KEK theory center, J-PARC branch
Workshop on Hadron-structure physics at J-PARC and related topics
March 18 (Monday), 2013
Room 227, Tokai 1st building, KEK Tokai campus

Toward a J-PARC proposal on hadron structure

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collaborating with

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Shin'ya Sawada (KEK), Jen-Chieh Peng (UIUC)

http://www-conf.kek.jp/hadron1/j-parc-hm-2013/

KEK theory center workshop on
Hadron physics with high-momentum hadron beams at J-PARC in 2013

Kobayashi Hall, 1st Floor, Kenkyu-Honkan (15th, 18th)
Seminar Hall, 1st Floor, 3rd buildling (16th, 17th)
January 15 - 18, 2013, KEK, Tsukuba, Japan

MENU

- 1st circular
- 2nd circular
- Program (slides)
- Participants
- Location: KEK
- Kenkyu-Honkan (M01)
- Kobayashi Hall
- Lounge for banquet
- Seminar Hall
- Visitor information (English)
- Visitor information (Japanese)
- How to reach KEK (General guide)
- Bus/taxi to KEK (Our original guide)
- to Urban hotel (Our original guide)
- KEK restaurant hours
- Nearby restaurants

[Update]
2012.08.09
Home page, 1st circular

2012.11.30

→ → A large size picture (4MB.jpg)

The talk files are available in "[MEN

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--------------------------- Program ---------------------------

Outline

- Very brief and selective review of ideas raised up in "KEK theory center workshop"
- Results of πN di-lepton experiments at low energies
- Compilation of physics programs
- Conceptual detector system
- Summary

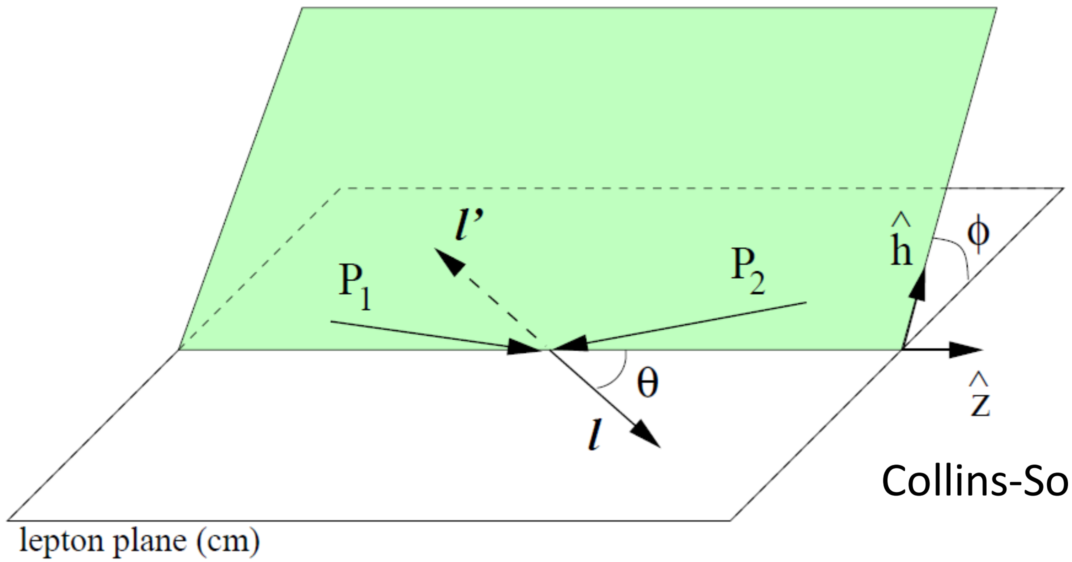
Jen-Chieh Peng

- Kaon-induced Drell-Yan for probing s and s-bar
- J/ψ production at forward *xF* in p-A collision for looking for intrinsic charm
- Proton-induced Drell-Yan in p-p collision for determining dbar/ubar at large x
- Proton-induced Drell-Yan in p-A collision for investigating flavor-dependent EMC effect
- Sivers and BM functions in Drell-Yan process.
- Forward-backward asymmetry in decay angular distribution of Drell-Yan for probing Weinberg angle at low Q^2

Wen-Chen Chang

- Pion-induced DY
  - Pion partonic structure
  - Violation of Lam-Tung relation: BM function or QCD vacuum
  - Pion DA
  - Pion TDA
  - Valance-quark distributions at large-x

Angular Distribution of Lepton Pair



Collins-Soper Frame

$$\frac{d\sigma}{d\Omega} \propto (1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi)$$

$$\propto (W_T(1+\cos^2\theta)+W_L(1-\cos^2\theta)+W_\Delta\sin 2\theta\cos\phi+W_{\Delta\Delta}\sin^2\theta\cos 2\phi)$$

$q\bar{q}$ annilation parton model:

$O(\alpha_s^0)$ $\lambda=1,\ \mu=\nu=0;\ W_T=1, W_L=0$

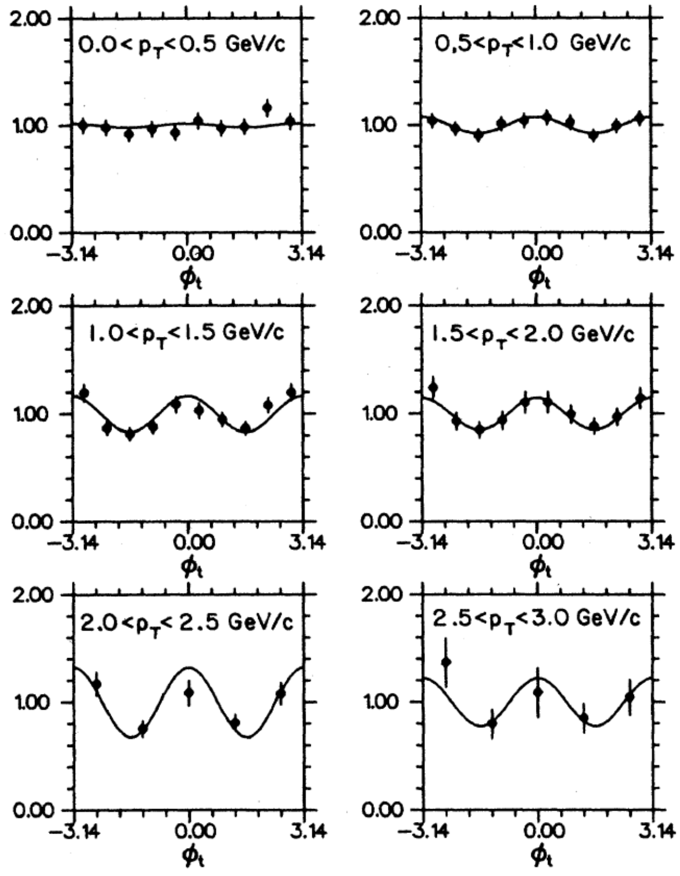
Lam and Tung (PRD 18, 2447, (1978))
Lam-Tung Relation

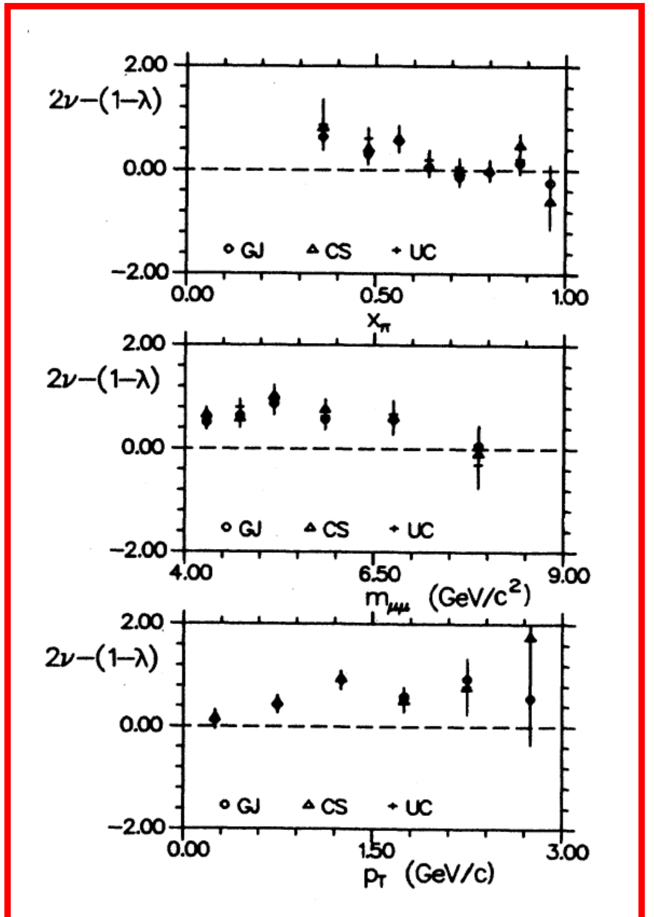
$$\frac{d\sigma}{d\Omega} \propto [W_T(1+\cos^2\theta) + W_L(1-\cos^2\theta) + W_\Delta \sin 2\theta \cos\phi + W_{\Delta\Delta} \sin^2\theta \cos 2\phi]$$

$$\frac{d\sigma}{d\Omega} \propto (1+\lambda\cos^2\theta + \mu \sin 2\theta \cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi)$$

pQCD: $O(\alpha_s^1)$, $W_L = 2W_{\Delta\Delta}$; $1-\lambda-2\nu=0$

E615 (PRD 39, 92 (1989))
Violation of LT Relation

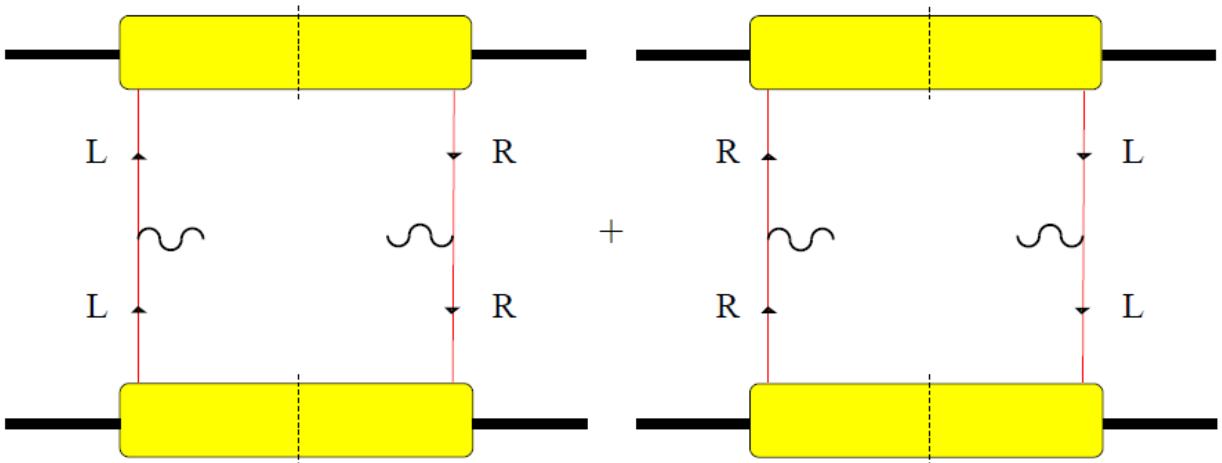




Angular asymmetry requires helicity flip

The $\cos 2\phi$ asymmetry arises from an interference between $+1$ and -1 photon helicities

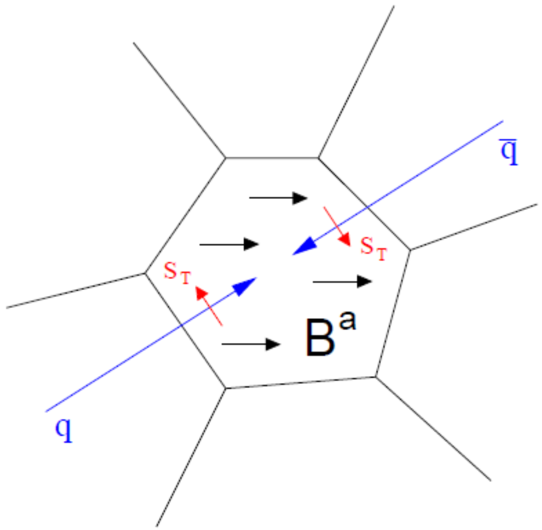
$\nu \neq 0$



This requires transversely polarized quark-antiquark annihilation

D. Boer

Explanation as a QCD vacuum effect



The QCD vacuum can induce a spin correlation between an annihilating $q\,\bar{q}$

Chromo-magnetic Sokolov-Ternov effect:
spin-flip gluon synchrotron emission leading to a correlated polarization of q and $\overline{q}$.

The spin density matrix becomes:

$$\rho^{(q,\bar{q})} = \frac{1}{4}\{\mathbf{1}\otimes\mathbf{1} + F_j\,\boldsymbol{\sigma}_j\otimes\mathbf{1} + G_j\,\mathbf{1}\otimes\boldsymbol{\sigma}_j + H_{ij}\,\boldsymbol{\sigma}_i\otimes\boldsymbol{\sigma}_j\}$$

If $H_{ij} = F_i G_j$, then the spin density matrix factorizes

$$\rho^{(q,\bar{q})} = \frac{1}{2}\{\mathbf{1} + F_j\,\boldsymbol{\sigma}_j\}\otimes\frac{1}{2}\{\mathbf{1} + G_j\,\boldsymbol{\sigma}_j\}$$

Brandenburg, et. al (Z. Phy. C60,697 (1993)) QCD Vacuum Effect

In average no quark polarization, but a spin correlation between an annihilating q and $\overline{q}$ is induced by nontrivial QCD vacuum.

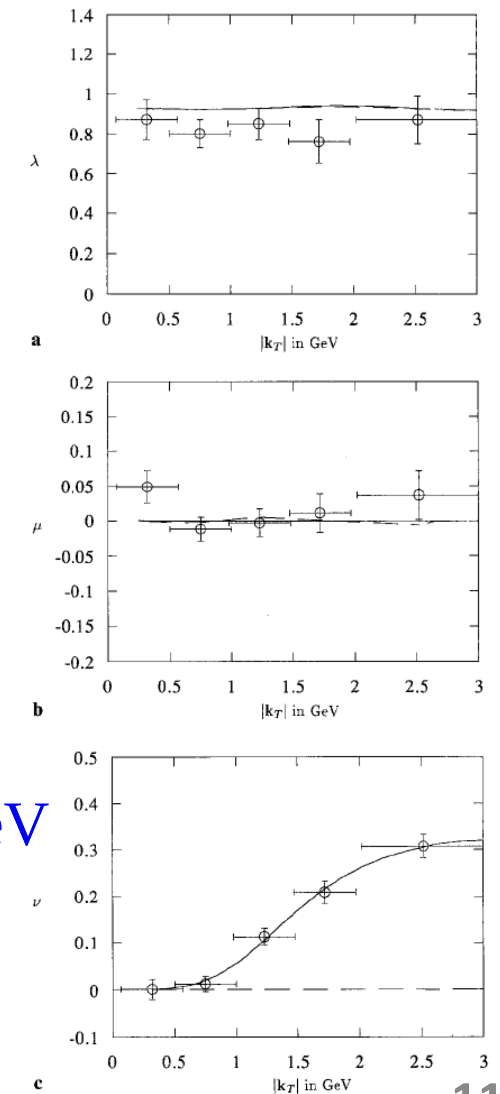
$q\bar{q}$ spin density matrix contains terms:

$$H_{ij}(\vec{\sigma}\cdot\vec{e}_i)(\vec{\sigma}\cdot\vec{e}_j)$$

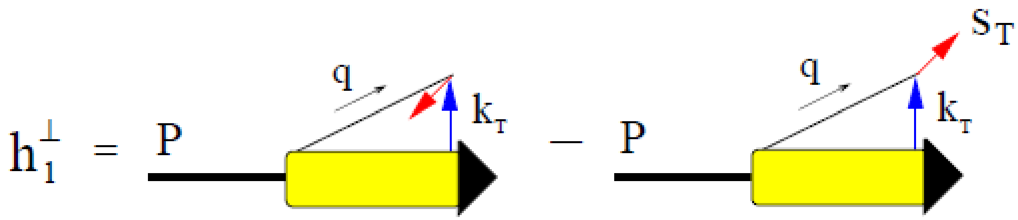
$$1-\lambda-2\nu \approx -4\kappa \approx -4\frac{H_{22}-H_{11}}{1+H_{33}}$$

$$\kappa = \kappa_0 \frac{|k_T|^4}{|k_T|^4+m_T^4}, \ \kappa_0 = 0.17, \ m_T = 1.5 \text{ GeV}$$

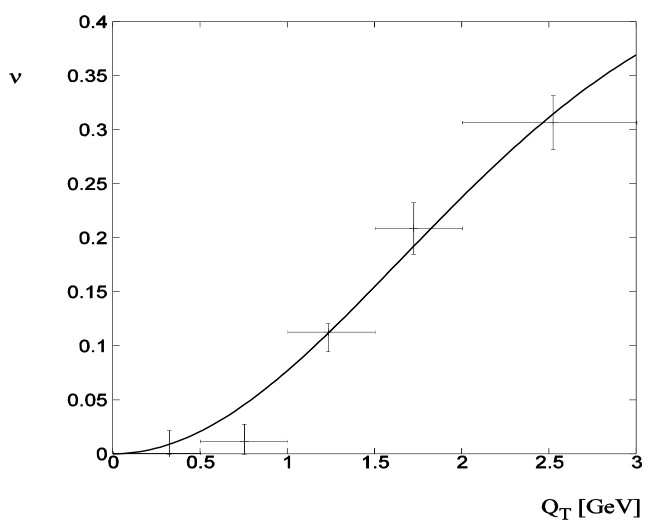
For large $|k_T|$, $\kappa \to \kappa_0$, a constant value.



Boer (PRD 60, 014012 (1999))
Hadronic Effect, Boer-Mulders Functions



- Boer-Mulders Function $h_1^\perp$: a correlation between quark's k_T and transverse spin in an unpolarized hadron
- $h_1^\perp$ can lead to an azimuthal dependence with $\frac{\nu}{2} \propto h_1^\perp(N)\overline{h}_1^\perp(\pi)$



$$h_1^\perp(x, k_T^2) = C_H \frac{\alpha_T}{\pi} \frac{M_C M_H}{k_T^2 + M_C^2} e^{-\alpha_T k_T^2} f_1(x),$$

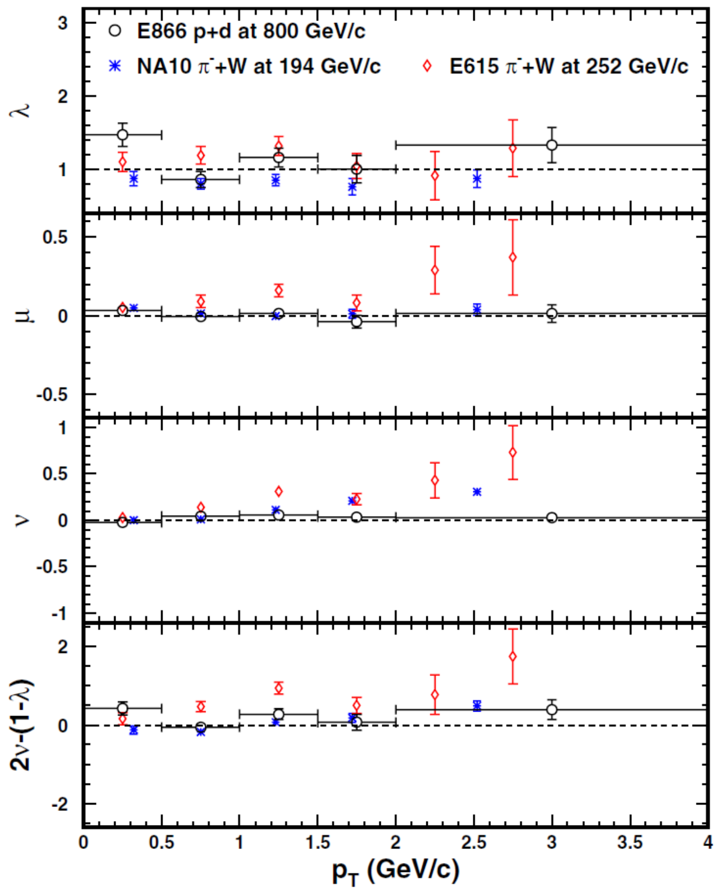
$$\nu = 16\kappa_1 \frac{p_T^2 M_C^2}{(p_T^2 + 4M_C^2)^2}, \quad \kappa_1 = C_{H_1} C_{H_2}/2$$

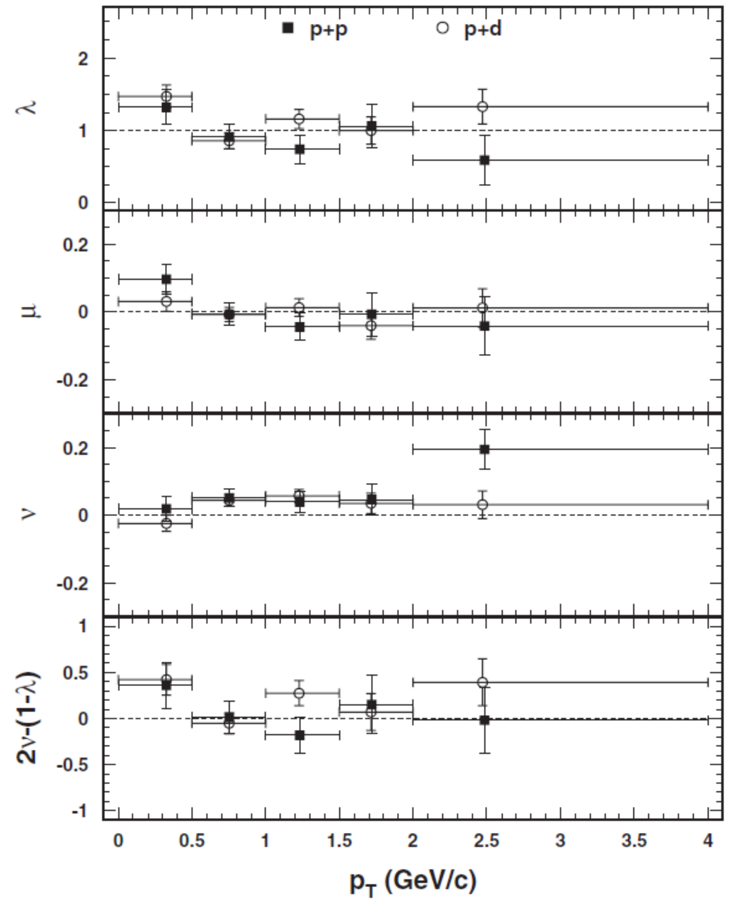
$$\kappa = \frac{\nu}{2} \to 0 \text{ for large } |k_T|$$

Consistency of factorization in term of TMDs

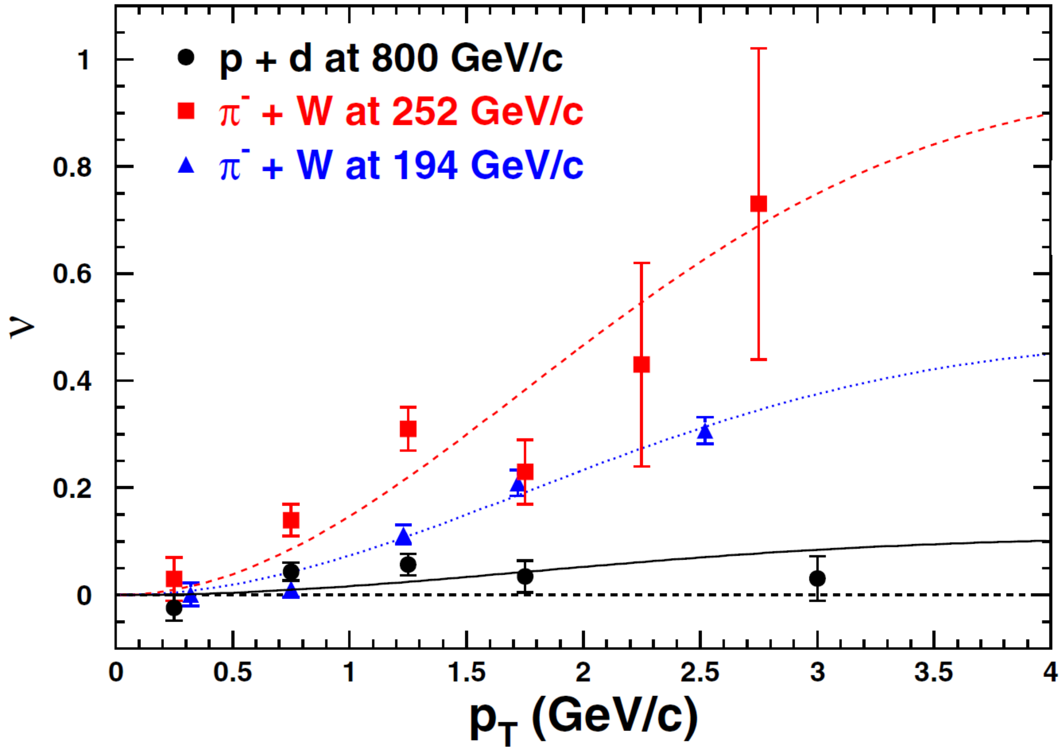
E866 (PRL 99 (2007) 082301; PRL 102 (2009) 182001)

Consistency of LT relation for DY events in pd, pp





E866 (PRL 99 (2007) 082301)
Azimuthal cos2Φ Distribution of DY events in pd



$$h_1^{\perp}(x, k_T^2) = C_H \frac{\alpha_T}{\pi} \frac{M_C M_H}{k_T^2 + M_C^2} e^{-\alpha_T k_T^2} f_1(x),$$

$$\nu = 16\kappa_1 \frac{p_T^2 M_C^2}{(p_T^2 + 4M_C^2)^2},$$

$$\kappa_1 = C_{H_1} C_{H_2}/2$$

$\nu(\pi^- W \to \mu^+\mu^- X) \sim$ [valence $h_1^{\perp}(\pi)$] * [valence $h_1^{\perp}(p)$]

$\nu(pd \to \mu+\mu- X)$ ~ [valence $h_1^{\perp}(p)$] * [sea $h_1^{\perp}(p)$]

Sea-quark BM functions are much smaller than valence quarks

Hsiang-nan Li

- The Glauber Gluon in the pion, the Nambu-Goldstone boson, is responsible for the violation of L-T relations in pion-induced DY.
- The proposal could be discriminated from the effects of BM functions by pbar+p DY.

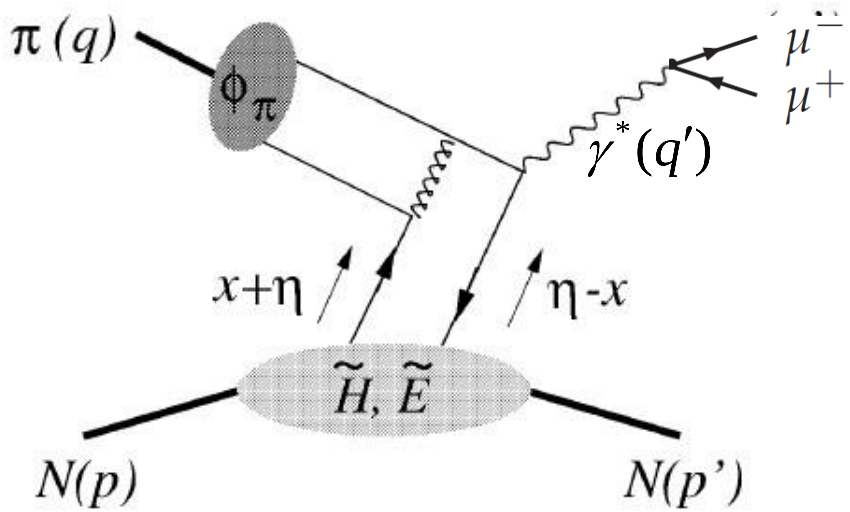
The proposal could also be tested by kaon-induced DY.

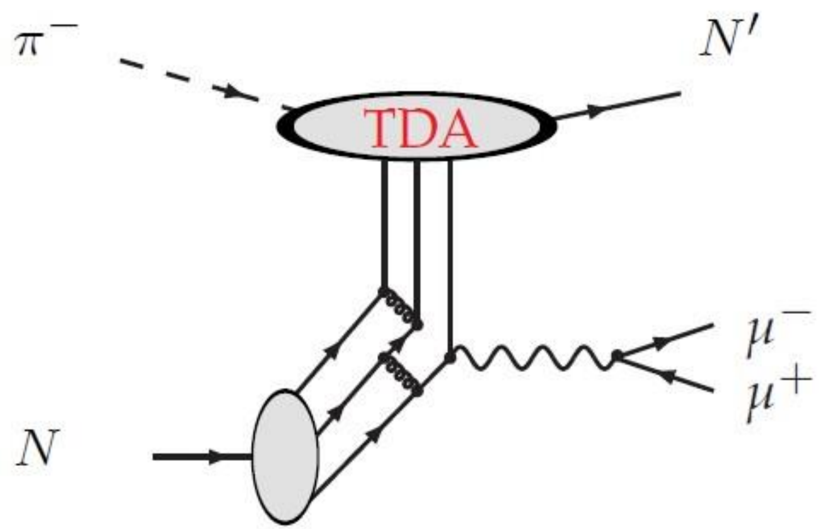
Exclusive Pion-Induced Drell-Yan Process

Bernard Pire , IWHS2011

small $t=(q-q')^2$

large $t=(q-q')^2$





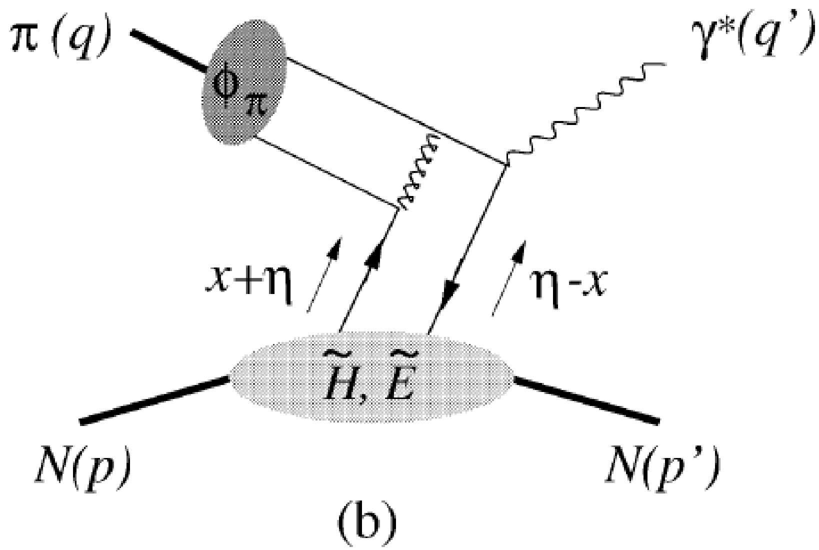
ϕ_π : pion distritribution amplitude (DA)

- DA characterizes the minimal valence Fock state of hadrons.
- DA of pion are also explored by pion-photon transition form factor in Belle and Barbar Exps.

TDA : π-N transistion distritribution amplitude

- TDA characterizes the next-to-minimal valence Fock state of hadrons.
- TDA of pion-nucleon is related to the pion cloud of nucleons.

πN→μ+μ-N
(PLB 523 (2001) 265)



$$M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) = -ie\frac{4\pi}{3}\frac{f_\pi}{Q'}\frac{1}{(p+p')^+}\bar{u}(p',\lambda') \times \left[\gamma^+\gamma_5\tilde{\mathcal{H}}^{du}(-\eta,\eta,t) + \gamma_5\frac{(p'-p)^+}{2M}\tilde{\mathcal{E}}^{du}(-\eta,\eta,t)\right]u(p,\lambda).$$

$$\tilde{\mathcal{H}}^{du}(\xi,\eta,t) = \frac{8}{3}\alpha_S\int_{-1}^{1} dz\,\frac{\phi_\pi(z)}{1-z^2} \times \int_{-1}^{1} dx\left[\frac{e_d}{\xi - x - i\epsilon} - \frac{e_u}{\xi + x - i\epsilon}\right] \times \left[\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t)\right],$$

$$\frac{d\sigma}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = \frac{\alpha_{em}}{256\pi^3}\frac{\tau^2}{Q'^6}\sum_{\lambda',\lambda}\left|M^{0\lambda',\lambda}\right|^2\sin^2\theta,$$

$$t = (p-p')^2$$

$$Q'^2 = q'^2 > 0$$

$$\tau = \frac{Q'^2}{2pq} \approx \frac{Q'^2}{s - M_N^2}$$

$$\eta = \frac{(p-p')^+}{(p+p')^+}$$

πN→$\mu^+\mu^-$N
(PLB 523 (2001) 265)

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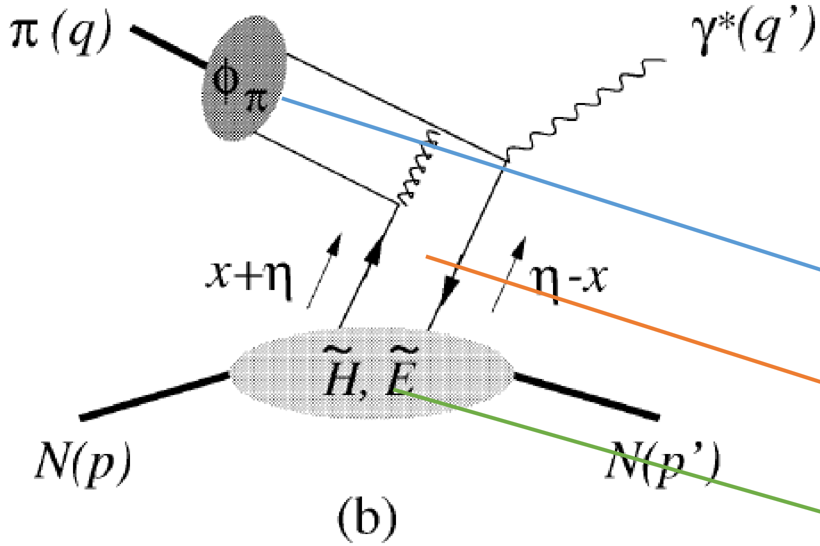

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$$\tau = \frac{Q'^2}{2pq} \approx \frac{Q'^2}{s - M_N^2}$$

$$\eta = \frac{(p-p')^+}{(p+p')^+}$$

Generalized Parton Distribution (GPD)

(K. Goeke et al. / Prog. Part. Nucl. Phys. 47 (2001) 401-515)

In the forward limit, $\eta, t \to 0$

$$H^q(x,0,0) = \begin{cases} q(x), & x > 0, \\ -\bar{q}(-x), & x < 0. \end{cases}$$

$$\tilde{H}^q(x,0,0) = \begin{cases} \Delta q(x), & x > 0, \\ \Delta\bar{q}(-x), & x < 0. \end{cases}$$

Dirac FF

$$\int_{-1}^{+1} dx\, H^q(x,\xi,t) = F_1^q(t),$$

Pauli FF

$$\int_{-1}^{+1} dx\, E^q(x,\xi,t) = F_2^q(t),$$

Axial Vector FF

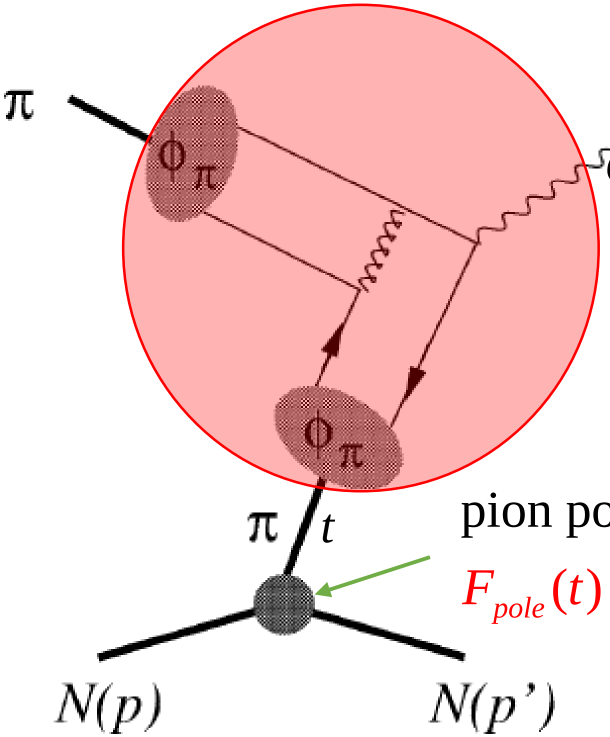
$$\int_{-1}^{+1} dx\, \tilde{H}^q(x,\xi,t) = g_A^q(t),$$

Pseudoscalar FF

$$\int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = h_A^q(t).$$

Pion-pole Dominance (PLB 523 (2001) 265)

pion Timelike Form Factor $F_\pi(Q'^2)$



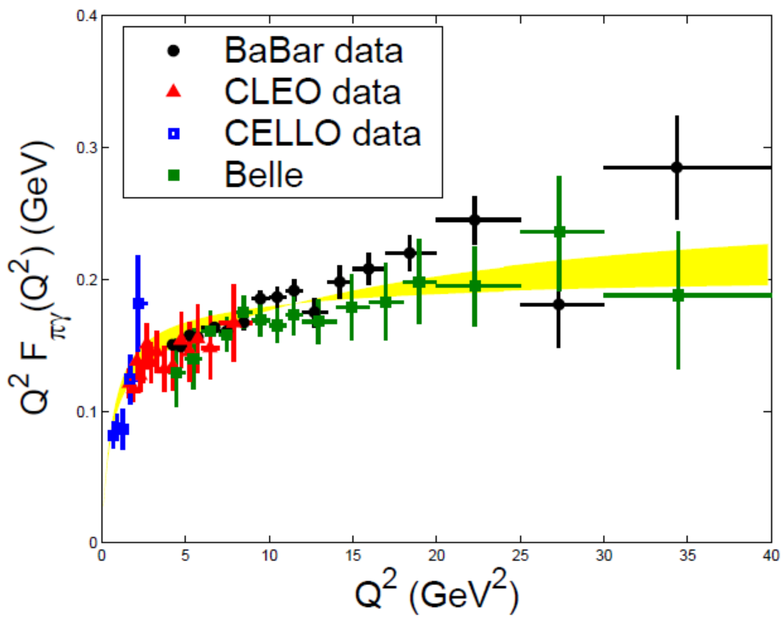
pion pole Form Factor

$F_{pole}(t)$

$$M^{0\lambda',\lambda}(\pi N \to \gamma^* N)$$
$$= -ieQ'F_\pi(Q'^2)\frac{F_{\text{pole}}(t)}{2Mf_\pi}\bar{u}(p',\lambda')\gamma_5 u(p,\lambda)$$
$$+ \text{non-pole terms.} \qquad (11)$$

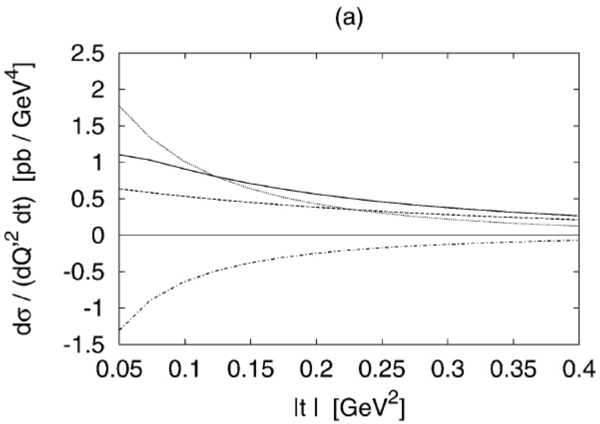
Pion-Photon Transition Form Factor

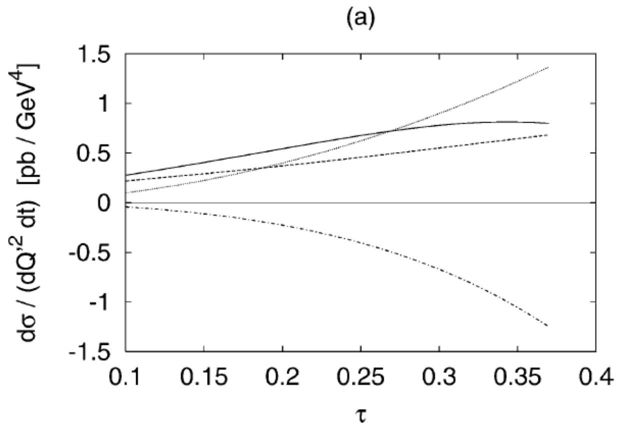
$F_{\pi\gamma}(Q'^2)$ in e^+e^- process

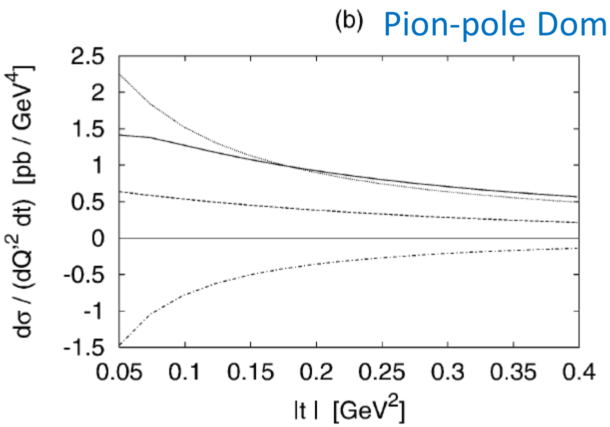


πN→$\mu^+\mu^-$N (PLB 523 (2001) 265)

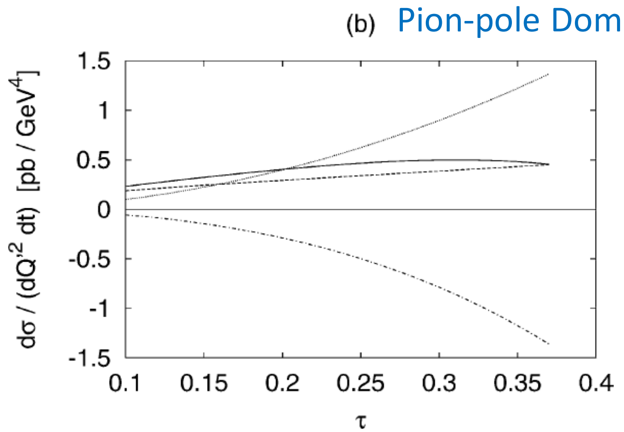
$$Q'^2 = q'^2 = 5\ GeV^2$$







Pion-pole Dominance

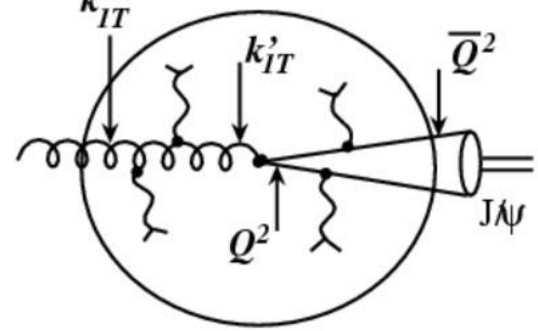


Pion-pole Dominance

$$\tau = \frac{Q'^2}{2pq} \approx \frac{Q'^2}{s - M_N^2} = 0.2$$

$t = (p - p')^2$=-0.2 GeV^2

Jianwei Qiu



- Charmonium (J/ψ) production
  - Production mechanism
  - Color transparency
  - Intrinsic charm of hadron
  - Multiple partonic scattering or energy loss
- Drell-Yan process
  - Parton energy loss in nuclei: x distribution of σ_A/σ_d.

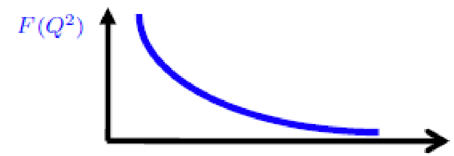
Production mechanism – a long history

- Discovery of J/ψ – November revolution – 1974
- Color singlet model: 1975 –

  Einhorn, Ellis (1975), Chang (1980), Berger and Jone (1981), …

  Only the pair with right quantum numbers

  Effectively No free parameter!

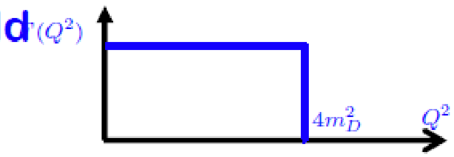


- Color evaporation model: 1977 –

  Fritsch (1977), Halzen (1977), …

  All pairs with mass less than open flavor threshold

  One parameter per quarkonium state



- NRQCD model: 1986 –

  Caswell, Lapage (1986)
  Bodwin, Braaten, Lepage (1995)
  QWG review: 2004, 2010

  By far, it is most successful!

  Infinite parameters – organized in powers of v and α_s

- pQCD factorization approach: 2005 –

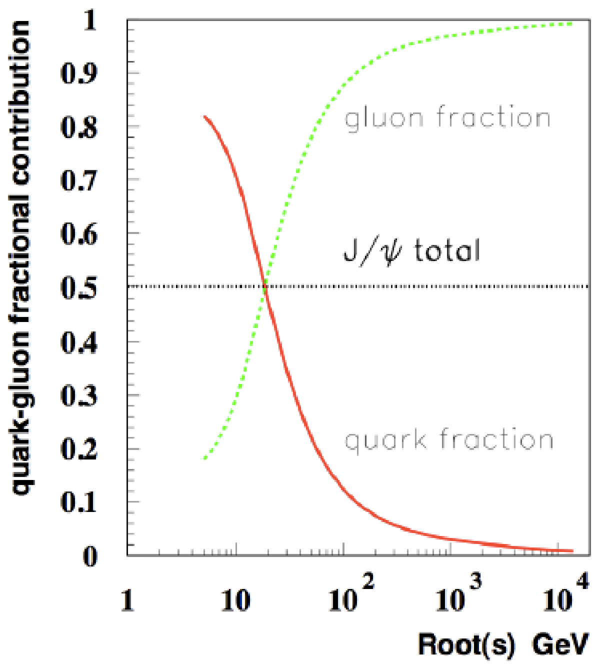
  Nayak, Qiu, Sterman (2005), …
  Kang, Qiu, Sterman (2010), …

  $P_T \gg M_H$: M_H/P_T power expansion + α_s – expansion

  Universal fragmentation functions – evolution/resummation

Uniqueness of J-PARC kinematics

❑ Quark-antiquark annihilation dominates:



- ✧ Pairs are likely in color states
- ✧ Pairs are produced with less momenta

P+A at J-PARC is very interesting!

- ✧ Initial-state likes DY
- ✧ Final-state is much more important
- ✧ Extremely sensitive to hadronization

❑ Very rich dynamics at relatively low p_T:

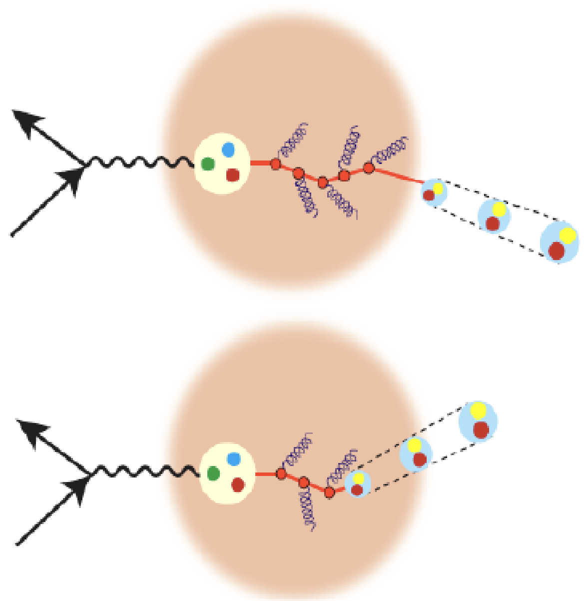
- ✧ Large "power correction" from multiple scattering
- ✧ Intrinsic charm contribution at large x_F

Brodsky's talk

Formation of pre-hadron state

❑ Uncertainty in extracting energy loss from SIDIS:

Kopeliovich et al, 1996, …
Accardi et al, 2003, …



✧ Relatively low energies at HERMES and Jlab

✧ The prehadron state could be formed in A

✧ Then, energy loss would be suppressed

✧ But, interaction between the prehadron state and nuclear matter is poorly known

❑ Some effort to separate these effects:

Accardi et al, 2006, …

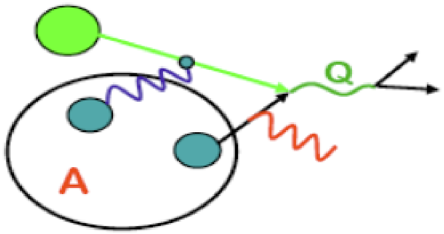
But, very much model dependent

Future Electron-Ion Collider should be able to do a good job on this

EIC White Paper by A. Deshpande et al., arXiv:1212.1701

Energy loss in Drell-Yan

- Ideal process to test energy loss mechanism:



$$\frac{d\sigma_{hA}}{dQ^2 dq_T^2 dy} = \frac{d\sigma_{hA}^S}{dQ^2 dq_T^2 dy} + \frac{d\sigma_{hA}^D}{dQ^2 dq_T^2 dy} + \ldots$$

  - ✧ Initial-state multiple scattering – cross check with the final-state effect
  - ✧ No energy loss from final-state
  - ✧ Unlike SIDIS, data with a larger Q (more localized probe)
  - ✧ More precise data available, in particular, from Fermilab E866, …

- Future data from Fermilab E906, and other facilities

- One major complication:

  - ✧ Nuclear PDFs vs energy loss? - two have different Q^2-dependence!

    Need data with a large span in Q^2!

NA3 (PLB104, 335 (1981))

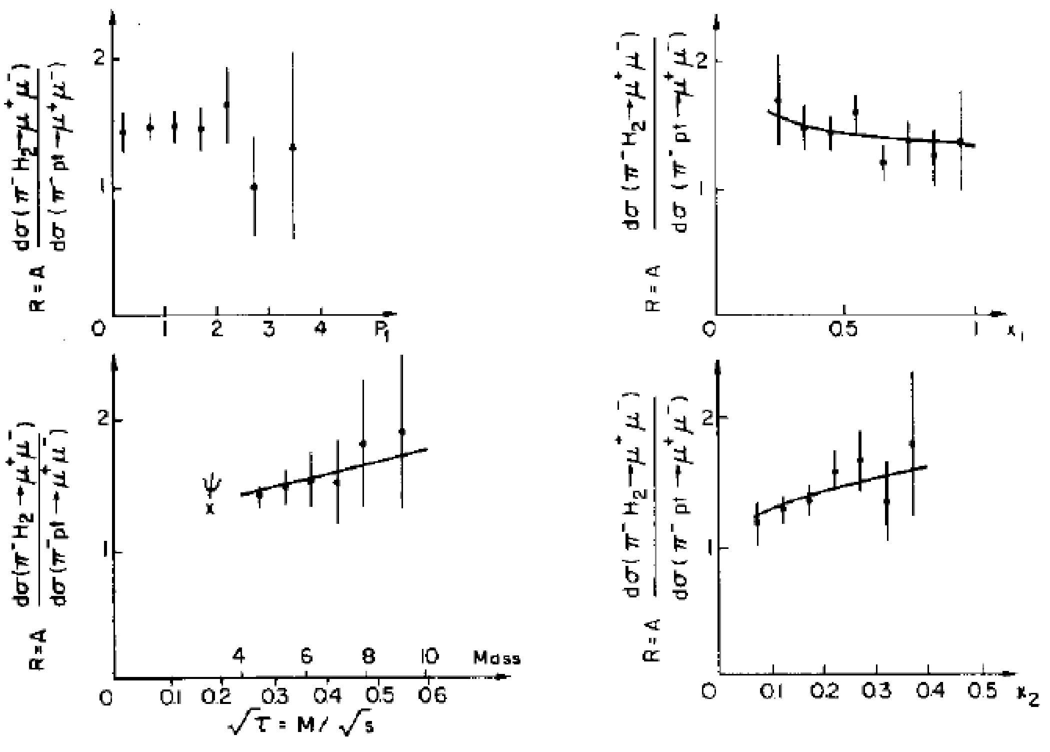


Fig. 2. Hydrogen to platinum cross section ratio (per nucleon) for incident π^- at 150 GeV as functions of P_t, x_1, x_2 and mass.

150 GeV π-

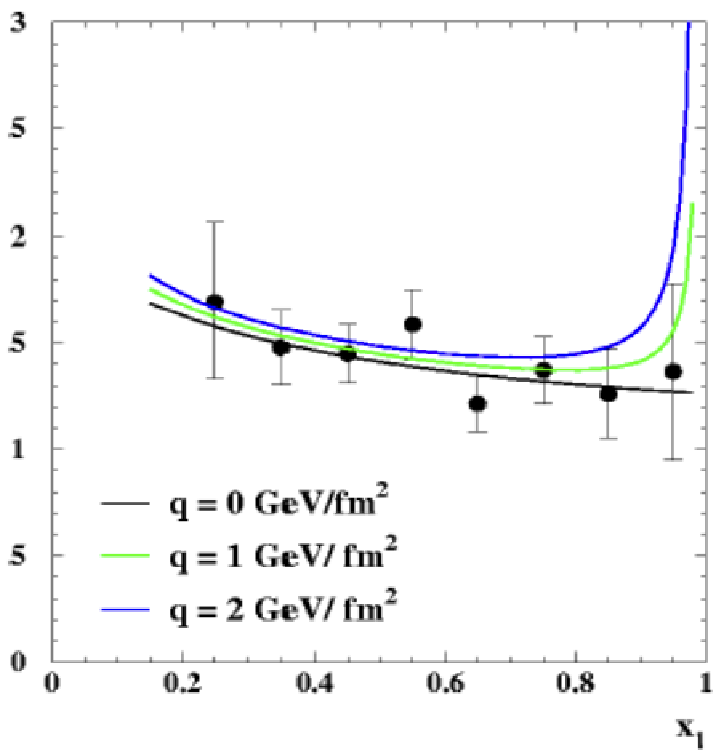
Drell-Yan data from π beam

- CERN SPS NA3 data on Drell-Yan:

$\sqrt{s} \approx 20$ GeV

Parton momentum fraction is not too small, x ~ 0.1 – PDFs are better constrained

- Large energy loss is not favored:



✧ Error bars at large x_1 are large!

✧ Fitted energy loss

$$-\frac{dE}{dx} = 0.20 \pm 0.15\ \mathrm{GeV/fm}$$

Similar to quark energy loss seen in SIDIS

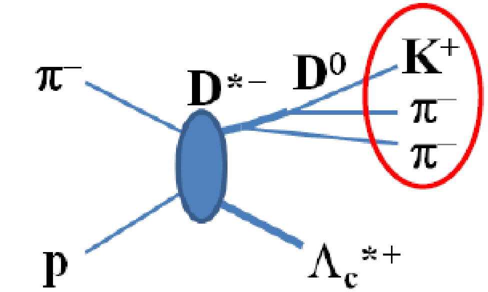
E906 and J-PARC can help clarify this!

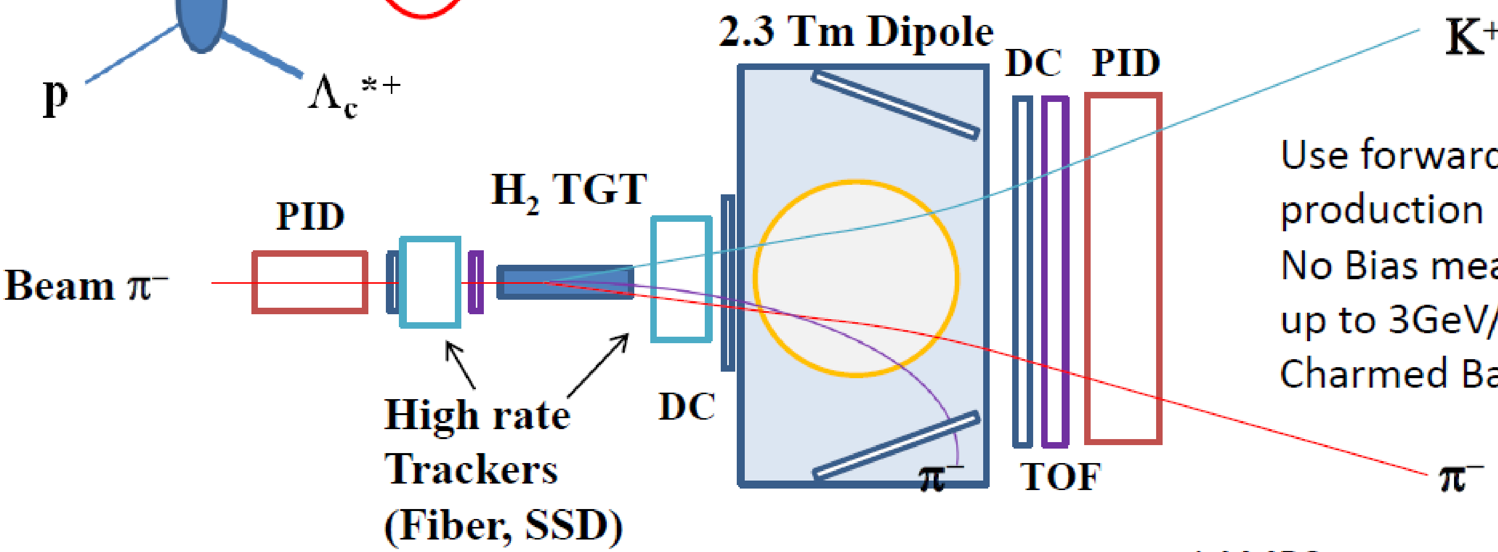
Need to take an advantage of the relation between broadening and energy loss

Makoto Oka, Kyoichiro Ozawa (J-PARC P50)

- Charmed baryons, Charmed deuteron/nucleus, Heavy exotics
- Di-quark configuration in the spectroscopy of charmed baryon.

Missing mass Spectroscopy

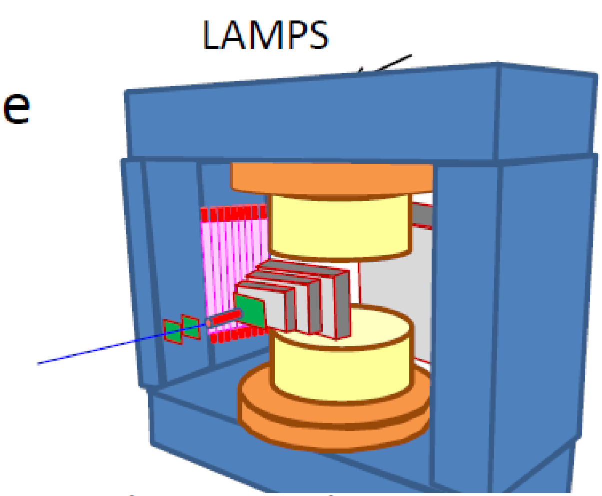




Use forward D mesons production

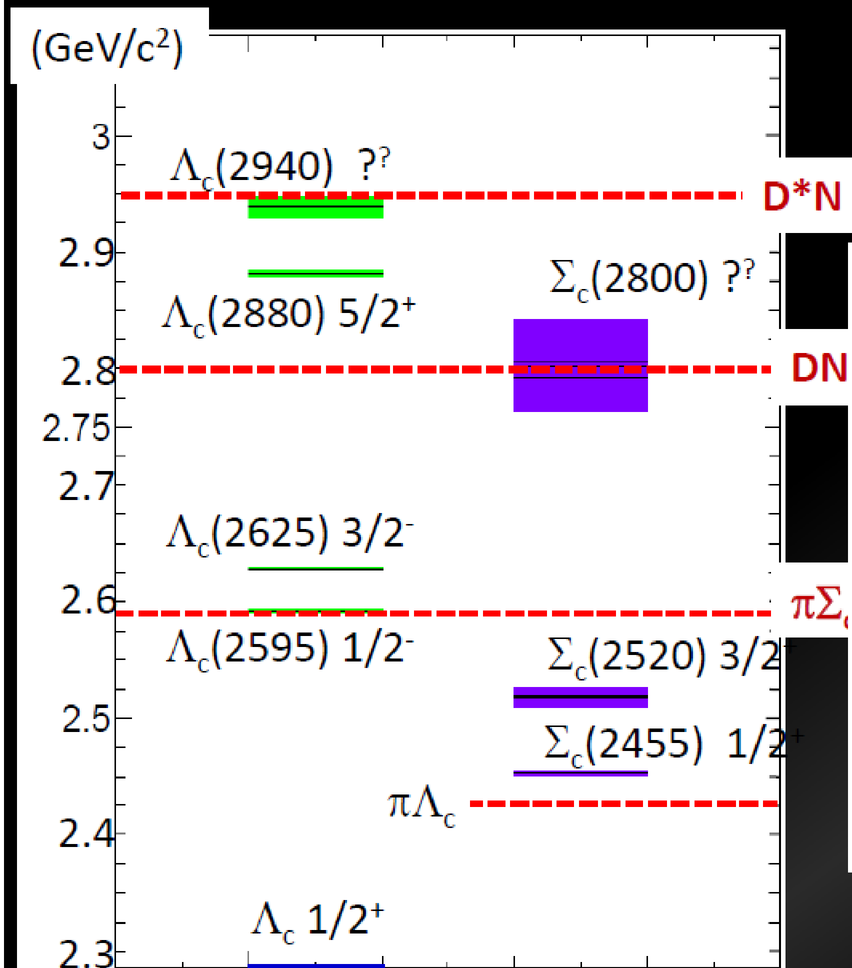
No Bias measurements up to 3GeV/c^2 of Charmed Baryon mass

- Large Acceptance, Multi-Particle
  - *K*, *π* from *D*⁰ decays
  - Soft π from *D**⁻ decays
  - (Decay products from Y_c*)
- High Resolution
- High Rate
  - SFT/SSD op. >10M/spill at K1.8

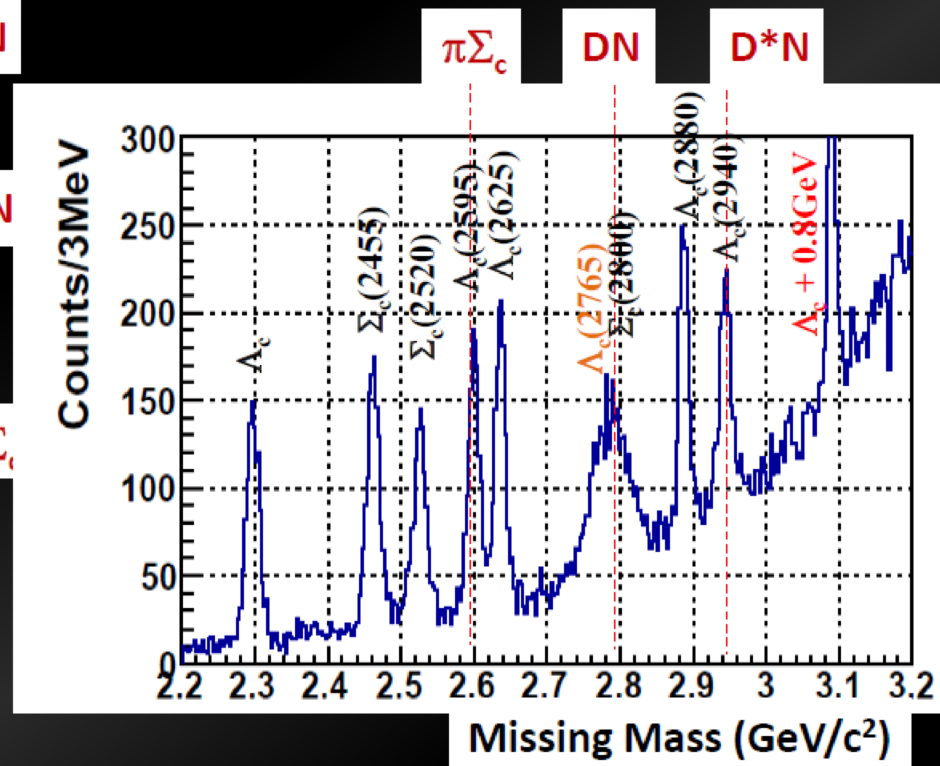


- Good mass resolution is required
  - D^0 meson: 4.5 MeV, D* meson: 0.7 MeV

Expected Spectrum in the (π, D^{*-}) reaction



Signal: 1 nb/Yc* :~1000 events
BG: 1.8 mb (JAM)



Physics with Kaon

- Un-separated secondary beam contains 1-10% Kaons. If a smart trigger system to select kaon is adopted, kaon physics can be done using a high momentum beam.
- Physics examples under discussions,
  - Ξ_c Spectroscopy
    - Investigate Strangeness and Charm sector
    - $K^- + p \to \Xi_c + D^-$ (Production Threshold: 10 GeV/*c*)
    - Use the same spectrometer with charm baryon spectroscopy. Experimental issues, such as yield, background, resolutions, are being evaluated.
  - Charmed exotic baryons
    - Θ_{cs} can be searched using a similar reaction.
    - $K^- + p \to \Theta_{cs} + D^+$

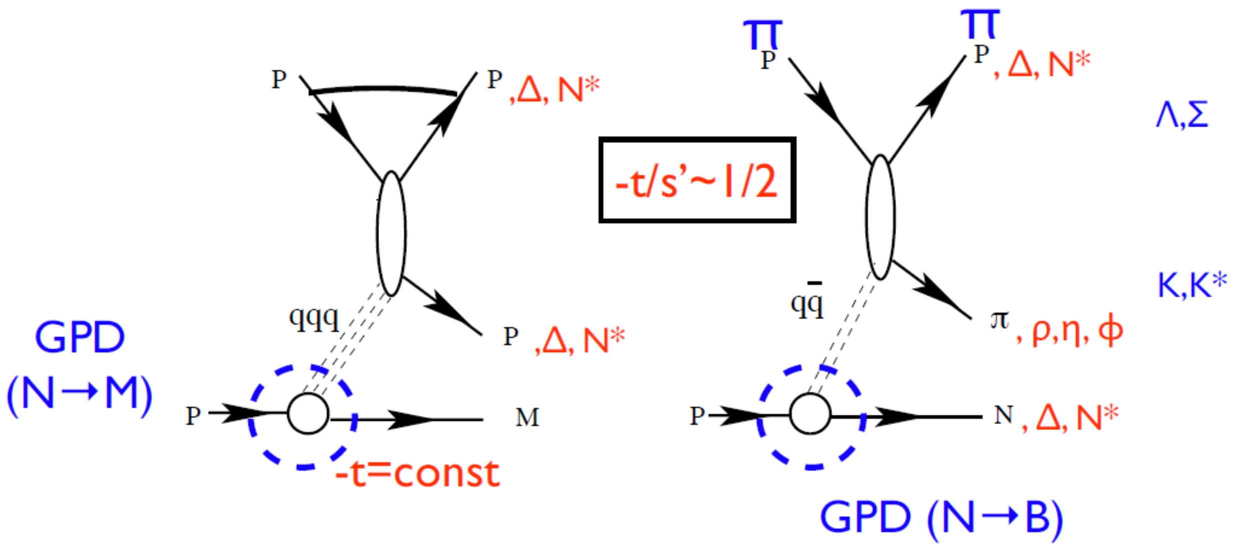
Mark Strikman

- 2→2, Color transparency

$$T(A, E_{inc}) = \frac{\sigma(h + A \to h_1 + h_2)}{A\sigma(h + N \to h_1 + h_2)} \underset{\text{CT}}{\Longrightarrow} 1$$

Mark Strikman

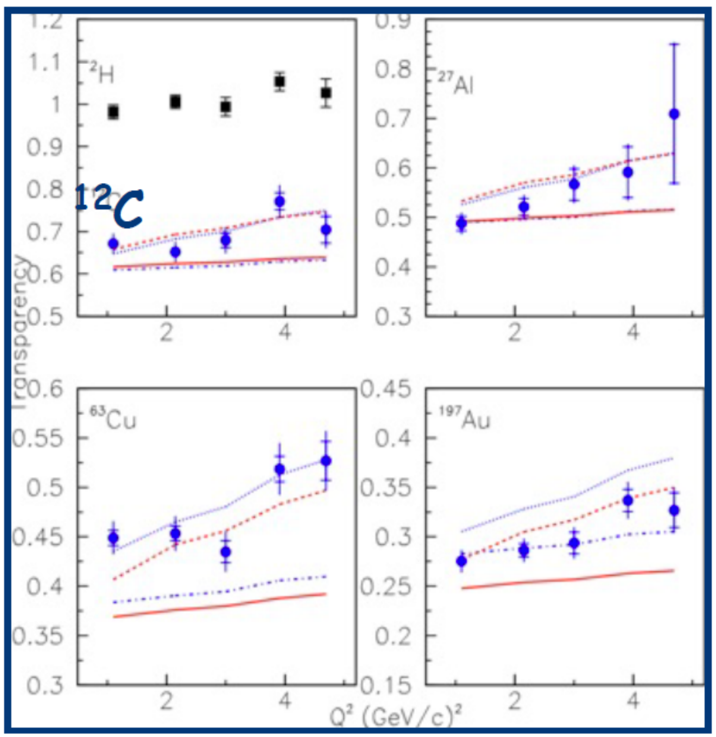
Many interesting channels, for example



28

Dipangkar Dutta

Pion Transparency



B. Clasie et al. PRL 90, 10001, (2007)
X. Qian et al., PRC81:055209 (2010),

$$T = \frac{\sigma_A^{\text{Expt}} / \sigma_A^{\text{Model}}}{\sigma_p^{\text{Expt}} / \sigma_p^{\text{Model}}}$$

solid : Glauber (semi-classical)
dashed : Glauber +CT (quantum diff.)
Larson, Miller & Strikman, PRC 74, 018201 ('06)

dot-dash : Glauber (Relativistic)
dotted : Glauber +CT (quantum diff.) +SRC
Cosyn, Martinez, Rychebusch & Van Overmeire, PRC 74, 062201R ('06)

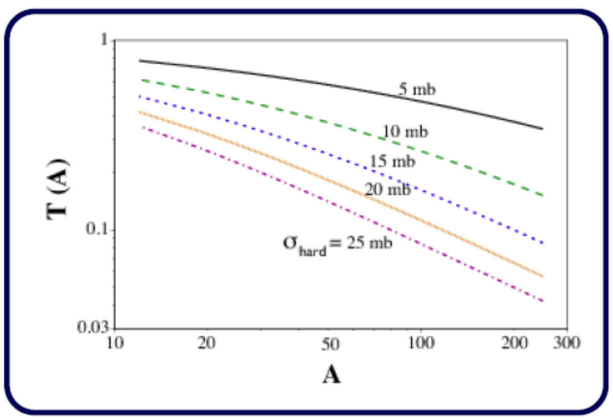
Wednesday, January 16, 13

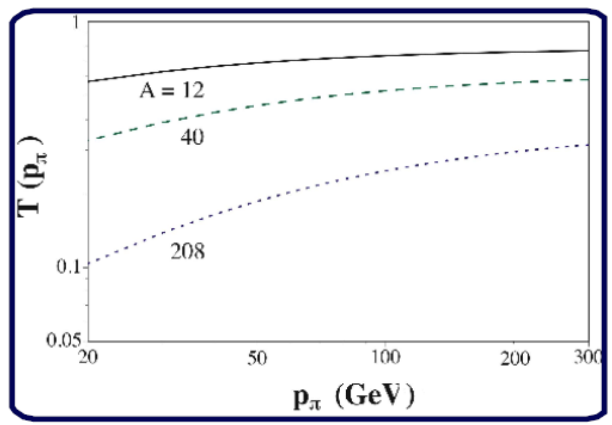
Dipangkar Dutta

New Observables

2 → 3 processes with pions $\pi + A \rightarrow \underbrace{\pi + \pi}_{\text{hard sub-process}} + A^*$

S. Kumano and M. Strikman PLB 683, 259 (2010)
S. Kumano, M. Strikman and K. Sudoh PRD 80, 073004 (2009)



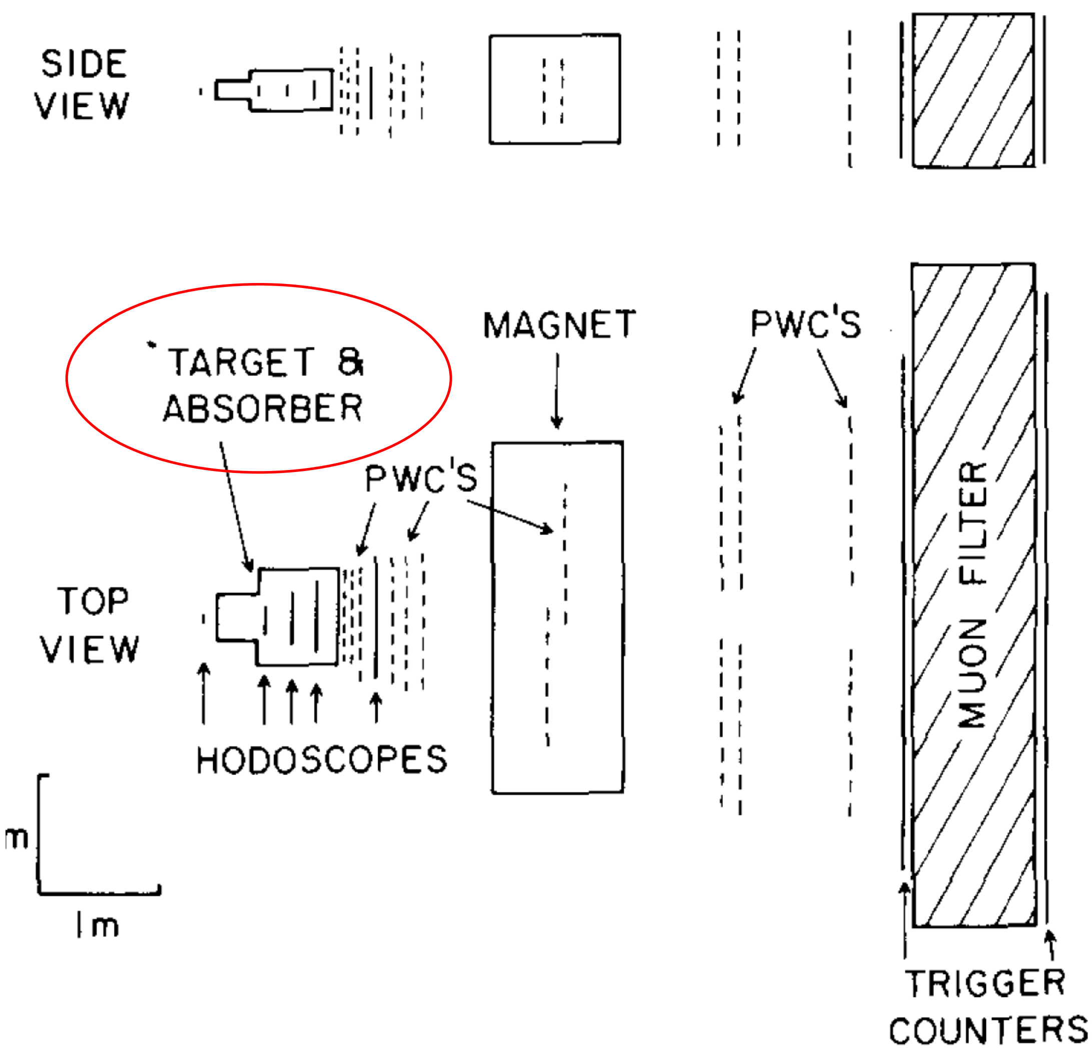


If the CT is observed, the space time evolution of the small size configuration can be studied by changing the initial pion momentum

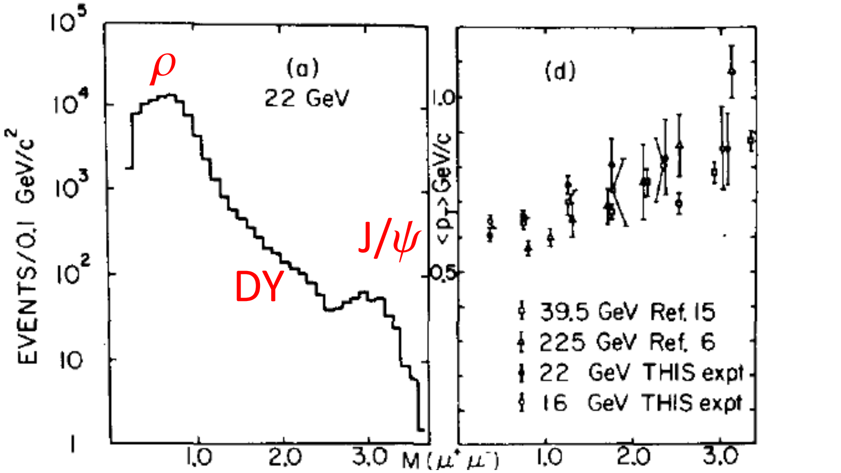
πN di-lepton experiments at low energies

- BNL (πN at 16 and 22 GeV):
  - Phys. Lett. B81 (1979) 397: di-lepton spectra
  - Phys. Lett. B81 (1979) 401: J/psi
  - Phys. Lett. B85 (1979) 427: Drell-Yan model
  - Phys. Lett. B85 (1979) 432: pion structure function
- IHEP, USSR (πN at 27 and 40 GeV):
  - Nucl. Phys. B179 (1981) 189

Hadron Absorber (24 inches of Brass)

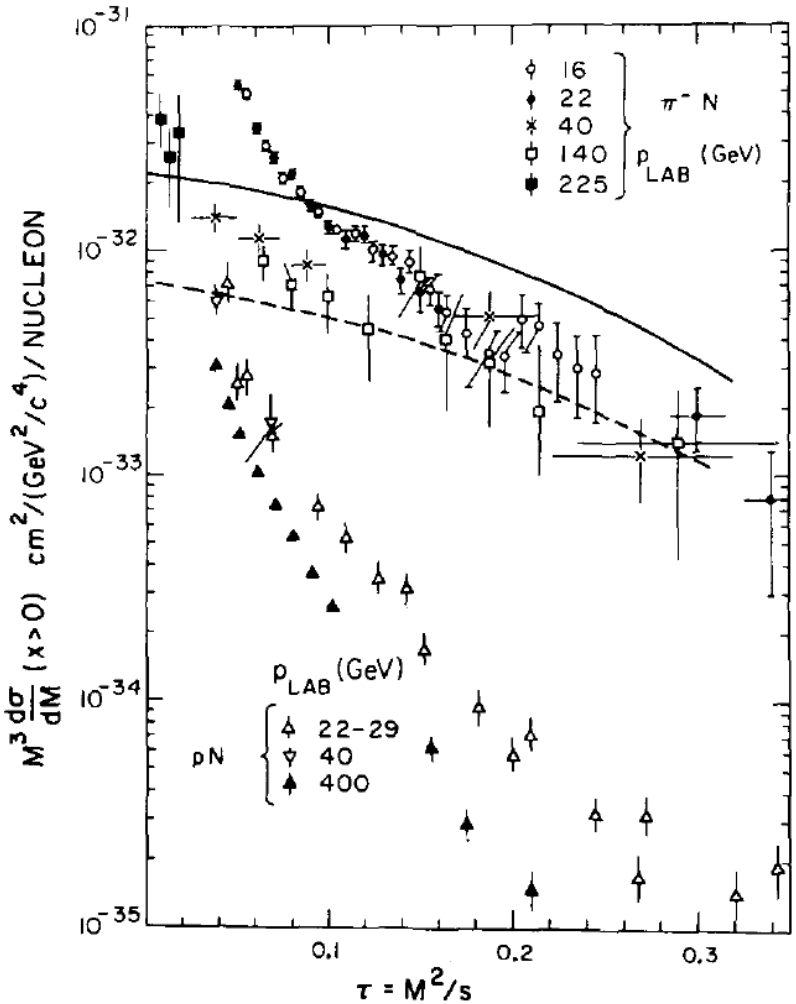


Muon pair production in 22 GeV πCu collisions



$< p_T >$ increases with $M_{\mu\mu}$

No results of angular distributions.



- σ(DY) scales with τ
- $\sigma(\pi N) \gg \sigma$(pN)

Muon pair production in 22 GeV πCu collisions

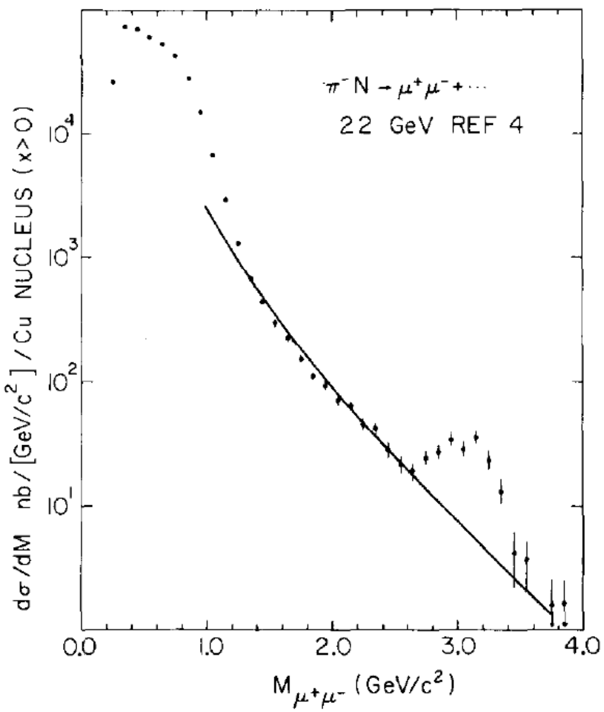
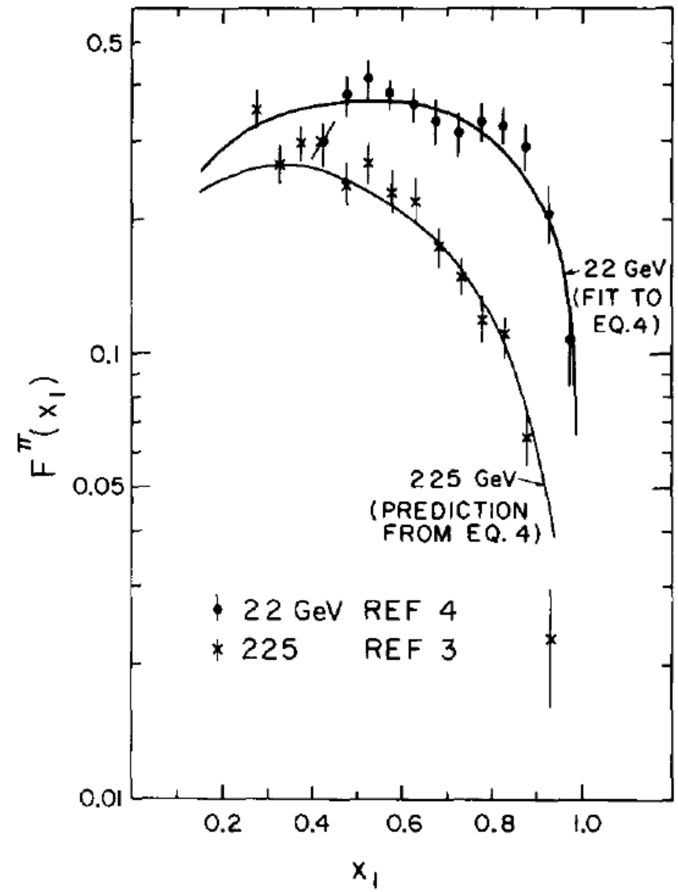
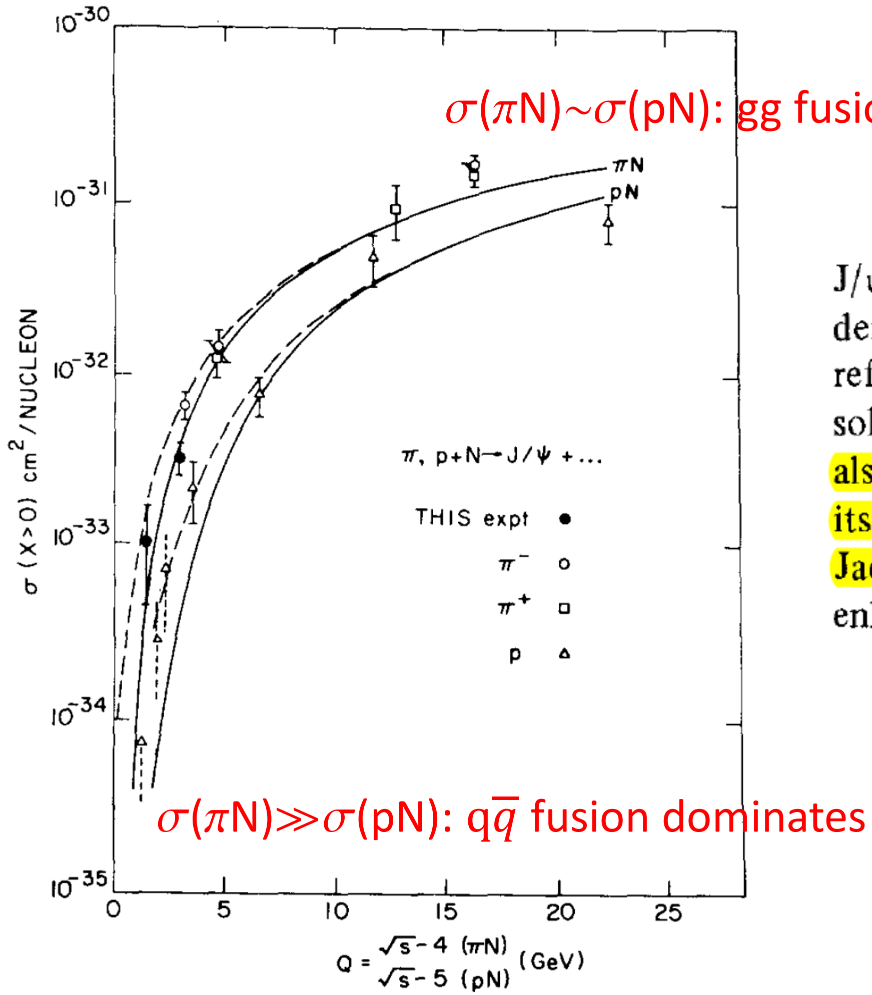


Fig. 3. The differential cross section $d\sigma/dM$ for dimuon production by 22 GeV π^- on a Cu target. The curve is the prediction of the Drell–Yan model using the observed pion structure function and the formalism of ref. [1].



J/ψ production in 22 GeV πCu collisions



In fig. 3 we show the energy dependence of the J/ψ production cross sections for $x > 0$ for both incident pions and protons [10]. Again, the dashed curves refer to the original quark fusion model [6] while the solid curves include the threshold condition. We have also examined the J/ψ decay angular distribution in its center of mass and find it to be isotropic in the Jackson frame. We also note the absence of a threshold enhancement and that the Fermi motion in the nucleus

Violation of Lam-Tung relation remains at low energies?

Muon pair production in 27 and 40 GeV πN collisions

In the near-threshold region these differences become even more distinct:

$$\left.\frac{\sigma(\pi N \to J/\psi^{+}\ldots)}{\sigma(pN \to J/\psi^{+}\ldots)}\right|_{x_F>0} = \begin{cases} 2, & \text{for } \tau = 0.02, \\ 20, & \text{for } \tau = 0.2. \end{cases} \tag{2}$$

This fact is also in quite reasonable agreement with the model of J/ψ production resulting from the fusion of quark-antiquark pairs.

Precise information of the angular distributions of Drell-Yan and J/ψ will be essential in understanding their production mechanisms at low energies.

πN Di-lepton Production: Drell-Yan & J/ψ

- Drell-Yan:
  - Pion partonic structure
  - BM function (Violation of L-T relation)
  - Pion DA
  - Valance-quark distributions at large-x
  - Parton energy loss
  - Nuclear PDF
  - Low-mass di-lepton spectrum
- J/ψ:
  - Production mechanism at low energies
  - Intrinsic charm of pion at large xF

- **Beam**: pion
- **Target**: proton, deuteron and nuclei
- **Detector**: hadron absorber, muon identification, di-muon trigger
- **Pros**: well-established approach, complementary to COMPASS.
- **Cons**: bad momentum resolutions due to relatively large multiple-scattering effect.

pN Di-lepton Production: Drell-Yan & J/ψ

- Drell-Yan:
  - p+d/p+p ratio measurement for u,d sea quark of nucleon at large-x.
  - BM function (Violation of L-T relation)
  - Parton energy loss
  - Nuclear PDF
  - Low-mass di-lepton spectrum
  - Forward-backward asymmetry in decay angular distribution of Drell-Yan for probing Weinberg angle at low Q^2
- J/ψ:
  - Production mechanism at low energies; J/Psi production as an alternative Drell-Yan to probe the sea-quark in nucleon.
  - Intrinsic charm of proton at large xF

- **Beam**: proton (30 GeV)
- **Target**: proton, deuteron and nuclei
- **Detector**: hadron absorber, muon identification, di-muon trigger
- **Pros**: well-established approach, complementary to E906/SeaQuest.
- **Cons**: bad momentum resolution of muons due to relatively large multiple-scattering effect.

KN Dilepton Production: Drell-Yan & J/ψ

- Drell-Yan:
  - K+d/K+p ratio measurement for strange sea quark of nucleon at large-x.
  - Kaon partonic structure
  - BM function or Glauber gluon responsible for L-T relation violation
- J/ψ:
  - Production mechanism at low energies.
  - Intrinsic charm of kaon at large xF

- **Beam**: kaon
- **Target**: proton, deuteron and nuclei
- **Detector**: beam PID, hadron absorber, muon identification, di-muon trigger
- **Pros**: novel measurement other than NA3.
- **Cons**: bad momentum resolution of muons due to relatively large multiple-scattering effect.

πN Exclusive Di-lepton Production

- Nucleon GPD
- Pion DA
- Pion-Nucleon TDA

- **Beam**: pion
- **Target**: proton, deuteron and nuclei
- **Detector**: hadron absorber, muon identification, di-muon trigger
- **Pros**: novel measurement for determining GPD; complementary to Jlab, GSI and COMPASS.
- **Cons**: bad momentum resolution of muons becomes crucial in ensuring the exclusive production; relatively small production cross section (1 pb).

πN Hard Exclusive Hadron Production

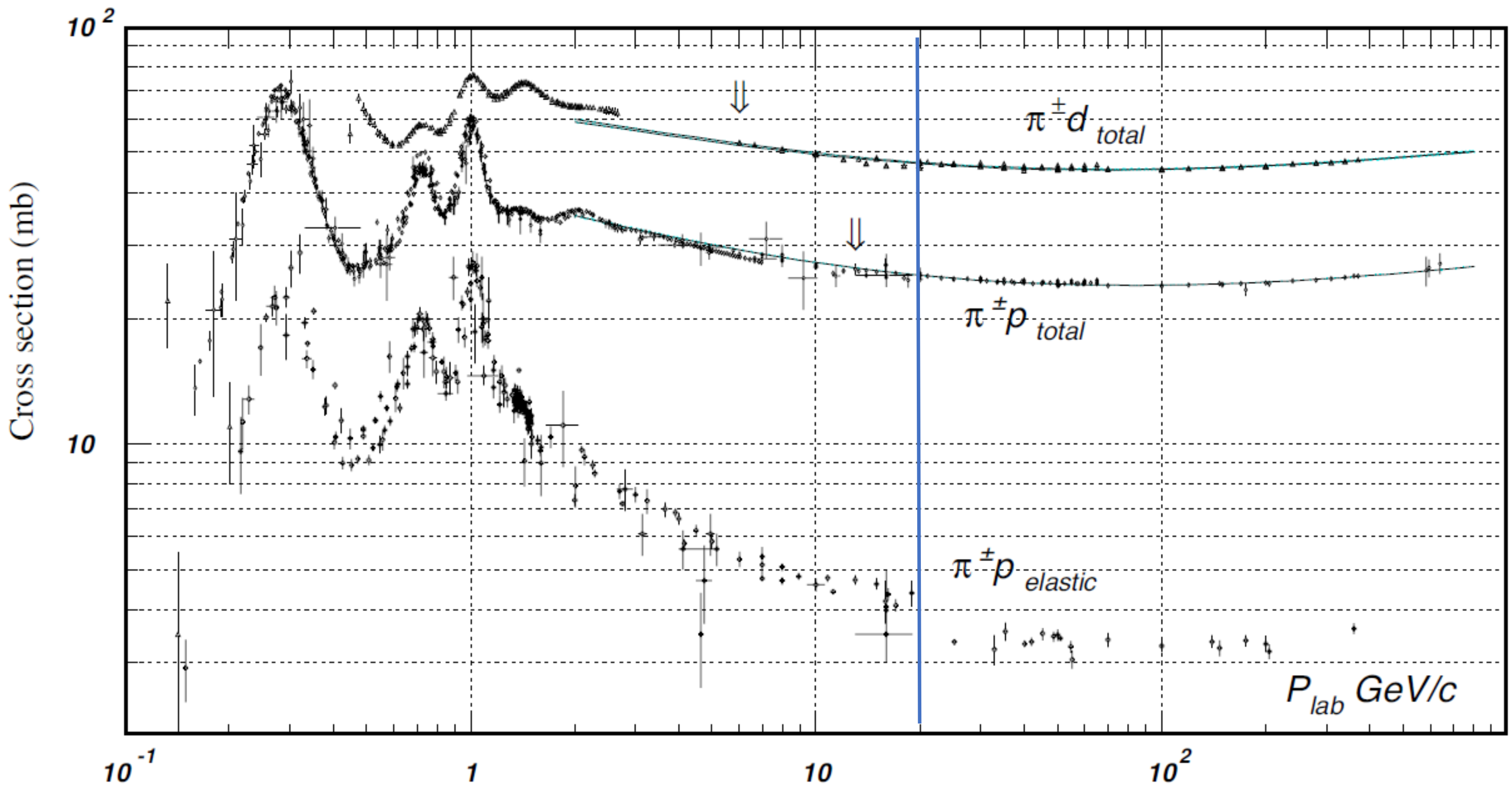
- Hadron tomography
- Color transparency
- Charmed baryons
- Heavy exotics

- **Beam**: pion-
- **Target**: proton, deuteron and nuclei
- **Detector**: good spectrometer
- **Pros**: novel measurement, large cross section
- **Cons**: Large background, online trigger might be needed.

Conceptual Detector System

- Beam PID
- Open aperture without hadron absorber before momentum determination
- Spectrometer with good momentum resolution and particle ID
- Muon ID in the forward direction at the very downstream

π + proton



10^2
10
Cross section (mb)
$\pi^{\pm}d_{total}$
$\pi^{\pm}p_{total}$
$\pi^{\pm}p_{elastic}$
P_{lab} GeV/c
10^{-1}
1
10
10^2

20-GeV π- + proton (25 mb)

```
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I  11 f + f' -> f + f' (QCD)       I         3717             0 I  1.359D+01 I
I  12 f + fbar -> f' + fbar'       I           17             0 I  6.216D-02 I
I  13 f + fbar -> g + g            I           34             0 I  1.243D-01 I
I  28 f + g -> f + g               I         1059             0 I  3.872D+00 I
I  53 g + g -> f + fbar            I            4             0 I  1.463D-02 I
I  68 g + g -> g + g               I          247             0 I  9.032D-01 I
I  91 Elastic scattering           I         2787          2787 I  3.790D+00 I
I  92 Single diffractive (XB)      I          990           990 I  1.355D+00 I
I  93 Single diffractive (AX)      I          921           921 I  1.216D+00 I
I  94 Double  diffractive          I          224           224 I  2.839D-01 I
I  95 Low-pT scattering            I            0         13935 I  0.000D+00 I
I                                  I                            I            I
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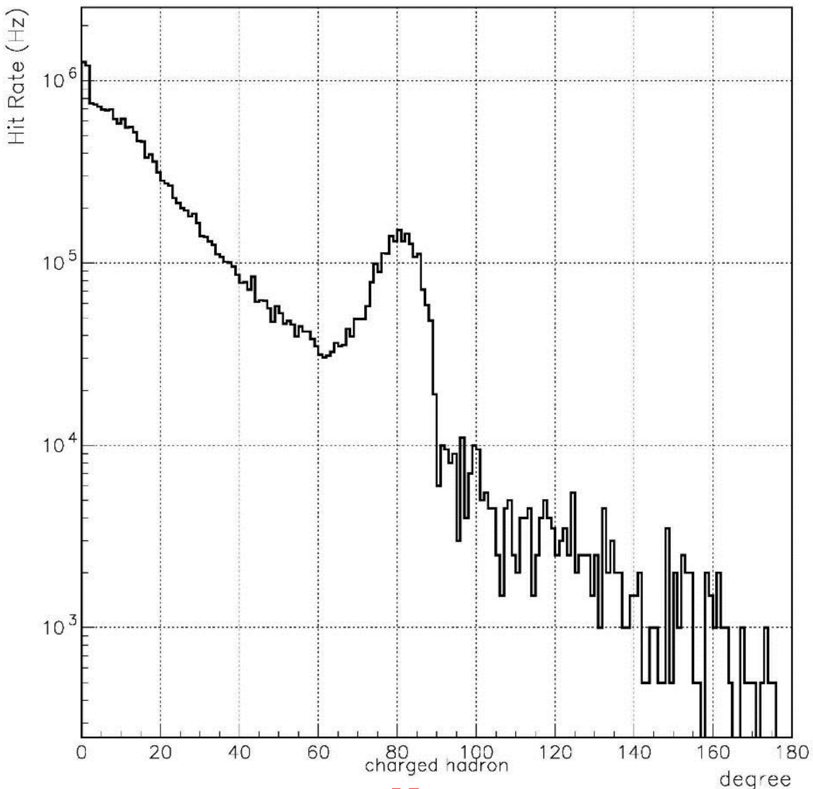
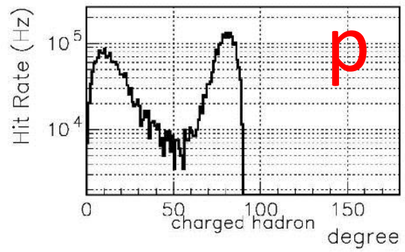
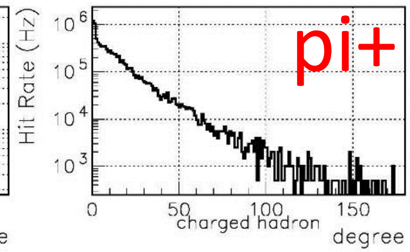
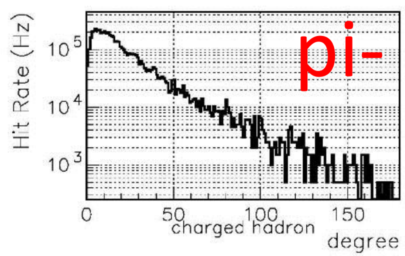
Estimated Hit Rate

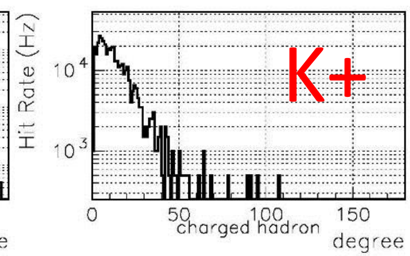
Hottest hit rate: 1Mhz/degree

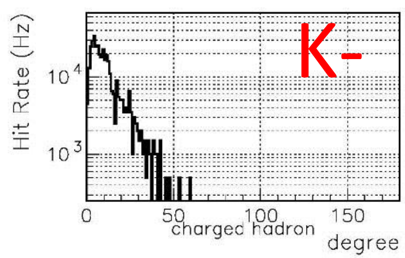










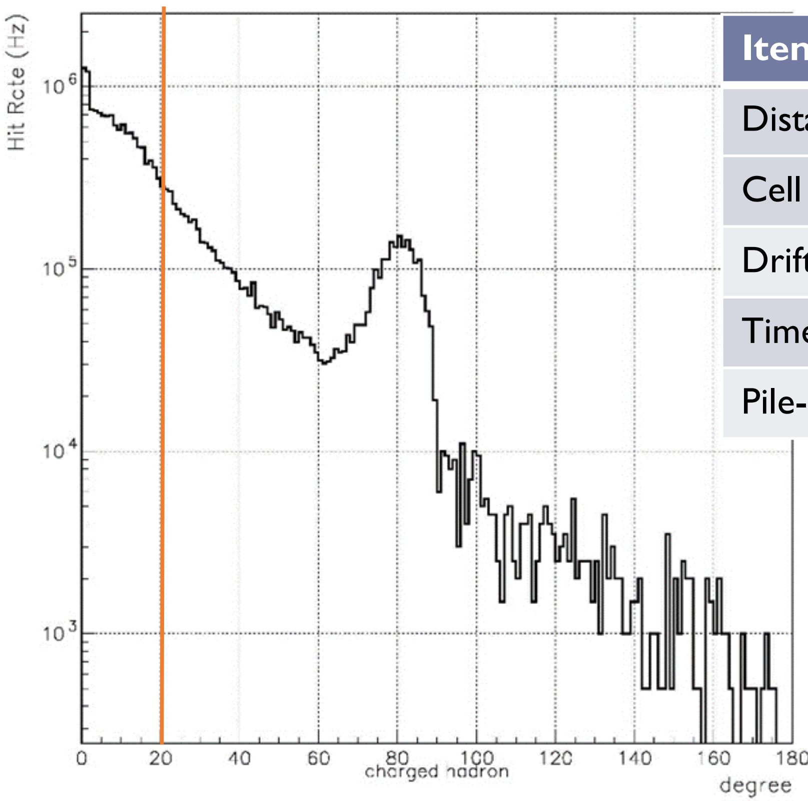


$$\frac{dN}{d\theta}(\text{per sec}) = \sigma_{\pi p} * \frac{N_p}{A} * L_\pi * \frac{dN}{d\theta}(\text{per event})$$

$$= 25\text{mb} * (2*10^{32} cm^{-2}) * (1*10^{8} s^{-1}) * \frac{dN}{d\theta}(\text{per event; Pythia})$$

Occupancy of Drift Chamber

20 degree for 1% pileup.

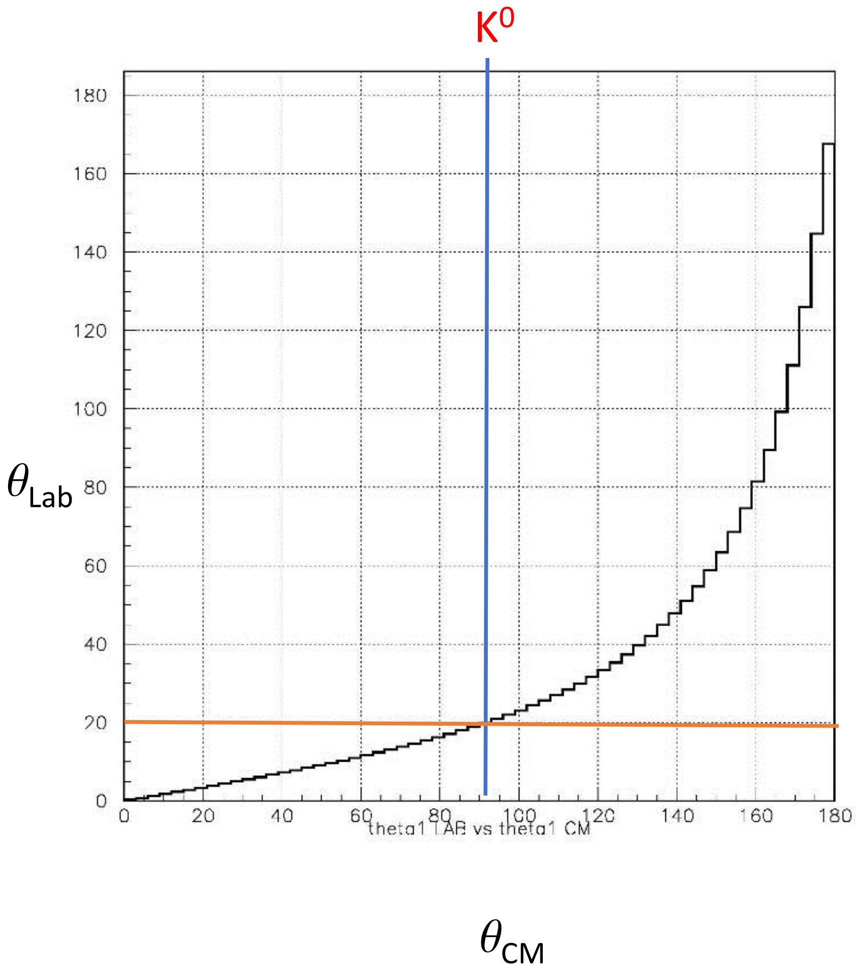


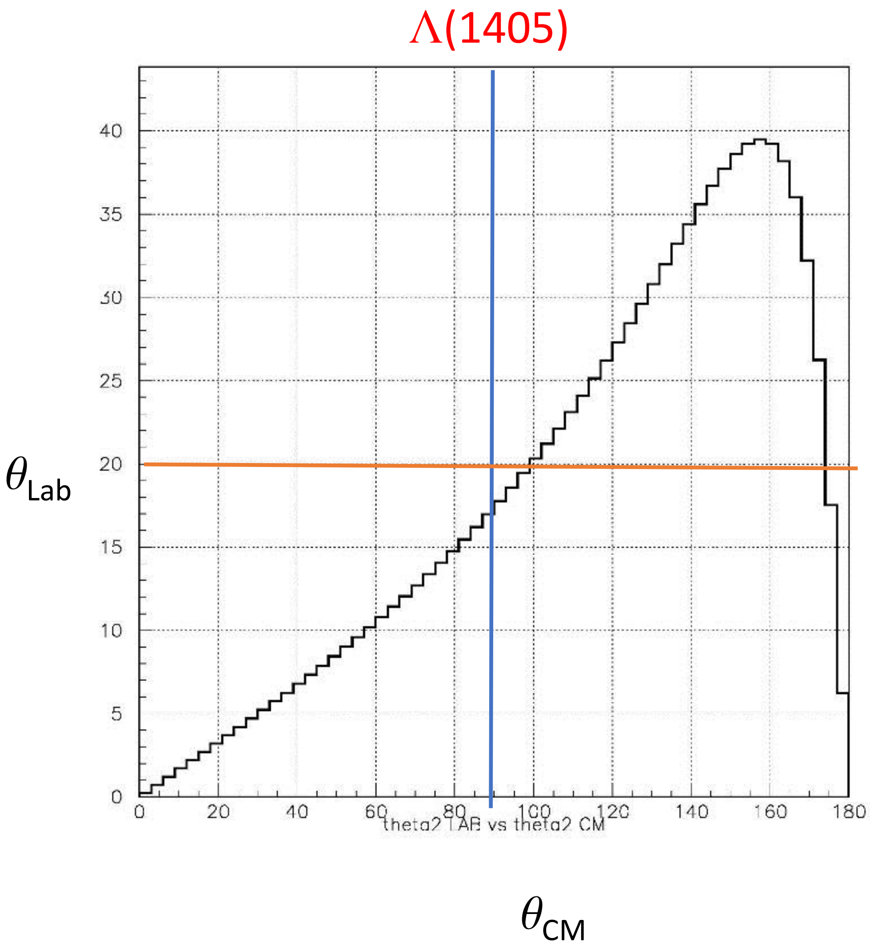
Item	Parameters
Distance*angle	1 m * 1 degree = 17.45 mm
Cell size	10 mm
Drift velocity	50 μm/ns
Time window	5 mm/ 50 μm/ns = 100 ns
Pile-up percent	100 ns/[1./(10**6/17.45*10) s]= 6 %

It is still possible to track all charged hadrons whose polar angles are less than 20 degree by

- detector with better granularity
- detector with fast operation

π- p→K^0 Λ(1405)





20-GeV π- + proton→μ+μ-X (487 pb)

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I----------------------------------I----------------------------I    (mb)    I
I                                  I                            I            I
I N:o Type                         I    Generated         Tried I            I
I                                  I                            I            I
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I                                  I                            I            I
I   0 All included subprocesses    I       100000       2955311 I  4.874D-07 I
I   1 f + fbar -> gamma*           I       100000       2955311 I  4.874D-07 I
I                                  I                            I            I
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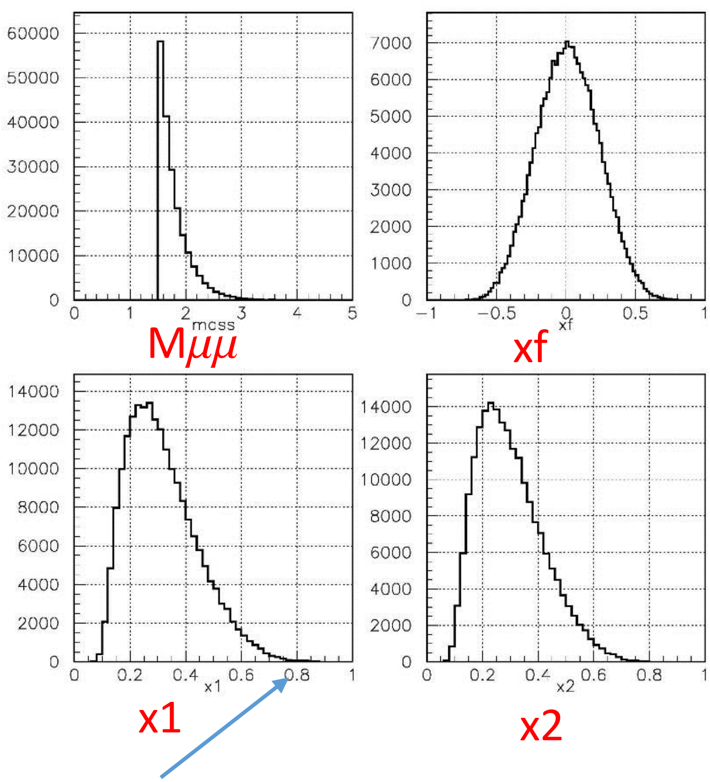
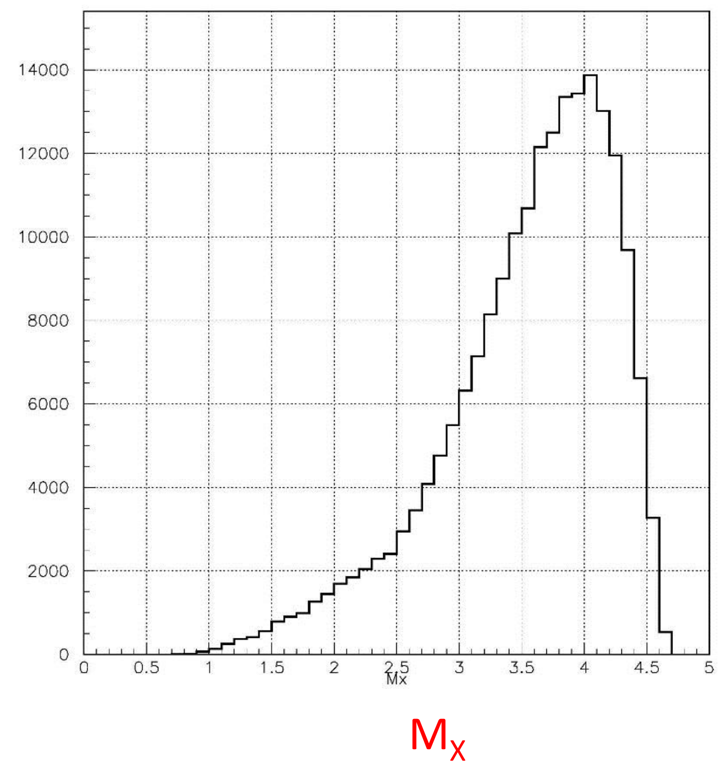
20-GeV π- + proton→μ+μ-X

Di-muon pair

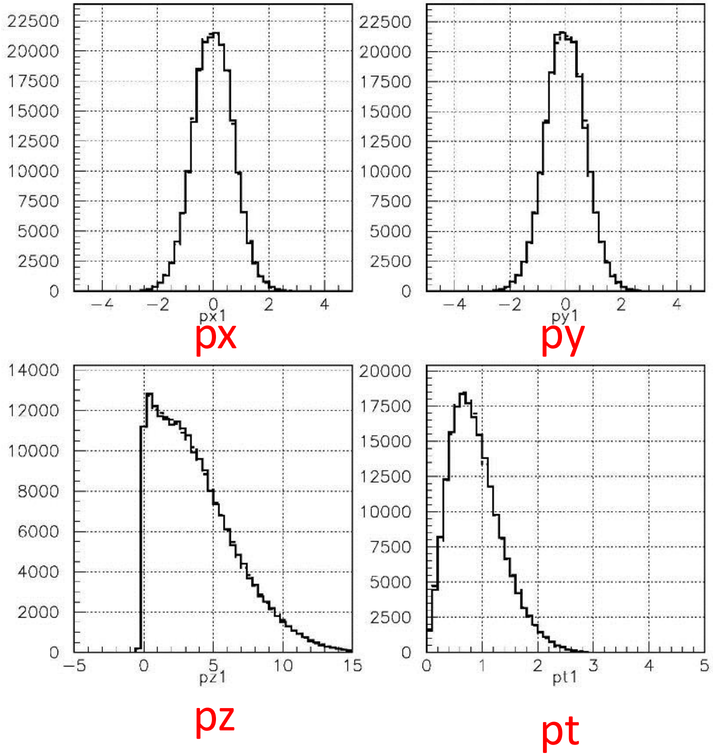


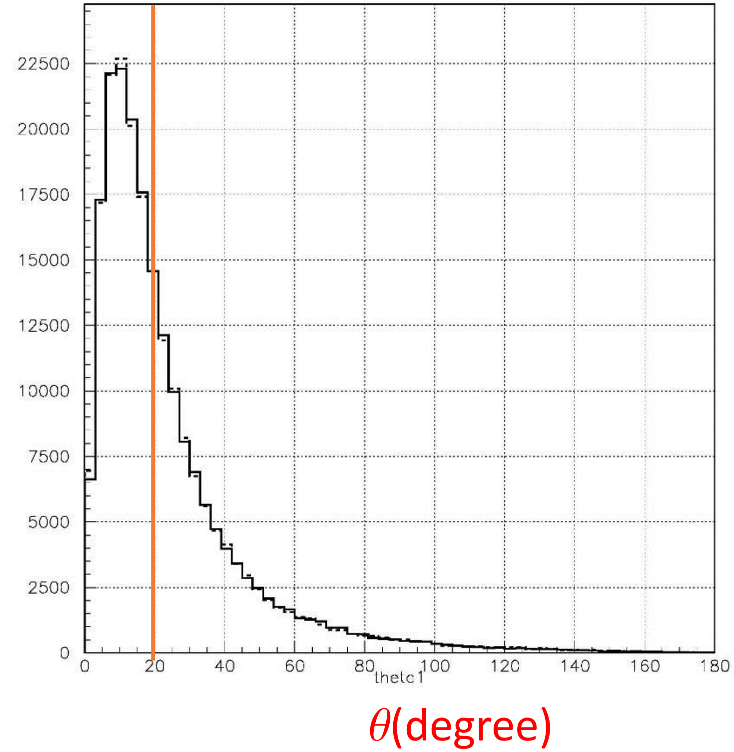


The x1 overage might not be sensitive to the energy loss determination!

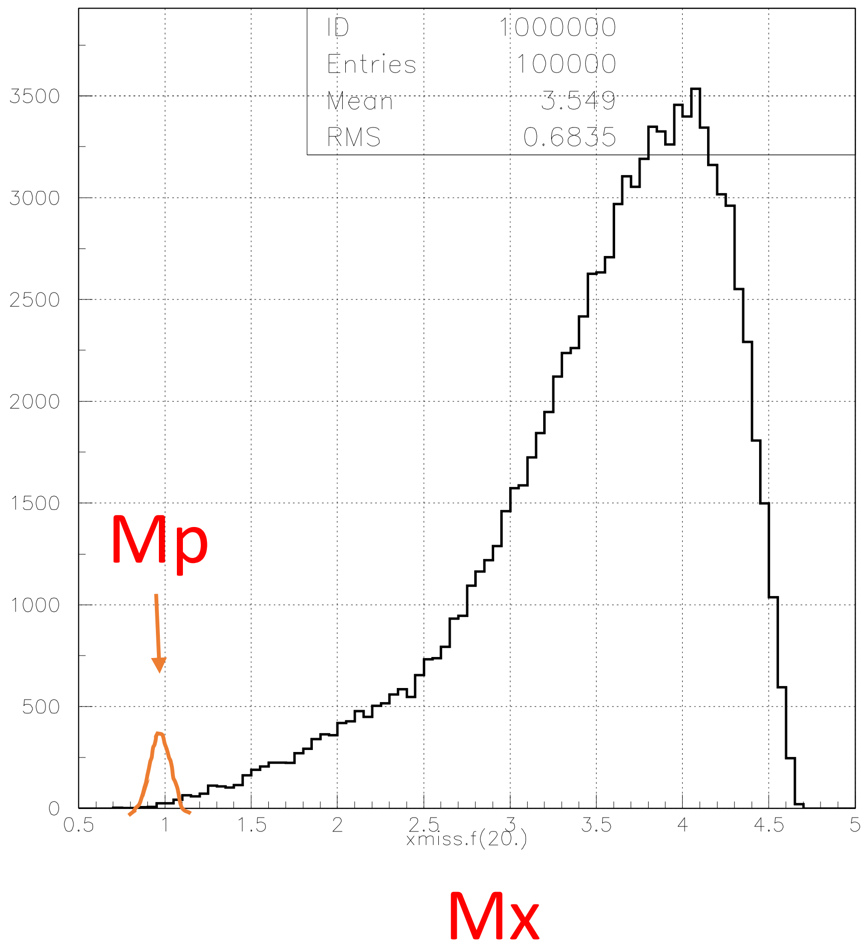
20-GeV π- + proton→μ+μ-X

Single muon



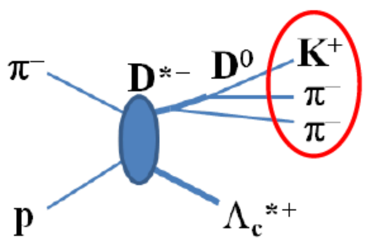


20-GeV π- + proton→μ+μ-X

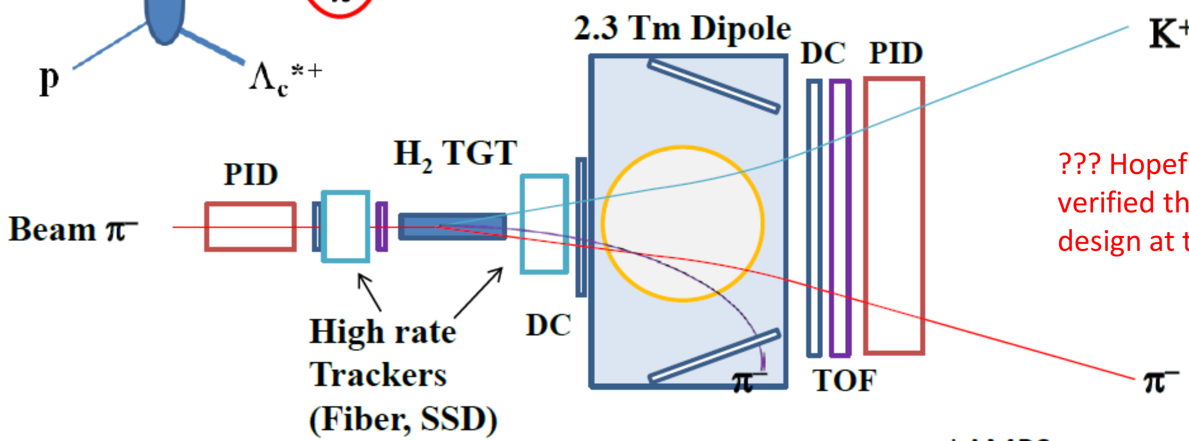


- At Mx=Mp, the cross section is about 487pb*8/100000=0.04 pb.
- The cross section of exclusive production is ~ 0.5 – 1.0 pb.
- S/B ~ 10 – 20.

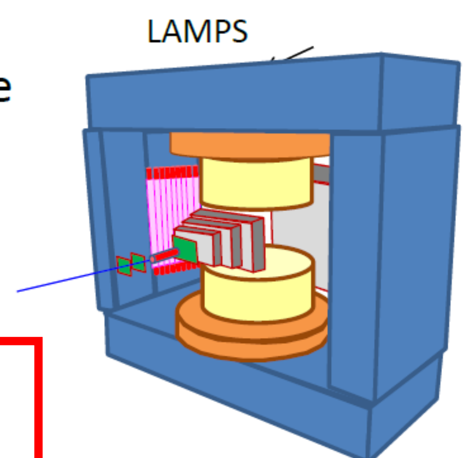
J-PARC P50 Spectrometer



Spectrometer Concept

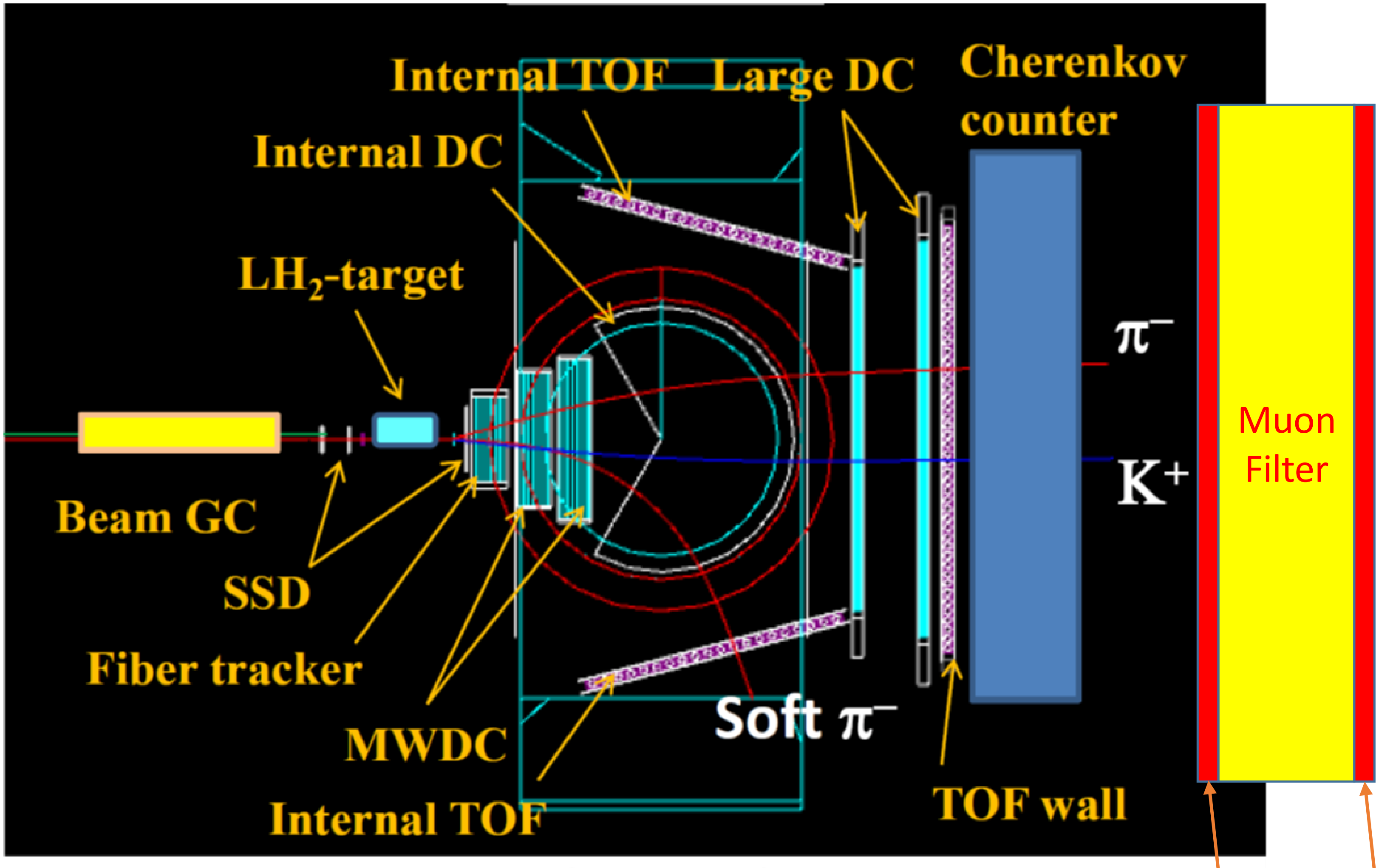


??? Hopefully J-PARC P50 collaborators have verified the tracking capability of the current design at the very forward direction.



- Large Acceptance, Multi-Particle
  - *K*, *π* from D^0 decays
  - Soft π from D^{*-} decays
  - (Decay products from Y_c*)
- High Resolution
- High Rate
  - SFT/SSD op. >10M/spill at K1.8

J-PARC P50 Spectrometer + MuID



2m

$|\theta|<60°$

Scintillator Muon trigger device

Muons from pion decay might be a concern.

Summary

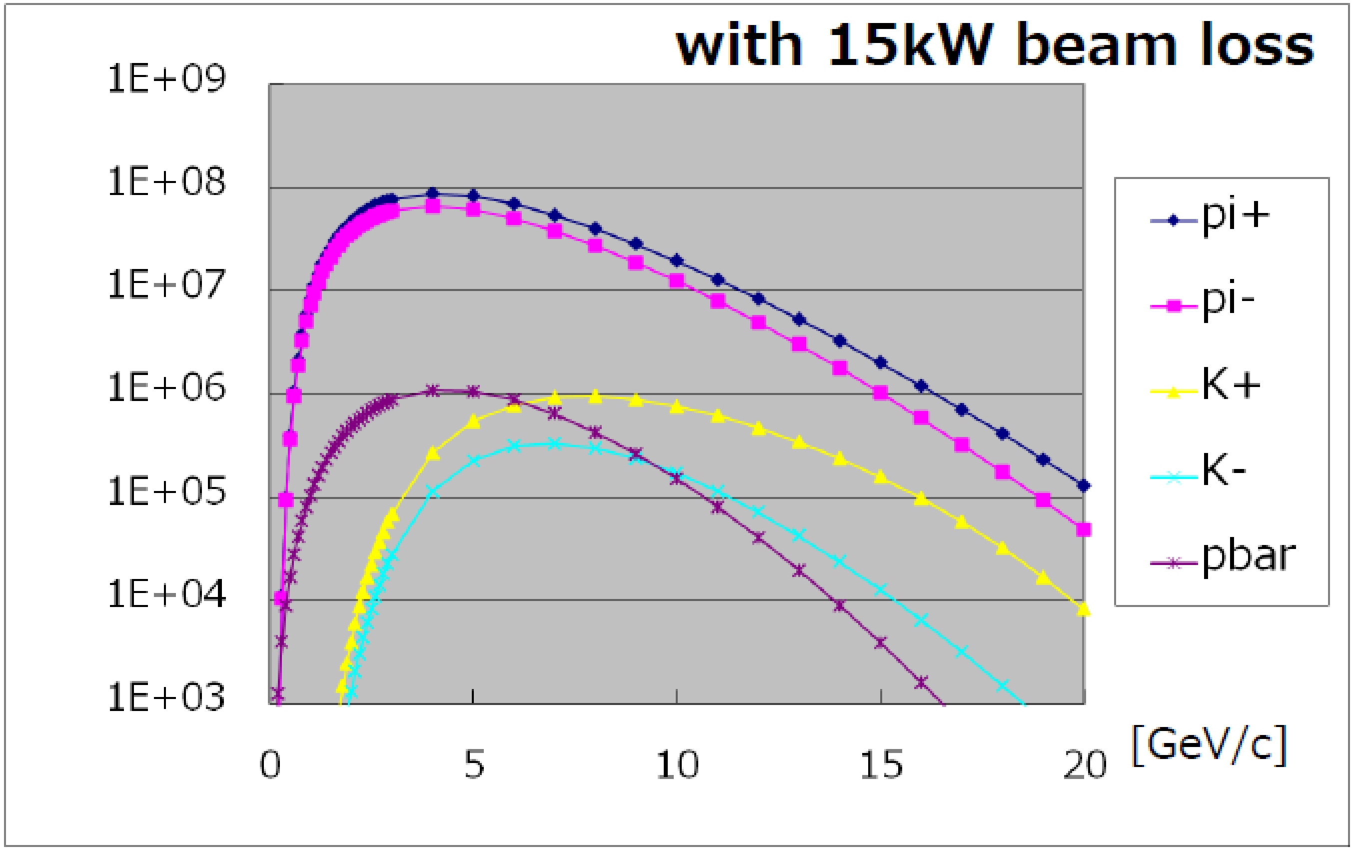
- The (p, π, K)-induced di-lepton and hard exclusive processes could be studied in the coming high-momentum beam line at J-PARC . These programs will offer important understanding on many aspects of QCD via
  - **Nucleon structure**: sea quarks PDF; GPD, TDA and TMD
  - **Pion structure**: PDF and TFF
  - **Kaon structure**
  - **Structure of exotic hadrons**
  - **Parton energy loss, J/ψ production**
  - **Color transparency**
- Spectrometer with a large acceptance and good mass resolution is required.
- More collaborators are surely needed to make things happen!

Backup Slides

R. Muto, KEK

secondary beam intensity

beam loss limit @ SM1:15kW
(limited by the thickness of the tunnel wall)



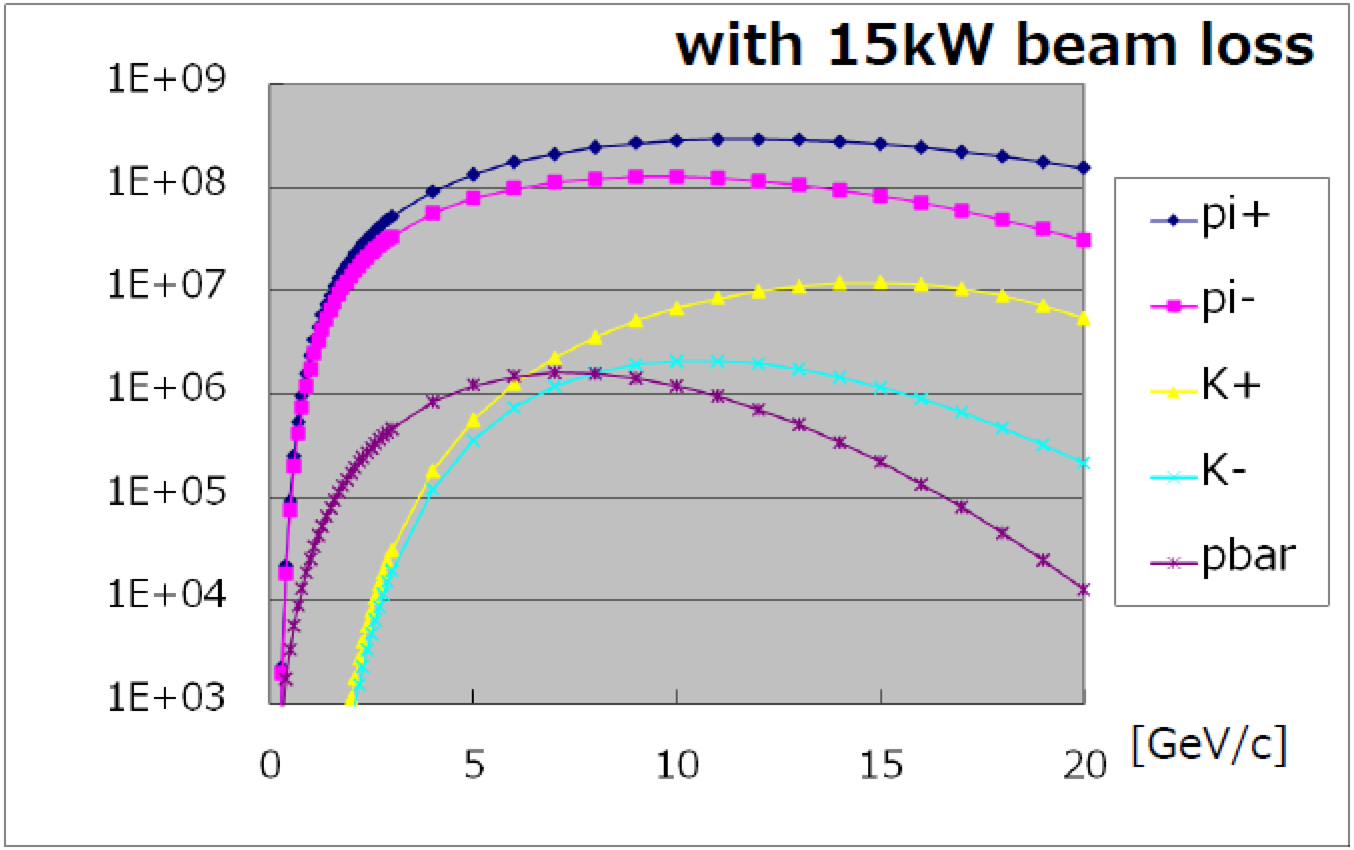
extraction angle : 5°

5

R. Muto, KEK

secondary beam intensity

beam loss limit @ SM1:15kW
(limited by the thickness of the tunnel wall)



extraction angle : 0°

R. Muto, KEK

expected secondary beam intensity

	p (GeV/c)	Yield 5°	Yield 0°
π+	5	**8.2E7**	**1.3E8**
π+	10	**1.9E7**	**2.8E8**
π-	5	**6.0E7**	**7.8E7**
π-	10	**1.2E7**	**1.3E8**
K+	5	**5.4E5**	**5.6E5**
K+	10	**7.6E5**	**6.8E6**
K-	5	**2.3E5**	**3.6E5**
K-	10	**1.7E5**	**2.1E6**
p bar	5	**1.1E6**	**1.2E6**
p bar	10	**1.5E5**	**1.2E6**

30 GeV proton

15 kW loss target

$(\Delta p/p)\Delta\Omega$:
0.16 msr%

beam line length :
120 m

Sanford-Wang
formula

Beam Configuration

- Primary 30-GeV proton beam at 10^{10}-10^{12}/s.
- Secondary beam:
  - Pion: 10-20 GeV at 10^{8}/s .
  - Kaon: 10-15 GeV at 10^{6}-10^{7}/s.
  - Anti-proton: 5-10 GeV at 10^{6}/s.

15-GeV π^- + proton$\rightarrow\mu^+\mu^-$X (500 pb)

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I                                  I                            I            I
I            Subprocess            I      Number of points      I    Sigma   I
I                                  I                            I            I
I----------------------------------I----------------------------I    (mb)    I
I                                  I                            I            I
I N:o Type                         I    Generated         Tried I            I
I                                  I                            I            I
==============================================================================
I                                  I                            I            I
I   0 All included subprocesses    I          100          2805 I  5.075D-07 I
I   1 f + fbar -> gamma*           I          100          2805 I  5.075D-07 I
I                                  I                            I            I
==============================================================================
```
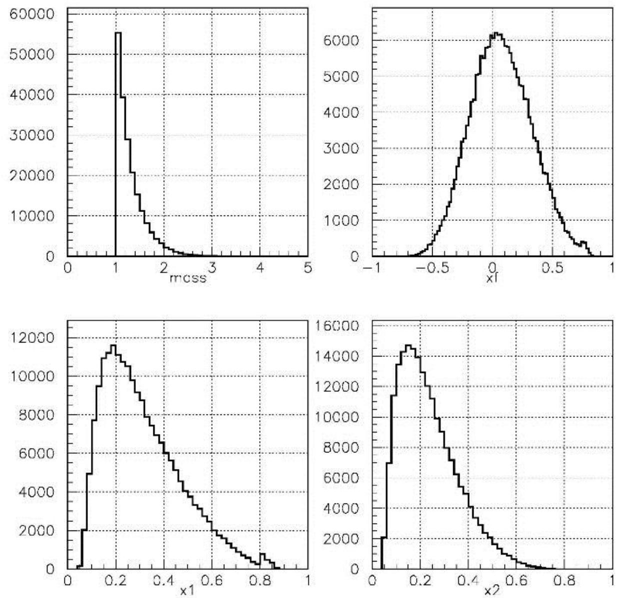
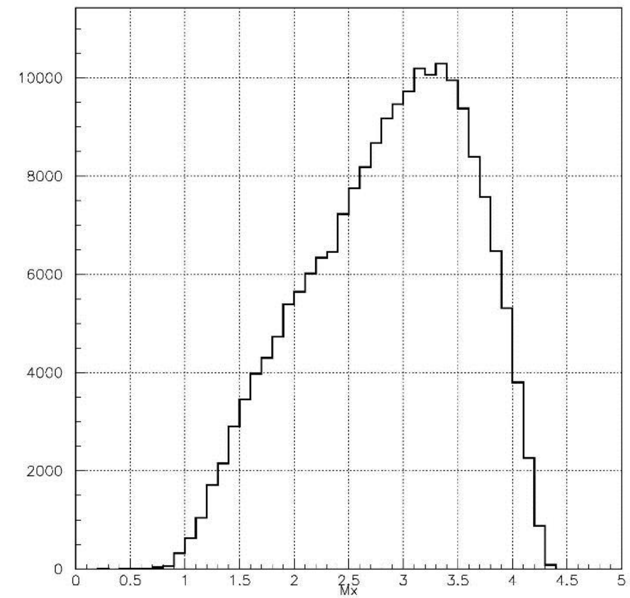
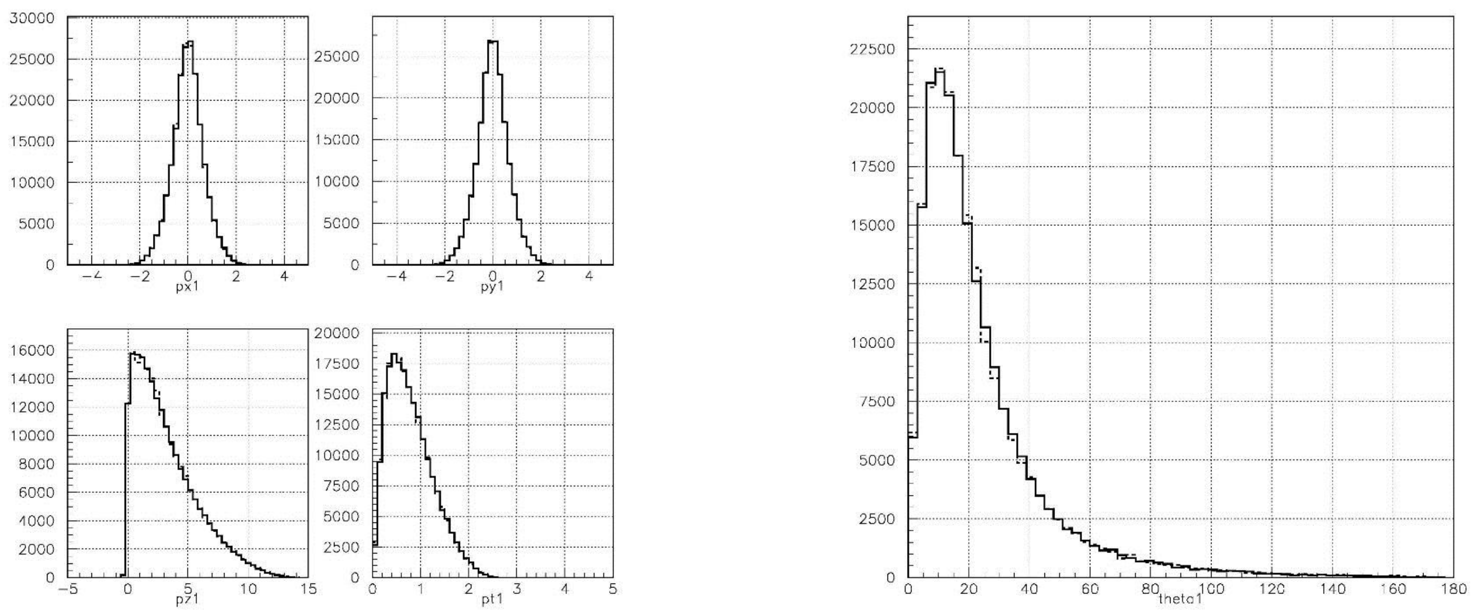

15-GeV π- + proton→μ+μ-X

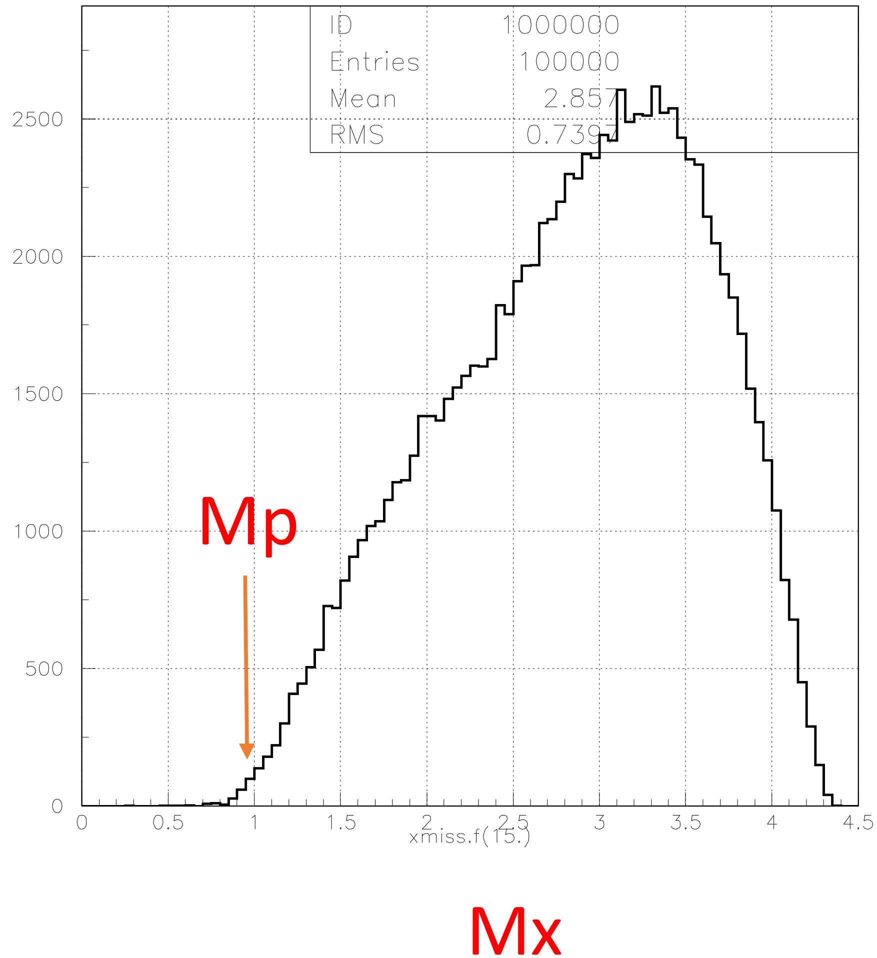




15-GeV π- + proton→μ+μ-X



15-GeV π- + proton→μ+μ-X



- At Mx=Mp, the cross section is about 500pb*60/100000=0.3pb.
- The cross section of exclusive production is ~ 0.5 – 1.0 pb.
- S/B ~ 1 – 2.