Impact of the PXD on the Vertex Reconstruction of π^0 particles

Fernando Abudinén

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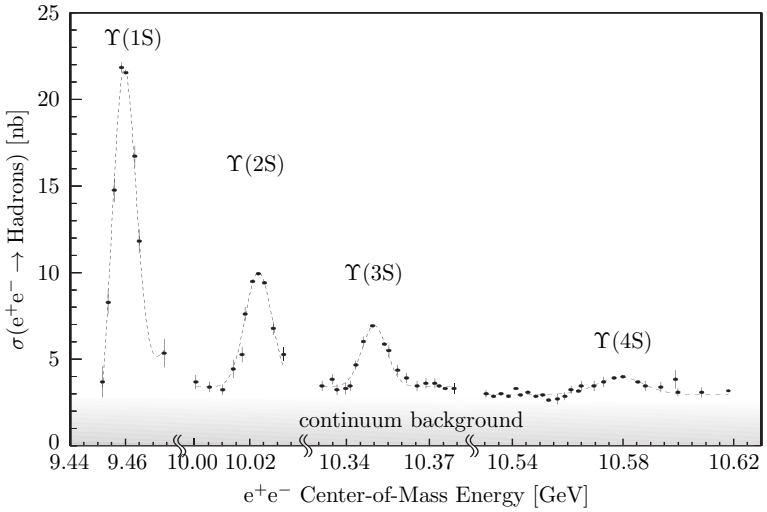
Max-Planck-Institut für Physik

Time-dep. CP-Analysis at B-Factories



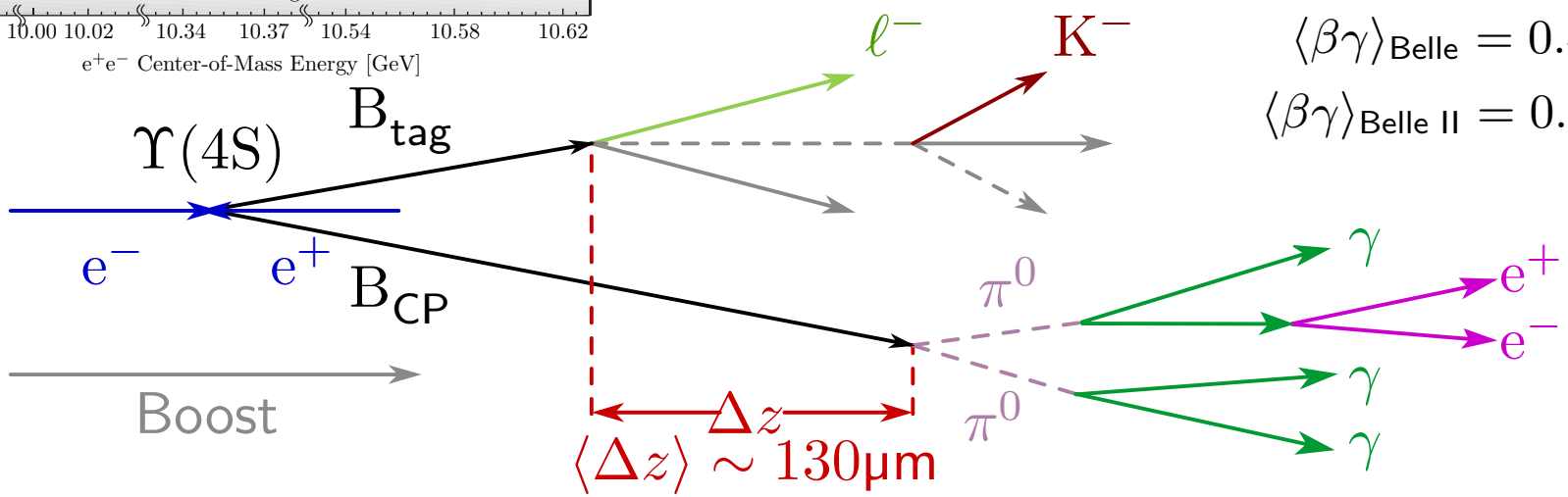
- $\Upsilon(4S)$ above $B\overline{B}$ prod. threshold

$\Rightarrow$ B-Factory

- $\sim 51\ \%$ are B^+B^-
- $\sim 48\ \%$ are $B^0\overline{B}^0$ $\quad q_{B^0,\overline{B}^0} = 1, -1$

$\langle\beta\gamma\rangle_{\text{Belle}} = 0.425$

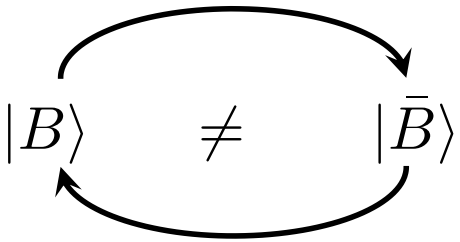
$\langle\beta\gamma\rangle_{\text{Belle II}} = 0.284$

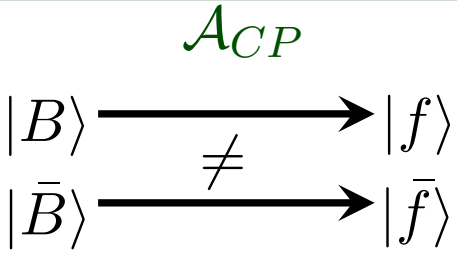


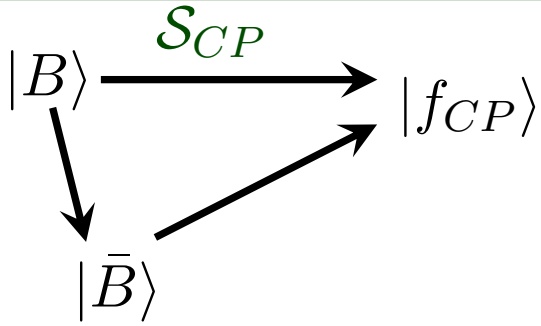
- $B^0\overline{B}^0$ at rest in CMS $\Delta t = \frac{\Delta z}{\langle\beta\gamma\rangle c} \Rightarrow$

$$\mathcal{P}^{\text{Sig}}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP}\cos(\Delta m \Delta t) + \mathcal{S}_{CP}\sin(\Delta m \Delta t)\right)\right]$$

Time-dependent CP-Analysis





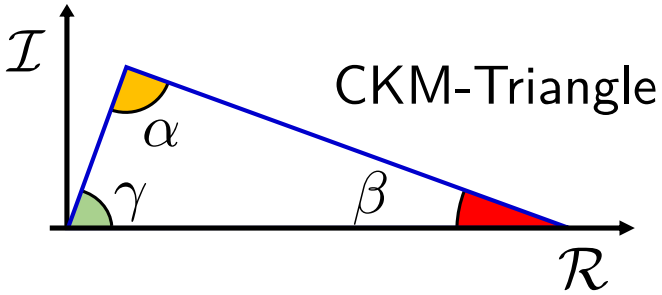


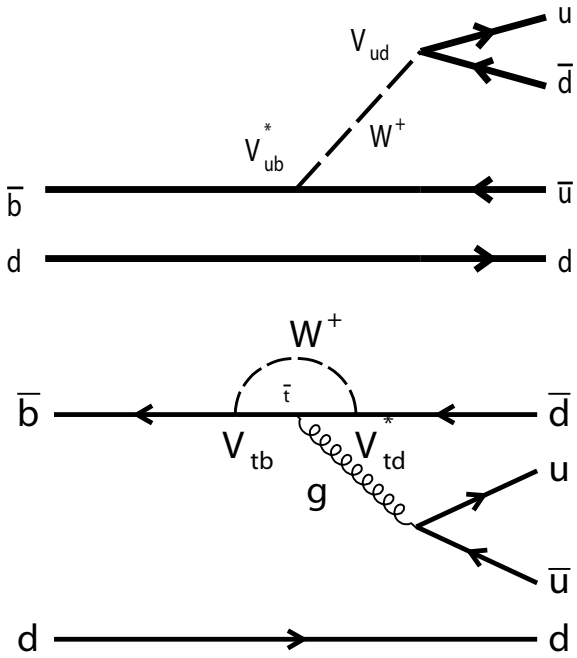
For $\mathrm{B} \to \pi\pi$: tree and penguin diags. contribute!

🌳: $\mathcal{A}_{CP} = 0$
$\mathcal{S}_{CP} = \sin(2\alpha)$

🌳 + 🐧: $\mathcal{A}_{CP} \neq 0$
$\mathcal{S}_{CP} = \sqrt{1 - \mathcal{A}_{CP}} \sin(2\alpha^{\text{eff}})$

$\Rightarrow \alpha^{\text{eff}} = \alpha - \Delta\alpha$





Extraction of α angle from $\mathrm{B} \to \pi\pi$

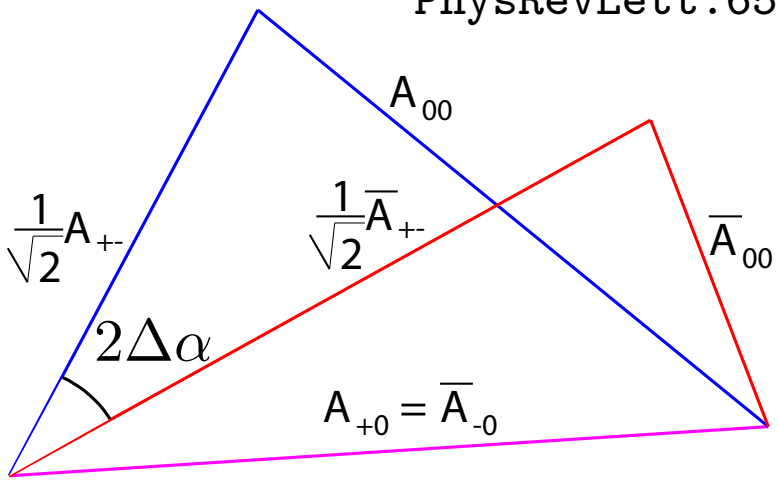
PhysRevLett.65.3381

- Extr. $\Delta\alpha$ through isospin analysis:

$$A^{+-} = A(\mathrm{B} \to \pi^+\pi^-)$$

- $\frac{1}{\sqrt{2}}A^{+-} + A^{00} = A^{+0}$
- $\frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$

Pure Tree: $A^{+0} = \bar{A}^{-0}$

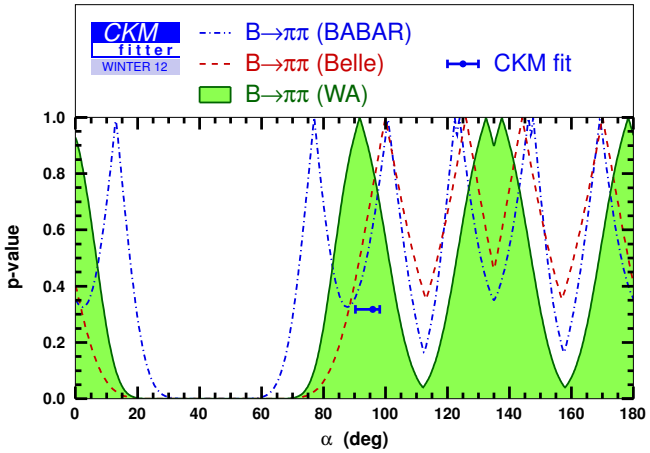


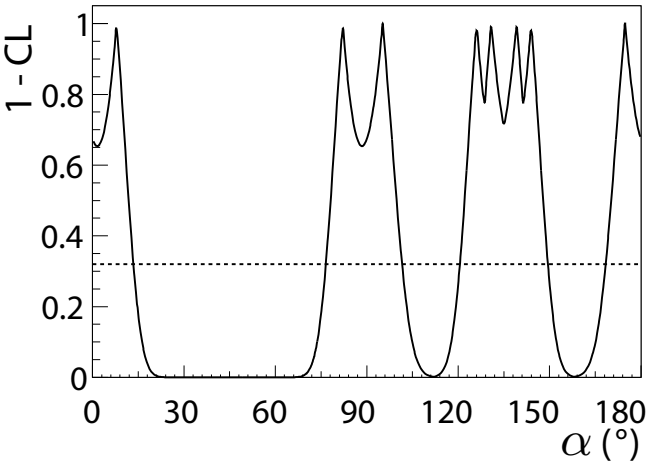
- Isospin analysis requires also $\mathcal{S}_{\pi^+\pi^-}$ and $\mathcal{S}_{\pi^0\pi^0}$.
- $\mathcal{S}_{\pi^0\pi^0}$ needs $\langle\Delta z\rangle \sim 130\mu\mathrm{m}$ of $\mathrm{B} \to \pi^0\pi^0$ where $\pi^0 \to \gamma\gamma$

$\Rightarrow$ Challenge!

Extraction of α angle from $\mathrm{B} \to \pi\pi$

- w/out $\mathcal{S}_{\pi^0\pi^0} \Rightarrow$ 8 fold ambiguity on α

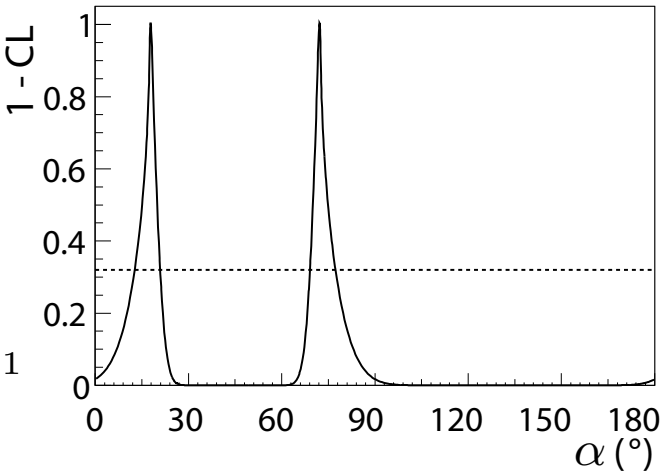




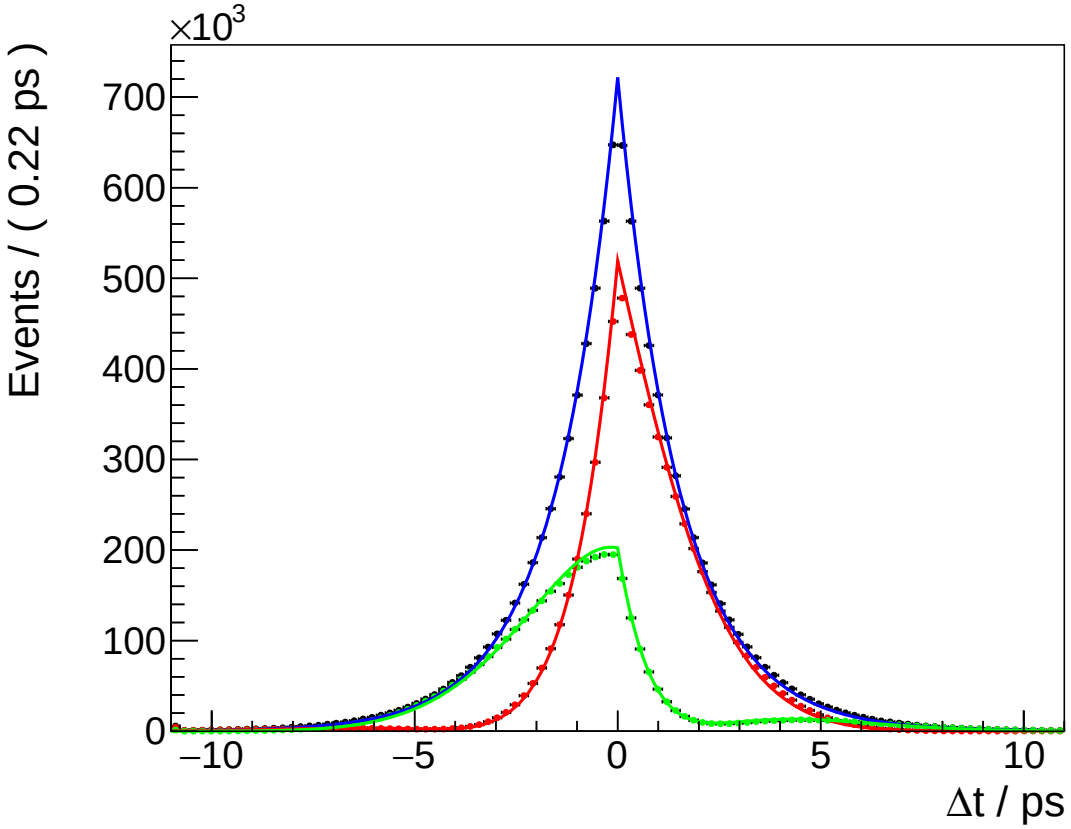
- with $\mathcal{S}_{\pi^0\pi^0} \Rightarrow$ 2 fold ambiguity on α
- Converted $\gamma \to \mathrm{e}^+\mathrm{e}^-$ and $\pi^0 \to \mathrm{e}^+\mathrm{e}^-\gamma$ req. for $\langle \Delta z \rangle$
- Possible with $\mathcal{L}_{\text{Belle II}} = 50 \cdot \mathcal{L}_{\text{Belle}}$ and Belle II PXD?

Extrapolated to $\mathcal{L}_{\text{Belle II}} = 50\text{ab}^{-1}$

arXiv:hep-ex/0703029



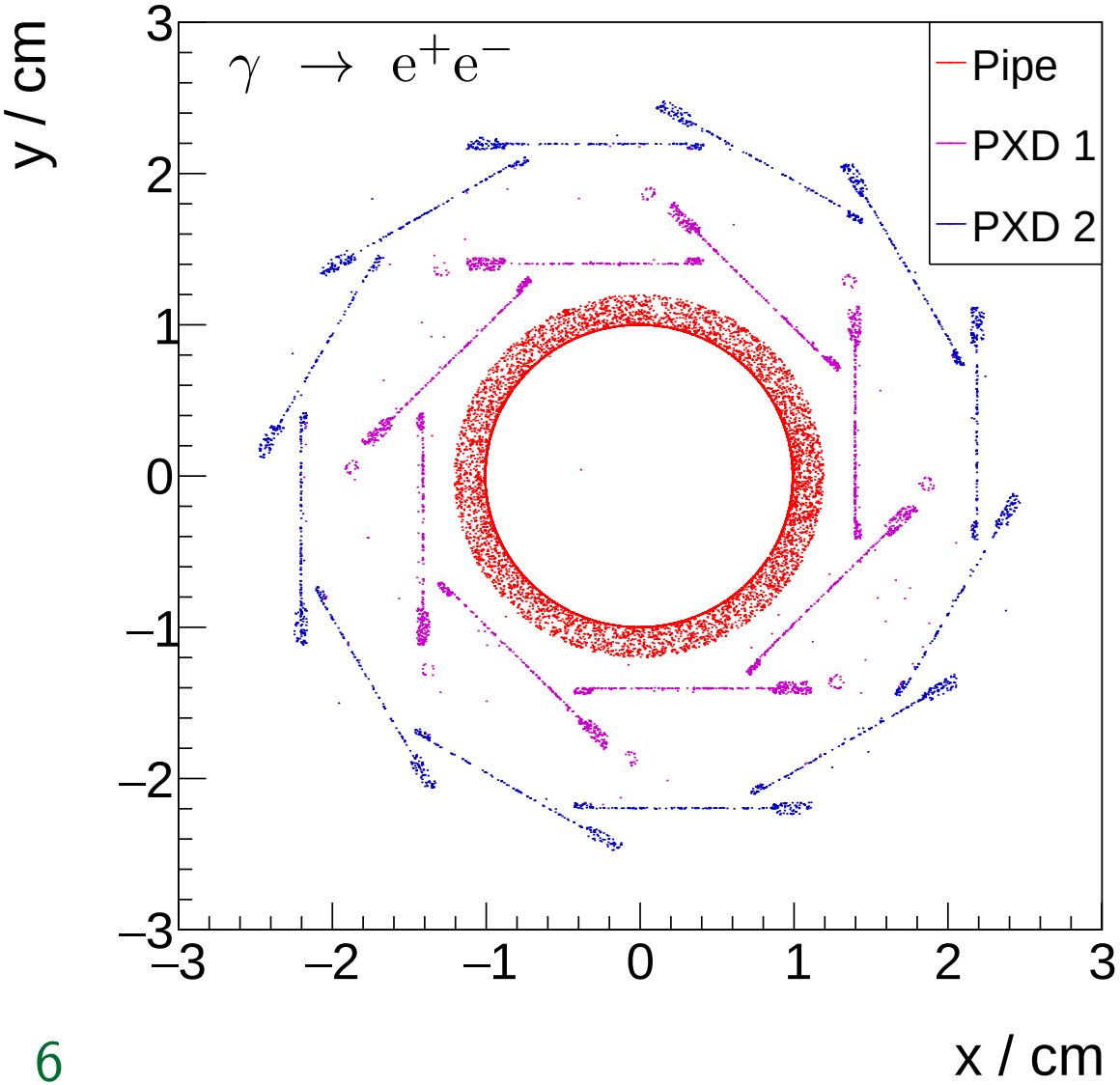
Expected Asymmetry



- $\mathcal{A}_{CP}{}^{\pi^0\pi^0} = 0.43$ (PDG)
- $\mathcal{S}_{CP}{}^{\pi^0\pi^0} = \sqrt{1-\mathcal{A}_{CP}}\sin 2\cdot(\alpha - \Delta\alpha^*) \approx 0.76$

*`hep-ex/0703039`

Vertex of γ-Conversions in $\mathrm{B}^0 \to \pi^0\pi^0$



- $\Upsilon(4S) \to \mathrm{B}^0{}_1\mathrm{B}^0{}_2 \to$
  $B_1 \to$ generic
  $B_2 \to \pi^0\pi^0$
- $\pi^0 \to \gamma\gamma \quad (\mathcal{B} = 98.82\%)$
- $\pi^0 \to \mathrm{e}^+\mathrm{e}^-\gamma \ (\mathcal{B} = 1.17\%)$
- $N_{\text{Belle II}} =$

$$\begin{aligned} \mathcal{L}_{\text{Belle II}} &\cdot \mathcal{B}(\Upsilon(4S) \to \mathrm{B}^0\overline{\mathrm{B}}^0) \\ &\cdot 2 \cdot \mathcal{B}(\mathrm{B}^0 \to \pi^0\pi^0) \sim \\ 50\text{ab}^{-1} &\cdot 1.1\text{nb} \cdot 0.49 \\ &\cdot 2 \cdot 1.91 \cdot 10^{-6} \end{aligned}$$

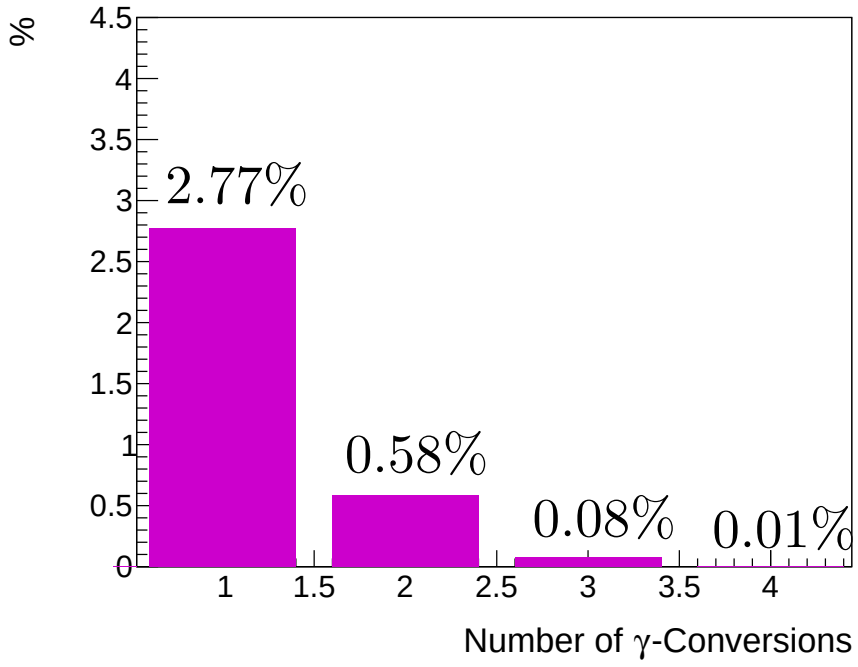
~ 100k events.

- Accept.: $\theta \in [17, 150]^\circ$
- ECL: $\theta \in [12.4, 155.1]^\circ$

Events with γ-Conversions

a) If there is an event with γ-conversions

$\Rightarrow$ How Many?



b) How many Events have at least one γ-conversion?

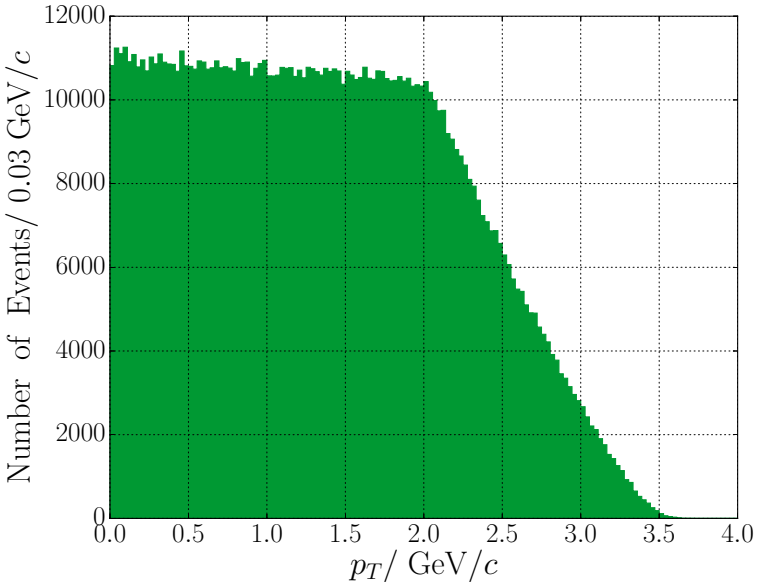
Vertex in	Events %
Beam Pipe	2.00 %
1st. PXD Layer	0.60 %
2nd. PXD Layer	0.50 %
Total inside PXD	3.10 %

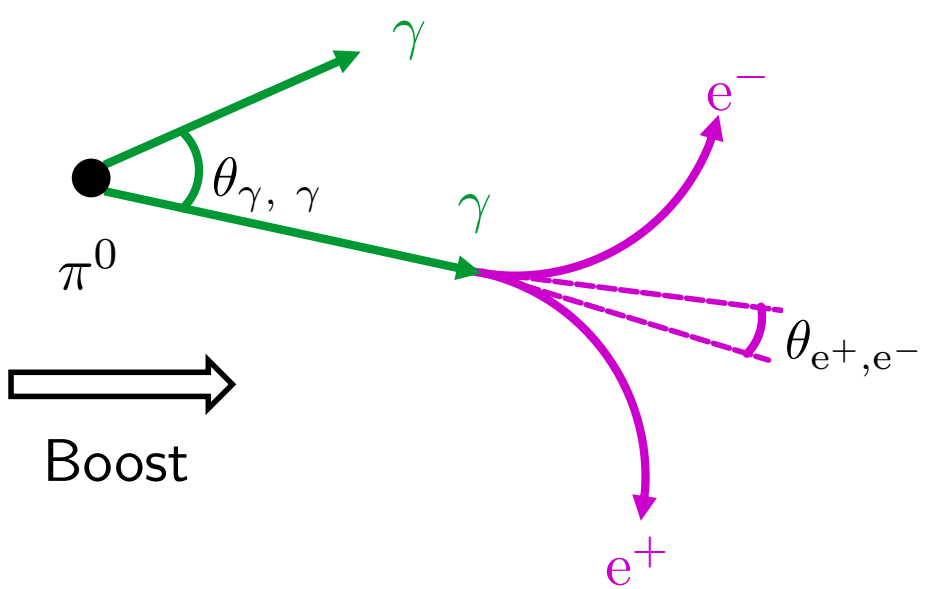
c) ... and at least one γ-conversion or one $\pi^0 \to e^+e^-\gamma$ decay?

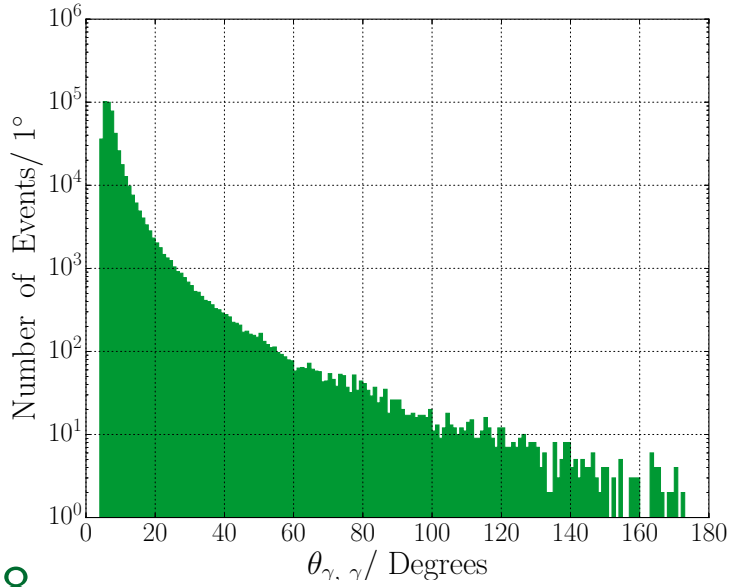
$\pi^0 \to e^+e^-\gamma$	2.00 %
Total $\pi^0 \cup \gamma$	5.05 %

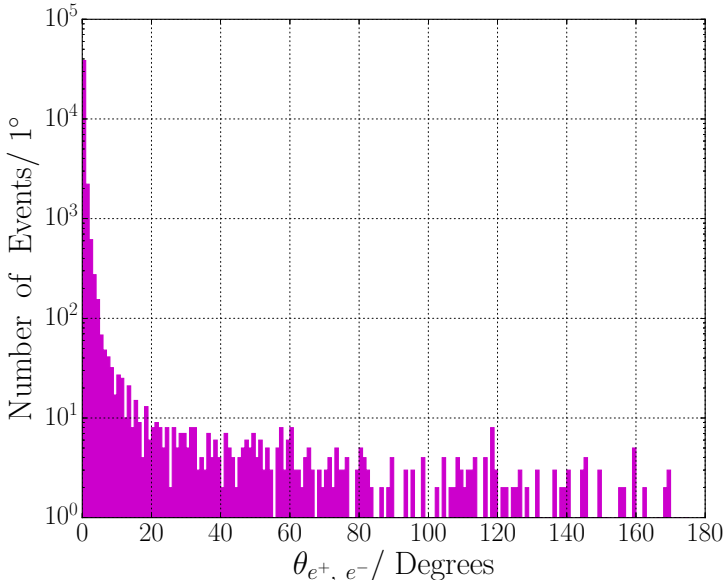
Requirement: All converted γ in accept. and not converted in ECL

$\pi^0 \to \gamma\gamma$ Kinematics

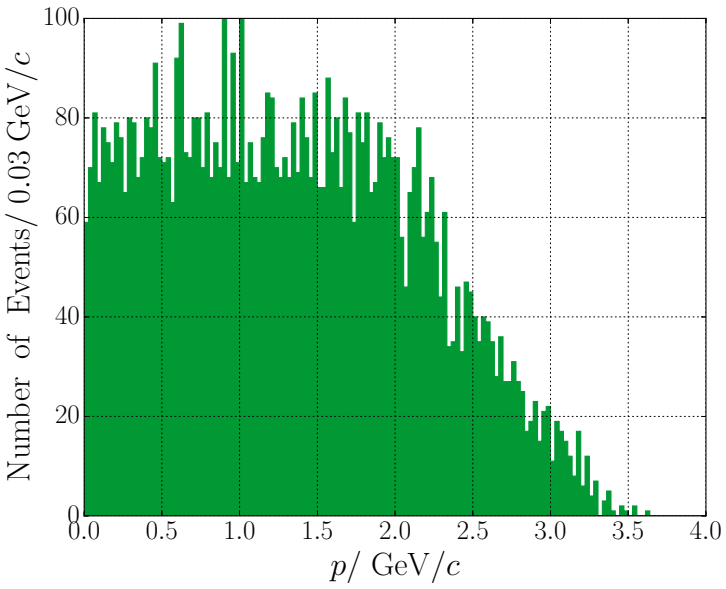


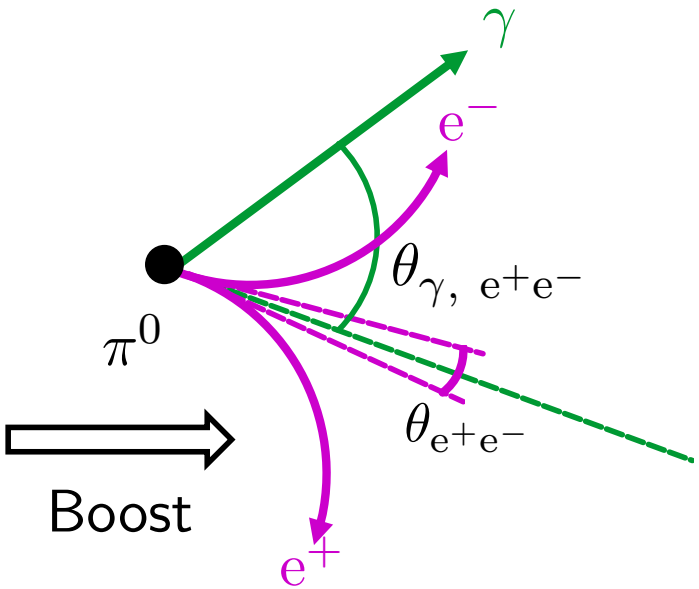


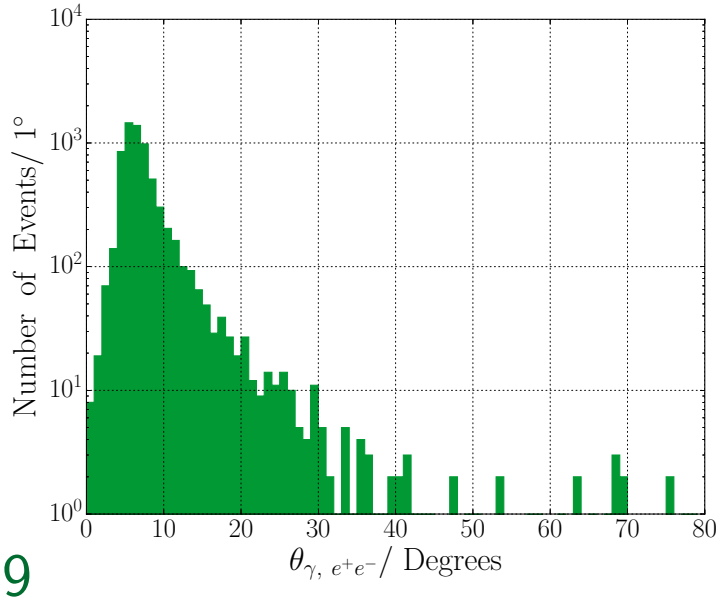


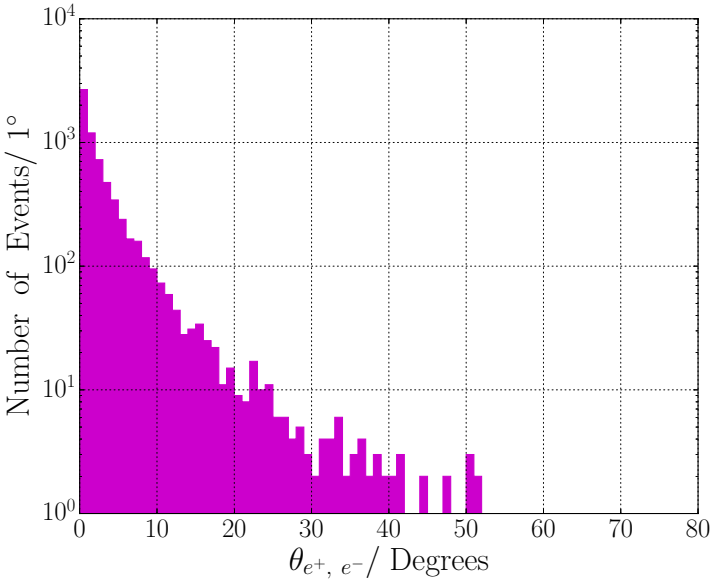


$\pi^0 \to e^+e^-\gamma$ Kinematics

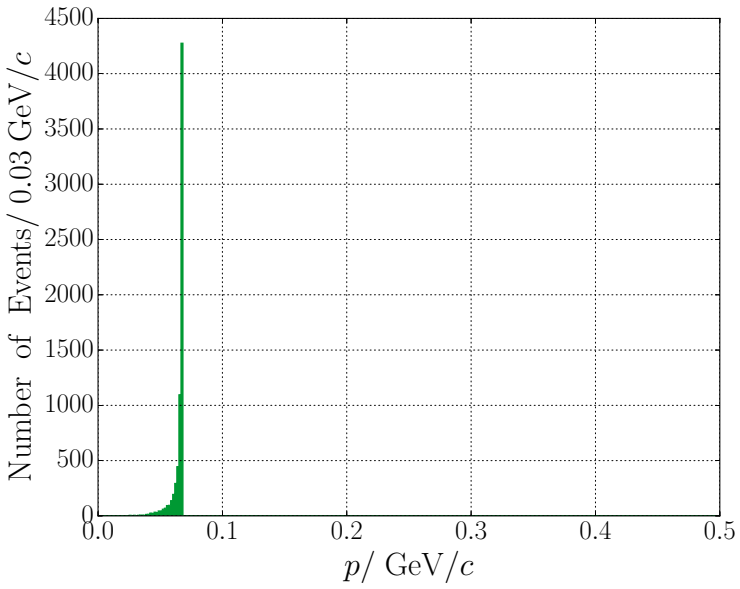


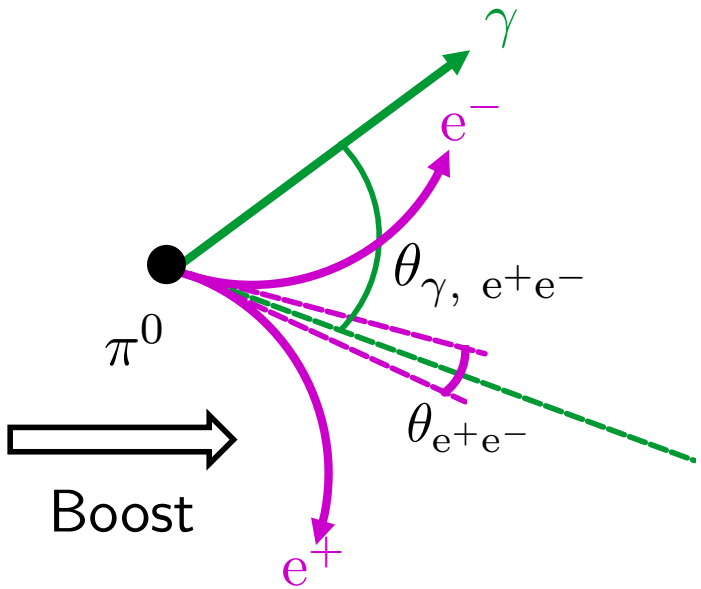


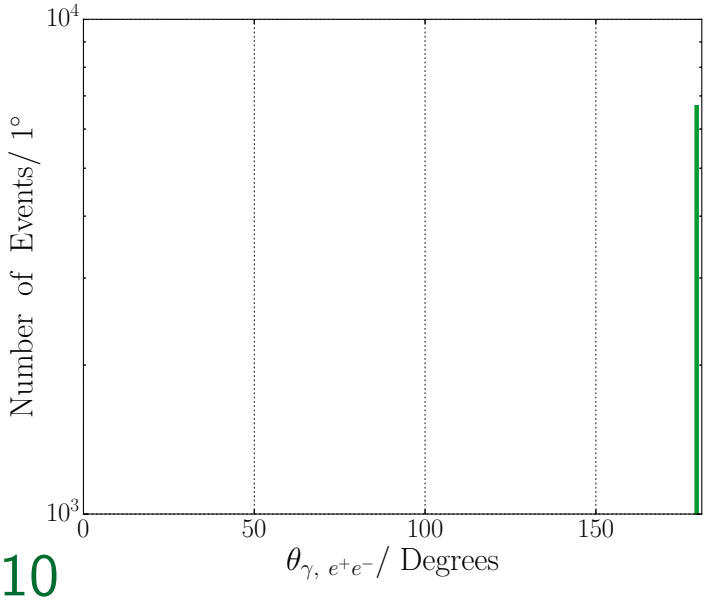


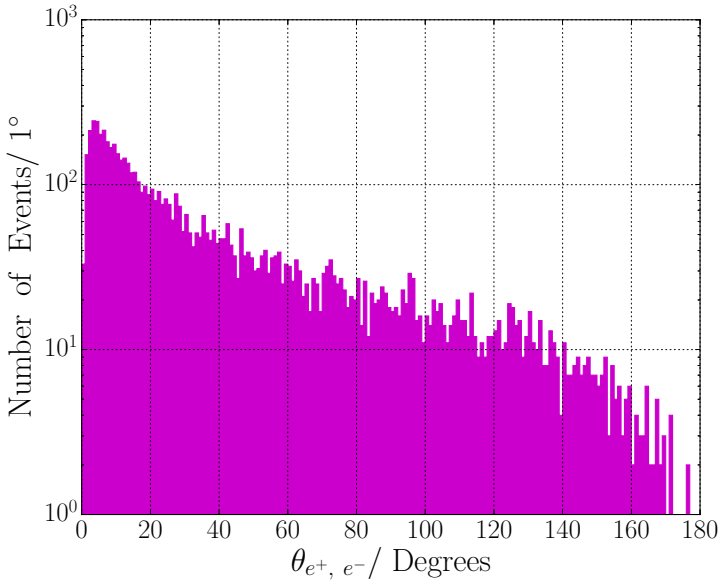


$\pi^0 \to e^+e^-\gamma$
CMS Kinematics









B^0 Vertex Reconstruction

Algorithm: Kinematic Vertex Fit

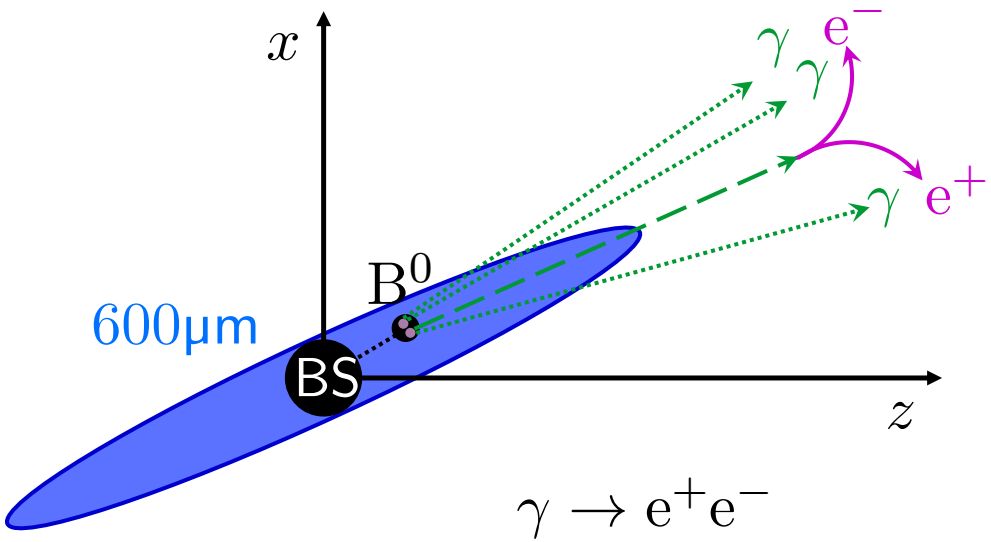
Access: RAVE (Reconstruction in a Abstract, Versatile Environment) TNS.2011.2119492

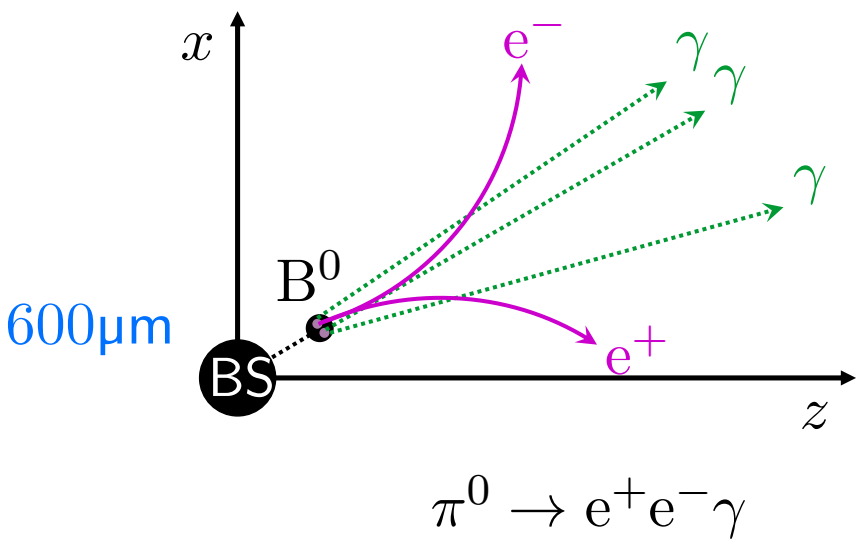
- Vertex Reconstruction with spatial constraint centered at the Beam Spot.

- $\tau_{\pi^0} \sim 0.9$ as $\cong$ 0.1 nm

$\Rightarrow$ π^0 Vertex $\hat{=}$ B^0 Vertex.

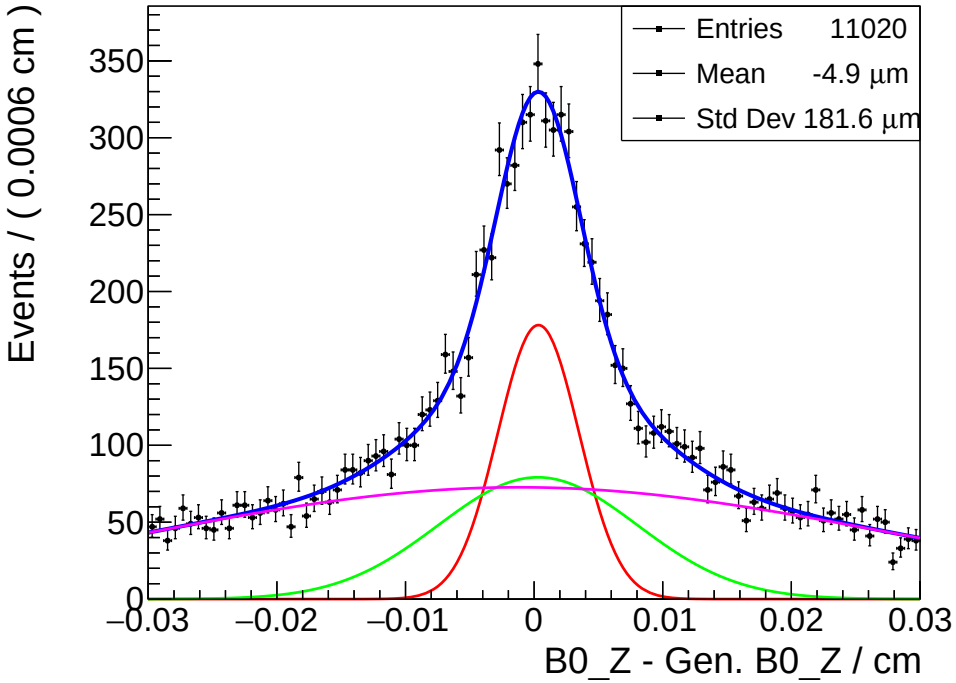
- ✂ on $e^{\pm}$ Tracks: At least one PXD hit.



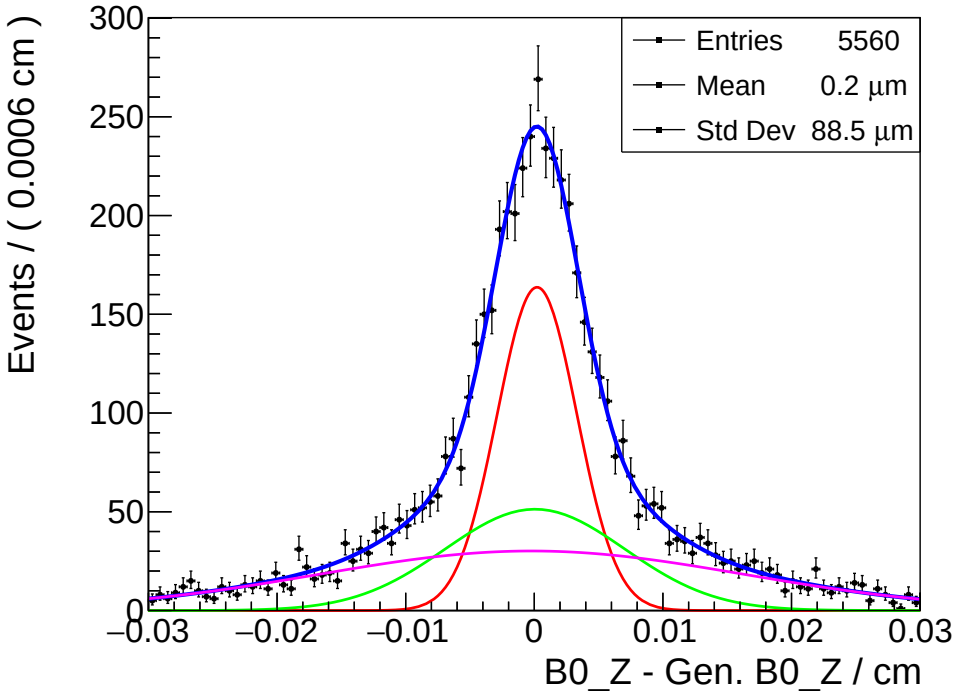


B^0 z-Vertex Resolution

$$B^0 \to \pi^0 \pi^0$$
$$\hookrightarrow \gamma \gamma$$
$$\hookrightarrow e^+ e^-$$



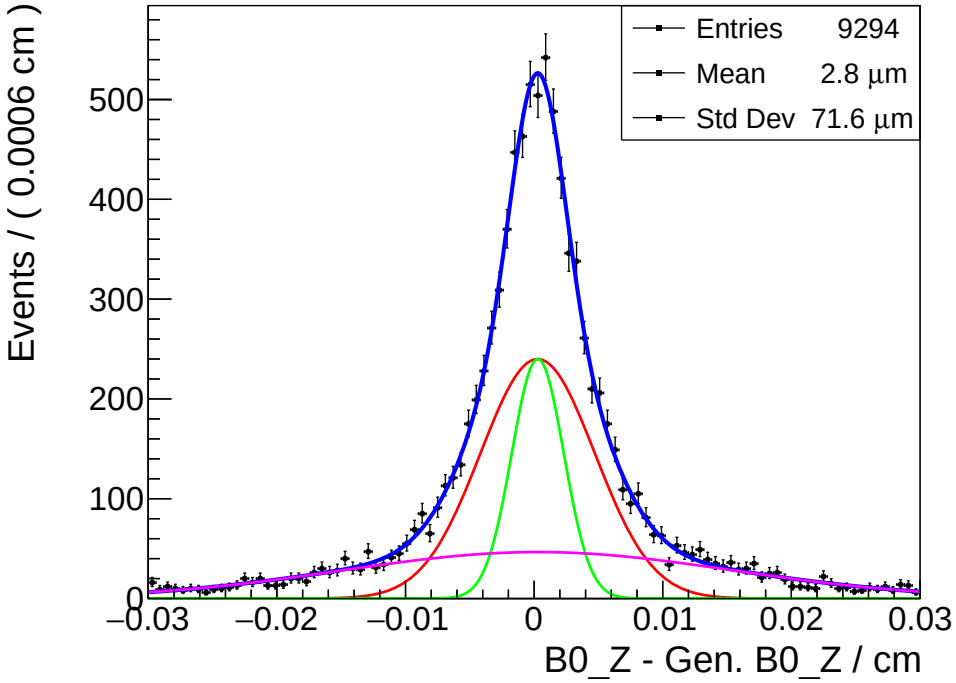
No PXD Hit required



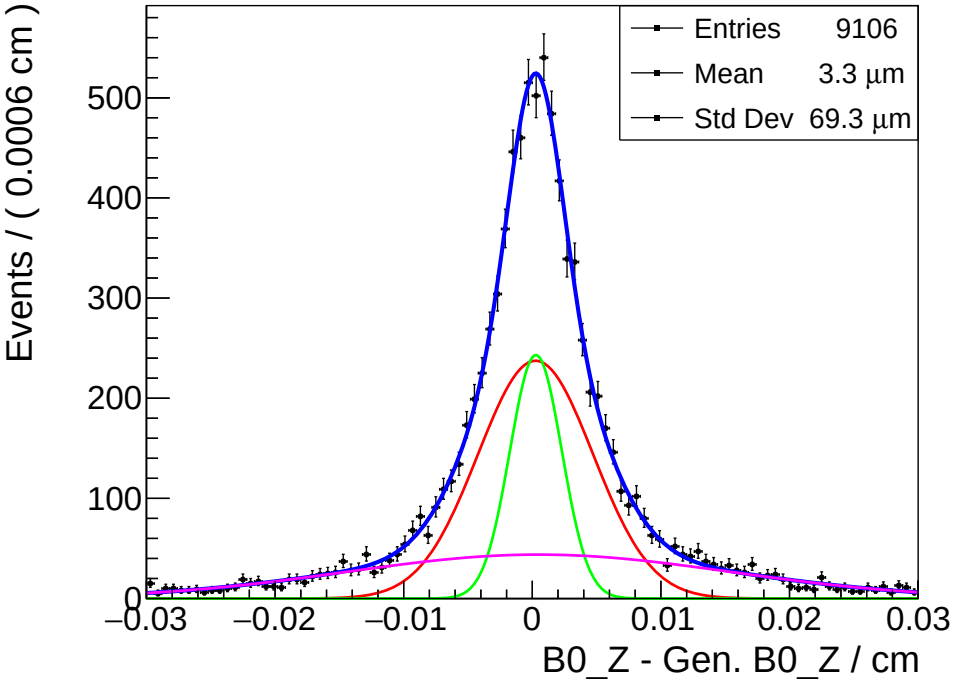
At least one track (e^+ or e^-) has one PXD Hit

B^0 z-Vertex Resolution

$$B^0 \rightarrow \pi^0 \pi^0$$
$$\hookrightarrow e^+ e^- \gamma$$



No PXD Hit required

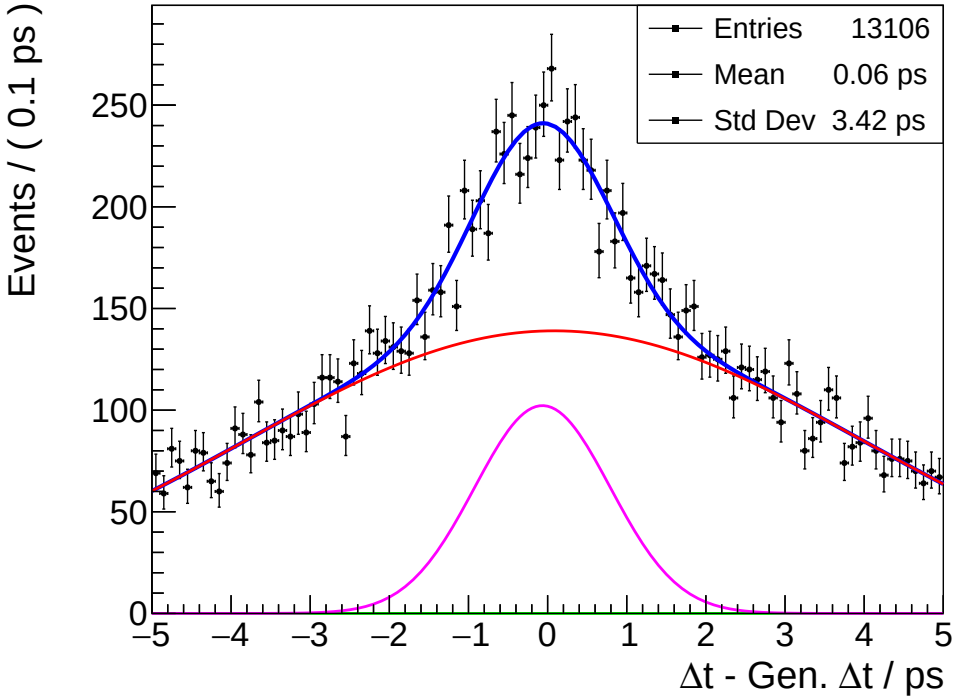


At least one track (e^+ or e^-) has one PXD Hit

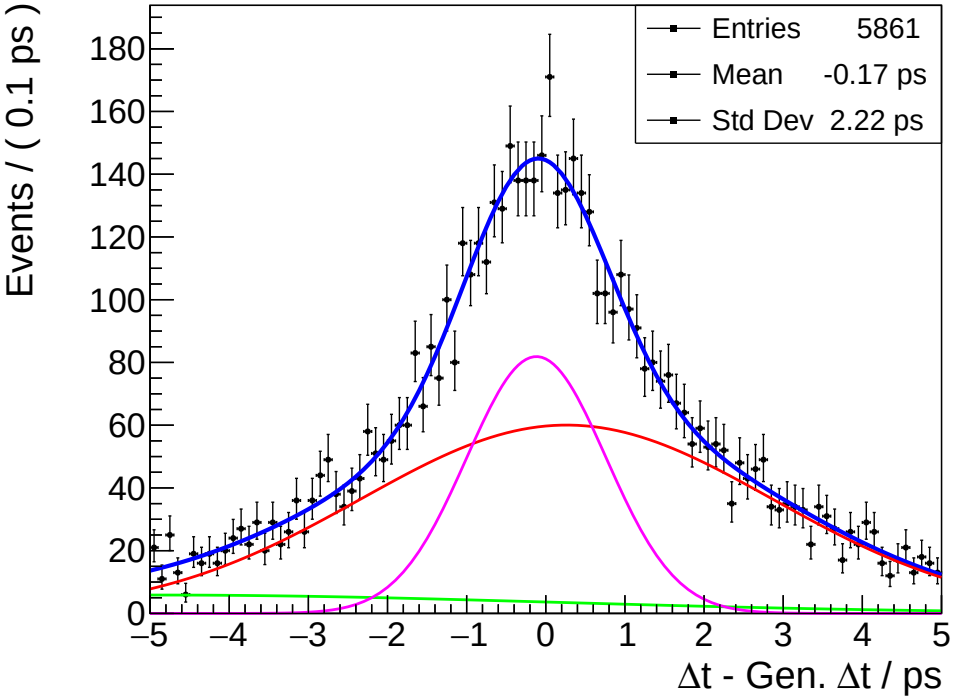
Δt Resolution

$$\Delta t = t_{\mathrm{B^0}_{\mathrm{CP}}} - t_{\mathrm{B^0}_{\mathrm{tag}}}$$

$$\mathrm{B^0}_{\mathrm{CP}} \rightarrow \pi^0\,\pi^0$$
$$\hookrightarrow \gamma\,\gamma$$
$$\hookrightarrow \mathrm{e^+e^-}$$



No PXD Hit required

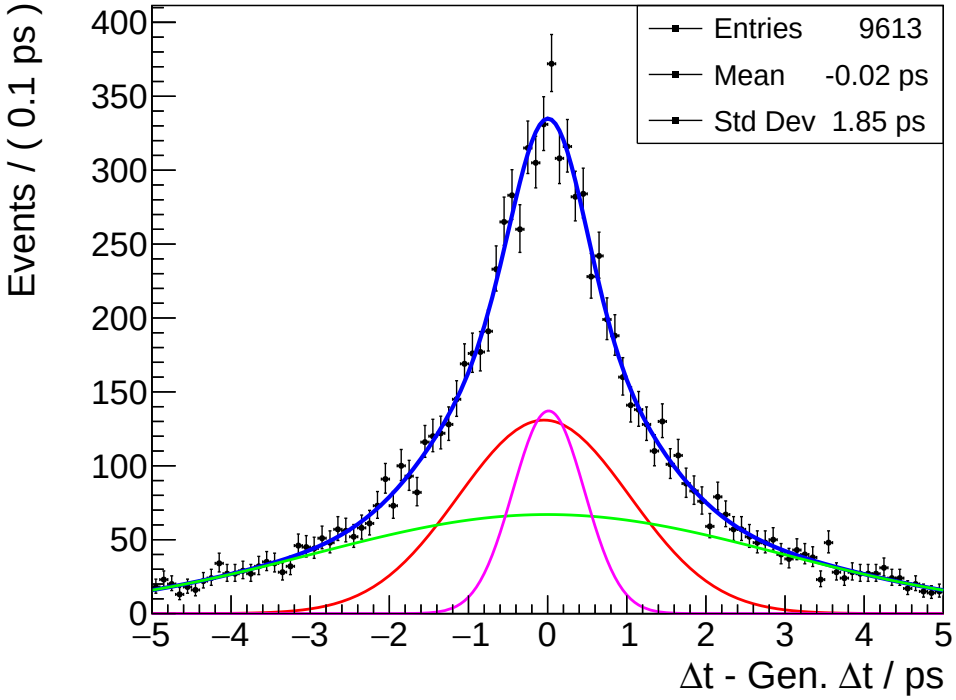


At least one track ($\mathrm{e^+}$ or $\mathrm{e^-}$) has one PXD Hit

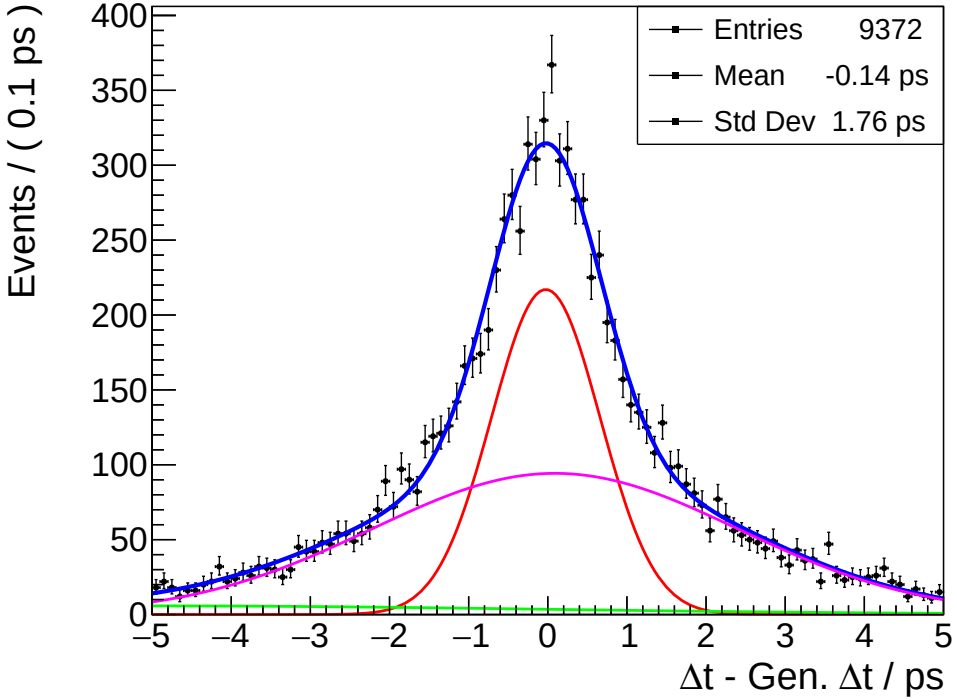
Δt Resolution

$$\Delta t = t_{\mathrm{B^0}_{\mathrm{CP}}} - t_{\mathrm{B^0}_{\mathrm{tag}}}$$

$$\mathrm{B^0}_{\mathrm{CP}} \rightarrow \pi^0\ \pi^0$$
$$\hookrightarrow \mathrm{e}^+\ \mathrm{e}^-\ \gamma$$



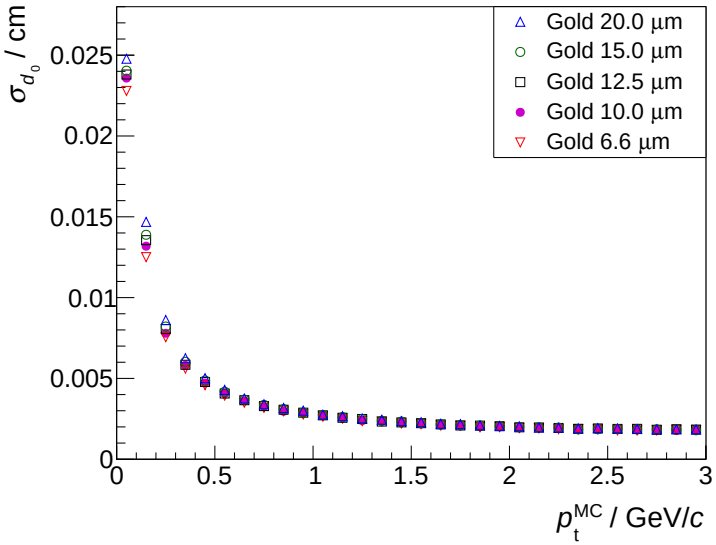
No PXD Hit required

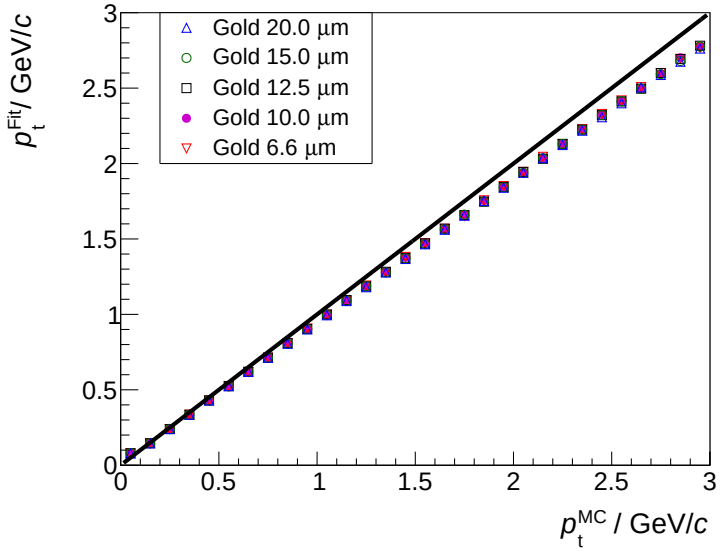


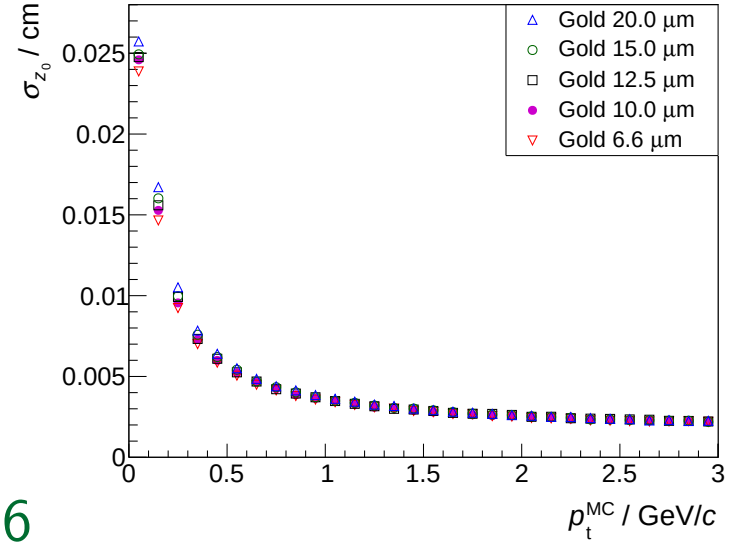
At least one track (e^+ or e^-) has one PXD Hit

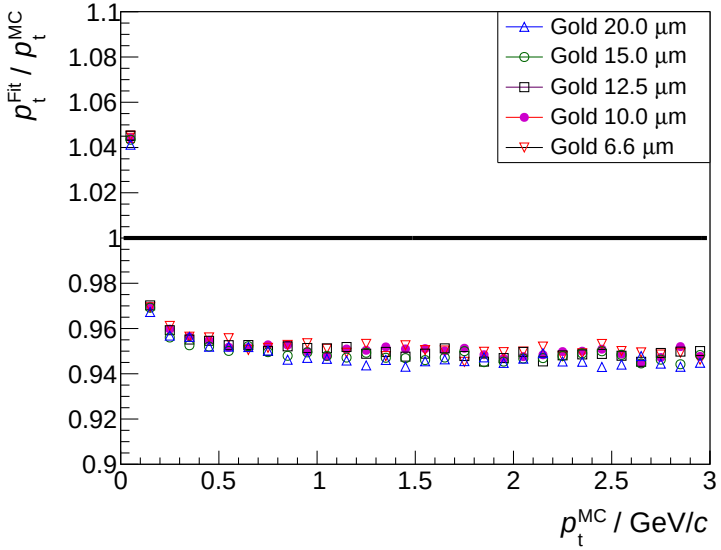
e^+, e^- Track Reconstruction

- e^+, e^-



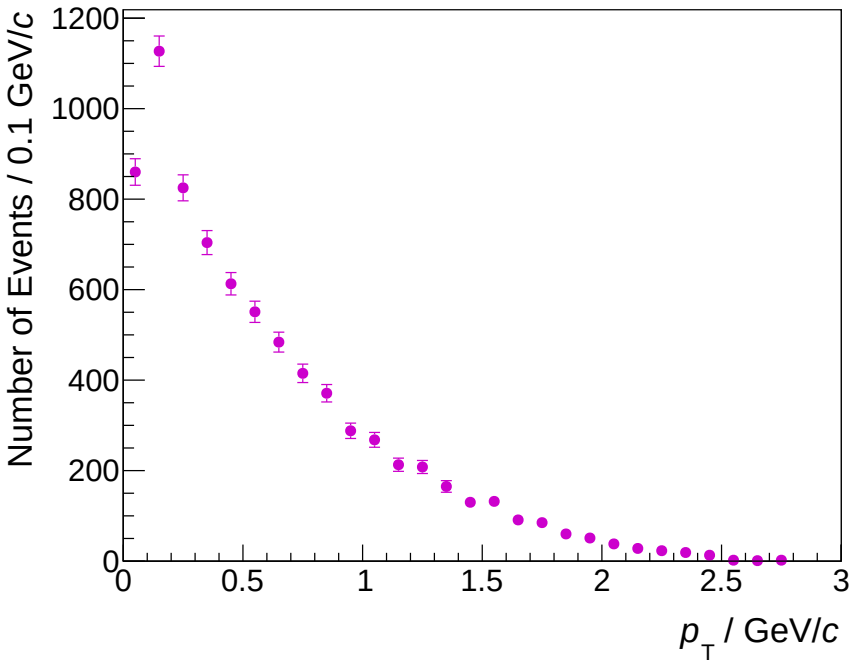


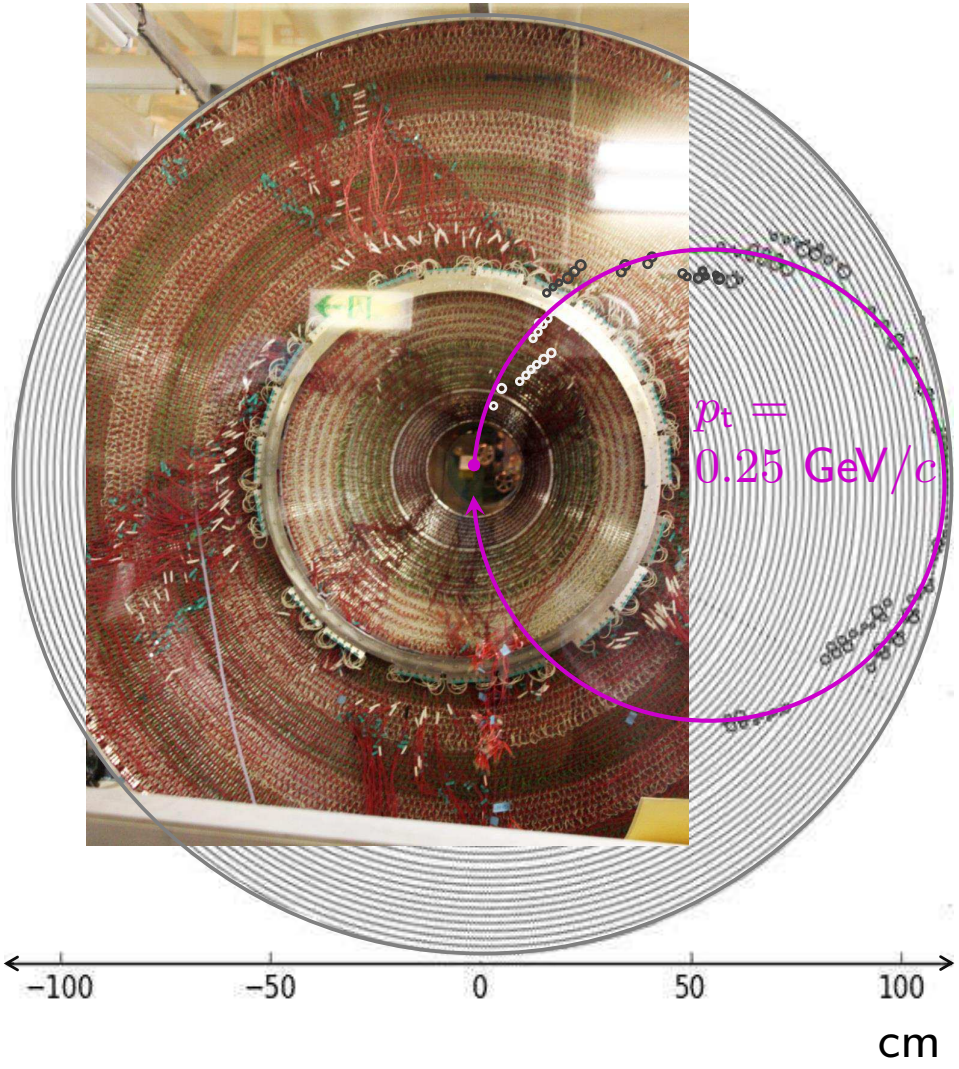




p_t-Distribution of γ-Daughters

- e^+ and e^- from γ



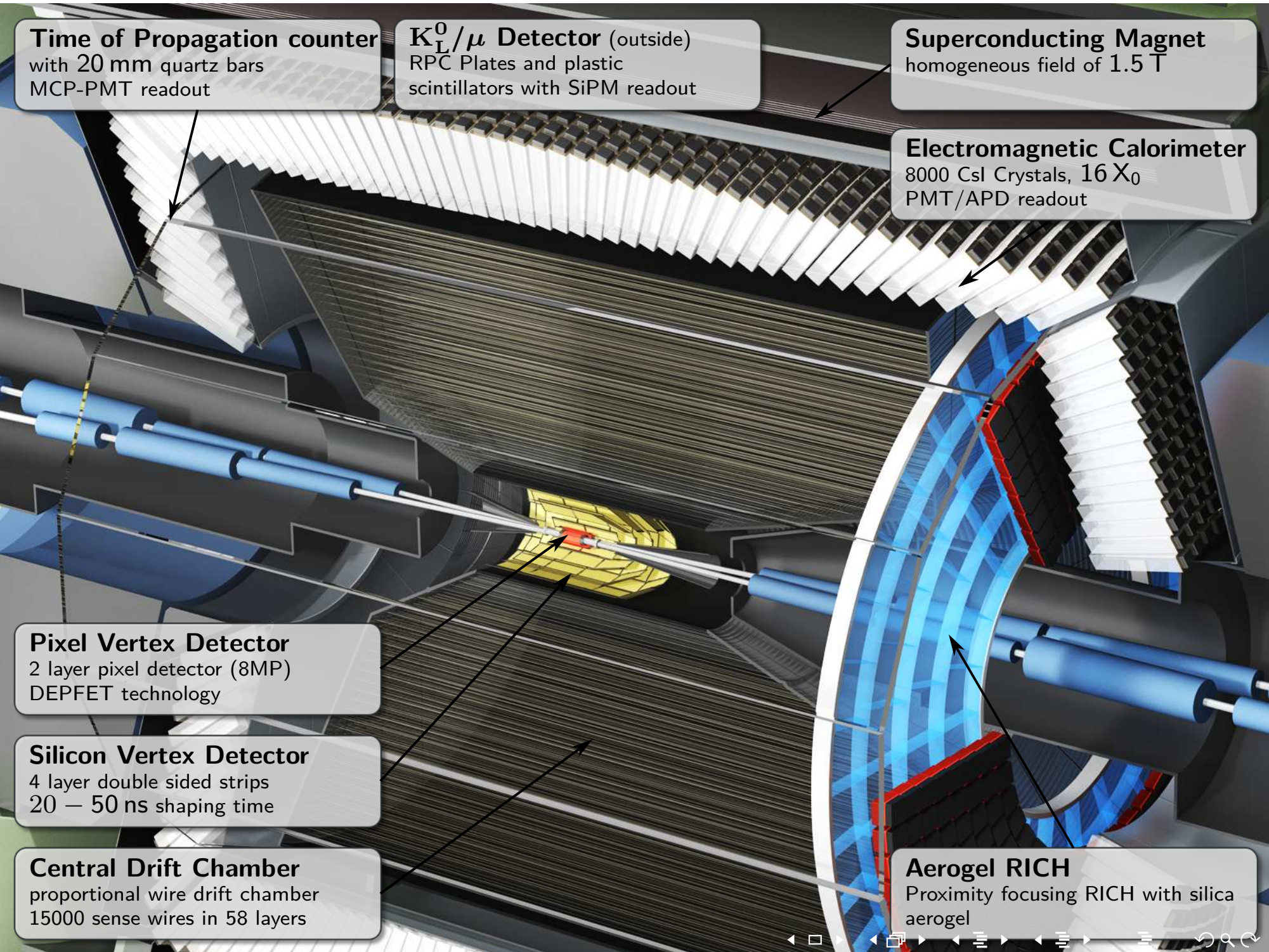


Summary and Outlook

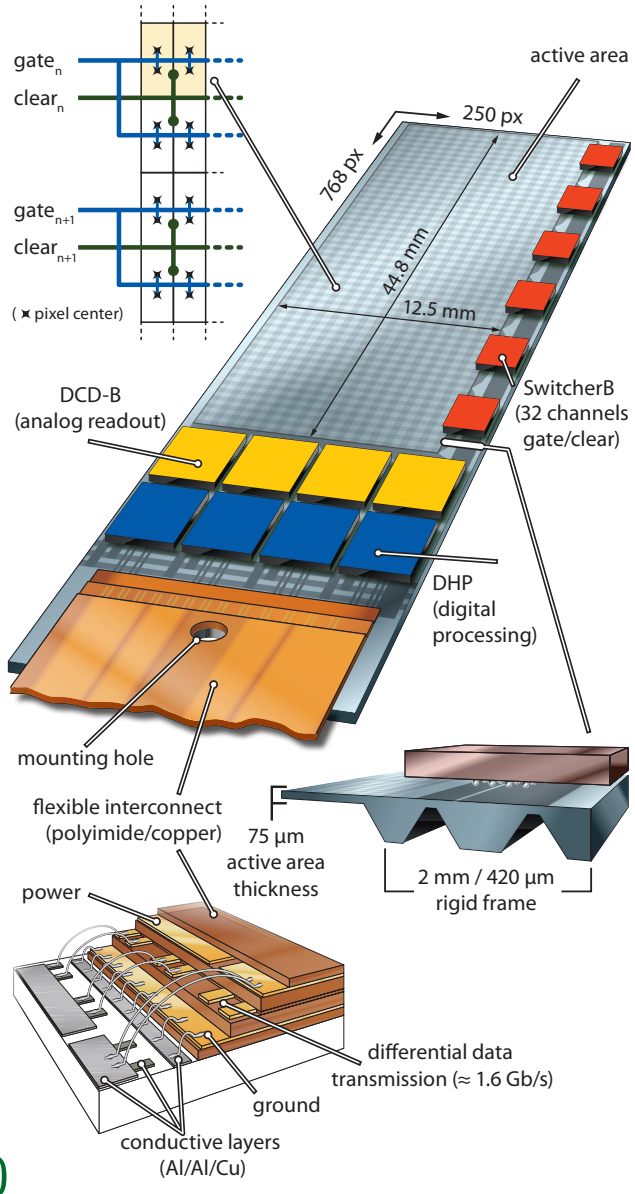
- Beam Spot constrained kinematic vertex fit reaches higher resolution with PXD Information.

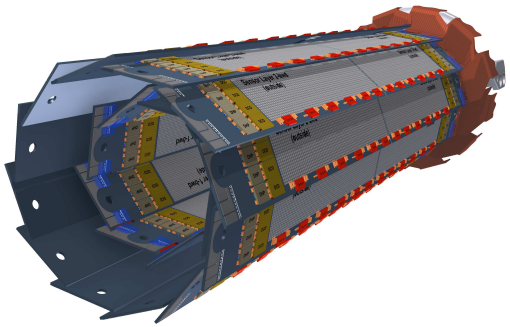
$\Rightarrow$ Higher Δt resolution.

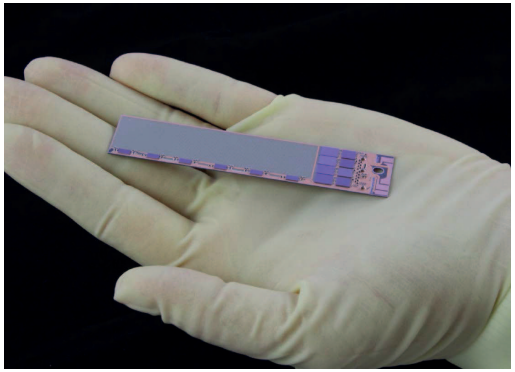
- $\mathrm{e}^{\pm}$ track fit result to be improved.
- Check new V0 Finder tool for $\gamma \to \mathrm{e}^{+}\mathrm{e}^{-}$.


Time of Propagation counter
with 20 mm quartz bars
MCP-PMT readout
K_L^0/μ Detector (outside)
RPC Plates and plastic
scintillators with SiPM readout
Superconducting Magnet
homogeneous field of 1.5 T
Electromagnetic Calorimeter
8000 CsI Crystals, 16 X_0
PMT/APD readout
Pixel Vertex Detector
2 layer pixel detector (8MP)
DEPFET technology
Silicon Vertex Detector
4 layer double sided strips
20 – 50 ns shaping time
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers
Aerogel RICH
Proximity focusing RICH with silica
aerogel

DEPFET Pixel Vertex Detector







- Inst. Lumi.: $\mathcal{L}_{\text{Belle II}} \sim 40 \cdot \mathcal{L}_{\text{Belle}}$

$\Rightarrow$ Background $\uparrow\uparrow\uparrow$

- Closest to IP

$\Rightarrow$ Occupancy ($\sim r^{-2}$) $\uparrow\uparrow\uparrow$

- $\langle\beta\gamma\rangle_{\text{Belle II}} < \langle\beta\gamma\rangle_{\text{Belle}}$

$\Rightarrow$ smaller Δz

$\Rightarrow$ Pixel Detector needed !

$\Rightarrow$ DEPFET Technology most suited

Depleted Field Effect Transistor

CP-Violation in the SM

- Why CP-Violation? $\Rightarrow$ Matter-Antimatter-Asymm. in the universe larger than in SM. (Sakharov)
- Why in the B^0-system? $\Rightarrow$ largest CP-V. within the SM.
- CP-V. in the SM $\Rightarrow$ Weak Interaction $\Rightarrow$ $\mathbf{V}_{CKM}$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

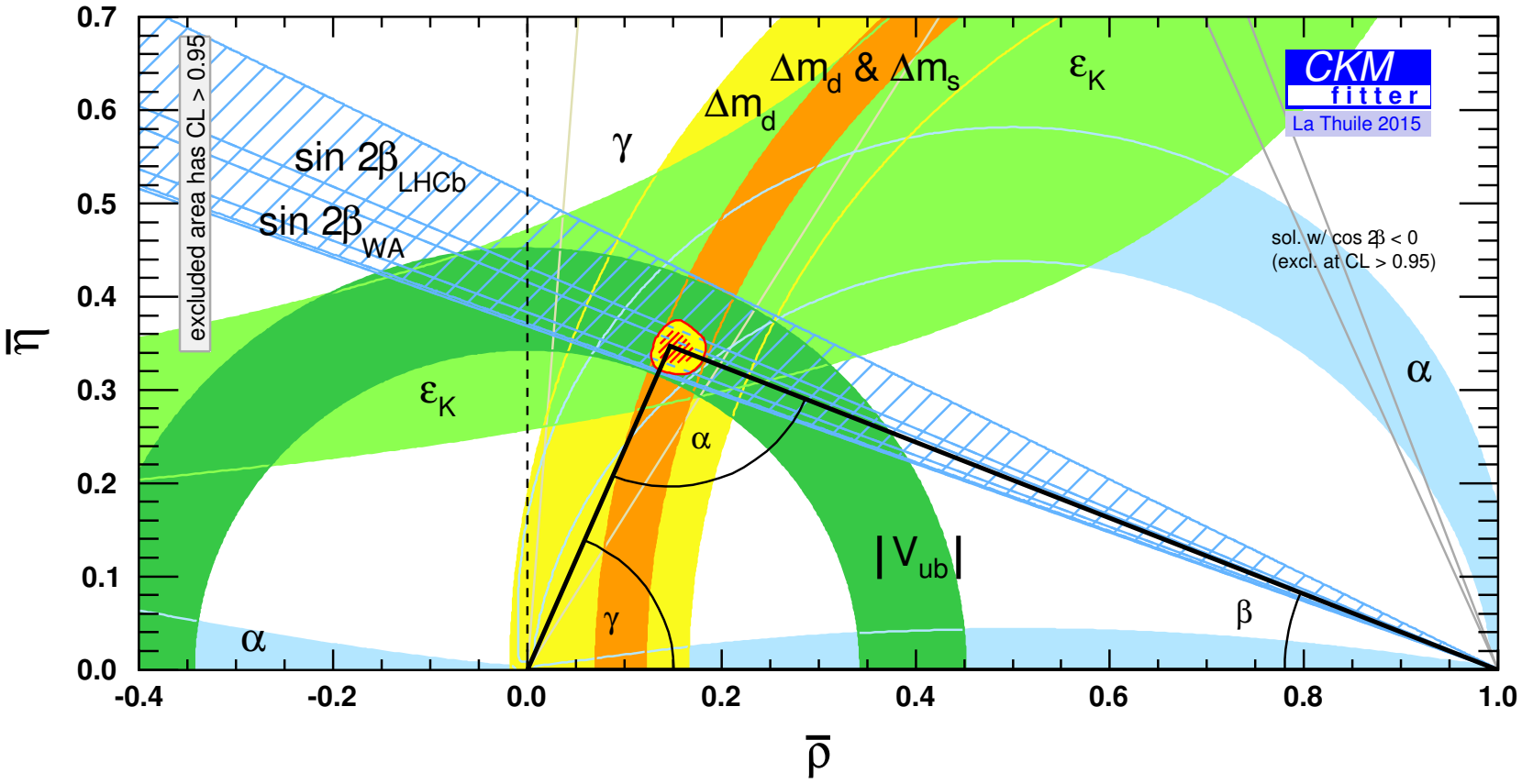
- Wolfenstein-Parameters: $\lambda = \sin\theta_C \approx 0.2, A, \rho, \eta$

$$\mathbf{V}_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta)] & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

$$\Rightarrow \mathcal{L}^{\text{Yuk}} \propto igW^\mu J_\mu^{cc} \Rightarrow J_\mu^{cc} \xrightarrow{CP} J_\mu^{cc\,\prime} \neq J_\mu^{cc}$$

- Unitarity: $\sum_k V_{ik}V_{jk}^* = 0 \Rightarrow \underbrace{V_{ud}V_{ub}^*}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{cd}V_{cb}^*}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{td}V_{tb}^*}_{\mathcal{O}(\lambda^3)} = 0$

CKM-Triangle



$$\bar{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \bar{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$