The Large Hadron electron Collider (LHeC) and its Detector

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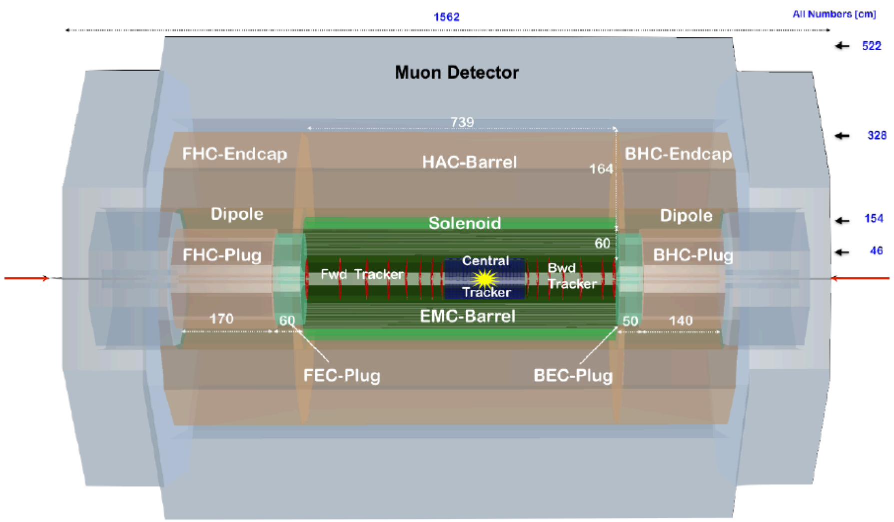
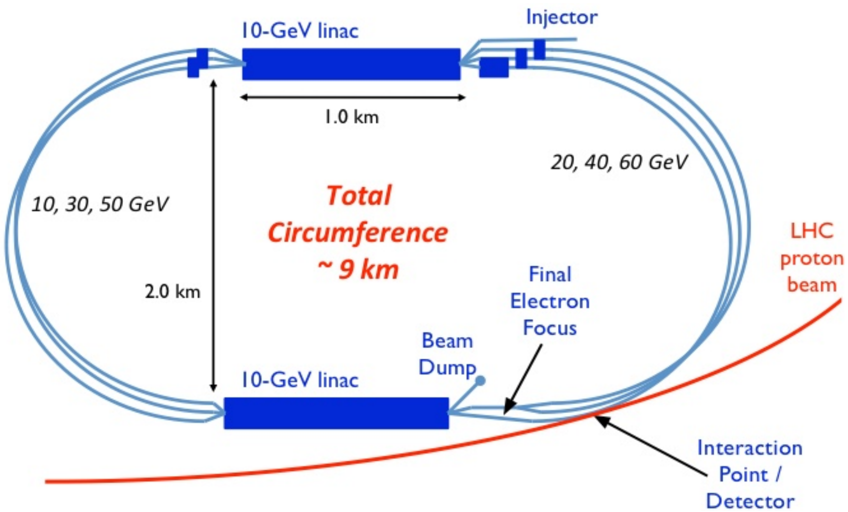
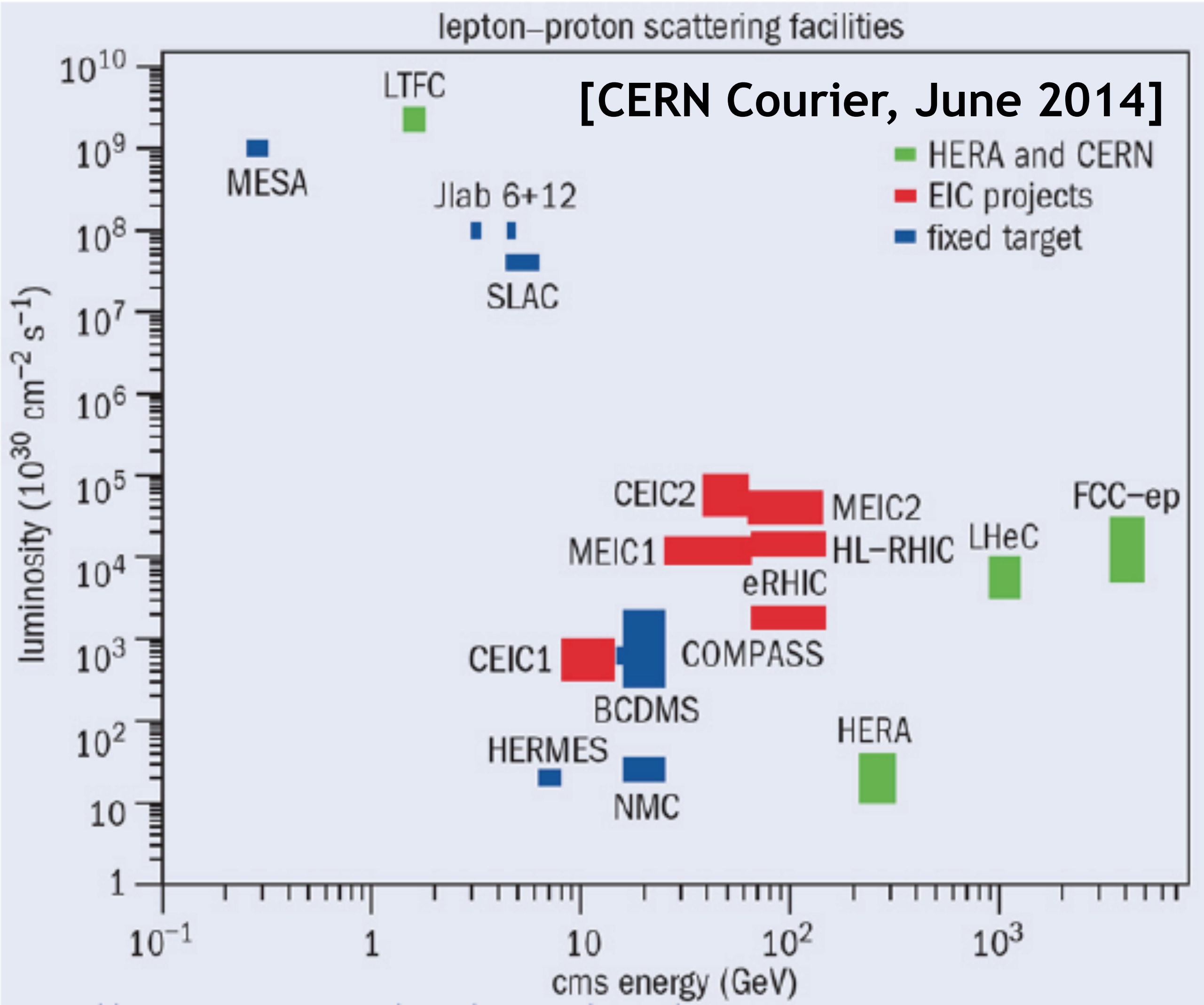




1) LHeC overview and physics
2) Some Detector ideas
3) Focus on beamline elements
4) The PERLE prototype

LHeC Context

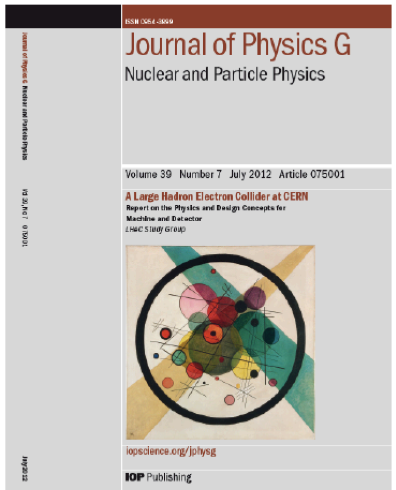


Proposed energy frontier high luminosity ep / eA facility → TeV scale physics at 10^{34} cm^{-2}s^{-1}

LHeC: 60 GeV electrons x LHC protons & ions
→ 10^{34} cm^{-2} s^{-1}
→ Simultaneous running with ATLAS / CMS in HL-LHC period

FCC-ep: 60 GeV electrons x 50 TeV protons from FCC

CDR 2012: "Fake news?" … lots changed



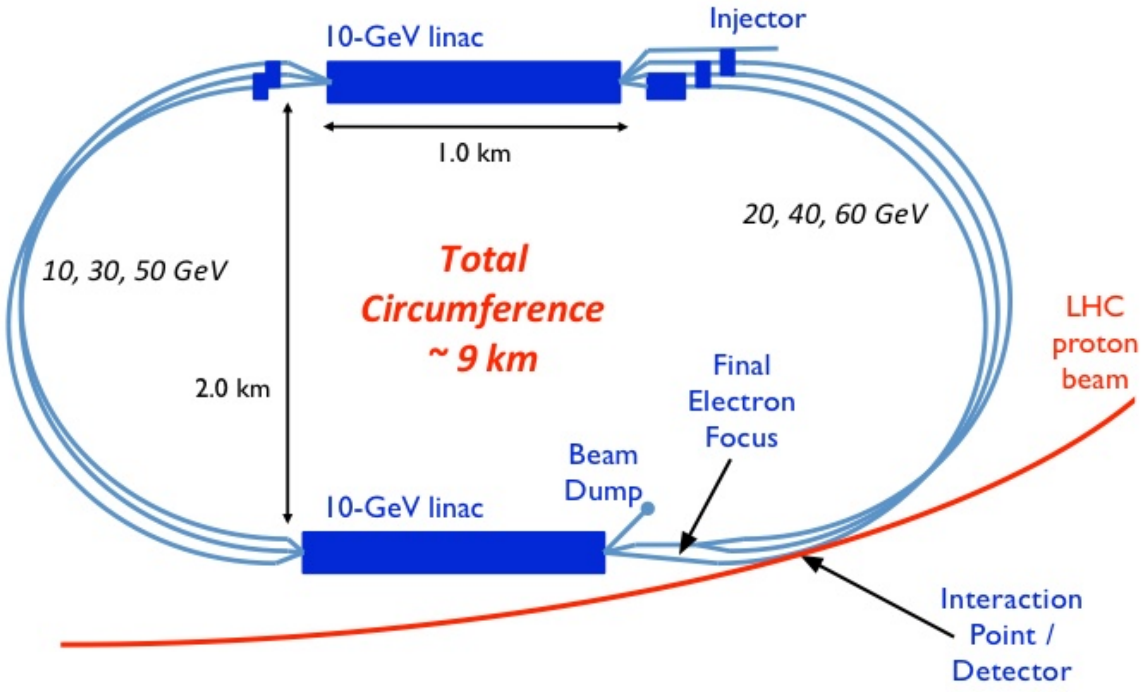
arXiv:1206.2913

Baseline# Design (Electron "Linac")

LHeC CDR, July 2012 [arXiv:1206.2913]

Design constraint: power consumption < 100 MW → E_e = 60 GeV

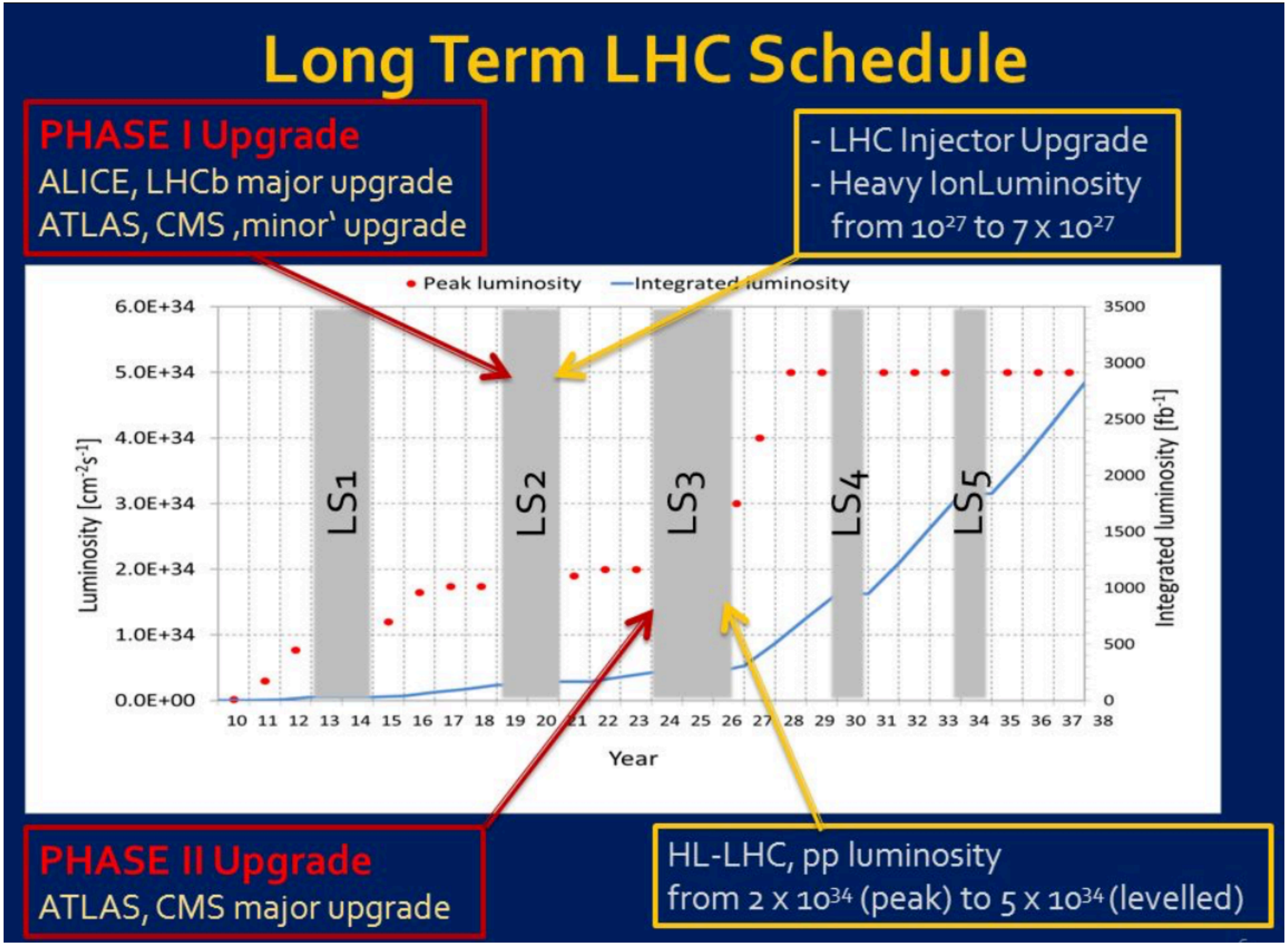
- Two 10 GeV linacs,
- 3 returns, 20 MV/m
- Energy recovery in same structures



- ep lumi → 10^{34} cm^{-2} s^{-1}
→ ~100 fb^{-1} per year →~1 ab^{-1} total
- **eD and eA collisions have always been integral to programme**
- **e-nucleon Lumi estimates ~ 10^{31} (3.10^{32}) cm^{-2} s^{-1} for eD (ePb)**

Alternative designs based on electron ring and on higher energy, lower luminosity, linac also exist

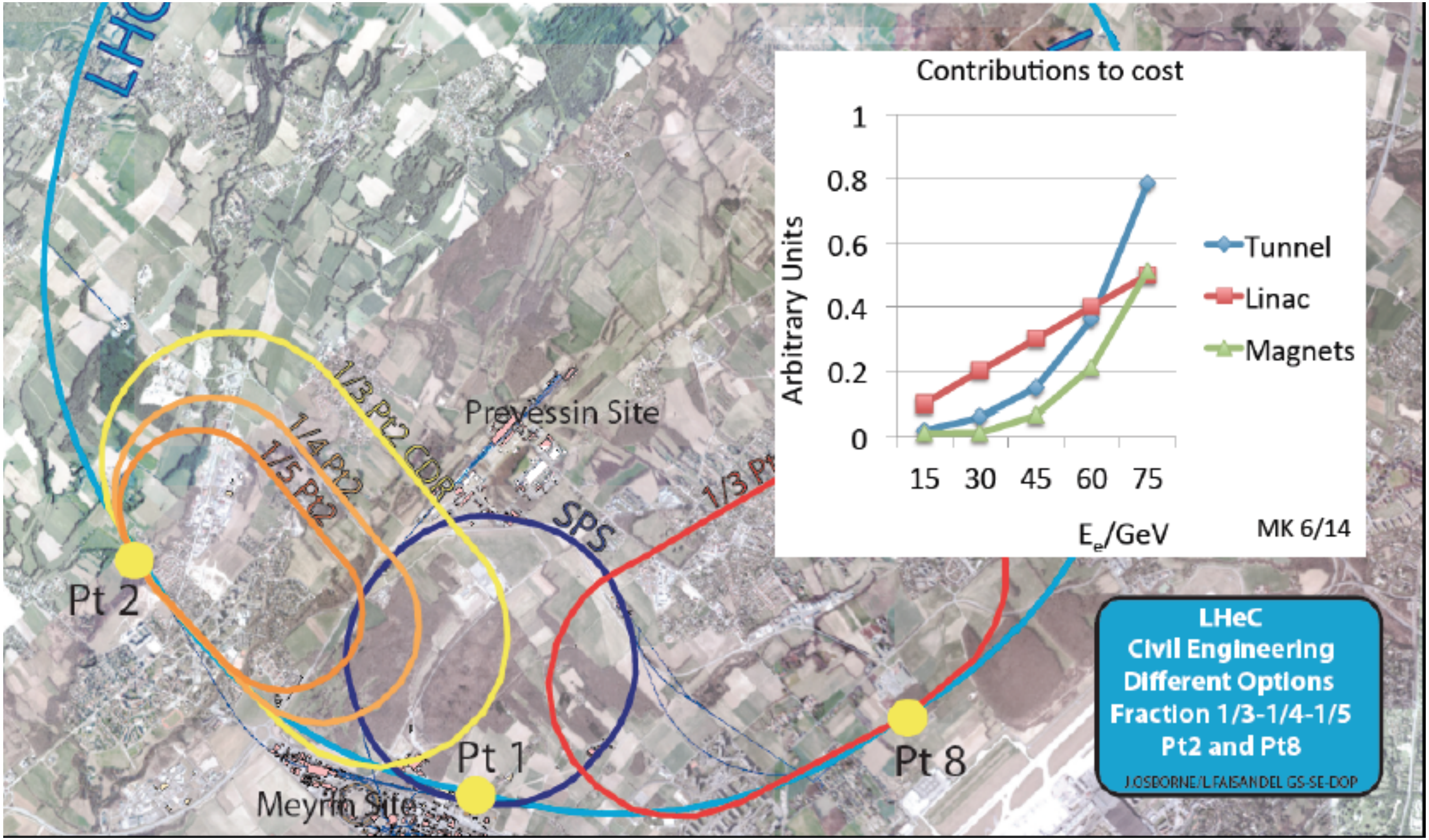
LHeC Timeline



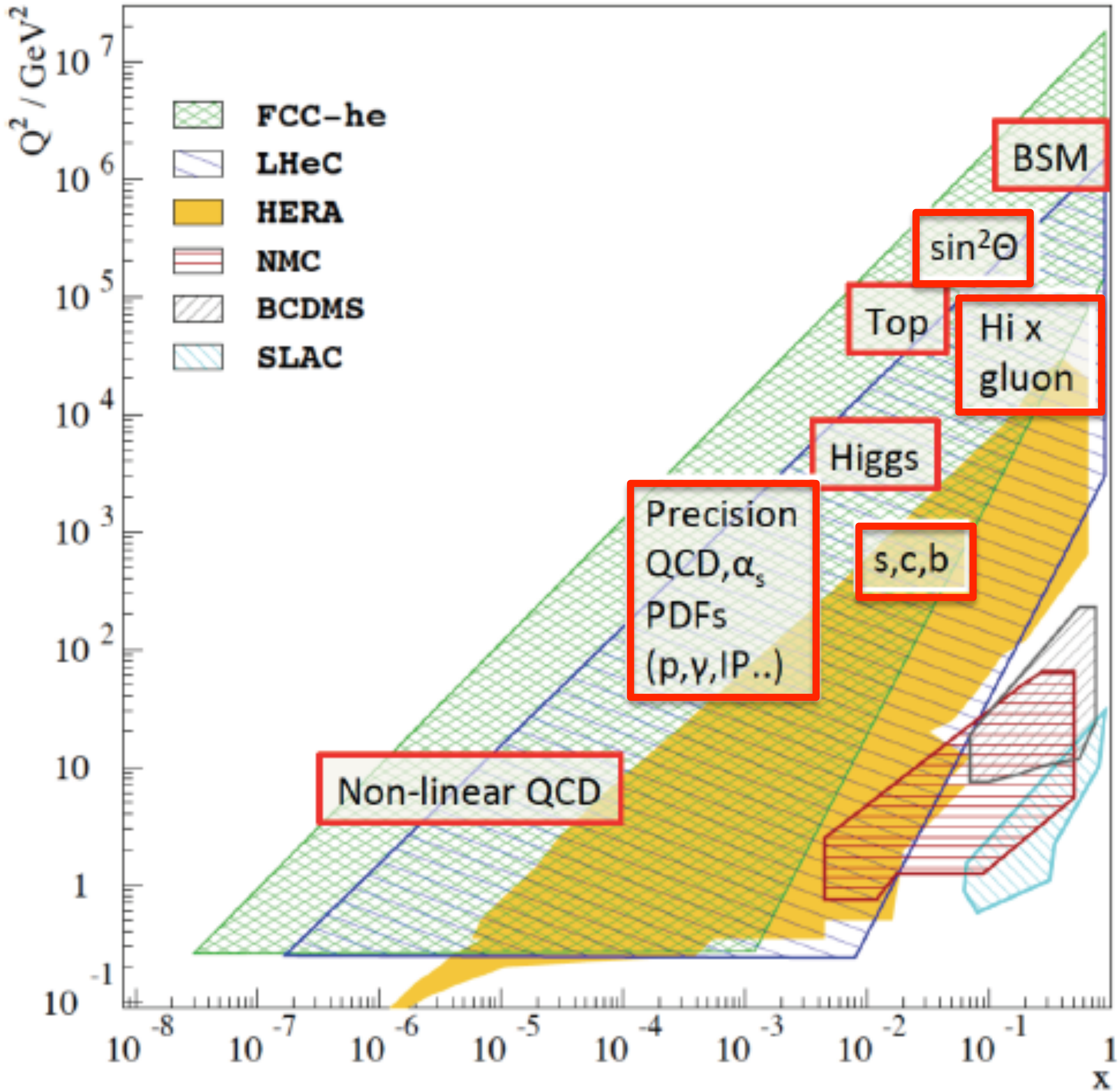
Not defined … but makes best sense in parallel with HL-LHC … schedule extends to ~2026-2040, with multiple shutdowns

Where could the LHeC be built?

- Default design is 1/3 at Point 2 (currently ALICE)
- Point 8 (currently LHCb) has also been considered



Complementary Physics Programme to EIC



- Standalone Higgs programme

- Revolutionary proton PDF precision enhances LHC new physics sensitivity

- Elucidates low x dynamics in ep & eA

- 4 orders of mag. in kinematic range of nuclear structure

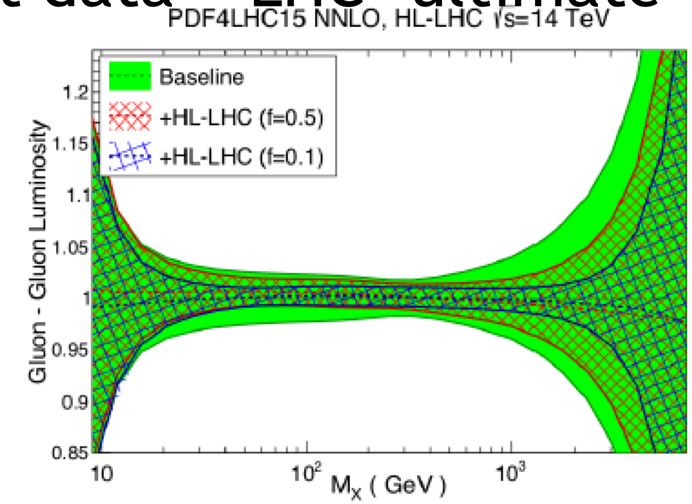
- No polarised targets

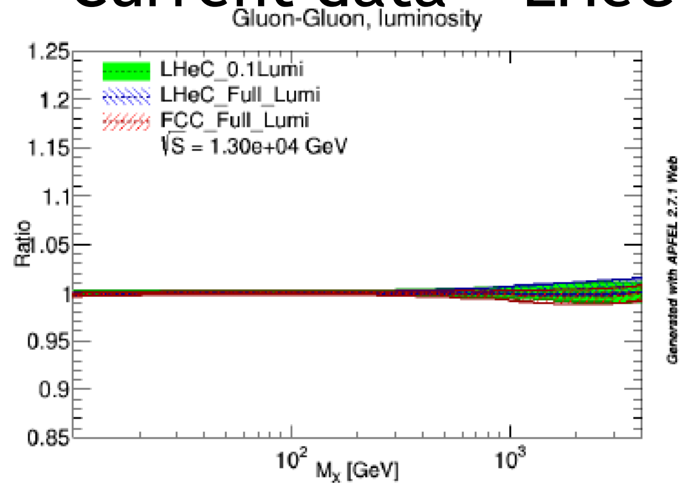
Transformational PDF precision & flavour decomposition: enabling LHC discovery

… much of LHC physics will become limited by PDFs → high x uncertainties limit searches, medium x limit Higgs precision etc

Current data + LHC 'ultimate' | **Current data + LHeC**

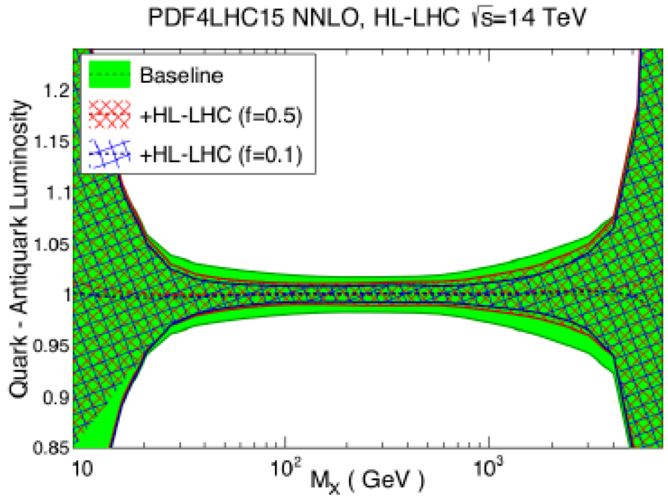
gg→X

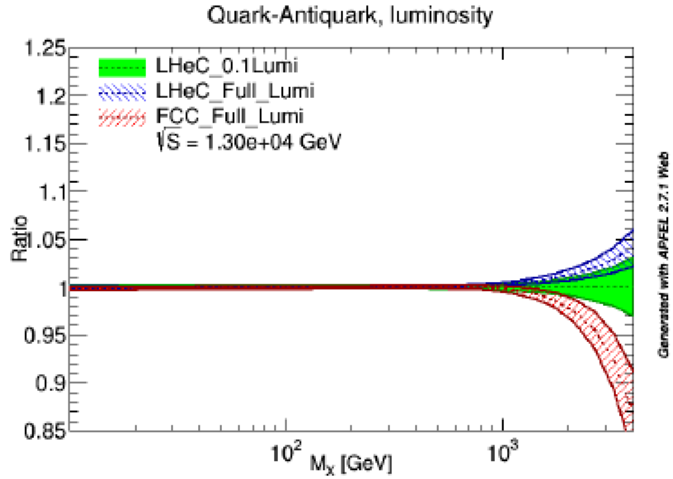




[work in Progress]

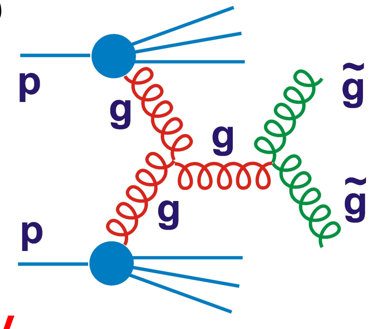
qqbar→X

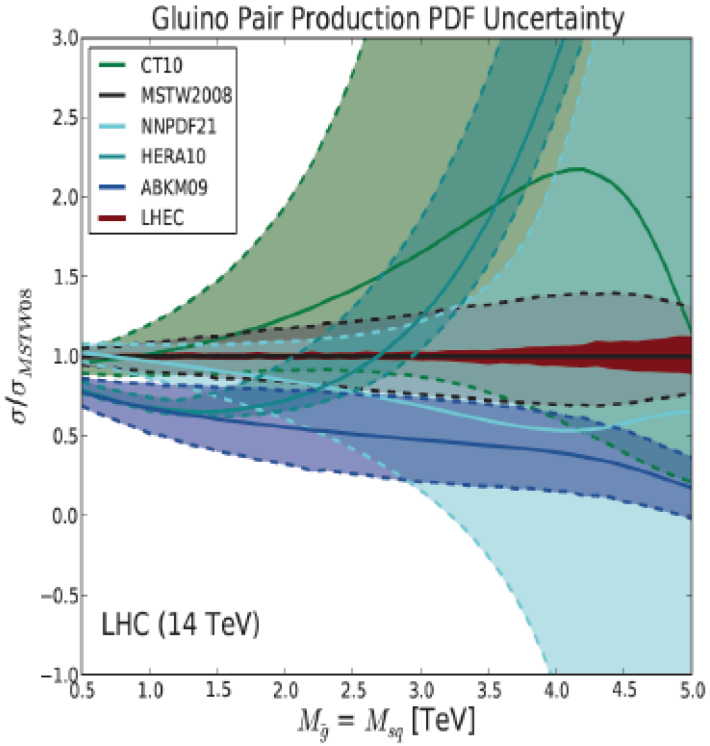


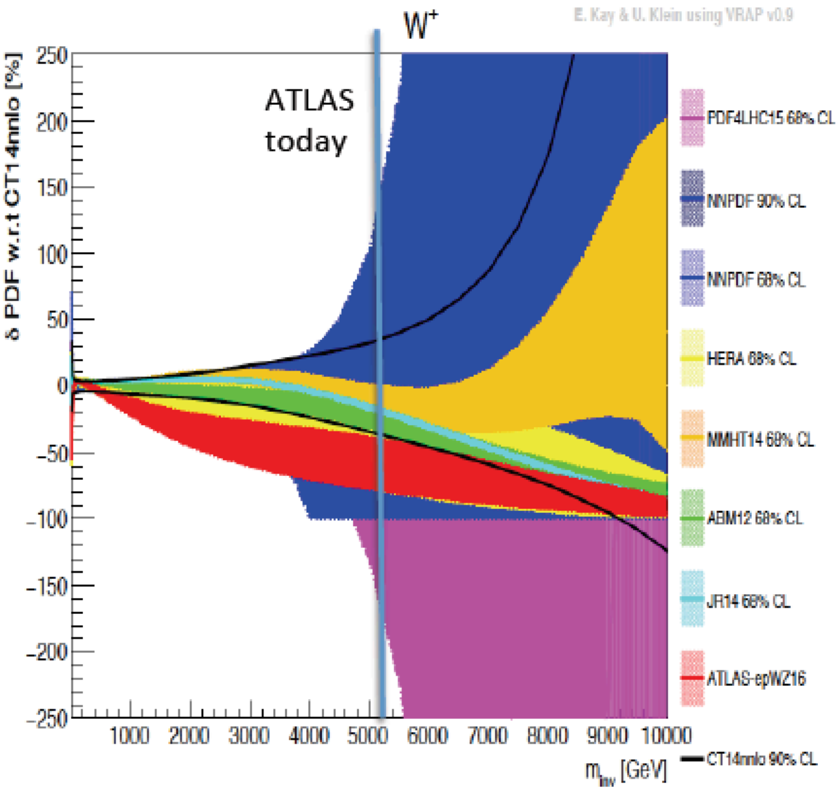


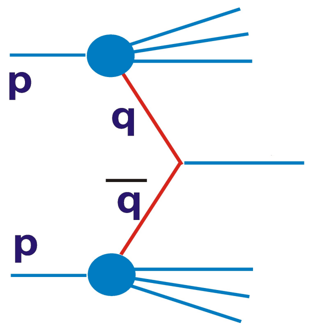
PDFs → eg New High Mass LHC Particles

- Gluino signature is excess @ large invariant mass
- Both signal & background uncertainties driven by error on gluon density … essentially unknown beyond ~2 TeV



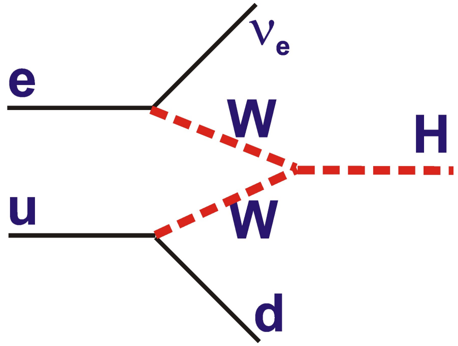






- BSM sensitivity to heavy W boson through excess in high mass lν or jj already limited by high x valence quark and antiquark uncertainties

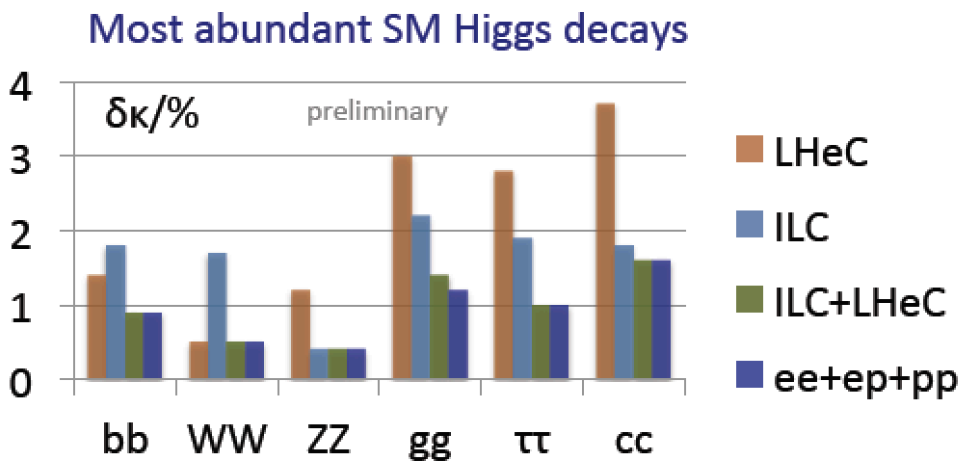
LHeC Standalone Higgs Sensitivity

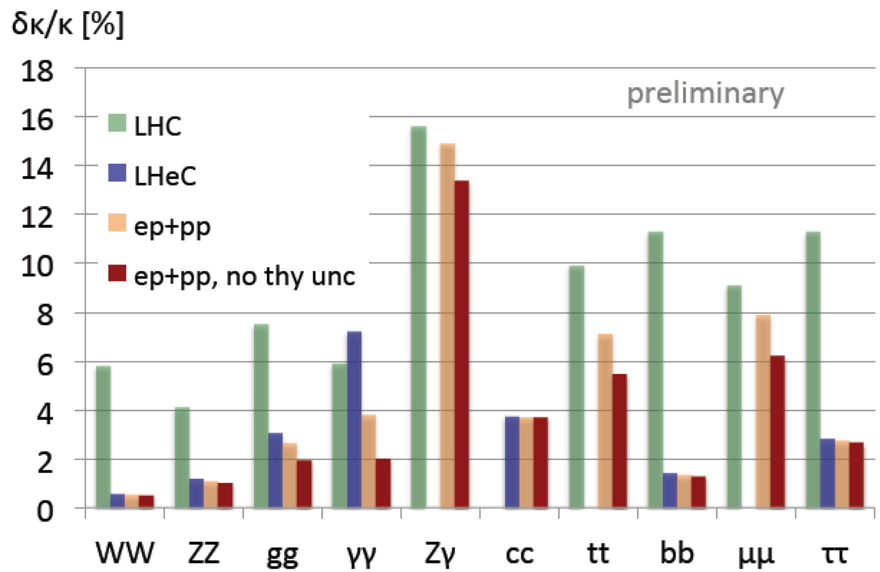


Estimated integrated yields …

Higgs in e^-p		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N^H_{CC}	N^H_{NC}	N^H_{CC}
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	270 000
$H \to \mu\mu$	0.00022	50	5	1 000
$H \to 4l$	0.00013	30	3	550
$H \to 2l2\nu$	0.0106	2 080	250	45 000
$H \to gg$	0.086	16 850	2 050	365 000
$H \to WW$	0.215	42 100	5 150	915 000
$H \to ZZ$	0.0264	5 200	600	110 000
$H \to \gamma\gamma$	0.00228	450	60	10 000
$H \to Z\gamma$	0.00154	300	40	6 500

-Known production mode each event via WW(CC) Or ZZ (NC)
- Detailed studies of bbar, ccbar, extrapolations of LHC performance for other modes
- Compare HL-LHC, ILC250, LHeC





Wide-ranging BSM Interest

References

[1] S. P. Das, J. Hernandez-Sanchez, S. Moretti and A. Rosado, *Prospects for discovering a light charged Higgs boson within the NMSSM at the FCC-eh collider*, 1806.08361.

[2] A. Caliskan and S. O. Kara, *Single production of the excited electrons at the future FCC-based lepton-hadron colliders*, 1806.02037.

[3] H. Hesari, H. Khanpour and M. Mohammadi Najafabadi, *Study of Higgs Effective Couplings at Electron-Proton Colliders*, *Phys. Rev.* **D97** (2018) 095041, [1805.04697].

[4] L. Duarte, G. Zapata and O. A. Sampayo, *Angular and polarization trails from effective interactions of Majorana neutrinos at the LHeC*, *Eur. Phys. J.* **C78** (2018) 352, [1802.07620].

[5] C. Han, R. Li, R.-Q. Pan and K. Wang, *Searching for the light Higgsinos at the CERN LHeC*, 1802.03679.

[6] G. Azuelos, H. Sun and K. Wang, *Search for singly charged Higgs bosons in vector-boson scattering at ep colliders*, *Phys. Rev.* **D97** (2018) 116005, [1712.07505].

[7] D. Curtin, K. Deshpande, O. Fischer and J. Zurita, *New Physics Opportunities for Long-Lived Particles at Electron-Proton Colliders*, 1712.07135.

[8] R. Li, X.-M. Shen, K. Wang, T. Xu, L. Zhang and G. Zhu, *Probing anomalous $WW\gamma$ triple gauge bosons coupling at the LHeC*, *Phys. Rev.* **D97** (2018) 075043, [1711.05607].

[9] K. He, H.-Y. Bi, R.-Y. Zhang, X.-Z. Li and W.-G. Ma, *P-wave excited B_c^{**} meson photoproduction at the LHeC*, *J. Phys.* **G45** (2018) 055005, [1710.11508].

[10] H. Sun, X. Luo, W. Wei and T. Liu, *Searching for the doubly-charged Higgs bosons in the Georgi-Machacek model at the electron-proton colliders*, *Phys. Rev.* **D96** (2017) 095003, [1710.06284].

[11] Y. O. Günaydin, M. Sahin and S. Sultansoy, *Resonance Production of Excited u-quark at the FCC Based $\gamma\, p$ Colliders*, 1707.00056.

[12] A. Caliskan, *Excited neutrino search potential of the FCC-based electron-hadron colliders*, *Adv. High Energy Phys.* **2017** (2017) 4726050, [1706.09797].

[13] L. Han, Y.-J. Zhang and Y.-B. Liu, *Single vector-like T-quark search via the $T \to Wb$ decay channel at the LHeC*, *Phys. Lett.* **B771** (2017) 106–112.

[14] I. Turk Cakir, A. Yilmaz, H. Denizli, A. Senol, H. Karadeniz and O. Cakir, *Probing the Anomalous FCNC Couplings at Large Hadron Electron Collider*, *Adv. High Energy Phys.* **2017** (2017) 1572053, [1705.06419].

[15] Y.-B. Liu, *Search for single production of vector-like top partners at the Large Hadron Electron Collider*, *Nucl. Phys.* **B923** (2017) 312–323, [1704.02059].

[16] Y.-J. Zhang, L. Han and Y.-B. Liu, *Single production of the top partner in the $T \to tZ$ channel at the LHeC*, *Phys. Lett.* **B768** (2017) 241–247.

[17] X. Wang, H. Sun and X. Luo, *Searches for the Anomalous FCNC Top-Higgs Couplings with Polarized Electron Beam at the LHeC*, *Adv. High Energy Phys.* **2017** (2017) 4693213, [1703.02691].

[18] H.-Y. Bi, R.-Y. Zhang, X.-G. Wu, W.-G. Ma, X.-Z. Li and S. Owusu, *Photoproduction of doubly heavy baryon at the LHeC*, *Phys. Rev.* **D95** (2017) 074020, [1702.07181].

[19] B. Coleppa, M. Kumar, S. Kumar and B. Mellado, *Measuring CP nature of top-Higgs couplings at the future Large Hadron electron collider*, *Phys. Lett.* **B770** (2017) 335–341, [1702.03426].

[20] H. Denizli, A. Senol, A. Yilmaz, I. Turk Cakir, H. Karadeniz and O. Cakir, *Top quark FCNC couplings at future circular hadron electron colliders*, *Phys. Rev.* **D96** (2017) 015024, [1701.06932].

[21] H.-Y. Bi, R.-Y. Zhang, H.-Y. Han, Y. Jiang and X.-G. Wu, *Photoproduction of the $B_c^{(*)}$ meson at the LHeC*, *Phys. Rev.* **D95** (2017) 034019, [1612.07990].

[22] S. P. Das and M. Nowakowski, *Light neutral CP-even Higgs boson within Next-to-Minimal Supersymmetric Standard model (NMSSM) at the Large Hadron electron Collider (LHeC)*, *Phys. Rev.* **D96** (2017) 055014, [1612.07241].

[23] J. Hernández-Sánchez, O. Flores-Sánchez, C. G. Honorato, S. Moretti and S. Rosado, *Prospect for observing a light charged Higgs through the decay $H^{+} \to cb$ at the LHeC*, *PoS* **CHARGED2016** (2017) 032, [1612.06316].

[24] S. Antusch, E. Cazzato and O. Fischer, *Sterile neutrino searches at future e^-e^+, pp, and e^-p colliders*, *Int. J. Mod. Phys.* **A32** (2017) 1750078, [1612.02728].

[25] S. Liu, Y.-L. Tang, C. Zhang and S.-h. Zhu, *Exotic Higgs Decay $h \to \phi\phi \to 4b$ at the LHeC*, *Eur. Phys. J.* **C77** (2017) 457, [1608.08458].

[26] A. Ozansoy, V. Ari and V. Çetinkaya, *Search for excited spin-3/2 neutrinos at LHeC*, *Adv. High Energy Phys.* **2016** (2016) 1739027, [1607.04437].

[27] G. R. Boroun, B. Rezaei and S. Heidari, *Nuclear longitudinal structure function in eA processes at the LHeC*, *Int. J. Mod. Phys.* **A32** (2017) 1750197, [1606.02864].

[28] Y. C. Acar, U. Kaya, B. B. Oner and S. Sultansoy, *Color octet electron search potential of FCC based e–p colliders*, *J. Phys.* **G44** (2017) 045005, [1605.08028].

[29] S. Mondal and S. K. Rai, *Probing the Heavy Neutrinos of Inverse Seesaw Model at the LHeC*, *Phys. Rev.* **D94** (2016) 033008, [1605.04508].

[30] M. Lindner, F. S. Queiroz, W. Rodejohann and C. E. Yaguna, *Left-Right Symmetry and Lepton Number Violation at the Large Hadron Electron Collider*, *JHEP* **06** (2016) 140, [1604.08596].

[31] H. Sun and X. Wang, *Exploring the Anomalous Top-Higgs FCNC Couplings at the electron proton colliders*, *Eur. Phys. J.* **C78** (2018) 281, [1602.04670].

[32] S. Mondal and S. K. Rai, *Polarized window for left-right symmetry and a right-handed neutrino at the Large Hadron-Electron Collider*, *Phys. Rev.* **D93** (2016) 011702, [1510.08632].

[33] G. R. Boroun, *Top reduced cross section behavior at the LHeC kinematic range*, *Chin. Phys.* **C41** (2017) 013104, [1510.02914].

[34] M. Kumar, X. Ruan, R. Islam, A. S. Cornell, M. Klein, U. Klein et al., *Probing anomalous couplings using di-Higgs production in electron–proton collisions*, *Phys. Lett.* **B764** (2017) 247–253, [1509.04016].

[35] Y.-L. Tang, C. Zhang and S.-h. Zhu, *Invisible Higgs Decay at the LHeC*, *Phys. Rev.* **D94** (2016) 011702, [1508.01095].

[36] W. Liu, H. Sun, X. Wang and X. Luo, *Probing the anomalous FCNC top-Higgs Yukawa couplings at the Large Hadron Electron Collider*, *Phys. Rev.* **D92** (2015) 074015, [1507.03264].

[37] G. R. Boroun, *Geometrical scaling behavior of the top structure functions ratio at the LHeC*, *Phys. Lett.* **B744** (2015) 142–145, [1503.01590].

[38] S. P. Das, J. Hernández-Sánchez, S. Moretti, A. Rosado and R. Xoxocotzi, *Flavor violating signatures of lighter and heavier Higgs bosons within the Two Higgs Doublet Model Type-III at the LHeC*, *Phys. Rev.* **D94** (2016) 055003, [1503.01464].

[39] L. Duarte, G. A. González-Sprinberg and O. A. Sampayo, *Majorana neutrinos production at LHeC in an effective approach*, *Phys. Rev.* **D91** (2015) 053007, [1412.1433].

[40] I. A. Sarmiento-Alvarado, A. O. Bouzas and F. Larios, *Analysis of top-quark charged-current coupling at the LHeC*, *J. Phys.* **G42** (2015) 085001, [1412.6679].

[41] G. R. Boroun, *Top structure function at the LHeC*, *Phys. Lett.* **B741** (2015) 197–201, [1411.6492].

[42] I. T. Cakir, O. Cakir, A. Senol and A. T. Tasci, *Search for anomalous $WW\gamma$ and WWZ couplings with polarized e-beam at the LHeC*, *Acta Phys. Polon.* **B45** (2014) 1947, [1406.7696].

[43] R.-Y. Zhang, H. Wei, L. Han and W.-G. Ma, *Probing L-violating coupling via sbottom resonance production at the LHeC*, *Mod. Phys. Lett.* **A29** (2014) 1450029, [1401.4266].

[44] J. T. Amaral, V. P. Goncalves and M. S. Kugeratski, *Probing gluon number fluctuation effects in future electron–hadron colliders*, *Nucl. Phys.* **A930** (2014) 104–116, [1312.4741].

[45] X.-P. Li, L. Guo, W.-G. Ma, R.-Y. Zhang, L. Han and M. Song, *Single (anti-)top quark production in association with a lightest neutralino at the LHeC*, *Phys. Rev.* **D88** (2013) 014023, [1307.2308].

[46] S. Dutta, A. Goyal, M. Kumar and B. Mellado, *Measuring anomalous Wtb couplings at e^-p collider*, *Eur. Phys. J.* **C75** (2015) 577, [1307.1688].

[47] I. T. Cakir, O. Cakir, A. Senol and A. T. Tasci, *Probing Anomalous HZZ Couplings at the LHeC*, *Mod. Phys. Lett.* **A28** (2013) 1350142, [1304.3616].

[48] S. Kuday, *Resonant Production of Sbottom via RPV Couplings at the LHeC*, *J. Korean Phys. Soc.* **64** (2014) 1783–1787, [1304.2124].

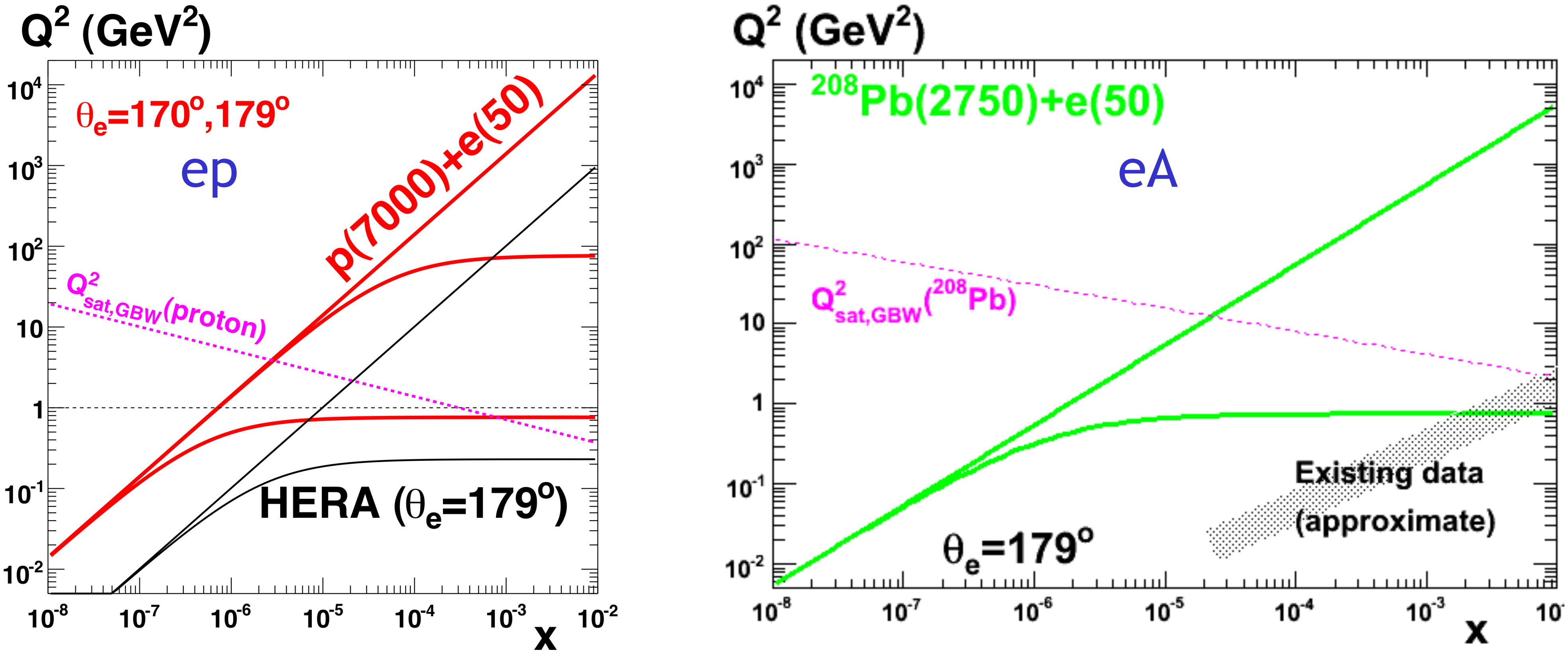
[49] M. Sahin, *Resonant production of spin-3/2 color octet electron at the LHeC*, *Acta Phys. Polon.* **B45** (2014) 1811, [1302.5747].

[50] I. T. Cakir, A. Senol and A. T. Tasci, *Associated Production of Single Top Quark and W-boson Through Anomalous Couplings at LHeC based γp Colliders*, *Mod. Phys. Lett.* **A29** (2014) 1450021, [1301.2617].

50 journal papers on NP with LHeC in recent years

Thanks to Hao Sun

Low x: 2 oders of magnitude extension for ep, 4 for eA … Saturation at perturbative Q^2



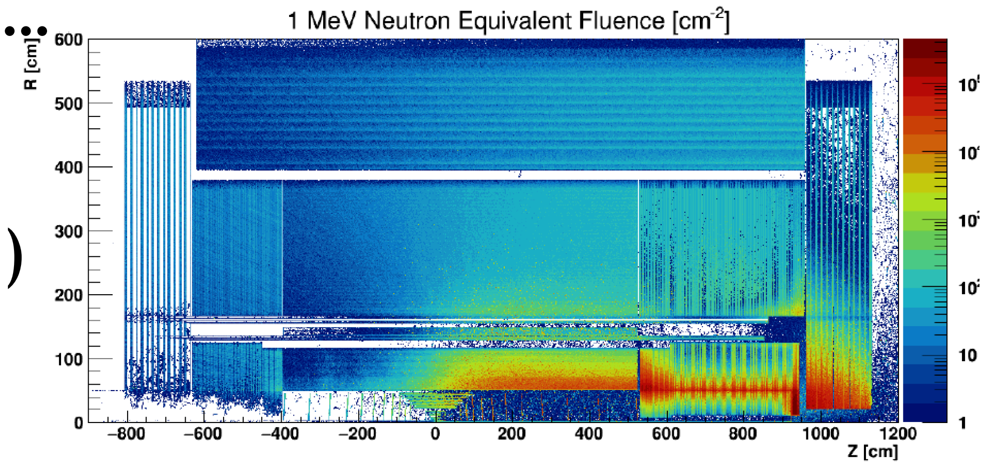
- Low x, Q^2 corner of phase space accesses expected saturated region in both ep & eA at perturbative Q^2 according to models

• Detailed understanding of saturation will be based on tensions between different observables e.g. F_2 , F_L , diffraciton in ep, eA

Detector Design: Philosophy

- Detector technologies evolve fast; current designs can only be indicative / based on current knowledge … will change

Fluences



- Conditions are relatively ‘easy’ …

… fluences <~ 10^5 1 MeV n cm-^{2} equiv (tiny fractions of HL-LHC)

… pile-up ~ 0.1 (cf 200 at HL-LHC)

- Most of current `baseline’ remains the 2012 CDR

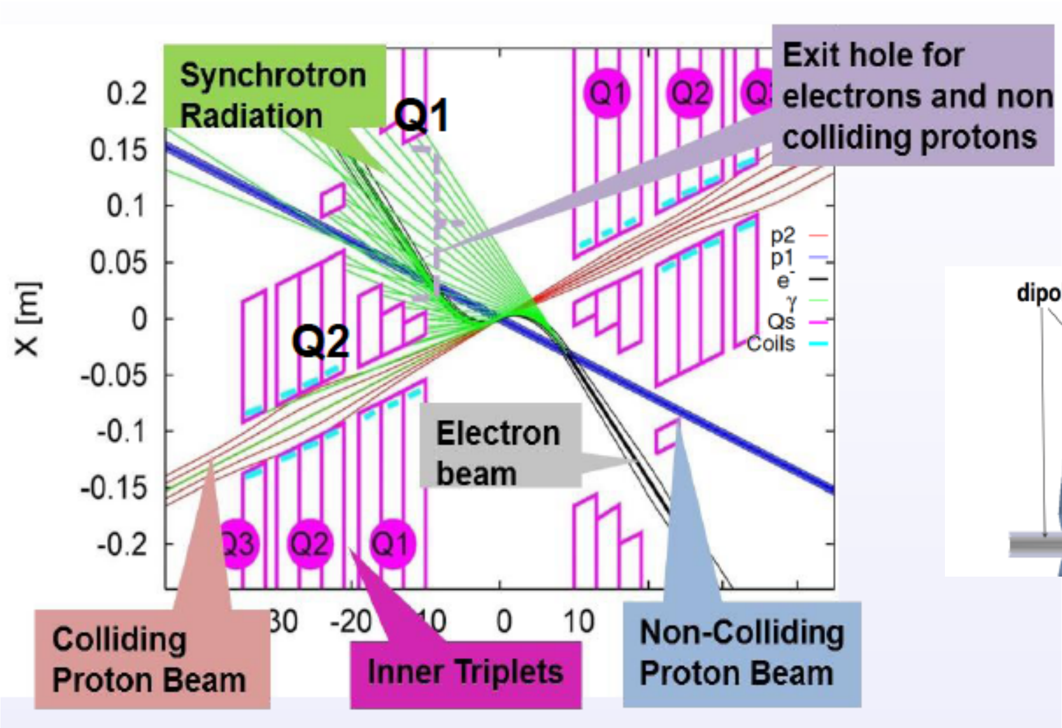
→ Leans heavily on LHC (esp. ATLAS) technologies

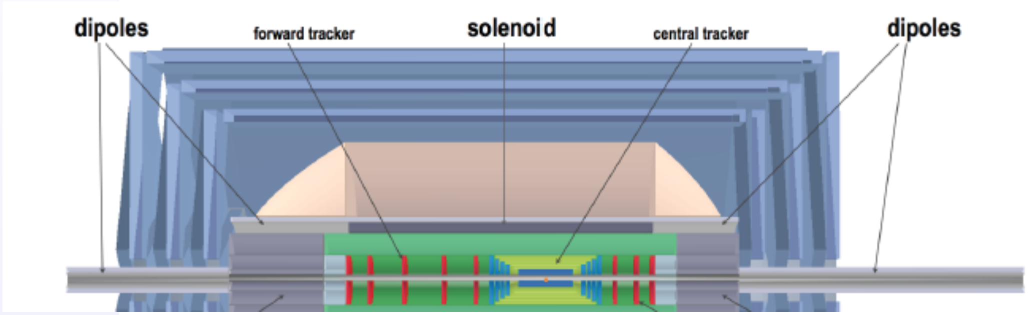
→ Was costed at CHF106M core cost

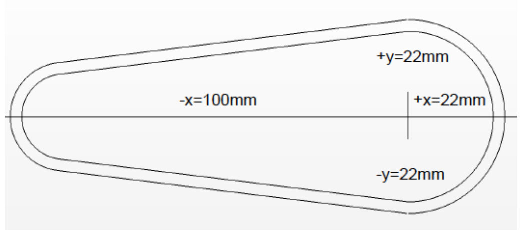
→ Feasibility and optimisation studies ongoing

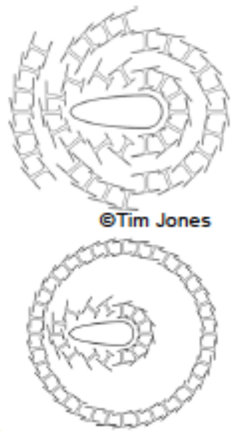
- Most challenging technology aspects are interaction region (synchrotron) and ER linac

Interaction Region & Magnets

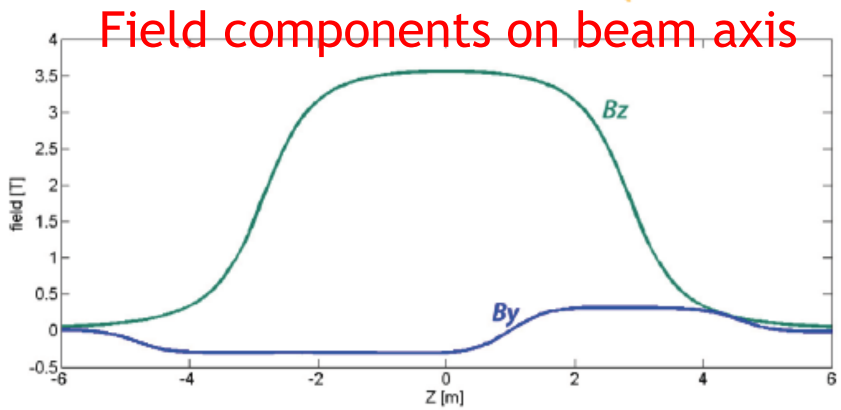




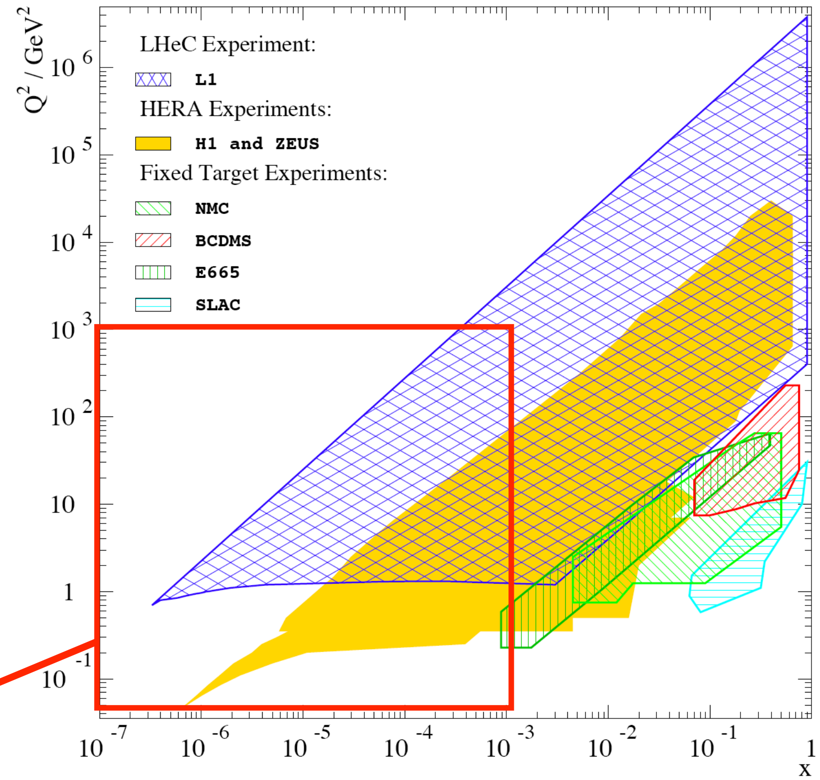




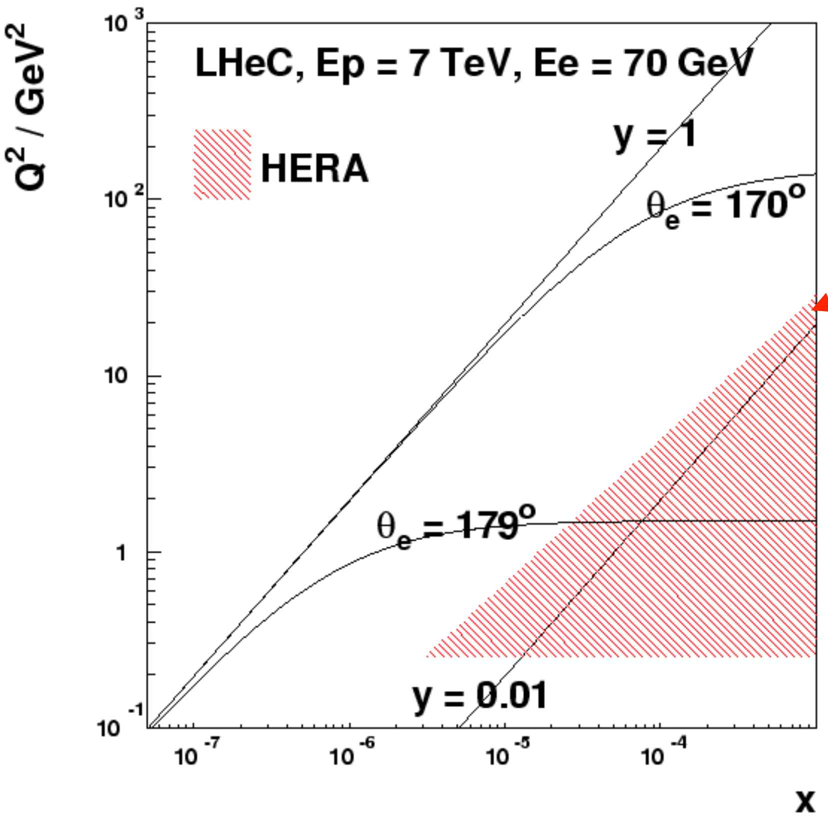
- Dual dipole magnets (0.15 – 0.3 T) throughout detector region (|z| < 14m) bend electrons into head-on collisions
- Eliptical beampipe (6m x 3mm Be) accommodates synchrotron fan
- 3.5 T Superconducting NbTi/Cu Solenoid in 4.6K liquid helium cryo.



LHeC Detector Acceptance Requirements

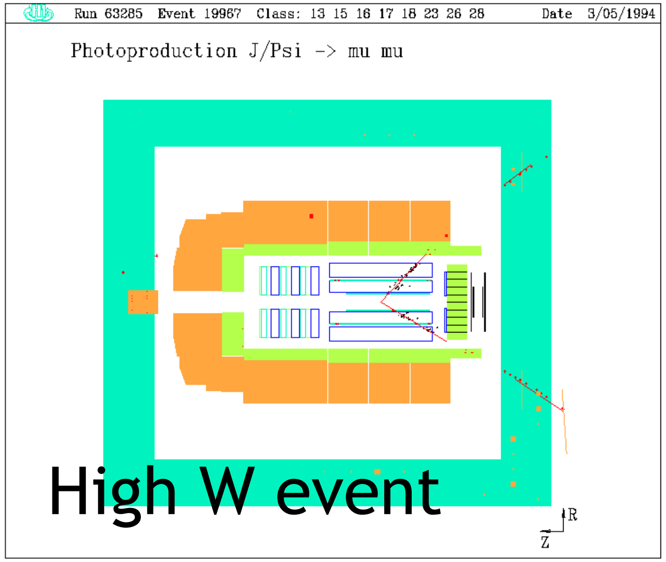


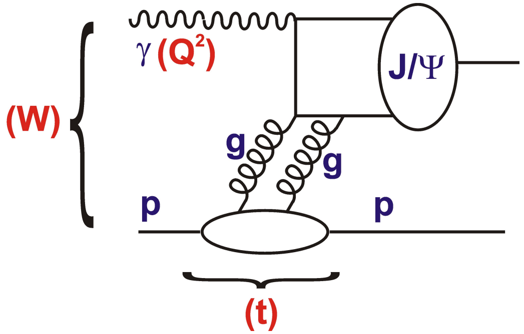
Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°



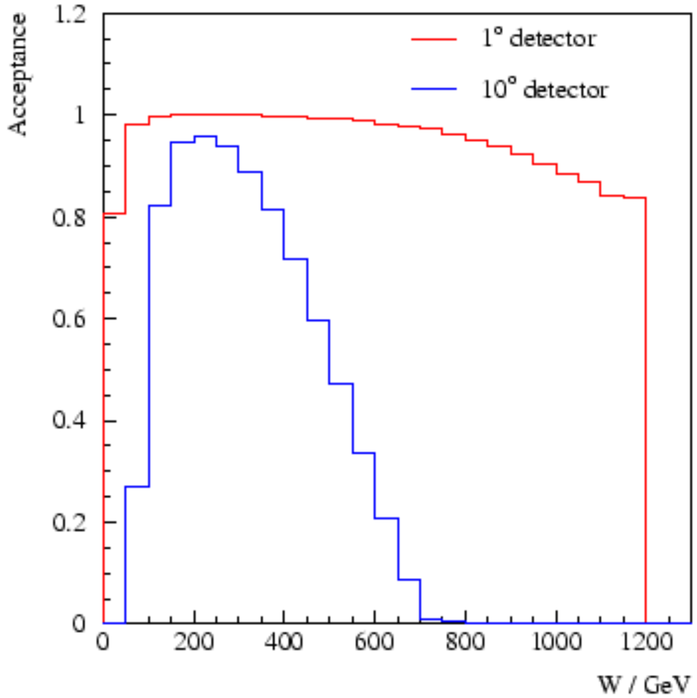
Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x (essential for good kinematic reconstruction)

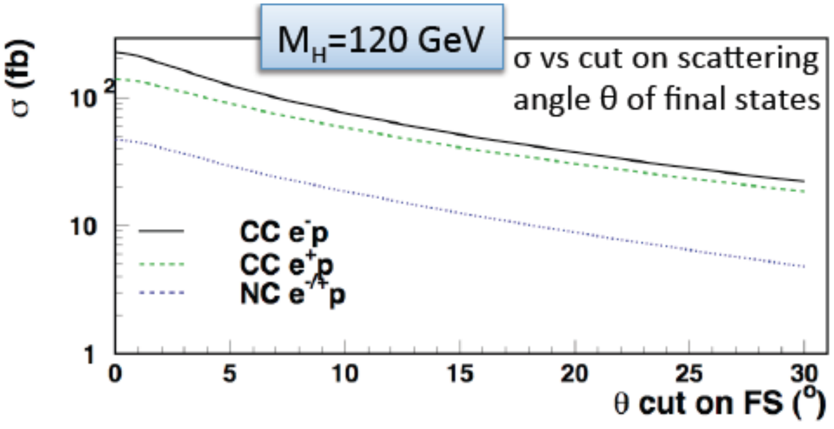
Acceptance Requirements, Final States



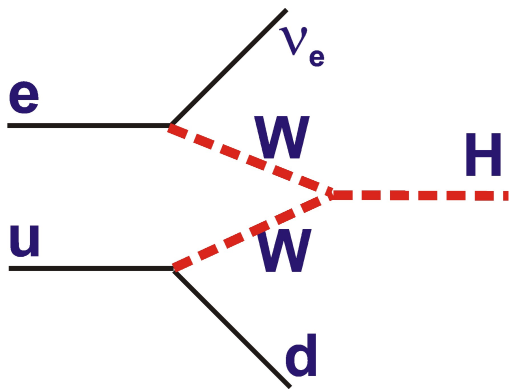


- Elastic J/Ψ Photoproduction

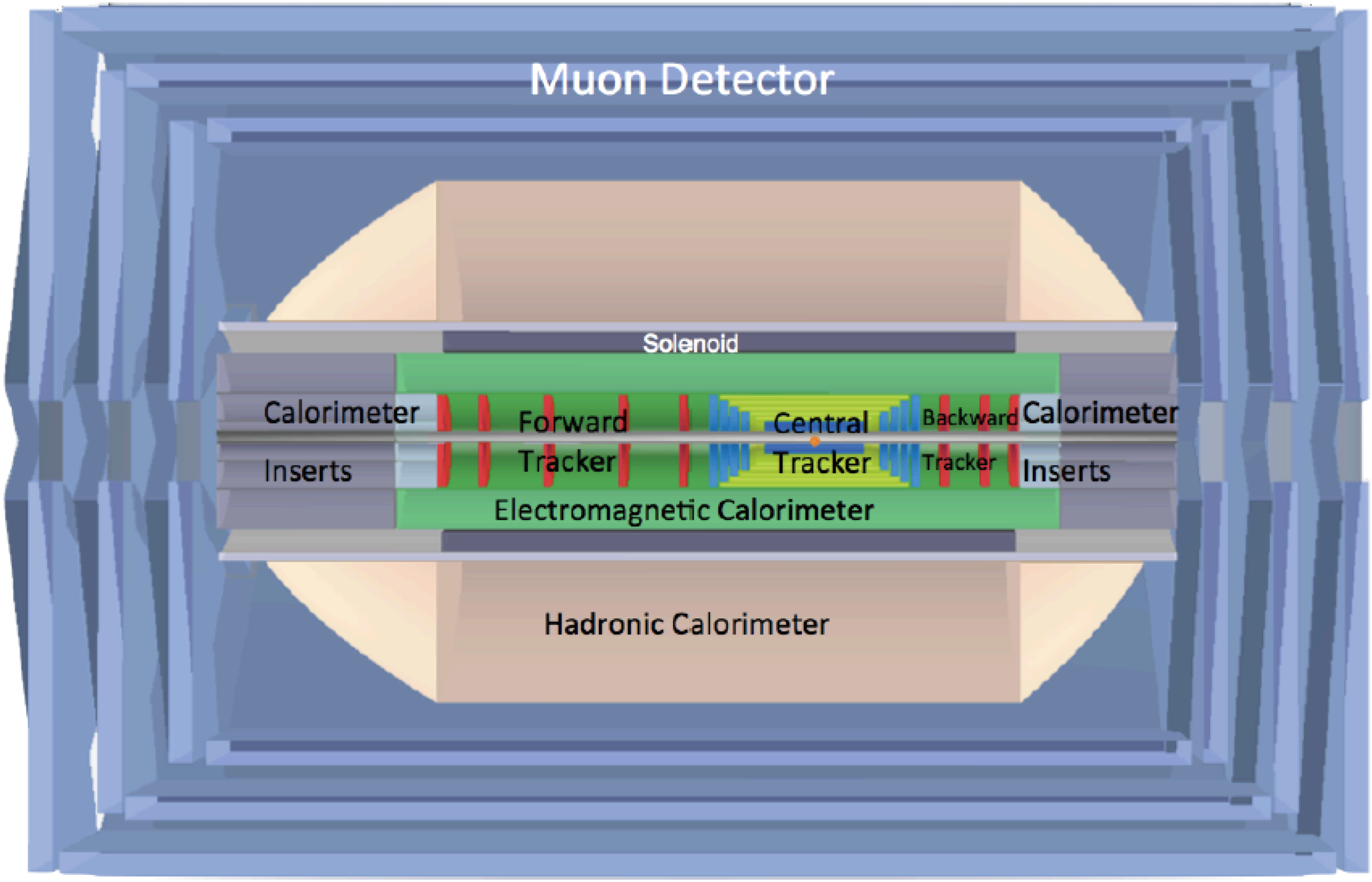




- Higgs Production



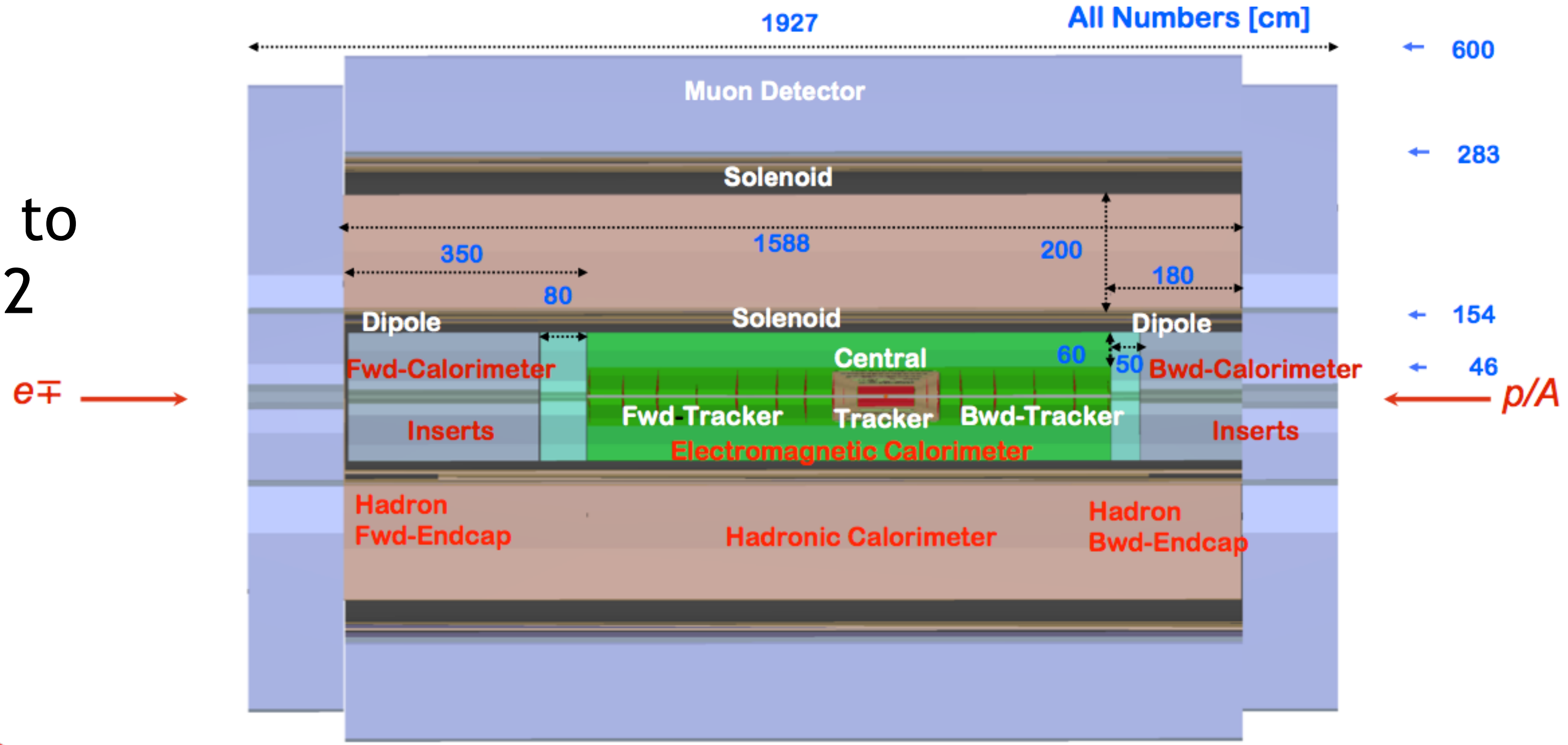
Detector Design from the CDR (2012)

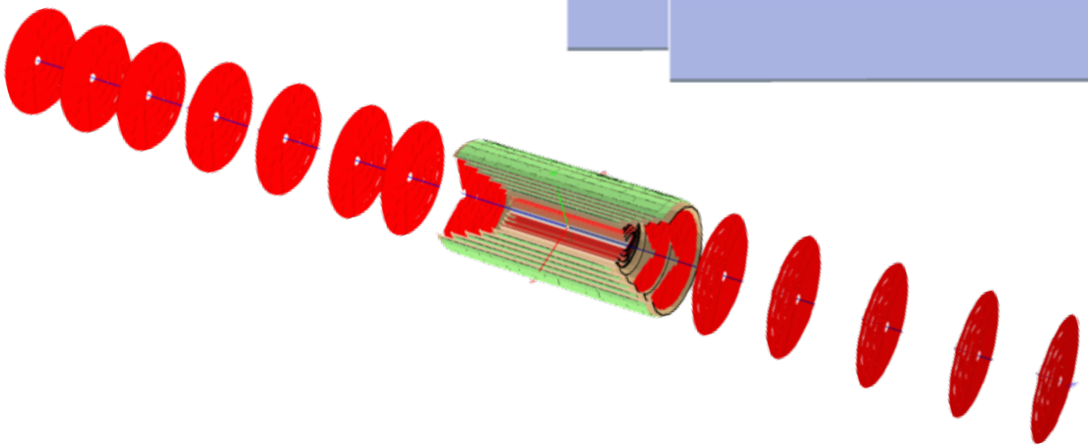


- Size 13m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- 1° tracking acceptance in both forward & backward directions
- Forward & backward beam-line instrumentation integrated

Detector for ep at a Future Circular Collider

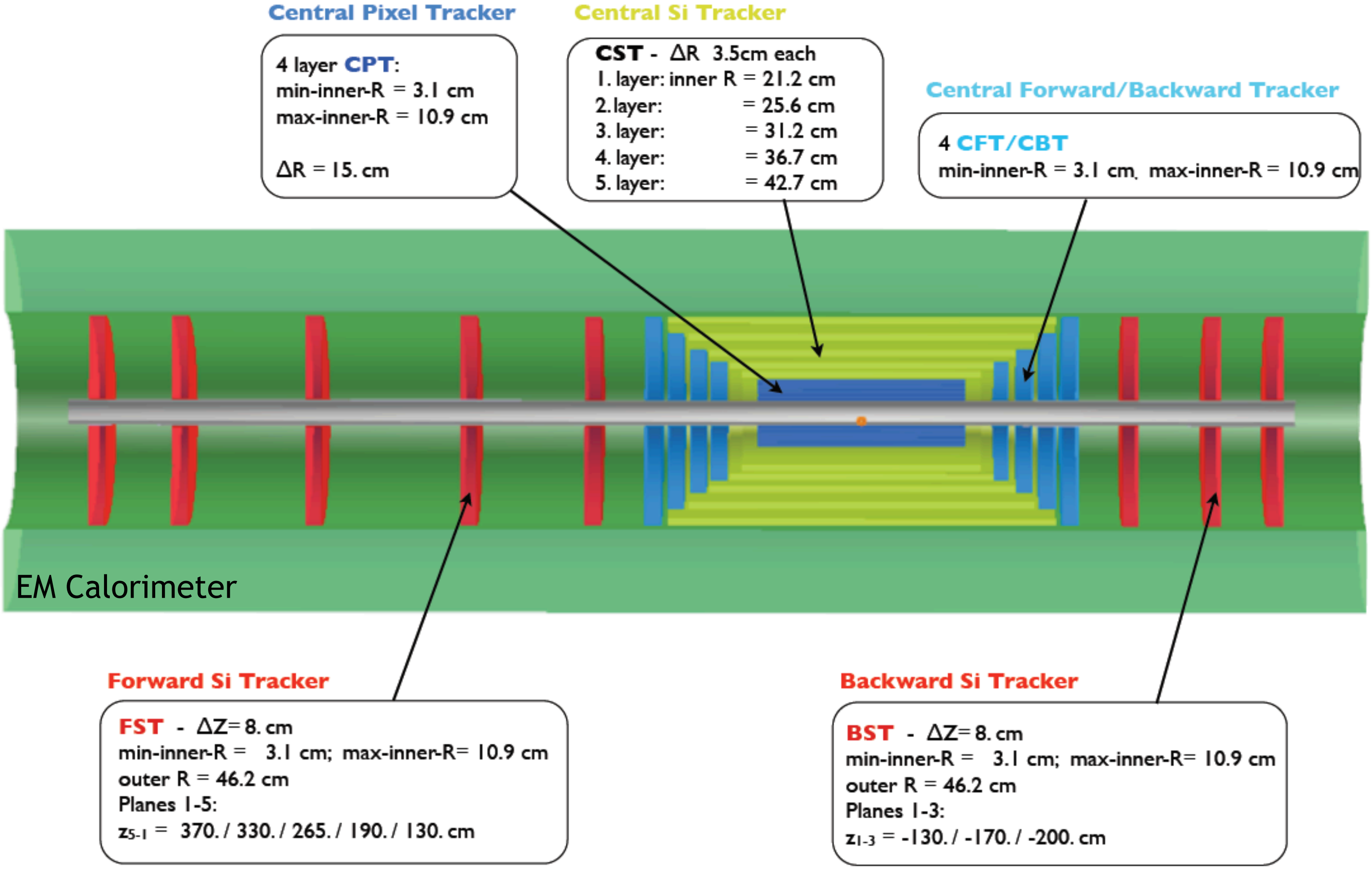
-Detector Scales in size by up to ln(50/7)~ 2





- Double solenoid + Dipole
- Even longer tracking region

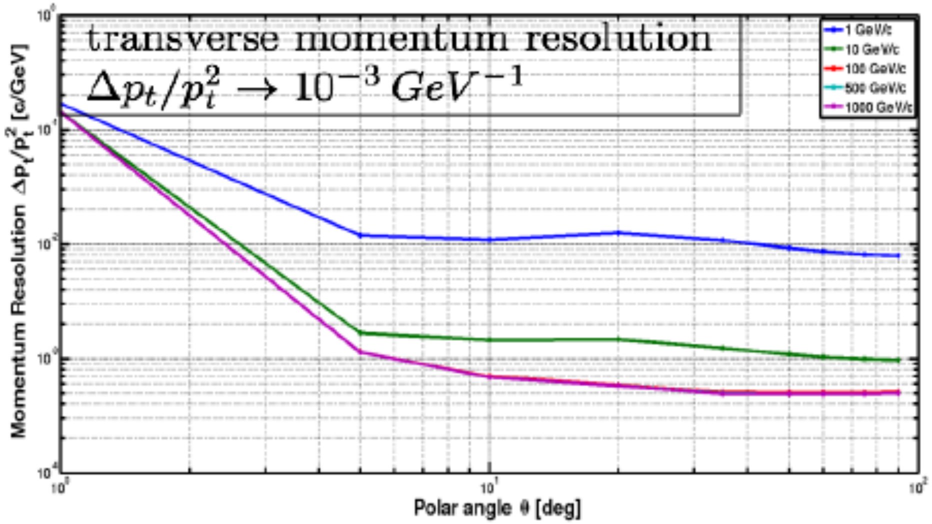
CDR Version Tracking Region

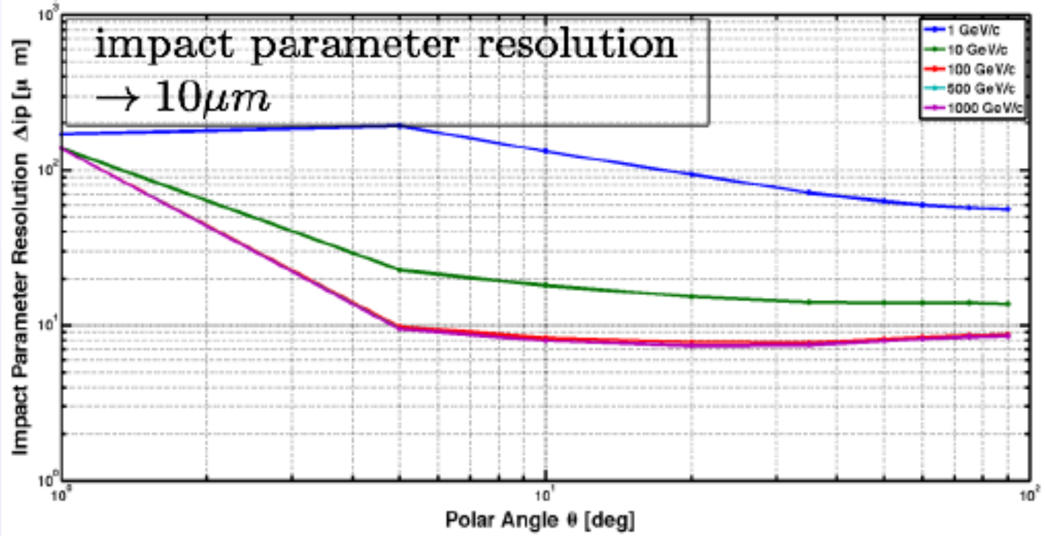


- Long tracking region → 1° electron hits 2 tracker planes
- Forward direction most demanding (dense, high energy jets)
- Pixels + Strips; possible technologies include MAPS / HV-CMOS

Tracking Simulation

Performance evaluated from basic layout (LicToy 2.0 program)





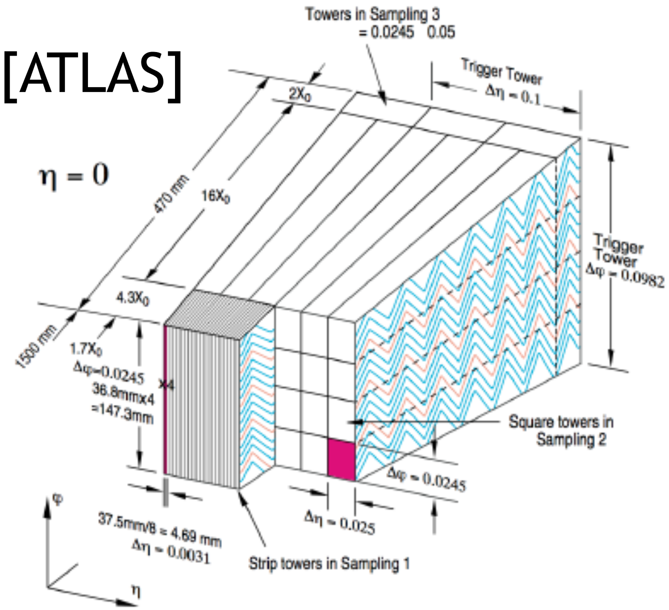
- Central tracks:
  - Excellent track resolution: $\Delta p_t/p^2_t \to 6\ 10^{-4}\ GeV^{-1}$
  - Excellent impact parameter resolution: → 10μm

- Forward / Backward tracks:
  - Degrades somewhat for $\theta <\sim 5^o$
  - At 1^o, bending field component = 0.36 T (similar to dipole)

CDR Barrel EM Calorimeter

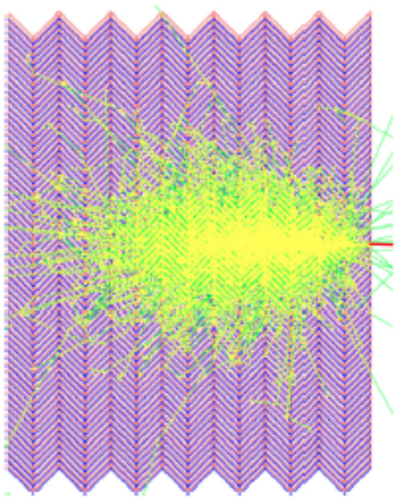
- $-2.3 < \eta < 2.8$
- Accordion geometry baseline design
- 2.2mm lead + 3.8mm LAr layers
- Total depth ~ 20 X_0

[ATLAS]

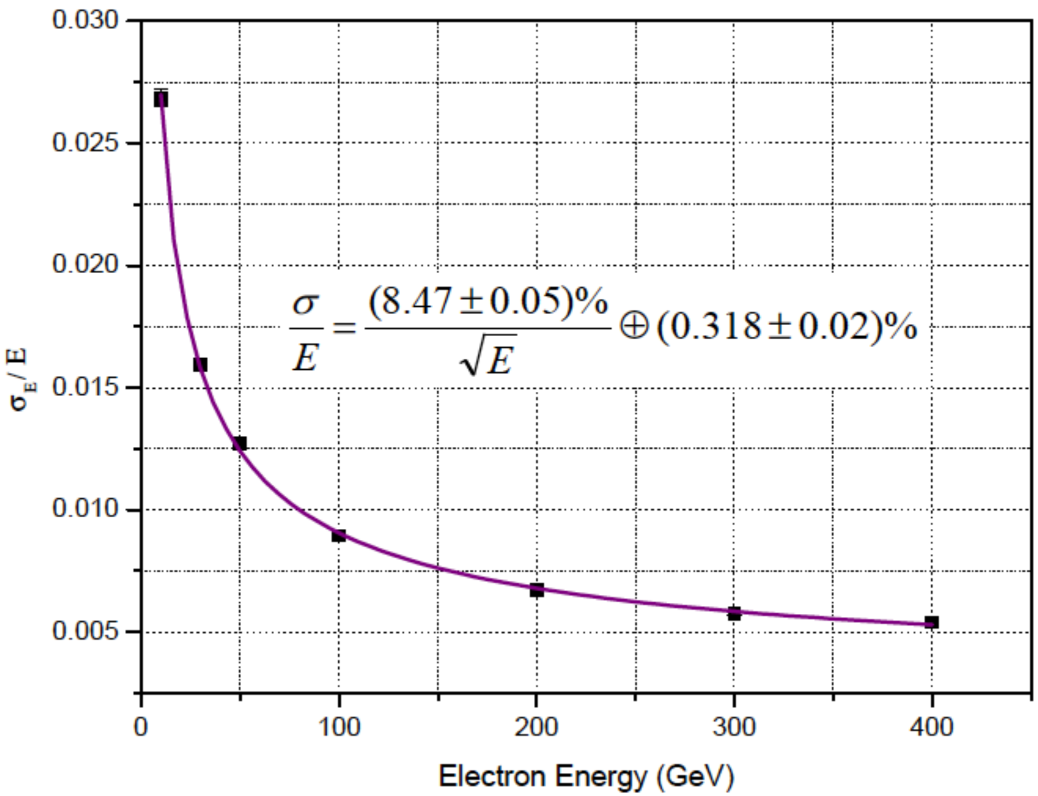


- GEANT4 simulation of response to electrons at normal incidence

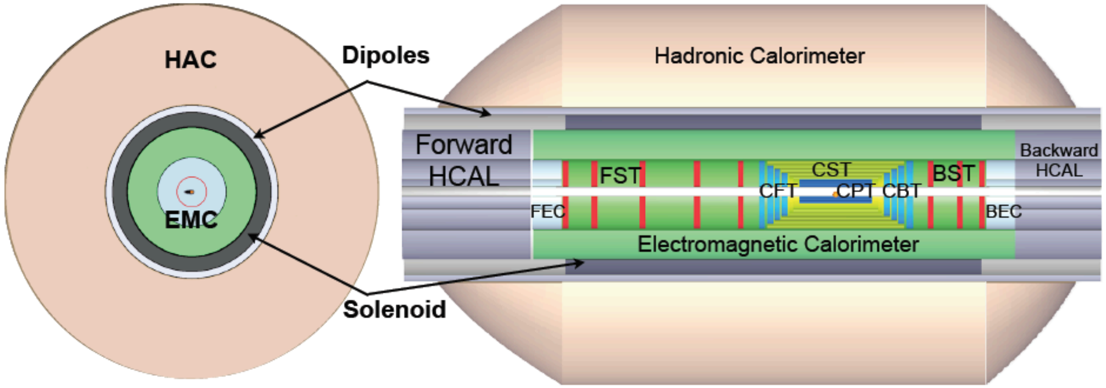
[cf ATLAS: 10%/√E + 0.35%]



[20 GeV electron shower)]

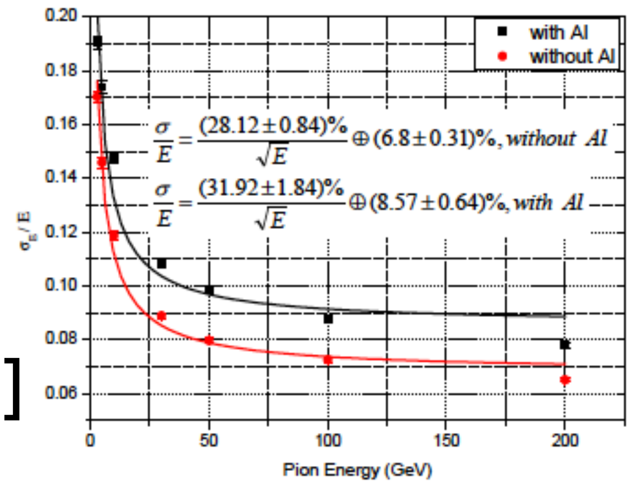


Other Calorimeters in the CDR



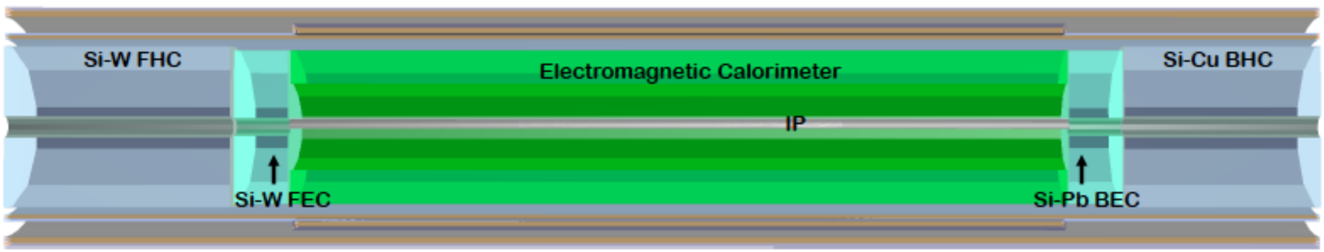
Current design based on (experience with) ATLAS (and H1), re-using existing technologies

- Barrel HAD calorimeter, outside coil
  → 4mm Steel + 3mm Scintilating Tile
  → 7-9 λ, σ_E/E ~ 30%/√E + 9% [~ ATLAS]



- Forward end-cap silicon + tungsten, to cope with highest energies & multiplicities, radiation tolerant EM → $30X_0$, Had→9λ

- Backward end-cap
Pb+Si for EM ($25X_0$)
Cu+Si for HAD (7λ)



CDR Muon System

Baseline: Provides tagging, but not momentum measurement

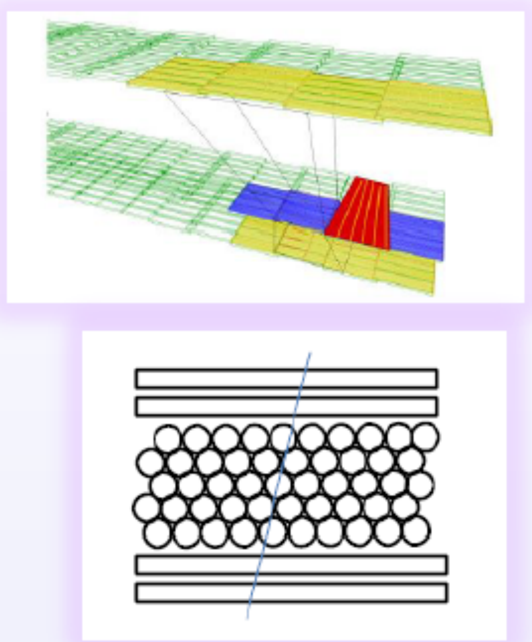
(under review in view of Higgs physics programme)

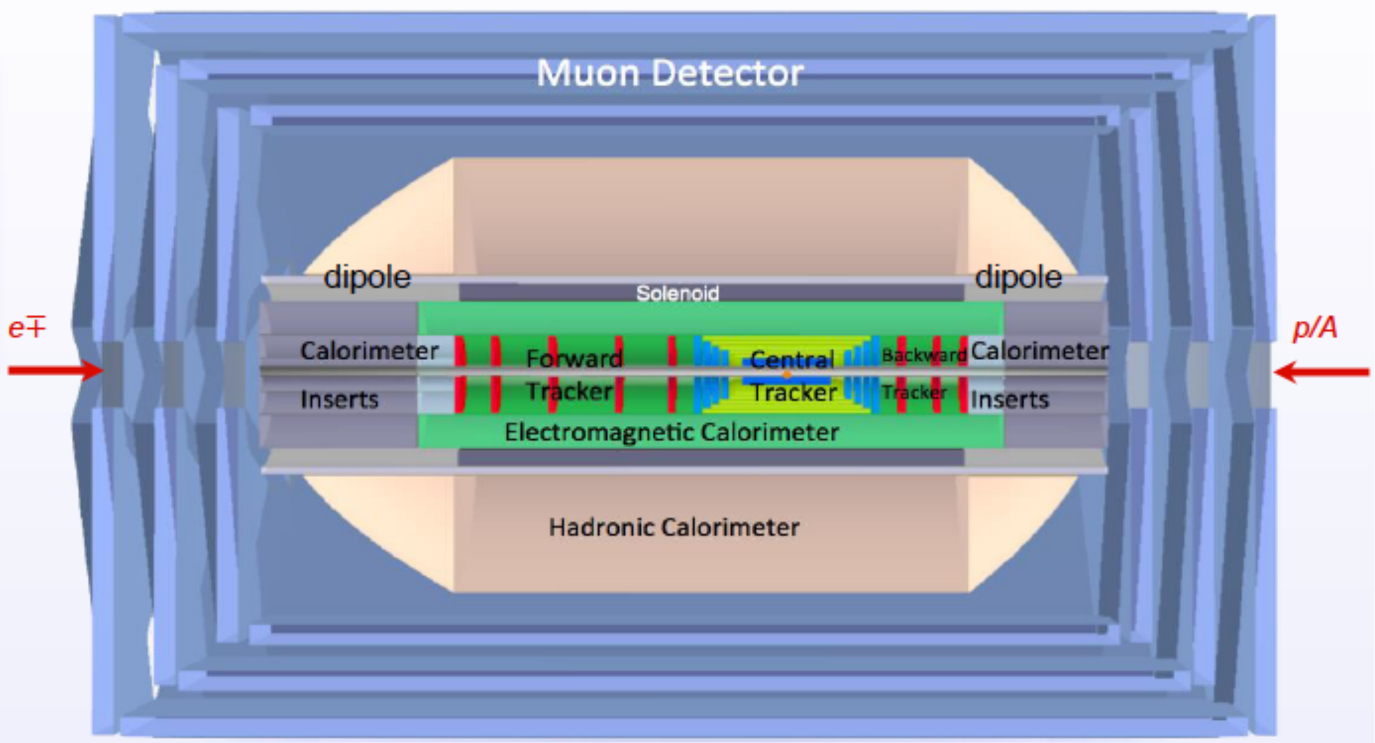
: Angular coverage → 1° vital eg for elastic J/Ψ

: Technologies used in LHC GPDs and their upgrades

(more than) adequate

[2 or 3 Superlayers]

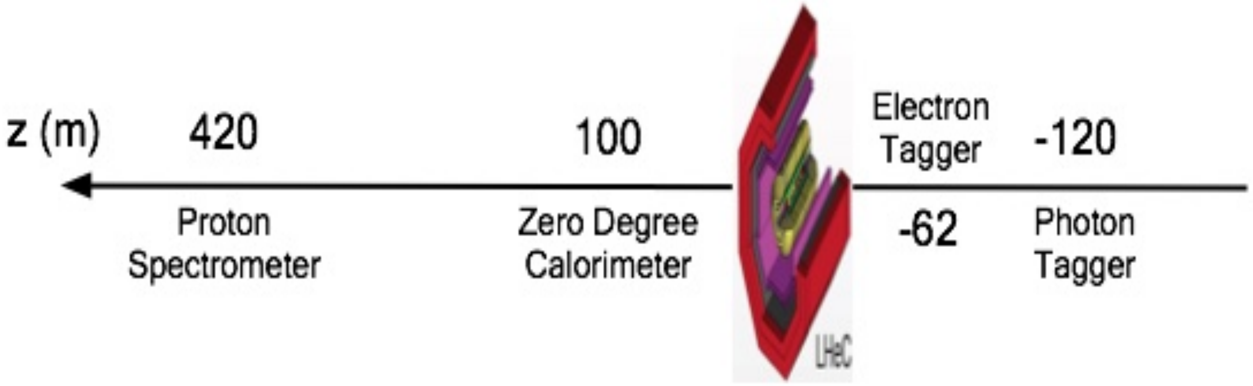




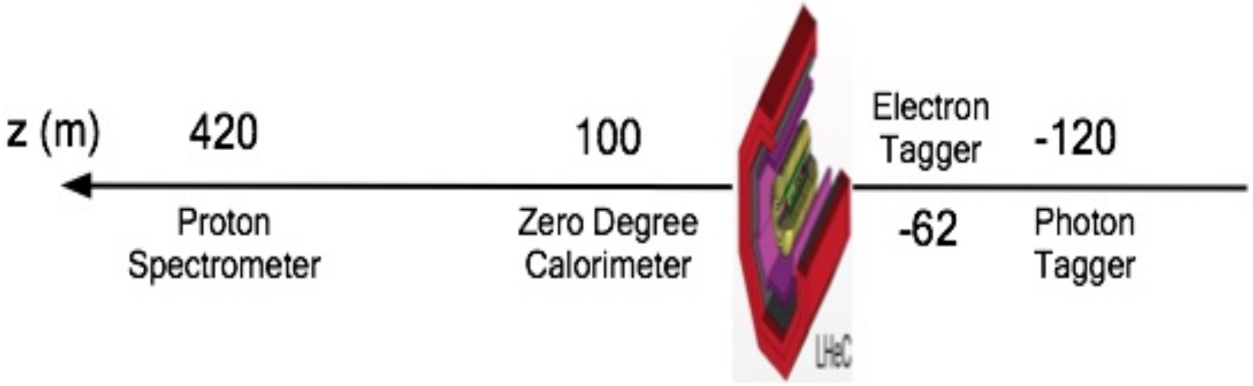
[Drift tubes / Cathode strip chambers → precision

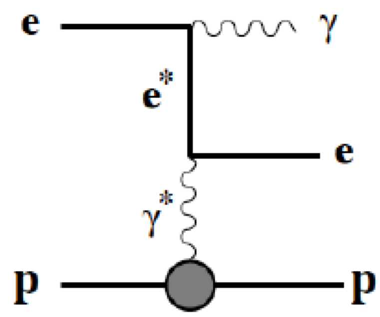
Resistive plate / Thin Gap chambers → trigger + 2nd coord]

Beamline Instrumentation



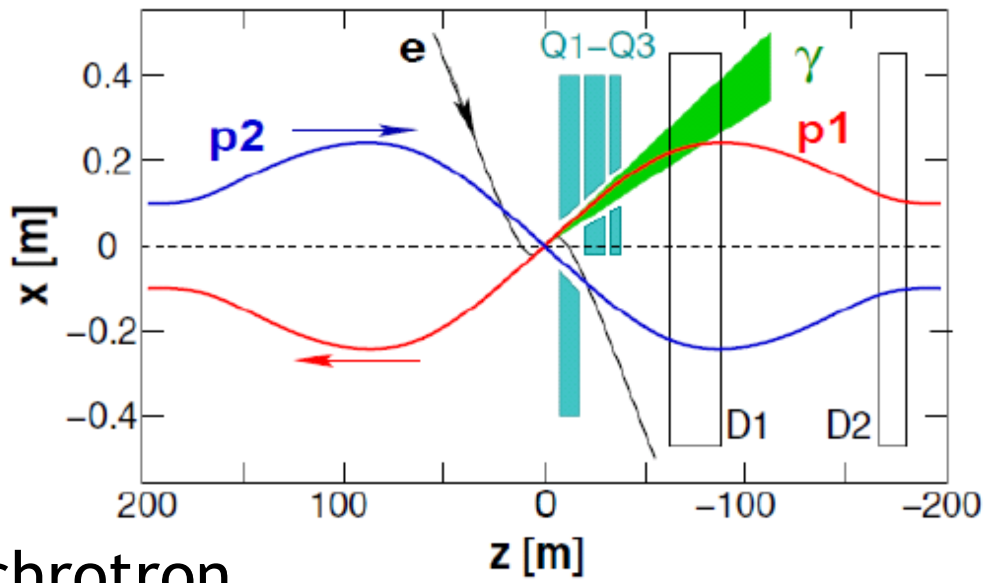
Beamline Instrumentation





Luminosity / Photon Tagging

- Use Bethe-Heitler (as HERA), measurement based on photon

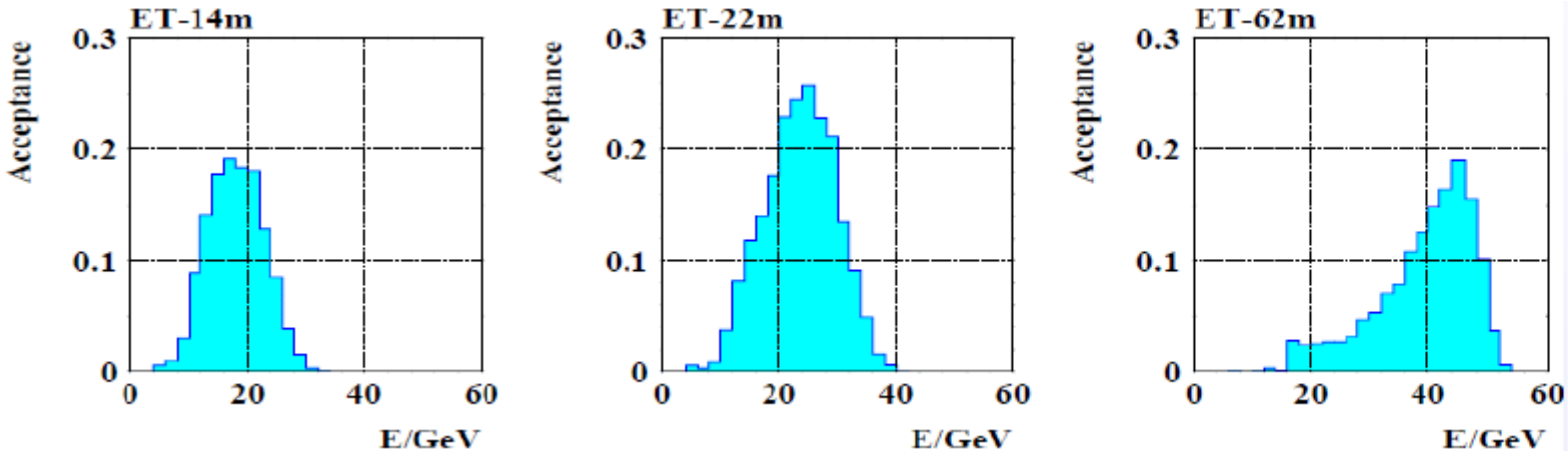


- Photons might be detected at z = -120 m after D1 proton bending dipole
- With sufficient apperture through Q1-Q3 magnets, 95% geometrical acceptance
- Signal via Cerenkov from synchrotron absorber coolant

→ 1% lumi measurement?

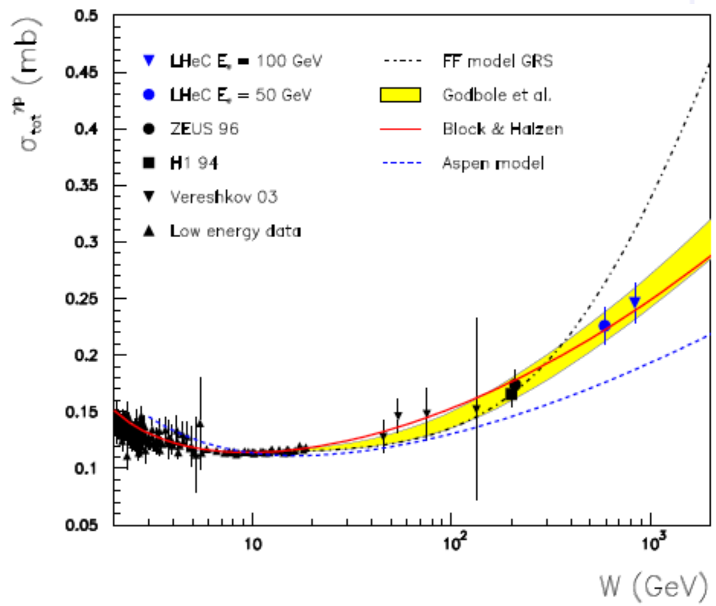
Low Angle Electron Tagging

- Reinforce luminosity measurement
- Tag γp for measurements and as background to DIS



- Acceptances ~ 20–25% at 3 different locations studied

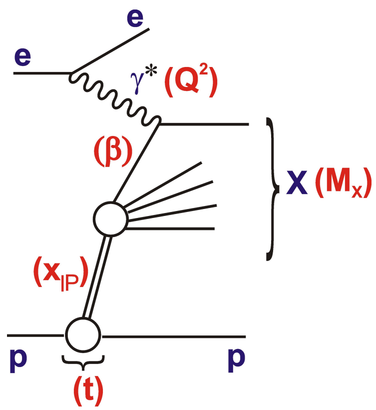
- 62m is most promising due to available space and synchrotron radiation conditions

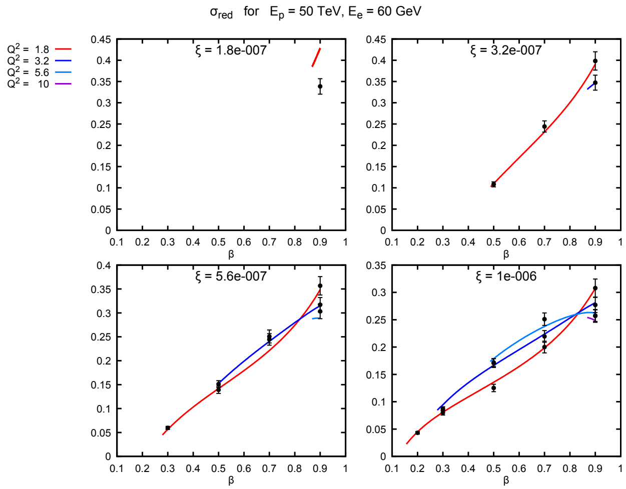


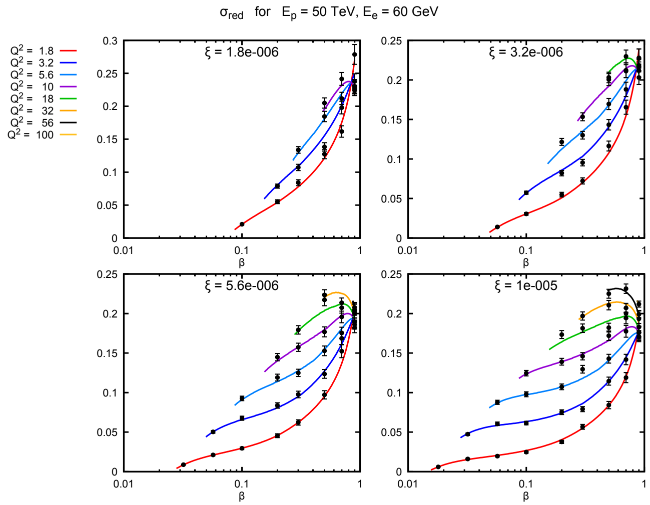
What we Dream of Measuring in Diffraction …

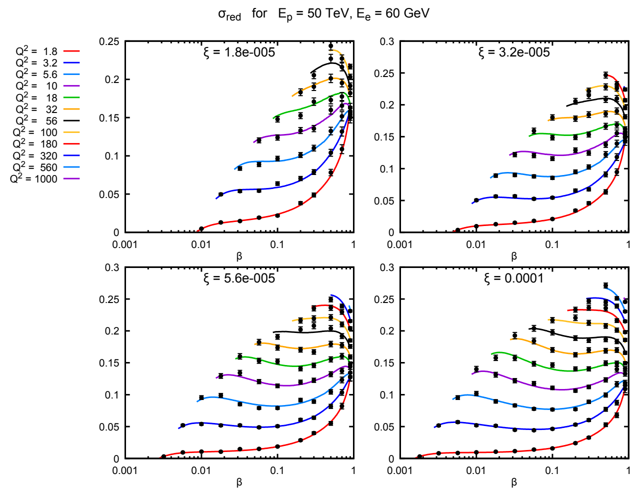
ξ (=x_{IP}) =1.8 x 10^{-7}

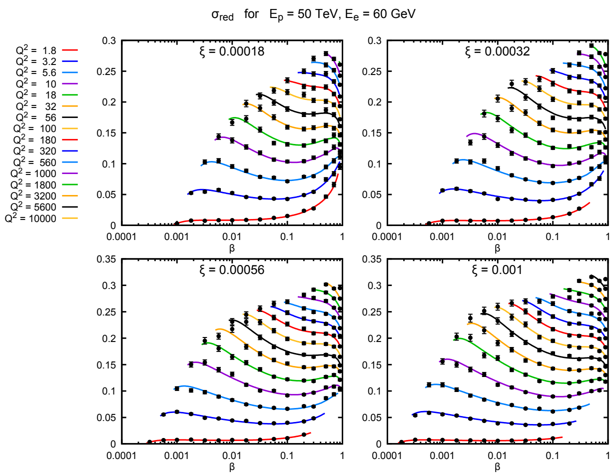
Simulated LHeC F_2^D data assumes full efficiency & acceptance

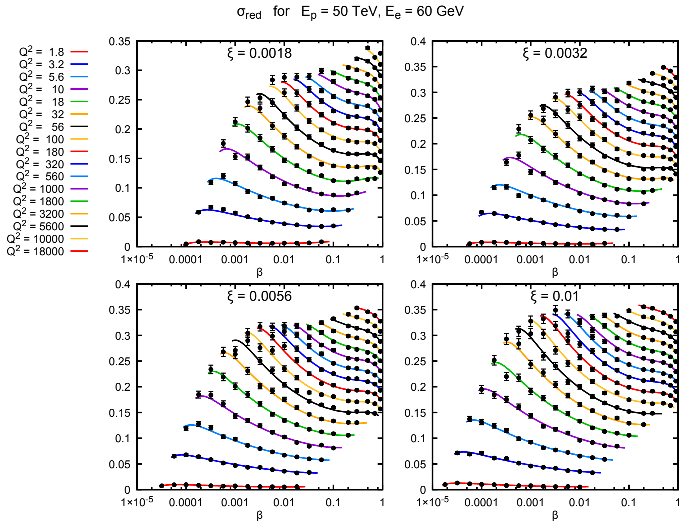


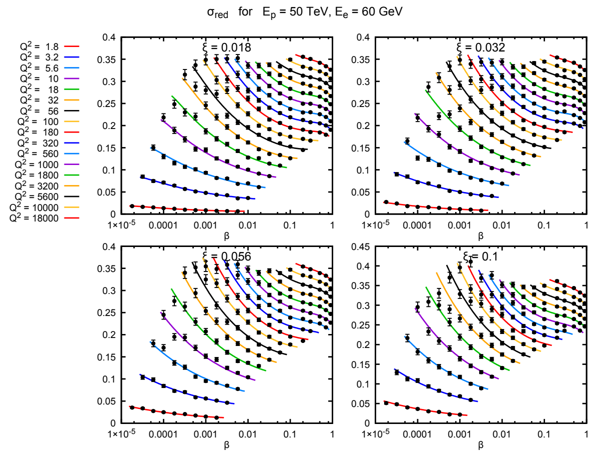












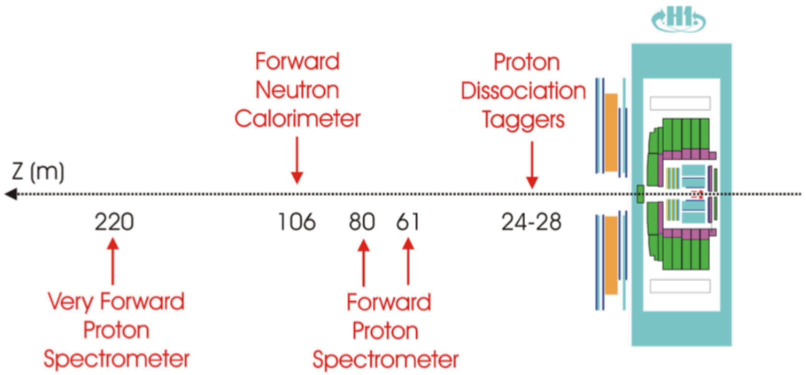
ξ=0.1

Methods for Diffraction and Elastics

… old slide from diffraction at HERA

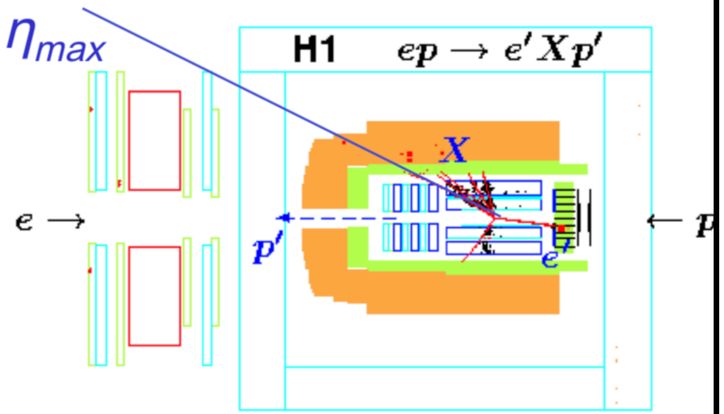
Signatures and Selection Methods

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



Limited by statistics and p-tagging systematics

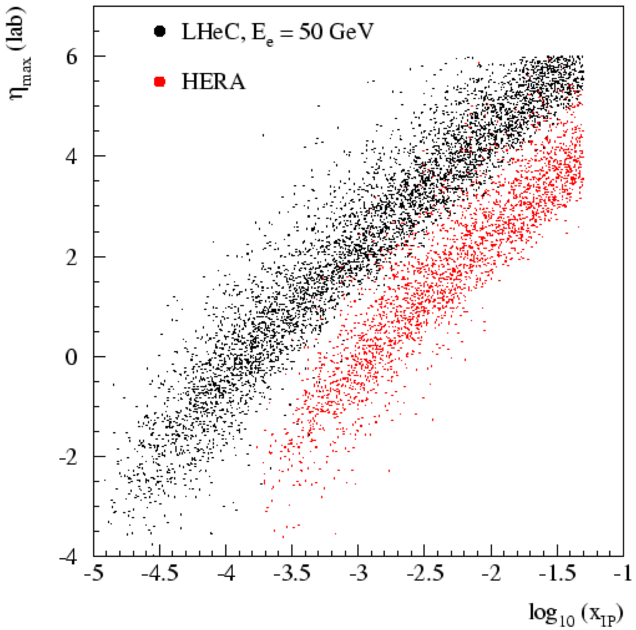
`Large Rapidity Gap' **(LRG)** adjacent to outgoing (untagged) proton

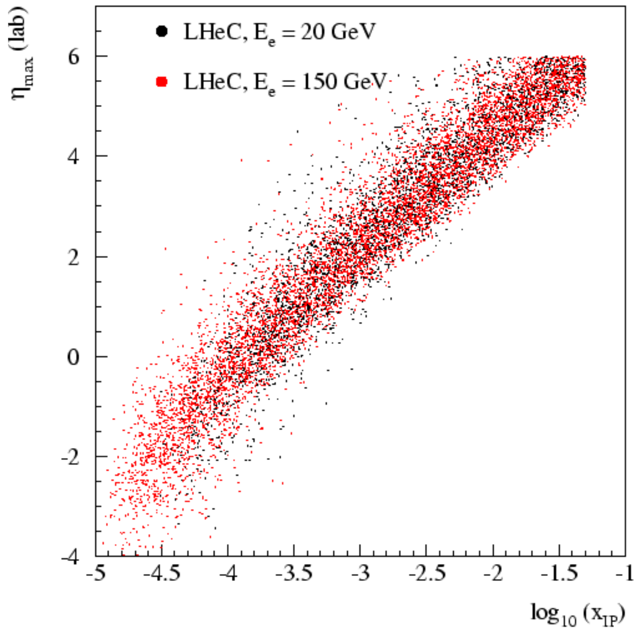


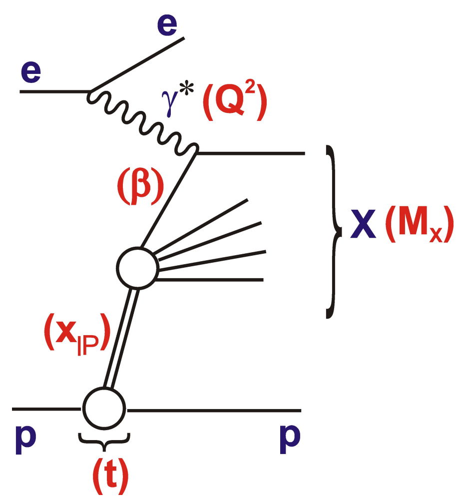
Limited by p-diss systematics

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

Rapidity Gap Selection with LHeC Kinematics

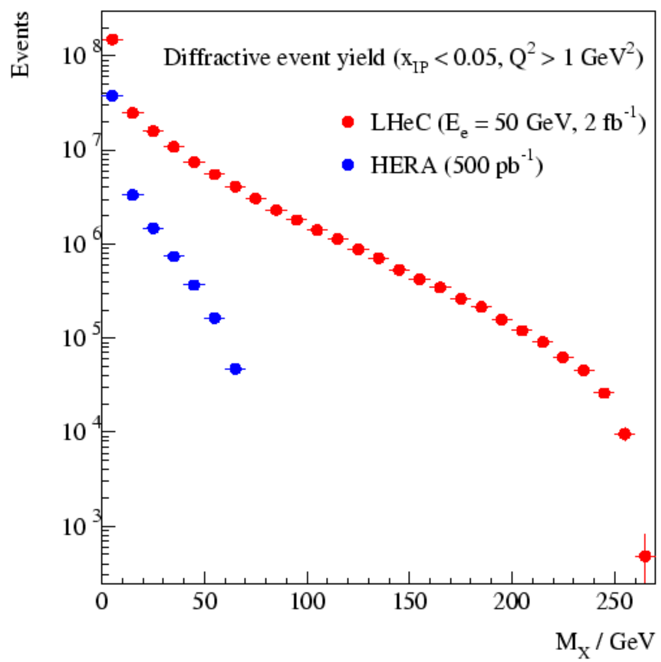




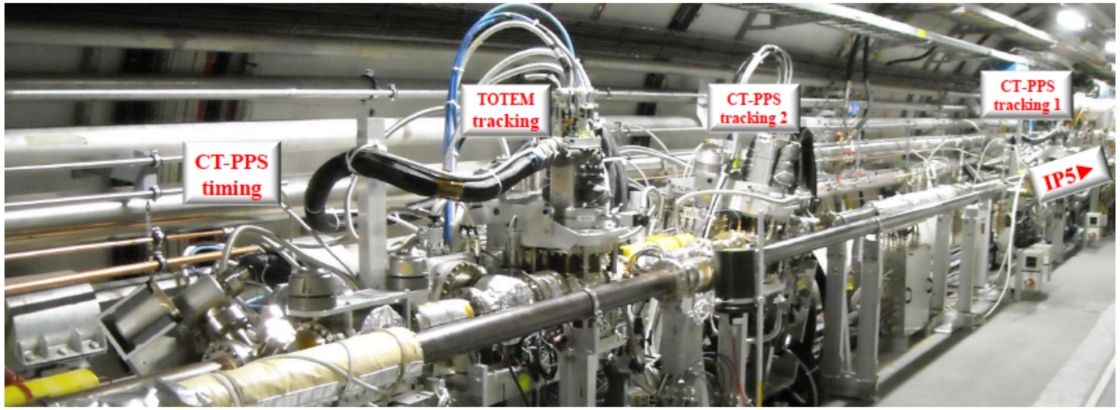


– η_{max} v ξ (= x_{IP}) correlation determined entirely by proton beam energy …
[LHeC proton kinematics same as LHC]

- 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

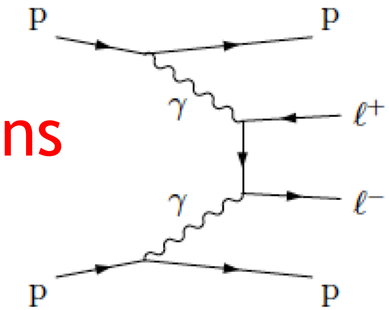


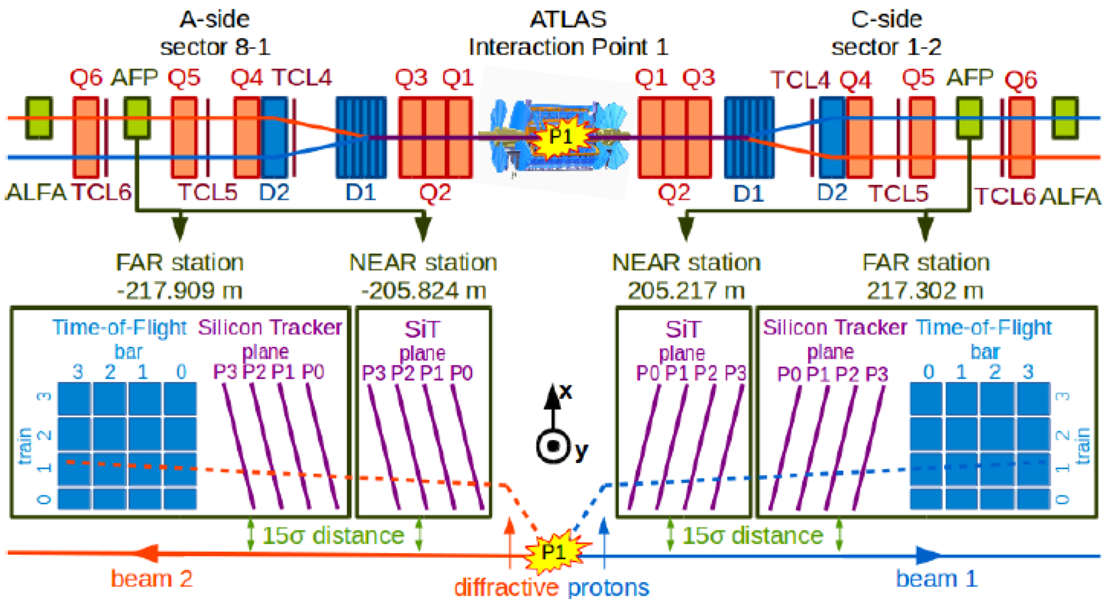
Proton Spectrometers Come of Age at LHC

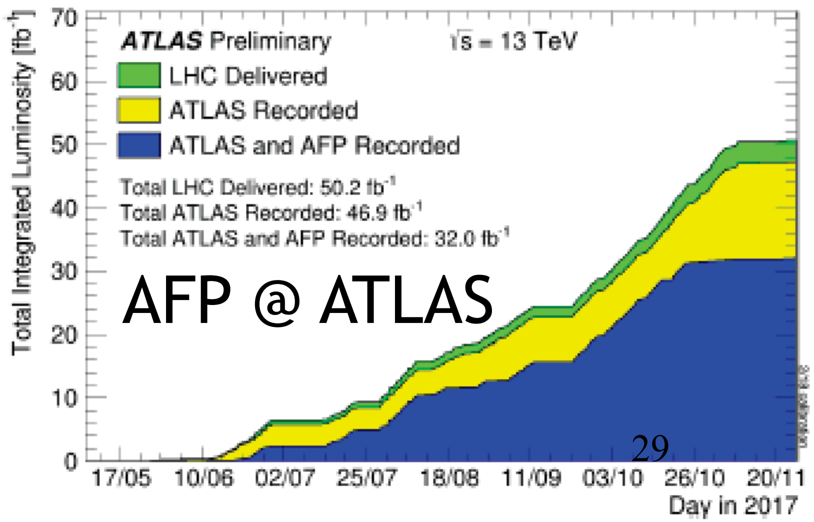


- e.g. TOTEM has 14 Roman pot stations (Hor & Vert), either for special runs (elastic pp→pp etc) or high luminosity physics

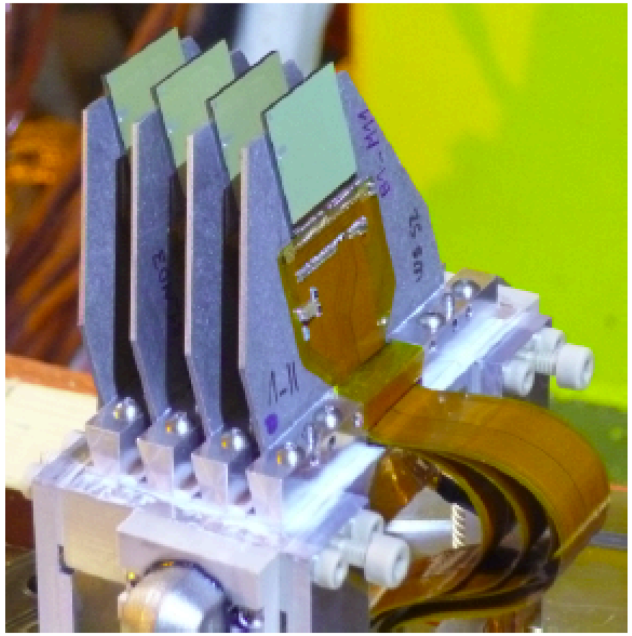
- Most advanced (PPS at CMS, AFP at ATLAS) now Routinely operating in standard LHC running conditions
→Transforms `diffractive' physics programme …





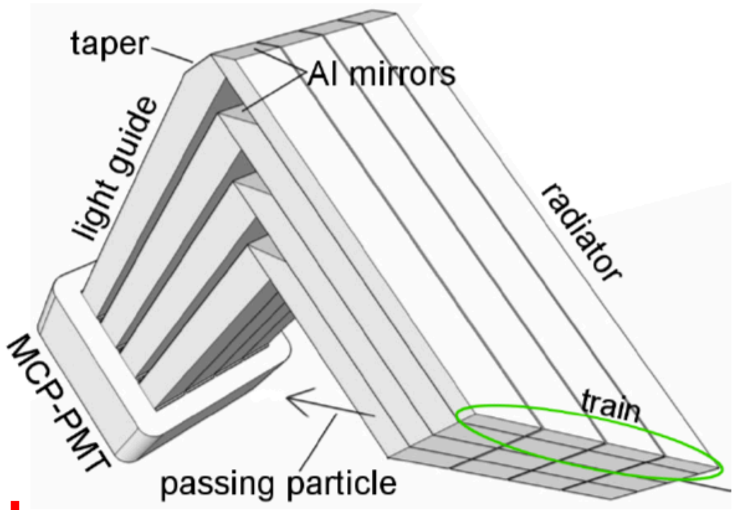


AFP Detectors inside Pots



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

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



But we can't just put them everywhere!
- Locations of pots restricted by beam elements
- Scattered proton trajectories blocked by collimators etc
- Sensitive detectors can't approach arbitrarily close to beam

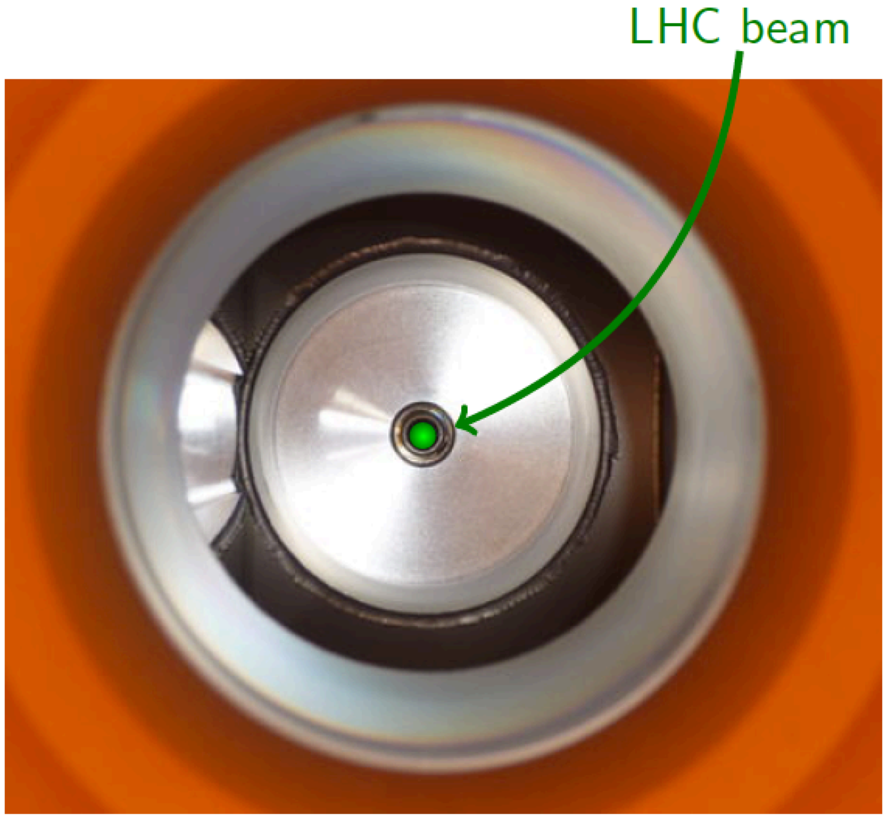
What Determines AFP Acceptance?

Advantages of Roman Pot Technology

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

What Determines AFP Acceptance?

Advantages of Roman Pot Technology



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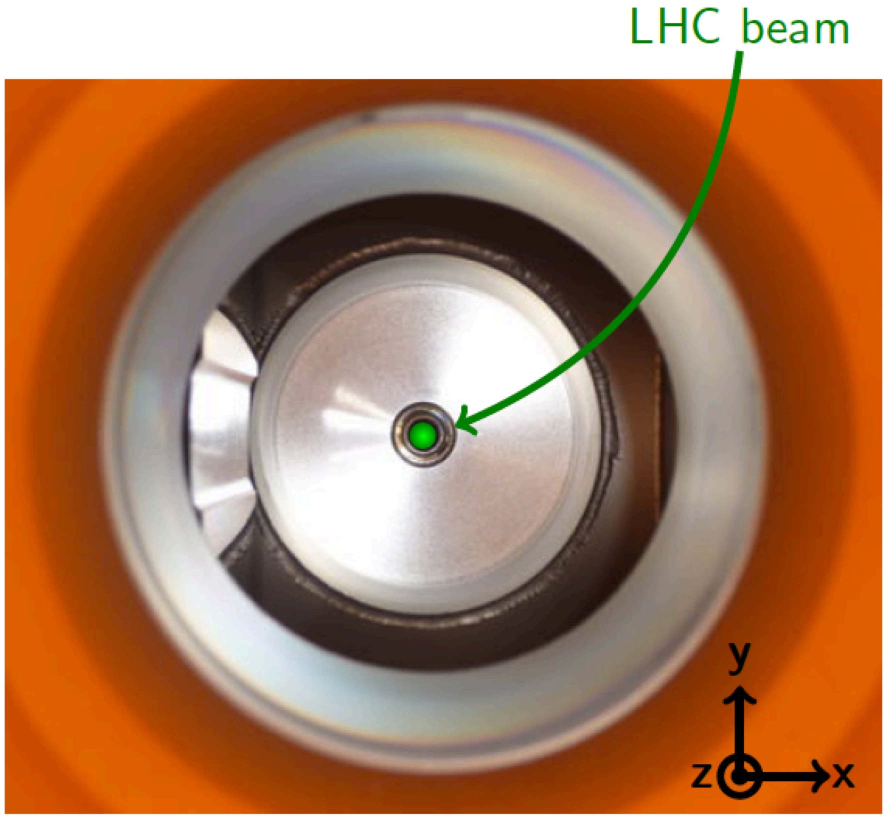

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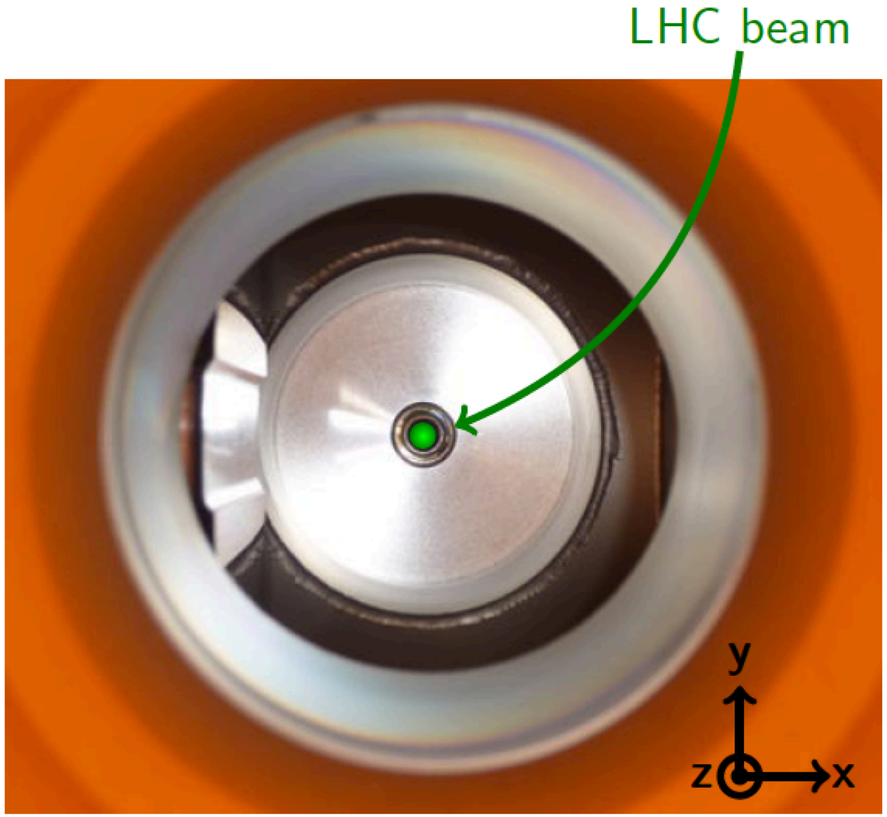

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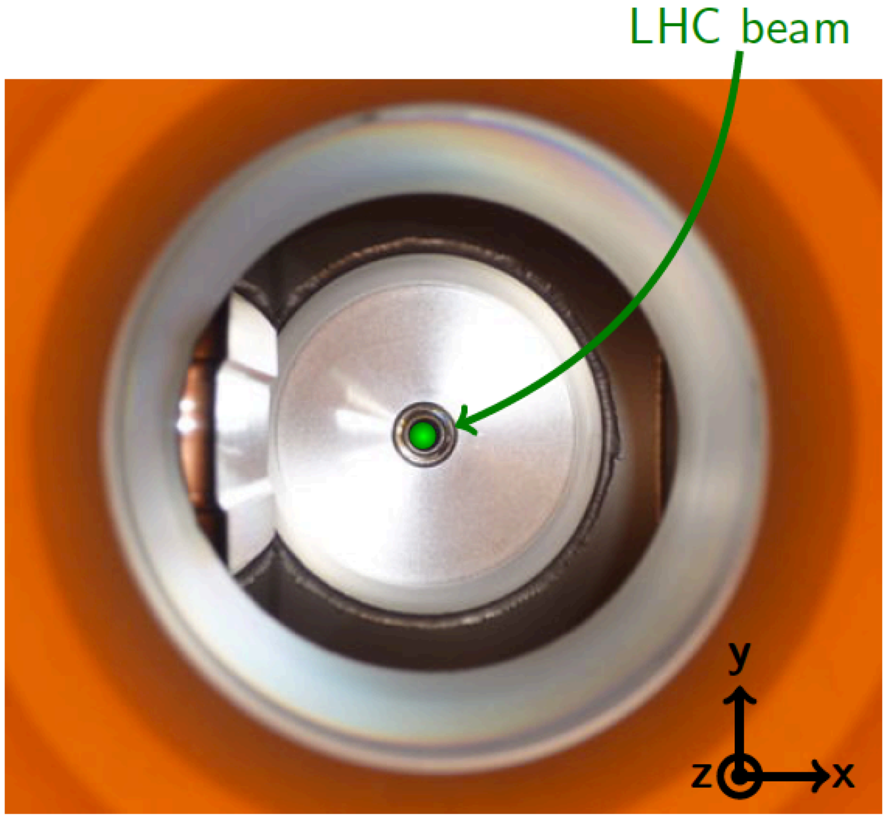

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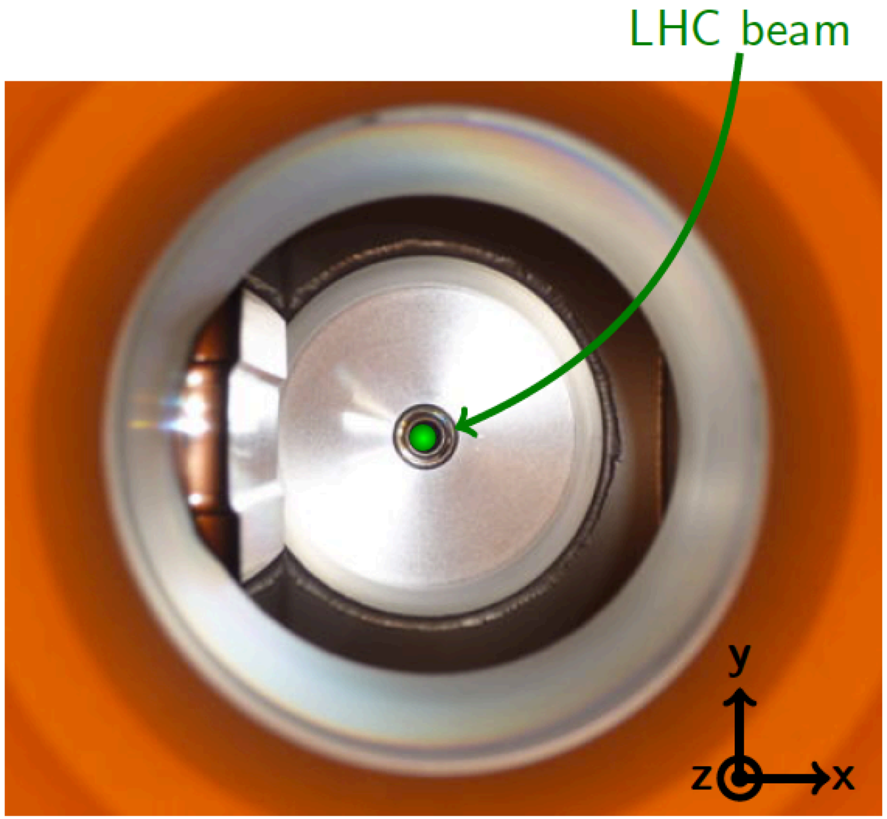

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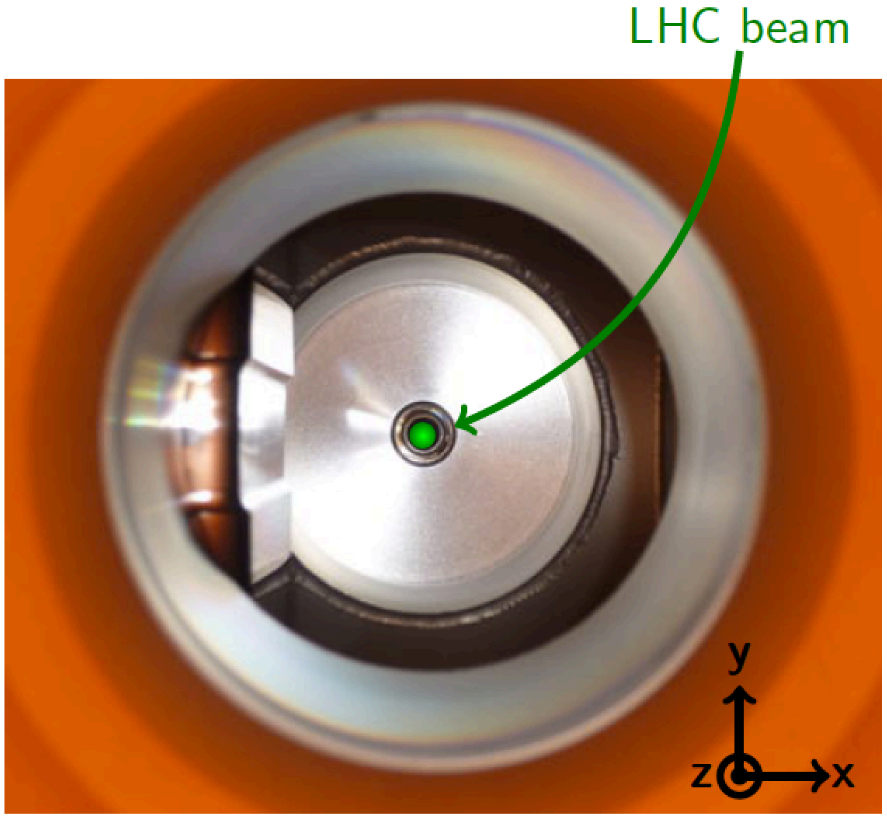

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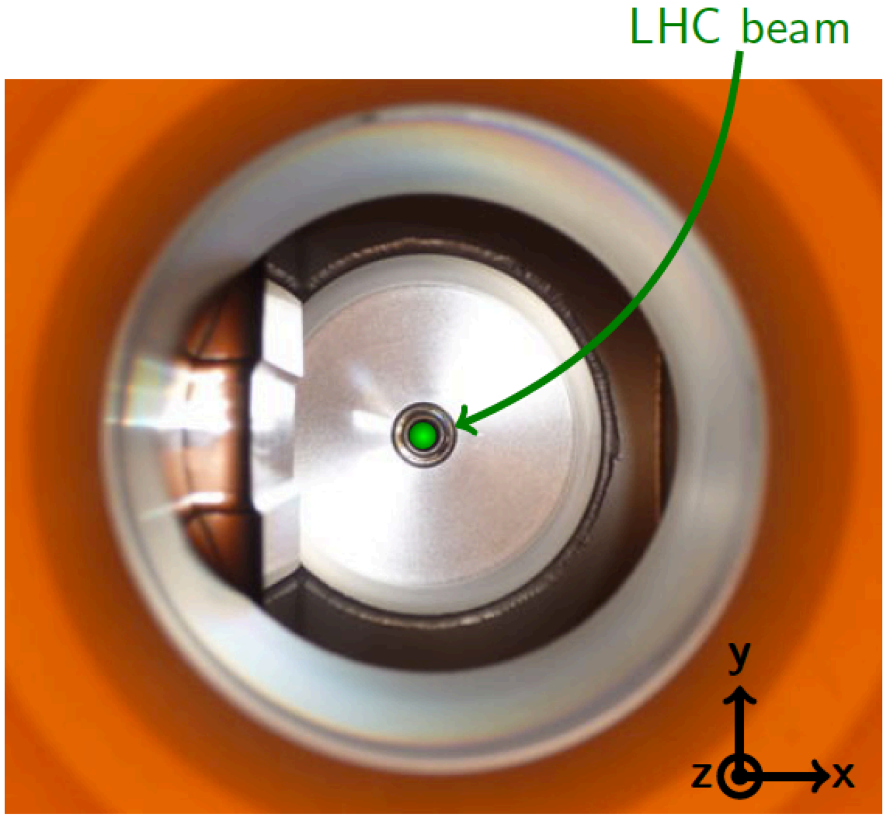

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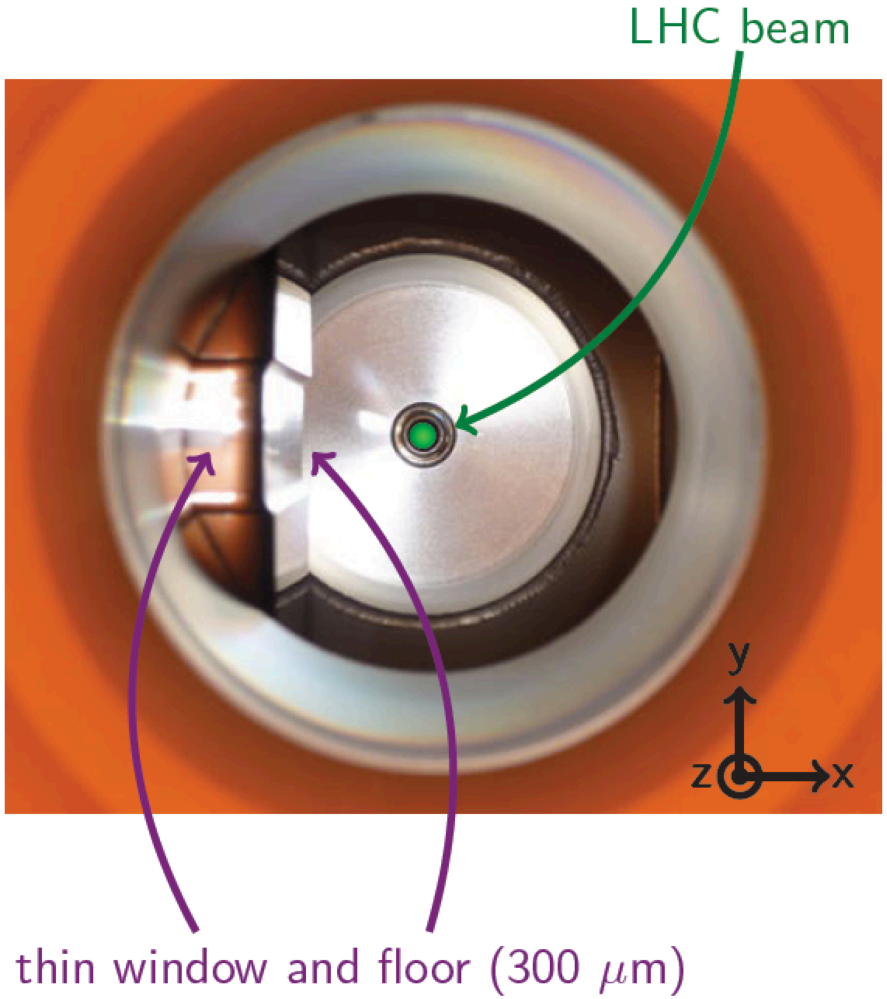

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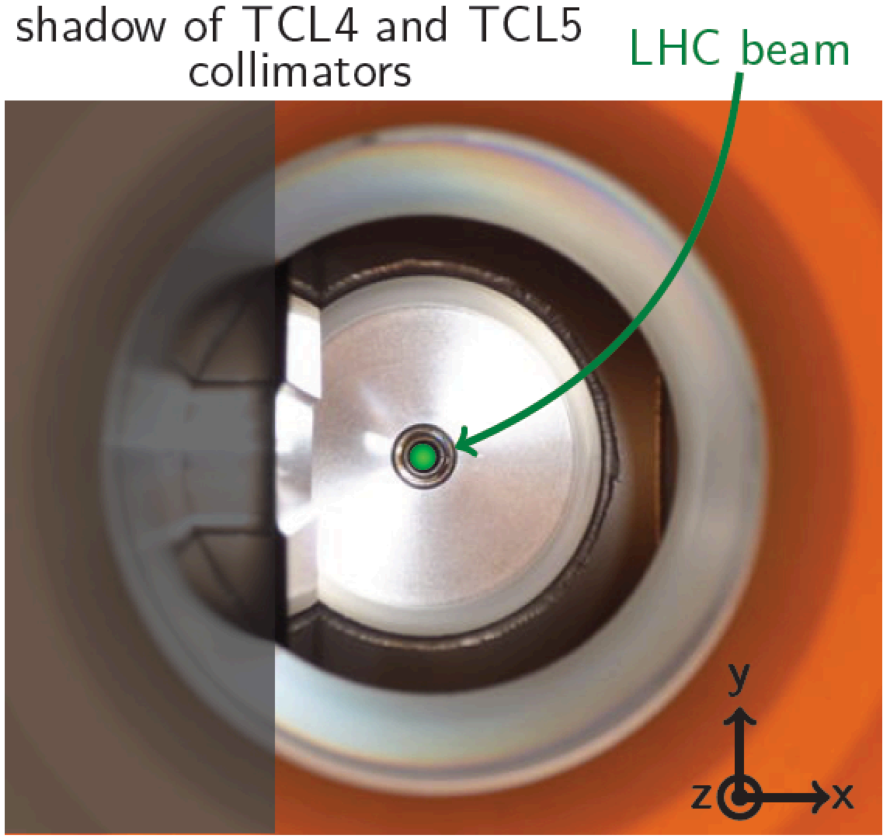


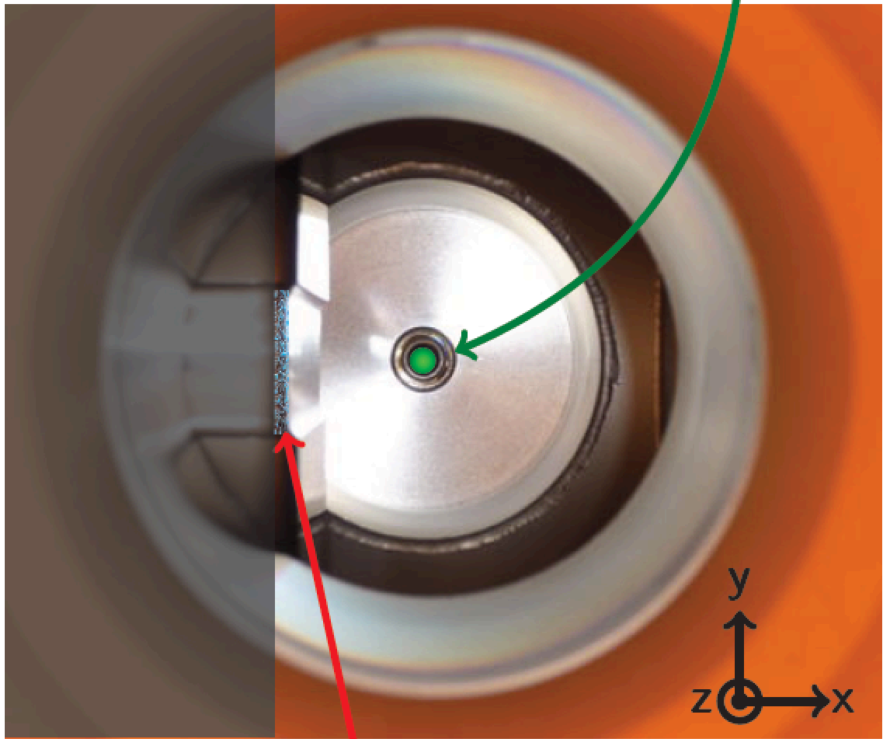
thin window and floor (300 μm)

What Determines AFP Acceptance?

Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

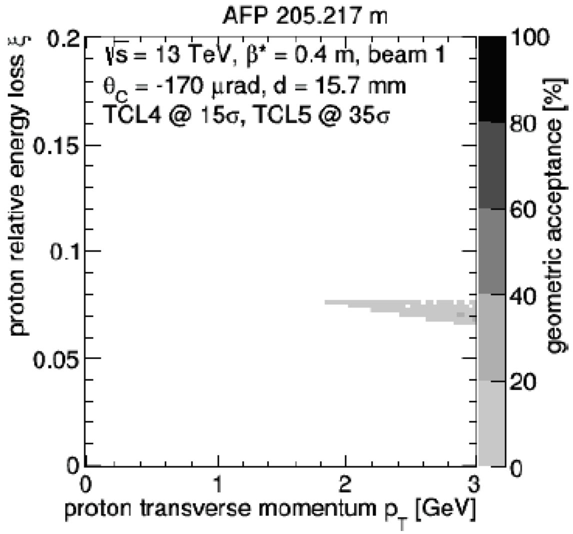
LHC beam



diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



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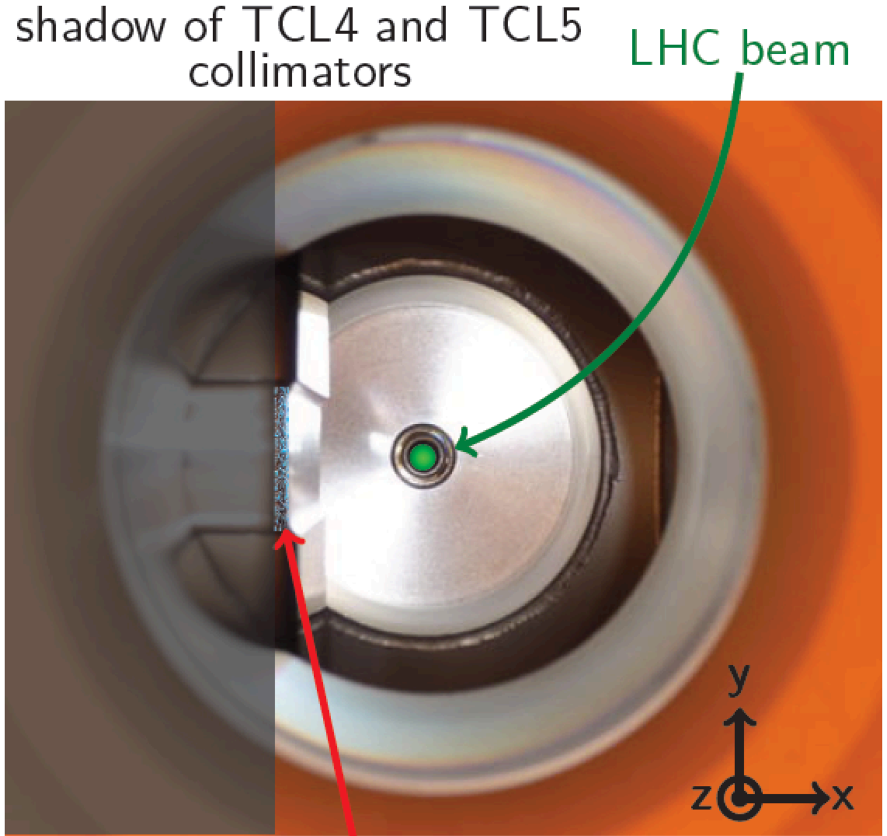
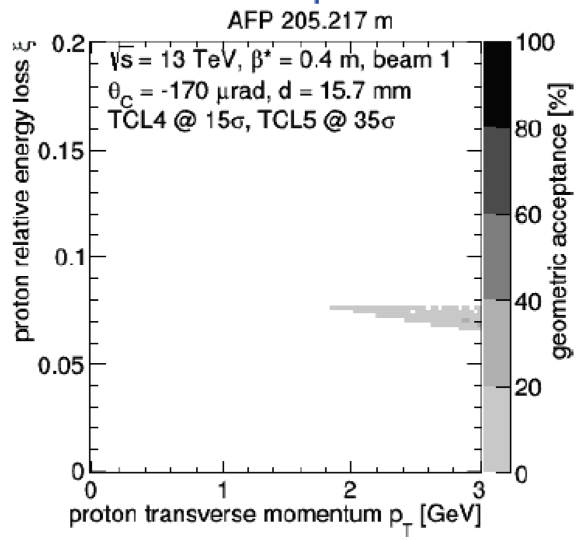
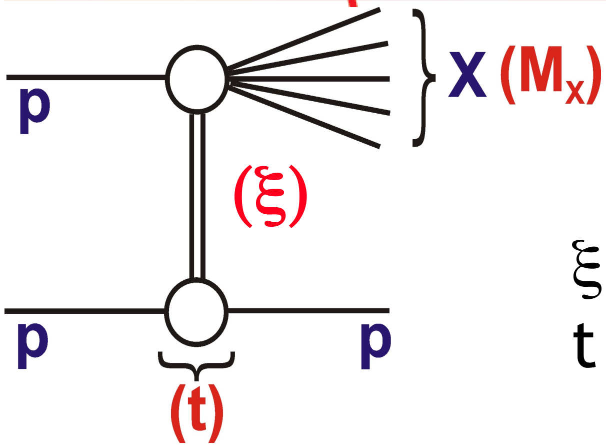


Geometric acceptance:





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

ξ = fractional proton energy loss

$t = -p_T^2$ of outgoing proton

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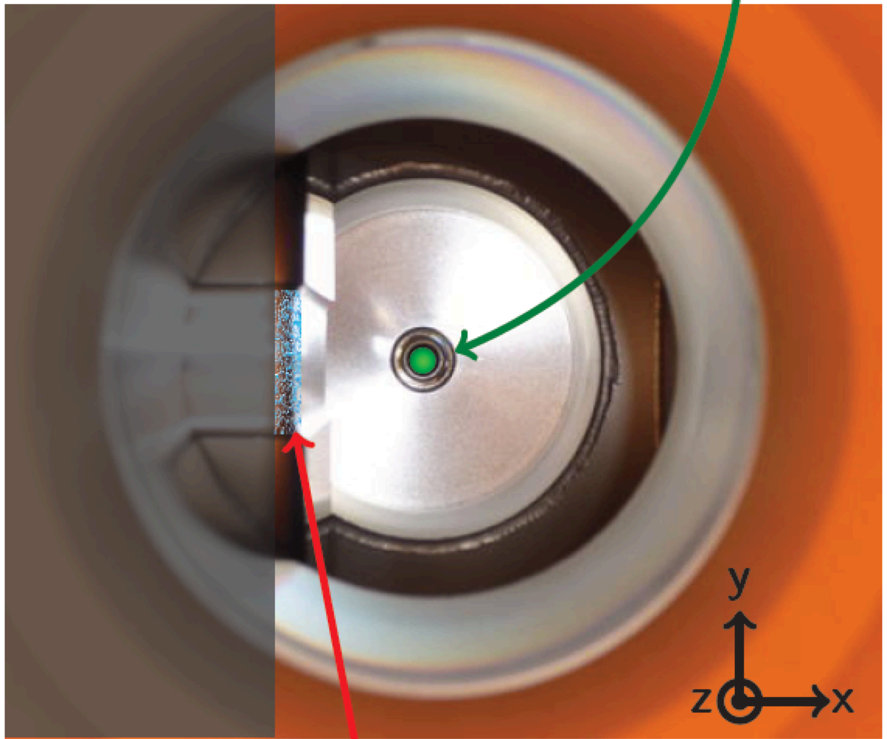
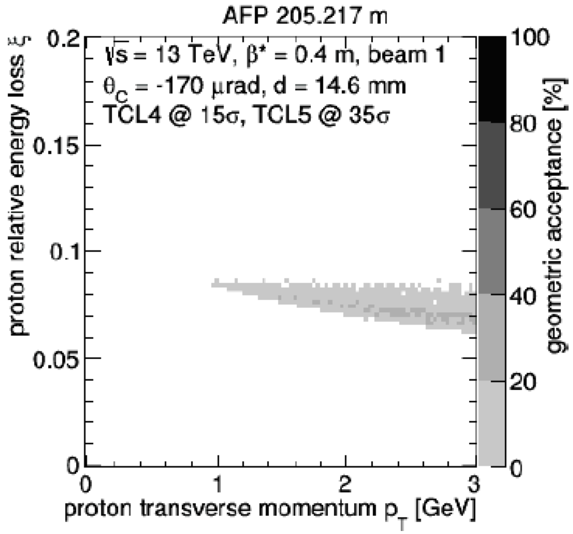
Advantages of Roman Pot Technology

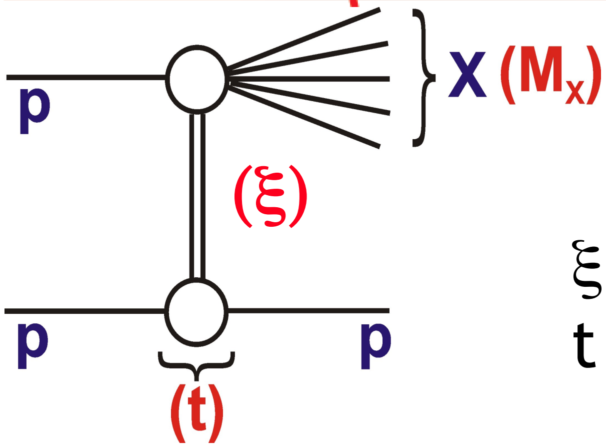
shadow of TCL4 and TCL5 collimators

LHC beam



Geometric acceptance:





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4/21

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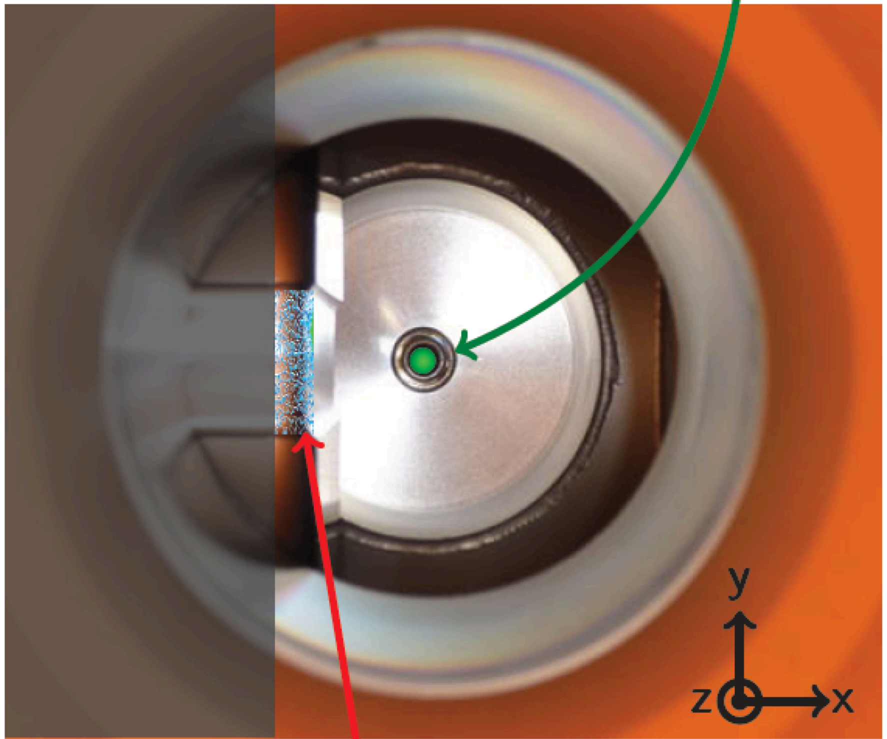
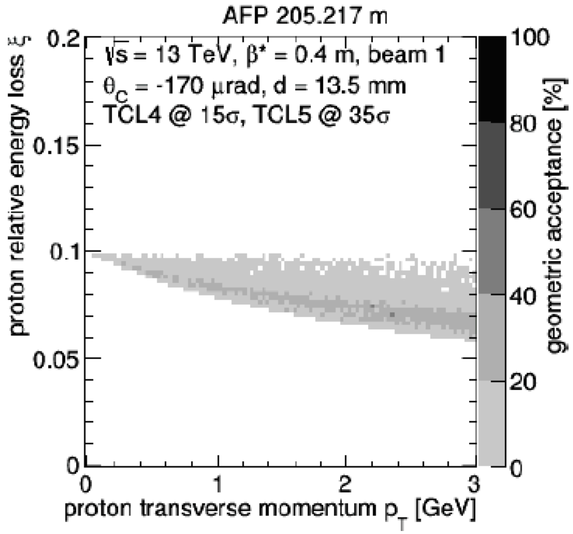
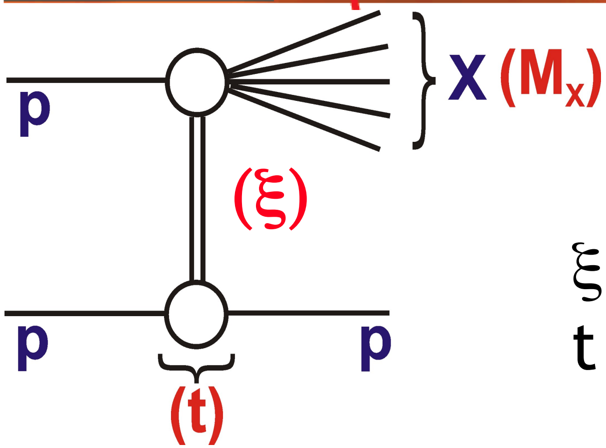


Geometric acceptance:





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

ξ = fractional proton energy loss

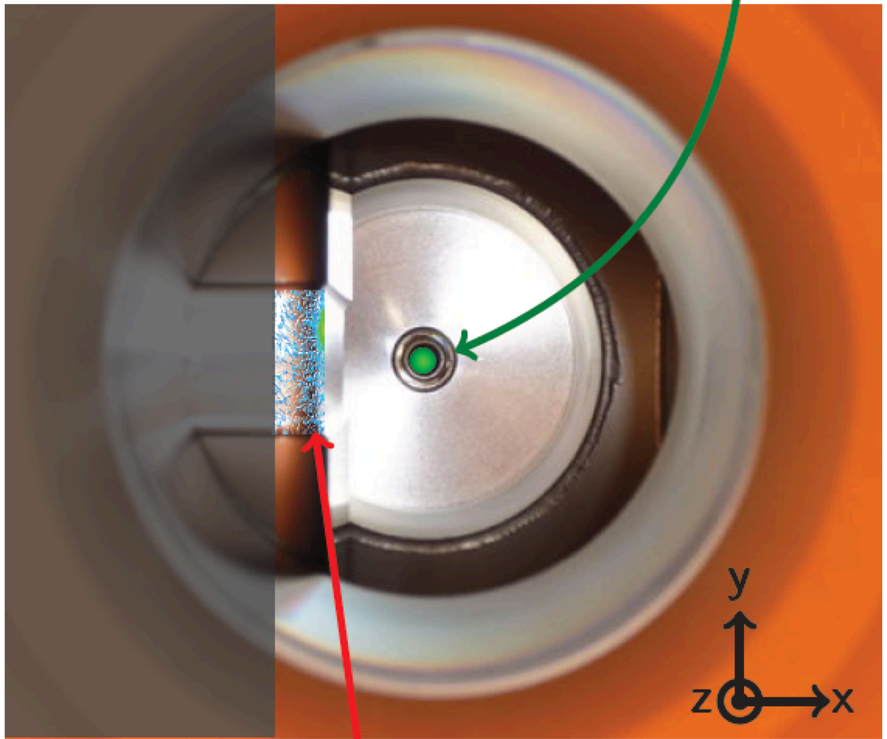
$t = -p_T^2$ of outgoing proton

What Determines AFP Acceptance?

Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

LHC beam



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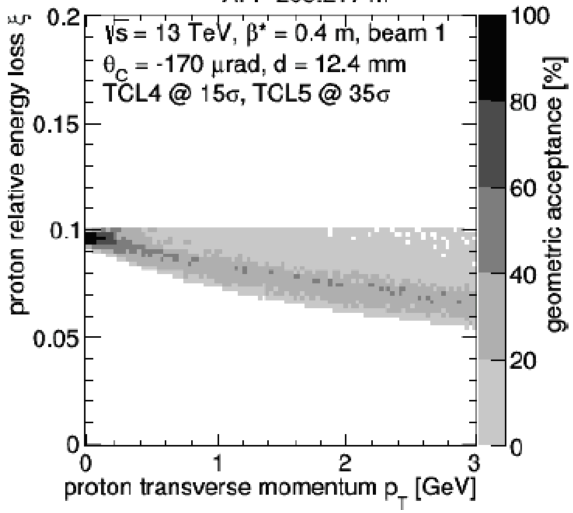

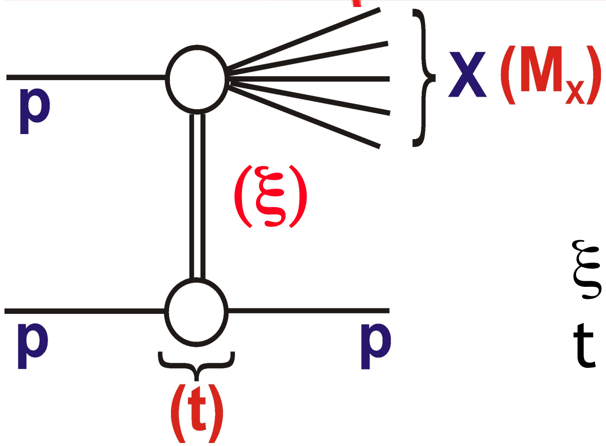

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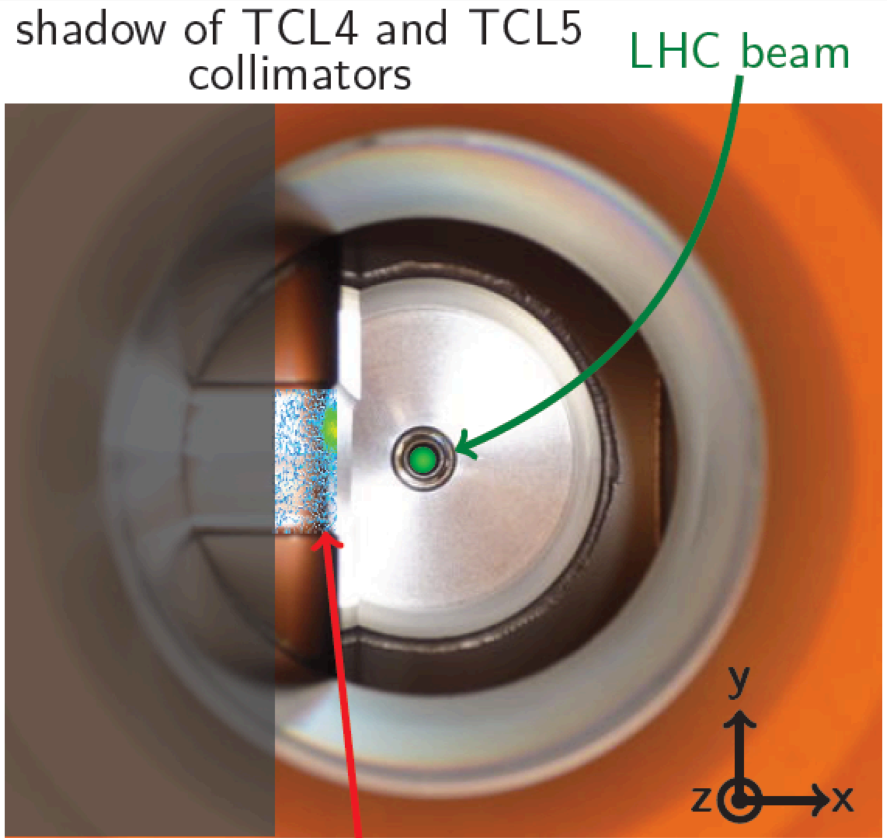

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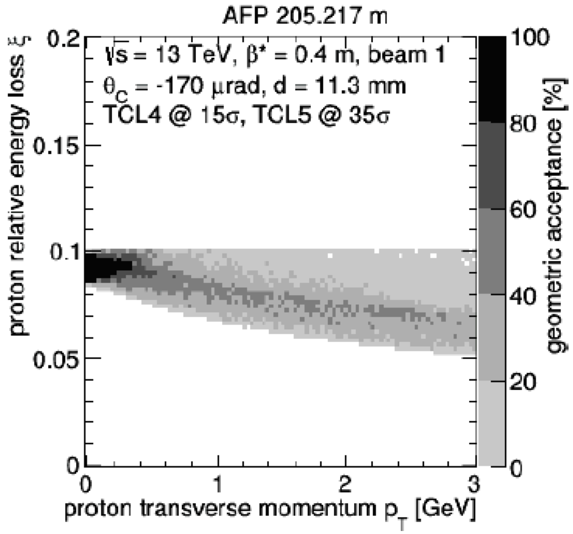

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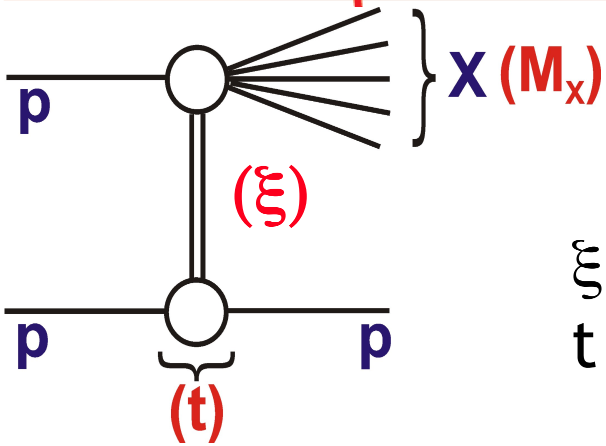

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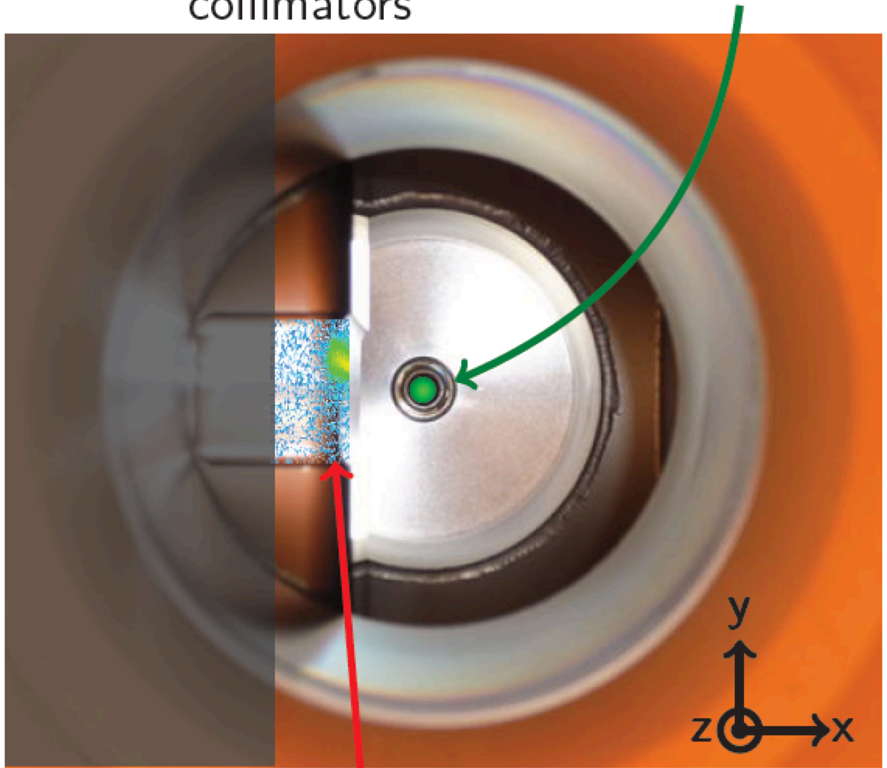

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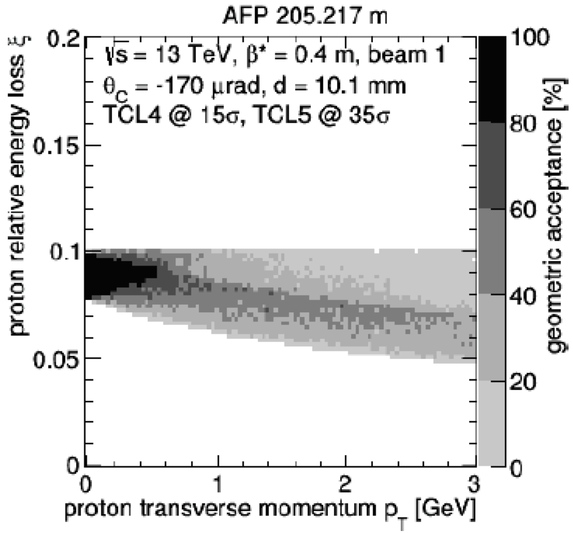

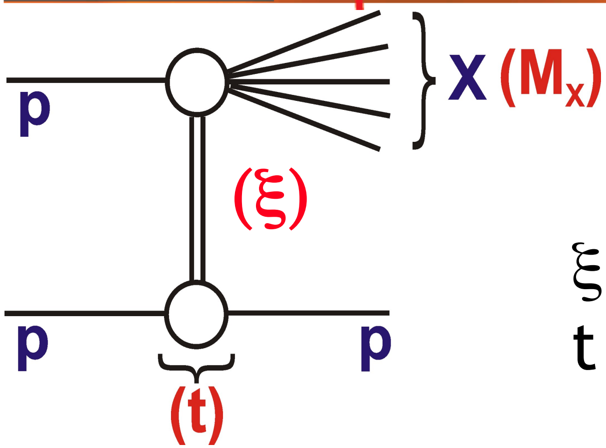

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4/21

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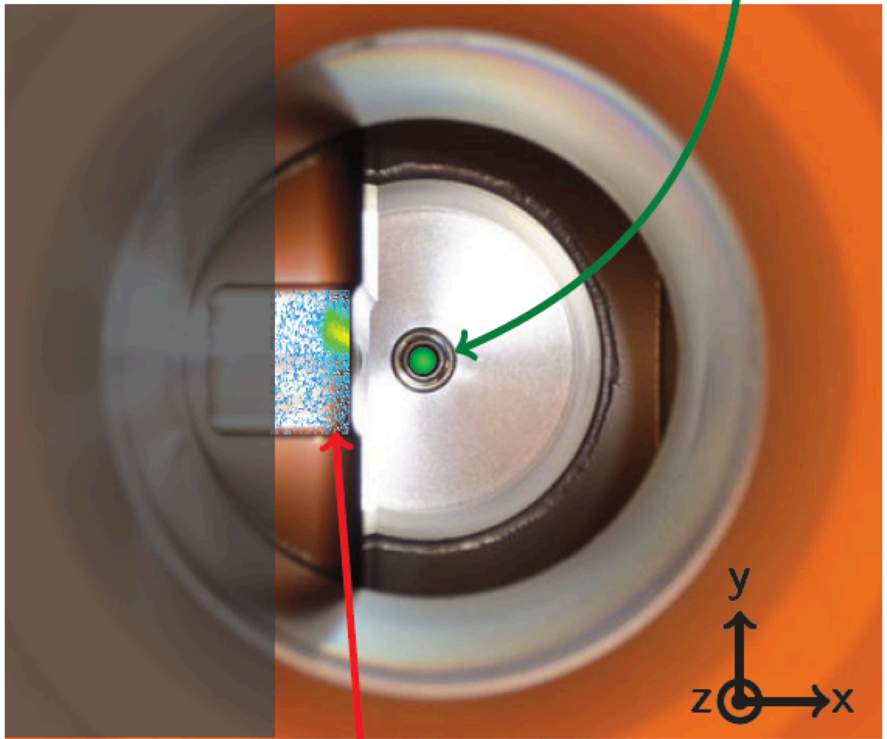

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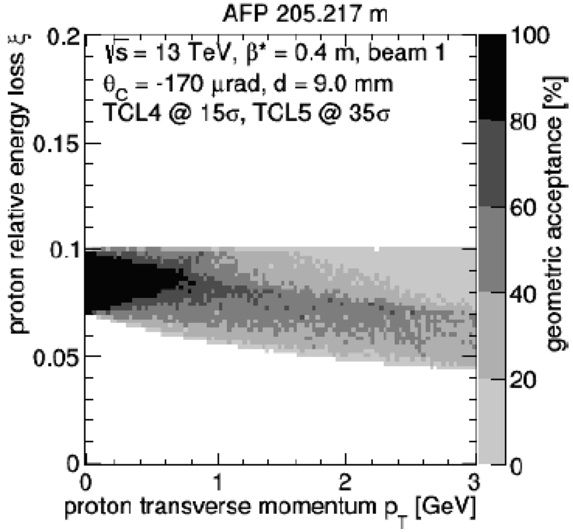

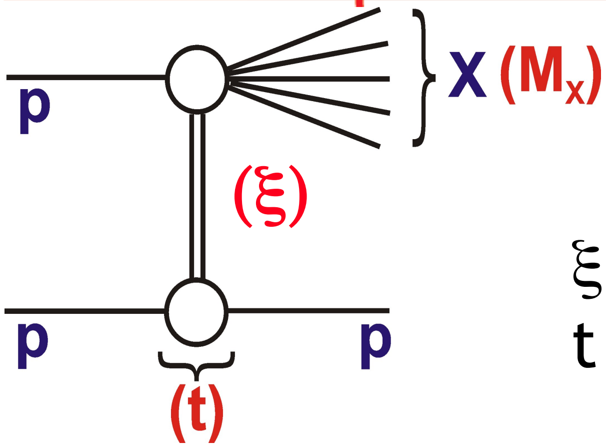

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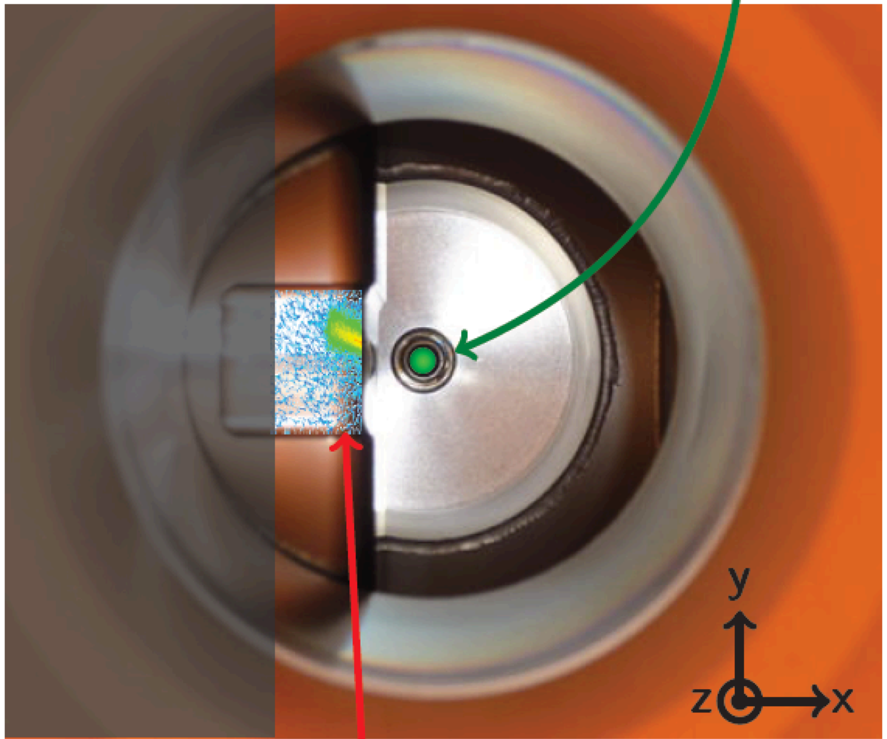

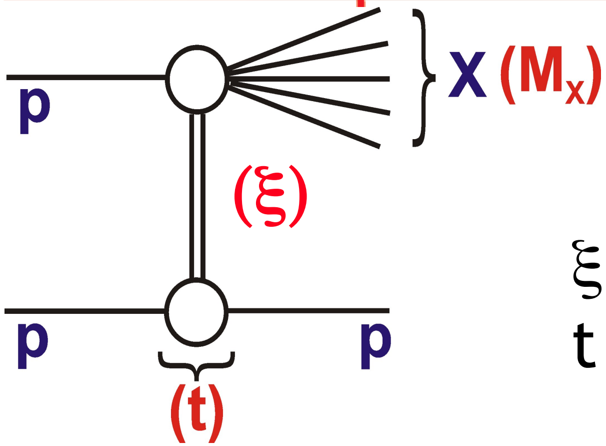

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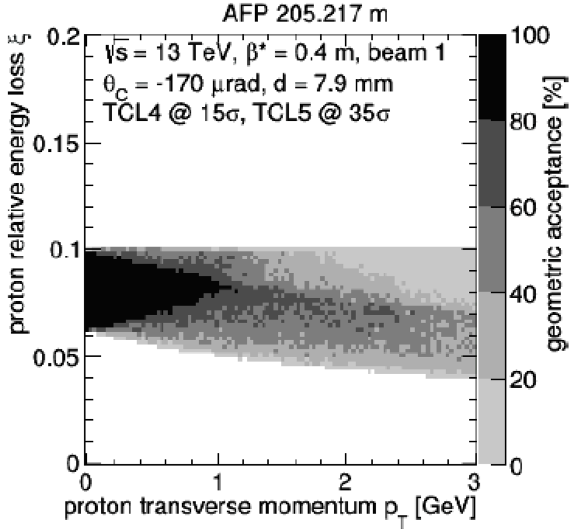

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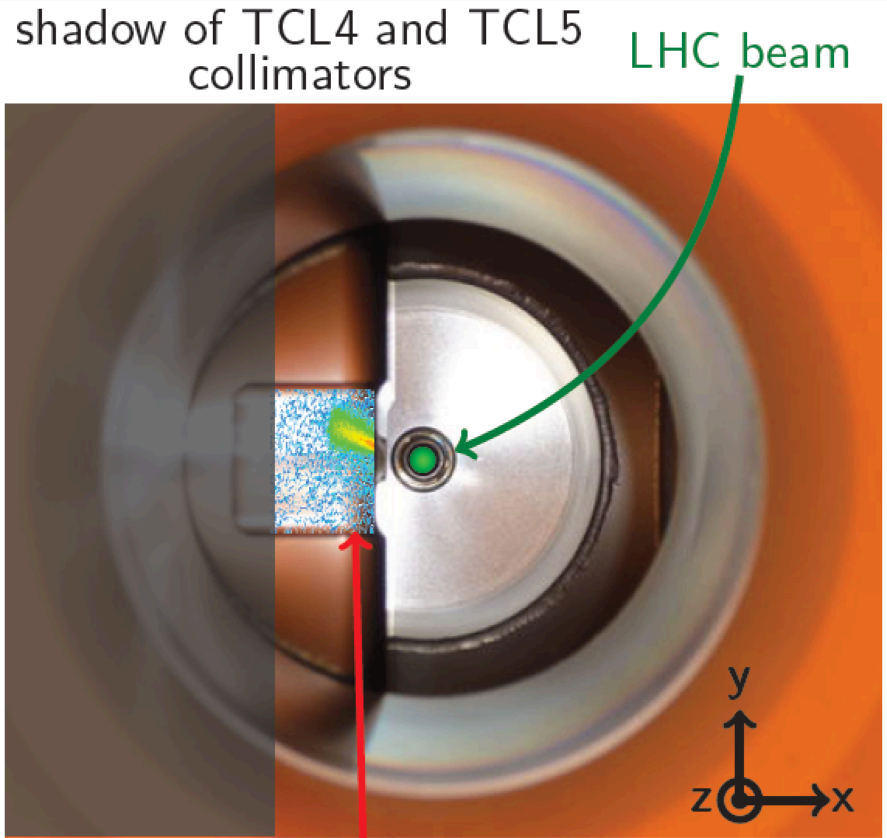

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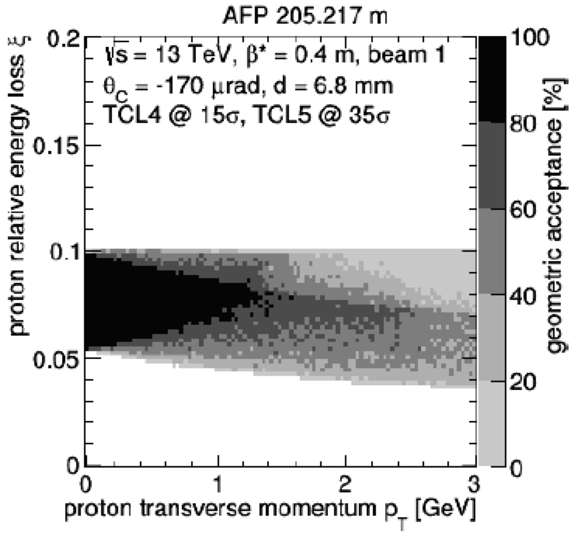

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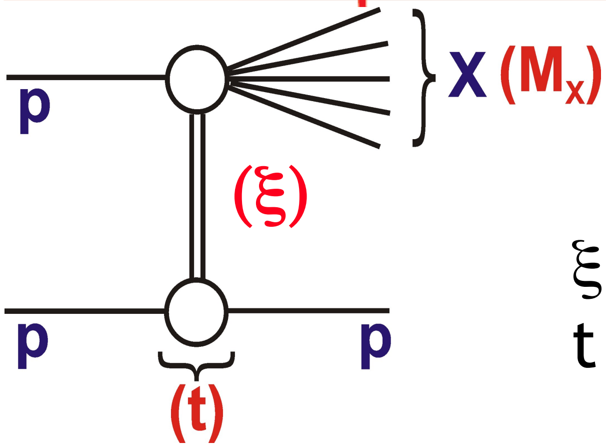

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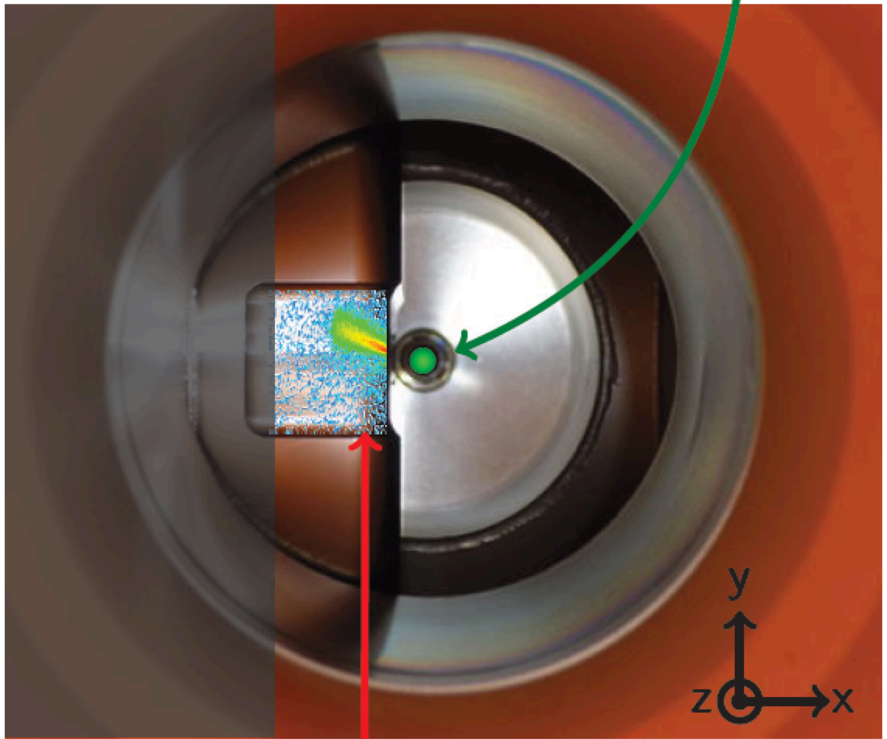

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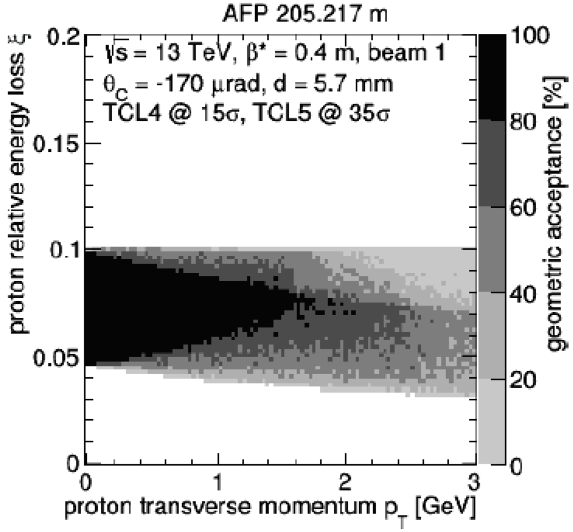

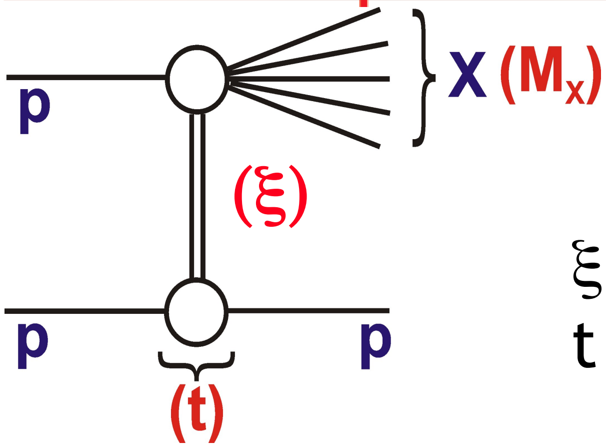

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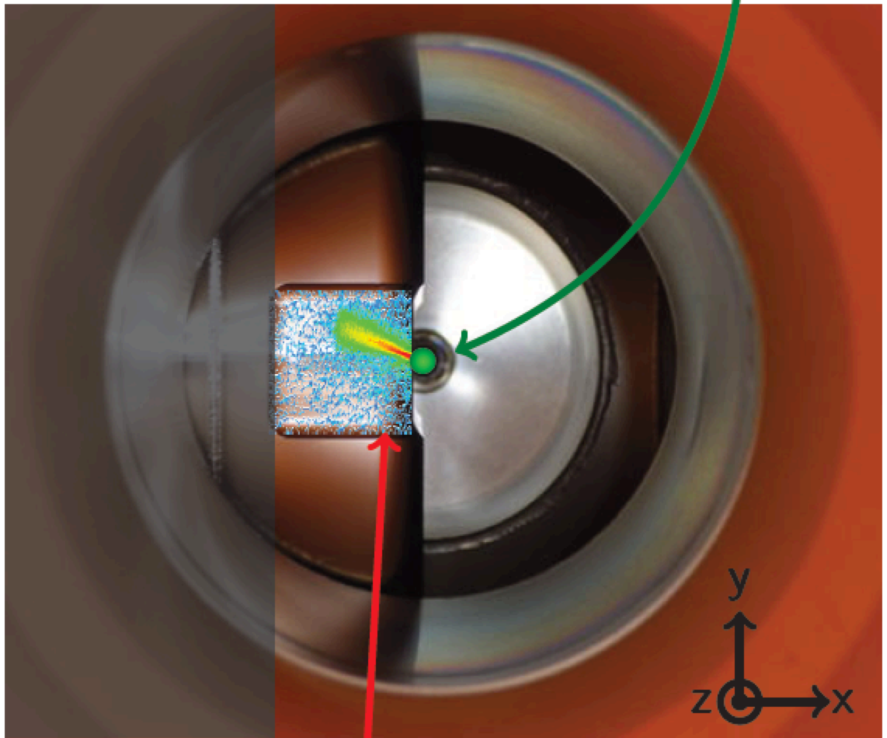

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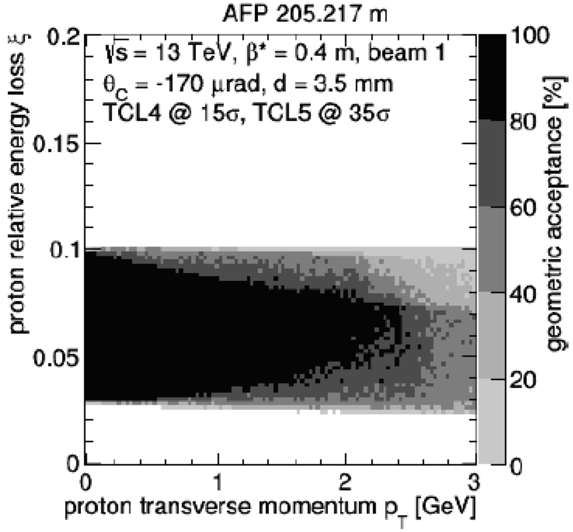

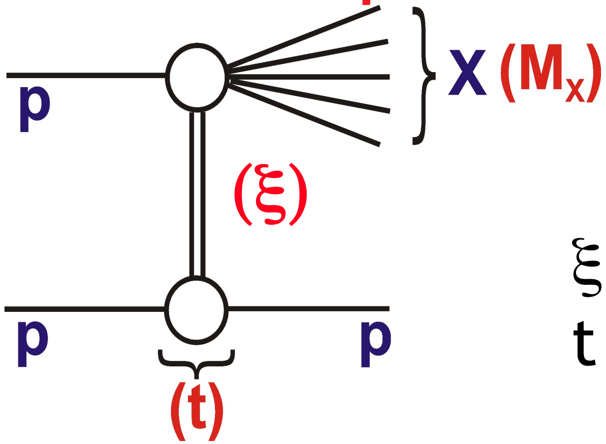

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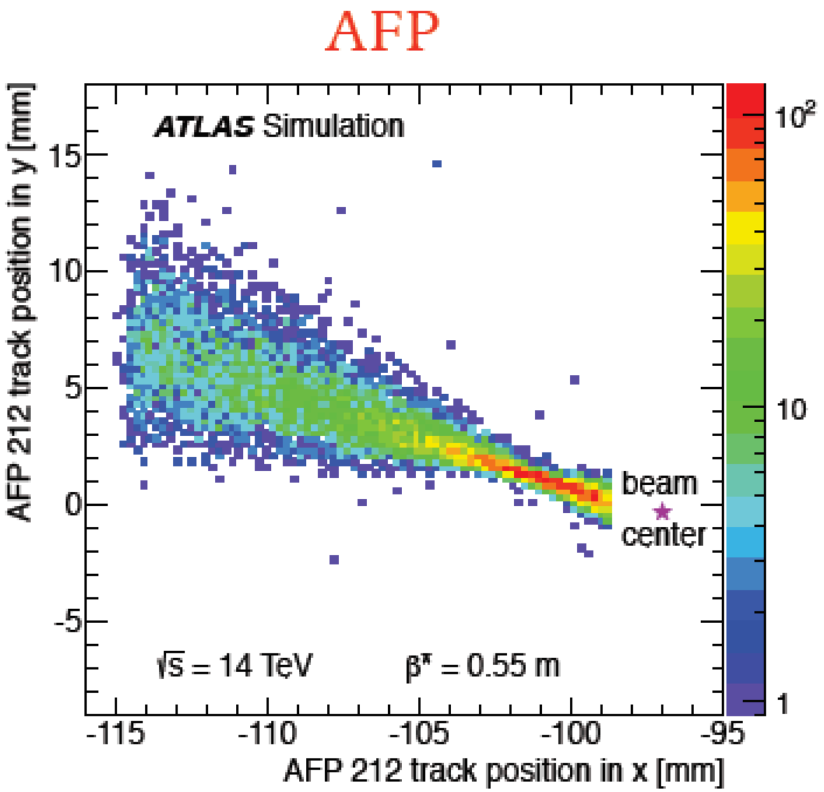
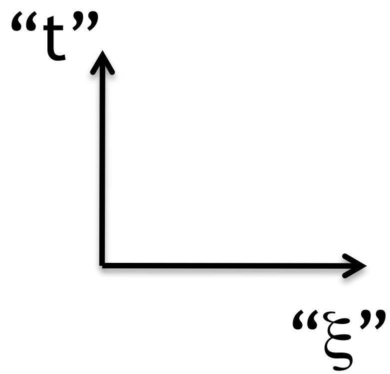
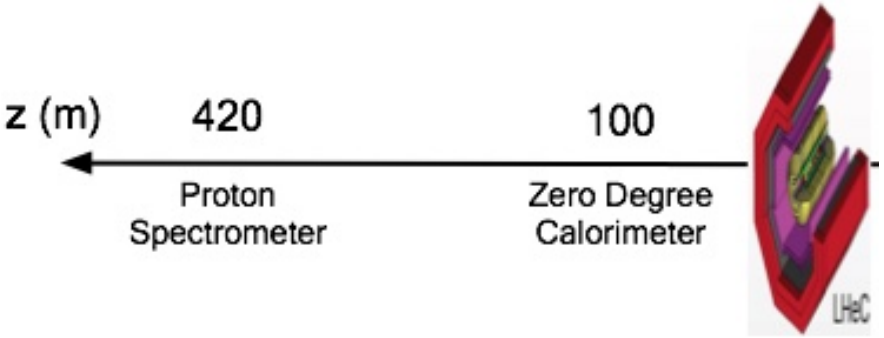
Acceptance Depends on Location and Orientation of Pot and on beam optics





- In ATLAS case, complementarity between ATLAS ALFA (vertical approach) and AFP (horizontal approach)
- AFP acceptance for inelastic diffraction with ξ >~ 0.02
- Current situation is result of prolonged study, also with machine group, and optimisation / compromise on beam optics.

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

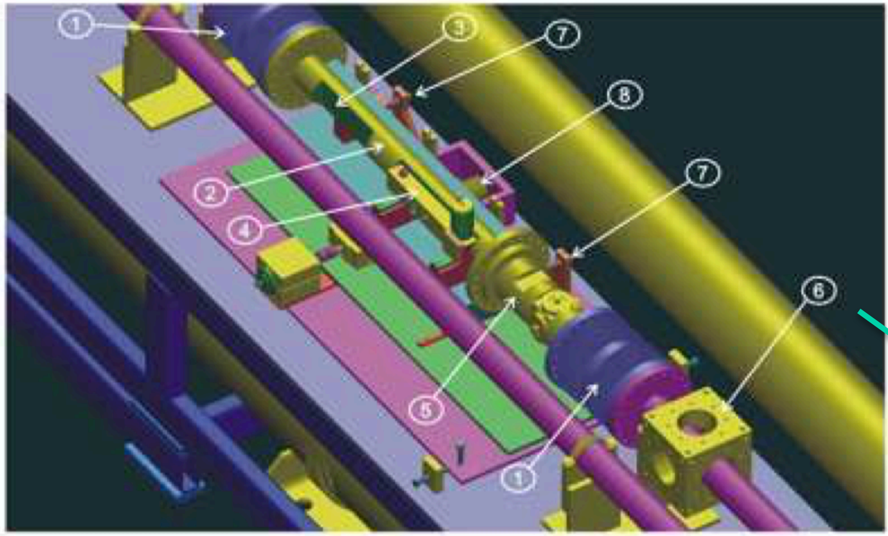
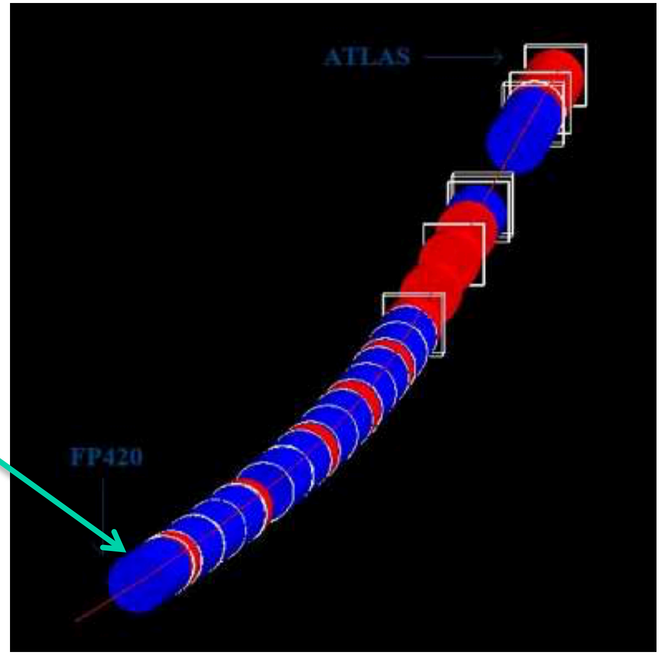
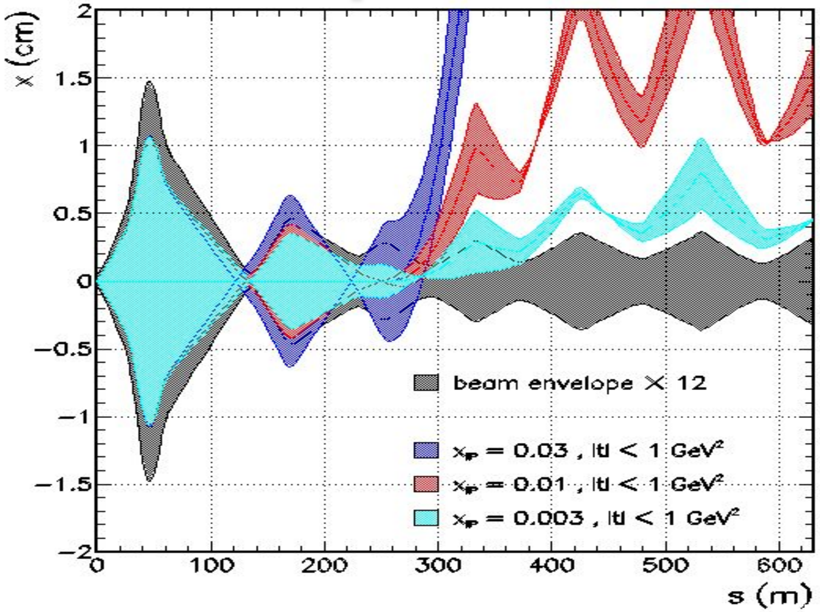


Fig. 50: Top view of one detector section: bellows (1), moving pipe (2), Si-detector pocket (3), timing detector (4), moving BPM (5), fixed BPM (6), LVDT position measurement system (7), emergency spring system (8).



An LHeC Forward Proton Spectrometer?

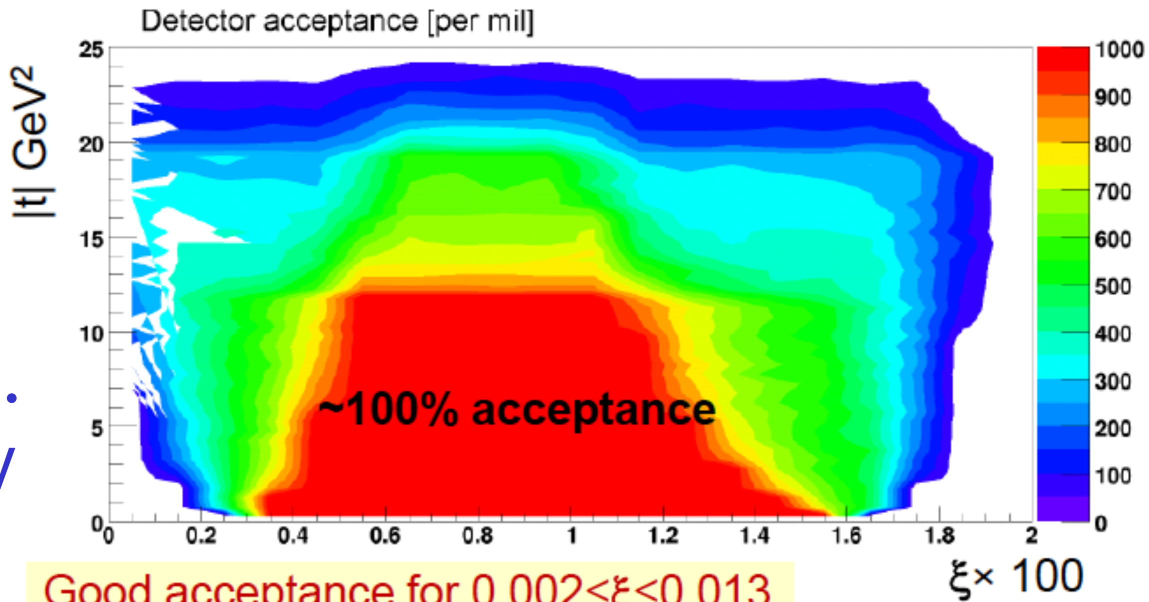


- Proton spectrometer in CDR is a copy of FP420 project (proposal for low ξ Roman pots at ATLAS / CMS – not yet adopted)

- 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

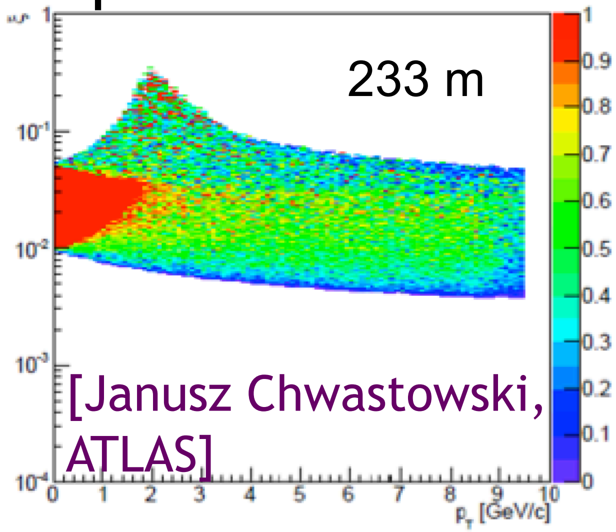
- Could also access higher ξ from AFP / CT-PPS like pots.
- Lower ξ requires pots very far from I.P. (but may be covered by gaps method)

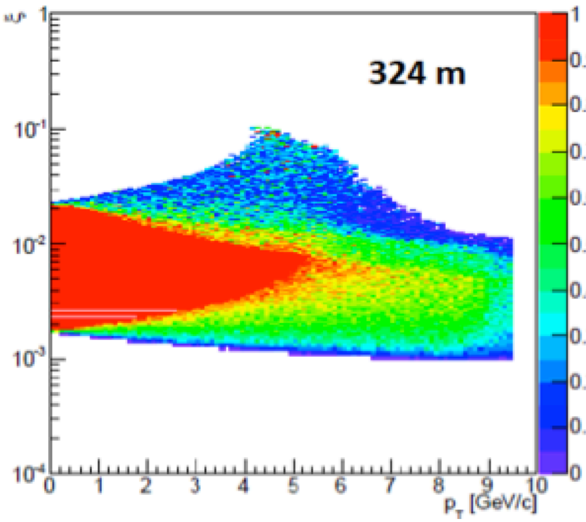


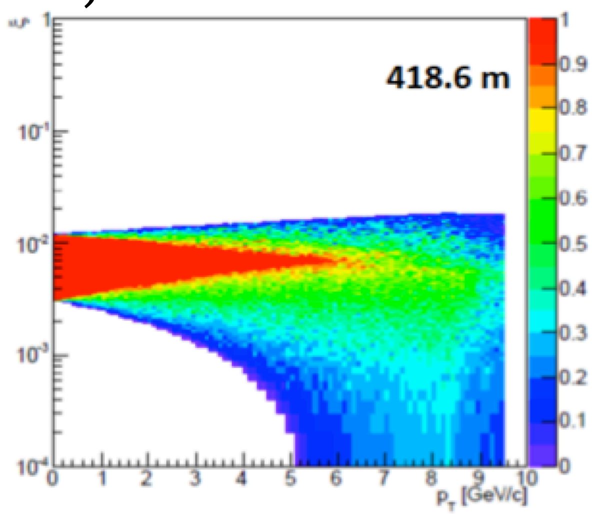
Good acceptance for 0.002<ξ<0.013

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

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

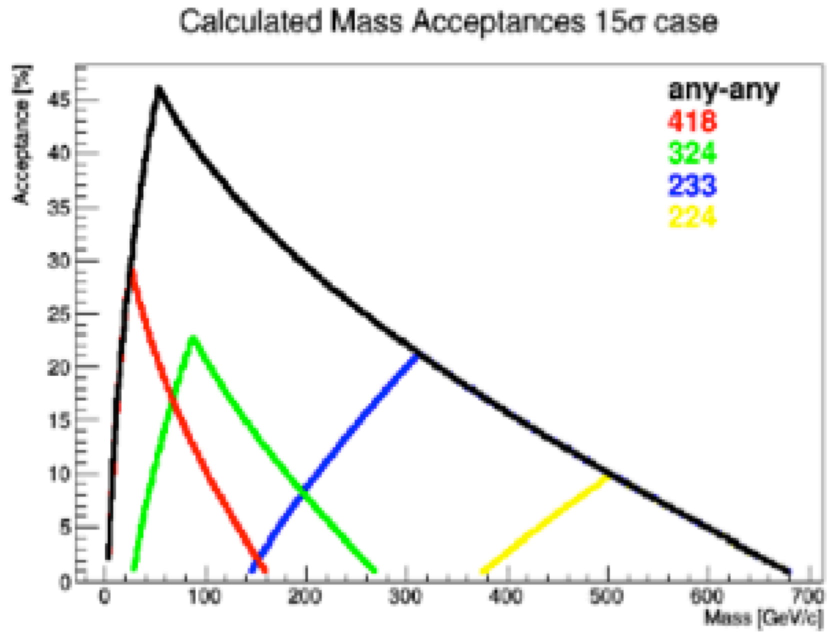






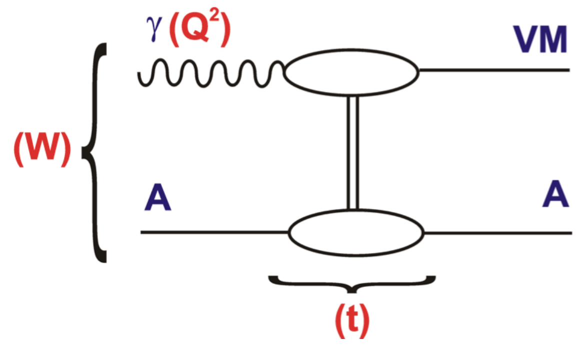
233m: Reduced ξ acceptance relative to that now in AFP region

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

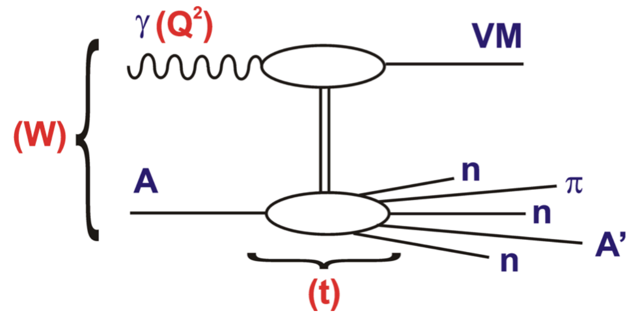


Leading Neutrons

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

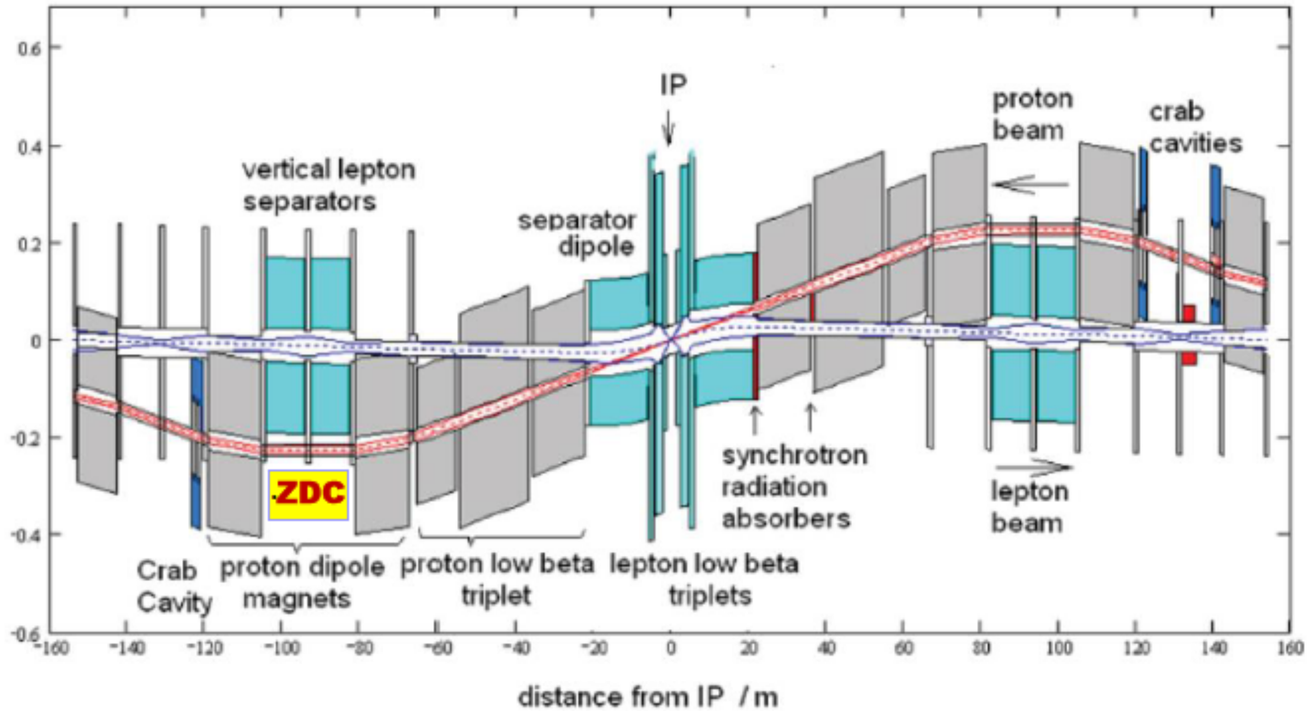


- Crucial in ed, to distinguish scattering from proton or neutron

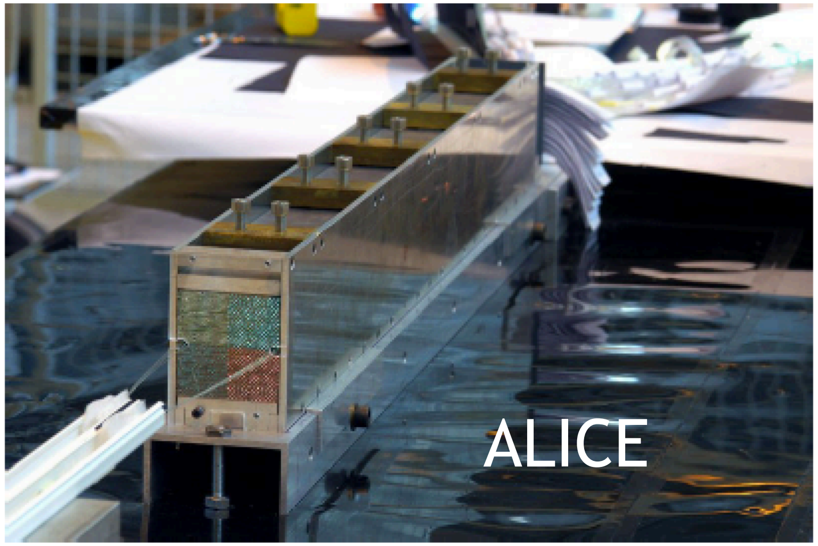


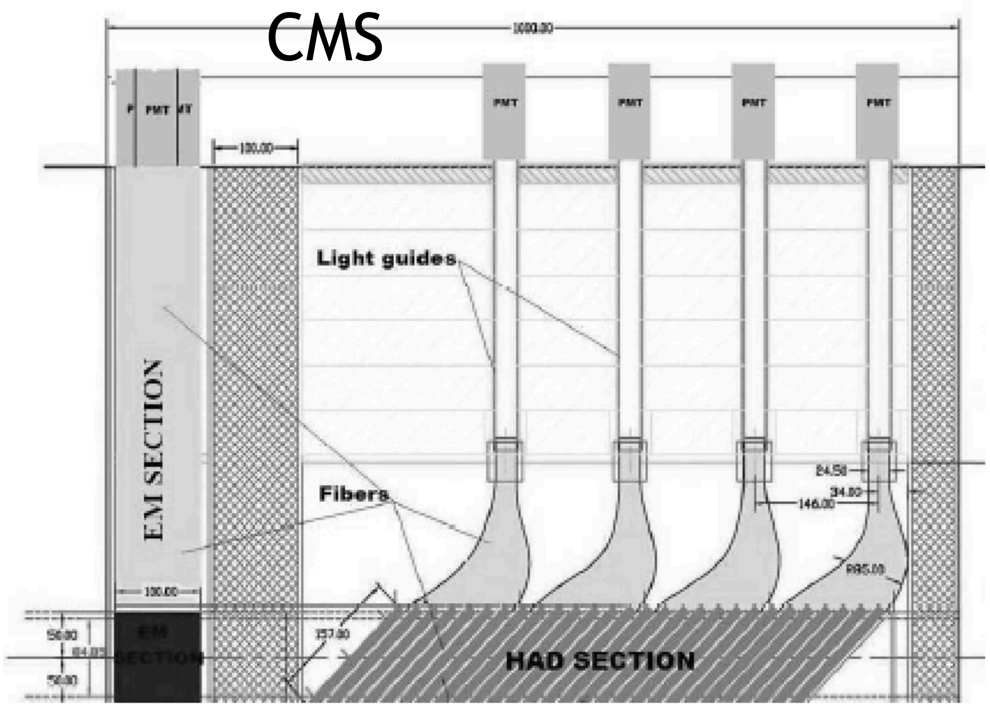
- Possible "straight on" space at z ~ 100m

- No detailed instrumentation studies yet → learn from LHC



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





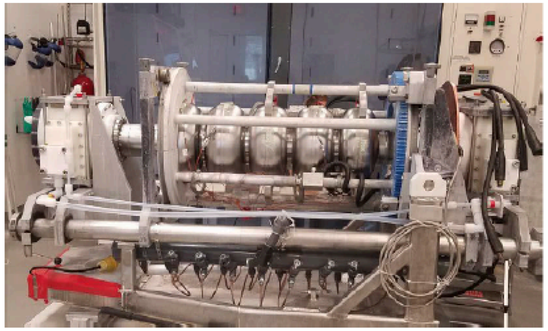
- ALICE, ATLAS, CMS all use
tungsten absorber + quartz fibres (Cerenkov).
- LHCf uses tungsten + plastic scintillator in special runs
- Improve hadronic response with dual quartz / scintillator?
- Longitudinal segmentation essential to distinguish
neutrons from photons.

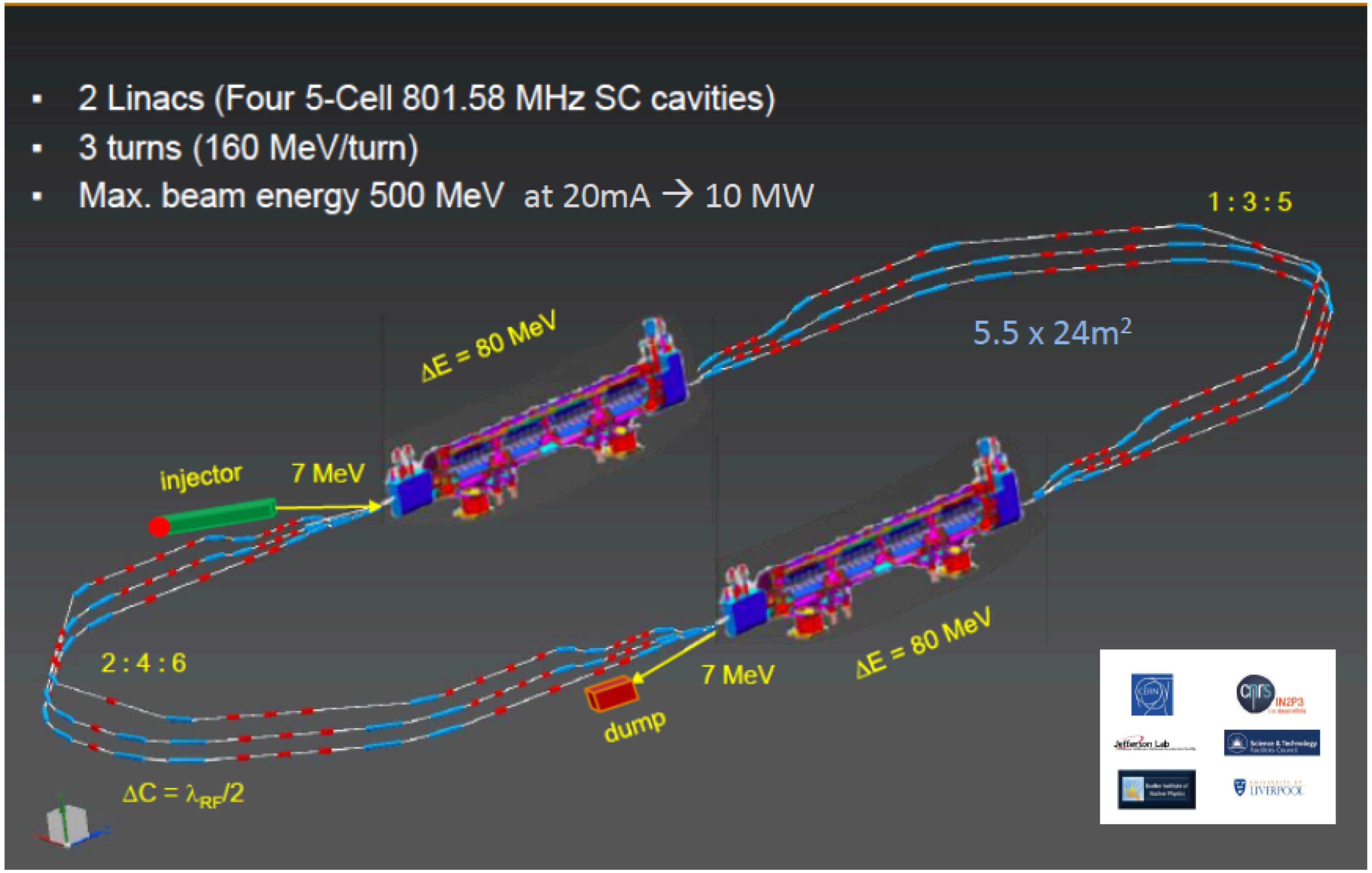
Critical Path Towards Realisation: PERLE

… Prototype high current energy recovery linac with superconducting RF …

Powerful ERL for Experiments at Orsay

First 802 MHz cavity successfully built (Jlab)





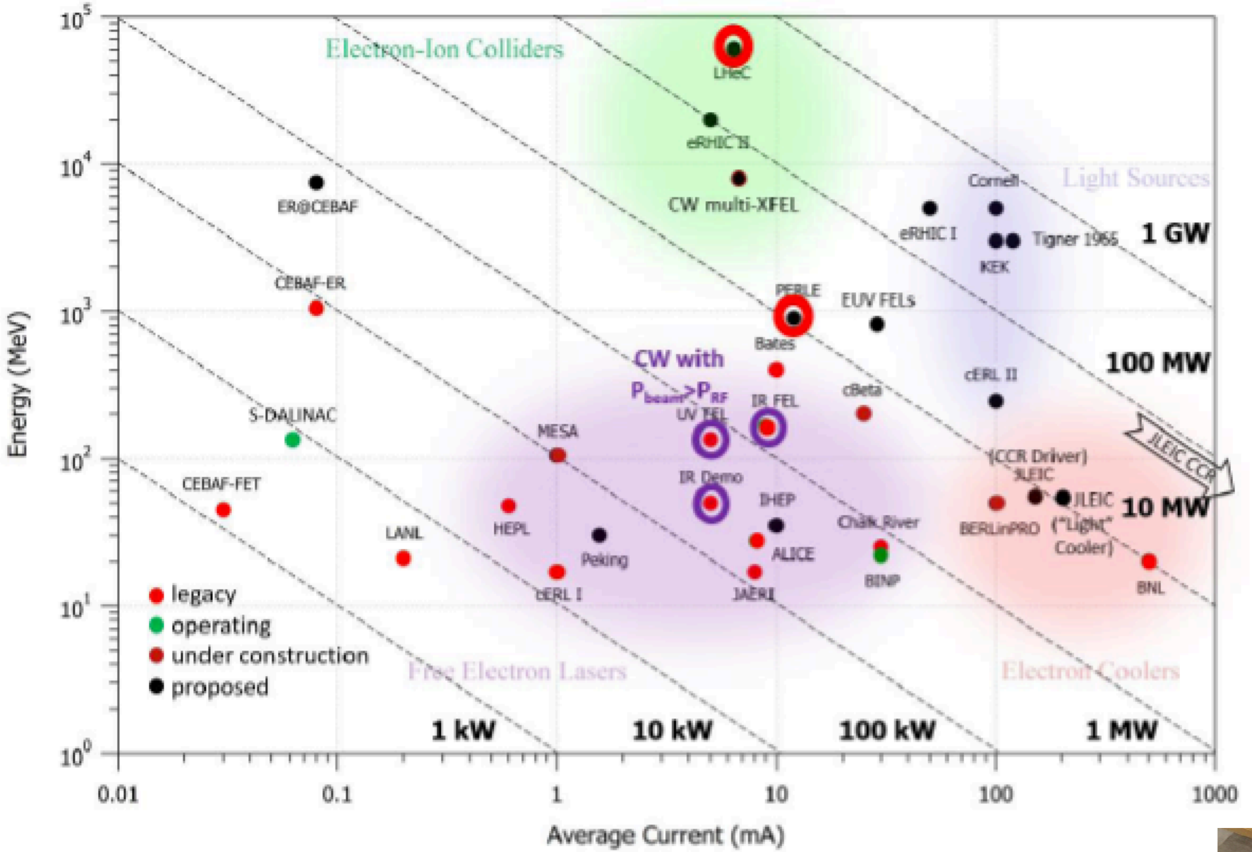
cf Walid Kaabi at Amsterdam FCC

New SCRF, High Intensity (100 x ELI) ERL Development Facility with unique low E Physics

… with excellent performance …

- Test centre for LHeC accelerator development with significant standalone physics potential (EW parameters, proton radius, photonuclear physics, dark photons

PERLE status and plans



→ Currently Only 1 operating SRF ERL!!!

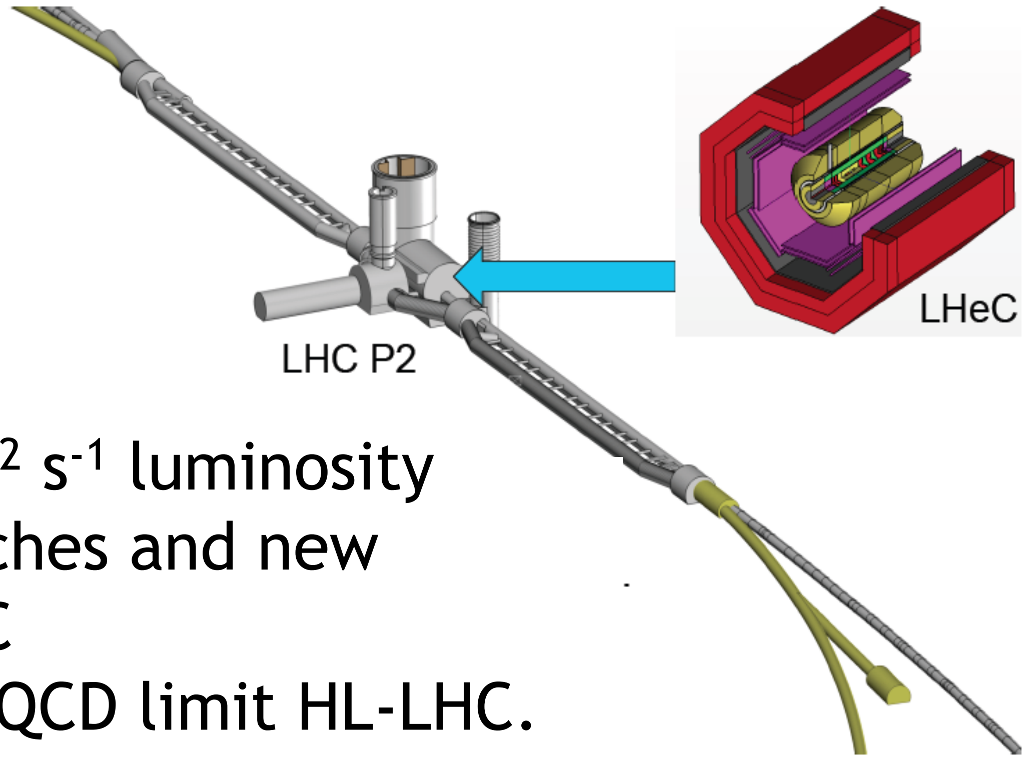
→ Current only demonstrated 1MW beam power in single ERL turn

→ Only 3 ERLs had demonstration of operation with $P_{beam} > P_{RF}$!!!

- Orsay experimentatal hall allocated with support for infrastructure

- MoU's being written, funding model being investigated, CDR exists, TDR and detailed costing planned for mid 2019.

LHeC Summary



- CDR 2012

- Changes since then …
    1) Possibility of 10^{34} cm^{-2} s^{-1} luminosity
    2) Higgs discovery, searches and new measurements at LHC
       → PDFs & QCD limit HL-LHC.
    3) Technical interest (high gradient cavities, ER linacs …)
    4) Longer term perspective of FCC

- Next goals …
    1) Update CDR (physics, technical) for 2020 Euro Strategy
    2) TDR for PERLE
    3) Further development of FCC concept and physics
    …