DIFFRACTION 2014

The CT-PPS Project

Ada Solano
Univ. of Torino and INFN

On behalf of the CMS and TOTEM Collaborations

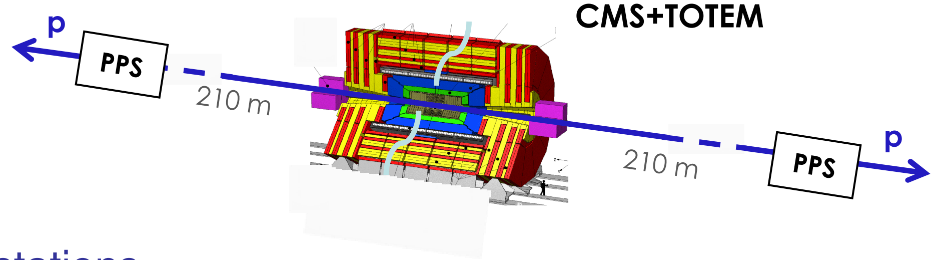
Outline

- Introduction and Physics motivations
- Experimental challenges and Detectors
- Project planning and Summary

Detector concept

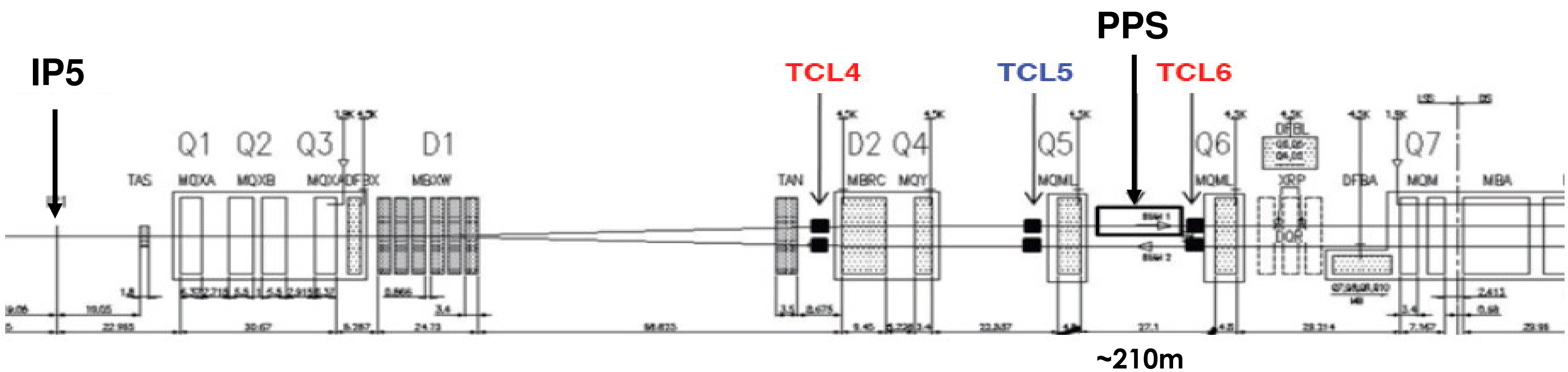
The **CMS-TOTEM Precision Proton Spectrometer** (CT-PPS) will allow precision proton measurements in the very forward regions on both sides of CMS during standard LHC running:

- Two stations for **tracking detectors** and two stations for **timing detectors** installed at ~210 m from the common CMS-TOTEM interaction point (IP5) on both sides of the central apparatus



- LHC magnets between IP5 and the detector stations used to bend out of the beam envelope protons that have lost a small fraction of their initial momentum in the interaction

→ **fractional longitudinal momentum loss (ξ) between 2% and 10%**



LHC lattice between IP5 and CT-PPS detector stations

Detector concept

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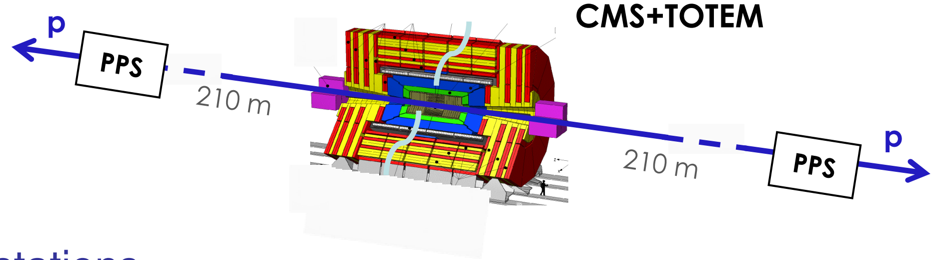

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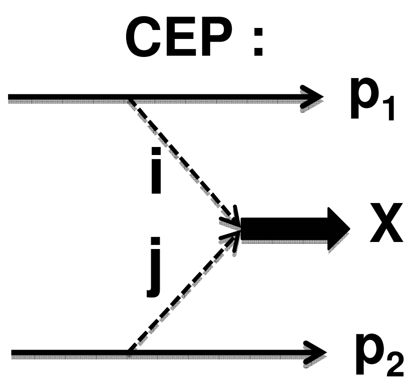
→ **fractional longitudinal momentum loss (ξ) between 2% and 10%**

A **Memorandum of Understanding** between **CERN** and the **CMS** and **TOTEM** Collaborations for a common physics program and detector development signed in **December 2013**

The TDR is ready and approved by the two Collaborations
Now presented to the LHCC (next meeting on Sep. 23rd-25th**)**
[CERN-LHCC-2014-021, CMS-TDR-13, TOTEM-TDR-003]

Physics motivations

Primary goal:
study of **central exclusive production (CEP)** in **proton-proton collision** during **standard low-β^* LHC running at high luminosity**



$$p\,p \;\rightarrow\; p + X + p$$

X = $\mu^+\mu^-$, W^+W^-, ZZ, high E_T jets, Z, H …

+ = rapidity gap

i, j = only photon and gluon exchanges are allowed

The measurement of the two scattered protons fully determines the kinematics of the central system X, irrespective of its decay mode.

$$\boxed{M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}}$$

CEP is a powerful process to access a variety of physics topics:

- **$\gamma\gamma$ exclusive production of W^+W^-, l^+l^-, but also ZZ and $\gamma\gamma$**
- **QCD program on hard diffraction**: exclusive high E_T jets, dPDFs, GPDs, S^2, …
- **photoproduction**
- **search of new resonances beyond the SM** (quantum numbers 0++, 2++)

Physics motivations

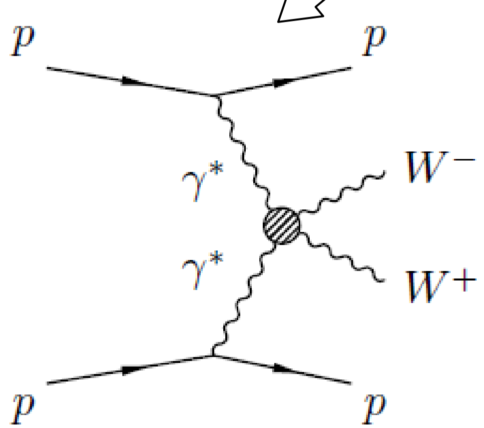
LHC as a photon-photon collider

- Measure $\gamma\gamma \rightarrow W^+W^-$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$
- Search for anomalous quartic gauge couplings (AQGC) with high sensitivity for $M_X > 1$ TeV
- Search for SM forbidden $ZZ\gamma\gamma$, $\gamma\gamma\gamma\gamma$ couplings
- Note: $\gamma\gamma \rightarrow \mu^+\mu^-$ can be used to calibrate the momentum scale of the spectrometer

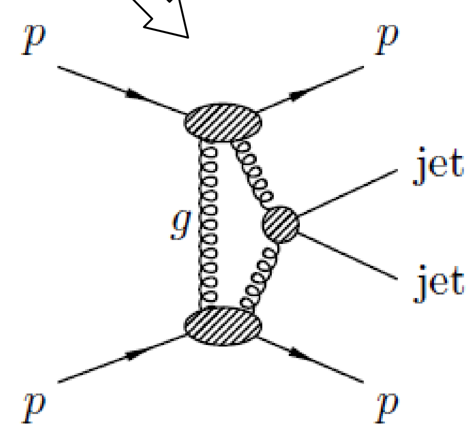
LHC as a gluon jet factory

- Gluon jet samples with small component of quark jets
- Exclusive two and three jet events, with M_X up to ~700-800 GeV
- Test of pQCD mechanisms of exclusive production

Two processes studied in detail for the TDR



Exclusive WW production



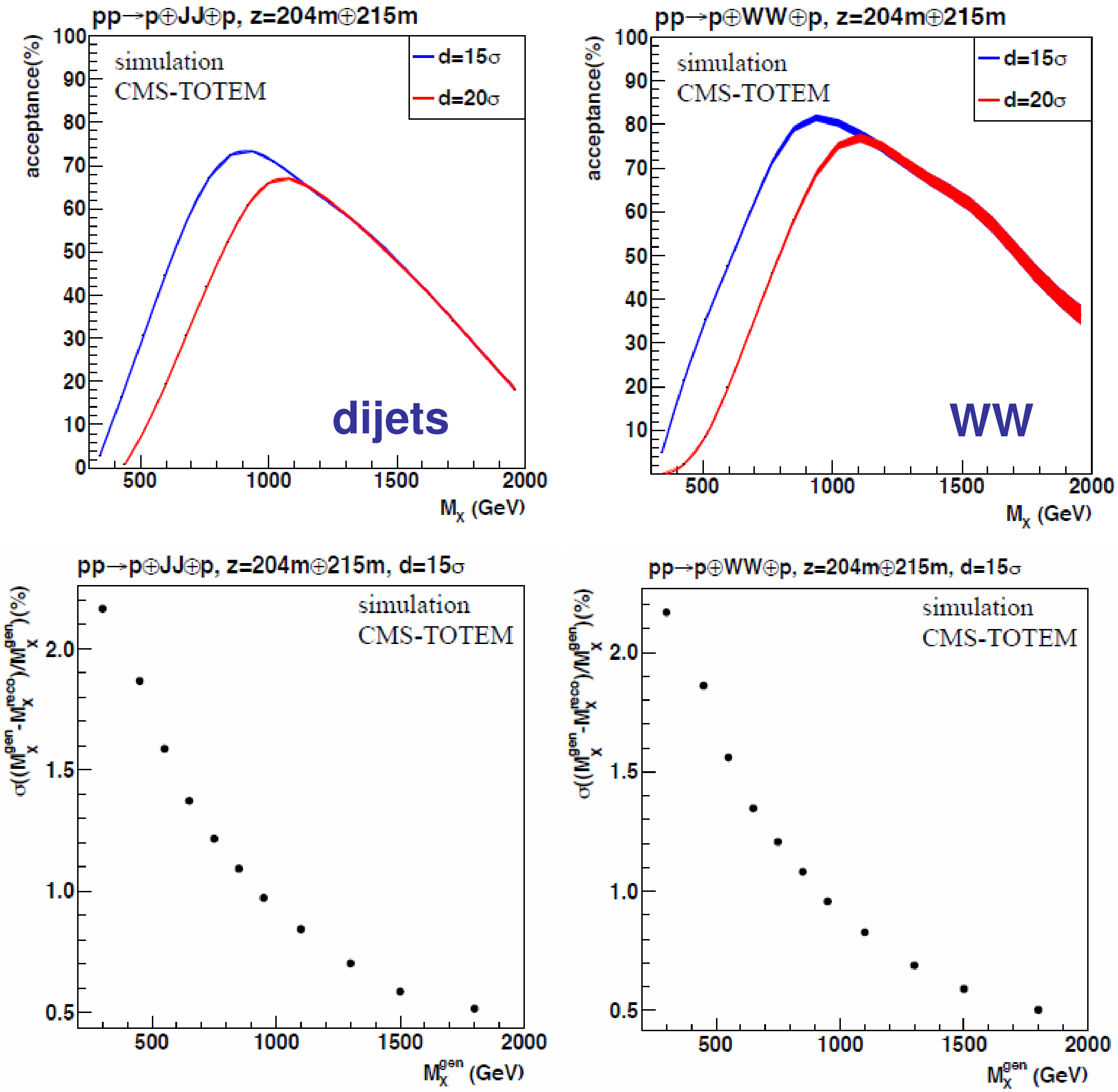
Exclusive dijet production

M_X acceptance and resolution

- With detectors at 15σ from the beam centre, PPS selects exclusive systems in the 350-1700 GeV range (ε>5%)

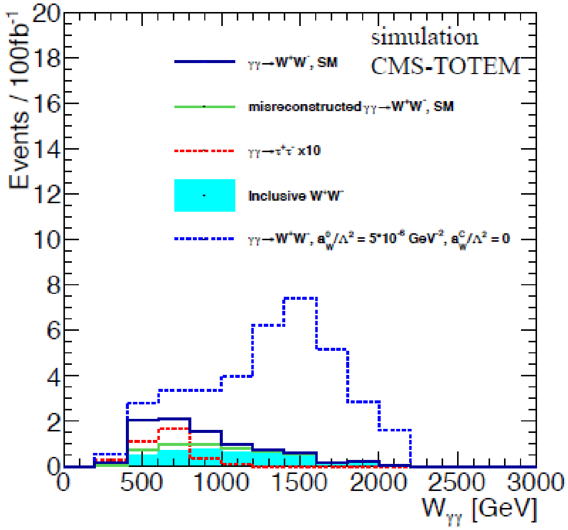
Search for exclusive (light) Higgs production is not possible

- At 15σ acceptance larger wrt 20σ for lower mass range
- γγ central system acceptance greater than that for gluon-gluon events because of smaller |t|
- Mass resolution ~1.5% at 500 GeV



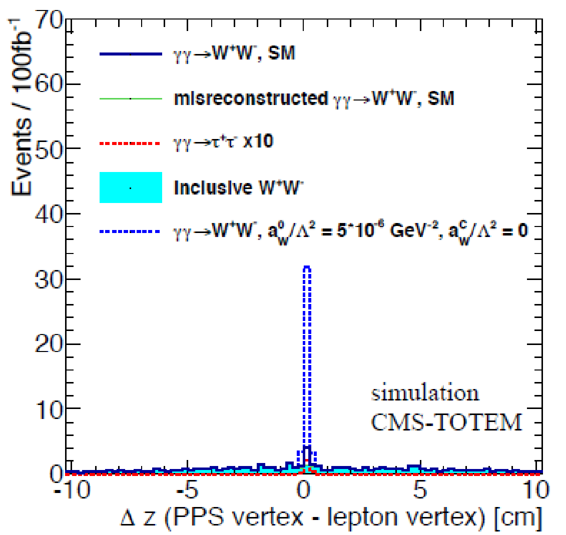
Exclusive WW production

- Study only **eμ final state**
- Dominant **background**: inclusive WW and exclusive ττ pair production



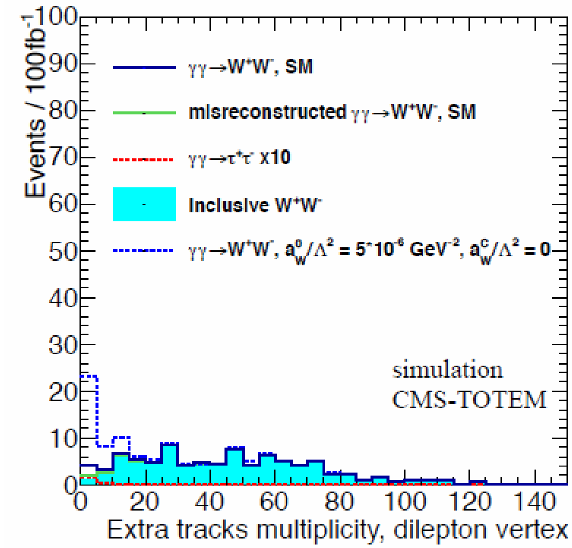
Tail of the $W_{\gamma\gamma}$ distribution ($W_{\gamma\gamma} = M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2} > 1$ TeV), where SM contribution is expected to be small, provides a very **clear separation of AQGC events**

Track multiplicity associated to the dilepton vertex after the timing selection cut



Proton timing is a powerful tool **to reject background**

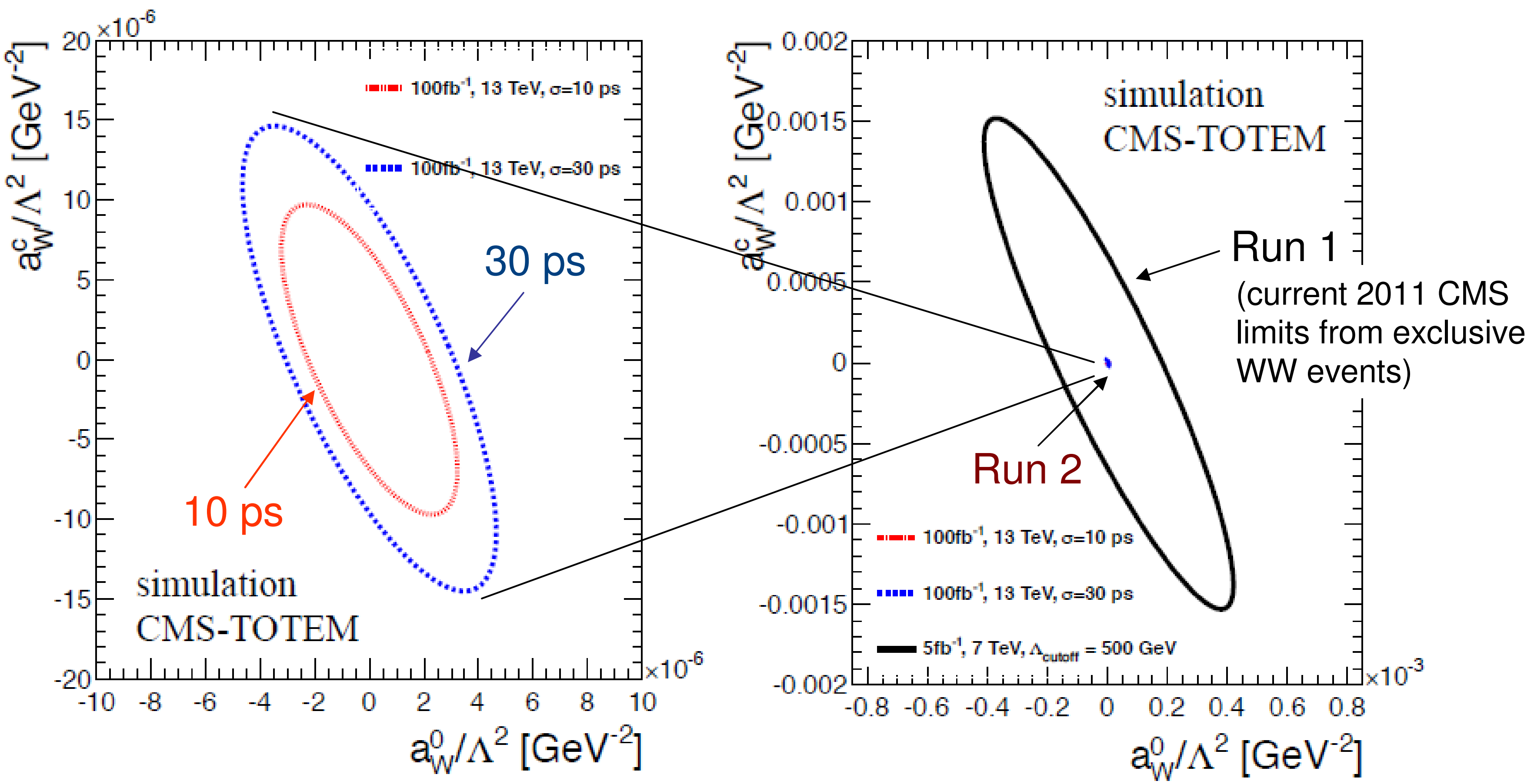
Timing resolution of **10 ps** is assumed



AQGC expected limits

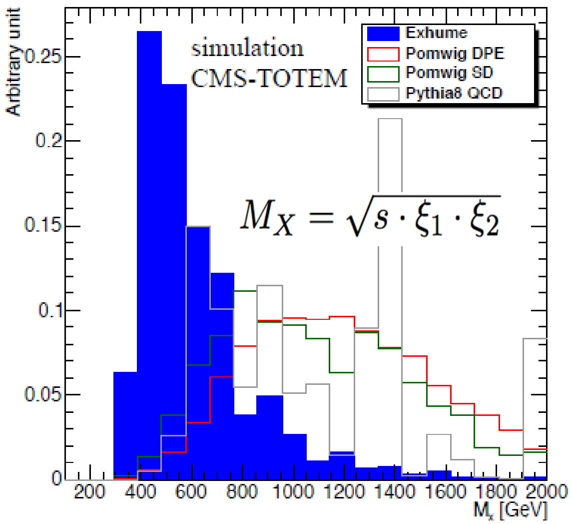
Expected limits @95%CL:

(areas outside the contours are excluded)



Exclusive dijet production

- Require 2 jets with p_T>100 GeV and $|\eta|$<2

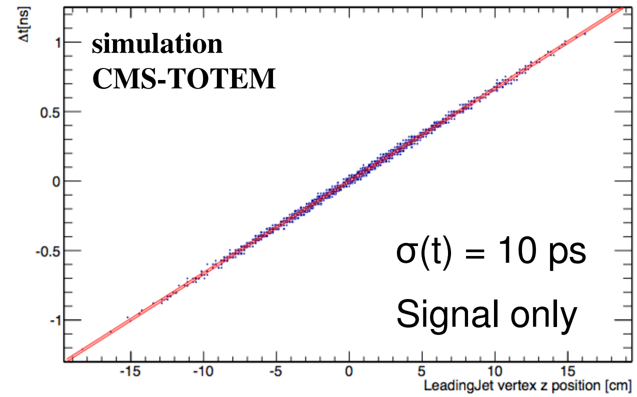


Proton timing as powerful discriminant for exclusive states:

•retain ~66% (1σ) of signal

•rejects ~70% of QCD bkg

PPS vertex vs vertex of leading jet



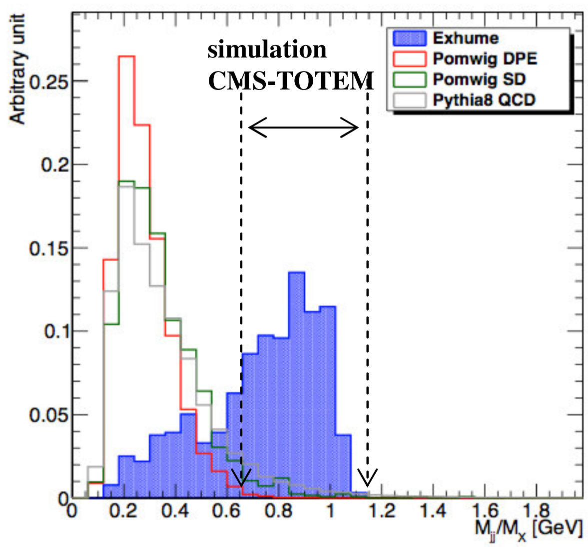
Exclusivity cuts

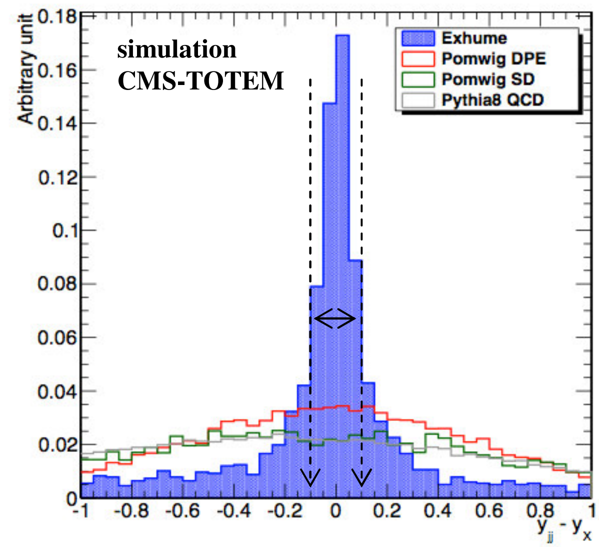
Rapidity difference:

y_{jj} (central detector) – y_x (PPS)

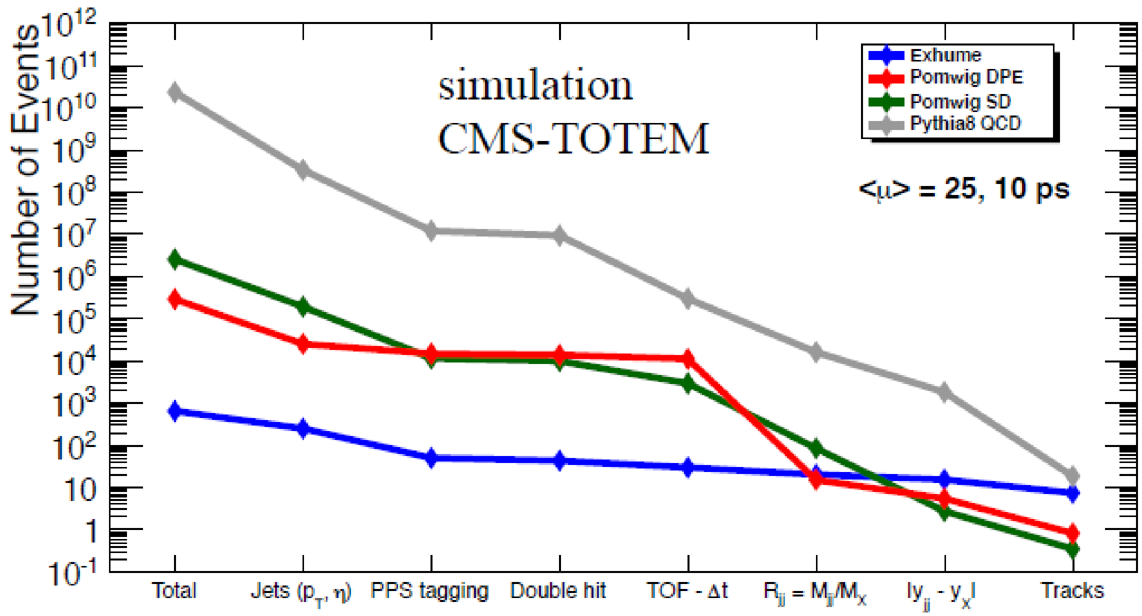
Dijet mass fraction:

$$\frac{M_{jj}\text{ (central detector)}}{M_X\text{ (PPS)}}$$





Yields per 1/fb - Pileup=25

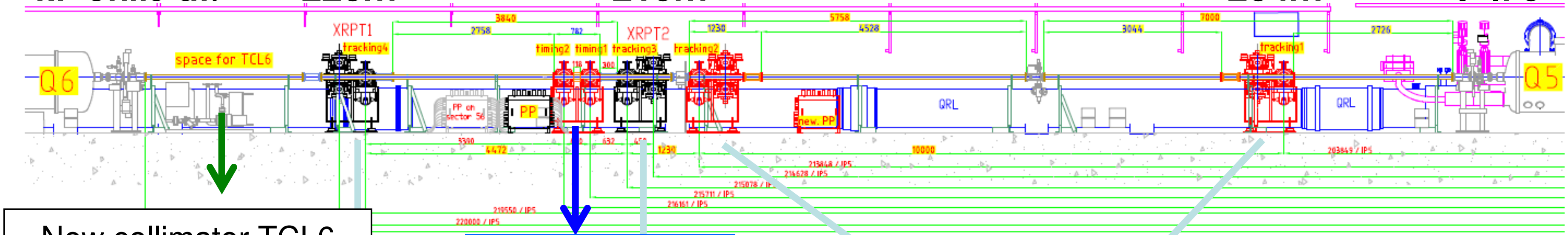


Event yields for signal and background processes as a function of the cuts applied.

$\Rightarrow$ S/B ~ 1/3

CT-PPS in the LHC beam line

RP units at: **220m** **~ 215m** **204m** **→ IP5**



New collimator TCL6 to protect magnet Q6

2 new horizontal cylindrical RPs

2 vertical + 1 horizontal RPs per station (relocated from 147m)

2 vertical + 1 horizontal RPs per station

Extreme flexibility in using Roman Pot units according to the running scenario

In particular, in the exploratory phase of 2015-2016:

- pursue the TOTEM / TOTEM+CMS physics programme at high-β^* low/medium luminosity
- prove the RP insertions and data taking at high luminosity and pileup

Relevant pots/detectors for low-β^* high luminosity runs:

2 new horizontal cylindrical RPs equipped with timing detectors

+

2 horizontal rectangular RPs equipped with tracking detectors

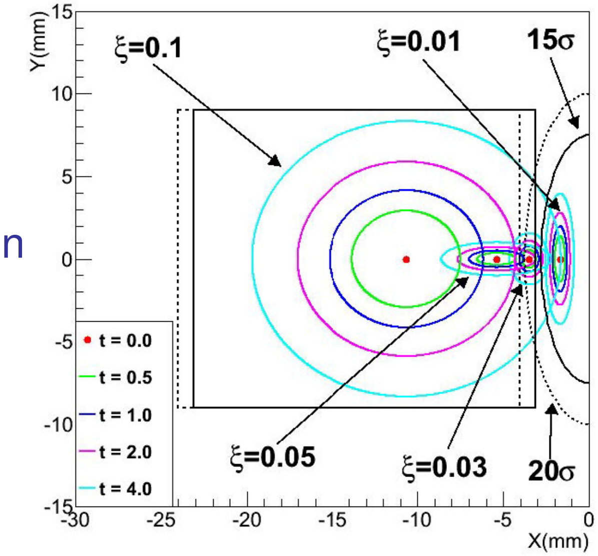
Experimental challenges

- Ability to **operate the detectors close to the beam (15-20σ)** to maximize acceptance for low momentum-loss protons

Need to **limit the additional RF impedence introduced by beam pockets**:
- ➢ now RPs with improved RF shielding
- ➢ R&D on Movable Beam Pipe as future beam pocket option

Need to **sustain very high radiation levels**. For 100 fb^{-1}:
- • proton flux up to $5 \cdot 10^{15}$ cm^{-2} in the **tracker detectors**
- • 10^{12} n_{eq}/cm^2 and 100 Gy in **photosensors** and **readout electronics**
- ➢ upgrade Si-strips to 3D Si pixel detectors
- ➢ R&D on solid state timing detectors (diamond, LGAD, 3D)

Position of scattered protons at 204m, for fixed (ξ,t)



2% < ξ < 10%

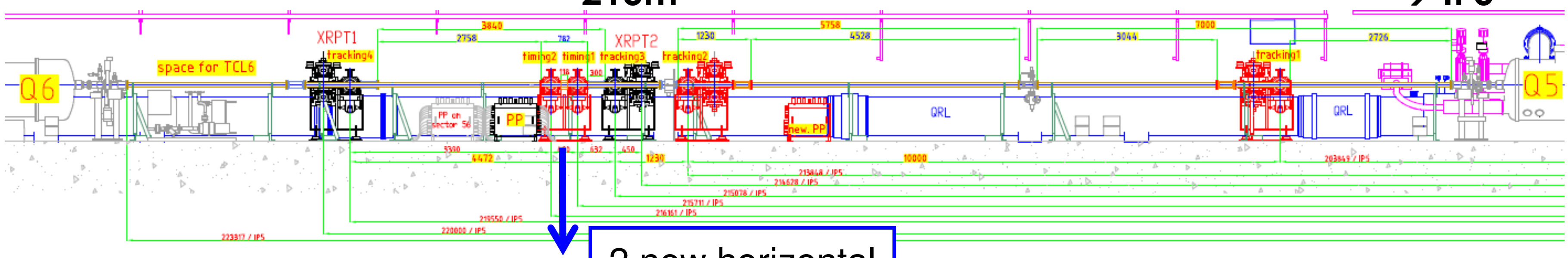
- Ability to **reject the background** expected in the high pile-up (μ=50) environment of normal LHC running, mainly inelastic events overlapping with SD protons from the same bunch crossing

Use **proton timing** for primary vertex determination

Exploit the **kinematical constraints** of CEP events

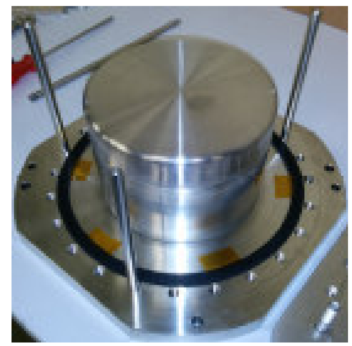
Timing detectors

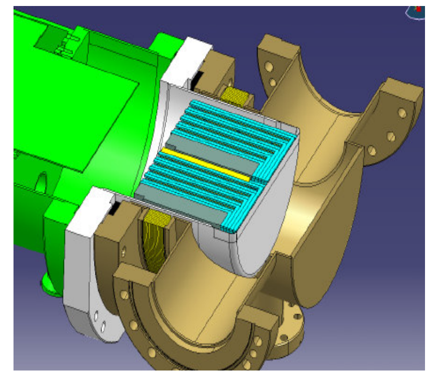
~ 215m → IP5



2 new horizontal cylindrical RPs

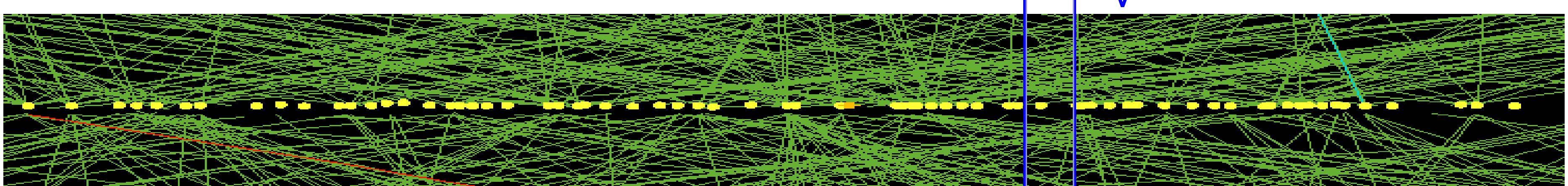
Proton timing measurement from both sides of CMS allows to determine the primary vertex, correlate it with that of the central detector and reject pile-up





- Time resolution ~10 ps → Vertex z-by-timing: ~2 mm
- Segmentation to cope with the high occupancy expected
- Edgeless (~ 200 μm)
- Radiation hard

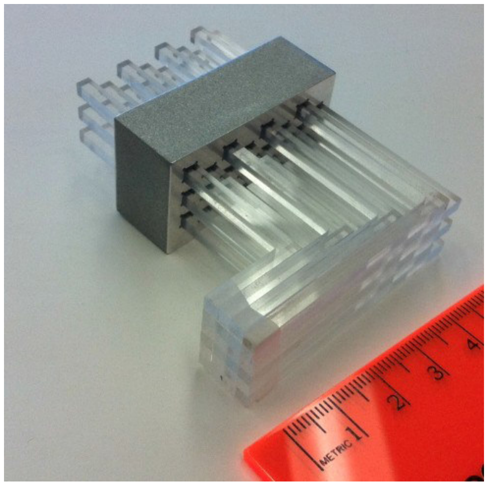
σ_V ~ 2 mm



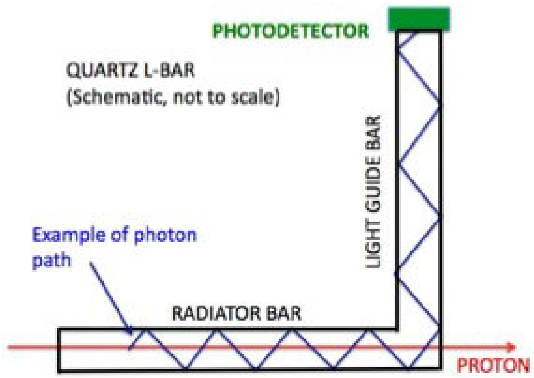
5 cm

Timing detectors

- **Baseline: L-bar Quartic**, Čerenkov detectors with quartz radiators

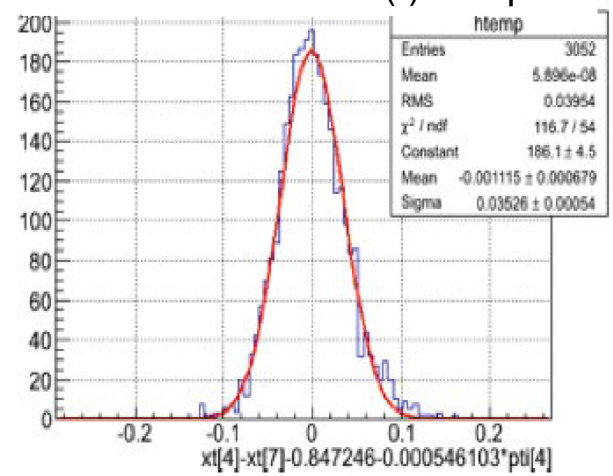


$4 \times 5 = 20$ 3×3 mm^2 bar elements



Beam test results:

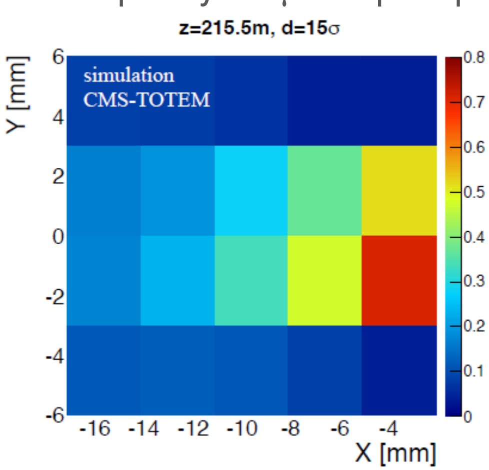
Time resolution: $\sigma(t)$=33 ps



2+2 in-line modules: $\sigma(t)$~15 ps

Detector installation foreseen at the end 2015

Occupancy for μ=50 pileup



High occupancy causes inefficiency due to overlapping hits (may reach ~40%)

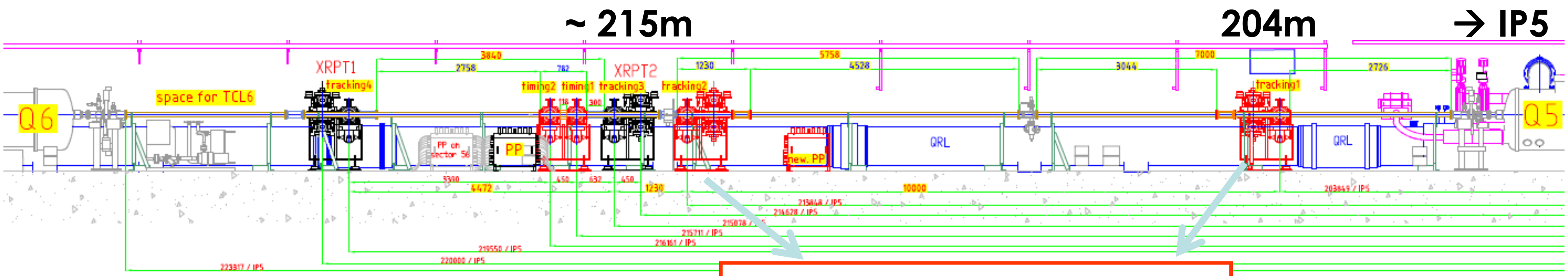
⇒

- **R&D** on **solid state detectors** as future alternative solutions: **Diamonds, LGADs, 3Ds**

Promising for:

- more radiation hardness
- smaller segmentation
- thin → more layers

Tracking detectors



2 horizontal rectangular RPs
~10 meters apart

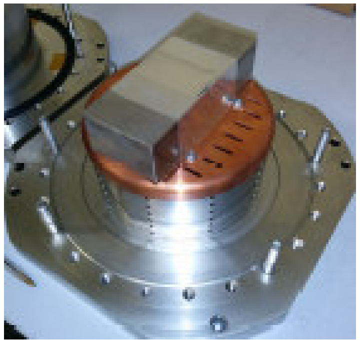
Position and angle, combined with the beam magnets, allow to determine the momentum of the scattered proton

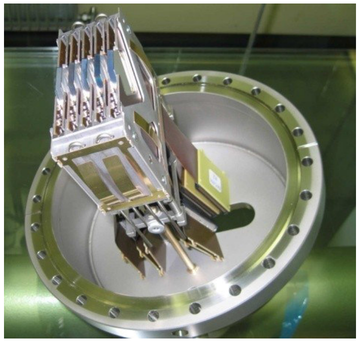
- Position resolution of ~10 μm
- Angular resolution of ~1-2 μrad
- Slim edges on side facing the beam
  → dead region ~100 μm
- Tolerance to inhomogeneous irradiation
  → ~$2 \cdot 10^{15}$ n_{eq}/cm^2 close to the beam (for 100 fb^{-1})

⇩

- **Baseline: 3D silicon pixel detectors**

- Detectors should fit into existing RPs

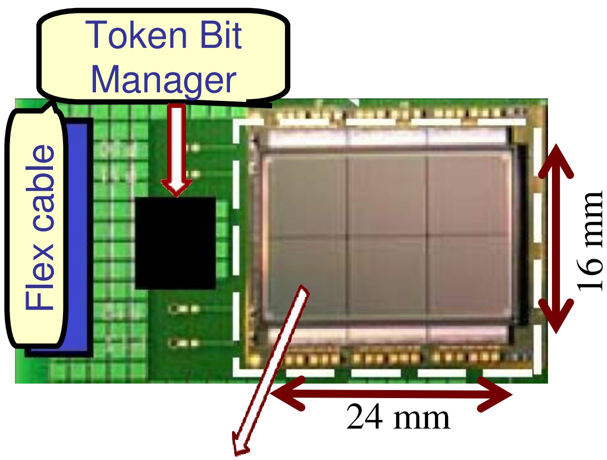




Tracking detectors

6 detector planes per station

For each plane:



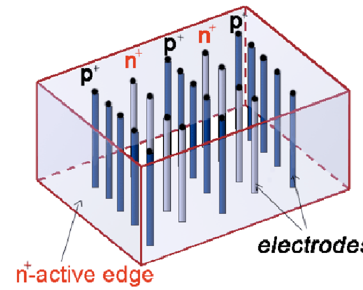
- 16 x 24 mm^2 **3D silicon pixel sensors**
- 150(x) x 100(y) μm^2 pixel pattern same as CMS pixel detectors
- **6 PSI46dig readout chips** (52x80 pixels each)

Same readout scheme as Phase-I upgrade of CMS Forward Pixel Tracker

→ Existing CMS DAQ components and software can be reused

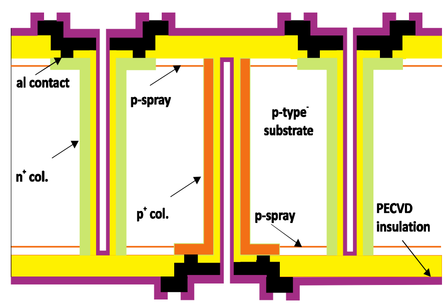
3D sensors consist of an array of columnar electrodes

- Mature technology after ATLAS IBL



Interesting features w.r.t. planar sensors:

- **Low depletion voltage** (~10 V)
- Fast charge collection time
- Reduced charged trapping probability and therefore **high radiation hardness**
- **Slim edges**, with dead area of ~100-200 μm or **Active edges**, with dead area reduced to a few μm
- Spatial resolution comparable with planar detectors



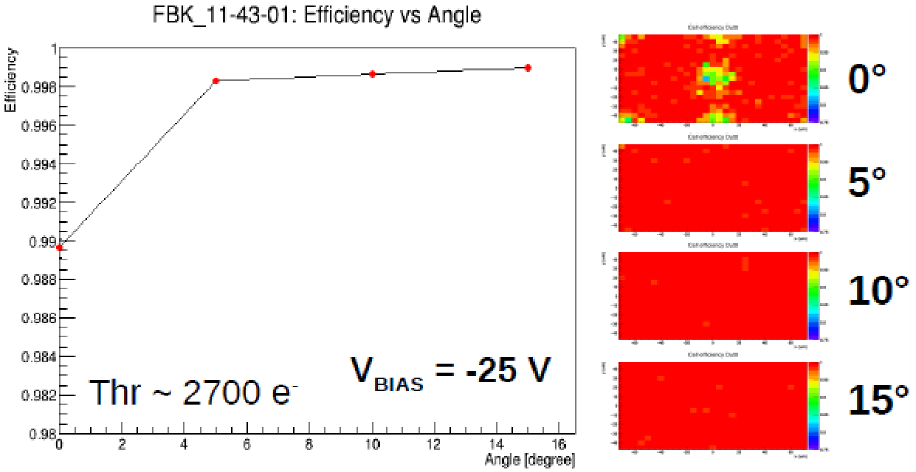
Favorite solution: FBK 3D with inter-electrode distance 62.5 μm

Detector installation foreseen in 2016

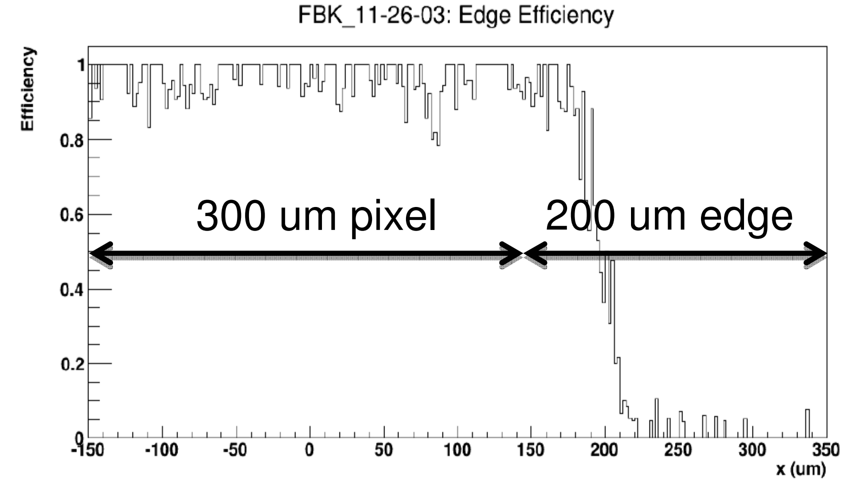
Tracking detectors

Preliminary results of un-irradiated FBK 3D sensors read out by PSI46dig ROCs, tested at Fermilab with a 120 GeV proton beam

Efficiency vs angle



Edge Efficiency



Detectors are tilted to reduce the geometrical inefficiency due to the empty electrode columns

Efficiency > 99.5% already at 5°

Spatial resolution for 2 pixel clusters : ~12 μm

Efficiency remains high up to 150 μm from the sensor's boundary

Measurements with the same detectors, irradiated at fluences from $1 \cdot 10^{15}$ to $1 \cdot 10^{16}$ n_{eq}/cm^2, were just taken during the last two weeks at Fermilab. Data analysis is on-going: results are promising.

Project planning

The CT-PPS project includes an **exploratory phase** in 2015-2016 and a **production phase** until LHC LS2 (2018)

- **Exploratory phase** (2015-16)
  - Prove the ability to operate detectors close to the beamline at high luminosity
    - Show that CT-PPS does not prevent the stable operation of the LHC beams and does not affect significantly the luminosity performance of the machine.
  - In 2015:
    - Evaluate RPs in the 204-215 m region
    - Demonstrate the timing performance of the Quartic baseline
    - Use TOTEM silicon strip detectors at sustainable radiation intensity
    - Integrate the CT-PPS detectors into the CMS trigger/DAQ system.
  - In 2016:
    - Evaluate the MBP option
    - Upgrade the tracking to pixel detectors
    - Upgrade the timing detectors if required/possible

- **Data Production phase**
  - Aim at accumulating 100 fb^{-1} of data before LHC LS2

Summary

The joint CMS-TOTEM Proton Precision Spectrometer project has started.
The TDR has been approved by the CMS and TOTEM Collaborations
and will be examined by the LHCC in two weeks.

CT-PPS adds **precision proton tracking and timing detectors** in the very forward region on both sides of CMS at ~200 m from IP5 to **study CEP events** in pp collisions during **standard low-β^* LHC running at high luminosity**.

Central Exclusive Production allows to study a **variety of physics topics**.

New radiation-hard, slim-edge timing and tracking detectors are necessary for the low-β^* high luminosity data taking.

Detector baseline: Roman Pots
Čerenkov L-bar Quartic detectors for timing
3D silicon pixel detectors for tracking

R&D: Movable Beam Pipe
Solid state timing detectors (Diamonds, Low Gain Avalanche Diodes, 3Ds)

Project planning: **Exploratory phase in 2015-2016**
Data Production phase, aiming to collect 100 fb^{-1} of data