Commissioning Plans for the LHC Synchrotron-Light Monitors

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CERN Collaborators

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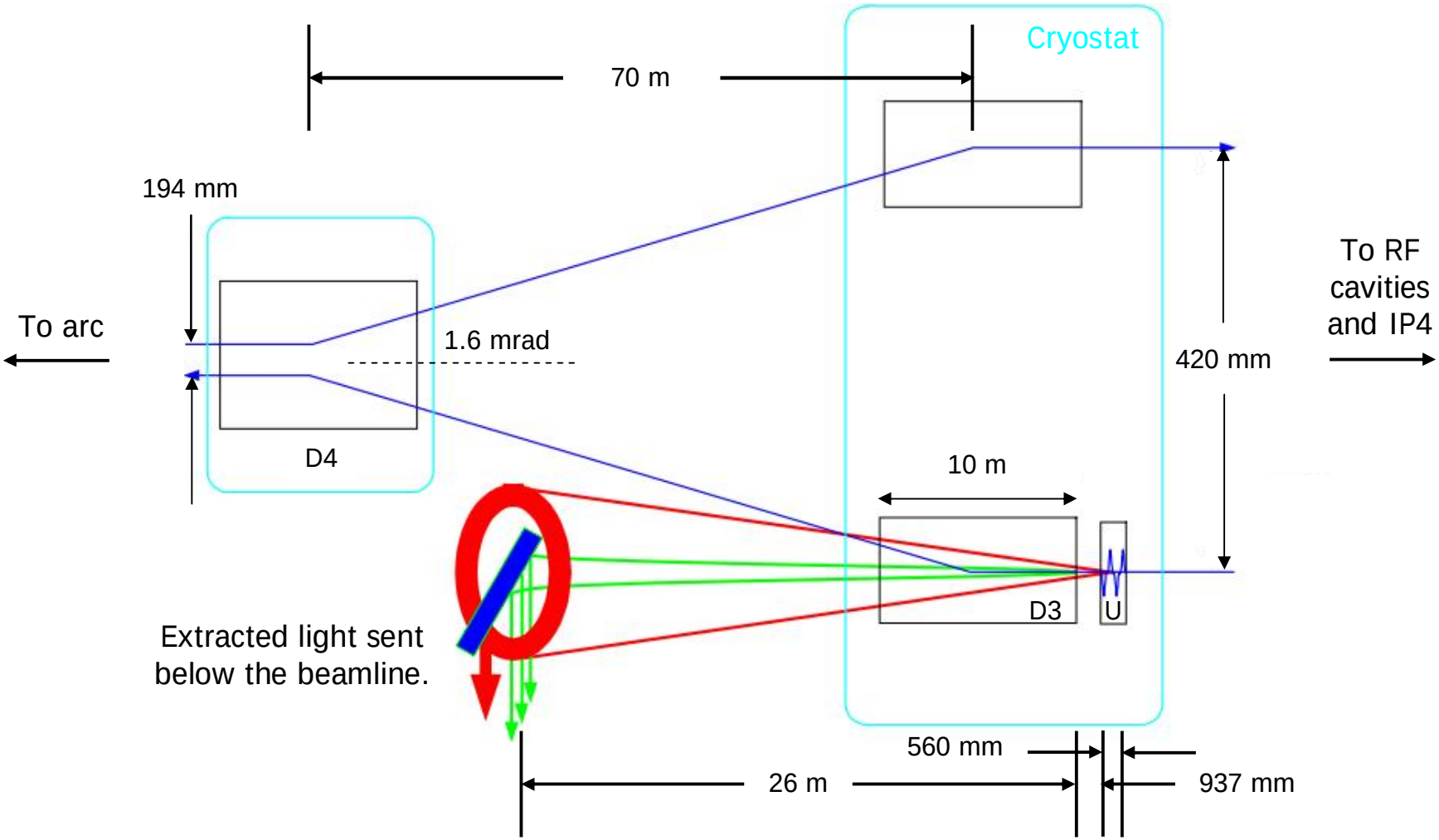
Synchrotron-Light Monitors

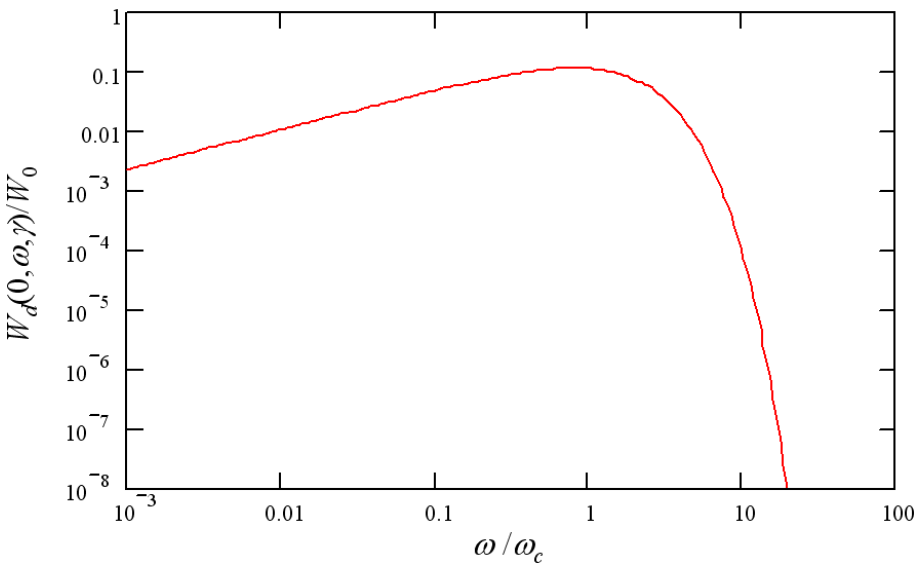
- Two applications:
  - BSRT: Imaging telescope, for transverse beam profiles
  - BSRA: Abort-gap monitor, to verify that the gap is empty
    - When the kicker fires, particles in the gap get a partial kick and might cause a quench.
- Two particle types:
  - Protons and lead ions
- Three light sources:
  - 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



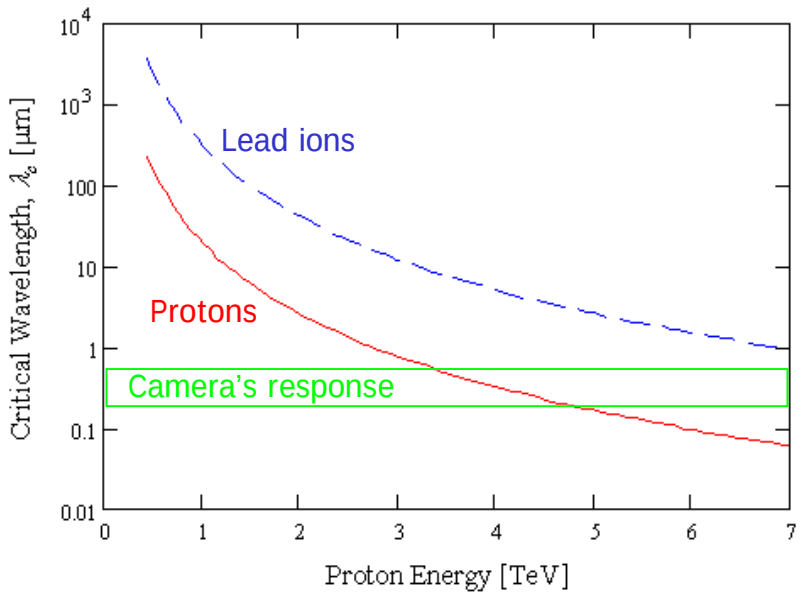
Spectrum of Central Dipole Radiation

Spectrum near Critical Frequency



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

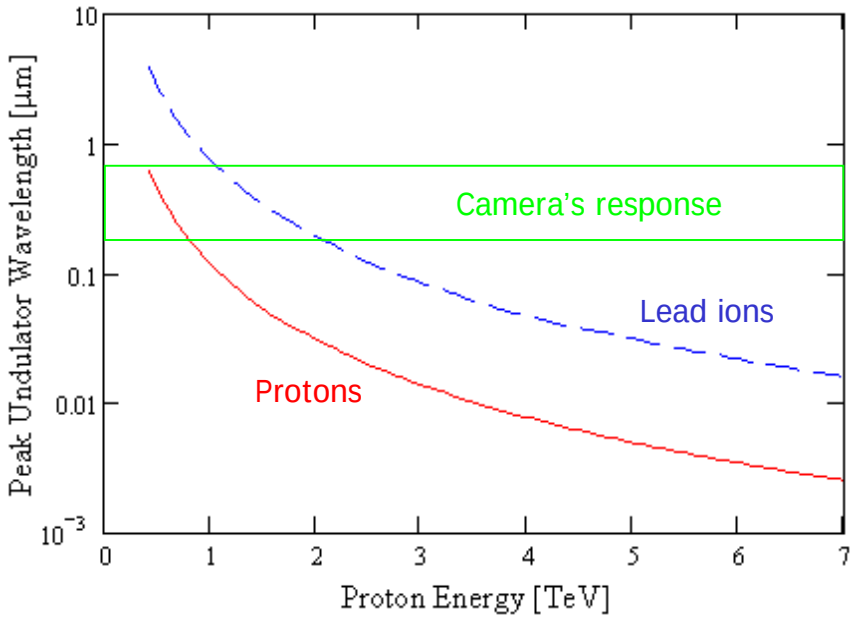
Critical Wavelength vs Beam Energy



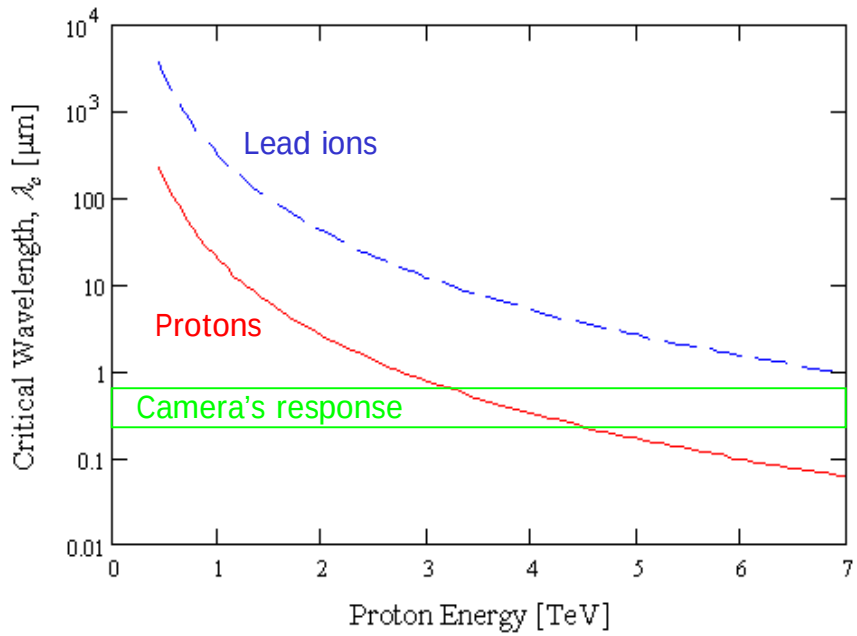
- Camera responds from near IR to near UV.
- Proton emission wavelength is too long at injection.
- Ion emission is too long below 3 TeV.
  - *i.e.*, dipole setting equivalent to 3-TeV protons

Undulator versus Dipole

Peak of Undulator Spectrum



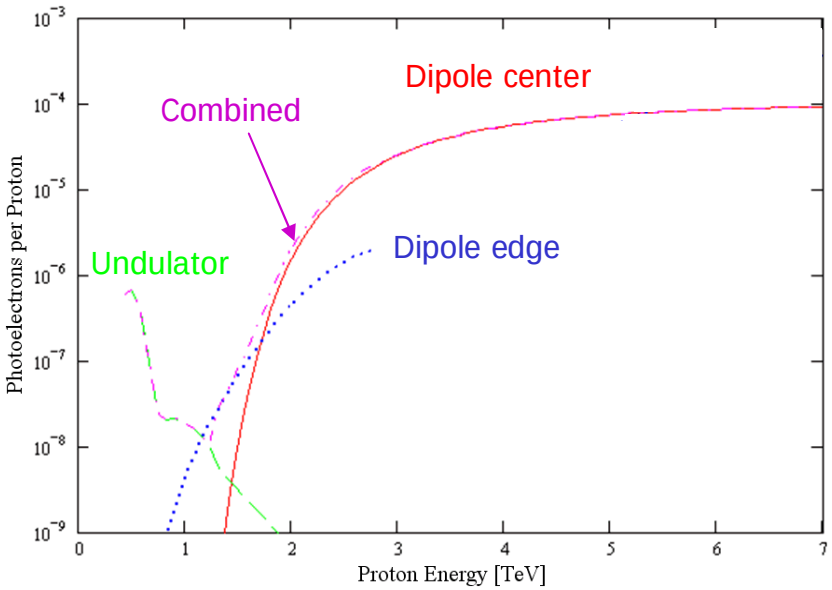
Critical Wavelength in Dipole



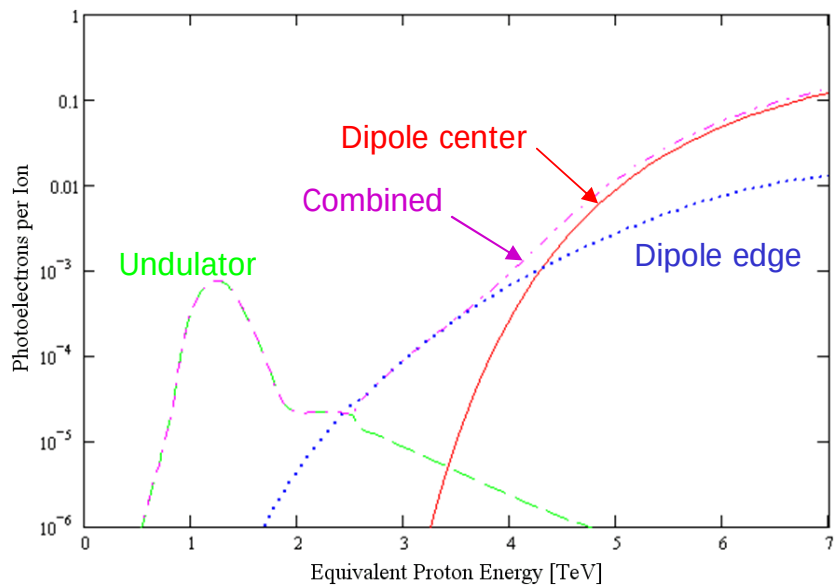
- Undulator provides response at proton injection.
- But response is still poor for ions at injection.

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

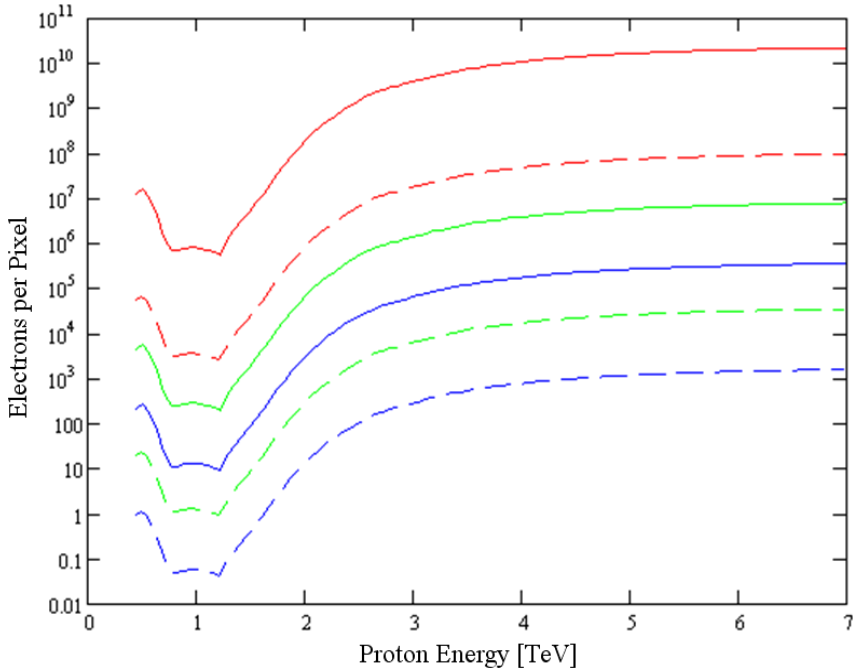
Beam Size and Critical Wavelength

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

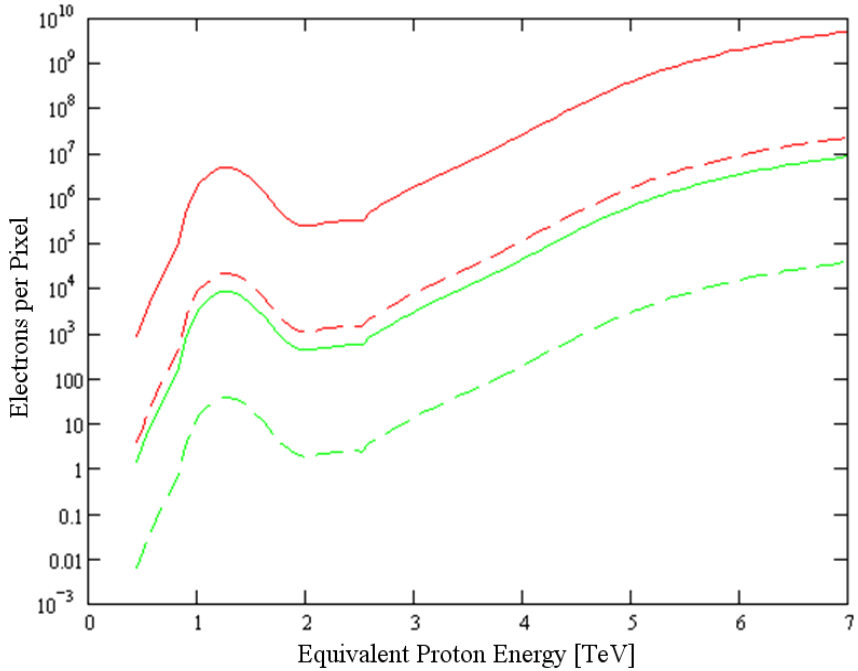
- Calculation includes geometric optics, depth of field, and diffraction.
- 400-nm wavelength is used, except at injection, where the undulator spectrum is shifted to the red and infrared.

Photoelectrons in the Peak Pixel

Protons



Lead Ions



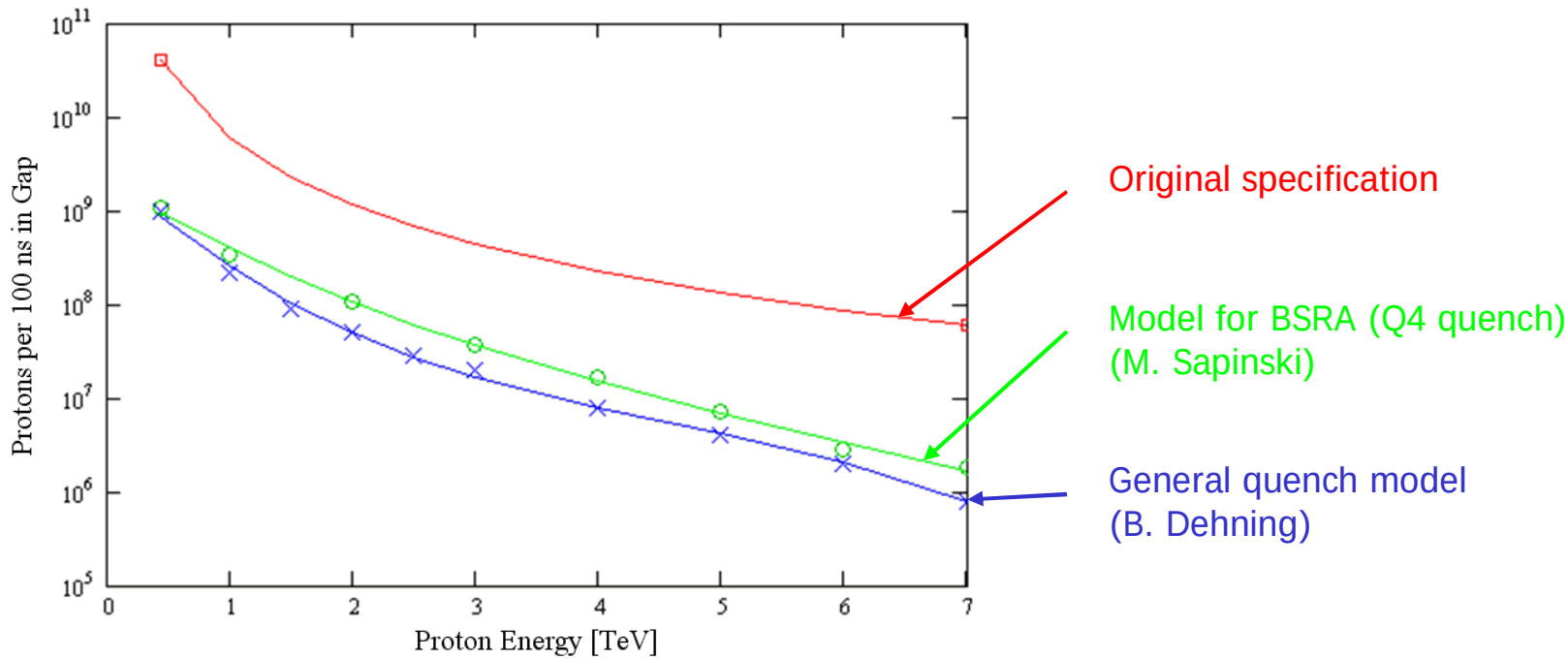
Pilot bunch
Single nominal bunch
Full ring
In one turn
In 20 ms

- 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

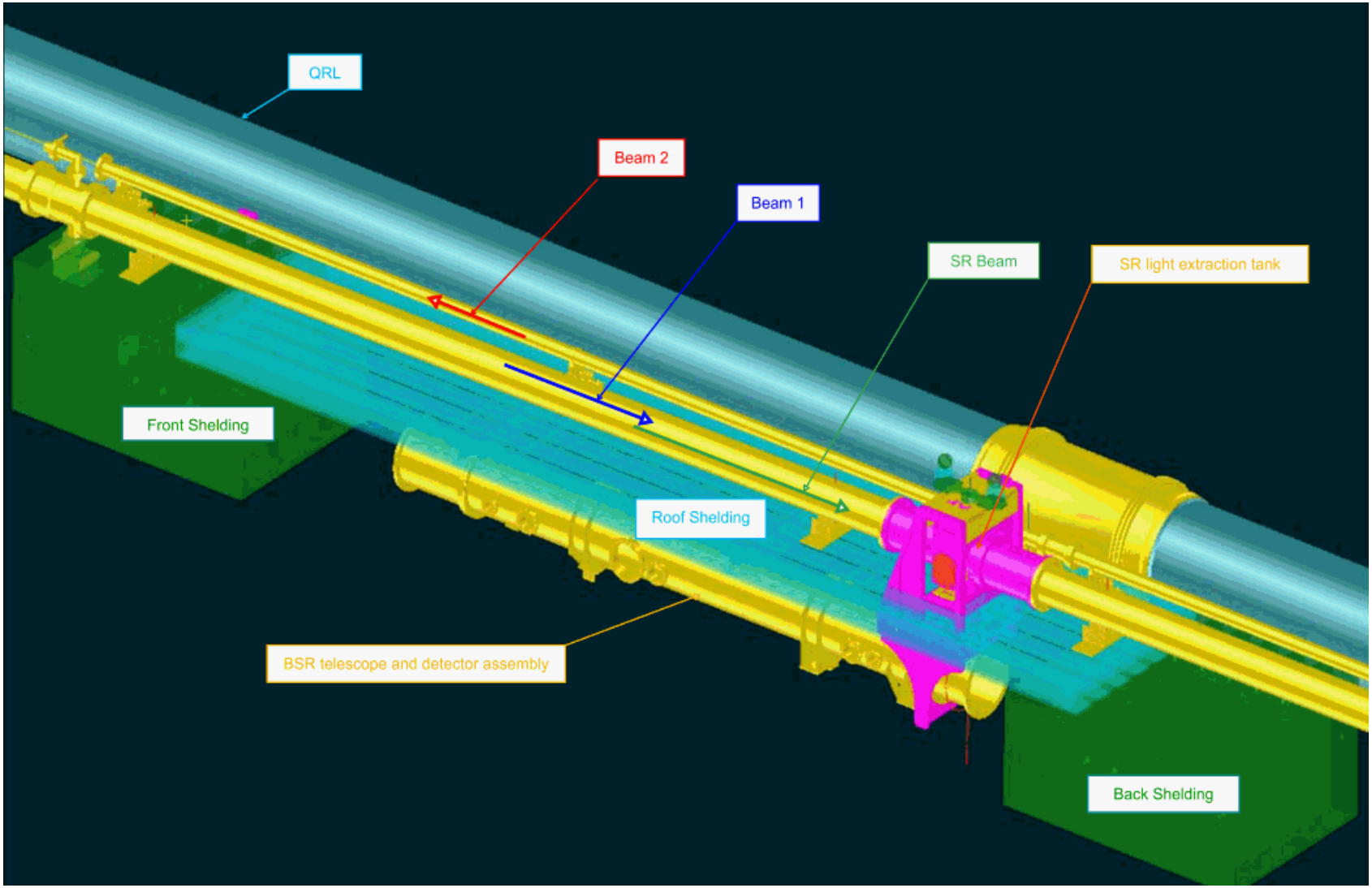


- Original threshold specification (given only at 0.45 and 7 TeV) was too generous.
- BLM group provided improved models. We used Sapinski's calculation.
- Ions fragment on beam screen, and deposit energy equivalent to *Z* protons at same point in ramp.

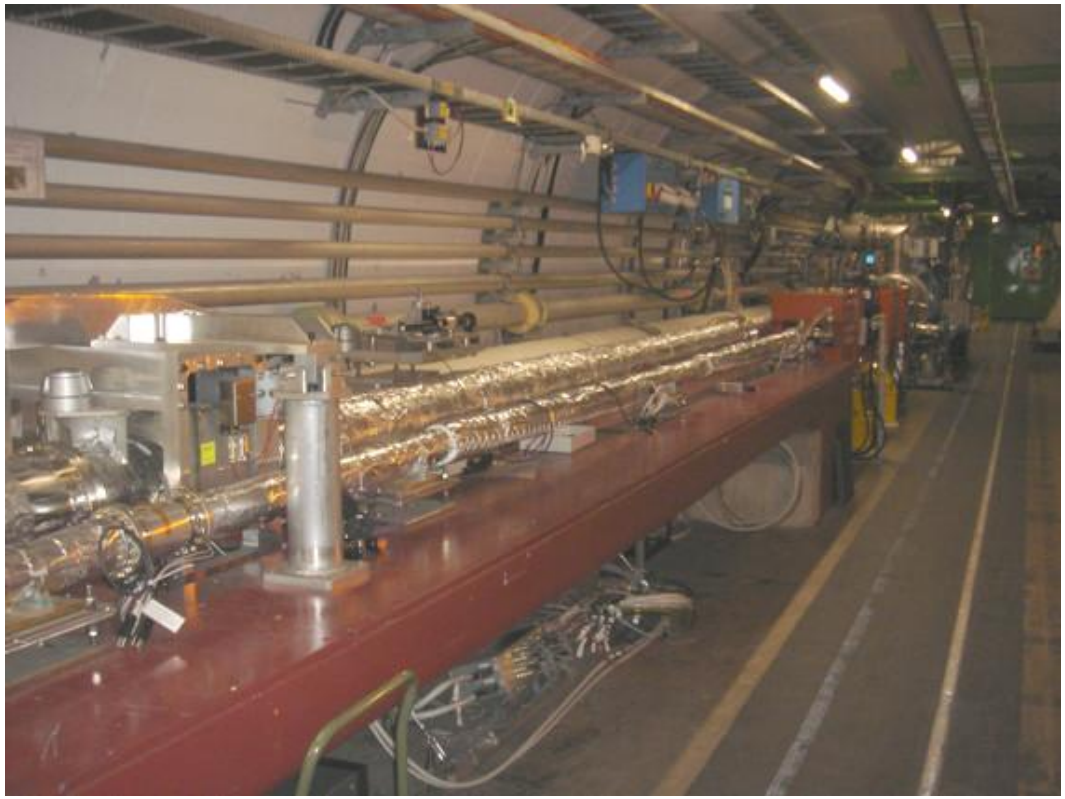
Re-examining the Optical Design

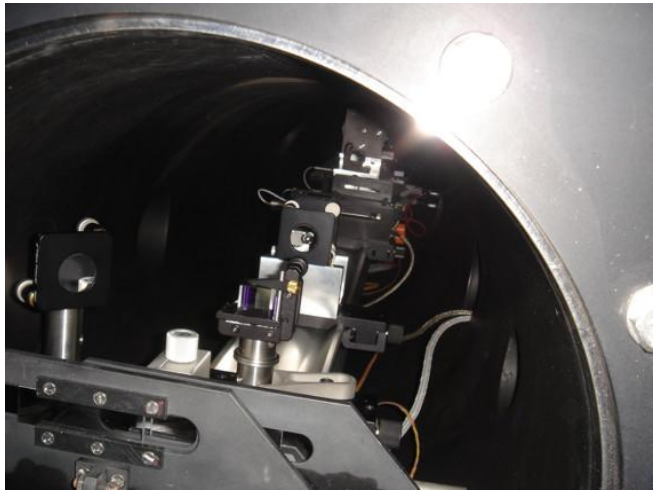
- Optical:
  - Add focus adjustment, since source moves during the ramp.
  - Add a calibration source.
- Mechanical:
  - The optics were housed in a tube (left over from LEP).
  - Replace with an optical table.
    - More space for optics. Better access for adjustment.
- Calculations:
  - Light level 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

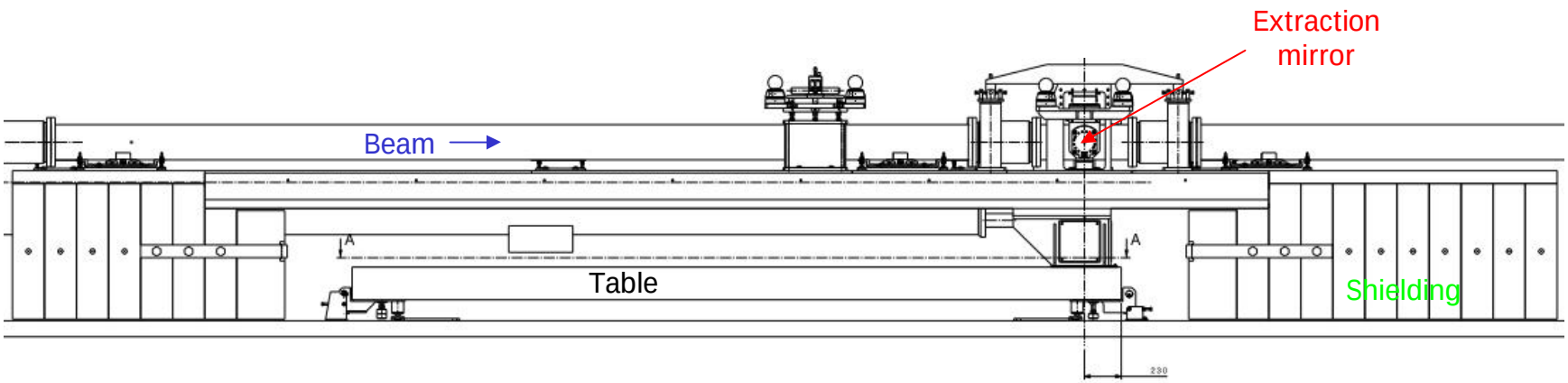


Poor Access with the Present Layout





Layout of New Optical Table



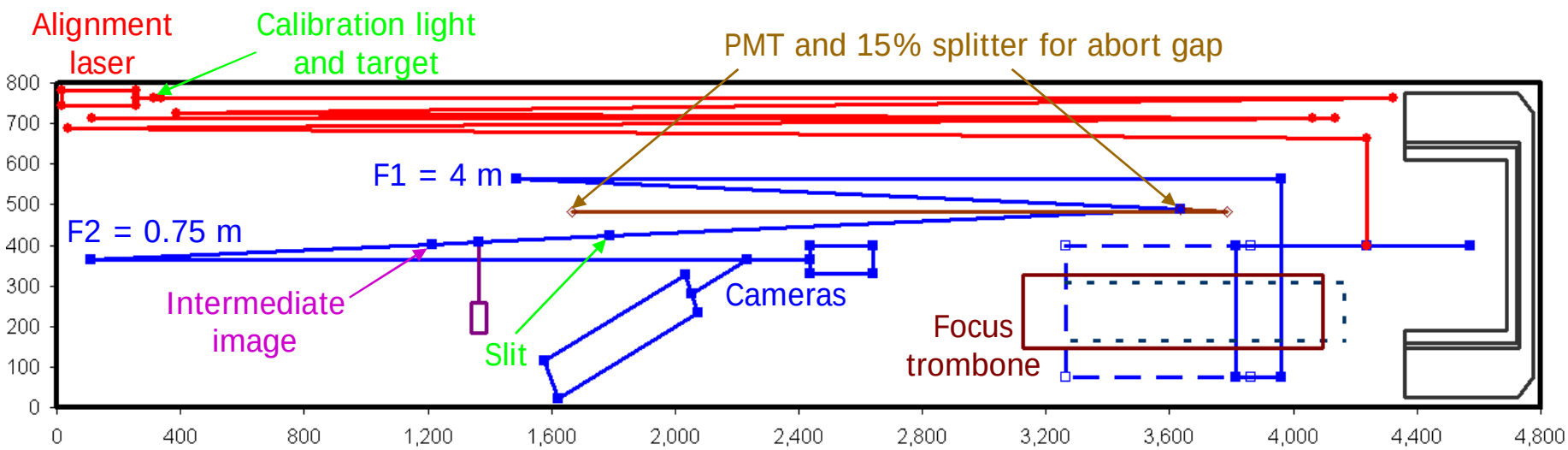
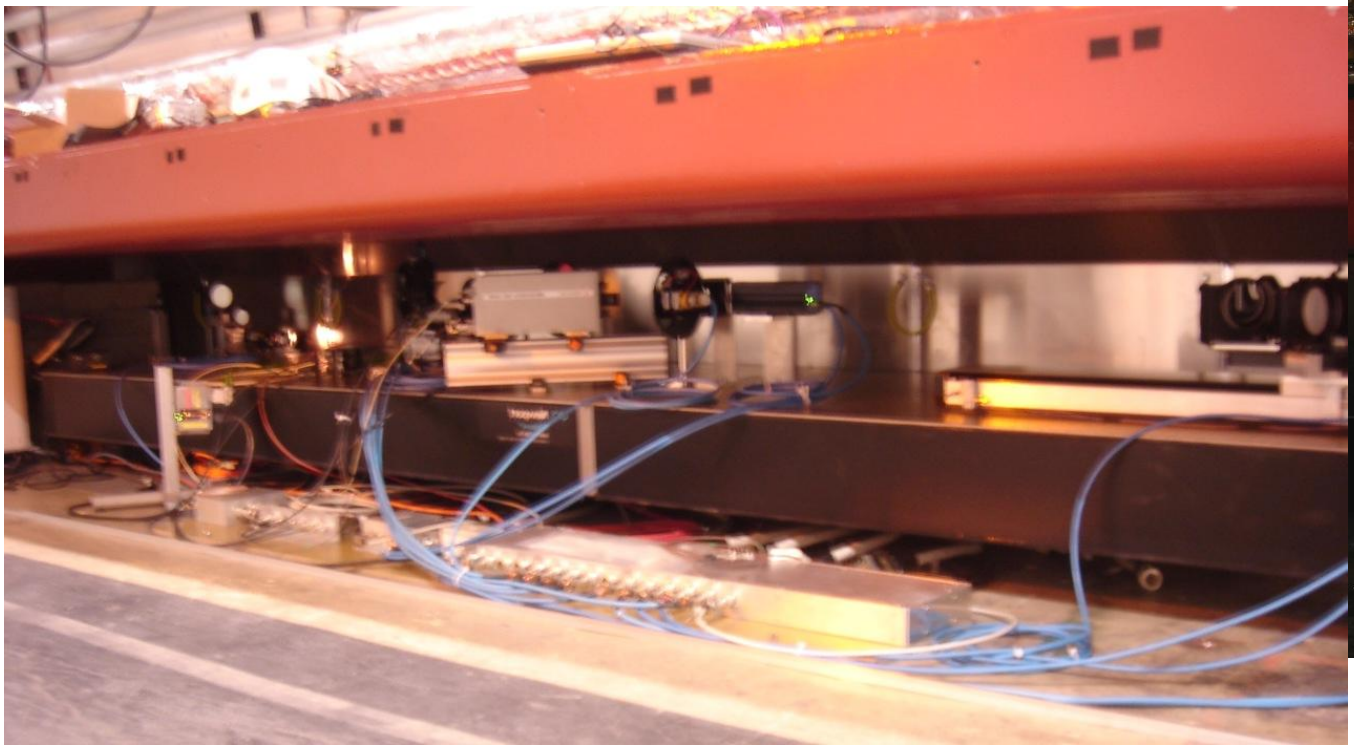
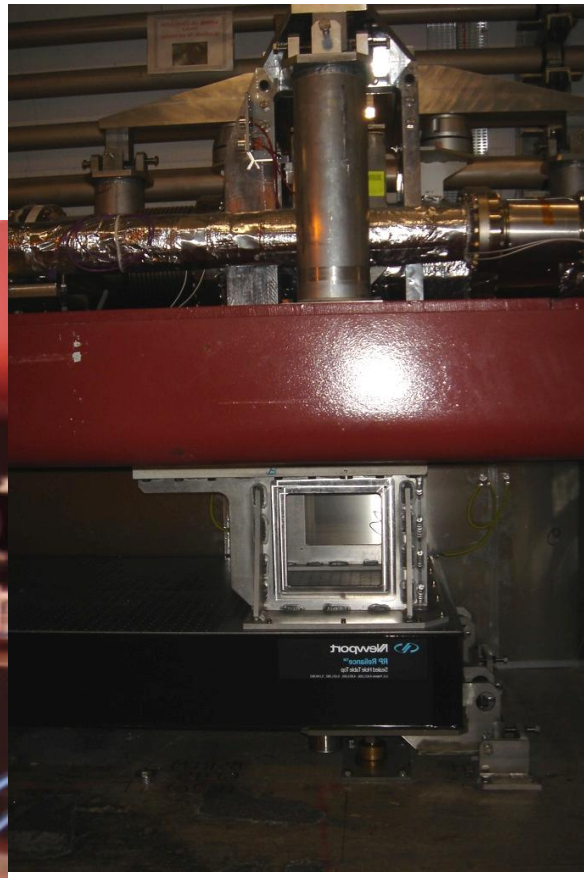


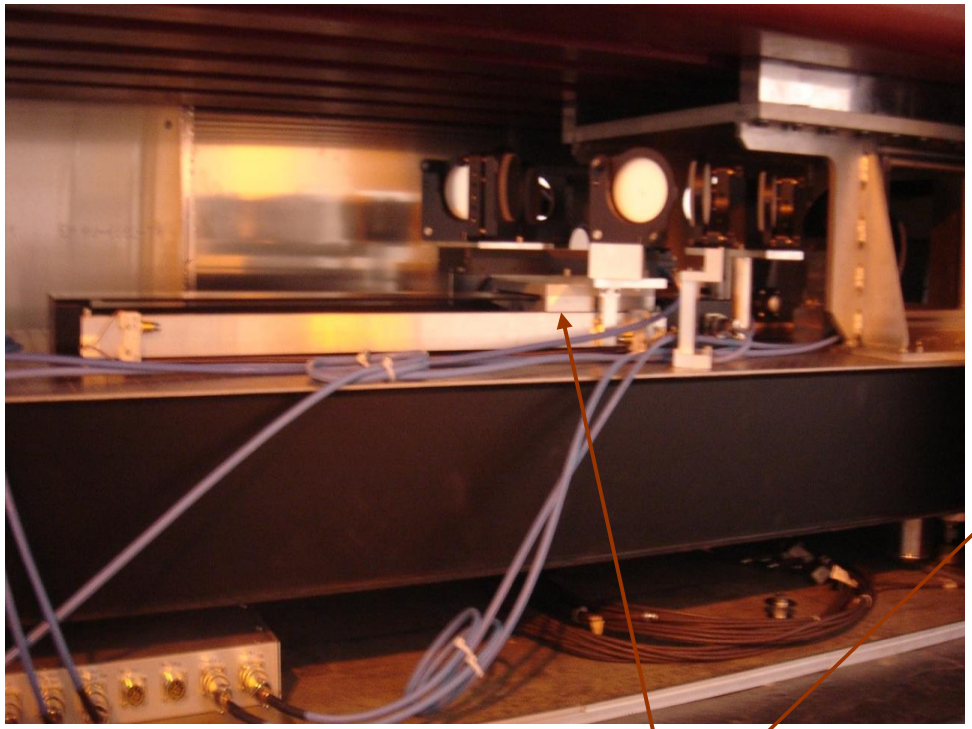
Table Coordinates [mm]

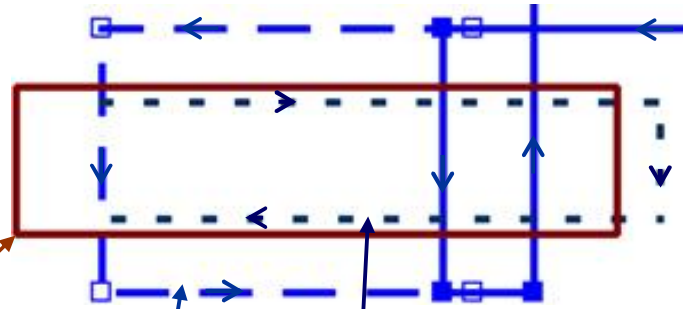
New Table Installed under Beamline





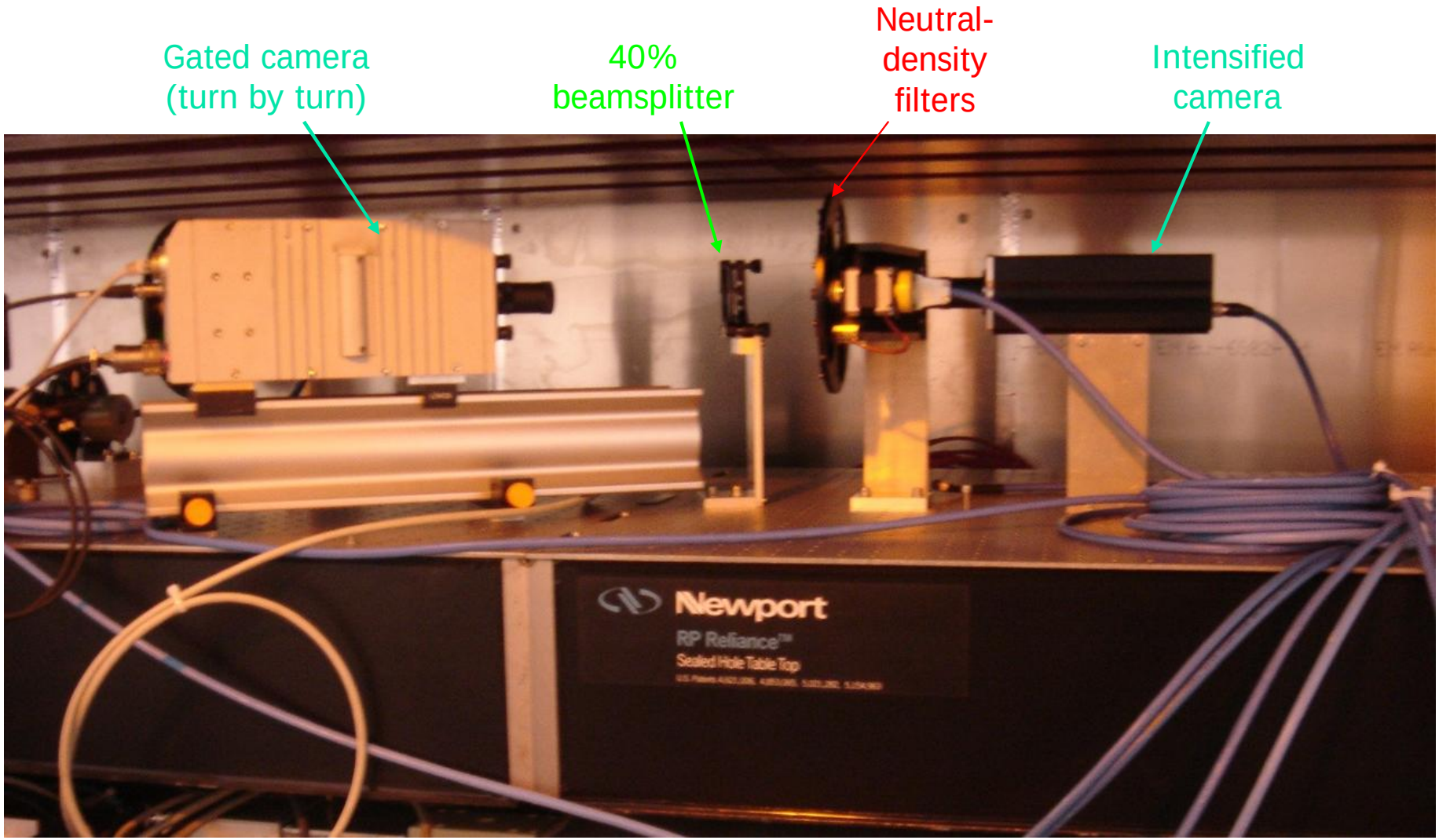
4-Pass Focus Trombone



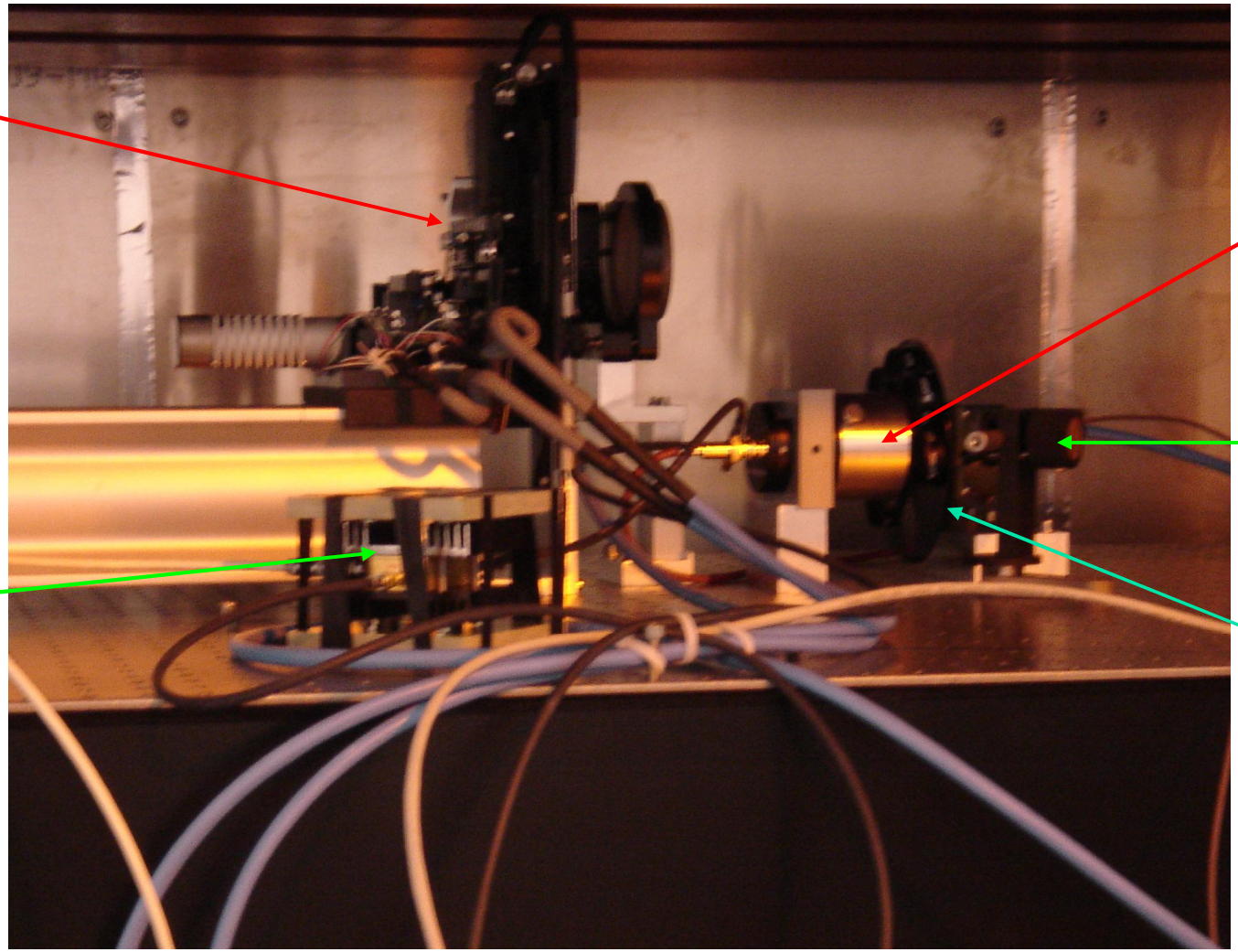


- 600-mm translation stage
  - Outer trombone: 2 passes gives a 1200-mm range.
  - Inserting 2 mirrors converts trombone to 4 passes.
    - With a fixed extra path, the 4-pass mode spans 600 to 3000 mm.

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?