THE LHC RING AS A NEW PHYSICS SEARCH MACHINE

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THE PLAN

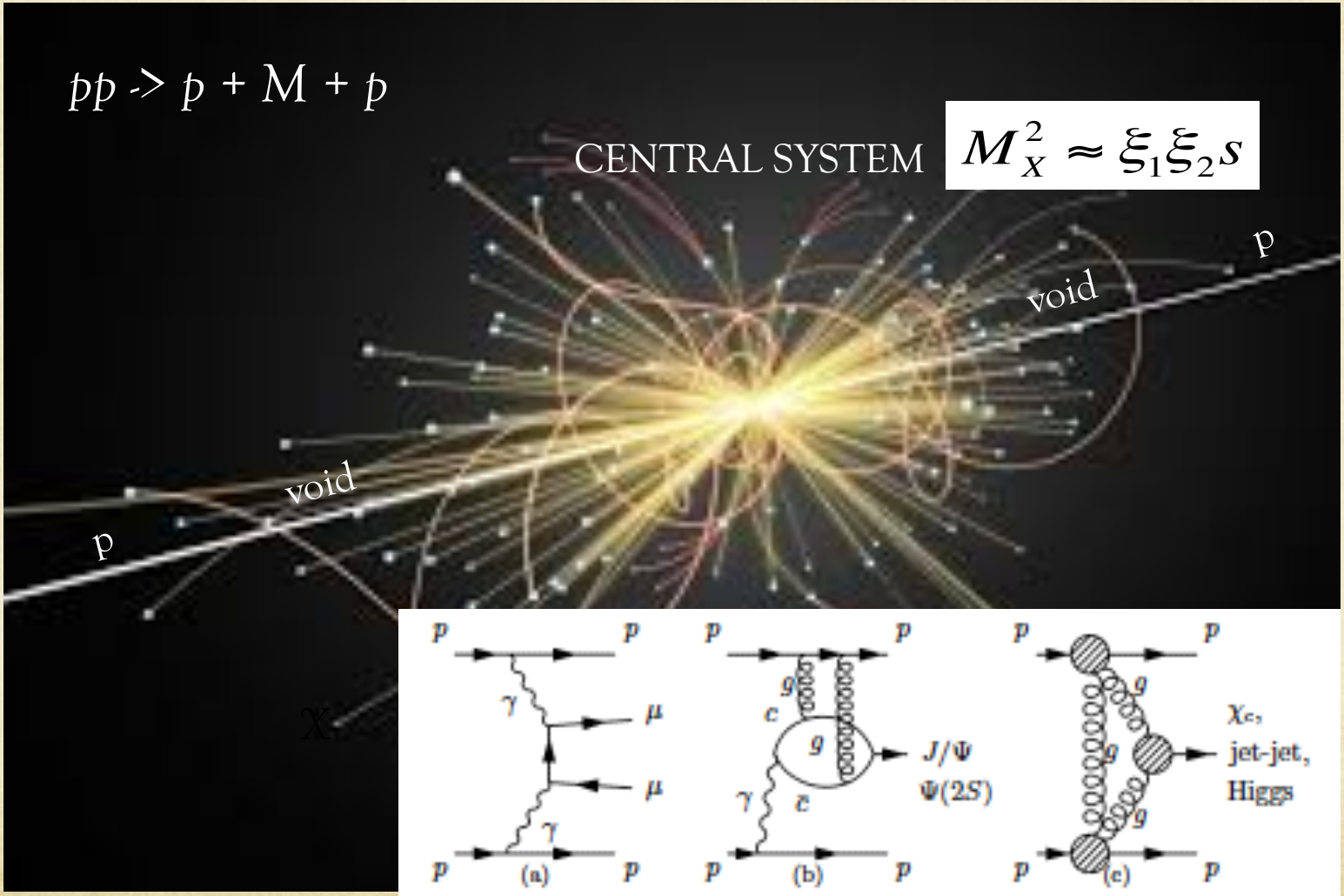
- LHC RING AS A CONTINUOUS ROMAN POT
- TAGGING PHOTON-PHOTON PROCESSES
- PHYSICS BACKGROUNDS
- FURTHER DEVELOPMENT
- SUMMARY

SCANNING FOR MASSIVE NEW PARTICLES

BY RECYCLING THE LEFT-OVER PROTONS

LHC beam collimation: S. Redaelli, D. Mirarchi et al. (CERN Beams Division), accelerator theory: Werner Herr (CERN Beams Division), theory: Lucian Harland-Lang (University College, London), K. Huitu(Division of Particle Physics and Astrophysics, University of Helsinki); Valery Khoze (University of Durham); M.G. Ryskin (Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg); V. Vento (University of Valencia and CSIC); experiments: A. De Roeck (CERN EP); M. Kalliokoski (CERN Beams Division); Beomkyu Kim (University of Jyväskylä); Jerry W. Lämsä (Iowa State University, Ames); C. Mesropian (Rockefeller University); Matti Mikael Mieskolainen (University of Helsinki); Toni Mäkelä (Aalto University, Espoo); Risto Orava (University of Helsinki, Helsinki Institute of Physics and CERN); J. Pinfold (FRSC, Centre for Particle Physics Research, Physics Department, University of Alberta); Sampo Saarinen (University of Helsinki); M. Tasevsky (Institute of Physics of Academy of Sciences, Czech Republic)...

CENTRAL EXCLUSIVE PRODUCTION



GLUON vs. PHOTON INDUCED PRODUCTION – EFFECTIVE LUMINOSITIES

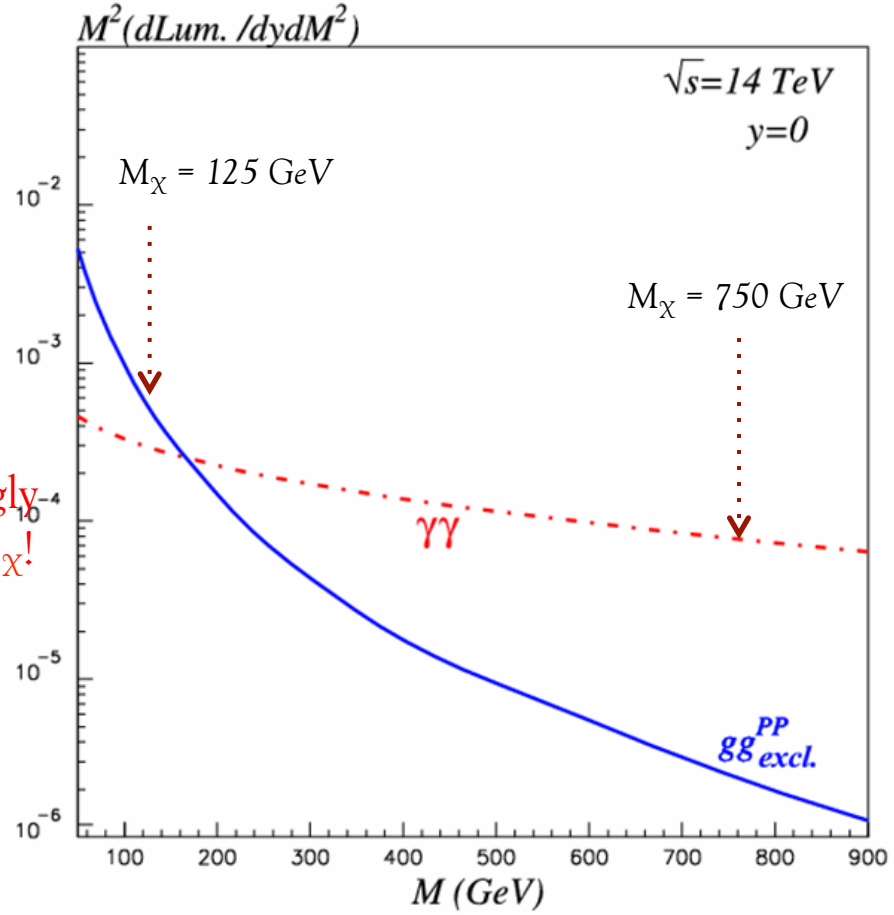
$\sigma(\gamma\gamma \to SMH) \approx 0.1\,fb$

$\sigma(PP- > SMH) \approx 3\,fb$

$\alpha_s^{\,2}/8 \to \alpha^2$

QCD 'radiation damage' in action

exclusive production strongly dominated by $\gamma\gamma$ at large M_χ!



KMR: arXiv 0111078(2001)

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

transverse vs. longitudinal roman pots

- traditional roman pots: **transverse** distance of a leading proton vs. the nominal beam – the distance of the active detector edge is dictated by the LHC collimator group – machine safety
- in case of nominal LHC runs have about 50 pile-up events within a *z*-span of some 15 cm's
- by measuring the exit protons **longitudinally** around the LHC Ring, substantially expand the physics reach

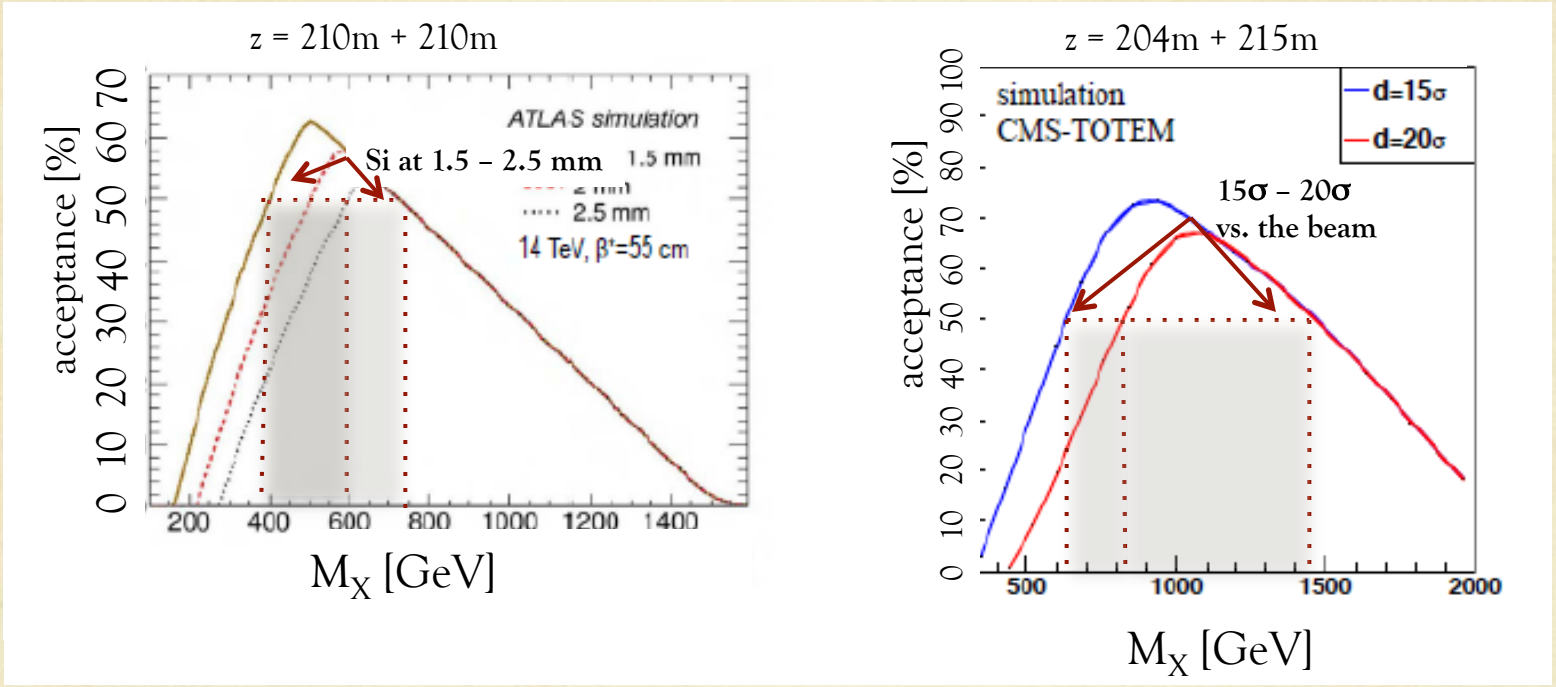
A SSC AUTOMATIC ROMAN POT SYSTEM PROPOSED BY DINO IN 1987

Proceedings of the Second International Conference on

Elastic and Diffractive Scattering
(Second "Blois Workshop")

The Rockefeller University, New York City, USA
October 15-18, 1987

TRANSVERSAL ROMAN POTS HAVE LIMITED ACCEPTANCES



50% acceptance

ATLAS: $M_X \approx 400/600 - 750$ GeV **CMS/TOTEM:** $M_X \approx 650/820 - 1450$ GeV

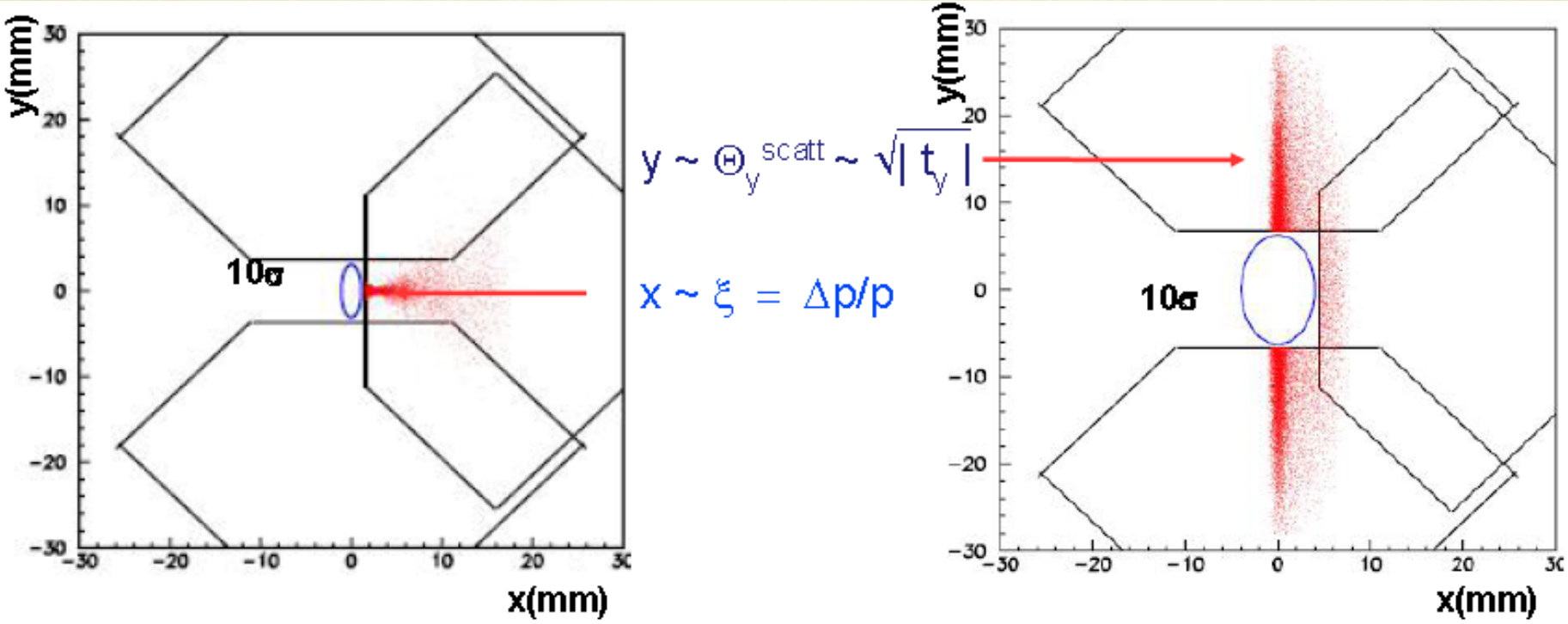
50% accept-ance

- allowed distances to the beam? collimator settings!!
- acceptance in ϕ & t?
- local bumps by the correction dipoles…

transverse roman pot techniques at around ±220 meters:
the horizontal rp's: diffractive protons in nominal LHC runs;
the vertical rp's: elastic protons in special high β* TOTEM-runs

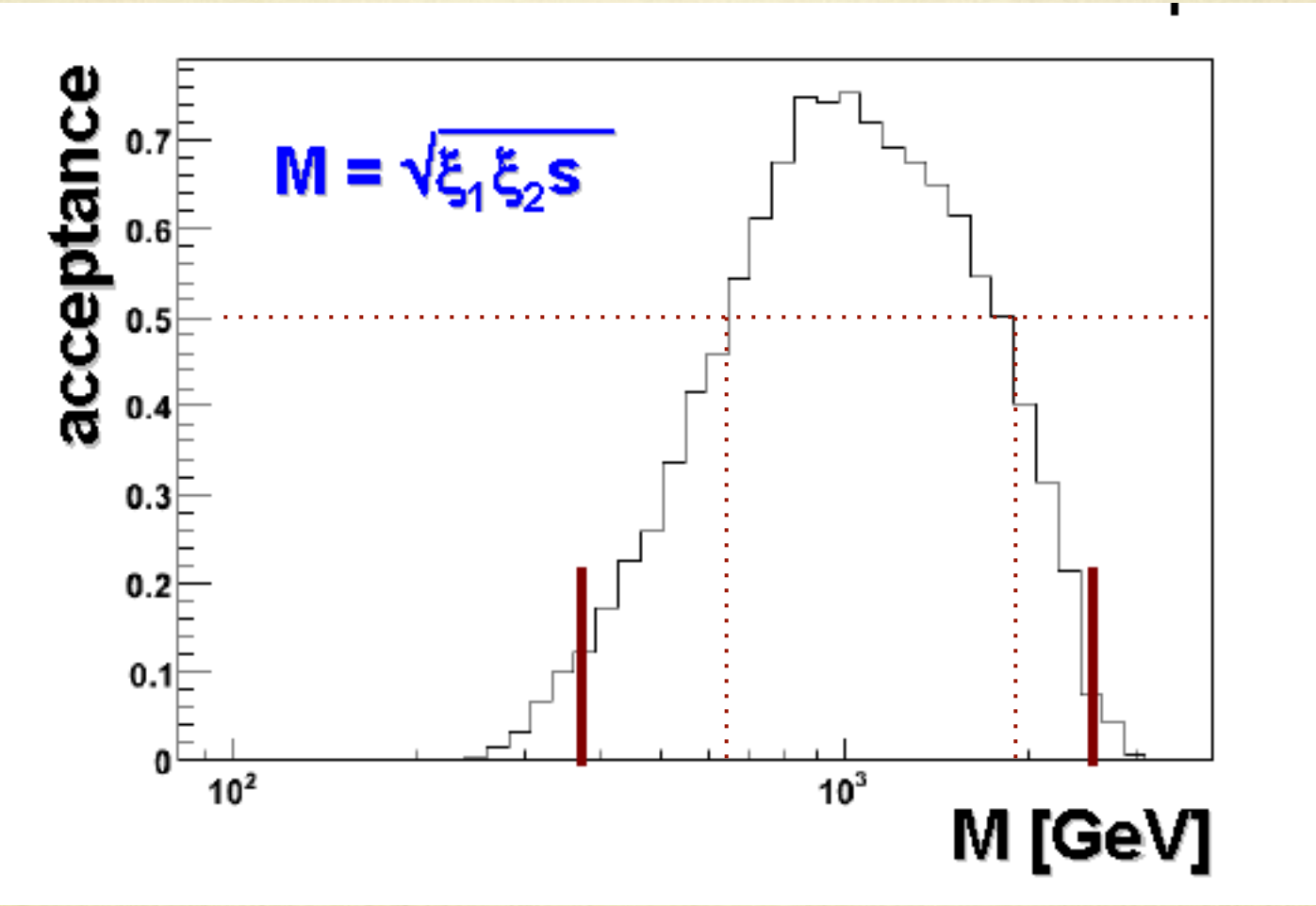
nominal low-β* runs

special high-β* runs



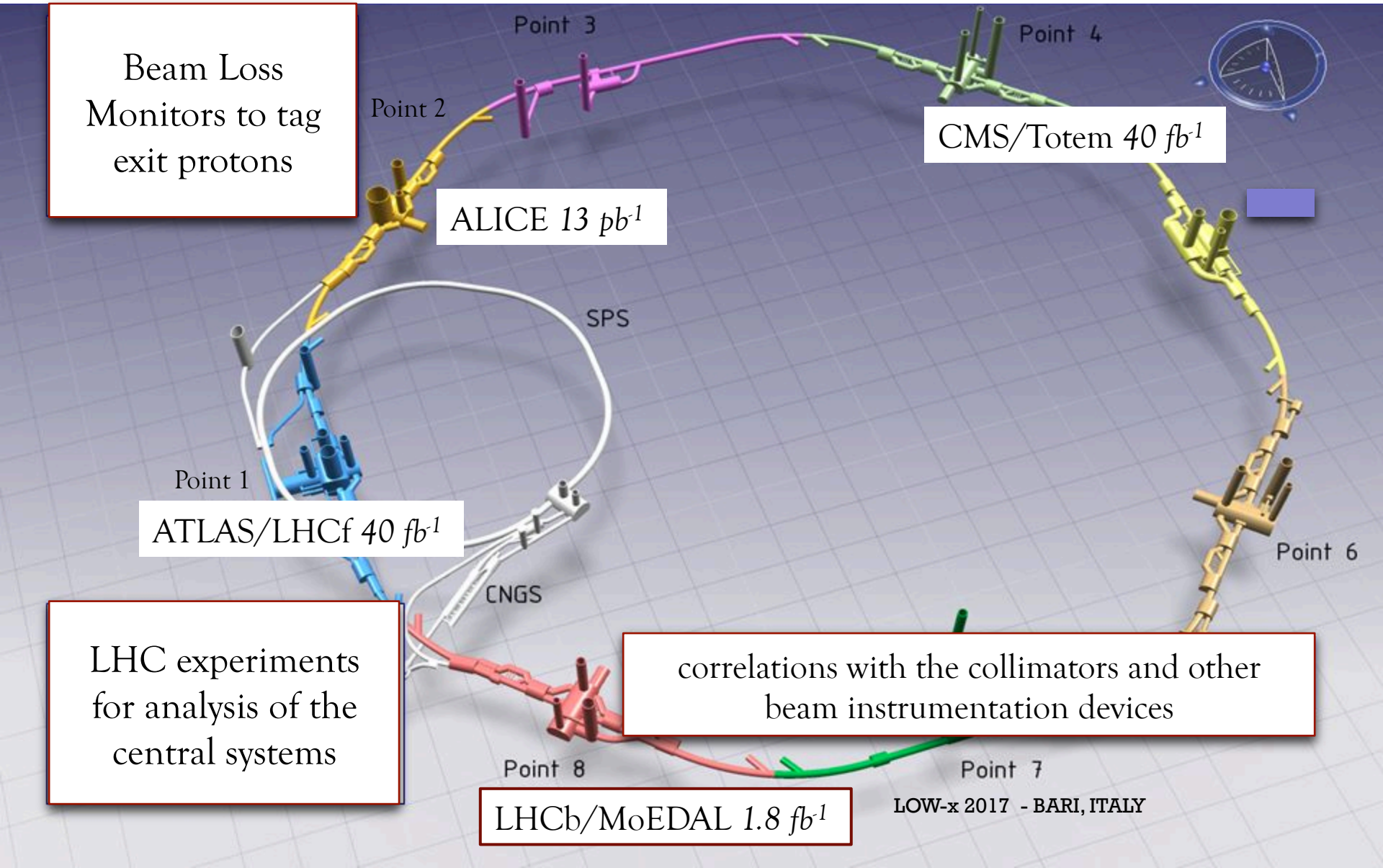
3 basic issues: alignement, alignement, alignement!

roman pot acceptance at low-β*

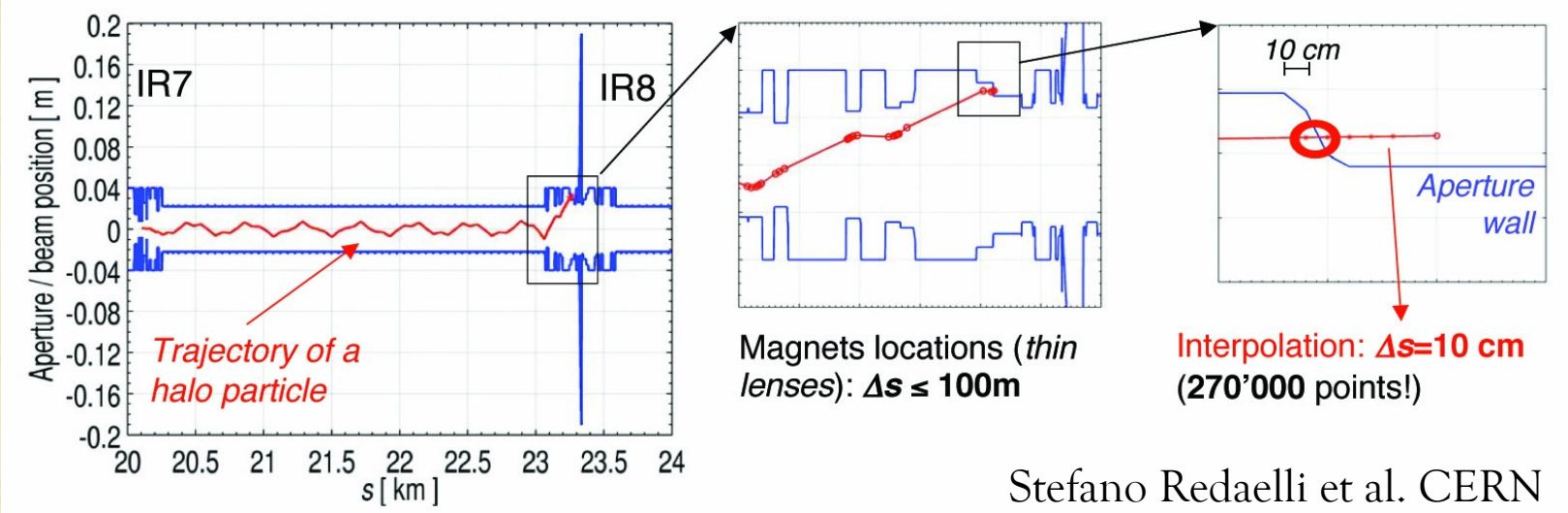


600 – 2000 GeV

LHC RING AS A NEW PHYSICS SEARCH MACHINE



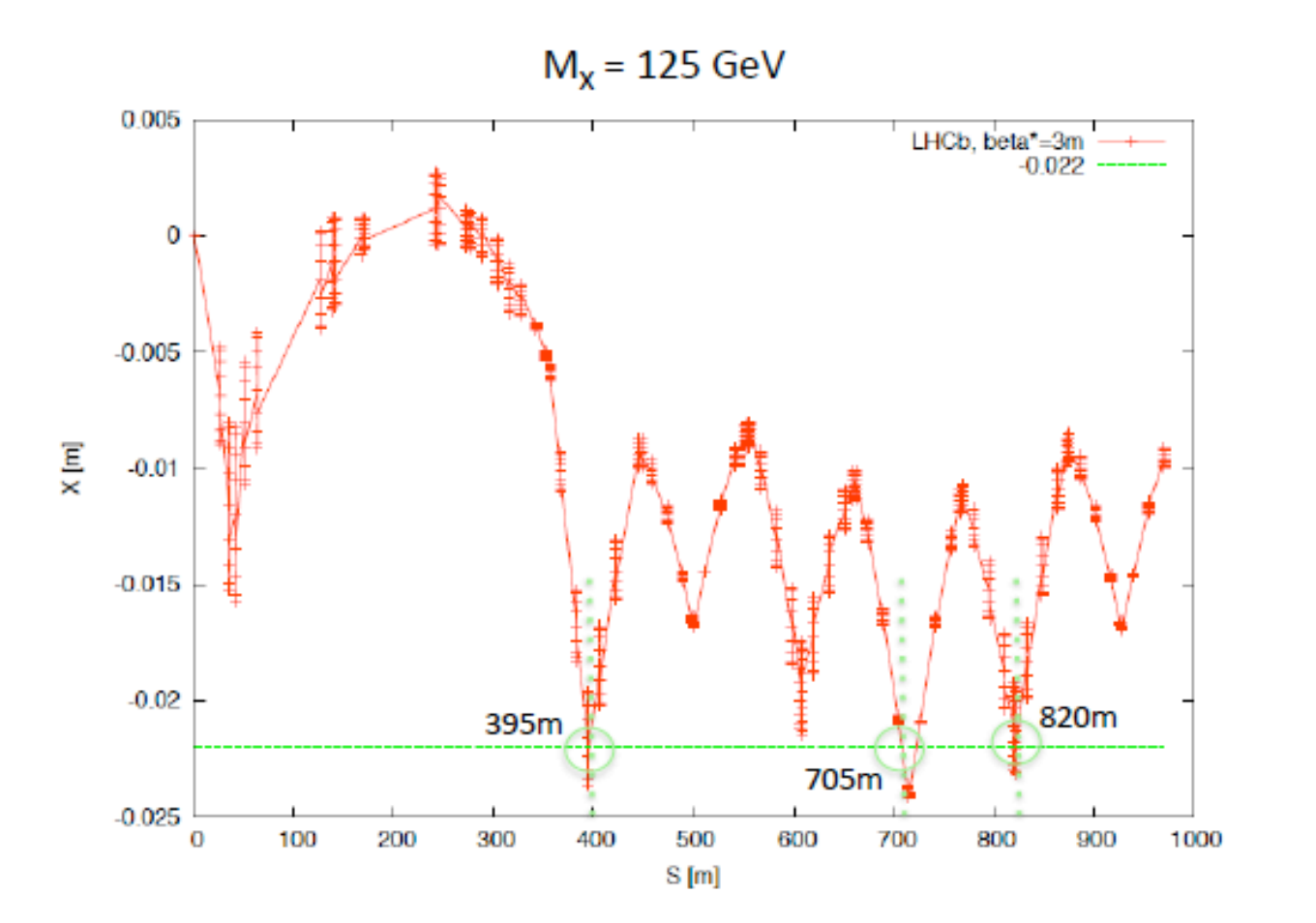
tracing the beam-like protons



Stefano Redaelli et al. CERN

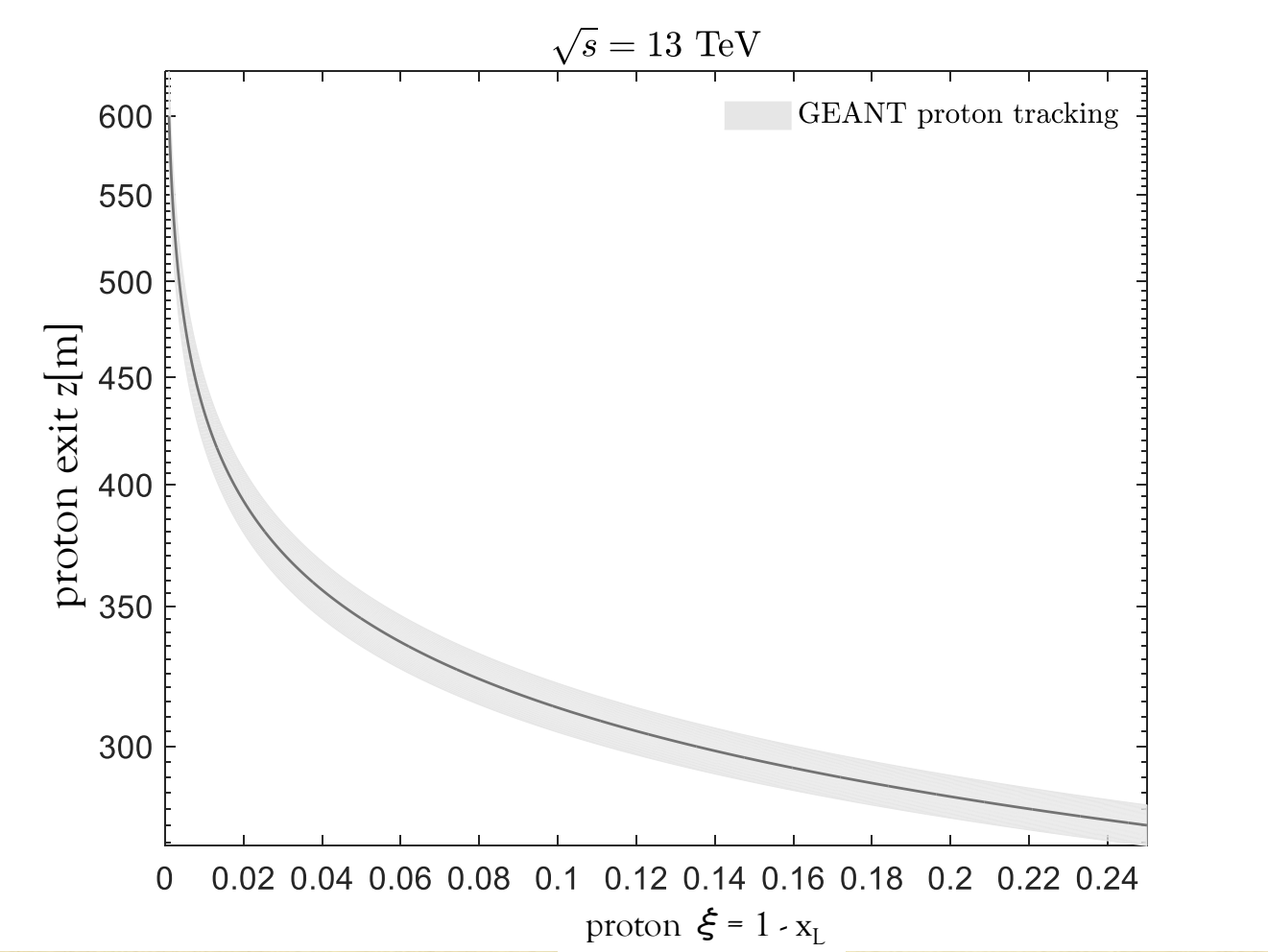
- simulation of beam-like protons (**MAD-X, SIXTRACK**)
- proton loss simulation at the BLMs – **GEANT4, Fluka**
- proton shower simulation in the machine elements – **GEANT4, Fluka**
- simulation of gluon and photon induced processes: **SuperChic**

proton exits in cep higgs events



pp -> p_1 + M_h + p_2, with $\xi_1 = \xi_2$ = 0.00962, corresponding to a symmetrically produced Standard Model Higgs boson with the mass $M_H \approx 125.09$ GeV.

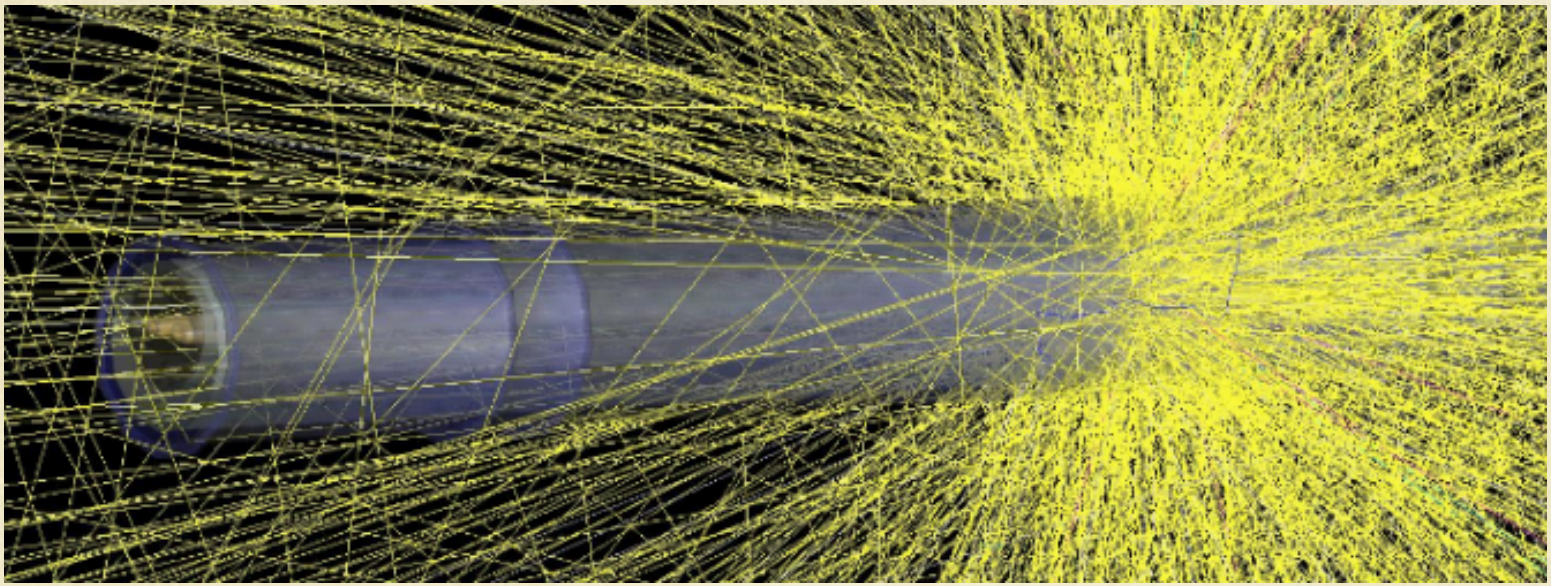
PROTON EXIT POINTS vs. ξ



Matti K. Kalliokoski, RO et al., arXiv:1604.5778; Diffraction 2016

J. Aaron. *Hacking the LHC to shift trash could help find a mystery particle* – 2016.New Scientist Daily News, 25th April.

PROTON EXIT WITHIN AN LHC DIPOLE



GEANT4 simulation by Matti Kalliokoski
- LHC dipole CAD description from the LHC data base

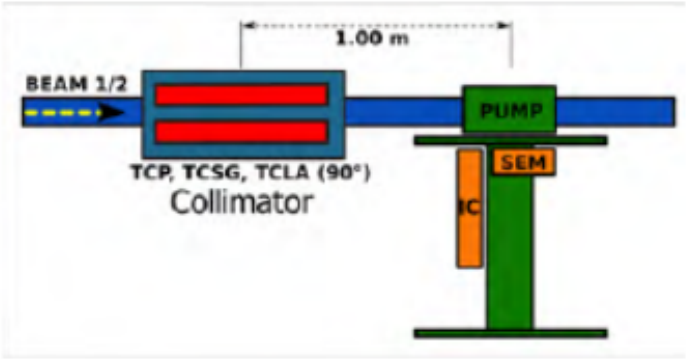
THE LHC Beam Loss Monitoring (BLM) SYSTEM IS UNIQUE

BLMs at quadrupole magnet

BLM at bending–bending magnet transition

BLMs at final focusing magnet

BLM at collimator



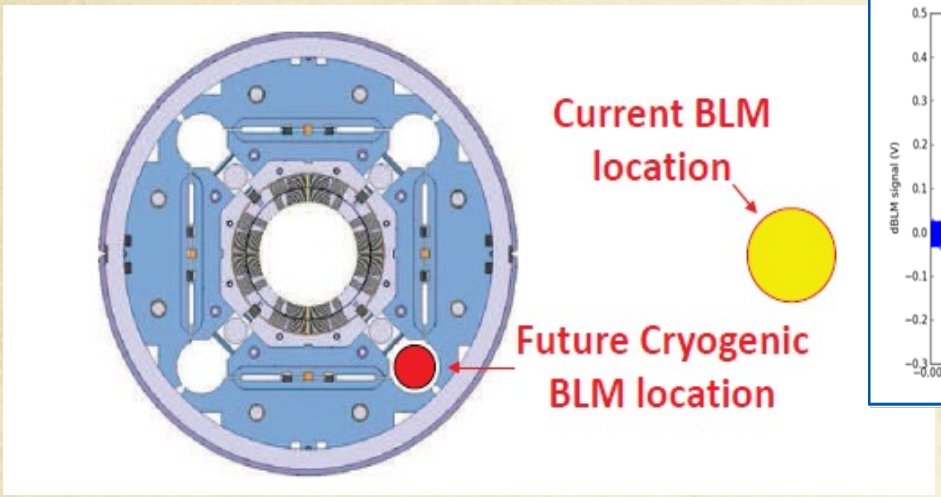
some 4000 detectors
along the LHC Ring

see: Matti Kalliokoski: AIP Conf.Proc.1819(2017)no.1,040022

THE BLM SYSTEM IS BEING UPGRADED FURTHER

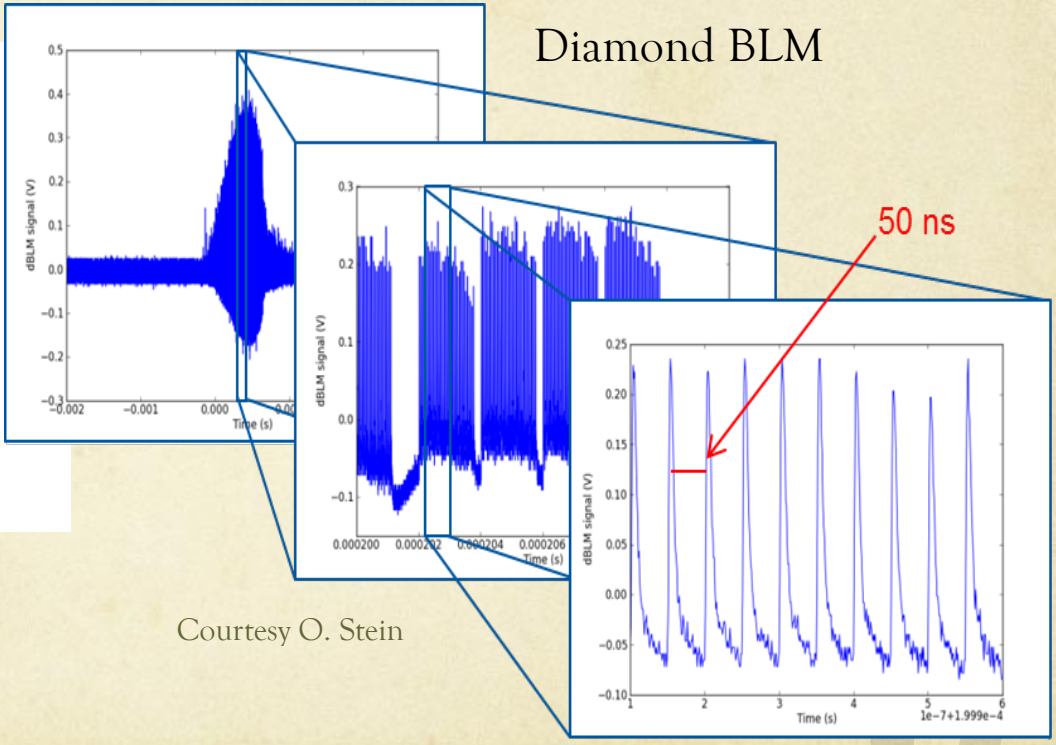
- several upgrade modalities

CRYO-BLM



M.R. Bartosik et al., IBIC2015

Diamond BLM



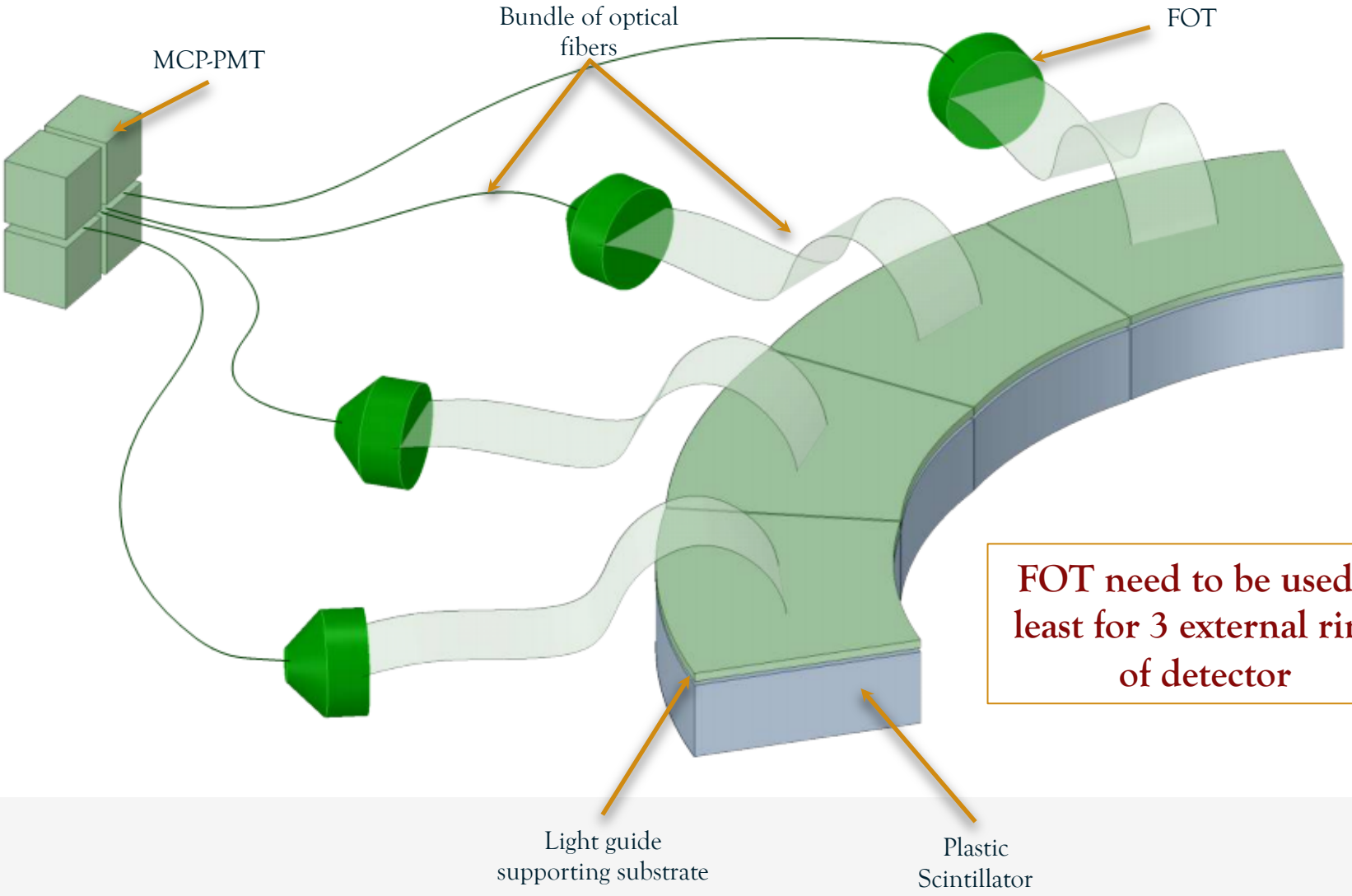
Courtesy O. Stein

DIRECT ACCESS TO THE BEAM VACUUM CHAMBER AT ±230m FROM THE IPs

- proton exits correspond here to central masses in excess of $M_\chi \approx 2000$ GeV
- ATLAS & CMS roman pots are here (ε = 50%): $M_\chi \approx 400 - 1400$ GeV

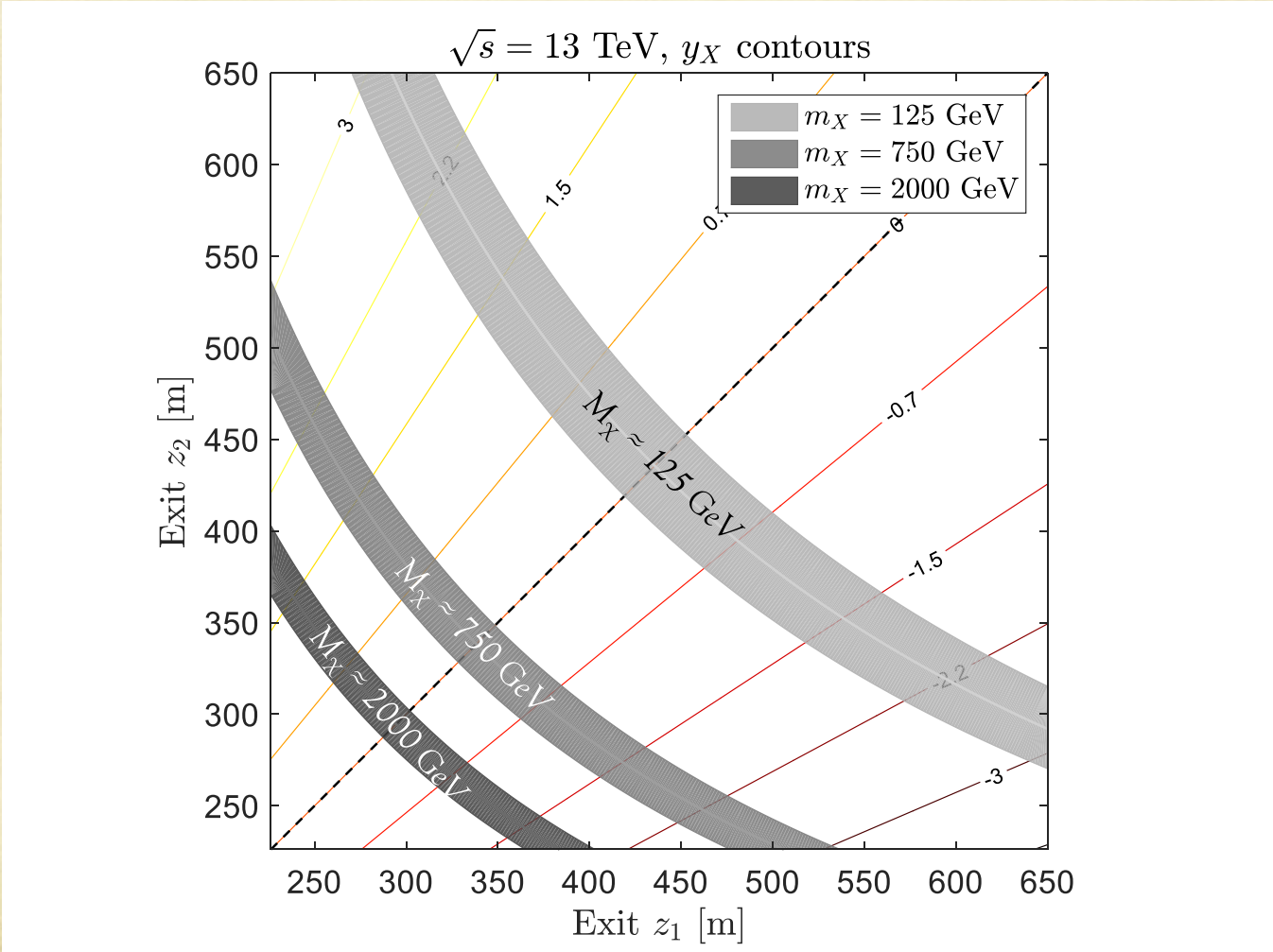
SIMPLE SCINTILLATOR DETECTORS CAN BE INSTALLED HERE AROUND THE BEAM PIPES:

FOT + MCP-PMT scintillation light readout scheme



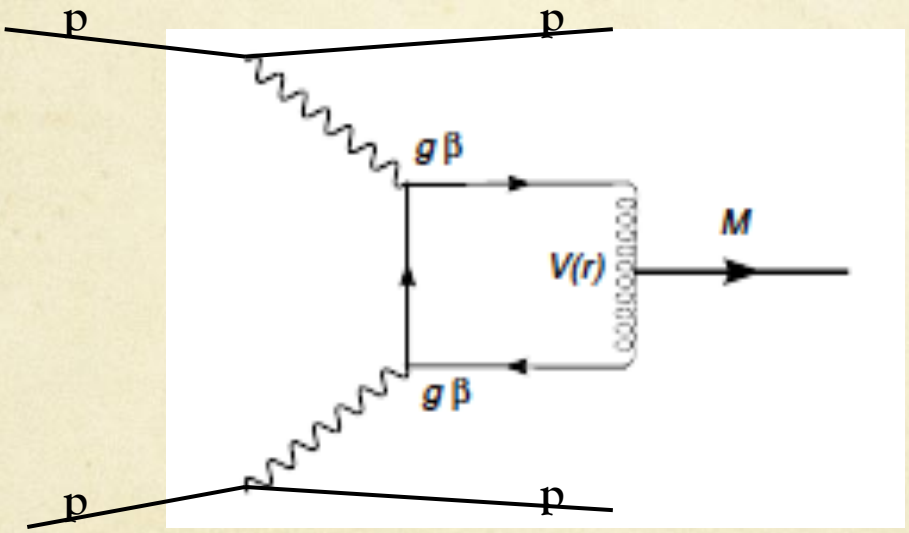
FOT need to be used at least for 3 external rings of detector

PAIRS OF PROTON EXIT POINTS MAP OUT THE CENTRAL MASSES



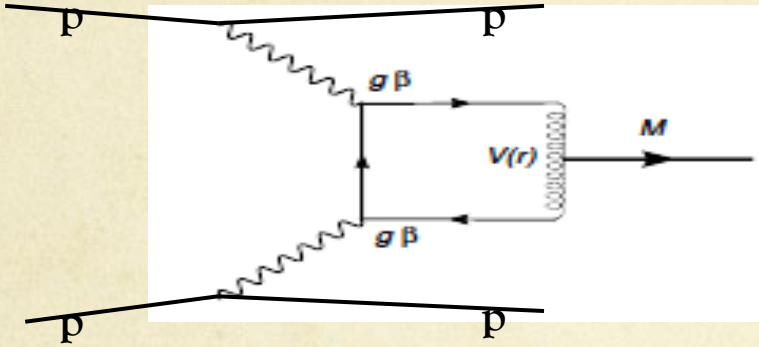
Matti K. Kalliokoski, RO et al., arXiv:1604.5778; Diffraction 2016

$z \approx 330$ *meters* – magnetic monopolium ?



MONOPOLIUM

- Epele, Fanchiotti, Garcia Canal and Vento proposed (2008) that *monopolium* might be easier to detect than a monopole by itself – look at the photon-photon interaction



$$\Gamma(E) = \frac{32\pi\alpha_g^2}{M^2}\left|\psi_M(0)\right|^2$$

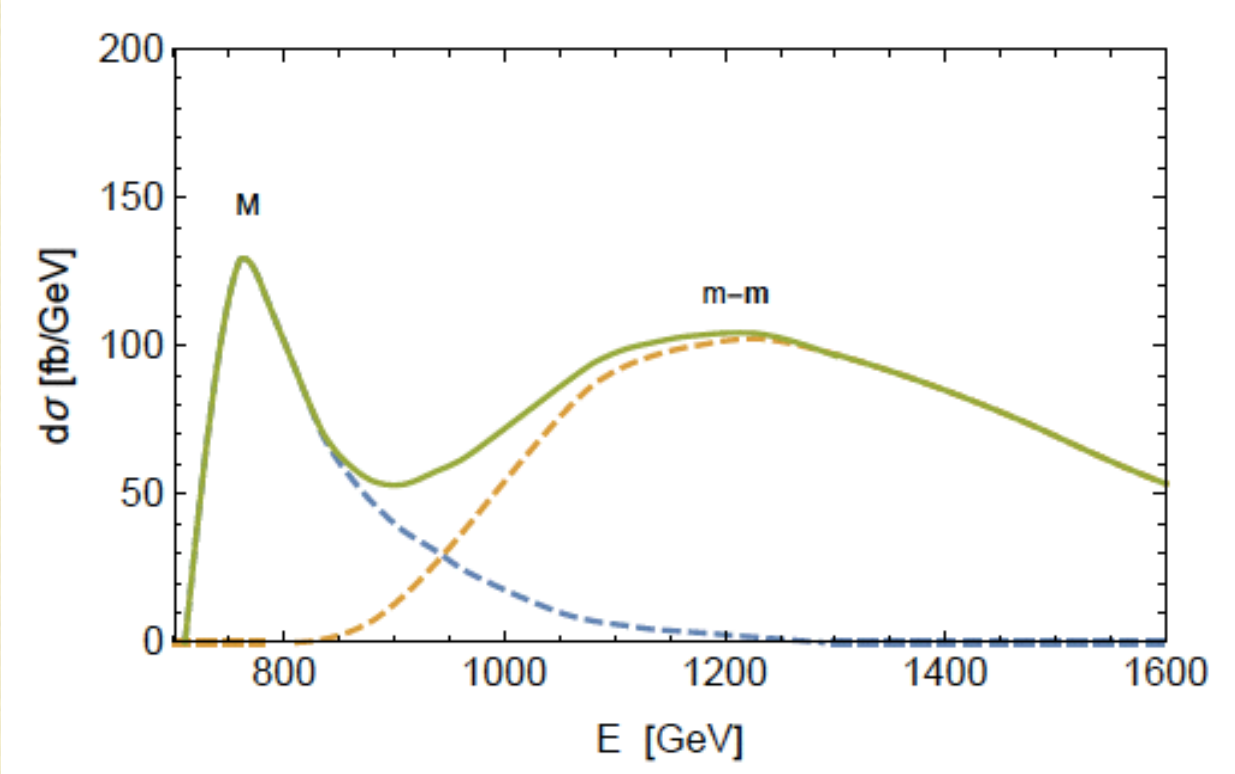
$$\sigma(2\gamma \to M) = \frac{4\pi}{E^2}\frac{M^2\Gamma(E)\Gamma_M}{(E^2-M^2)^2+M^2\Gamma_M^2}$$

In their models : $\Gamma(E) = 2\left(\frac{\beta_s^2}{\alpha}\right)^2\left(\frac{m}{M}\right)^3\left(2-\frac{M}{m}\right)^{3/2} E.$

with $\beta_s = 1$ or $\beta_s = \sqrt{1-s^2/M^2}$ where s is the $\gamma\gamma$ center of mass energy

- Luis N. Epele et al., "Monopolium detection at the LHC", arXiv:1107.3684v1 [hep-ph] 19 Jul 2011
- implementation to SuperChic bu Lucian Harlad-Lang

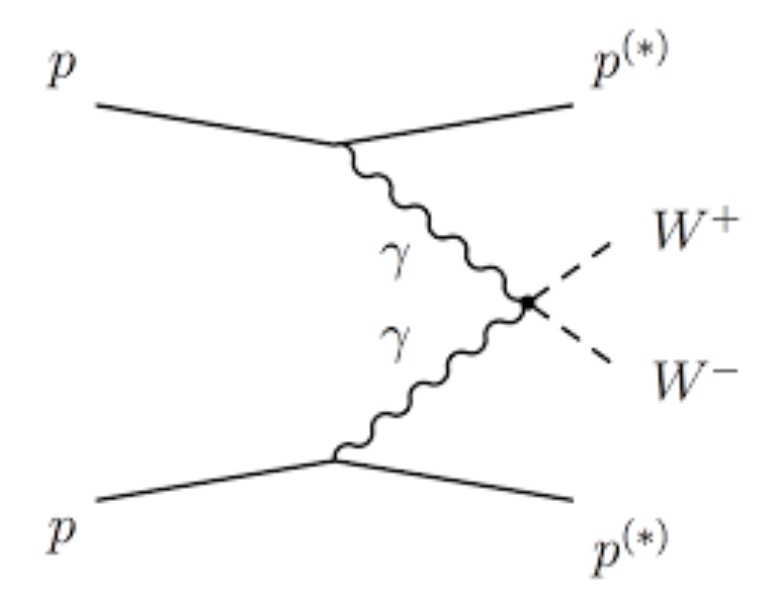
MONOPOLIUM



150 to 400 meters - anomalous couplings

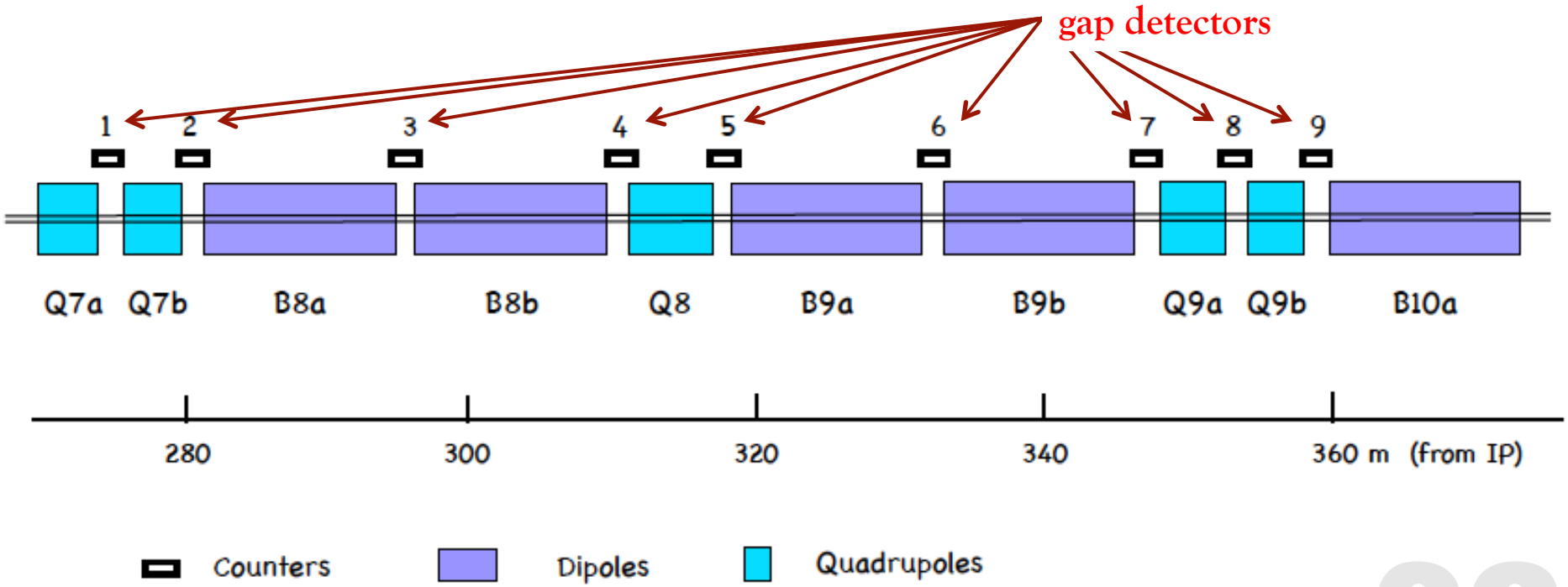
W'W'/Z'Z', SUSY, LARGE EXTRA DIMENSIONS...

400 meters – W^+W^- pairs

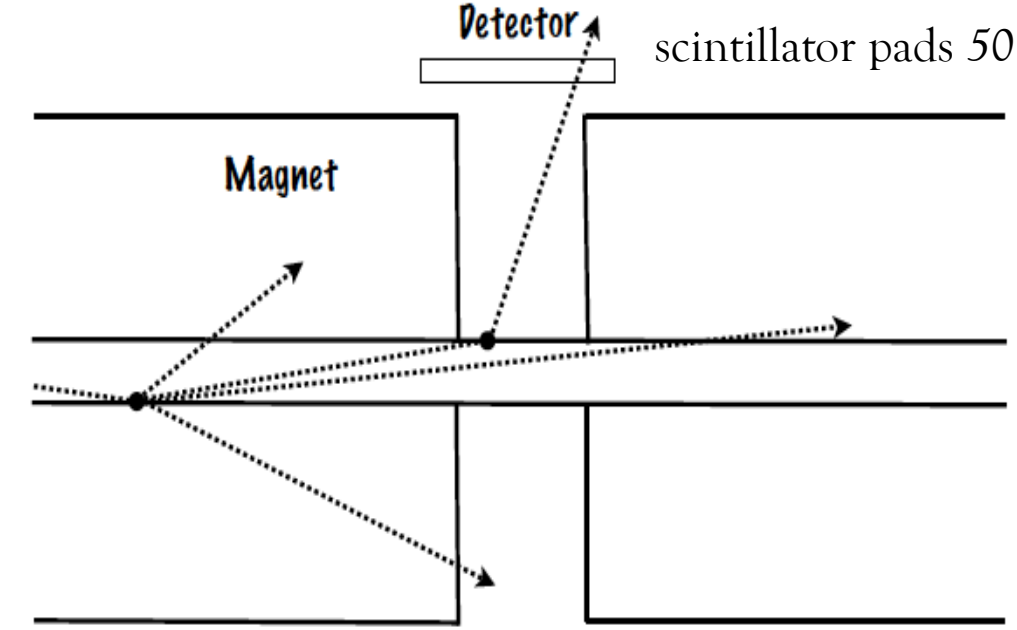


- a *calibration* process
- anomalous couplings
- see Christoph's talk in this meeting!

LHC MAGNET GAP DETECTORS - LOCATIONS



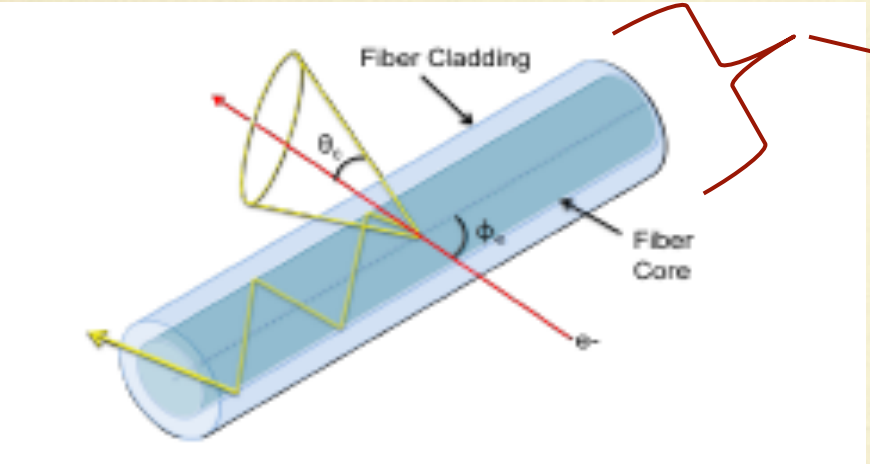
LHC GAP DETECTORS - LAYOUT



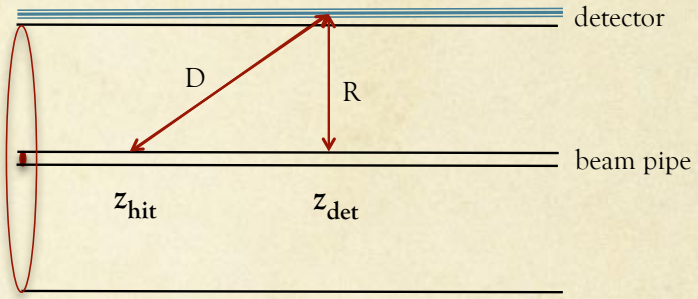
scintillator pads $50 \times 50\ cm^2$

optical beam loss monitors - oblm

- a continuous quartz fiber detector along the beam line, z_0
- the z_0-hit values smeared with a Gaussian resolution function, s.d. = 100 cm or s.d. = 50 cm.

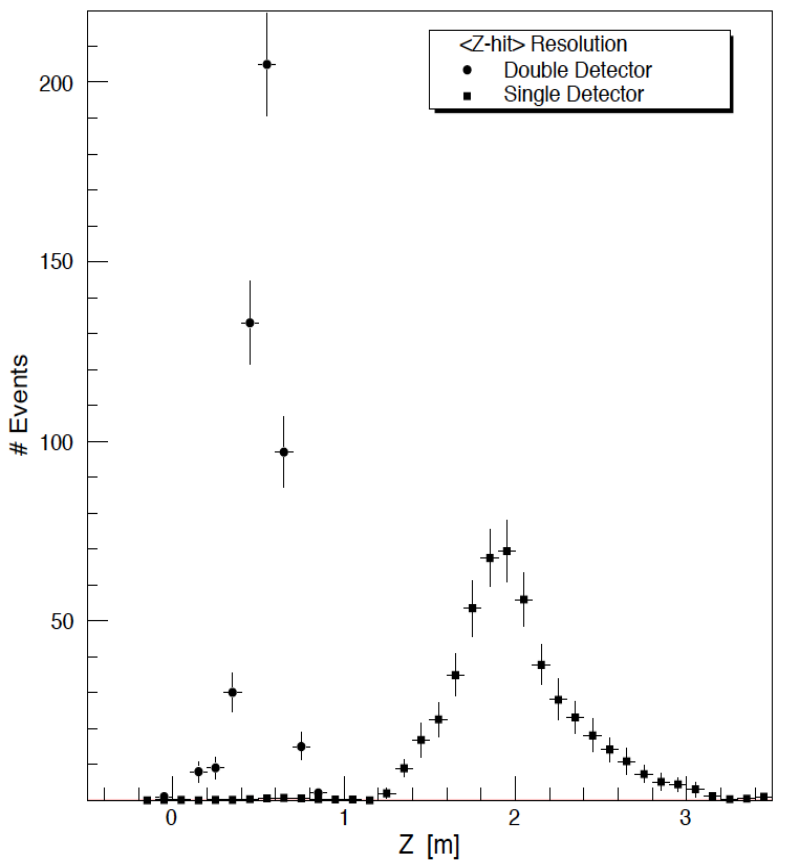


Operation principle of the Cherenkov quartz fiber detector



A sketch of the Cherenkov quartz fiber detector assembled on the outer surface of the LHC dipole cryogenic vessel. The qurtz fiber detector extends for the whole length of the dipole and is read out at both ends of the fiber. In variables used in the figure are: R = radius of the LHC dipole, D = the hit distance from the proton exit point, z_{hit} = the proton exit point in z_{det} = the registered hit position in z. An alternative detector arrangement has two adjacent quartz fiber detectors at a distance of 20 cm

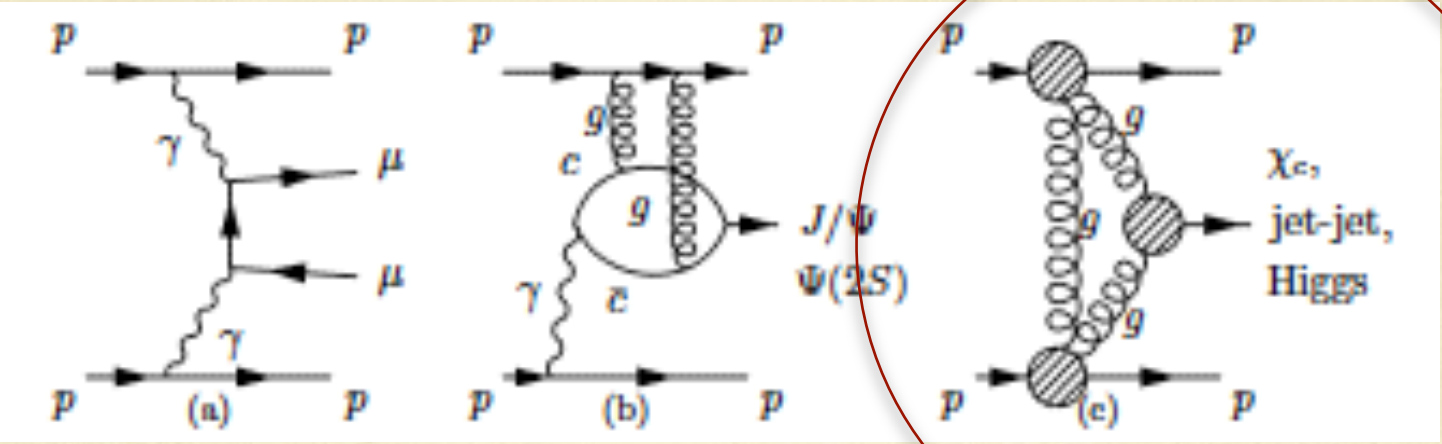
EXIT POINT MEASUREMENT – OPTICAL BLM



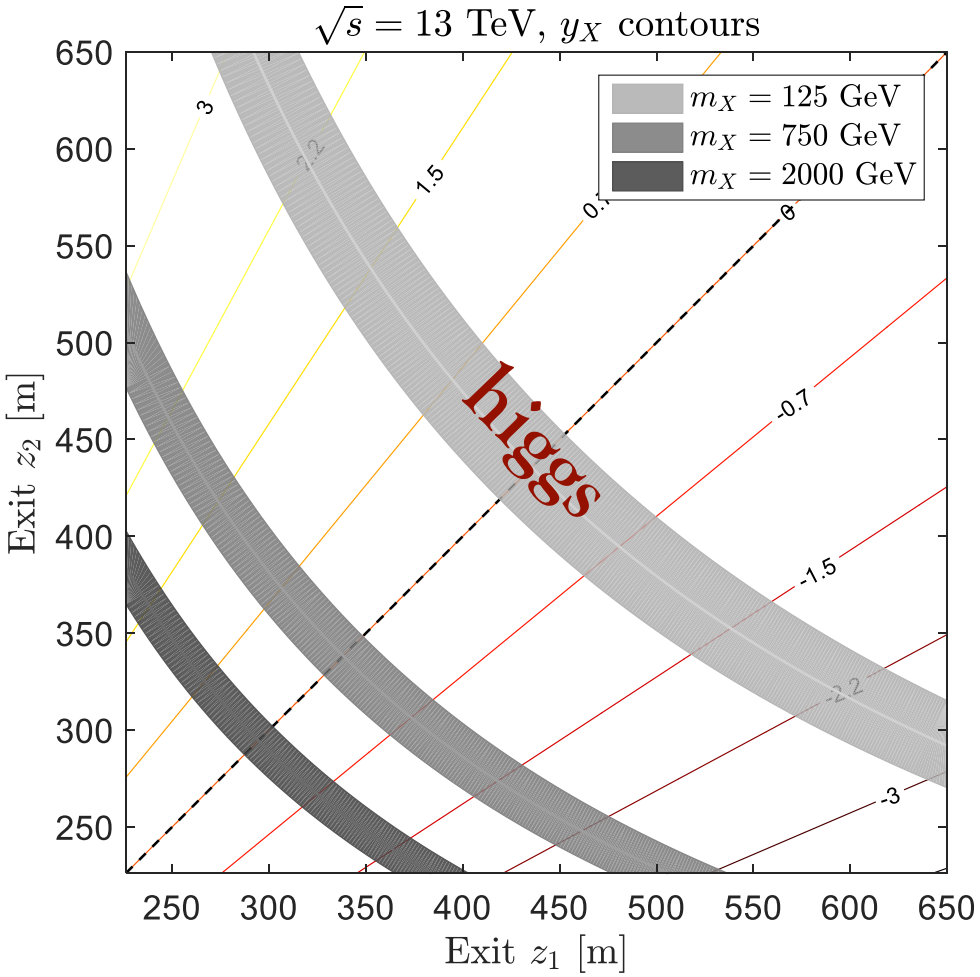
- *Simulated hit distribution recorded by the Cherenkov quartz fibers at the surface of an LHC dipole magnet.*
- *The distribution measured by a single fiber detector (open circles) allows the proton exit point to me measured with a resolution of 30 cm.*
- *A double detector arrangement (two parallel fiber detectors 20 cm apart) allows the proton impact point to be measured with a resolution of 10 cm (closed circles).*

simulation by Jerry W. Lämsä

validation tests – higgs?

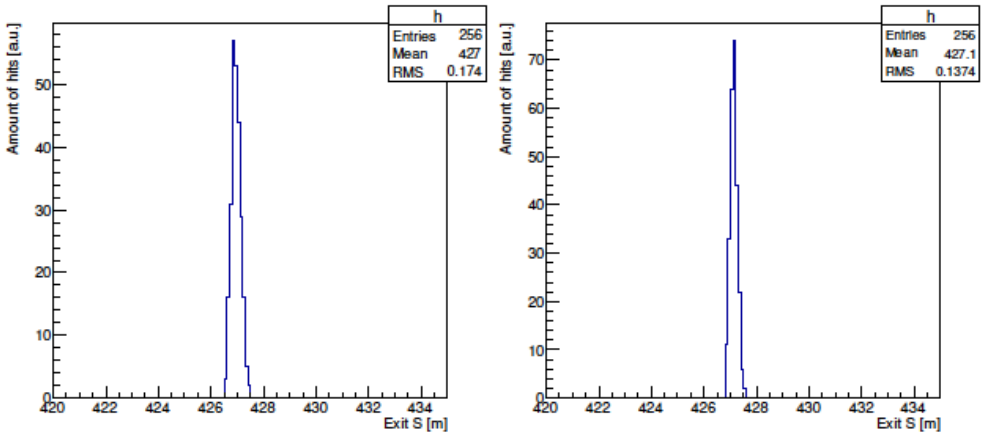


PROTON PAIRS IN CENTRAL EXCLUSIVE PRODUCTION: EXIT POINTS



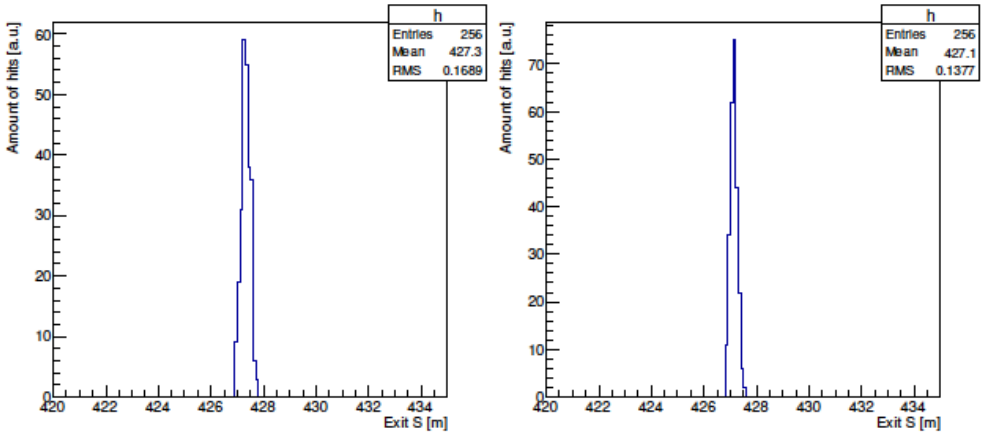
arXiv:1604.5778

SM Higgs – exit points: z, p_T, ϕ



(a) $\phi = 0°$

(b) $\phi = 90°$



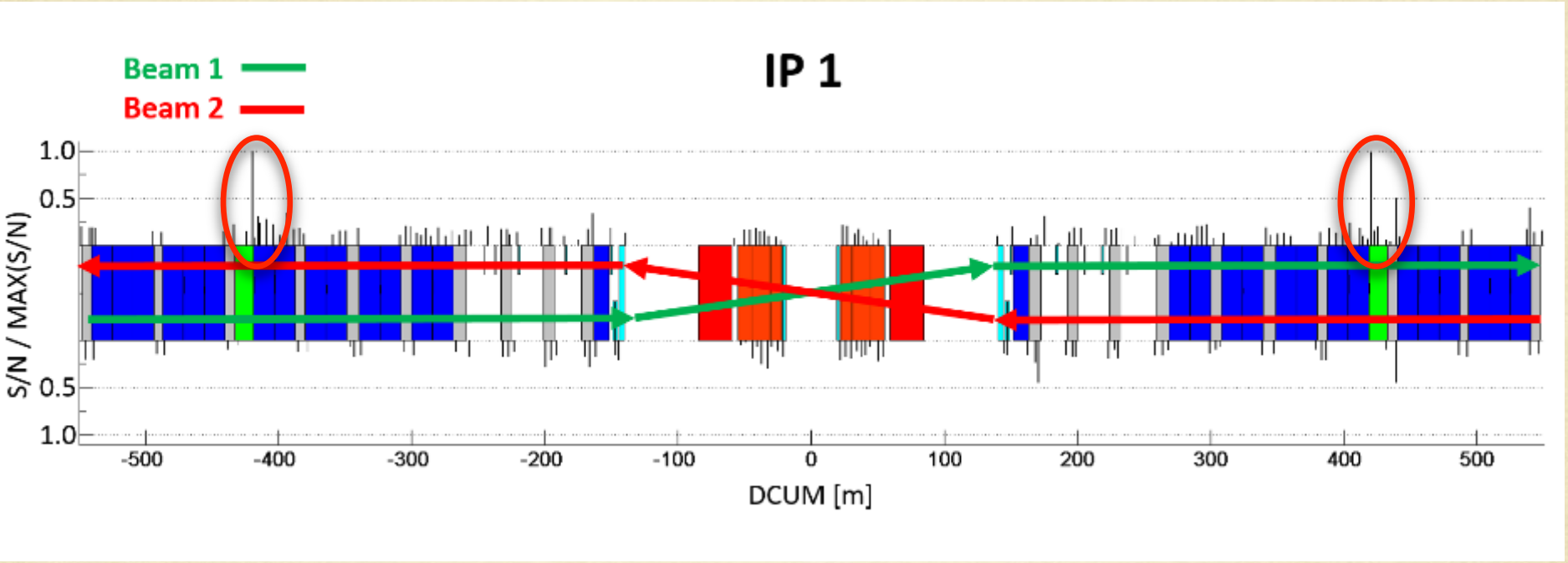
(c) $\phi = 180°$

(d) $\phi = 270°$

Figure 1: p_T from 0 to 100 MeV

- measure exit point to *10 cm*
- azimuthal angle measurable in selected locations

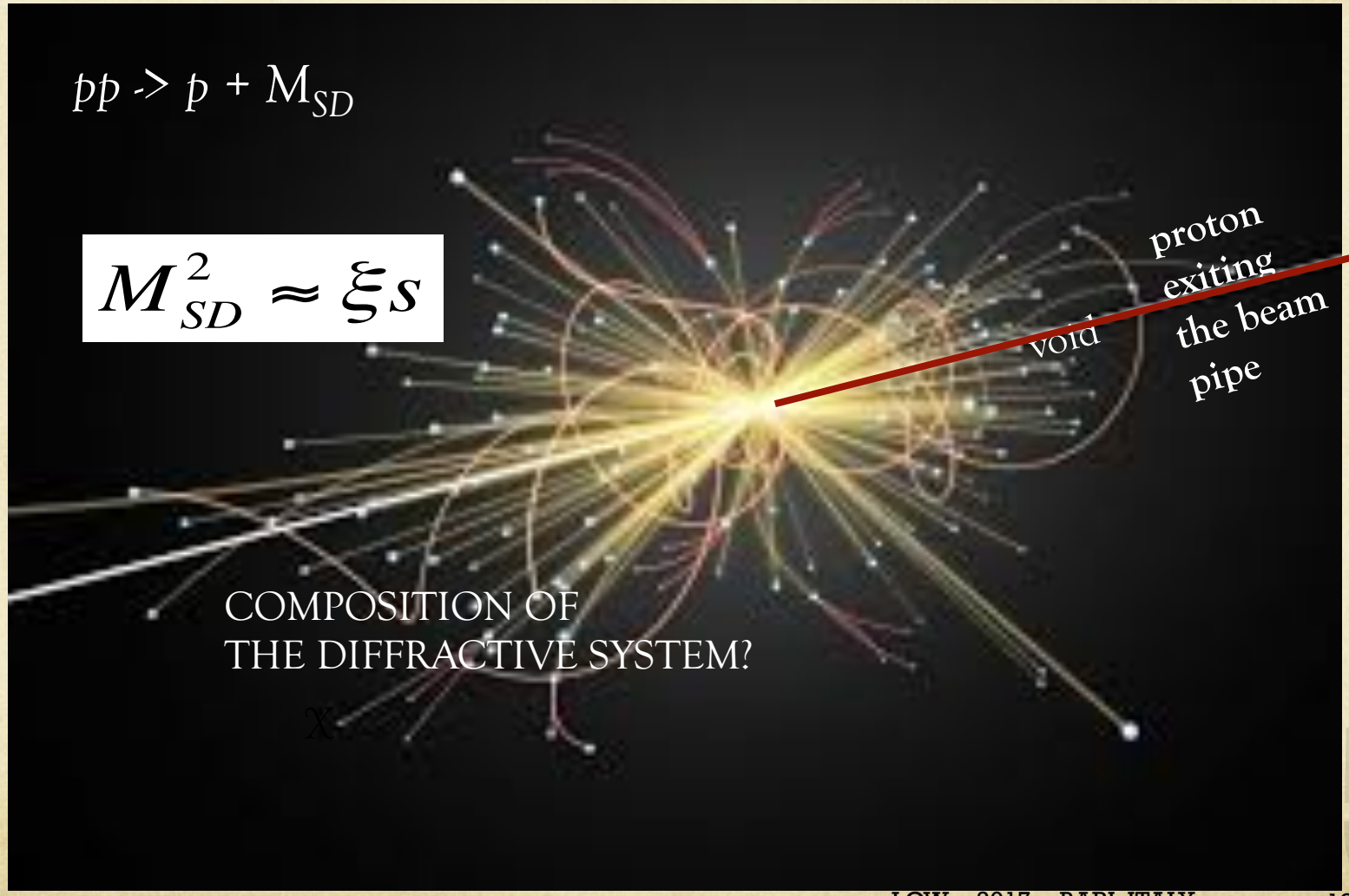
CEP Higgs?



Matti Kalliokoski et al. , AIP Conf.Proc.1819(2017)no.1,040022
A. DeRoeck, V.A. Khoze, A.D. Martin, R. Orava and M.G. Ryskin, Eur. Phys. J. C25, 391 (2002)

HIGH MASS SINGLE DIFFRACTION: *BEYOND GOOD AND EVIL*

HIGH MASS SINGLE DIFFRACTION

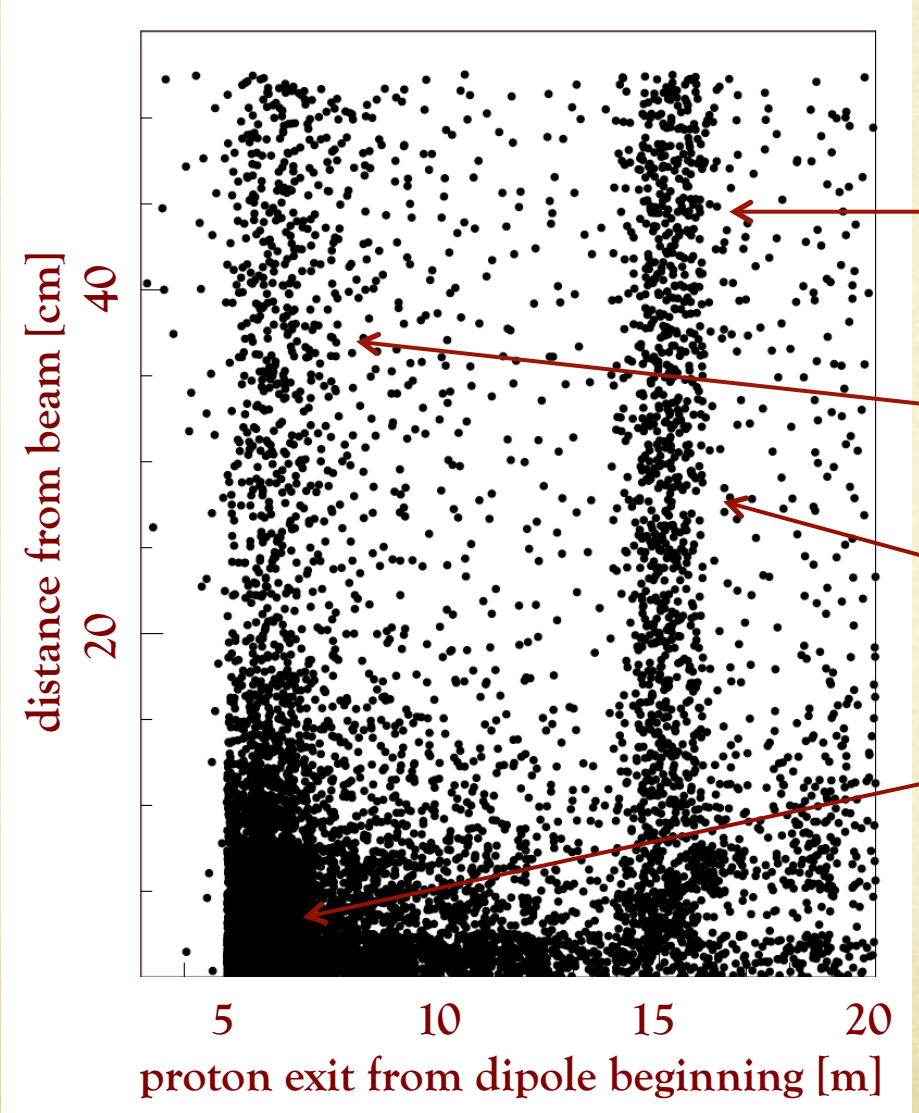


ultra high mass diffraction at the lhc

strategy:

- locate the proton exiting the beam pipe at the **maximum distance** along the beam direction, z, from the IP (on either side)
- reconstruct the ξ-value, $\xi = \Delta p/p_{beam}\ (=1\text{-}x_L)$, by using **the z-location of the exit point** (z_0)
- **analysis** of composition of the high mass forward system at the Interaction Point (IP)

proton showers in lhc dipoles



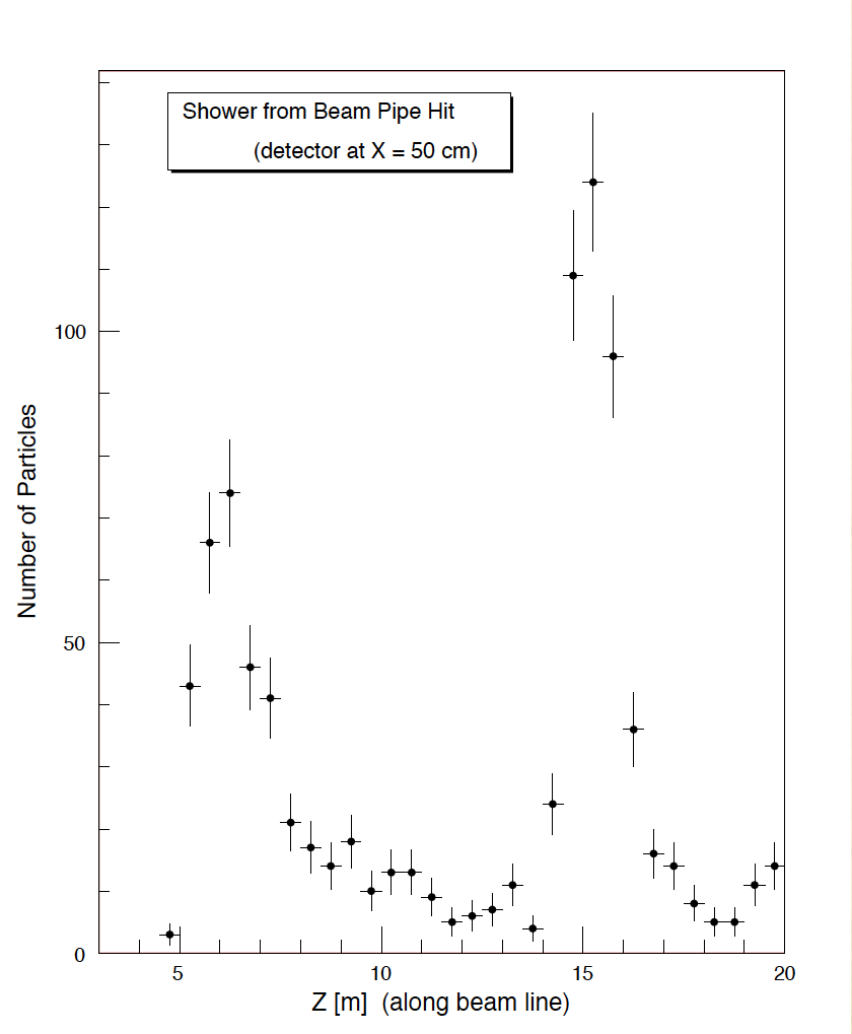
in gaps between the dipoles
soft secondaries extend further
in transverse direction

shower secondaries
at the exit point

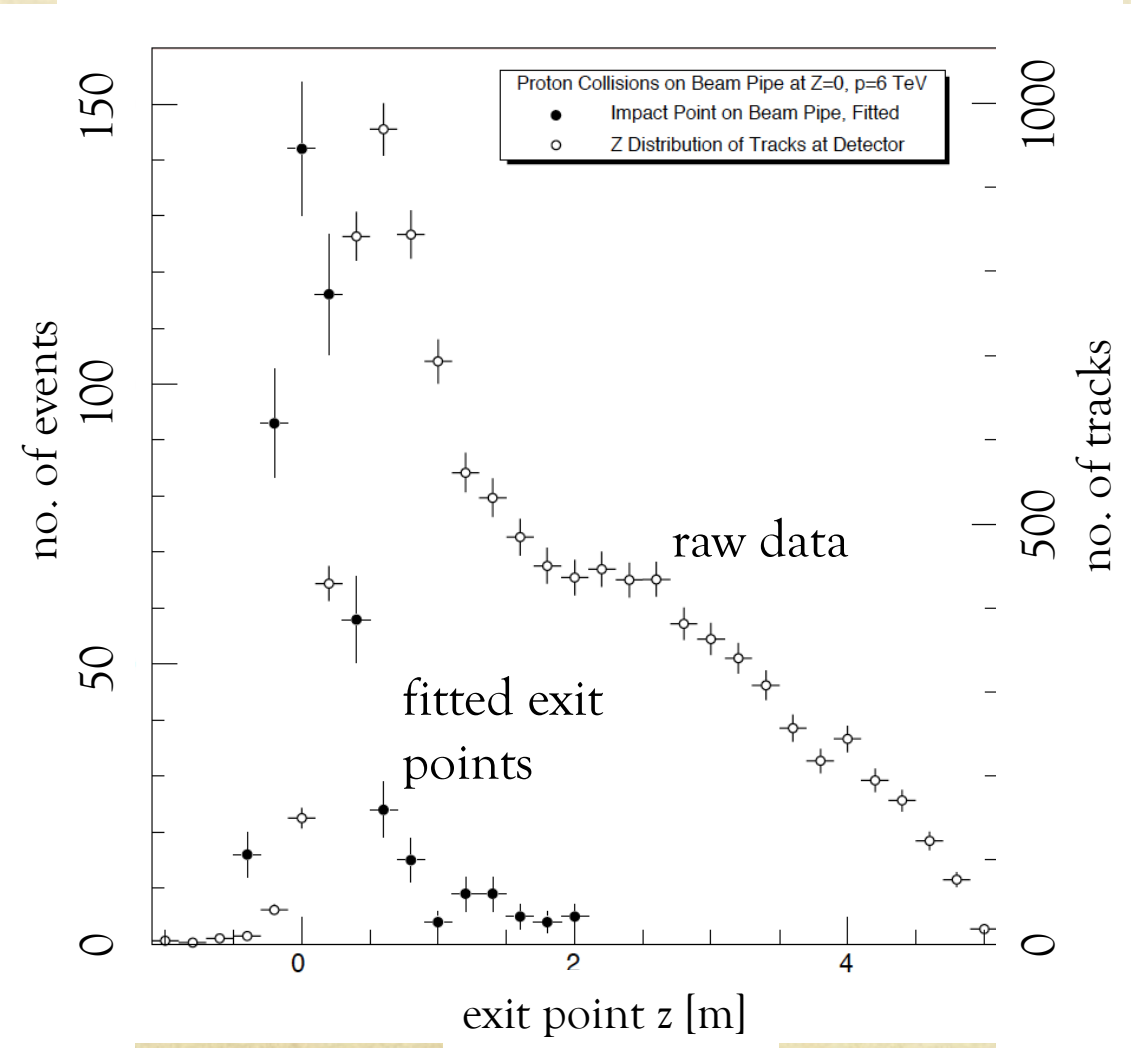
shower secondaries
at the gap between the dipoles

exit protons
generate showers

proton showers in lhc dipoles

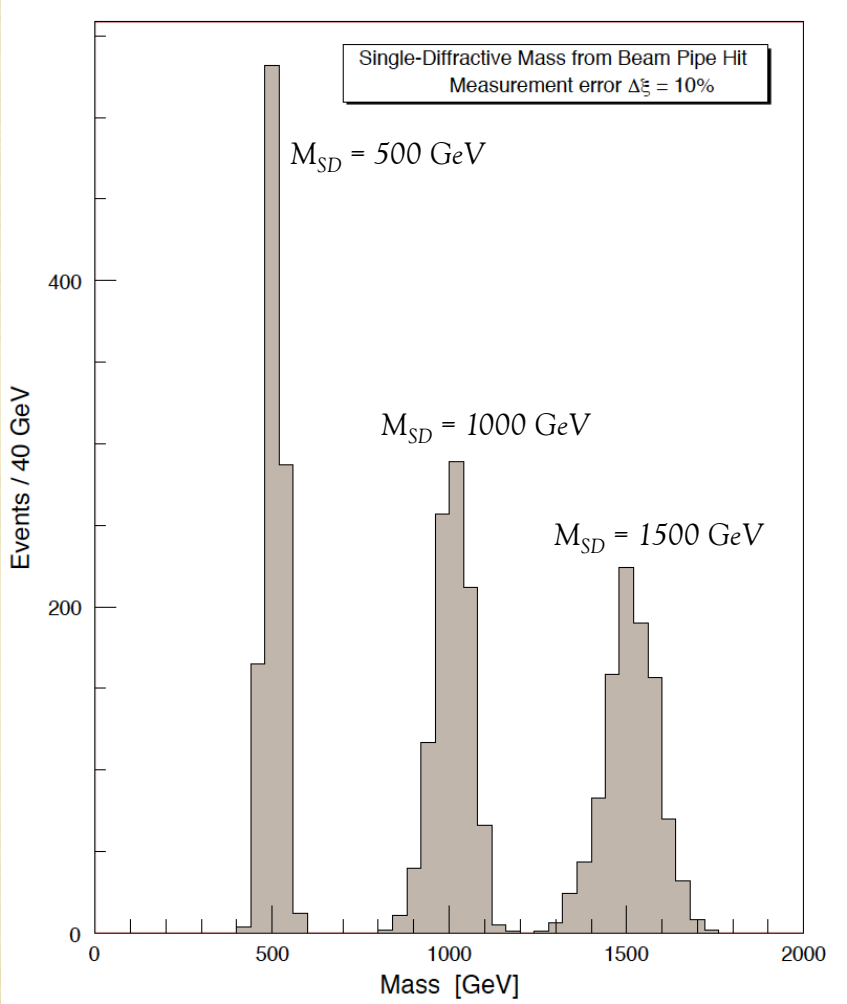


LHC GAP DETECTORS – PROTON EXIT POINTS



simulation by Jerry W. Lämsä

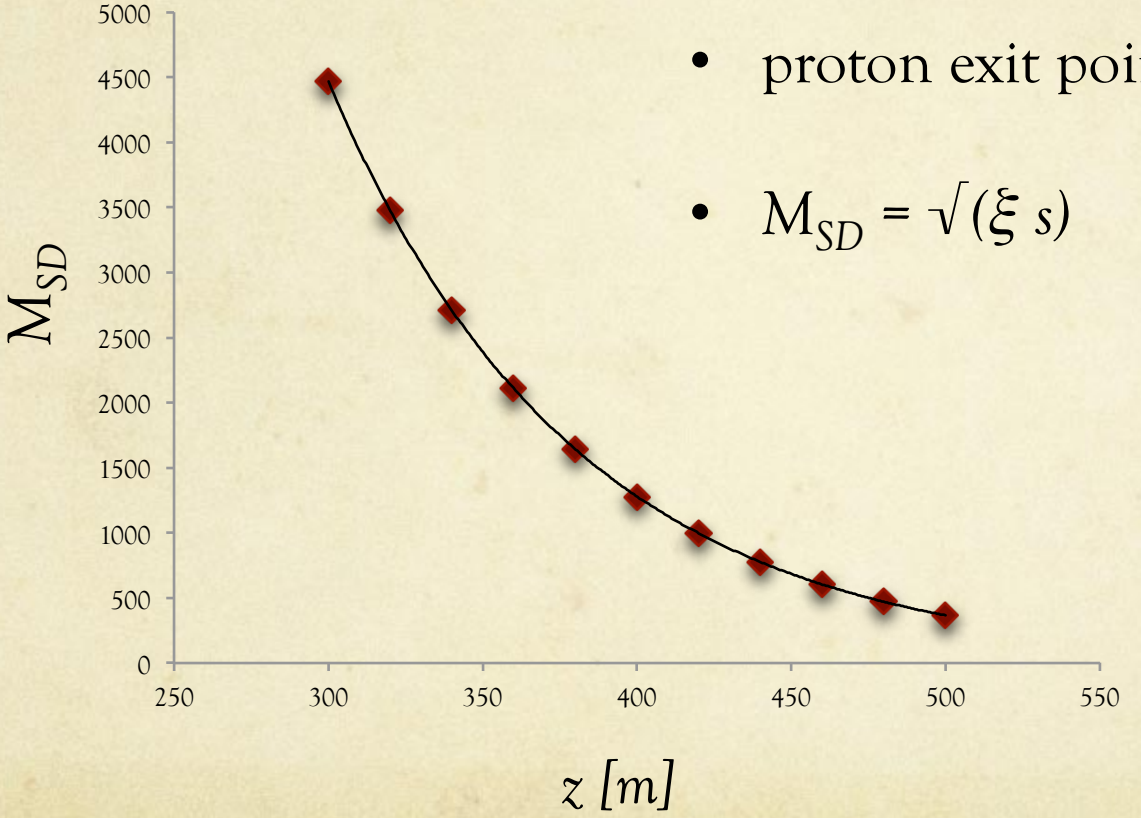
DIFFRACTIVE MASS RECONSTRUCTION



- reconstructed masses of the single diffractive systems
- $\Delta\xi$ = 10%

simulation by Jerry W. Lämsä

M_{SD} vs. distance from IP



- proton exit point locations ➔ $\xi = \Delta p/p$
- $M_{SD} = \sqrt{(\xi\, s)}$

the LHC Ring represents a continuous "Roman Pot" !

(ultra)high mass diffraction

triple pomeron cross section at $M^2 \to \infty$

$$\frac{\sigma_{SD}^2}{M^2 dt} \approx \frac{1}{s}\left[couplings, ff's\right]\left(\frac{s}{M^2}\right)^{2\alpha_P(t)-1}\left(M^2\right)^{\alpha_P(0)-1}$$

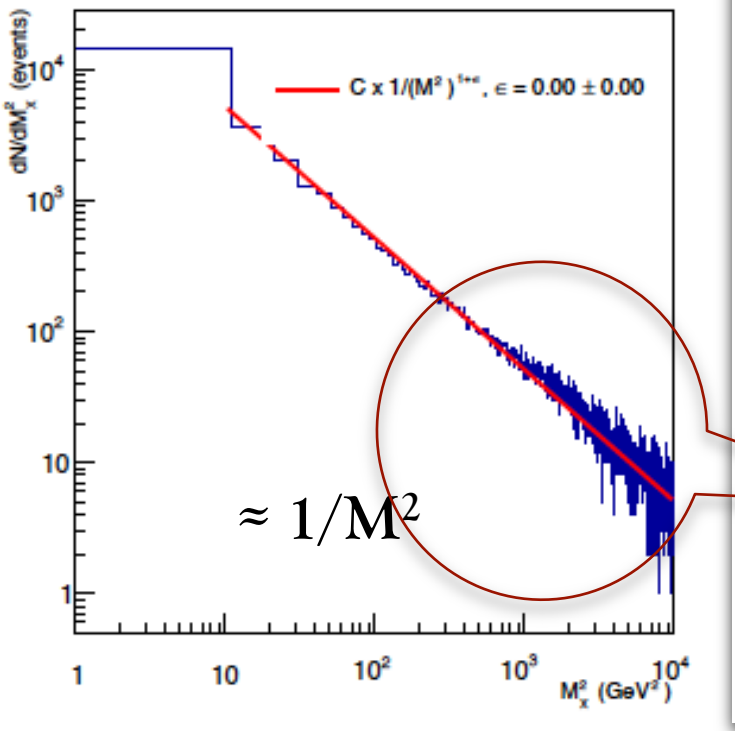
where the effective soft Pomeron trajectory is usually parametrized as

$\alpha_P(t) = 1 + \varepsilon + \alpha' t,$ where the intercept $\varepsilon \approx 0.08,$ and the slope $\alpha' \approx 0.25\text{GeV}^{-2}.$

at the limit $t \to 0$: $\left.\frac{\sigma_{SD}}{dM^2}\right|_{t=0} \approx \frac{s^{2\varepsilon}}{\left(M^2\right)^{1+\varepsilon}}$ or $\frac{d\sigma}{dM} = \frac{2}{M^{(1+2\varepsilon)}}$

modulo survival factors - compensate rise with s

high mass sd: pythia_8



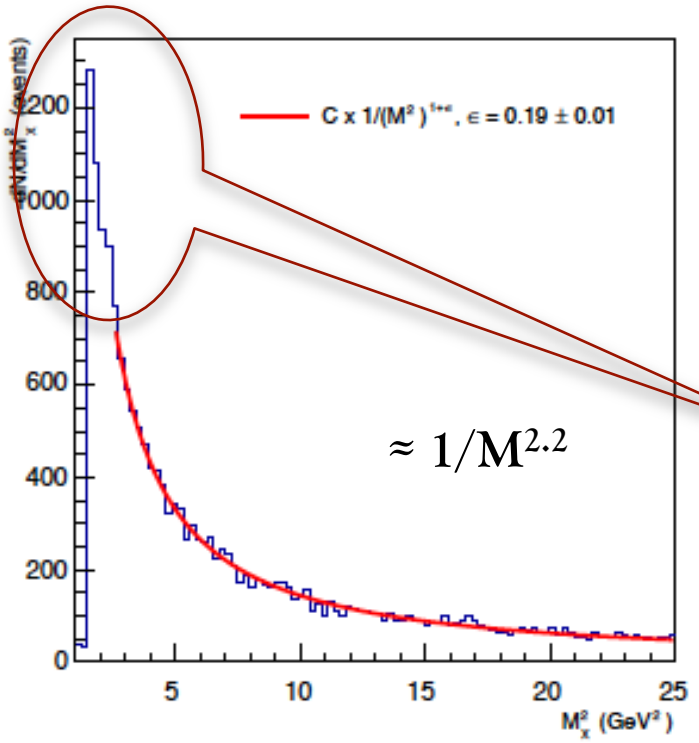
$$\left.\frac{\sigma_{SD}}{dM^2}\right|_{t=0} \approx \frac{s^{2\varepsilon}}{\left(M^2\right)^{1+\varepsilon}} \quad \text{or} \quad \frac{d\sigma}{dM} = \frac{2}{M^{(1+2\varepsilon)}}$$

high mass diffractive systems are not properly understood

simulation by Mikael Mieskolainen

modulo survival factors - compensate rise with s

low mass sd: pythia_8

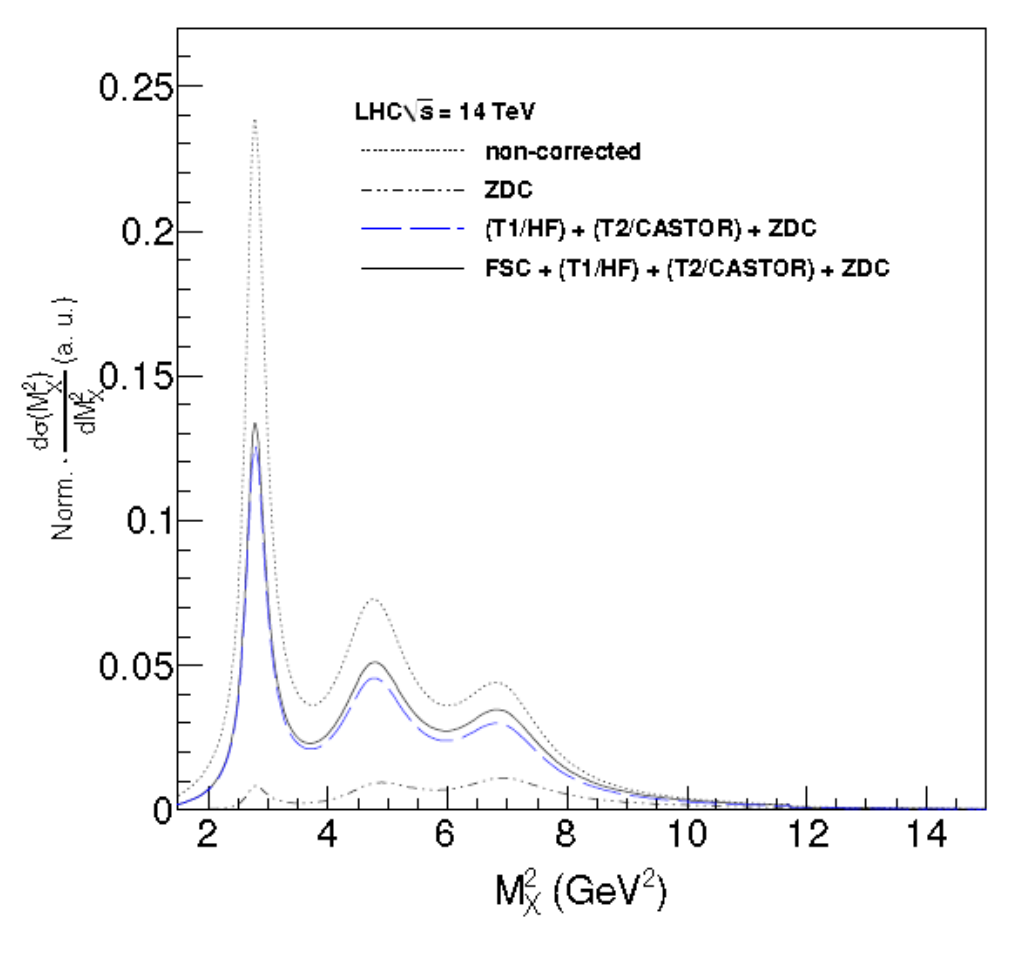


$$\left.\frac{\sigma_{SD}}{dM^2}\right|_{t=0} \approx \frac{s^{2\varepsilon}}{\left(M^2\right)^{1+\varepsilon}} \quad \text{or} \quad \frac{d\sigma}{dM} = \frac{2}{M^{(1+2\varepsilon)}}$$

low mass diffraction not well measured since the ISR

simulation by Mikael Mieskolainen

low mass diffraction



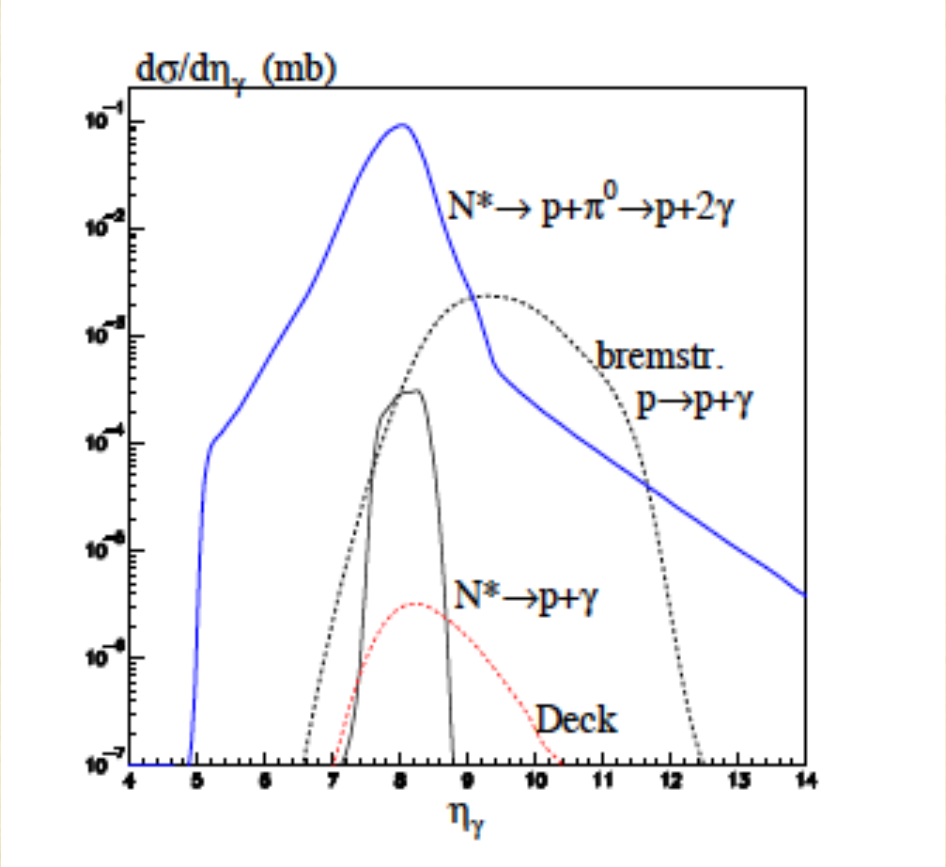
for calculating σ_{tot}^{pp} need to measure the inelastic rate.

$\sigma_{SD}(M_{SD}<10\ GeV)$ =

several mb's..

L.Jenkovzsky, O. Kuprash, J.W. Lämsä, V.Magas, RO,Phys. Rev. D 83, 056014.

N* background



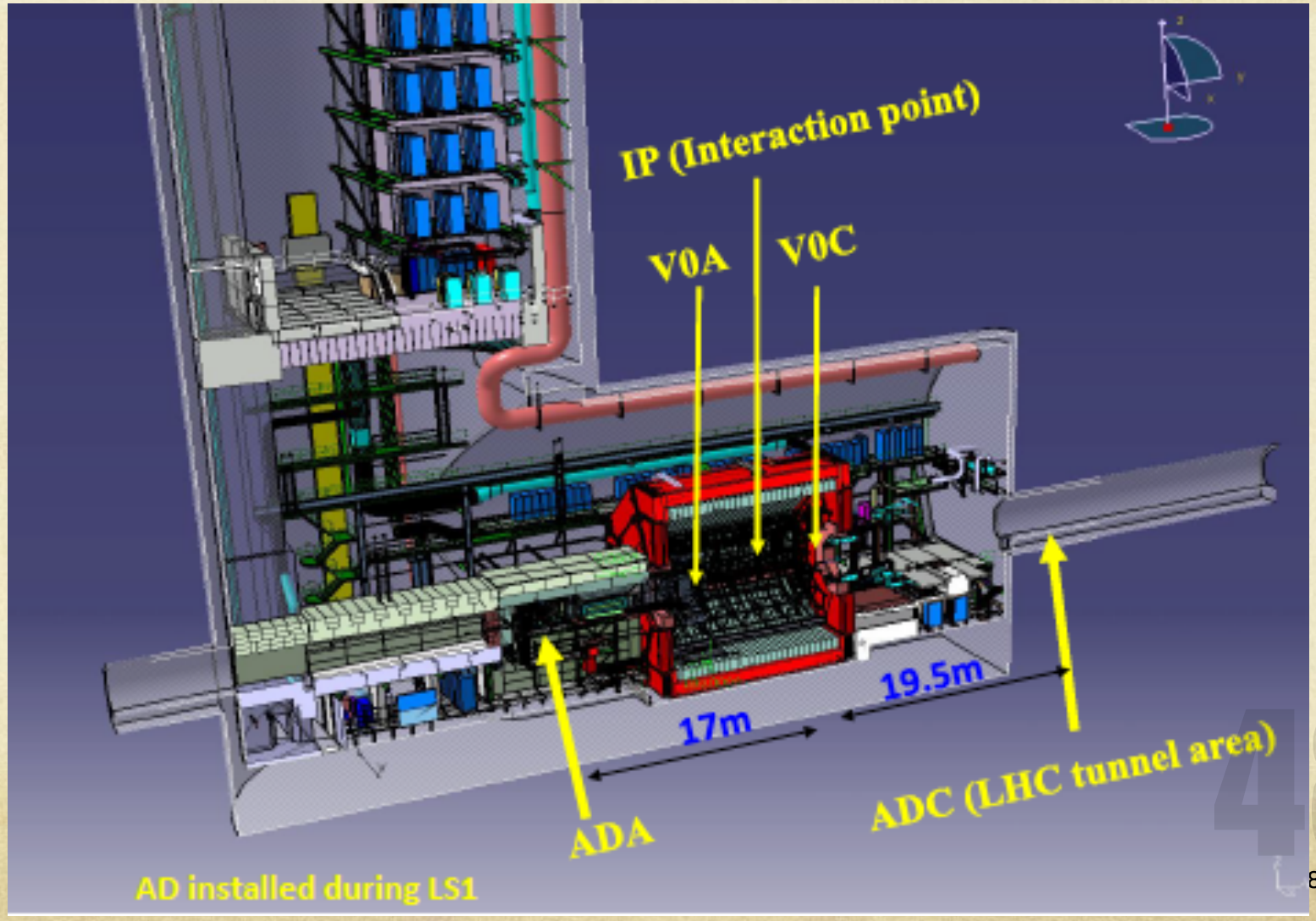
Khoze,Martin,Ryskin,https://arxiv.org/pdf/1702.05023.pdf

STATUS OF FORWARD DETECTORS AT THE LHC

forward acceptances of the lhc experiments are limited:

- **charged particles:** $0.9 < x_F < 1.0$ (pseudorapidities $|\eta| > 5.0$)
  - elastic & single diffractive (SD) 'roman pot' protons -ATLAS & CMS/TOTEM ($0.02 < \xi < 0.20$)
  - forward 'ZDP'-protons – ALICE
  - forward muon spectrometer – ALICE
- **neutrals**
  - forward 'ZDC' neutrons ($E_n > 500$ GeV) – ALICE, ATLAS/LHCf, CMS
  - forward 'ZDC' gammas ($E_\gamma > 50$ GeV) – ALICE, ATLAS/LHCf, CMS

ALICE AD upgrade



x_F vs. p_T acceptances

LHC Ring

- as a continuous "Roman Pot"

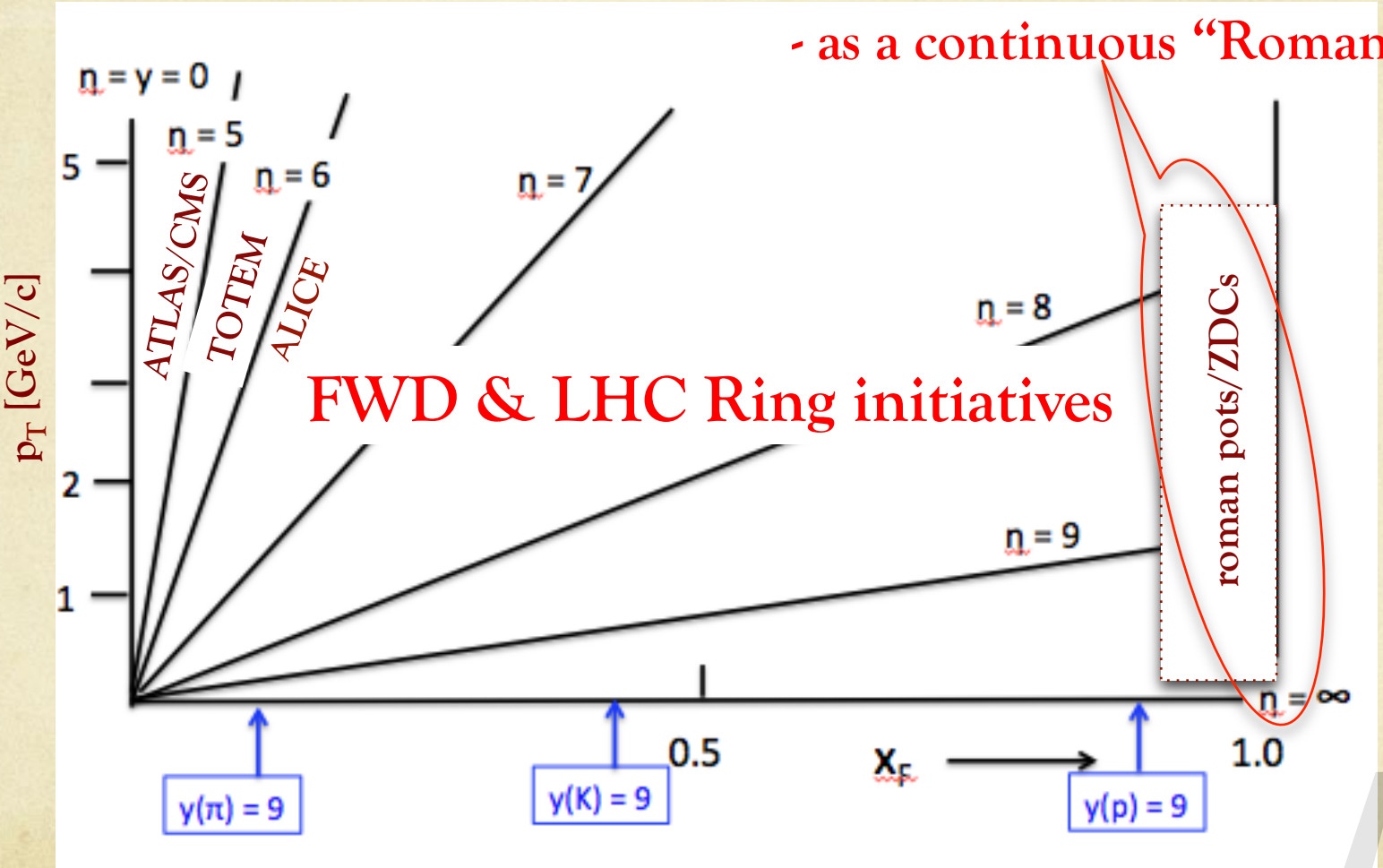


figure adopted from M. Albrow – modified by RO

SUMMARY

- NEW HEAVY PARTICLES, SUCH AS MONOPOLIUM, W'/Z', SUSY, EXTRA DIMENSIONS - PRODUCED IN CEP - ARE SCANNED – INDEPENDENTLY OF THEIR DECAY MODES - BY USING THE PROTON EXIT POINTS ALONG THE LHC RING
- A WAY TO SEARCH FOR INVISIBLE DECAYS –TURNING LHC INTO A DARK MATTER FACTORY – DEEP LEARNING (see Mikael's talk)/DARK SIDE/AI
- FIRST CANDIDATE EVENTS BEING LOOKED AT, ACCEPTANCE IN ξ EFFICIENCY CALCULATIONS ONGOING
- THE METHOD CAN BE EXTENDED TO ALL LHC IPs; CORRELATIONS WITH EXISTING DETECTORS, COLLIMATORS etc. WILL BE EXPLOITED
- AUTOMATIC SCANNING OF THE BLM DATA TBD
- TRIGGERING OF THE CEP EVENT CANDIDATES vs. CENTRAL MASS etc.

NEXT

- ANALYSIS OF CURRENT LHC BEAM LOSS MONITOR (BLM) DATA
- INITIAL UPGRADES: MAGNET GAP DETECTORS, OPTICAL BLM ETC: FAST DETECTORS
- FULL BORN LHC RING DISCOVERY MACHINE INTEGRATED WITH THE LHC EXPERIMENTS – ENHANCED BY SMALL ANGLE SPECTROMETER