Looking forward
The Precision Proton Spectrometer at the LHC

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LIP Lisbon

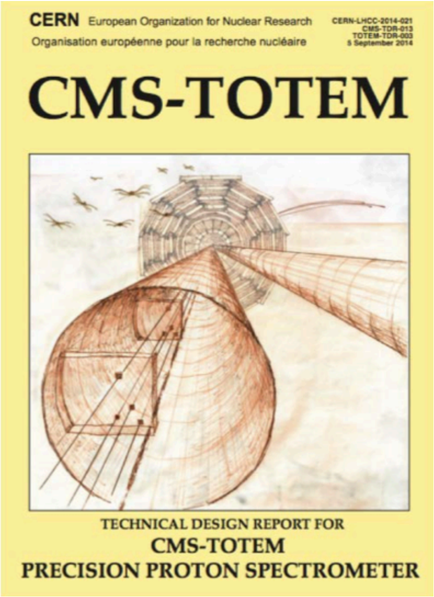
May 26, 2018

- ✓ Overview
- ✓ Physics motivations
- ✓ Tracking and timing detectors
- ✓ Status, R&D, and prospects
- ✓ Summary

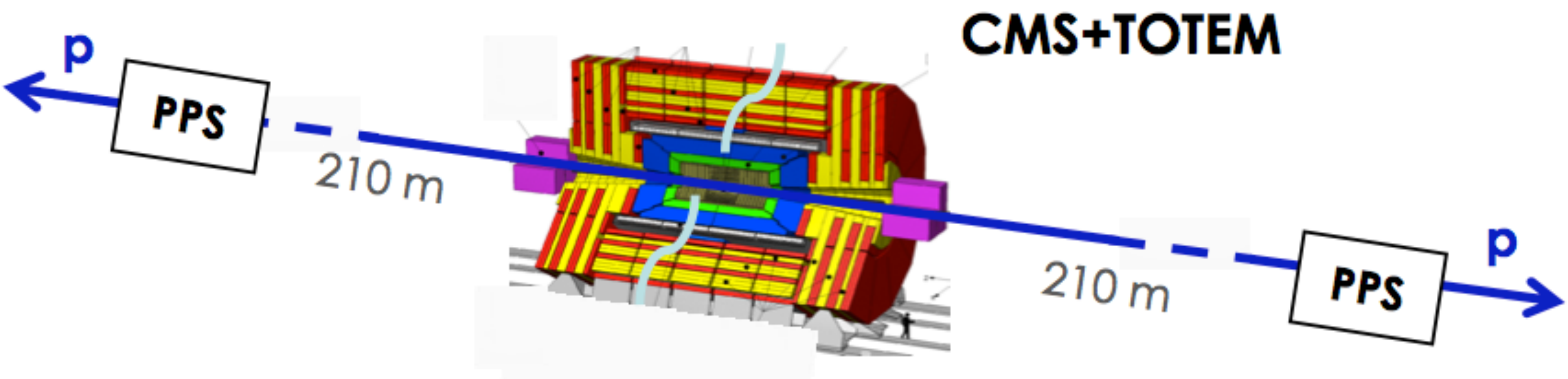
CERN-LHC-2014-021

Overview

- It is a joint CMS and TOTEM project that aims at measuring the surviving scattered protons on both sides of CMS in standard running conditions
- Tracking and timing detectors inside the beam pipe at ~210m from IP5
- Approved (2014), exploratory phase in 2015, data taking started in 2016, pixels installed from 2017, full detectors in 2018

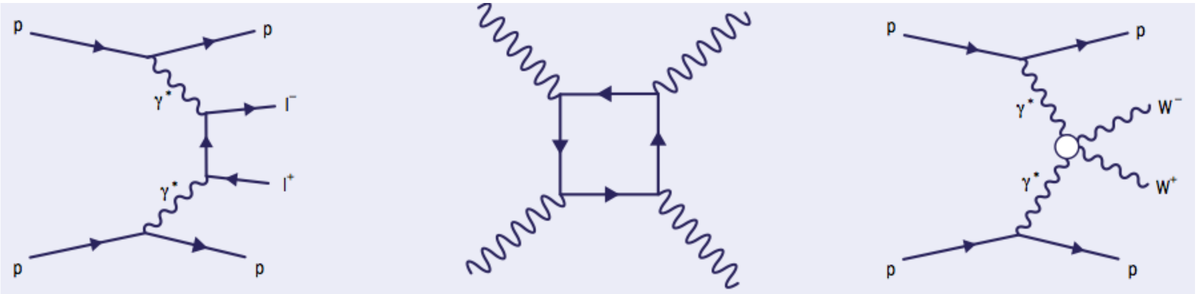


CERN-LHC-2014-021



Physics motivations

- Central Exclusive Production
  - photon-photon collisions
  - gluon-gluon fusion in color singlet, $J^{PC}=0^{+}$
- High-mass system in central detector, together with very forward protons in PPS
  - momentum balance between central system and forward protons, provides strong kinematical constraints
  - Mass of central system measured by momentum loss of the two leading protons
- Gauge boson production by photon-photon fusion and anomalous couplings ($\gamma\gamma WW$, $\gamma\gamma ZZ$, and $\gamma\gamma\gamma\gamma$)
- Search for new BSM resonances
- Study of QCD in a new domain

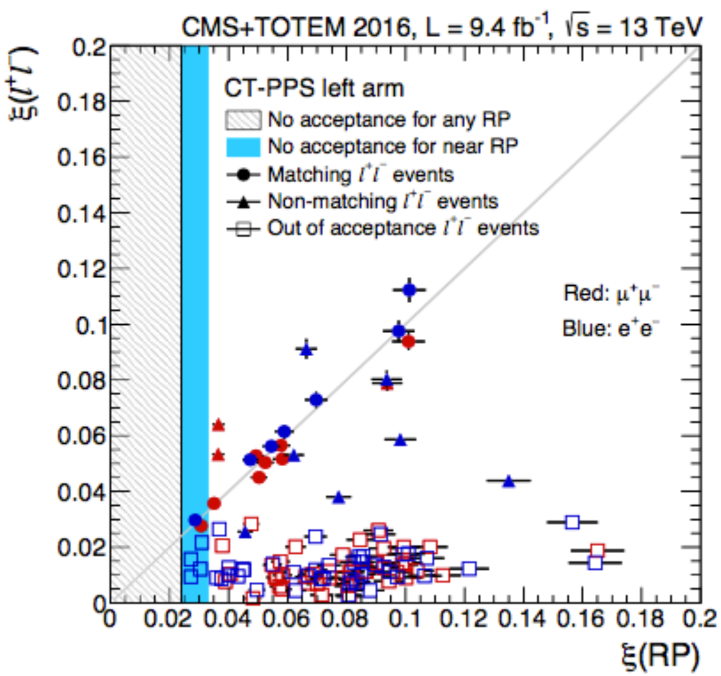


Exclusive dilepton production

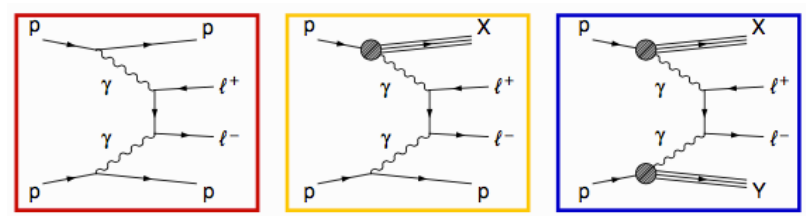
arXiv:1803.04496

presentation by J. Hollar

- Study exclusive processes at the EWK scale
- Observation of $\gamma\gamma$ interaction with proton tag



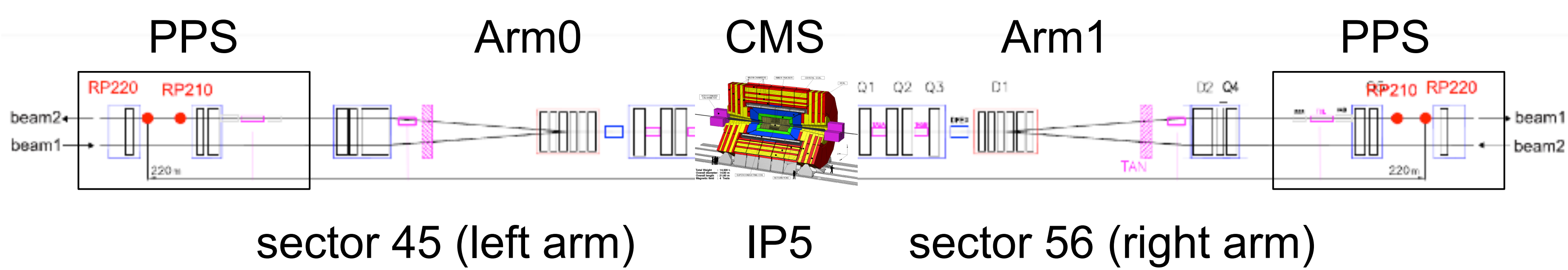
signal bkg: SD, DD, DY, dibosons, PU



- Correlation between the ξ values in central system vs PPS
- $12\mu\mu$, 8ee candidates observed ($>5\sigma$ over expected bkg)

Experimental challenges

- Ability to operate the detectors close to beam (15-20σ, i.e. ~1-3 mm) to maximize acceptance for low momentum loss (ξ) protons
- Limit impedance introduced by beam pockets
  - improved RF shielding of RPs
- Sustain high radiation levels
  - For 100/fb, proton flux up to 5×10^{15}cm^{-2} in tracking detectors, $10^{12}n_{eq}/cm^2$ and 100Gy in photosensors and readout electronics
- Reject background in the high-pileup (μ=50) of normal LHC running



Data taking

- Successful RP insertions in 2016 at 15σ
- Regular near-beam operation at high-luminosity

2016 – collected ~15/fb

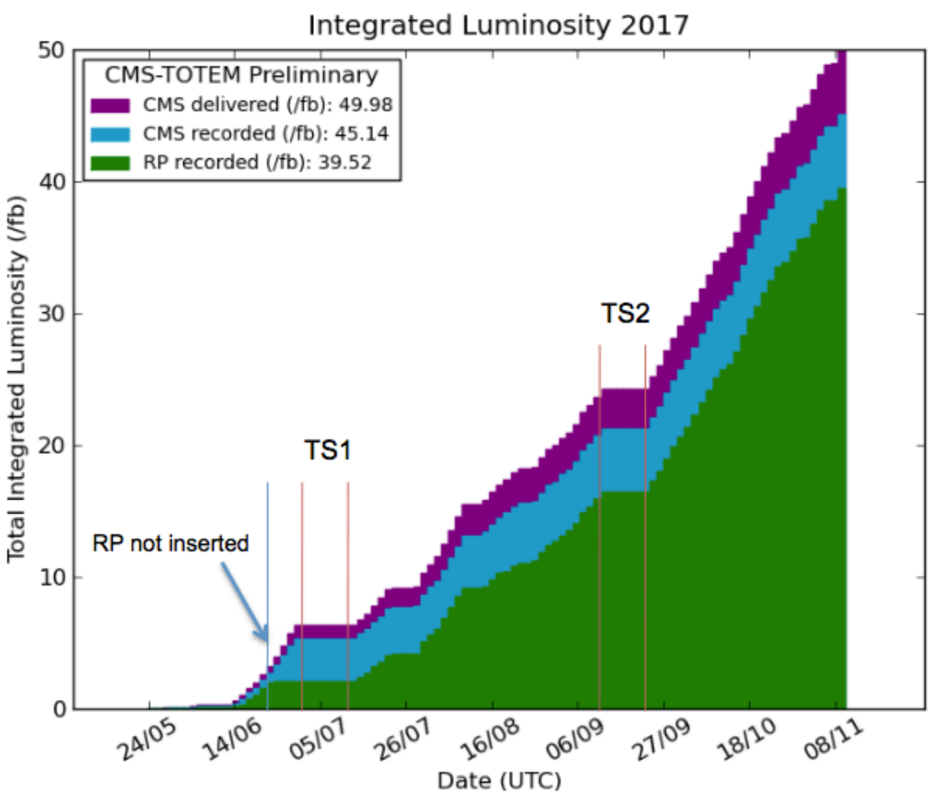
- Silicon strips+diamond

2017 – collected ~40/fb

- Tracking: silicon strips + 3D silicon pixels (first installation in CMS)
- Timing: diamond+UFSD (1st time in HEP)
- Detectors fully integrated in central DAQ from first fill

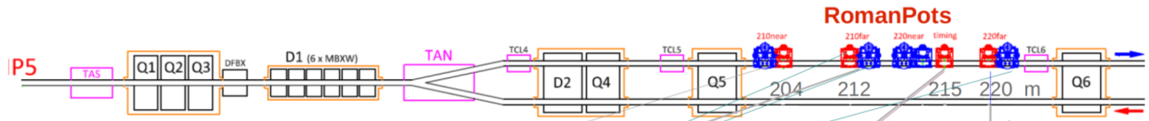
2018 – expect to collect ~50/fb (?)

- full scope with Si pixels+diamonds



Detectors in 2017 and 2018

2017



Aligned
Not equipped with detectors

Tracking
Si-strips

CTPPS_TOT/TOTDET
("VME" FEDs 578+580)

Fast timing
3 single-layer **diamond** planes
1 **UFSD** plane

CTPPS_TOT/TOTDET
("VME" FEDs 582+583)

Tracking
3D pixels

CTPPS/CTPPS
(uTCA FEDs 1462+1463)

V. Avati

2018

Aligned
Not equipped with detectors

Tracking
3D pixels

CTPPS/CTPPS
(uTCA FEDs 1462+1463)

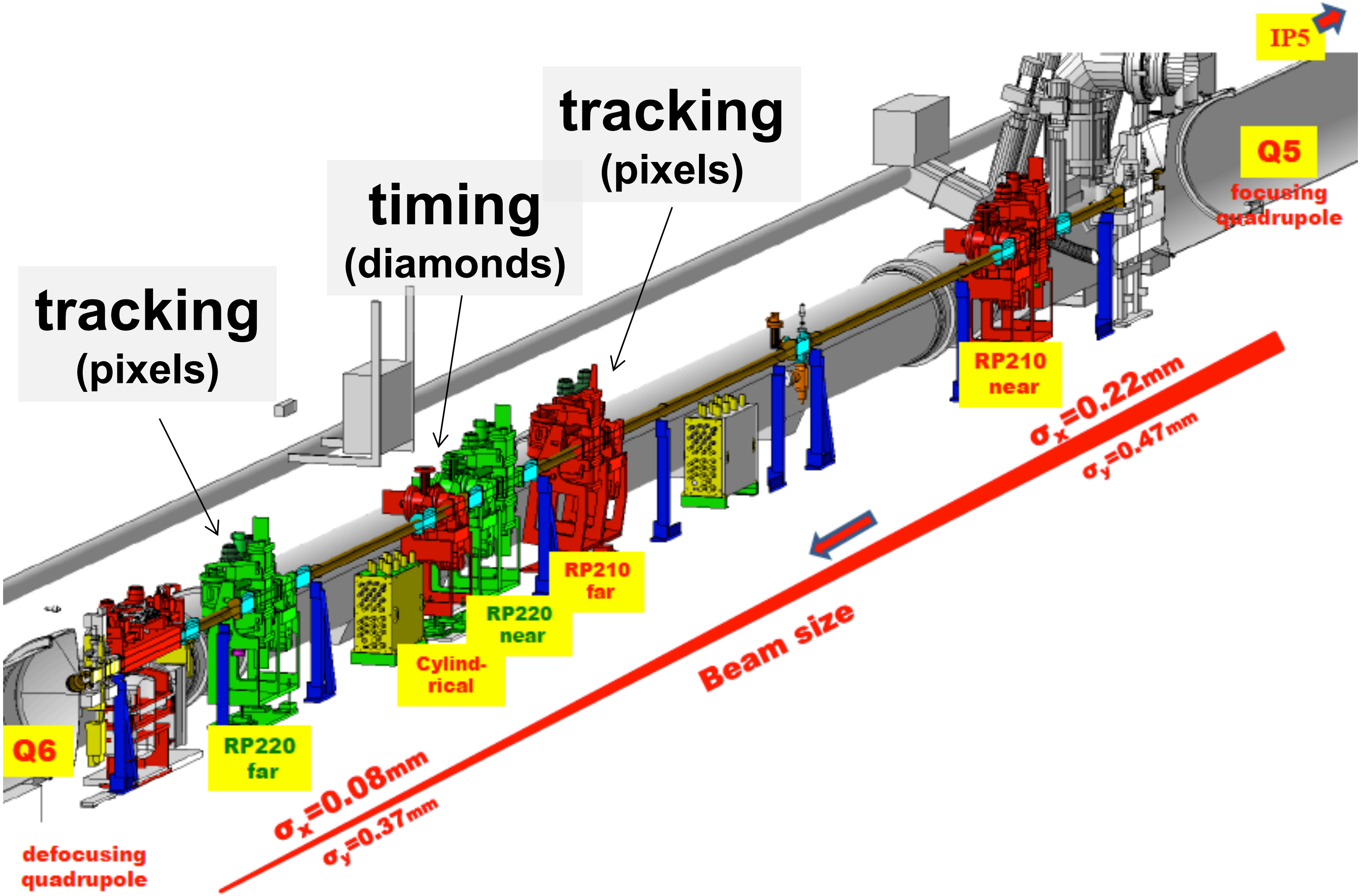
Fast timing
4 single- and double-layer **diamond** planes

CTPPS_TOT/TOTDET
("VME" FEDs 582+583)

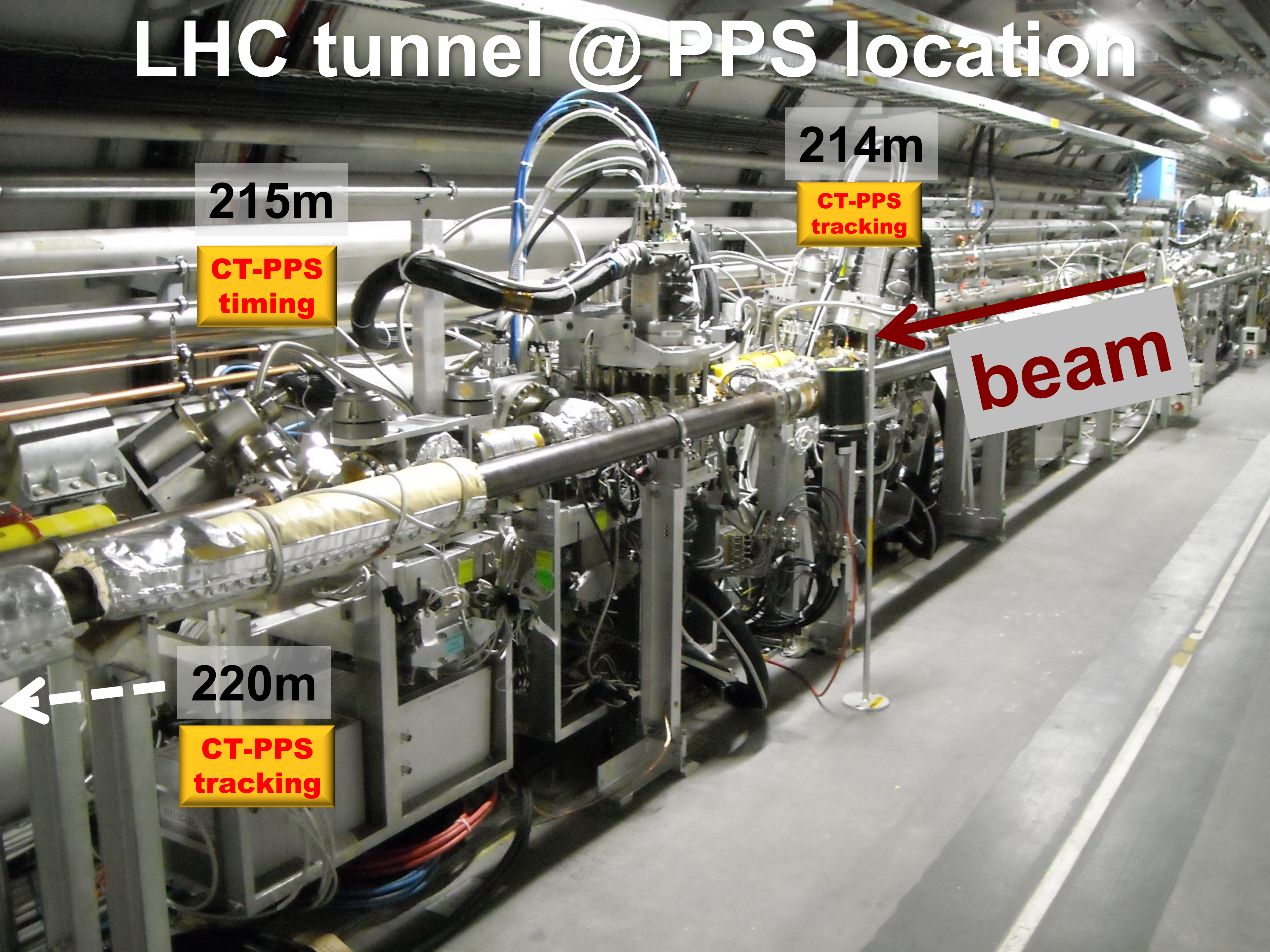
Tracking
3D pixels

CTPPS/CTPPS
(uTCA FEDs 1462+1463)

PPS in 2018

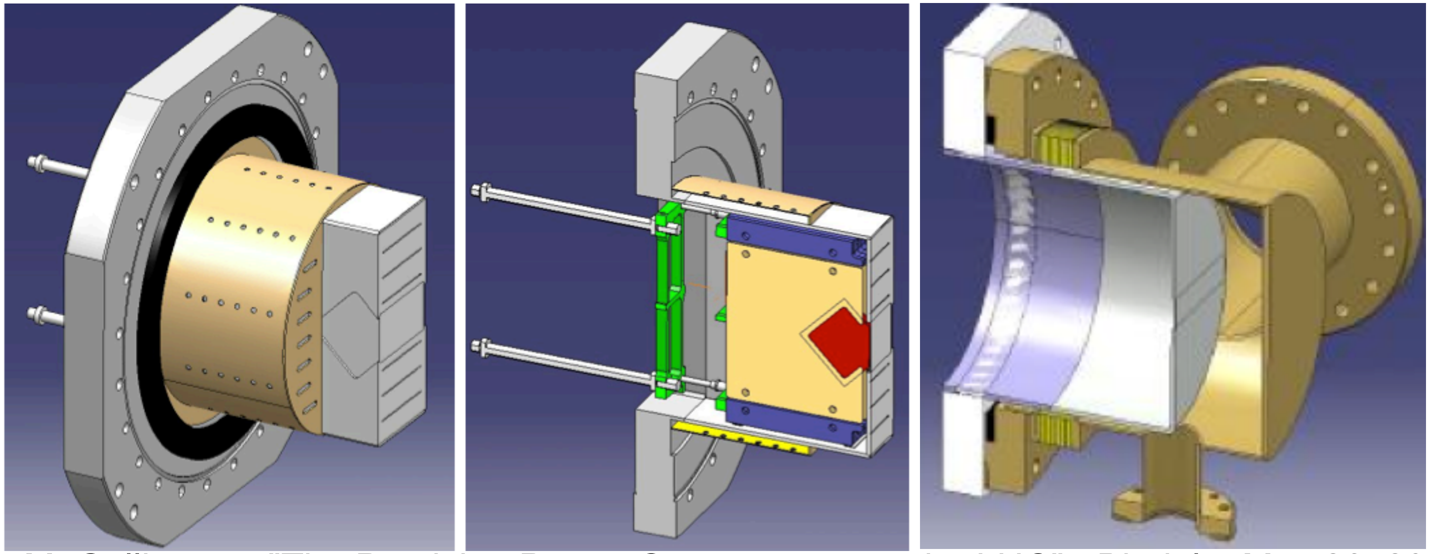


IP5
tracking
(pixels)
timing
(diamonds)
tracking
(pixels)
Q5
focusing quadrupole
RP210 near
σ_x=0.22mm
σ_y=0.47mm
RP210 far
RP220 near
Cylind-rical
Beam size
Q6
RP220 far
σ_x=0.08mm
σ_y=0.37mm
defocusing quadrupole


LHC tunnel @ PPS location
215m
CT-PPS
timing
214m
CT-PPS
tracking
beam
220m
CT-PPS
tracking

Roman Pot insertion

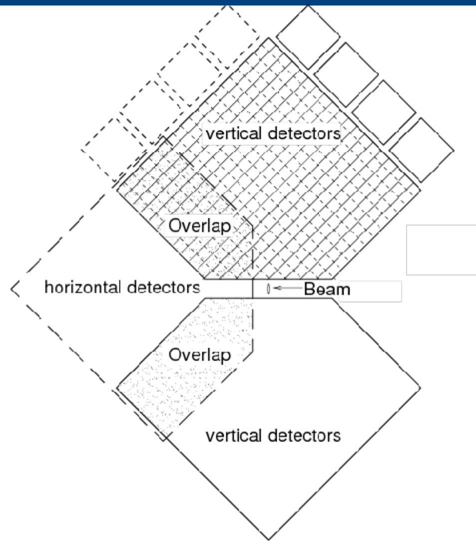
- Insertion procedure validated in 2016 by the LHC
  - Improvements carried out wrt earlier versions (RF shielding, cylindrical pots, ferrite, copper coating)
- Minimum distance of approach dramatically affects detector acceptance and physics reach
- Goal is 15σ from beam in nominal high-luminosity runs
  - Monitor beam losses, showers, interplay with collimators, beam impedance (heating, vacuum and beam orbit stability)

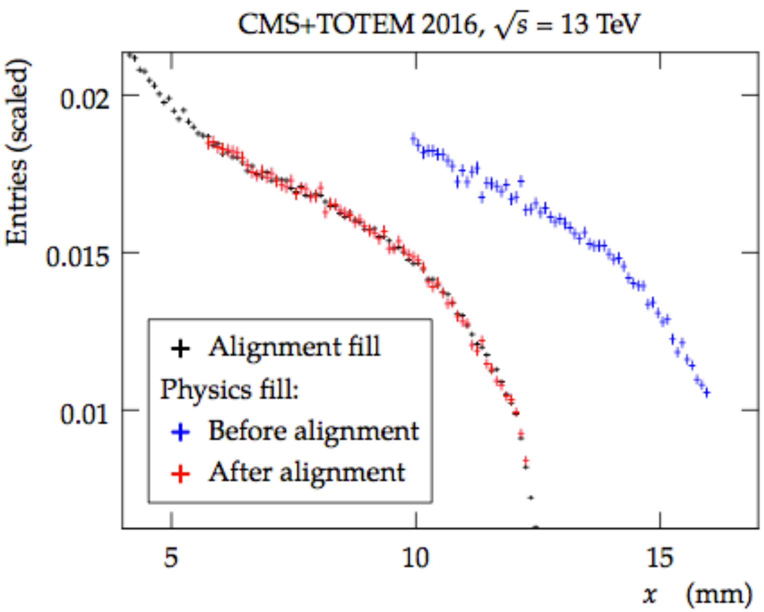


Detector alignment

Relative alignment

- Dedicated low-lumi alignment runs
- One per beam optics setting
- Detector approach to beam edge
- Inter-detector alignment with overlapping vertical-horizontal detectors (minimize residuals)
- Alignment wrt beam from hit occupancy distributions

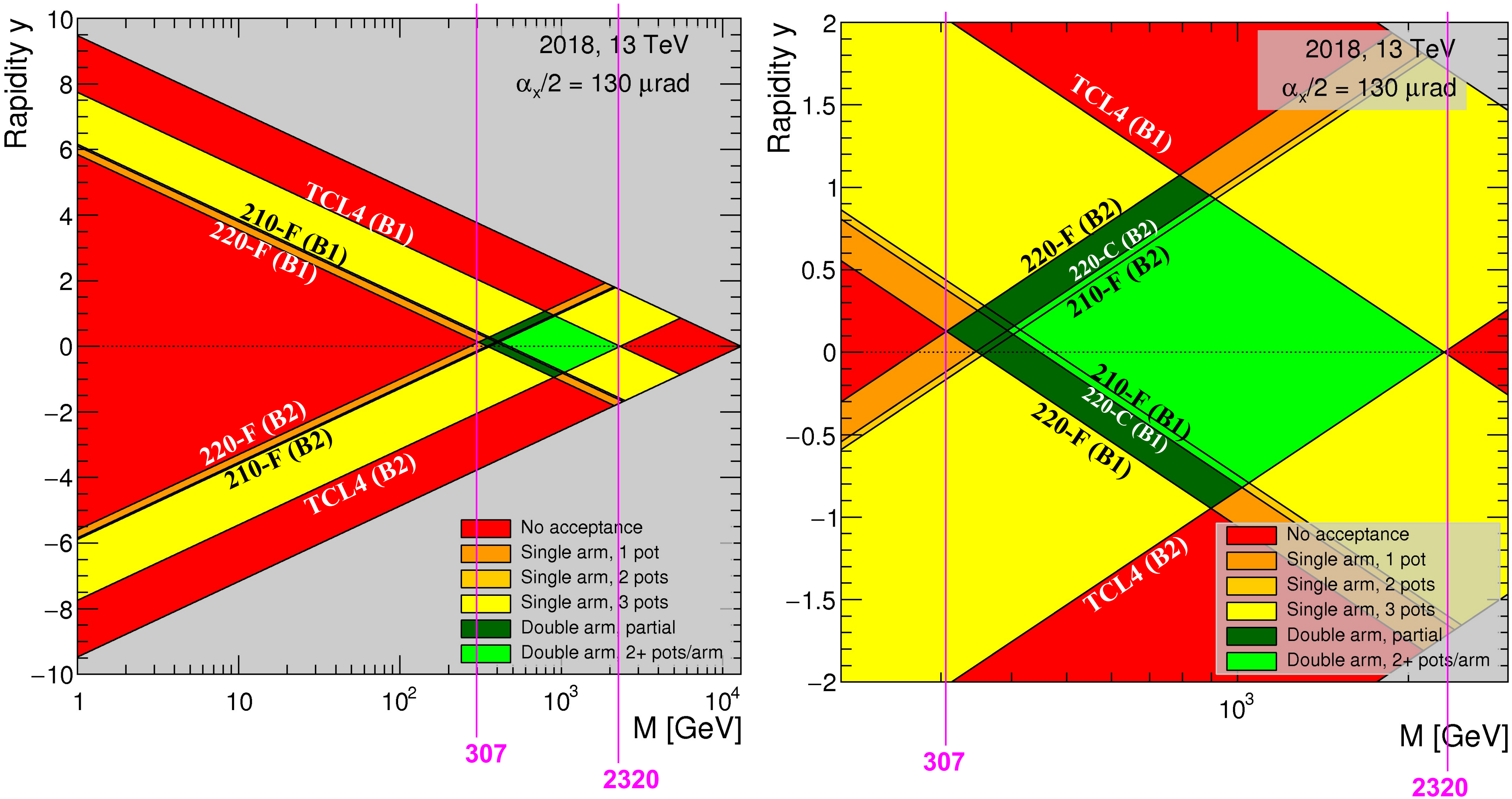




Global alignment

- Each ``physics” fill
- Match x distribution from alignment fill

RP Acceptance in 2018



Reference Timing

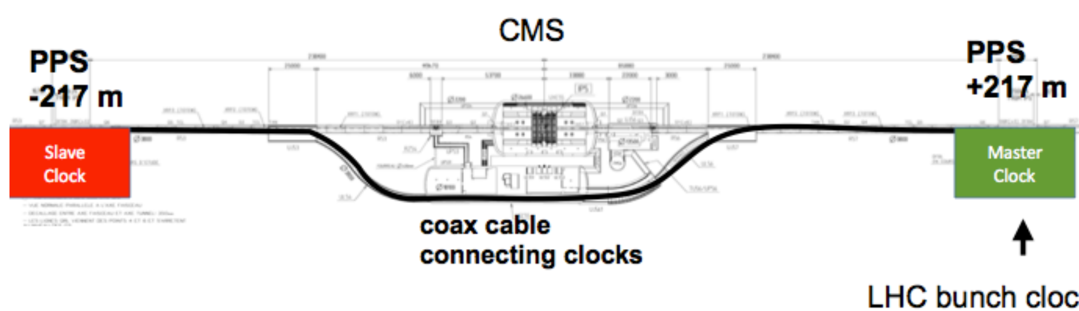
presentation by E. Bossini

Provide absolute measurement of time of arrival wrt clock edge

Reference clock: system providing low jitter (<1ps) replica of master clock

1. “RF clock”: relative timing
   - Locks the two arms
   - absolute timing tied to internal clock in one arm
2. “Optical clock”: absolute timing
   - Absolute taken from beam 1 (CMS source)
   - Then, sent to two arms

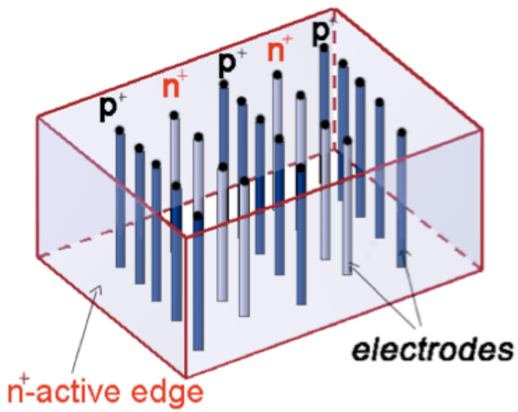
- Status
  - Use RF clock as main precise clock
  - optical clock as input to HPTDC
  - cross-monitoring possible



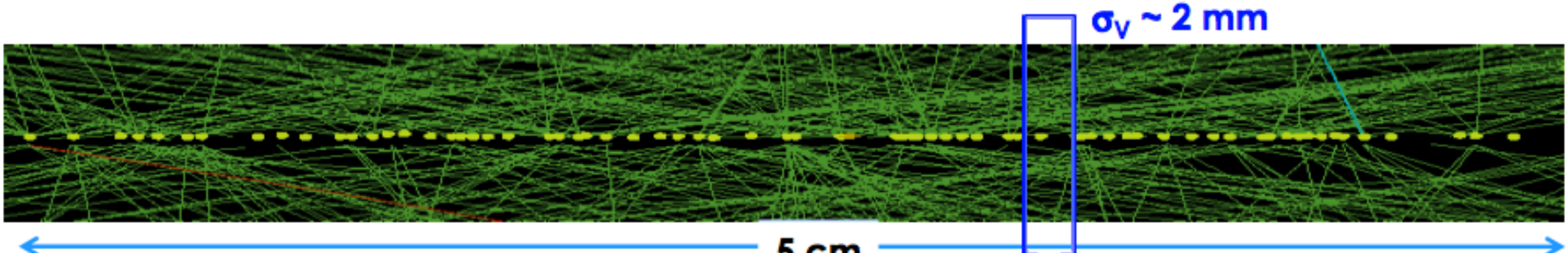
Detectors

- Tracking detectors
  - Goal: measure proton momentum
  - Technology: silicon 3D pixels (6 planes per pot)

"3D" pixel sensors with columnar electrodes



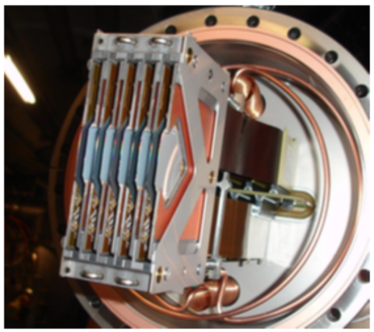
- Timing detectors
  - Goal: identify primary vertex, reject "pileup"
  - σ_{time}~10ps $\Rightarrow$ σ_z~2mm
  - Technology: silicon/diamond

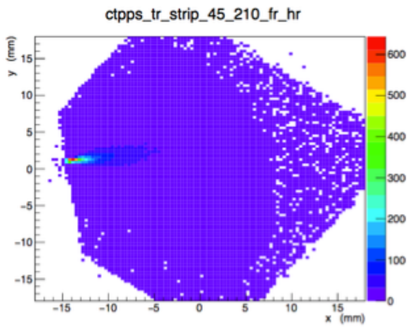


Tracking detectors

presentation by F. Ravera

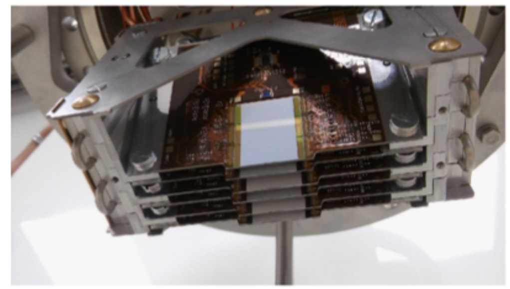
Silicon strips

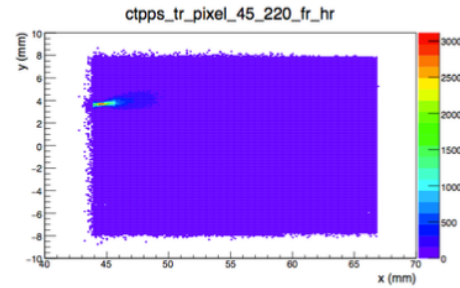




- 10 planes per station of "edgeless" silicon strip detectors (5U+5V)
- Pitch 66μm; track resolution ~12μm
- Designed for low-lumi running
- Used in 2016 and 2017

Silicon pixels

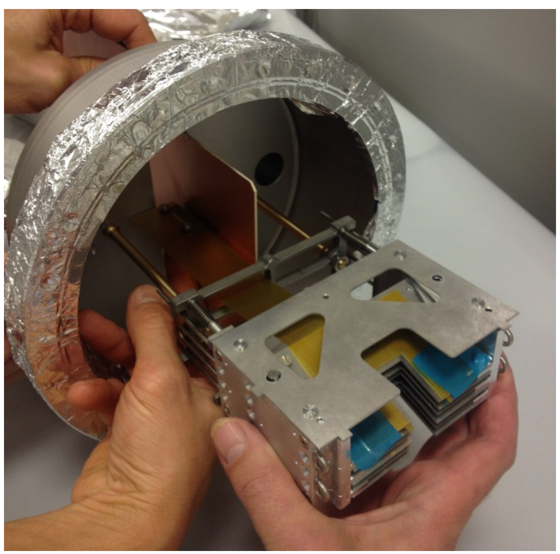


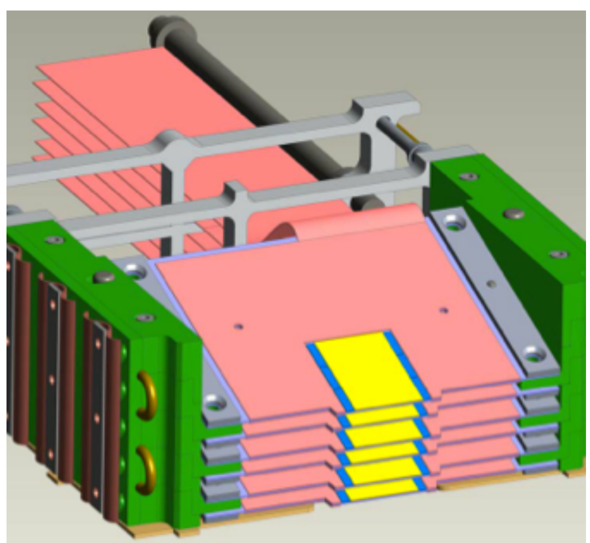


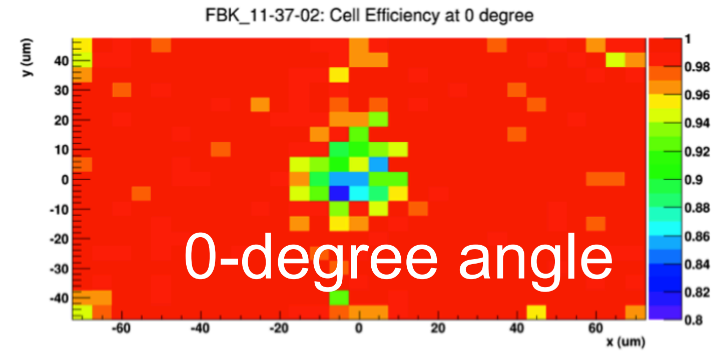
- 6 planes per station of "slim-edge" tilted silicon 3D pixel detectors
- Pixel size 100μm x 150μm; track resolution ~20μm
- Designed for high-lumi running
- Multi-track capability

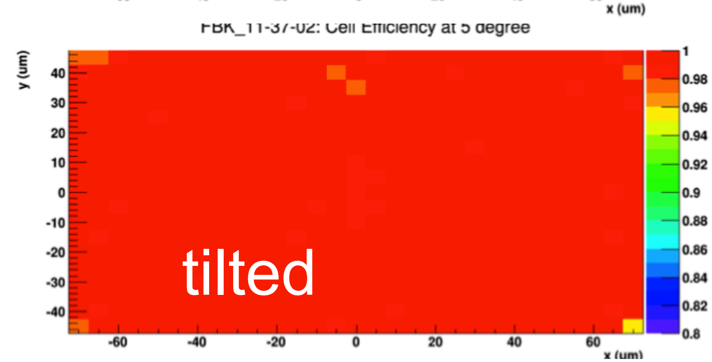
Tracking detectors

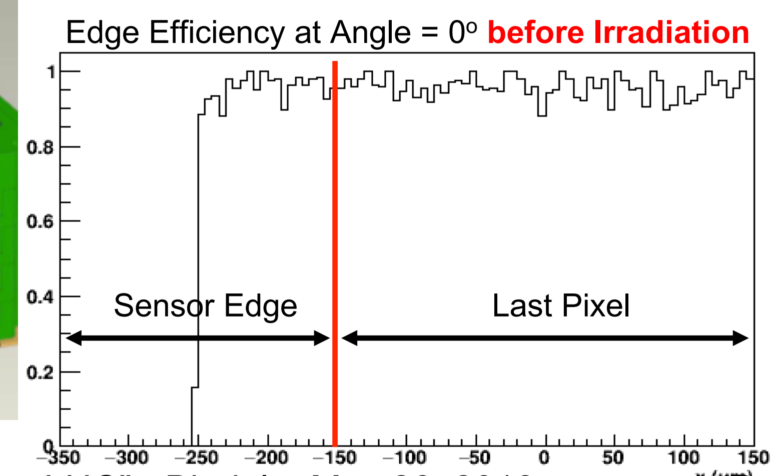
- 3D silicon pixel detectors
- 2 stations per side, 6 detector planes each pot
- Planes tilted to optimize efficiency and resolution
- Thin design studied to minimize impact on beam, insertion in pot, approach to beam
- Designed for high-luminosity running
- Multi-track capability



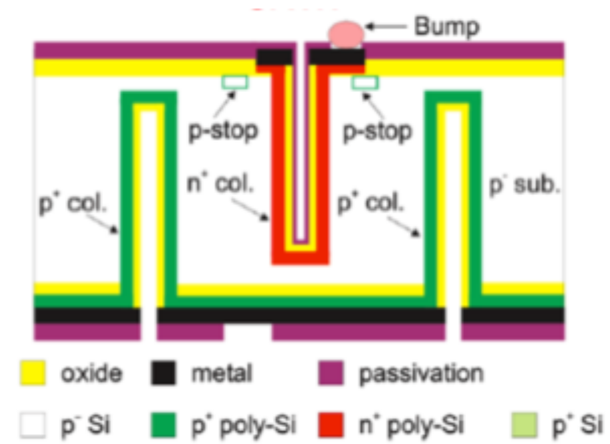






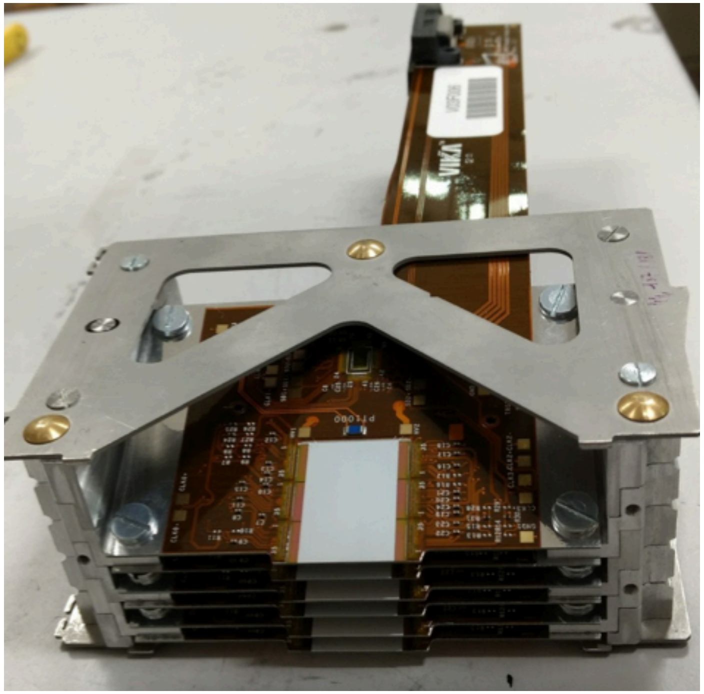


Tracking detectors (cont.)



Sensors:

- 3D sensor technology
- Intrinsic radiation hardness (to withstand overall integrated flux of $5x10^{15}$ protons/cm^2
- Pixel size 100μm x150μm
- 150μm slim edges (small dead edge to approach beam as close as possible)
- Spatial resolution <30μm



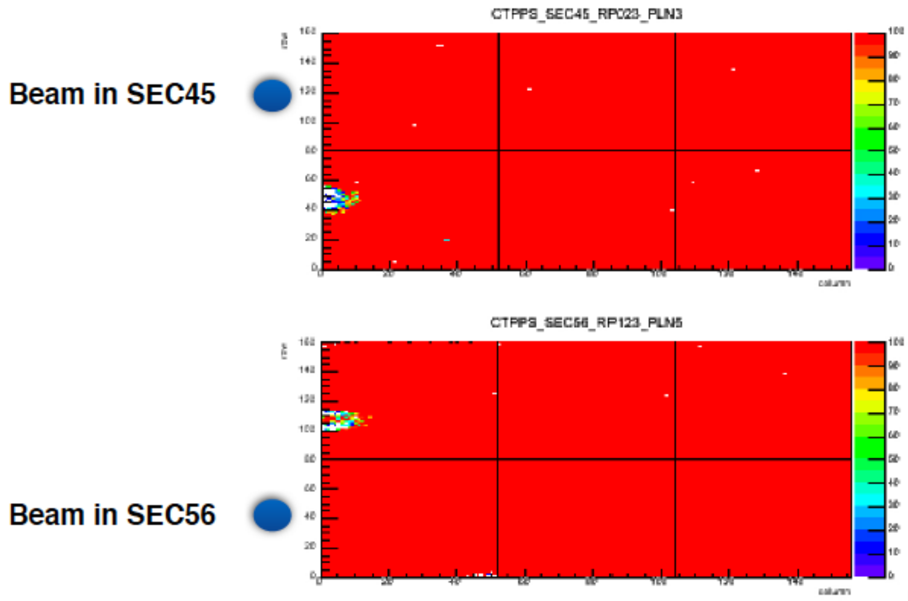
Front-end:

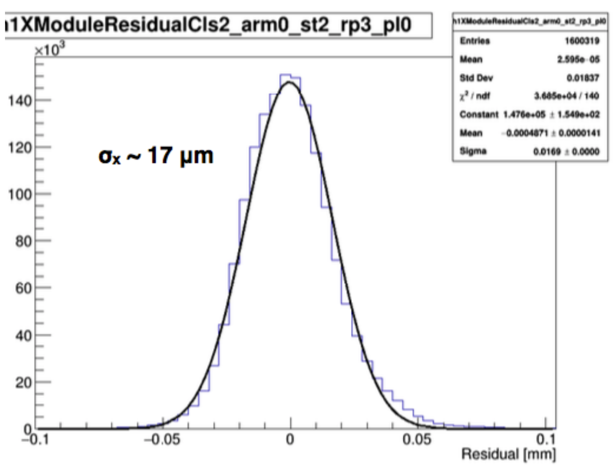
- PSI46dig, same as CMS Pixel Phase 1 upgrade
- Phase 1 DAQ components

Tracking: status and performance

- Excellent performance of pixel detectors in 2017
  - Track resolutions compatible with expectations
- RP movement and BX shift to cope with radiation
- New detectors installed in 2018 (replacing strip detectors)
- Detector packages swapped btw 45 and 56 to minimize inefficiency

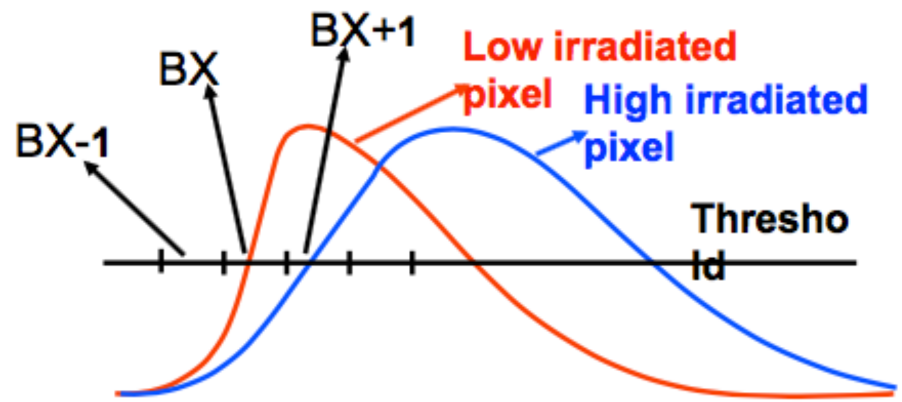
- Excellent spatial resolution, consistent with beam tests
- Single track events ~40%

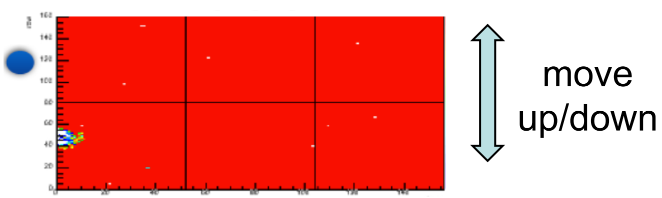


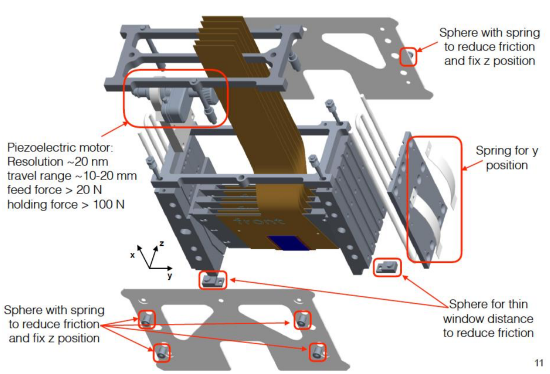


Tracking: Radiation

- Non-uniform irradiation
- Pixels not responding in same BX
- Effect due to readout chip





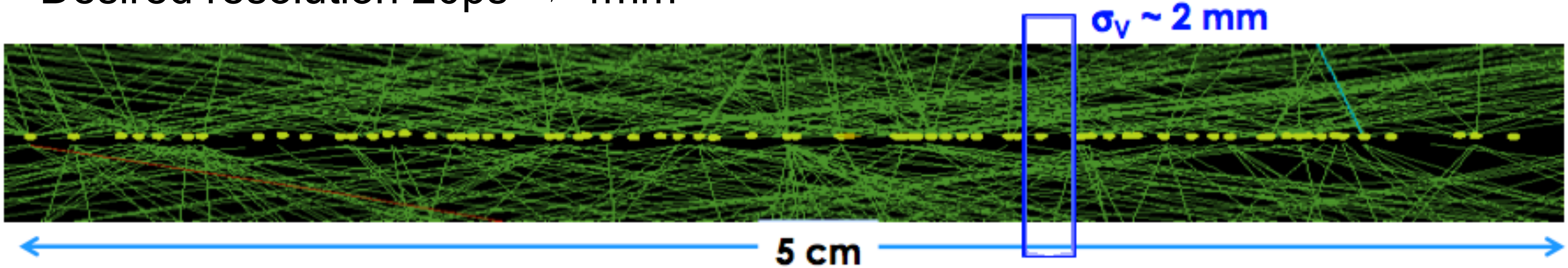


- Localized radiation damage near beam spot after ~10/fb
- Shift detector package to cope with radiation
- New stations with piezoelectric motor connected to detector package

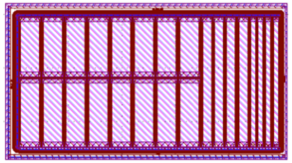
Timing detectors

Time-of-flight measurement to reject pileup bkg (uncorrelated proton tracks)

- Desired resolution 20ps ⇒ 4mm

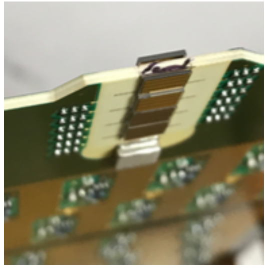


Ultra-Fast Silicon



- 1 plane (in 2017) per station
- Pixels of different sizes
- From test beam: single plane resolution ~30ps
- Will be used in high-β special run
- R&D to improve radiation hardness

Diamonds

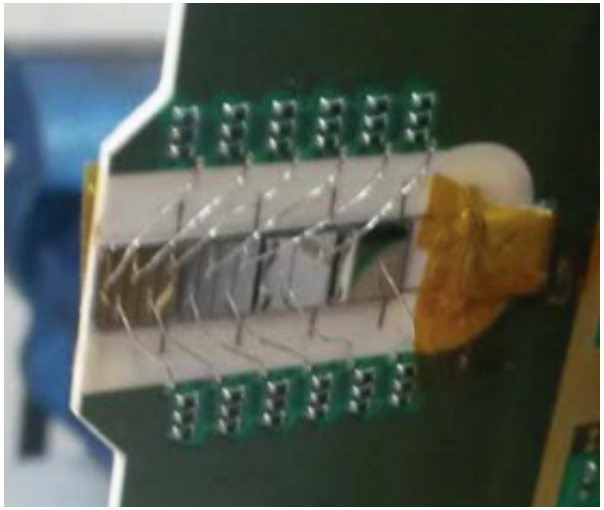


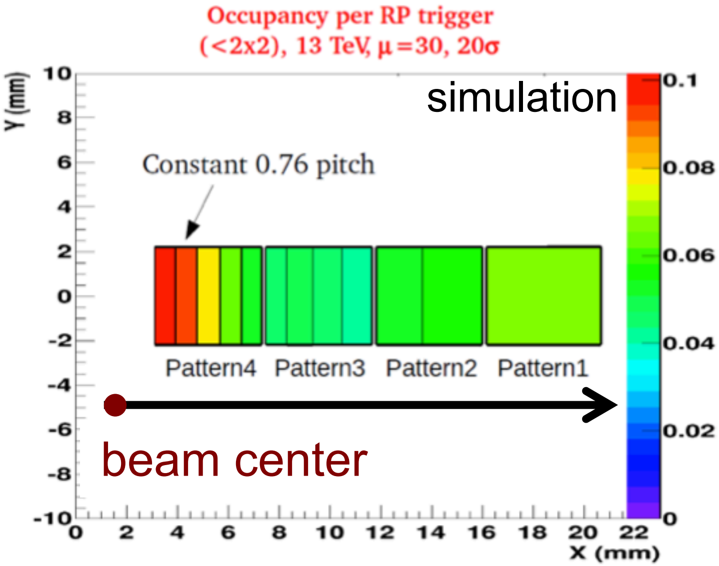
- 4 planes per station
- Pixels of different sizes
- Single plane resolution ~80ps
- Radiation hard

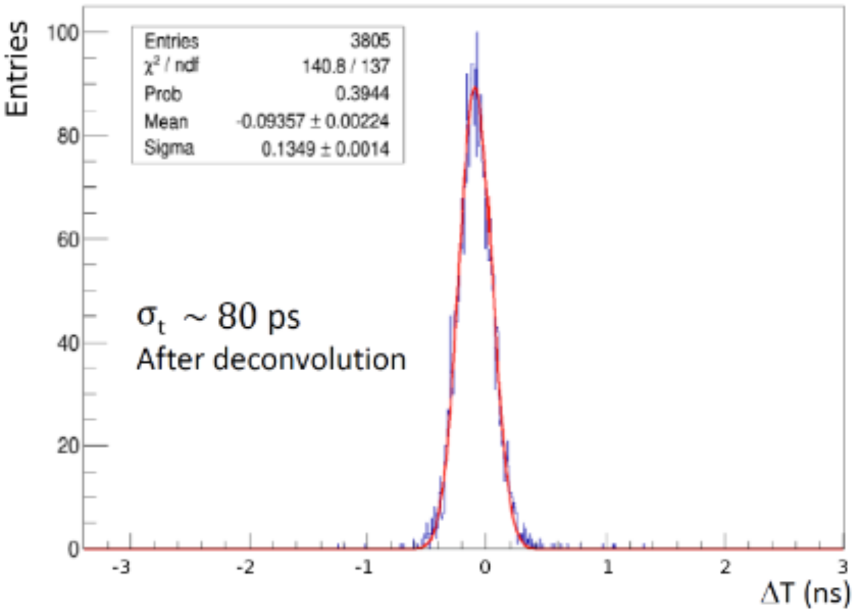
presentation by N. Minafra

Diamond detectors

- Diamond detectors
  - σ_T~80ps per plane, i.e. ~50ps with 4 planes
  - Four 4x4mm^2 sensors per plane
  - Variable pad dimensions to optimize occupancy
- Custom-made readout electronics
  - NINO (discriminator)+HPTDC
- Intrinsic radiation hardness
- Allow for high granularity







Timing detector R&D

Pursuing R&D to improve performance

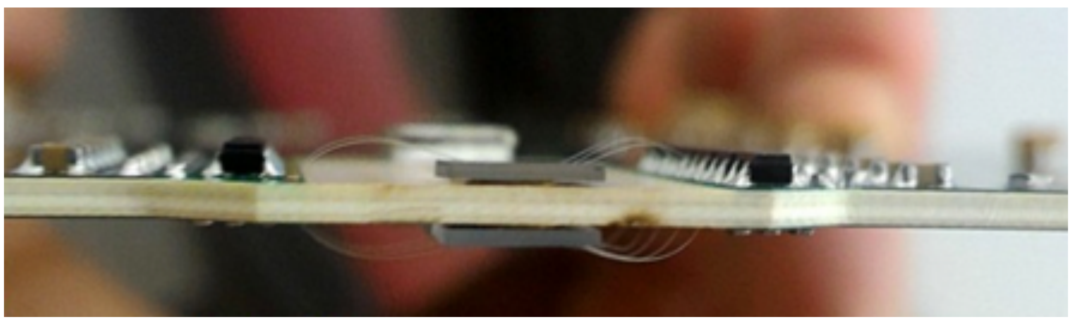
- Diamonds, silicon-based, quartz, etc.

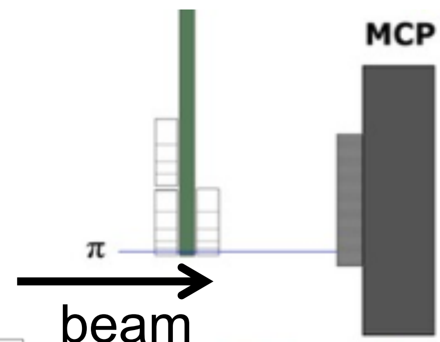
Challenges

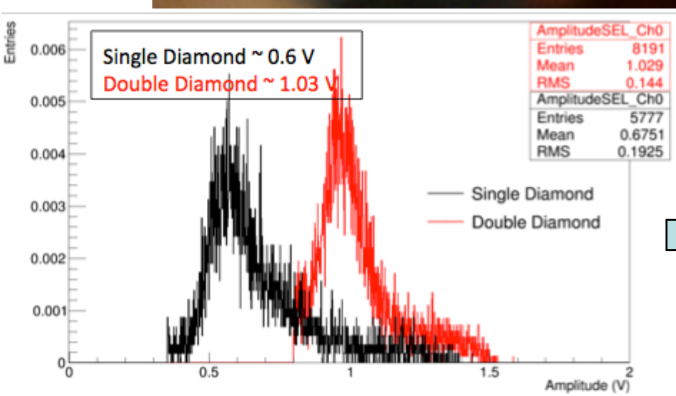
- Radiation-hardness
- Fast signals
- Finer segmentation reducing channel occupancy
- Thin and light, allow multiple layers N
  - reducing nuclear interaction
  - time resolution ~1/sqrt(N)

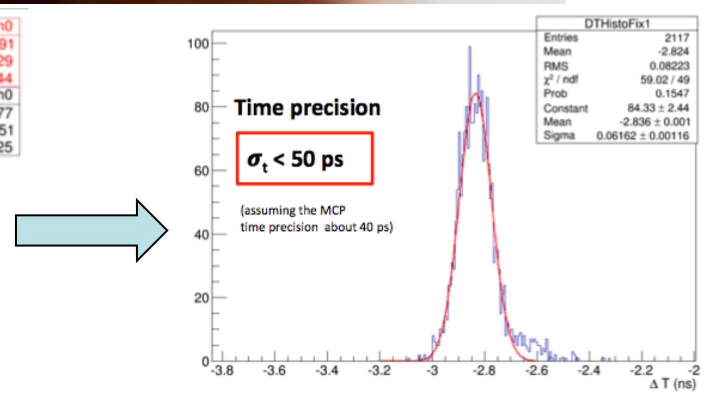
Double diamond layer

- Connected “sandwich” with two diamond sensors
- Beam tests in 2016/2017
- Performance improved: time resolution of 50 ps/plane (instead of 85-90ps) for 0.5x0.45mm sensors
  - Larger signal amplitude dominant over extra capacitance
- With 4 diamond sandwich-planes could reach 25 ps



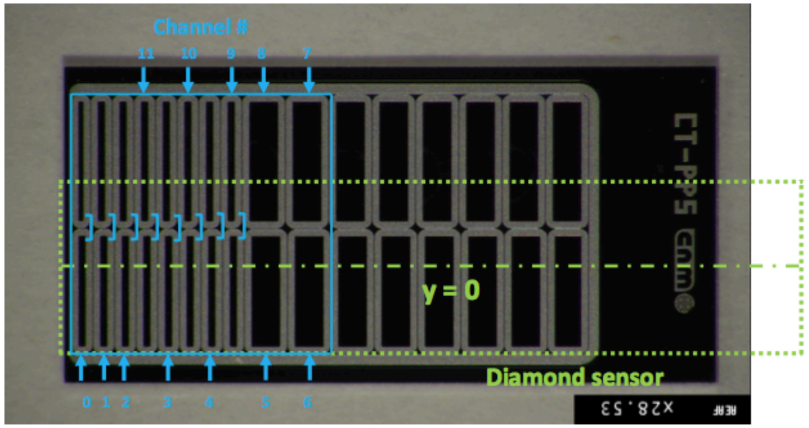


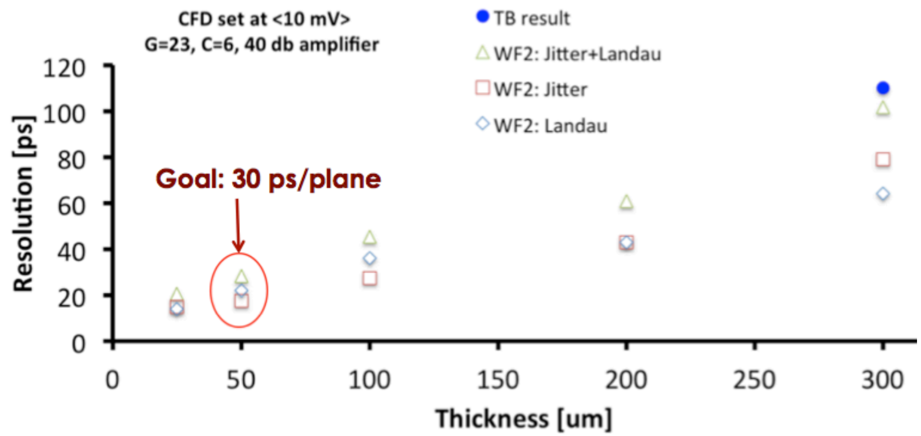




Ultra-Fast Silicon Detectors

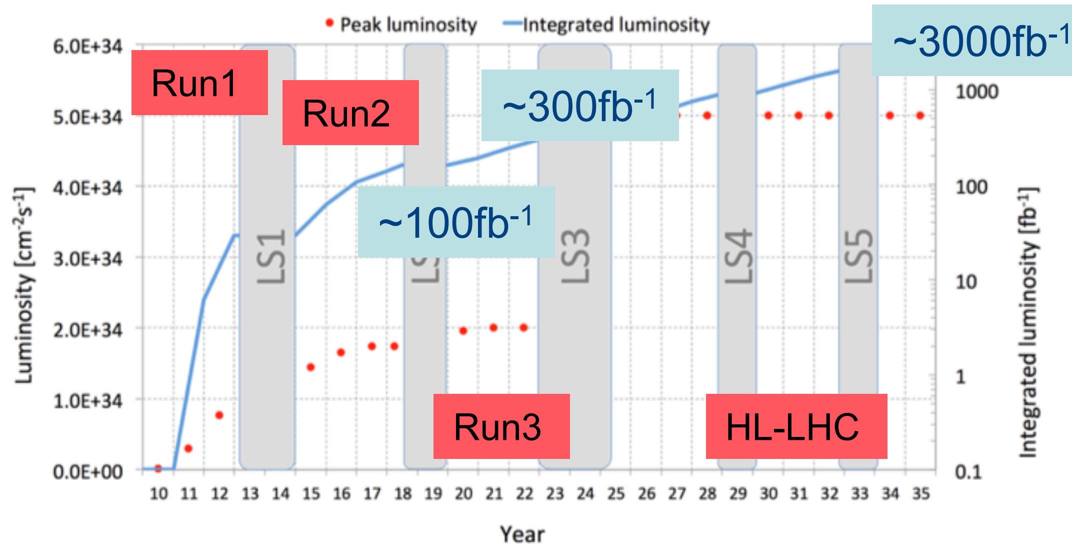
- Silicon Detectors for timing measurements
- Low Gain Avalanche Detectors
  - 50μm thickness
- Thin sensors
  - Higher collection efficiency
  - Short drift time
- Time resolution
  - Preliminary results at test beam: time resolution ~30-40ps @50um-thickness
- 2017: 1 plane used (first time in HEP)
- Radiation hardness
  - Lifetime ~10^{14} p/cm^2
  - R&D to improve rad-hardness ongoing
  - Carbon doping offers x2 rad-hardness
- High segmentation

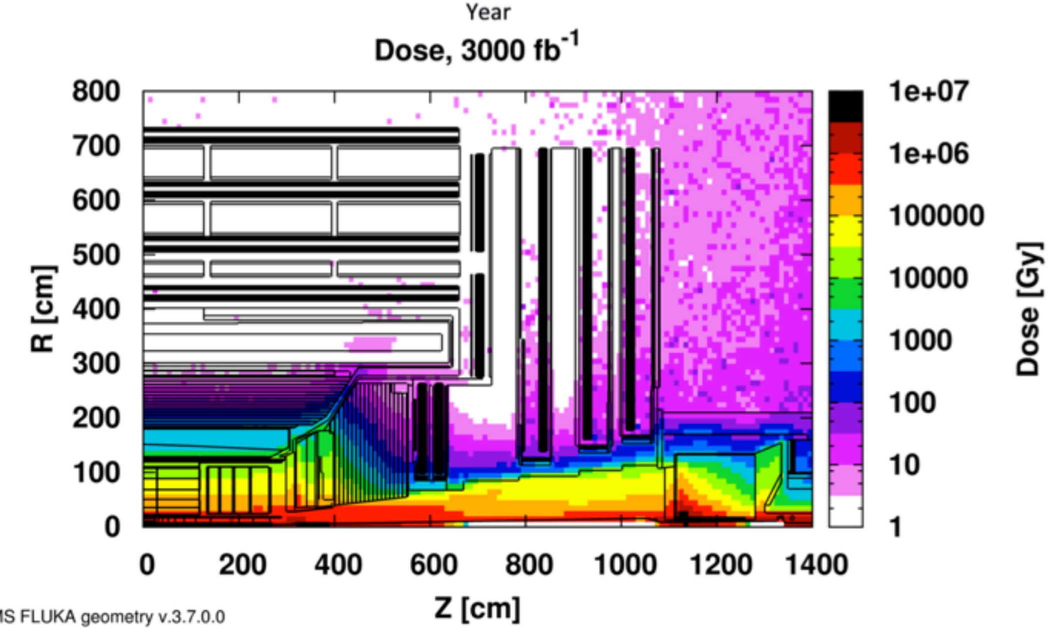




Prospects for Run3 and beyond

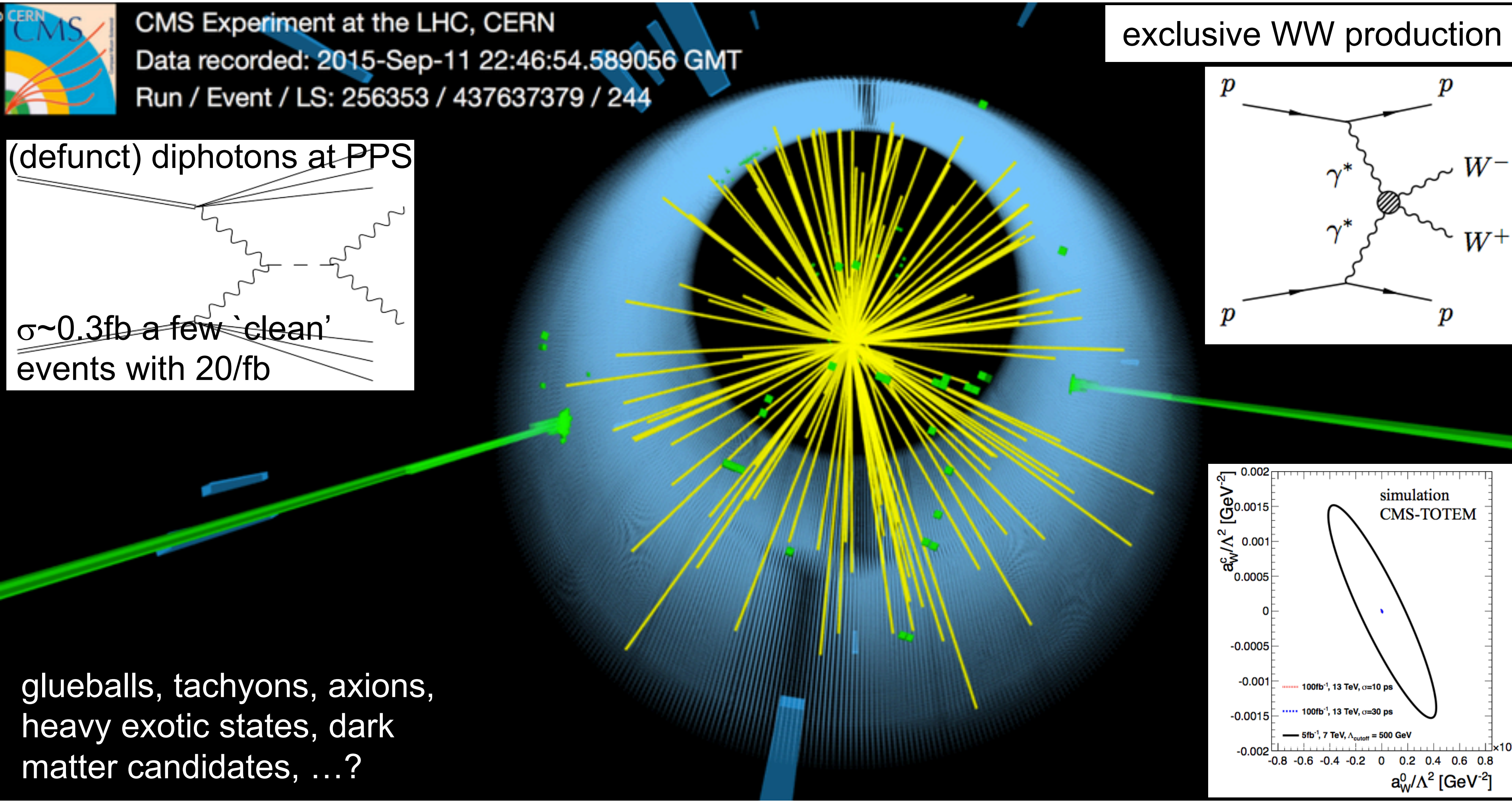
- More luminosity in a more challenging environment
- Will enhance the mass reach in the search for new particles
- Need to meet experimental challenges
  - Aging of detector, improve/adapt capability
  - Integrated luminosity: 300-3000/fb
  - peak luminosity of $2x10^{35}cm^{-2}s^{-1}$
  - pileup will be ~150 or higher (Phase2)
  - large radiation doses





presentations by N. Turini, M. Deile

BSM searches: resonances, etc.



Summary

- PPS extends coverage to very forward regions
  - Additional sensitivity to New Physics searches
  - Collected ~50/fb in 2016/2017
  - Taking data in 2018 with improved detectors
- Exclusive dilepton production
  - Exclusive process at the EWK scale
  - First physics results published
  - More data to be analyzed and to be collected in 2018
- PPS regularly taking data in high-luminosity fills