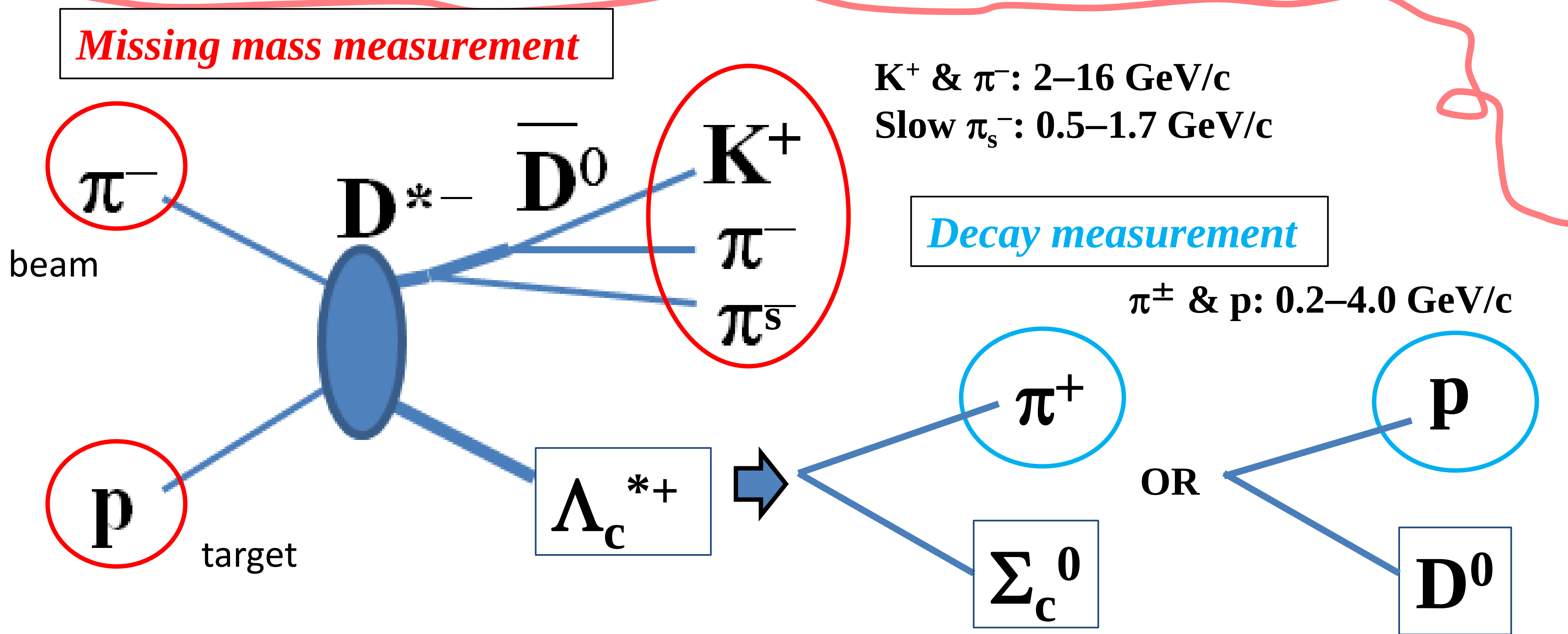
チャームバリオン分光実験における高速トラッキング検出器の開発

大阪大学RCNP
教務補佐員
浅野秀光 for the E50 collaboration

E50 : Missing mass spectroscopy of charmed baryon



$\pi^- + p \rightarrow Y_c^{*+} + D^{*-}$ reaction @ 20 GeV/c

1) Missing mass spectroscopy
   - $D^{*-} \rightarrow \bar{D}^0 \pi_s^- \rightarrow K^+ \pi^- \pi_s^-$: $D^{*-} \rightarrow \bar{D}^0 \pi_s^-$ (67.7%), $\bar{D}^0 \rightarrow K^+ \pi^-$ (3.93%)

2) Decay measurement
   - Decay particles ($\pi^\pm$& proton) from Y_c^*

* tagging both D* and D^0 to reduce background by order of 6 to 7

contents

-- High-p beam line

-- E50 Spectrometer (デザイン中)

-- 高速トラッキング検出器 (デザイン中)

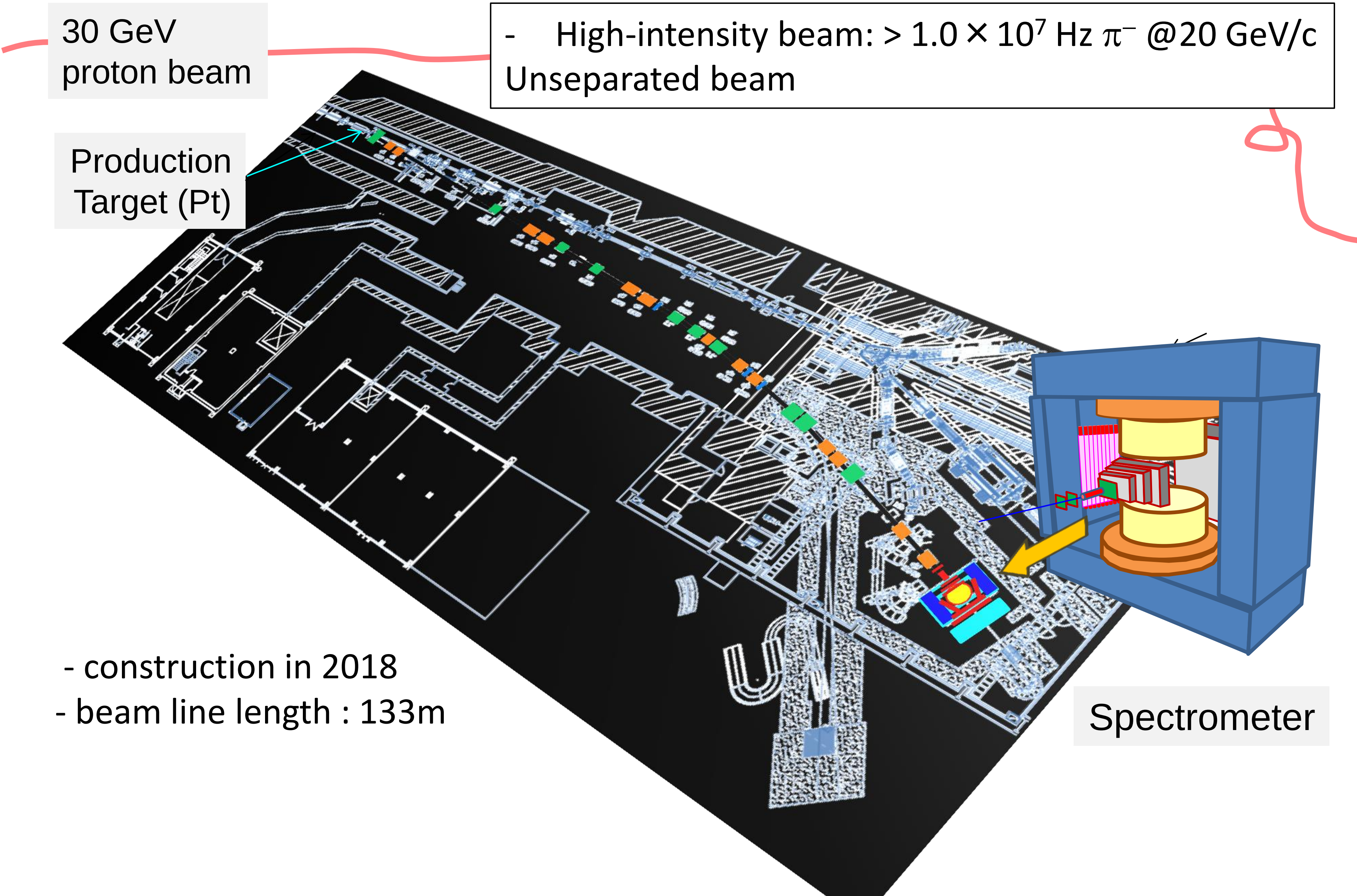
High rate ($O(10^7)$ Hz)のビームのトラッキングが必要

これを如何に行うか？

-- Scintillating fiber tracker

-- Silicon strip detector

High-momentum Beam Line at J-PARC

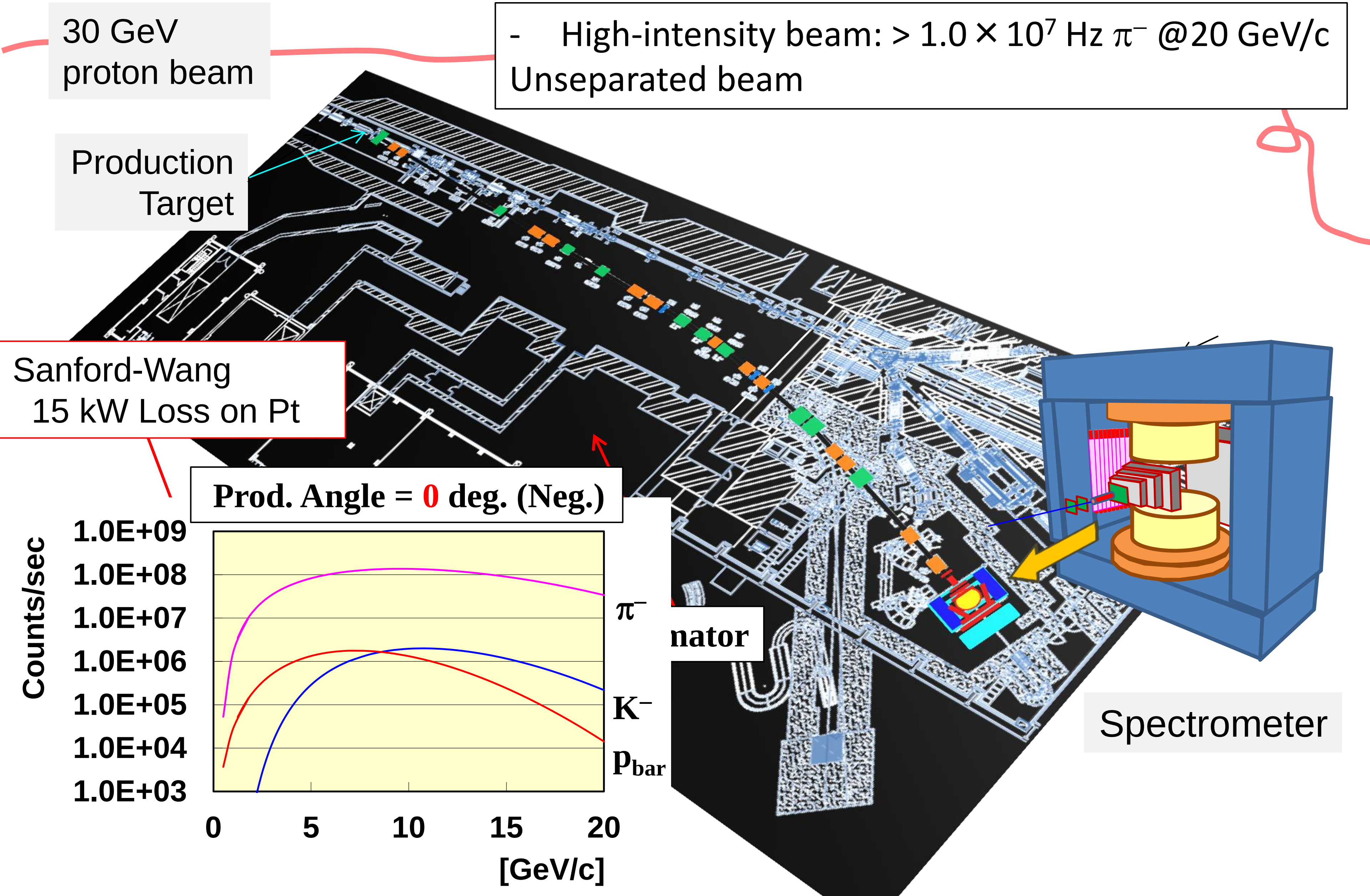


- High-intensity beam: > 1.0×10^7 Hz π^- @20 GeV/c
Unseparated beam

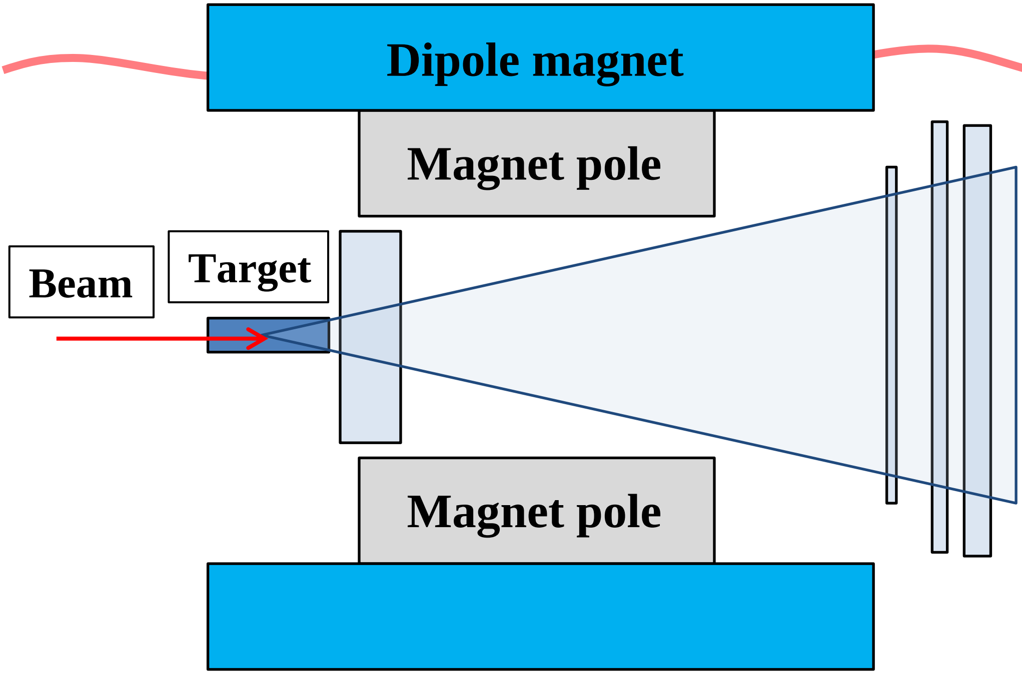
- construction in 2018
- beam line length : 133m

High-momentum Beam Line at J-PARC

- High-intensity beam: > 1.0×10^7 Hz π^- @20 GeV/c
Unseparated beam



Spectrometer design

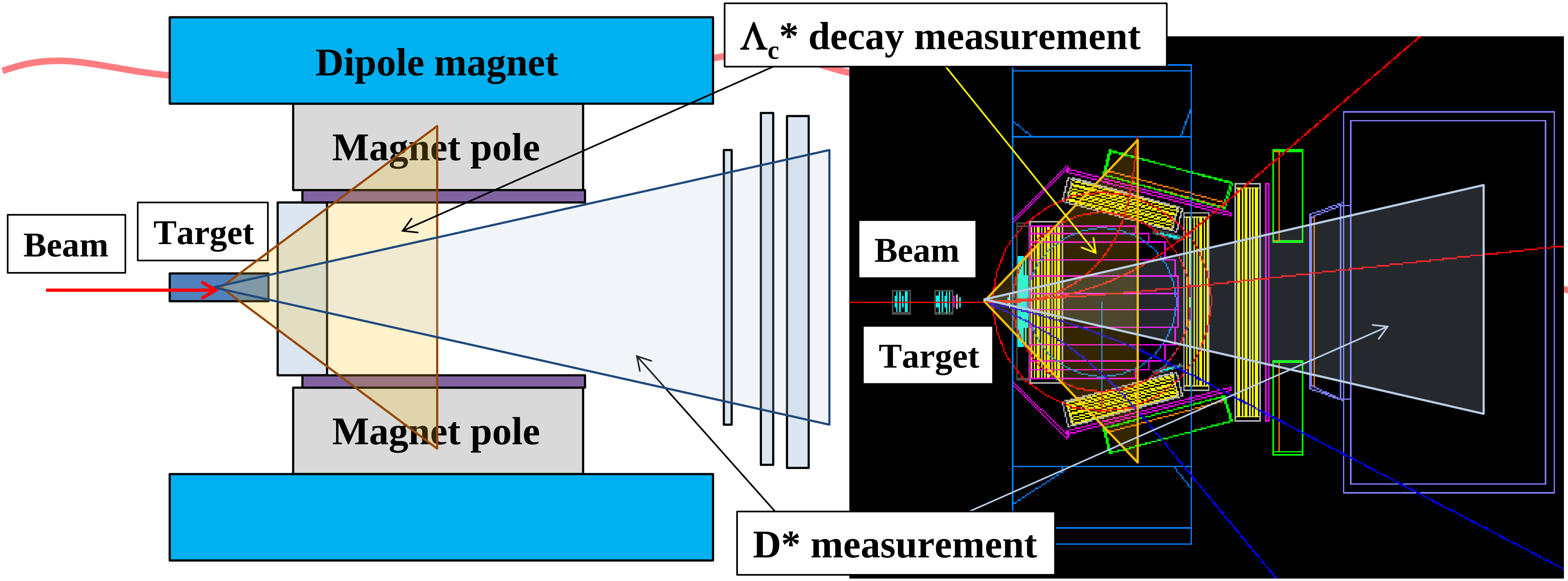


FM cyclotron magnet

- Forward + Internal detectors ($\theta < 40°$)
  - D^* detection by forward detectors
    - High-momentum K^+ and π^-: Forward detectors
    - π^- from D^{*-} decay: Internal detectors
  - Y_c^* decay particle detection
    - Horizontal direction
    - Vertical direction

  ⇒ Decay measurement: Both pole and azimuthal angles

Spectrometer design

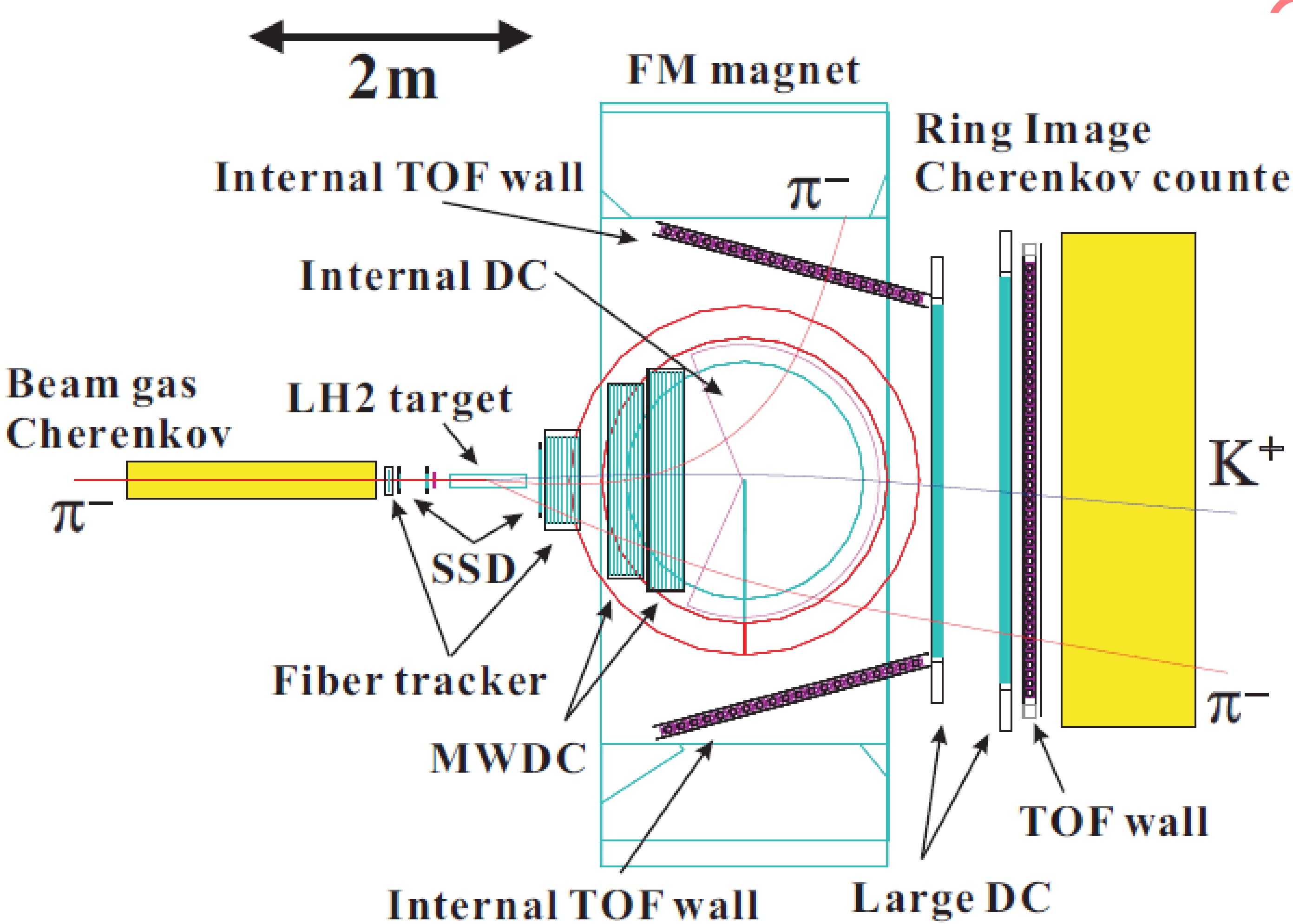


- Forward + Internal detectors ($\theta < 40°$)
  - D^* detection by forward detectors
    - High-momentum K^+ and π^- from D^0 : Forward detectors
    - π^- from D^{*-} decay (soft pion) : Internal detectors
  - Y_c^* decay particle detection
    - Horizontal direction: Internal TOF counter
    - Vertical direction: Pole face TOF counter

  ⇒ Decay measurement: Both pole and azimuthal angles

高速トラッキング検出器（検討中）

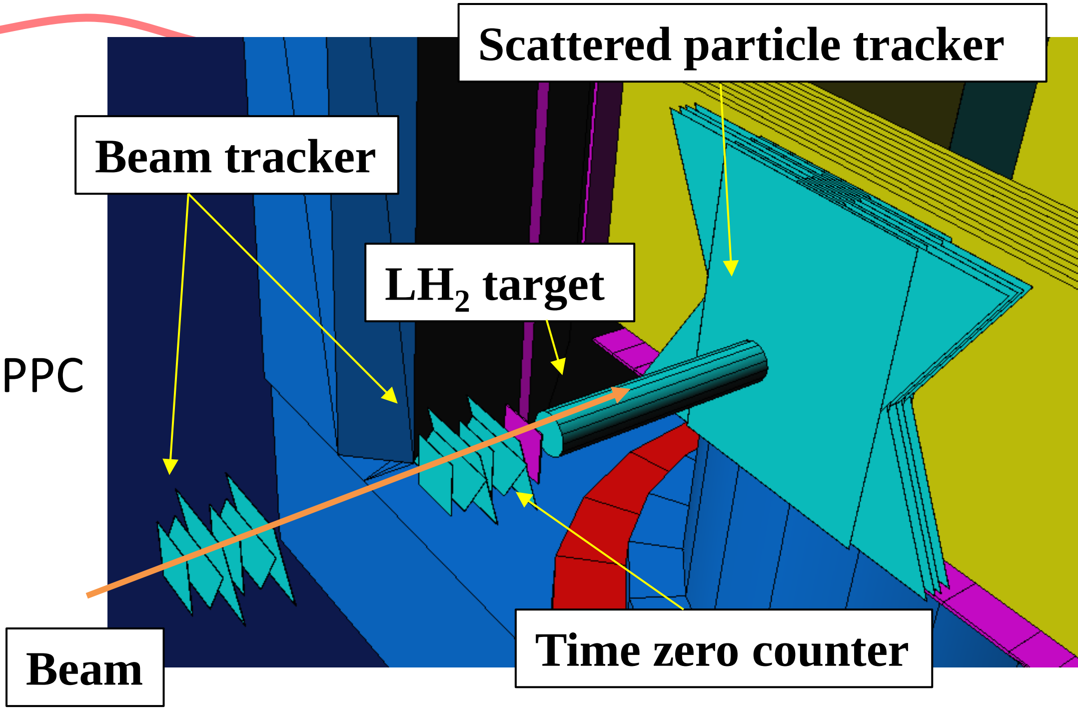
E50 : オリジナルプロポーザル案



target 周辺の検出器

Time zero counter （T0)

- Reference timing for TOF
- 時間分解能: < 100 ps(rms)
- 3 mm幅シンチレータ + 3 mm MPPC



LH2 target : 57 cm

Beam Tracker

active area

: 10 cm ＊ 10 cm

- hit rate : 30 MHz

Scattered particle tracker

active area

:60 cm * 80 cm

- reaction rate : ~2 MHz

高速トラッキング検出器（検討中）

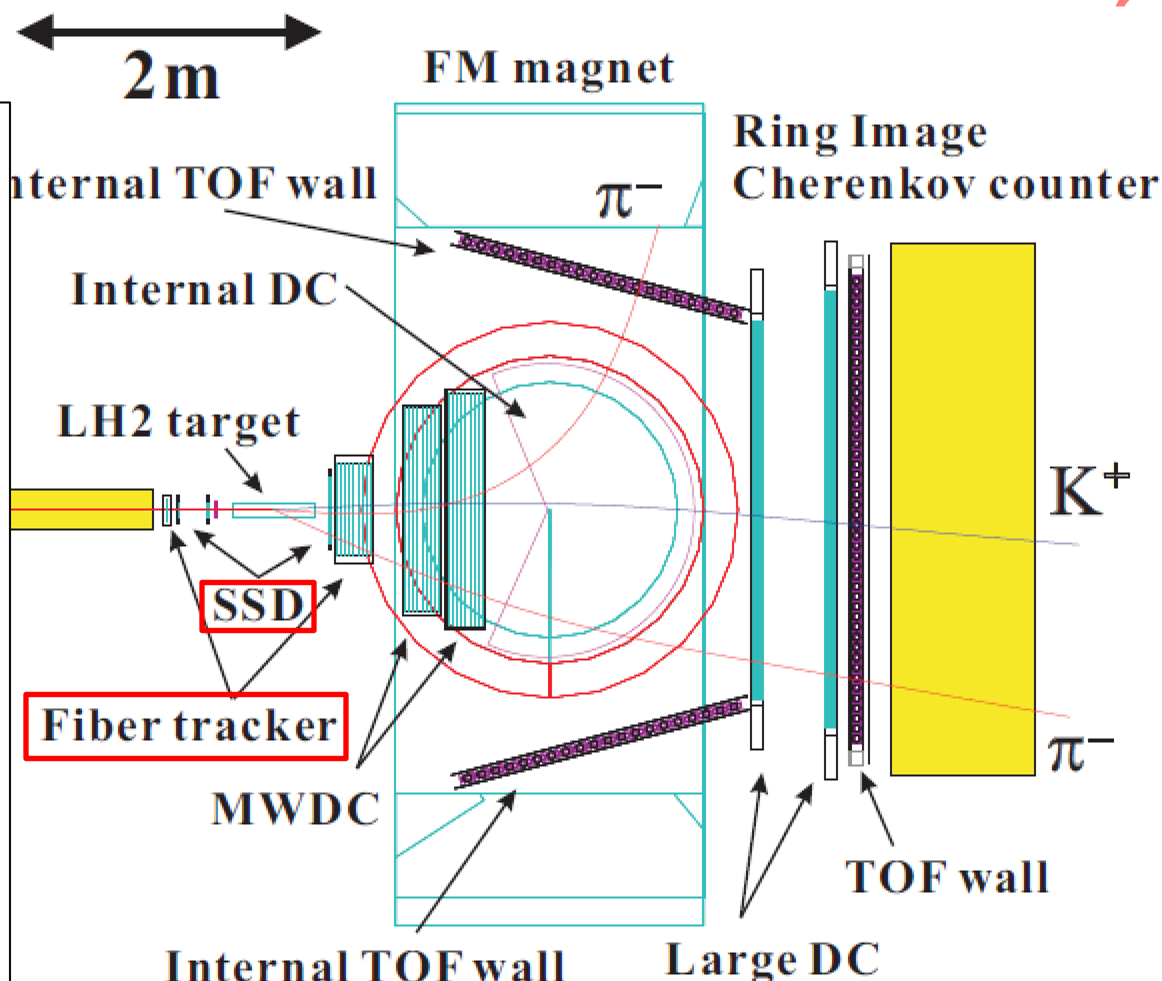
E50：オリジナルプロポーザル案

標的前後に
シリコンストリップ検出器 (SSD)
（高位置分解能 ）

シンチレーティングファイバー
検出器（高時間分解能
~1nsec）

ビームの運動量測定
$\Delta p/p \sim 0.1$ % @ 20 GeV/c
標的での位置分解能
Δx (y) < 500 um

散乱粒子の運動量測定
$\Delta p/p = 0.2\%$ @ 5 GeV/c



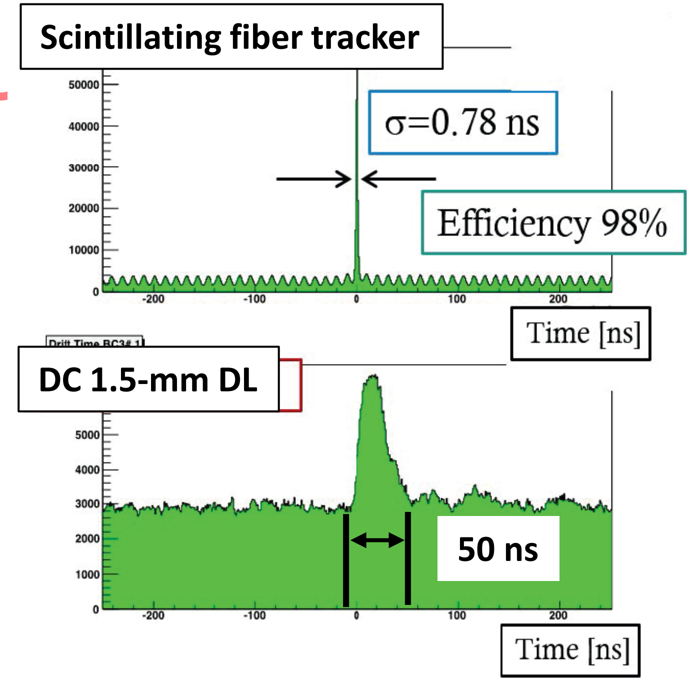
Fiber Tracker

＊J-PARC beam: time structure
⇒ Narrower time gate is more essential to suppress accidental hits.

- E50: 30 MHz @ 2 sec spill

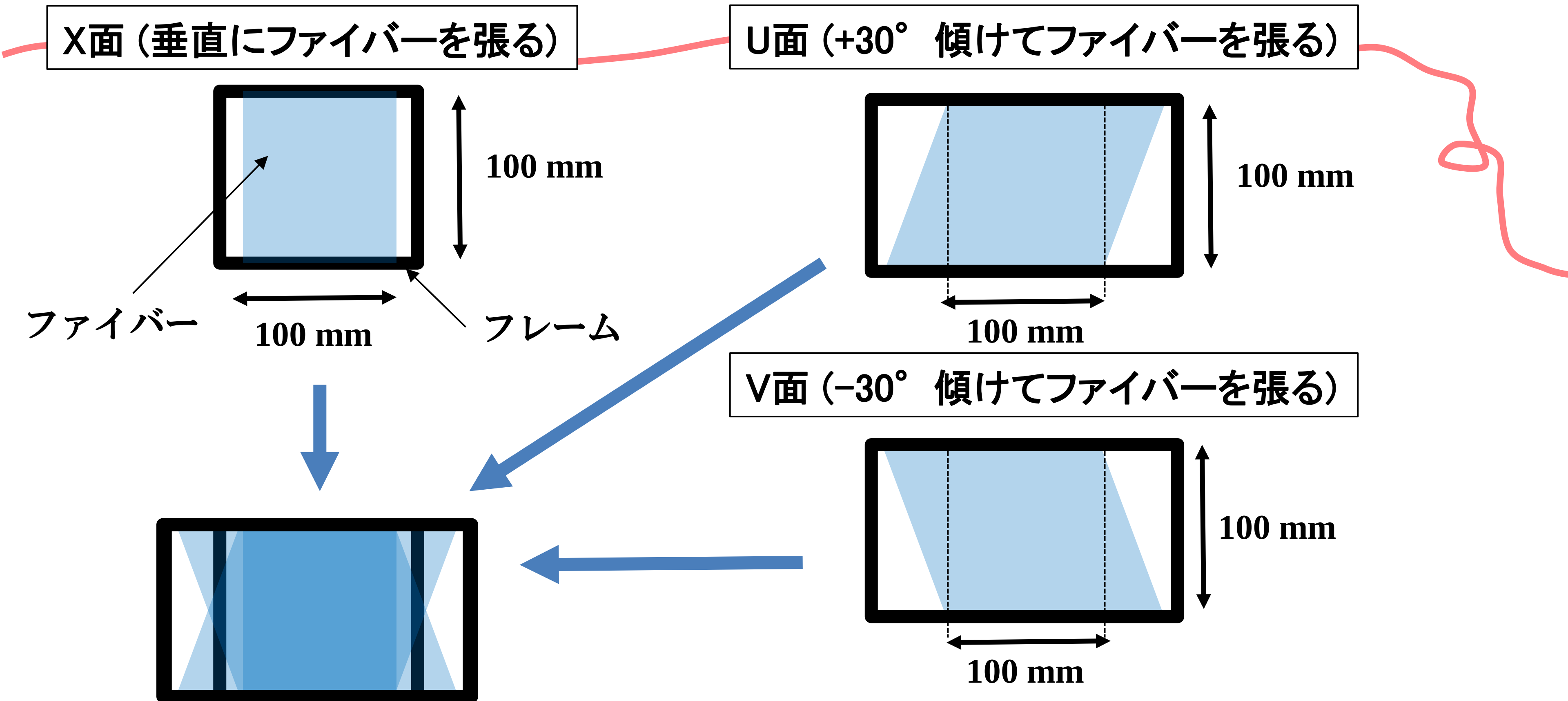
- Requirements
  - 1 MHz/1 mm fiber
  - Tracking efficiency: ~99%
  - Thin material thickness

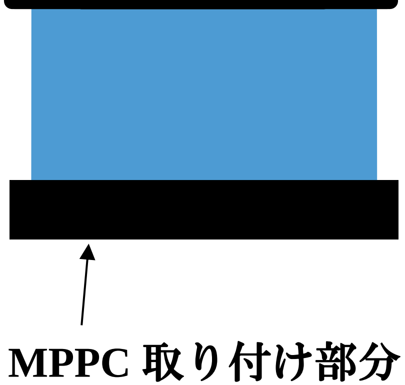
- Beam tracking
- Target downstream tracking
  - Detector design
  - Simulation study
  - Readout electronics development



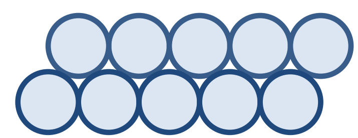
E10: 12 M/spill (6 MHz) beam

Fiber tracker 試作機



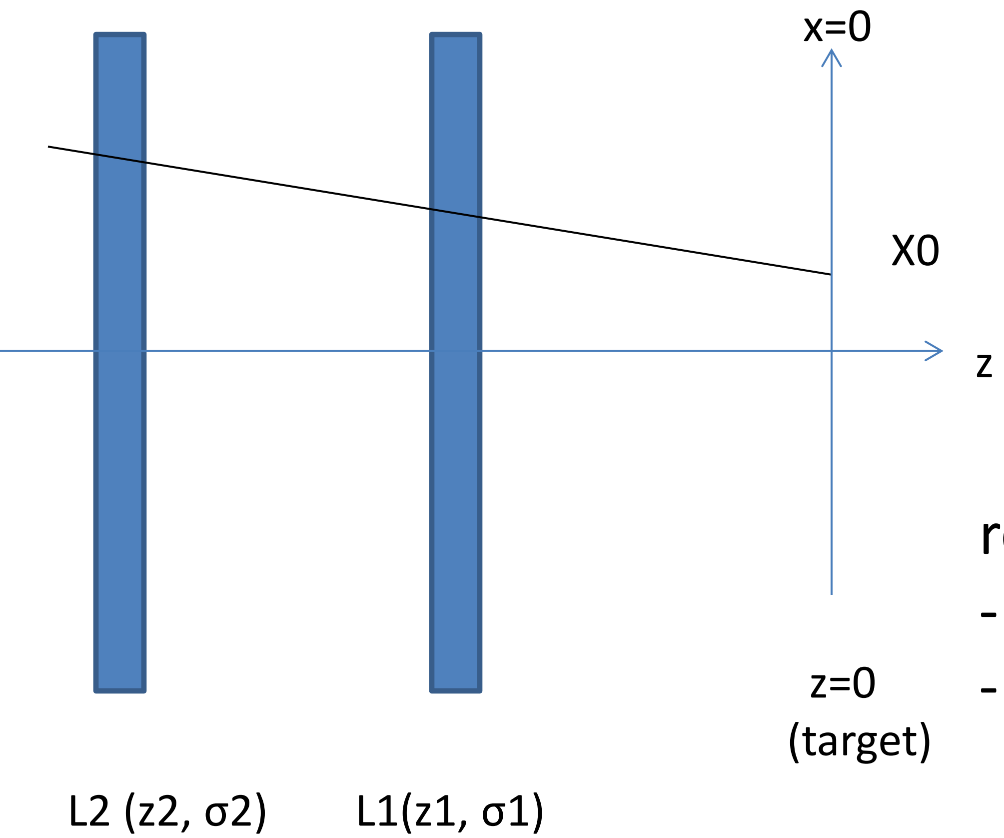


直径 1mm (300 umのも検討中)
２層俵積み



- 最終的に全体をブラックシートで覆って遮光する
- MPPC 読み出しは ESIROC board (cf. 本多さん講演）
  (将来的には CITIROC/PETIROC chip board に置き換え）

配置の検討



2次元でz=0に射影したときの
位置分解能

$$\sigma(X_0) = \frac{\sqrt{\sigma_1^2 z_2^2 + \sigma_2^2 z_1^2}}{z_2 - z_1}$$

(cluster size in x-axis ~ 1.5)

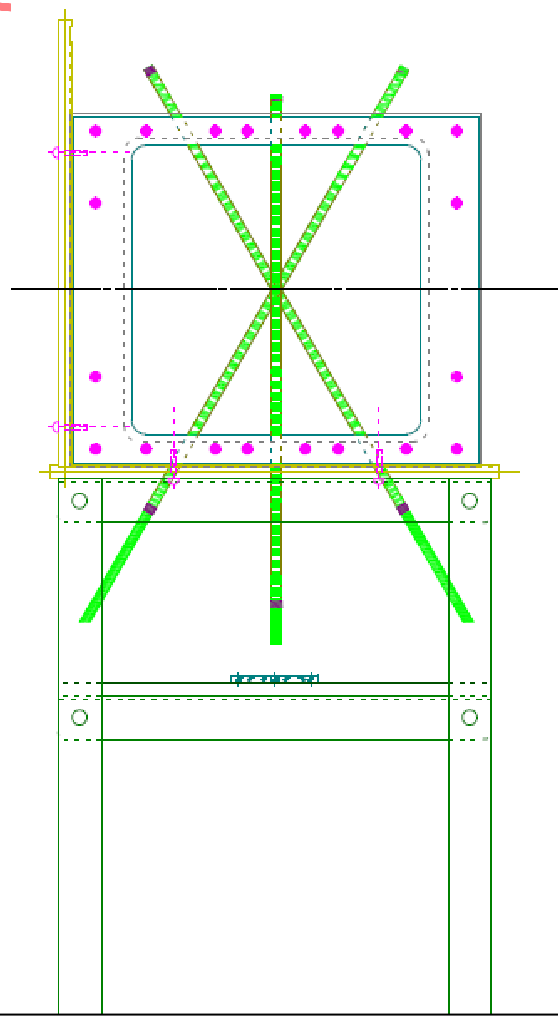
~0.40 mm (z1=40 mm, z2=370 mm)

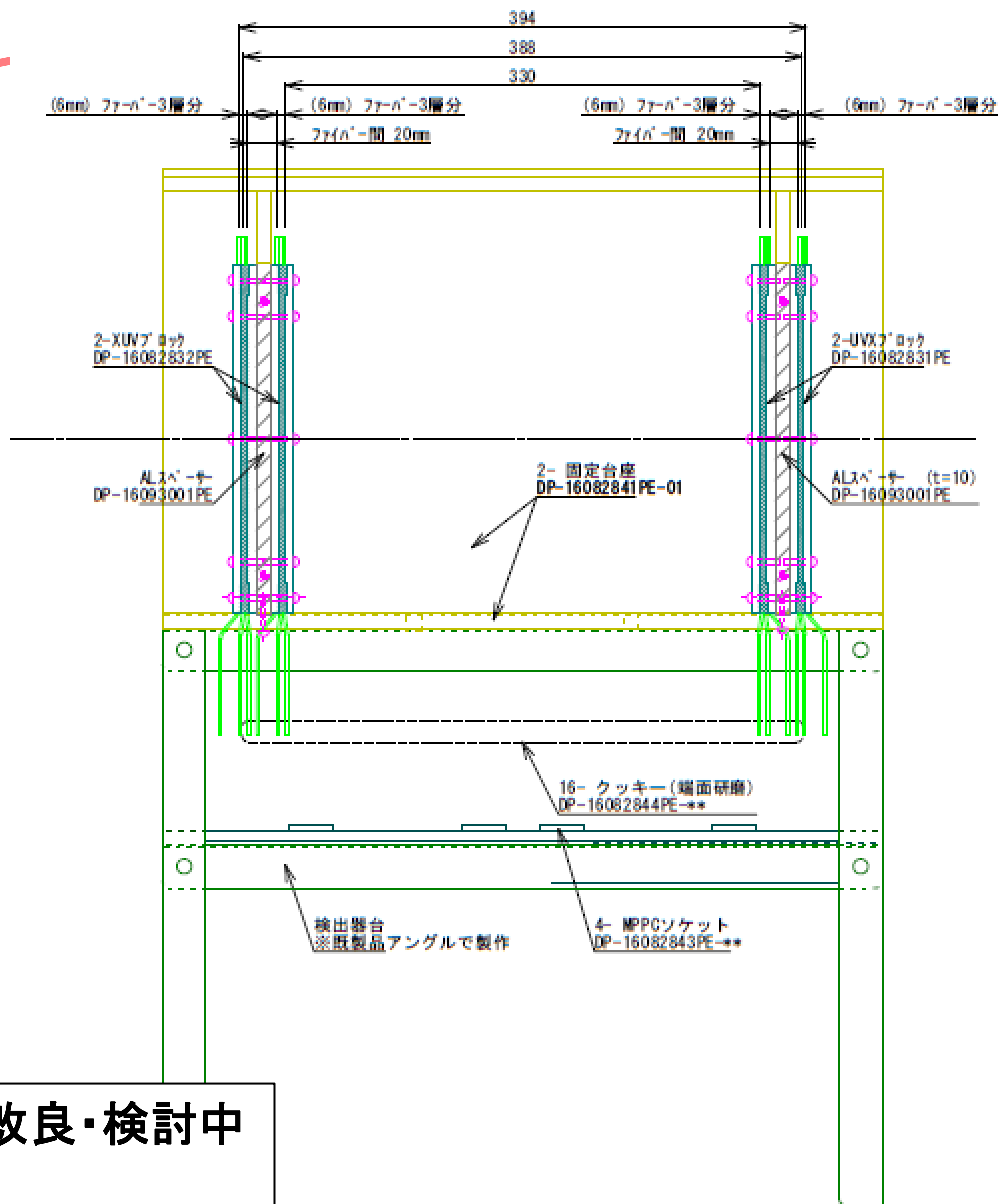
redundancy の必要性?

- 検出効率
- remove ghost track

物質量は小さくしたい
(ファイバー上でのreactionが
event rateを上げるため)

Fiber design work





Drift chamberのやり方も踏まえ改良・検討中
・ファイバーの位置出し方法

高速トラッキング検出器（検討中）

- Fiber tracker 単独でも一応目標の運動量分解能 ($\Delta p/p \sim 0.1\%$) は達成
- 懸念事項
  - -- MPPCの放射線損傷, High-pでの放射線レベル
  - -- 各ファイバーのアラインメント精度

- シリコン検出器（SSD)はオプションとして検討中
  - さらにmissing mass 分解能向上
  - 高精度なvertex検出によるバックグラウンド除去

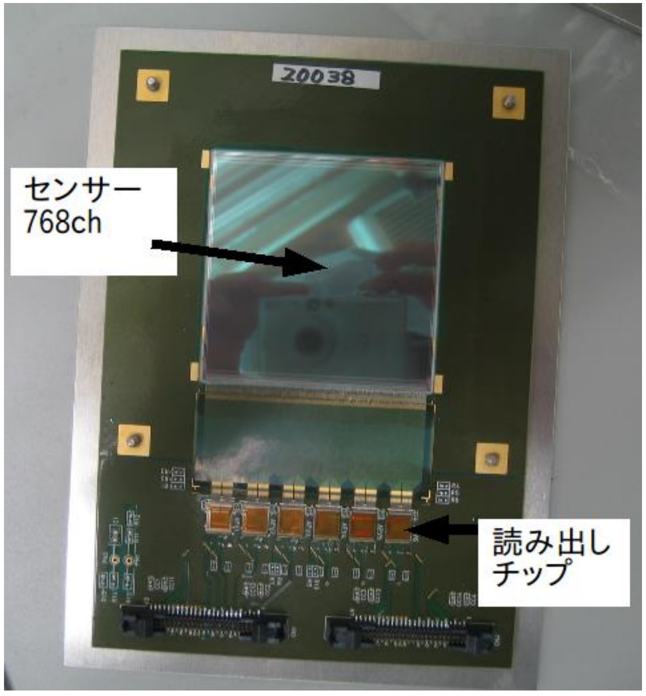
シリコンストリップ検出器(SSD)　案

Single Side Strip sensor をAPV25-s1 (developed by CMS collaboration)で読み出し。

E10 (中性子過剰ラムダハイパー核実験)

active area:
6 cm x 6 cm

strip pitch
80 um

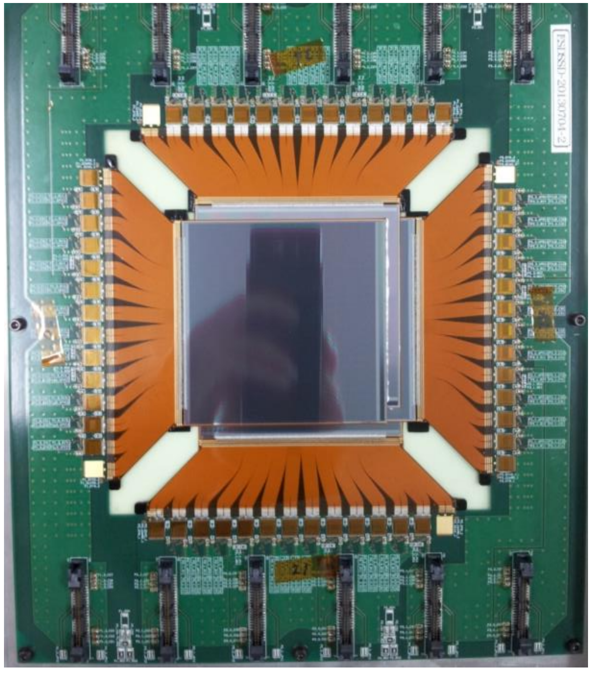


H. Asano, K. Tanida *et al.*

E07
(エマルジョンによるダブルハイパー核実験)

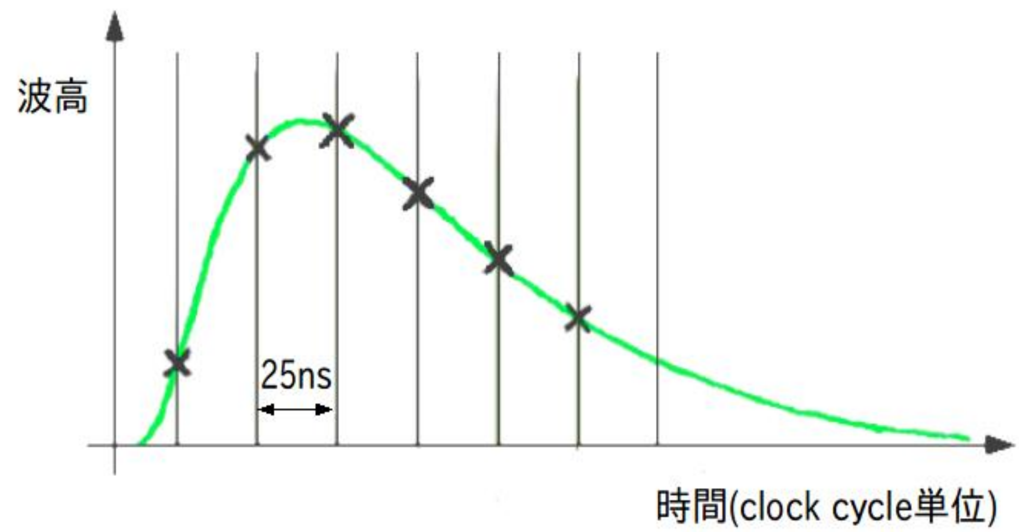
active area
7.6 cm x 7.6 cm

strip pitch
50 um



Developed by E07 collaboration

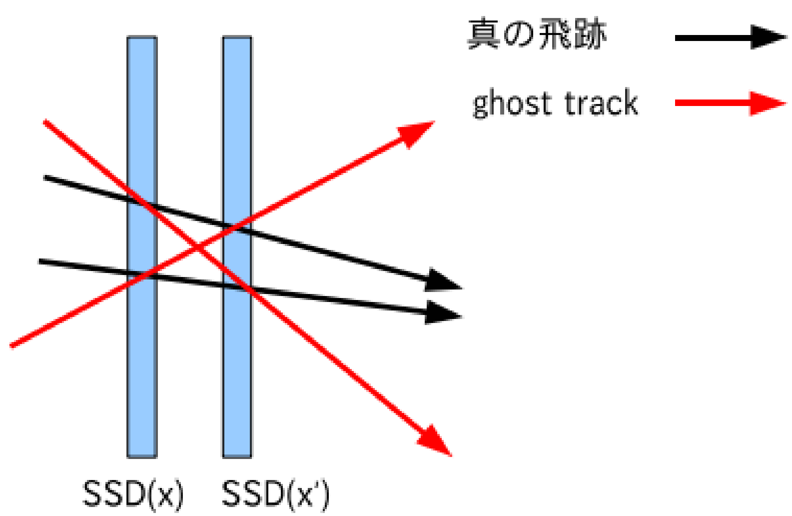
シリコンストリップ（SSD） 案



APV25-s1 chip

CMSグループが開発
・128chの読み出し
・multiplexerによりシリアル化
・波形解析が可能

E10で使用されたもので
時間分解能 ~ 3 nsecを達成。
(ref. R. Kiuchi, H. Asano et al.
NIMA763 (2014) 399-403)



シリコンセンサーの高位置分解能
＋APVによる高時間分解能

High rate のDC beam のトラッキングにも有効

シリコンストリップ（SSD） 案

☹APV25-s1の仕様と、streaming DAQ とのミスマッチ

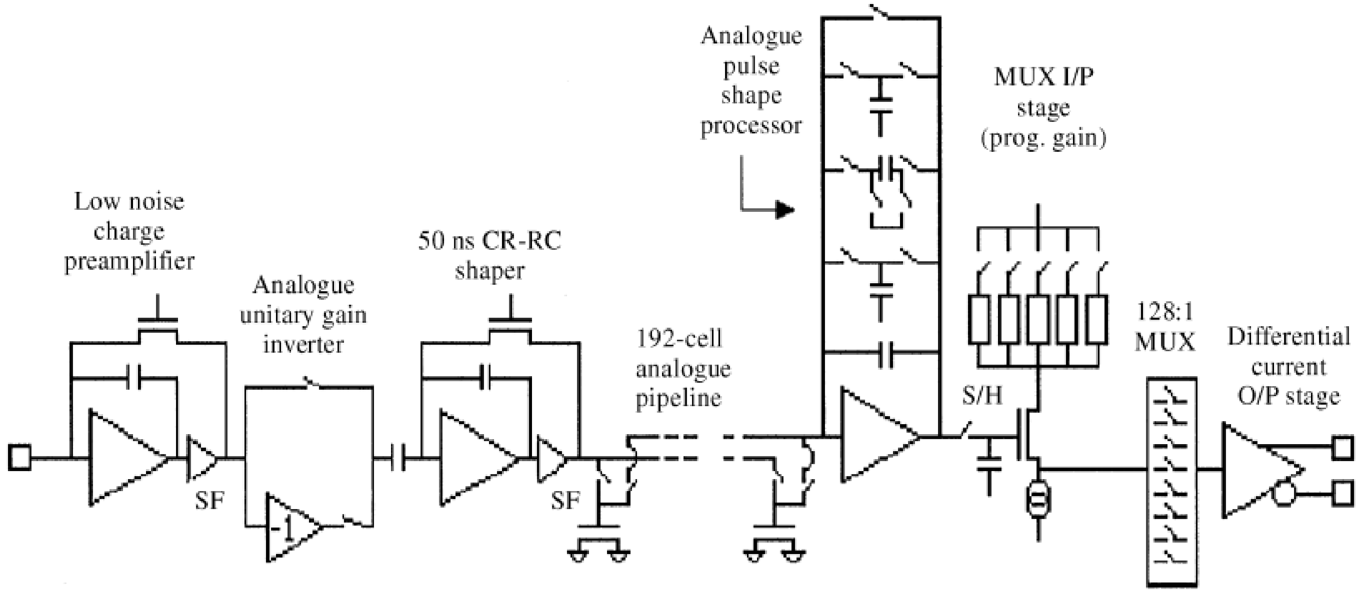


Fig. 1. Block diagram of one channel of the APV25.

ref. NIM A 466 (2001) 359–365

-analogue pipeline というのが ring buffer になっていて、外部からのトリガーがくると、データをシリアル化して転送。

外部トリガーの必要性 ⟷ **streaming DAQの思想**

シリコンストリップ(SSD) 案

E50のデザインにマッチするもの

- self-trigger 可能なもの
- 高時間分解能

候補、実際の性能等を調査中。

- FSSR2 (BTeV, SuperB @INFN, CLAS12@JLab)
- n-XYTER (EU FP-6 NMI3 project DETNI＠FAIR)
- STS-XYTER (CBM@FAIR)
- VMM (LHC-ATLAS upgrade)
- PASTA (PANDA)

or 新たにASICを開発 ？

高速トラッキング検出器

O(10^7) Hz のDC beam に対して、現状考え得る飛跡検出器

- **高速応答**
- **高レート耐性**
- **高位置分解能**
- **低物質量**

- scintillating fiber tracker + streaming (trigger-less) DAQ による readout

- Streaming DAQ に対応したSSD

- Streaming DAQに対応したMPGD ？

まとめ

- チャームバリオン分光実験のための高速トラッキング検出器の開発

- High rate ($O(10^7)$ Hz)のビーム測定
- Fiber tracker ＋ streaming DAQ の開発を主軸
- Silicon Strip Detector を加えることによる、精密なトラッキングも視野。方法を模索中。

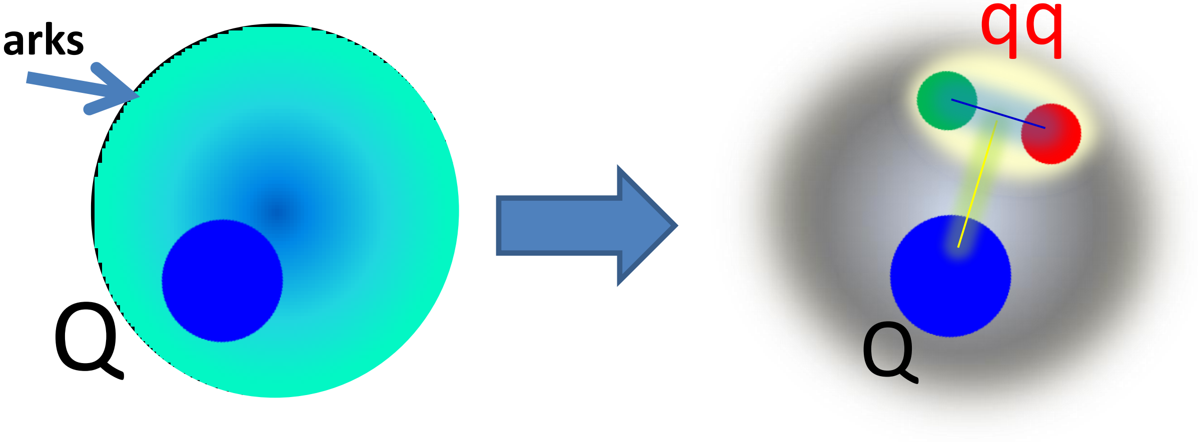
backup

baryons with heavy quark (Q)

Heavy baryon

quark model

“Cloud of light quarks and gluons”
(Brown Muck)

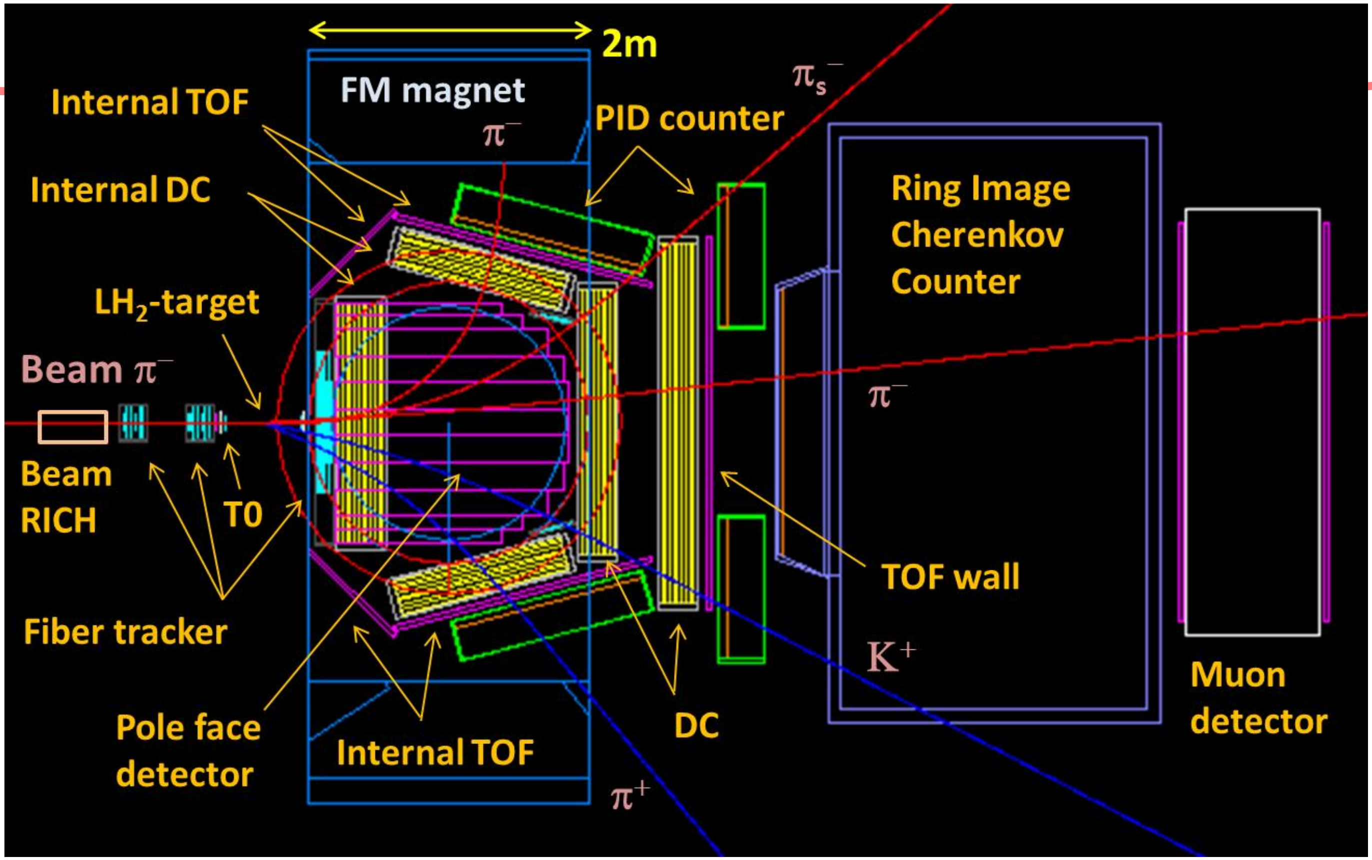


- Bare Heavy quark (Q) is already good “constituent” of baryons.

- color-spin interaction between quarks $\propto 1/m_i m_j$

➡ **sheds light on diquark correlation inside baryons**

Charmed baryon spectrometer



- Acceptance
  - Momentum: 0.2–20 GeV/c
  - Angle: < 40°

  ⇒ D*: 50–60%,

  Decay particle: ~80%

  - Wide angular coverage

Resolution

$\Delta p/p$ = 0.2% @ 5 GeV/c

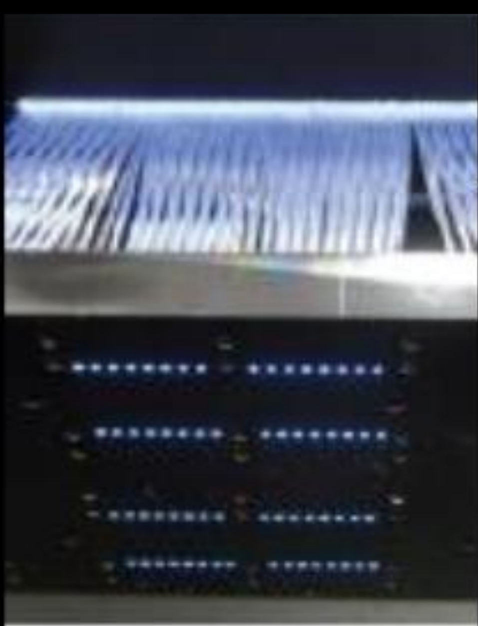
$\Delta M_{\Lambda c^*}$ = 10 MeV @ 2.8 GeV/c^2

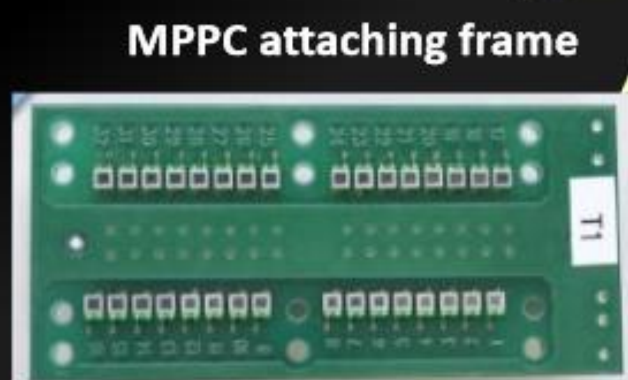
Design for realistic layout is under progress

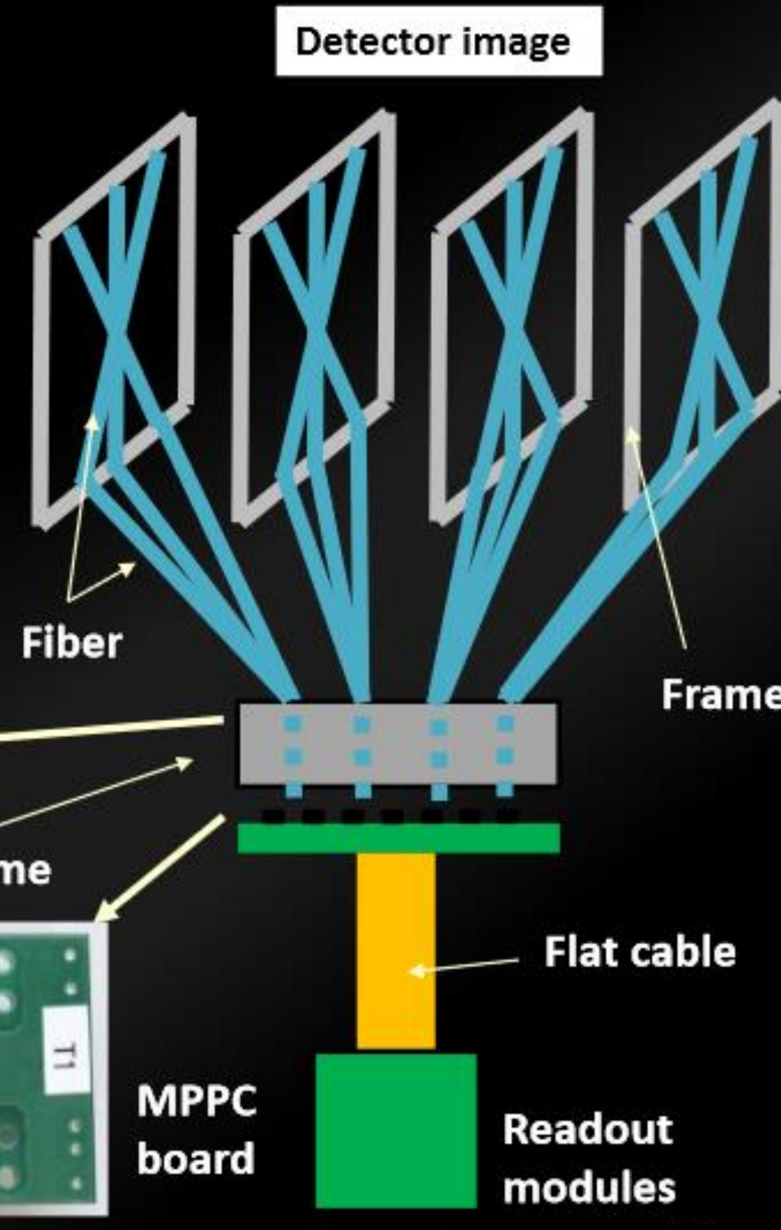
Prototype of Scintillating Fiber tracker

- Scintillating Fiber tracker :
  - will install upstream and downstream of target
  - tracking beam and scattered particle under high rate condition (~ 6 x 10^6 Hz)
  - ~ 1 nsec time resolution
  - 300~400 micron position resolution

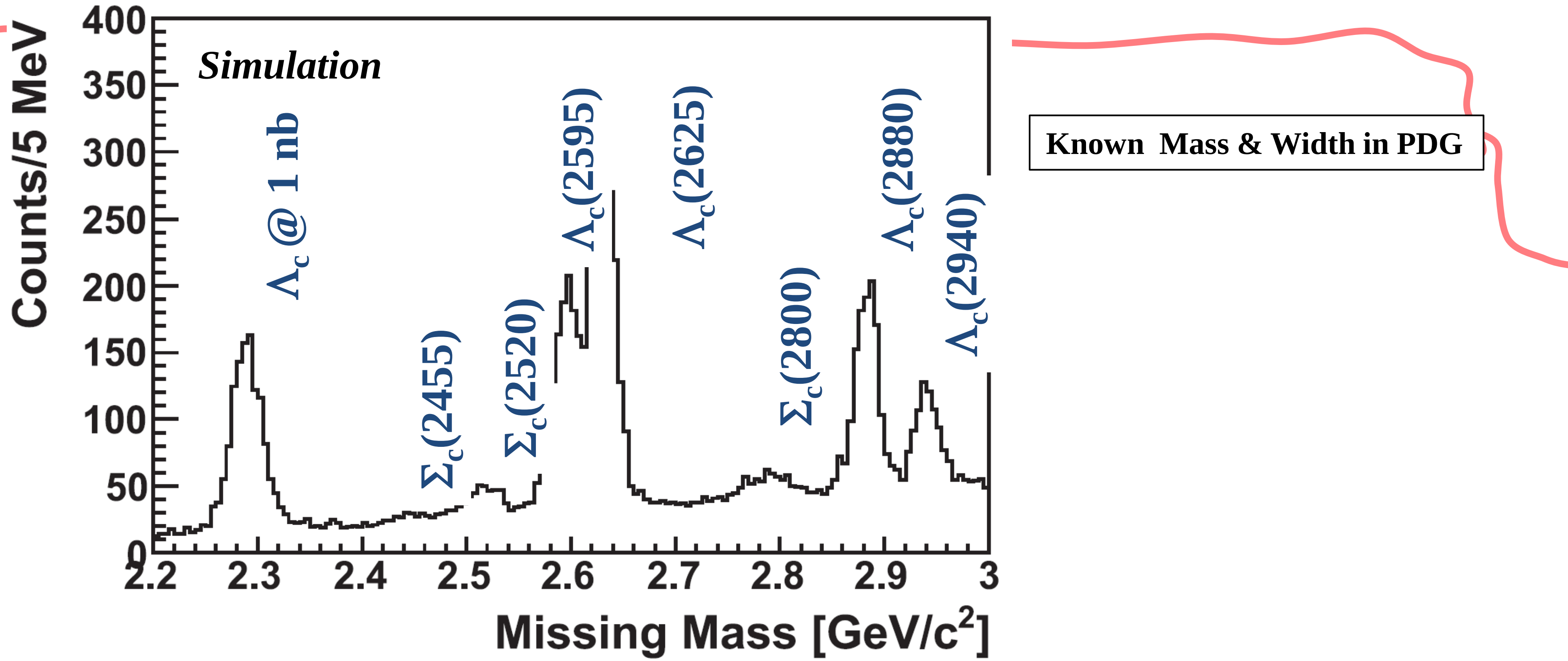
  producing prototype and will test in this summer







Expected spectra (simulation)



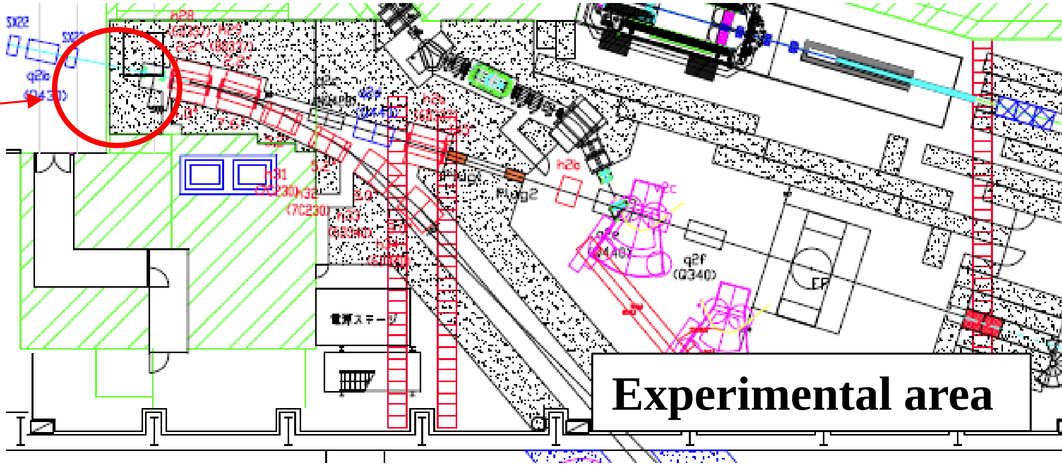
~ assumed : 100 days, (total efficiency = 0.5)

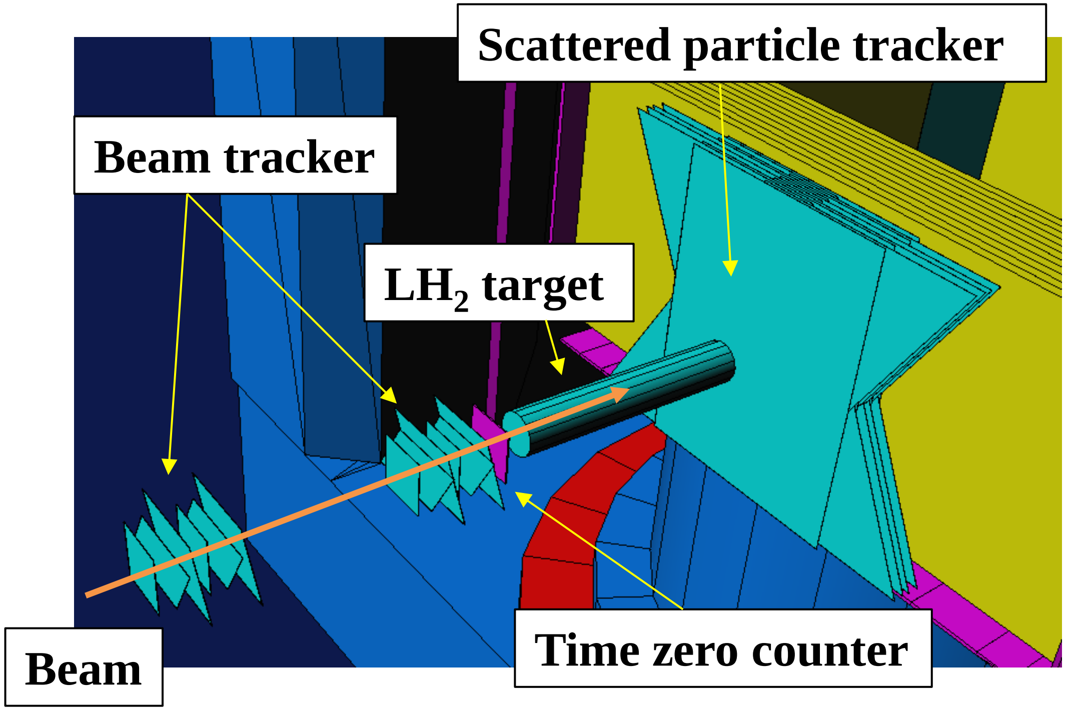
- Λ_c(g.s.): 1 nb production cross section
  - Production ratio for excited states
- Background level and reductions were studied by JAM.

∗ Achievable sensitivity of 0.1–0.2 nb: (3σ level, Γ < 100 MeV) by tagging both D* and D^0

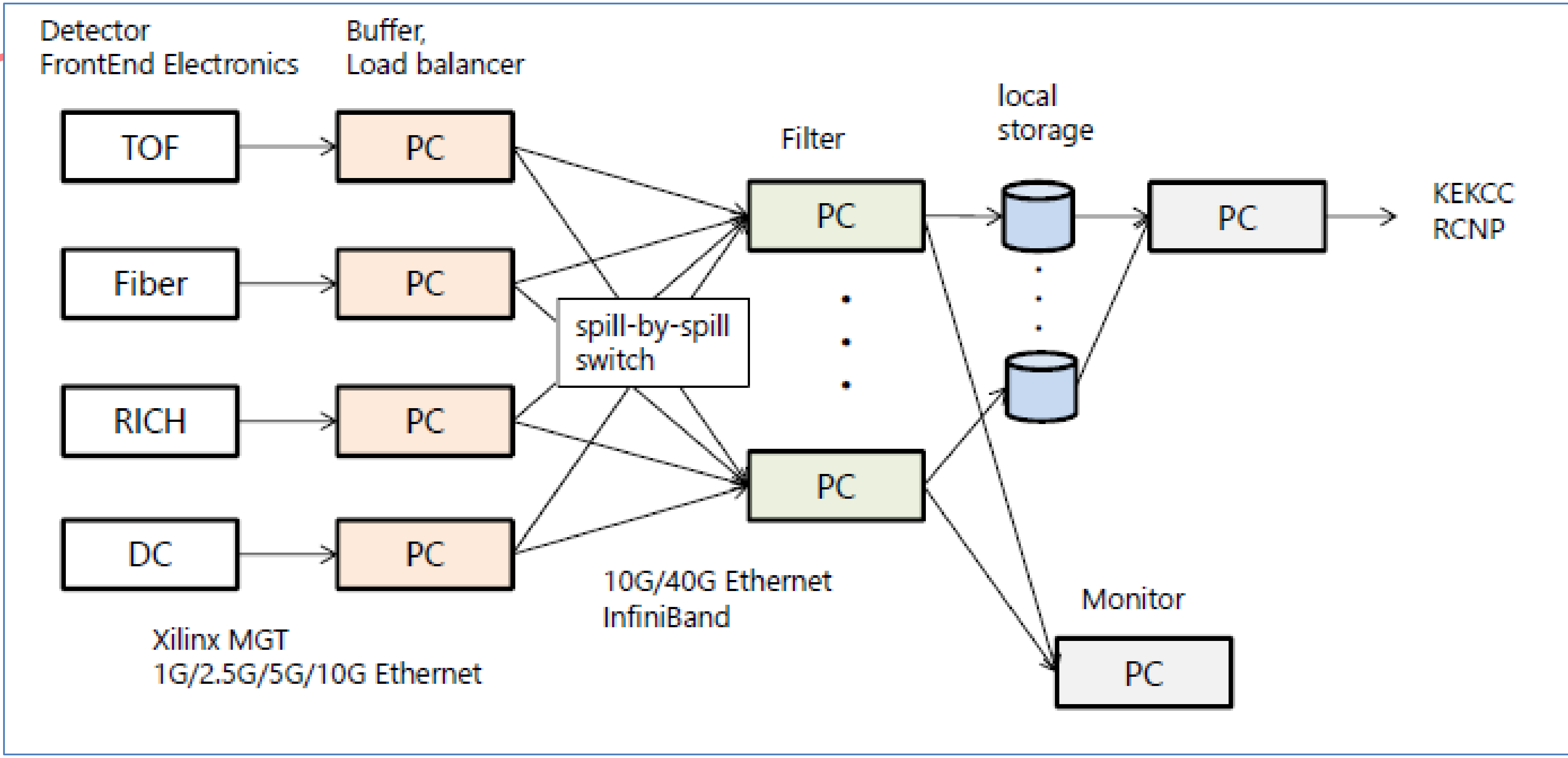
detector R&D

- Focal plane detector
  - Focal plane region
  - Beam momentum analysis
    - Position and angle
- Beam tracker
  - At the target upstream
  - Beam tracking
- Scattered particle tracker
  - At the target downstream
  - Scattered particle tracking
- Time zero counter
  - At the target upstream
  - Reference timing for TOF





trigger-less DAQ system



- Conventional way :
  -- need Hardware trigger
  -- need specific module
- No flexibility for byproducts

trigger-less DAQ system:

- events are immediately reconstructed and selected in PC clusters during the data taking.
- High-speed data taking
- flexibility for byproducts measurement

Byproducts

E50

- large acceptance spectrometer & trigger-less DAQ system enables to measure many byproducts

Baryon with strangeness

- Y baryons: Yield = $Y_c \times 10^4$
  - $\pi^- + p \rightarrow Y^0 + K_S^0$
  - $\pi^- + p \rightarrow Y^0 + K^{*0}$
  - $\pi^- + p \rightarrow Y^- + K^{*+}$
  - $\pi^- + p \rightarrow \Theta^+ + K^{*-}$
- Ξ baryons: Yield = $Y_c \times 10^3$
  - $K^- + p \rightarrow \Xi^0 + K^{*0}$
  - $K^- + p \rightarrow \Xi^- + K^{*+} : (K_S^0 + \pi^+)$
  - $\pi^- + p \rightarrow \Xi^- + K_S^0 + K^+$
  - $\pi^- + p \rightarrow \Xi^- + K^{*0} + K^+$
- Ω baryons: Yield = $Y_c \times 10^2$
  - $K^- + p \rightarrow \Omega^- + K_S^0 + K^+$
  - $K^- + p \rightarrow \Omega^- + K^{*0} + K^+$

Drell-Yan process

- $\pi^- + p \rightarrow n + \mu^+ + \mu^-$
- $K^- + p \rightarrow Y^0 + \mu^+ + \mu^-$

Penta Quark (P_c)

$\pi^- + p \rightarrow P_c^0 (cc_{bar}\ udd)$

- $\pi^- + p \rightarrow P_c^0 \rightarrow J/\psi + n$
- $\pi^- + p \rightarrow P_c^0 \rightarrow Y_c^{*+} + D^{*-}$

... and more ?

S/N ratio

Background reduction

- Total reduction: 112 × 434 × 43 ~ 2 × 10^6
- Event selection: 16

- Signal: 12 nb (1 nb × 12 states)
  - B.R. × 0.026 ⇒ 0.312 nb
  - Event selection × 1/2 ⇒ 0.156 nb
- BG: 2.43 mb ((K^+, π^-, π^-) final state)
  - 0.081 nb

⇒ S/N = 2.1 for D^0 and D* mass region

S/N estimation

- Signal: 12 × 1000 = 12000 counts
- BG: 12000/2.1 = 5700 counts

⇒ Mass region: 2.2-3.4 GeV ⇒ ~5 counts/MeV

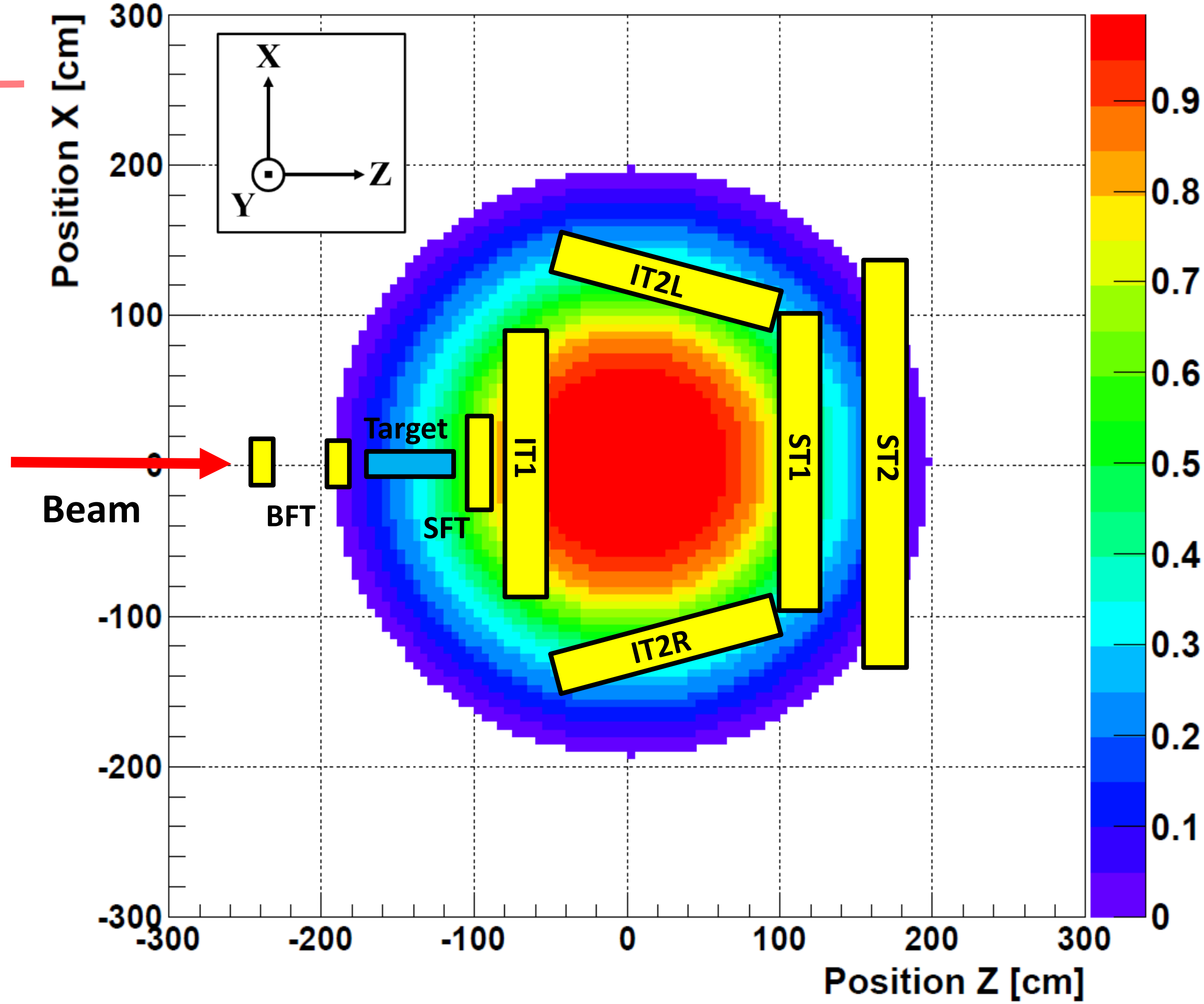
⇒ S/N = 1000/150 ~ 7
  - 30 MeV region: 150 counts
- S/√N = 100/√1000 ~ 3
  - Signal: σ= 0.1 nb, Γ = 100 MeV: ⇒ 100 counts
  - BG: 200 MeV region ⇒ 1000 counts

Fiber trackers in simulation

- Focal plane tracking
  - Area size: 120 mm × 120 mm
  - 1 mm fiber (single fiber layer) × 100 /layer
  - 12 layers (xuv,xuv,uvx,uvx), x(0°), u(30°), v(–30°): 1440 ch in total
  - Δx = 200 mm(rms)
  - Layer spacing to beam direction: 30 mm
- Beam tracking
  - Area size: 120 mm × 120 mm
  - 1 mm fiber (single fiber layer) × 100 /layer
  - 12 layers (xuv,xuv,uvx,uvx), x(0°), u(30°), v(–30°): 1440 ch in total
  - Δx = 200 mm(rms)
  - Layer spacing to beam direction: 30 mm
- Target downstream
  - Area size: 600 mm × 800 mm
  - 0.75 mm fiber (single fiber layer) × 800 /layer
  - 12 layers (xuv,xuv,uvx,uvx), x(0°), u(30°), v(–30°): 9600 ch in total
  - Δx = 200 mm(rms)
  - Layer spacing to beam direction: 10 mm

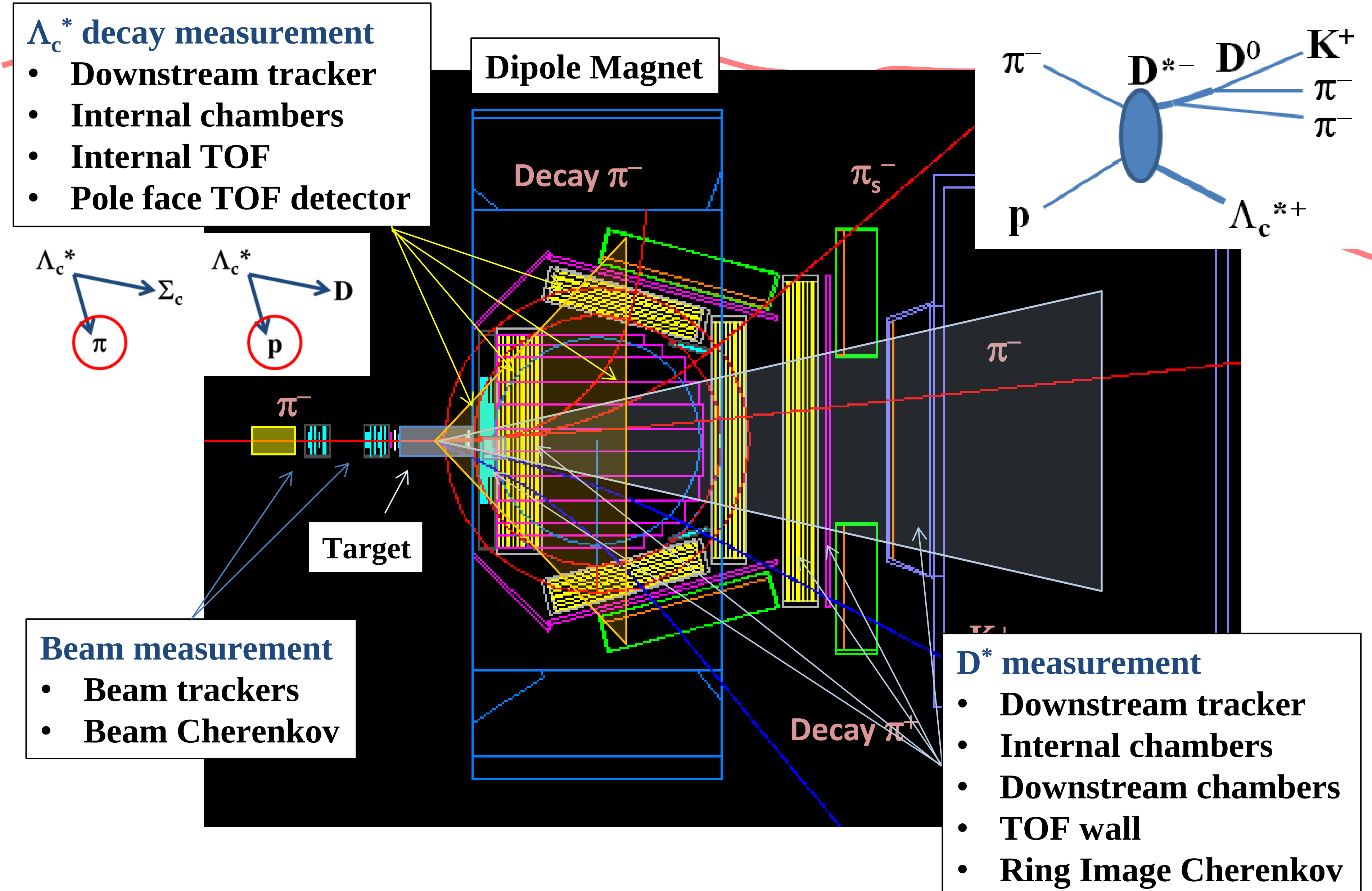
Total: 12,480 ch

Magnetic field: ZX plane(Y=0)



- All trackers in the magnetic field
- Detector positions are determined by keeping the maximum acceptance.

Spectrometer design



Backgrounds

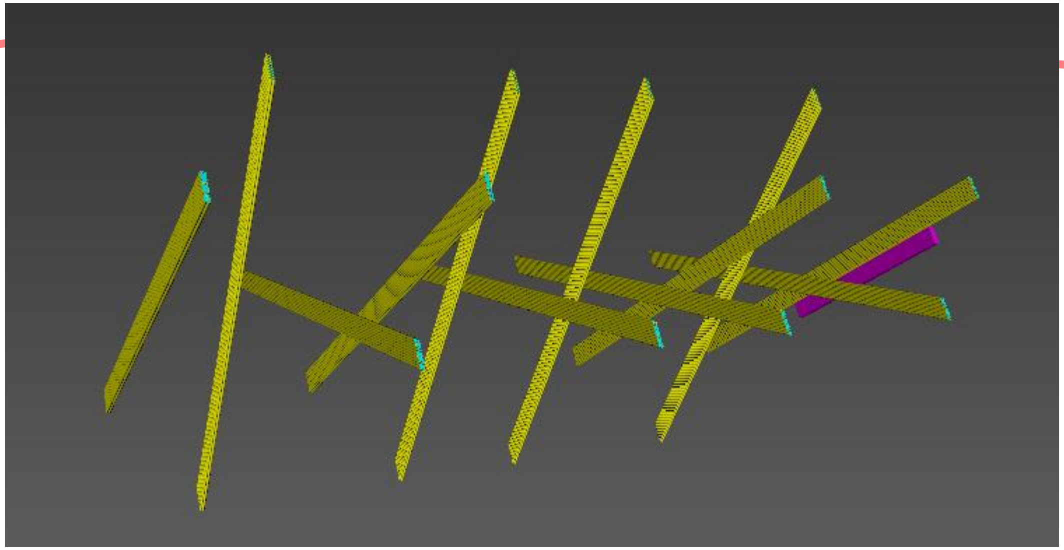
1. Main background
   - Strangeness production: (K^+, π^-, π_s^-) in final state
   - 10^6 time higher than charmed baryon production

2. Wrong particle identification: 30% of Main BG
   - Dominant cases: (π^+, π^-, π_s^-), (p, π^-, π_s^-)
     - Miss-identification of K^+

3. Associated charm production: D^{*-}
   - Highly excited D*
   - DD_{bar} pair
   - Charmonium

Contribution (peaking or not) checked by analysis

SFT Round Fiber type (Φ= 1 mm) (new)



- 10 fibers x 2 sublayers x 12 layers (x, u (30°) v(-30°)) (x,u,v,x,u,v, u,v x, u,v x)

- fiber length : 200 mm