Forward Physics: Updates

Lucian Harland-Lang, University of Oxford

HL/HE-LHC Meeting - SM (WG1)

CERN, 20 June 2018

Outline

- Two contributions to Yellow Report:

  ❖ **Forward EW** (5 pages): focus on exclusive photon-induced production.

  ❖ **Forward and Soft QCD physics** (8 pages - shared with DPS/UE): focus on exclusive/diffractive QCD.

→ Will provide updates on both contributions.

a. **Forward EW physics** (5 pages)

Contributors: -- light-by-light and photon-induced processes:

Johanna Gramling Kristof Schmieden (ATLAS), Lucian Harland-Lang (TH)

a. **Forward and Soft QCD physics** (8 pages)*

Contributors:

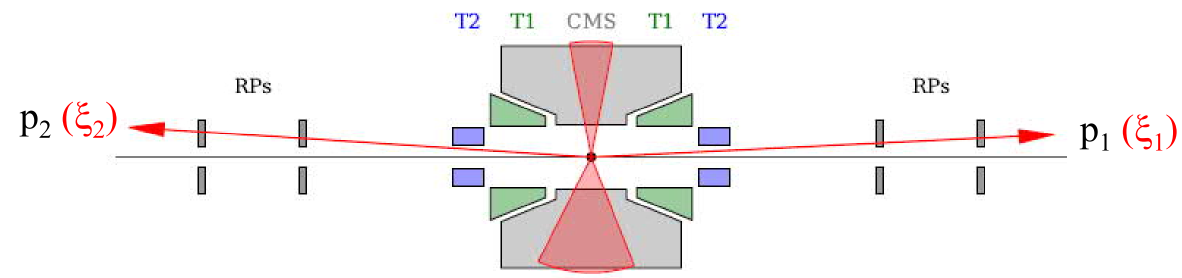
--- DPS/UE: Jonathan Richard Gaunt (TH), Marc Dunser (CMS), Deepak Kar (ATLAS)

--- Forward QCD, light-by-light and proton tagging: Christoph Mayer, Evgeny Kryshen (ALICE) Johanna Gramling Kristof Schmieden (ATLAS), Lucian Harland-Lang (TH), Michael Rijssenbeek, Janusz Chwastowski (ATLAS), Christophe Royon (CMS), Grigorios Chachamis and Agustin Sabio Vera.

Central Exclusive Production - recap

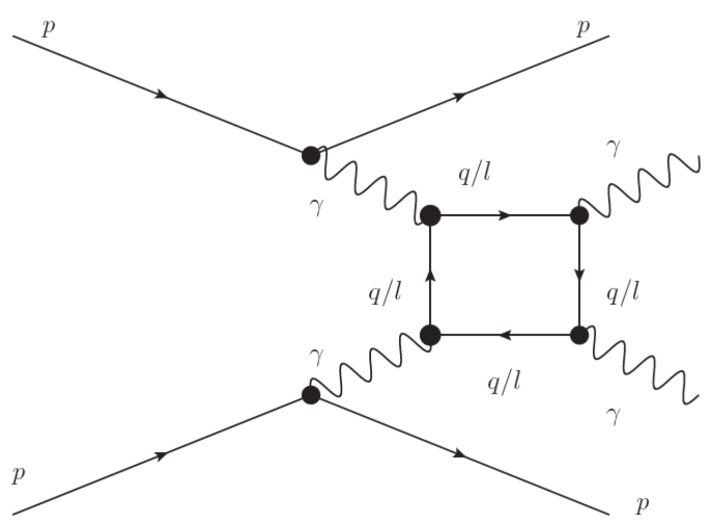
- CEP: production of object X + nothing else:

$$pp \rightarrow p + X + p$$

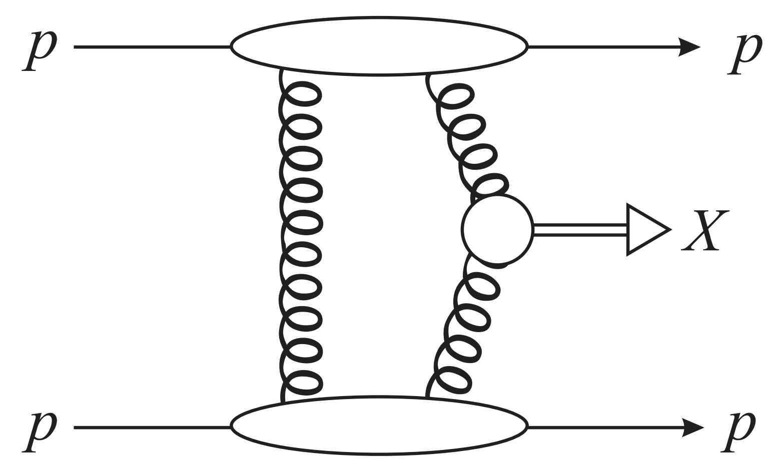


X = all products except the 2 leading protons

- Two production mechanisms of interest*:



Photon-induced



QCD-induced

- Sensitive to different physics/areas of phase space - complementary.

*In addition- photoproduction

Measuring CEP

- Two methods to select exclusive events:

★ **Proton tagging:**

- Dedicated detectors close to beam line and O(100m) from IP.
- With timing $\longrightarrow$ can select CEP during regular HL running.
- Focus of **ATLAS/CMS** prospects/contributions to YR.

★ **Gap vetoing:** no activity between system and beam directions. More suitable for low lumi/pile-up (possible at high pile up with vertex vetoes).

- No activity between system and beam directions.
- More suitable for low lumi/pile-up: **ALICE** prospects.
- Special runs? Not foreseen, and harder to motivate at HL (why not before?). Will not focus on this in YR.

Proton Tagging at HL-LHC

- Dedicated (unofficial) studies of proton tagging possibilities at HL-LHC:

ATLAS IP - M. Rijssenbeek, J. Chwastowski et al.

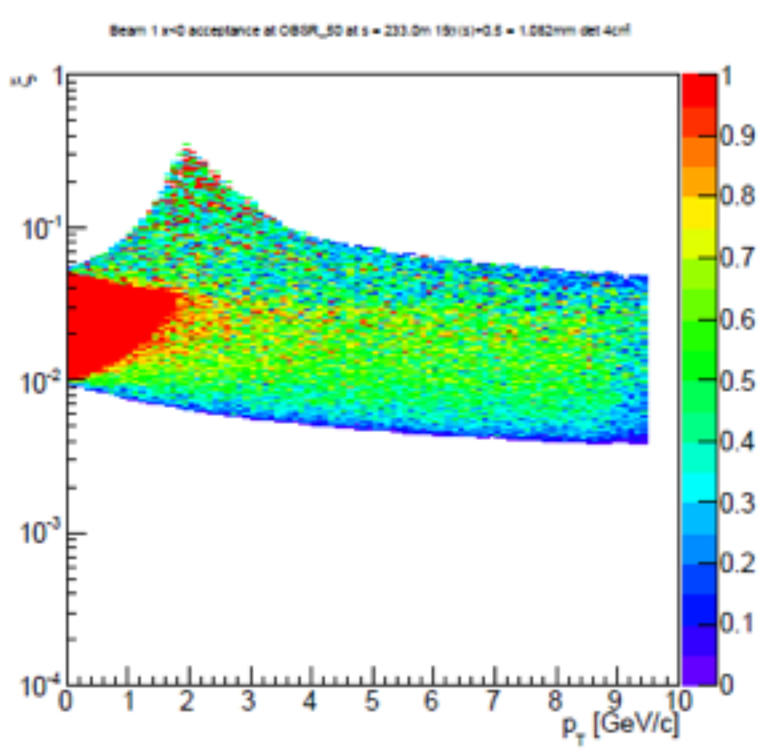
CMS IP - M. Deile et al.

- **ATLAS** - range of detector positions considered: **235, 285, 324 & 419 m** (last one - cold region).
- First study with baseline HL-LHC optics performed (no collimation):

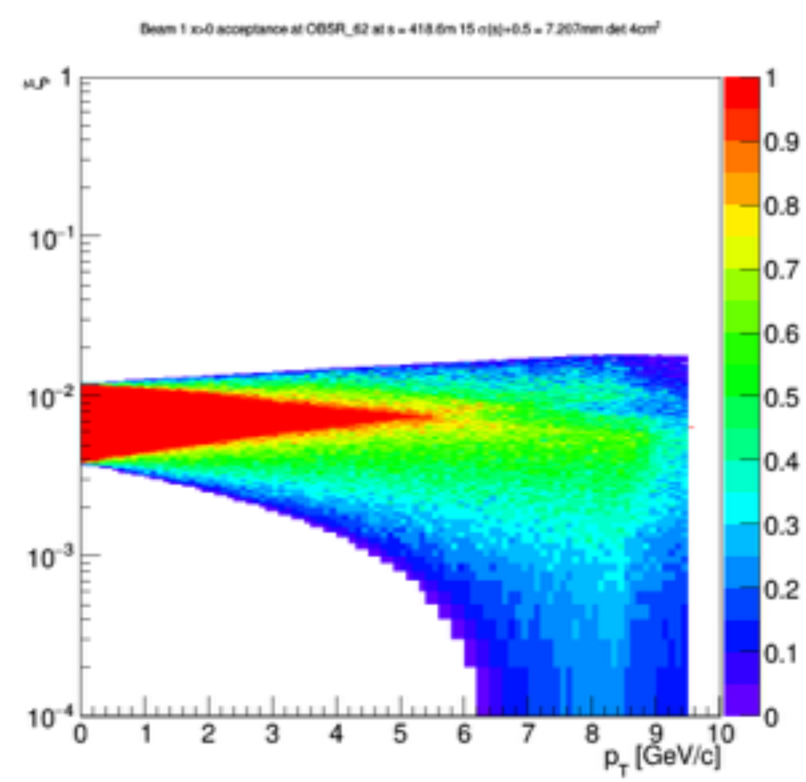
$$\xi \sim \frac{M_X}{\sqrt{s}}$$

Vertical crossing

234m



418m

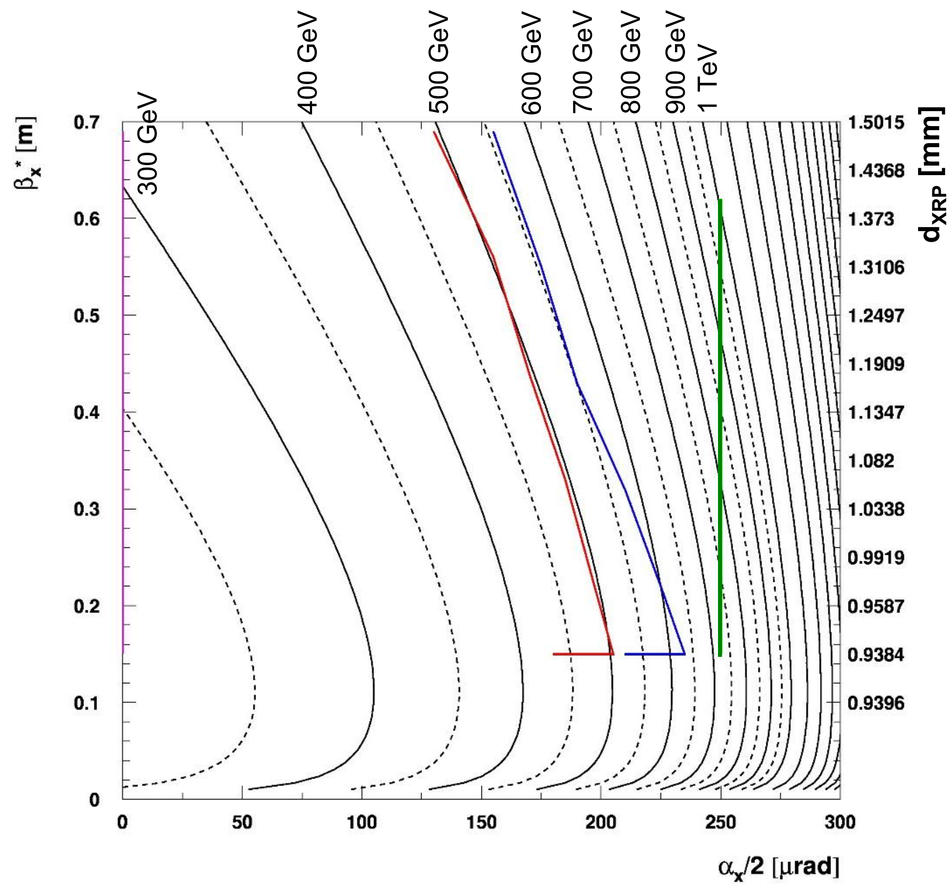


Proton Tagging at HL-LHC

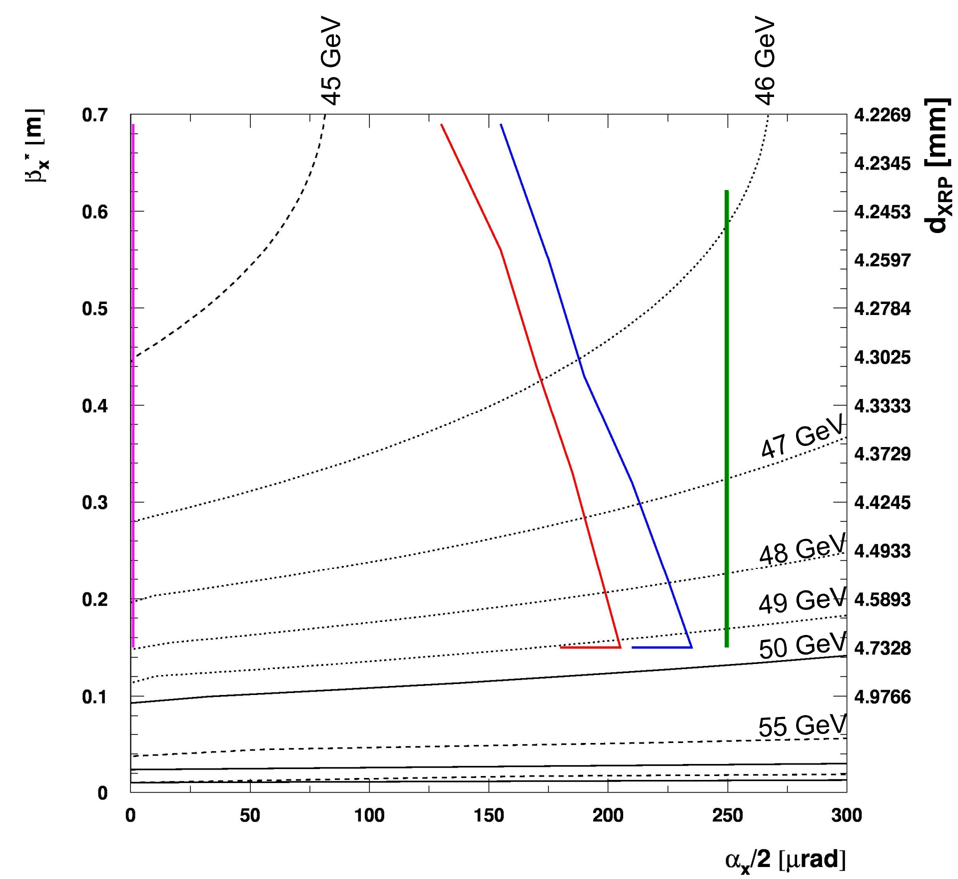
- **CMS** (CT-PPS) - 4 detector locations considered: **196, 220, 234, 420m** (latter in cold region).
- First study with HL-LHC optics scenarios.

Minimum M_X

234m



420m



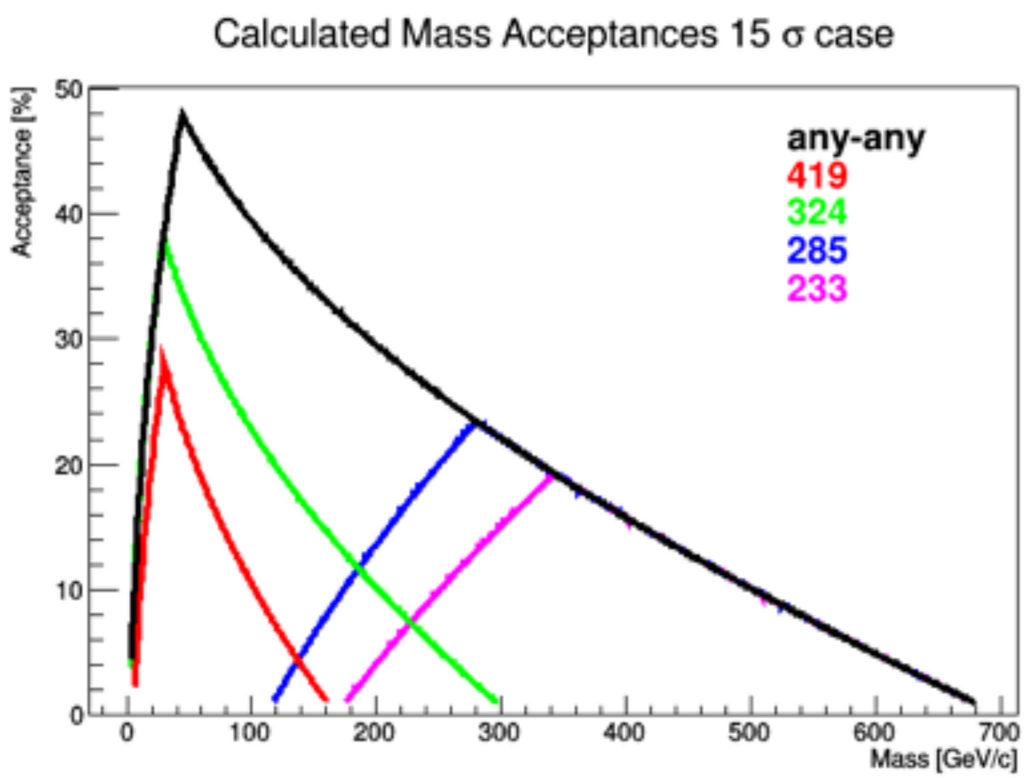
- Baseline
- Relaxed adaptive
- Aggressive adaptive
- Vertical crossing (any trajectory)

⟶ Vertical crossing essential if no 420m detector.

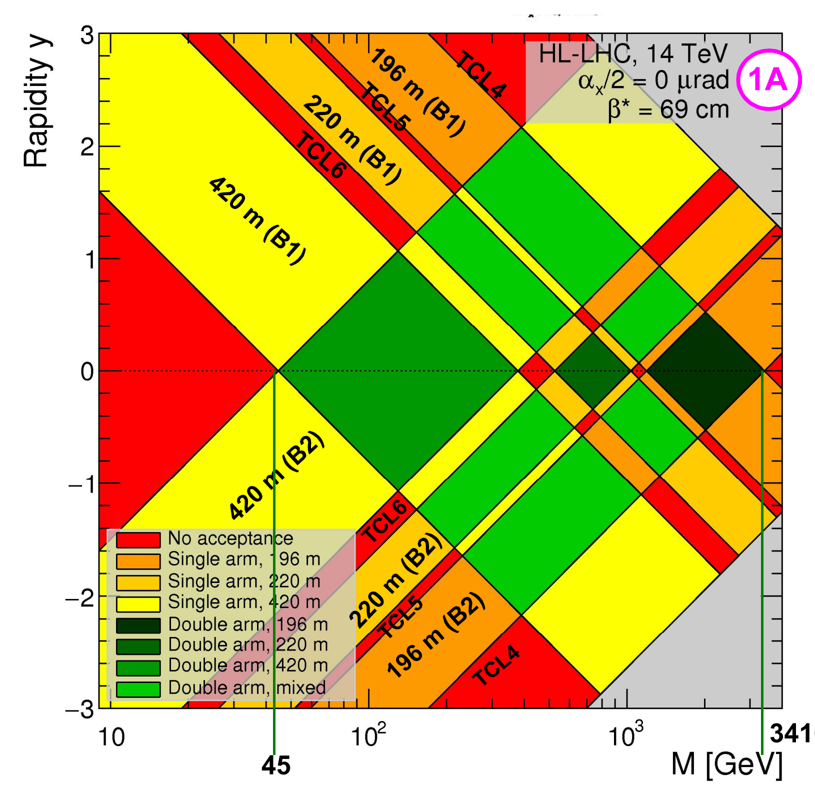
Proton Tagging at HL-LHC

- Range of detector positions, from ~ 200 m (higher mass $M_X \gtrsim 300\,\mathrm{GeV}$) to ~ 400 m (lower mass $M_X \gtrsim 20-50\,\mathrm{GeV}$) considered.
- Physics possibilities driven by these: exciting potential to probe **wide range** of **masses**, from low to high.

ATLAS



CMS (CT-PPS)



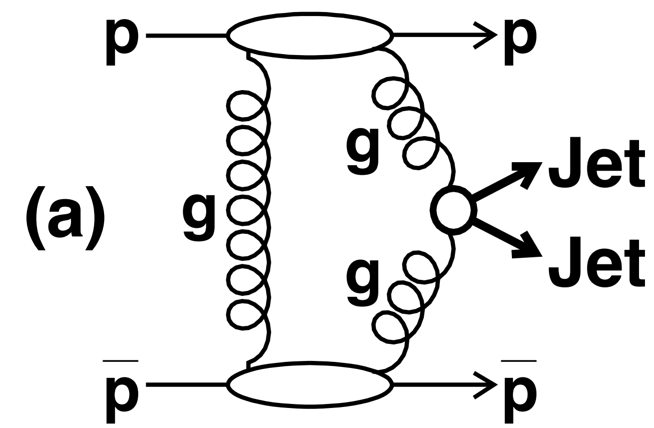
Vertical crossing

- Still further issues to consider (ATLAS - impact of collimation, CMS- new technology needed for 420m…). YR contributions from both **ATLAS/CMS** discussing these.

Physics with tagged protons - QCD

- QCD-induced baseline high mass channels- exclusive jets and Higgs.

★ **Exclusive jets:**



- Exclusive jets: CEP theory: dominantly gg colour singlet dijets. Novel features (radiation patterns/ zeros) in trijets.
- New QCD regime - data from Tevatron but not from LHC (yet).
- Challenging measurement, but cross section high.

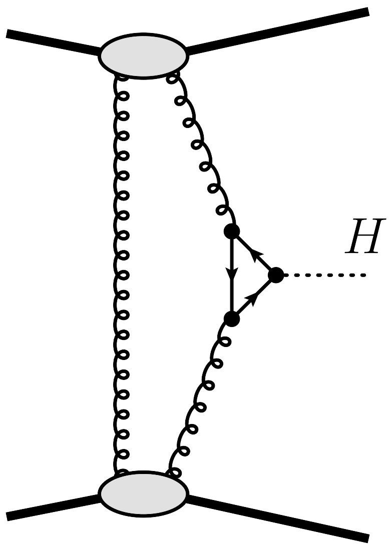
$p_\perp^j > 25\,\text{GeV}$
$|\eta_j| < 3$
$q = u, d, s, c$

M_{jj} [GeV]	$\sigma(gg)$ [pb]
100	35
200	1
300	0.14
400	0.024
500	0.0053
600	0.0014

LHL

Physics with tagged protons - QCD

★ **Exclusive Higgs:**



- Completely novel (and so far unseen) production channel.
- $H \to b\bar{b}$: QCD $gg \to b\bar{b}$ background dynamically suppressed.

V.A. Khoze et al. Phys. Lett. B 401 330 (1997)

- Combined with proton tagging: handle on CP.
- Cross section $O(\text{fb}) \Rightarrow$ clear benefit from higher lumi.

• Lower mass acceptance highly desirable for jets and essential for Higgs $\Rightarrow$ detectors at $\gtrsim 300$m needed.

Physics with tagged protons - QED

- Exclusive photon-initiated production of particular interest for **BSM**- clean and well understood $\gamma\gamma$ initial state (prob. of pp MPI interactions low).

$\longrightarrow$ LHC as a (high energy) $\gamma\gamma$ collider!

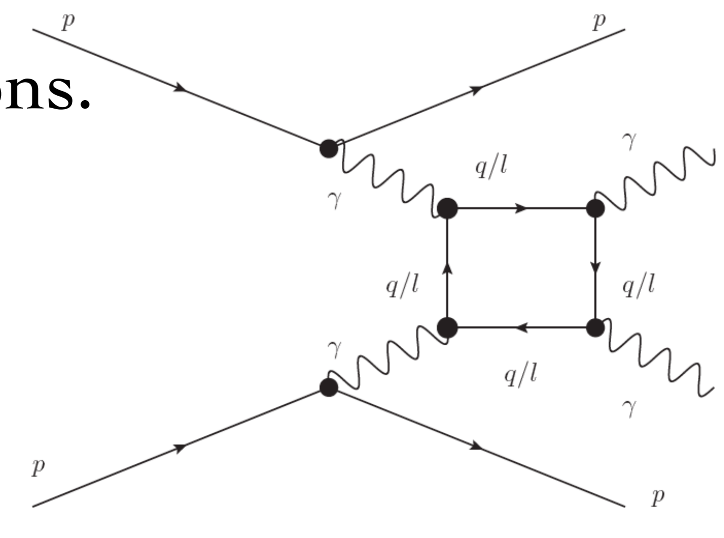
C. Royon, C. Barrera

★ Baseline process: stringent limits on (or discovery of) **anomalous** gauge boson **couplings**. Dedicated study/projections (see next slides).

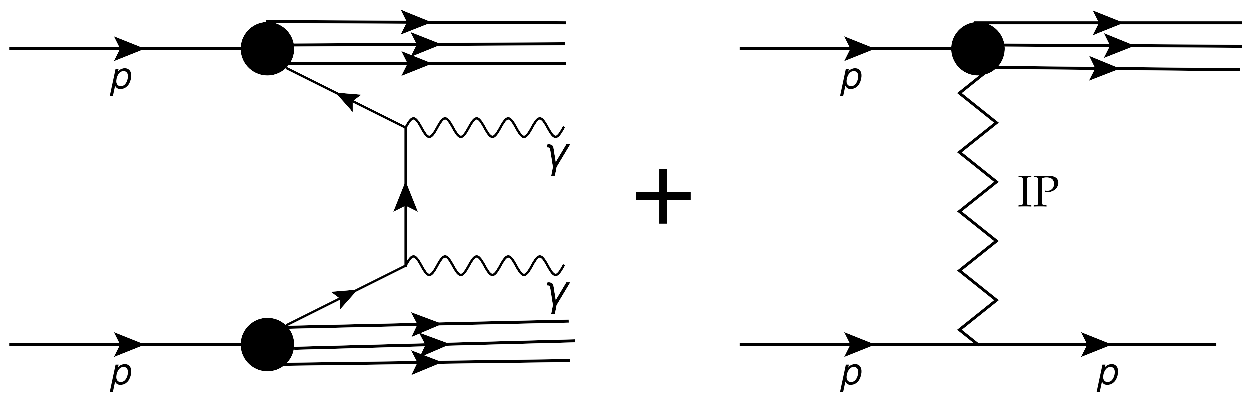
★ $\gamma\gamma \to t\bar{t}$: clean probe of top, $t\bar{t}$ turn-on in colour-singlet state. **J. Howarth**

★ Other **BSM channels**: heavy axion-like particles, new charged particles in compressed mass (SUSY…) scenarios, monopoles searches. **LHL, C. Royon.**

★ SM benchmark and probe of pp interactions - dileptons.



Suppressing pile-up BG - timing



Pileup + non-exclusive diphoton signal = Fake $pp + \gamma\gamma$ signal.

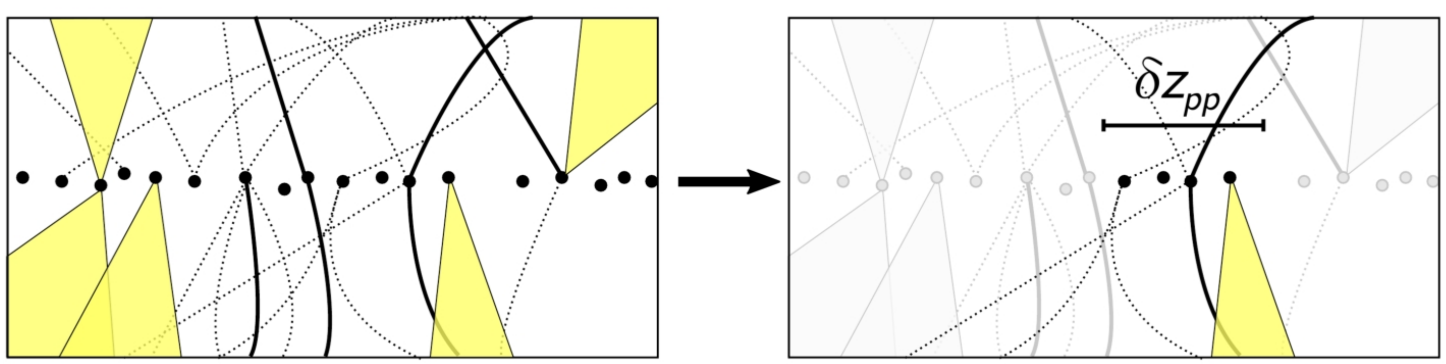


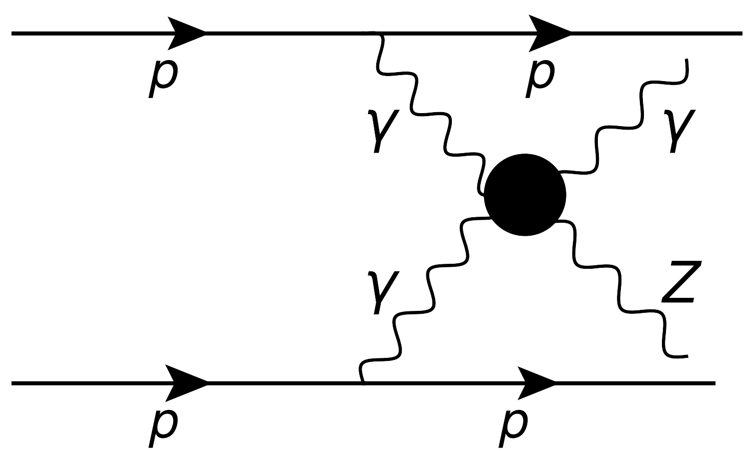
Fig. by L. Forthomme

Precise time-of-flight measurement allows discrimination of pileup vertices. Vertex precision $\delta z_{pp} = \frac{c}{\sqrt{2}}\delta t$. For a timing precision $\delta t = 10$ ps, $\delta z_{pp} \sim 2$ mm, allows rejection of pile-up events by a factor of 50.

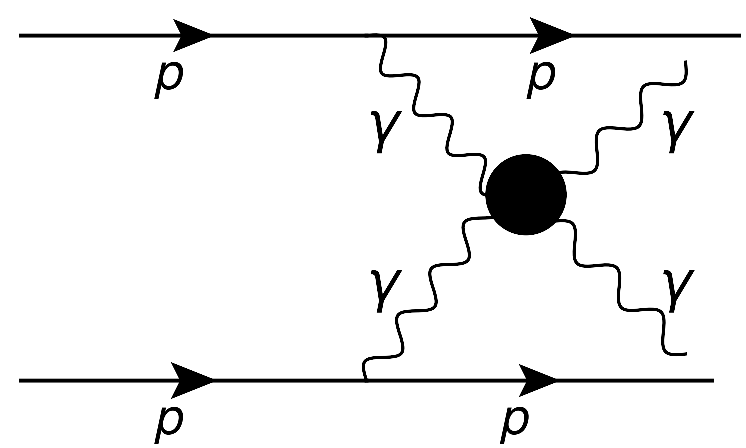
Matching kinematics (mass/rapidity) also helps greatly suppress BG

Anomalous couplings

- The $\gamma\gamma \to VV$ process via CEP is a sensitive probe of gauge boson (V) anomalous couplings to γ .
- Measurements underway for standard LHC running w/ tagged protons.
- **Dedicated study** here for extended reach provided by HL-LHC



$$\mathcal{L}_{\gamma\gamma\gamma Z} = \zeta_1^{3\gamma Z} F^{\mu\nu} F_{\mu\nu} F^{\rho\sigma} Z_{\rho\sigma} + \zeta_2^{3\gamma Z} F^{\mu\nu} \tilde{F}_{\mu\nu} F^{\rho\sigma} \tilde{Z}_{\rho\sigma}$$

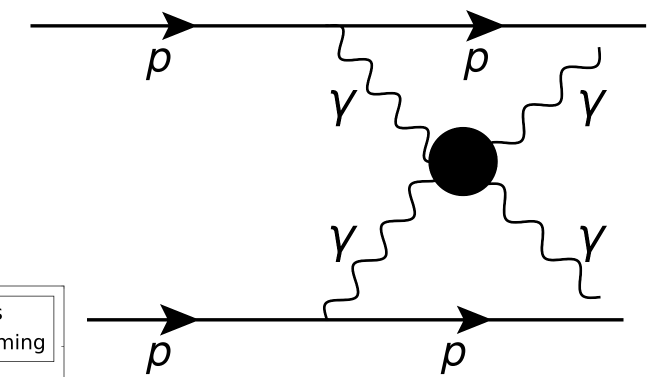


$$\mathcal{L}_{\gamma\gamma\gamma\gamma} = \zeta_1^{4\gamma} F^{\mu\nu} F_{\mu\nu} F^{\rho\sigma} F_{\rho\sigma} + \zeta_2^{4\gamma} F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

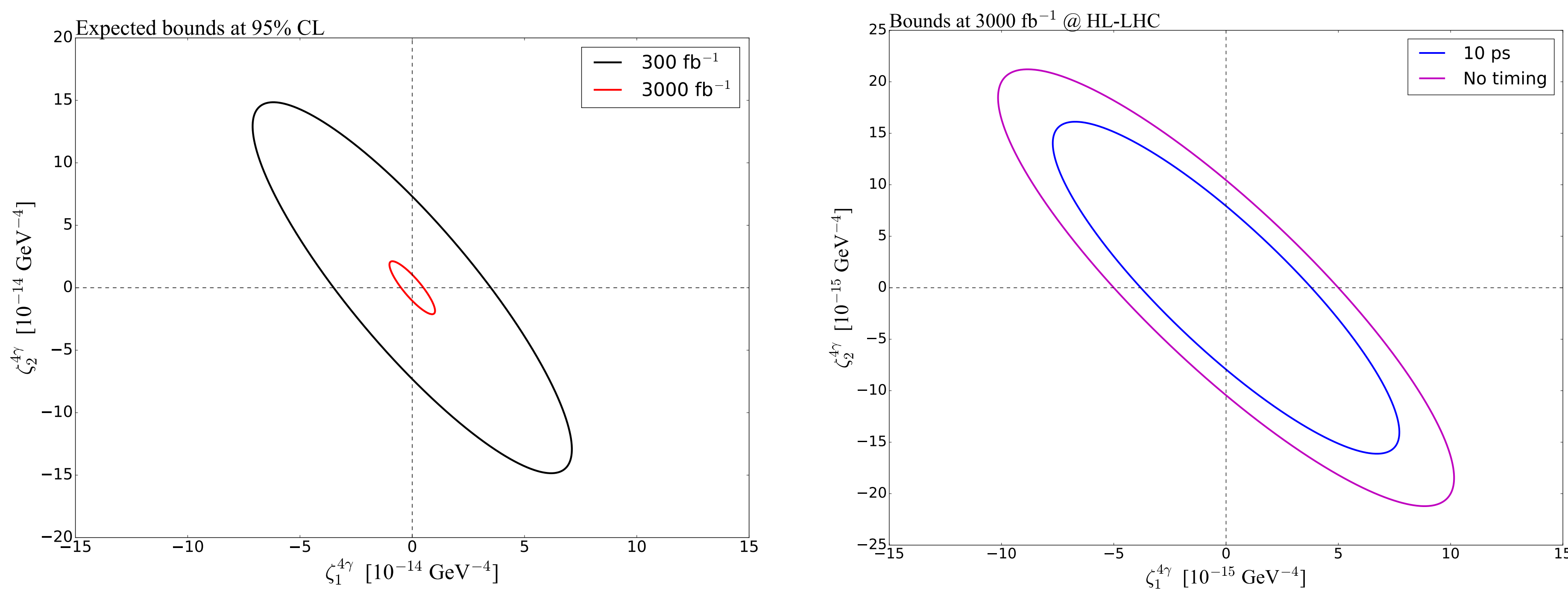
C. Royon, C. Barrera

Anomalous couplings - 4γ

- Model interaction via EFT, two dimension 8 operators:



$$\mathcal{L}_{\gamma\gamma\gamma\gamma} = \zeta_1^{4\gamma} F^{\mu\nu} F_{\mu\nu} F^{\rho\sigma} F_{\rho\sigma} + \zeta_2^{4\gamma} F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

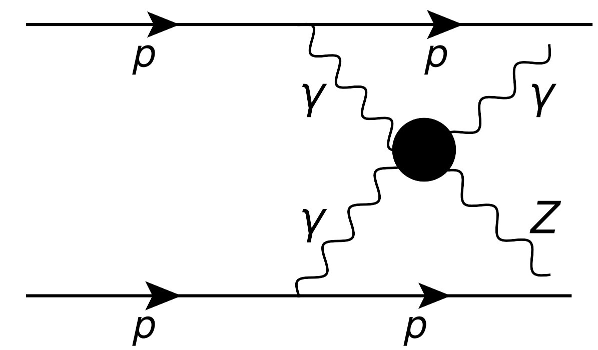


Left: comparison between 300 fb^{-1} and 3000 fb^{-1}. **Right:** (zooming-in, see change of scale in X-Y axis) comparison between the use of timing and $\delta t = 10$ ps (not much difference if 5 ps and 2 ps are used).

- HL-LHC can improve bound on EFT operators by ~ an **order of magnitude**. Little sensitivity to precise level of timing precision.

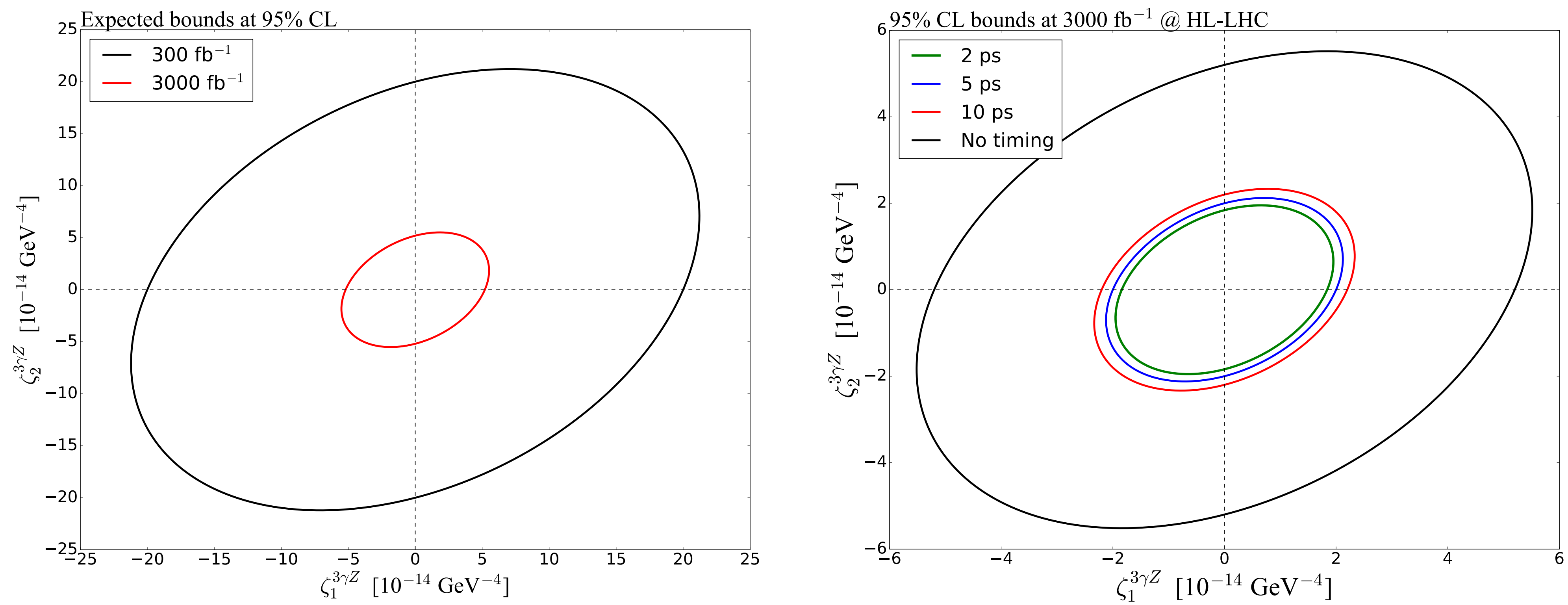
$$\sqrt{48\zeta_1^2 + 11\zeta_2^2 + 40\zeta_1\zeta_2} \leq 2.4 \cdot 10^{-13}\,\mathrm{GeV}^{-4} \longrightarrow 4.2 \cdot 10^{-14}\,\mathrm{GeV}^{-4}$$

Anomalous couplings - γZ



- Again set limits via EFT operators:

$$\mathcal{L}_{\gamma\gamma\gamma Z} = \zeta_1^{3\gamma Z} F^{\mu\nu} F_{\mu\nu} F^{\rho\sigma} Z_{\rho\sigma} + \zeta_2^{3\gamma Z} F^{\mu\nu} \tilde{F}_{\mu\nu} F^{\rho\sigma} \tilde{Z}_{\rho\sigma}$$

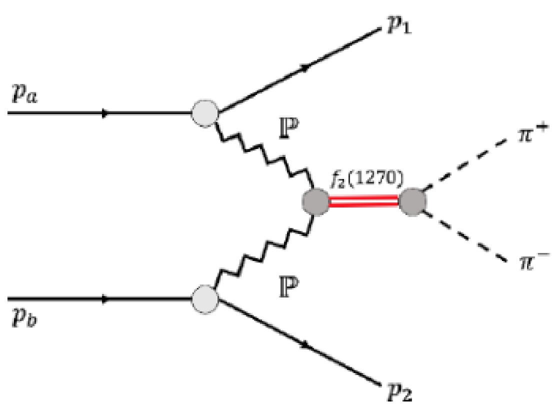


Left: Comparison between 300 fb^{-1} and 3000 fb^{-1}. **Right:** (Zoomed-in; change of scale in X-Y axis) comparison between the use of timing $\delta t = 2, 5, 10$ ps. $Z\gamma \to \text{hadrons} + \gamma$ benefits the most from the use of timing.

- Once again, expected **improvements** from HL-LHC impressive ~ an **order of magnitude** (~ 5 orders of magnitude better than current best inclusive limits).

Lower luminosity running - ALICE

- ALICE - luminosity estimate (not approved) of $200\,\mathrm{pb}^{-1}$ in pp by end of run 4, potential to increase in run 5.
- All **low pile-up** $\Rightarrow$ broad programme of lower mass QCD studies and spectroscopy anticipated. Benefits from excellent PID, low thresholds and larger rapidity coverage of ALICE detector.
- Benchmark analyses:



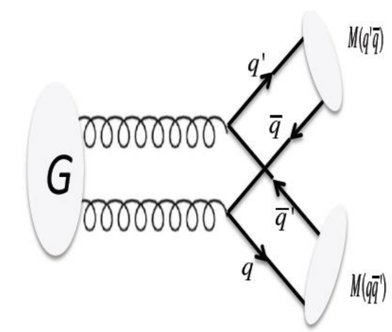
★ Precision scalar and tensor meson **spectroscopy**:

- Many decay channels ($\pi\pi$, KK, pp...), partial wave analyses.
- Probe of soft QCD dynamics.
- Expand knowledge of still poorly understood sector of QCD.

See E. Kryshen's talk at March '18 meeting for more details.

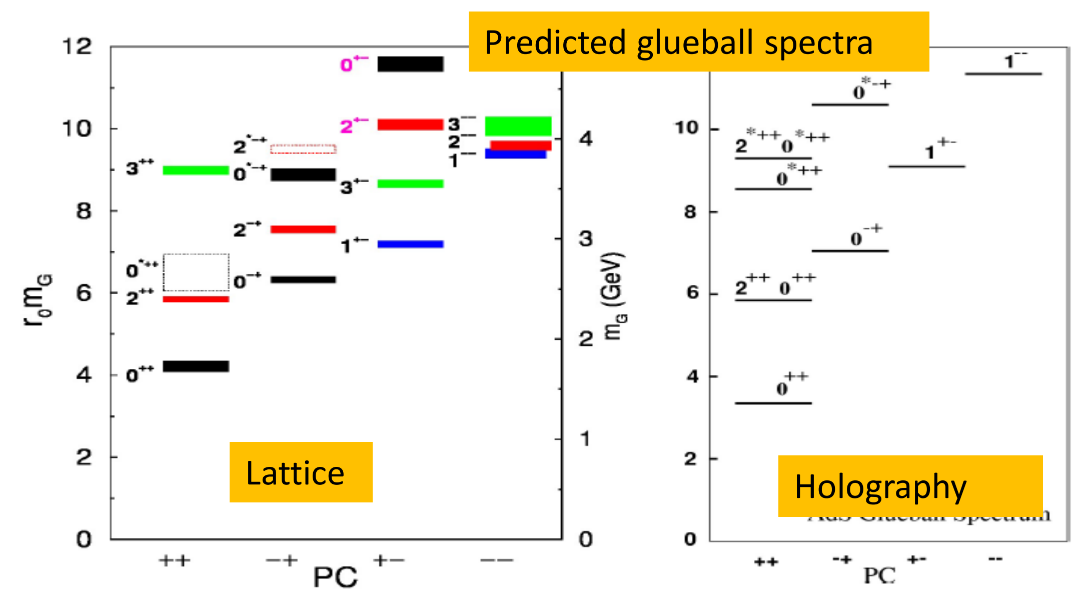
E. Kryshen, C. Mayer

Lower luminosity running - ALICE



★ **Glueball** searches:

- As yet no clear evidence of states that QCD tells us should be there.
- Gluon rich CEP environment ideal channel to look.
- Data on decays clear indication of gluball nature



★ Exclusive charmonia: probe of gluon PDFs, $gg \to \chi_c$ modelling. Many decay channels analysed. Realistic possibilities for $\chi_{c(0,2)}$.

Channel
$\chi_{c0} \to \pi\pi$
$\chi_{c0} \to KK$
$\chi_{c0} \to 4\pi$
$\chi_{c0} \to 2\pi 2K$
$\chi_{c1} \to \pi\pi$
$\chi_{c1} \to KK$
$\chi_{c1} \to 4\pi$
$\chi_{c1} \to 2\pi 2K$
$\chi_{c2} \to \pi\pi$
$\chi_{c2} \to KK$
$\chi_{c2} \to 4\pi$
$\chi_{c2} \to 2\pi 2K$

★ **Other benchmarks**: exclusive jets, magnetic monopole searches.

Yellow Report - contributions

- **Detector-specific** projections/studies: **ATLAS IP - M. Rijssenbeek, J. Chwastowski et al.**
  - Proton tagging detectors for ATLAS + CMS. HL-LHC specific studies of possible locations, acceptances, beam optics… **CMS IP - M. Deile et al.**
  - ALICE: lumi projections, efficiencies, expected yields **ALICE - E. Kryshen et al.**
- **Photon-initiated** (high mass) physics studies/motivation:
  - Basic theory - motivation for BSM studies. Projections for benchmark processes ($t\bar{t}$, dileptons, ALPs, new EW states…). **LHL, C. Royon, J. Howarth et al.**
  - Dedicated HL-LHC study: anomalous EW boson couplings. **C. Royon, C. Barrera**
- **QCD** physics studies/motivation:
  - High mass - basic theory/motivation. Projections for benchmark processes (jets, Higgs…). **LHL**
  - Low mass - basic theory/motivation. Projections for benchmark processes (hadron spectroscopy, glueball searches, quarkonia, jets…) **E. Kryshen**

Yellow Report - open issues

See talk - March meeting

- Light-by-light scattering in pp (w/out tagged p) - **K. Schmeiden and J. Gramling**. Currently - separating LbyL vertex (w/ conversion) from pile-up vertices not efficient & no triggering strategy. Include discussion of this?
- Potential of $M_X = O(20 - 50\,\mathrm{GeV})$ CEP w/ tagged protons. Examine processes of interest, expected yields for baseline scenarios (**LHL**).
- Non-CEP related studies. BFKL…?
- **HE-LHC**. Aim to extend projections for e.g. anomalous couplings.
- **LHCb**? Expected pile-up will be high $\Rightarrow$ selecting gaps difficult (though not impossible $\rightarrow$ vertices). Currently no contribution offered- should pursue.
- **Sections of Yellow Report** - currently divided between EW and QCD. However experiment specific contributions relevant to both. How to arrange? Combining sections may be sensible.

Thank you for listening!

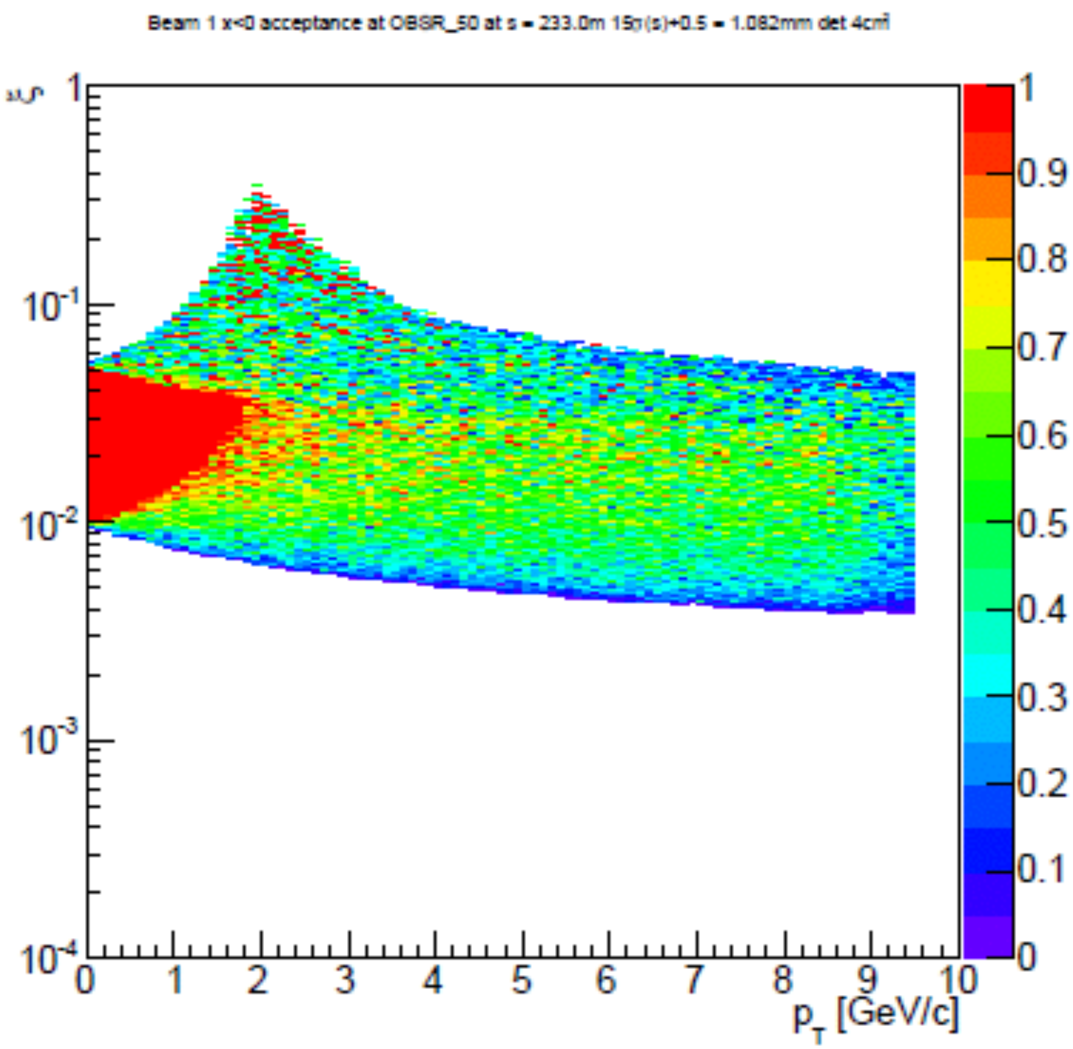
Backup - proton tagger @ HL-LHC

Acceptances versus s – 233m from the ATLAS IP

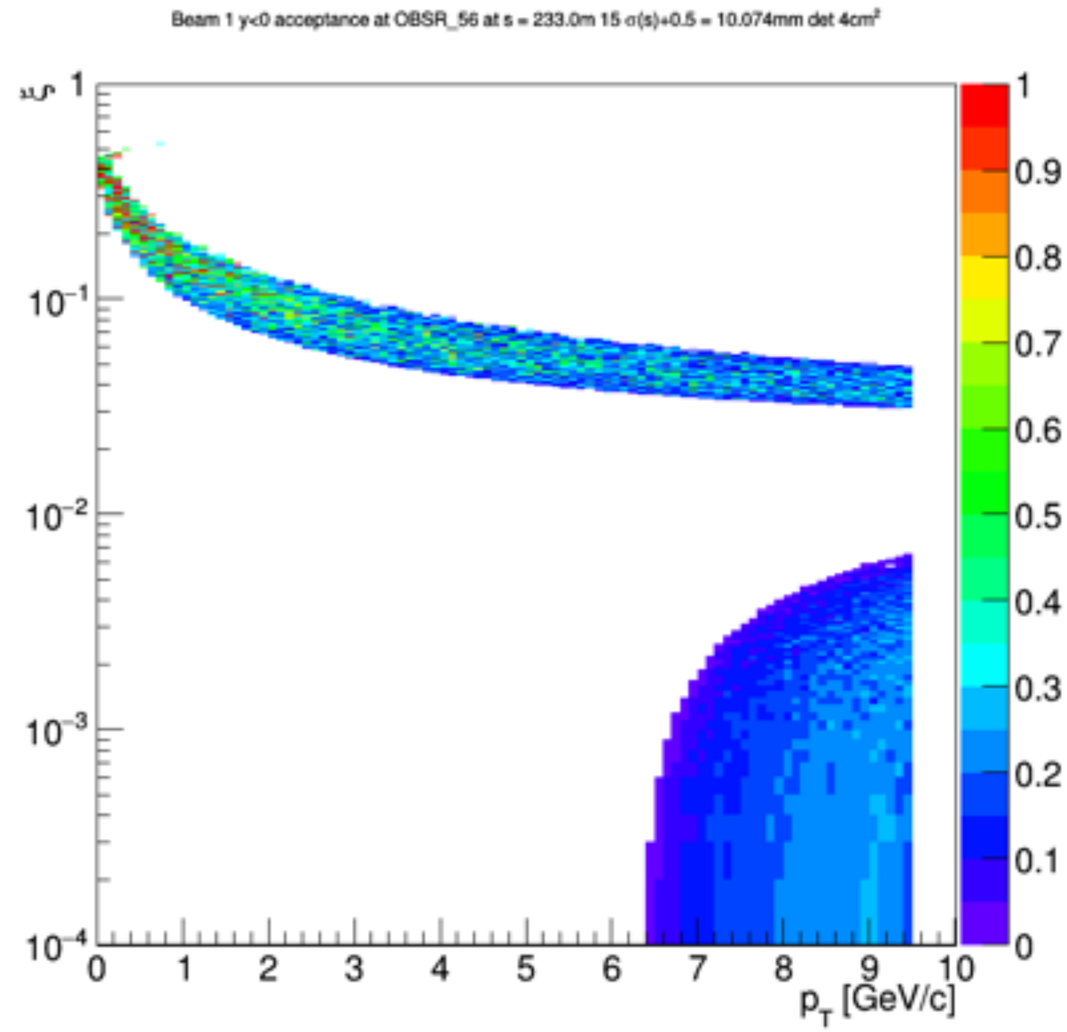
2 x 2 cm^2 Detector and 15σ + 0.5 mm distance to the beam; no collimators

Beam 1

Vertical tilt of the beam



Horizontal tilt of the beam



Narrower ξ acceptance range for both beams w.r.t. the present situation

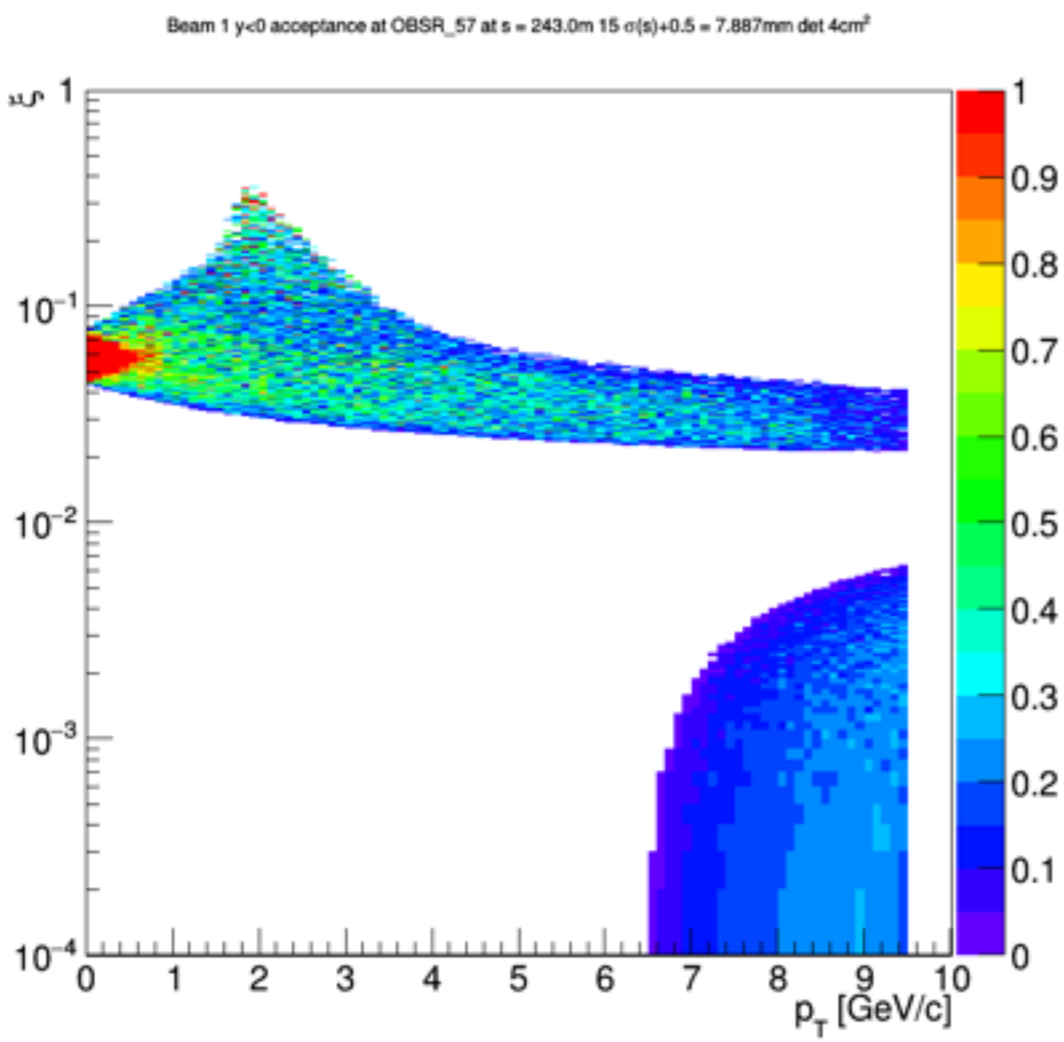
Horizontal tilt kills the acceptance

Acceptances versus s – 243m from the ATLAS IP

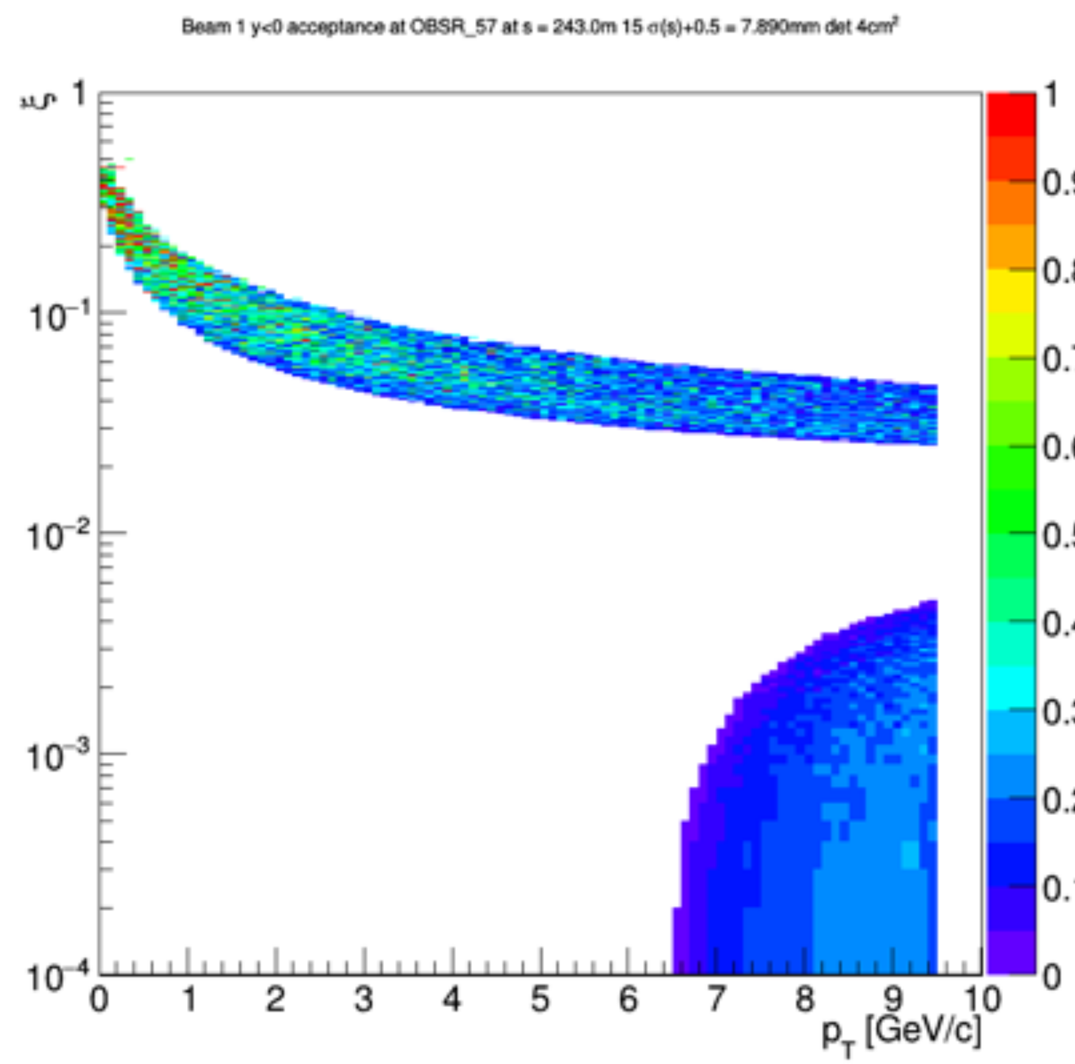
2 x 2 cm^2 Detector and 15σ + 0.5 mm distance to the beam; no collimators

Beam 1

Vertical tilt of the beam



Horizontal tilt of the beam



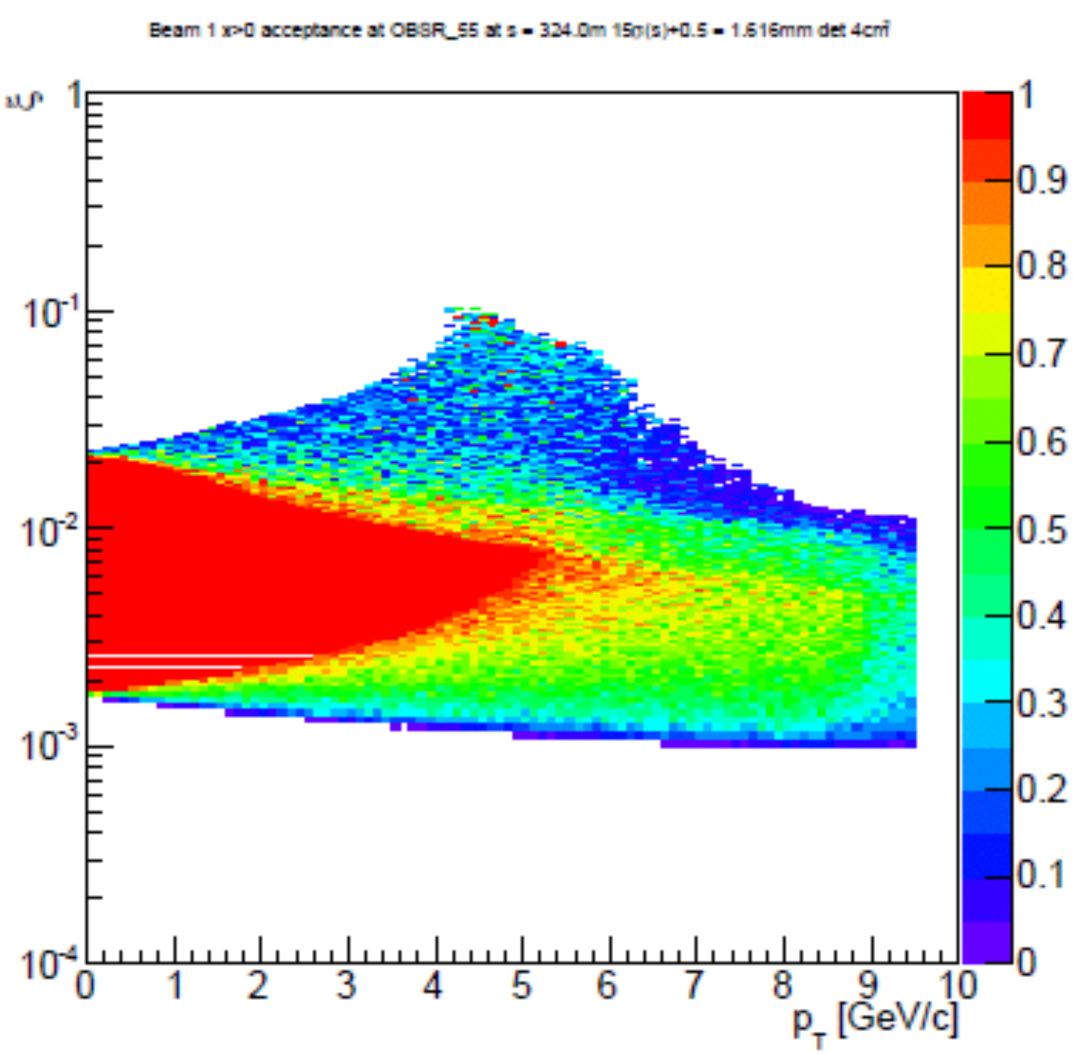
Narrower ξ acceptance range for both beams w.r.t. the present situation
Horizontal tilt kills the acceptance

Acceptances versus s – 324m

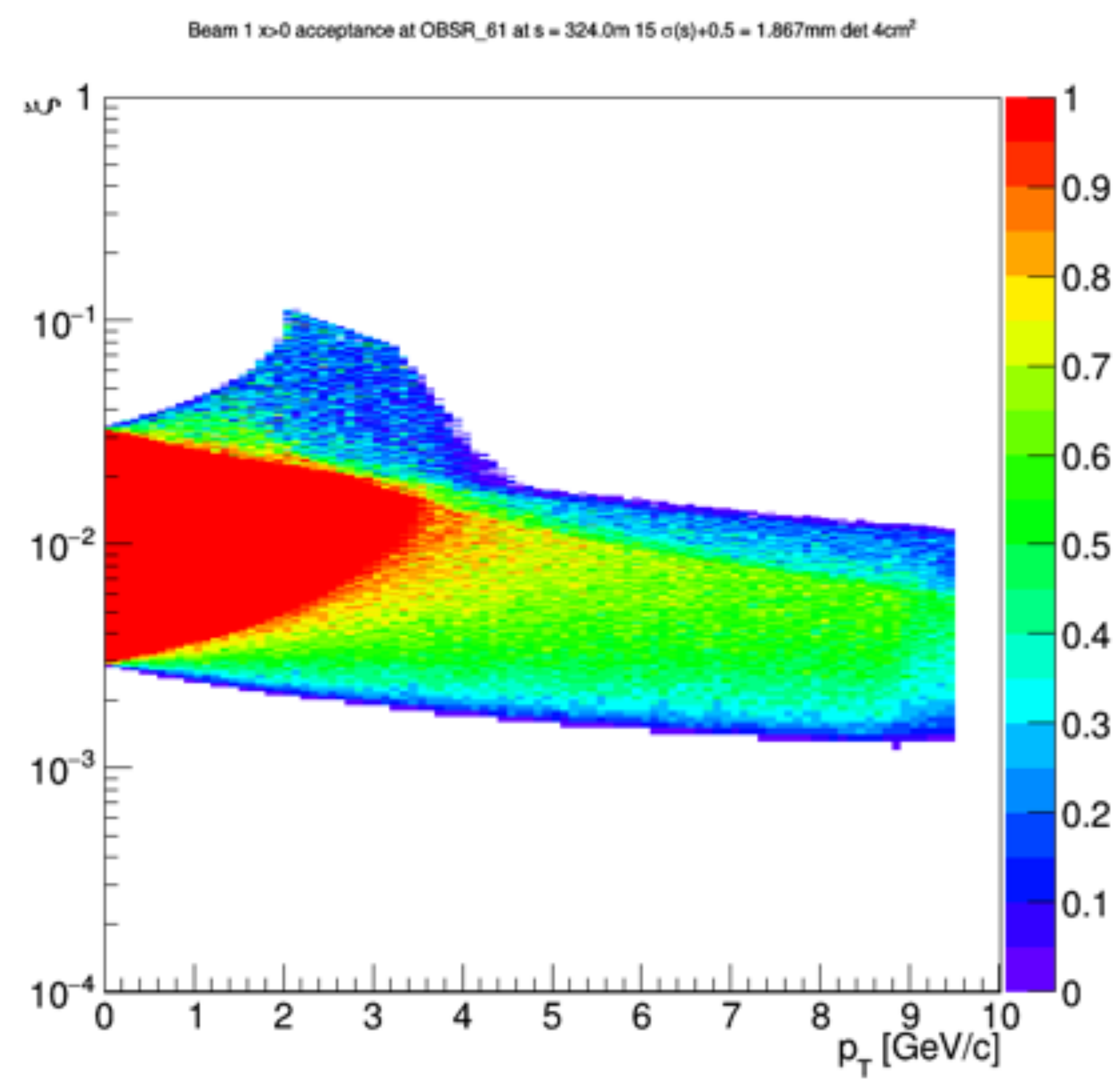
2 x 2 cm^2 Detector and 15σ + 0.5 mm distance to the beam; no collimators

Beam 1

Vertical tilt of the beam



Horizontal tilt of the beam



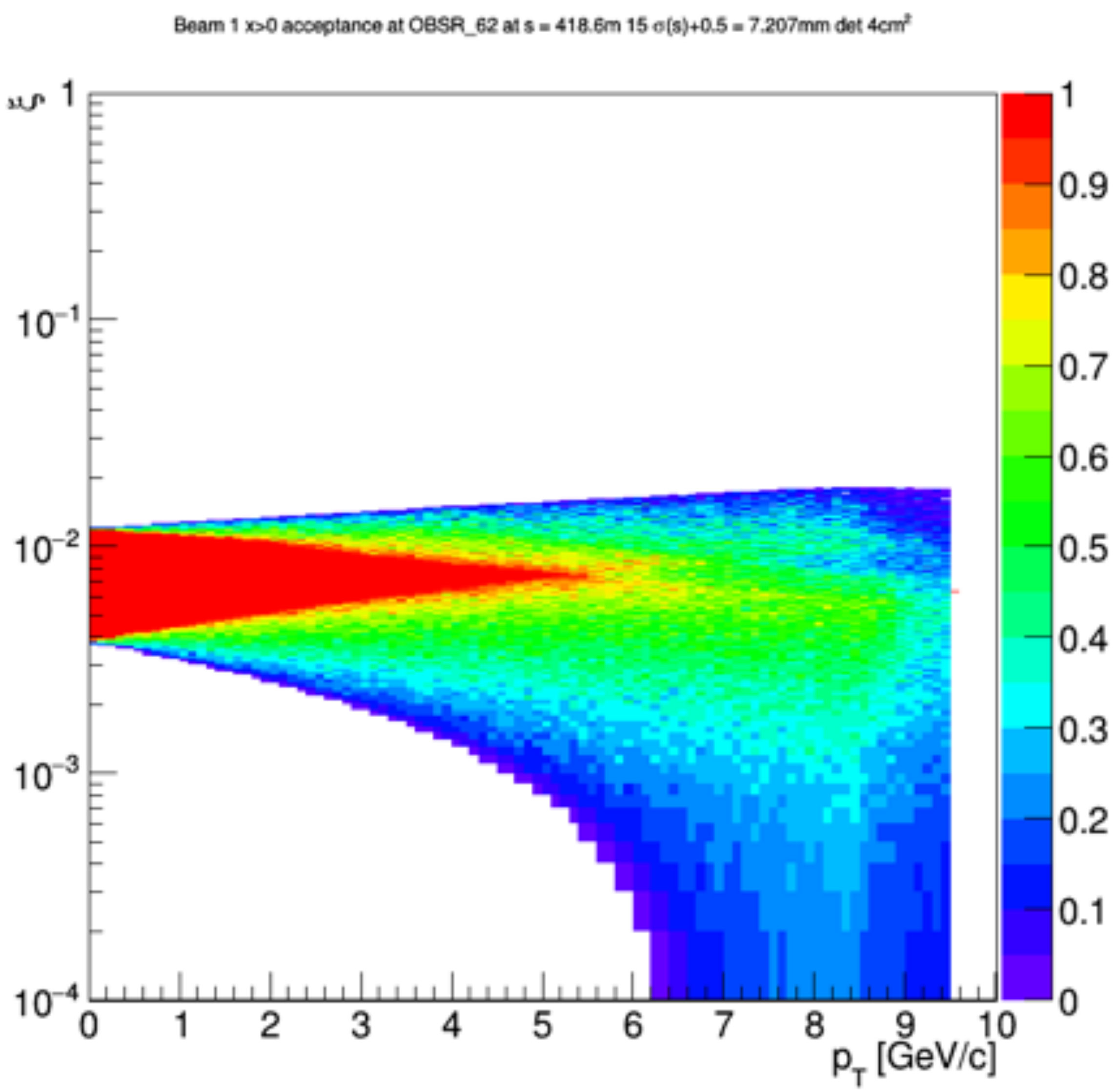
ξ acceptance ranges matching the Higgs region;
wide p_T range
horizontal tilt alter ther acceptance ranges

Acceptances versus s – 418 m cold region

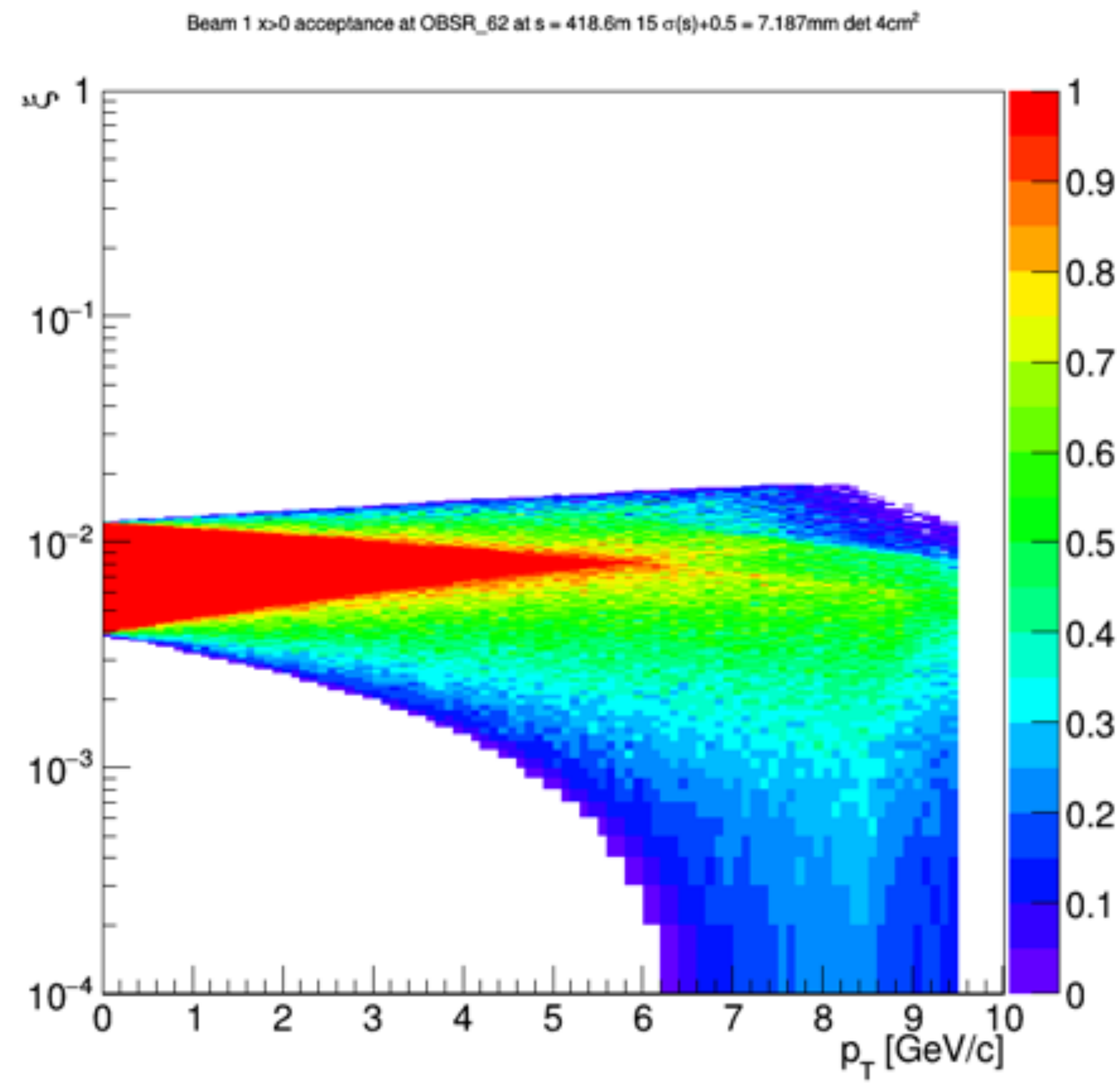
2 x 2 cm^2 Detector and 15σ + 0.5 mm distance to the beam; no collimators

Beam 1

Vertical tilt of the beam

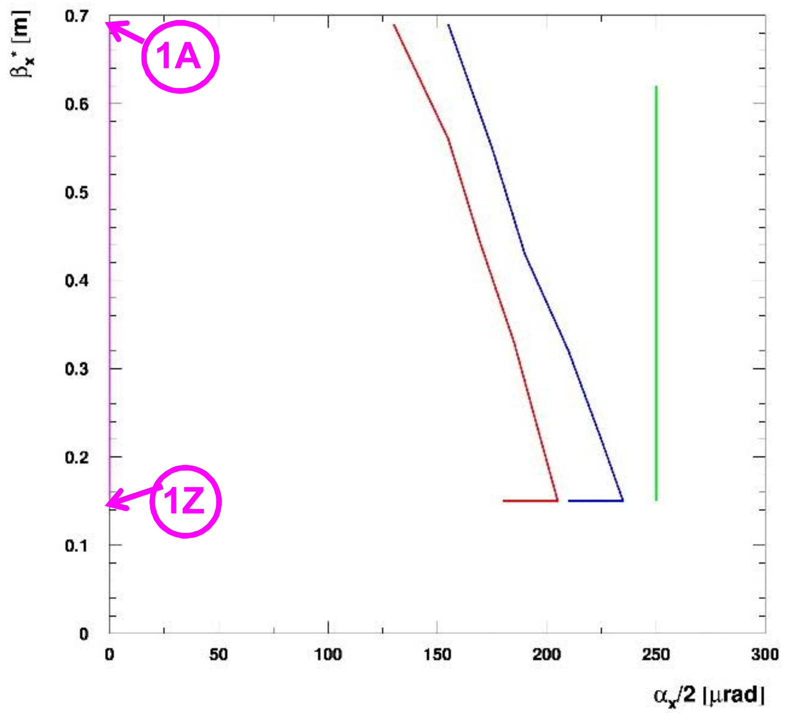


Horizontal tilt of the beam



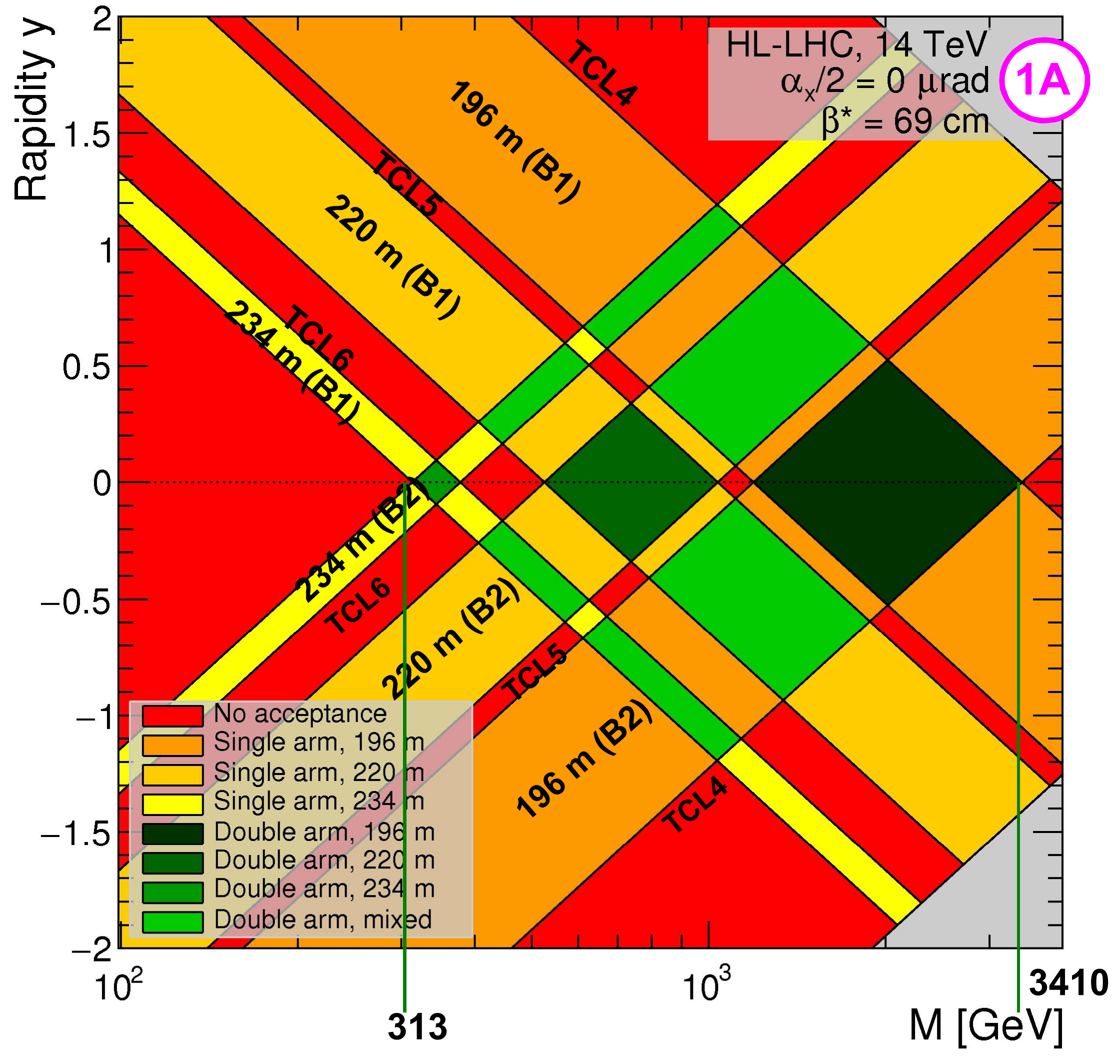
ξ acceptance ranges matching the Higgs region
wide p_T range

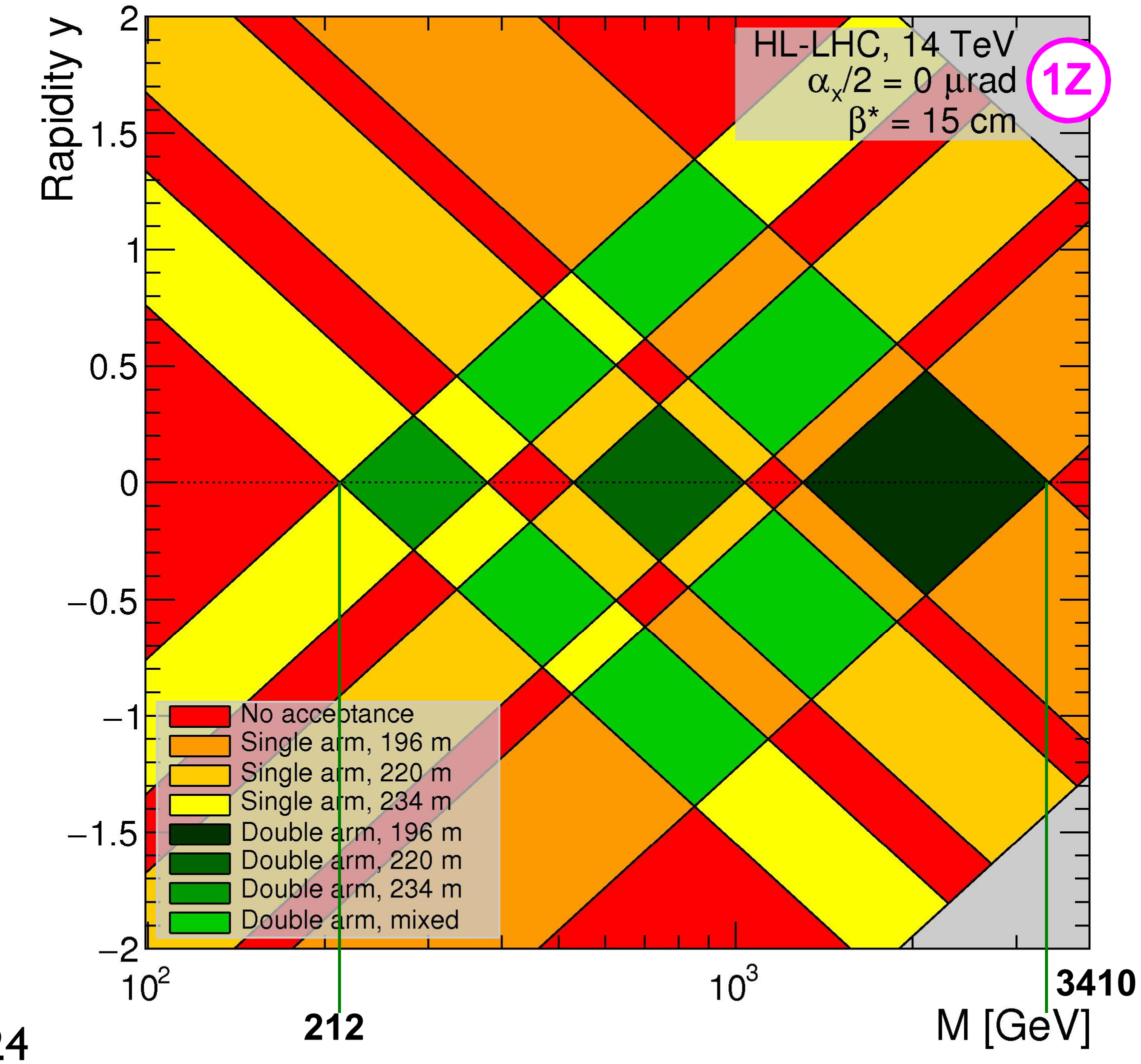
Acceptance in the Mass – Rapidity Plane: Vertical Crossing, Option 1



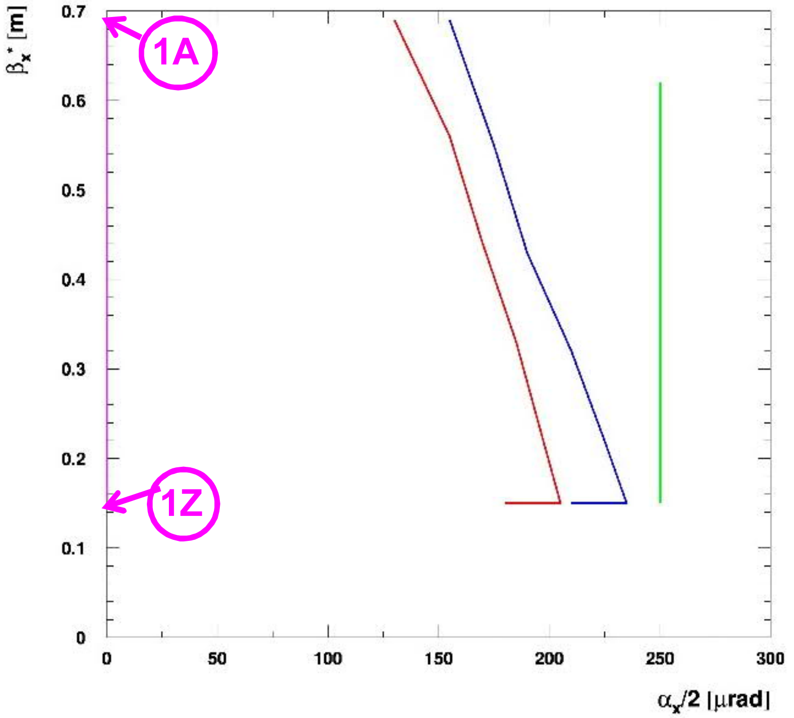
Levelling trajectories:
- Baseline
- Relaxed adaptive
- Aggressive adaptive
- Vertical crossing (any trajectory)

M. Deile- PPS@HL-LHC





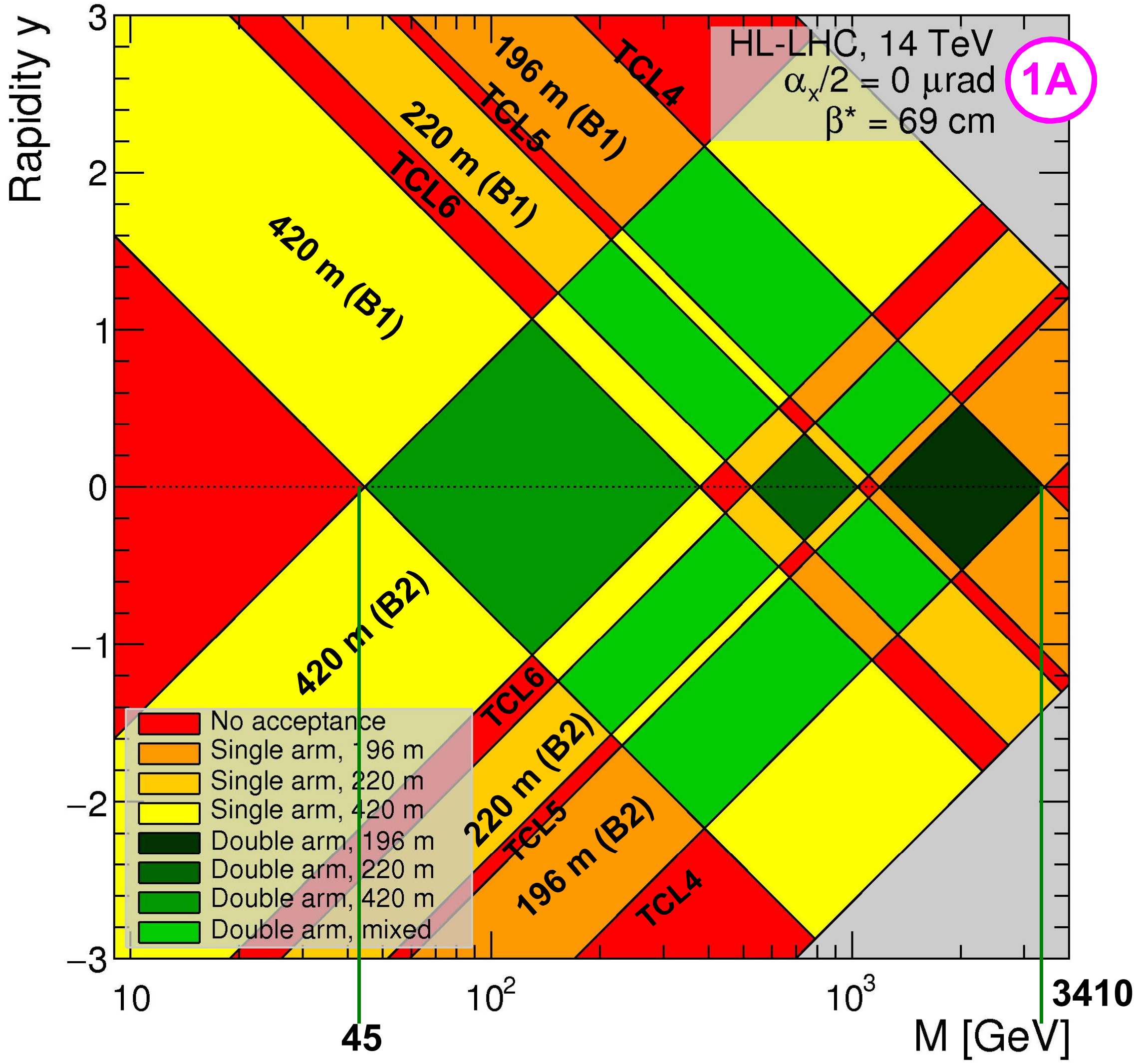
Acceptance in the Mass – Rapidity Plane: Vertical Crossing, Option 2

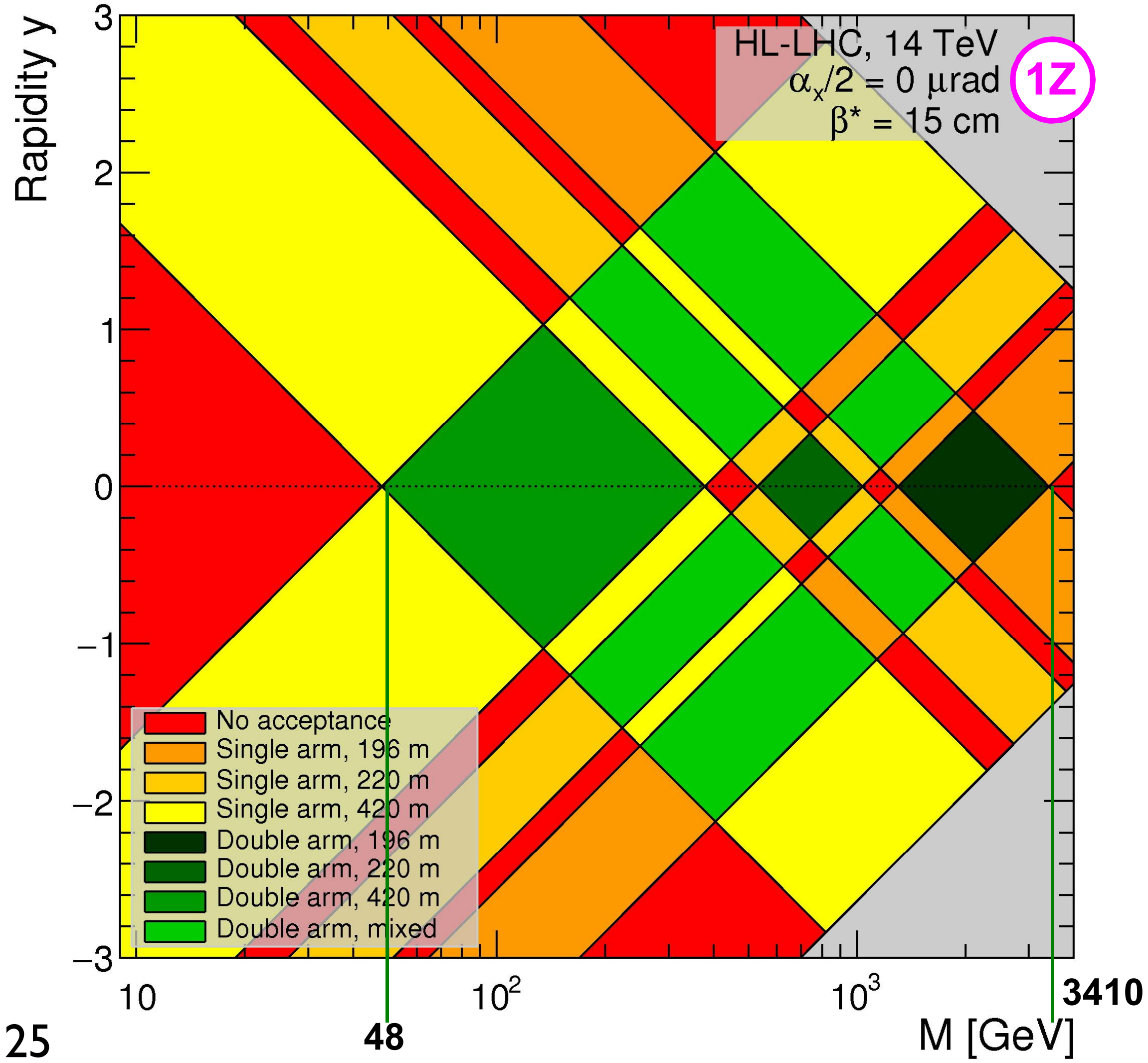


Levelling trajectories:
- Baseline
- Relaxed adaptive
- Aggressive adaptive
- Vertical crossing (any trajectory)

M. Deile- PPS@HL-LHC

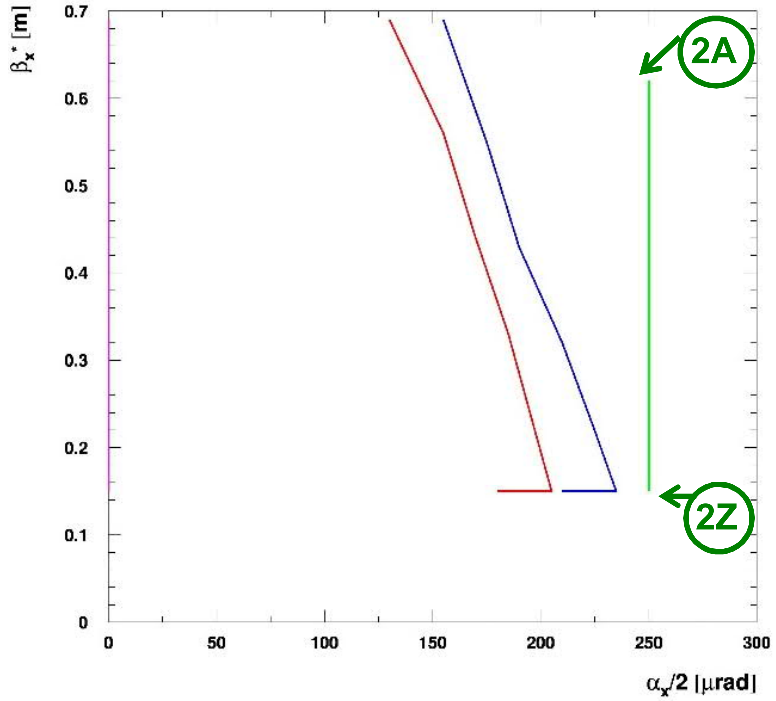
420 m instead of 234 m



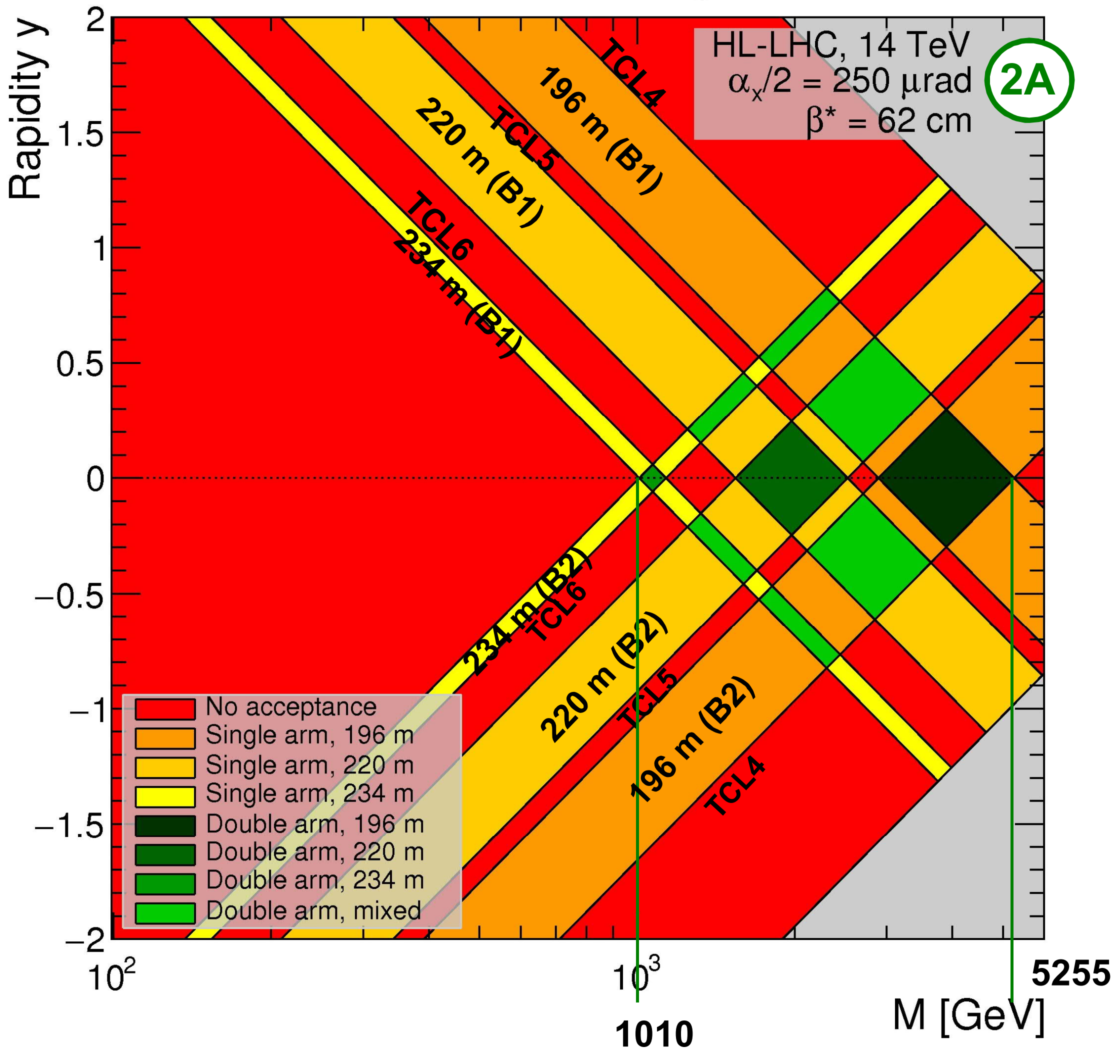


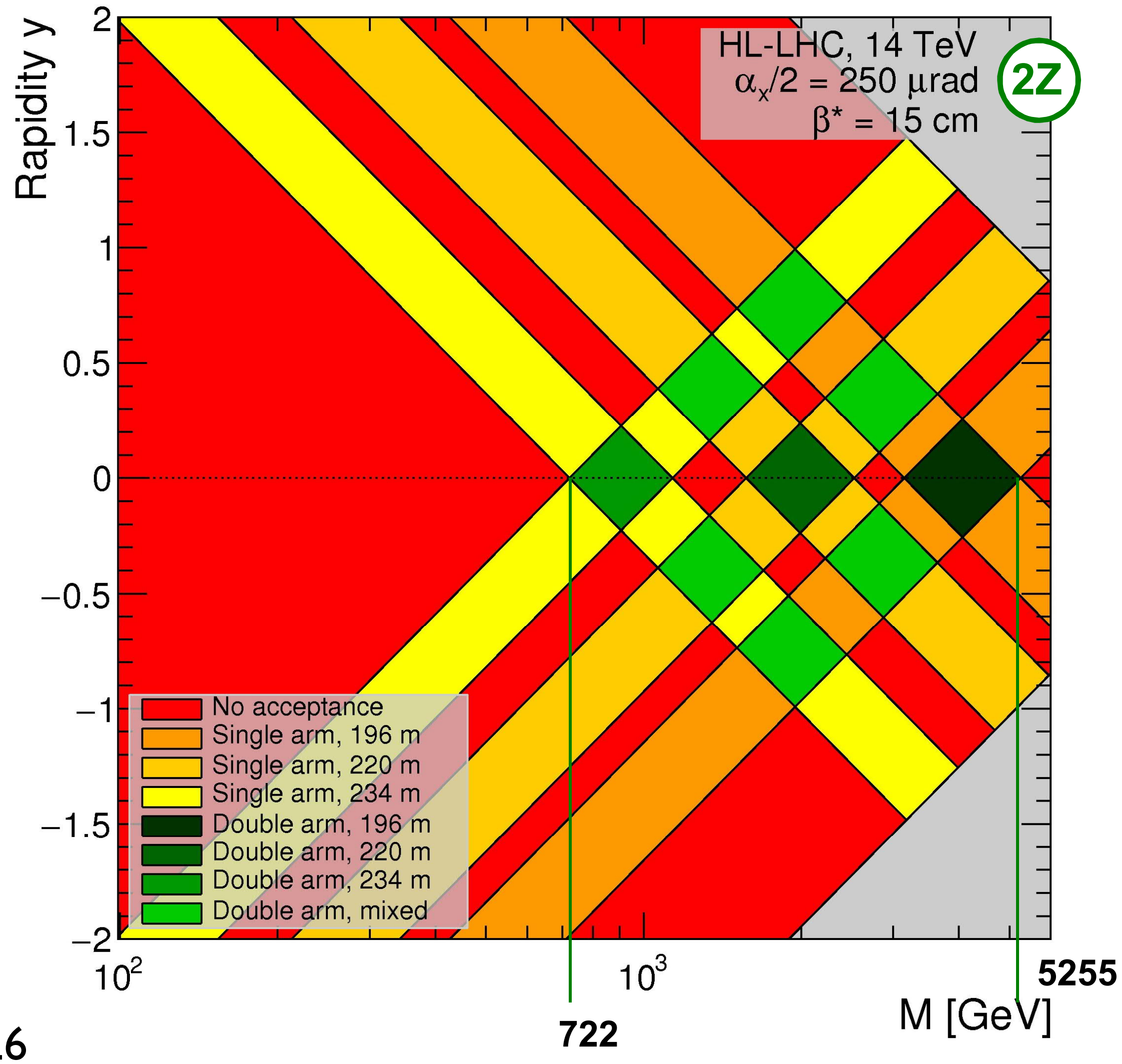
Acceptance in the Mass – Rapidity Plane: Horizontal crossing, Baseline Trajectory, Option 1

M. Deile- PPS@HL-LHC

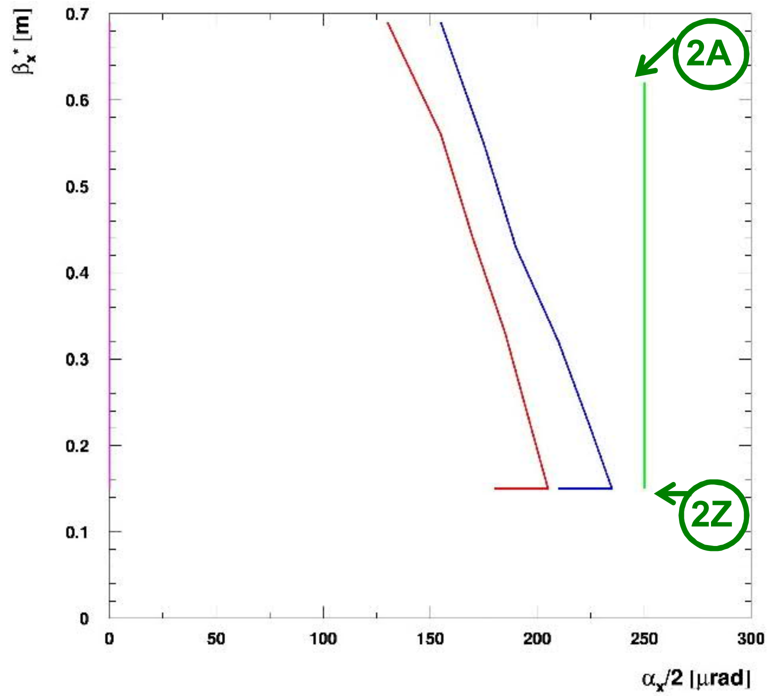


Levelling trajectories:
- Baseline
- Relaxed adaptive
- Aggressive adaptive
- Vertical crossing (any trajectory)





Acceptance in the Mass – Rapidity Plane: Horizontal crossing, Baseline Trajectory, Option 2



Levelling trajectories:
- Baseline
- Relaxed adaptive
- Aggressive adaptive
- Vertical crossing (any trajectory)

M. Deile- PPS@HL-LHC

420 m instead of 234 m