



Ricerca di violazione di CP nei
decadimenti $\Lambda_b^0 \rightarrow p h^- h^+ h^-$ con
 $h = \pi, K$ a LHCb

Andrea Merli (INFN Milano & UniMi)

Motivazioni fisiche

- Testare meccanismo CKM anche nei barioni
Violazione di CP (CPV) mai osservata in decadimenti barionici
- Sensibile ad effetti di nuova fisica: nuove particelle possono contribuire nei diagrammi a loop
- Interferenza non trascurabile tra il diagramma ad albero e a pinguino

Phys.Rev. D66 (2002) 094004

Diagramma ad albero

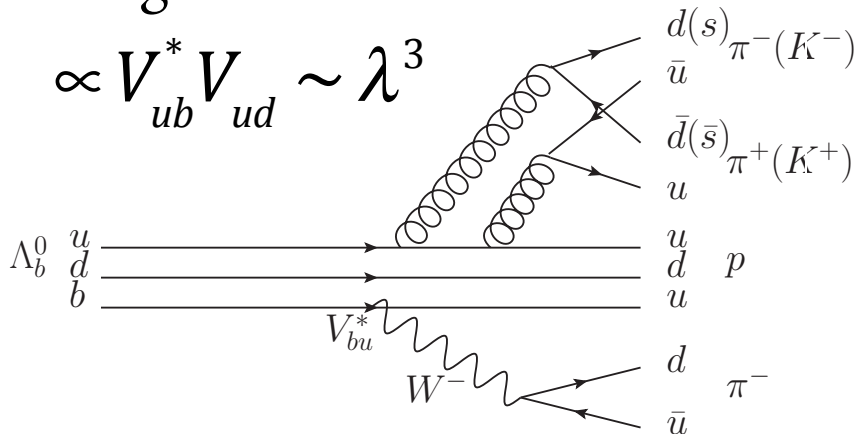
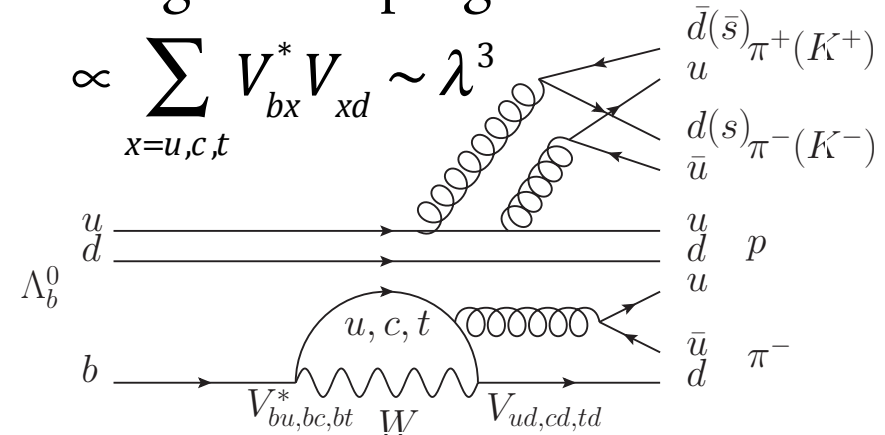


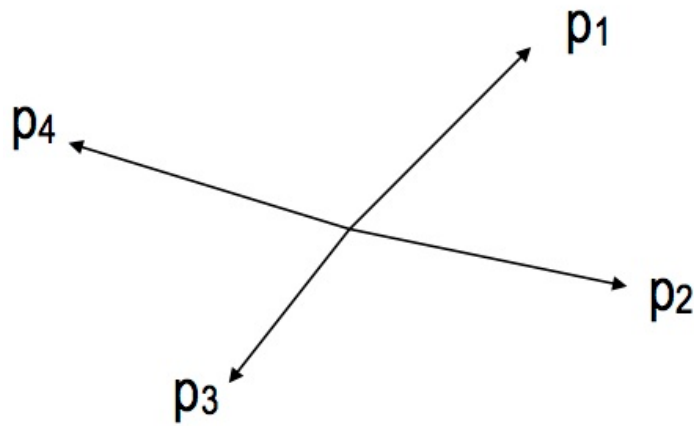
Diagramma pinguino



Tecnica sperimentale

Definizione di una osservabile \hat{T} -dispari $\hat{T}: t \rightarrow -t$

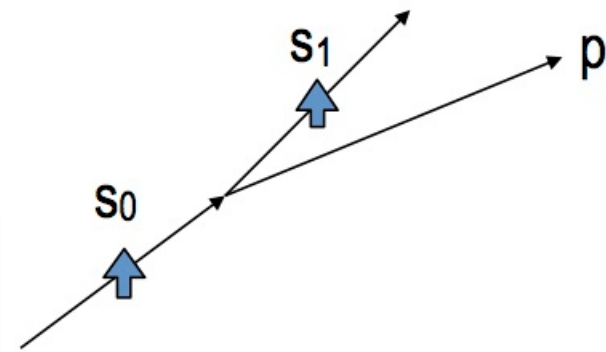
Usando i momenti



$$C_T = p_1 \cdot (p_2 \times p_3)$$

$$\bar{C}_T = \bar{p}_1 \cdot (\bar{p}_2 \times \bar{p}_3)$$

Usando gli spin e momenti



$$C_T = s_0 \cdot (s_1 \times p)$$

$$\bar{C}_T = \bar{s}_0 \cdot (\bar{s}_1 \times \bar{p})$$

Noi costruiamo le osservabili \hat{T} -dispari con i momenti delle particelle finali

Asimmetrie \hat{T} -dispari

Asimmetrie

- Misuriamo due asimmetrie separatamente per particelle e antiparticelle

$$A_T = \frac{N(C_T > 0) - N(C_T < 0)}{N(C_T > 0) + N(C_T < 0)} \quad \text{per } \Lambda_b^0, \Xi_b^0$$

$$\bar{A}_T = \frac{N(-\bar{C}_T > 0) - N(-\bar{C}_T < 0)}{N(-\bar{C}_T > 0) + N(-\bar{C}_T < 0)} \quad \text{per } \bar{\Lambda}_b^0, \bar{\Xi}_b^0$$

- Osservabile sensibile a violazione di CP : cancella le interazioni di stato finale

$$a_{CP}^{T-odd} = \frac{1}{2}(A_T - \bar{A}_T)$$

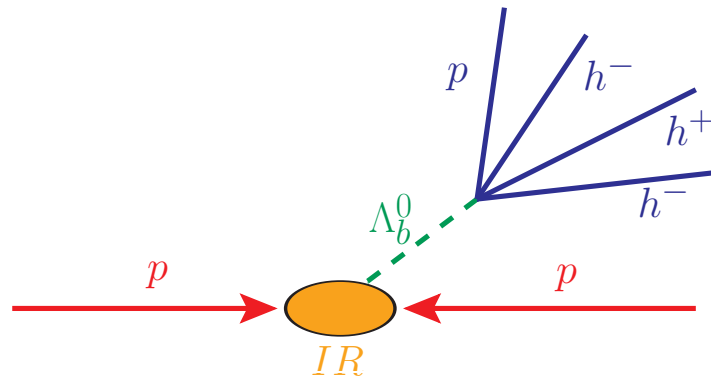
Phys.Rev. D84 (2011) 096013

Insensibile ad asimmetrie di produzione $\Lambda_b^0/\bar{\Lambda}_b^0$

Insensibile ad asimmetrie di ricostruzione h^+/h^-

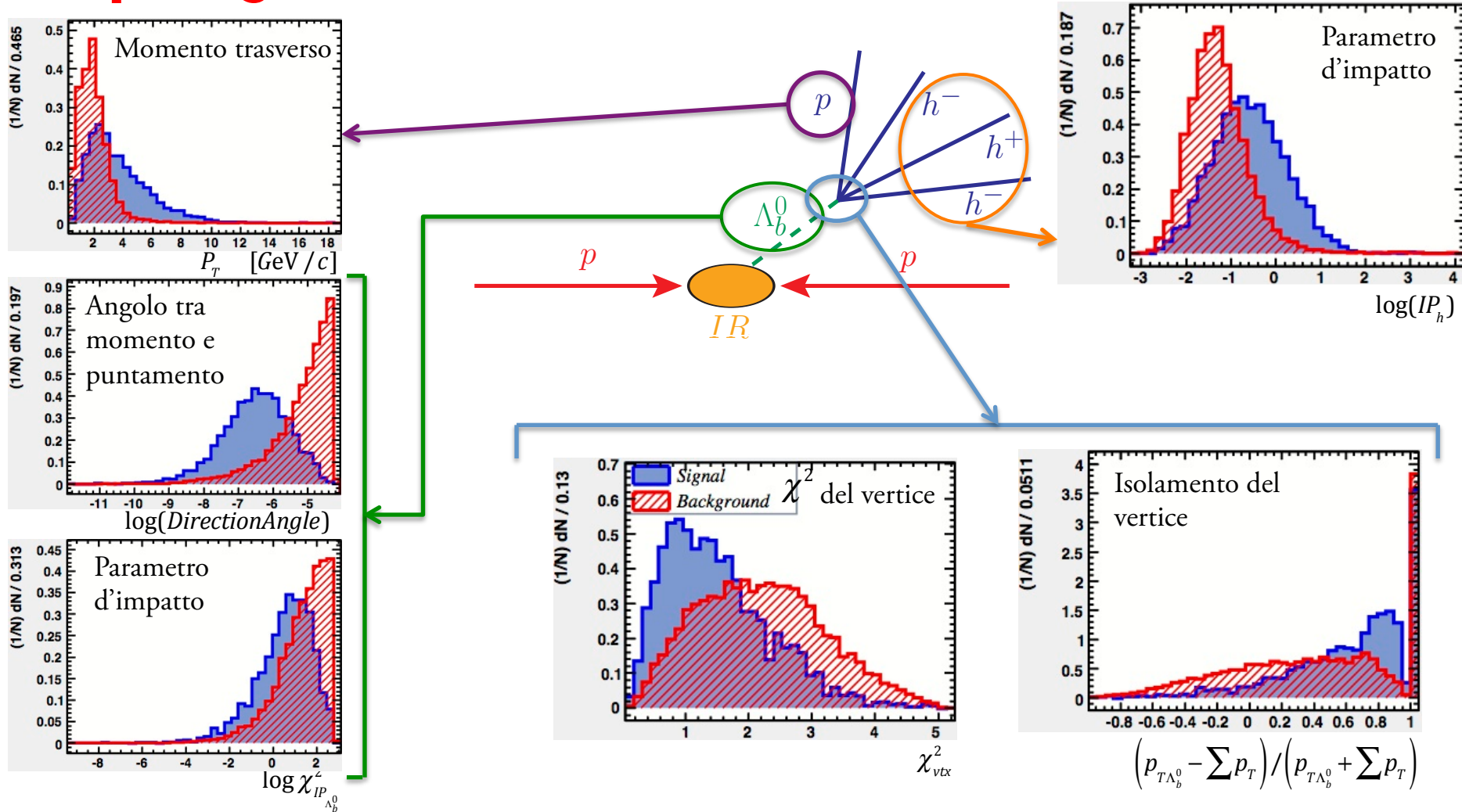
incertezze
sistematiche
ridotte

Topologia del decadimento



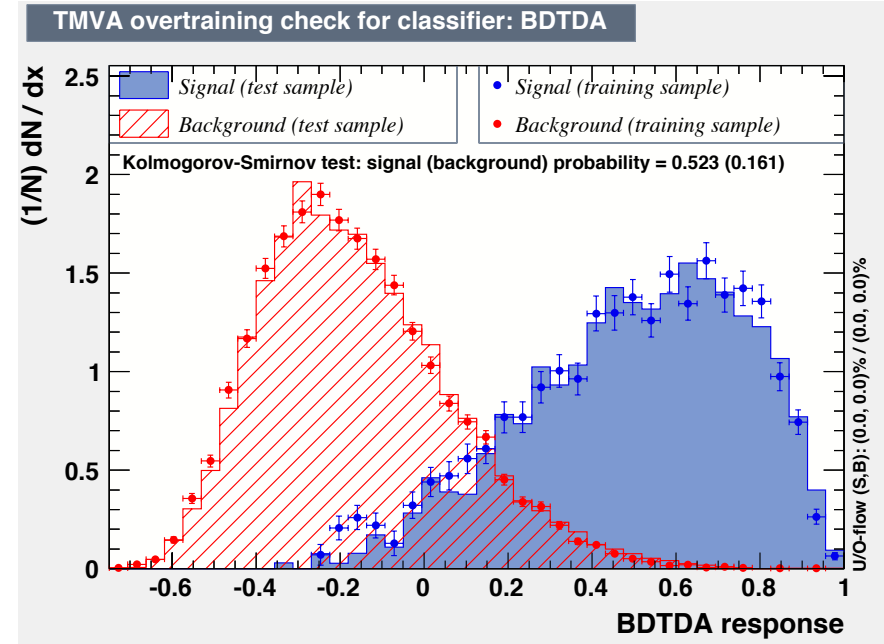
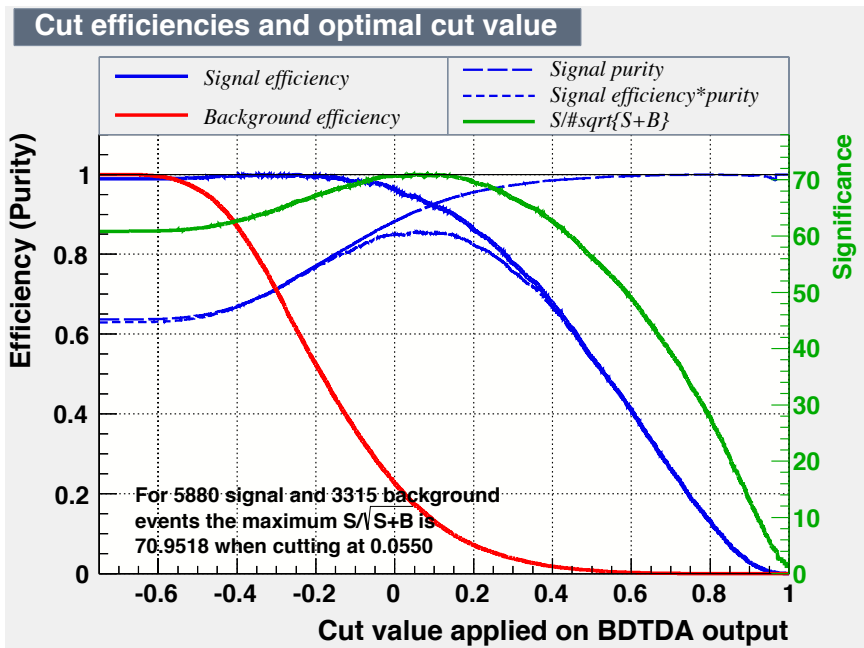
Selezione

Topologia del decadimento



Classificatore Multivariato

Output del classificatore multivariato

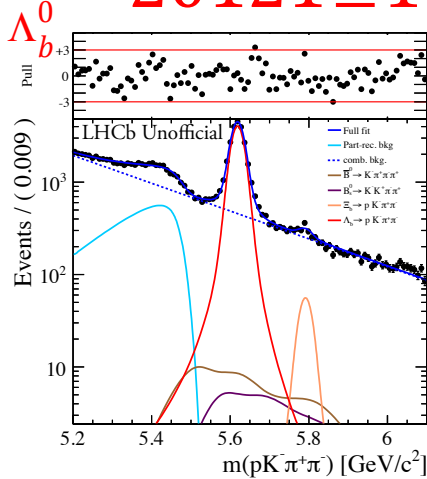


Ottimizzazione della significatività $\frac{S}{\sqrt{S+B}}$

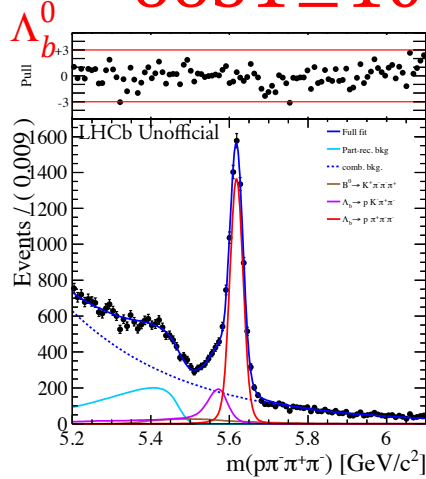
- Efficienza segnale $\sim 90\%$
- Reiezione fondo $\sim 90\%$

Prime osservazioni

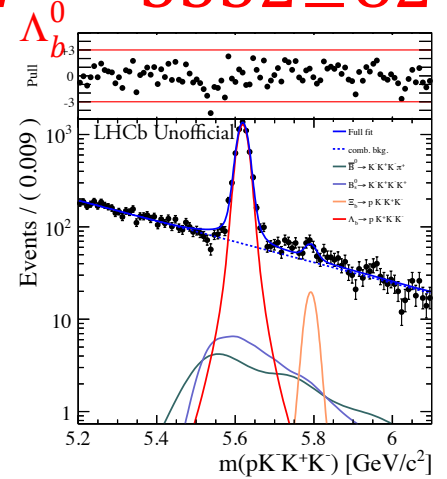
$N_{\Lambda_b^0} = 20121 \pm 173$



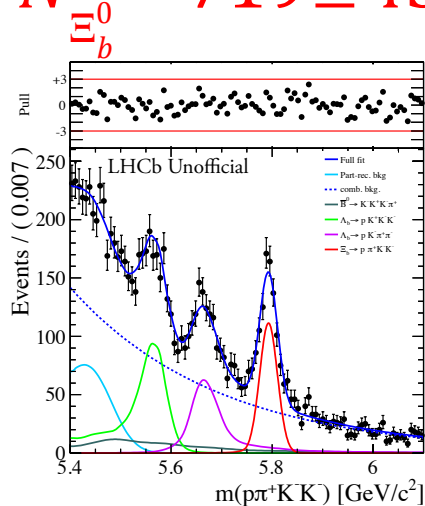
$N_{\Lambda_b^0} = 6631 \pm 105$



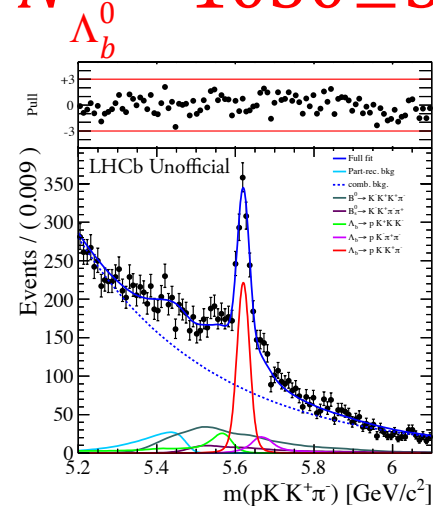
$N_{\Lambda_b^0} = 5332 \pm 82$



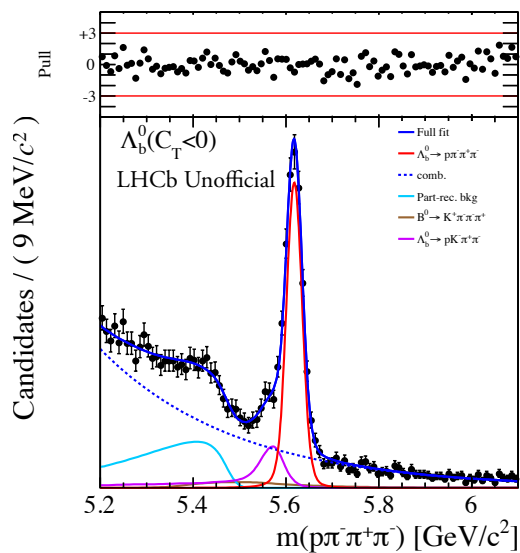
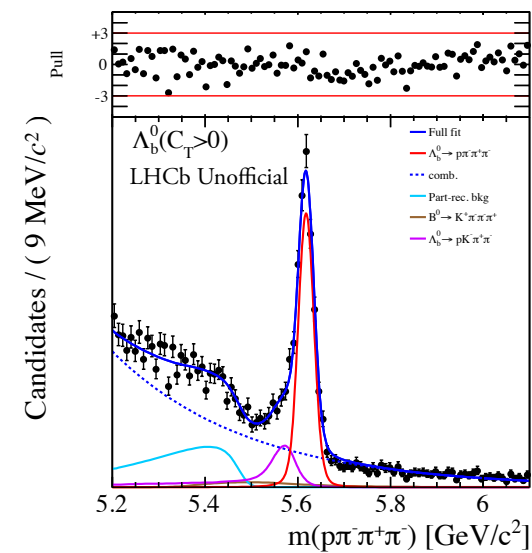
$N_{\Xi_b^0} = 719 \pm 43$



$N_{\Lambda_b^0} = 1030 \pm 56$

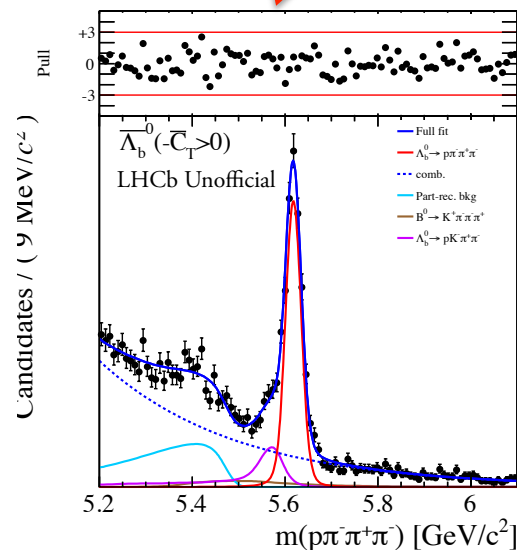
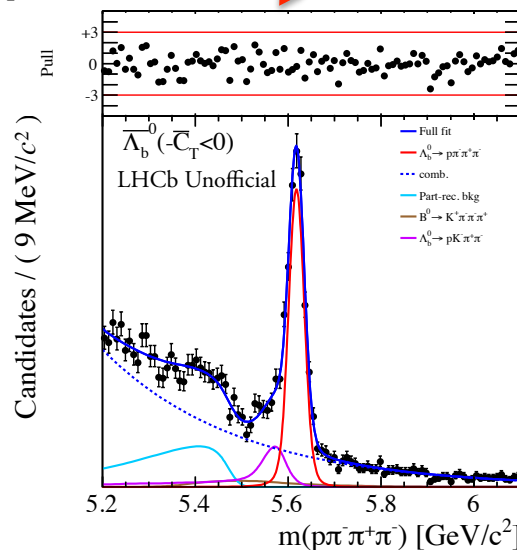


Misura delle asimmetrie



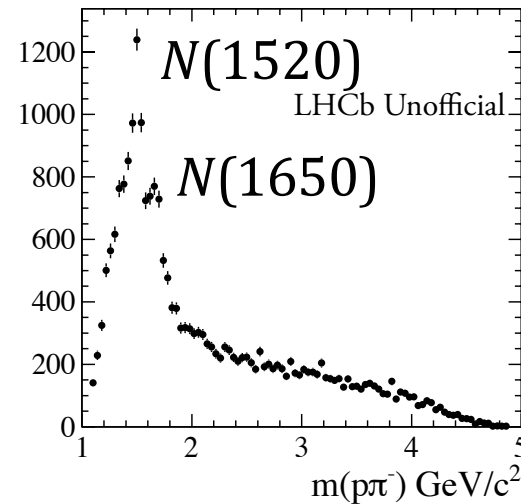
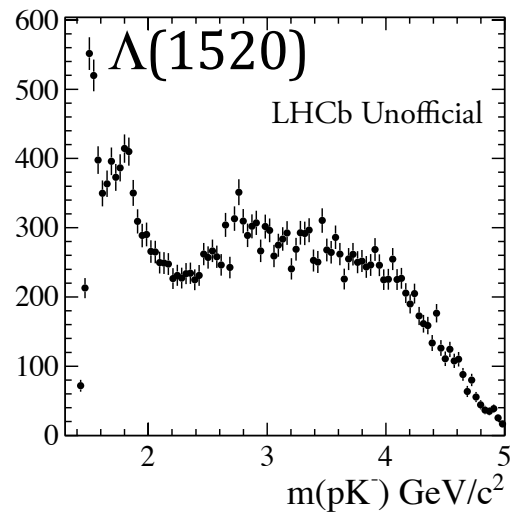
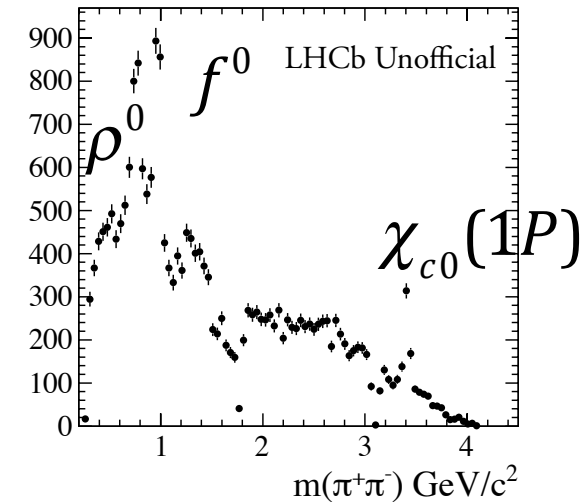
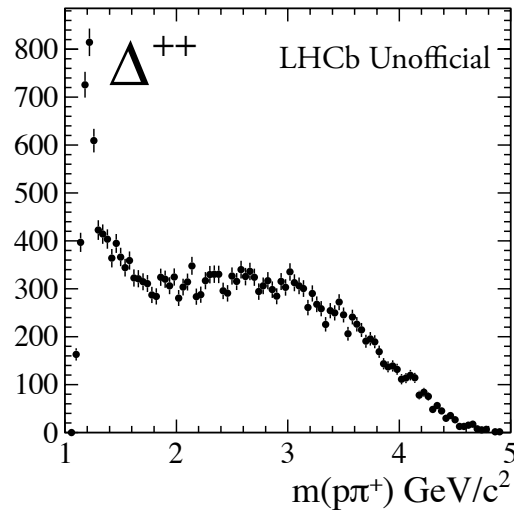
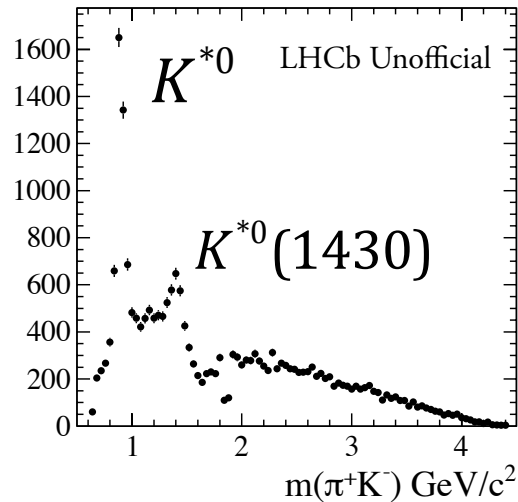
$$\bar{A}_T = \frac{N(-\bar{C}_T > 0) - N(-\bar{C}_T < 0)}{N(-\bar{C}_T > 0) + N(-\bar{C}_T < 0)}$$

$$A_T = \frac{N(C_T > 0) - N(C_T < 0)}{N(C_T > 0) + N(C_T < 0)}$$



Distribuzione del segnale nello spazio delle fasi

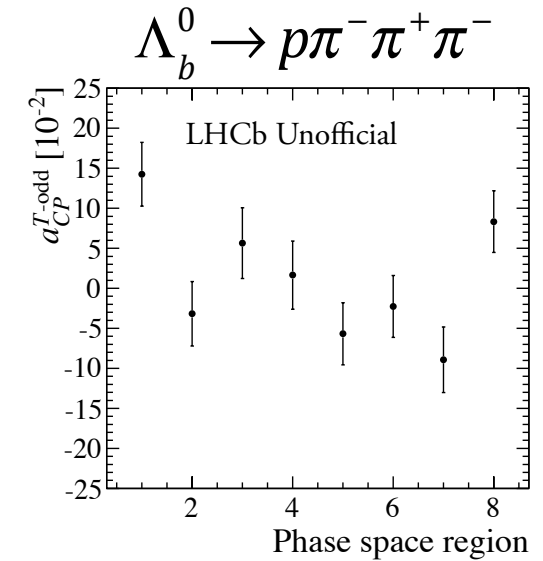
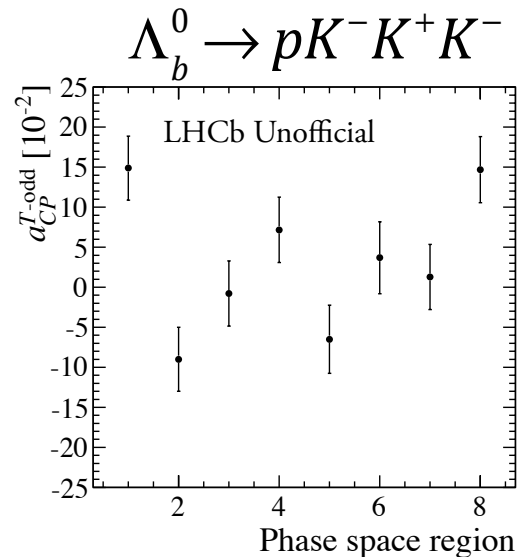
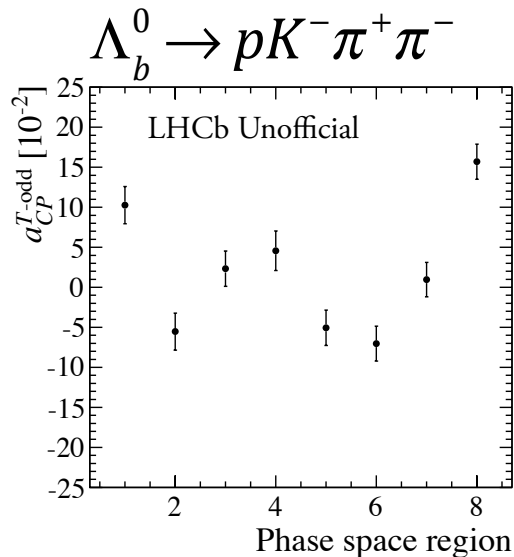
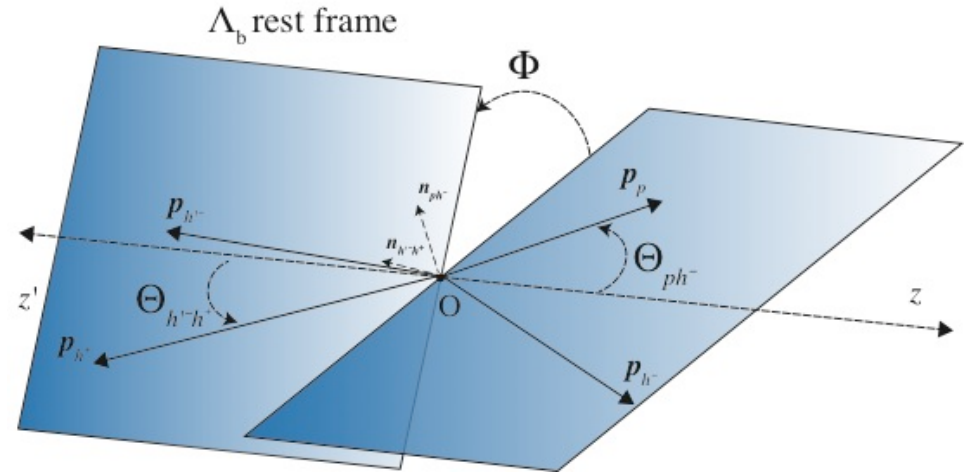
$$\Lambda_b^0 \rightarrow p K^- \pi^+ \pi^-$$



Ricerca di CPV nello spazio delle fasi

Variabili usate per parametrizzare lo spazio delle fasi:

- $m^2(ph^-)$, $m^2(h^+h^-)$, $\cos(\theta_1)$, $\cos(\theta_2)$, ϕ



Incertezze sistematiche

Bias sperimentale

$$\Delta a_{CP}^{T\text{-odd}} \sim 0.3\%$$

$$\Delta A_T, \Delta \bar{A}_T \sim 0.4\%$$

Stimato dal campione di controllo $\Lambda_b^0 \rightarrow \Lambda_c^- (\rightarrow pK^-\pi^+)\pi^-$ con $\sim 114k$ eventi

Cabibbo favorito \longrightarrow CPV trascurabile

Risoluzione su C_T

$$\Delta a_{CP}^{T\text{-odd}} \sim 0.05\%$$

$$\Delta A_T, \Delta \bar{A}_T \sim 0.05\%$$

La risoluzione finita su C_T può indurre migrazione tra le categorie di fit $C_T > 0$ e $C_T < 0$ \longrightarrow stimato da MC

Modello di fit

$$\Delta a_{CP}^{T\text{-odd}} \sim 0.05 - 0.2\%$$

$$\Delta A_T, \Delta \bar{A}_T \sim 0.1 - 1\%$$

Stimato con pseudoesperimenti simulati e utilizzando modelli alternativi di fit per segnale e fondo

Risultati

Prima osservazione di decadimenti senza quark "charm"
per Λ_b^0 e Ξ_b^0 in 4 corpi

Sensibilità a CPV

Decay	A_T (%)	\bar{A}_T (%)	$a_{CP}^{T\text{-odd}}$ (%)
$\Lambda_b^0 \rightarrow pK^- \pi^+ \pi^-$	$x.x \pm 1.1 \pm 0.5$	$x.x \pm 1.2 \pm 0.4$	$x.x \pm 0.8 \pm 0.3$
$\Lambda_b^0 \rightarrow pK^- K^+ K^-$	$x.x \pm 2.1 \pm 0.5$	$x.x \pm 2.1 \pm 0.5$	$x.x \pm 1.5 \pm 0.3$
$\Lambda_b^0 \rightarrow p\pi^- \pi^+ \pi^-$	$x.x \pm 2.1 \pm 0.5$	$x.x \pm 2.1 \pm 0.4$	$x.x \pm 1.5 \pm 0.3$ \Leftarrow
$\Lambda_b^0 \rightarrow pK^+ K^- \pi^-$	$x.x \pm 6.8 \pm 1.1$	$x.x \pm 6.1 \pm 0.7$	$x.x \pm 4.6 \pm 0.4$ \Leftarrow
$\Xi_b^0 \rightarrow pK^- K^- \pi^+$	$x.x \pm 7.4 \pm 0.5$	$x.x \pm 6.8 \pm 0.6$	$x.x \pm 5.0 \pm 0.3$

\Leftarrow : potenziali effetti di CPV aspettati nel Modello Standard

- Misura più sensibile a CPV nei barioni pesanti ad oggi
- Misura limitata dalla statistica \longrightarrow promettente per il futuro

Grazie per l'attenzione

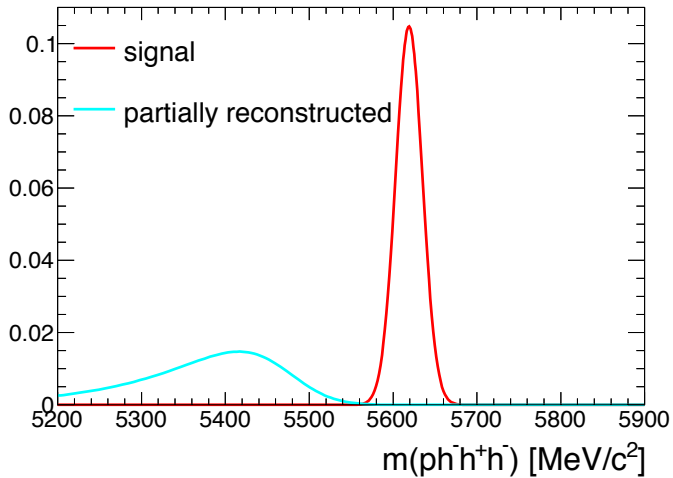
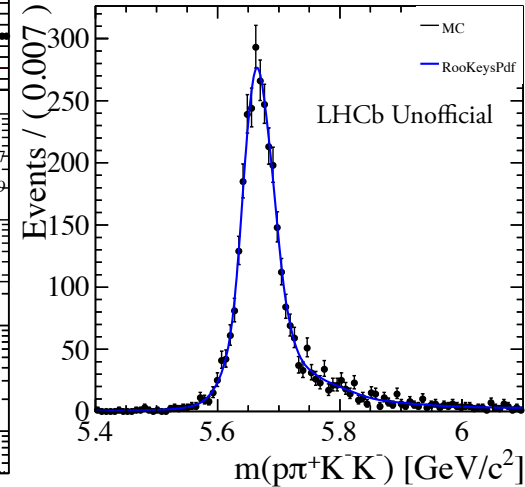
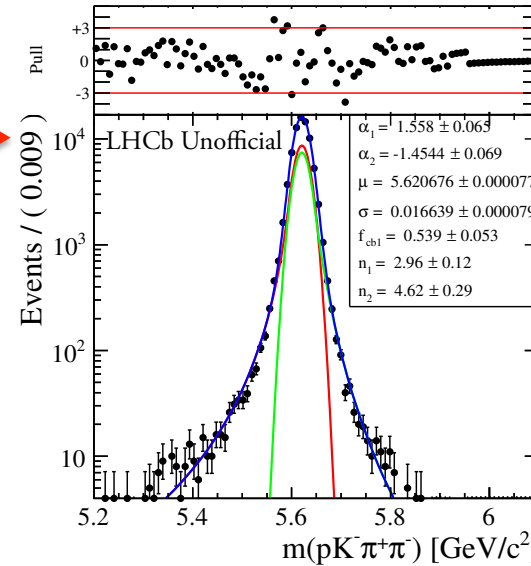




Back-up

Parametrizzazione del modello di fit

- **Segnale** → somma di due Crystal Ball
- **Combinatorio** esponenziale



- Λ_b^0 parzialmente ricostruite
argus convoluta con gaussiana
 π^0, γ persi
- **Cross feed** stimati da MC

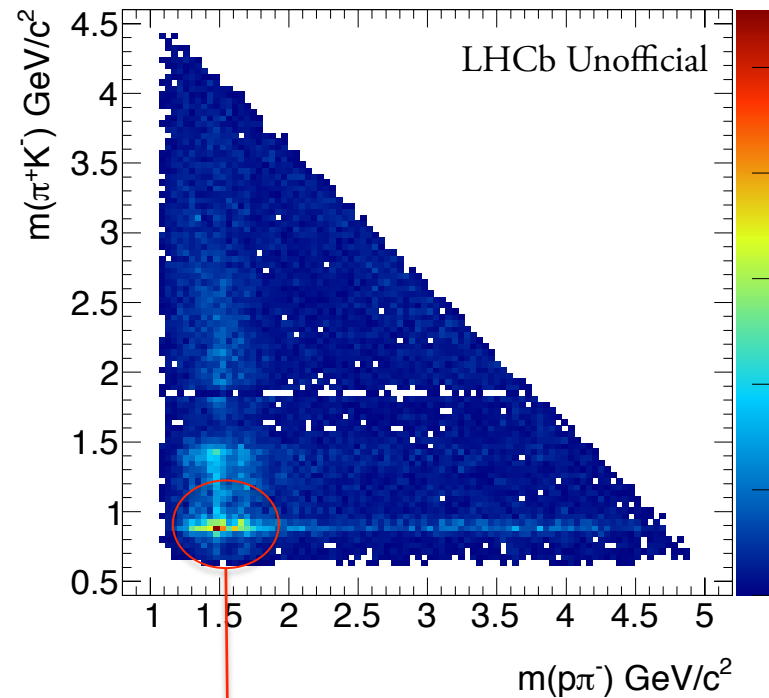
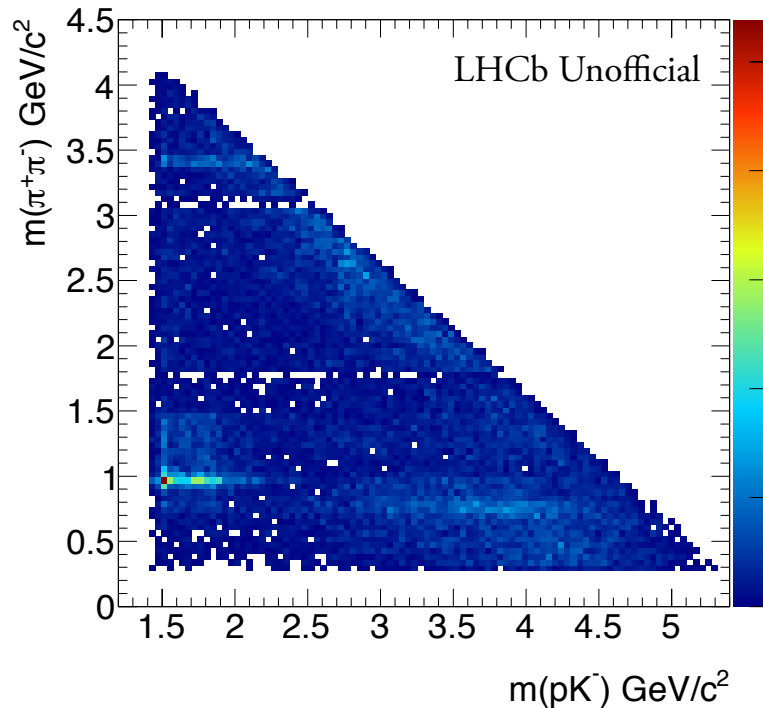
Parametrizzazione del segnale

Somma di due Crystal Ball

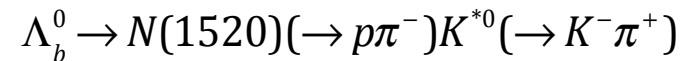
$$pdf_{sig} = f \cdot CB^+(x; \mu, \sigma, \alpha^+, n^+) + (1 - f) \cdot CB^-(x; \mu, \sigma, \alpha^-, n^-)$$

$$CB(x; \mu, \sigma, \alpha, n) = N \cdot \begin{cases} \frac{\left(\frac{n}{|\alpha|}\right)^n e^{-\frac{1}{2}\alpha^2}}{\left(\frac{n}{|\alpha|} - |\alpha| - \frac{x - \mu}{\sigma}\right)^n} & x < -|\alpha| \\ e^{-\frac{1}{2}\left(\frac{x - \mu}{\sigma}\right)^2} & x > -|\alpha| \end{cases}$$

Distribuzione del segnale nello spazio delle fasi

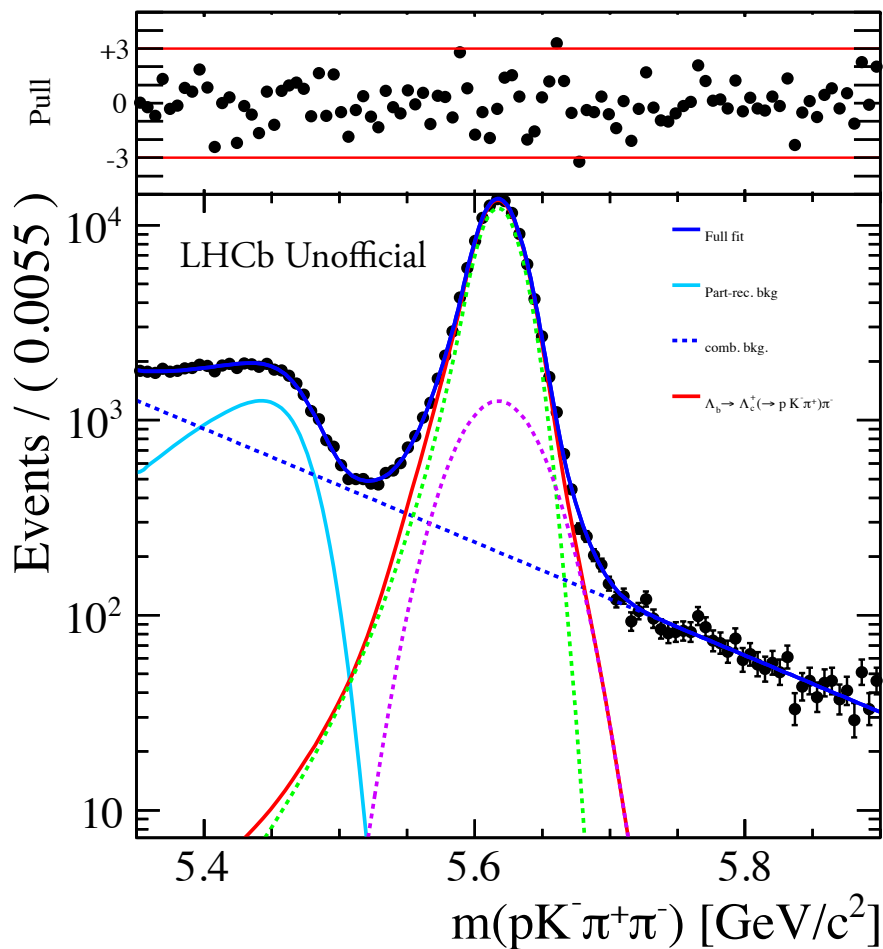


Indizio di produzione associata di risonanze



$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) \pi^-$ control sample

$$N_{sig} = 113612 \pm 399$$



$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow pK^-\pi^+) \pi^-$ control sample

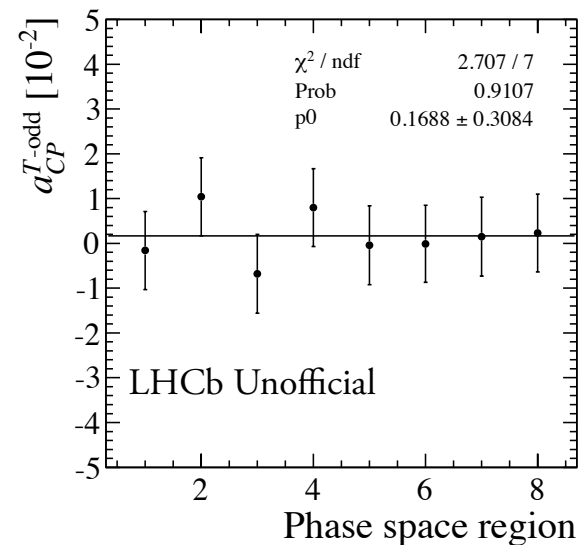
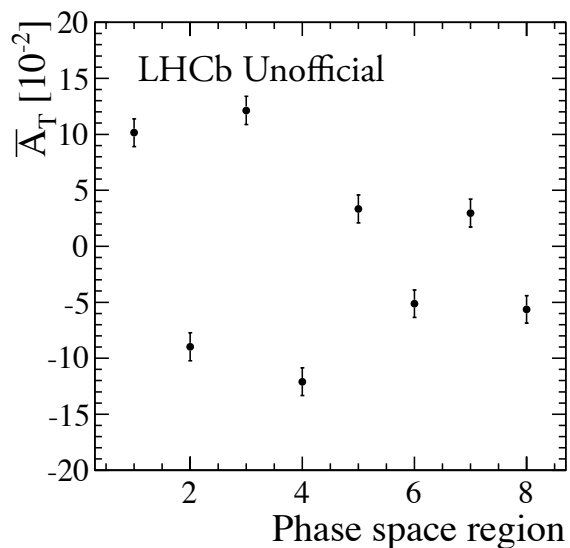
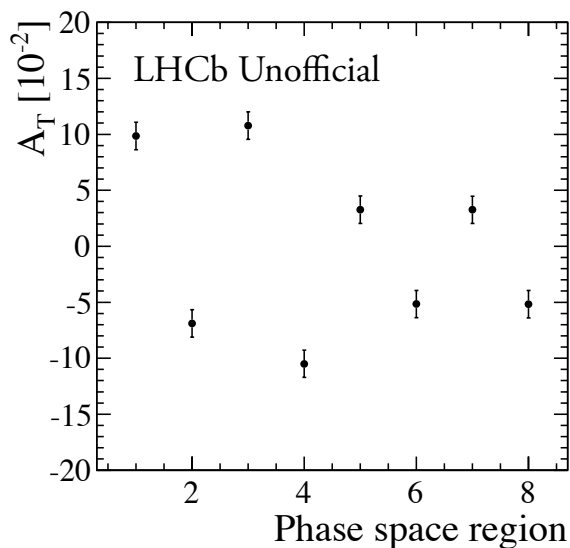
Asimmetrie integrate nello spazio delle fasi:

$$A_T = (-0.10 \pm 0.43)\%$$

$$\bar{A}_T = (-0.41 \pm 0.44)\%$$

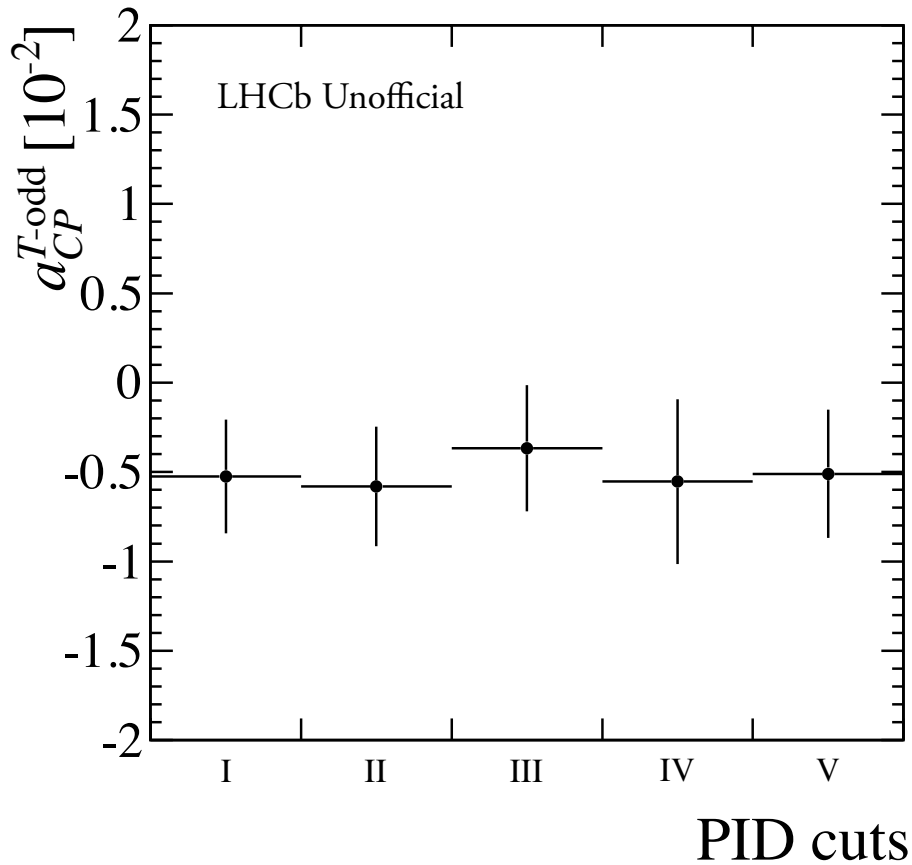
$$a_{CP}^{T\text{-odd}} = (-0.15 \pm 0.31)\%$$

Asimmetrie in bin dello spazio delle fasi:



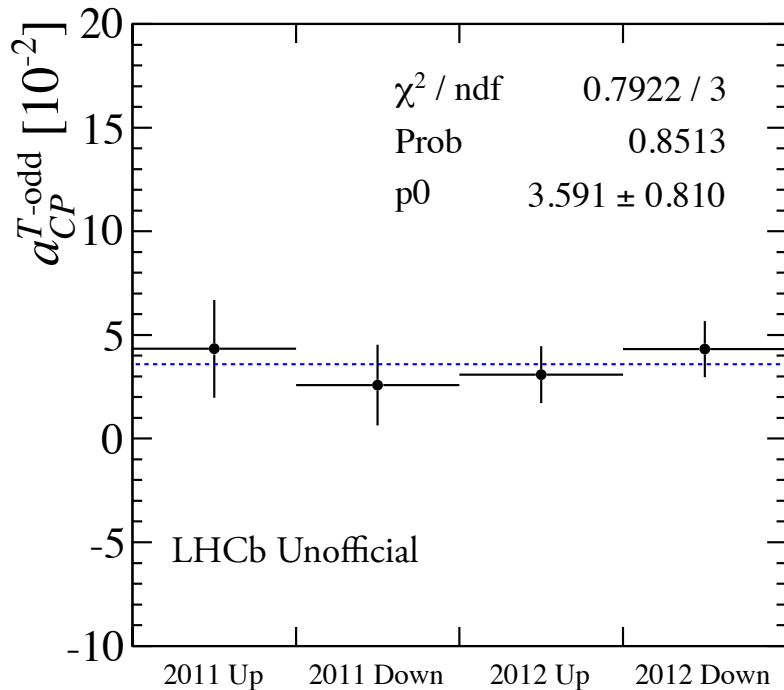
$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow pK^-\pi^+) \pi^-$ control sample

PID cuts	I	II	III	IV	V(nominal cut)
$\text{ProbNN}p(p) \cdot (1 - \text{ProbNN}K(p)) \cdot (1 - \text{ProbNN}\pi(p))$	> 0.0	> 0.2	> 0.2	> 0.3	> 0.2
$\text{ProbNN}K(K) \cdot (1 - \text{ProbNN}\pi(K)) \cdot (1 - \text{ProbNN}p(K)) \cdot (1 - \text{ProbNN}\mu(K))$	> 0.1	> 0.0	> 0.1	> 0.3	> 0.1
$\text{ProbNN}\pi(\pi) \cdot (1 - \text{ProbNN}K(\pi)) \cdot (1 - \text{ProbNN}p(\pi)) \cdot (1 - \text{ProbNN}\mu(\pi))$	> 0.1	> 0.1	> 0.0	> 0.3	> 0.1

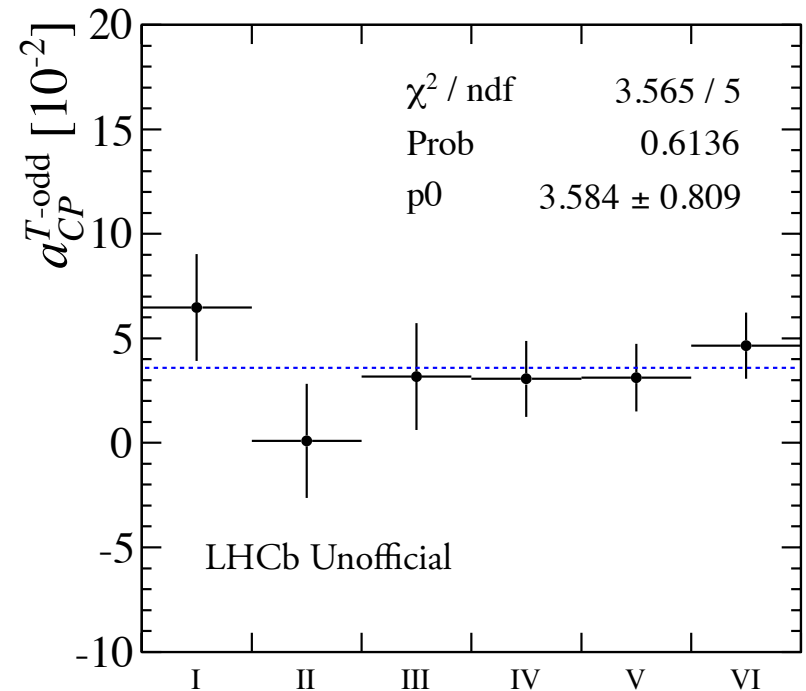


Stabilità del risultato

per anno & polarità del magnete

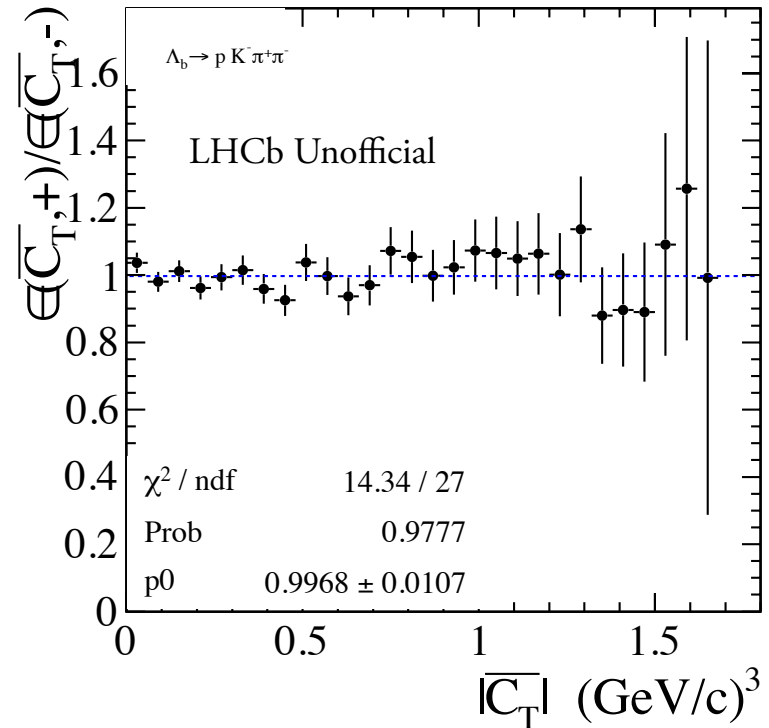
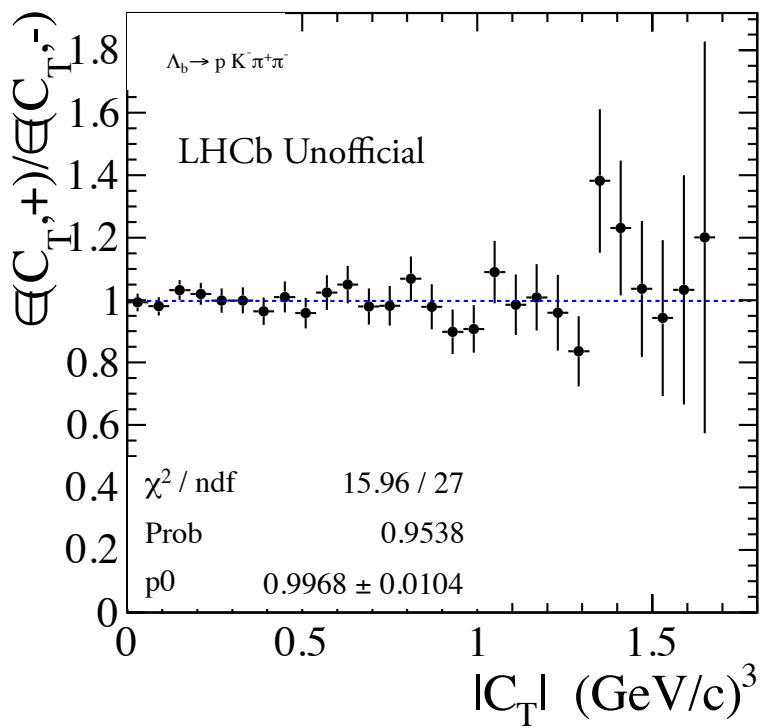


per periodi entro i maggiori stop tecnici

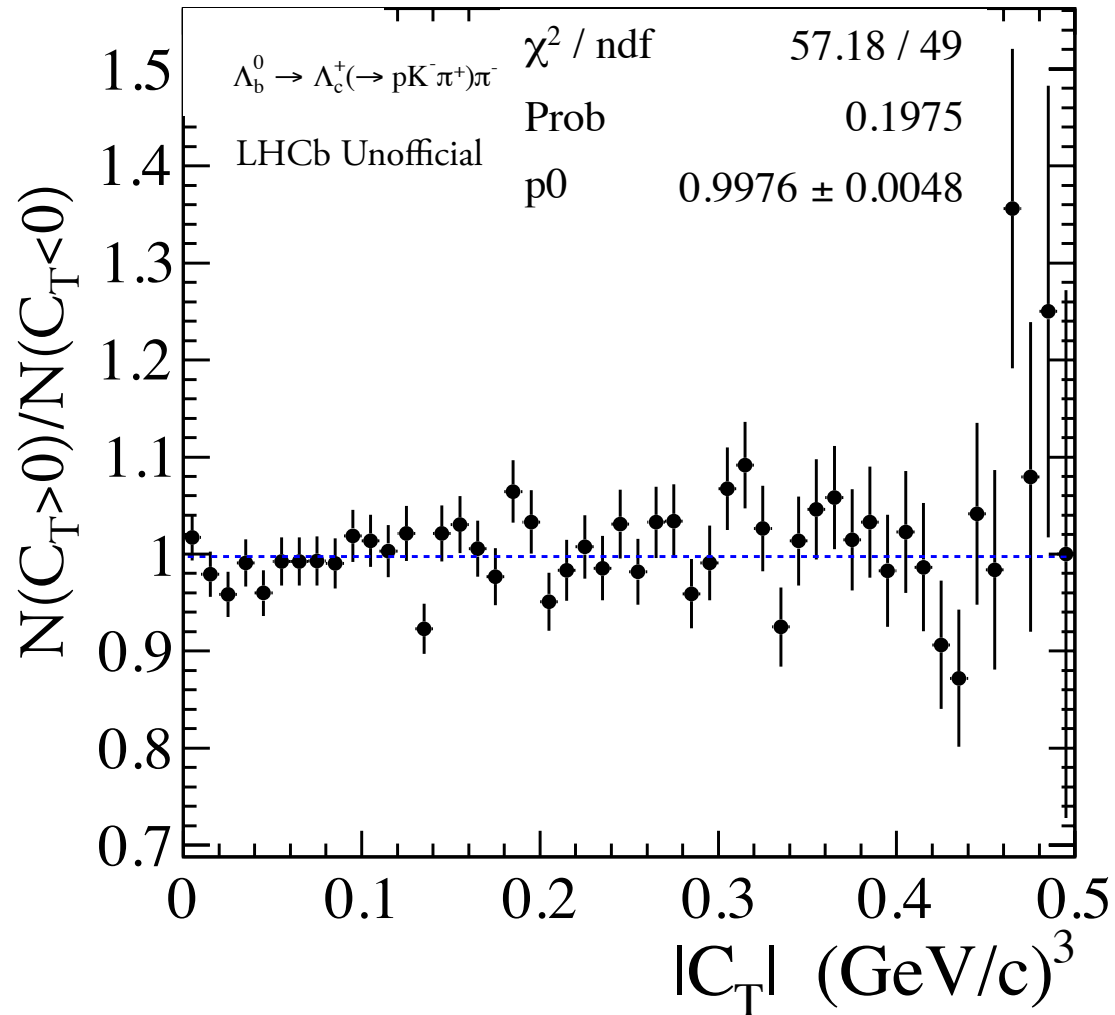


Efficienza di ricostruzione del segnale (MC)

$$\epsilon(C_T, \pm) = \frac{(C_T \gtrless 0)_{rec}}{(C_T \gtrless 0)_{gen}}$$

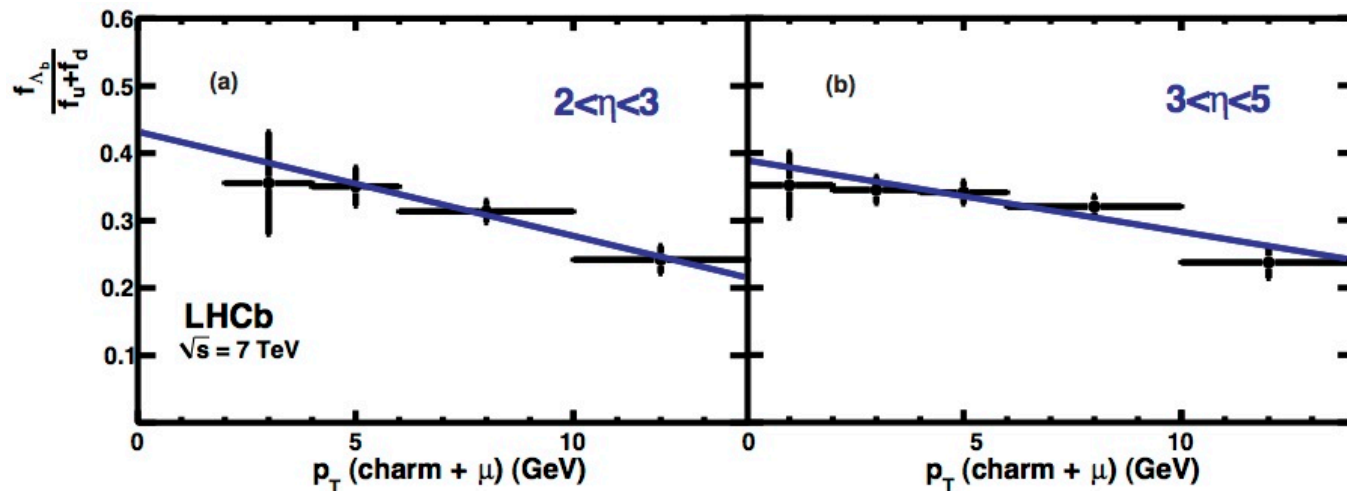


Efficienza di ricostruzione del segnale (control sample)



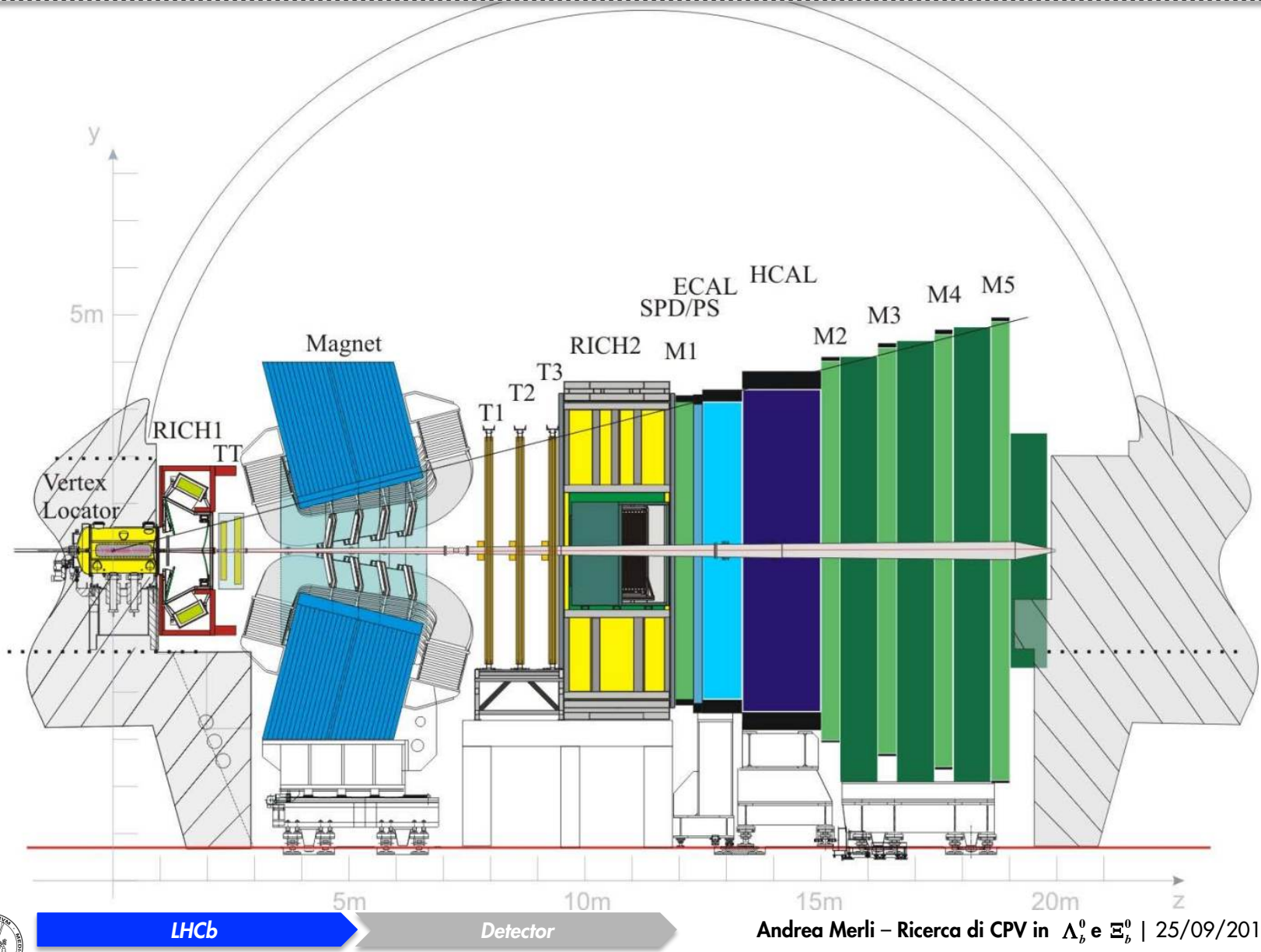
Esperimento LHCb

- Collisioni pp a 7-8 TeV
- Esperimento dedicato alla fisica dei sapori pesanti (CPV , decadimenti rari, spettroscopia):
 - Accettanza LHCb/ 1fb^{-1} a 7 TeV:
 - 10^{11} coppie $b\bar{b}$: $\sigma(pp \rightarrow b\bar{b}X) = (75.3 \pm 14.0)\mu\text{b}$
 - 10^{12} coppie $c\bar{c}$: $\sigma(pp \rightarrow c\bar{c}X) = (1.23 \pm 0.19)\text{mb}$
- Grande produzione di barioni pesanti con quark b



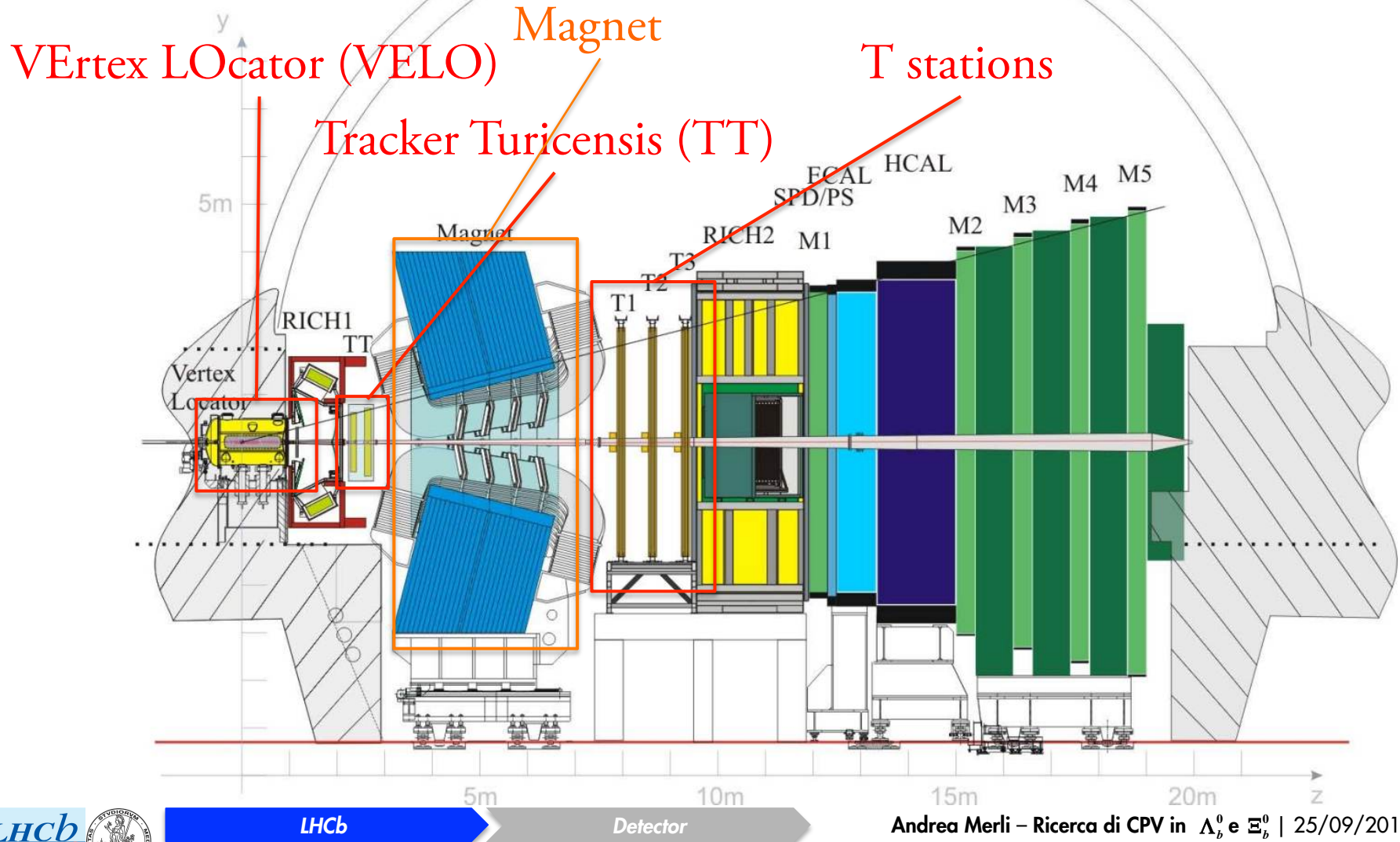
Diventano possibili misure di precisione sui barioni

LHCb detector



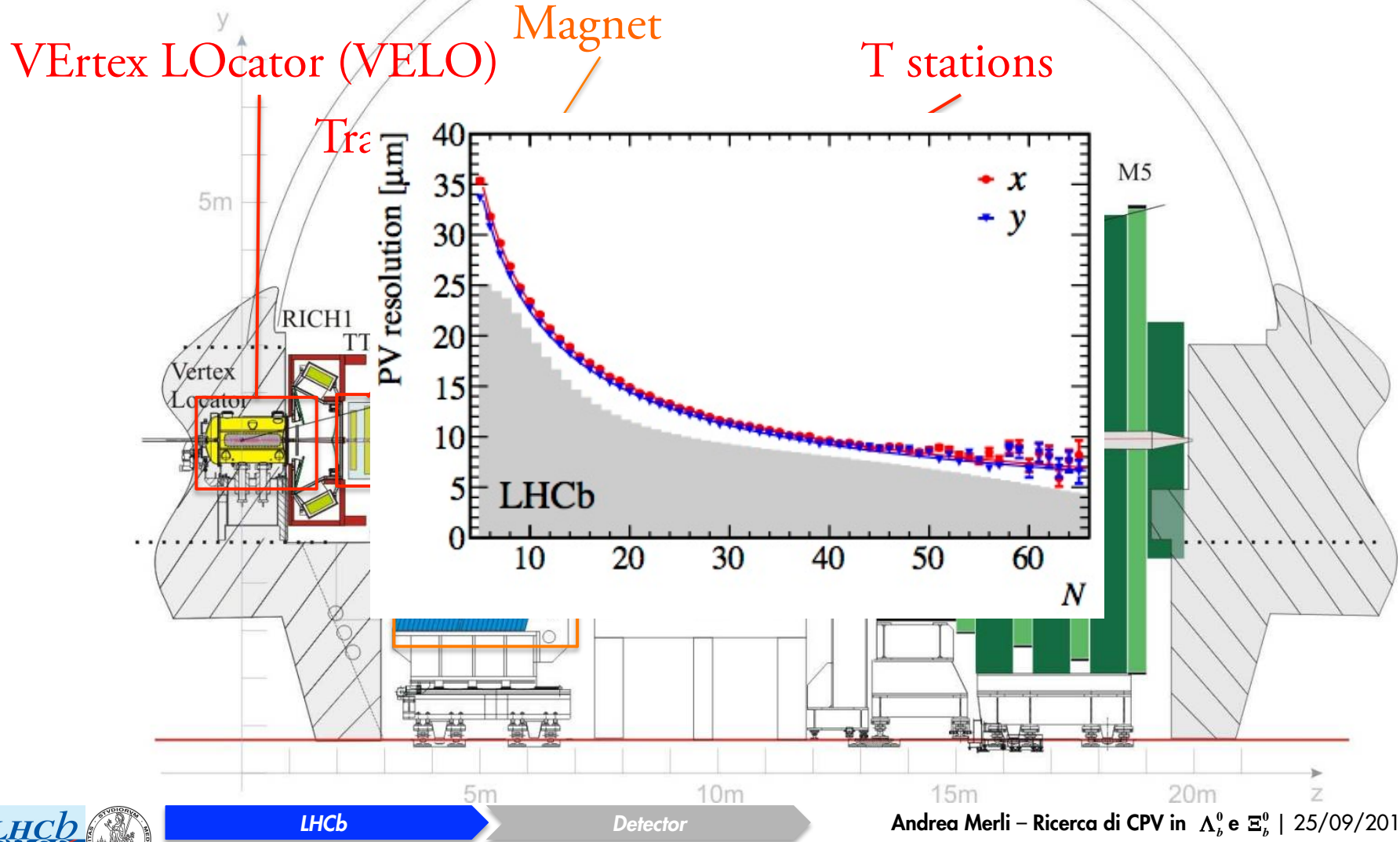
LHCb detector

Sistema di tracciatura



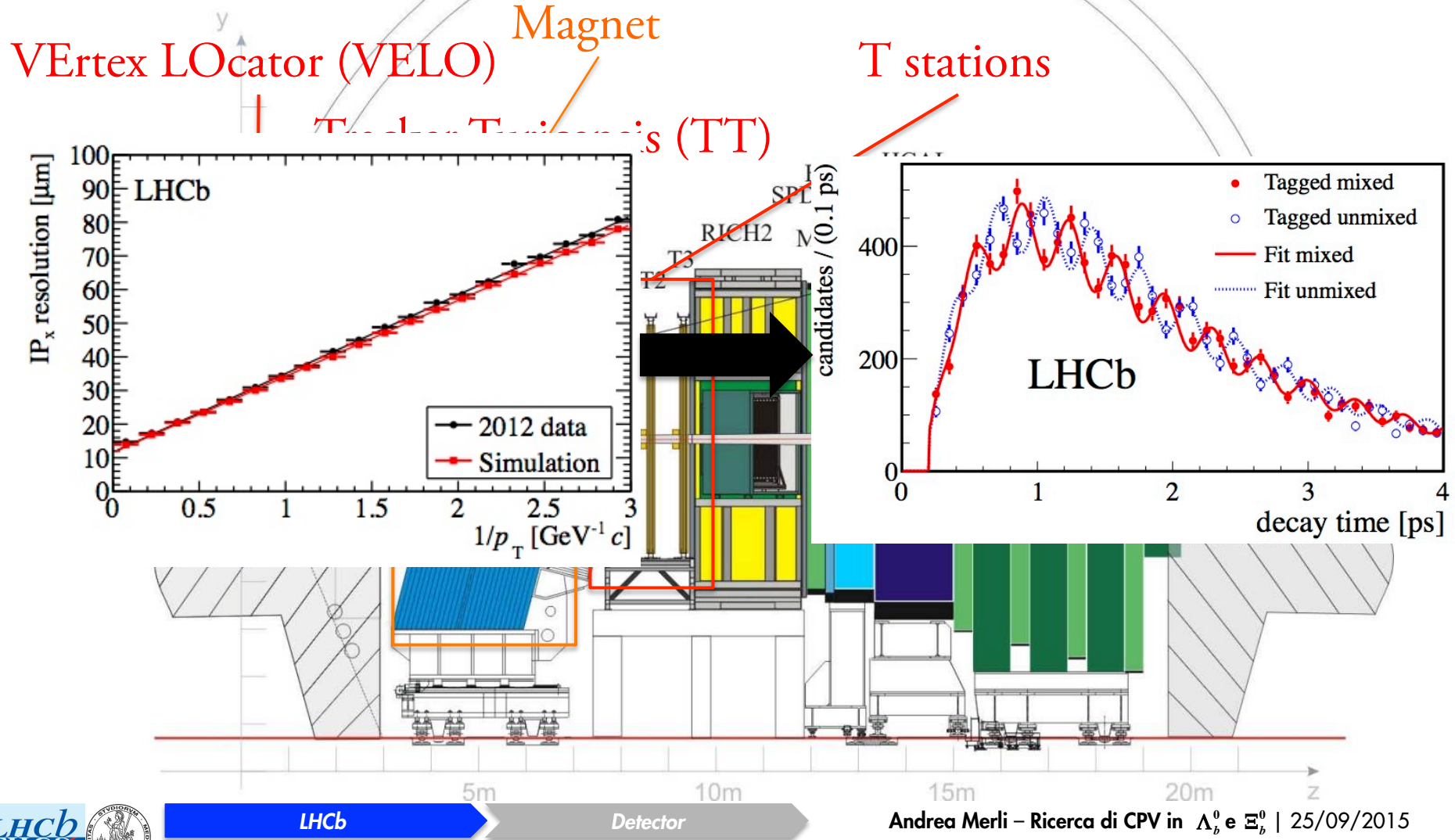
LHCb detector

Sistema di tracciatura



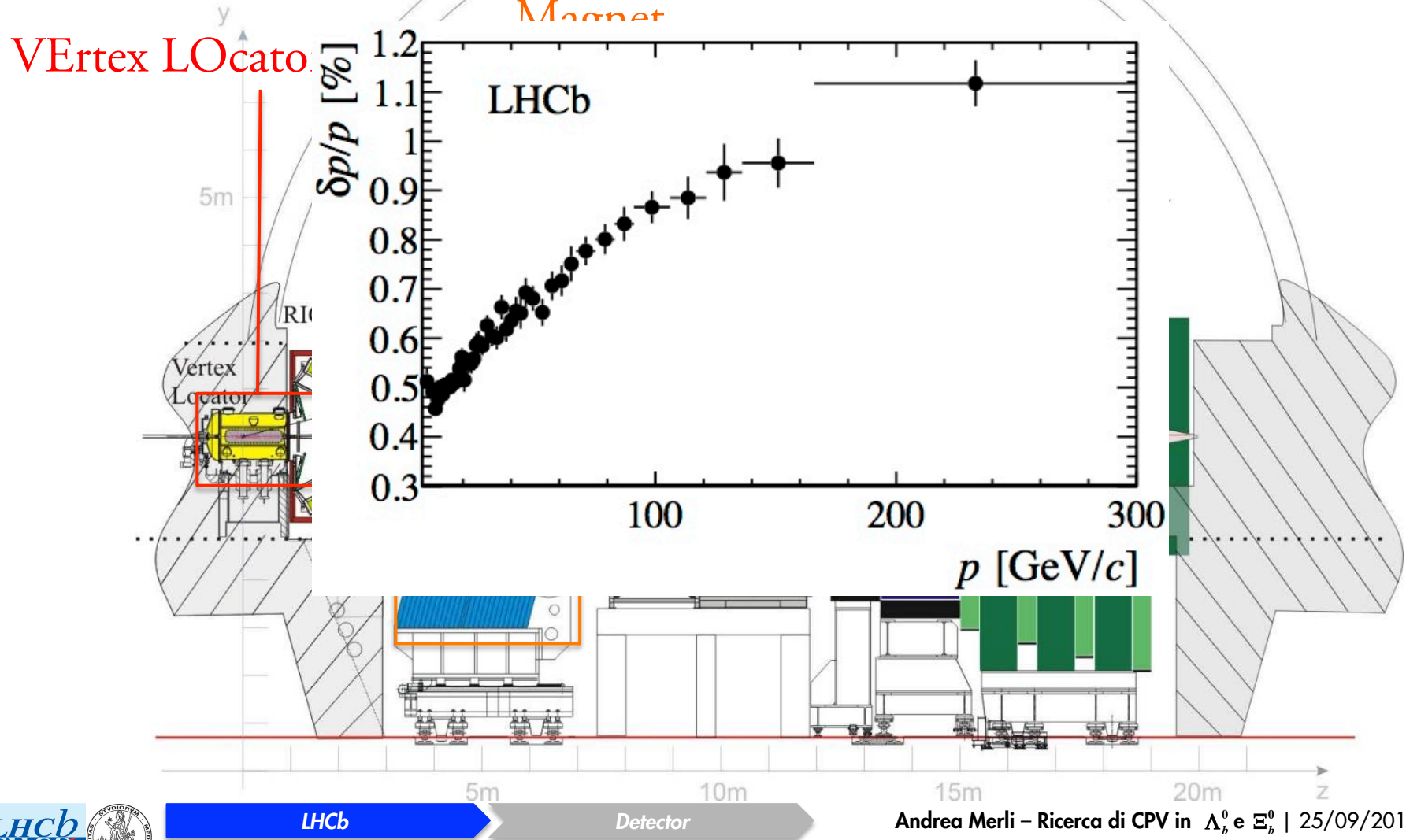
LHCb detector

Sistema di tracciatura



LHCb detector

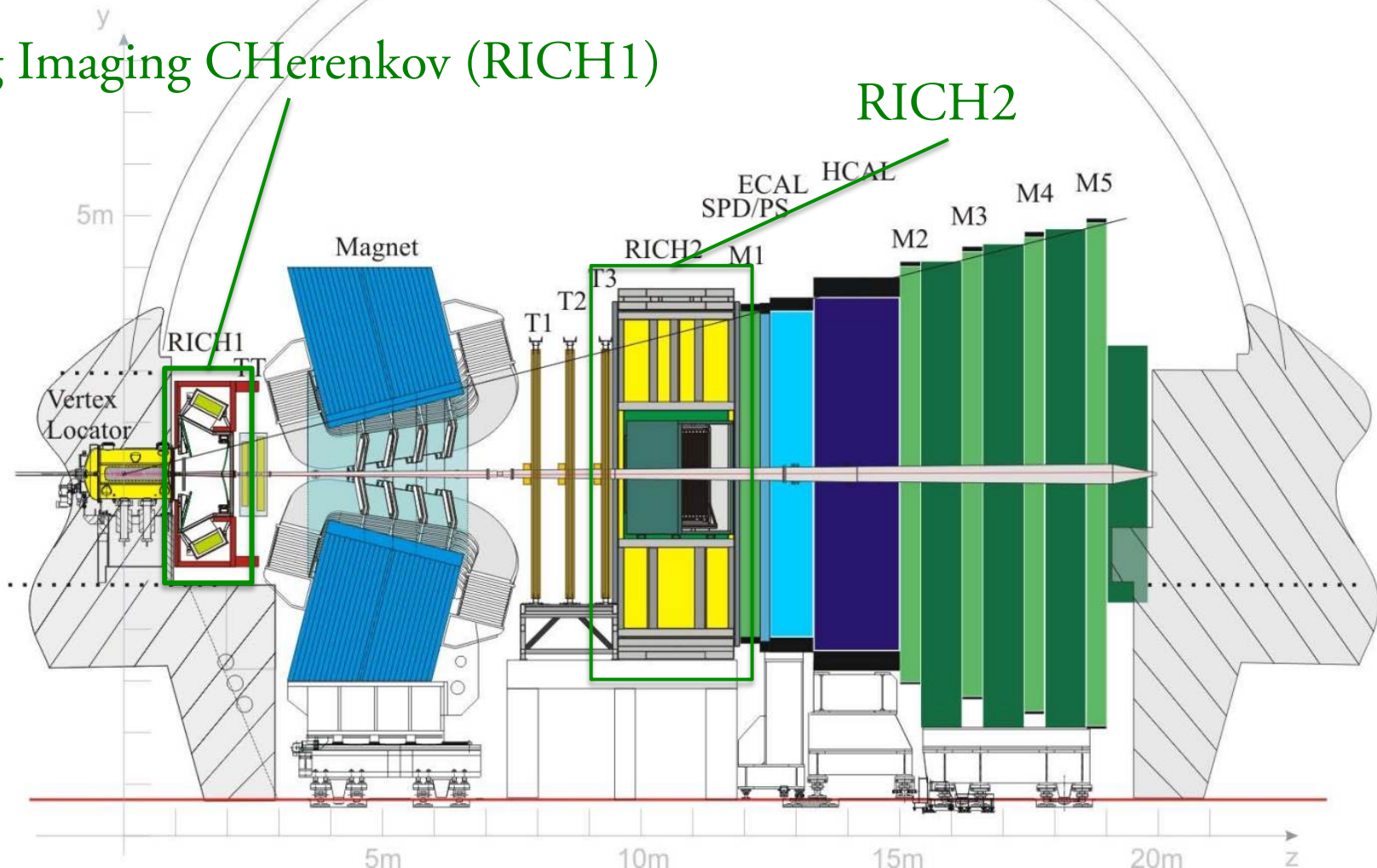
Sistema di tracciatura



LHCb detector

Sistema di identificazione di particelle

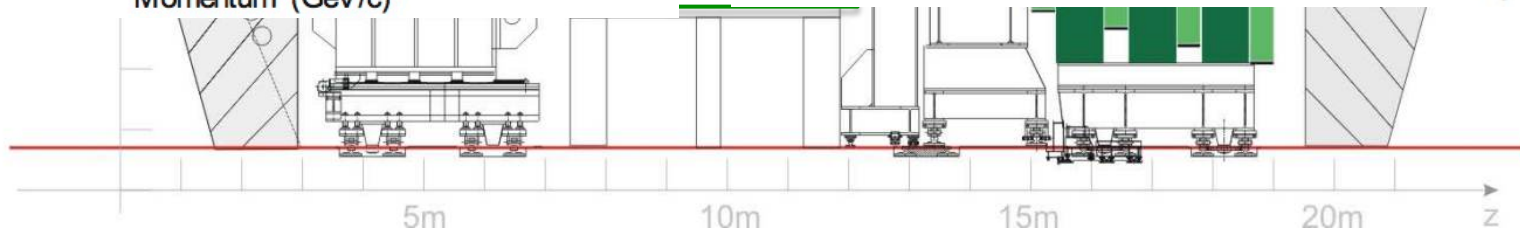
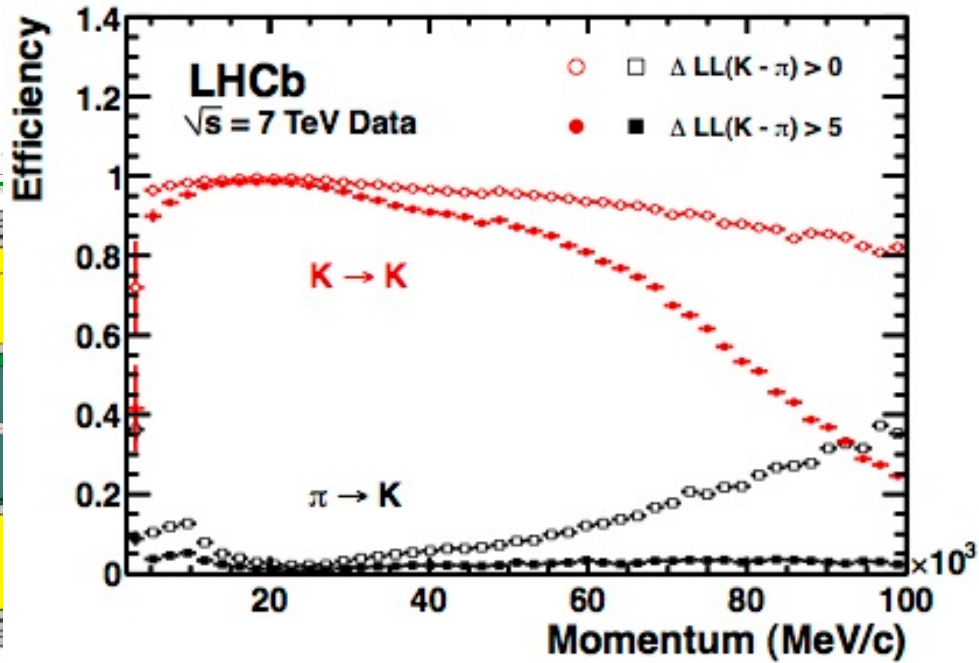
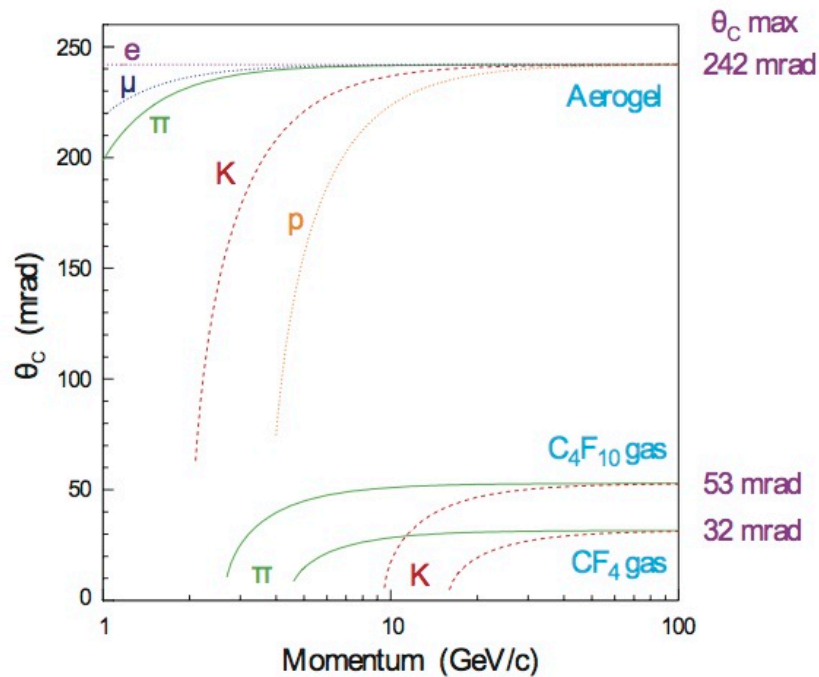
Ring Imaging CHerenkov (RICH1)



LHCb detector

Sistema di identificazione di particelle

Ring Imaging CHerenkov (RICH1)

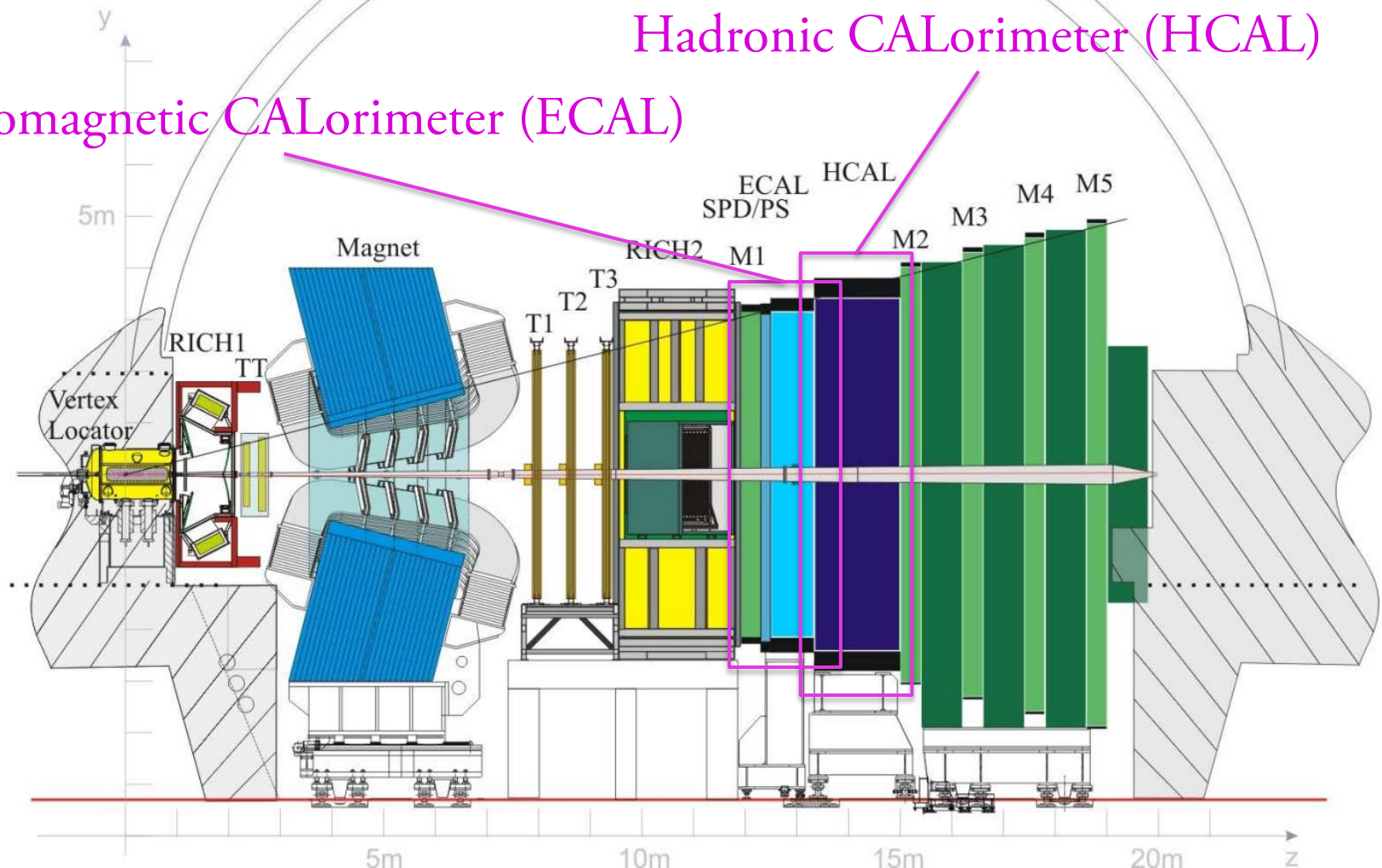


LHCb detector

Sistema di Calorimetria

Hadronic CALorimeter (HCAL)

Electromagnetic CALorimeter (ECAL)

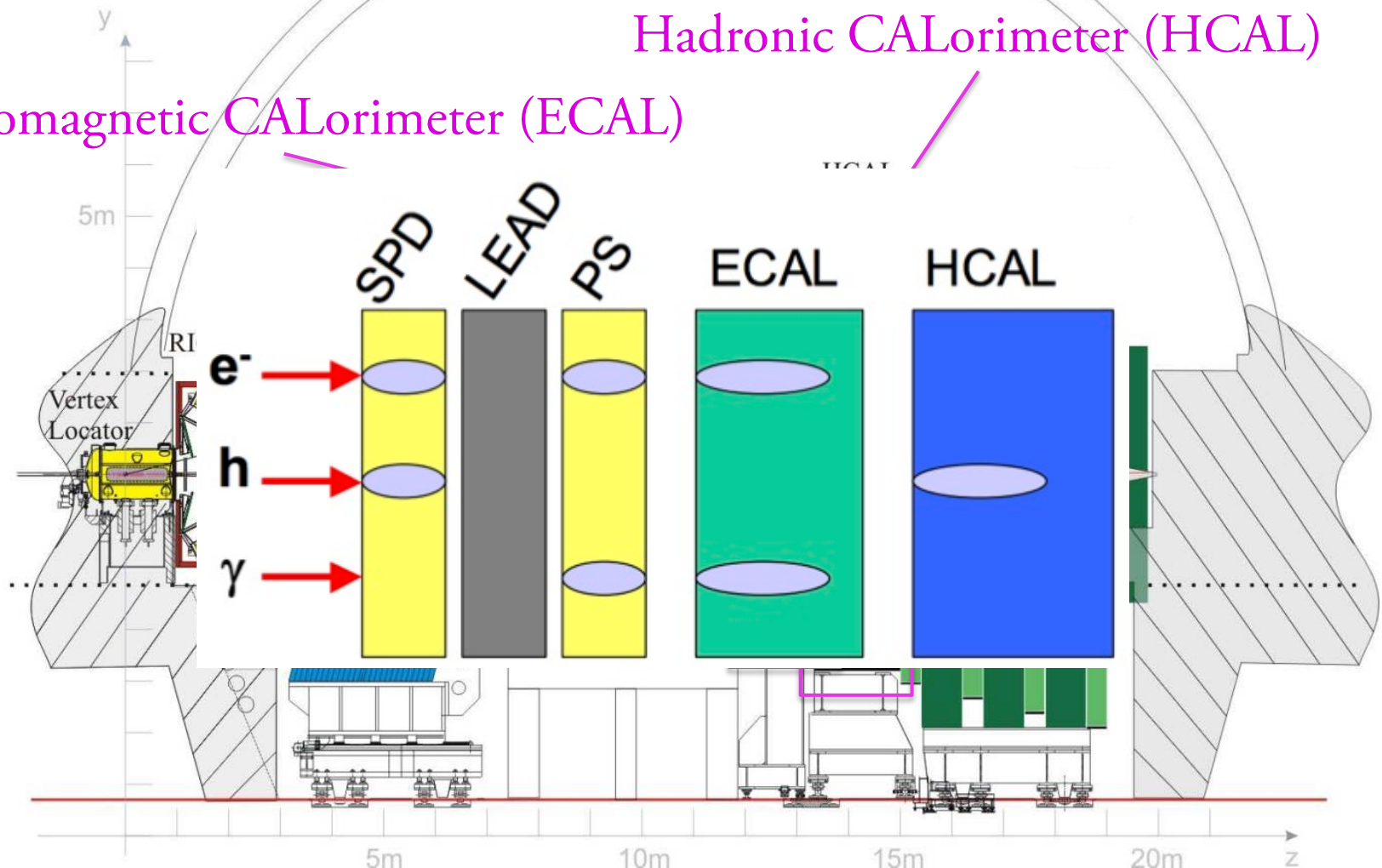


LHCb detector

Sistema di Calorimetria

Hadronic CALorimeter (HCAL)

Electromagnetic CALorimeter (ECAL)

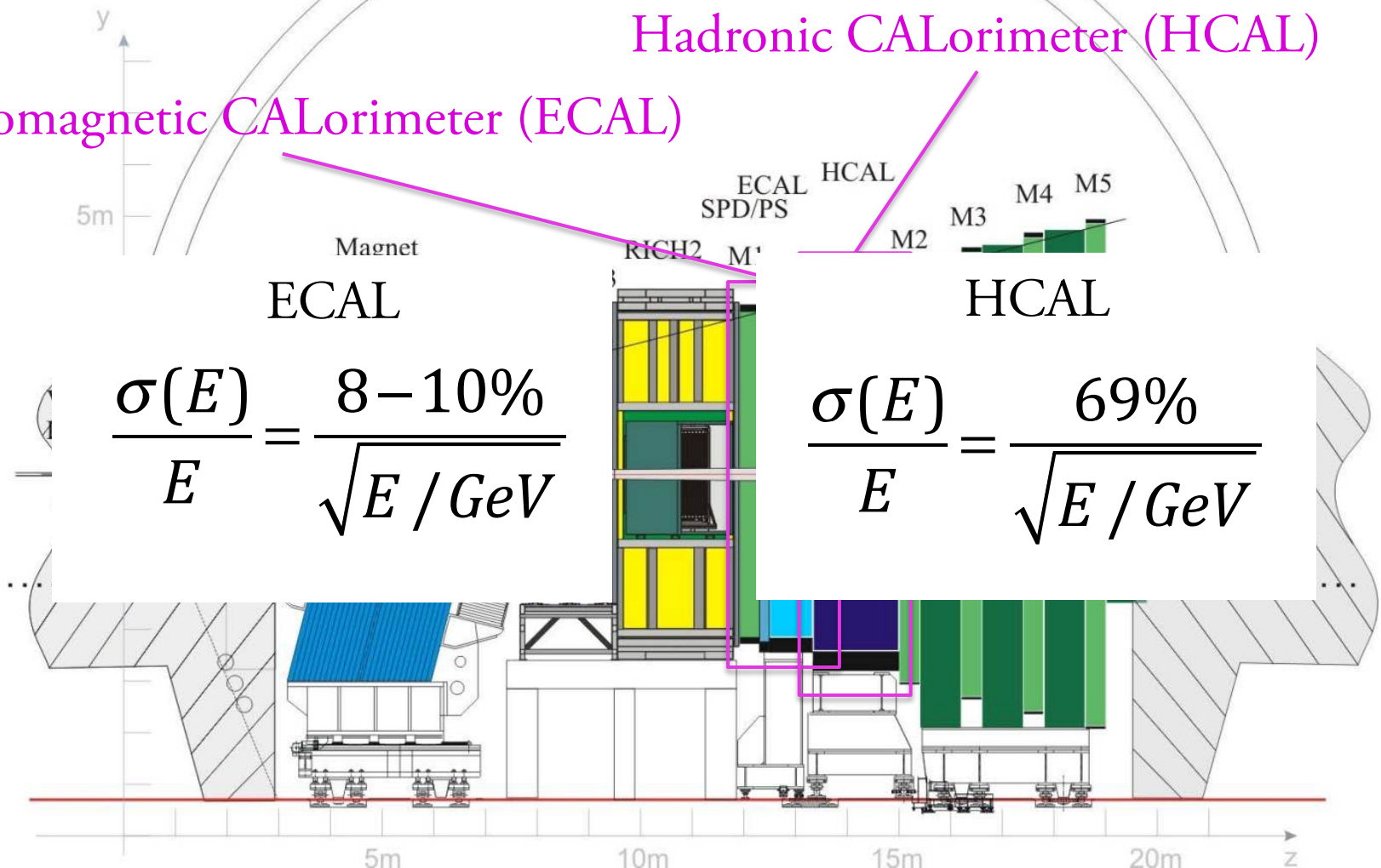


LHCb detector

Sistema di Calorimetria

Electromagnetic CALorimeter (ECAL)

Hadronic CALorimeter (HCAL)

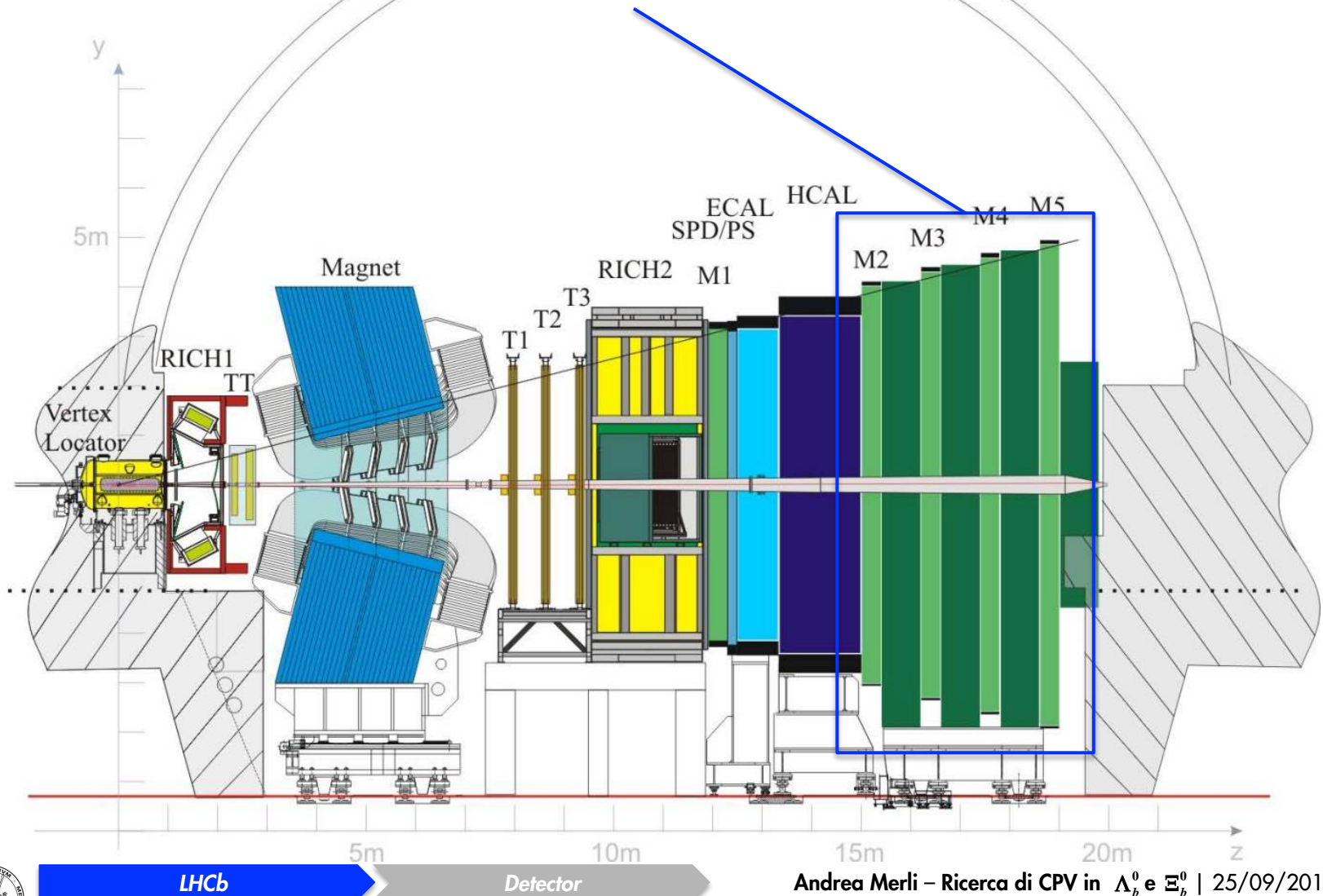


$$\frac{\sigma(E)}{E} = \frac{8-10\%}{\sqrt{E / \text{GeV}}}$$

$$\frac{\sigma(E)}{E} = \frac{69\%}{\sqrt{E / \text{GeV}}}$$

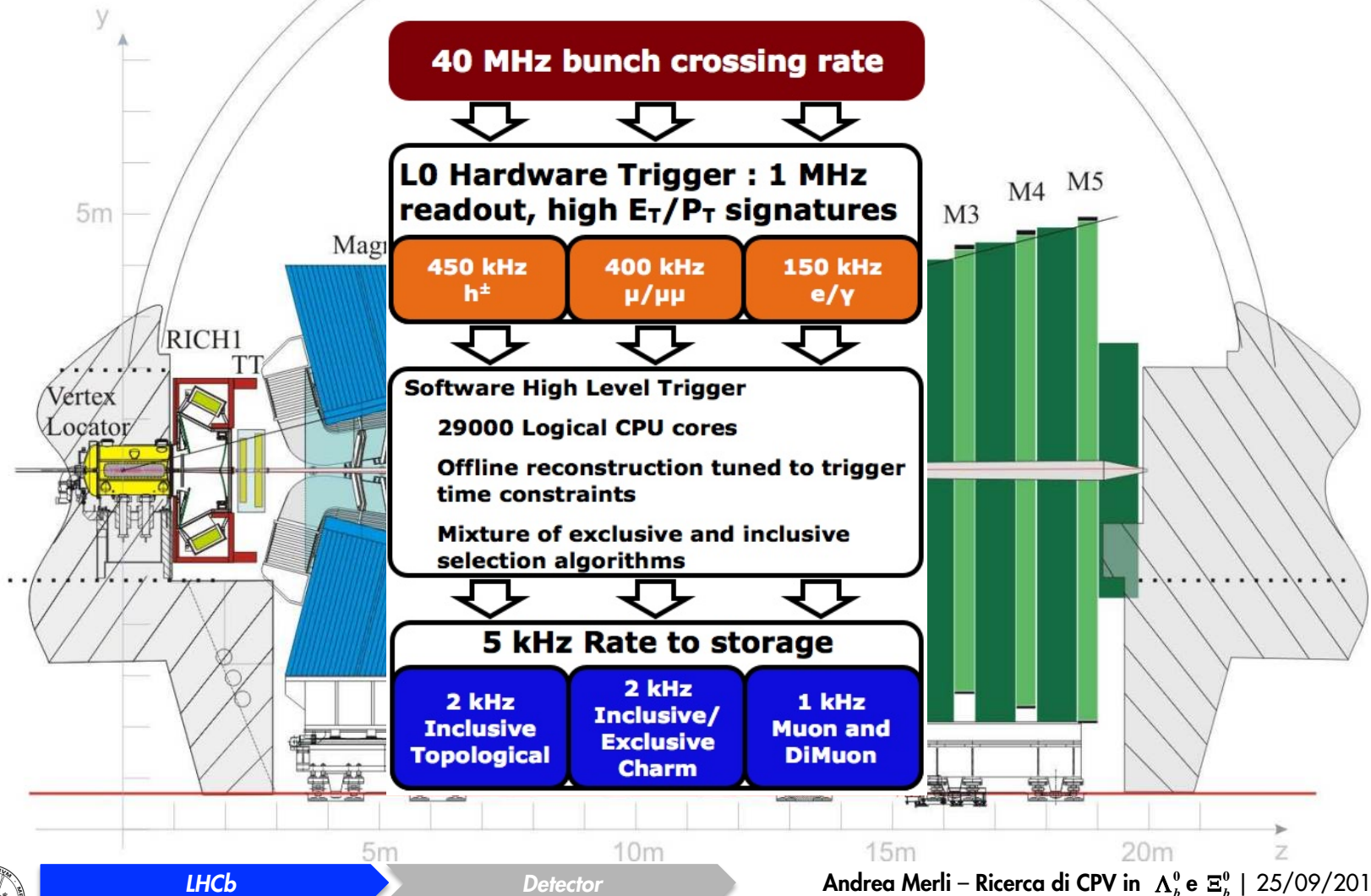
LHCb detector

Stazioni di Muoni



LHCb detector

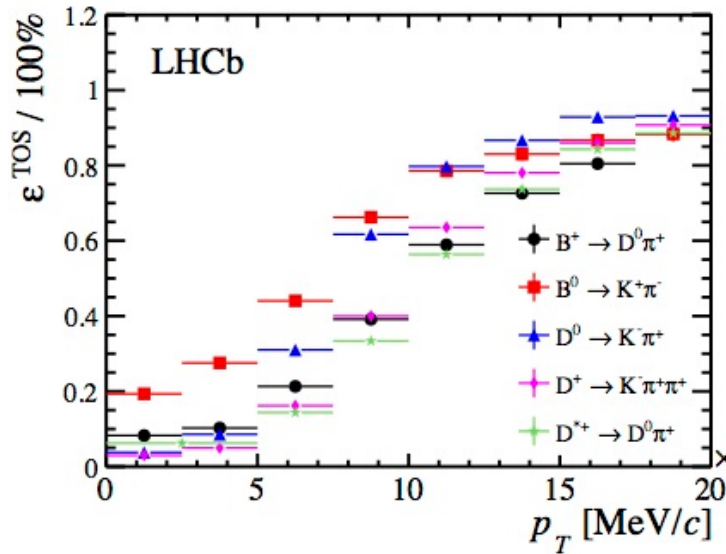
Trigger



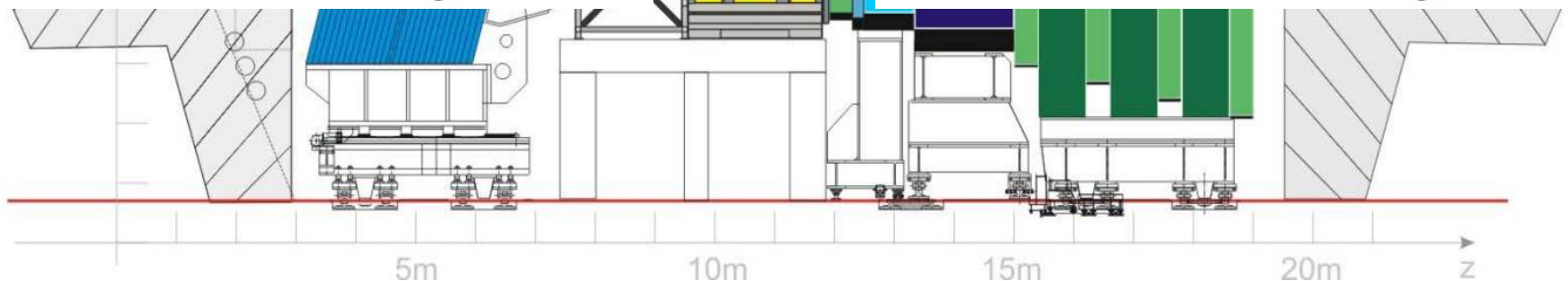
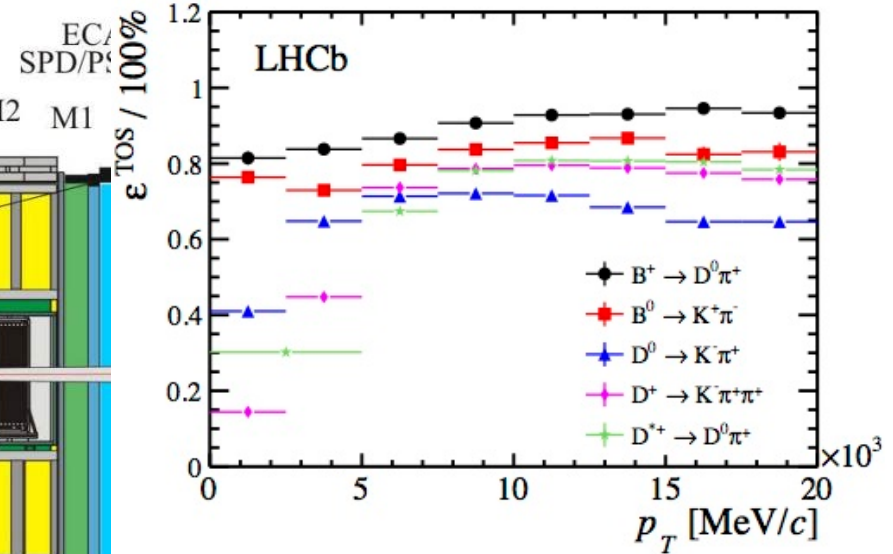
LHCb detector

Trigger

L0 trigger efficiency



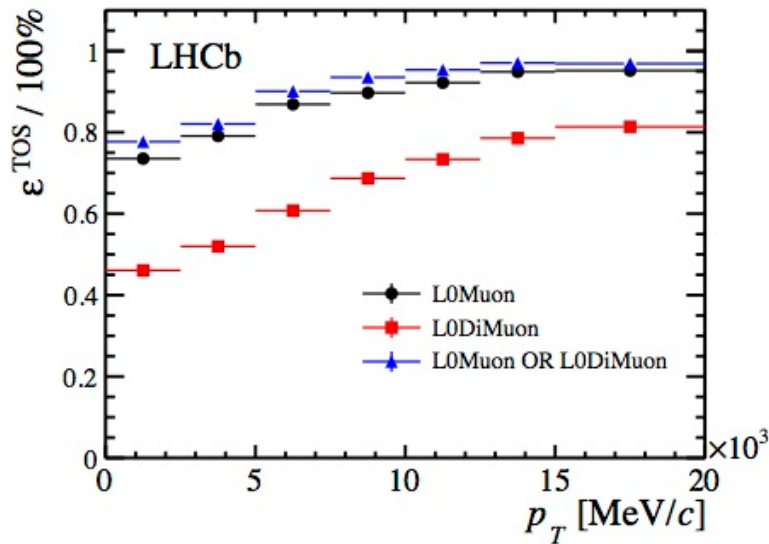
HLT1 trigger efficiency



LHCb detector

Trigger

L0 trigger efficiency



HLT1 trigger efficiency

