

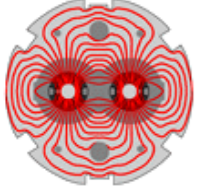
LHC Luminosity: Operational aspects

Alick Macpherson

LHC Lumi Days 2012

1 March 2012

Acknowledgements: Reyes Alemany Fernandez, Helmut Burkhardt ,Gabriel Mueller, Giulia Papotti, Stefano Redaelli, Georges Trad, Mariusz Sapinski, Jorg Wenninger



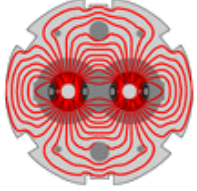
Introduction

- LHC in 2012: normal operation
 - Changes in Beam Conditions for 2012

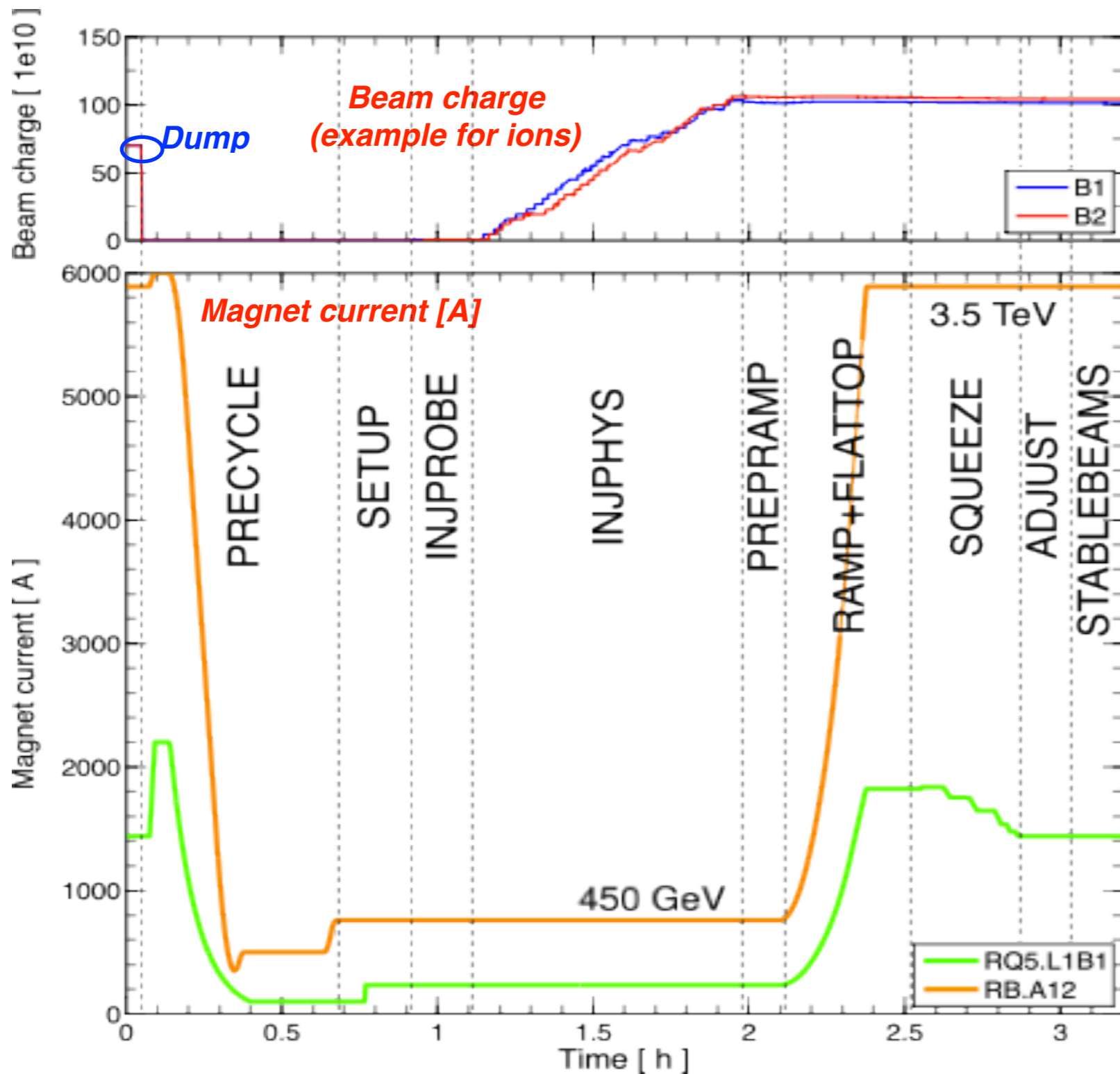
- Special Runs
 - Luminosity Calibration:
 - Van der Meer Scans
 - Length Scale Calibration
 - Software changes associated with Luminosity Scans

 - High β optics
 - β^* of 90m and 500m

The LHC in normal operation



LHC operational cycle

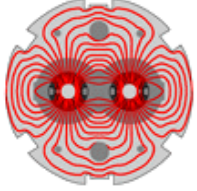


Time-functions for settings of

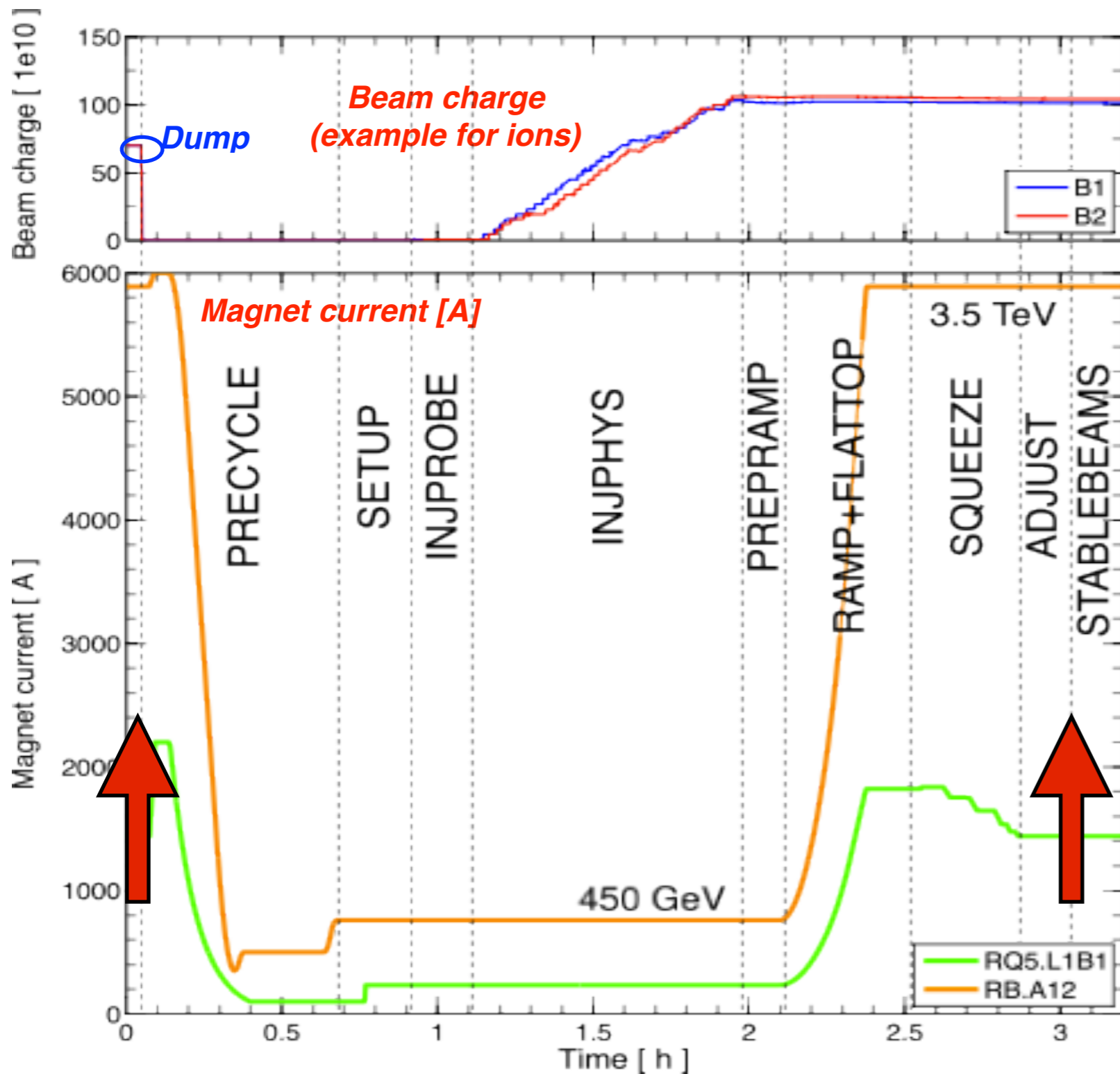
- (1) ramp,
- (2) squeeze(s),
- (3) collisions,
- (4) pre-cycle (without beam).

Discrete ("actual") settings for:

- (1) injection,
- (2) prepare ramp,
- (3) flat-top,
- (4) adjust (end of squeeze),
- (5) stable beams.



LHC operational cycle



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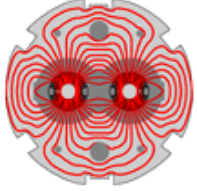
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End of Fill
Studies

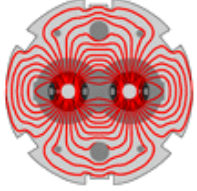
Luminosity
Optimzation



LHC in 2012: What's new in the optics

Parameter	Value at 450 GeV	Value at top energy
Energy [GeV]	450	4000
$\beta^*_{IP1/5}$ [m]	11.0	0.6
β^*_{IP2} [m]	10.0	3.0
β^*_{IP8} [m]	10.0	3.0
Parallel separation [mm]	2.0	0.67
Crossing angle IP1/5 [μ rad]	170	145
Crossing angle IP2 [μ rad]	170	90+
Crossing angle IP8 [μ rad]	170 (H)	100 (V)

These changes require tight collimator settings: TCPs @ 4.3σ , TCTs @ 9σ



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Operational Sequence: Turnaround Improvements

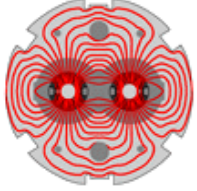
Ramp duration [s]: **770 s** (2010: 1020 s)

Squeeze duration [s] **819 s** (0.6 m) (2010: 548 s (1.0 m))

Collision BP duration [s] **56 s** (2010: 56 s)

Theoretical time from Start of Ramp to collisions is the same from 2012 to 2010

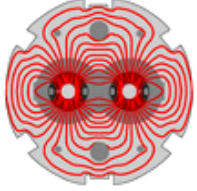
Crossing angle rotation in IP8 ~ **200 s**



LHC in 2012: What else is new

- Luminosity improvements compared to starting parameters of 2011
 - $E = 3.5\text{TeV}$ $I_{\text{bunch}} = 1.1\text{e}11$ $\beta^* = 1\text{m}$ $\epsilon_n = 2.0\mu\text{m}$ Crossing angle = $240\ \mu\text{rad}$
 - Increase I_{bunch} from $1.1\text{e}11 \rightarrow 1.6\text{e}11$: Luminosity Increase = 112%
 - Emittance Increase: ϵ_n from $2.0 \rightarrow 2.5\ \mu\text{m}$ Luminosity Increase = -18%
 - Decrease β^* from $1\text{m} \rightarrow 0.6\text{m}$ Luminosity Increase = 56 %
 - Beam Energy from $3.5 \rightarrow 4\text{TeV}$ Luminosity Increase = 12.5 %
 - Crossing angle: $240 \rightarrow 290\ \mu\text{rad}$: Luminosity Increase = -4.6 %

Total Peak Lumi improvement over '2011 start conditions' = **187 %**
Total improvement over '2011 end conditions' ($I_{\text{bunch}} = 1.4\text{e}11$) = **76 %**



LHC in 2012: What else is new

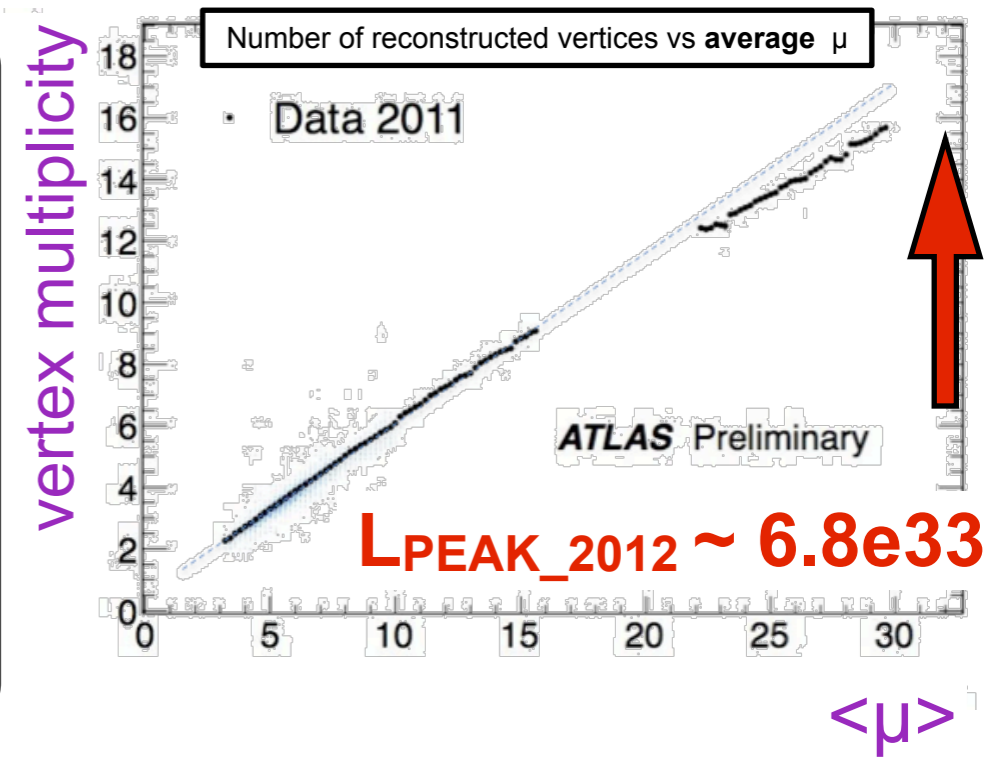
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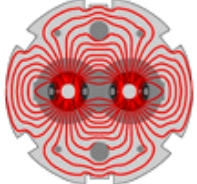
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However: Pileup ...

- Expected Av number events/crossing $\langle \mu \rangle = 34.2$
- Av. vertex multiplicity should scale linearly with μ
- Expts: reconstruction algorithms not fully optimized

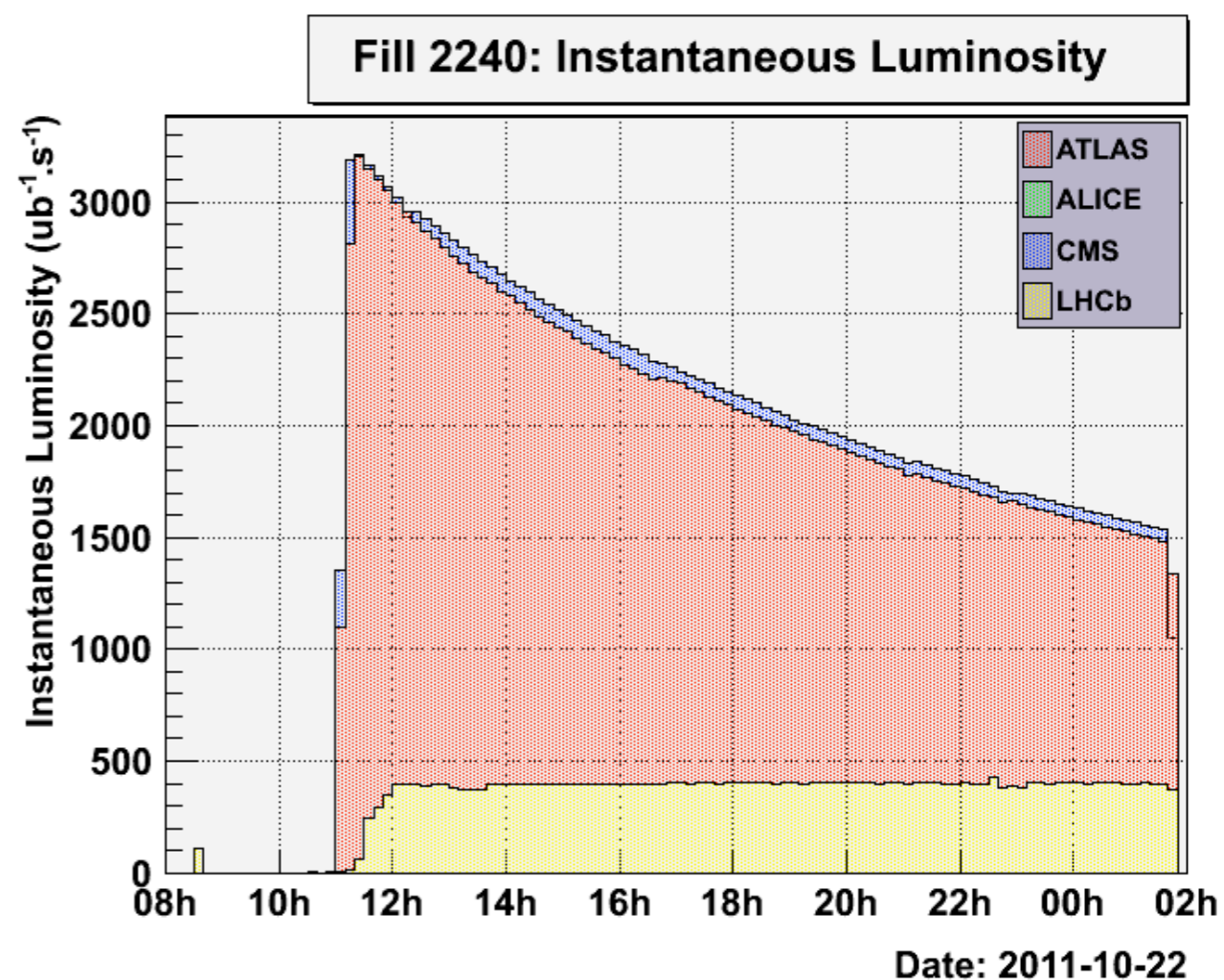
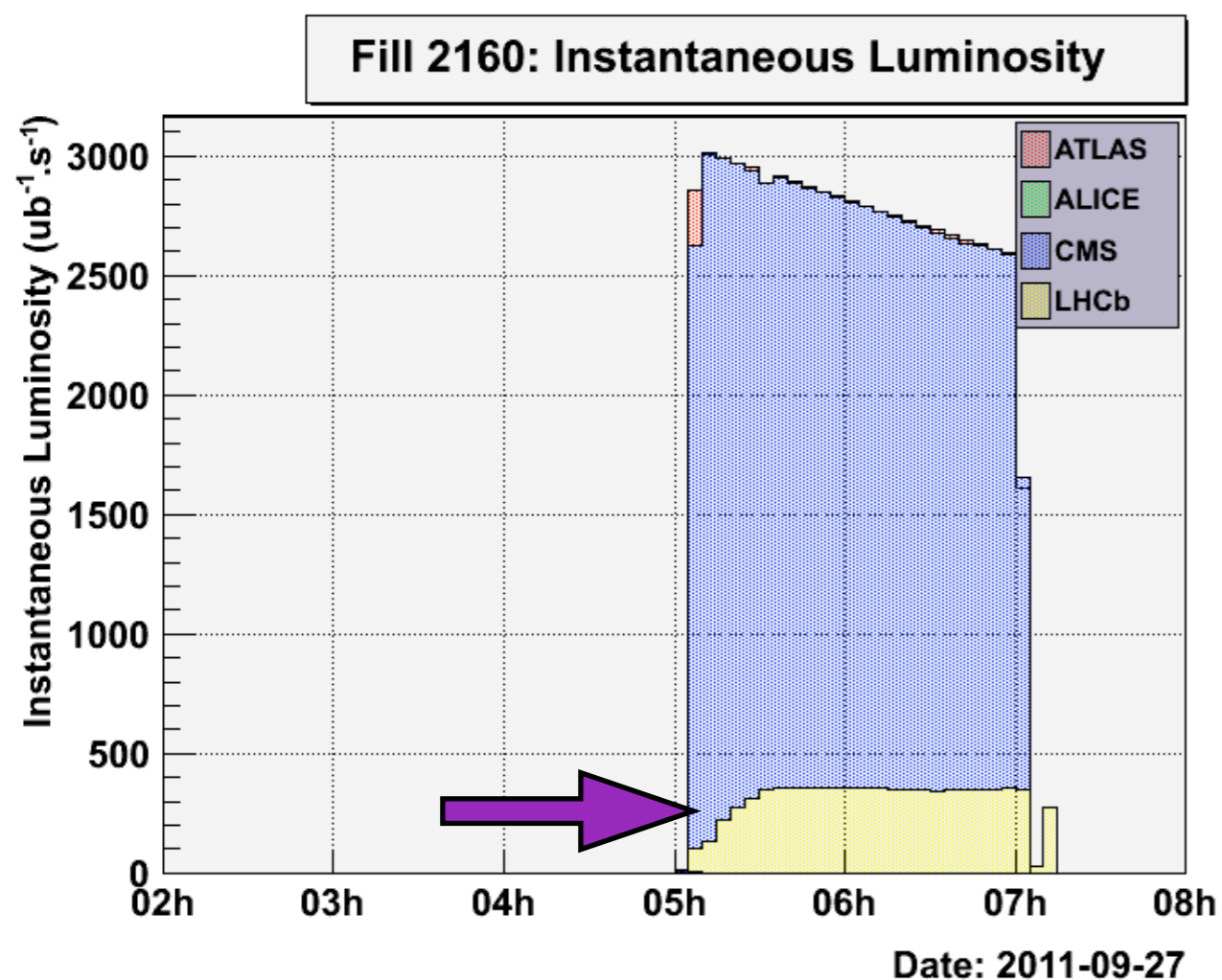
=> Clear feedback from Expts on useful delivered luminosity is needed



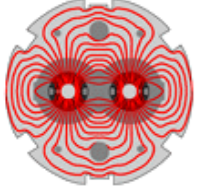


Luminosity Leveling

- Control of Instantaneous luminosity and pileup levels
 - Introduced in 2011. Now **Standard Operational Procedure**:
 - Luminosity regulated apply transverse offset in separation plane
 - Can be applied to all experiments



Luminosity Target value, Increment size, and time between increments controlled by each experiment

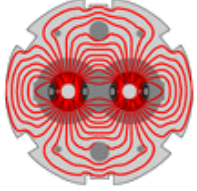


The new squeeze

- $\beta^* = 0.9$ m: Standard
 - 2011 collimator settings. (like in 2011). No issues
- $\beta^* = 0.7$ m: Significant commissioning (optics, orbit, Q')
 - Need to switch from **standard** to **tight** collimator settings.
 - Tight settings used in physics (EoF) in 2011 ... but some issues.
 - Orbit control in squeeze.
 - Instability/impedance control
 - Better chromaticity control .
- $\beta^* = 0.6$ m: Nominally straight forward once $\beta^*=0.7$ m done
 - Tight collimator settings. Re-arrangement of TCSG6-TCDQ-TCT.

Plan for Initial running

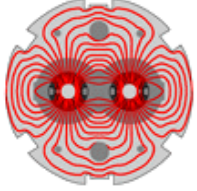
- Prepare squeeze sequences to $\beta^* = 0.6$ m and 0.7 m
- Commission with low intensity to $\beta^* = 0.6$ m.
- **Then take a decision on β^* value.** ie 0.6 or 0.7m



Procedure to get to Stable Beams

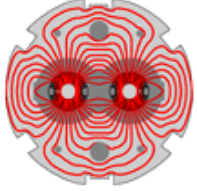
- After the squeeze
 - Collapse the separation bumps
 - **Optimize luminosity in crossing angle plane** (All expts simultaneously)
 - **Declare Stable beams**
 - Optimize in separation plane (All expts where Lumi leveling not used)
 - Turn on Luminosity leveling in all required IRs
 - Take reference orbit once all Lumi leveling targets are reached

- One little complication ...



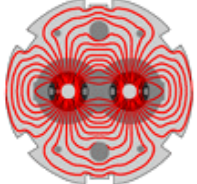
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- One little complication ...
 - LHCb Request: change from horizontal to vertical external crossing angle
 - Reason:
 - beam-beam @ 25ns: Ensure beam separation of 1st parasitic encounter $>12\sigma$
 - New scheme: crossing angle (hence machine config) independent of spectrometer polarity
 - LHCb: Crossing angle independent of polarity removes one systematic error
 - Implementation: Not yet defined ...
 - crossing angle rotation at injection if aperture margin
 - After LHCb squeezed to 3m and while IP1/5 squeezing to 0.6m
 - After the squeeze



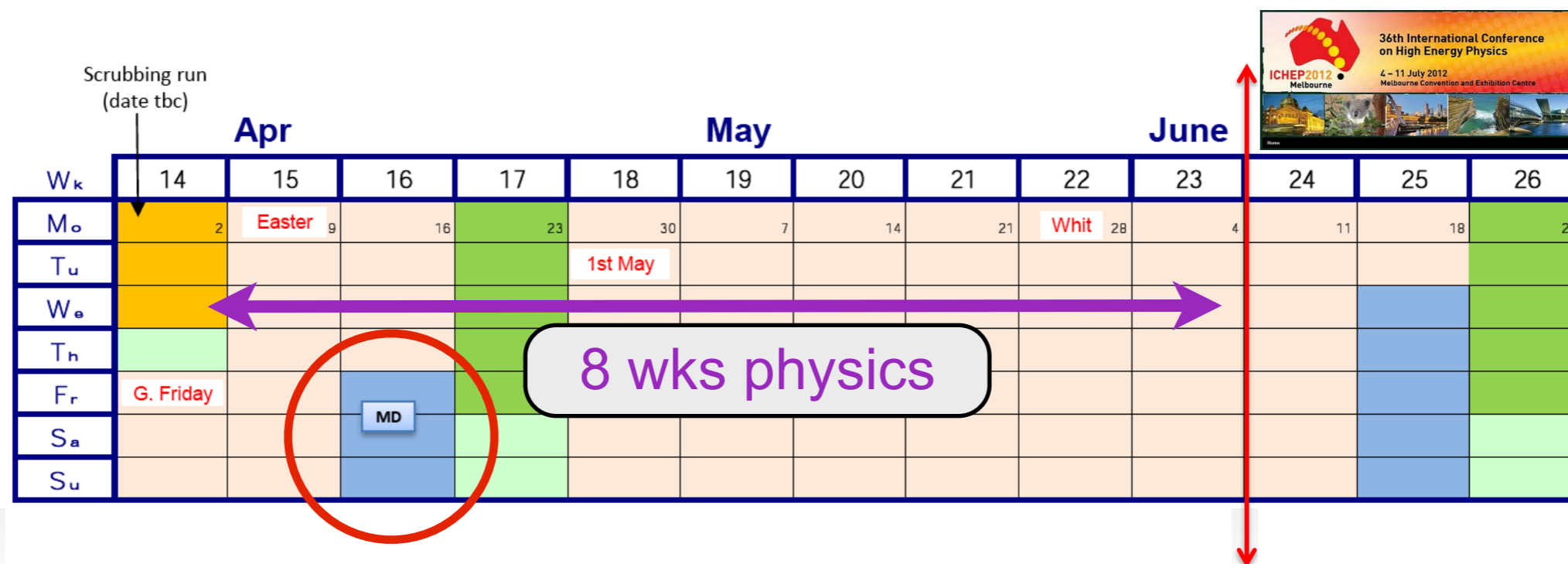
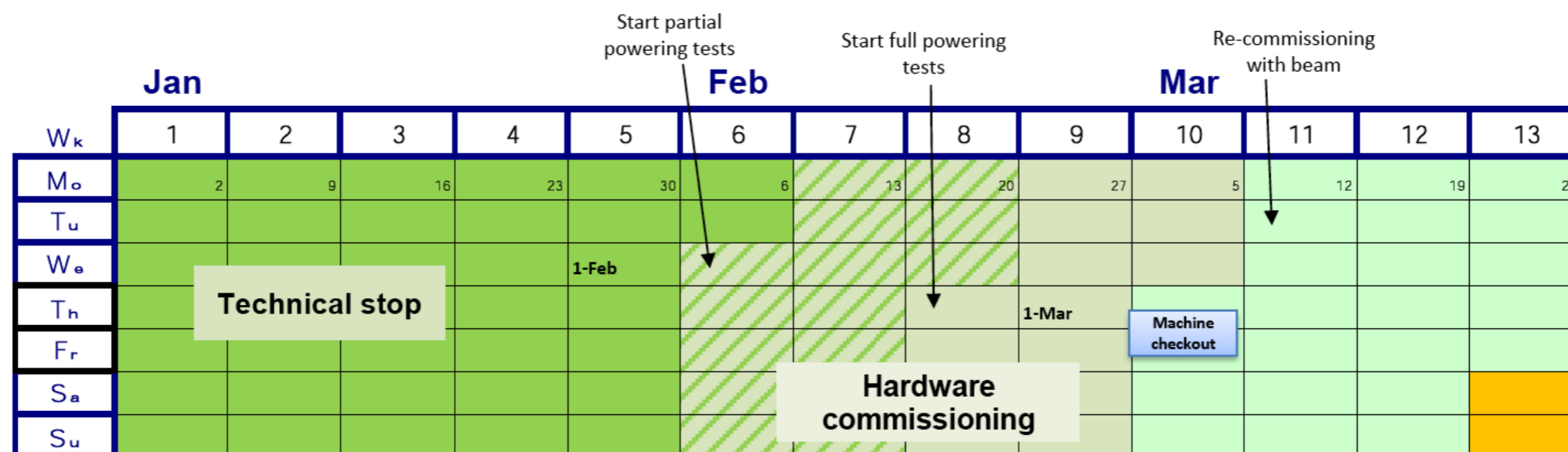
From the LPC ...

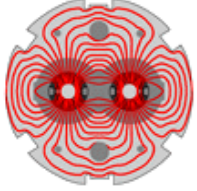
- Emphasis on luminosity production
 - Concentrate special runs towards the 2nd part of 2012
- Special Runs: Two higher priority tasks
 - Luminosity calibration ... what is requested?
 - One VdM scan with $\beta^*=11$ m to reach ultimate precision
 - Perform the scan at sufficiently low μ (~ 1 or 2)
 - Keep transverse luminous size larger than vertex resolution
 - to investigate correlations between horizontal and vertical beam profiles
 - May also ask for calibration at nominal β^*
 - High beta physics
 - 2 physics goals:
 - Diffractive physics at $\beta^*=90$ m (mainly TOTEM)
 - Highest β^* to approach Coulomb interference region for elastic scattering
 - Only one of physics run is likely within the present schedule
 - **Proposal: A mixed setup with 90m in IP5 and 500m in IP1**
- Other requests
 - Beam splashes events at expts, 10M evts in Low pileup sample ($\mu=0.01$), very high pileup runs, stable beams fills 25 ns
 - Sufficient advance planning required to allow for preparation and setup



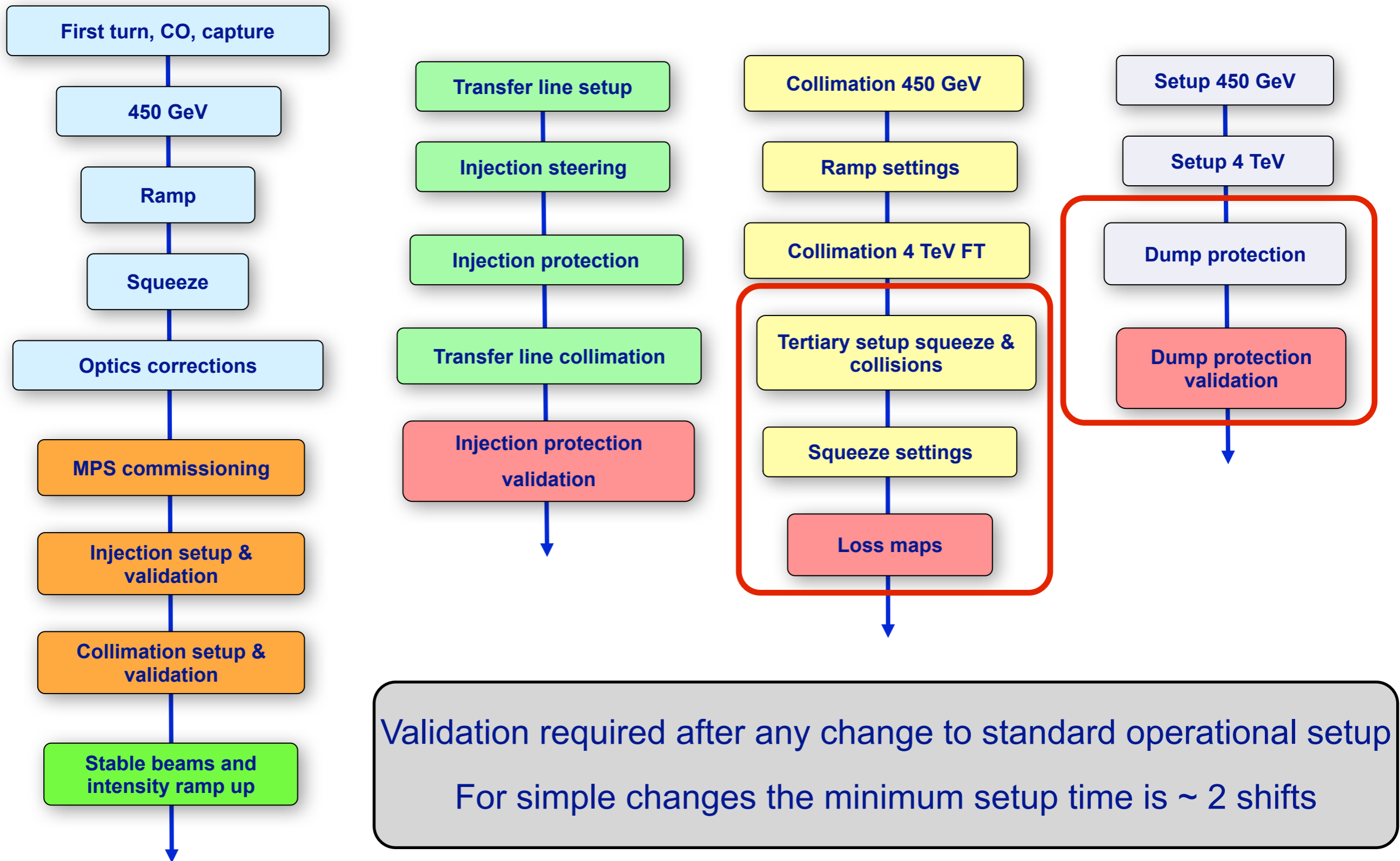
LHC Schedule

- Re-commissioning with beam: 21 days + 3 days of scrubbing.
- Physics @ Easter...
- Earlier scrubbing, shorter 1st MD => Maximize $\int Ldt$ for ICHEP
- LPC to clarify when details for Special Runs in first part of the year.

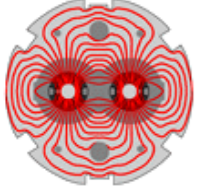




LHC re-commissioning and special setups



Special Runs: Luminosity Calibration



Luminosity Calibration

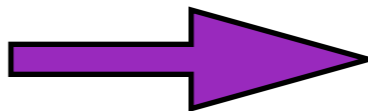
- In 2011 this procedure matured and is now standard
- Luminosity Calibrations is a multi-step process

- **Beam Size measurements**

- Errors: 5% (Wires scans), 10% (BSRT)

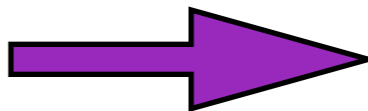
- **Van der Meer Scans**

- Stepwise scan 1 beam across the other
 - Luminosity as a function of beam separation
 - Scan in orthogonal planes
 - Repeat VdM with scan directions reversed



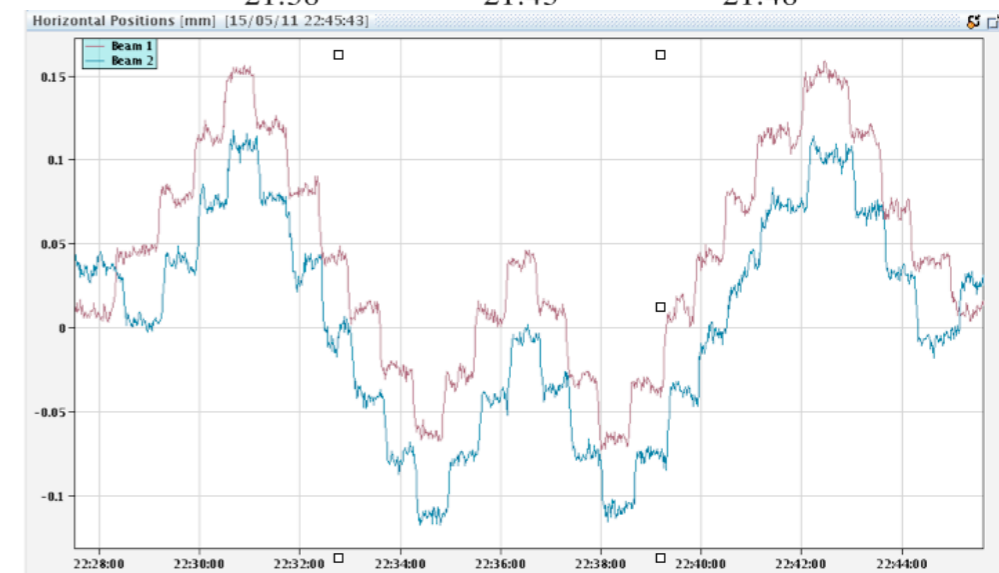
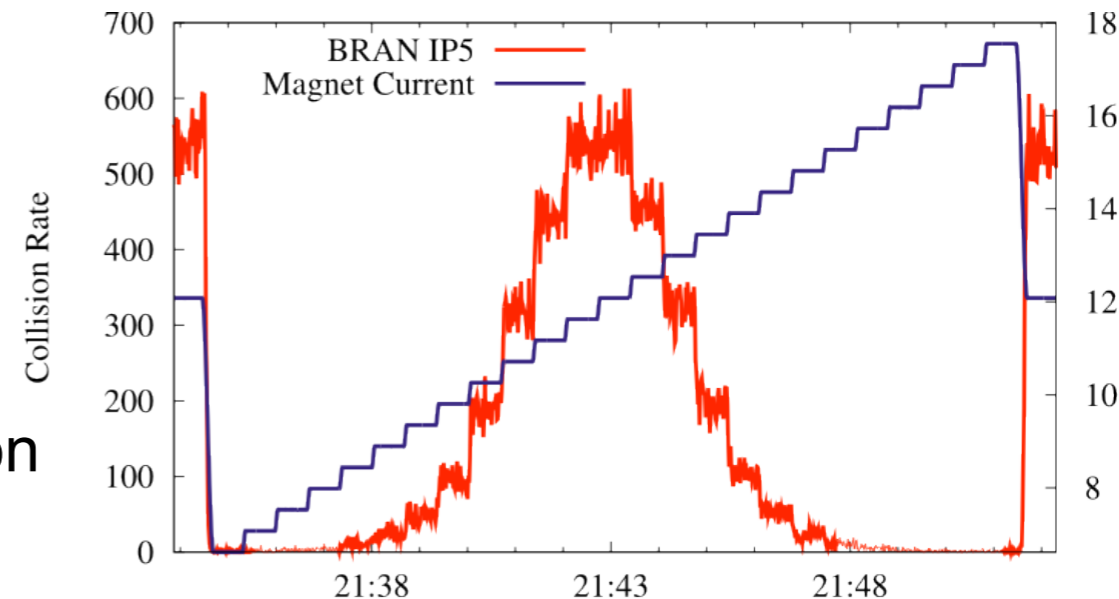
- **Length Scale Calibrations**

- Correlate beam movement with vertex offset



- **Other calibration effects**

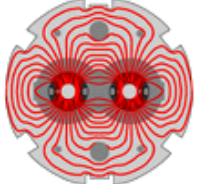
- Energy (Jorg), beam beam effects (Werner)



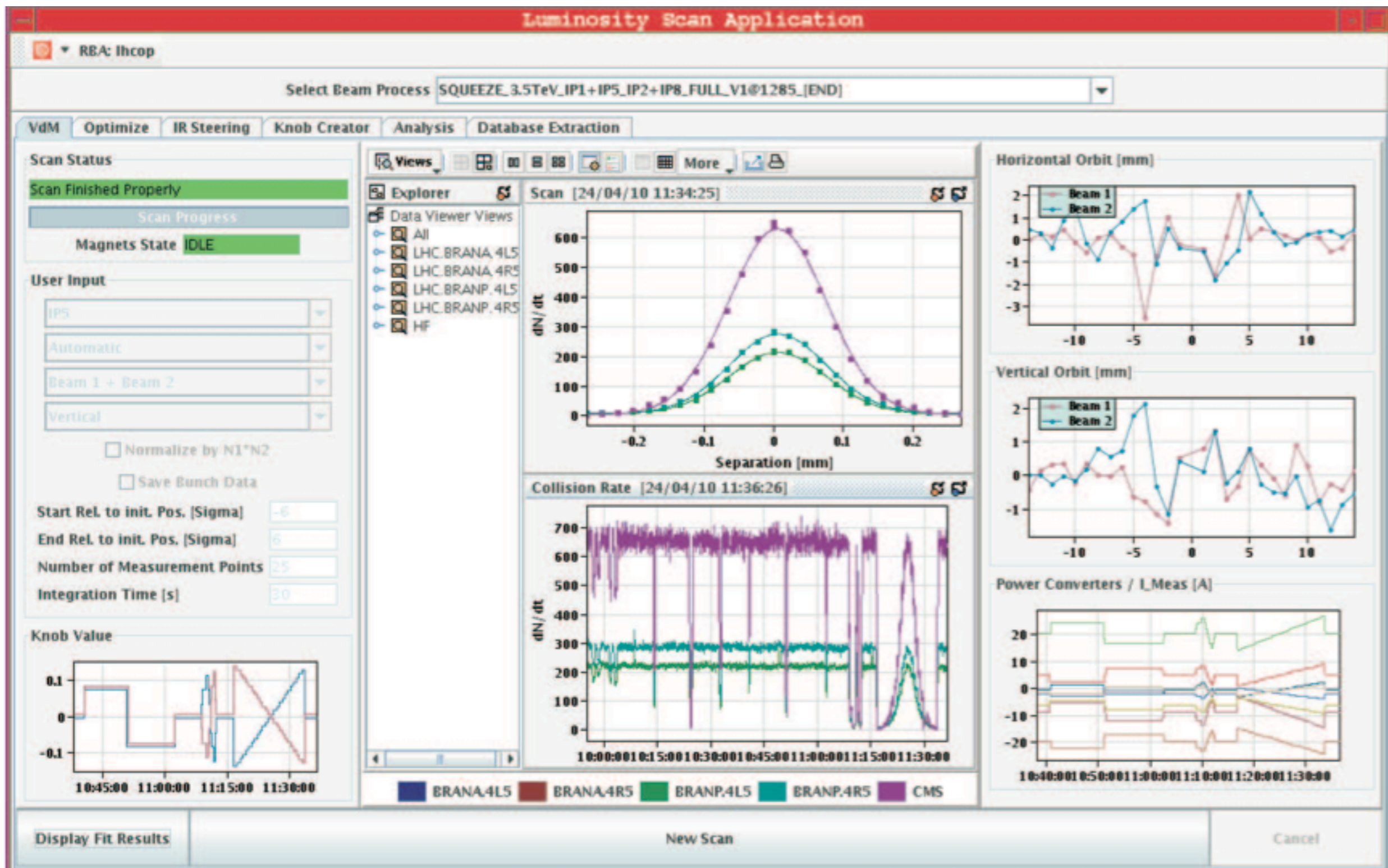
- VdM: Must guarantee Aperture Margin at IPs and TCTs

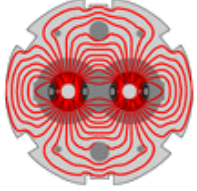
VdM: Aperture Margin OK for $\beta^* = 10\text{m}$ and $\beta^* = 0.6\text{m}$ @4 TeV

- VdM for $\beta^* = 0.6\text{m}$ uses $\sim 0.19\sigma$ @ TCT (Aperture budget is 0.2σ)



Luminosity Calibration





Luminosity Calibration

VdM Scans:

Scans in orthogonal planes

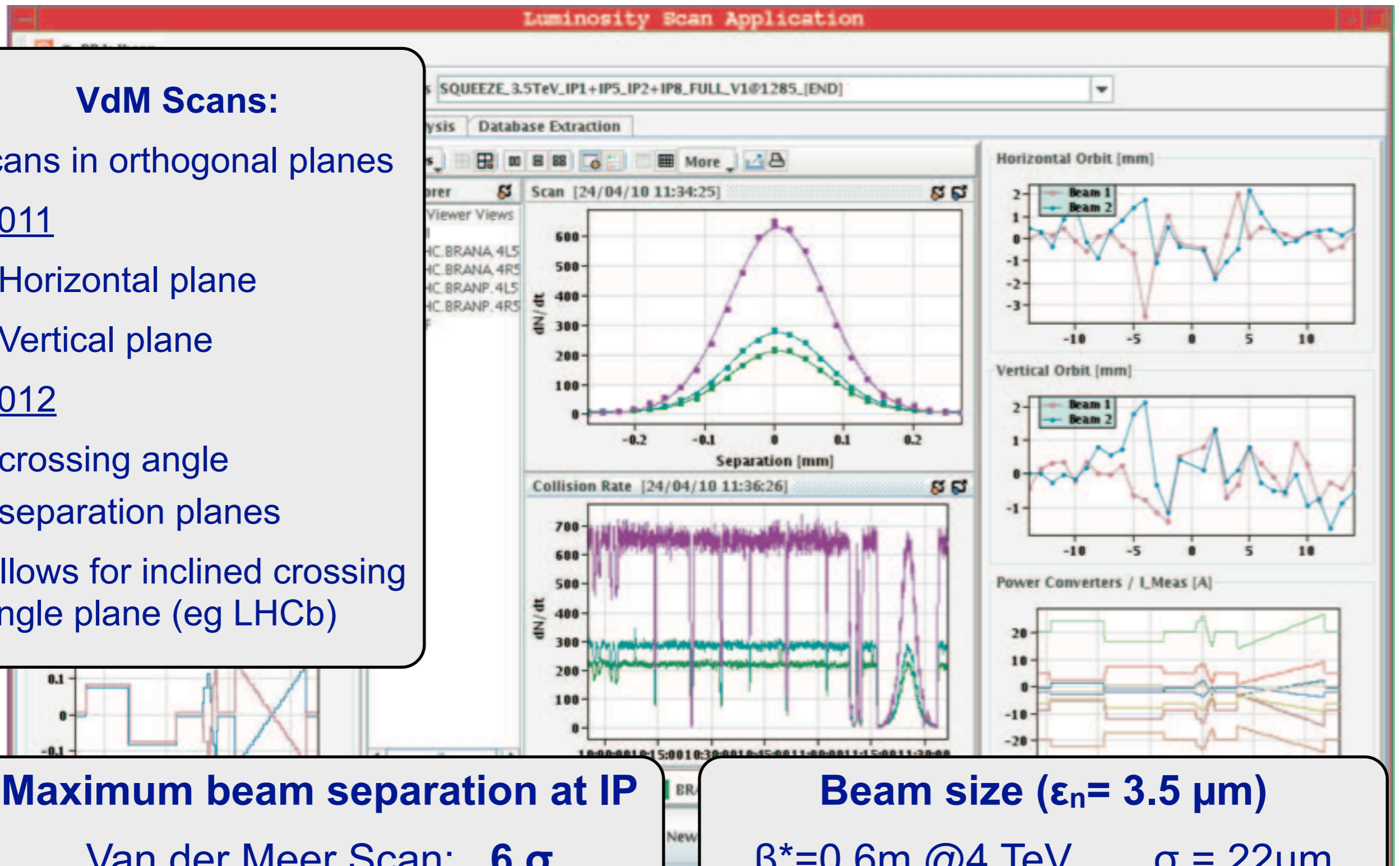
In 2011

- Horizontal plane
- Vertical plane

In 2012

- crossing angle
- separation planes

Allows for inclined crossing angle plane (eg LHCb)



Maximum beam separation at IP

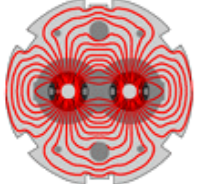
Van der Meer Scan: **6 σ**

Lumi Optimization: **2 σ**

Beam size ($\epsilon_n = 3.5 \mu\text{m}$)

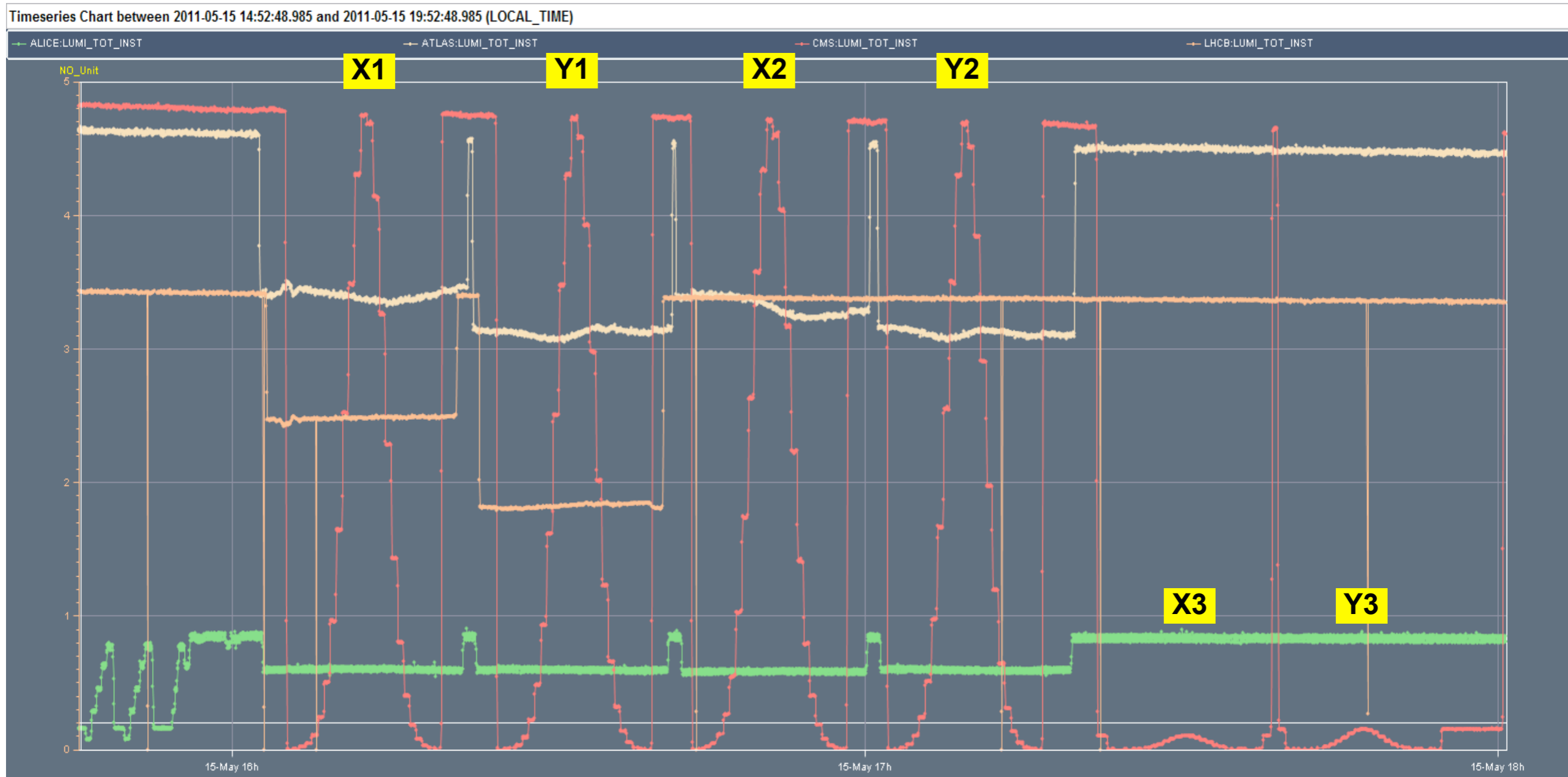
$\beta^* = 0.6\text{m}$ @4 TeV $\sigma = 22\mu\text{m}$

$\beta^* = 1.0\text{m}$ @3.5 TeV $\sigma = 31\mu\text{m}$



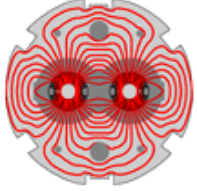
Van der Meer Scans in 2011

VdM at collision settings



VdM scans: Typically 2-beam symmetric.
 Max Beam separation = $\pm 6 \sigma$

VdM with offset in other plane
 Off set = 160 μ m



Example : VdM Scan in May 2011 (Fill 1783)

■ Conditions:

- p-p @3.5 TeV, β^* : 1.5/10/1.5/3 m $I_{\text{bunch}} \approx 0.8e11$
- Vdm Program Duration: **~11 hrs**
- Filling Scheme: Single_38b+1small_14_16_22_4bpi11inj

■ Scans per IP at collision settings:

- VdM **20** minutes each plane (H,V)
- H-plane VdM with V-offset: **15** minutes
- V-plane VdM with H-offset: **15** minutes

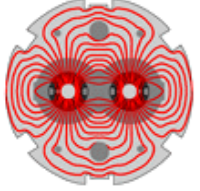
■ Length Scale Calibration (LSC)

- "Fast" LSC: **15** min per plane (full loop, and reversed)
- "Leap-frog" LSC: **2 hrs** per plane (Special request by ATLAS)

Minimum time for Lumi Calibration Run

$$\text{Duration} = 4 \times 2 \times (\text{VdM}_{1\text{-plane}}) + 4 \times 2 \times (\text{VdM}_{\text{offset}}) + 4 \times 2 \times \text{LSC}_{\text{Fast}} = \mathbf{400 \text{ min}}$$

=> **Lumi Calibration is possible in 1 shift ... But** special scan patterns take longer



Luminosity Scanning software improvements

■ Ongoing ...

- Ability to scan in crossing angle and separation planes (default)
 - implementation ongoing ...
 - depends somewhat on implementation of LHCb crossing angle rotation
- Luminosity Leveling functionality for all IPs
- Optimization Status to be published to Expts
- Ability to pause/resume VdM scan sequence

Details:

[EDMS Doc 1133551](#)

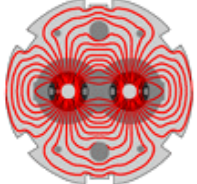
■ To be implemented ...

- Ability to load predefined scan sequence
 - Each expt can define its scan procedure
 - VdM scans with single or both beam trims
 - LSC scans with leap-frog or fixed separation method.
- Perform VdM scans at different IPs in parallel if requested
- Make available LUMI-SCAN trims to experiments

Details:

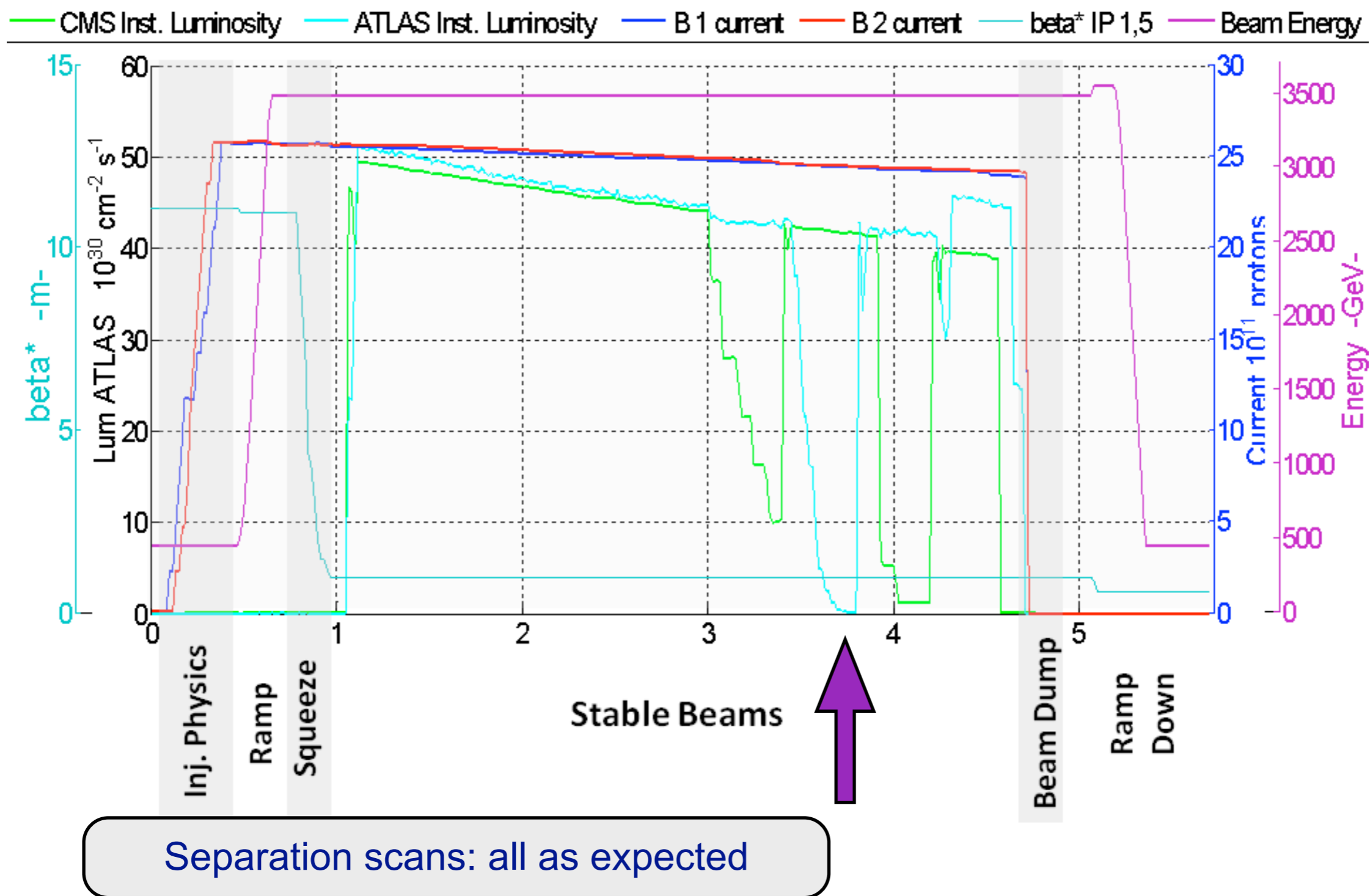
[EDMS Doc 1184480](#)

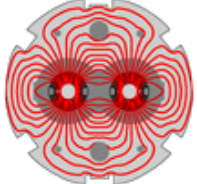
For 2012 startup, **standard functionality assured** but testing/validation needed for more complicated requests ... end of fill tests etc.



Note of caution ...

High Pileup run - FILL 2252: $N \approx 2.3 \cdot 10^{11}$ protons per bunch $\epsilon_n \approx 2.5 \mu\text{m}$

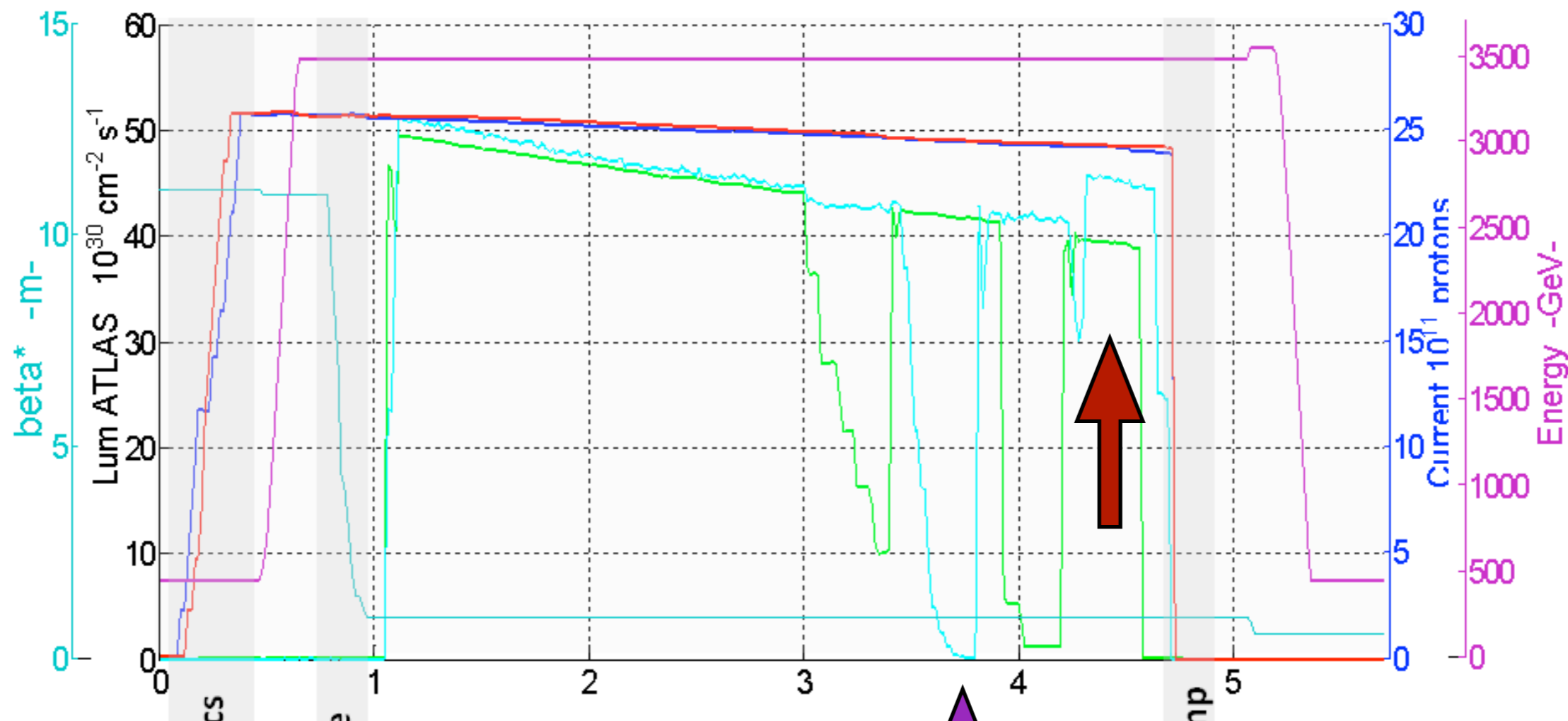




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CMS Inst. Luminosity ATLAS Inst. Luminosity B 1 current B 2 current beta* IP 1,5 Beam Energy

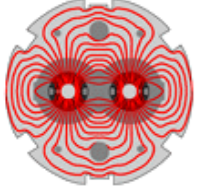


Separation scans: all as expected

Lumi re-optimization at EOF

- ATLAS shows a ~10% jump
- ATLAS confirms data is correct
- Reason: not optimised in vertical at start of fill

Special Runs: High β

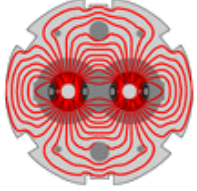


High β operation

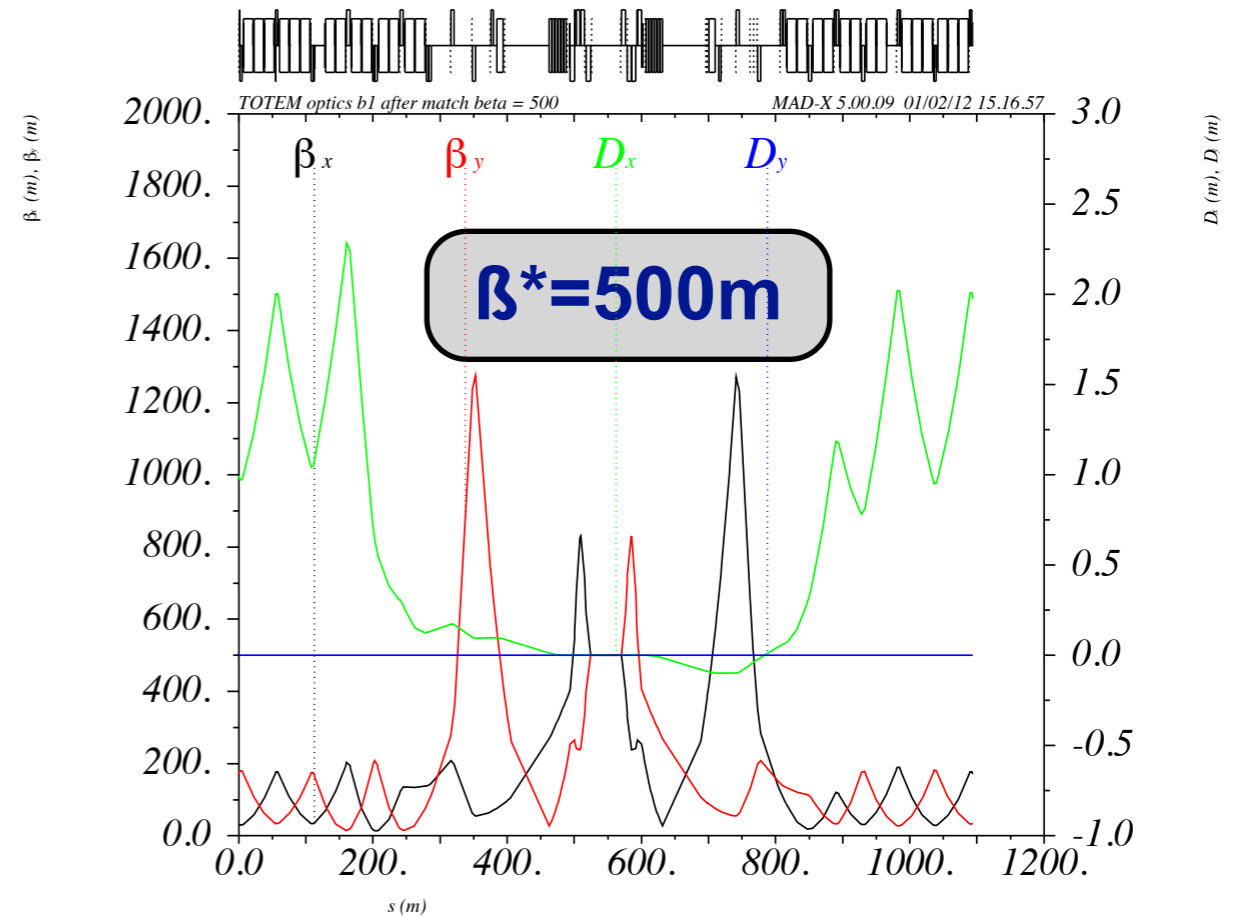
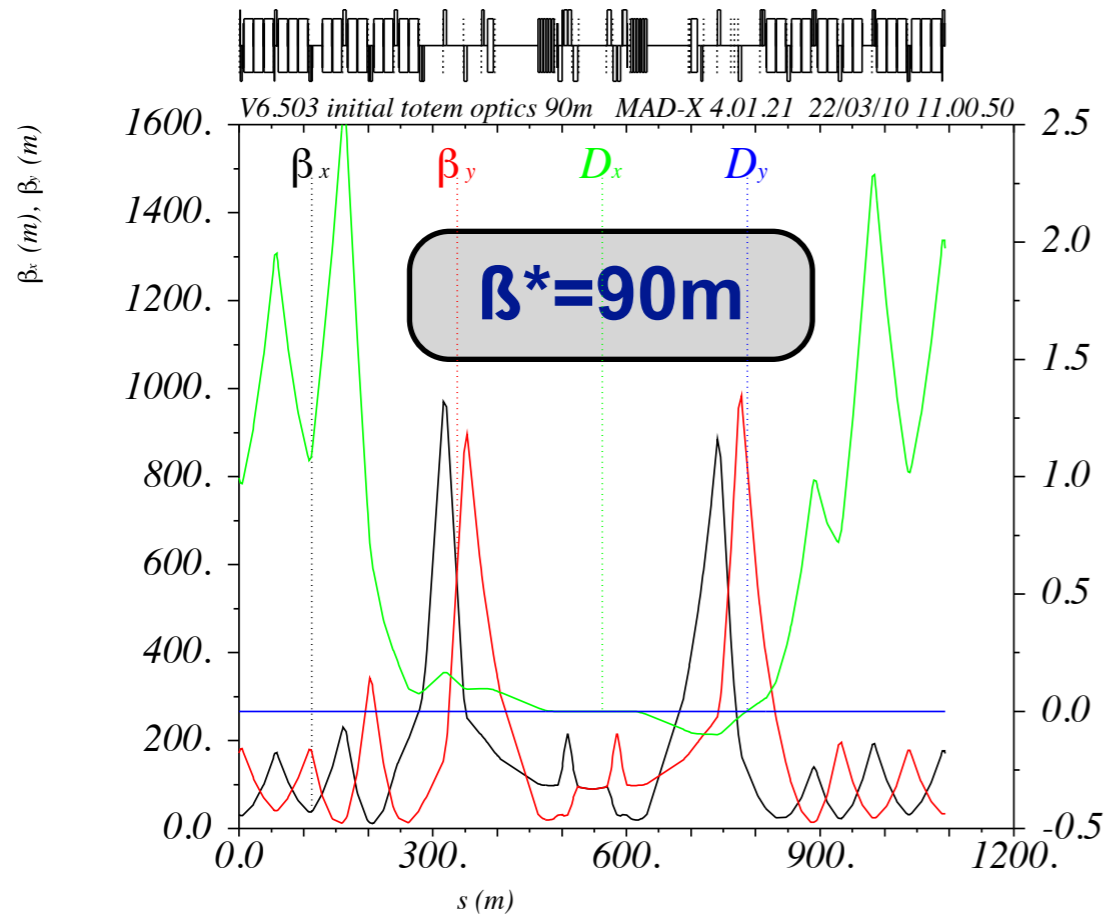
- High β operation is classified as Special Running
 - Physic coordinator defines priority: **~8 days** of Special Runs allocated
 - High β program: need Special Runs + Machine Development time to meet the physics program
 - Only one of physics run can be supported within present schedule
 - **Proposal:** A mixed setup with **90m in IP5** and **500m in IP1**

- Setup time for High β
 - $\beta=90\text{m}$: Re-commission the de-squeeze for 4TeV
 - $\beta=500\text{m}$: full commission of the de-squeeze for 4TeV
 - Preparation: New optics and extended operational sequence
 - Setup:
 - Full commissioning of new de-squeeze
 - Orbit + optics checks at matched points

 - De-squeeze to 90 and 500 m will be commissioned together.



High β^* optics: going from 90m to 500m



■ De-squeeze to 90 m (as usual) then extend to 500m in steps

□ At each Step (matched point)

- Require vertical phase advance (IP to RP) $\Delta\mu_v = 90^\circ$. No constraint on $\Delta\mu_H$
- Cabling constraint on Beam1:Beam2 ratio of Quadruple strengths (Q4 to Q8)

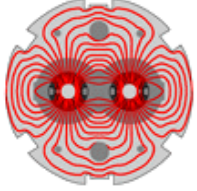
□ $0.5 < k_{b1}/k_{b2} < 2.0$

□ Current basis and status :

■ Optics: 1st iteration exists optics for $\beta^* = 90 - 500$ m sequence

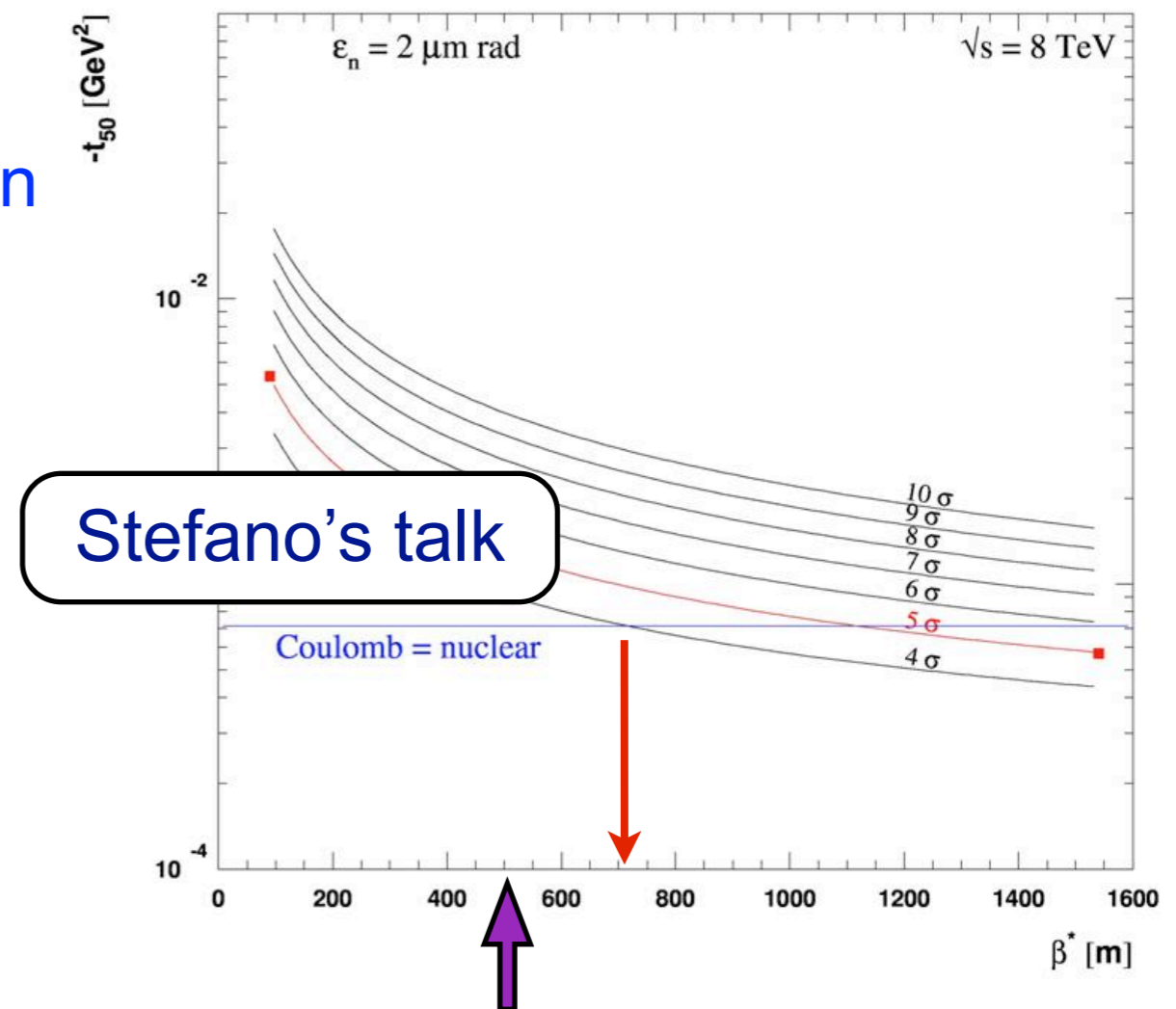
- All constraints satisfied, but smoothing and validating required

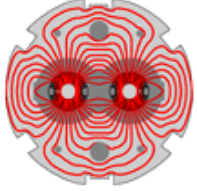
Talks by Helmut and Sophie



Operational Issues

- De-Squeeze sequence
 - ~17 match points to go from β^* of 10m to 500m
- Orbit control:
 - Need regular orbit control/correction
 - Constraint
 - de-squeeze beam separation ~ 2mm
- Get Roman Pots close to beam
 - Possibility of scraping to $\epsilon_n \sim 1 \mu\text{m}$
 - Try to probe Coulomb region
- Setups for High β runs
 - $I_{\text{bunch}} \sim 3 \times 10^{10}$
 - no crossing angle => up to 156 bunches.
 - Equipment setup: ADT, Feedbacks, BCTs, BPMs
 - Only standard equipment re-configurations



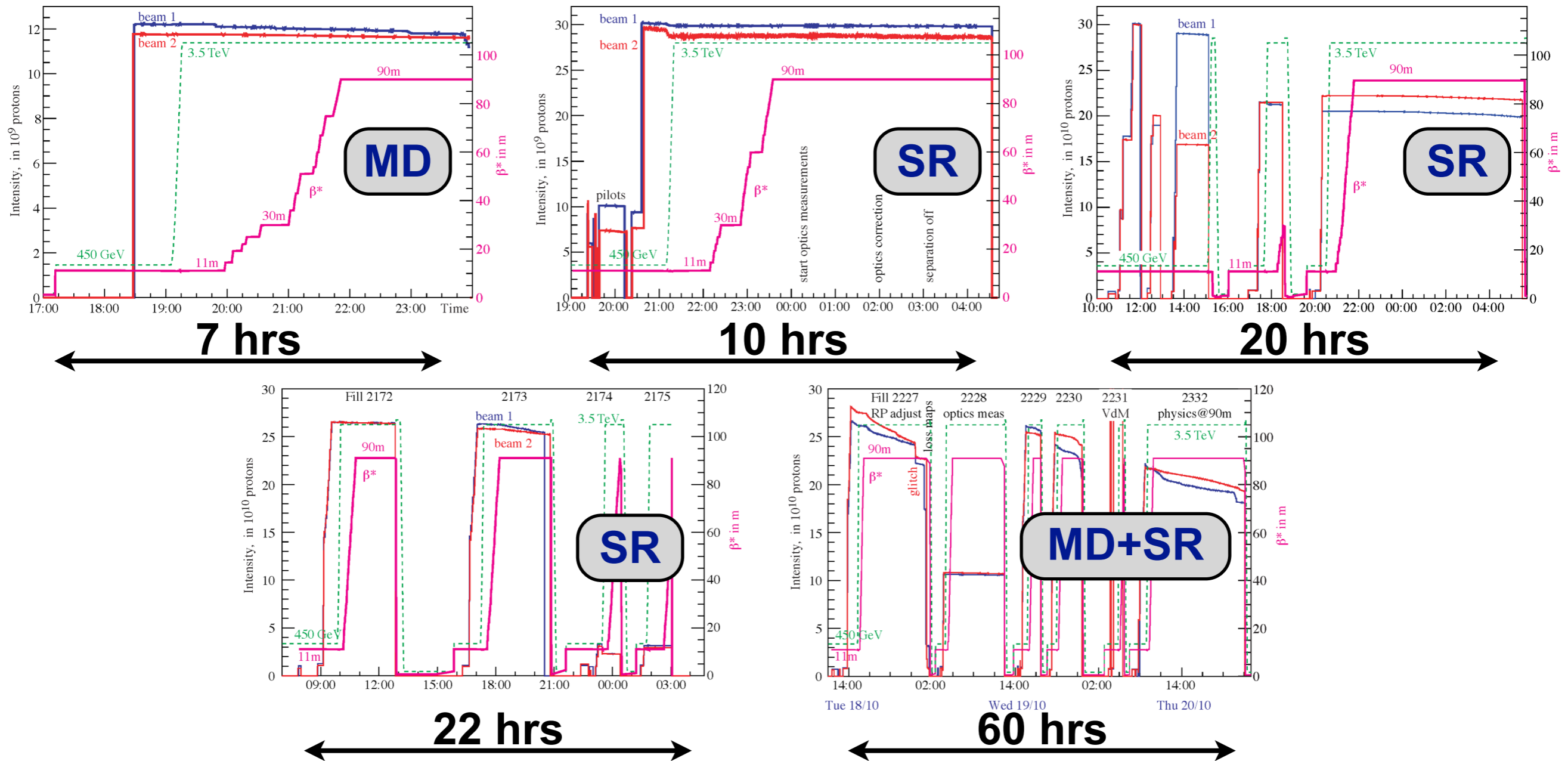


High β commissioning ... time estimates

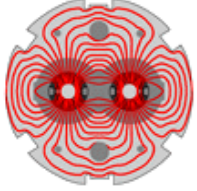
- Fill 1: Established feasibility, first optics measurements **(1-2 shifts)**
 - Probe beams. Several de-squeezes probably needed
- Fill 2: Validate operational sequence all the way to collisions. **(1 shift)**
 - Probe beams
- Fill 3: Beam based alignment of Roman Pots **(1 shift)**
 - Few nominal bunches
 - Optics measurements and checks
- Fill 4: Roman Pots to "physics" settings => validate stable beams **(1 shift)**
 - 10-20 nominal bunches.
 - Complete set of loss maps in physics settings + Async dump test
- Fill 5: Stable beams running at High β setting with Roman Pots in **(1 shift)**
 - Optional: Make luminosity calibration measurements (VdM and Length Scale Calib) in IP8 & IP2 while taking physics data in IP1&5

Total high β setup time (optimistic): 5+1 non-consecutive shifts

High β running: Experience from 2011



- Total High $\beta^*=90\text{m}$ time: 119 hrs - 15hrs physics = **104 hrs ~13 shifts**
 - Time spread over 5 periods
 - No beam dumps directly triggered by the β^* de-squeeze.
- Expectation for 2012:
 - Commissioning of $\beta^*=500\text{m}$ should take about the same time ...



Summary

■ 2012 Standard operation

□ The 2012 LHC priority is to deliver luminosity

- **5 fb⁻¹ by June is tough:** 8 wks @ $\beta^*=0.6\text{m}$ $I_{\text{bunch}}=1.6\text{e}11 \Rightarrow L_{\text{DEL}} \sim 6.6 \text{ fb}^{-1}$

- Commission to $\beta^*=60 \text{ cm}$. Decide on β^* then intensity ramp up

- Adiabatic increase of I_{bunch} up to $1.6\text{e}11$ (as machine permits)

□ Optimization of operational cycle

- Turnaround trimmed & Minimal procedure to declare stable beams

□ Rotation of LHCb crossing angle

- Details and procedure still being finalized

■ Special runs: Priorities mostly set. Now scheduling needed

□ Lumi Calibration: Firm up details on what and when

□ Lumi Scan and VdM software upgrade is ongoing ...

- Lumi leveling functionality for all IPs

□ High β : Only 1 run seems likely \Rightarrow confirm required configuration

- ie $\beta=90\text{m}$ for TOTEM and $\beta=500 \text{ m}$ for ALFA, no pilots, $I_{\text{bunch}} \sim 3\text{e}10$ etc

- **Optics for $\beta=500 \text{ m}$ is in good shape.**