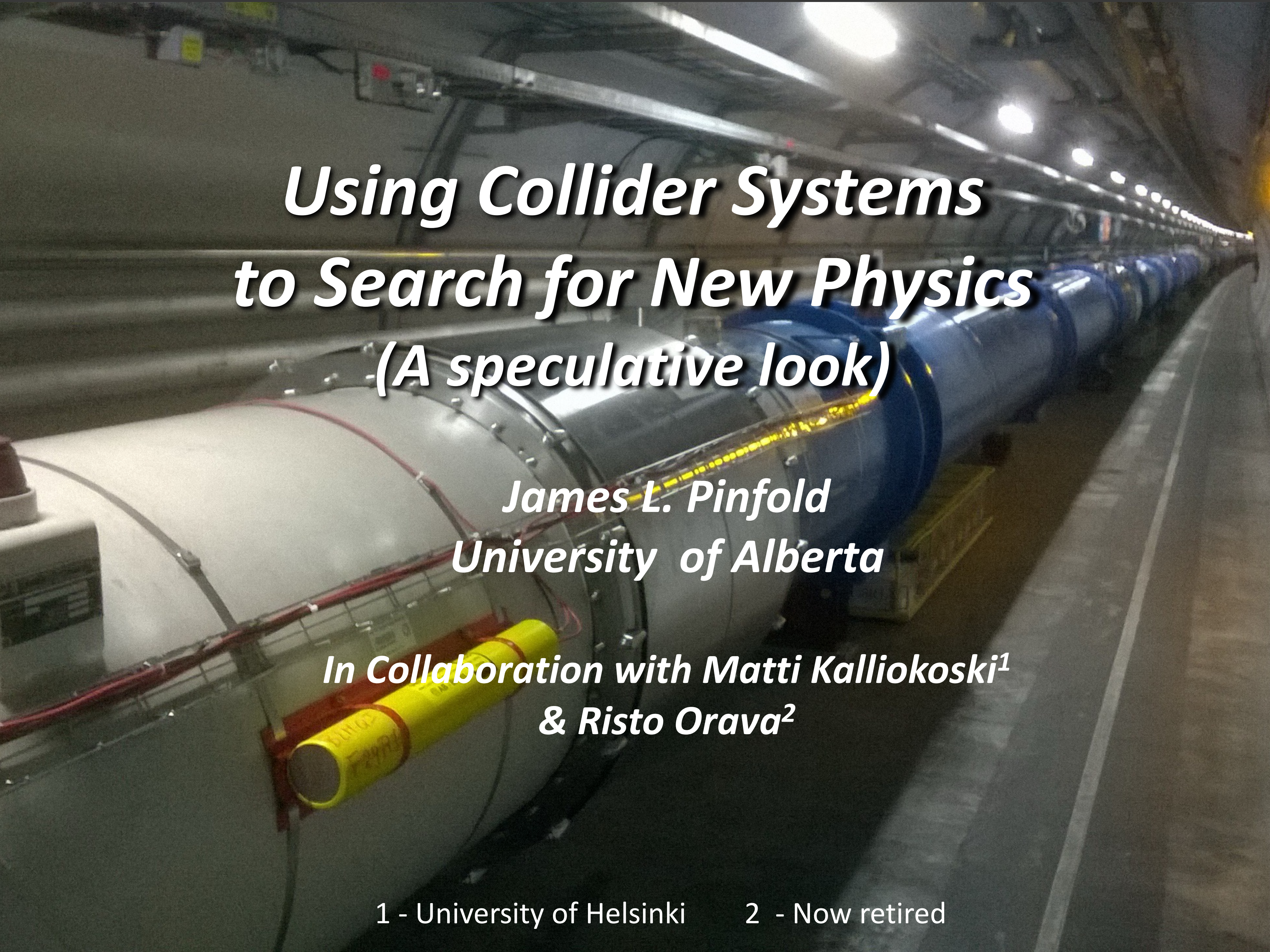


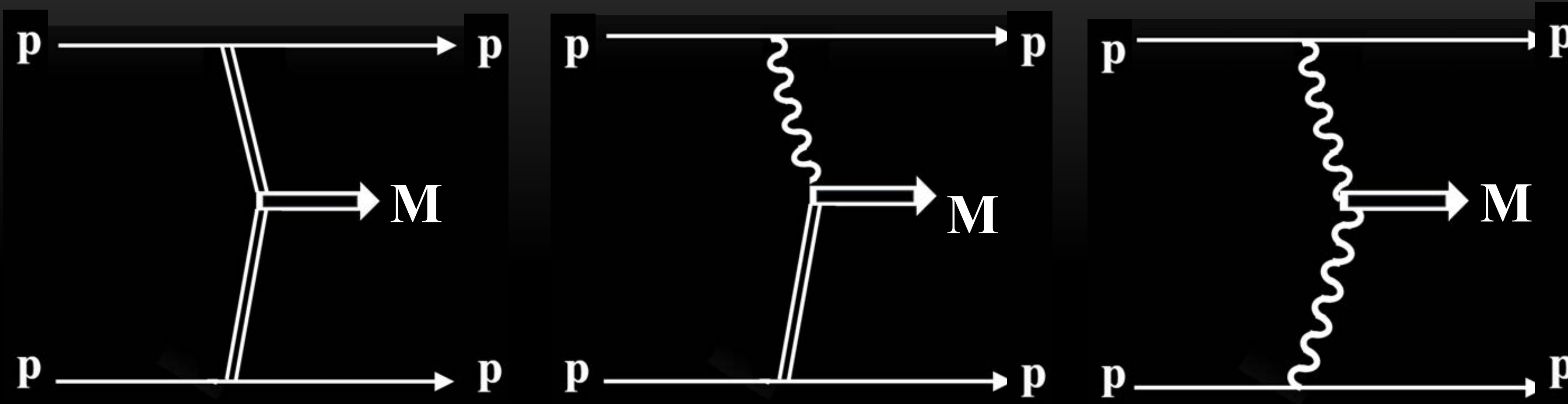
Using Collider Systems to Search for New Physics (A speculative look)

James L. Pinfold
University of Alberta

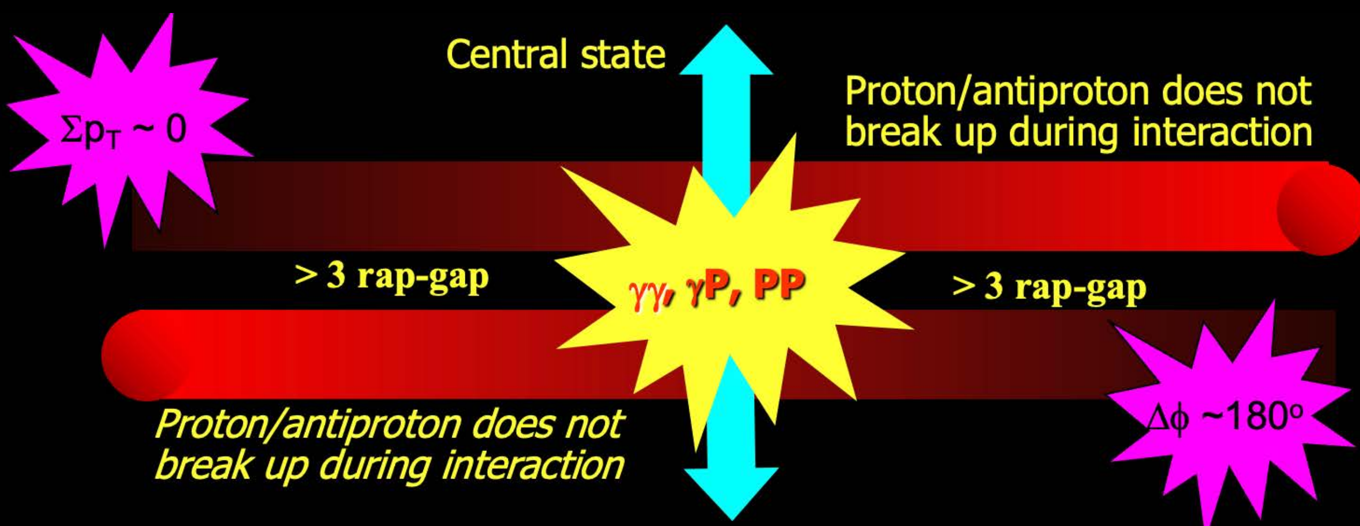
In Collaboration with Matti Kalliokoski[1] & Risto Orava[2]

1 - University of Helsinki   2 - Now retired

Central Exclusive Production (CEP)



$$pp \rightarrow p + X + p$$

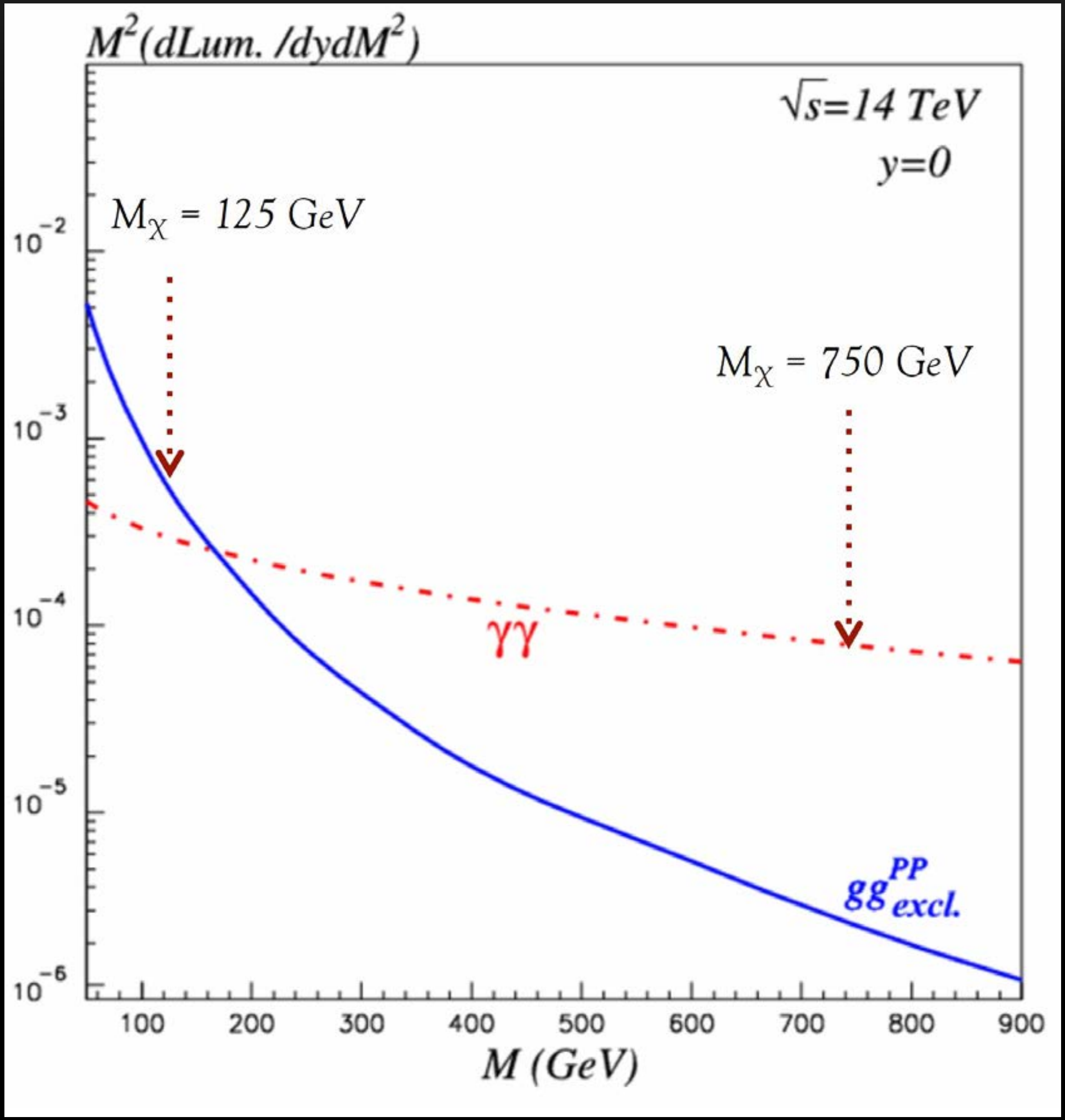


Makes the LHC into a $\gamma\gamma$, gγ and a gg collider!

Gluon versus Photon Induced CEP

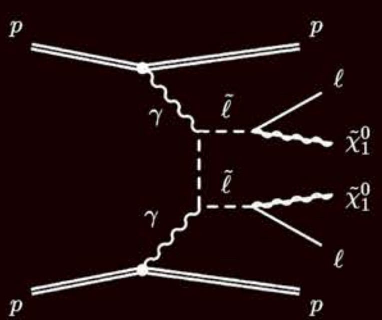
Exclusive production strongly dominated by γγ at large M_X

Eur.Phys.J.C19:313 (2001)



Probing BSM Physics with CEP at the LHC

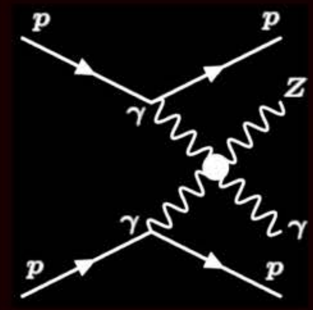
Compressed SUSY



LHL et al., JHEP 1904 (2019) 010

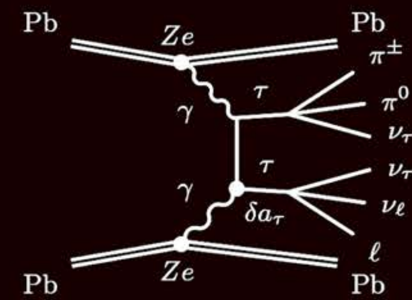
L. Beresford and J. Liu, PRL 123 (2019) no.14

Anomalous couplings



C. Baldenegro et al, JHEP 12 (2020) 165, JHEP 06 (2017) 142

tau g-2



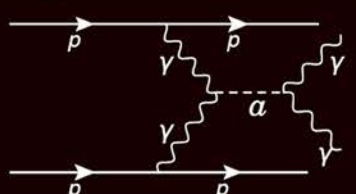
L. Beresford and J. Liu, PRD 102 (2020) 11, 113008

M. Dyndal et al., PLB 809 (2020) 135682

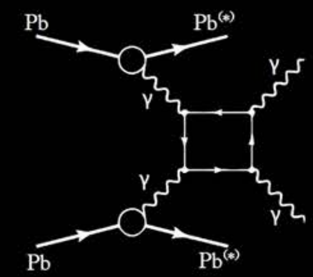
Axion-like Particles

LHL and M. Tasevsky, arXiv:2208.10526

C. Baldenegro et al., *JHEP* 06 (2018) 131

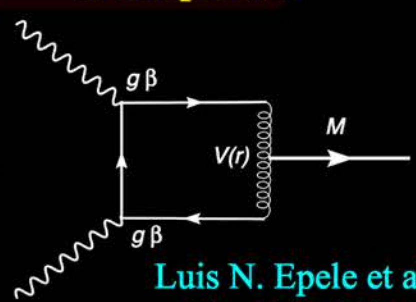


LbyL scattering/ALPS



C. Baldenegro et al, JHEP 06 (2018) 131, S. Knapen et al, PRL 118 (2017) 17, 171801, D. d'Enterria, G. da Silveira, PRL 116 (2016) 12

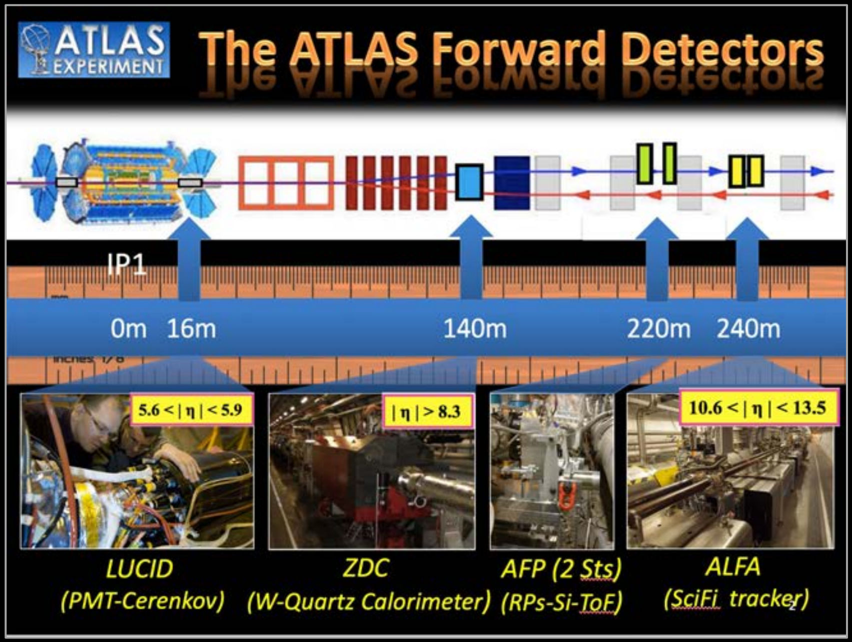
Monopolium

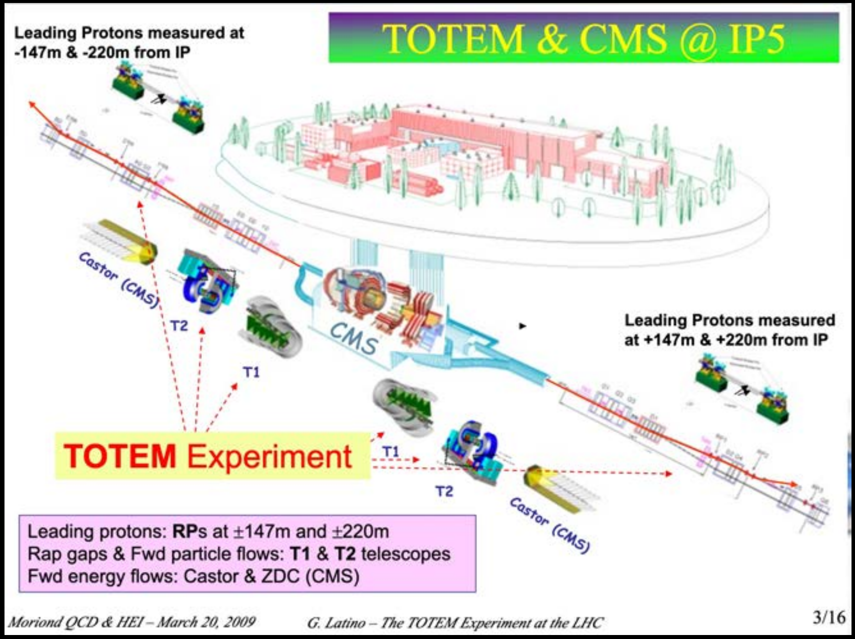


Luis N. Epele et al., "Monopolium detection at the LHC", arXiv:1107.3684v1 [hep-ph] 19 Jul 2011

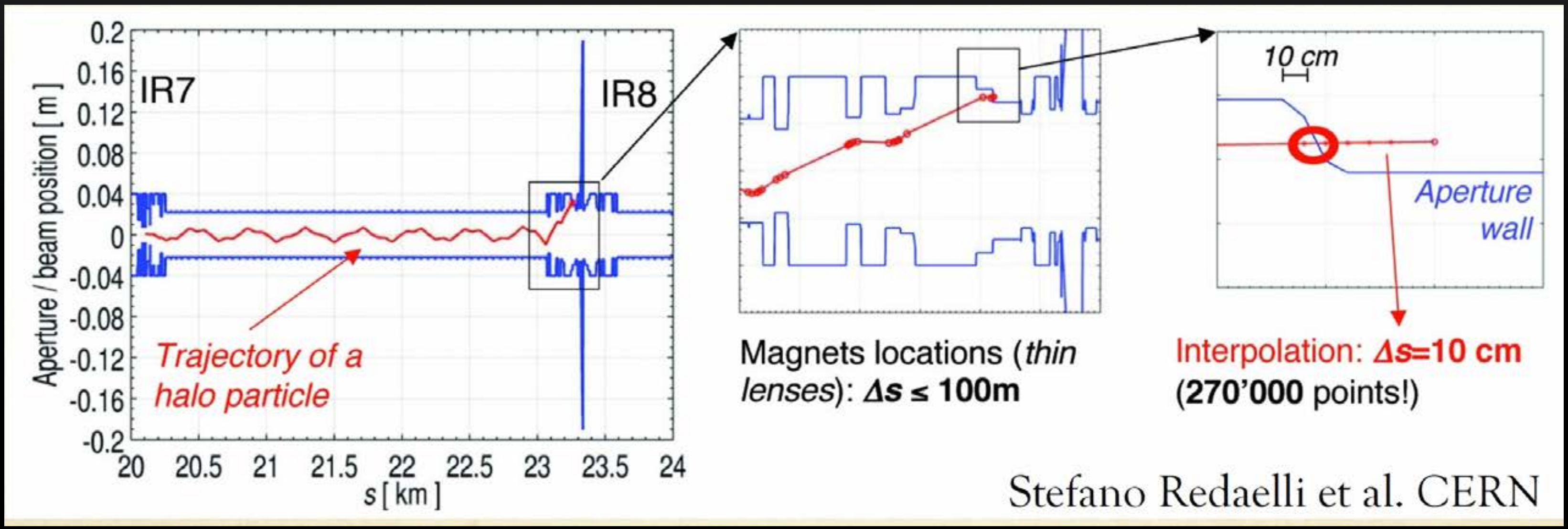
Roman Pots – Getting Near the Beam

- *In exclusive interactions at LHC IPs, the interacting protons will lose a part of their E/p, which, if high enough will move these protons out of the beam core.*
- *These off-momentum particles could be detected by placing detectors inside the beam vacuum using an insertion device called a Roman Pot.*
- *The LHC has a few experiments using RPs they are TOTEM, AFP and ALFA.*



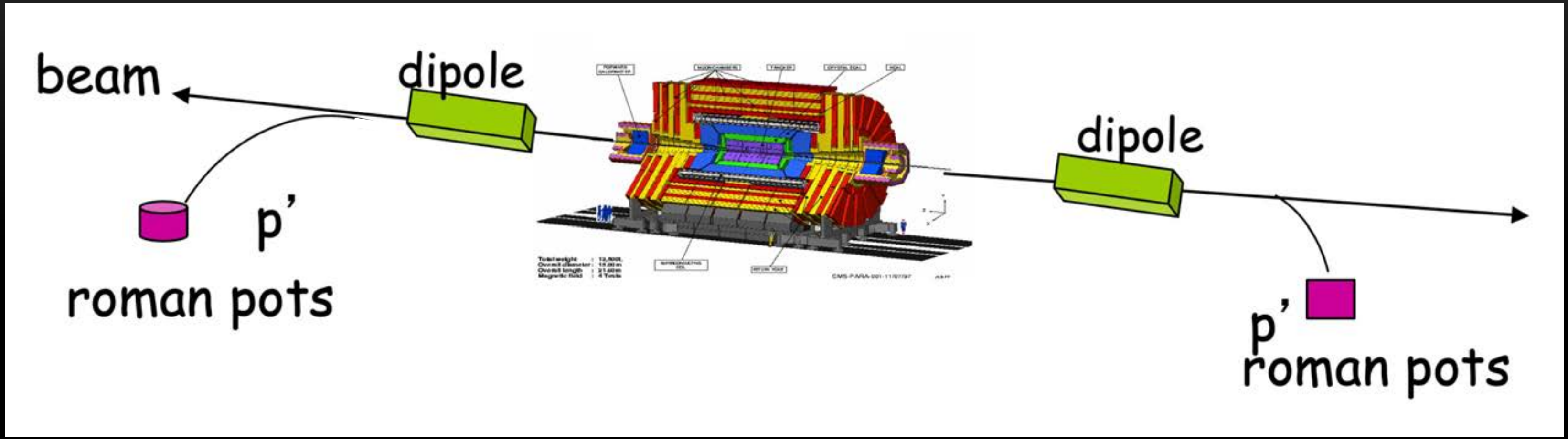


Tracing the CEP Protons



- *We can trace the protons after a CEP process*
  - *Simulation of beam-like "scattered" protons (MAD-X SIXTRACK)*
  - *Proton loss simulation at the BLMs – GEANT-4, Fluka*
  - *Proton shower simulations in the machine elements GEANT-4, FLUKA*
  - *Simulation of gluon and photoinduced processes Super-Chic, etc.*

Determining the Central State's Mass



- *The masses and widths of the centrally produced M-particles are correlated with the fractional (longitudinal) momentum losses, $\xi_{1,2} = 1 - p_{f1,2} / p_i$, final state protons (f1,2 and initial state proton beam (i)*

$$M_X^2 \approx \xi_1 \xi_2 s,$$

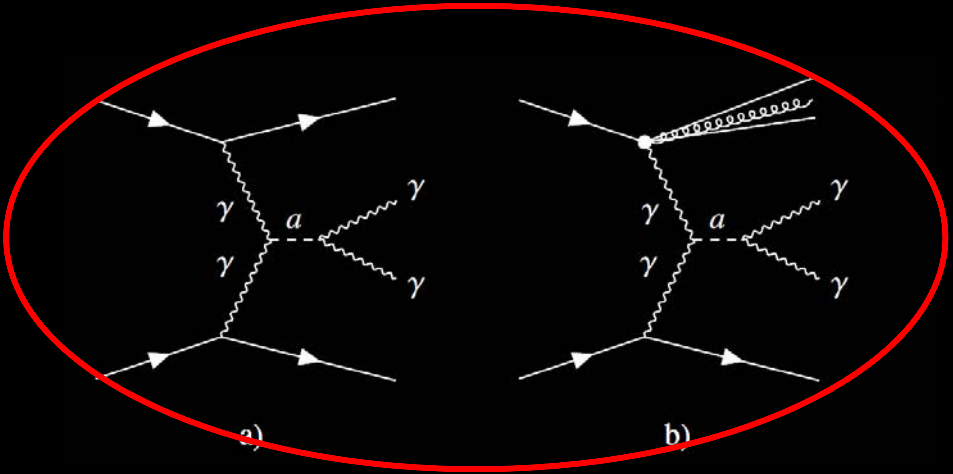
Tracing of beam-like "scattered" protons using MAD-X orSIXTRACK)

$\xi_1 \xi_2$ s = M^2
With
$\sqrt{s}$=14TeV,
M=120GeV
on average:
$\xi \approx 0.009$
$\approx 1\%$

A Search for ALPS from ATLAS Forward Protons

Search for an axion like particle with forward proton scattering in association with photon pairs at ATLAS

JHEP07 2023 234

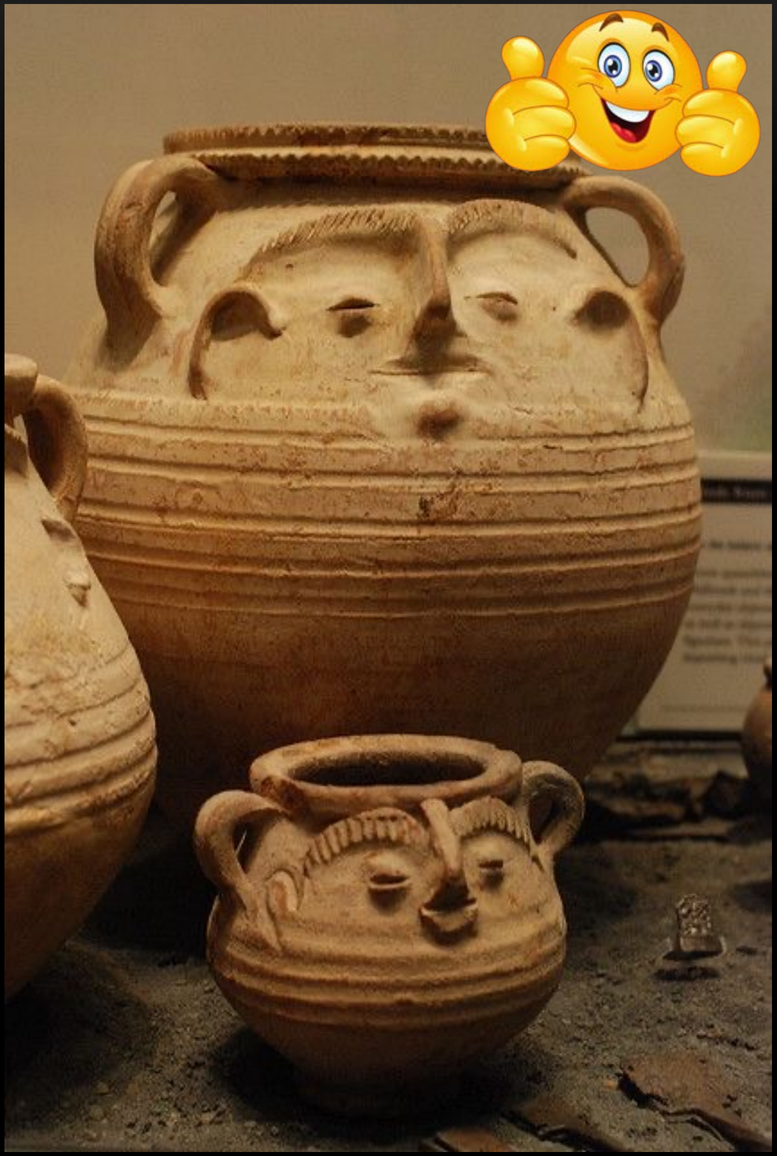


- *The Axion-Like-Particle (ALP) search in the reaction $\gamma\gamma \rightarrow \gamma\gamma$ uses an AFP proton tag to reduce the background,*

- *A search for a $\gamma\gamma$ resonance was formed over the mass range 500 → 1600 GeV, no signal was observed (14.6 fb^{-1} Luminosity was used)*
- *The inferred upper limit on the ALP coupling constant assuming a 100% a→$\gamma\gamma$ branching ratio is in the range 0.04 →0.0 TeV^{-1} at the 95% CL.*
- *These results are similar to those of CMS-TOTEM (PRL 129 2022 011801)*

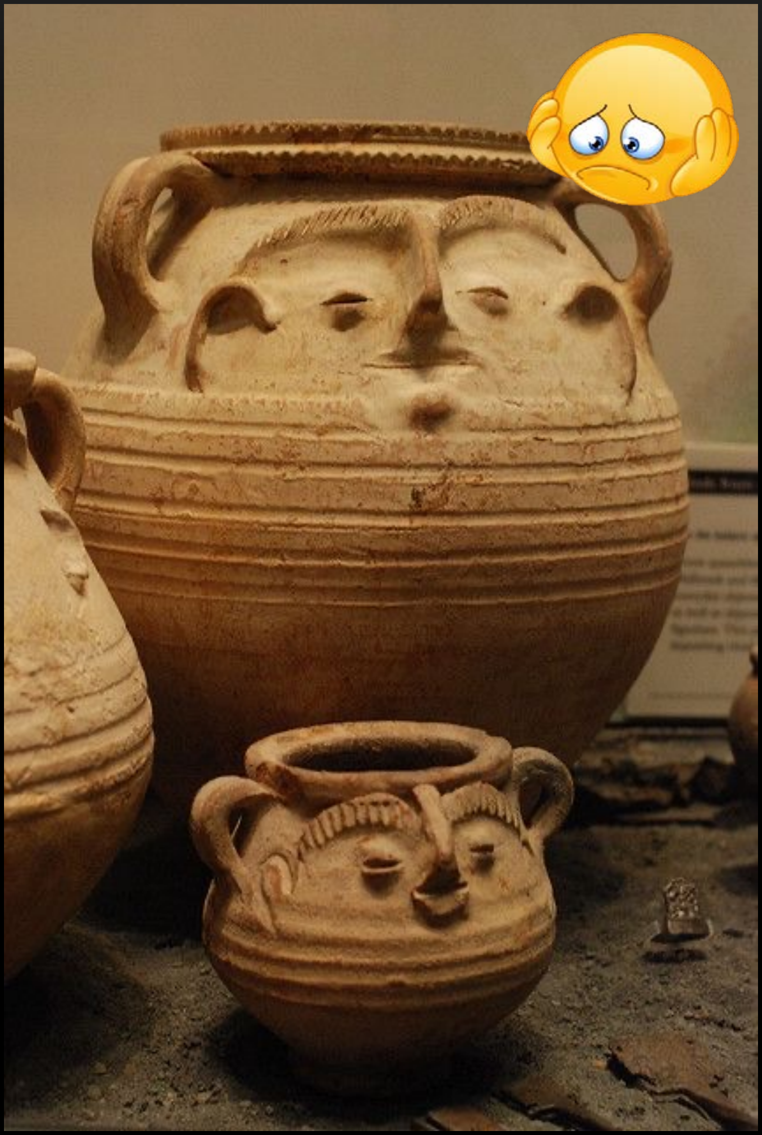
The Benefits of CEP & Roman Pots

- *RPs allow the study of CEP events, pp → p + X + p, at the LHC*
- *In CEP events, the state M_X is produced at central rapidities, and the scattered protons do not leave the beam pipe. Thus, we need RP's to detect them.*
  - *The kinematics of X can be fully reconstructed from that of the protons, giving access to non-visible final states*
  - *CEP allows unique sensitivity to BSM physics*
  - *$J^{PC} = 0^{++}$ selection rule for if a BSM particle is seen at all in this process, we have a good determination of its QNs*
  - *The Jz =0 rule reduces QCD backgrounds from quark-antiquark jets*

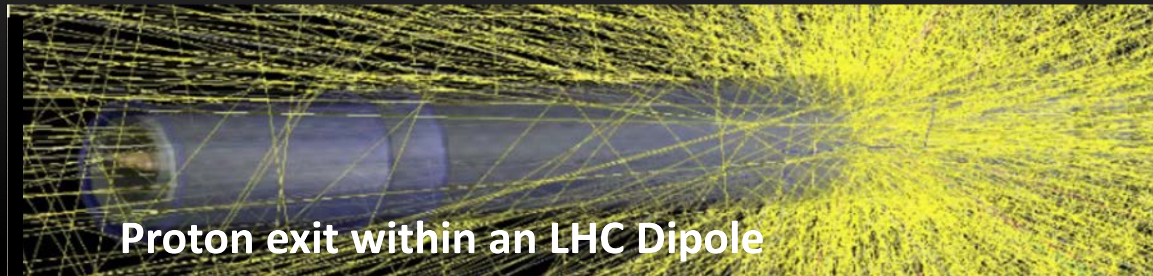


The Problem with Roman Pots

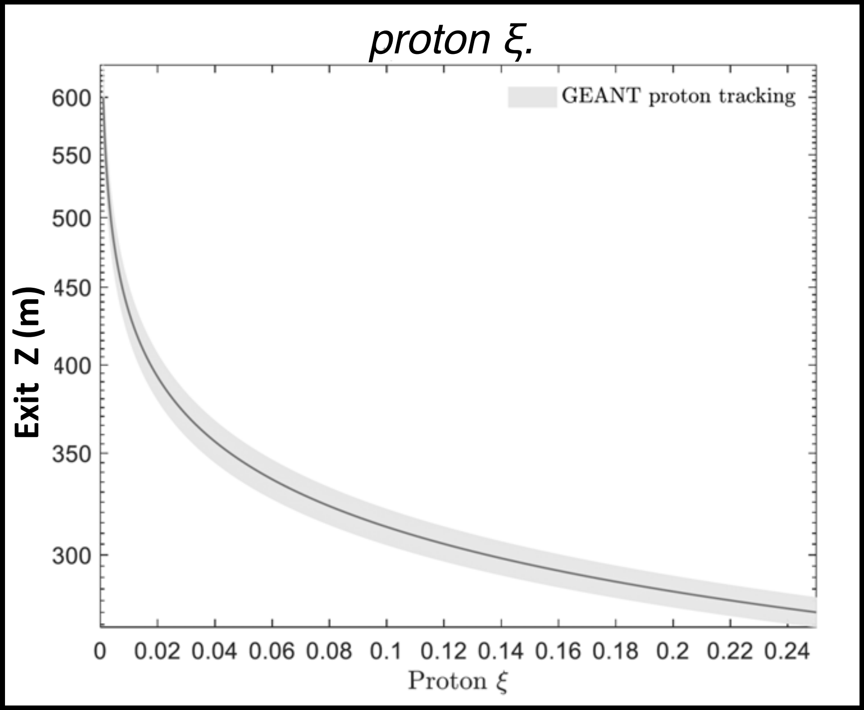
- *All devices installed in the beam vacuum impact beam stability.*
- *RPs also cause the production of large numbers of downstream secondaries, thus*
  - *1) RP placement can be challenging, or*
  - *2) RPs can only be inserted during special runs where the beam intensity is lower*
- *For CEP, placement of the RPs determines a limited mass range of detectable states.*
- *Pileup closes rapidity gaps, confusing the association between the central and forward systems*
- *RP systems are vulnerable to changes in the beam configuration*
- *Large radiation backgrounds for detectors*



The Fate of Off-Momentum Protons



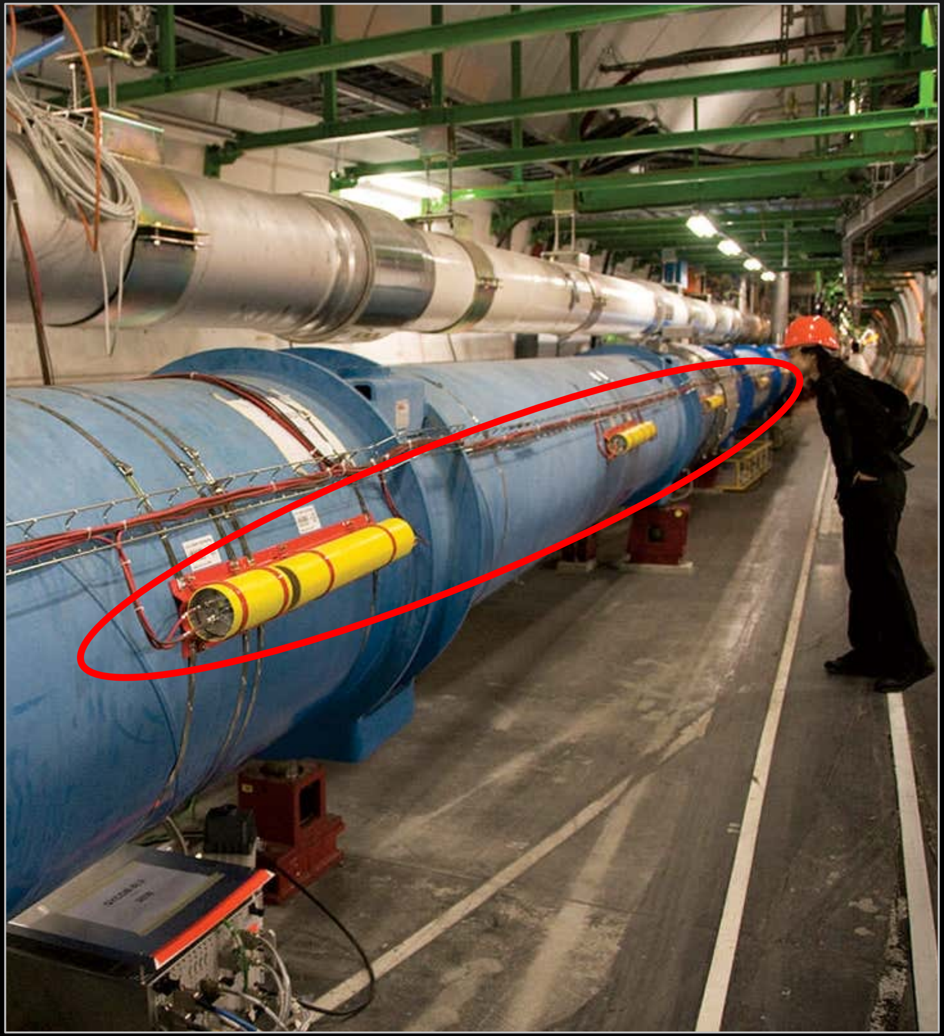
- *The final state protons from CEP process enter the LHC beam optics……*
- *To the machine these protons are "off-momentum"*
- *These CEP protons are eventually lost, either by:*
  - *LHC cleaning-collimator system,*
  - *Exiting the beam-pipe at a distance, z, dictated by the fractional momentum loss ξ.*



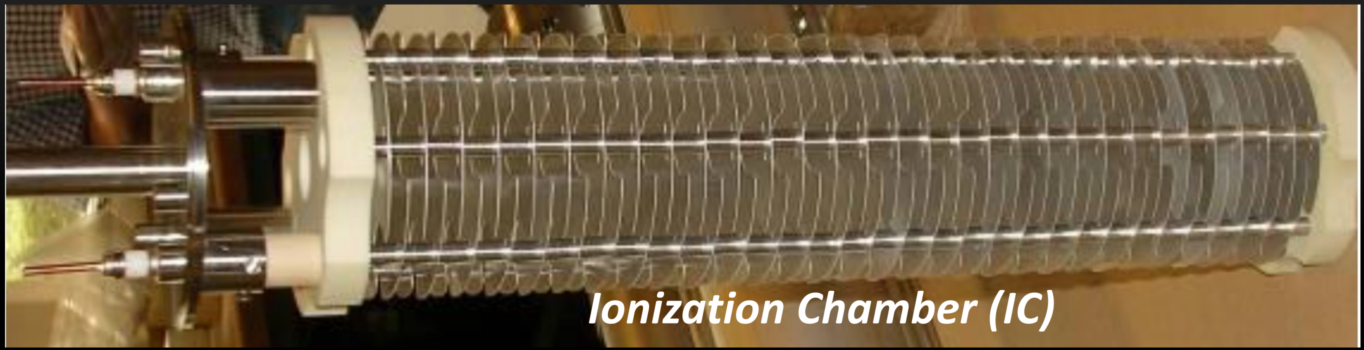
The proton exit point (from IP5) , z, in CEP: pp → p + X + p, as a function of the frac. momentum loss, ξ (solid line). the shaded band reflects smearing in proton transverse momentum.

Beam Loss Monitoring System (1)

- *The beam losses of the LHC are monitored with the Beam Loss Monitoring (BLM) system.*
- *The function of the system is to protect the machine from losses.*
- *Irregular Beam Losses:*
  - *RF trips & vacuum leaks*
  - *Injection losses*
  - *Beam instabilities*
  - *Obstacles in the beam (UFOs etc)*
- *Regular Beam Losses*
  - *Debris from IP(collider)*
  - *Losses from beam setup*
  - *Losses at aperture limits (collimation)*



Beam Loss Monitoring System (2)



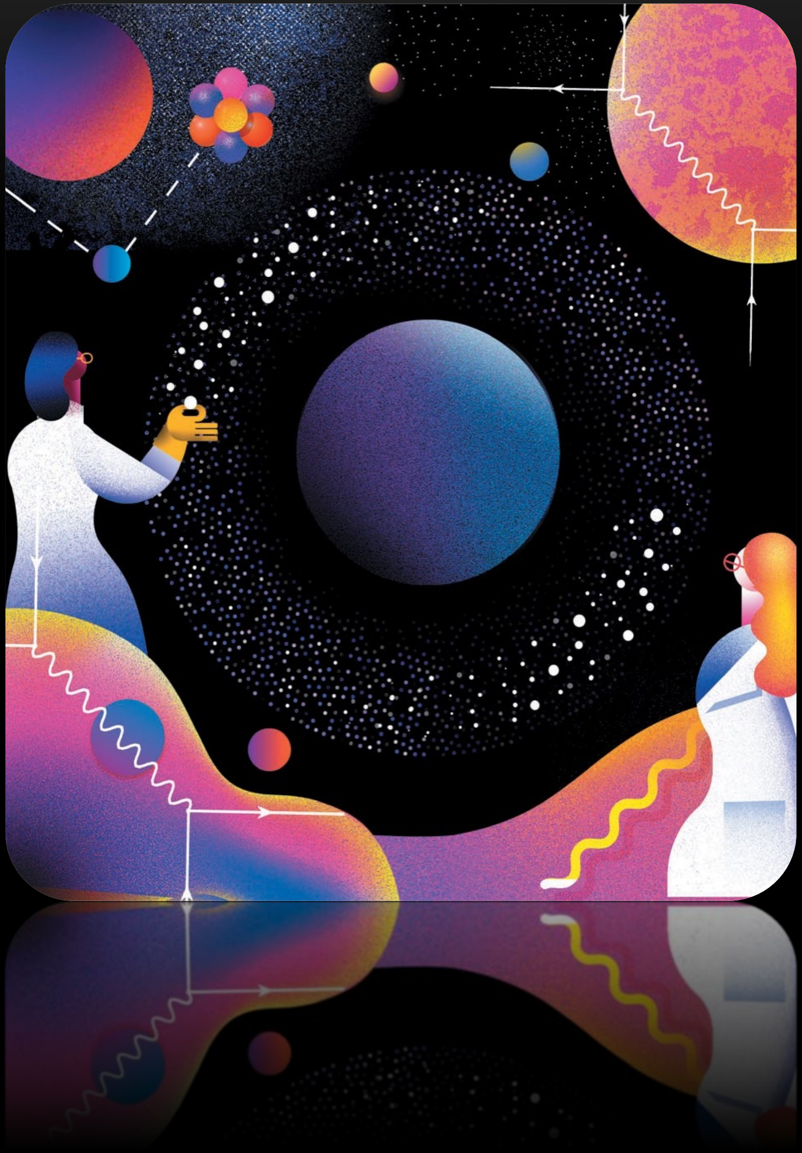
Length 50 cm, high pressure N2 gas, SV 1.5L, ion collection time 85 ms,

Lngth 10 cm, $P<10^{-7}$ bar

- *Placement of Beam Loss Monitors (BLMs) at critical and likely loss locations:*
  - *6 ICs around each quadrupole*
  - *IC + SEM after each collimator/absorber*
  - *Injection and extraction elements, movable elements,*
- *3600 Ionization chambers (IC) interlock (97%) and observation*
- *300 Secondary emission monitors (SEM) for observation*

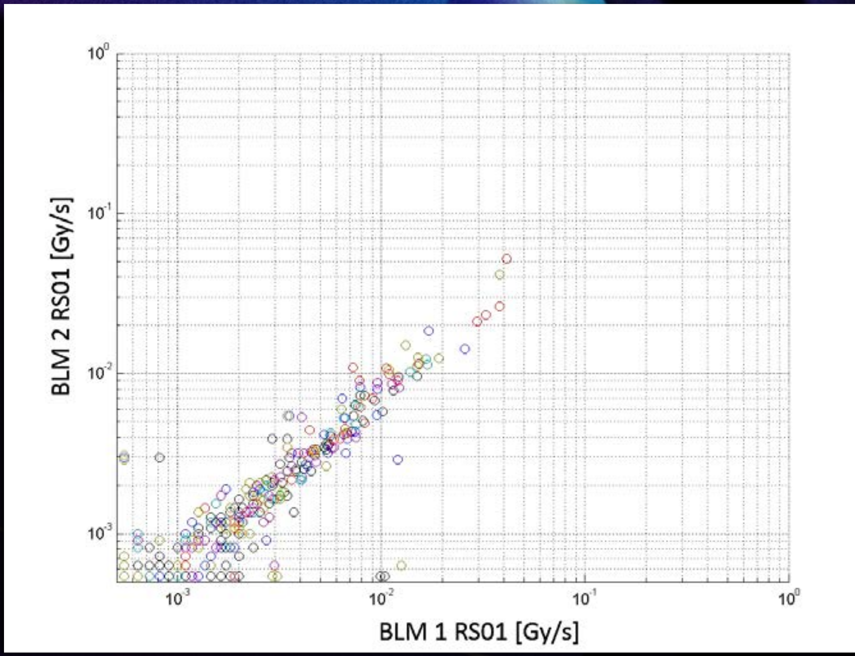
Single Proton Losses

- *Measuring single proton losses is challenging, as the distance between BLMs can be as much as 15m.*
- *The signals are digitized with a CFC*, & the produced pulses are summed over 40 µs.*
  - *These counts are further sampled over 12 different time intervals (running sums, RS), spanning 40 µs - 84 s.*
  - *Only the highest value from each integration window/s is stored. Thus, for each monitor, 12 values/s is stored*
- *When a single proton exits the BP, the loss is fast < 25 ns. A fast loss is seen as an increase in the absorbed dose rate in the shortest integration window.*
  - *If there are no other fast loss events, the highest value will be the single proton loss.*



Single Proton Losses (2)

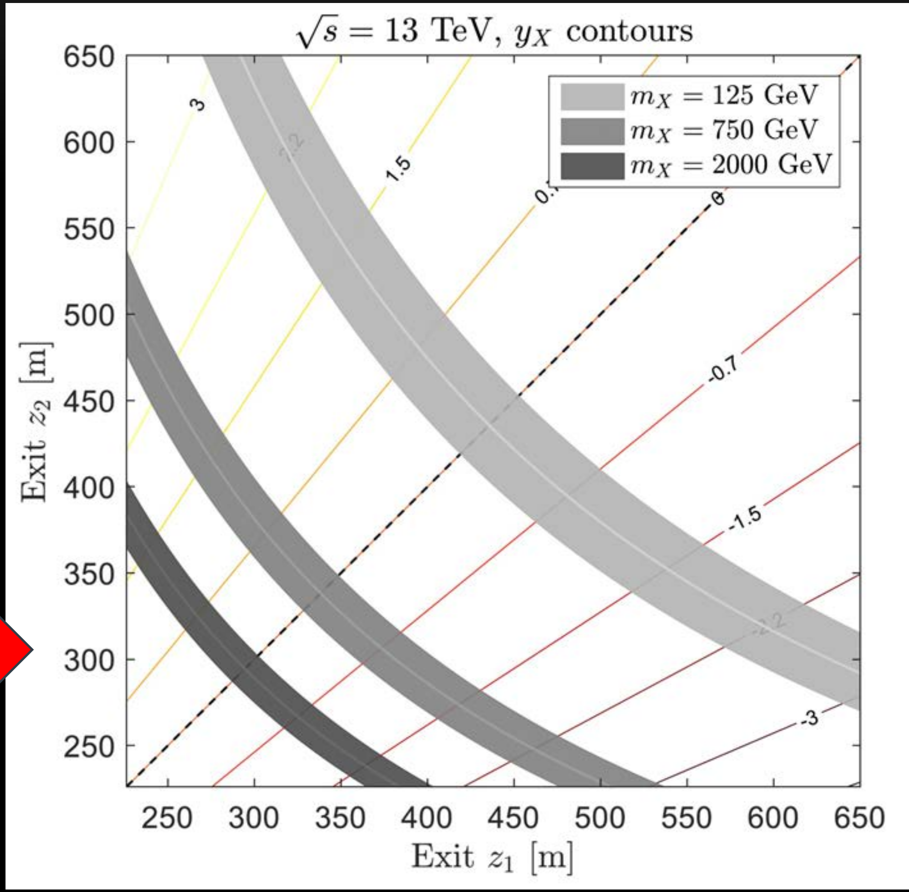
- *For single proton loss, the loss shower is narrower compared to other loss types.*
- *Multiple neighboring monitors should not measure similar loss pattern within the same timestamp.*
  - *Simulations show the shower from single proton losses has a spread covered by only 2 BLMs, if within few meters of each other.*
- *Most of the losses are highly correlated and thus not from single proton loss events.*
  - *The interesting cases are the outliers in the distribution*
- *To determine if we have a real loss event, values from 1-year of ops can be compared.*
- *Different beam modes can be used to analyze the beam offset and the baseline level of the monitors.*



The Figure shows the correlation between two neighbouring monitors.

Tagging CEP Protons Without RPs

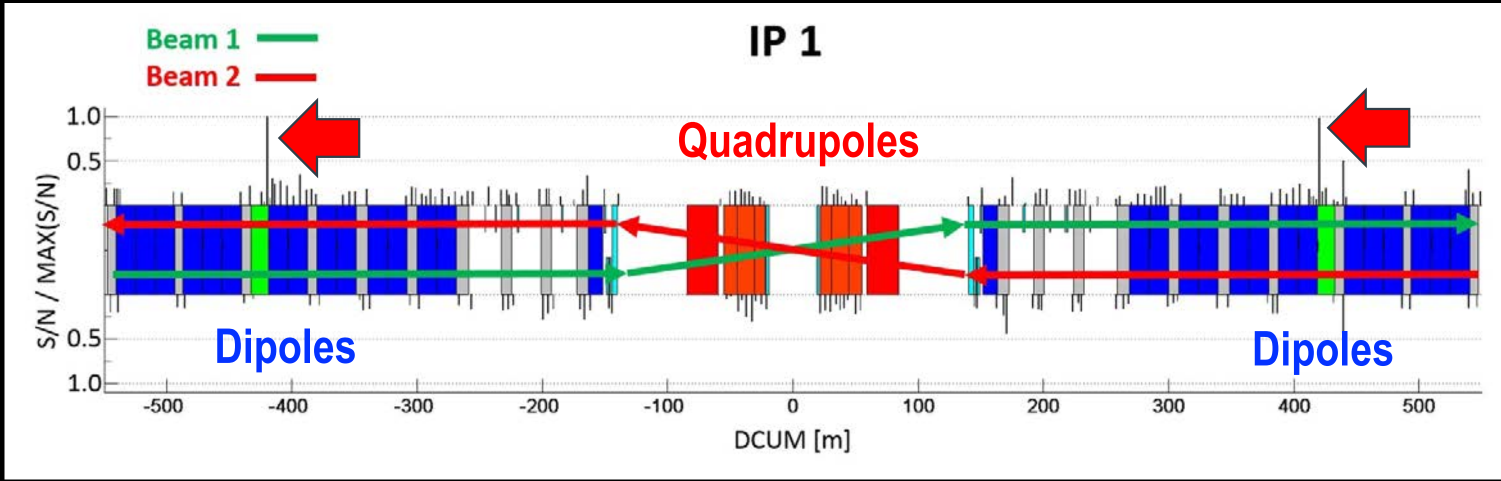
- *All CEP events producing massive states, can be tagged by detecting the proton-pairs exiting the LHC beam region.*
  - *This is independent of their decay mode*
- *The larger M_x the shorter the distance to the exit point.*
- *The exit points of the leading protons out from the beam vacuum chamber are given in meters from the IP55*
  - *The symmetric cases ($\xi_1 \approx \xi_2$) have $z_1 \approx z_2$ (dashed diagonal line)*



The proton exit point combinations in CEP: pp → p + X + p, as a function of the central mass, M_X (the grey bands).

Symmetric Events

- *In the central exclusive production (CEP), the colliding protons transfer part of their energy momenta to the central system.*
- *The loss data from the BLM system could be used to detect this type of events.*
  - *As the LHC is rather symmetric around the IPs, the off-momentum protons are lost at similar distances from the IP.*
  - *Also, since the material budget is close to same at both sides, the measured dose rates should be at the same level.*
  - *Using the filtering methods described previously only a small number of correlated events are left for comparison.*



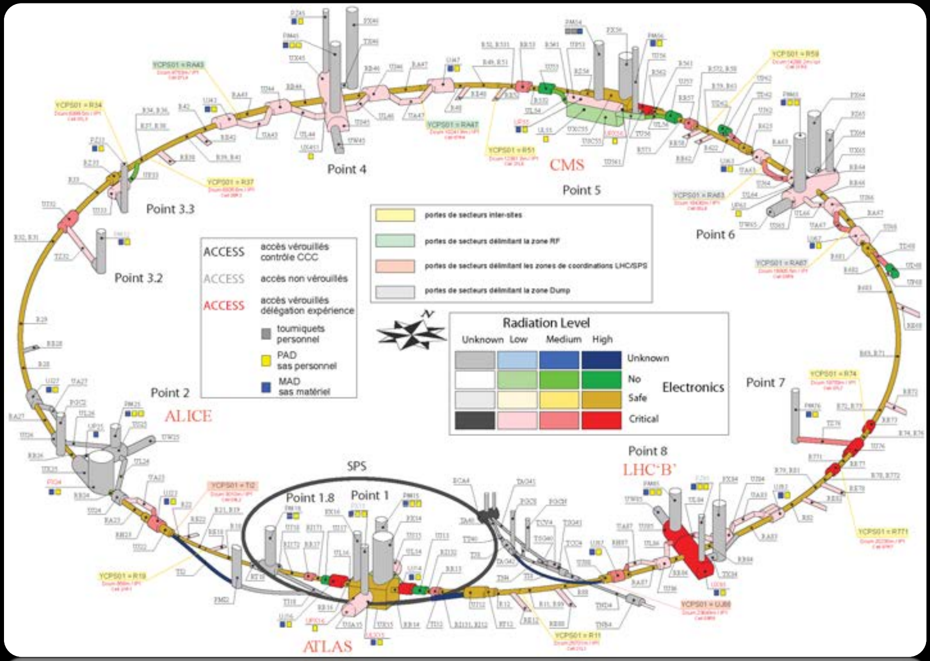
Tagging the CEP event candidates

The following steps are taken to tag the CEP event candidates for each IP (IP1/ATLAS, IP2/ALICE, IP5/CMS, and IP8/LHCb):

(i) Candidate CEP events are scanned by locating pairs of coincident p-exits on the opposite sides of the interaction point (IP) in question.

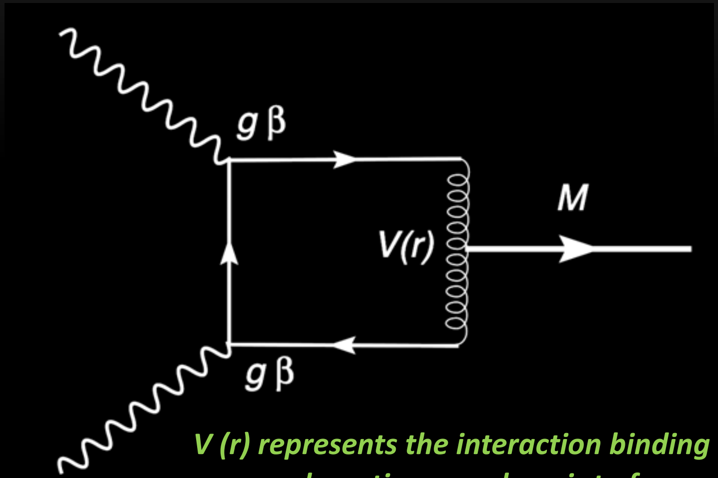
(ii) The tagged events are correlated with the LHC Beam Crossings (BCs) within the time window for the chosen IP

(iii) The tagged LHC BCs are analyzed as CEP event candidates with central masses corresponding to a registered pair of exit points

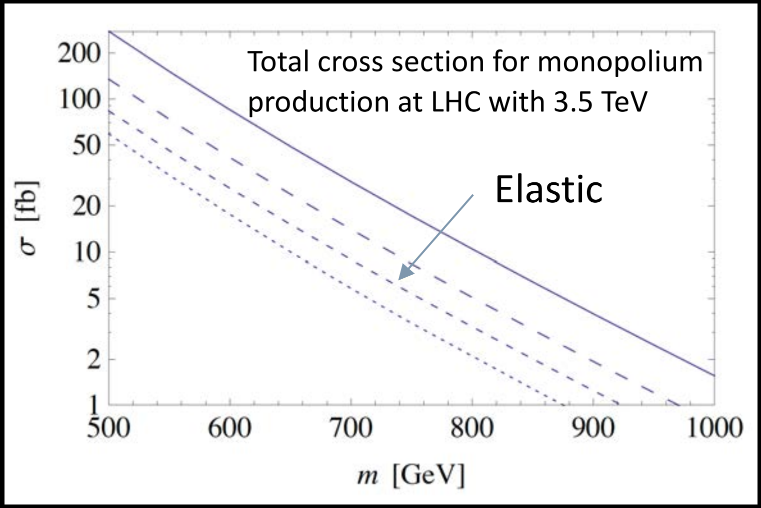


The 1st Search for New Physics Using BCMs - Monopolium?

- *The MoEDAL-MAPP Collaboration is currently studying the possibility of using the LHC BCM system to search for Monopolium*
- *Use Central Exclusive Production to generate monopolium*
  - *Monopolium is a monopole – anti-monopole bound state.*
  - *The state is neutral and thus not observable*
  - *For a monopolium mass of ~2 TeV, expect exit points of protons ~300 m on either side of the IP.*
  - *Assume for this search that the monopolium is "detector stable"*



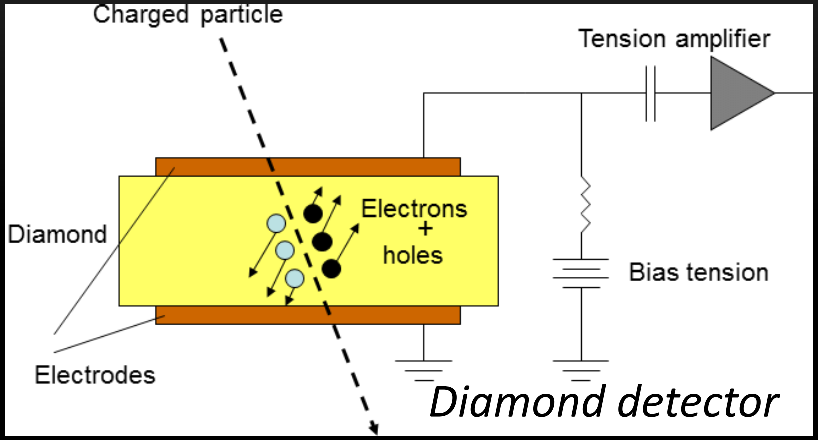
V (r) represents the interaction binding the monopole-antimonopole pair to form monopolium. arXiv:1107.3684v1 [hep-ph] 2011



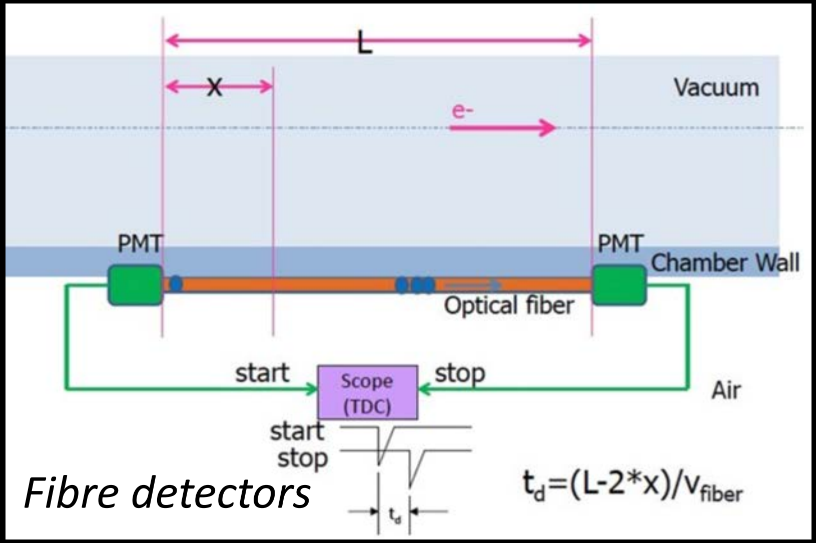
Upgrading the BLM System for Physics

- *To improve ID a faster sampling rate is needed. Within a 1s sampling window, ~ 40M BCs take place at the IPs*
  - *If all 40 μs bins are be stored, each value would still correspond to about 1600 BCs*

    Two faster detection methods being tested are:
  - ***Diamond detectors** – shown to resolve single MIPs with < 1ns timing resolution + rad hard.*
  - ***Optical fibres** – can cover distances up to 100 meters* without significant signal attenuation*
- *Other rad hard scintillator/ Cerenkov detectors can be installed as required to optimize the LHC as a particle physics detector*



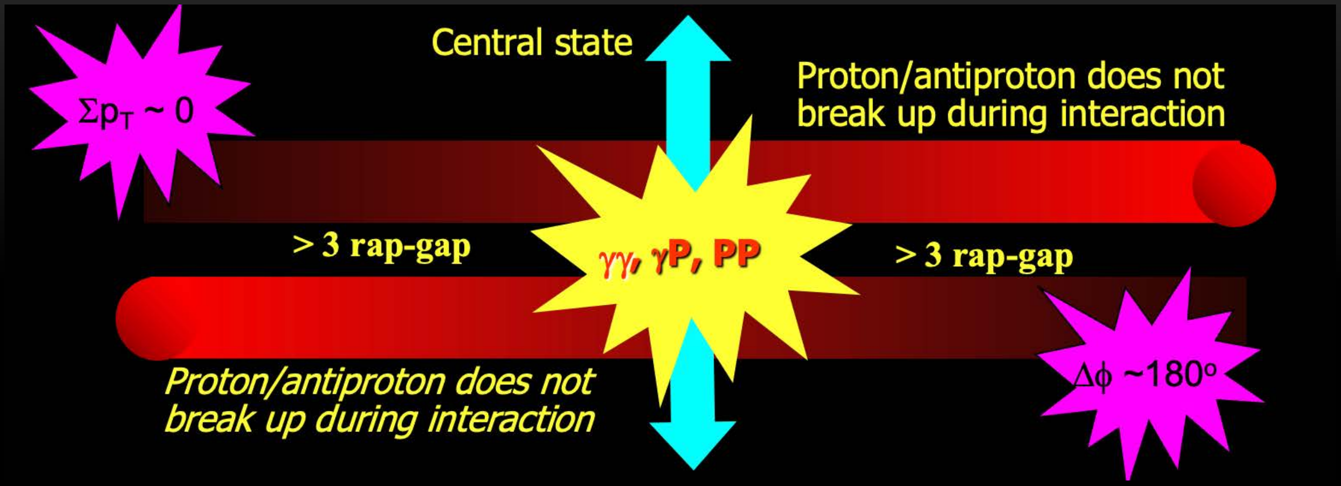
Diamond detector



Fibre detectors

**1 fibre can cover several FODO-cells (6 dipole + 2 quadrupole magnets) in the LHC arcs.*

Summary of the Challenge



- ***The LHC's BLM system can be used to turn the LHC into a new physics search machine for g-g, g-γ and the γ–γ "collisions".***
- ***Searches would be independent of decay mode and include invisible decays.***
  - *By tagging the CEPs, heavy particle states can be scanned as a function of their masses by detecting the exit points of the final state proton pairs.*
  - *With small additions to the existing BLM system, an on-line trigger (using optical fibres) for new particle states could be provided.*
- *One could perhaps use this technique to study the Higgs a la FP420*

Environmental Assessment

- *All protons utilized are being reused after interaction*
- *We essentially use the protons from the LHC beam-cleaning system – i.e. from the trash*
- *We also largely reuse the existing LHC structures to do the searches*
- *We should at least pass environmental assessment with flying colours.*

EXTRA SLIDES

The $J^{PC} = 0^{++}$ Rule

Since the pomeron is a Regge trajectory running over states with quantum numbers $J^{PC} = \{0^{++}, 1^{++}, 2^{++}, \ldots\}$ and $I^G = 0^+$, the resonance is restricted to have $J^{PC} = \{0^{++}, 2^{++}, 4^{++}, \ldots\}$ and $I^G = 0^+$, where J is the total angular momentum, I is the isospin, P is the parity, C is the charge parity,

$J_Z = 0$ Rule

parity, while the production of states with non–$J_z^P = 0^+$ quantum numbers (where J_z is the projection of the object angular momentum on the beam axis) is strongly suppressed [5, 6]. This suppression is predicted in the Durham pQCD–based model to be at the level of two orders of magnitude.