PRELIMINARY STUDIES ON Υ(1S) VISIBLE/INVISIBLE DECAYS AT THE BELLE II EXPERIMENT

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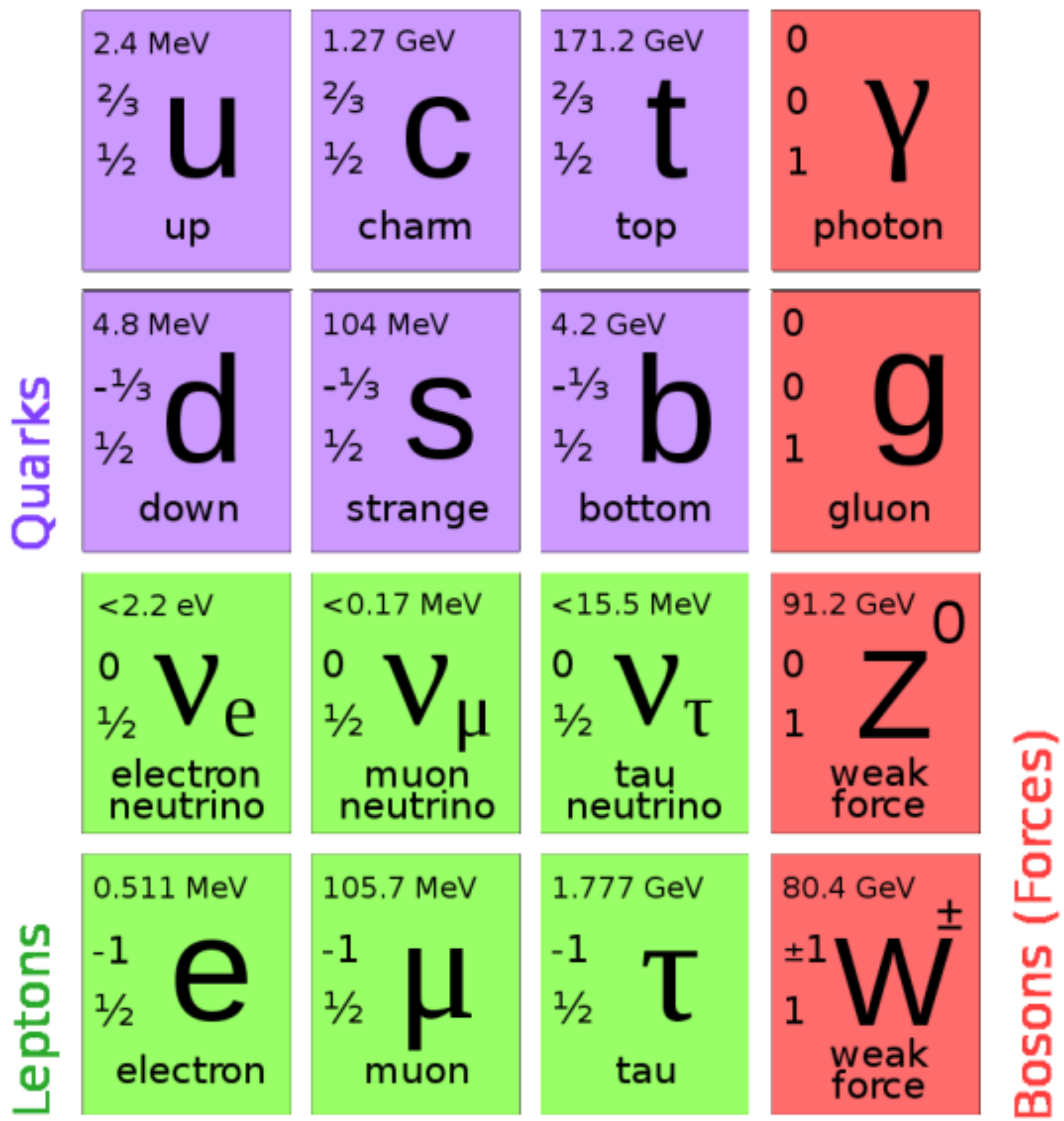
OUTLINE

- Theoretical overview and motivation
- Introduction to the Belle II experiment
- Feasibility study of Υ(nS) visible/invisible decays
- Conclusions

Standard Model of Particle Physics (SM)



Leading Model in the Last ~50 Years

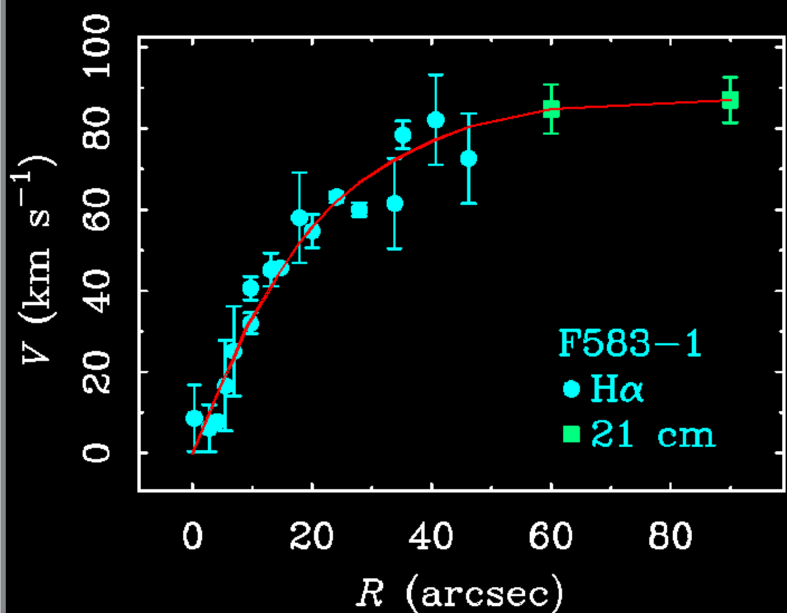
- 3 particles families and generations
- $SU(3)_C \times SU(2)_L \times U(1)_Y \longrightarrow$ **Higgs boson**
- 25 free parameters

Is SM sufficient for fundamental description of nature?

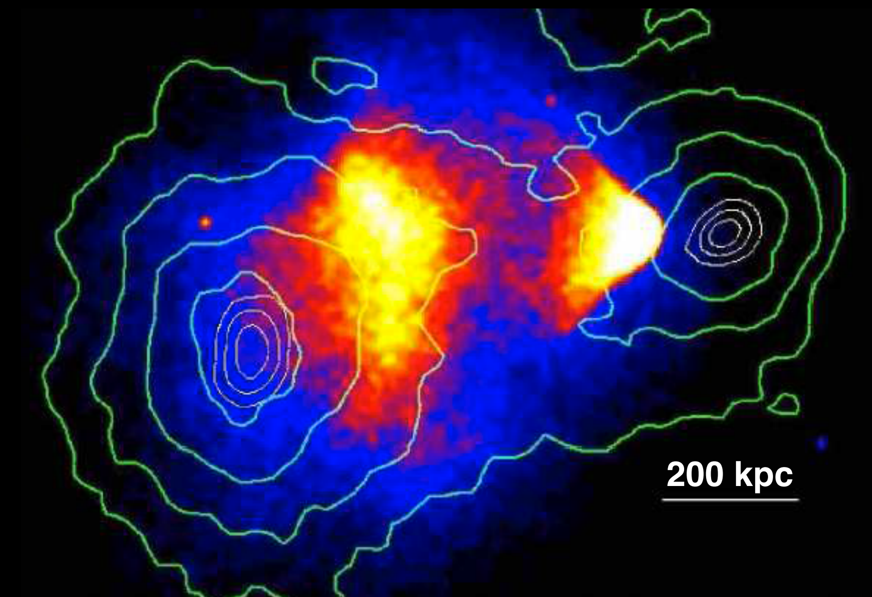
Many evidences for new physics…

- *Neutrinos non-zero masses*
- *Hierarchy problem*
- *Dark Matter and Dark Energy*
- …

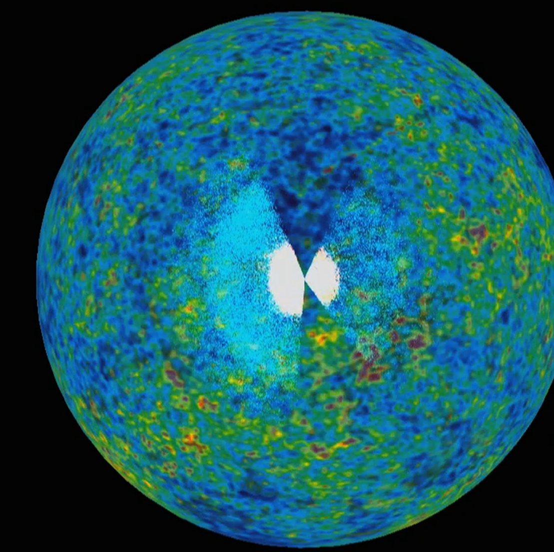
Motivation for Dark Matter (DM) Search



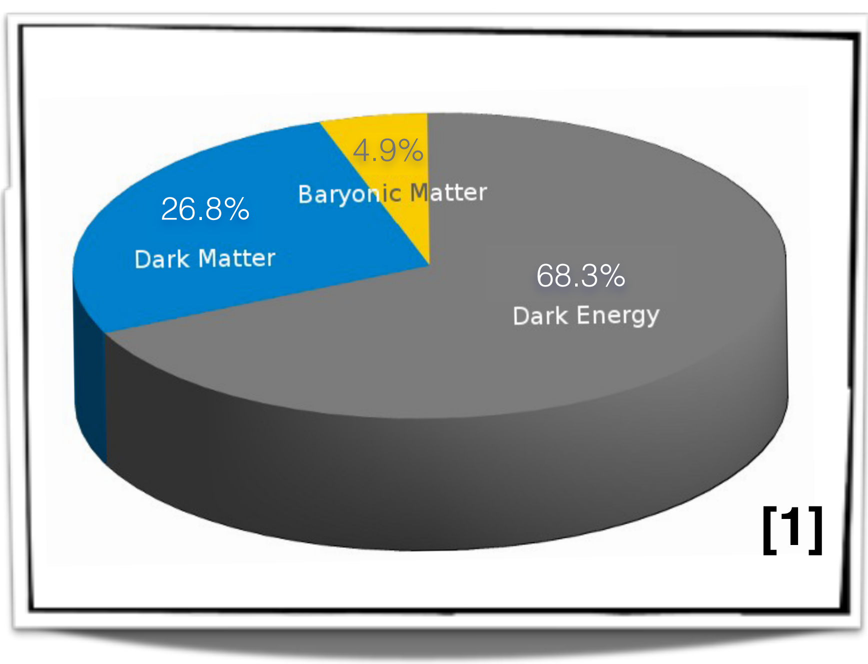
Galaxy Rotational Curves



Bullet Cluster Collision



CMB Anisotropies



[1] - [arXiv:1502.01589]

Many DM models...

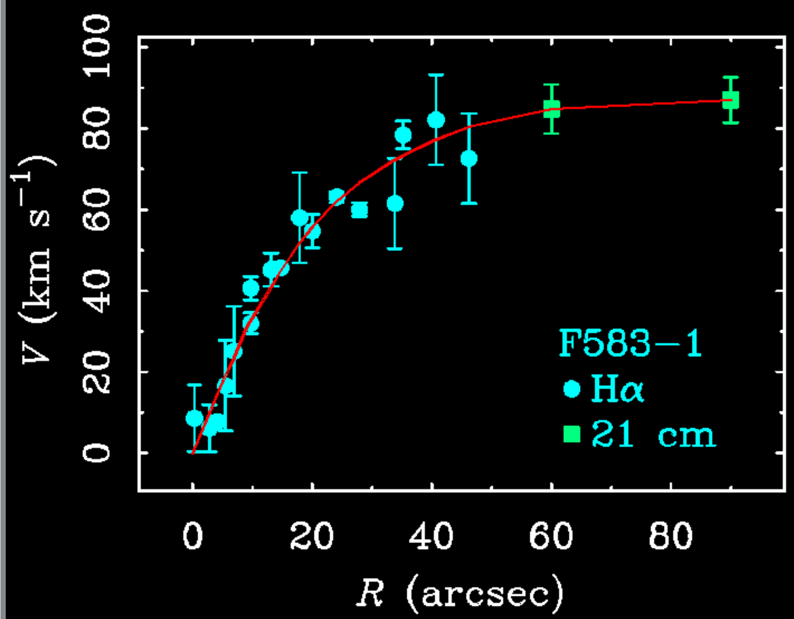
ADM Models:

- *Cold*
- *Dark*
- $\frac{\Omega_{DM}}{\Omega_{BM}} \sim 5$

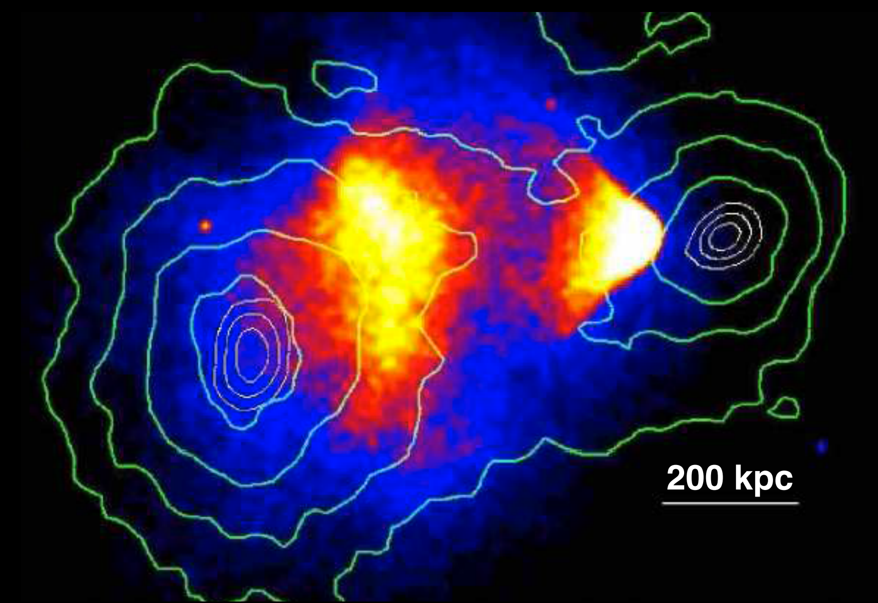
and many DM candidates...

Hard to detect!

Motivation for Dark Matter (DM) Search



Galaxy Rotational Curves



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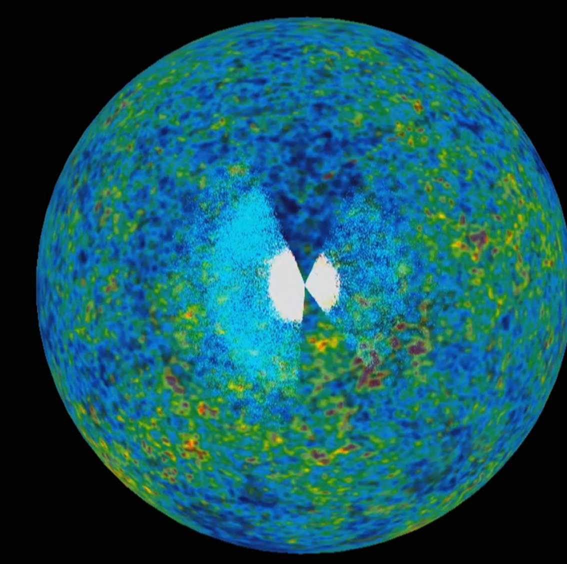
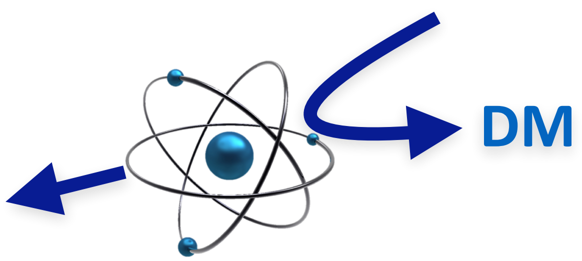
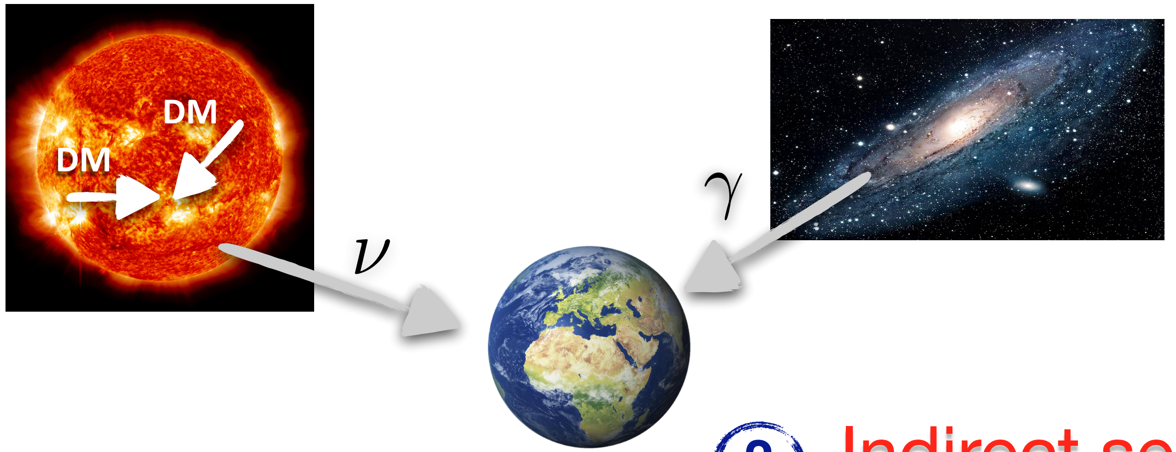


CMB Anisotropies

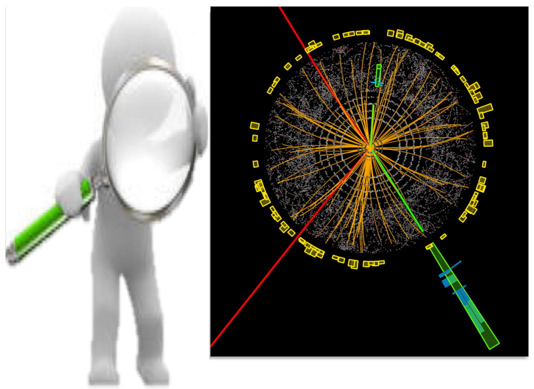
① Direct search





② Indirect search

DM Detection Techniques

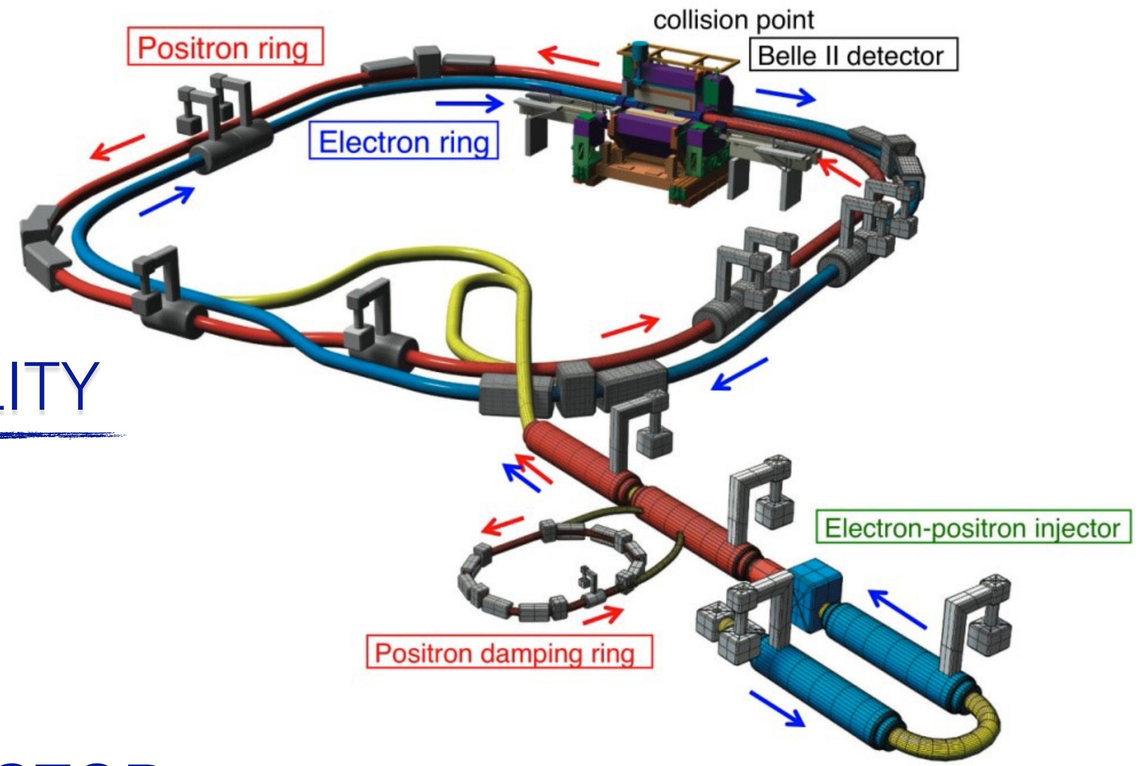


③ Colliders

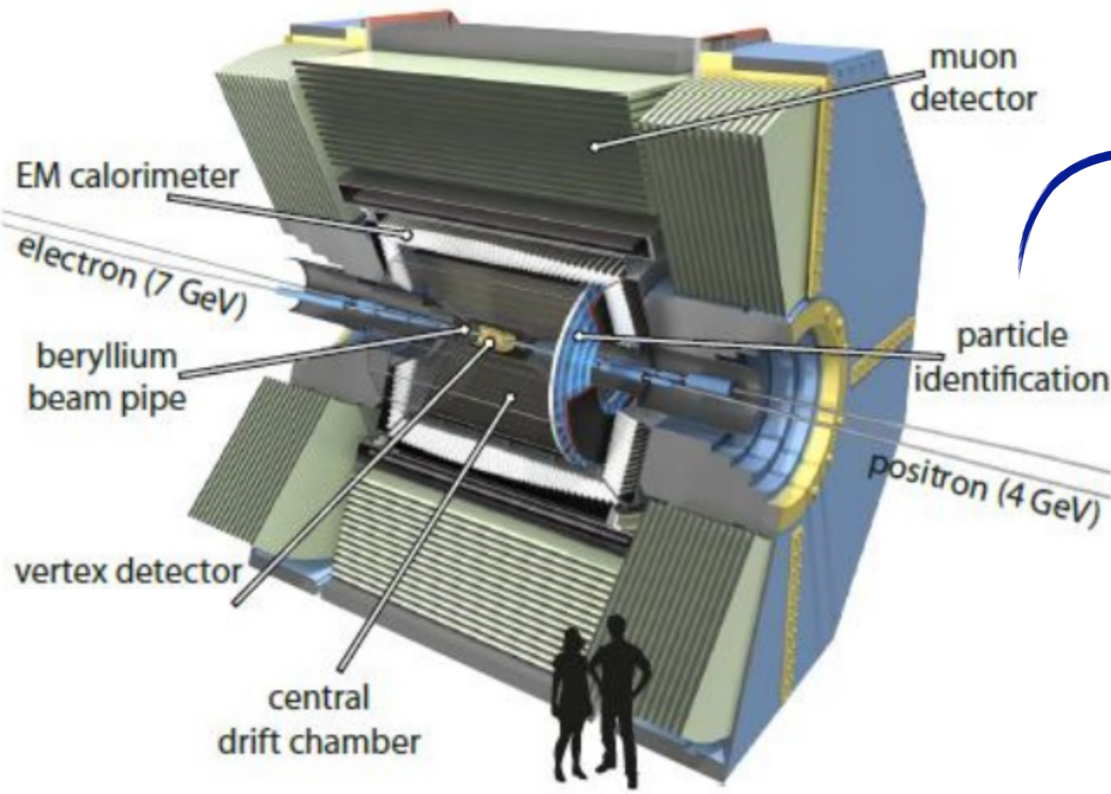
Flavour Factories!

DM Studies at the Belle II Experiment

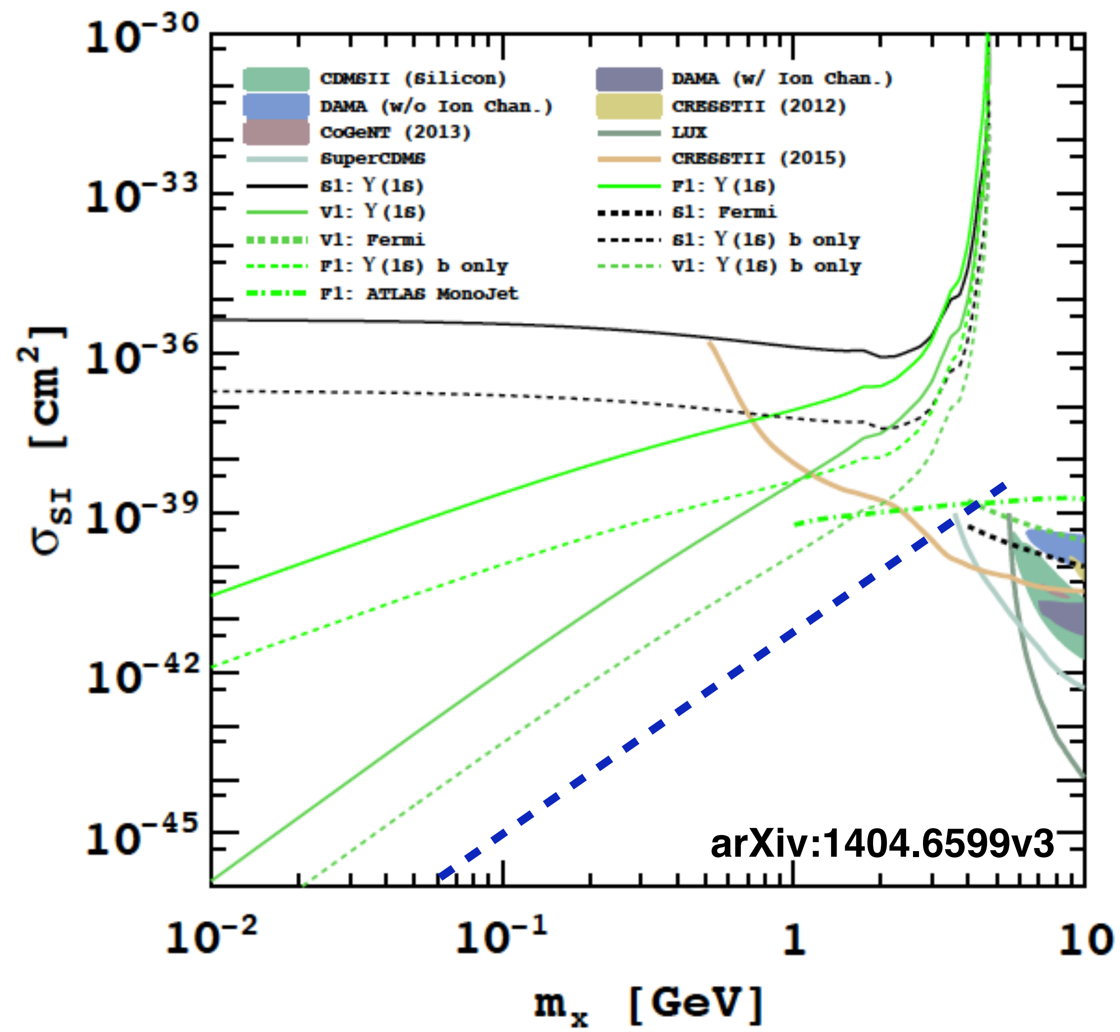
Facility



Detector



- *Asymmetric* energy accelerator
  $\rightarrow \beta\gamma \sim 0.28$
- e^+e^- colliding @ $\sqrt{s} = M_{\Upsilon(4S)} = 10.58$ GeV
- Record integrated luminosity, up to **50 ab^{-1}**



DM Studies at the Belle II Experiment

$$\frac{BR(\Upsilon(1S) \to \nu\bar{\nu})}{BR(\Upsilon(1S) \to e^+e^-)} = \frac{27G^2 M^4_{\Upsilon(1S)}}{64\pi^2\alpha^2}(-1 + \frac{4}{3}\sin^2\theta_W)^2 = 4.14 \times 10^{-4}$$

where $BR(\Upsilon(1S) \to \nu\bar{\nu}) \sim 9.9 \times 10^{-6}$

- *Low mass* DM particles might play a role in invisible decays of Υ(1S)
  [Phys. Rev. D **80,** 115019, 2009]
- In absence of any enhancement, the SM process $\Upsilon(1S) \to \nu\bar{\nu}$ could be observed

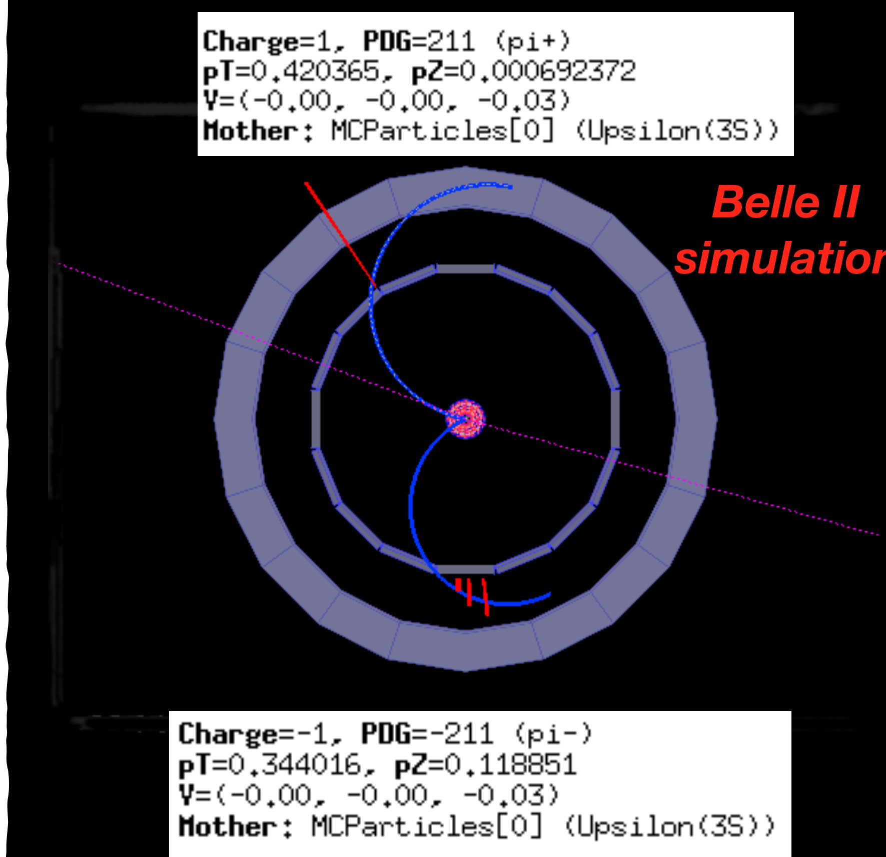
$\Upsilon(1S) \to invisible$:

Any signal would be seen as an excess of events in the recoil mass distribution (M_r) *of the di-pion system, equivalent to the mass of the* Υ*(1S)* [9.460 GeV/c^2]

$$M_r^2 = s + M^2_{\pi^+\pi^-} - 2E^{cms}_{\pi^+\pi^-}\sqrt{s}$$

$$e^+e^- \to \Upsilon(4S)$$
$$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S)$$
$$\Upsilon(1S) \to invisible$$

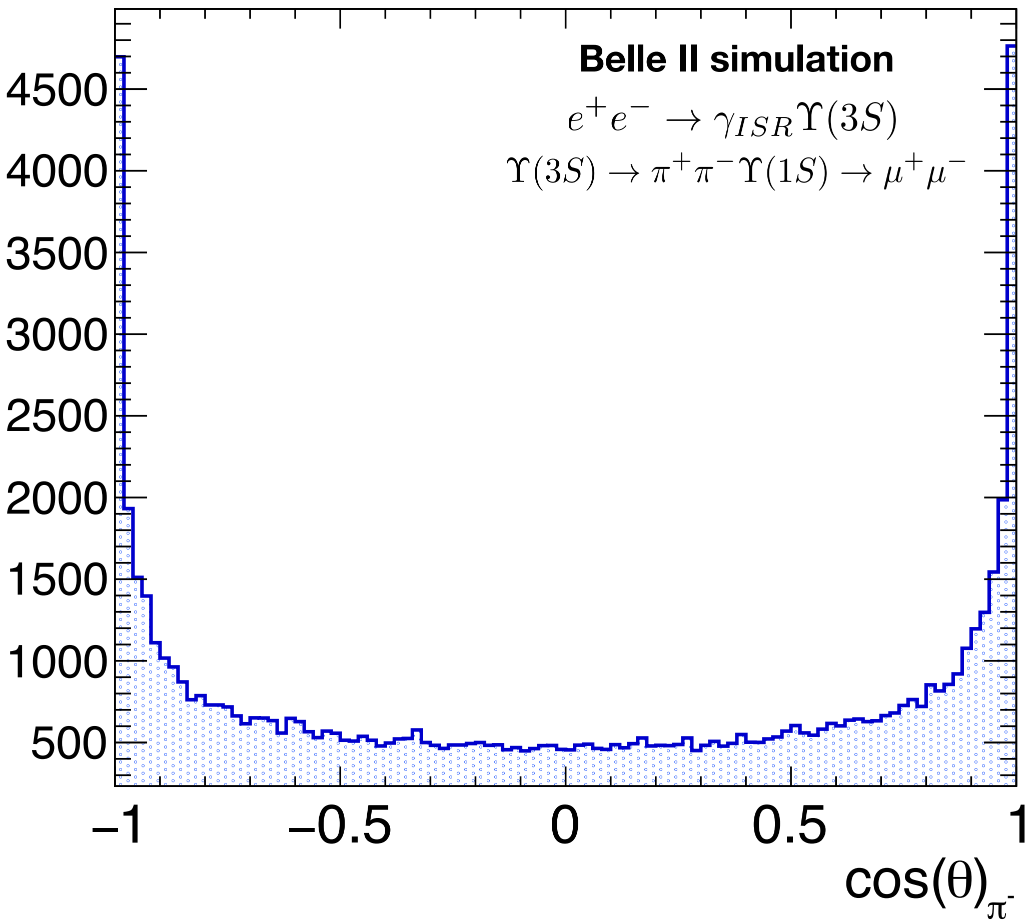
$$e^+e^- \to \gamma_{ISR}\Upsilon(3S)$$
$$\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$$
$$\Upsilon(1S) \to invisible$$

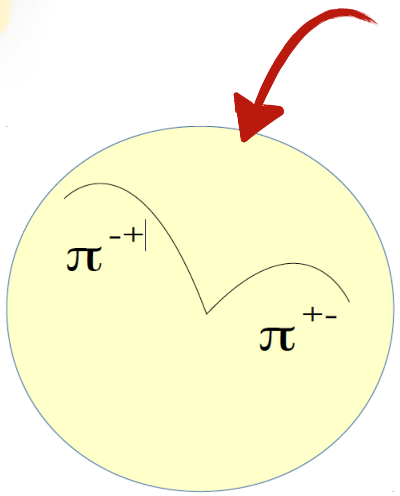


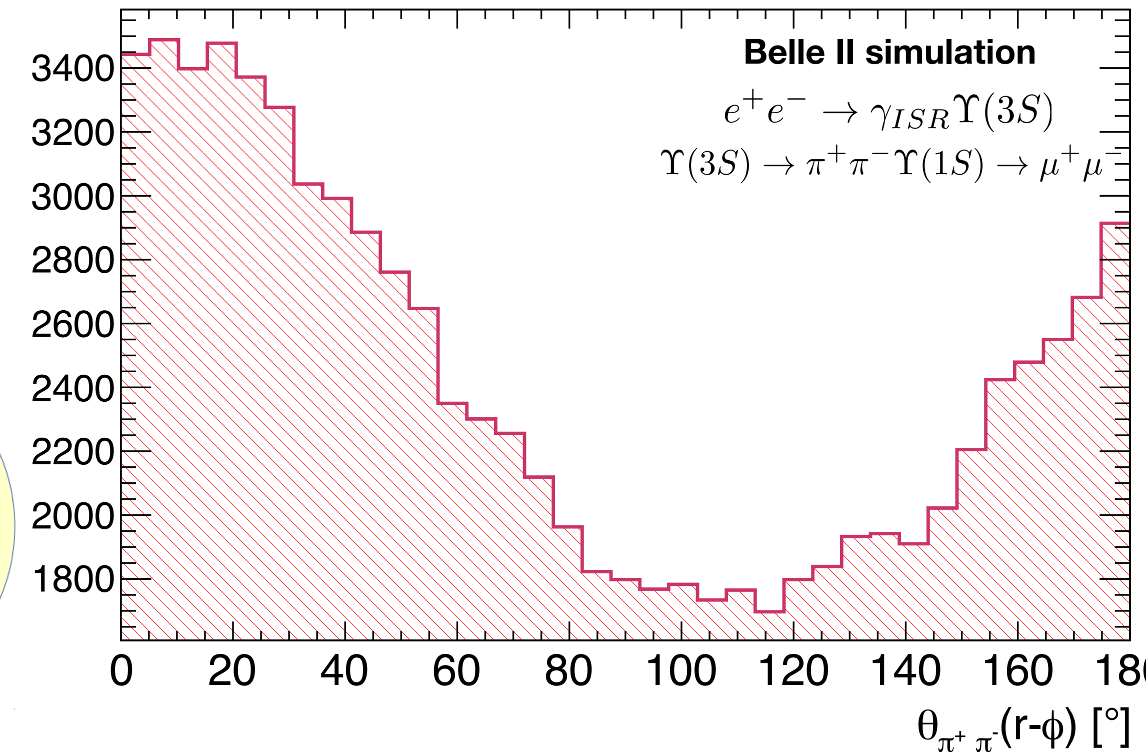
$\Upsilon(4S)$, $\Upsilon(3S)$ Decays at Belle II

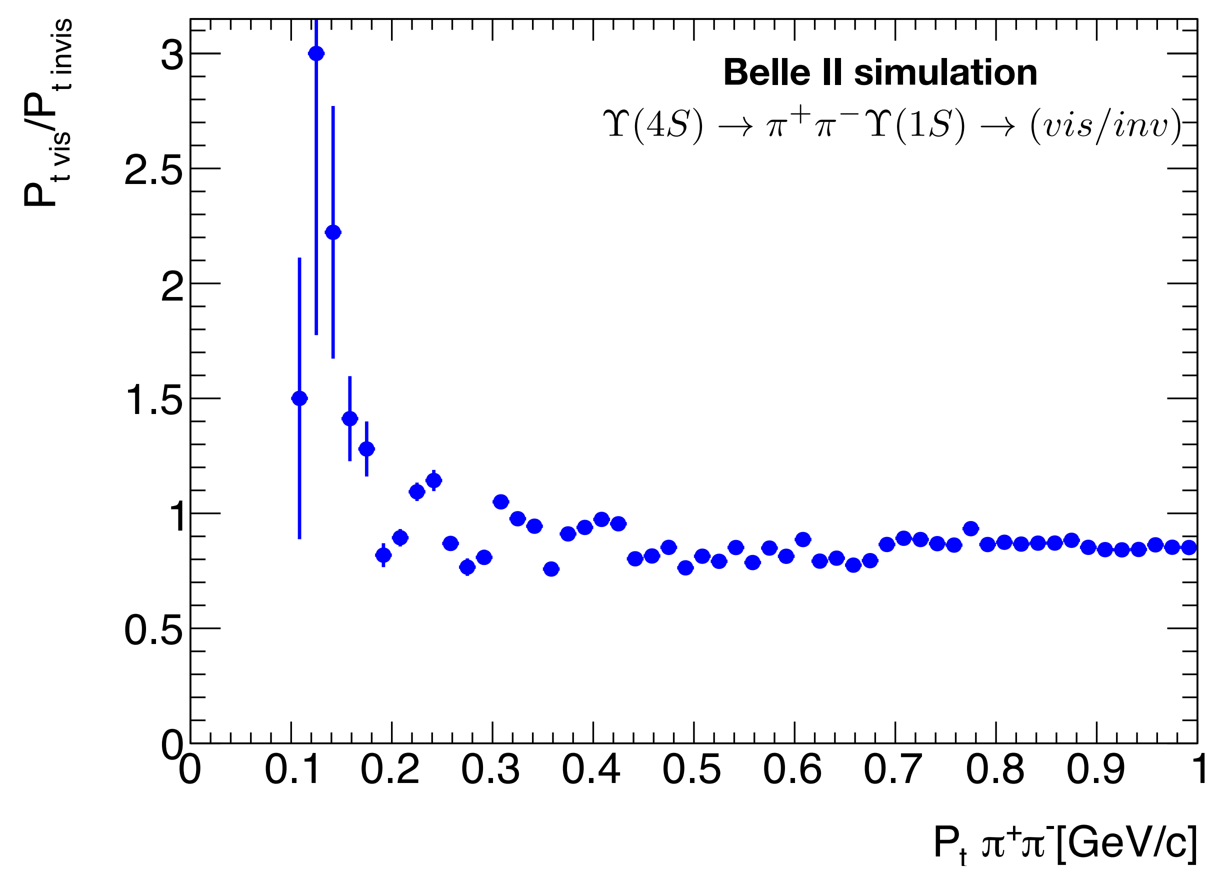
Visible channels → **Control Sample**

100k simulated



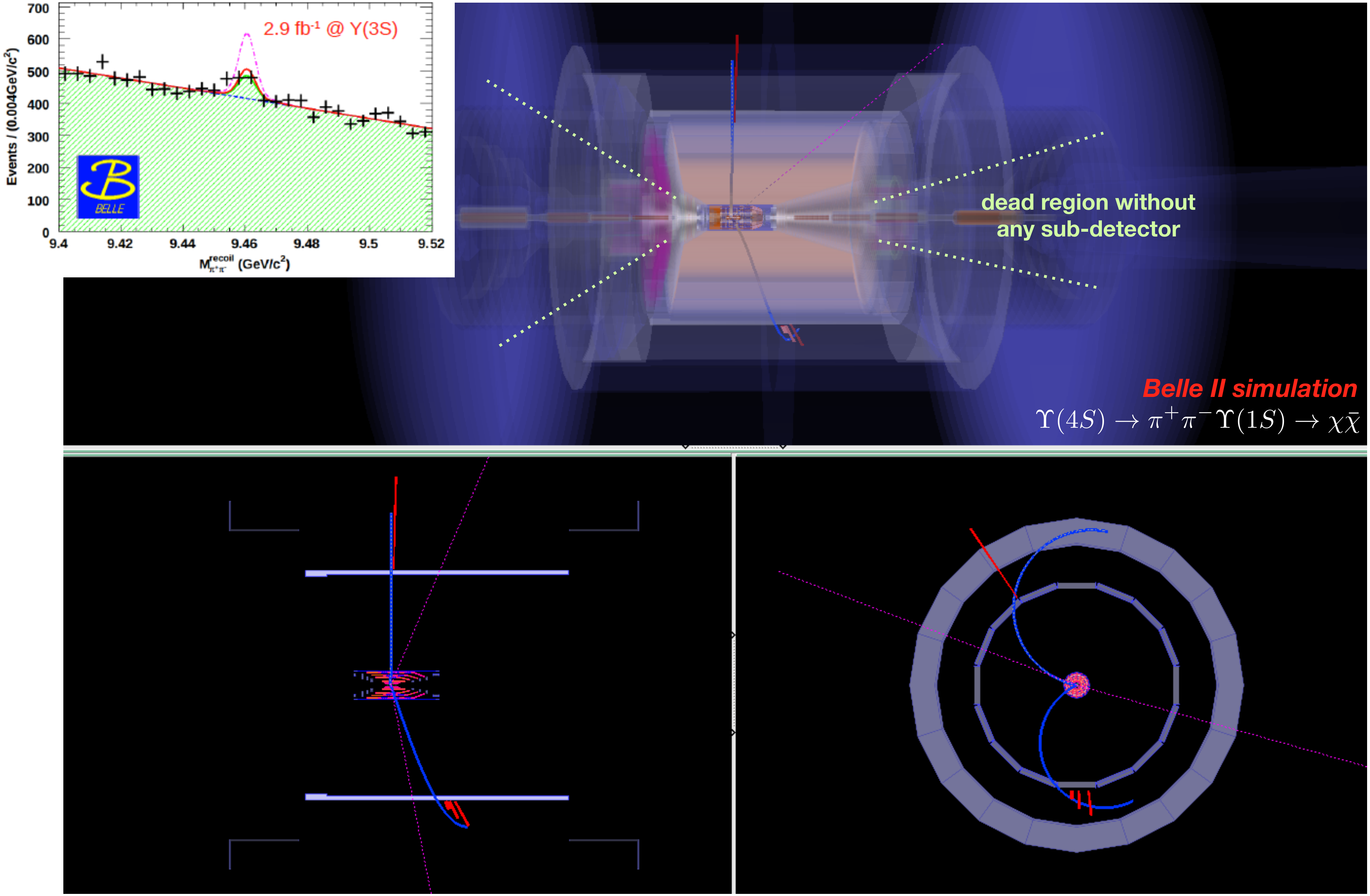




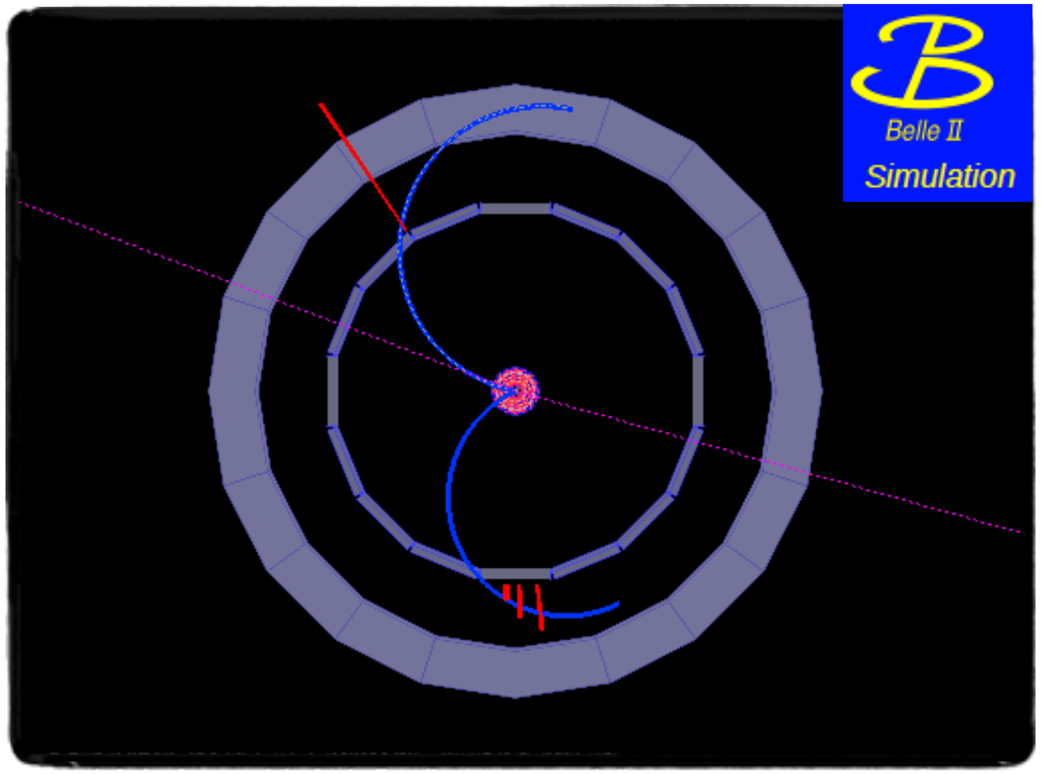


- More events in the *forward* and *backward* direction

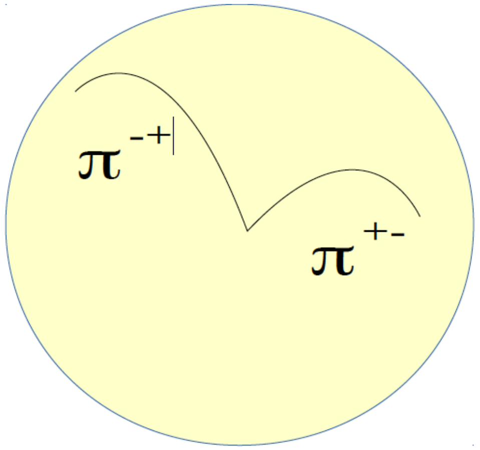
SIGNAL&BACKGROUND CONSIDERATIONS



Trigger Efficiency Considerations



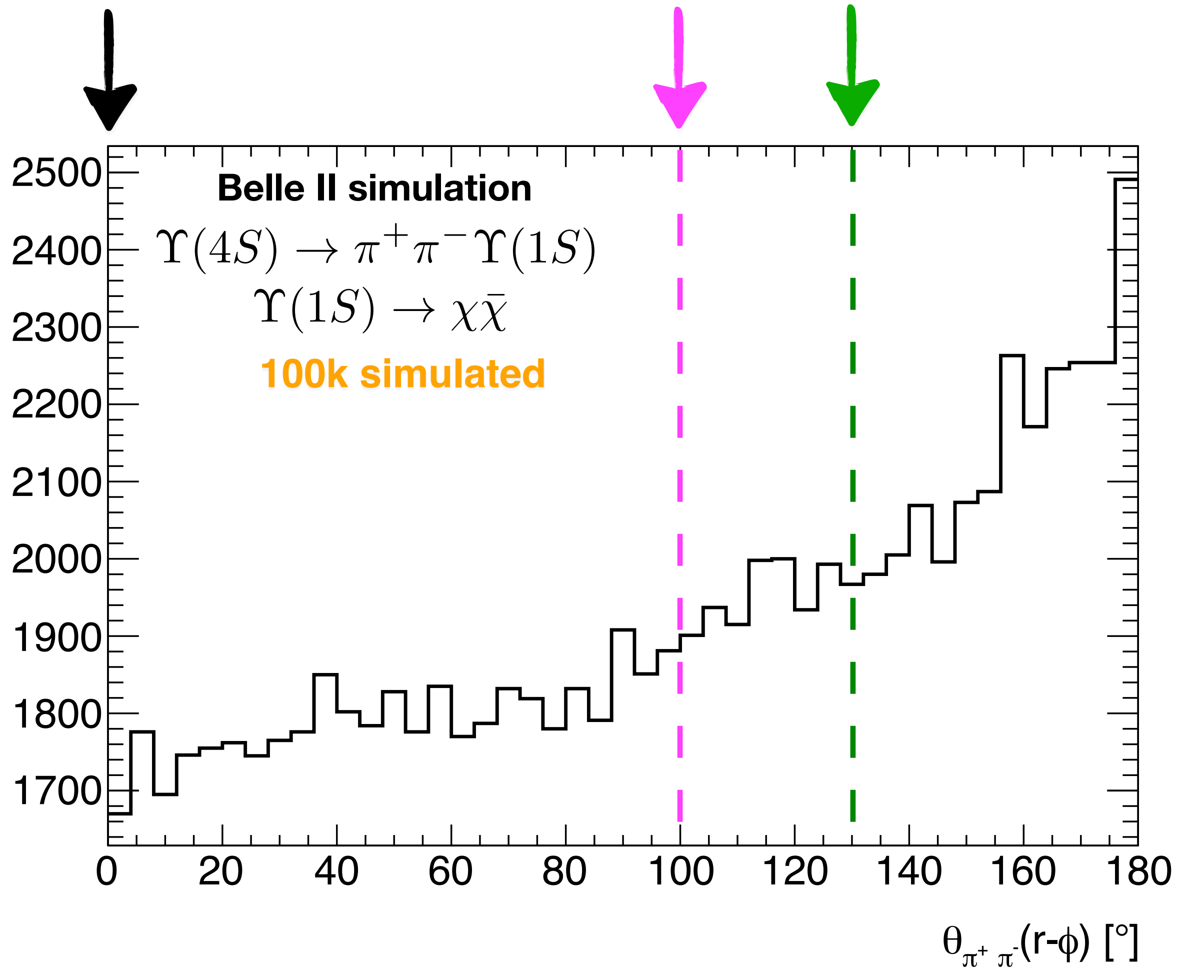
$$\varepsilon = \frac{\#\text{reconstructed events}}{\#\text{simulated events}}$$



Need for a Dedicated Trigger ?

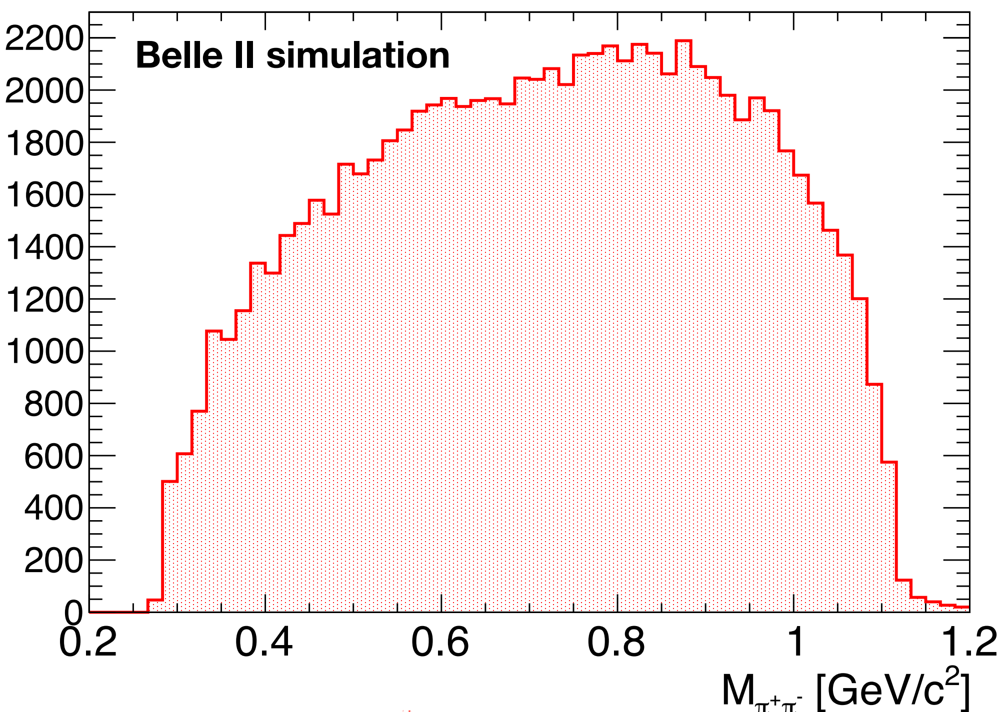
… since we are looking for two low momentum pions

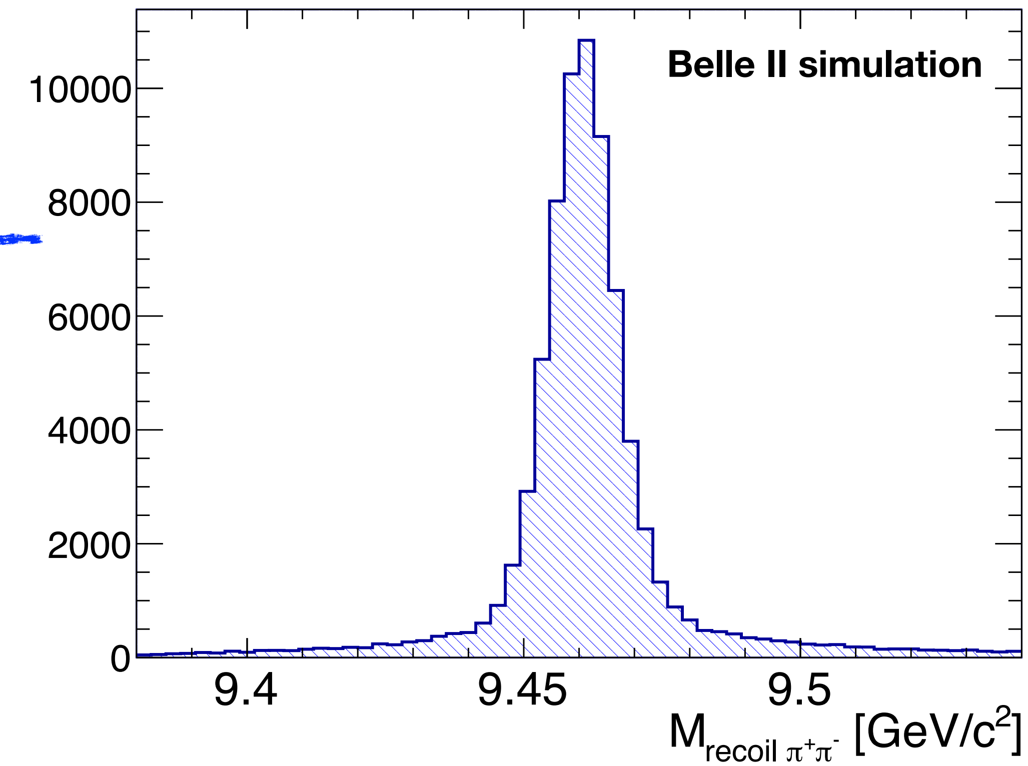
constraints on π-π opening angle



$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to \chi\bar{\chi}$ DECAYS AT BELLE II

100k simulated



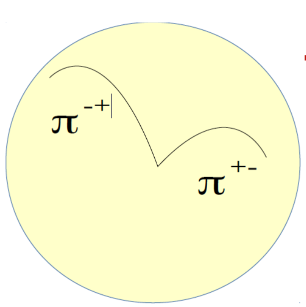


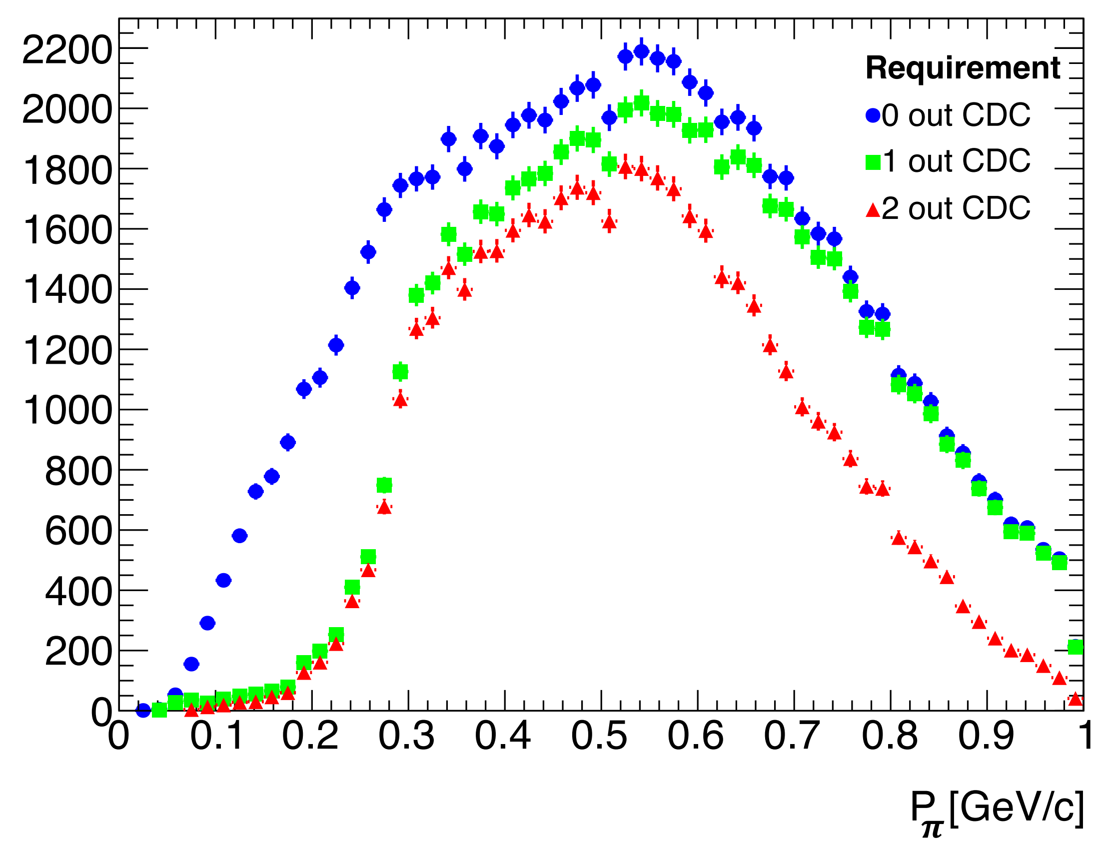
π-π system

$\Upsilon(1S)$ is correctly reconstructed

- $M_{\Upsilon(4S)} = 10.580\, GeV/c^2$
- $M_{\Upsilon(1S)} = 9.460\, GeV/c^2$

~ 1.12 GeV available for pions

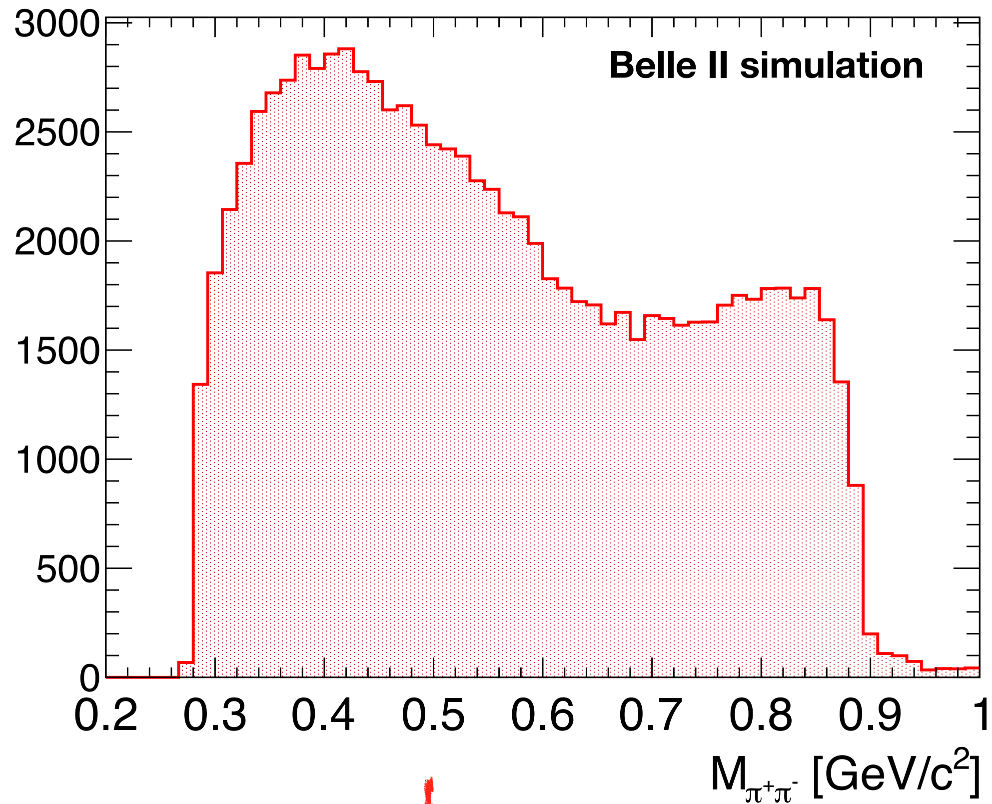




Det. acceptance	**~78%**
Trigger requirement: 2out CDC +PID +cuts	
π-π opening angle	*#ev*
(0°-180°)	**~49%**
(100°-180°)	**~25%**
(130°-180°)	**~18%**

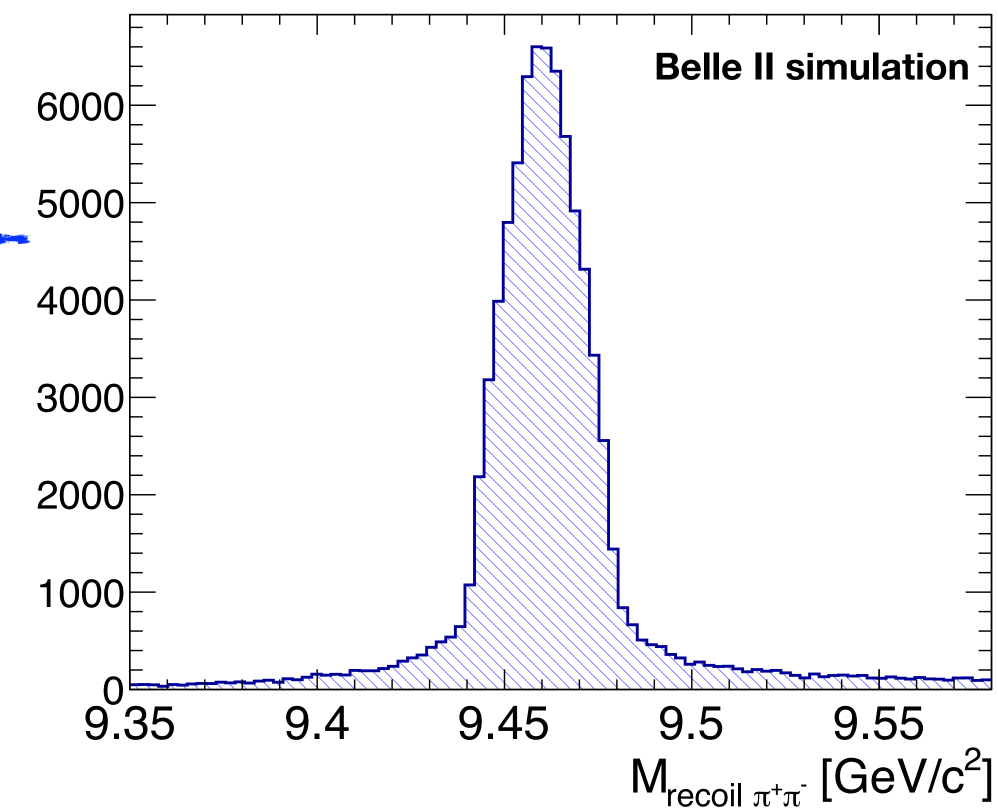
$e^+e^- \to \gamma_{ISR}\Upsilon(3S)$, $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to \chi\bar{\chi}$ Decays at Belle II

100k simulated



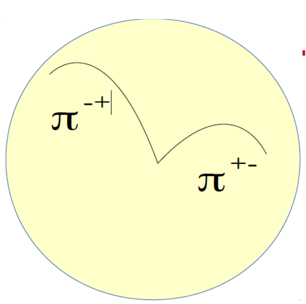
π-π system

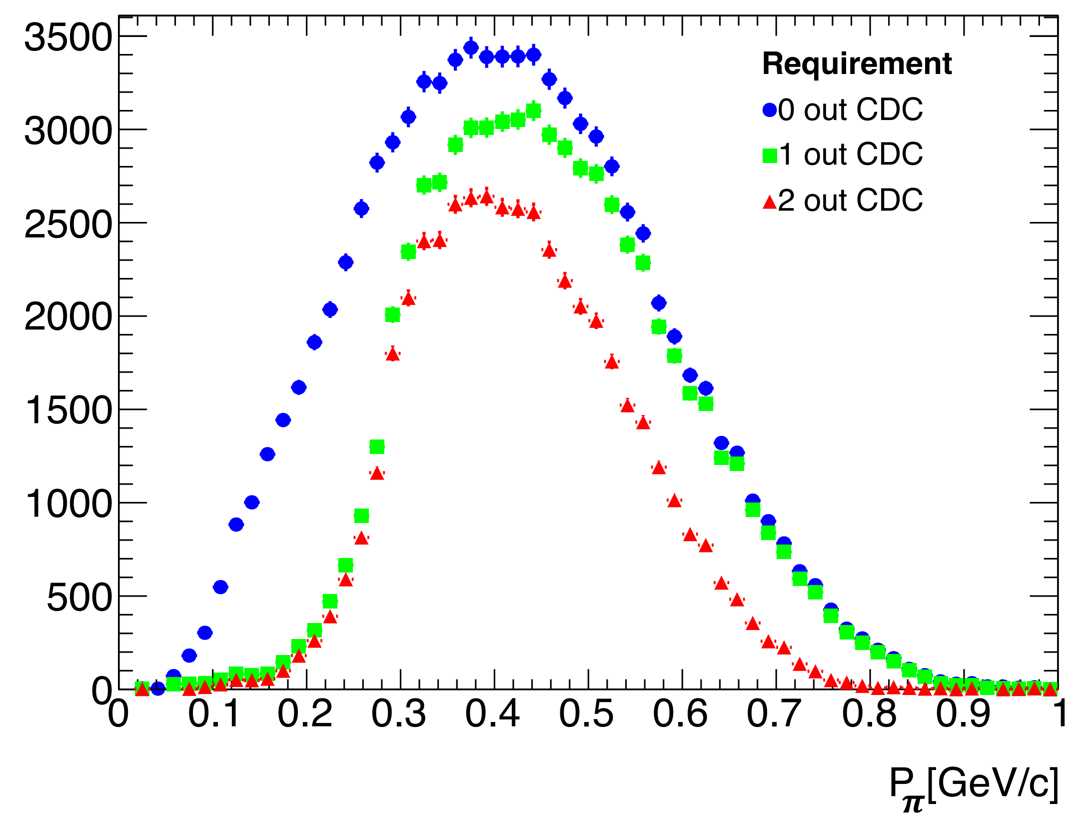
$\Upsilon(1S)$ is correctly reconstructed



- $M_{\Upsilon(3S)} = 10.355\, GeV/c^2$
- $M_{\Upsilon(1S)} = 9.460\, GeV/c^2$

~ ***900 MeV available for pions***





Det. acceptance	**~87%**
Trigger requirement: 2out CDC **+PID +cuts**	
π-π opening angle	*#ev*
(0°-180°)	**~47%**
(100°-180°)	**~19%**
(130°-180°)	**~14%**

Conclusions

- In 2017 Belle II will start collecting data at various center of mass energies, aiming to collect an integrated luminosity of **50 ab^{-1}**

- Direct detection of low-mass DM is very difficult. This motivates feasibility studies @BelleII of decays where DM might show up:

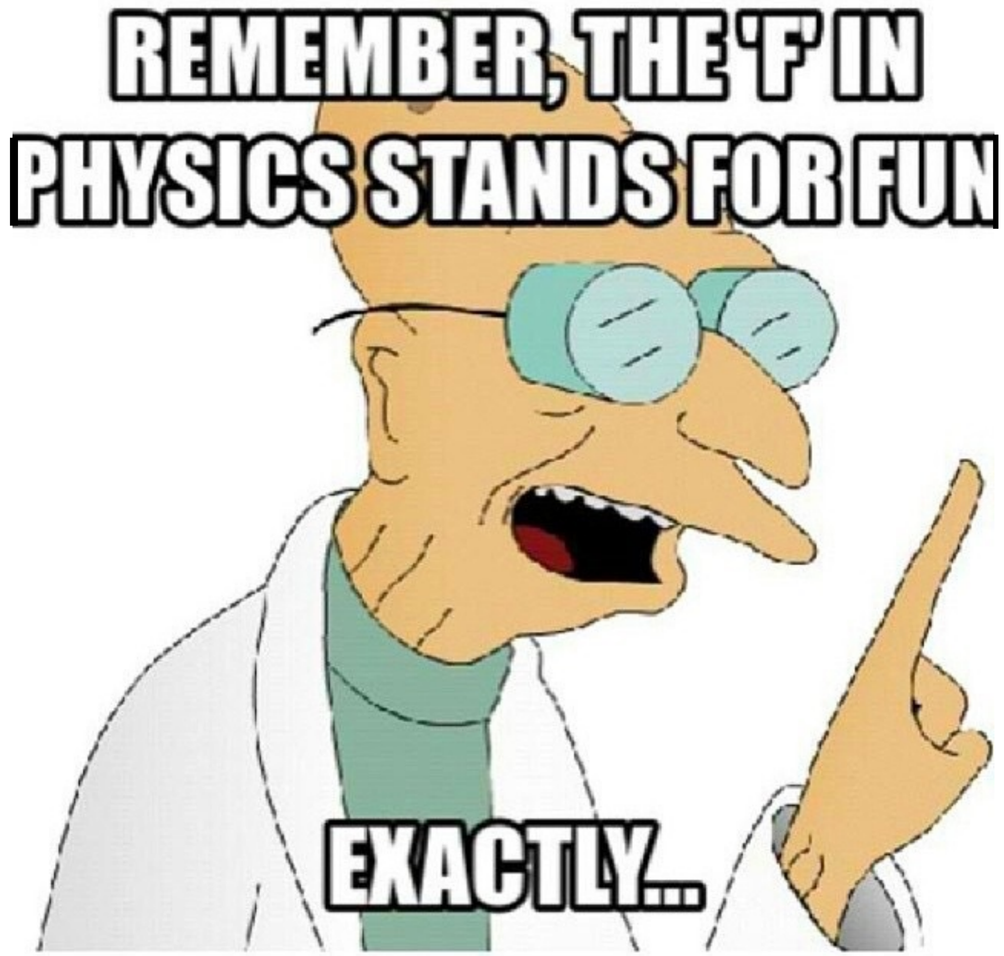
$$\longrightarrow \quad \Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S) \to \chi\bar{\chi}$$

$$\longrightarrow \quad e^+e^- \to \gamma_{ISR}\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S) \to \chi\bar{\chi}$$

- We studied acceptance, reconstruction and trigger efficiencies for the two channels + control samples. The total efficiency for each channel is >~14%

- According to obtained results, Belle II will be *able* to search for DM in invisible Υ(1S) decays, using di-pion transitions and ISR techniques.

→ ***„ Observing a signal would be a clear sign of new physics ! ”***

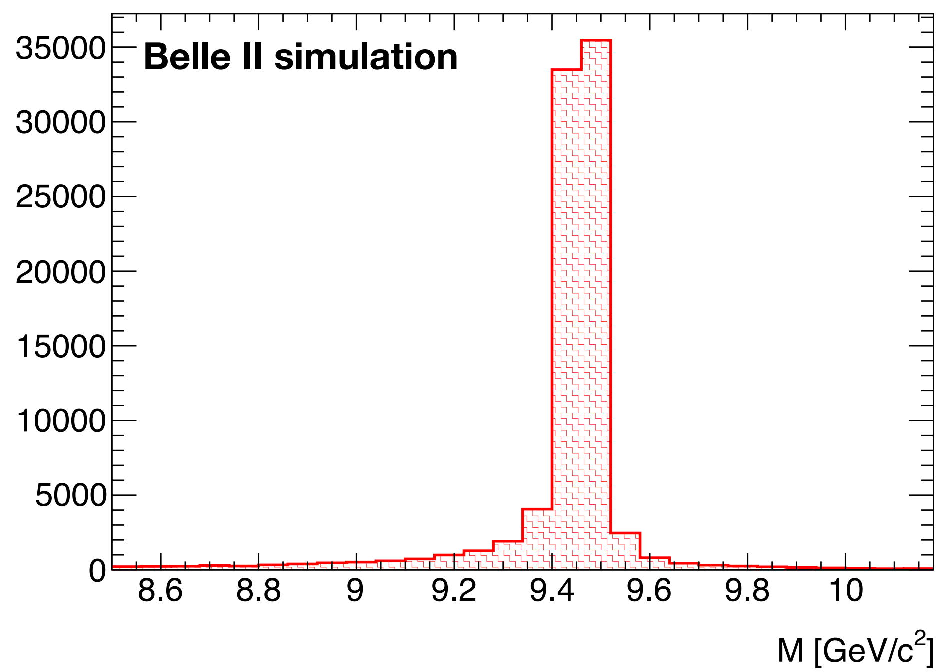


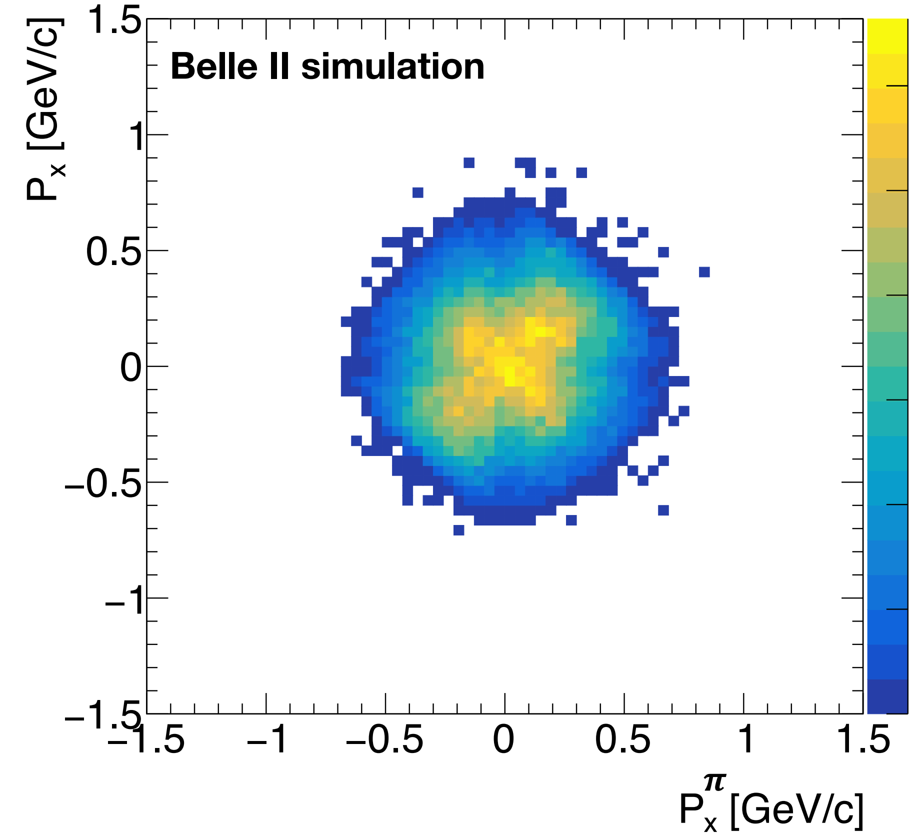
THANK YOU FOR YOUR ATTENTION !

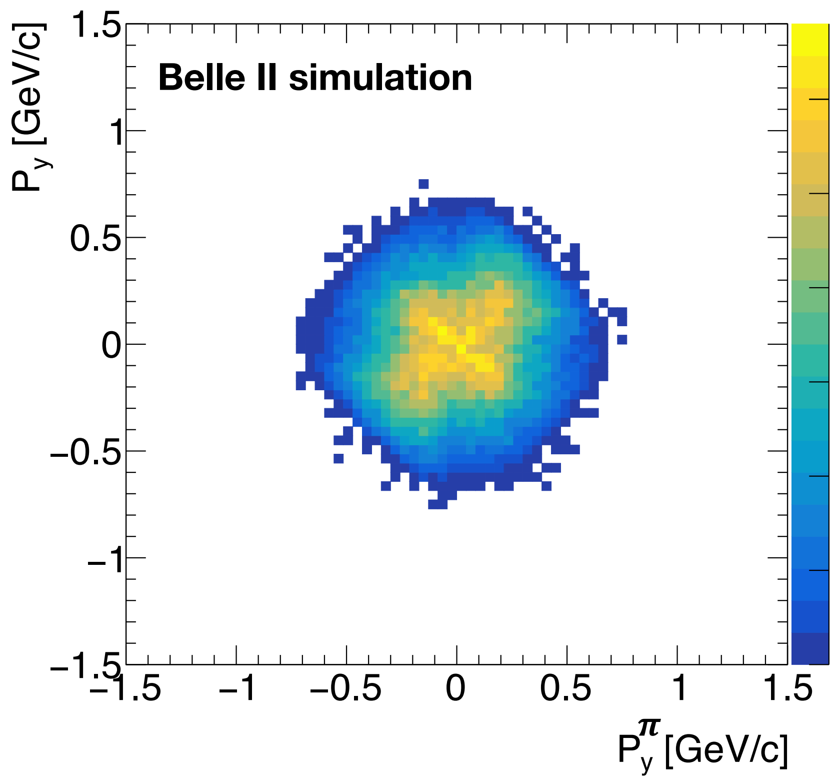
BACKUP

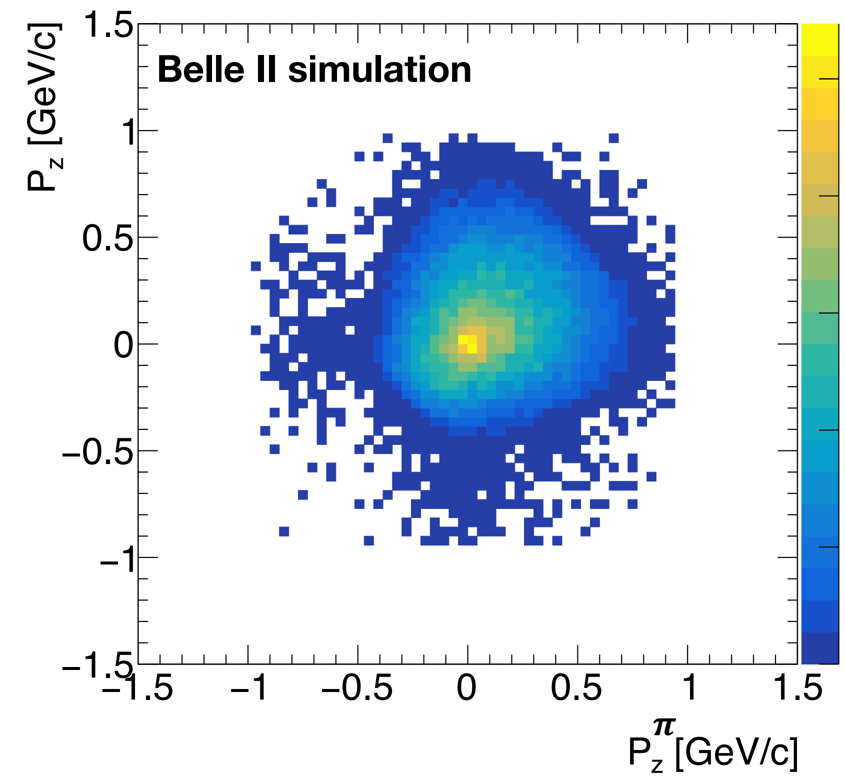
$e^+e^- \to \gamma_{ISR}\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S) \to \mu^+\mu^-$ Decays at Belle II

100k simulated



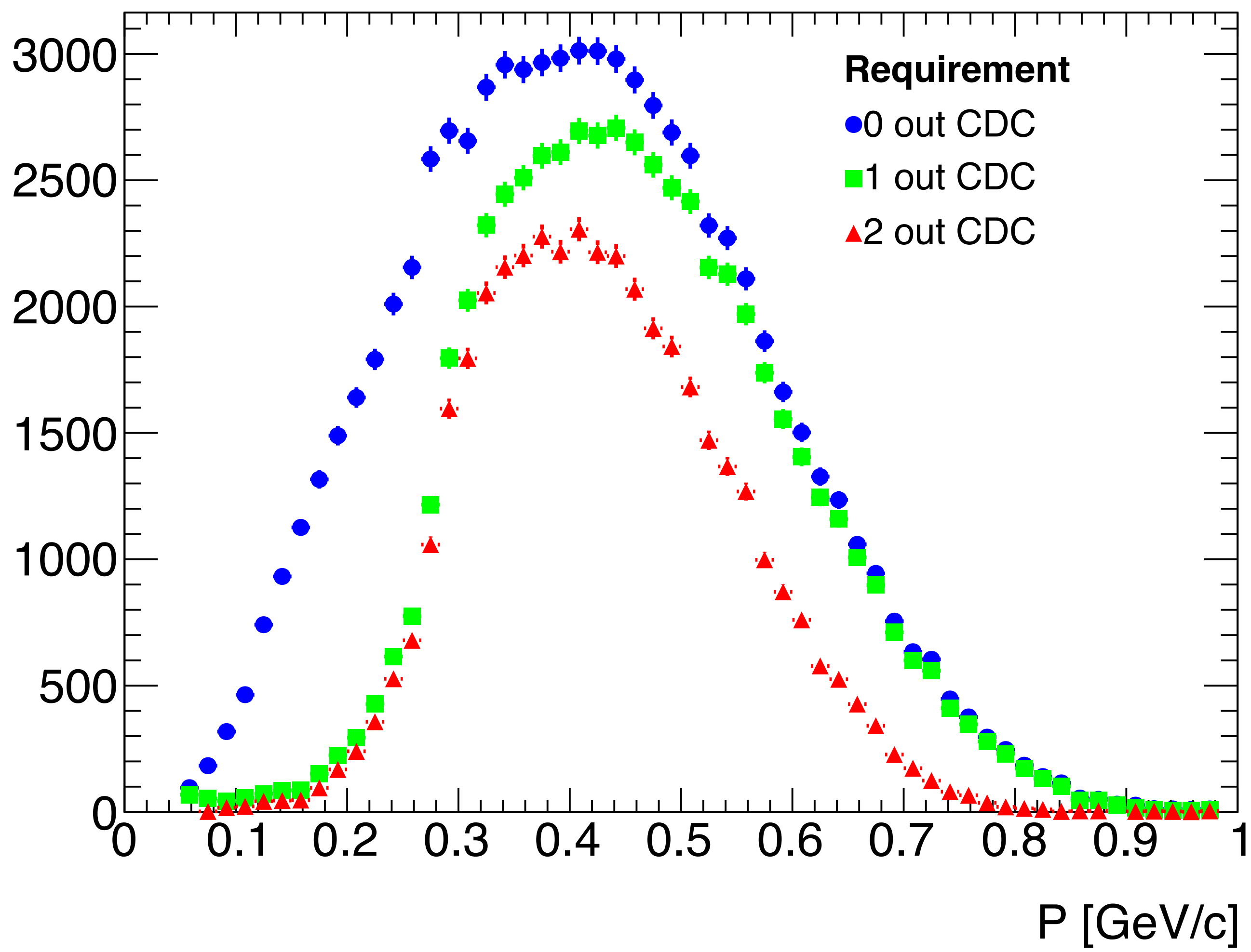






$e^+e^- \rightarrow \gamma_{ISR}\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S) \rightarrow \mu^+\mu^-$ DECAYS AT BELLE II

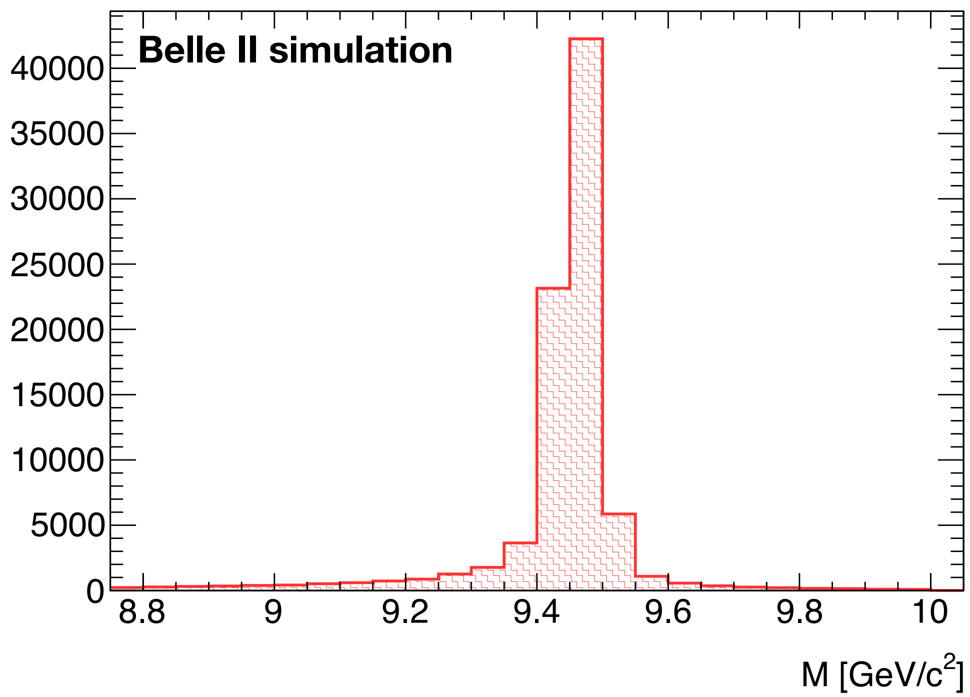
100k simulated

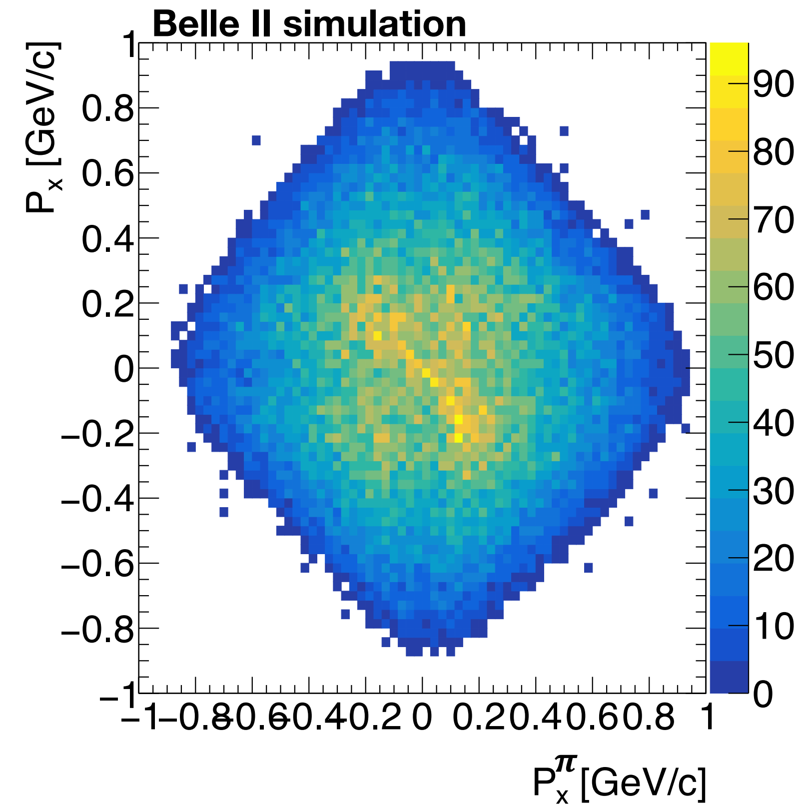


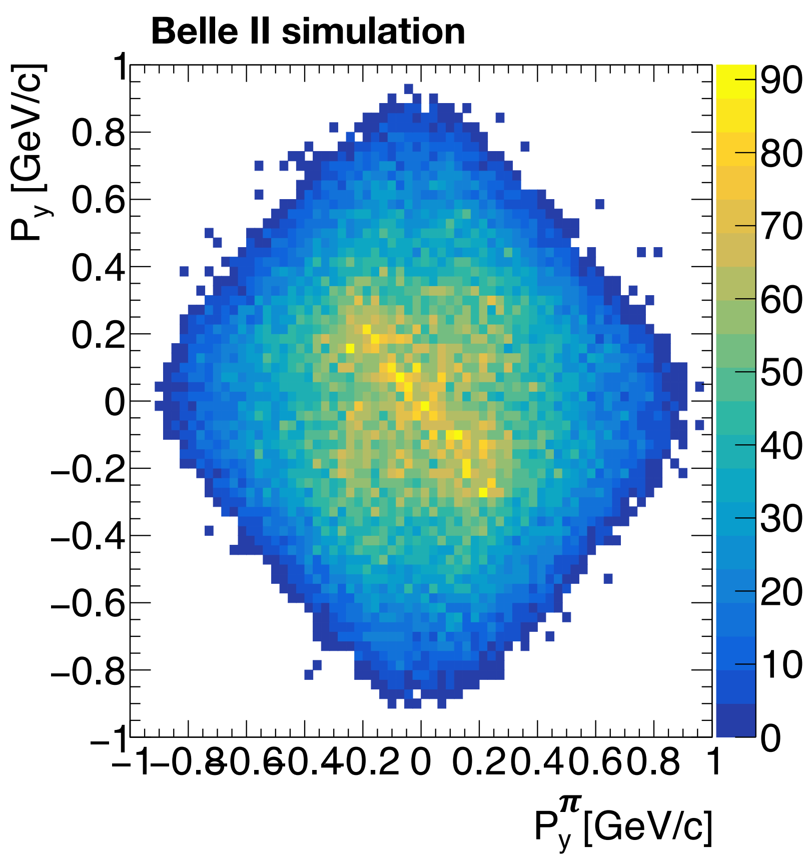
Det. acceptance	**~78%**
Trigger requirement: 2out CDC +PID +cuts	
π-π opening angle	*#ev*
(0°-180°)	**~42%**
(100°-180°)	**~16%**
(130°-180°)	**~12%**

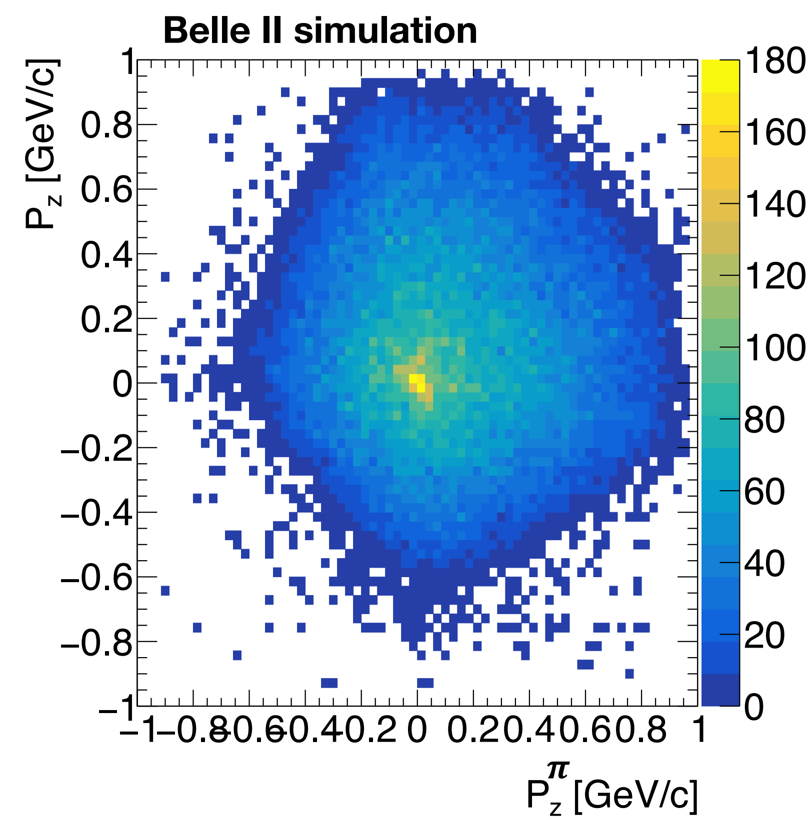
$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S) \to \mu^+\mu^-$ DECAYS AT BELLE II

100k simulated



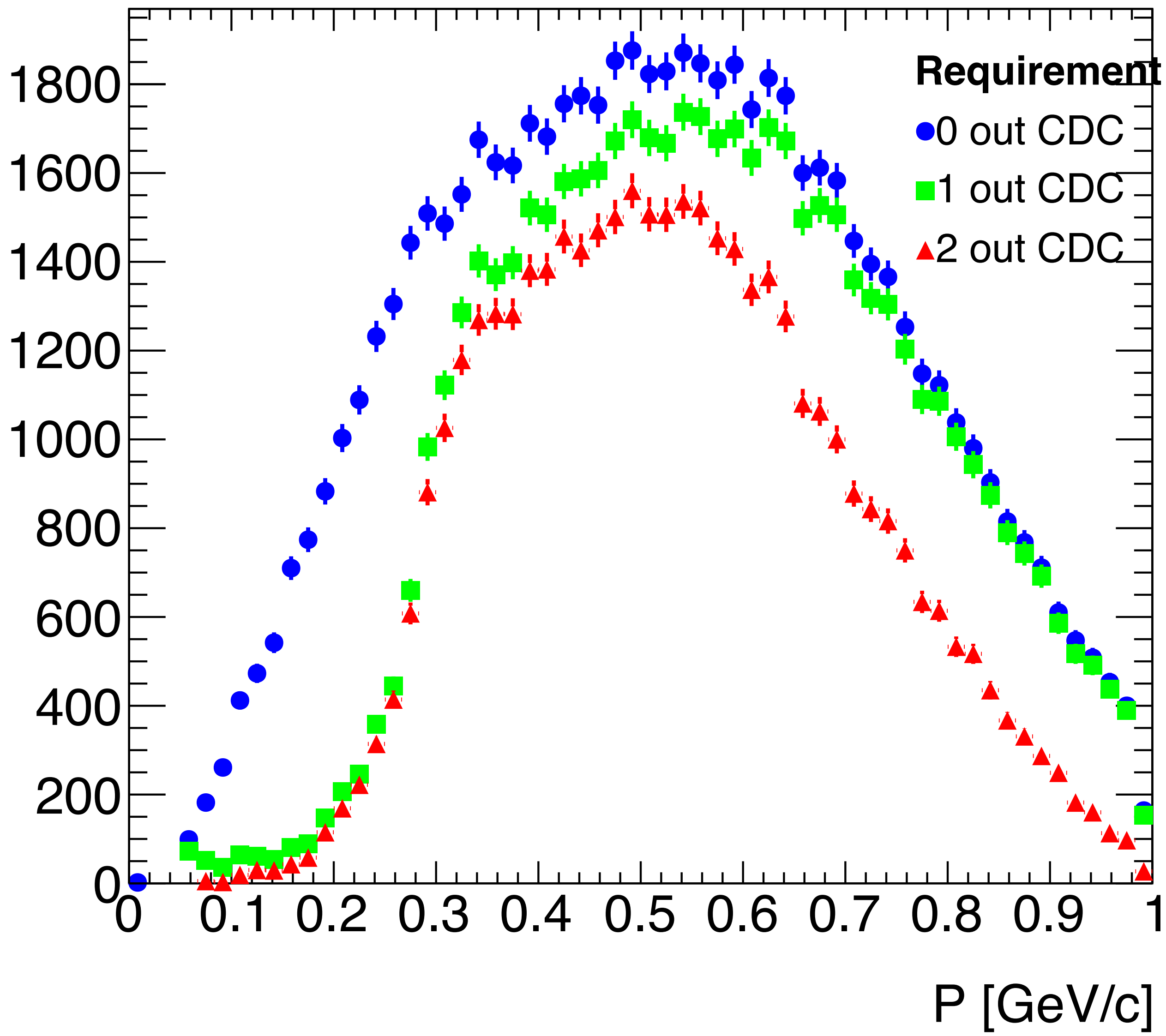






$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S) \to \mu^+\mu^-$ Decays at Belle II

100k simulated



Det. acceptance	~69%
Trigger requirement: 2out CDC +PID +cuts	
π-π opening angle	*#ev*
(0°-180°)	**~43%**
(100°-180°)	**~22%**
(130°-180°)	**~16%**

INVISIBLE DECAYS AT BELLE II

100k simulated