Search for Heavy Stable Charged Particles in the CMS Experiment using the RPC Phase-II upgraded detectors

Speaker: Gabriel Ramírez Sánchez.
Centro de Investigación y de Estudios Avanzados (Mexico)
On behalf of the CMS collaboration.

XIV Workshop on Resistive Plate Chambers and related detectors Puerto Vallarta, Mexico

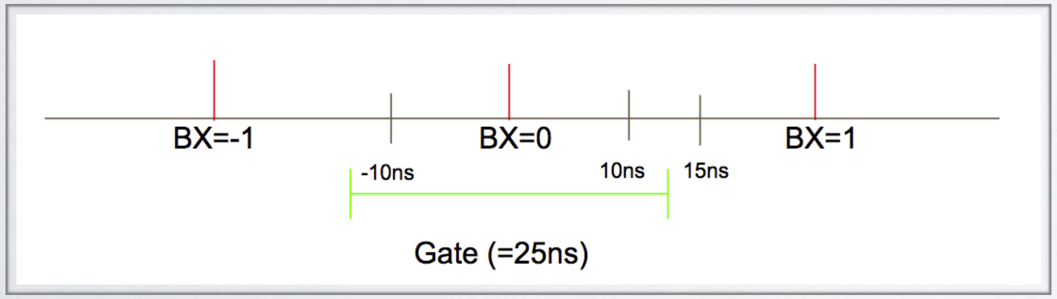
Outline

- Introduction.
- Heavy Stable Charged Particles (HSCP) previous analysis.
- Time-of-Flight (TOF) technique.
- Trigger strategy.
- Conclusions.

Introduction

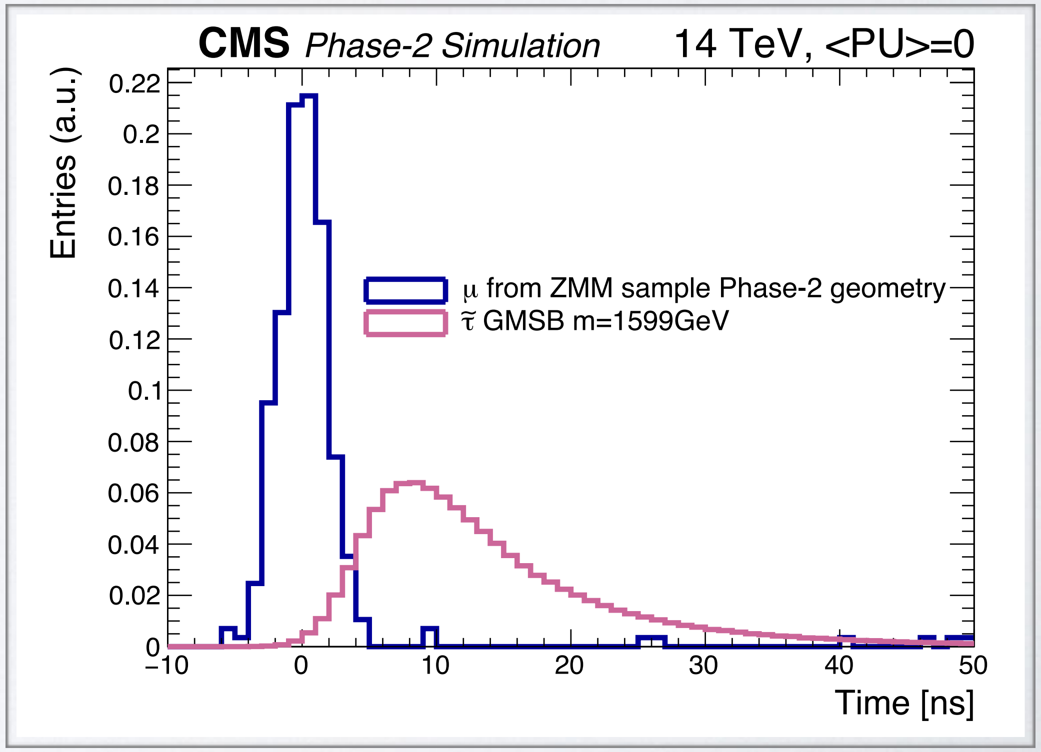
Several theoretical models inspired in the idea of super- symmetry (SUSY) accommodate the possibility of HSCPs (Heavy Stable Charged Particles). The phase-II upgrade of the CMS-RPC system will allow the trigger and identification of these kind of particles exploiting the Time of Flight Technique with the improved time resolution that a new DAQ system will provide (1.5 ns).

The RPC detectors have an intrinsic time resolution of the order of 1.5 ns but the link system records the RPC hits information in steps of one Bunch Crossing BX (25 ns), degrading the full timing resolution of the detector.

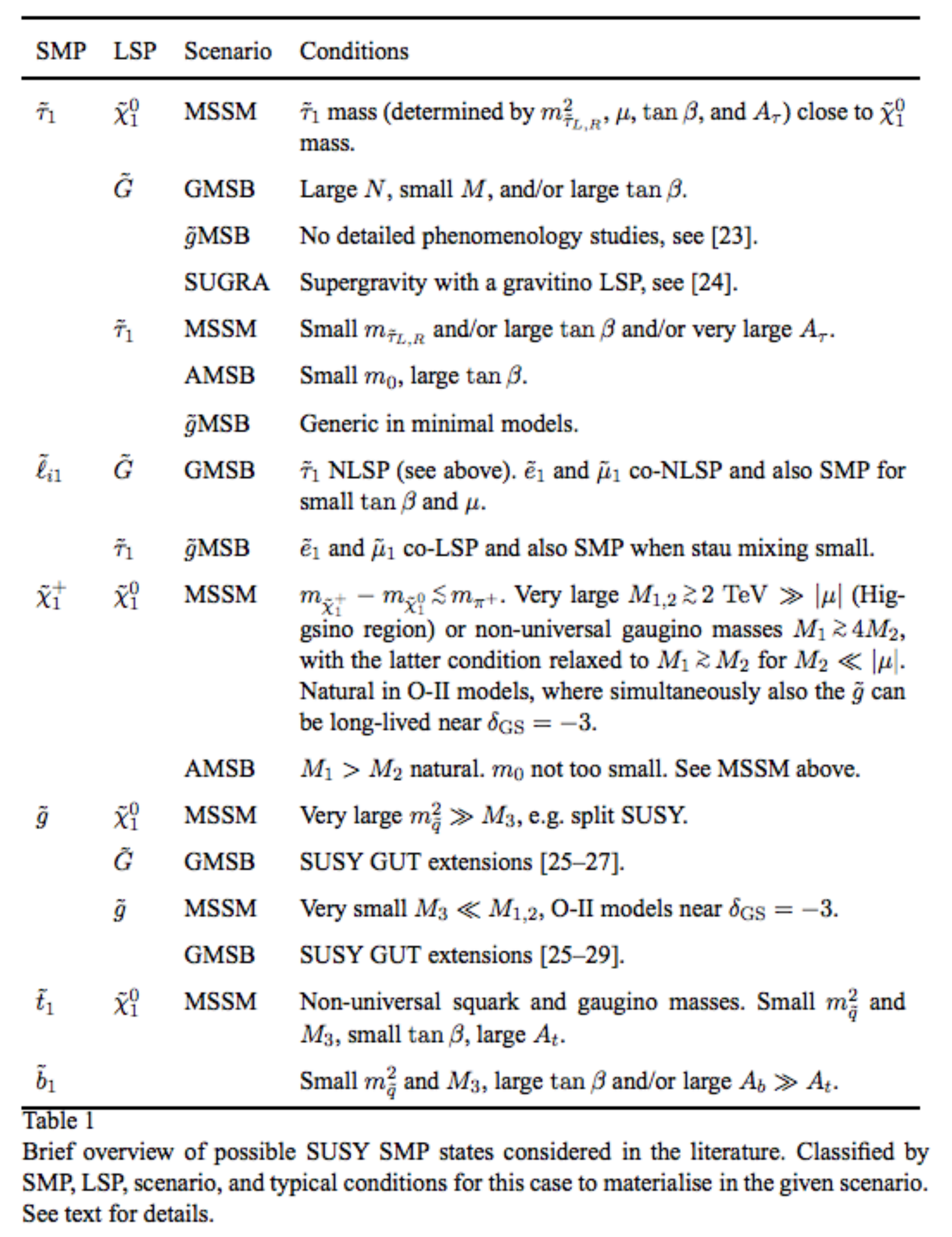


In the upgrade that will take place in 2023 the Link System of the complete RPC detector will be replaced. This will allow it to match the intrinsic resolution of the detector.

The upgrade of the RPC system will allow the trigger and identification of slowly moving particles by measuring their time of flight to each RPC station with a resolution of O(1) ns.



Heavy Stable Charged Particles



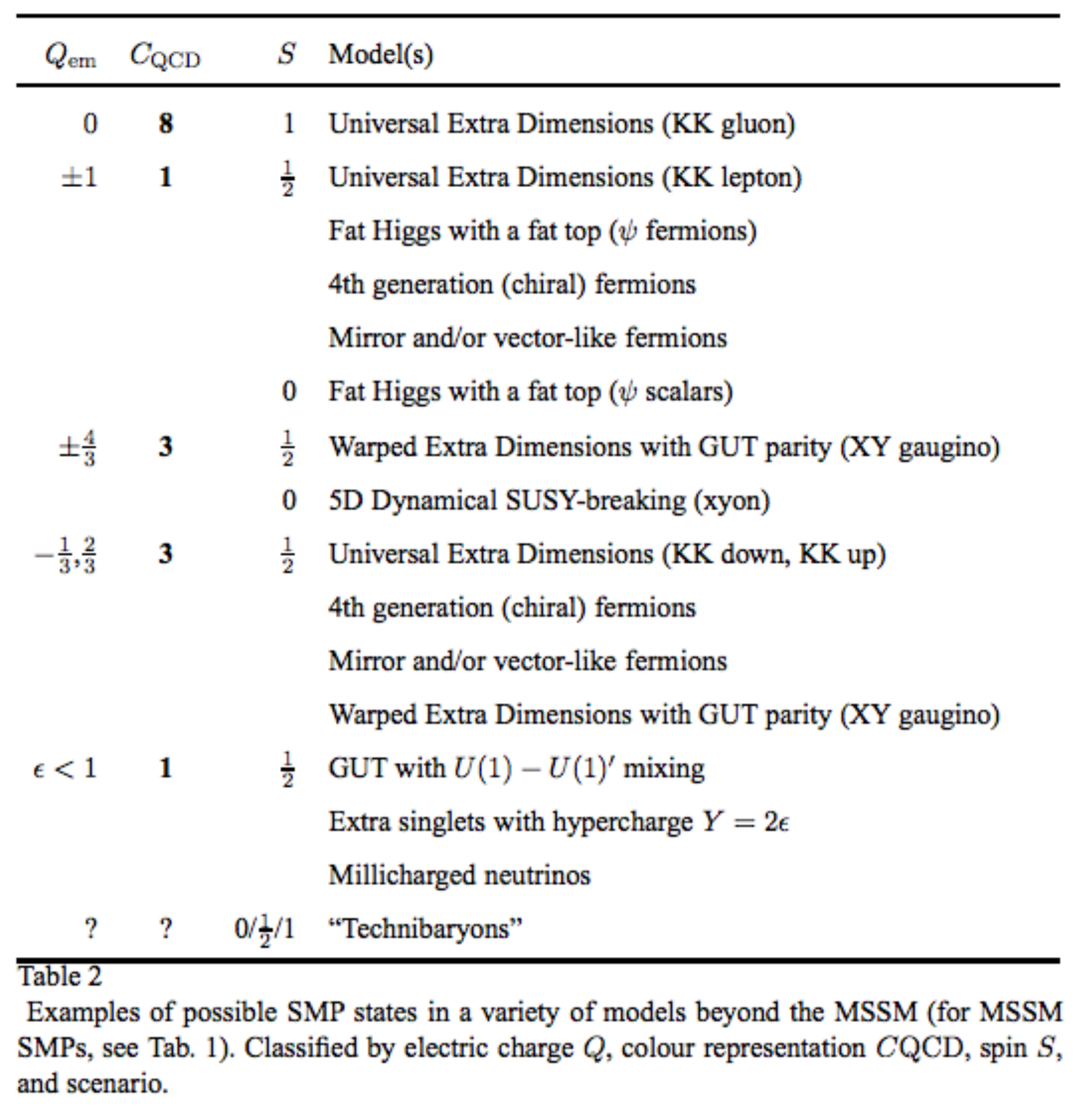
SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg \|\mu\|$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll \|\mu\|$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{\mathrm{GS}} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{\mathrm{GS}} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Table 1
Brief overview of possible SUSY SMP states considered in the literature. Classified by SMP, LSP, scenario, and typical conditions for this case to materialise in the given scenario. See text for details.

arxiv:hep-ph/0611040

- **Heavy**: Implies slow particles, $\beta < 1.0$
- **Stable**: Lives long enough so it can reach tracker and/or muon detectors or even get past them.
- **Charged**: Can be detected by the muon detectors.

HSCP are predicted in many theoretical models beyond Standard Model (BSM).



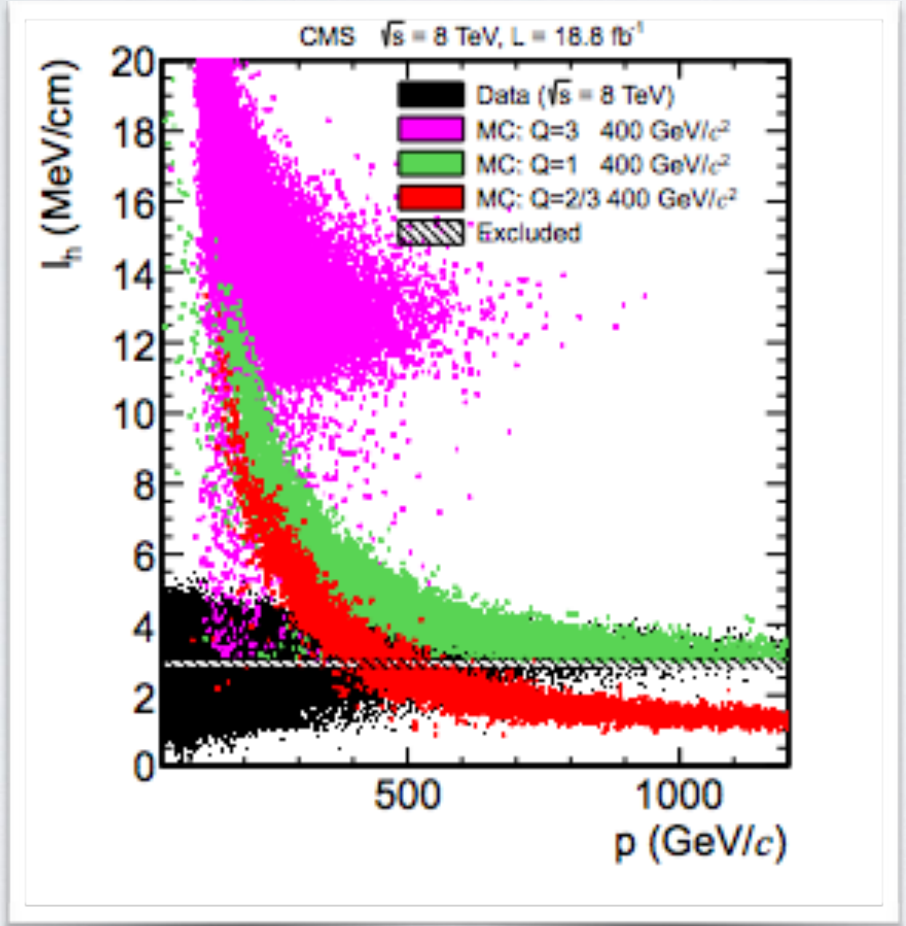
Q_{em}	C_{QCD}	S	Model(s)
0	**8**	1	Universal Extra Dimensions (KK gluon)
± 1	**1**	$\frac{1}{2}$	Universal Extra Dimensions (KK lepton)
			Fat Higgs with a fat top (ψ fermions)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
		0	Fat Higgs with a fat top (ψ scalars)
$\pm\frac{4}{3}$	**3**	$\frac{1}{2}$	Warped Extra Dimensions with GUT parity (XY gaugino)
		0	5D Dynamical SUSY-breaking (xyon)
$-\frac{1}{3},\frac{2}{3}$	**3**	$\frac{1}{2}$	Universal Extra Dimensions (KK down, KK up)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
			Warped Extra Dimensions with GUT parity (XY gaugino)
$\epsilon < 1$	**1**	$\frac{1}{2}$	GUT with $U(1) - U(1)'$ mixing
			Extra singlets with hypercharge $Y = 2\epsilon$
			Millicharged neutrinos
?	?	$0/\frac{1}{2}/1$	"Technibaryons"

Table 2
Examples of possible SMP states in a variety of models beyond the MSSM (for MSSM SMPs, see Tab. 1). Classified by electric charge Q, colour representation $CQCD$, spin S, and scenario.

Analysis Techniques

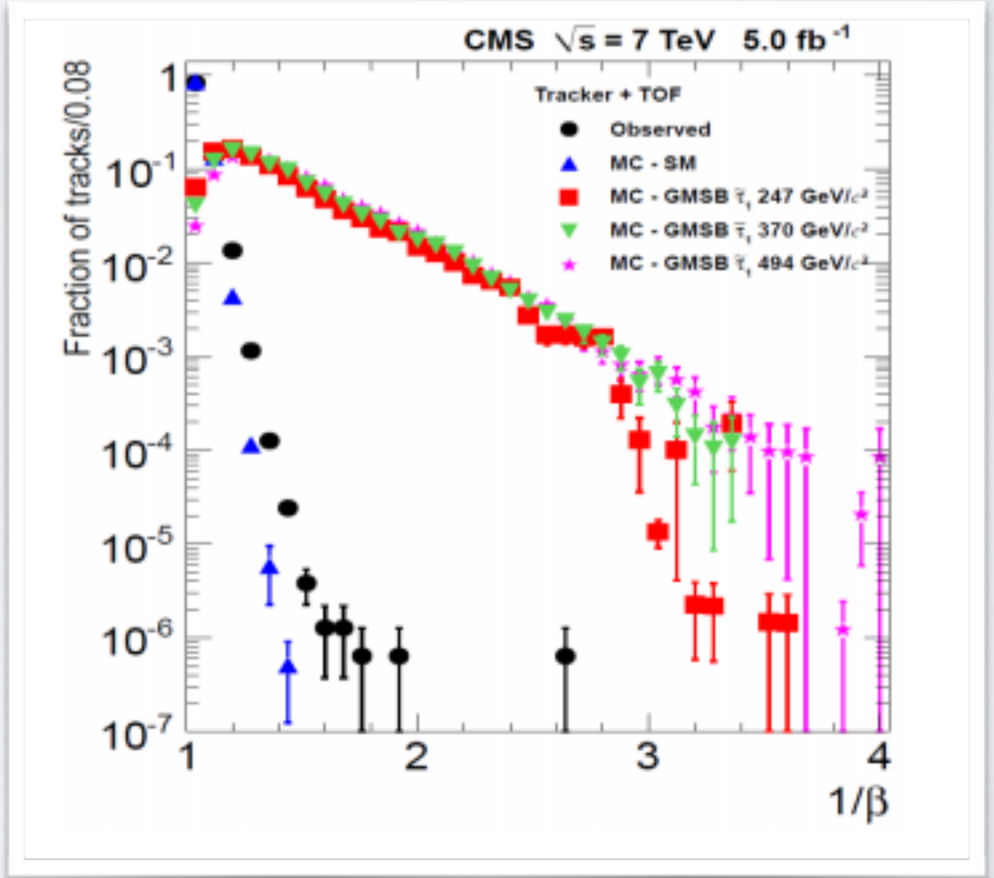
- **dE/dx:** Ionization energy lost.

$$\frac{dE}{dx} \approx Q^2\left[\frac{A}{\beta^2}+B\right] \text{ for } \beta << 1$$



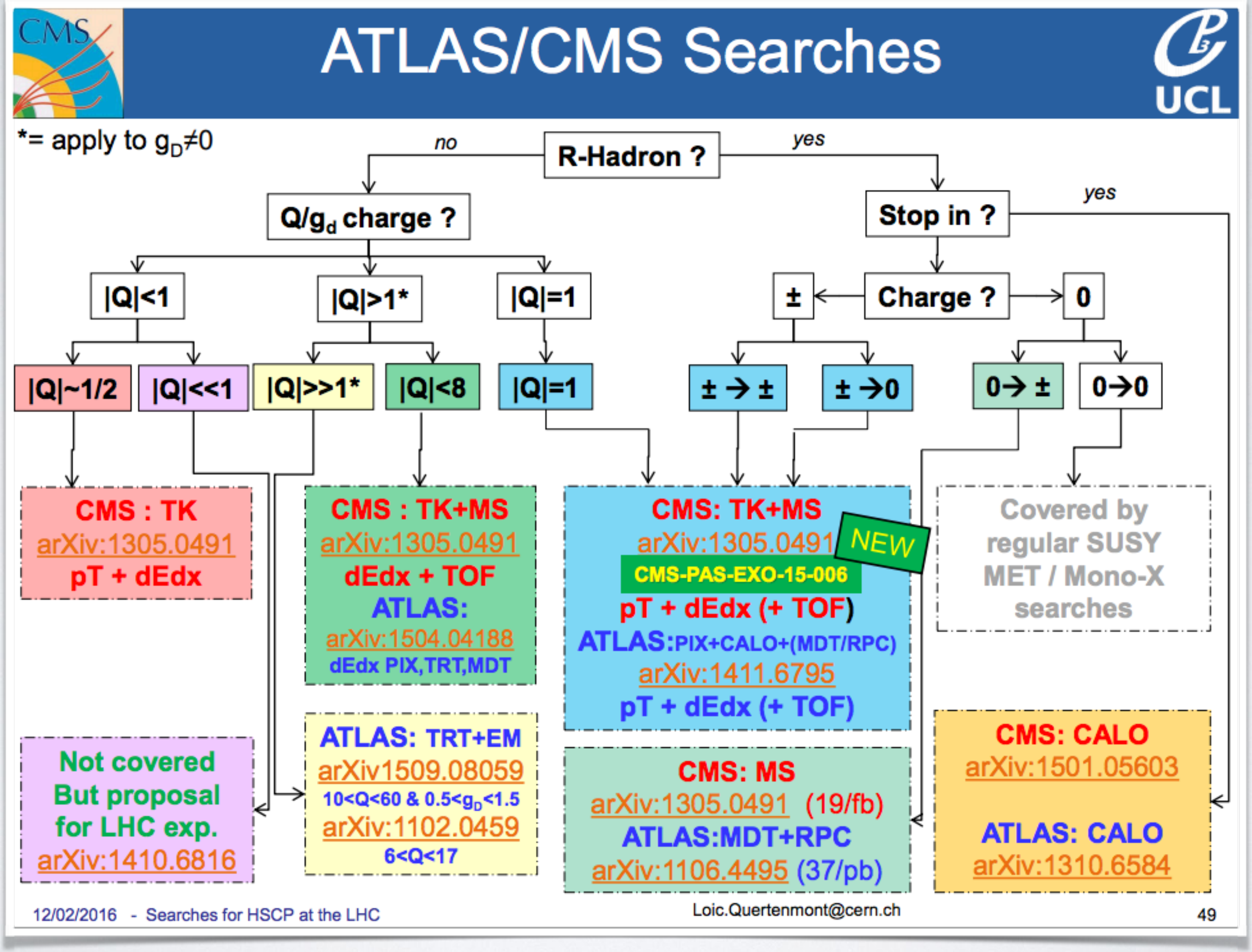
- **TOF:** Time of flight

$$\frac{1}{\beta} = 1 + \frac{c\delta_t}{L}$$



arXiv:1305.0491v2

Searches of HSCP



ATLAS/CMS Searches

UCL

*= apply to $g_D \neq 0$

R-Hadron ?

no

yes

Q/g_d charge ?

Stop in ?

yes

|Q|<1

|Q|>1*

|Q|=1

±

Charge ?

0

|Q|~1/2

|Q|<<1

|Q|>>1*

|Q|<8

|Q|=1

± → ±

± → 0

0 → ±

0 → 0

CMS : TK
arXiv:1305.0491
pT + dEdx

CMS : TK+MS
arXiv:1305.0491
dEdx + TOF
ATLAS:
arXiv:1504.04188
dEdx PIX,TRT,MDT

CMS: TK+MS
arXiv:1305.0491
CMS-PAS-EXO-15-006
NEW
pT + dEdx (+ TOF)
ATLAS:PIX+CALO+(MDT/RPC)
arXiv:1411.6795
pT + dEdx (+ TOF)

Covered by regular SUSY MET / Mono-X searches

Not covered
But proposal
for LHC exp.
arXiv:1410.6816

ATLAS: TRT+EM
arXiv1509.08059
10<Q<60 & 0.5<g_D<1.5
arXiv:1102.0459
6<Q<17

CMS: MS
arXiv:1305.0491 (19/fb)
ATLAS:MDT+RPC
arXiv:1106.4495 (37/pb)

CMS: CALO
arXiv:1501.05603

ATLAS: CALO
arXiv:1310.6584

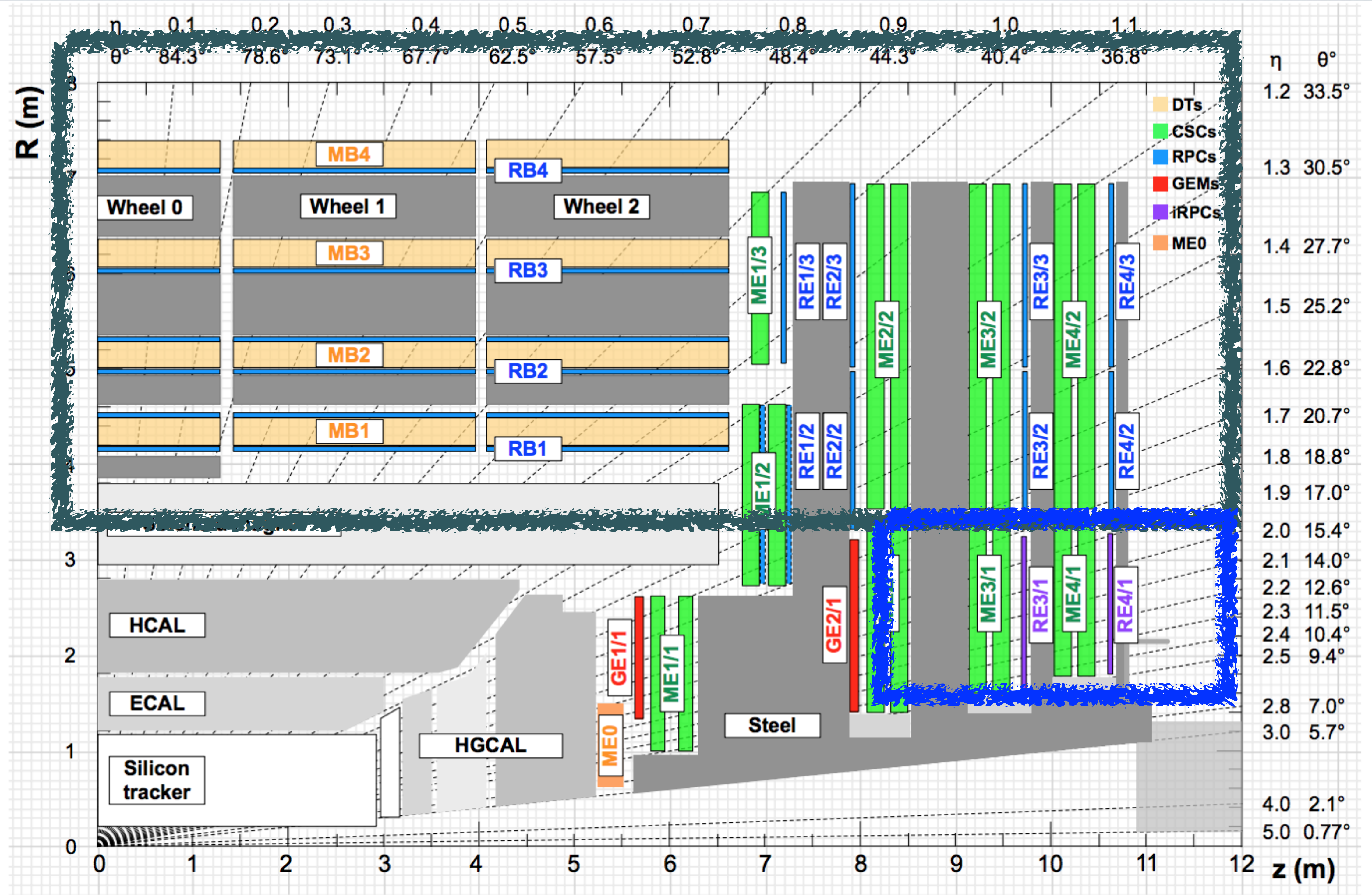
12/02/2016 - Searches for HSCP at the LHC

Loic.Quertenmont@cern.ch

49

Searches for Heavy Stable Charged Particles at the LHC Past, Present and Future, Loïc Quertenmont. 12 February 2015

RPC link system upgrade and addition of iRPCs



Previous RPC HSCP trigger in CMS

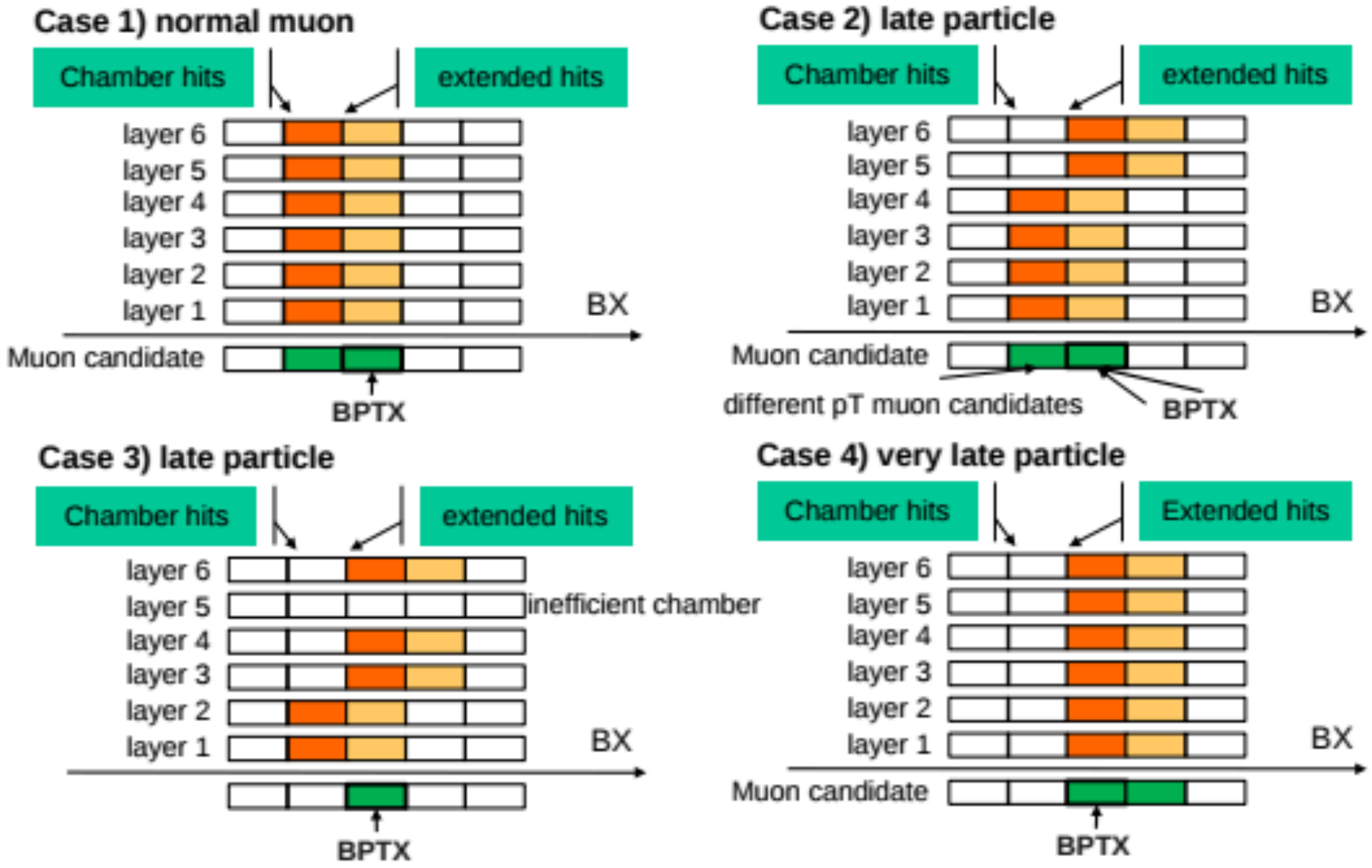
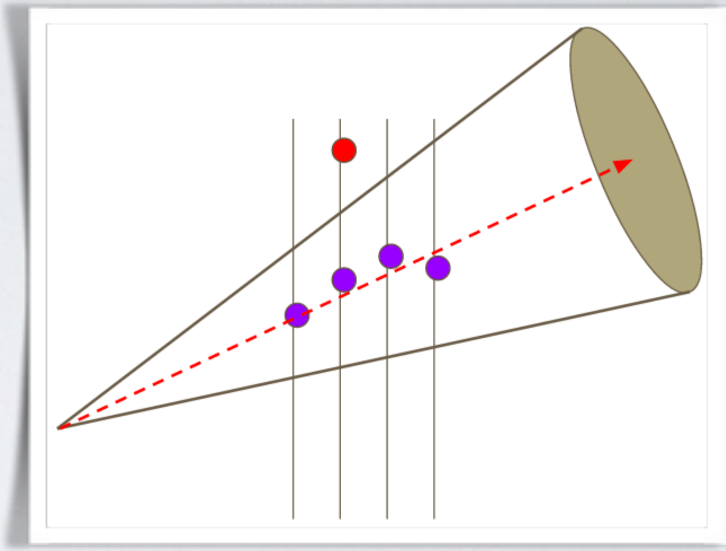


Figure 65: The principle of operation of the RPC HSCP trigger for an ordinary muon (case 1), and a slow minimum ionizing particle, which produces hits across two consecutive bunch crossings (cases 2, 3) or in the next BX (case 4). Hits that would be seen in the standard PAC configuration are effectively those shown in pale orange; additionally observed hits in the HSCP configuration are those shown in dark orange. In case 1 the output of both configurations is identical, in case 2 the HSCP configuration uses the full detector information, in case 3 only the HSCP configuration can issue a trigger, and in case 4 the HSCP configuration brings back the event to the correct BX.

arXiv:1609.02366v2

Time-of-Flight (TOF) technique.

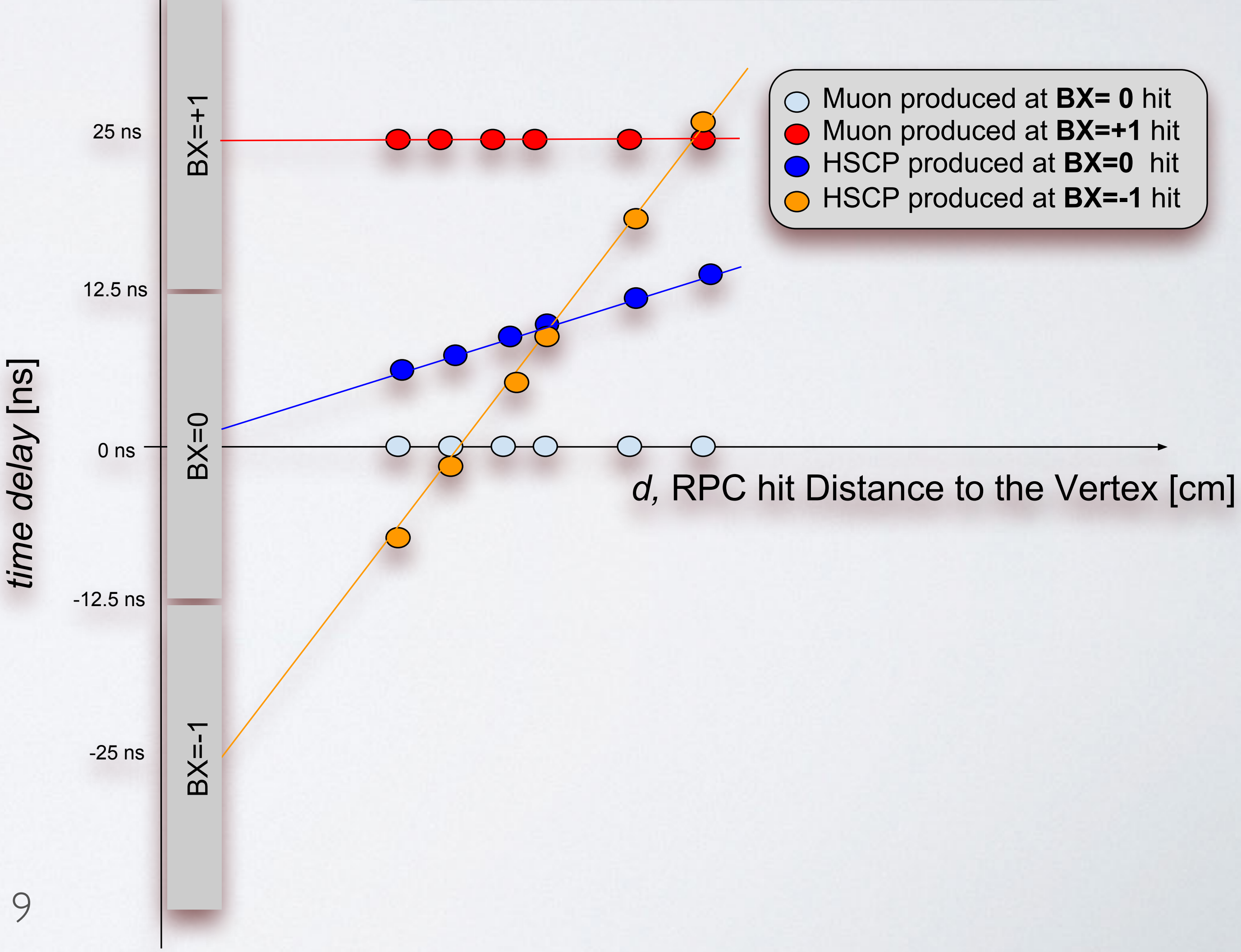
We use of the new precise time measurement to identify the time when the particle was created and also the speed of the particle.
In order to perform measurement of β and t_0 we have to do first the matching of the RPC hits with the generated particles.



The time measured at different RPC stations for particles originating at different BXs with different velocities will leave different signatures in the detector.

Hence, relativistic particles are represented by horizontal lines on this diagram. We can identify the following particular cases: HSCP in time (blue), HSCP out of time (orange), muon in time (red) and muon out of time (Grey).

Clock at all RPC stations is tuned so that particles moving with the speed of light are registered with the exact same "local" times.



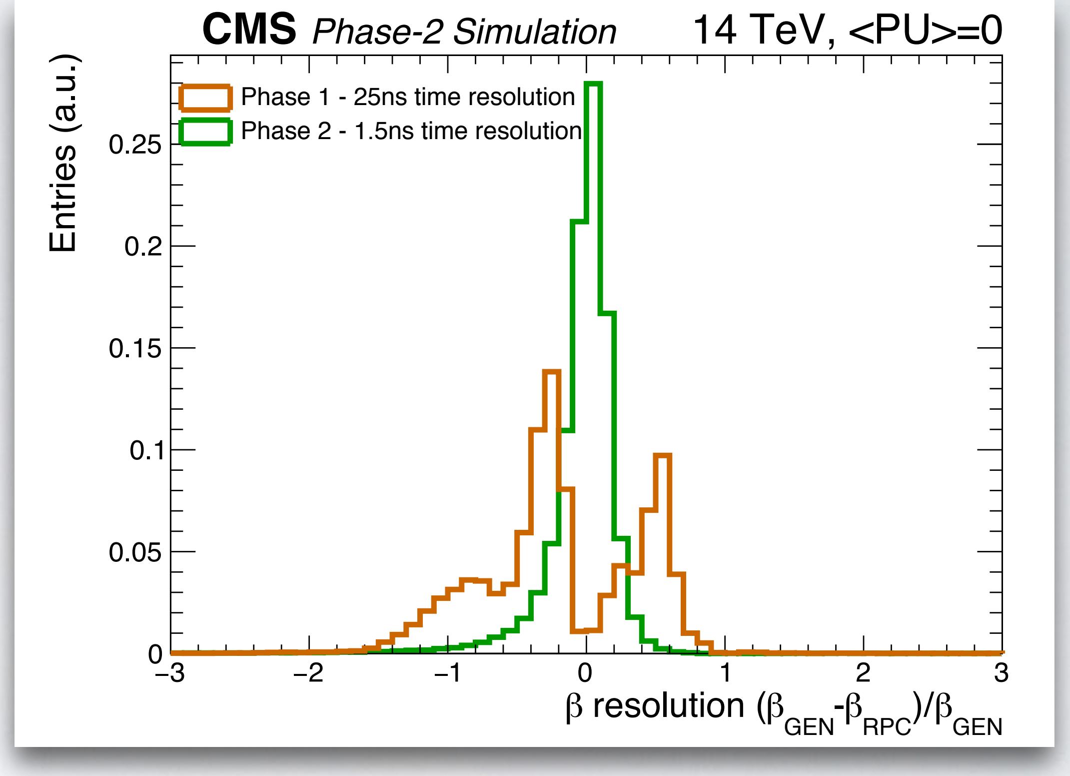
Time and Speed measurement

Starting from the simple equation:

$$v_{layer} = \frac{|\overrightarrow{RPCHit}|}{ToF}$$

After some algebra we have that β and t_0 are related by the following expression:

$$t_{delay} = t_0 + \frac{d}{c}(\beta^{-1} - 1)$$



where t_{delay} is the time measured with respect to a particle moving at speed of light, d is the distance from the interaction point to the impact point and c is the speed of light. For the muon the second term in Eq. 2 vanishes. For the HSCPs we performed a Least Squares Fit, using the linear form:

$$y = a + bx$$

where:

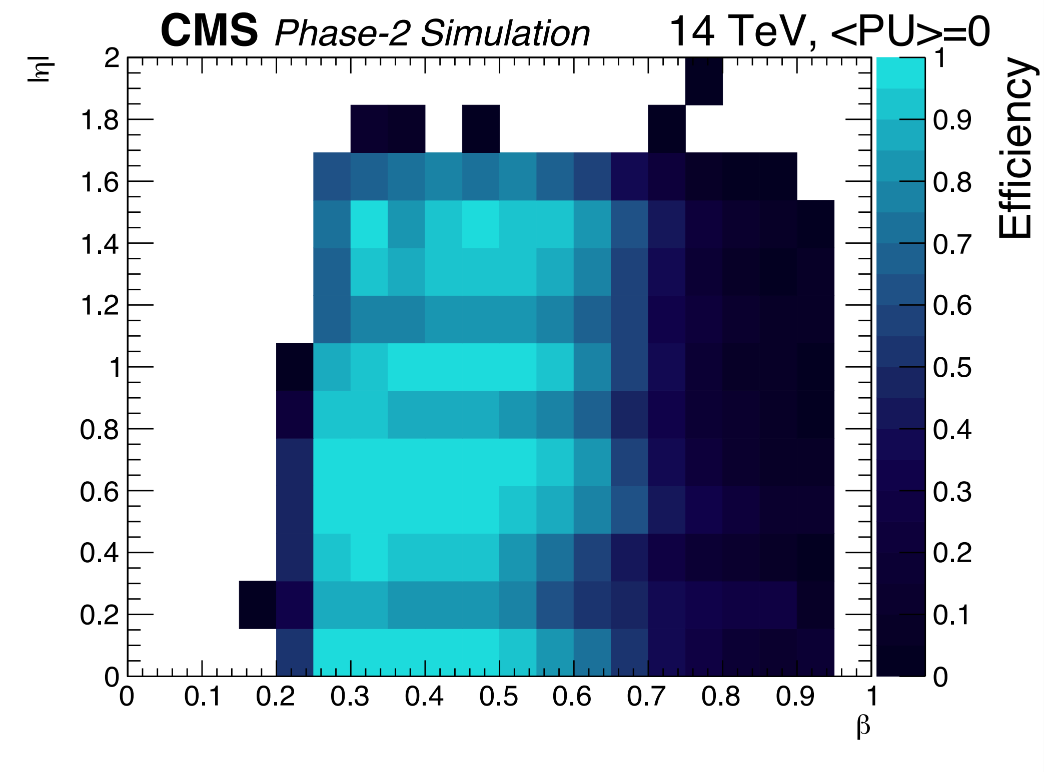
$$\text{a} = t_0 \text{ and b} = \frac{\beta^{-1} - 1}{c}$$

Trigger Algorithm proposal

The trigger algorithm is:

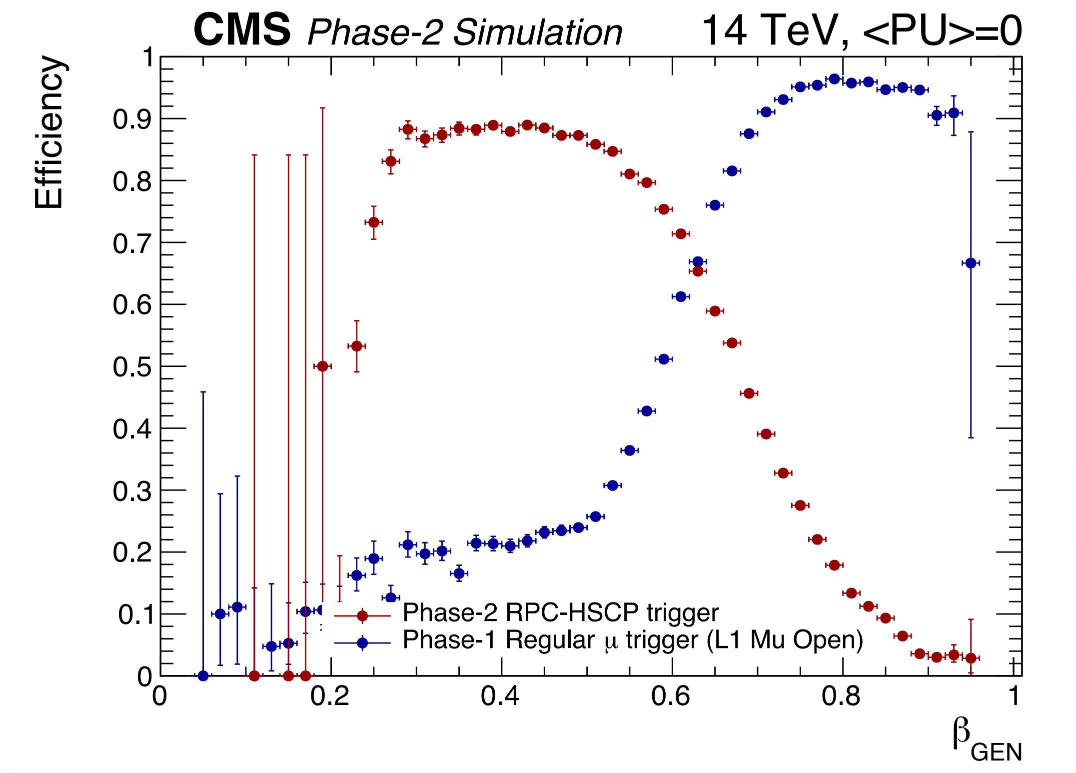
1. at least 3 hits correlated in space.
2. error in beta < 30% (to assure good quality of the fit)

3. slope > 0 (to exclude muons and identify slow moving particles)



EFFICIENCIES.

The new trigger proposal will be complement for the present muon trigger whose efficiency sharply drops for particles with **β** < 0.6



BxConstrained

Normal trigger algorithm is required at least 3 points. But in iRPC region, this algorithm do not work well. In iRPC region, at least 3 hits event is rare. So we need another algorithm: BxConstrained.

Assume : Each event's bunch crossing (Bx) is 0. Get the $(\Delta R^{err})^2$ using the position, hit time, φ, η of each particle.

$\beta = 1/(1+c \cdot \text{hit\_time}/\text{position magnitude})$

$(\Delta R^{err})^2 = [\Sigma(\Delta\varphi)^2 - \{ \Sigma(\Delta\varphi) \}^2/\text{num\_}\beta] + [\Sigma(\Delta\eta)^2 - \{ \Sigma(\Delta\eta) \}^2/\text{num\_}\beta]/\text{num\_}\beta$

Average β value (slope), using the Bx = 0 point & rpcHits of each event.

Conclusions

- The time resolution of the RPC detector, affecting all the present RPCs, will be greatly improved by the upgrade of the link system

- The CMS HSCP trigger capabilities will be extended from the present limitation of $\beta \sim 0.6$ down to $\beta \sim 0.2$.

- The trigger purity is expected to be high and can be improved even further by combining the HSCP muon system trigger with a better brunch crossing identification at trigger level.

Phase2 HSCP-RPCs trigger proposal will help to don't miss BSM LLP signatures for the remainder of the LHC program.

BACKUP SLIDES

TRIGGER WITH ON-TIME CONSTRAINT (IRPC) (OLD)

In the $|\eta| > 1.8$ region, there are only two RPC stations are available. The fitting method described previously is not reliable. to achieve the same goal by modifying the algorithm to take in account a better timing and space resolution of those chambers as well as making hypotheses on the origin of the particle (produced at BX = 0)

To distinguish between a muon and a HSCP we use the TOF information. We build a χ^2-like estimator designed to quantify the probability of a pair of hits to be compatible with a muon produced at BX = 0

$$\chi^2 = \Sigma_{i=1}^{N} \frac{\left(t_{\mathrm{tof,i}} - t^{\mu}_{\mathrm{tof,i}}\right)^2}{\sigma_{\mathrm{tof}}}$$

given that $\sigma_{\mathrm{tof}} \approx 1$ ns and the timing of the chamber is defined in such a way that $t_{\mathrm{tof,i}}(\mu) = 0$, we obtain

$$\chi^2 = t^2_{\mathrm{tof,31}} + t^2_{\mathrm{tof,41}}$$

Larger is the value of χ^2 lower is the probability that the hit patter is produced by a muon and higher is the probability that it matches a τ. Therefore we require to tag a τ.

$$\begin{aligned} \chi^2 &> 30 \\ \Delta t &> -5\,ns \end{aligned}$$

optimized according to the τe vs muon distributions