Beam-Beam Study strategy

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Acknowledgements: L. Rivkin, R. Tomas, Beam Dynamics Group members

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FCC week Workshop

11-15 April 2016 Rome, Italy

Baseline and Ultimate Scenarios

Baseline parameter document delivered to EU

Baseline: 1.25ab^{-1} per 5 year cycle
- considering shutdowns, stops, MDs, …

= 2fb^{-2} per day

Ultimate: 5ab^{-1} per 5 year cycle
= 8fb^{-2} per day

Total 17.5ab^{-1}

Focus on ultimate parameters

Injection energy 3.3TeV

	FCC-hh Baseline	FCC-hh Ultimate
Luminosity L [10^{34}cm^{-2}s^{-1}]	5	20-30
Background events/bx	170 (34)	<1020 (204)
Bunch distance Δt [ns]	25 (5)	
Bunch charge N [10^{11}]	1 (0.2)	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2(0.44)	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8 (3)	3.5 (1.6)
RMS bunch length σ_z [cm]	8	
Crossing angle [σ□]	12	Crab. Cav.
Turn-around time [h]	5	4

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LHC scaled versus Challenging scenario
Need to guarantee the Baseline and work hard to reach the Ultimate!

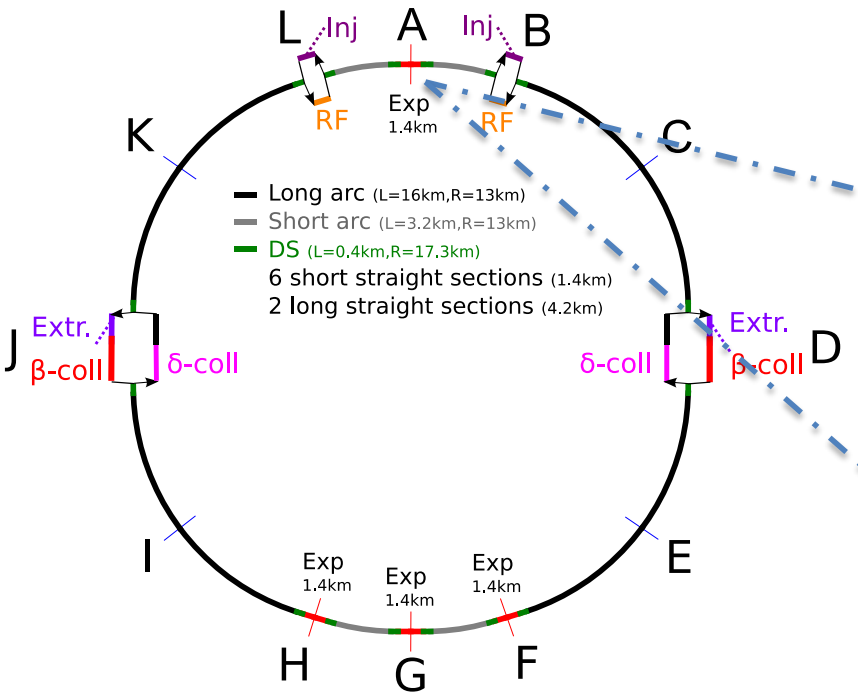
Beam-Beam Interactions

Luminosity

$$\mathcal{L} \propto \frac{N_p^2}{\sigma_x \sigma_y} \cdot n_b$$

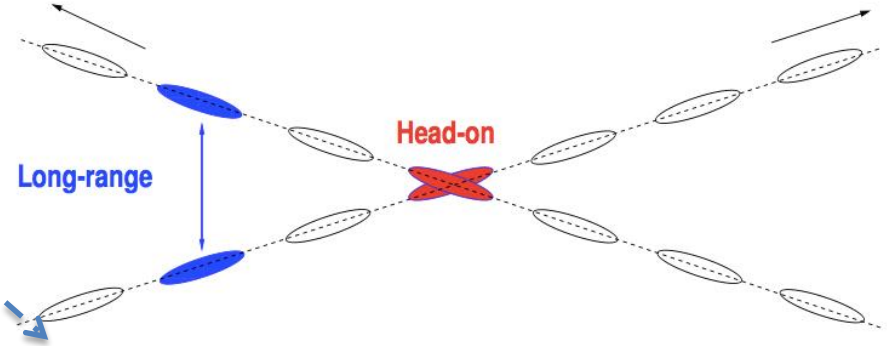
Beam-Beam Force

$$F \propto \frac{N_p}{\sigma} \cdot \frac{1}{r} \cdot \left[1 - e^{-\frac{r^2}{2\sigma^2}}\right]$$



Separation is typically 12-14 σ
Scaled from LHC

FCC collider: bunches
2 Experiments with Head-On collision

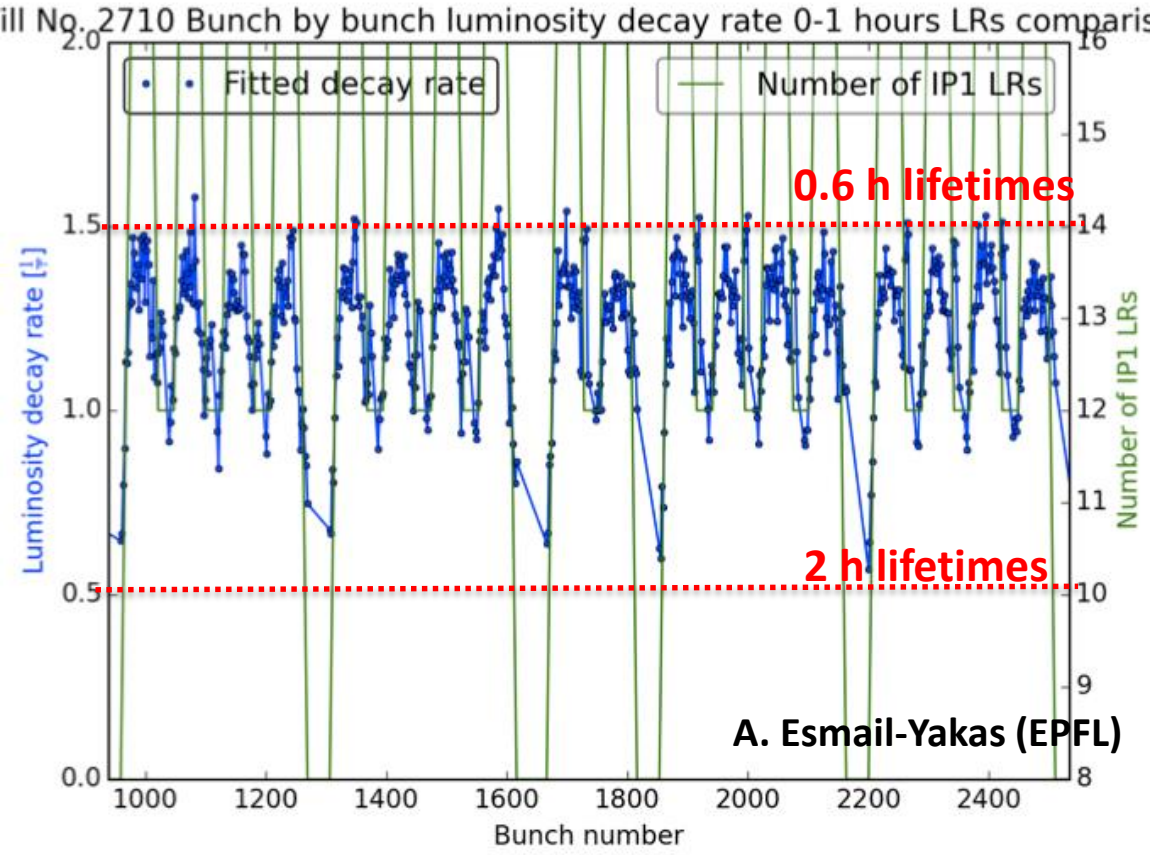


10600 bunches…
25 ns bunch spacing → beams will meet every 3.75 m
For L*45m 60 beam-beam Long Range encounters per experiment

Several localized long range interactions
Need local separation (crossing angle)

LHC Experience Not Controlled Beam-Beam effects

Regular Physics Fill of 2012 RUN LHC 4 TeV



Clear Long Range pattern in the Luminosity Decay rates

→ BB can change integrated luminosity reach significantly!

→ Particle Losses

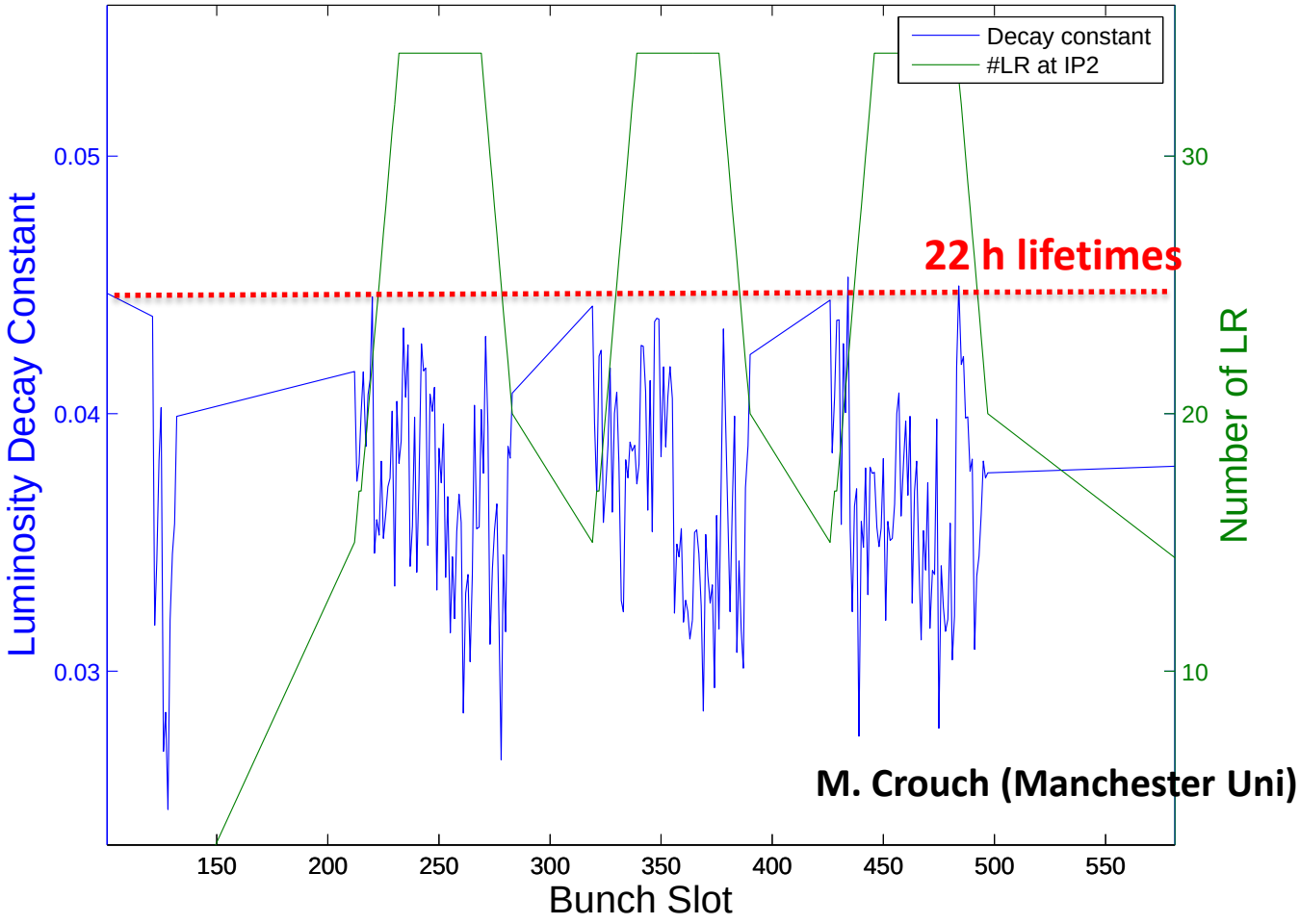
→ Emittance growth

$$\mathcal{L} \propto \frac{N_p^2}{\sigma_x \sigma_y} \cdot n_b$$

Beam-Beam dynamics defines particle losses and emittance evolution
→ Integrated Luminosity (emittances evolution) and machine protection (100TeV beams)!

LHC Experience 2015 Weak Beam-Beam Effects

LHC Physics Fill of 2015



Beautiful Luminosity lifetimes…

No evident beam-beam signature in luminosity and spec lumi lifetimes

→ Low losses and negligible emittance blow-up

First Phase: feedback for IR design

Start with a solid baseline scenario scaling from LHC and HL-LHC studies and first estimates

- **intensities, emittances**
- **optics (round versus flat)**
- **crossing angles**
- **Optics distortion (dynamic beta)**
- **Crossing schemes HV HH VV**
- **Orbit effects, chromaticity, tune shifts**
- **Multipolar errors effects**
- **Working point sensitivity**
- **Modulation**
- **Crab Crossing with cavities**

Assumptions: HV crossing, L*=45m, round optics 30cm b*

Study type

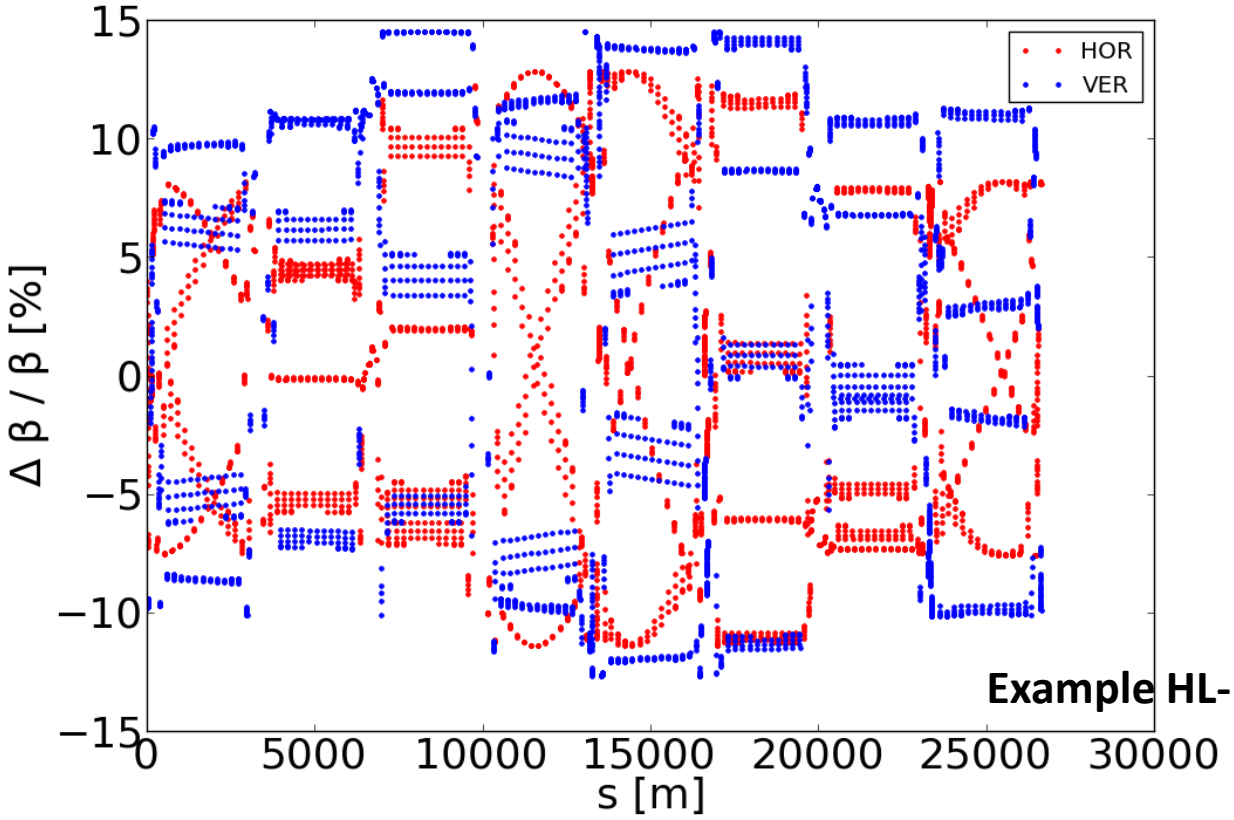
- **Single particle dynamics →Dynamic aperture, magnets multipolar errors**
- **Optics distortions**
  →tune shifts, spread
  →orbit effects
  → dynamic beta
  → PACMAN bunches

Feedback for design

- **IR design**
- **Machine protection/collimation**
- **Magnets Field quality**
- **Luminosity reach**

Optics distortions and implications

$$\xi_{bb} = 0.02$$



Example HL-LHC lattice

Synergy with optics group

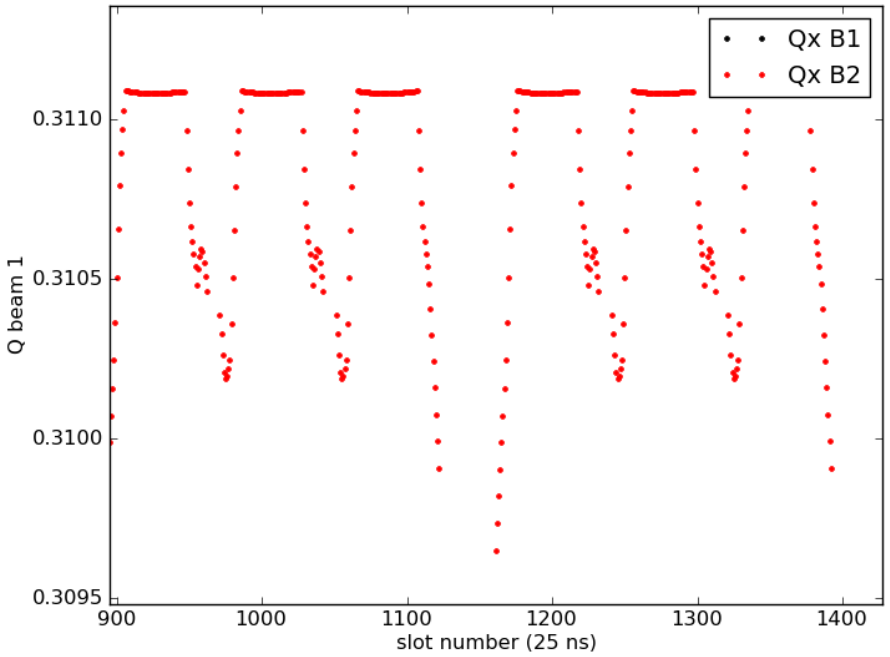
Experimental test of local correction in the LHC (R.Tomas et al.)

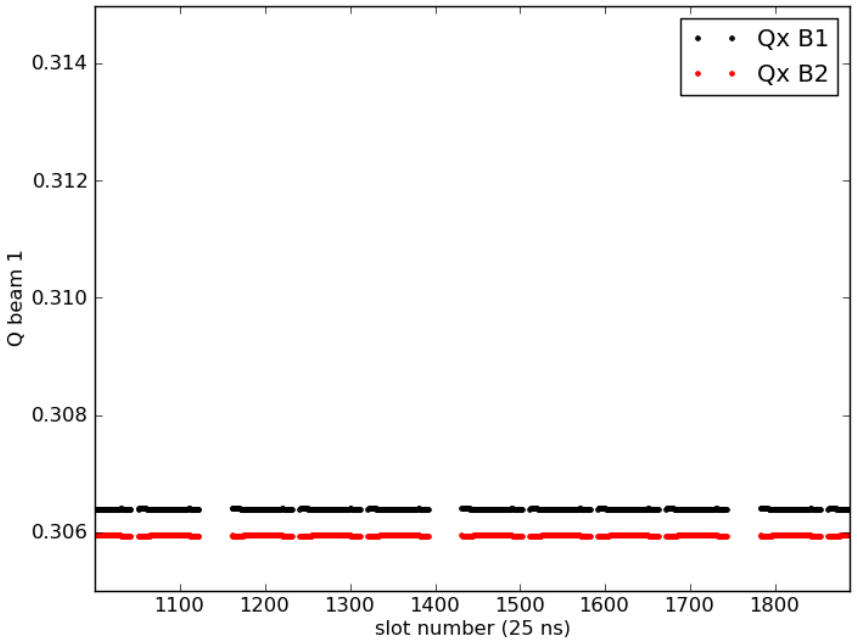
P. Jorge (EPFL student) implications of BB beating, optics dependency, phase advance and impact on collimation and performances

Study On-going

Crossing schemes: HV-HH-VV mixed

H crossing scheme versus HV crossing





Horizontal-Vertical crossing used in the LHC

Provides passive compensation of long-range tune shifts, chromaticity!

Important to explore alternative schemes HH, VV or mixed 45'…..

Study On-going: tool modification

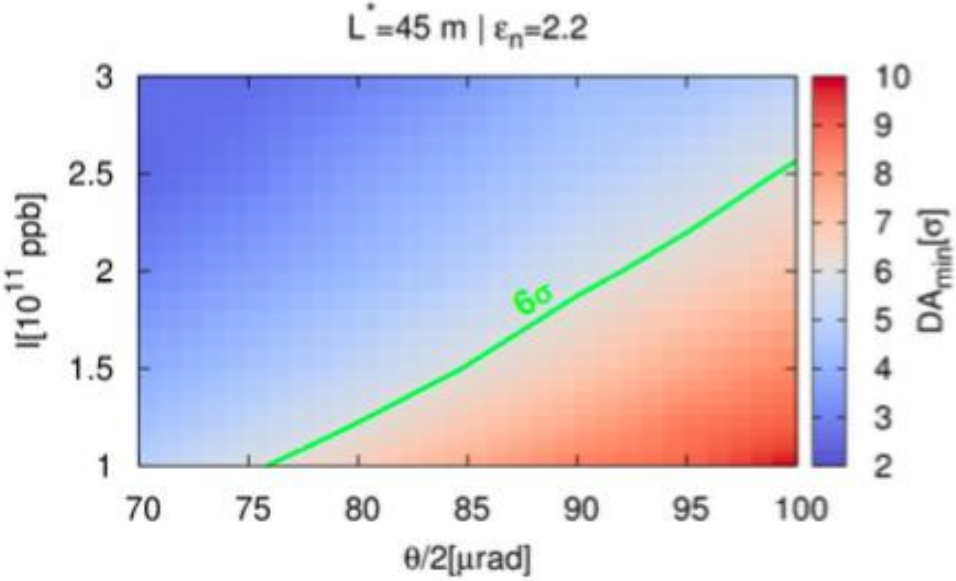
Crossing angle set-up

Dynamic Aperture studies for round optics

Results. Baseline L^*=45 m

For the baseline parameters a 6σ DA is ensured with a θ/2~76 μrad, i.e. $\mathbf{d_{sep}}$= **12.8σ**.

This is consistent with previous studies done with a toy lattice.



Study On-going

Talk J. Barranco (EPFL)

- Parameter space
- Spectrometer impact
- Round/flat Optics
- Crab Cavities
- Magnets multipolar errors
- Possible operational scenarios (octupoles , chroma)
- Active compensators (wires, elens, octupoles)
- …..

Second Phase: emittance and diffusion studies

- **Explore the beam-beam limit**
  - Intensity evolution for different BB configurations
  - Emittance evolution (quantum excitation, IBS) and limitations
  - External Noise from machine elements (e.g. crab cavities)
- **Mitigation techniques (wires, e-lenses, octupoles)**
- **Stability and Collective effects:**
  - Beam stability studies: Landau damping
  - **Impedance driven instabilities and Beam-beam (with impedance model)**
  - Operational scenario.

Study type

- Single Particle dynamics and multi-particle studies

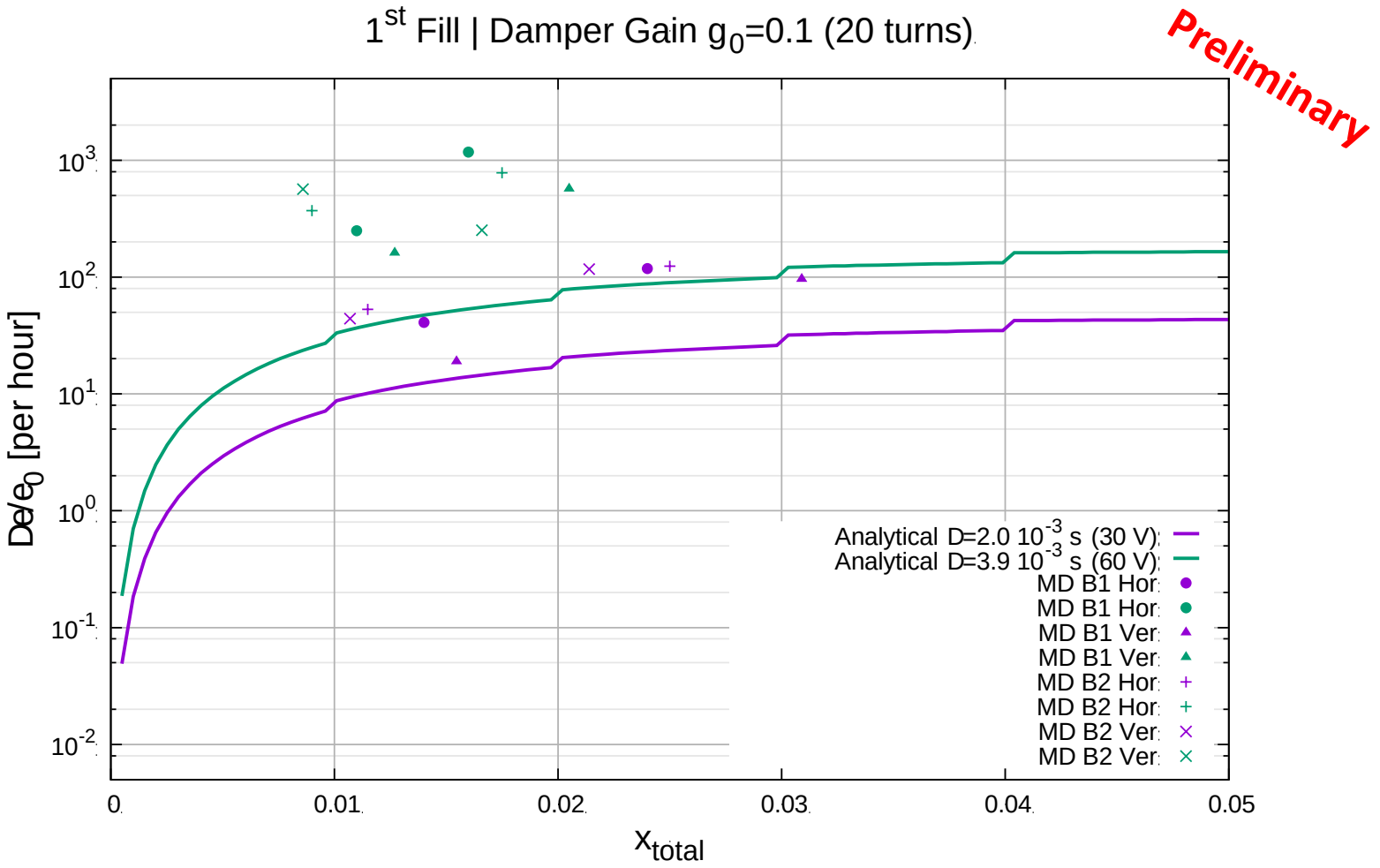
→Need major development of numerical tools and models

Feedback for design

- **Machine protection/collimation**
- **Noise tollerances/spec**
- **Intensity limitations**
- **Luminosity reach**

Predictive power on this subjects not yet satisfactory

Noise on colliding beams at injection

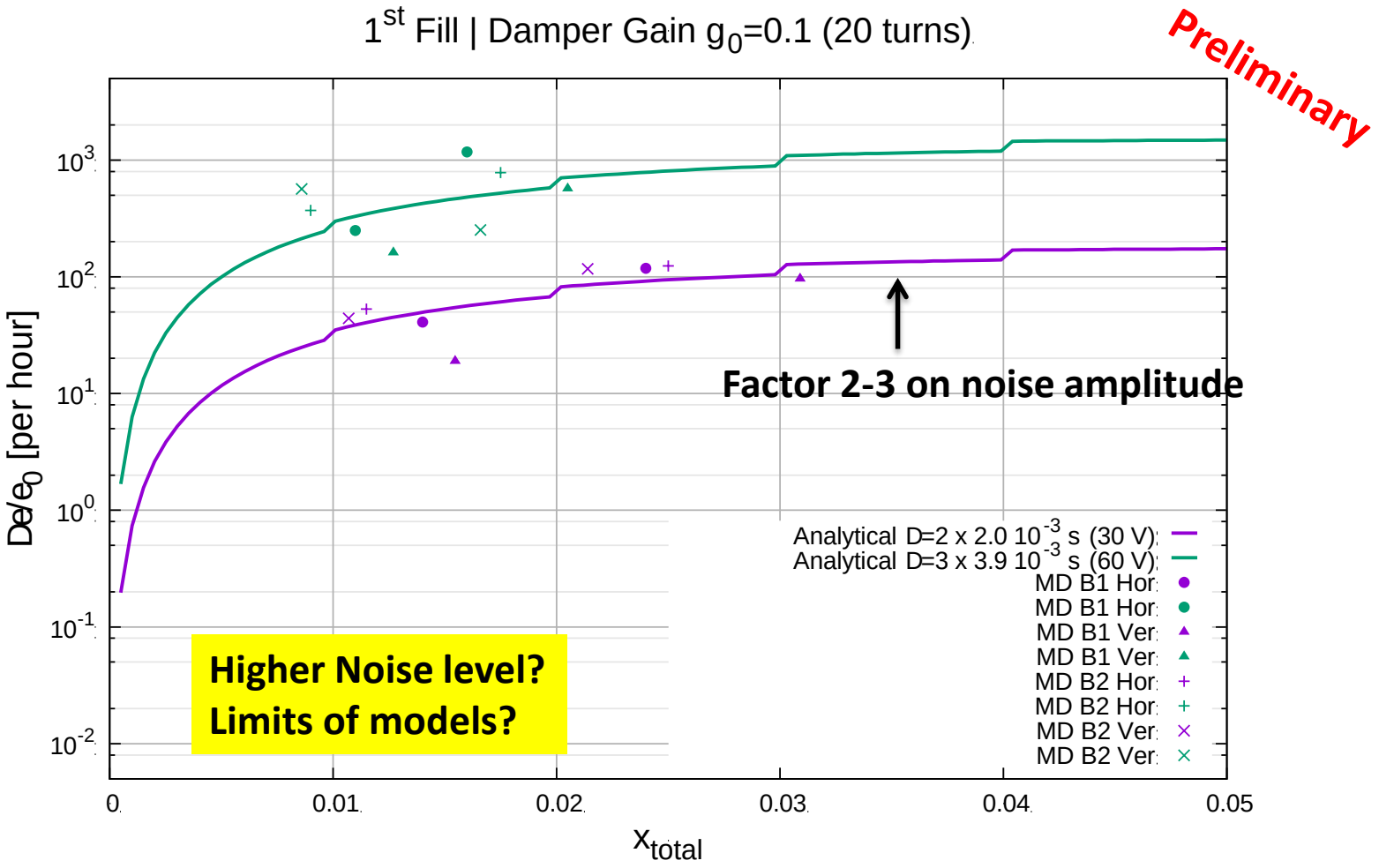


Injection Energy: introduce white noise with different amplitudes

Single bunches with different BB parameter in collision

Big discrepancy Model-Experimental data

Noise on colliding beams at injection



Missing ingredients in the model, beam-beam dependency consistent with expectations!
To be understood to estimate HO limits!

Models and Tools

- **Sixtrack** single particle tracking for Dynamic aperture studies
  - **DA for beam-beam (crossing angles, intensity scaling, long-range wires)**
- **Frequency Map Analysis** (from Sixtrack developed for HL-LHC need parallelization)
- **COMBI** (Coherent Multi Bunch multi Interaction code)
  - **Coherent Beam-beam**
  - **Impedance and beam-beam interplay**
  - **Landau Damping**
  - **Beam Intrinsic noise (quantum excitation, IBS…) → BB Limit**
  - **Emittance evolution studies**
- **TRAIN** code → self consistent orbit, tune and chromaticity computations
- **MADX** code → optics distortions: tune shifts, particle detuning with amplitude, dynamic beta and beating

Standard tools for Beam-Beam studies at CERN need extensions and modifications to model FCC dynamics

Summary

Start with a solid baseline scenario scaling from LHC and HL-LHC studies and first estimates

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  - Beam stability studies: Landau damping
  - Impedance driven instabilities and Beam-beam (with impedance model)
  - Operational scenario.

Tools and Models development and extension

Benchmark to experimental results: LHC machine development program

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Start with a solid baseline scenario scaling from LHC and HL-LHC studies and first estimates

- **intensities, emittances**
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- **Optics distortion (dynamic beta)**
- **Modulation**

P. Jorge (EPFL till July 2016)
J. Barranco (EPFL Post-doc)
T. Pieloni 25% (CERN)
X. Buffat 10% (CERN)

- **Explore the beam-beam limit**
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2 PhD students (EPFL)
1 Post-doc (EPFL)

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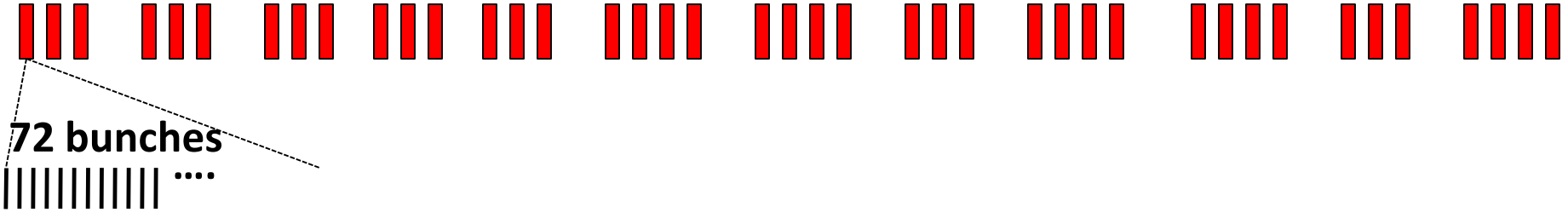
Thank You!

Complications

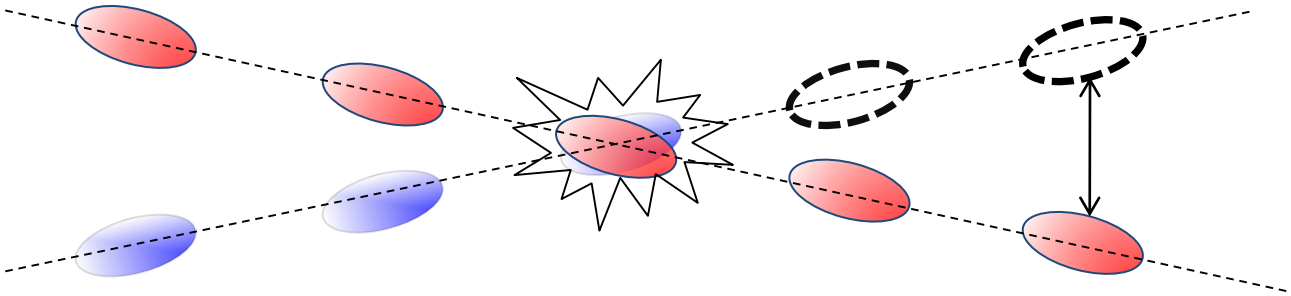
PACMAN bunches



Pacman:

miss long range BBI

(120-40 LR interactions)

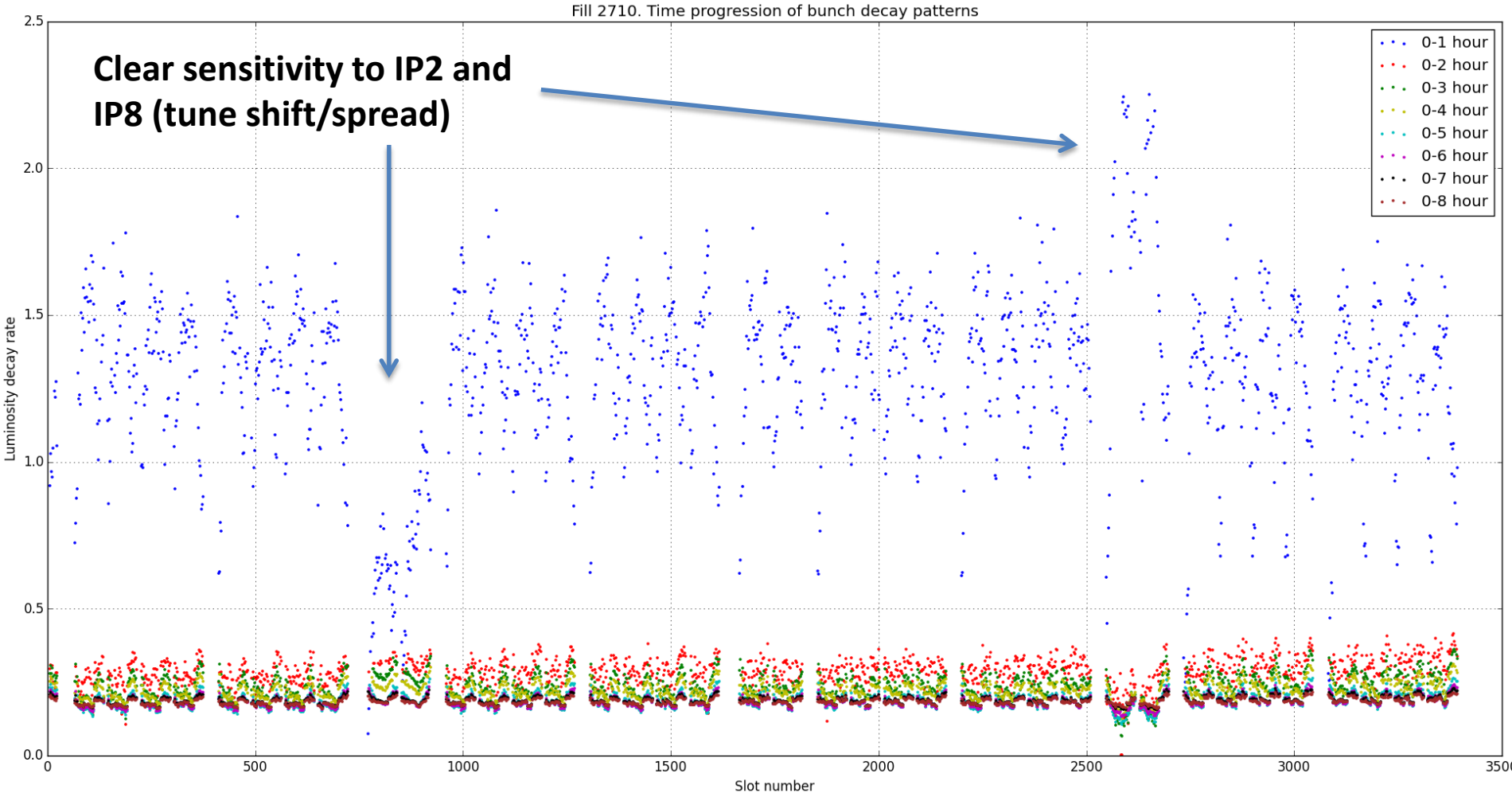


Different number of long-ranges → Different bunch families

Long Range effect 2012

Regular Physics Fill of 2012 RUN LHC

A. Esmail-Yakas



Beam-Beam pattern visible in first 2 Hours of physics fills

Also special IP2 and IP8 effects visible missing head-on collision and/or long ranges

Crossing schemes: HV-HH-VV mixed

HV crossing scheme versus H crossing