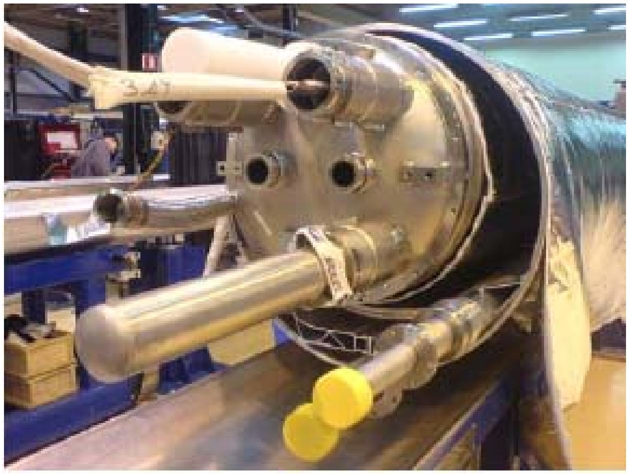
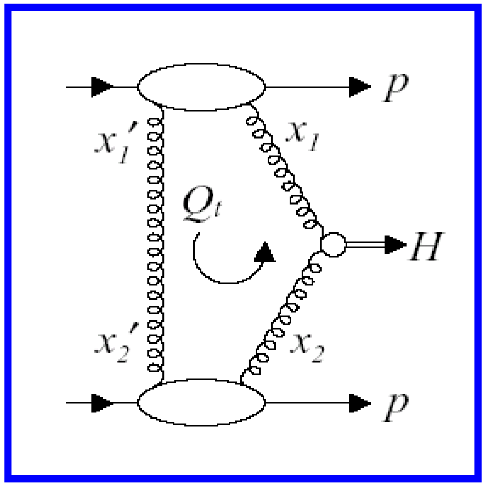
The FP420 Project:

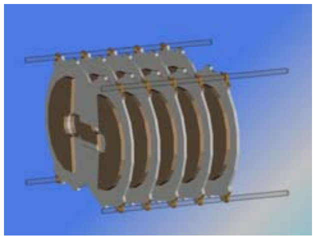
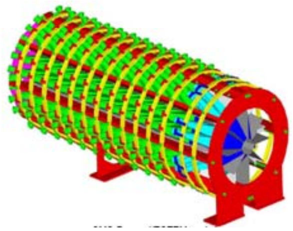
Albert De Roeck
CERN
and University of Antwerp
and the IPPP Durham

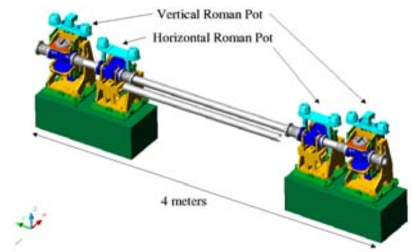




Forward detectors at LHC

TOTEM -T2 | CASTOR | ZDC/FwdCal | TOTEM-RP | FP420?

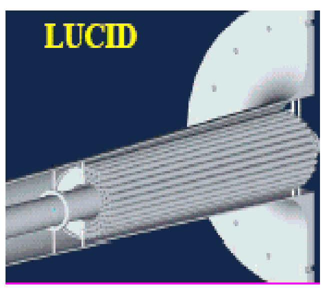



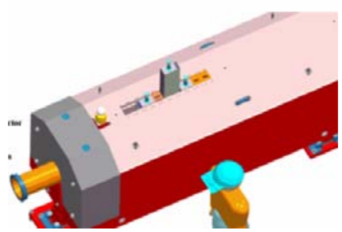
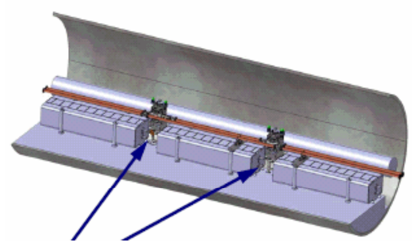
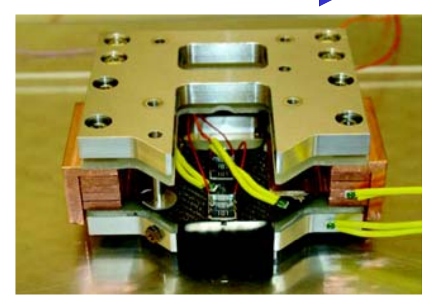


IP5

14 m | 16 m | 140 m | 147m - 220 m | 420 m

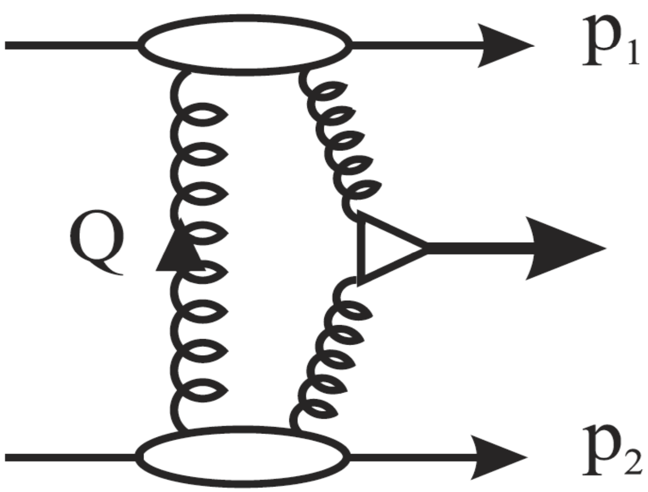
IP1



LUCID | ZDC | ALFA/RP220 | FP420?

Exclusive Central Production



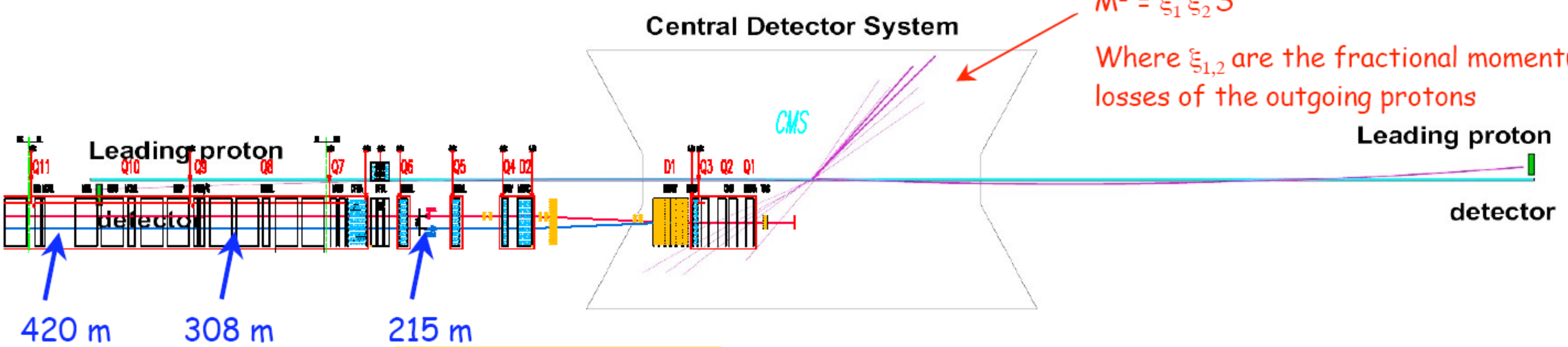
- Selection rules mean that central system is 0^{++} $\Rightarrow$pinning down the quantum numbers
- CP violation in the Higgs sector shows up directly as azimuthal asymmetries
- Tagging the protons means excellent mass resolution (~ GeV) irrespective of the decay products of the central system. LO QCD backgrounds suppressed
- Proton tagging may be the discovery channel in certain regions of the MSSM.
- Unique access to a host of interesting QCD processes

Very schematically: exclusive central production is a glue – glue collider where you know the beam energy of the gluons - source of pure gluon jets - and central production of any 0^{++} state which couples strongly to glue is a possibility …

FP420: Detectors at 420m

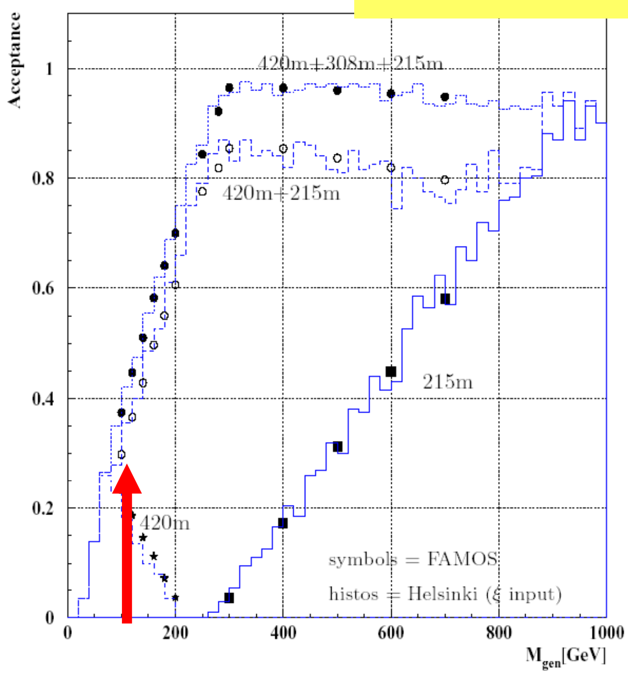
$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons



FP420

TOTEM (ATLAS/RP220)



Low β^*: (0.5m): Lumi 10^{33}-10^{34}cm^{-2}s^{-1}

215m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.02$

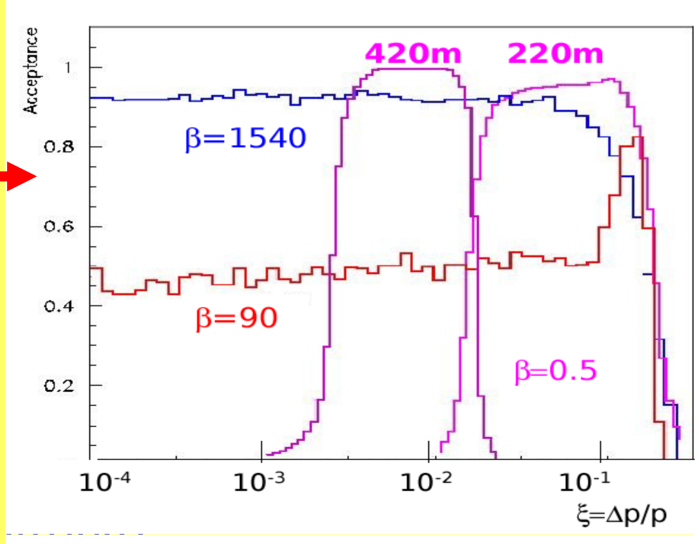
Detectors in the cold region are needed to access the low ξ values

FP420 R&D Study

FP420 R&D Study

- Feasibility study and R&D for the development of detectors to measure protons at 420 m from the IP, during low β optics at the LHC
  - Main physics aim pp → p+ X + p
    - Higgs, New physics
    - QCD/diffractive studies
    - Photon induced interactions
  - Study aims
    - Mechanics/stability for detectors at 420 meter (cryostat region)
    - Detectors to operate close to the beam
    - Fast timing detectors (10-20 picosecond reso
    - RF issues, integration, precision alignment, radiation, resolution,…
    - Trigger/selection issues/pile-up for highest luminosity

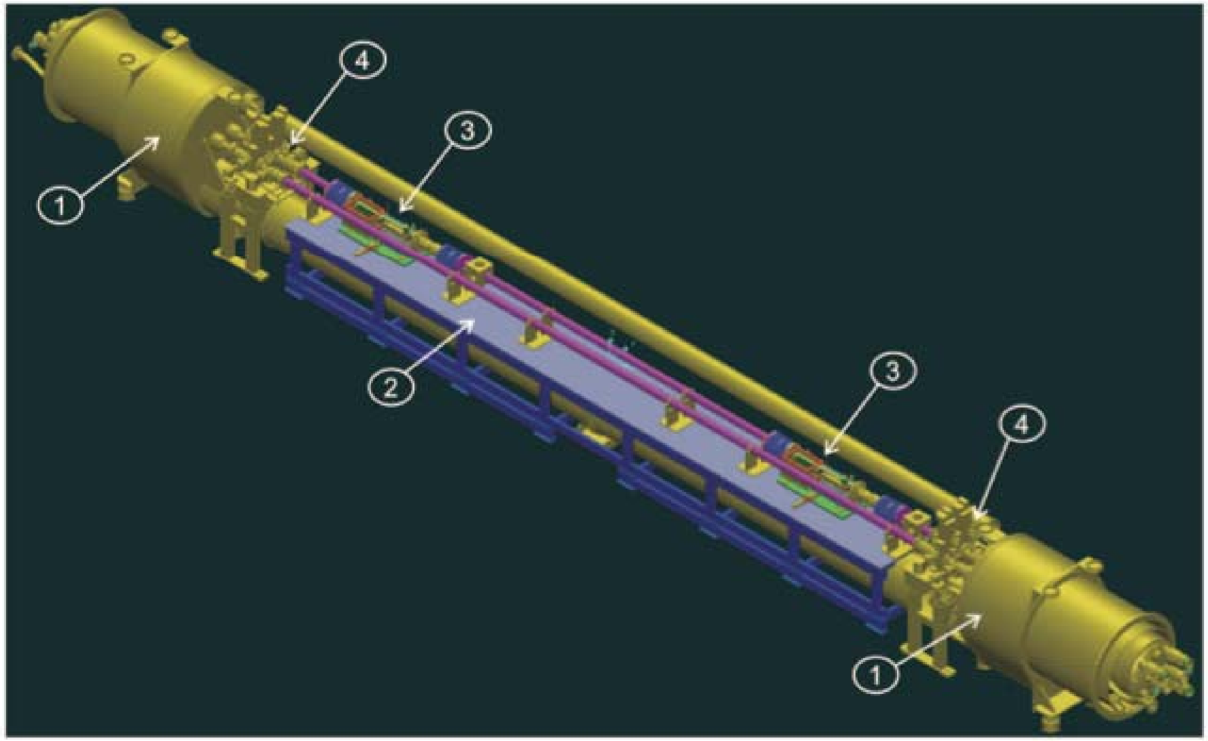
      ⇒To be built/deployed by ATLAS and/or CMS, when successful
- Collaboration web page: http://www.fp420.com



Excellent collaboration with machine/cryo groups; Keith Potter mediator

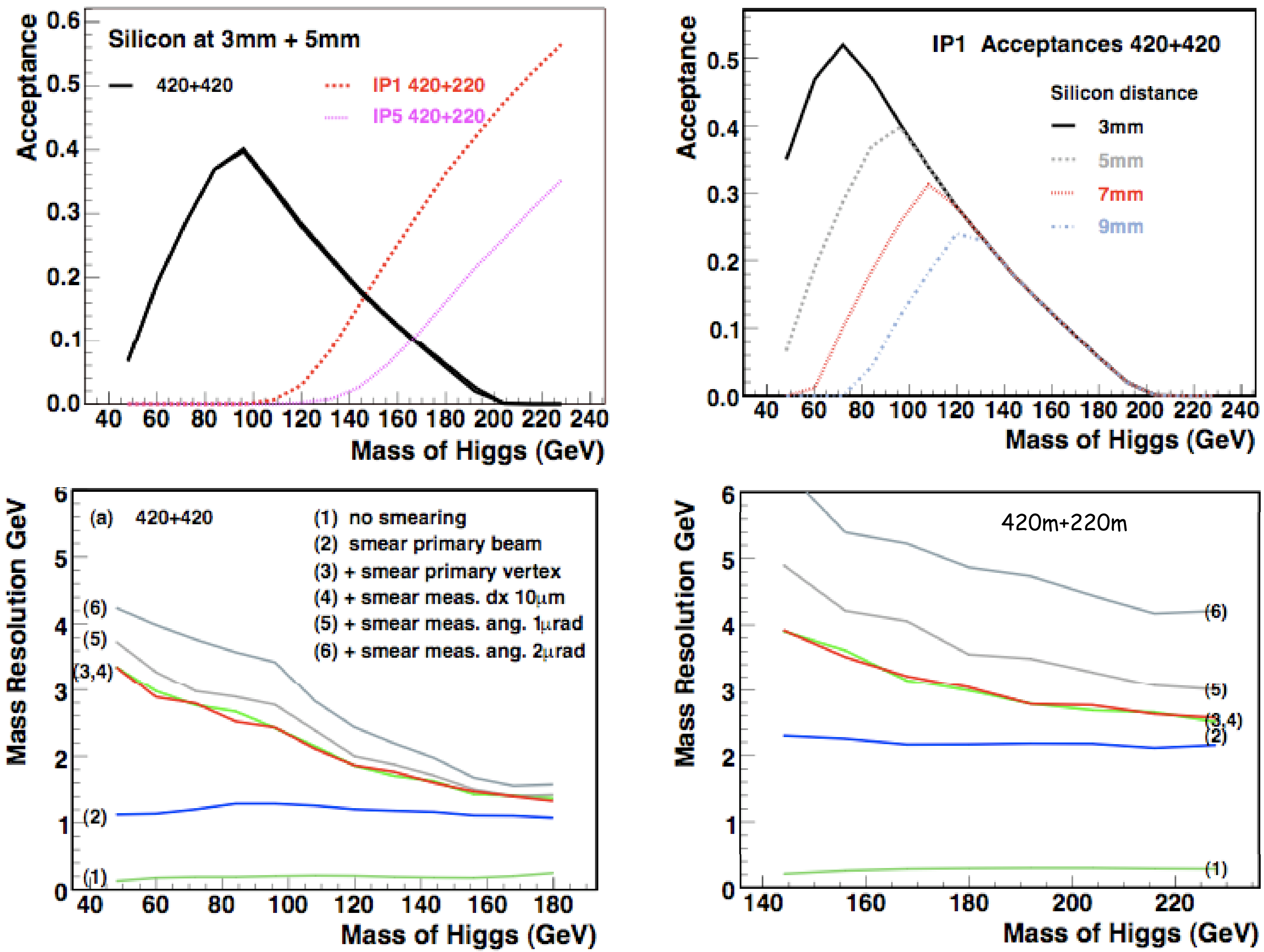
FP420

Detectors at 420 m from the IP to detect forward protons



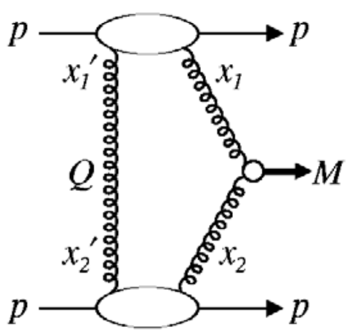
Replace empty cryostat with ATMs and "FP420" beampipe described in the document

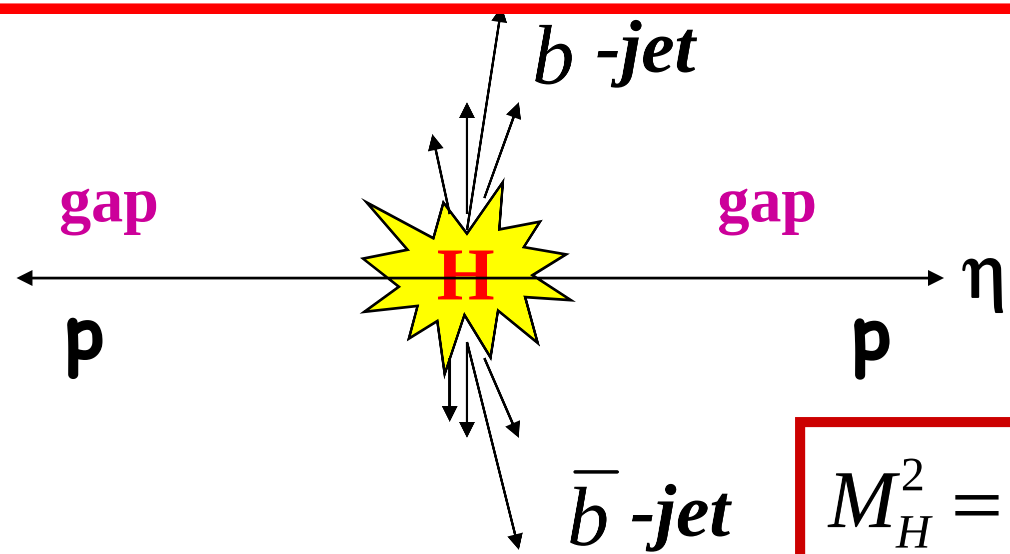
Acceptance and Resolution



Central Exclusive Higgs Production

Central Exclusive Higgs production pp→ p H p : 2-10 fb (SM)
~10-100 fb (MSSM)

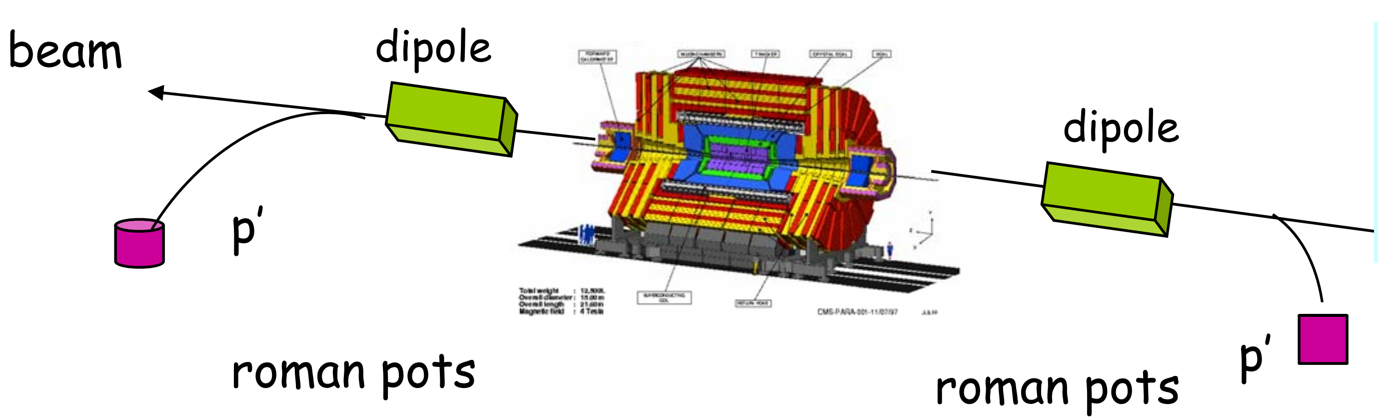




E.g. V. Khoze et al
ADR et al.
M. Boonekamp et al
B. Cox et al.
V. Petrov et al...
Brodsky et al.

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC

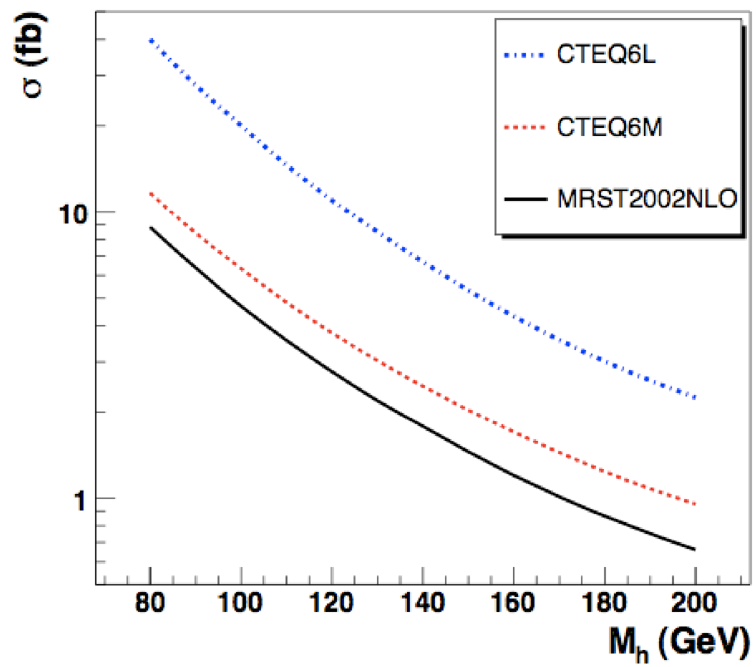
FP420 R&D Project
http://www.fp420.com

$pp \rightarrow p+H+p$ cross section

Checkered history: range of possible numbers existed until 1-2 years ago
Durham numbers were checked by J. Forshaw et al, and by a Protvino group
More importantly the Tevatron predictions for dijets and diphotons are confirmed within a factor of ~ 2

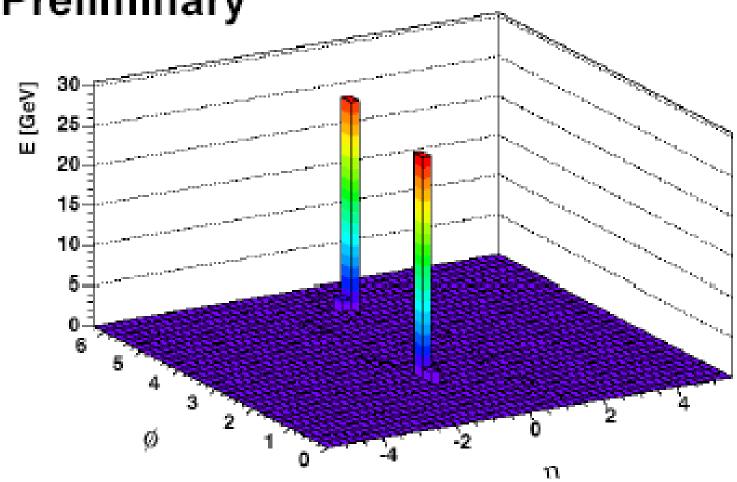
Main uncertainties
-Proton survival probability (Tevatron → LHC)
Could be pinned down with early LHC data
$pp \rightarrow p\, WW\, p$
-PDF uncertainty

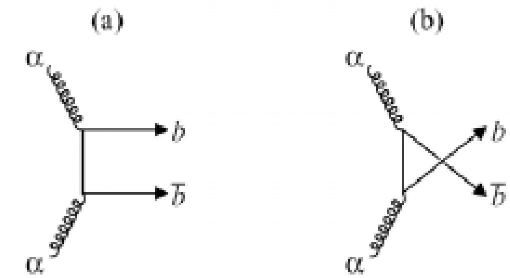
Take pessimistic approach in most cases: MRST PDFs



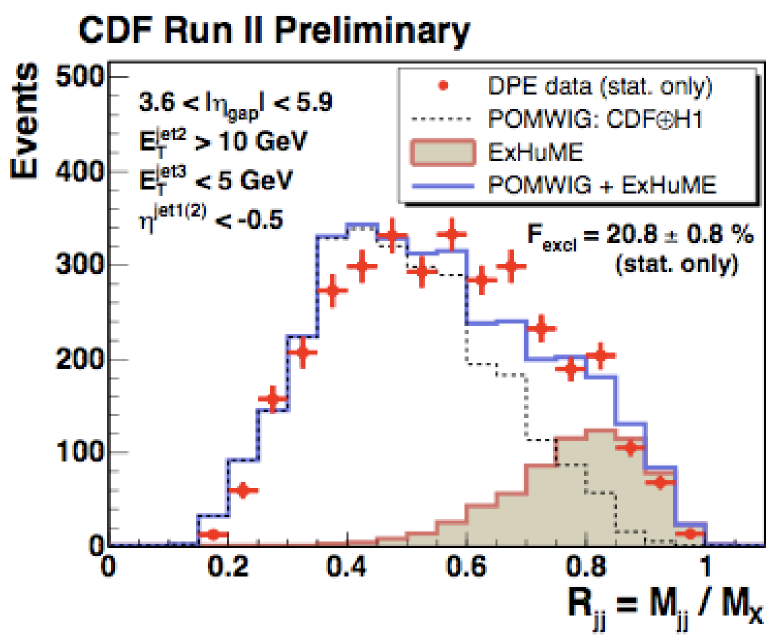
Evidence for Exclusive Production at Tevatron

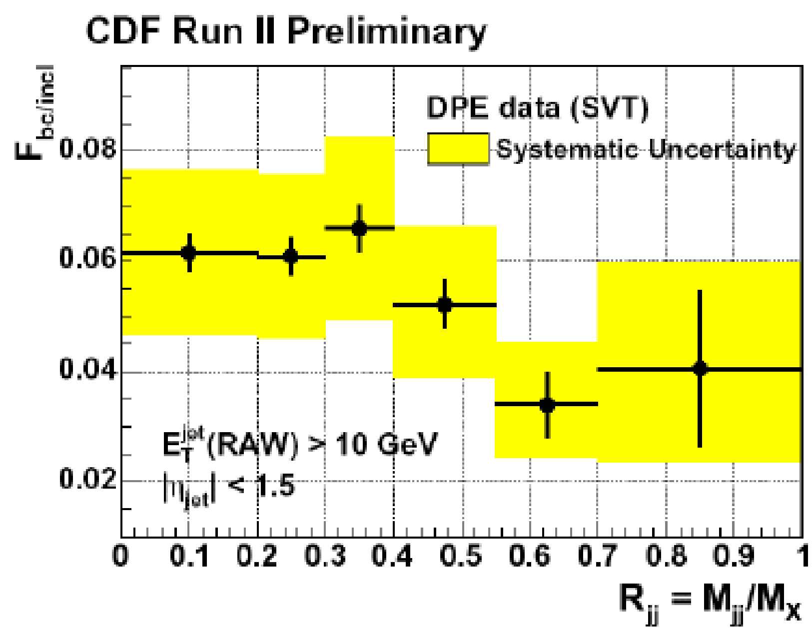
CDF Preliminary





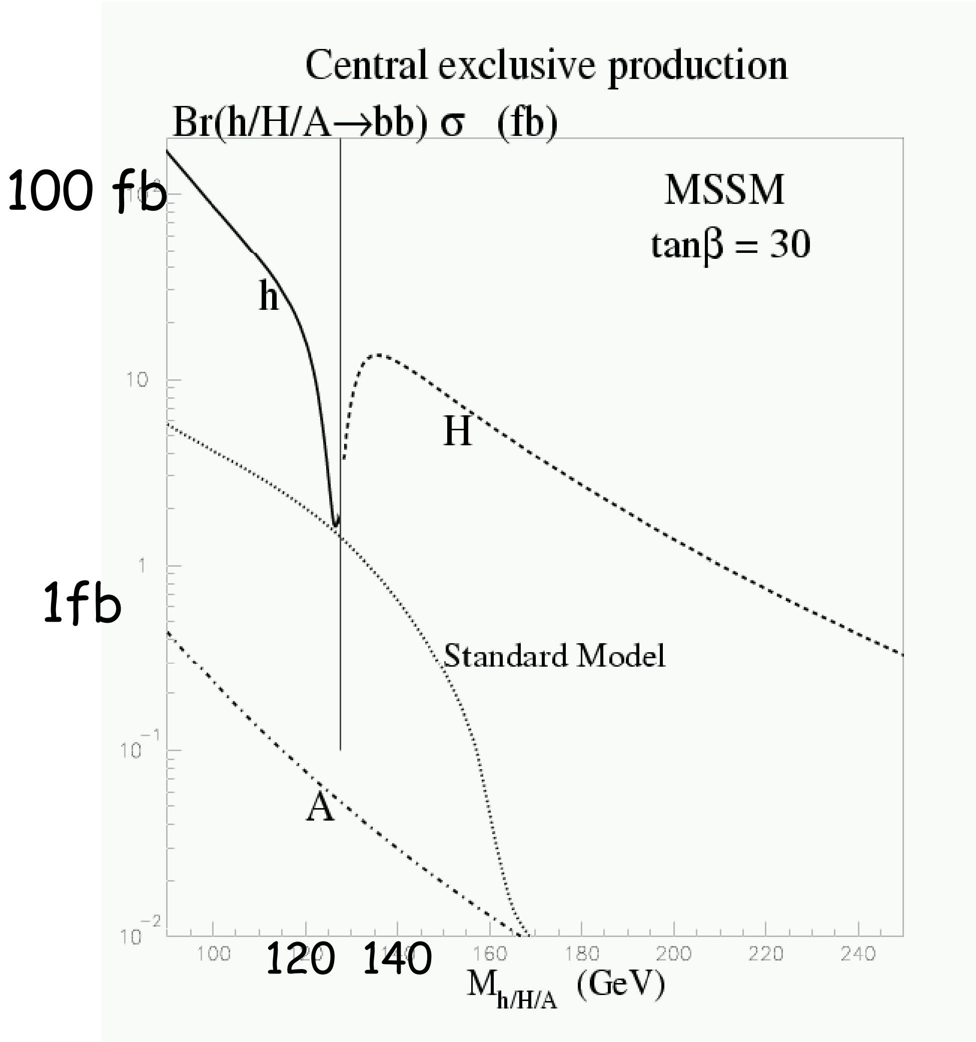
J_z=0 -> for colour singlet bbar production, the born level contributions of a) and b) cancel in the limit m_b -> 0





Also: Observation of exclusive 2 photon and di-lepton events in CDF

Higgs Studies



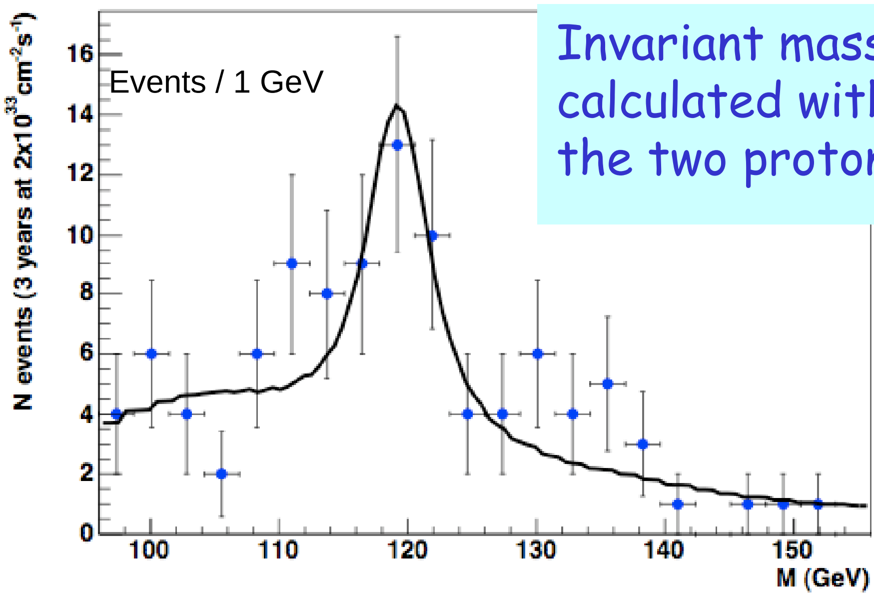
Cross section factor
> 10 larger in MSSM
(high tanβ)
⇒ Few 100 events with
~ 10 background events
for 30 fb^{-1}

Kaidalov et al.,
hep-ph/0307064

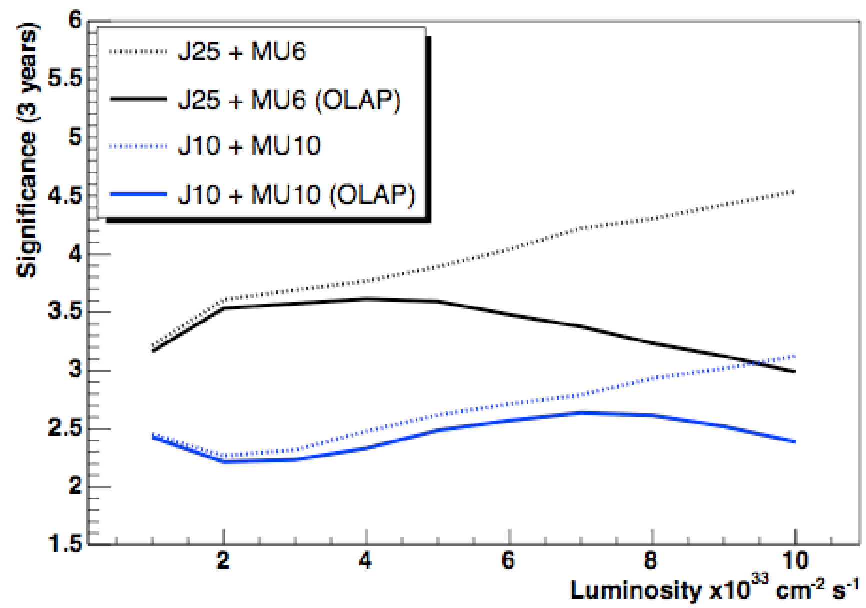
H→bb

M_h^{max} MSSM scenario: H→bb

(m_A=120 GeV, $\tan\beta$ = 40, 60 fb^{-1}) σ= 20 fb



Invariant mass calculated with the two protons



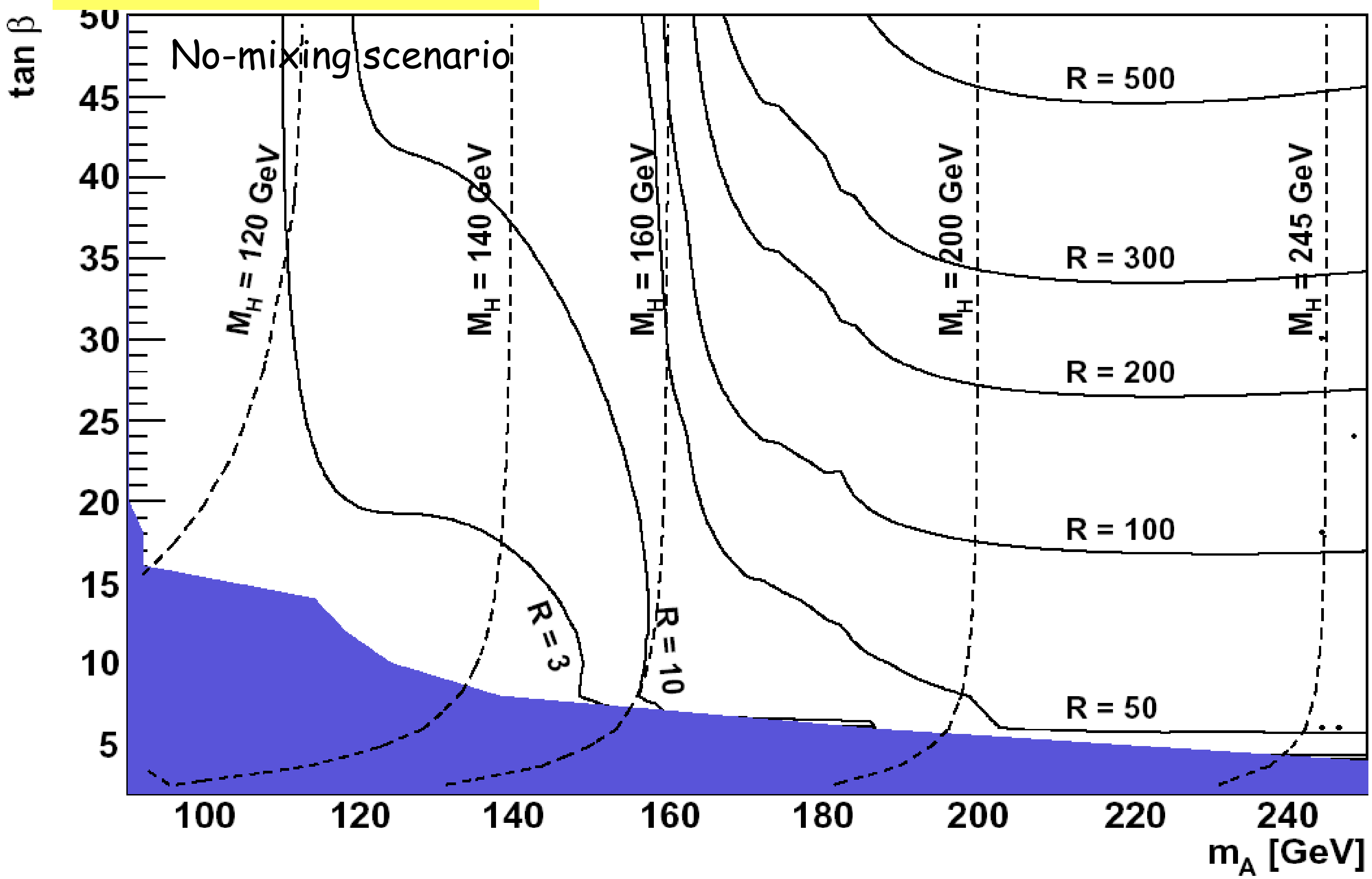
New trigger strategy:
Open L1 jet thresholds and accept 10-25 KHz
Clean at HLT with FP420 protons to few Hz
Trigger acceptance > 50% * proton acceptance
Pile-up taken into account

Taking into account acceptance, trigger efficiencies etc.

Presently:SM H→bb will be marginal

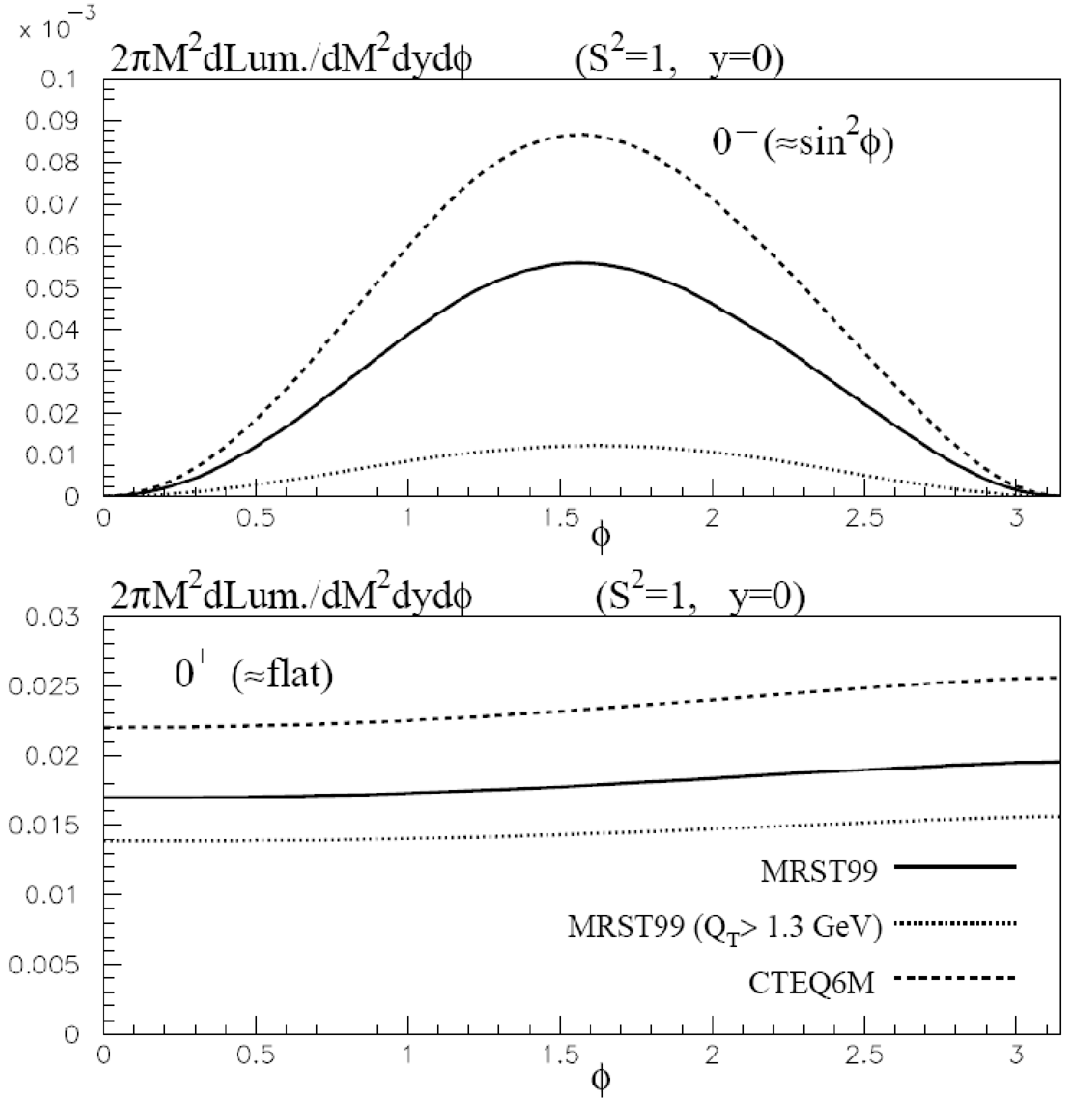
MSSM Scenario Studies

M_A = 130 GeV   H→bb



Contours of ratio of signal events in the MSSM over the SM

Measuring the Azimuthal Asymmetry



Khoze et al., hep-ph/0307064

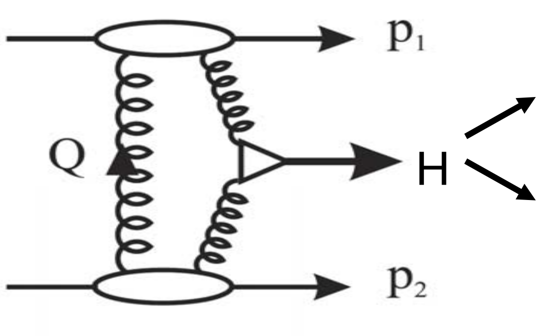
Azimuthal correlation between the tagged protons

Allows to eg to differentiate O^+ from O^-

A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC

H→WW

Standard Model Higgs



WW* : M_H = 120 GeV s = 0.4 fb

M_H = 140 GeV s = 1 fb

M_H = 140 GeV : 3-4 signal / O(3) background in 30 fb^{-1}

M_H = 140 GeV : 17 signal / O(15) background in 300 fb^{-1}

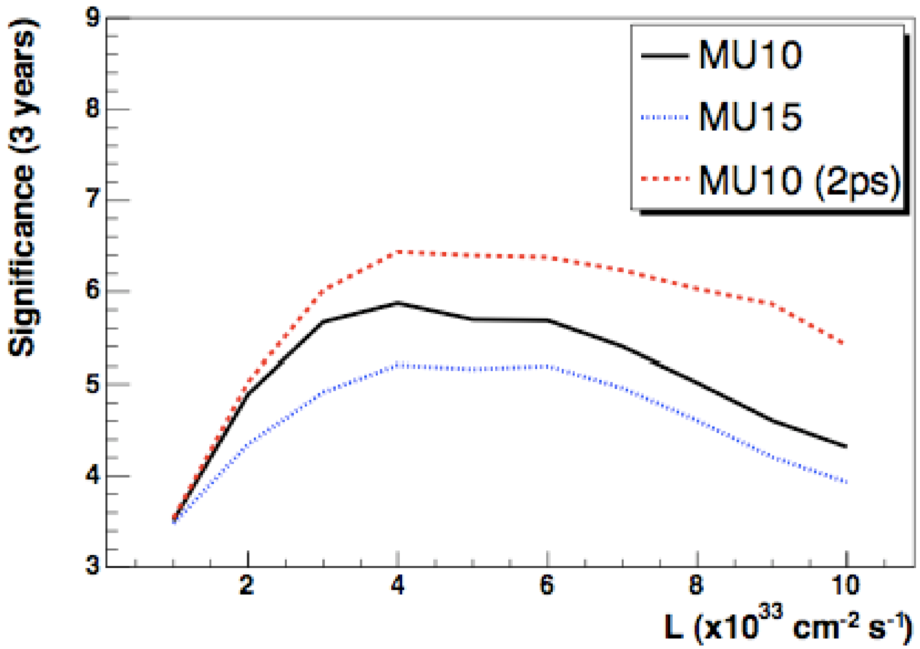
M_H = 120 GeV : 5 signal in 300 fb^{-1}

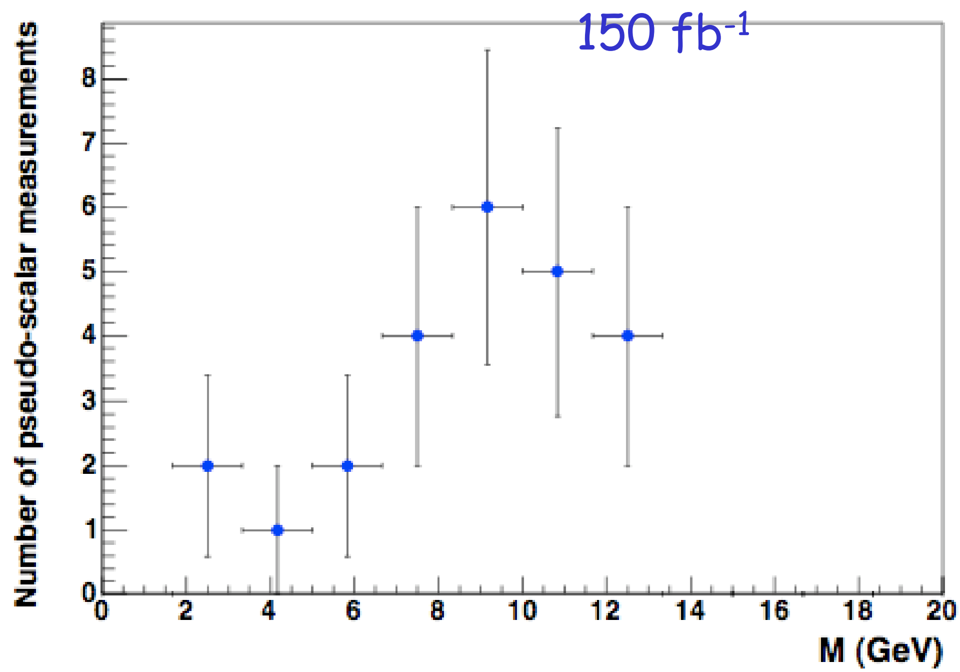
with fast simulation for detector

- In certain MSSM space the signal rate goes up by a factor 4
- The WW* (ZZ*) channel has no: no trigger problems, better mass resolution at higher masses (even in leptonic / semi-leptonic channel)

$h \to aa \to \tau\tau\tau\tau$

Low mass higgs in NMSSM: If $m_a < m_B$ difficult (impossible) at standard LHC
J. Gunion: FP420 may be the only way to see it at the LHC

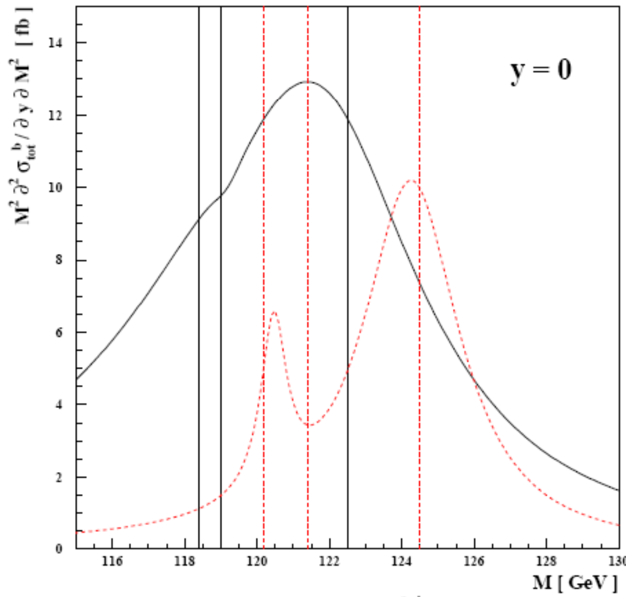




“lineshape analysis”

J. Ellis et al.
hep-ph/0502251

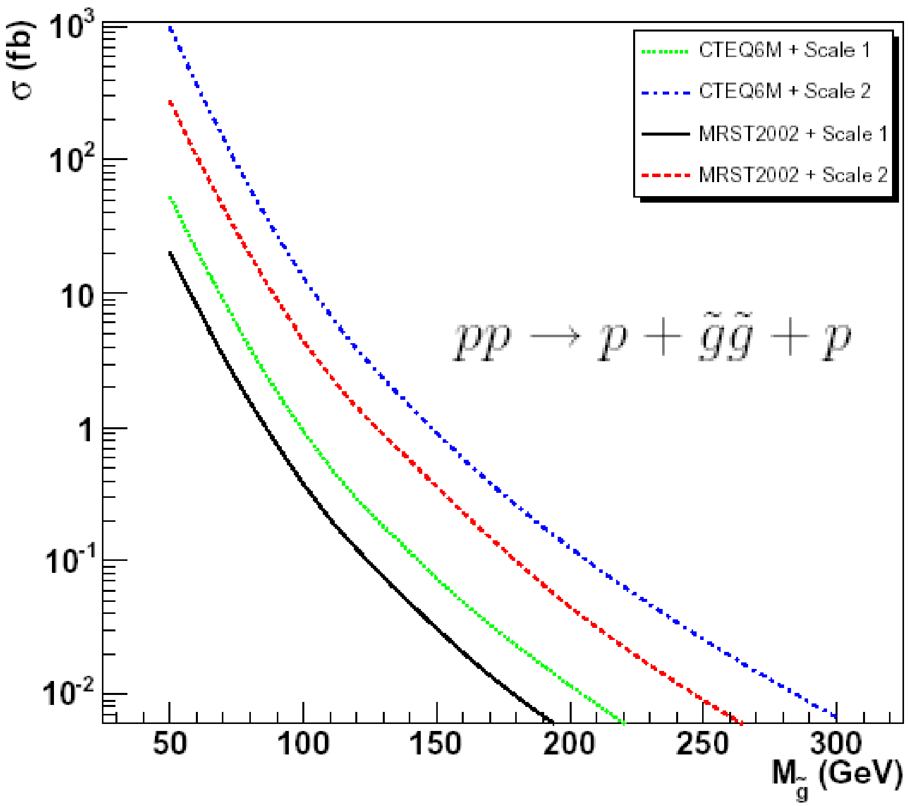
Scenario with CP violation in the Higgs sector and tri-mixing



This scenario needs a mass resolution of about 1 GeV and 100 fb-1

This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

Long Lived gluinos at the LHC



P. Bussey et al
hep-ph/0607264

$m_{\tilde{g}}$ (GeV)	$\sigma_{m_{\tilde{g}}}$ (GeV)	$\frac{\sigma_{m_{\tilde{g}}}}{\sqrt{N-1}}$ (GeV)	N
200	2.31	0.19	145
250	2.97	0.50	35.0
300	3.50	1.10	10.2
320	3.61	1.54	6.5
350	3.87	2.45	3.5

Gluino mass resolution with 300 fb^{-1} using forward detectors and muon system

The event numbers includes acceptance in the FP420 detectors and central detector, trigger…

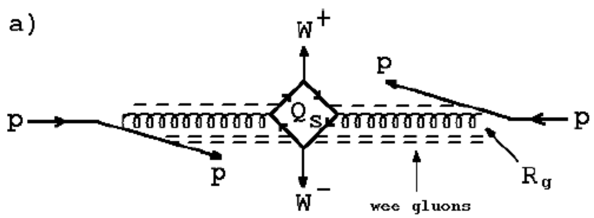
Measure the gluino mass with a precision (much) better than 1%

Exotics Anomalous WW Production?

Alan White: theory of supercritical pomeron→ reggeized gluon+many (infinite) wee gluons

- color sextet quarks required by asymptotic freedom, have strong colour charge, (at least) few 100 GeV constituent mass
- Sextet mesons → EWSB
- UDD neutron dark matter candidate
- Explain high energy cosmic rays, Knee?
- Color sextet quarks couple strongly to W and Z and to the pomeron
- Phenomenology: Anomalous production of WW when above threshold ie. At the LHC (with possibly some onset already detectable at the Tevatron

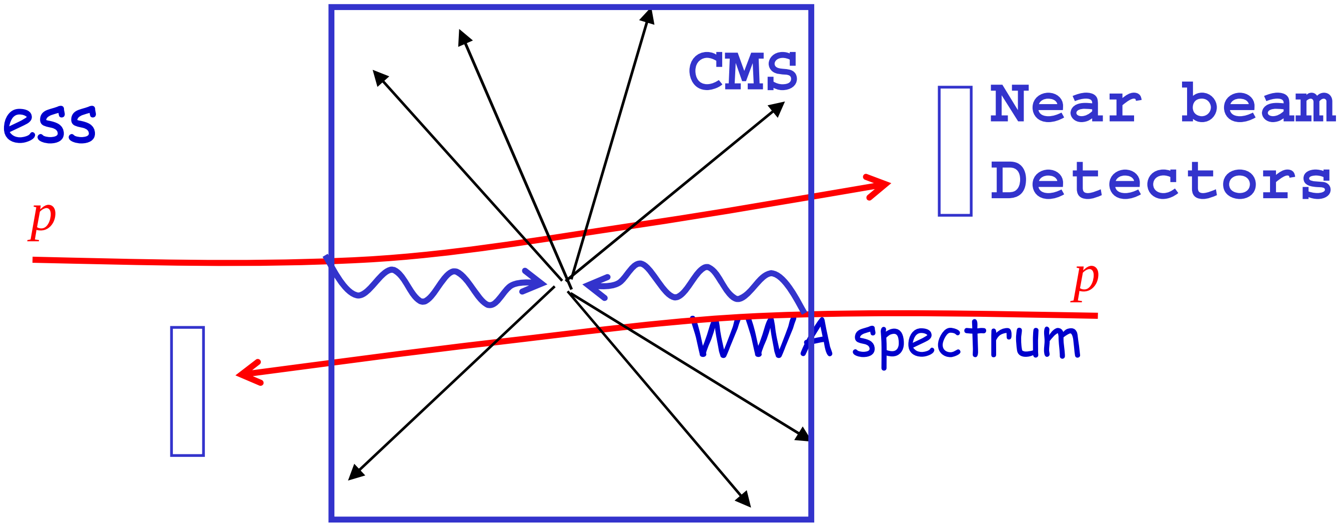
color triplets			color sextets
u	c	t	U
d	s	b	D



⇒Measure exclusive WW,ZZ cross sections in DPE at the LHC
Expected cross section to be orders of magnitude larger than in SM

Photon-photon and photon-proton @ LHC

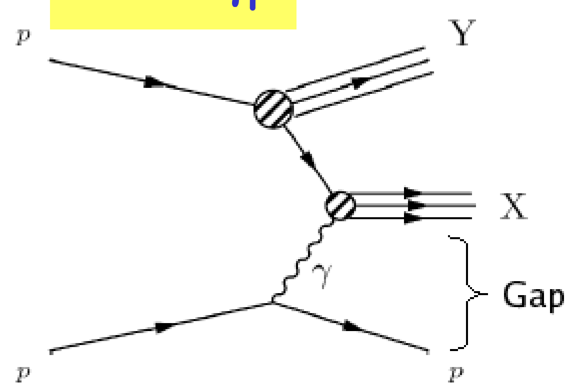
Process



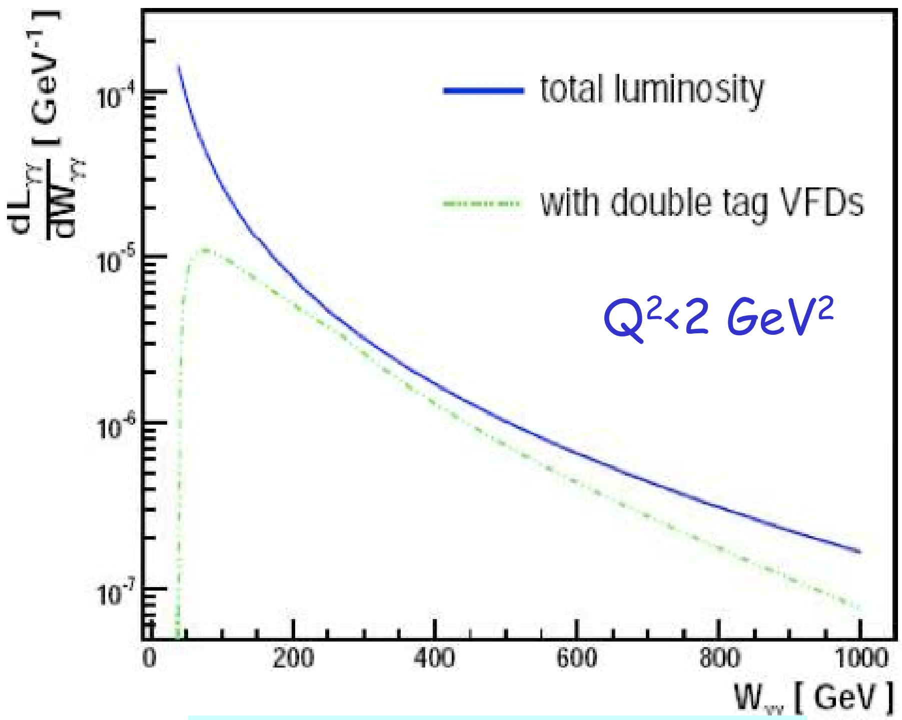
Extensive Program

- $\gamma\gamma \rightarrow \mu\mu$, ee QED processes
- $\gamma\gamma \rightarrow$ QCD (jets..)
- $\gamma\gamma \rightarrow$ ZZ/WW anomalous couplings
- $\gamma\gamma \rightarrow$ top pairs
- $\gamma\gamma \rightarrow$ Higgs
- $\gamma\gamma \rightarrow$ Charginos
- …

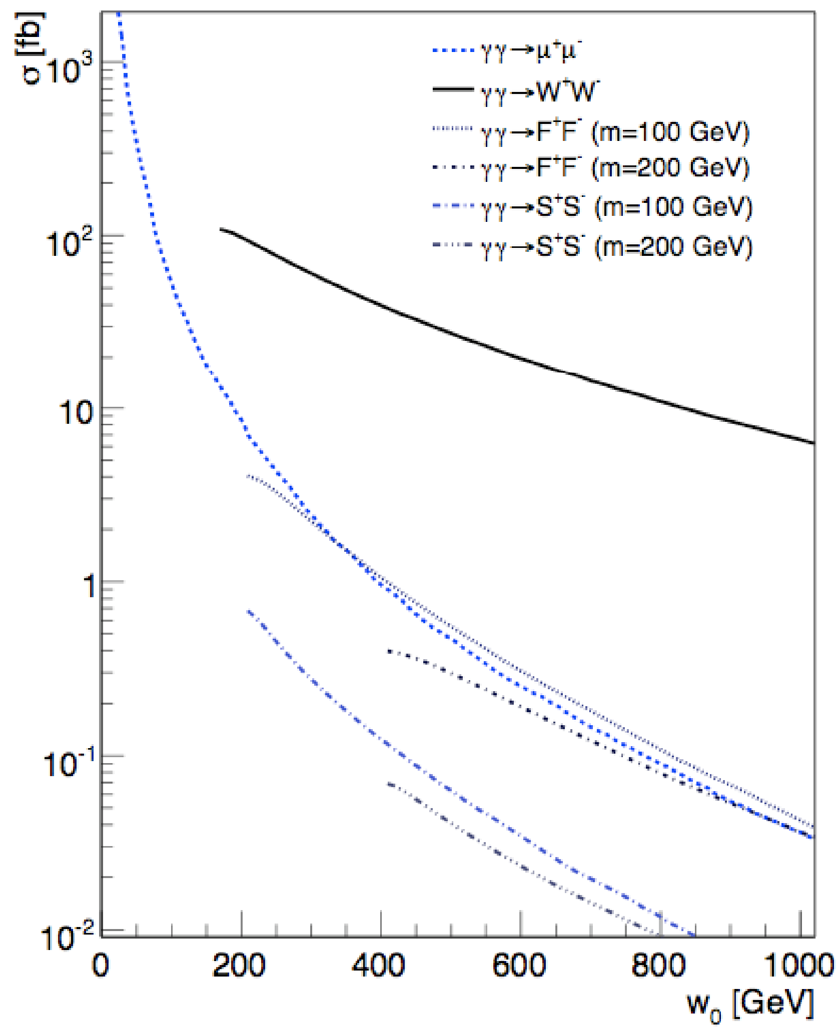
…and γp



Two photon processes



Relative elastic luminosity
for 20 GeV <Eγ < 900 GeV



WW Quartic Anomalous Couplings

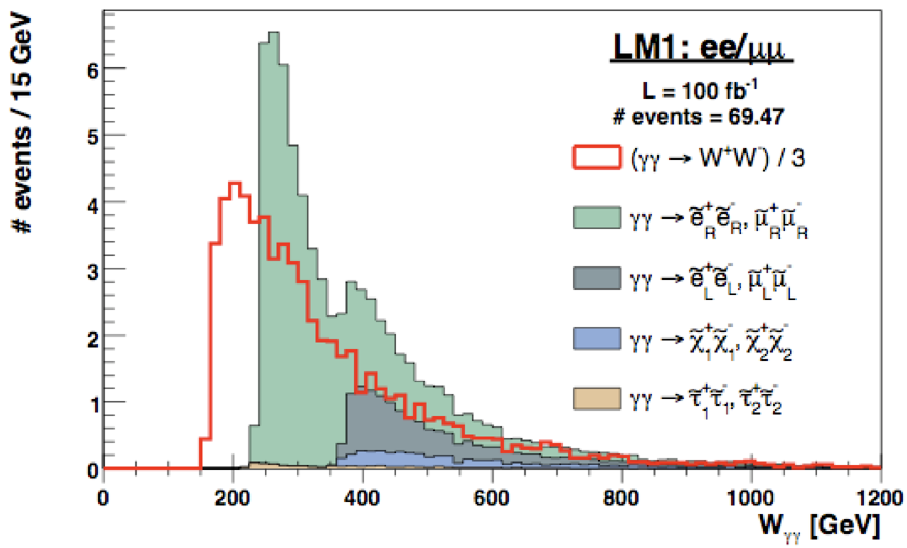
$$\langle W_{\gamma\gamma\to WW}\rangle \approx 500 \text{ GeV.}$$

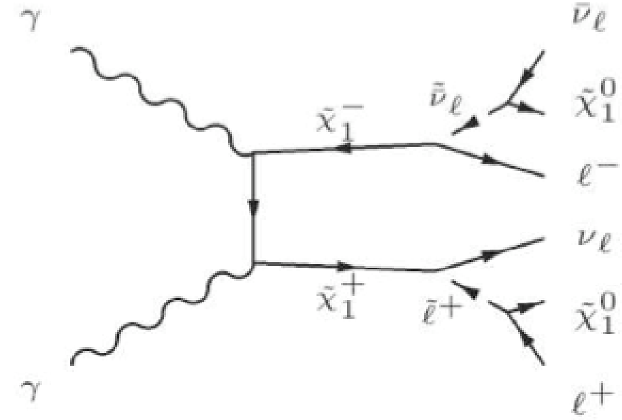
$\sigma^{\rm up}$ [fb]	$\gamma\gamma \to W^+W^-$ $\sigma^{\rm SM}_{\rm acc} = 4.081$ fb	$\gamma\gamma \to ZZ$ $\mathrm{N_{obs}} = 0, \lambda^{\rm up} = 2.996$
$\int \mathcal{L} = 1\ \mathrm{fb}^{-1}$	9.2	3.0
$\int \mathcal{L} = 10\ \mathrm{fb}^{-1}$	5.3	0.30

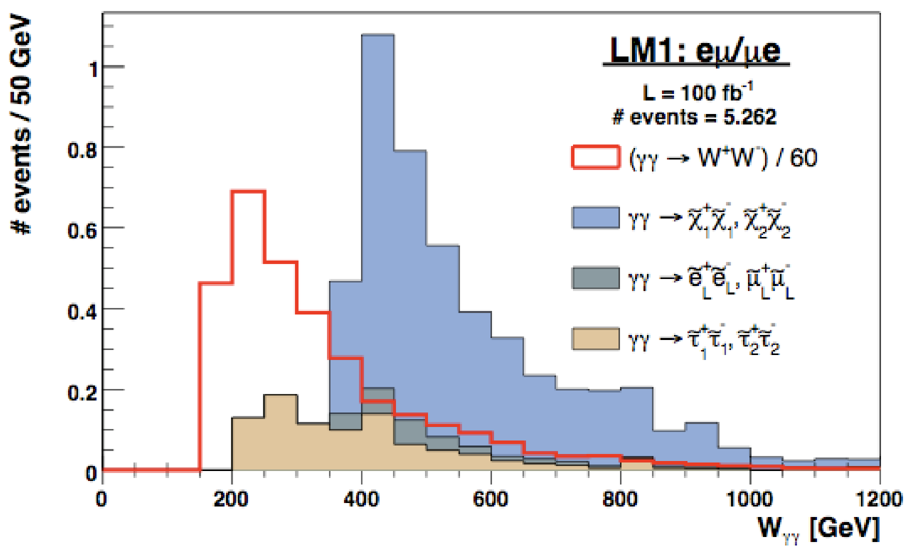
Coupling limits [10^{-6} GeV^{-2}]	$\int \mathcal{L} = 1\ \mathrm{fb}^{-1}$	$\int \mathcal{L} = 10\ \mathrm{fb}^{-1}$
$\|a_0^Z/\Lambda^2\|$	0.49	0.16
$\|a_C^Z/\Lambda^2\|$	1.84	0.58
$\|a_0^W/\Lambda^2\|$	0.54	0.27
$\|a_C^W/\Lambda^2\|$	2.02	0.99

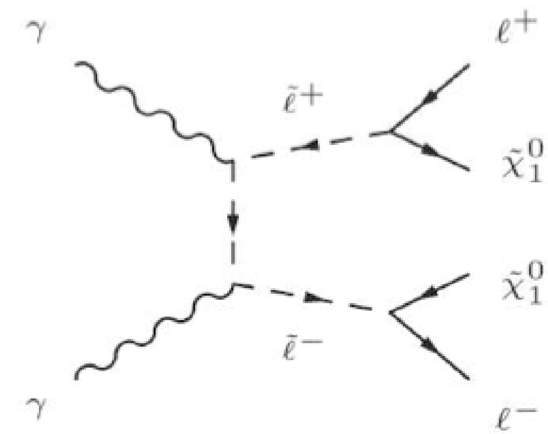
10000 better than the best established LEP limits

Supersymmetric Particles

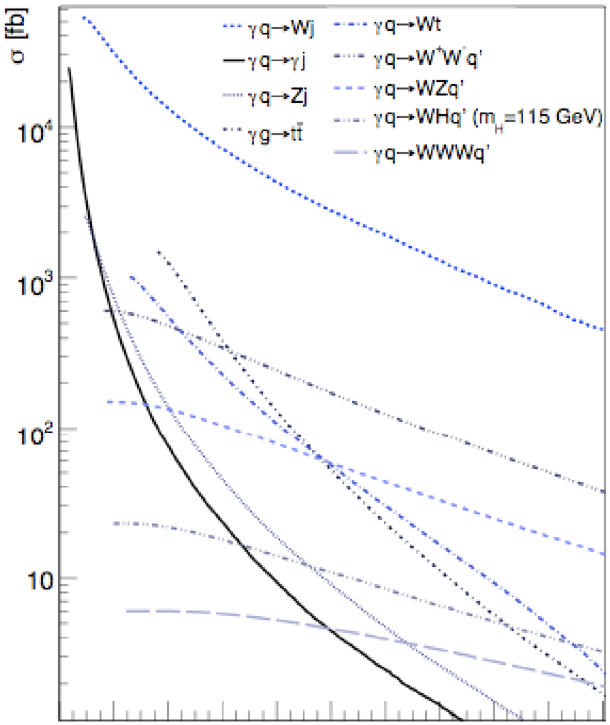


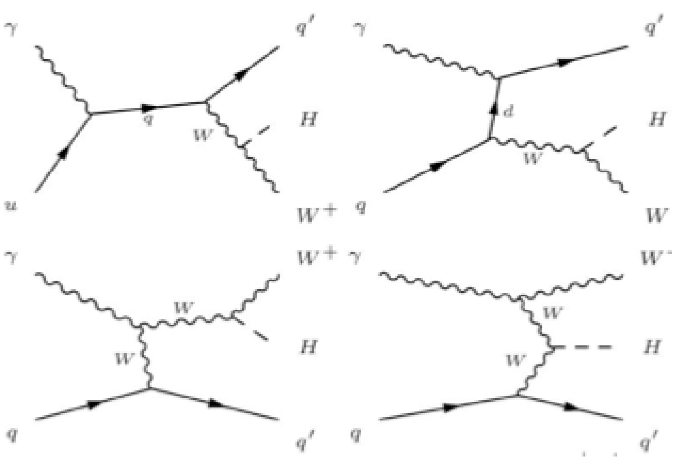






Photon-Proton Processes





Associated WH production

Topology	$\ell b\bar{b}$	$jj\ell^+\ell^-$	$jj\ell\tau_h$	$\ell\ell\ell$	$jj\ell^\pm\ell^\pm$
	m_H = 115 GeV/c^2			m_H =170 GeV/c^2	
σ WHq'	5.4	0.14	0.52	0.55	1.2
σ_{acc}	0.12	0.01	0.03	0.07	0.22
Irreducible processes					
σ_{acc} Wt	1.1	4.2	1.0	-	-
$t\bar{t}$	2.3	24.	6.1	-	-
$Wb\bar{b}q'$	0.20	-	-	-	-
$W\ell\ell q'$	-	0.40	0.07	0.25	0.11
WZq'	-	1.4	0.11	0.98	0.06
$WWWq'$	-	0.11	0.06	0.03	0.10
σ_{acc} total	3.7	30.	7.3	1.3	0.27

Anomalous top production

Coupling limits	$\int\mathcal{L} = 1$ fb^{-1}	$\int\mathcal{L} = 10$ fb^{-1}
$k_{tu\gamma}$	0.043	0.024
$k_{tc\gamma}$	0.074	0.042

Table 9: Expected limits for anomalous couplings at 95% CL.

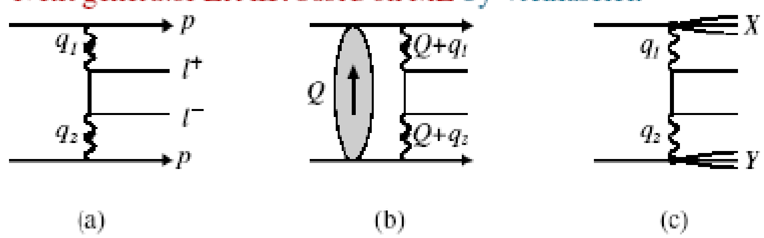
QED Processes for Alignment

Exclusive lepton pairs

Done at HERA, done at Tevatron!

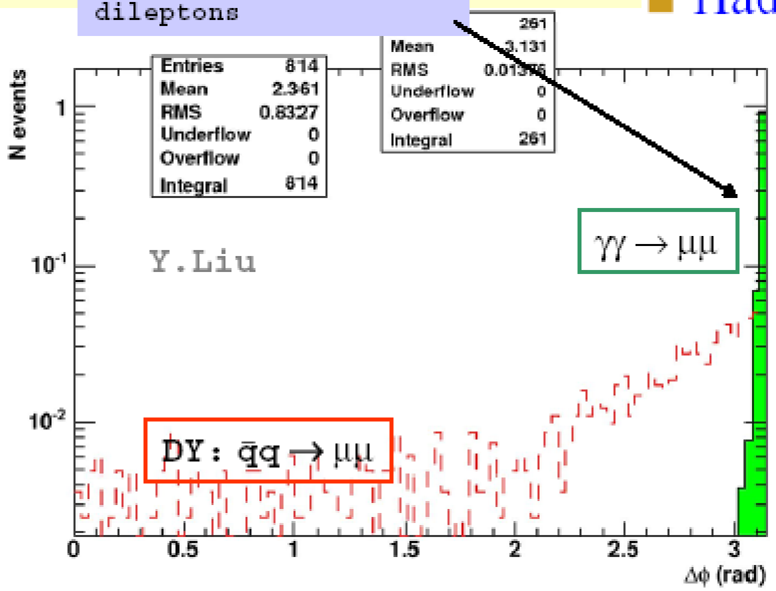
- QED process (a) production σ precisely known

event generator LPAIR based on ME by Vermaseren



- Hadronic corrections [(b) (c)] small.

Key signature: Acoplanarity angle for dileptons



Calibration process both for luminosity and energy scales, has striking signatures and can be well triggered and reconstructed by central detectors alone

Observed CMS cross-section for di-muons is about 3 pb

FP420

CERN-LHCC-2005-025
LHCC-I-015
FP420 : An R&D Proposal to Investigate the Feasibility of Installing Proton Tagging Detectors in the 420m Region at LHC

- Spokespersons : Brian Cox (Manchester, ATLAS) and Albert DeRoeck (CERN,CMS)
- Technical Co-ordinator : Cinzia DaVia (Manchester)

Collaboration : FNAL, The University of Manchester, University of Eastern Piedmont, Novara and INFN-Turin, The Cockcroft Institute, University of Antwerpen, University of Texas at Arlington, The University of Glasgow, University of Calabria and INFN-Cosenza, CERN, Lawrence Livermore National Laboratory, University of Turin and INFN-Turin, University of Lund, Rutherford Appleton Laboratory, Molecular Biology Consortium, Institute for Particle Physics Phenomenology, Durham University, DESY, Helsinki Institute of Physics and University of Helsinki, UC Louvain, University of Hawaii, LAL Orsay, University of Alberta, Stony Brook University, Boston University, University of Nebraska, Institute of Physics, Academy of Sciences of the Czech Republic, Brookhaven National Laboratory, University College London, Cambridge University

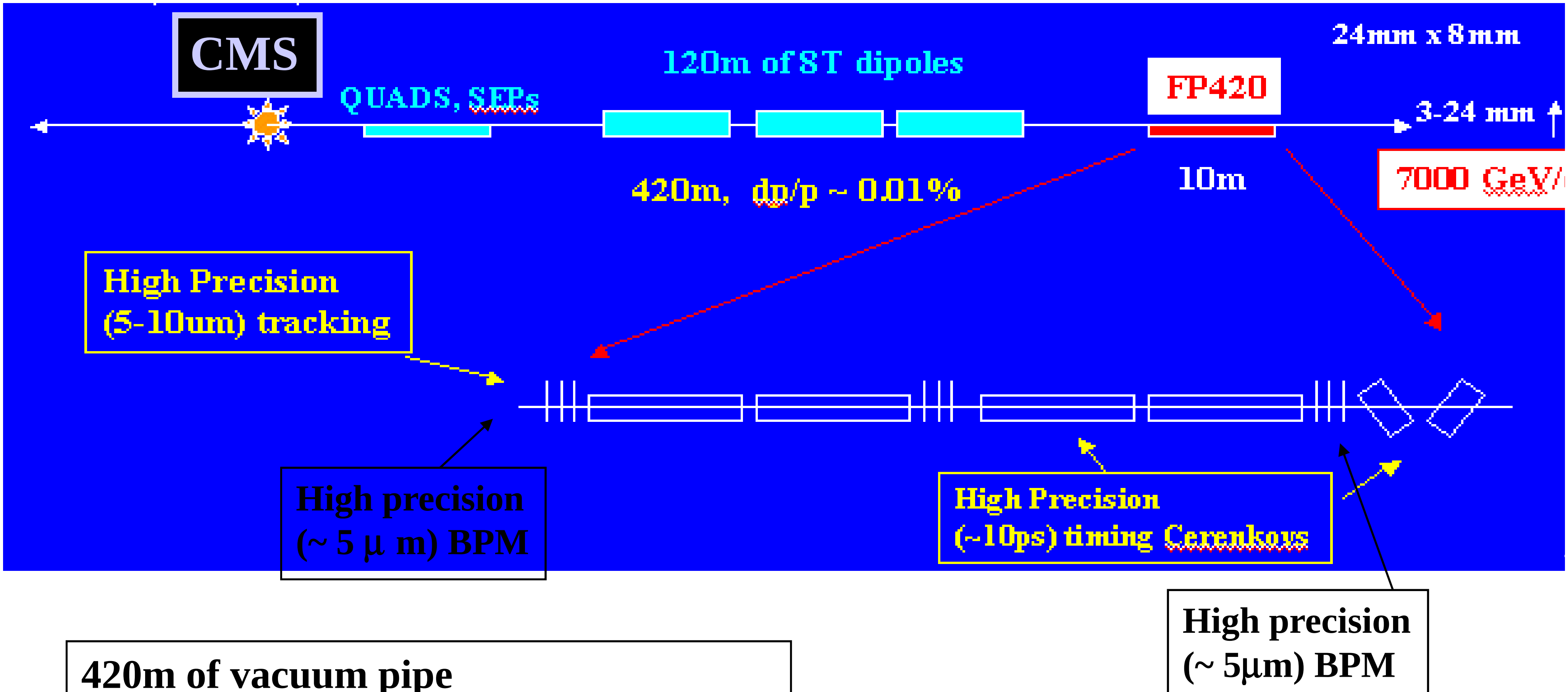
Status 2006

FP420 R&D Funding (ATLAS & CMS) → R&D document:

"The panel believed that this offers a unique opportunity to extend the potential of the LHC and has the potential to give a high scientific return." - UK PPRP (PPARC)

R&D funding : £500k from UK (Silicon, detector stations, beam pipe + LHC optics and cryostat design), $100k from US (QUARTIC, Andrew Brandt/UTA), €100k Belgium (+Italy / Finland) (mechanics)

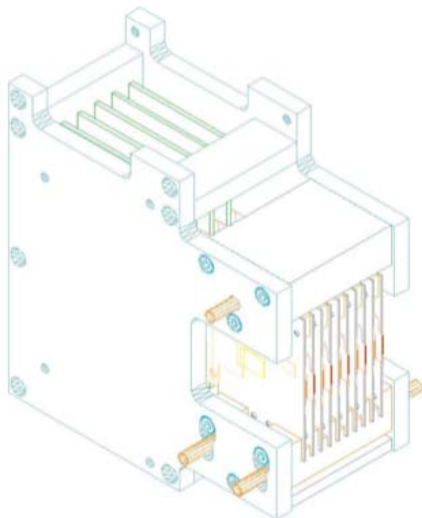
Schematic of Extremely High Precision Proton Spectrometer

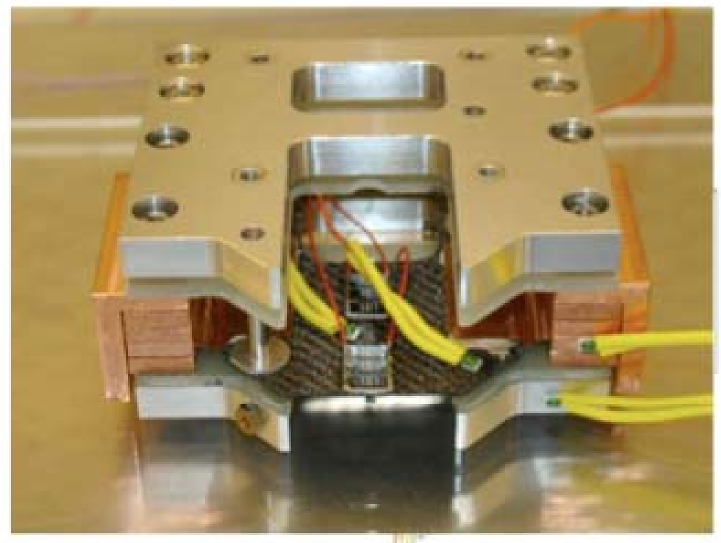


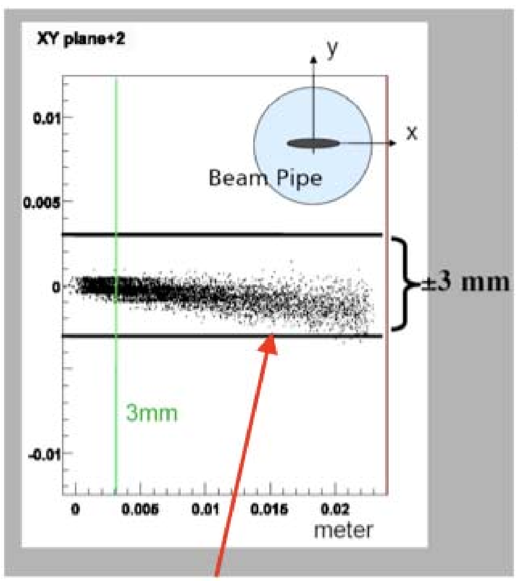
420m of vacuum pipe
120m of 8T dipoles
Precision ~ 5 μ m on track displacement
and ~ 1 μ rad on angle w.r.t. beam.

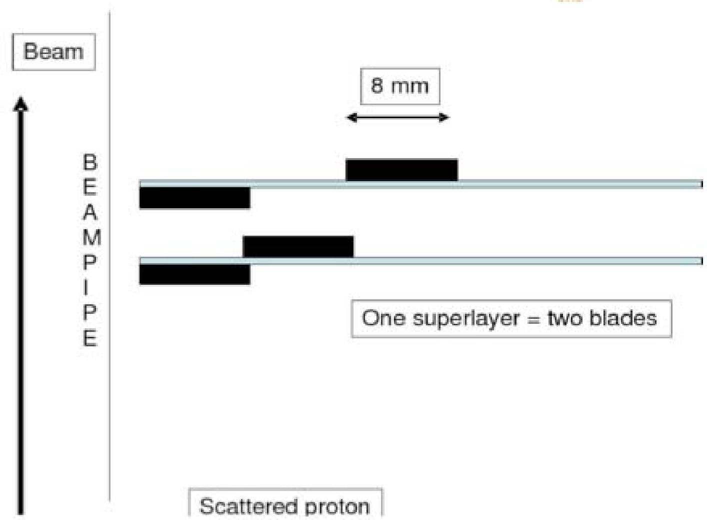
Layout schematic ...
Still being optimized

Silicon tracker mechanical design







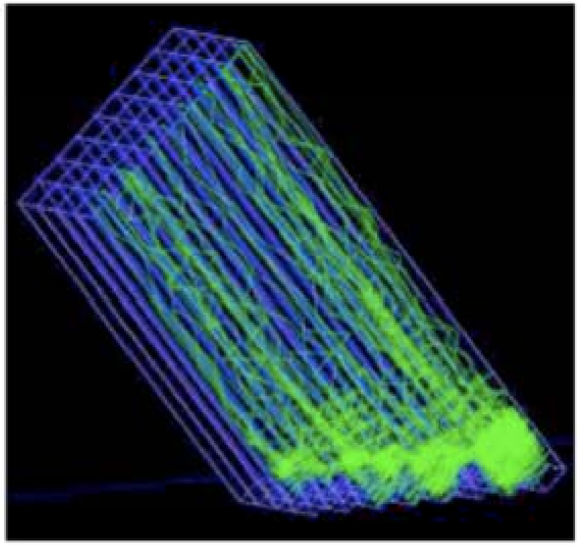


7.2 mm x 24mm (7.2 x 8 mm^2 sensors)

Bump-bonded onto ATLAS pixel readout

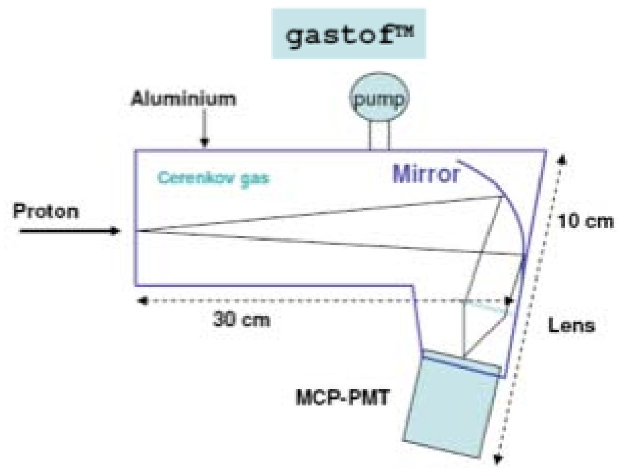
Fast Timing System

Quartic (FNAL, Alberta, UTA)



More than 50% of the photons arrive within the first 5 ps.

GASTOF (Louvain)



all the photons arrive within ≈ 3 ps

Burle 85011-501 with 25 μm pores

Hamamatsu R3809U-50 with 6 μm pores

Test beam FNAL March 2007:

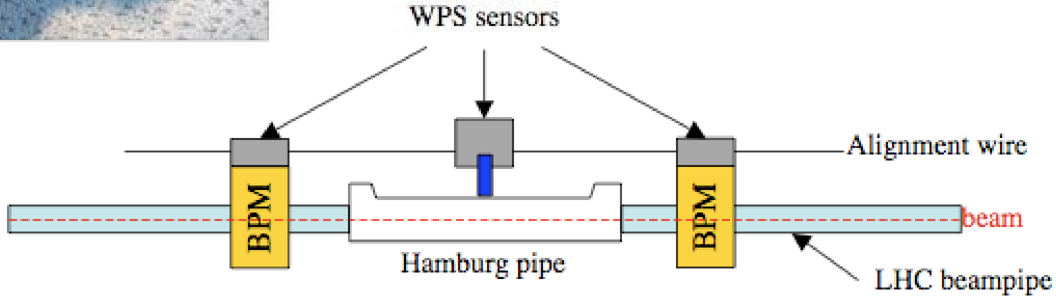
δt (G1) = 32ps

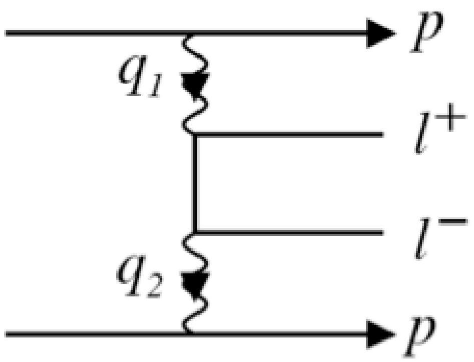
δt (G1) = 13ps

δt (Quartic) = 82ps / bar - 13 measurements / detector -> 23ps

FP420 Allignment

CLIC BPMs + wire positioning system : aim for 10 microns relative to beam





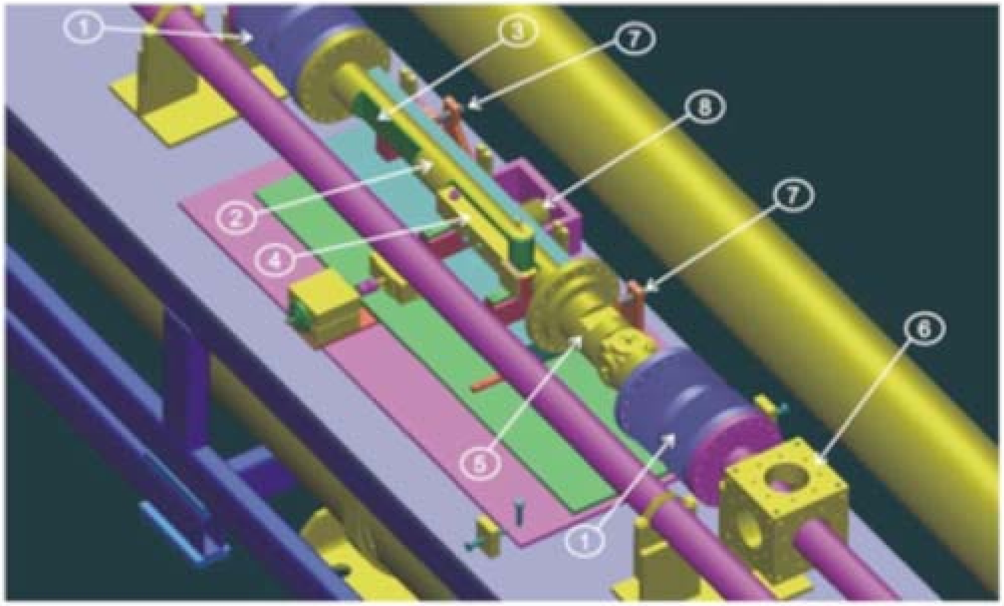
@ 10^{33} $cm^{-2}s^{-1}$ with standard ATLAS triggers, have ~ 30 di-muon events / fill in FP420 acceptance (σ ~ 7pb)

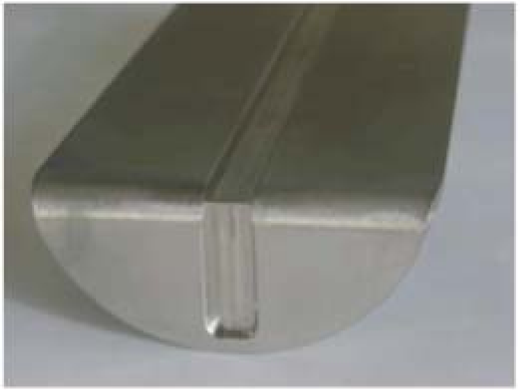
Thanks to Lars Soby, Rhodri Jones, Helene Mainaud-Durand, Andreas Herty and Robert Boudot

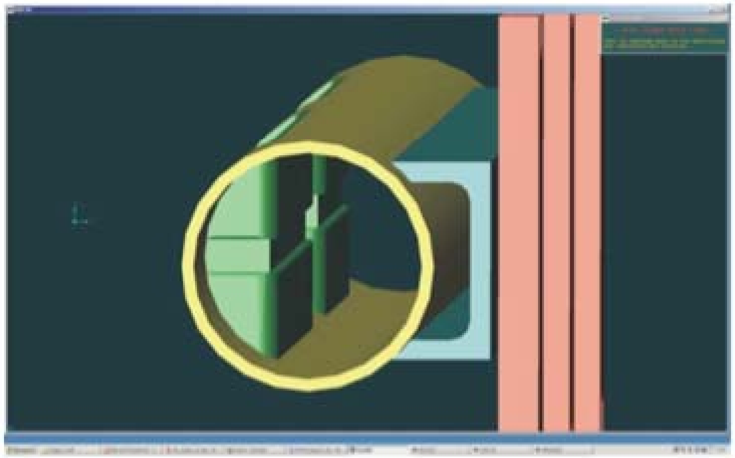
FP420 Detector System

1824

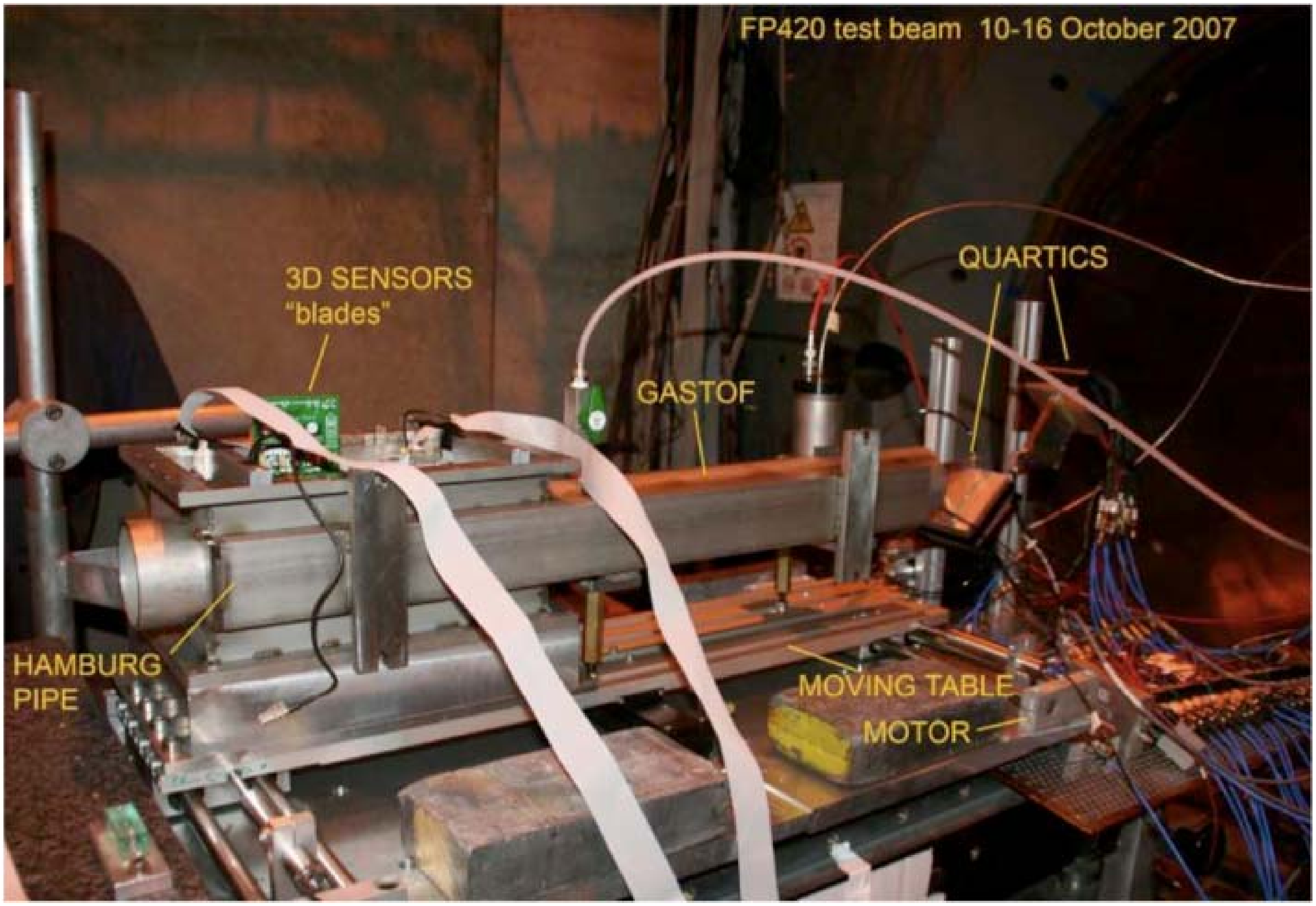
The FP420 detector system







October Testbeam at CERN



Summary

- Near beam detectors at 420m will extend the physics potential of the central detector CMS.
  - Main physics aim pp $\rightarrow$ p+ X + p
    - Higgs, in particular iMSSM, New physics, Exotic physics
    - QCD/diffractive studies
      - dijets, WW, 2 photon production measurements etc.
    - Photon induced interactions
      - Significant sensitivity to new physics
  - Data taking at 10^{34} $cm^{-2}s^{-1}$ seems feasible
- ATLAS: FP420 part of the 'forward detector package'
- CMS: project being evaluated by internal referees
- FP420 is an excellent 'extension' of the CMS/ATLAS baseline detector. First DPE events in FP420 in 2010?

Backup

• The FP420 R&D report will be published this month.

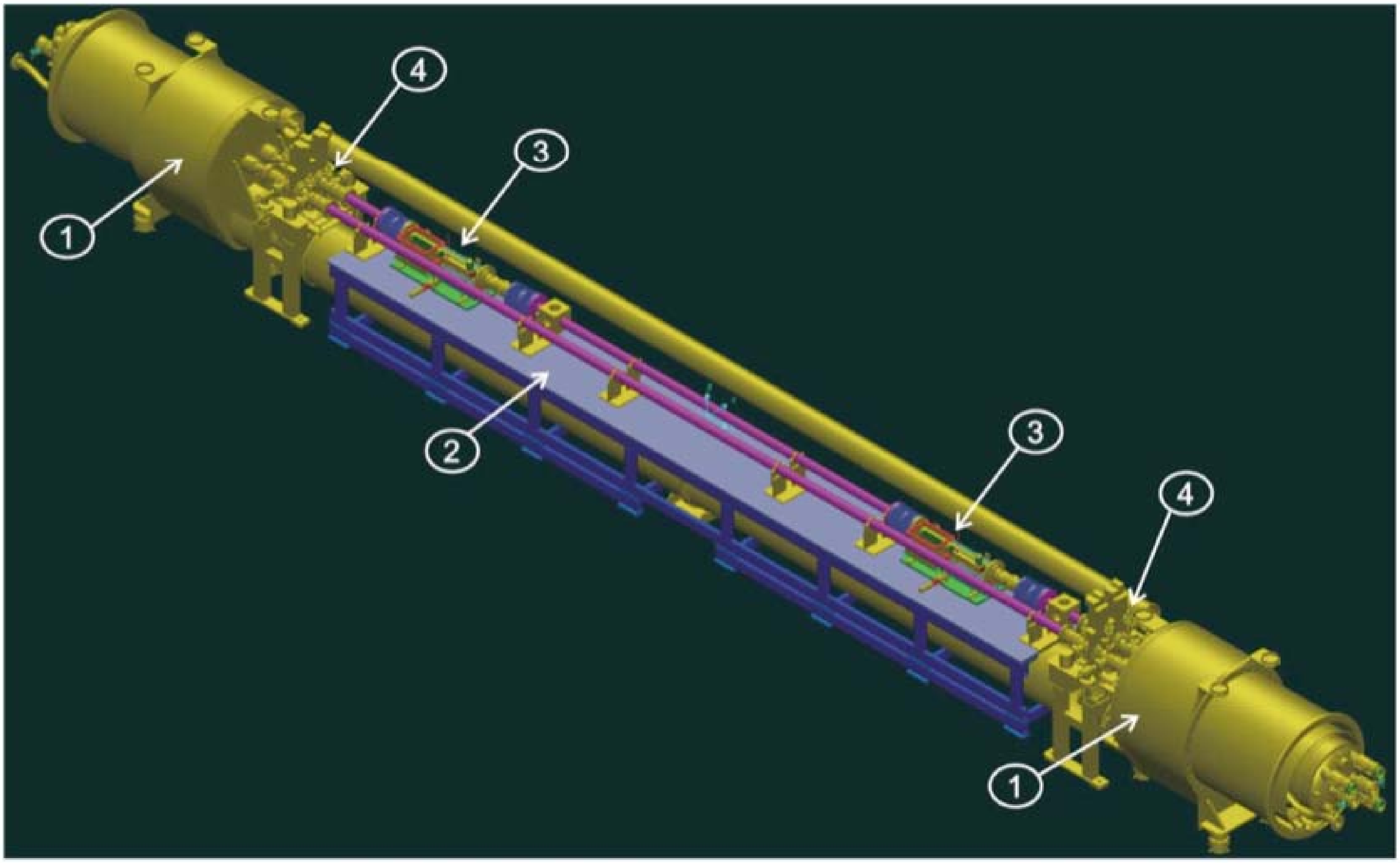
• The R&D phase ends with a complete cryostat design and a prototyped, tested concept for high precision near-beam detectors at LHC

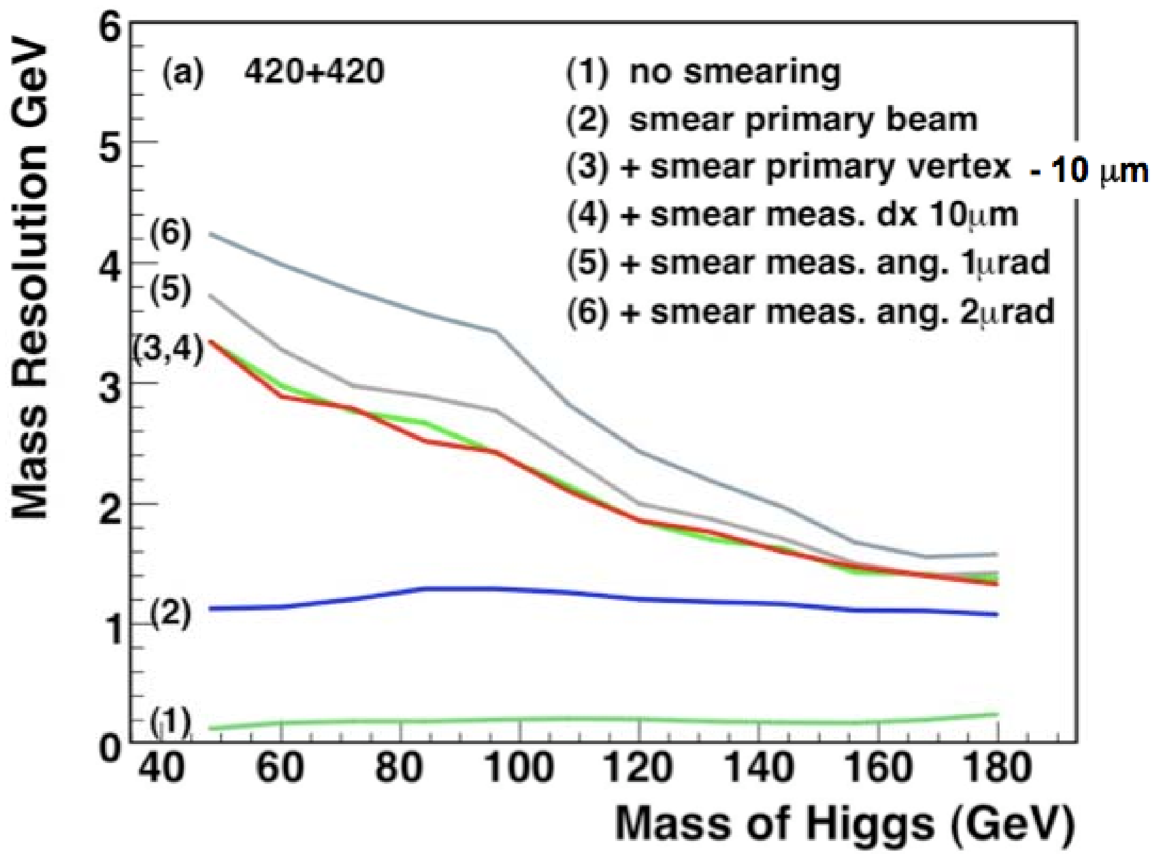
• At ATLAS, ex-FP420 groups will join with current forward physics group (ALFA) and new groups led by Saclay to propose unified upgrade program at 420m and 220m. The FP420 HH pipe will be used in both locations

• CMS is in the process of evaluating the FP420 project, with a decision expected within the next few months

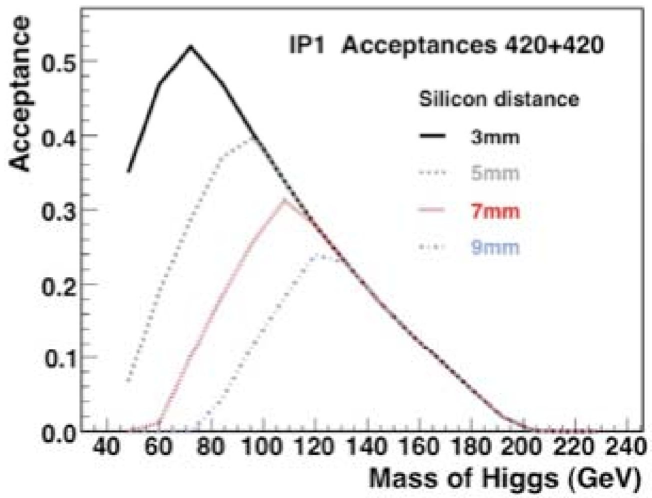
• The physics case for forward proton tagging spans central exclusive production (Higgs mass, quantum numbers, discovery in certain regions of MSSM / NMSSM), $\gamma\gamma$ and γP, diffractive physics, gap survival / underlying event, study of gluon jets …..

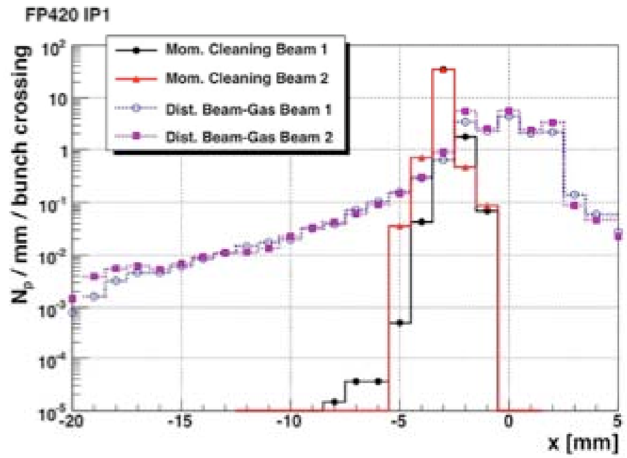
• For low cost, forward proton detectors add significant additional physics potential can be added to the GPDs with no effect on the operation of the LHC. There is a large, experienced community ready to implement them.

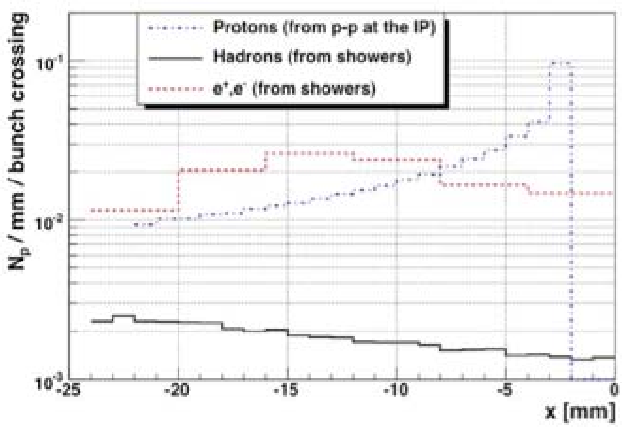

4
3
1
2
3
4
1

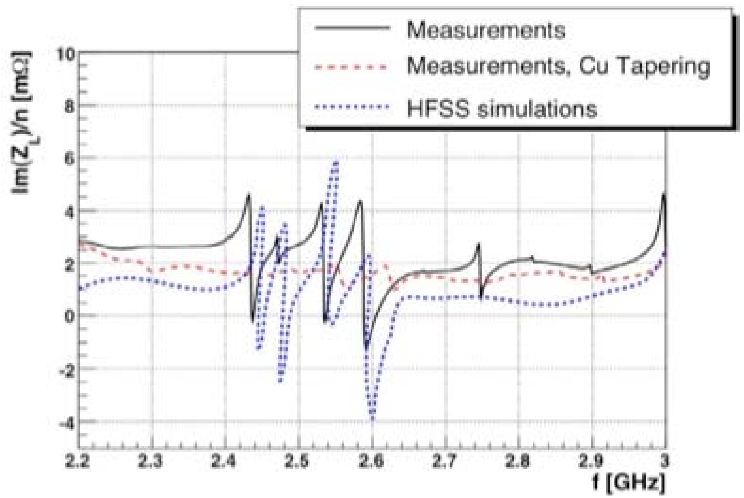

Mass Resolution GeV
(a) 420+420
(1) no smearing
(2) smear primary beam
(3) + smear primary vertex - 10 μm
(4) + smear meas. dx 10μm
(5) + smear meas. ang. 1μrad
(6) + smear meas. ang. 2μrad
(6)
(5)
(3,4)
(2)
(1)
0
1
2
3
4
5
6
40
60
80
100
120
140
160
180
Mass of Higgs (GeV)

How close to the beams?

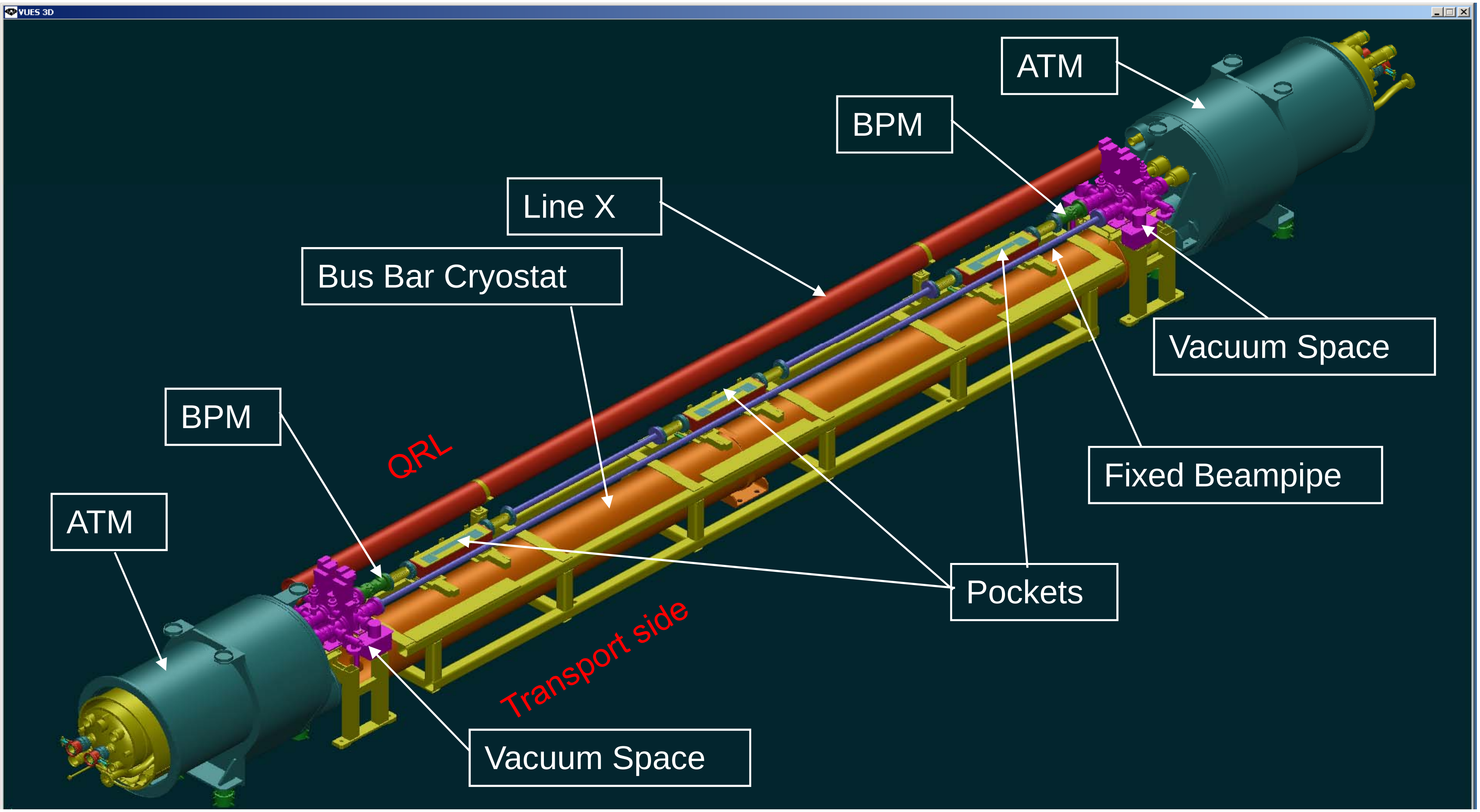




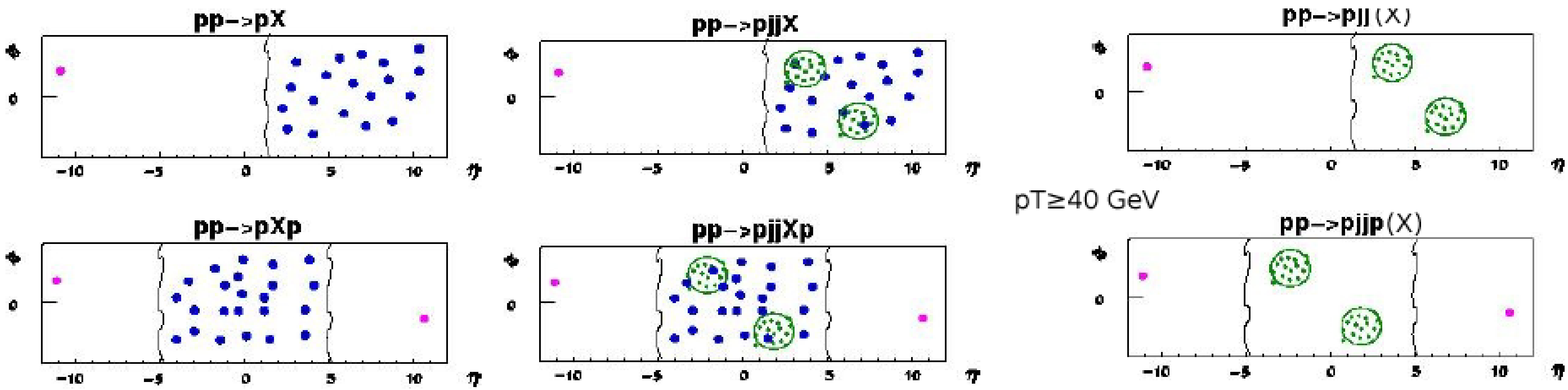




Integration of the moving beampipe and detectors



Running Scenarios



soft diffraction | (semi)-hard diffraction | hard diffraction/exclusive processes

← Cross section — Luminosity →

σ	mb	μb		nb
L ($cm^{-2}\ s^{-1}$)	10^{28}	10^{30}	10^{32}	10^{34}
β (m)	1540	90	2	0.5
	TOTEM runs		Standard runs	

The accessible physics depends on : luminosity

β (different proton acceptance)*

Simulated measurement MSSM h -> bb (see **JHEP 0710:090,2007** for more details)