The Drell-Yan measurement at COMPASS-II

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26/05/2011
PHOTON 2011 - Spa (Belgium)

Outline

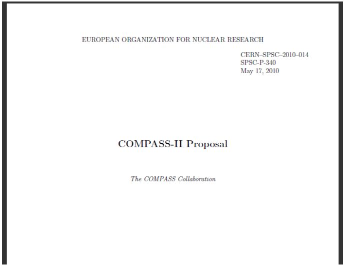
Transverse Momentum Dependent PDFs

The Drell-Yan process

TMD PDFs and Drell-Yan

DY@COMPASS

Introduction



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–SPSC–2010–014
SPSC-P-340
May 17, 2010

COMPASS-II Proposal

The COMPASS Collaboration

A new measurement of transverse momentum dependent parton distribution functions (TMD PDFs) is presented.

The Drell-Yan process allows to extract the transversity and the other TMDs, like the Sivers function and the Boer-Mulders function.

The Drell-Yan measurement is part of the **COMPASS-II Proposal** which was recommended for approval by the SPS Committee. The CERN Research board approved it on 1st December 2010

Jumping into PDFs land...

When k_T dependence is taken into account, eight parton distribution functions are used to describe the nucleon at LO

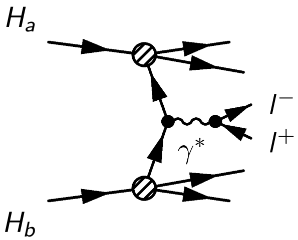
quark \ nucleon	unpol.	long. pol.	transv. pol.
unpol.	f_1		$f_{1T}^{\perp}$ Sivers
long. pol.		g_{1L}	g_{1T}
transv. pol.	$h_1^{\perp}$ B-M	$h_{1L}^{\perp}$	h_1 transv. $h_{1T}^{\perp}$ Pretzl.

TMD PDFs

The three TMD PDFs below describe important properties of spin dynamics of nucleon

- $f_{1T}^{\perp}\left(x, k_T^2\right)$: the Sivers effect is related to an azimuthal asymmetry in the parton intrinsic transverse momentum distribution induced by the nucleon spin
- $h_1^{\perp}\left(x, k_T^2\right)$: the Boer-Mulders function describes the correlation between the transverse spin and the transverse momentum of a quark inside the unpolarised hadron
- $h_{1T}^{\perp}\left(x, k_T^2\right)$: the Pretzelosity function describes the polarisation of a quark along its intrisic k_T direction making accessible the orbital angular momentum information

The Drell-Yan process



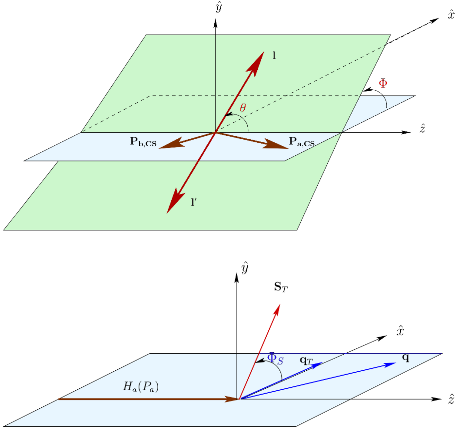
The Drell-Yan process is the annihilation of a quark-antiquark pair coming from two hadrons. Being an electromagnetic process, at Born level in collinear approximation, the Drell-Yan cross section can be calculated

$$\sigma_{DY} = \sum_q \int \mathrm{d}x_a \int \mathrm{d}x_b f_a(x_a) f_b(x_b) \; \hat{\sigma}_0$$

$P_{a,b}$ = momenta of incoming hadrons
q = momentum of the virtual photon γ^*
$q^2 = M^2_{\mu\mu}$
$s = (P_a + P_b)^2$
$x_{a,b} = \frac{q^2}{2P_{a,b} \cdot q}$
$\tau = \frac{M^2_{\mu\mu}}{s}$

Massless quarks approximation

Definition of angles



The Collins-Soper frame: virtual photon rest frame, P_a and P_b lie in the x-z plane, z axis in the direction of $(P_a - P_b)$. The CS frame is usually choosen to study the Drell-Yan angular distribution

θ and ϕ are the angles defined by the lepton pair w. r. t. the hadrons plane

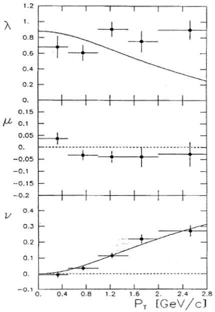
ϕ_S is the azimuthal angle of the target spin vector in the target rest frame (if target is polarised)

Drell-Yan angular distributions

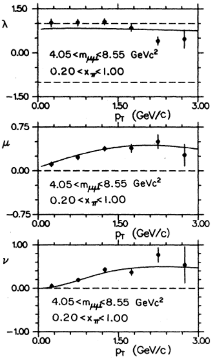
The unpolarised Drell-Yan angular distribution is:

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1 + \lambda\cos^2\theta + \mu\sin^2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi\right)$$

λ, μ and ν as a function of virtual photon transverse momentum



λ, μ, ν in CS frame
Falciano et al, Z. Phy. C 31, 513 (1986)



λ, μ, ν in GJ frame
Conway et al, Phys. Rev. D 39, 92 (1989)

The parameters λ, μ and ν are related by the Lam-Tung sum rule[1]:

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

At LO, in collinear approximation:

$\lambda = 1$ and $\mu = \nu = 0$

but

NA10 and E615 showed non-zero values for λ, μ, ν and also a $\cos 2\phi$ modulation

[1] C. S. Lam and W. K. Tung, Phys. Rev. D 21, 2712 (1980)

TMD PDFs and Drell-Yan

The *collinear approximation is clearly not sufficient* to justify the value of λ, μ and ν. The Lam-Tung sum rule may still hold, but NA10 and E615 seem to suggest a possible breaking.
The angular distribution can be expressed as the sum of convolutions of TMD PDFs of the two hadrons

$$
\begin{aligned}
\frac{d\sigma}{d^4q\, d\Omega} = \frac{\alpha_{em}^2}{F\, q^2} \times \\
\Big\{ & \Big((1+\cos^2\theta)\, F_{UU}^1 + (1-\cos^2\theta)\, F_{UU}^2 + \sin 2\theta \cos\phi\, F_{UU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UU}^{\cos 2\phi} \Big) \\
& + S_{aL} \Big(\sin 2\theta \sin\phi\, F_{LU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LU}^{\sin 2\phi} \Big) \\
& + S_{bL} \Big(\sin 2\theta \sin\phi\, F_{UL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UL}^{\sin 2\phi} \Big) \\
& + |\vec{S}_{aT}| \Big[\sin\phi_a \Big((1+\cos^2\theta)\, F_{TU}^1 + (1-\cos^2\theta)\, F_{TU}^2 + \sin 2\theta \cos\phi\, F_{TU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TU}^{\cos 2\phi} \Big) \\
& \qquad + \cos\phi_a \Big(\sin 2\theta \sin\phi\, F_{TU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TU}^{\sin 2\phi} \Big) \Big] \\
& + |\vec{S}_{bT}| \Big[\sin\phi_b \Big((1+\cos^2\theta)\, F_{UT}^1 + (1-\cos^2\theta)\, F_{UT}^2 + \sin 2\theta \cos\phi\, F_{UT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UT}^{\cos 2\phi} \Big) \\
& \qquad + \cos\phi_b \Big(\sin 2\theta \sin\phi\, F_{UT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UT}^{\sin 2\phi} \Big) \Big] \\
& + S_{aL} S_{bL} \Big((1+\cos^2\theta)\, F_{LL}^1 + (1-\cos^2\theta)\, F_{LL}^2 + \sin 2\theta \cos\phi\, F_{LL}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{LL}^{\cos 2\phi} \Big) \\
& + S_{aL} |\vec{S}_{bT}| \Big[\cos\phi_b \Big((1+\cos^2\theta)\, F_{LT}^1 + (1-\cos^2\theta)\, F_{LT}^2 + \sin 2\theta \cos\phi\, F_{LT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{LT}^{\cos 2\phi} \Big) \\
& \qquad + \sin\phi_b \Big(\sin 2\theta \sin\phi\, F_{LT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LT}^{\sin 2\phi} \Big) \Big] \\
& + |\vec{S}_{aT}| S_{bL} \Big[\cos\phi_a \Big((1+\cos^2\theta)\, F_{TL}^1 + (1-\cos^2\theta)\, F_{TL}^2 + \sin 2\theta \cos\phi\, F_{TL}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TL}^{\cos 2\phi} \Big) \\
& \qquad + \sin\phi_a \Big(\sin 2\theta \sin\phi\, F_{TL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TL}^{\sin 2\phi} \Big) \Big] \\
& + |\vec{S}_{aT}| |\vec{S}_{bT}| \Big[\cos(\phi_a+\phi_b) \Big((1+\cos^2\theta)\, F_{TT}^1 + (1-\cos^2\theta)\, F_{TT}^2 + \sin 2\theta \cos\phi\, F_{TT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TT}^{\cos 2\phi} \Big) \\
& \qquad + \cos(\phi_a-\phi_b) \Big((1+\cos^2\theta)\, F_{TT}^1 + (1-\cos^2\theta)\, F_{TT}^2 + \sin 2\theta \cos\phi\, F_{TT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TT}^{\cos 2\phi} \Big) \\
& \qquad + \sin(\phi_a+\phi_b) \Big(\sin 2\theta \sin\phi\, F_{TT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TT}^{\sin 2\phi} \Big) \\
& \qquad + \sin(\phi_a-\phi_b) \Big(\sin 2\theta \sin\phi\, F_{TT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TT}^{\sin 2\phi} \Big) \Big] \Big\}
\end{aligned}
$$

The $F_{UTL,UTL}^{f(\phi,\theta)}$ hide convolutions of TMD PDFs of the two hadrons

S. Arnold et al., Phys. Rev. D 79, 034005 (2009)

Single (un)polarised Drell-Yan

In case of a single polarised Drell-Yan, the Drell-Yan cross-section simplifies to (at LO):

$$\begin{aligned}\frac{\mathrm{d}\sigma}{\mathrm{d}^4 q \mathrm{d}\Omega} &= \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \Big\{ \Big(1 + D_{[\sin^2\theta]} A_U^{\cos 2\phi} \cos 2\phi\Big) \\ &+ |\mathbf{S}_T| \Big[A_T^{\sin\phi_S} \sin\phi_S + D_{[\sin^2\theta]} \Big(A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) \\ &+ A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S) \Big) \Big] \Big\}\end{aligned}$$

with $D_{[f(\theta)]}$ = depolarisation factors, S = spin target components, F = flux of incoming hadrons and A = the azimuthal asymmetries, $\hat{\sigma}_U$ = cross section surviving the integration of ϕ and ϕ_S

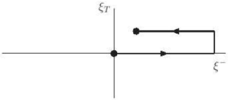
SIDIS vs DY: a crucial test of TMDs factorization

SIDIS and DY are complementary way to extract PDFs
$\longrightarrow$ it is possible to perform a test of QCD

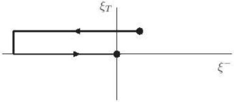
$f_{1T}^{\perp}(DY)$ and $h_1^{\perp}(DY)$ are naïvely T-odd

A gauge link appears in the definition of the two naïve T-odd functions

SIDIS



DY



$\Rightarrow$ QCD expectation is:

$$
\begin{aligned}
f_{1T}^{\perp}(DY) &= -f_{1T}^{\perp}(SIDIS) \\
h_1^{\perp}(DY) &= -h_1^{\perp}(SIDIS)
\end{aligned}
$$

$\Leftarrow$ generalized universality

What can be measured at COMPASS

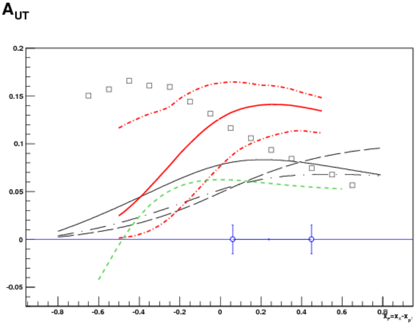
At COMPASS, it will be possible to measure the asymmetries in single polarised Drell-Yan using a pion beam on a transversely polarised proton target

Each asymmetry gives access to two TMD PDFs:

- $A_U^{\cos 2\phi}$: access to the Boer-Mulders functions of the incoming hadrons
- $A_T^{\sin \phi_S}$: access to the Sivers function of the target nucleon
- $A_T^{\sin(2\phi+\phi_S)}$: access to the Boer-Mulders function of the beam hadron and to the pretzelosity function of the target nucleon
- $A_T^{\sin(2\phi-\phi_S)}$: access to the Boer-Mulders function of the beam hadron and the transversity function of the target nucleon

Statistical errors and predictions

Predictions exist for the single spin asymmetry due to the Sivers effect, for the virtual photon mass range 4-9 GeV/c^2 and for the COMPASS kinematics. They are compared with the expected errors (1-2%) coming from a two bins analysis of two years of data taking.

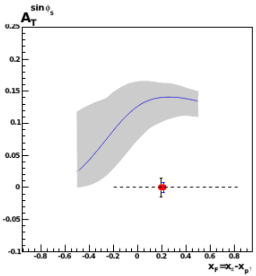


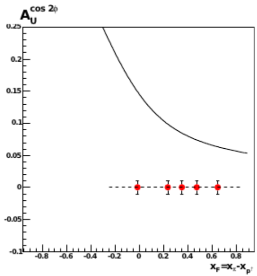
- Efremov et al, PLB612 (2005) 233 (solid and dashed)
- Collins et al, PRD73 (2006) 014021 (dot-dashed)
- Anselmino et al, PRD79 (2009) 054010 (red solid, red dot-dashed)
- Bianconi et al, PRD73 (2006) 114002 (boxes)
- Bacchetta et al, PRD78 (2008) 074010 (green short-dashed)

Predictions for asymmetries: 4-9 GeV/c^2 @ COMPASS

Sivers

M. Anselmino et al, Phys. Rev. D 79, 054010 (2009)

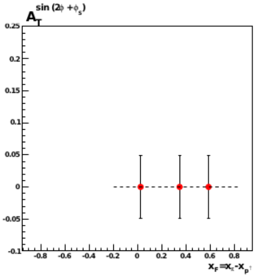


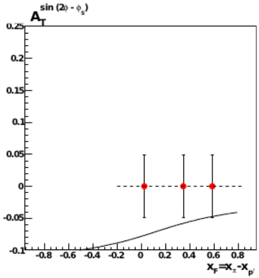


Boer-Mulders

B. Zhang et al, Phys. Rev. D 77, 054011 (2008)

BM ⊗ pretz.



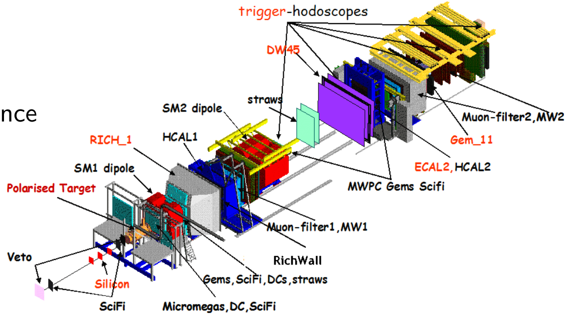


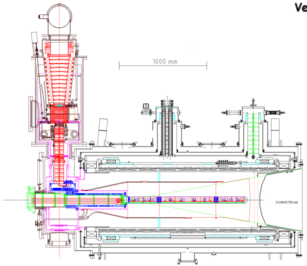
BM ⊗ transv.

A. N. Sissakian, Phys. Part. Nucl. 41, 64-100 (2010)

The COMPASS spectrometer

- μ, p, π, K beam
- 50-270 GeV/c momentum
- $\pm$180 mrad angular acceptance



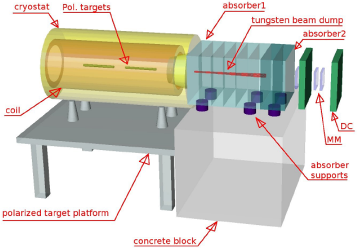


- NH_3 target polarisation $\sim$90%
- dilution factor 0.15 (SIDIS)
- three cells target

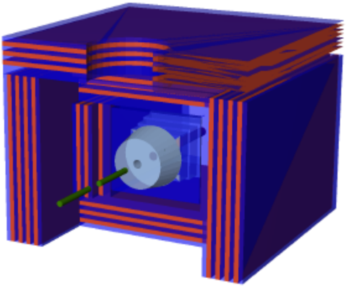
What there is and what is needed

At COMPASS will be studied: $\pi^- p^{(\Uparrow)} \rightarrow \mu^+\mu^- + X$

- unique polarised target
- wide angular acceptance
- muon tracking system
- muon triggers



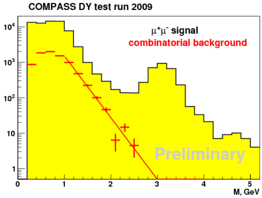
Possible setup of the target and absorber

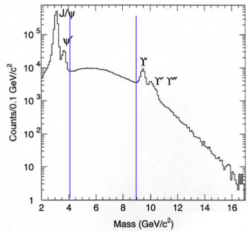


Structure of the absorber and its shielding

- 240 cm Al_2O_3 absorber with a W beam dump

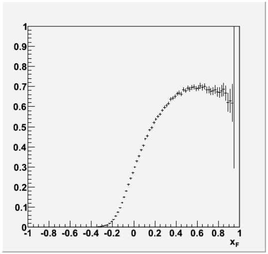
Acceptance to Drell-Yan events



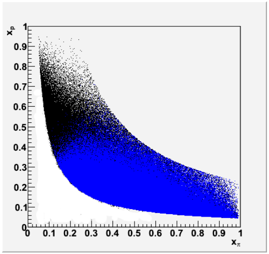


The safe mass interval is between 4 and 9 GeV/c^2

The COMPASS acceptance covers the valence quark region ($x > 0.1$)



x_F acceptance plot

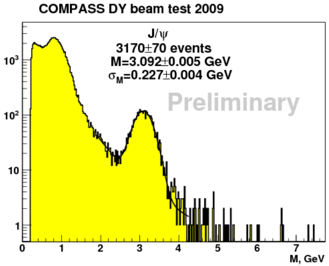


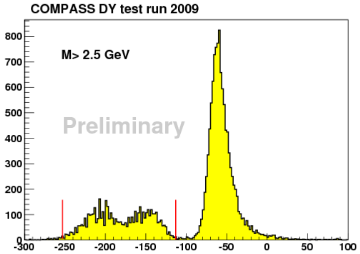
x_p vs x_π scatter plot: in black all generated events, in blue events in acceptance

Asymmetries are expected to be significant in valence quark region, up to 10%

Drell-Yan tests

In 2007, 2008 and 2009 important tests was performed at COMPASS. The most recent one was done in the condition of the future measurement, with the hadron absorber. During the short data taking, the feasibility was proved, the J/ψ peak and Drell-Yan events were observed as expected and the two cells were distinguished.





→ target temperature ok!

→ radioprotection limits respected!

→ detector occupancies ok!

→ agreement of simulations and reality!

Conclusions

- the Drell-Yan measurement is part of the COMPASS-II Proposal
- the SPS Committee recommended the Proposal for approval in September 2010 $\longrightarrow$ the CERN Research board approved it on 1st December 2010
- according to COMPASS Collaboration plans, we will have first data on single polarised Drell-Yan in 2014
- a crucial test of TMD PDFs factorization can be done: change of sign of Boer-Mulders and Sivers functions

Thank You!

Backup

J/ψ-DY duality[1]

Since the J/ψ is a vector particle like the photon and the helicity structure of $\bar{q}q\,(J/\psi)$ and $(\bar{q}q)\,\gamma^*$ couplings is the same, it is possible to establish an analogy between the two processes $H_a H_b \rightarrow J/\psi X \rightarrow l^+ l^- X$ and $H_a H_b \rightarrow \gamma^* X \rightarrow l^+ l^- X$

Studying the J/ψ production will be possible:

- check the duality hypothesis
- dramatically enlarge statistics (for region of mass around J/ψ mass)

[1] N. Anselmino, V. Barone, A. Drago and N. Nikolaev, Phys. Lett. B 594, (2004) 97
A. Sissakian, O. Shevchenko and O. Ivanov, JETP Lett. 86 (2007) 751

Expression of asymmetries

$$F_U^1 \stackrel{\text{LO}}{=} \mathcal{C}\left[f_a \bar{f}_a\right]$$

$$A_U^{\cos 2\phi} \stackrel{\text{LO}}{=} \mathcal{C}\left[\left(2\left(\mathbf{h}\cdot\mathbf{k}_{aT}\right)\left(\mathbf{h}\cdot\mathbf{k}_{bT}\right) - \mathbf{k}_{aT}\cdot\mathbf{k}_{bT}\right) h_1^{\perp}\bar{h}_1^{\perp}\right] \Big/ M_a M_b F_U^1$$

$$A_T^{\sin\phi_S} \stackrel{\text{LO}}{=} \tilde{A}_T^{\sin\phi_S}$$

$$\stackrel{\text{LO}}{=} \mathcal{C}\left[\mathbf{h}\cdot\mathbf{k}_{bT} f_1 \bar{f}_{1T}^{\perp}\right] \Big/ M_b F_U^1$$

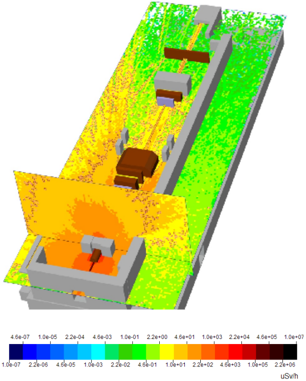
$$A_T^{\sin(2\phi+\phi_S)} \stackrel{\text{LO}}{=} -\mathcal{C}\left[\left(2\left(\mathbf{h}\cdot\mathbf{k}_{bT}\right)\left[2\left(\mathbf{h}\cdot\mathbf{k}_{aT}\right)\left(\mathbf{h}\cdot\mathbf{k}_{bT}\right) - \mathbf{k}_{aT}\cdot\mathbf{k}_{bT}\right]\right.\right.$$
$$\left.\left. -\mathbf{k}_{bT}^2\left(\mathbf{h}\cdot\mathbf{k}_{aT}\right)\right) h_1^{\perp}\bar{h}_{1T}^{\perp}\right] \Big/ 4 M_a M_b^2 F_U^1$$

$$A_T^{\sin(2\phi-\phi_S)} \stackrel{\text{LO}}{=} -\mathcal{C}\left[\mathbf{h}\cdot\mathbf{k}_{aT} h_1^{\perp}\bar{h}_1\right] \Big/ 2 M_a F_U^1$$

where $\mathbf{h} = \mathbf{q}_T / q_T$

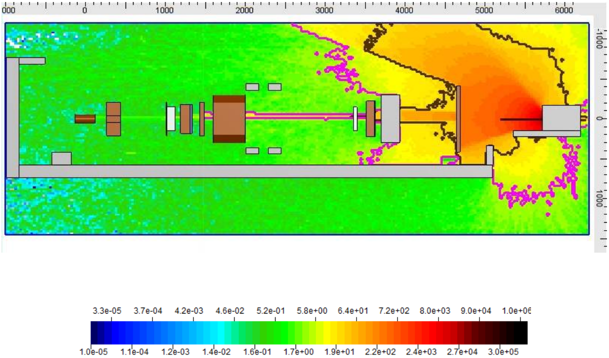
Looking deep in one issue: radioprotection

COMPASS is a ground experiment: that means that radioprotection rules define limits to beam intensity (then to luminosity). Moreover an absorber in the middle of the experimental hall completely changes the dose rate w. r. t. experienced muon or hadron conditions



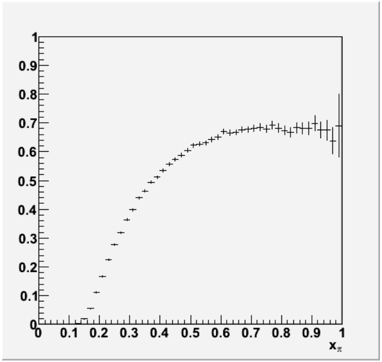
Fluka simulations by H. Vincke, CERN

More on looking deep in one issue: radioprotection

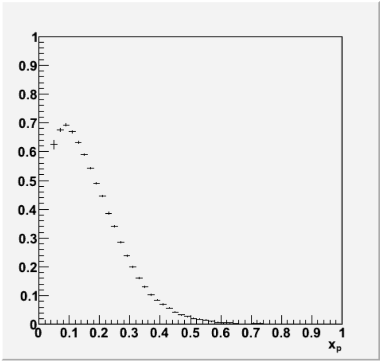


Fluka simulations by H. Vincke, CERN

More on acceptances



x_π acceptance plot



x_P acceptance plot