Possibility of Diffractive Bremsstrahlung Measurement at the LHC

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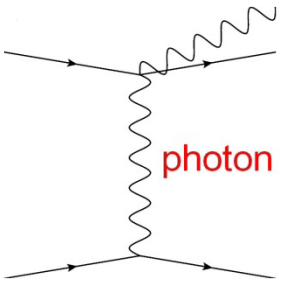
Bremsstrahlung

Simple three particle final state: particles at very large rapidities

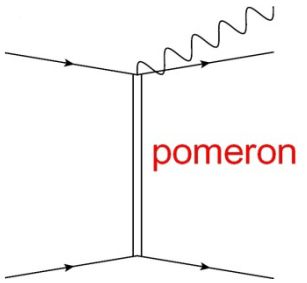
A very attractive tool for high energy experiments (lumi, beam diagnostic @ HERA)

At the 13TeV LHC EM bremsstrahlung in the UPC approximation of pp has the cross-section of about 60 nb for 100 GeV < E_γ < 1500 GeV



V. A. Khoze et al. JINST **6** (2011) P01005

Measure bremsstrahlung accompanying elastic pp scattering
The cross-section is of the order of microbarns



Considerably extended by P.Lebiedowicz and A. Szczurek (formfactors, re-scattering, …)
Phys. Rev. D87 (2013) 114013

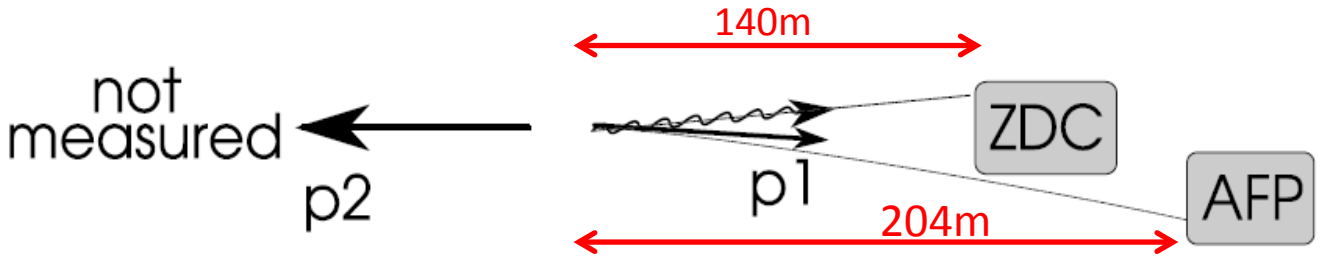
Implemented into the GenEx generator, R. Kycia et al. arXiv: **1411.6035** [hep-ph]

Low $\beta^*(0.55m)$ study

Low β^* study – coincidence measurement

$\beta^* = 0.55$ m

$E_{beam} \approx E_\gamma + E_p$



Angular distribution of photons:

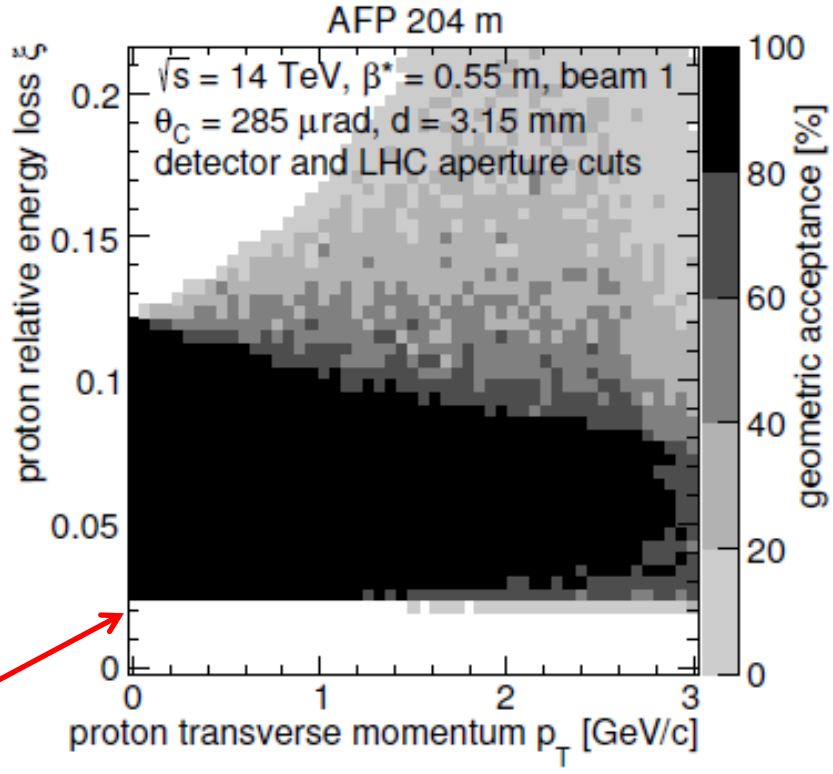
$$\frac{d\sigma}{d\Theta_\gamma} \sim \frac{\Theta_\gamma}{\left(\frac{m_p^2}{E_p^2} + \Theta_\gamma^2\right)^2}$$

$$|E_{beam} - (E_{\gamma,ZDC} + E'_{AFP})| < \delta$$

$E_{\gamma,ZDC}$ – photon energy measured in the ZDC
E'_{AFP} – unfolded proton energy (resolution 10 GeV)

Proton energy range: $0.02 \leq \xi \leq 0.12$

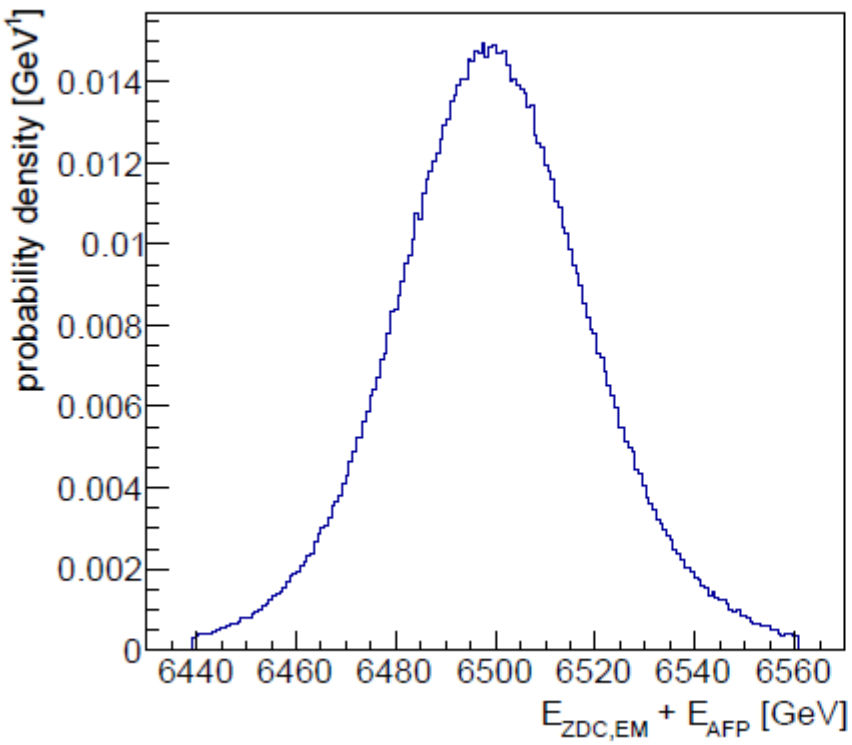
Important factor: beam-AFP detector distance

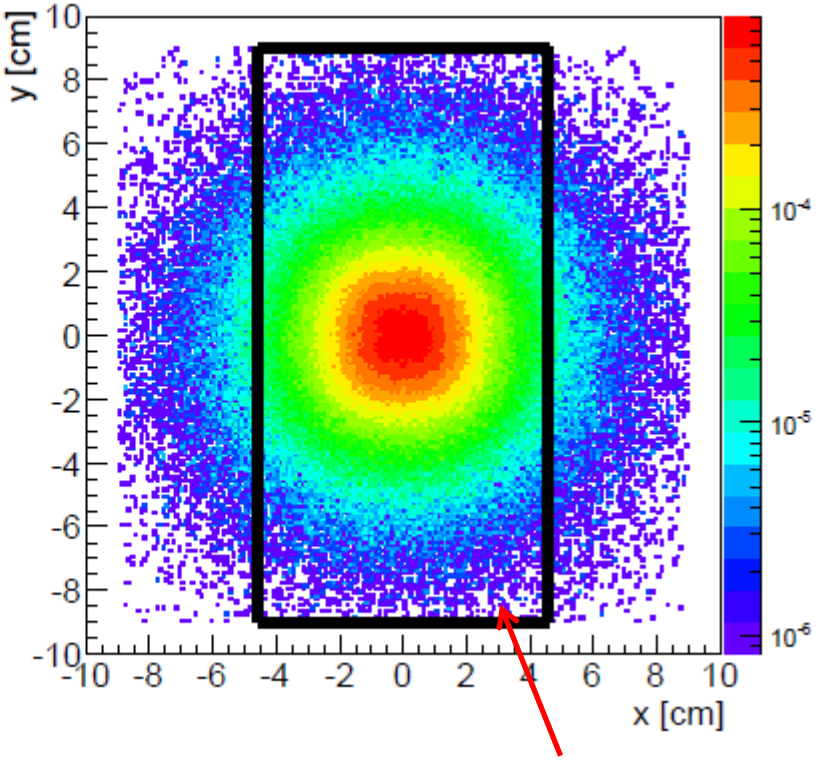


Low β^* - coincidence measurement

$\sigma_{gen,signal}(100 < E_\gamma < 1500\ GeV) = 1.75\mu b$

Photon position at the ZDC face





ZDC fiducial area in TAN

δ set to the triple width of the $(E_{\gamma,ZDC}+E'_{AFP})$ distribution

δ = 78 GeV

Backgrounds

Experimentally:

$$|E_{beam} - (E_{ZDC}+E_{AFP})| < \delta + \text{``empty'' ATLAS detector}$$

``empty'' ATLAS detector:

the inner tracker veto: no particle with $p_T > 1$ GeV and $|\eta| < 2.5$
the calorimeter veto: no particle with $E_T > 1$ GeV and $|\eta| < 4.8$

} High mass diffractive and ND processes

ZDC hadronic energy below 30 GeV (both sides)
EM energy measured in the ``other side'' ZDC below 30 GeV

} Mainly double diffractive processes

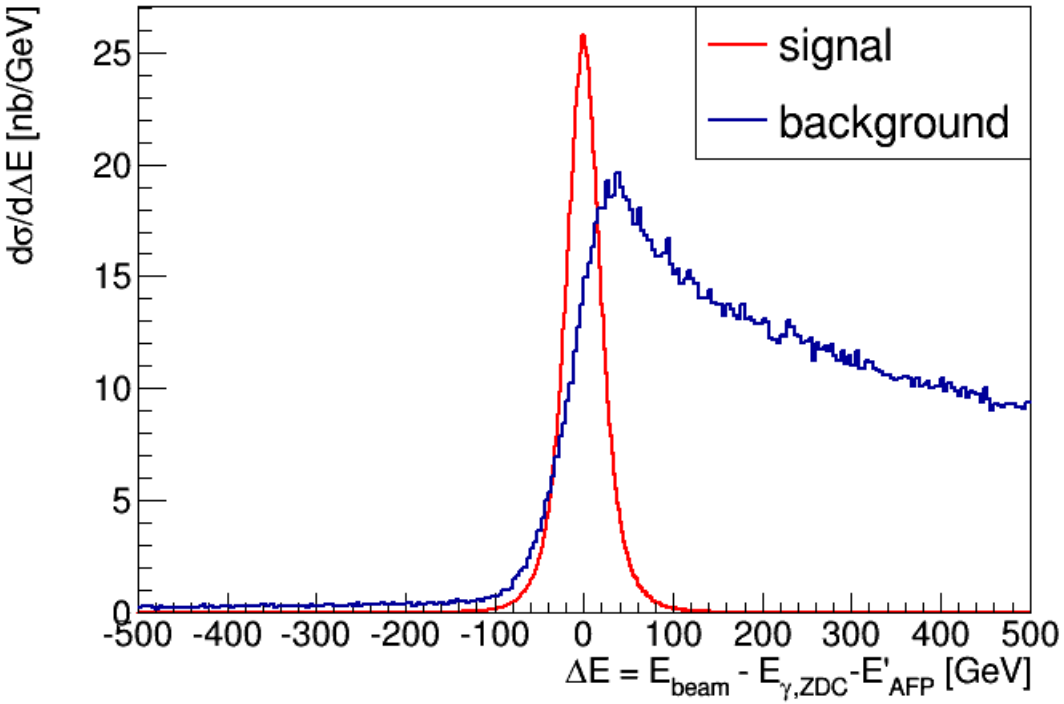
Events generated with PYTHIA 8

Single and double diffractive dissociation; reported cross-section: 21.4 mb
Sample: 1 000 000 000 events

Dominating process is π^0-strahlung: $p+p \rightarrow p\ p\ \pi^0$

Use the ZDC spatial resolution to reduce its influence;
π^0 decay photons not closer than 5 mm at the ZDC face at the 13 TeV LHC

Cuts optimisation - low β^*case



Largely different shapes

Background shifted towards large values

Request:

$| E_{beam} - (E_{\gamma,ZDC}+E'_{AFP})| < 78$ GeV - effectively rejects background

results:

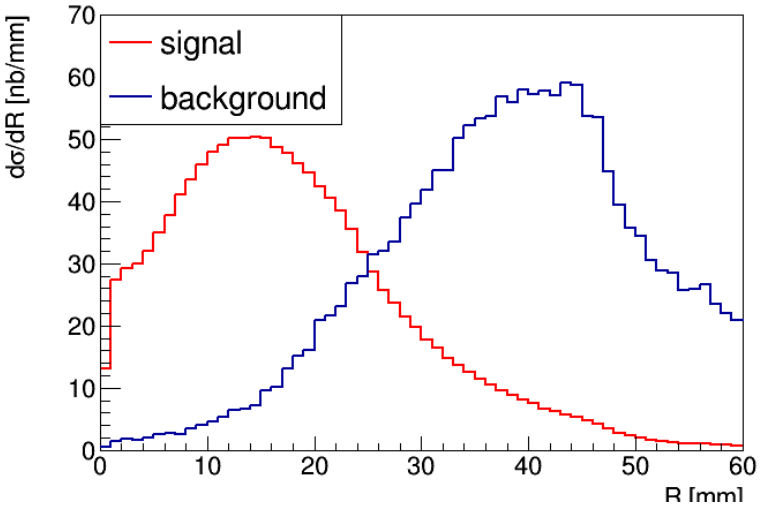
$\sigma_{vis,signal} = 1.31$ μb

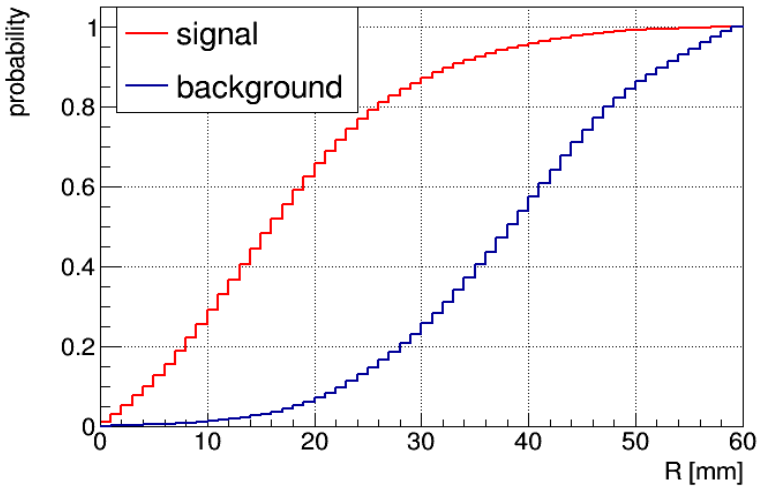
$\sigma_{vis,background} = 1.88$ μb

S/B ~ 2/3

Cuts optimisation - low β^*case

Photon position w.r.t. the ``beam position" at the ZDC face





Signal:
- a clear maximum at about 14 mm,
- quickly falling tail

Background:
- increasing with increasing R,
- plateau 32 mm - 44 mm,
- and then rapidly decreases

Probability P(r<R):

requirement of R ≤ 30 mm
- retains about 85% of the signal
- rejects about 75% of the remaining background

Hence,

$\sigma_{vis,signal}$ = 1.12 μb

$\sigma_{vis,background}$ = 394 nb S/B ~ 3

Results of the low β^* measurement

The AFP acceptance strongly depends on the active detector – beam distance

This distance depends on the beam properties and is measured in units of the local beam width, σ = 0.14 mm for β^* = 55 cm.

Increased by 0.5 mm
- 0.3 mm the pot floor thickness,
- 0.2 mm the floor – detector edge distance.

distance	$\sigma_{vis,signal}$ [nb]	$\sigma_{vis,signal}$ [nb]	S/B
10σ	1047	280	3.5
15σ	915	291	3.1
20σ	745	299	2.5
25σ	614	298	2.1
30σ	497	290	1.8

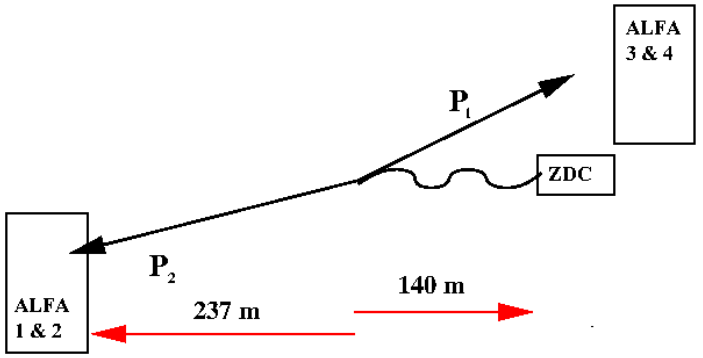
High β^*(90m) study

Large β^* - exclusive measurement

$\beta^* = 90$m

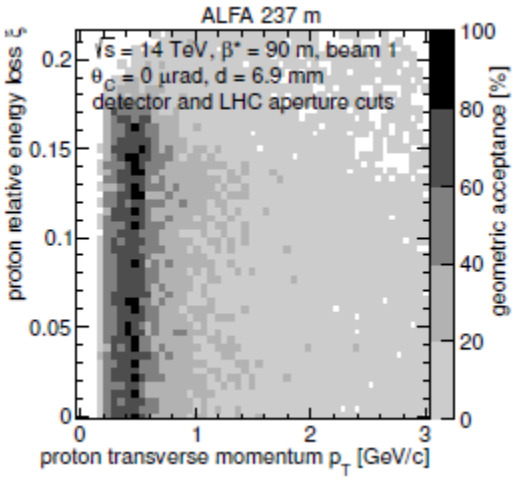
- Aim:

  use ALFA stations and the ZDCs to perform **exclusive measurement**



- Event signature:
  - photon in the ZDC,
  - protons registered in both arms of the ALFA system,
  - empty central detector
  - veto on the other ZDC

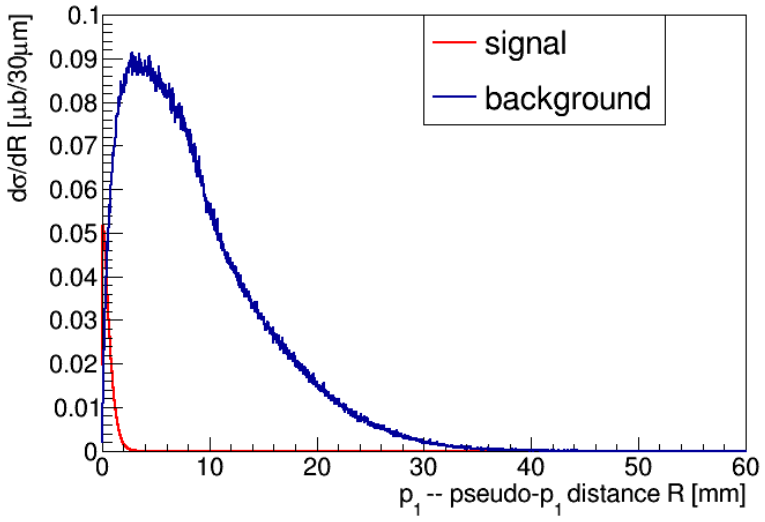
- Complication:
  - ALFA information on the registered proton energy not accessible
  - energy conservation equation cannot be used
- A way out:
  - use p_T conservation at the vertex and construct a pseudo-particle

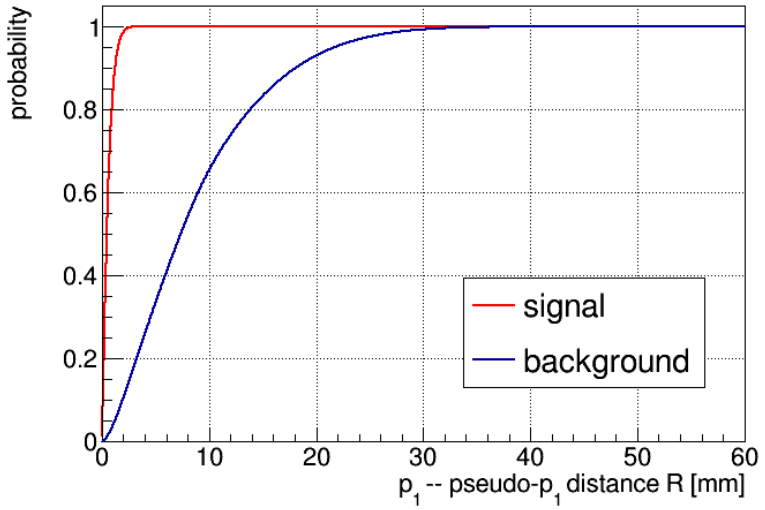


1. Energy of a proton in the photon hemisphere $E_{p1} = E_{beam} - E_{ZDC}$
2. Second proton energy $E_{p2} = E_{beam}$
3. Trace it back to (0,0,0) (elastic transport matrices)
4. Use p_T conservation to construct a pseudo+proton accompanying photon (pseudo-p_1)
5. Use parameterisation to transport it to the ALFA station in appropriate arm
6. Compare positions of p_1 and pseudo-p_1 in ALFA stations

Cuts optimisation for large β^* measurement

- cut on the photon position w.r.t. the ``beam position" at the ZDC face – same as for low β^*
- check the p_1 and pseudo-p_1 positions





Signal:
almost all events within R < 2 mm,
quickly falling

Background:
initial increase,
maximum at R ~ 3-4 mm,
and then a rapid decrease

Probability P(r<R):

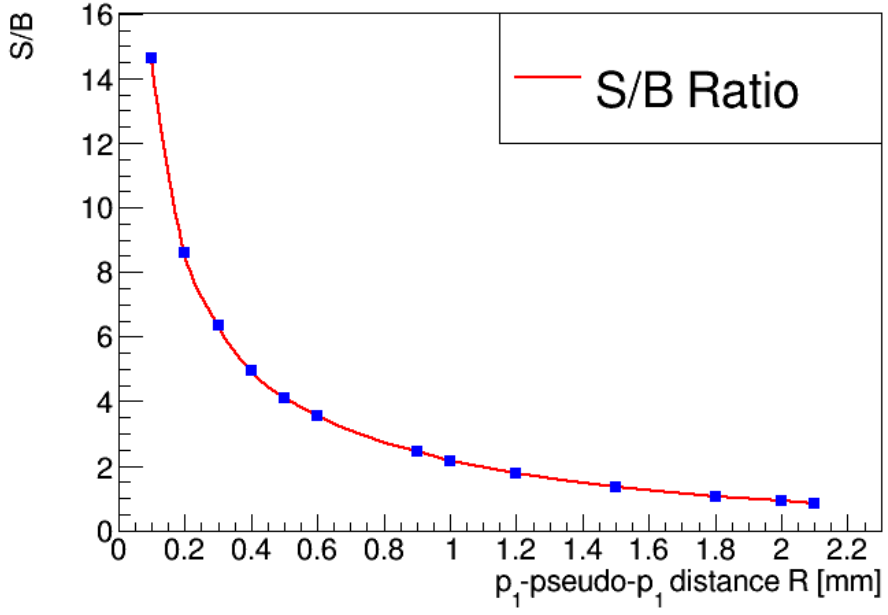
R < 2 mm retains nearly 100% of the signal
while rejecting about 90% of the background

Results of the 90m β^* study

The ALFA acceptance depends on the active detector – beam distance

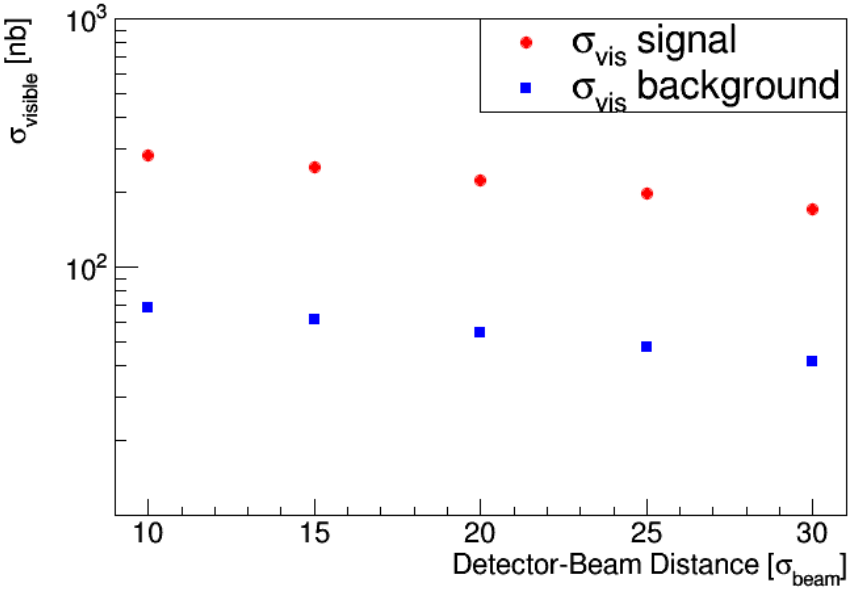
This distance depends on the beam properties and is measured in units of the local beam width, σ = 0.19 mm.

Additional 0.5 mm includes the 0.3 mm of the pot floor thickness and 0.2 mm floor – detector edge.



S/B deteriorates with increasing R (~14 to ~1)

Visible cross-sections for R = 0.5 mm



For R = 0.5 mm S/B(~4) does not depend on the detector-beam distance

Results of the 90m β^* measurement

The ALFA acceptance depends on the active detector – beam distance

Its size follows from the beam properties
It is measured in units of the local beam width, σ = 0.19 mm at high β^*.

Additional 0.5 mm includes:
- 0.3 mm of the pot floor thickness,
- 0.2 mm the floor – detector edge distance.

distance	$\sigma_{vis,signal}$ [nb]	$\sigma_{vis,signal}$ [nb]	S/B
10σ	281	68	4.1
15σ	252	61	4.1
20σ	224	54	4.1
25σ	197	48	4.1
30σ	171	41	4.1

Summary

- Feasibility studies of the diffractive bremsstrahlung measurement at the $\beta^* = 0.55$ m and 90m LHC running at the centre of mass energy of 13 TeV were presented
- $\beta^* = 0.55$ (the AFP-ZDC case)
  - Coincidence measeuremnt
  - The signal visible cross-section ranges between 1050 nb and 500 nb depending on the detector-beam distance (10σ to 30σ)
  - The signal to background ratio decreases from 3.5 to about 2 with increasing beam-detector distance from 10σ to 30σ
- $\beta^* = 90$m (the ALFAs-ZDC case)
  - Exclusive measurement
  - The signal visible cross-section ranges between 50 nb and 540 nb depending on the track-pseudo-track cut (0.5mm to 2 mm)
  - The S/B ratio decreases from about 14 to about 1 with increasing track-pseudo-track distance (from 0.5 mm to 2 mm)
- The measurement could be performed assuming a single interaction per bunch crossing i.e. using the data gathered in the LHC runs with very low pile-up
- The influence of the machine background is unknown and has to be studied experimentally
- Possibility to use this process to calibrate the proton relative energy loss measurement