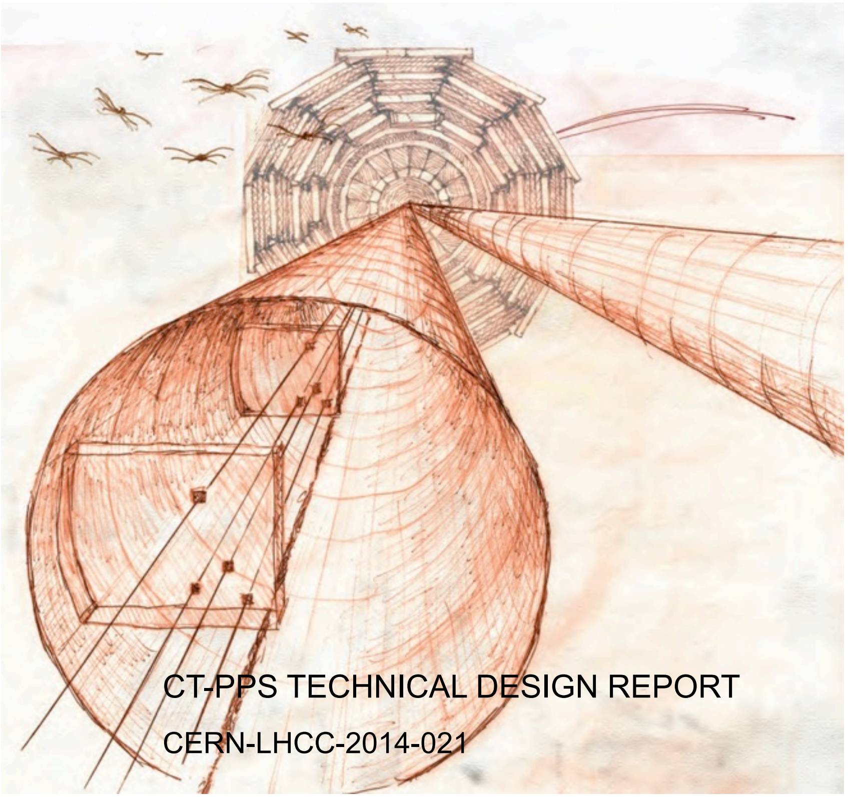


The CT-PPS project and timing detectors

Joao Varela, LIP

WORKSHOP ON PICOSECOND PHOTON SENSORS

Prague, 8-10 June 2015

CT-PPS project

CMS-TOTEM Precision Proton Spectrometer

CMS-TOTEM Memorandum of Understanding:

- CMS and TOTEM jointly undertake the PPS project

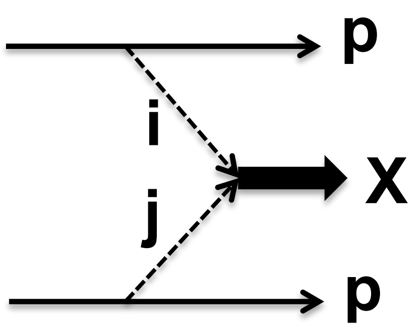
CT-PPS project approval:

- CERN Research Board, December 2014

Central exclusive production

CEP : $p\,p \rightarrow p + X + p$

where X is a **state measured in the central region**



X = μ+μ-, Z, H, WW, ZZ, and high E_T jets, …

+ = rapidity gap

i, j = only photon and gluon exchanges are allowed

Four-momentum of X is fully constrained by the two protons kinematics:

ξ – proton fractional momentum loss

t – proton Mandelstam invariant

Physics motivations

QCD

QCD physics

- Exclusive two and three jet events
- Test of pQCD mechanisms of exclusive production.
- Gluon jet samples with small component of quark jets

EWK

LHC as a photon-photon collider

- Measure $\gamma\gamma \rightarrow W^+W^-$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$
- Search for AQGC with high sensitivity
- Search for SM forbidden $ZZ\gamma\gamma$, $\gamma\gamma\gamma\gamma$ couplings

BSM

Search for new physics

- Clean events (no underlying pp event)
- Independent mass measurement by pp system
- J^PC quantum numbers 0++, 2++

High cross section — TOTEM

bridge

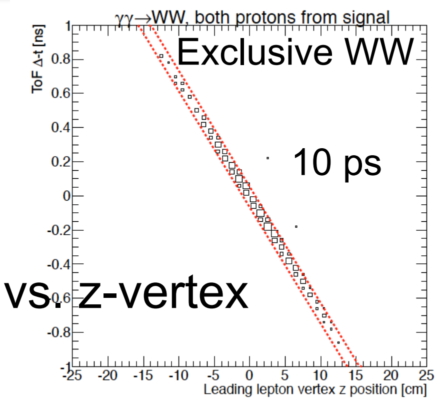
Low cross section — CMS

Detector concept

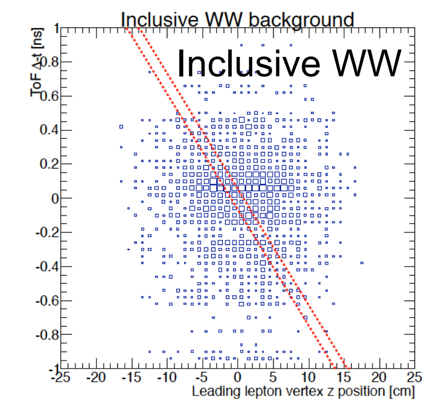
CT-PPS concept:

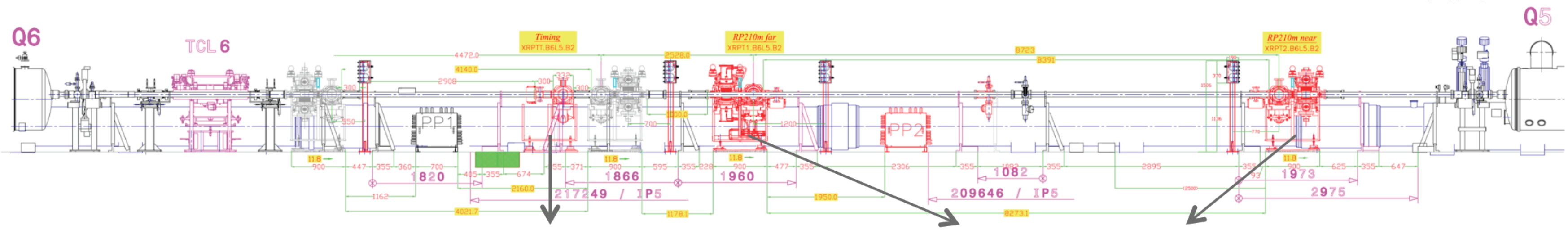
1) Proton spectrometer making use of **machine magnets**
2) Two tracking stations with **3D pixel detectors**
2) One stations with **timing detectors**

- Use timing to reject pileup background
  – time difference of two protons is correlated to collision vertex



ToF vs. z-vertex





2 new horizontal cylindrical RPs (1 in LS1)

2 horizontal box-shaped RPs

Main experimental issues

- Physics performance at high luminosity (2.10^{34} cm^{-2} s^{-1})
  - pileup background, beam background
- Detector operation close to the LHC beam
  - RF impedance, showers originated in the detectors
- Radiation levels
  - in detectors and front-end electronics
- Timing detectors
  - challenge is 10 ps resolution and high rates
- Tracking detectors
  - challenge is fluence 5.10^{15} $protons.cm^{-2}$ (100 fb^{-1})

Project phases

- The CT-PPS plan includes an **exploratory phase** in 2015-16 followed by a **production phase**.

- **Exploratory phase (2015-16):**

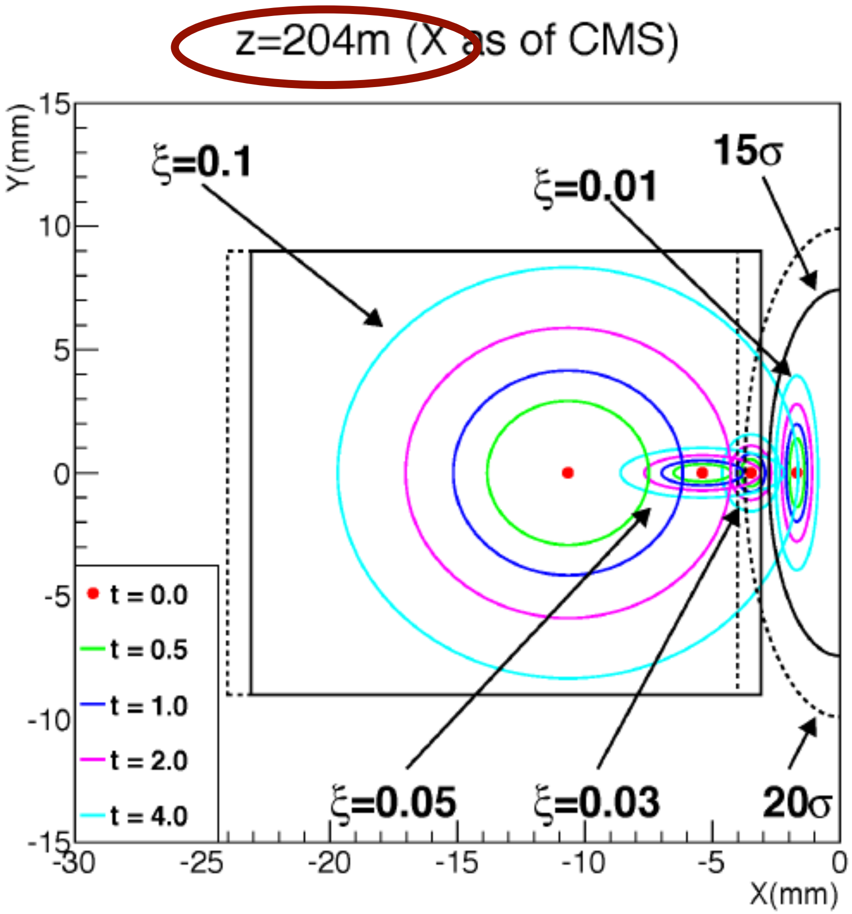
  Show that CT-PPS does not prevent the stable operation of the LHC beams and does not affect significantly the luminosity performance of the machine.

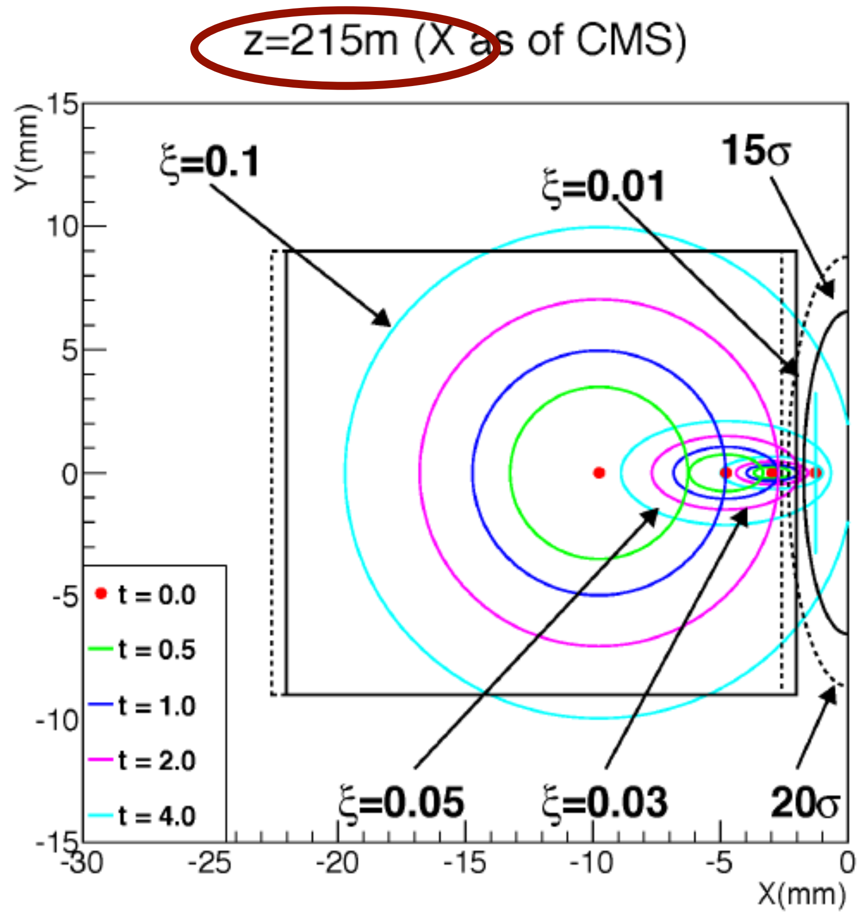
Detector and physics performance

Detector acceptance

Acceptance: X vs Y (includes ξ,t ellipses)

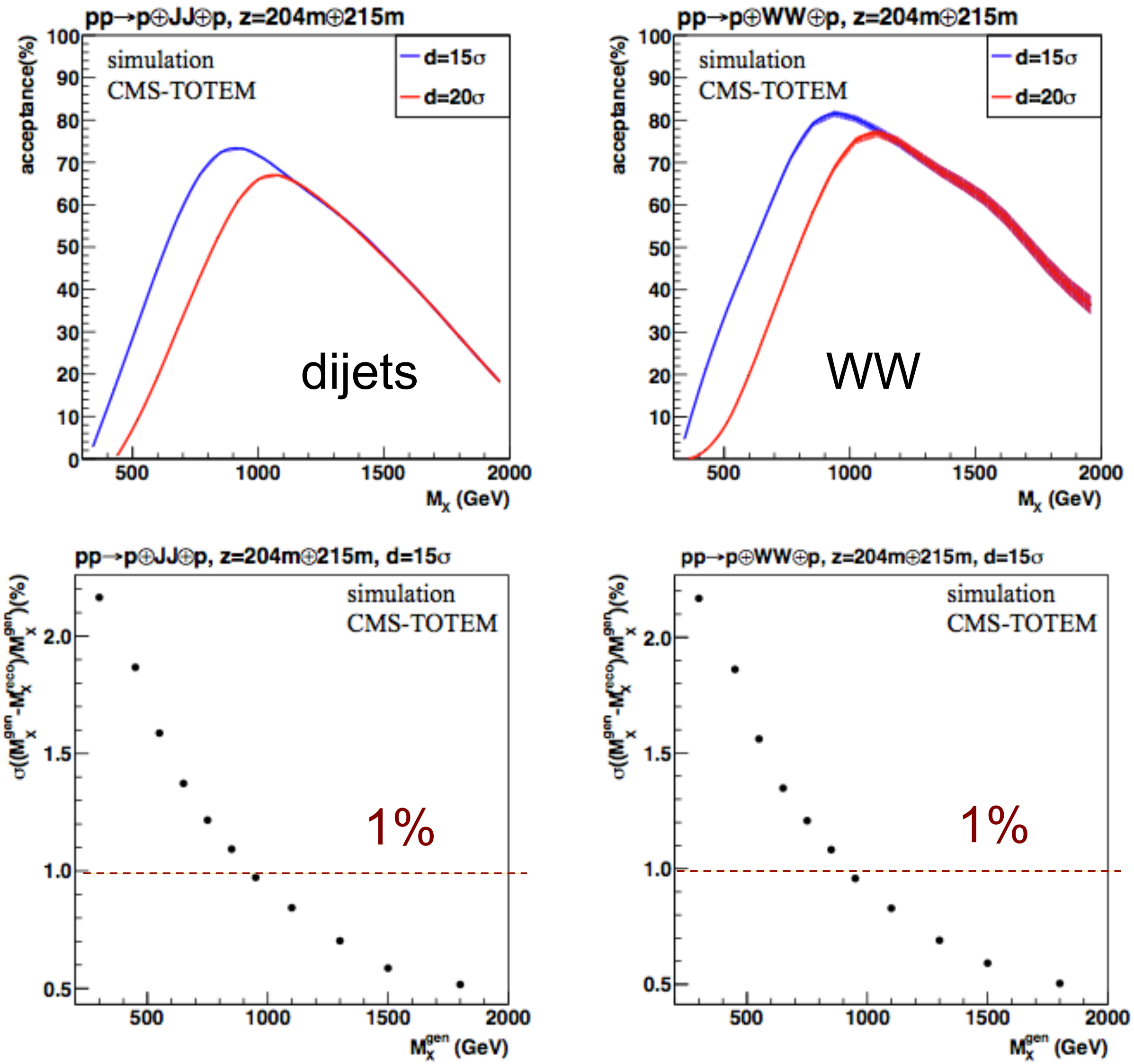
- Particle gun (t,ξ,φ) based on HECTOR at √s = 13 TeV





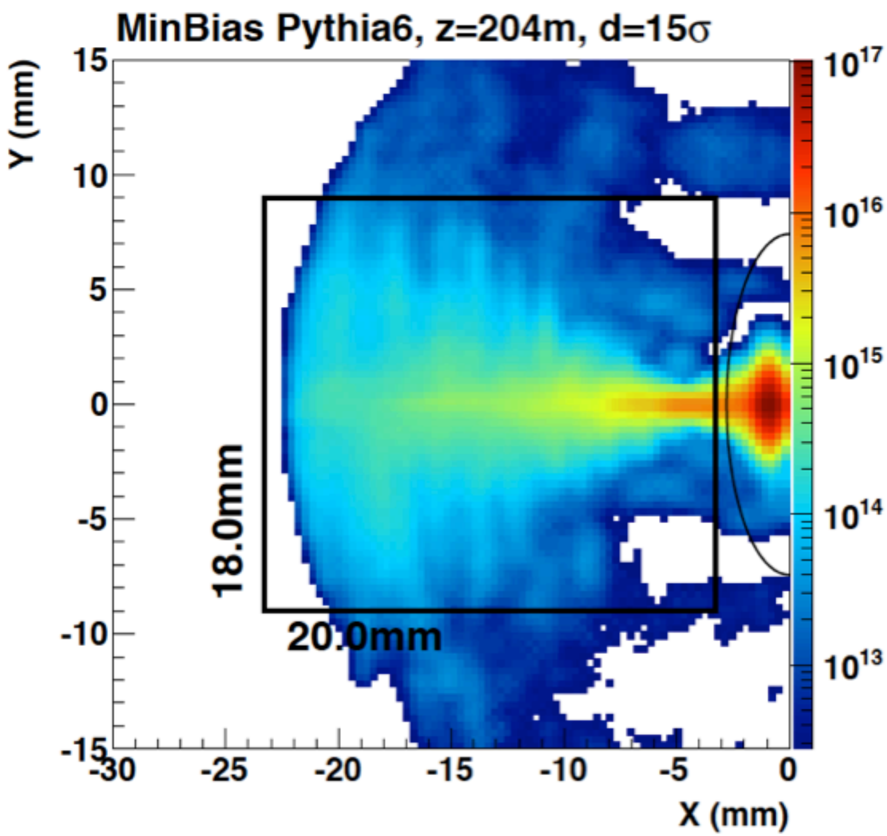
Mass acceptance and resolution

- Mass acceptance and resolution vs M_X
- PPS selects exclusive systems in 300-1700 GeV range (ε>5%)
- At 15σ acceptance larger by a factor of two (wrt 20σ) for lower masses
- Mass resolution ~1.5% at 500 GeV



Radiation levels

Radiation levels in the detector volume were studied using TOTEM data and simulations



Per 100 fb^{-1}:

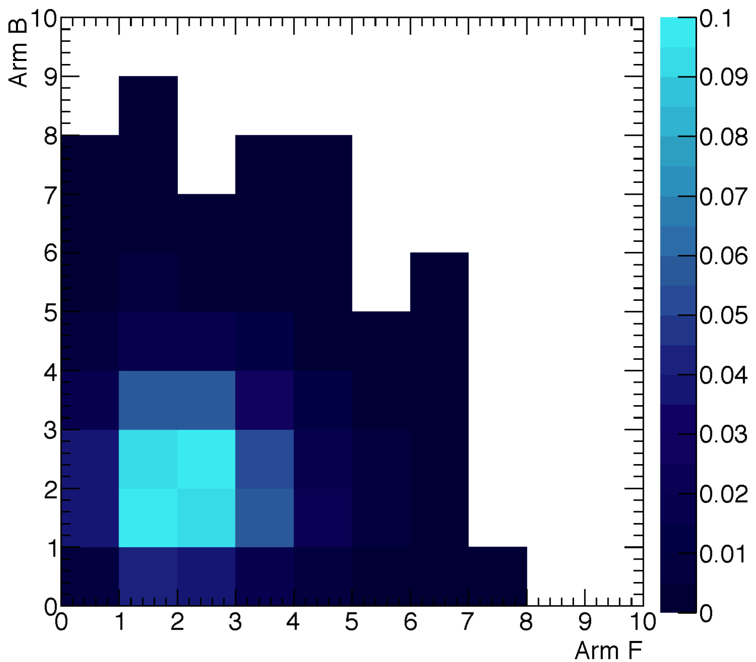
- Proton flux up to 5.10^{15} cm^{-2} in the **pixel detectors**
- 10^{12} neq/cm^2 and 100 Gy in **photosensors** and **readout electronics**

Detector occupancy

Effect of single diffraction pileup

- Average proton multiplicity in detectors for WW signal with pilup μ =50 is approx. 2

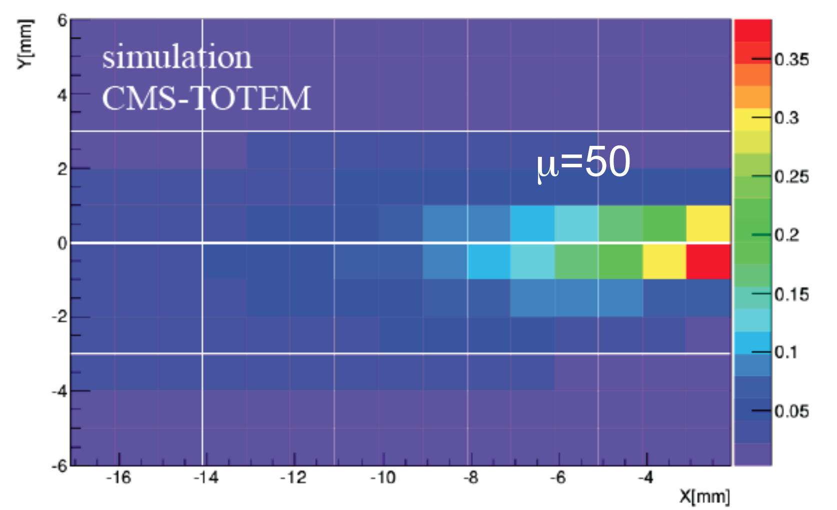
Particle Multiplicity



Expected occupancy:

- Beam-related backgrounds and pileup interactions are included.
- Occupancy of detectors at 15 σ from the beam

Occupancy /mm^2



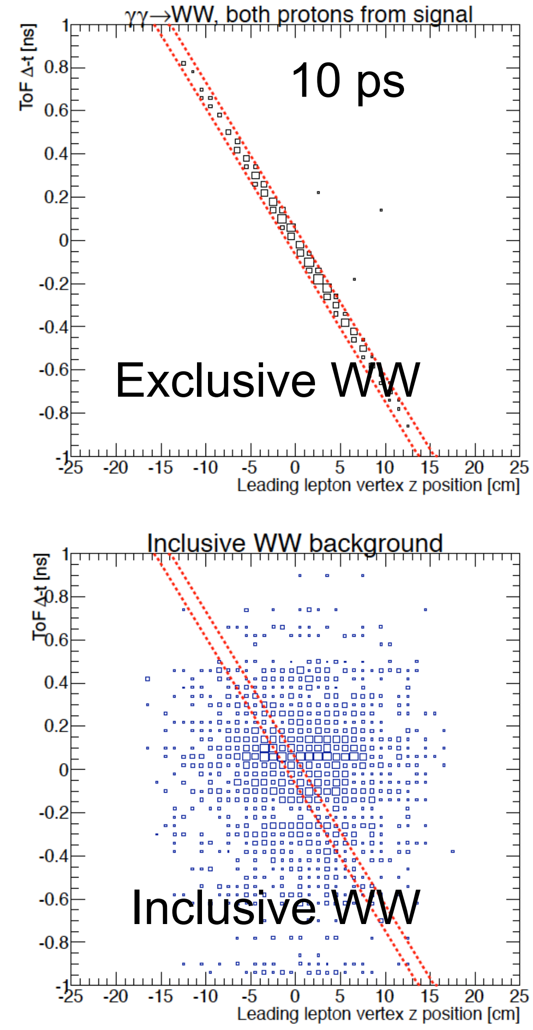
CT-PPS timing vs. z-vertex

- Use timing to reject pileup background
- Two scenarios were studied:
  - 10ps and 30ps time resolution

High occupancy in baseline timing detector (Quartic 3x3 mm^2)

Inefficiency due overlapping hits ~40%

Strong motivation for R&D on new timing technologies

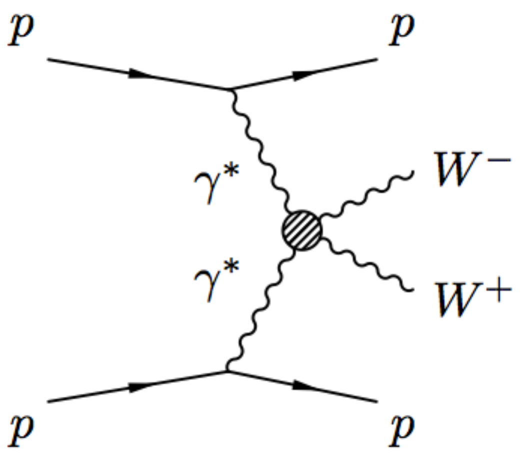


Study of WW production

- Study of process: **pp→pWWp**
  - Exclusive production of W pairs via photon exchange

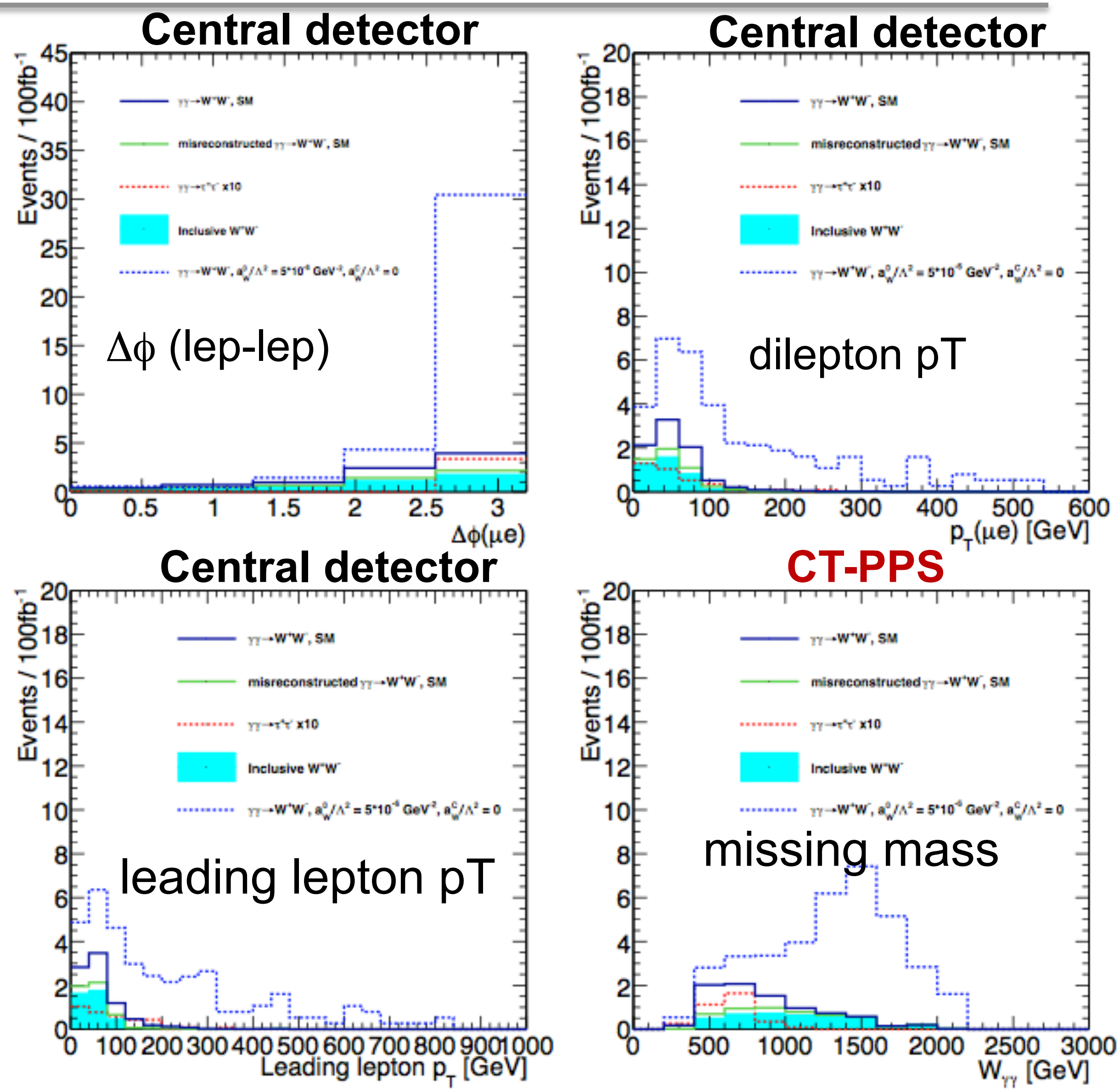
- **Events:** W pair in central detector, intact protons detected in CT-PPS
- Study only **eμ final state**

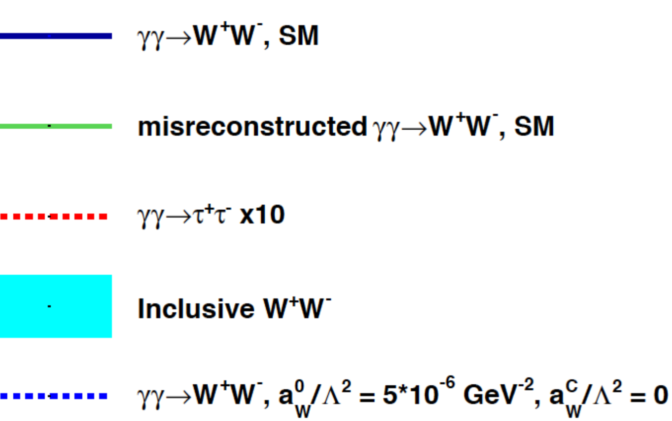
- **Two steps:**
  1. SM observation of WW events
     - σ_{WW}=95.6 fb
  2. Study of anomalous coupling
     - AQGCs predicted in BSM theories
     - Two points: $a_0^W/\Lambda^2=5\times10^{-6}$, $a_C^W/\Lambda^2=5\times10^{-6}$



Kinematical distributions

Missing mass distributions provide a very clear separation of AQGC events





AQGC yields (in fb)

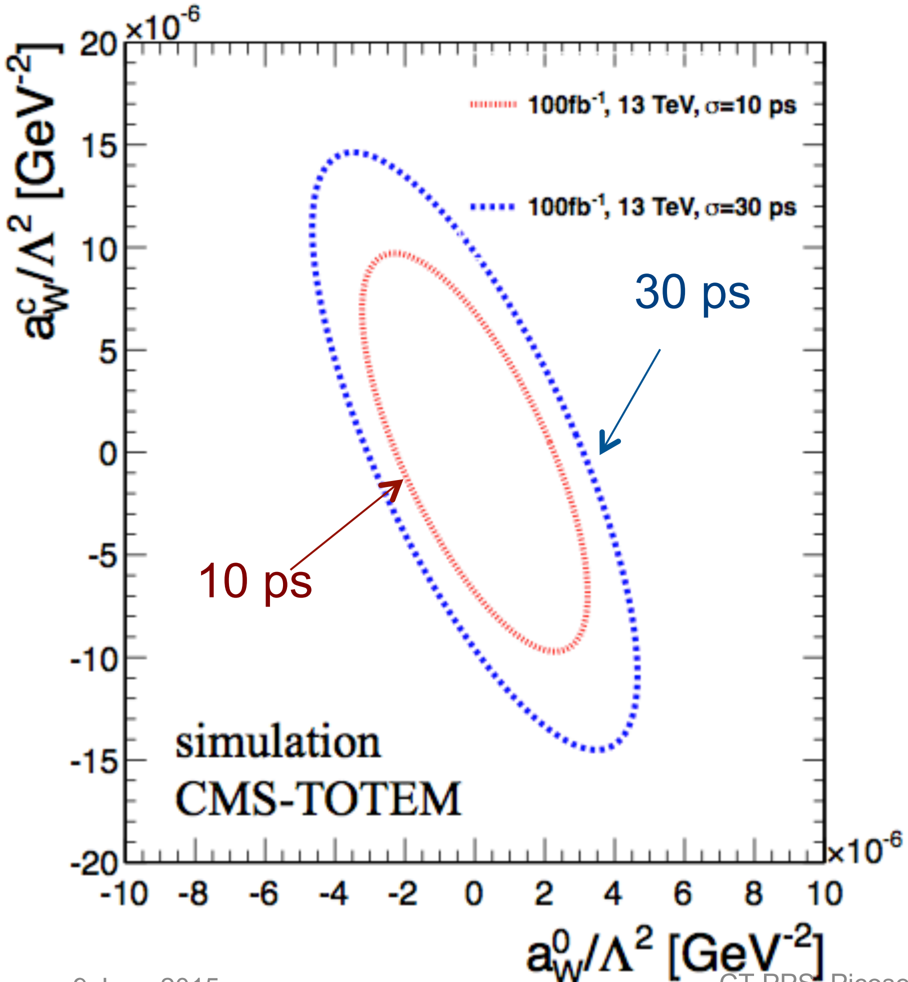
Table 4: Cross section (in fb) for the expected exclusive WW events due to anomalous quartic gauge couplings, for different values of anomalous coupling parameters (a_0^W and a_C^W) after each selection cut (for a timing resolution of 10 ps). In case of different values, numbers in parentheses are for a timing resolution of 30 ps. Only the $e\mu$ final state is considered. Statistical uncertainties are shown.

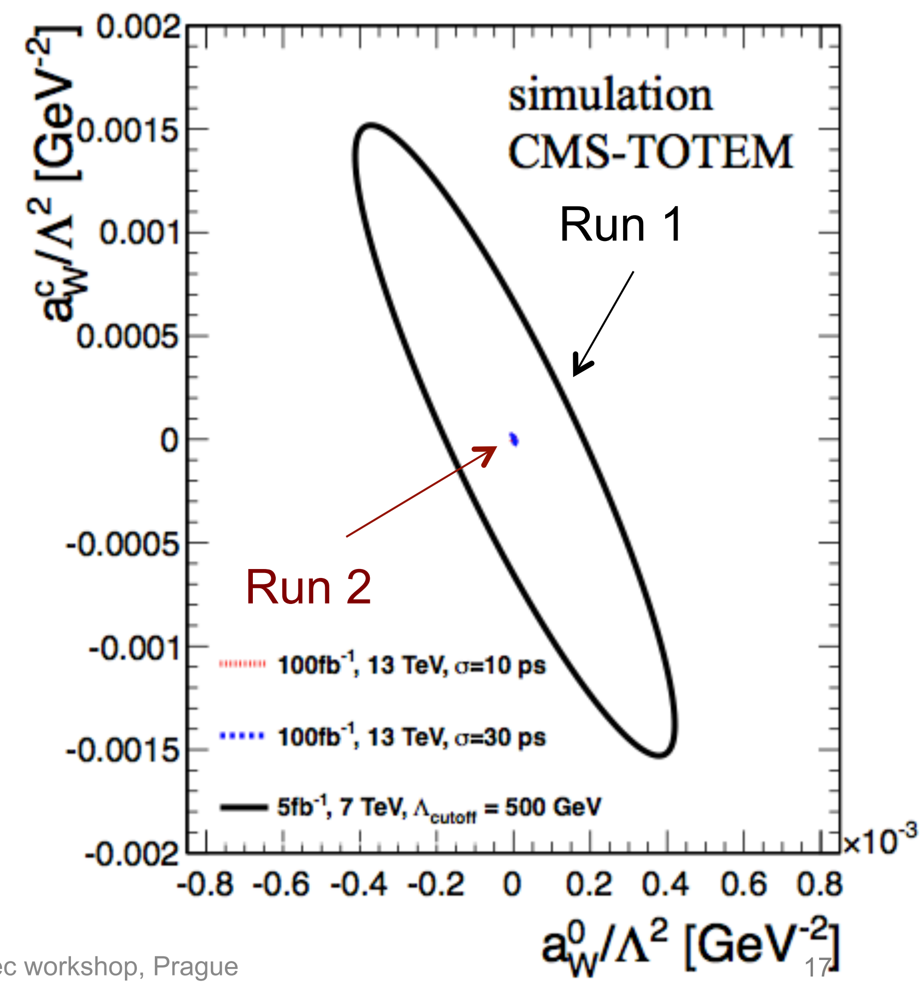
selection	cross section (fb)	
	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}\text{GeV}^{-2}$ ($a_C^W = 0$)	$a_C^W/\Lambda^2 = 5 \times 10^{-6}\text{GeV}^{-2}$ ($a_0^W = 0$)
generated $\sigma \times \mathcal{B}(WW \to e\mu\, \nu\bar{\nu})$	3.10±0.14	1.53±0.07
≥ 2 leptons ($p_T > 20$ GeV, $\eta < 2.4$)	2.33±0.08	1.00±0.04
opposite sign leptons, "tight" ID	1.82±0.08	0.78±0.03
dilepton pair $p_T > 30$ GeV	1.69±0.07	0.68±0.03
protons in both PPS arms (ToF and TRK)	0.52 (0.50)±0.04	0.18 (0.17)±0.02
no overlapping hits in ToF detectors	0.35 (0.32)±0.03	0.12 (0.11)±0.01
ToF difference, $\Delta t = (t_1 - t_2)$	0.35 (0.32)±0.03	0.12 (0.11)±0.01
$N_{\text{tracks}} < 10$	0.27 (0.24)±0.03	0.11 (0.10)±0.01

AQGC expected limits

Expected limits @95%CL:

$$a_0^W/\Lambda^2 = 2 \times 10^{-6} \; (3 \times 10^{-6}),$$
$$a_C^W/\Lambda^2 = 7 \times 10^{-6} \; (10 \times 10^{-6}),$$





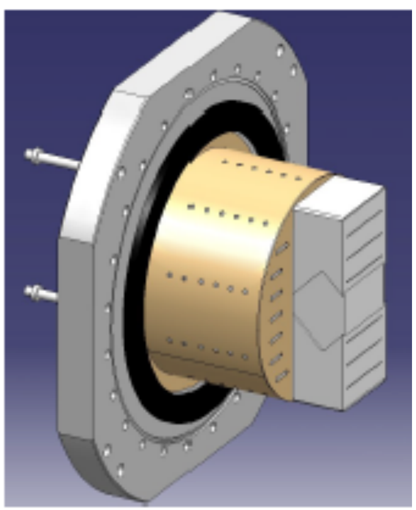
Beam pockets

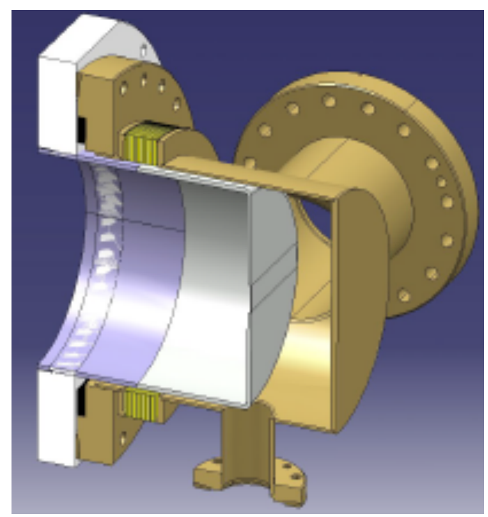
Approaching the beam

- Options considered:
  - Roman Pots (RP) developed by TOTEM
  - Movable Beam Pipe (MBP)
- RP will be tested in the exploratory phase in 2015
- The MBP solution is pursued in parallel
  - low RF impedance option
  - aiming at joint project of LHC collaborations and machine

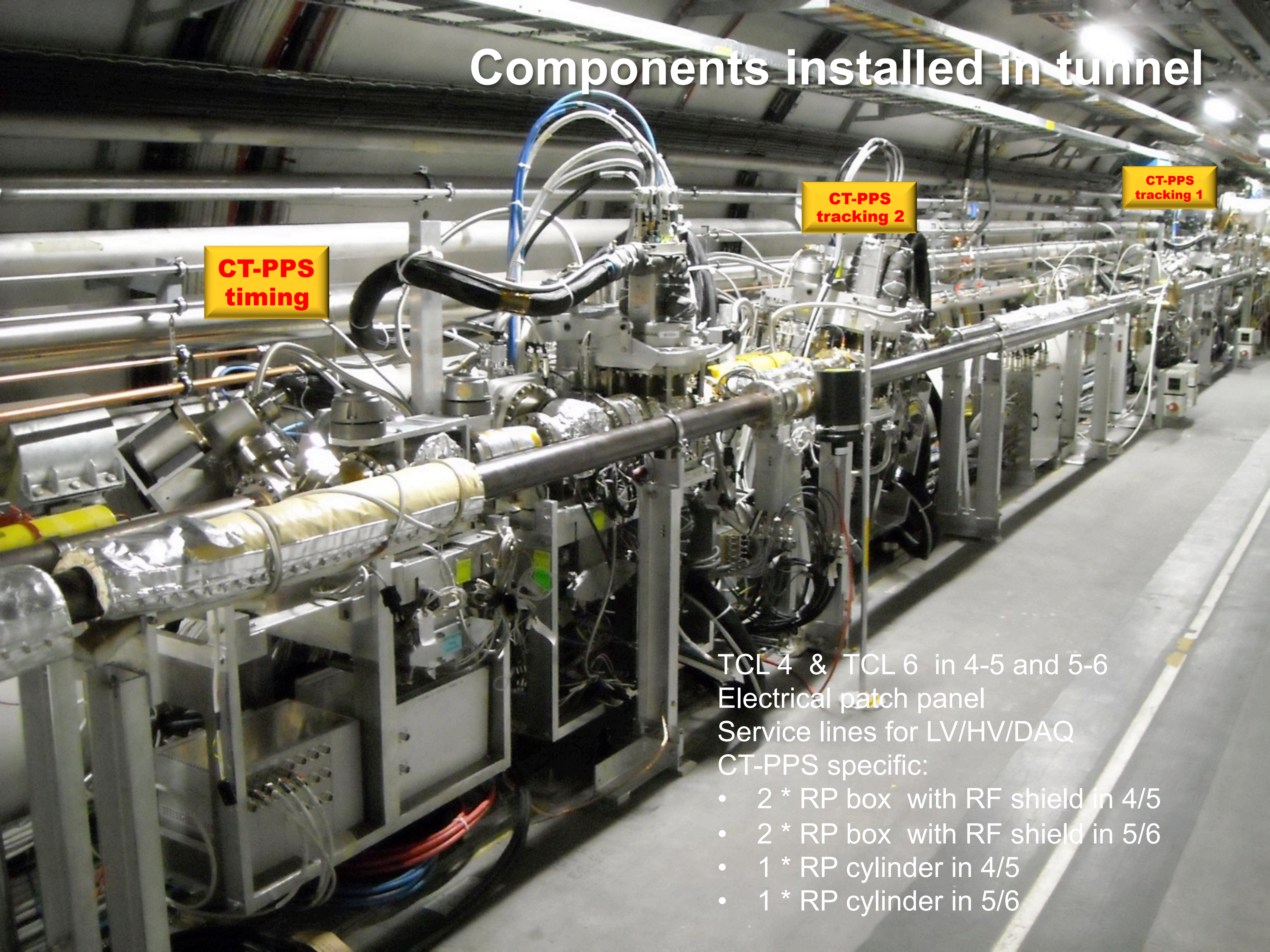
Roman Pots

- Tests of TOTEM RPs at high luminosity revealed important issues (vacuum, beam dumps, heating).
- Several improvements have been carried by TOTEM (and CMS) in collaboration with BE-ABP.
  - New RF shielding in standard box-shaped RPs
  - New cylindrical RP for timing detectors
  - 10 um thick copper coating
  - New ferrites





Components installed in tunnel



TCL 4 & TCL 6 in 4-5 and 5-6
Electrical patch panel
Service lines for LV/HV/DAQ
CT-PPS specific:

- 2 * RP box with RF shield in 4/5
- 2 * RP box with RF shield in 5/6
- 1 * RP cylinder in 4/5
- 1 * RP cylinder in 5/6

RPs insertion at low β^*

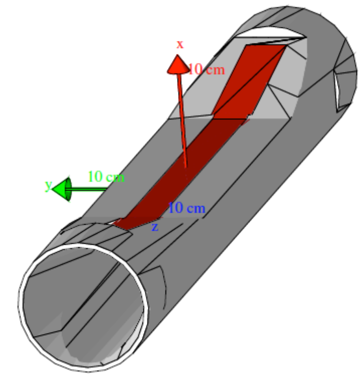
Final goal:

- Establish Roman Pot insertions for physics operation in regular fills from 2016

RP insertion commissioning:

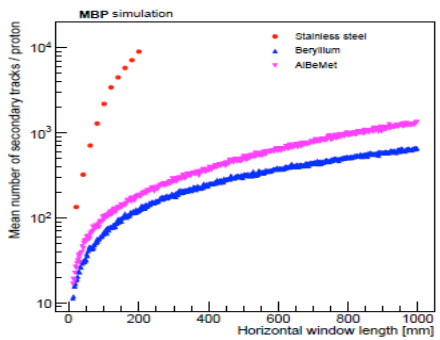
- RP insertions at low beta* and highest beam intensities will be tested in the exploratory phase in 2015.

R&D: Movable beampipe

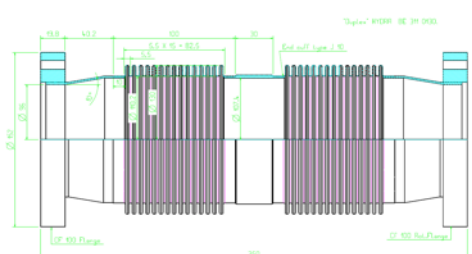


- Design for MBP main body was developed

- Thin window material evaluated with GEANT simulations
  - Improved secondary/shower production and angular resolution with Be/Be-Al alloy options



- MBP will be connected to LHC beamline by standard double bellows
  - New RF shielding design developed by TE-VSC group



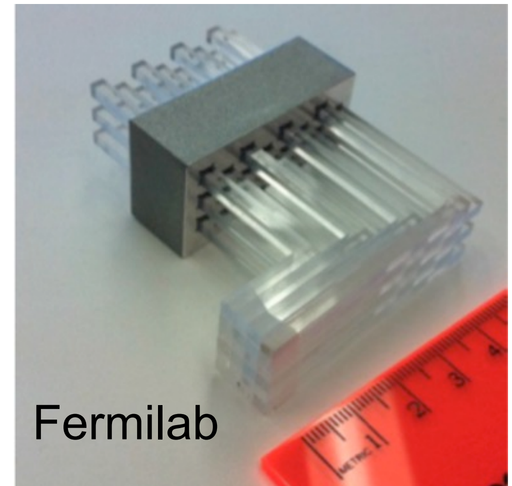
Timing detectors

Baseline Timing Detector

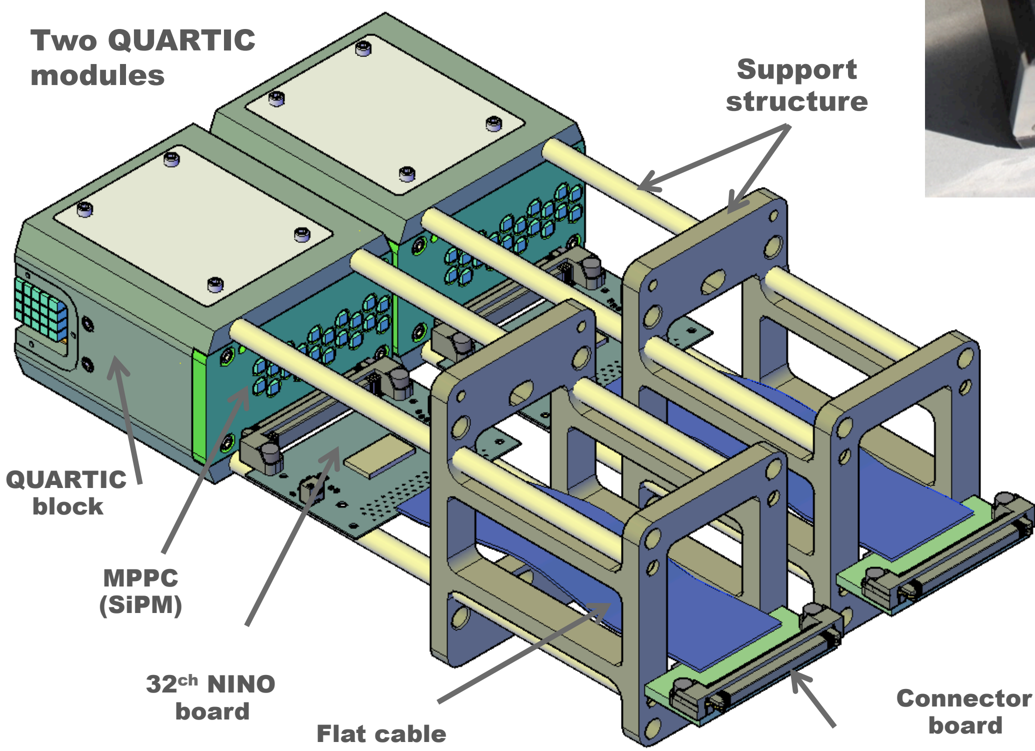
Quartic detector:

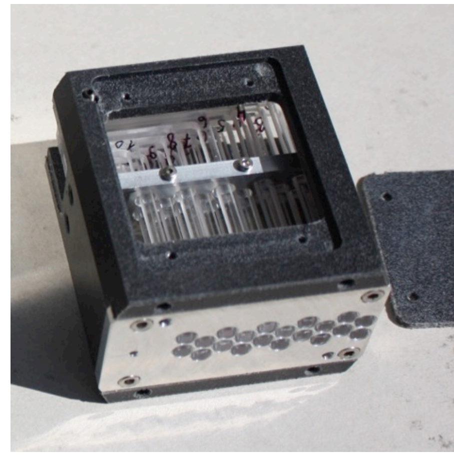
- Detector is a 4 x 5 array of quartz bars, 3 x 3mm^2, SiPM light detection.
- SiPMs Hamamatsu MPPC S12572-050
- Two such modules in one Roman pot in each arm.
- L-bar geometry allows SiPMs to be 70 mm from the beam.
- Radiator bars separated by 100 μm for total internal reflection
- Beam tests achieved $\sigma(t)$ = 30 ps/module (~ 20 ps for 2-in-pot)

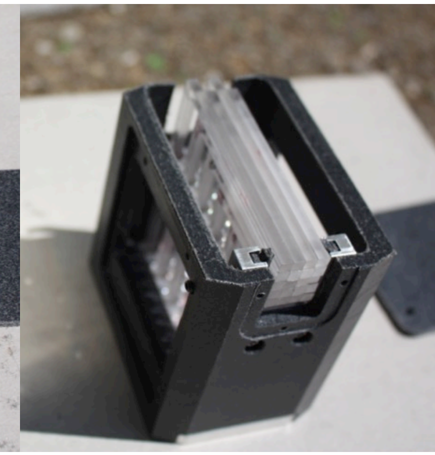
- **Detectors will be delivered to CERN for August integration and tests.**

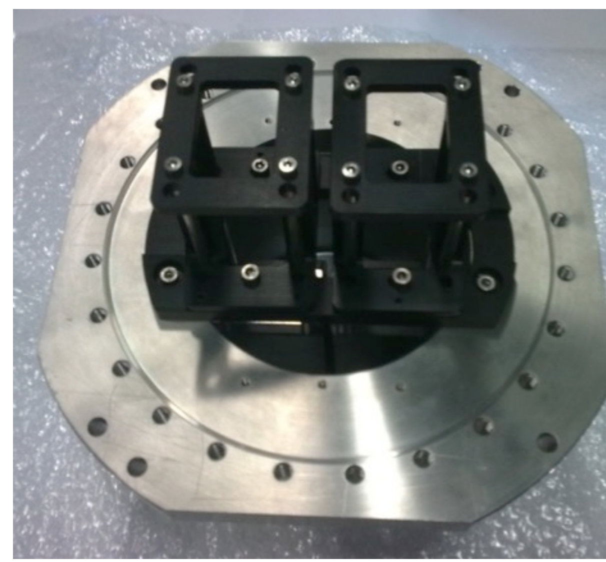


Quartic module & mechanics





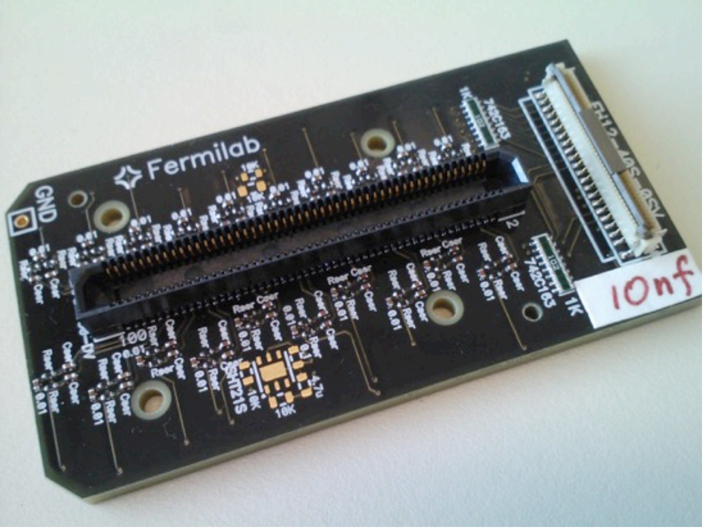




SiPM and Control boards

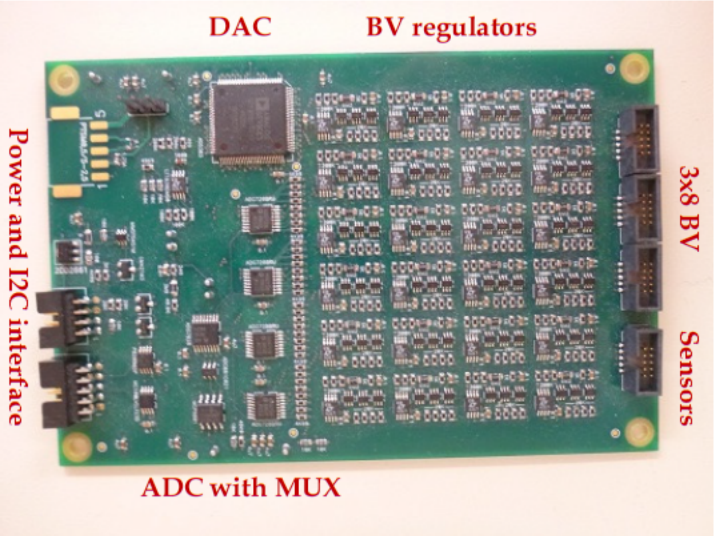
SiPM mounting board:

- Connects to MPPCs (100 pin connector)
- Connector with individual Bias Voltages and environmental sensor signals
- **Ready**



SiPM **Control Board** designed for CMS HCAL upgrade:

- Provides SiPMs with individual regulated Bias Voltages
- Measures SiPM leakage currents, temperature and humidity
- I2C controlled
- **Available**

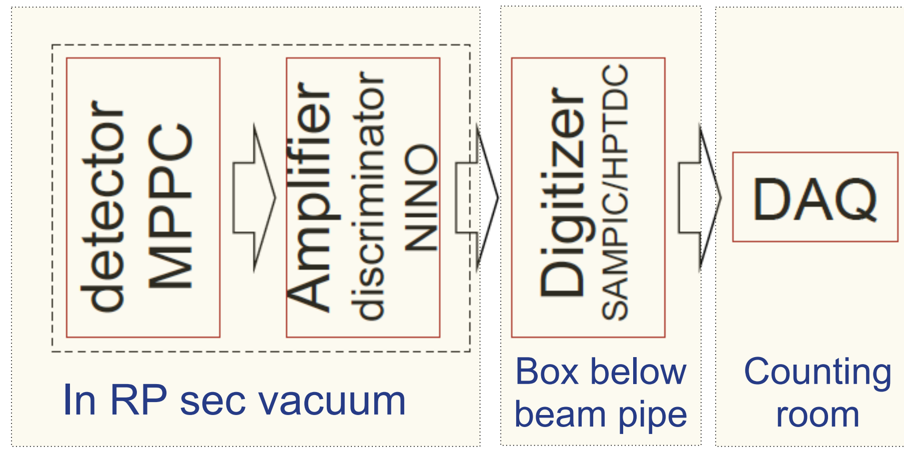


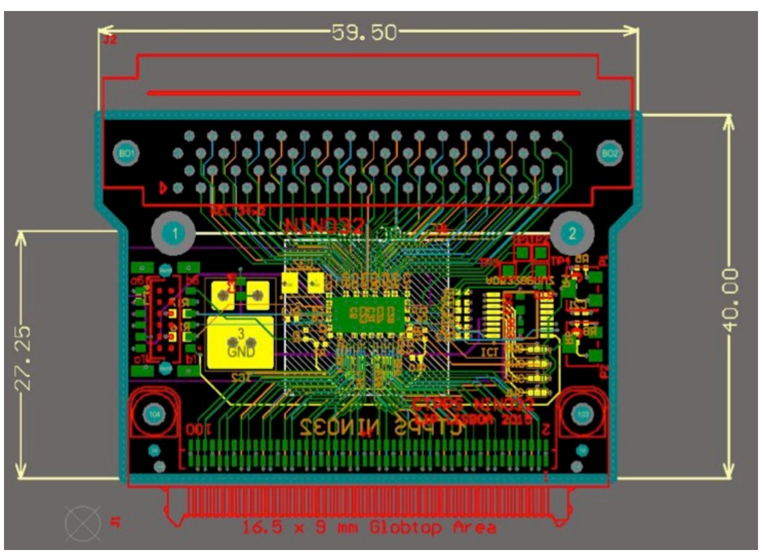
Front-end electronics

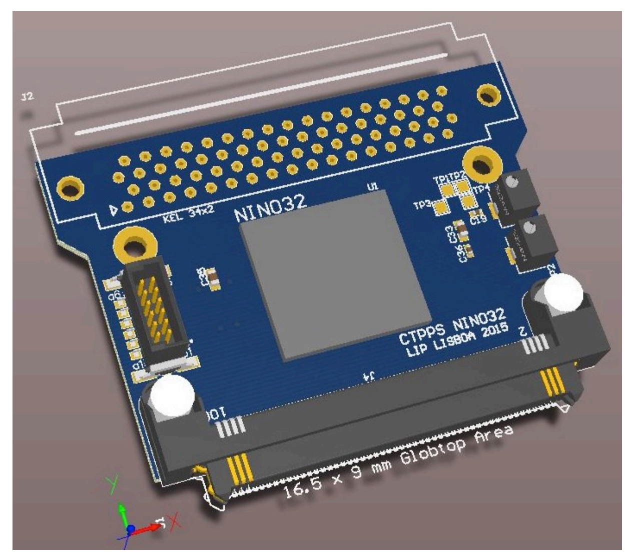
NINO Board:

- based on NINO chip (fast amplifier-discriminator)
- 32 differential inputs; 32 LVDS outputs
- time resolution ~5 ps
- installed inside RP
- PCB layout ready for production
- **Boards expected in July**

Quartic readout chain

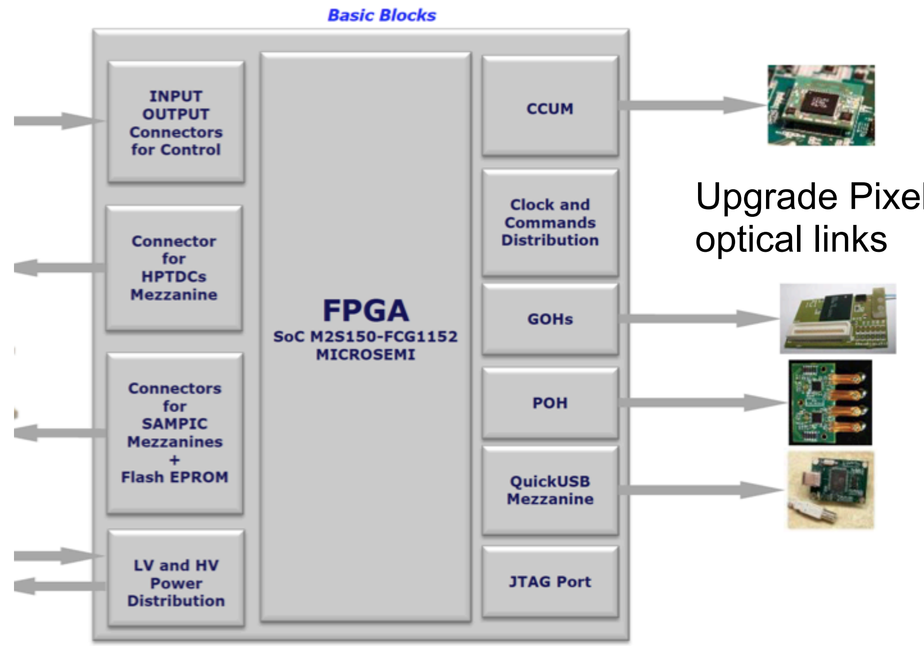




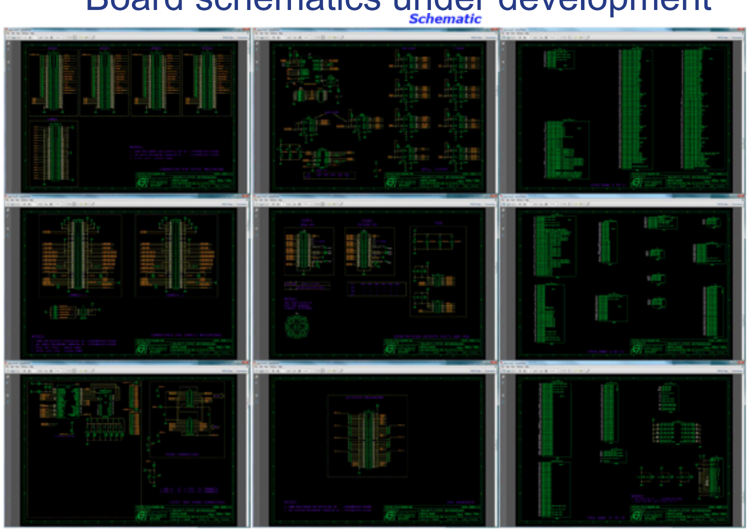


Digitizer board

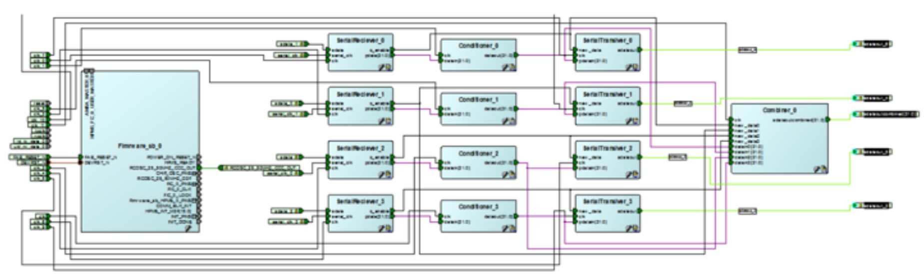
- common CT-PPS & TOTEM development
- time to digital conversion (TDC)
- time over threshold measurement (ToT)
- mezzanine board HPTDC/SAMPIC
- **board expected in August**



Board schematics under development



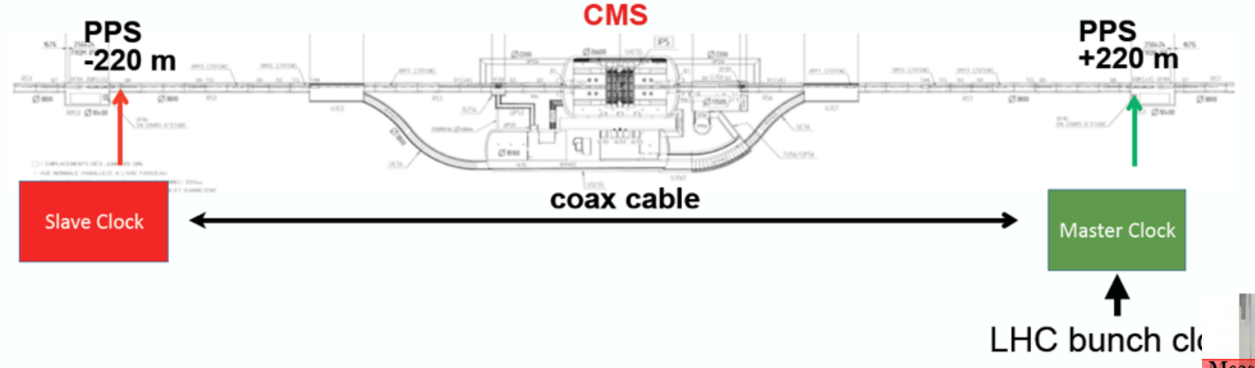
Firmware under development



Timing reference system

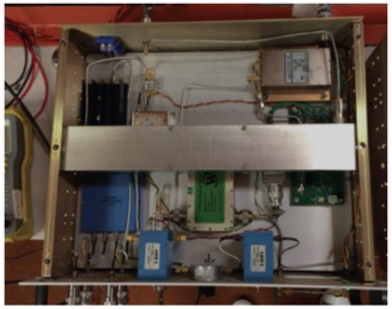
Clock distribution with ~1 ps jitter

- **CMS/SLAC system:**
  - based on a system in use at SLAC Linac Coherent Light Source (LCLS)
  - system expected in November for tests
  - install coaxial cable through the bypass (~470 m total length) at Year End TS.

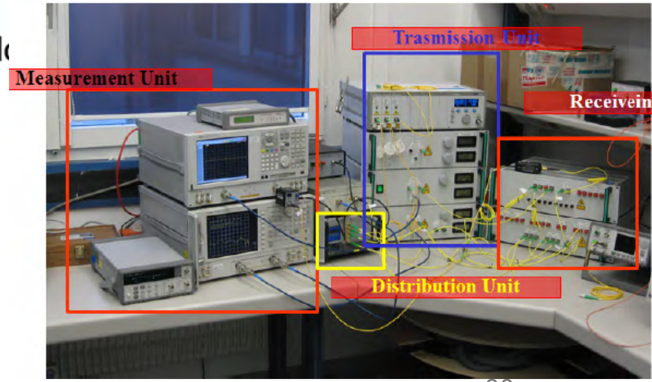


Master Clock

Slave Clock



- **Totem/GSI system:**
  - based on the optical system for FAIR at GSI
  - full system architecture outlined
  - first system under test

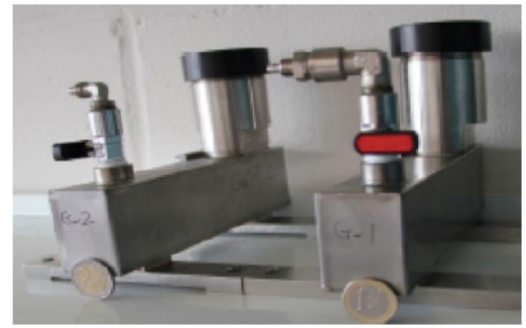


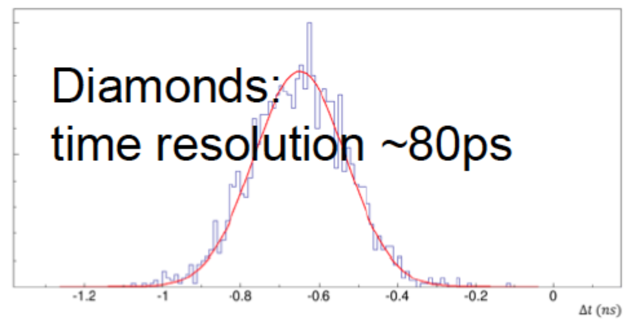
Timing R&D

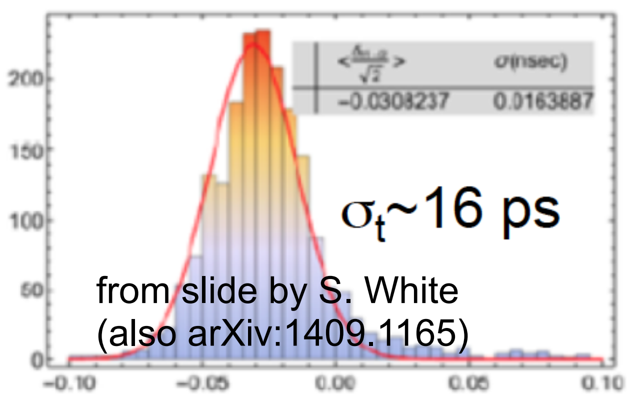
GasTOF system
- prototype for test beam is on-going

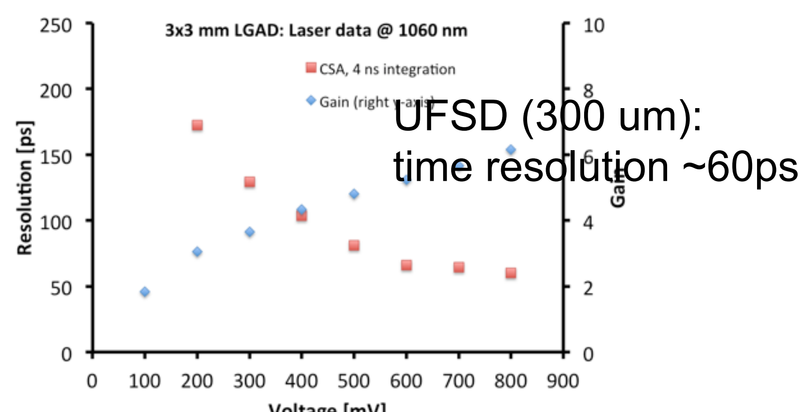
Diamond detectors
- effort led by TOTEM
- demonstrated 50 ps with 4 planes

Silicon detectors
- Fast Silicon Detectors (UFSD):
    - 60 ps with new prototypes (laser)
    - test beam in 2015
- Start exploiting Avalanche PhotoDiodes







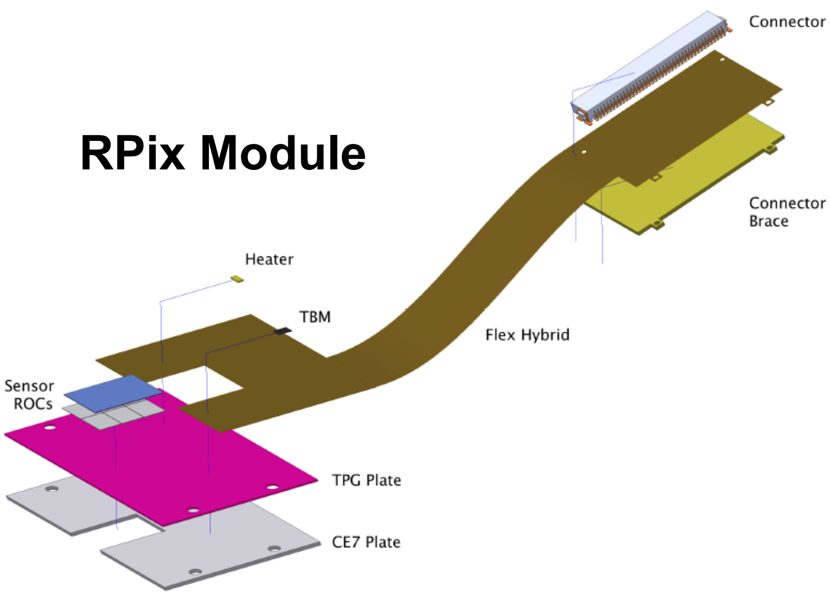


Tracking detectors

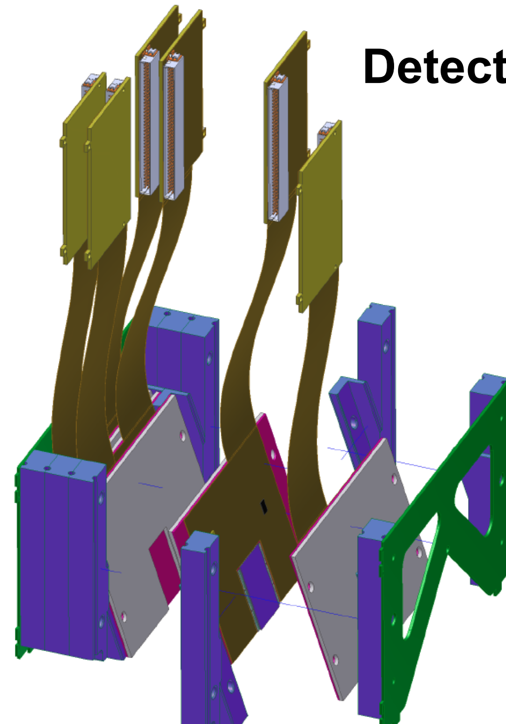
Tracking baseline

- 3D silicon sensors (manufactured by CNM)
- PSI46dig ROC, with same readout scheme as for Phase I Upgrade of the CMS pixel system
  - existing CMS DAQ components and software can be reused
- 6 detector planes per station
  - detectors are tilted in one direction
  - number of planes provide adequate redundancy

RPix Module



Detector support

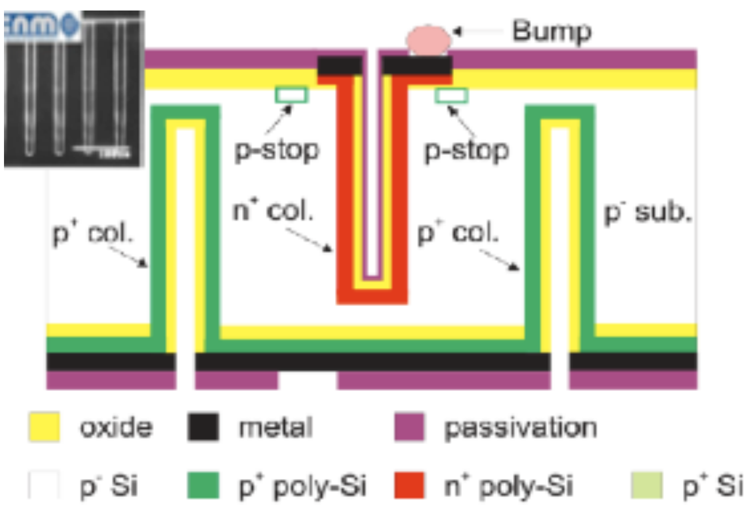


3D sensors by CNM

We are producing:

- 2E pixel configuration, i.e. 2 readout columns [1E as backup]
- 200 µm slim edges
- 2x3 sensors (6 ROCs)

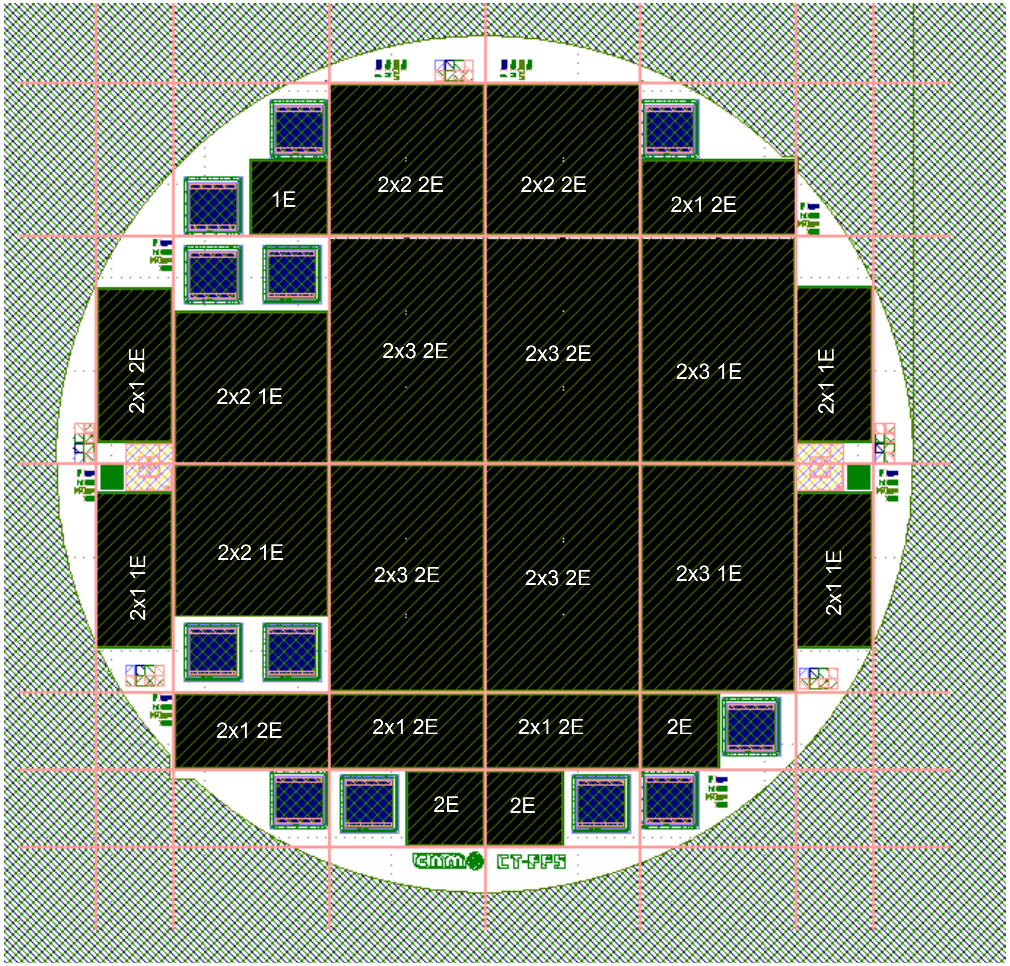
CNM technology as for the ATLAS IBL production:



4” wafers, 230 µm thickness
Double side, not passing through columns
Slim edges (200 µm)

Foreseen yield is ~60%

3D sensors – wafer layout in production



Wafer thickness 230 μm

FZ HR <100> silicon
p-type N=10^{12}atm/cm^3
p-stop isolation

	2E	1E
■ 6 detectors 2x3	4	2
■ 4 detectors 2x2	2	2
■ 8 detectors 2x1	5	3
■ 4 single chip	3	1
■ Diodes	6	6

With the first 12 wafers:

- 48 sensors 2x3 & 2E and we need 24

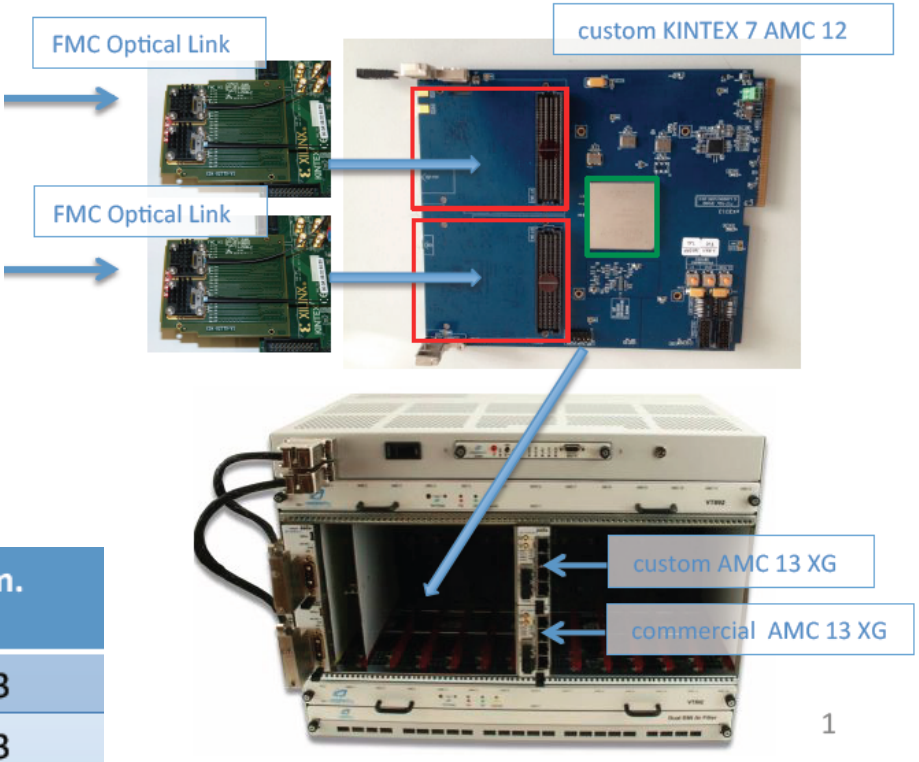
In case of problems we could still mount 2x2 sensors (+ 2x1 sensors)

Same readout scheme as Phase-1 upgrade of the CMS Pixel Tracker.

Used both for CT-PPS Timing and Tracking detectors

MicroTCA crate including:

- 2 CTA-FED, 2 CTA-tkFEC, 1 CTA-pkFEC
- FMC Optical mezzanines

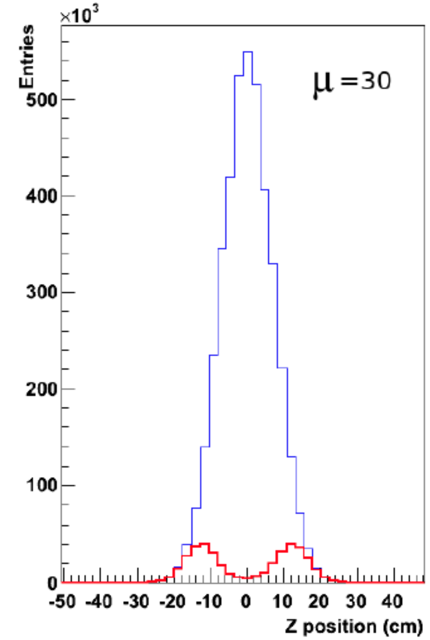


Component	Prod.	Test & Spares	Prelim. Req.
uTCA Crates	1	2	3
AMC13XG	1	2	3
CTA	5	5(*)	10-12
GLIB	0	2(**)	0
FED FMC	3	3-4	6-7
FEC FMC	4	6-8	10-12

Trigger strategy

- Two-photon physics:
  - the leptonic final states are captured by the CMS lepton triggers
    - The trigger efficiency is expected to be very high given that the lepton thresholds are 30 GeV or below.
  - Final states with hadronic decays of one W or one tau will be accessible using the lepton+jet triggers.

- Hadronic physics
  - Large inclusive QCD jet background
  - L1 timing trigger selecting events in the tails of the distribution of the collision z-vertex



In red distributions of the vertexes separated by at least 1 cm

Summary of project status

Roman Pots

- Roman Pots are installed & calibrated in the LHC tunnel at ip5
- Collimators TCL4 and TCL6 are installed
- Plan of insertion tests of RPs at low β* presented and agreed LPC and LMC

Timing

- Quartic fabrication and integration in cylindrical Roman Pot is well advanced
- Quartic electronics is in production (NINO) or final design (HPTDC)

Tracking

- Production of 3D silicon sensors started at CNM
- PSI46dig ROCs were produced, waiting for wafers testing

DAQ

- Procurement of Pixel readout and DAQ components is being discussed with CMS Pixel Project and CERN group

Tests

- Testbeams scheduled at Fermilab & CERN SPS to study Timing detectors and to study CNM 3D sensors

R&D

- Active R&D on several fronts is being pursued