Commissioning Plans for the LHC Synchrotron-Light Monitors

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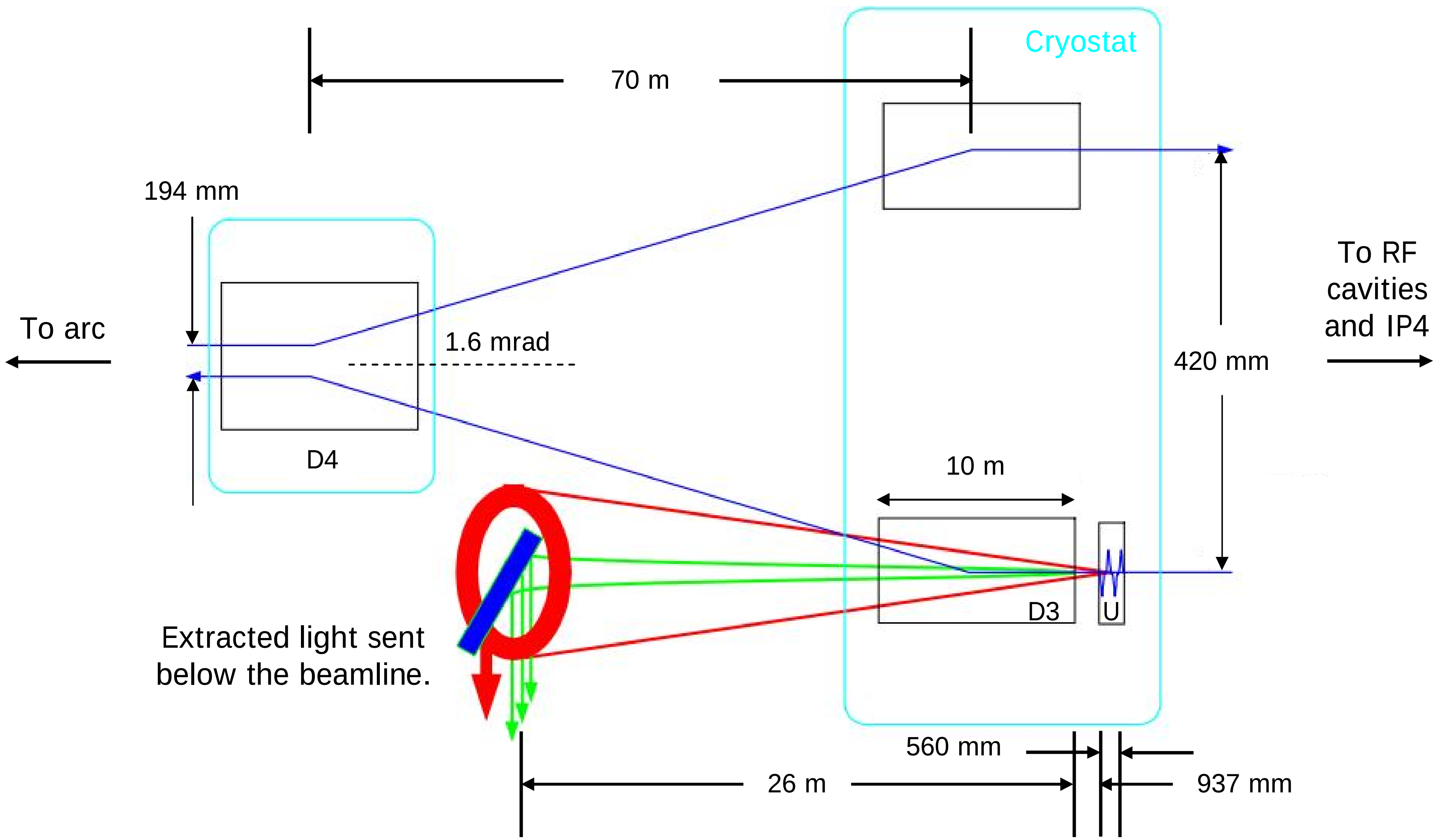
Synchrotron-Light Monitors

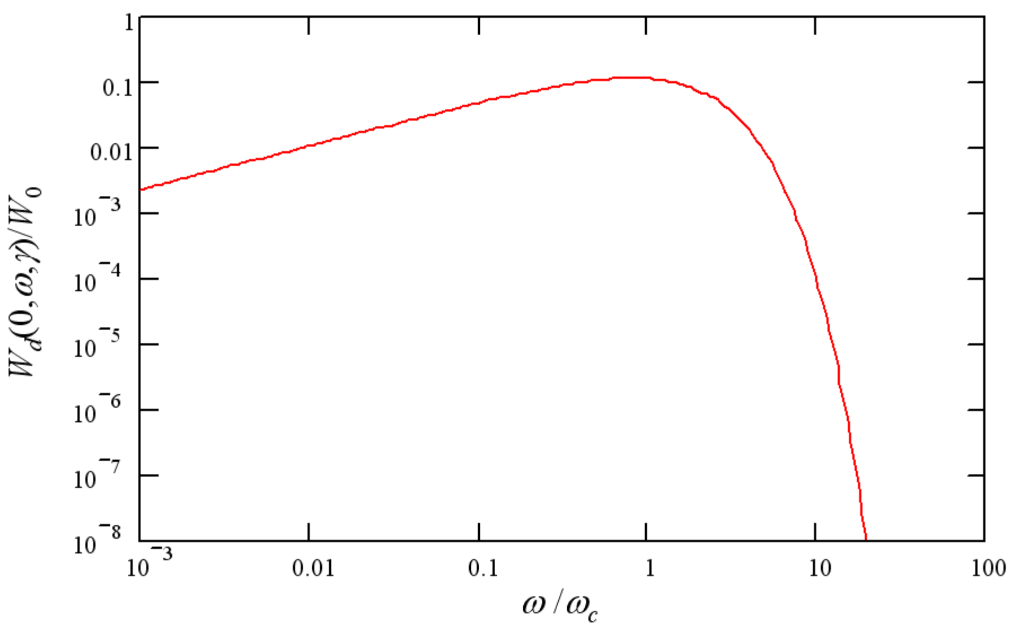
- Two applications:
  - BSRT: Imaging telescope, for transverse beam profiles
  - BSRA: Abort-gap monitor, to verify that the gap is empty
    - When the kicker fires, particles in the gap get a partial kick and might cause a quench.
- Two particle types:
  - Protons and lead ions
- Three light sources:
  - Undulator radiation at injection (450 GeV)
  - Dipole edge radiation at intermediate energy (2 to 3 TeV)
  - Central dipole radiation at collision energy (3.5 to 7 TeV)
  - Spectrum and focus change during ramp.

Layout: Emission and Extraction

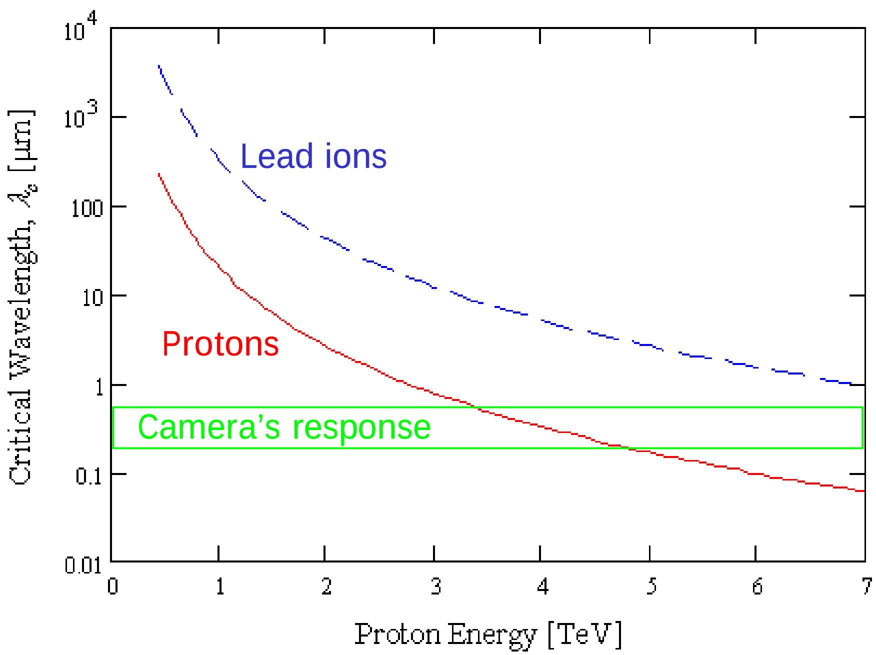


Spectrum of Central Dipole Radiation

Spectrum near Critical Frequency



Critical Wavelength vs Beam Energy

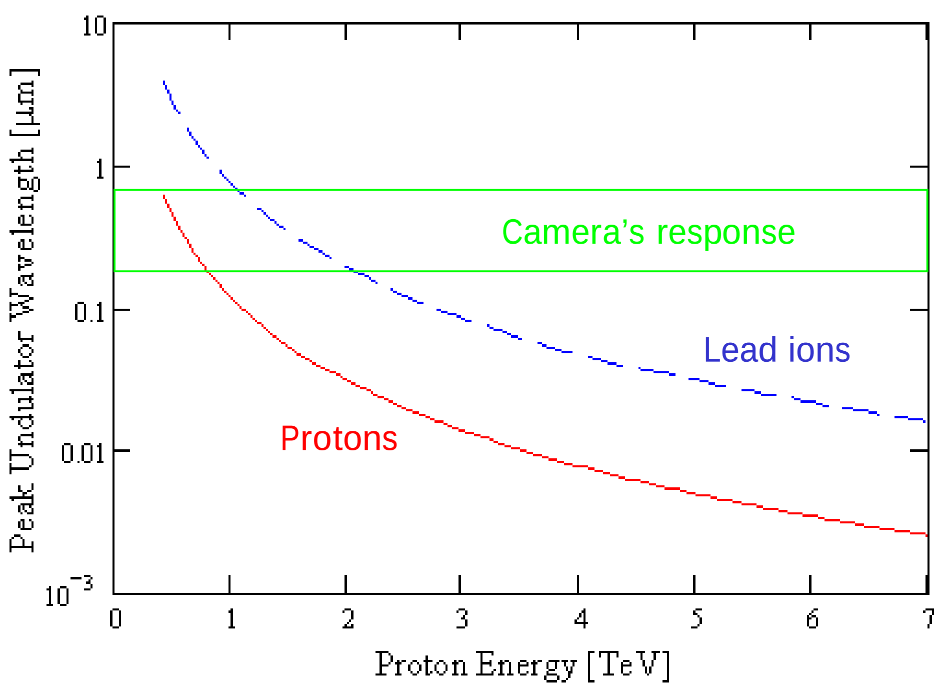


- Normalized emission energy in dipole
- Frequency normalized to critical frequency

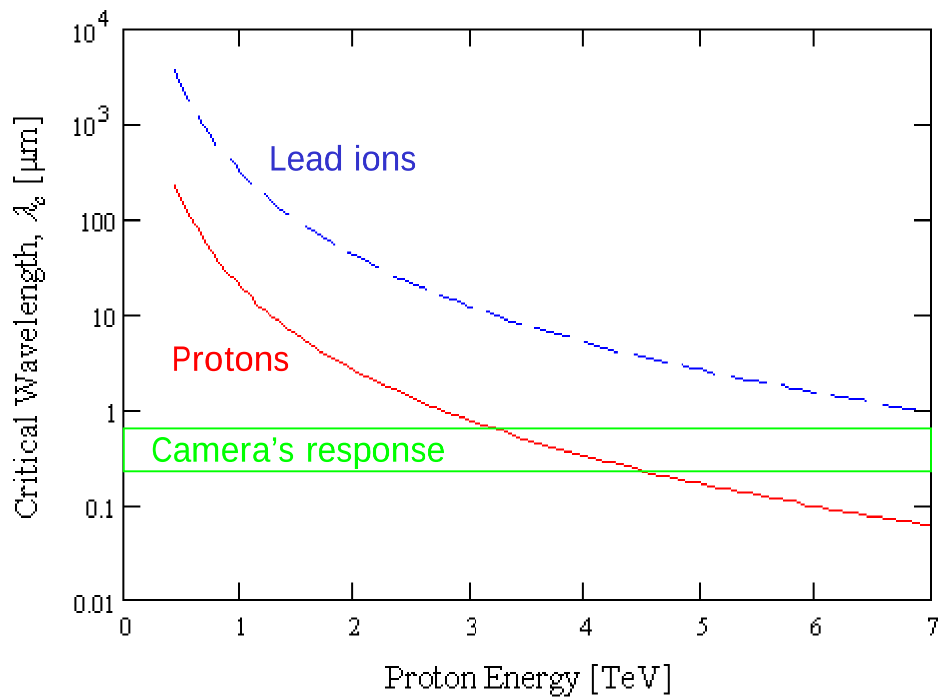
- Camera responds from near IR to near UV.
- Proton emission wavelength is too long at injection.
- Ion emission is too long below 3 TeV.
  - *i.e.*, dipole setting equivalent to 3-TeV protons

Undulator versus Dipole

Peak of Undulator Spectrum



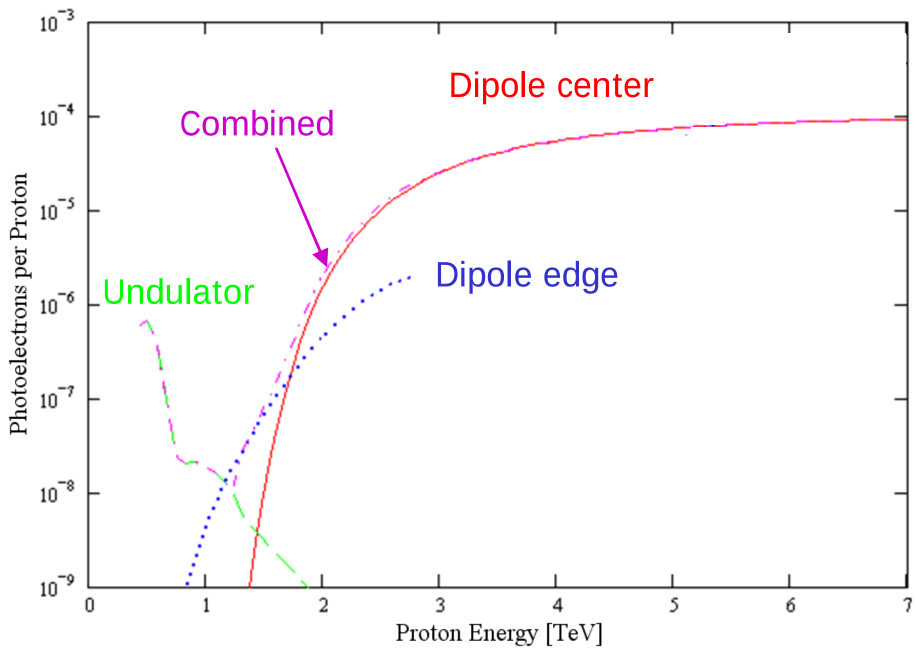
Critical Wavelength in Dipole



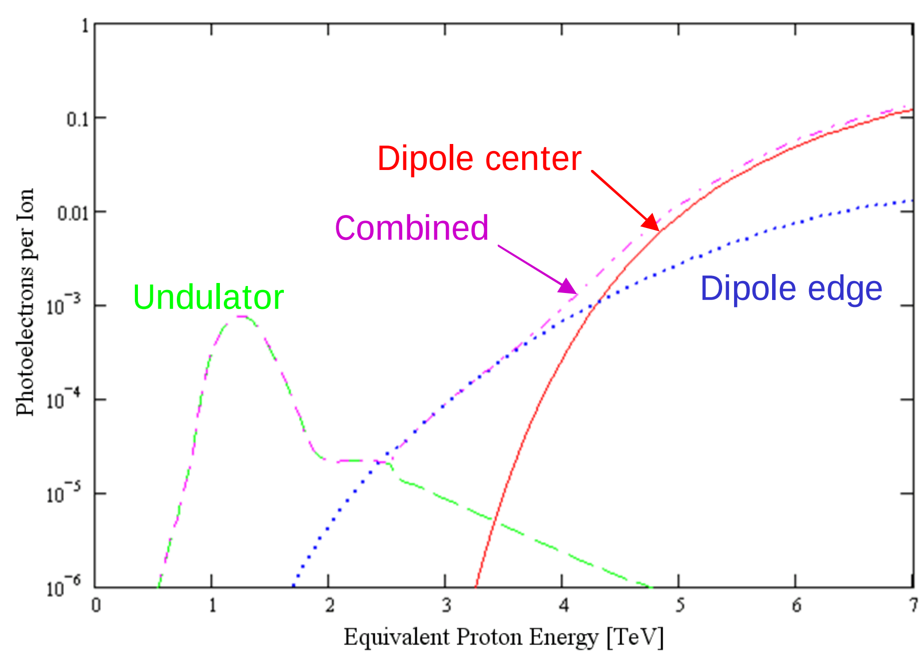
- Undulator provides response at proton injection.
- But response is still poor for ions at injection.

Photoelectrons per Particle at Camera

Protons



Lead Ions



- In the crossover region between undulator and dipole radiation:
  - Weak signal
  - Two comparable sources: poor focus over a narrow energy range
- Focus moves with energy: from undulator, to dipole edge, and then to dipole center.
- Dipole egde radiation is distinct from central radiation only for $\omega >> \omega_c$

Particles per Bunch and per Fill

	Protons	Lead Ions
Particles in a pilot bunch	5×10^{9}	7×10^{7}
Particles in a nominal bunch	1.15×10^{11}	7×10^{7}
Bunches in early fills	1 to 43	1 to 62
Bunches in a full ring	2808	592

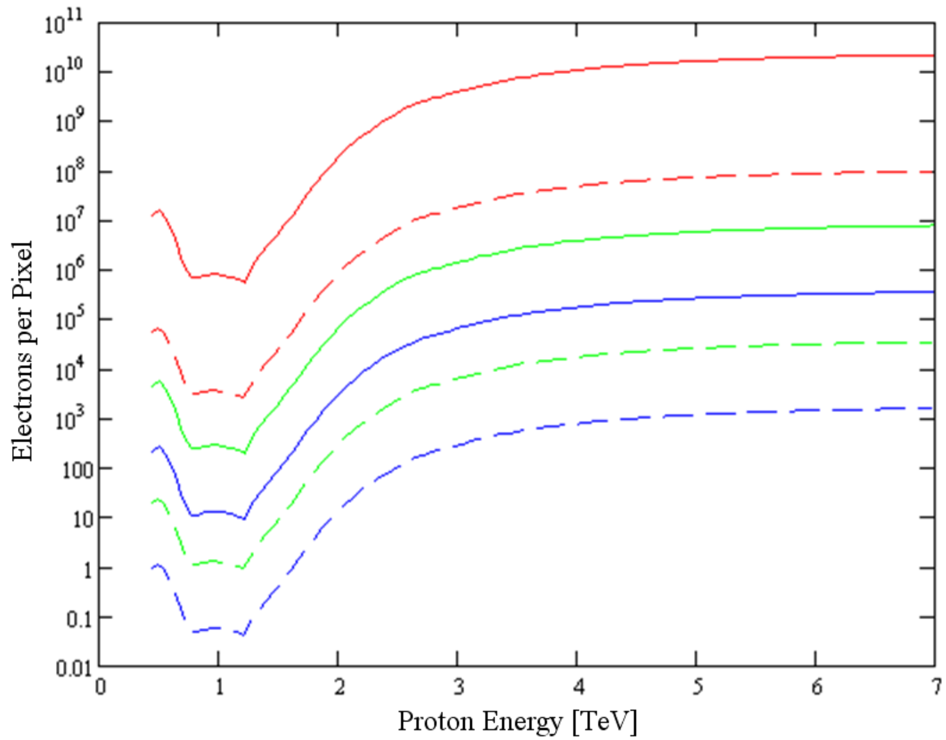
Beam Size and Critical Wavelength

Beam Energy		Beam Size at Source Point		Calculated Size on the Camera		Increase over Magnified Size (M = 0.3)	
(TeV)		(μm RMS)		(μm RMS)		(μm RMS)	
		x	*y*	*x*	*y*	*x*	*y*
Protons	0.45	1302	1244	391	373	1.002	0.999
	3.5	473	447	146	139	1.030	1.035
	7	334	315	98.5	111	0.983	1.179
Ions	0.45	1304	1246	392	375	1.003	1.004
	3.5	473	447	144	135	1.013	1.006
	7	335	315	104	98.8	1.033	1.044

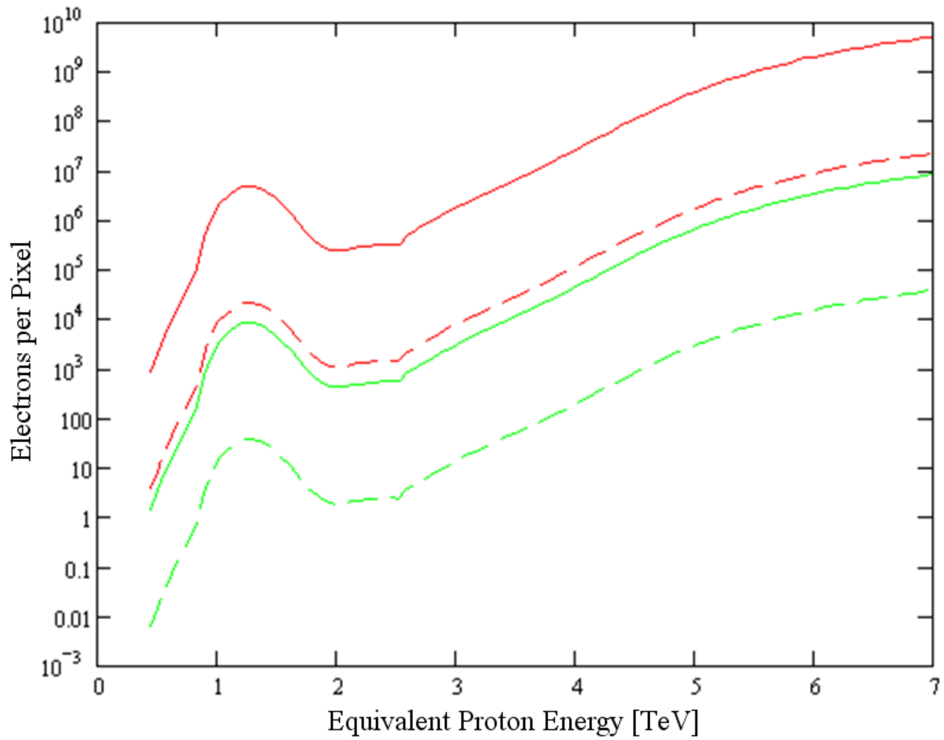
- Calculation includes geometric optics, depth of field, and diffraction.
- 400-nm wavelength is used, except at injection, where the undulator spectrum is shifted to the red and infrared.

Photoelectrons in the Peak Pixel

Protons



Lead Ions



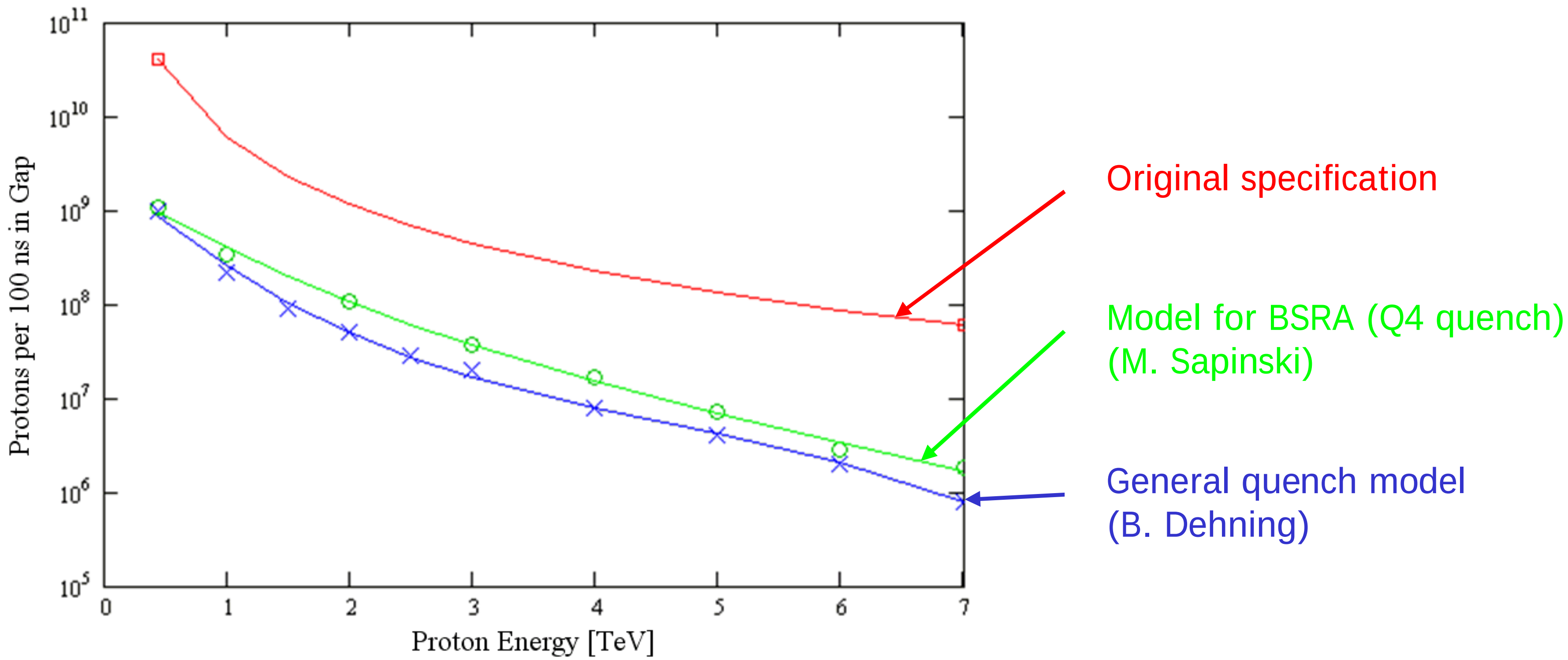
- Pilot bunch (blue)
- Single nominal bunch (green)
- Full ring (red)
- - - - - In one turn
- —— In 20 ms

- Emission increases with energy while beam size shrinks, giving a strong variation of the signal on the peak pixel.

Abort-Gap Monitor

- Gated photomultiplier gets ~15% of collected light.
  - PMT is gated off except during the 3-μs abort gap:
    - High gain needed during gap.
    - No saturation when filled bunches pass by.
  - Pick off before all slits or filters for maximum light.
- Digitize the gap signal in 30 100-ns bins.
  - Sum over 100 ms and 1 s.
  - Longer integration needed when emission in PMT band is weak (protons at crossover and ions at injection).
    - Worst case signal-to-noise is 10 for 1-s integration at 10% of threshold.
- Requirement: Detect whether any bin has a population over 10% of the quench threshold.

Protons/100ns at Quench Threshold

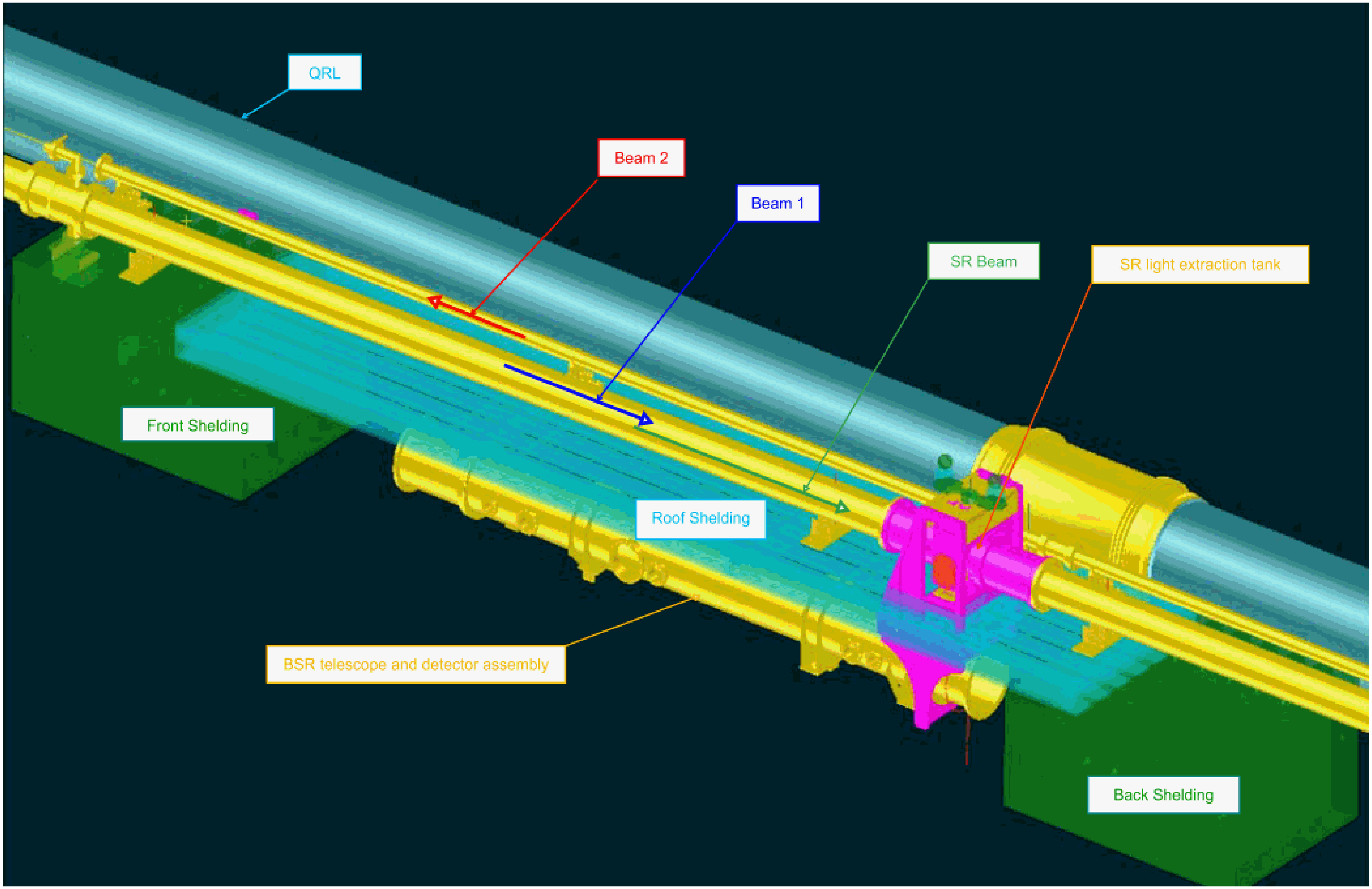


- Original threshold specification (given only at 0.45 and 7 TeV) was too generous.
- BLM group provided improved models. We used Sapinski's calculation.
- Ions fragment on beam screen, and deposit energy equivalent to *Z* protons at same point in ramp.

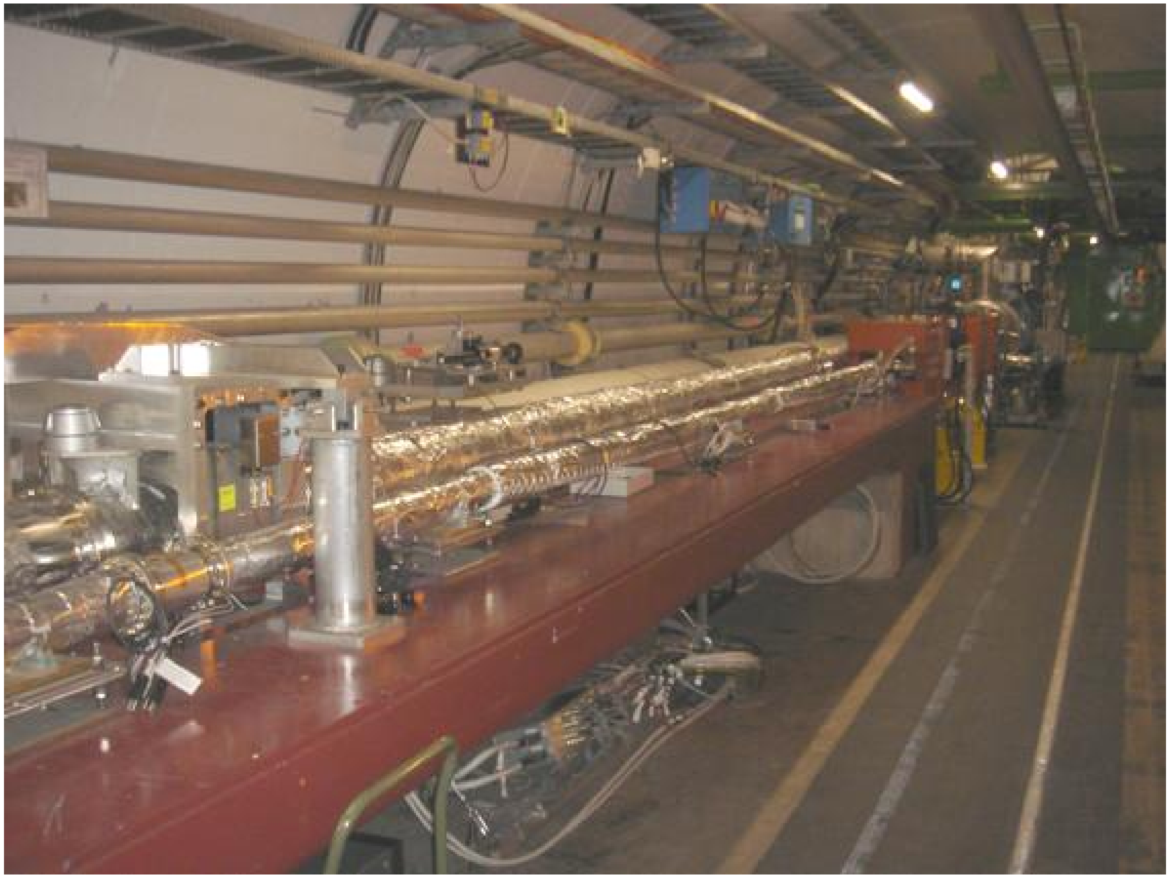
Re-examining the Optical Design

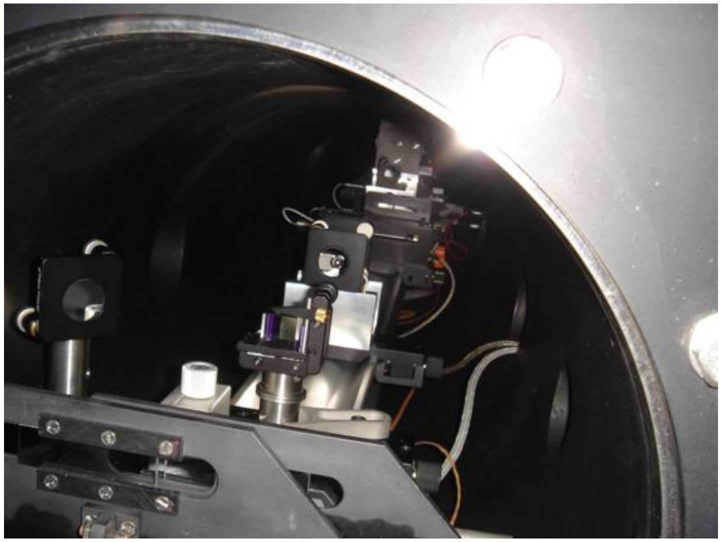
- Optical:
  - Add focus adjustment, since source moves during the ramp.
  - Add a calibration source.
- Mechanical:
  - The optics were housed in a tube (left over from LEP).
  - Replace with an optical table.
    - More space for optics. Better access for adjustment.
- Calculations:
  - Light level from protons and ions
  - Can the undulator stay on at high energy?
  - Minimize blurring from diffraction and depth of field.
  - Improve the optics for better imaging.
  - Monitoring abort gap even with weak light at injection.

Original Optics Housed in a Tube

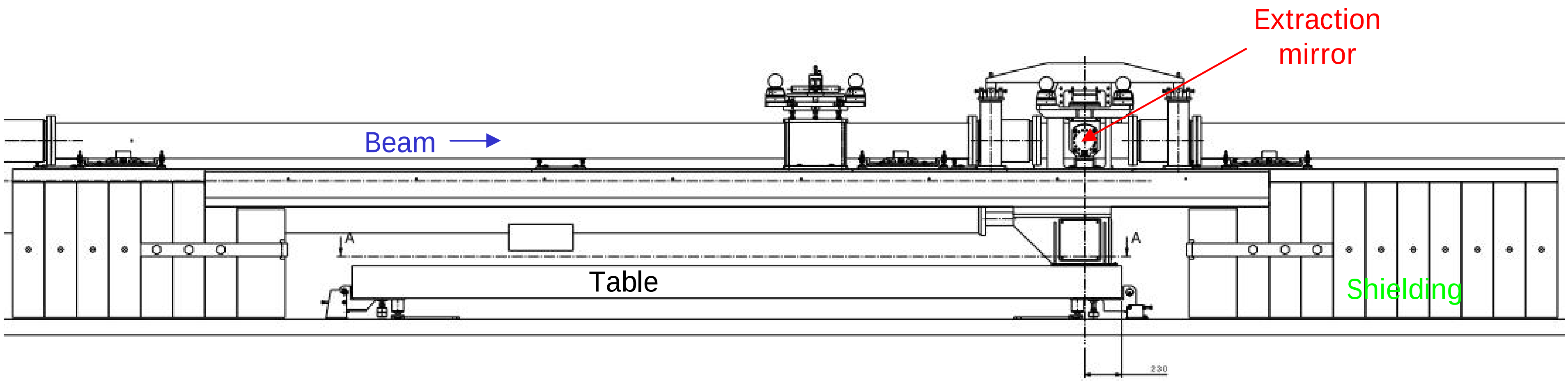


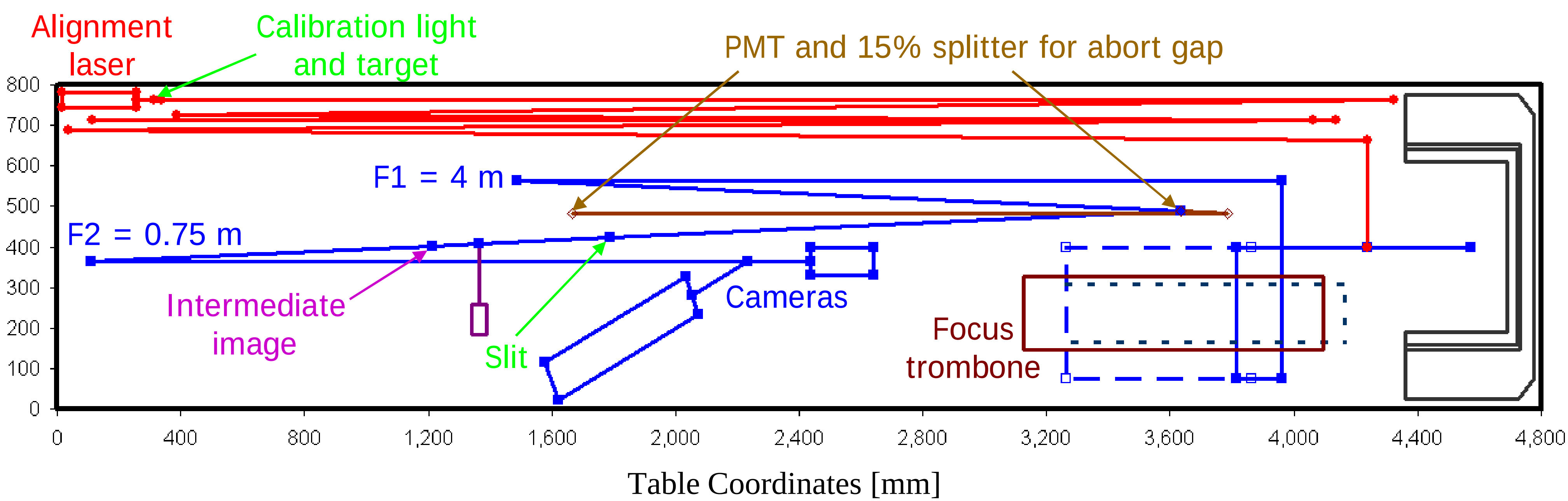
Poor Access with the Present Layout



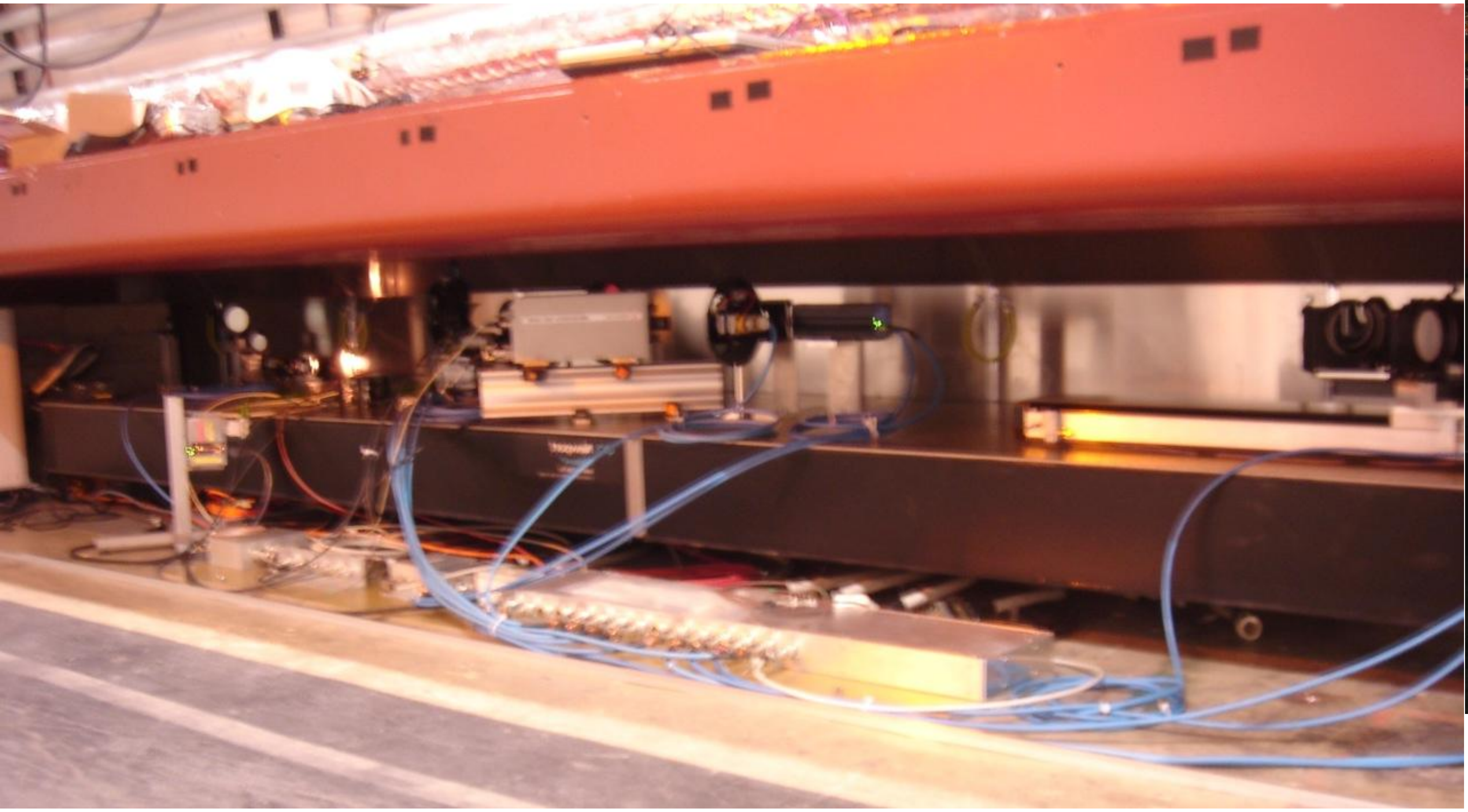


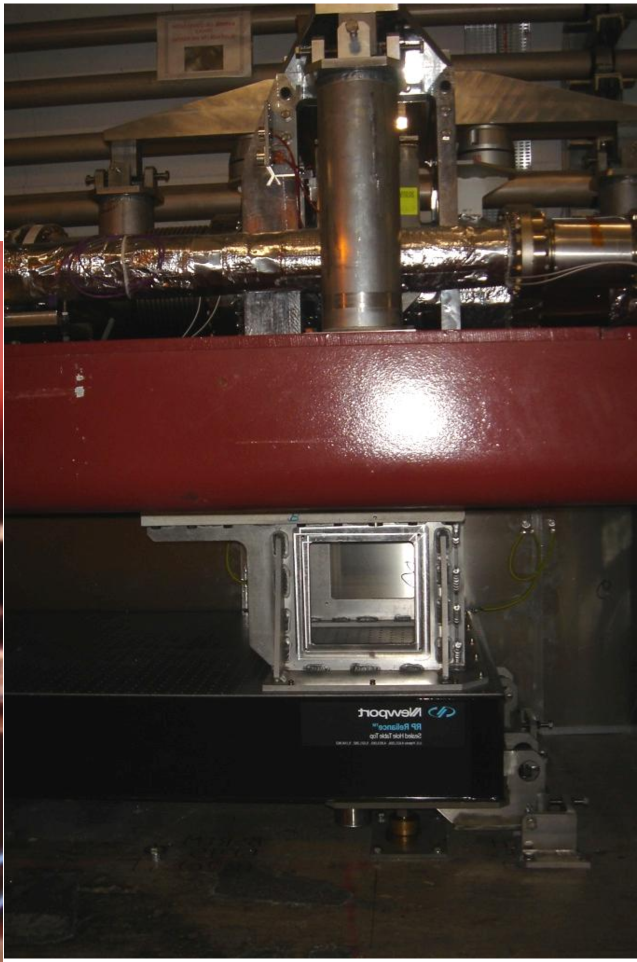
Layout of New Optical Table



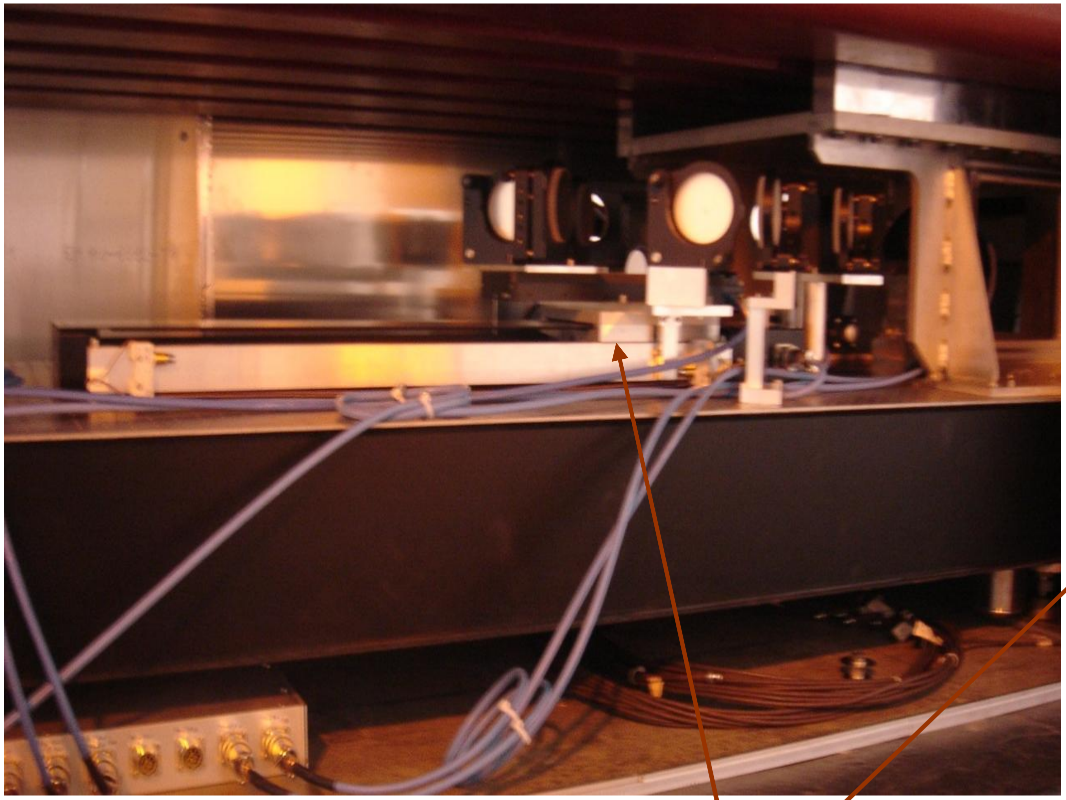


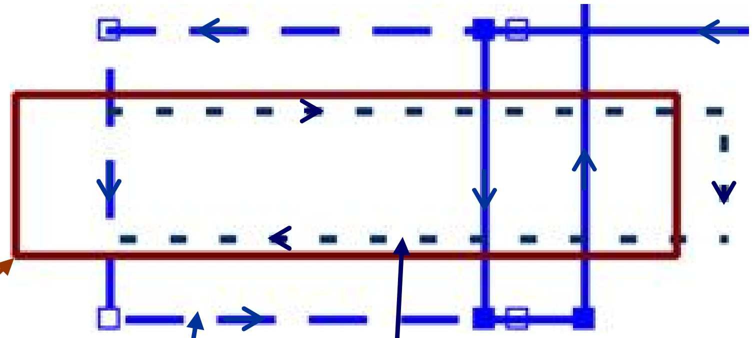
New Table Installed under Beamline





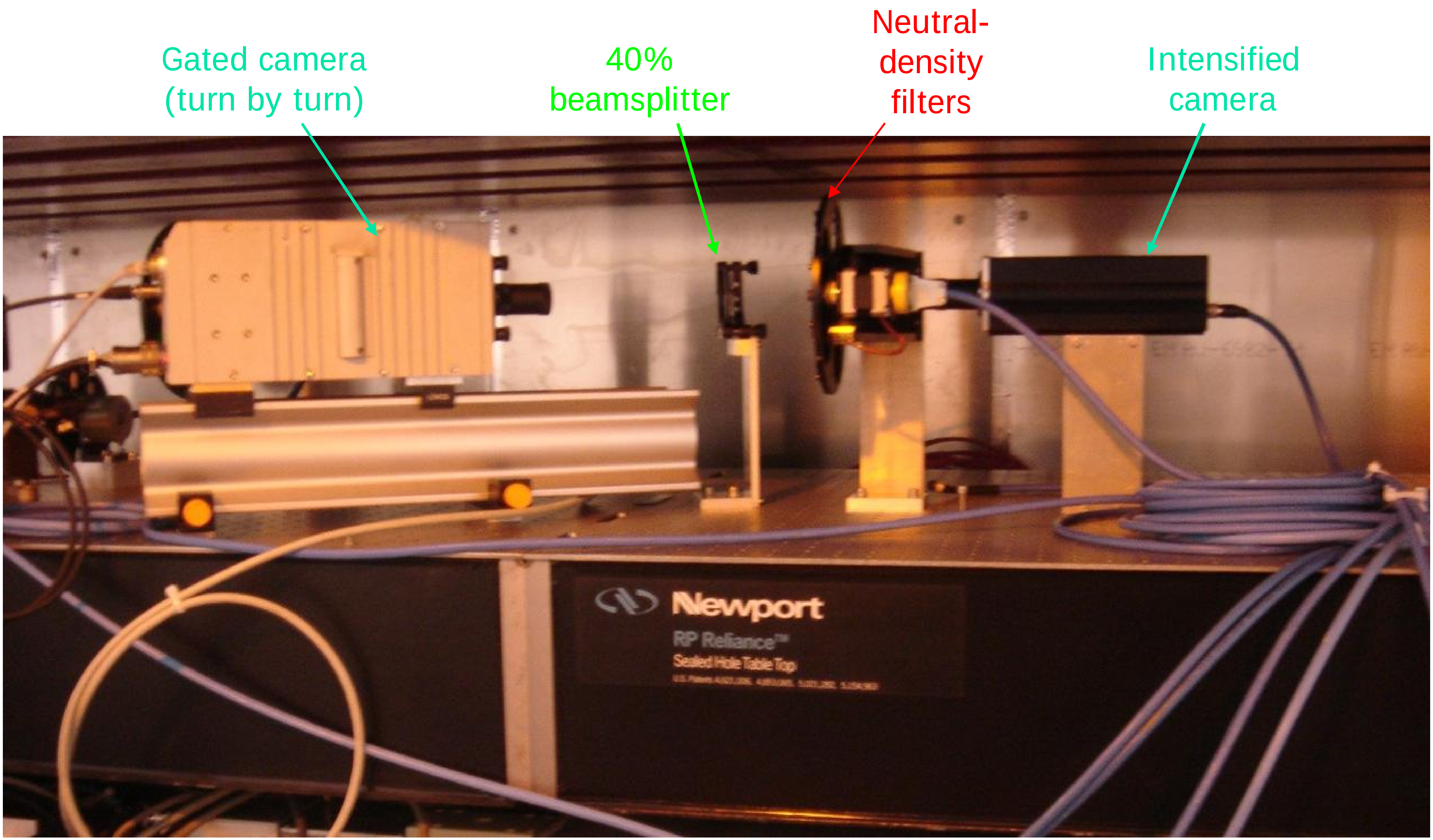
4-Pass Focus Trombone



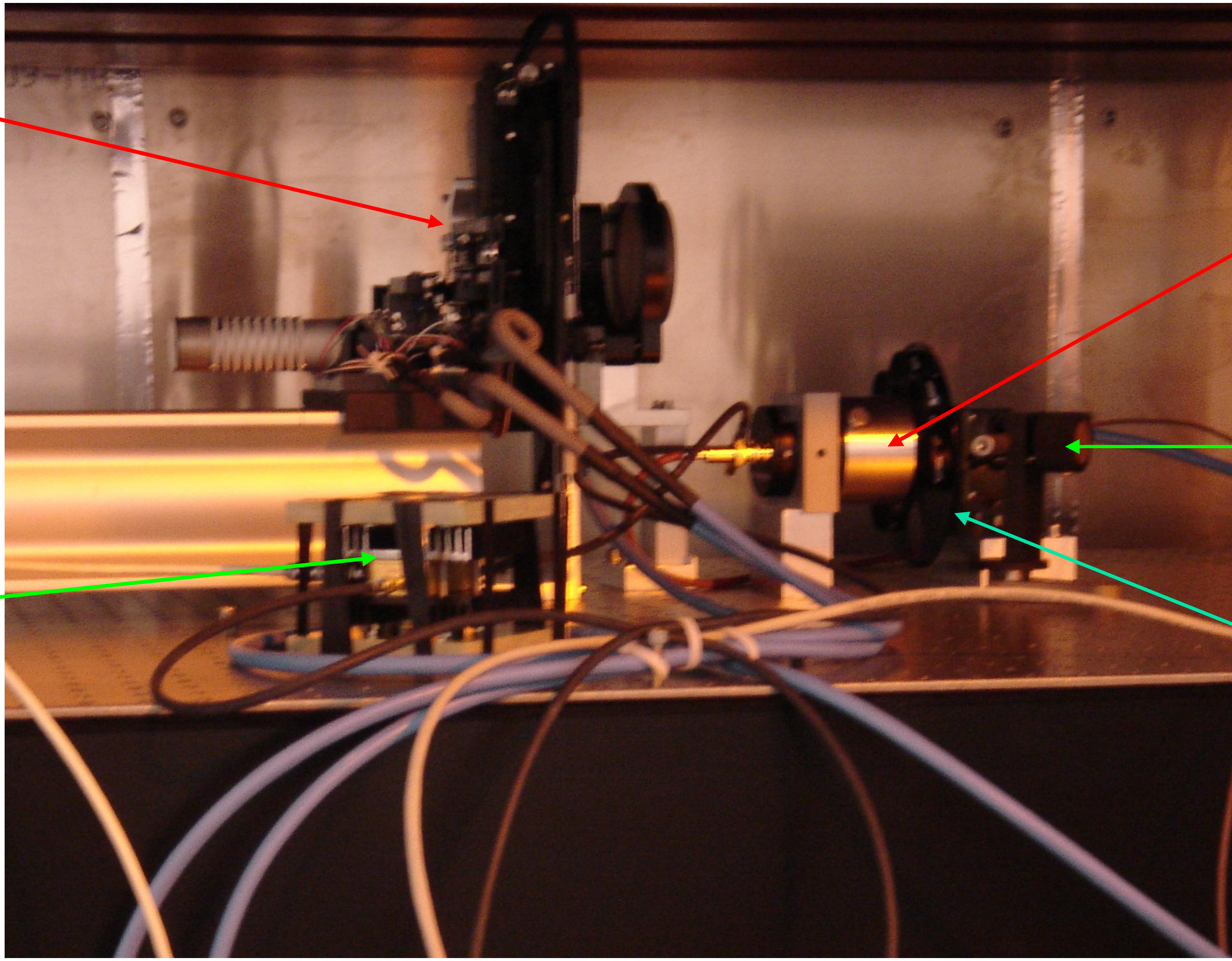


- 600-mm translation stage
  - Outer trombone: 2 passes gives a 1200-mm range.
  - Inserting 2 mirrors converts trombone to 4 passes.
    - With a fixed extra path, the 4-pass mode spans 600 to 3000 mm.

Intensified and Gated Cameras



Abort-Gap Monitor



Commissioning: Setup for First Beam

- Undulator at full field
- Extraction mirror inserted
- Trombone at minimal delay (100 mm)
  - Source (undulator) is at longest distance
  - Inner trombone switched out
- No neutral-density or color filters inserted
- Maximum gain for intensified camera and PMT
- Maximum integration time for gated camera

Commissioning: 450-GeV Pilot Bunch

- BSRA (Abort-Gap Monitor):
  - Set a wide gate that includes the pilot bunch.
  - Steer first two mirrors to find a signal on the PMT.
    - Avoid damaging PMT: Software alarm or feedback on high voltage
  - Insert filters as needed.
  - Shorten the gate. Verify timing using the pilot bunch.
  - Calibrate the signal level with the pilot bunch.
  - Reset the gate to span only the abort gap.
  - Remove filters for sensitivity to threshold gap population.

Commissioning: 450-GeV Pilot Bunch

- BSRT Cameras:
  - Adjust steering as needed to get light on cameras.
    - Check that light remains on the PMT.
      - 10-mm diameter photocathode, placed at intermediate waist.
    - Adjust intensifier gain and gated-camera integration as needed.
  - Focus by scanning the trombone (expect ±100 mm).
    - Determine steering needed to keep light on center of cameras.
  - Determine settings for:
    - Pilot bunch, 1 turn (gated camera) and 20 ms (intensified camera)
    - Nominal bunch, 1 turn and 20 ms
    - Multiple nominal bunches

Commissioning: Ramping the Pilot

- Don't change light path at first:
  - Measure beam displacements.
  - Measure intensity changes.
    - But keep the detectors from saturating.
- At end of ramp:
  - Resteer the light.
  - Adjust intensity.
  - Recalibrate the BSRA and cameras.
- Build up a calibration table for each energy step:
  - Steering
  - Intensity control

Commissioning: Automatic Operation

- Automatic (software) control depending on:
  - Particle type (proton/ions)
  - Beam charge
  - Bunch charge
  - Beam energy
- Adjustments:
  - BSRA settings:
    - Neutral-density filters and PMT high voltage
  - Motorized mirrors
  - Motorized slit on the focal plane of first focusing mirror
  - Camera settings:
    - Color and neutral-density filters
    - Gain and shutter for intensified camera
    - Integration time and framing speed for gated camera

Schedule

- Stored beam expected in the next couple of weeks.
- I will go to CERN on Nov. 28 and stay until the holiday shutdown (Dec. 19).
- A proton photo album for CM14?