Sources of Background at the LHC (Background 101)

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LHC – Sources of Background

- Make distinction between:
  - Ultra Fast Losses – nasty
  - Operational losses during machine cycle
  - Background….

- Background
  - Experiments on, disturbed (trigger, occupancy) by…
  - products of the secondary cascades, caused by proton losses upstream and downstream of the experiment
  - Wide range of spatial orgins for secondaries

Loss Mechanisms

- Abnormal (Fast & Ultra fast loss)
  - Equipment malfunction etc.
    - Injection: wrongly set empty machine, pre-fires
    - Beam dump: Abort gap, Pre-fires
    - Fast trips: warm magnets e.g D1 trip
  - Aim to catch most of it on protection devices
    - TDI, TCDQ, TCLI, Collimators
    - Vital to have rigourously set-up machine with all protection deviecs correctly set – note importance of collimation system in this regard
- Short lifetimes
  - Beam instabilities, resonances
  - Parameter control challenges (persistent currents etc.)
    - Chromaticity, Tune, Energy, Orbit, Operator, Collimation

Minimum beam lifetimes

Mode	T [s]	τ [h]	R_{loss} [p/s]	P_{loss} [kW]
Injection	continuous	1.0	0.8×10^{11}	6
	10	0.1	8.6×10^{11}	63
Ramp	≈ 1	0.006	1.6×10^{13}	1200
Top energy	continuous	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

Nominal cycle – hot spots

Injection	Losses at injection: injection oscillations, RF capture
Injection plateau	Big beams, lower dynamic aperture, full buckets, un-captured beam, long range beam-beam, crossing angles, persistent current decay Won't be pretty. 10 hours lifetime will be good
Start ramp	Un-captured beam lost immediately we start the ramp (~5% total) Snapback: chromaticity, tunes all over the place
Ramp	Things should calm down, assume 10 hour lifetime
Squeeze	Tunes, chromaticity, collimator, TCDQ adjustments – expect some lifetime dips
Collide	Beam finding, background optimization (?)
Physics	Collisions, beam-gas, halo production etc.
Adjust	Squeezing IR2, roman pot adjustment
Dump	Should be squeaky clean, very occasion pre-fire…

Operational Cycle

Phase	Loss	Destination
Injection	2% transverse	IR7 collimators, TDI
	1% longitudinal	IR3 collimators
Injection plateau	20 minutes - 10 hour lifetime	IR7 collimators mainly
Start ramp – out of bucket flash	~5% beam (max!)	IR3 collimators
Start ramp - snapback	1 minute – 1 hour lifetime	IR7 collimators
Ramp	20 minutes – 10 hr lifetime	Ring, collimators
Squeeze	10 minutes – 1 hour lifetime 2*10 s dips to 0.2 hr lifetime	IR7 collimators

Loss Mechanisms – Steady State

- Stable beam
  - Transverse
    - Beam gas
    - Collisions
    - Halo production:
      - Nonlinearities, Long range beam-beam, Electron cloud, Intra Beam Scattering, ground motion, power supply ripple…
    - Electon capture by pair production
  - Longitudinal
    - Touschek
    - RF noise
    - Intra Beam Scattering
  - Synchrotron radiation damping
    - reasonably significant effect at 7 TeV
    - ~ counters IBS and beam-beam

In General

- Particles can be:
  - Kicked gently and stay within beam
  - Kicked to large betatron or momentum amplitude
    - scattering, collimation
    - lost on physical or dynamic aperture
  - Scattered directly out of the aperture
  - Annilation
  - Pushed slowly to large betatron or momentum amplitude
    - Diffusion or Emittance growth – various means
    - On to collimation system

Our three main ways of doing these:

- beam-gas
- collisions
- collimation

Beam Gas

→ mostly H, C, O from H_2, CO, CO_2, CH_4 , H_2O

- **Elastic**
  - Scattered at point-like Coulomb field of the nucleus of the residual gas atom
  - Particle transversely deflected, increasing it's betatron amplitude.
  - Also elastic scattering from the electrons - negligible
- **Multiple Coulomb scattering**
  - Emittance growth at injection
  - Negligible effect at 7 TeV
- **Inelastic**
  - Nuclear interaction: 7 TeV proton beam on a fixed target
  - Fragments lost within 10 -15 metres
- **Diffractive**
  - Pomeron exchange, Δp

Beam Gas

Cross-sections

Incident proton energy [GeV]	Centre of mass energy [GeV]	σ_{pp}^{tot}	σ_{pp}^{el}	σ_{pp}^{SD}
7000	114.6	~46.9 mb	~8 mb	~5.2 mb
450	29.1	~40 mb	~7 mb	~3.3 mb

Given a beam-gas lifetime, e.g. $\tau_{gas} \approx 100$ hours, can assign losses proportionally

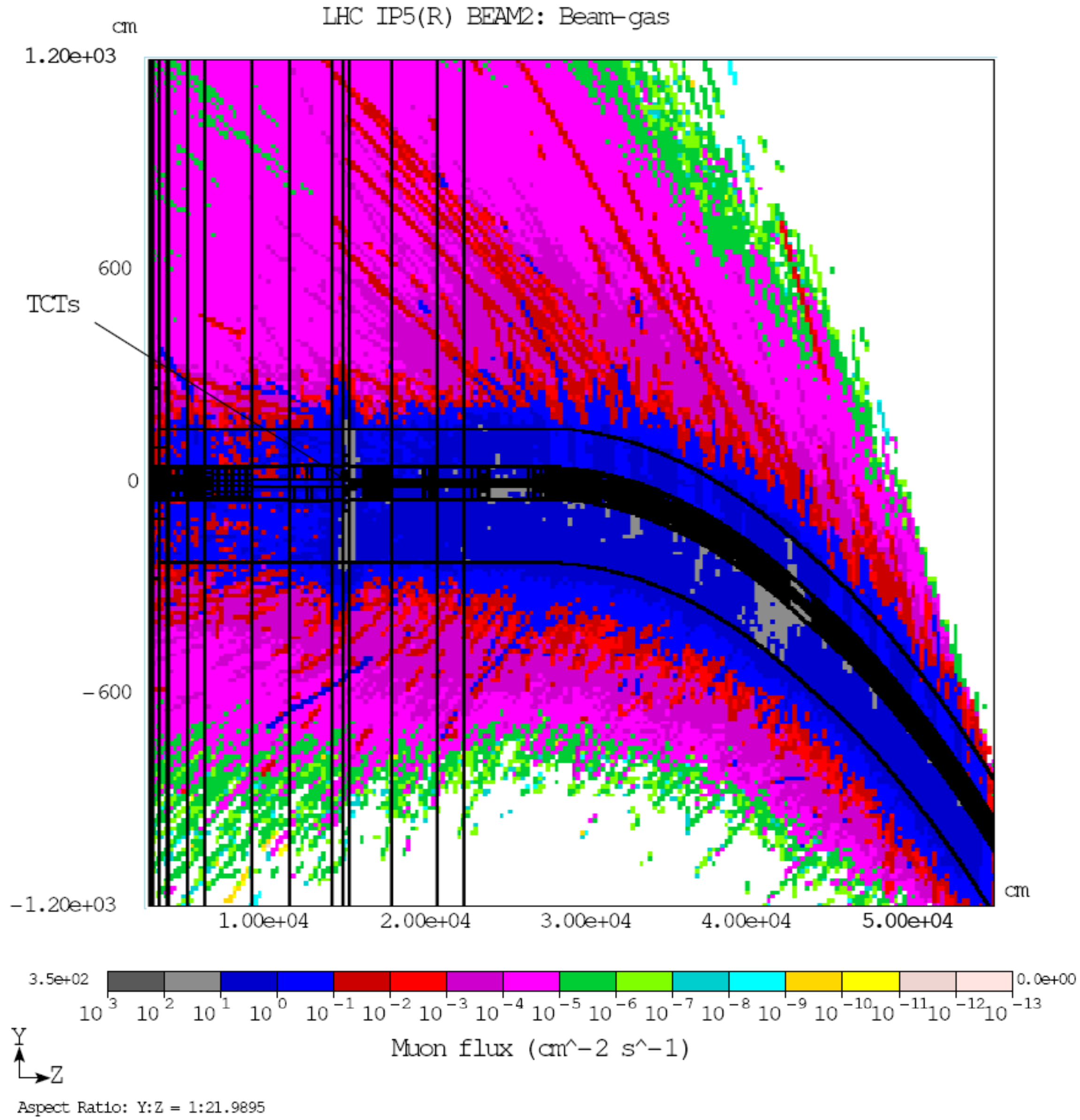
Inelastic:

Local losses (dominates) within 10s of metres of interaction

Elastic:

1. **small angle scattering: < 6 σ** particle stays within beam – emittance growth
2. **mid-range: 6 σ – 24 σ** populate halo to be lost on next aperture restriction – collimators, experiment's IRs, TCDQ etc.
3. **large: lost locally**

Beam-Gas



N.V. Mokhov

Beam Gas – Arcs - Elastic

$$\frac{d\sigma}{dt} = ae^{-b(t,s,A)|t|}$$

$$\sqrt{\langle \theta^2 \rangle} = \frac{1}{p\sqrt{b}}$$

COM 4.7 mrad ✸ ~40 μrad Lab

- **<β> of around 110 m**
- **7 TeV – large arc aperture – 24 σ**
- **Roughly 70% of the scattered protons might be expected to stay within the aperture – will be transported to next IR and any aperture restriction.**

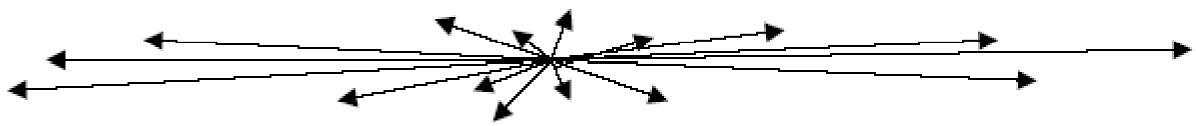
Background

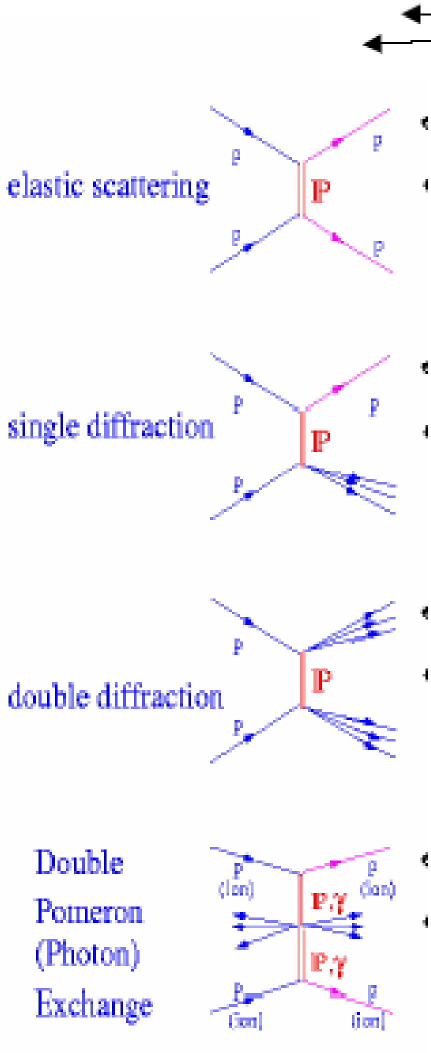
Beam Gas as background source

IP +/- 23 m	Inelastic	beam loss rate in the detector regions depends linearly on the gas pressure
LSS 23 to 270 m	Inelastic	Hadron & Muons Only particles outside outer shielding radius reach IR1 directly
Adjacent arcs	Elastic	Scattered protons caught on tertiary collimators.
		Depends on residual gas pressure in cold ares – potentially large contribution.

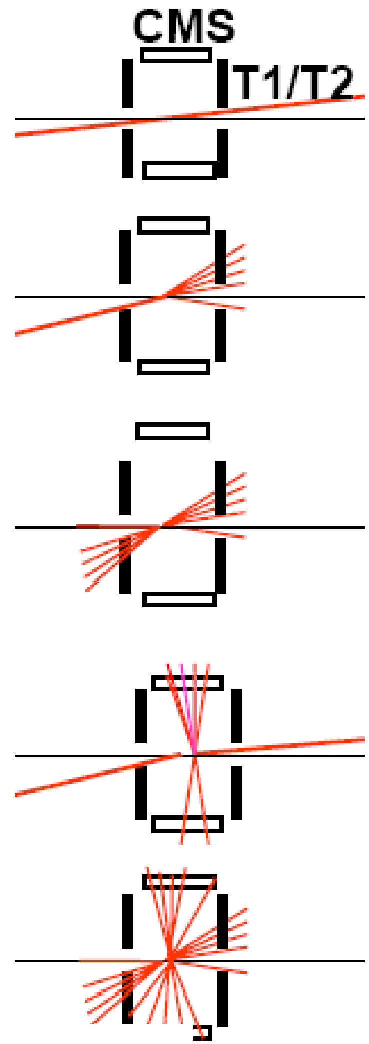
Clearly directly dependent on vacuum conditions at relevant locations

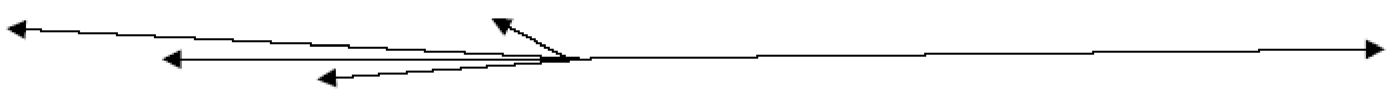
Collisions





- Total cross-section 110 mbarns
  - Inelastic
  - Single diffractive – low t
  - Single diffractive – higher t
  - Elastic
- SD & elastic come barreling down the beam pipe, along with some inelastic debris





Collisions

Collision	Cross-section	Destination	τ_N [hours]
Inelastic	~60 mbarn	IRs [triplet, D1, TAN, TAS]	108
Single diffractive	~2.4 mbarn	Dispersion Suppressors in IR $[\delta p,min(0.01) < \delta p < \delta p,max(0.25)]$	2700
Single diffractive	~9.6 mbarn	Momentum Cleaning - check	674
Elastic	~40 mbarn	ε blow-up	See later

Collisions - Inelastic

- Essentially the Experiments problem/opportunity

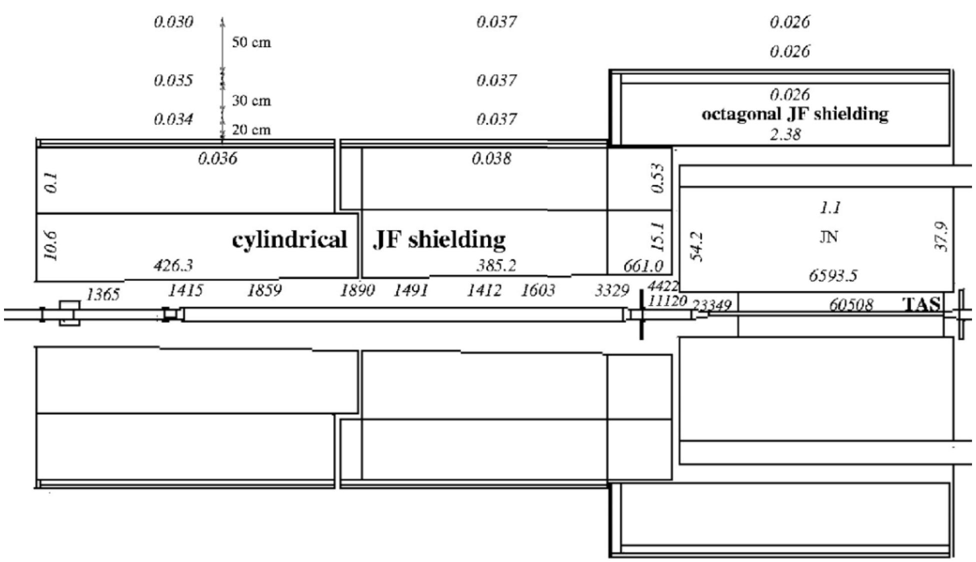
- E.g. Neutrons fly around the ATLAS cavern for a few seconds until they are thermalised, thus producing a kind of permanent neutron-photon “bath” resulting in a steady rate of Compton electron and spallation protons, which are observed in the muon system.

- This component, i.e. additional hits created by long living particles, is called "cavern background".

- Neutrals also come barreling down the beam pipe to be mopped up by the TAN

JF & TAS

- The JF shielding and TAS are placed behind the end-cap toroids close to the end of the experimental hall.
- The length of the front part of the JF shielding is 6.5 m and its distance from the interaction point is ~13 m.
- The JF shielding protects the muon spectrometer chambers against neutrons and photons, which are mainly produced in the copper collimators and surrounding material nearby the vacuum beam pipe



Very effective in catching hadron component of BG

Some muons make it through

Collisions - Elastic

Emittance Growth

$$\frac{d\sigma}{dt} = ae^{-b(t,s,A)|t|} \longrightarrow \sqrt{\langle \theta^2 \rangle} = \frac{1}{p\sqrt{b}} \longrightarrow \left(\frac{d\varepsilon}{dt}\right) = \frac{\left(\beta^*_{1x} L_1 + \beta^*_{2x} L_2\right) \cdot \sigma_{el} \cdot \langle \theta_x^2 \rangle}{M \cdot N_b}$$

34 μrad

Mostly scattered within beam

→

Emittance growth

87 hours (one degree of freedom)

↓

beam life time of around 310 hours

Higher amplitude elastics from collisions are only going to make it to the next IP (in the first approx).

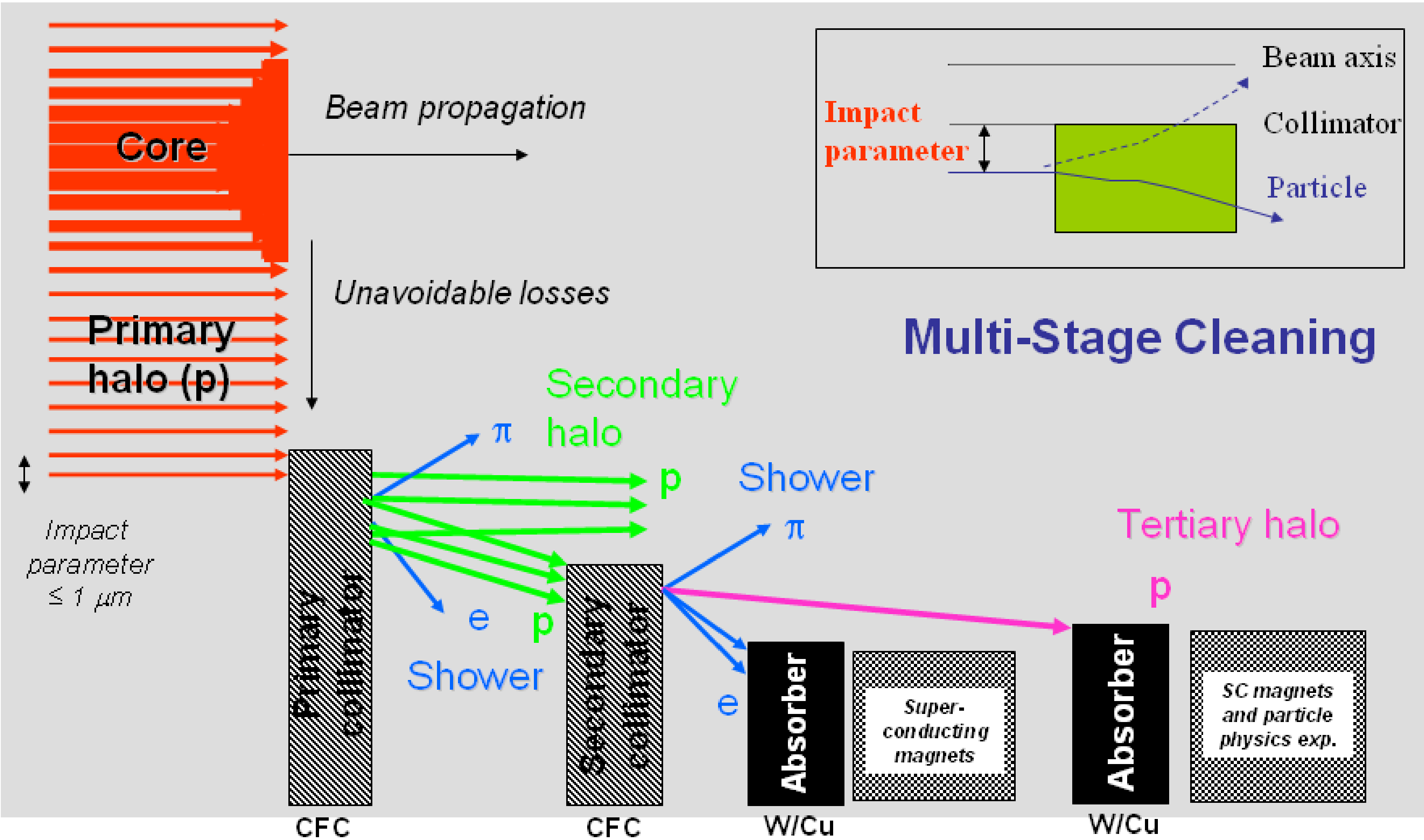
Only relevant for the case of influence of IP1 on the background in the IR2 and 8.

Halo - Emittance growth

	Growth rate[hours] 450 GeV	Growth rate [hours] 7 TeV
Residual gas – multiple Coulomb scattering	~17	≈500
Collisions – elastic scattering	-	87
Transverse IBS	38	80
Longitudinal IBS	30	61
Long range beam-beam		Cuts in above 6σ
Longitudinal emittance damping	-	-13
Transverse emittance damping	-	-26

$$N_b(t) = N_0 e^{-t/\tau_{gas}} \Bigg/ \left[1 + \frac{1}{\tau_N} \frac{1 - e^{-t\left(\frac{1}{\tau_{gas}} + \frac{1}{2\tau_x} + \frac{1}{2\tau_y}\right)}}{\frac{1}{\tau_{gas}} + \frac{1}{2\tau_x} + \frac{1}{2\tau_y}} \right]$$

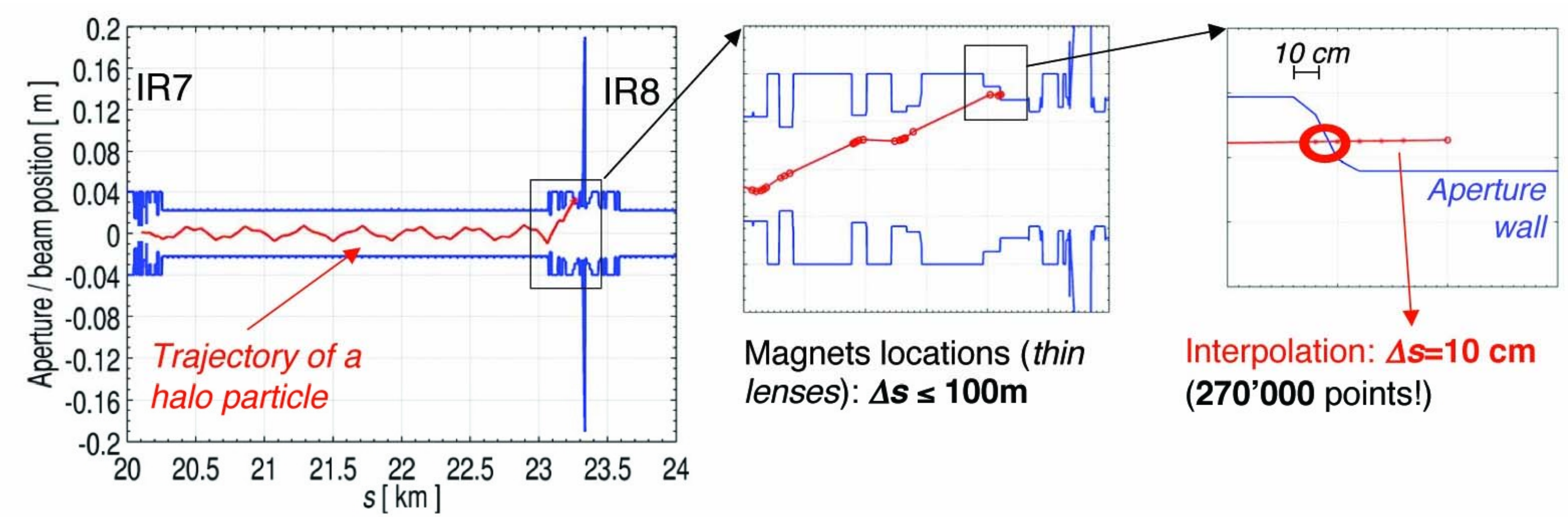
Halo



Ralph Assmann

Collimation

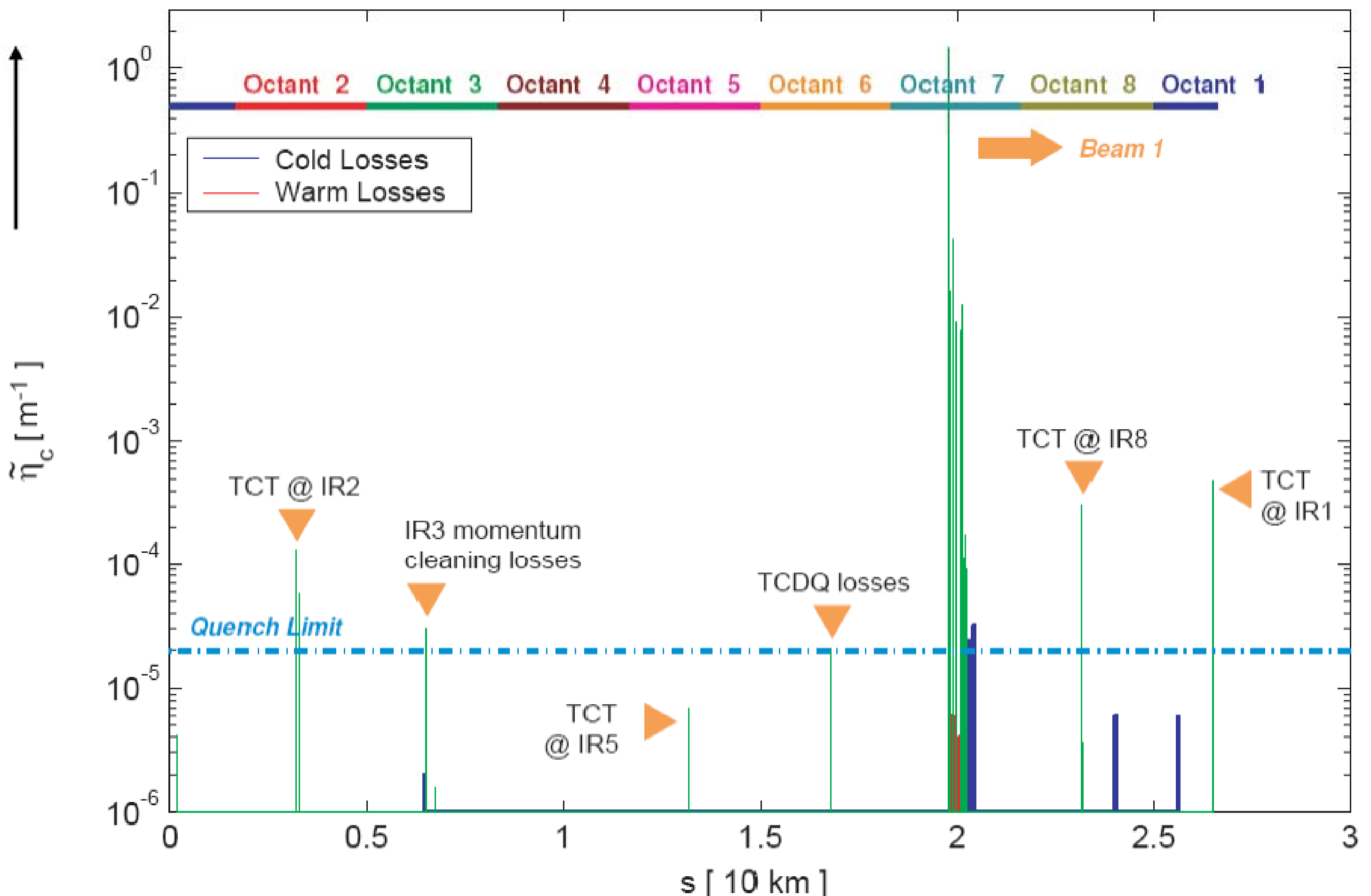
- Collimation system has to mop up a very percentage of particle that make it out to high amplitudes (β, Δp)



Stefano Redaelli

Tertiary Halo

p losses
~ inefficiency



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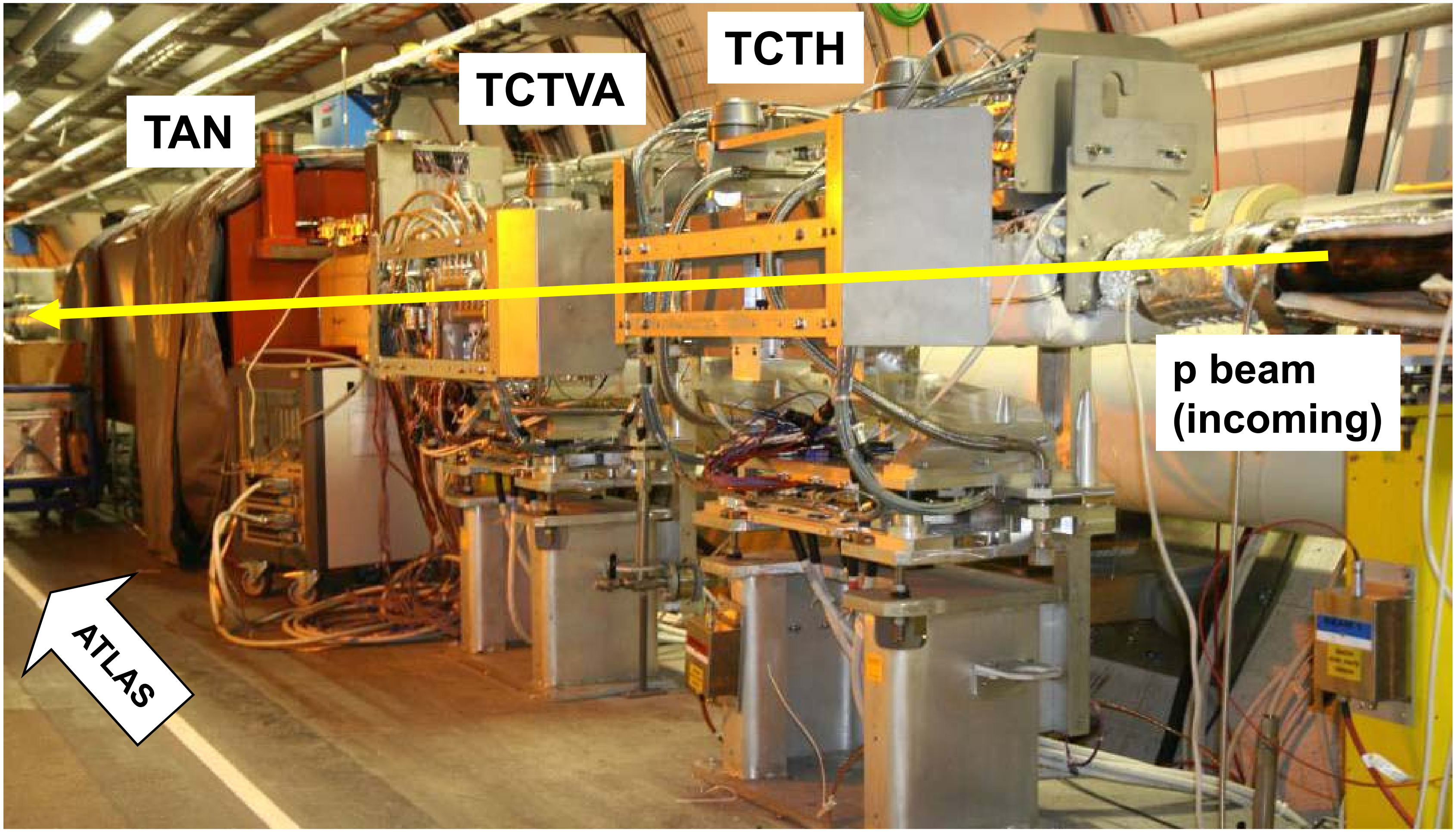
Tertiary Losses

- Betatron halo losses at tertiary collimators
  - (nominal intensity, nominal cleaning efficiency, nominal optics, IR2/8 retracted):
  - 0.05% of the total losses
  - Below ~4e6 p/s in stable physics conditions (20h beam lifetime)
  - Below ~4e8 p/s for "long spikes" (0.2h beam lifetime for up to 10s)

- Plus a contribution from the inefficiency of momentum cleaning in point 3

Ralph Assmann

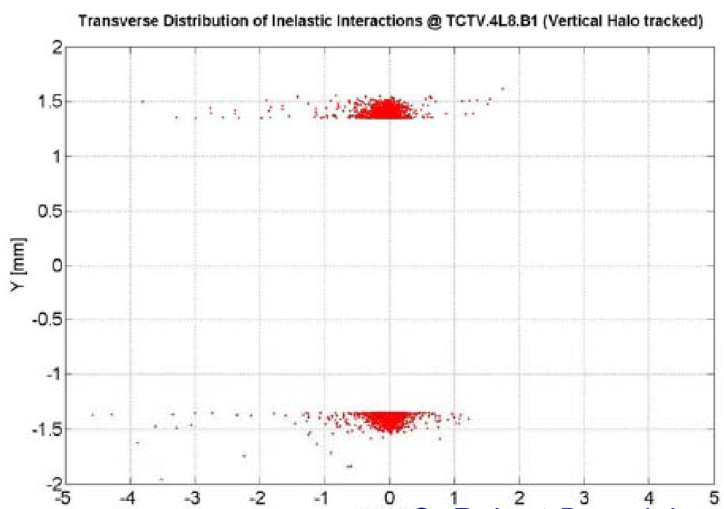
Tertiary collimators



Tertiary collimators

- Tungsten, 1 meter long, incoming beam,
- Stops protons dead
  - Resulting cascades – additional sources of $\pi\pm$ K± - decay into muons in downstream drift (see V. Talanov)
- Nominal setting: 8.4 σ
  - 1 & 5 fully squeezed, crossing angle on. Further out 2 & 8
- Tertiary collimators in close
  - To protect inner triplets – aperture bottleneck
    - From tertiary halo
    - From beam dump mis-fires

Background



G. Robert-Demolaize

Tertiary Collimators - Background

Beam-gas in LSS	BG pushed up somewhat by presence of tertiary collimators
Tertiary halo from collimation system	Direct source of background
Elastically scattered beam-gas from upstream adjacent arc	“The losses on the tertiary collimators from beam-gas scattering in the arcs are potentially the main source of background”
Elastically scattered from collisions	From IP1 to IPs 2 & 8

Conclusions

- A pedagogical summary of LHC background sources has been presented

- Other issues
  - Satellite bunches
  - Pressure bumps
  - Roman pots
  - Optics dependency
  - Commissioning and evolution
  - Optimization
  - Ions

- Lunchtime!