Photon-photon collisions with ATLAS

Mateusz Dyndal (DESY)

DESY FH Fellow Meeting

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Personal Data

- Born in Tarnogrod, Poland (1988)

- Involved with ATLAS since 2010 (BSc+MSc theses)

- PhD thesis: Krakow/Saclay (doctorat cotutelle) within the ATLAS collaboration (2012-2015)

- Postdoc at DESY in the ATLAS group (since Feb 2016)

PhD thesis

- Phenomenology of photon-photon interactions in proton-proton collisions at the LHC
    - Elastic $pp\ (\gamma\gamma) \rightarrow pp\ X$ interactions
    - Calculation of absorptive corrections to these processes

- Measurement of exclusive $\gamma\gamma \rightarrow \ell^+\ell^-\ (\ell = e, \mu)$ production in proton-proton collisions at √s=7 TeV with the ATLAS detector

- Involvement in the ATLAS Forward Proton (**AFP**) project -> forward proton spectrometers of ATLAS
    - GEANT4 simulation of ATLAS forward region + AFP detectors
    - Full simulation chain for AFP (including data model, digitization, reconstruction)

Theory: elastic pp ($\gamma\gamma$) $\rightarrow$ pp X
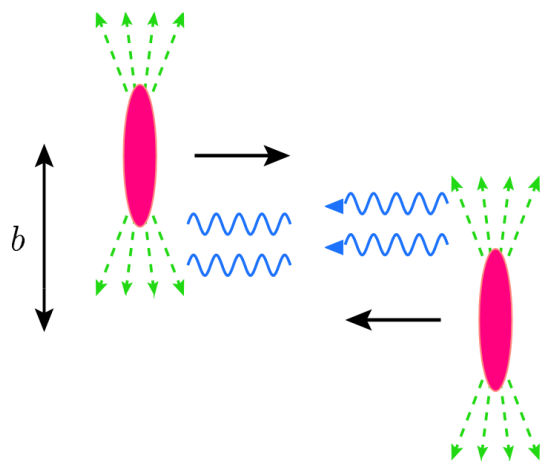
Chen et al., Phys. Rev. D7 (1973) 3485-3502.
Budnev et al., Nucl. Phys. B63 (1973) 519-541.
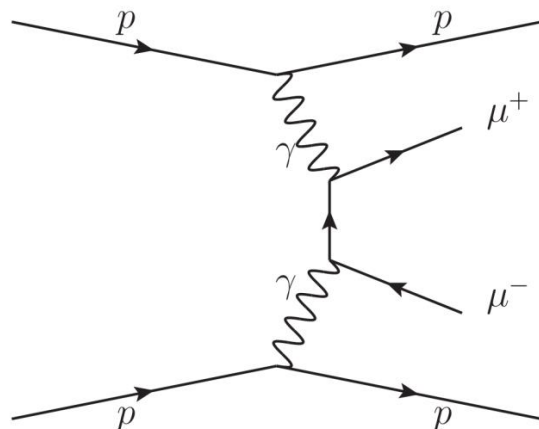
The cross-section for this process is calculated:

(1) Using the number of equivalent photons (EPA) by integration over the whole virtuality range:

$$dN = \frac{\alpha}{\pi} \frac{dQ^2}{Q^2} \frac{dx}{x} \left[(1-x)\left(1 - \frac{Q^2_{min}}{Q^2} F_E(Q^2)\right) + \frac{x^2}{2} F_M(Q^2) \right]$$

$$Q^2_{min} \simeq m_p^2 \frac{x^2}{1-x} \qquad Q^2_{max} = 2\,\text{GeV}^2$$

Integrand contains the proton EM form factors (calculations originally done by Chen, Terazawa, et al. for $\gamma\gamma \rightarrow \mu^+\mu^-$ process)
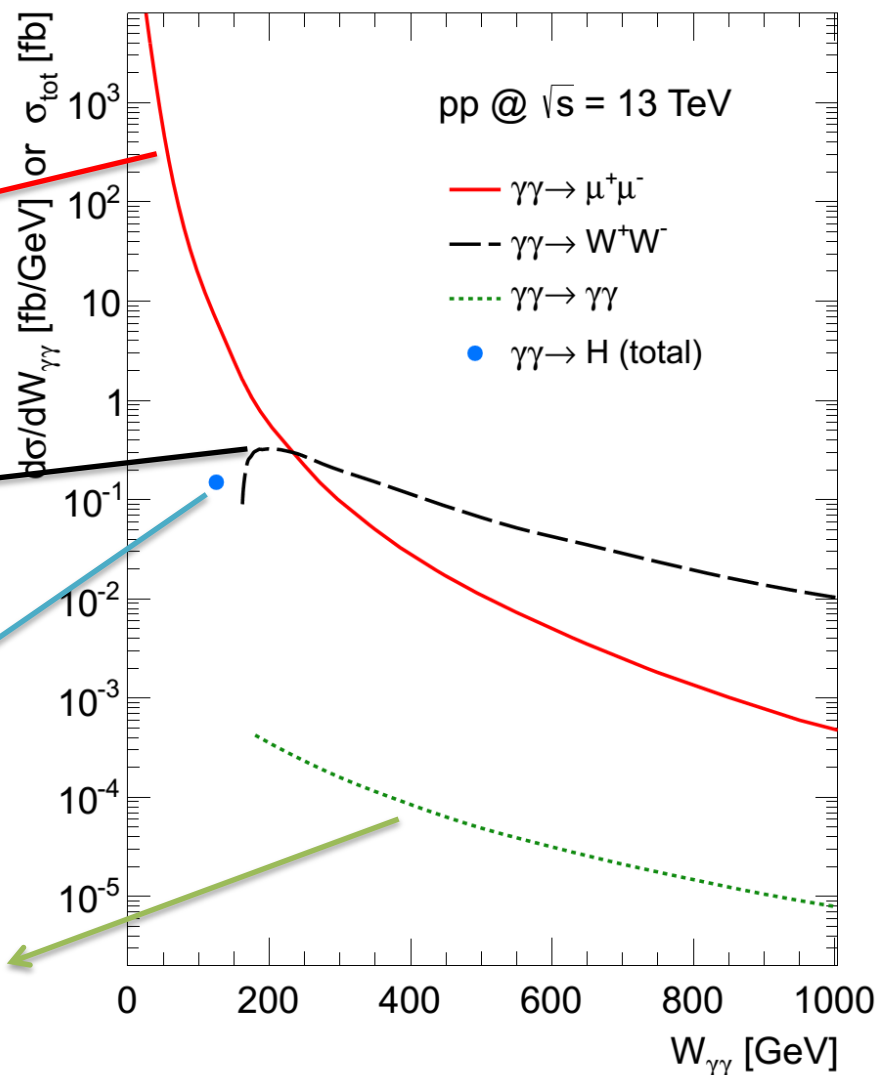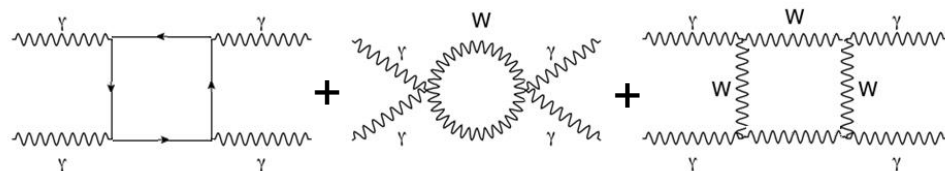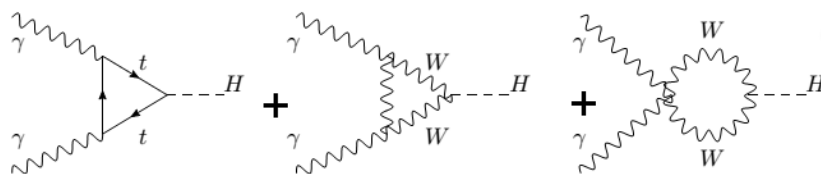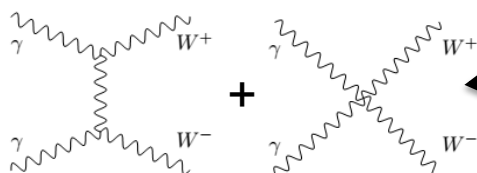
(2) EW $\gamma\gamma \rightarrow$ **X** cross-section.

Theory: elastic pp (γγ) → pp X

- Some cross-sections for √s = 13 TeV
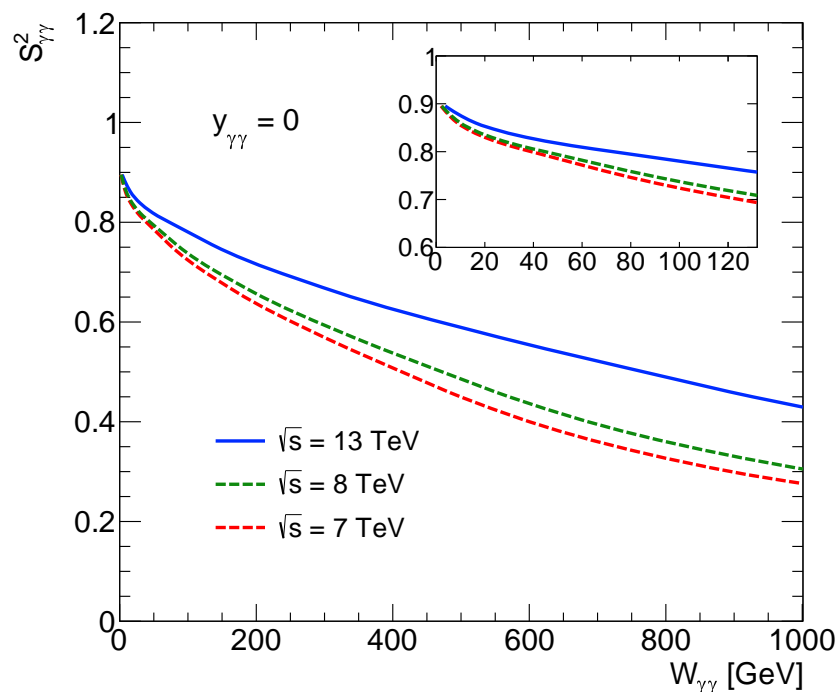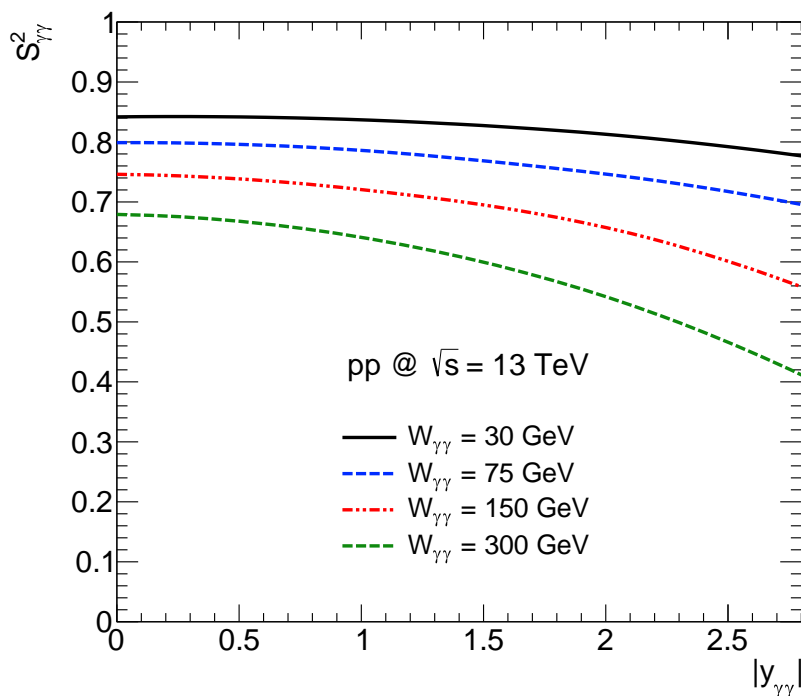 - O(pb) for $W_{\gamma\gamma}$ > 10 GeV ($\gamma\gamma \to \ell^+\ell^-$)
  - O(fb) for $W_{\gamma\gamma}$ > 200 GeV ($\gamma\gamma \to W^+W^-$)

pp @ √s = 13 TeV

- $\gamma\gamma \to \mu^+\mu^-$
- $\gamma\gamma \to W^+W^-$
- $\gamma\gamma \to \gamma\gamma$
- $\gamma\gamma \to H$ (total)
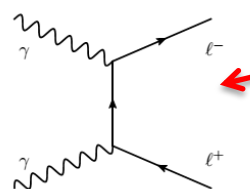
Finite-size effects

- Requirements: protons should remain intact / photons emitted coherently

- Strong dependence on invariant mass of the system

- Small dependence on rapidity of the system (for smaller inv. masses)

$$S_{\gamma\gamma}^2 = \frac{\int_{b_1>r_p}\int_{b_2>r_p} \mathrm{d}^2\vec{b}_1\mathrm{d}^2\vec{b}_2 \; n(\vec{b}_1,\omega_1)n(\vec{b}_2,\omega_2) \; P_{\text{non-inel}}(|\vec{b}_1-\vec{b}_2|)}{\int_{b_1>0}\int_{b_2>0} \mathrm{d}^2\vec{b}_1\mathrm{d}^2\vec{b}_2 \; n(\vec{b}_1,\omega_1)n(\vec{b}_2,\omega_2)}$$

pp @ $\sqrt{s}$ = 13 TeV

$W_{\gamma\gamma}$ = 30 GeV
$W_{\gamma\gamma}$ = 75 GeV
$W_{\gamma\gamma}$ = 150 GeV
$W_{\gamma\gamma}$ = 300 GeV

$y_{\gamma\gamma}$ = 0

$\sqrt{s}$ = 13 TeV
$\sqrt{s}$ = 8 TeV
$\sqrt{s}$ = 7 TeV

More details in: MD, Laurent Schoeffel, **Phys. Lett. B741 (2015) 66-70**

Data analysis context

- Exclusive dilepton production as a ``**standard candle**'' for the other photon-induced processes

- Small theory (QED) uncertainties serve the possibility to use the $\gamma\gamma \to \mu^+\mu^-$ reactions for **luminosity determination at the LHC**
    - However, a correct treatment of **absorptive corrections** needs to be applied (included in this work)

- Goal of the analysis (in brief - measurement of two numbers):
    - Fiducial cross-sections for exclusive production (lepton pairs)
    - Data/theory (QED) ratios -> proton finite-size effects

Event topology

Run 190644, Event 51422085
Time 2011-10-09, 16:29 CEST
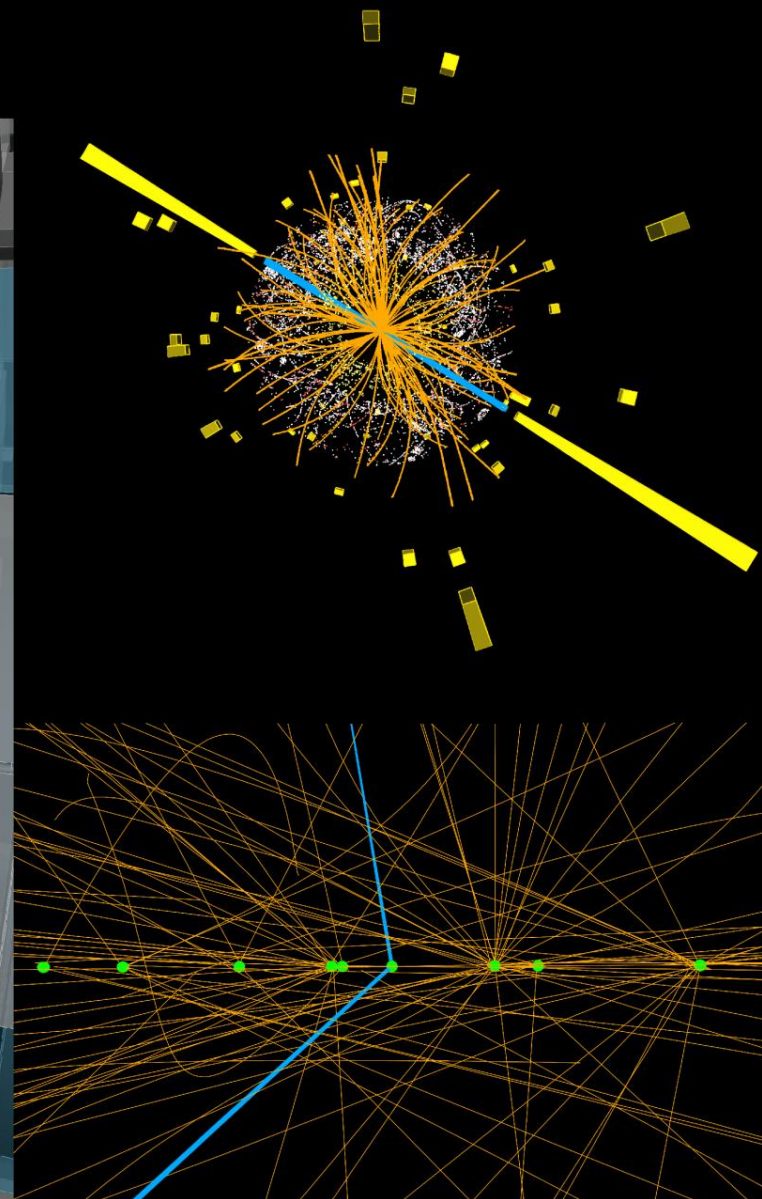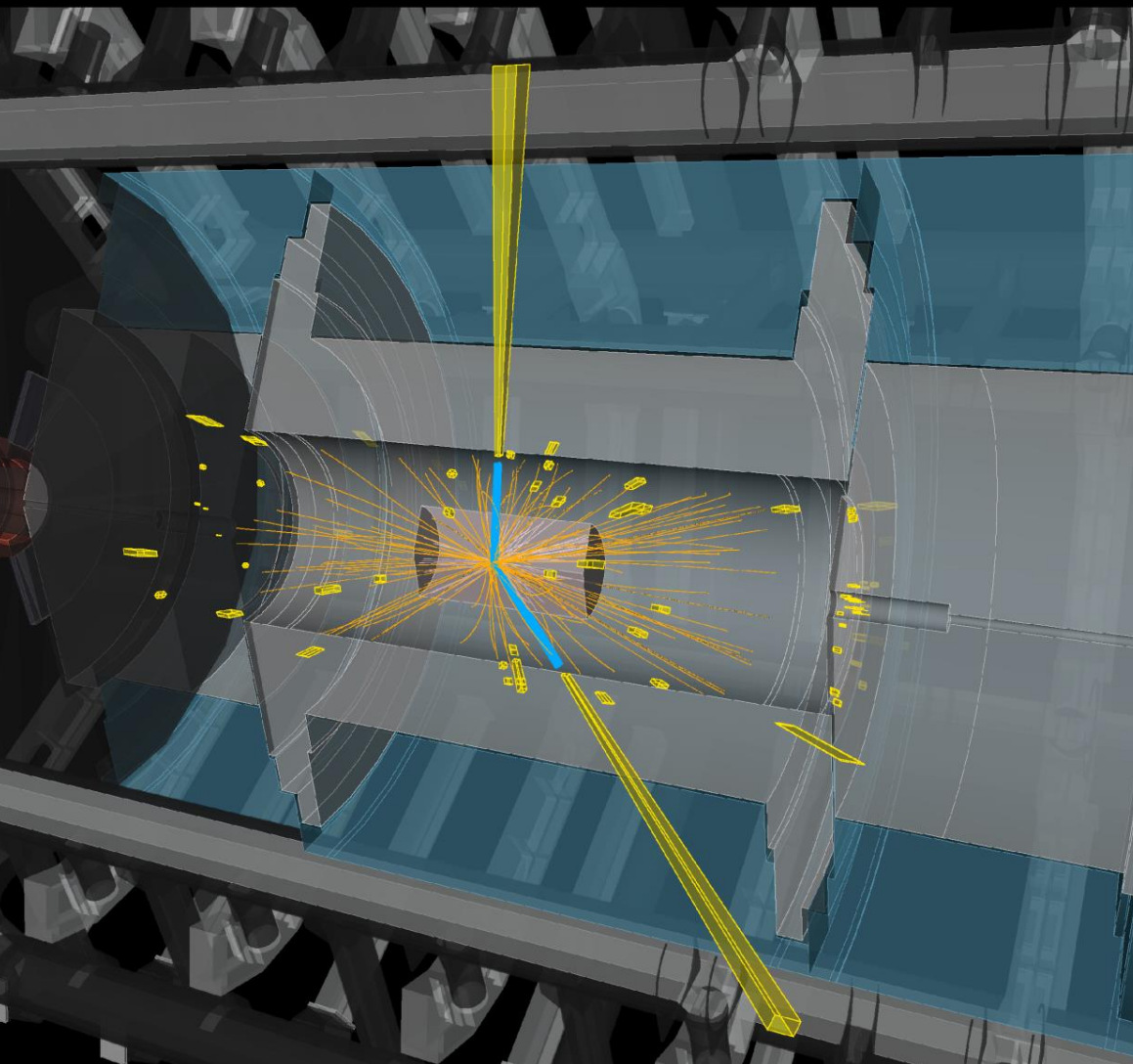
Event selection

- Exclusivity veto:
  - Exactly **2 tracks** in the dilepton vertex
  - Distance di-lepton vtx - closest vtx (or track) > **3 mm**

- Elastic selection:
  - p_T of the dilepton system **< 1.5 GeV**

- Number of selected events in data is below the expectations (~**80%**)
  - **Proton absorptive corrections** (not included in **exclusive** and **s-diss.** MC)
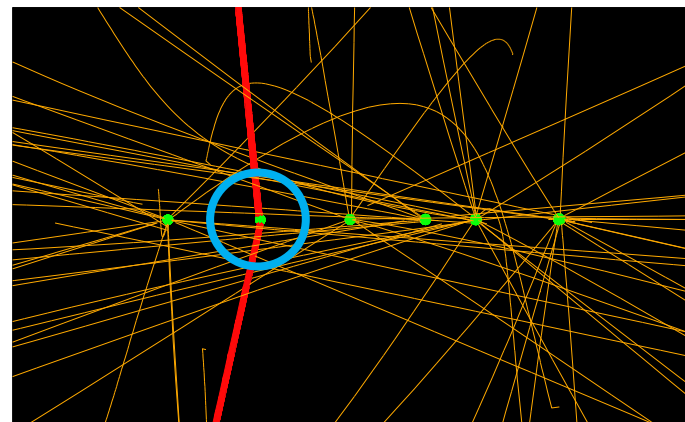
| Selection	$\gamma\gamma \to \ell^+\ell^-$ Signal	$\gamma\gamma \to \ell^+\ell^-$ S-diss.	$\gamma\gamma \to \ell^+\ell^-$ D-diss.	$Z/\gamma^* \to \ell^+\ell^-$	Multi-jet	$Z/\gamma^* \to \tau^+\tau^-$	$t\bar{t}$	Di-boson	Total predicted	Data
				Electron channel ($\ell = e$)						
Preselection	898	2096	2070	1 460 000	83 000	3760	4610	1950	1 560 000	1 572 271
Exclusivity veto	661	1480	470	3140	0	9	0	5	5780	5410
Z region removed	569	1276	380	600	0	8	0	3	2840	2586
$p_T^{\ell^+\ell^-} < 1.5$ GeV	438	414	80	100	0	2	0	0	1030	869
				Muon channel ($\ell = \mu$)						
Preselection	1774	3964	4390	2 300 000	98 000	7610	6710	2870	2 420 000	2 422 745
Exclusivity veto	1313	2892	860	3960	3	8	0	6	9040	7940
Z region removed	1215	2618	760	1160	3	8	0	3	5760	4729
$p_T^{\ell^+\ell^-} < 1.5$ GeV	1174	1085	160	210	0	3	0	0	2630	2124

Results interpretation

- Summary plot (including also CMS measurement)
- **EPA** corrected for absorptive effects describes the data
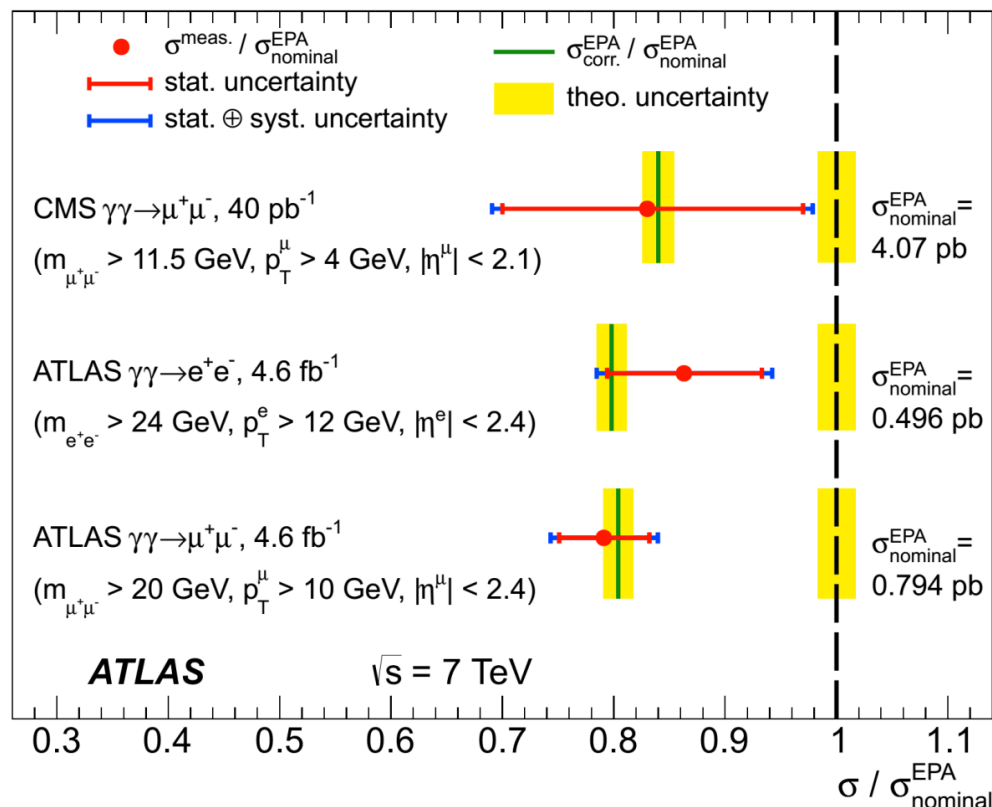
More details in: ATLAS Collaboration, **Phys. Lett. B749 (2015) 242-261**

ATLAS Forward Proton (AFP) project

- <u>Core idea</u>: measure intact protons far away from the ATLAS interaction point (**210 m**) during LHC Run-2

- Initial physics program: **diffractive processes**

- However, also unique way to measure **photon-induced reactions**
    - **Very robust** background reduction due to **forward proton tagging**

- **Detector setup:**
    - Horizontal Roman Pots
    - Silicon tracker to measure proton position
    - Time-of-Flight Quartz Cherenkov detectors for vertex reconstruction
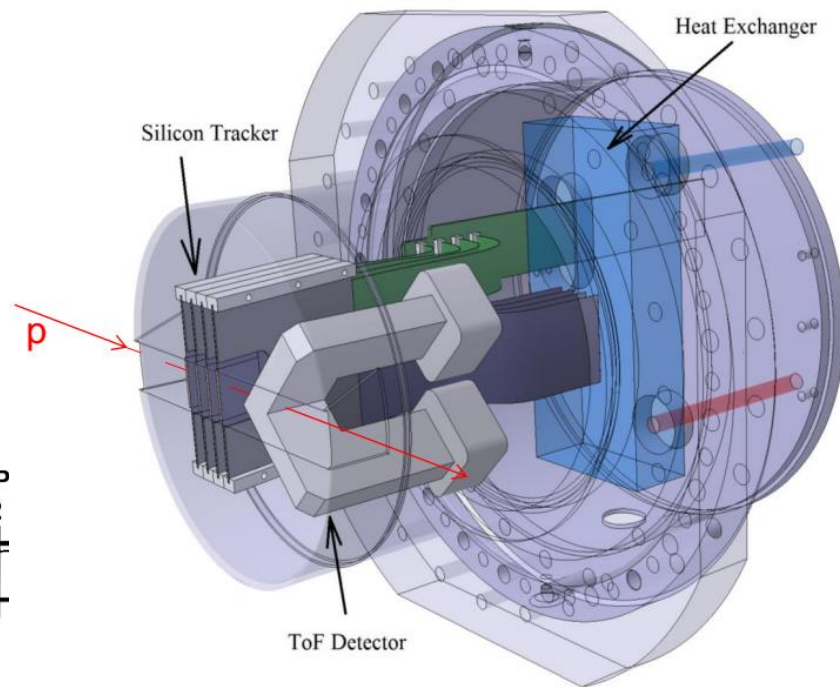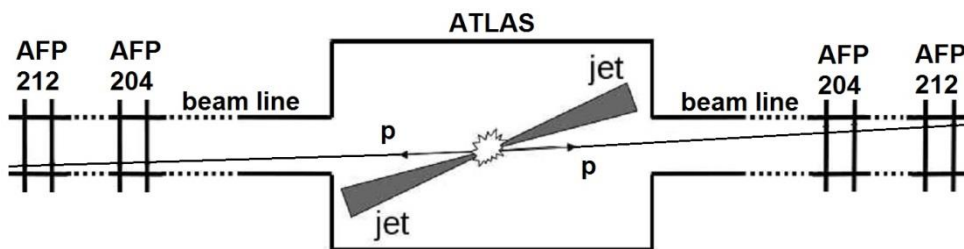
AFP Detector Simulation

- Full **GEANT4** simulation of **Forward Region + AFP Stations** in the ATLAS Athena framework prepared:

  - **Geo Models** of: Forward Region, Roman Pots, Silicon and Timing Detectors

  - Forward Region simulation (for the 1st time)

    - Magnetic field specification

    - Contains beam pipe, collimators and beamscreens models

    - Plan to study the effect of dead material, starting from the closest (most affecting) regions

  - Description of **Sensitive Detectors** (+ data models)

  - **Reconstruction** algorithms for proton tracking + timing

  - **AFP physics objects** scheme also prepared

LQBar 45 deg bend

AFP Stations

ATLAS
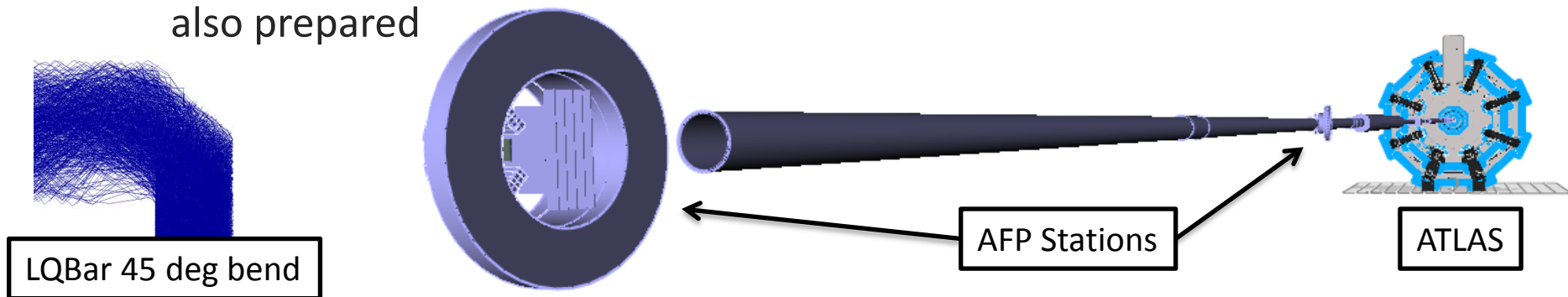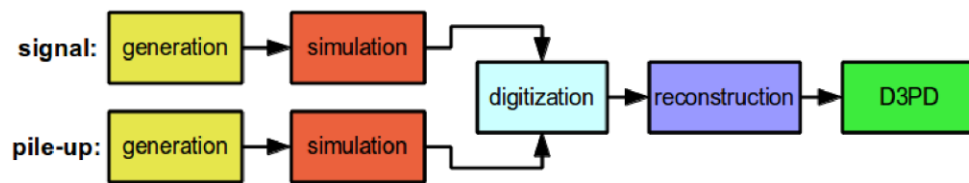
AFP Silicon tracker simulated performance

- **x-y proton track position hitmap** for outer Roman Pot station before (left) and after (right) track matching included

- Tracks matched between inner and outer stations are considered

- Very good reduction of shower background
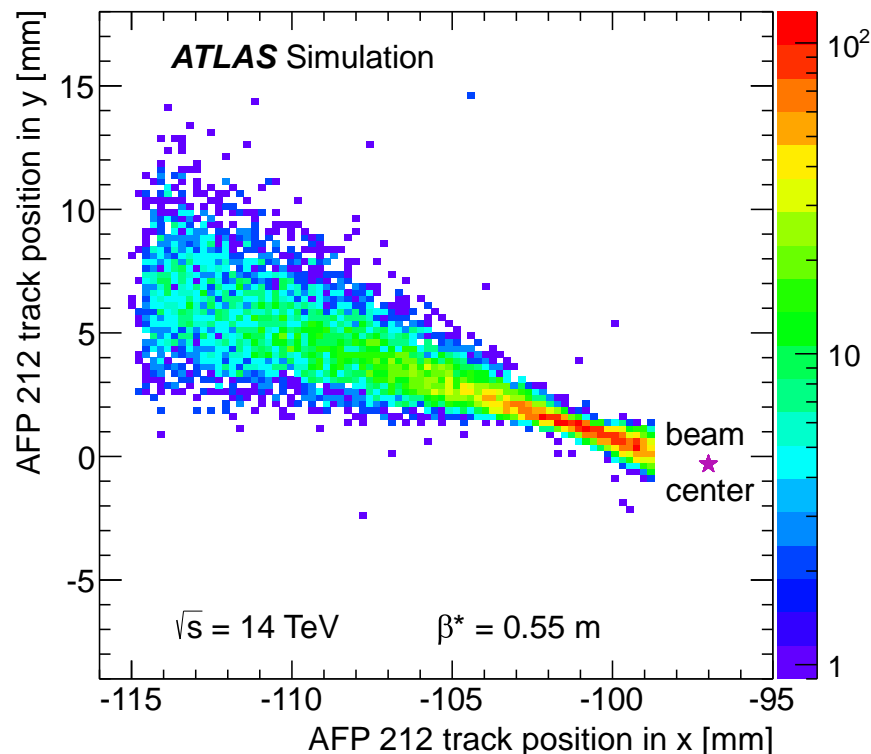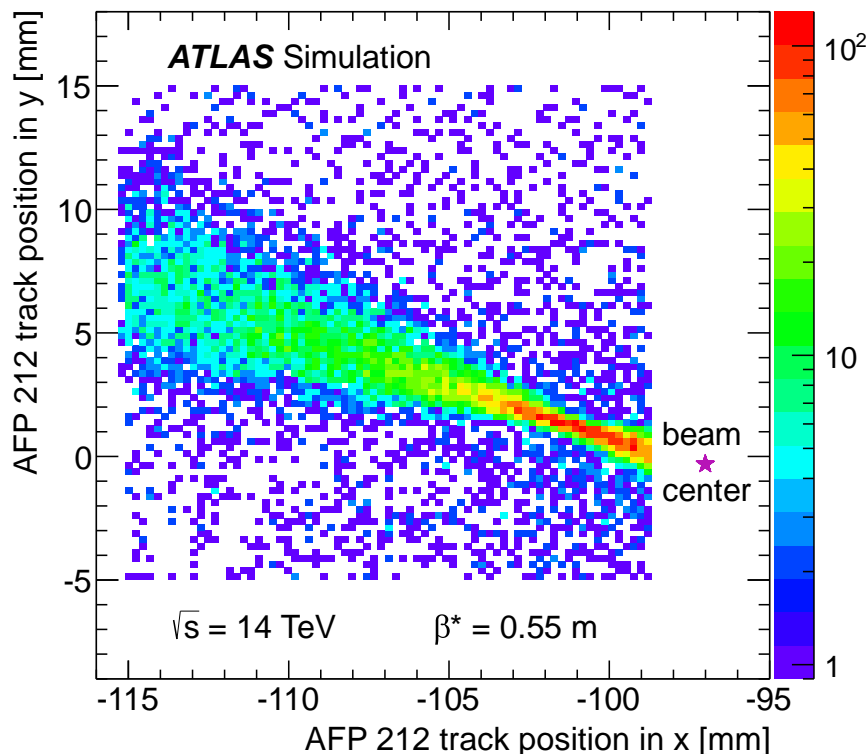
More details in: ATLAS Collaboration, **ATLAS-TDR-024 (2015)**

Present / future

- Within the ATLAS DESY group:
  - SM measurements (both precision and searches for rare processes)
  - SCT calibration loop software expert

ATLAS-CONF-2016-111