Collimation Aspects in the LHC and SPS

Frederik Van der Veken, R. Alemany Fernandez, F. Asvesta, H. Bartosik, R. Bruce, J. Flowerdew, A. Lasheen, K. Li, B. Lindström, P. Hermes, D. Mirarchi, C.E. Montanari, M. Patecki, M. Rakic, S. Redaelli, N. Triantafyllou

- *on behalf of the collimation and OP teams*

JAP '24   11/12/2024

Outline

LHC performance in 2024

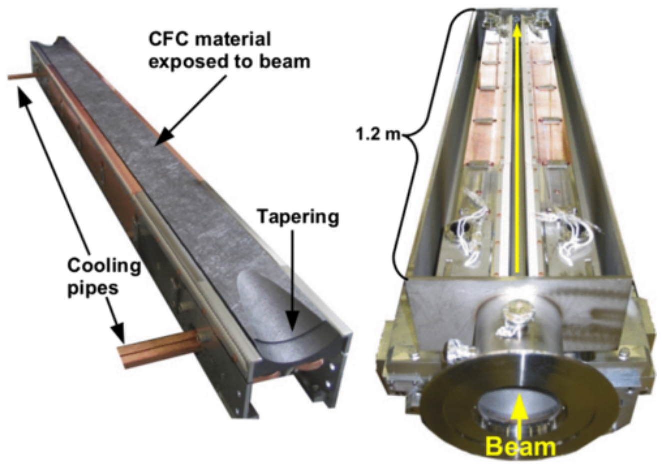
Charaterisation of LHC-type beams

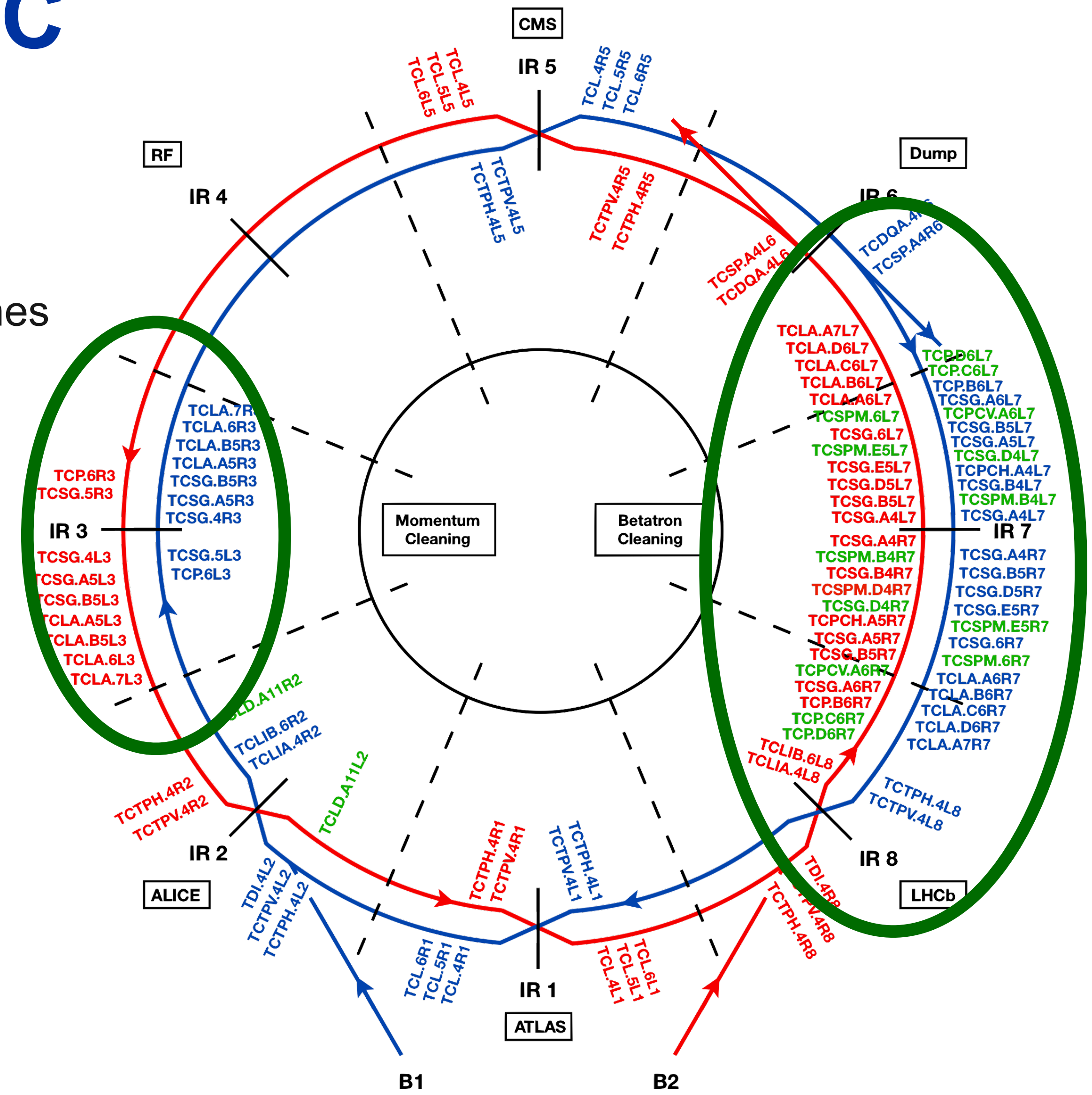
Modelling losses in CERN's accelerators

Are ready for the future?

Collimation System at the LHC

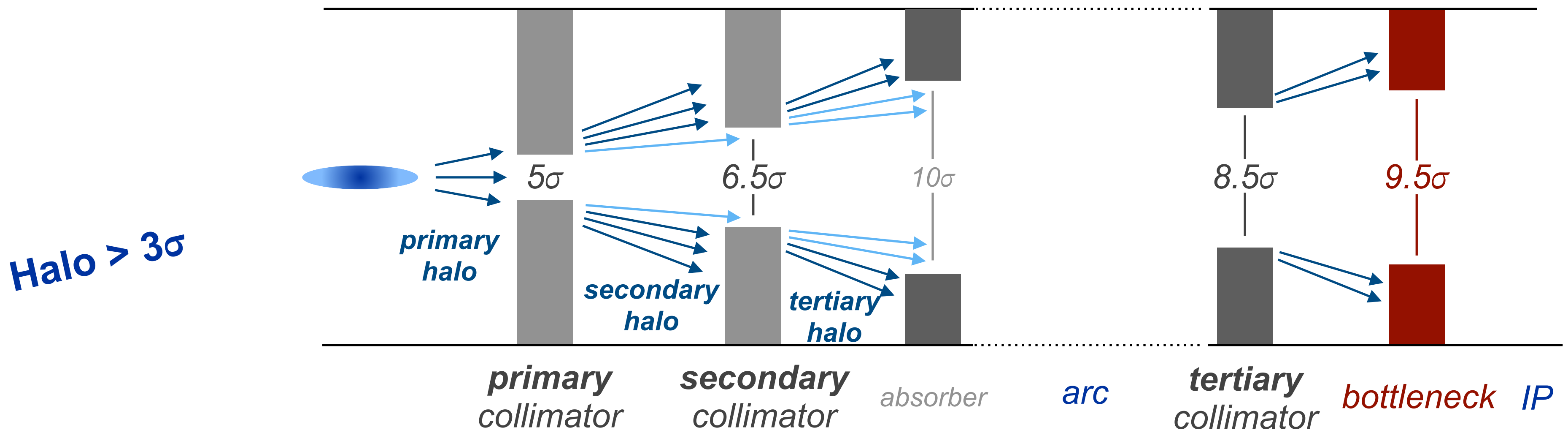
- More than **400MJ** stored beam energy in LHC
  (up to 700MJ for HL-LHC)!
- 101 collimators to protect machine against damage and quenches
- Multi-stage system, mainly in **IR7** and **IR3**:
  - **Primary** collimators closest to the beam
  - **Secondary** and **tertiary** collimators to intercept showers, protect the IPs, and reduce the background





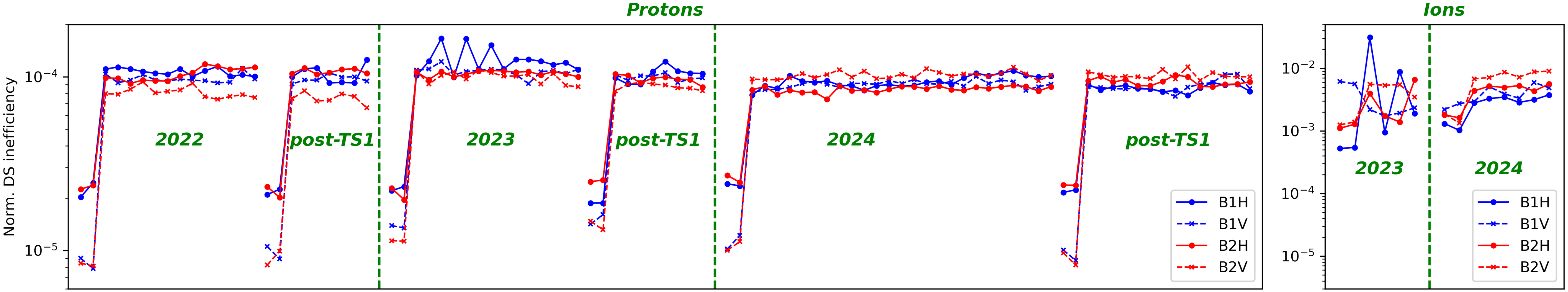
Collimation Hierarchy and Transverse Beam Halo

- Collimators follow **strict hierarchy**: primary - secondary - tertiary
  - *Collimator layout is designed at optimal phase advances to ensure good cleaning*
- **Aligned** around beam centre, opening defined in **beam size**
  - *Bunch-dependent orbit shifts make each bunch see a different collimator cut!*



Settings at 30cm [σ]	
TCP.7	5σ
TCS.7	6.5σ
TCLA.7	10σ
TCP.3	15σ
TCS.3	18σ
TCLA.3	20σ
IR6	7.3σ
TCT.1/5	8.5σ (8σ)
TCT.2	37σ
TCT.8	11.5σ

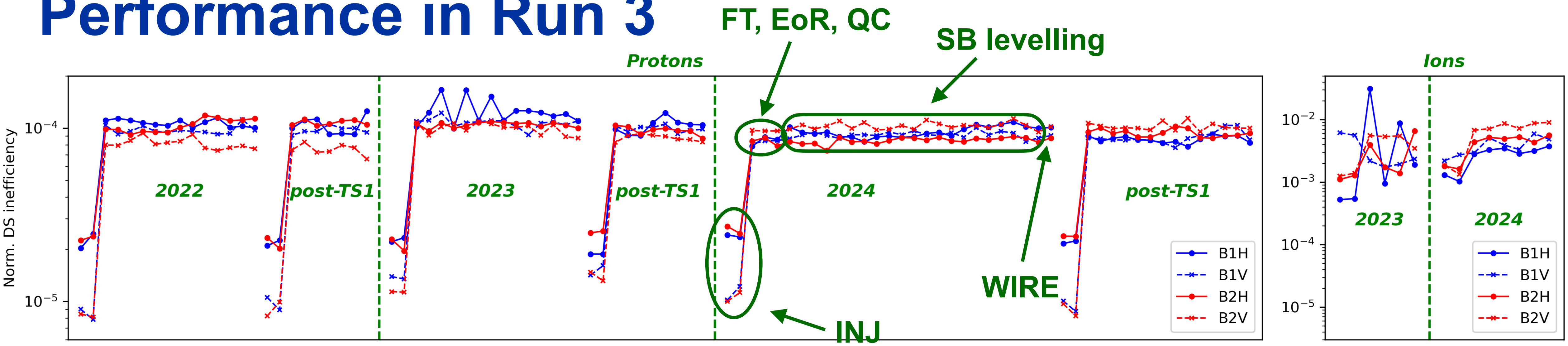
Performance in Run 3



- Very **stable performance** of losses in the DS during Run 3:
  - Proton losses very similar over various qualifications
  - Ion losses vary more, but remain at same order
  - Fluctuations in 2023 were **revalidated** after realignment

courtesy of P. Hermes

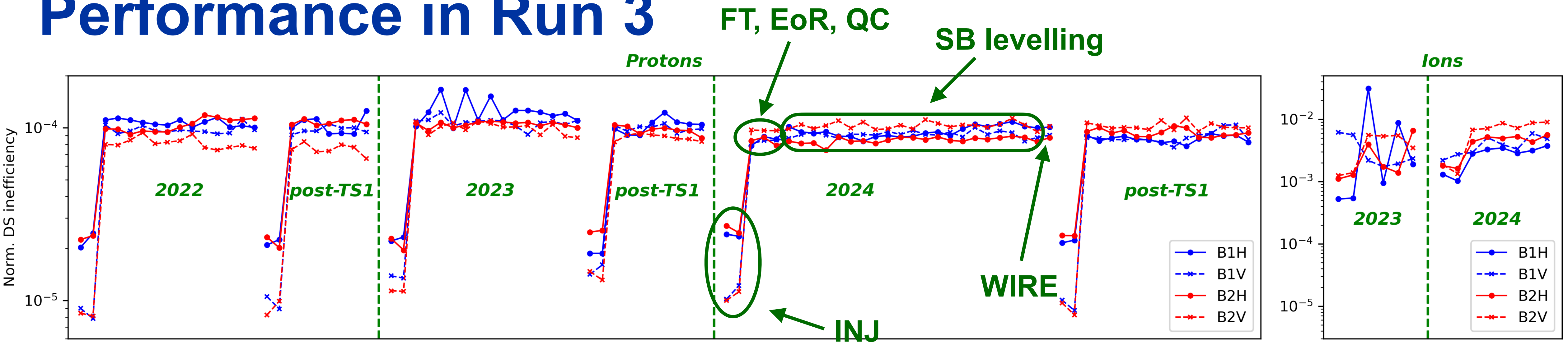
Performance in Run 3



- Very **stable performance** of losses in the DS during Run 3:
  - Proton losses very similar over various qualifications
  - Ion losses vary more, but remain at same order
  - Fluctuations in 2023 were **revalidated** after realignment

courtesy of P. Hermes

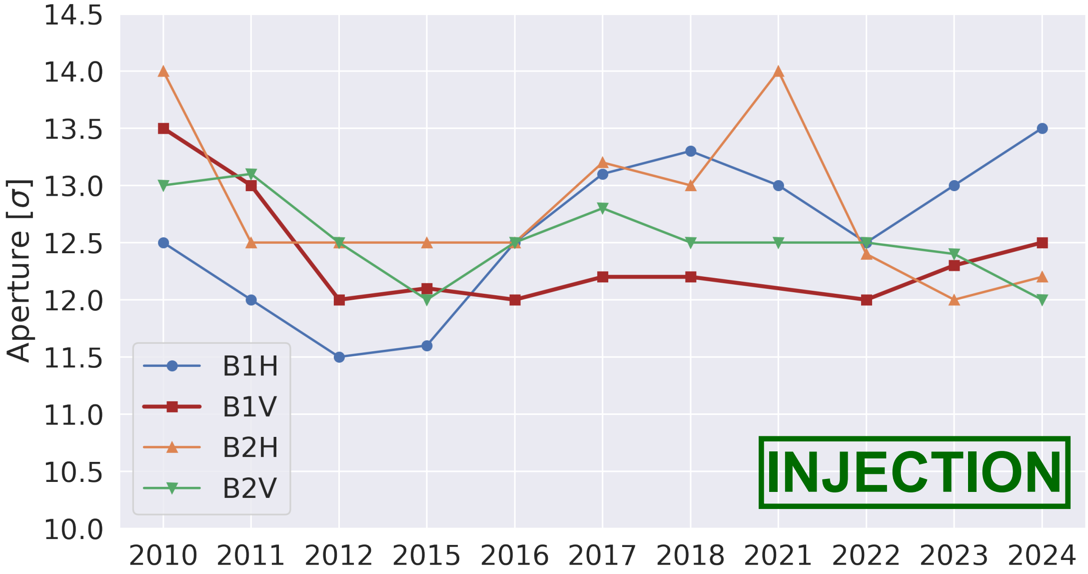
Performance in Run 3



- Very **stable performance** of losses in the DS during Run 3:
  - Proton losses very similar over various qualifications
  - Ion losses vary more, but remain at same order
  - Fluctuations in 2023 were **revalidated** after realignment

- Aperture measurements **consistent** over the years:
  - Consistently sufficient aperture at injection
  - Vertical aperture at 30cm slighly reduced with RP

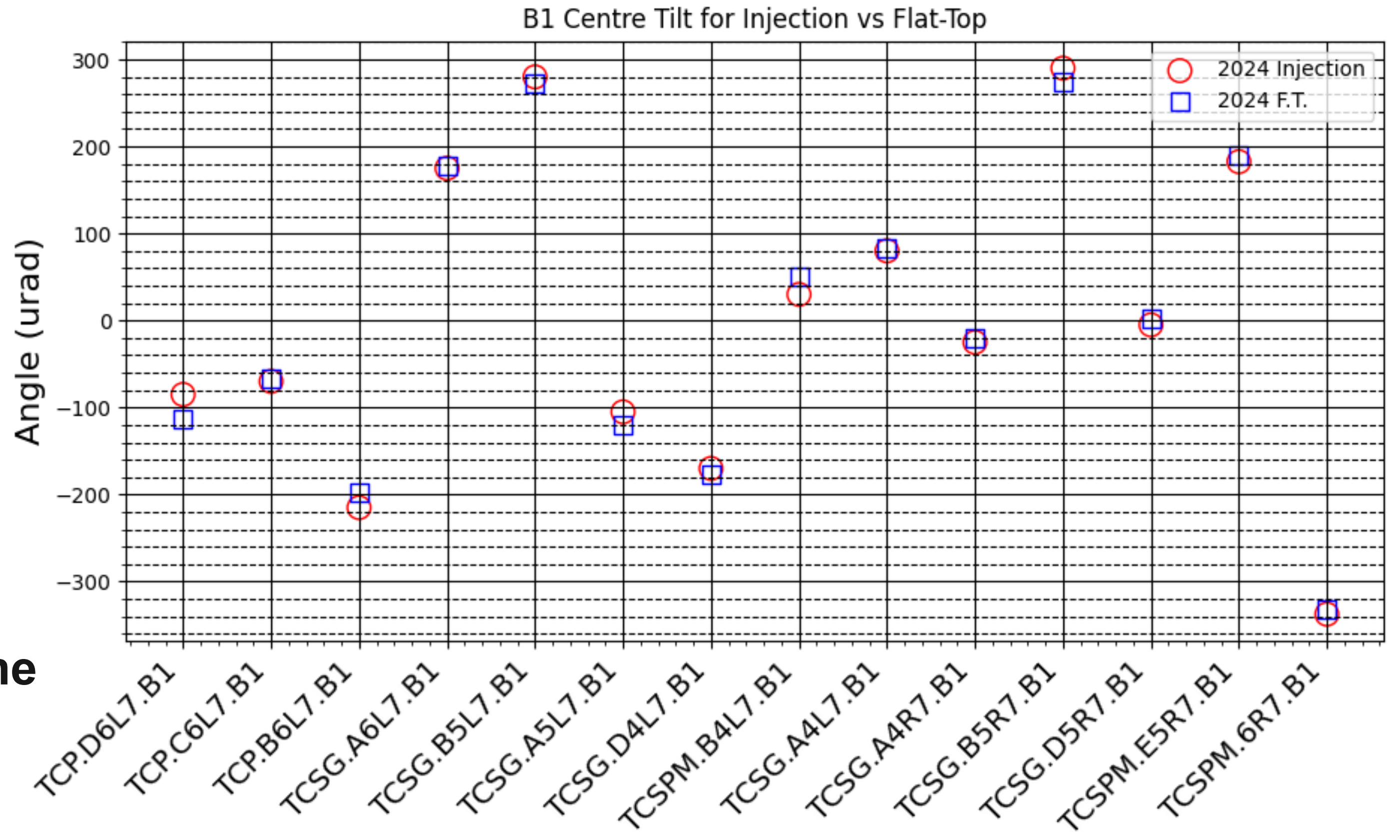
    → *adapted TCT settings and xing angle*



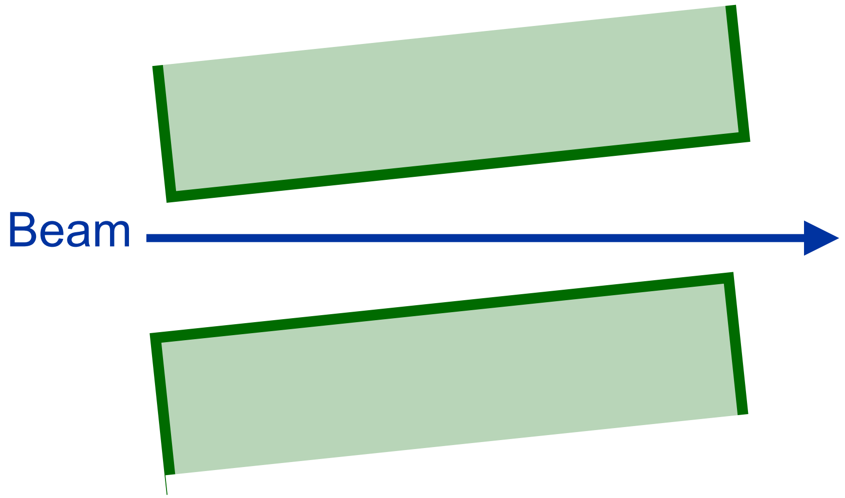
courtesy of P. Hermes

Angular Alignment

- Investigated collimator tilts in IR7 (TCP and TCSG)
- Angular alignment expected to **improve cleaning** and long-term performance
- Tilt at injection and flat top are **similar** hence probably **mechanical** origin
- Applied tilt corrections in operation **for first time**

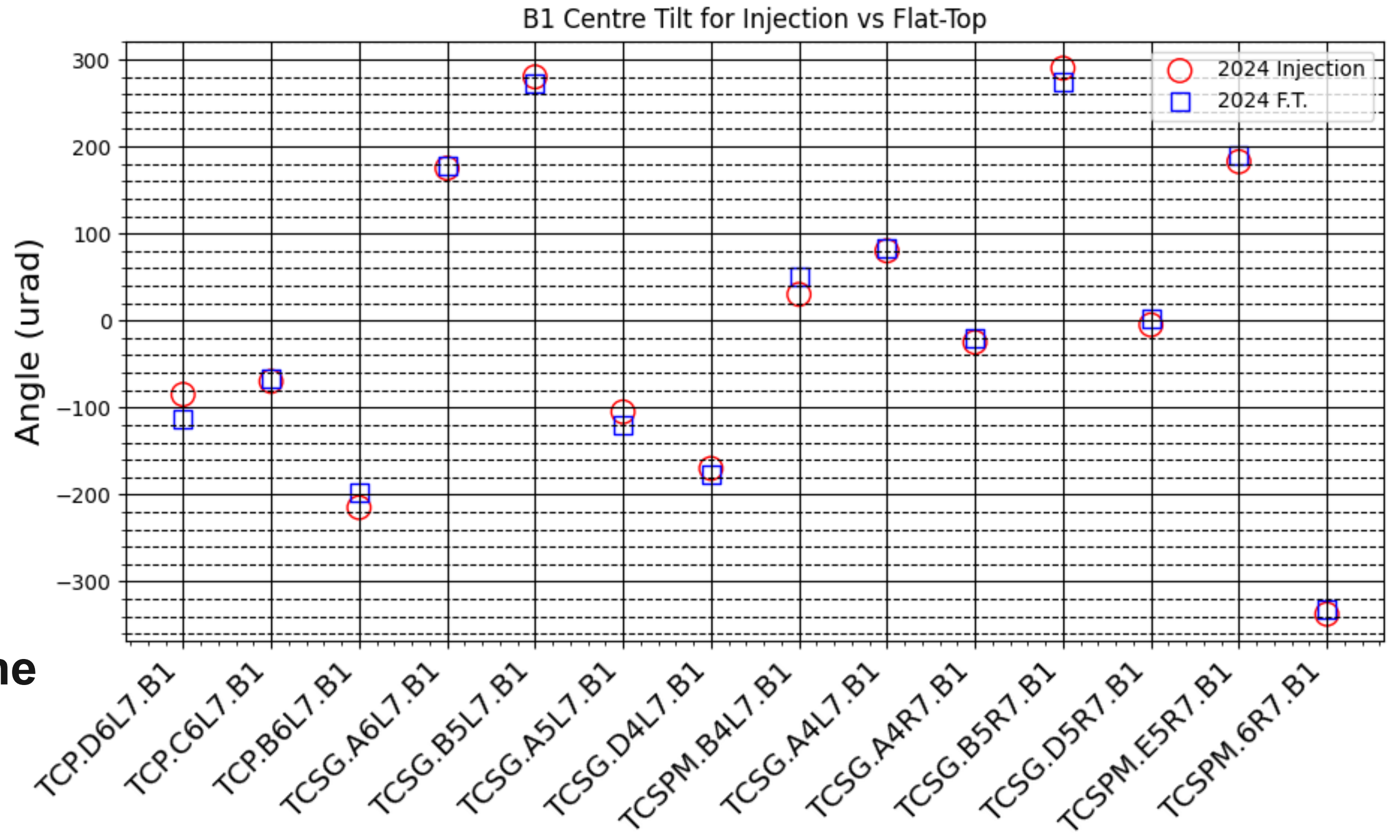


courtesy of A. Vella

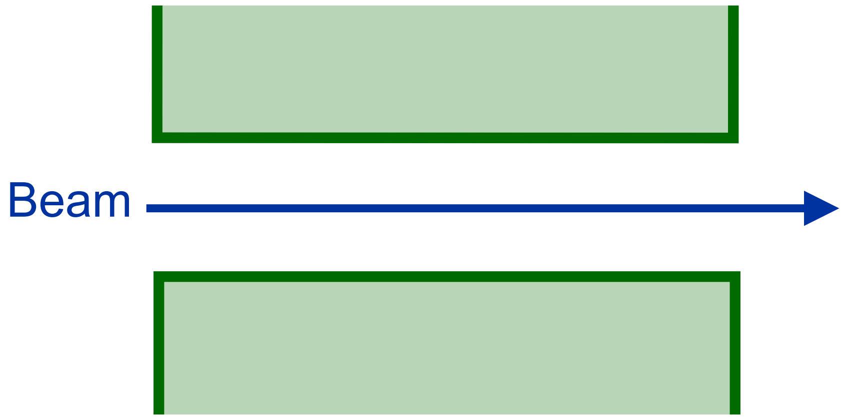


Angular Alignment

- Investigated collimator tilts in IR7 (TCP and TCSG)
- Angular alignment expected to **improve cleaning** and long-term performance
- Tilt at injection and flat top are **similar** hence probably **mechanical** origin
- Applied tilt corrections in operation **for first time**

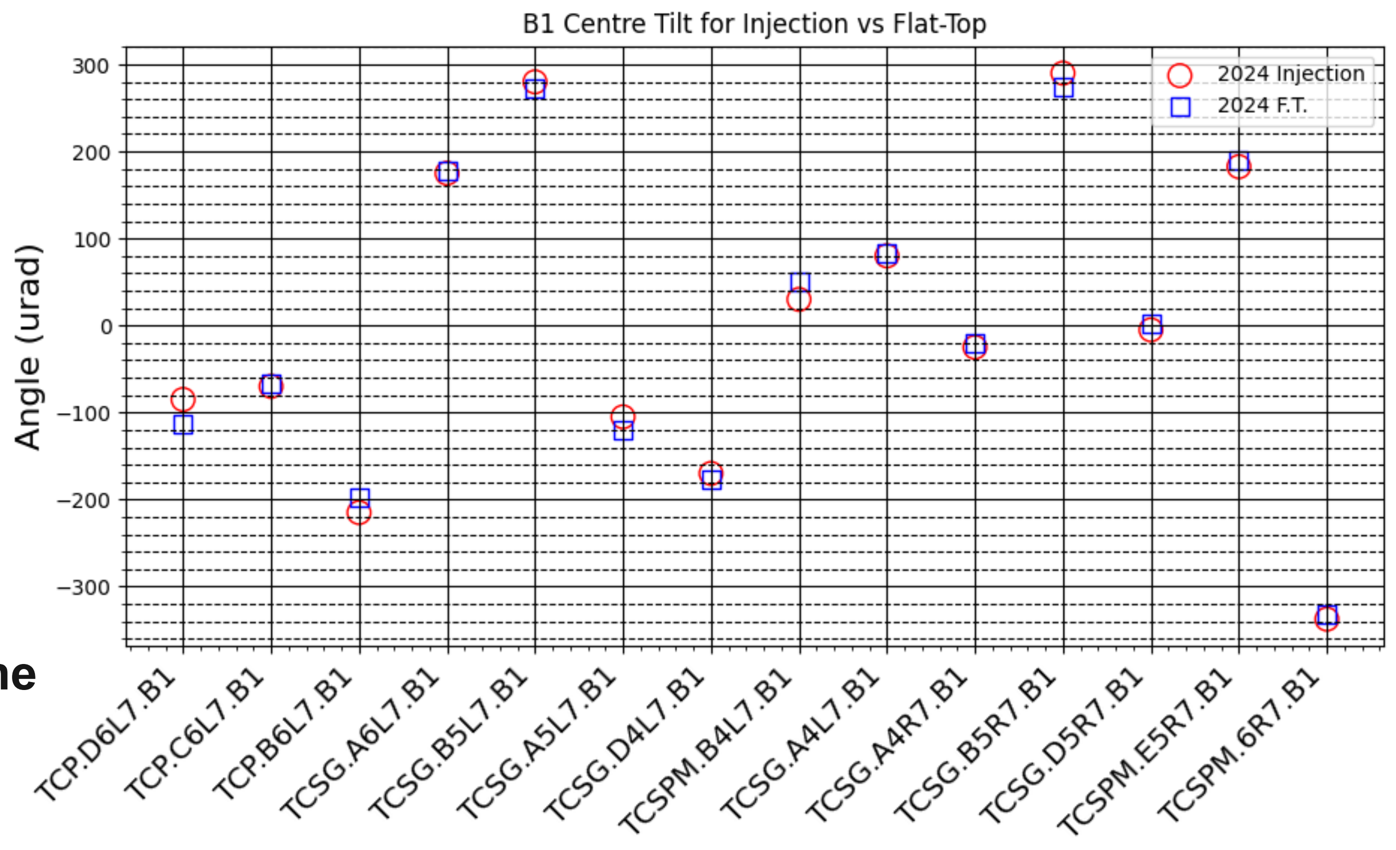


courtesy of A. Vella

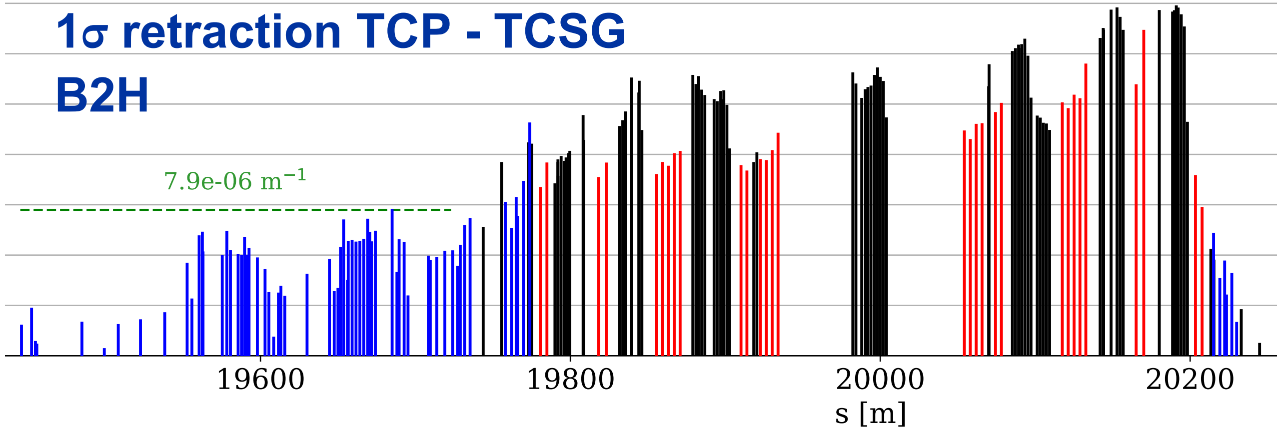


Angular Alignment

- Investigated collimator tilts in IR7 (TCP and TCSG)
- Angular alignment expected to **improve cleaning** and long-term performance
- Tilt at injection and flat top are **similar** hence probably **mechanical** origin
- Applied tilt corrections in operation **for first time**



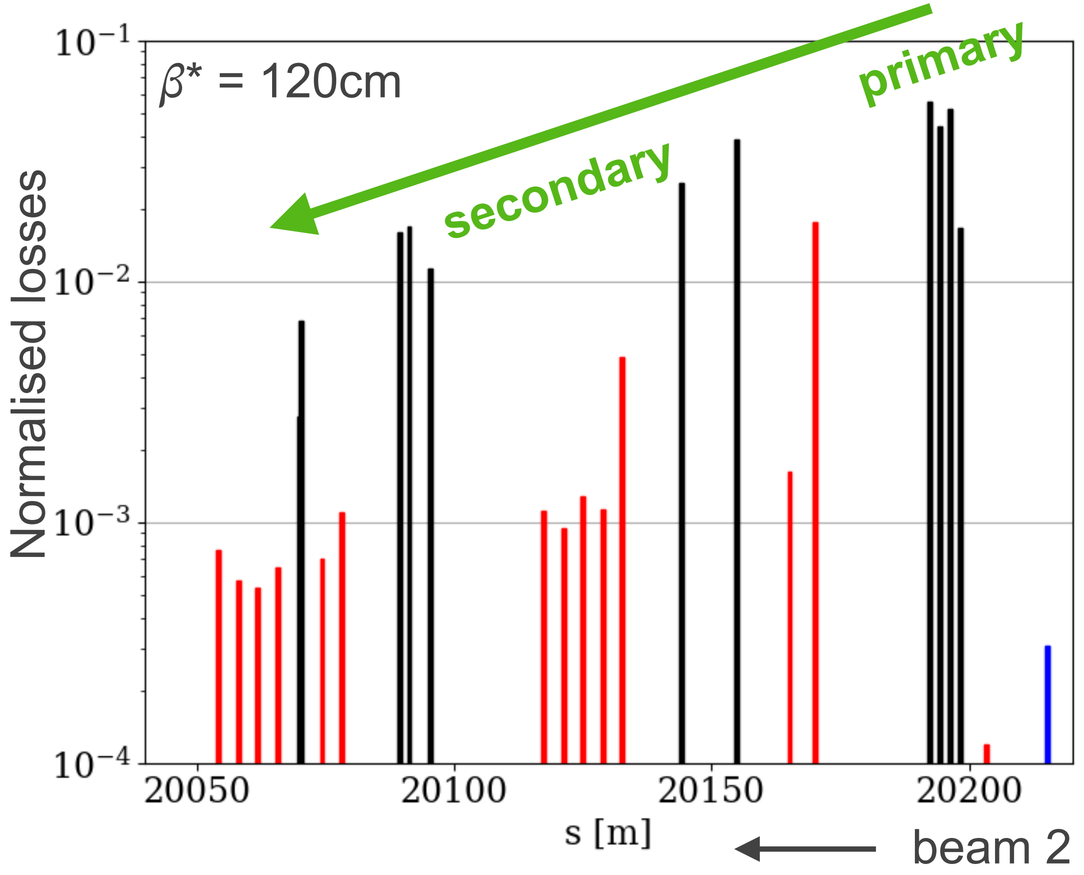
courtesy of A. Vella



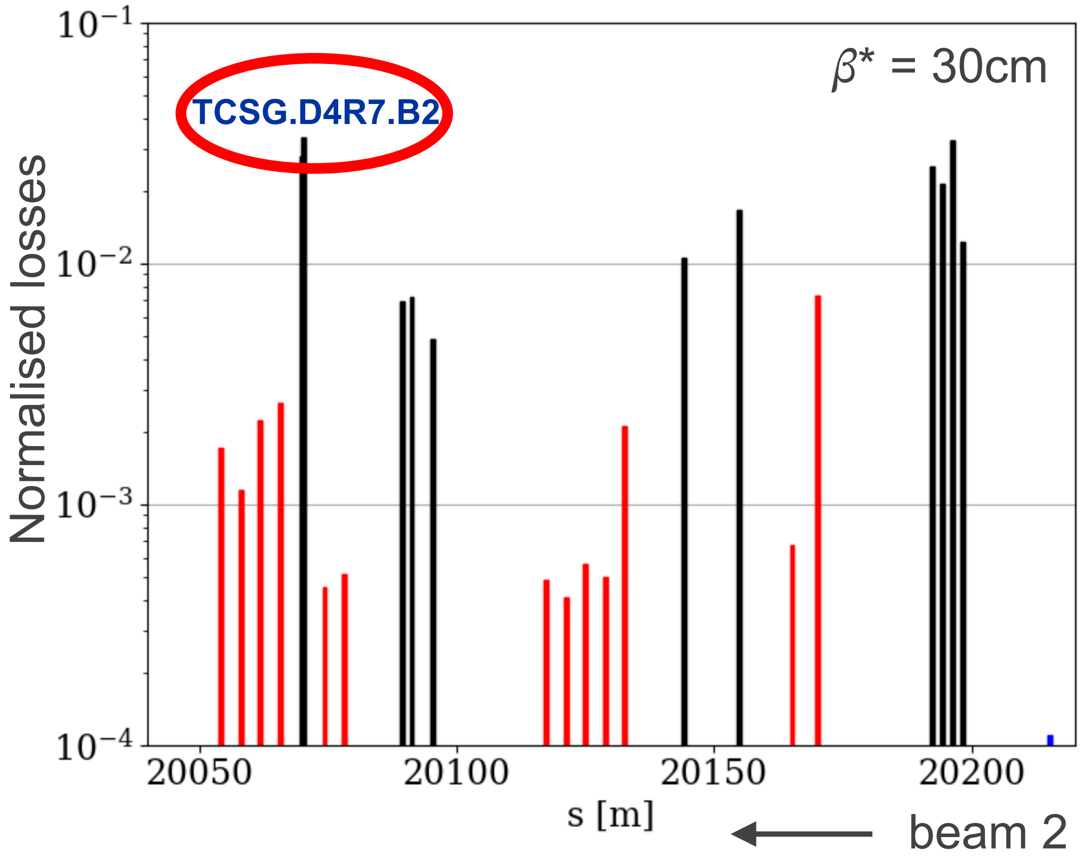
- Opening doors to **tighter hierarchy!**
- Promising results (tests during commissioning):
  - Up to **20%** losses shift from DS to coll (B2H)
- **Validated** for high intensity for MD12663!

Hierarchy Breaking at the LHC

Good Hierarchy

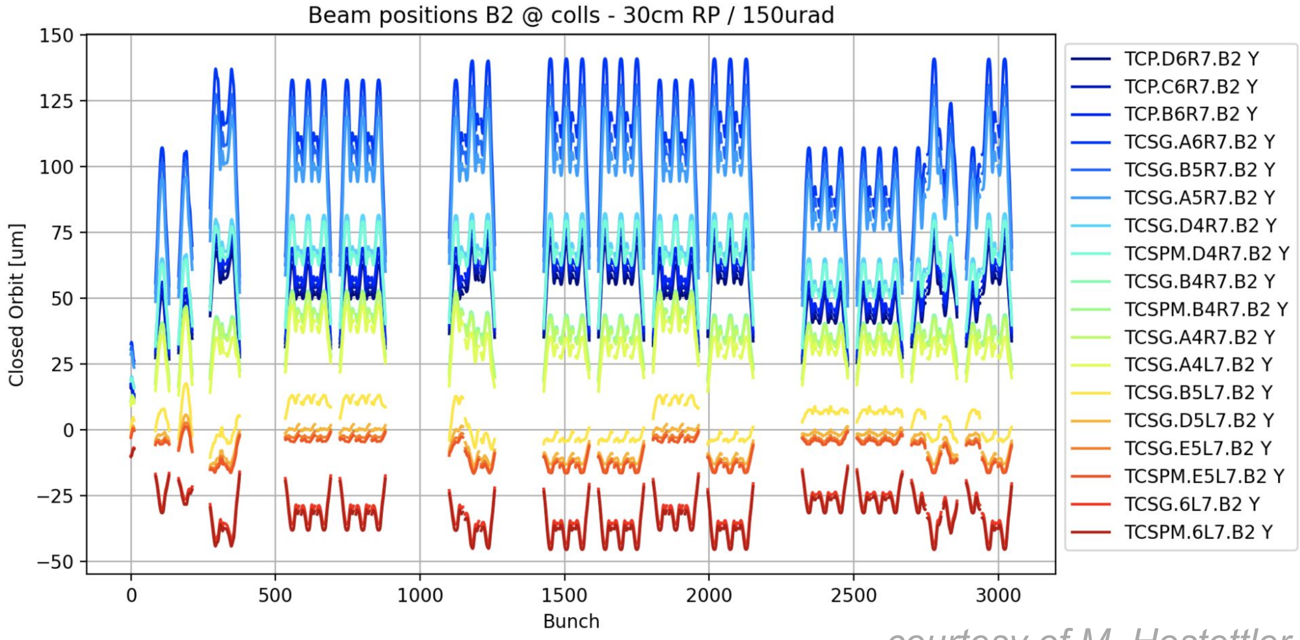


Broken Hierarchy



Collimation Commissioning vs Operation

- Collimation system commissioned (alignment, loss maps) with:
  - Low non-linearities → *but high NL can **move losses** (TDIS 2022)*
  - Individual bunches → *but trains have* | ***orbit shifts***
*high-intensity **beam-beam** effects*

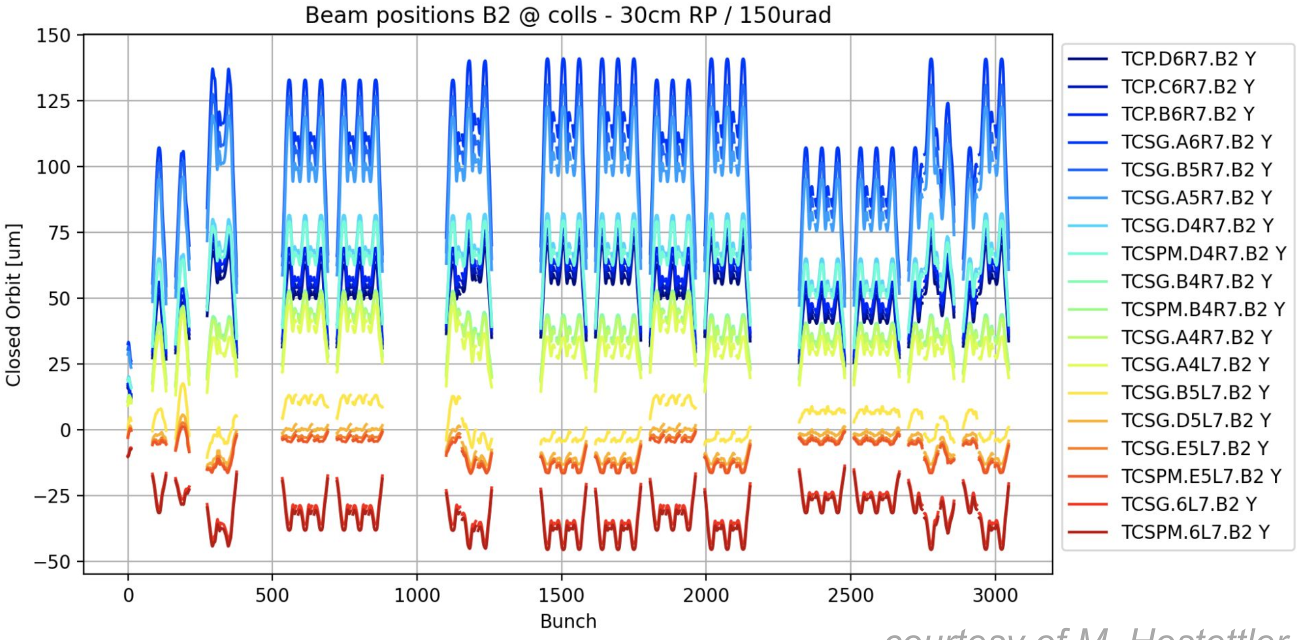


courtesy of M. Hostettler

Collimation Commissioning vs Operation

INDIV (low NL)
≠
INDIV (high NL)
≠
TRAIN

- Collimation system commissioned (alignment, loss maps) with:
  - Low non-linearities → *but high NL can **move losses** (TDIS 2022)*
  - Individual bunches → *but trains have | **orbit shifts** / high-intensity **beam-beam** effects*

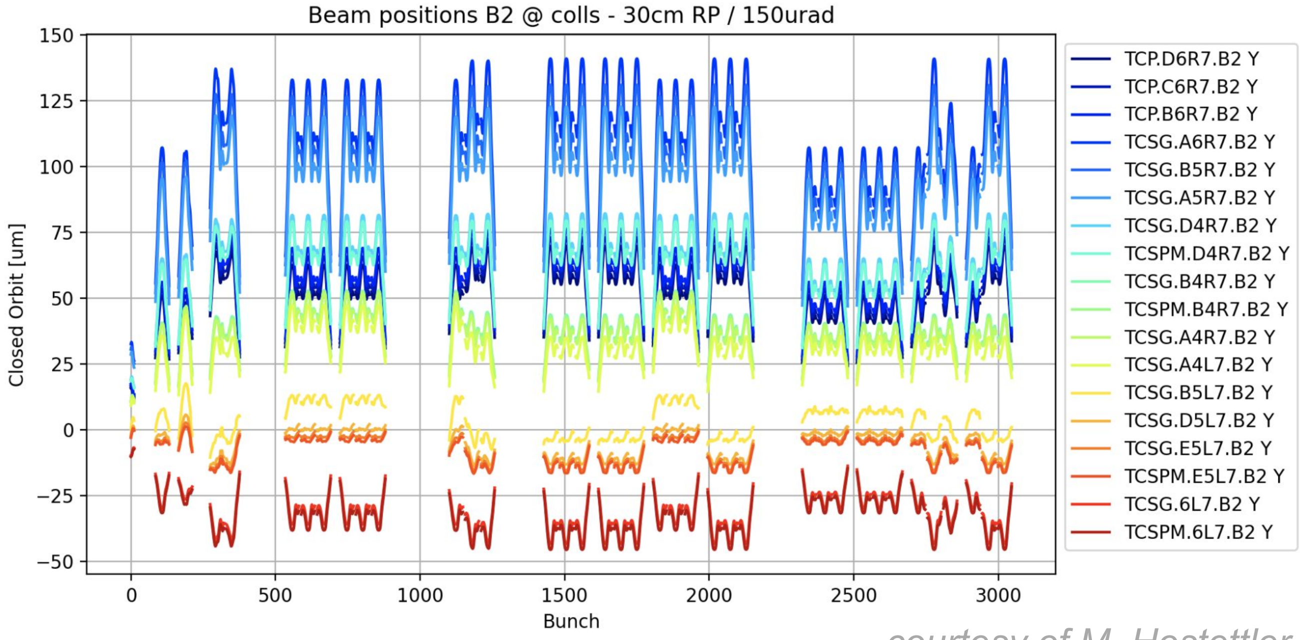


courtesy of M. Hostettler

Collimation Commissioning vs Operation

INDIV (low NL)
≠
INDIV (high NL)
≠
TRAIN

- Collimation system commissioned (alignment, loss maps) with:
  - Low non-linearities → *but high NL can **move losses** (TDIS 2022)*
  - Individual bunches → *but trains have | **orbit shifts** / high-intensity **beam-beam** effects*
- Hierarchy breaking 2024 under control, but...
  - How to avoid breaking in new scenario?
    → *5% lumi lost in 2024!*
  - All factors resurface when tightening hierarchy!

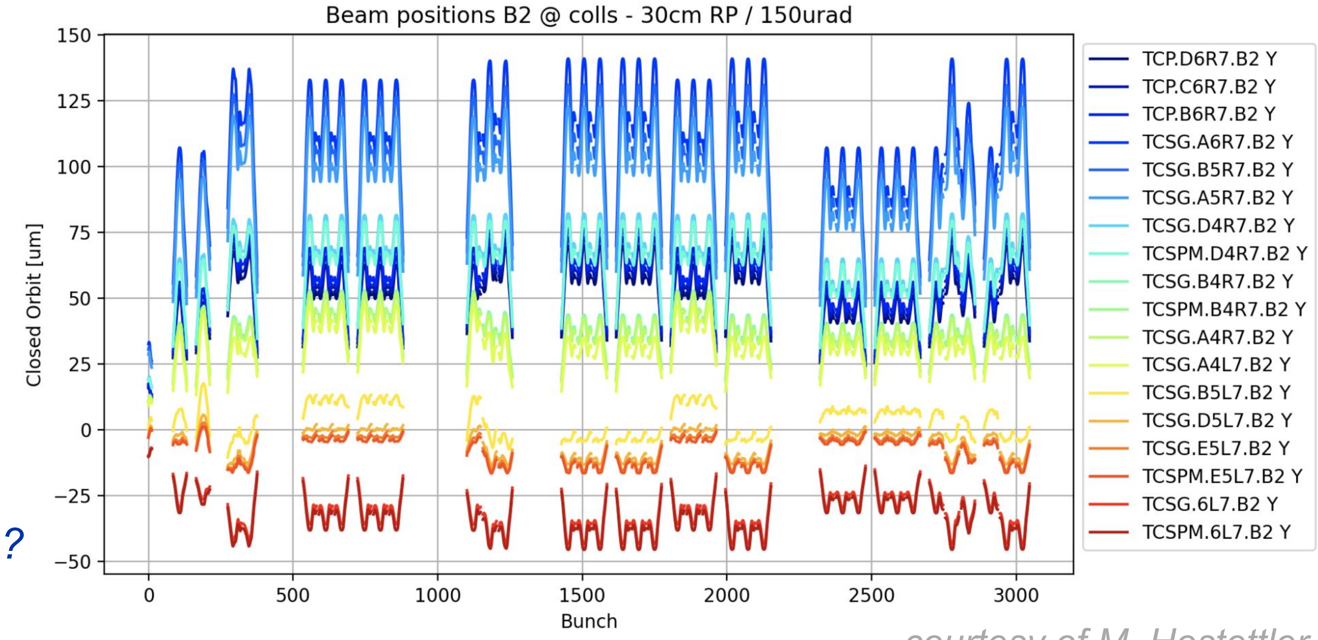


courtesy of M. Hostettler

Collimation Commissioning vs Operation

INDIV (low NL) ≠ INDIV (high NL) ≠ TRAIN

- Collimation system commissioned (alignment, loss maps) with:
  - Low non-linearities → *but high NL can **move losses** (TDIS 2022)*
  - Individual bunches → *but trains have* | ***orbit shifts*** / *high-intensity **beam-beam** effects*
- Hierarchy breaking 2024 under control, but...
  - How to avoid breaking in new scenario?
    → *5% lumi lost in 2024!*
  - All factors resurface when tightening hierarchy!
- **Future mitigation ideas:**
  - Keep hierarchy margin
  - Extend validation to assess impact of trains
    → *move TCS in steps to assess "real" hierarchy*
    → *use few TRAINs, only blow up single bunches?*
  - Move dBLM to center of IR7?
  - Leverage vertical dispersion?



courtesy of M. Hostettler

Outline

LHC performance in 2024

Charaterisation of LHC-type beams

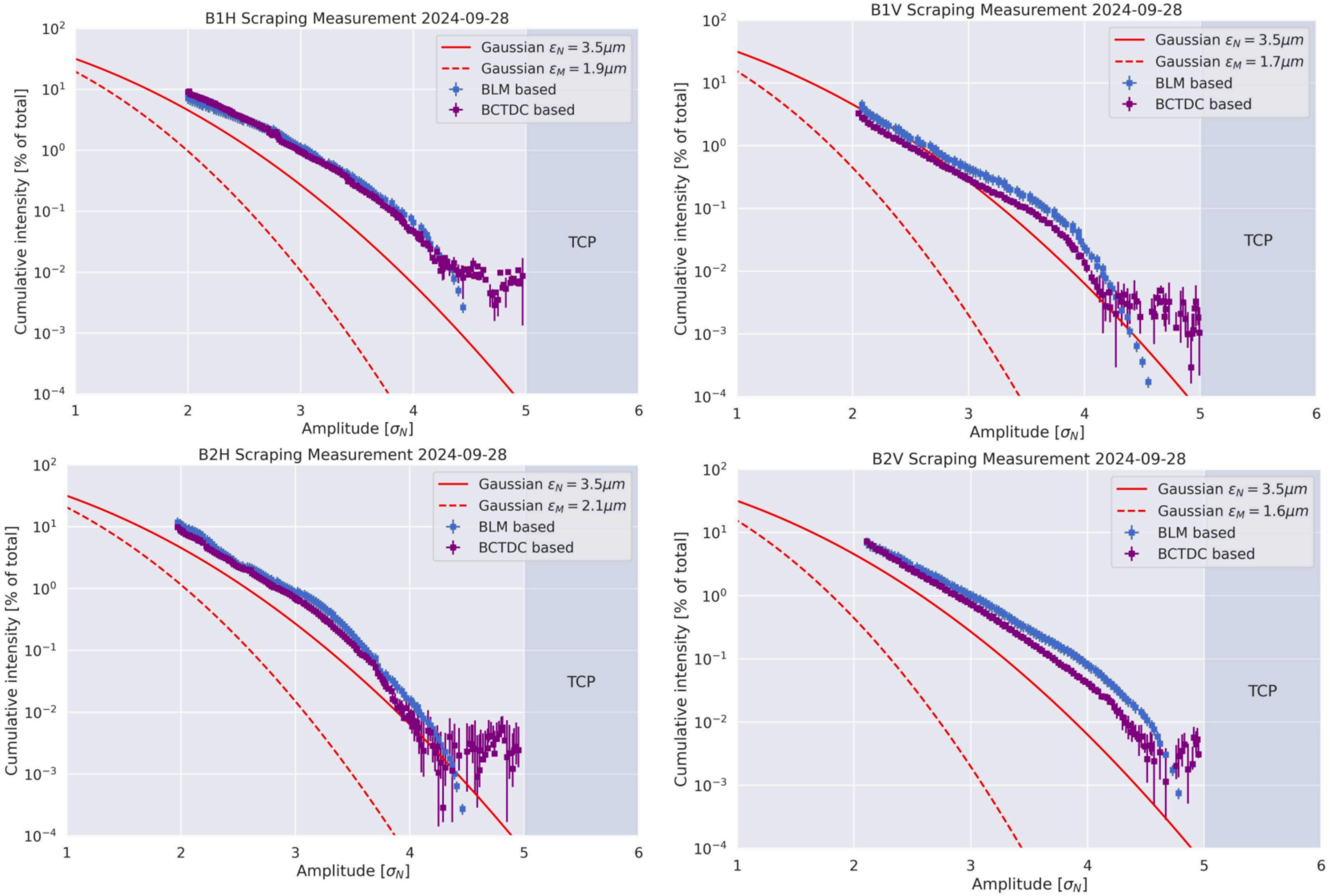
Modelling losses in CERN's accelerators

Are ready for the future?

Transverse Beam Halo

- Halo is beam population beyond $3\sigma_N$ (defined with emittance 3.5μm)
- Up to **34MJ stored beam energy** (HL-LHC)
  - → *risk of damage to collimation system*
  - → *risk of magnet quenches*
  - → *performance limitations (many dumps)*

- Halo shape can be assessed by **q-value** of q-Gaussian fit
- Higher q = less Gaussian-like = more tails

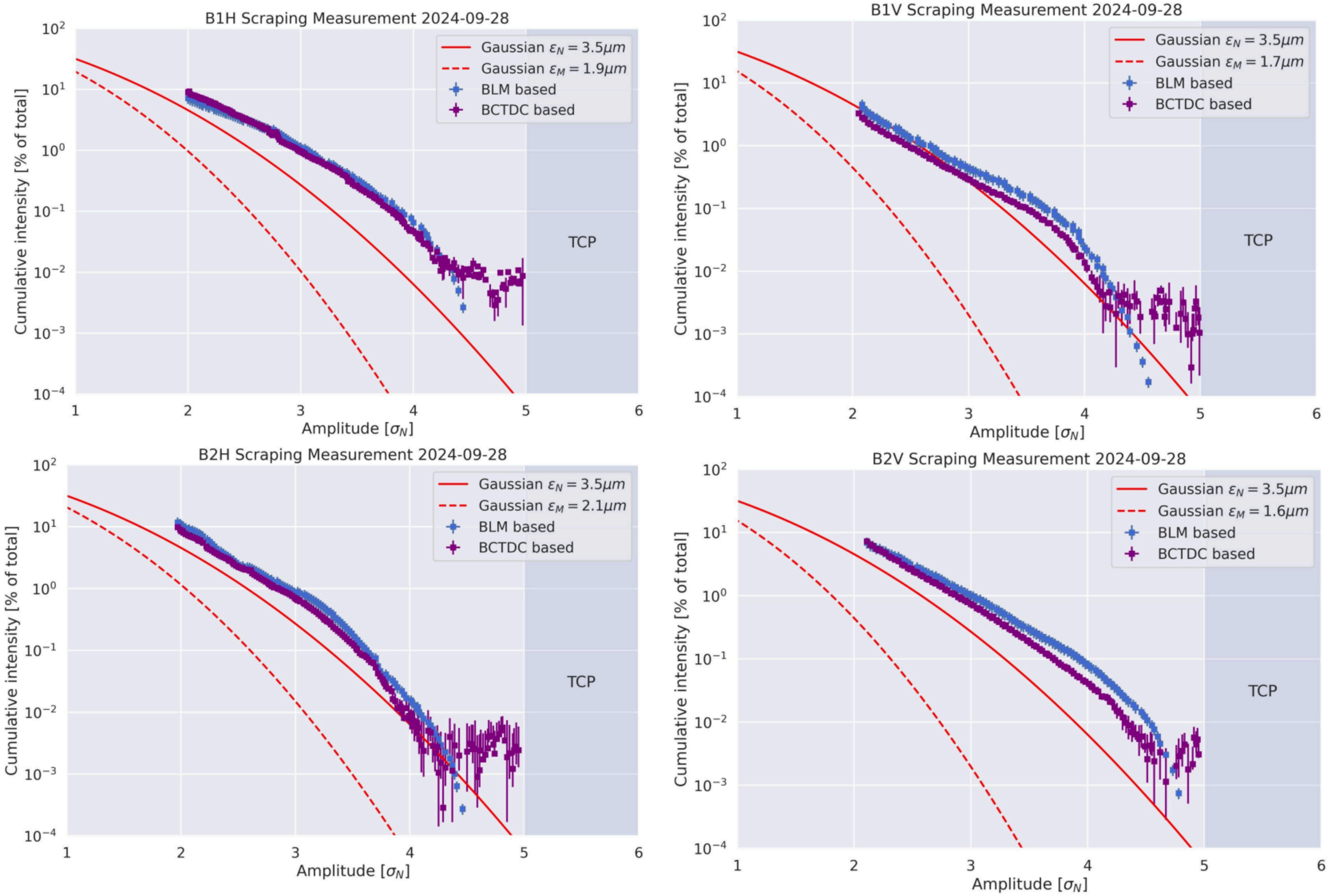


courtesy of M. Rakic

Transverse Beam Halo

- Halo is beam population beyond $3\sigma_N$ (defined with emittance 3.5µm)
- Up to **34MJ stored beam energy** (HL-LHC)
  - → *risk of damage to collimation system*
  - → *risk of magnet quenches*
  - → *performance limitations (many dumps)*

- Halo shape can be assessed by **q-value** of q-Gaussian fit
- Higher q = less Gaussian-like = more tails



courtesy of M. Rakic

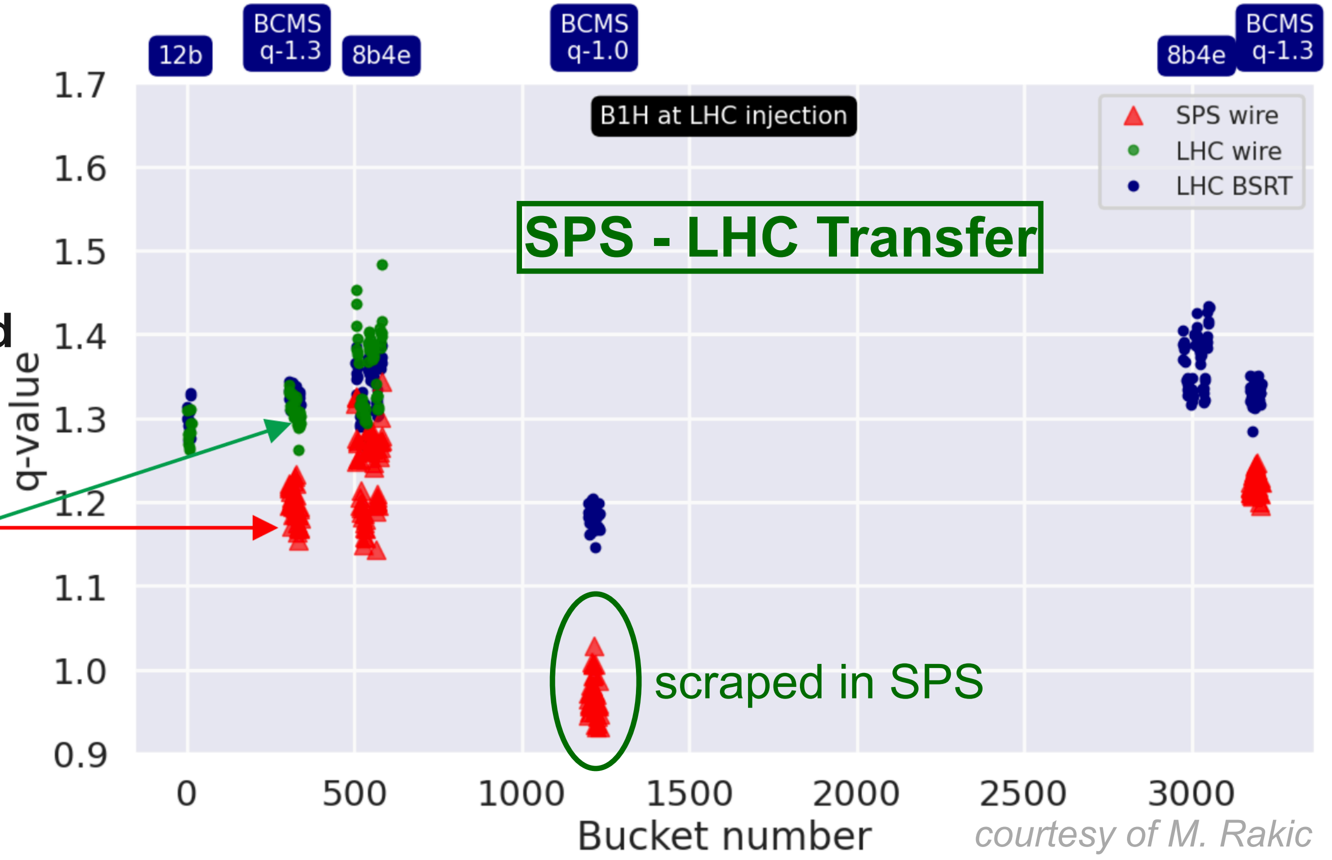
- Analysed 140 LHC scraping measurements, End of Fill (high intensity, top energy)
- Halo **overpopulated** in both Runs
- **Improvement in Run 3** w.r.t. Run 2

TCP	Run 2	Run 3
3σ	0.2% - 6.2%	0.2% - 1.2%
3.5σ	0.2% - 3.5%	0.05% - 1.5%

Halo Evolution

- Tail population **increases** during transfer
- Relative increase in halo biggest for **SPS scraped trains**, but final q-value still **smaller**

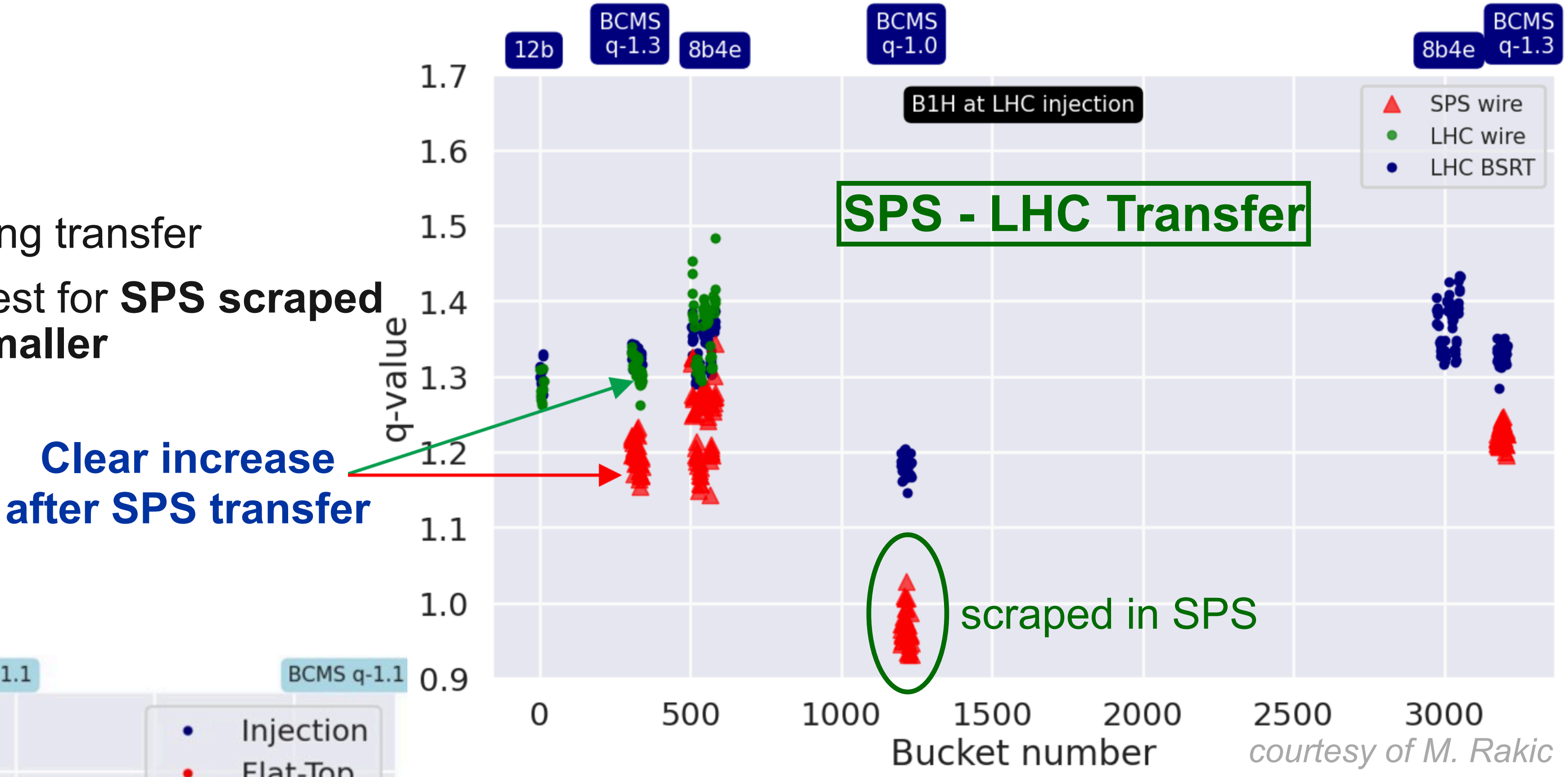
Clear increase after SPS transfer

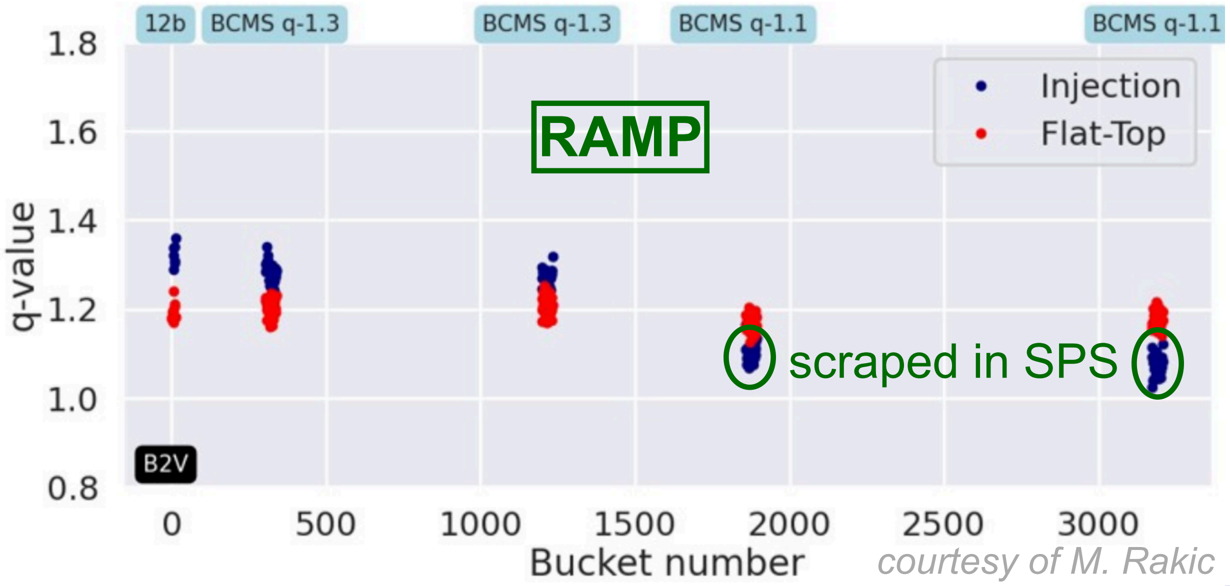


courtesy of M. Rakic

Halo Evolution

- Tail population **increases** during transfer
- Relative increase in halo biggest for **SPS scraped trains**, but final q-value still **smaller**

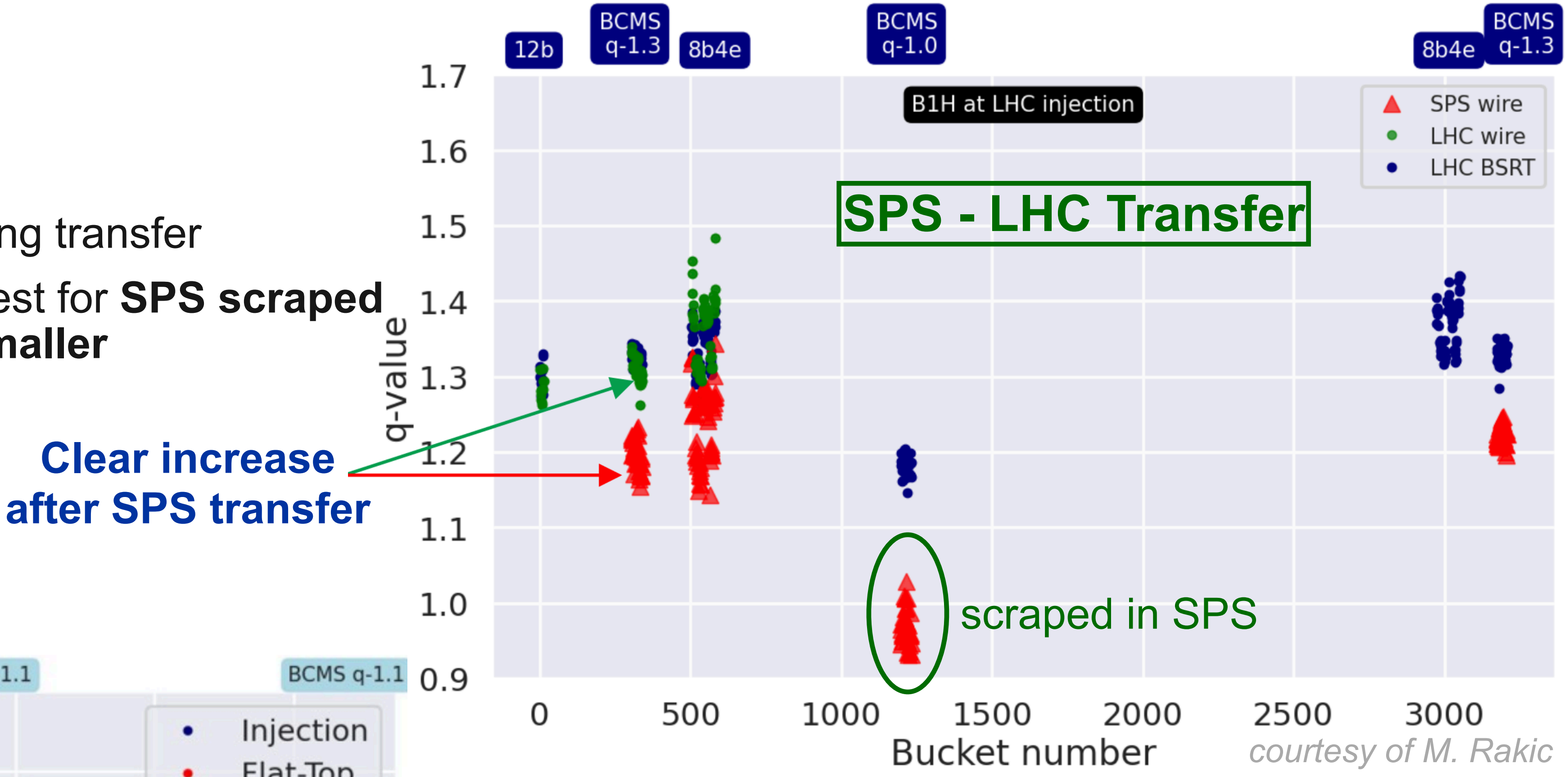


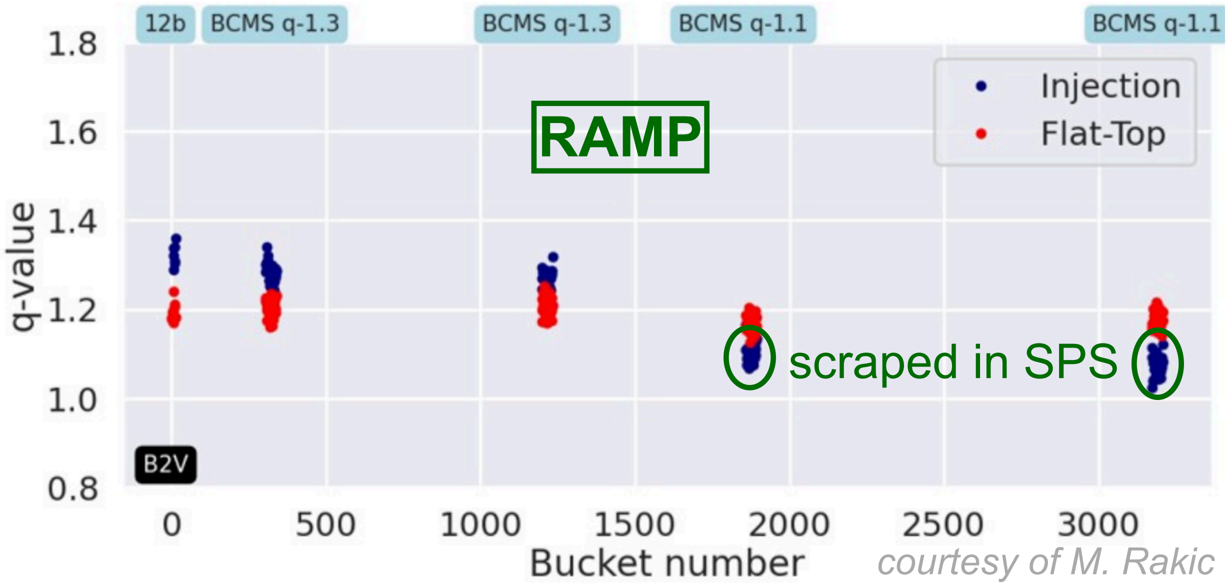


- Tail population **increases** during ramp...
  - **unless** scraped in SPS!

Halo Evolution

- Tail population **increases** during transfer
- Relative increase in halo biggest for **SPS scraped trains**, but final q-value still **smaller**

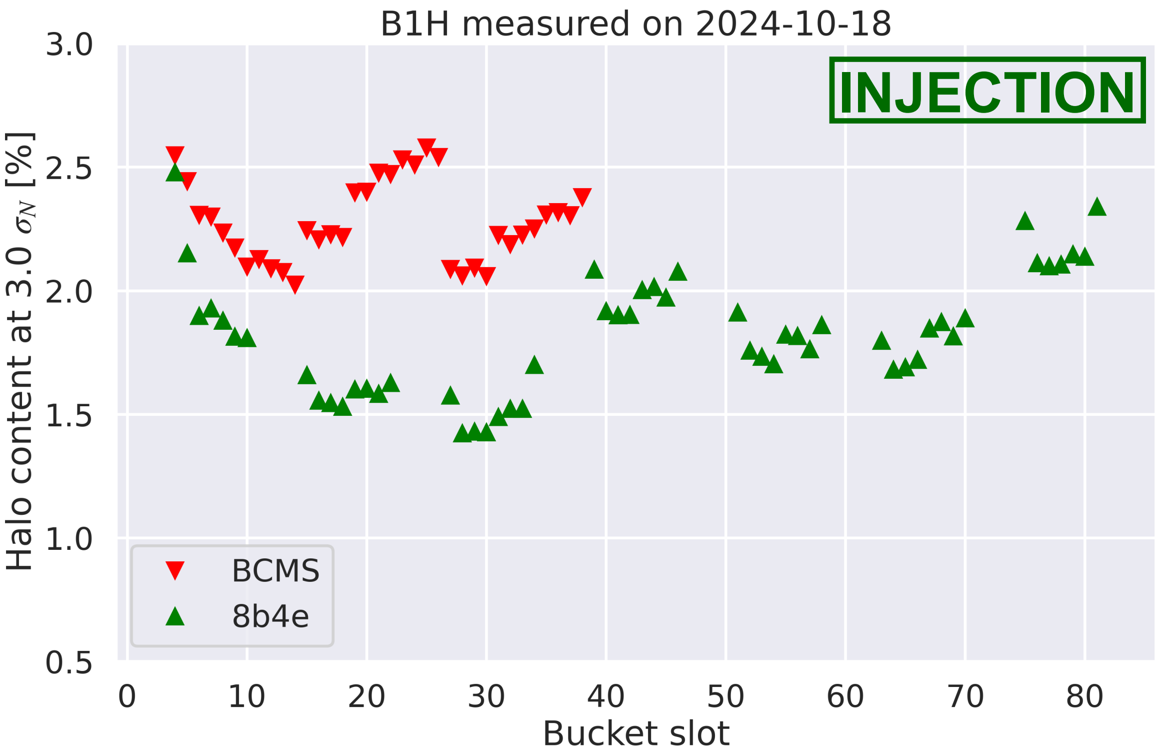


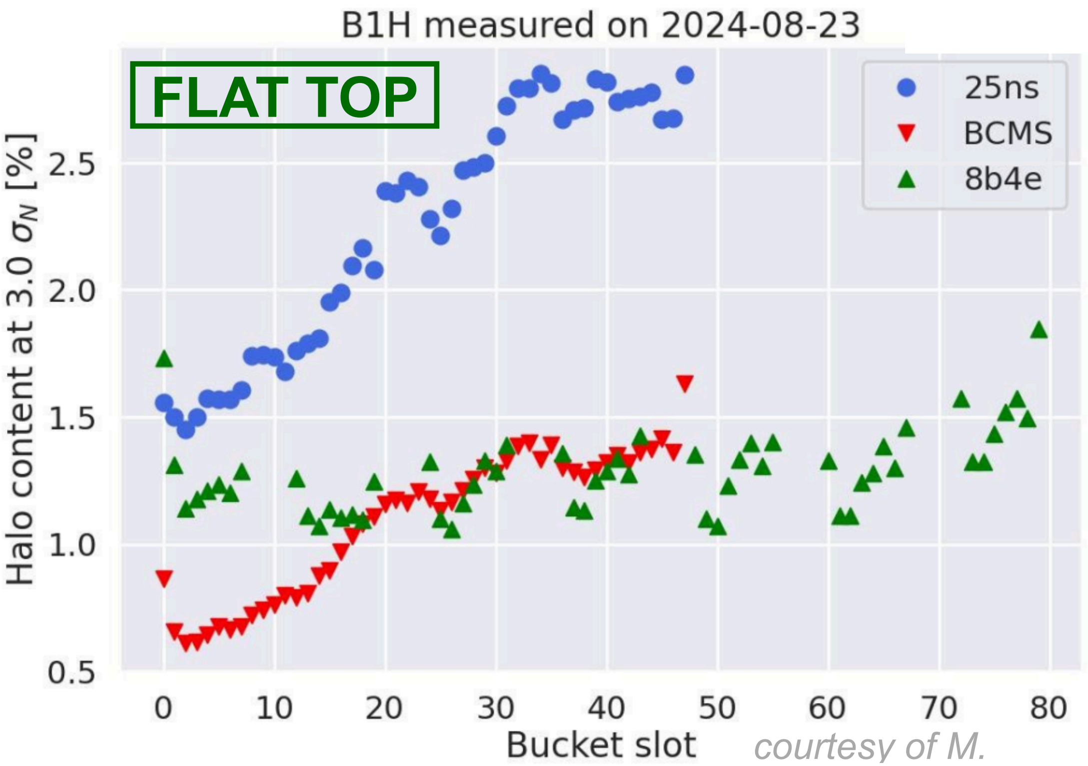


- Tail population **increases** during ramp...
  - **unless** scraped in SPS!
- Planned tests severly affected by MD availability
  - Many missing measurements
  - **High priority** to continue studies in Run 3

WIP

Electron Cloud Effects on Halo





courtesy of M.

- Halo increase **suppressed with 8b4e**
- Strong e-cloud influence at **Flat Top** (not so much at injection)
- Injection phase knob reduces halo formation (see talk L. Mether this morning)

Impact of WIRE on Halo

- Two EOF scrapings:
  - Fill 9808: wire OFF 1h before scraping
  - Fill 9996: wire ON 5.5h before scraping

Fill	No. bunches	Scraping no.	Wire state	B1H	B1V	B2H	B2V
9808	1238	1	OFF	0.8	/	0.3	/
		2	ON	0.15	/	< 0.1	/
9996	2351	1	ON	0.7	0.1	0.4	0.2
		2	OFF	0.15	0.01	/	/

Table: Measured halo content in [%] at 3σ. *courtesy of M. Rakic*

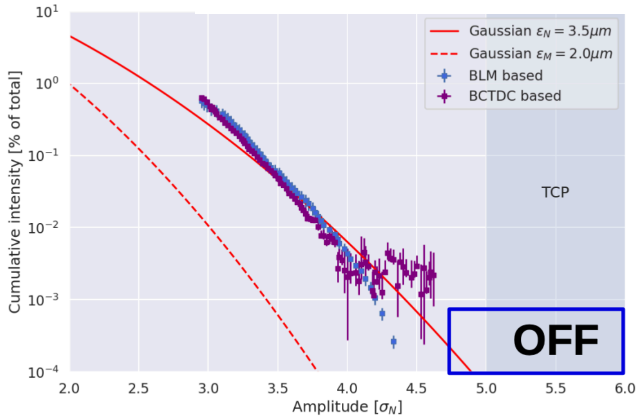
Impact of WIRE on Halo

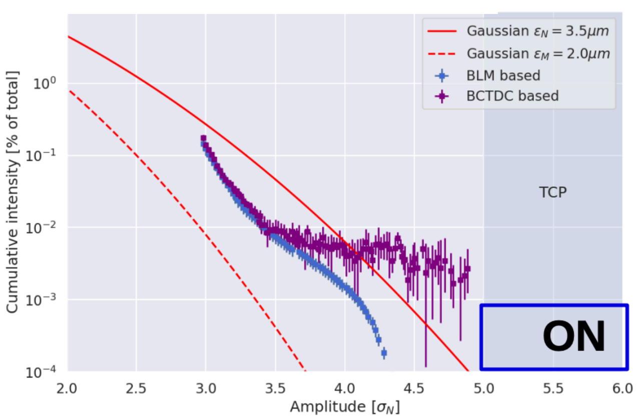
- Two EOF scrapings:
  - Fill 9808: wire OFF 1h before scraping
  - Fill 9996: wire ON 5.5h before scraping

Fill	No. bunches	Scraping no.	Wire state	B1H	B1V	B2H	B2V
9808	1238	1	OFF	0.8	/	0.3	/
		2	ON	0.15	/	< 0.1	/
9996	2351	1	ON	0.7	0.1	0.4	0.2
		2	OFF	0.15	0.01	/	/

Table: Measured halo content in [%] at 3σ. *courtesy of M. Rakic*

- Dedicated measurements in MD9325





courtesy of M. Rakic

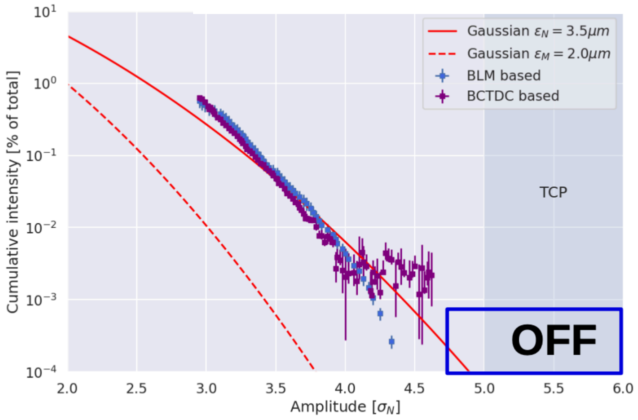
Impact of WIRE on Halo

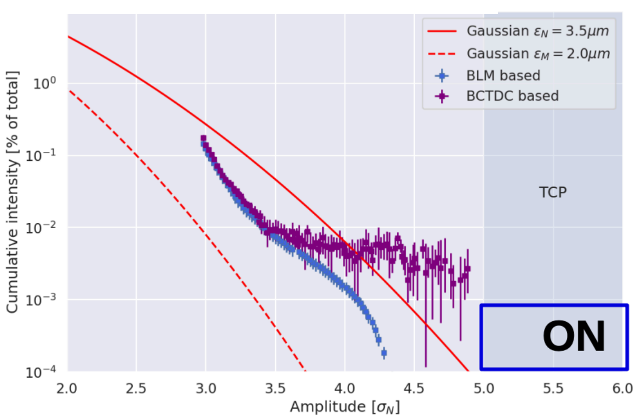
- Two EOF scrapings:
  - Fill 9808: wire OFF 1h before scraping
  - Fill 9996: wire ON 5.5h before scraping

Fill	No. bunches	Scraping no.	Wire state	B1H	B1V	B2H	B2V
9808	1238	1	OFF	0.8	/	0.3	/
		2	ON	0.15	/	< 0.1	/
9996	2351	1	ON	0.7	0.1	0.4	0.2
		2	OFF	0.15	0.01	/	/

Table: Measured halo content in [%] at 3σ. *courtesy of M. Rakic*

- Dedicated measurements in MD9325





courtesy of M. Rakic

- **Not enough time** for halo to repopulate
  - Time between ON/OFF was 10 min
- System is out of equilibrium → **change** of population shape
- For comparable measurements, **longer times** between wire configurations are needed

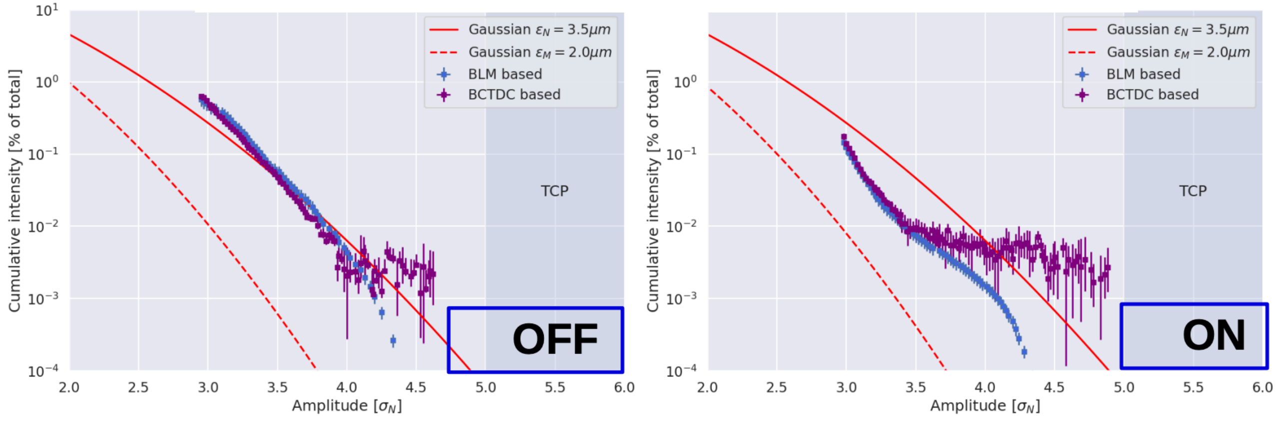
Impact of WIRE on Halo

- Two EOF scrapings:
  - Fill 9808: wire OFF 1h before scraping
  - Fill 9996: wire ON 5.5h before scraping

Fill	No. bunches	Scraping no.	Wire state	B1H	B1V	B2H	B2V
9808	1238	1	OFF	0.8	/	0.3	/
		2	ON	0.15	/	< 0.1	/
9996	2351	1	ON	0.7	0.1	0.4	0.2
		2	OFF	0.15	0.01	/	/

Table: Measured halo content in [%] at 3σ. *courtesy of M. Rakic*

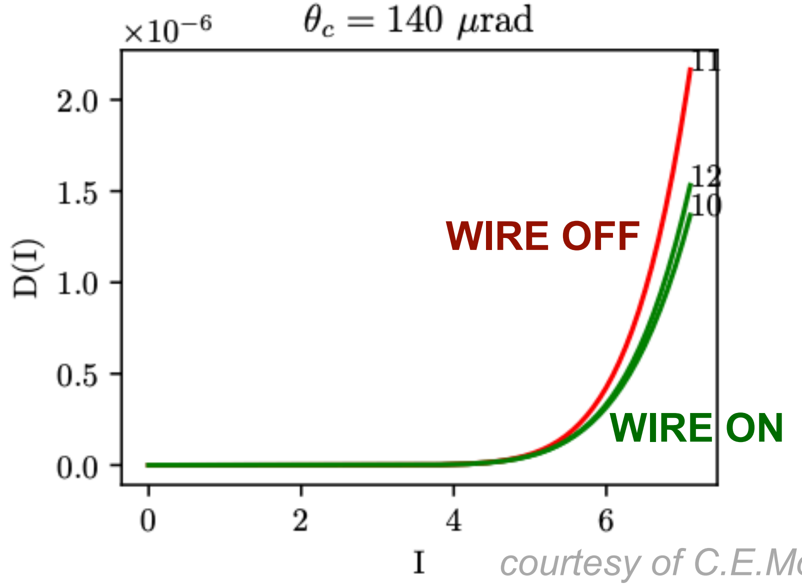
- Dedicated measurements in MD9325



courtesy of M. Rakic

- **Not enough time** for halo to repopulate
  - Time between ON/OFF was 10 min
- System is out of equilibrium → **change** of population shape
- For comparable measurements, **longer times** between wire configurations are needed

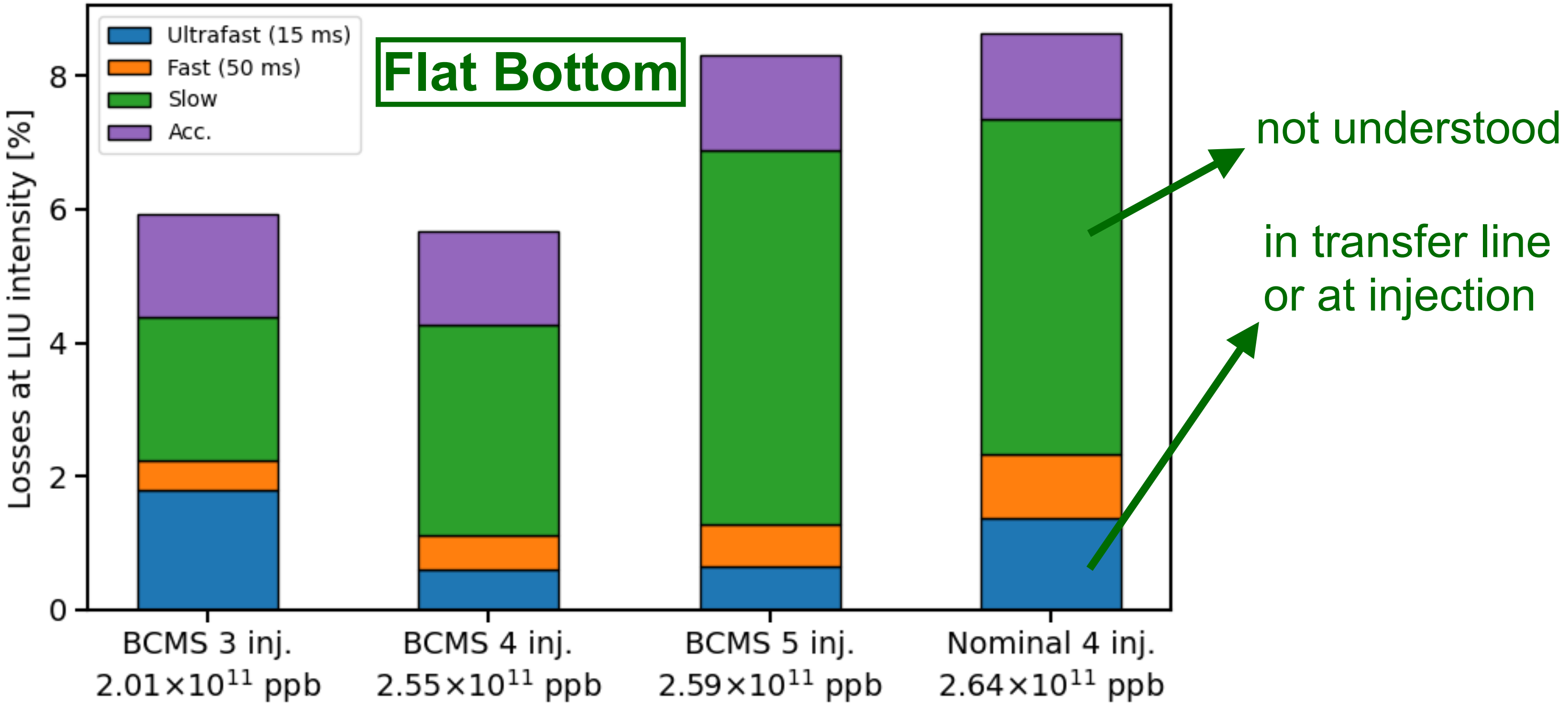
- **Diffusion** measurements performed in fill 7386
  - Observed reduction of diffusion speed



courtesy of C.E.Montanari

Beam Losses Characterisation in SPS

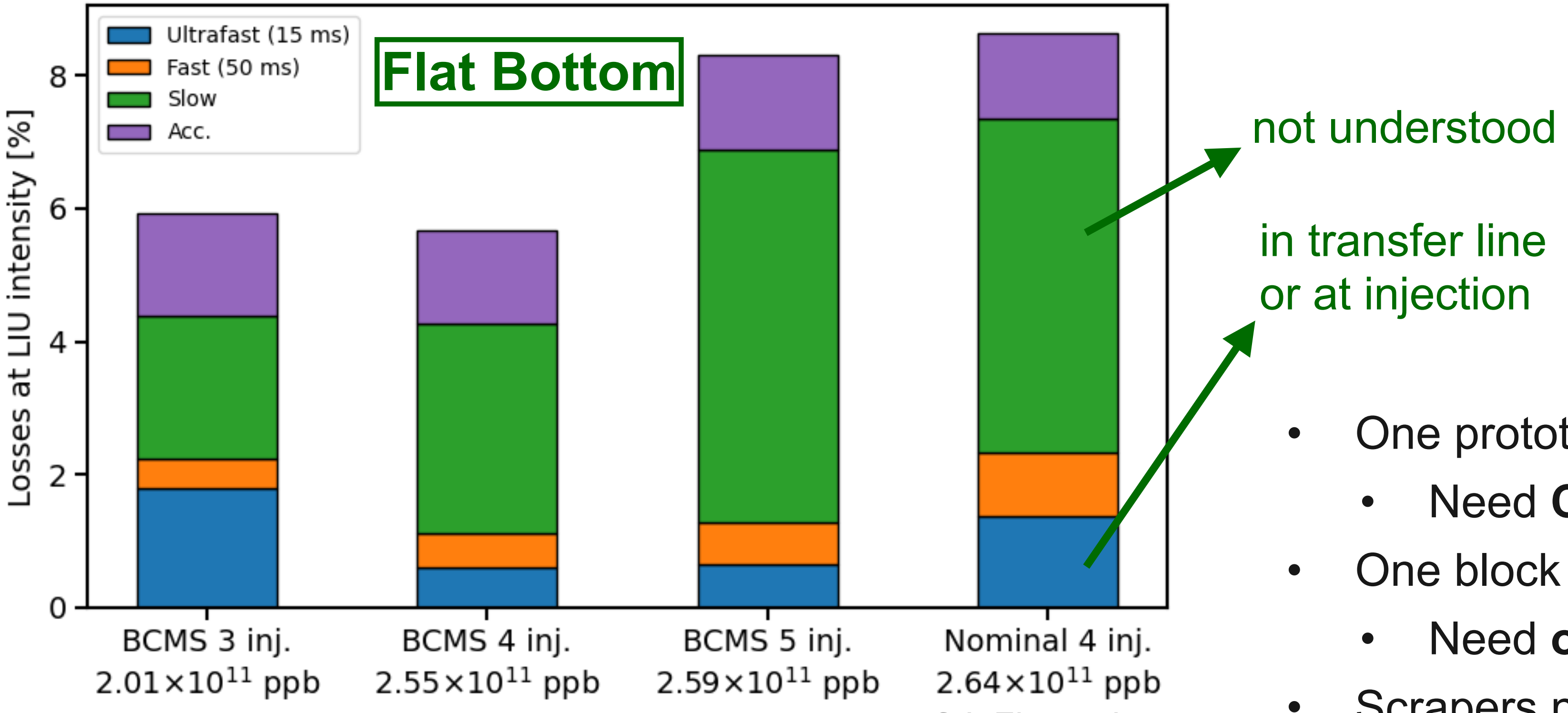
- Understanding losses in SPS is **crucial** for high-quality beams to LHC
- Several short/parallel tests performed in previous years
- Dedicated collimation MDs: understand origin and nature of **slow losses**
- Good understanding to be able to decide on **need for new hardware**



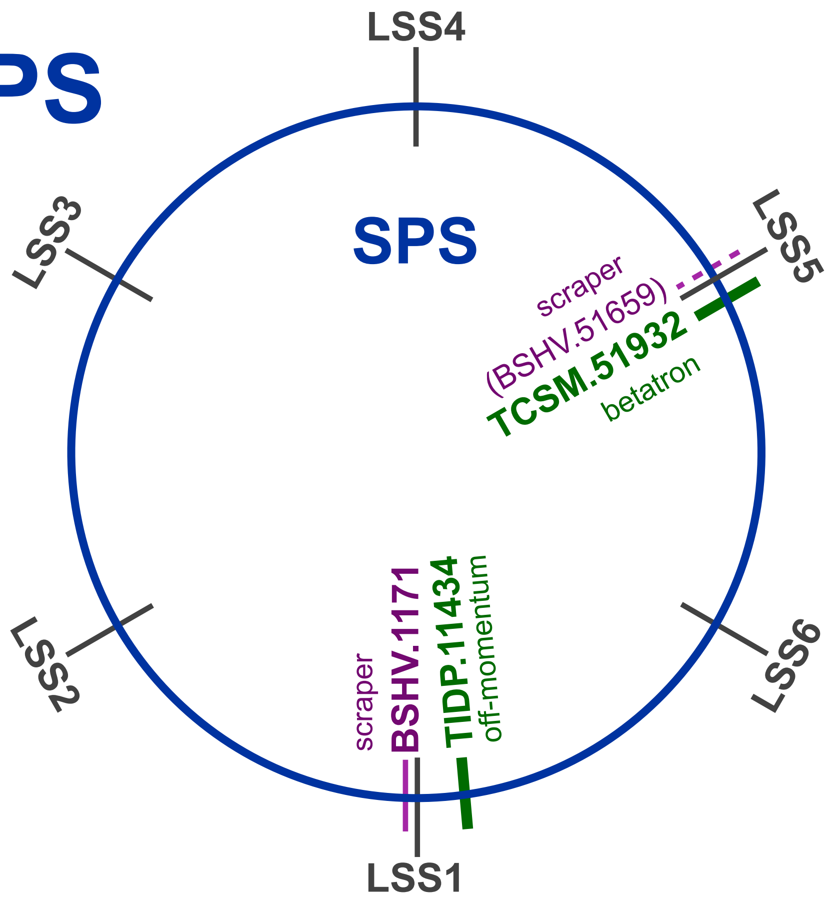
courtesy of J. Flowerdew

Beam Losses Characterisation in SPS

- Understanding losses in SPS is **crucial** for high-quality beams to LHC
- Several short/parallel tests performed in previous years
- Dedicated collimation MDs: understand origin and nature of **slow losses**
- Good understanding to be able to decide on **need for new hardware**



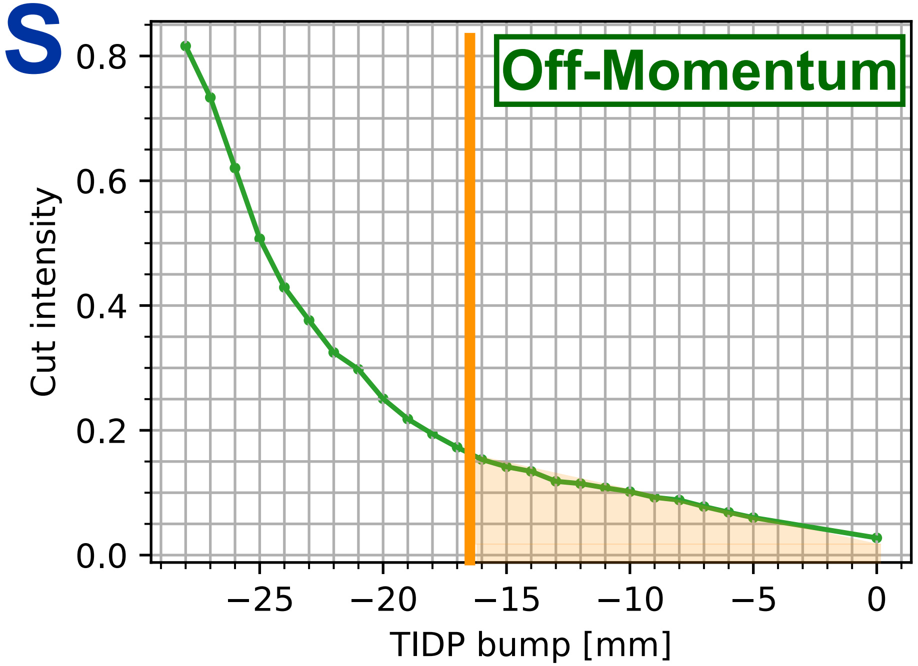
courtesy of J. Flowerdew



- One prototype betatron collimator (H): **TCSM.51932**
  - Need **COAST** to have time to fully move
- One block in dispersion region: **TIDP.11434**
  - Need **orbit bumps** to reach
- Scrapers not (yet) used for MD

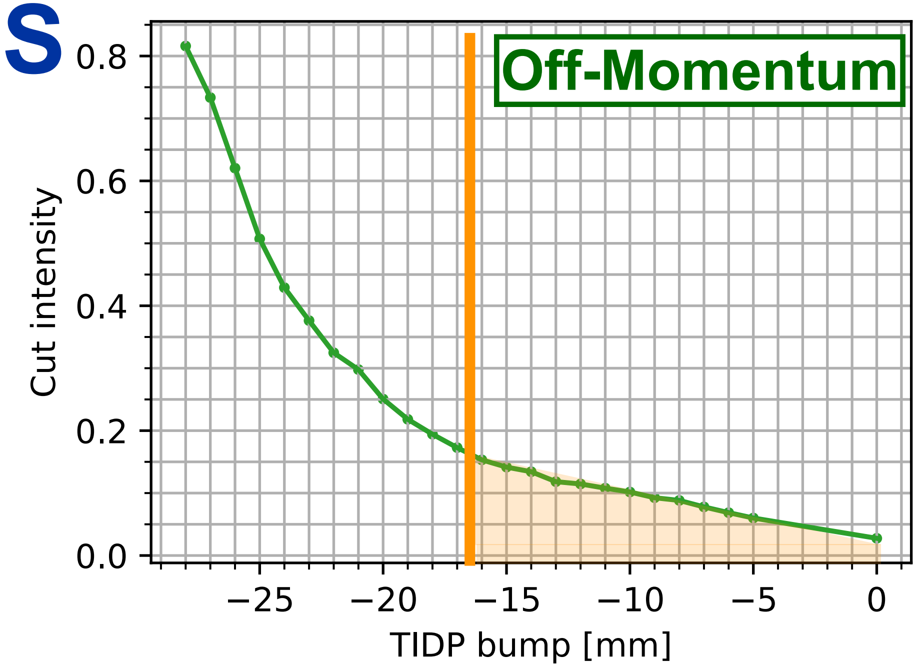
Scraping Measurements at the SPS

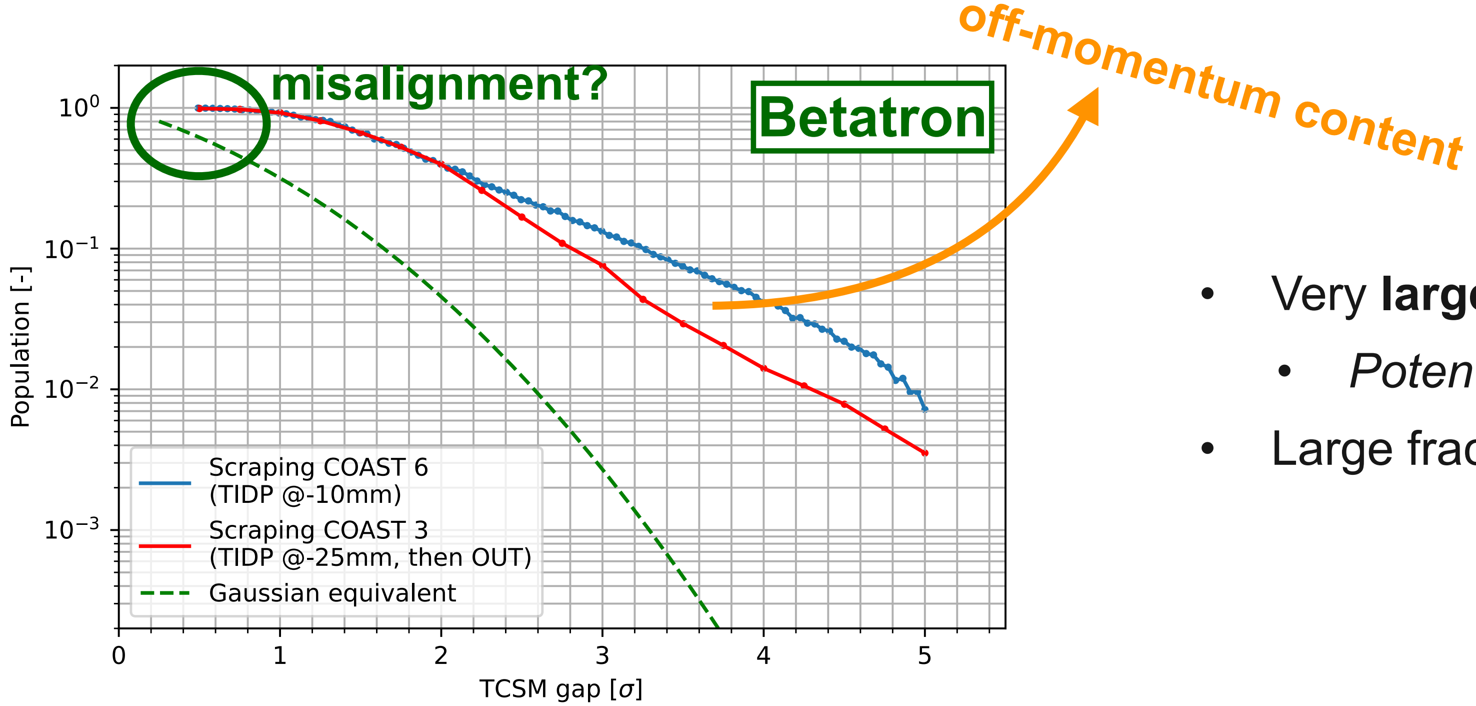
- Very large population **out of RF bucket**
  - *But large **uncertainty** on TIDP position...*
- Probably not uncaptured beam (not enough losses at start of ramp)
- Orange region also contains **steady losses** pushed on TCSM
- **Correlation** between betatronic and dispersive contributions



Scraping Measurements at the SPS

- Very large population **out of RF bucket**
  - *But large **uncertainty** on TIDP position...*
- Probably not uncaptured beam (not enough losses at start of ramp)
- Orange region also contains **steady losses** pushed on TCSM
- **Correlation** between betatronic and dispersive contributions



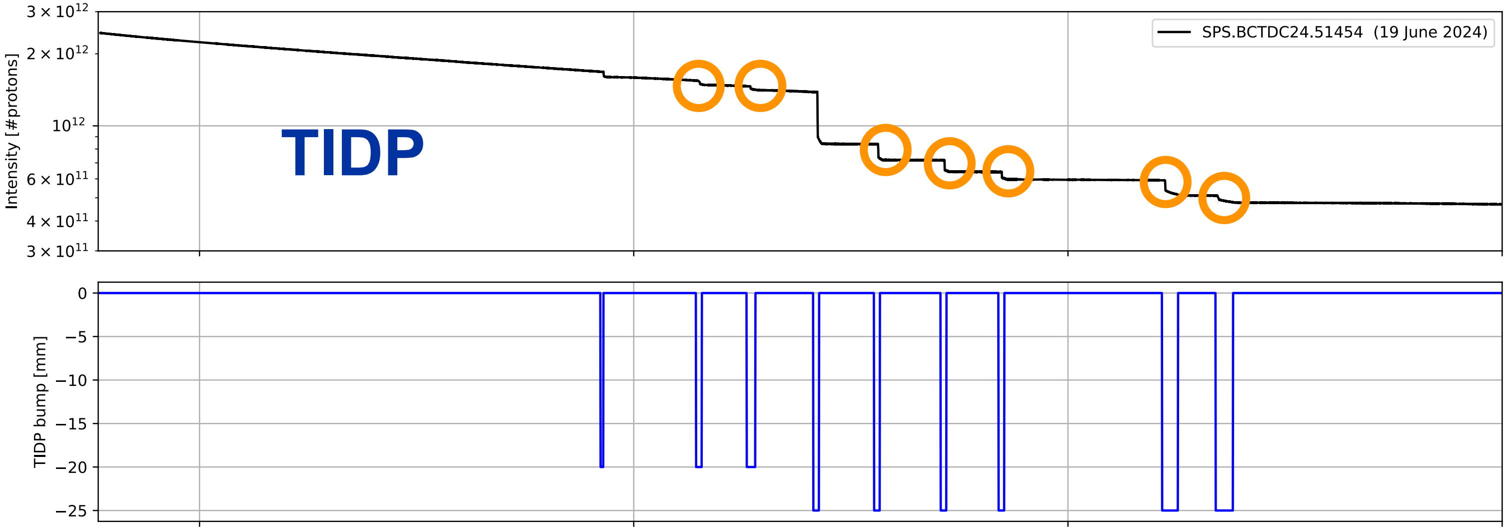


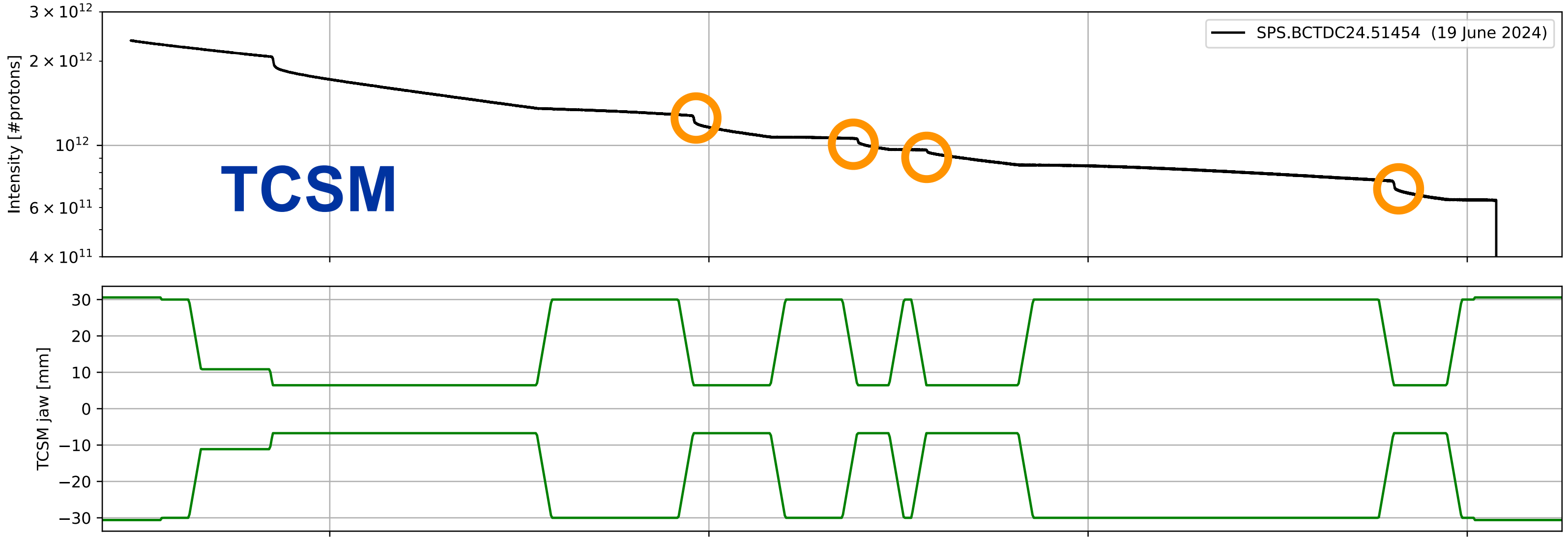
- Very **large betatron tails** ~15% at 3σ
  - *Potential misalignment of TCSM*
- Large fraction of tails is **correlated** to longitudinal

Tail Repopulation

- Clear hints of repopulation!
  - Both betatronic and off-momentum
- Continuous losses clearly visible

- Repopulation rate scales with time
  - 0.14 to 0.54 % per second





- Results not conclusive:
  - Settings were too tight (might have cut in core)
  - Need more statistics

Outline

LHC performance in 2024

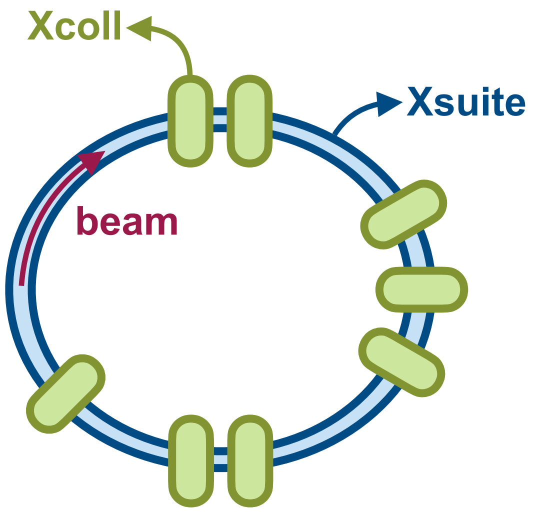
Charaterisation of LHC-type beams

Modelling losses in CERN's accelerators

Are ready for the future?

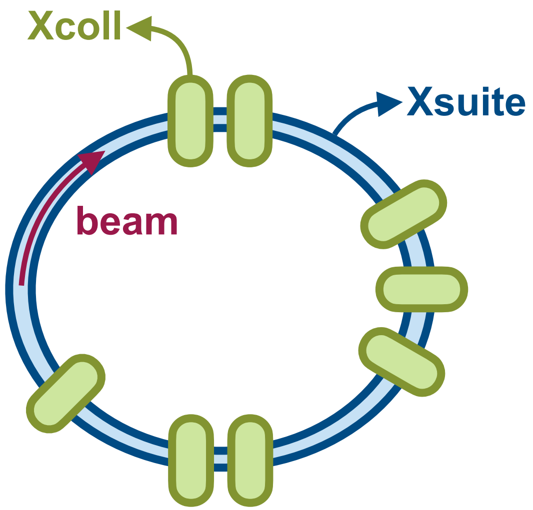
Particle Tracking Simulations with Collimation

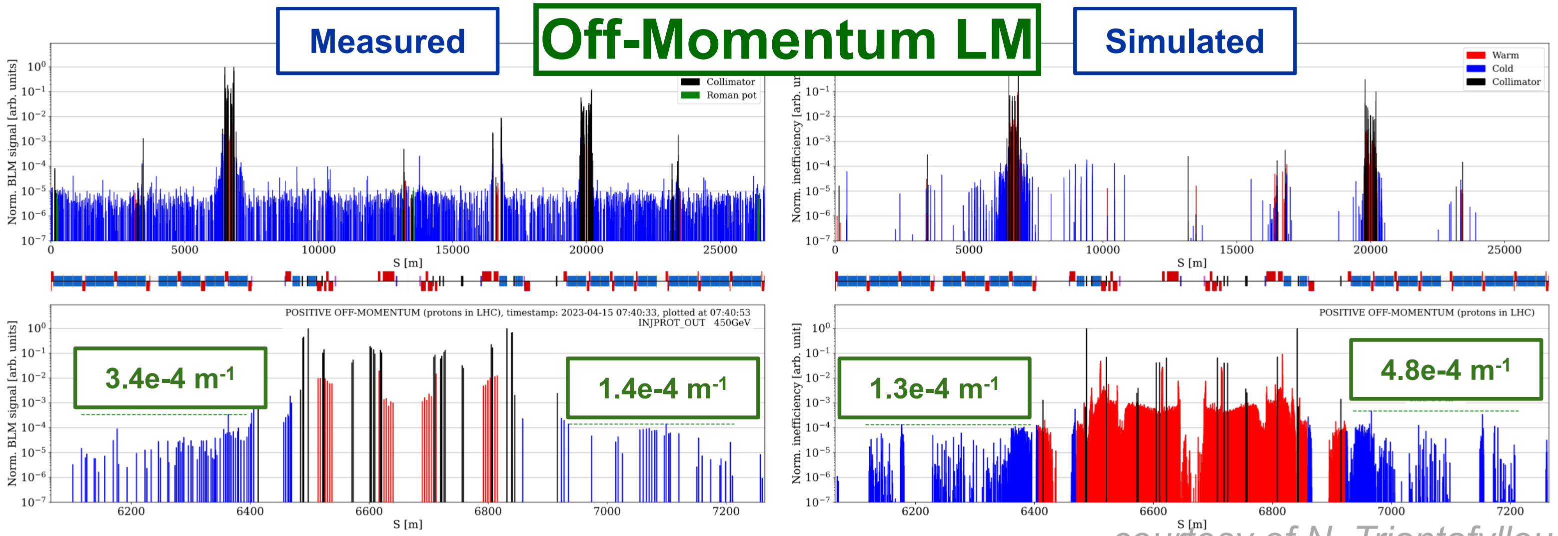
- New tool **Xsuite** built on SixTrack legacy; **Xcoll** for collimation studies



Particle Tracking Simulations with Collimation

- New tool **Xsuite** built on SixTrack legacy; **Xcoll** for collimation studies
- Flexible code devolpment ensures **vast range** of applications:
  - **Loss map simulations** (betatron, off-momentum, asynch dump)

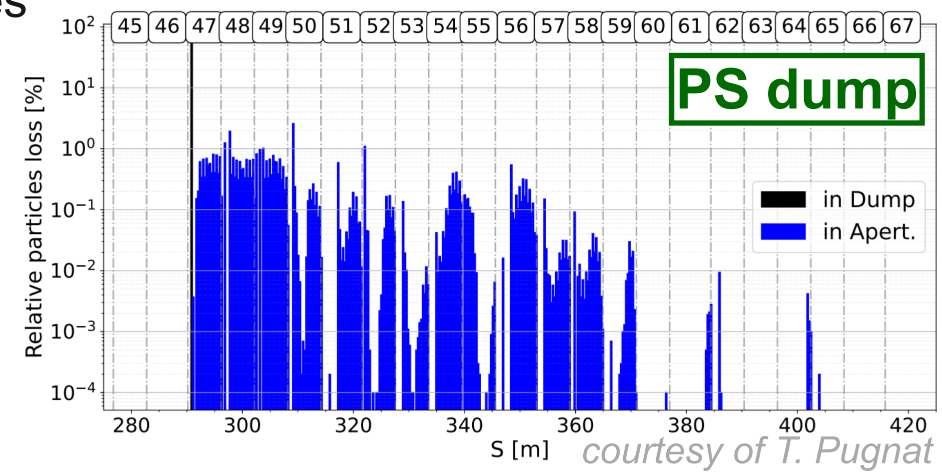




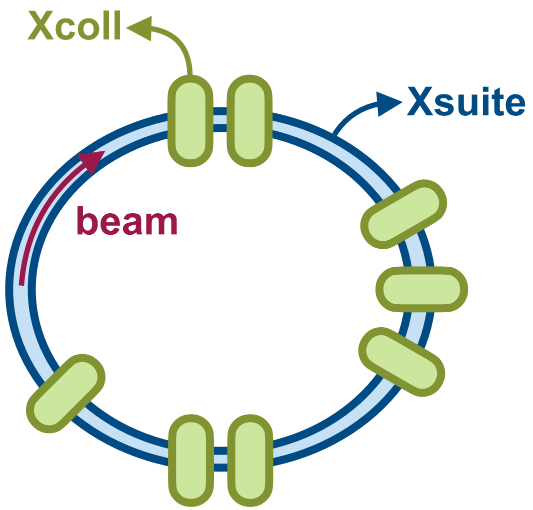
courtesy of N. Triantafyllou

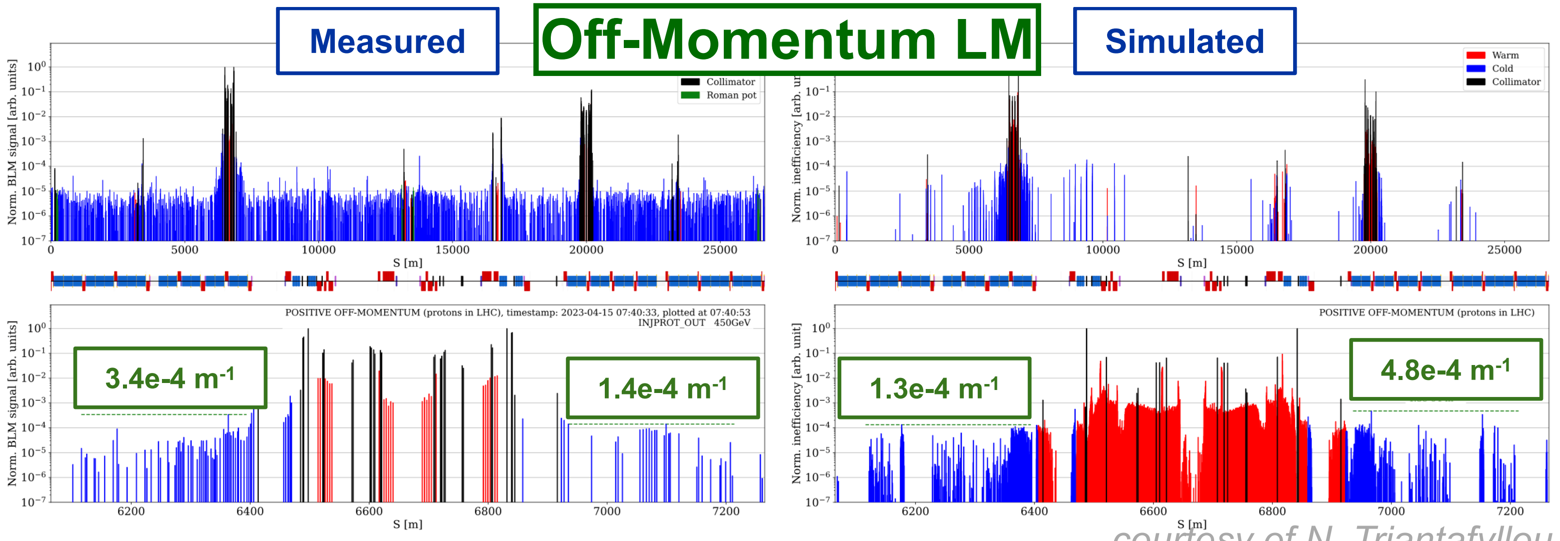
Particle Tracking Simulations with Collimation

- New tool **Xsuite** built on SixTrack legacy; **Xcoll** for collimation studies
- Flexible code devolpment ensures **vast range** of applications:
  - **Loss map simulations** (betatron, off-momentum, asynch dump)
  - Simulated **aperture** measurements
  - Characterising **halo** particles
  - **Hierarchy breaking**
  - Losses behaviour (e.g. SPS, PS dump, ...)
  - ...



courtesy of T. Pugnat

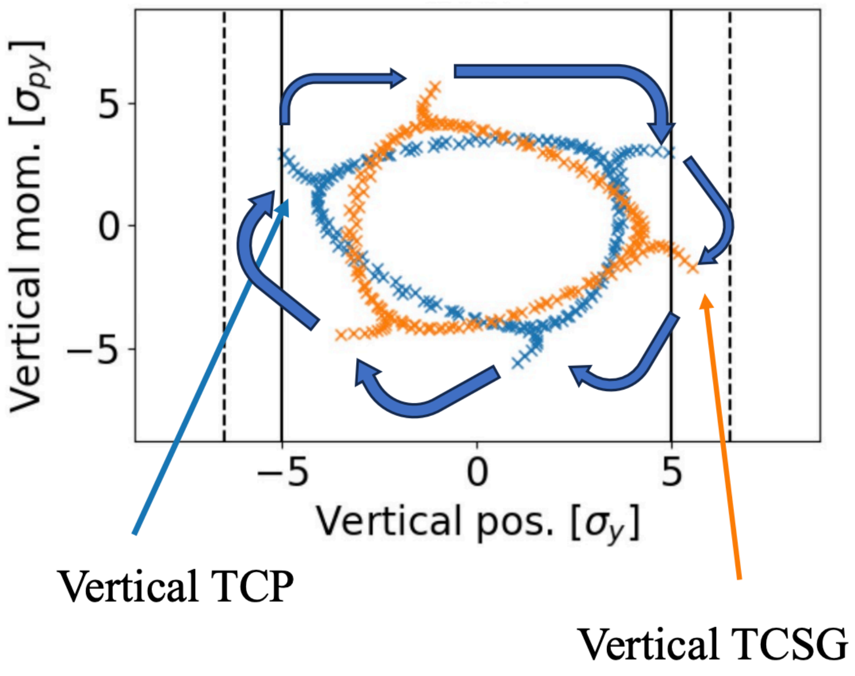




courtesy of N. Triantafyllou

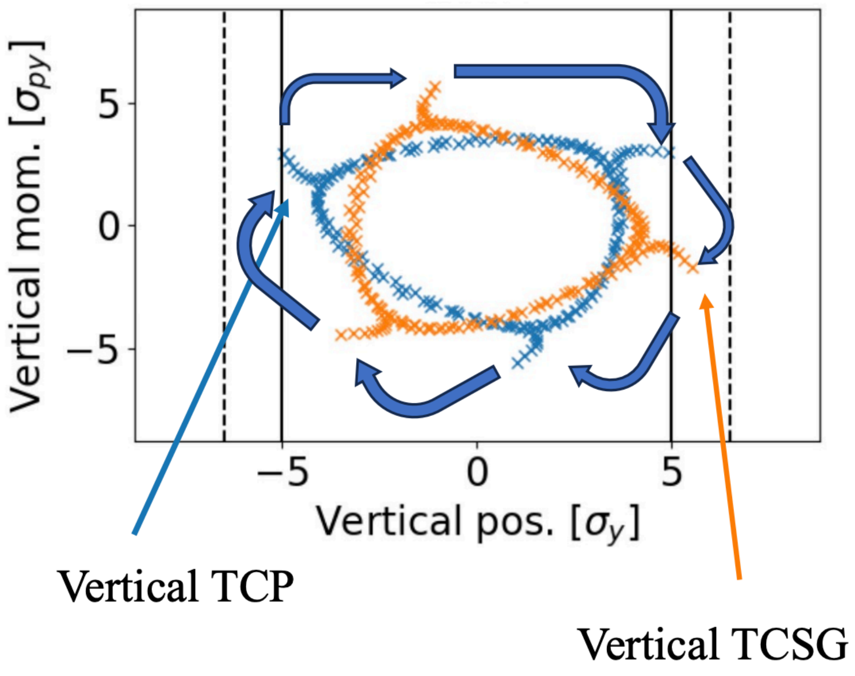
Hierarchy Breaking at the LHC

- Hierarchy breaking appeared in beam 2 during the last step of levelling
- Not observed with single beam! => clear **beam-beam effect**
- Dedicated measurements have shown different contributions:
  - orbit errors and **orbit distortion** from beam-beam effects
  - beta-beating (has minimal impact $\sim \sqrt{10\%}$)
  - spurious **vertical dispersion**
  - 3Qy resonance from **a3** lattice inhomogenities
  - **long range beam-beam** enhances 3Qy



Hierarchy Breaking at the LHC

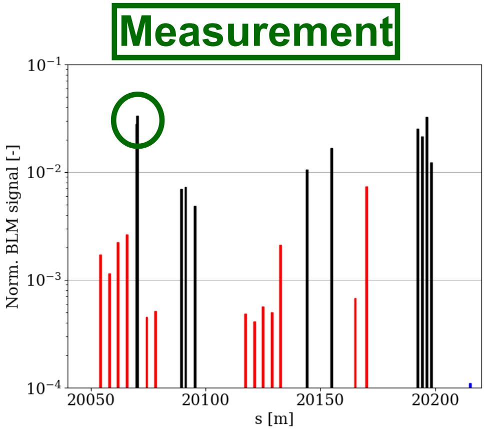
courtesy of K. Paraschou



- Hierarchy breaking appeared in beam 2 during the last step of levelling
- Not observed with single beam! => clear **beam-beam effect**
- Dedicated measurements have shown different contributions:
  - orbit errors and **orbit distortion** from beam-beam effects → retain dipolar kicks
  - beta-beating (has minimal impact $\sim \sqrt{10\%}$) → BBLR & BBHO
  - spurious **vertical dispersion** → add manual dispersion
  - 3Qy resonance from **a3** lattice inhomogenities → add lattice inhomogenities (WIP)
  - **long range beam-beam** enhances 3Qy → BBLR & BBHO

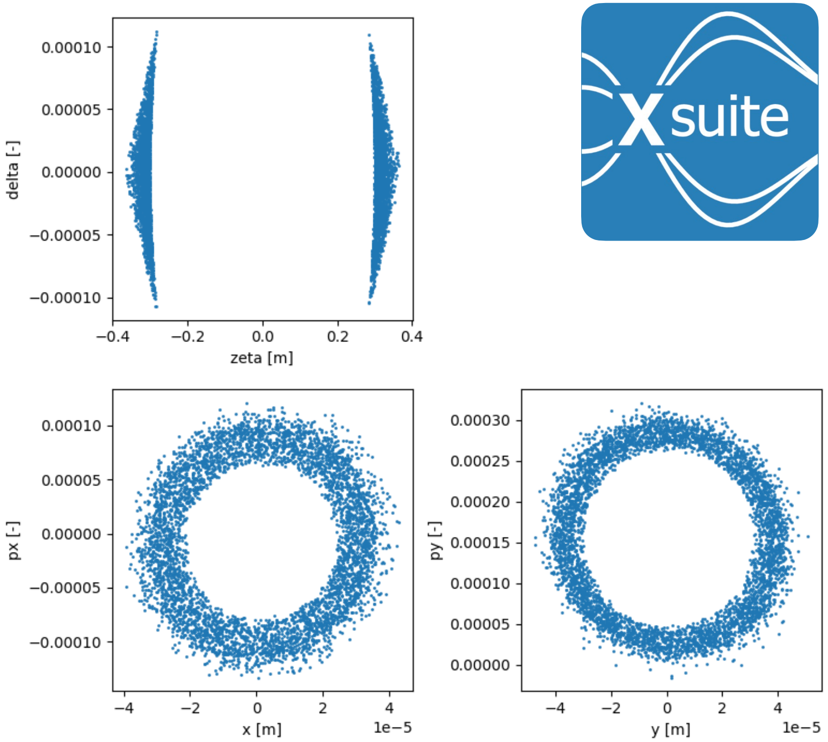
Simulating Hierarchy Breaking

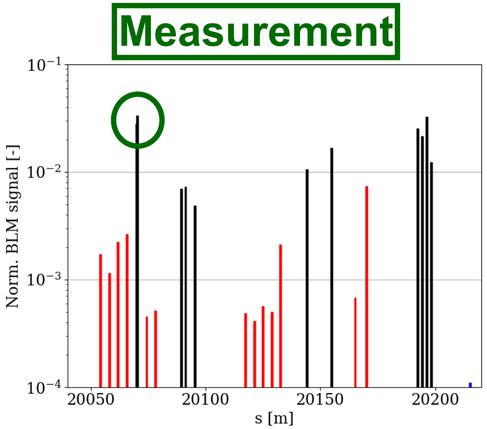
- First LHC simulation to fully **combine collimation and beam-beam!**



Simulating Hierarchy Breaking

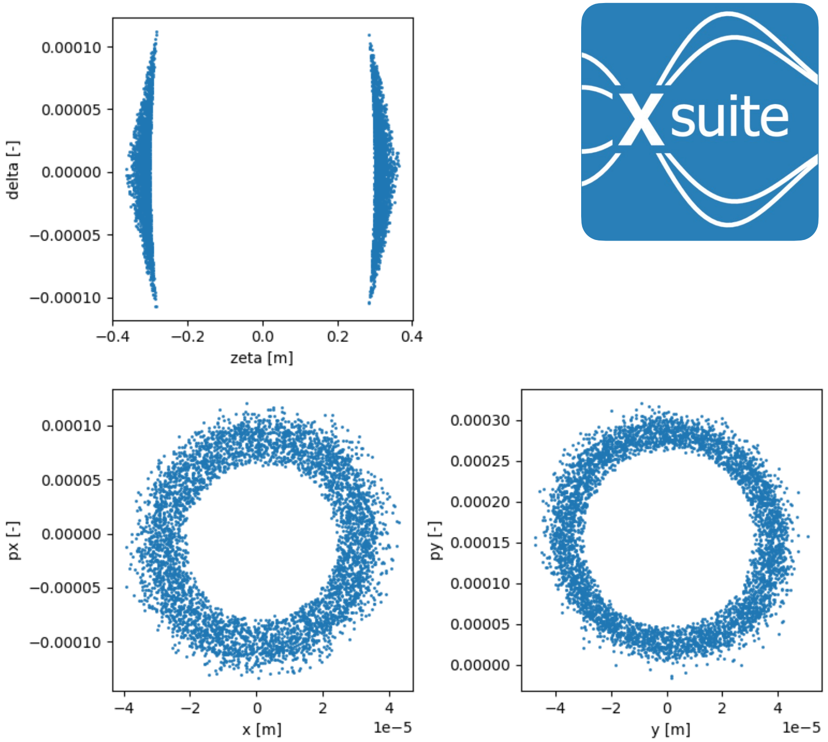
- First LHC simulation to fully **combine collimation and beam-beam!**
- Simulated shell of initial particles: **high off-momentum**, high betatron
  - Two variants: let evolve by **diffusion** (slow) or soft **blow-up** (faster)
  - No difference in results

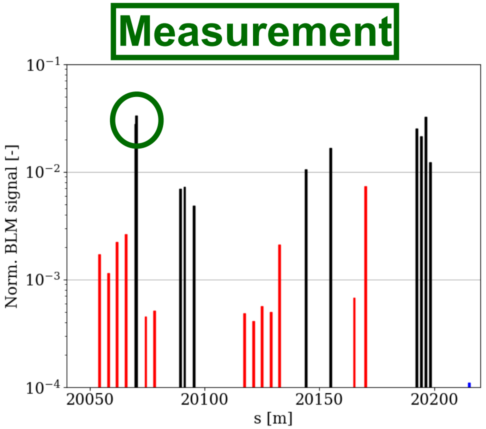


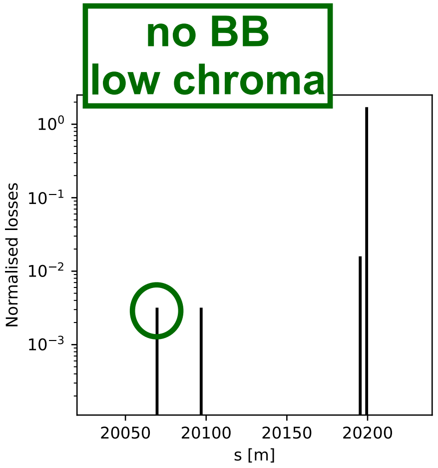


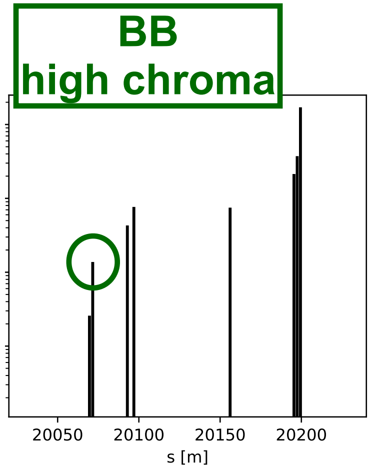
Simulating Hierarchy Breaking

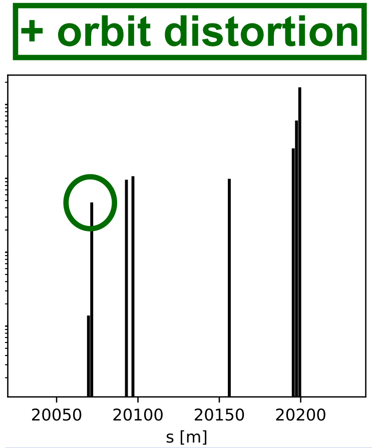
- First LHC simulation to fully **combine collimation and beam-beam!**
- Simulated shell of initial particles: **high off-momentum**, high betatron
  - Two variants: let evolve by **diffusion** (slow) or soft **blow-up** (faster)
  - No difference in results
- Compared several scenarios (w/wo BB, low/high chroma, w/wo orbit)



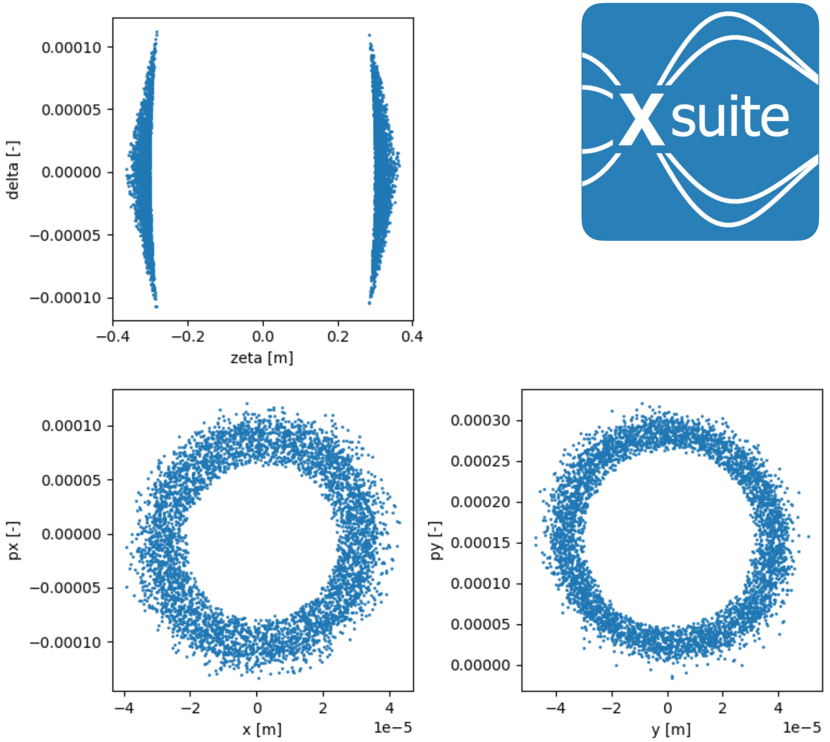






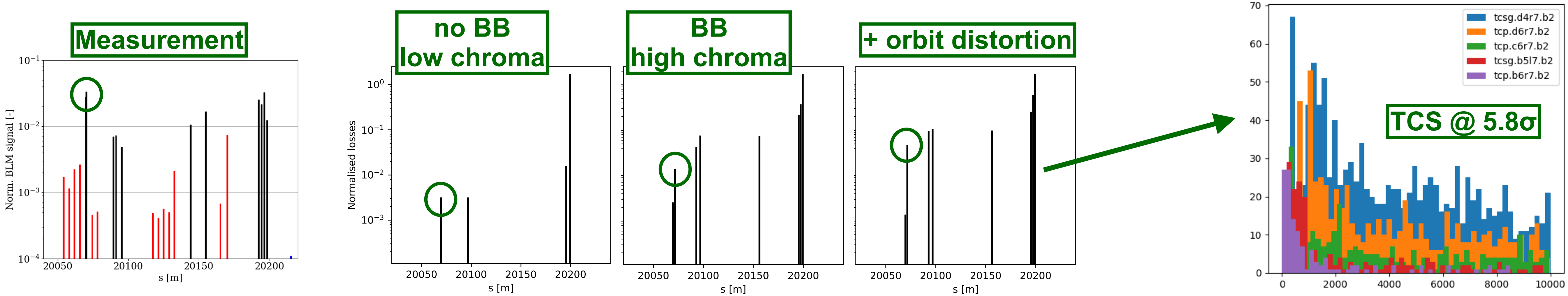


Simulating Hierarchy Breaking



- First LHC simulation to fully **combine collimation and beam-beam!**
- Simulated shell of initial particles: **high off-momentum**, high betatron
  - Two variants: let evolve by **diffusion** (slow) or soft **blow-up** (faster)
  - No difference in results
- Compared several scenarios (w/wo BB, low/high chroma, w/wo orbit)
- Clear increase on TCS
  - Fraction of beam **hitting first** on the TCS

    → ***hierarchy breakage** for part of the halo!*
  - Need realistic BLM response (& showers around TCP) for quantitative comparison



Outline

LHC performance in 2024

Charaterisation of LHC-type beams

Modelling losses in CERN's accelerators

Are we ready for the future?

Are we Ready?

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!

- Much better **understanding of LHC halo**: first indications of its characterisation and evolution

- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)

- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
  - *Need to adequately prepare for NomH - RPV and identify potential issues*
  - *Need to define **adequate validation strategy***
  - *What if tighter hierarchy is needed?*
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
  - *Need to adequately prepare for NomH - RPV and identify potential issues*
  - *Need to define **adequate validation strategy***
  - *What if tighter hierarchy is needed?*
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
  - *Halo is very variable and non-reproducible: need much more **statistics***
  - *Need **targeted MD** studies to investigate impact of WIRE and repopulation*
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
  - *Need to adequately prepare for NomH - RPV and identify potential issues*
  - *Need to define **adequate validation strategy***
  - *What if tighter hierarchy is needed?*
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
  - *Halo is very variable and non-reproducible: need much more **statistics***
  - *Need **targeted MD** studies to investigate impact of WIRE and repopulation*
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
  - *Clear **contradictions** in our understanding of the problem...*
  - ***Continuing MD** studies in 2025 is a necessity to understand the need of a dedicated collimation system*
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
  - *Need to adequately prepare for NomH - RPV and identify potential issues*
  - *Need to define **adequate validation strategy***
  - *What if tighter hierarchy is needed?*
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
  - *Halo is very variable and non-reproducible: need much more **statistics***
  - *Need **targeted MD** studies to investigate impact of WIRE and repopulation*
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
  - *Clear **contradictions** in our understanding of the problem...*
  - ***Continuing MD** studies in 2025 is a necessity to understand the need of a dedicated collimation system*
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)
  - *Existing tools are easily applied to all accelerators: correlate upcoming SPS **simulations to measurement***
  - *This allows us to build on an existing **SPS collimation proposal** and improve/extend it by need*

Are we Ready?

YES!

but ...

- Very **good performance** in 2024, good expectation for 2025
  - **Tamed** and understood the **hierarchy** problem!
  - *Need to adequately prepare for NomH - RPV and identify potential issues*
  - *Need to define* ***adequate validation strategy***
  - *What if tighter hierarchy is needed?*
- Much better **understanding of LHC halo**: first indications of its characterisation and evolution
  - *Halo is very variable and non-reproducible: need much more* ***statistics***
  - *Need* ***targeted MD*** *studies to investigate impact of WIRE and repopulation*
- First steps towards **understanding losses** in the **SPS** (steady losses clearly visible, over-populated halo in both off-momentum and betatron, clear evidence of repopulation)
  - *Clear* ***contradictions*** *in our understanding of the problem...*
  - ***Continuing MD*** *studies in 2025 is a necessity to understand the need of a dedicated collimation system*
- Unprecendent progress in **simulation** tools and setup
  - Good mastery of LHC studies, with new tools providing new opportunities (aperture simulations, blow up, ...)
  - *Existing tools are easily applied to all accelerators: correlate upcoming SPS* ***simulations to measurement***
  - *This allows us to build on an existing* ***SPS collimation proposal*** *and improve/extend it by need*

Thanks a lot for your attention!

home.cern

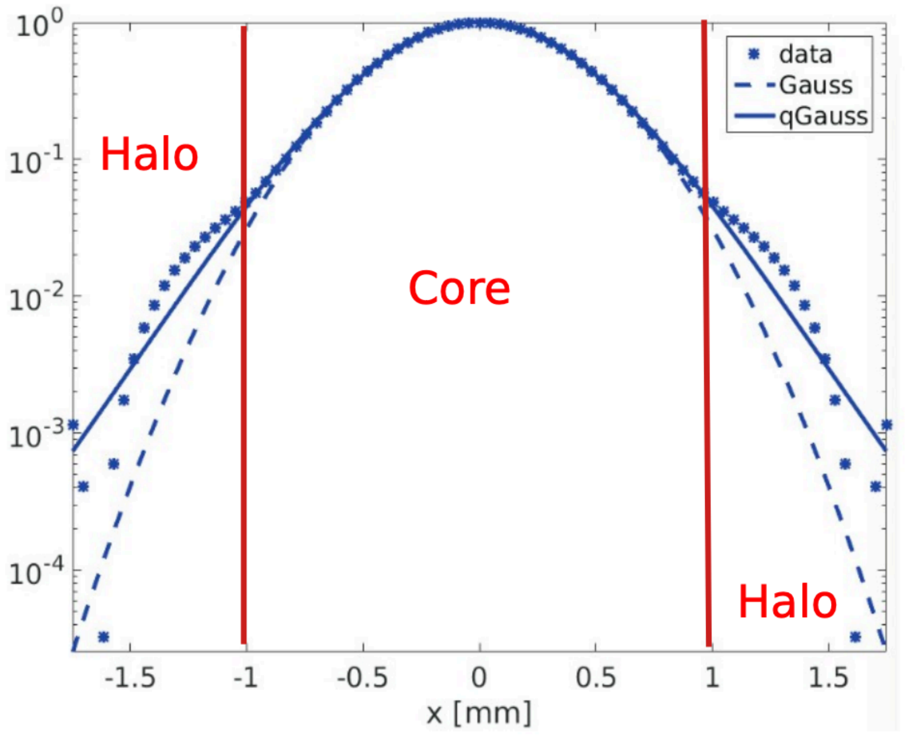
Backup Slides

Transverse Beam Halo at the LHC

- Halo is beam population beyond $3\sigma_N$ (defined with emittance 3.5μm)
- Measured halo during Run 1 and 2 was larger than Gaussian → **overpopulation**
- Up to 5% in the tails → **34MJ stored beam energy**

- No e-lens for halo cleaning and energy increase to HL-LHC:
  - Danger to the collimation system (in case of sudden orbit shifts)
  - Risk of **magnet quenches**
  - Frequent beam dumps would strongly **limit performance**

- Need to **understand** halo population (formation and evolution)!

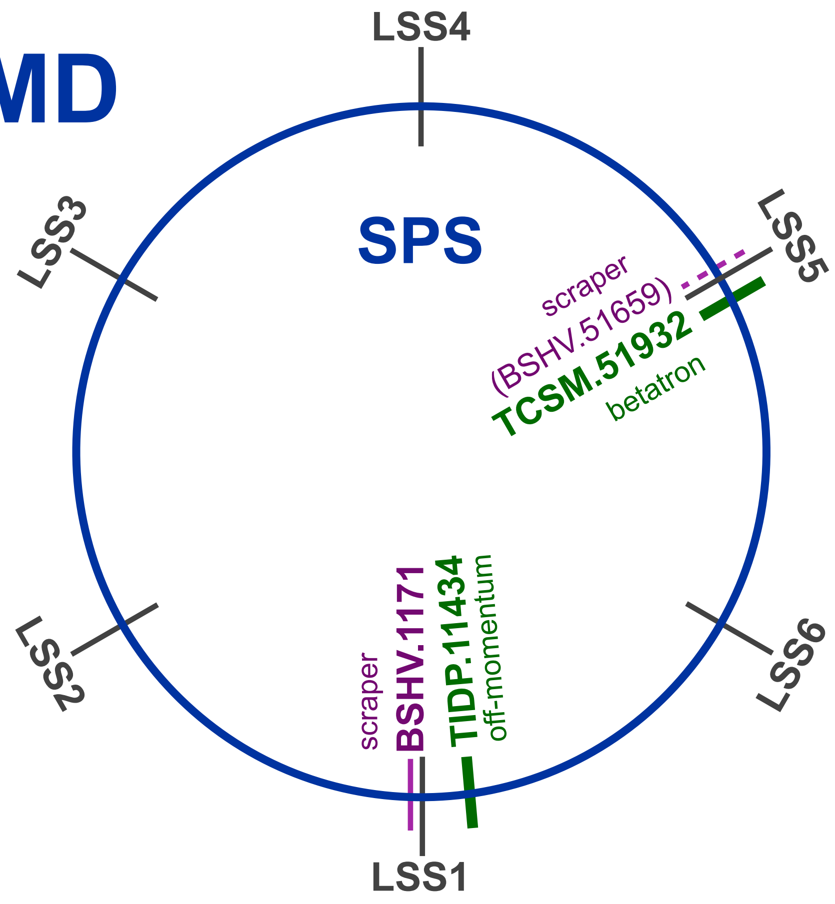


courtesy of M. Rakic

Collimation in the SPS - Dedicated MD

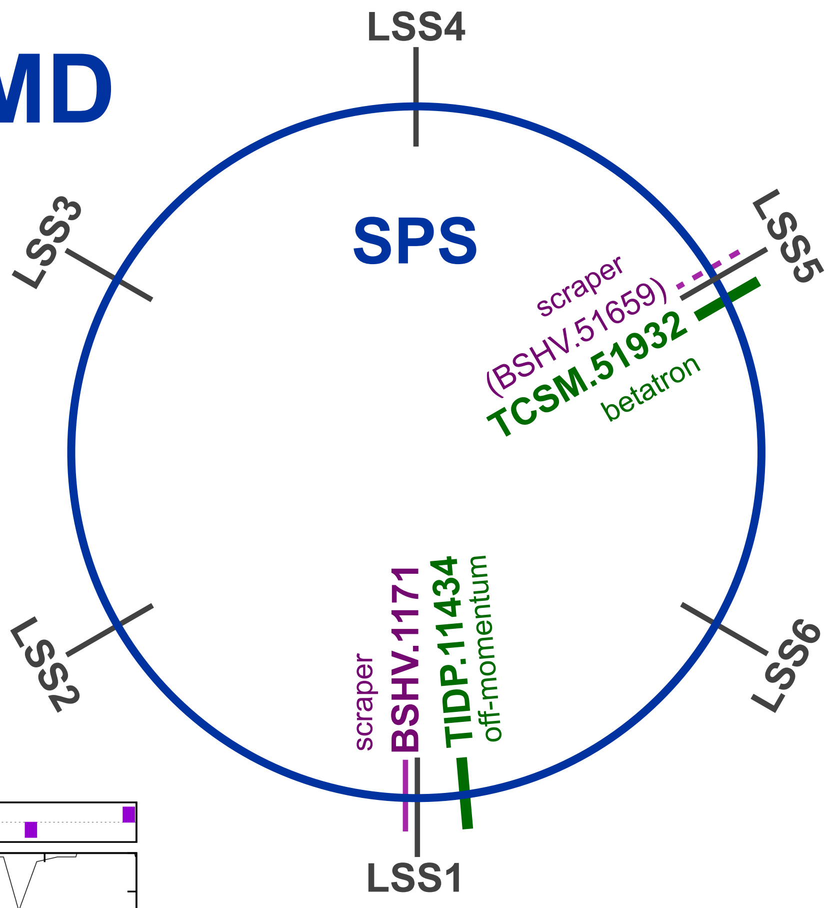
- SPS has one (horizontal) betatron collimator: **TCSM.51932**
  - **Prototype** to develop controls and for beam dynamics studies
  - Hollow inside, so limited intensity (~72 bunches ok)

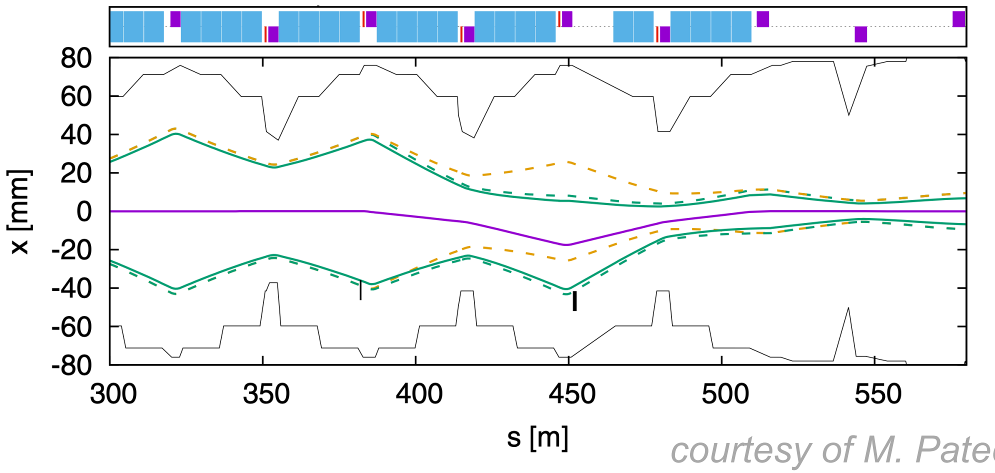
- Standard SPS cycle (~27.6s) not long enough to move TCSM IN/OUT
  - **COAST** allows us to stay as long as we want (by glueing cycles)



Collimation in the SPS - Dedicated MD

- SPS has one (horizontal) betatron collimator: **TCSM.51932**
  - **Prototype** to develop controls and for beam dynamics studies
  - Hollow inside, so limited intensity (~72 bunches ok)
- Standard SPS cycle (~27.6s) not long enough to move TCSM IN/OUT
  - **COAST** allows us to stay as long as we want (by glueing cycles)
- SPS has a block in dispersion region to clean off-momentum: **TIDP.11434**
  - Can only be reached by **orbit bumps**
- Also vertical **scrapers: BSHV**
  - Not (yet) used for MD





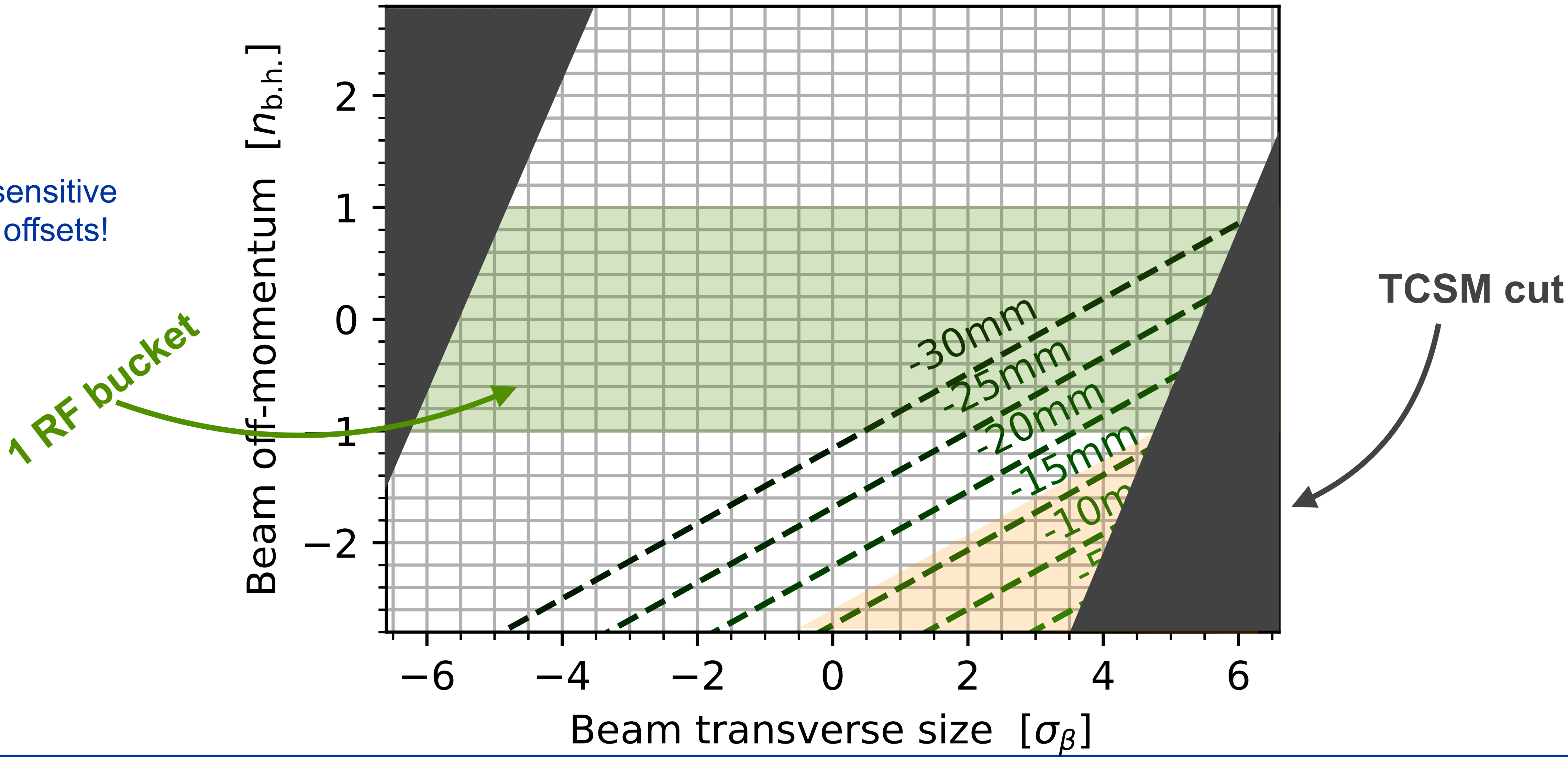
courtesy of M. Patecki

Last SPS MD: 19/06/2024 - Succesful Campaigns

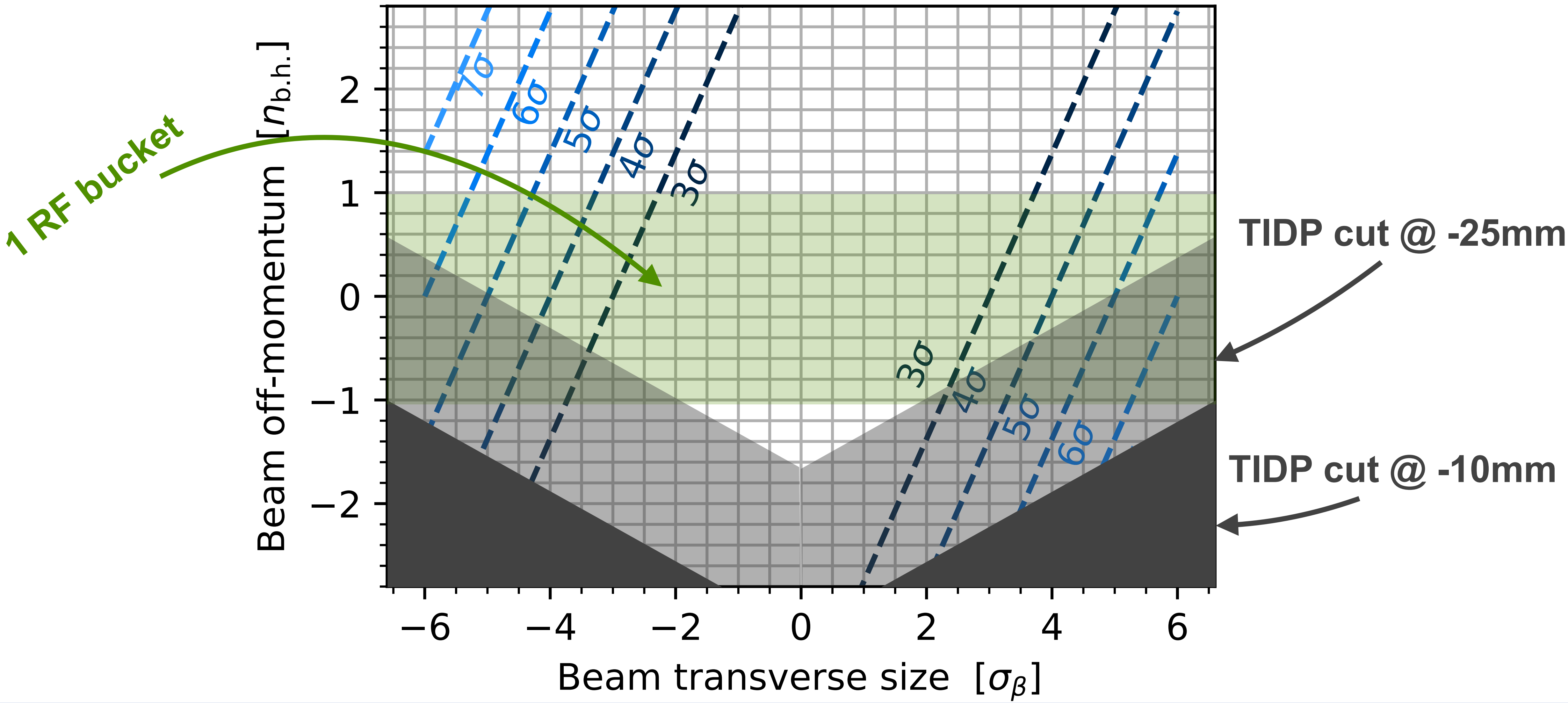
COAST 1	12:36:49	13:08:07	*alignment*	TCSM (close to core)
COAST 2	13:12:42	13:33:25	*alignment*	TCSM (further out in the halo) - result confirmed
			scraping (end)	TIDP -5mm to -28mm (in steps of 1mm)
CYCLEs	15:20:05	15:48:23	*calibration*	TIDP bumps -30mm to -20mm (in steps of 1mm, 3 times each)
COAST 3	15:53:50	16:18:14	*repopulation*	TIDP IN/OUT -20mm and -25mm (TCSM @5σ)
			scraping (end)	TCSM 5σ to 0.5σ (in steps of 0.25σ)
COAST 4	16:22:21	16:41:14	*repopulation*	TCSM IN/OUT 3σ (TIDP OUT)
COAST 5	17:14:35	17:44:02	*repopulation*	TCSM IN/OUT 3σ (TIDP @ -20mm)
			scraping (end)	TIDP bumps -20mm to -30mm (in steps of 0.25mm)
COAST 6	17:47:14	17:56:00	*scraping*	TCSM 5σ to 0.5σ (in steps of 100μm) TIDP @ -10mm
COAST 7	17:57:49	18:15:47	*scraping*	TIDP -7mm to -30mm (in steps of 0.25mm)

Off-Momentum Scraping (TCSM @ 5.4σ)

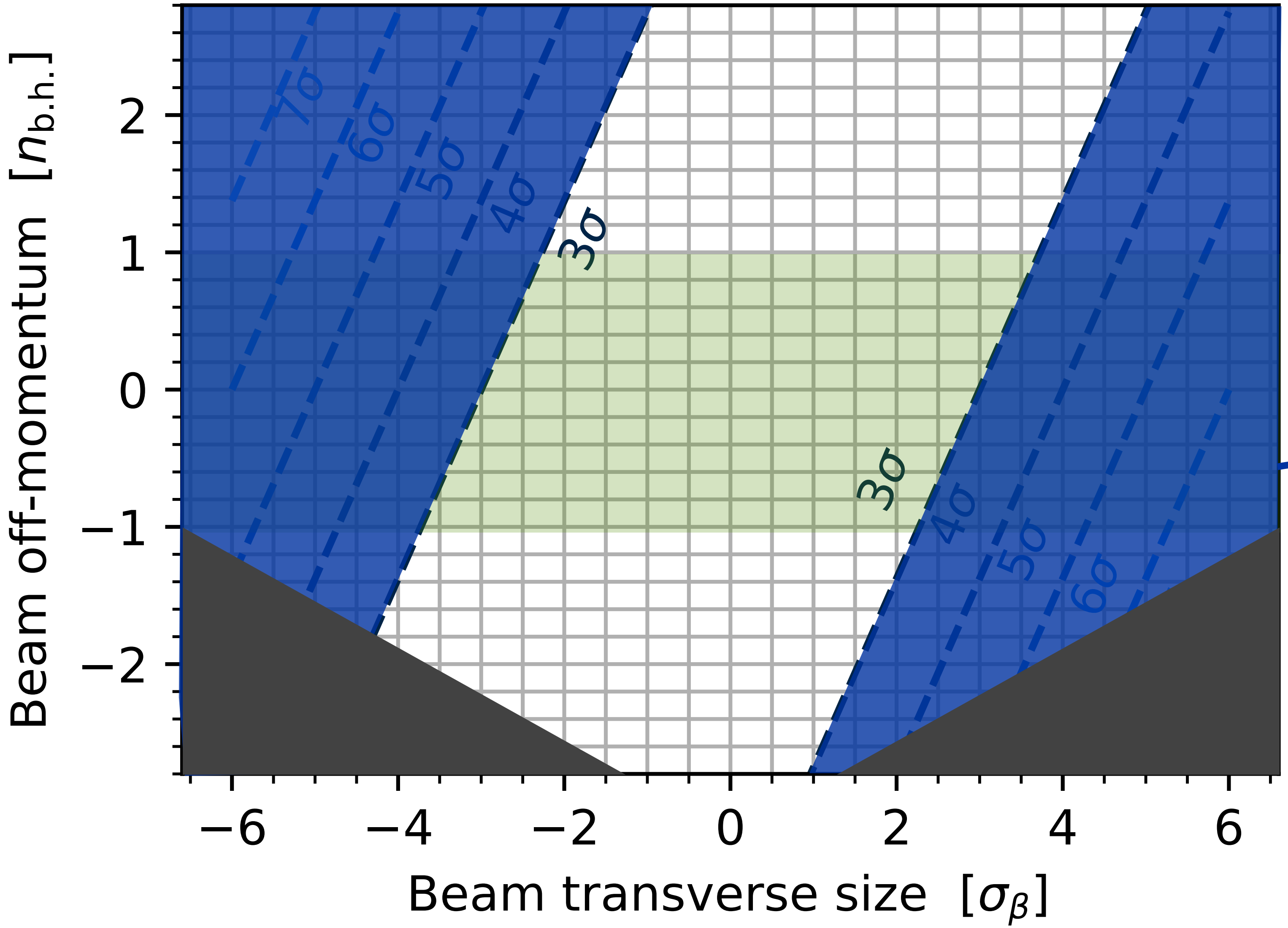
This is sensitive
to orbit offsets!



Betatron Scraping (TIDP @ -10mm & -25mm)

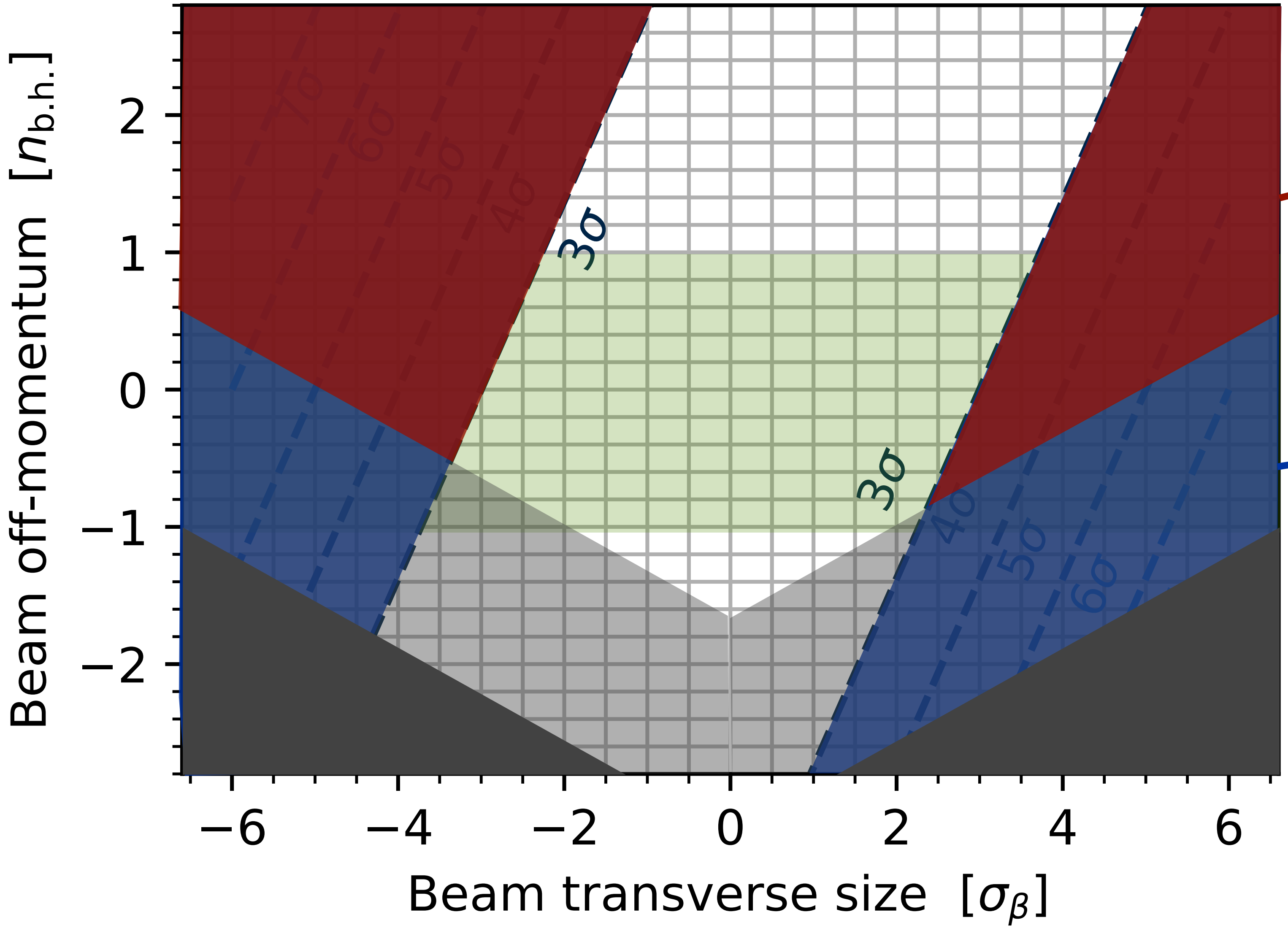


Betatron Scraping (TIDP @ -10mm & -25mm)



scraped away by TCSM with TIPD @ -10mm

Betatron Scraping (TIDP @ -10mm & -25mm)



scraped away by TCSM with TIPD @ -25mm

scraped away by TCSM with TIPD @ -10mm

SPS Collimation MD Requests for 2025-2026

- In order to better understand nature of losses, we need various measurements:
  - Alternative configurations for COAST (30GeV, 200GeV, no RF)
  - Loss map around the ring (need to adapt BLM gain)
  - PS beam with lower momentum spread (reduce long. emitt. and go down in intensity)

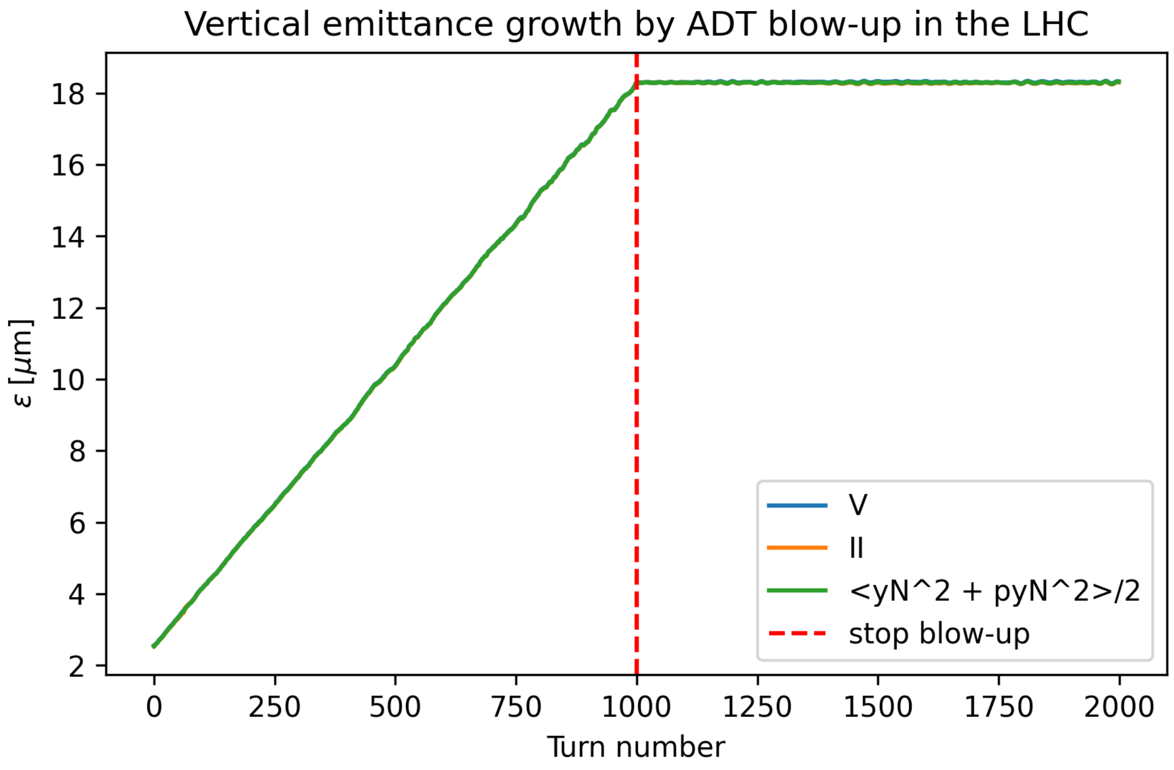
- Requests:
  - Test readiness (BLM gain, various COAST configs, collimator controls & BPM) during commissioning / scrubbing
  - Three dedicated MD slots (2 in 2025, 1 in 2026) to be able to perform all tests, and have a backup in case of issues

New Tools: EmittanceMonitor and BlowUp

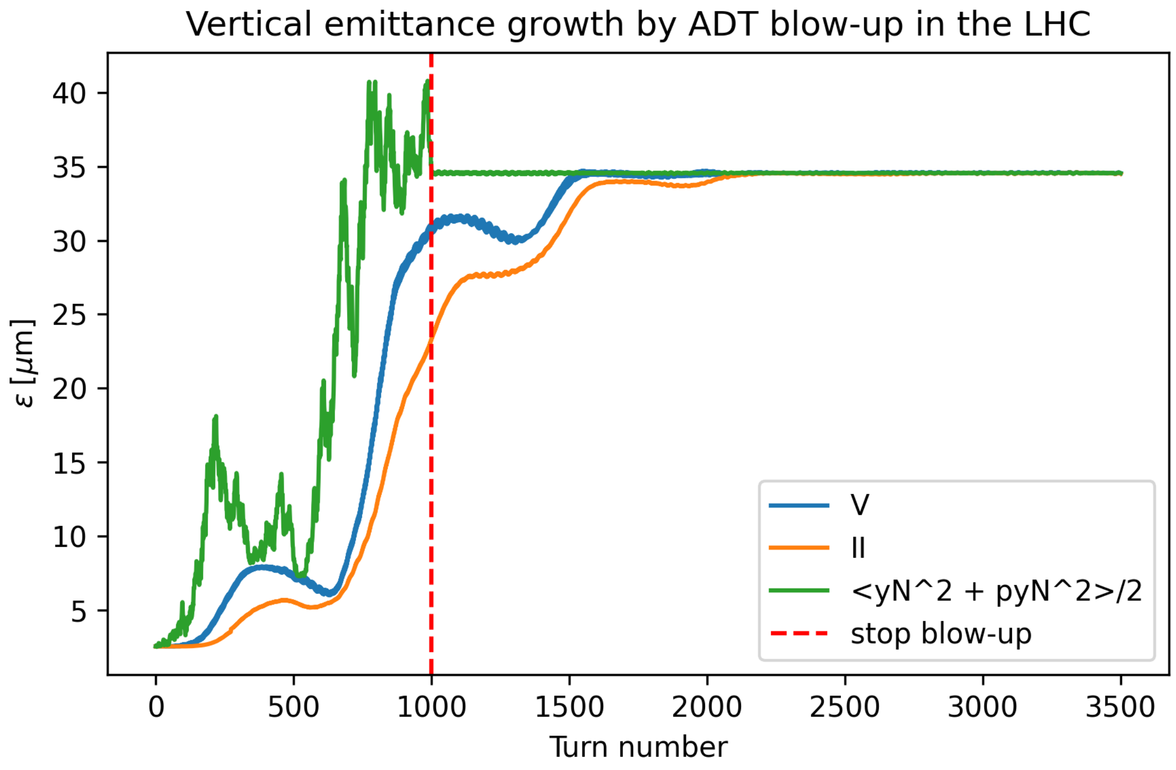
- `EmittanceMonitor:`
  - Logs emittance per turn (geometric & normalised, plane-by-plane and orthogonal modes)
  - GPU-friendly
- `BlowUp:`
  - Adds random kicks to particles to induce emittance growth
  - Two modes:
    - *random kick per particle* (quick smooth blow-up)
    - *random kick per bunch* (more realistic)

New Tools: EmittanceMonitor and BlowUp

random kicks per particle



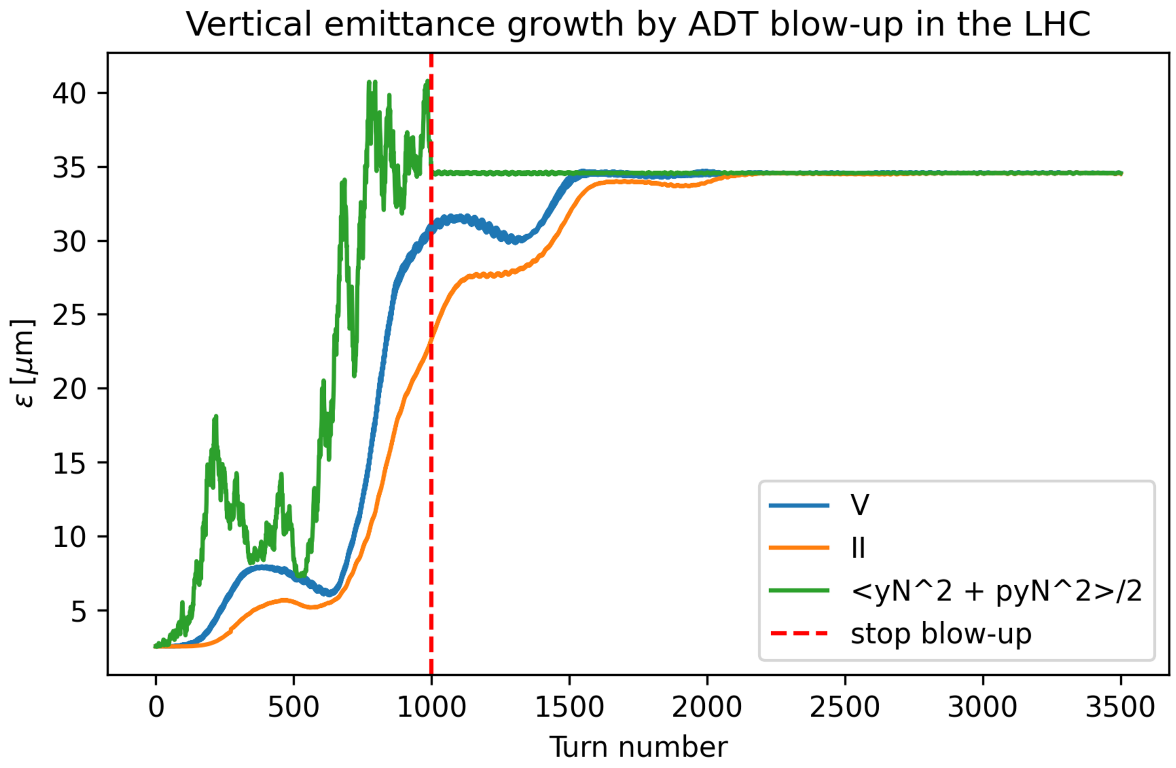
random kicks per bunch



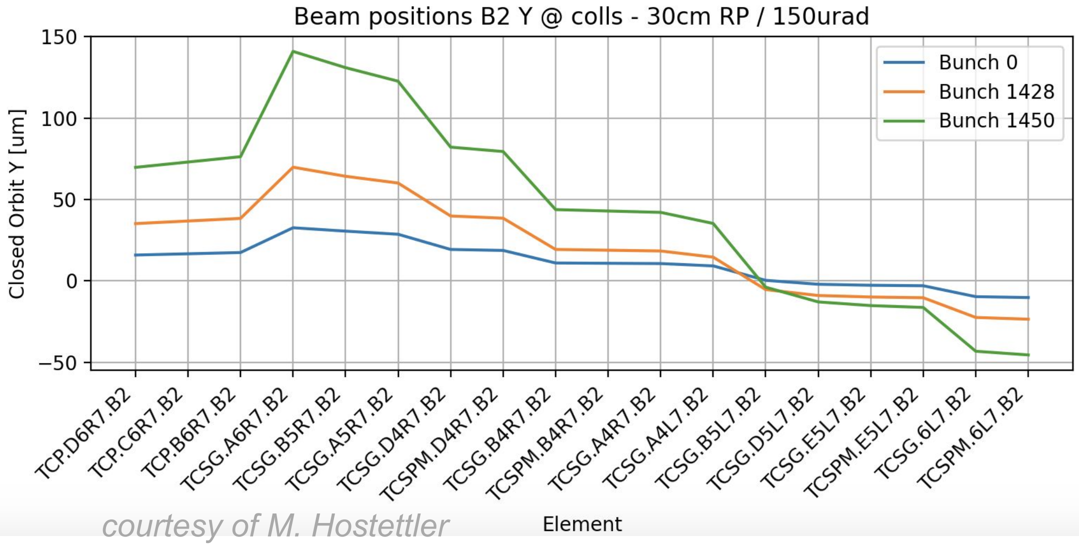
New Tools: EmittanceMonitor and BlowUp

- The beam is shaken around and is no longer matched
- In other words: coordinate covariances do not relate to beam parameters anymore
- After blow-up, beam needs time to decohere again (1000 turns of blow-up; 1500 turns of relaxation time)
- Emittance calculation based on normalised coordinates is less correct for unmatched beam

random kicks per bunch



Orbit Distortion

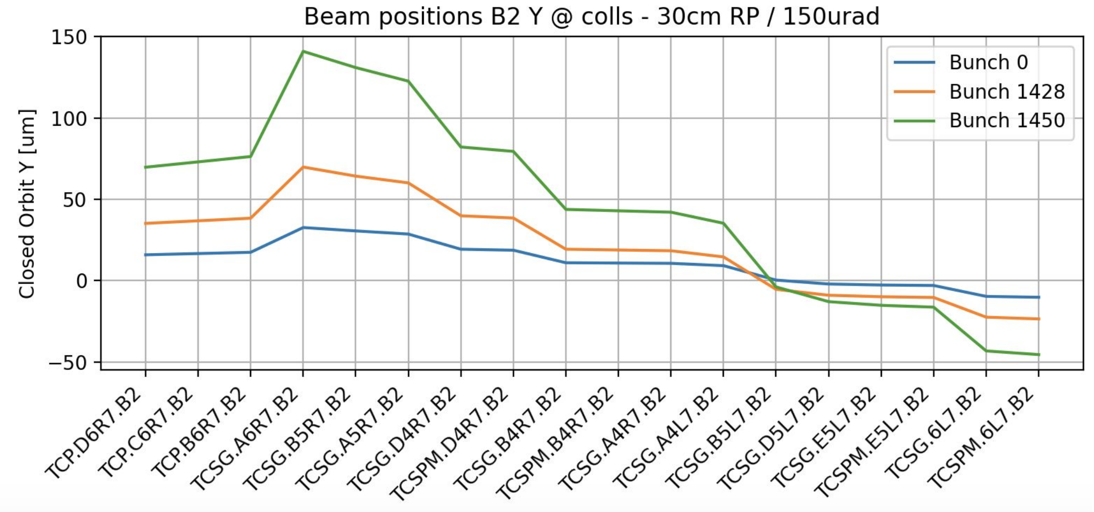


courtesy of M. Hostettler

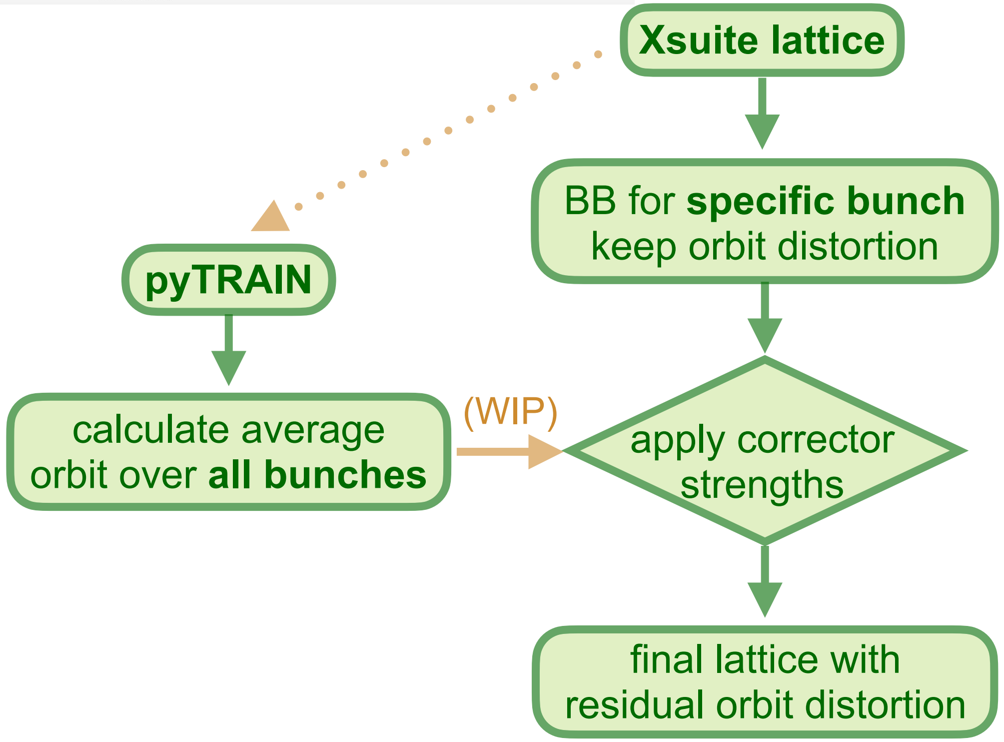
- Clear differences bunch-by-bunch
- Hierarchy becomes bunch-dependent
- This is the full effect on orbit; in practice the LHC has an **orbit feedback** system that corrects the average
- Still some orbit distortion left, up to 60um (0.25σ) between collimators

Orbit Distortion

- Clear differences bunch-by-bunch
- Hierarchy becomes bunch-dependent
- This is the full effect on orbit; in practice the LHC has an **orbit feedback** system that corrects the average
- Still some orbit distortion left, up to 60um (0.25σ) between collimators
- In typical BB simulations, orbit distortion is **ignored** (dipolar kick is subtracted from the element)
- WIP to implement a realistic orbit distortion including orbit feedback
- For now, use **varying strength** of orbit distortion



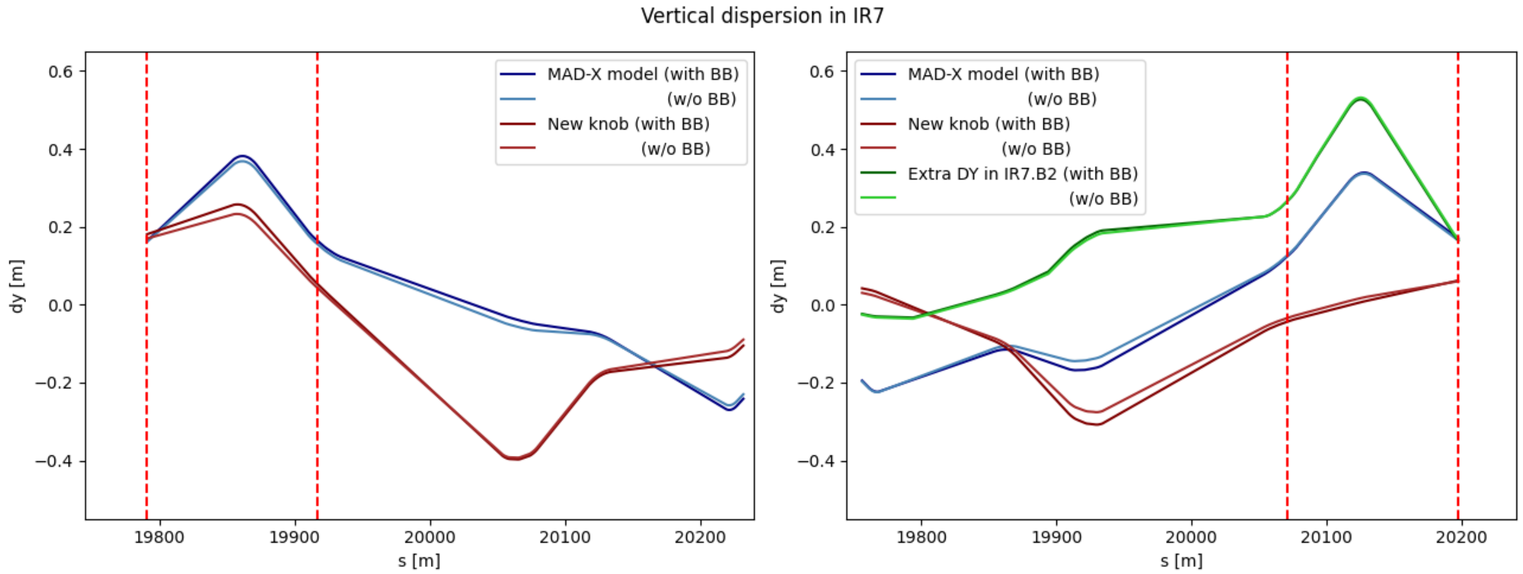
courtesy of M. Hostettler

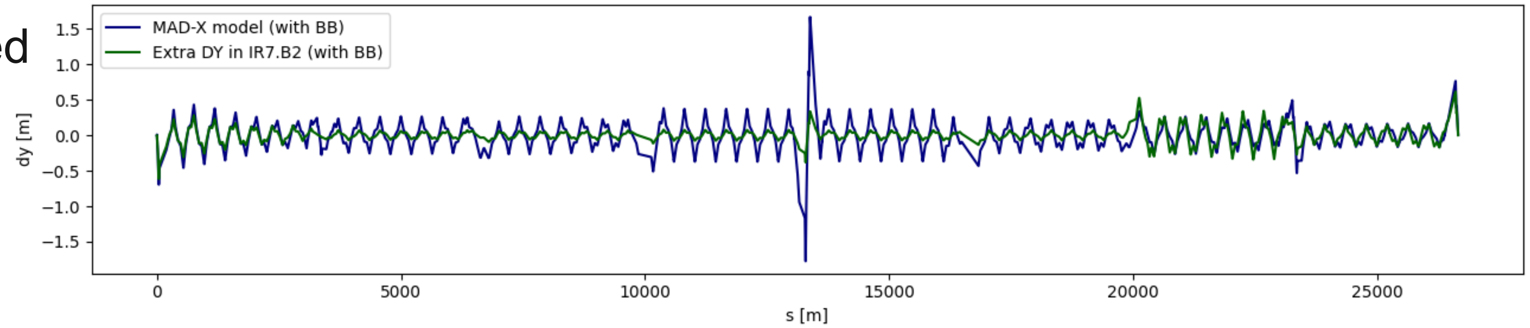


Spurious Vertical Dispersion

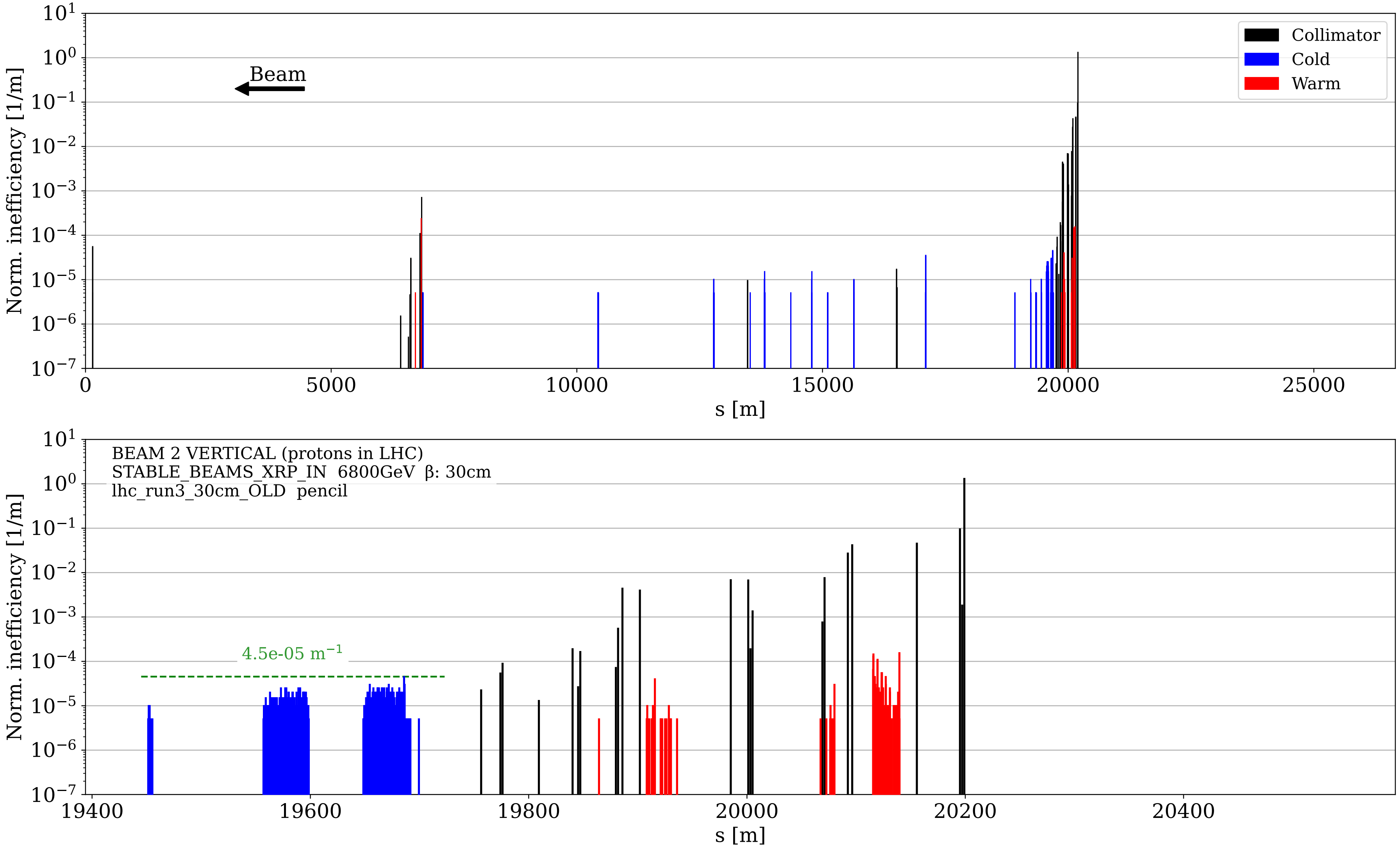
- Measured **vertical dispersion** in IR7 is **higher** than predicted from the MAD-X model, at the location of the secondary

- Mimic in simulation:
  - Installed vertical dipoles in IR7 to introduce spurious dispersion
  - Orbit is not affected, nor is dx
  - Limitation of model is that dy is affected everywhere around the ring
  - Implemented overcompensated knob



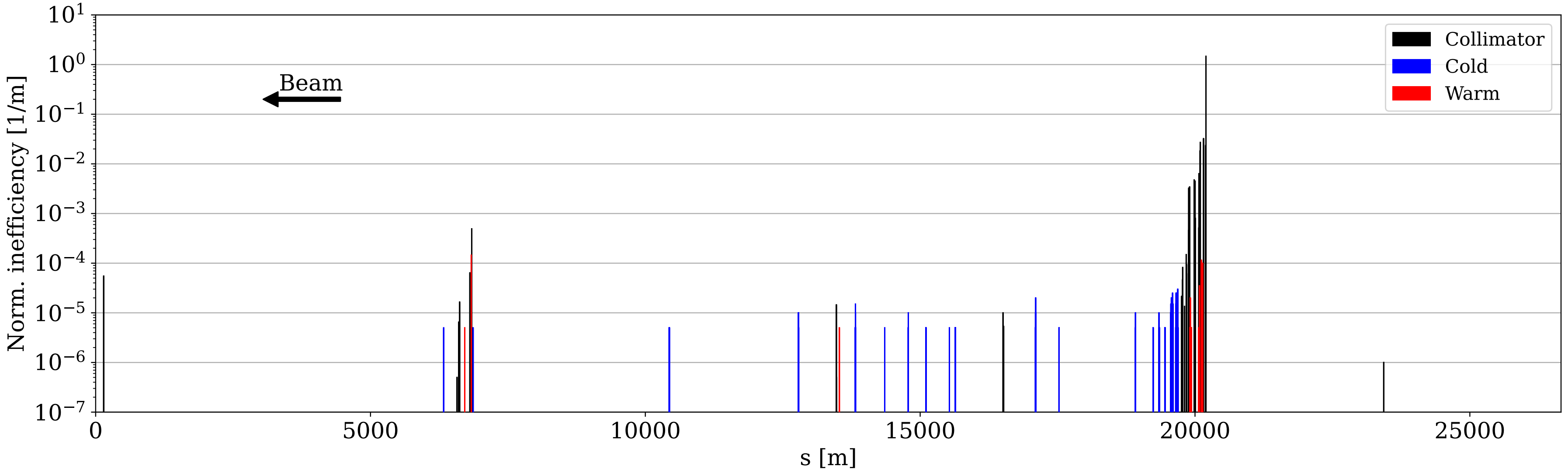


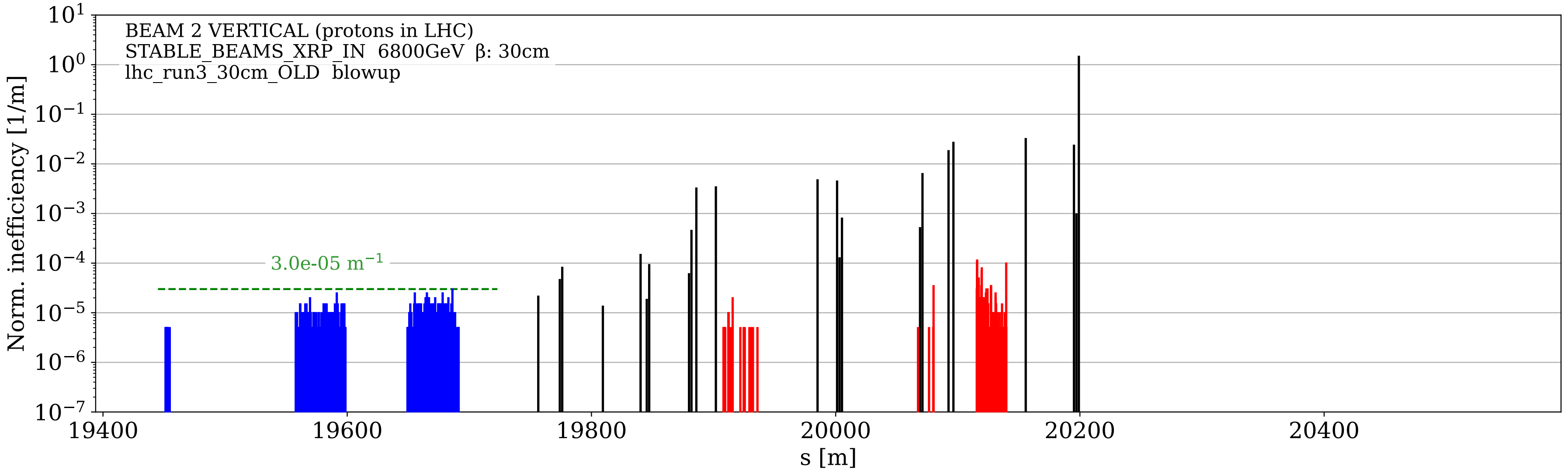
Validation of Lattice and BlowUp with Loss Maps



pencil beam

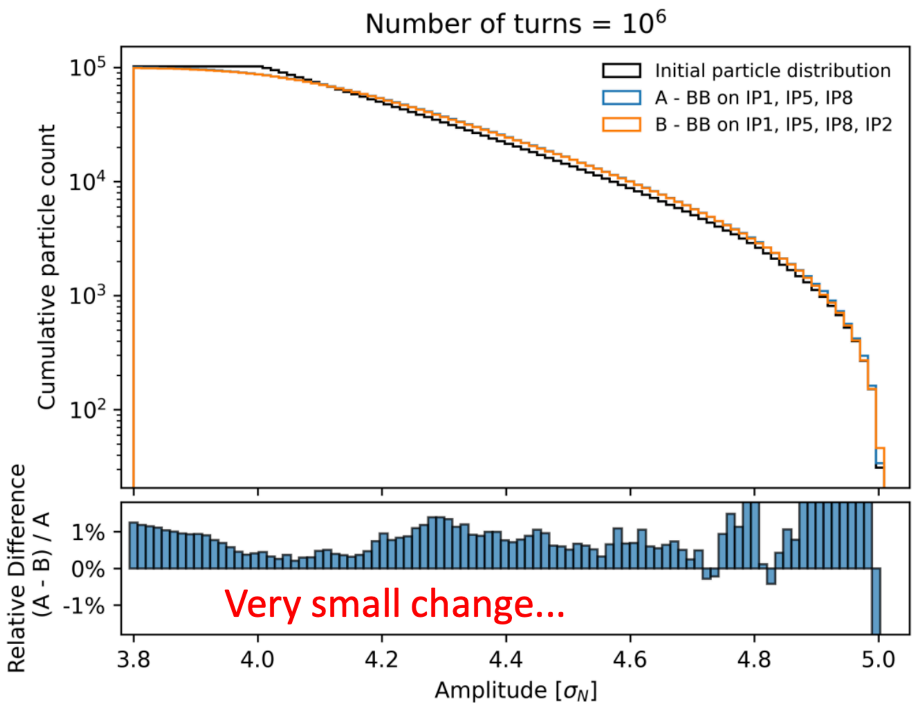
Validation of Lattice and BlowUp with Loss Maps

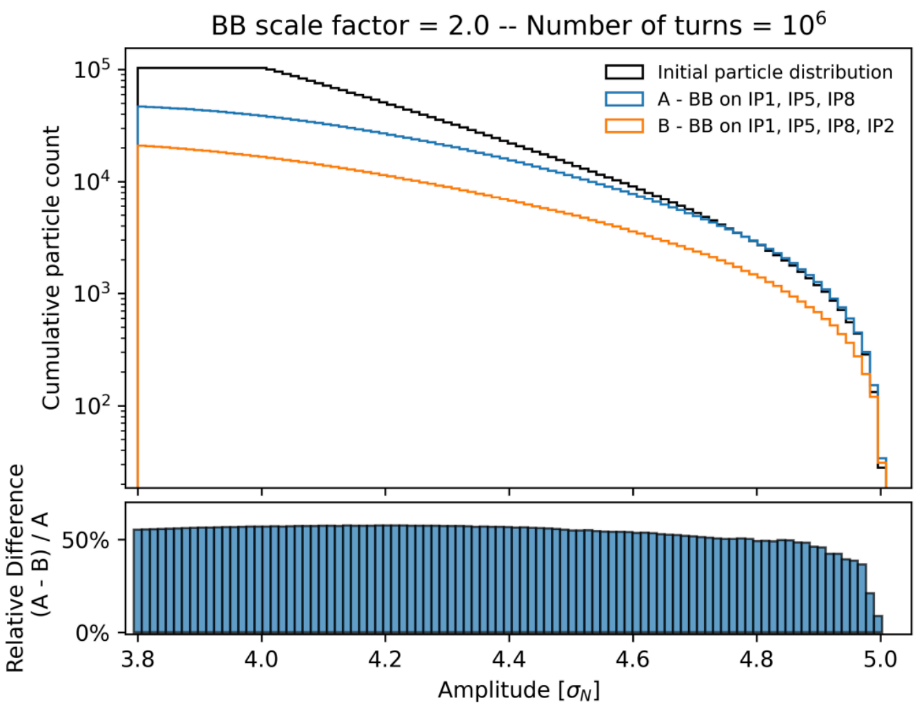




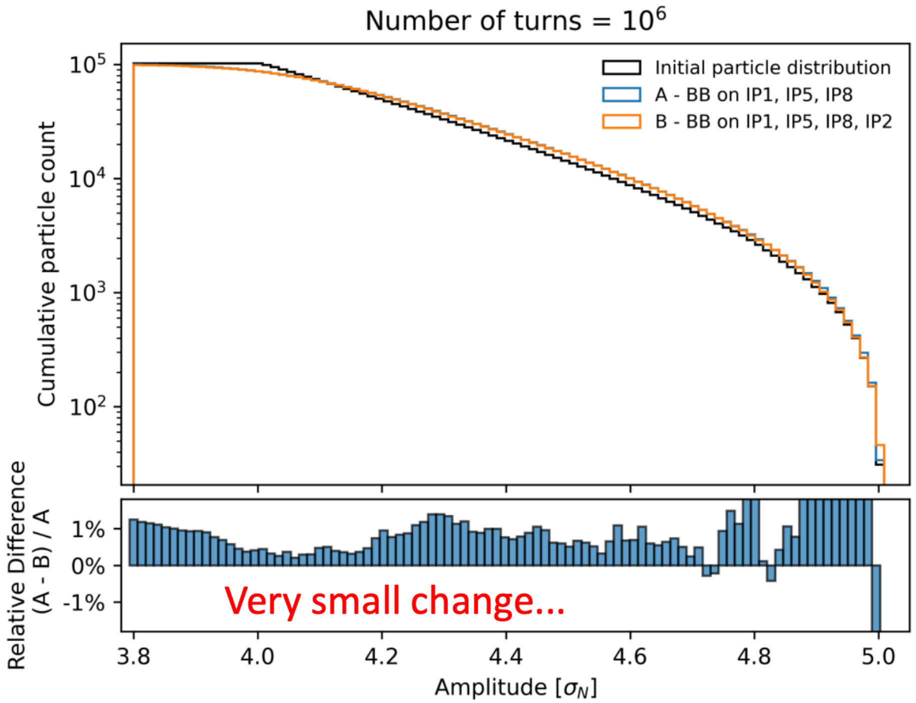
blow-up

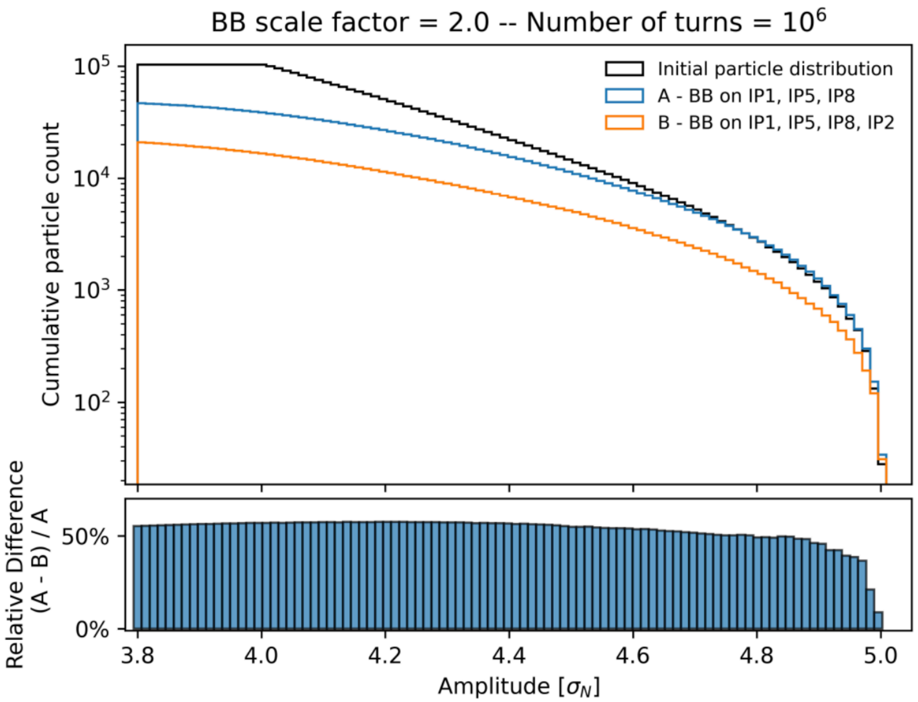
Beam-Beam Halo Simulations





Beam-Beam Halo Simulations





courtesy of M. Rakic & C.E. Montanari