Effects of Machine Background on Experiments

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With special thanks for input, comments & discussions to

ATLAS: N.Ellis, W.Kozanecki & whole ATLAS Background WG

CMS: W.Smith, J.Spalding, N.Mokhov, M.Spiropulu, O.Buchmueller, J.Varela

LHCb: G.Corti

ALICE: A.Morsch

EST/LEA: D.Macina & several people form machine

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Sources of Machine Background

MIB = Any particles that come from beyond z=26m into the cavern
+ beam gas within experiment (usually considered separately)

Source can be divided into 2 components with different characteristics:

(1) inelastic beam-gas in arcs and SS (and UX)

proportional to beam current and residual pressure

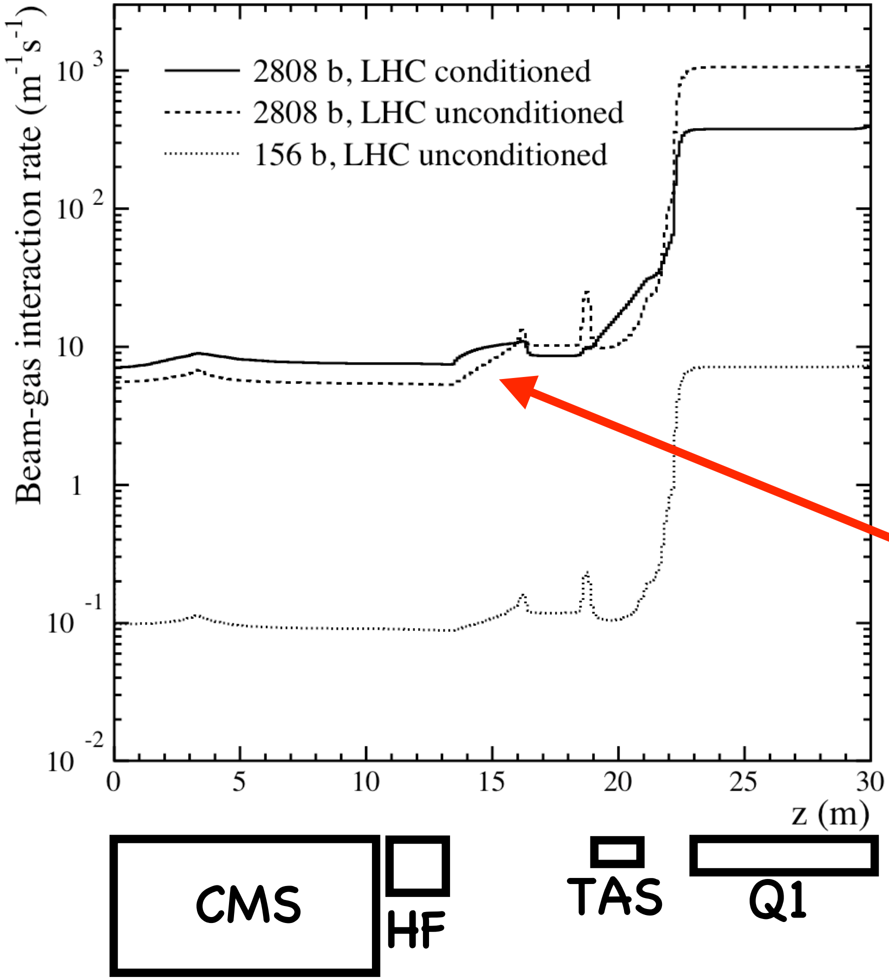
(2) loss of tertiary protons halo at limiting appertures (TCT)

depends on beam current,
cleaning efficiency,
machine optics,
luminosity of other experiments,
(elastic) beam-gas rate etc...

Component of main concern: High-energy muons

Beam Gas in UX

Pressure maps from A.Rossi (LHC Project Report 783, 2004)



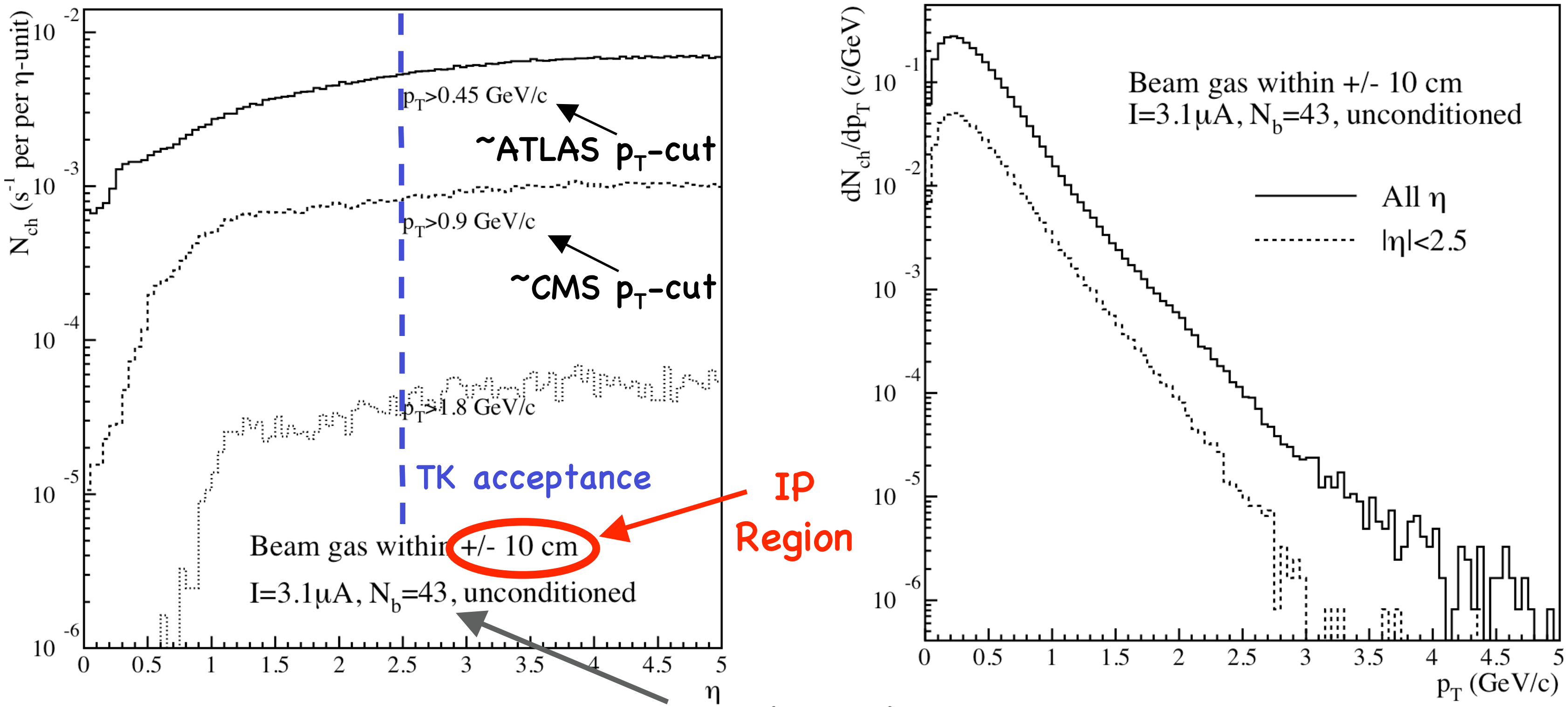
NEG coating of warm sections reduces outgasing and electron cloud buildup

Extremely good vacuum in experiment

About 400 Hz of beam-gas in UX (towards experiment) in nominal LHC

Beam Gas in IP region

Studied in view of early tracker alignment prior to colliding beams
43 bunches, vacuum unconditioned



~startup machine (7 TeV)

p_T-cut = p_T required to reach outer tracker radius ≠ reconstruction cut

Only 4.5 tracks (with p_T>0.9) per hour in TK acceptance

Beam-gas in UX: conclusions

ATLAS, CMS:

If rates are as (low as) predicted:

- Local (e.g. UX) beam gas is unlikely to ever be any issue
- ATLAS study confirms: muons from BG are no trigger issue even at much (>100 times) higher pressure
- Pure beam gas events are likely to be useless for alignment
  - Rate (esp of tracks in acceptance) too low
  - pT-spectrum too soft

ALICE:

- Beam-gas predicted to give ~10% of total dose

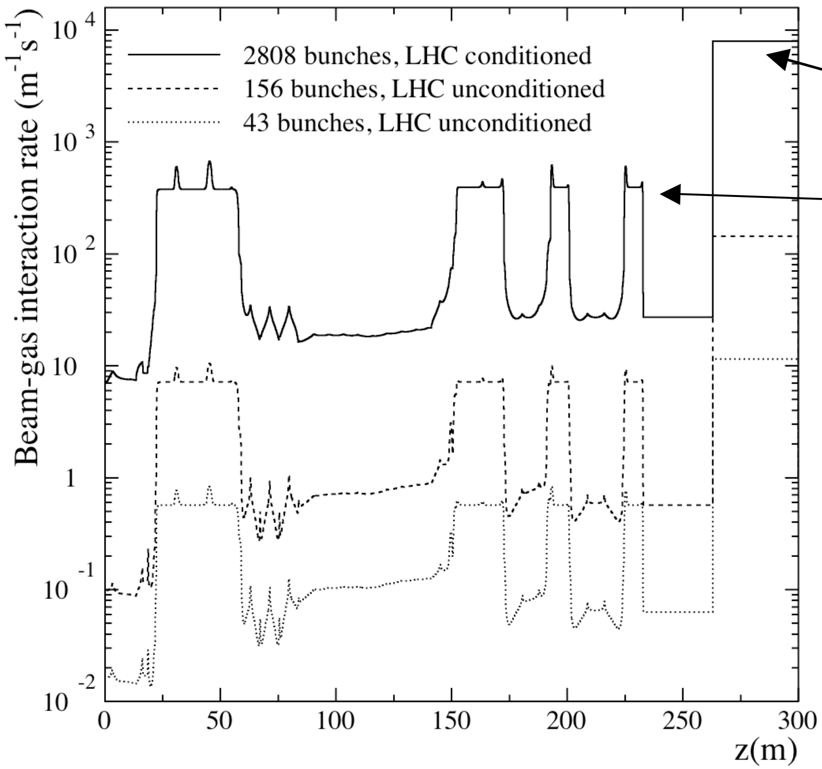
LHCb:

- Beam-gas within VELO, superposed with pp-event, could fake secondary vertex in trigger (but ~negligible rate)

Beam-gas in arcs & LSS

The CMS assumption (Huhtinen, Mokhov 2005):

- Pressure maps from A.Rossi (LHC Project Note 783)
- Pressure in arc set to 20 times that of cold straight sections



Values used in our 1996 study:

2×10^4 in arcs

500 in LSS

I propose to adopt these new pressure maps as standard assumptions (FORTRAN routine sampling interaction point available from MH)

Collimation tails

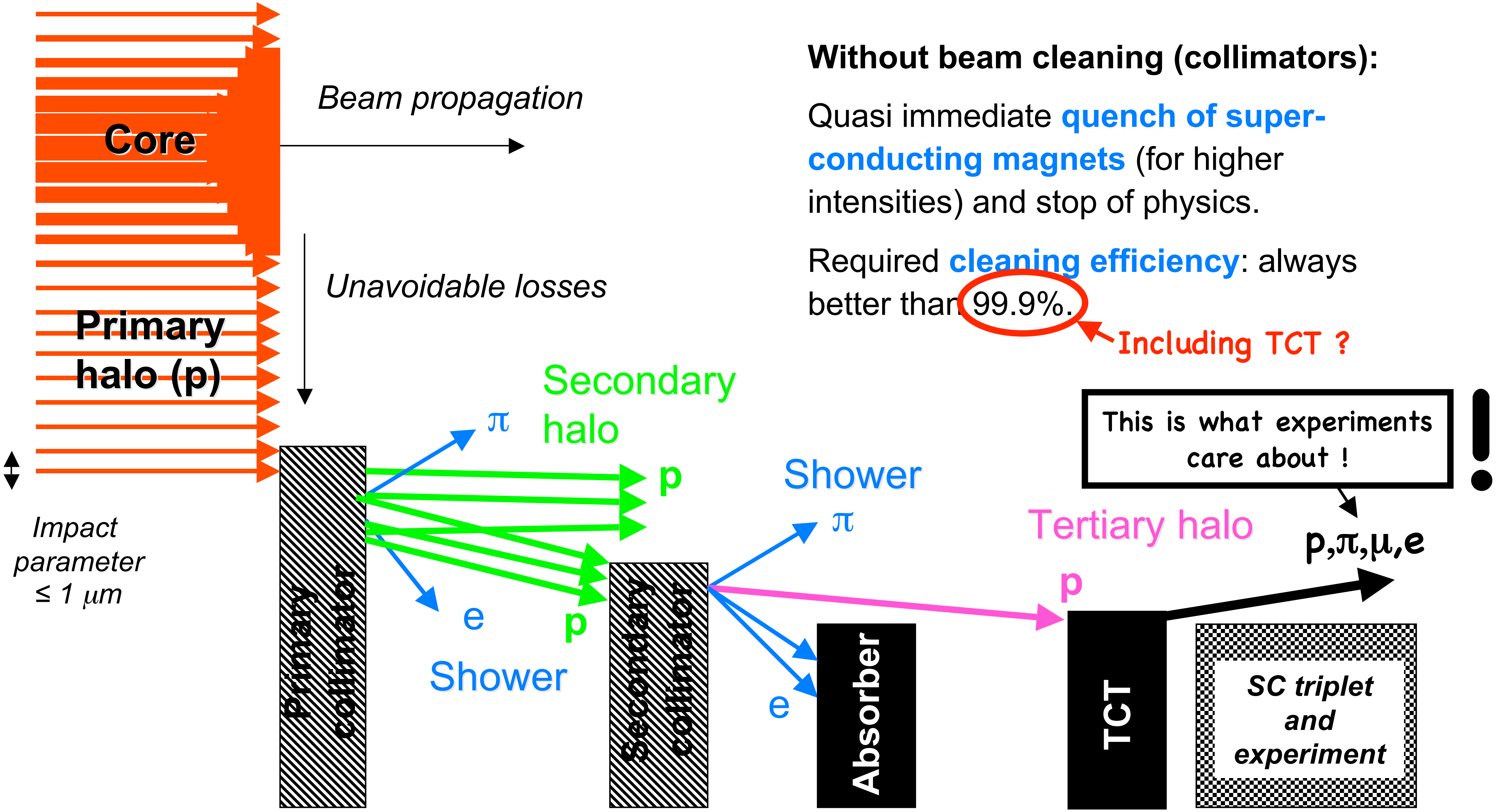
Without beam cleaning (collimators):

Quasi immediate **quench of super-conducting magnets** (for higher intensities) and stop of physics.

Required **cleaning efficiency**: always better than 99.9%.

Including TCT ?

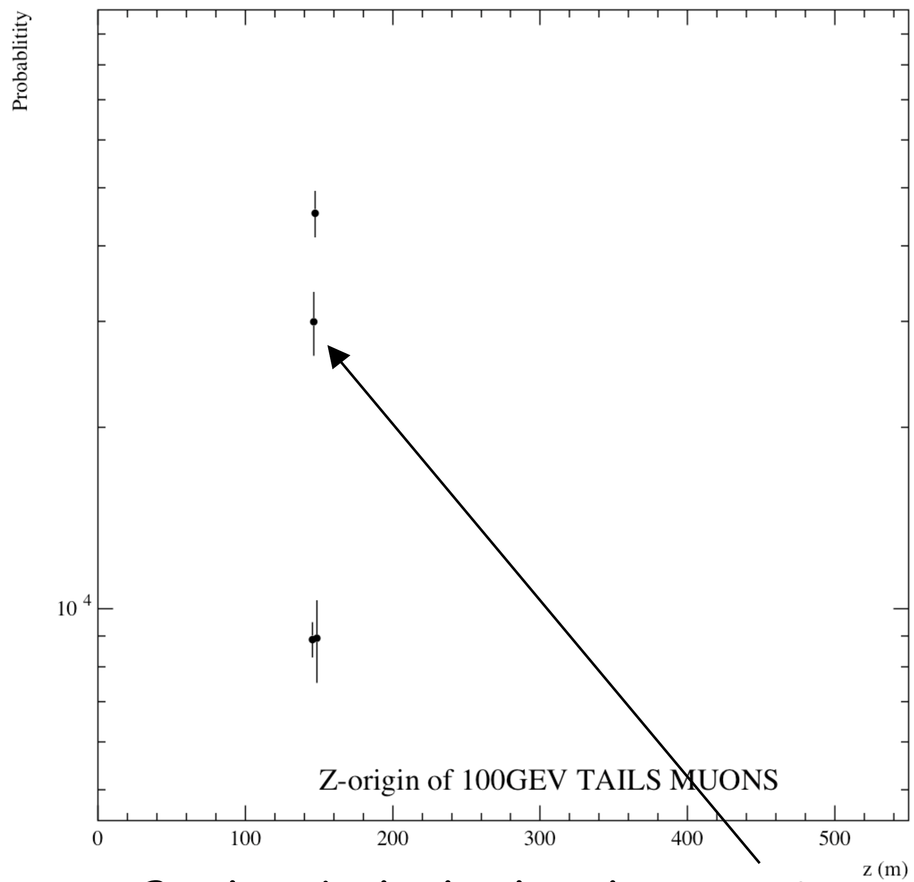
This is what experiments care about !



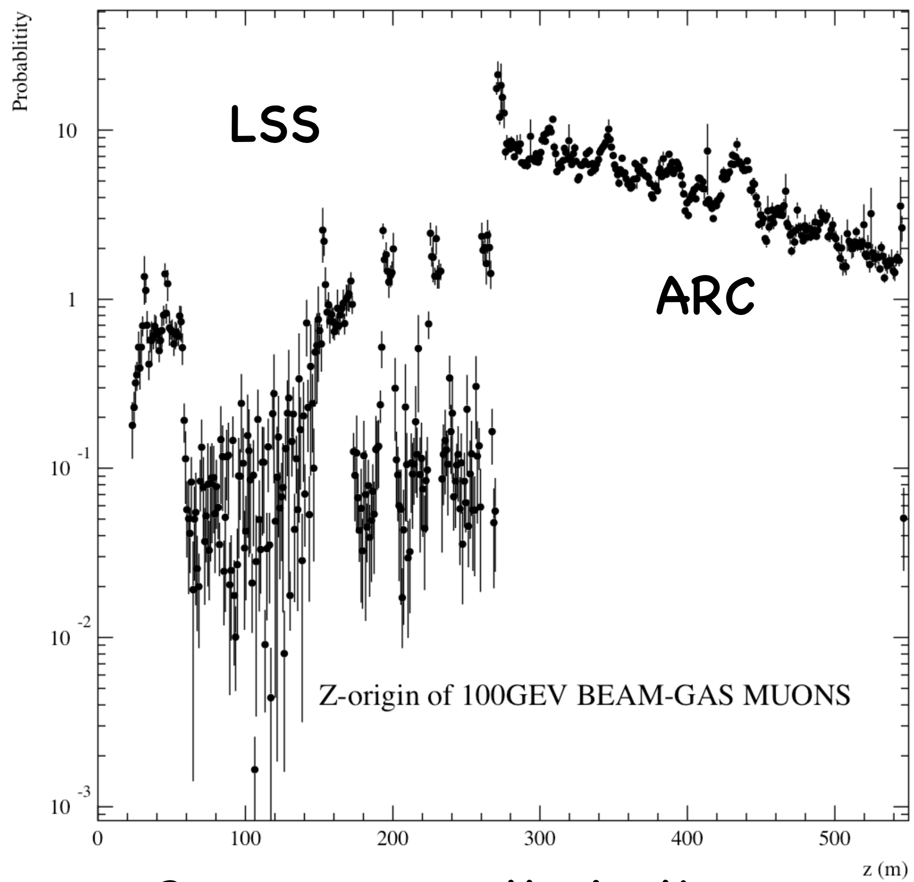
Original by R.Assmann

Origin of muons

Plots show for each muon seen at the 26m plane the z-coordinate where the beam-proton was lost



Proton halo lost only on TCT (at least in this model…)



Beam-gas mostly in the arc (even from beyond 550m)

Based on files provided by N.Mokhov Aug 2007

Tertiary halo losses on TCT

R.Assmann, (MIBWG 15.6.2007):

Losses on TCT 3-5x10^{-4} (of total) on worse side

Loss around ring (for 20h beam-lifetime): 4x10^{9} p/s

About 2x10^{6} protons on ("worse side") TCT in normal operation

Mokhov used in latest IR5 simulations 2.1x10^{6} for TCT (beam 2)

Apparent inconsistency (?):

I.Bayshev (MIBWG 29.9.2006):

9x10^{8} p/s beam-gas around ring of which 1-3x10^{7} p/s on each TCT

This is 1-3x10^{-2} of total, i.e. 2 orders of magnitude larger inefficiency !

➡ Cleaning efficiency only ~98% !!!

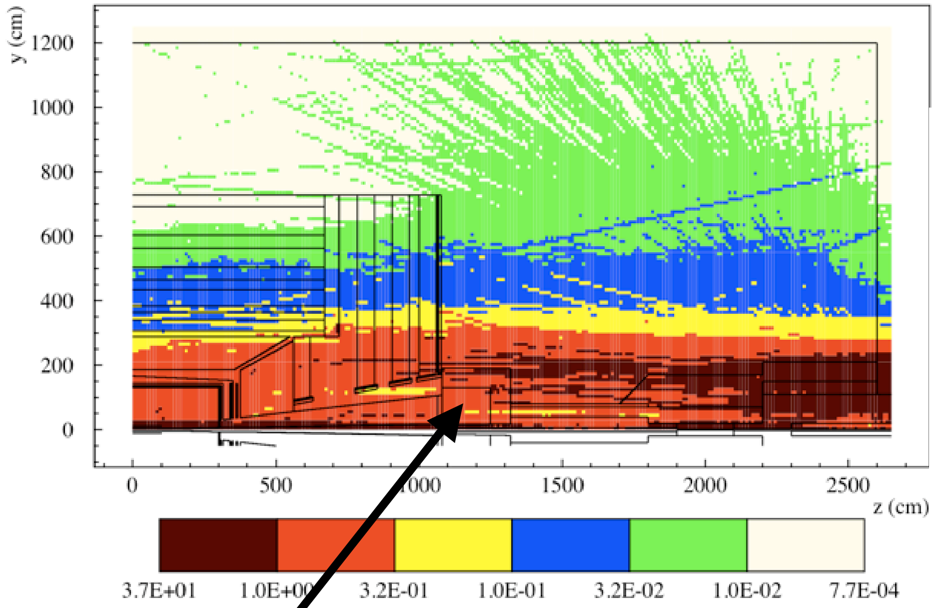
THIS NEEDS TO BE CLARIFIED

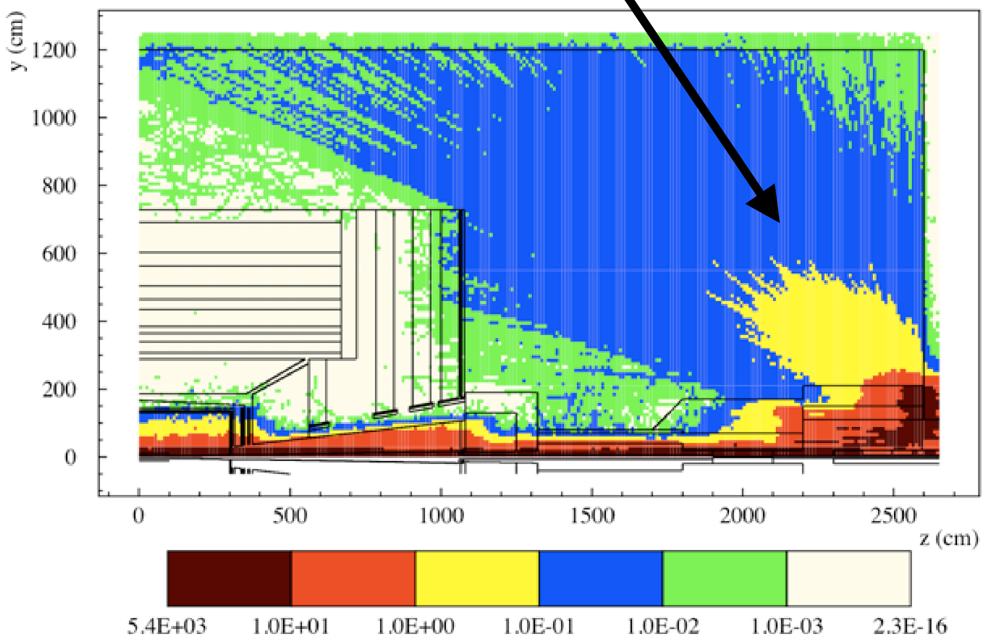
Machine Background Simulations

First complete study in 1996 by Mokhov, Drozhdin and Huhtinen: **NIM A 381 (1996) 531**

Introduced the concept of "interface plane" at ~26m
(here detector simulations can take over from machine)

request to block tunnel entry
(to stop hadron & EM halo)
Request to never have beam
without TAS present





muons not an occupancy issue
-(compared to pp-background @ 1E34)

Shielding of UX-areas

ATLAS & CMS:

- Tunnel Entry blocked by forward shielding
- TAS blocks low-E background near beamline (and should protect against point-like beam losses on detector itself)

We have known since >15 years that we will face unprecedented radiation levels

ALICE:

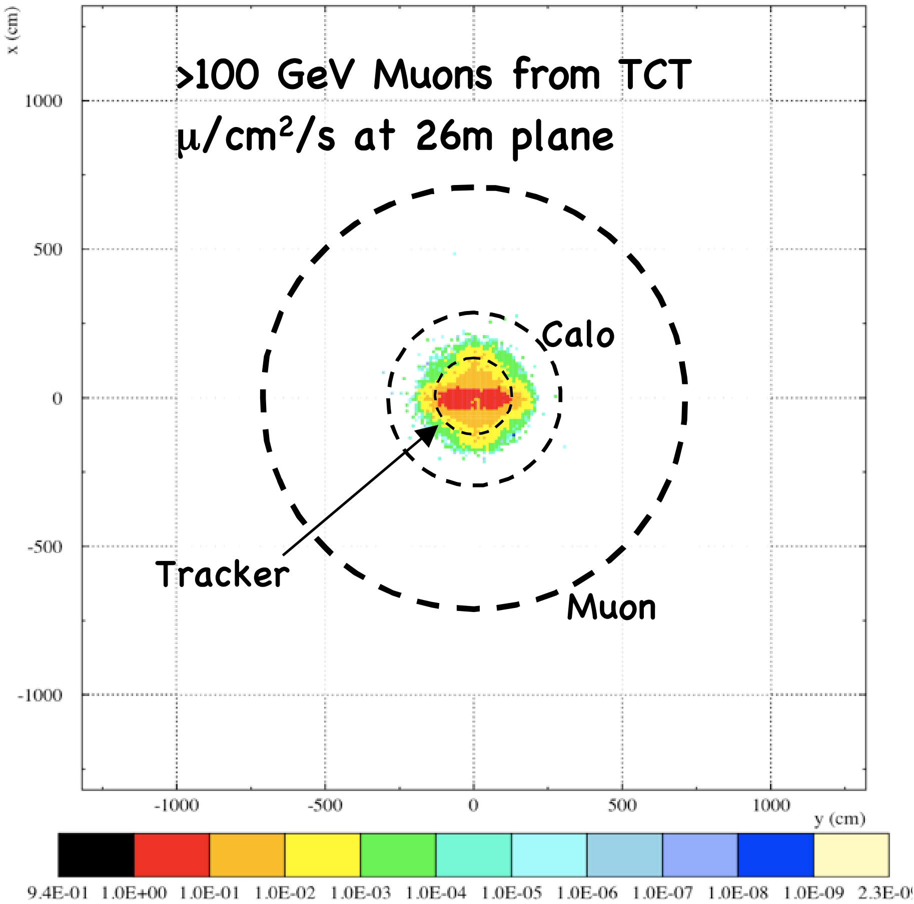
- Tunnel entry only partly covered by shielding
- No TAS

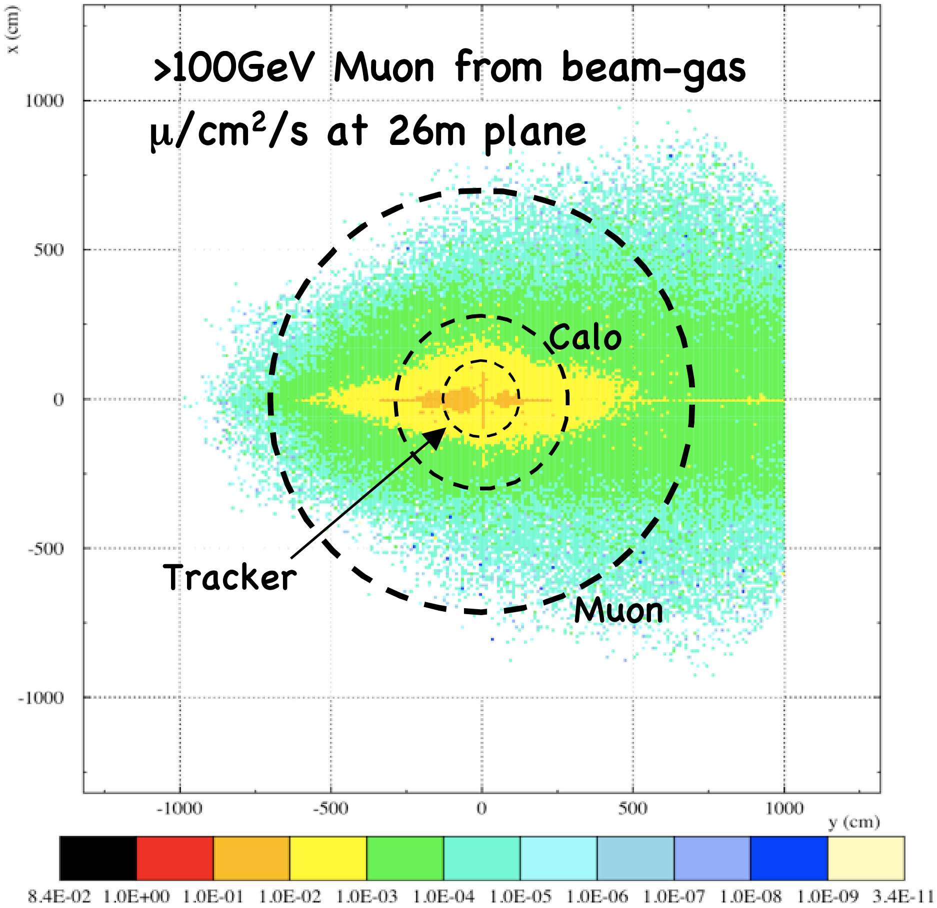
LHCb:

- Shields in tunnel close to velo reduce rates significantly, but have been partially staged
- Shields in tunnel also on "Muon" side
- No TAS

Lower nominal luminosity and weaker forward shielding make ALICE and LHCb more sensitive to MIB than ATLAS/CMS

ϕ-dependence of MIB (Muons)





Based on MARS simulations of N.Mokhov, Aug. 2007

Understood sources & open issues

✓ Inelastic beam-gas in LSS & arcs (*)

✓ Tertiary halo on limiting apertures (TCT) (*)

Q: Elastic in arcs (can it reach TCT on partial turn, see slide 9) ?

Q: Experiment to experiment, e.g. ATLAS -> ALICE ?

Might be an issue due to factor ~3000 in relative pp-luminosity

Q: Spikes in Background:

R.Assmann: could be 100 times above "normal", but when ?
Also during "stable physics" ?

Q: Recent comment from N.Mokhov:

High-E protons scattered by TCT can hit experiment.
This requires a detailed study to quantify effect/risk

(*) NEED CONSISTENT (in terms of input) CALCULATIONS

Cumulative radiation damage

CMS, ATLAS (L_{pp}=1E34):

Designed to survive ~5E16 pp-interactions, e.g. cold Si etc ← !

Over same time, expect ~1E8s * 2E6 p/s = 2E14 p on TCT

Hadron flux ratio at CMS Pixels: p-on-TCT/pp = 1E-5

Predicted MIB-damage (TCT losses) equivalent to ~10s normal running
(beam gas in arcs + beam-gas in UX, both same order of magnitude)

But note that the p-on-TCT/pp=1E-5 implies that rare events with
a multi-TeV proton lost on expt. beam-pipe can quickly dominate.
At ~1E-5 level these might be out of reach of our present MC samples.

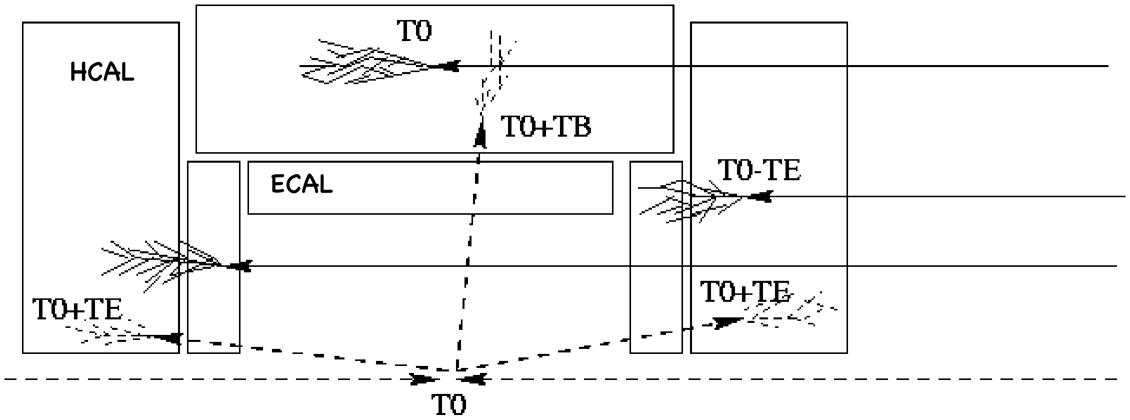
LHCb (L_{pp}=2E32):

Cold Si - no issue, despite less FW shielding than CMS/ATLAS

ALICE (L_{pp}=3E30):

Warm Si, MIB dose ~ collision dose (no TAS & little FW shielding)
Muon chamber ageing is a potential issue
(esp in hot spots created by quadrupole fields)

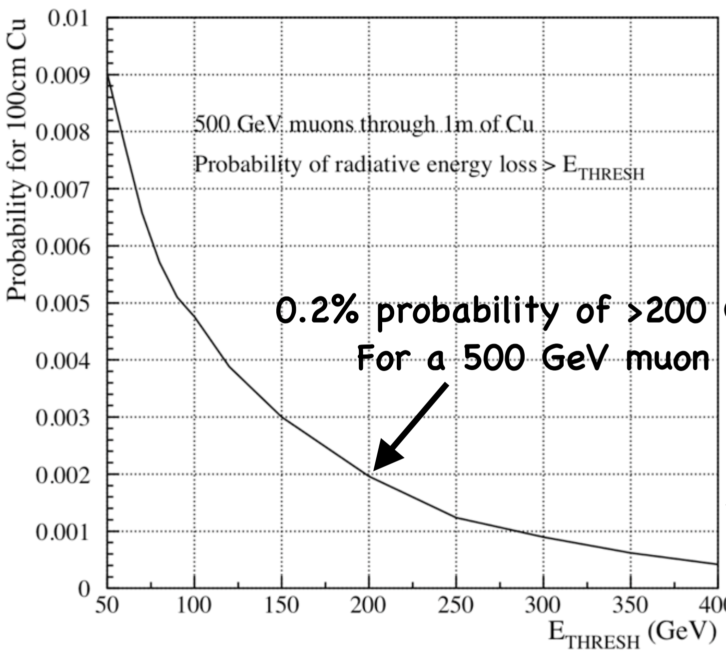
Missing ET trigger



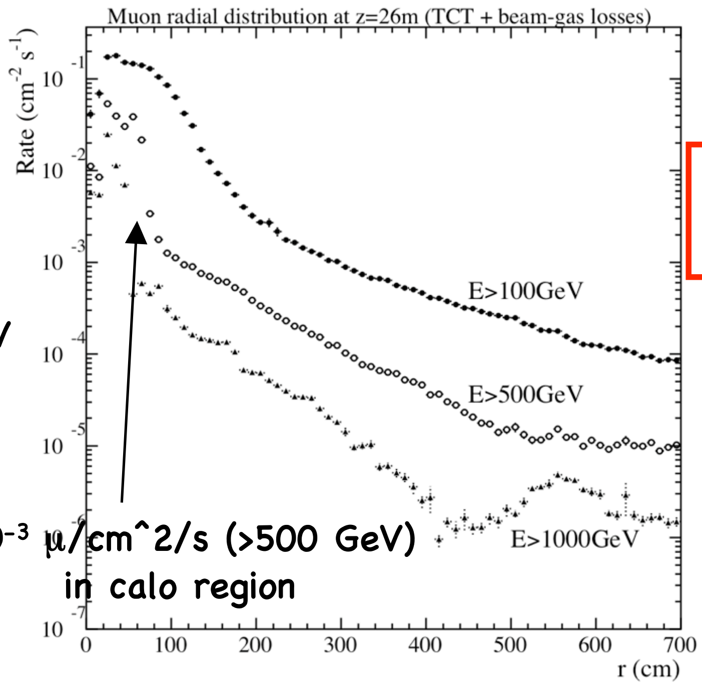
Timing match (usually) only downstream

Wrong shower direction in barrel

Often wrong EM/HAD signal ratio



0.2% probability of >200 GeV
For a 500 GeV muon



~10^{-3} μ/cm^2/s (>500 GeV)
in calo region

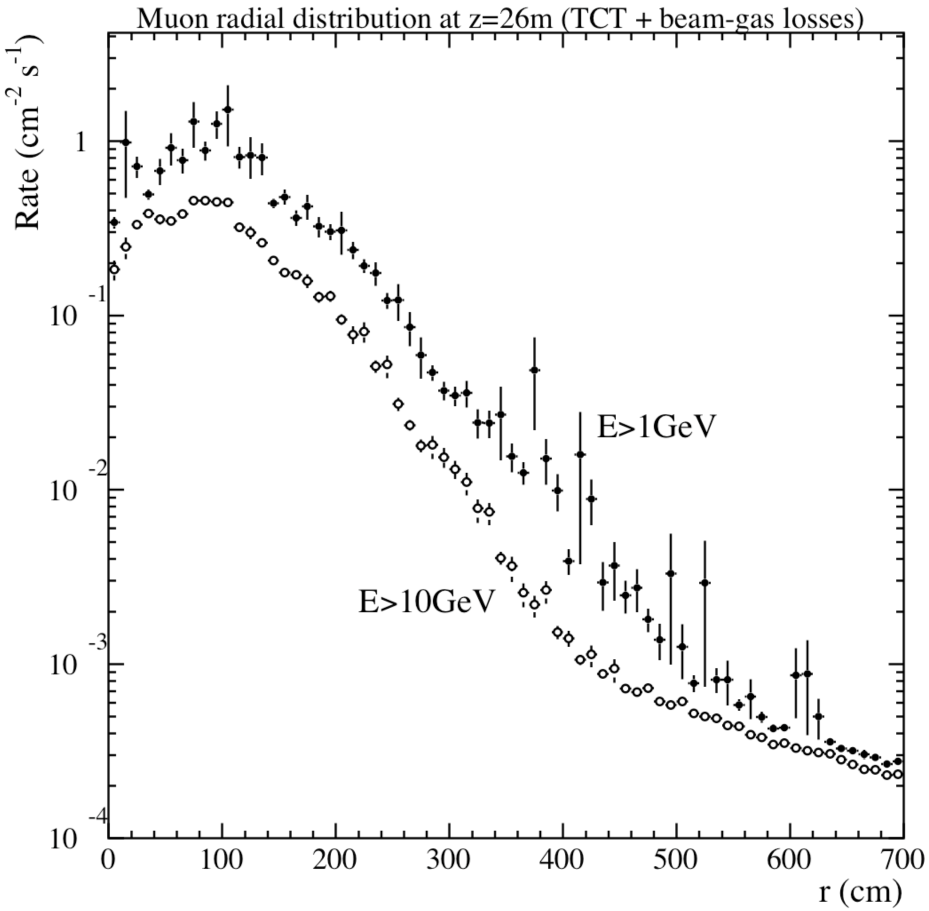
Calorimeter area ~25m^2

Rate of order of Hz
HLT bandwidth O(100Hz)

(of course a detailed simulation with full muon spectra etc would be needed)

ATLAS/CMS Muon Trigger

Could low energy LHC muons add to L1 trigger rate ?



- Both ATLAS & CMS require muons to point to IP (even L1) even in toroidal ATLAS field the geometric acceptance for this is negligibly small

- Like for MET-trigger, large fraction of machine muons will be out of time in most of the detectors (RPC, CSC)

- For random hits, the pp-background will dominate, at least for $L>10^{32}$

ALICE/LHCb specific issues

ALICE increase of TPC data volume

- The TPC integrates over 180μs, so it will accumulate MIB over 2 full orbits

LHCb L0 trigger very sensitive to background

- With 3E6 p/s on TCT the L0 rate would be ~3 kHz with installed shield and ~1 kHz with full shield (L0 bandwidth 1 MHz)
- But more serious problem is overlap of MIB + MinBias, few percent of bandwidth (with few E6 p/s on TCT).
  Would go to few tens of % if few E7 p/s on TCT !

Early operation

Experiments will start with trigger wide open

thus much more sensitive at low than at high luminosity

PRELIMINARY
Under Study in CMS

L1 bit (unprescaled)	Threshold 2E30	Threshold 2E31	Threshold 1E32	Threshold 2E33
Single-EG	5 GeV	8 GeV	15 GeV	23 GeV
Single-Mu	7 GeV	7 GeV	7 GeV	14 GeV
Single-Jet	30 GeV	50 GeV	100 GeV	140 GeV

In addition prescaled bits with even lower thresholds - and prescales increasing with luminosity

Double-object triggers likely to be most sensitive by "promoting" events from single to double due to MIB+pp pileup

Background to Physics

Concern (CMS/ATLAS): Overlay of a high radiative loss with a triggered jet event

Very rare - but so are SUSY events…

Offline handles (some could apply already at HLT):

- No tracks associated with energy deposition
- Shower not pointing to the IP
- Signal only in ECAL or HCAL (wrong EM-fraction)
- Could even try to find the muon track in Tracker or Muon-endcap

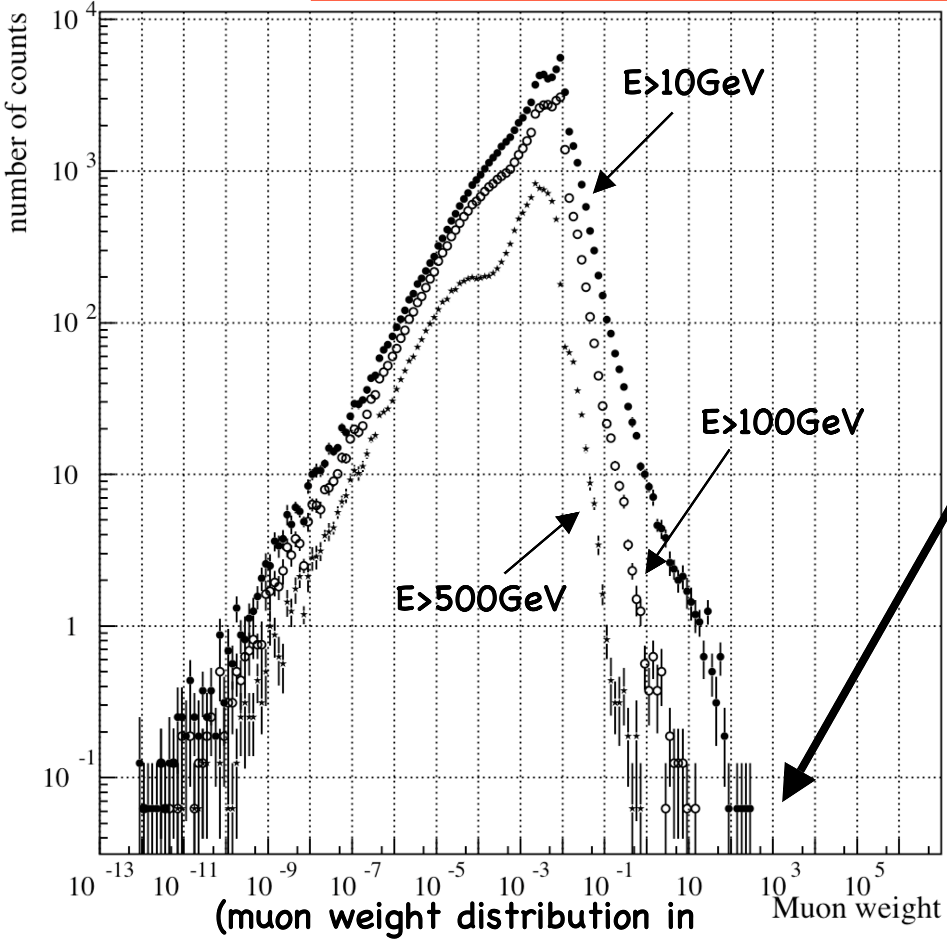
Concern (LHCb)

- Overlay of events and local beam-gas, faking secondary vertex

  Should remain L0 trigger issue, discarded already at HLT

Technical problem: weighted files...

The LHC background simulations are heavily biased - so each particle carries a weight...



(muon weight distribution in beam-gas files of N.Mokhov)

Muon weights vary by 14 orders of magnitude !

Weights arise from biasing, needed to study deep-penetration problems in any decent CPU time

How to sample from this event-by-event ?

Impossible to take into account correlations

Luminosity measurement & FW physics

FW physics/lumi probably most sensitive to beam-gas & satellite bunches

Satellite bunches @ ATLAS/CMS:

Nominal crossing angle: 285 μrad → Smallest bunch-satellite separation ~100um

RF-bucket every 2.5ns (75cm) →

$\beta_s = \beta^* + s^2/\beta^*$ → σ_{xy}~25μm at s=37.5cm for b*=55cm

No issue in nominal mode - but could disturb early (no Xing) running !

→ Issue for early luminosity measurements/calibration ?

(Offline will discard these, but lumi-measurement probably not)

(Luminosity variations (e.g. bunch-to-bunch) are significant for trigger, but not discussed here. See talks by experiments.)

In FW physics MIB could spoil the rapidity gap triggers/measurements possibly in an irrecoverable way (often no tracking info to do IP-pointing)

Need exclusive MIB event simulations to study correlations

Measuring the background

ALICE, LHCb will always have single beam phases (e.g. abort/injection gaps)

CMS, ATLAS: wish for some runs with removed (unpaired) bunches, about 250ns (tbc) worth to allow for detectors to become "clean" (TOF etc).

To minimize luminosity loss, prefer to remove bunches in front of batch

- Technically possible ?
- Unpaired bunches still representative ?

Note: abort gap used for timing - do not remove bunches adjacent to it

Need info from machine which bunches are removed

Cost in luminosity < 1%, but not needed in every fill (maybe once a week or every 2 weeks)

Use of MIB for alignment

MIB could be useful, especially, to align endcap detectors wrt. each other

ATLAS & CMS:

- CMS Tracker endcaps big rigid bodies (by mechanics & internal alignment): few k tracks enough
- CMS Muon endcaps tied by alignment system, but more MCS (in CMS iron): ~1M tracks (~24h with I_{beam}=3.1 μA, i.e. 43 b)
  (ATLAS MIB-based alignment studies just starting)
- Can use MIB for detector timing already with single beam

LHCb

- Use MIB for VELO alignment.
- Would prefer beam1 for any single beam runs (because of timing)

"MIB is better than nothing, but clean collisions better than MIB"

ALICE:

- Some thoughts of MIB-alignment, but no studies done

No need to 'maximize' background - at least not during collisions

Summary of concerns

Under normal operation (e.g. no significant spikes)

	ATLAS	CMS	LHCb	ALICE
Trigger bandwidth	Minor	Minor	Yes	No
Physics background	Event + MET Lumi	Event + MET Lumi & FW	No	No
Cumulative damage	No	No	No	Yes (Si + Muon detectors)
Occupancy issues	Unlikely	No	No	No
Alignment (incl. Timing)	Useful	Useful	Useful	Useful

If background is higher than predicted the first to seriously suffer are ALICE (cumulative damage) and LHCb (Trigger)

Some questions

Q: Is the TCT increasing the background wrt no-TCT (esp. for large β^*)

Q: Can there be halo losses between TCT and IP (none in present simulations)

Q: When and how will the TCT (and others) be aligned during commissioning

Q: What is the roadmap to reach full collimation efficiency (in IR7 & IR3)

Q: Are there local monitors to measure losses on the TCT
(would be useful to disentangle TCT and beam-gas background)

Conclusions

ATLAS/CMS are designed for high luminosity pp-operation, normal LHC background should be negligible (no detector damage)

ATLAS/CMS do not expect any serious trigger or physics issues due to MIB. Most sensitive in early running (open triggers)

LHCb - operating at lower lumi and being more 'near-beam' will be more affected (trigger rate)

ALICE: MIB is a significant fraction of total dose, i.e. cumulative,damage. Any excess losses on TCT to be avoided (triplet not limiting aperture).

MIB should not be increased by using the TCT for beam cleaning, e.g. relaxing IR7 collimation in first years (thus increasing TCT losses)

All experiments ask for MIB simulations using consistent, up-to-date machine parameters, Preferably also some non-weighted events (needed for trigger simulations)