Concepts for IR Absorber Luminosity Instrumentation

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Why instrument the IR absorbers ?

- The objective for instrumentation of the IR absorbers is to provide LHC machine operations with a simple, reliable, dedicated device for maximizing luminosity for all operating scenarios

A team has been assembled to address IR absorber instrumentation issues:

- application to storage ring operation
- beam-beam interaction
- detector physics
- radiation effects
- signal processing and data acquisition
- hardware design

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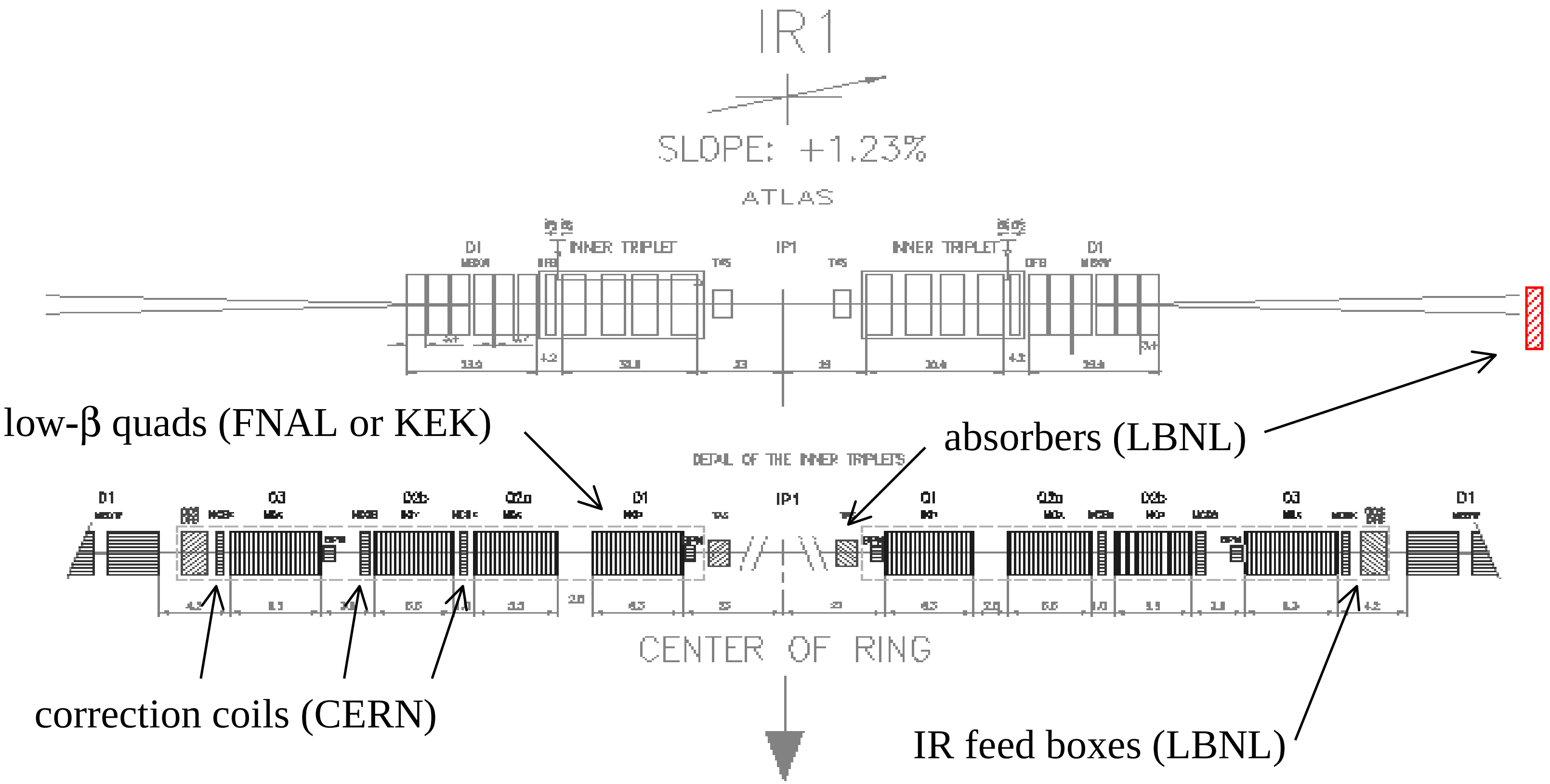
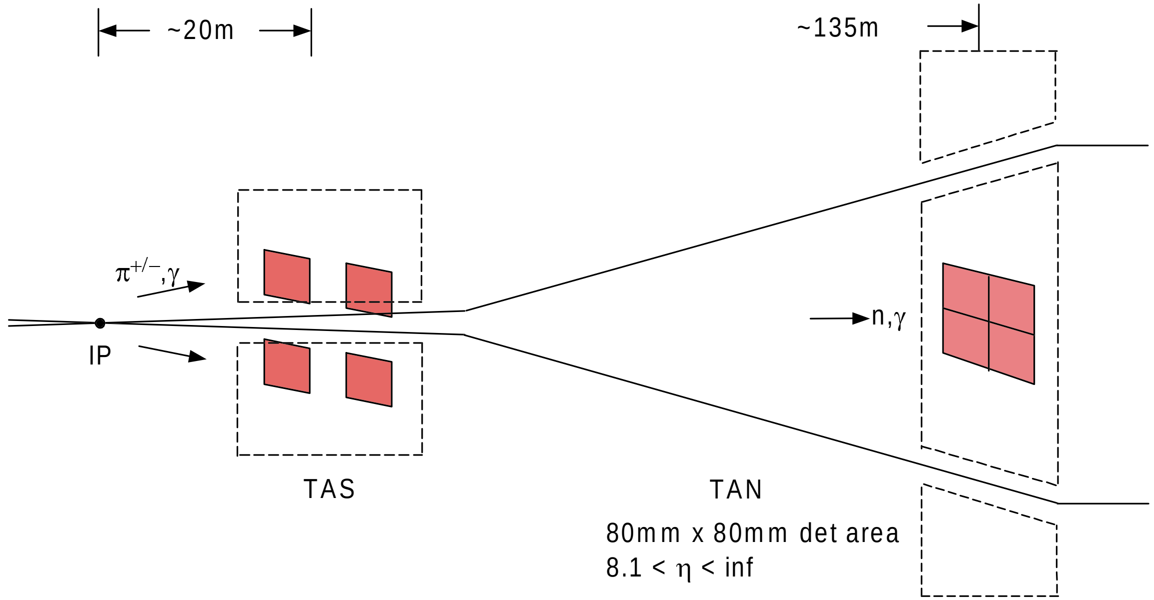
Schematic of components in IP1(5), v6.0

- Luminosity instrumentation would be located in the front quadrupole (TAS) and neutral particle (TAN) absorbers



Schematic of TAN and TAS instrumentation

- Fast gas ionization sampling chambers are located near the shower maxima inside the absorbers to take advantage of ;
  - multiplication of the collected charge due to shower production and gas ionization
  - increased sensitivity to the most energetic IP collision fragments, shielding from soft particles
  - negligible impact on lattice space



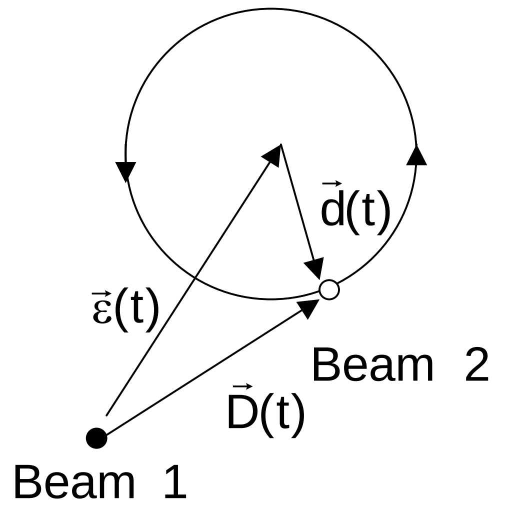
What can be measured with absorber instrumentation?

1. Luminosity
2. Beam-beam separation
3. RMS beam size
4. Beam-beam crossing angle
5. Transverse position of the IP

- Bunch by bunch measurements are feasible
- Measurement of beam-beam separation can be used in feed-back to bring the beams into collision and optimize L
- Items 1. to 3. can be accomplished with TAN only single element detectors
- Items 4. and 5. require segmenting the detectors into quadrants and instrumenting the TAS and TAN

- An intentional transverse sweep of one beam introduces a time dependent modulation of luminosity
  - $\boldsymbol{\varepsilon}$ = error offset amplitude
  - d = intentional sweep amplitude

$$L \approx L_0 - L_0 \frac{\varepsilon d}{2\sigma_*^2}\cos(\omega t - \varphi);\ \varepsilon, d << \sigma_*$$



- Define the detector current

$$I(t) = e\alpha\varepsilon_{\det} m\sigma_{inel} L$$

- Integrate to obtain the luminosity and error offset, 0 < *t* < *T*, $T = n\dfrac{2\pi}{\omega}$

$$L_0 = \frac{\int_0^T I(t)dt}{e\alpha\varepsilon_{det} m\sigma_{inel} T};\qquad \vec{\varepsilon} = -\frac{\hat{e}_x \int_0^T \cos(\omega t) I(t)dt + \hat{e}_y \int_0^T \sin(\omega t) I(t)dt}{\left(\dfrac{d}{4\sigma_*^2}\right) e\alpha\varepsilon_{\det} m\sigma_{inel} T}$$

- Integration times are sufficiently short to be practical even for the lowest luminosity envisioned (TOTEM)
  - Bunch by bunch measurements increase the integration times by the number of bunches (x2835 for L = 10^{34}, x236 for TOTEM)
  - The practical sweep frequency needed for beam-beam separation measurements (1 Hz ?) will determine the integration time at the highest luminosity

		Integration time(sec/turns)		
L $cm^{-2}s^{-1}$	$\frac{\sigma_L}{L} = 0.01$	$\sigma_\varepsilon = 0.1\sigma_*$	$\sigma_\psi = 1\mu rad$	$\sigma_{a_x^*} = \sigma_*$
10^{34}	$6.2\text{x}10^{-5}$/ 0.7	$1.0\text{x}10^{-3}$/ 11	$2.55\text{x}10^{-4}$/ 2.9	$3.8\text{x}10^{-3}$/ 42.6
10^{28}	62/ $7.0\text{x}10^{5}$	$1.0\text{x}10^{3}$/ $1.1\text{x}10^{7}$	$2.55\text{x}10^{2}$/ $2.9\text{x}10^{6}$	$3.8\text{x}10^{3}$/ $4.26\text{x}10^{7}$

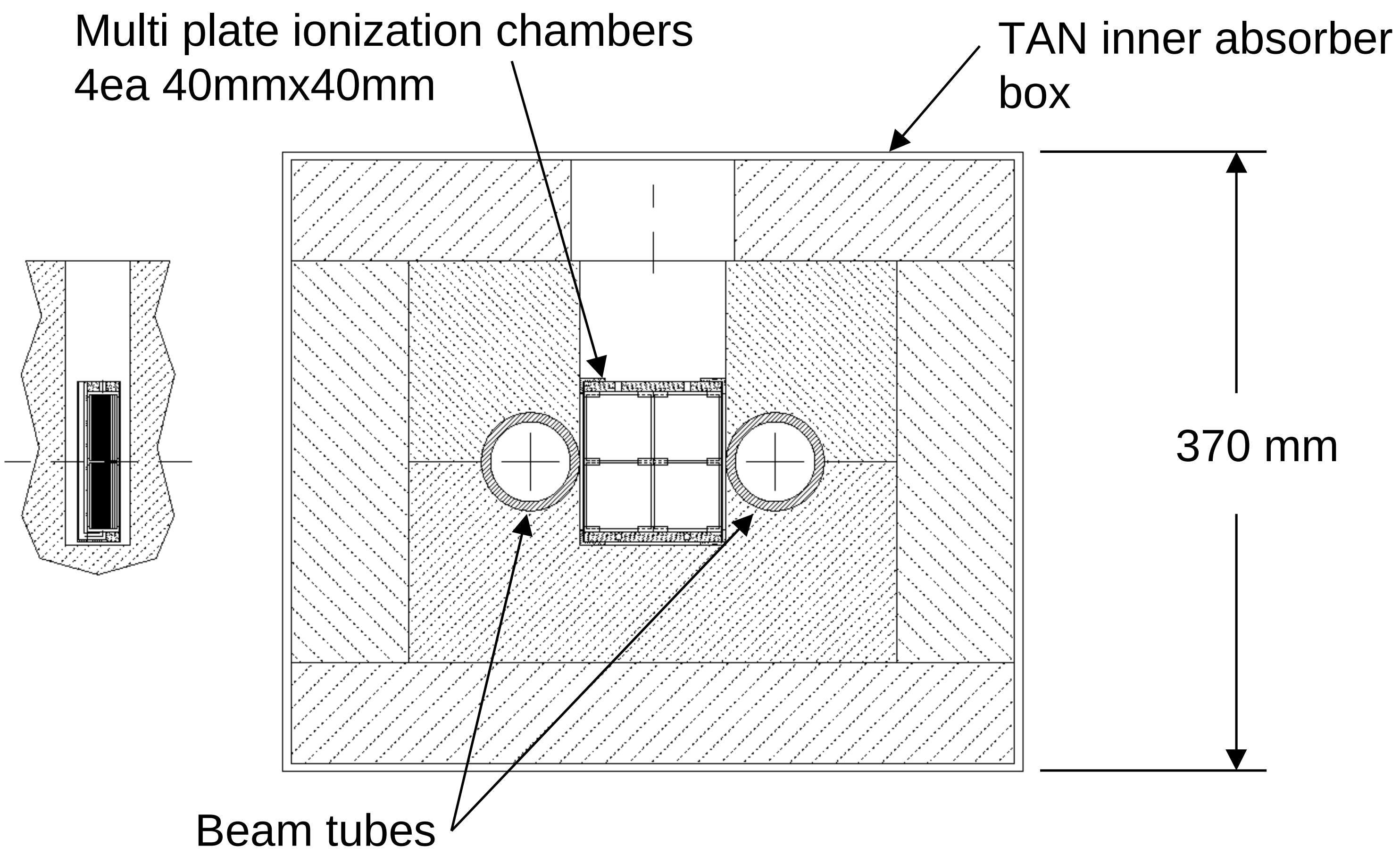
Bringing the beams into initial collision

- One approach - start with a coarse grid map with successively finer mesh followed by application of the beam sweeping method with successively smaller radii
- An extreme example - TOTEM, L = $10^{28}cm^{-2}s^{-1}$

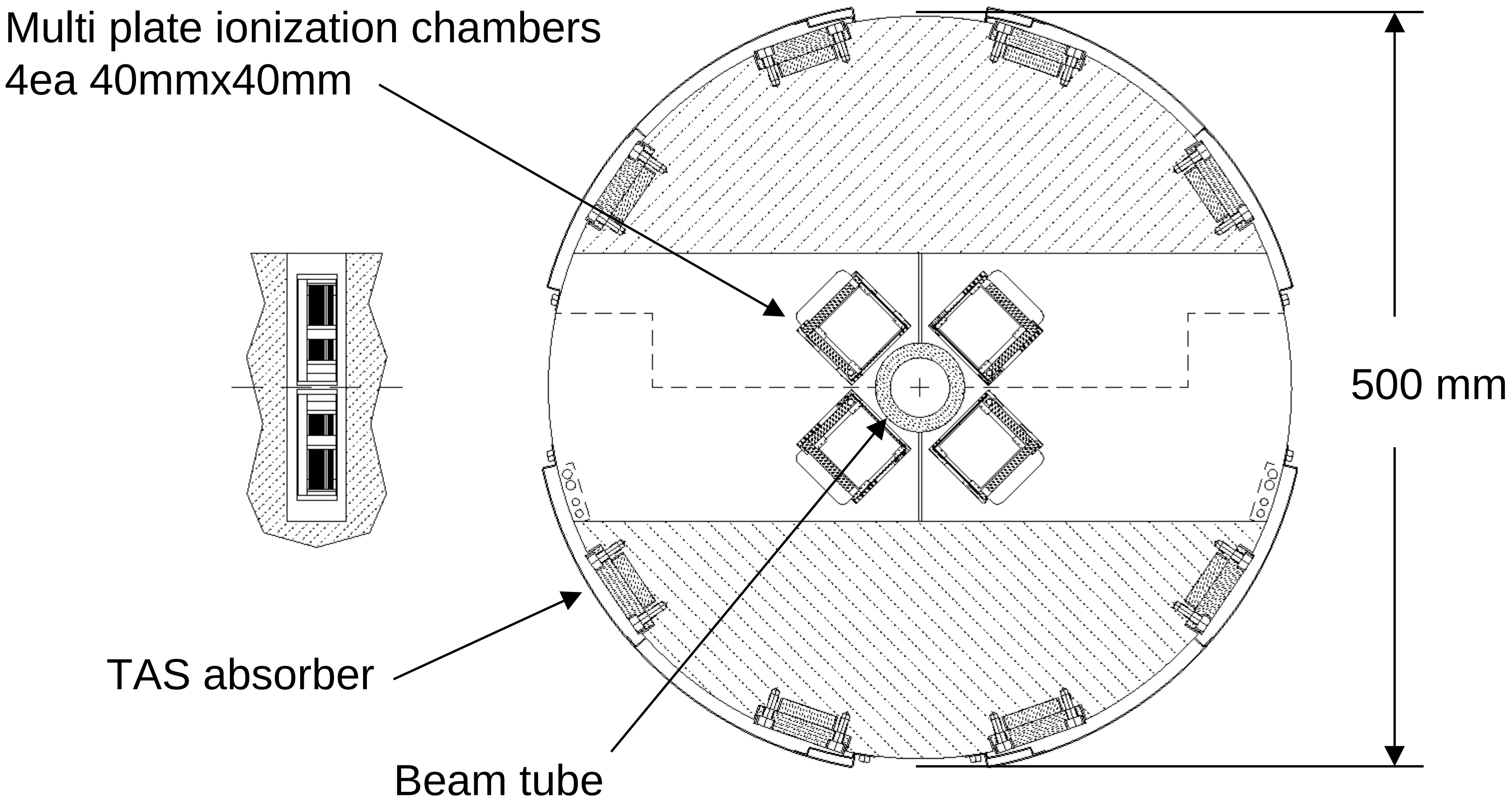
Domain	Grid size	$\delta L/L$	Integration time (sec)
$\pm 4\sigma \times \pm 4\sigma$	2σ	10%	15.5
$\pm 2\sigma \times \pm 2\sigma$	1σ	5%	62.5
Sweep radius		σ_ε	
1σ	NA	1σ	10
$.5\sigma$	NA	$.5\sigma$	40
$.2\sigma$	NA	$.2\sigma$	250
$.1\sigma$	NA	$.1\sigma$	1000

- Total integration time allowing for two iterations of each beam sweep = approximately 45 min

Layout of TAN ionization chamber



Layout of TAS ionization chamber



Parameters for an ionization chamber module:

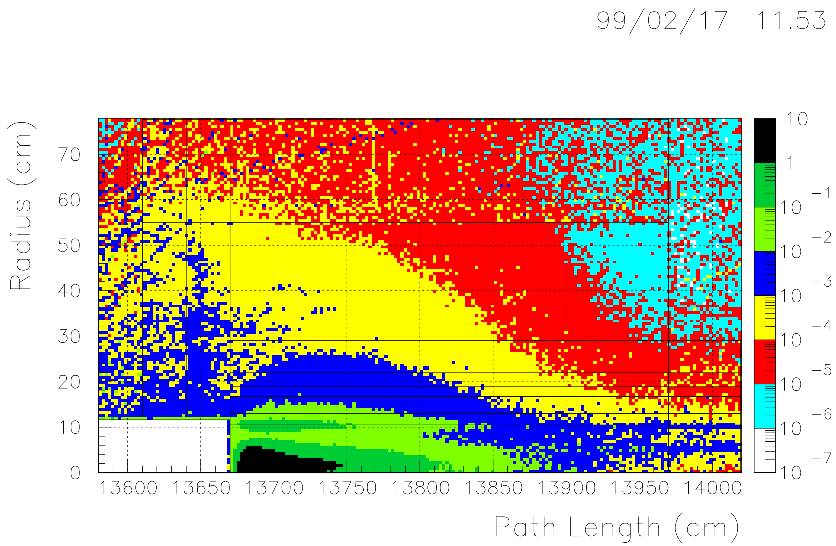
Active area(1 quadrant)	40mm x 40mm	
Plate gap	0.5 mm	
No. of gaps	12	
Capacitance/gap	28.3 pF	
Gas	$Ar+N_2$(1%), 760 Torr	
Elec gap transit time	21.7 nsec	
Bunch freq/Rev freq	40.079 MHz/11.2455 kHz	
Bunch structure	12x(3x81+2x8+38) = 3,564	
Inel pp int/bunch xing@10^{34}	20	
mip per pp int	268	
mip per bunch xing@10^{34}	$5.35x10^3$	
Electron/ion pairs/cm-mip	97	
Ioniz e^-/pp int	$1.3x10^3$(1 gap)	$1.56x10^4$(12 gaps)
Ioniz e^-/bunch xing@ 10^{34}	$2.6x10^4$(1 gap)	$3.1x10^5$(12 gaps)

Dynamic range

- The magnitude of charge collected in a single pp interaction is adequate for pulse shaping, digitizing and acquisition (see companion presentation by Datte and Manfredi)
- If the data are accumulated bunch by bunch, the dynamic range needed for front end electronics is a factor of ~ 40 to cover luminosity from an arbitrarily low value up to 10^{34} $cm^{2}sec^{-1}$ bb
- The dynamic range increases linearly with the bunch accumulation factor

- Radiation deposition and activation have been studied in great detail with the MARS code
  - power density ~ 3 W/kgm at ionization chambers
  - power density < 10^{-5} W/kgm at front end electronics located on the outer radius and at the back of the TAN
- Although the ionization chambers become activated there do not seem to be difficulties with induced radiation background or radiation damage to sensitive electronics

TAN power deposition (mW/gm)



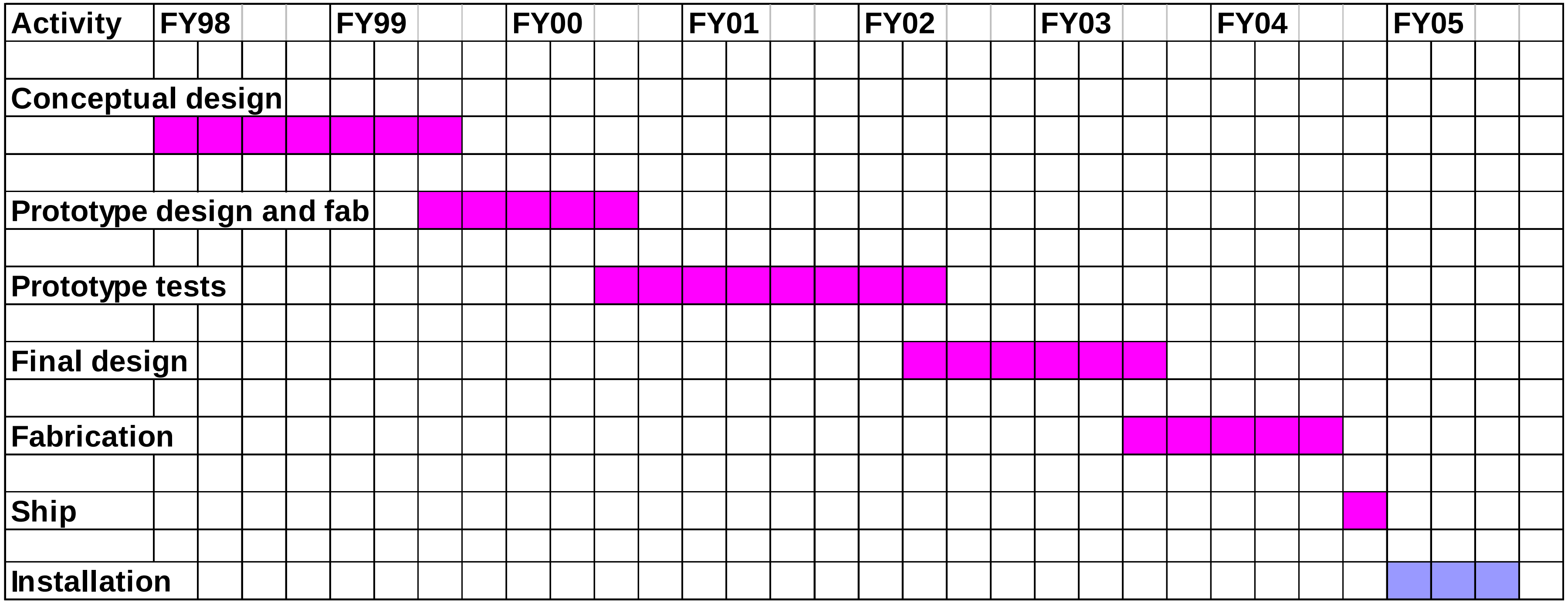
Backgrounds

- Backgrounds and systematic effects have been examined due to
  1. beam gas collisions
  2. beam-halo scraping
  3. drift of the IP position
  4. drift of crossing angle
  5. ac modulation of the crossing angle at the beam sweeping frequency
  6. activation of the Cu absorber and ionization chamber gas
  7. electronic noise
- Items 4. and 5. contributed the largest backgrounds (to luminosity and beam-beam separation respectively)
- In all cases the backgrounds have been estimated to be small compared to the expected signals

Estimated luminosity background rates are small compared to the pp inelastic collision rate

Process	Scaling	Rate(sec-1)
pp inel. collisions	~L	8×10^{8}
beam gas collisions (10^{-10}Torr)	~$L^{1/2}$	3.5×10^{4}
beam halo scraping (1:6,500 cleaning eff)	~L	8×10^{4}
1μm slow drift of IP	~L	8×10^{3}
1μrad slow drift of xing angle	~L	1.2×10^{6}

Preliminary schedule



Options for IR absorber instrumentation

- Instrument TAN only or TAN + TAS
- Instrument IPs 1 and 5 or IPs 1,2,5 and 8
- Single bunch (40 MHz) or multi-bunch bandwidth (~4 MHz)
- Quadrant or single element ionization chambers

Summary

- Instrumentation of the IR absorbers is a potentially useful beam operations tool for optimizing luminosity

- Gas ionization chambers are practical radiation hard devices that can be engineered for high reliability

- Operational characteristics can be validated under LHC like conditions in an SPS test beam with 25 nsec bunched protons (H4 beamline)