Study of Drell-Yan processes with COMPASS

Oleg Denisov, INFN sez. Torino

Basic ideas, experimental apparatus, feasibility, expected DY event rates

International Workshop on Structure and Spectroscopy, Freiburg, 19-21/03/2007

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DY at COMPASS

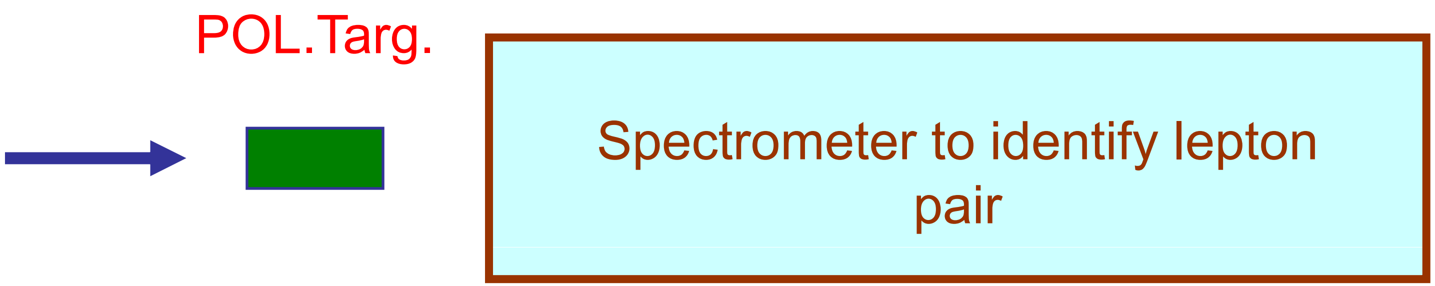
- October 2004, CERN SPSC meeting at Villars – study of DY processes with COMPASS was at first time proposed and discussed (proposal by R.Bertini, O.Denisov and S.Paul)
- 2005 - 2007 – feasibility study (SPS hadron beams, Compass polarised target, CERN safety regulations (radioprotection), trigger system, spectrometer lay-out, possible ways of the background suppression, competition and complementarity, methods elaboration, two DY workshops were organized: Dubna in December 2006 and Torino in March 2007)
- Summer 2007 – DY COMPASS Beam Test
- December 2007 – possibly first draft of the proposal

Drell-Yan Kinematics

Kinematics

- $x_1 = \frac{Q^2}{2p_1 q}, \quad x_2 = \frac{Q^2}{2p_2 q}$ – fractions of the longitudinal momentum of the hadrons A and B carried

Valence quarks PDFs - π^- or pbar



Small cross sections – high beam intensity (high secondary particles flux)

- ϕ_S – azimuthal angle of the hadron polarization measured with respect to lepton plane

Hadron beam spin physics with COMPASS

- Drell-Yan physics with transversally polarised target
  - Transversity and its accompanying T-odd PDF:
    - Sivers function $f_{1T}^{\perp}(x, \mathbf{k}_T^2)$
    - Boer-Mulders function $h_1^{\perp}(x, \mathbf{k}_T^2)$
    - Get information on transversity $h_1(x)$
- Drell-Yan physics with longitudinally polarised target
  - Pion light-cone distribution amplitude (O.Teryaev)
- "Conventional" spin physics with hadron beam and polarised target
  - Spin asymmetries in multi-pion production (talk by Marco Radici)
  - Possible extension to Λ_c and Λ polarization

Basic features of the experiment

I. Intense ($2x10^7$ p/s) hadron beams

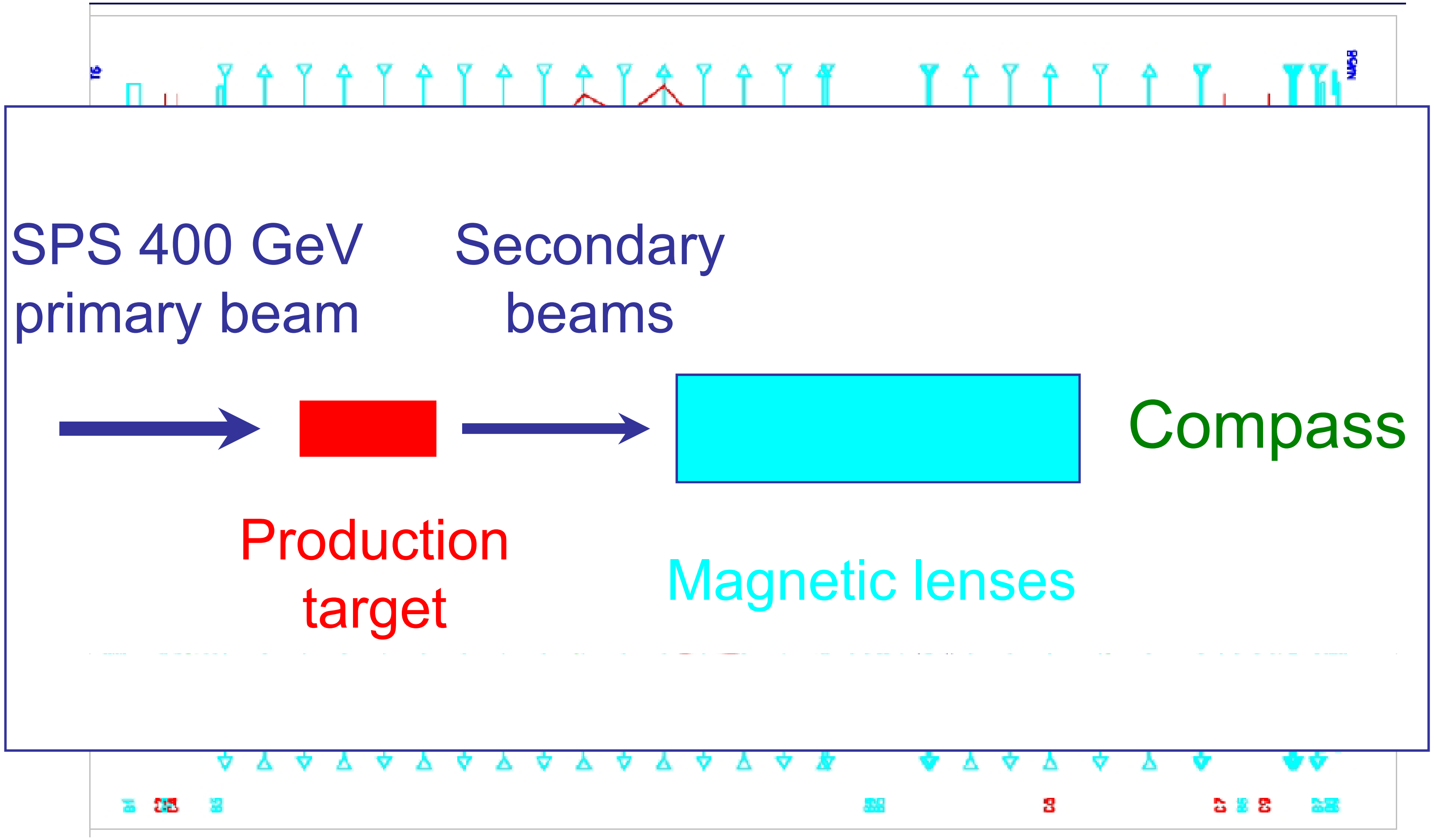
II. Exellent large acceptance polarised target (NH_3, ^6LiD)

III. Multipurpose running spectrometer:

- Advanced and flexible triggering system with the possibility to trigger on muons, electrons and hadrons
- Good hadron/electron/muon separation in the final state
- Large muon/electron acceptance
- High capacity DAQ system
- Open structure of the spectrometer
- Compass is a running experiment

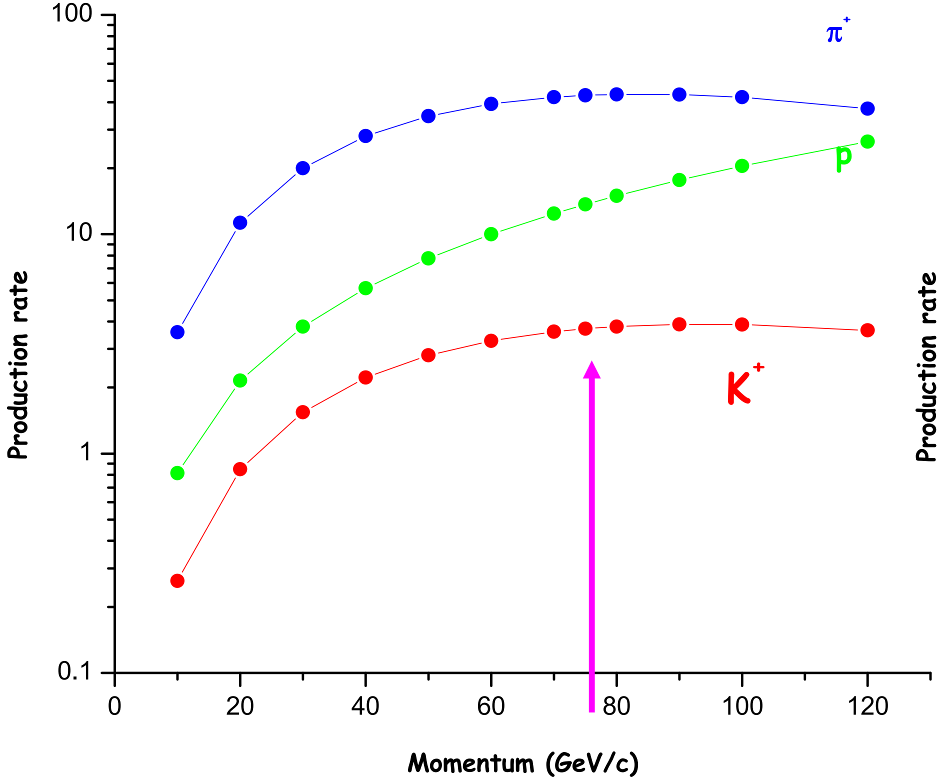
SPS M2 beam line

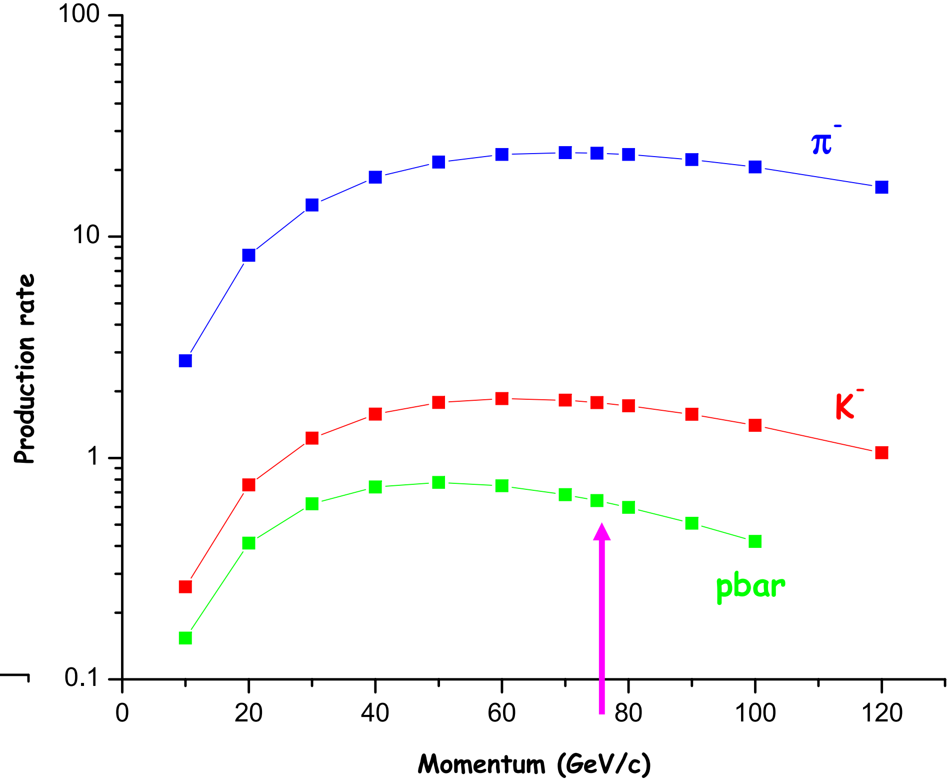
reference person - Lau Gatignon (CERN)



Particle production at 0 mrad

Apply Atherton formula for 0 mrad (approximative only for $p \leq 60$ GeV/c).
Obtain # particles per steradian per GeV/c and per 10^{12} interacting protons:





At -100 GeV/c one may expect the following beam composition (in %):

Particle type	Fraction at T6	Fraction at COMPASS
$\bar{p}$	1.7	2.1
K^-	5.8	1.6
π^-	84.5	86.3
e^-	8.0	10.0

In present M2 line π^- beam ≈ 10^8 $\bar{\pi}$/spill

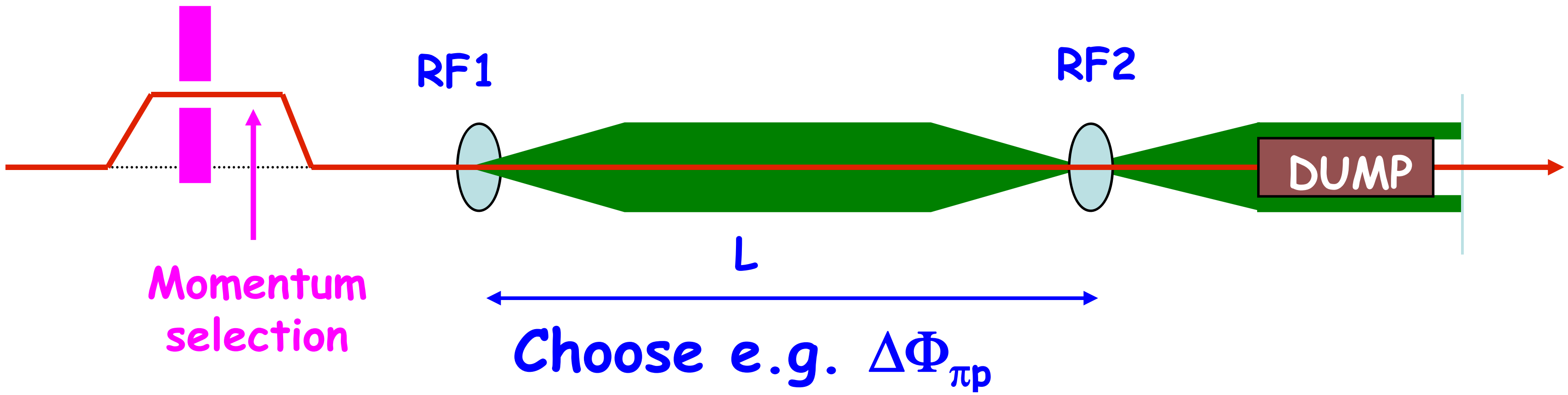
In present M2 line pbar ≤ 2 10^6 $\bar{p}$/spill

(due to 10^8 limit on total beam flux for RP)

WHAT ABOUT A RF SEPARATED $\bar{p}$ BEAM ???

First and very preliminary thoughts, guided by
- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g.
  http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



$$\Delta\Phi = 2\pi \, (L\, f \,/\, c)\, (\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

VERY PRELIMINARY CONCLUSION

H.W.Atherton formula tells us : 0.42 $\bar{p}$ / int.proton / GeV

Then for 10^{13} ppp on target one obtains:

particles per spill ≈ **8 10^7 $\bar{p}$pp**

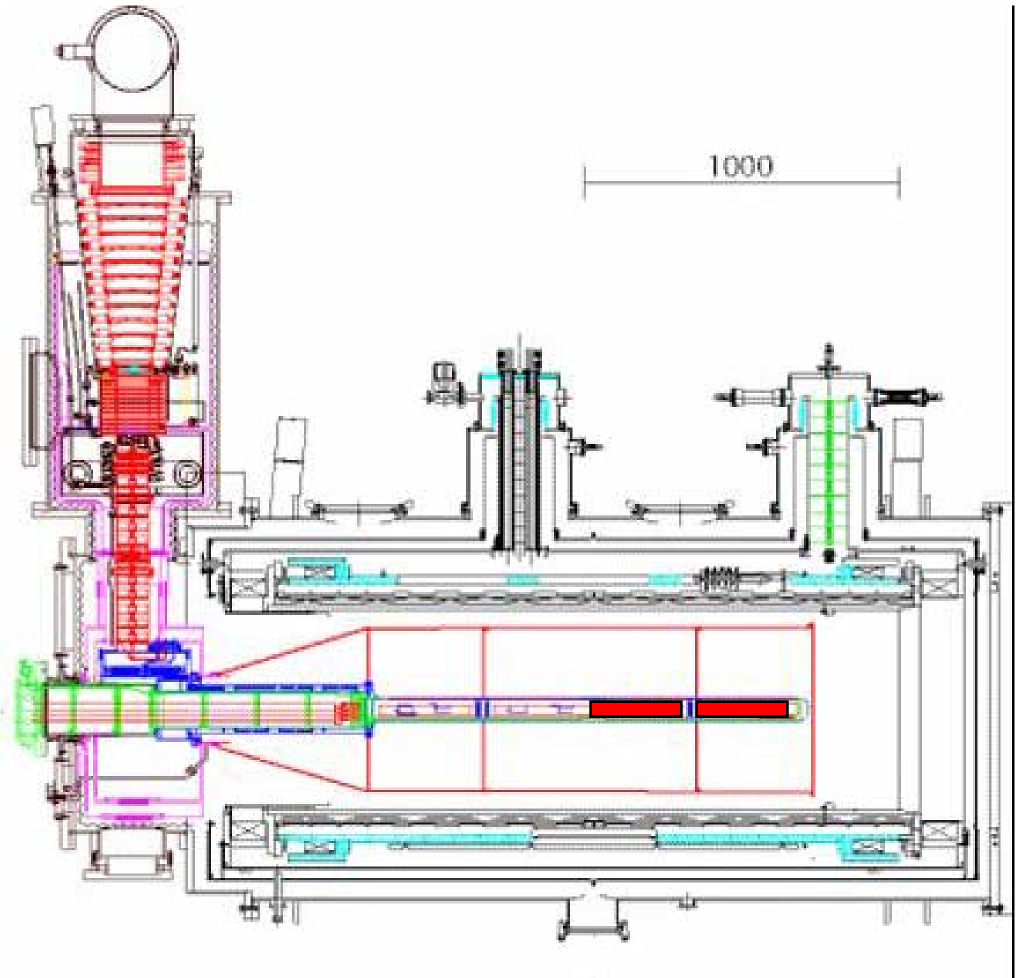
for a total intensity probably not exceeding 10^{13} ppp,
knowing that e^- and π^- are well filtered, but K^- only partly.

Due to 10^8 limit on total flux, max antiproton flux remains limited by purity (probably about 50%). Hence **≈ 5 10^7 $\bar{p}$pp**

Compass PT for DY physics

Contact persons: **W.Meyer, N.Doshita**

three cells target
with opposite polarization

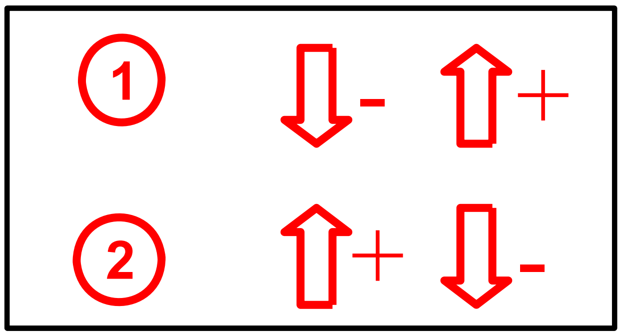


NH_3 — **Polarization 90%**, **Dilution factor 0.18**

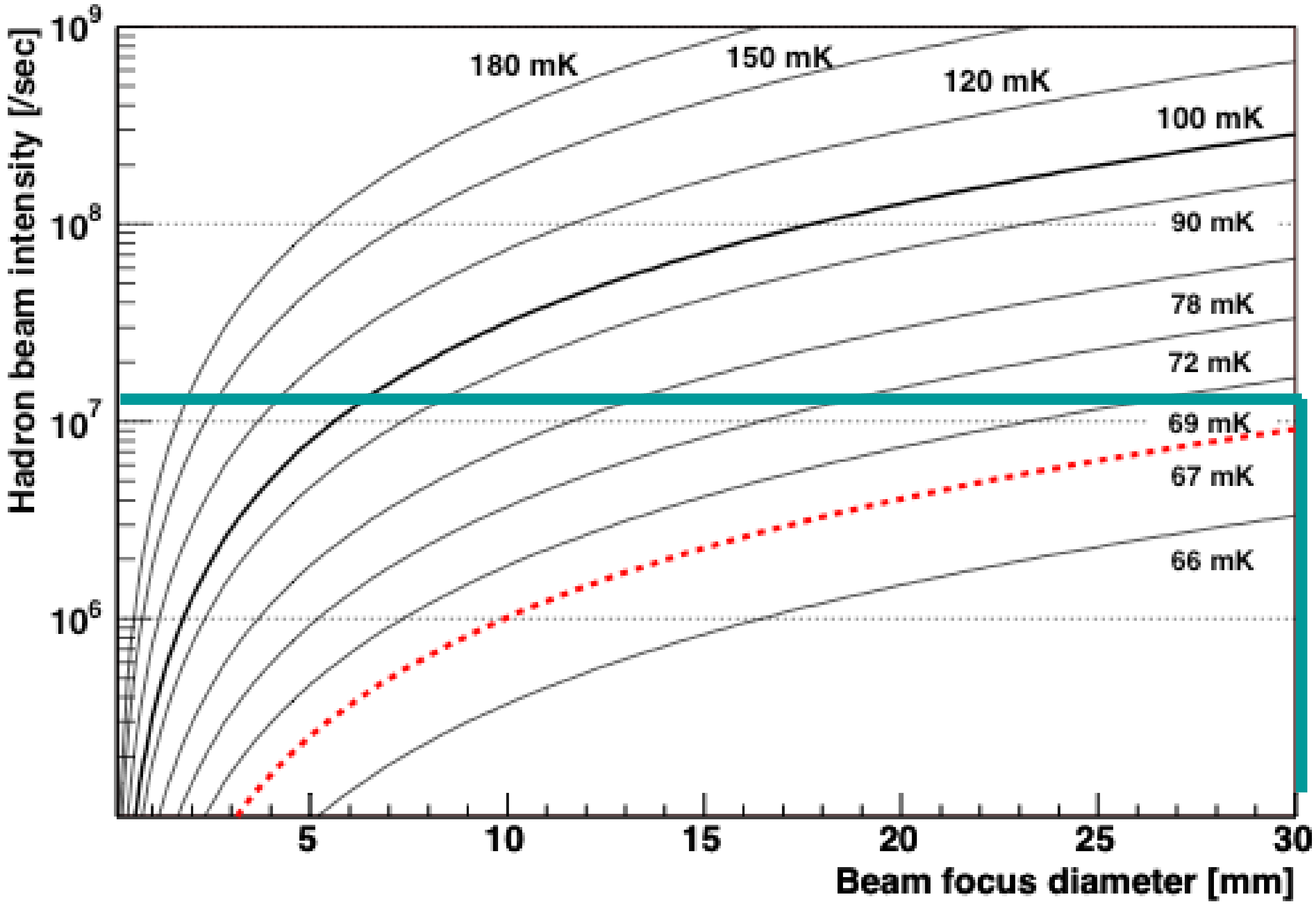
^6LiD — **Polarization 50%**, **Dilutionfactor 0.48**

180 mrad acceptance

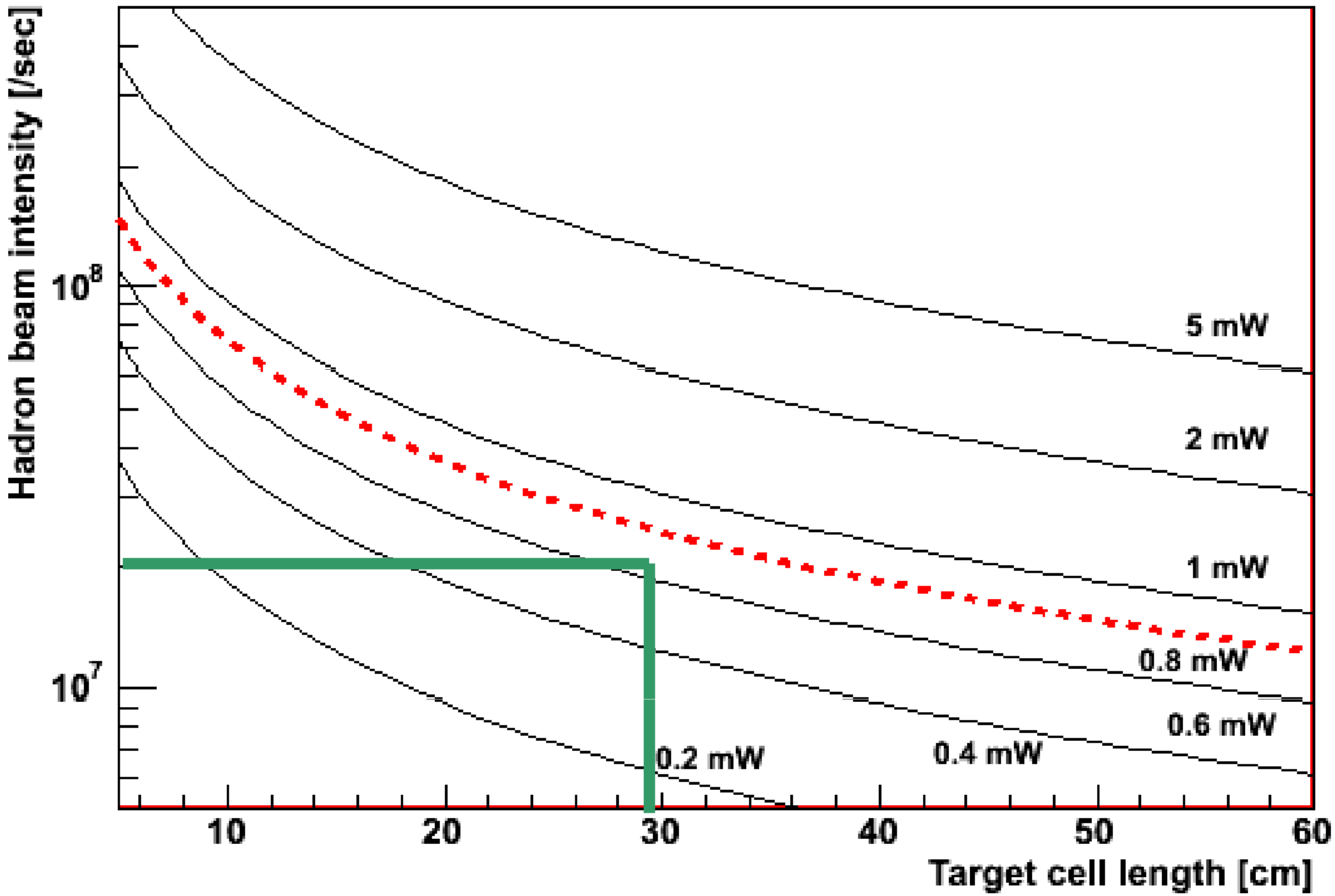
For transversity:



Hadron beam vs beam focus size for NH_3



Acceptable heating of the cells



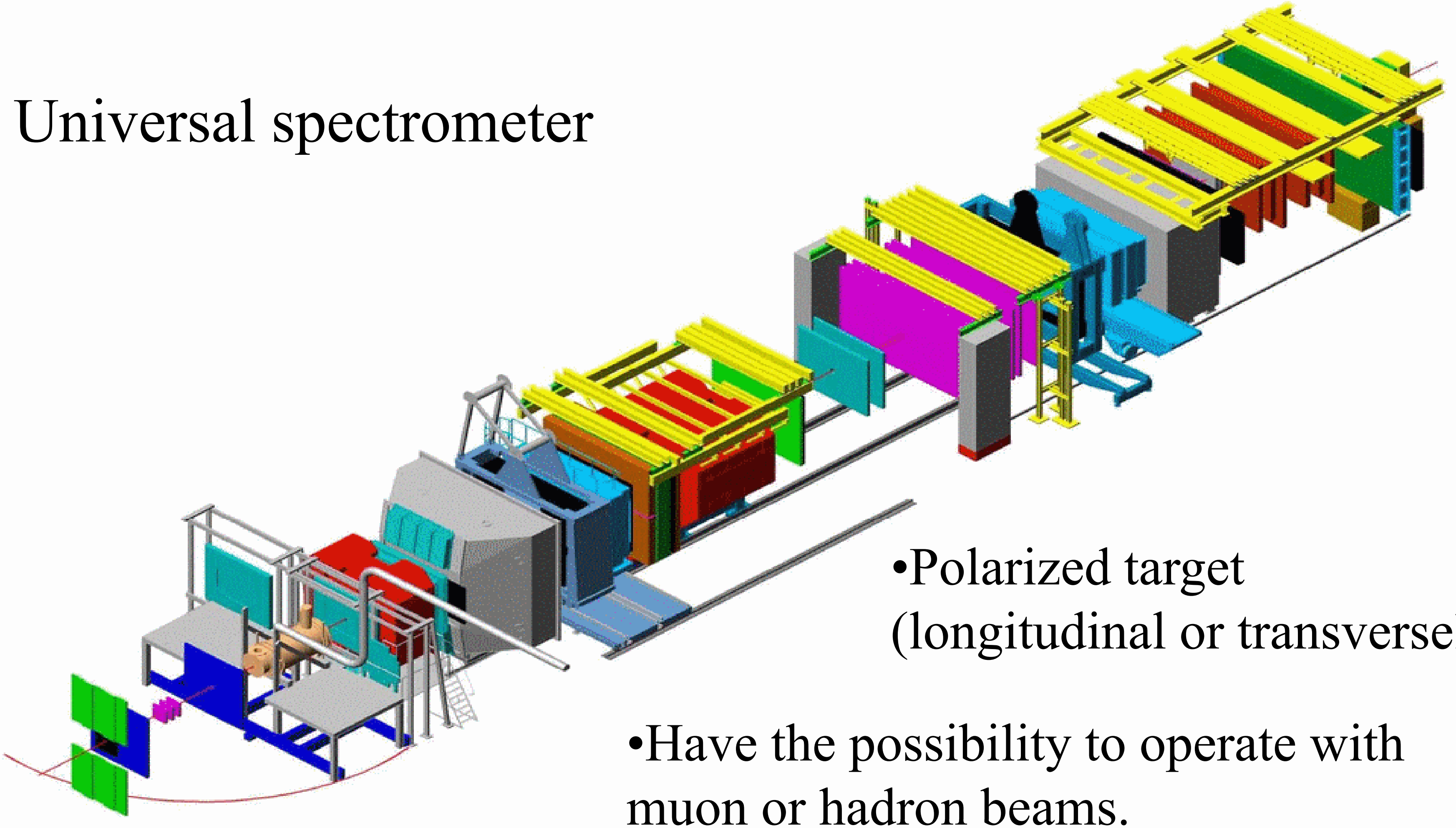
Compass spectrometer features

Multipurpose running spectrometer:

- Advanced and flexible triggering system with the possibility to trigger on muons, electrons and hadrons
- Good hadron/electron/muon separation in the final state
- Large muon/electron acceptance
- High capacity DAQ system
- Open structure of the spectrometer
- It is running spectrometer

COMPASS

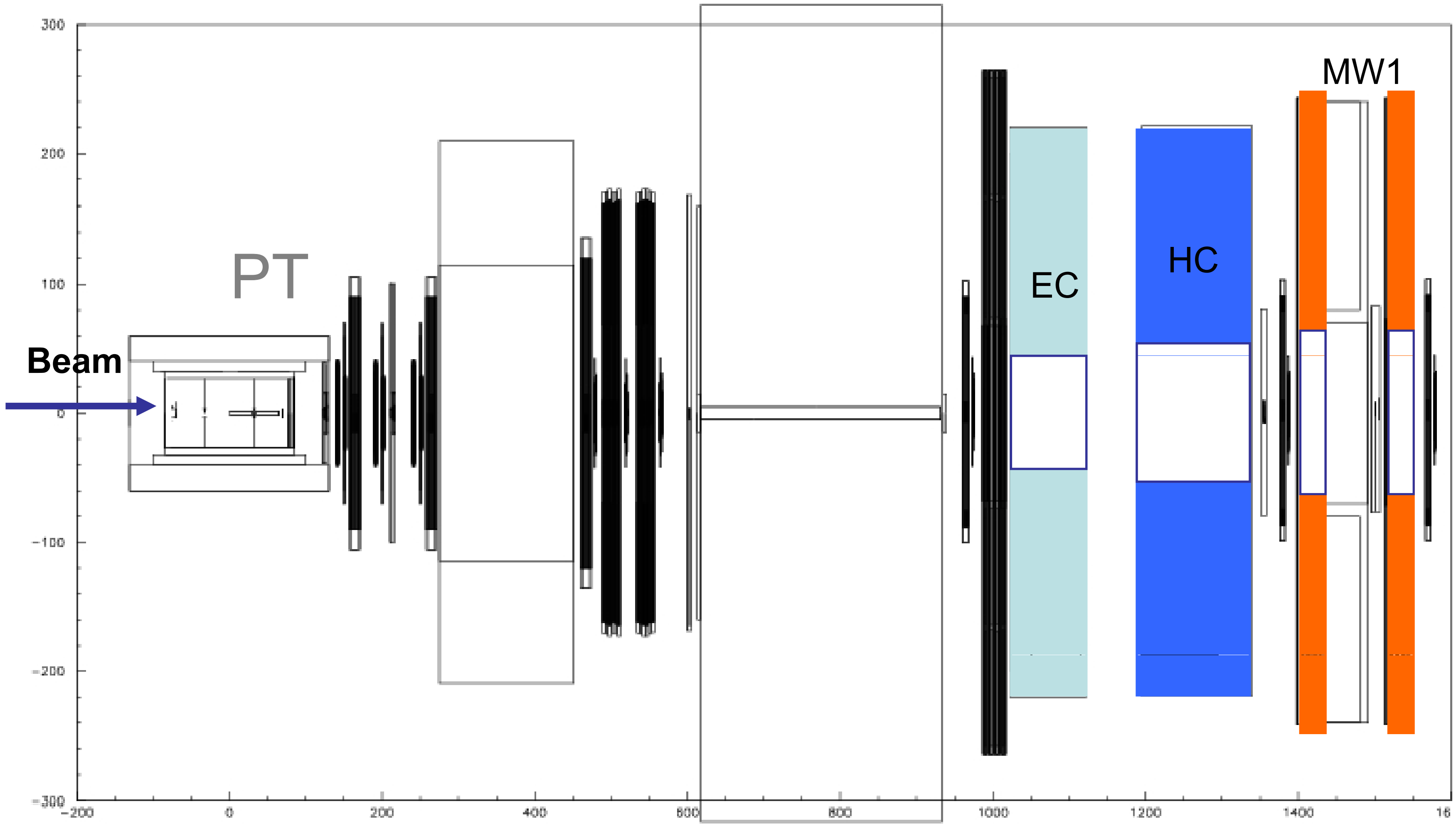
Universal spectrometer



•Polarized target (longitudinal or transversely)

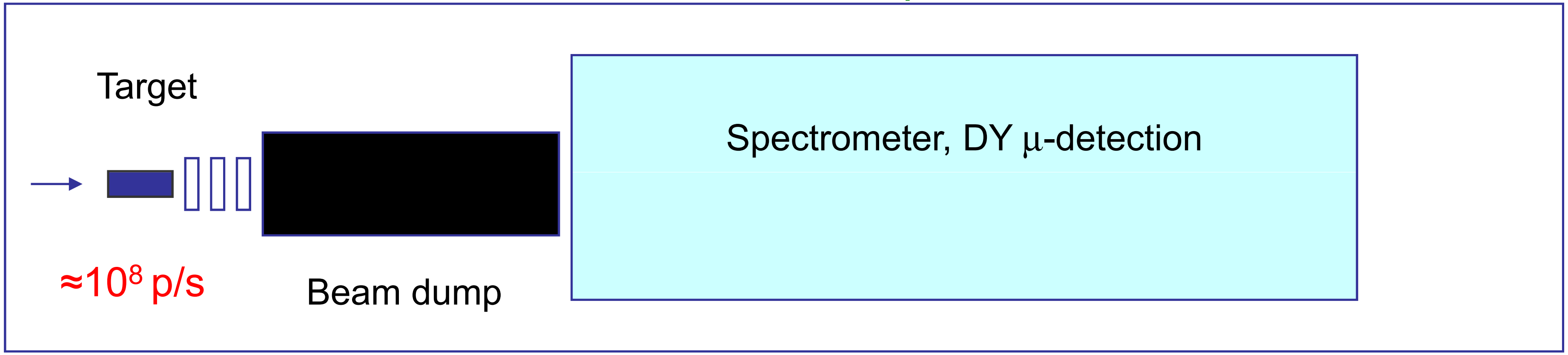
•Have the possibility to operate with muon or hadron beams.

Compass layout for DY measurements

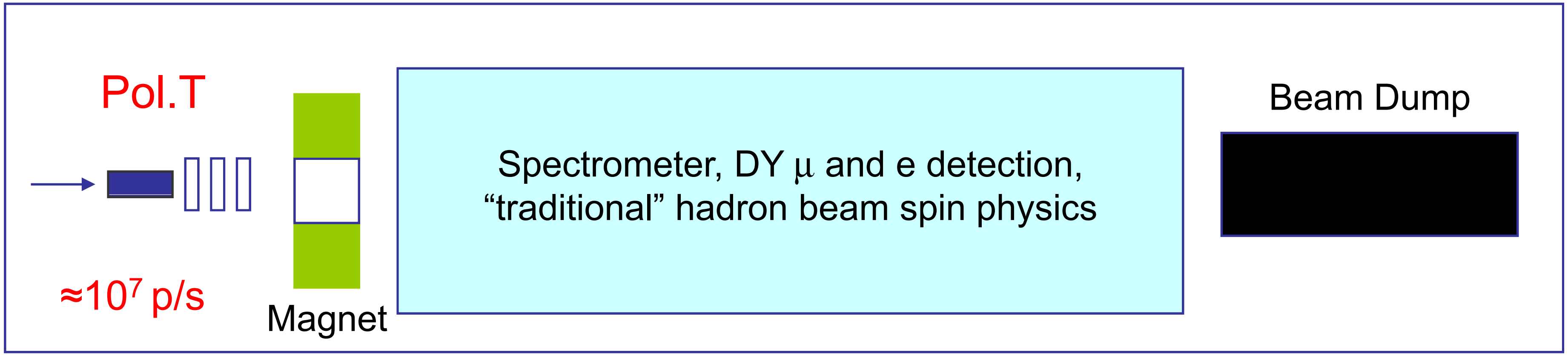


Compass comparison to old fashion DY experiments

OLD fashion DY experiment



COMPASS

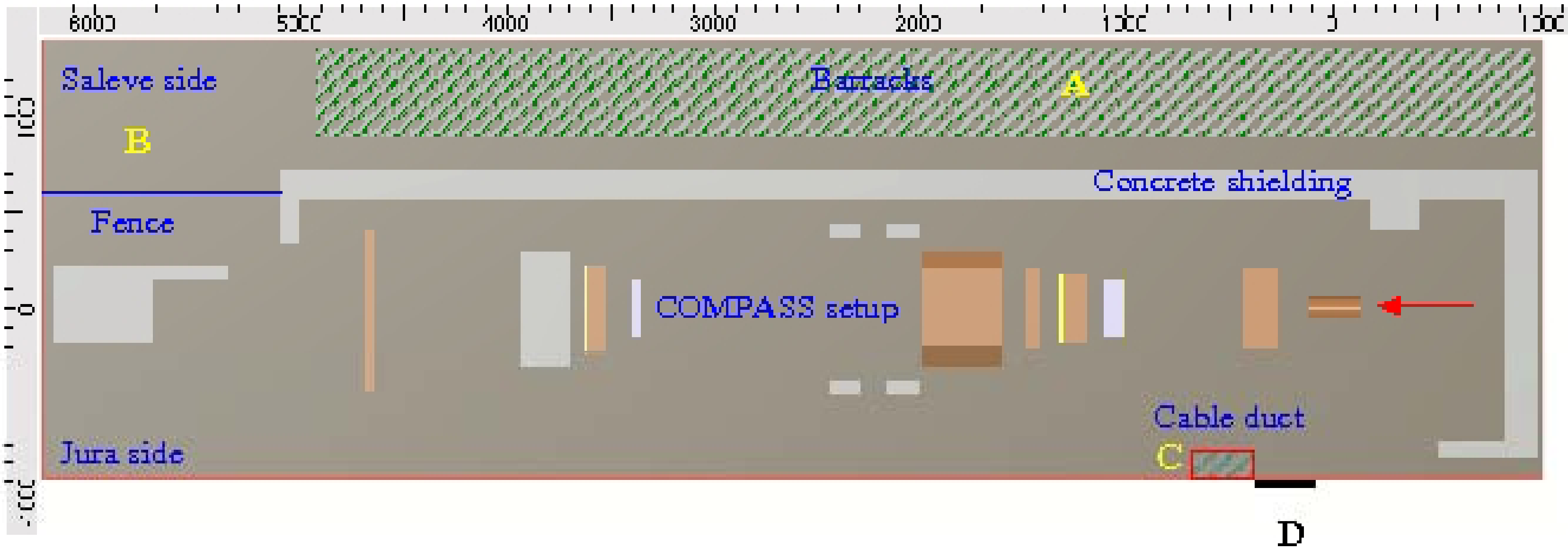


CERN safety regulations

Reference person - Heinz Vincke (CERN)

Two major limitations:

- Hadron beam intensity less then $2x10^7$ p/s
- Integrated material budget less then 20% of one interaction length



CERN safety regulations

NOT OFFICIAL

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... s) w ... ws) :

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be approved for ... with

50% of interaction le... h

polarised target and 2x10... π/s

Internal Compass limiting factors

- High charged particles flux
- $\mu^+\mu^-$ DY channel - high background from pion decays (soft hadrons absorber?)
- e^+e^- DY channel - thick target, γ-conversion and Dalitz-pair production
- Very selective trigger because of the small cross section

COMPASS DY layout I

Advantages:

- Possibility to measure both ($\mu^+ \mu^-$) and ($e^+ e^-$) channel
- Higher statistics + better systematics control ?
- (Semi)Exclusive DY processes
- Possibility to use in the DY trigger Hadron Calorimetry
- Traditional hadron beam spin physics (π asym., Λ_c etc.)

Disadvantages:

- High secondary particles flux though set-up
- Higher background for $\mu^+ \mu^-$ from $\pi \rightarrow \mu\nu$ decays

COMPASS DY layout II

Advantages:

- Lower irradiation degree of the spectrometer
- Background suppression for $\mu^+ \mu^-$ channel by factor of 10^2

Disadvantages:

- One only channel of DY and nothing else apart of DY $\mu\mu$ - channel
- No use of the hadron calorimetry in trigger

Compass DY program beam test

The Only reliable way to study the DY feasibility is to run Compass DY beam test in the real Compass environment with high intensity hadron beam and Compass polarised target

Compass DY beam test in 2007

Conditions:

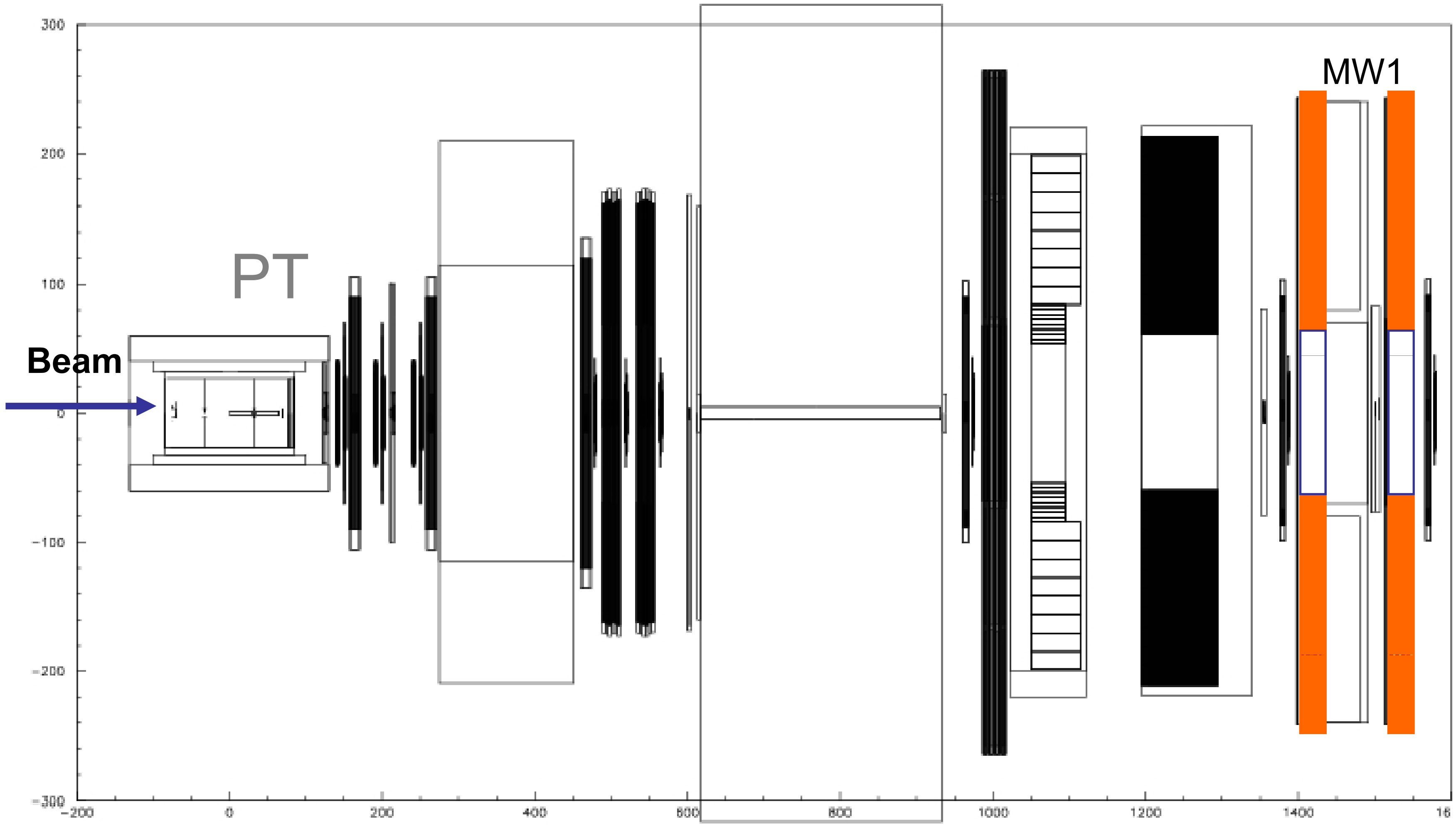
- Hadron beam intensity (π^-) – 10^7 p/sec
- Compass polarised target NH_3 polarised transversally
- Mu

Goa

- Com ... beam
- Com ... d thick polar
- Test ... ntal hall with intense hadron beam and Compass polarised target

VERY IMPORTANT!!!

Spectrometer layout in the DY MC



Torino DY Workshop recommendations

Summary of the Informal Workshop on "Drell-Yan physics at COMPASS"

March 5th-6th Torino, Italy
summary

In this meeting was discussed the kinematical range, for DY processes, that can be covered with the Compass spectrometer and with π^- beams hitting NH_3 polarised target. The conclusion is that we have to cover the region for valence quarks with $x-$ Bjorken $x_{1,2} \geq 0.1$.

For the continuum region of the dilepton masses larger than the J/ψ and ψ' resonances ($4.GeV \leq M_{ll} \leq 9.GeV$), the so-called safe region, higher twists are expected to be small and the perturbative QCD fully applicable. The cut on transverse momentum of dilepton pair $p_T > 1.GeV$ looks valid. It has been suggested that the J/ψ region can be treated similarly, but some difficulties can arise from the not well established polarization of the J/ψ. In any case, the investigation of the J/ψ formation mechanism with polarised target at $s = 200 \div 300 GeV^2$ energies would be by itself an interesting matter, due to the lack of experimental measurements in this kinematics.

At the same s but lower Q^2 the QCD corrections to DY processes are large. It has been suggested that the NLO contributions to DY spin asymmetries expected to be small because of the cancellation of K factors for both polarised and unpolarized cross sections. We can check experimentally this for the case of the valence quarks contributions.

The NLO corrections (as well as the high twist effects, at least for not too large p_T values, $p_T \leq 3GeV$) can not explain the large asymmetry observed in the angular distributions of the unpolarized DY cross sections, where an anomalously large coefficient ν of the $\cos(2\phi)$ term is observed. This corresponds to strong violation of the Lam-Tung relation. The Boer-Mulders PDF is introduced to explain that discrepancy.

DY Monte Carlo with COMPASS

Michela Chiosso

External DY generator (A.Bianconi) -> COMGeant -> CORAL ->PHAST
π^- beam on transversely polarized NH_3 target
Various energies of the incoming beam (s= 100-300 GeV^2)
Different intervals of $M_{\mu\mu}$
0.1 GeV/c < P_T < 10.0 GeV/c
-1 < X_f < +1

FOR DETAILS, Please, follow the reference on the COMPASS WEB page (analysis).

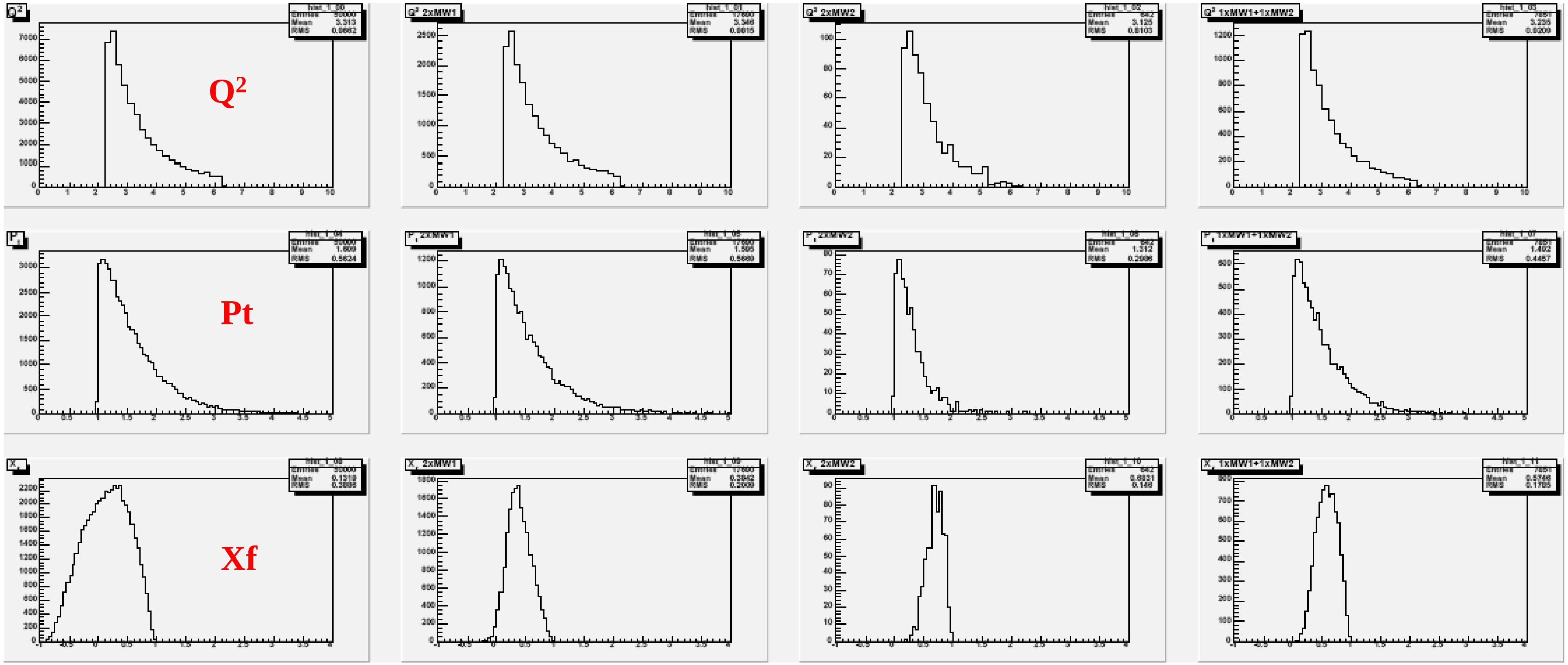
The best compromise of the beam energy is ≈ 160 GeV (s=300 GeV^2):
- **better statistics in high dilepton mass region**
- **in the interesting Muu mass region the dominant contribution is coming from valence quarks annihilation (x_1, x_2) > 0.1**

Compass DY MW1 and MW2 acceptance

MW1 and MW2 acceptance 160 GeV pion beam

Total acceptance = μ+μ– in MW1 + μ+μ– in MW2 + μ+(–) in MW1 and μ–(+) in MW2

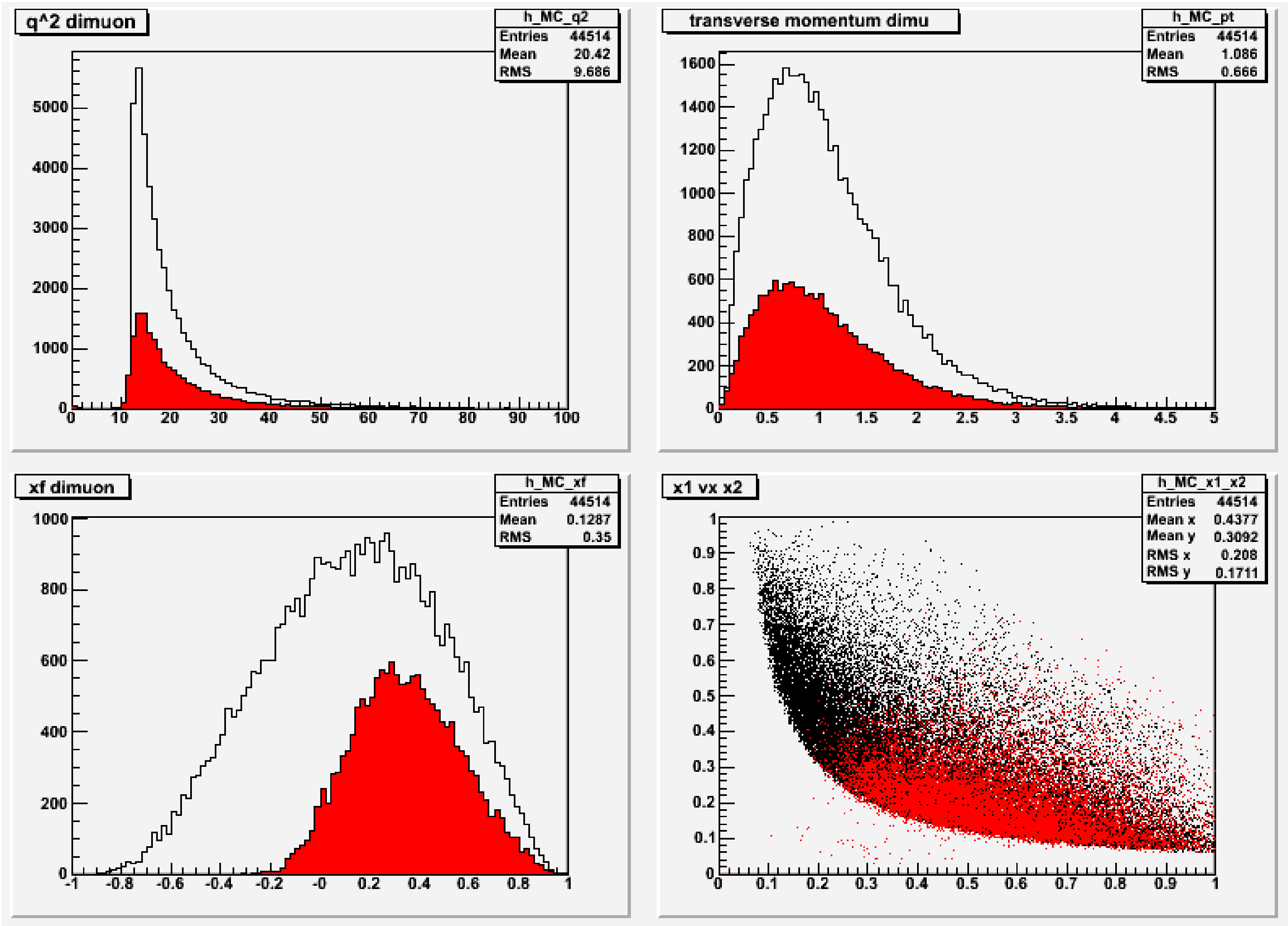
generated | μ+μ– in MW1 | μ+μ– in MW2 | μ+(–) in MW1, μ–(+) in MW2



67.5% | 2.5% | 30%

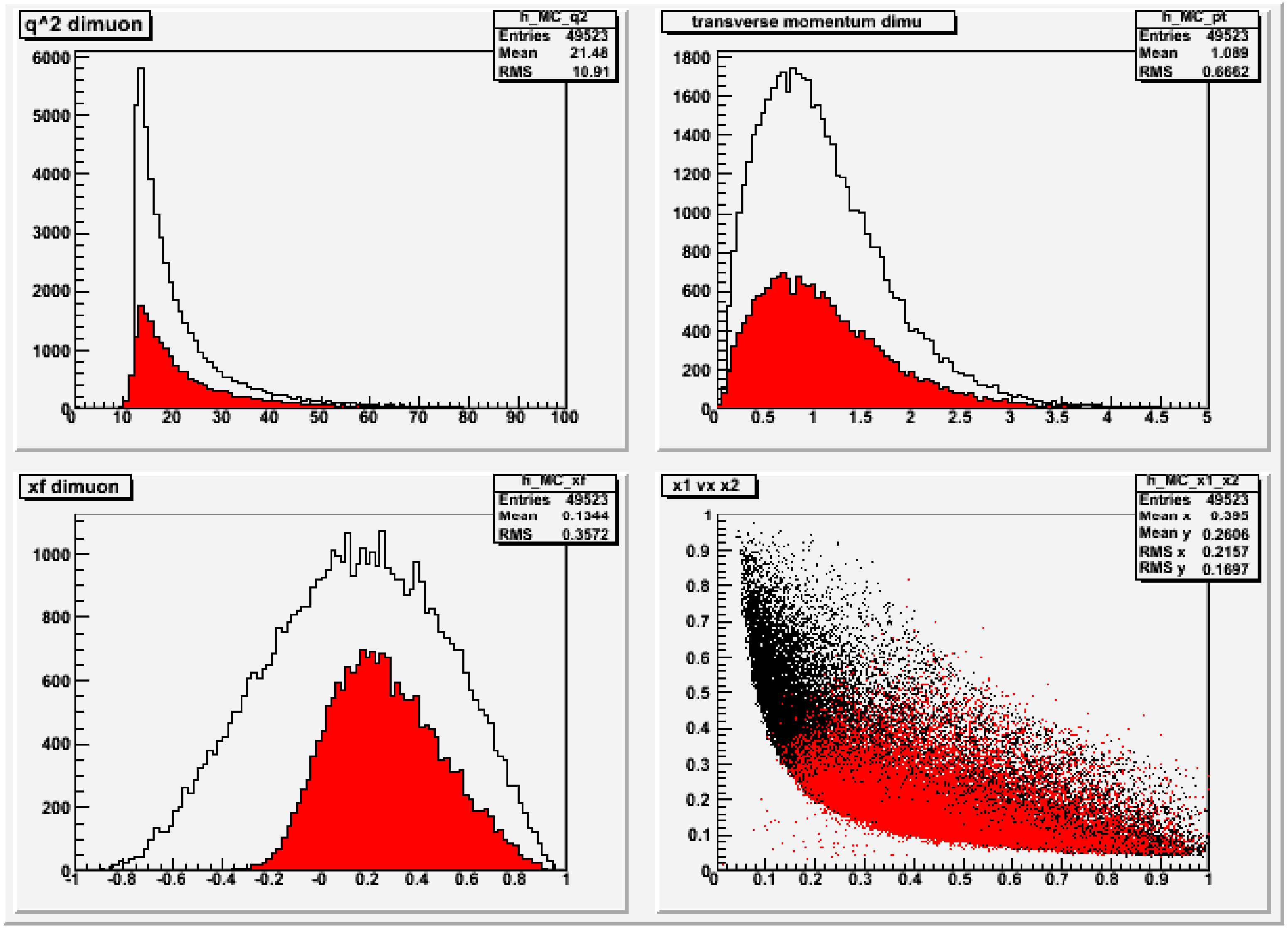
Compass DY acceptance

$s = 200\ GeV^2$ π^- beam $3.5\ GeV < M_{\mu+\mu-} < 9\ GeV$



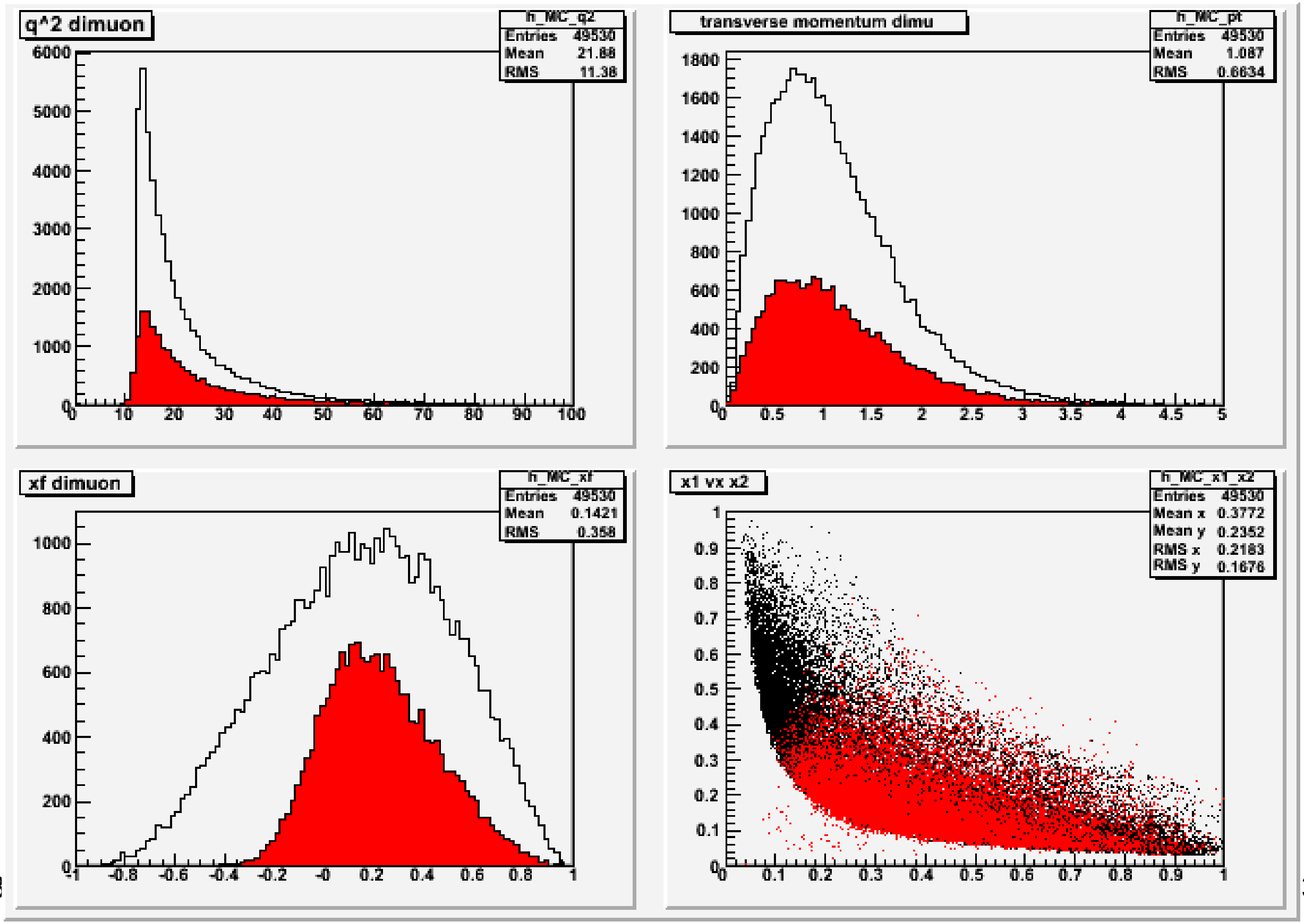
Compass DY acceptance

s = 300 GeV^2 π^- beam 3.5 GeV < Mμ+μ– < 9 GeV



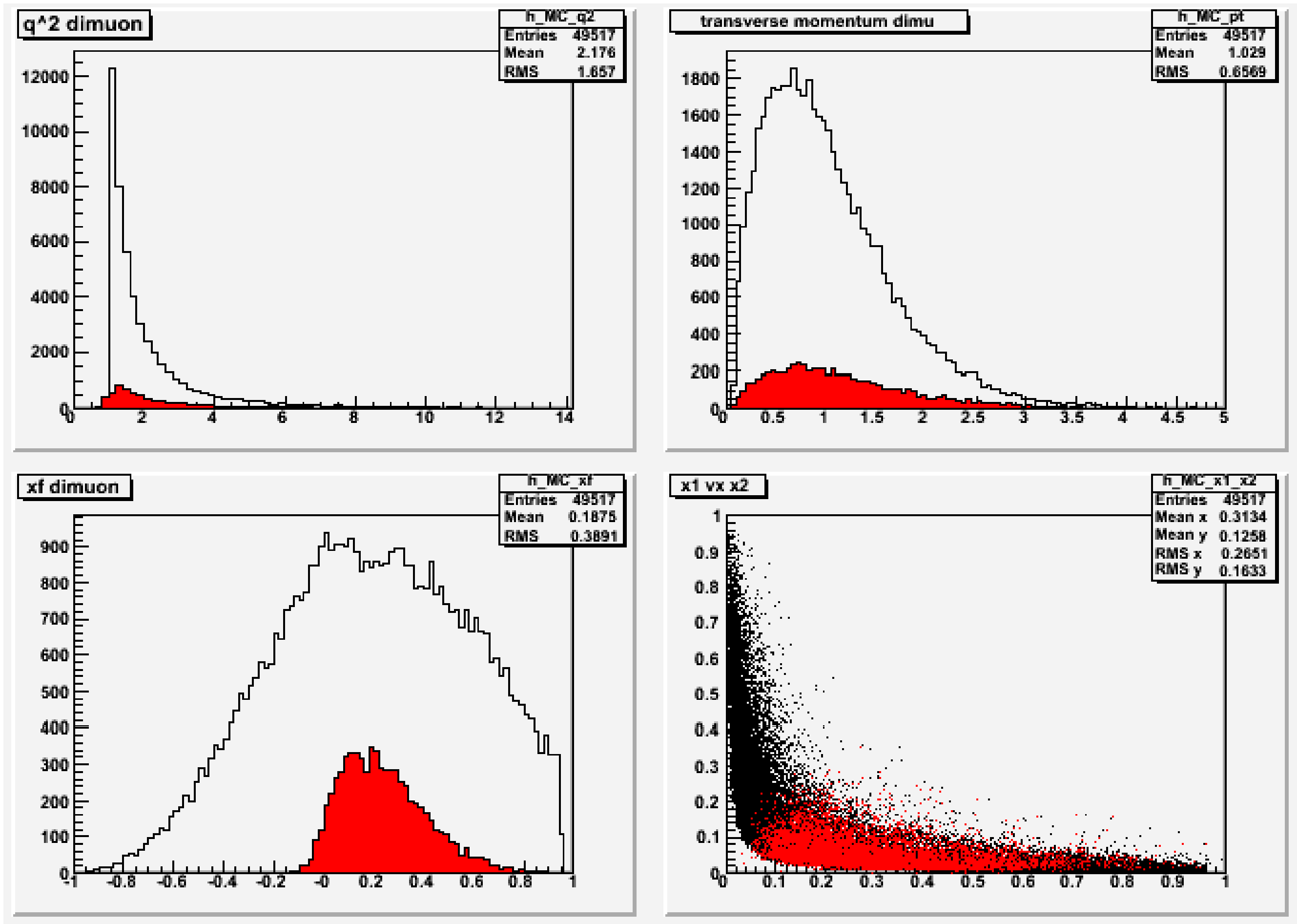
Compass DY acceptance

s = 375 GeV^2 π^- beam   3.5 GeV < $M_{\mu+\mu-}$ < 9.0 GeV



Compass DY acceptance

$s = 300\ GeV^2$ π^- beam 1.0 GeV < $M\mu+\mu-$ < 3.5 GeV



Compass DY vs E615 acceptance

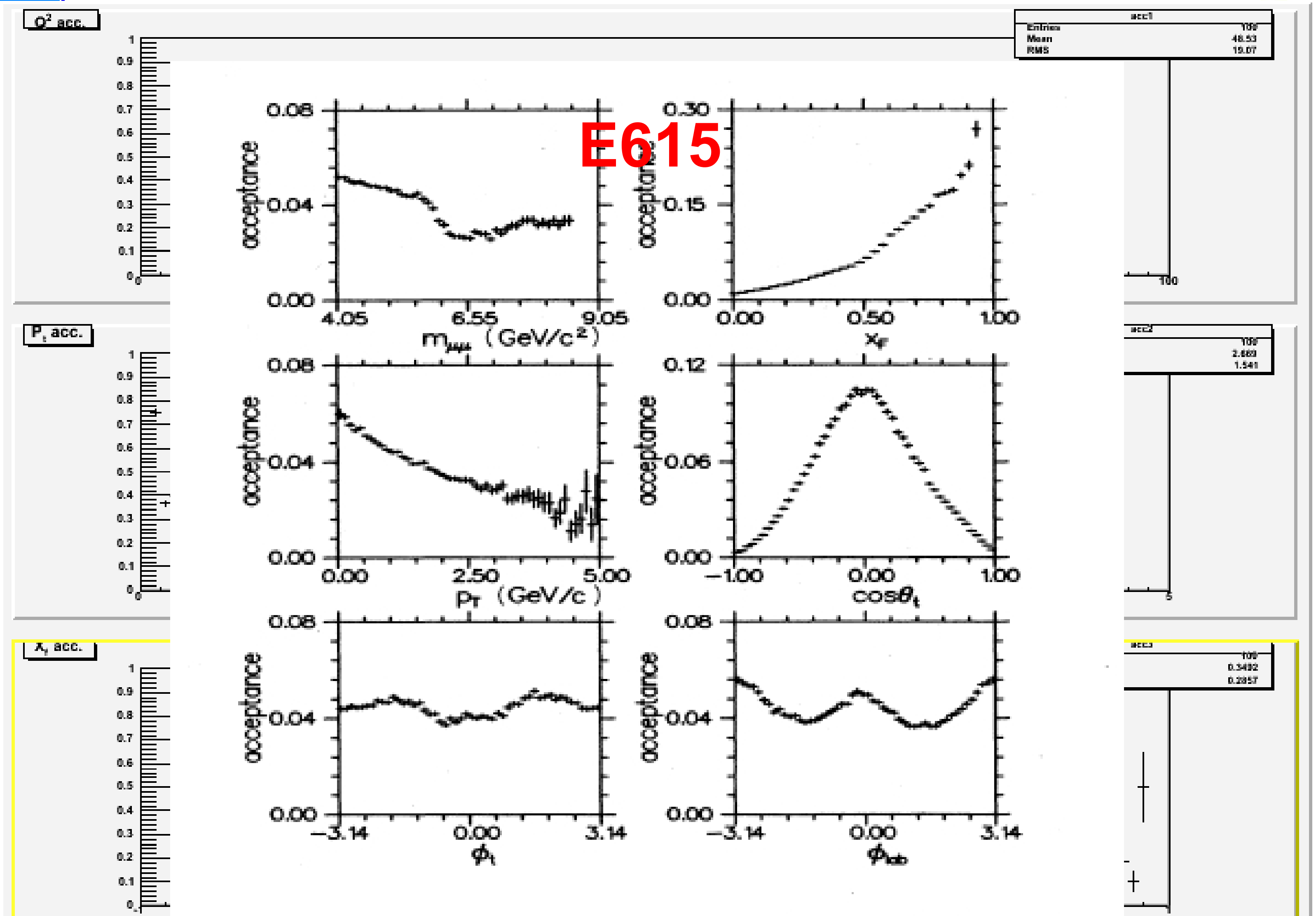
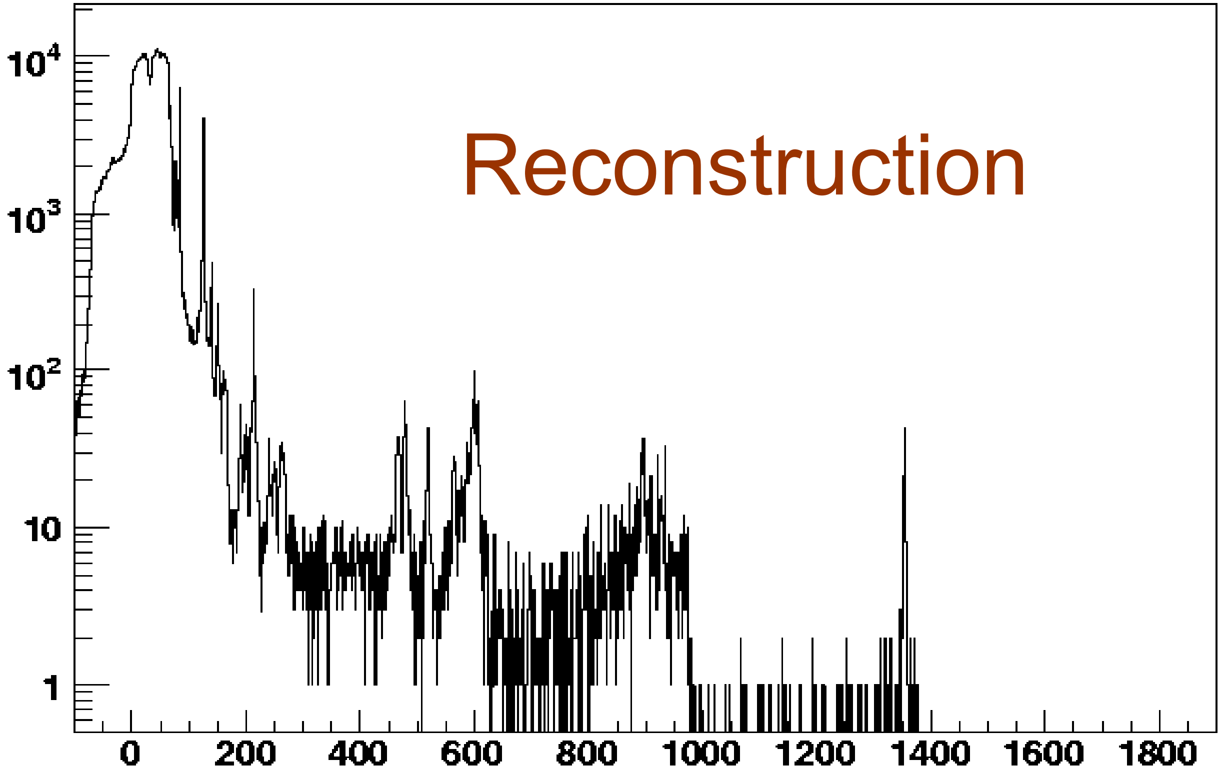


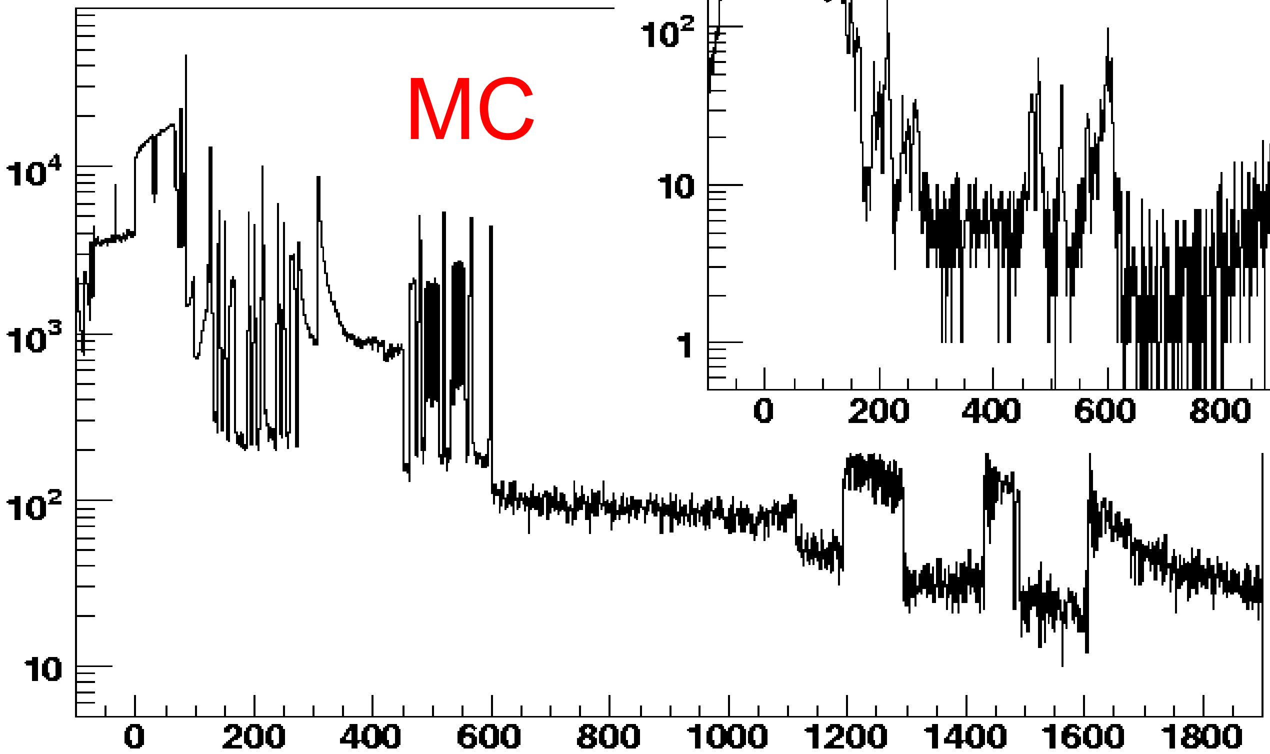
FIG. 10. Integrated detector acceptance for each kinematic variable.

DY background simulation (just started)

L.Colantoni,

S.Petrochenkov, ..

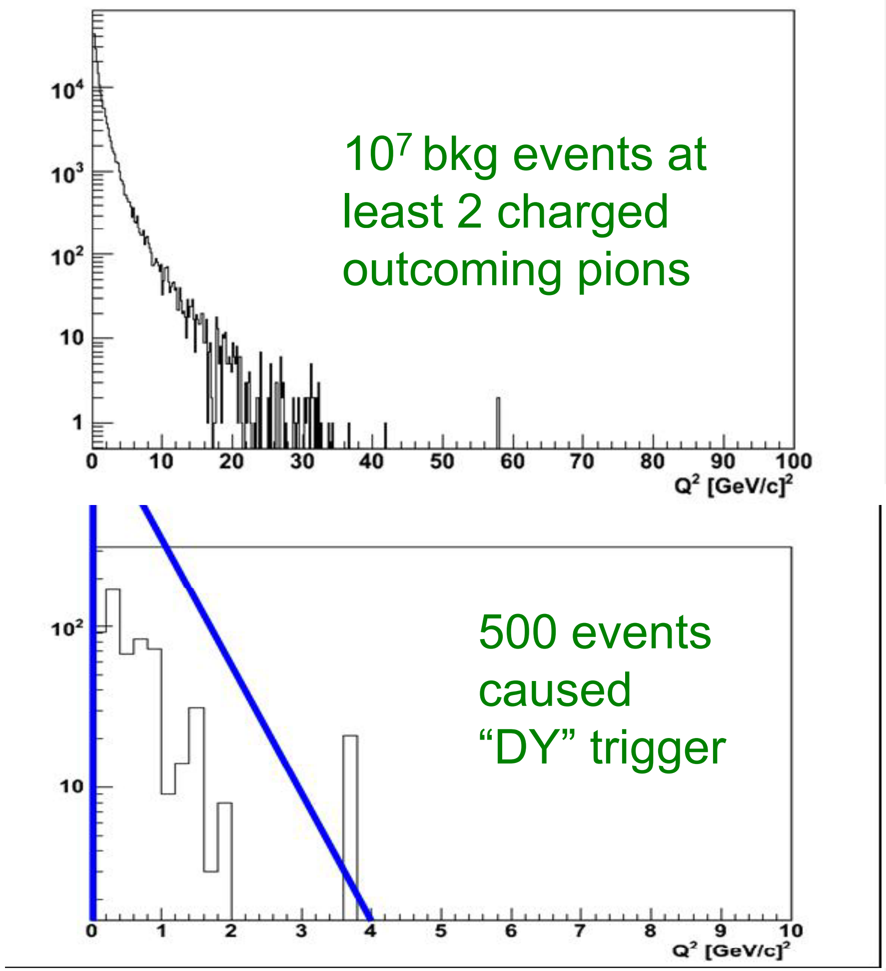


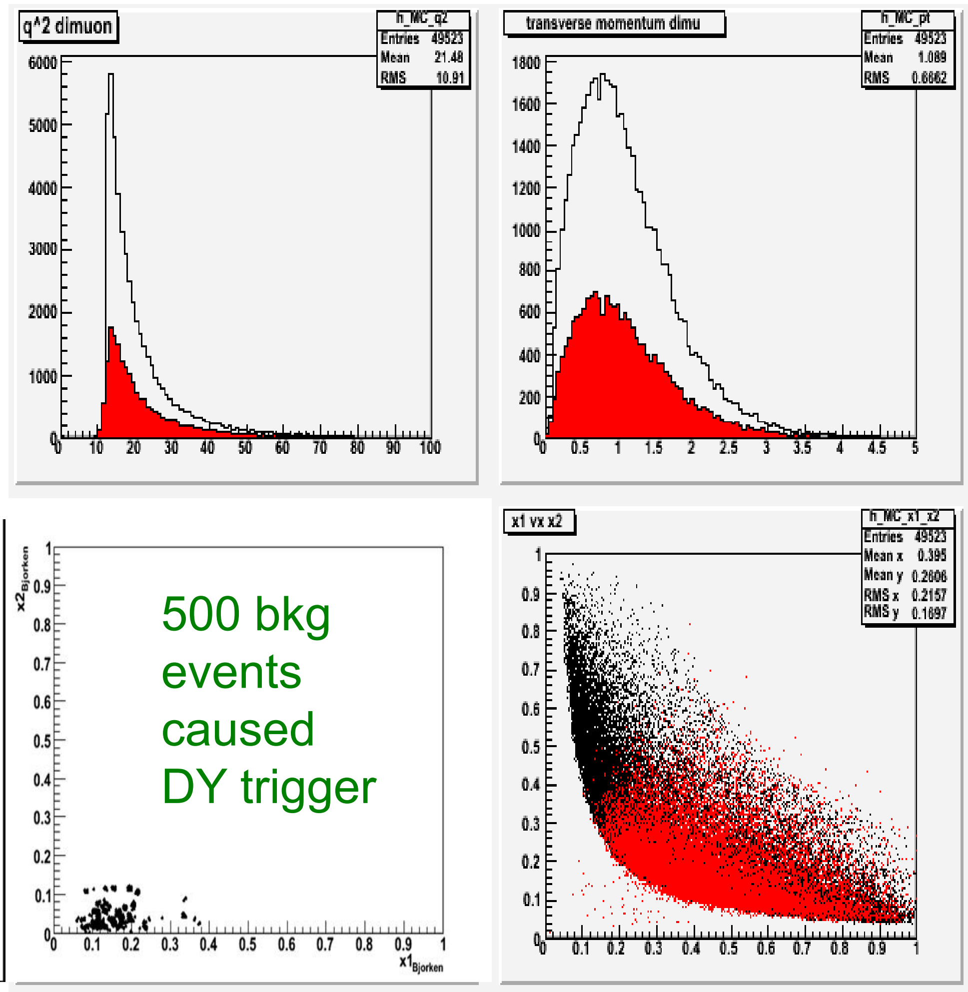


DY background.vs.signal
(not normalised to cross sections)

Minimum bias

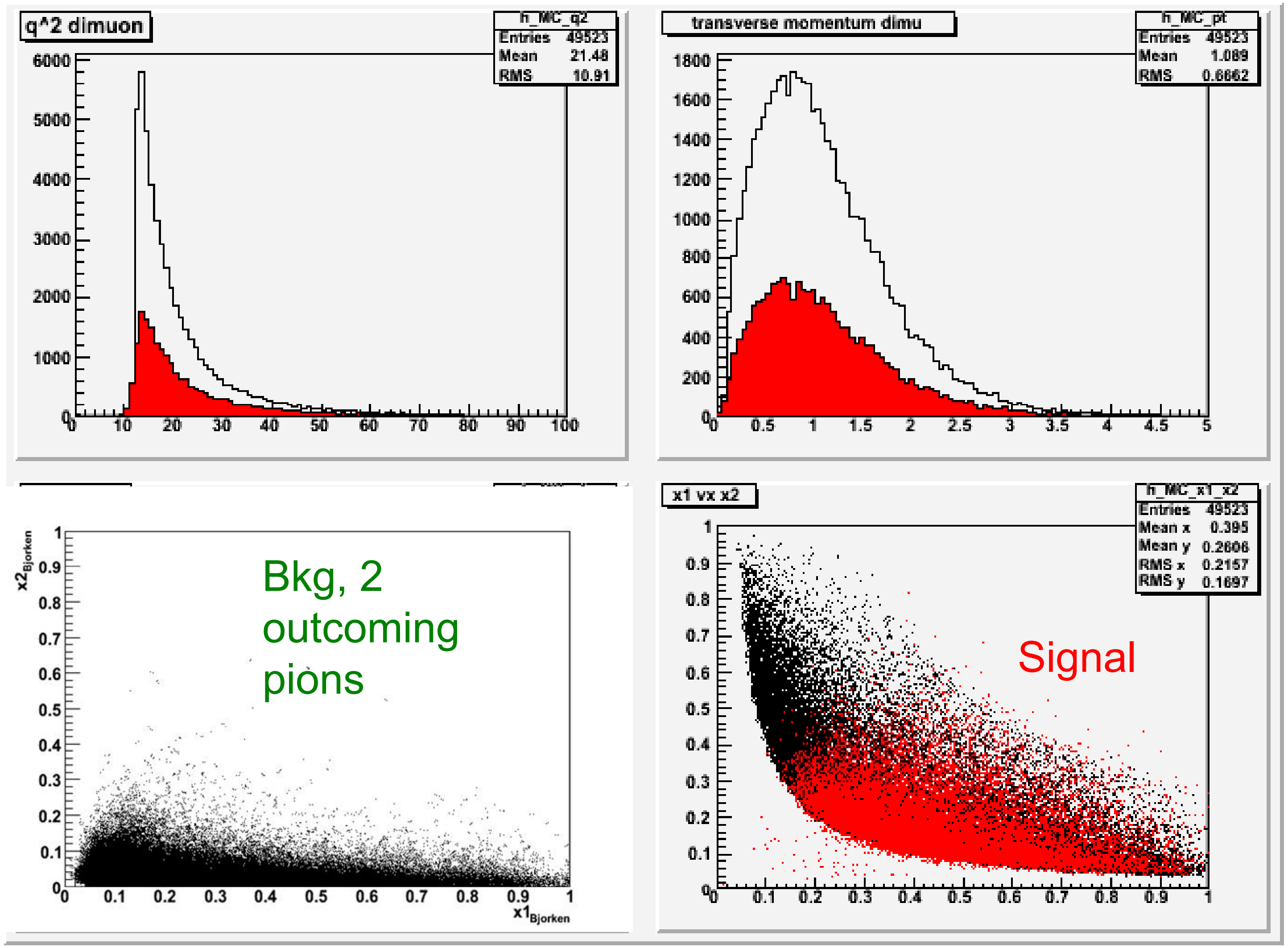
DY 3. GeV < Mμμ < 9. GeV, s = 300 GeV





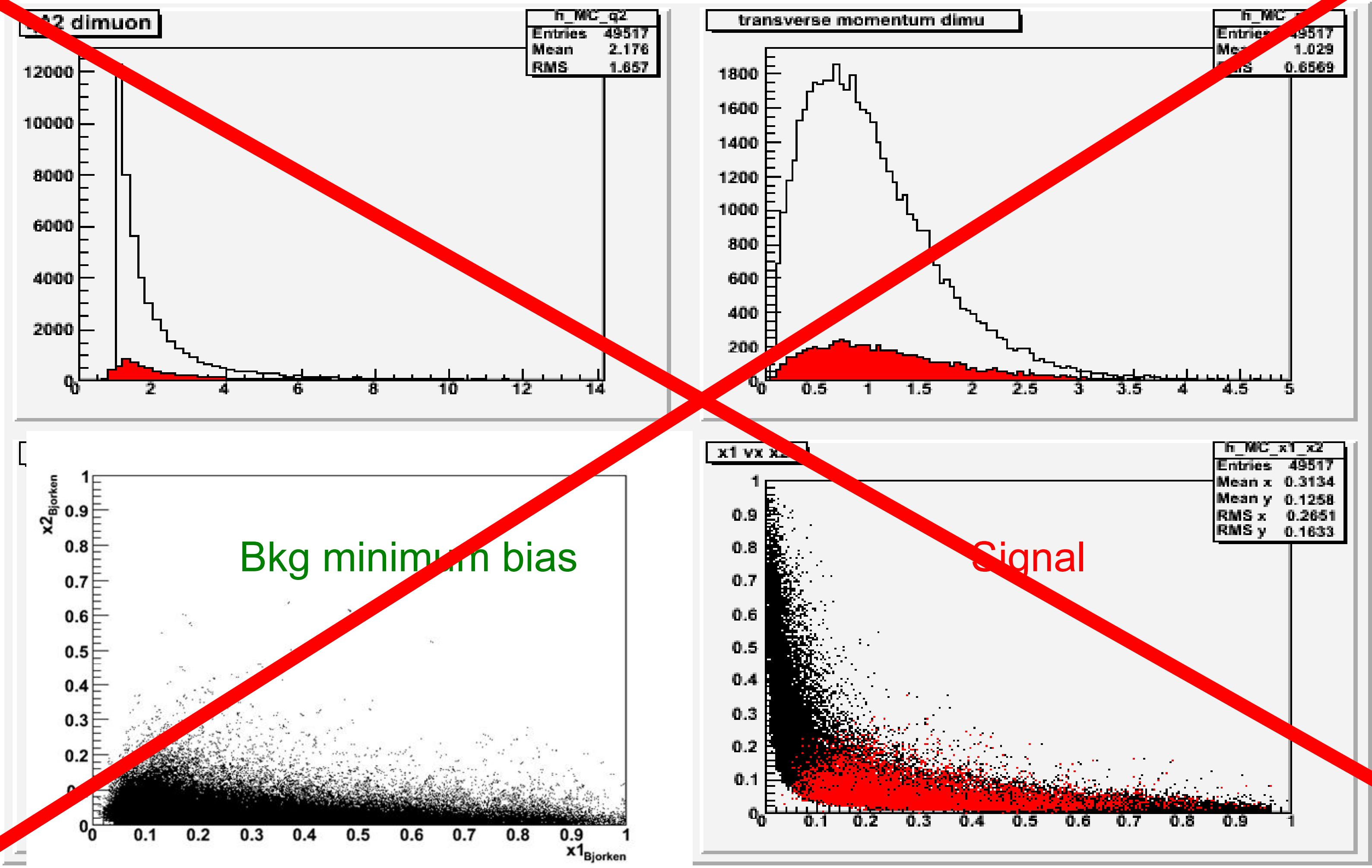
DY background.vs.signal (not normalised to cross sections)

DY 3. GeV < Mμμ < 9. GeV, s = 300 GeV



DY background.vs.signal
(not normalised to cross sections)

DY 1. GeV < Mμμ < 2.5 GeV, s = 300 GeV



Very preliminary DY event rates estimate

- Target: two cells 30 cm each : L_{NH3}=30 cm
- Target material: NH_3
- Density of NH_3: $\rho_{NH3} = 0.85$ g/cm^3
- Mass of the NH_3 mole: $D_{NH3} = 17$
- π^- beam intensity: $I_{beam} = 2\times10^7$ p/s

Luminosity: $\mathcal{L} = L_{NH3} \times N_{cell} \times \rho_{NH3} \times N_A \times 1/D_{NH3} \times I_{beam} \approx$

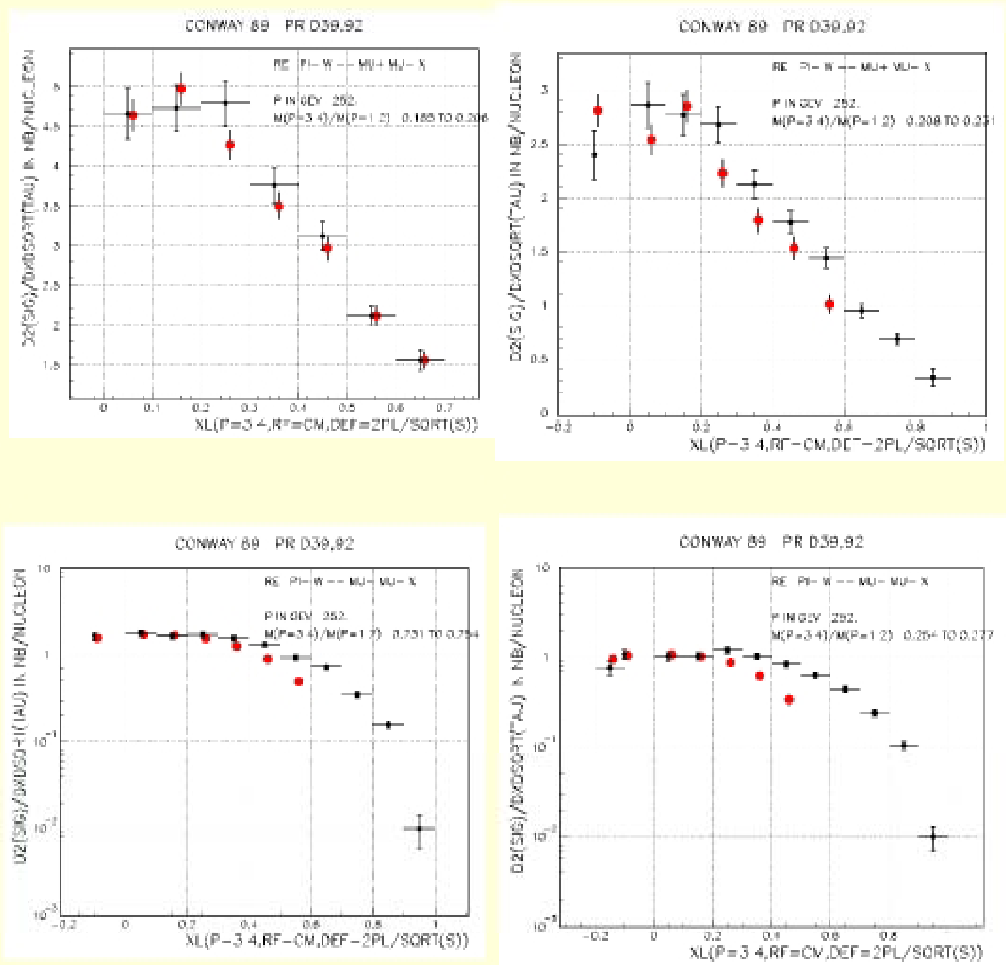
$4.\times10^{31}$ cm^{-2} s^{-1}

Very preliminary DY event rates estimate

- Compass DY pairs reconstruction efficiency (acceptance included) : A ≈ 0.4
- DY cross section on NH_3: $\sigma_{NH3} = N_{corr} \times \sigma_{\pi p}$, where N_{corr}=13 and $\sigma_{\pi p}$ taken from table given below (by A.Bianconi)
- D_{spill} = 5 s (duration of spill), N_{spill} =4000 (number of spills per day), E_{sps}= 80% (efficiency of the machine)
- Duration of the Run 100 days: D_{RUN}=100

$$R = L \times N_{corr} \times \sigma_{\pi p} \times A \times D_{spill} \times N_{spill} \times E_{SPS} \times D_{RUN}$$

DY Cross sections taken from PYTHIA



The differential cross sections from PYTHIA (red points) are qualitively agreed with E1615 data.

From PYTHIA - **2.5 nb**

DY cross sectionsin nbarn

S, GeV^2	Q^2= 1-6.25 GeV^2	Q^2= 6.25-16 GeV^2	Q^2= 16-81 GeV^2
100	0.3	0.2	0.01
200	0.7	0.5	0.1
300	0.8	0.7	0.15

The expected number of DY per year for pion beam energy E=100 GeV and Q^2= 16-81 GeV^2 is about 35-40 K

DY cross sections and statistics estimate (very preliminary, 100 days of running)

M ($\mu^+\mu^-$), GeV S, GeV^2		2.5-4.	4.-9.
100		0.35 nb	0.1 nb
200		0.5 nb	0.25 nb
300		0.6 nb	0.35 nb

M ($\mu^+\mu^-$), GeV S, GeV^2		2.5-4.	4.-9.
100		70000	2400
200		170000	34000
300		240000	52000

VERY PRELIMINARY

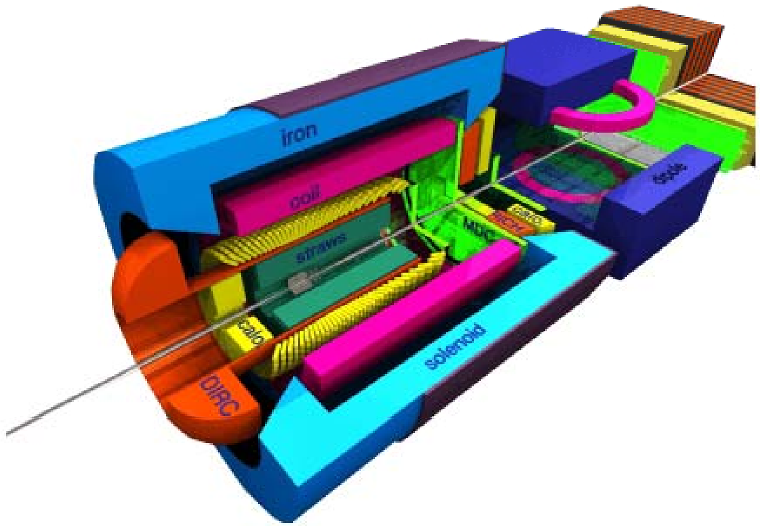
Competition and complementarity I

SPIN Physics at GSI:

Two LoI submitted:

1. ASSIA (Collider mode)
2. PAX polarised antiproton beam and proton polarised internal target

The **Panda Detector** (as propsed in the GSI **CDR** from Nov. 2001)



- $L = 2.7\times10^{31}$ cm^{-2} s^{-1}
- S = 30 GeV^2
- e^+e^-, alternative $\mu^+\mu^-$
- Not yet approved

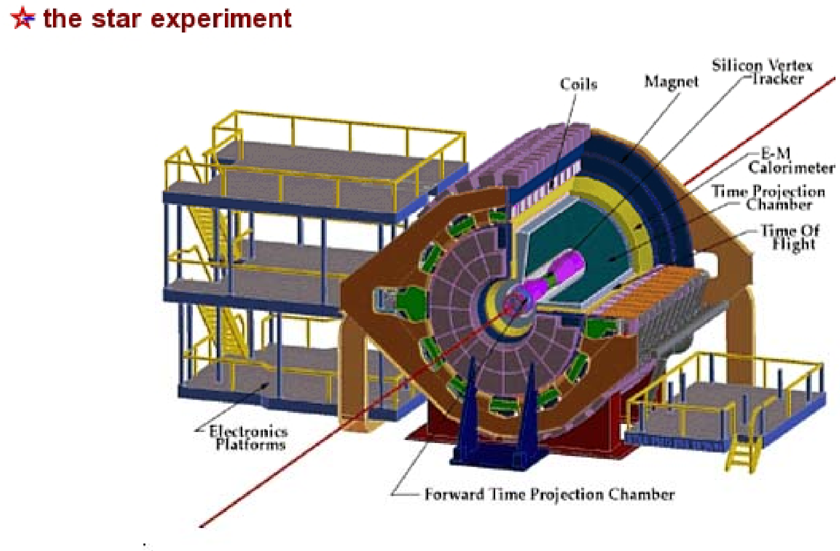
- $L =$ 10^{31} cm^{-2} s^{-1}
- S = 30 GeV^2
- $\mu^+ \mu^-$, alternative e^+e^-
- YEAR 201?

Competition and complementarity II

J-PARC
Japan Proton Accelerator Research Complex
JAEA and KEK Joint Project

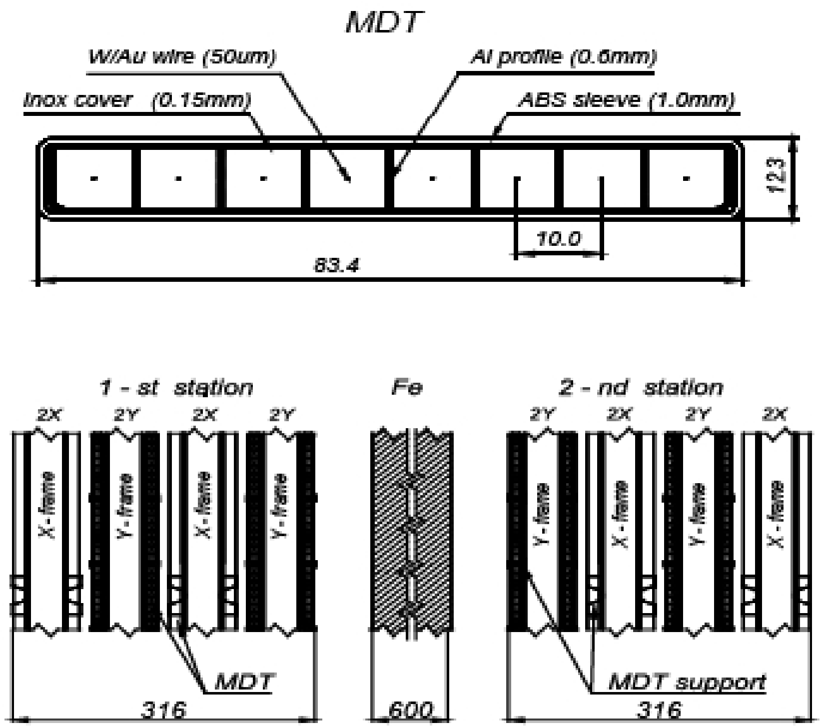
J-PARK,

The DY measurement is under discussion, no detailed information is available yet



- $L \approx 10^{31}\ cm^{-2}s^{-1}$ (polarised pp)
- $\sqrt{s}$ = 200 GeV
- small x, pp collision

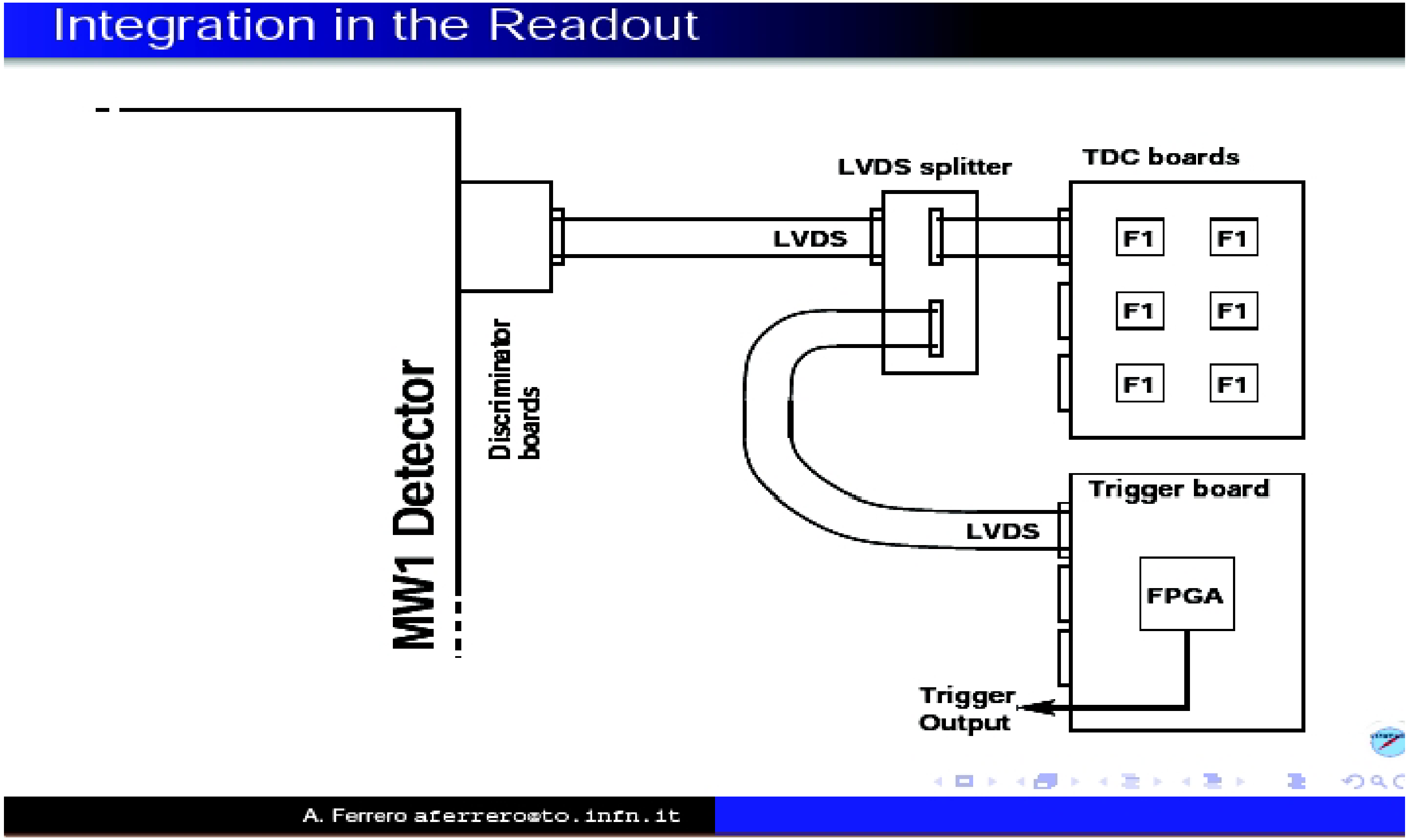
Muon Trigger in LAS I



- The basic detector element is the Mini Drift Tube (MDT)
- Vertical (X) and horizontal (Y) planes are formed by $\sim$ 60 MDTs each
- Two stations of 4X and 4Y planes sorround a 60 cm thick hadron absorber

A. Ferrero aferrero@to.infn.it

Muon Trigger in LAS II



Short term DY plans

- DY physics with Compass spectrometer – Expression of Interest: possibly June 2007
- Compass DY Beam test: July-August 2007
- DY physics with Compass spectrometer – possibly first draft of the technical proposal: December 2007
- Proposal merging with the proposal on GPDs measurements with Compass: beginning of 2008

Summary I

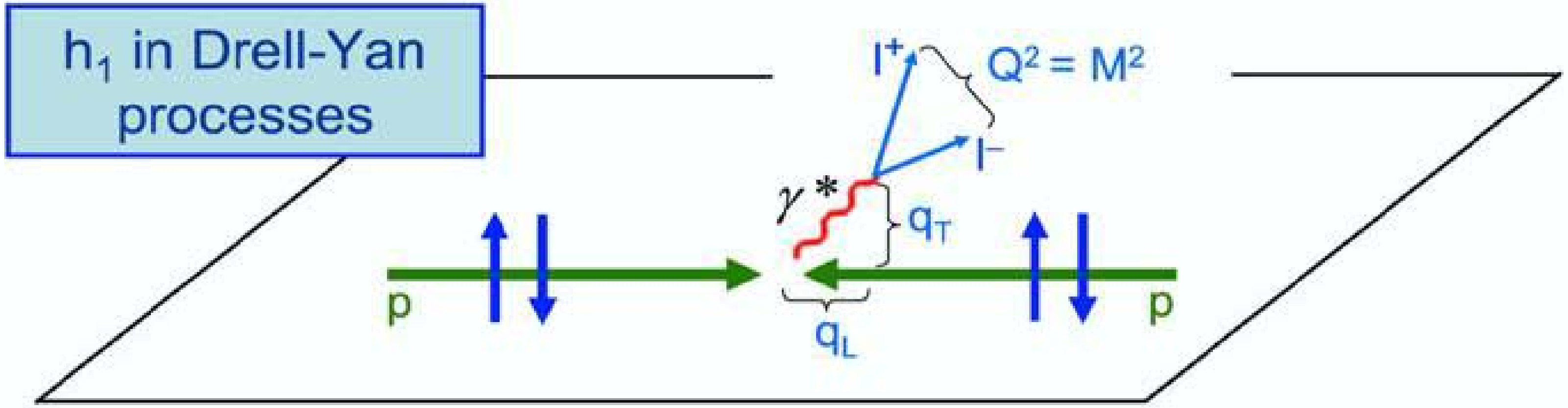
- Compass spectrometer + SPS M2 secondary hadron beams offers a valid facility for DY physics study:
  - Right kinematical range
  - Compass polarised target
  - Very universal and flexible spectrometer
- Two spectrometer schemes has to be examined (2007 beam test is decisive):
  - Pure DY ($\mu^+\mu^-$) set-up with hadron absorber in the first spectrometer
  - Universal spectrometer scheme, DY ($\mu^+\mu^-$), (e^+e^-), pions, charmed hyperons in the final state

Summary II

- Right now we have no any show stopper but still a lot of work has to be done to prove the feasibility of the project
- According to optimistic and very preliminary estimates in a one year of data taking we can expect statistics comparable with classical E615 and NA10 experiments

spares

h_1 in Drell-Yan process



Elementary LO interaction: $q\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$

$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\pi\alpha^2}{9M^2 s}\frac{1}{x_1 + x_2}\sum_a e_a^2 [q_a(x_1)\,\bar{q}_a(x_2) + \bar{q}_a(x_1)\,q_a(x_2)]$$

$$x_F = x_1 - x_2 \qquad x_1 x_2 = M^2/s \equiv \tau \qquad x_F = 2q_L/\sqrt{s}$$

3 planes: plane $\perp$ to polarization vectors,
$p-\gamma^*$ plane, $l^+ - l^-$ plane ⇨ plenty of spin effects

Lam-Tung sum rule violation E615

$$1 - \lambda - 2\nu = 0$$

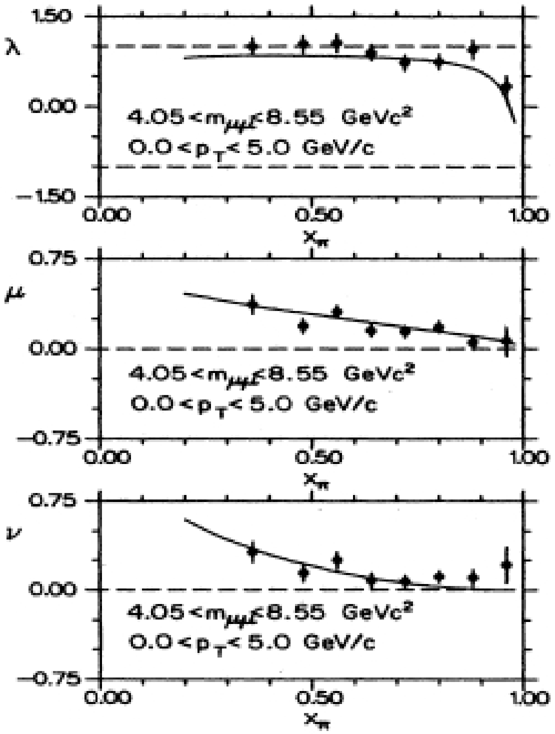


FIG. 34. Result for λ, μ, and ν as a function of x_π in the GJ frame; curves are for generated Monte Carlo events.

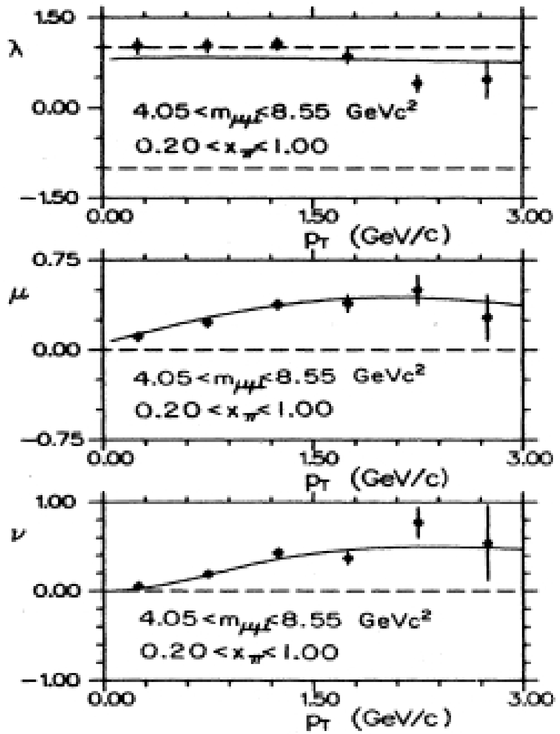
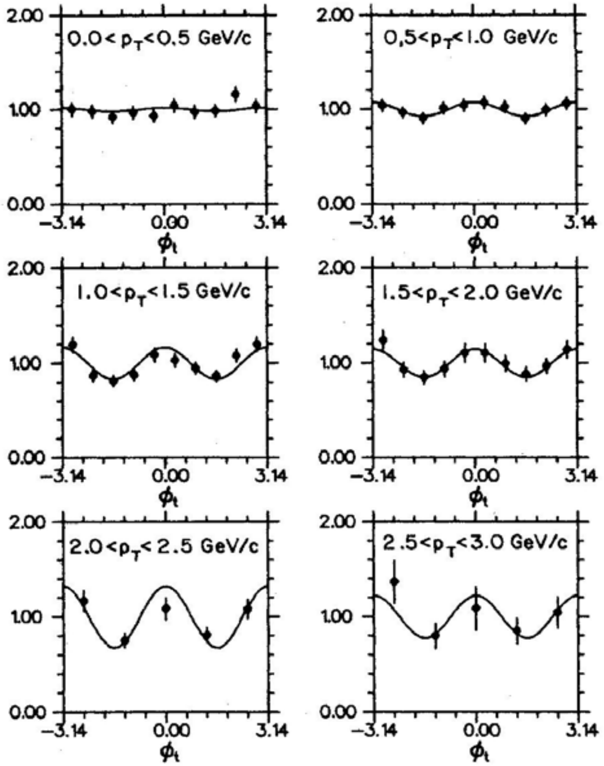


FIG. 36. Result for λ, μ, and ν as a function of P_T in the GJ frame; curves are for generated Monte Carlo events.

J.S.Conway et al., Phys.Rev. D, 1989, Vol.39, p.92

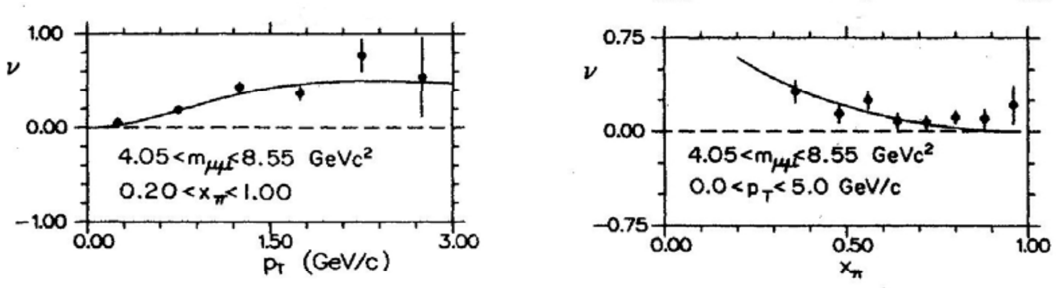
E615

The approach to angular distribution analysis was taken from
J.S. Conway et al ., Phys. Rev. D39 (1989) 92
NA10 Collab., Z. Phys. C31 (1986) 513
NA10 Collab.,Z. Phys. C37 (1988) 545.



$$\frac{d^2\sigma}{d\cos\theta\, d\phi} \propto 1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\nu/2\sin^2\theta\cos 2\phi$$

The DY events from PYTHIA are weighted with parameterizations on ν versus x_1 and q_T from
J.S. Conway et al ., Phys. Rev. D39 (1989) 92.



The parameters λ and μ were taken equal to 1 and 0 respectively

Charged pions asymmetry

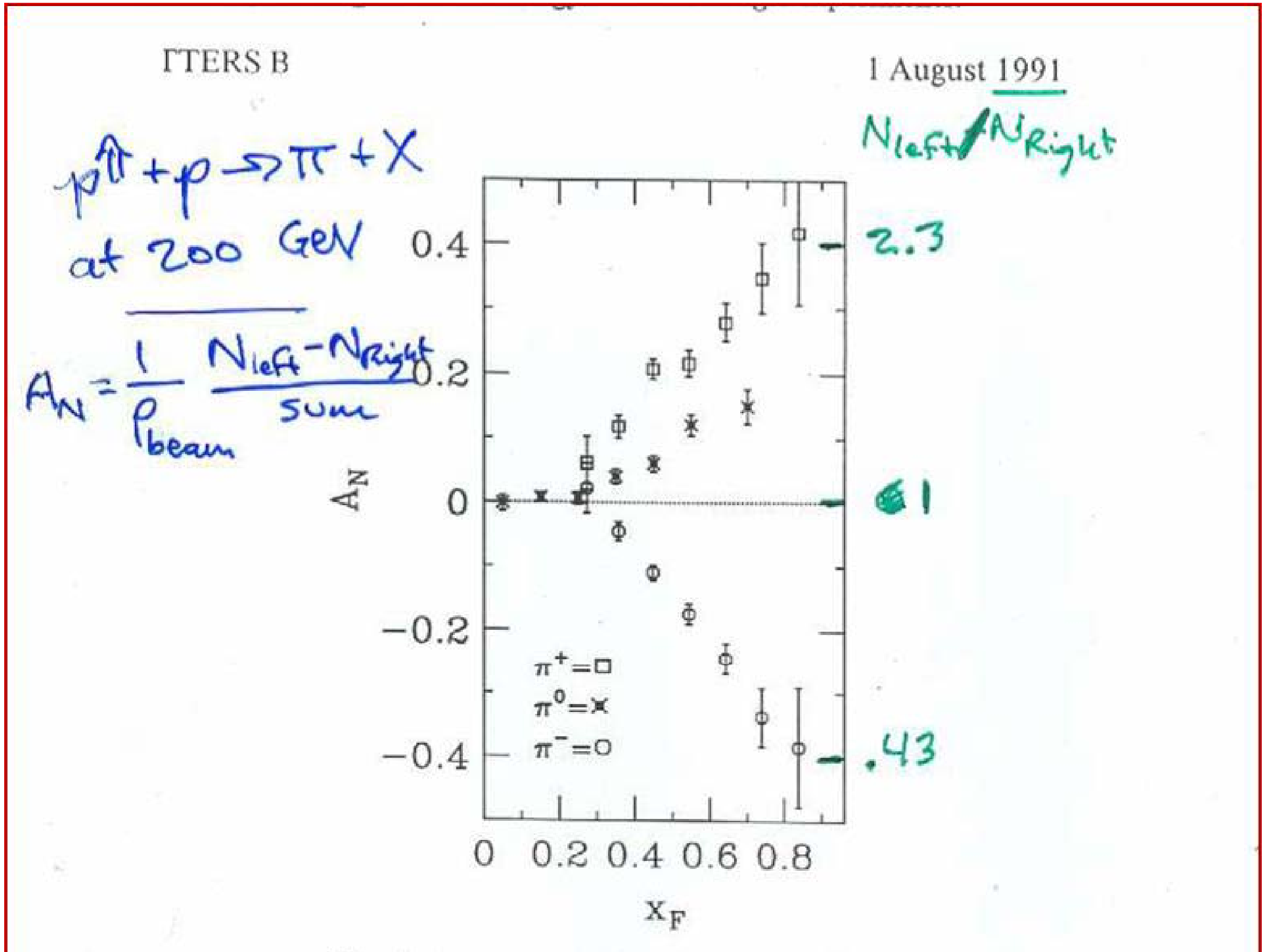


Fig. 4. A_N versus x_F for π^+, π^- and π^0 data.

J/Ψ region angular distributions

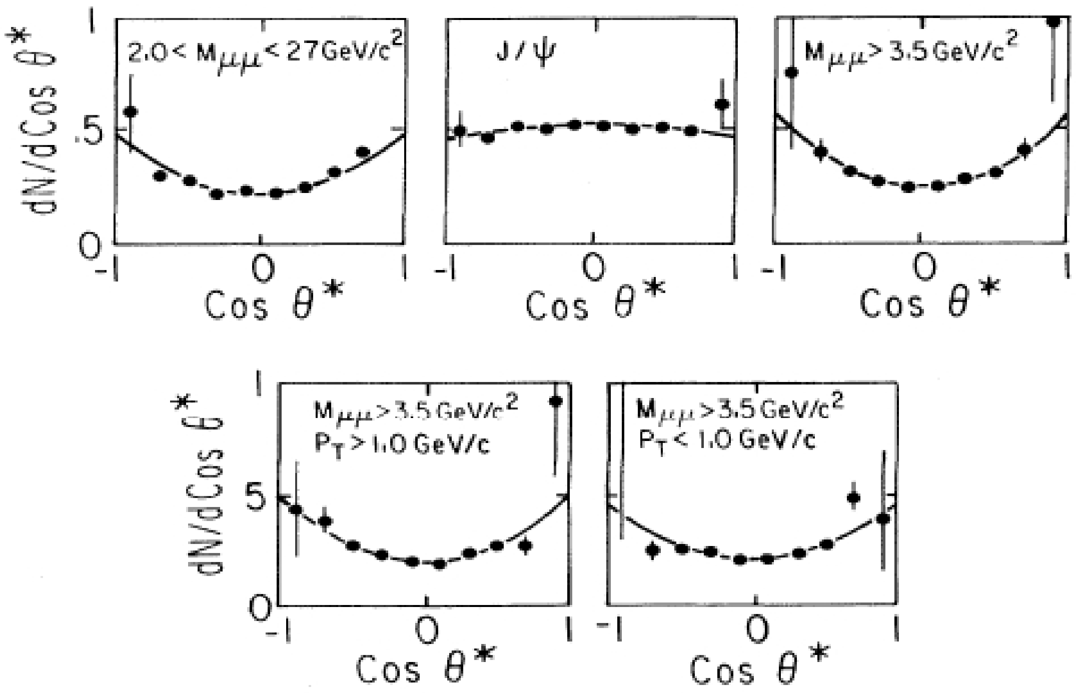


FIG. 3. Helicity angular distributions in three different mass intervals. The $M > 3.5$ GeV/c^2 interval is also shown divided in two p_T intervals. The Collins-Soper angle (θ^*) is defined in the text.

G.E.Hogan et al., Phys.Rev.Lett. 1979, V42, p.948