V.Petrov, R.Ryutin, A.Godizov, A.Sobol, V.Samoilenko

πp and $\pi\pi$ scattering: towards the first LHC results

R.Ryutin, IHEP

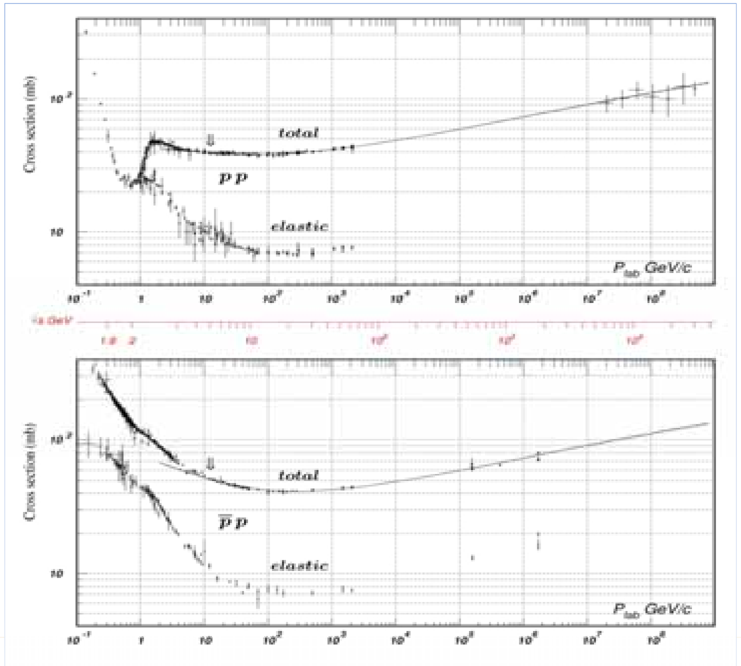
Plan

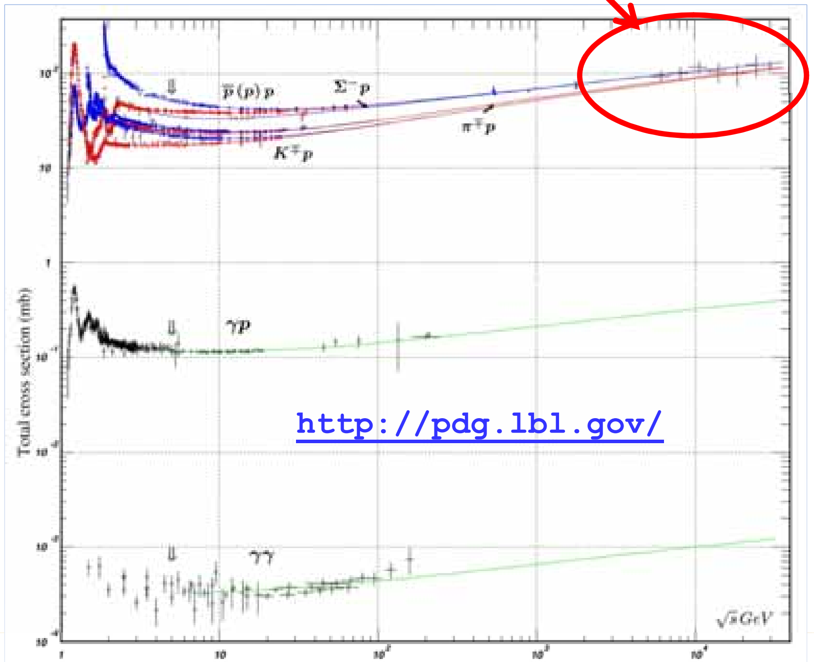
- Historical outlook and motivations
- Model for charge exchange processes
- Extraction of the cross-sections from data. Theoretical errors.
- Experimental situation.
- Total πp and $\pi\pi$ cross-sections. Monte-Carlo and real data at 900 GeV and 7 TeV.
- Future prospects: elastic and inclusive di-jet cross-sections

Historical outlook and motivations

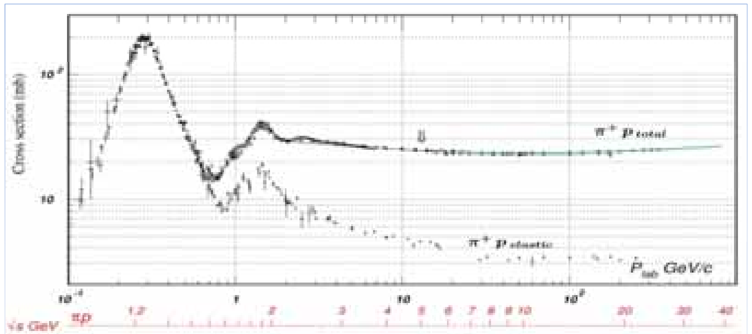
pp ($\bar{p}$p) : $\sqrt{s}_{max}$ ~10 TeV

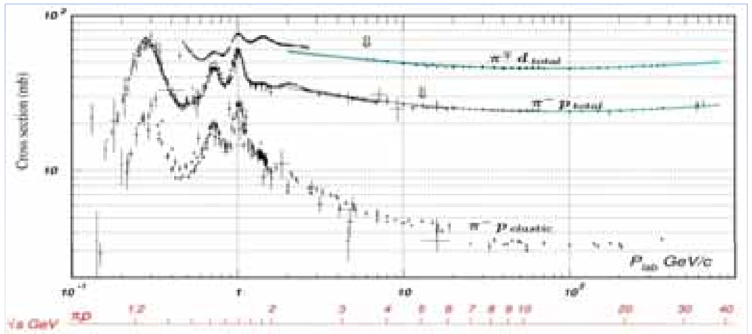
Universality of strong interactions at super-high energies





π p : $\sqrt{s}_{max}$ ~30-40 GeV !





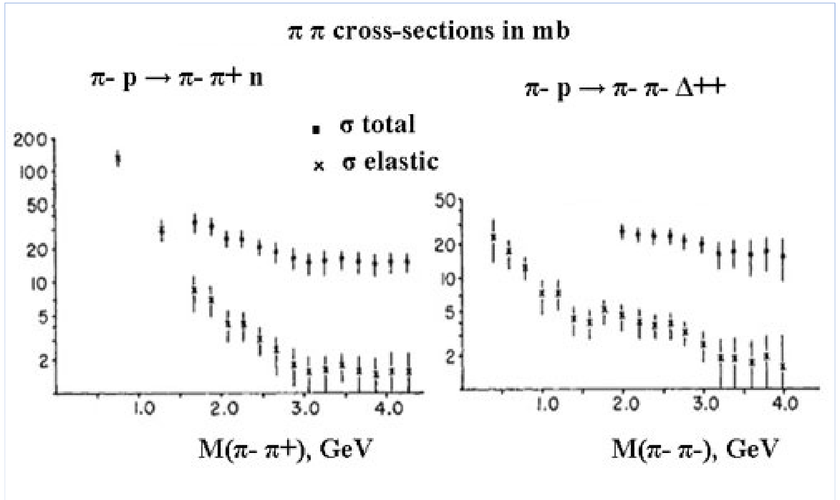
Historical outlook and motivations

Extraction of πp and $\pi\pi$ cross-sections

[W.J. Robertson, W.D. Walker, J.L. Davis, Phys. Rev. D7 (1973) 2554]

Basic idea of the extrapolation to $t \to m_\pi^2$:

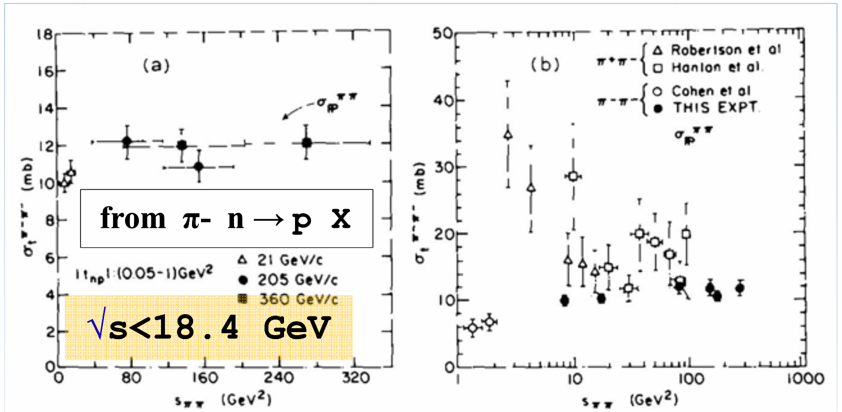
[G.F. Chew, F.E. Low, Phys. Rev. 113 (1959) 1640]
[C. Goebel, Phys. Rev. Lett. 1 (1958) 337]



from $\gamma^* p \to \pi^+ \pi^- p$

[H. Abramowicz et al., Nucl. Phys. B166 (1980) 62]

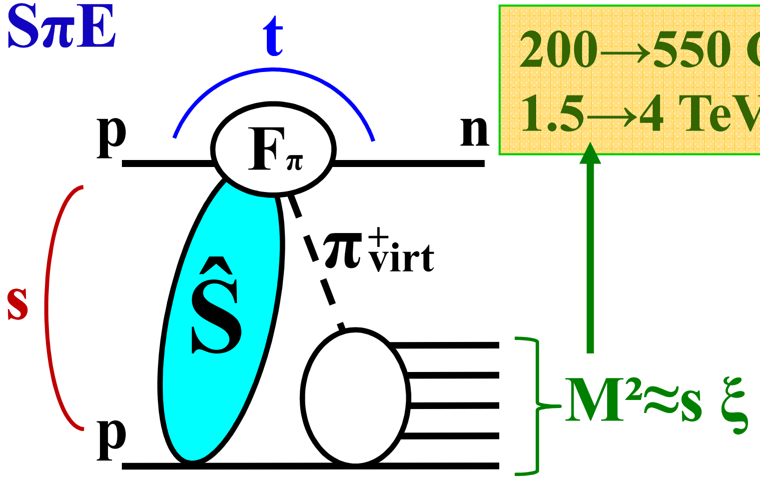
$\sigma_{tot}(\pi p) = 31 \pm 3.6$ mb at $\sqrt{s} = 50$ GeV



[M.G. Ryskin, Y.M. Shabelski, Yad. Fiz. 61(1998) 89]
[J.Breitweg (ZEUS Collab.), Eur. Phys. J. C2 (1998) 247]

Model for Charge Exchange processes

SπE



200→550 GeV at 0.9 TeV
1.5→4 TeV at 7 TeV

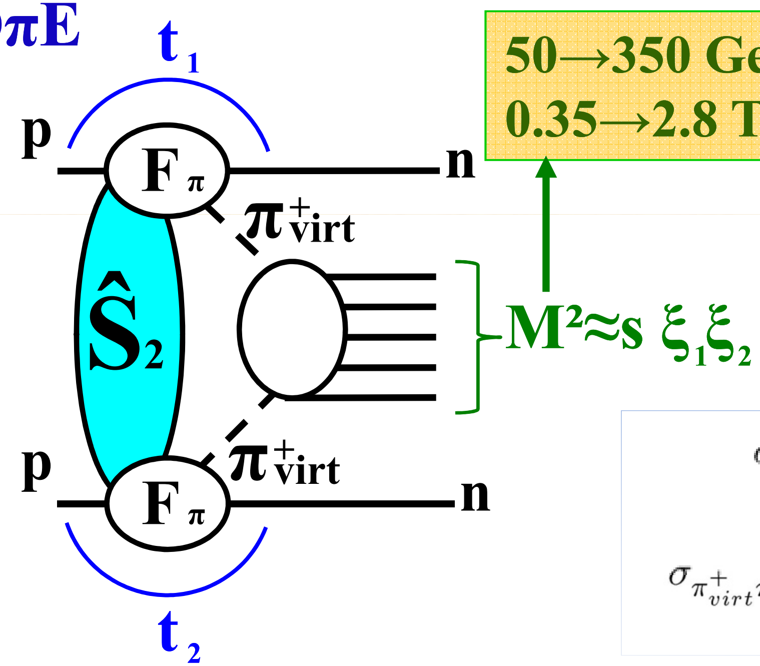
$$F_0(\xi,t) = \frac{G^2_{\pi^+pn}}{16\pi^2}\frac{-t}{(t-m_\pi^2)^2}e^{2bt}\xi^{1-2\alpha_\pi(t)}$$

$$-t \simeq \frac{\vec{q}^{\,2}+m_p^2\xi^2}{1-\xi},\quad G^2_{\pi^+pn}/(8\pi) = 13.75$$

$$\alpha_\pi(t) \simeq 0.9(t-m_\pi^2),\quad b \sim 0.3\ \mathrm{GeV}^{-2}$$

$$\frac{d\sigma_{S\pi E}}{dt\,d\xi} = F_0(\xi,t)S(s/s_0,\xi,t)\underline{\sigma_{\pi^+p}(s\,\xi)}$$

DπE



50→350 GeV at 0.9 TeV
0.35→2.8 TeV at 7 TeV

$$\frac{d\sigma_{D\pi E}}{dt_1 dt_2 d\xi_1 d\xi_2} = F_0(\xi_1,t_1)F_0(\xi_2,t_2)S_2(s/s_0,\xi_{1,2},t_{1,2})\underline{\sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2)}$$

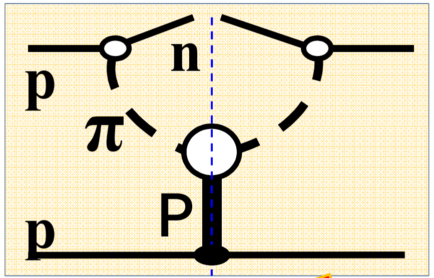
$$\sigma_{\pi^+_{virt}p}(s\,\xi) = \sigma_{\pi^+p}(s\,\xi)$$

$$\sigma_{\pi^+_{virt}\pi^+_{virt}}(s\,\xi_1\xi_2) = \sigma_{\pi^+\pi^+}(s\,\xi_1\xi_2)$$

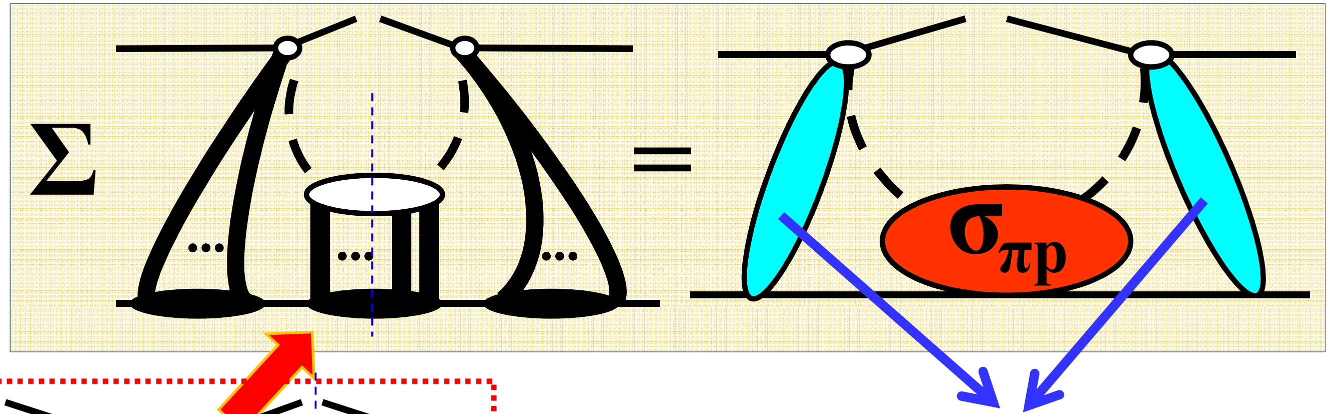
Main contribution
for |t|<0.3 GeV²
virtual → real pion

Model for Charge Exchange processes

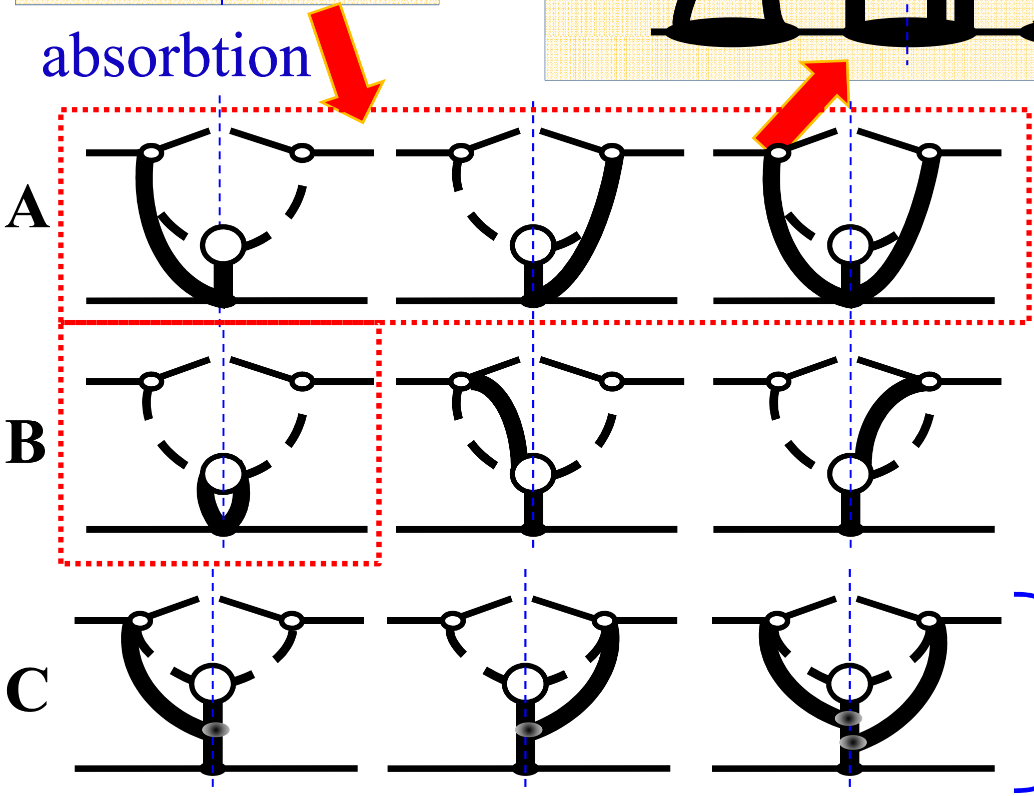
SπE Born term



Leading contributions (eikonalization)



absorbtion



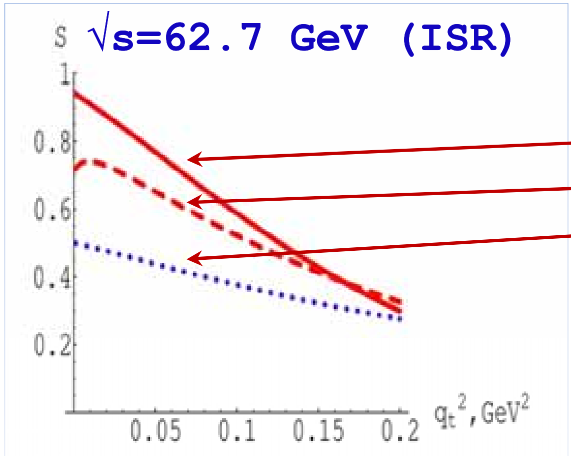
[V.A. Petrov, A.V. Prokudin, Eur. Phys. J. C23 (2002) 135]

It is possible to keep interpretation of πp scattering

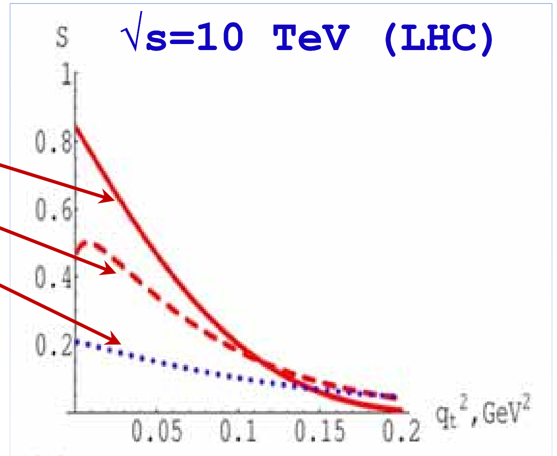
"enhanced" diagrams with 3IP vertexes

[A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C47 (2006) 385]

Model for Charge Exchange processes

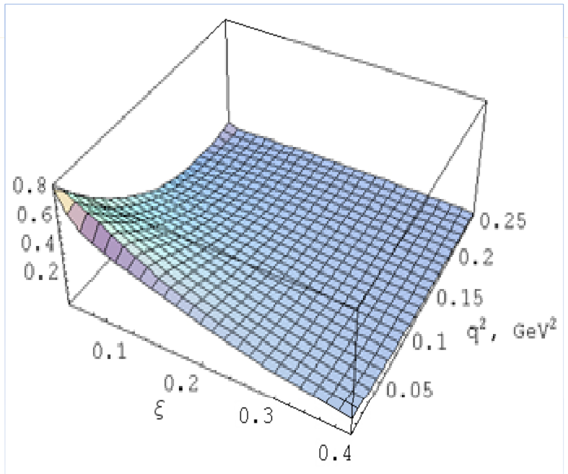


M, GeV	ξ	M, TeV
0.627	0.0001	0.1
19.8	0.1	3.16
34.3	0.3	5.48

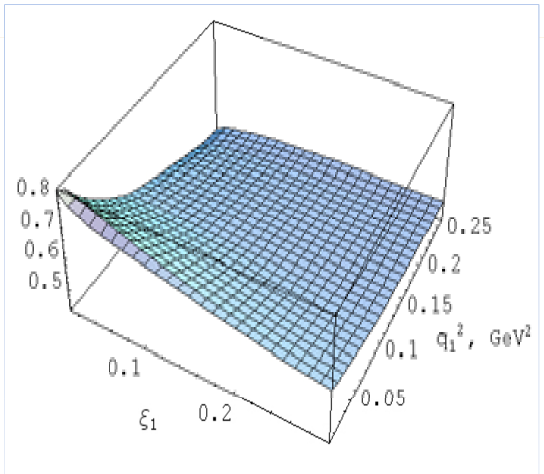


Absorbtion at $\sqrt{s}$=10 TeV

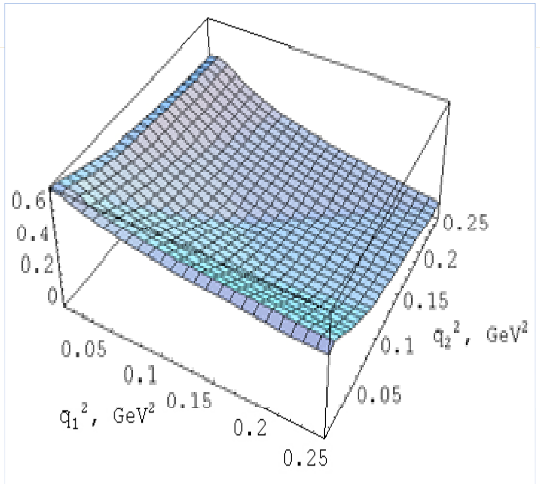
$S(\xi,\bar{q}^2)$



$S_2(\xi_1,\bar{q}^2_1,\xi_2=0.1,\bar{q}^2_2\sim 0)$

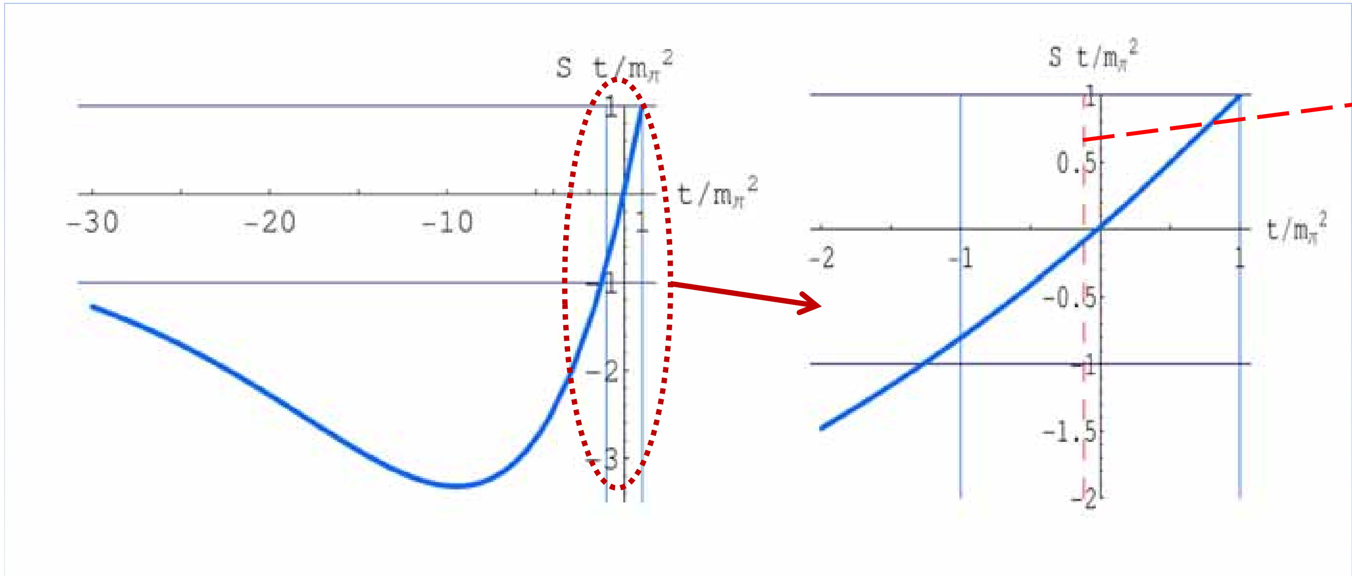


$S_2(\xi_{1,2}=0.1,\bar{q}^2_1,\bar{q}^2_2)$



Extraction of π p and π π cross-sections

Function $S*t/m_\pi^2$ for $\xi=0.05$



The boundary of phys.reg.:

$$t_0 = -\frac{m_p^2\xi^2}{1-\xi}$$

Exact extrapolation procedure ("model independent")

$$\sigma_{\pi^+p}(s\ \xi) = \lim_{t\to m_\pi^2} \sigma_{\pi^+p}(s\ \xi)\frac{S(s/s_0,\xi,t)t}{m_\pi^2} = \lim_{t\to m_\pi^2} E(\xi,t)\frac{d\sigma_{S\pi E}}{d\xi dt}$$

$$\sigma_{\pi^+\pi^+}(s\ \xi_1\xi_2) = \lim_{t_{1,2}\to m_\pi^2} \sigma_{\pi^+\pi^+}(s\ \xi_1\xi_2)\frac{S_2(s/s_0,\xi_{1,2},t_{1,2})t_1t_2}{m_\pi^4} = \lim_{t_{1,2}\to m_\pi^2} E(\xi_1,t_1)E(\xi_2,t_2)\frac{d\sigma_{D\pi E}}{d\xi_1 d\xi_2 dt_1 dt_2}$$

$$E(\xi,t) = -\frac{(t-m_\pi^2)^2}{m_\pi^2}\frac{16\pi^2}{G^2_{\pi^+pn}\mathrm{e}^{2bt}\xi^{1-2\alpha_\pi(t)}}$$

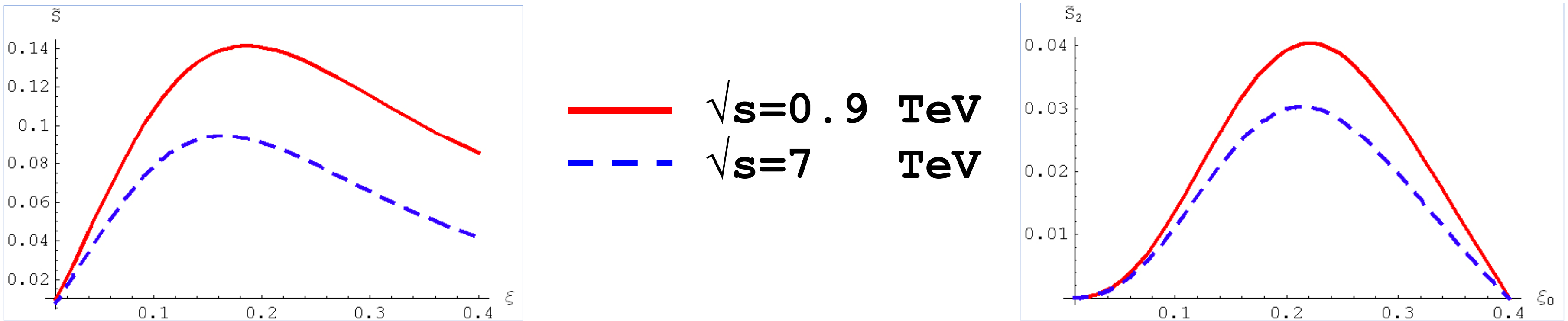
Extraction of π p and $\pi\,\pi$ cross-sections

Integral extraction procedure

(depends on the model for absorbtion,

but can be normalized to pp cross-sections!)

Without LHC measurements (TOTEM, …) at 10 TeV theoretical error from most popular models is about 10%, at 0.9 TeV errors are low, since we have the data at 1.9 TeV.



$$\tilde{S}(\xi) = \int_{t_{min}}^{t_{max}} dt\; S(s/s_0, \xi, t) F_0(\xi, t)$$

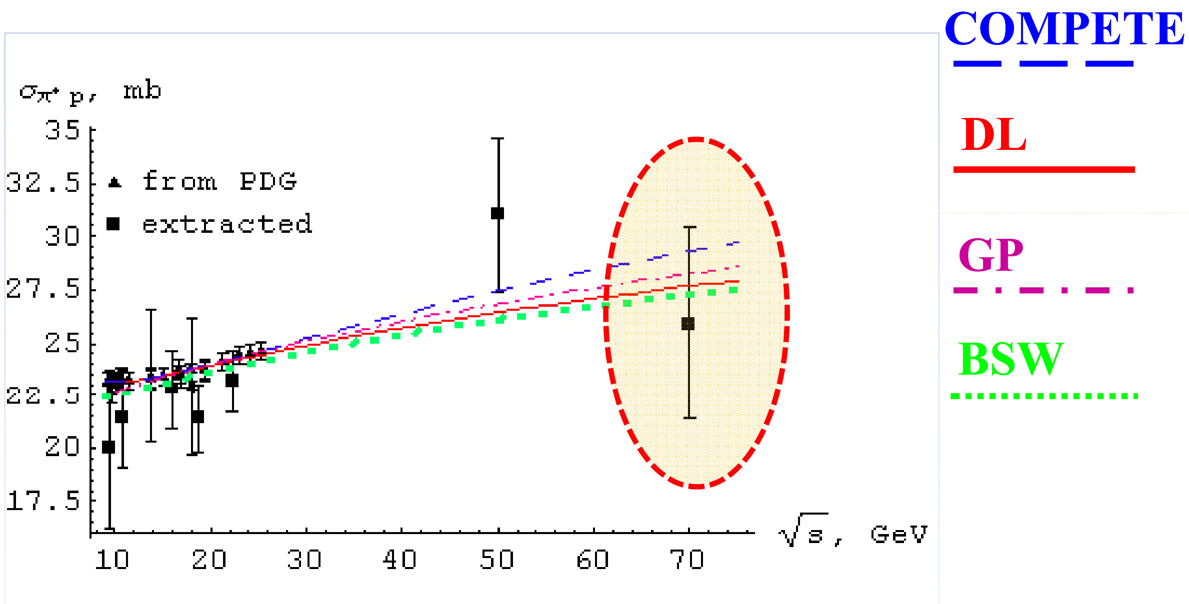
$$\tilde{S}_2(\xi_0) = \int_{t_{min}}^{t_{max}} dt_1 dt_2 \int_{-y_0}^{y_0} dy\; S_2(s/s_0, \{\xi_0 e^{\pm y}\}, \{t_i\}) F_0(\xi_0 e^{y}, t_1) F_0(\xi_0 e^{-y}, t_2)$$

$$\sigma_{\pi^+ p}(M^2_{\pi p}) = \frac{\frac{d\sigma_{S\pi E}}{d\xi}}{\tilde{S}(s,\xi)}, \quad \xi \simeq \frac{M^2_{\pi p}}{s}$$

$$\sigma_{\pi^+\pi^+}(M^2_{\pi\pi}) = \frac{\frac{d\sigma_{D\pi E}}{d\xi_0}}{\tilde{S}_2(s,\xi_0)}, \quad \xi_0 = \frac{M_{\pi\pi}}{\sqrt{s}}, \quad y_0 = \ln\frac{\xi_{max}\sqrt{s}}{M_{\pi\pi}}$$

Extraction of π p cross-sections from data

	NA49	ISR				HERA	PHENIX
$\sqrt{s}$	9.4	10.8	15.9	18.7	22.2	50	70
σ(ext.)	20±3.8	21.4±2.3	22.8±1.9	21.4±1.6	23.2±1.5	31±3.6	25.9±4.5
σ(PDG)	23.2	23.19	23.55	23.85	24.27	27.43	29.3



[B. Nicolescu et al. (COMPETE Coll.), ArXiv: hep-ph/0110170]

[A. Donnachie, P.V. Lanshoff, Phys. Lett. B296 (1992) 227]

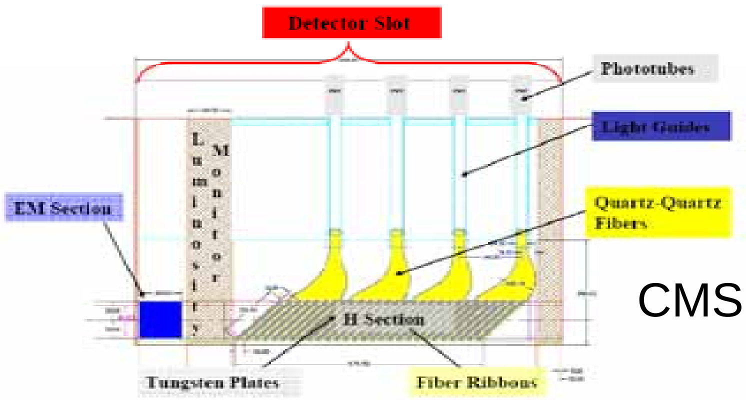
[A.A. Godizov, V.A. Petrov, JHEP 0707 (2007) 083]

[C. Bourrely, J. Soffer, T. T. Wu, Eur. Phys. J. C28(2003)97]

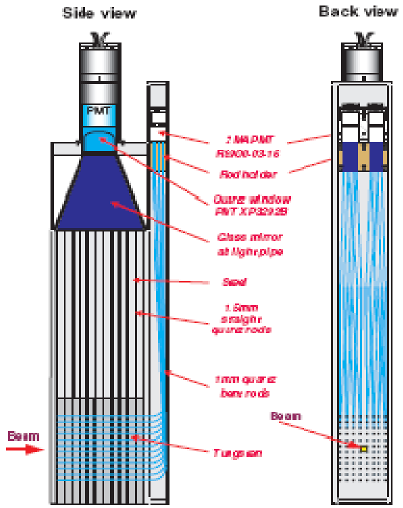
Experimental tools

At 140 m for 5 TeV neutron t ~ 0.128 R^2: t < 0.3 =>R<1.5 cm

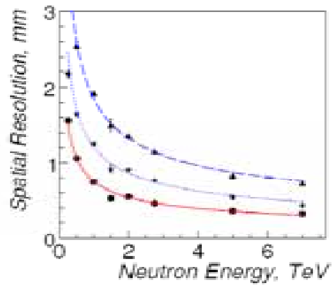
Central cell (2x10 cm) of EM ZDC: t<1.2 GeV-2



CMS ZDC



ATLAS ZDC



We suggest to change fiber layers by THGEM plates

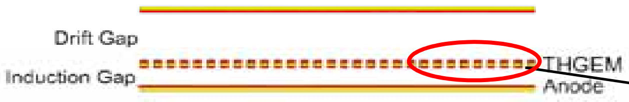
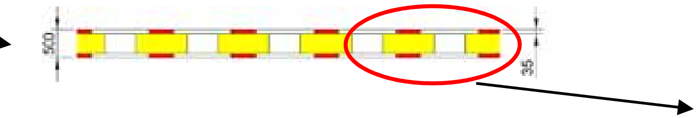
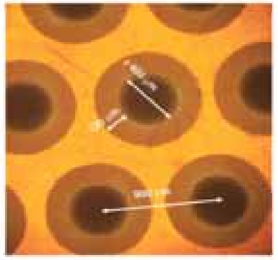


Fig. 1. Schematic view of the THGEM.





Microscope photograph of the THGEM electrode.

1. A Concise review on THGEM **detectors. Nucl.Instrum.Meth.A598:107-111,2009**.
e-Print: **arXiv:0807.2026** [physics.ins-det]

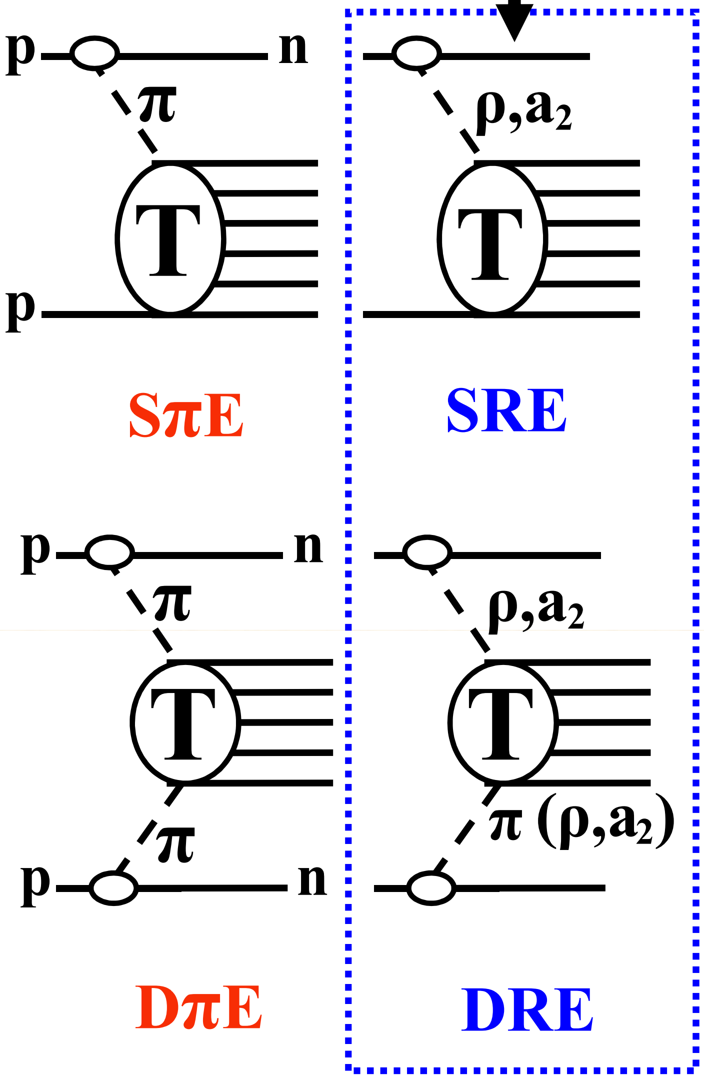
2. Development of detector active element based on thgem**.**
e-Print: **arXiv:0906.4441** [physics.ins-det]

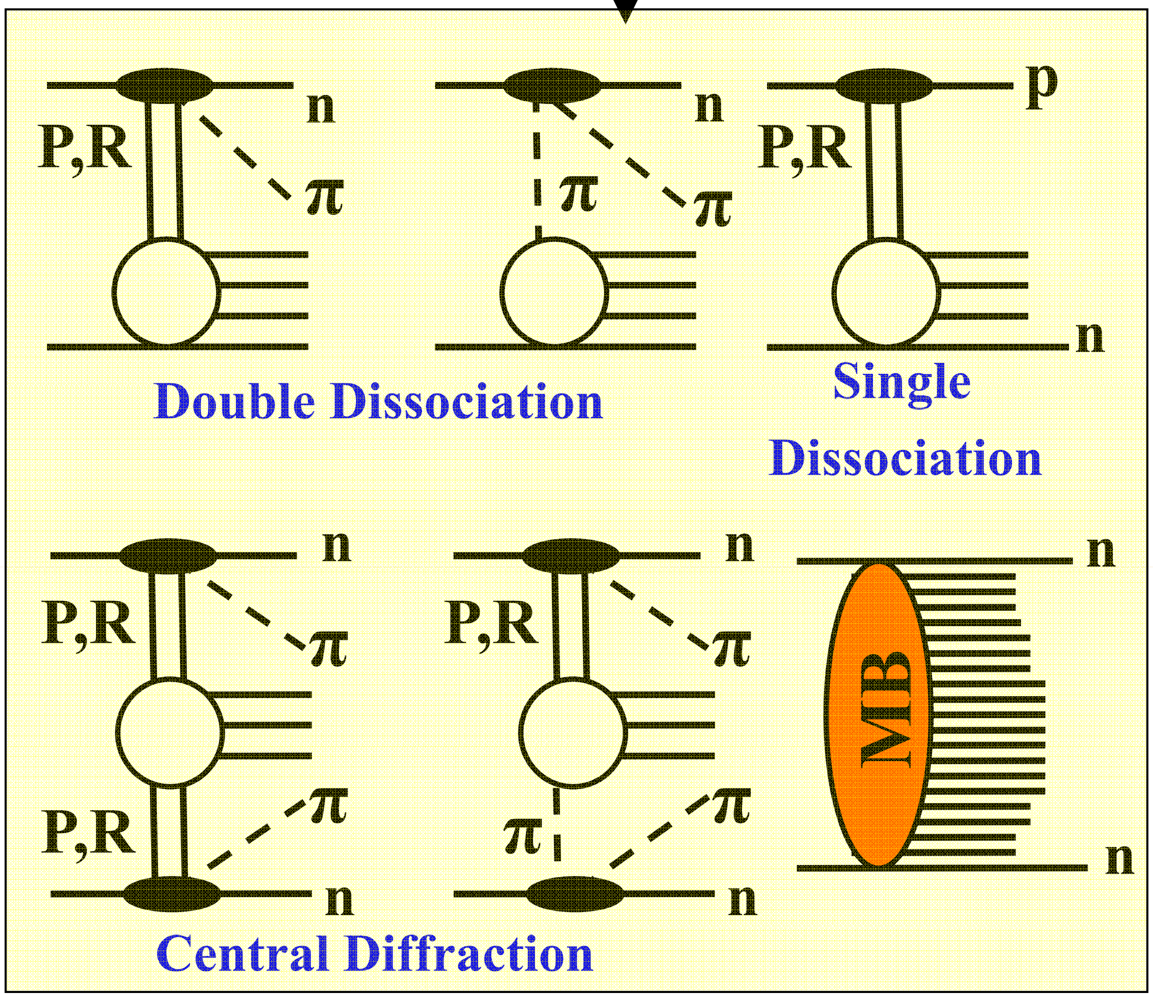
- **cheap**
- **fast**
- **high rad. resistance**
- **coordinate and energy measurement**
- **upgrade HE CMS**

Signal and backgrounds

[R.Ryutin ,V.Petrov, A.Sobol, in preparation]

[V.Petrov, R.Ryutin, A.Sobol, EPJC 65 (2010) 237]
[A.Sobol, R.Ryutin, V.Petrov and M.Murray, Arxiv:1005.2984]

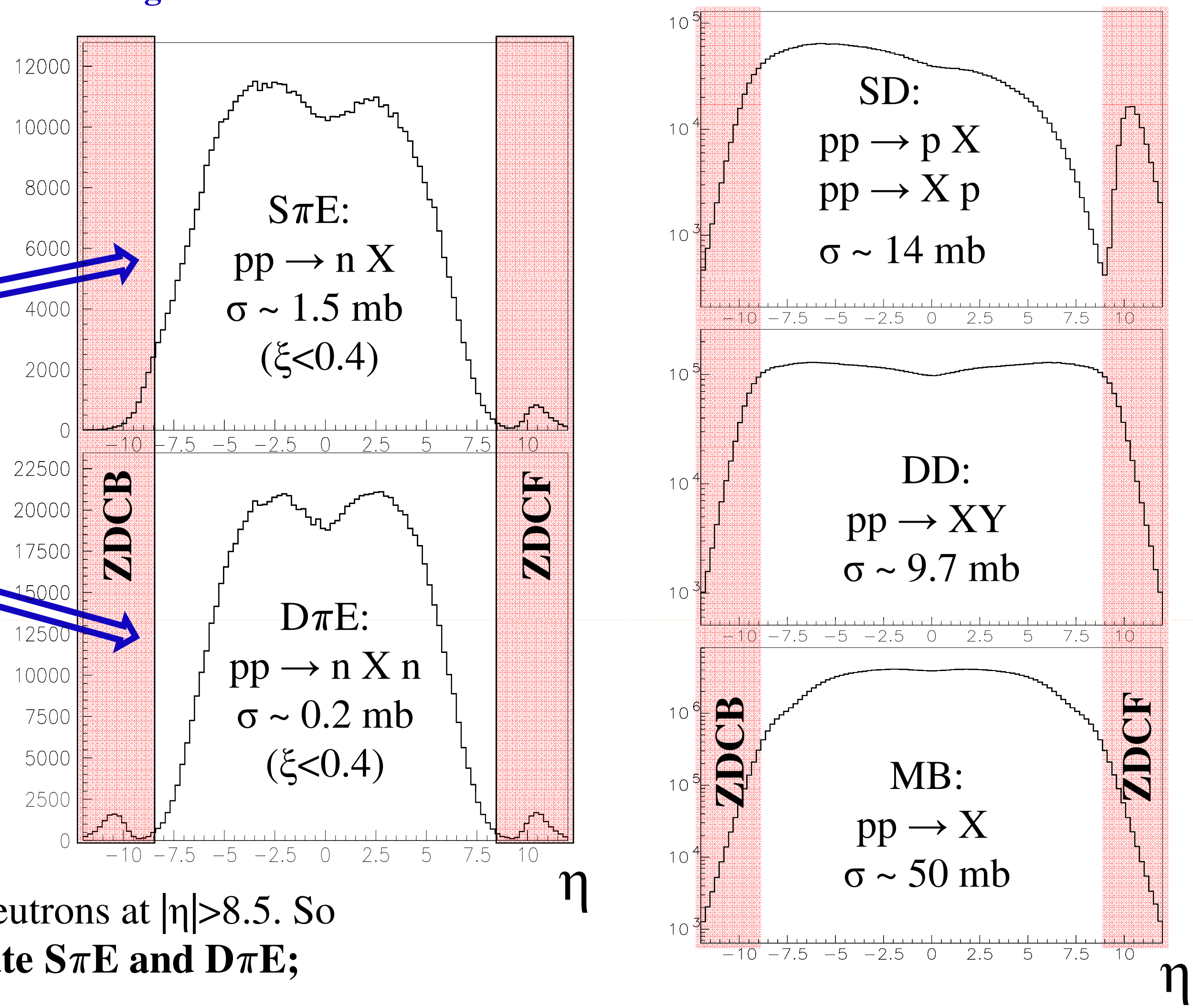




Signal and backgrounds distributions

We propose to perform measurements of CE and DCE processes at LHC.
For the leading neutron detection Zero Degree Calorimeter could be used.

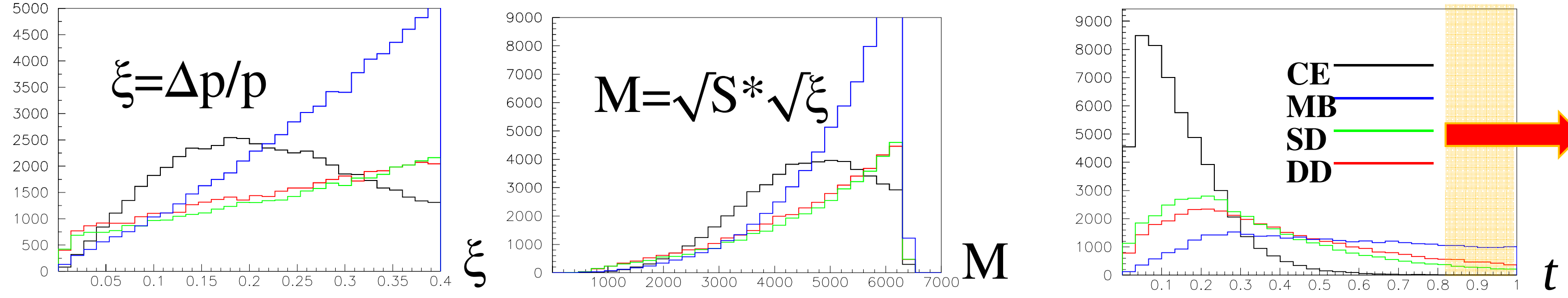
MC Generator MonChER1.0: (Monte-Carlo for Charge Exchange Reactions)



All processes have leading neutrons at |η|>8.5. So

- **SD, DD and MB can imitate SπE and DπE;**
- **SπE can imitate DπE**

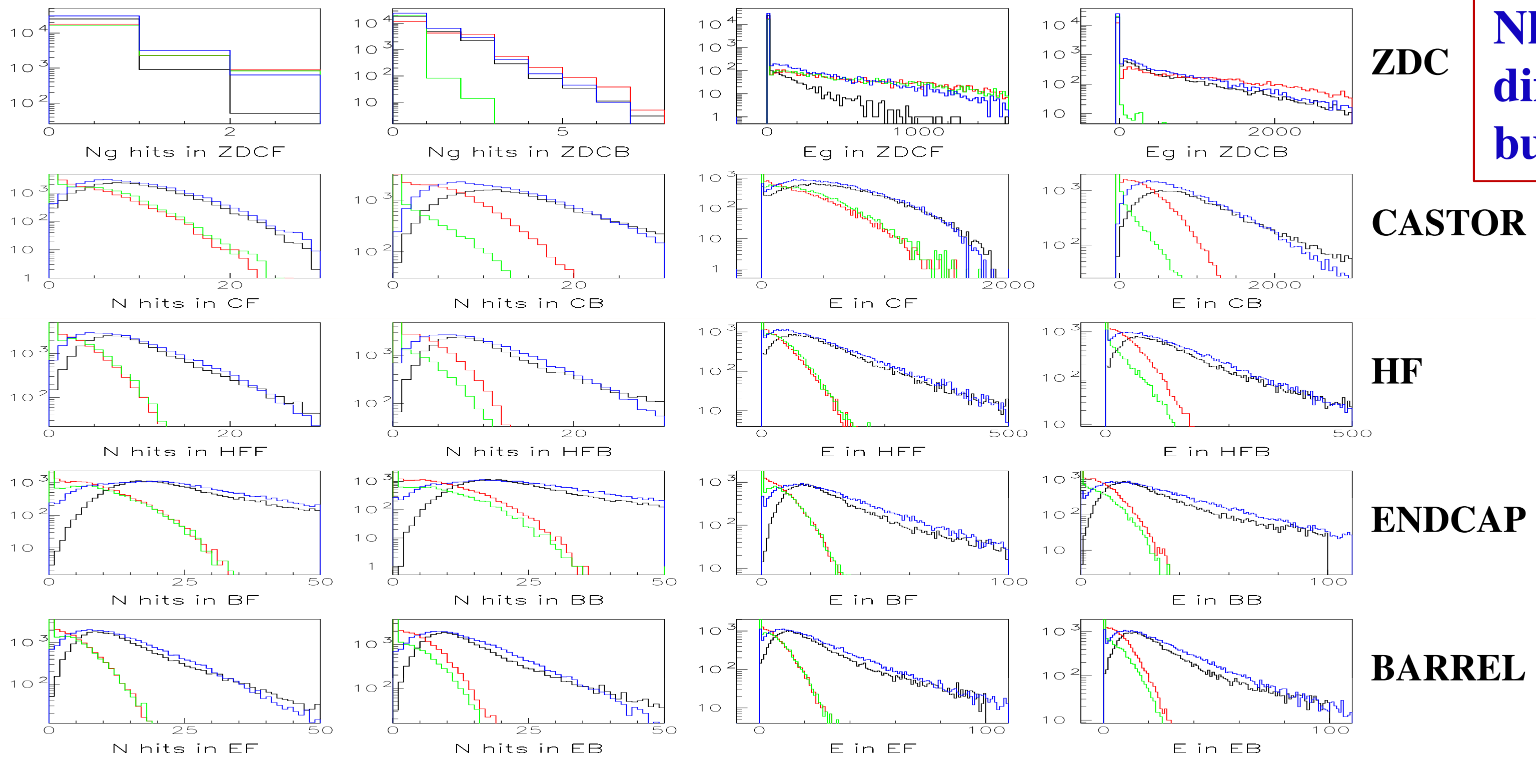
Monte-Carlo for CE (methods)



BG /S ~ 0

We selected events with 1 neutron detected in ZDCForward and look on Calo in forward and backward region

N forward hits | **N backward hits** | **E forward** | **E backward**



Nhits(HF) >7
diffraction ~ 0,
but MB ~ CE

Total π p &π π cross-sections from CE&DCE (MC)

CE & DCE at 10 TeV

No selection

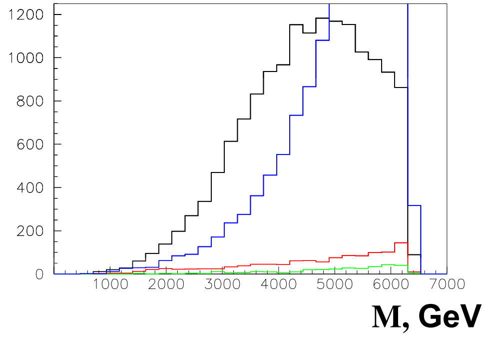
	S/B
CE	1/28
DCE	1/380

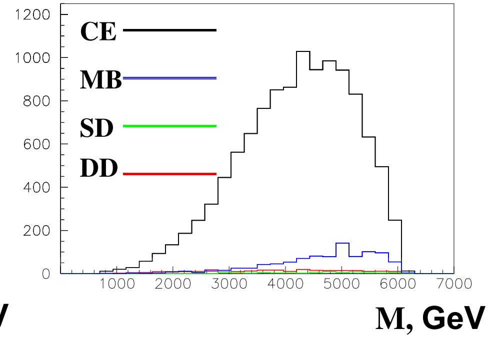
Simple selection:

$$(\mathrm{CE1}): \left[\begin{array}{lll} N_n^f > 0 & \& & N_n^b = 0 \\ N_n^f = 0 & \& & N_n^b > 0 \end{array}\right. \qquad (\mathrm{DCE1}): \left\{\begin{array}{l} N_n^f > 0 \\ N_n^b > 0 \end{array}\right.$$

	S/B
{ξ<0.4 & CE1} (CE)	1/2.7
{ξ<0.4 & DCE1} (DCE)	1/1.6

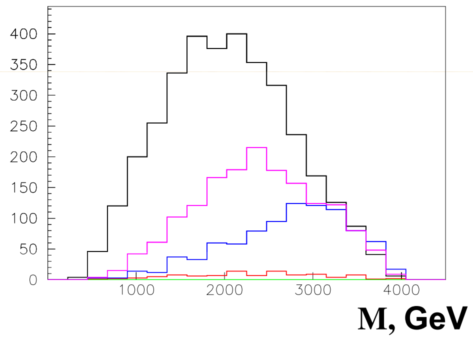
Additional selections

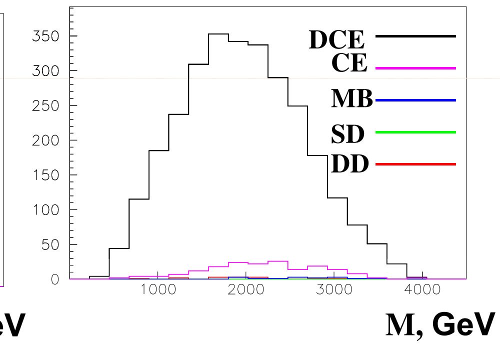




CE: Nhits(HF)>7
S/B ~ 1/0.56

CE: |t|<0.2 GeV²
S/B ~ 1/0.08





DCE: Nhits(HF)>7
S/B ~ 1/0.7

DCE: |t|<0.3 GeV²
S/B ~ 1/0.07

Total π p &π π cross-sections from CE&DCE (MC)

CE & DCE at 900 GeV

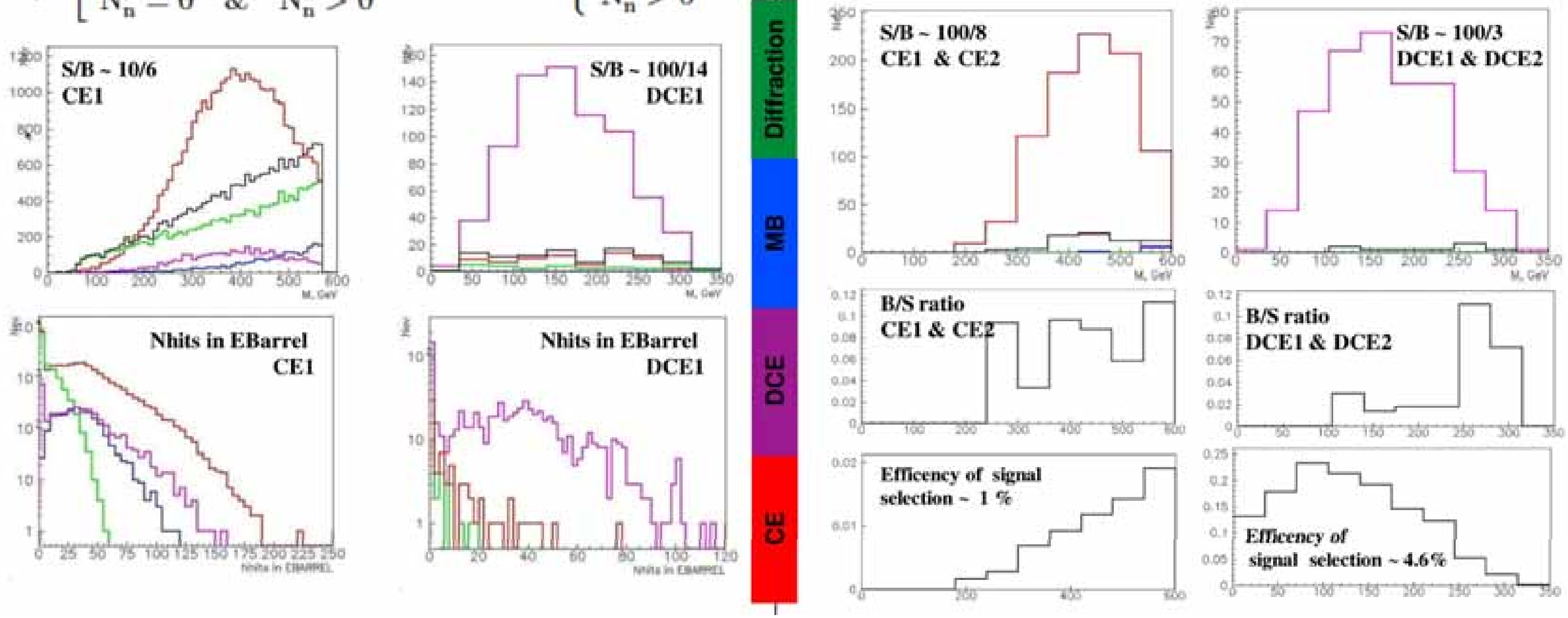
Process	CE	DCE	SD	DD	MB	Elastic	Total
σ, mb	1.76	0.14	11.7	6.4	32.5	12.8	65.3

CE selection	CE	:	DCE	:	Diffraction	:	MB	$(S:B)_{CE}$
NO	1	:	0.08	:	10.3	:	19.5	1:30
CE1	1	:	0.11	:	0.44	:	0.07	10:6
CE1 & CE2	1	:	0.07	:	0	:	0.007	100:8

DCE selection	DCE	:	CE	:	Diffraction	:	MB	$(S:B)_{CE}$
NO	1	:	12.5	:	128.8	:	243.8	1:385
DCE1	1	:	0.1	:	0.04	:	0	100:14
DCE1 & DCE2	1	:	0.03	:	0	:	0	100:3

$$(\mathrm{CE1}): \left[\begin{array}{lll} N_n^f > 0 & \& & N_n^b = 0 \\ N_n^f = 0 & \& & N_n^b > 0 \end{array}\right. \qquad (\mathrm{DCE1}): \left\{\begin{array}{l} N_n^f > 0 \\ N_n^b > 0 \end{array}\right.$$

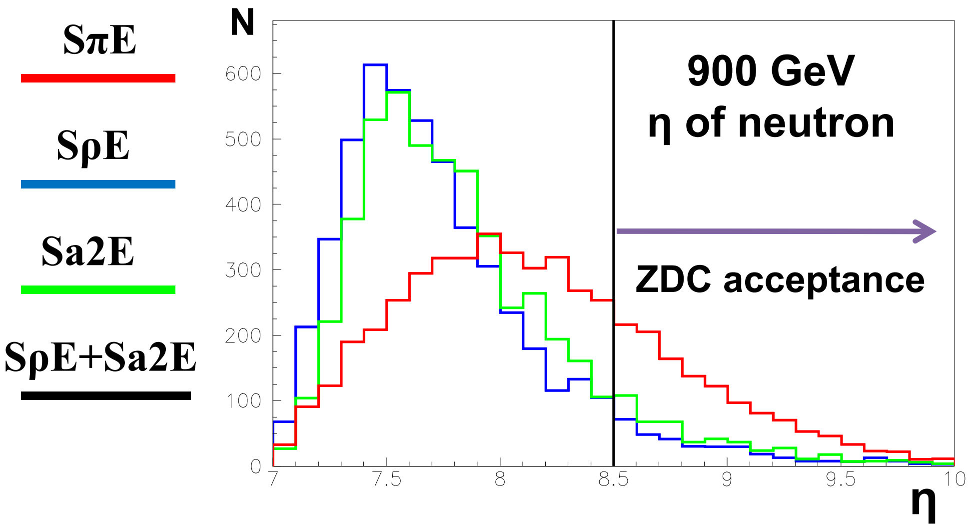
$$(\mathrm{CE2}): \quad N_{hits}^{EB} > 100 \qquad (\mathrm{DCE2}): \quad N_{hits}^{EB} > 20$$

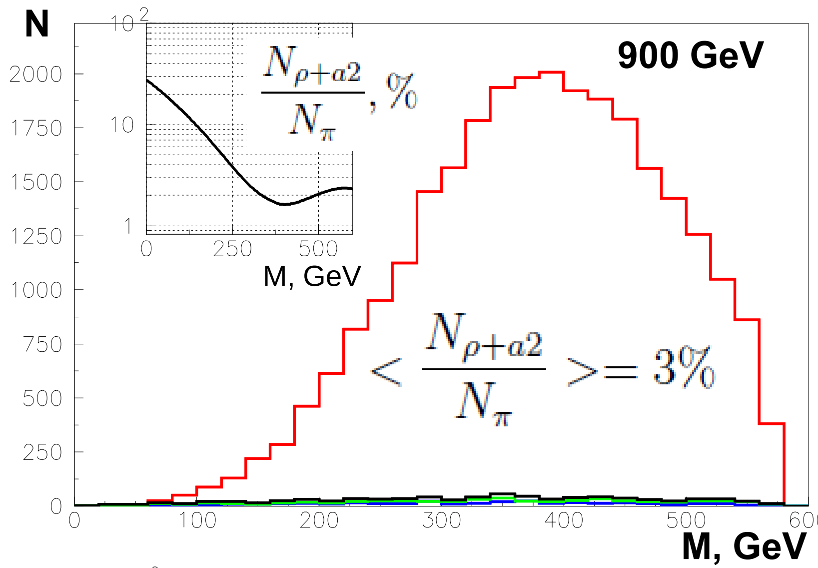


At 900 GeV we have good chances to get **10^7 CE and 10^6 DCE events at 1 pb^-1,** using ZDC+CMS Calorimeters only!

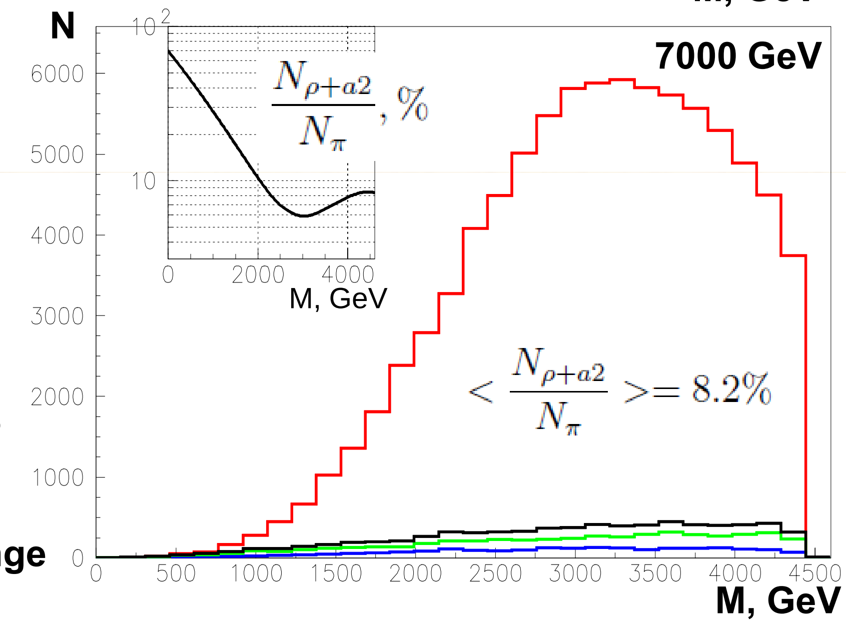
Model dependent extraction of π p & π π total cross-sections at 200-600 & 50-350 GeV

Total {π,ρ,a₂}p cross-sections from CE (MC)



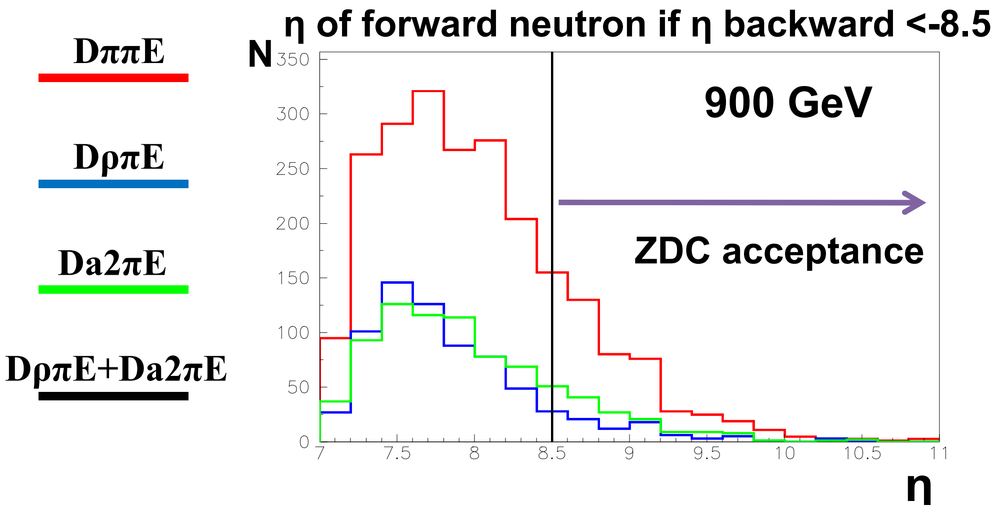


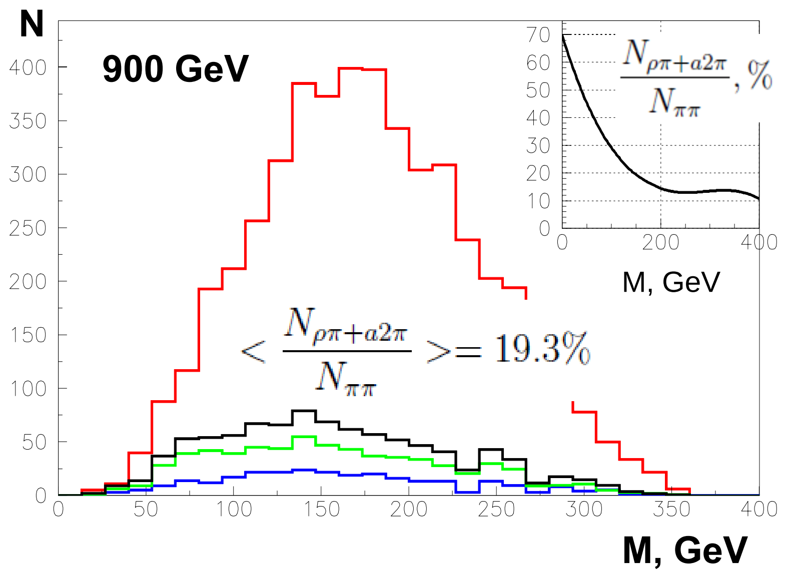
CME, GeV		900	7000
$\frac{\sigma_{\rho+a2}}{\sigma_\pi}$, %		10.7	8.2
ZDC acceptance, %	$S\pi E$	27.8	86.6
	$S\rho E$	10.8	86.8
	Sa_2E	6.7	86.7
$\frac{N_{\rho+a2}}{N_\pi}$, %		3.0	8.2

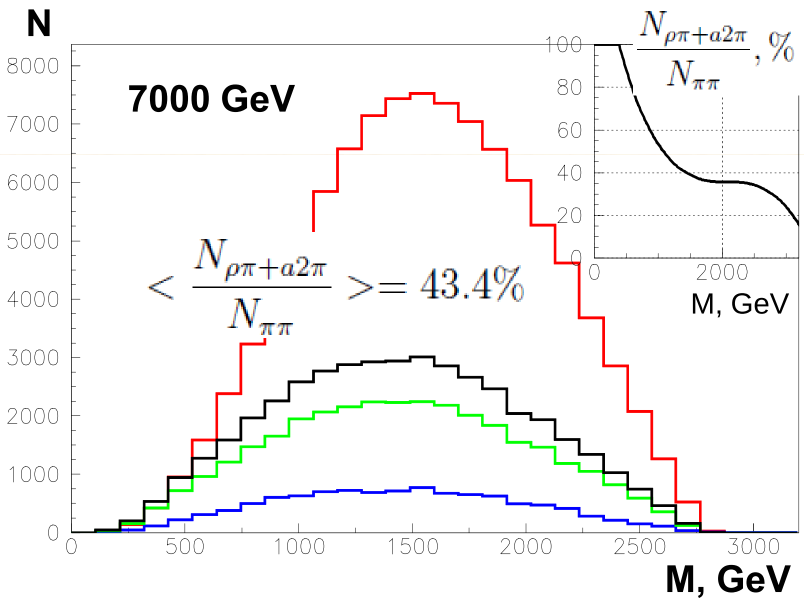


At 900 GeV ρ and a2 exchanges are suppressed up to 3% just by ZDC acceptance due to different neutron kinematics.
At 7000 GeV there is no such difference and ρ+a2 exchange remains at level ~8%.

Total {π,ρ,a₂}π cross-sections from DCE (MC)







CME, GeV		900	7000
$\frac{\sigma_{\rho\pi+a2\pi}}{\sigma_{\pi\pi}}$, %		47.3	43.4
ZDC acceptance, %	$D\pi\pi E$	4.80	99.6
	$D\rho\pi E$	0.28	99.8
	$Da_2\pi E$	0.65	99.7
$\frac{N_{\rho\pi+a2\pi}}{N_{\pi\pi}}$, %		19.3	43.4

At 900 GeV ρπ and a2π exchanges are suppressed from 47% to 19 % by ZDC acceptance.

At 7000 GeV ρπ+a2π exchanges remain at level ~43%.

Elastic πp & ππ cross-sections from CE&DCE (MC)

Elastic CE & DCE at 10 TeV

No selection

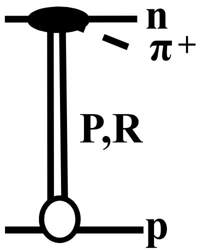
	S/B
CE	0.004
DCE	0.0025

Simple selection:

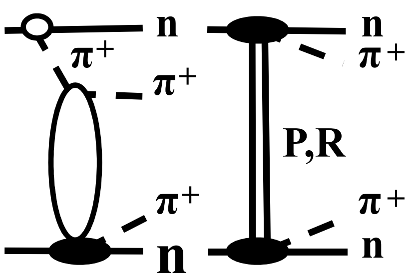
		S/B
(CE1) : $\left[\begin{array}{lll} N_n^f > 0 & \& & N_n^b = 0 \\ N_n^f = 0 & \& & N_n^b > 0 \end{array} \right.$	{ξ<0.4 & CE1} (CE)	0.05
(DCE1) : $\left\{ \begin{array}{l} N_n^f > 0 \\ N_n^b > 0 \end{array} \right.$	{ξ<0.4 & DCE1} (DCE)	0.04

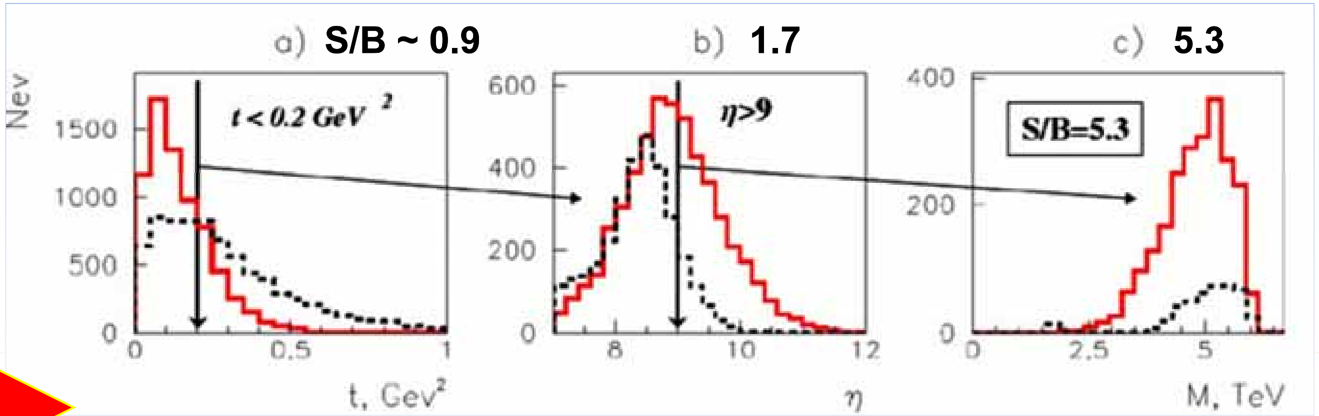
Nhits(Barrel,Endcap, HF,CASTOR,EZDC)=0

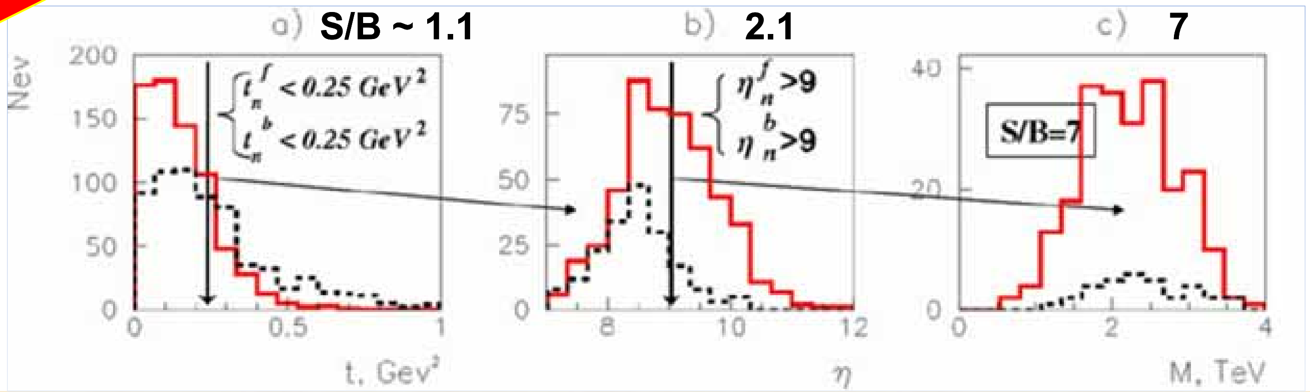
CE S/B ~ 0.9



DCE S/B ~ 1.1

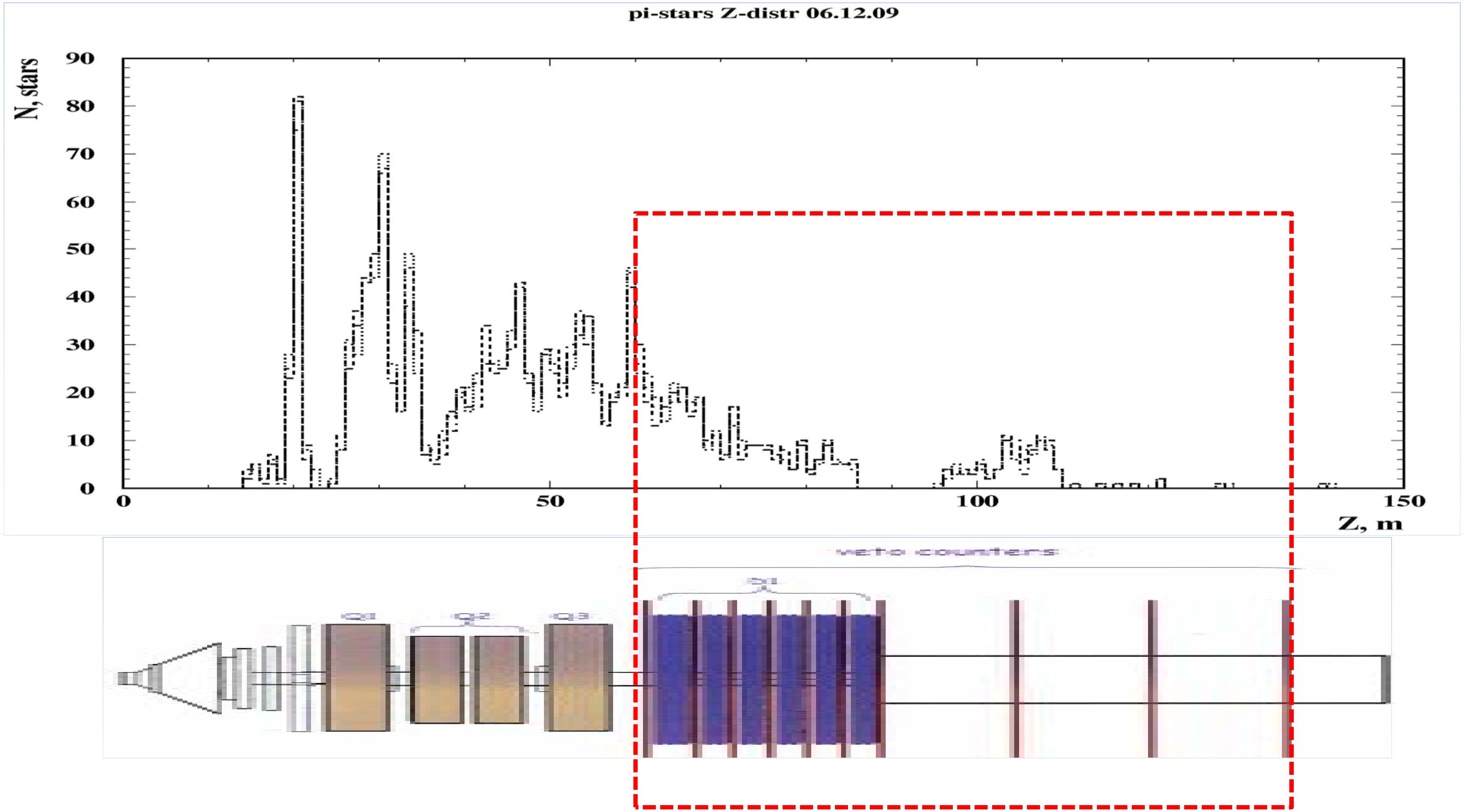






Elastic πp cross-sections from CE

Elastic CE at 10 TeV: pion detection

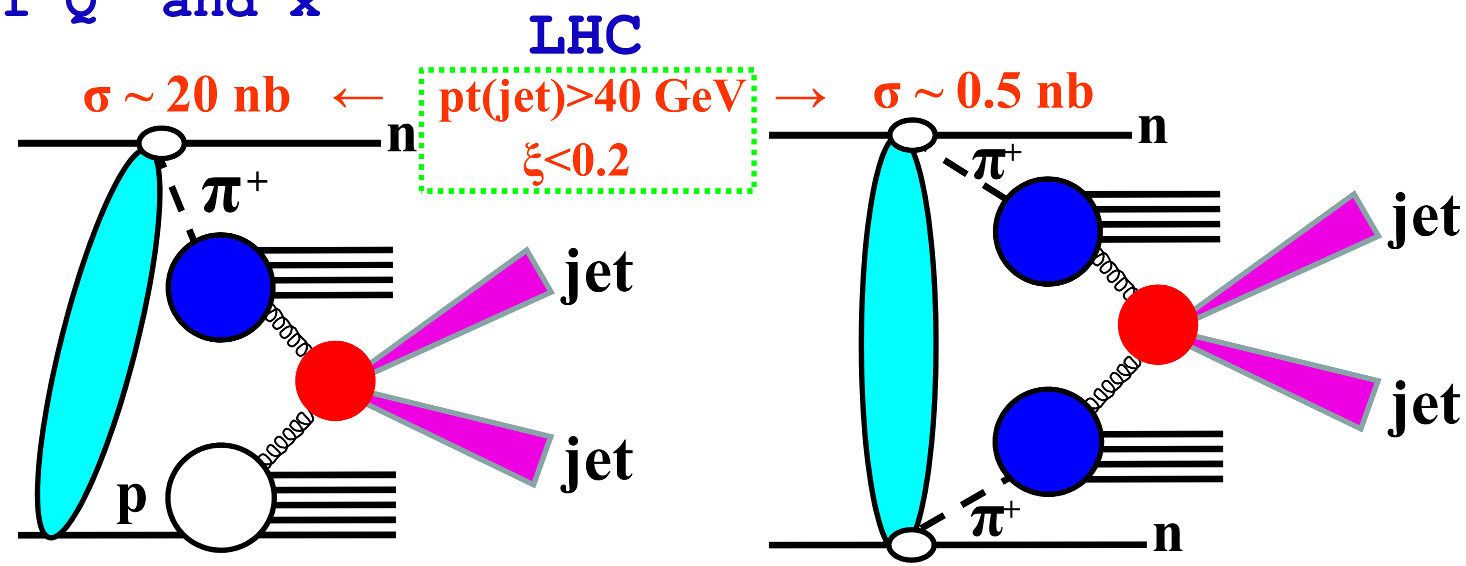


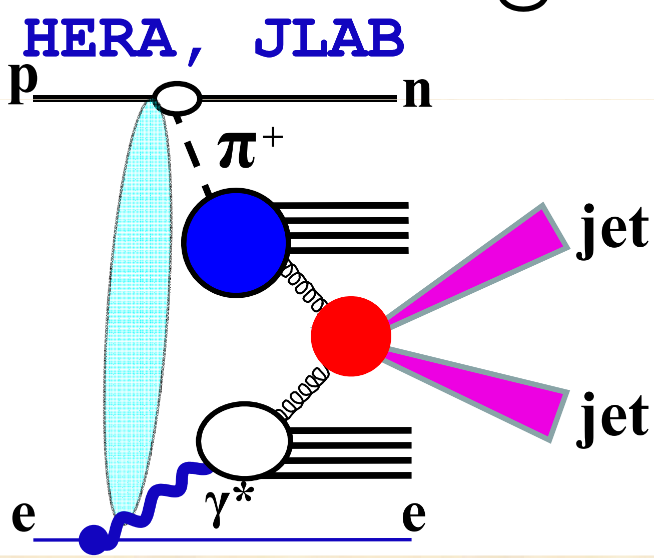
[M. Albrow et al., JINST 4, (2009) P10001]

Forward Shower Counters (FSC): 8<η<11

Future prospects: pion structure functions

Parton distributions in a pion in a still unexplored domain of Q^2 and x





Summary

• CE (pp→nX) and DCE (pp→nXn) processes measured at LHC could provide us with unique information on π+p and π+π+ cross sections at very high c.m. energy (up to several TeV): total, elastic, inclusive jet cross-sections, … => universal behaviour, value of absorbtion, diffractive patterns, parton distributions in a pion, …

• Cross-sections for CE & DCE processes are estimated to be 1.5 mb & 0.2 mb at 10 TeV (very large number of events, even with low efficiency of registration)

• Model for charge exchange processes (with π, ρ and a2 reggeons) in the range $0<q_t<0.5$ GeV, $0.0001<\xi<0.4$, 0.9 TeV$<\sqrt{s}<$14 TeV was developed and applied to MC (generator MonChER1.0: 4 models for pion-proton scattering, 3IP model for absorbtion)

• Model-independent extraction of π+ p and π+ π+ cross-sections is possible for LHC if we can measure t-distributions. It is not possible for the present design of ZDC (or at 900 GeV with some restrictions) => At this moment only model-dependent extraction is possible with uncertainties in absorbtion (can be normalized to pp, at present we have 10% model error from most popular models)

• Backgrounds: SD,DD,CD,MB are suppressed at $|t|<0.25$ GeV^2 (S/B~10). But even for the whole ZDC acceptance we can reach also S/B~10 with efficiency 1-3% for SπE and 5-10% for DπE without t-cuts, using the information from CMS detectors. Reggeon backgrounds can reach 3% (8%) at 0.9 (7) TeV for CE and 19% (43%) for DCE. Pile-up is supposed to be low at first runs.

• Total and inclusive dijet cross-sections π p and π π cross-sections could be extracted from the real data at 0.9!!! and 7 TeV in a model-dependent way.

• For elastic cross-sections and t-measurements we need modifications of detectors (FSC, ZDC, THGEM).

Backup slides (absorbtion formulaes)

$$\Phi_B(\xi,\vec{q}^{\,2}) = \frac{N(\xi)}{2\pi}\left(\frac{1}{\vec{q}^{\,2}+\epsilon^2} + \imath\frac{\pi\alpha'_\pi}{2(1-\xi)}\right)\exp(-\beta^2\vec{q}^{\,2}),$$

$$N(\xi) = (1-\xi)\frac{G_{\pi+pn}}{2}\xi^{\frac{\alpha'_\pi\epsilon^2}{1-\xi}}\exp\left[-b\frac{m_p^2\xi^2}{1-\xi}\right],$$

$$\beta^2 = \frac{b+\alpha'_\pi\ln\frac{1}{\xi}}{1-\xi},\quad \epsilon^2 = m_p^2\xi^2 + m_\pi^2(1-\xi),$$

$$\Theta_0(b,\xi,|\vec{q}|) = \frac{2\pi\; b\; J_0(b\,|\vec{q}|)}{N(\xi)}\int_0^\infty dk\; k\; J_0(b\;k)\Phi_B(\xi,k^2),$$

$$\Theta_s(b,\xi,|\vec{q}|) = \frac{2\pi\; b\; J_1(b\,|\vec{q}|)}{N(\xi)}\int_0^\infty dk\; k^2\; J_1(b\;k)\Phi_B(\xi,k^2)$$

$$V(b) = \exp\left(-\Omega_{el}(s/s_0,b)\right),$$

$$\Omega_{el} = \sum_{i=1}^{3}\Omega_i,$$

$$\Omega_i = \frac{2c_i}{16\pi B_i}\left(\frac{s}{s_0}\mathrm{e}^{-\imath\frac{\pi}{2}}\right)^{\alpha_{IP_i}(0)-1}\exp\left[-\frac{b^2}{4B_i}\right],$$

$$B_i = \alpha'_{IP_i}\ln\left(\frac{s}{s_0}\mathrm{e}^{-\imath\frac{\pi}{2}}\right) + \frac{r_i^2}{4}.$$

i	c_i	r_i^2 (GeV^{-2})
1	53.0 ± 0.8	6.3096 ± 0.2522
2	9.68 ± 0.16	3.1097 ± 0.1817
3	1.67 ± 0.07	2.4771 ± 0.0964

$$\Phi_0 = \frac{N(\xi)}{2\pi}\int_0^\infty db\;\Theta_0(b,\xi,|\vec{q}|)V(b),$$

$$|\vec{q}|\Phi_s = \frac{N(\xi)}{2\pi}\int_0^\infty db\;\Theta_s(b,\xi,|\vec{q}|)V(b),$$

$$S = \frac{m_p^2\xi^2|\Phi_0(s/s_0,\xi,\vec{q}^{\,2})|^2 + \vec{q}^{\,2}|\Phi_s(s/s_0,\xi,\vec{q}^{\,2})|^2}{(m_p^2\xi^2+\vec{q}^{\,2})|\Phi_B(\xi,\vec{q}^{\,2})|^2}$$

$$\bar{\Phi}_{ij} = \frac{N(\xi_1)N(\xi_2)}{(2\pi)^2}\int_0^\infty db_1 db_2 I_\phi(b_1,b_2)\Theta_i(b_1,\xi_1,|\vec{q}_1|)\Theta_j(b_2,\xi_2,|\vec{q}_2|),$$

$$I_\phi(b_1,b_2) = \int_0^\pi \frac{d\phi}{\pi}V\left(\sqrt{b_1^2+b_2^2-2b_1b_2\cos\phi}\right),$$

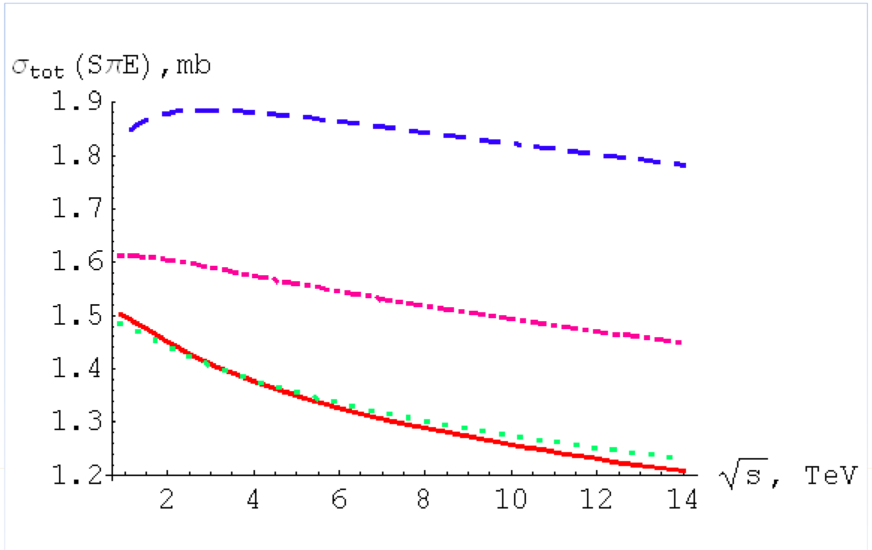
$$\rho_{00} = m_p^2\xi_1\xi_2,\;\; \rho_{0s} = m_p\xi_1,\;\; \rho_{s0} = m_p\xi_2,\;\; \rho_{ss} = 1,$$

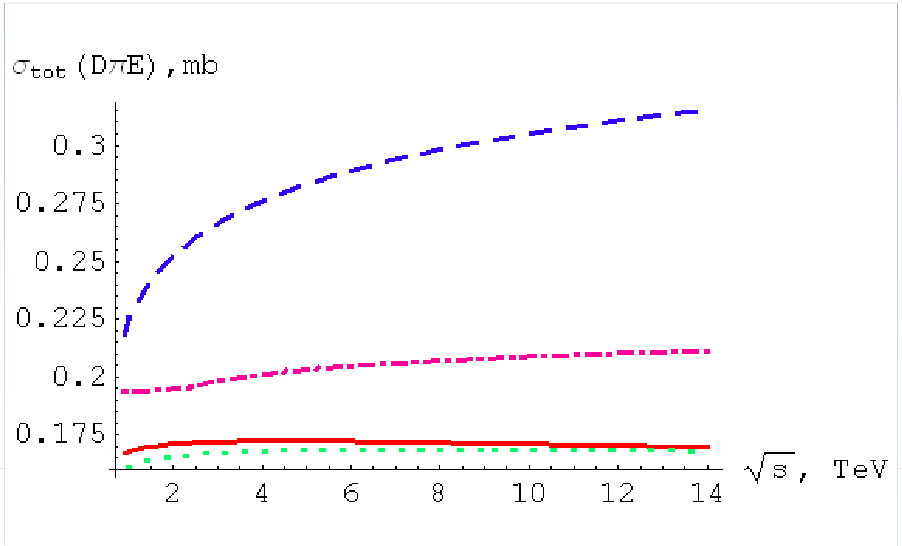
$$S_2 = \frac{\sum\limits_{i,j=0,s}\rho_{ij}^2|\bar{\Phi}_{ij}(s/s_0,\{\xi_i\},\{\vec{q}_i^{\,2}\})|^2}{\prod\limits_{i=1}^{2}\left[(m_p^2\xi_i^2+\vec{q}_i^{\,2})|\Phi_B(\xi_i,\vec{q}_i^{\,2})|^2\right]}$$

Backup slides (total SπE and DπE cross-sections)

Total CE and DCE cross-sections in the region $\Omega=\{0<qt<0.5\text{ GeV},\ 0.0025<\xi<0.4\}$

COMPETE — DL — GP — BSW parametrizations for $\sigma_{\pi p}$





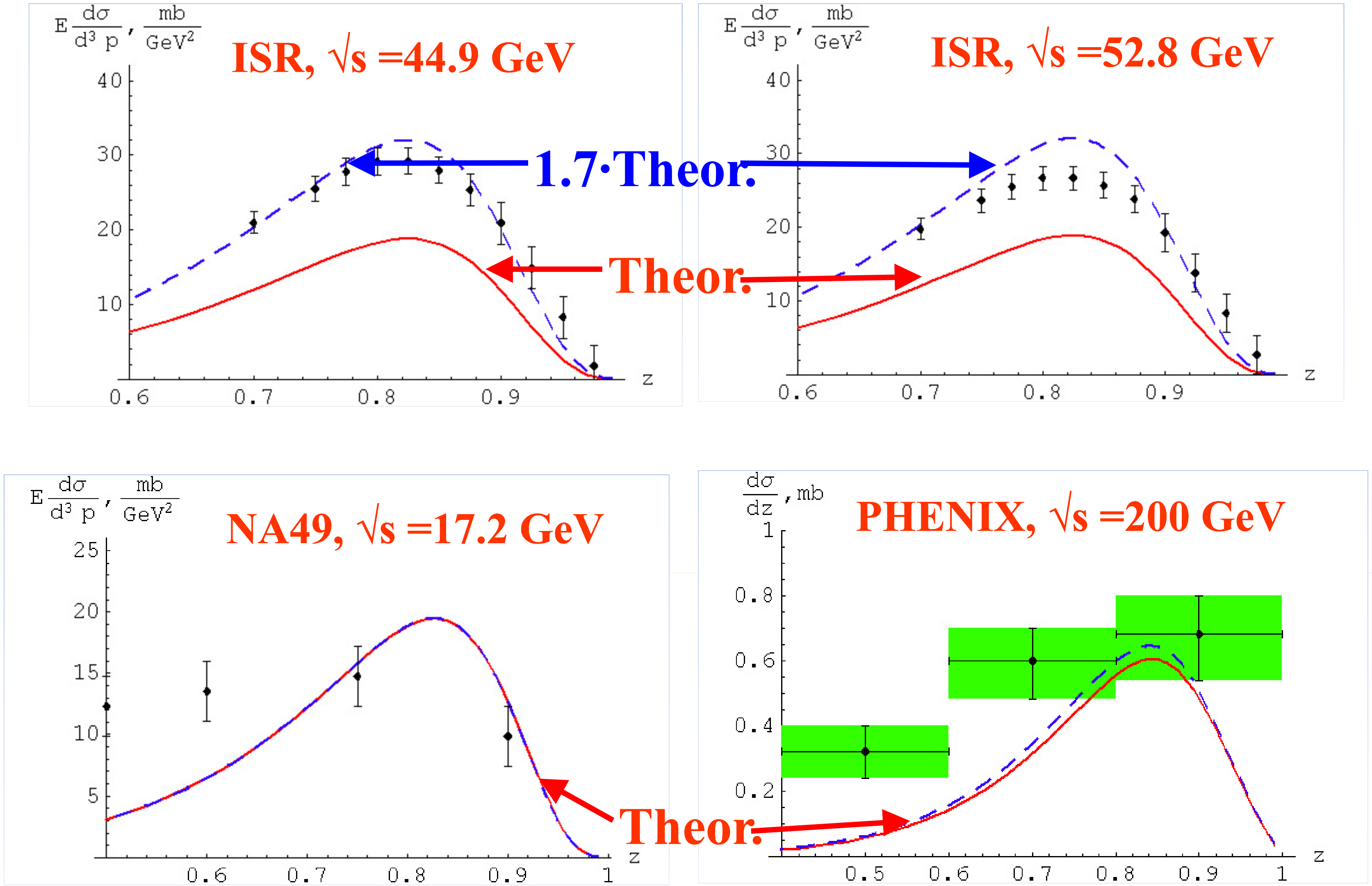
Since there are no real data for ππ cross-sections, we can use factorization assumptions:

COMPETE, DL: $$\sigma_{\pi\pi} = \frac{\sigma_{\pi p}^2}{\sigma_{pp}}$$

GP, BSW: $$\beta_{\pi\pi}(t) = \frac{\beta_{\pi p}(t)^2}{\beta_{pp}(t)}$$

β(t) are residues of reggeon poles in eikonals

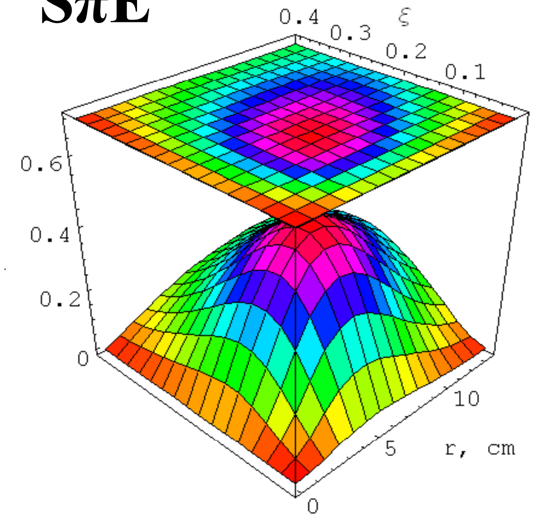
Backup slides (π p cross-sections from data)



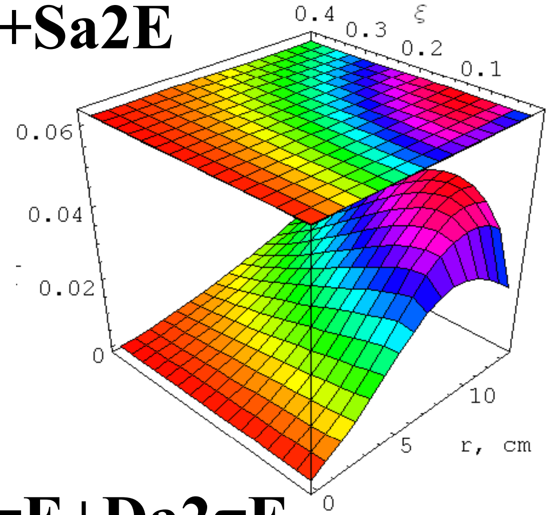
Backup slides (cross-sections at 900 GeV)

dσ/drdξ (mb/cm)

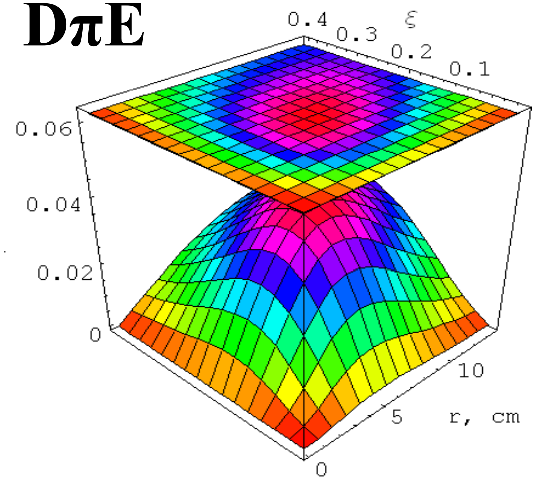
SπE



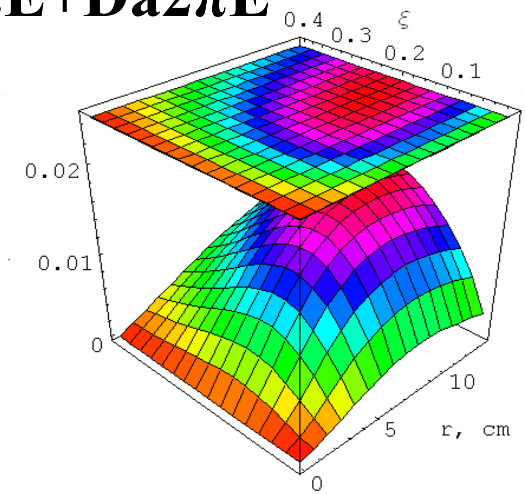
SρE+Sa2E



DπE



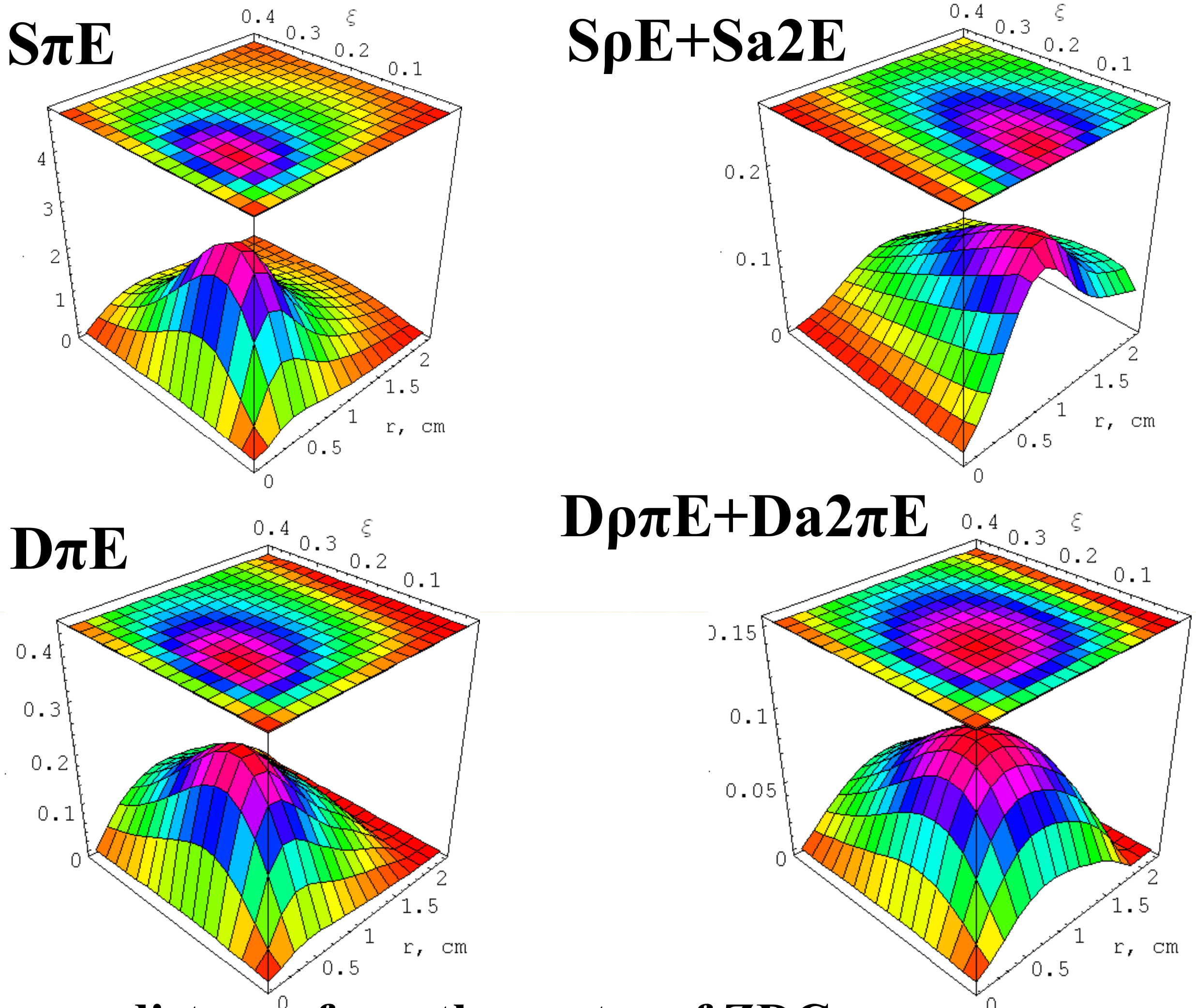
DρπE+Da2πE



r is the transverse distance from the center of ZDC

Backup slides (cross-sections at 7 TeV)

dσ/drdξ (mb/cm)



r is the transverse distance from the center of ZDC