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B Factories and New Measurements

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C.-C. Peng & K.-F. Chen
National Taiwan University

Missing Energy Studies at Super Belle

< with the Super Forward Detector >

Introduction & Motivation

- The studies associated with missing energies are the potential physics topics at the super *B*-factory era:
  - *B* decays with neutrinos (e.g. $B \to K(^*)\nu\nu$, $B \to \tau\nu$, $B \to D(^*)\tau\nu$, etc.)
  - Dark matter related searches (e.g. $\Upsilon(1S) \to$ nothing.)
- Requirements for the analyses:
  - Large data set & a high luminosity machine.
    - ⇨ Since the reconstruct efficiencies are very small (<<0.1%).
  - A clean environment.
    - ⇨ In order to control the background level.
- Detector design target:

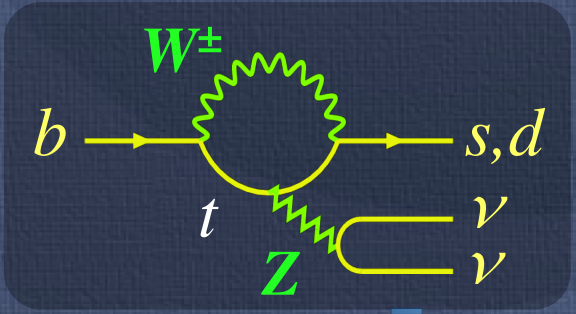
Large acceptance w/ high detecting efficiencies

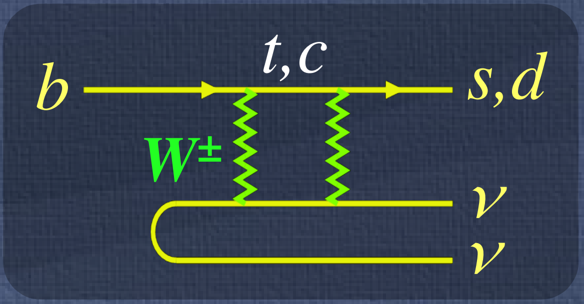
➔ Bench mark mode in this talk: $B \to K(^*)\nu\nu$

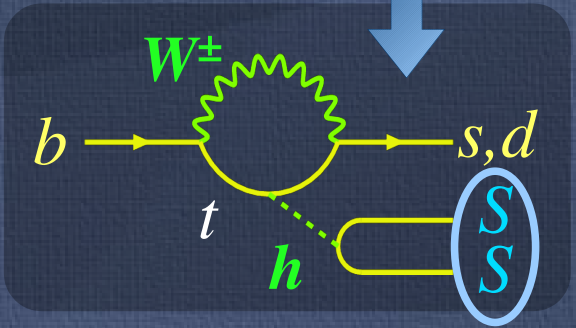
$B \to K^{(*)}\nu\nu$: Introduction

- Proceed through electroweak penguin + box diagram.
- Sensitive to the New Physics in the loop diagram.
- Theoretically clean: no long distance contributions.
- May be sensitive to light dark matter:

For example: C. Bird, PRL 93, 201803 (2004)

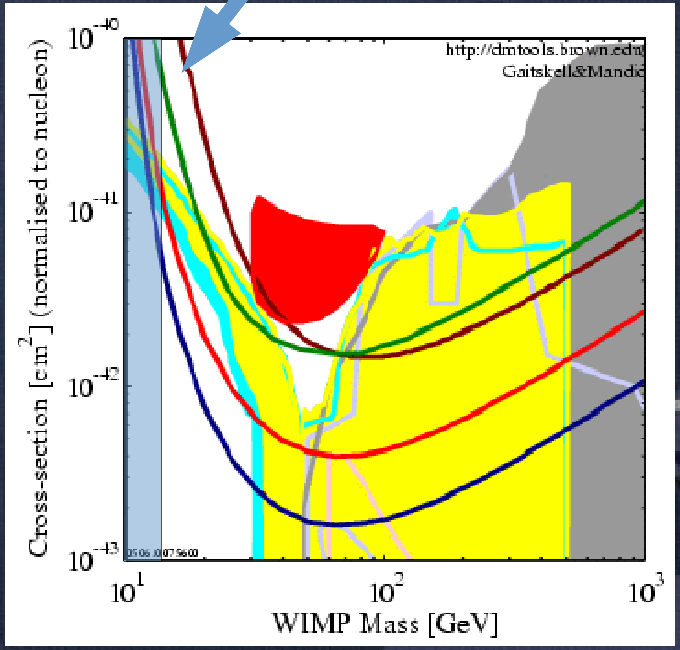






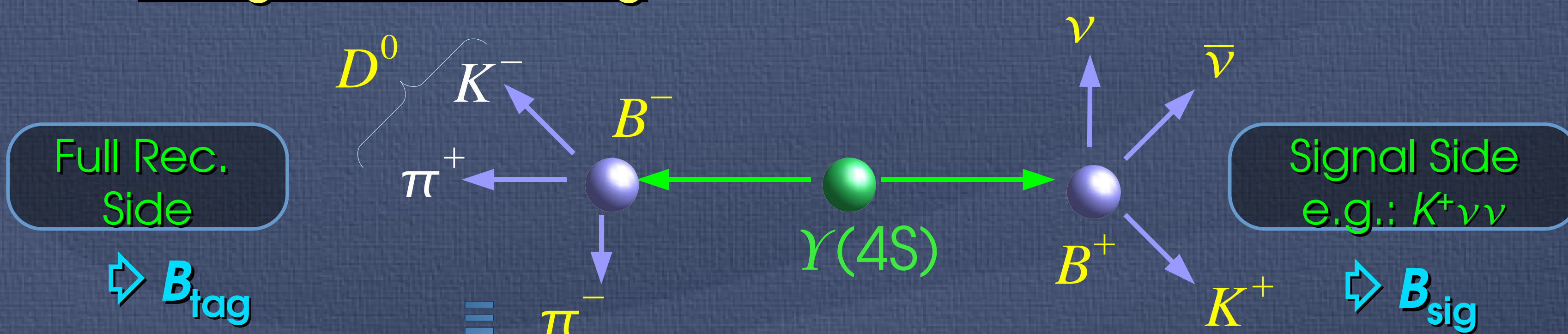
$b \to s$ + Missing E may be enhanced by this extra diagram.

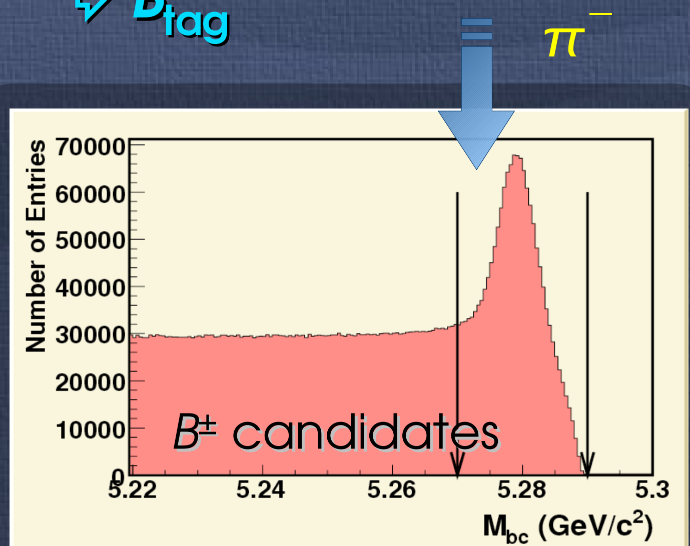
No sensitivity to light dark matter (M<10 GeV) in direct searches



$B \to K^{(*)} \nu\nu$: Reconstruction

- Event signature: fully reconstruct one of the *B* mesons in one of the hadronic modes: $D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, or $D^{(*)}D_s^{(*)}$.
- Check whether the residual energy on the tag side is consistent with a single $K^{(*)}$ + nothing.





A powerful tool for analyzing decays with missing energy/neutrinos

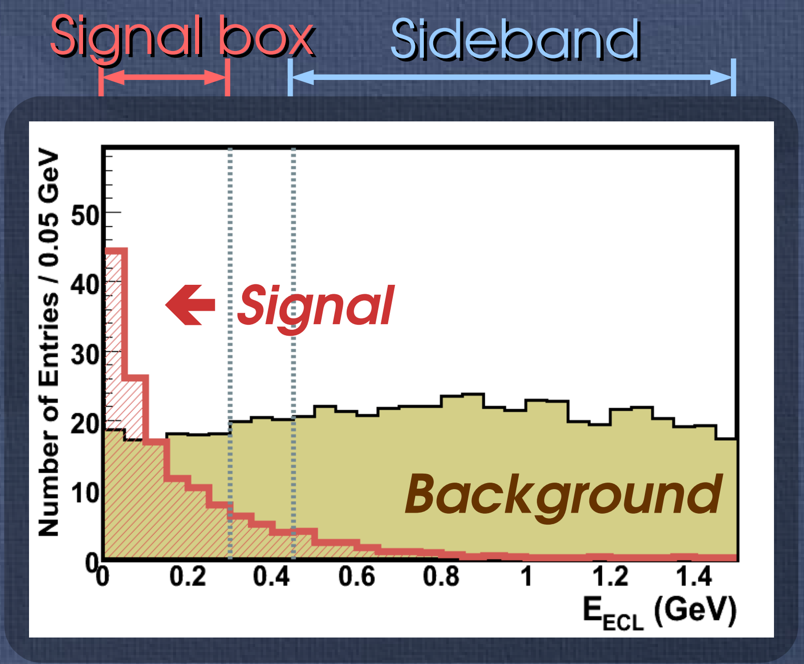
- Typical tagging rate: ~0.1–0.3%.
- *B* momentum & flavor are well measured.

$B \to K^{(*)}\nu\nu$: Reconstruction

Key Variable: Extra Energy in Calorimeter, E_{ECL}

- The most powerful variable for separating signal & background.
- Summation over neutral clusters that are not associated with the reconstructed B_{tag} and B_{sig}:

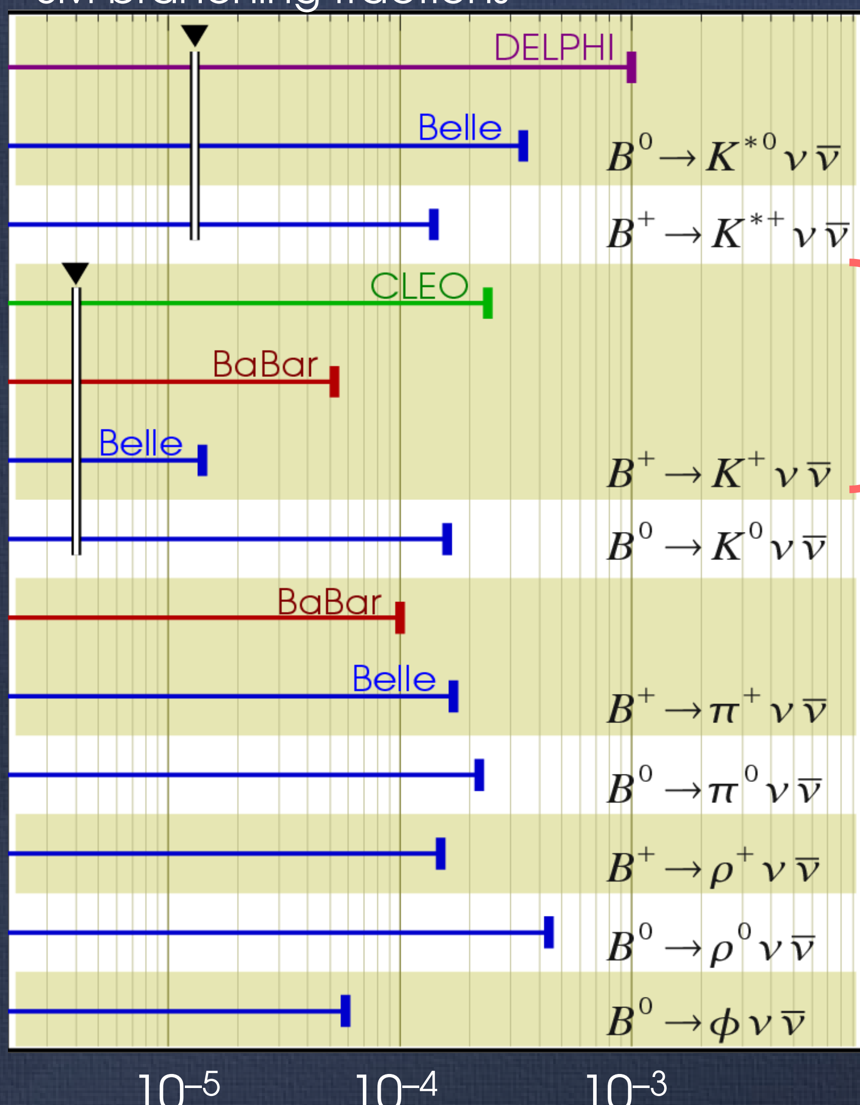
$$E_{ECL} = E_{total} - E_{rec.}$$



- **Signal**: zero or small E_{ECL} from beam background.
- **Background**: larger E_{ECL} due to additional neutral clusters.
- Events with any **additional track** or π^0 are rejected.

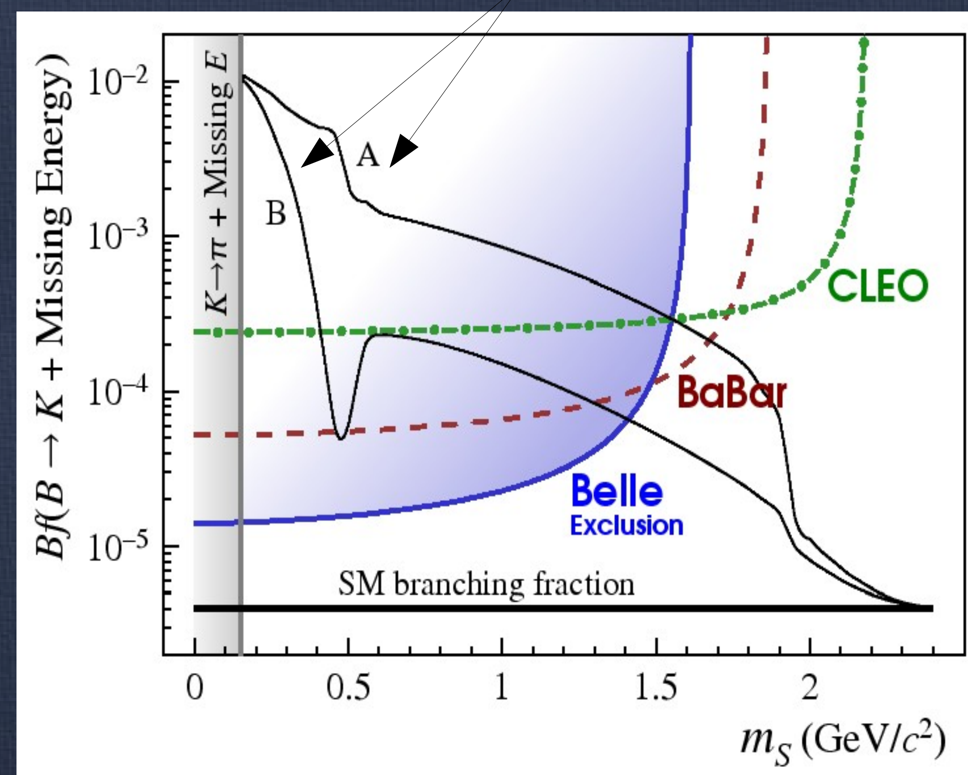
$B \to K^{(*)}\nu\nu$: Results

SM branching fractions



- Limit on light dark matter based on the $K^+\nu\nu$ limits:

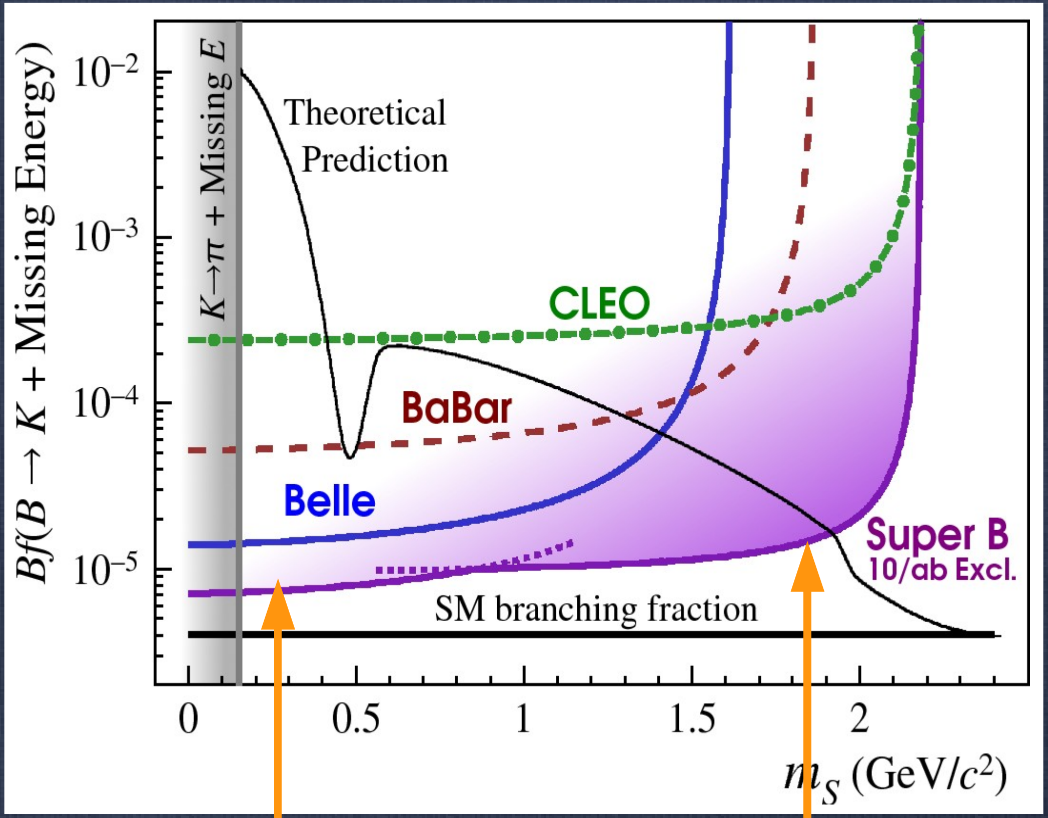
Theoretical predictions
Ref. C.. Bird, PRL 93, 201803 (2004)



The curvature is due to the lower bound on $P^*(K)$

$B \to K^{(*)}\nu\nu$: Prospects for 10/ab

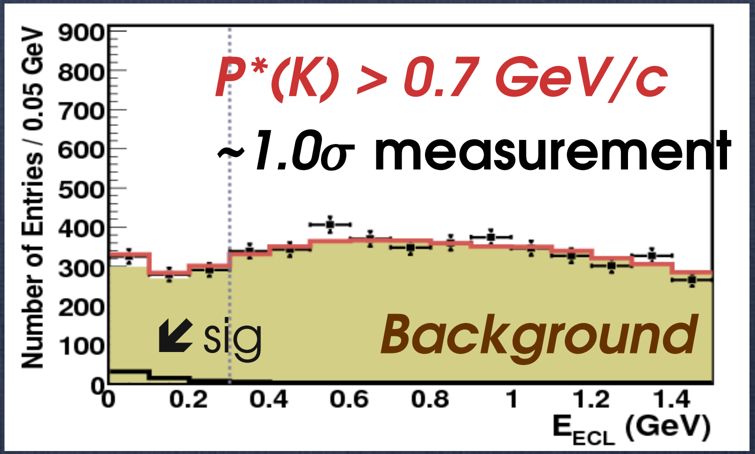
- Suppose there is no change on the analysis & detector:

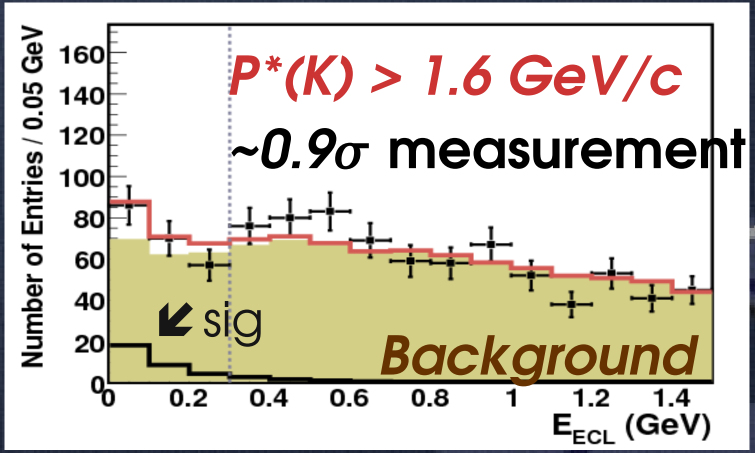


W/ the same $P^*(K)$ threshold (1.6 GeV)

W/ a lower $P^*(K)$ threshold (0.7 GeV)

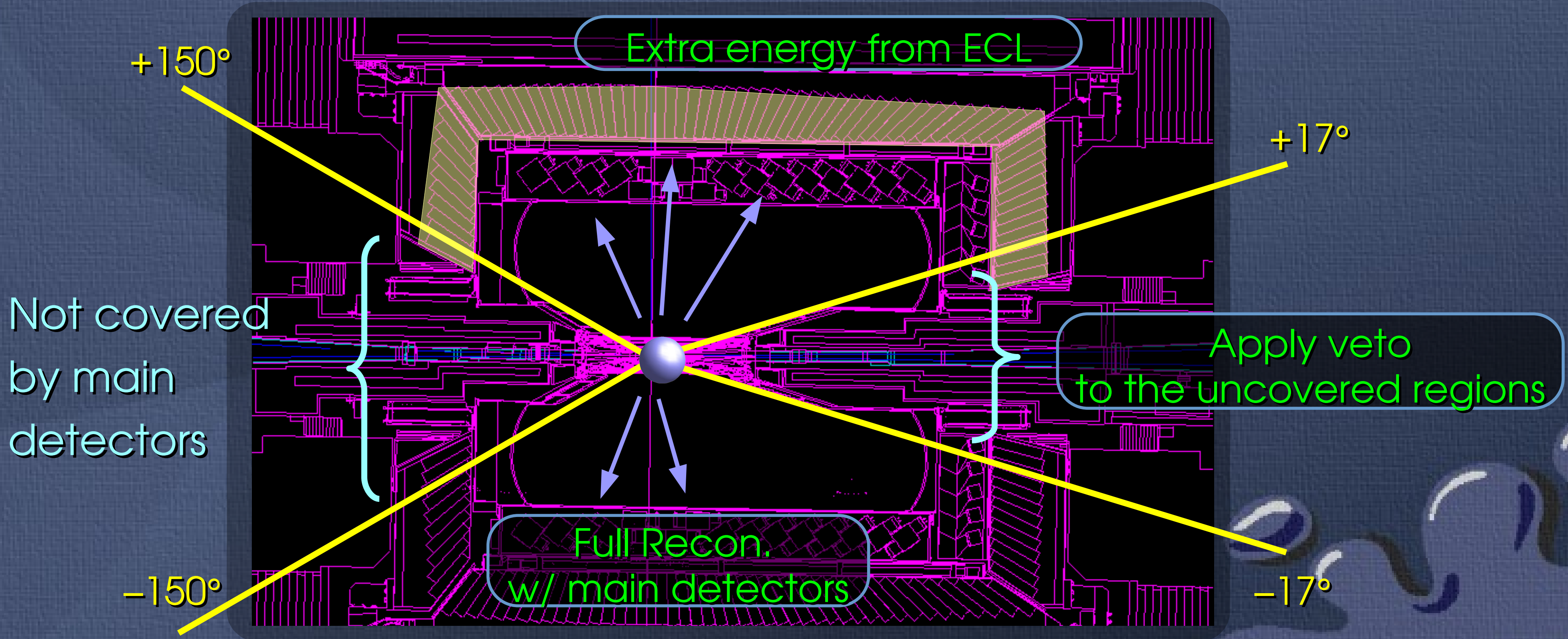
Toy MC results:





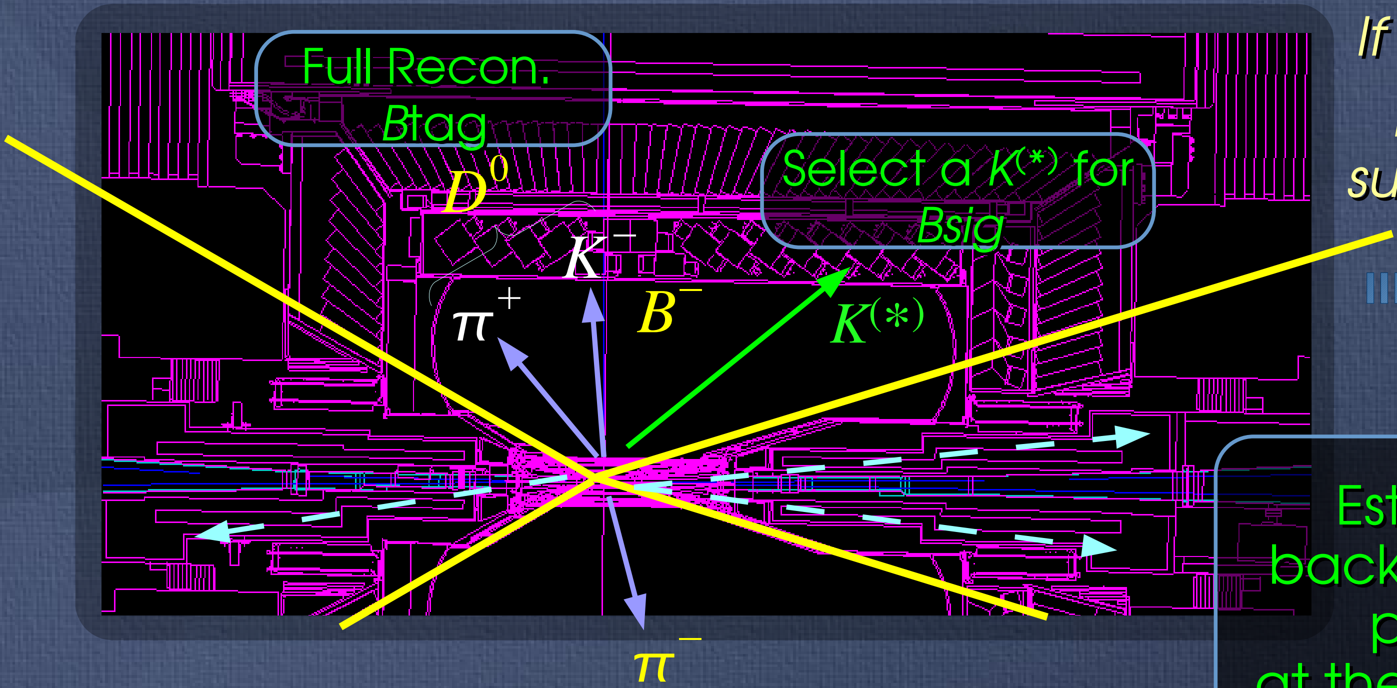
$B \to K^{(*)}\nu\nu$ w/ Super Forward Detector

- Minimum hypothesis:
  A super forward detector without precise tracking or energy resolution. *(No direct contribution to the full-reconstruction part)*
- Treat as a veto detector covering small and large angles.



Zeroth Order Study

- MC simulation + reconstruction with current Belle detector.
- Guesstimate the extra background suppression power by applying vetos to the generator particles in the uncovered region.

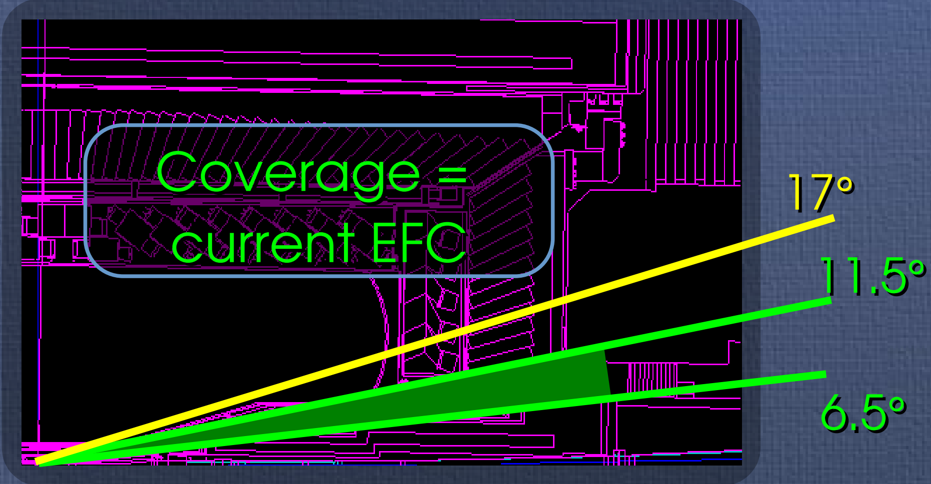


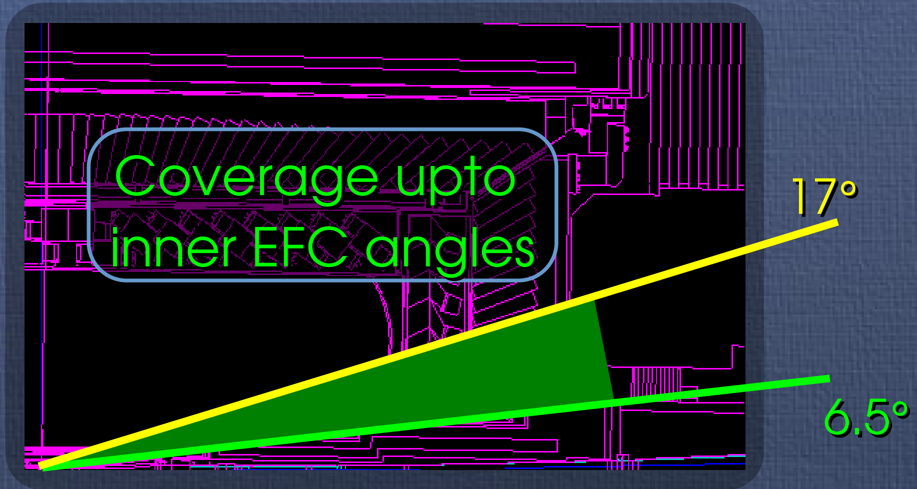
If a generator particle passed the "virtual" super forward detector

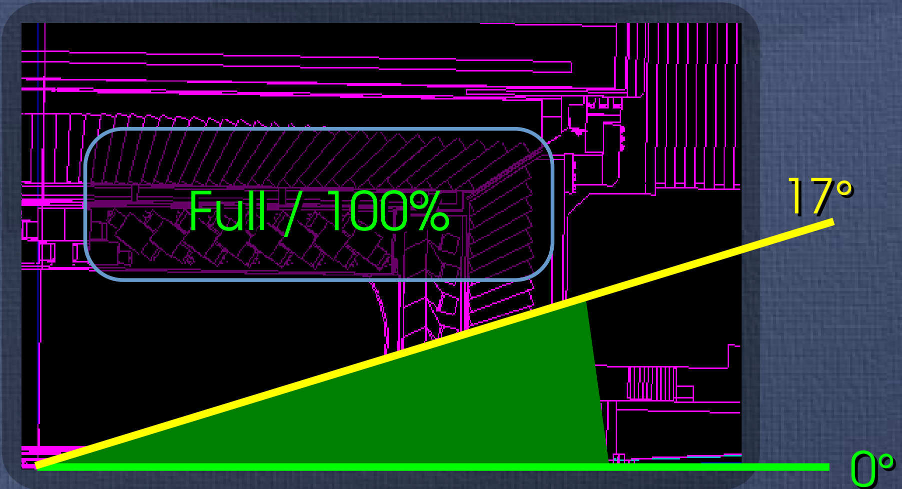
⇒ *Drop the event*

Estimated the extra background suppression power by looking at the generator particles.

Configurations & Assumptions







Detecting capability:

- Muon only.
- Charged tracks.
- Charged tracks + photon

Assuming an uniform 95% detecting efficiency for now

Zeroth Order Study: Results

- Extra background suppression power:

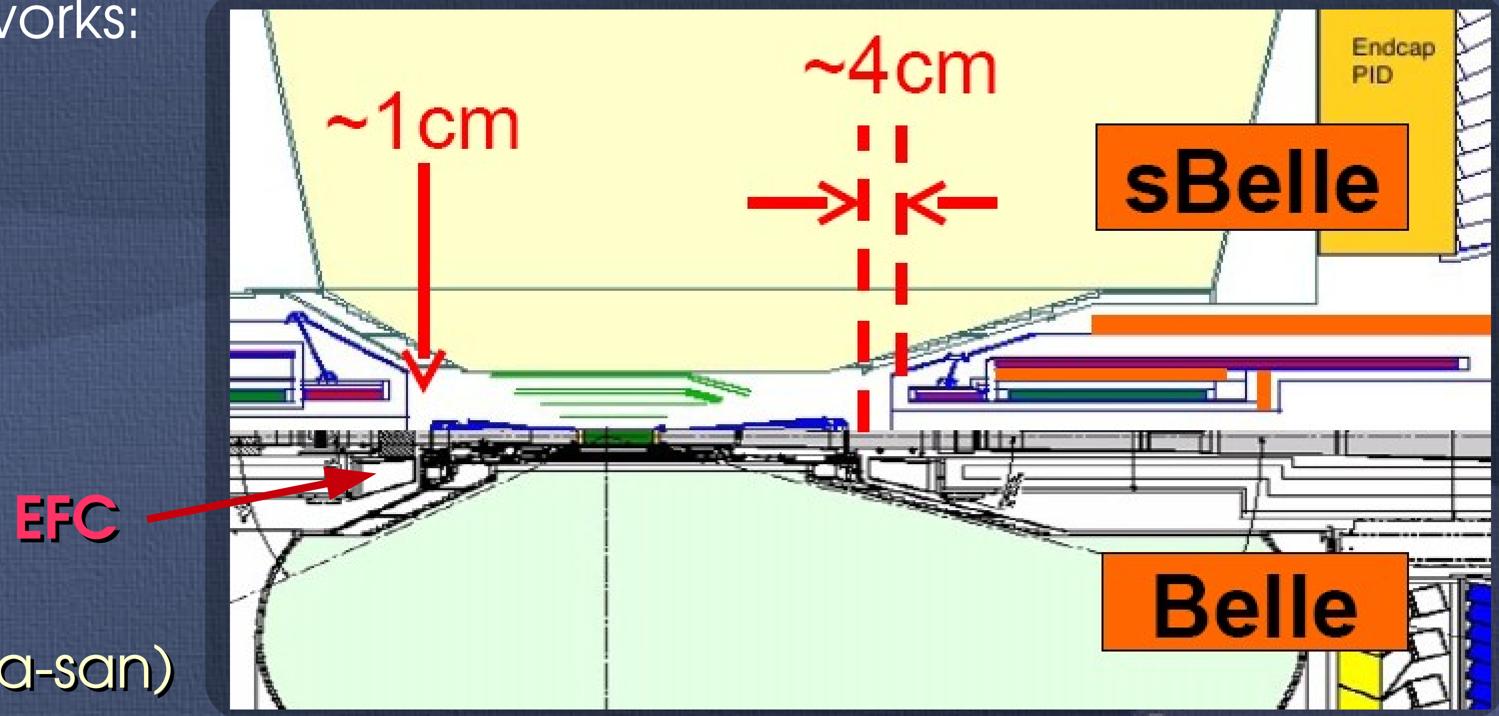
	Muon only	Charged tracks	tracks + photons
EFC Coverage	6%	21%	29%
Upto inner EFC angle	18%	51%	64%
100% Coverage	19%	55%	69%

  - In principle if we can reject all the charged tracks up to the coverage of inner EFC, we should be able to kill another **20-50%** of the background.
  - In practical, we should do a real simulation instead of such counting studies, and take the new design of IR/KEKB into account.

Extreme Forward Calorimeter ➔ Super Forward Detector

First Order Study: Geant4 Simulations

- Minimum hypothesis & target:
  A forward TRACKER for improving detector acceptance.
  (No direct contribution to main analysis, but as a veto detector)
- Reject the prompt tracks from IP for the full-reconstruction analyses.
- No space so far, so it's better to demonstrate the capability before any other works:

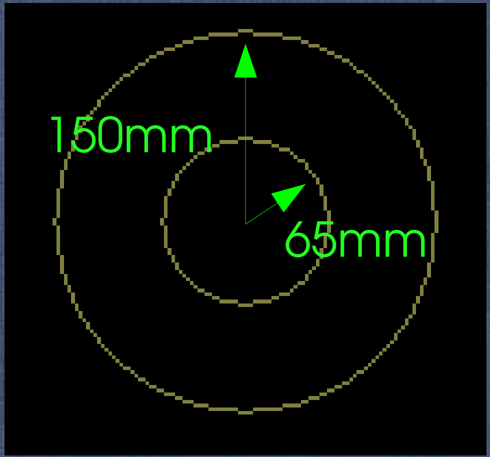


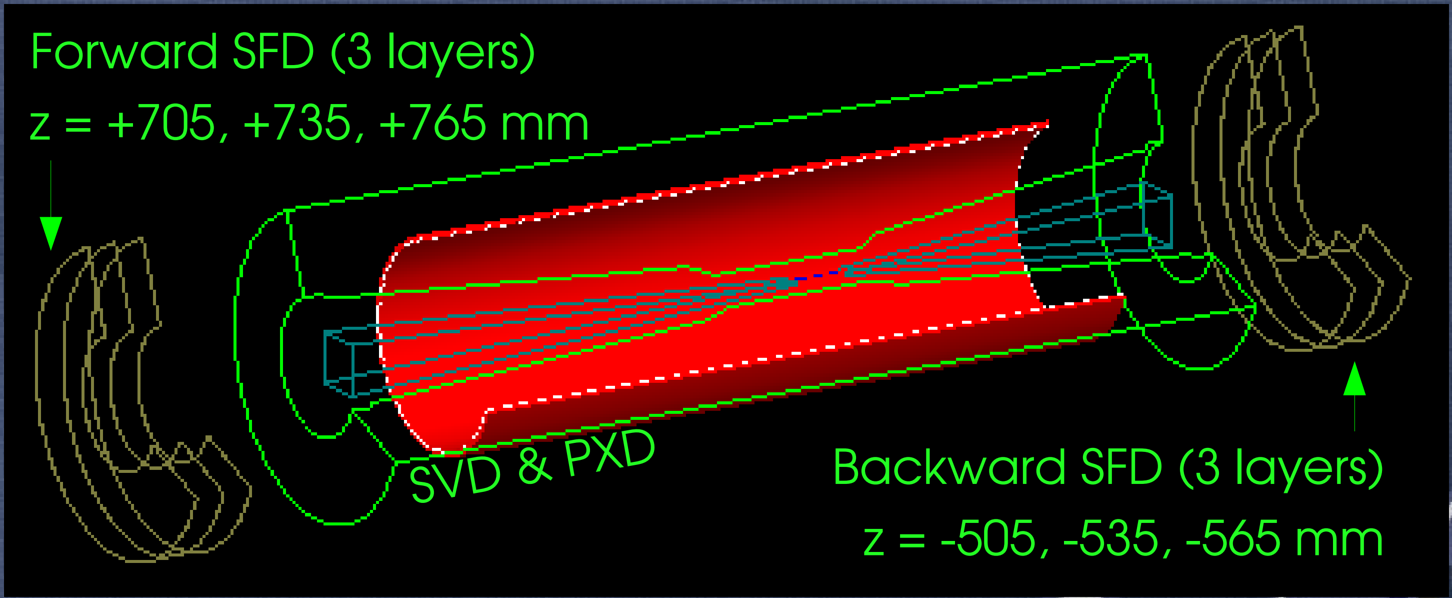
(From Tajima-san)

Preliminary Geometry

- Regardless of the space, we prepared a geant4 module under the framework of Super Belle simulations.
- Assuming a silicon pixel detector with large cells: 2mm x 2mm.
- Sensors only at this moment:

Sensor:

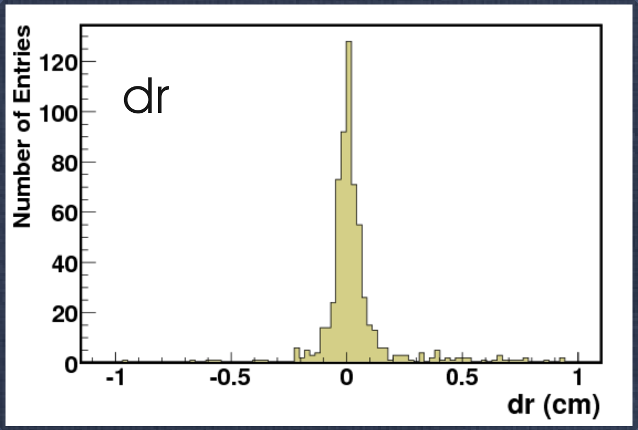


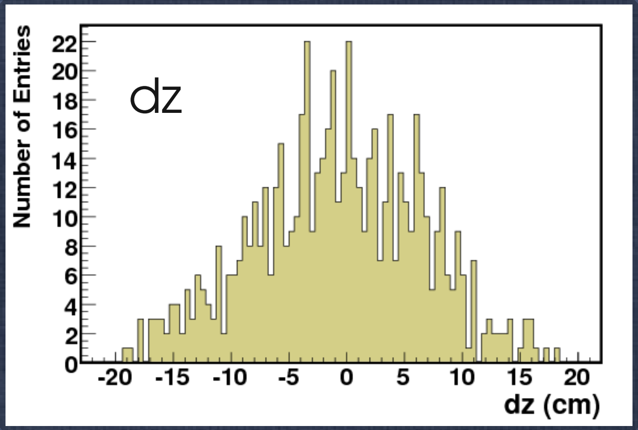


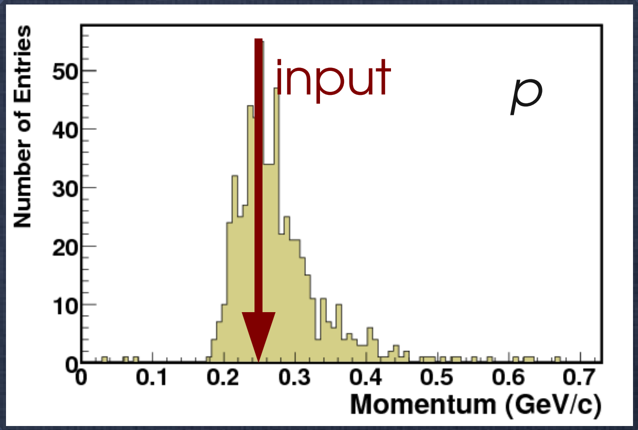
Coverage: FW (5.3°–11.1°), BW(165.1°–172.7°)

Track Finding: Helix Fit

- Track fit on 3 SFD hits with helix parameters. (very challenging!)
- Input: single forward muon with p = 250 MeV/c.
- Output: efficiency ~76% (with cuts |dr| < 1cm & |dz| < 20 cm)



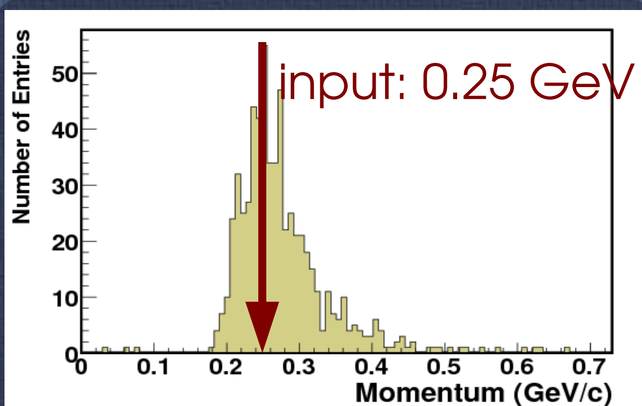


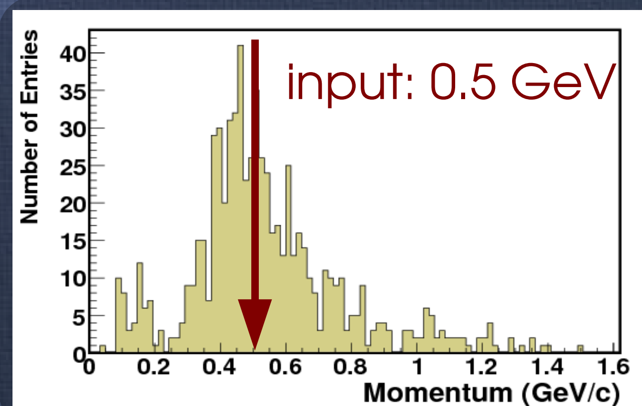


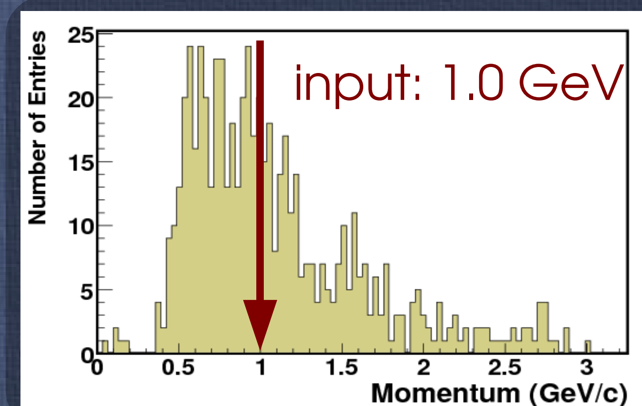
It's working in principle, but not realistic...
We should consider more stuff (e.g. shielding, noise, etc.)

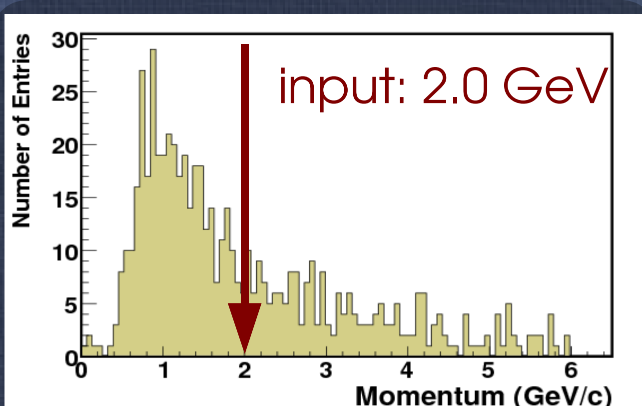
Track Finding: Helix Fit

- Helix fits are not really working for harder tracks (>0.5 GeV/*c*):
  (since the tracks become "too straight" with higher momentum)





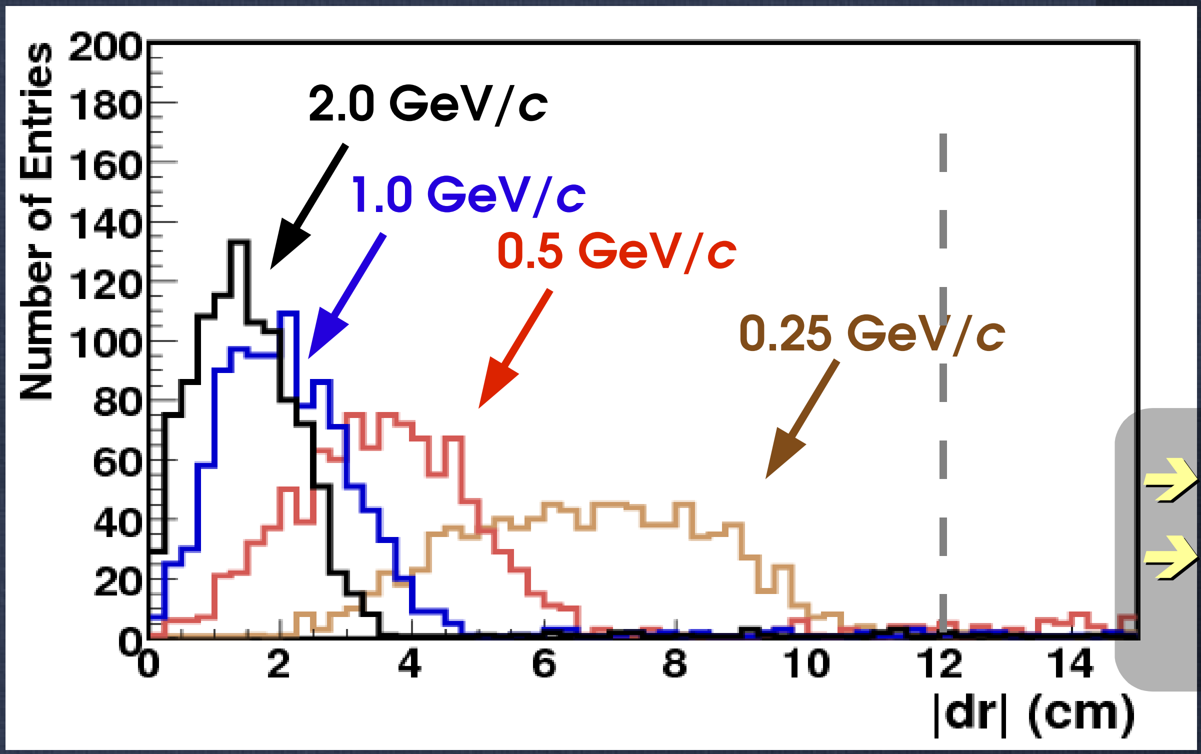




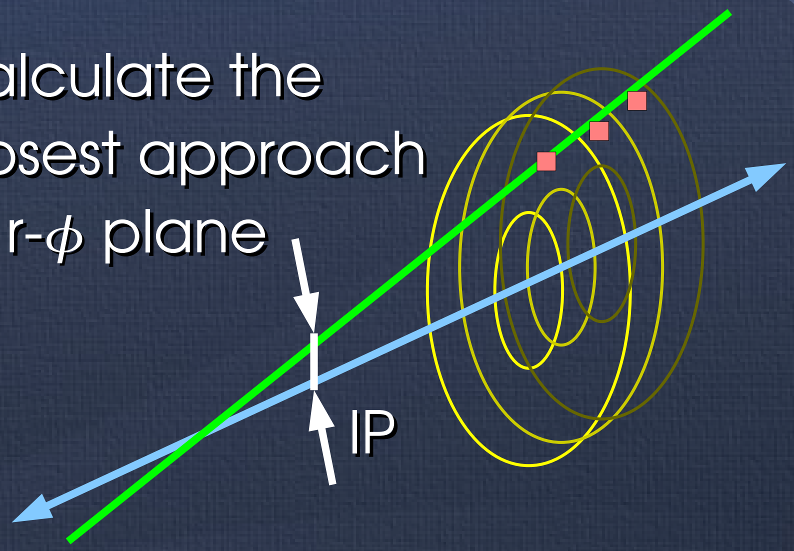
➔ *Give up helix fits, but just work with straight lines. (A much simpler case!)*

Track Finding: Straight lines

- Input: single forward muon with p = 0.25, 0.5, 1.0, 2.0 GeV/c.
- Output: efficiency >95% (cut |dr|<12 cm)



Calculate the closest approach at r-ϕ plane



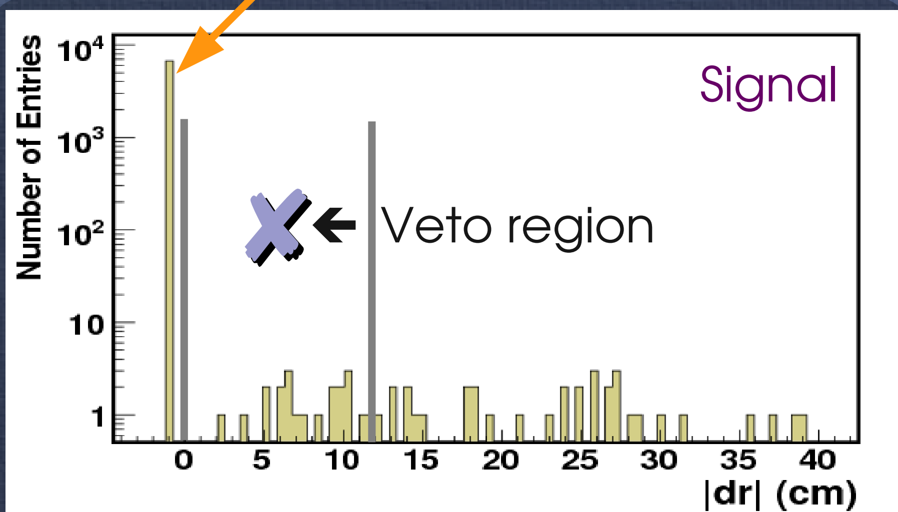
➔ *Works very well.*

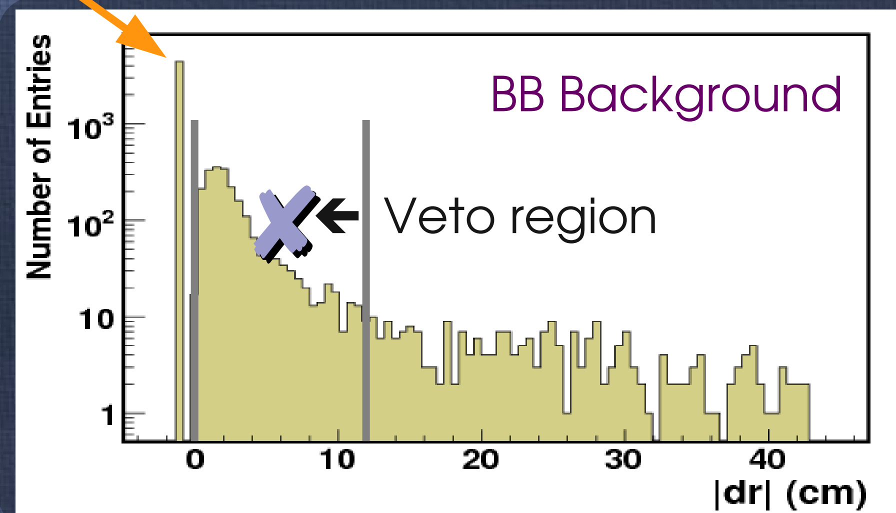
➔ *check the performance on background suppression.*

Preliminary Effects on $B\to K^{(*)}\nu\nu$

- Veto the events with one or more track(s) reconstructed:

No track(s) reconstructed





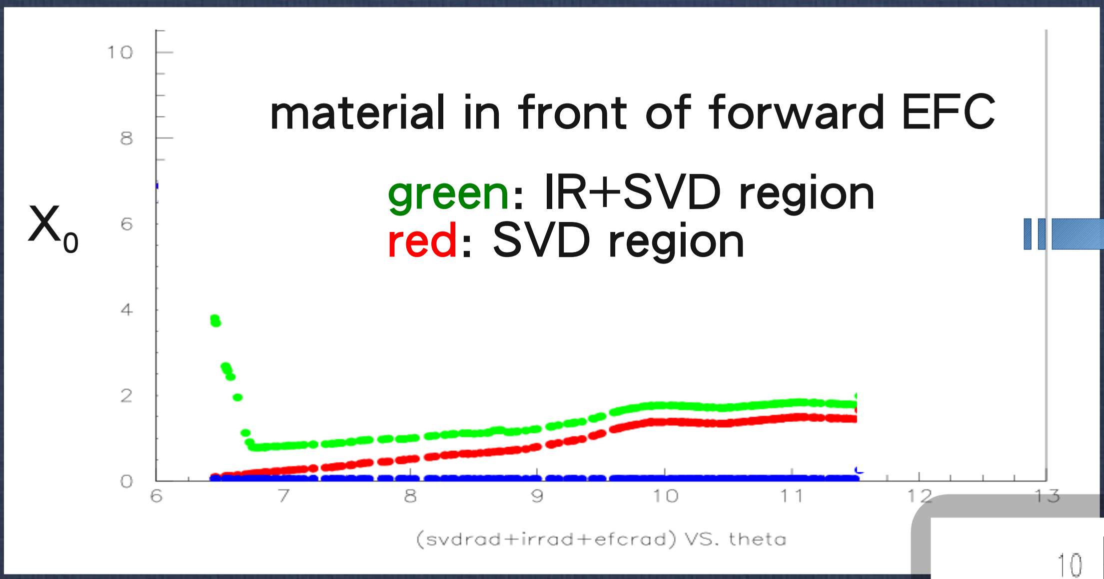
Signal efficiency: 99.7%

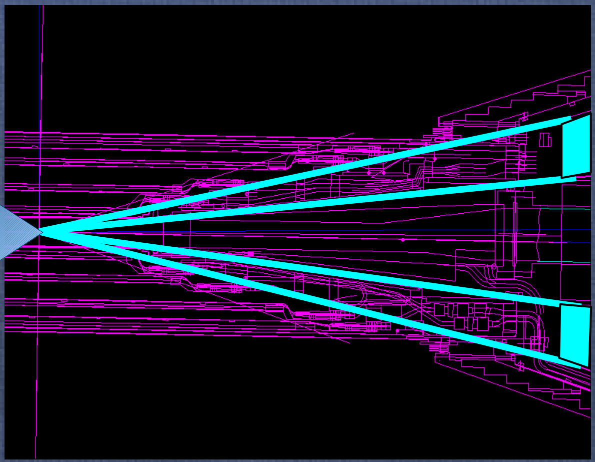
Background reduction: 31.5%

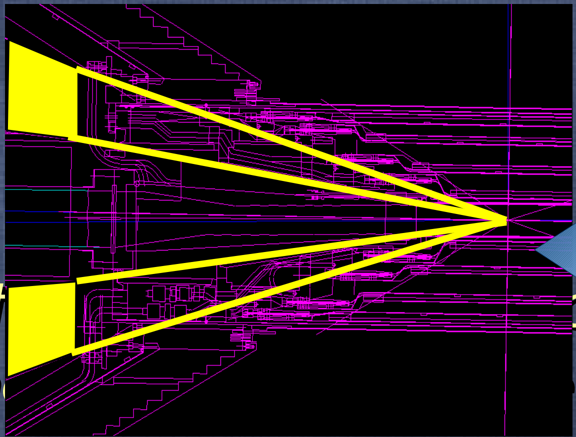
➔ *More studies are required to have a conclusive result:*
e.g. material in front of the detector,
supporting structure, shielding, etc.

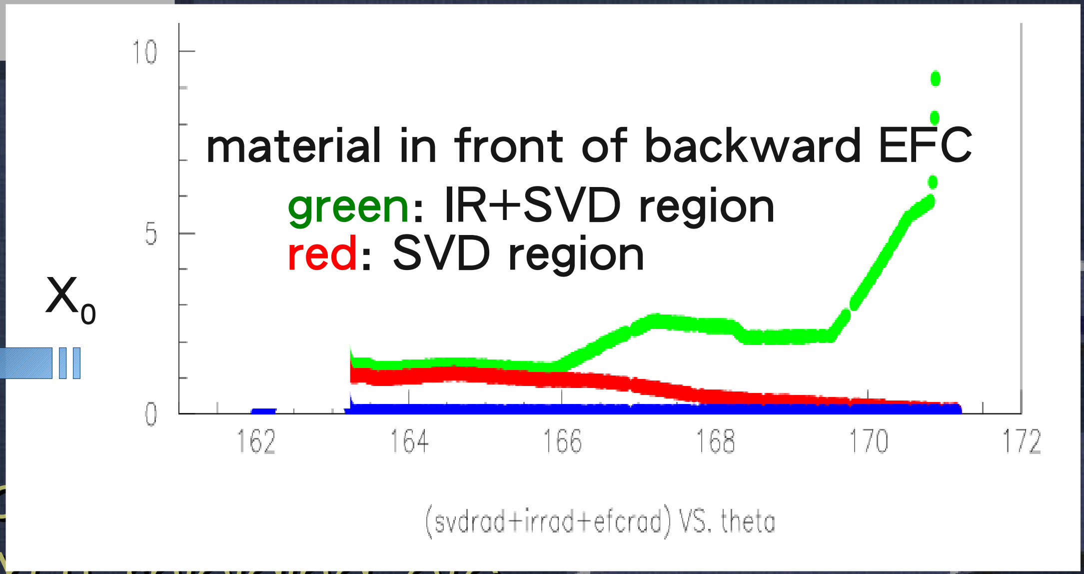
Remarks

- Material effects in front of current EFC:









➔ More st... o

e.g. m... c

inner detectors (SVD&PXD), shielding, etc.

Summary

- **MISSING ENERGIES TOPICS** have a high potential at the Super *B*-factory (e.g. $B \to K(^*)\nu\nu$, $B \to \tau\nu$, $B \to D(^*)\tau\nu$, $\Upsilon(1S) \to$nothing etc.)
  (Also see the talks in Physics Parallel section)
- This kind of study can be only achieved with a detector with good hermeticity at a clean environment.
- Using the decays of $B \to K(^*)\nu\nu$ as a bench mark mode, a preliminary configuration of the Super Forward Detector has been tested.
- Based on the geant simulations, we are able to remove ~30% of the backgrounds from *B* decay by rejecting the charged tracks pointing from the IP.
- More detailed / careful studies should be carried out.