Fast Timing Detectors and Forward Physics Project at the LHC

- ***Forward Physics motivation:***
  - *Diffraction, CEP Higgs, γp and $\gamma\gamma$*
- ***Forward Detectors***
  - *AFP, FP-420: Spectroscopy & ToF*

Fast timing fused silica detectors

- *Recent results from AFP timing group*

- ***Gießen abilities and plans***

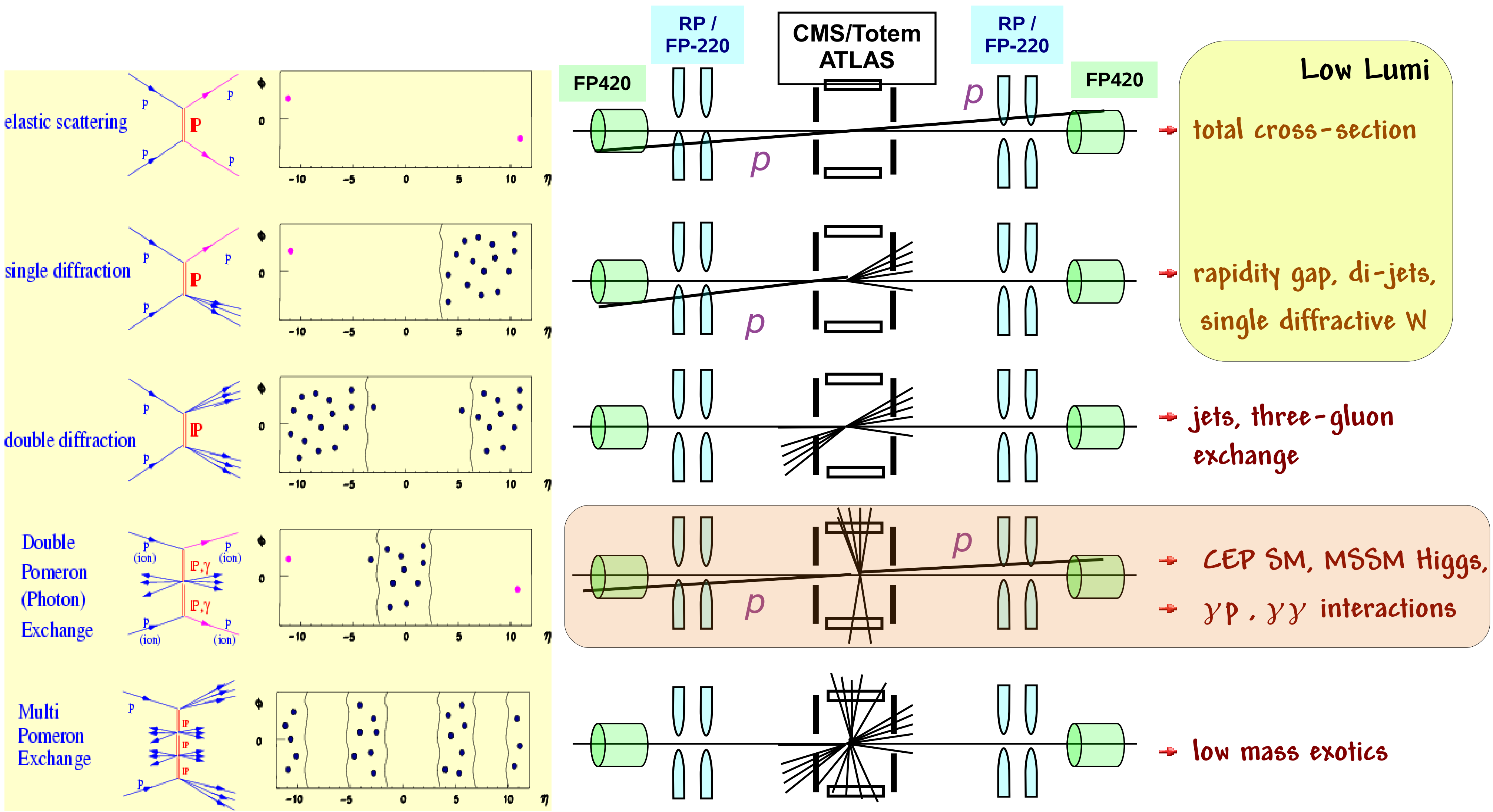
2. Detector Workshop of the Helmholtz Alliance "Physics at the Terascale"

Hamburg, 2-3 April, 2009

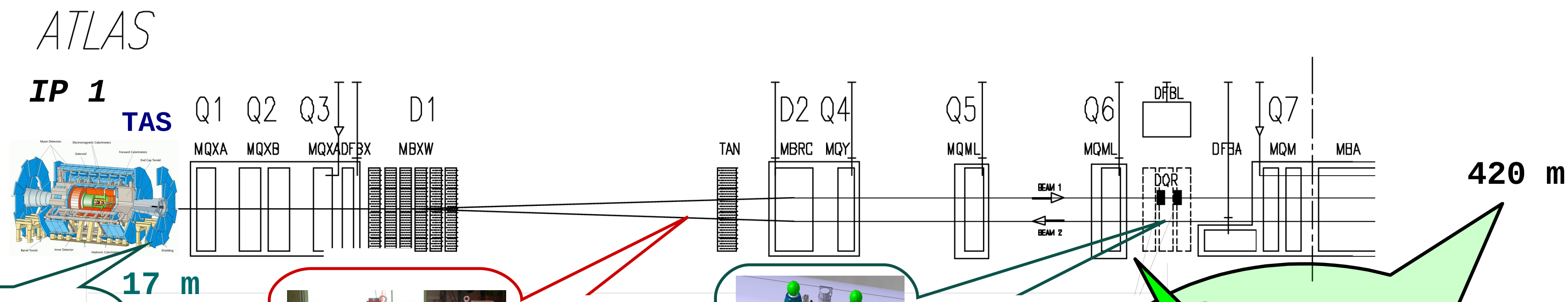
Anatoli Astvatsatourov

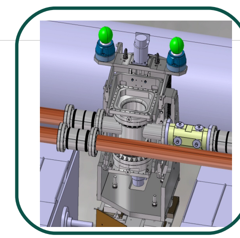
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

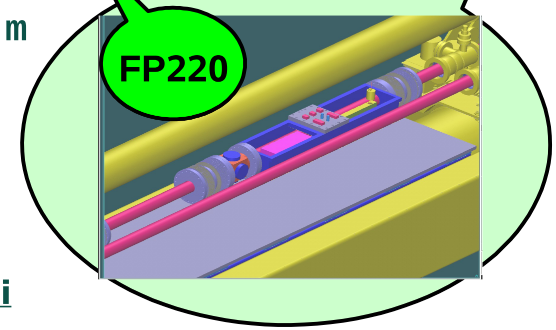
Diffraction with Forward Detectors in pp at LHC



Forward Detectors at ATLAS







LUCID

Luminosity monitor

Čerenkov tubes, pointing to the IP, placed around beam at ~17 m from IP.

TAN: *ZDC*

Neutral Particles

W[74]/Quartz calorimeter in beam-pipes junction point at 0° to IP.

ALFA Roman Pots

Elastic scattering & Lumi

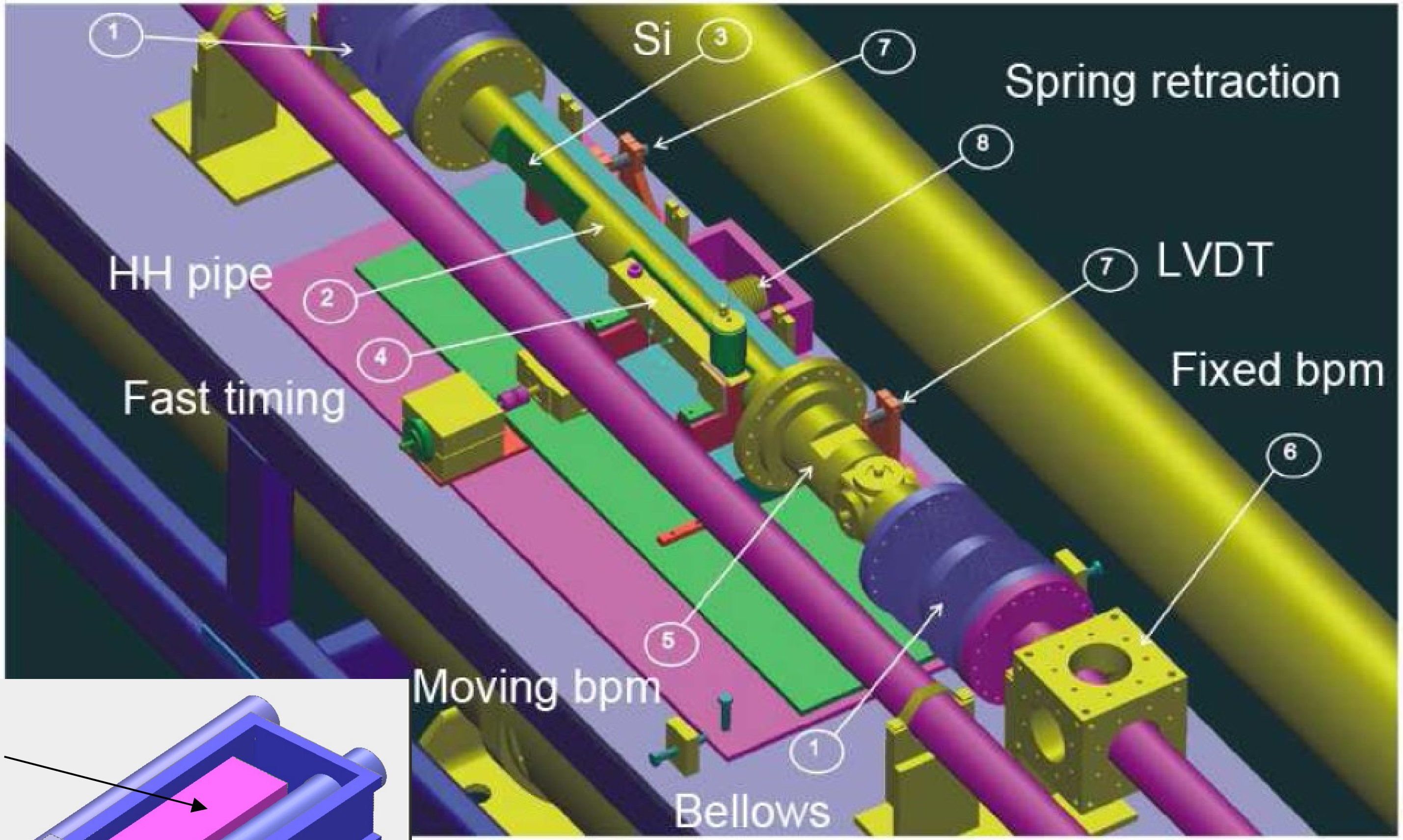
Moveable fiber planes trackers in "Roman Pot" inside the beam-pipe at 240 m from IP.

AFP, FP-420

"Hamburg pipe" moving pocket at 420 m and 220 m from IP.

Upgrade ~ 2012

Moving "Hamburg pipe"

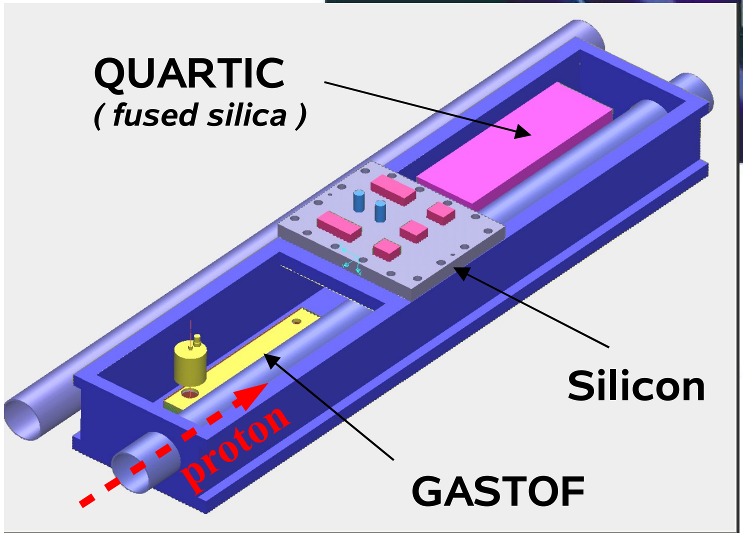


Moveable detector:

- parking position
- measuring position

Distance to the beam:

- beam conditions
- acceptance



Spectrometer/ToF inbetween beam magnets

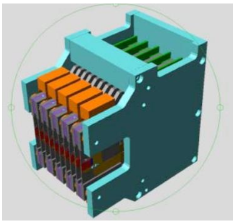
Tracking: Silicon

Timing: GASTOF + QUARTIC

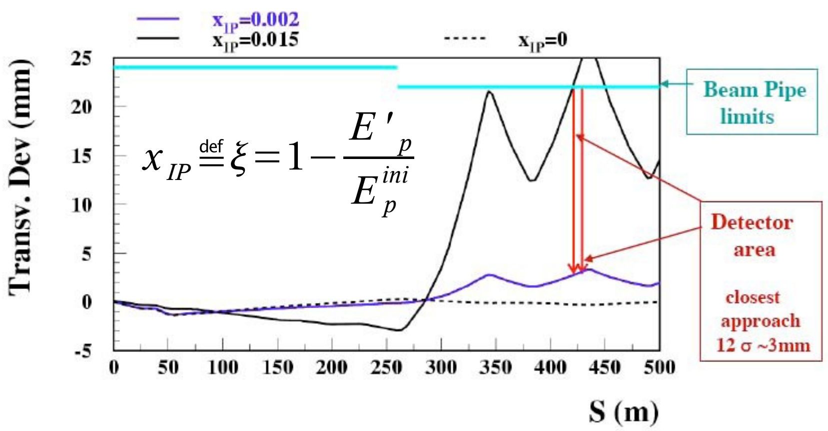
FP420 Desing Report: arXiv: 0806.0302 [hep-ex]

AFP, FP-420 Spectrometry

Silicon tracker



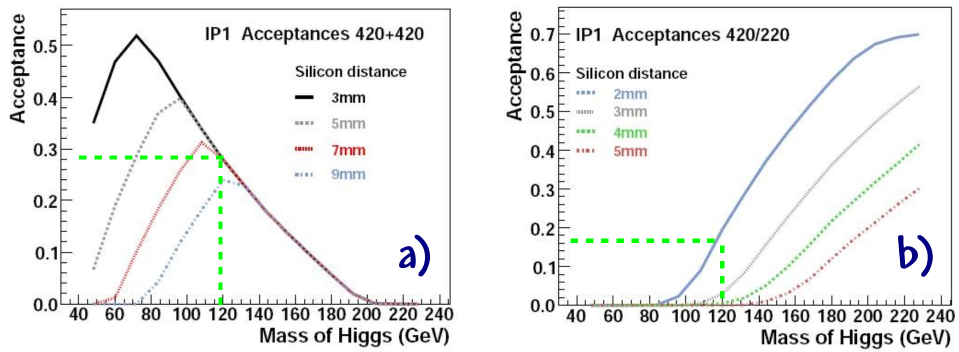
Spectrometer/ToF inbetween beam magnets



420 m: $0.002 < \xi < 0.02$

220 m: $0.02 < \xi < 0.2$

Acceptance for Higgs: a) 420+420 b) 420+220

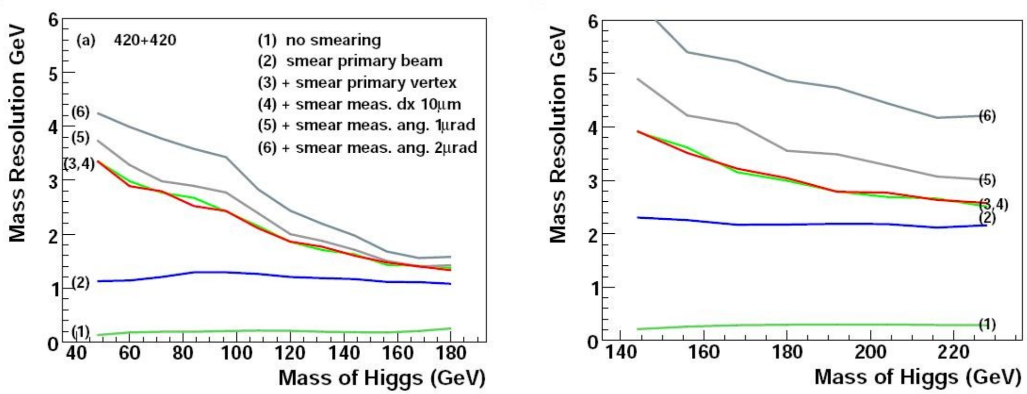


Central system mass: $M^2 \approx \xi_{p1} \ \xi_{p2} \ s$

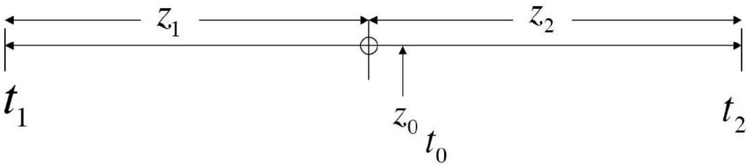
two tagged protons: ~50 GeV < M < 1 TeV

Proton tagging:

study of Higgs with good mass resolution in SM and MSSM

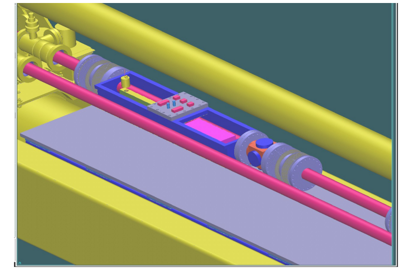


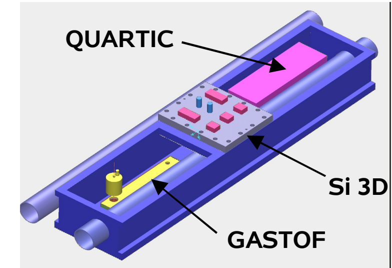
Fast Timing System (ToF)

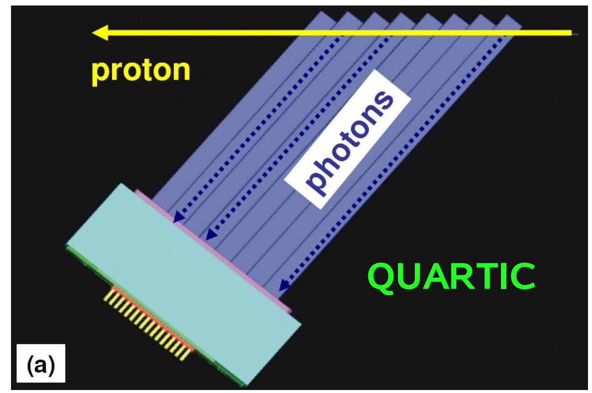


$$t_1 - t_0 = \frac{c}{|z_1| + z_0}; \quad t_2 - t_0 = \frac{c}{|z_2| - z_0}$$

($|z_i|$ are distances but z_0 is signed)







fused silica bars

single bar δt ≈ 40-45 ps

combinative → 10-20 ps

+

GASTOF

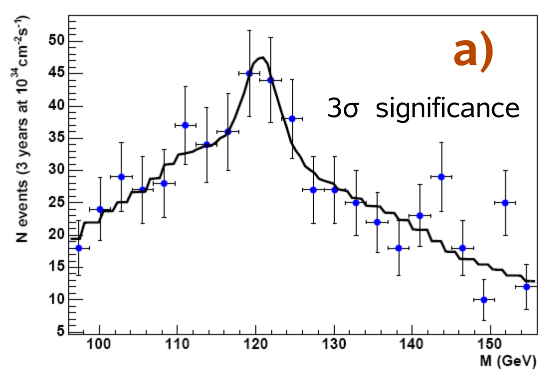
Central Exclusive Process with AFP, FP-420:

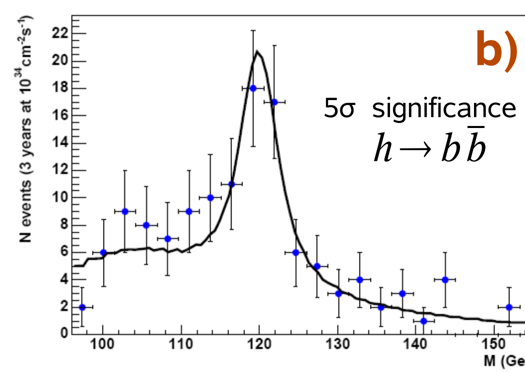
1) clean quantum numbers determination 0^{++} (C, P, J_z selection rules)

2) direct relation: energy in FP420 ↔ central system invariant mass

3) increase signal /noise RATIO

MSSM Higgs (tan β = 40 , M_A = 120GeV): min 3 years nominal lumi





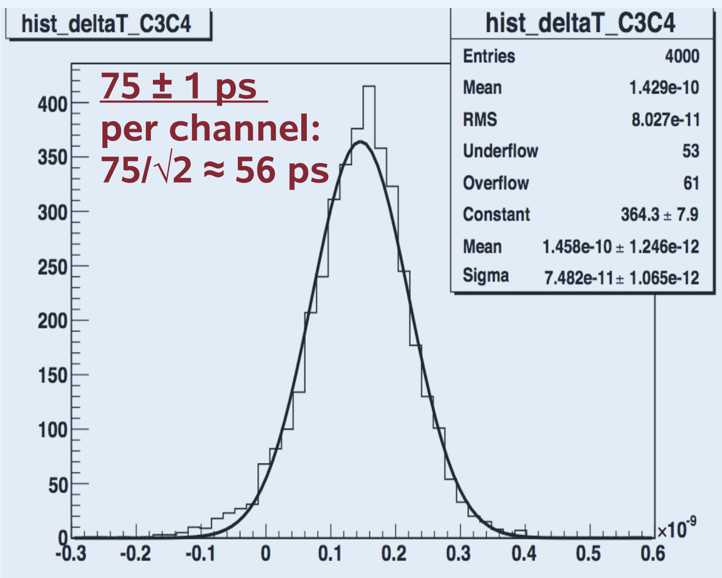
a) → b) : pile-up background rejection with ToF system

QUARTIC ToF

Preliminary results, UTA, Andrew Brandt

Mean Pulse Height vs Frequency normalized to 1 kHz pulse height

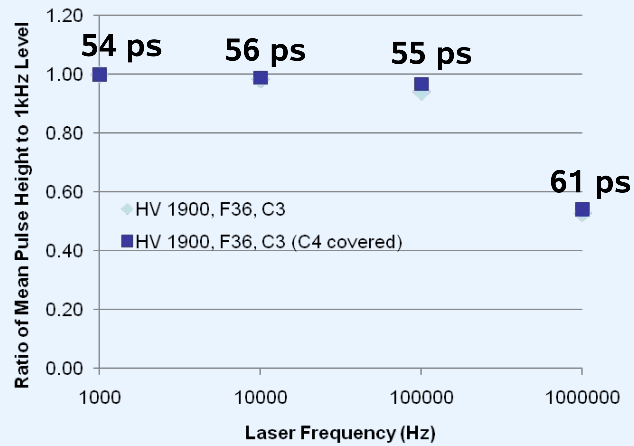
Hamamatsu PLP-10 405 nm
Burle-85001 4 ch 25 μm
(initial studies with 25 μm tube, 10 μm coming soon)
beam is about 5 mm diameter



Goal for 10 μm tube is < 40 ps / channel

(~10 pe, gain ~0.8E5)

25 μm Gain vs Frequency (Beam size 0.24 cm²)



Pulse height decreases to 60% of initial value, timing 10% worse for 1MHz (~ equivalent to proton rate in max rate pixel @2x10³³ at 420m)

blue squares: repeated amplitude vs rate for one channel only -- no change in rate behavior -- implies that limitation is local current

Initial Laser Test Goals

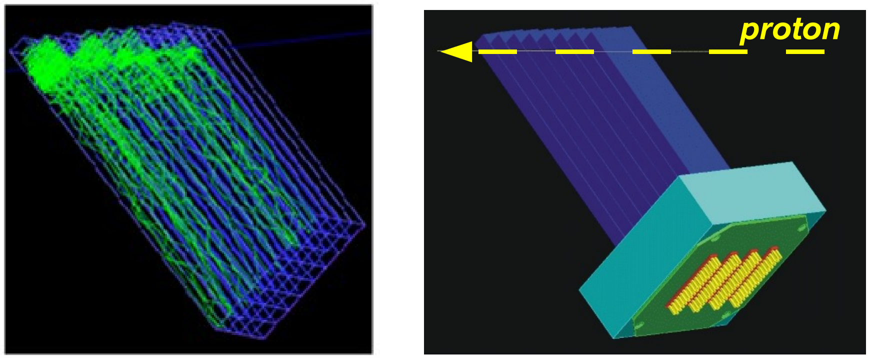
Develop useful flexible laser test facility

Study rate properties (gain, timing) of MCP-PMT's

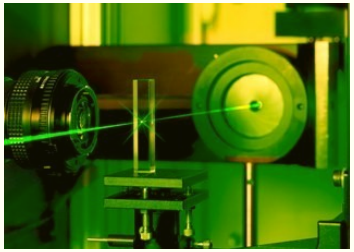
Specific to ATLAS Forward Proton: Establish minimum gain to achieve timing goals of our detector given expected number of pe's. Evaluate different amp / cfd / tdc choices at the working point of our detector

Fused Silica Bars

AFP simulation



Giessen group plans to order *from HEREUS:*

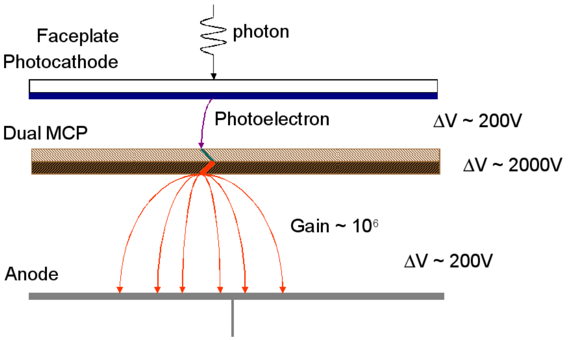


Suprasil 311

- optically isotropic 3D-material
- free from striations in all dimensions
- High degree of resistance to radiation
- Residual strain: ≤ 15 nm on the edge

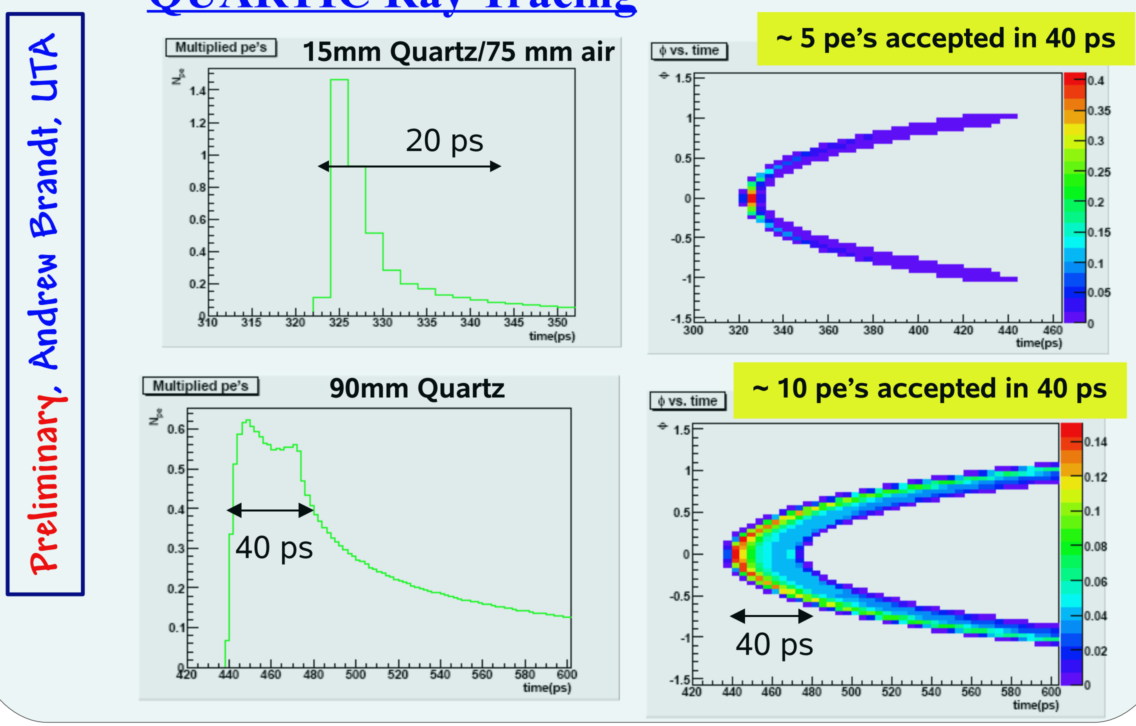
MCP-PMT

to reach 40 ps / bar:



M. Akatsu et al., *" MCP-PMT timing property for single photons"*, NIM, A 528 (2004) 763–775

QUARTIC Ray Tracing



<u>Plans</u> of Gießen Group for AFP

- **Laser and cosmics tests with fused silica (QUARTIC) bars**
- **Contribution in construction of a QUARTIC prototype for AFP**

1) QUARTIC bars optical properties:
  a) optimisation of polishing, positioning and configuration
  b) photoelectrons multiplicity and variety

2) MCP read-out properties:
  a) gain, efficiency, resolution
  b) read-out dependencies: temperature, laser pulse frequency

<u>Interest</u> from German Groups to AFP

- **II. Physik. Institut, Uni. Gießen**
- ATLAS-DESY-HH
- Kirchhoff-Institut für Physik, Uni. Heidelberg

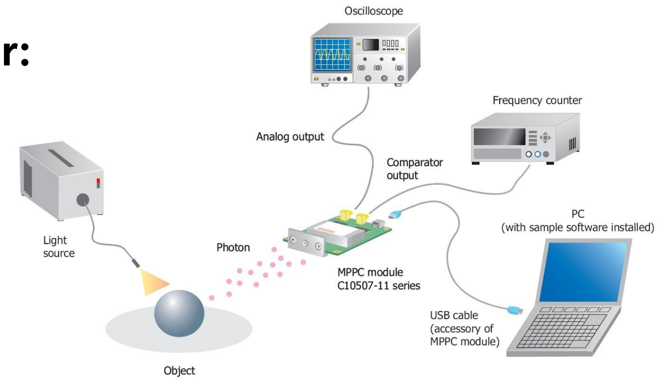
Gießen Laser Lab: new equipment

single photon measurements

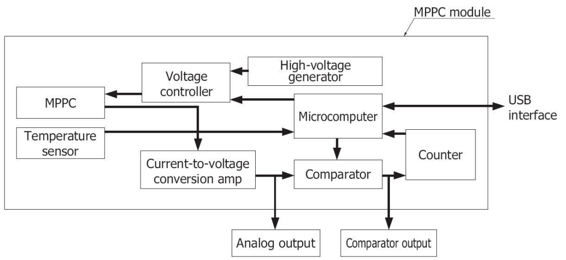
Light propagation tests in fused silica:

Multi Pixel Photon Counter:
MPPC C10751-03

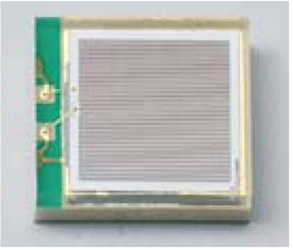

100 pixels



Pixel size: 100 µm
Gain: ~2,4 × 10 ^{6}
Spectral response: 320 – 900 nm



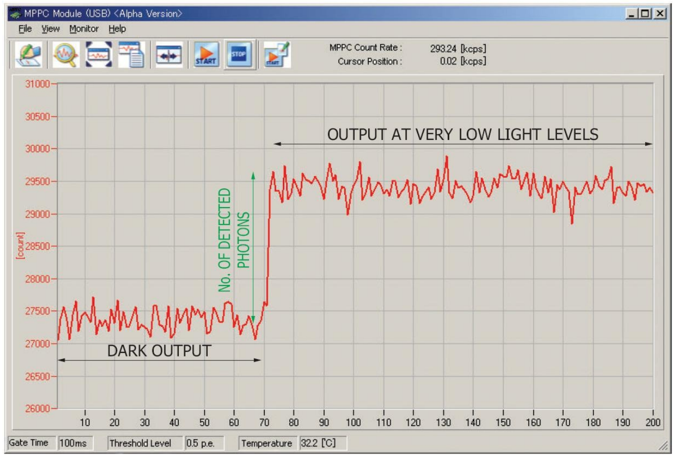
3.5 x 3.5 mm


900 pixels

5 x MPPC S10931-100 P

3 x MPPC S10985-100 C

For time resolution tests we need MCP-PMTs



Newport Power Meter Model 2935-C

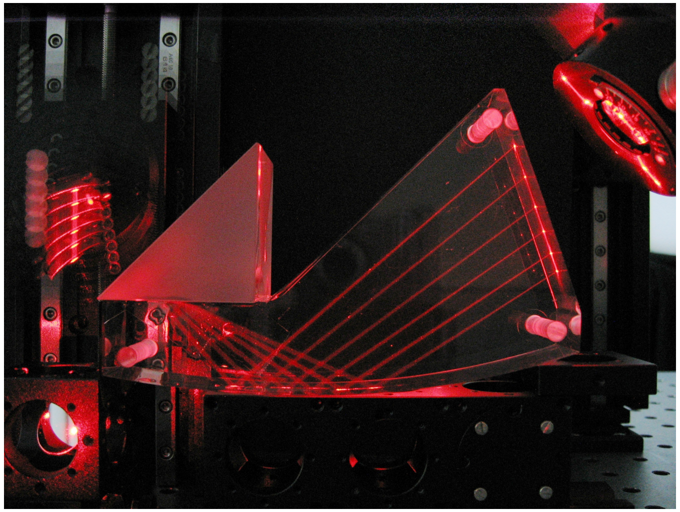
Gießen Laser Lab: experience

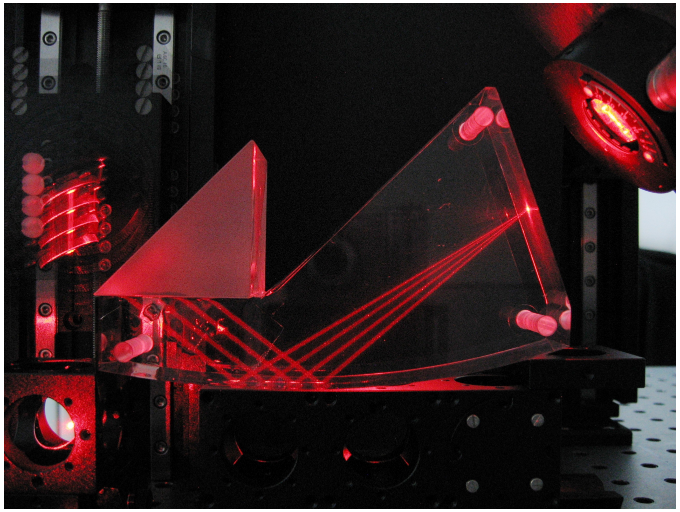
Test stand

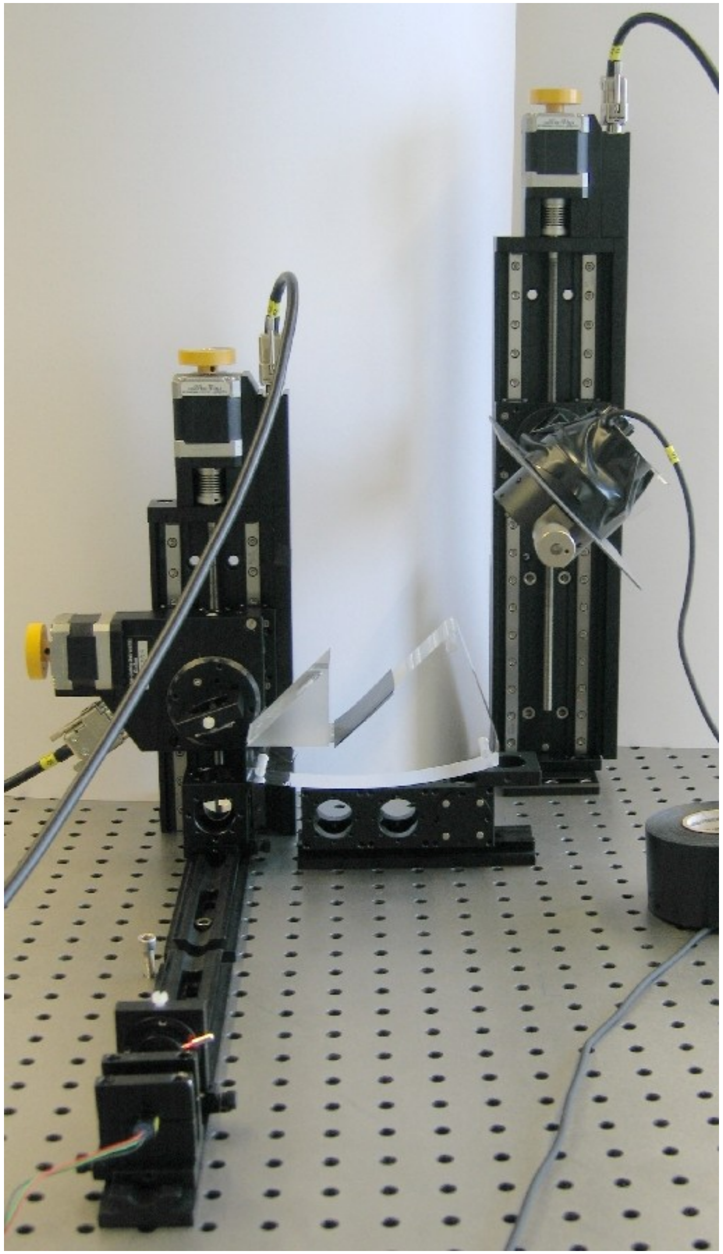
- focusing properties
- light intensity, total reflection

To measure

- pulse frequency ,
- temperature dependencies







Summary

- The FP-420 project for ATLAS $\rightarrow$ AFP
  - * Diffraction, forward QCD
  - * CEP Higgs prodiction
  - * γp and $\gamma\gamma$ interactions

- Timing measurements for AFP
  - * pile-up background rejection for CEP events
  - * essential progress of the AFP project

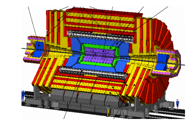
``The FP420 R&D Project: Higgs and New Physics with Forward Protons at the LHC," FP420 R&D, arXiv:0806.0302 [hep-ex].

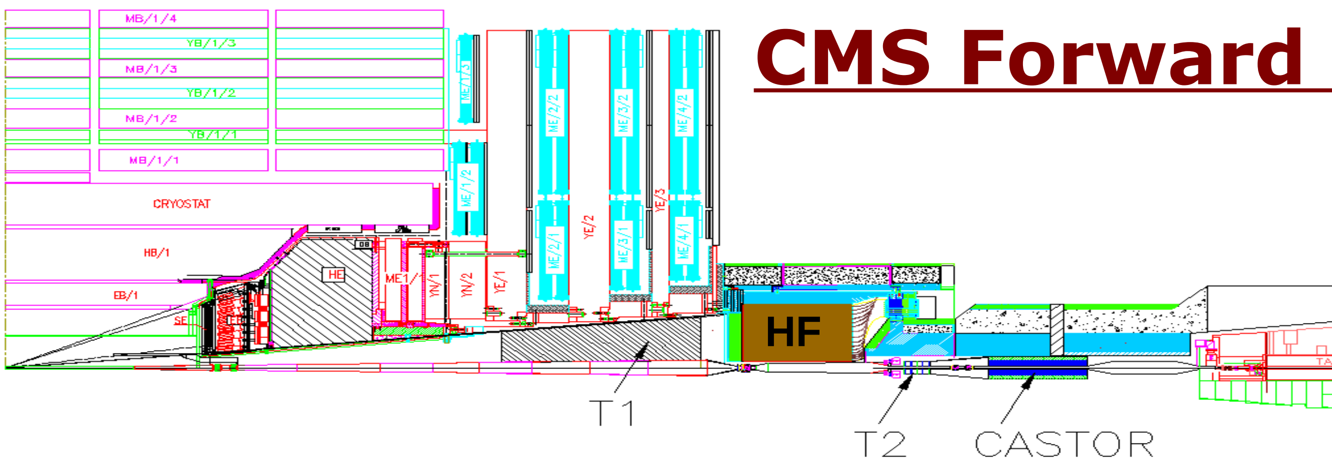
``Letter of Intent for ATLAS FP: A project to install forward proton detectors at 220 m and 420 m upstream and downstream of the ATLAS detector" A. Brandt, B. Cox, C. Royon *et al.*, AFP Collaboration

- Gieflen group plans to participate in the fast timing detectors development for AFP
  - * fused silica bars, MCP-PMTs, TDCs,
  - * laser tests

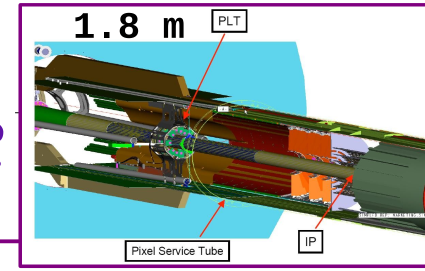
Back Up

CMS Forward Detectors





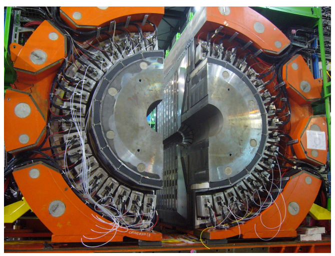
upgrade



PLT – Pixel Luminosity Telescope lumi monitor for CMS upgrade. Use single-crystal diamond as active sensor (diamond pixel)

FP 420, 220 – Spectrometer / ToF Detector inbetween LHC magnets

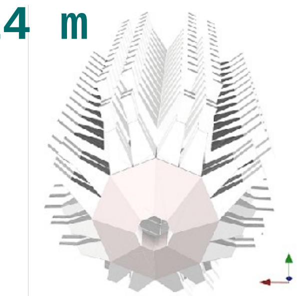
to IP: 11 m



HF - Forward Hadronic iron/quartz fibers calorimeter

$3 \le |\eta| \le 5$

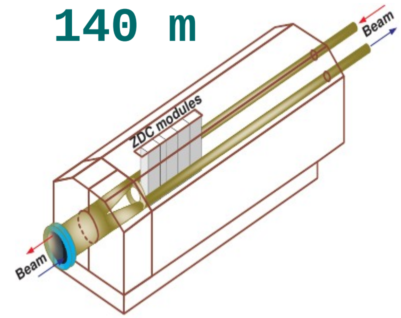
14 m



CASTOR – tungsten quartz plates sampling calorimeter

$5.2 \le |\eta| \le 6.6$

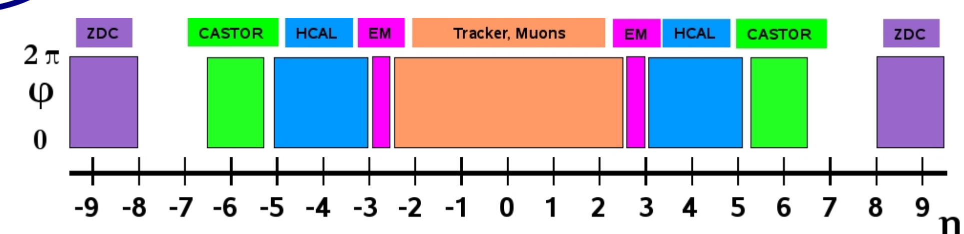
140 m



ZDC – tungsten /quartz calorimeter at 0^0 to IP in beam pipes junction point

$|\eta| > 8$

luminosity, forward QCD: diffraction, low-x



Diffraction with AFP → CEP

<u>Low Lumi:</u>
Single Diffraction, di-jets vector-bosons : *pp → pX*

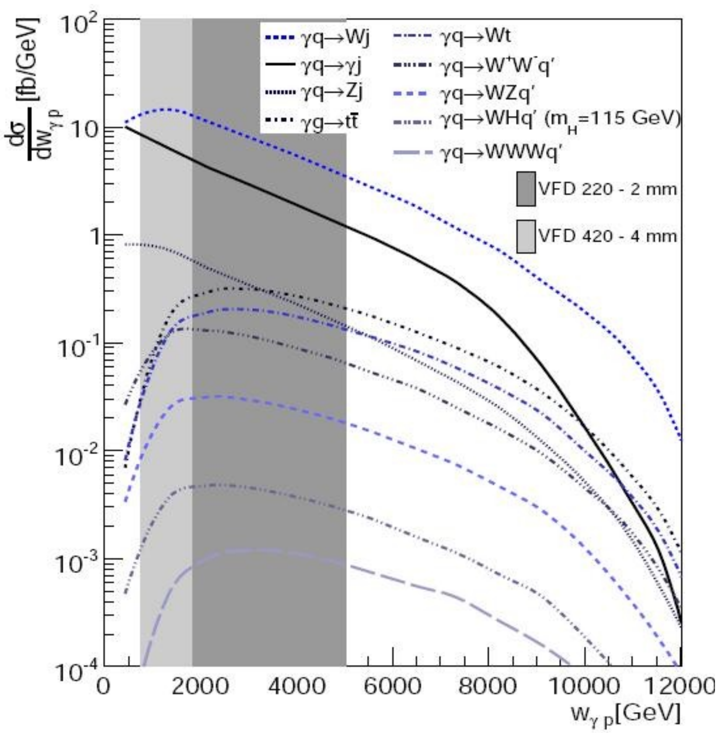
<u>Nominal Lumi:</u>
Double IP Exchange, Double γ Exchange :
pp → pXp

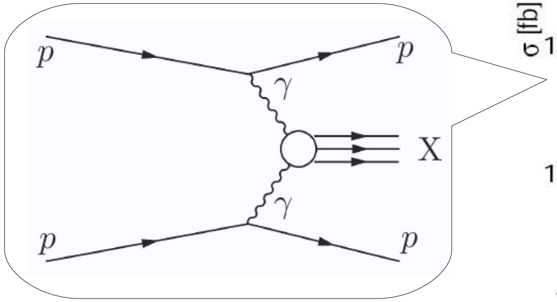
CEP selection: rapidity-gap survival probability (SP):
soft hadronic scattering correction

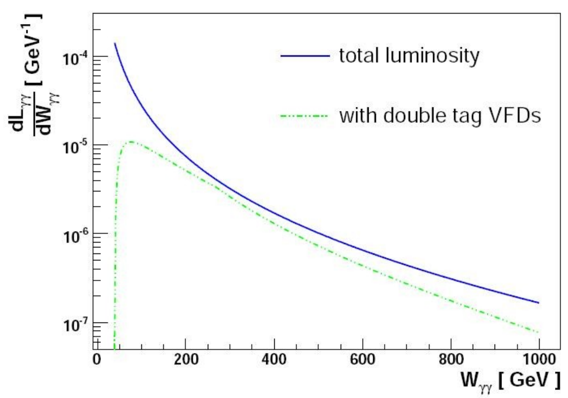
$$A(p_{t1}, p_{t2}, \Delta\Theta) = (1 + A_{SP}) \cdot A_{(WW, t\bar{t})}$$

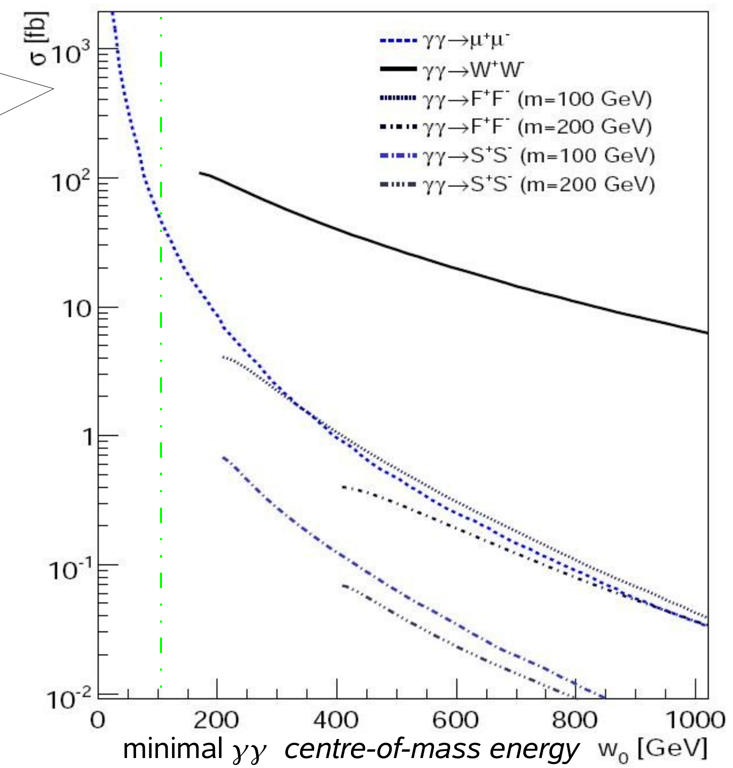
γp and $\gamma\gamma$ interactions

pp(γq/g→X) → pY







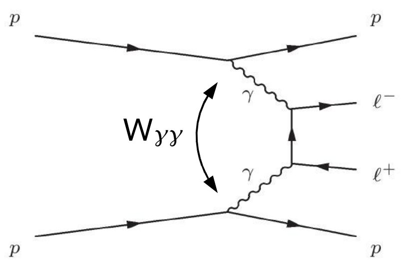


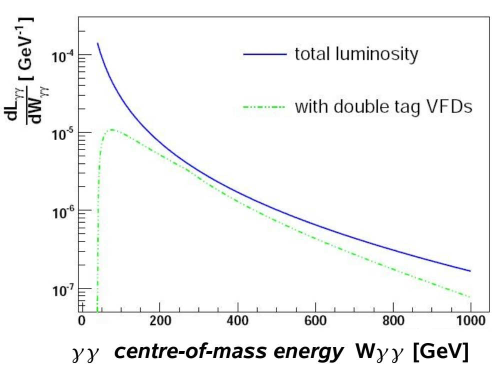
$\gamma\gamma$ and γp interactions

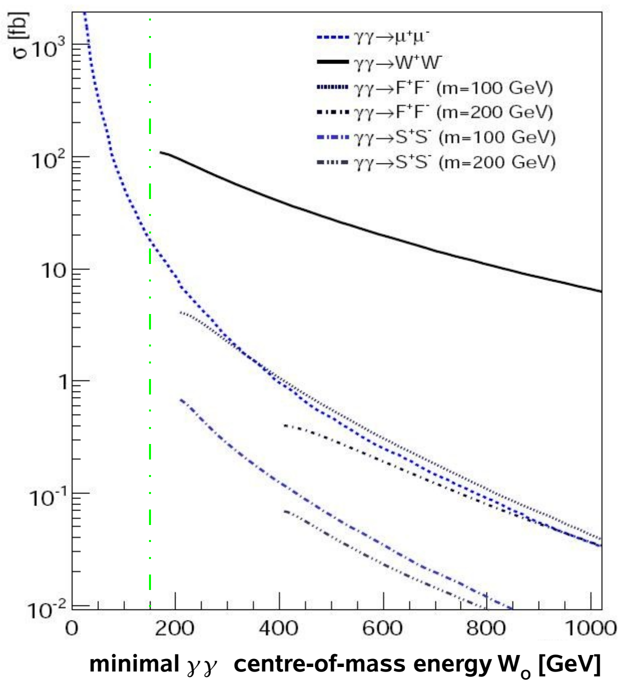
J.Hollar and the CMS collaboration, Nucl.Phys B, Proceedings Supplements, Volumes 179-180, August 2008, Pages 237-244

$\gamma\gamma \rightarrow \ell^+\ell^-$

can provide additional luminosity calibration at the early LHC running: zero pile-up, clean final state, ($\Delta N_{stat}^{\gamma\gamma \rightarrow \mu^+\mu^-}$ at 100 pb^{-1} CMS luminosity —> $\Delta L \sim 4\%$)



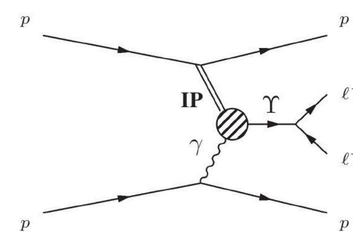


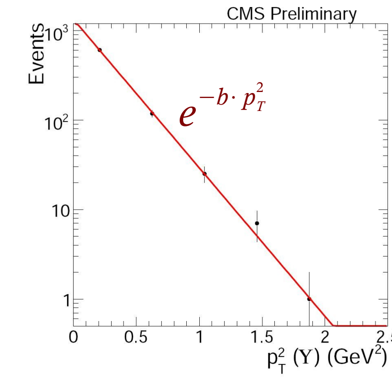


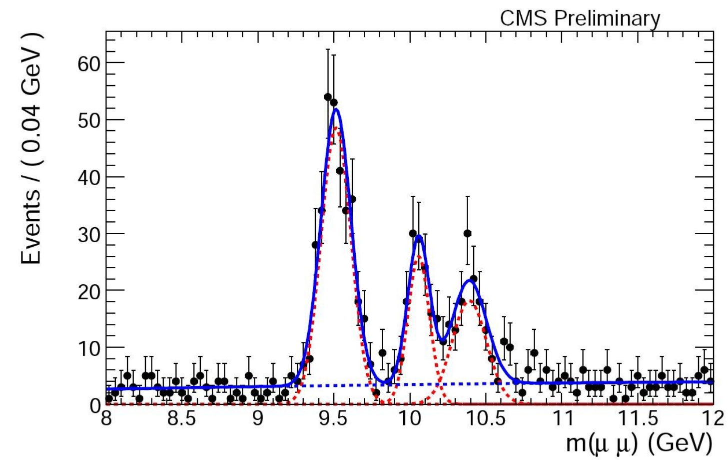
Exclusive dilepton events (two back-to-back leptons)

$\gamma p \rightarrow \Upsilon p \rightarrow \ell^+\ell^- p$

- GPDs - generalized parton densities
- Alignment and calibration of forward detectors (used for lumi measurement)
- b-slope <—> diffractive p_T







Rate and Lifetime Issues

Rate limit is dependent on local current: I=Proton Rate*pe's/proton*e*Gain

Lifetime due to photocathode damage from +ions: Q/year = I*10^7 sec/year
(MCP damage lurking just beyond photocathode damage?)

For 420 m 2*10^{33} Luminosity:
Proton Rate=.01 (acceptance/interaction)*40 MHz*5 (interactions/crossing)=2MHz
Most populated pixels see ½ this rate so 1 MHz proton rate (not so bad!)
but: 420 m Max Lum 5 x worse 220 m 3x worse than 420 m (or 15 MHz!)

[QUESTION CAN WE RUN 220m detectors at 10^{34} ????]
So assuming 10 pe's/proton and gain of 10^6
I at 220 max lum=15*10^6 PR* 10 pe's/proton * 1.6*10^{-19}*10^6 = 24 μA!
Q at 220 max lum=240 C! (in a 0.36 cm^2 pixel!)
Those are big numbers—might cause some people to give up on MCP's altogether

Easiest (partial) fix would be to lower gain—can we go x10 lower? Conventional wisdom says yes but for a price in timing—we have been studying this.
A factor of 10 in gain and 5 for starting at low lum would bring us down to
0.16 μA / 0.48 μA for 220m/420m and 1.6 C to 4.8C/yr keeping in mind that it'll be 5x worse in ~3 to 4 years (so gain reduction alone not sufficient)

Initial Laser Test Goals

- Develop useful flexible laser test facility
- Study rate properties (gain, timing) of MCP-PMT's
- Some questions we are trying to answer:

4) How does timing depend on gain as f(#pe's)
5) What is maximum rate? How does this depend on gain, number of pe's, area, pore size, number of pixels hit?
3) Establish minimum gain to achieve timing goals of our detector given expected number of pe's (~10). Evaluate different amp/cfd/tdc choices at the working point of our detector
4) Eventually lifetime test

NOTE: All results are preliminary (some extremely)

Components of Fast Timing System