New Forward Detectors for CMS

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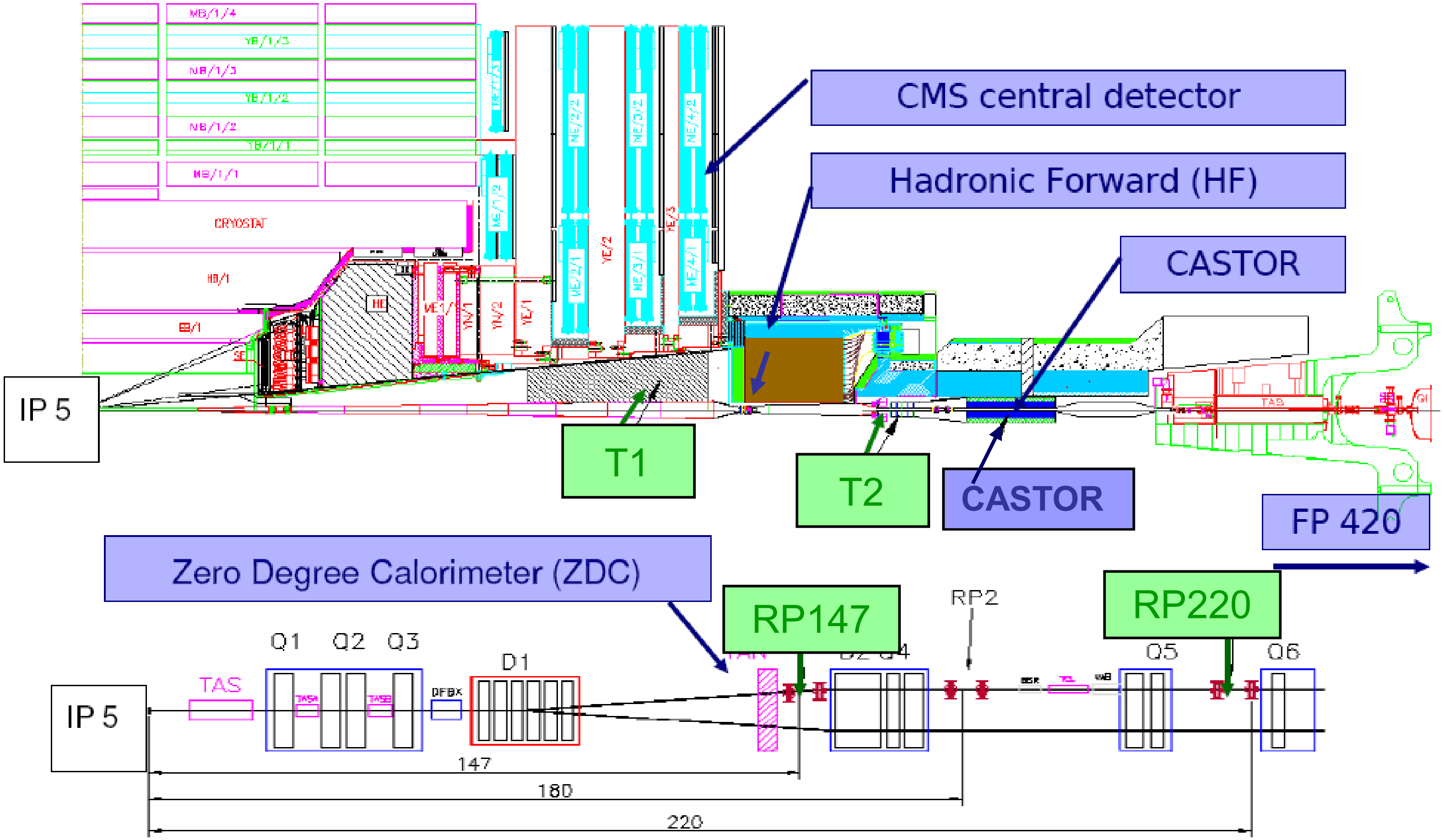
- Introduction: Forward view at CMS
- New forward proton detectors for CMS
- Summary/Outlook

XIII International Conference on Elastic & Diffractive Scattering

CERN, 29 June – 3 July, 2009

Forward detectors @ IP5



CMS: blue

TOTEM: green

Early forward physics @ CMS

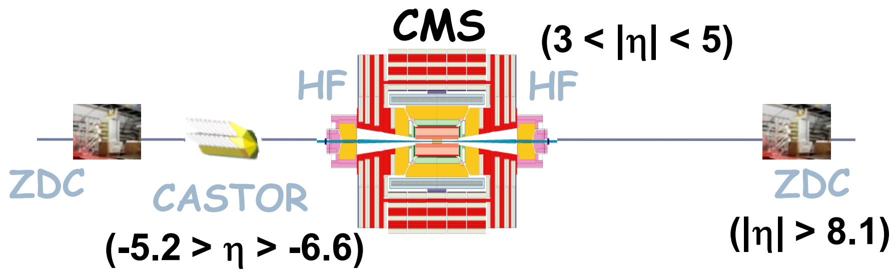
Low-x QCD with forward jets

Underlying event tuning & cosmic rays shower modeling

Exclusive di-jets, di-photons and di-leptons production & absolute luminosity measurements

Vector meson photoproduction

Observation of hard-diffraction



Physics with 1 pb^{-1} - 100 pb^{-1}

Use Large Rapidity Gap signatures

No pile-up conditions assumed

Beyond 2010 (with large event pileup) new techniques needed:

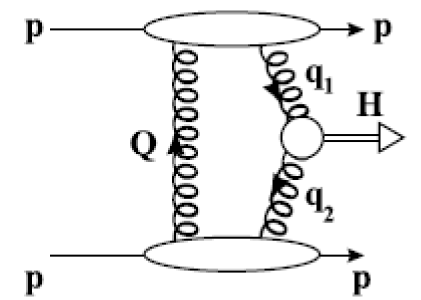
Forward proton detectors @ high-luminosity

Low cross-sections exclusive states: New Physics

Forward Physics at LHC

Forward physics	→	Exclusive production
Low luminosity	$(\sim 2.10^{33})$	High luminosity
Use Large Rapidity Gap Signature and forward calorimeters:		Use track based exclusivity:
Large x-sections, low-x physics, (semi-)inclusive diffraction, forward n		Low cross-sections, Exclusive production high mass dileptons, diphotons, dijets, etc.

New forward detectors:



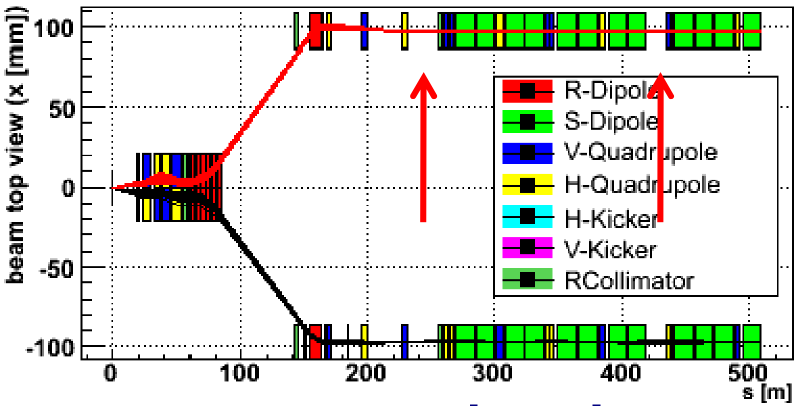
: Central Exclusive Production (CEP): $pp \to p+H+p$

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

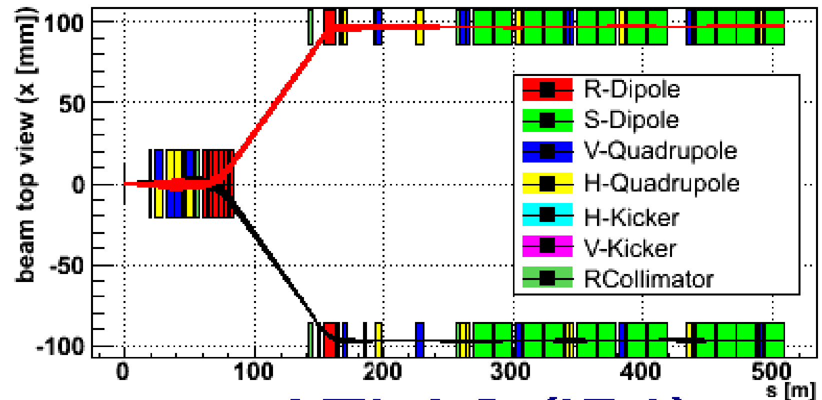
M. G. Albrow[1], R. B. Appleby[2], M. Arneodo[3], G. Atoian[4], I.L. Azhgirey[5], R. Barlow[2], I.S. Bayshev[5], W. Beaumont[6], L. Bonnet[7], A. Brandt[8], P. Bussey[9], C. Buttar[9], J. M. Butterworth[10], M. Carter[11], B.E. Cox[2,⋆], D. Dattola[12], C. Da Via[13], J. de Favereau[7], D. d'Enterria[14], P. De Remigis[12], A. De Roeck[14,6,⋆], E.A. De Wolf[6], P. Duarte[8,†], J. R. Ellis[14], B. Florins[7], J. R. Forshaw[13], J. Freestone[13], K. Goulianos[15], J. Gronberg[16], M. Grothe[17], J. F. Gunion[18], J. Hasi[13], S. Heinemeyer[19], J. J. Hollar[16], S. Houston[9], V. Issakov[4], R. M. Jones[2], M. Kelly[13], C. Kenney[20], V.A. Khoze[21], S. Kolya[13], N. Konstantinidis[10], H. Kowalski[22], H.E. Larsen[23], V. Lemaitre[7], S.-L. Liu[24], A. Lyapine[10], F.K. Loebinger[13], R. Marshall[13], A. D. Martin[21], J. Monk[10], I. Nasteva[13], P. Nemegeer[7], M. M. Obertino[3], R. Orava[25], V. O'Shea[9], S. Ovyn[7], A. Pal[8], S. Parker[20], J. Pater[13], A.-L. Perrot[26], T. Pierzchala[7], A. D. Pilkington[13], J. Pinfold[24], K. Piotrzkowski[7], W. Plano[13], A. Poblaguev[4], V. Popov[27], K. M. Potter[2], S. Rescia[28], F. Roncarolo[2], A. Rostovtsev[27], X. Rouby[7], M. Ruspa[3], M.G. Ryskin[21], A. Santoro[29], N. Schul[7], G. Sellers[2], A. Solano[23], S. Spivey[8], W.J. Stirling[21], D. Swoboda[26], M. Tasevsky[30], R. Thompson[13], T. Tsang[28], P. Van Mechelen[6], A. Vilela Pereira[23], S.J. Watts[13], M. R. M. Warren[10], G. Weiglein[21], T. Wengler[13], S.N. White[28], B. Winter[11], Y. Yao[24], D. Zaborov[27], A. Zampieri[12], M. Zeller[4], A. Zhokin[6,27]

FP420 R&D Collaboration

Optimal places for tagging CEP at the LHC: @ 220/240m and 420m from IP

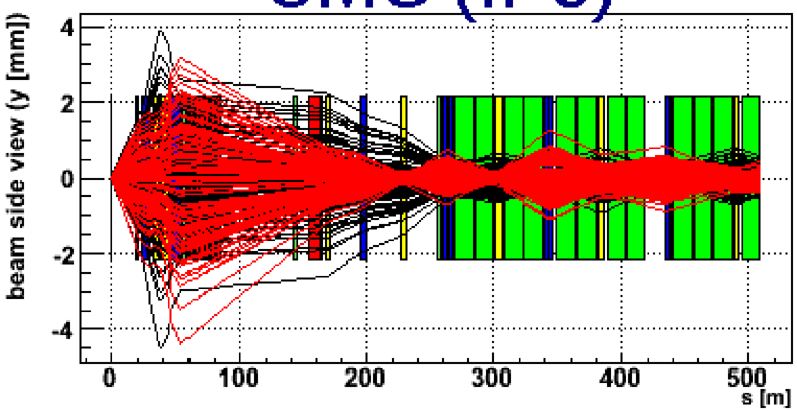


top

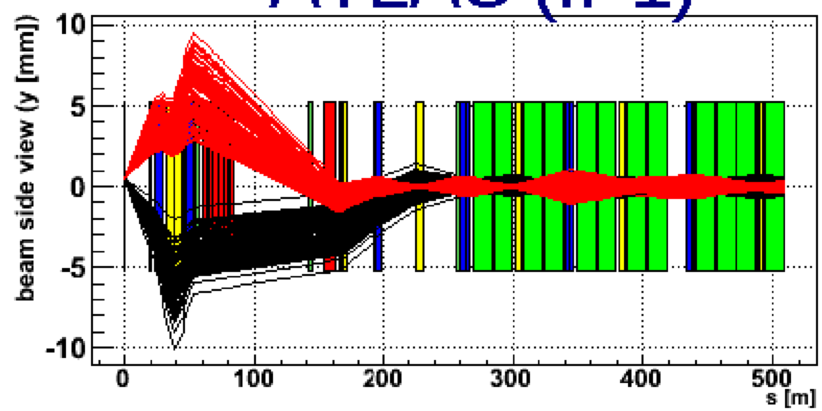


CMS (IP5)

ATLAS (IP1)



side

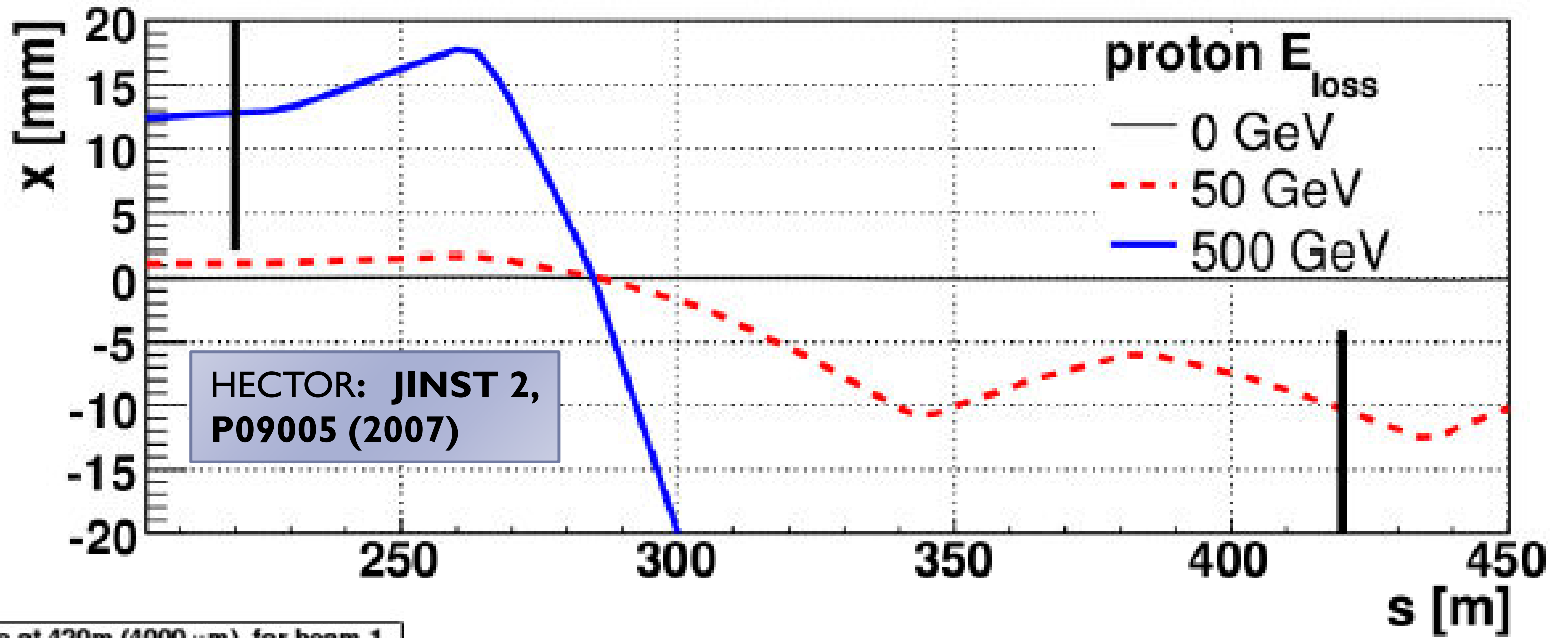


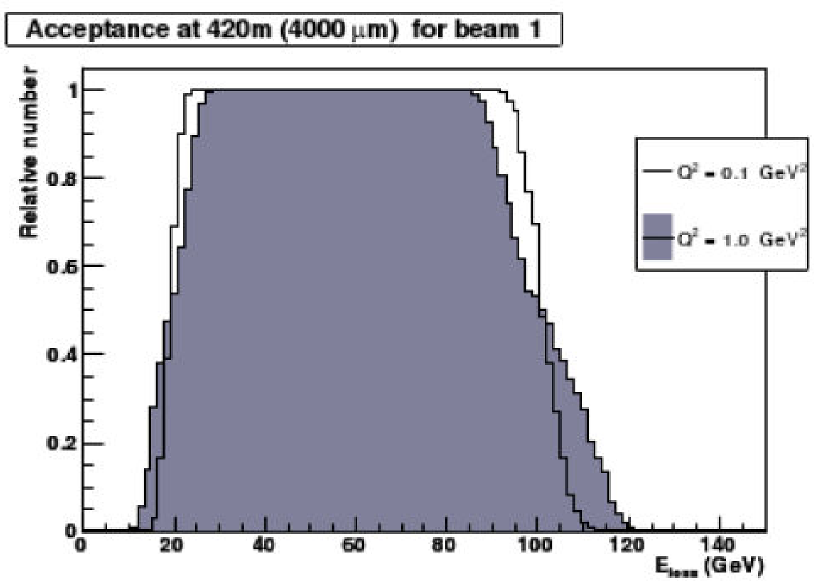
Horizontal crossing plane

Vertical crossing plane

HECTOR: **JINST 2, P09005 (2007)**
For nominal low-β LHC optics

Forward proton acceptance @ $\beta^* = 0.5$ m

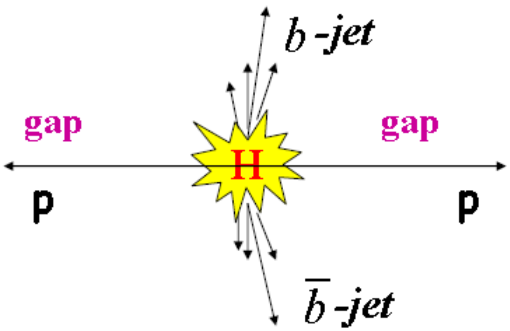




To detect forward protons for CEP of light Higgs (M_h ~ 120 GeV) one needs FP420 detectors;

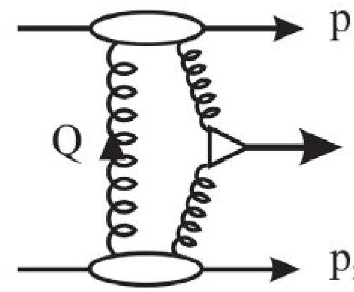
Note: Acceptance is mostly driven by energy loss NOT scattering angle (p_T)

Exclusive Higgs bosons at LHC

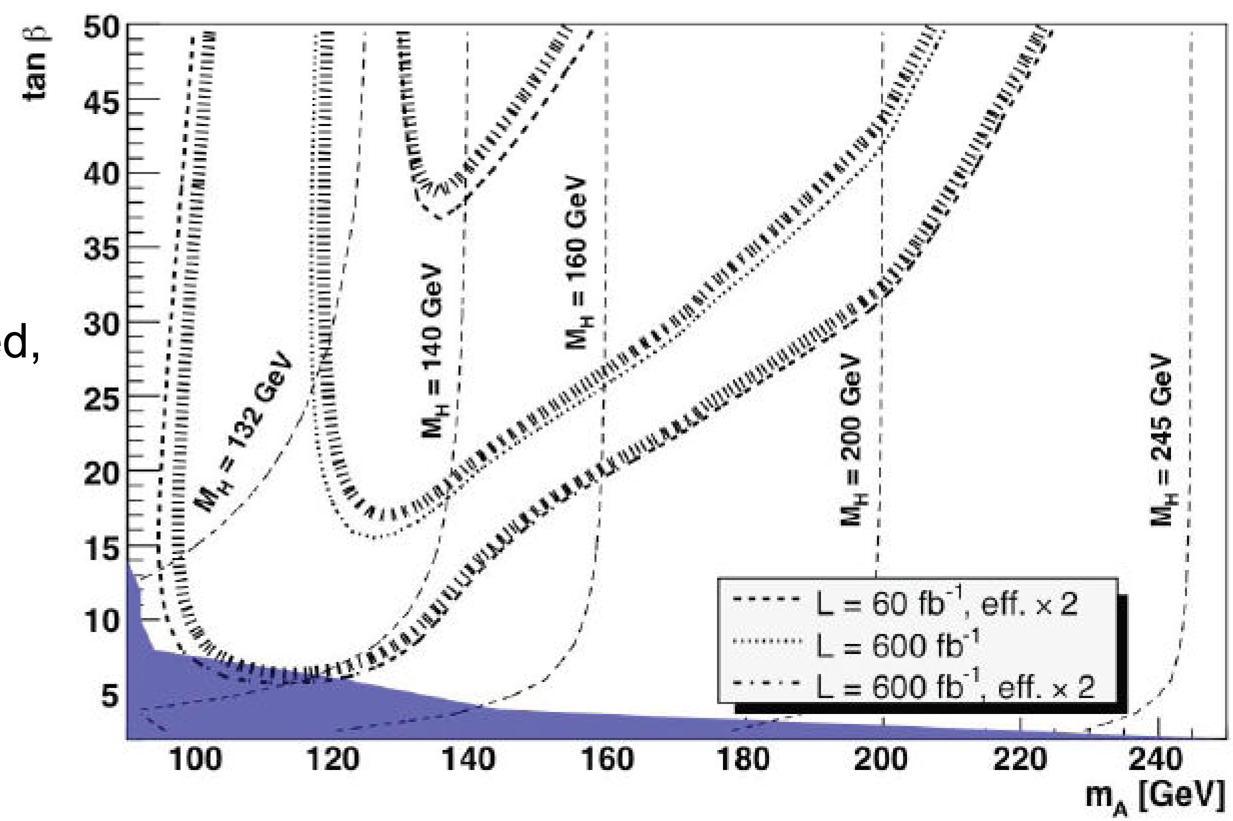


Main motivation for FP420

Higgs kinematics fully reconstructed with forward detectors! Access to Higgs mass and quantum numbers.



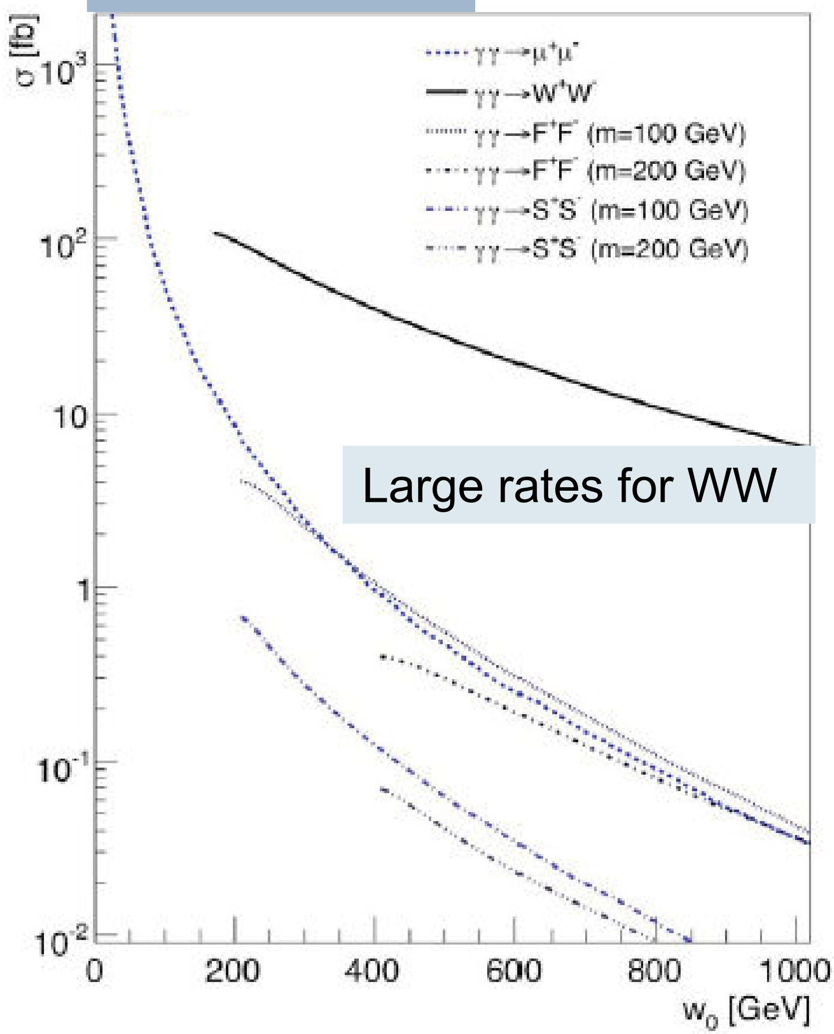
SM Higgs signal statistically limited, larger for MSSM case:



5σ $H \rightarrow bb$, M_h^{max}, $\mu = +200$ GeV, arXiv:0708.3052

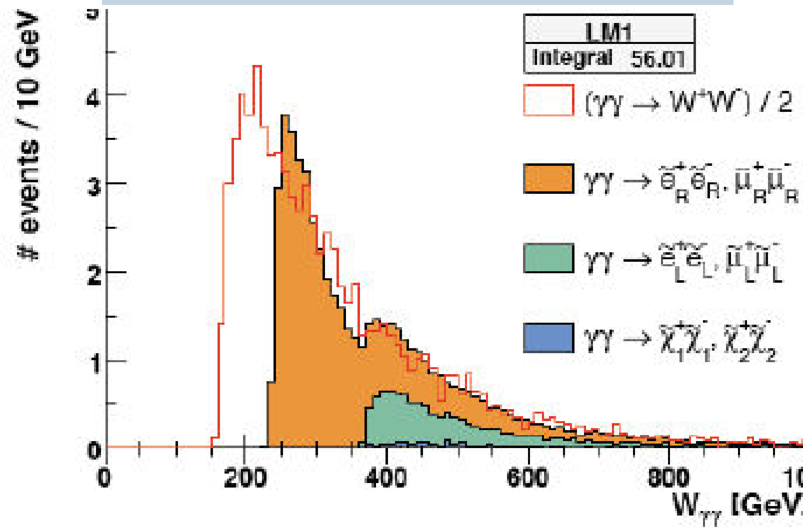
Two-photon physics

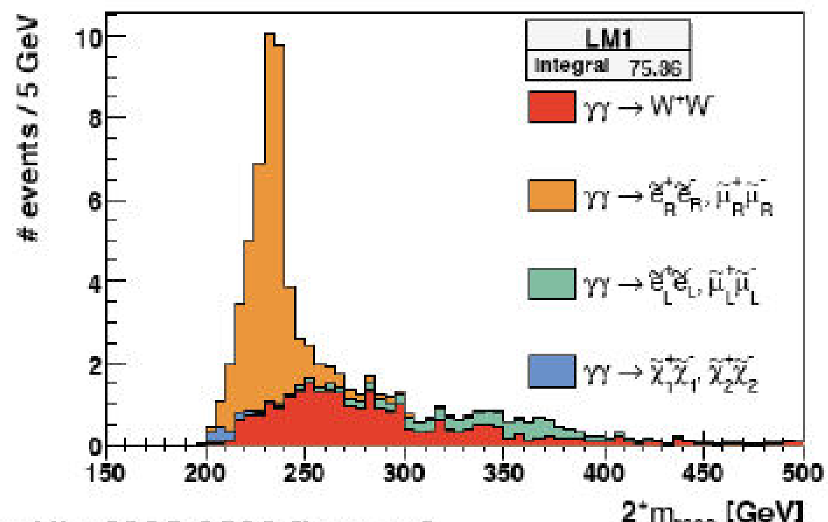
arXiv:0807.1121



Large rates for WW

MSSM: 100 fb-1 (no pileup)

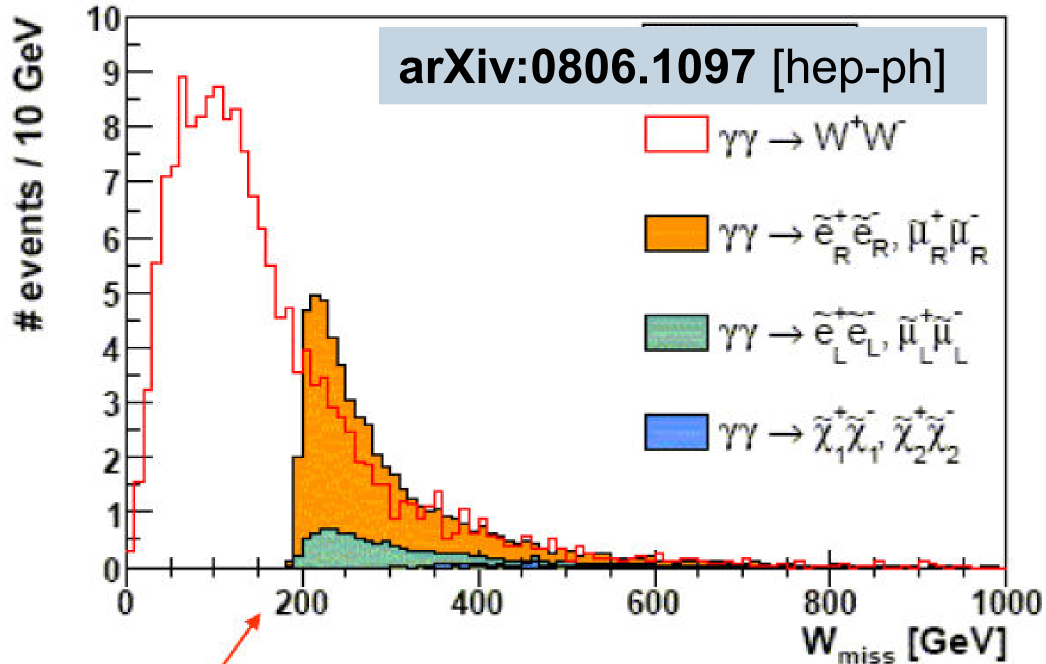




:iv:0808.0322 [hep-ph],arXiv:0806.1097 [hep-ph], arXiv:0806.0302 [hep-ex]

(Light) SUSY case

arXiv:0806.1097 [hep-ph]



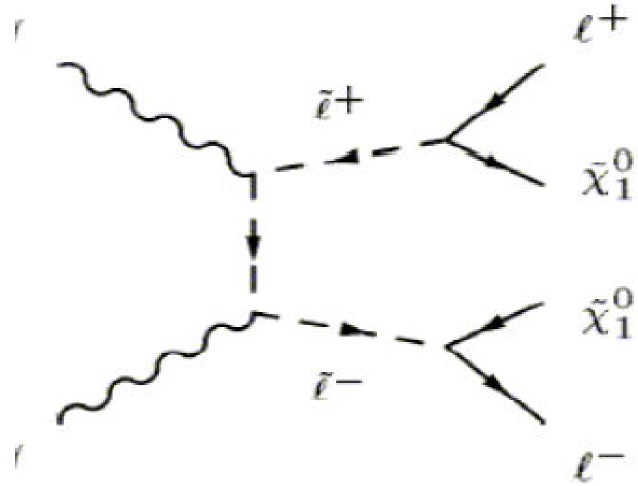


Figure 3. Distribution of missing invariant mass W_{miss} for the LM1 MSSM benchmark for the integrated luminosity L = 100 fb^{-1}. It starts at about $2\,m_{LSP}$ for SUSY, at zero for the WW background.

$$W_{miss} = \sqrt{E^2_{miss} - P^2_{miss}}$$

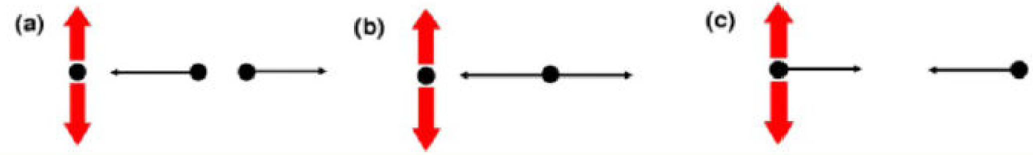
Forward detectors crucial for kinematics reconstruction (charged dilepton states only!):

Unique contribution!

Accidental overlays

Additional background arises from **accidental coincidence** where the detected system X in the central detector and the forward protons in VFD do not come from the same vertex :

arXiv:0806.0302



At the LHC, **<$N_{pile\text{-}up}$>** is ~5 events for $\mathcal{L} = 2{*}10^{33}\ cm^{-2}\ s^{-1}$ — *Poisson* distributed
~25 events for $\mathcal{L} = 1{*}10^{34}\ cm^{-2}\ s^{-1}$

* Single diffraction (pp->Xp)
σ = 14.30 mb

ε_{FP220} = 15%
ε_{FP420} = 12% --> σ_{VFD} = 3.8 mb

* Double diffraction (pp->X)
σ = 10.21 mb

ε_{FP220} = 1.3%
ε_{FP420} = 0.02% --> σ_{VFD} = 0.13 mb

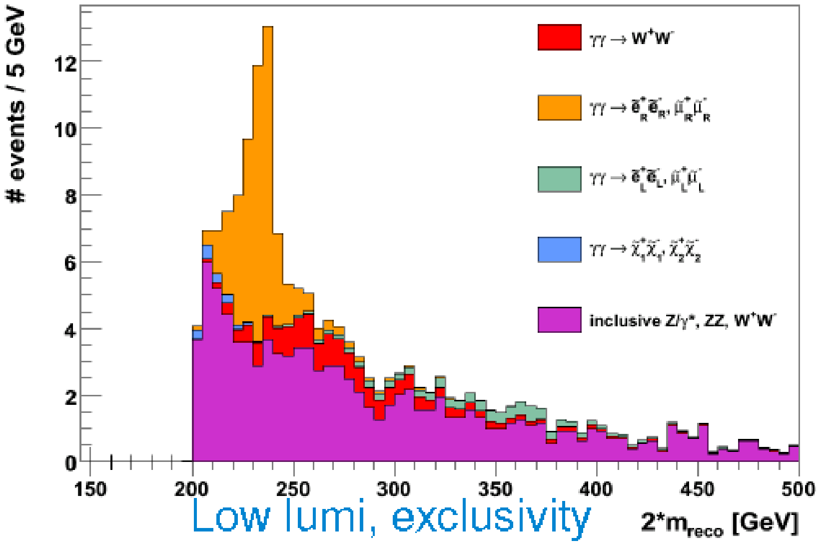
* Non-Diffractive inelastic (pp->X)
σ = 54.71 mb

ε_{FP220} = 0.33%
ε_{FP420} < 0.01% --> σ_{VFD} = 0.18 mb

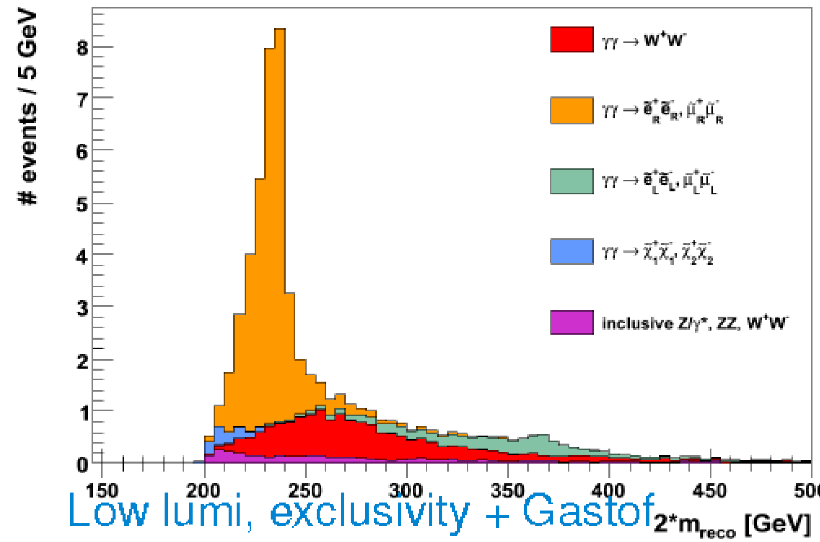
==> Global: $<\varepsilon_{FP240}>$= 2.165% $<\varepsilon_{FP420}>$= 3.015% --> $\sigma_{VFD,TOT}$ = 4.10 mb

Use timing for background suppression

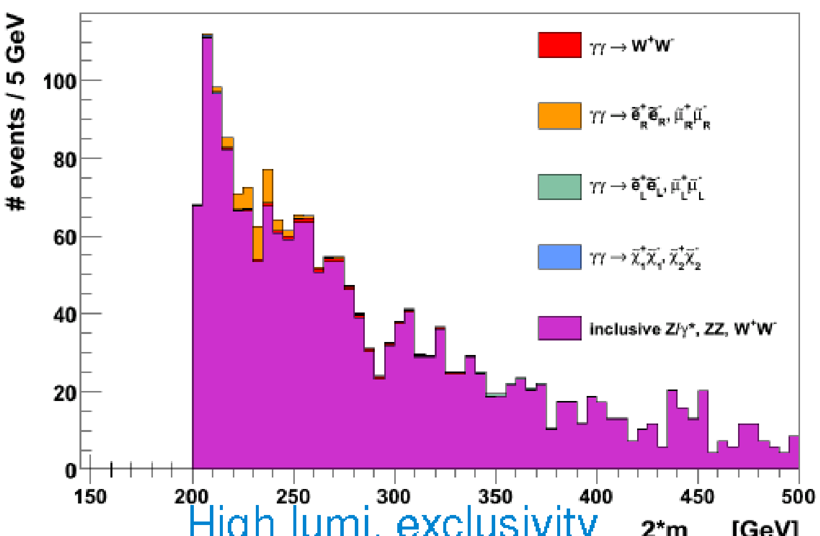
N. Schul at SUSY'09: Assume 10 ps resolution on each proton



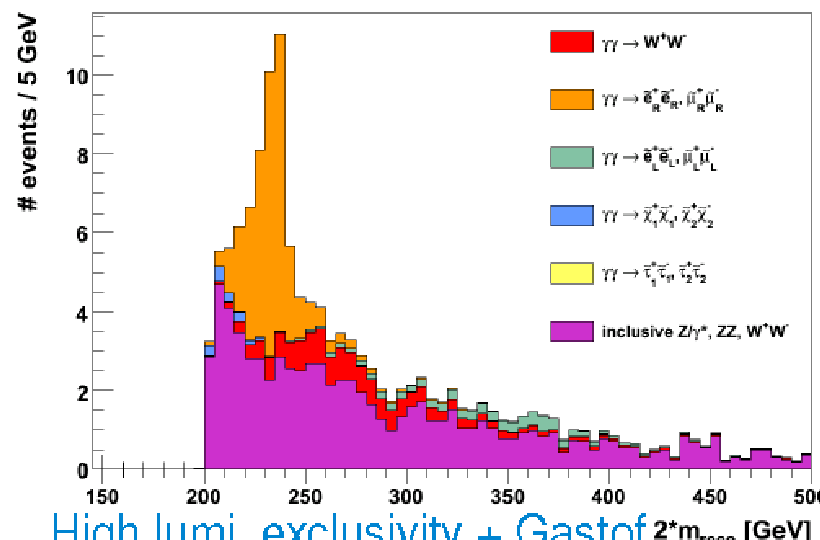
Low lumi, exclusivity



Low lumi, exclusivity + Gastof



High lumi, exclusivity

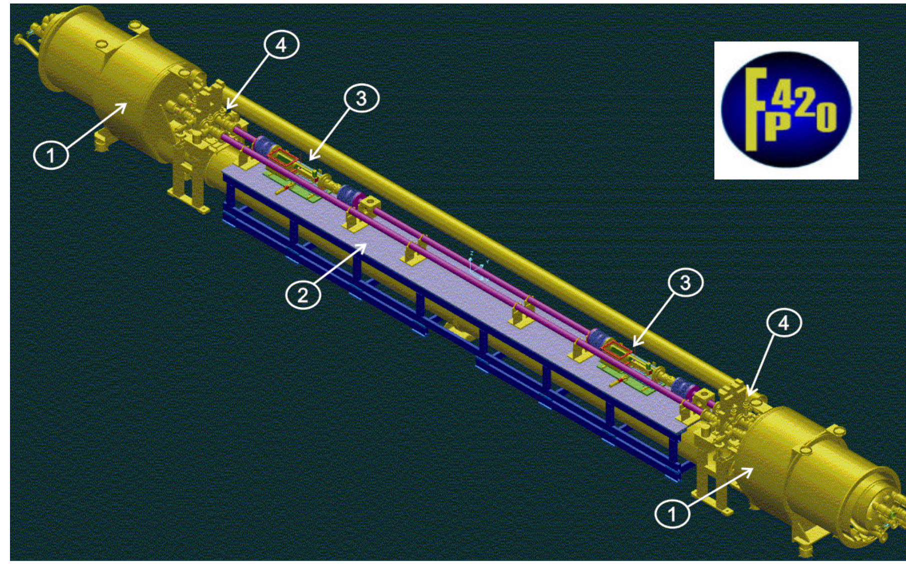


High lumi, exclusivity + Gastof

Timing detectors are mandatory to keep few GeV mass resolution in case of high luminosity

Forward proton detectors @ 420 m

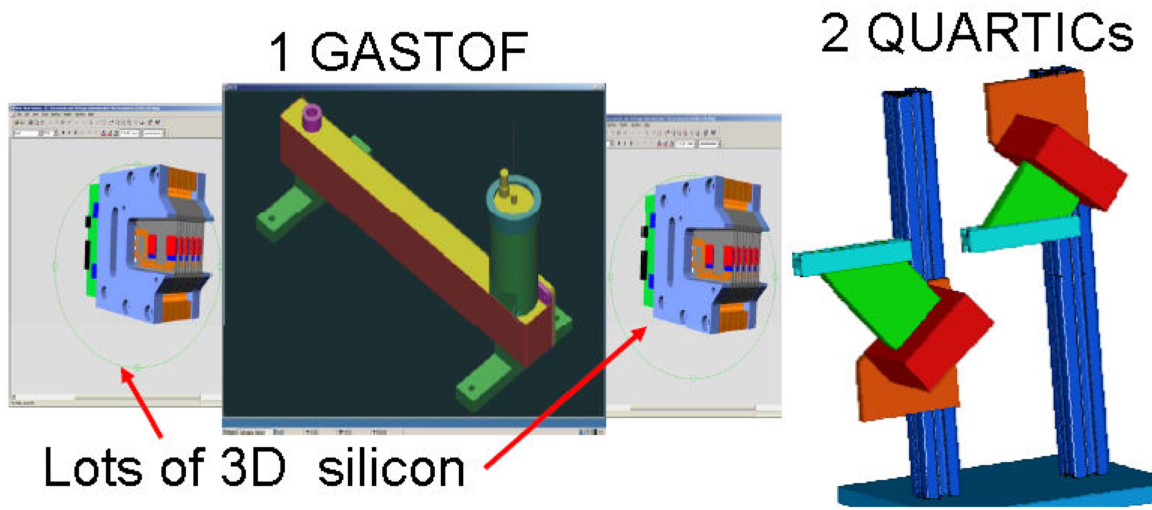
- Installation of Si detectors in cryogenic region of LHC, i.e. cryostat redesign needed
- Strict space limitations rule out Roman Pot technology, use movable beampipe instead
- Radiation hardness required of Si is comparable to those at SLHC, use novel 3-D Silicon technology
- To control pile-up background use very fast timing detectors (σ ~ 10ps)



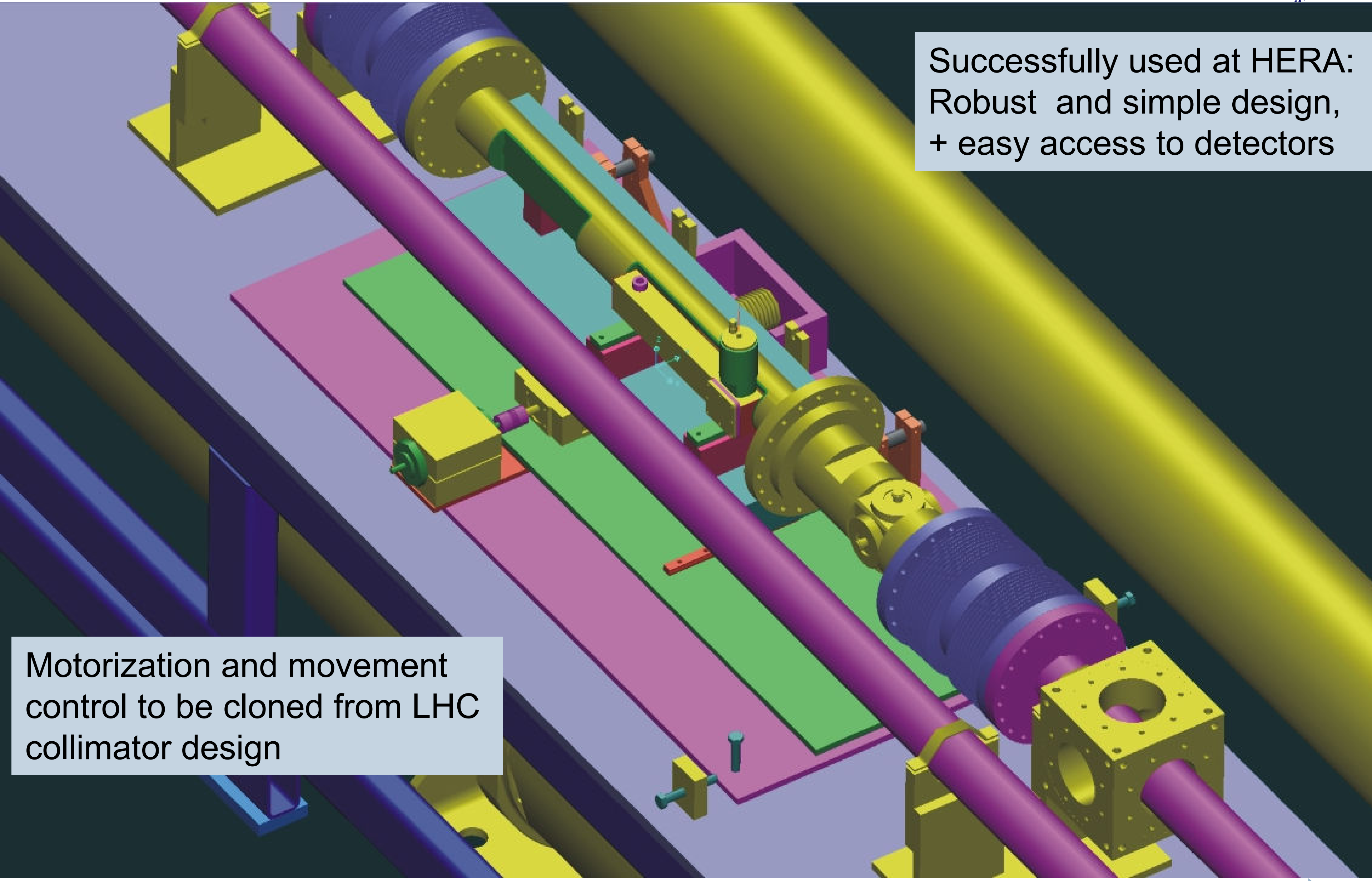
Acceptance: (At nominal LHC β^* = 0.5 m)

$0.002 < \xi < 0.02$

Two detector stations per arm (4 in total): each station contain tracking <u>and</u> timing detectors



Moving Hamburg pipe concept

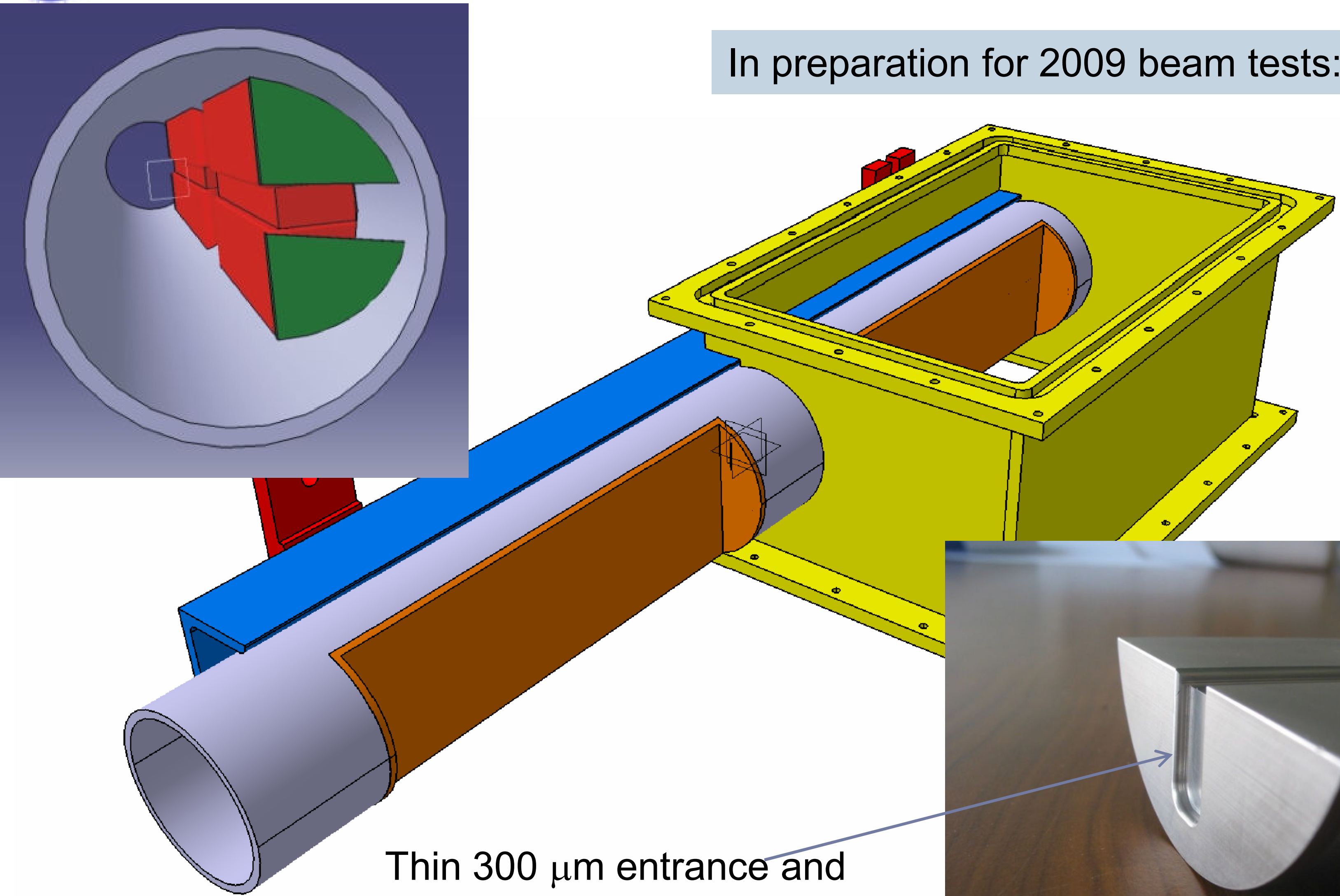


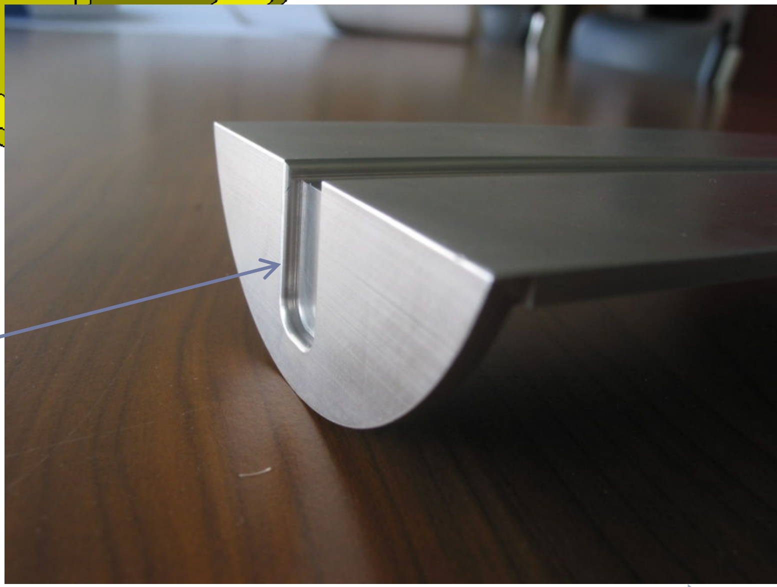
Successfully used at HERA:
Robust and simple design,
+ easy access to detectors

Motorization and movement
control to be cloned from LHC
collimator design

Moving pipe: Detector ‘pockets’

In preparation for 2009 beam tests:

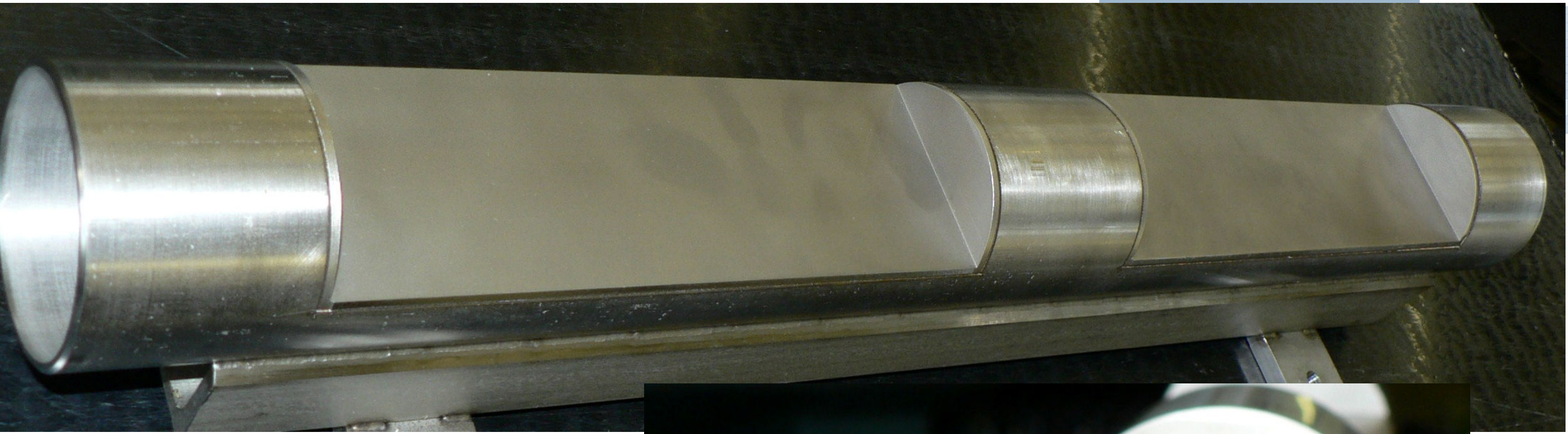


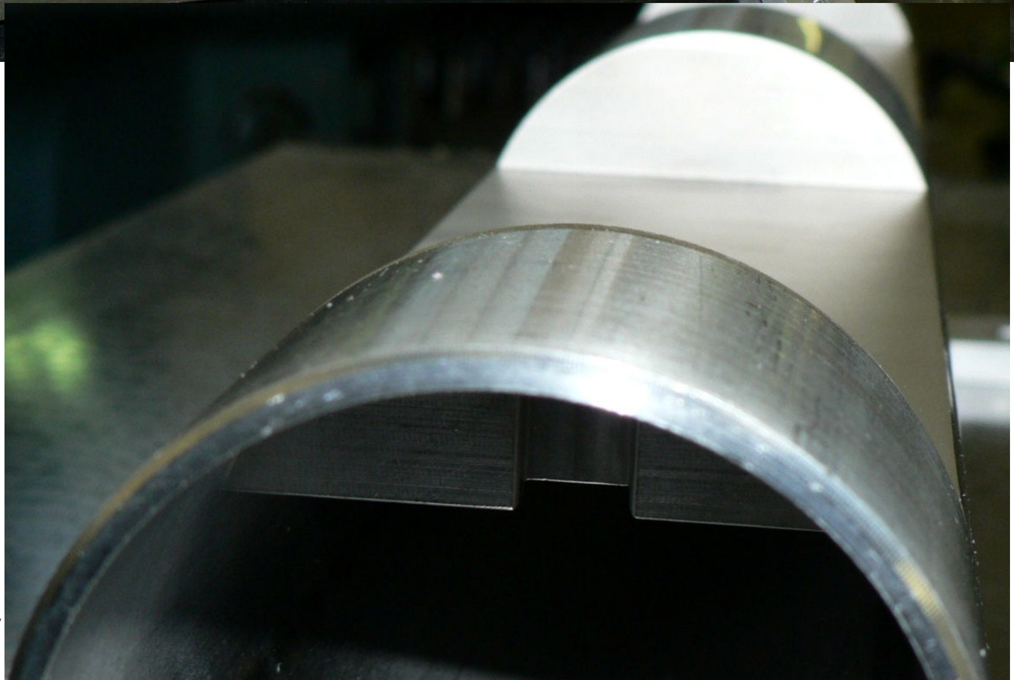


Thin 300 μm entrance and side windows

Hamburg moving beam pipe prototype

UCLouvain

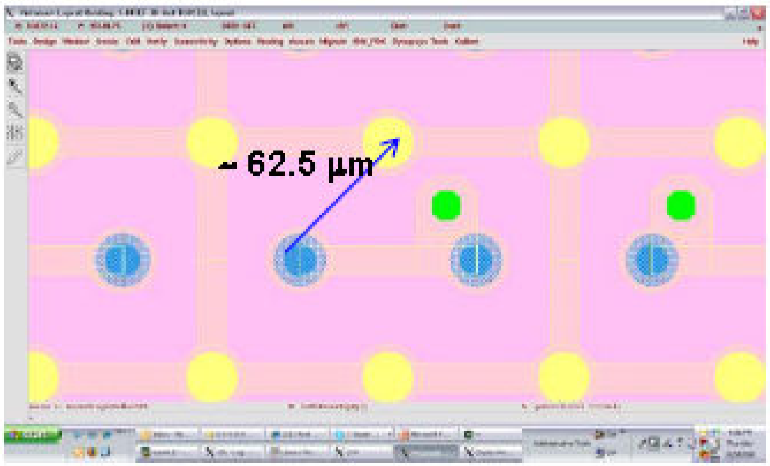


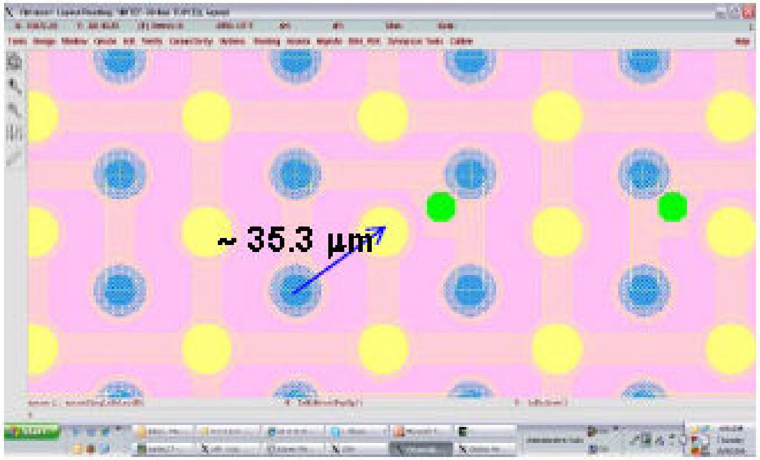


- Two pockets laser welded ready for test beam

CMS 3 D configurations

BOLLA, PURDUE





- CMS PSI46 100 µm ×150 µm
- Implemented 2 variations
  - 2 columns pixel
  - 4 columns pixel

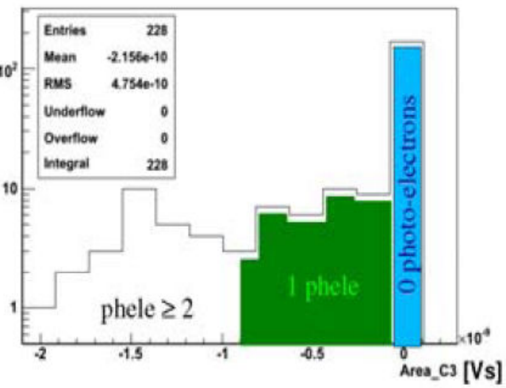
Profit from CMS R&D for SLHC:

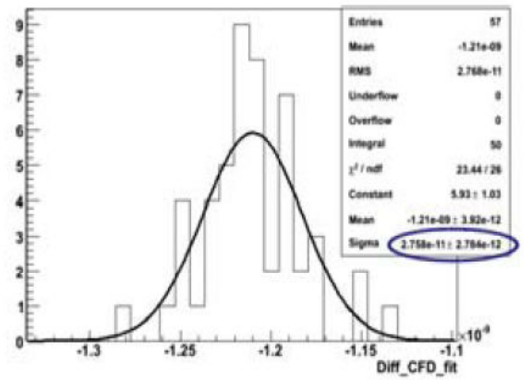
Beam tests of first 3D modules with CMS pixel chips planned this fall

GasToF: Cosmic-ray tests

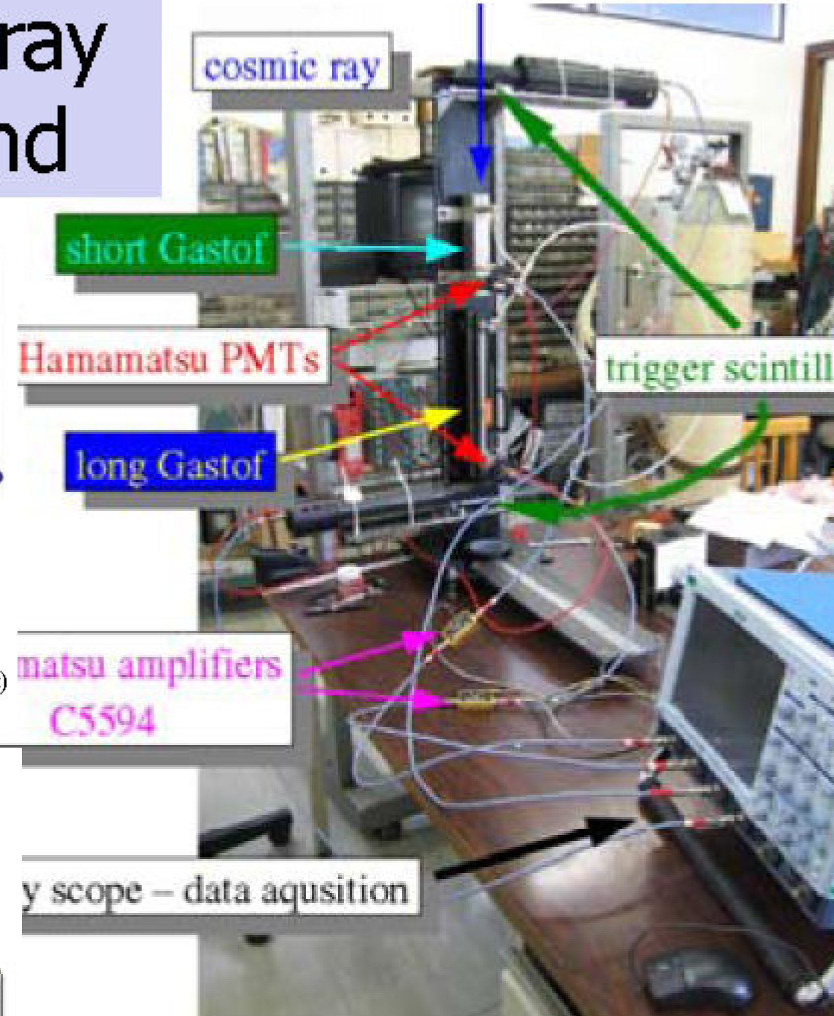
From TIPP09 (KEK, March):
Resolution < 20 ps for 1 p.e.!

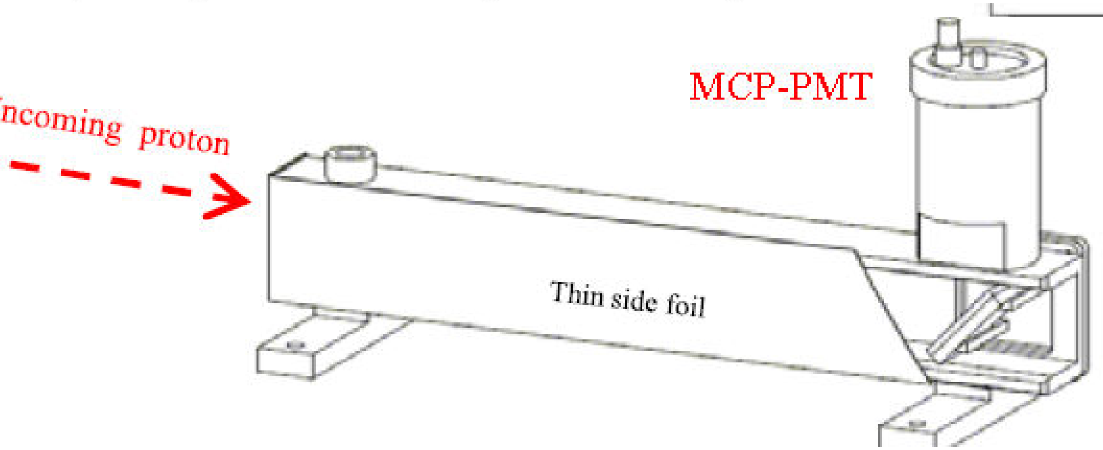
Cosmic ray test stand





Two Gastof detectors are coupled to R3809U-50 MCP-PMTs. Anode charge distribution (on 50 Ω) of a Gastof detector (left plot) shows two peaks corresponding to 1 and 2 photoelectrons, and the measured time difference spread (right plot) corresponds to a single detector resolution below 20 ps. The MCP-PMTs were operated at 3000 V.

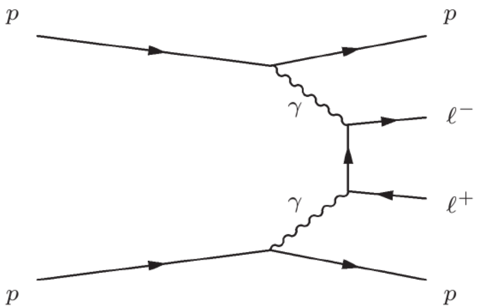




Quartic at test-beam in Fall

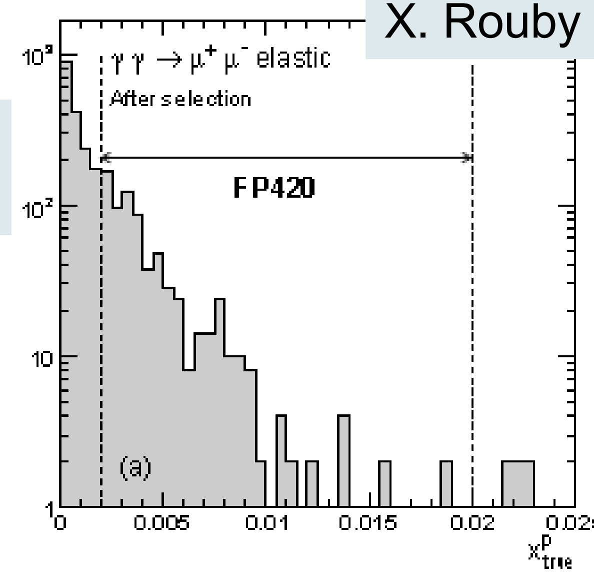
Calibration with exclusive di-muons

$pp \rightarrow pp\, l^+l^-$



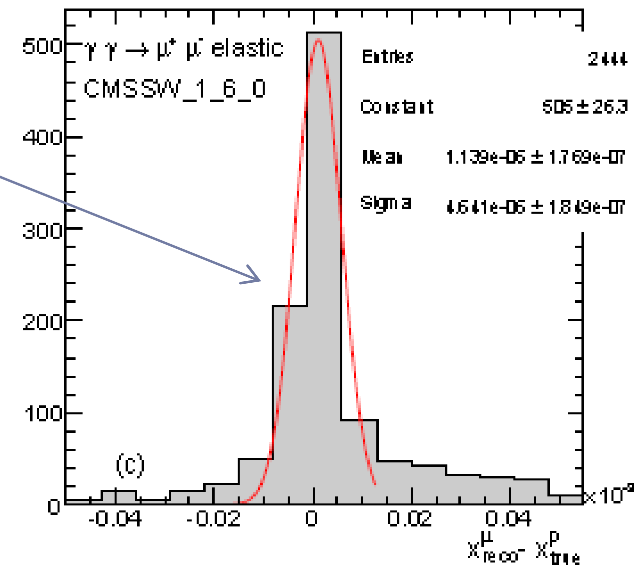
X. Rouby

~ <u>700 μμ events in 100 pb^{-1}</u>
(single-interaction data @ 14TeV)



- Nearly pure QED process
- Calibration/alignment of FP420 detectors (about 40% protons detected!):

Expected resolution of x=Eγ/E is ~5.10-6 !

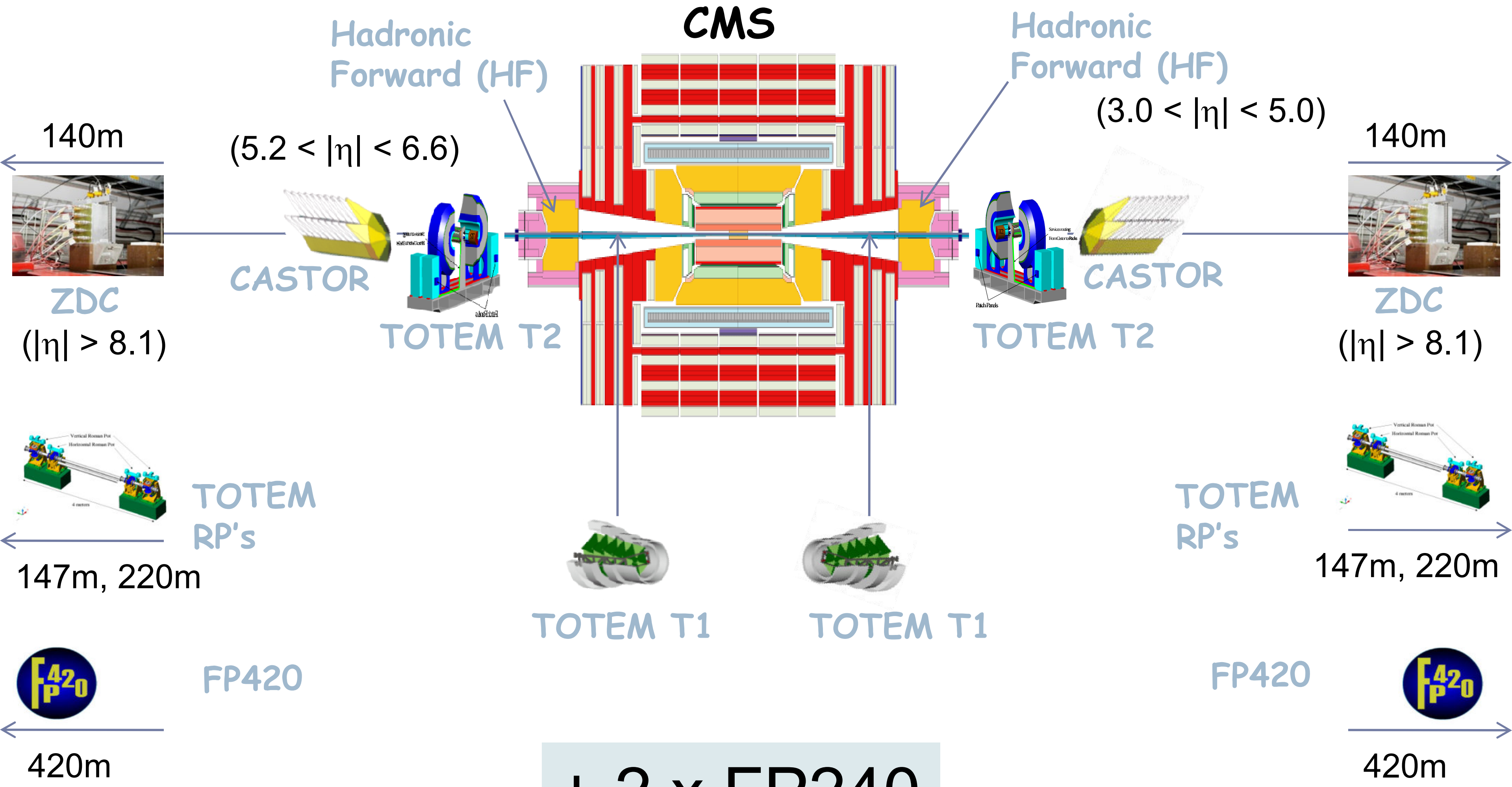


Calibration procedure itself can be very well controlled using exclusive Upsilon data!

BOTTOMLINE:

Exclusive low-mass dimuons crucial for FP420

Forward detectors @ IP5

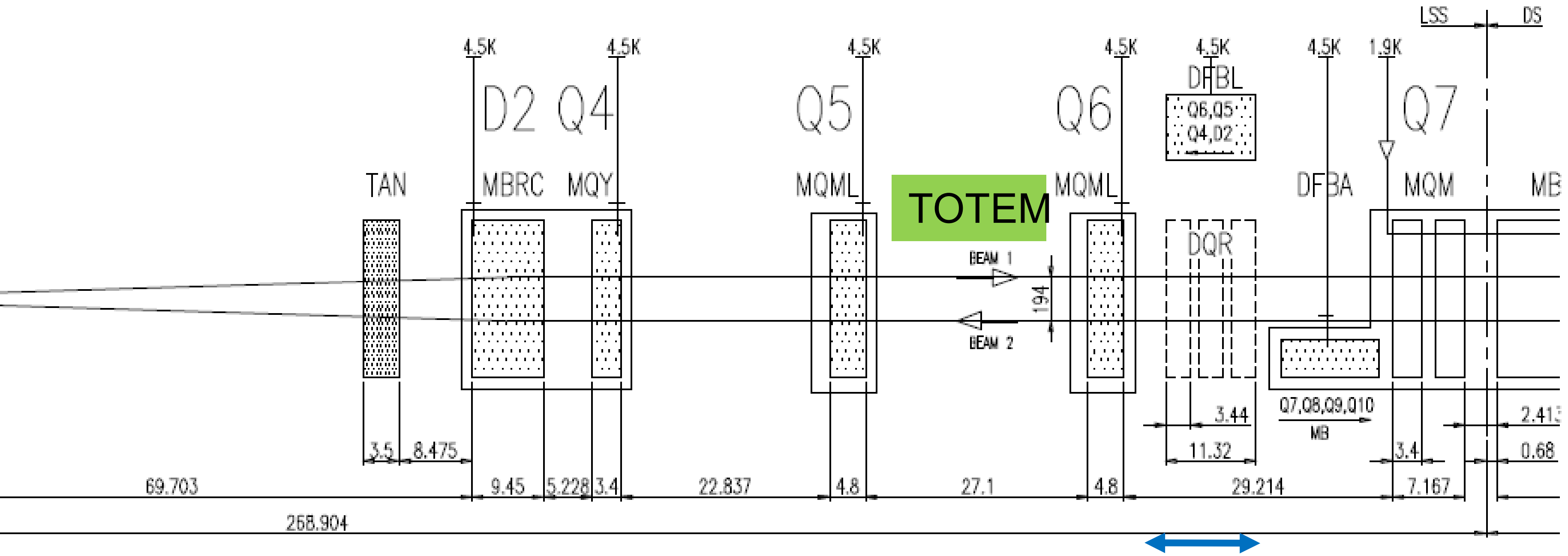


+ 2 x FP240

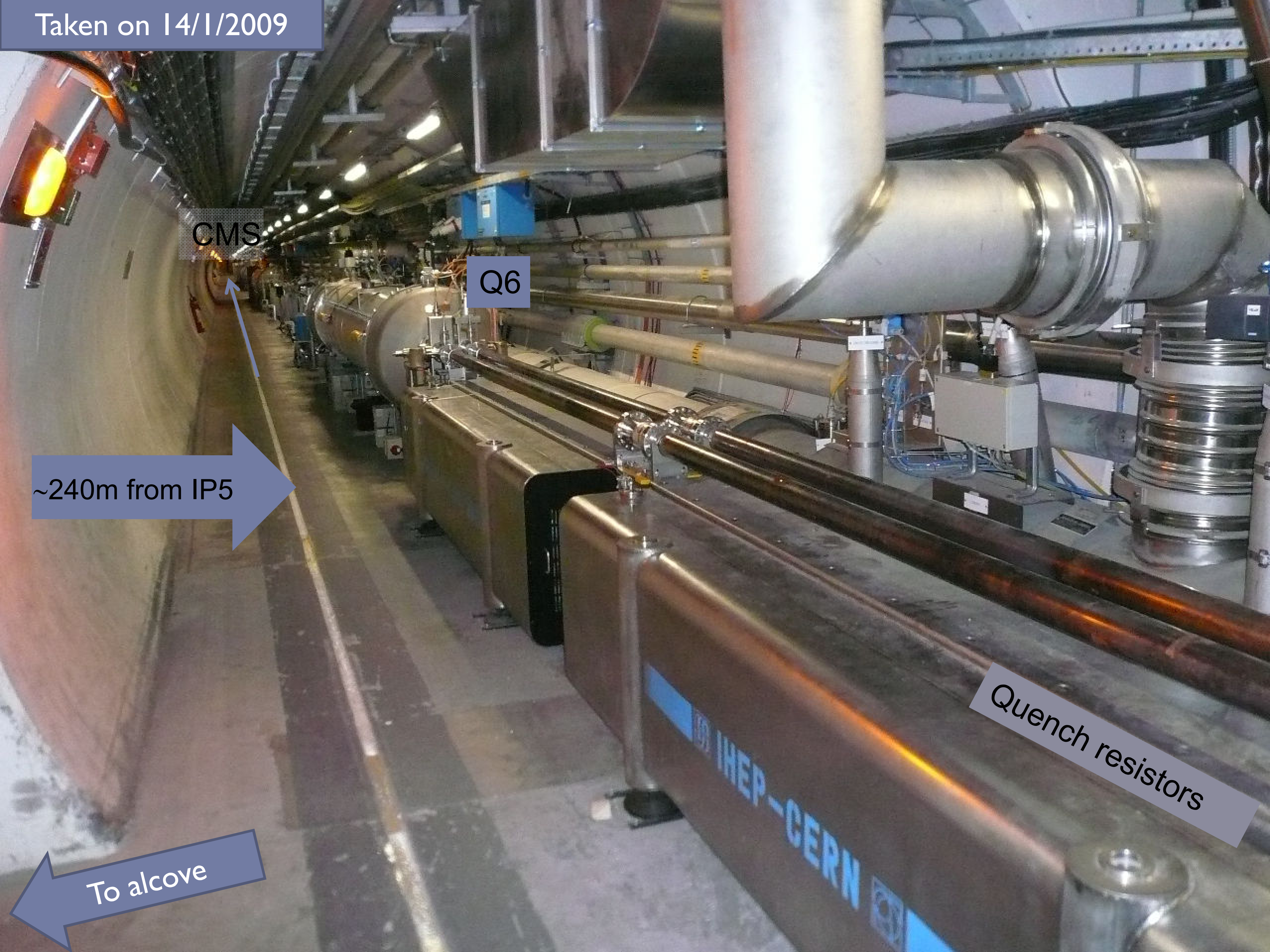
Motivation for proton detectors @ 240 m

- Tagging at 420 m and 240 m is complementary – together $\sim 0.1 – 10\%$ energy loss range is covered !
- This leads to significantly higher tagged cross sections
- Both 240 m locations are 'warm&free' – just bare beam-pipes
- At IP5, locations at 220 m are occupied by TOTEM → go at 240 m - it is still possible to send triggers to CMS!
- Note: SM H → bb could be triggered using FP240
- One does not need to modify the LHC beamline -> can be done before FP420

LHC beam-line close to 240 m



Available space of ~ 12 m !


Taken on 14/1/2009
CMS
Q6
~240m from IP5
Quench resistors
To alcove
IHEP–CERN

Summary/Outlook

- The FP420 R&D report published, is basis of the CMS (and ATLAS) FP420 proposal

- The R&D (first) phase ends with a complete cryostat design and a pre-prototyped, tested concept for high precision near-beam detectors at LHC

- CMS evaluated the FP420 proposal and asked for some further work before preparation of TDR – we are in position to start it now; we propose to include FP240 detectors

- Physics case for forward proton tagging spans central exclusive production, $\gamma\gamma$ and photon-proton physics, diffractive physics, gap survival /underlying event, study of gluon jets …..

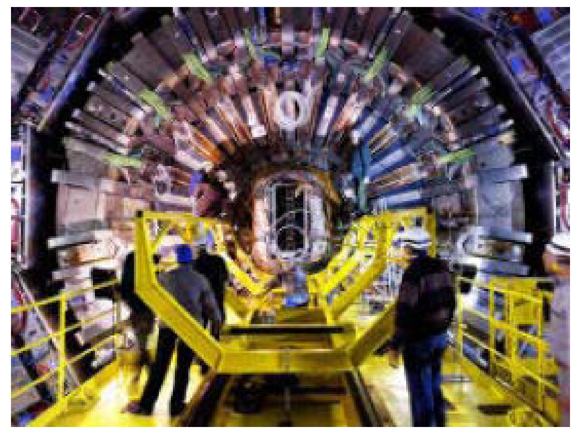
- For low incremental cost, forward proton detectors add significant physics potential to CMS with no effect on the operation of the LHC.

Phys. Rev. Lett. **102**, 242001
(issue of 19 June 2009)
Title and Authors

24 June 2009

A Higgs Boson without the Mess

Particle physicists at CERN's Large Hadron Collider (LHC) hope to discover the Higgs boson amid the froth of particles born from proton-proton collisions. Results in the 19 June *Physical Review Letters* show that there may be a way to cut through some of that froth. An experiment at Fermilab's proton-antiproton collider in Illinois has identified a rare process that produces matter from the intense field of the strong nuclear force but leaves the proton and antiproton intact. There's a chance the same basic interaction could give LHC physicists a cleaner look at the Higgs.



CERN

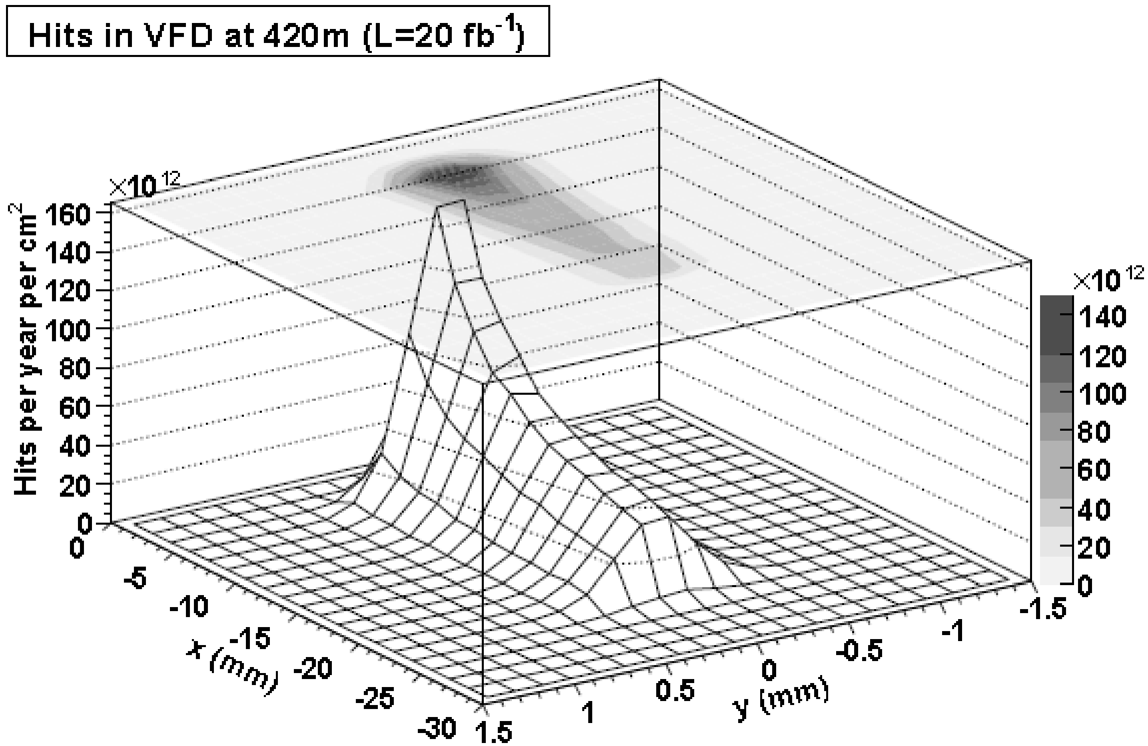
Higgs machine. If CERN's Large Hadron Collider (LHC) can create Higgs bosons, a handful may appear in rare "exclusive" reactions that don't destroy the colliding protons--similar to a reaction now observed at Fermilab. CERN's ATLAS and CMS teams are considering adding equipment to their detectors (CMS shown here) to look for such events (click image to enlarge).

A proton is always surrounded by a swarm of ghostly virtual photons and gluons associated with the fields of the electromagnetic and strong nuclear forces. Researchers have predicted that when two protons (or a proton and an antiproton) fly past one another at close range, within

Backup slides

Proton fluence at FP420

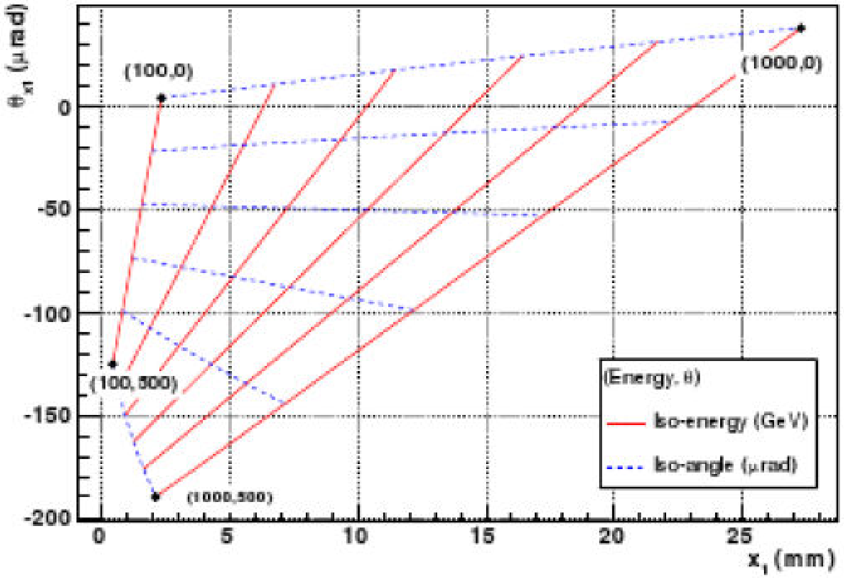
HECTOR



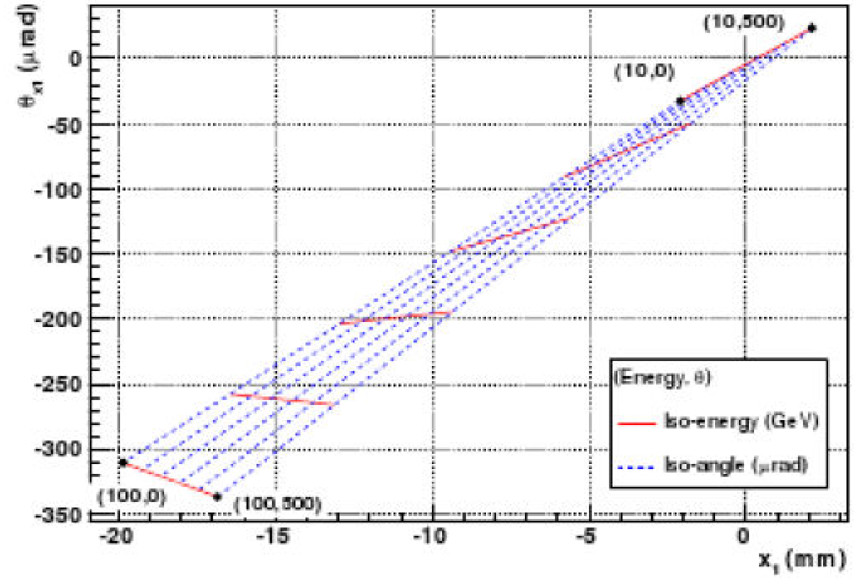
Chromacity grids

HECTOR

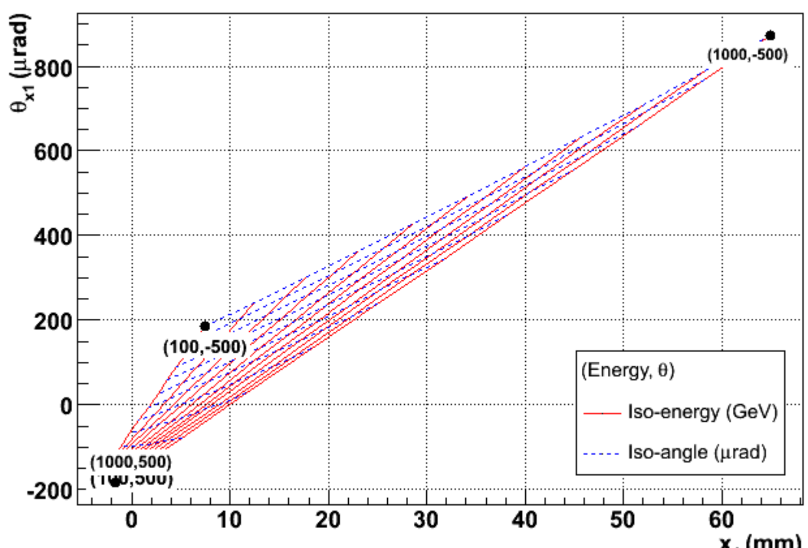
Chromaticity grid at 220 m



Chromaticity grid at 420 m



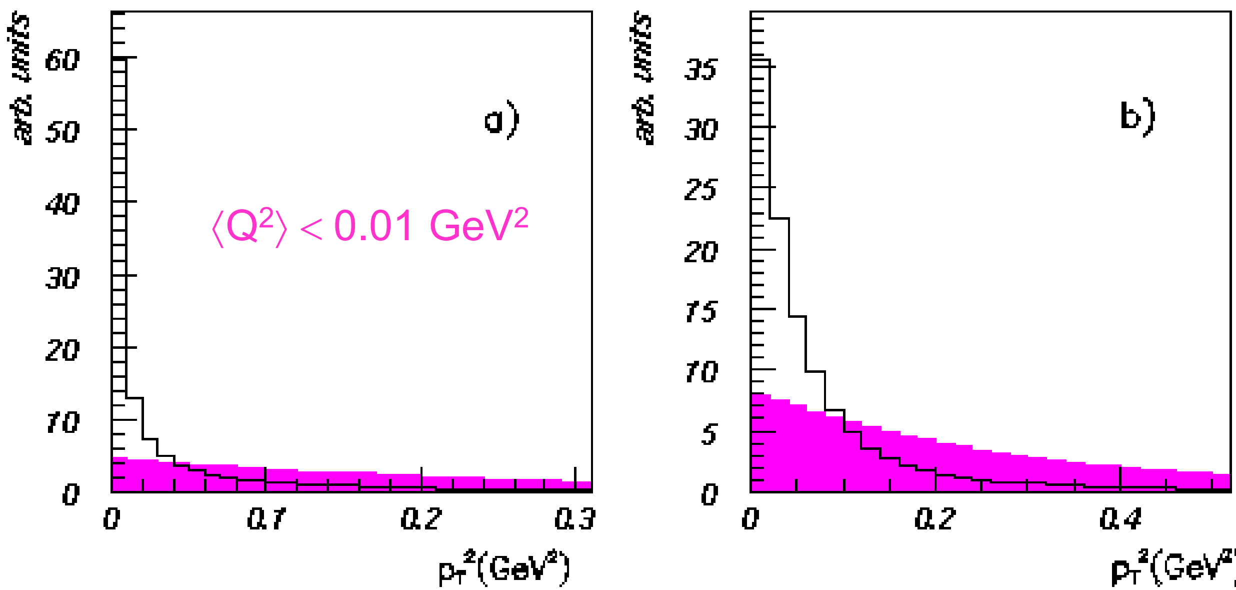
Chromaticity grid at 240 m



Problem: <u>Same</u> signature (one or two very forward protons) has also *central diffraction* (i.e. *pomeron-pomeron* scattering) in strong interactions

Both processes weakly interfere, and transverse momentum of the scattered protons are in average much softer in two-photon case

a) `true' distributions; b) distributions smeared due to beam intrinsic p_T; all plots normalized for $p_T^2 < 2\ GeV^2$



p_T gives powerful separation handle provided that size of $\gamma\gamma$ and pomeron-pomeron cross-sections are not too different

Assuming ultimate p_T resolution ≈ 100 MeV; i.e. neglecting detector effects

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