Diffractive Bremsstrahlung with ALICE 3

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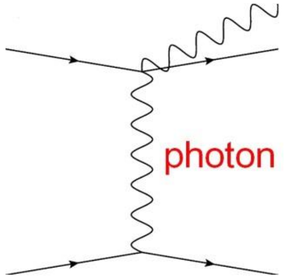
Bremsstrahlung

Simple three-particle final state; all particles at very large rapidities

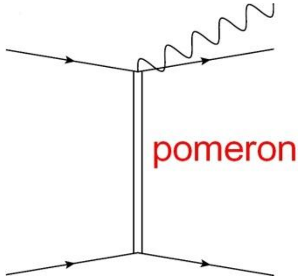
A very attractive tool for high-energy experiments (lumi, beam diagnostic @ HERA, EIC)

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 which gives ~60 Hz at 10^{33} cm^{-2} s^{-1}



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 (form factors, re-scattering, …)
Phys. Rev. D87 (2013) 114013;
+ O. Nachtmann Phys. Lett. B843 (2023) 138053 includes also pp → p γγ p

Implemented into the GenEx generator, R. Kycia et al. Commun. Comput. Phys 24 (2018) 860, arXiv: **1411.6035** [hep-ph]

What can we learn from earlier studies?

Take advantage of the existing apparatus:

1. Measure photons with the very forward calorimeters
2. Use the LHC as a magnetic spectrometer – machine optics dependent

Options to be considered: coincidence and exclusive measurement

1. Coincidence measurement - low β^*(0.55m) optics

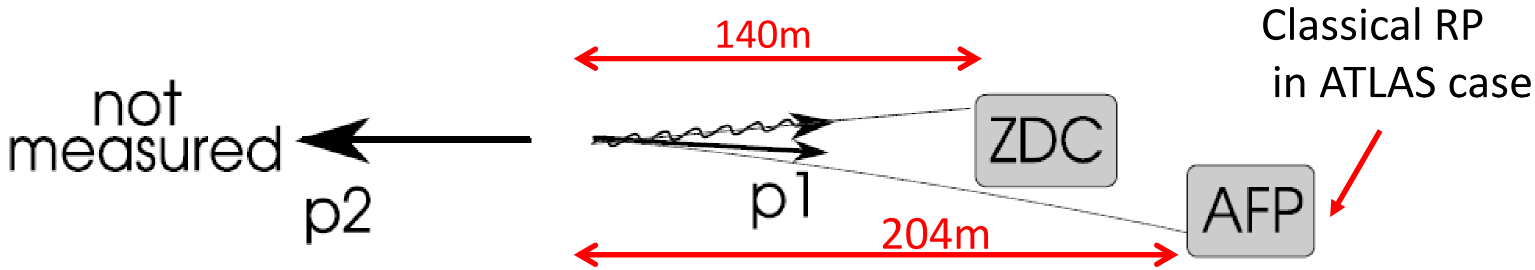
ATLAS central detector+AFP+ZDC

Eur. Phys. J. C 76 (2016) 6, 354

Coincidence measurement - low β^*

$\beta^* = 0.55$ m

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



Angular distribution of photons:

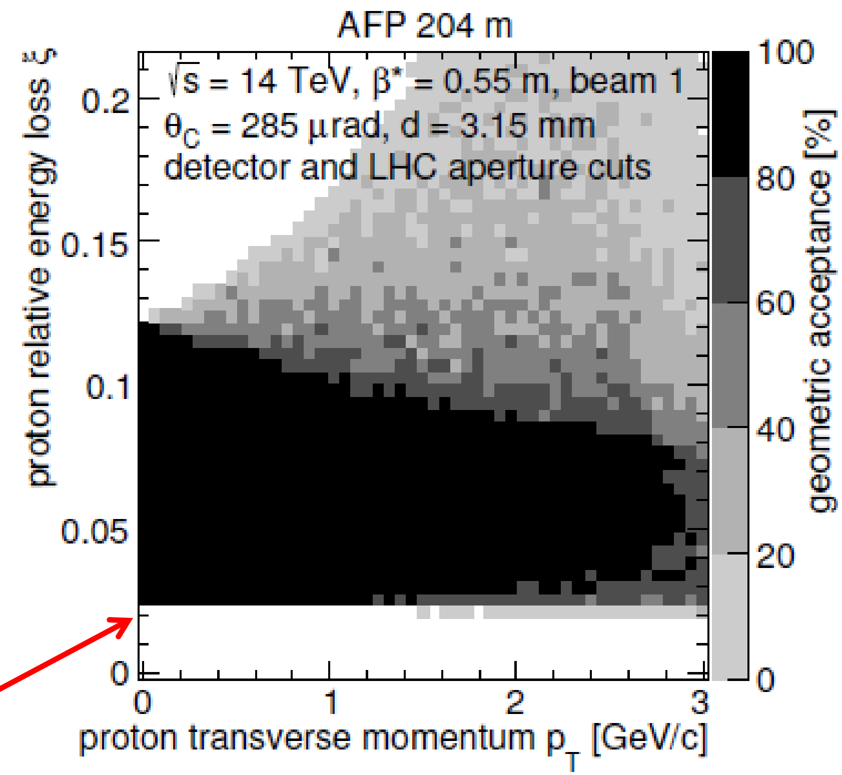
$$\frac{d\sigma}{d\Theta_\gamma} \sim \frac{\Theta_\gamma}{\left(\frac{m_p^2}{E_p^2} + \Theta_\gamma^2\right)^2} \qquad \langle \Theta_\gamma \rangle \sim \frac{1}{\gamma} \ (\sim 144\ \mu rad)$$

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

$E_{\gamma,ZDC1}$ – photon energy measured in the ZDC
E'_{AFP} – unfolded proton energy (resolution 10 GeV)

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

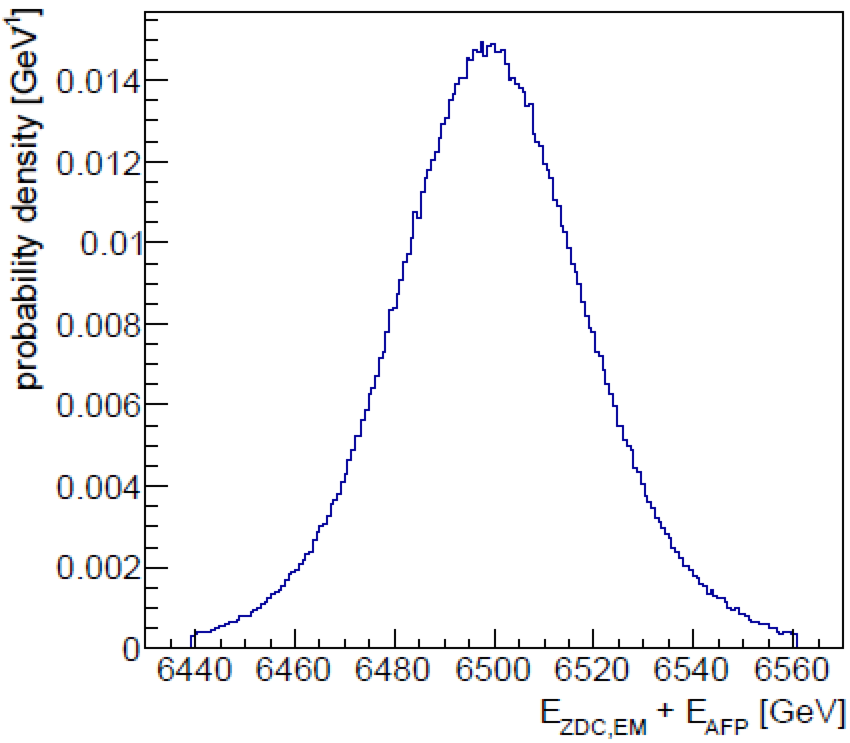
Important factor: beam-AFP detector distance

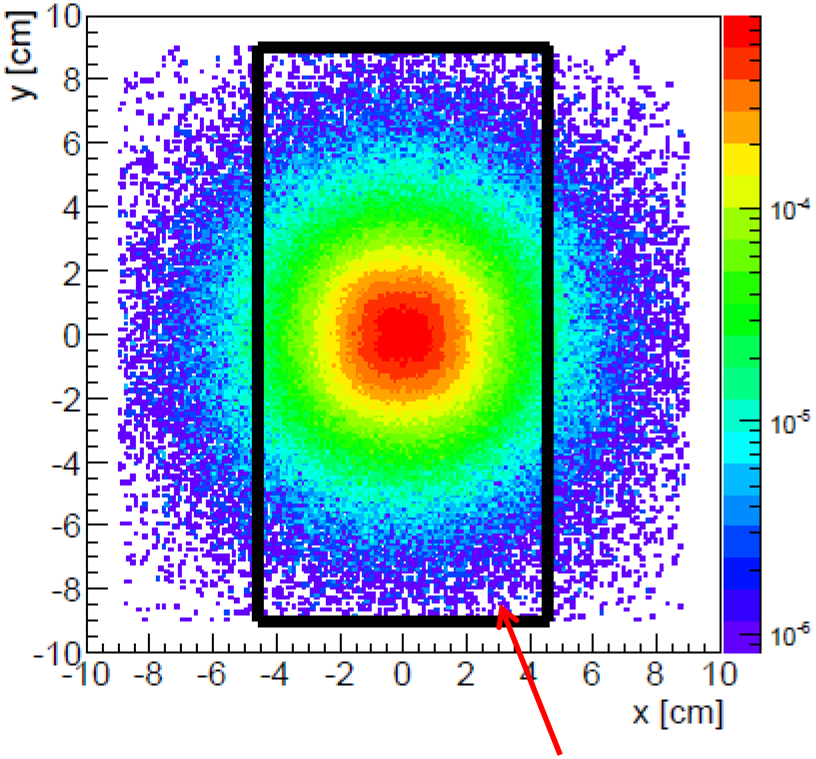


Coincidence measurement - low β^*

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

Photon position at the ZDC1 face





ZDC1 fiducial area in TAN

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

δ = 78 GeV

Coincidence measurement - 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

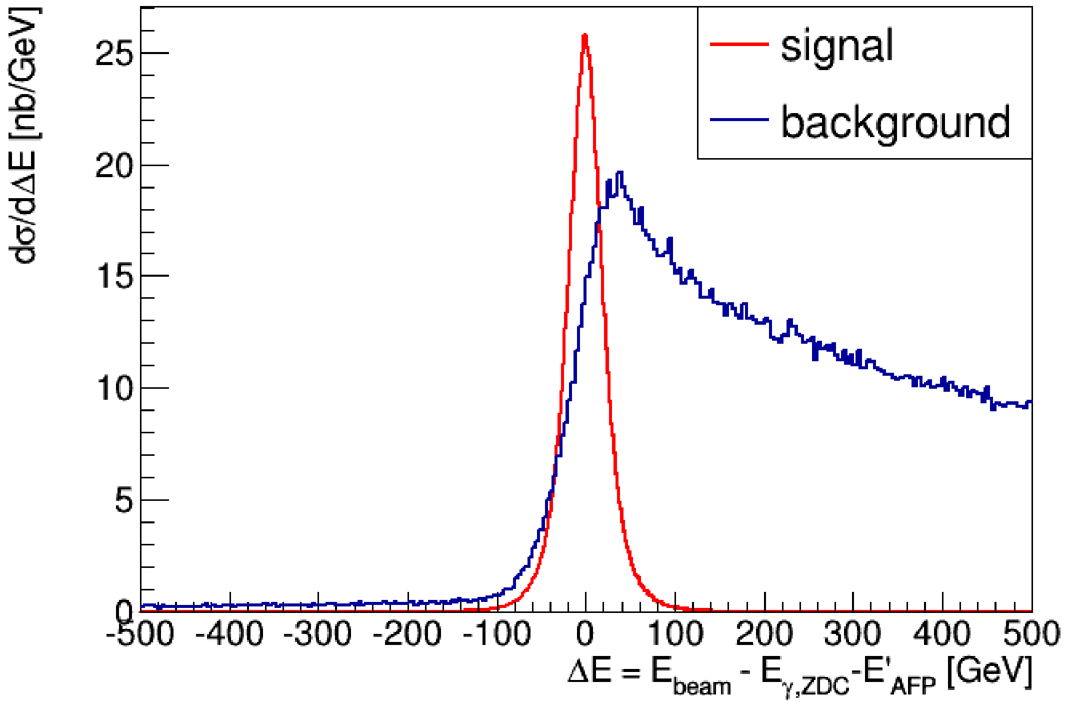
Events generated with PYTHIA 8

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 → p p π^0

Use the ZDC spatial resolution (σ ~1 mm) to reduce its influence;
π^0 decay photons not closer than 5 mm at the ZDC1 face at the 13 TeV LHC

Coincidence measurement – optimisation of cuts



Energy conservation in an event

Largely different shapes

Background shifted towards large values

Request:

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

results:

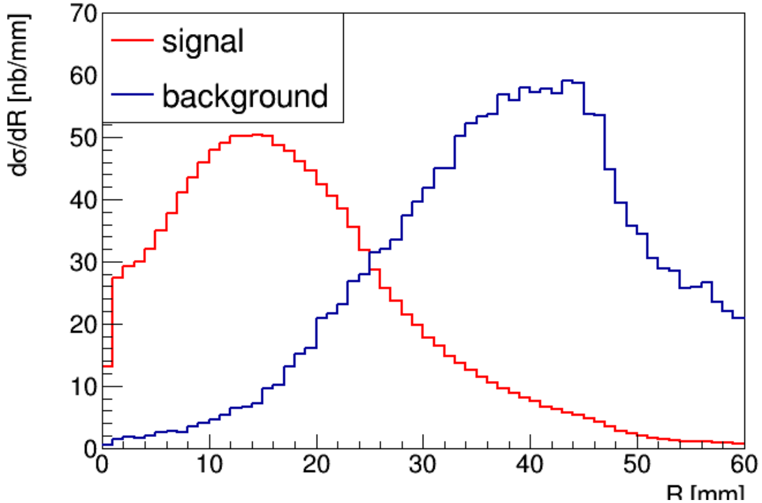
$\sigma_{vis,signal}$ = 1.31 μb

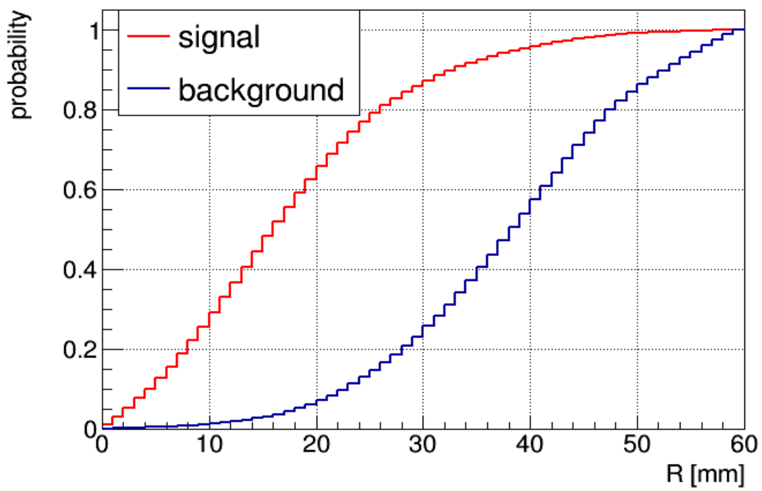
$\sigma_{vis,background}$ = 1.88 μb

S/B ~ 2/3

Coincidence measurement – optimisation of cuts

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, relatively flat in 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

Coincidence measurement - results

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

related to the beam properties given by the local (detector position) beam width

for the AFP (204m) $\sigma = 0.14$ mm for $\beta^* = 0.55$ m.

Distance*	$\sigma_{vis,signal}$ **[nb]**	$\sigma_{vis,bckgd}$ **[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

**takes into account an additional 0.5 mm*
0.3 mm – the pot floor thickness,
0.2 mm – the floor–detector edge distance.

2. Exclusive measurement - high β^* optics

Eur. Phys. J. C 77 (2017) 4, 216

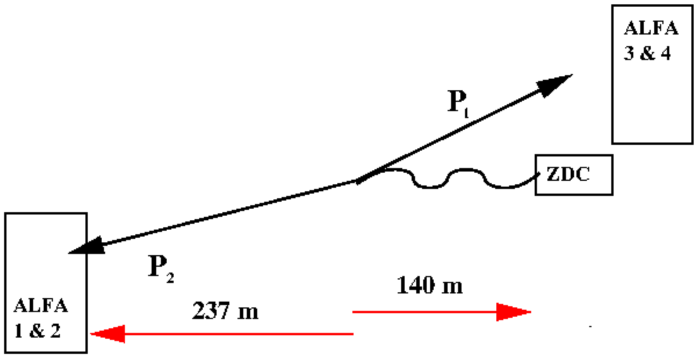
$\beta^* = 90\text{m}$

- Aim:

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

- Event signature:

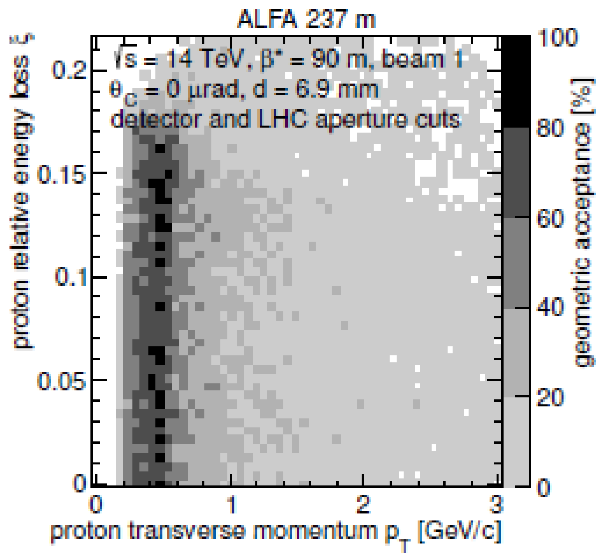
  photon in the ZDC,
  protons registered in both arms of the ALFA system,
  ``empty'' central detector,
  veto on the other ZDC

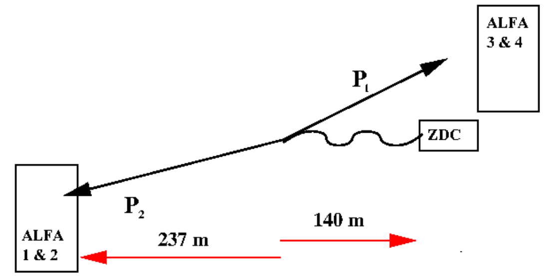


Exclusive measurement - large β^*

$\beta^* = 90m$

Complication:





ALFA information on the registered proton energy not accessible

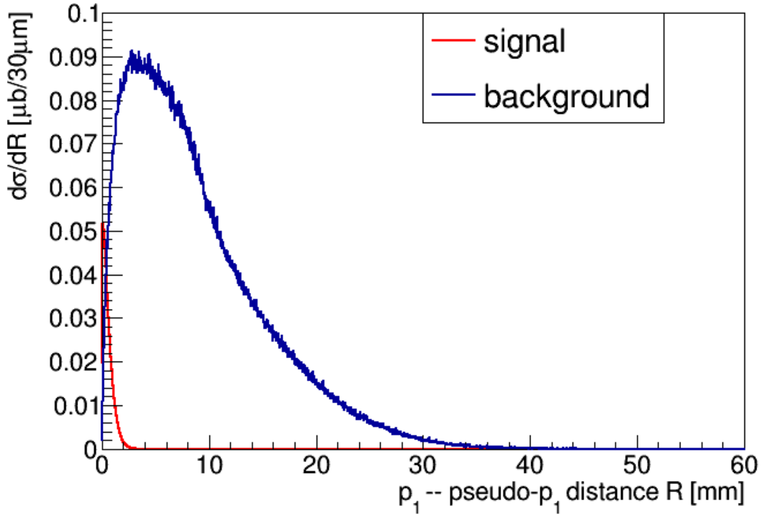
energy conservation equation cannot be used

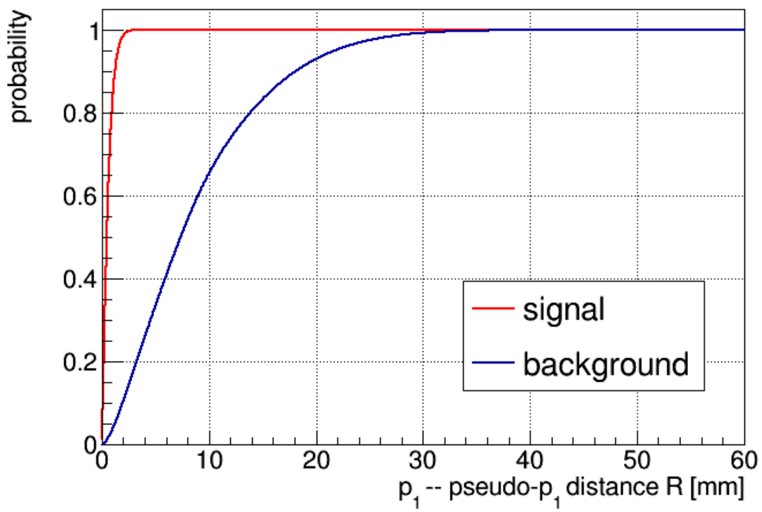
A way out: use p_T conservation at the vertex and construct a pseudo-particle

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 the appropriate arm
6. Compare positions of p_1 and pseudo-p_1 in ALFA stations

Exclusive measurement - optimisation of cuts

- **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

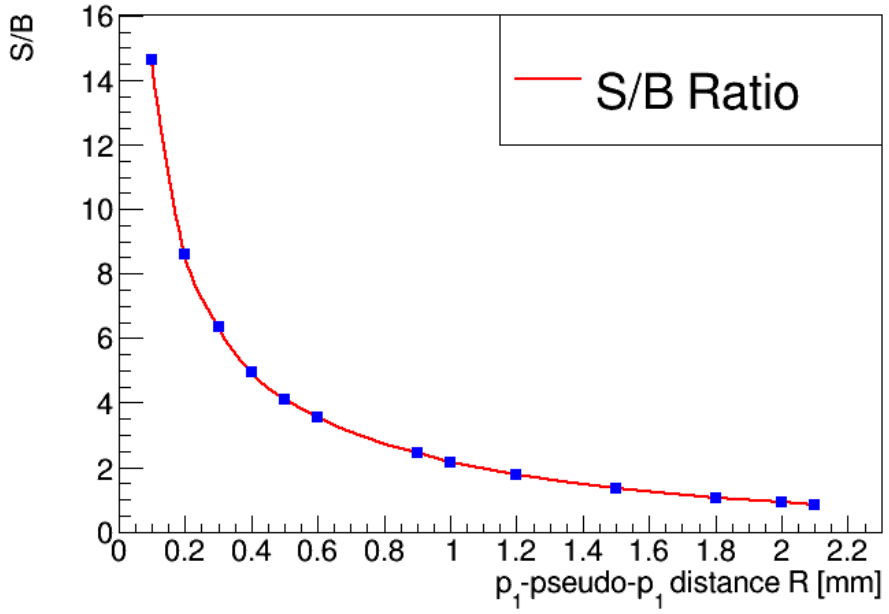
Exclusive measurement - results

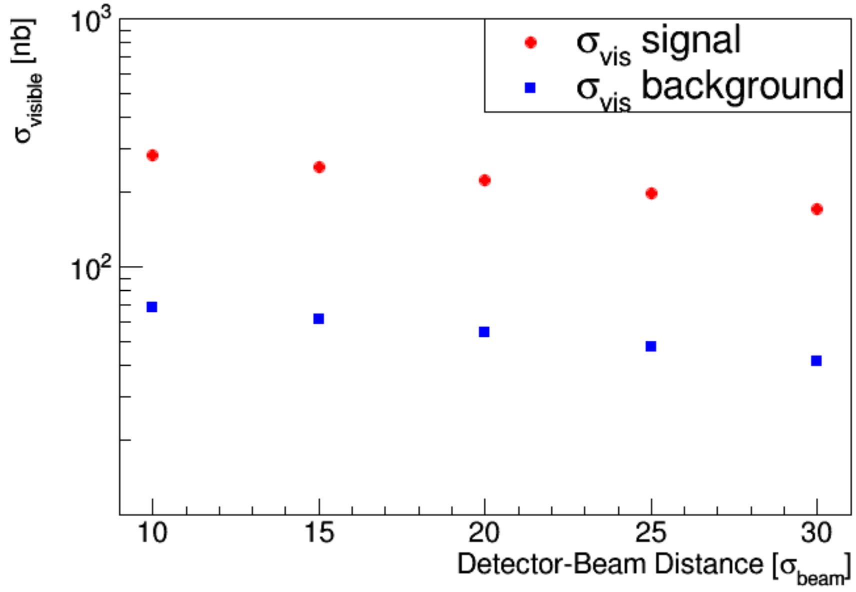
The ALFA acceptance strongly depends on the active detector–beam distance

related to the beam properties given by the local (detector position) beam width

for ALFA (237m) σ = 0.19 mm for β^* = 90 m.

Visible cross-sections for R = 0.5 mm



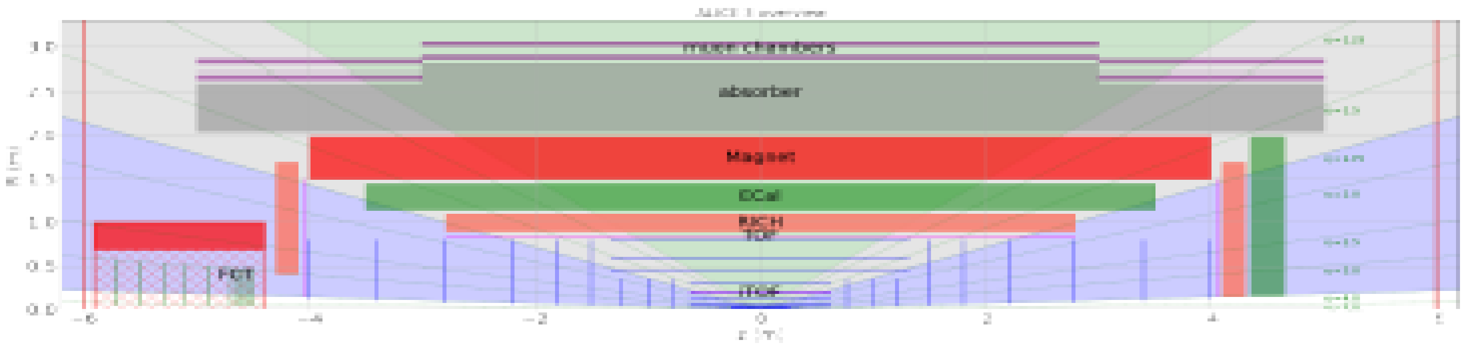


S/B deteriorates with increasing R (~14 to ~1)

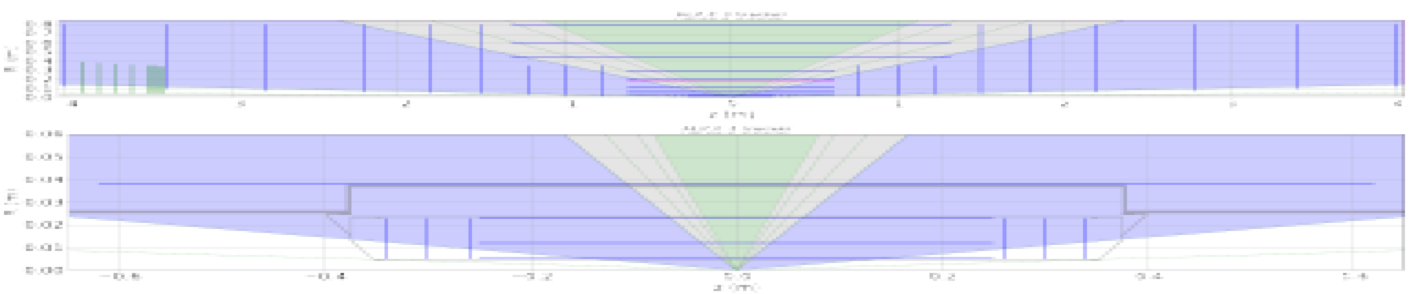
For R = 0.5 mm S/B(~4) does not depend on the detector-beam distance

ALICE 3

Longitudinal cross section



Vertex detector+ outer tracker |η| < 4, |z| < 400 cm, 0.5 cm < R < 80 cm



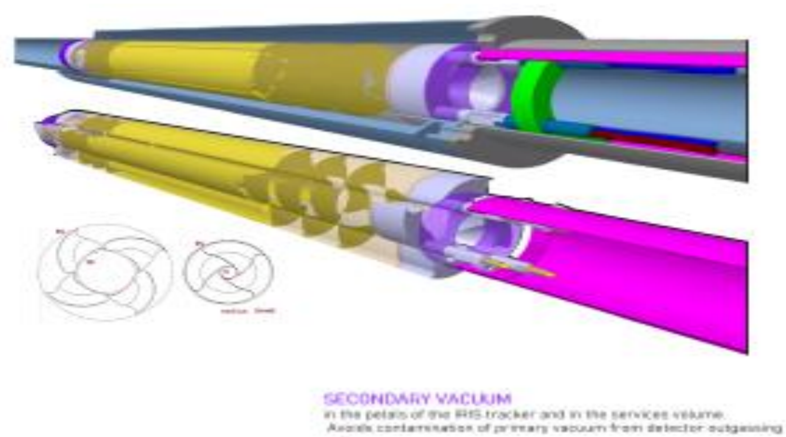
The tracker is much wider: |η| < 4 vs. |η| < 2.5 @ ATLAS
The calorimeters narrower: |η| < 4 vs. |η| < 4.8 @ ATLAS

ALICE 3

Forward Detectors:

- ``Pots'': One may use the vertex detector idea (consult with the machine):

a 5 mm opening should be OK. The beam $\sigma_{x,y}$ ~ 200 μm



- Location: 80 m (~40 m space)
  150 m (~18 m)
  180 m (~50 m)

- ?? – ξ ranges,
  elastic option?? – dedicated running

- requires intensive studies - beam transport
  MAD-X limits ξ to 0.2

- Another issue – Zero Degree Calorimeters
  EMCAL+HCAL, good spatial (~1 mm) and energy resolutions

Summary

- Past feasibility studies of the diffractive bremsstrahlung measurement at the β^{*} = 0.55 m and 90m LHC running at the centre of mass energy of 13 TeV were presented
- β^{*} = 0.55 (the AFP-ZDC case)
  - Coincidence measeurement
  - $\sigma_{vis,signal}$ between 1050 nb and 500 nb with S/B between 3.5 and 2 depending on the detector-beam distance (10σ to 30σ)
- β^{*} = 90m (the ALFA-ZDC case)
  - Exclusive measurement
  - $\sigma_{vis,\ signal}$ 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
- ALICE 3 case requires extensive simulations + more detailed knowledge on the experimental set-up

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Distance*	$\sigma_{vis,signal}$ [nb]	$\sigma_{vis,bckgd}$ [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

**takes into account an additional 0.5 mm*
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