The Pomeron as little helper in tracking down the Higgs ? - Forward Physics at the LHC: The FP420 project

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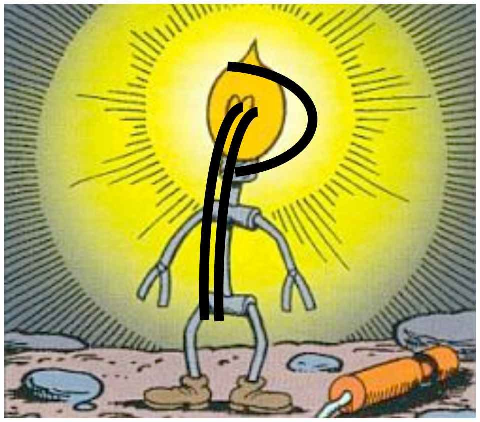
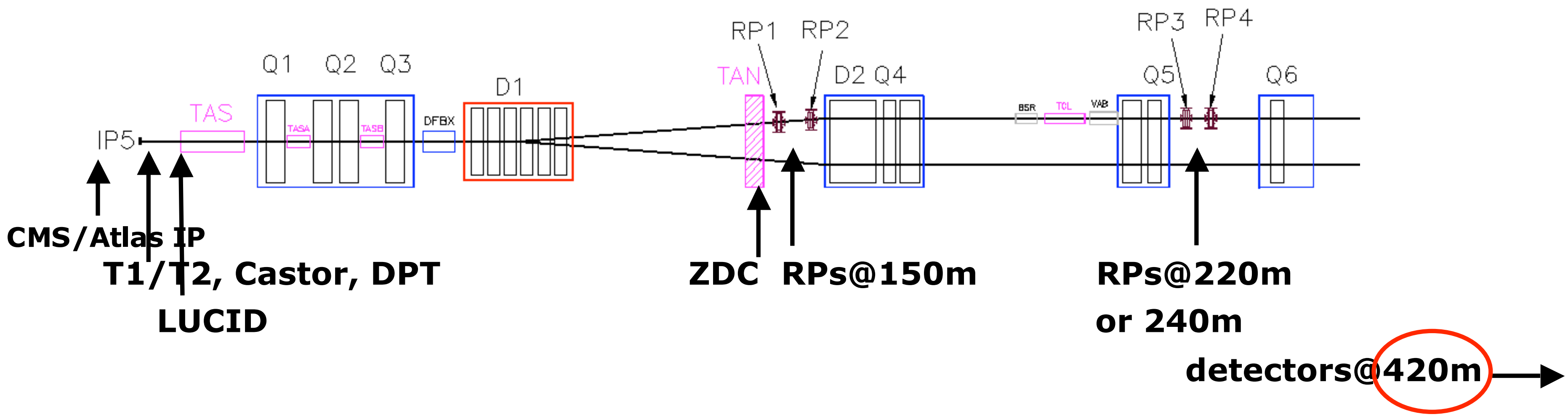
Zurich Jan 2006

What is FP420 ?
The physics case for FP420
Technical aspects of FP420
Status and timeline



Forward detectors at the LHC



CMS detectors along beam line:
Cal with $|\eta| \leq 5$
Castor calorimeter, downstream of T2
Lumi: **Diamond pixel telescope**
Zero-degree calorimeter **ZDC**

Atlas detectors:
Lumi: **LUCID** Cerenkov counters &
Roman pots with Silicon fiber detectors on 2 sides at **240m**
ZDC at **140m**

TOTEM detectors:
T1 (CSC) in CMS endcaps
T2 (GEM) in shielding behind HF
T1 + T2: $3 \leq |\eta| \leq 6.8$
Roman pots with Si detectors on 2 sides at up to **220 m**

Full disclosure:
Speaker has bias towards CMS

What is FP420 ?

An R&D project, in close collaboration with the LHC machine group and acknowledged by the LHCC, to assess the feasibility of integrating off-momentum particle detectors 420 m downstream of a high luminosity collision region (ATLAS and/or CMS)

Ingredients:
- A new connection cryostat
- Warm beam pipes
- Near beam detectors

→ An 8 m long spectrometer with detection down to a few mm from the LHC beam that would be installed as a phase II detector

See **www.fp420.com**

Proposal submitted to LHCC last June

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

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CDF, D0, LHC

Close collaboration with ATLAS and CMS

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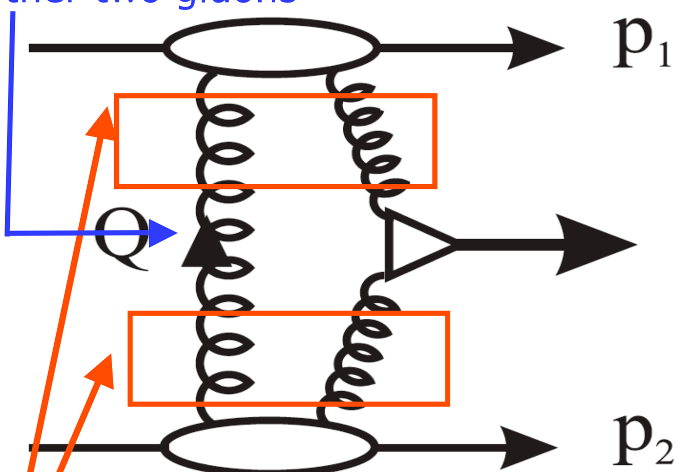
The physics case for FP420

Central exclusive production $pp \rightarrow pXp$

shields color charge of other two gluons



Vacuum quantum numbers
"Double Pomeron exchange"

Selection rules result in the central system being (to good approx) $J^{PC} = 0^{++}$

I.e. a particle produced with proton tags has known quantum numbers

Excellent mass resolution (~GeV) from the protons, independent of the decay products of the central system

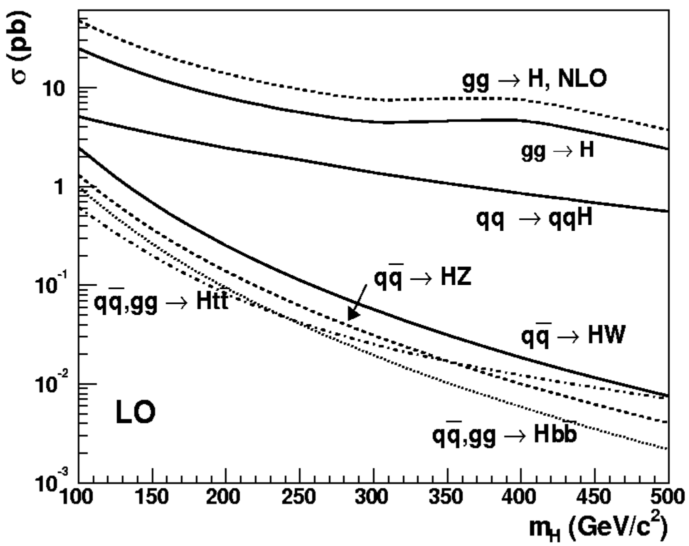
CP violation in the Higgs sector manifests itself as azimuthal asymmetry of the protons

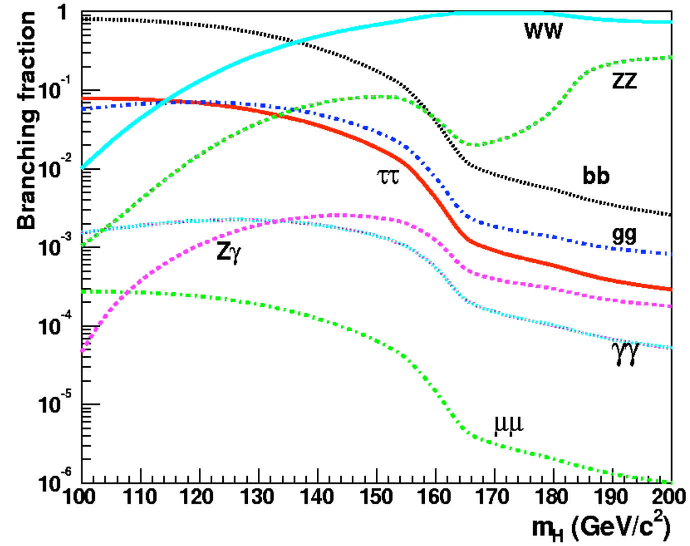
Proton tagging may be the discovery channel in certain regions in the MSSM

"A glue-glue collider where the beam energy of the gluons is known and at which central 0^{++} states are produced."

The physics case for FP420

Detecting a light SM Higgs at the LHC





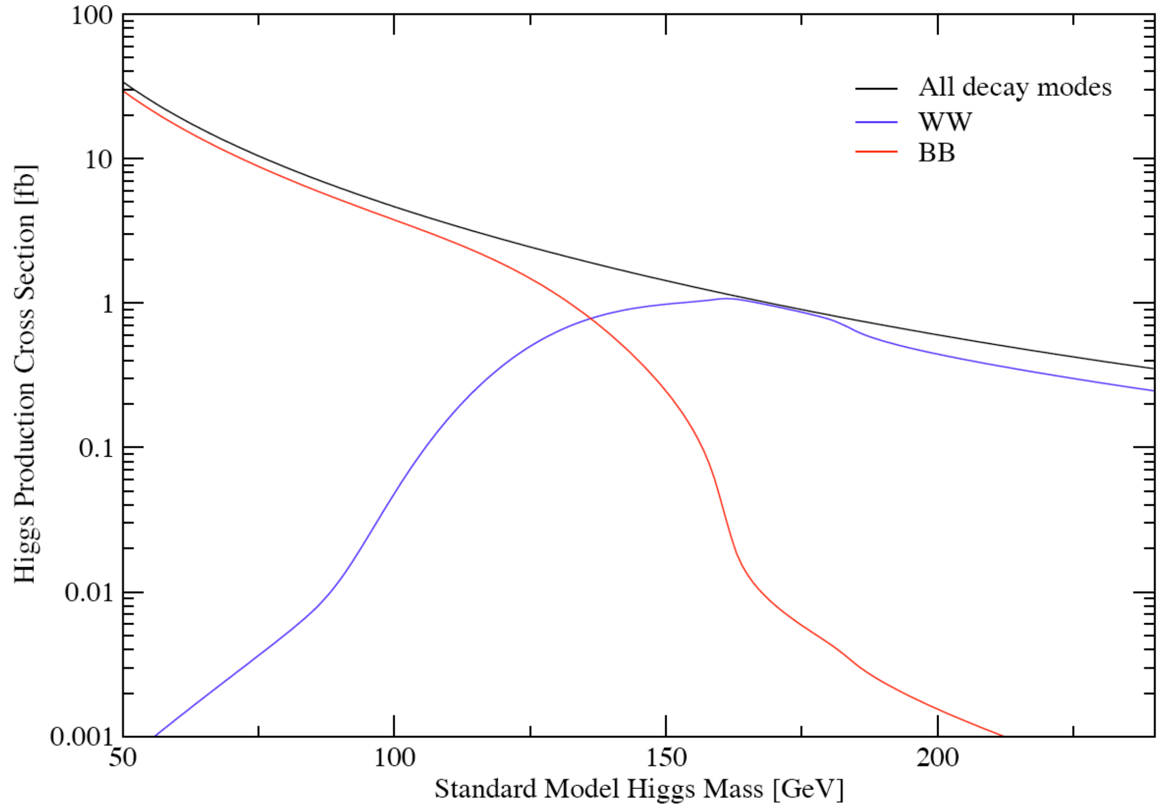
SM Higgs with ~120 GeV:

gg → H, H → b bbar mode has highest BR
But signal swamped by gg → b bbar

Best bet with CMS: H → γγ, where in 30 fb^{-1} $S/\sqrt{B} \approx 4.4$

The physics case for FP420

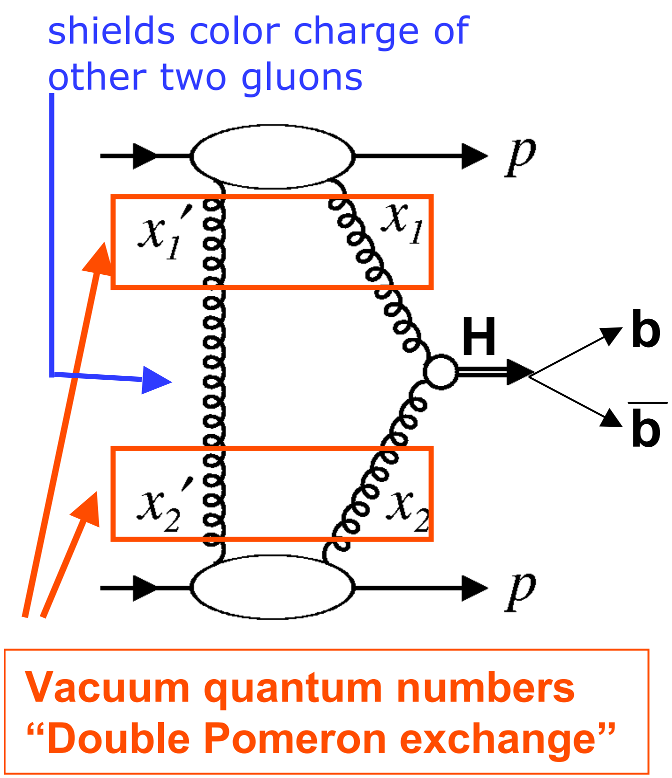
Detecting a light SM Higgs at the LHC (II)



Production cross section times branching ratio for CEP
From implementation of KMR model in Exhume MC

The physics case for FP420

Detecting a light SM Higgs at the LHC (III)



b jets : M_H = 120 GeV s = 2 fb (uncertainty factor ~ 2.5)

M_H = 140 GeV s = 0.7 fb

M_H = 120 GeV : 11 signal / O(10) background in 30 fb^{-1}
with detector cuts : $S/\sqrt{B}$ = 3.5

WW^* : M_H = 120 GeV s = 0.4 fb

M_H = 140 GeV s = 1 fb

M_H = 140 GeV : 8 signal / O(3) background in 30 fb^{-1}
with detector cuts : $S/\sqrt{B}$ = 4.6

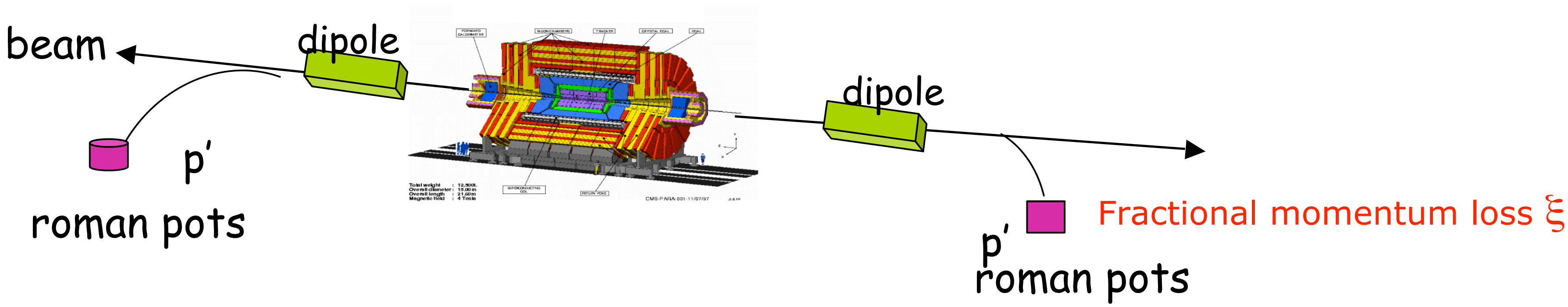
Cross section calculations by Khoze, Martin, Ryskin
(also other models available)

In CEP background reduced dramatically because:

- of excellent mass resolution
- of J_z selection rule: to accuracy $(m_b/E_t)^2$ only $J^{PC} = 0^{++}$ states produced

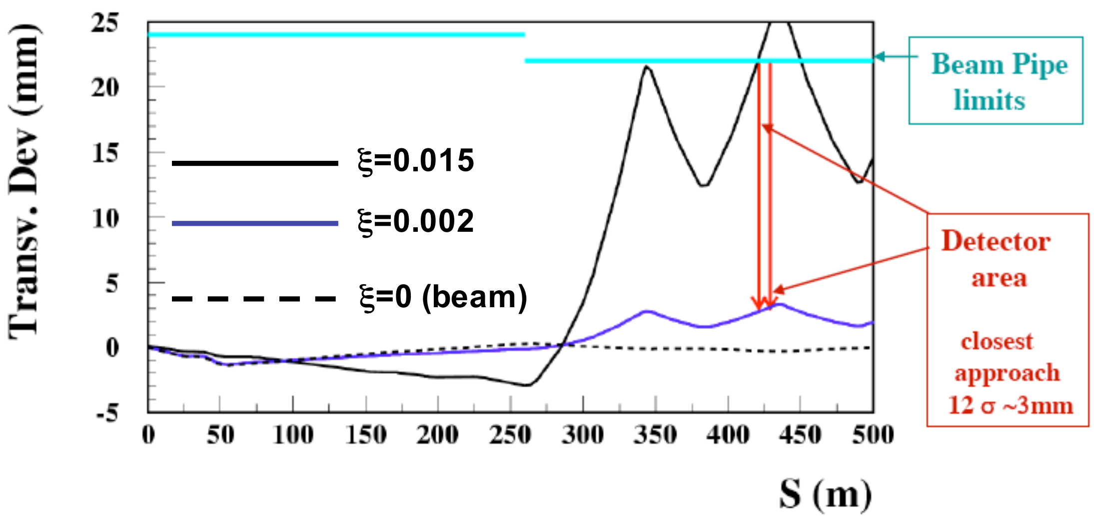
Models can be tested at Tevatron run II (CEP of $\chi_{c,b}$, dijets)

CEP of a light SM Higgs: Necessary ingredients



1) Central apparatus to measure b bbar jets (ATLAS/CMS)
2) 2-arm spectrometer to measure the scattered protons

With nominal LHC optics:

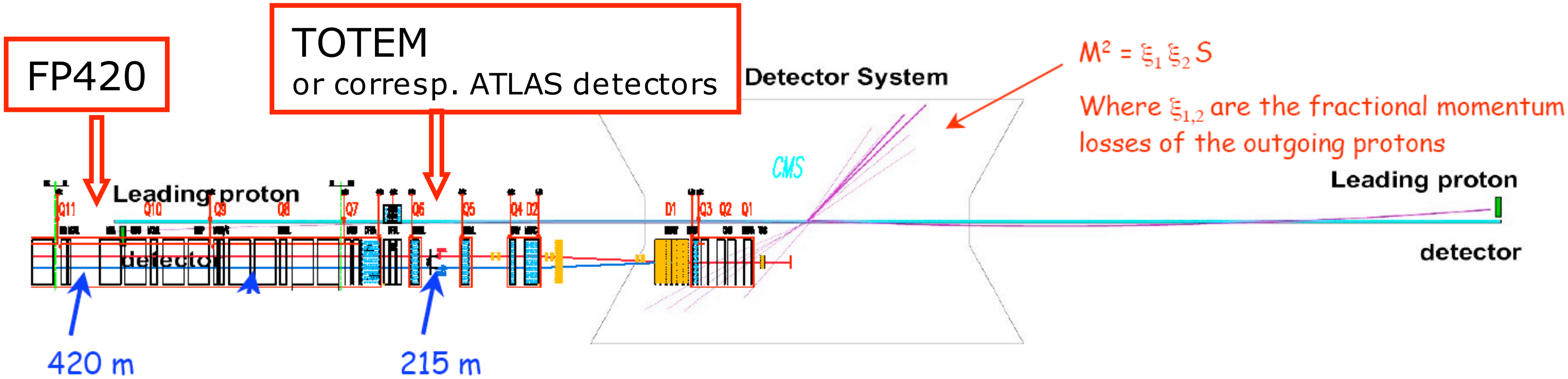


$\xi_1 \xi_2 s = M^2$

With √s=14TeV, M=120GeV on average:

$\xi \approx 0.009 \approx 1\%$

CEP of a light SM Higgs: Necessary ingredients (II)

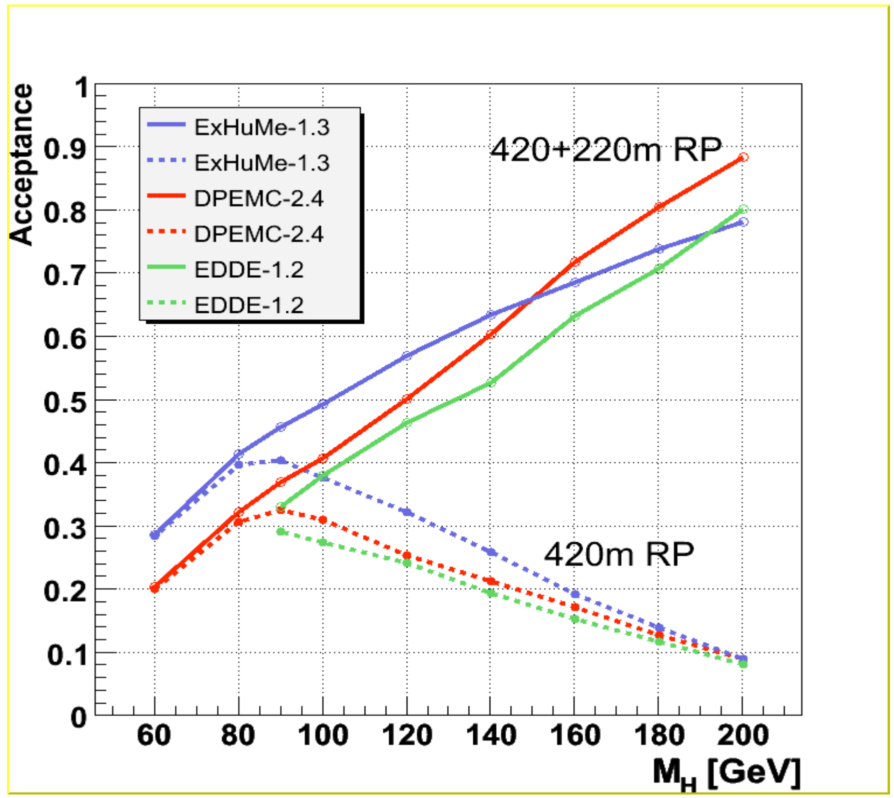


Nominal LHC beam optics

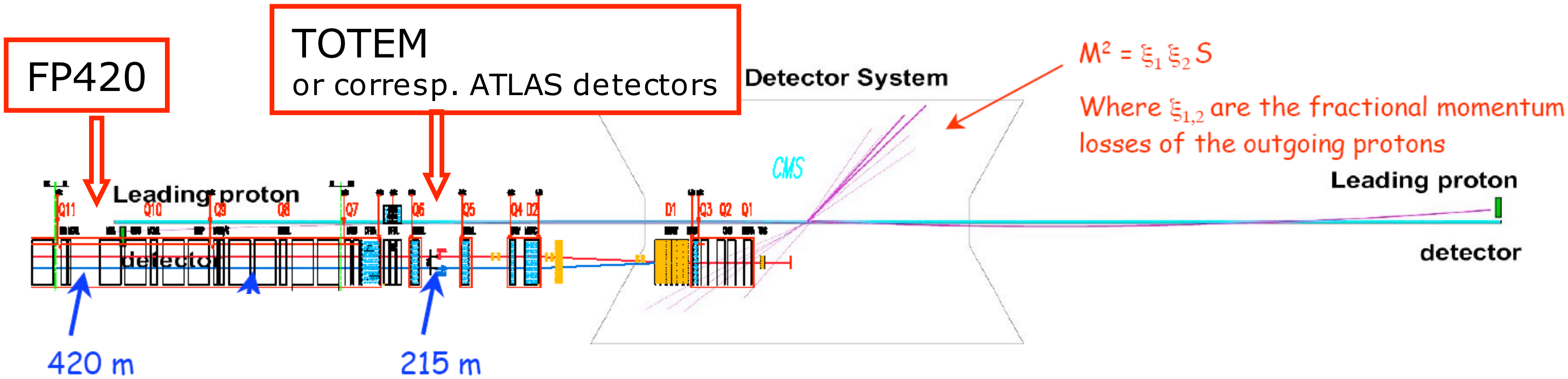
Low β^* (0.5m): Lumi 10^{33}-10^{34} cm^{-2}s^{-1}

TOTEM: $0.02 < \xi < 0.2$

FP420: $0.002 < \xi < 0.02$



CEP of a light SM Higgs: Necessary ingredients (III)



Detectors at 420m

- complement acceptance of 220m detectors
- needed to extend acceptance down to low ξ values, i.e. low M_{Higgs}

Detectors at ~220m

- needed in addition to optimize acceptance (tails of ξ distr.)
- can be TOTEM RP detectors and/or, after upgrade, RP detectors of ATLAS luminosity system

Detectors at 420m - challenging:

- ➢ 420m is in the cold region of the LHC
- ➢ 420m is too late for the CMS/ATLAS L1 trigger, i.e. need to trigger with central apparatus

The physics case for FP420

MSSM: intense coupling regime

Intense-coupling regime of the MSSM:
$M_h \sim M_A \sim M_H \sim O(100\text{GeV})$: their coupling to $\gamma\gamma$, WW*, ZZ* strongly suppressed
→ discovery very challenging at the LHC

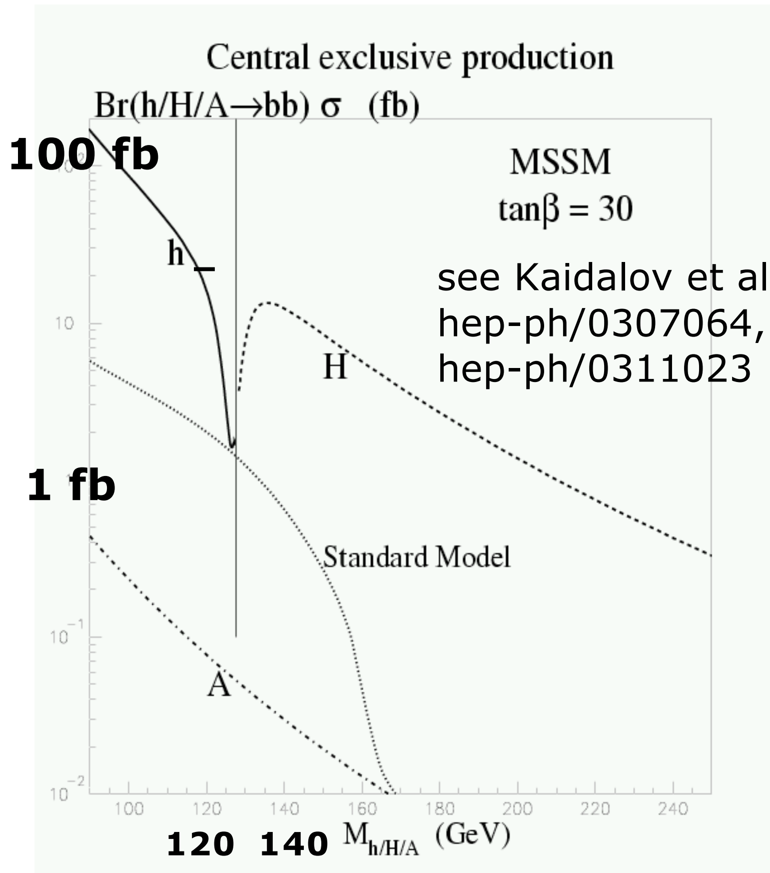
Cross section of two scalar (0+) Higgs bosons enhanced compared to SM Higgs

Production of pseudo-scalar (O-) Higgs suppressed because of J_Z selection rule

Superior missing mass resolution from tagged protons allows to separate h, H

Spin-partity of Higgs can be determined from the azimuthal angles between the two tagged protons (recall J_Z rule only approximate)

→ **CEP as discovery channel**

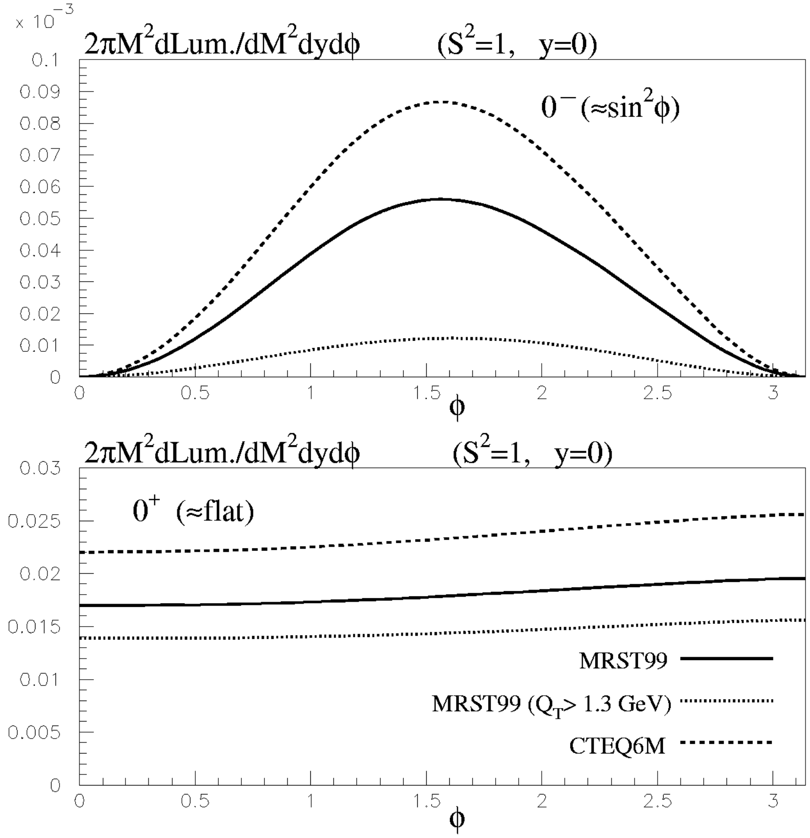


see Kaidalov et al, hep-ph/0307064, hep-ph/0311023

The physics case for FP420

MSSM: intense coupling regime

Azimuthal angle between outgoing protons sensitive to Higgs spin-parity: $J^P=0^+$ vs $J^P=0^-$ (recall J_Z selection rule only approximate)



0^-

0^+

Kaidalov et al., hep-ph/0307064

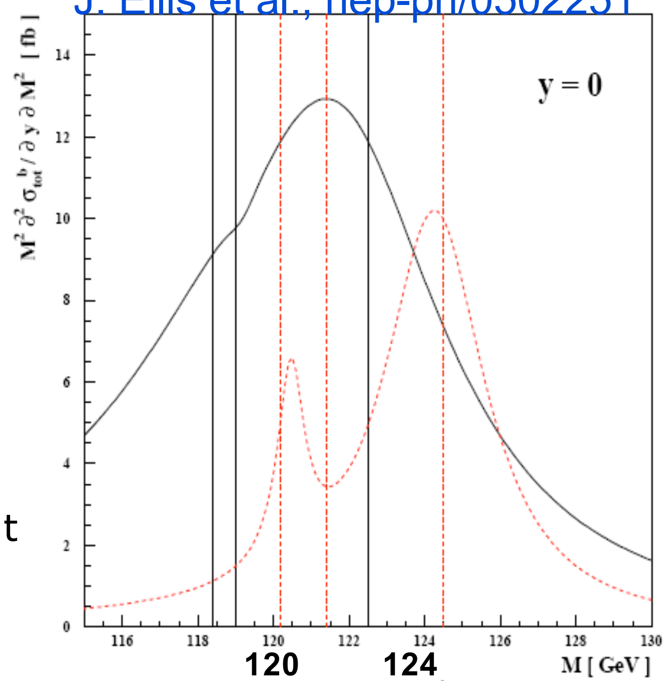
The physics case for FP420

MSSM: CP violation in the Higgs sector

“3-way mixing” scenario of CP-violating MSSM:
the 3 neutral Higgs bosons are nearly degenerate, mix strongly and have masses close to 120 GeV

Superior mass resolution from tagged proton allows disentangling the Higgs bosons by measuring their production line shape

J. Ellis et al., hep-ph/0502251

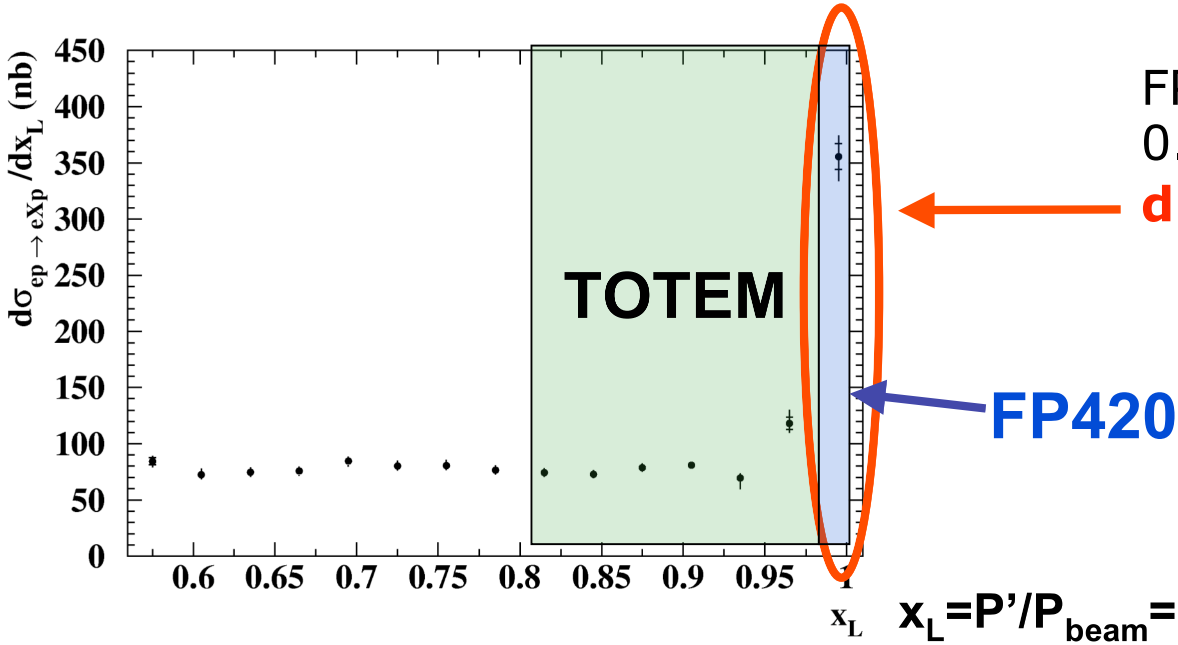


Hadronic level cross section when Higgs bosons decay into b bbar, for different values of mixing angles

Explicit CP-violation in Higgs sector manifests itself as asymmetry in the azimuthal distribution of tagged protons (interference of P- and P+ amplitudes) (Khoze et al., hep-ph/0401078)

→ **CEP as CP and line-shape analyzer !**

QCD and the structure of the proton



$x_L = P'/P_{beam} = 1 - \xi$

FP420 acceptance covers $0.002 < \xi < 0.02$, the so-called **diffractive peak**

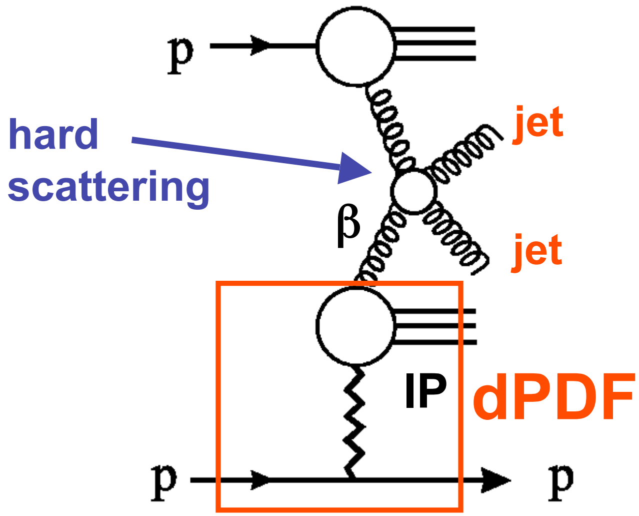
Explore hard-diffractive interactions at high lumi – follow path of HERA and Fermilab

i) low-x structure of the proton through diffractive PDFs and generalised parton densities (GPDs)

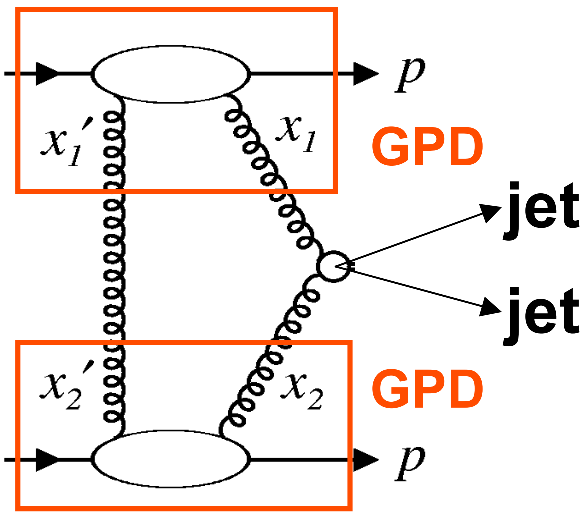
ii) QCD in the high density regime (saturation, RHIC physics…)

iii) Rapidity gap survival – multi-parton interactions

QCD: diffractive PDFs and GPDs



- Diffractive PDFs: probability to find a parton of given x in the proton under condition that proton stays intact – sensitive to low-x partons in proton, complementary to standard PDFs



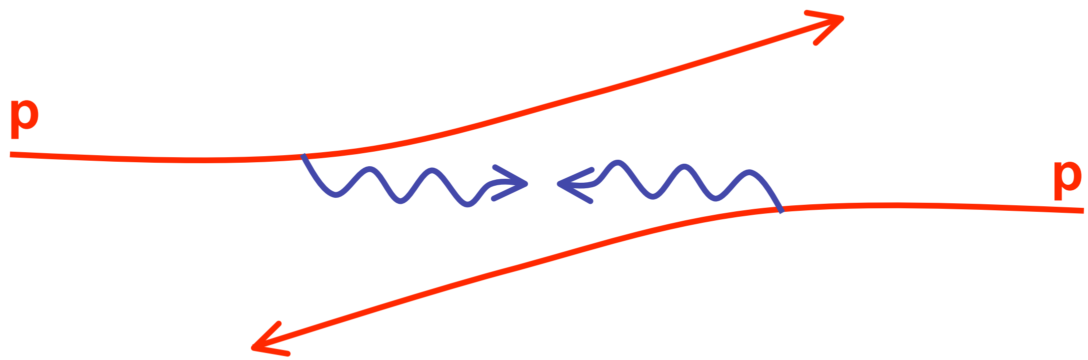
- Generalised Parton Distributions (GPD) quantify correlations between parton momenta in the proton; t-dependence sensitive to parton distribution in transverse plane

- When x′=x, GPDs are proportional to the square of the usual PDFs

The physics case for FP420

Photon-Photon interactions

• Tag two protons $\rightarrow \gamma\gamma$ interactions (K. Piotrzkowski, PRD 63 071502)



• 2-γ production of W pairs: studies of quartic gauge couplings $\gamma\gamma WW$

σ = 110 fb with $\langle M_{\gamma\gamma} \rangle > 300$GeV → ~ 1000 evts in lept. channels (30 fb^{-1})

Sensitivity to anomalous quartic couplings significantly better than LEP2 limits (no other way at LHC to have such sensitivity)

• Tag a single proton → γp interactions
Eg W boson production at high transverse momentum
top pair production via photon-gluon fusion

FP420: Summary of physics potential

- Observing a Higgs boson accompanied by proton tags means a O^{++} states
- Light standard model Higgs can be seen in WW/WW* and b bbar modes with S/B ~ 1
- In certain regions of MSSM parameter space, S/B > 20, and double tagging is the discovery channel at the LHC
- In other regions of the MSSM parameter space, explicit CP violation in the Higgs sector would be visible as azimuthal asymmetry in the tagged protons $\rightarrow$ direct probe of CP structure of the Higgs sector at the LHC

  "Exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production" J. Ellis et al.

- Unique access to a host of interesting QCD processes (p structure, low-x...)
- Rich program of $\gamma\gamma$ and γp physics

Technical aspects of FP420

Connection cryostat
Near-beam detectors: Edgeless 3-D Silicon
Trigger

FP420 technical aspects: Connection cryostat

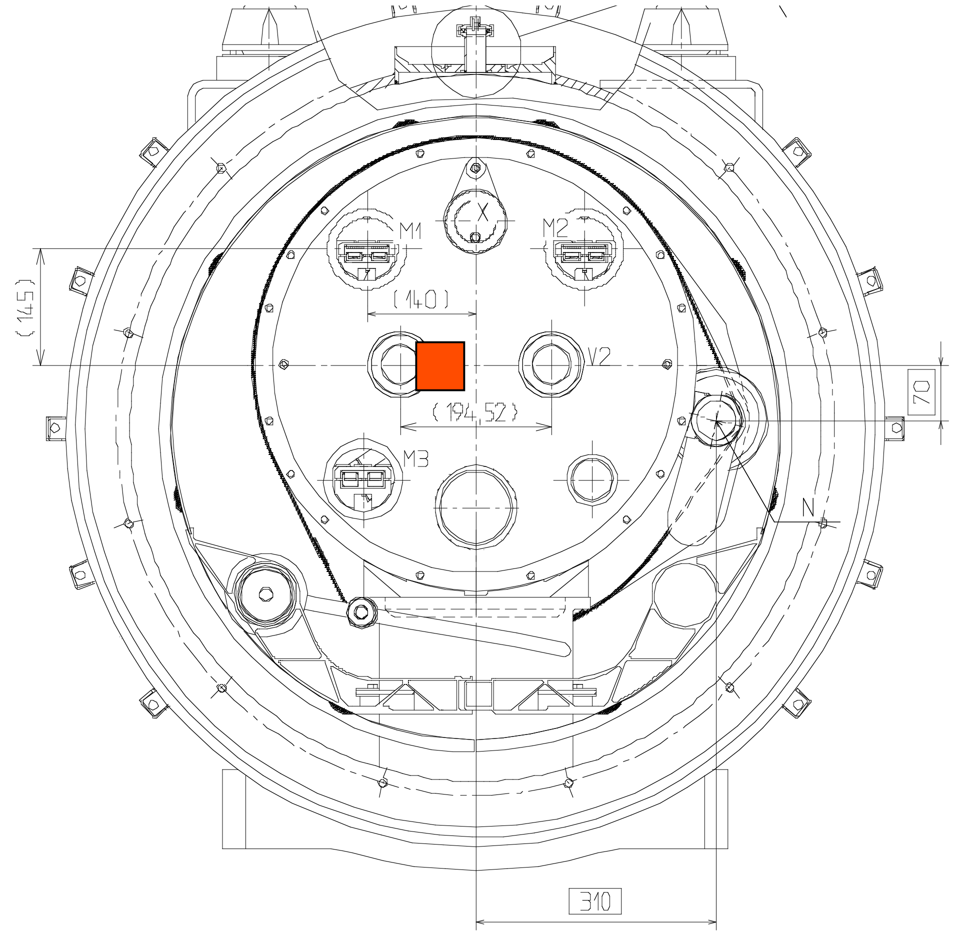
At 420 m after P1 and P5 an off-momentum proton lies between the two beam pipes, which are at 1.9 K

Beam protons
$\Delta p/p$ beam = 0.011 %
10 σ beam ≈ 3mm

Off-momentum proton
Δp = 0.5 %
Δx = 10 mm

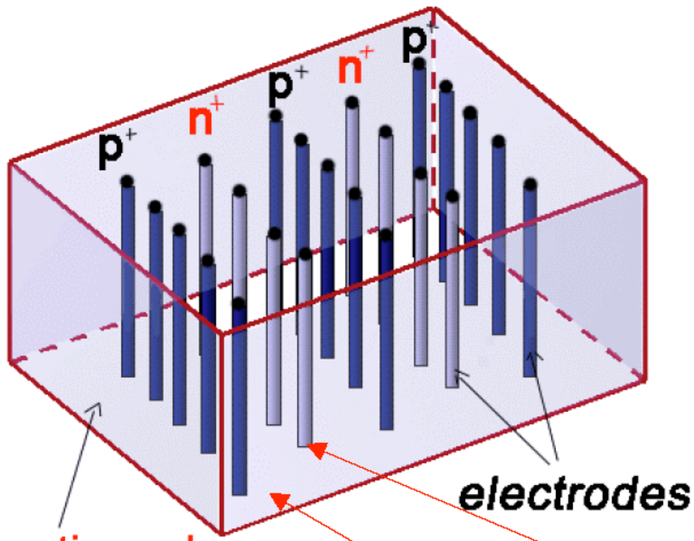
i.e. still inside the 44 mm diameter beam-pipe

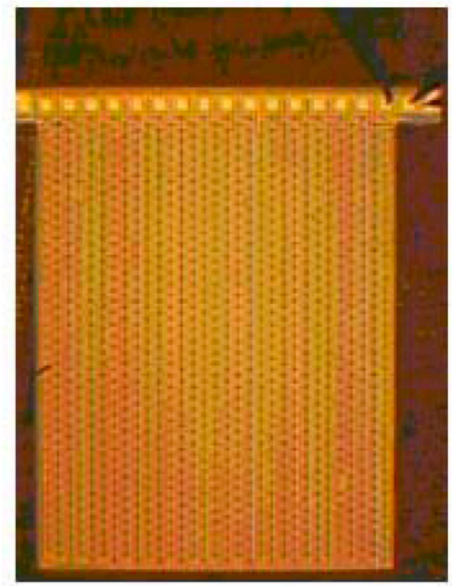
Need "near-beam" moveable detectors, integrated with cryostat



Most likely scenario: Cryogenic bypass with 15m cold-warm transition,
warm beam pipes, detectors at room temp
Insertion mechanism under disc.: Roman pots, movable beam-pipe, microstations, ...

FP420 technical aspects:
3D edgeless Silicon





1. NIMA 395 (1997) 328
2. IEEE Trans Nucl Sci 464 (1999) 1224
3. IEEE Trans Nucl Sci 482 (2001) 189
4. IEEE Trans Nucl Sci 485 (2001) 1629
5. IEEE Trans Nucl Sci 48 6 (2001) 2405
6. CERN Courier, Vol 43, Jan 2003, pp 23-26

3D silicon detectors were proposed in 1995 by S. Parker, and active edges in 1997 by C. Kenney.

Combine traditional **VLSI** processing and **MEMS** (Micro Electro Mechanical Systems) technology.

Electrodes are processed inside the detector bulk instead of being implanted on the Wafer's surface.

The edge is an electrode! Dead volume at the Edge < 5 microns! Essential for
-Large area coverage
-Forward physics

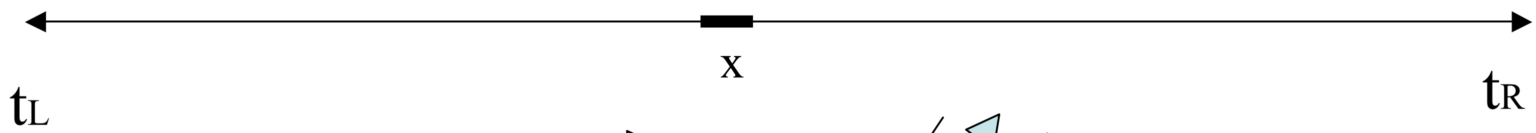
CDV- Manchester Dec.2005

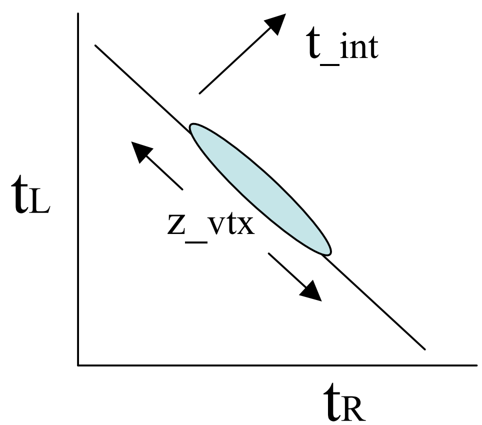
Other advantage of 3D Si: rad hard
Use ATLAS pixel chip (rad hard) for readout

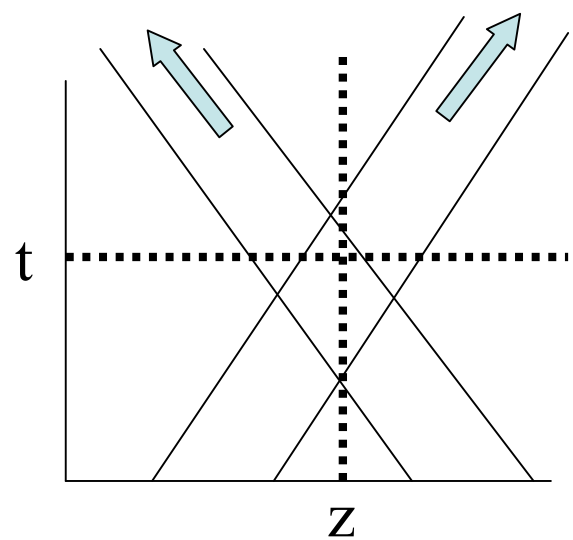
FP420 technical aspects: Fast TOF detectors

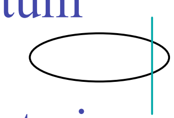
Put at back of 420m (220m?) tracking high precision timing counters.
Eg.Quartz Cerenkov + ~ Microchannel PMT → tested (Japanese Gp) → **10 ps = 3mm!!**

Check that p's came from same interaction vertex (& as central tracks)



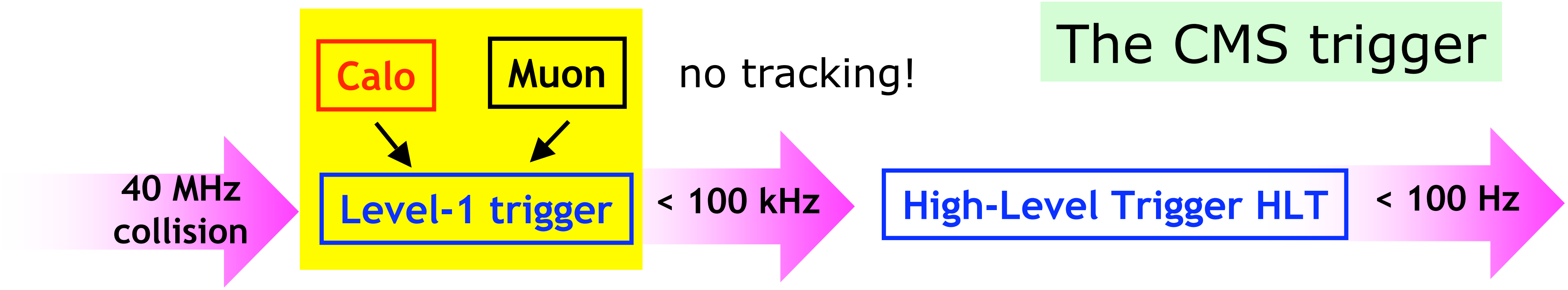




Know position in each bunch of interacting p's.
Position-momentum correlation → 
Reduce uncertainty in incoming momenta.

Potentially valuable e.g. MSSM triplet (Higher cross section & close states)

The difficulty of triggering on a light Higgs



The difficulty of triggering on a light Higgs, e.g at 120 GeV:
L1 jet trigger signature: 2 jets in CMS Cal, each with E_T < 60 GeV

- Measured L1 jet E_T on average only ~60% of true jet E_T
- L1 trigger applies jet E_T calibration and cuts on calibrated value
- Thus: 40 GeV (calibrated) ~ 20 to 25 GeV measured
- Cannot go much lower because of noise

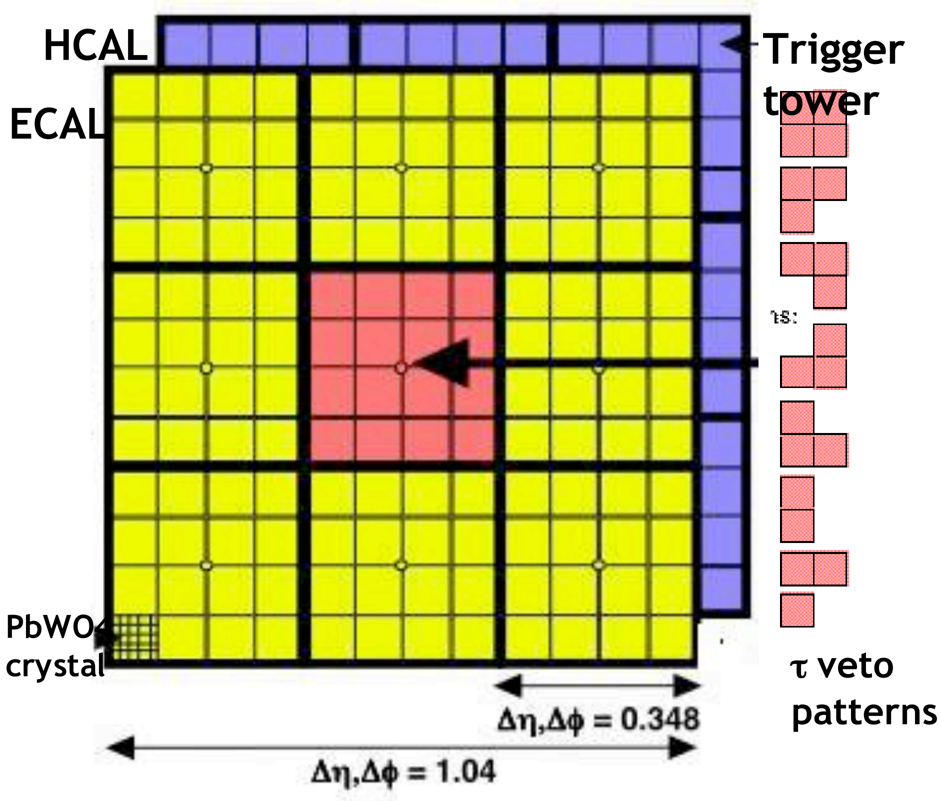
→ Use rate/efficiency @ L1 jet E_T cutoff of 40 GeV as benchmark

L1 2-jet rate for central jets ($|\eta|<2.5$) @ L1 jet E_T cutoff of 40 GeV for Lumi 2 x 10^{33} cm^{-2} s^{-1}: ~**50 kHz** , while considered acceptable: **O(1 kHz))**

Need additional conditions in trigger: Forward detectors !

Triggering on a light Higgs:

Central detector jet trigger



- **4x4 trigger towers = region**
- Search for jets with a sliding 3x3 regions window
- **Jet = 3x3 region** with local energy max in middle
- Reconstructed L1 jet E_T on average ~ 60% of real jet E_T, thus need for jet E_T calibration
- **Jet = 144 trigger towers**, with typical jet dimensions: $\Delta\eta \times \Delta\phi = 1 \times 1$

H_T condition = isolation condition for jets:
2 jets in central Cal ($|\eta|<2.5$) with $\Sigma(E_T$ 2 jets)/HT > threshold
H_T = scalar sum of E_T of all jets in the event with E_T(jet)>threshold

--> Provides factor ~2 rate reduction

Triggering on a light Higgs:

Single-sided 220 m condition

- → Very good reduction of rate in absence of pile-up
- → However, reduction decreases substantially in the presence of pile-up which contains ~30% diffractive events

Luminosity $[cm^{-2}s^{-1}]$	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40$GeV per jet	Total reduction needed	Reduction when requiring track in RP detectors at 220 m	
					$\xi < 0.1$
1×10^{32}	0	2.6	2	370	
1×10^{33}	3.5	26	20	7	15
2×10^{33}	7	52	40	4	10
5×10^{33}	17.5	130	100	3	5
1×10^{34}	35	260	200	2	3

single-sided 220m condition without and with cut on ξ

Achievable total reduction: 10 x 2 (H_T cond) x 2 (topological cond) = 40

Jet isolation criterion

Can win additional factor ~2 in reduction when requiring that the 2 jets are in the same η hemisphere as the RP detectors that see the proton

Triggering on a light Higgs:

220m and 420m conditions

For H (120 GeV, CEP) → b bbar, adding L1 conditions on the RPs at 220m is likely to provide a rate reduction sufficient to meet the CMS L1 bandwidth limits at luminosities up to 2x 10^{33} cm^{-1} s^{-1}

To go even further up in luminosity need additional handle to stay within bandwidth limits

... So what about triggering with the 420 m RPs ?

At the current CMS L1 latency of 3.2 μs they are too far away from IP for inclusion in L1

Note: This is a hardware limit - cannot be changed without replacing trigger pipelines of CMS tracker and preshower detectors with deeper ones

Should this however happen (under discussion for SLHC: L1 latency 6.4 μs, determined by ECAL pipeline depth) then ....

Triggering on a light Higgs:

Asymmetric 220/420m condition

Require hits on one side in 220m RPs and on one side in 420m RPs

- In effect means on opposite sides: events where ξ values of 2 protons are very different
- Can be used either in L1 after increase in L1 latency, or on HLT

Lumi nosity $[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40$GeV per jet	Total reduc tion needed	Reduction when requiring track in RP detectors				
				at 220 m		at 420 m	at 220 m & 420 m (asymmetric)	
					$\xi < 0.1$			$\xi < 0.1$
1×10^{32}	0	2.6	2	370				
1×10^{33}	3.5	26	20	7	15	27	160	380
2×10^{33}	7	52	40	4	10	14	80	190
5×10^{33}	17.5	130	100	3	5	6	32	75
1×10^{34}	35	260	200	2	3	4	17	39

See www.cern.ch/grothe/heralhc/heralhc.ps

All results are preliminary

For H (120 GeV, CEP) → b bbar, adding L1 conditions on the RPs at 220m and 420m would provide a rate reduction sufficient to meet the CMS L1 bandwidth limits at luminosities up to 10^{34} cm^{-1} s^{-1}

Triggering on a light Higgs:
Summary

❖Triggering on CEP of a light Higgs with a rap gap trigger is not an option in the presence of pile-up

❖Can trigger with the central detector alone by using the muon trigger
Efficiencies with already foreseen CMS L1 thresholds:
10% for H(120GeV) → b bbar, 20% for H(140GeV) → WW*

❖Can also use the L1 jet trigger when combining it with RP condition
Requires defining a new CMS trigger stream
Efficiencies around 10%

Goal: Define trigger table for a dedicated diffractive trigger stream with target output rates of
1 kHz out of 100 kHz total on L1 and
1 Hz out of 100 Hz total on HLT

Status of the FP420 project

Project goal is to establish the feasibility of

- Modifying the cryostat at 420m – produce design that satisfies the machine and allows insertion of detectors with appropriate mechanics
- Operating edgeless detectors (eg 3D Si pixel detectors)
- Being able to trigger and retain sufficient signal acceptance

All of the above, with no interference with LHC, ATLAS, CMS, TOTEM
Estimated time for this: early 2007

Once/if feasibility established:

- ATLAS and CMS members of FP420 will go back to their collaborations, propose the addition – then, if accepted, collaboration(s) will submit TDR
- Installation: not before the first long LHC break – ie no interference with machine startup

Status of the FP420 project (II)

- First meeting at FNAL in April 2005
- Green light for UK funding (100 k£ seedcorn)
- Submitted proposal to the LHCC in June; M. Martinez referee
  LHCC reaction:

"The LHCC acknowledges the scientific merit of the FP420 physics programme and the interest in exploring its feasibility"

- Accelerator interface issues, including redesign of 420m cryostat, funded by UK (Cockroft Institute)
- Funding of other groups (B, US, I…) being discussed
- New funding bid in UK in March 2006: design and construction of prototype cryostat, development of the 3D detectors and electronics
- Test beams in spring and summer 2006 at Fermilab and CERN (mechanics, detectors)
- Take decisions based on R&D work by the end of 2006
- Aim for NIM paper in spring 2007
- Construction could start by the end of 2007

Last words...

FP420 adds to the discovery potential of the LHC, by making it possible to capitalize on the unique advantages of central exclusive production.

"QCD at a hadron collider is always a ghetto, and there the worst neighborhood is diffraction." - W.Smith

Now the Pomeron is even socializing with the Higgs crowd. We are on the way to respectability !