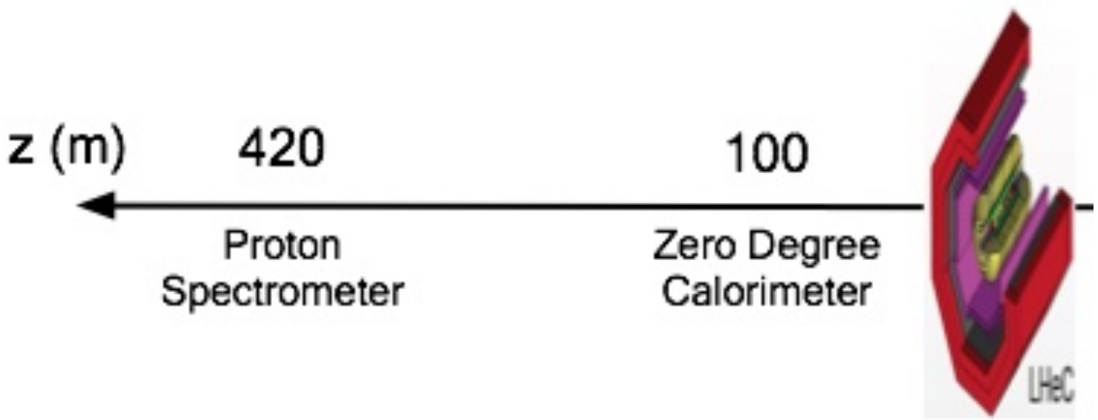
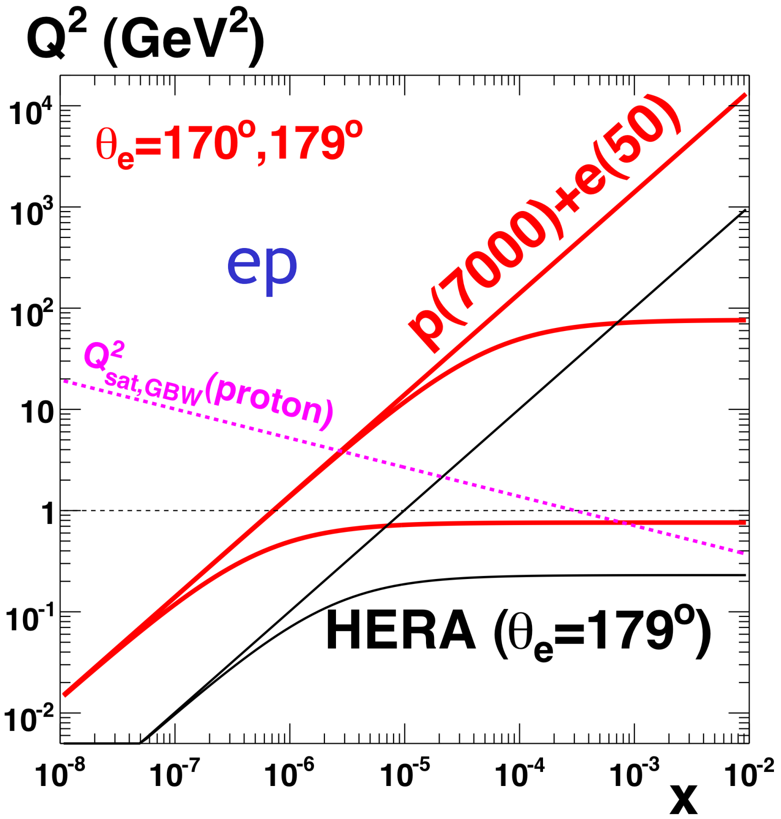
Forward Instrumentation from HERA via the LHC to the LHeC:

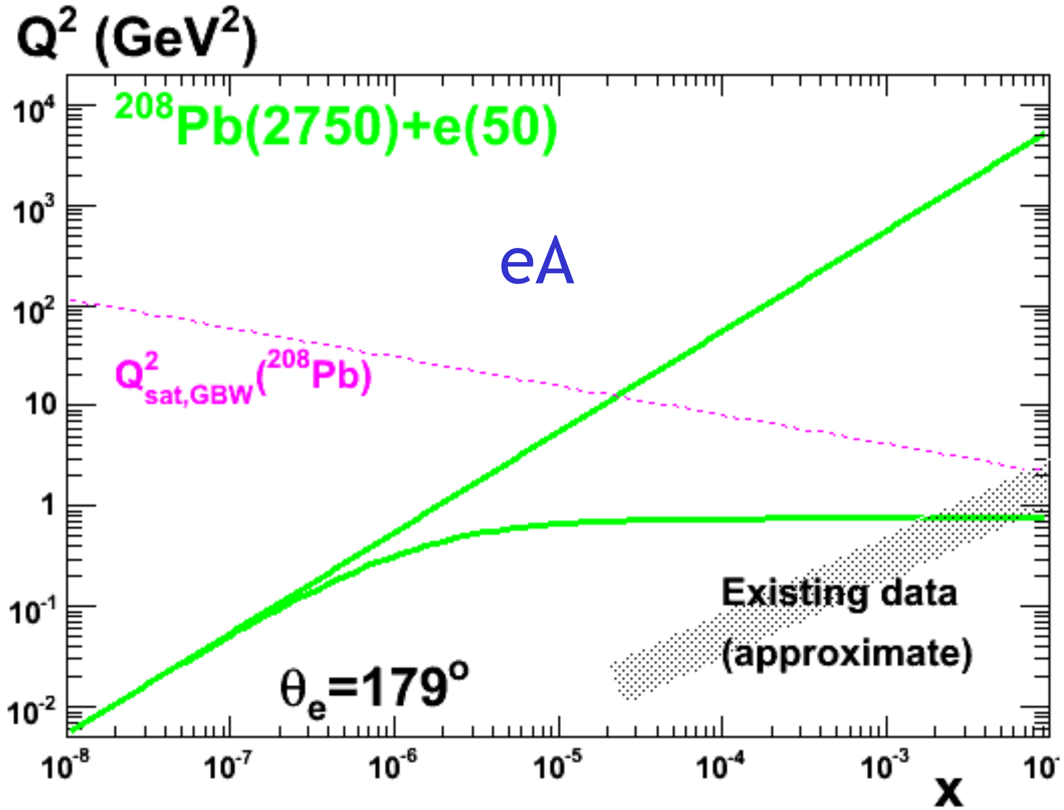
Paul Newman
(University of Birmingham)



1) Main LHeC detector
2) Acceptances of LHC Roman pots
3) LHeC leading protons and neutrons

LHeC Inclusive: Accessing low x at large Q^2

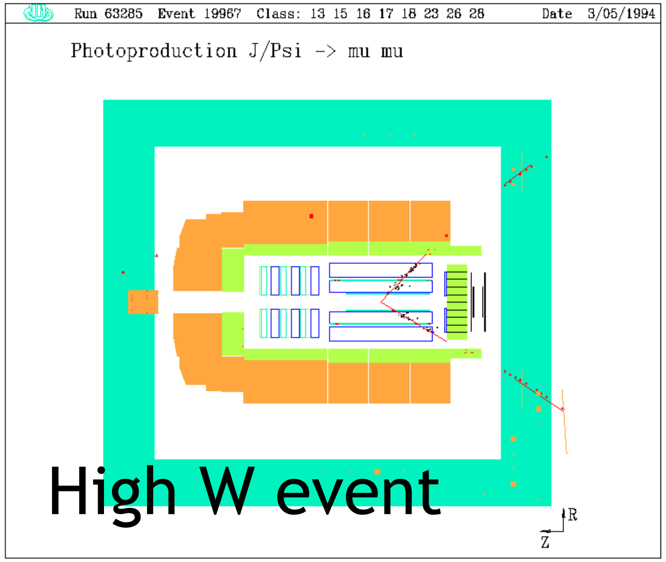


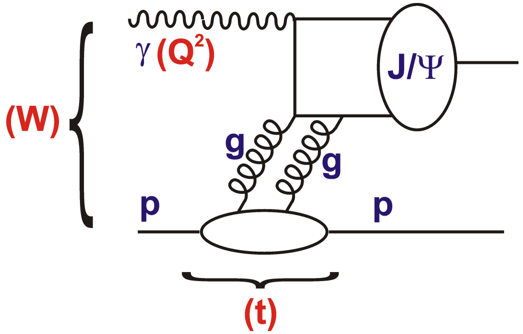


- Low x, Q^2 corner of phase space vital to LHeC QCD programme … accesses expected saturated region in both ep & eA at perturbative Q^2 according to models … but not by much!...

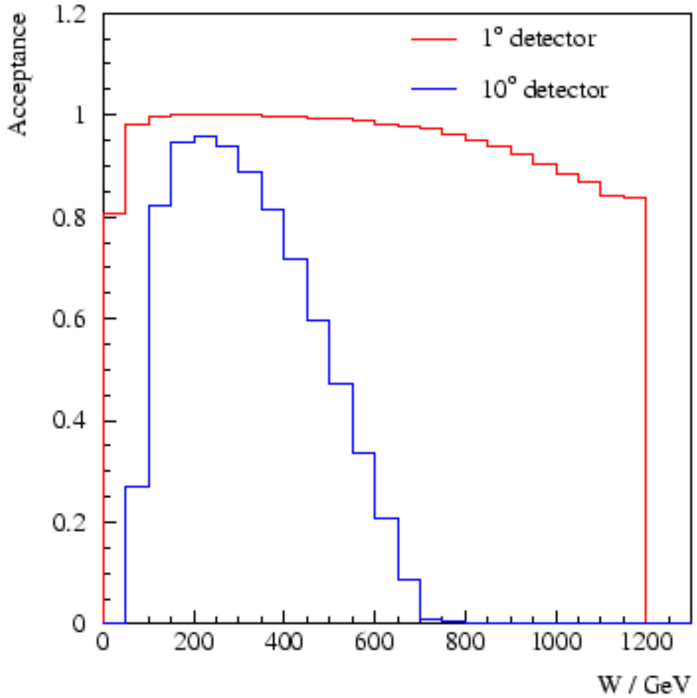
- Every degree of scattered electron acceptance is precious!

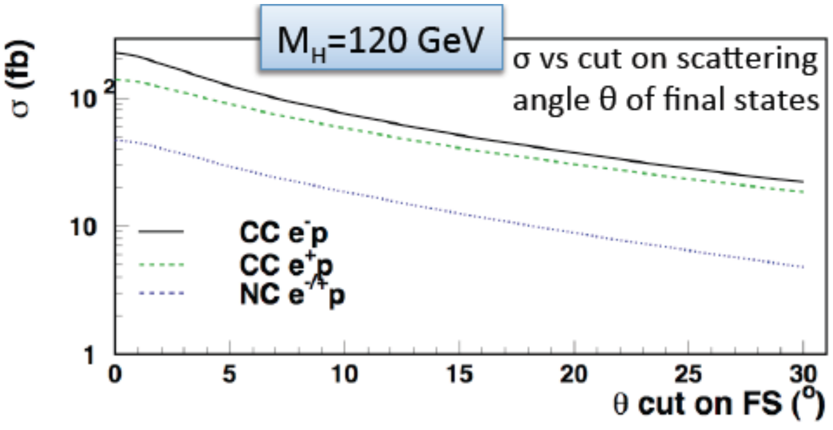
Acceptance Requirements, Final States



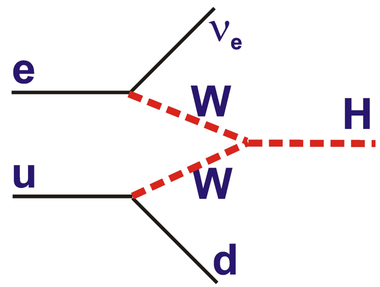


- Elastic J/Ψ Photoproduction



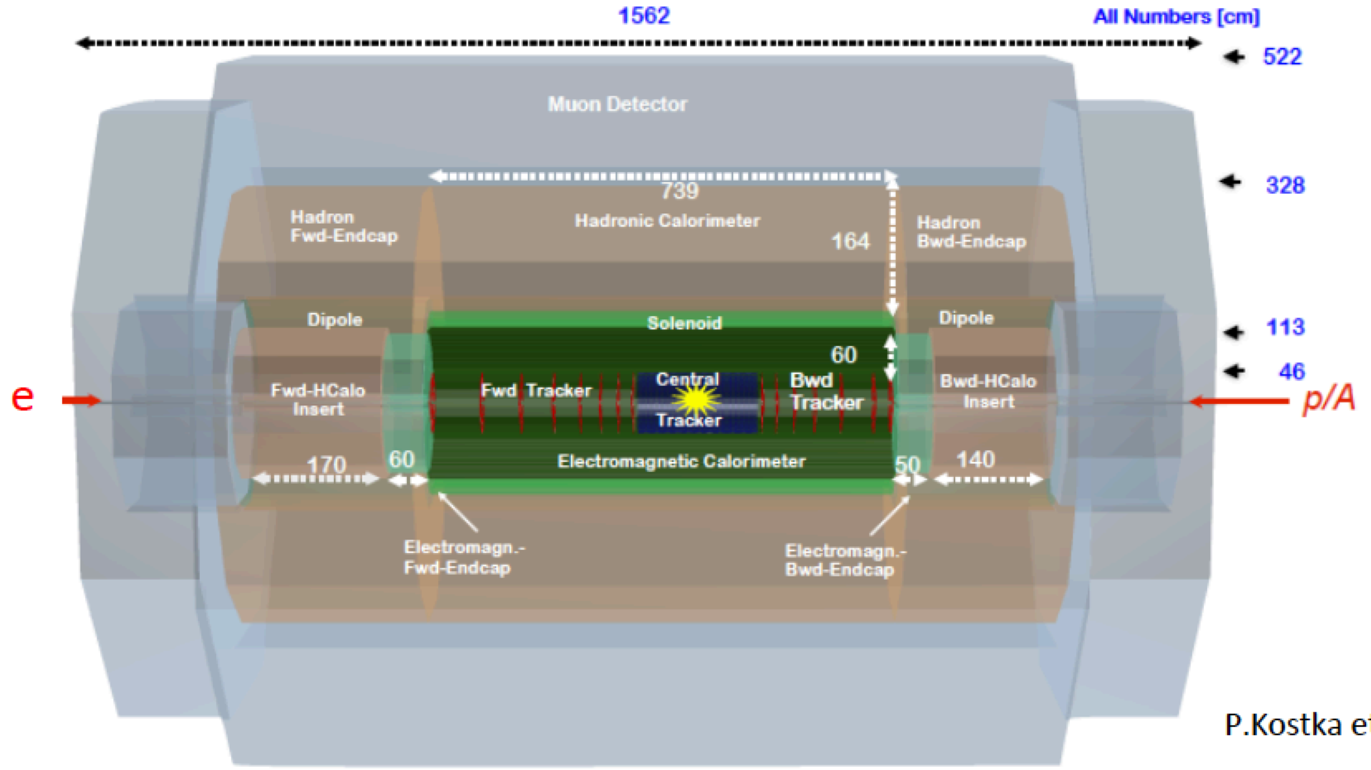


- Higgs Production

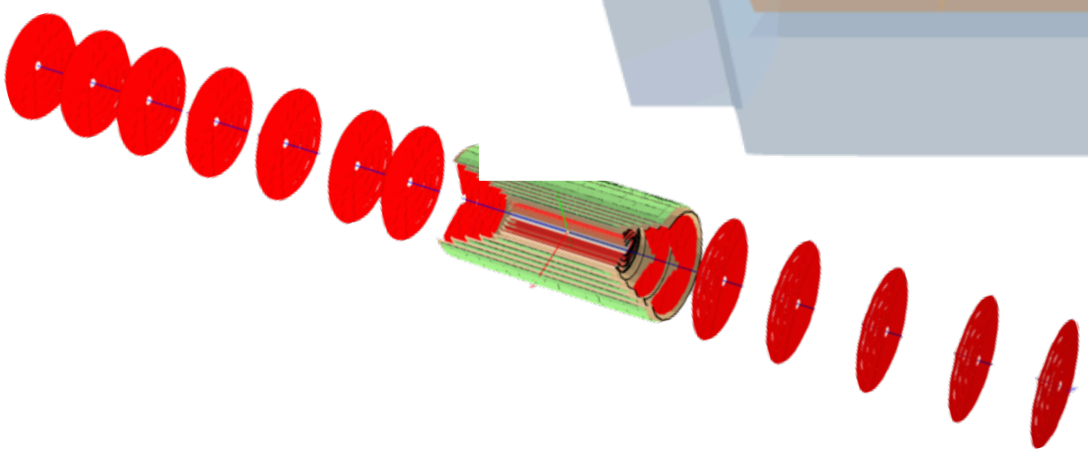


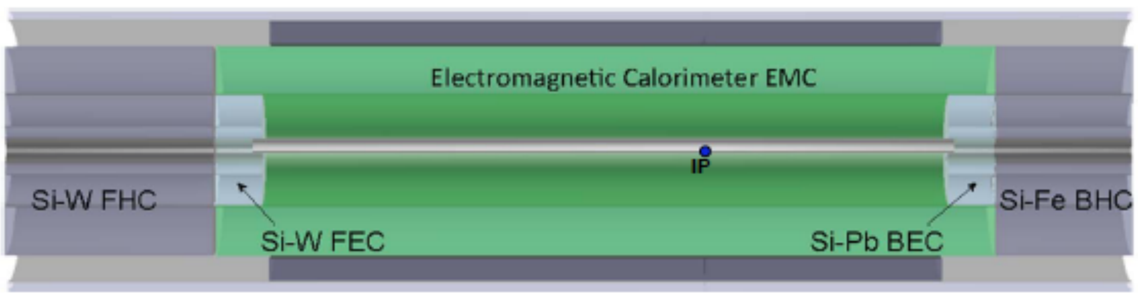
- Hadronic reconstruction as far forward as possible for low y kinematic reconstruction, forward jets etc …

Detector for LHeC



P.Kostka et al





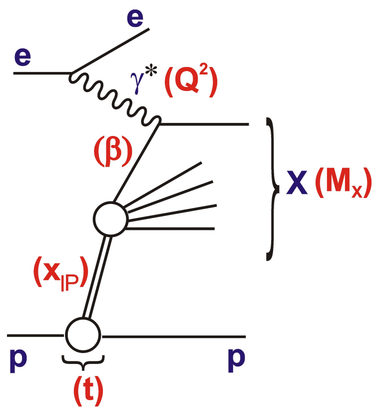
- Multiple silicon disks ensure good tracking performance down to small angles ~ 1°

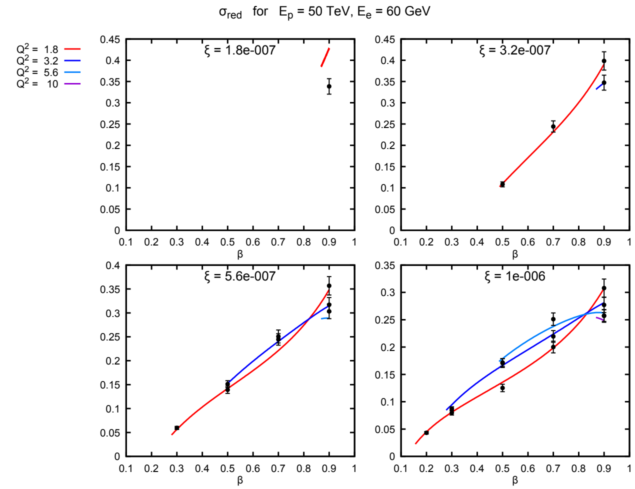
- Highly performant compact forward end-cap calorimeters

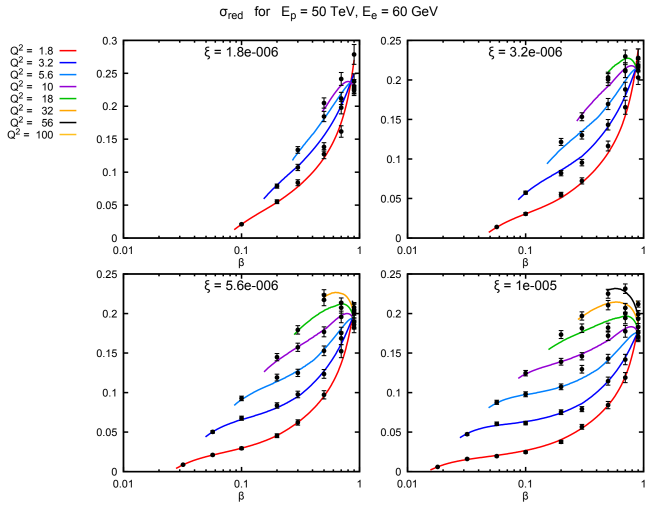
What we Dream of Measuring in Diffraction …

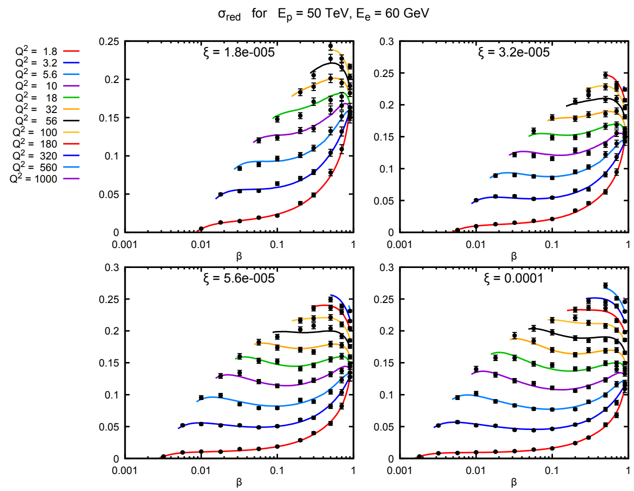
$\xi\ (=x_{IP}) = 1.8 \times 10^{-7}$

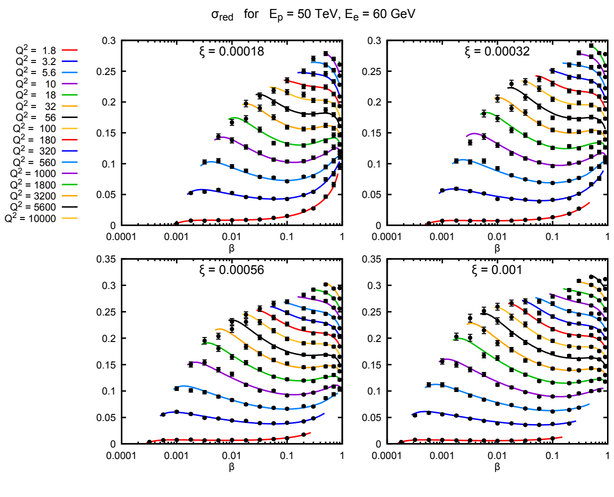
Simulated LHeC F_2^D data (Anna Stasto's talk) assumes full efficiency / acceptance

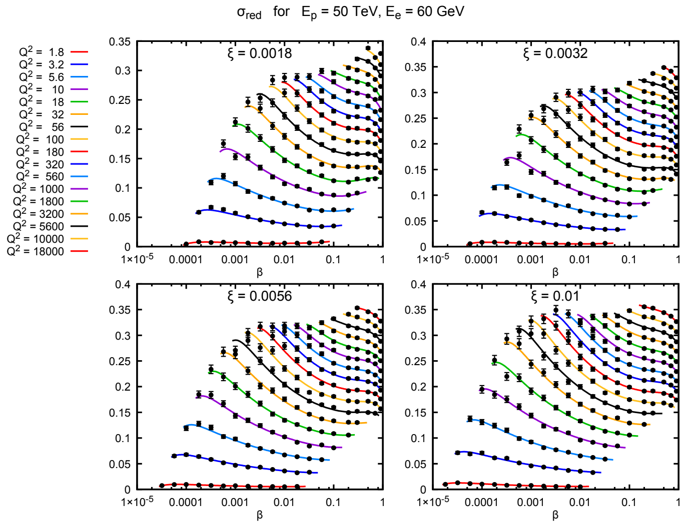


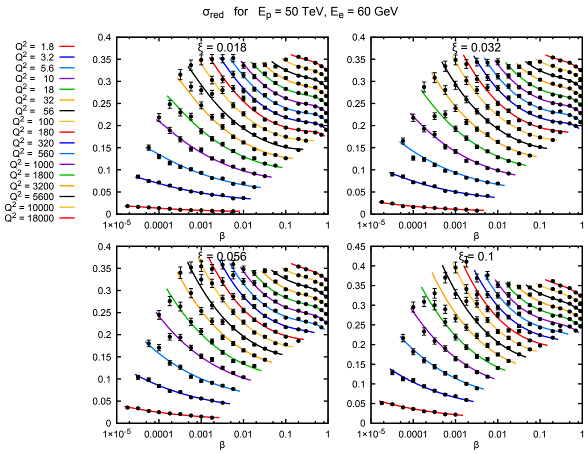












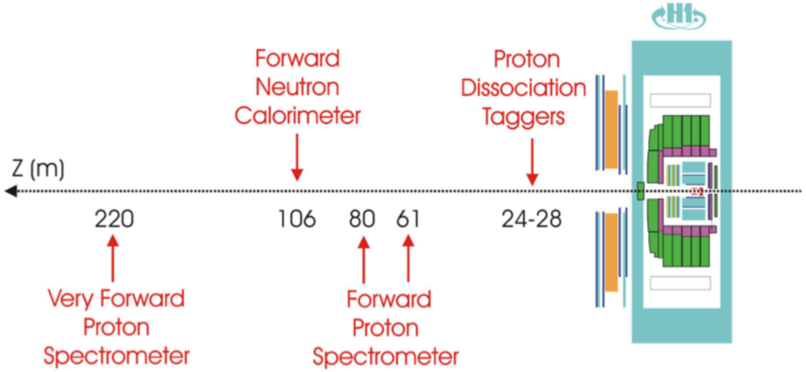
$\xi = 0.1$

Methods for Diffraction and Elastics

… old slide from diffraction at HERA

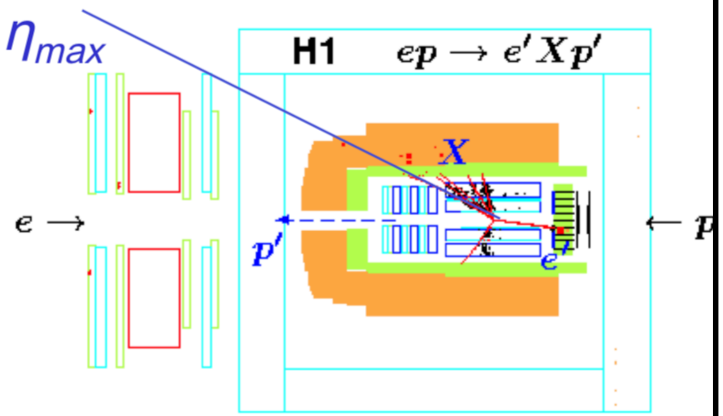
Signatures and Selection Methods

Scattered proton in Leading Proton Spectrometers **(LPS)**



Limited by statistics and p-tagging systematics

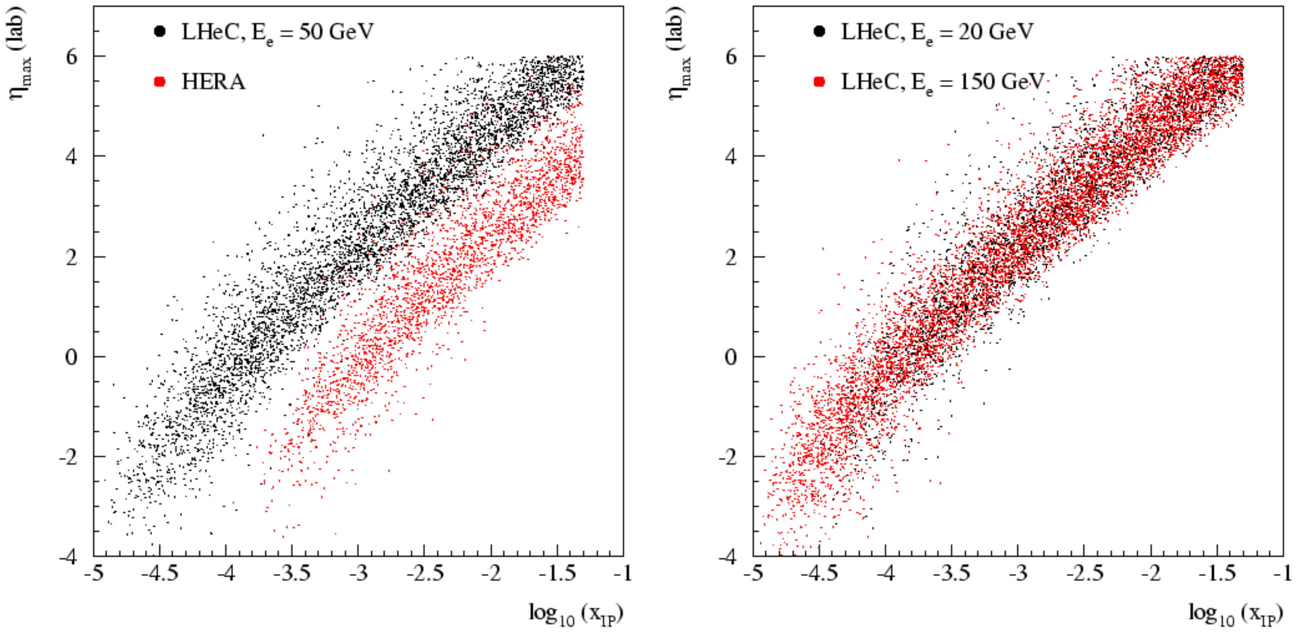
\`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton

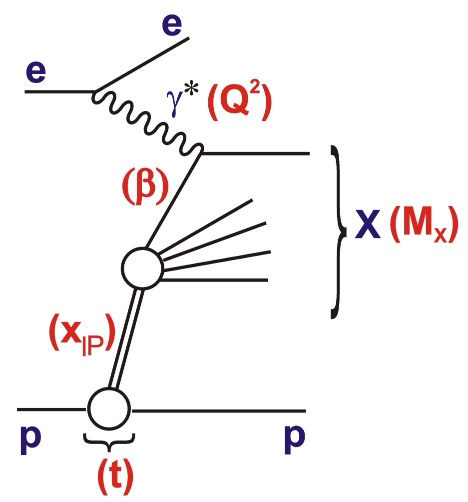


Limited by p-diss systematics

Partially still true for LHeC (but proton tagging technology got better and kinematics make rapidity gap methods harder)

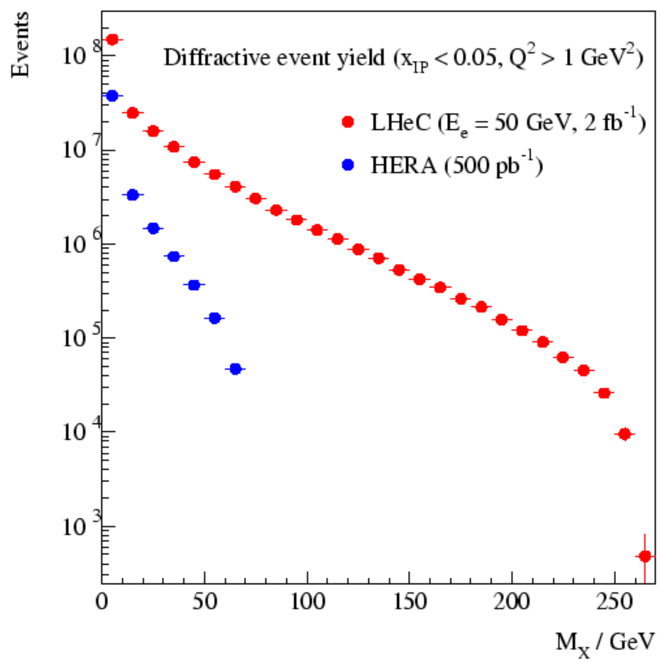
Rapidity Gap Selection with LHeC Kinematics





– η_{max} v ξ (= x_{IP}) correlation determined entirely by proton beam energy …
[Recurring theme … LHeC is like LHC …]

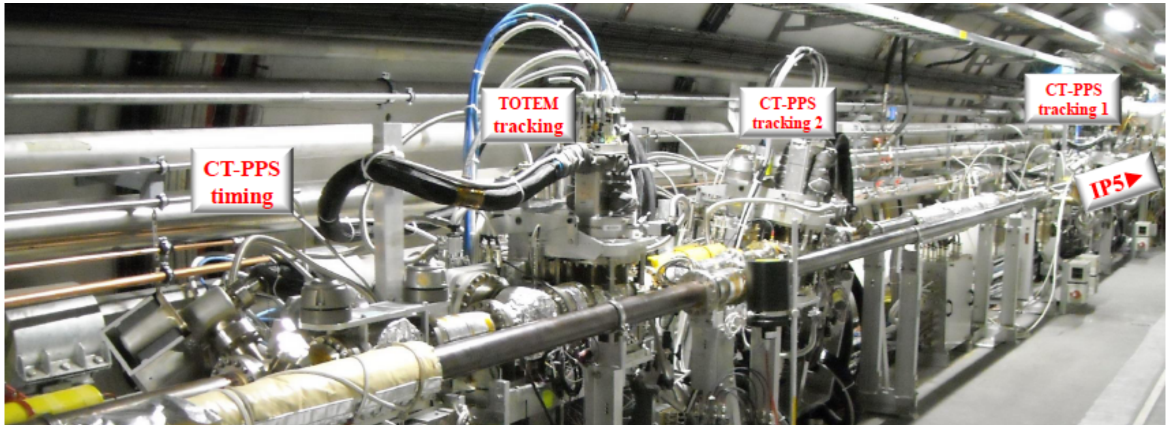
- LHeC cut around η_{max} ~ 3 selects events with x_{IP} <~ 10^{-3} (cf x_{IP} <~ 10^{-2} at HERA), but misses lots of diffractive physics at largest dissociation masses, M_X

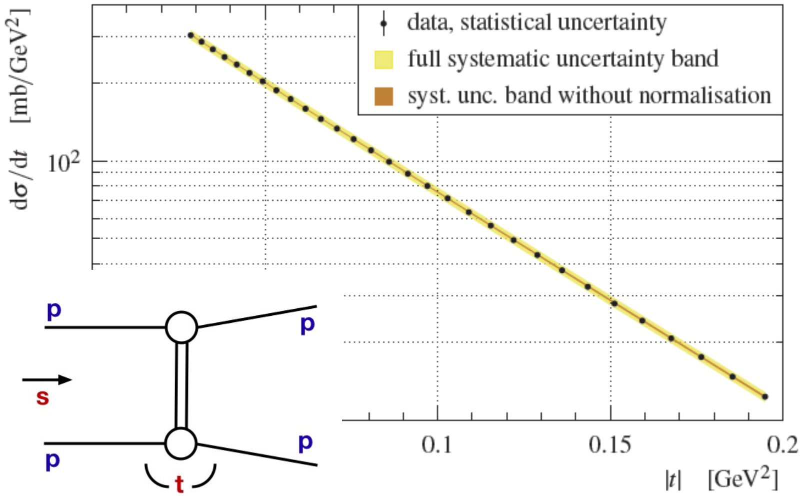


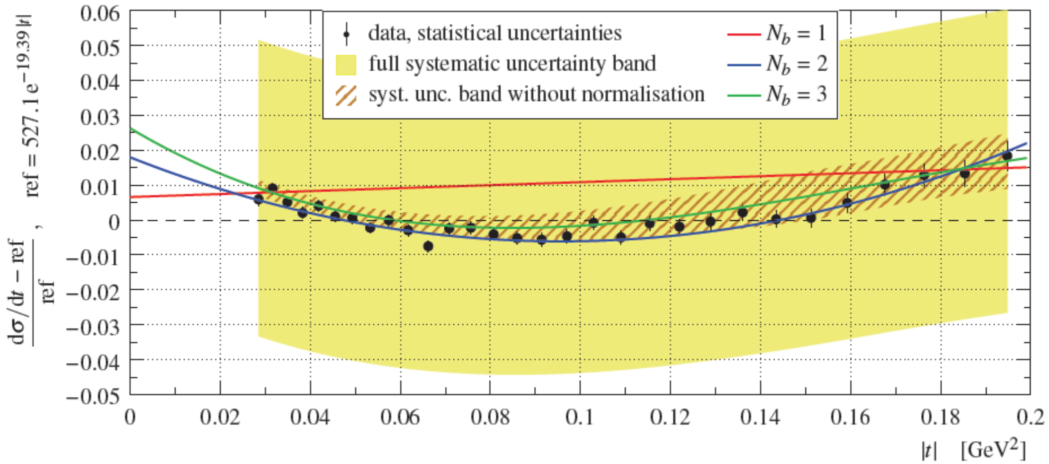
Proton Spectrometers Come of Age

LHC experiments (TOTEM, ALFA@ATLAS) have shown that it's possible to make precision measurements and cover wide kinematic range with Roman pots.
e.g. TOTEM currently operates 14 pots

→Sensitivity to subtle new effects eg non-exponential term in elastic t dependence …

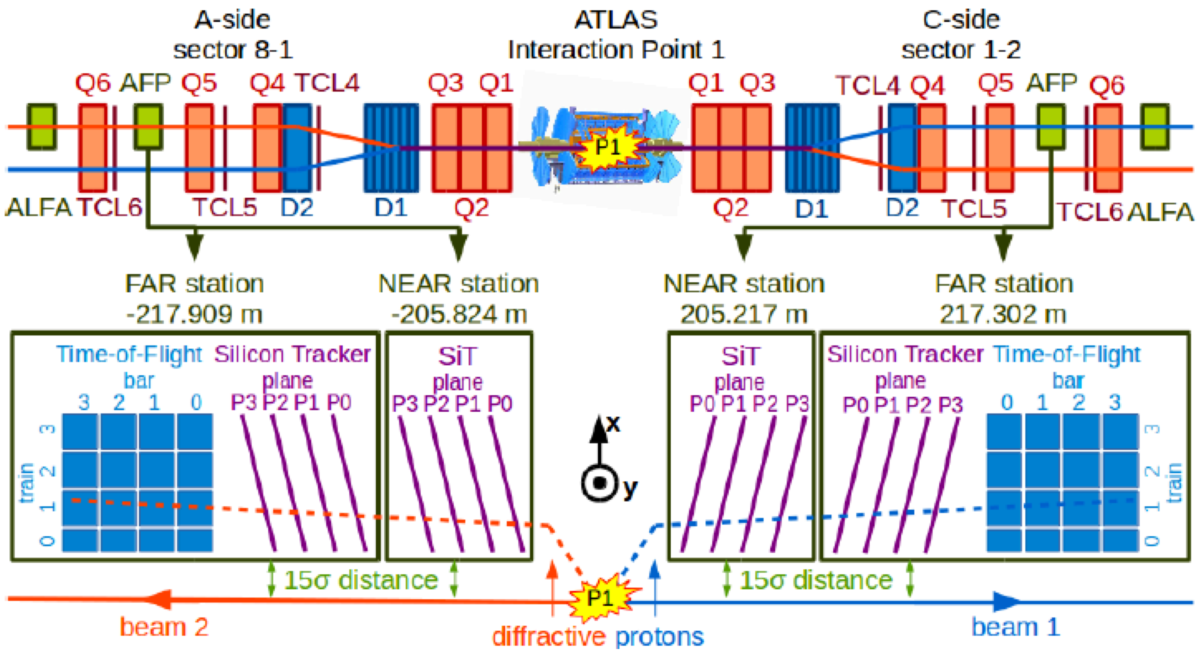






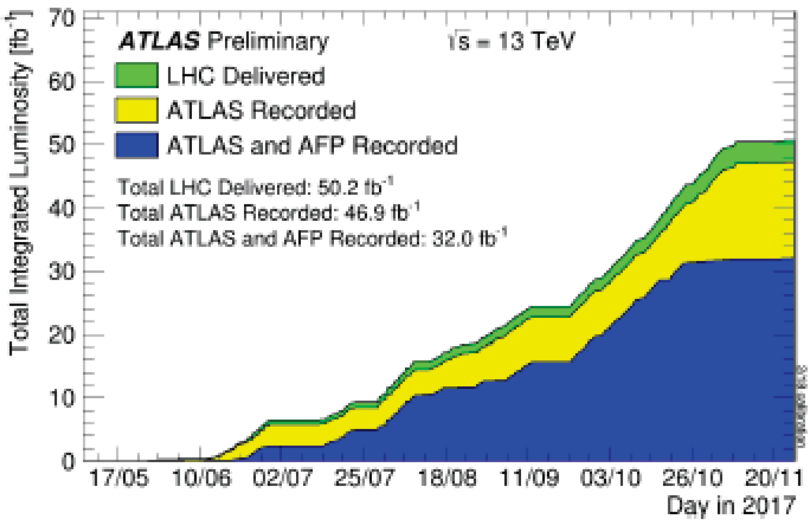
Second Generation LHC Proton Spectrometers (CT-PPS at CMS and AFP at ALFA)

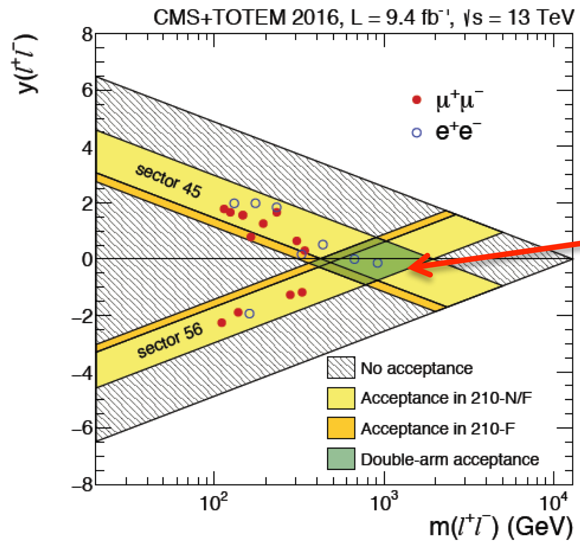
AFP
@
ATLAS

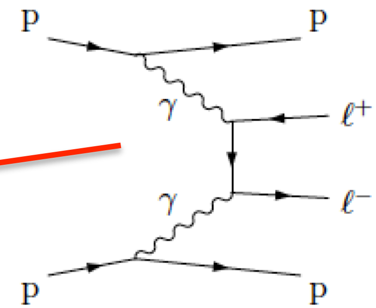


Now routinely operating in standard LHC running conditions

Transforms physics programme …



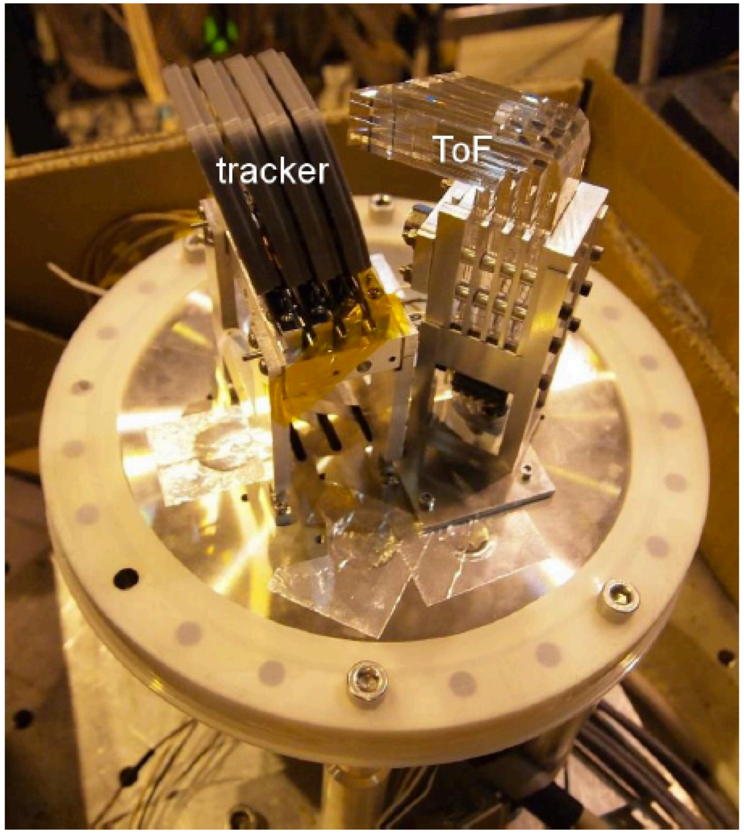


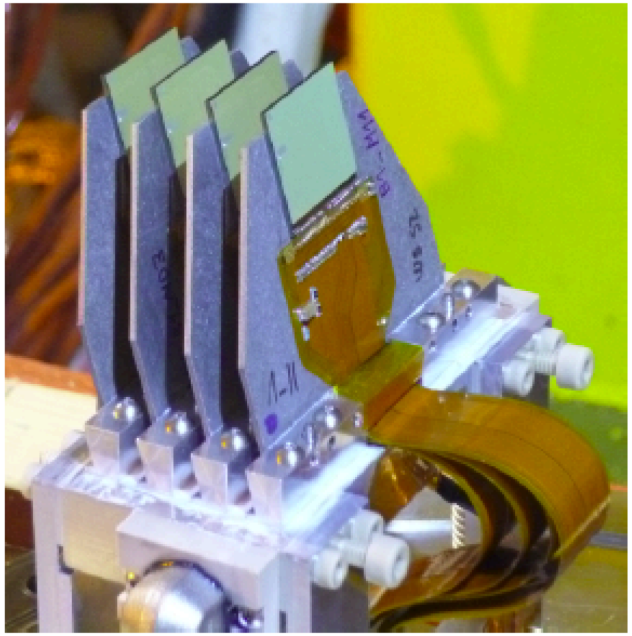


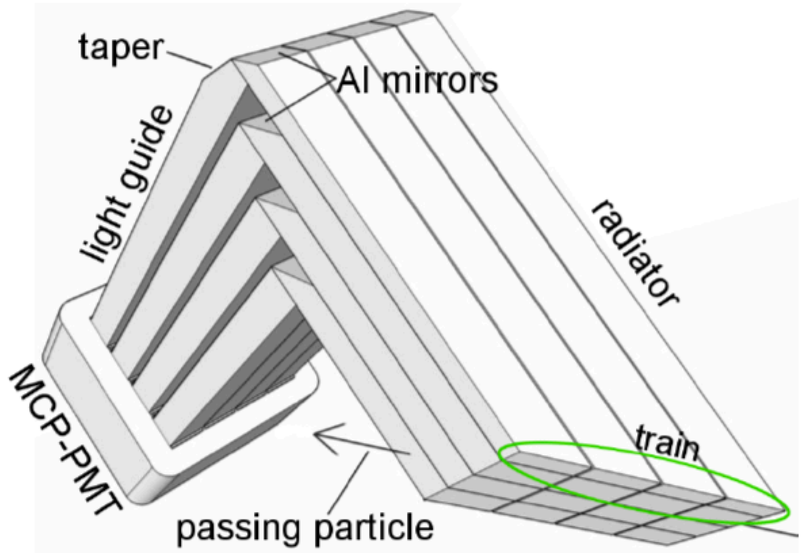
AFP Detectors

Tracking: four slim-edge 3D pixel sensor planes per station (IBL)
- Pixel sizes 50x250 μm
- 14^o tilt improves x resolution (hence ξ)
  → δx = 6 μm, δy = 30 μm
- Trigger capability

Timing: 4x4 quartz bars at Cerenkov angle to beam. Light detected in PMTs
→ expected resolution 25ps



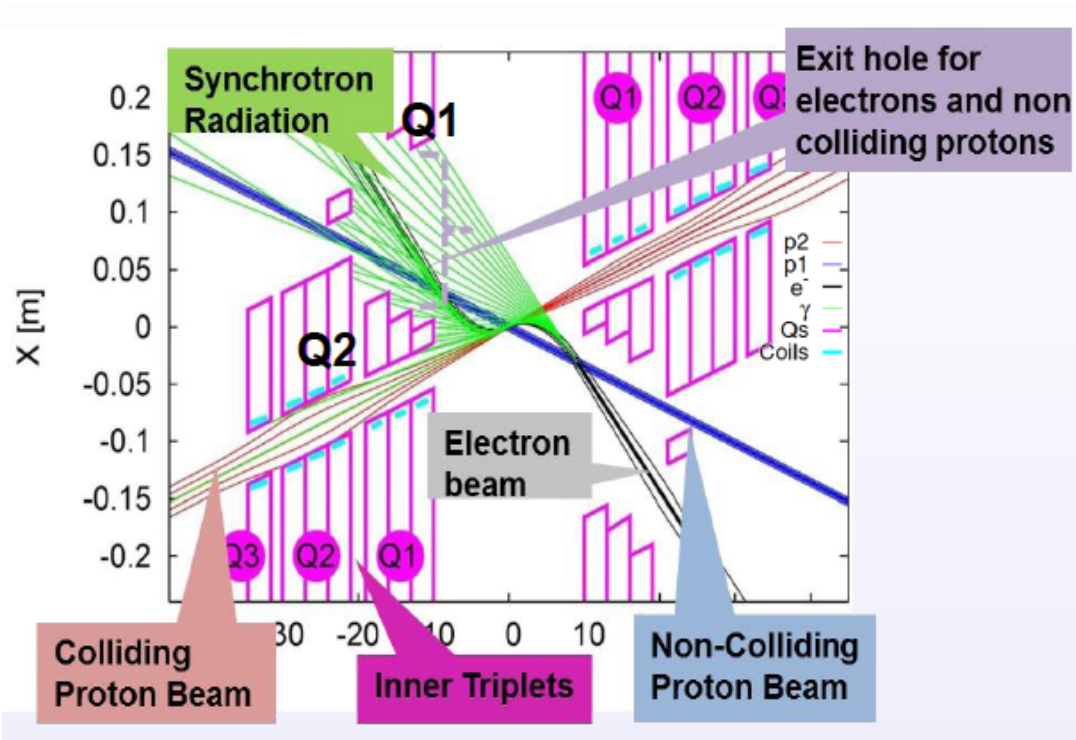




So … Can we have full acceptance for scattered protons with lots of pots?

- Locations of pots restricted by beam elements
- Scattered proton trajectories blocked by collimators etc
- Sensitive detectors can’t approach arbitrarily close to beam

[ATLAS and CMS/TOTEM Roman pot groups work closely with machine group to find acceptable optics year on year …]



[LHeC interaction region]

What Determines AFP Acceptance?

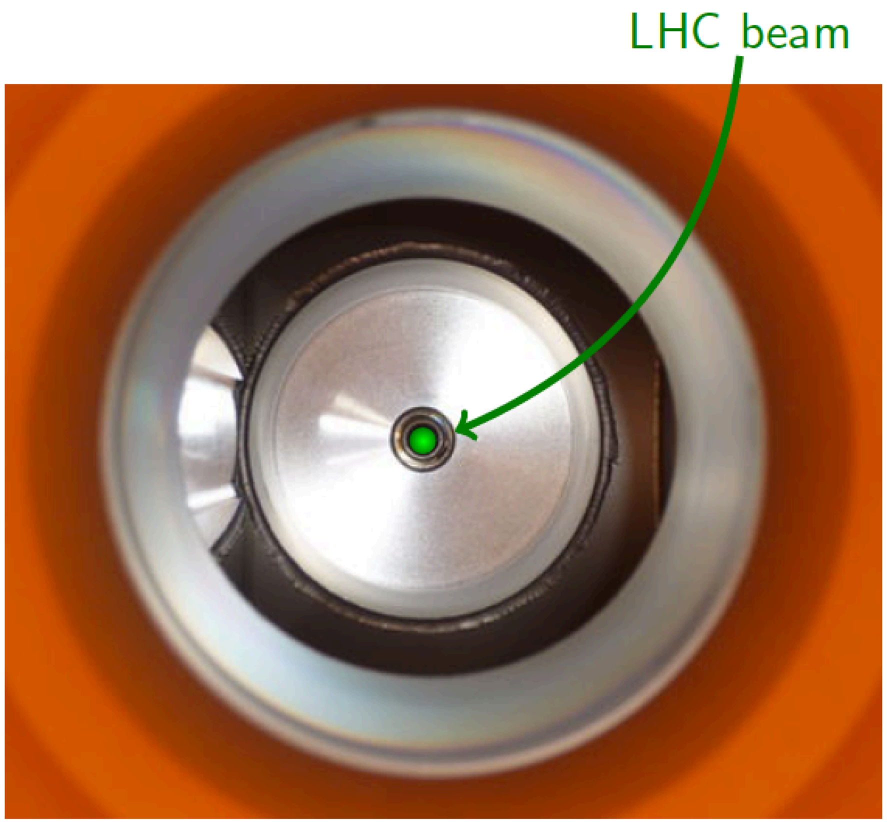
Advantages of Roman Pot Technology

M. Trzebiński AFP Detectors 4/21

[a nice illustration, from AFP, with thanks to Maciej Trzebinski]

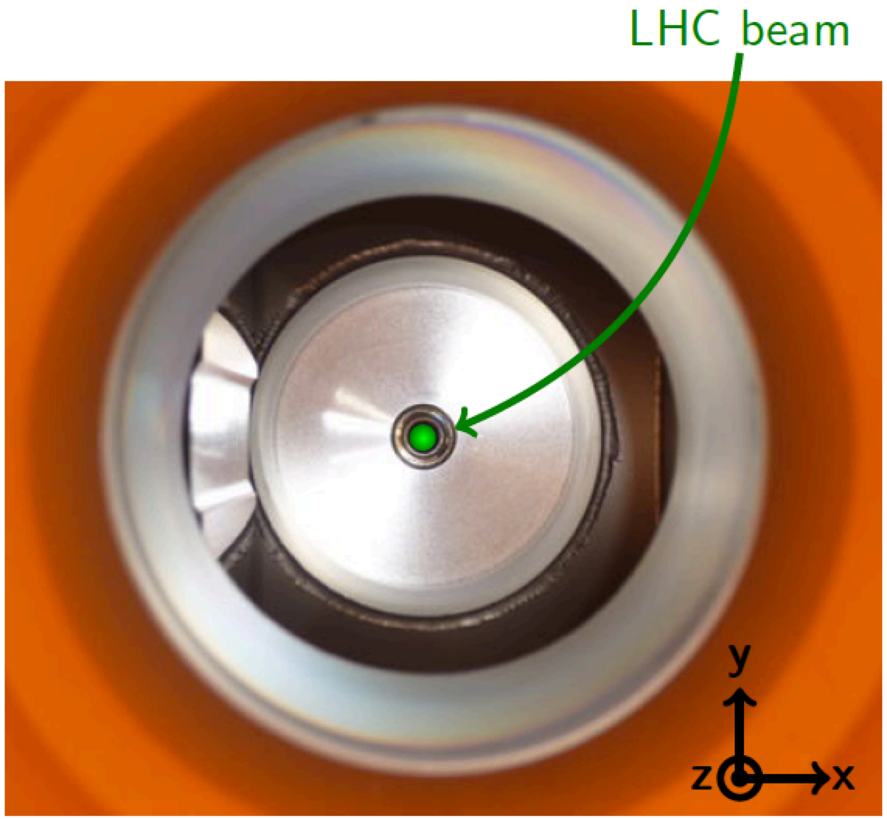
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



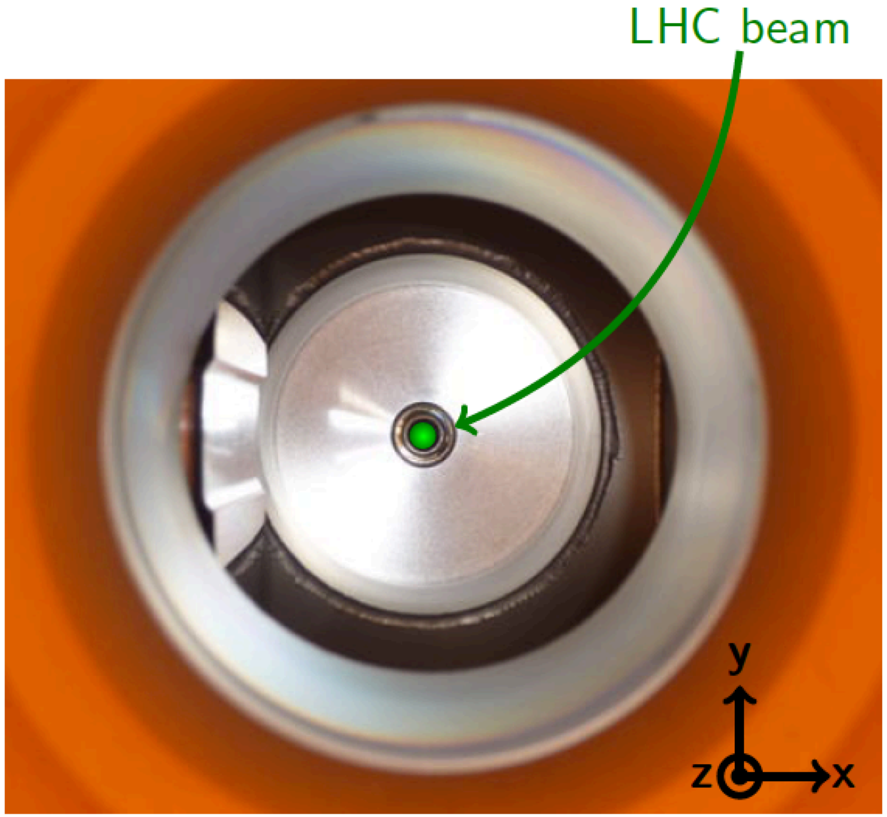
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



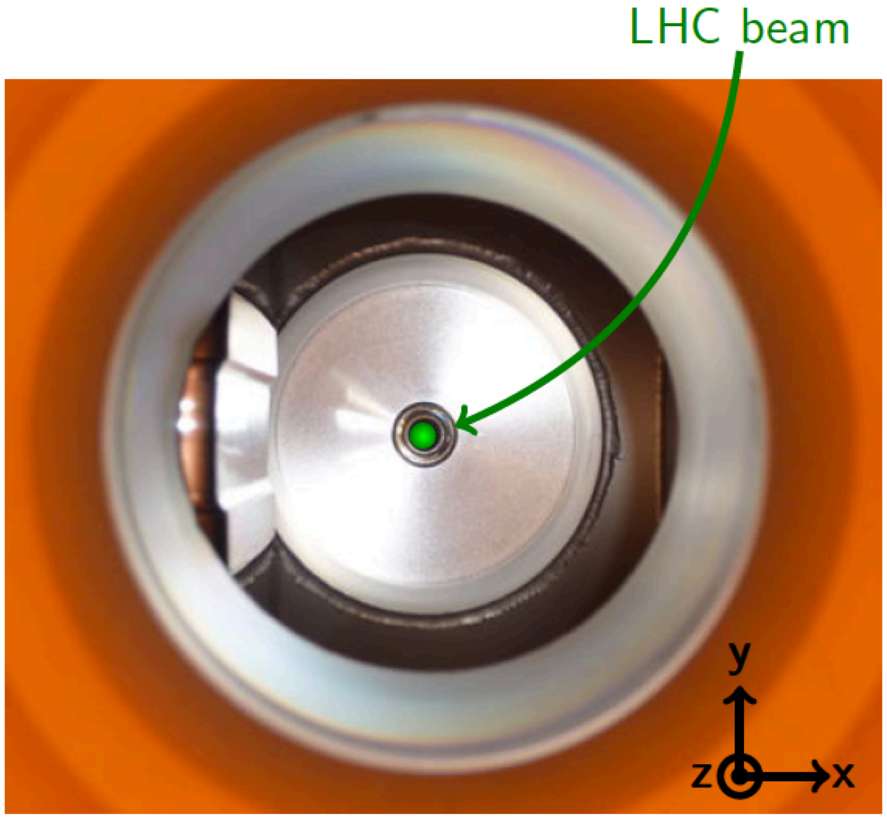
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



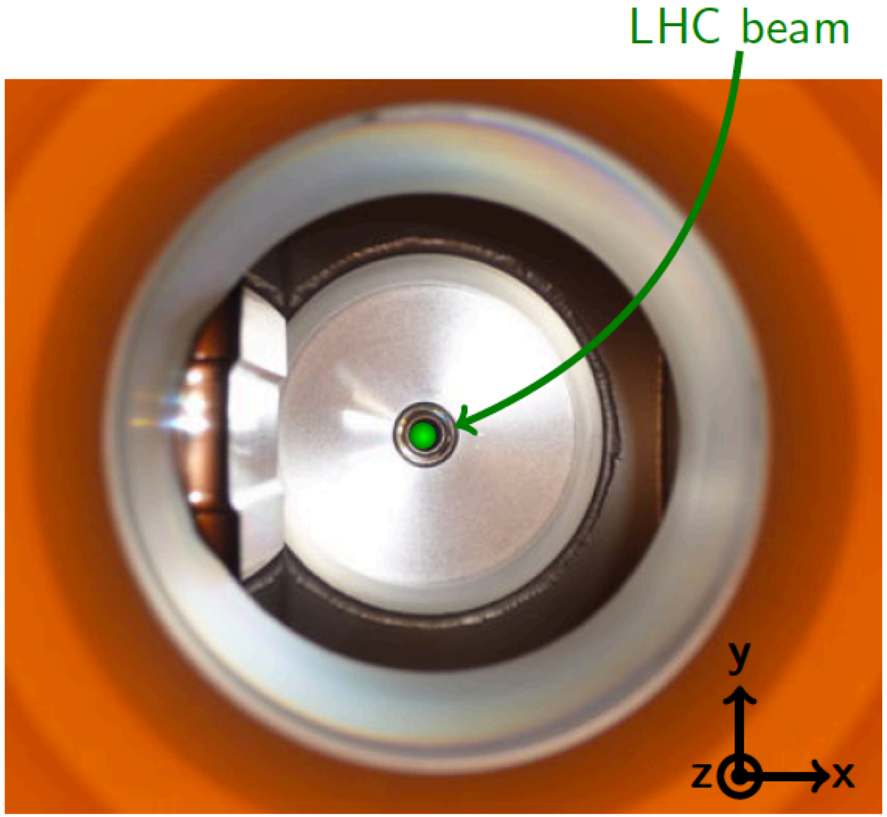
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



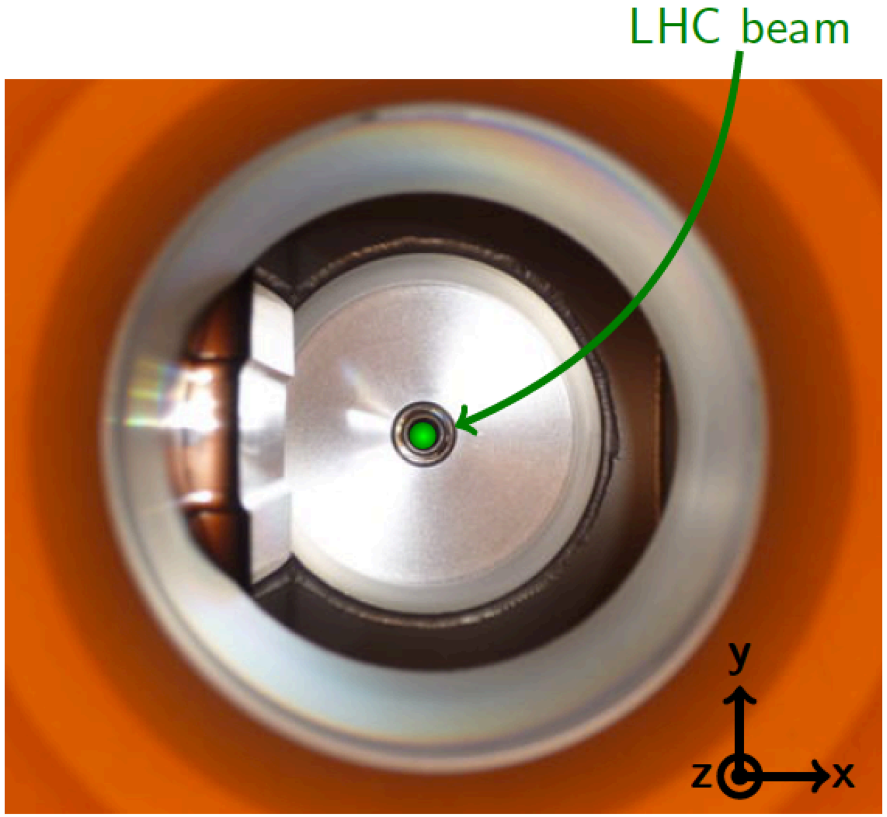
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



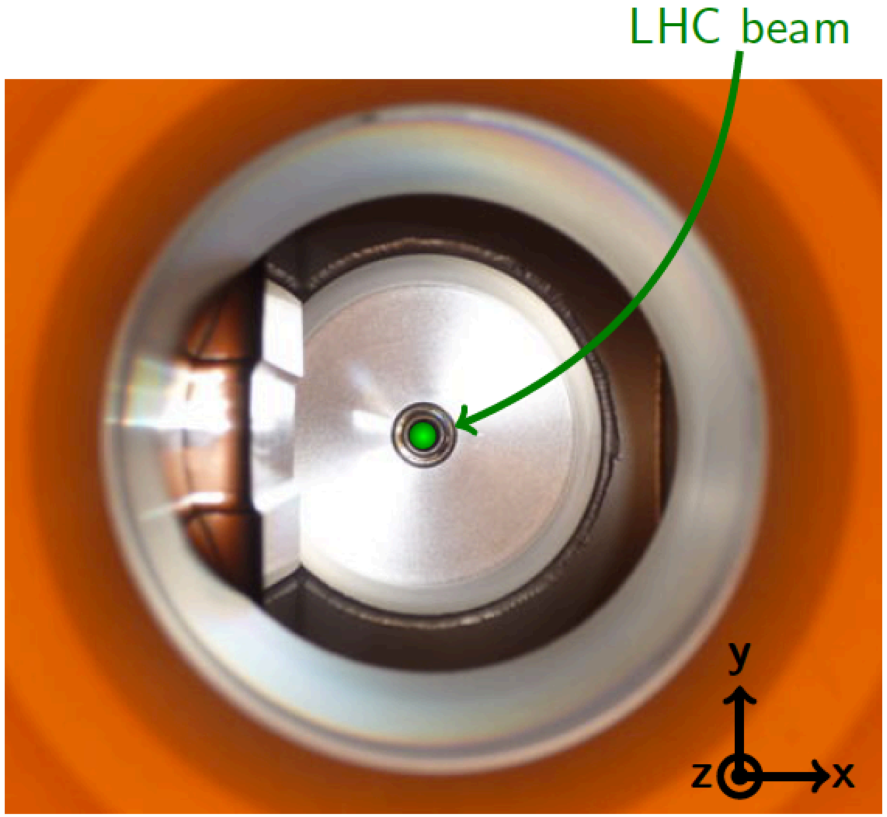
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



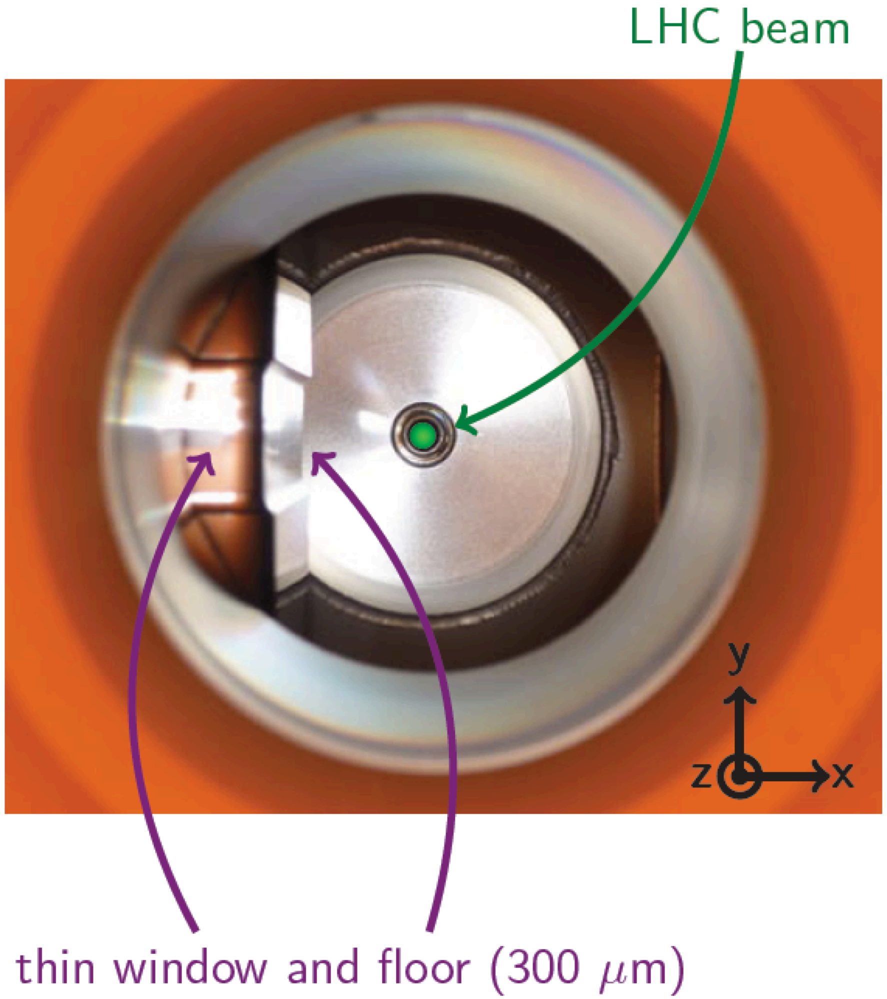
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



What Determines AFP Acceptance?

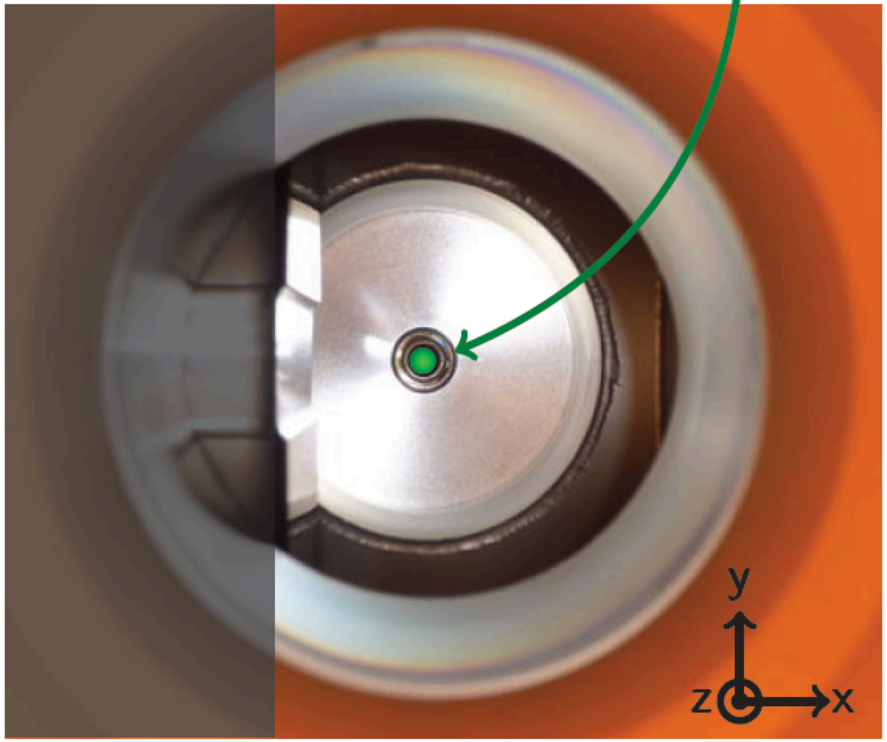
Advantages of Roman Pot Technology



What Determines AFP Acceptance?

Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators



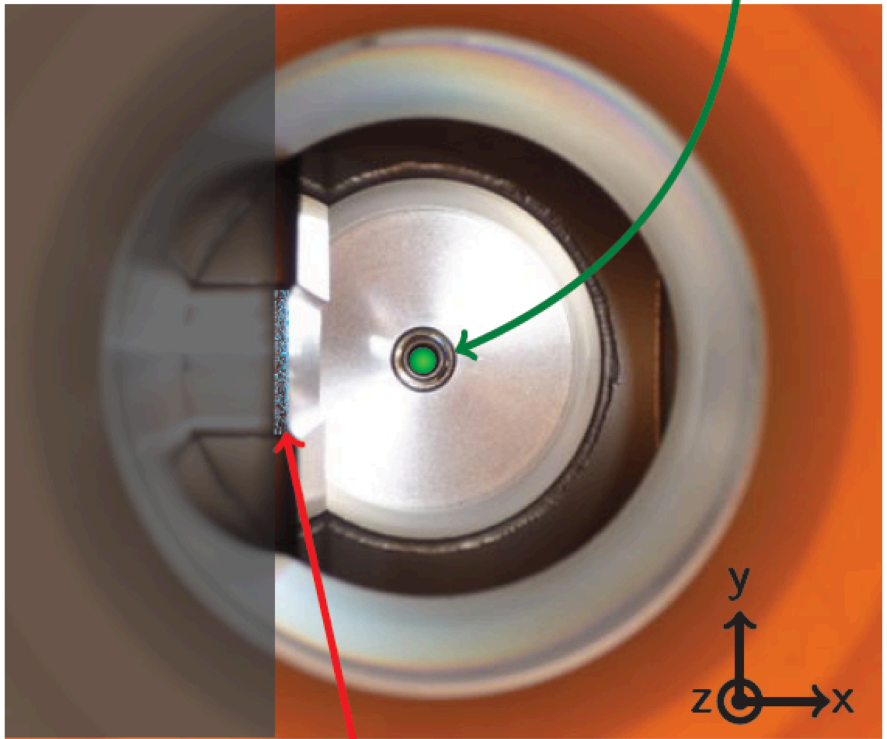
thin window and floor (300 μm)

What Determines AFP Acceptance?

Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

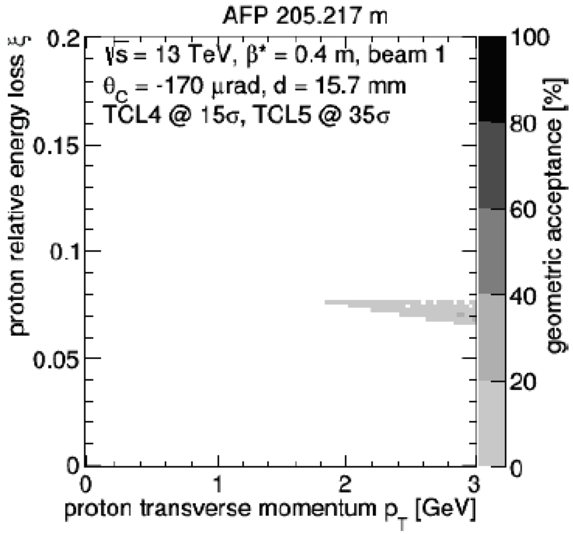
LHC beam



diffractive protons

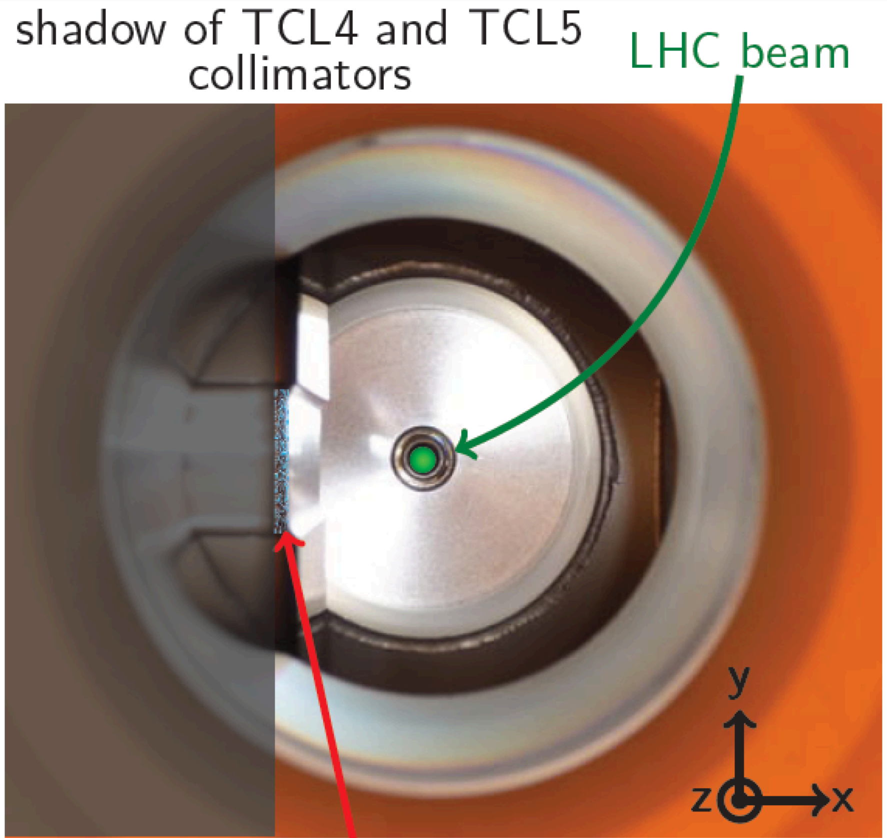
thin window and floor (300 μm)

Geometric acceptance:

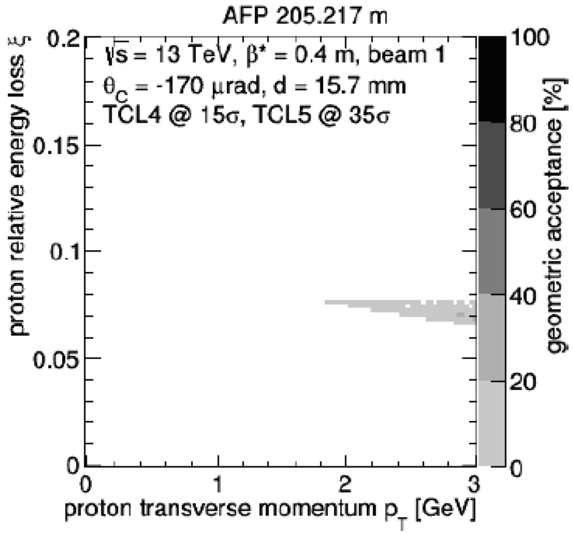


What Determines AFP Acceptance?

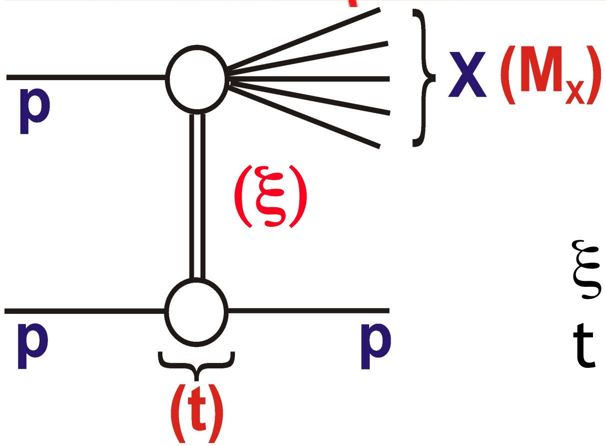
Advantages of Roman Pot Technology



Geometric acceptance:



Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

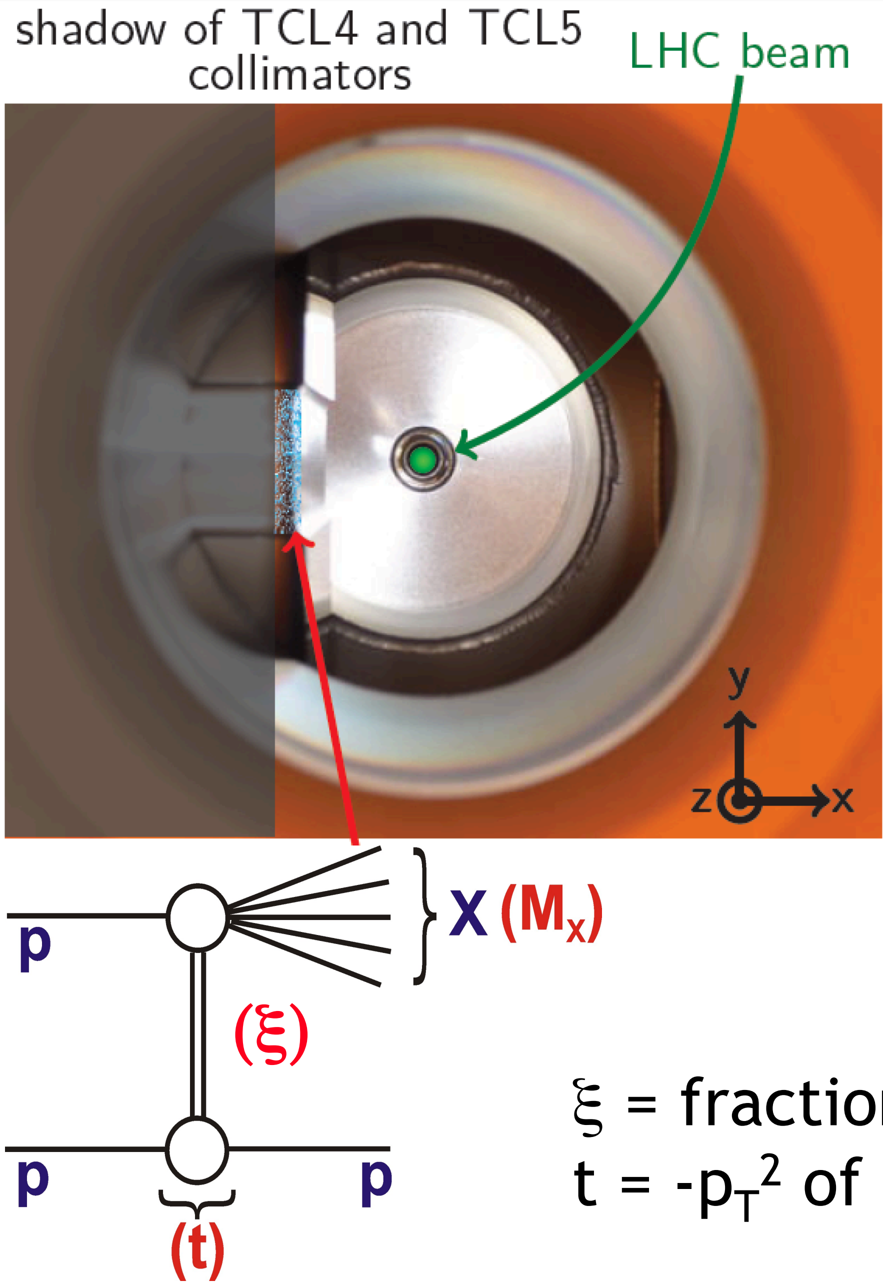


ξ = fractional proton energy loss

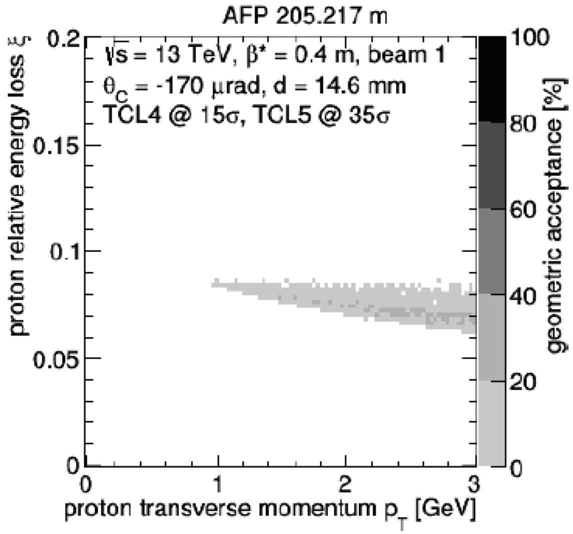
$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?

Advantages of Roman Pot Technology



Geometric acceptance:



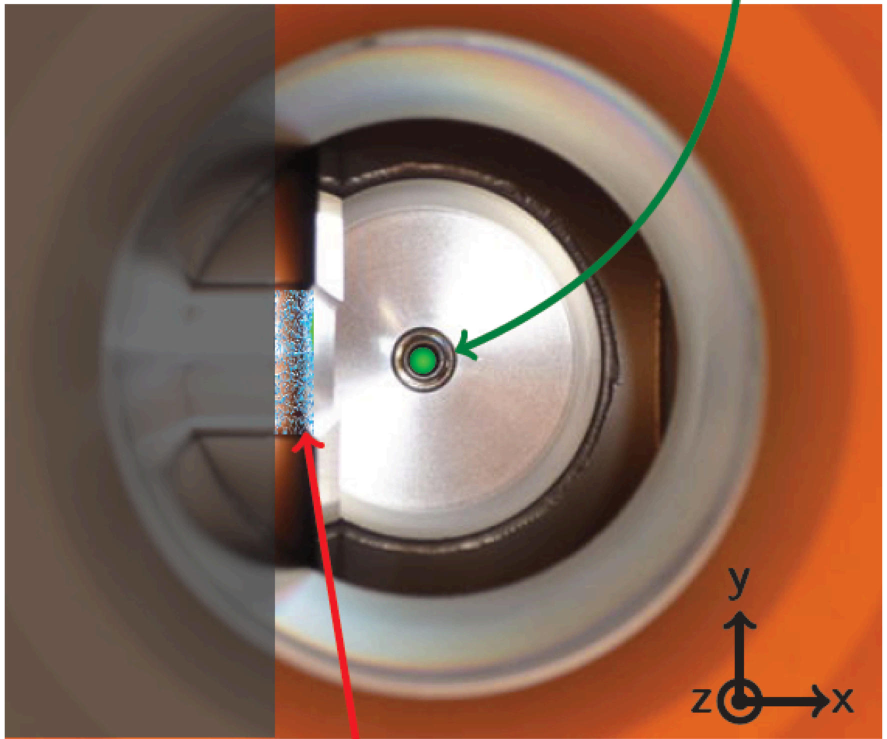
Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

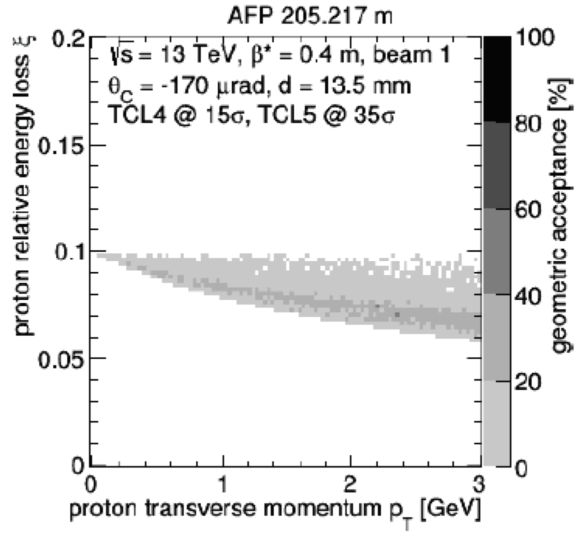
$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?

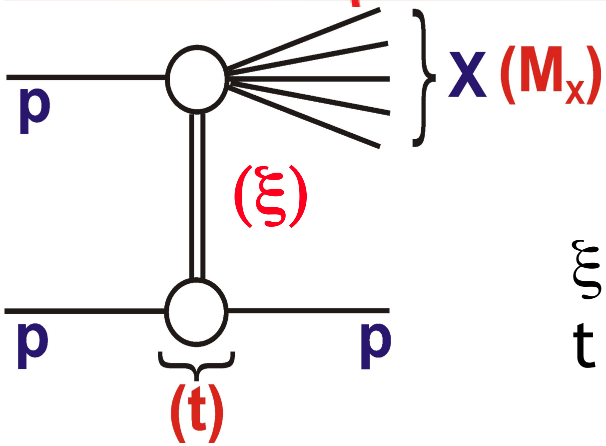
Advantages of Roman Pot Technology



Geometric acceptance:



Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)



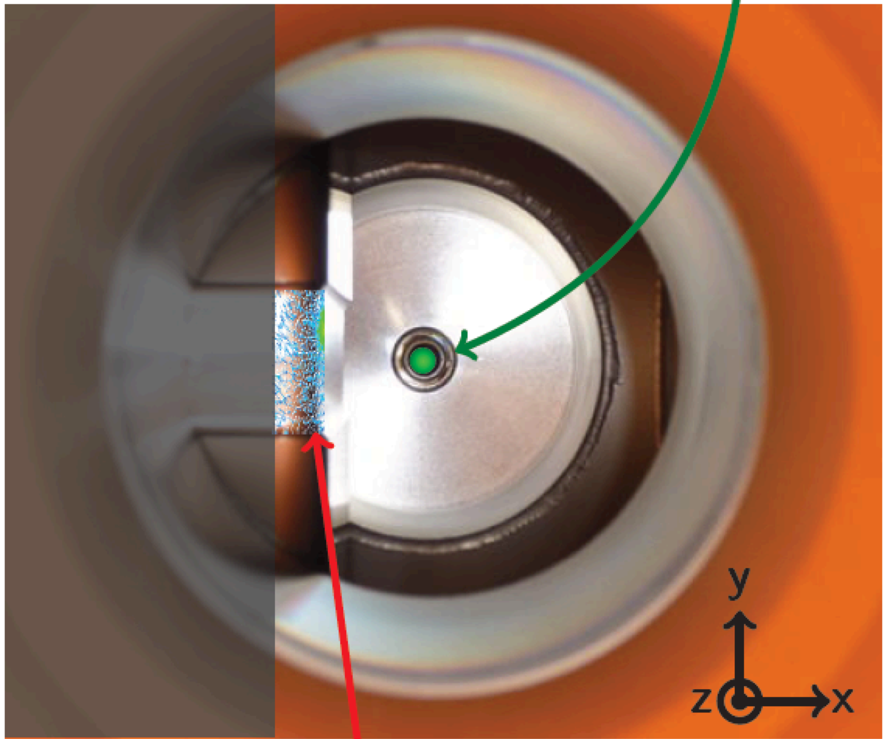
ξ = fractional proton energy loss

$t = -p_T^2$ of outgoing proton

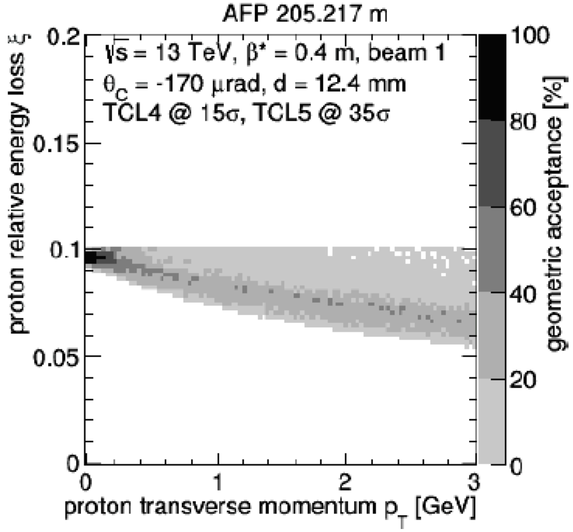
What Determines AFP Acceptance?

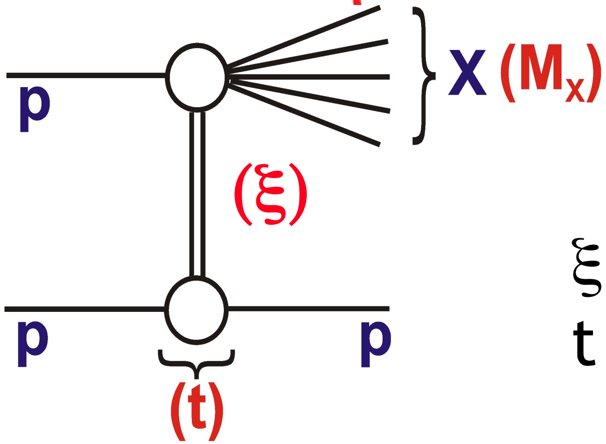
Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators



Geometric acceptance:





Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

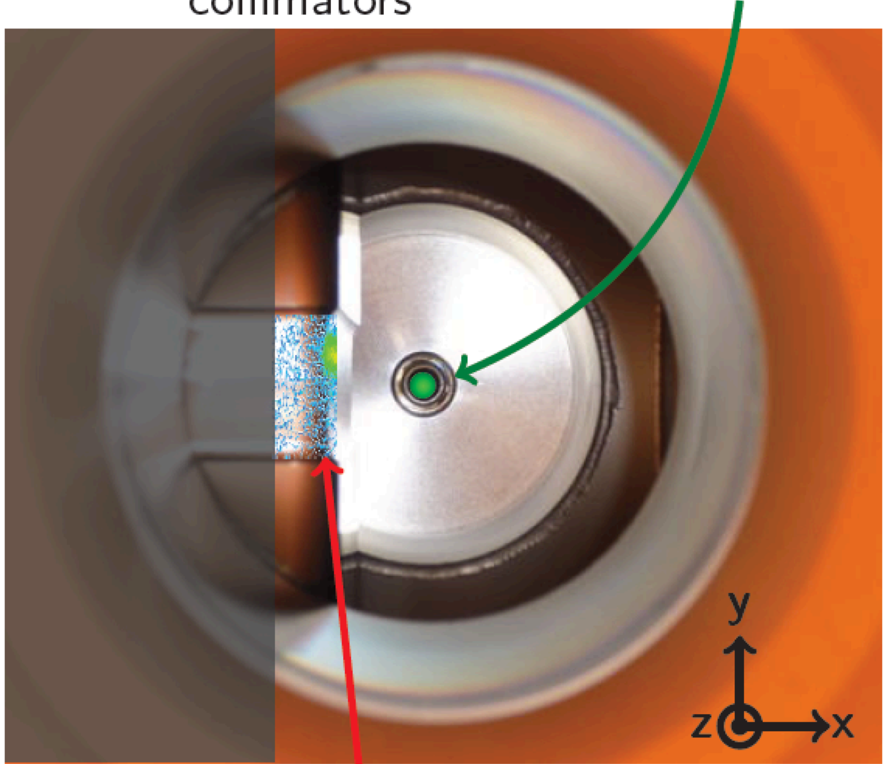
ξ = fractional proton energy loss

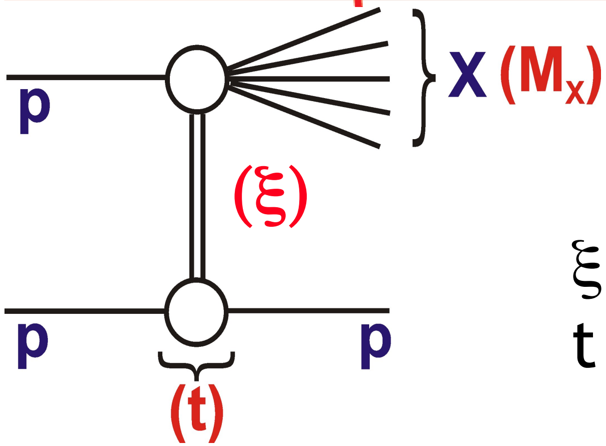
$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?

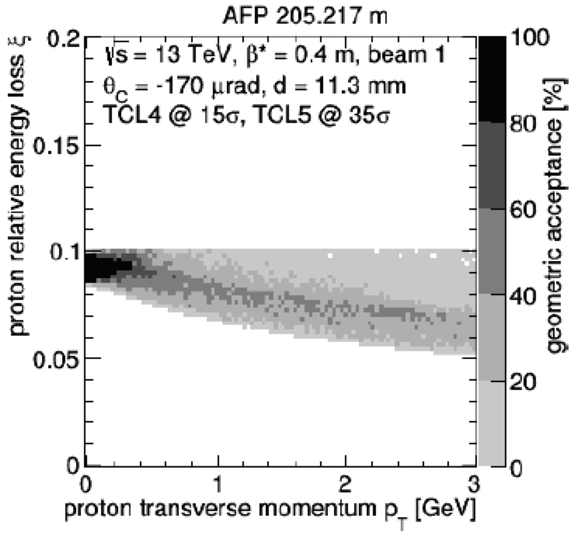
Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators





Geometric acceptance:



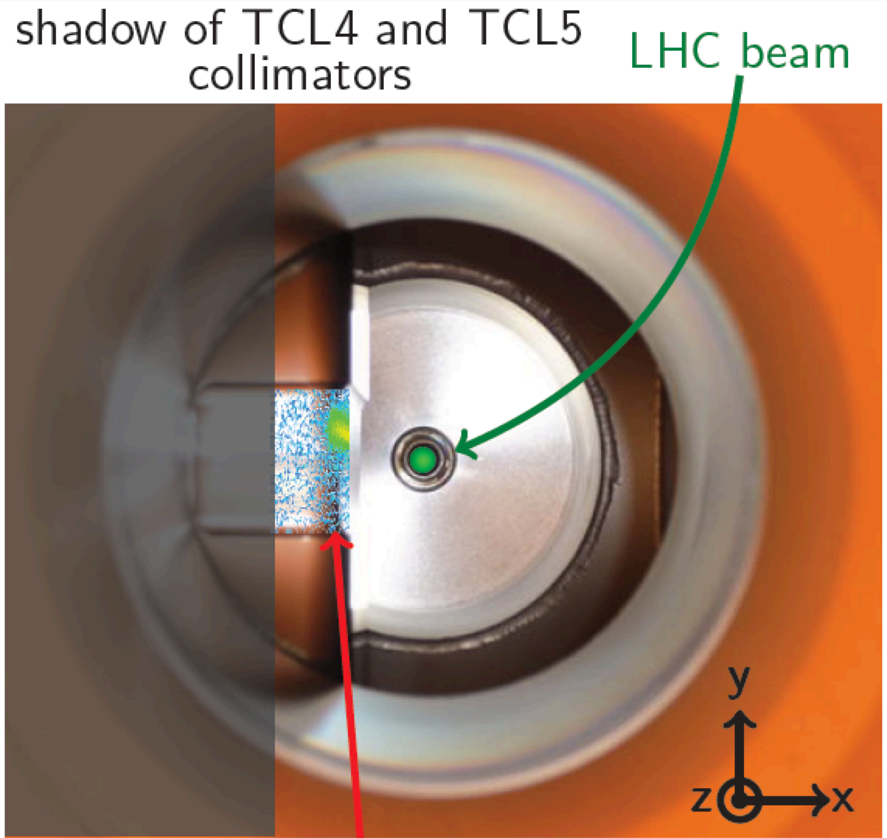
Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

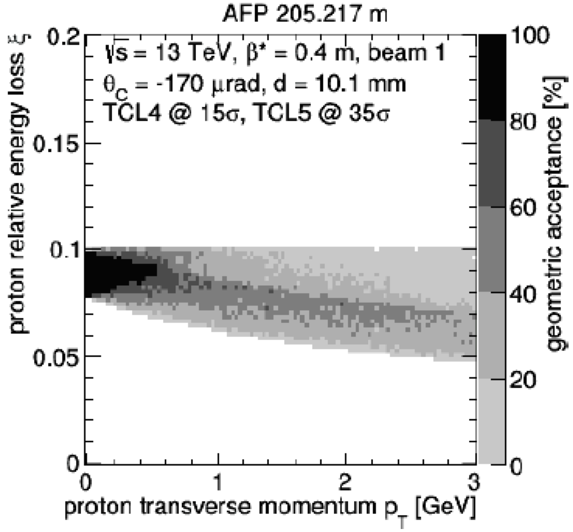
$t = -p_T^2$ of outgoing proton

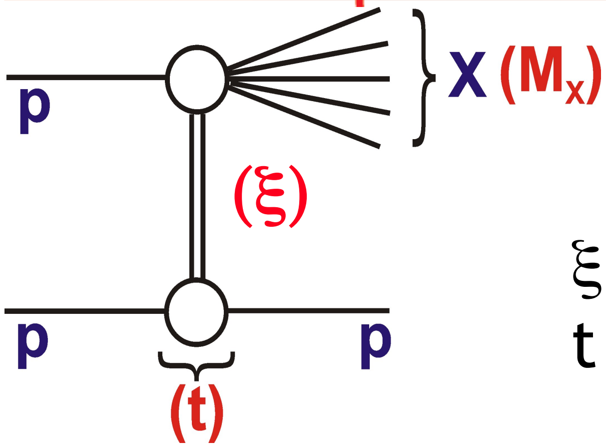
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



Geometric acceptance:





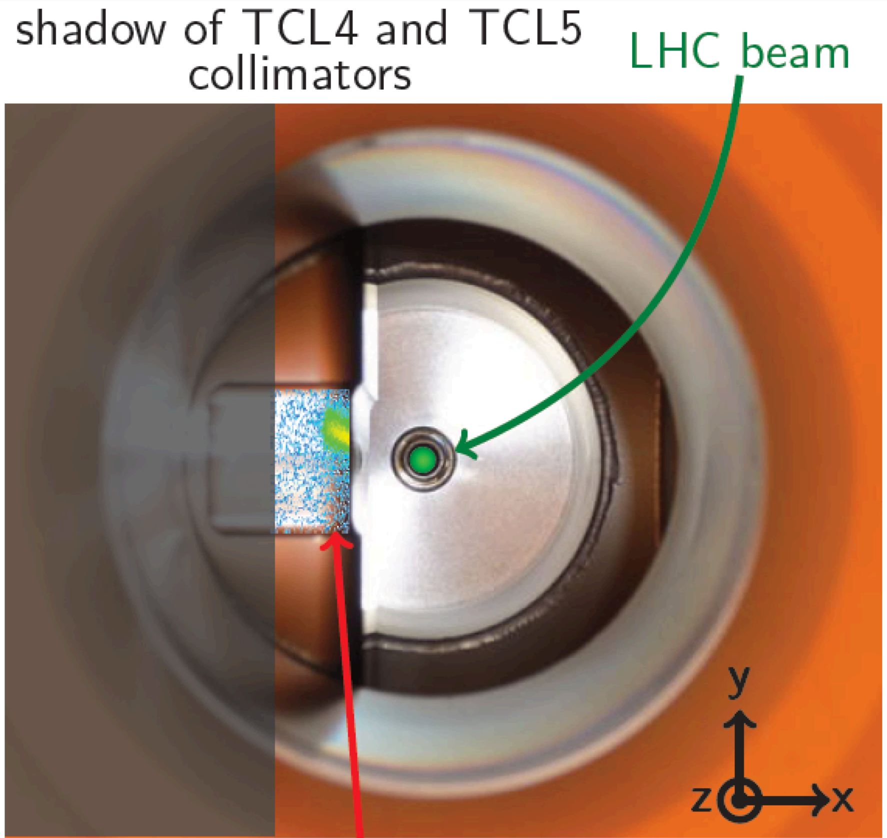
Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

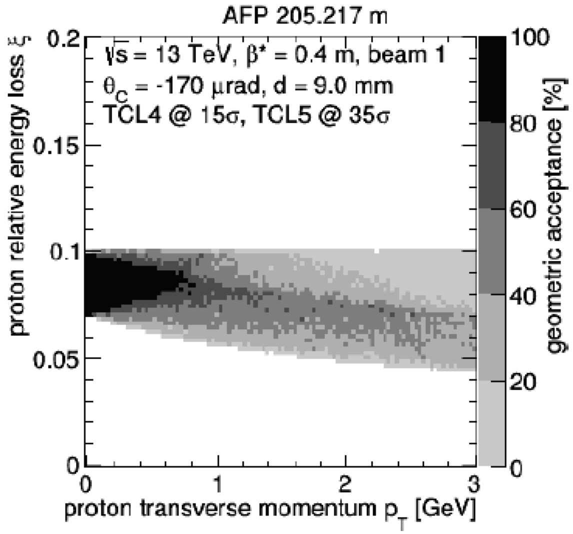
$t = -p_T^2$ of outgoing proton

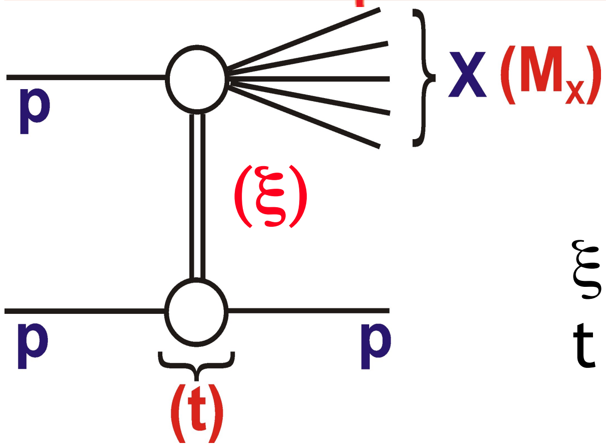
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



Geometric acceptance:





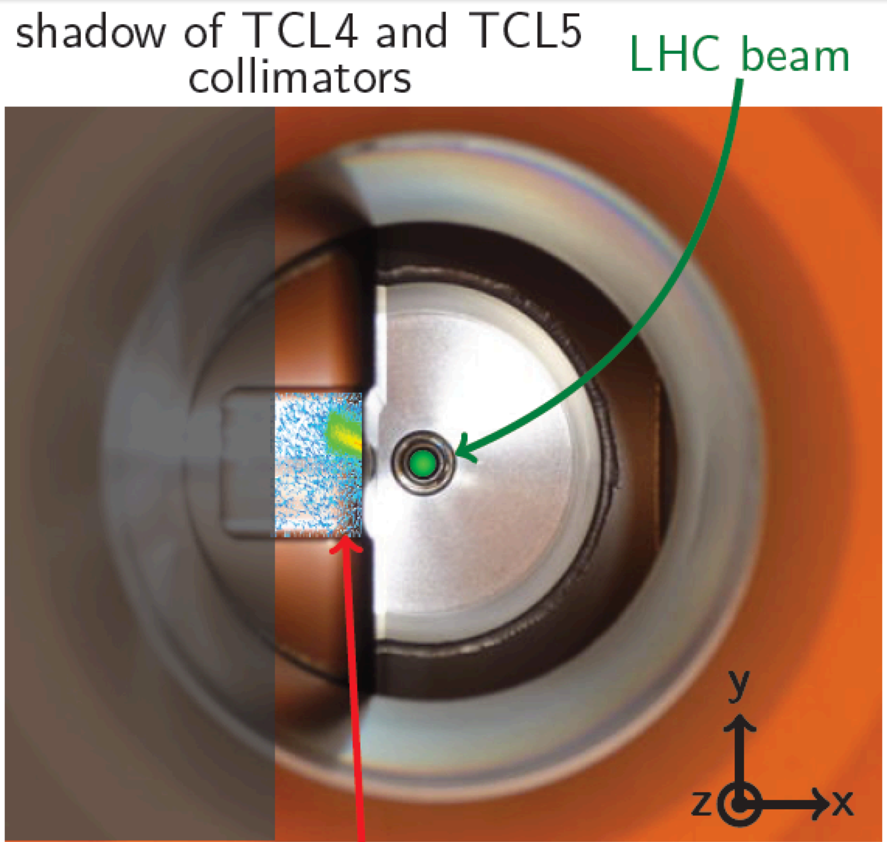
Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

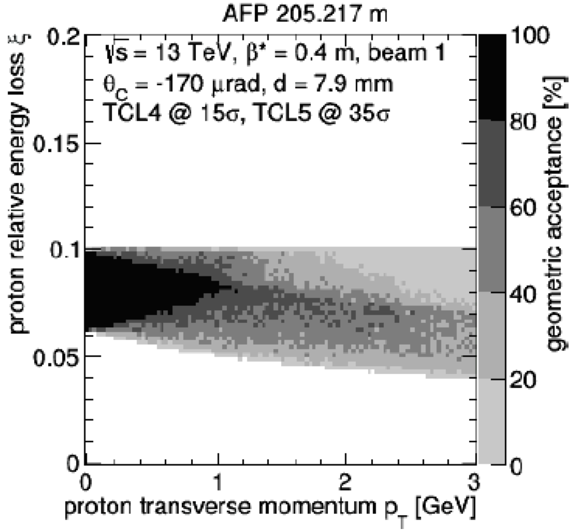
$t = -p_T^2$ of outgoing proton

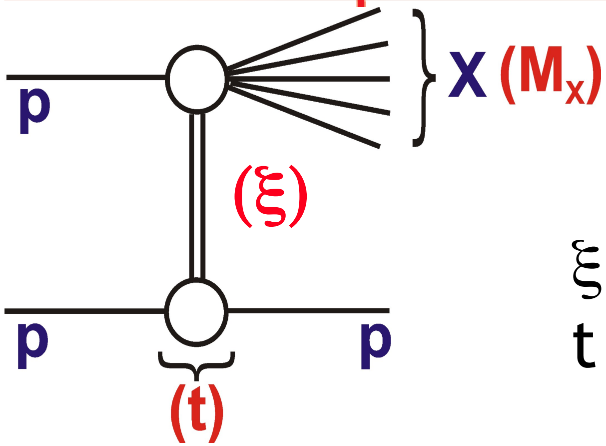
What Determines AFP Acceptance?

Advantages of Roman Pot Technology



Geometric acceptance:





Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

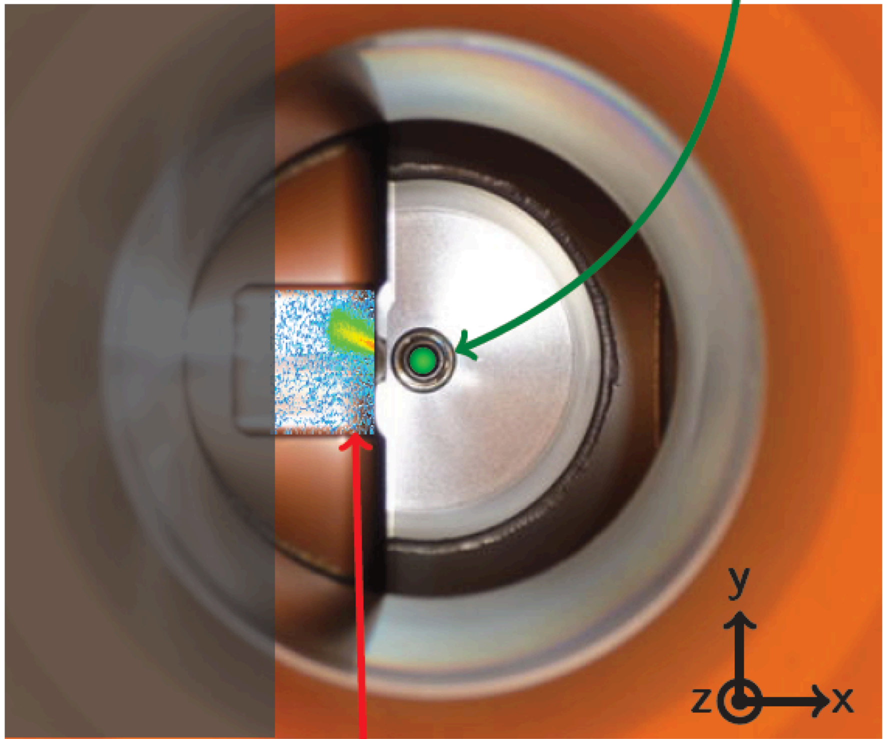
$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?

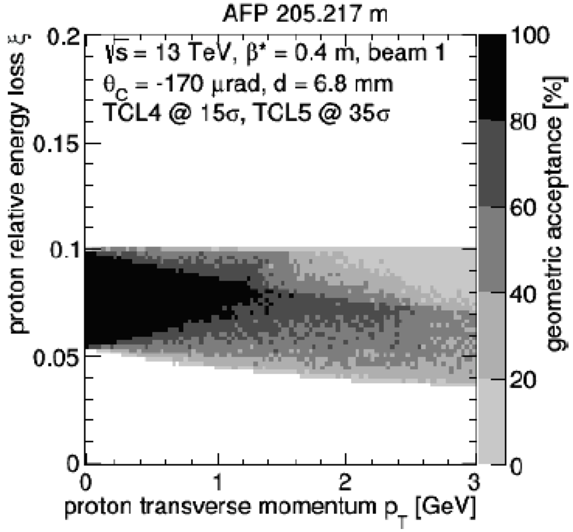
Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

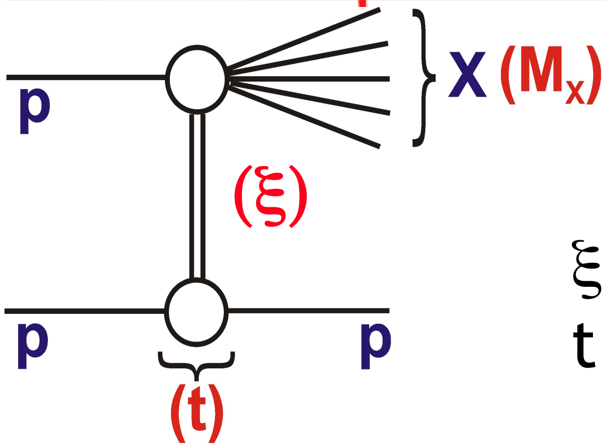
LHC beam



Geometric acceptance:



Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)



ξ = fractional proton energy loss

$t = -p_T^2$ of outgoing proton

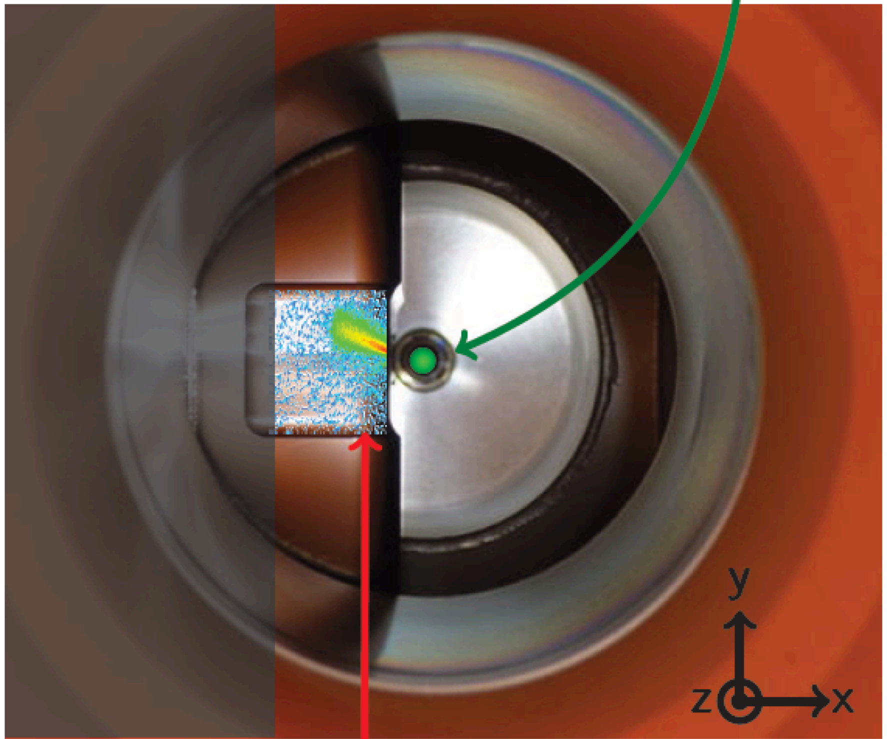
4/21

What Determines AFP Acceptance?

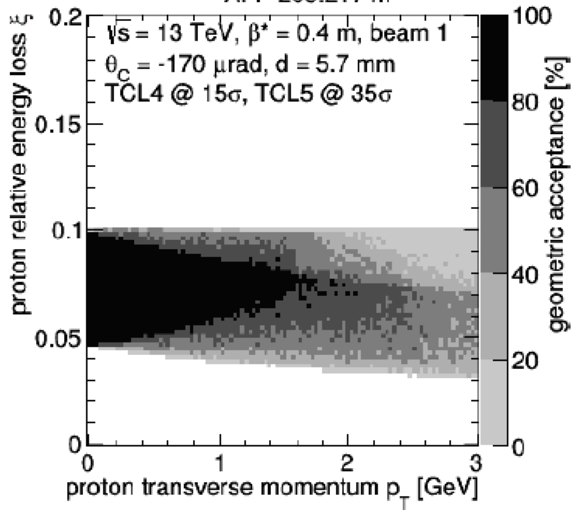
Advantages of Roman Pot Technology

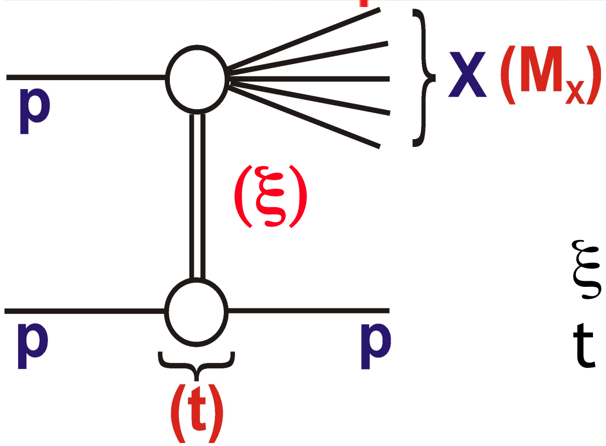
shadow of TCL4 and TCL5 collimators

LHC beam



Geometric acceptance:



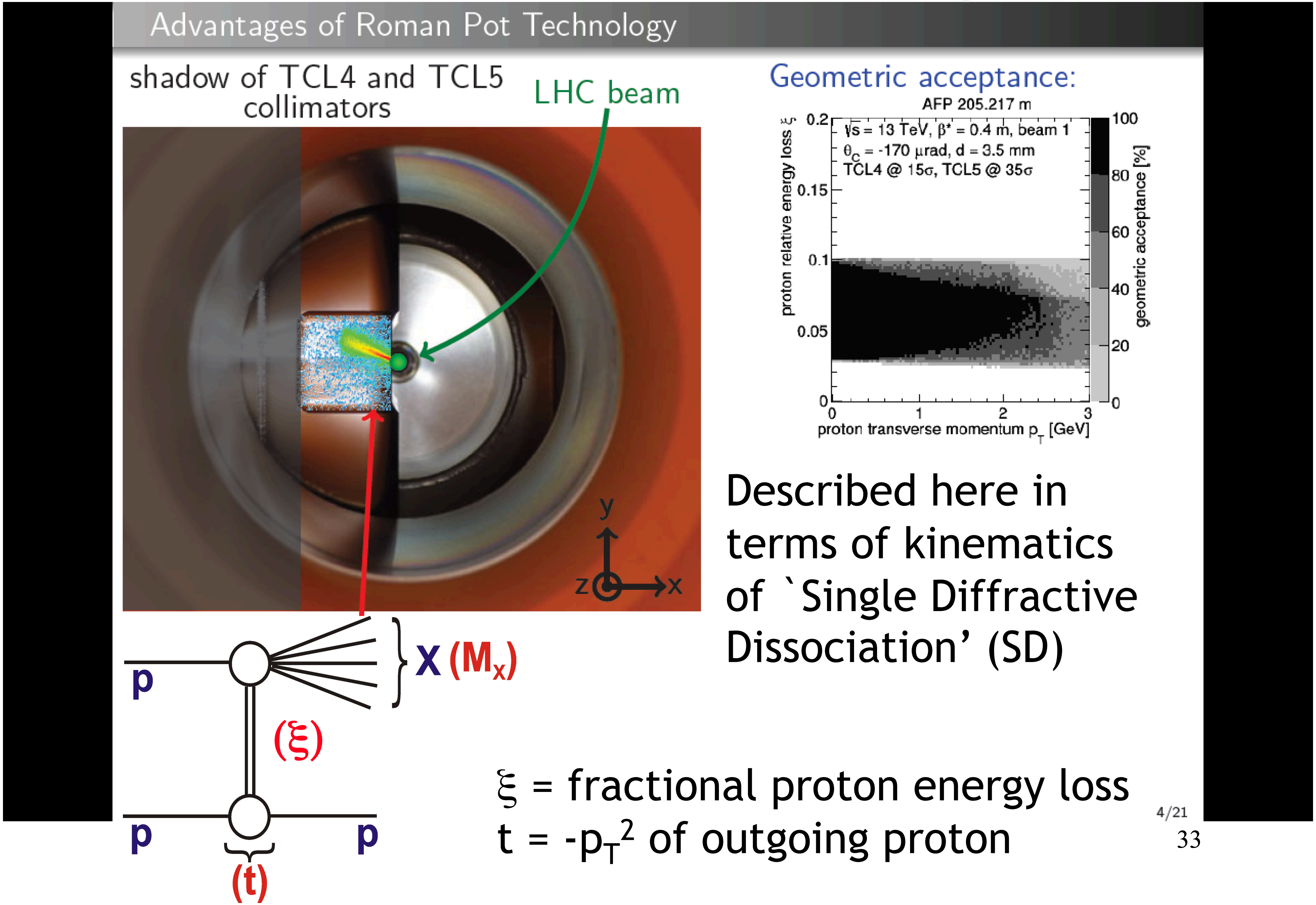


Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

ξ = fractional proton energy loss

$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?



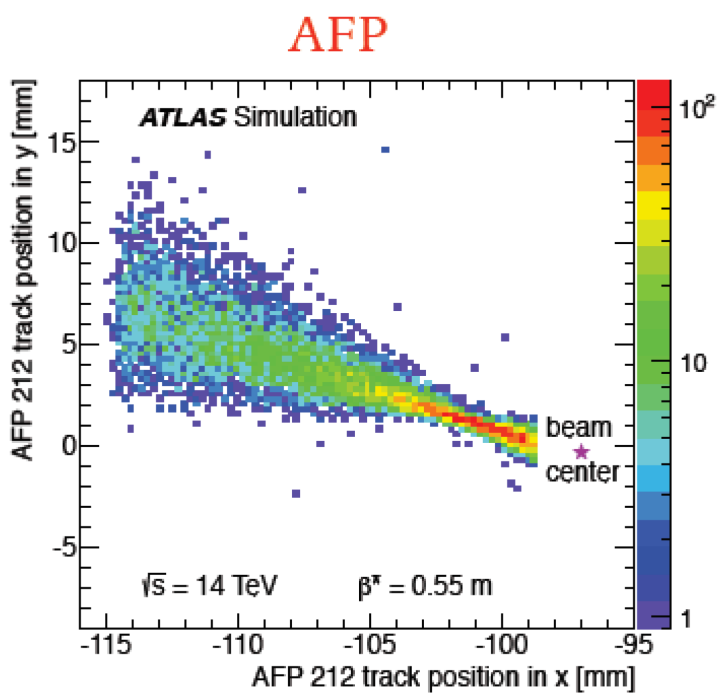
Described here in terms of kinematics of `Single Diffractive Dissociation' (SD)

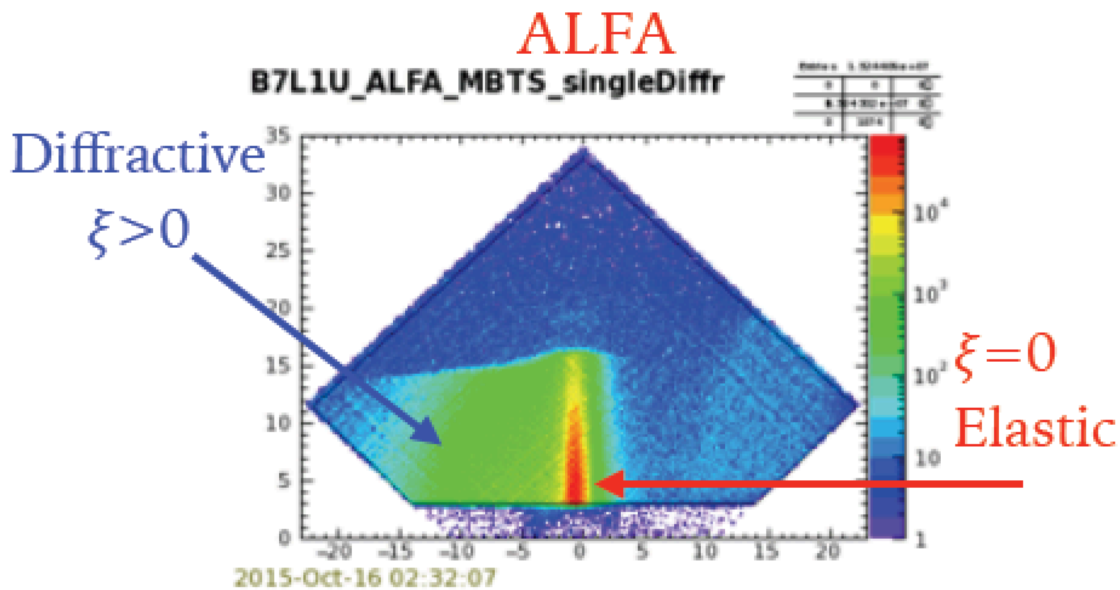
ξ = fractional proton energy loss

$t = -p_T^2$ of outgoing proton

Acceptance Depends on Location and Orientation of Pot and on beam optics

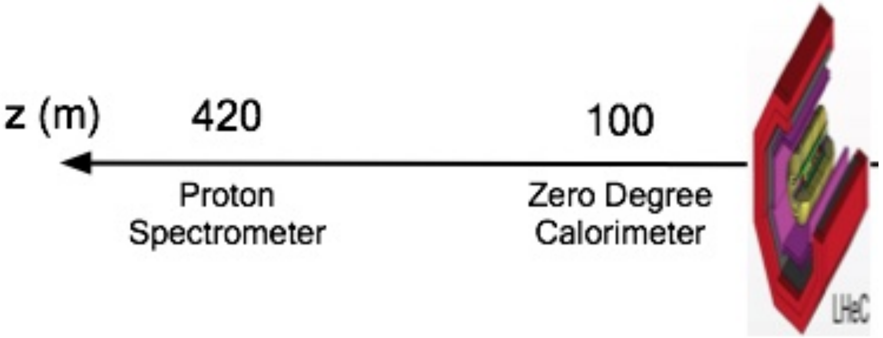
e.g. complementarity between ATLAS ALFA (vertical approach) and AFP (horizontal approach)





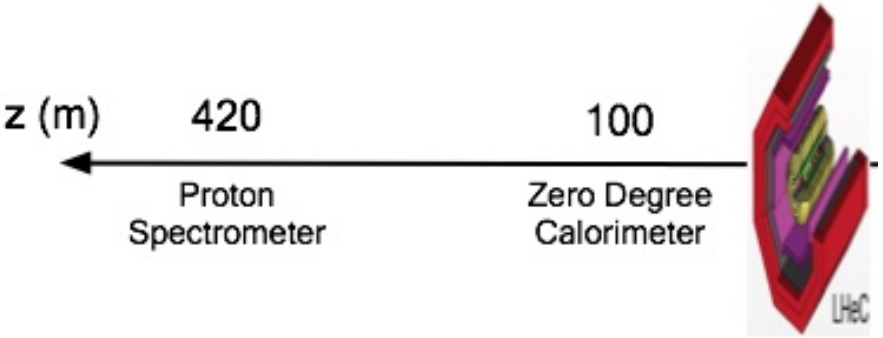
- ALFA is optimised for Elastic scattering with special beam optics
- AFP acceptance for inelastic diffraction with ξ >~ 0.02

Ideas for LHeC Fwd Beamline Instrumentation



… exploiting dependence of exclusive process kinematics only on proton beam …

Ideas for LHeC Fwd Beamline Instrumentation



… exploiting dependence of exclusive process kinematics only on proton beam …

Proton Spectrometer based on FP420 …

The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC

arXiv:0806.0302v2 [hep-ex] 2 Jan 2009

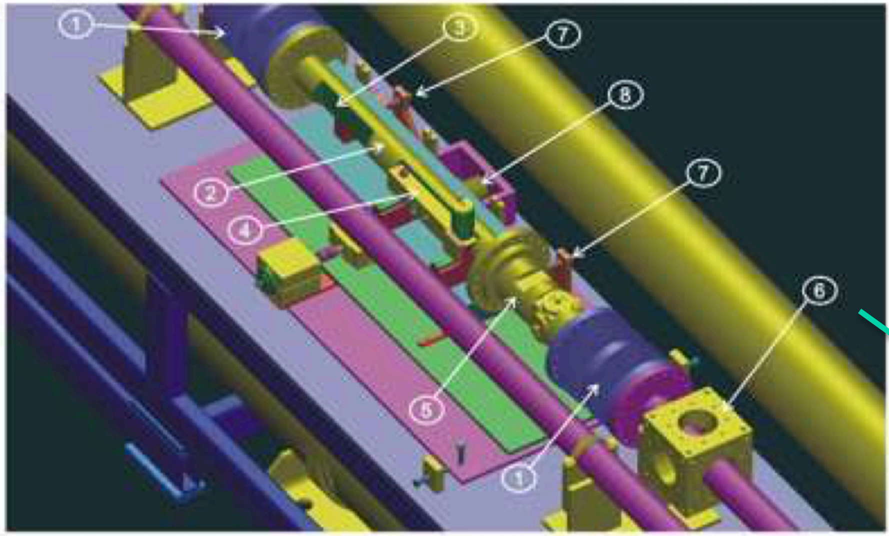
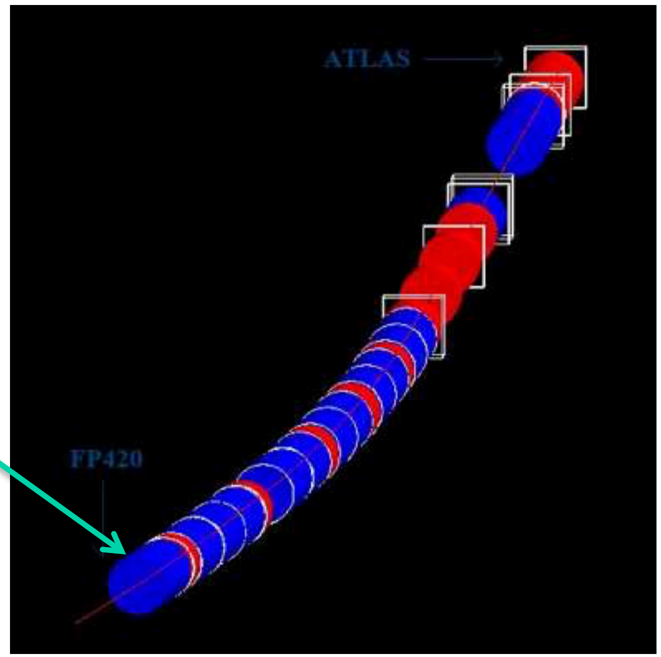
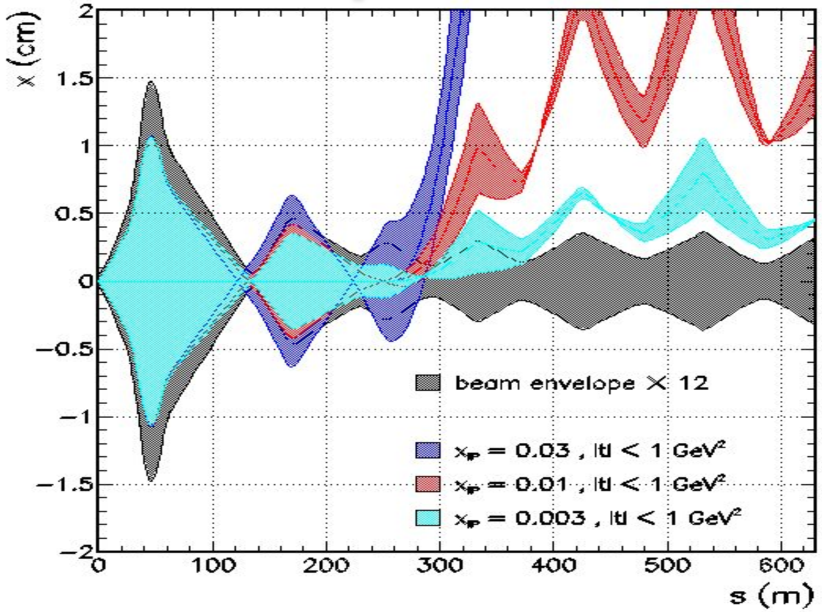


Fig. 50: Top view of one detector section: bellows (1), moving pipe (2), Si-detector pocket (3), timing detector (4), moving BPM (5), fixed BPM (6), LVDT position measurement system (7), emergency spring system (8).



An LHeC Forward Proton Spectrometer?

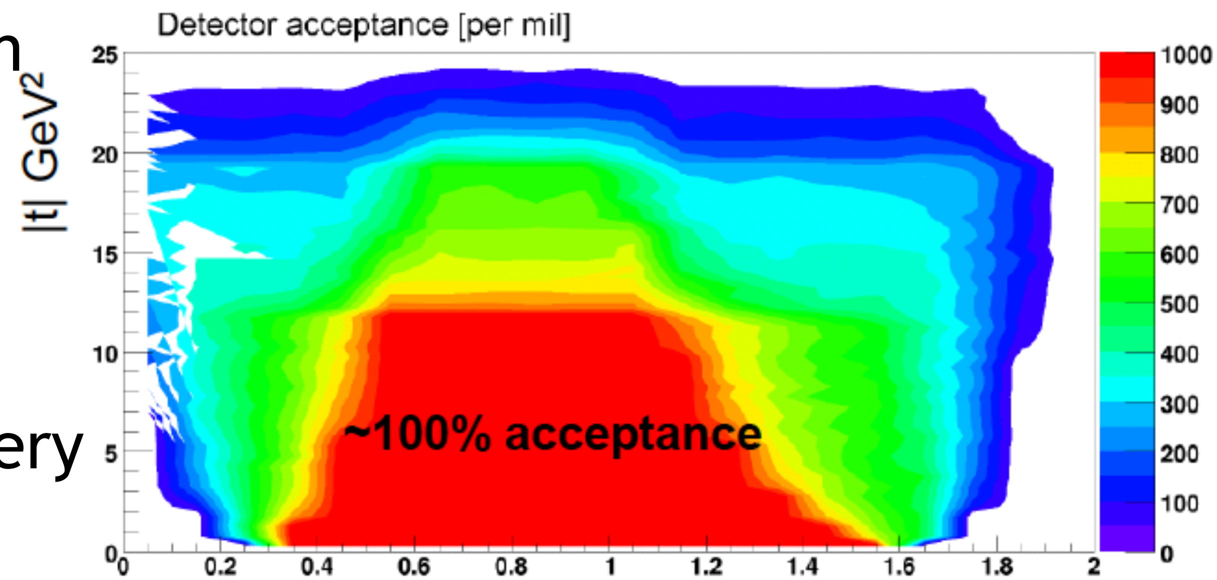


- Proton spectrometer in CDR is a copy of FP420 project (proposal for low ξ Roman pots at ATLAS / CMS – not yet adopted)

- Approaching beam to 12σ (~250 μm) tags elastically scattered protons with high acceptance over a wide x_{IP}, t range

- Requires access to beam though cold part of LHC

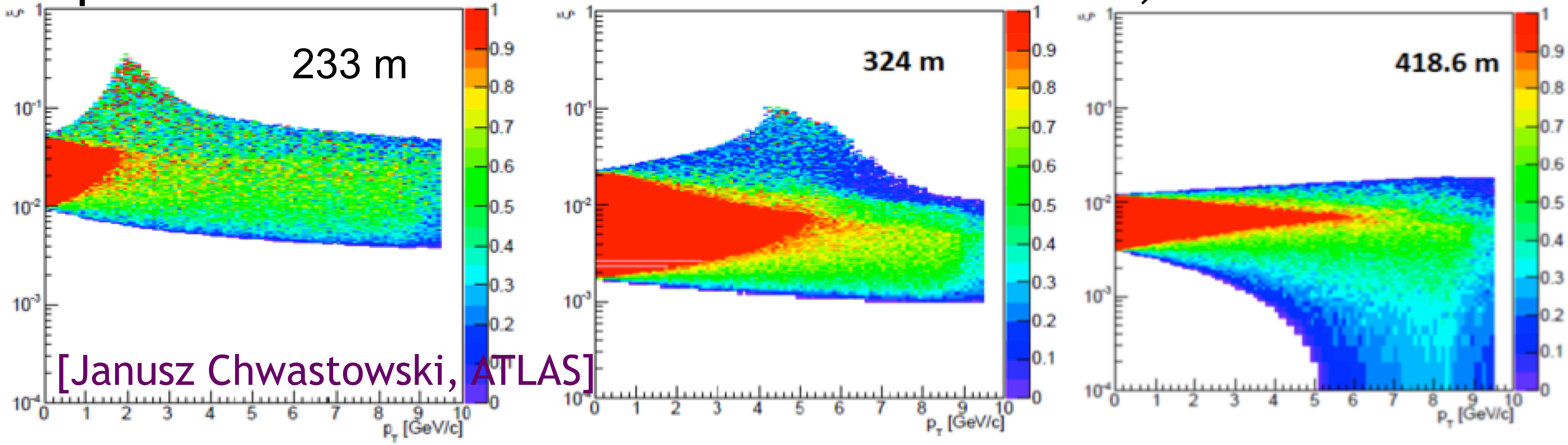
- Higher ξ from AFP / CT-PPS like pots.
- Lower ξ requires pots very far from I.P. (but may be covered by gaps method)



Good acceptance for 0.002<ξ<0.013

... but that was for (old) Standard LHC optics
... First Studies with nominal HL-LHC Optics ...

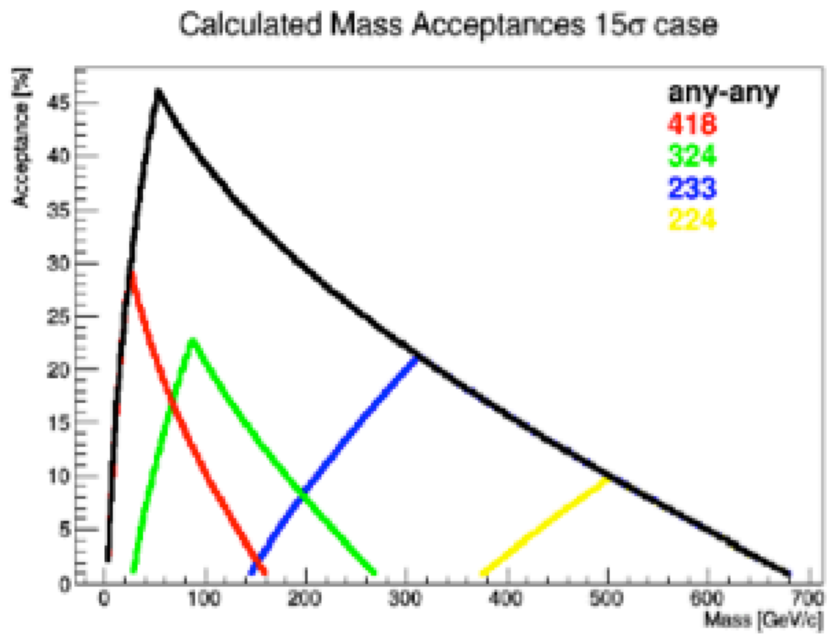
Acceptances for 2x2cm detector @ 15σ+0.5mm, no collimators



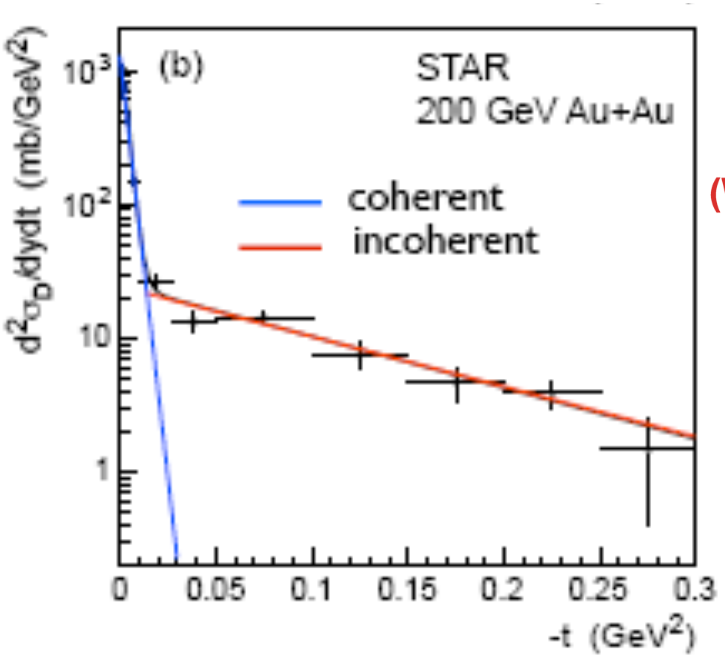
[Janusz Chwastowski, ATLAS]

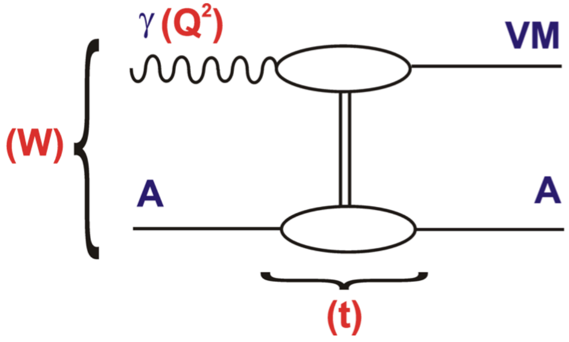
233m: Reduced ξ acceptance relative to that now in AFP region

324,420m: Attractive ξ acceptance extending into SM Higgs region and very wide t range at possible deployment points in cold sections

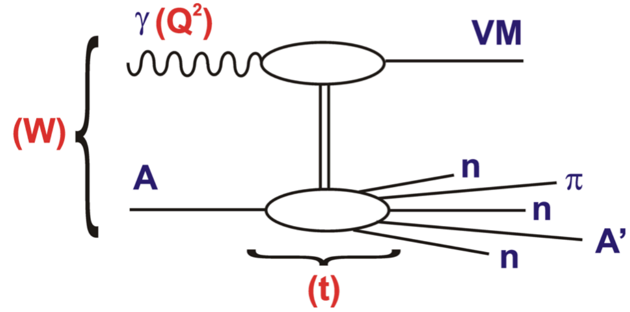


What can be done in eA?





Coherent



Incoherent

Coherent diffraction has `impossibly' small proton displacement
… |t| < 0.01 GeV^2 corresponds to ~ 10^{-4} mrad for heavy ion
… Roman pots would be kilometers from interaction point!

Can we use Roman pots nearer to interaction point to detect dissociating beam fragments *inside* the beam-pipe?

→ Identify low mass double dissociation in ep gap method
→ Separate coherent and incoherent processes in eA?

Leading Neutrons

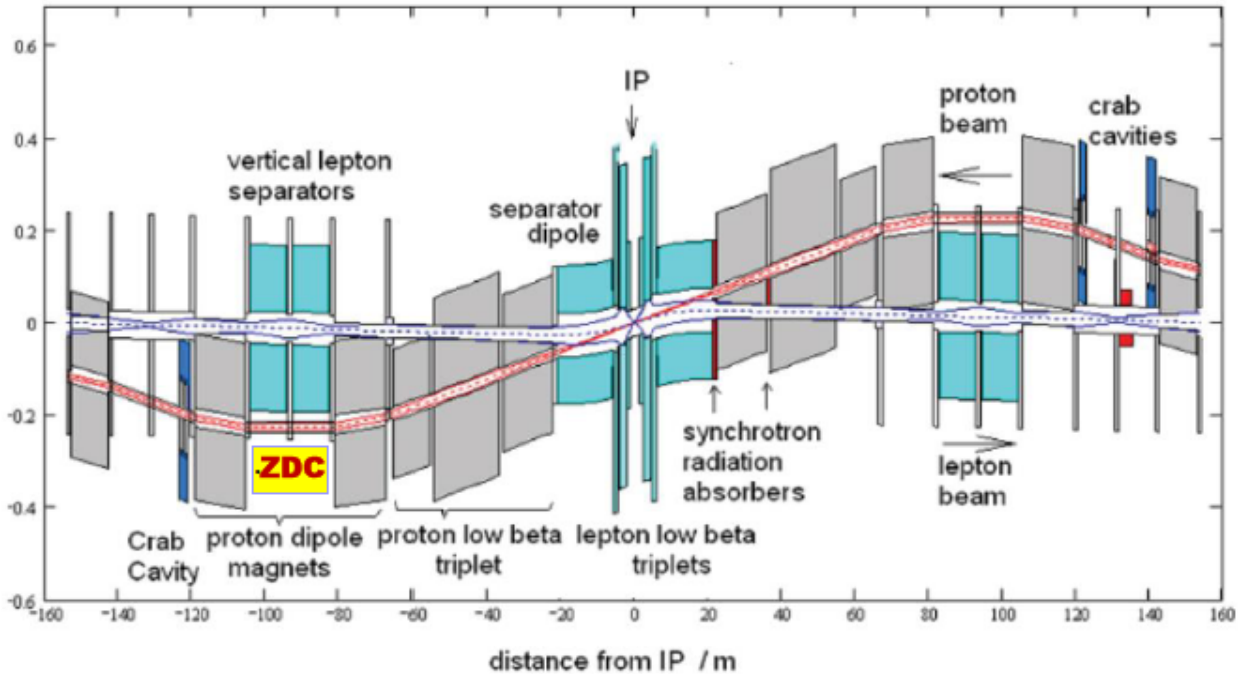
- Crucial in eA, to determine whether nucleus remains intact e.g. to distinguish coherent from incoherent diffraction

- Crucial in ed, to distinguish scattering from proton or neutron

- Forward γ and n cross sections relevant to cosmic ray physics

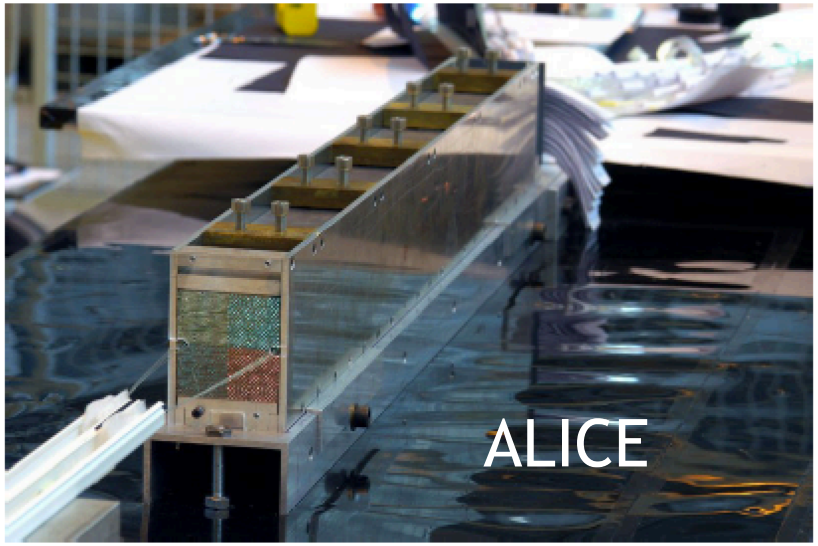
- Has previously been used in ep to study π structure function

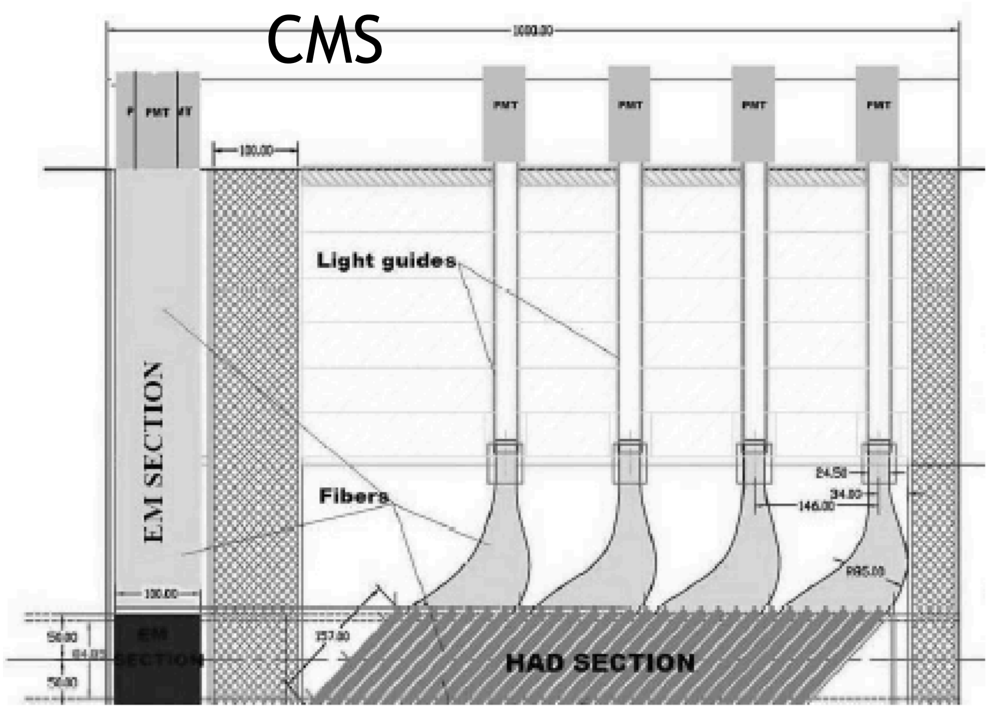
Possible "straight on" space at z ~ 100m



No detailed instrumentation studies yet → learn from LHC again

Leading Neutrons: Solutions from LHC
… needs to be compact and radiation-hard





- ALICE, ATLAS, CMS all use tungsten absorber + quartz fibres (Cerenkov). LHCf uses tungsten + plastic scintillator in special runs
- Improve hadronic response with dual quartz / scintillator?
- Longitudinal segmentation essential to distinguish neutrons from photons.

Summary / Discussion Points

- Proton beam characteristics entirely drive kinematics of forward / exclusive particle production … we can learn much of what we need to know from LHC experiments

- More detailed studies with realistic optics (crossing angle?... dipoles?... crab cavities?) are needed!

- Favoured proton detector technology is Si pixels. Challenges:
  … Radiation hardness levels for HL-LHC
  … `Edgeless' detectors

- Neutron detector is Tungsten + Quartz/Scintillator? Challenges:
  … Hadronic response / distinguishing n from γ

- Is Roman pot fragment tagging inside beampipe possible?