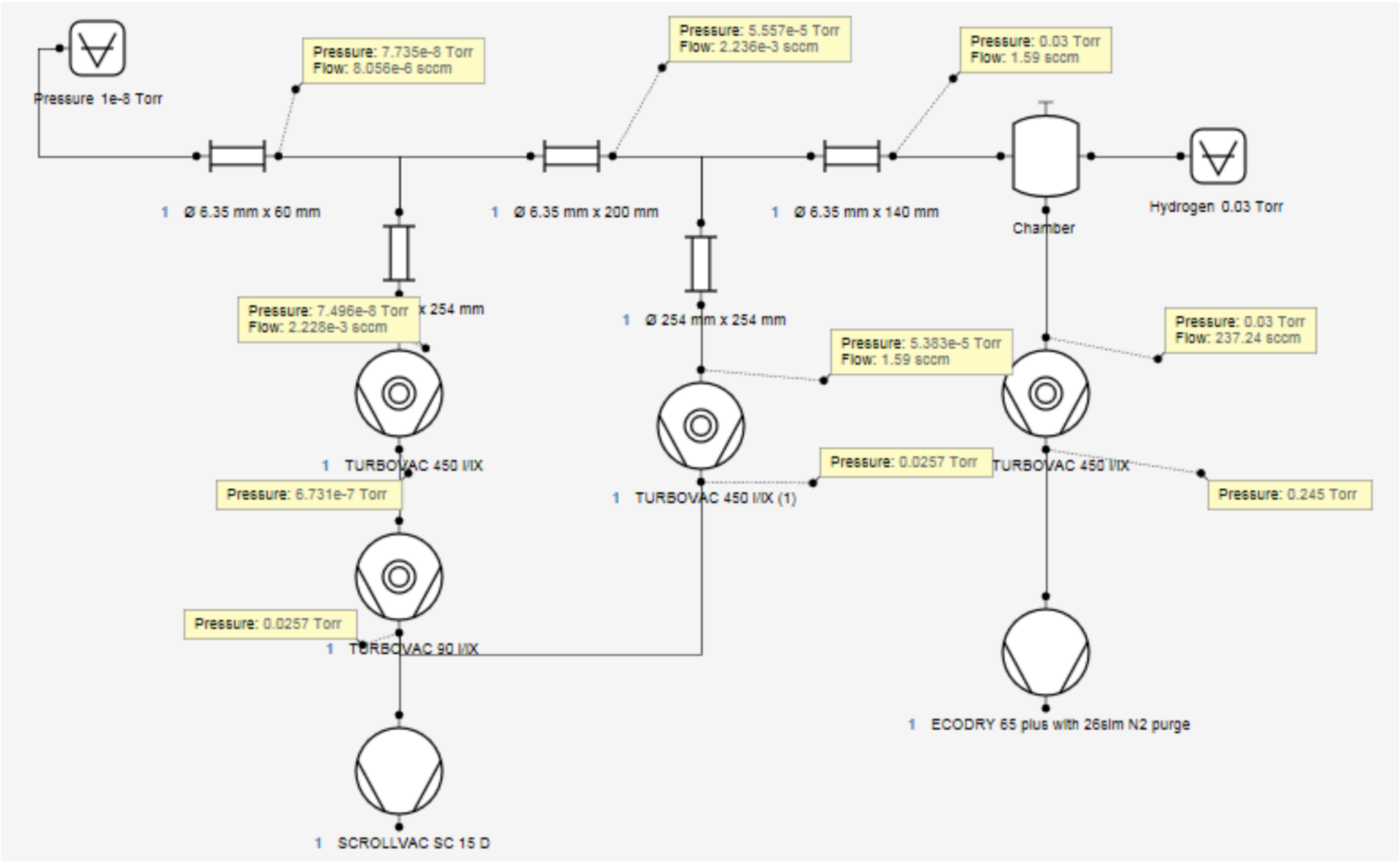
	D [cm]	L[cm]	C [l/s]	S [l/s]	P [torr]	Pump
Experiment					5	
Stage 1	0.5	10	4.1E-01	440	4.6E-03	TurboVac 450
Stage 2	1.2	60	9.4E-01	440	9.9E-06	TurboVac 450
Stage 3	1.7	400	4.0E-01	440	9.0E-09	TurboVac 450

Temp [K]	293
Mass H2 =2 He2=4	4



Next Steps

- We need to work with vendors on pump choices etc.



E.g. Laybold Simulations from Navid Vafaei-Najafabadi

Conclusion

- FACET-II needs a differential pumping system to avoid using windows in the beamline
- Early implementation will focus on first experiments with Li Oven
- Differential pumping system likely will be suitable for multiple experiments at end of development
- Differential pumping will introduce small apertures into IP Area upstream of experiments
- FACET-II needs to work with vendors to take the concept further