TOTEM status report

K. Österberg,
Department of Physics, University of Helsinki & Helsinki Institute of Physics

on behalf of
TOTEM collaboration

LHCC open session 30.11.2016

Outline:

- ✓ TOTEM physics
- ✓ CT-PPS

TOTEM physics (special runs)

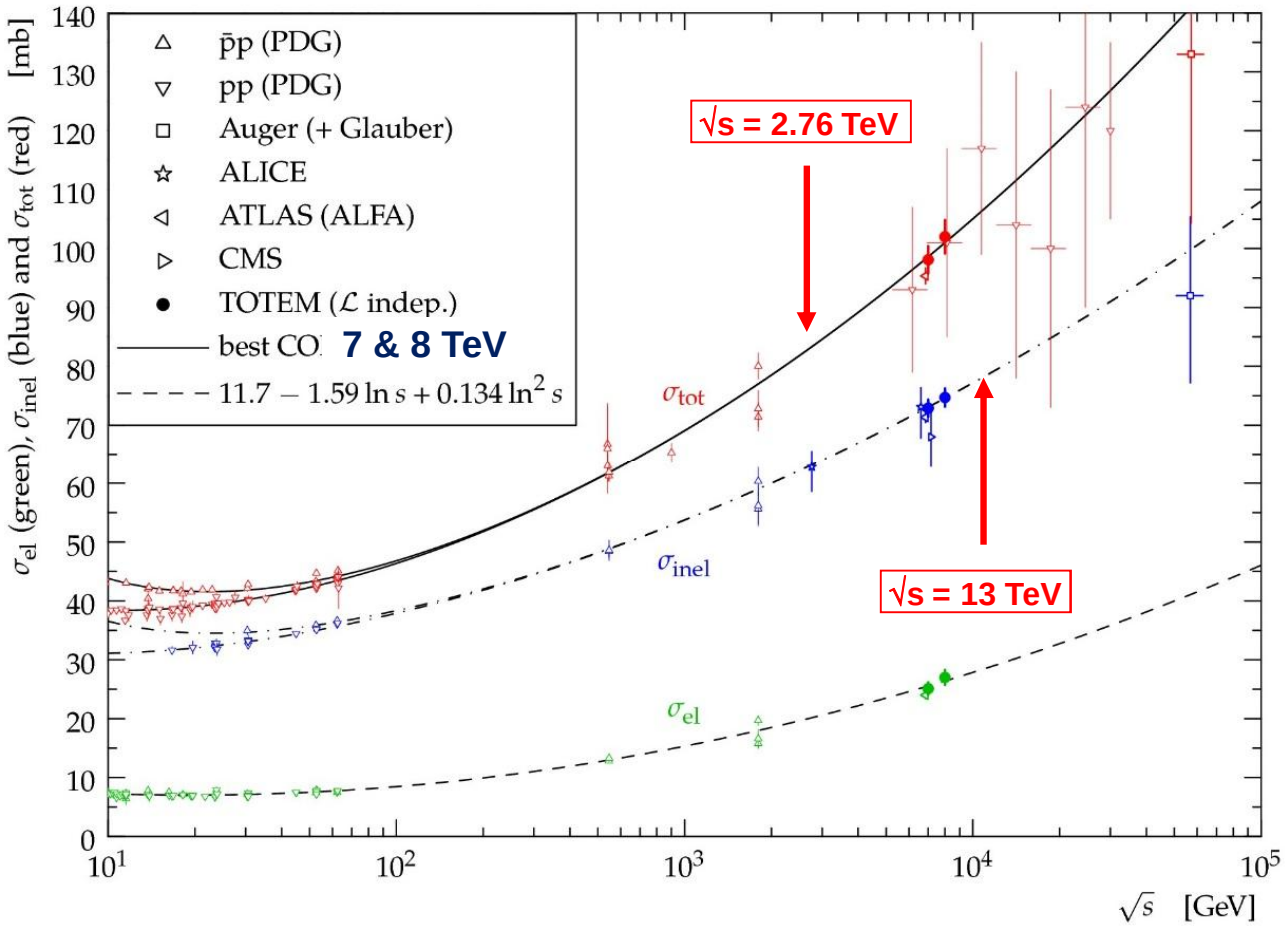
- Total pp cross-section (σ_{tot})
- ρ (ratio of real & elastic hadronic amplitude at $t = 0$)
- Glueball candidate & low mass resonance study (with CMS)

σ_{tot} measurements

Luminosity independent method:

$$\sigma_{tot} = \frac{16\pi}{(1+\rho^2)} \frac{(dN_{el}/dt)_{t=0}}{(N_{el}+N_{inel})}$$

- $\sqrt{s}$ = 7 TeV (β^* = 90m) & 8 TeV (β^* = 90 m & 1 km) results published
- $\sqrt{s}$ = 2.76 TeV (β^* = 11 m) close to be completed
- $\sqrt{s}$ = 13 TeV (β^* = 90 m) progressing well



σ_{tot} @ $\sqrt{s}$ = 2.76 TeV elastic

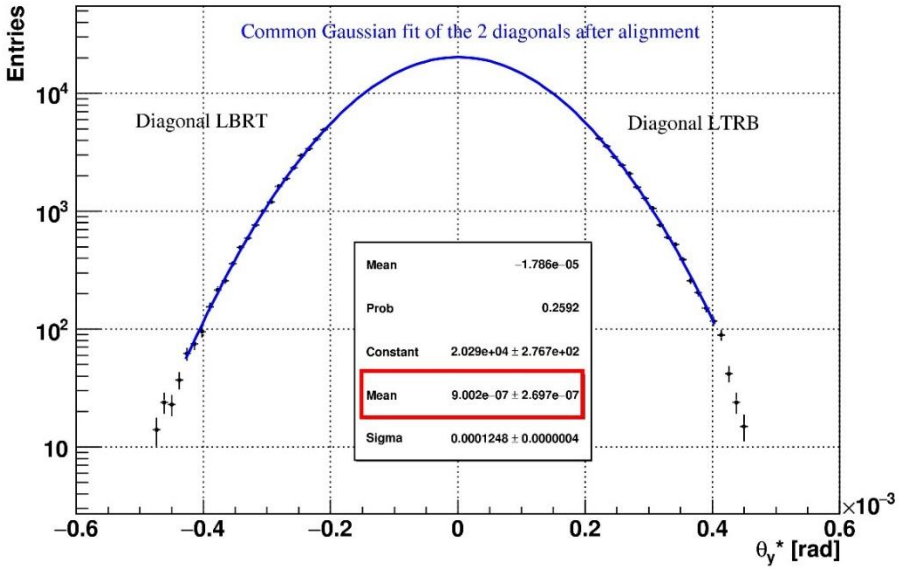
Jan 2013, RPs at 4.3σ

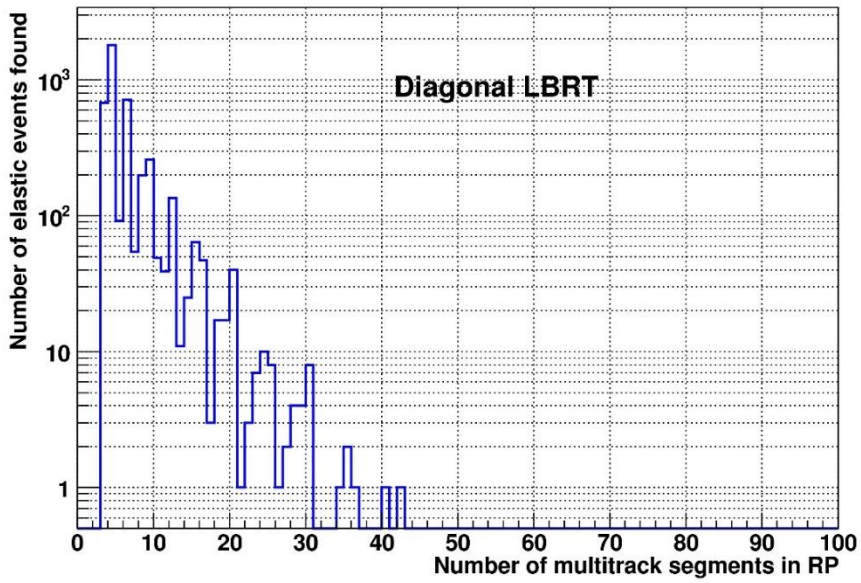
β^* = 11 m optics (not optimized for σ_{tot} measurement)

- Optics more sensitive to LHC perturbations & IP vertex size
- Beam divergence large (~20 μrad) $\Rightarrow$ limits scattering angle resolution
- Extrapolation to t = 0 longer (observe ~3 % of σ_{el} $\leftrightarrow$ 80 – 90 % at β^* = 90m)

Other challenges overcome:

- Horizontal RPs not inserted $\Rightarrow$ RP top – RP bottom relative alignment from ϕ symmetry of elastic scattering
- Only ~ 60 % of elastic single track in RP (due to overlapping activity) $\Rightarrow$ dedicated multitrack RP reconstruction to recover majority of elastic





σ_{tot} @ $\sqrt{s}$ = 2.76 TeV

Inelastic rate completed:
analysis method identical to 7 & 8 TeV

- Count events with charged particles in T1 & T2 (~ 97 % of inelastic).
- Trigger: at least one track in T2.
- Uncertainty: ~ 2 % (< @ 7 & 8 TeV)

largest contribution:
low mass diffraction (M_{diff} < 2.1 GeV)

Aim at similar uncertainty for σ_{tot} as 7 & 8 TeV despite added complexity for elastic part

Elastic almost completed:
analysis method similar to 7 & 8 TeV

Analysis steps:
1. Geometrical & beam divergence acceptance corrections (completed)
2. Unfolding (completed)
3. DAQ efficiency (completed)
4. Optics reconstruction (completed)
5. Alignment (completed)
6. Multitrack (completed)
7. Single & double RP inefficiency (being verified)
8.Trigger inefficiency (on-going)
8. Extrapolaton to t = 0 (tested)
9. Integral of t-distribution N_el (tested)

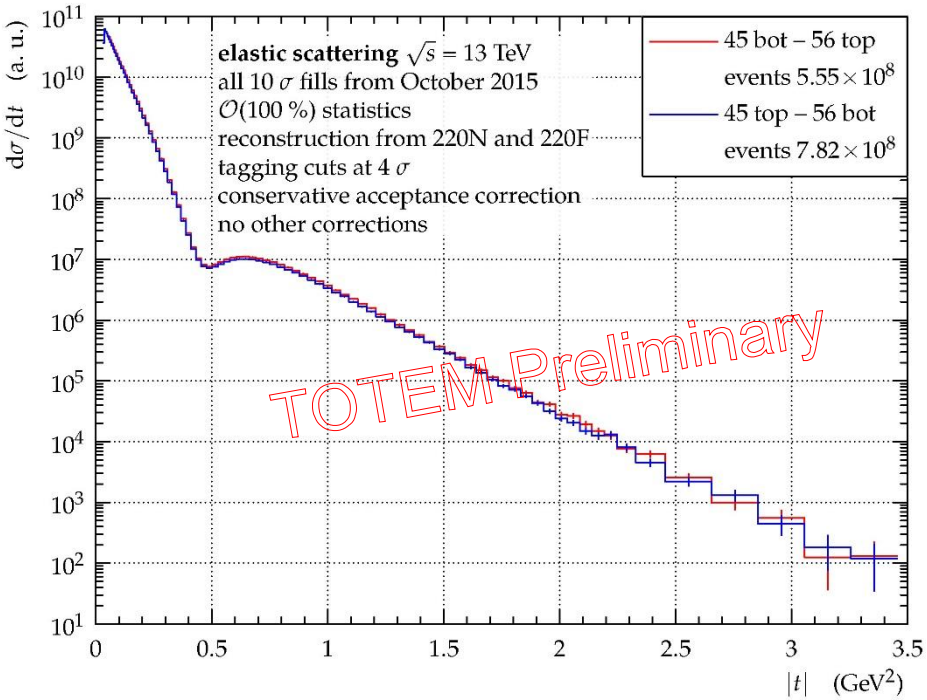
σ_{tot} @ $\sqrt{s}$ = 13 TeV

Elastic & inelastic analysis progressing well:

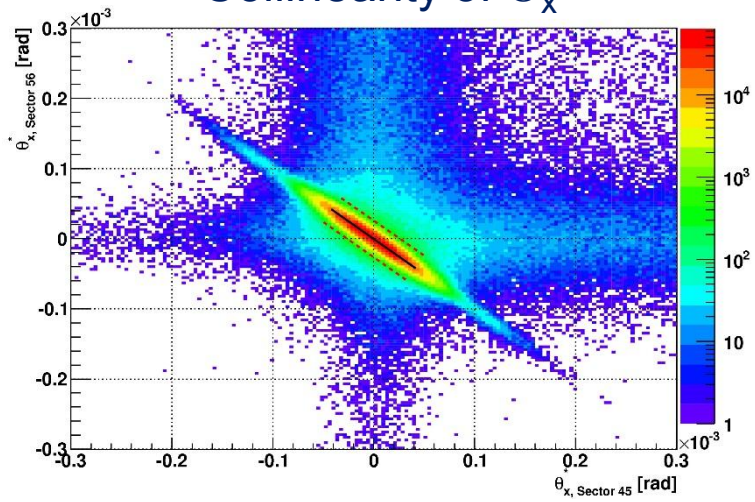
analysis method identical to 7 & 8 TeV β^* = 90 m

Elastic analysis:

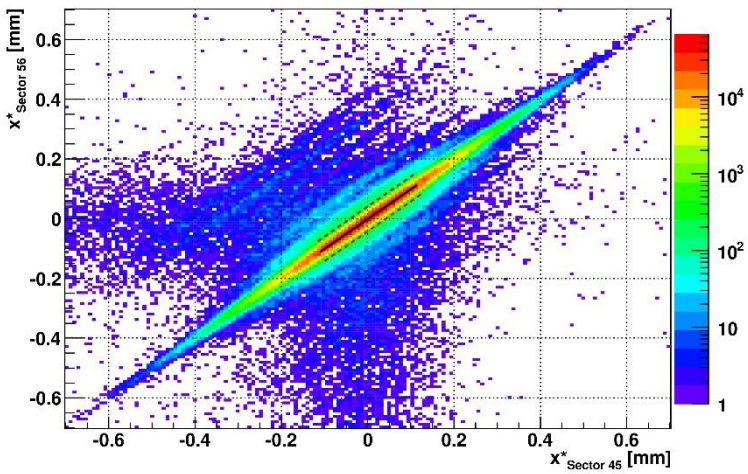
β^* = 90 m, Oct 2015, RPs at 5σ & 10σ
fill dependent cuts & corrections being tuned



Collinearity of Θ_x^*

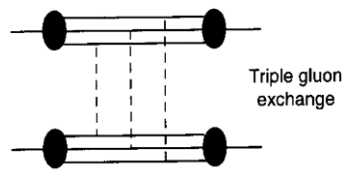


Correlation of vertex x



No structures at high-|t| !

- Rules out many model
- Physics interpretation: transition between diffraction & pQCD a la Donnachie-Landshoff

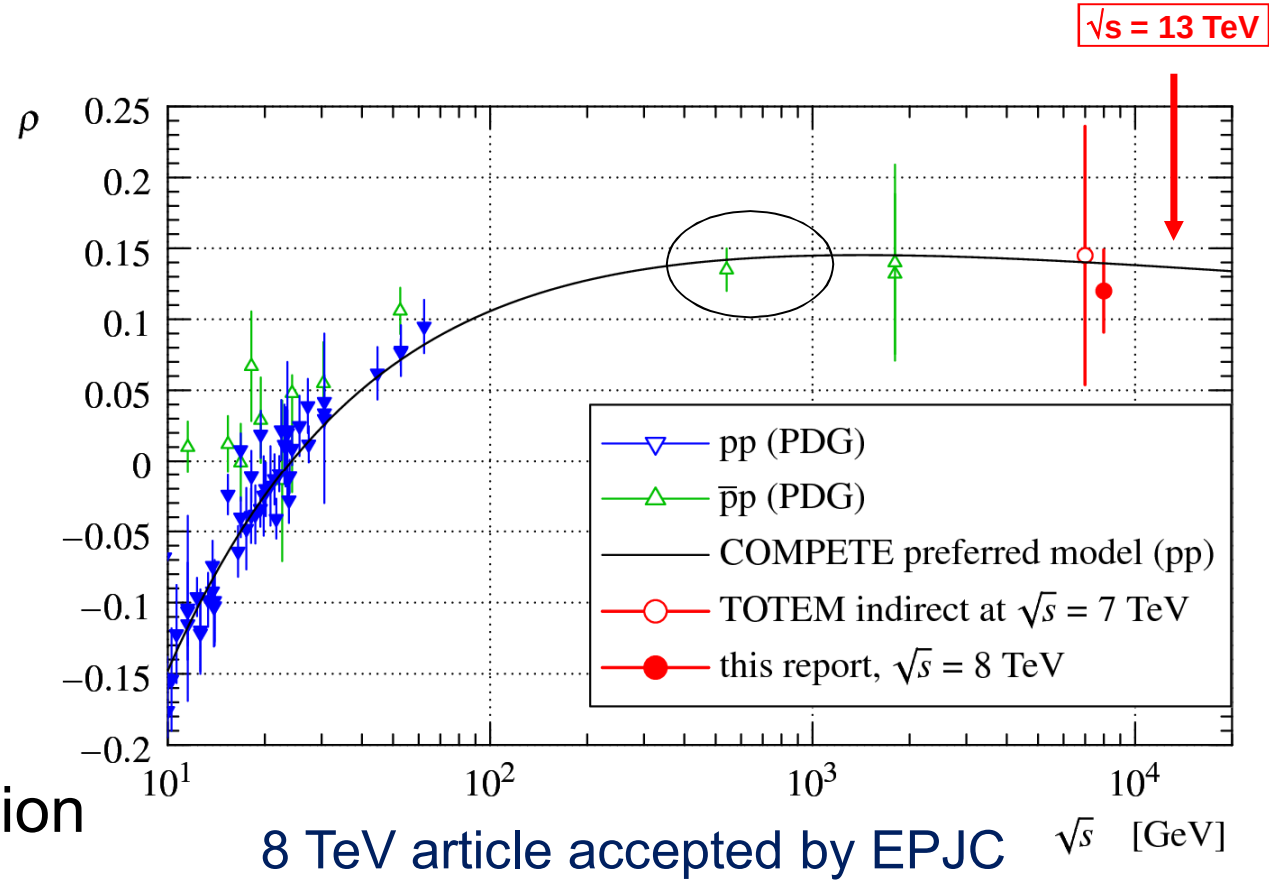


ρ measurements

By studying Coulomb-hadronic interference at very low |t| able to measure ρ:

$$\rho = \left.\frac{\Re\mathcal{A}^N}{\Im\mathcal{A}^N}\right|_{t=0}$$

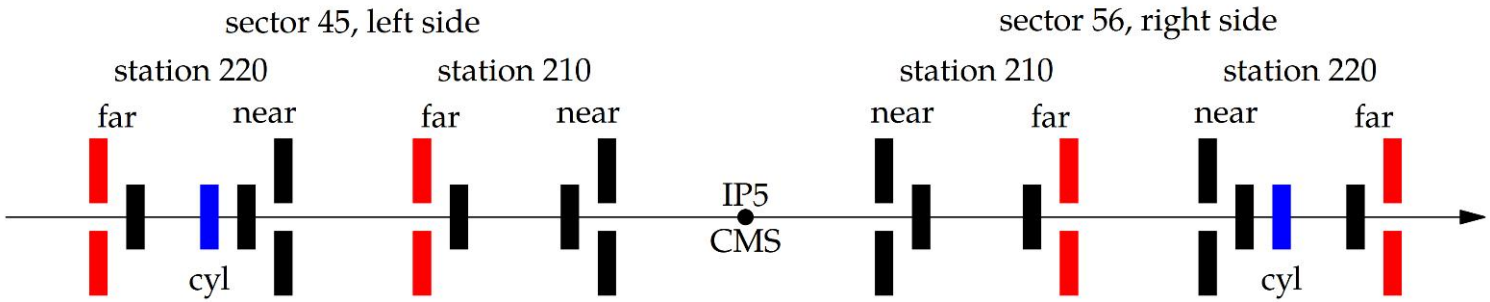
measure ρ with 0.01 precision



8 TeV article accepted by EPJC

β* = 2.5 km run @ 13 TeV in Sep 2016

RPs (red) used in run



$\beta^* = 2.5$ km run @ 13 TeV

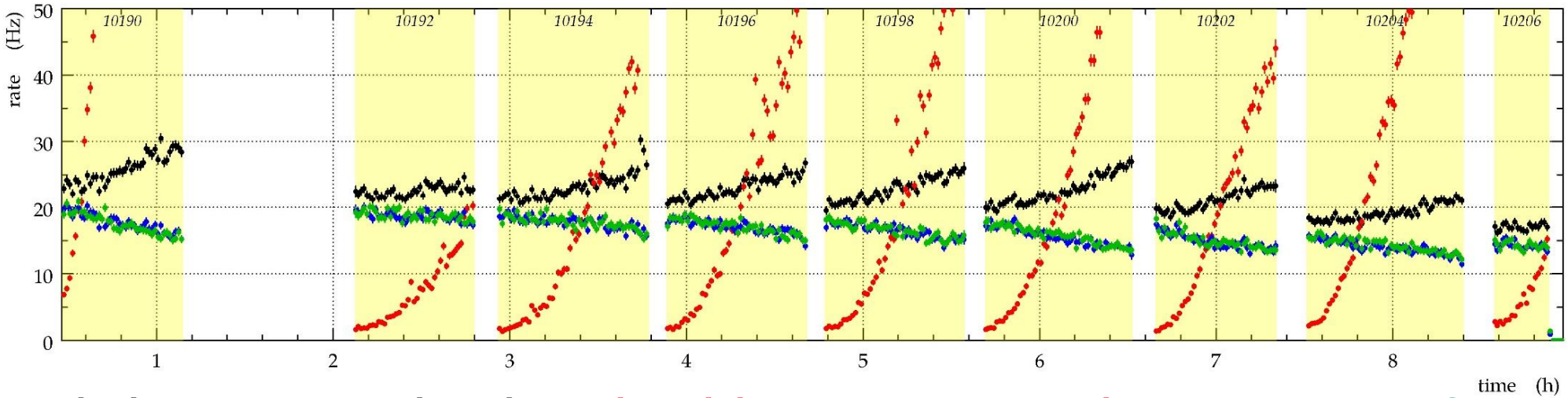
RPs at $3\sigma \Rightarrow |t|_{min} \approx 4 \cdot 10^{-4}$

$\mathcal{L}_{int} \approx 0.38\ nb^{-1}$

~6.3 M elastic candidates
(if requiring 4 RP out of 4)

fill	length	periods	$\mathcal{L}_{int}$ (nb^{-1})	N_{ev}
5313	8.5 h	9	0.036	0.7 M
5314	8.5 h	9	0.050	0.8 M
5317	28 h	21	0.177	3.4 M
5321	12 h	9	0.118	1.4 M

Reasonable background $\Rightarrow$ regular beam cleaning procedure

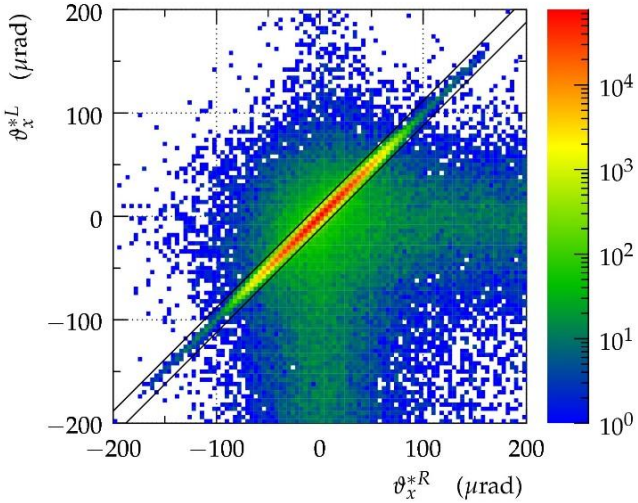


Black: reconstructed tracks, red: activity not reconstructed, green: 4 RP out of 4

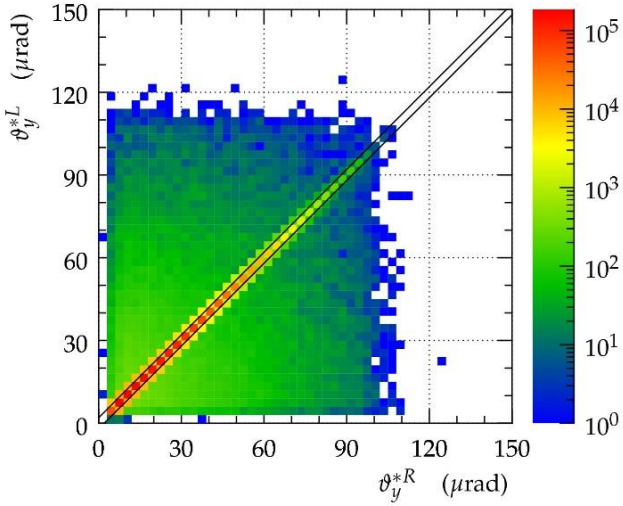
2.5 km analysis

Impression from first analysis: data quality good, alignment, optics & background not an issue $\Rightarrow |t|_{min}$ acceptance possible to optimize using 2 RP out of 4

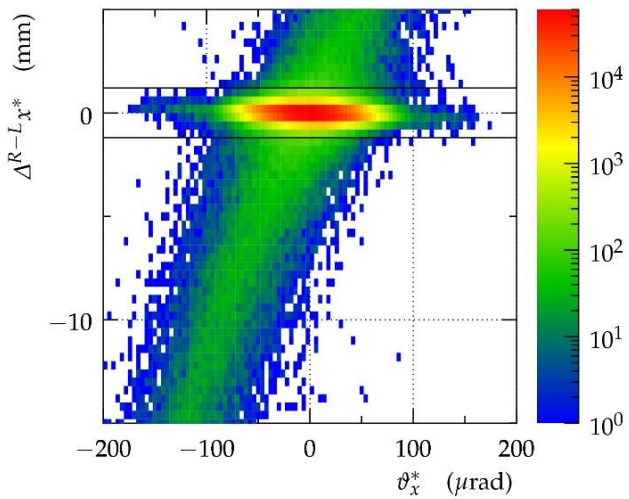
Collinearity of Θ_x*



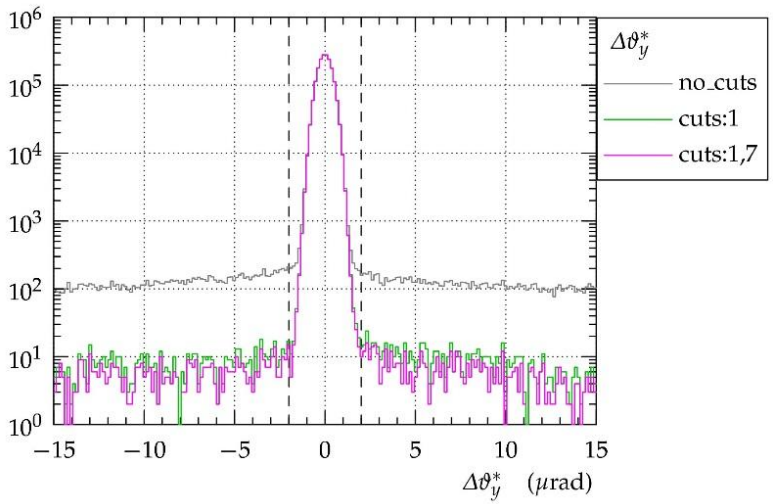
Collinearity of Θ_y*



Same vertex x

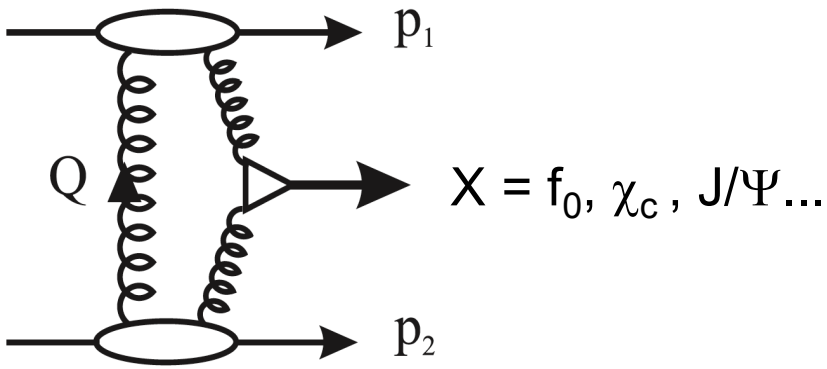


background estimate: left-right Θ_y* difference as function of elastic selection steps



Glueball candidate & low mass resonance studies

CMS-TOTEM $\sqrt{s}$ = 13 TeV, Oct 2015,
β^* = 90 m, $\mathcal{L}_{int}$ = 0.4 pb^{-1}
L1 Trigger exchange,
dedicated exclusive low mass trigger
independent DAQs $\Rightarrow$ offline merging



- Tuning and validation of special low p_T tracking & vertexing to optimize reconstruction for such topologies (low multiplicity & low mass (1-2 GeV)) during summer 2016

- Exclusive low mass trigger data stream re-reconstructed & remerged (~ few months) $\Rightarrow$ significant increase of statistics in analysis, quantitative effects on glueball candidate study being evaluated

- Analysis also on-going on other trigger streams eg. dimuon & dijet

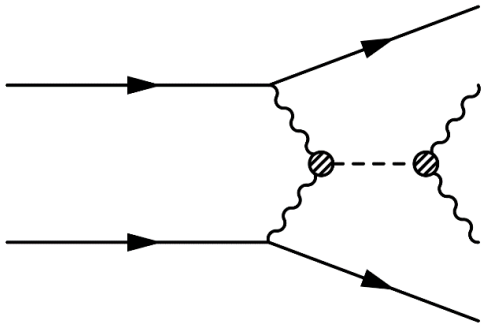
CT-PPS

- CMS-TOTEM Precision Proton Spectrometer (PPS)
- Data taking
- Diamond
- Physics potential
- EYETS activities

CT-PPS has initiated high luminosity diffractive physics program at LHC

CT-PPS

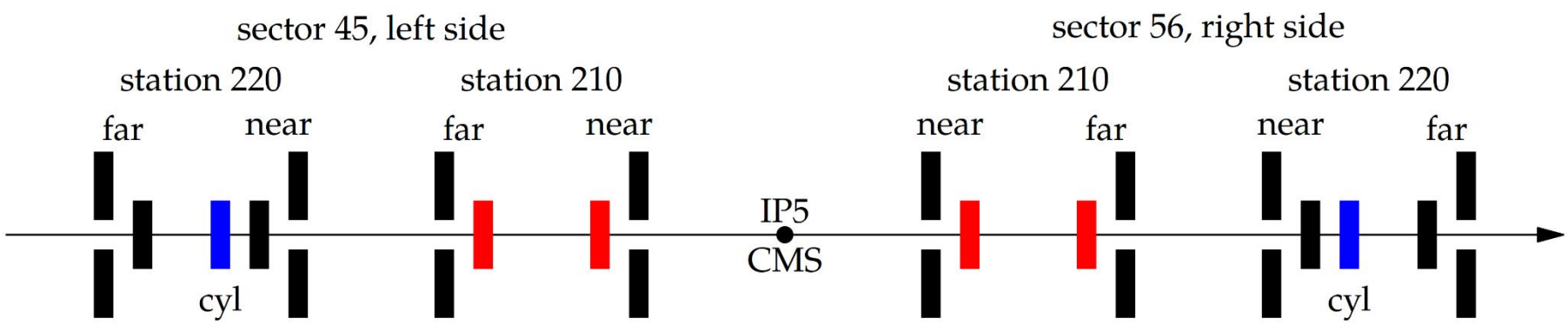
Motivation: study high mass exclusive central production at standard high luminosity runs



$$M_{\gamma\gamma} = M_{pp}$$

Accelerated CT-PPS for 2016: using existing/advanced developed technology

- Beam pockets: horizontal RPs (with RF shields or new cylindrical design)
- Tracking detectors: TOTEM Si strips (red)
- Timing detectors: TOTEM diamonds



CT-PPS detectors fully integrated into CMS DAQ

CT-PPS data taking

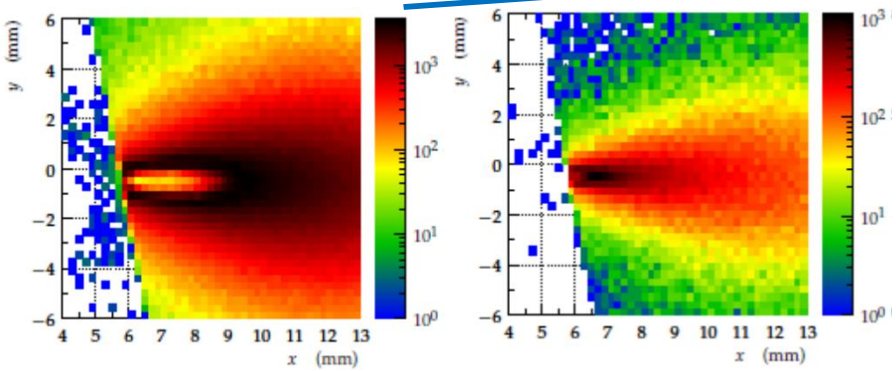
RPs at15σ & readout as part of CMS standard high luminosity running

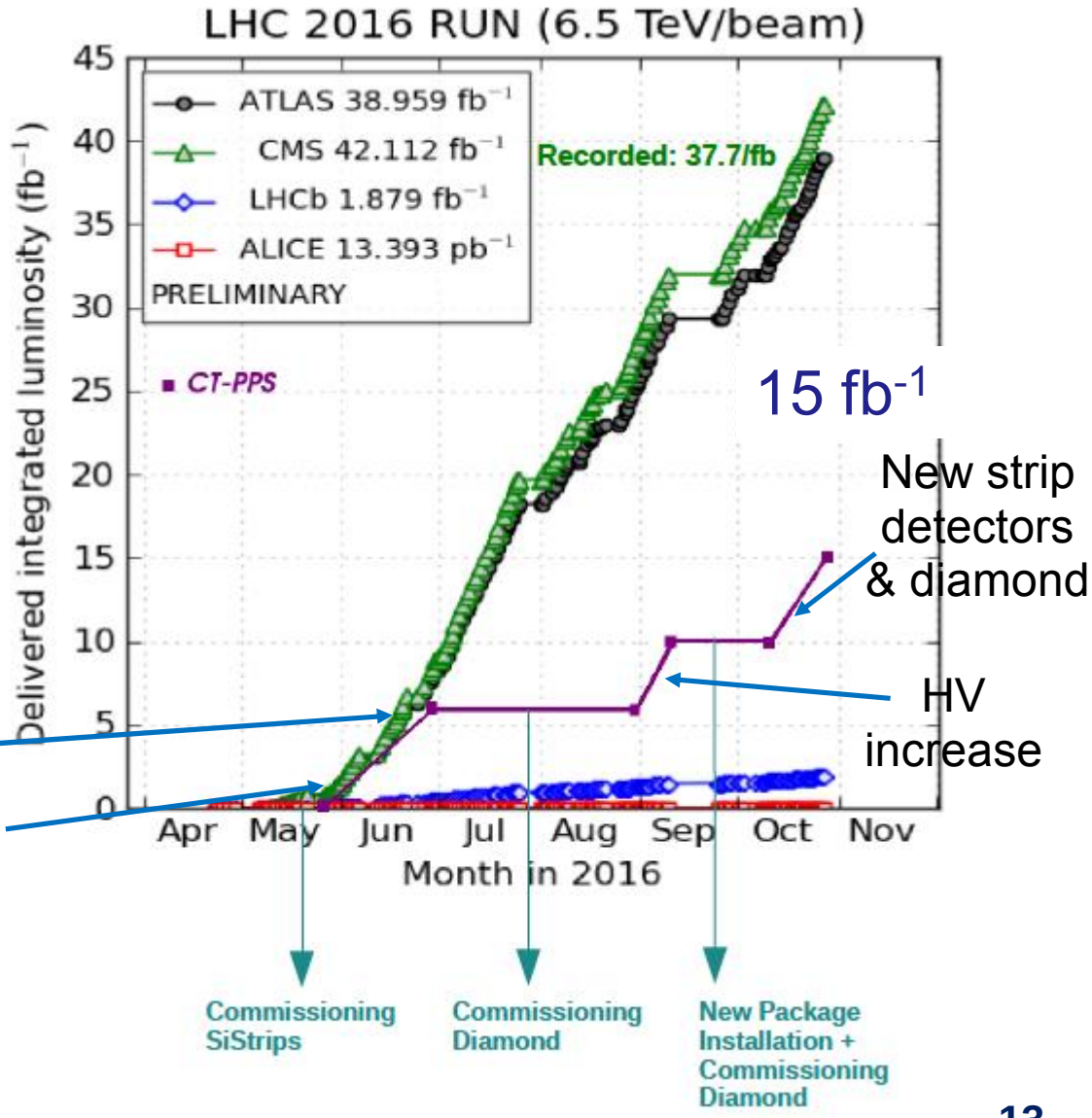
2016 luminosity with CT-PPS:

- Strip detectors 15 fb^{-1}
- Diamond detectors 2.5 fb^{-1}

~ 2/3 of data strip detector fully efficient, ~ 1/3 efficiency loss in most occupied region due to radiation damage in silicon

e.g. in 56 210-far:



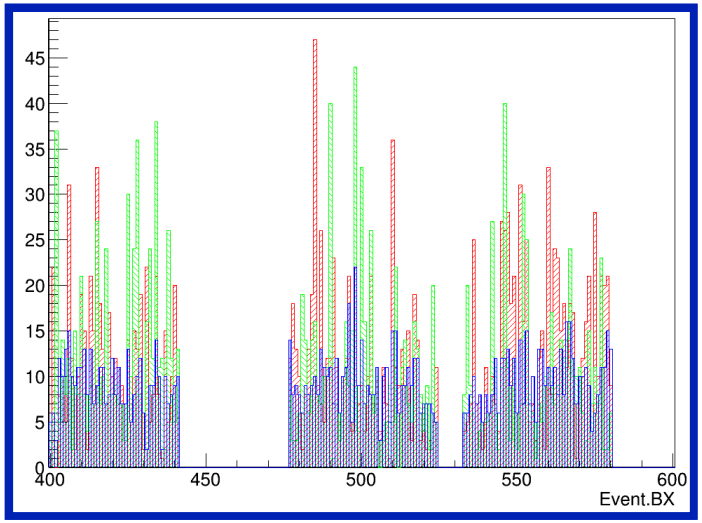


Diamond detector data taking

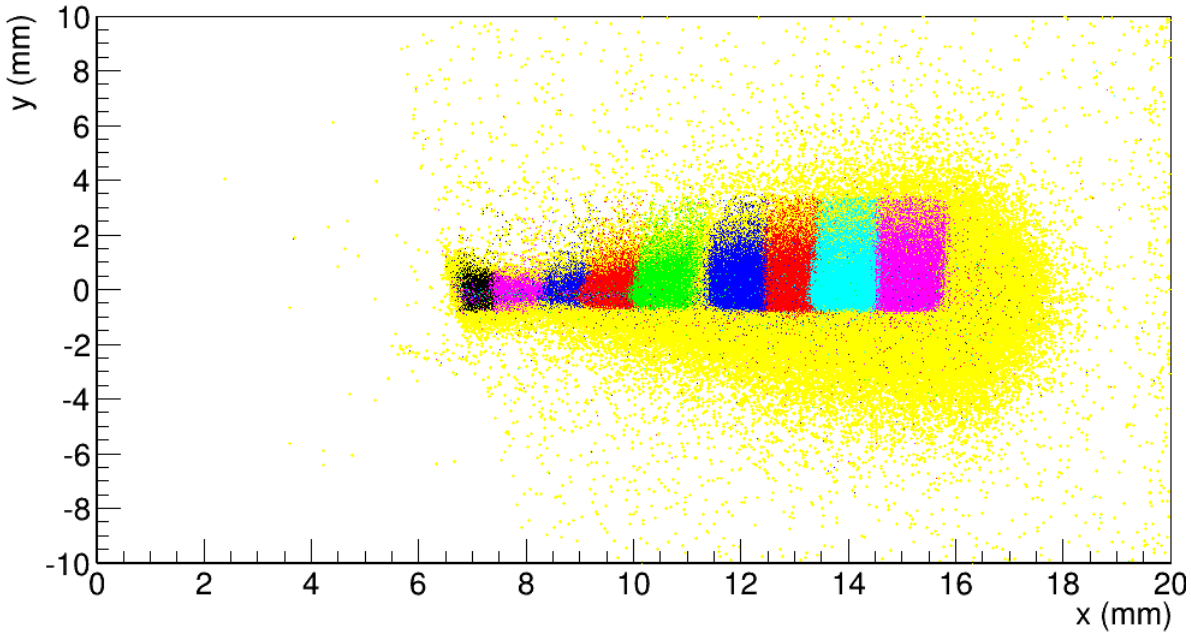
Diamond included in standard high luminosity data taking during last week of pp run (~ 2.5 fb^{-1})

synchronisation verified with strip detector data

Activity in
Diamonds 45 Diamonds 56 Strips



Diamond pixels (colour) on 45 arm in coincidence with strip detectors (yellow)



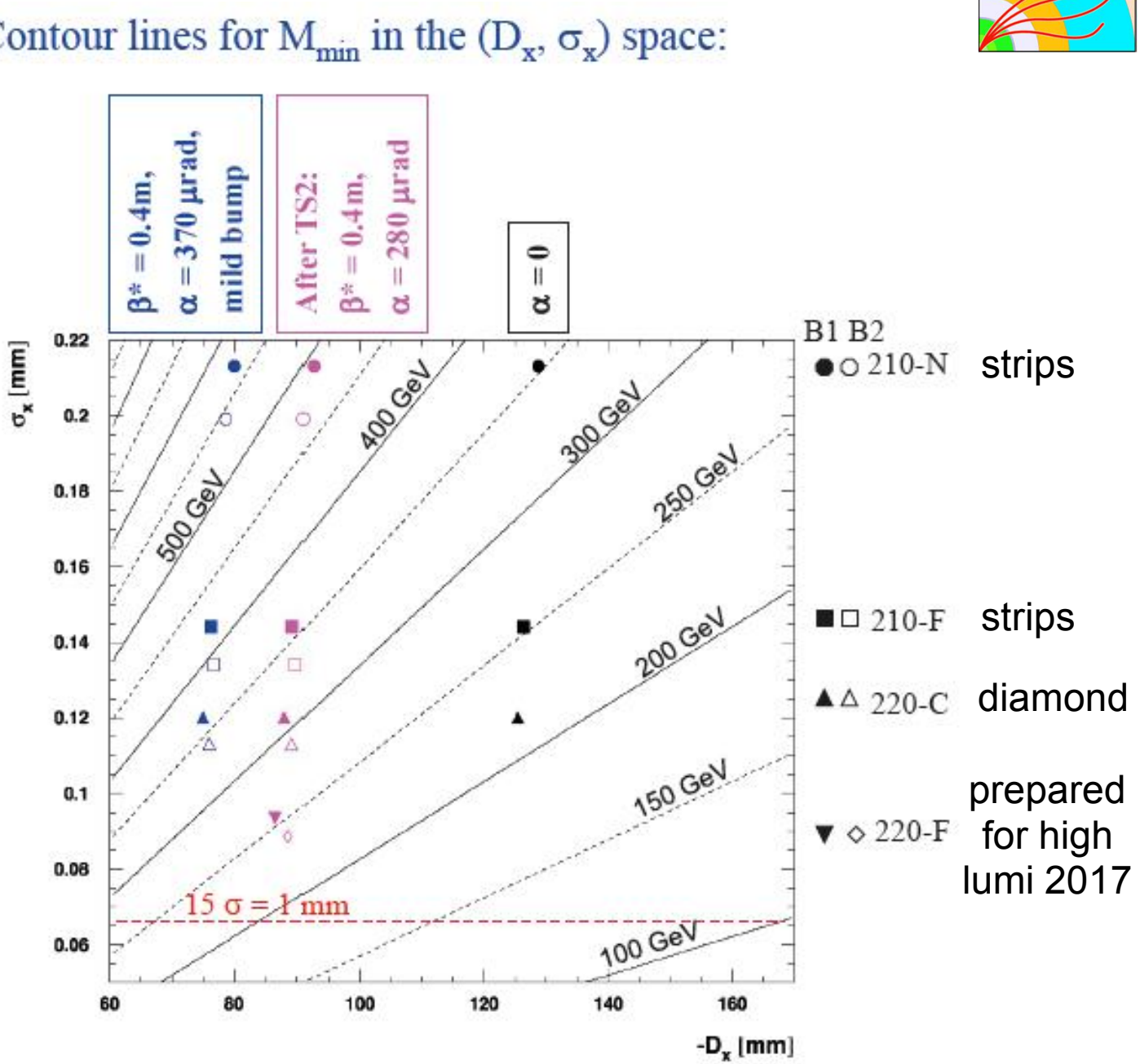
Diamond detectors misaligned with respect to beam by about 2 mm in both arms

CT-PPS mass acceptance

Minimum mass reach 2016 (assuming nominal optics)

Upper mass limit 2016: 1950 GeV

For 2017 discussions with optics team started



CT-PPS physics potential

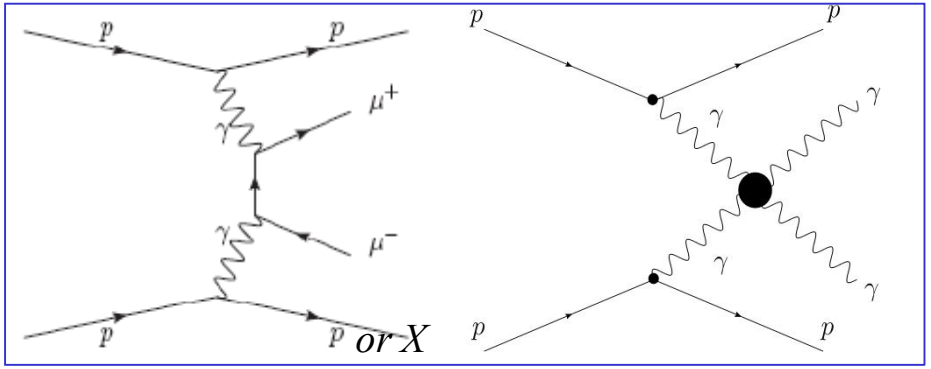
Exclusive Production:

- photon-photon fusion
- gluon-gluon fusion in colour-singlet state ($J^{PC} = 0^{++}, 2^{++}$ ..)

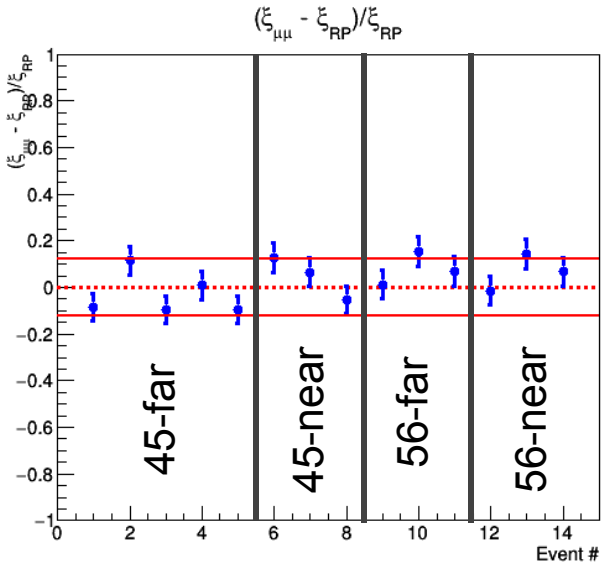
Strategy: require correlation central system & forward protons

Early analyses (does not require timing detectors):

Diphoton production sensitive to anomalous quartic couplings ($\gamma\gamma\gamma\gamma$).



Proton kinematic reconstruction cross-checked using $pp \rightarrow p + \mu\mu + X$ events

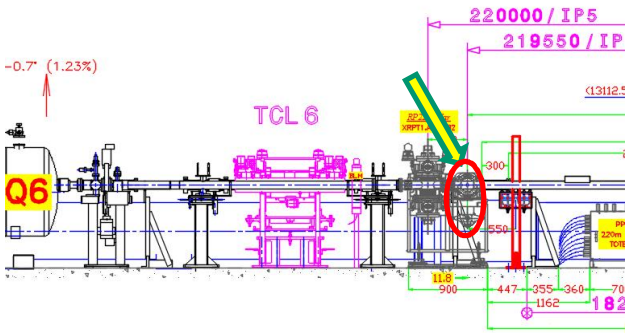


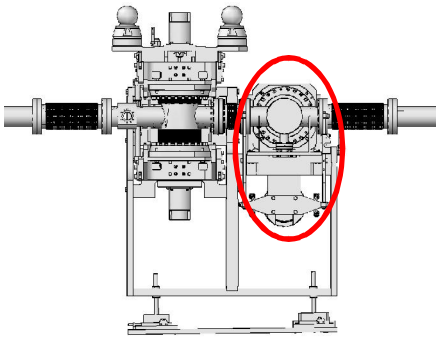
$\pm 2\sigma$

With timing detectors and/or more statistics:

- Exclusive WW
- Exclusive dijets
- Inclusive missing mass/missing energy
- …

Main EYETS activities





Preparation of horizontal RP220 far for operation at high luminosity

- exchange ferrites & install RF shields in RP220 far
- installation of additional line for warm mode cooling in RP220 near
- separate the secondary vacuum lines of the RP 210 & 220 and separate cooling of RP cylindrical (timing)
  - independent pressure/temperature operation points of the tracking and timing detectors

Installation of detectors

- installation of pixel detector packages
- Installation of timing detector components

Level beam tube and RPs (CMS request)

TOTEM run strategy

- ✓ **Run at full luminosity with CTPPS whole year in 2017 (BSM searches)**
- ✓ Low $\sqrt{s}$ [450-900 GeV] run with special high β^* optics to measure ρ in SppS region (whenever convient)
- ✓ Continue to explore physics cases for joint $\beta^* = 90$ m runs with CMS (missing mass, glueballs,...)
- ✓ Readiness for special run at $\beta^* = 90$ m to measure σ_{tot} at $\sqrt{s} = 14$ TeV (whenever 14 TeV will be reached)

Summary

TOTEM physics:

- σ_{tot} at $\sqrt{s}$ = 2.76 TeV soon finalized
- σ_{tot} at $\sqrt{s}$ = 13 TeV progressing well
- β^* = 2.5 km data large potential for precise ρ measurement

CT-PPS:

- RPs operated at 15σ & highest luminosity
- 15 fb^{-1} of data with CT-PPS (in ~ 2/3 strips 100 % efficient)
- Commissioned diamond detectors & collected first data
- First analysis on-going
- Prepare RP220 far for high luminosity running

J. Varela, CT-PPS LHCC referee meeting 29.11.2016

CT-PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis.

CMS and TOTEM have paved the way for other such spectrometers.

Backup

CT-PPS Data Taking Summary

STRIPS (PACK2) : 45 NR-FR / 56 FR
DIAMONDS : 45/ 56
OPTICS_140 L=2.5/fb

STRIPS (PACK2) : 45 NR-FR / 56 FR
OPTICS_140
L=2.8/fb

STRIPS (PACK1) : 45 NR-FR / 56 NR-FR
OPTICS_185
L=3.8/fb

STRIPS (PACK1) : 45 NR-FR / 56 NR-FR
OPTICS_185
L=5.6/fb

STRIPS (PACK1) : 45 NR-FR / 56 NR-FR
With margin
OPTICS_185 L=0.6/fb

Fill	Runs	Recorded Lumi /pb	RP IN (15σ+0.5mm) [Local time]	Comments
5451	284029 284035 284036 284037 284038 284039 284040 284041 284042 284043	332.25	09:10:00 AM	diamonds IN / HV strips 300 V
5450	284006 284014	106.42	02:00:00 AM	diamonds IN / HV strips 300 V
5448	283946 (LS115) 283964	366.03	07:40:00 AM	diamonds IN / HV strips 300 V
5446	283934	280.27	06:40:00 PM	diamonds IN / HV strips 300 V
5443	283884 (LS406) 283885	386.06	12:05:00 AM	diamonds IN global / HV strips=300V
5442	283876 283877	411.45	03:50:00 AM	diamonds IN global
5441	283865	220.28	06:25:00 PM	diamonds IN global
5439	283820 283830 283834 283835	383.4	09:00:00 PM	diamonds IN global
		2475.15		
5437	283675 283676 283680 283681 283682	126.83	01:30:00 AM	Run 283685/ test diamond with beam separation
5433	283548 (LS 244) 283549 283550 283551 283553 283560	156.97	11:36:00 PM	HLT: PixelScan ?
5427	283478 283481	209.65	04:30:00 AM	
5424	283453	110.6	07:30:00 PM	
5423	283408 283413 283414 283415 283416	487.88	10:10:00 PM	HV=250 V
5421	283353 283358 283359	413.41	08:16:00 PM	
5418	283306 283307 283308	348.81	09:57:00 PM	
5406	283050 283062 283059 283067	213.71	06:16:00 AM	HV=150V at 1pm run 283059 LS 447 ; HV=200 at 1.13pm run283067 LS 31
5405	283041 283042 283043	149.47	09:48:00 PM	
5401	282917(LS 146) 282918 282919 282920 282921 282922 282923 282924	188.09	01:37:00 AM	
5393	good runs 282733 282734 282735	384.45	01:06:00 PM	NEW packages; 56nrhr not in data; HV=100 V ; ~75/pb in commissioning
		2789.86		
5288	280384, 280385	374.33	08:57:30 AM	HV=250V
5287	280330, 280349, 280363, 280364	505.53	8:35:20 AM (from 4:05 to 4:48 in garage)	HV=250V
5279	280187,280188,280189,280190,280191,280192 ,280194	286.48	08:32:43 PM	HV=250V
5277	279993,279994,279996,280001,280002,280006 ,280007,280013,280014,280015,280016,28001 7,280018	522.31	12:36:00 AM	HV=250V
5276	279975	242.72	03:24:11 PM	HV=250V
5275	279966	92.44	09:37:46 AM	HV=250V
5274	279931	471.25	11:51:28 AM	HV=250V
5267	279844 (279845 279846 279848 279849)	146.2	09:38:43 AM	HV=250V Rps out at ~2:45PM
5266	279841	382.27	06:36:49 PM	HV=250 V
5265	279823	82.15	12:14:18 PM	HV=250V
5264	279794	224.66	01:58:38 AM	HV=250V 56-fr-hr = off
5261	279760 279766 279767	513.64	10:35:43 PM	HV=250V for all ; Run279767 LS=337 56-fr LV trip (then pot off)
		3843.95		
5052	275911 275912 275913 275918 275920 275921 275922 275923 275931	327.04	04:10:24 AM	Run 275920=raw mode ; 275921 crashed tried HV=300V , pots out
5048	275886 275887 275890	237.37	10:59:54 AM	275890 LS>821 => 45FR 200V
5045	275828 275829 275831 275832 275833 275834 275835 275836 275837 275838 275841 275846 275847	649.62	06:54:16 PM	
5043	275757 275758 275759 275761 275763 275764 275766 275767 275768 275769 275772 275773 275774 275776 275777 275778 275781 275782 275783	472.01	06:54:25 AM	
5038	275656 275657 275658 275659	73.94	06:37:12 AM	SW integration
5030	275375 275376	505.42	04:08:41 AM	
5029	275370 275371	133.99	06:37:16 PM	
5028	275344 275345	100.72	10:31:26 AM	
5027	275319 275336 275337 275338	181.99	09:06:04 PM	
5026	275309 275310 275311	387.75	04:00:24 PM	
5024	275282 275283 275284 275285 275286 275289 275290 275291 275292 275293	158.79	02:21:58 AM	
5021	275124 275125	191.39	08:13:33 PM	
5020	275059 275062 275063 275064 275066 275067 275068 275073 275074	365.32	07:19:49 PM	
5017	274998 274999 275000 275001	464.58	06:33:06 AM	
5013	274966 274967 274968 274969 274970 274971	400.21	12:47:36 AM	
5005	274954 274955 274956 274957 274958 274959	42.83	12:02:02 PM	
4990	274440 274441 274442 274443	219.43	09:54:45 PM	
4988	274420 274421 274422	338.64	10:44:31 PM	
4985	274387 274388	293.83	09:53:38 PM	
4964	274241(LS1156) 274243 274244	55.64	10:12:01 PM	
		5600.52		
4976	274282 274283 274284 274285 274286	48.78	06:36:00 AM	
4964	274240 274241	134.23	04:58:00 PM	
4961	274198 274199 274200	130.56	10:37:00 PM	
4960	274172	5.9	03:03:00 AM	
4953	274094	9.36	04:37:17 AM	
4947	273725 273728 273730	256.59	06:42:00 AM	
		585.42		

TOTAL : 15.3/fb