Towards HL-LHC

Optics Studies for ATLAS Roman Pots

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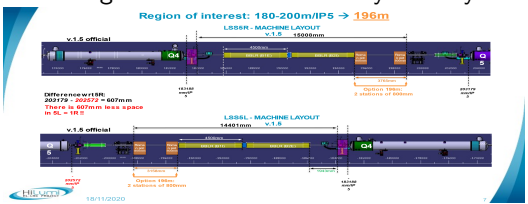
Introduction

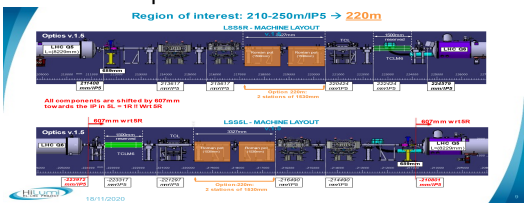
- RP for ATLAS @ HL-LHC are discussed internally.
  - despite interest on its own, it is very good to have a possibility of independent cross-check of results.
- CT-PPS expressed interest in having Roman pots at HL-LHC.
- ARP would double the dataset size as we can combine the results from ATLAS and CMS-TOTEM.
- Potentially, presence of Roman pots can enhance measurement capabilities of 'central' detector.
- At high pile-up environment main focus is on photon induced processes and Beyond Standard Model searches:
  - exclusive $\gamma\gamma \to WW$,
  - exclusive $\gamma\gamma \to ZZ$,
  - exclusive $t\bar{t}$,
  - ALP searches,
  - ...
- The key factor, and a starting point, is acceptance of forward detectors.
- In this talk, acceptance for few possible locations in vicinity of ATLAS collision point will be discussed.

Optics

Optics

- HL-LHC ver. 1.5 is used for studies.
- $\sqrt{s} = 14$ TeV, $\beta^* = 15$ cm and crossing angle of 250 μrad with 4 phases: $\phi = 0$ $(+x)$, $\phi = 90$ $(+y)$, $\phi = 180$ $(-x)$, $\phi = 270$ $(-y)$.
- Emittance $\varepsilon = 2.5$ μm·rad (instead of 3.5 used in Run 1 – 3)
- According to HL-LHC machine layout only few locations are possible:

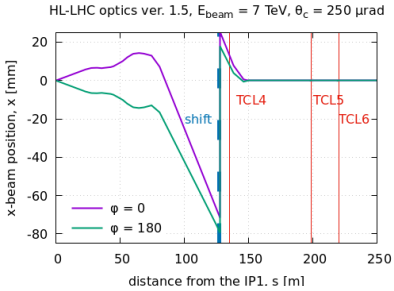


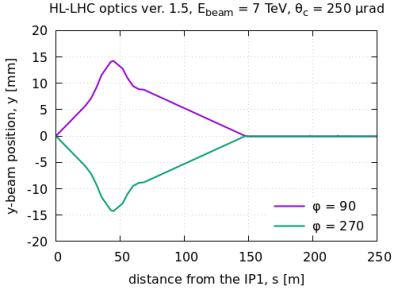


- R1A at 195.5 m
- R1B at 198.0 m
- R2A at 217.0 m
- R2B at 219.5 m
- R3A at 234.0 m
- R3B at 237.0 m
- R3C at 245.0 m

- Collimators are located at:
  - "TCLPX.4": 136.114m
  - "TCL.5": 199.518m
  - "TCL.6": 221.057m

Beam Trajectory



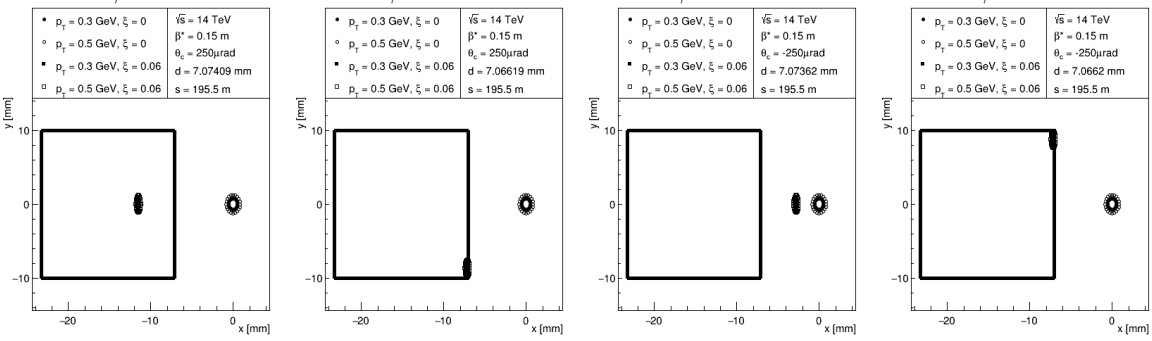


- Beam trajectory between IP1 and 250 m:
  - $x_0 = y_0 = z_0 = 0$
  - $p_x = \cos(\phi) \cdot 250 \cdot 10^{-6} \cdot 7000$ GeV,
  - $p_x = \sin(\phi) \cdot 250 \cdot 10^{-6} \cdot 7000$ GeV,
  - $E = 7000$ GeV.
- **Top** plot – position wrt. x axis with horizontal crossing angle. Before 127 m reference system is wrt. IP ($(x, y) = (0, 0)$). At 127 m there is a shift of 97 mm to reflect that beam is going from common beampipe to a separate one.
  - The beam in location of TCL5 and TCL6 is in the middle of beampipe, but at TCL4 it is shifted. This shift would make TCL4 jaw closure asymmetric wrt. beam-pipe center and has to be taken into account in acceptance calculations.
- **Bottom** – position wrt. y axis with vertical crossing angle.

Proton Positions

- Phase (direction) of crossing angle has certain impact of protons that lost energy:

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$



- $\phi = 0$ moves protons outside the ring center $\rightarrow$ it can be imagined that they are "more distant",
- oppositely, $\phi = 180$ moves protons towards the ring center $\rightarrow$ it can be imagined that they are "more packed",
- $\phi = 90$ and $\phi = 270$ are symmetric wrt. each other $\rightarrow$ they move diffractive protons "down" or "up".

Collimators

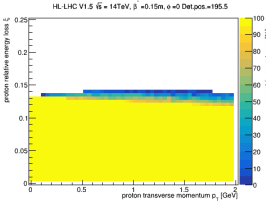
TCL4 – Default

- TCL4 has impact on acceptance of pots in all considered locations.
- By default, TCL4 jaws will be at 14.2σ, symmetrically around beam center:

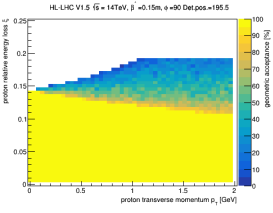
crossing angle, ϕ	beam center, x_{beam} [mm]
0	11.304
90	8.986
180	6.668
270	8.986

- Acceptances for RP1A:

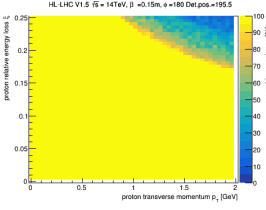
$\phi = 0$



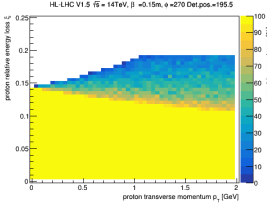
$\phi = 90$



$\phi = 180$



$\phi = 270$

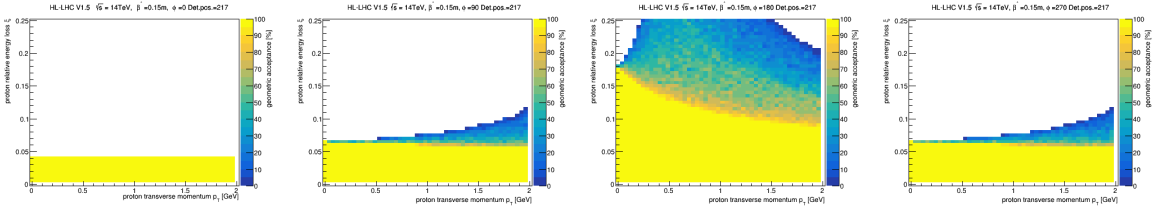


- For all phases the limitations on acceptance with TCL4 closed to 14.2σ are acceptable $\rightarrow$ upper limit on acceptance is of about ξ of 0.13.

TCL5 – Default

- TCL5 has impact on acceptance of RP2X and RP3X.
- By default, TCL5 jaws will be at 14.2σ (beam center is practically at 0).
- Situation for RP2A: (TCL4 closed to 14.2σ):

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$

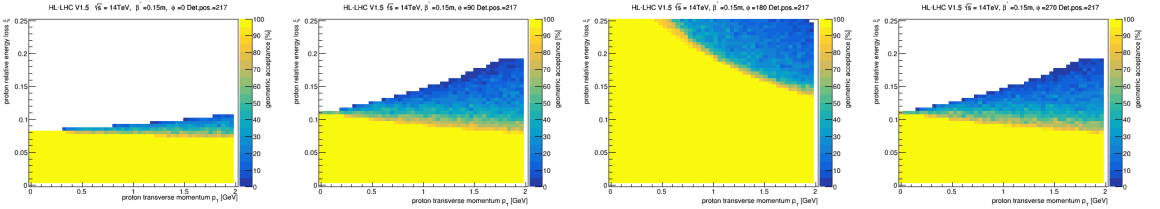


- Except for $\phi = 180$, acceptance is very limited.
- Note that during Run2/3 35-42σ was used.

TCL5 Opened to 30 and 35σ

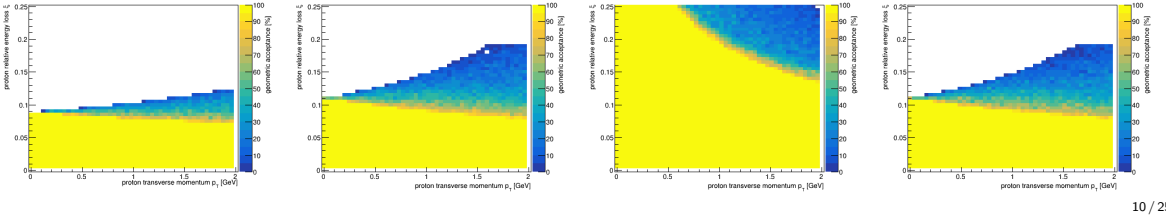
- TCL5 at 30σ seems to be acceptable for the vertical crossing angle:

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$



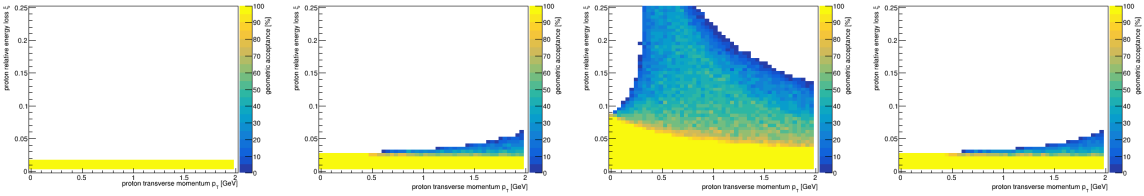
- TCL5 should be opened to at least 35σ for $\phi = 0$:

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$

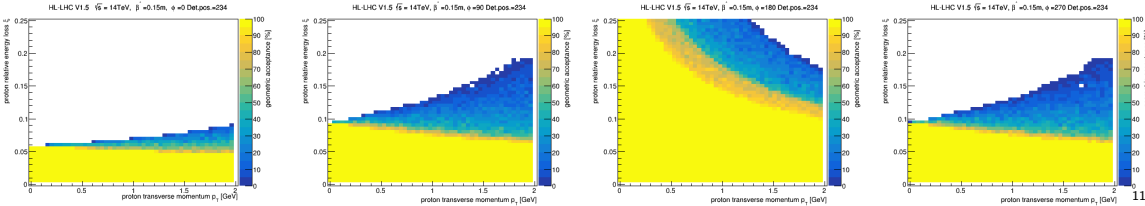


TCL6 - Default

- TCL4 is closed to 14.2σ, TCL5 is fully opened and TCL6 at 14.2σ:



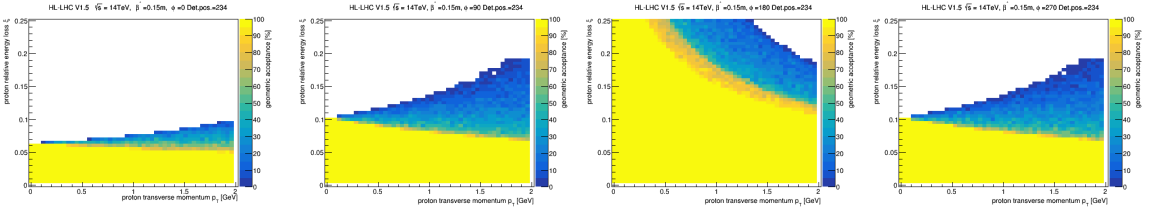
- For the default settings, acceptance is unacceptably small, except for the case of $\phi = 180$ (but also here an increase of upper boarder is desired).
- Situation for TCL6 opened to 55σ becomes more acceptable for vertical crossing angle, but still not enough for $\phi = 0$:



Opened TCL6

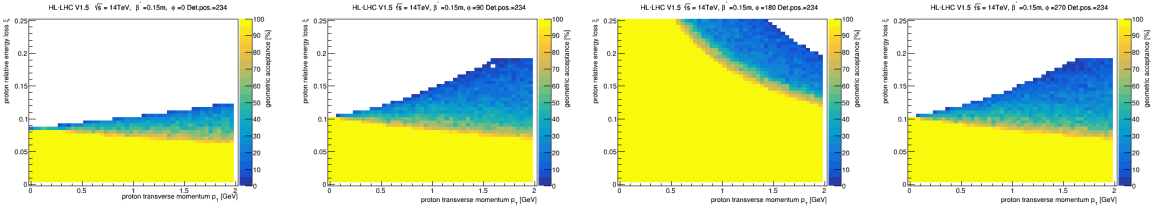
- TCL6 opened to 60 σ:

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$



- TCL6 completely opened (limits only due to TCL4 and aperture):

$\phi = 0$ $\phi = 90$ $\phi = 180$ $\phi = 270$

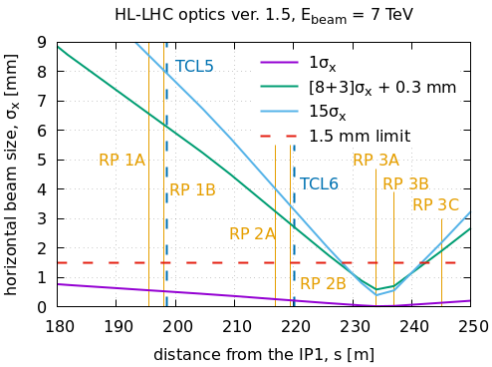


Collimators – Summary

- Each collimator has an impact on acceptance of certain pot (location):
  - RP1A/B: TCL4,
  - RP2A/B: TCL4 and TCL5,
  - RP3A/B/C: TCL4 and TCL5 and TCL6.
- With collimators opened to default values (14.2σ) having pots located after TCL5 will be pointless $\rightarrow$ expect for the case of $\phi = 180$, there will be no acceptance.
- For studied optics case the following conclusions can be drawn:
  - TCL4 can be opened to default 14.2σ,
  - TCL5 should be opened to (at least):
    - 35σ for $\phi = 0$,
    - 30σ for vertical crossing angle,
    - 14.2σ (default) for $\phi = 180$,
  - TCL6 should be opened to (at least):
    - $> 60\sigma$ (fully opened) for $\phi = 0$,
    - 55σ for vertical crossing angle,
    - 14.2σ (default) for $\phi = 180$ (but profitable will be to open it more, *e.g.* to 30σ).

Acceptance

Beam Width



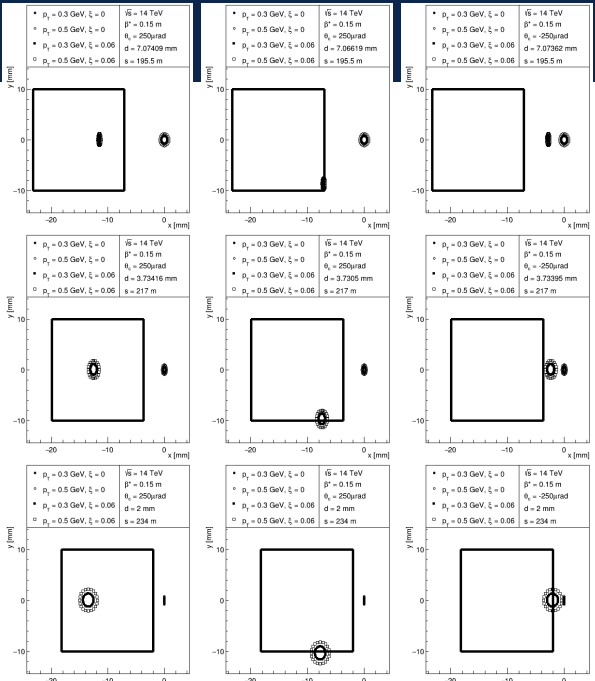
- Beam width: $\sigma_x = \sqrt{\frac{\varepsilon \cdot \beta_x}{\gamma}}$, where
  - emittance $\varepsilon = 2.5$ μm·rad,
  - $\gamma \approx 7460$ and
  - β_x is taken from a twiss file.
- In Run 2 and Run 3 the limit on how close pot can move to the beam during nominal run was due to TCT collimator: $d_{min} = [TCT_{setting} + 3] \cdot \sigma + 0.3$ mm:
  - usually, minimal possible $TCT_{setting}$ was around 8-9,
  - another limiting factor was reaching a hard limit of 1.5 mm.
- "Optimistic, yet realistic" assumption of d_{min} computed wrt. $TCT_{setting}$ results in smaller detector-beam distances in almost all positions w.r.t. "15σ" approach used *e.g.* in AFP TDR.
- "Hard limit" is reached for RP3A and RP3B.
- In addition, 0.5 mm of "dead material" (pot thin floor + detector-pot gap + detector dead area) will be considered when computing the acceptance.

Proton Position

- Collimators are widely opened.
- Plots represent the following situation:

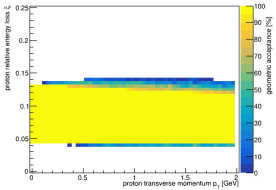
RP1A $\phi = 0$	RP1A $\phi = 90$	RP1A $\phi = 180$
RP2A $\phi = 0$	RP2A $\phi = 90$	RP2A $\phi = 180$
RP3A $\phi = 0$	RP3A $\phi = 90$	RP3A $\phi = 180$

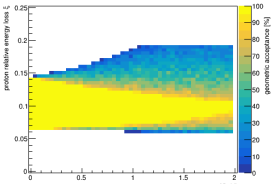
- Situation for $\phi = 270$ is symmetric to $\phi = 90$ $\rightarrow$ diffractive protons are going "up".
- "Ellipses" are for p_T of 0.3 and 0.6 GeV.
- "Right" ellipses are for $\xi = 0$ (beam), "left" for $\xi = 0.06$ (diffractive proton).
- In the following slides, constraint on acceptance will be due to detector-beam distance, LHC aperture and collimators.
- There will be no cut on "y" or "detector size" as this is assumed to be adjusted accordingly to maximize the acceptance.

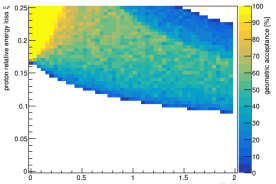


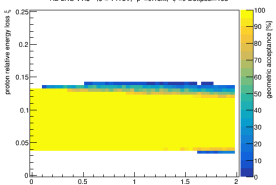
Acceptances at RP1A (195.5 m) and RP1B (198 m)

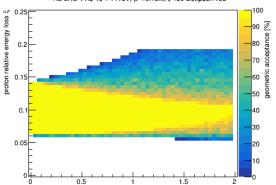
pot	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
RP1A	TCL4/5/6: 14.2/–/–	TCL4/5/6: 14.2/–/–	TCL4/5/6: 14.2/–/–
RP1B	TCL4/5/6: 14.2/–/–	TCL4/5/6: 14.2/–/–	TCL4/5/6: 14.2/–/–

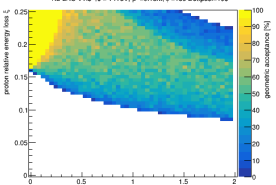






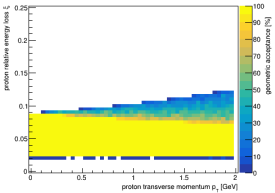


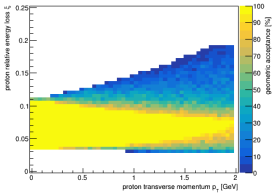


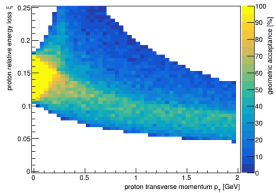


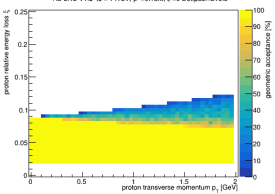
Acceptances at RP2A (217 m) and RP2B (219.5 m)

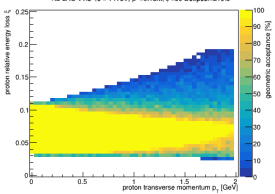
pot	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
RP2A	TCL4/5/6: 14.2/35/–	TCL4/5/6: 14.2/30/–	TCL4/5/6: 14.2/14.2/–
RP2B	TCL4/5/6: 14.2/35/–	TCL4/5/6: 14.2/30/–	TCL4/5/6: 14.2/14.2/–

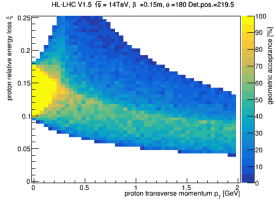




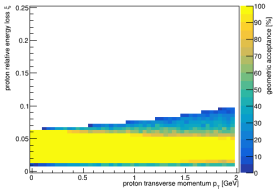
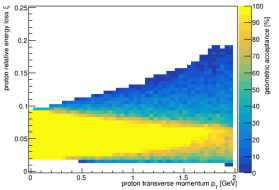
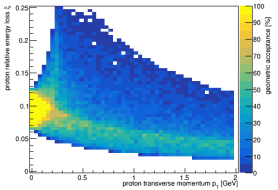
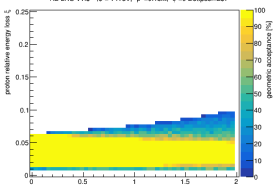
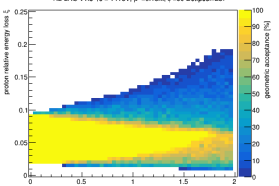
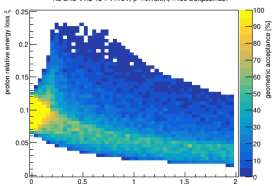






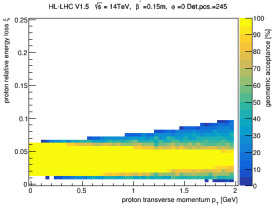


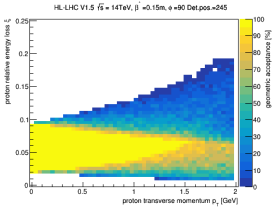
Acceptances at RP3A (234 m) and RP3B (237 m)

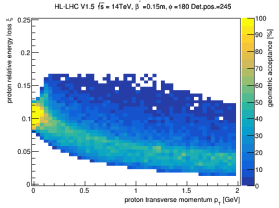
pot	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
RP3A	TCL4/5/6: 14.2/35/open	TCL4/5/6: 14.2/30/55	TCL4/5/6: 14.2/14.2/20
			
RP3B	TCL4/5/6: 14.2/35/open	TCL4/5/6: 14.2/30/55	TCL4/5/6: 14.2/14.2/20
			

Acceptances at RP3C (245 m)

pot	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
RP3C	TCL4/5/6: 14.2/35/open	TCL4/5/6: 14.2/30/55	TCL4/5/6: 14.2/14.2/20



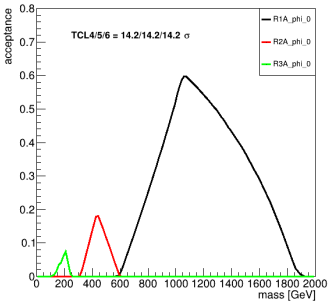


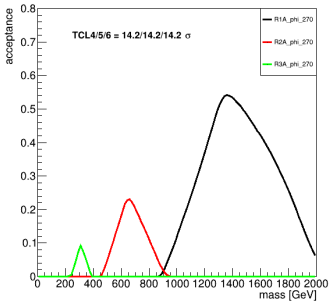


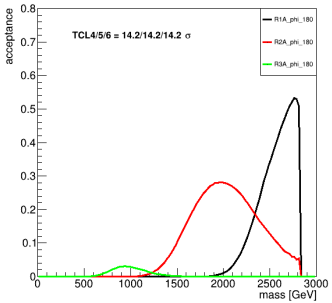
Mass Acceptance – Closed Collimators

- Geometric acceptance can be translated into a mass acceptance:
  - if both protons are tagged, then from their measured ξ an energy (mass) of "central" system can be computed.
- For collimators closed to 14.2σ the acceptance for RP2A/B and RP3A/B/C is very limited:

$\phi = 0$ $\phi = 90/270$ $\phi = 180$

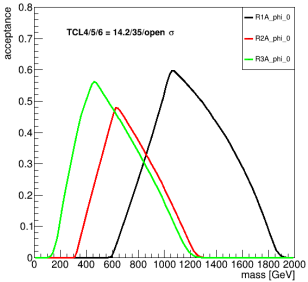


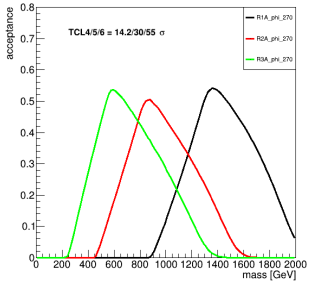


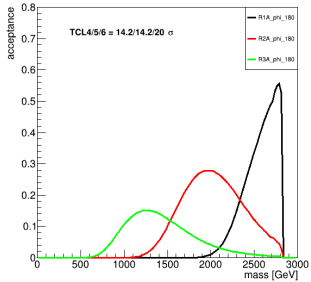


Mass Acceptance – (More) Opened Collimators

- Assuming that collimators can be more opened (as discussed before), the acceptance becomes more reasonable:





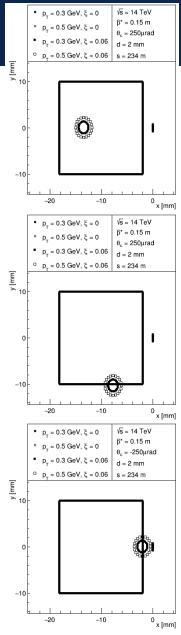


- As can be deduced from plots, 10% acceptance level is for masses in range:

	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
TCL4/5/6	14.2/35/open	14.2/30/55	14.2/14.2/20
RP1A	$700 < M < 1800$	$1000 < M < 2000$	$2200 < M < 2800$
RP2A	$400 < M < 1100$	$550 < M < 1450$	$1500 < M < 2600$
RP3A	$200 < M < 1050$	$300 < M < 1200$	$1000 < M < 1700$

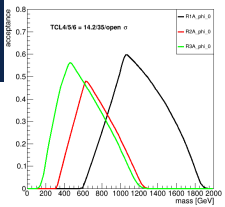
Acceptance and Proton Position – Remarks

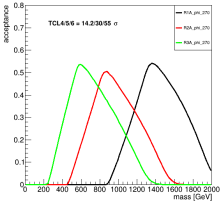
- For $\phi = 0$ protons are "more distant" – crossing angle moves diffractive protons away the beam center:
  - this would require TCL5/6 being opened much wider than in default settings,
  - with 2 pots located at RP1X and 2 more on RP2X or RP3X this would result with a marvelous acceptance for very wise range of ξ.
- For the vertical crossing-angle diffractive protons are moved "up" or "down" depending on the sign:
  - very nice acceptance (for collimators opened as in Run2/3) for all considered locations,
  - since sign of crossing angle may change, detectors would have to cover very large area in y or have a mechanism to allow movement.
- For $\phi = 180$ protons are "packed" – crossing angle moves diffractive protons towards the beam center:
  - this is the reason of fair acceptance for TCL4/5/6 being opened to default value of 14.2σ,
  - the drawback is negative impact on proton position (thus kinematics) reconstruction $\rightarrow$ very fine detector granularity will be required.

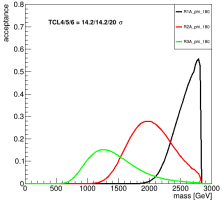


Few Thoughts...

- Is it possible to have a vertical crossing angle in IP1?
  - TCL5 and TCL6 would have to be open as in Run 2/3 to at least 30 and 55σ – would it be possible?
  - If 4 pots / side are feasible then a combination of RP1 + RP3 would give a very nice acceptance in a mass range between 300 and 2000 GeV.
  - If only 2 pots are feasible then where is the most interesting physics: $300 < M < 1200$, $550 < M < 1450$ or $1000 < M < 2000$ GeV?
- Is it possible to have $\phi = 0$ (towards the ring center)?
  - TCL5 would have to be open to at least 35σ and TCL6 almost fully – how wide their gap can be?
  - If 4 pots / side are feasible then a combination of RP1 + RP3 would give a very nice acceptance in a mass range between 200 and 1800 GeV.
  - If only 2 pots are feasible then where is the most interesting physics: $200 < M < 1050$ (TCL6 opened), $400 < M < 1100$ (TCL5 at 35σ) or $700 < M < 1800$ GeV (with TCL5&6 closed)?
- $\phi = 180$ option is certainly the "worst" one:
  - In all positions it gives acceptance only for very high masses.
  - Still, if this a region of interest from physics point of view, detectors would need a very fine granularity as protons will be quite "packed" (much weaker $\xi(x_{RP})$ dependence than for other phases.







Summary

- ARP community prepares a physics case for HL-LHC $\rightarrow$ exclusive $\gamma\gamma \rightarrow$WW, ZZ, exclusive tt, ALP, ...
- HL-LHC optics defines geometric acceptance of detectors.
- Other constraints are coming from elements planned to be installed at HL-LHC – there are more constraints w.r.t. Run 1 – Run 3. Taking these limitations into account, the following positions are considered: R1A at 195.5 m, R1B at 198.0 m, R2A at 217.0 m, R2B at 219.5 m R3A at 234.0 m, R3B at 237.0 m and R3C at 245.0 m.
- For studied optics case (V1.5) the following conclusions can be drawn:
  - TCL4 can be opened to default 14.2σ,
  - TCL5 should be opened to (at least): 35σ for $\phi = 0$, 30σ for vertical crossing angle, 14.2σ (default) for $\phi = 180$,
  - TCL6 should be opened to (at least): $> 60\sigma$ (fully opened) for $\phi = 0$, 55σ for vertical crossing angle, 14.2σ (default) for $\phi = 180$ (but profitable will be to open it more, *e.g.* to 30σ).
- Assuming $11\sigma + 0.3 + 0.5$ mm distance from the beam, the mass acceptance is:

	$\phi = 0$	$\phi = 90/270$	$\phi = 180$
TCL4/5/6	14.2/35/open	14.2/30/55	14.2/14.2/20
RP1A	$700 < M < 1800$	$1000 < M < 2000$	$2200 < M < 2800$
RP2A	$400 < M < 1100$	$550 < M < 1450$	$1500 < M < 2600$
RP3A	$200 < M < 1050$	$300 < M < 1200$	$1000 < M < 1700$

- There are many open questions:
  - possible direction (phase) of crossing angle,
  - possible opening of collimators,
  - preferred detector locations.

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